Title: Adventures with Superstrings

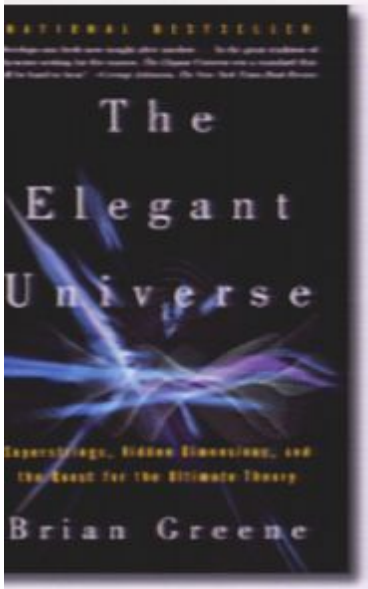
Date: Aug 03, 2009 09:10 AM

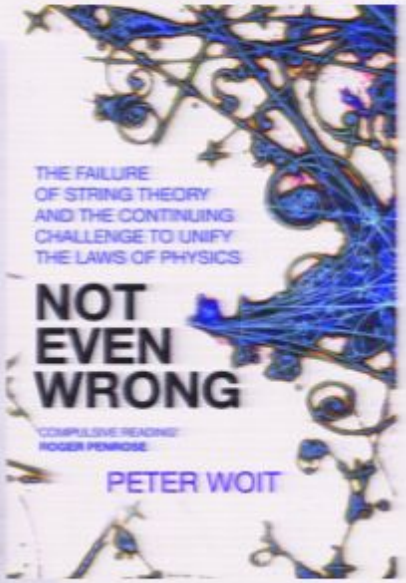
URL: http://pirsa.org/09080022

Abstract: Physics emerged from the twentieth century with two remarkably successful descriptions of nature which stand in striking contrast. Quantum mechanics describes the subatomic realm with intrinsic uncertainties and probabilities. On the other hand, Einstein's general relativity describe gravitational phenomena in an exacting geometric arena. Theoretical physicists have struggled for over fifty years trying to combine these views in a single unified framework. More recently, superstring theory has drawn a huge amount of interest as a leading contender to provide such a unification. Superstring theory is a theory of strings, branes, extra spacetime dimensions and much more. In my lecture, I will try to give a flavour for what superstring theory is all about and why physicists, like myself, continue to be so excited about this, perhaps the final theory.

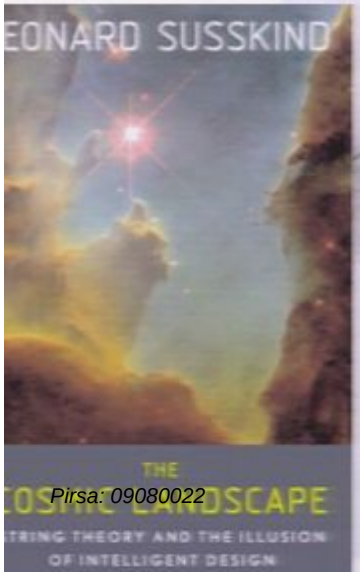
ERIMETER INSTITUTE
R THEORETICAL PHYSICS
The Superstring Adventure
Robert Myers
(Einstein-Plus: August 3, 2009)

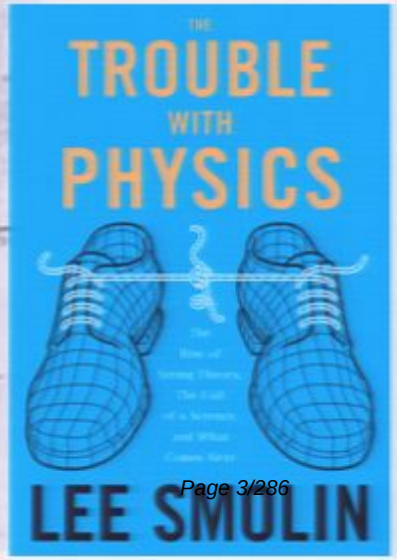
New Yorker magazine:



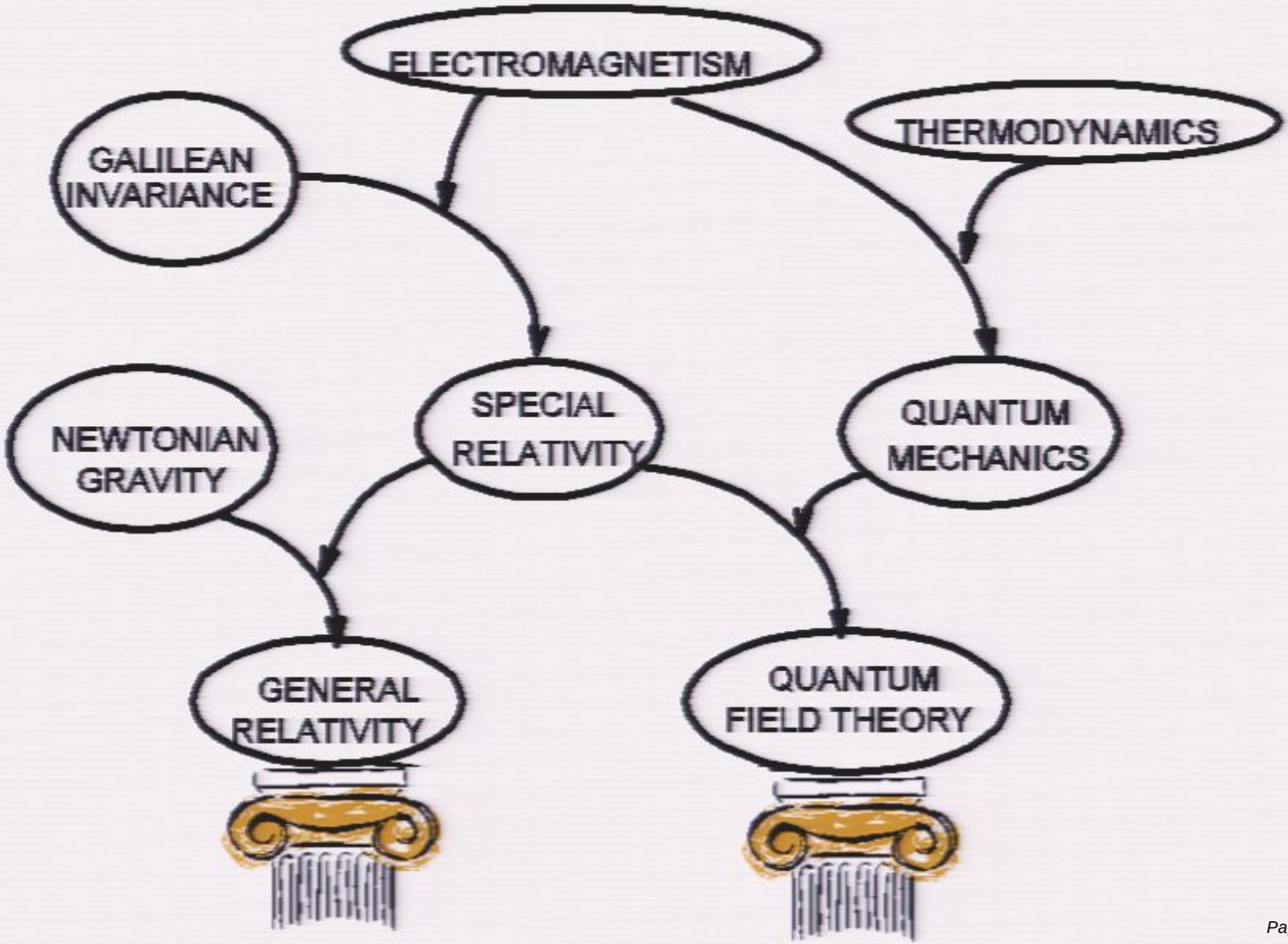


"It's all string theory to me."





Physics of the 20th century: A grand synthesis and progression of ideas!



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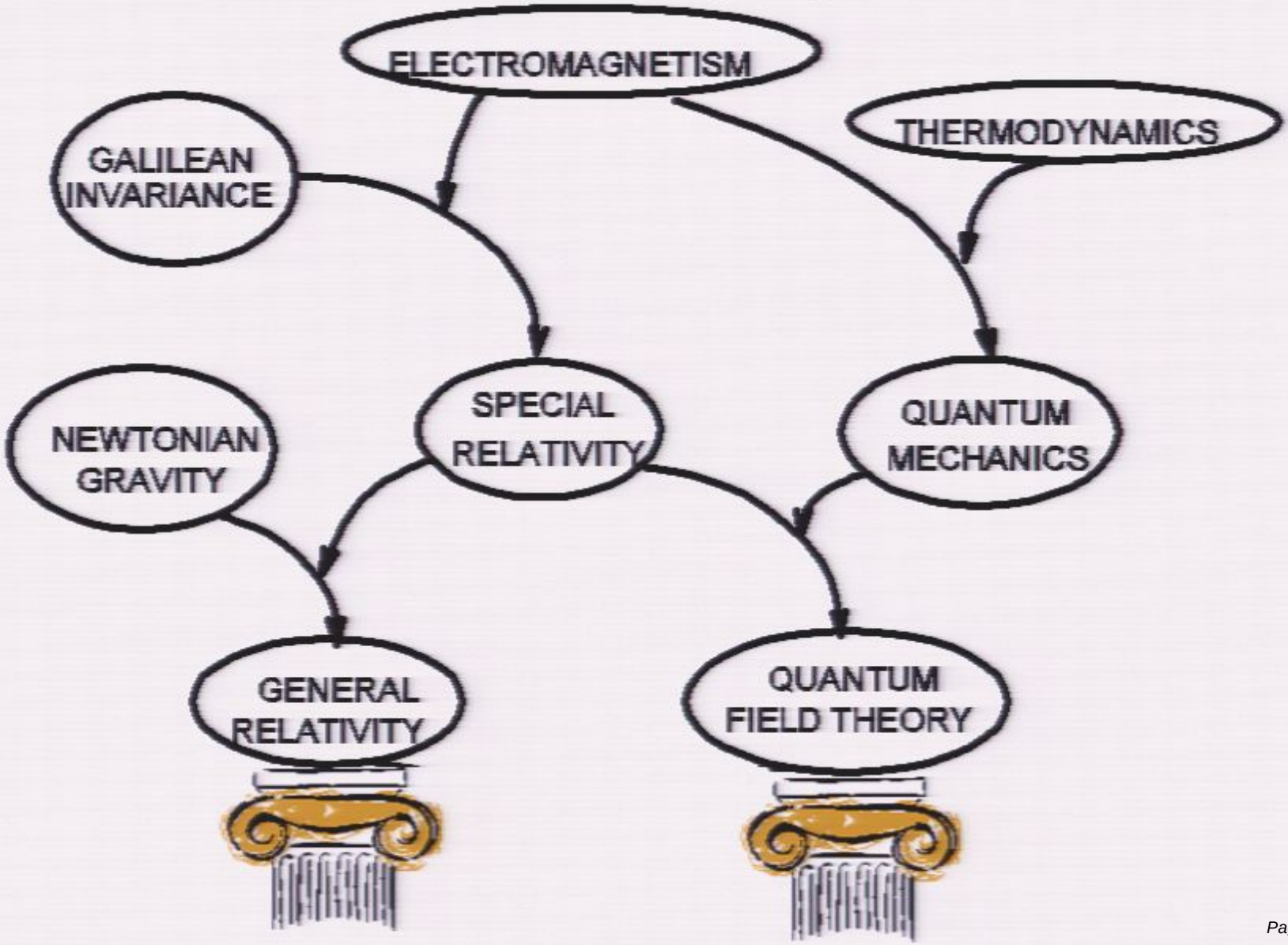

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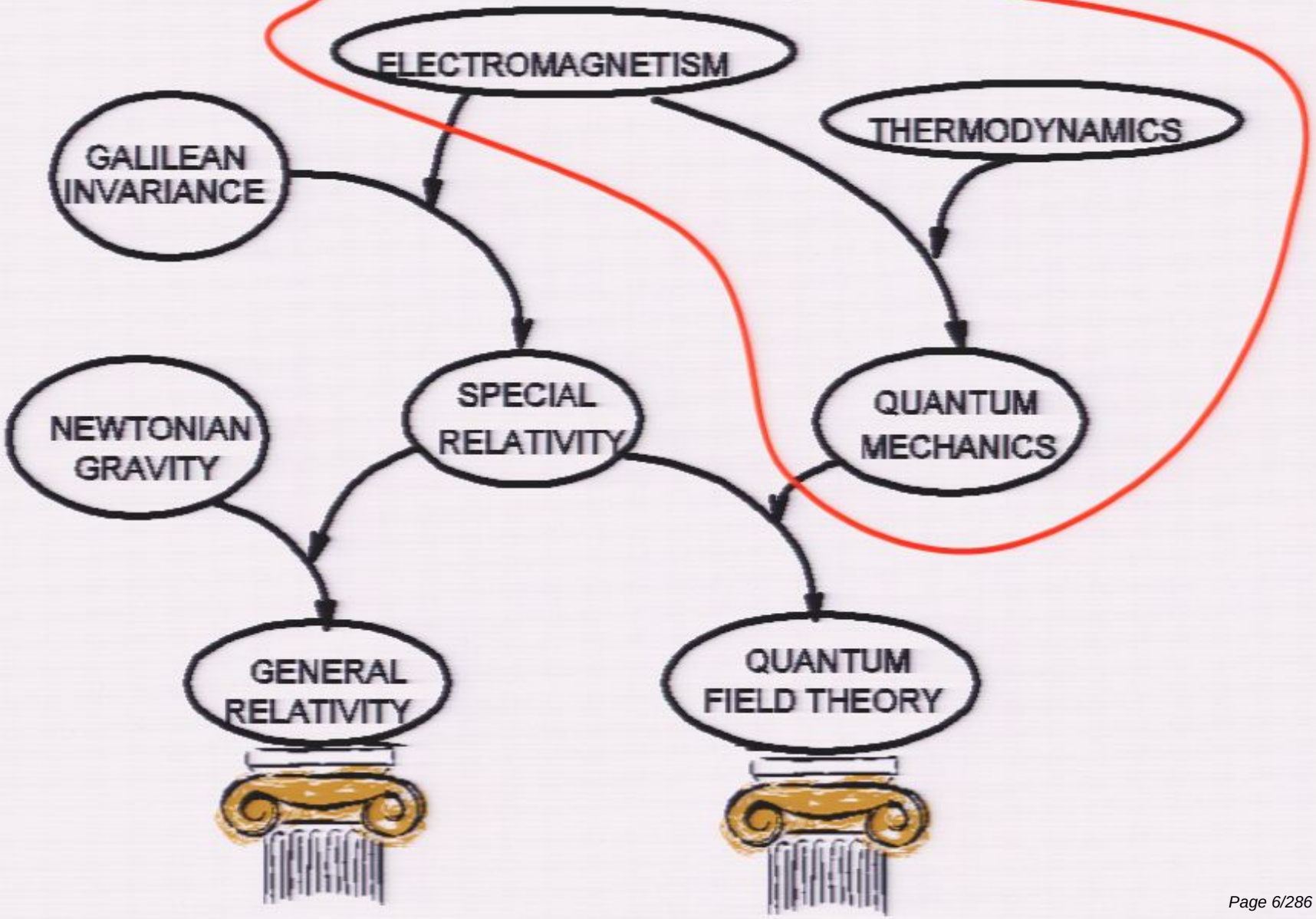

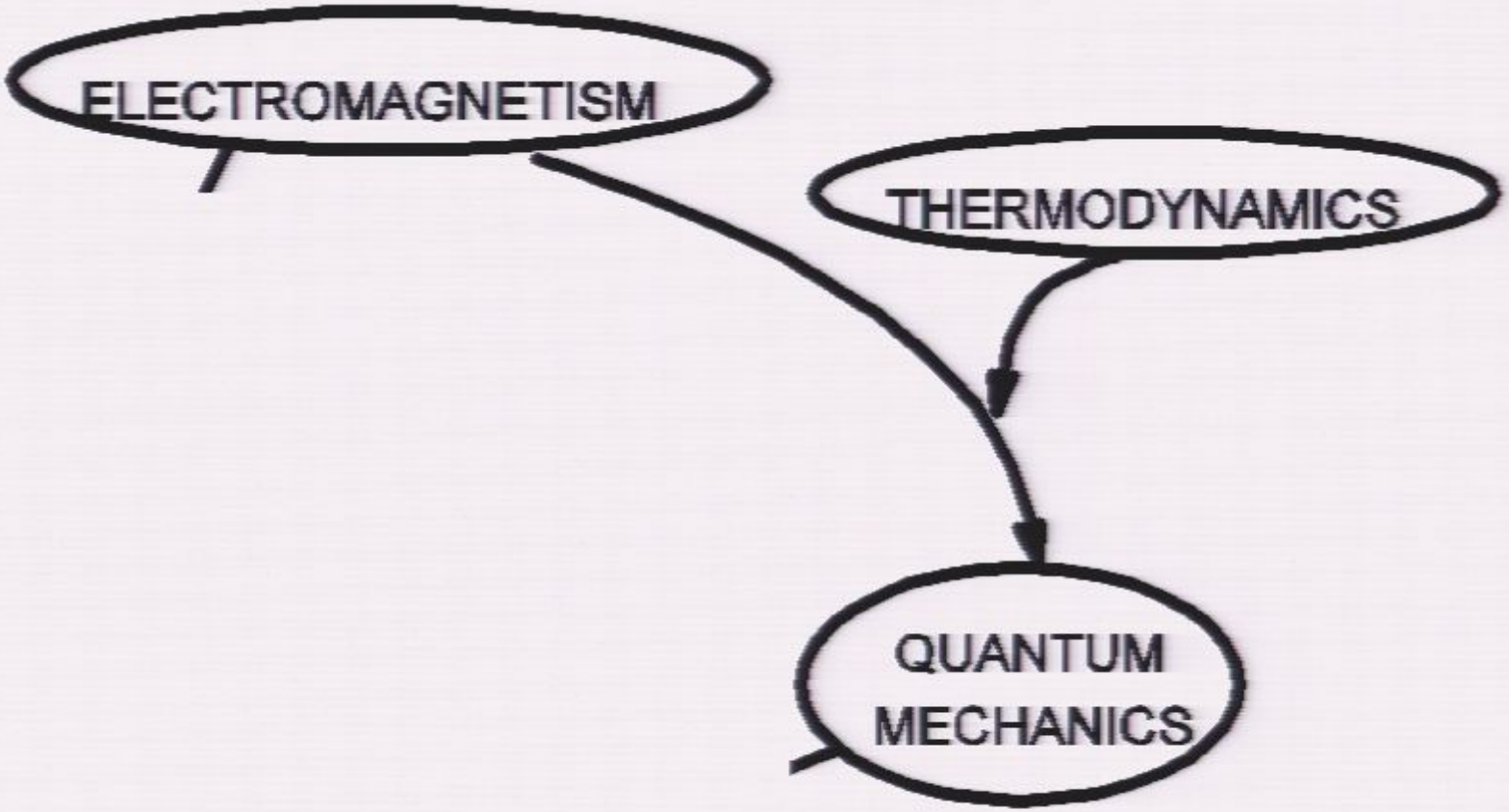
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THERMODYNAMICS
QUANTUM
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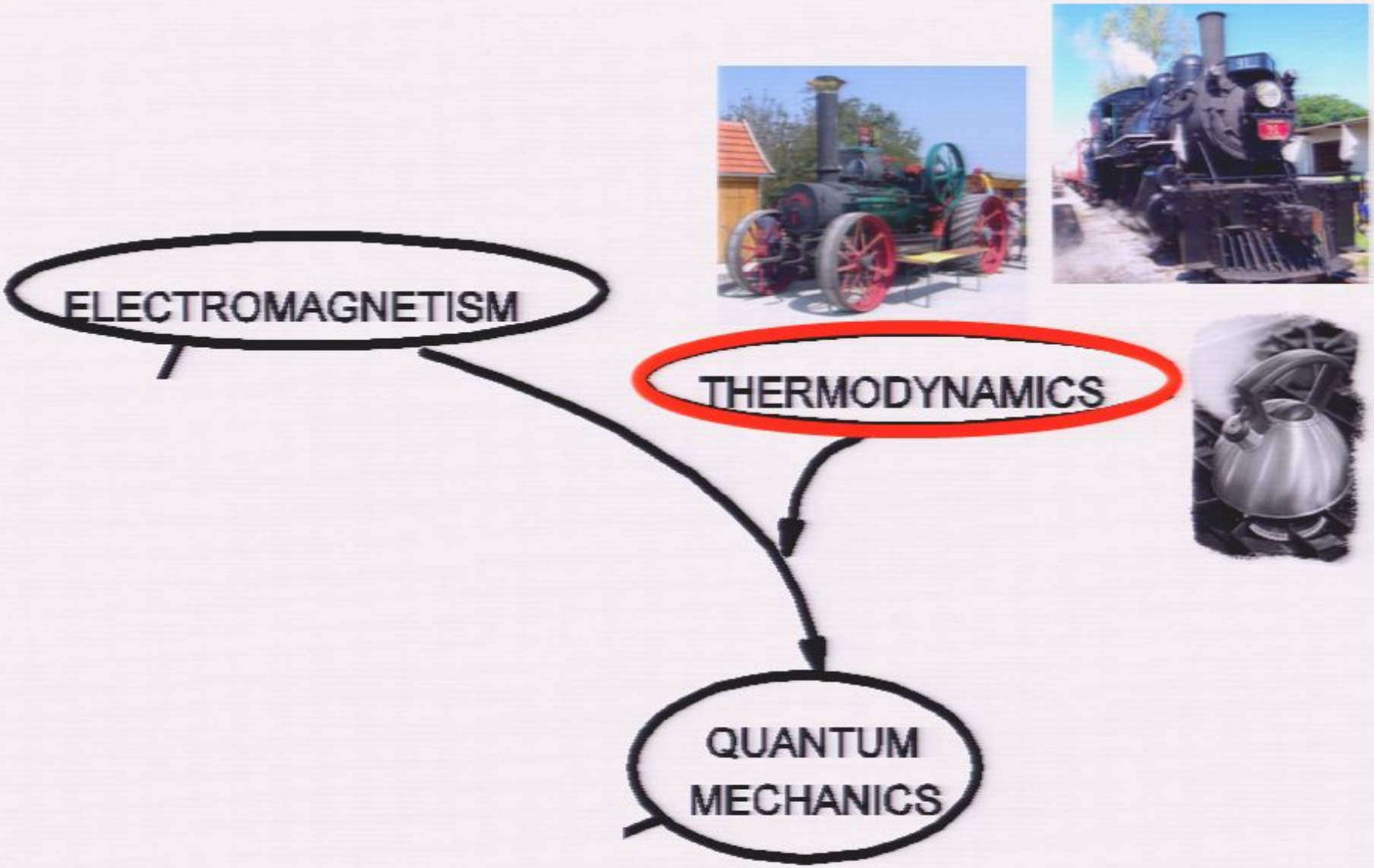
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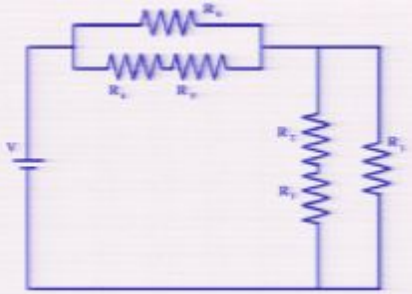

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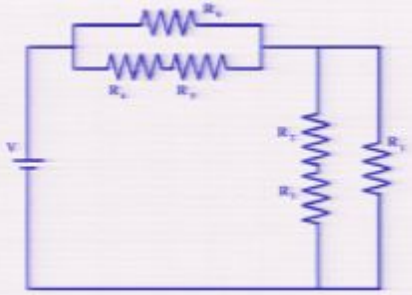

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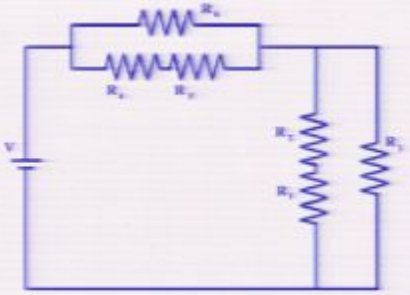

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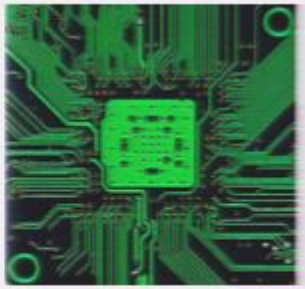

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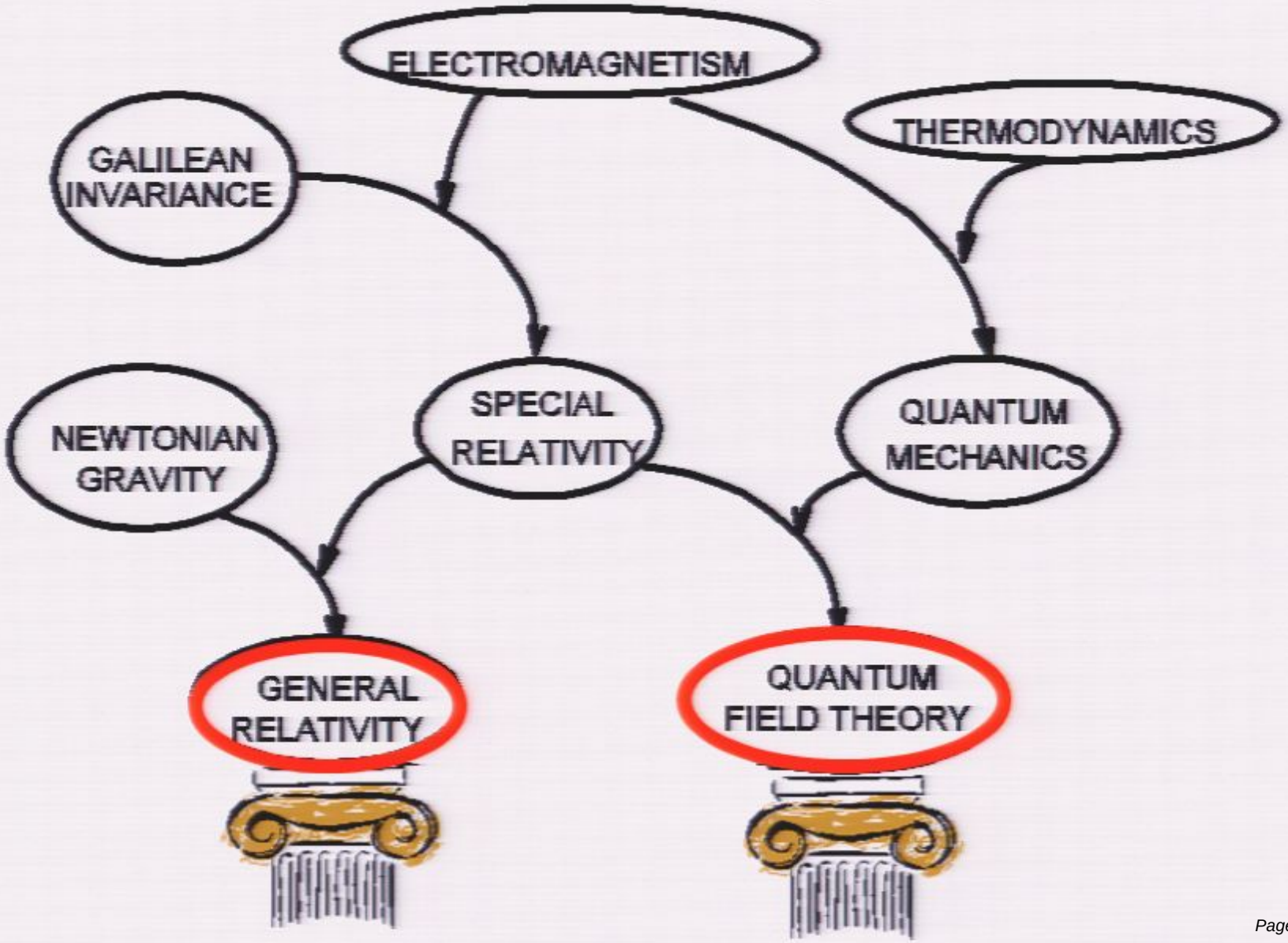
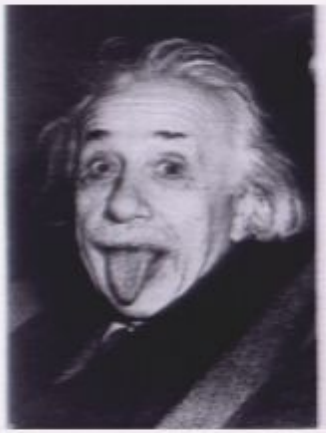


Einstein:



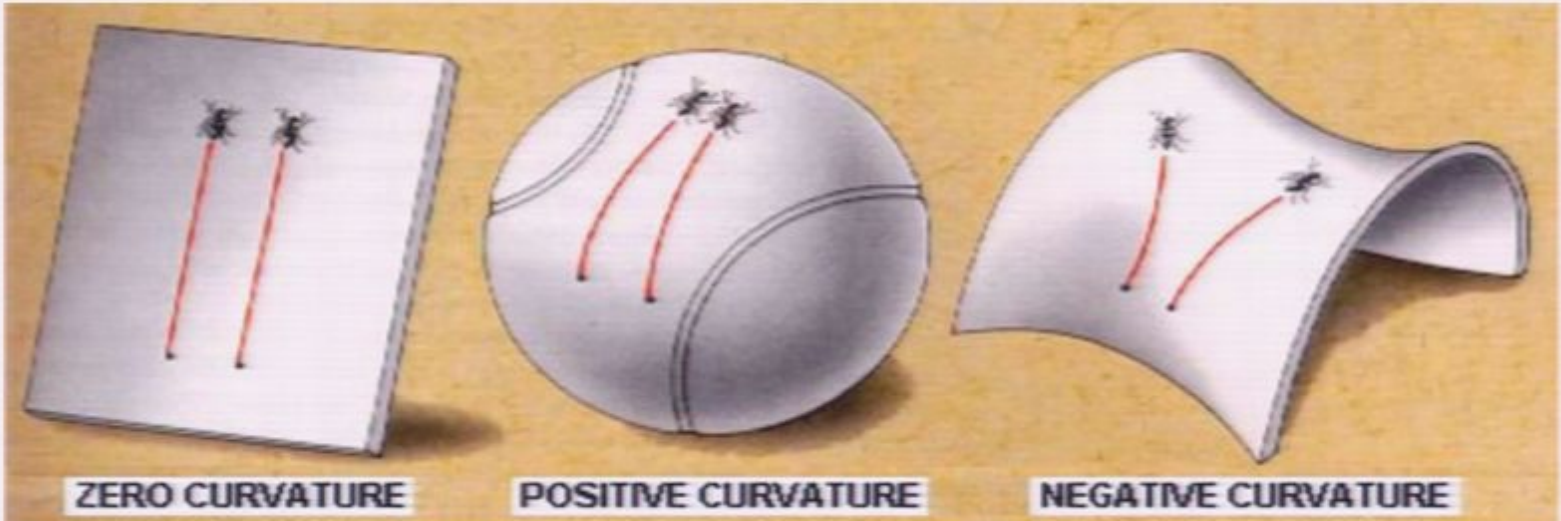
Gravity: It's all just straight lines!

Special Relativity (1905):

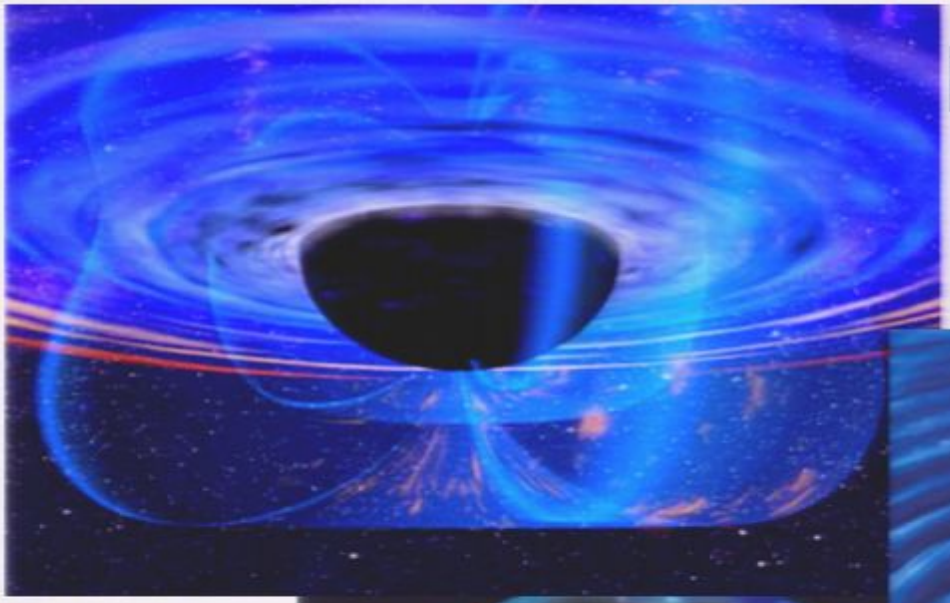
Space and time are inextricably linked ➡ Spacetime

General Relativity (1915):

Gravity is a manifestation of spacetime curvature.

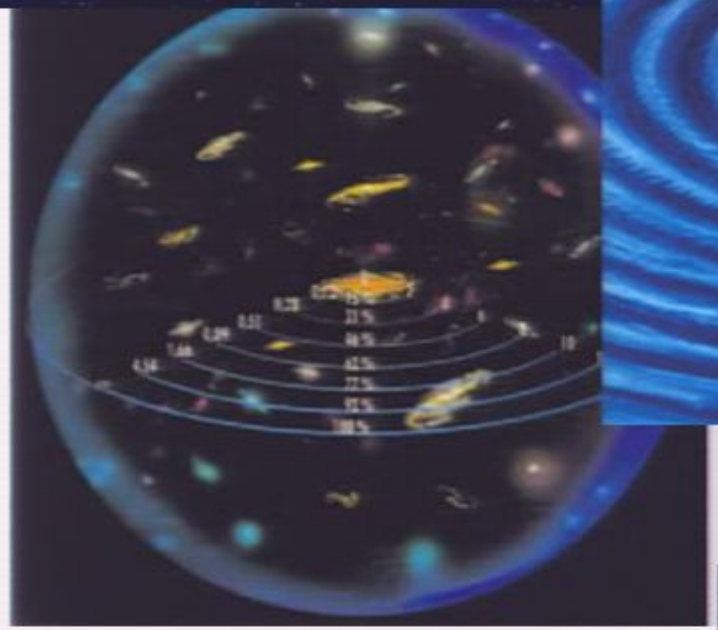


General Relativity: a rich source of new ideas



Black holes

Gravitational waves

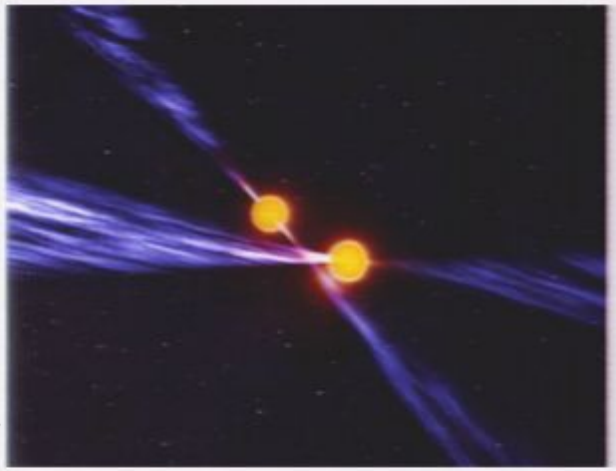


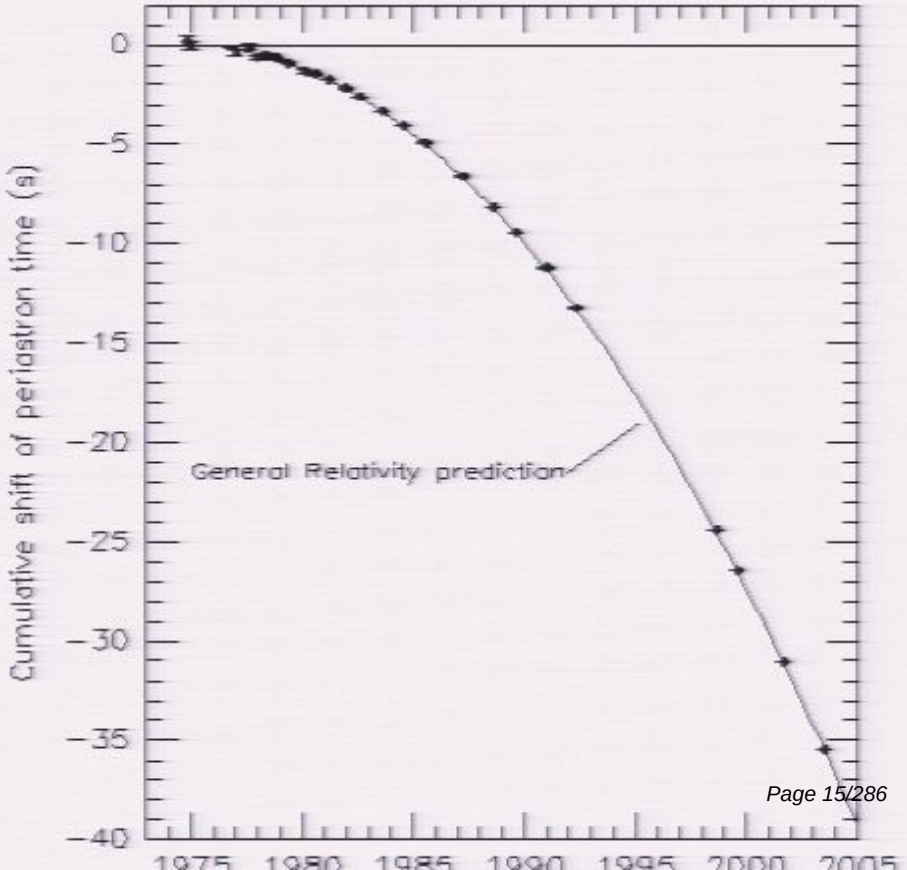
Expanding universe

General Relativity is rigorously tested!!

- Deflection of Light by the Sun
- Gravitational Redshift
- Precession of the Perihelion of Mercury
- Time Delay of Light, ...

Hulse and Taylor: Nobel Prize in 1993!!

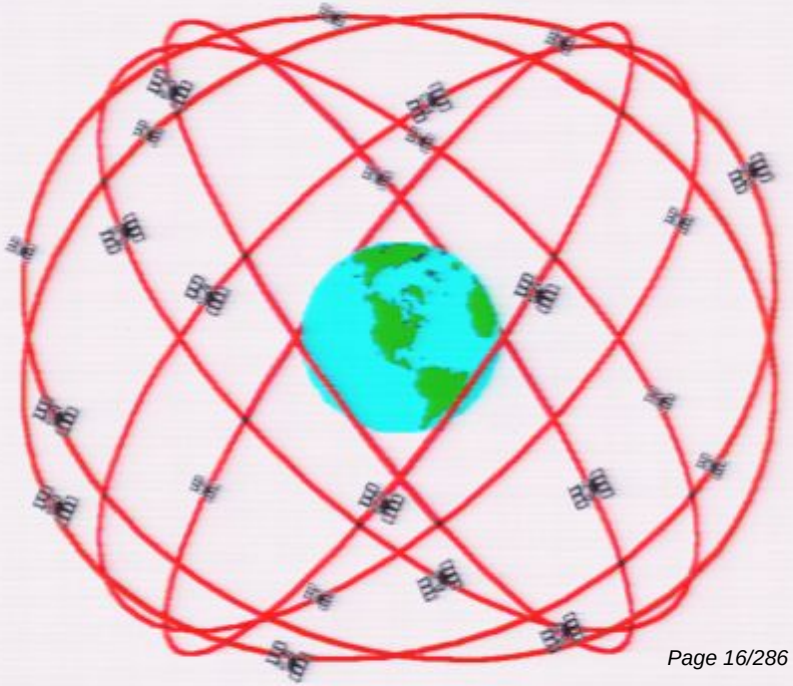




General Relativity is rigorously tested!!

Global Positioning System (GPS):

Accurate positioning requires accounting for affects of general relativity on clocks in orbit and on earth



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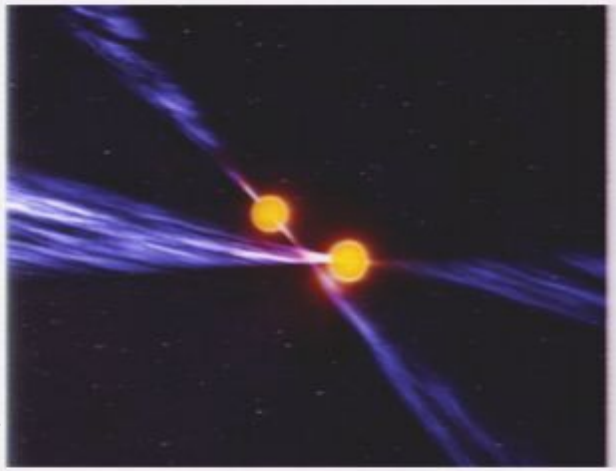

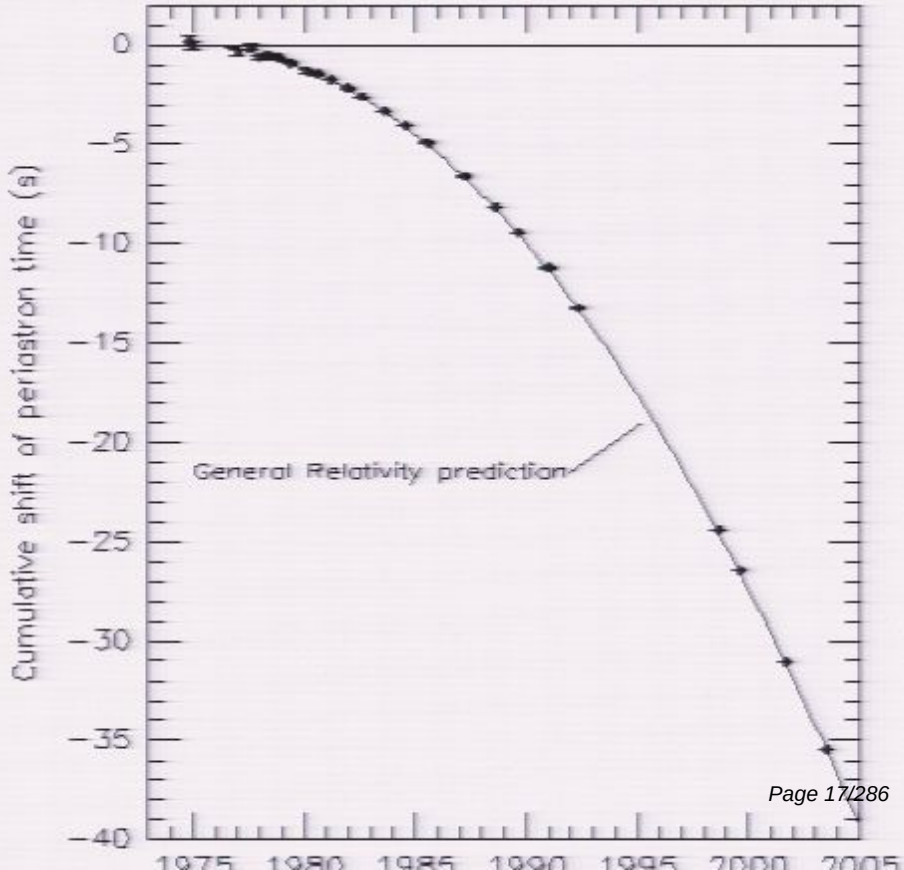

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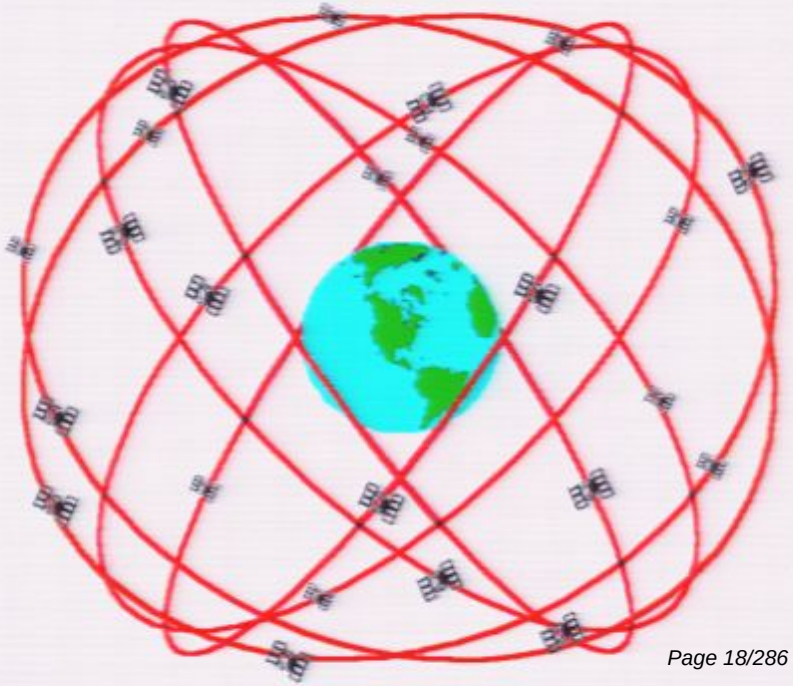

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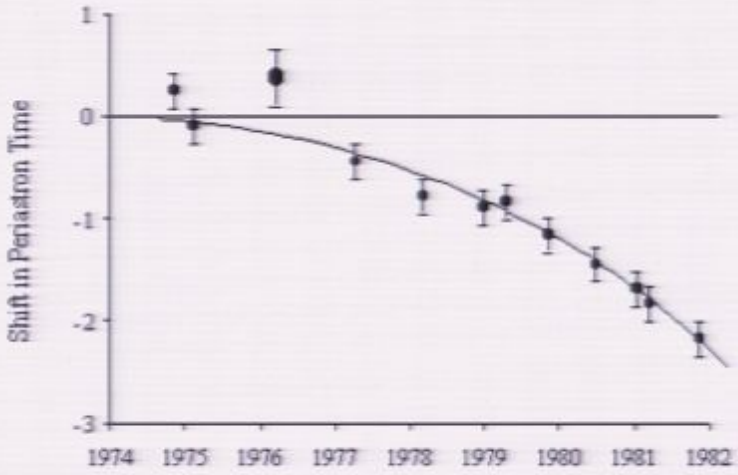
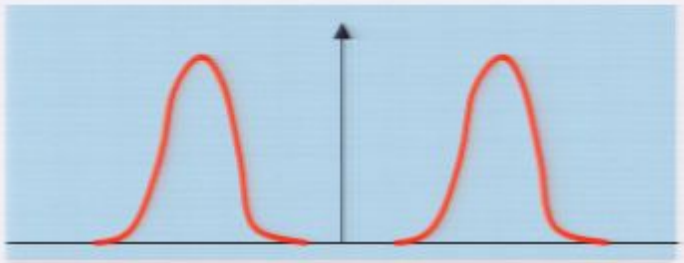


General Relativity is the geometric arena of physics on very large scales:

planets, stars, galaxies, cosmology

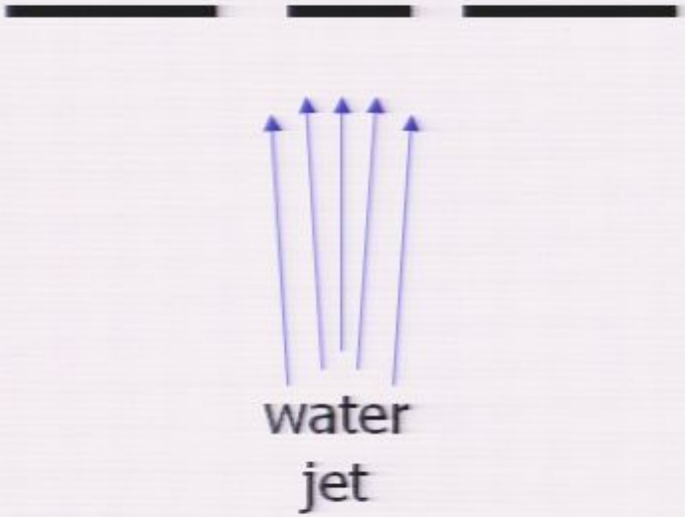
Quantum Mechanics (or Quantum Field Theory) is the probabilistic arena of physics on very small scales

Particles can act like waves!



de Broglie wavelength: $\lambda = \frac{2\pi\hbar}{p}$ ← Planck's constant

$$\lambda_{\text{rain drop}} \approx 4 \times 10^{-30}\,\text{m}$$



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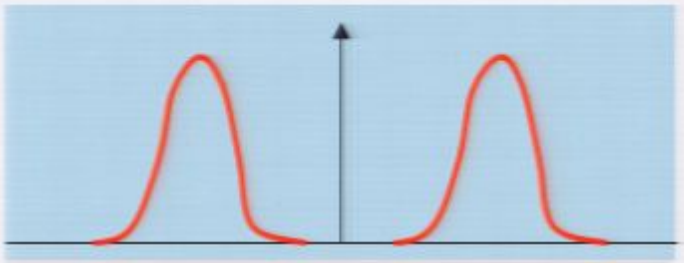

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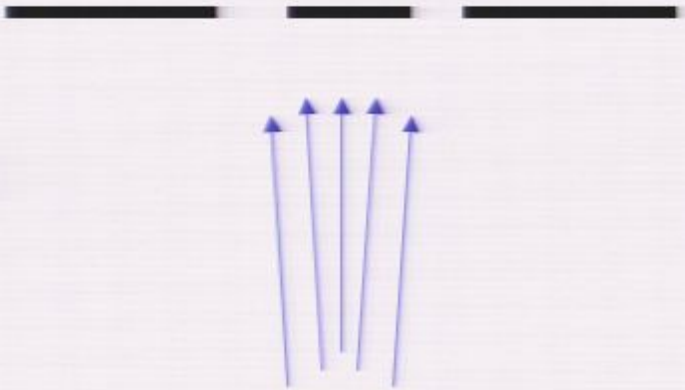
$$\approx .000000\cdots000004\,\text{m}$$

30 digits



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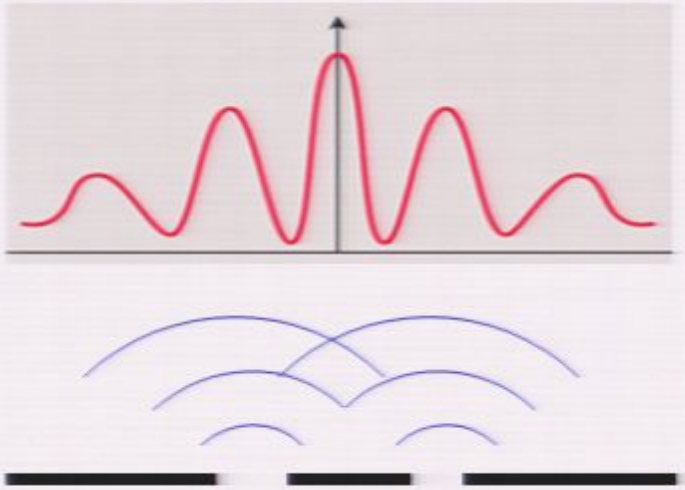
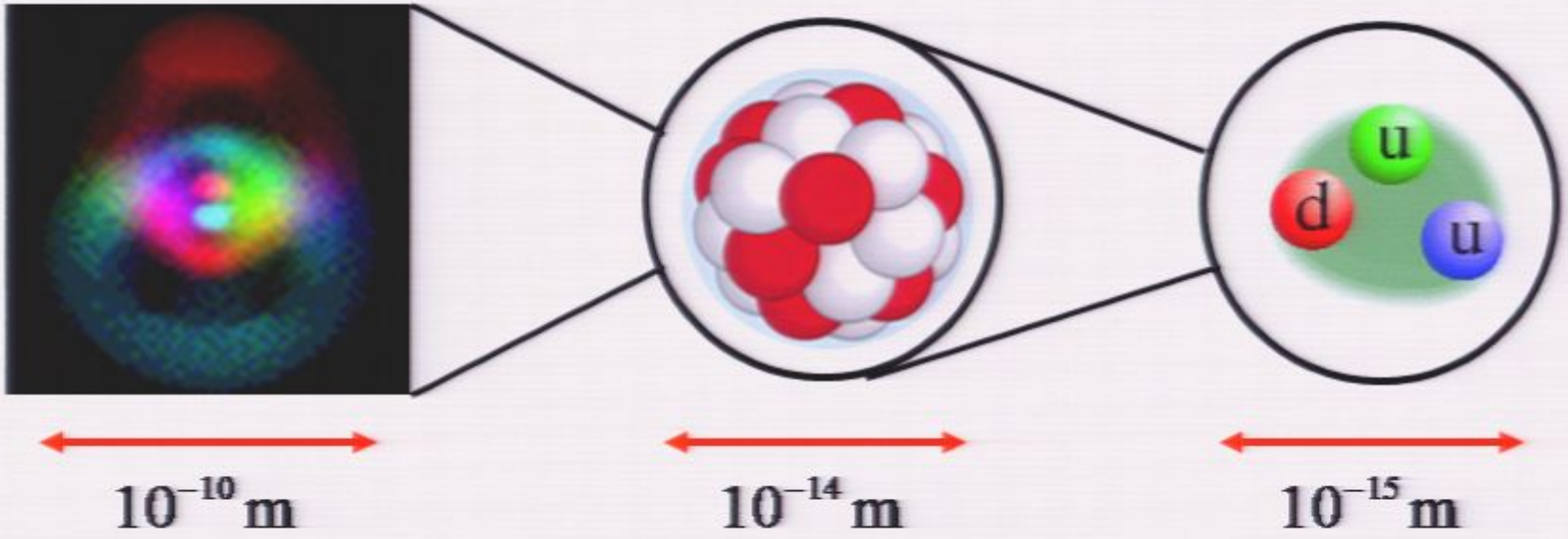


$$\lambda_{\text{rain drop}} \approx 4\times10^{-30}\,\text{m}$$

$$\lambda_{\text{electron}} \approx 3\times10^{-10}\,\text{m} = 3\ \text{Å}$$

Quantum fluctuations are manifest in behavior of subatomic particles

Quantum Field Theory is the probabilistic arena of physics on very small scales



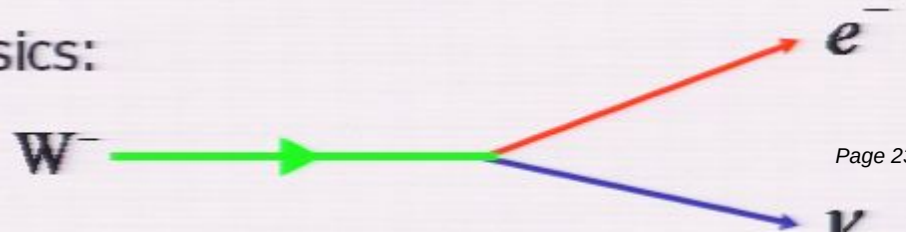
Elementary Particles (10^{-17} m)

Fermions:
- electron, muon, tauon
- neutrinos (3 flavors)
- quarks - up, down, strange, charm, bottom, top

Bosons (Force Mediators):
- photon (electromagnetism)
- gluon (strong)
- $W^{\pm}$, Z (weak)
- Higgs particle

Standard Model of Subatomic Physics:

above particles plus interactions (and ~20 free parameters)



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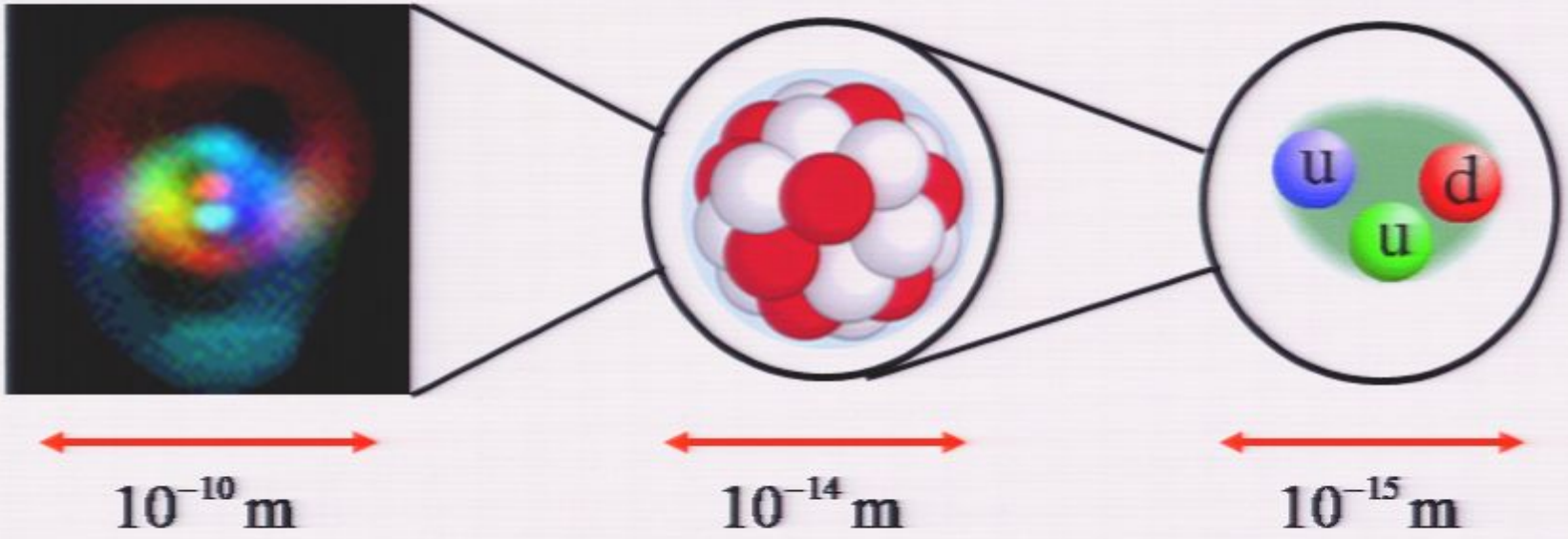

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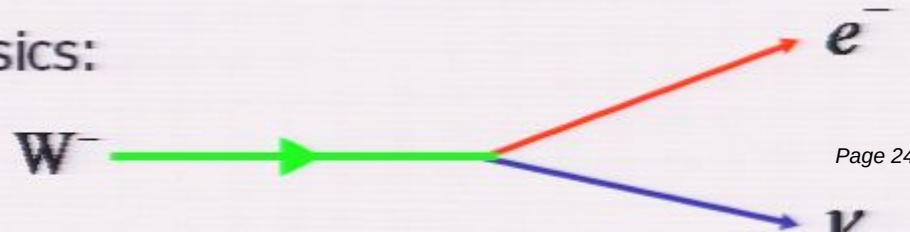

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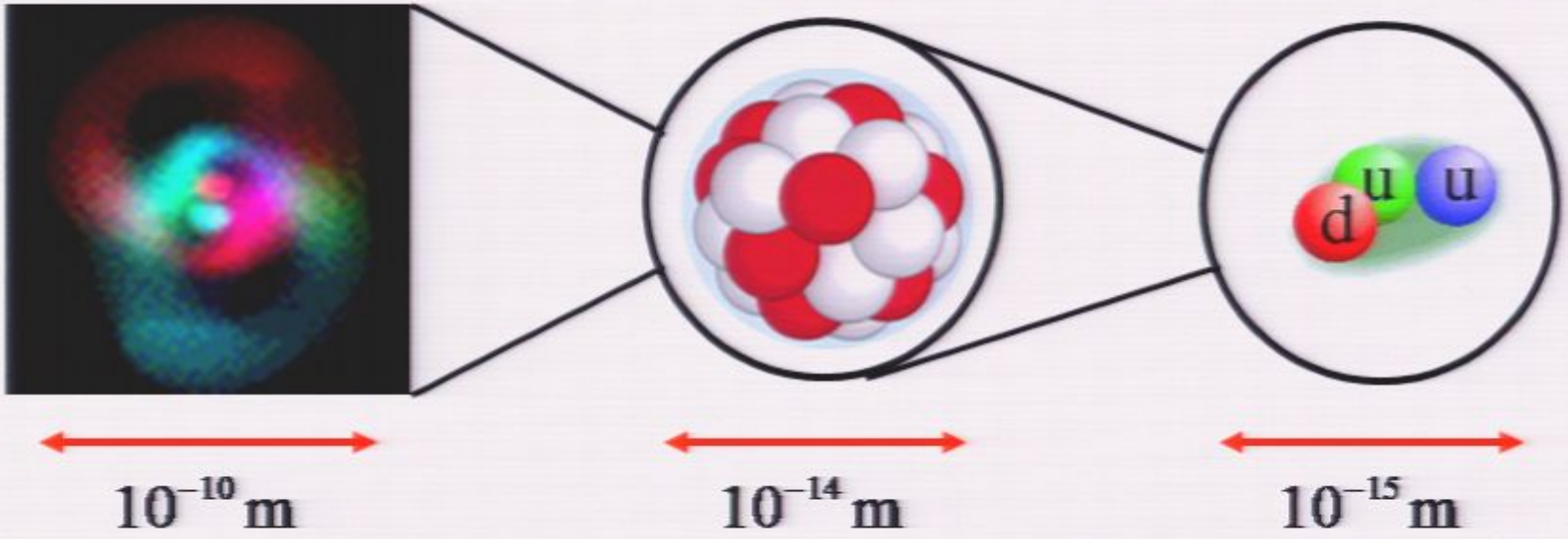

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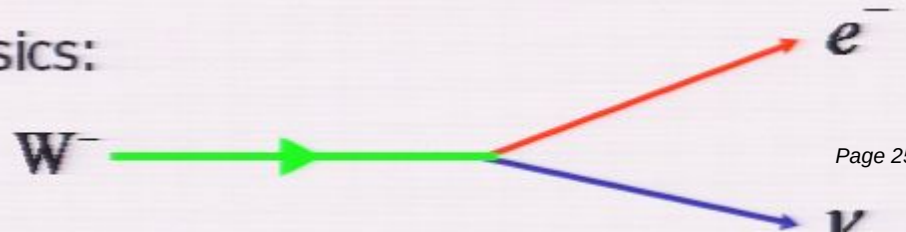

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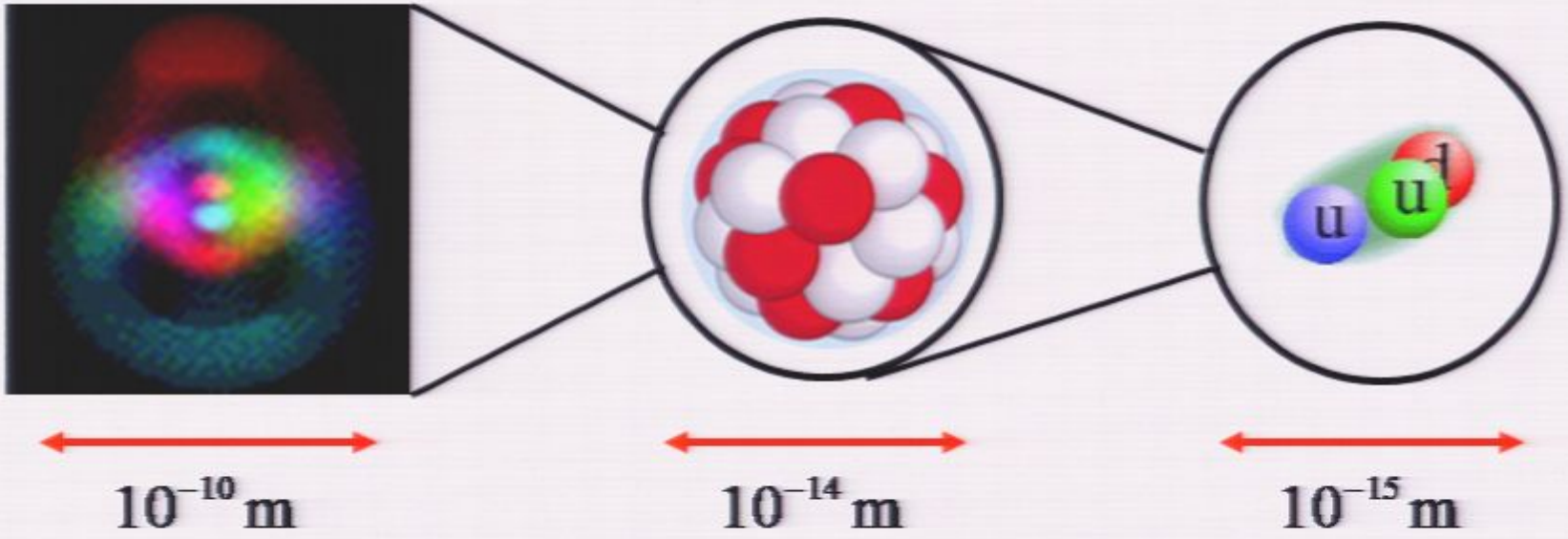

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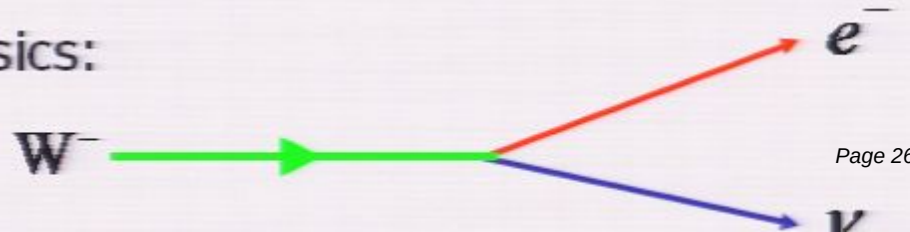

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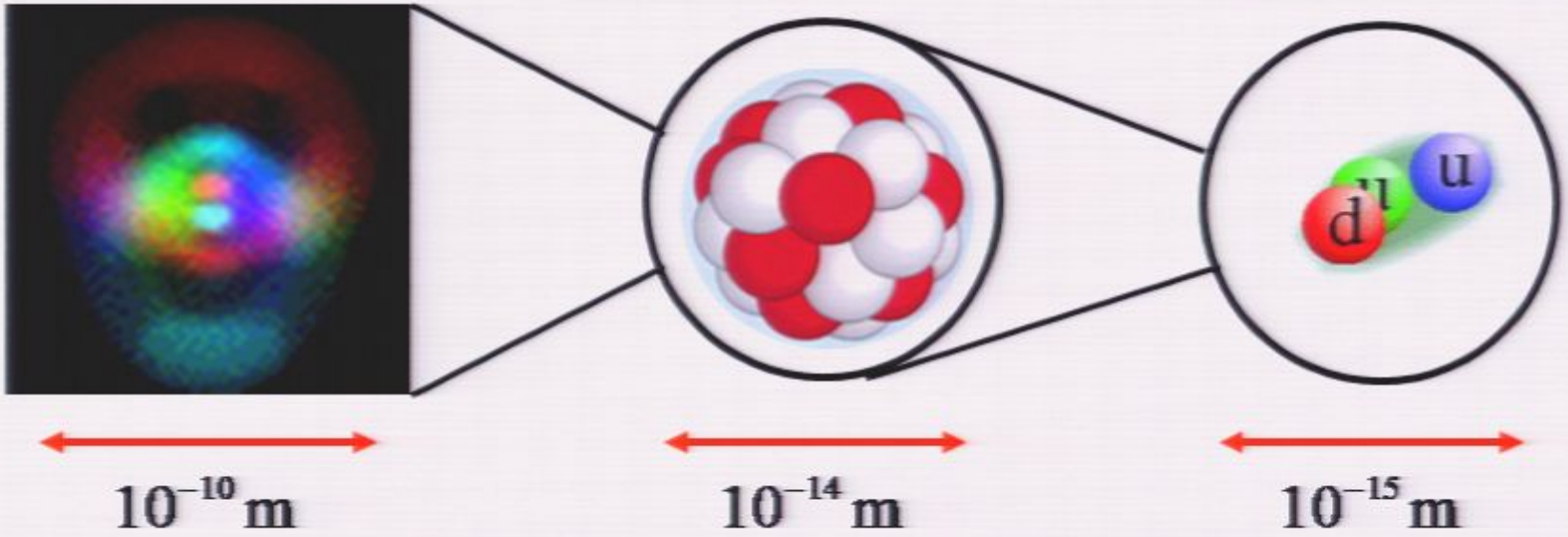

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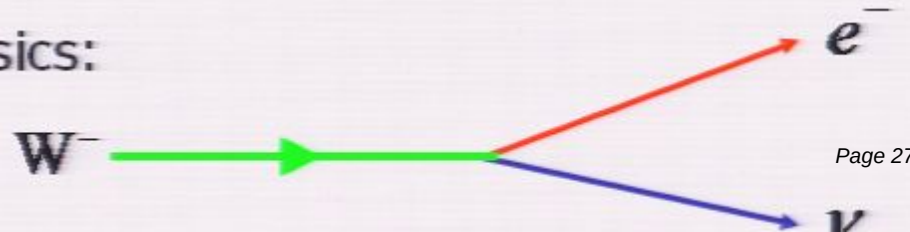

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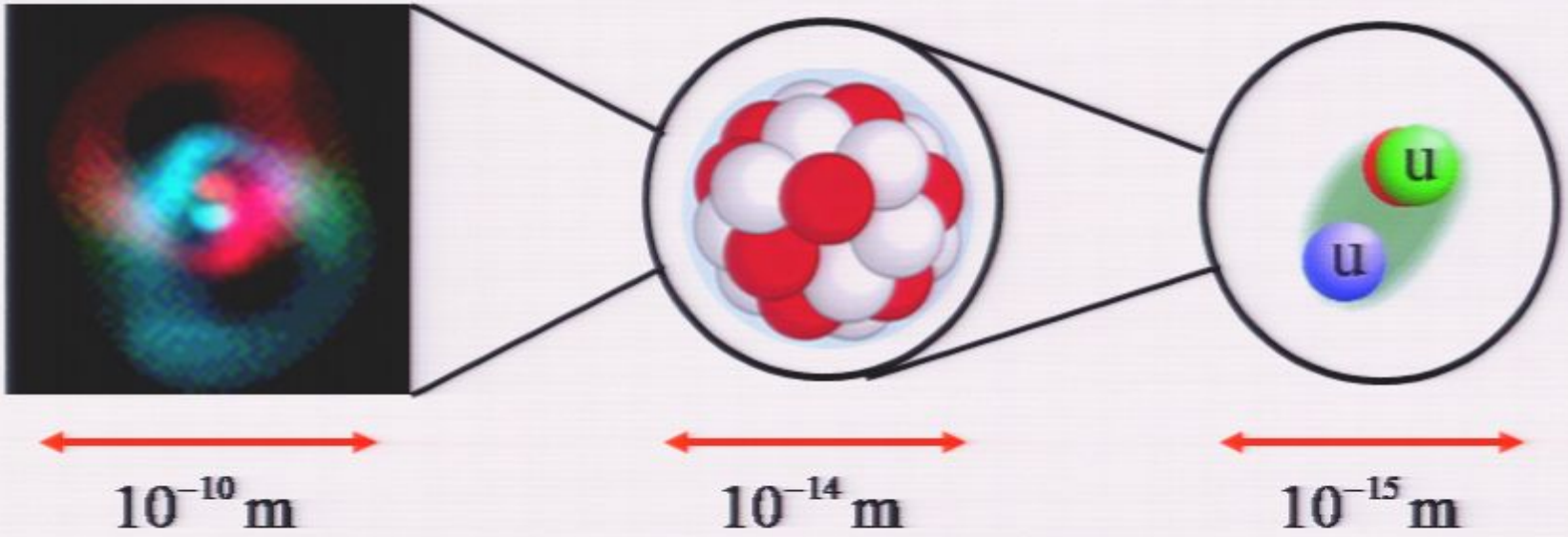

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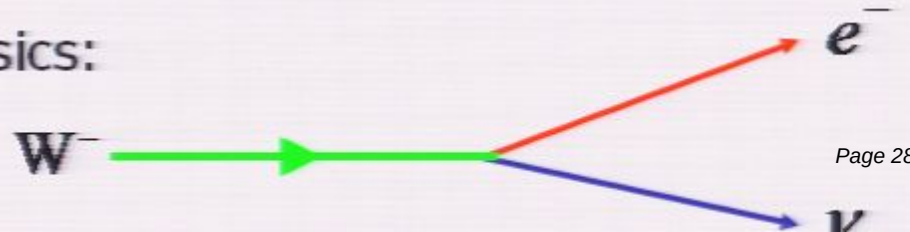

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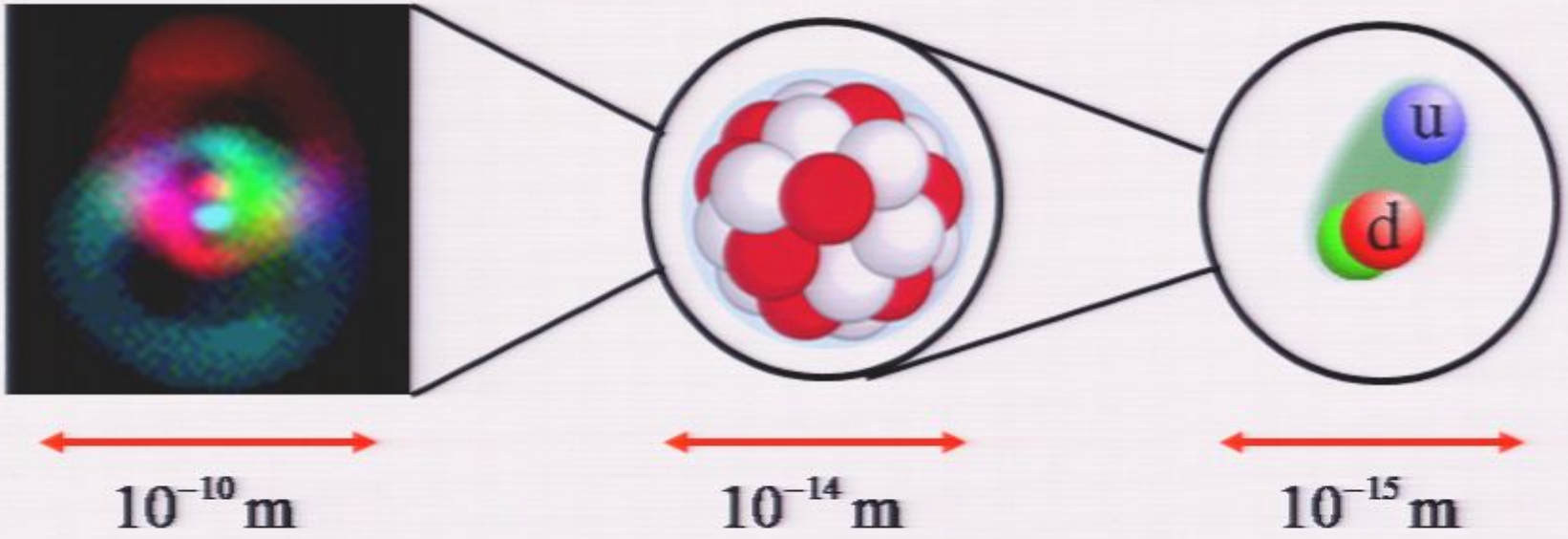

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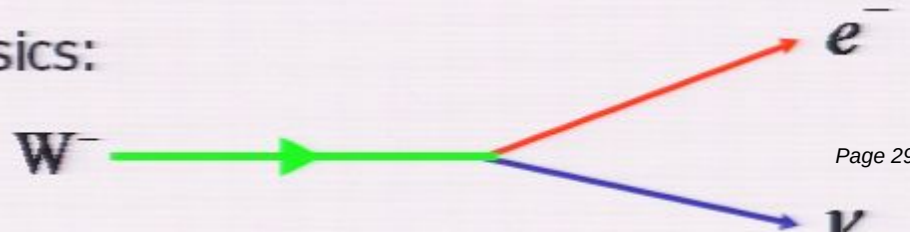
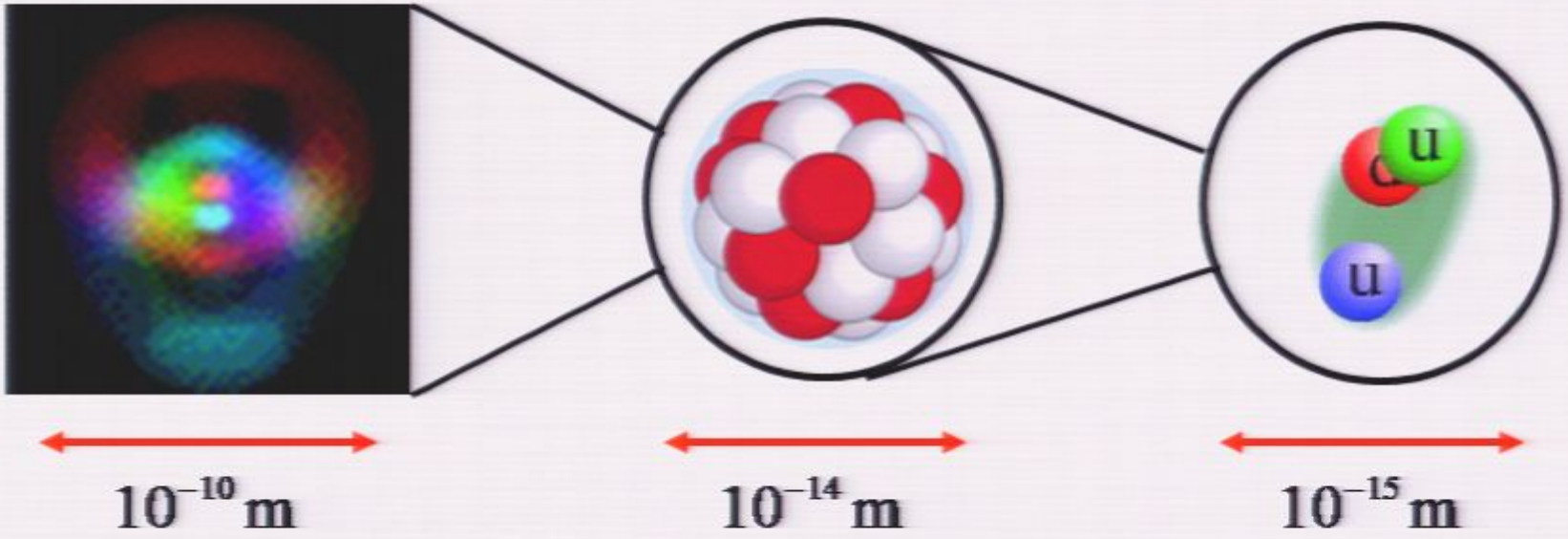


Quantum Field Theory is the probabilistic arena of physics on very small scales



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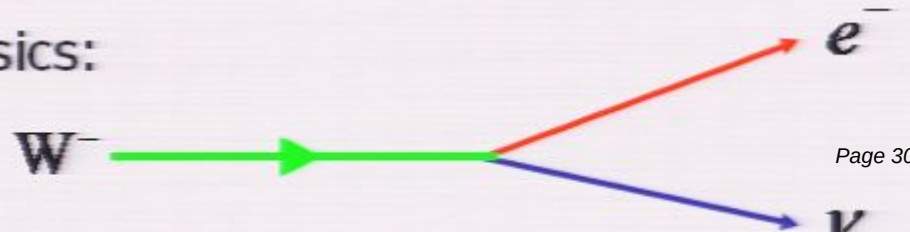

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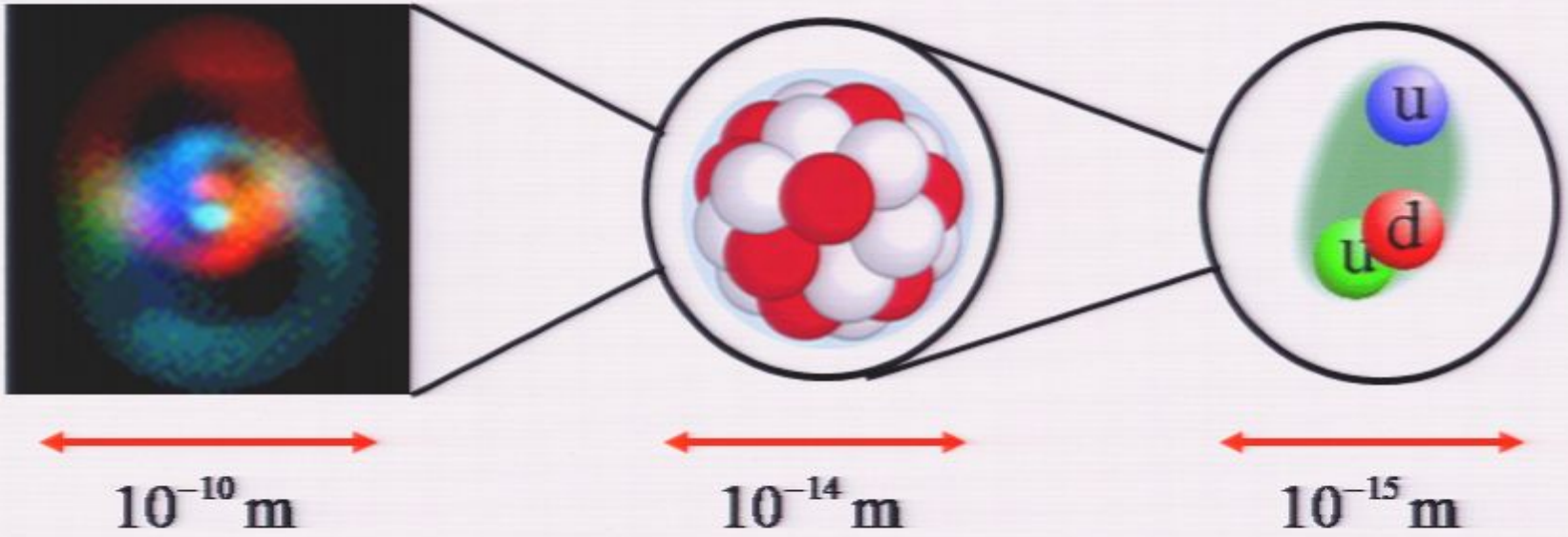

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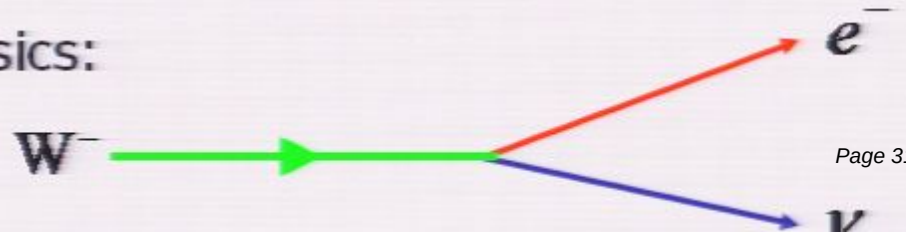

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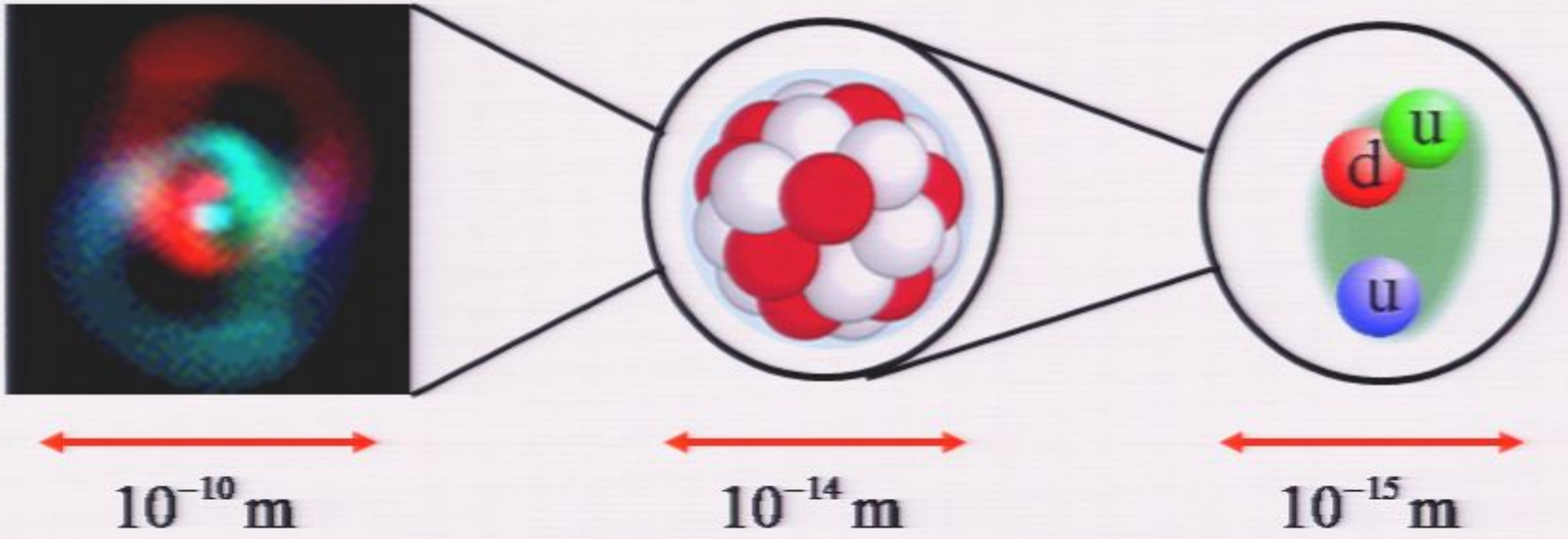

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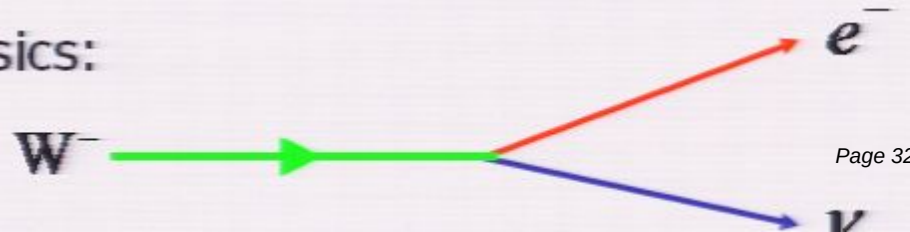

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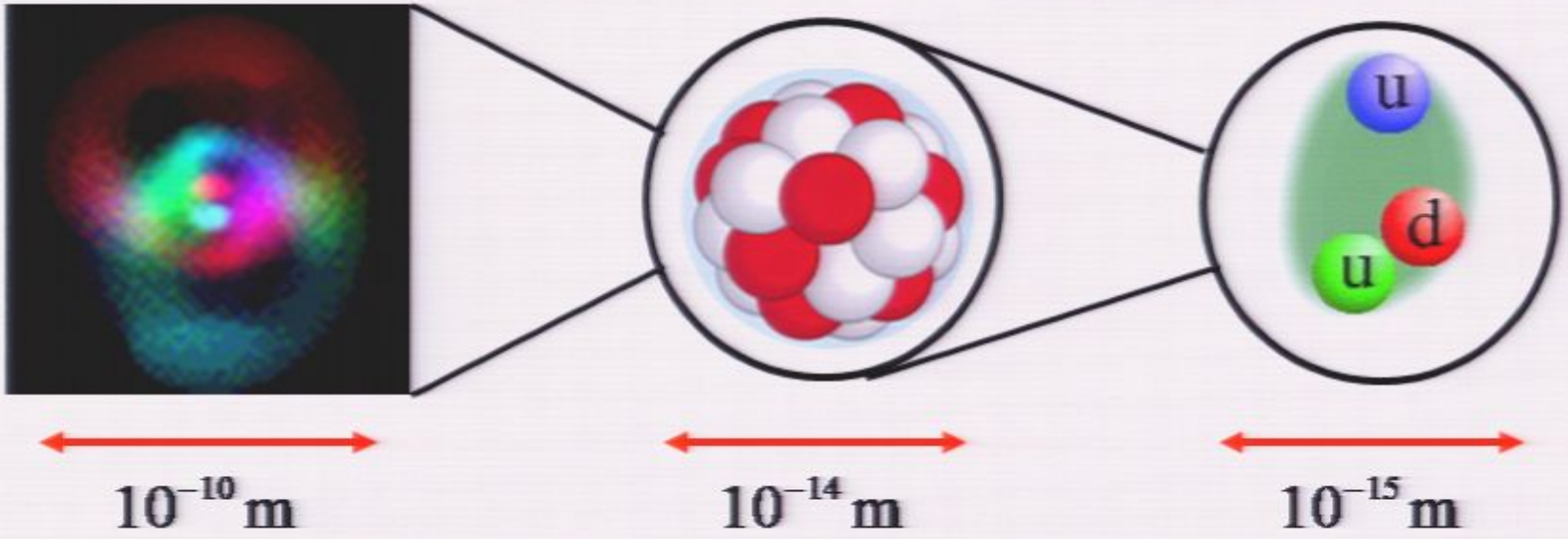

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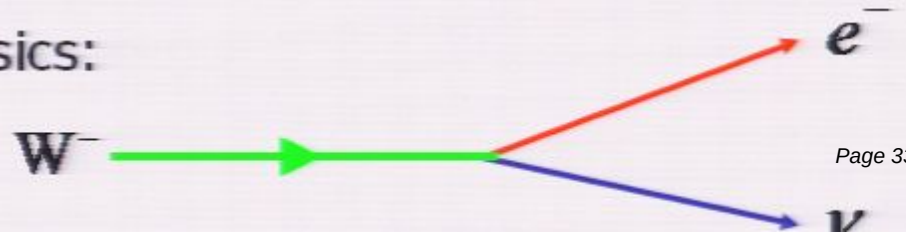

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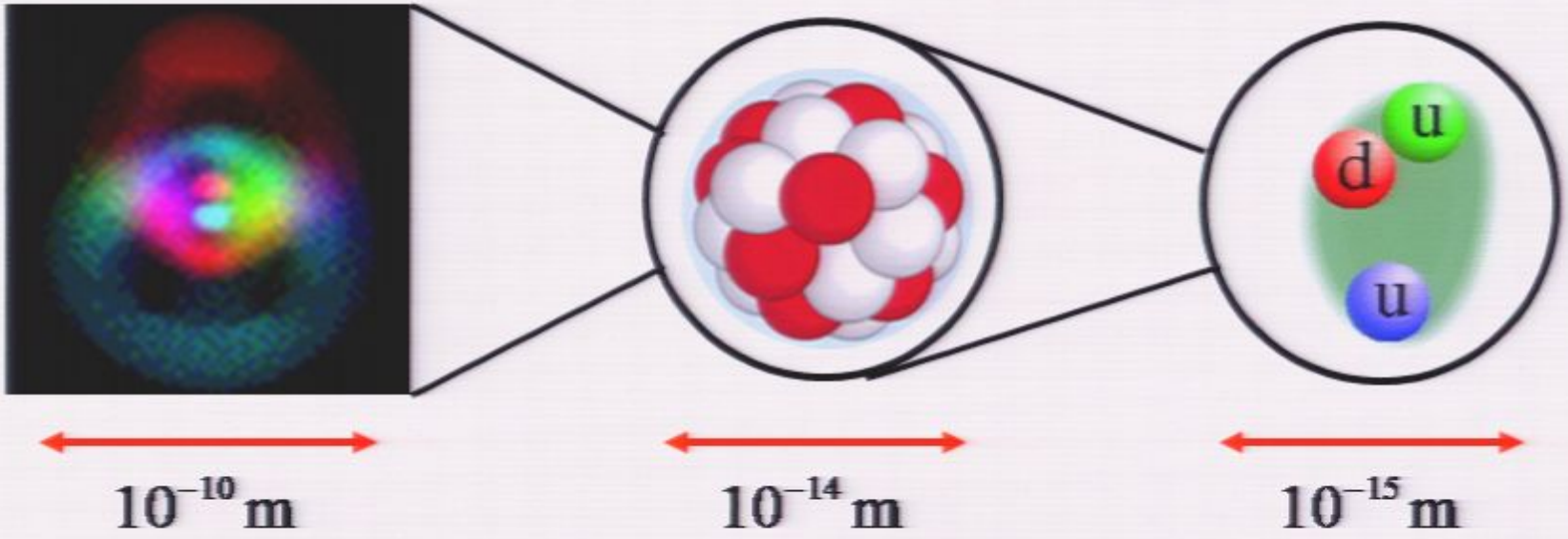

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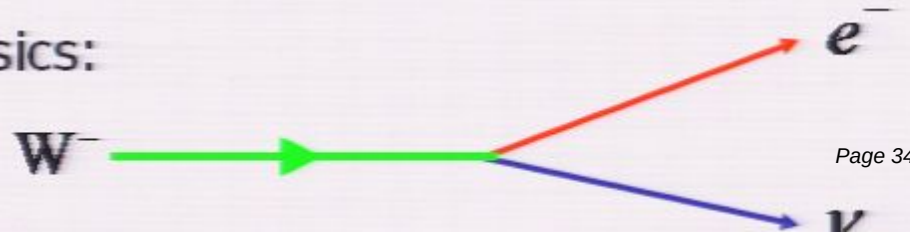

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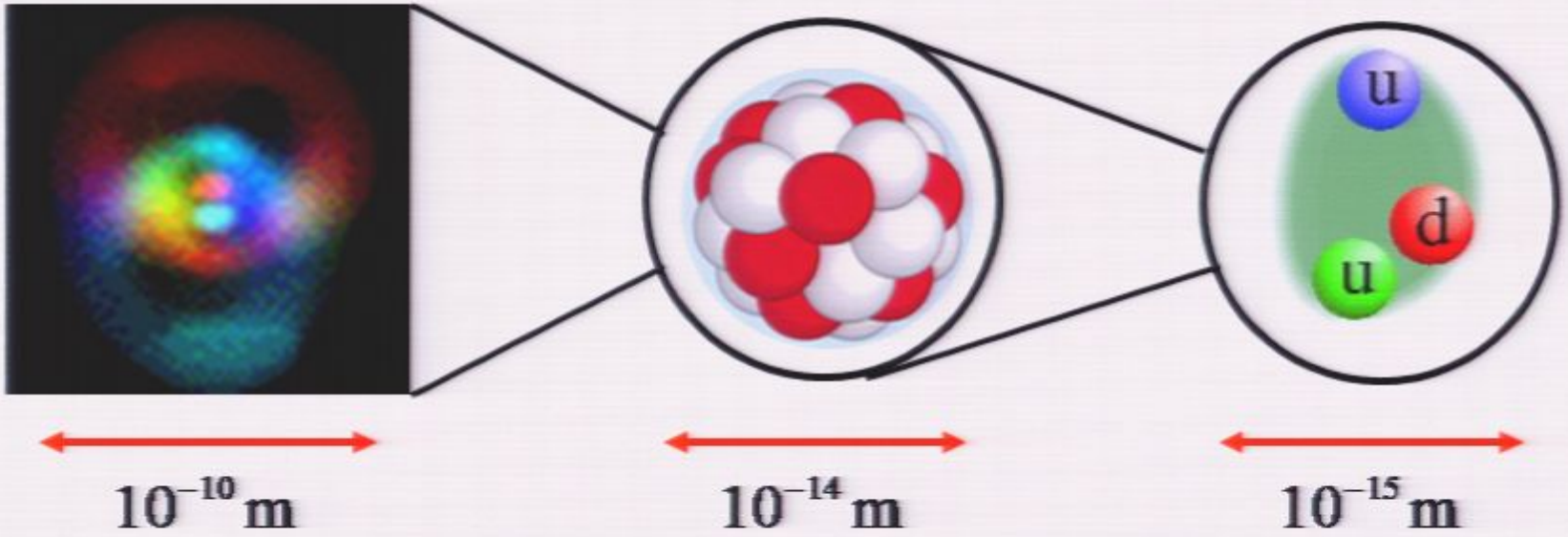

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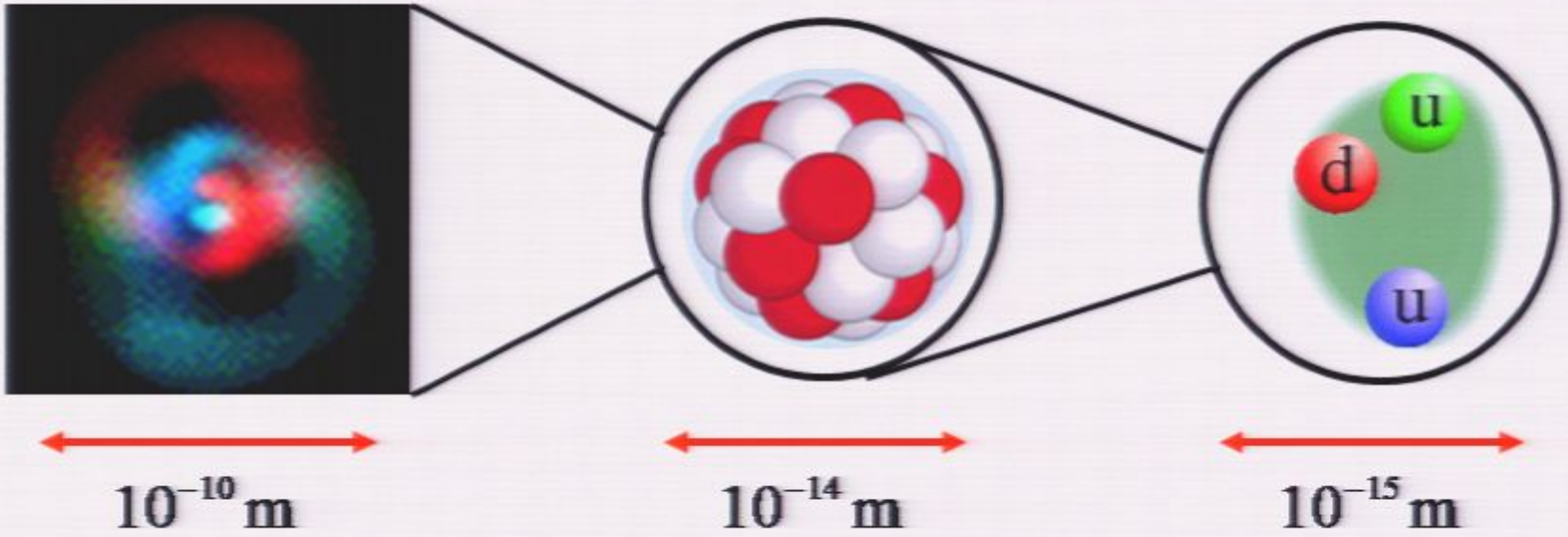

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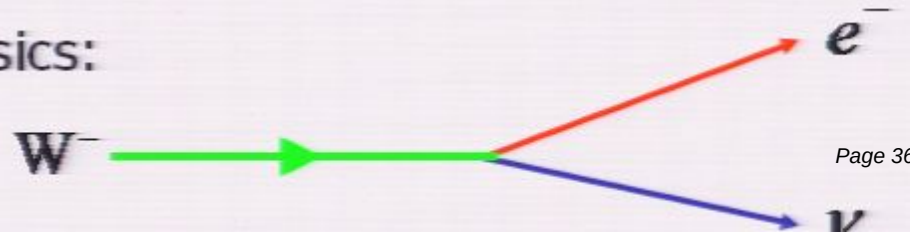

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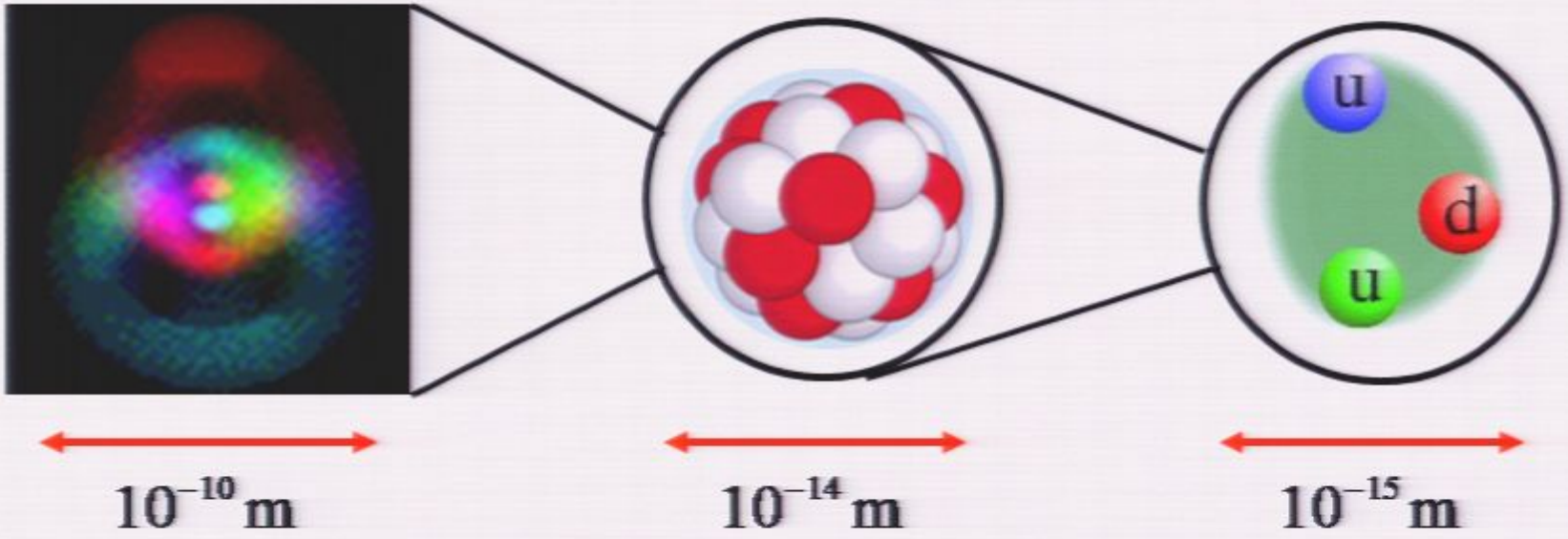

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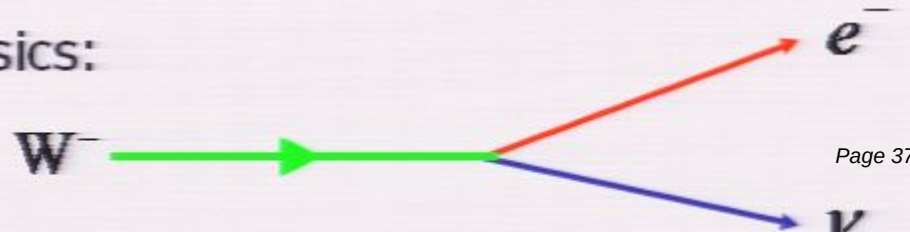

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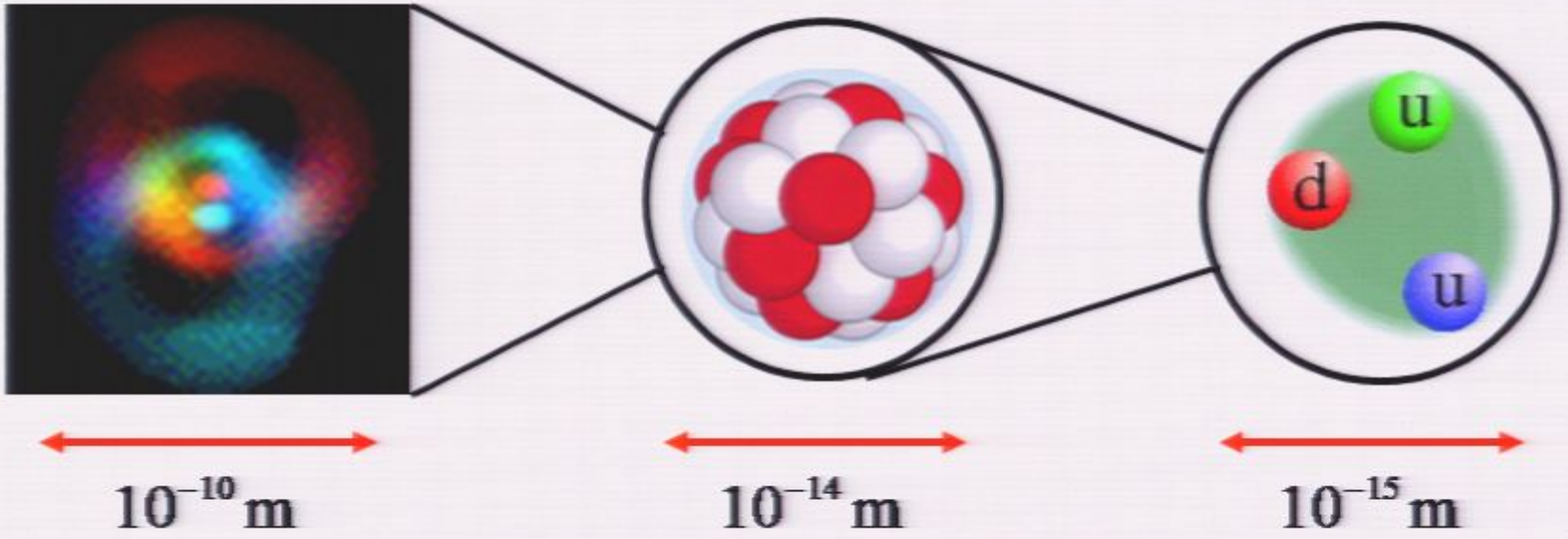

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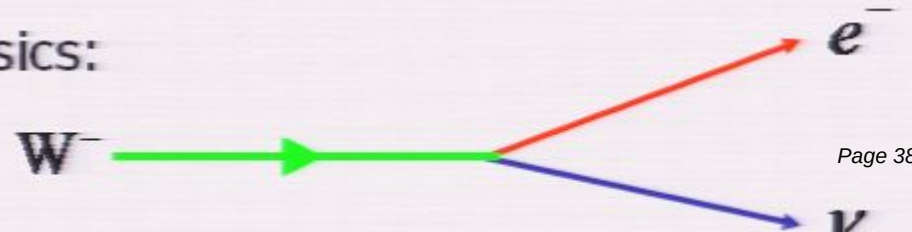

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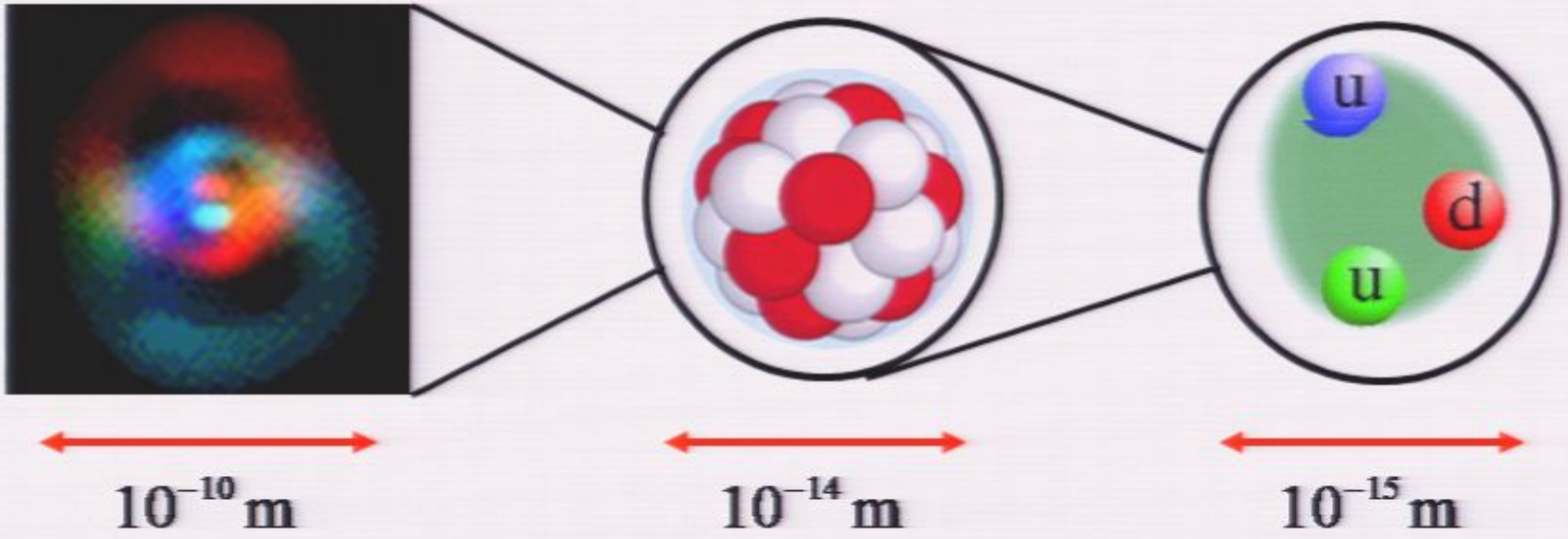

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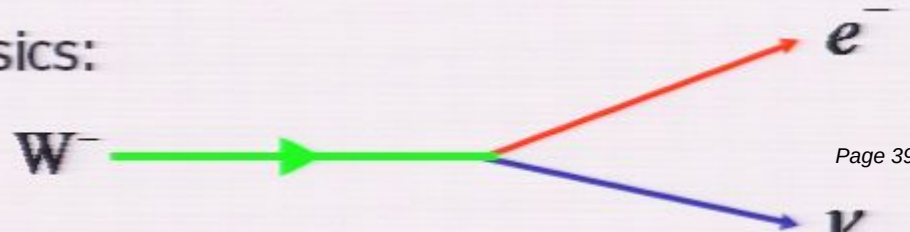

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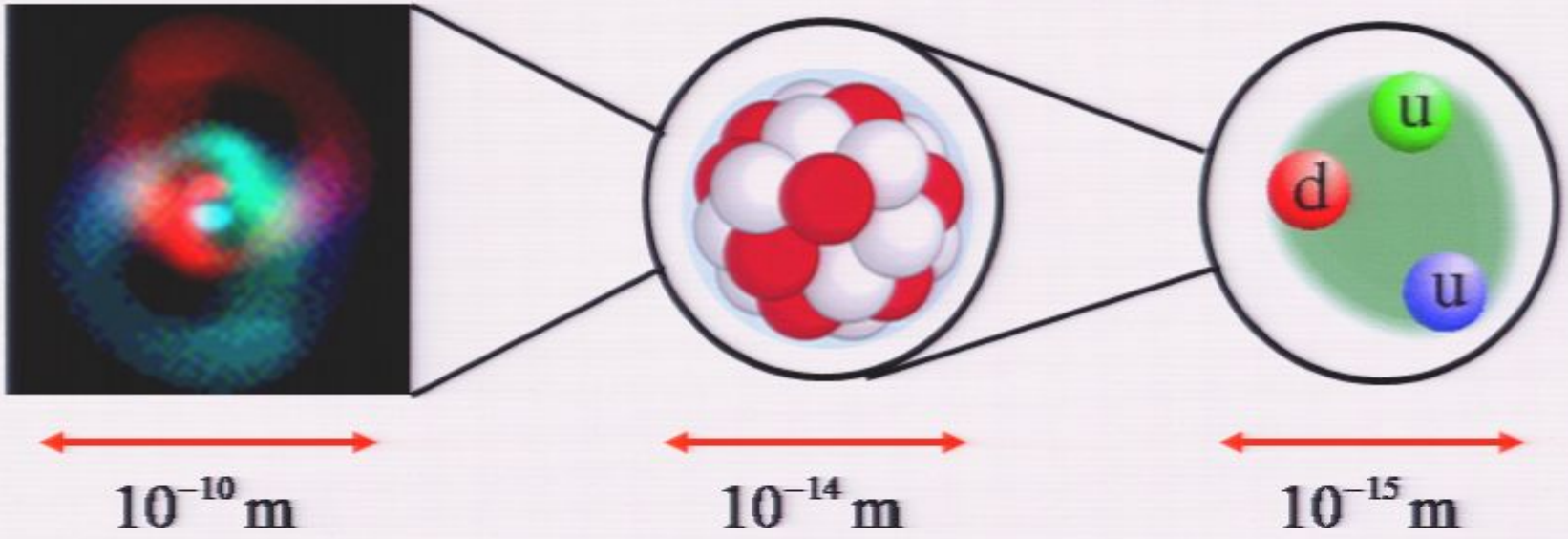

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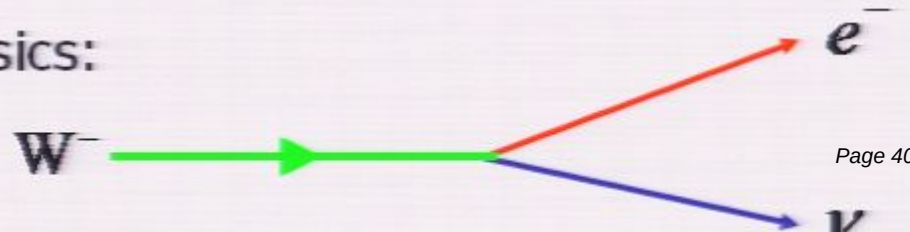

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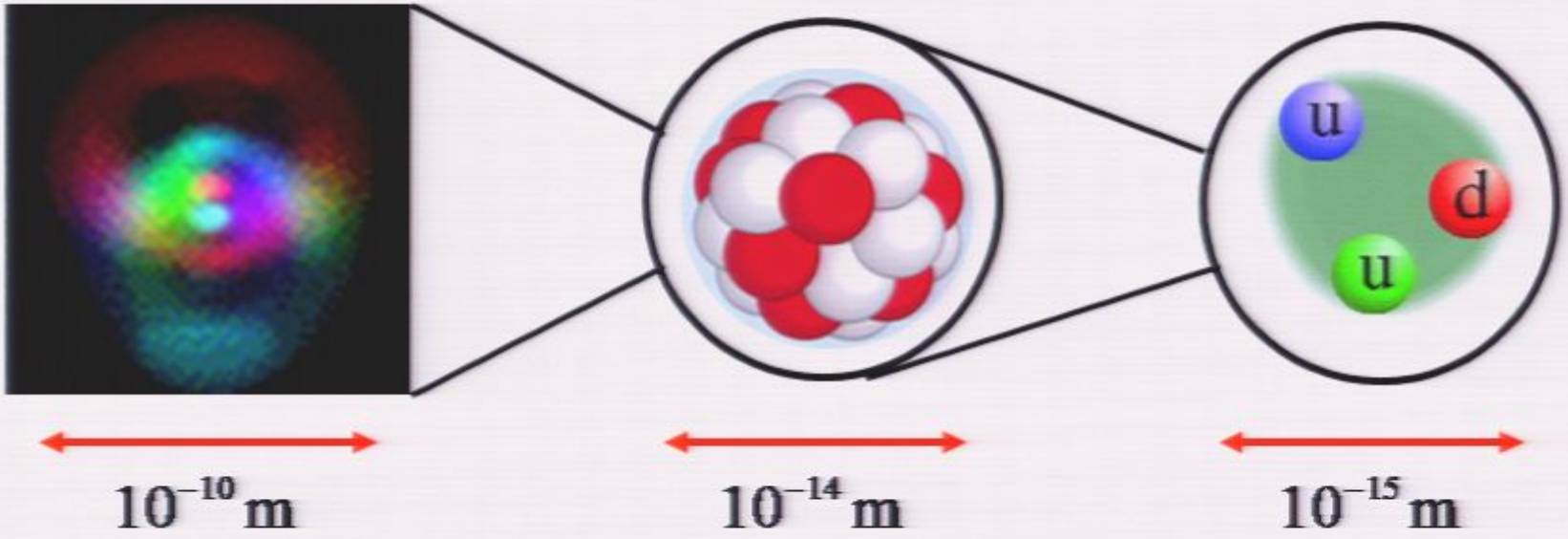

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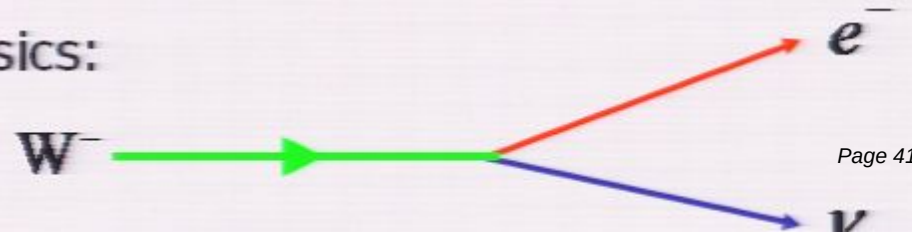

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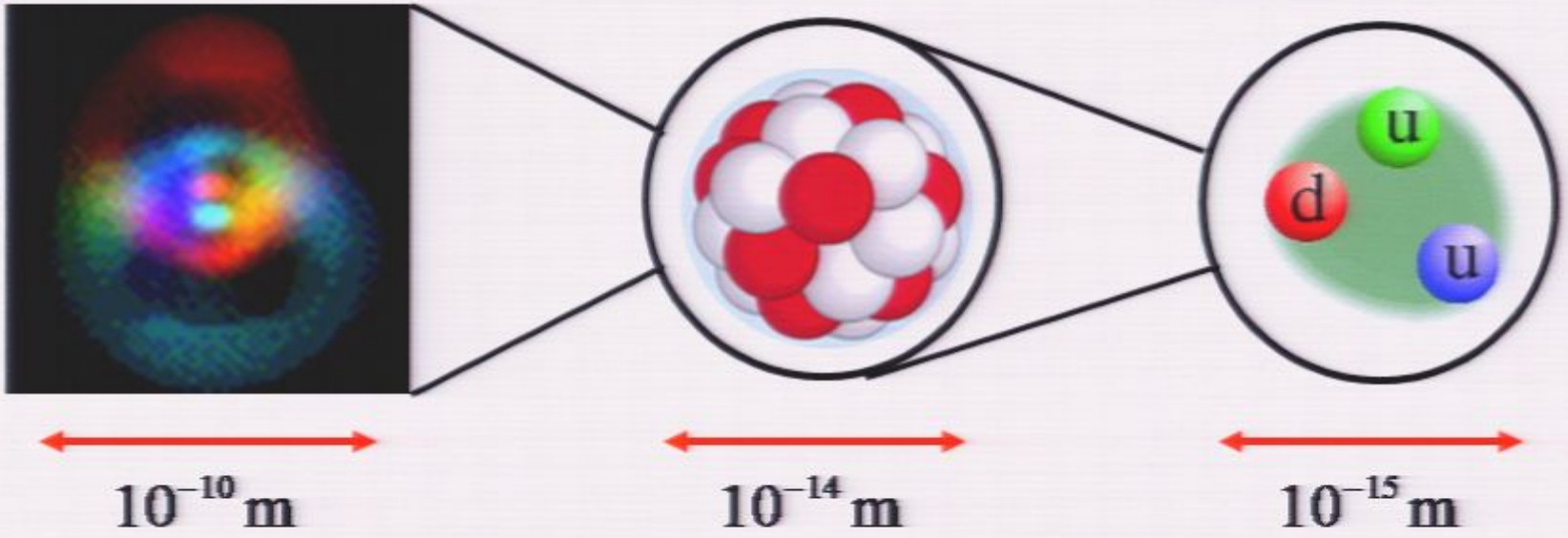

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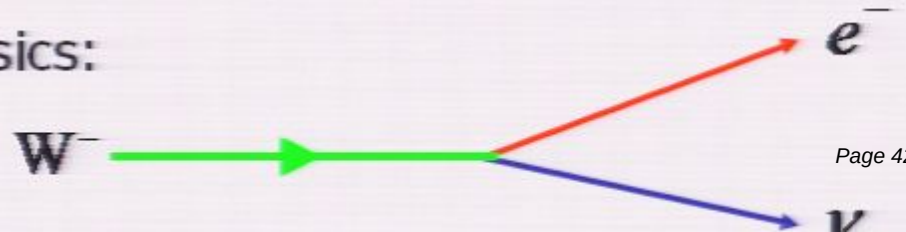

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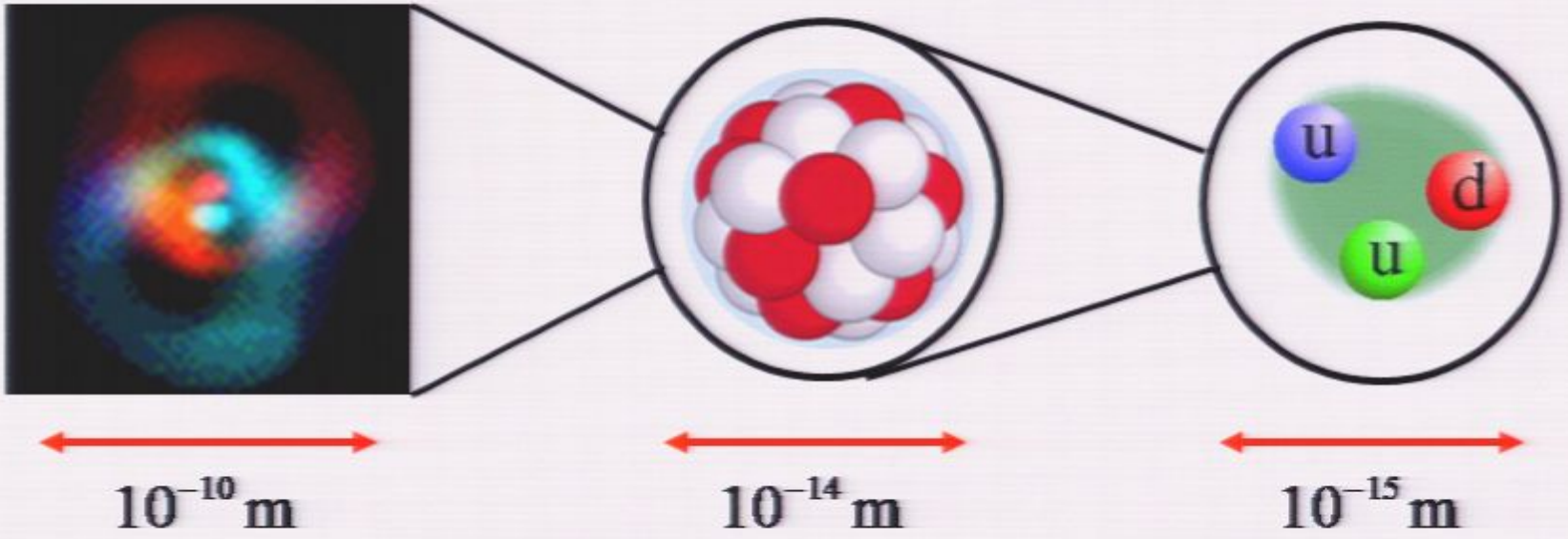

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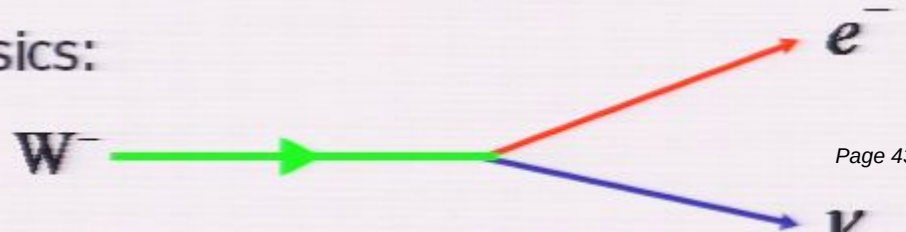

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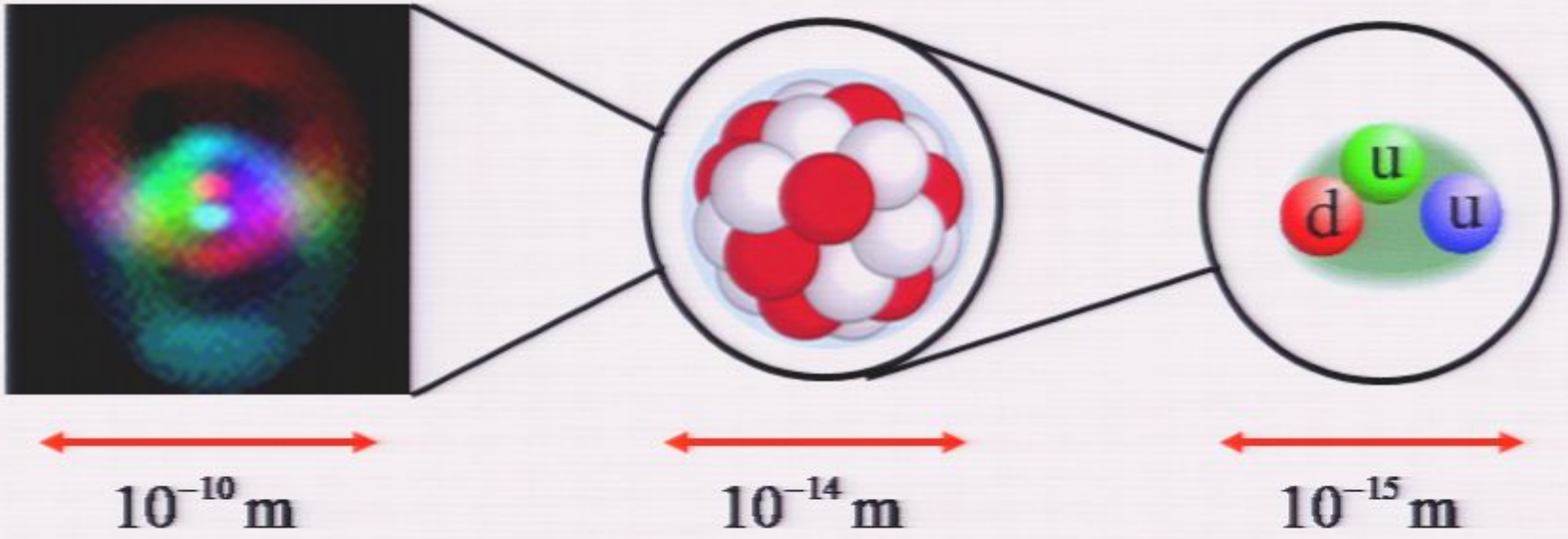

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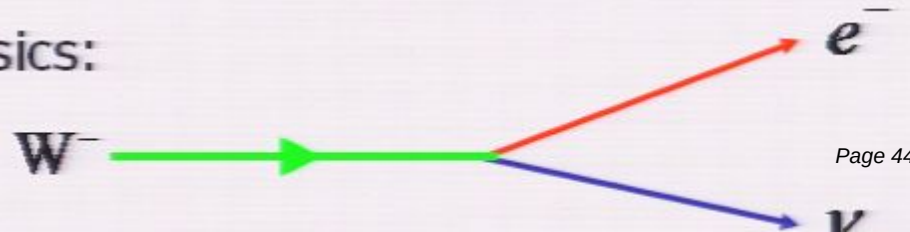

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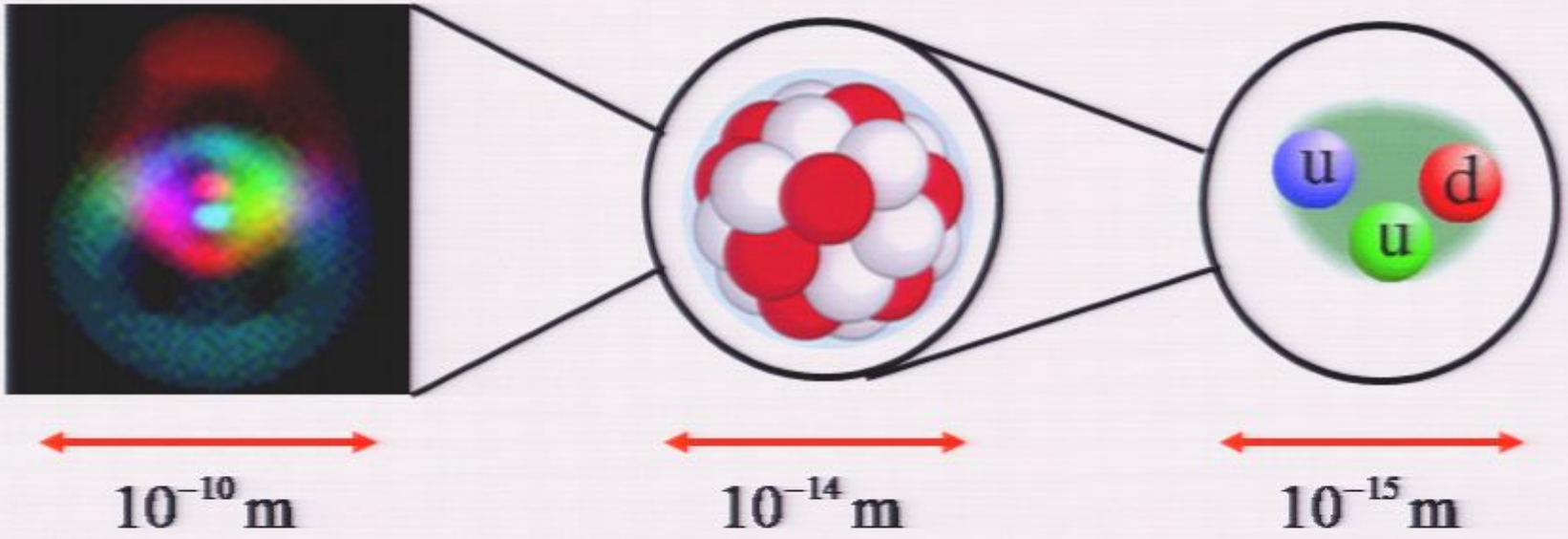

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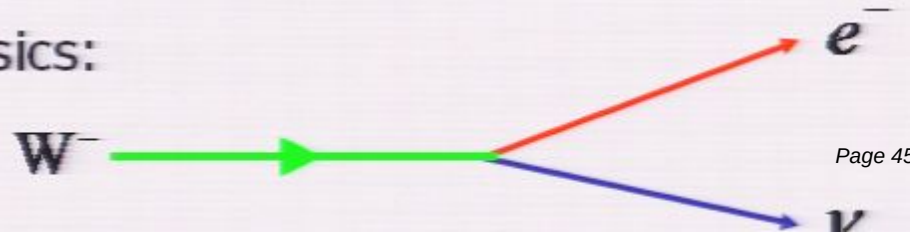

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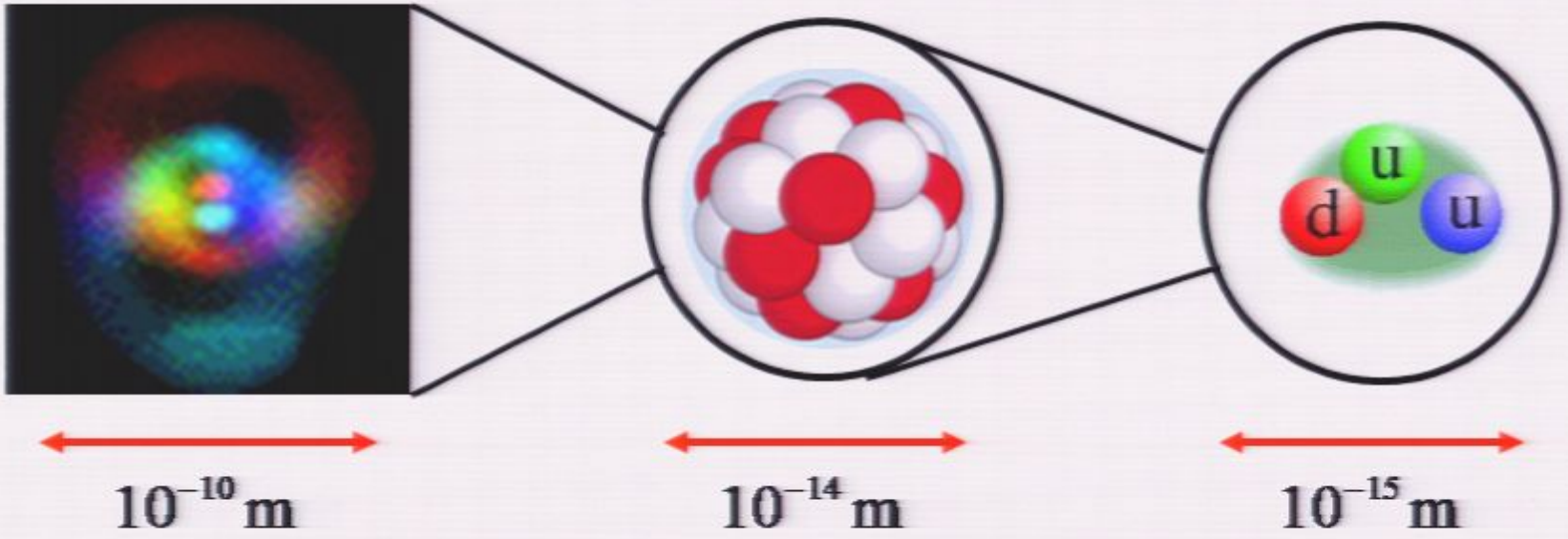

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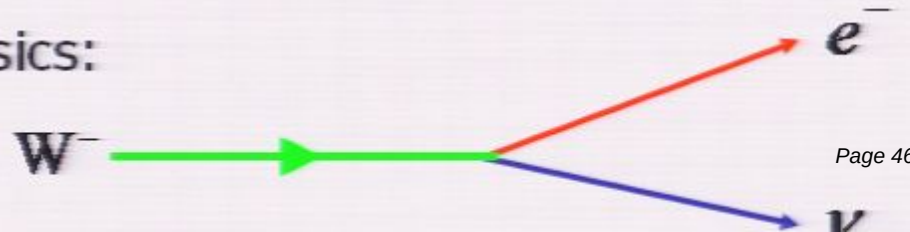

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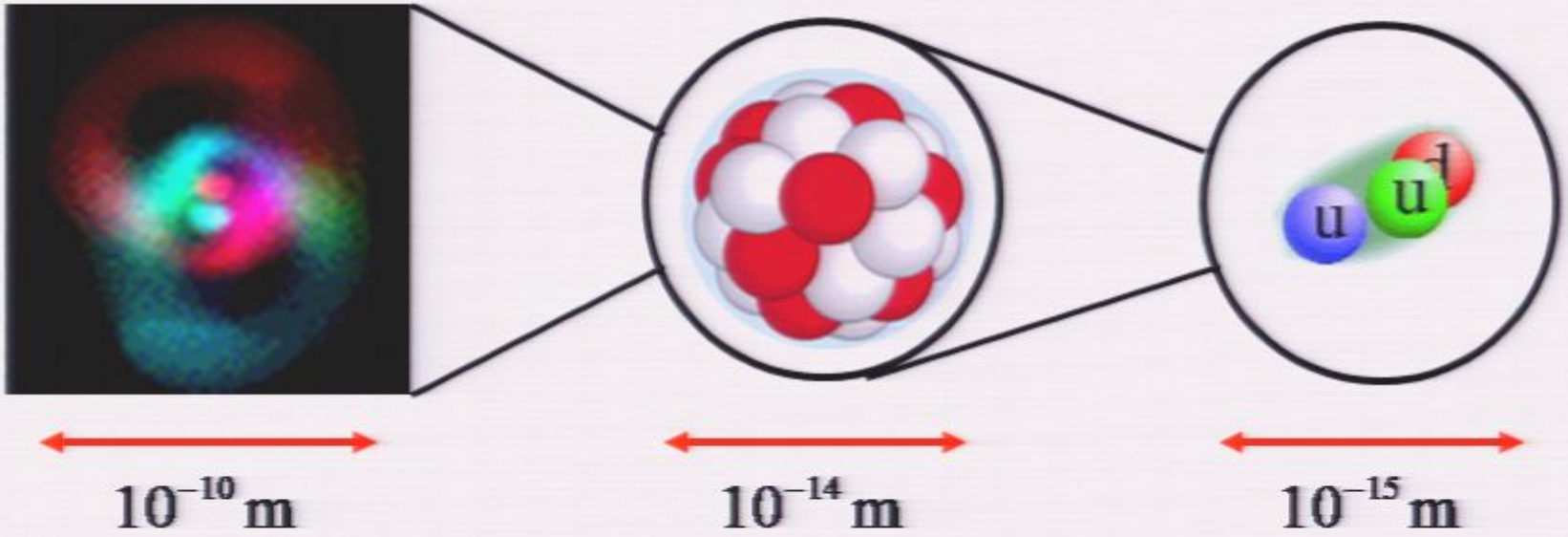

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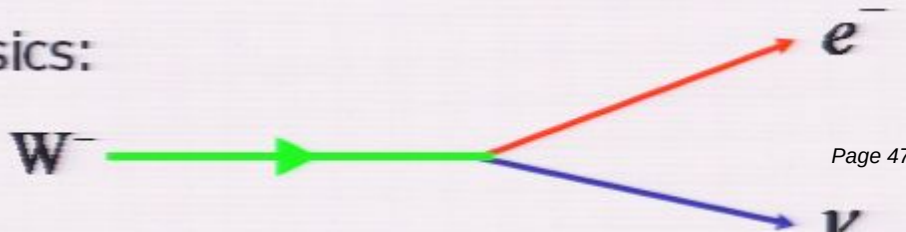

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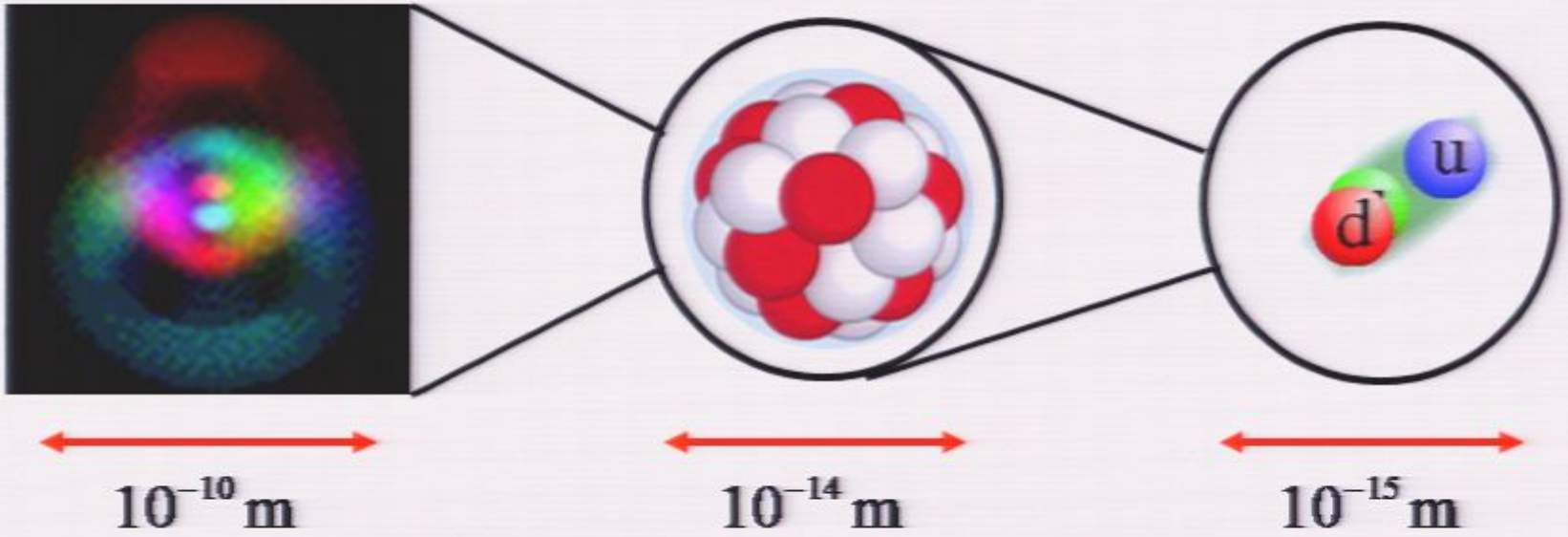

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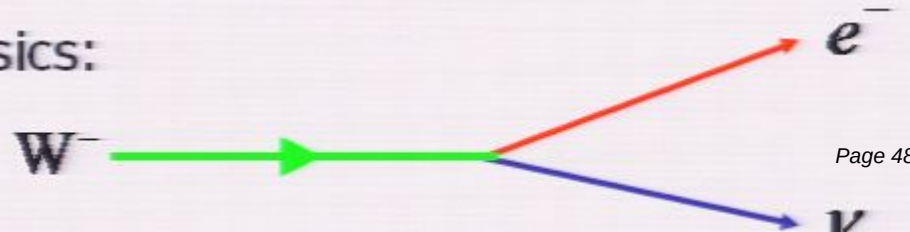

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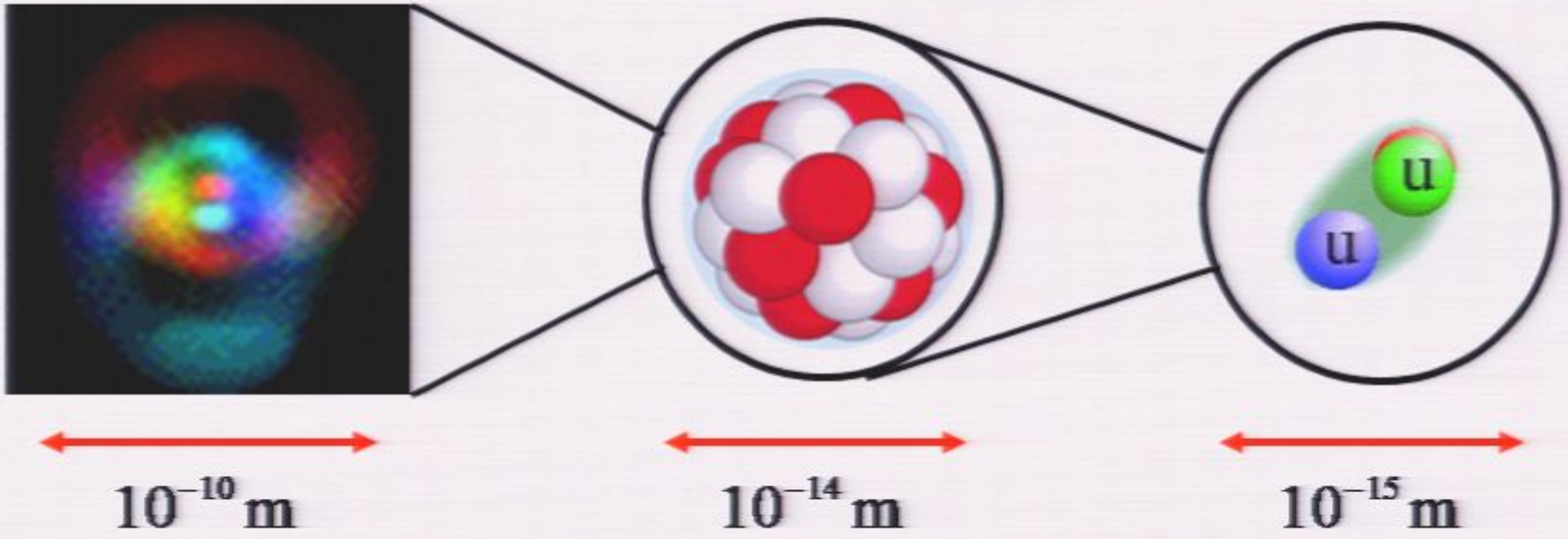

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- electron, muon, tauon
- neutrinos (3 flavors)
- quarks - up, down, strange, charm, bottom, top

Bosons (Force Mediators):
- photon (electromagnetism)
- gluon (strong)
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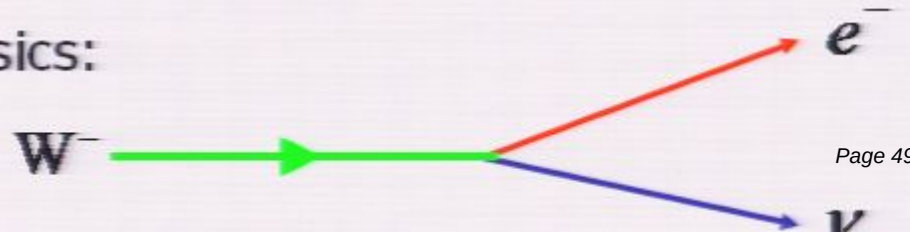
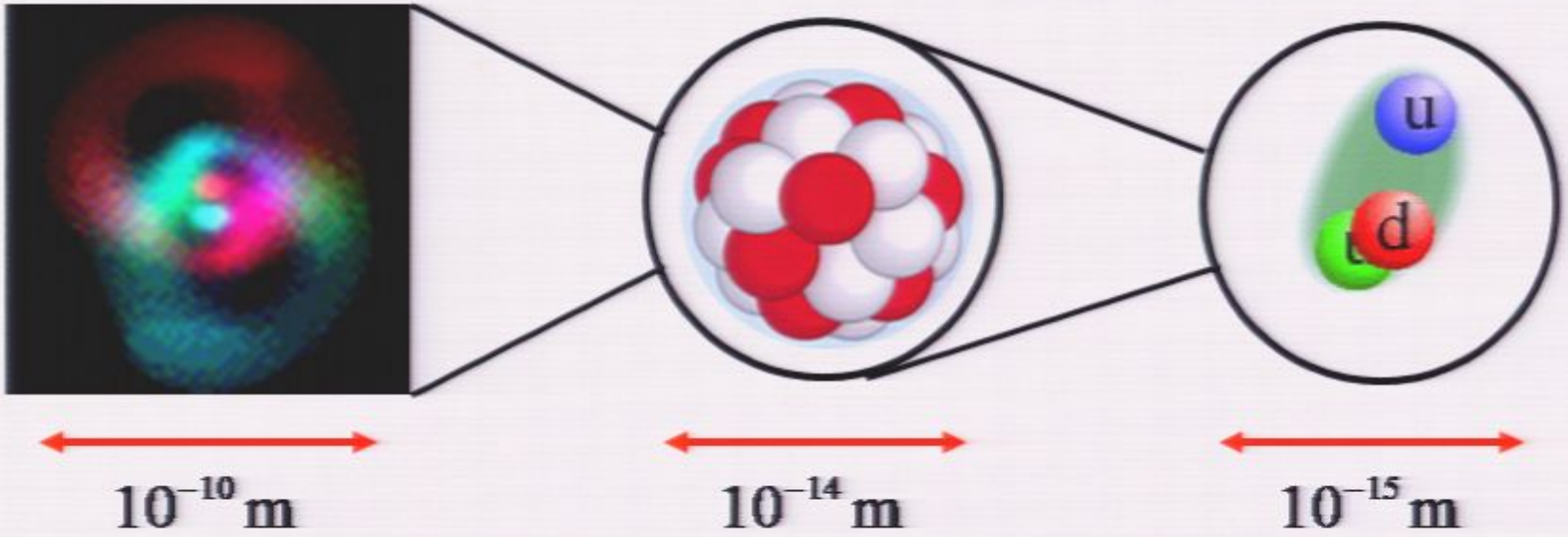
Standard Model of Subatomic Physics:

above particles plus interactions (and ~20 free parameters)



Quantum Field Theory is the probabilistic arena of physics on very small scales



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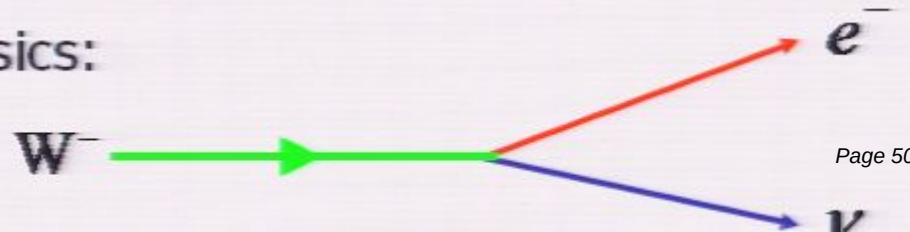

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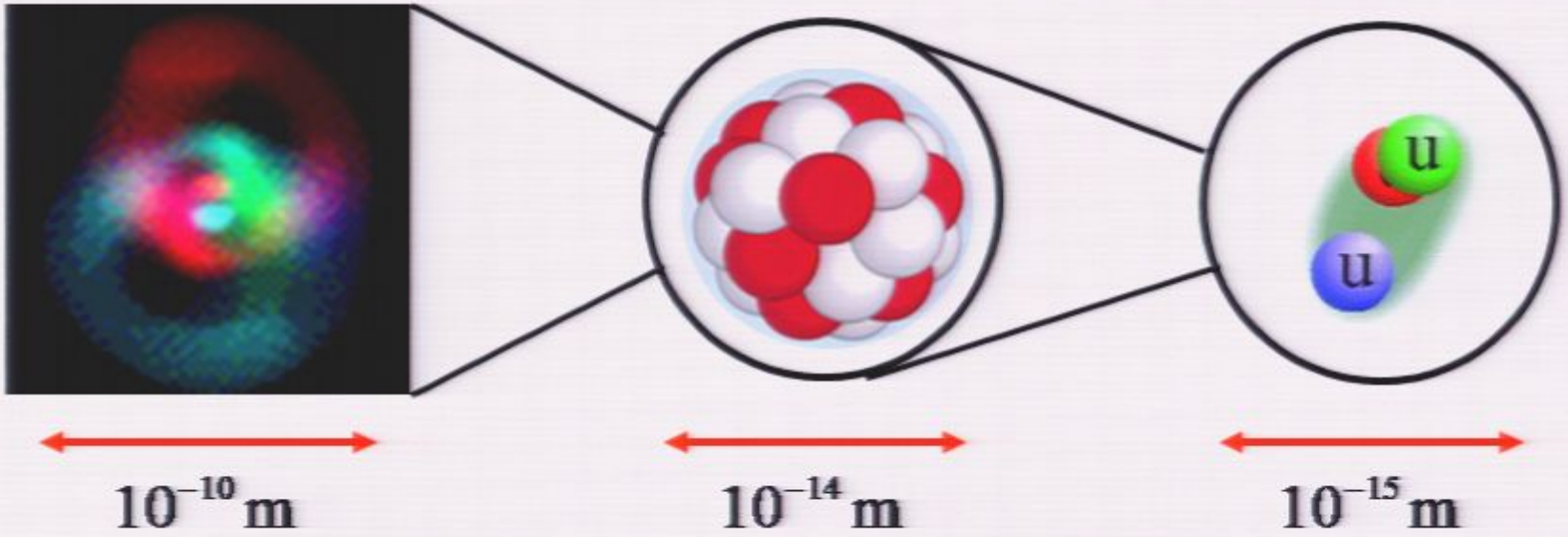

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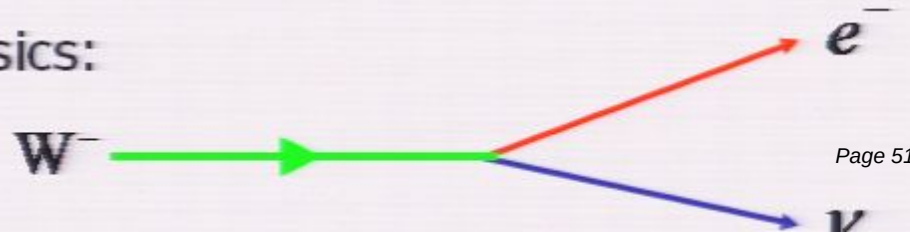

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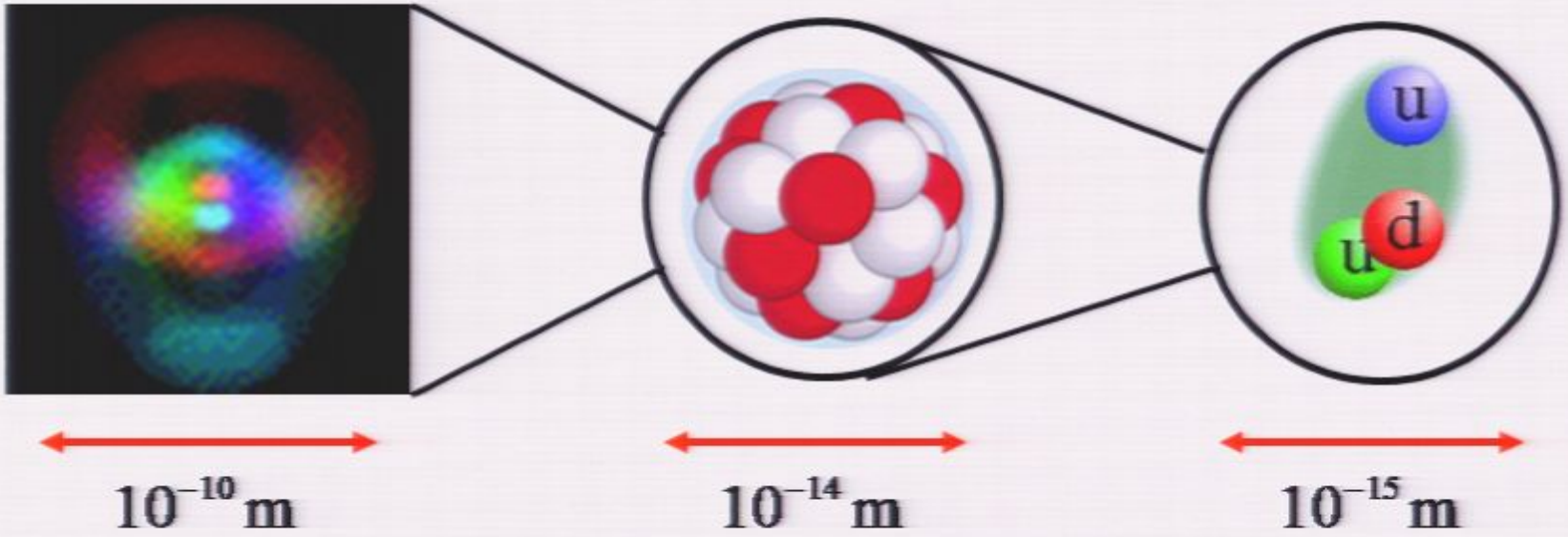

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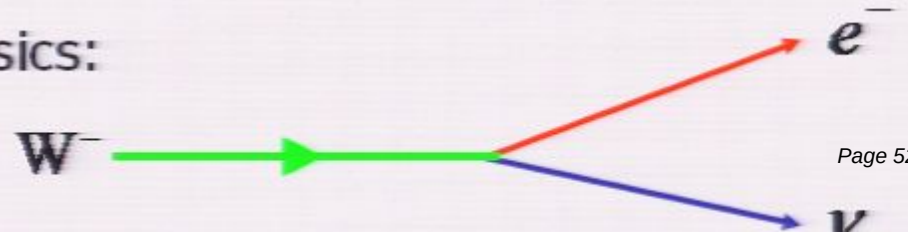

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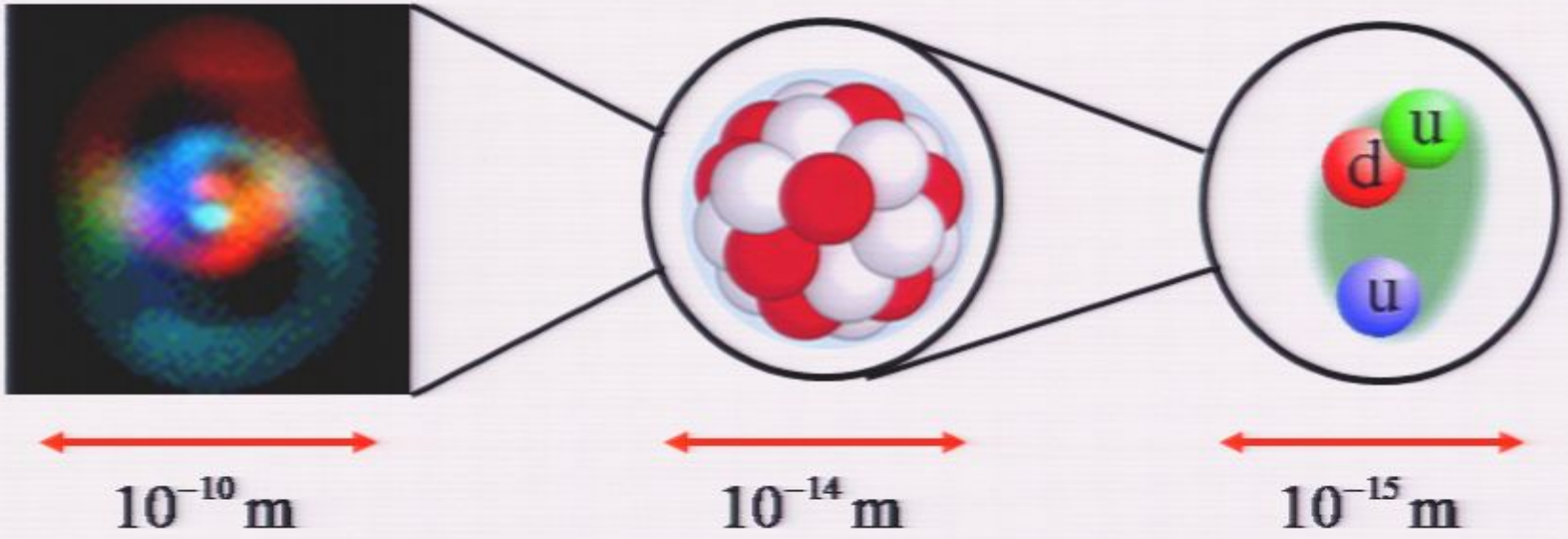

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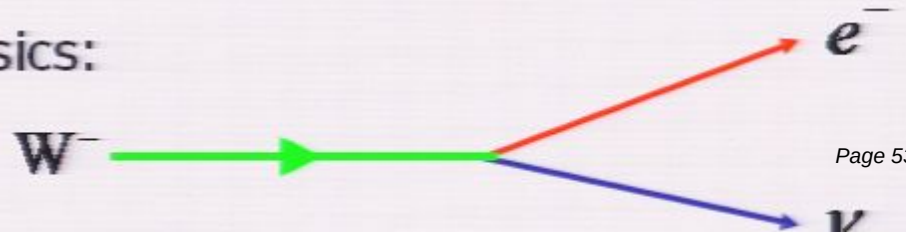

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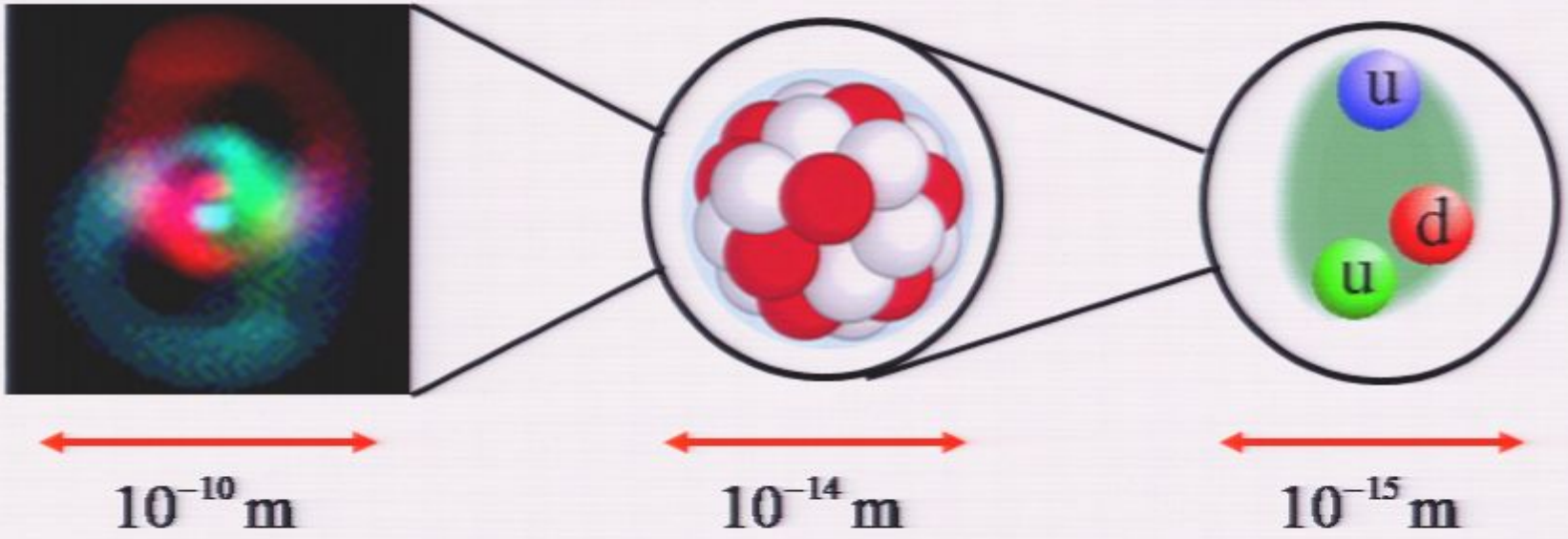

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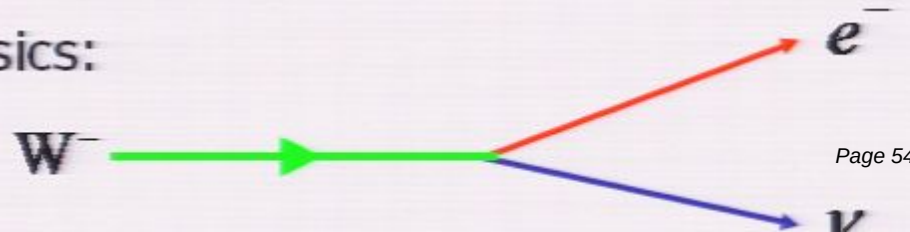

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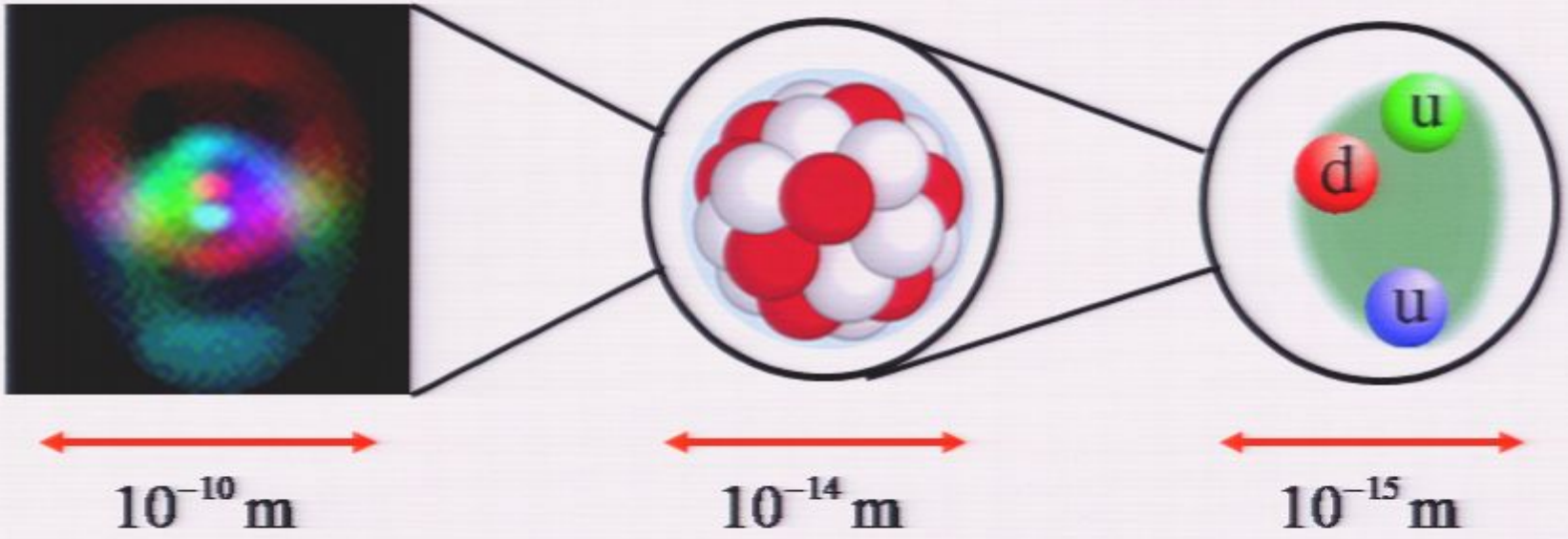

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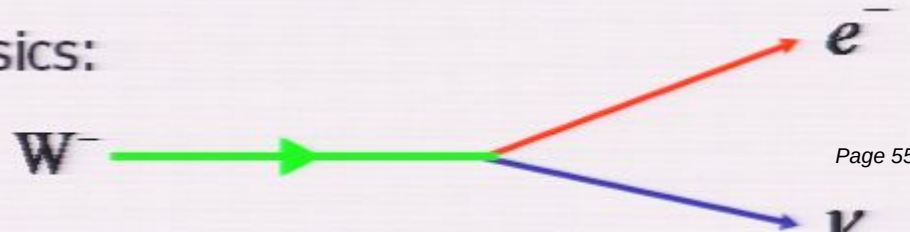

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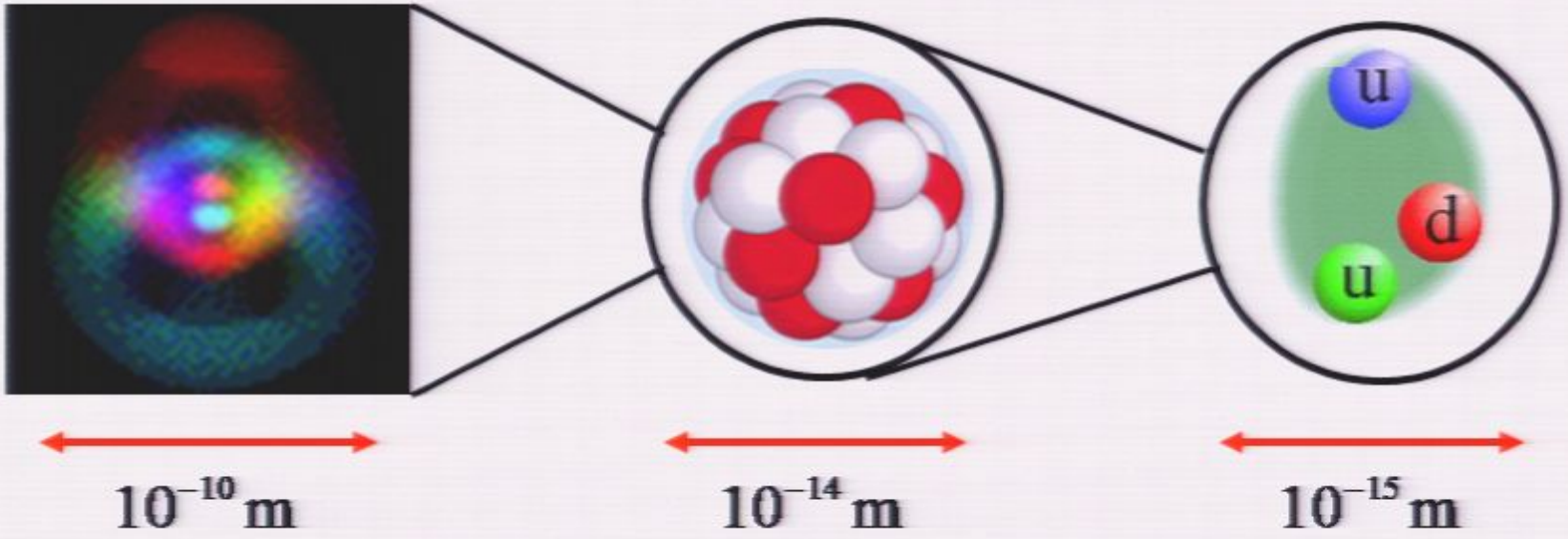

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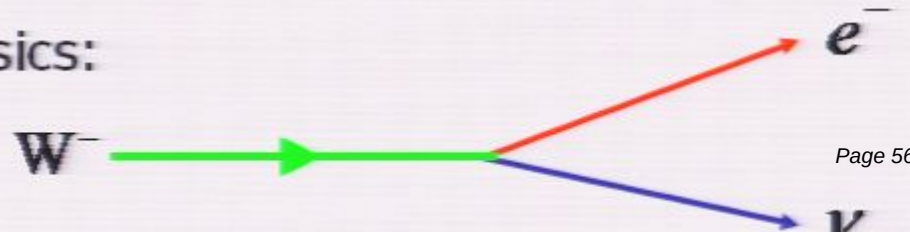

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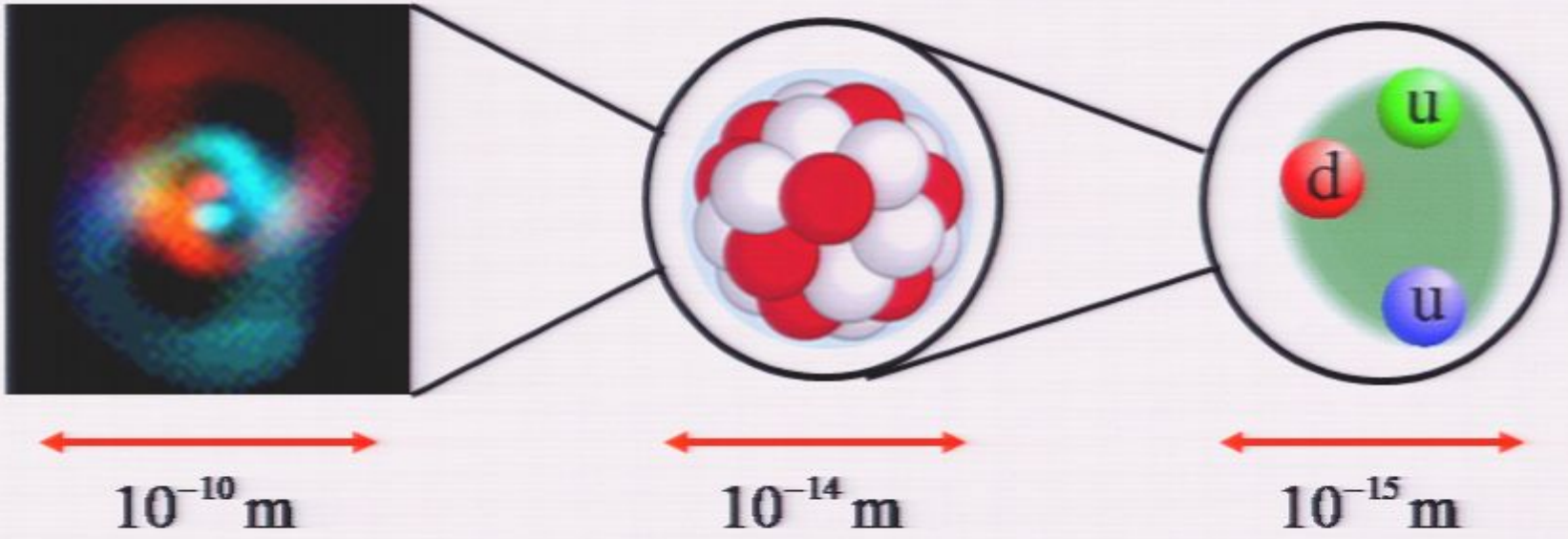

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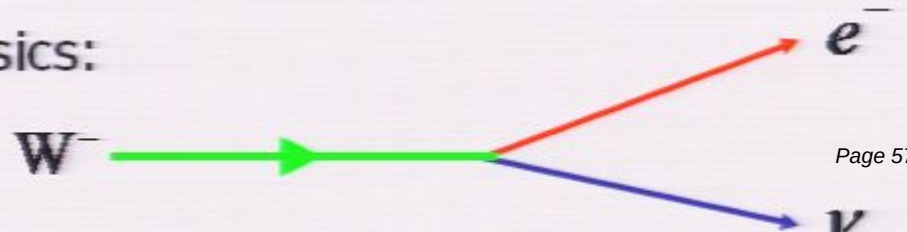

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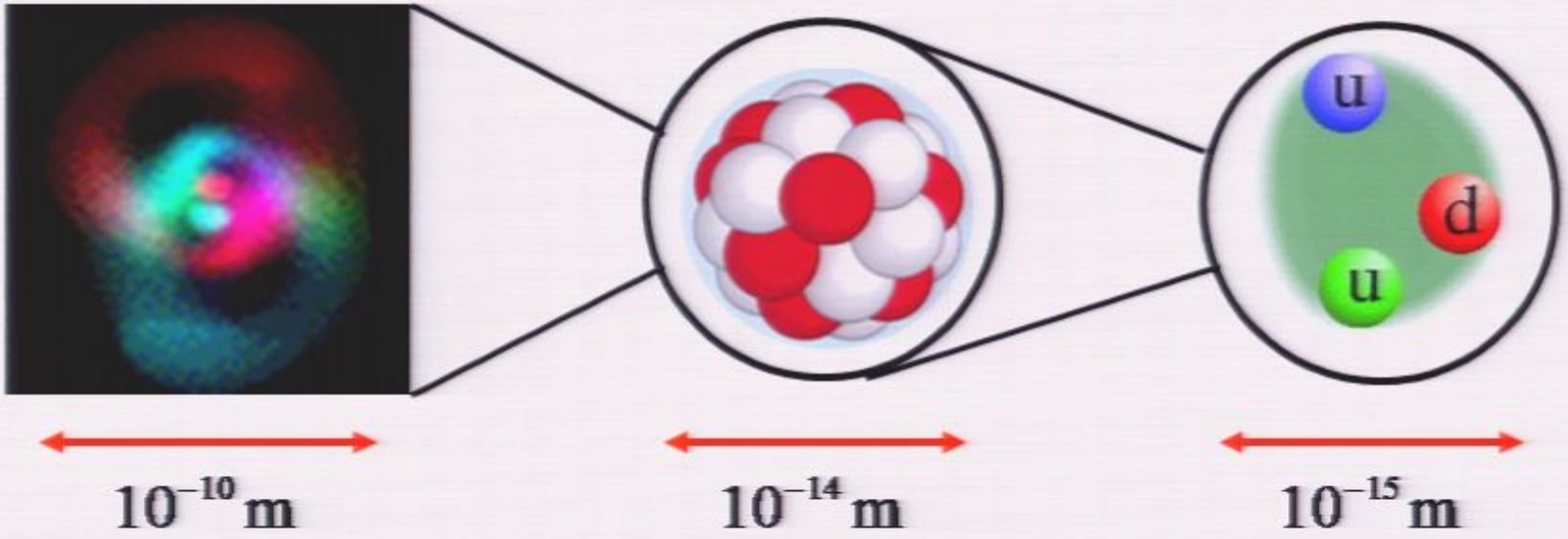

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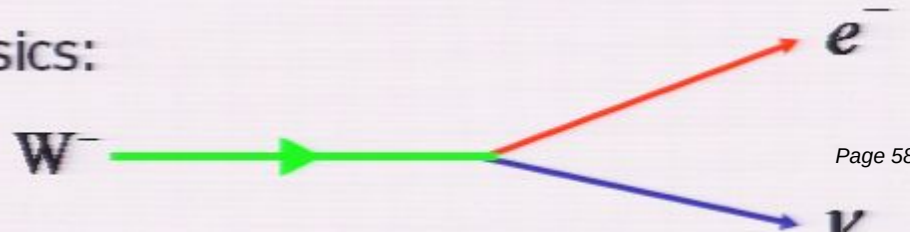

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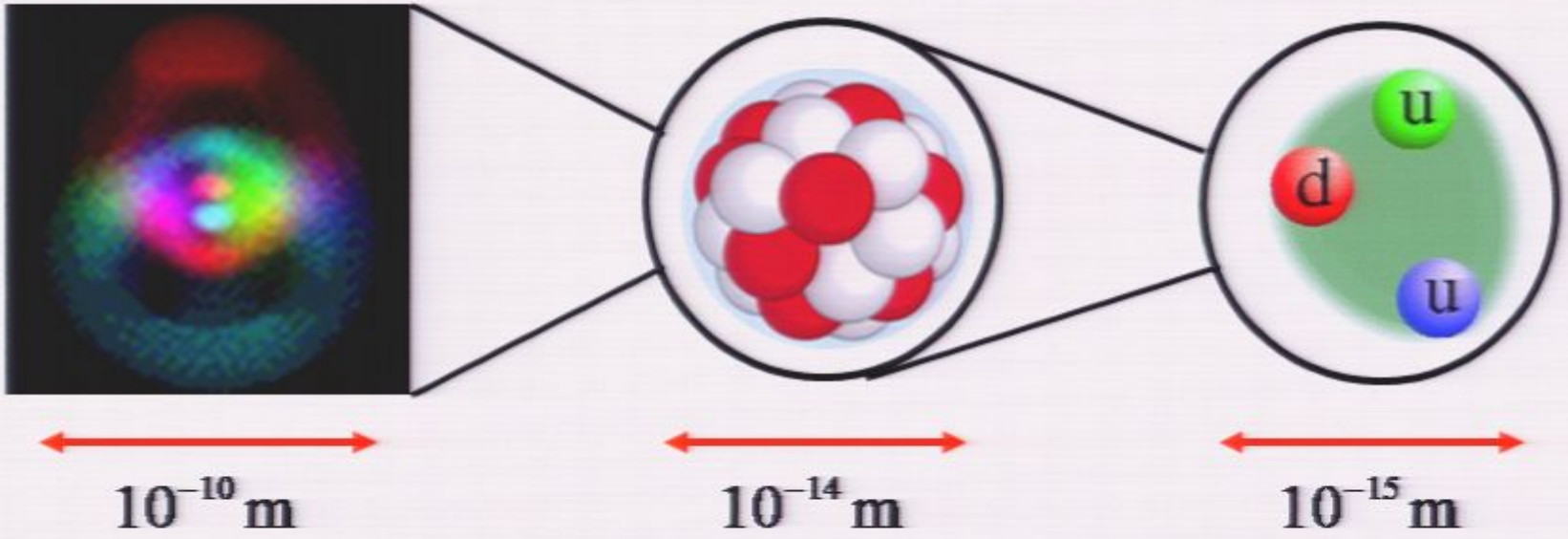

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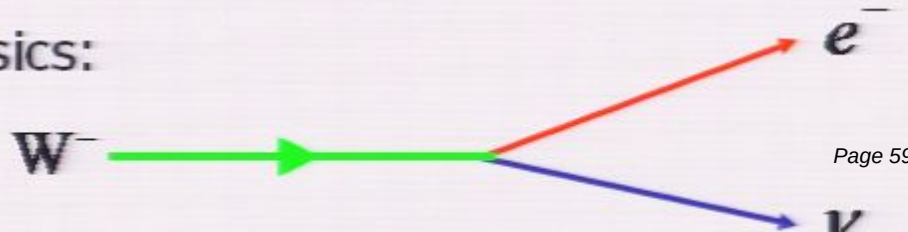

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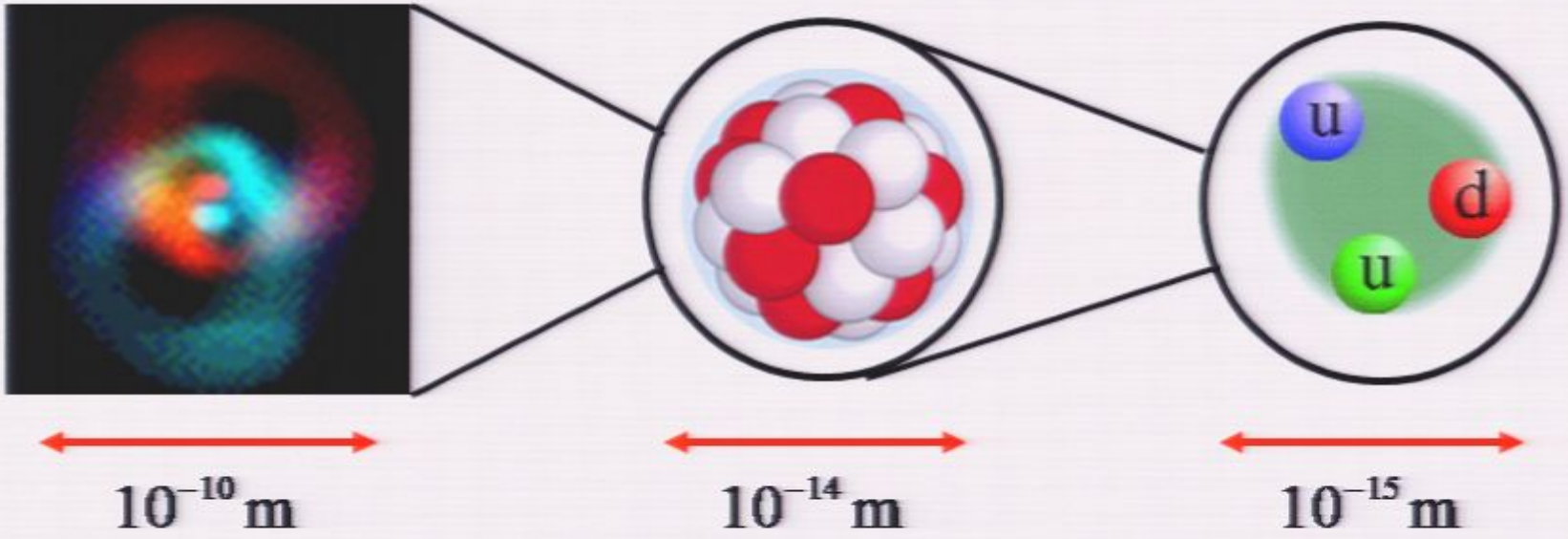

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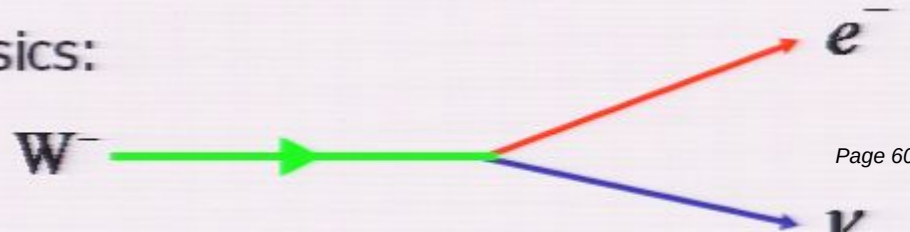

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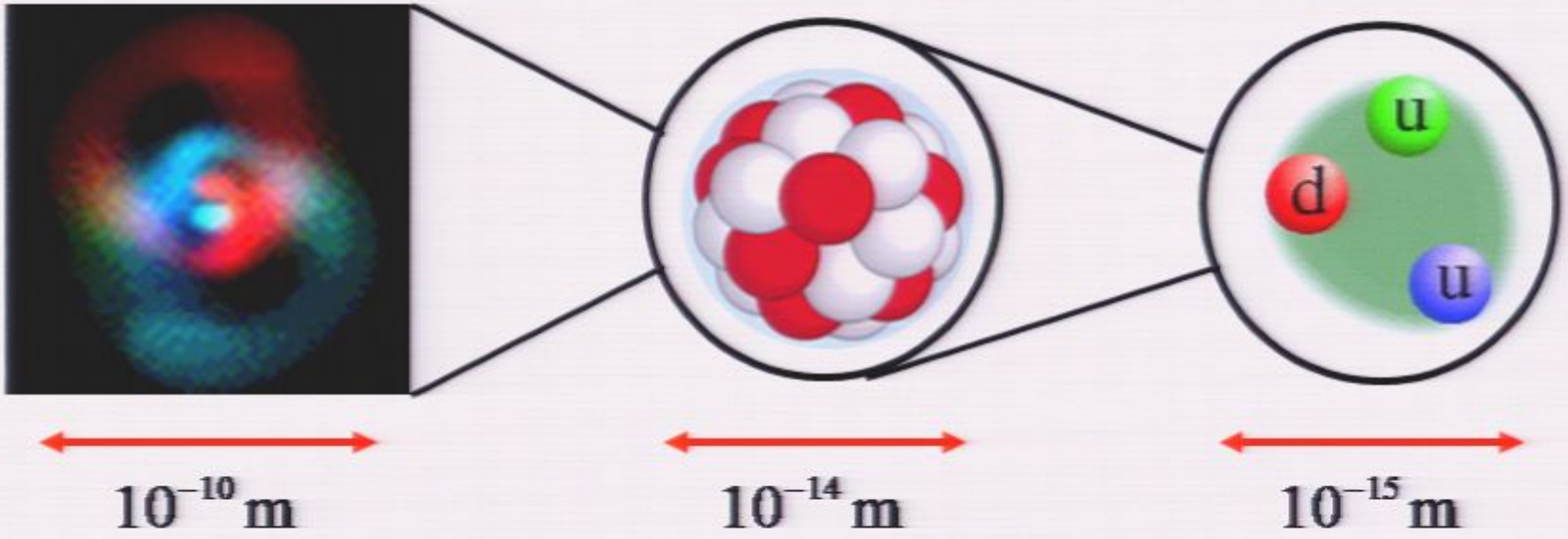

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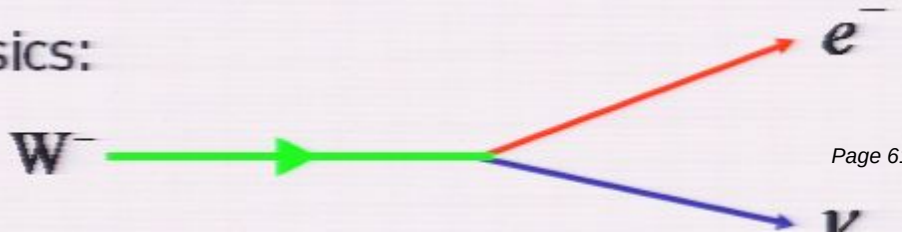

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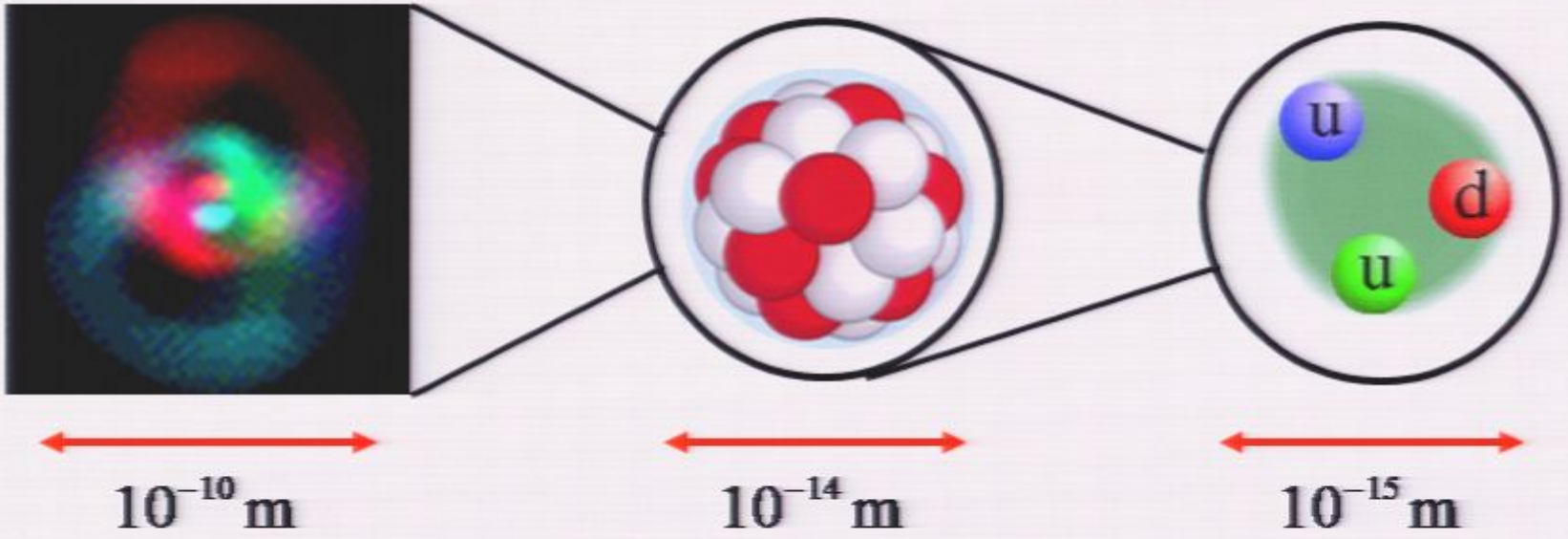

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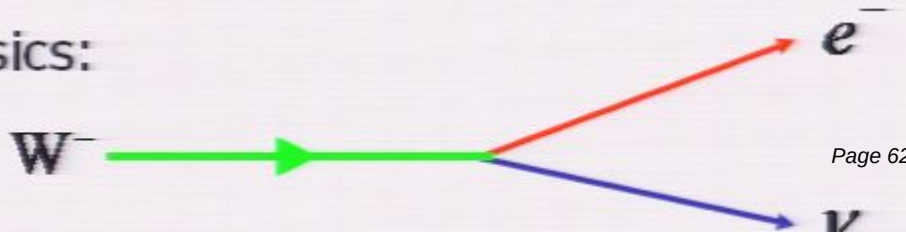

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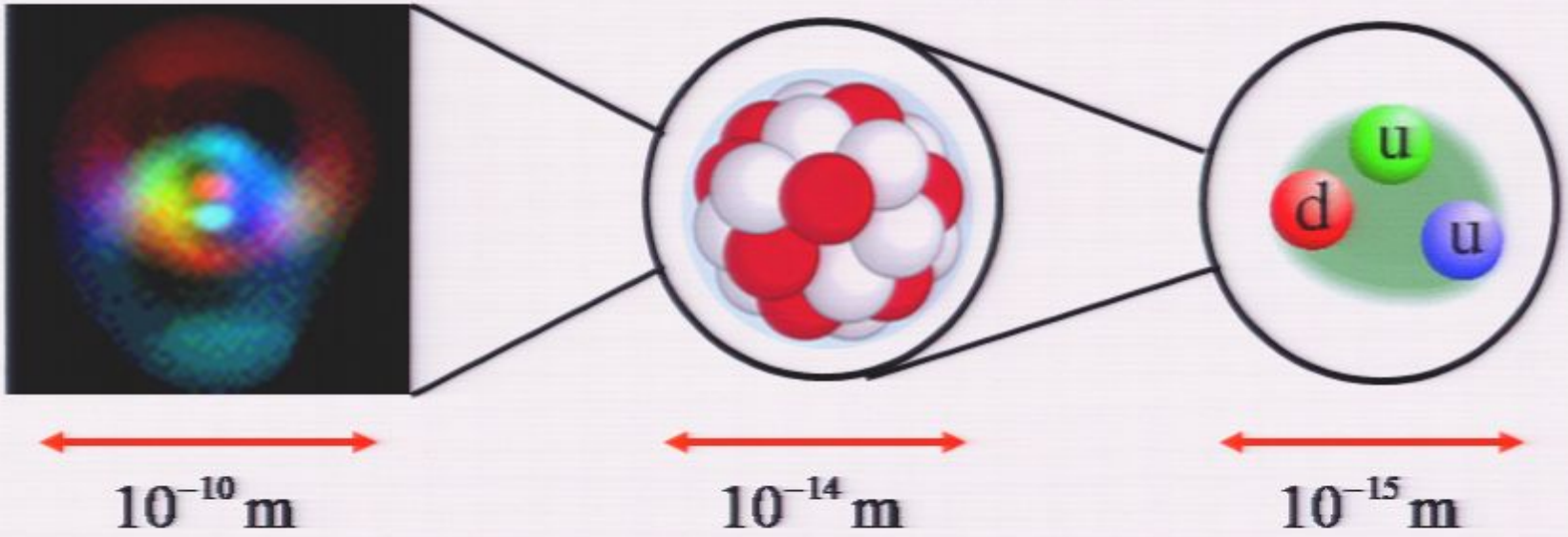

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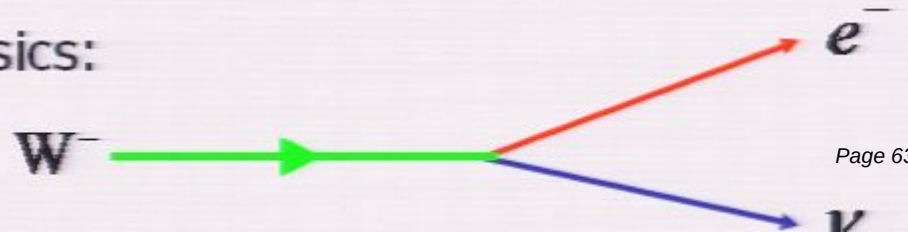

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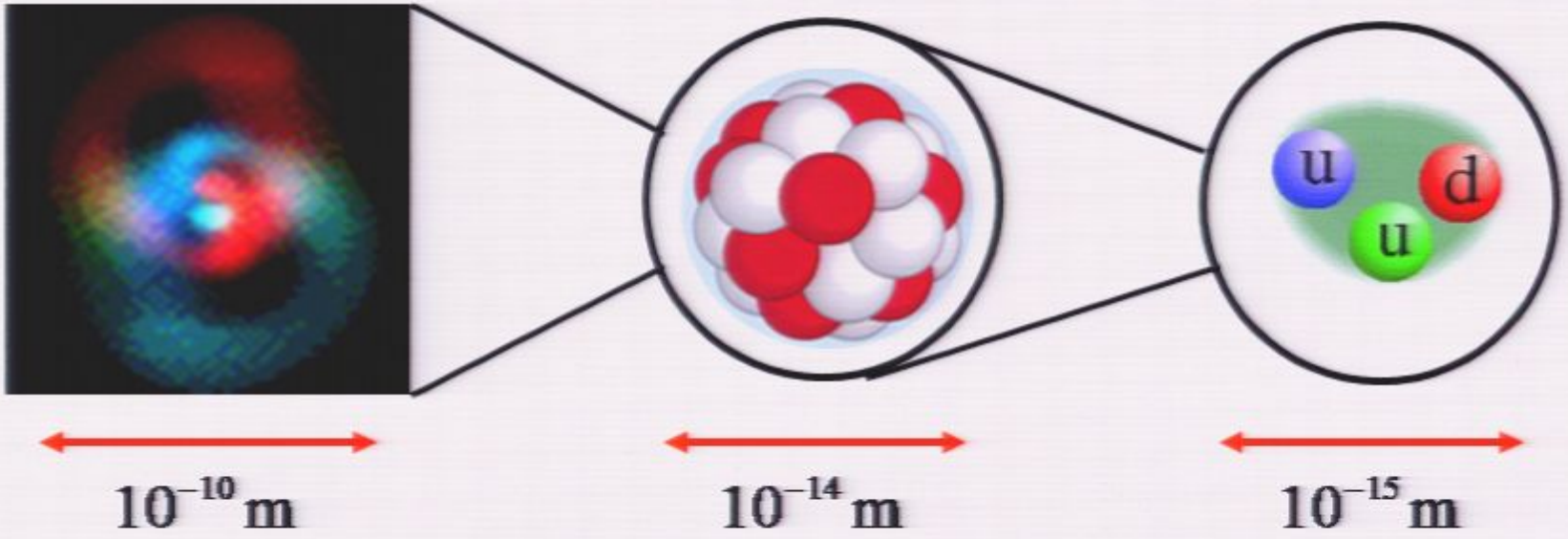

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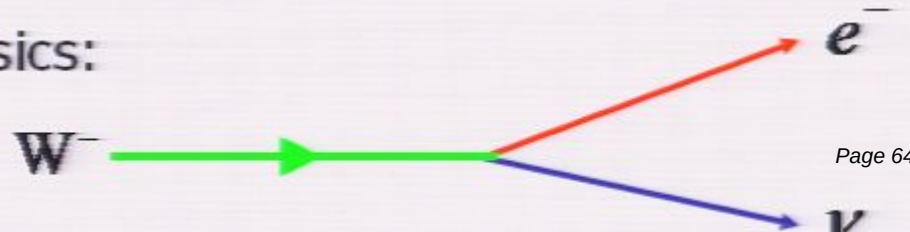

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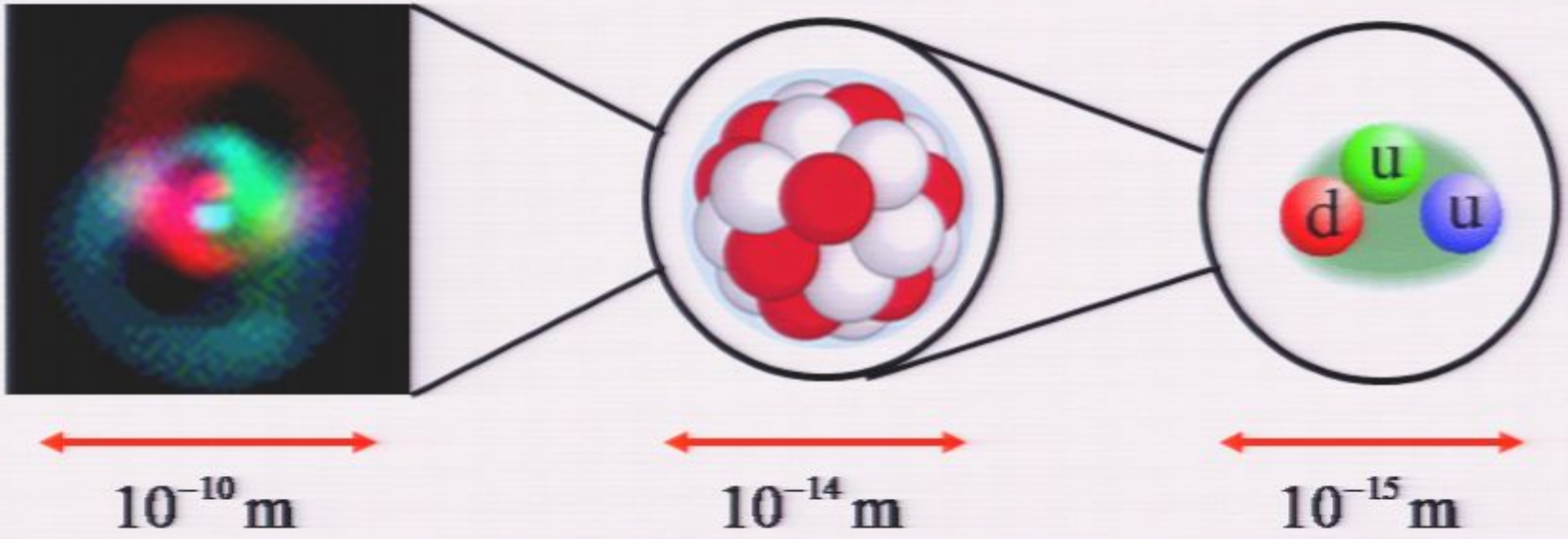

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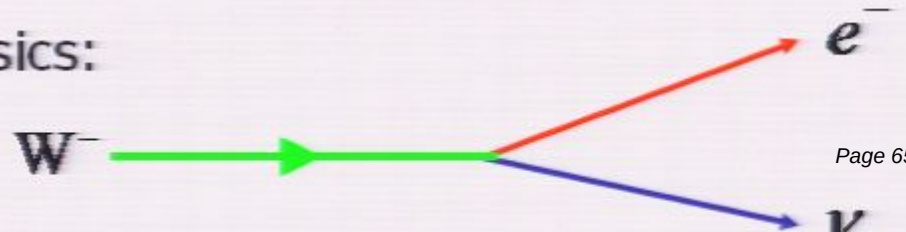

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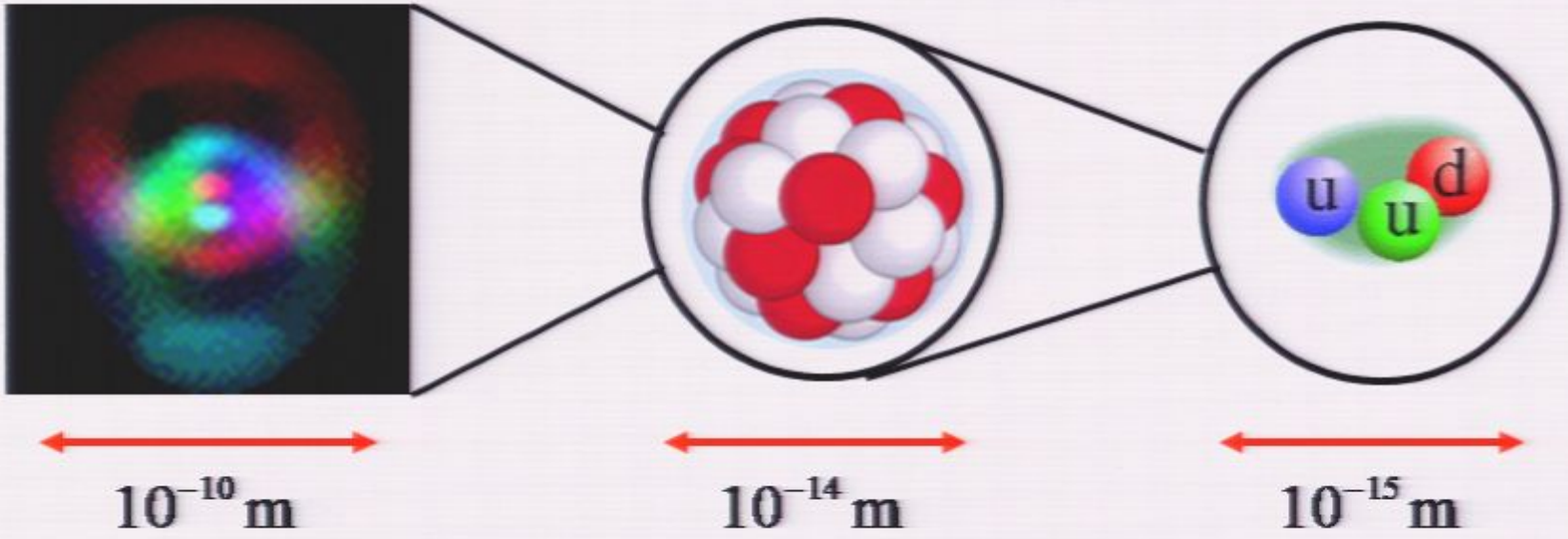

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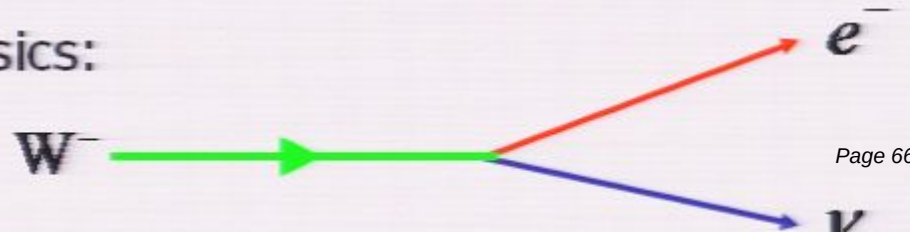

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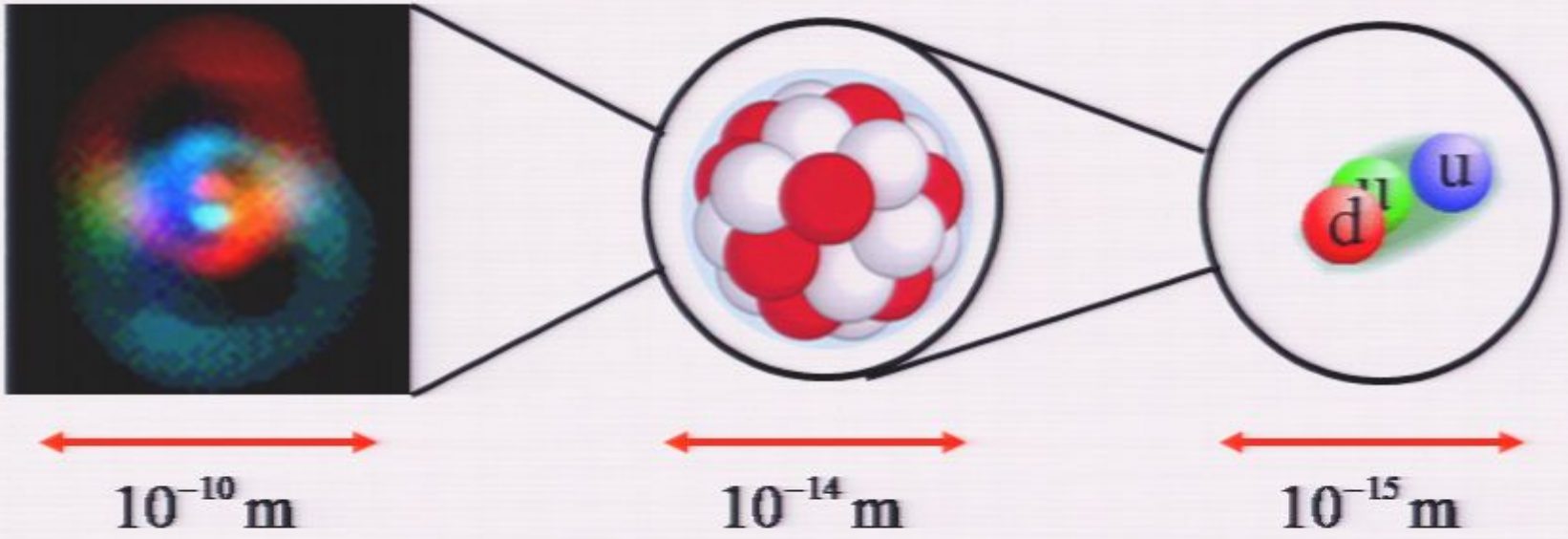

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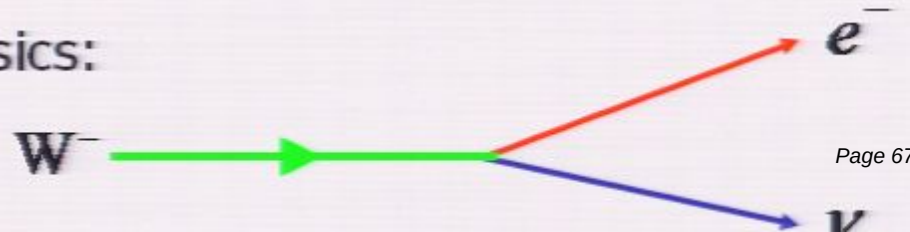

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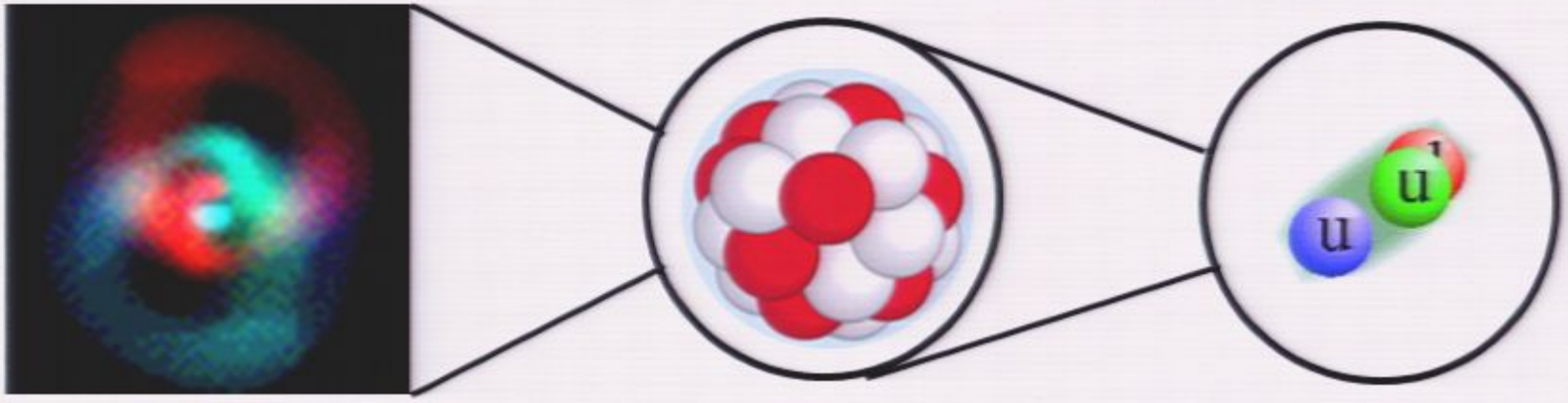

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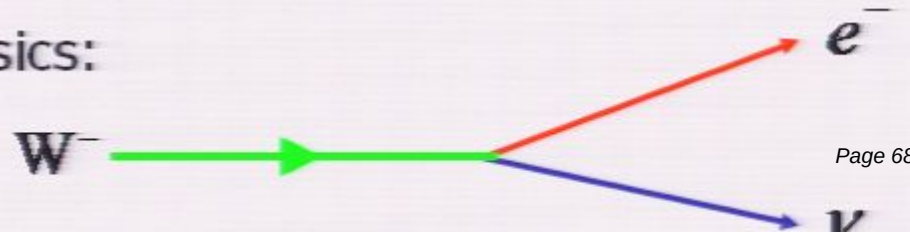
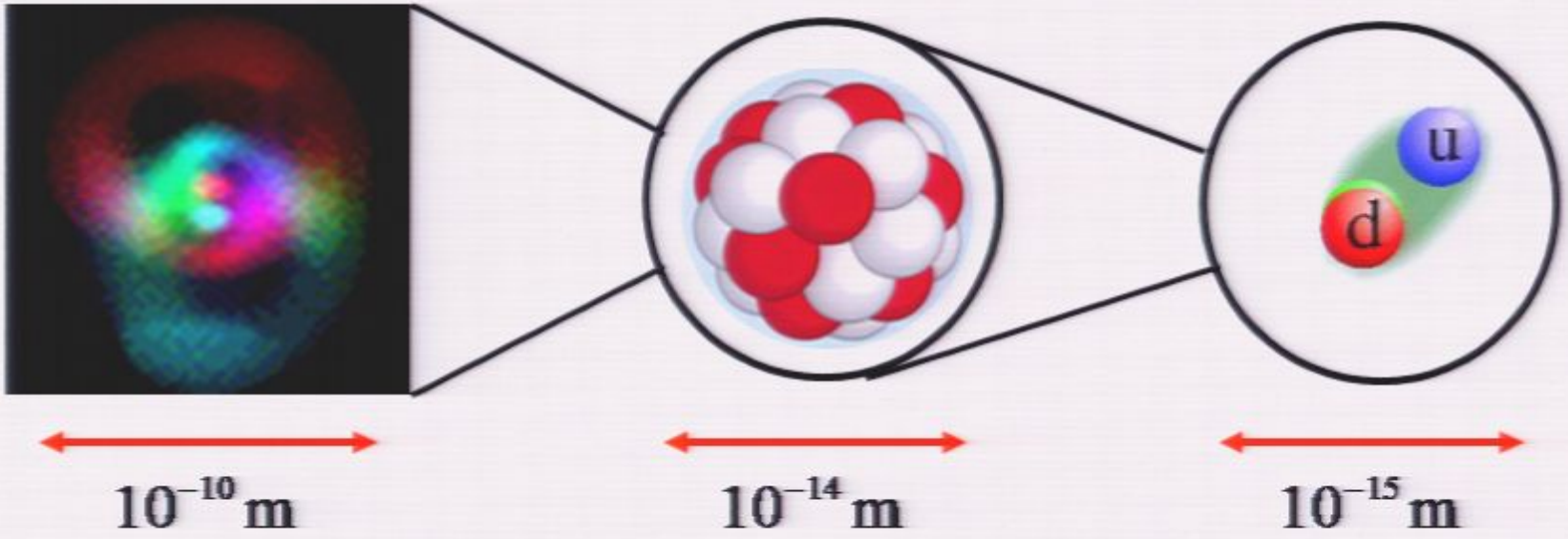


Quantum Field Theory is the probabilistic arena of physics on very small scales



Elementary Particles (10^{-17} m)

Fermions:
- electron, muon, tauon
- neutrinos (3 flavors)
- quarks - up, down, strange, charm, bottom, top

Bosons (Force Mediators):
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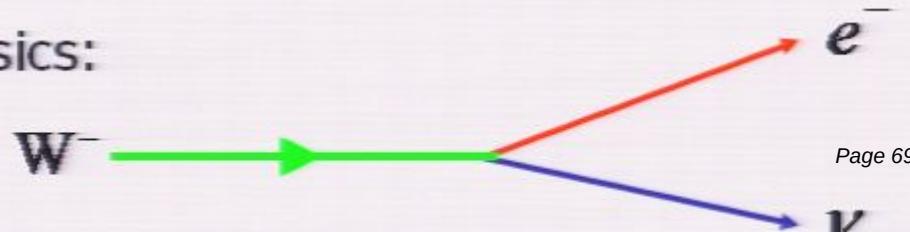

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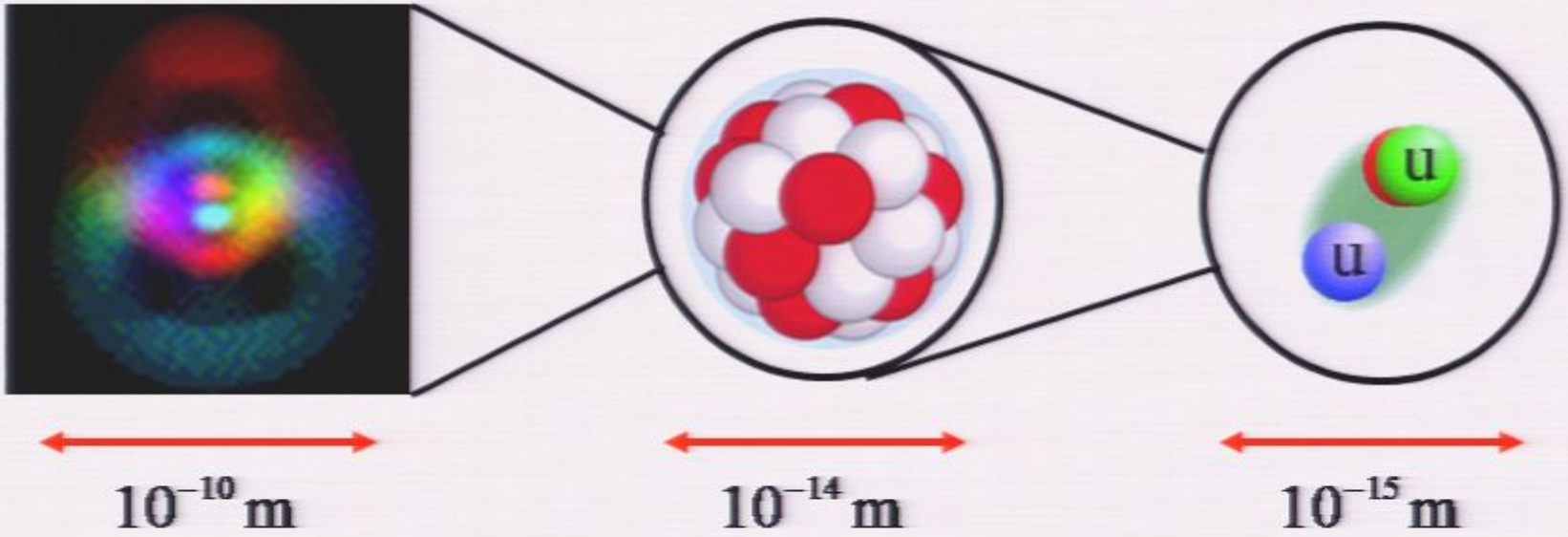

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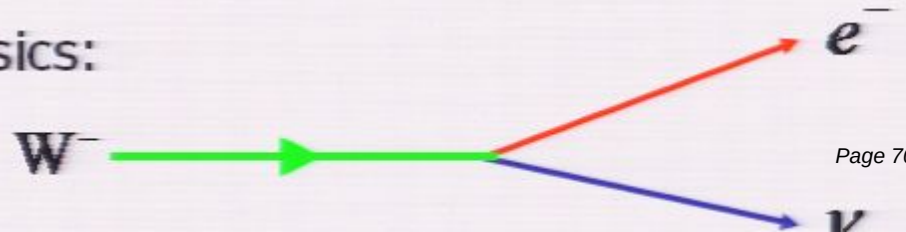

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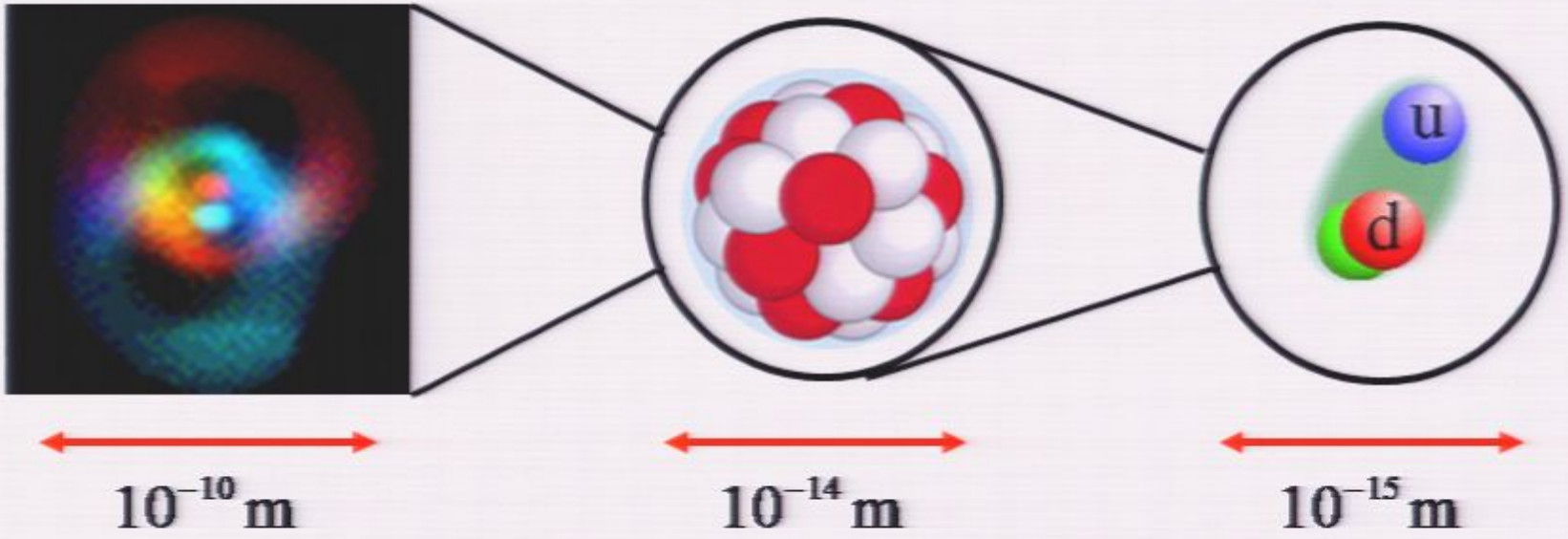

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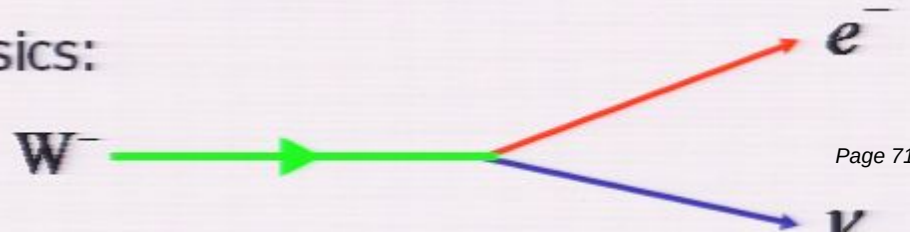

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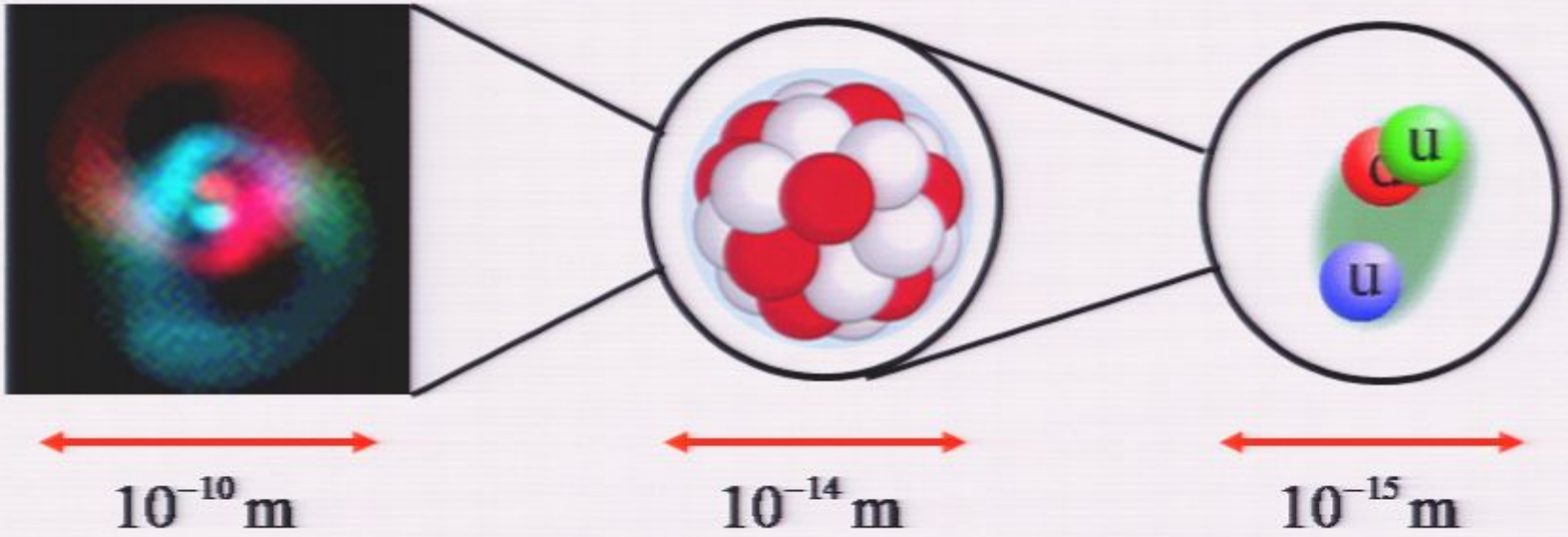

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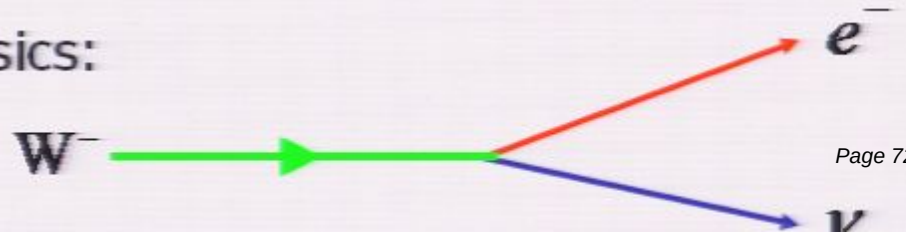

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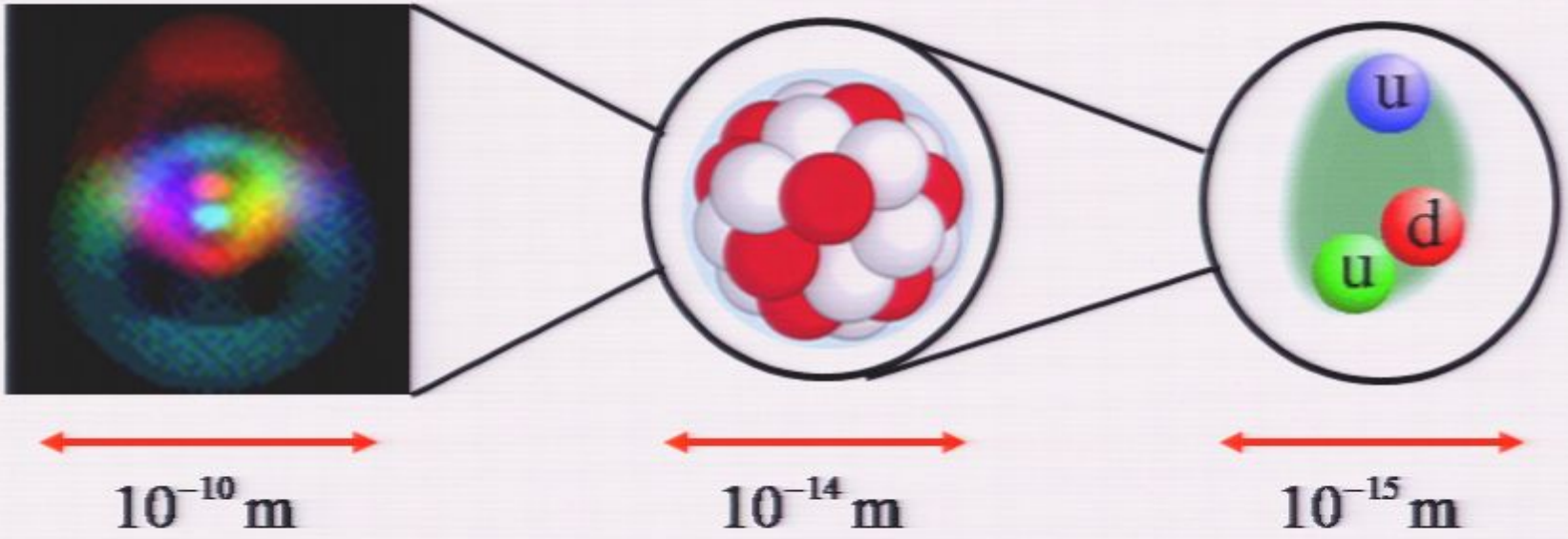

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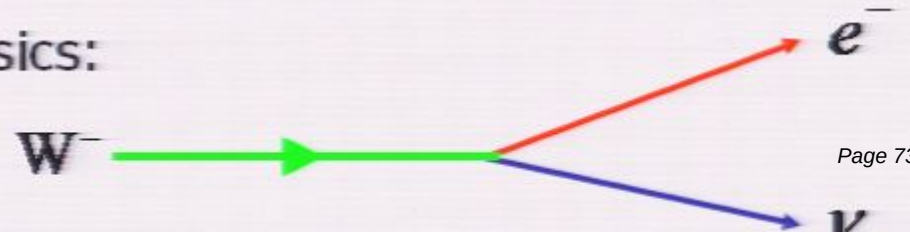

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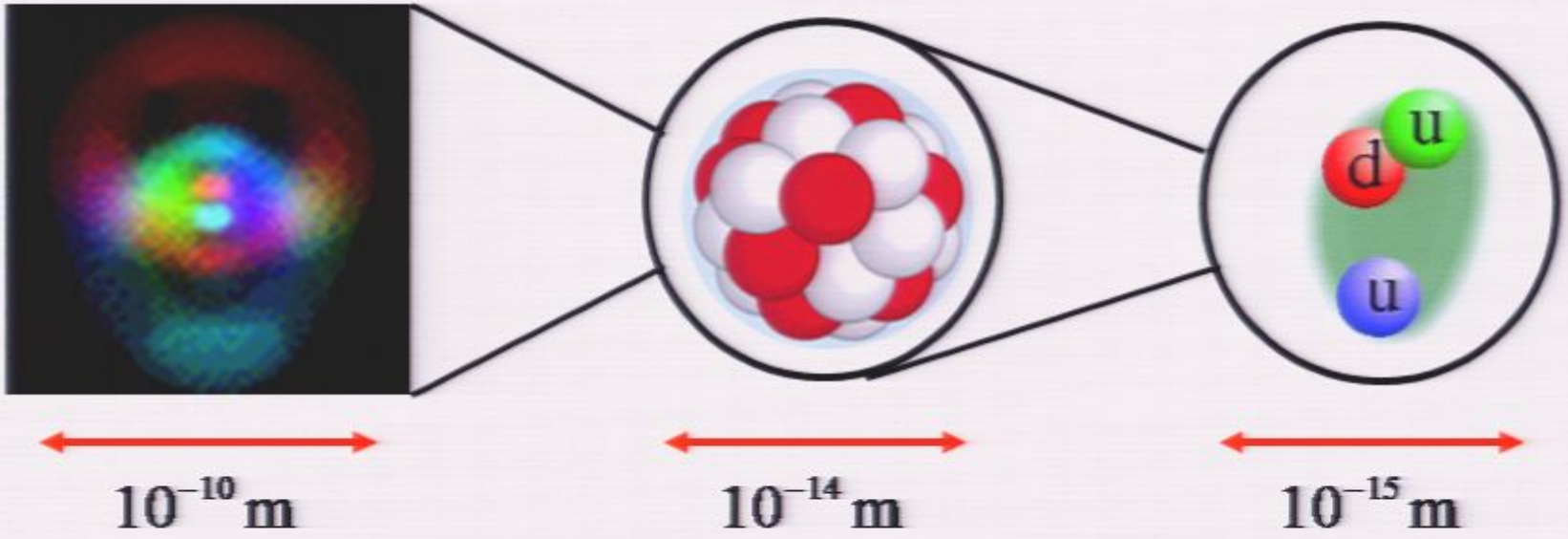

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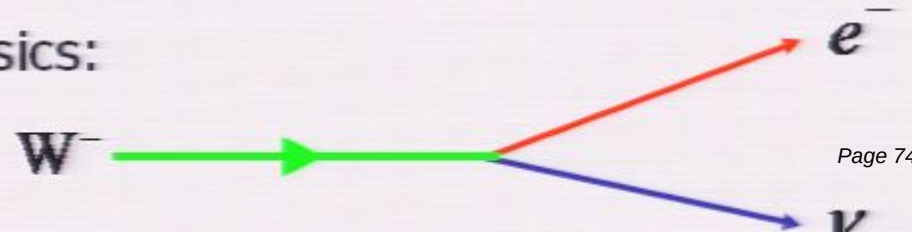

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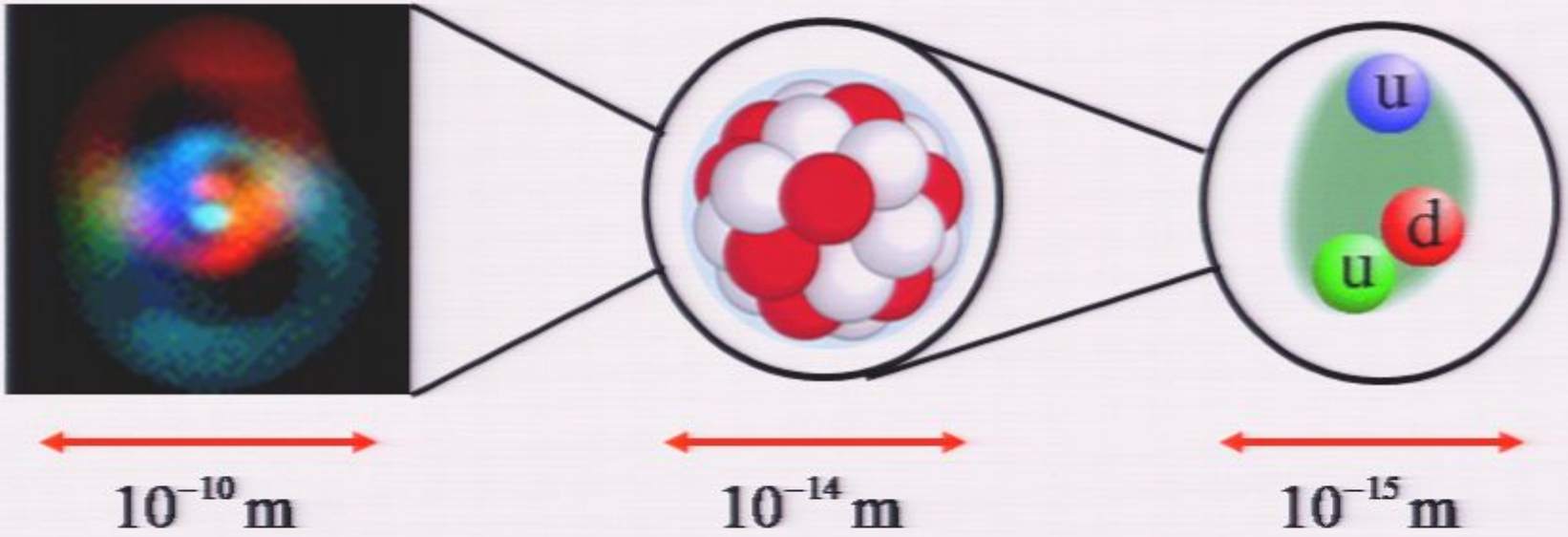

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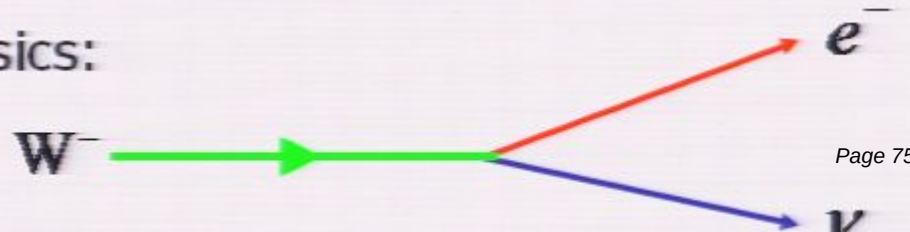

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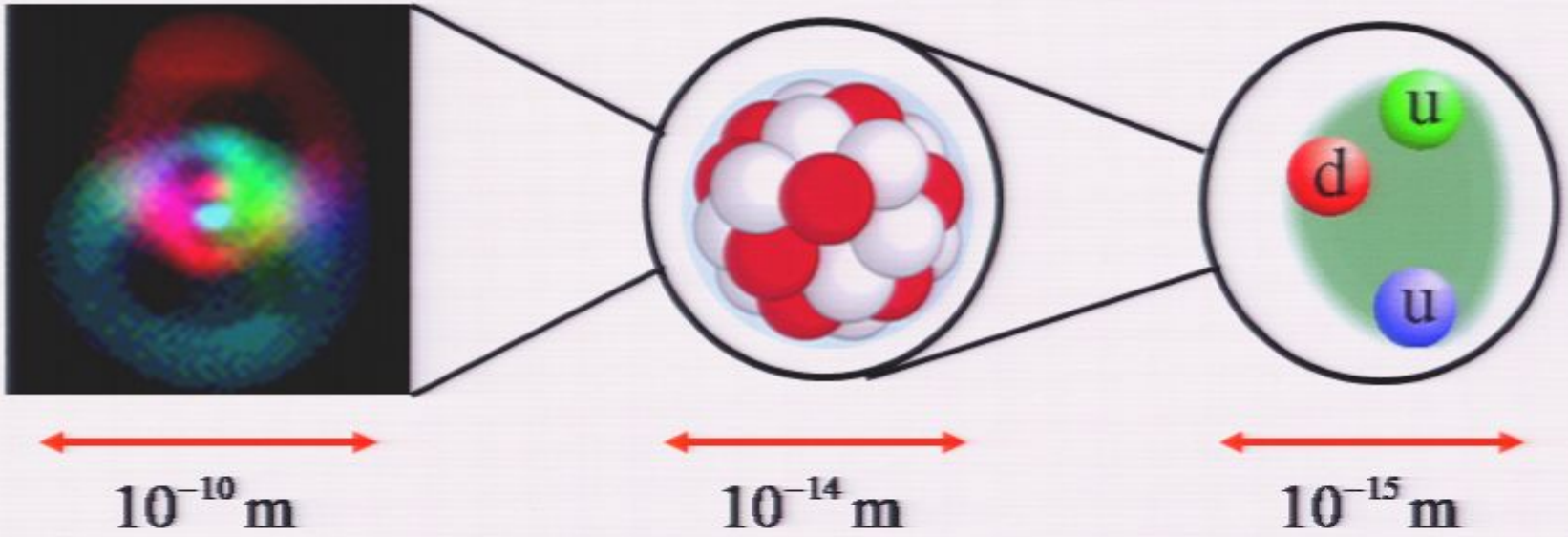

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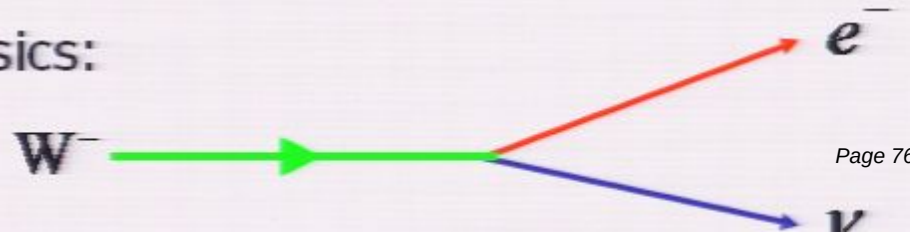

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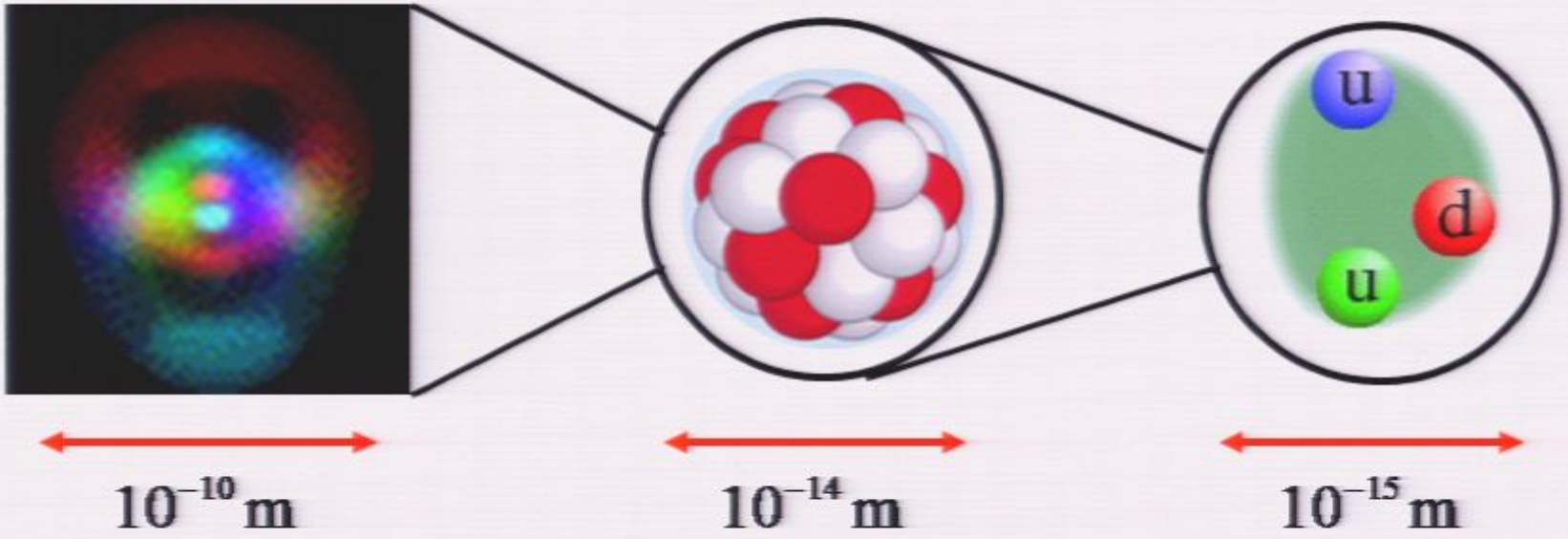

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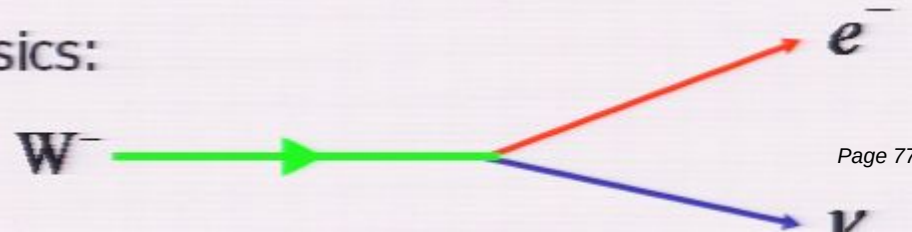

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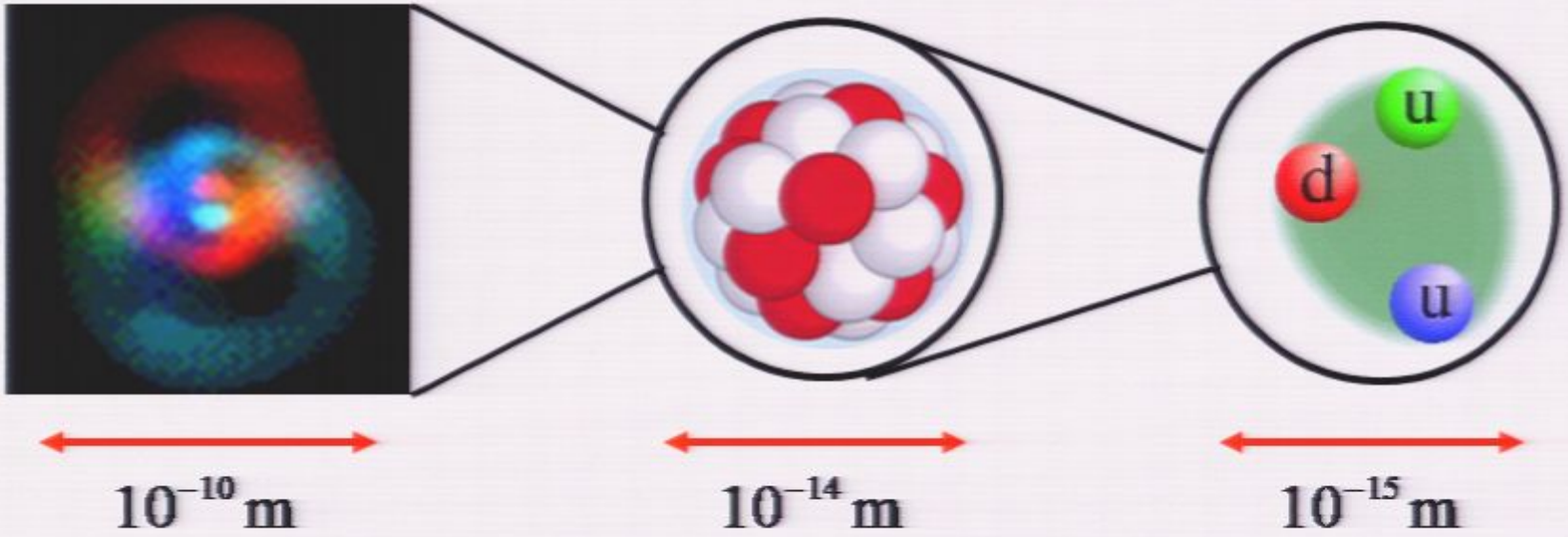

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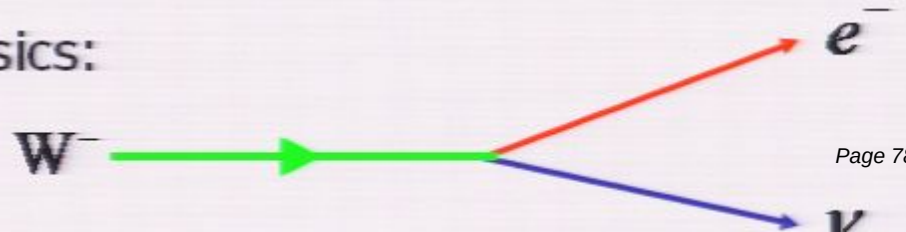

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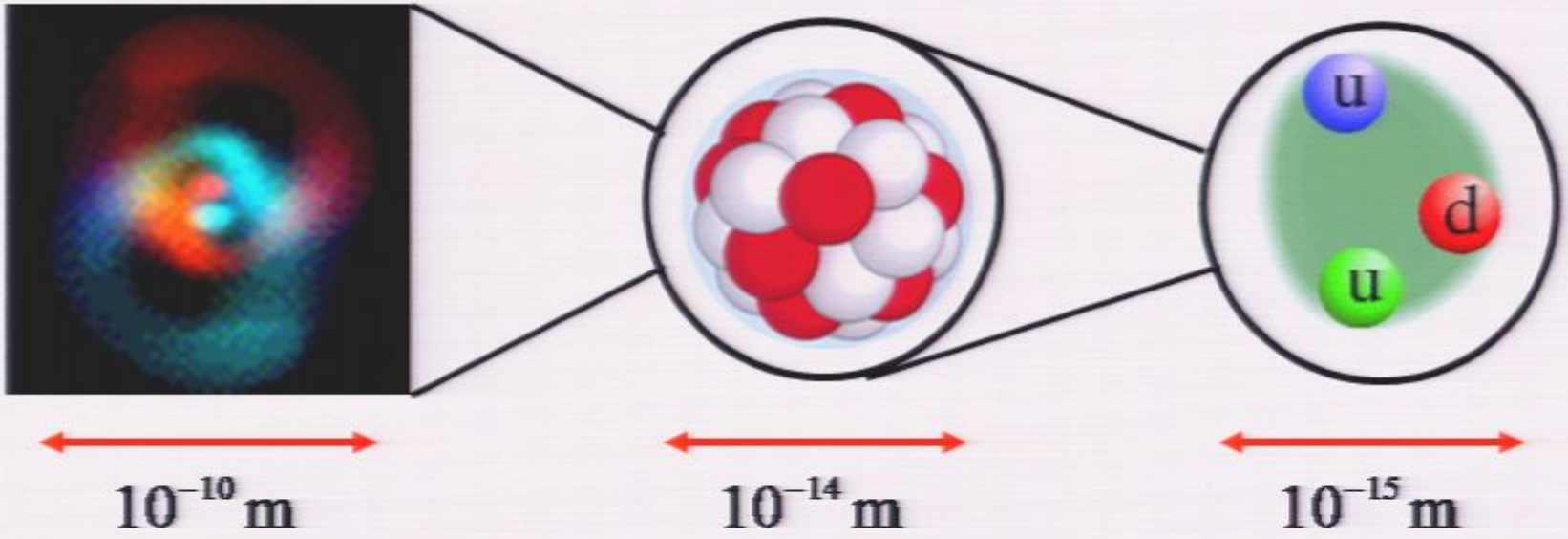

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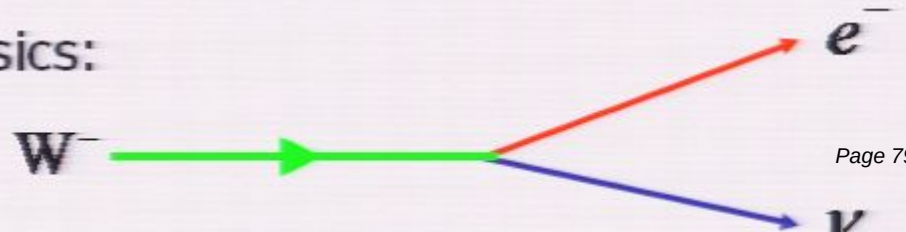

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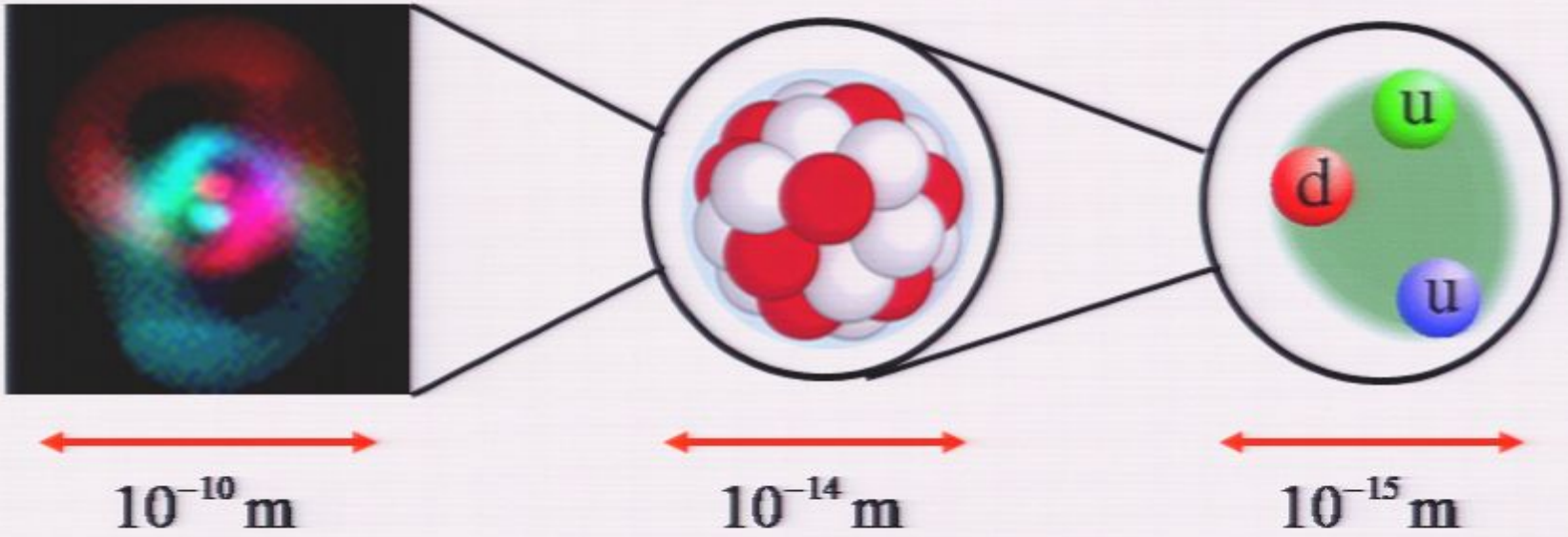

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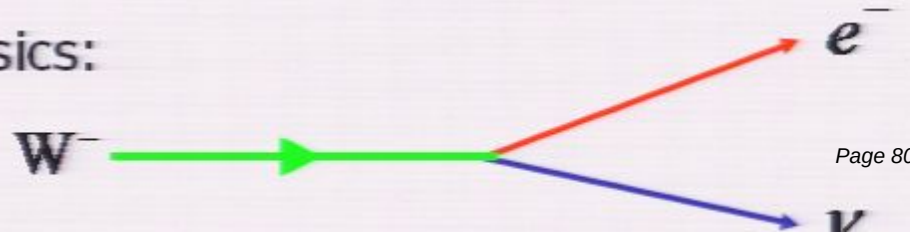

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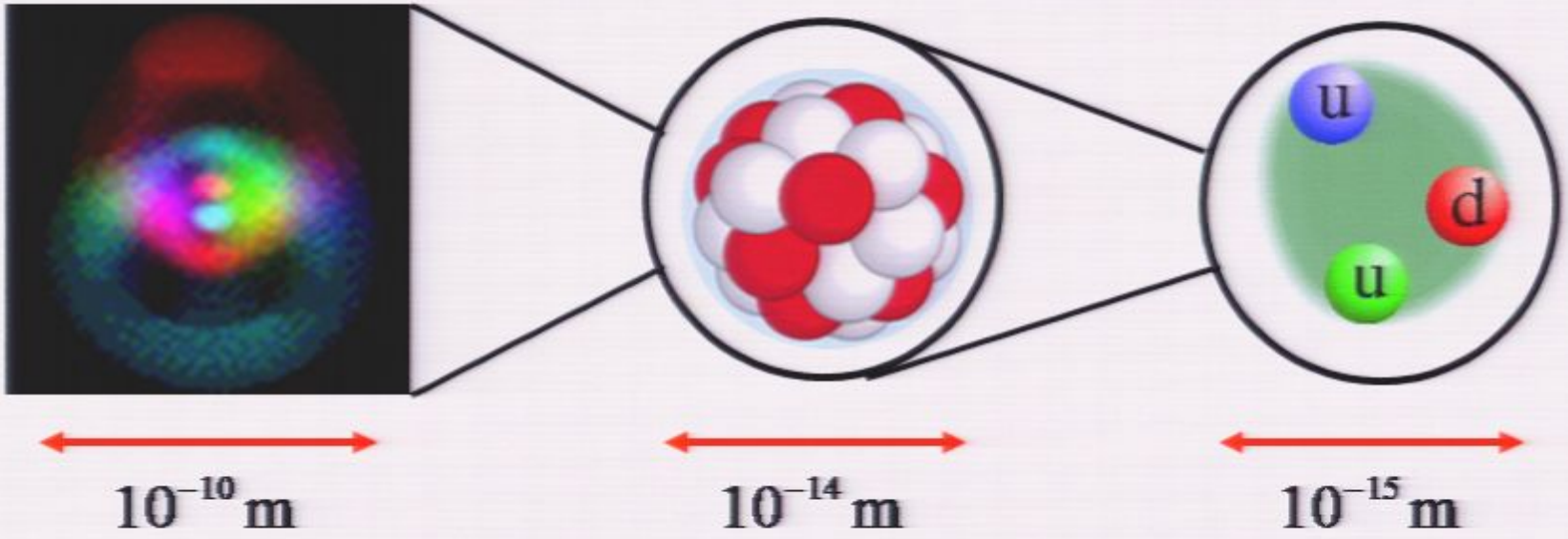

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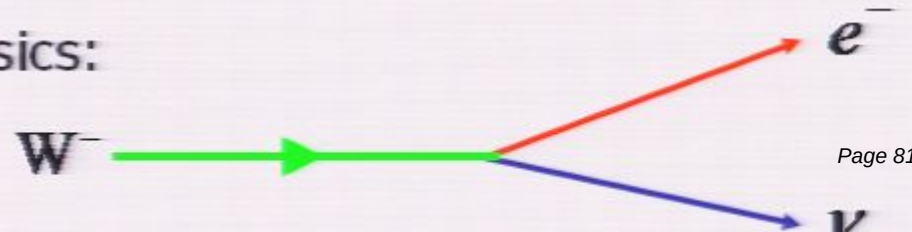

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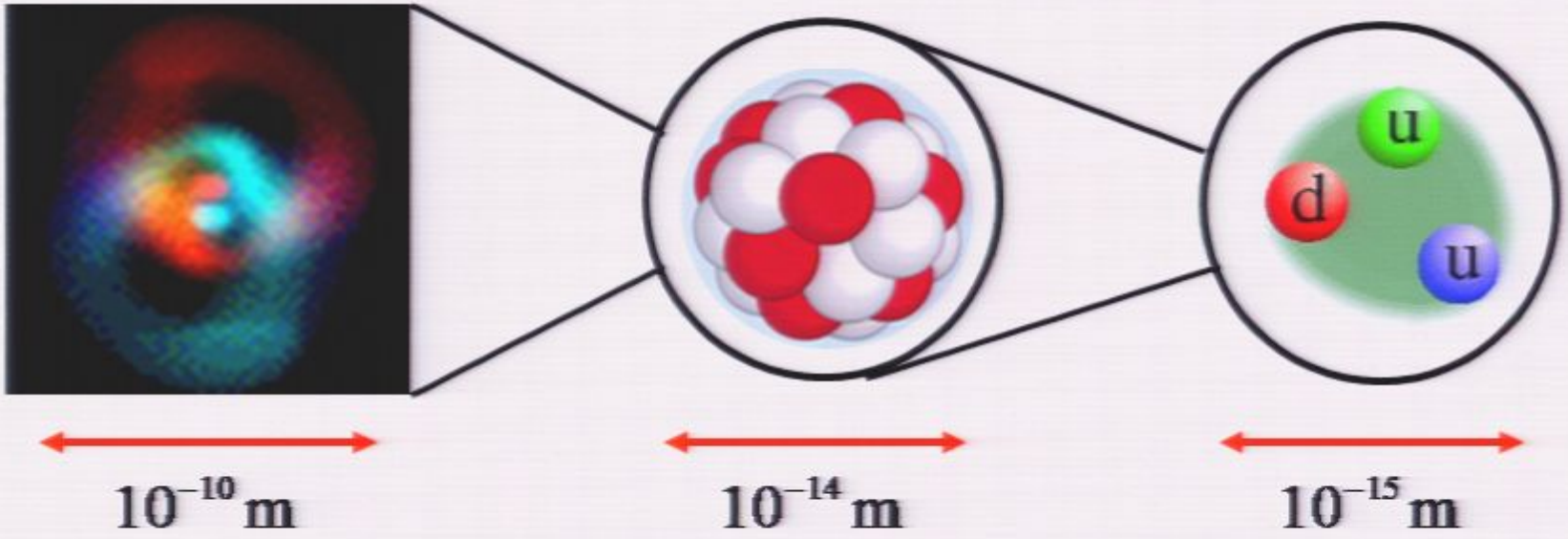

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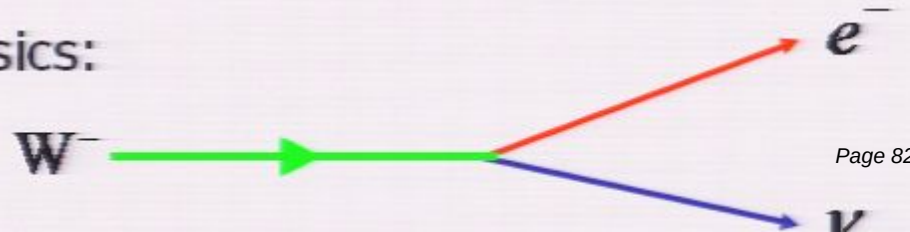

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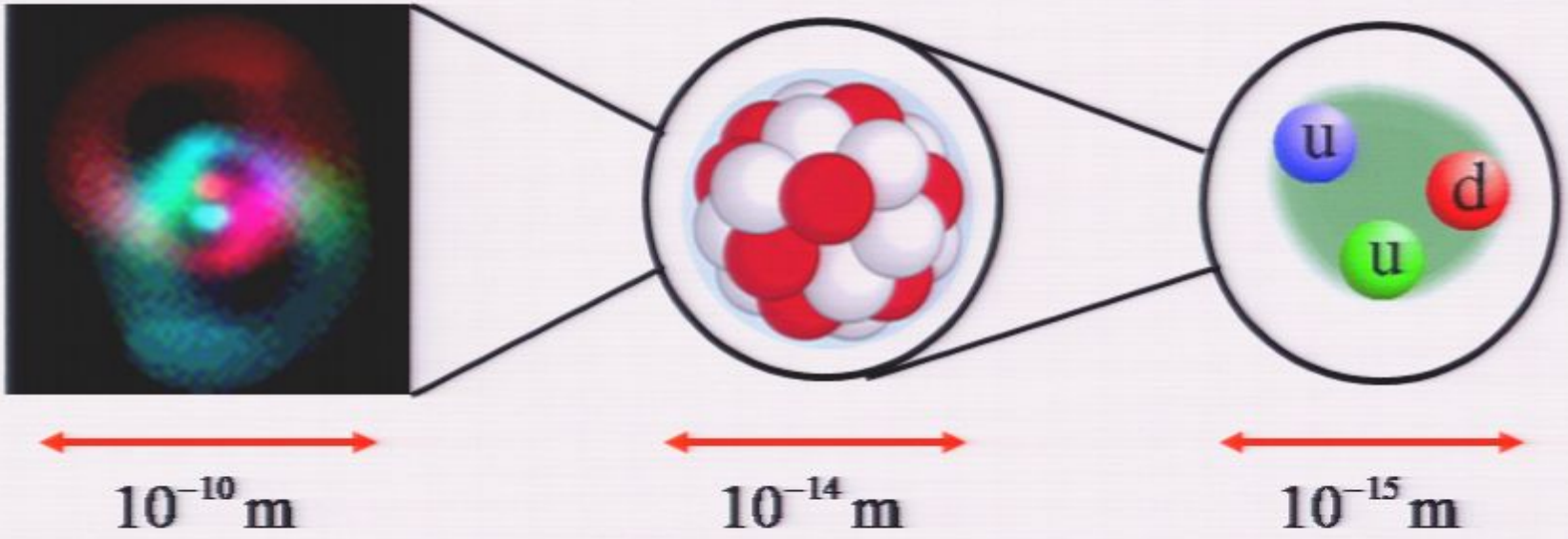

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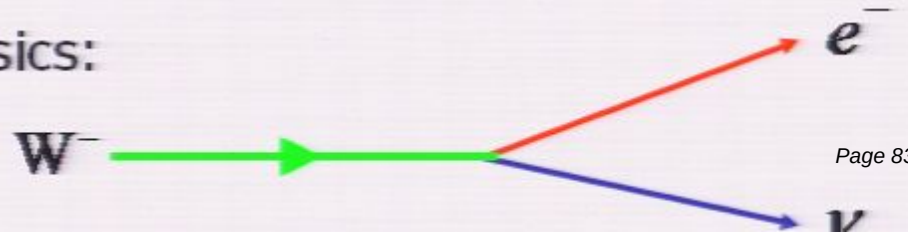

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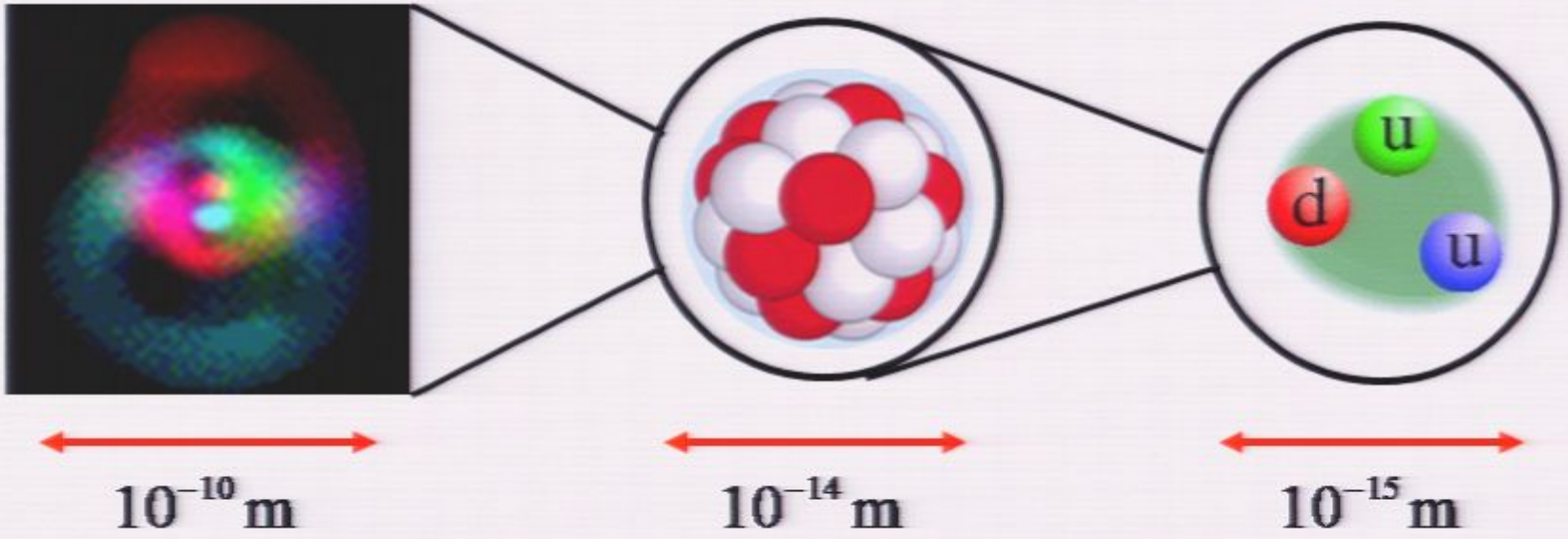

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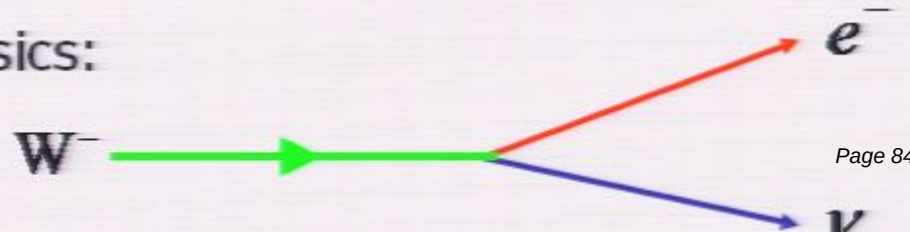

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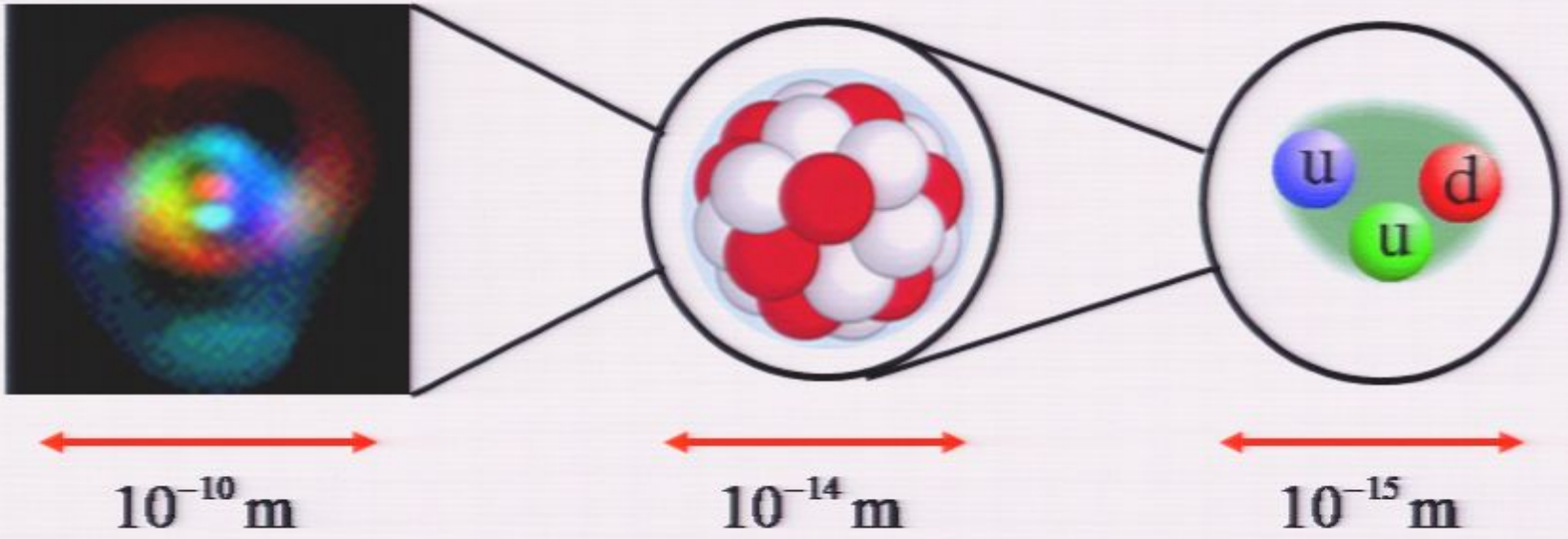

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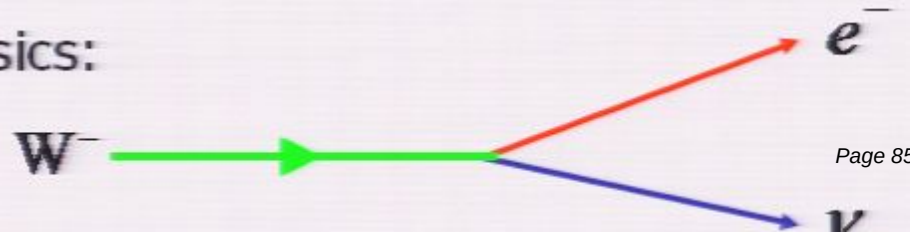

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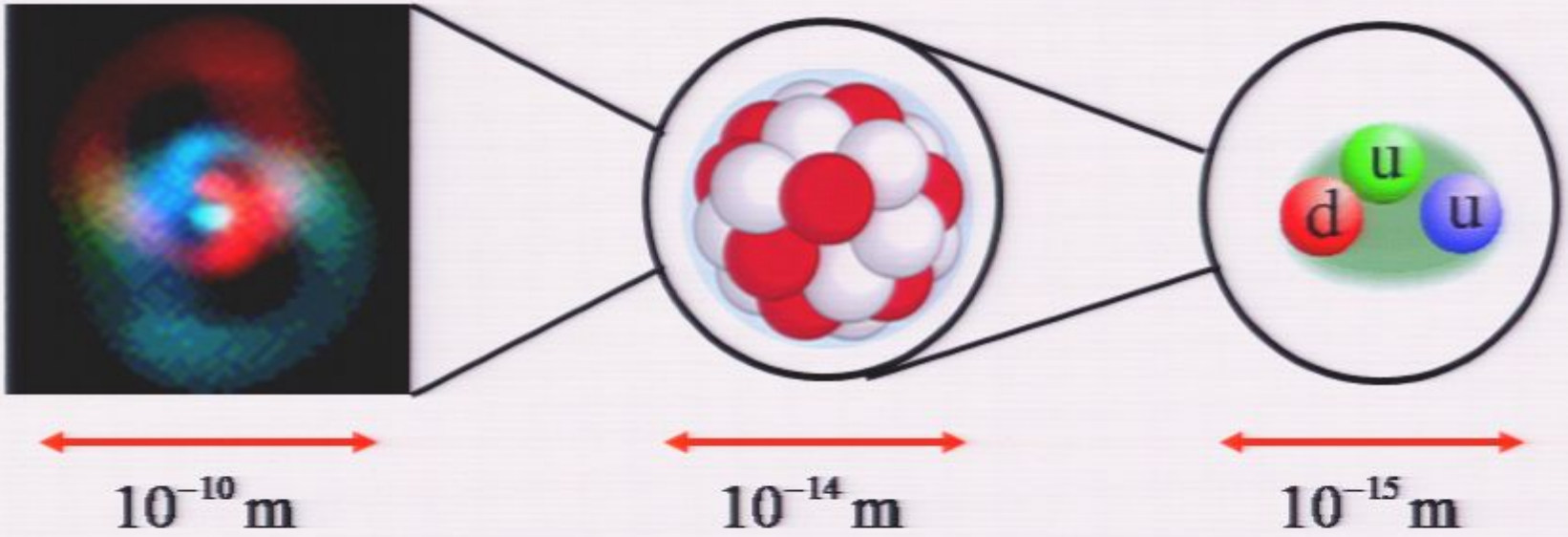

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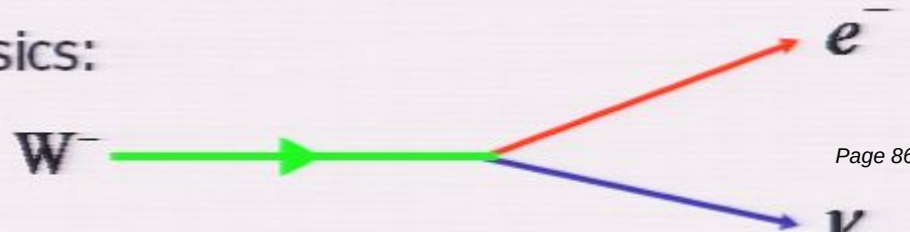

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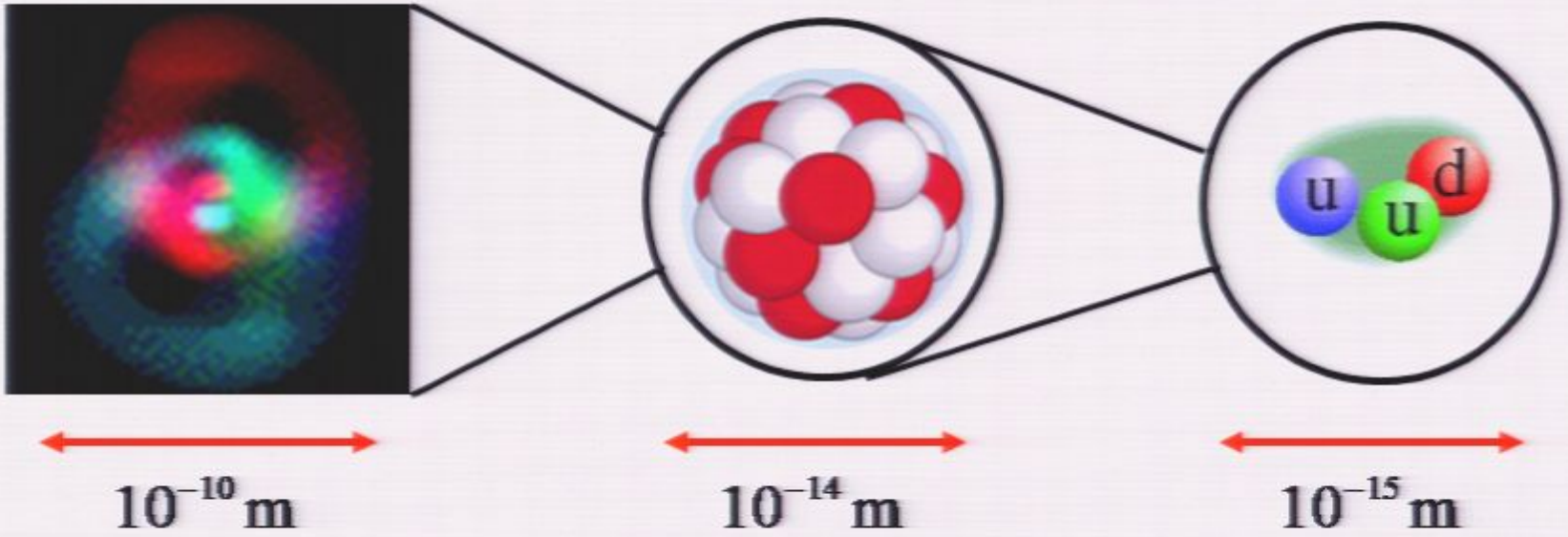

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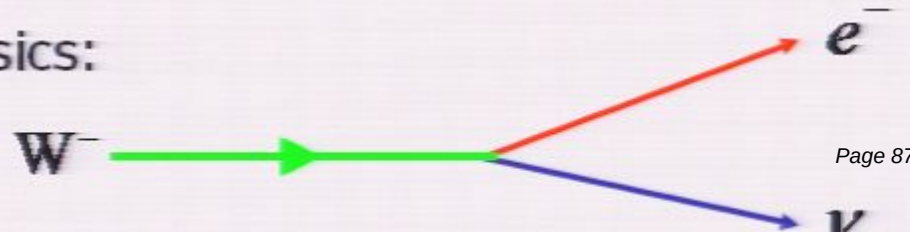

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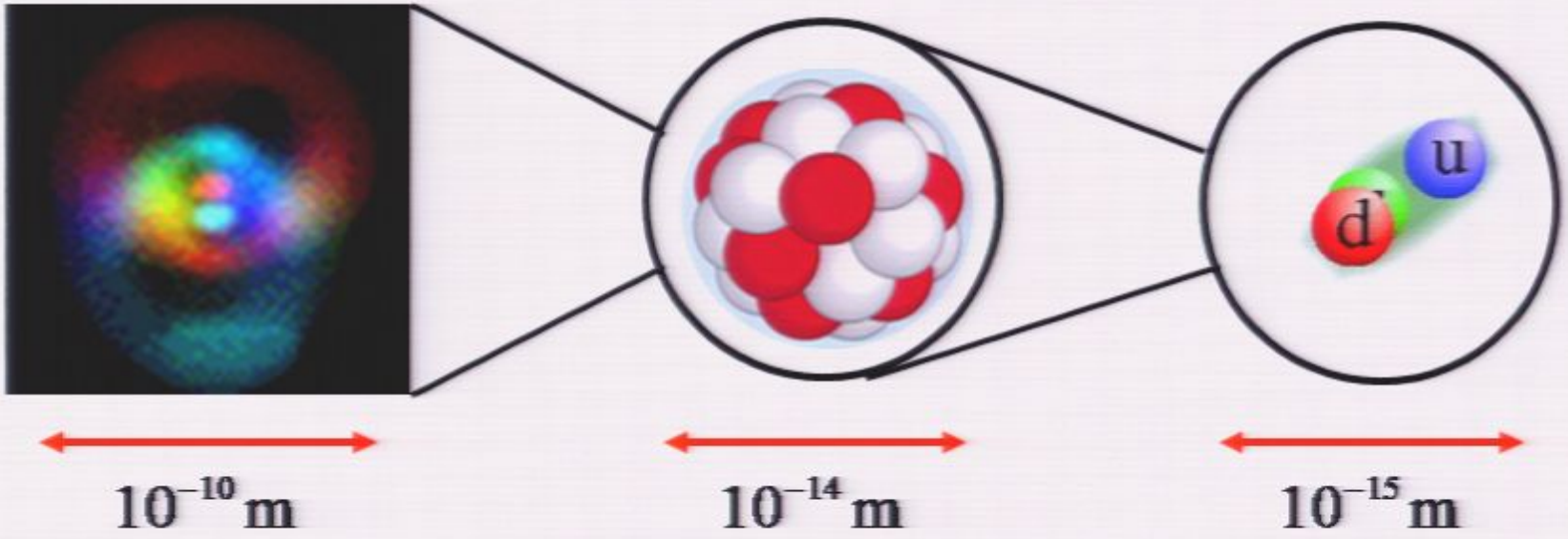

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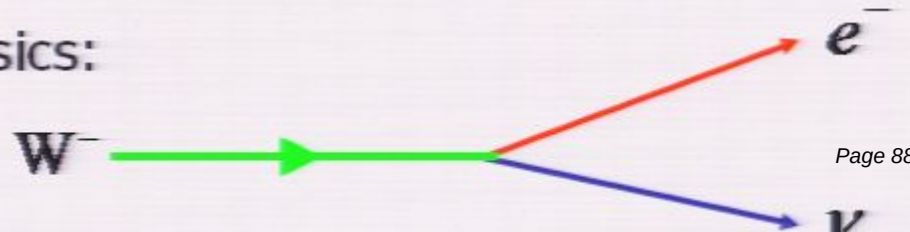
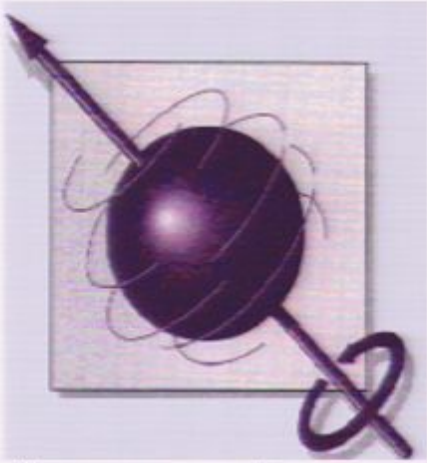
Standard Model of Subatomic Physics:

above particles plus interactions (and ~20 free parameters)



Quantum theory is rigorously tested!!



Example: electrons are tiny magnets

$$\mu_e = g\ e\hbar/4m_e \quad \text{with} \quad g \approx 2$$

precise value of magnetic moment depends on quantum fluctuations

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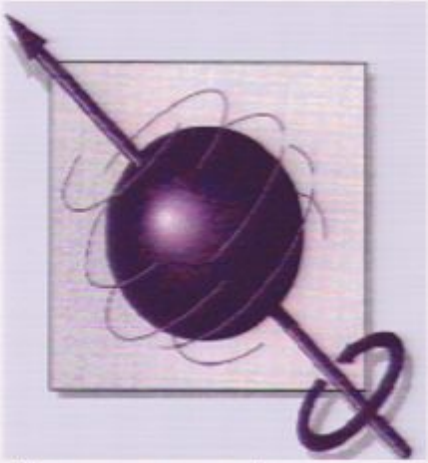

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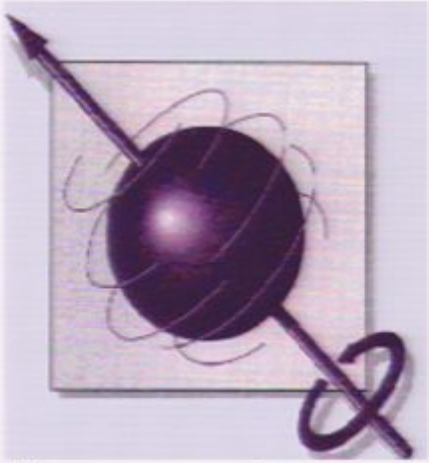

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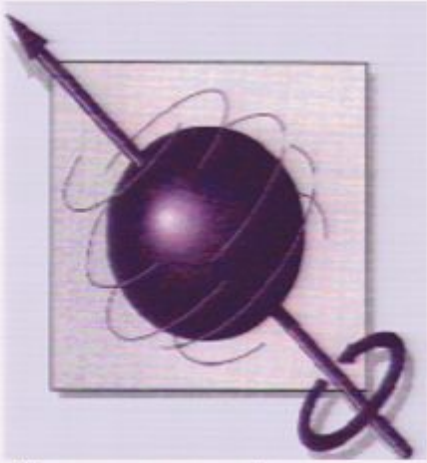

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$$\left| \frac{\mu_{\text{calculated}} - \mu_{\text{measured}}}{\mu_{\text{measured}}} \right| < 10^{-10}$$

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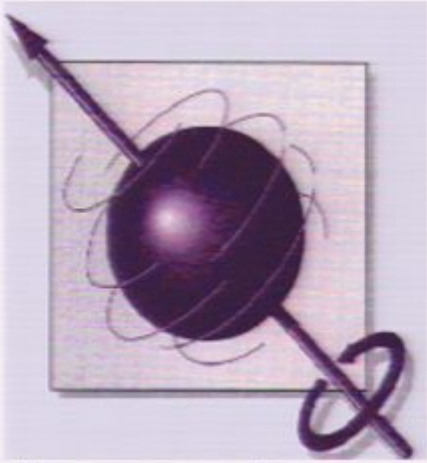

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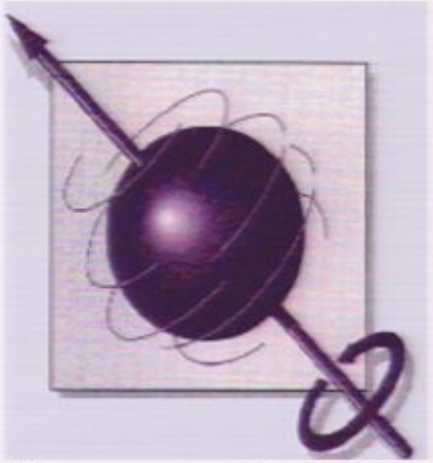

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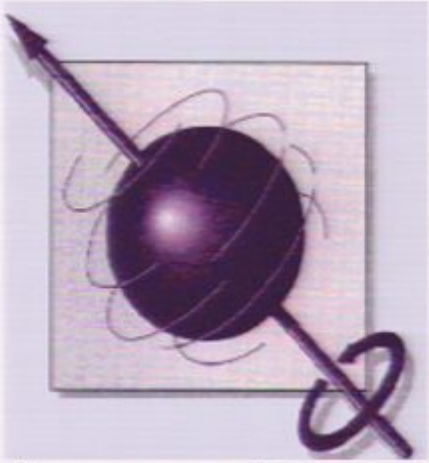

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(neither answer absolutely correct)

Quantum theory is rigorously tested!!

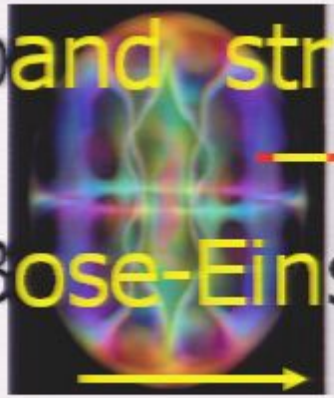
e.g., magnetic moment of the electron, $\mu_e = g\frac{e\hbar}{4m_e}$,
is modified by quantum fluctuations

$$\left|\frac{\mu_{\text{theory}} - \mu_{\text{experiment}}}{\mu_{\text{experiment}}}\right| \leq 10^{-10}$$

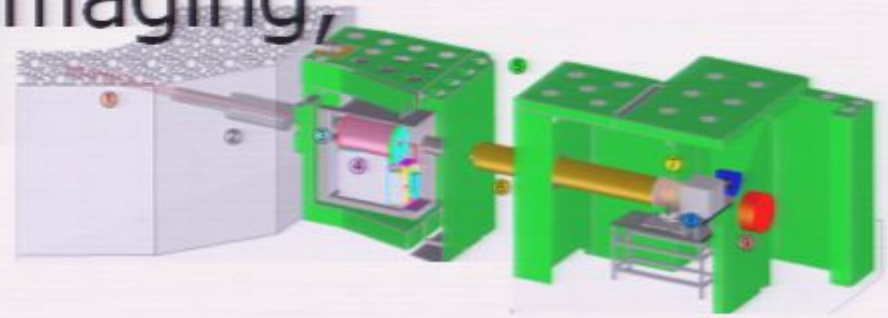
e.g., Lamb shift: shift between $2S_{1/2}$ and $2P_{1/2}$
energy levels of hydrogen atom (f = 1057 MHz)

$$\left|\frac{f_{\text{theory}} - f_{\text{experiment}}}{f_{\text{experiment}}}\right| \leq 10^{-6}$$

Quantum Theory: a rich source of new ideas



- band structure in materials → semiconductor technology
- Bose-Einstein condensation → superfluids, superconductors
- quantum Hall effect, neutron diffraction, electron microscopy, lasers, magnetic resonance imaging, ...



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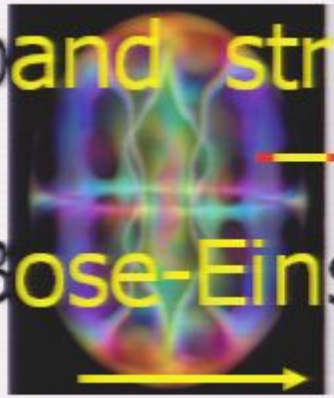

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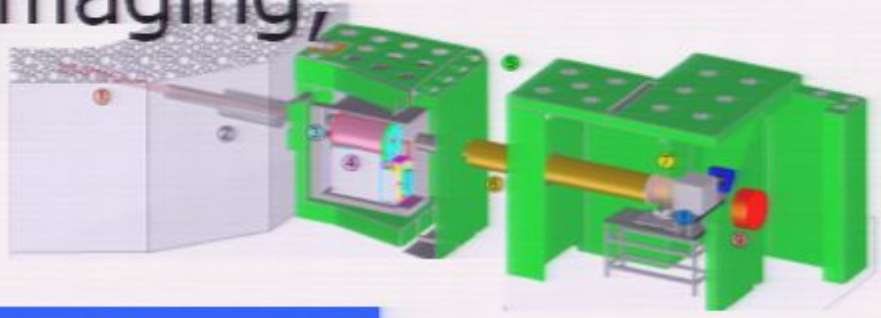
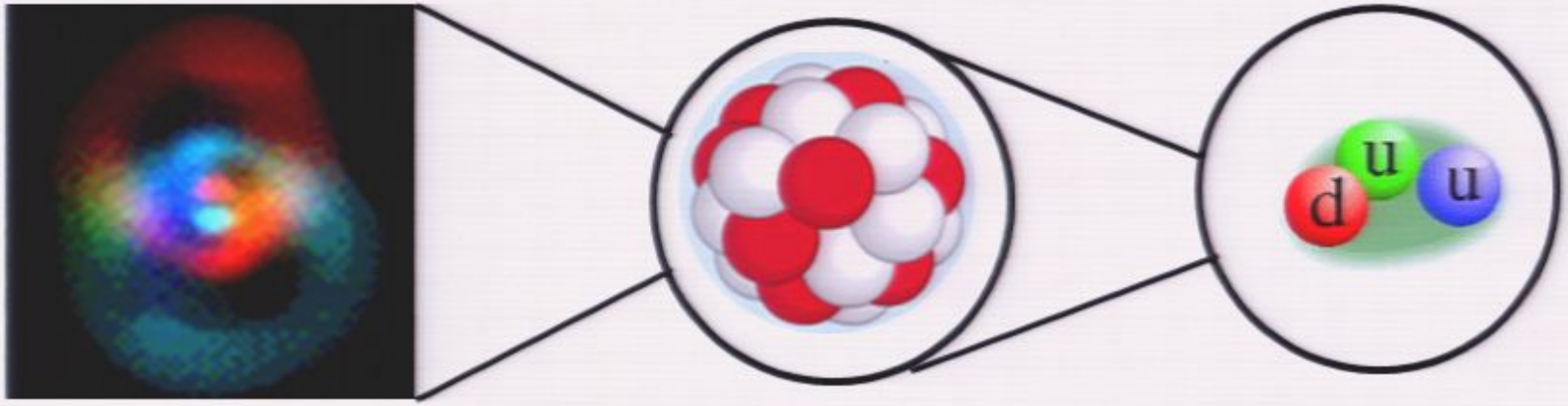


Nobel prizes galore!!

Subatomic Physics



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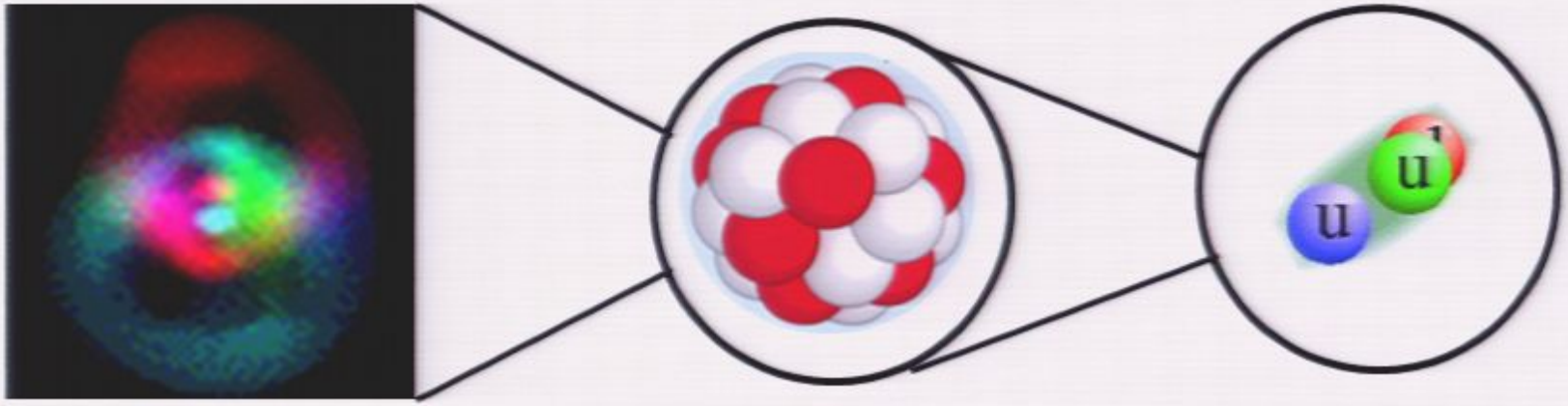

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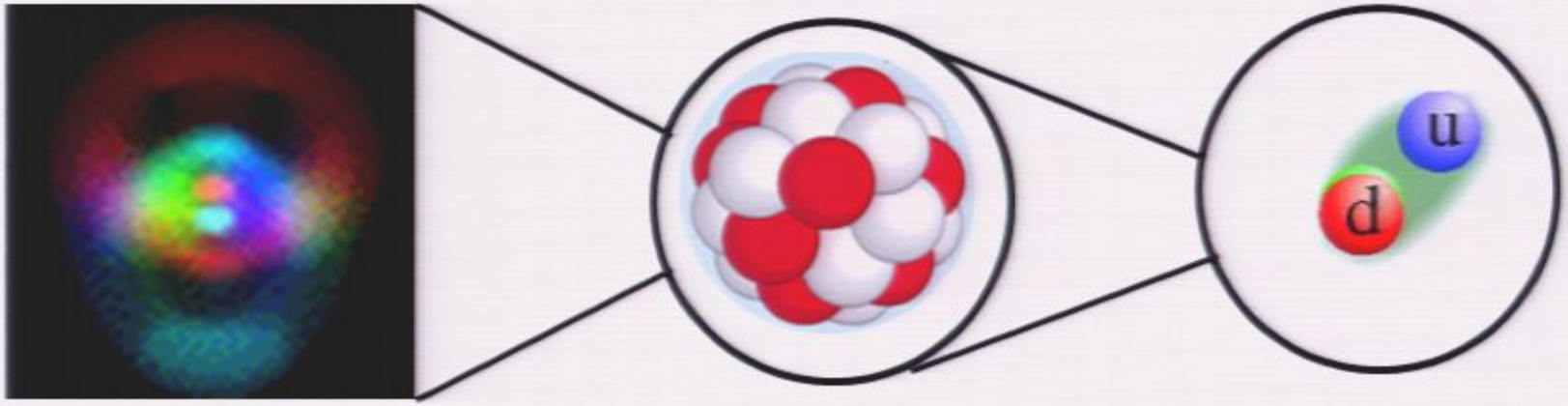

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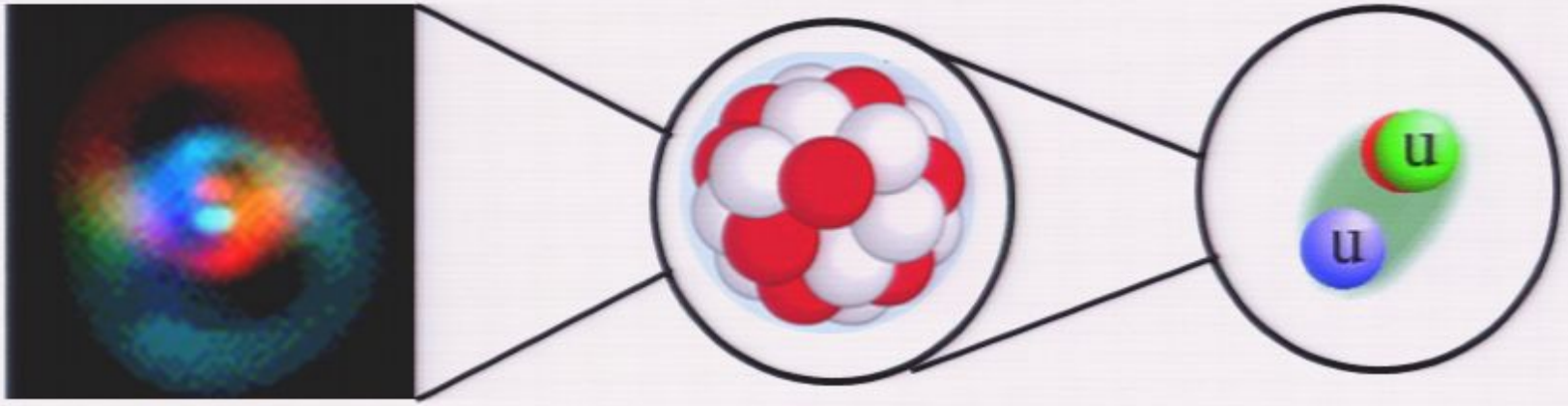

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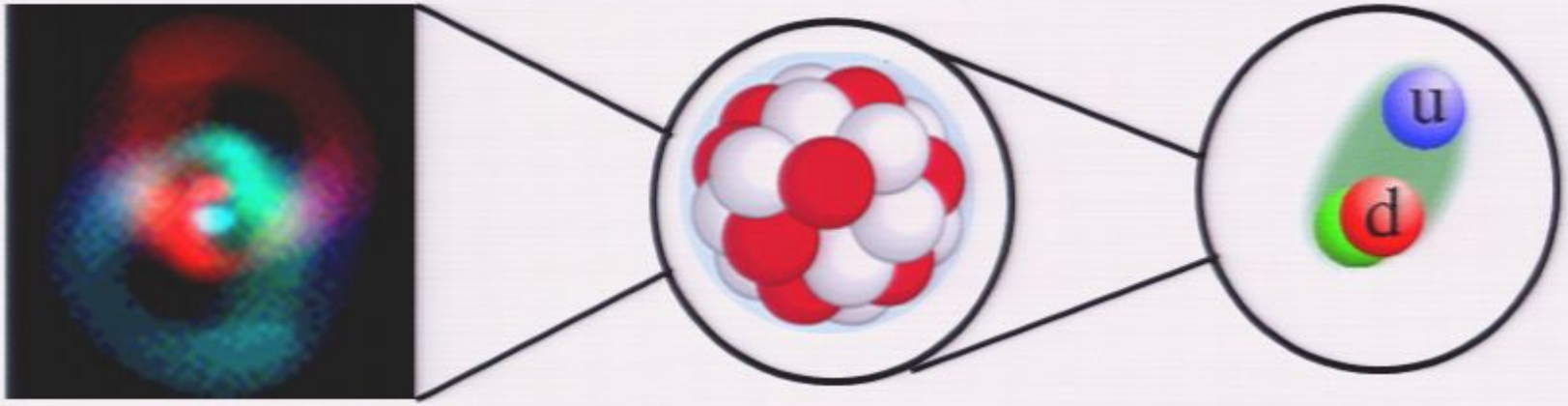

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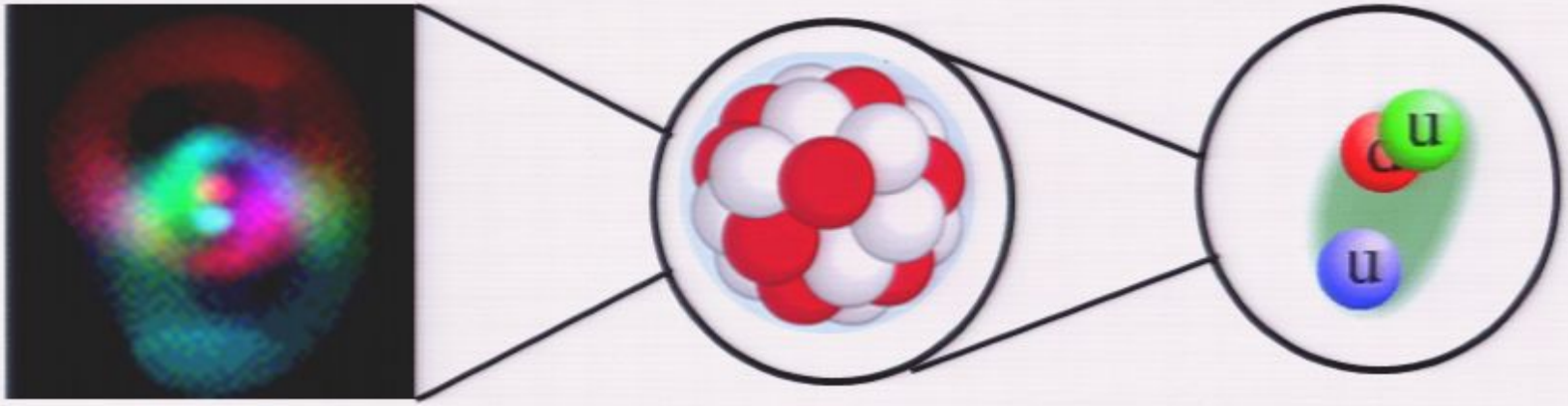

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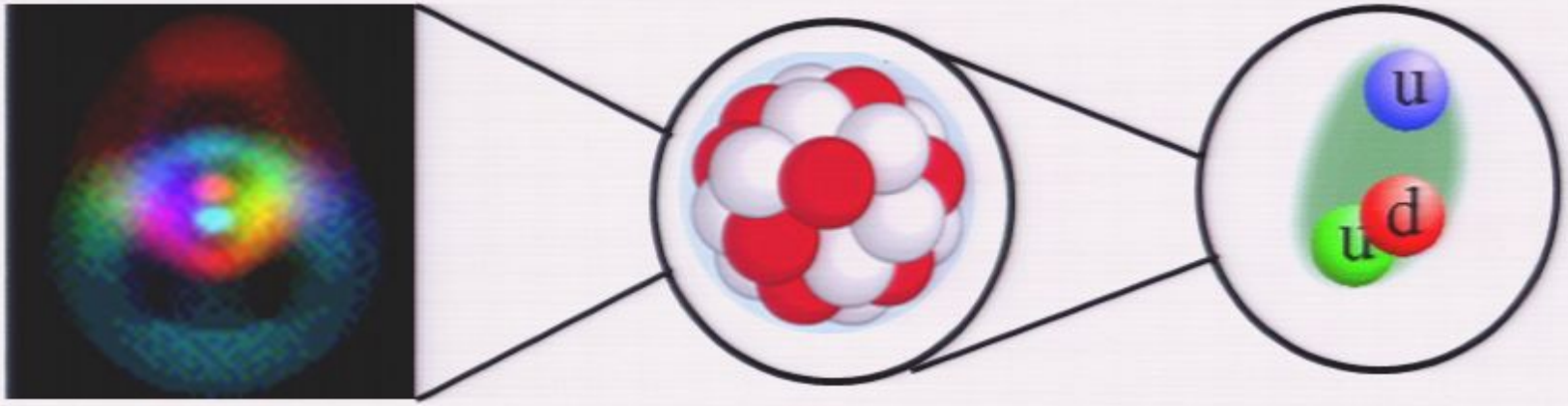

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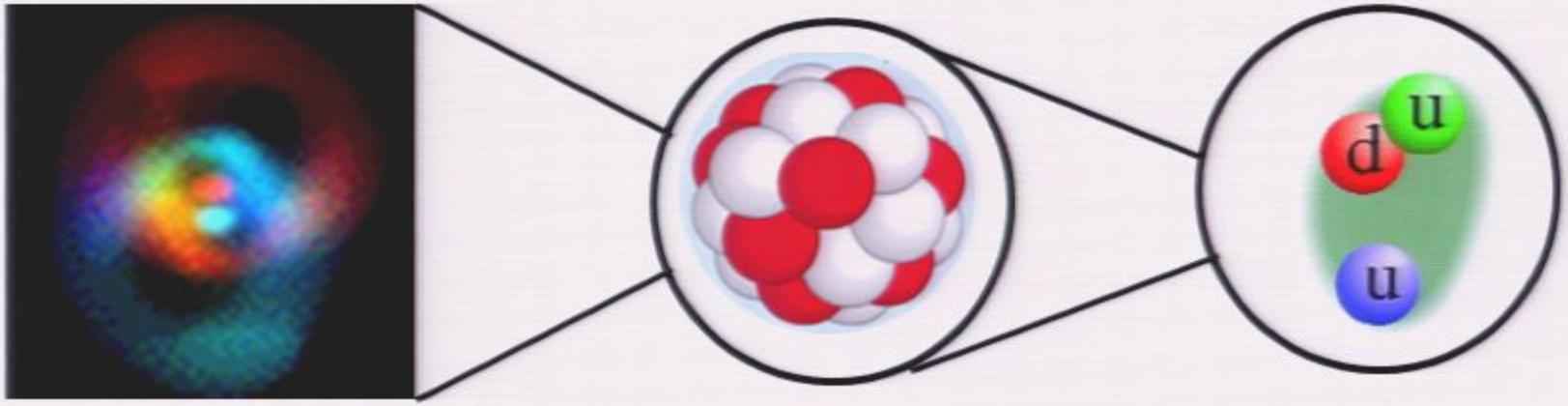

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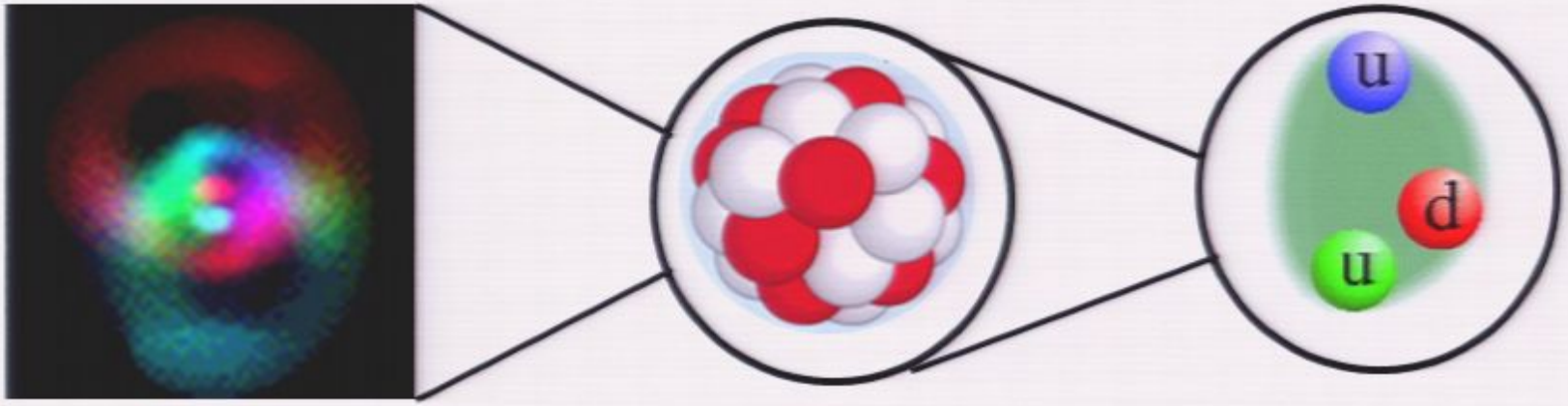

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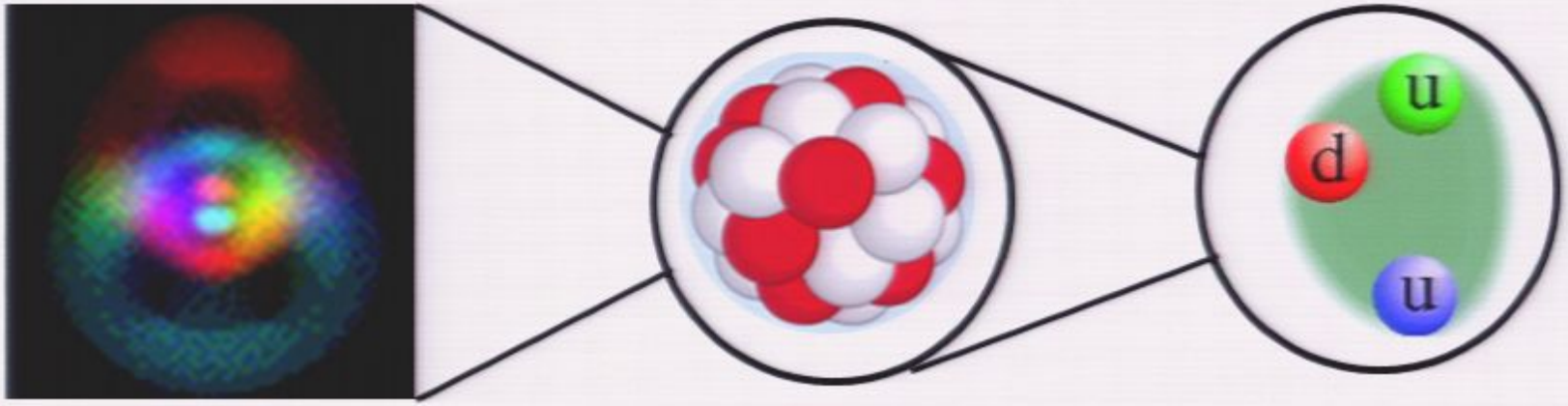

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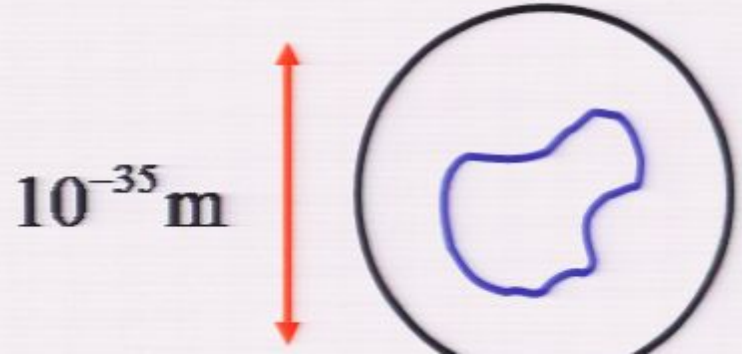

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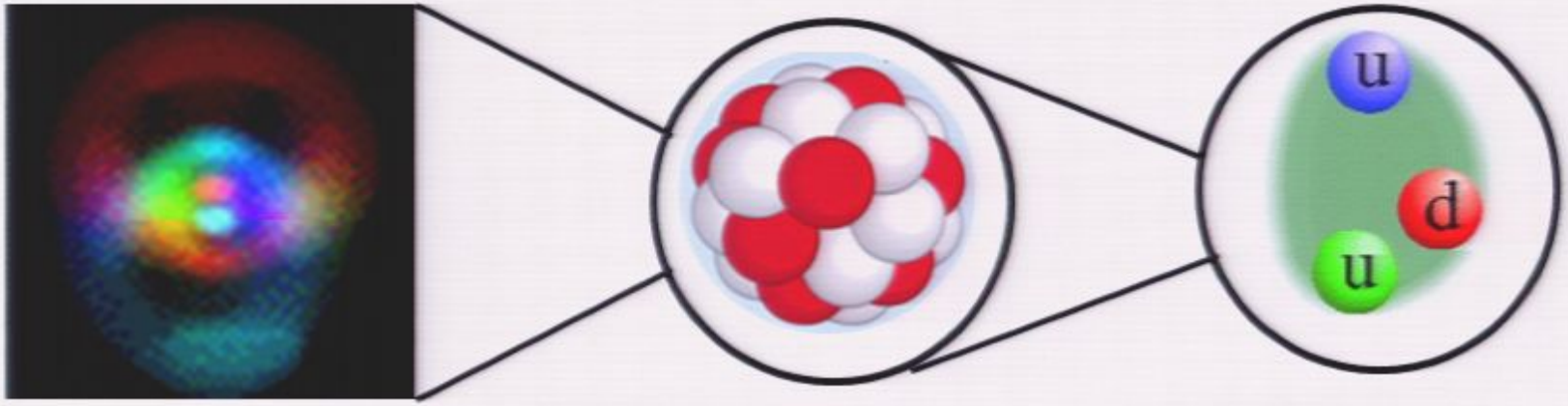

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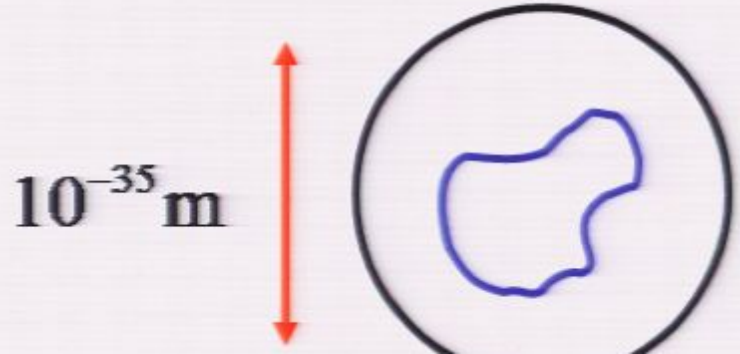

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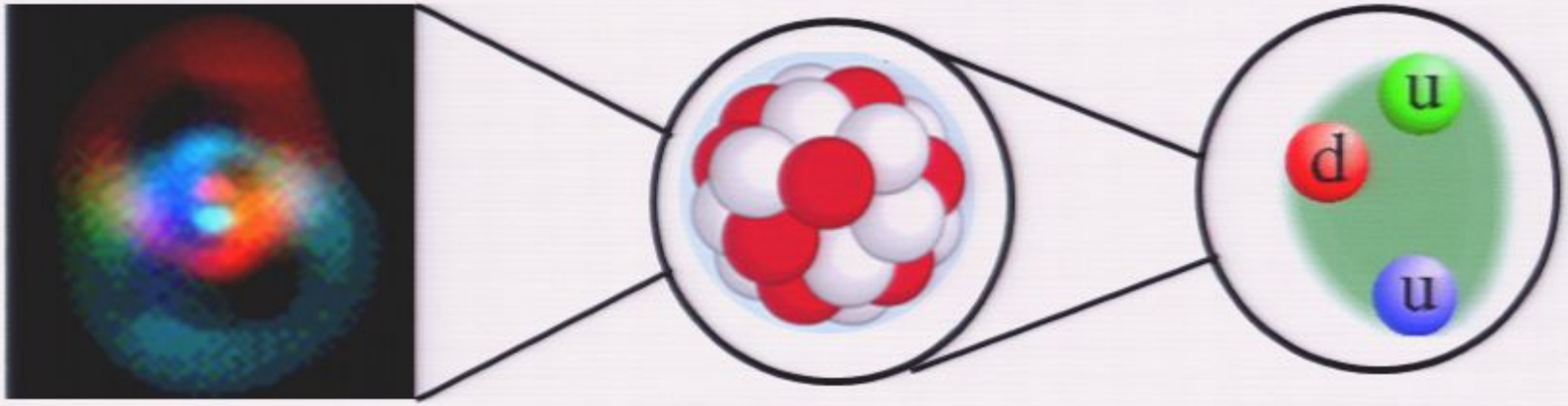

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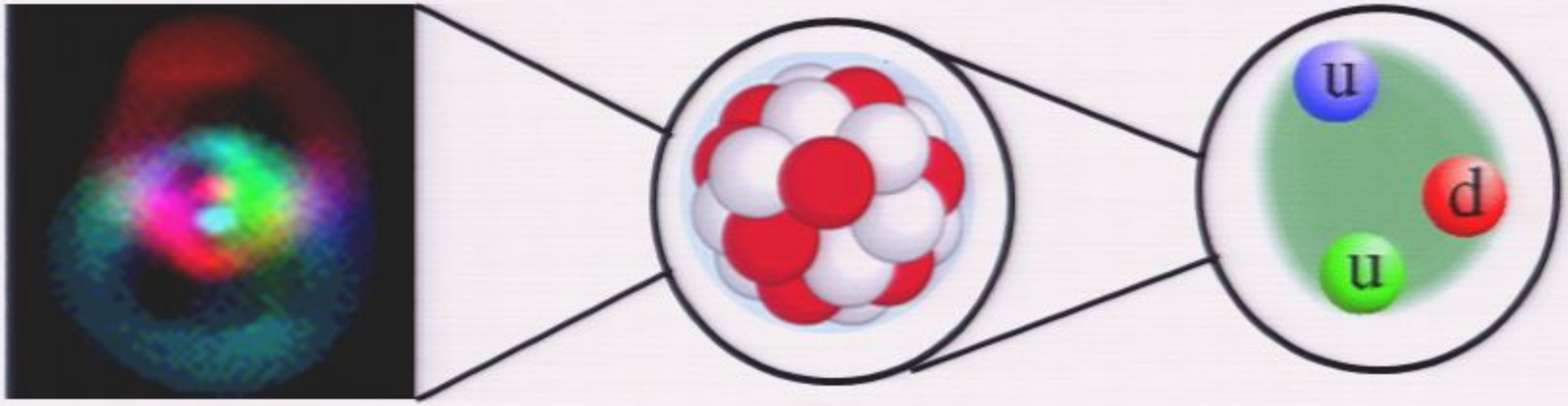

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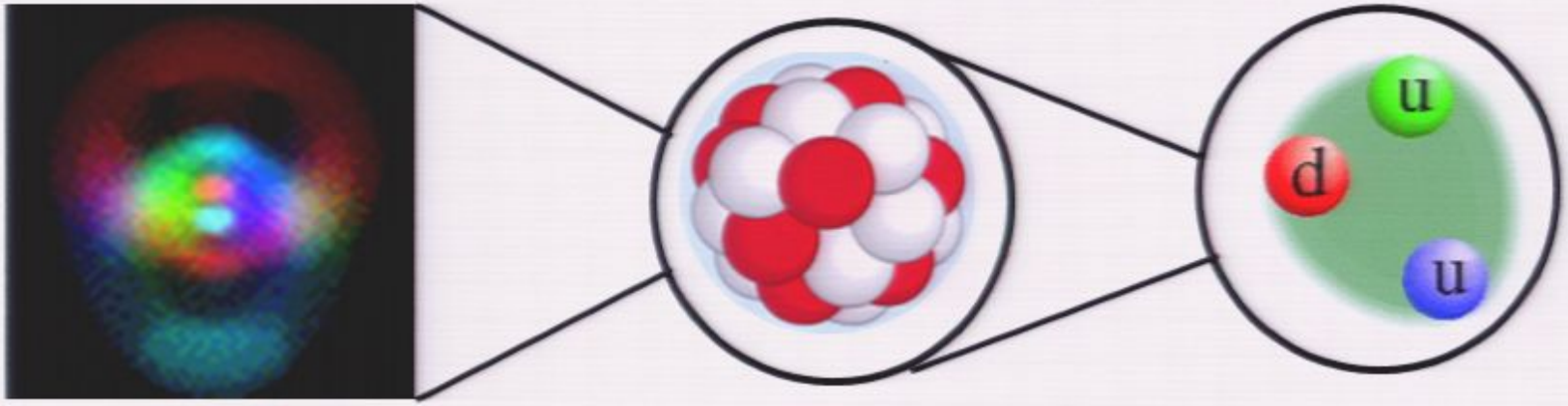

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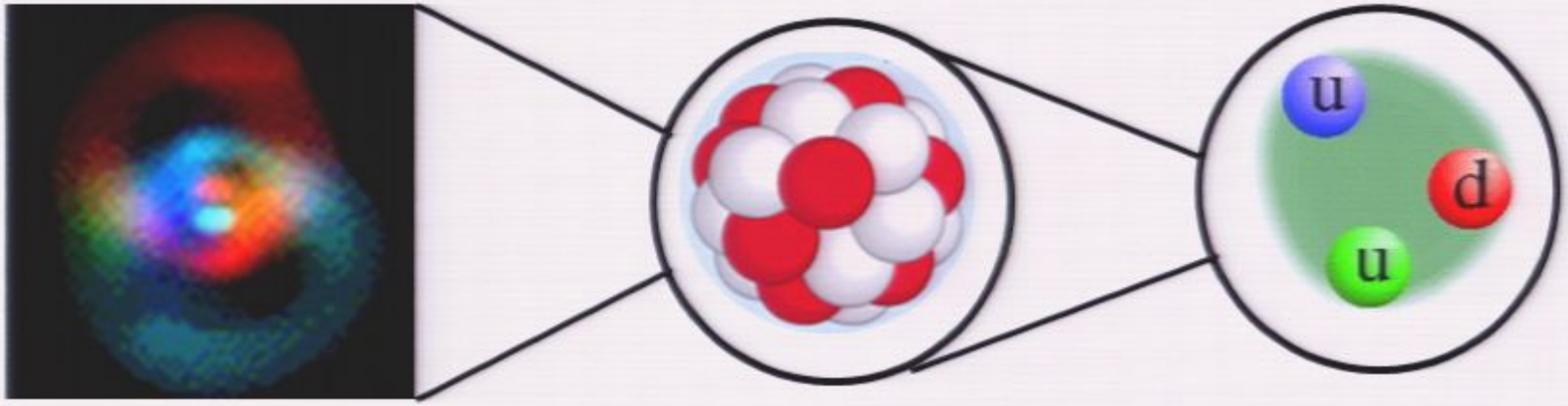

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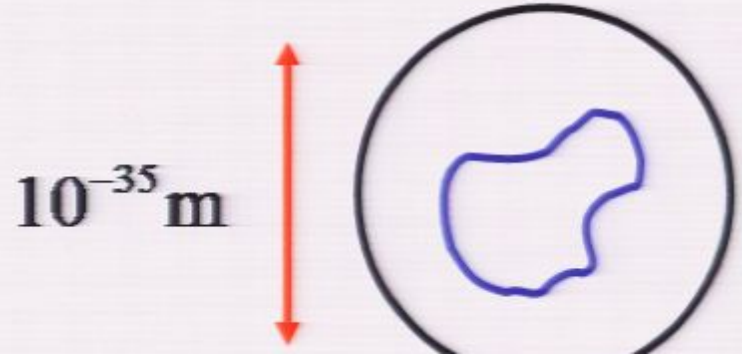

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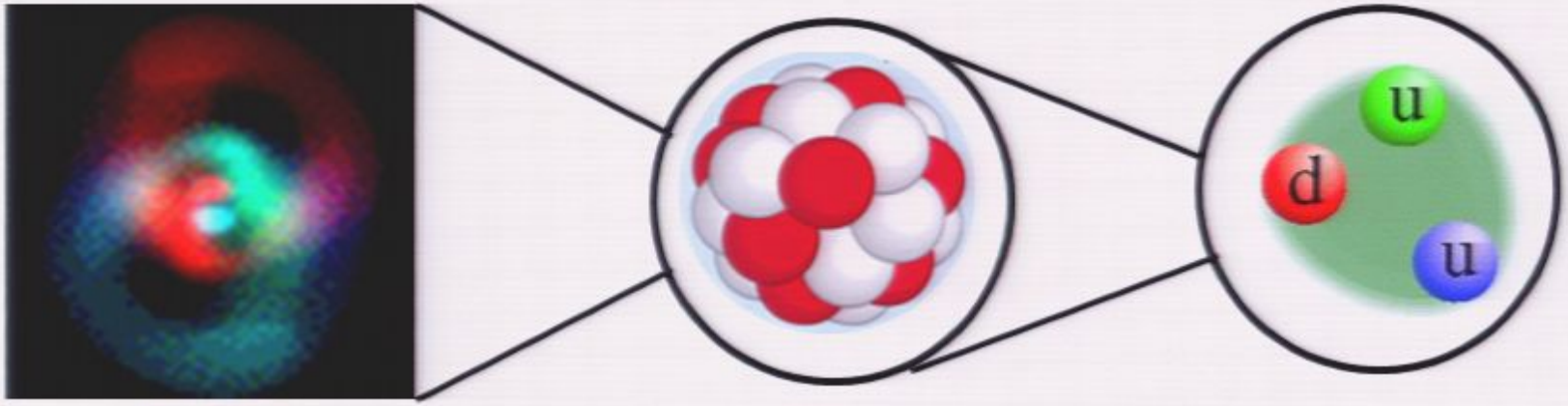

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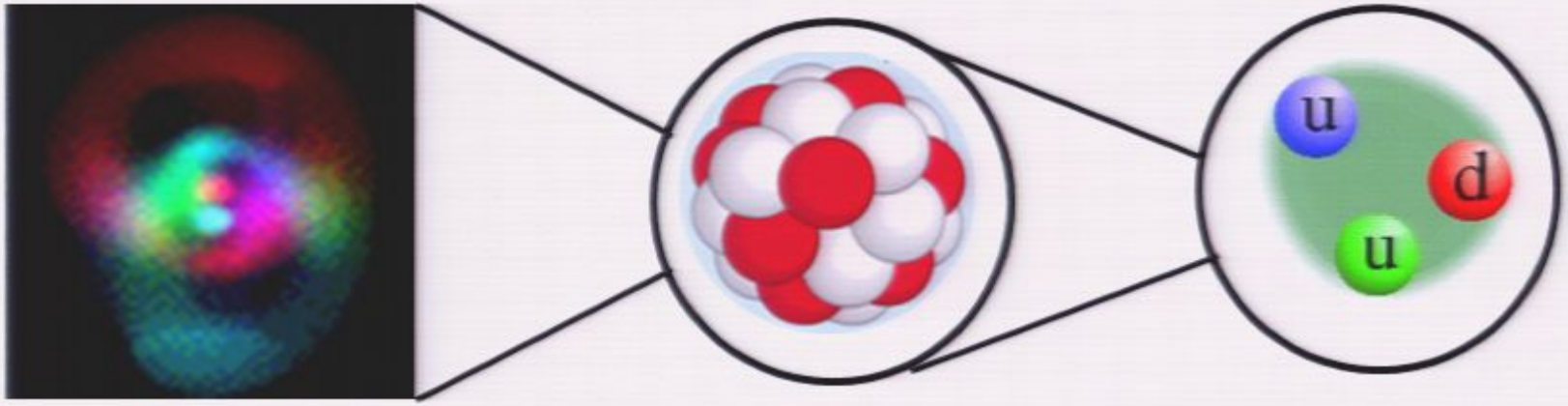

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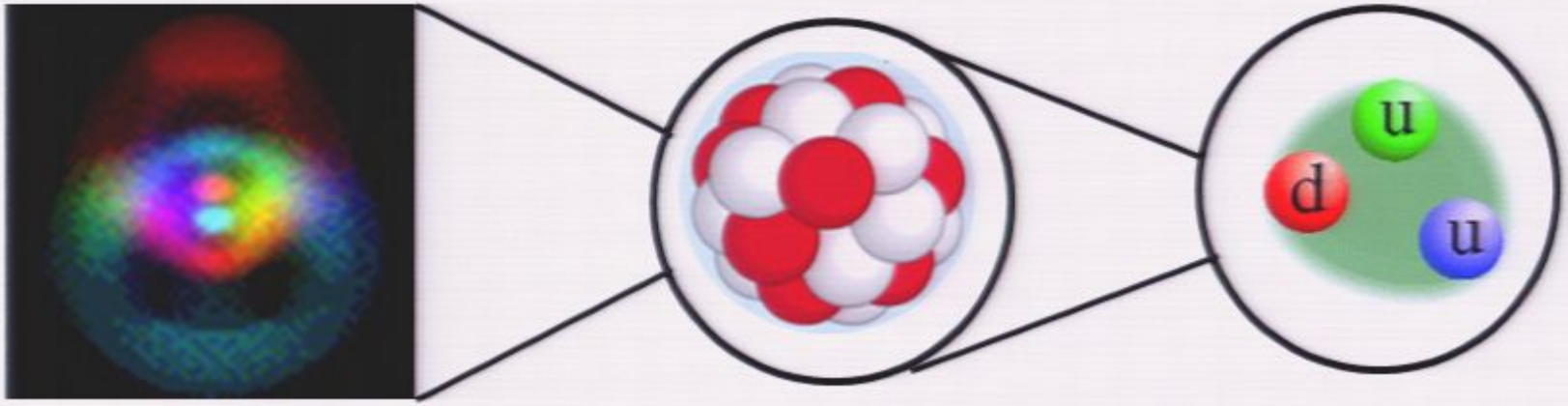

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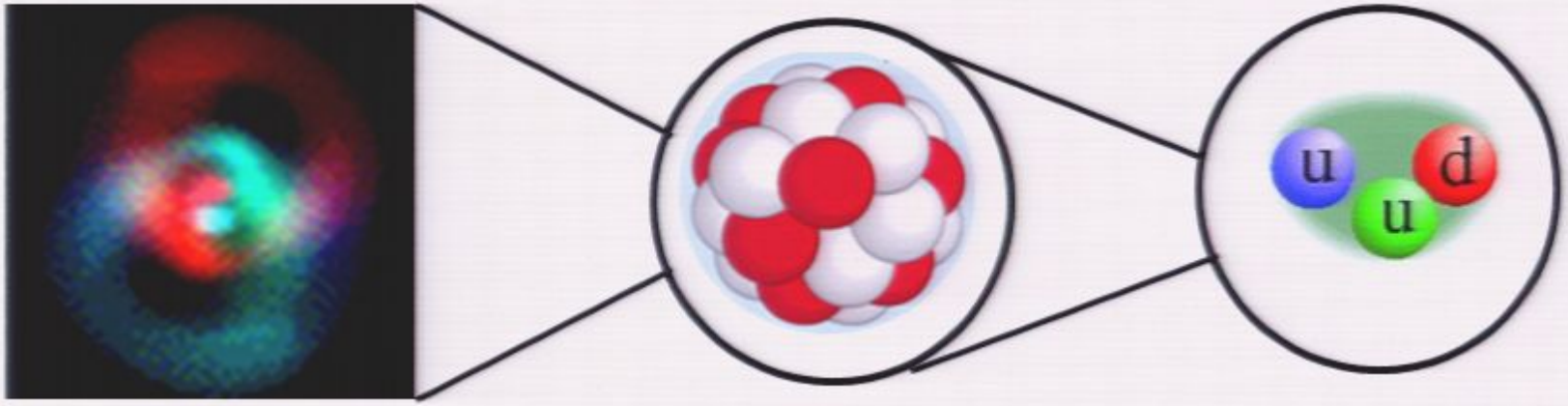
Strings tame the particle zoo!

Subatomic Physics → a theory of strings!



Elementary Particles (10^{-17} m)

Fermions:
- electron, muon, tauon
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- quarks - up, down, strange, charm, bottom, top

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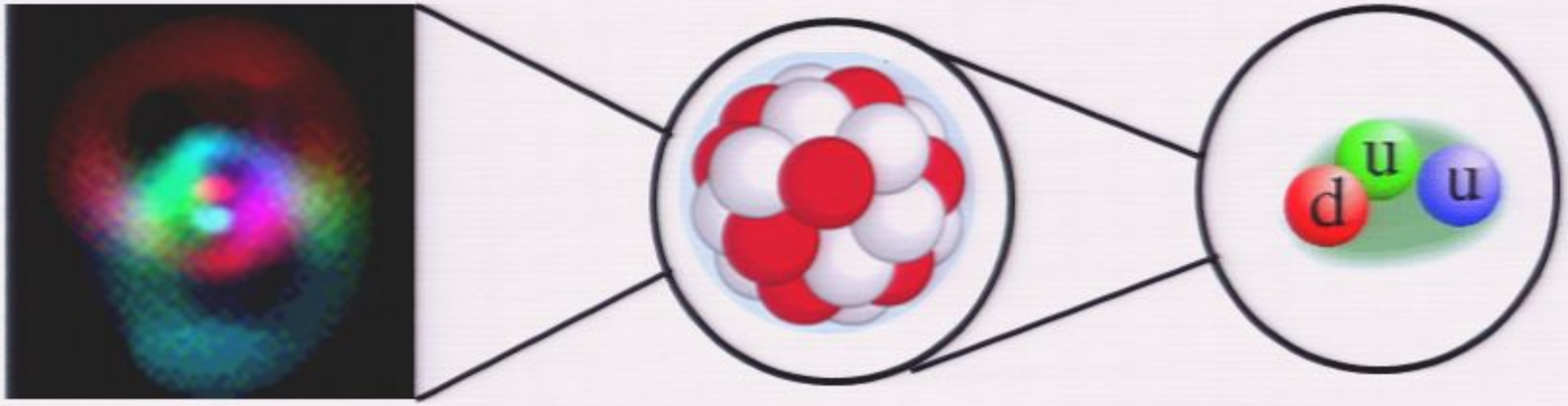

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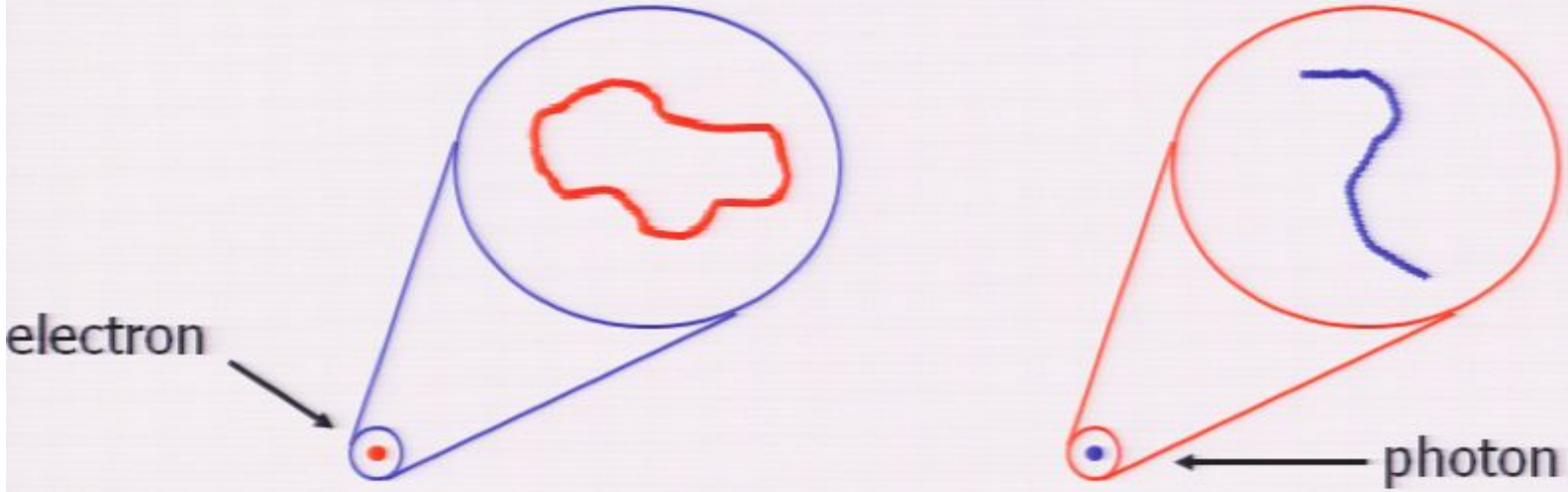
with sufficient resolution, all elementary particles are one-dimensional objects (strings)



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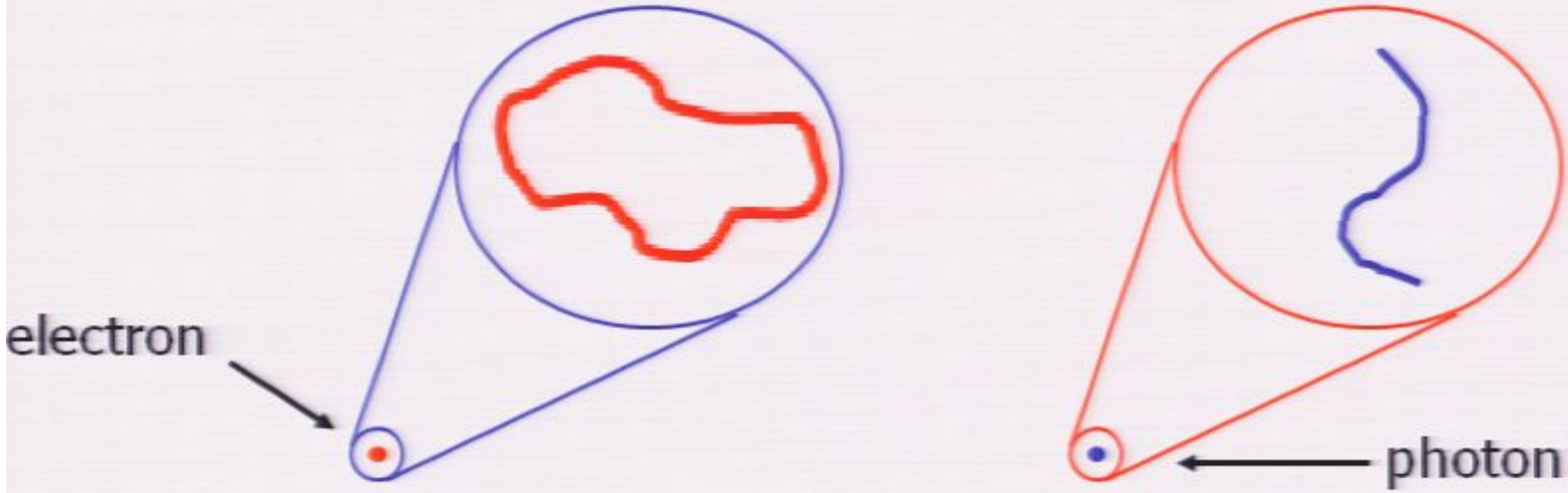

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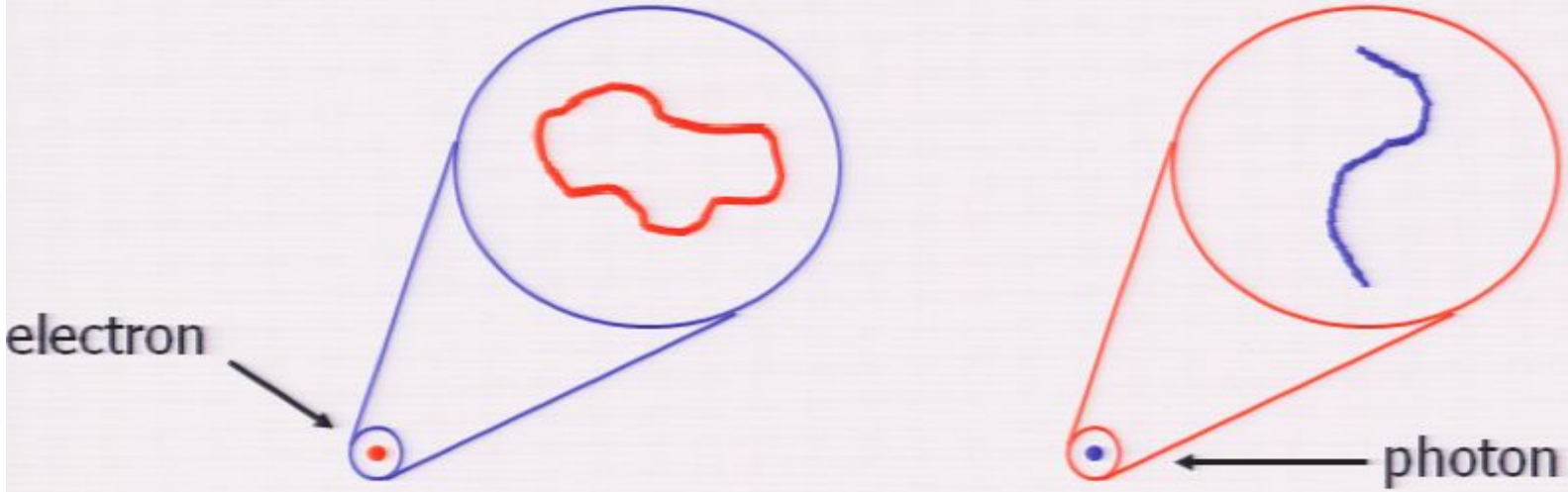

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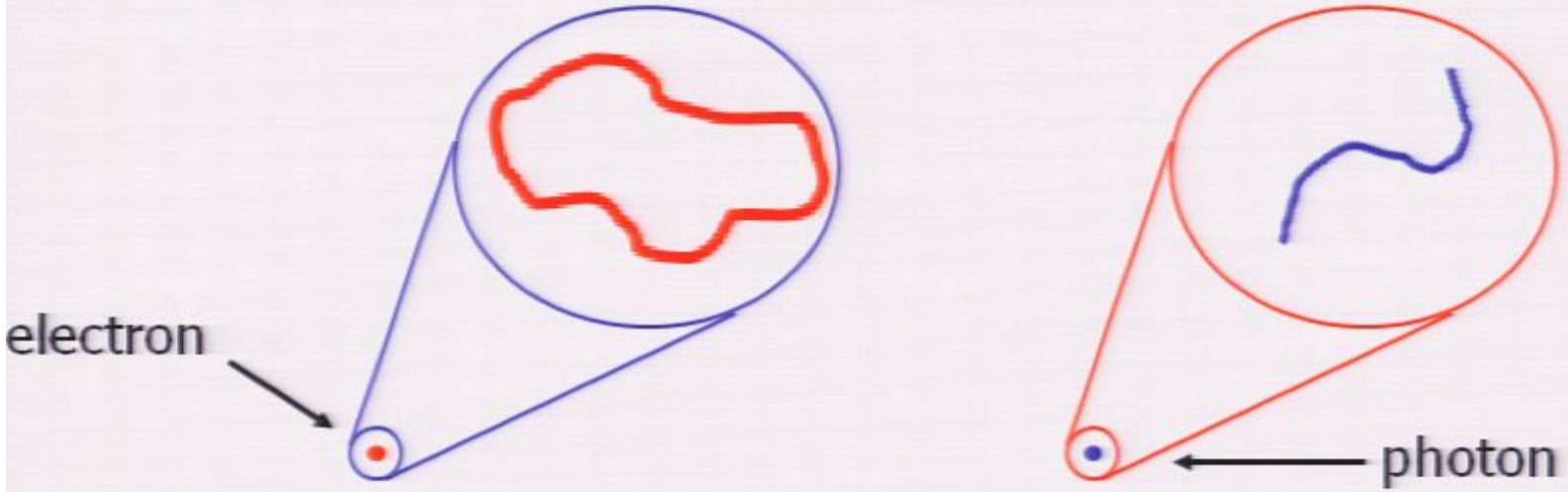

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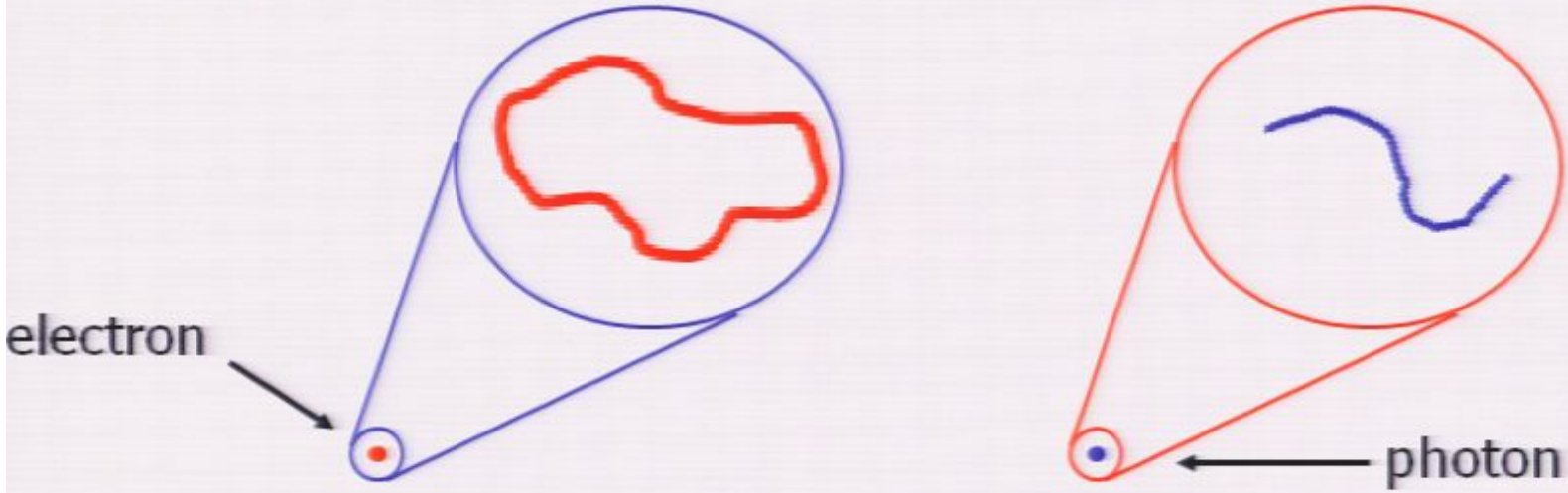

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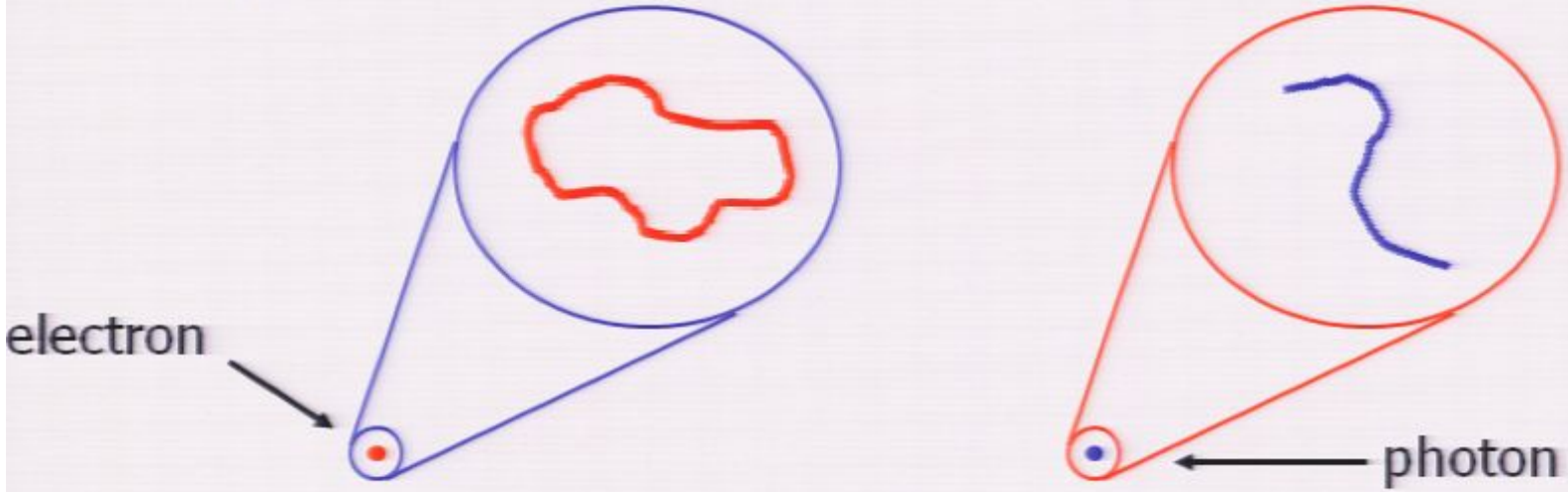

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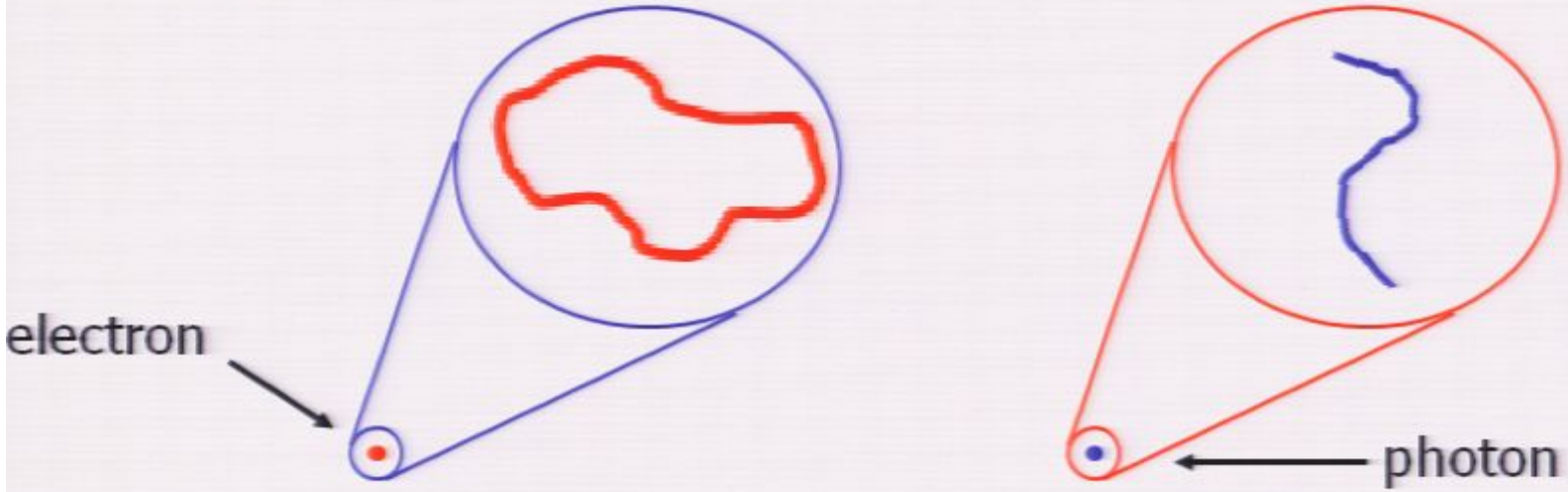

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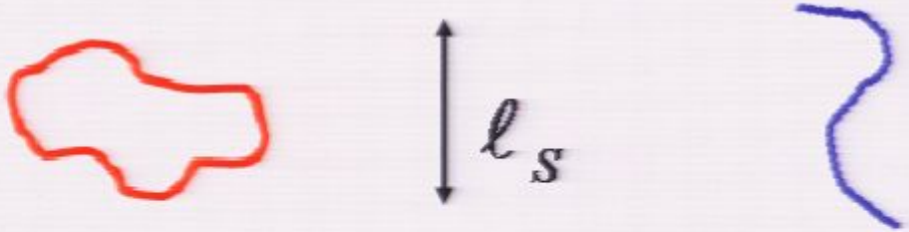

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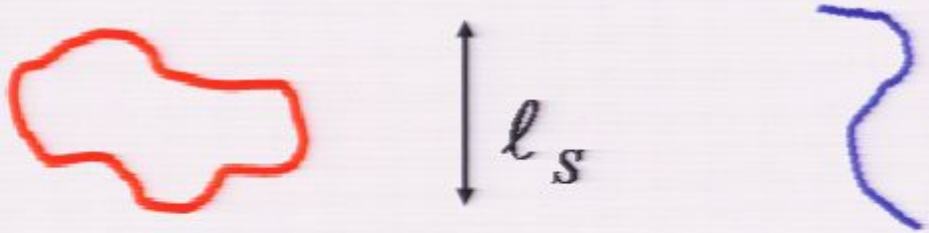

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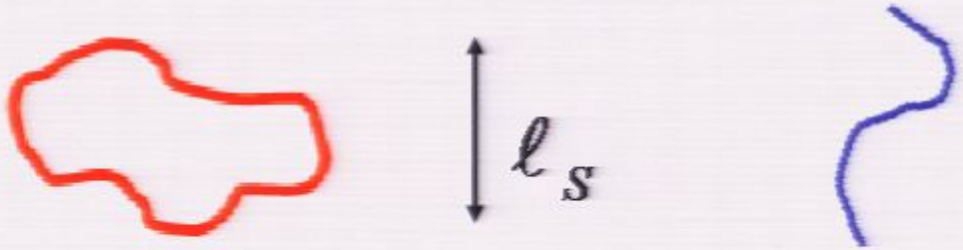

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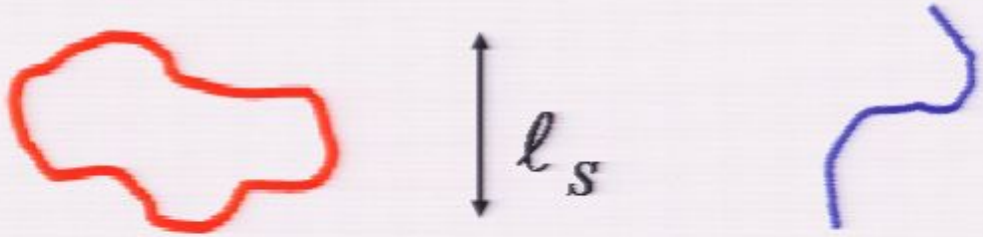

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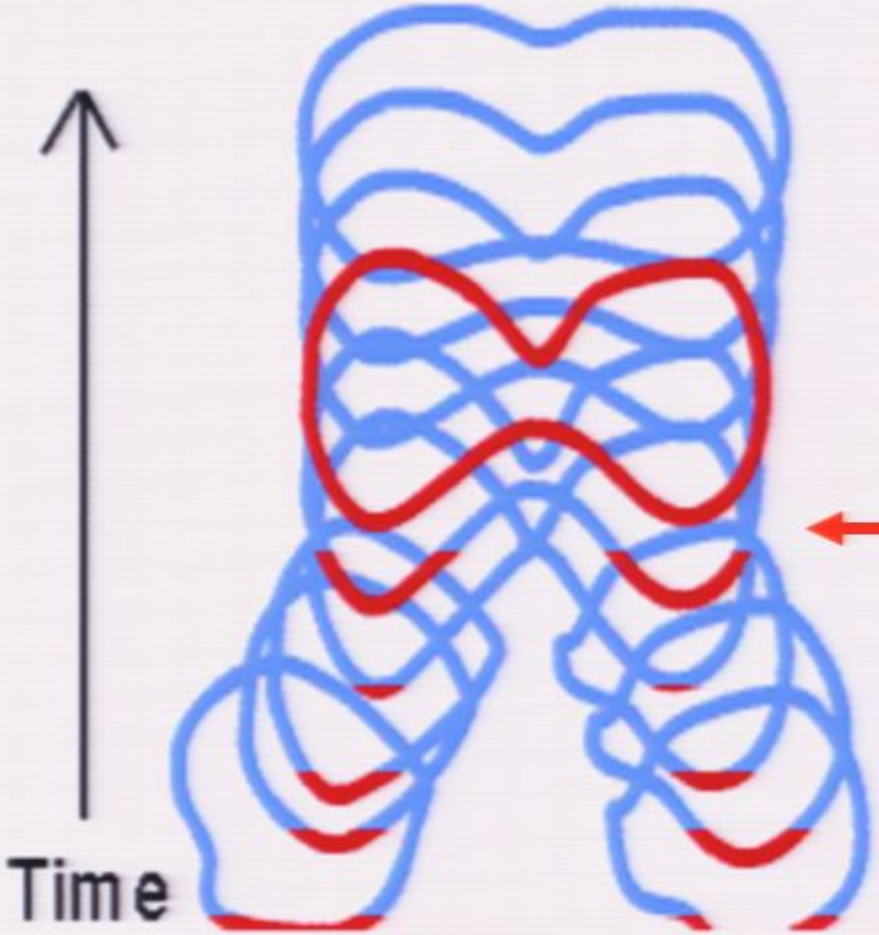

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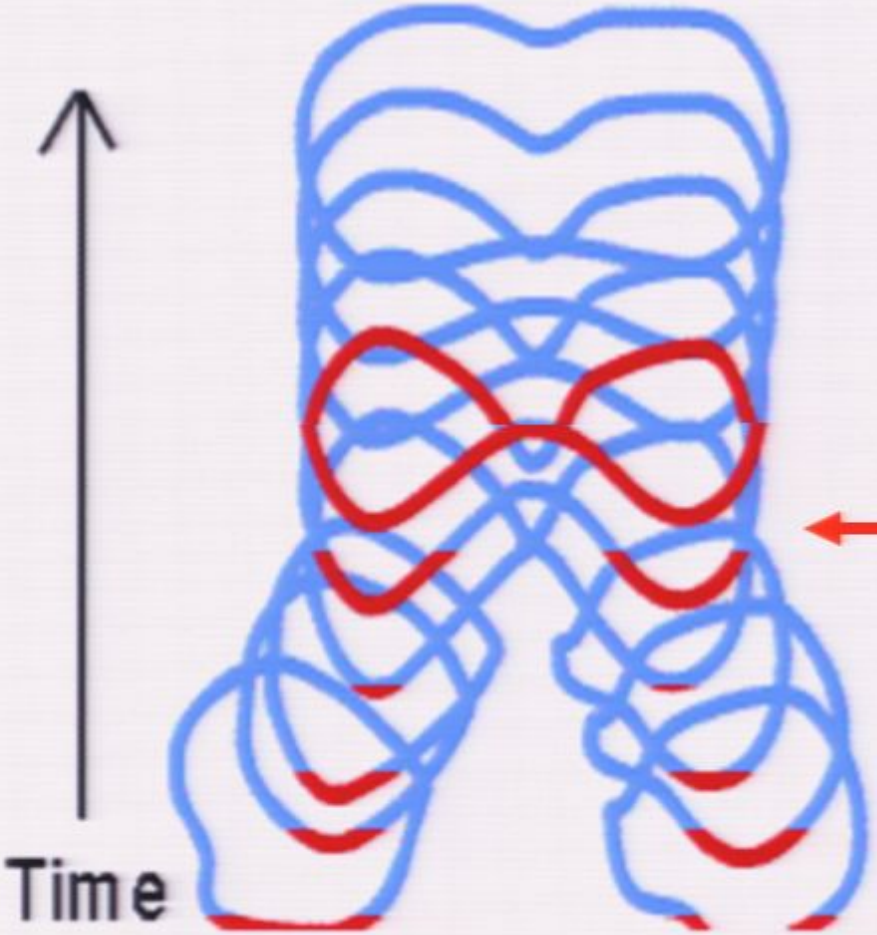

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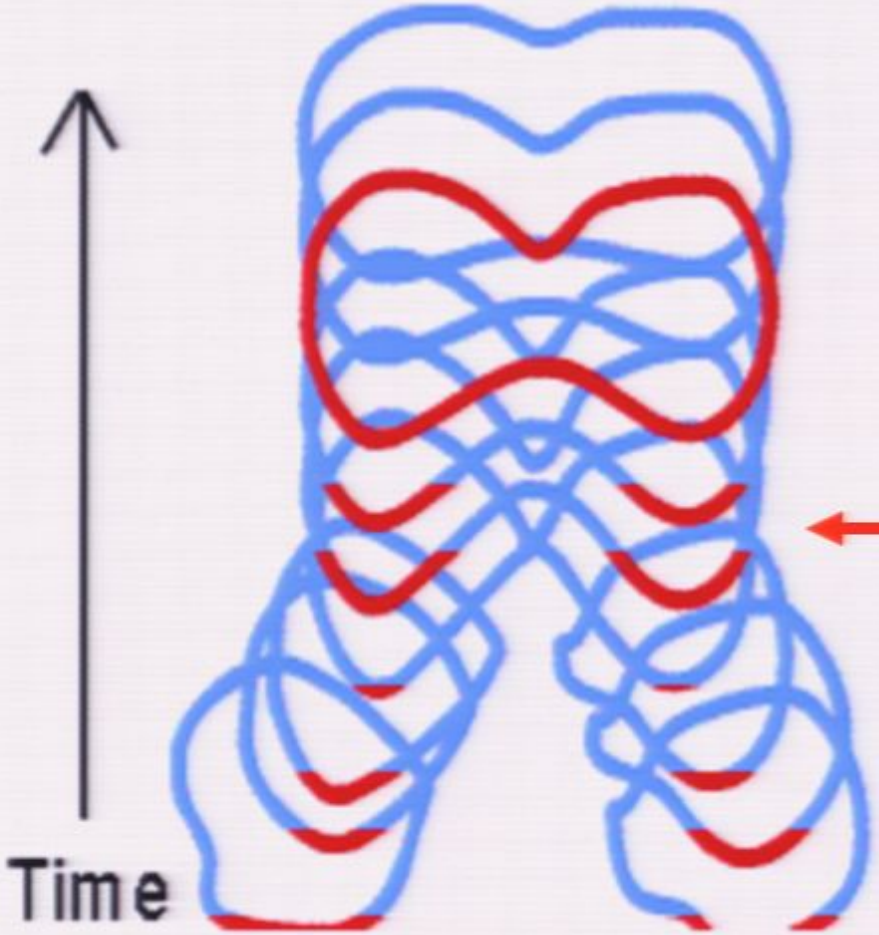

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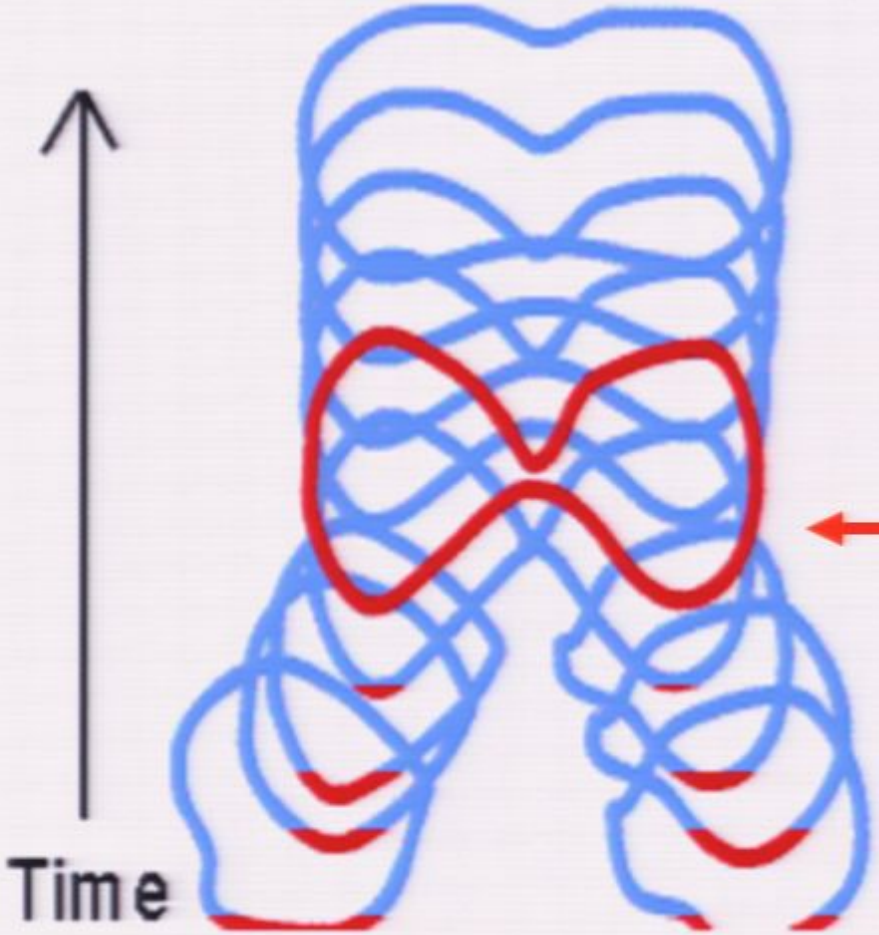

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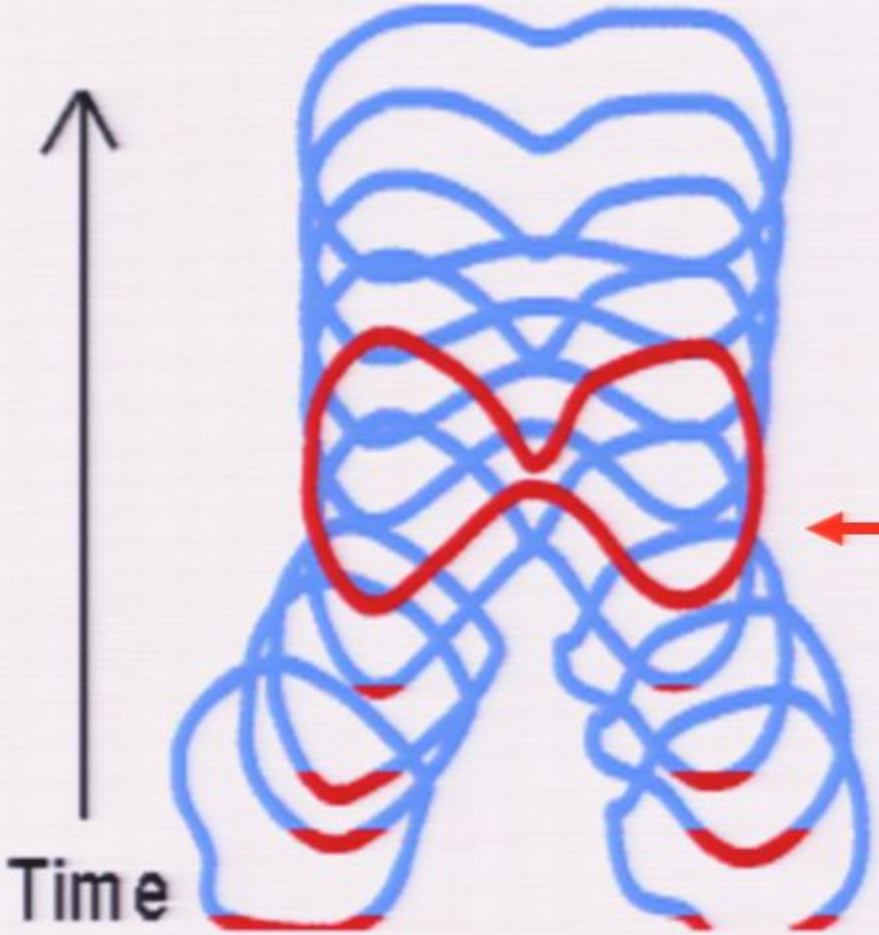

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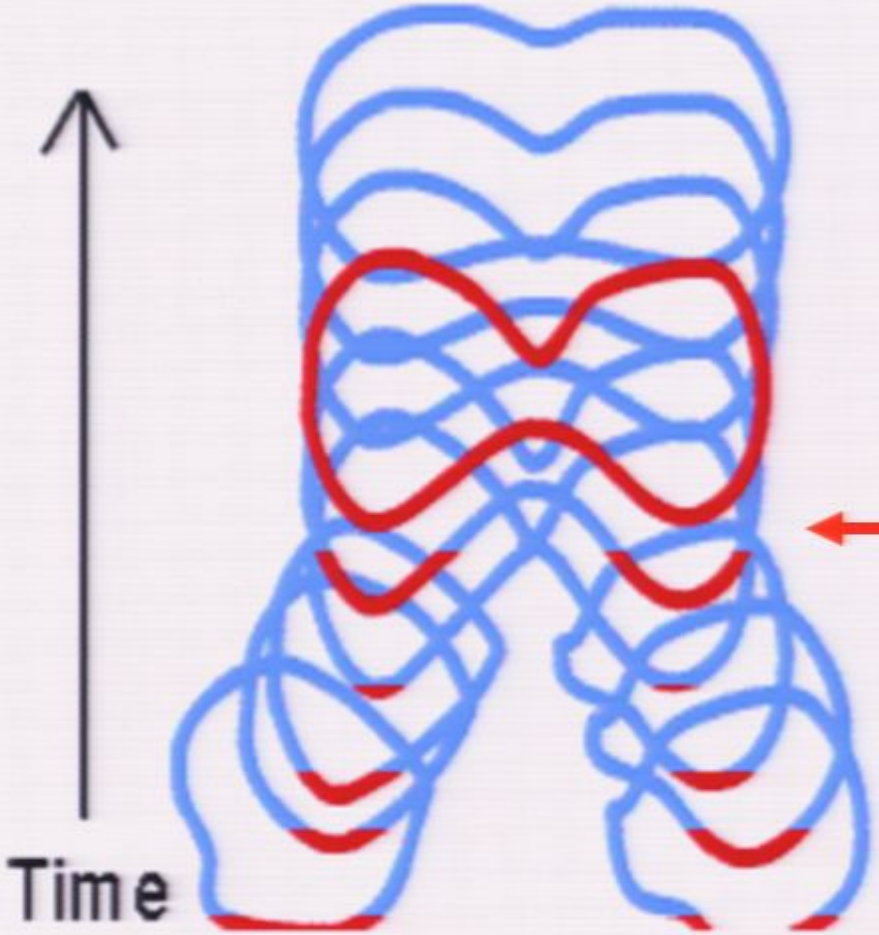

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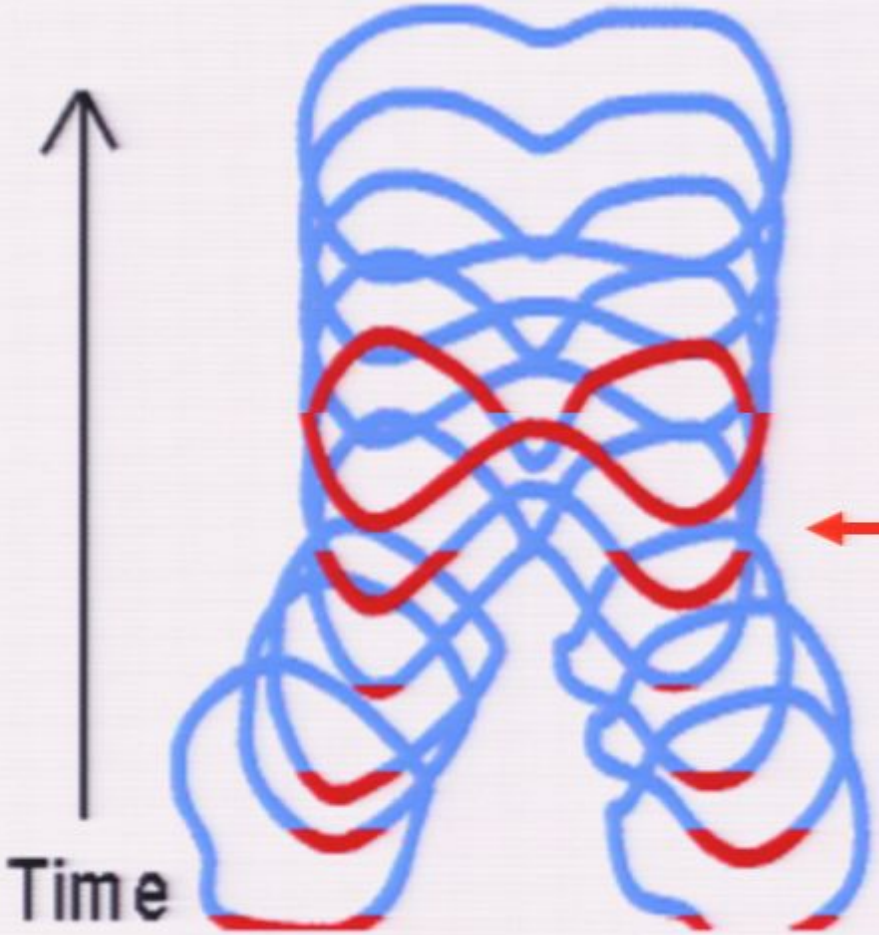

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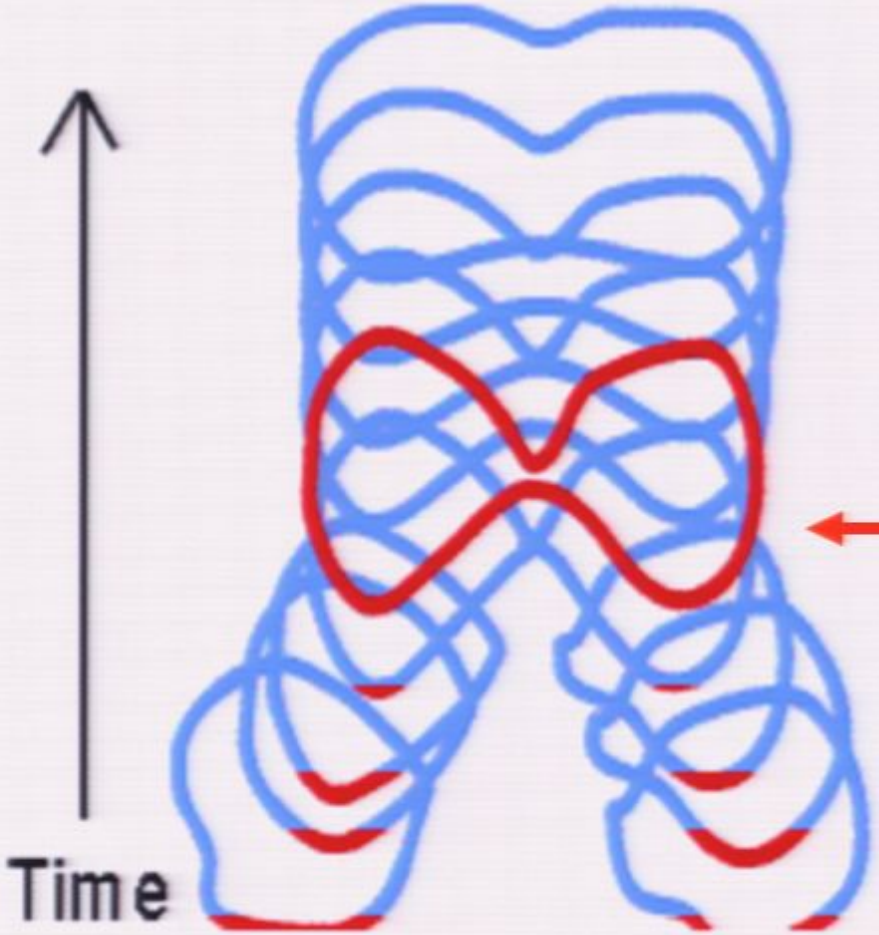

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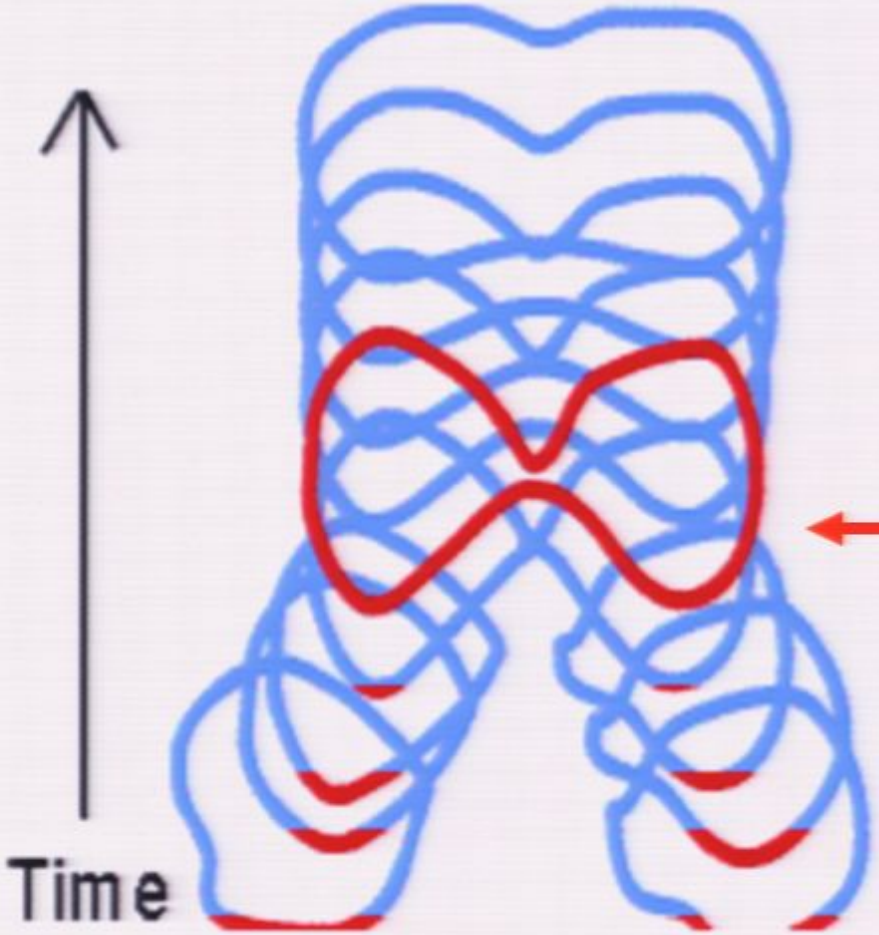

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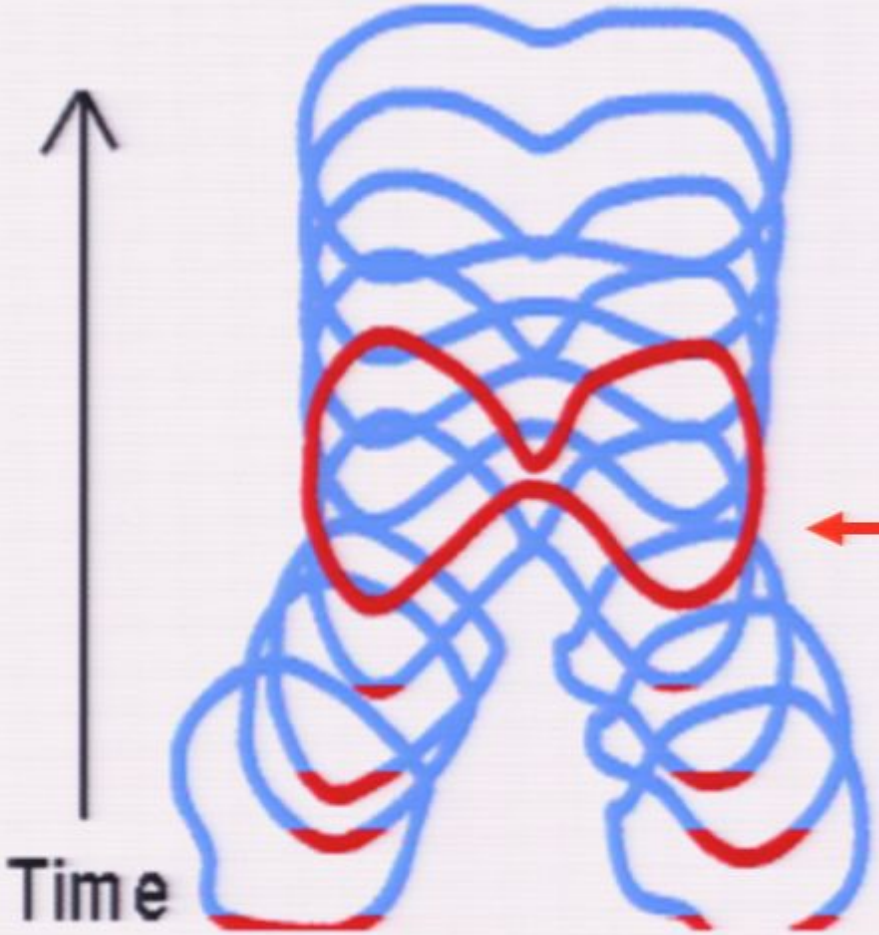

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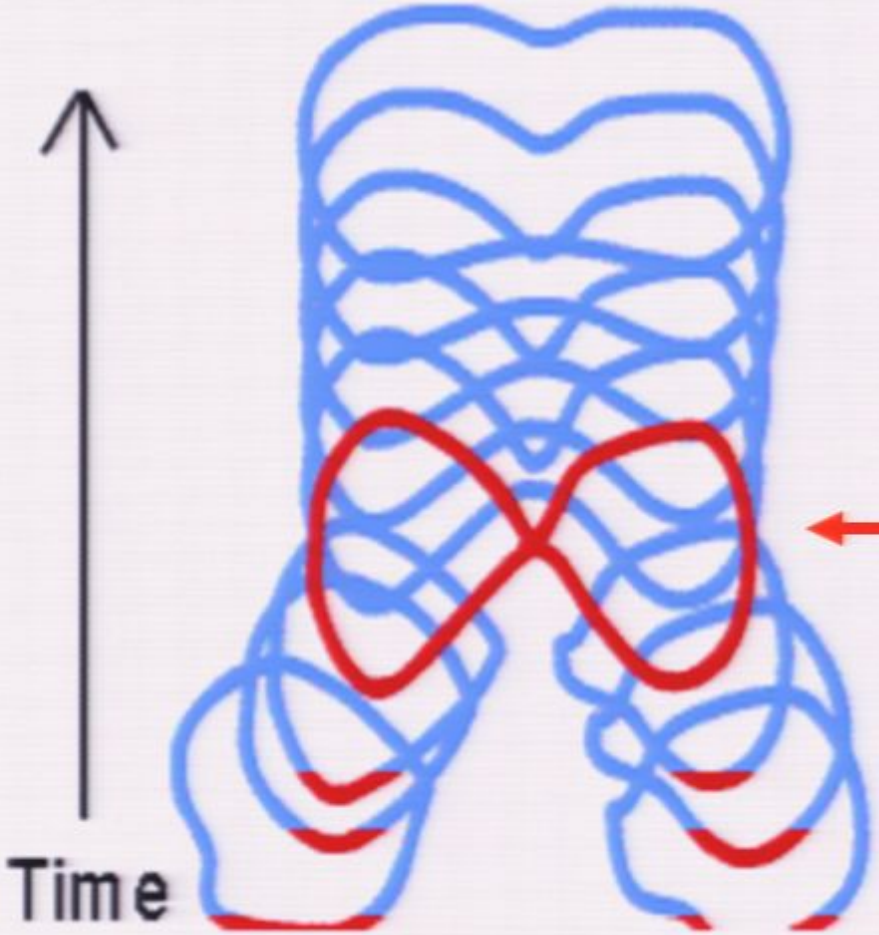

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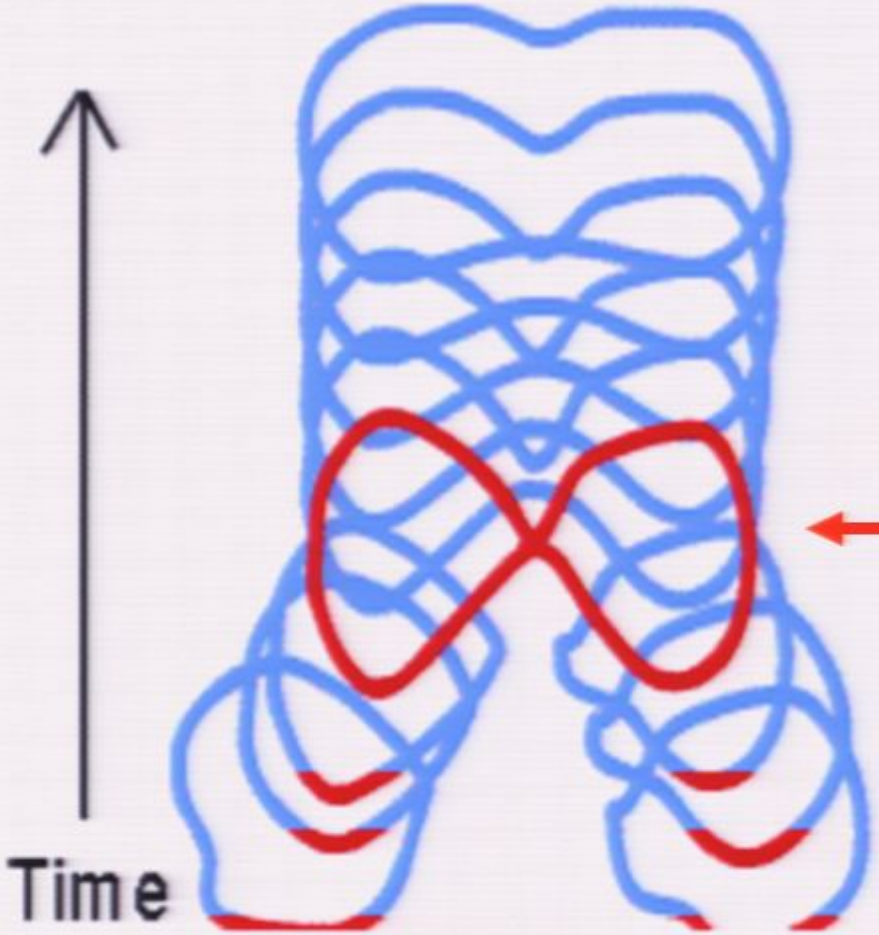

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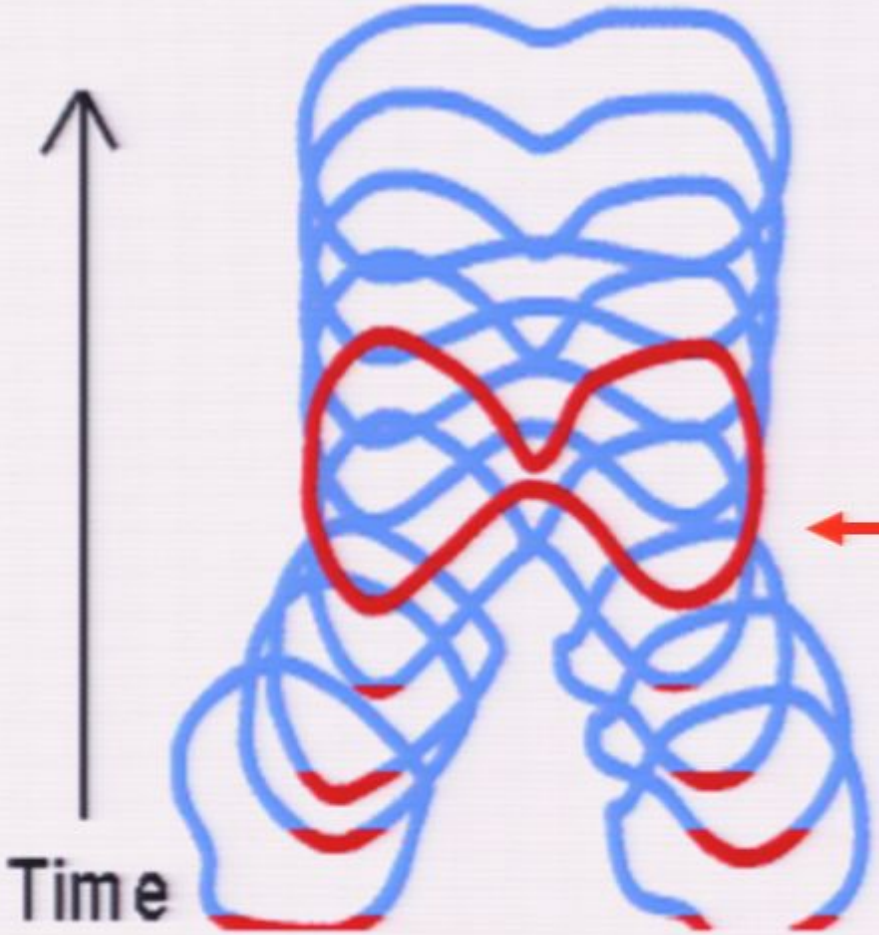

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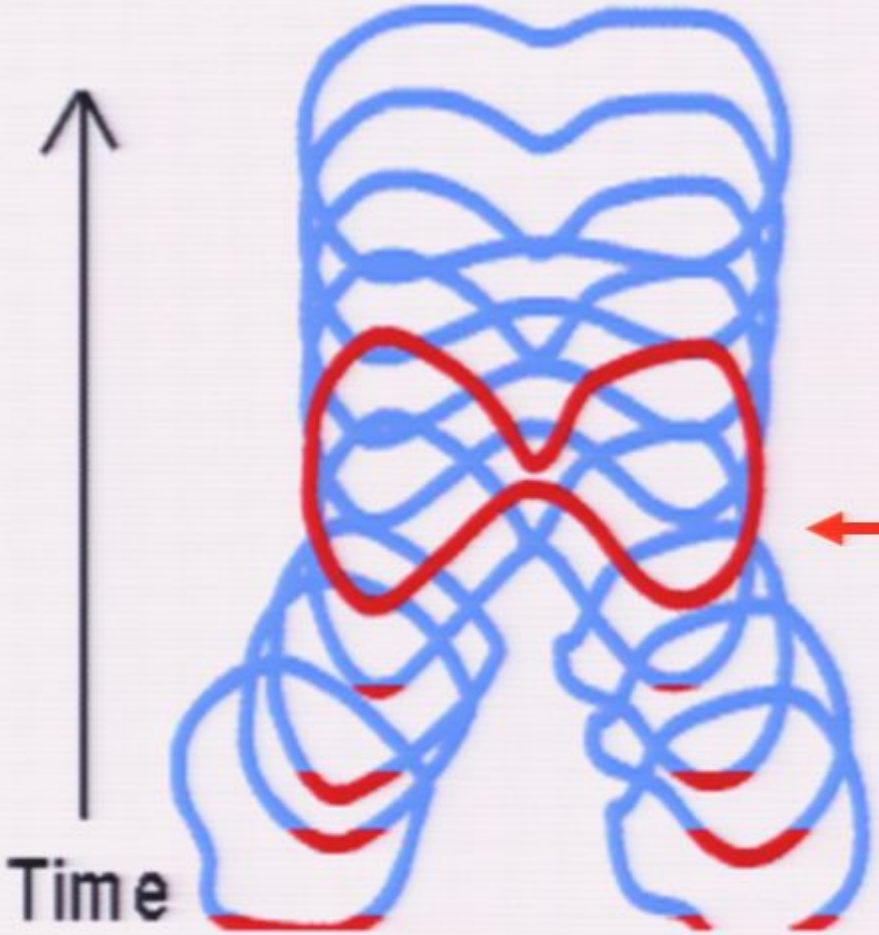

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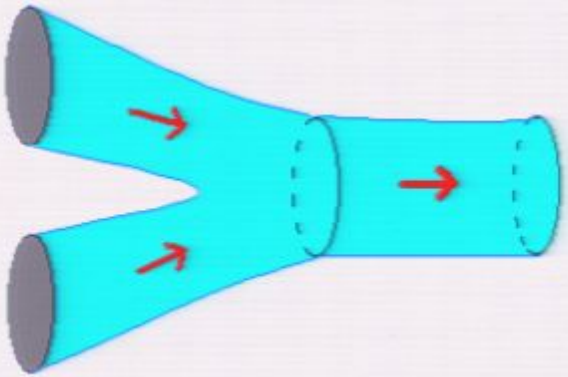

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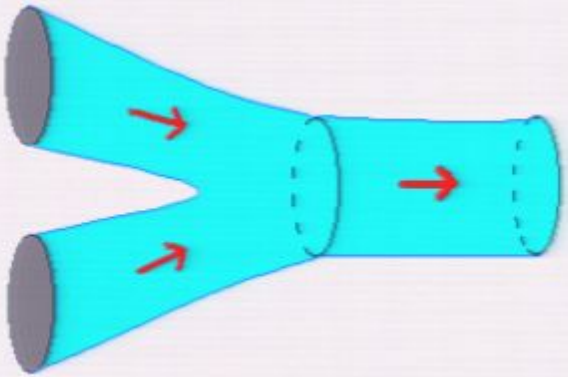

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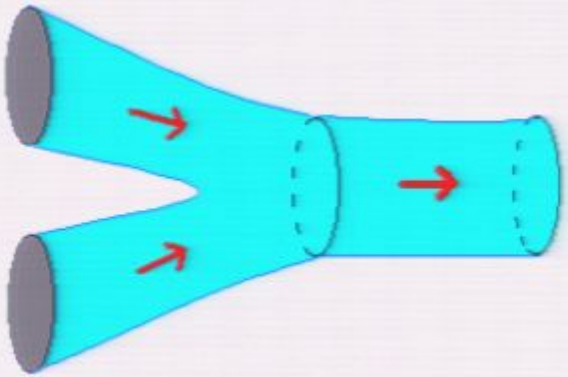

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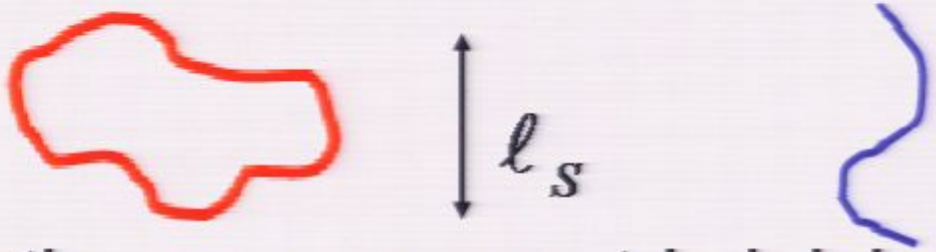

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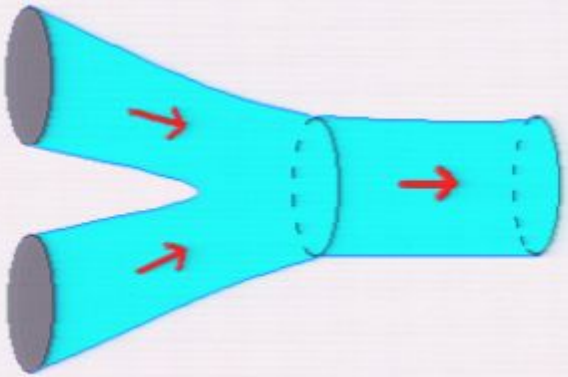

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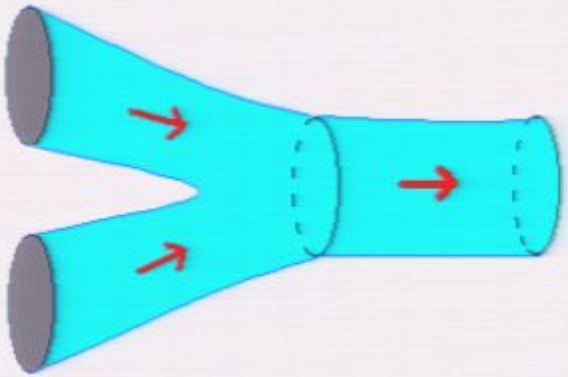

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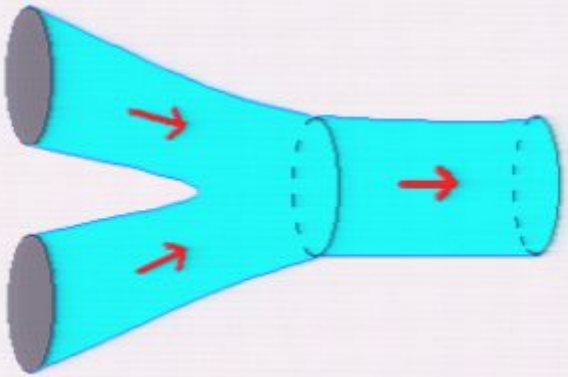

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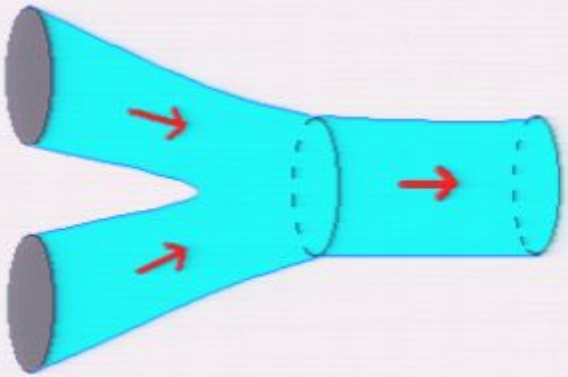

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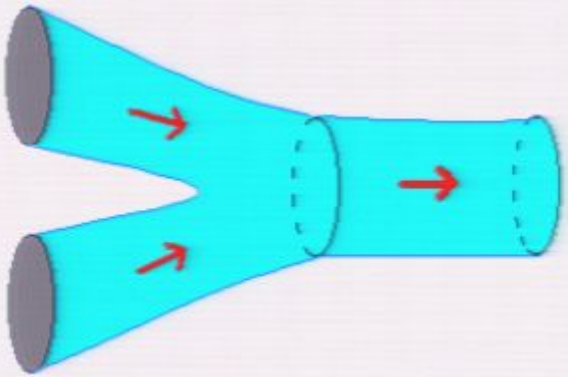

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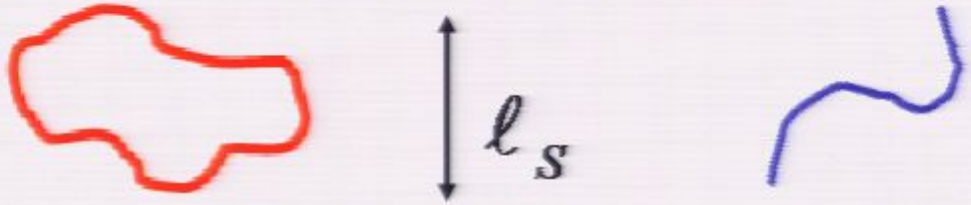

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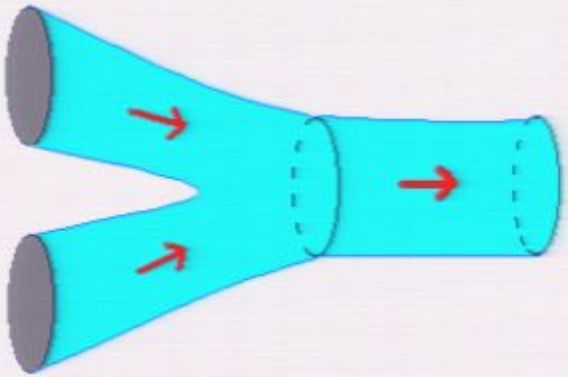

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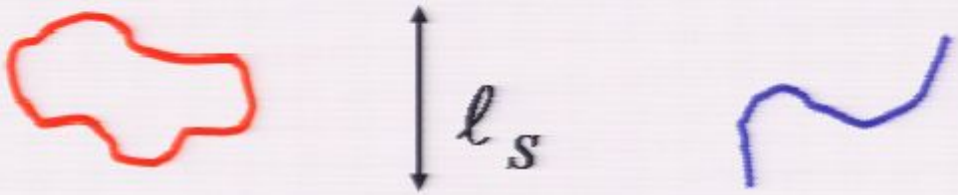

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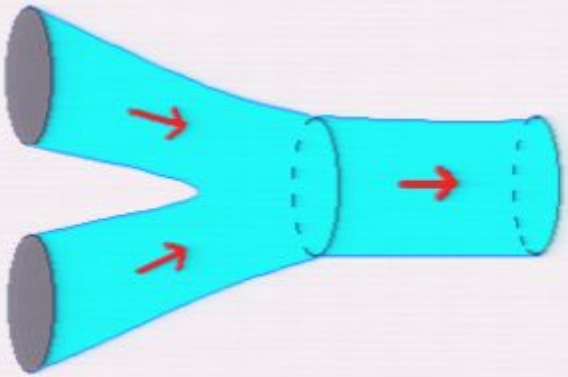

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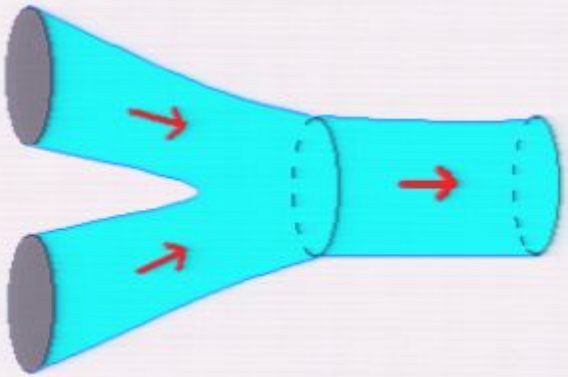

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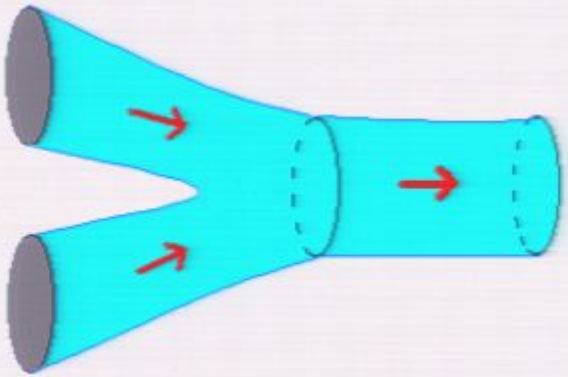

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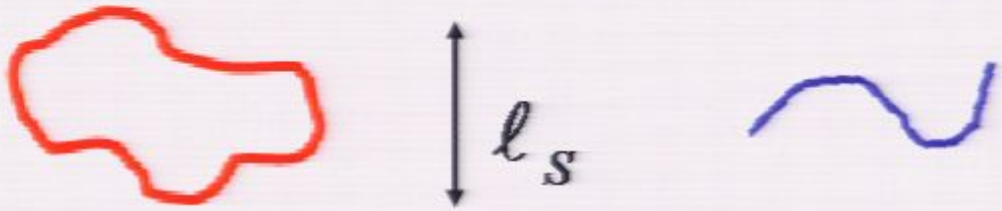

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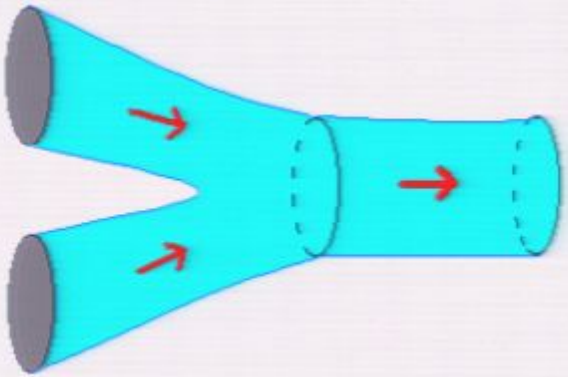

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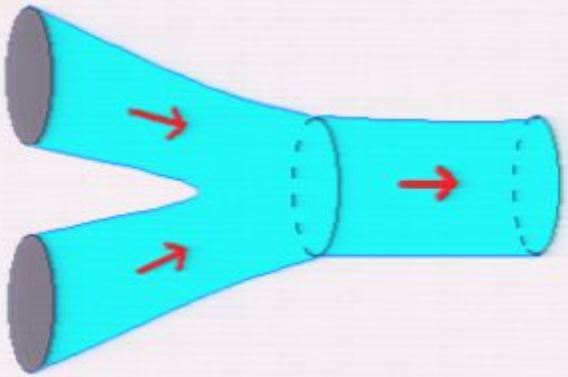

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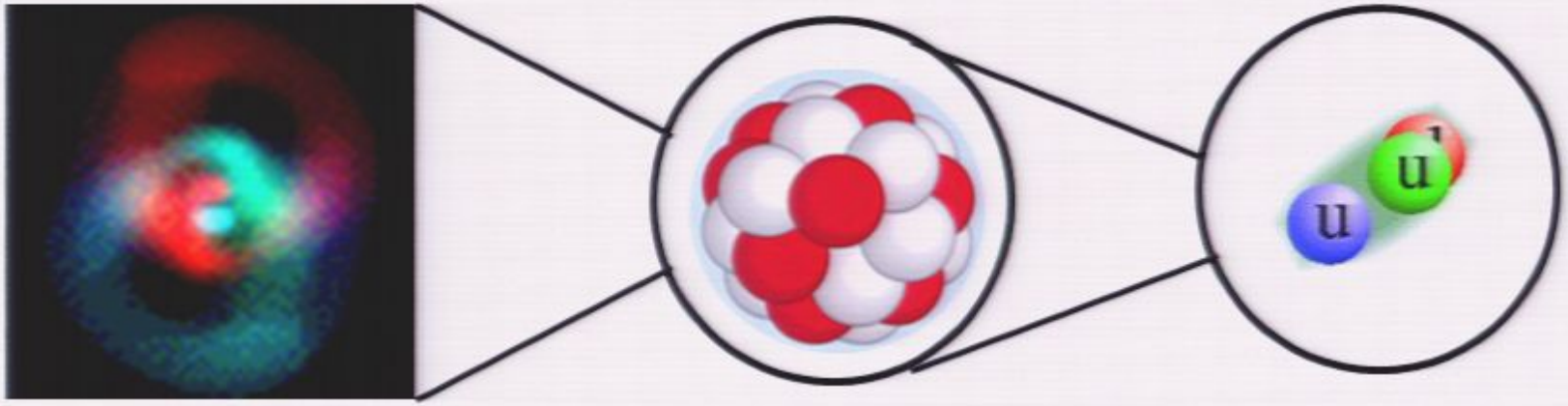

Elementary Particles (10^{-17} m)

Fermions:
- electron, muon, tauon
- neutrinos (3 flavors)
- quarks - up, down, strange, charm, bottom, top

Bosons (Force Mediators):
- photon (electromagnetism)
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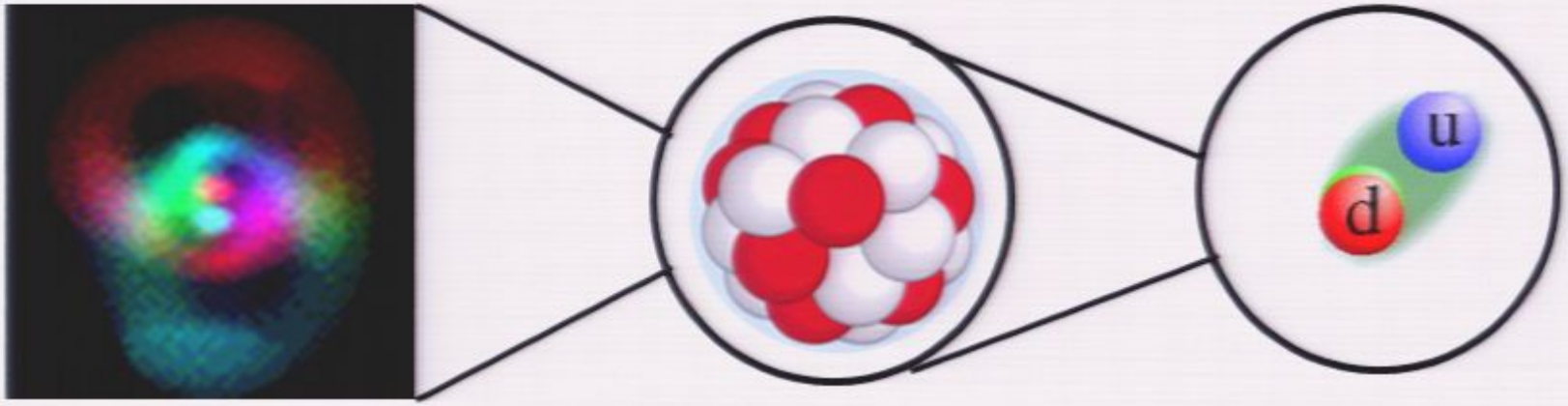

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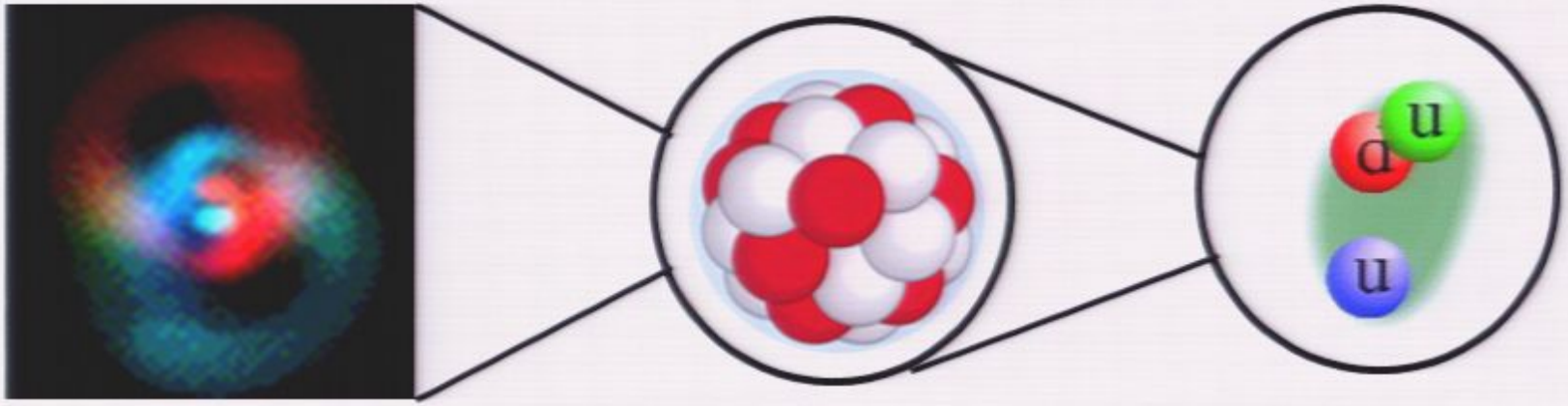

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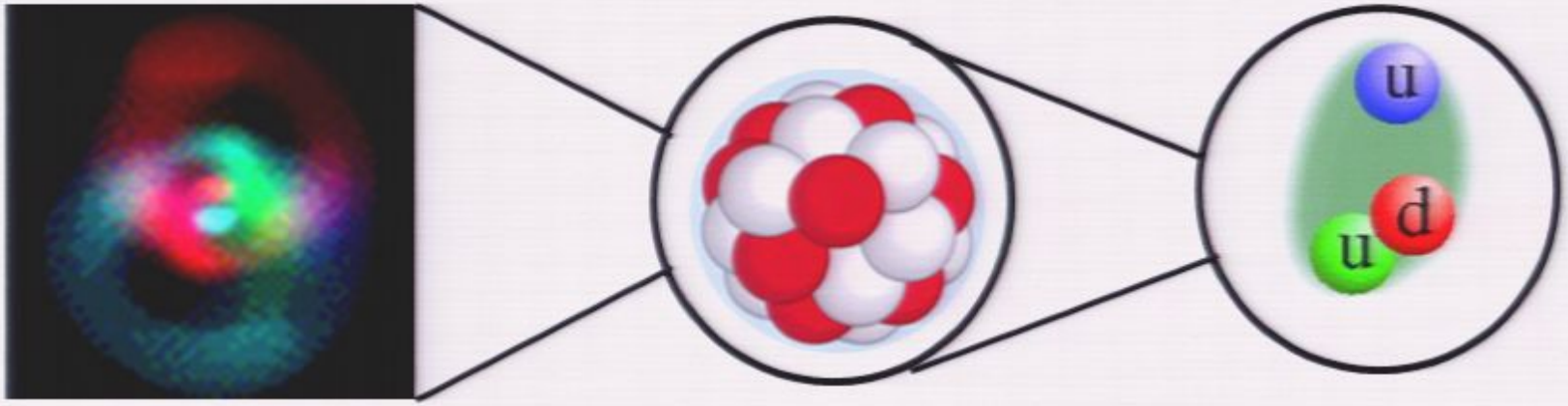

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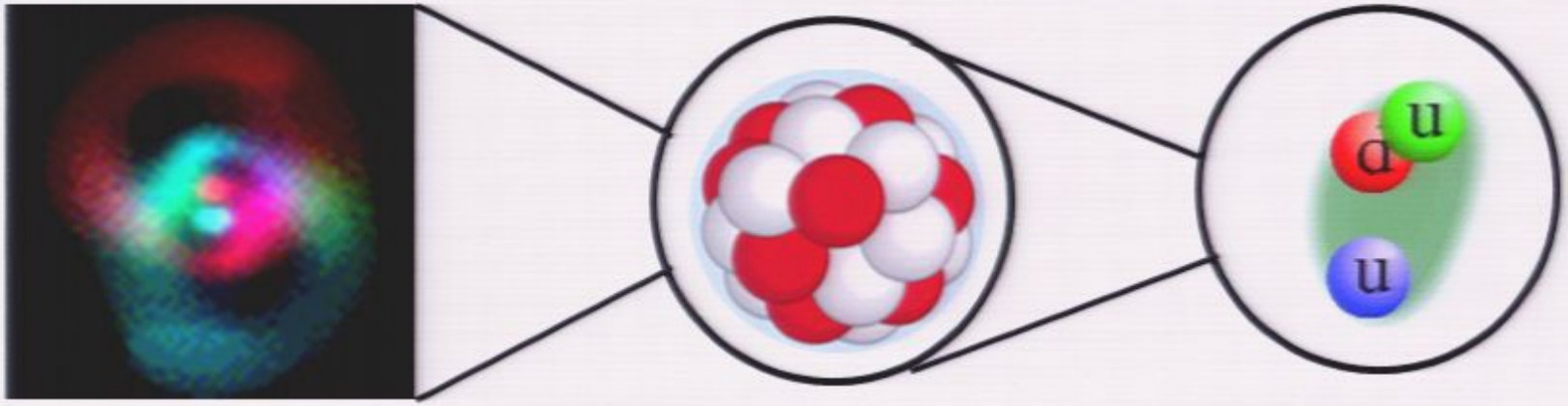

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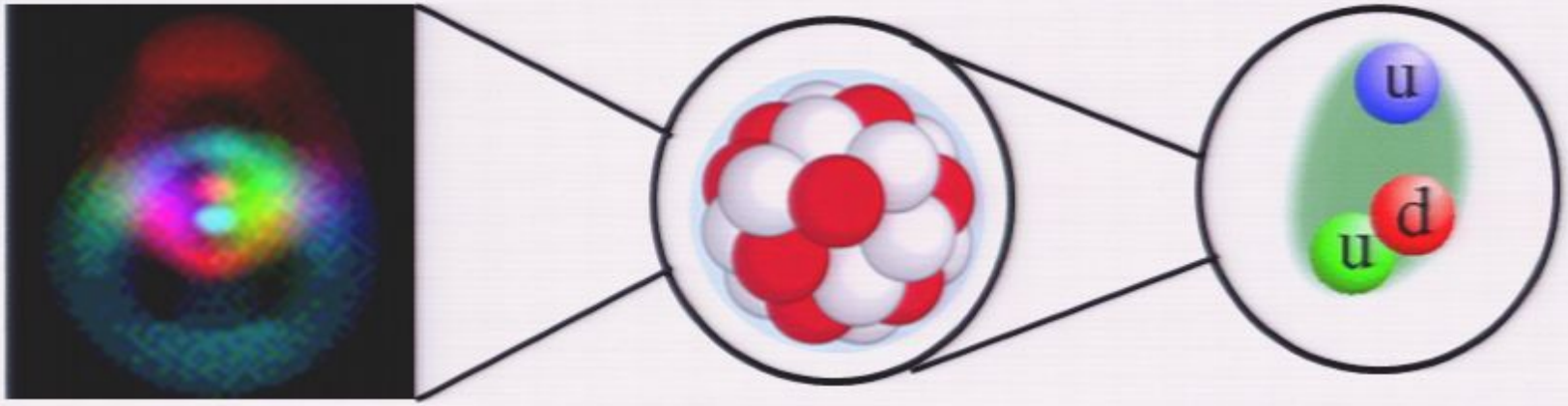

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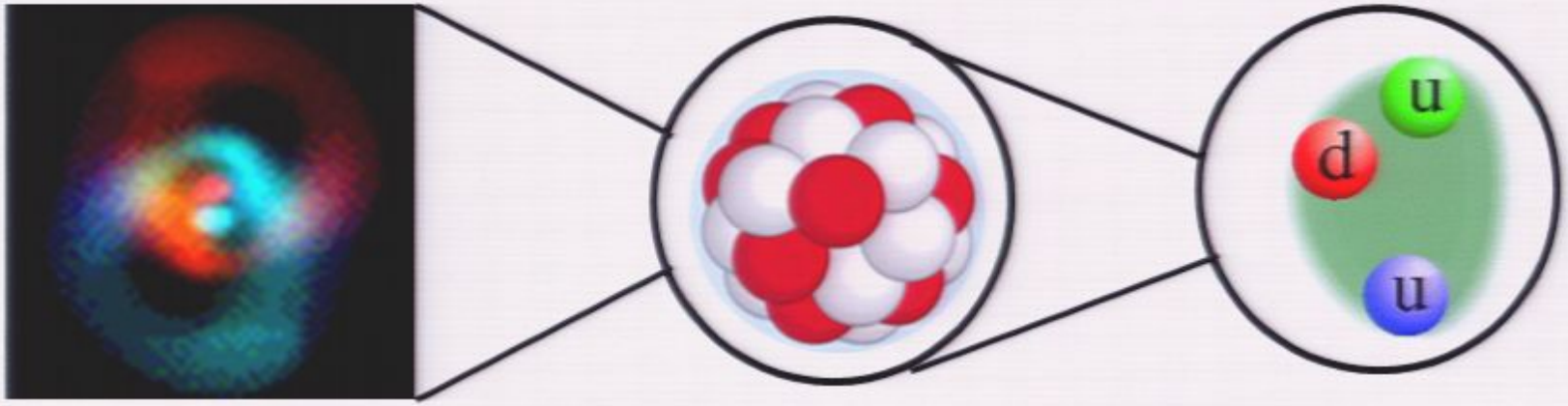

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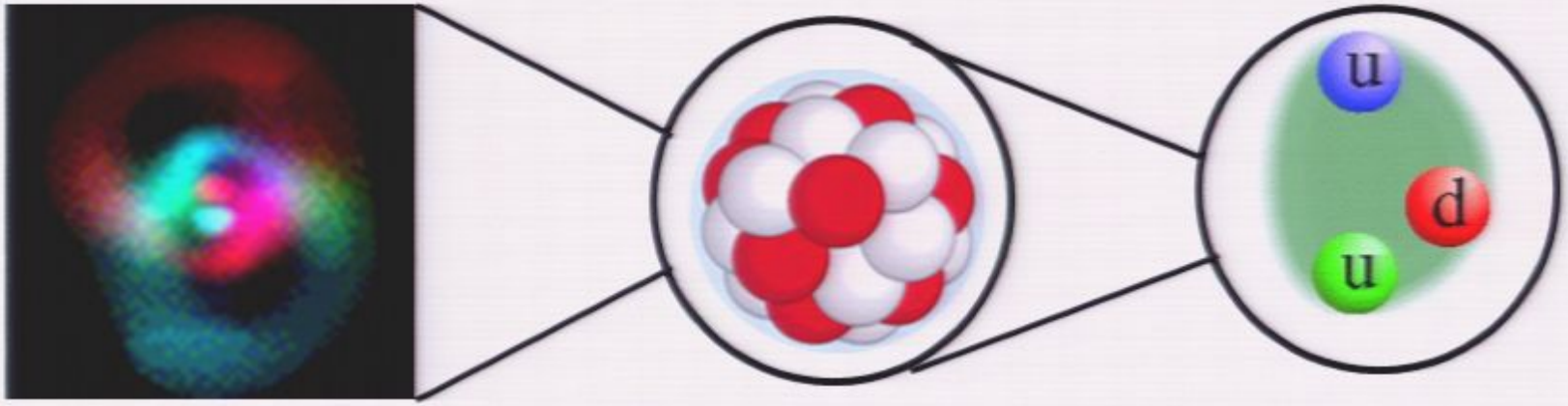

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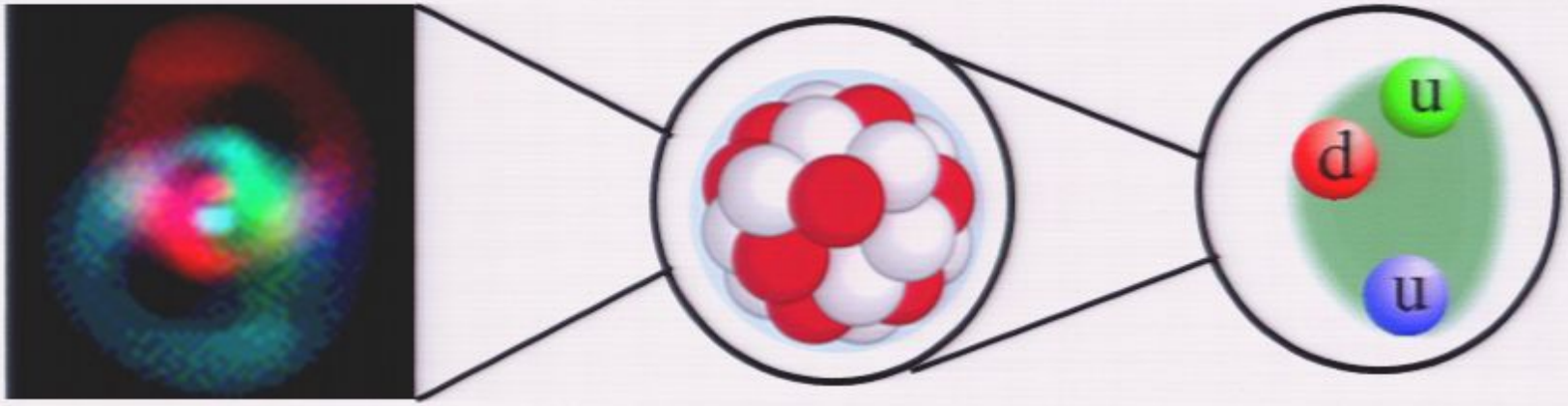

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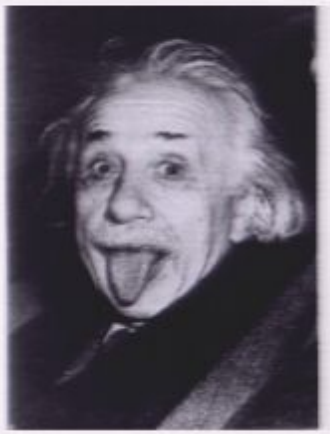

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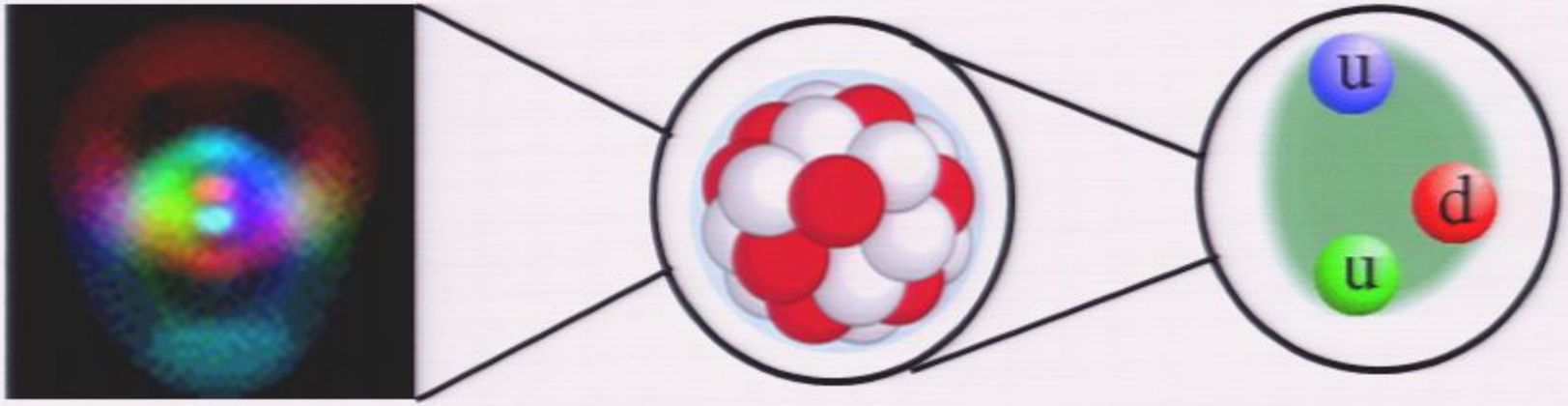

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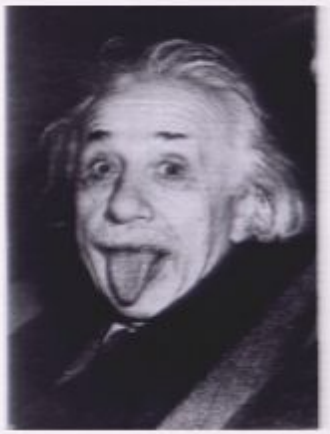

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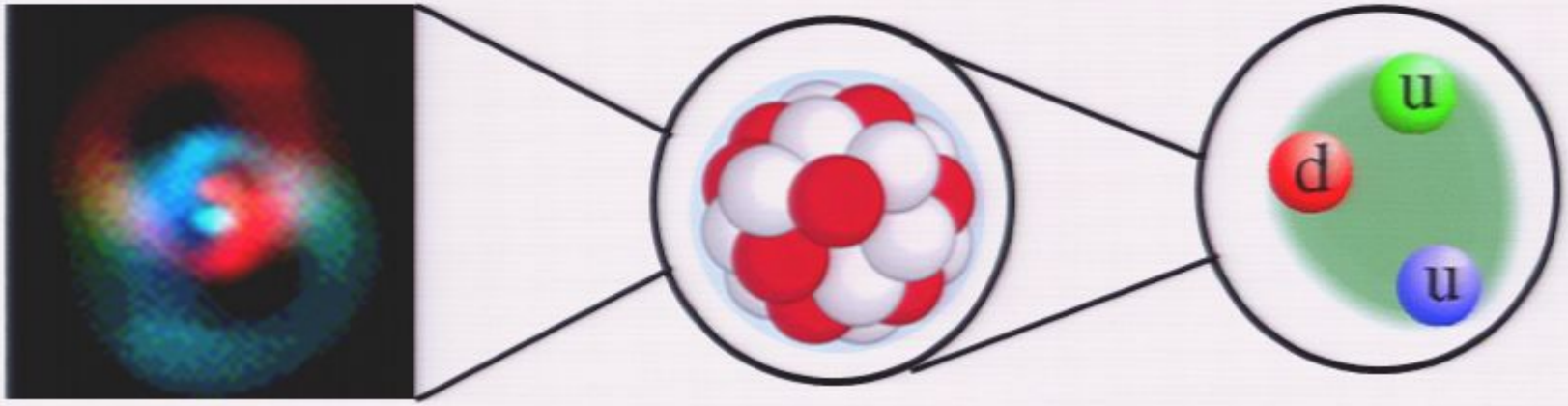

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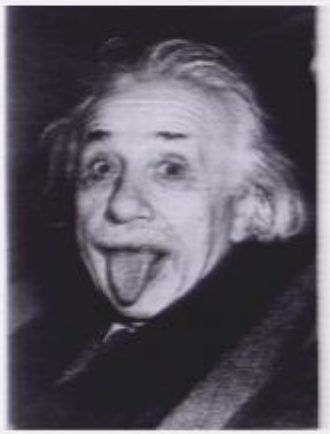

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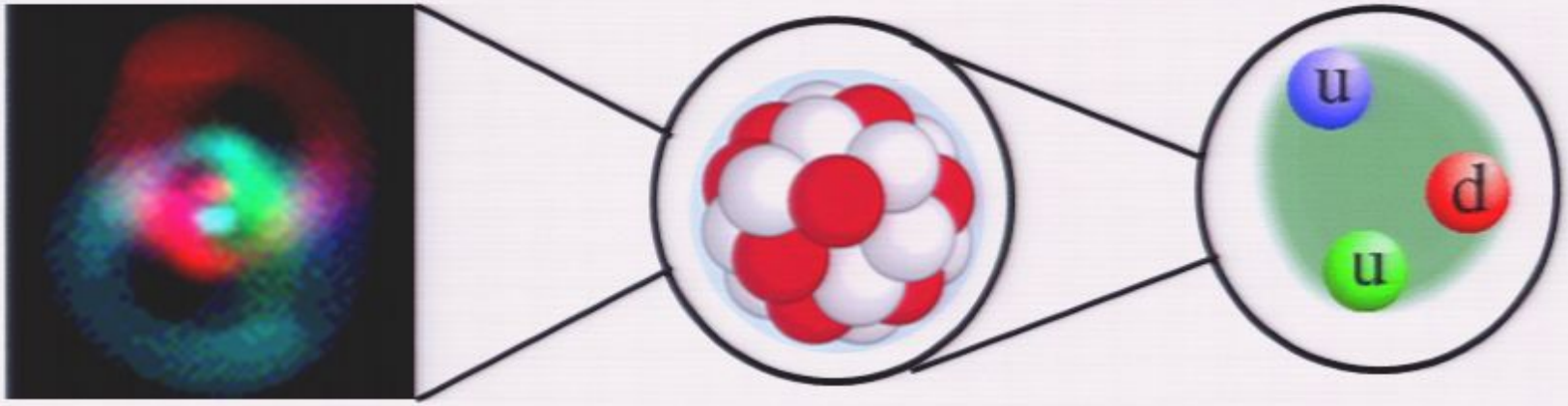

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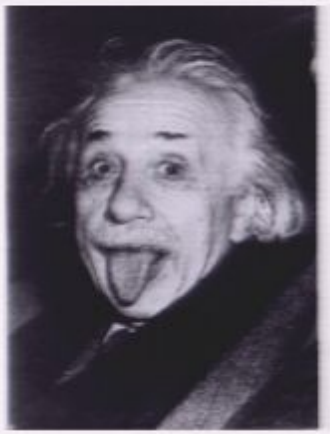

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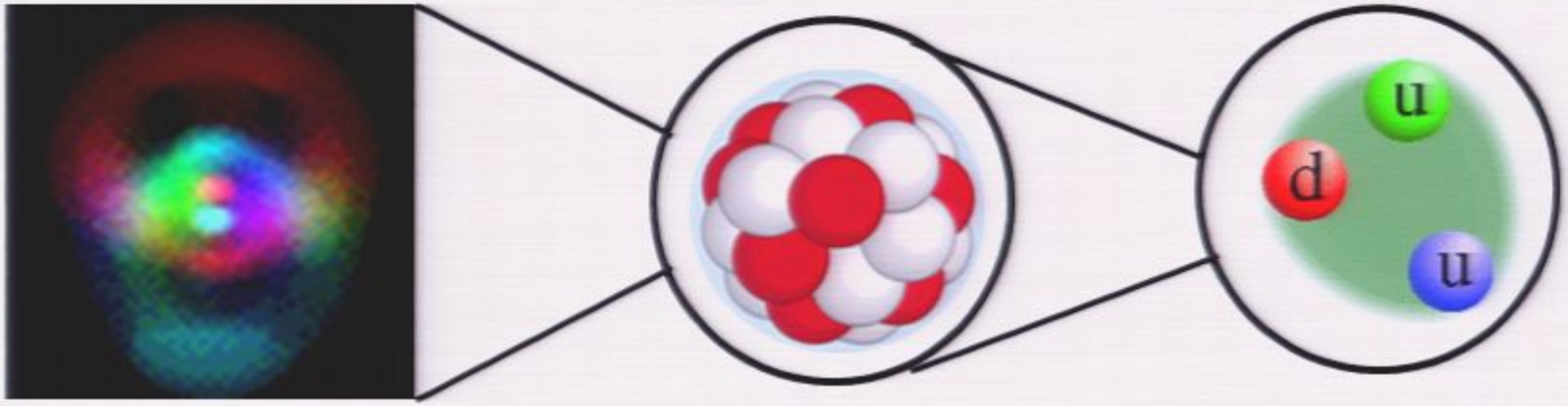

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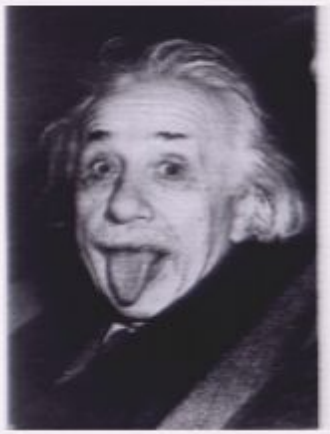

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at long distances much greater than ℓ_s, reproduces Einstein's gravitational equations

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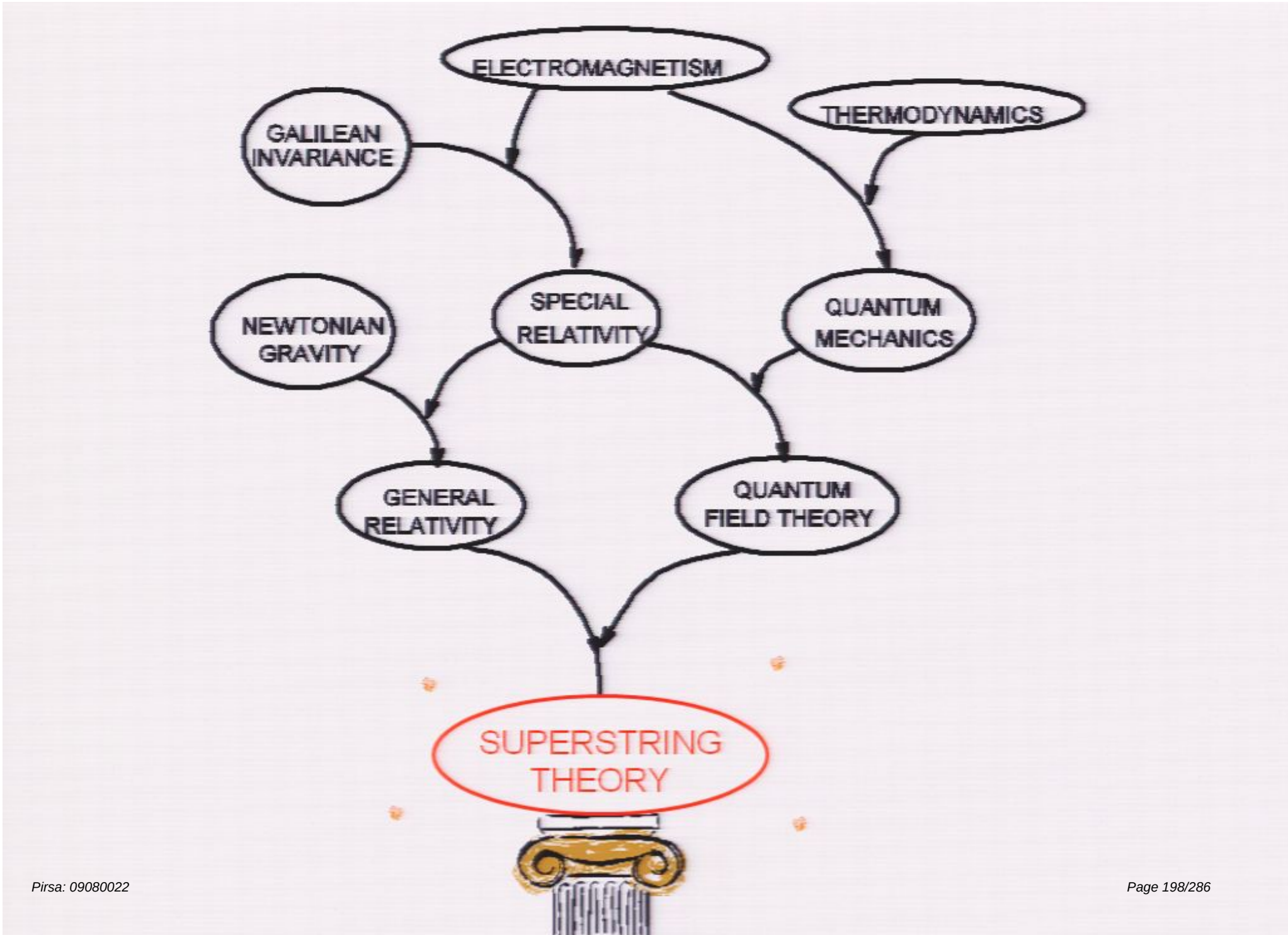
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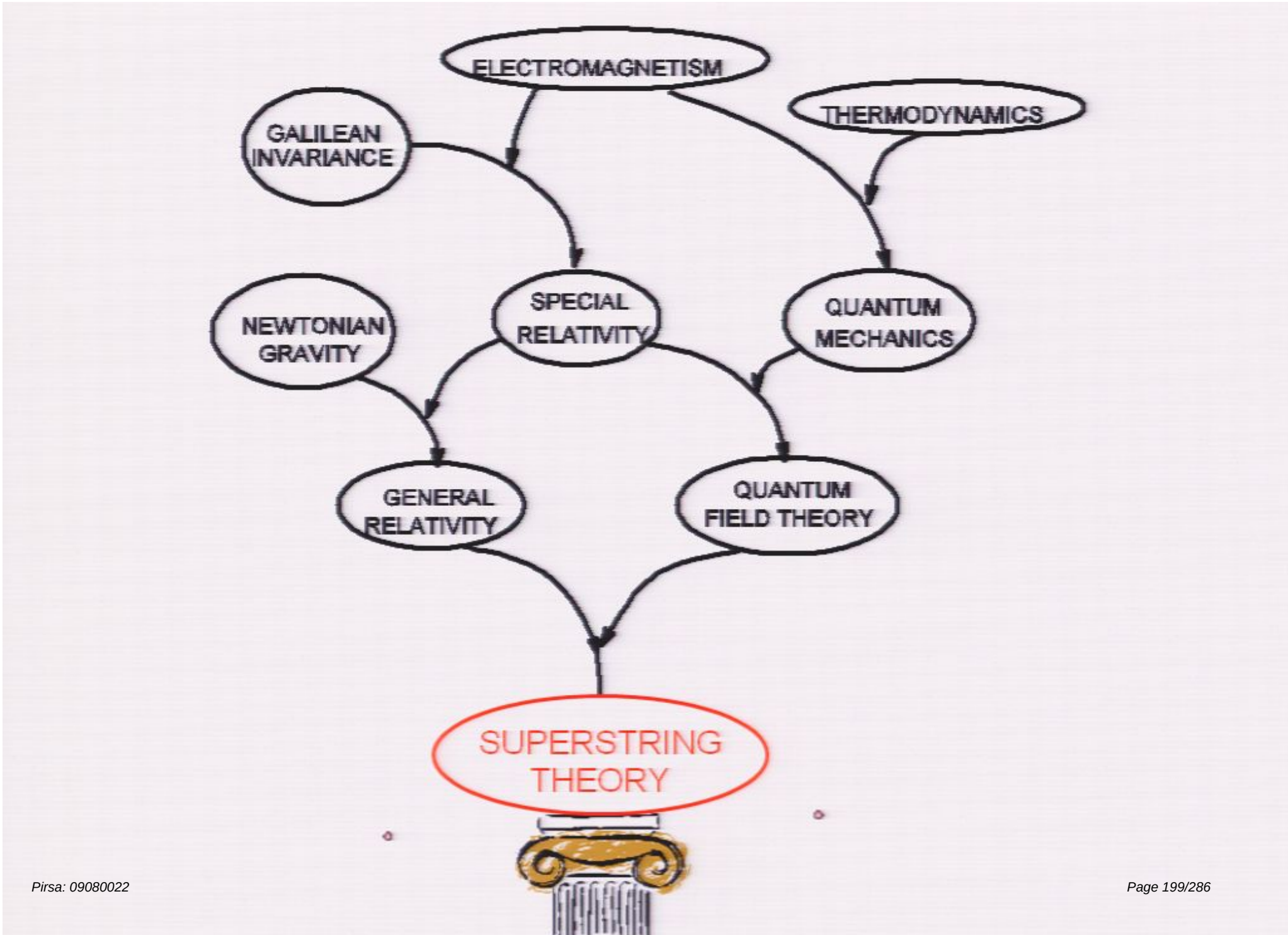
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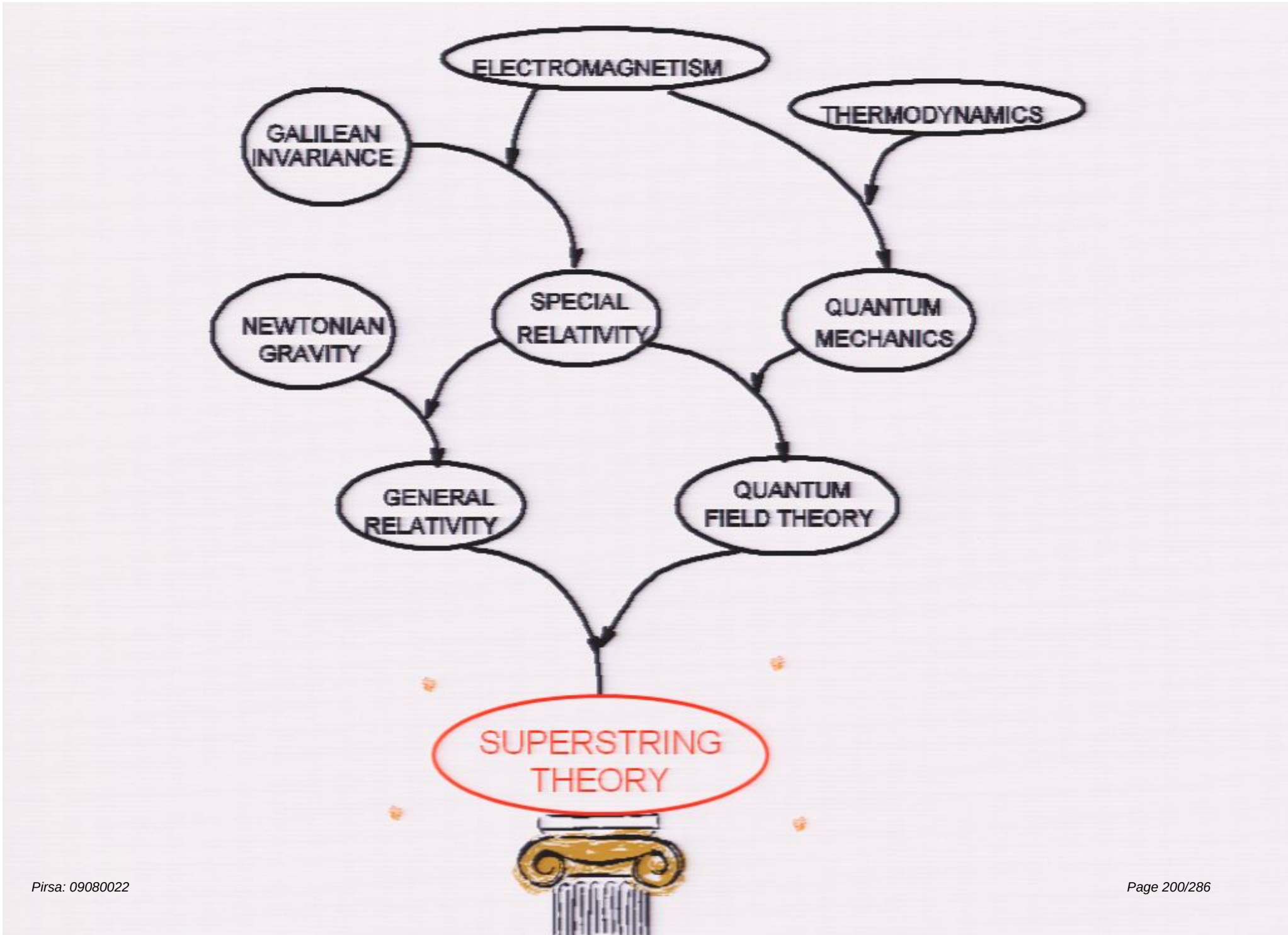
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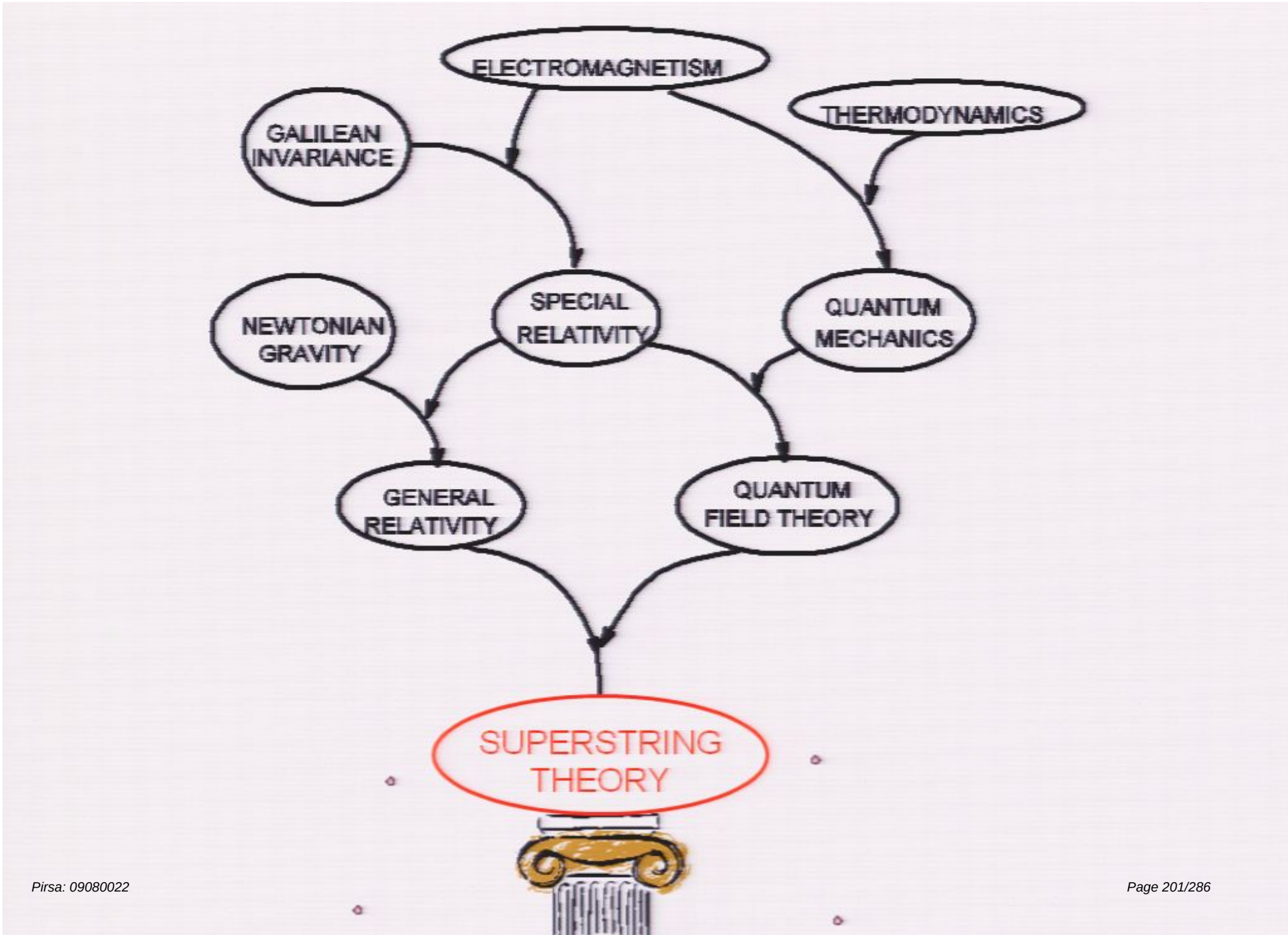
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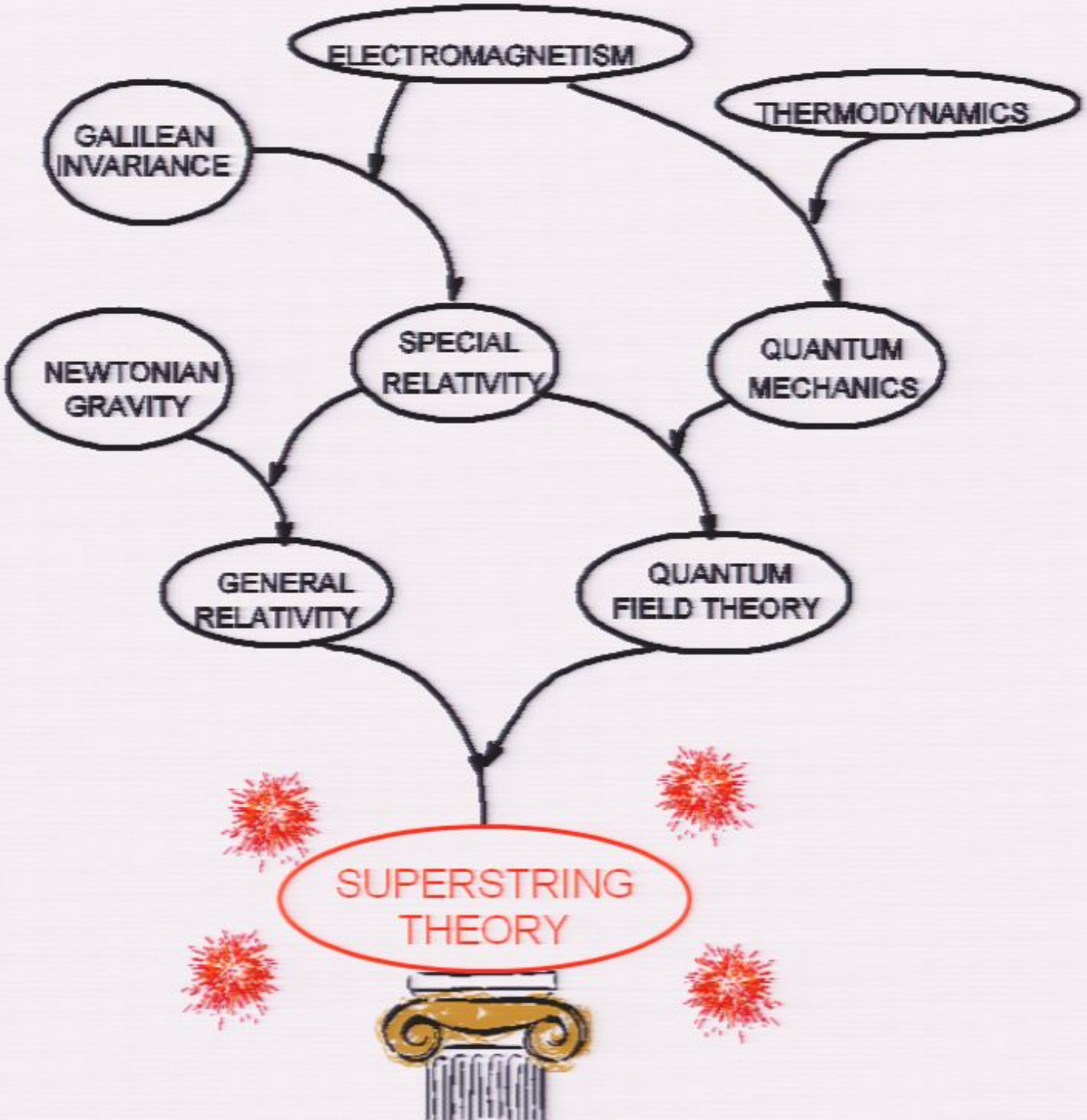
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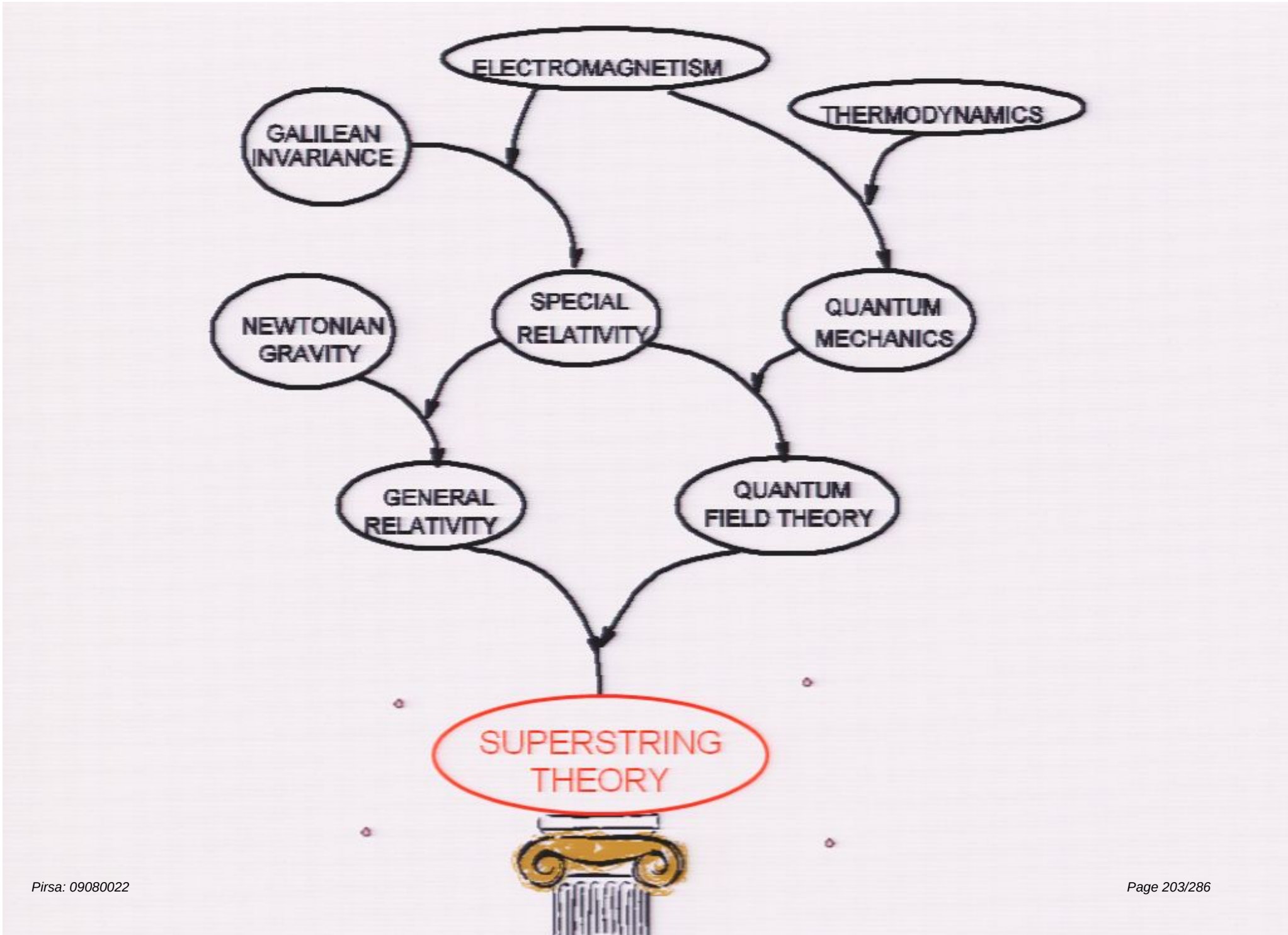
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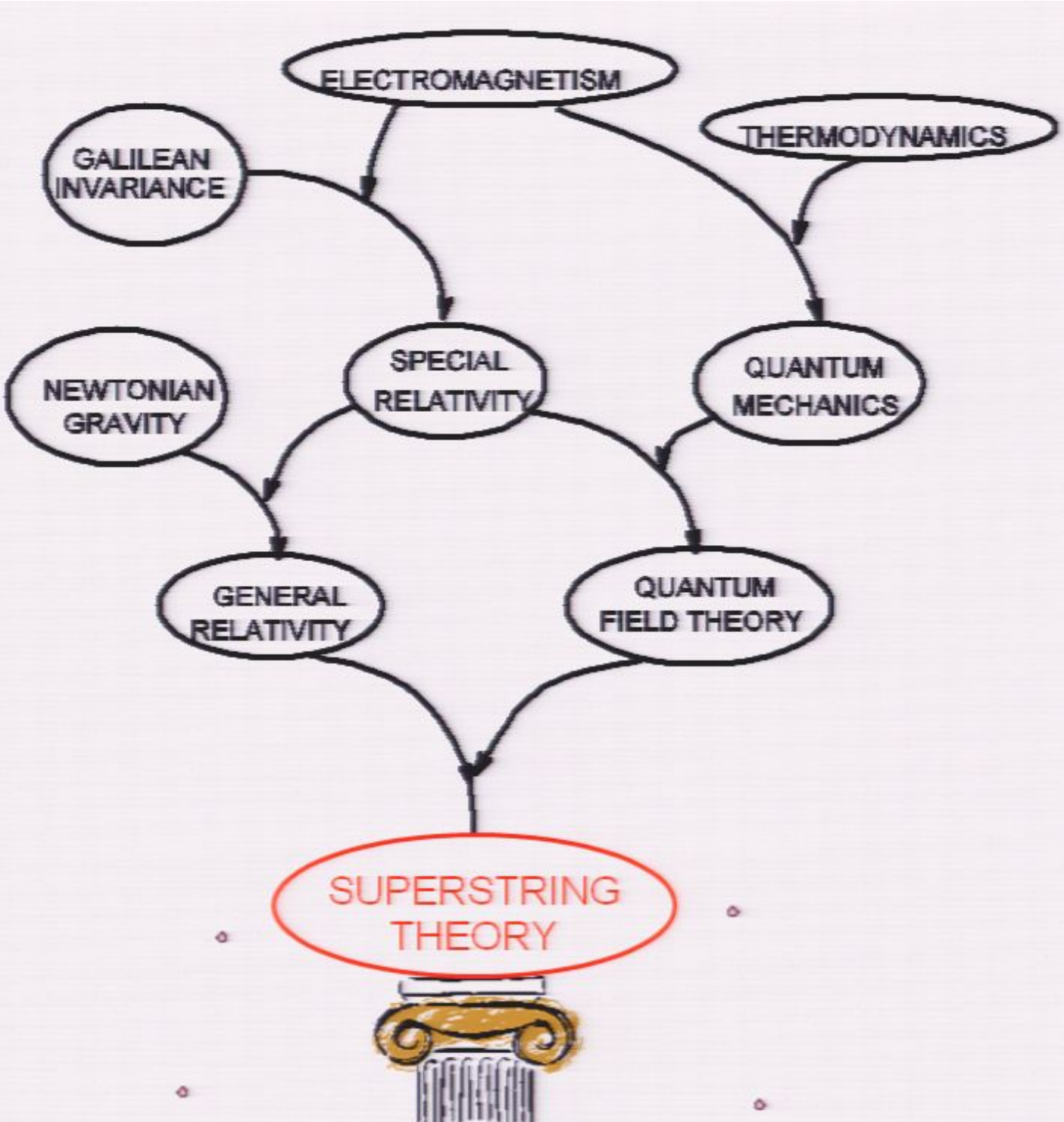
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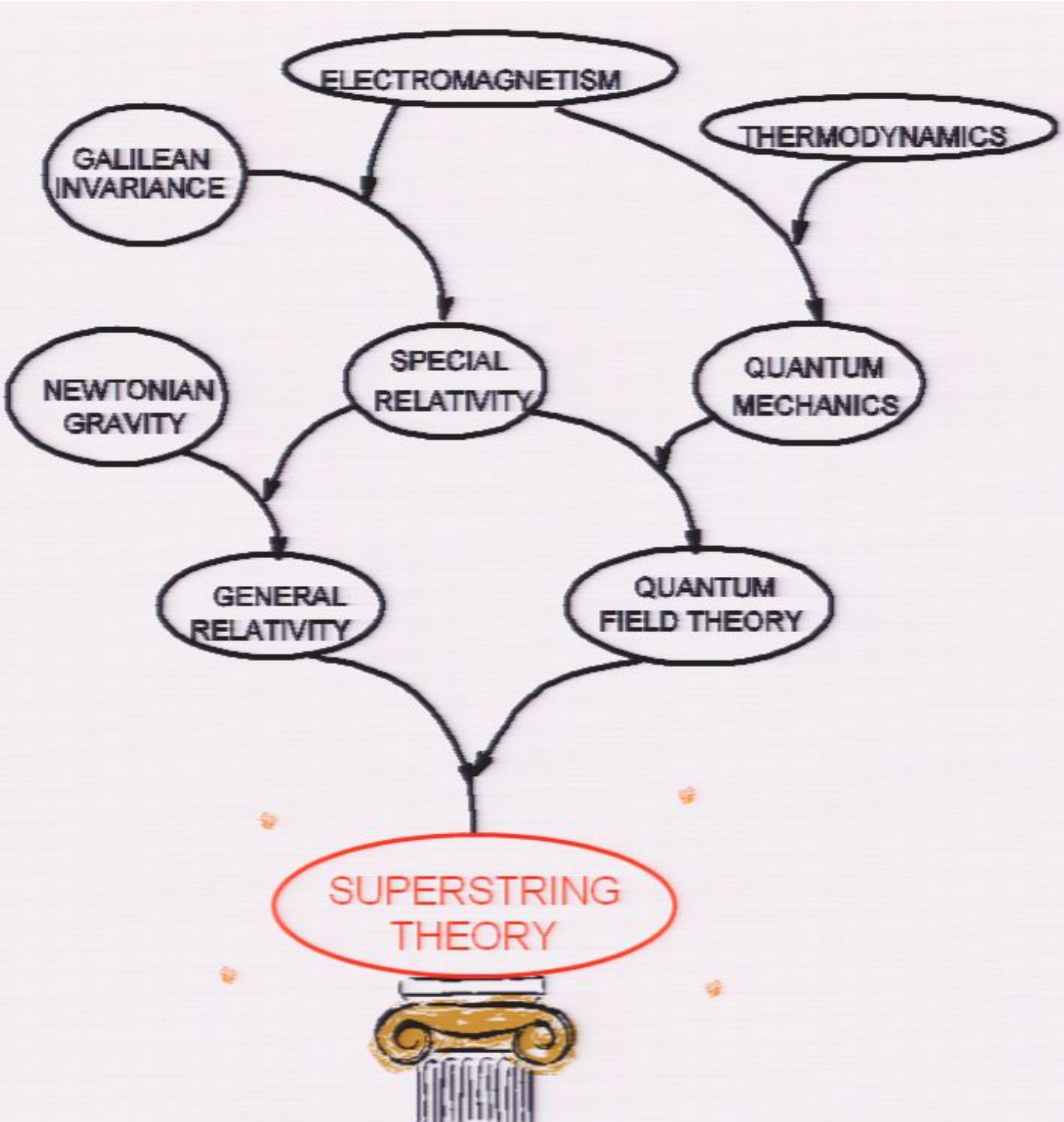
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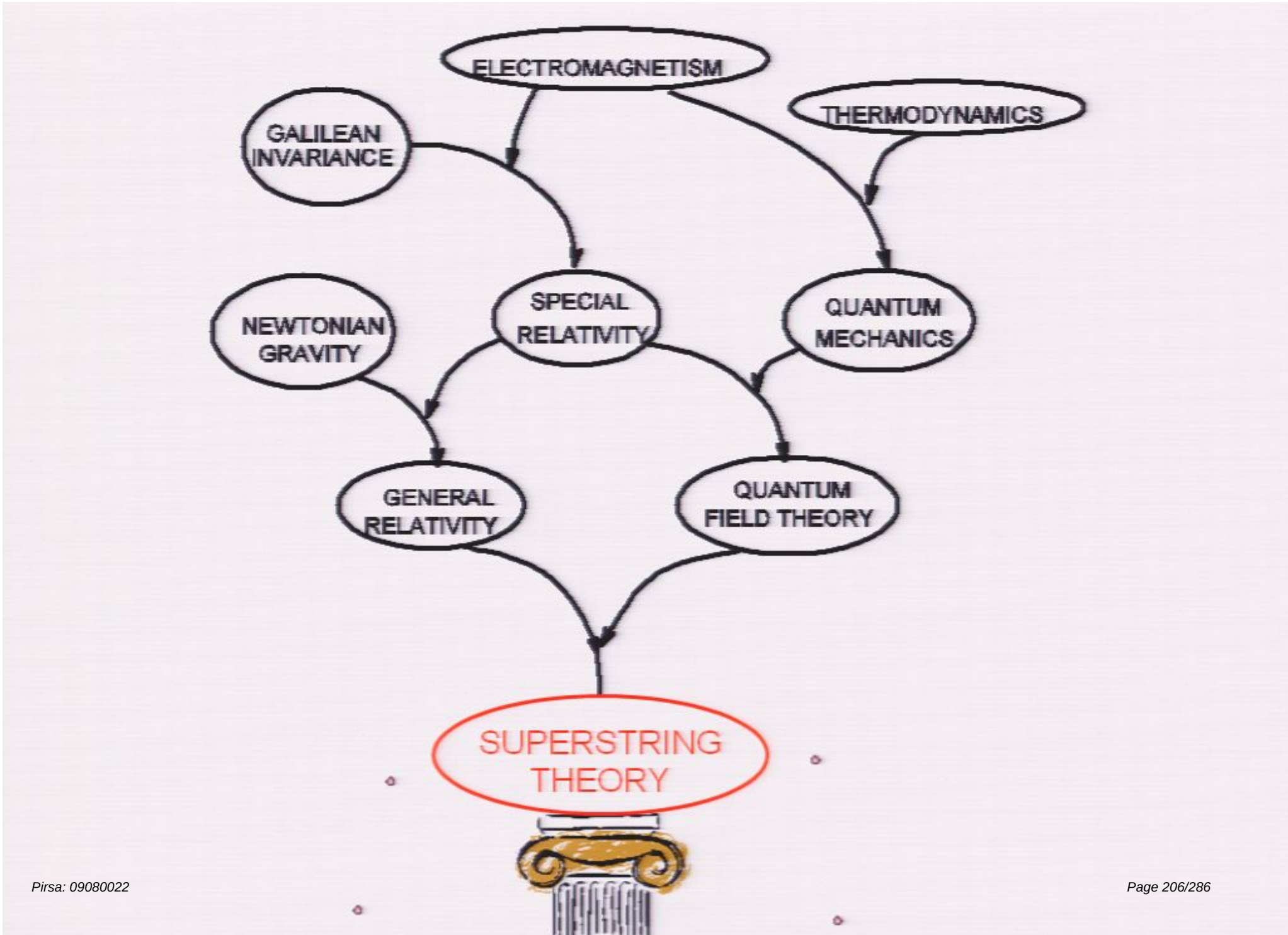
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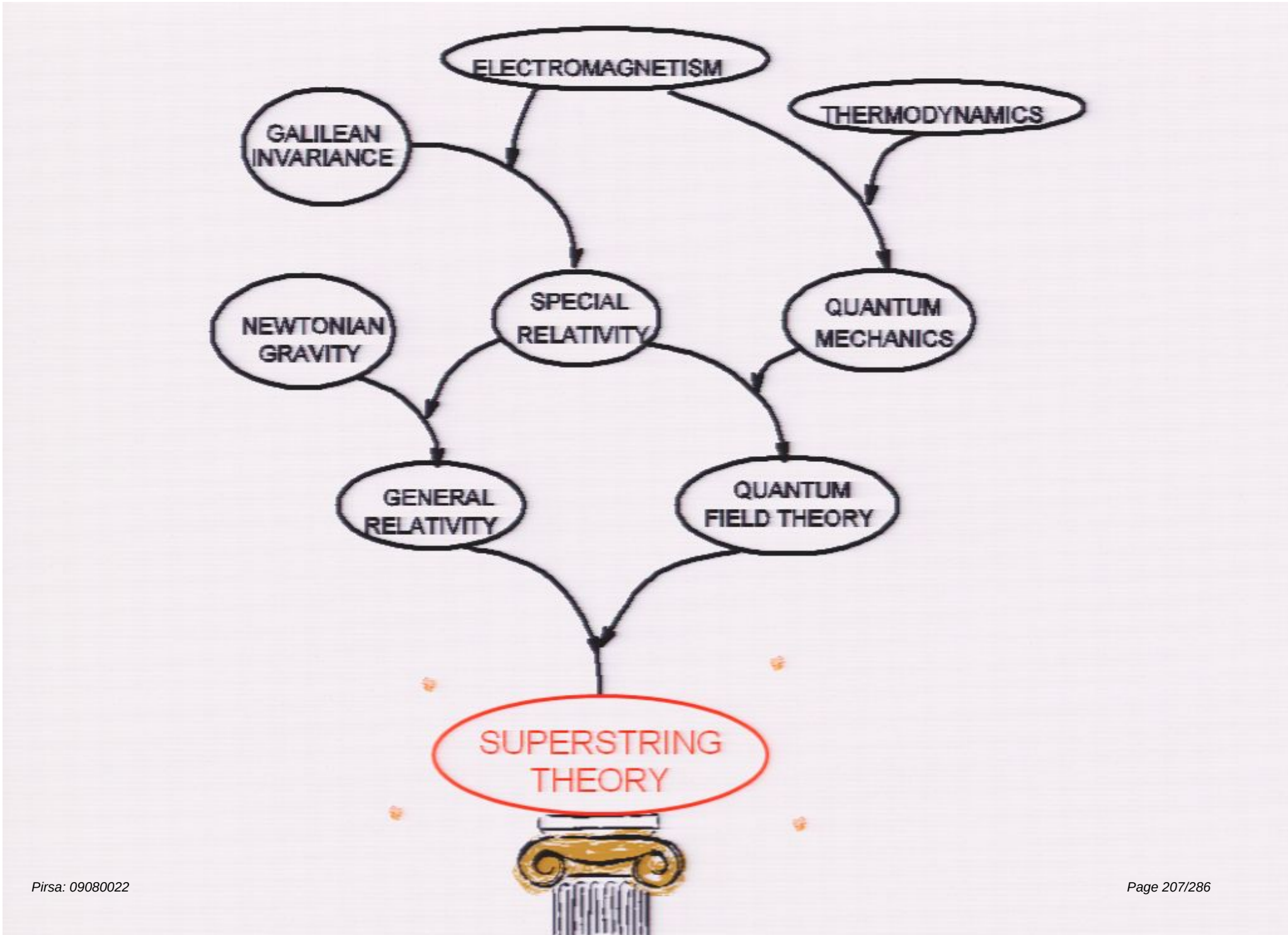
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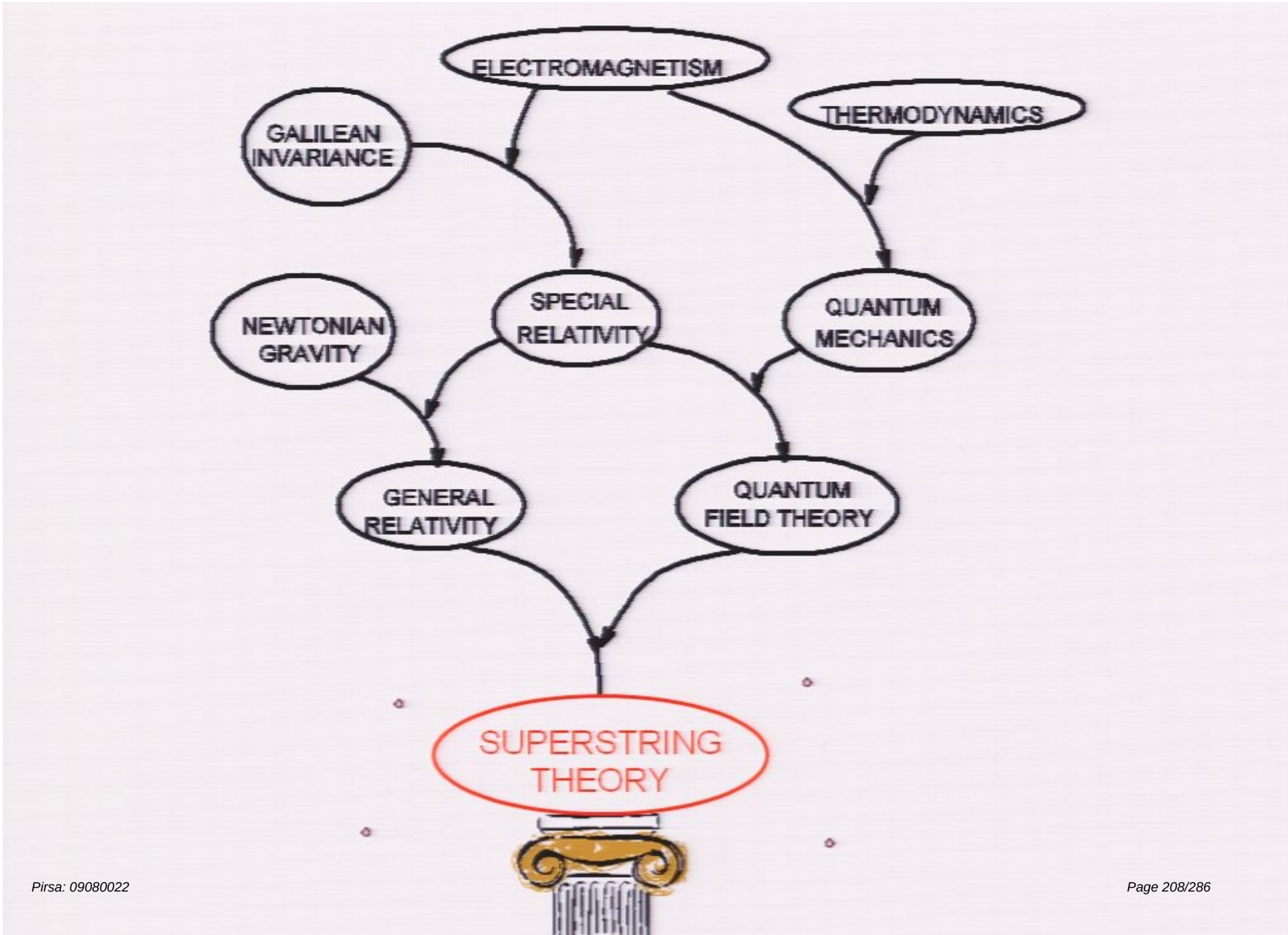
SUPERSTRING THEORY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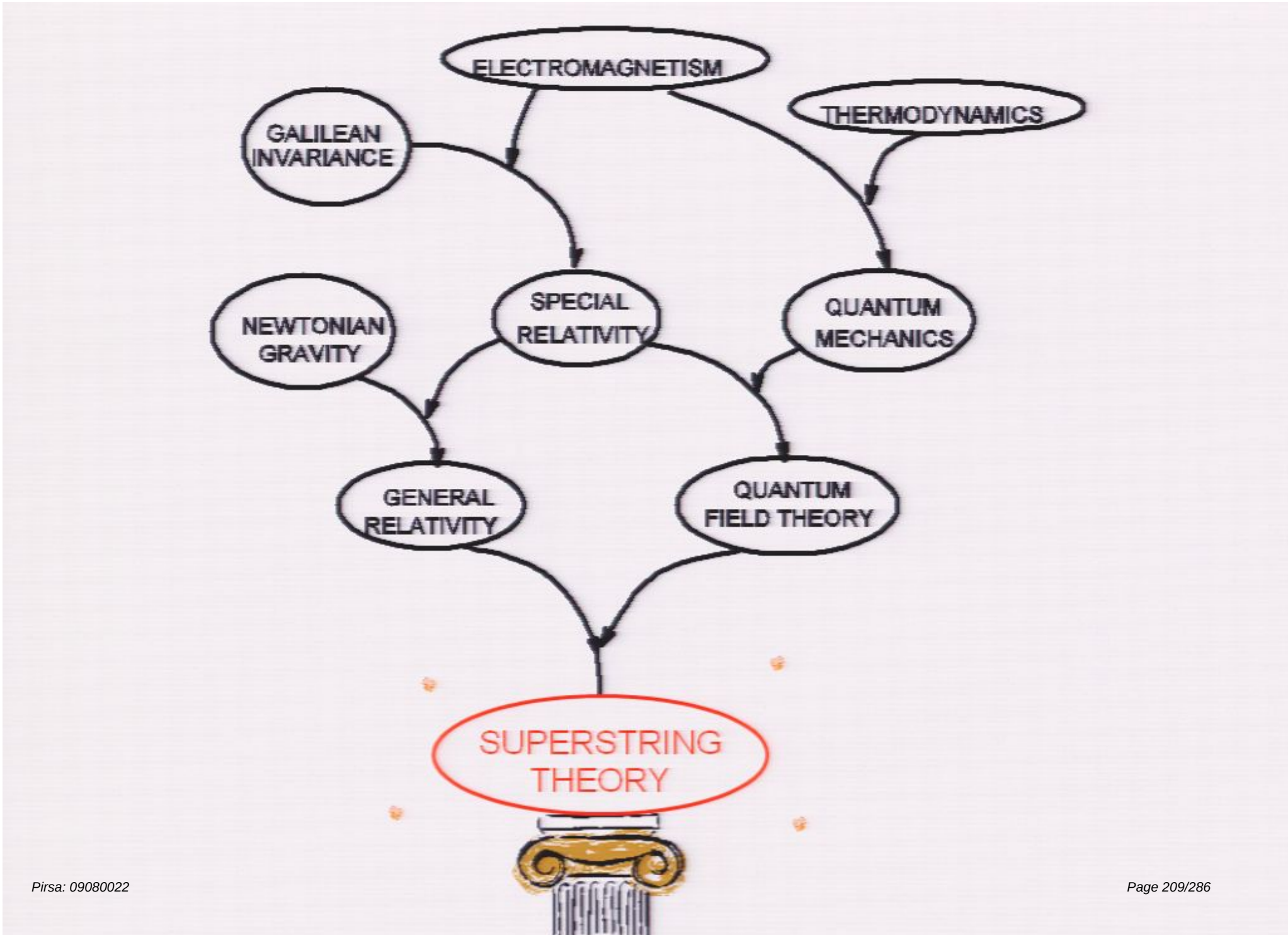
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Superstring theory: The devil is in the "details"

- Predicts we live in 10 spacetime dimensions!!

Experimental update: we live in 4 dimensions!
(1 time and 3 space)

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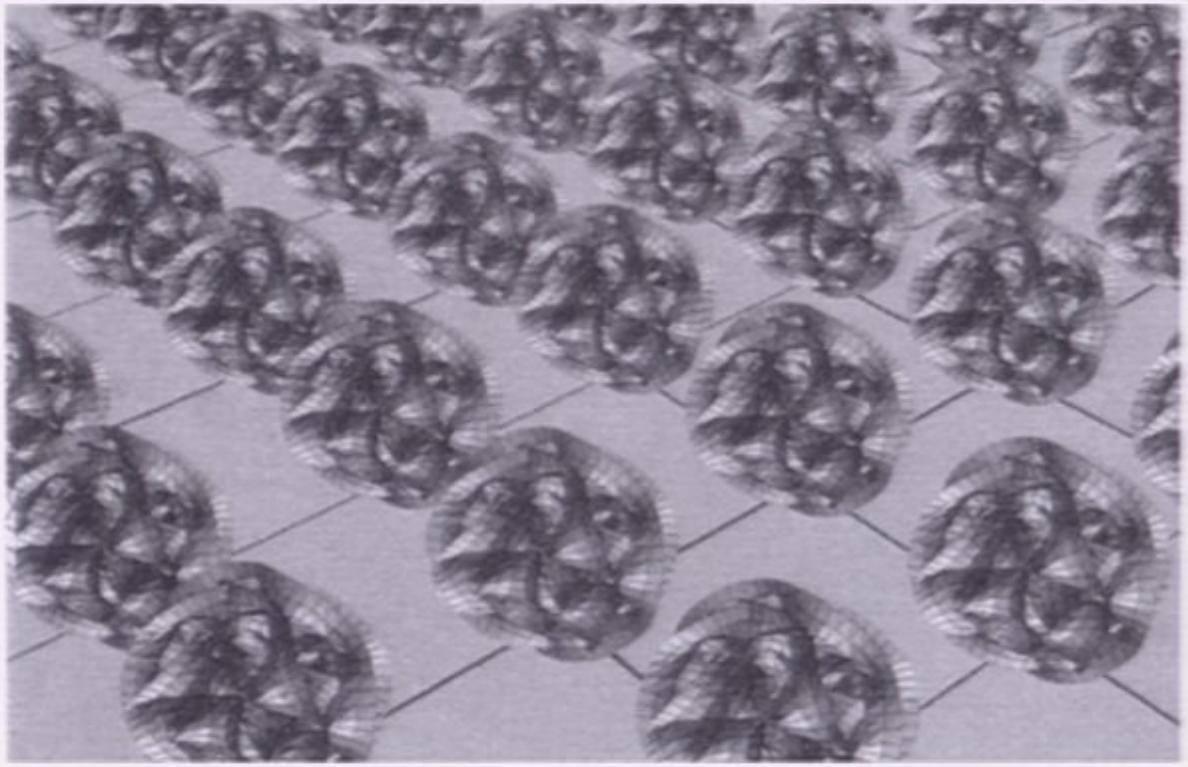

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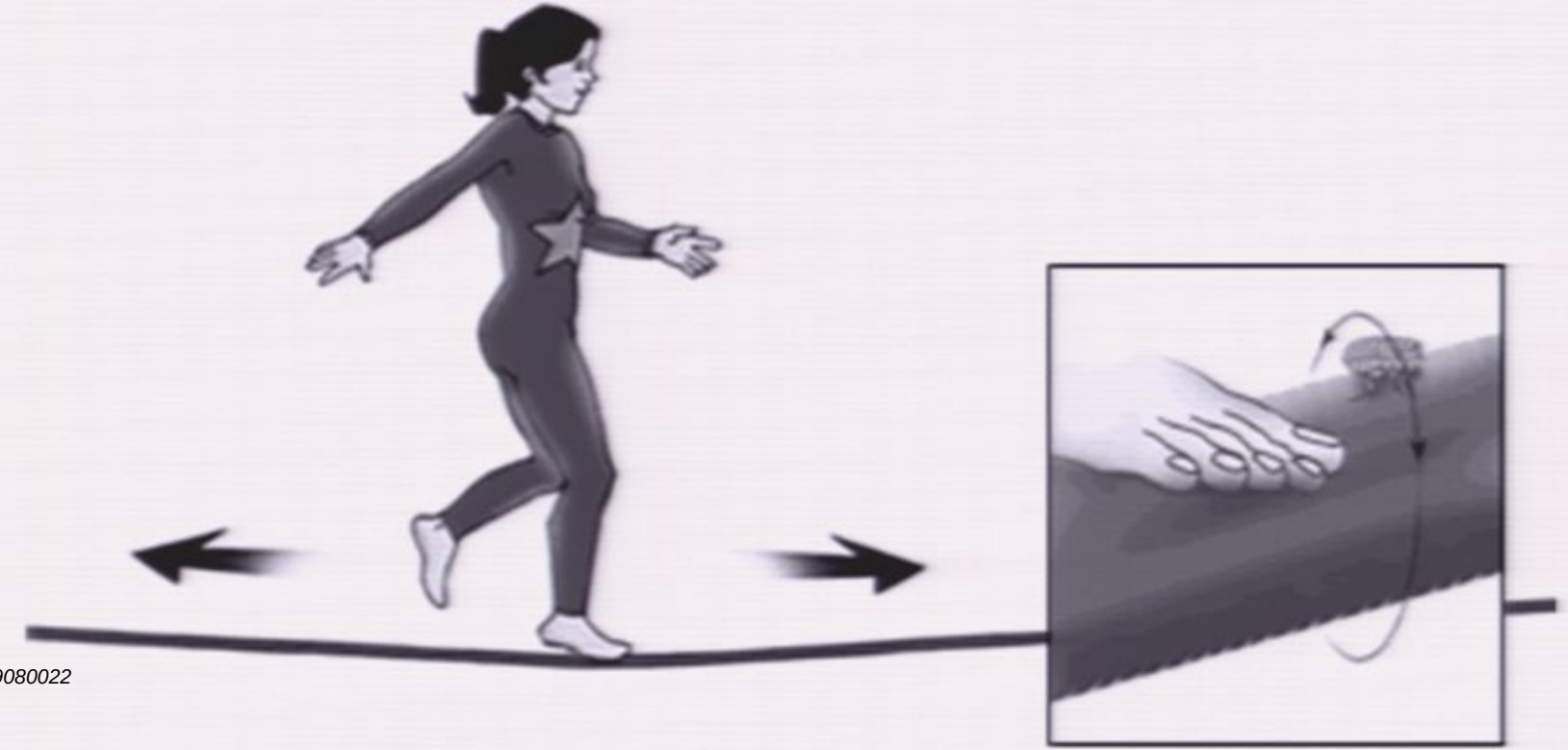

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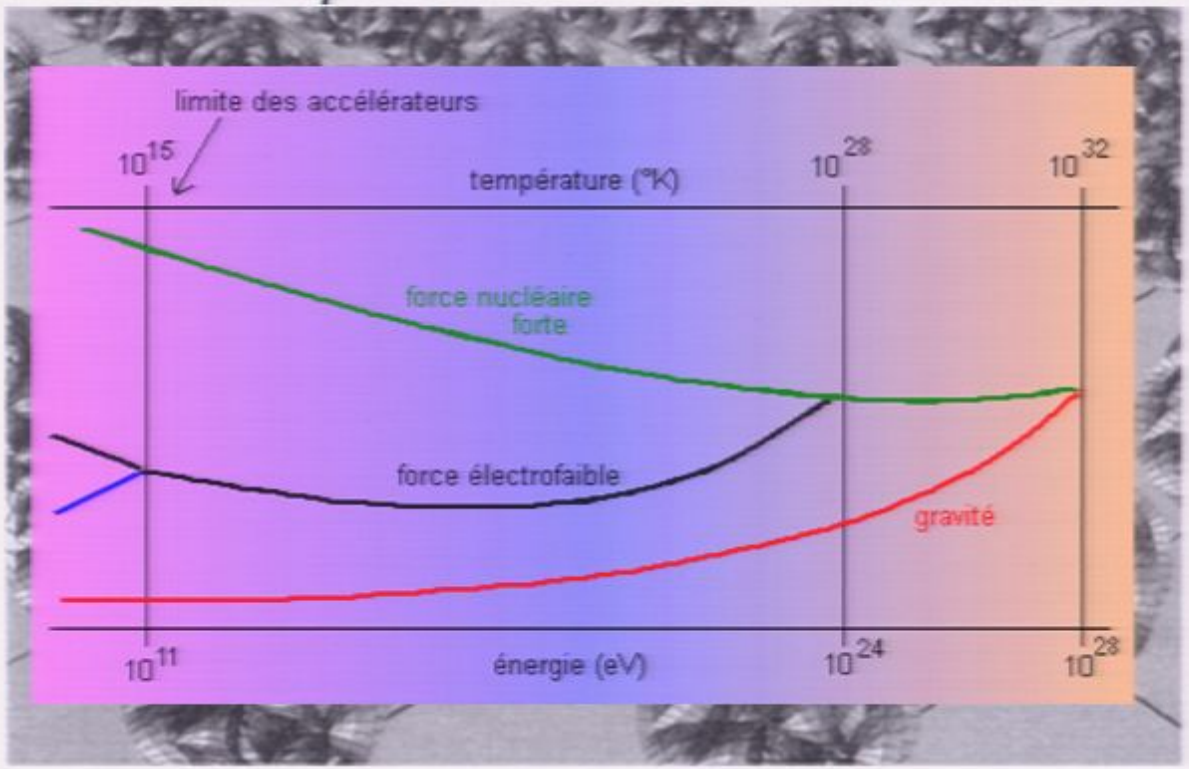

Benefit: richness of four-dimensional physics comes from geometry of the extra dimensions

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- Conjecture: all known string theories are different solutions of single fundamental theory

→ M-theory

Essential ingredients for M-theory conjecture:

- Dualites: two mathematical descriptions describe identical physical phenomena

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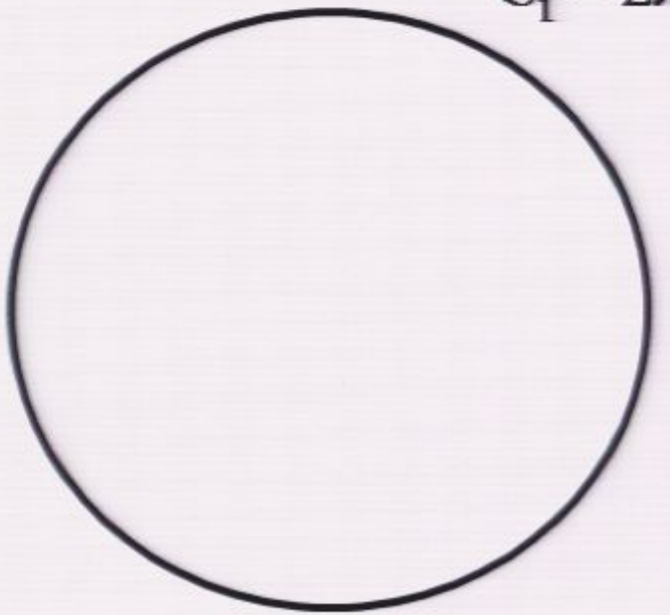

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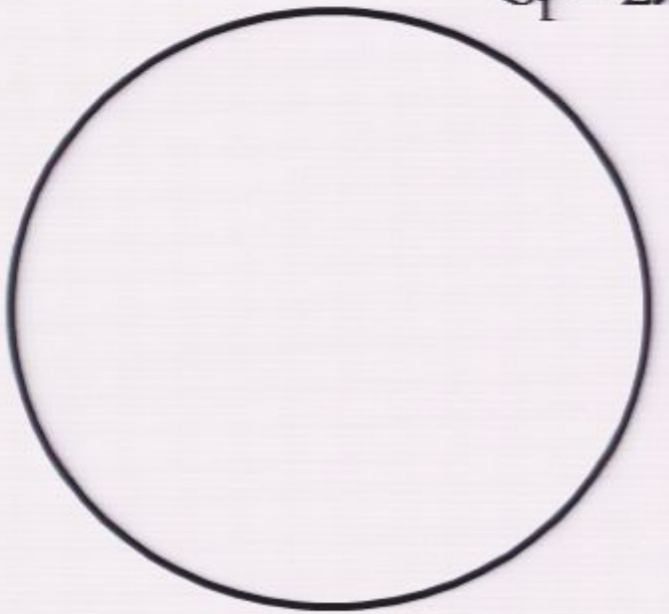

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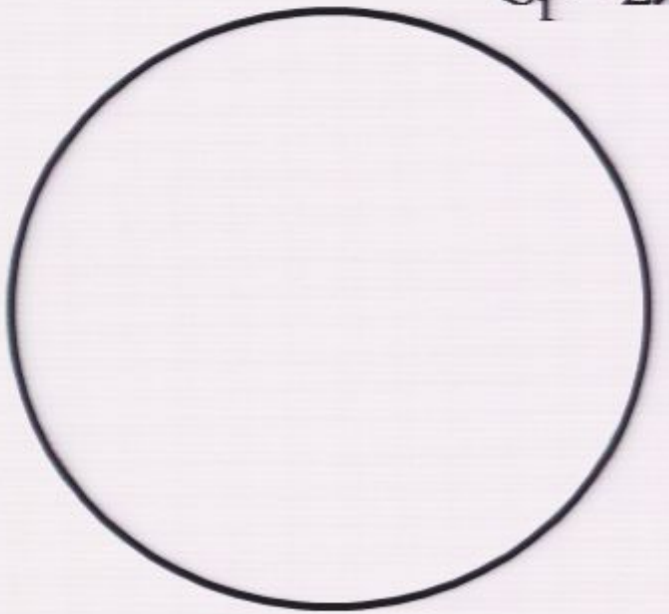

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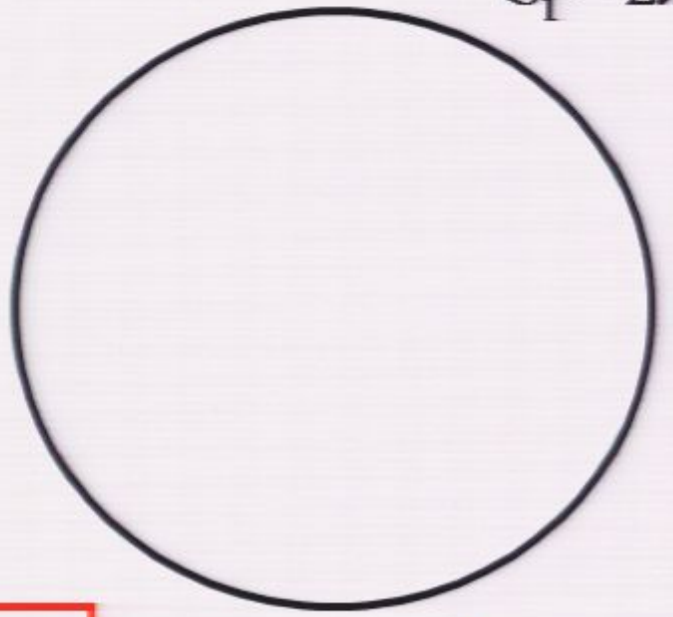

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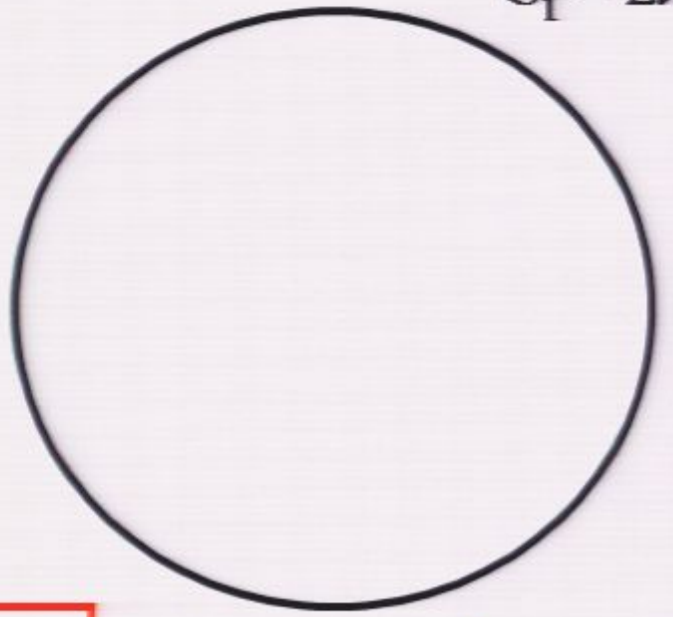

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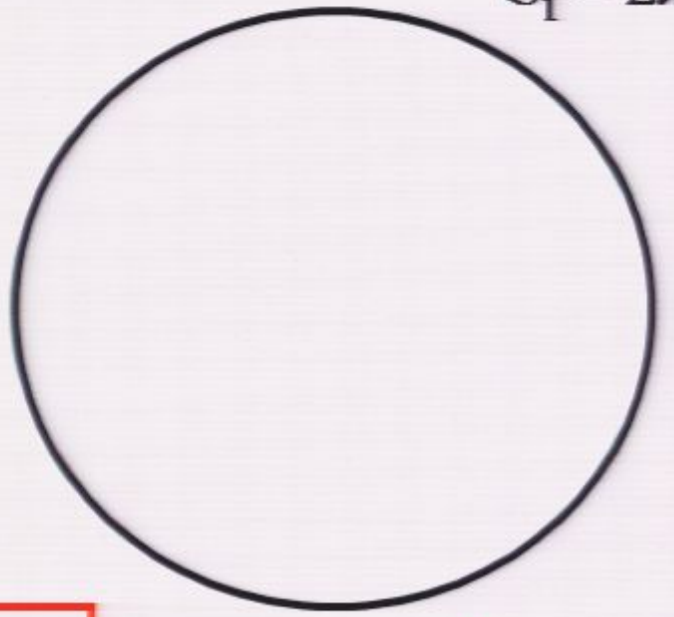

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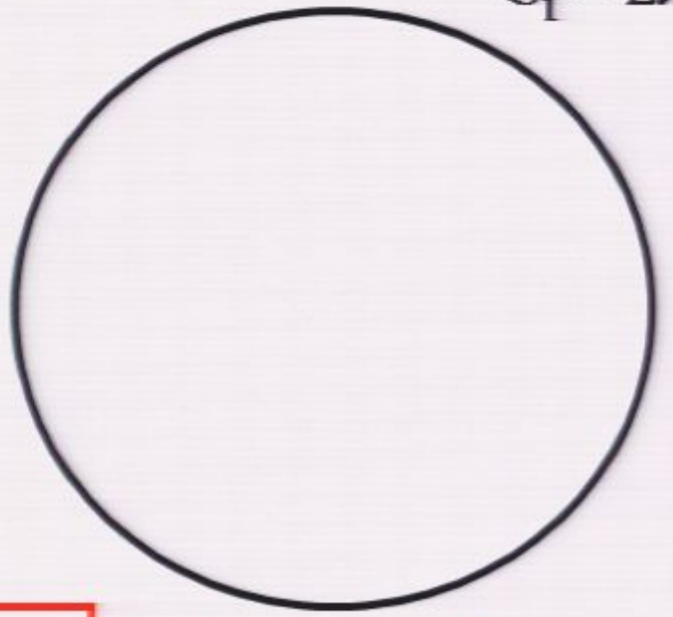

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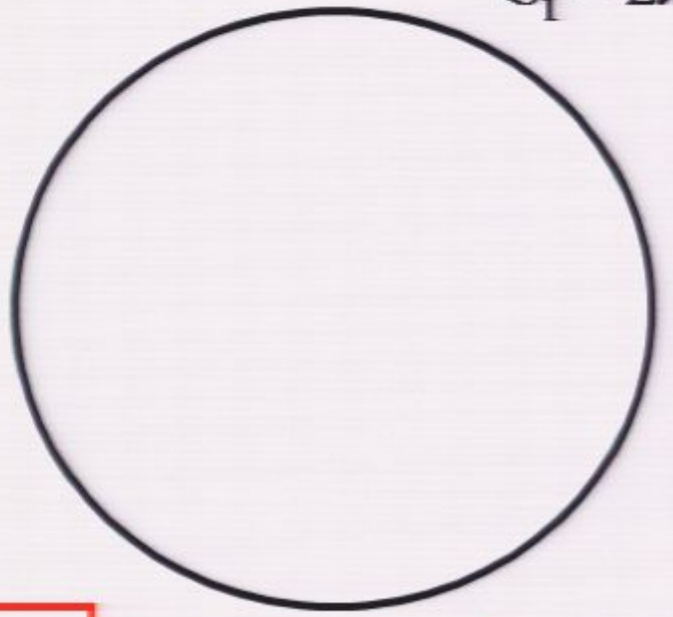

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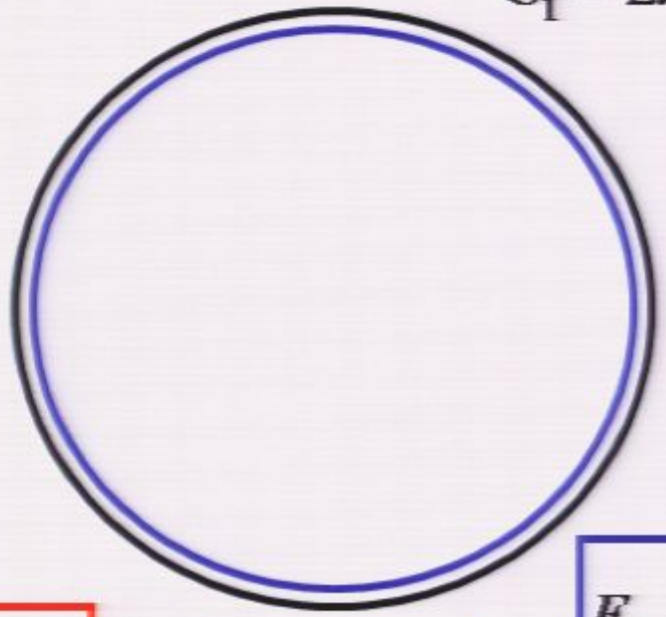

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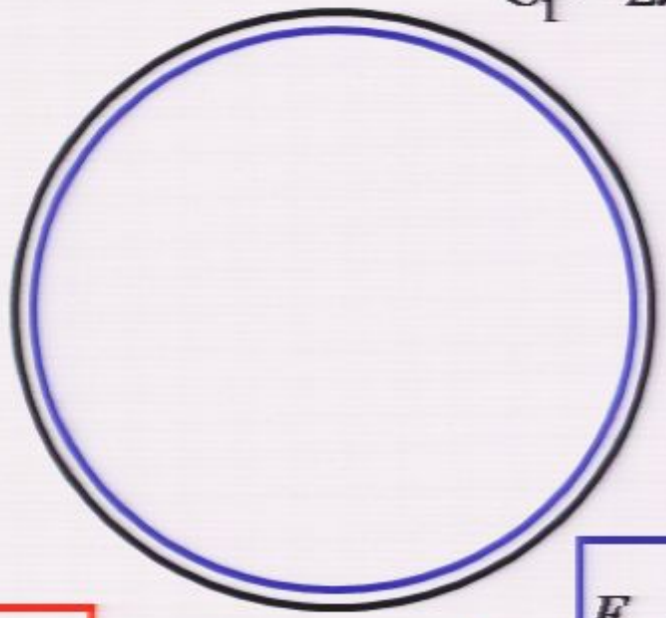

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String theory is more than a theory of strings!

- D-branes: string theory contains other kinds of objects extended in 0, 1, 2, . . . dimensions

particles strings membranes p-branes

$$T_p = \frac{2\pi}{(2\pi\ell_s)^{p+1} g}$$

← extremely heavy in weak coupling

← extremely important in strong coupling

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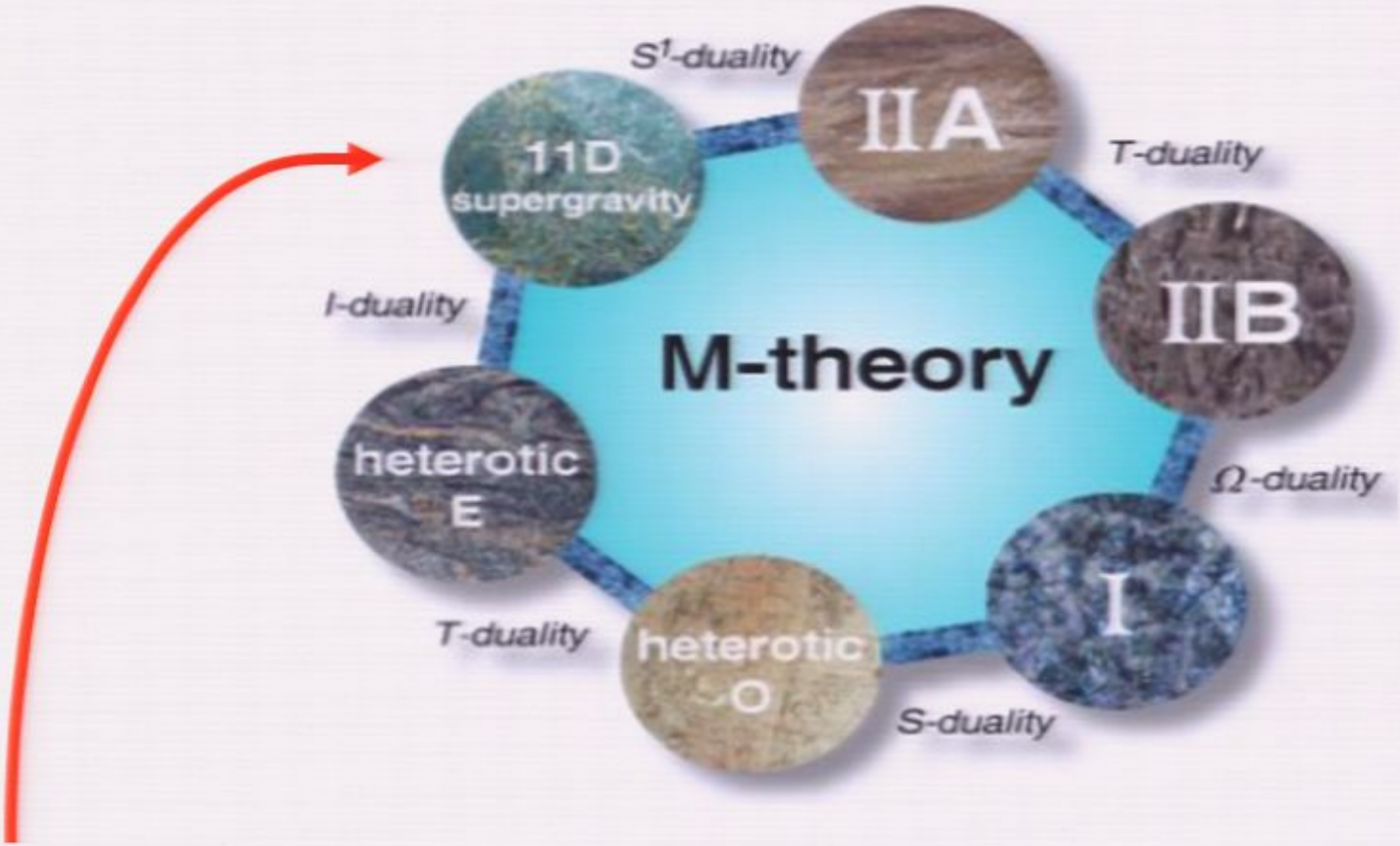
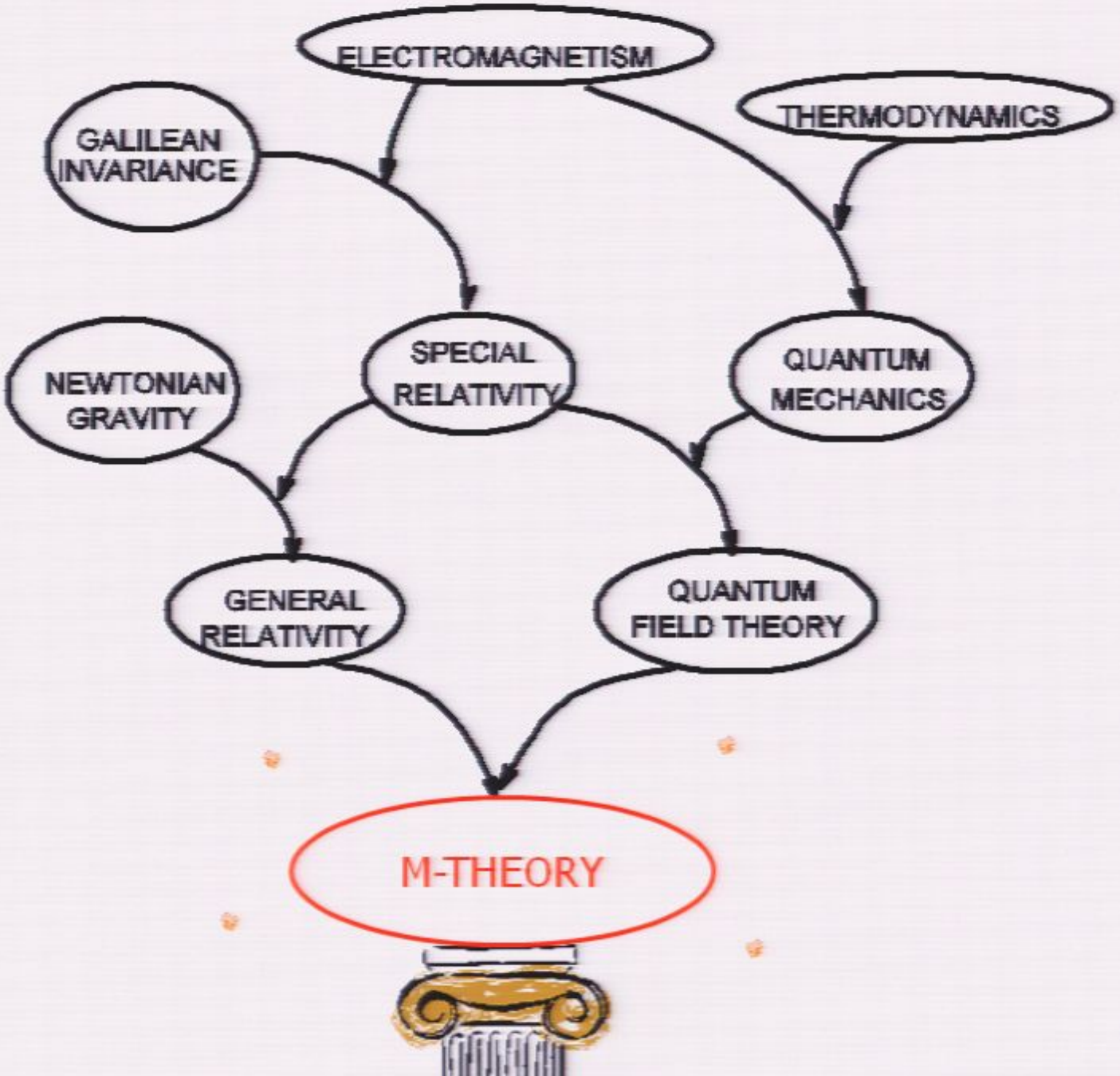


M-theory also includes 11-dimensional supergravity!

String/M-theory is a rich source of new ideas



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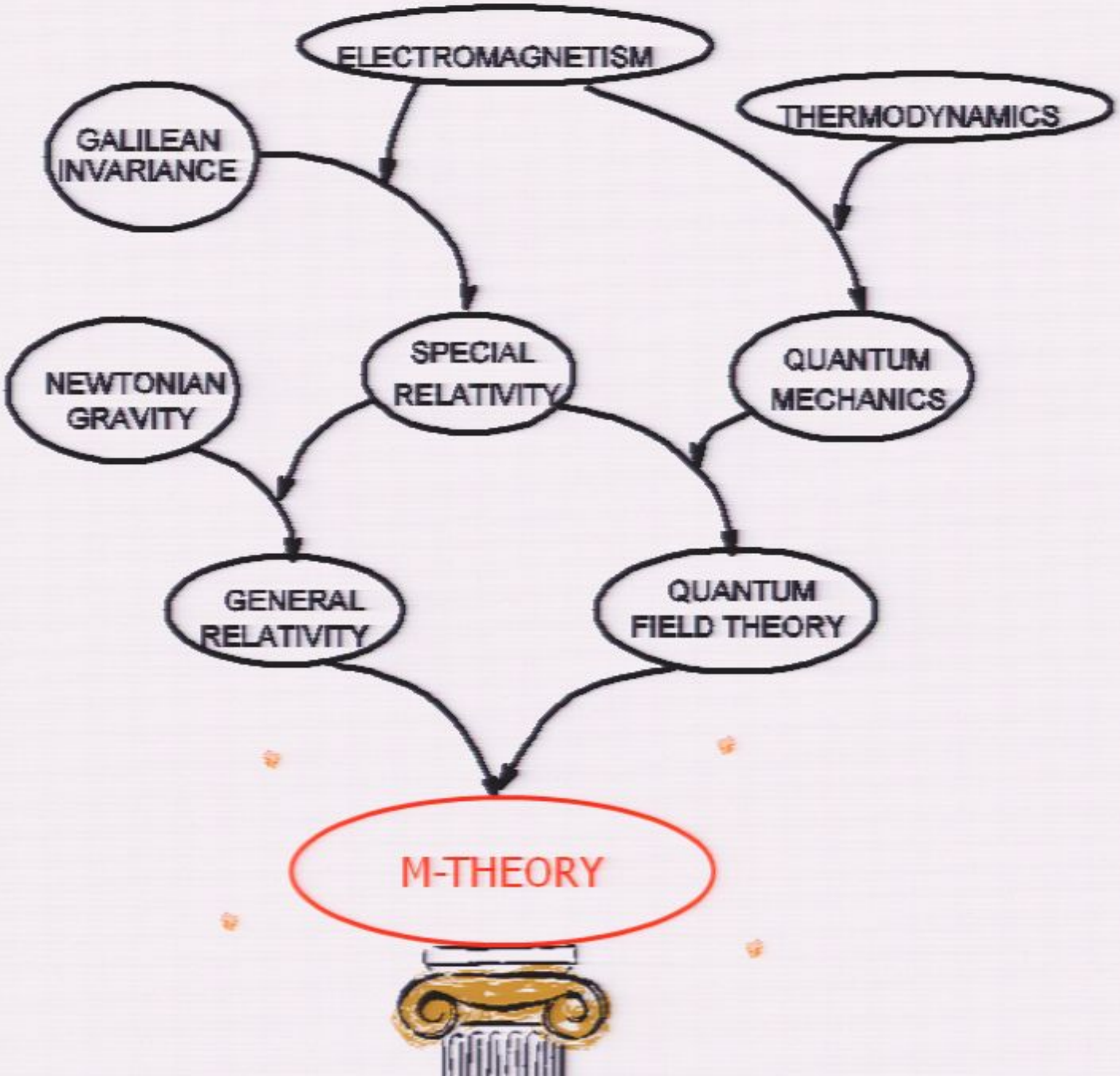

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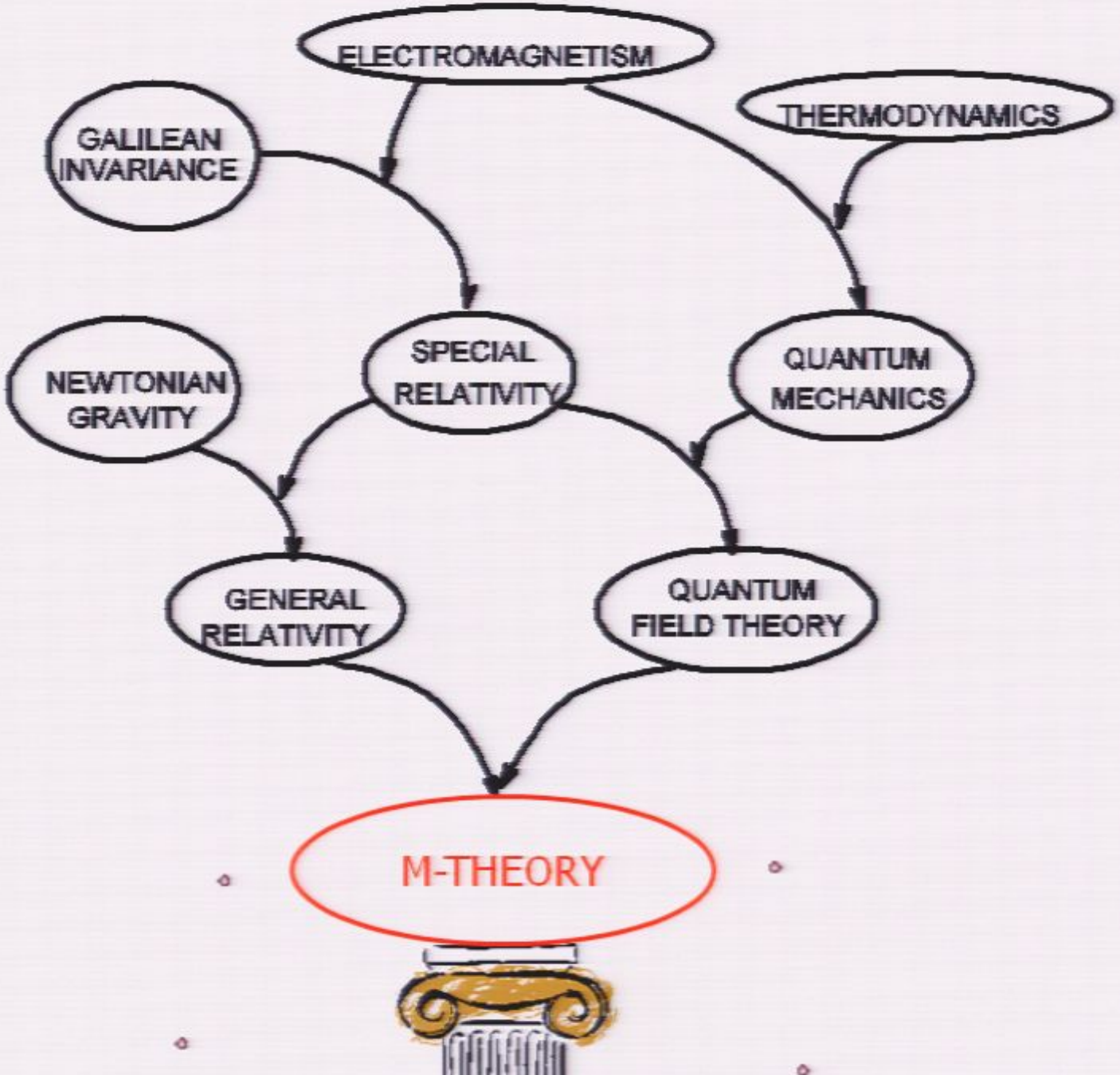

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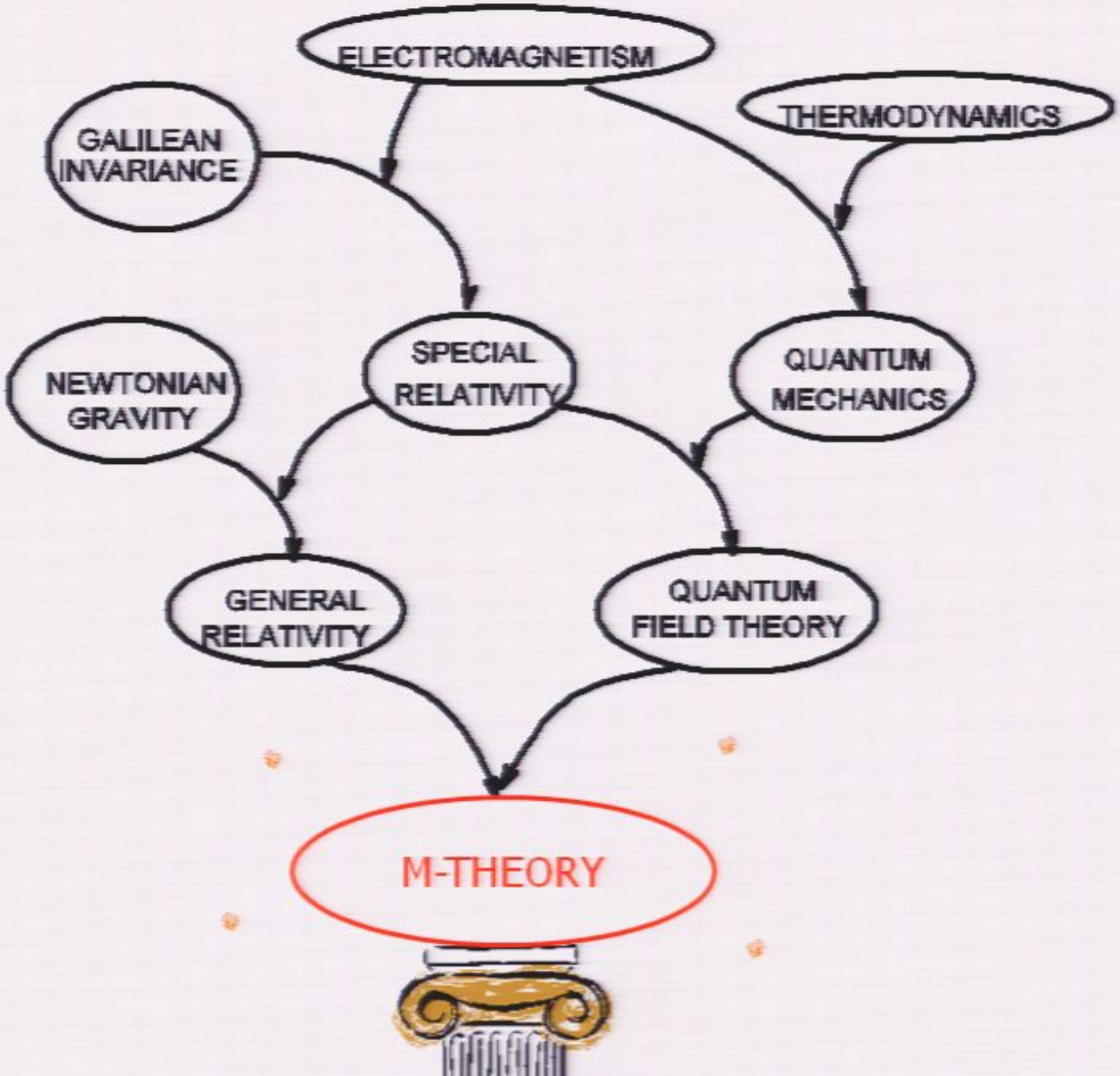

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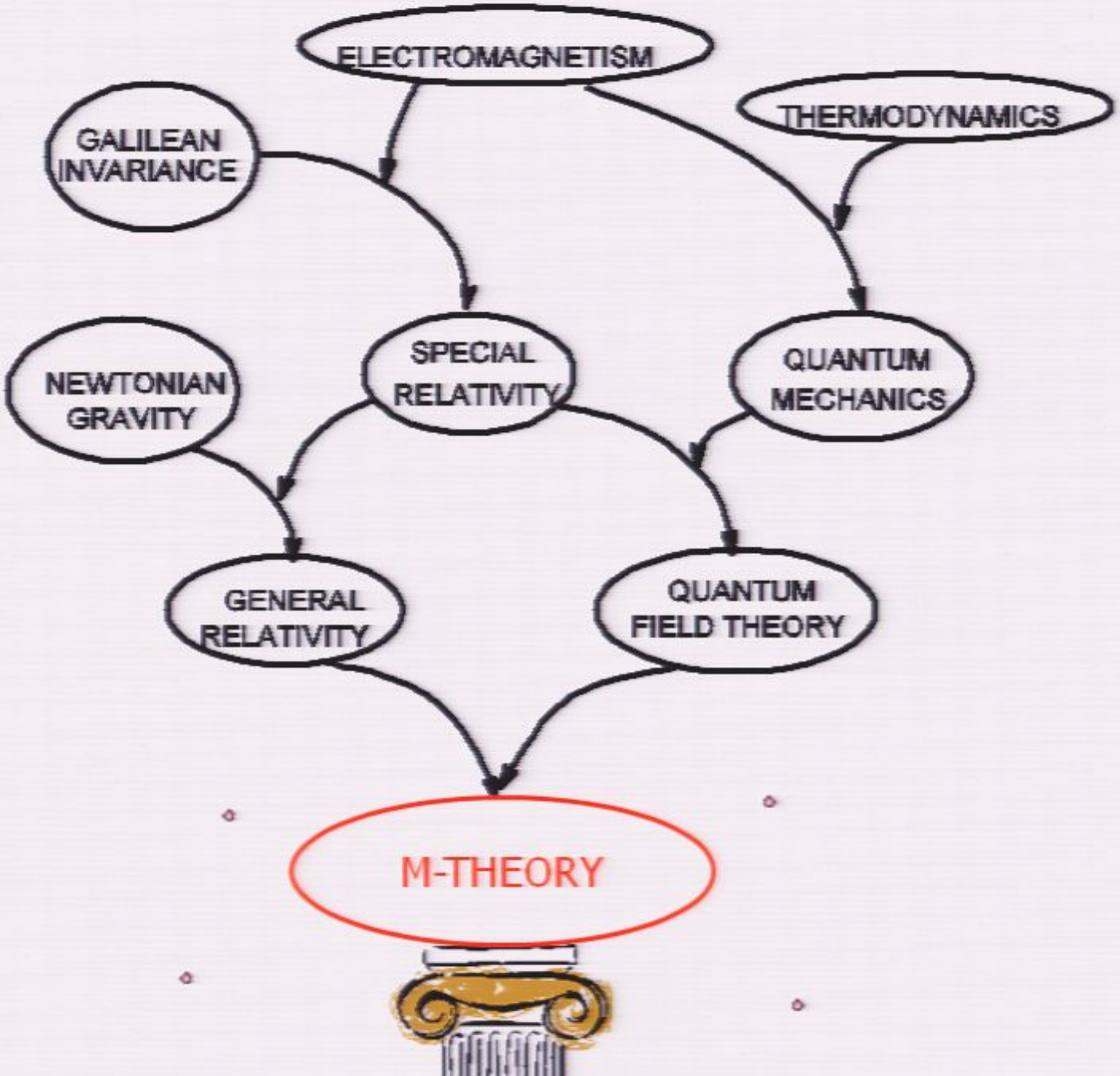

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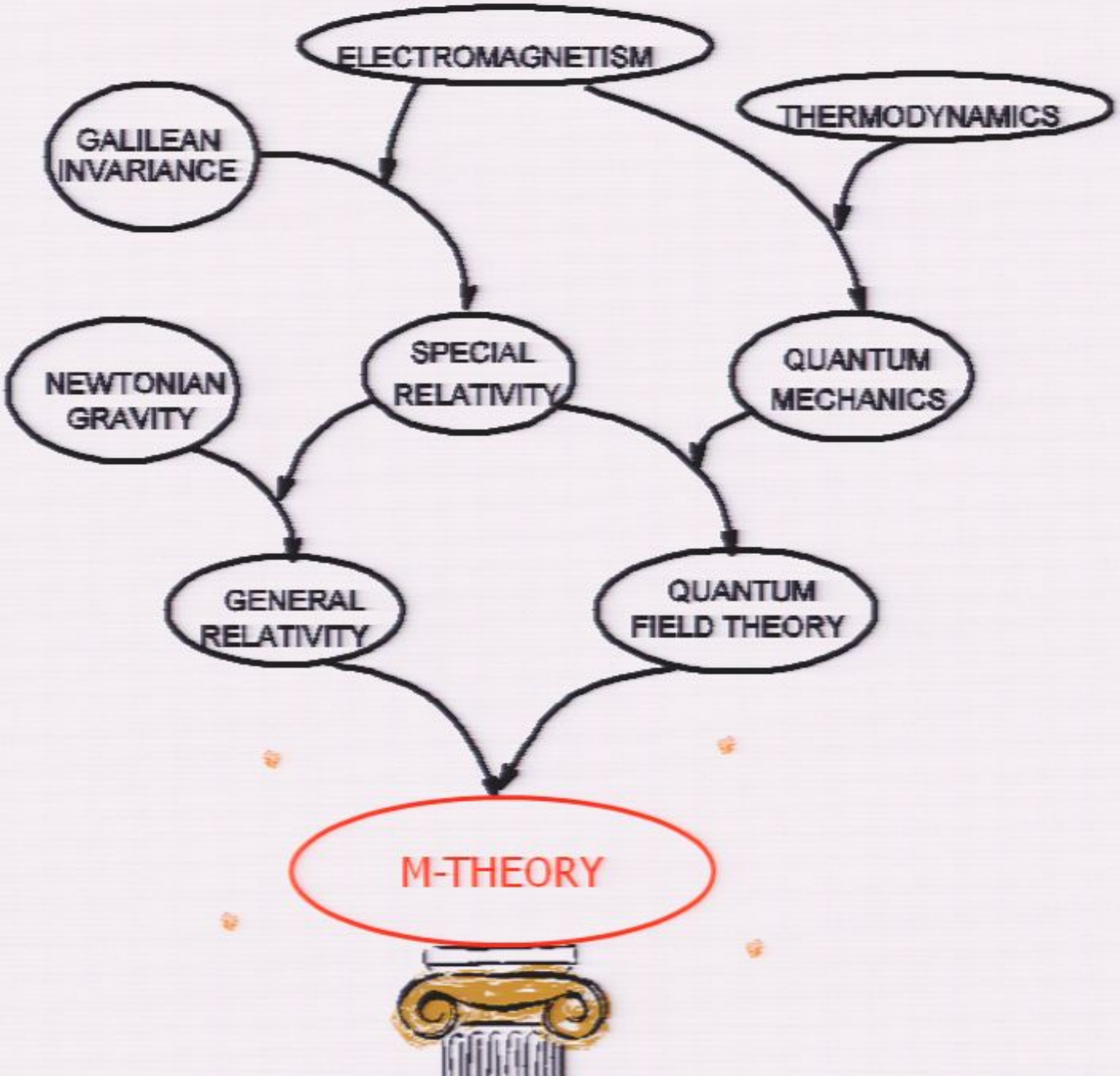

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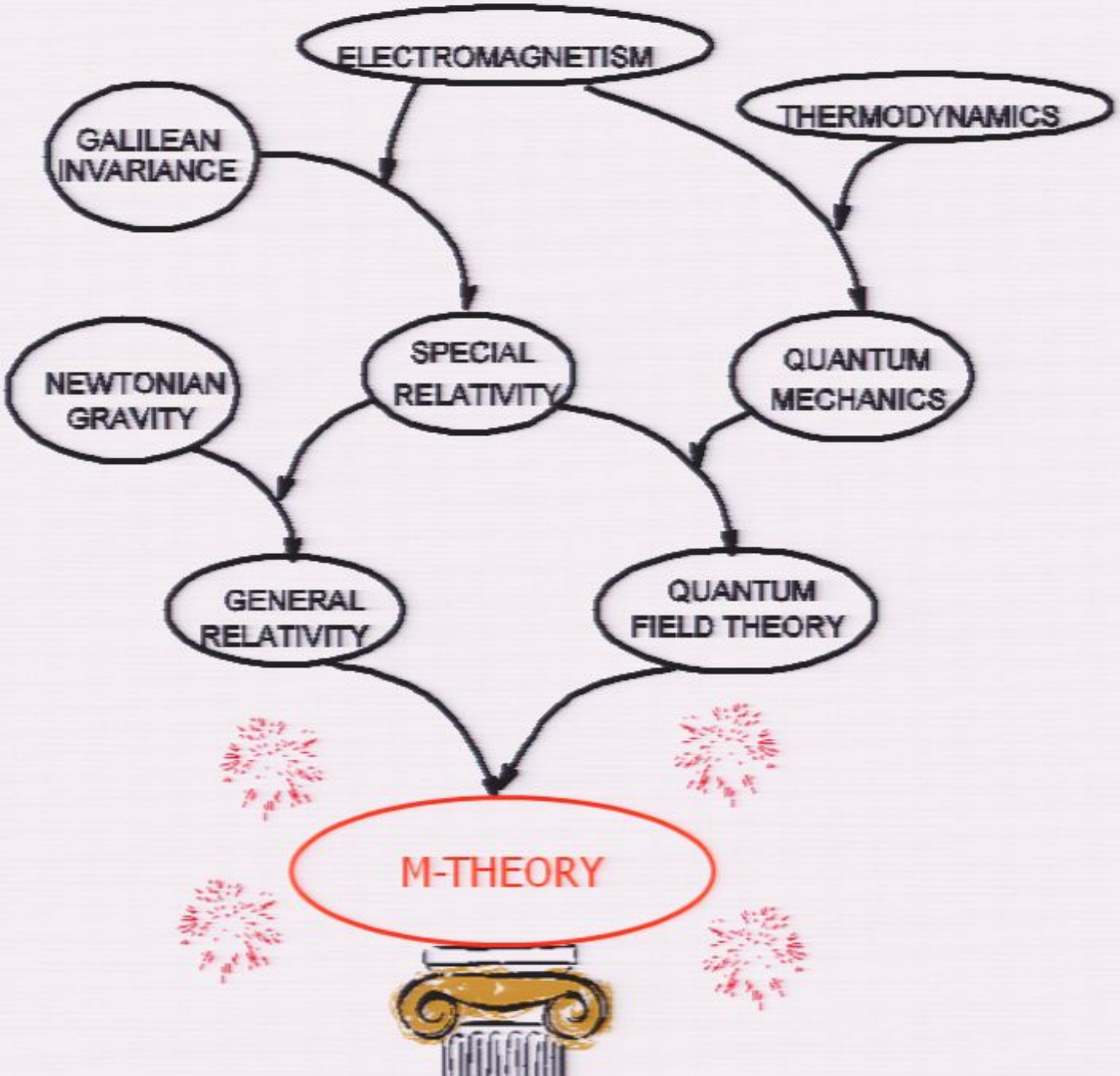

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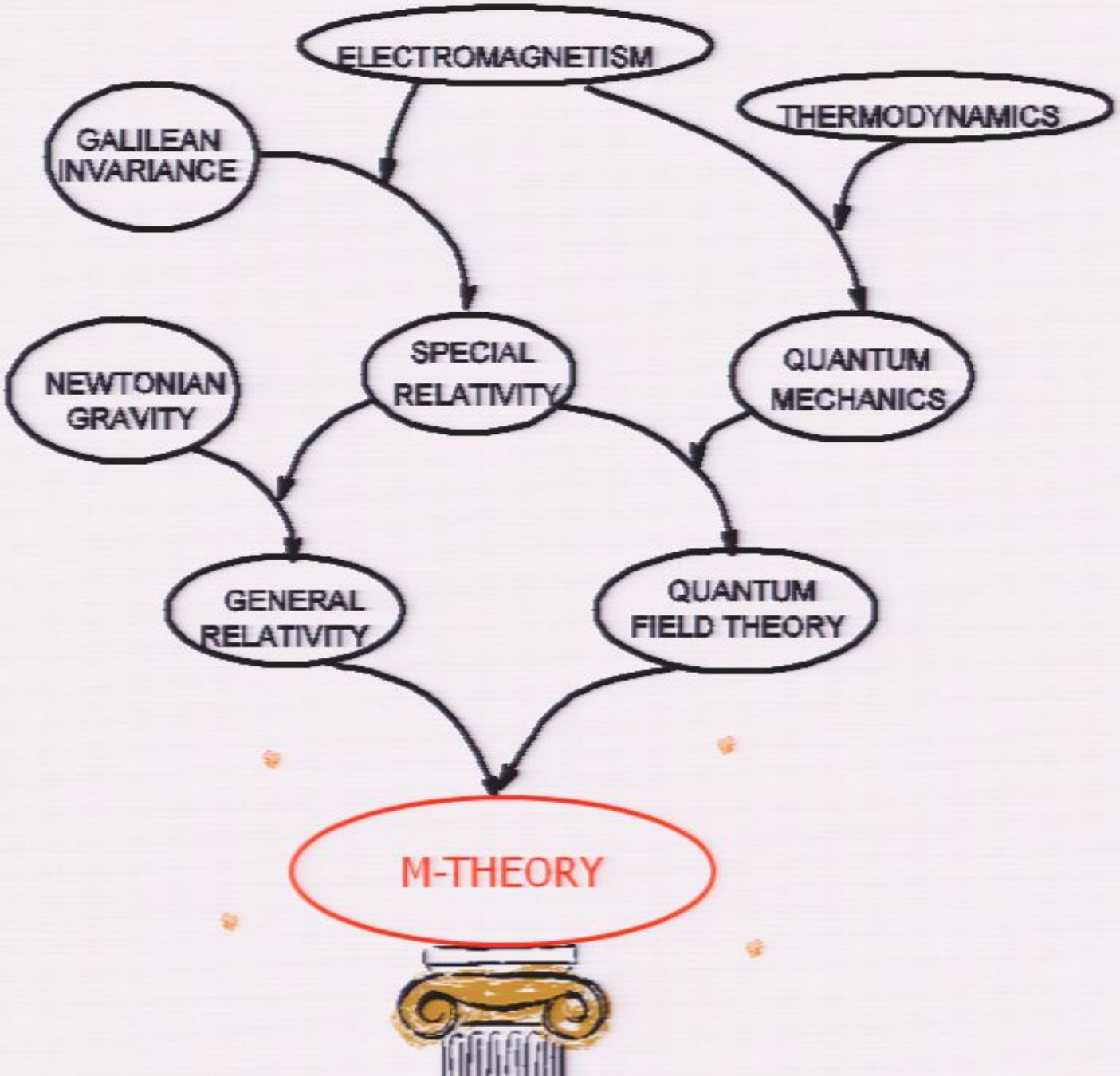

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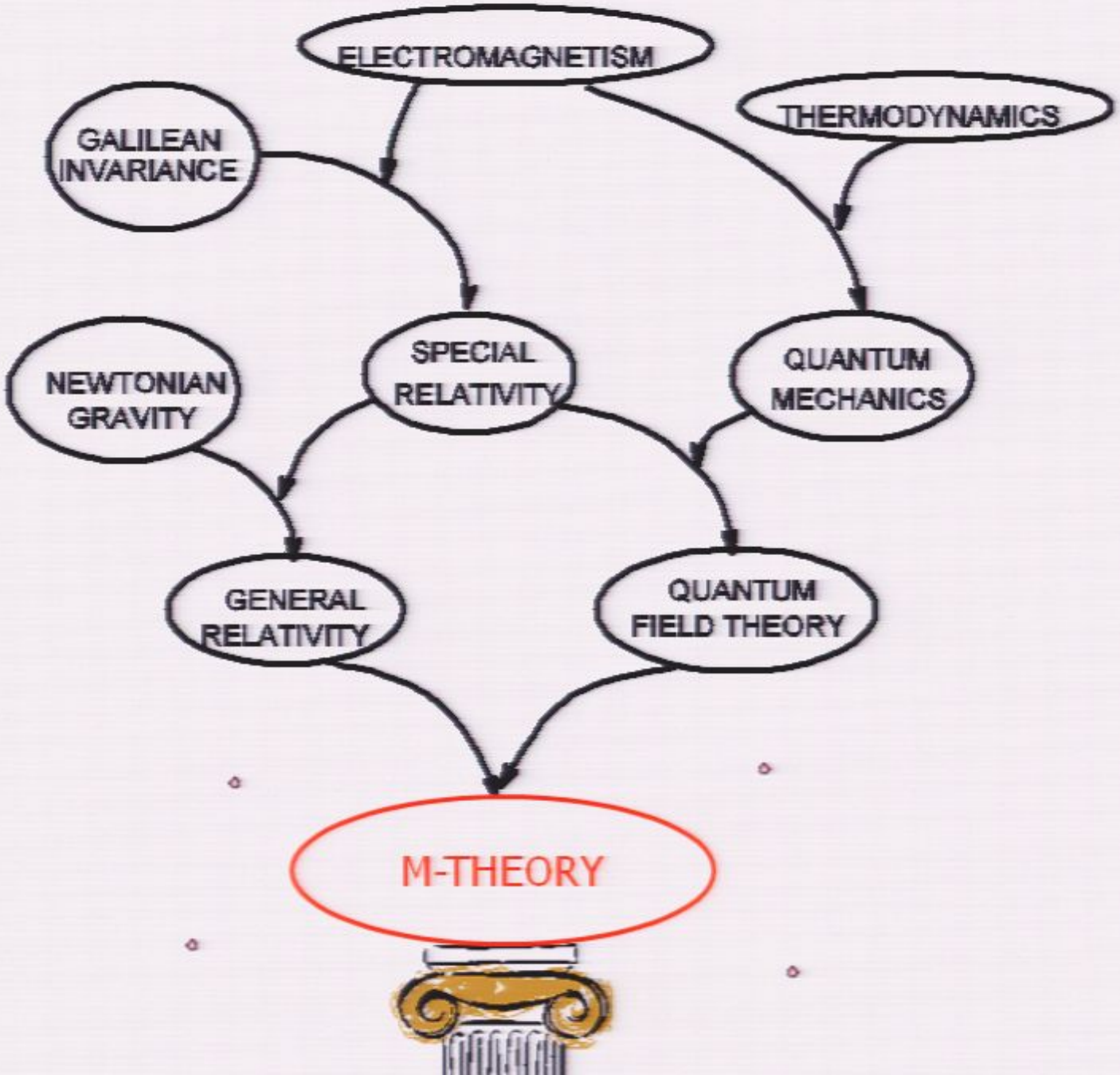

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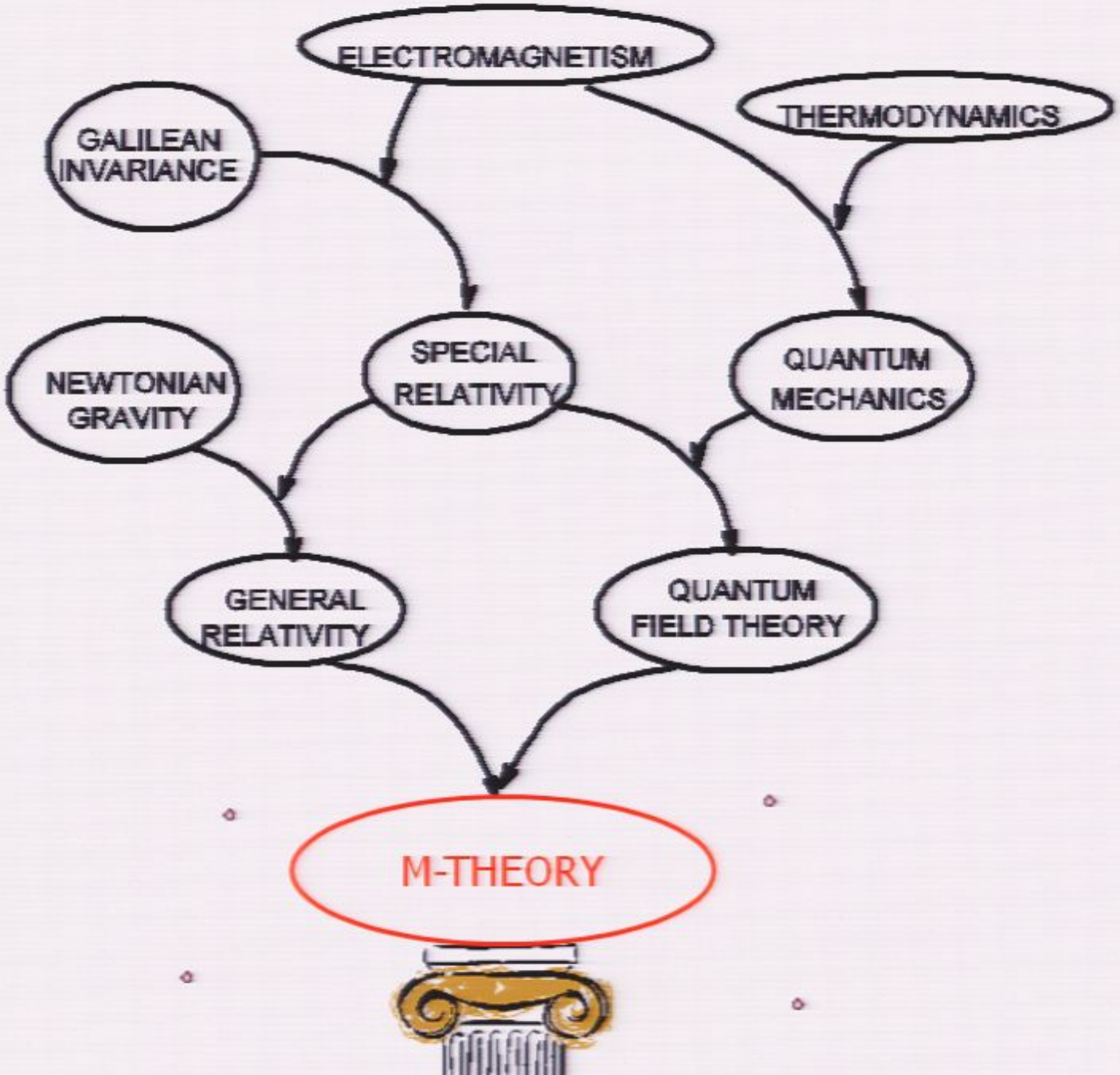

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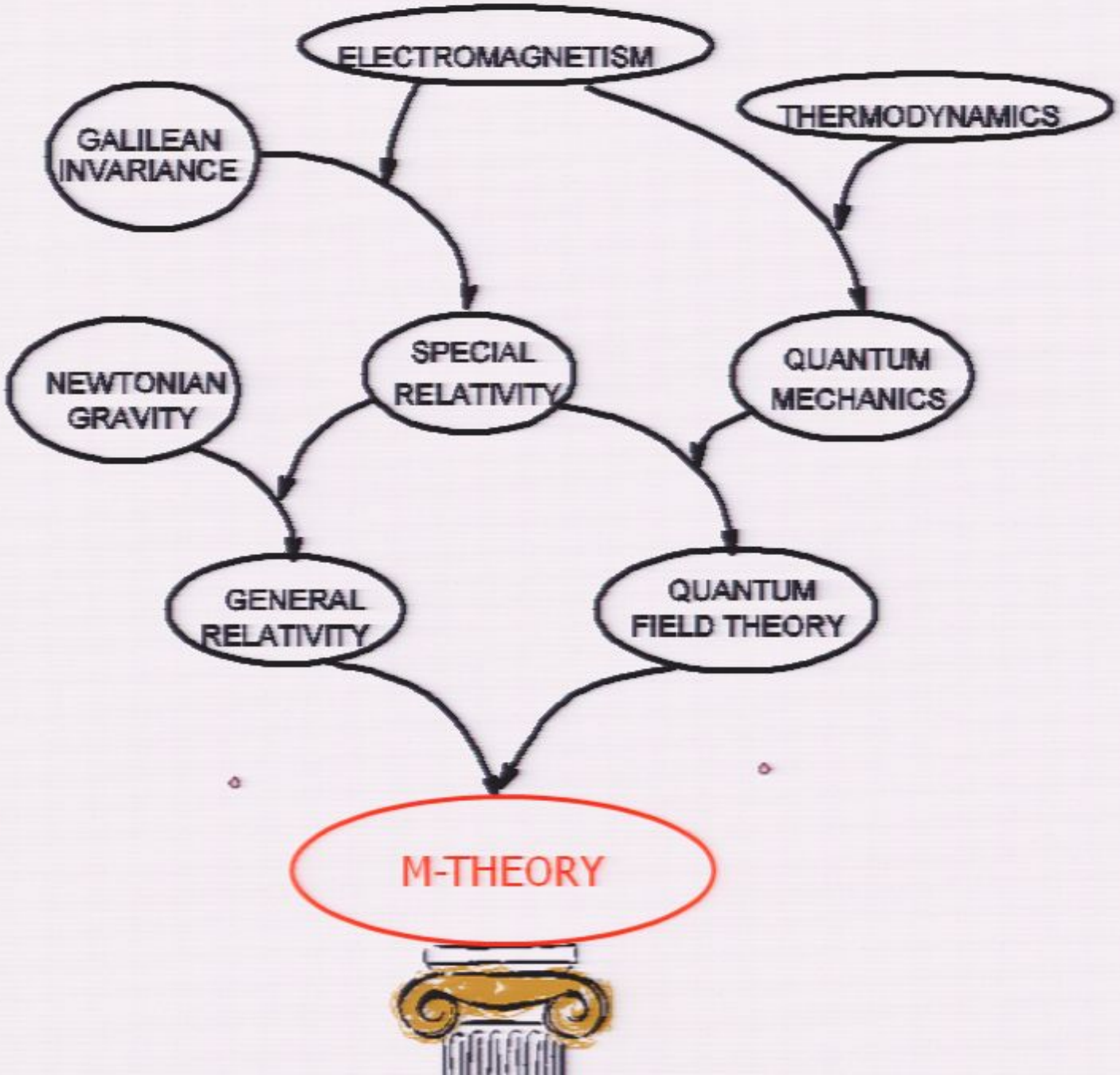

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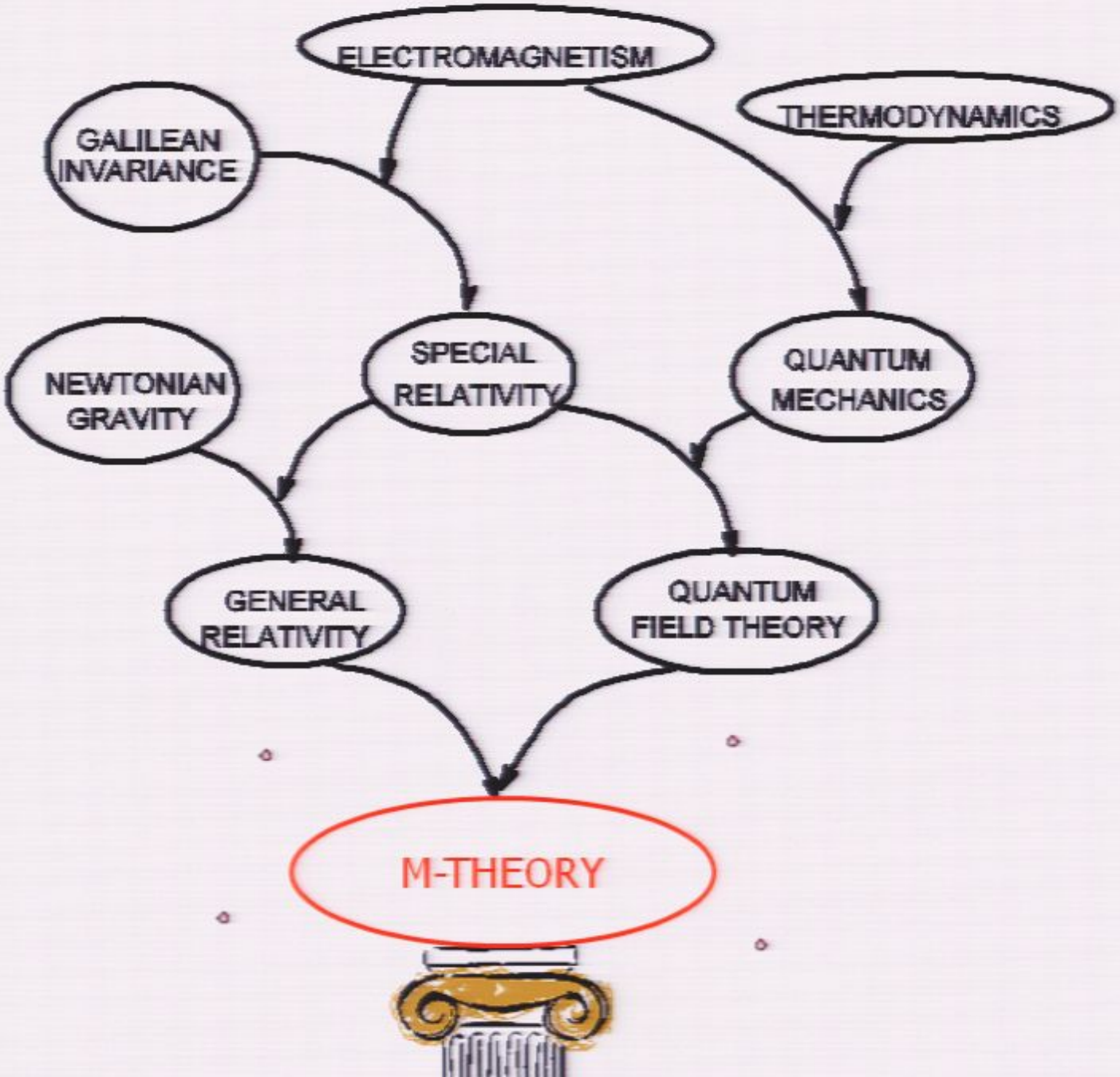

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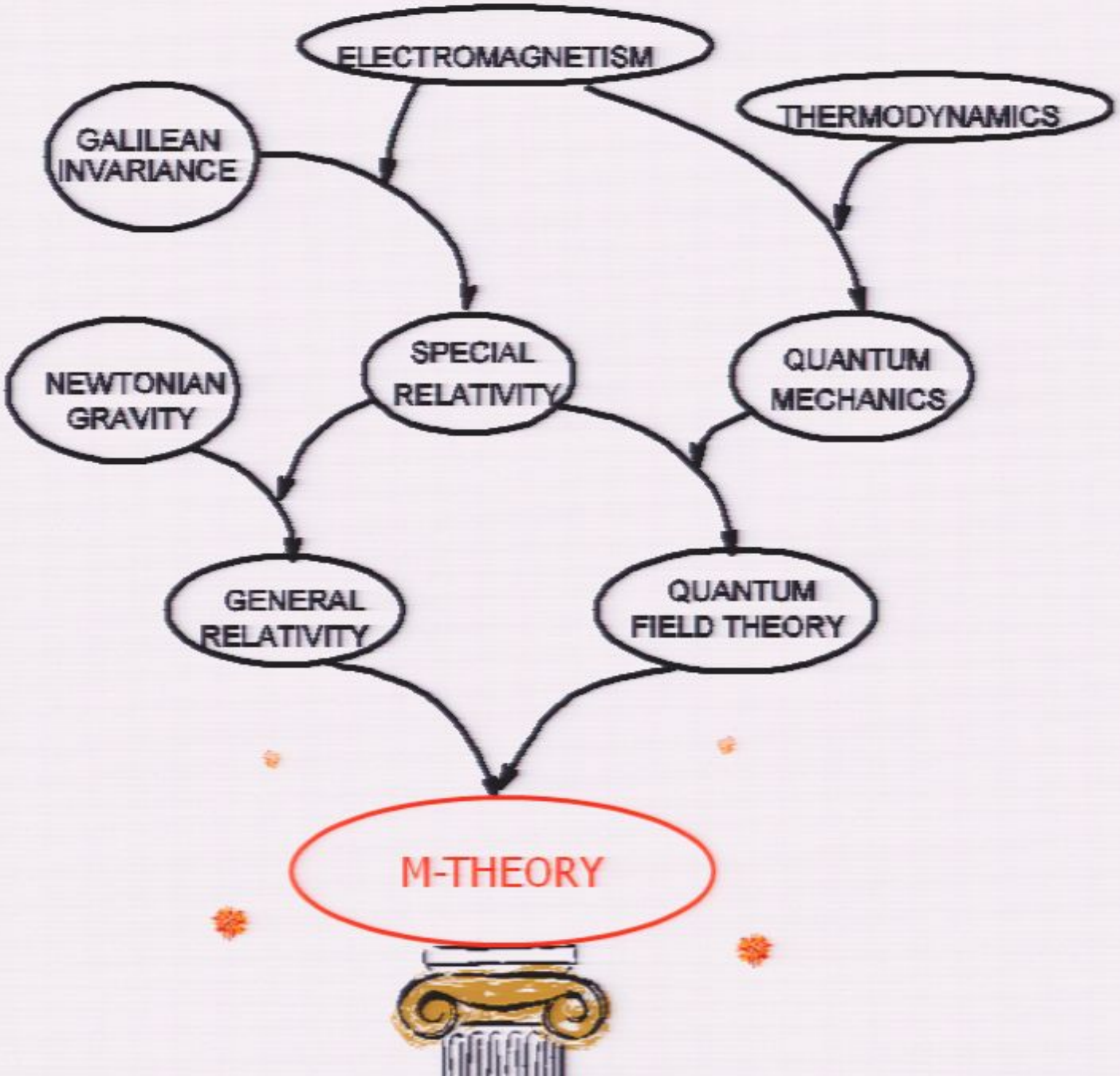

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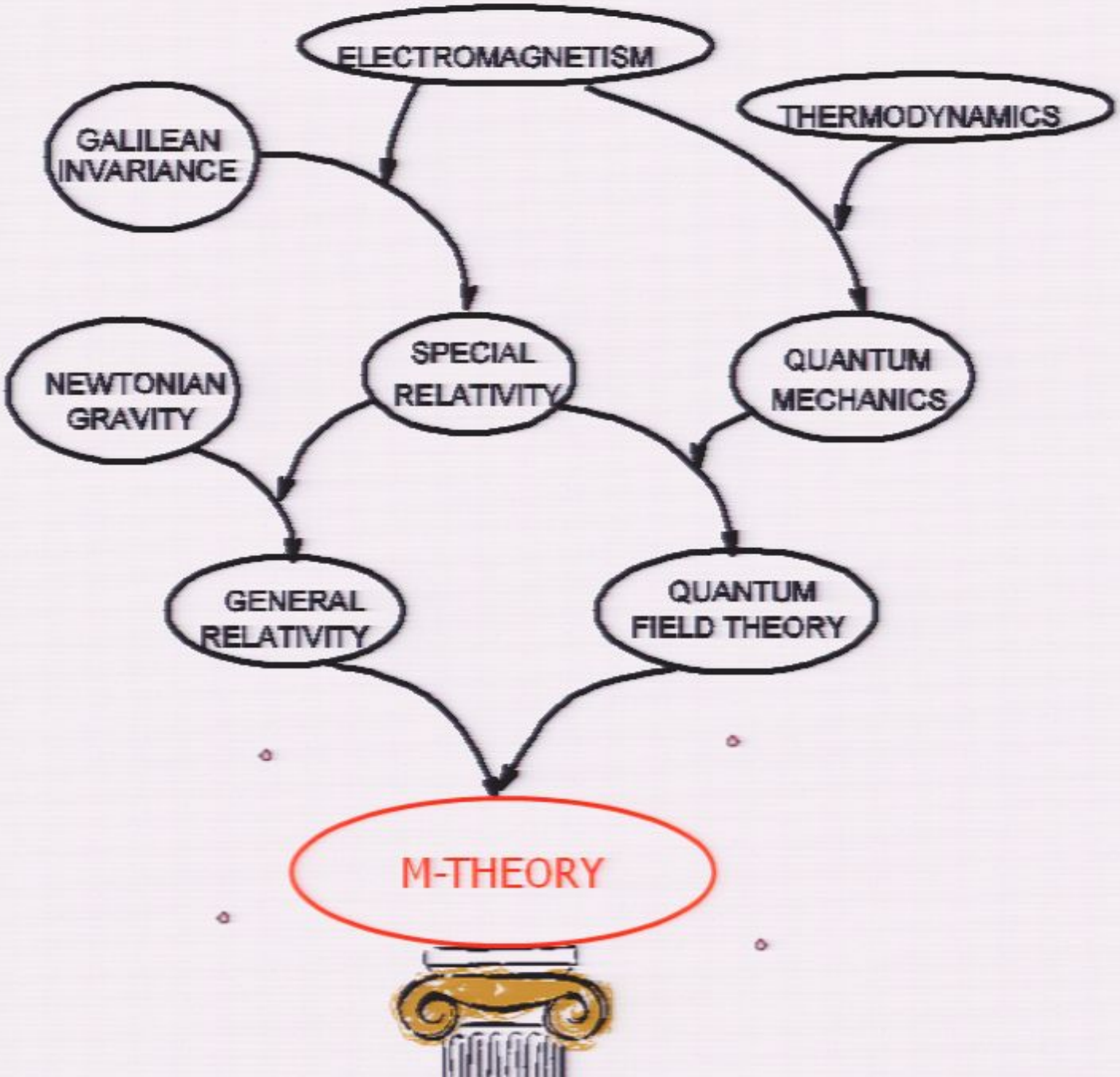

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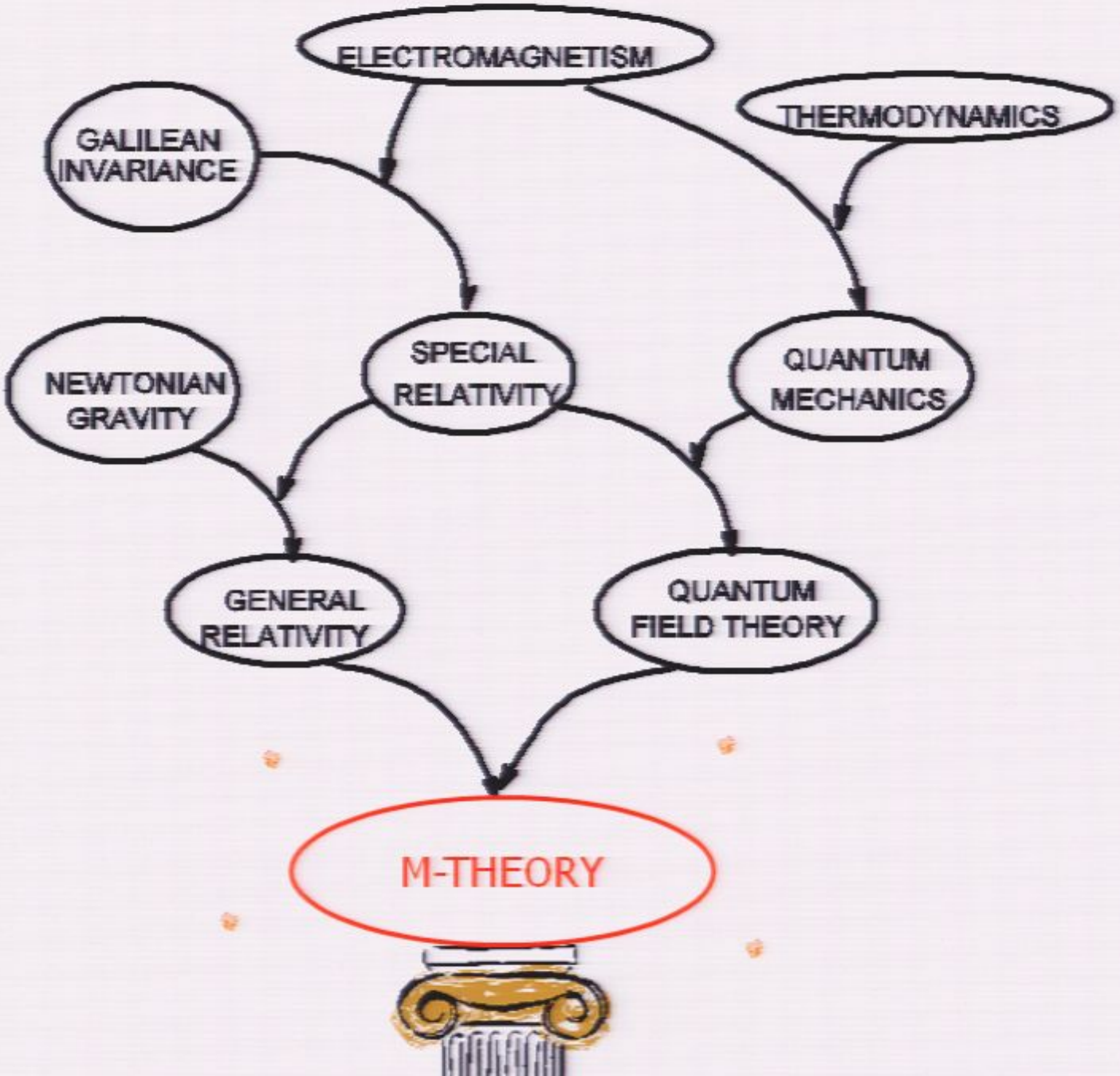

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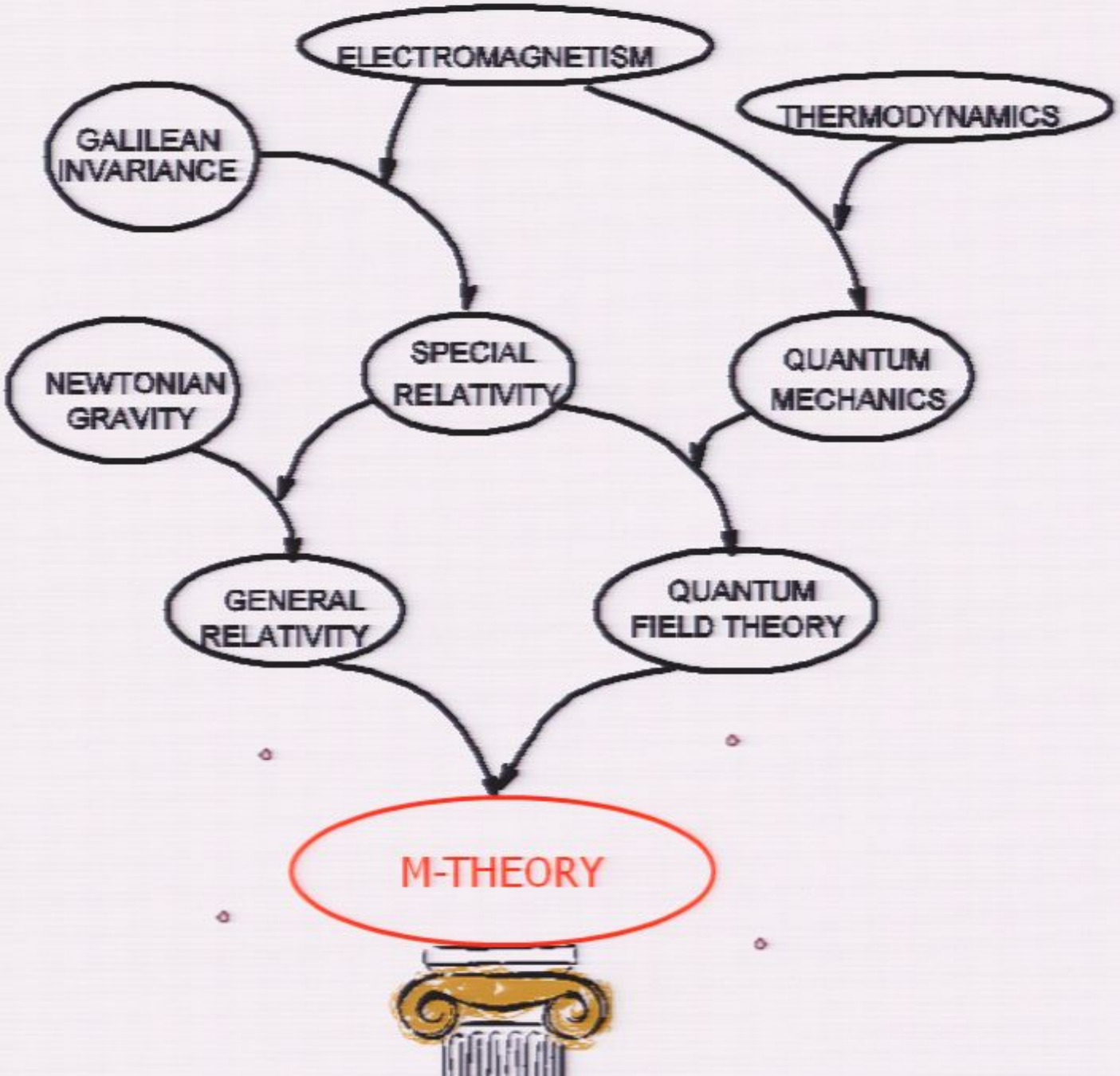

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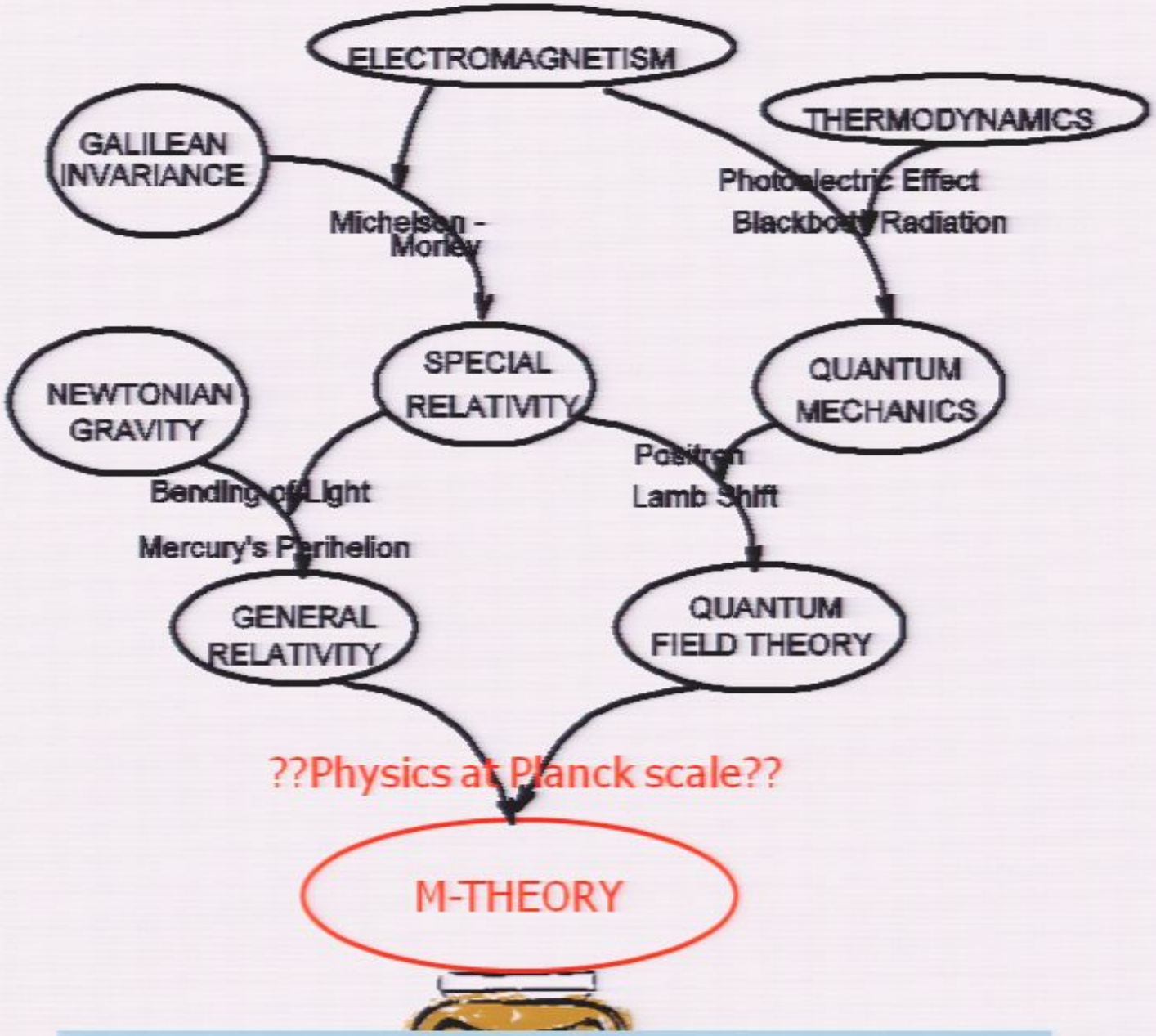
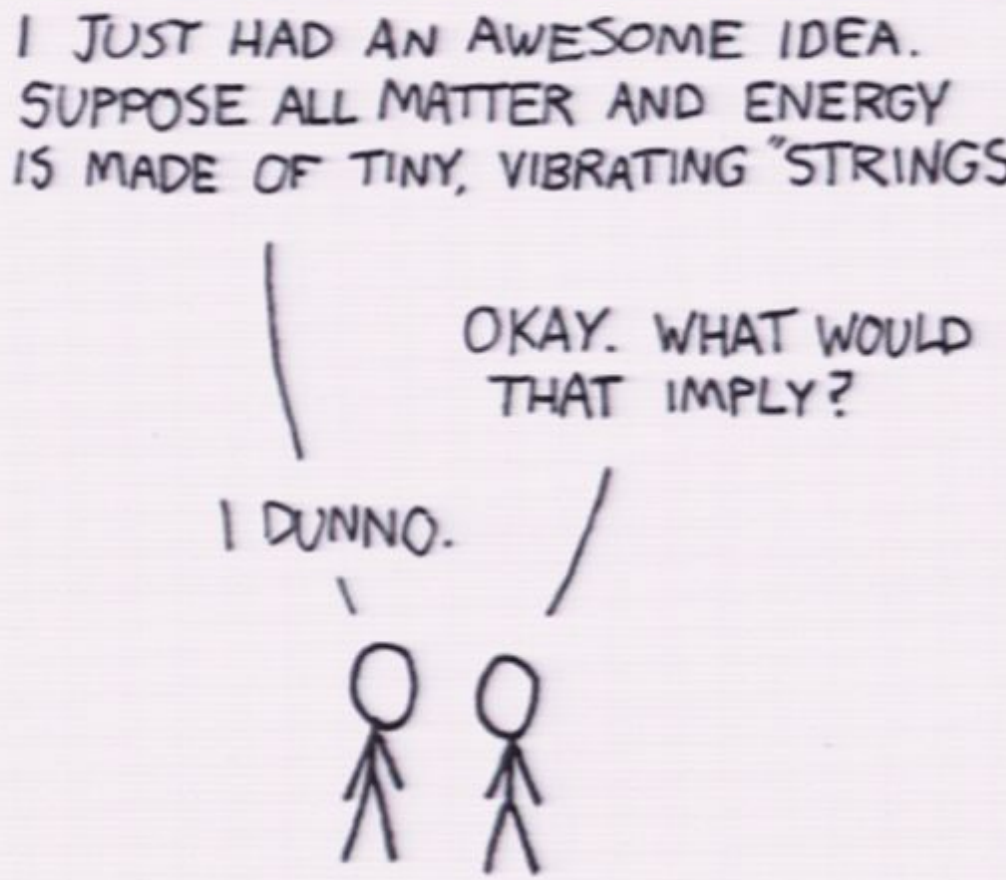


But contact with experiment is crucial

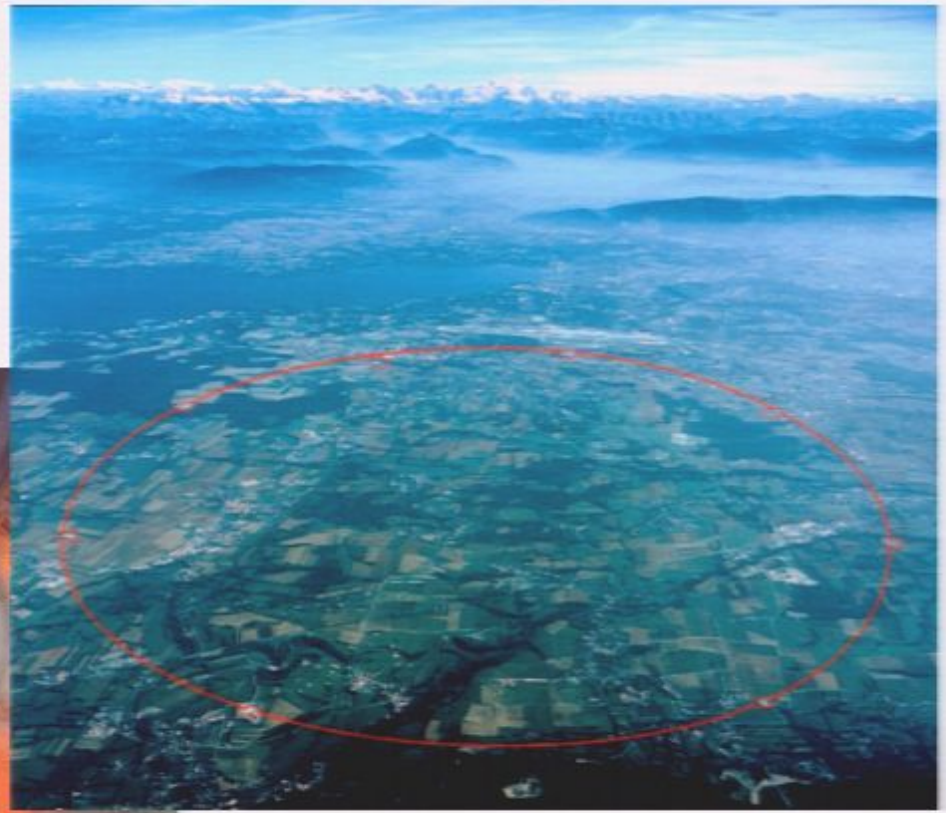
STRING THEORY SUMMARIZED:

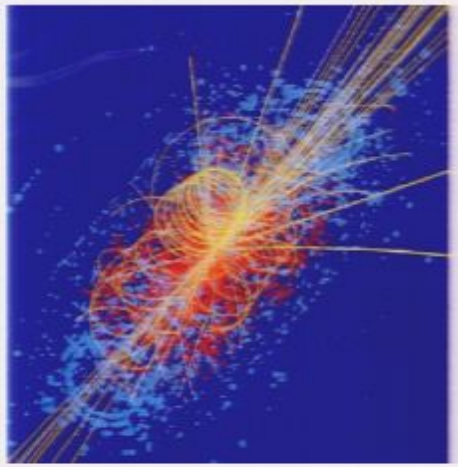


Superstring theory: a theory looking for a good experiment

accelerator experiments: probe 10^{12} eV and beyond

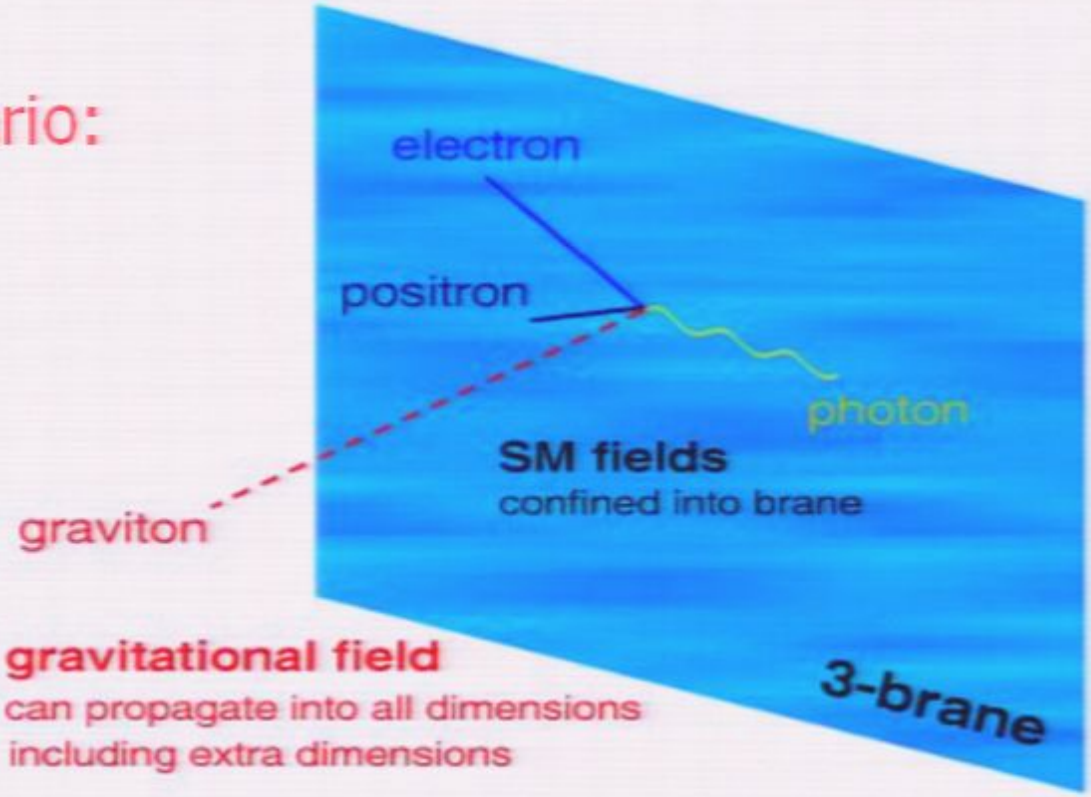
Tevatron, Large Hadron Collider, ...





How far away is the Planck scale really?

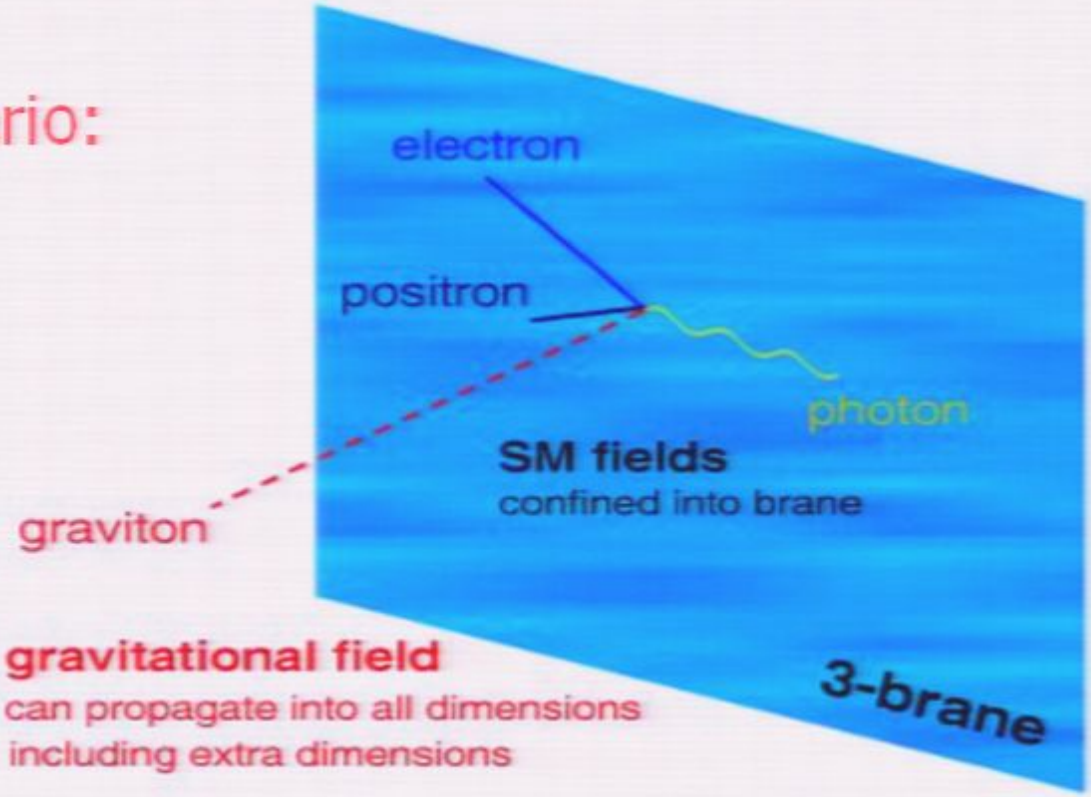
Brane-world scenario:



(Some) Extra dimensions may be very large!

How far away is the Planck scale really?

Brane-world scenario:



(Some) Extra dimensions may be very large!

Advantage: $G_4 = G_{10}/V_6$

How far away is the Planck scale really?

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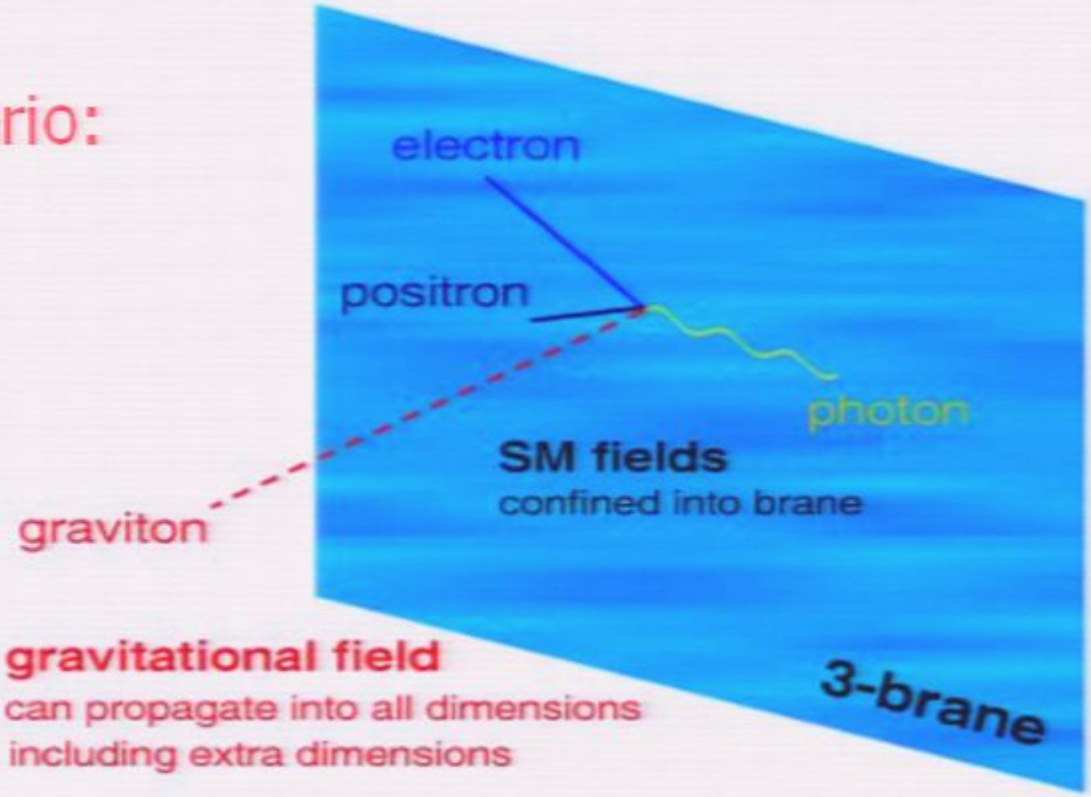


(Some) Extra dimensions may be very large!

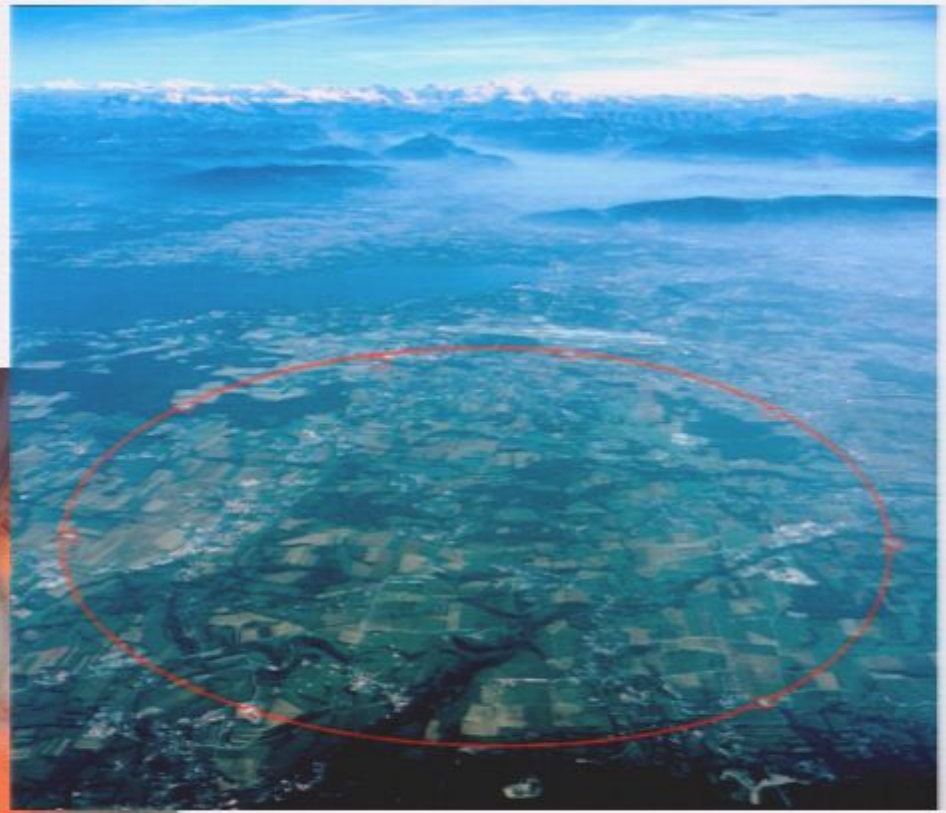
Advantage: $\ell_{P,10}^{8} = V_6 \, \ell_{P,4}^{2}$

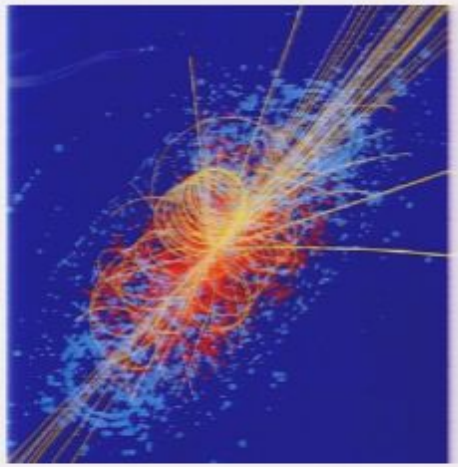
Planck scale may be within reach!!

Superstring theory: a theory looking for a good experiment

accelerator experiments: probe 10^{12} eV and beyond

Tevatron, Large Hadron Collider, ...





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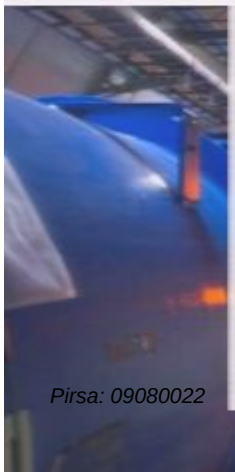
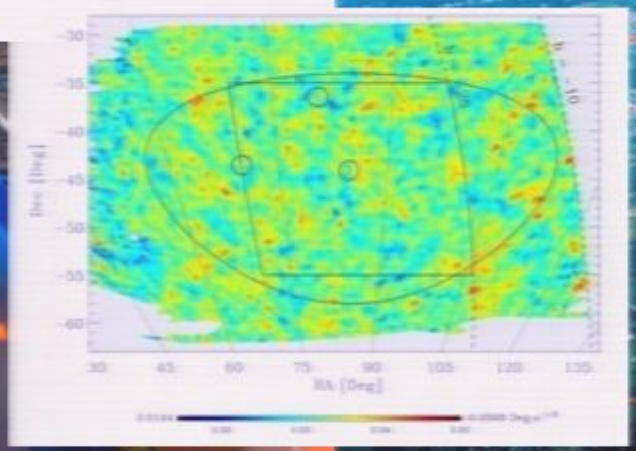
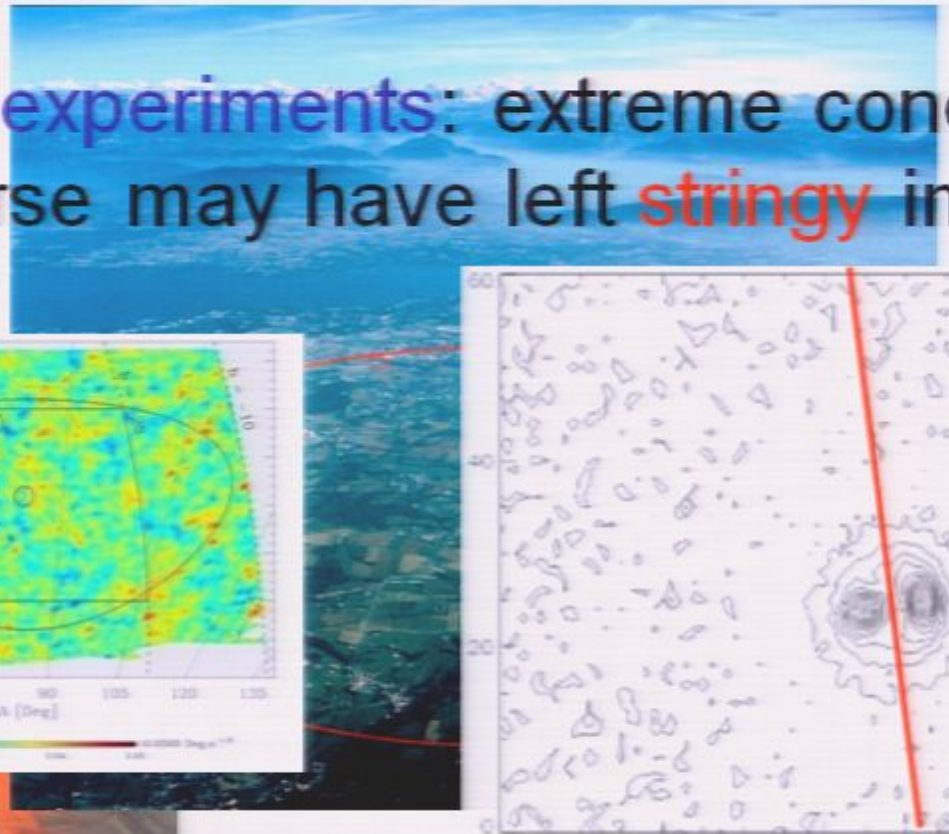
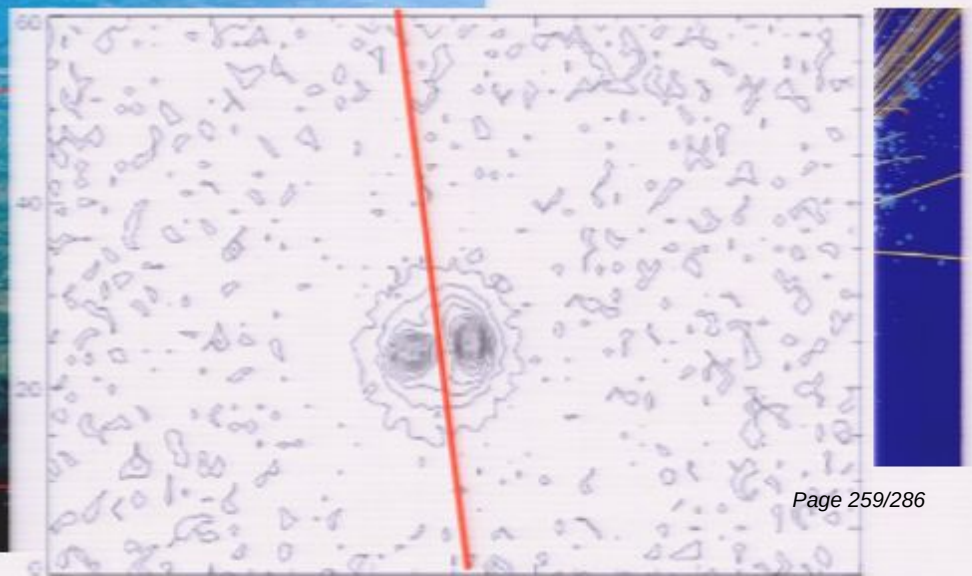
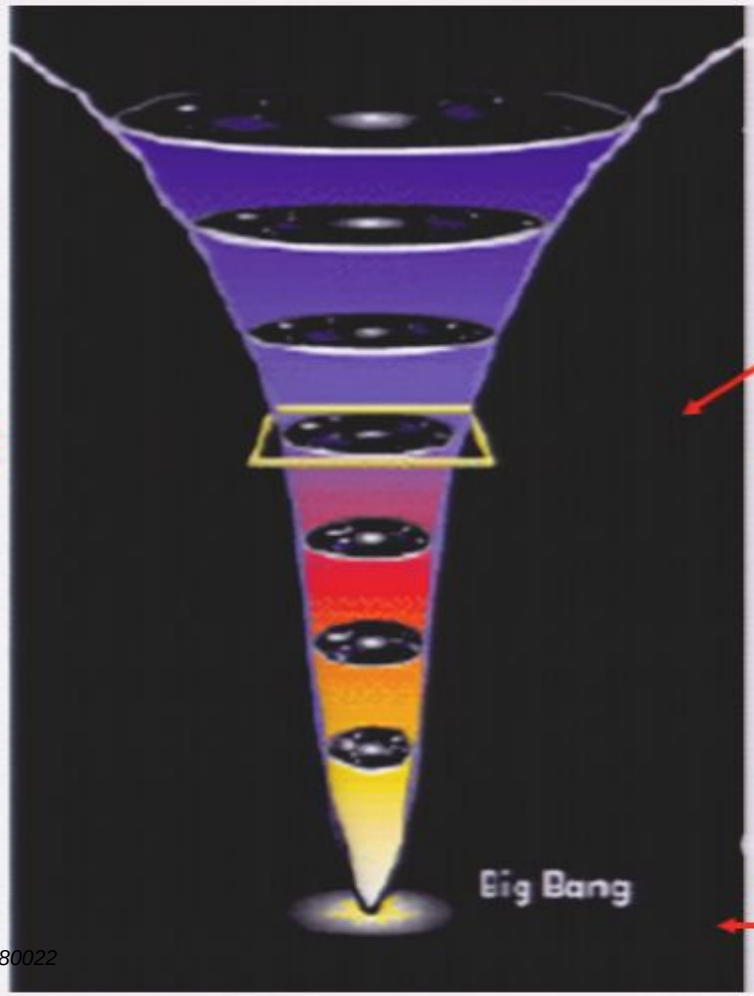








Cosmology: extreme conditions of early universe give a window on small scales and high energies



ıture

esent

Past

Stringy relics or imprints now?

We need to understand the optics of our "microscope"

String physics is manifest

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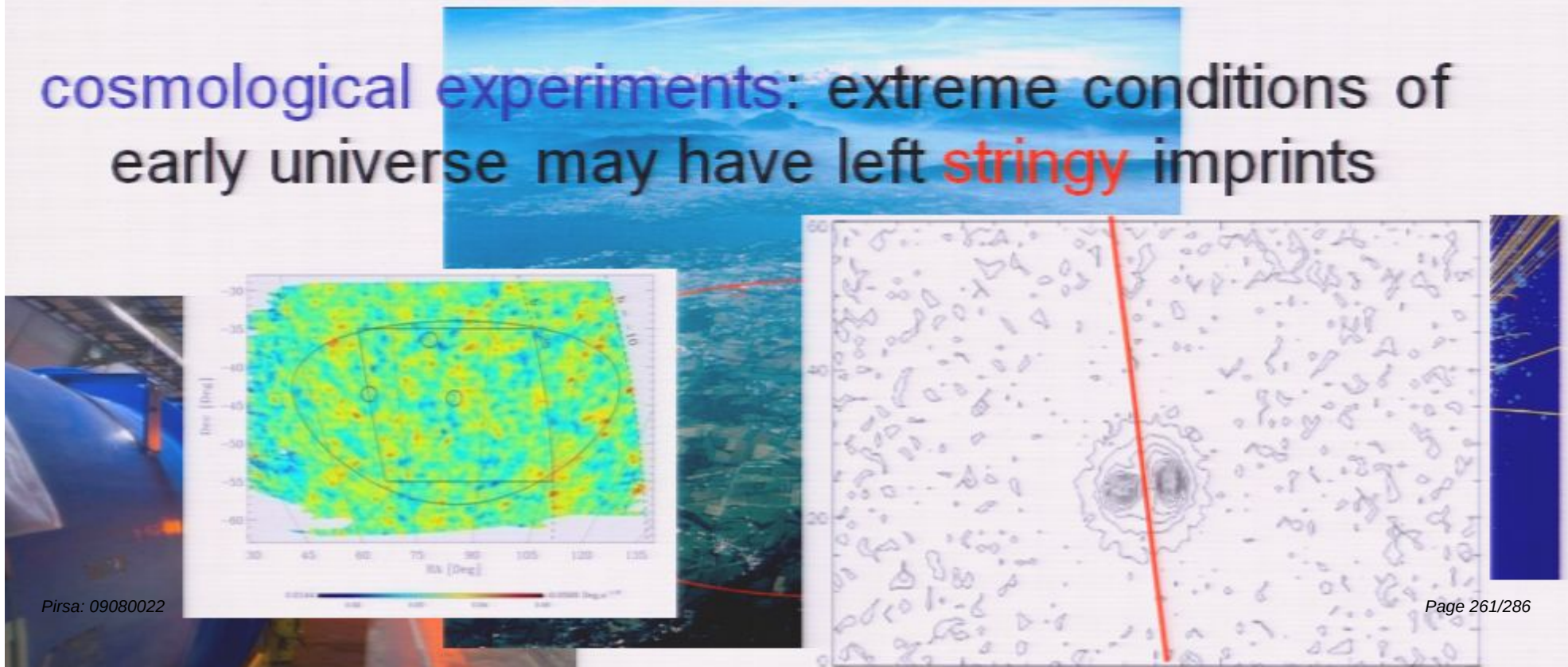

Superstrings:

a mathematical model of our physical universe

Studies of string theory draw upon an enormous range of modern mathematics:

complex analysis, group theory, fibre bundles, gerbes, topology, differential geometry, mirror symmetry, K-theory, derived categories, noncommutative geometry

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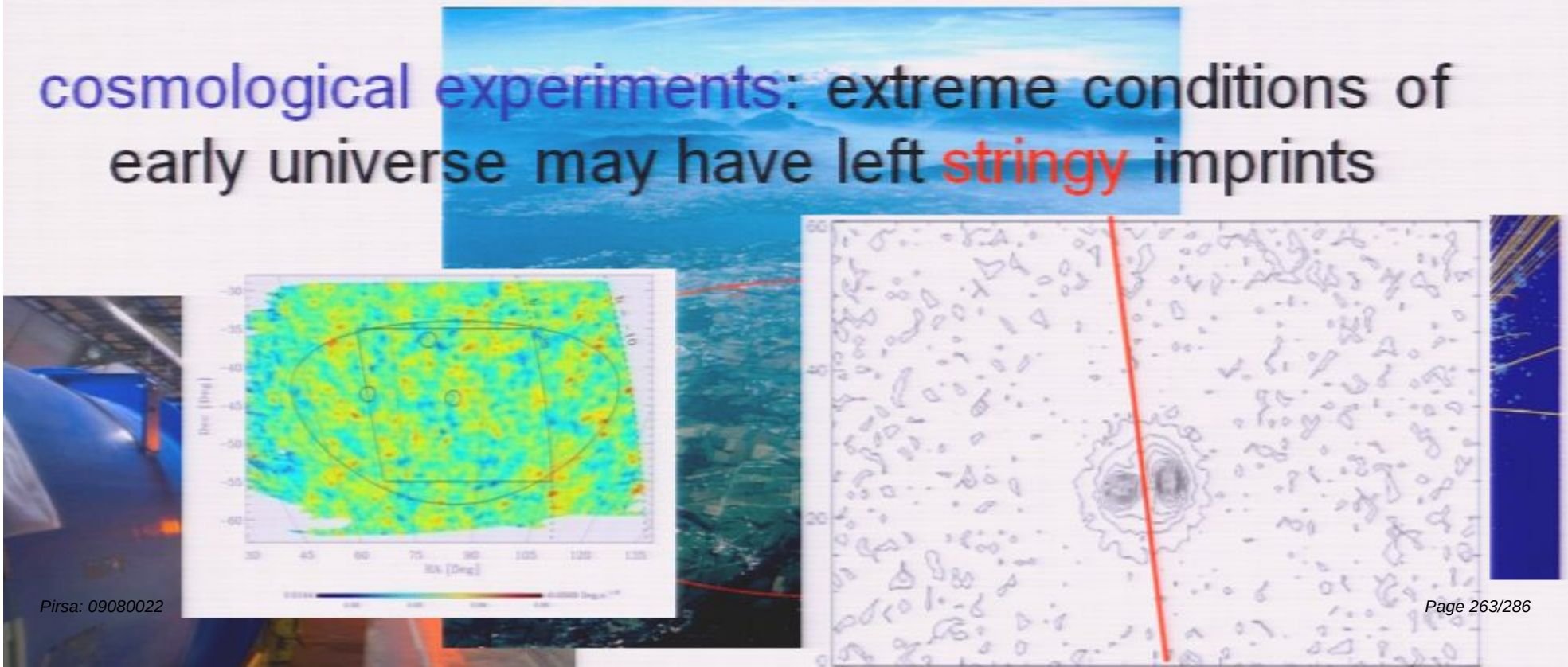

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We are still groping for the language of string theory!

Superstrings:

a mathematical model of our physical universe

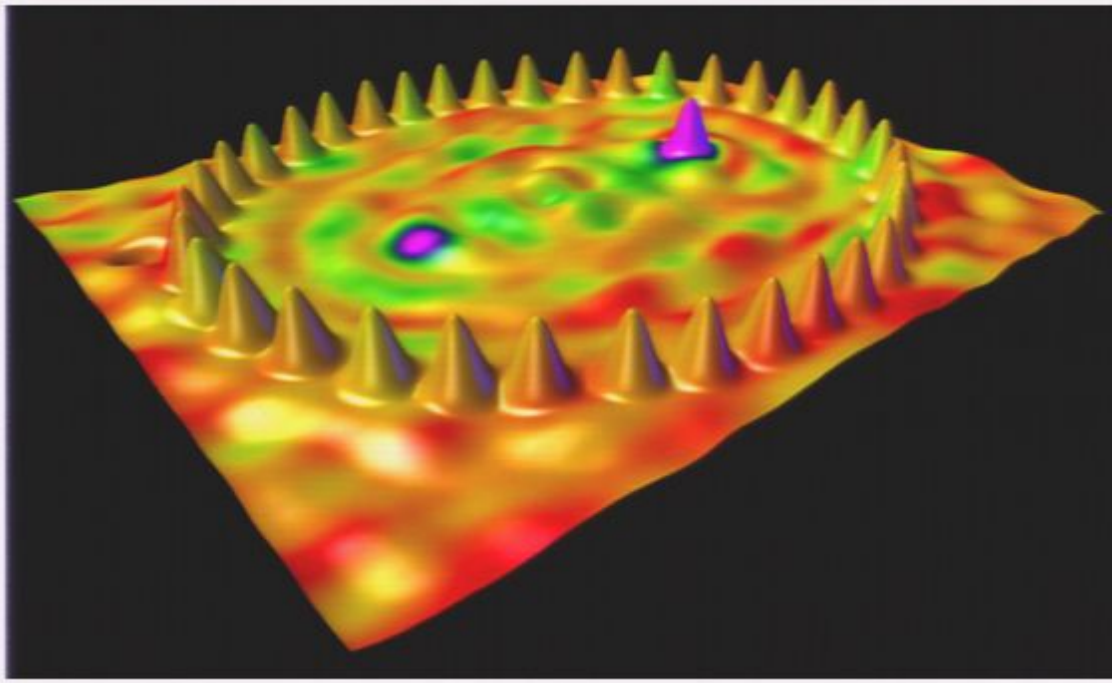
We are still searching for the full picture!

early 1900's –

Ernst Mach: "atoms are physically unverifiable entities"

early 1990's –

individual atoms are manipulated using atomic force microscopy



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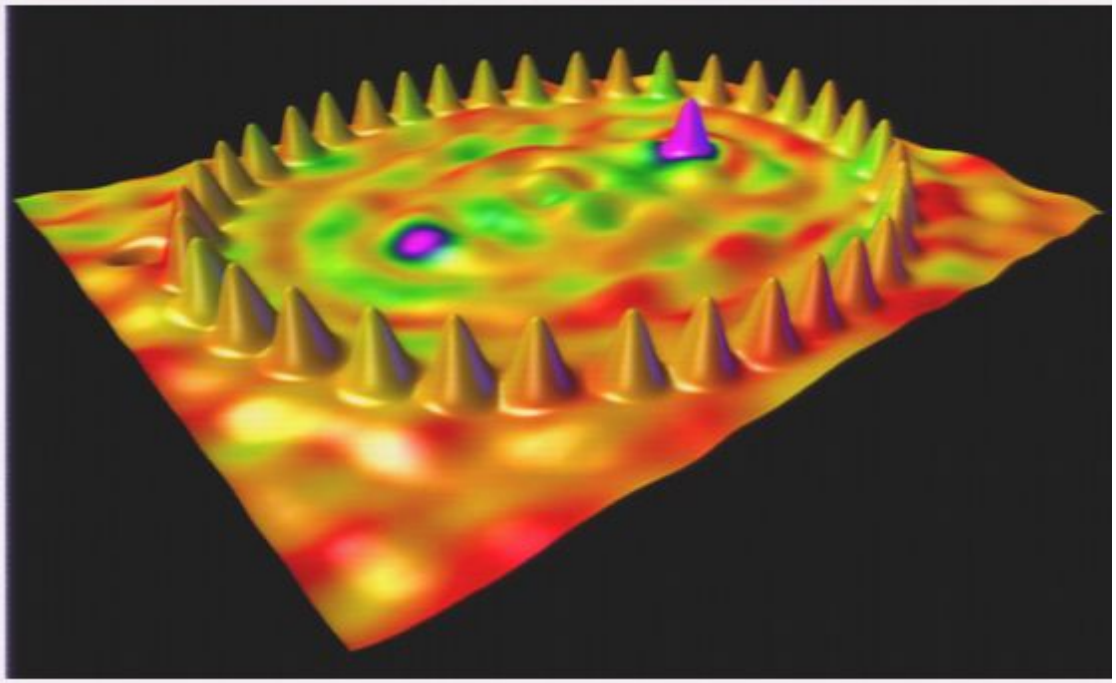


For superstrings,
the adventure is still only beginning!

More strings on the web:

"The Elegant Universe"
Brian Greene
http://www.pbs.org/wgbh/nova/elegant/

Superstrings!
http://www.sukidog.com/jpierre/strings/

The Official String Theory Web Site:
http://superstringtheory.com/

"It's the 21st century—
time to feed your brain!"

Essential ingredients for M-theory conjecture:

- Dualites: two mathematical descriptions describe identical physical phenomena

Eg, T-duality relates large and small circle compactifications

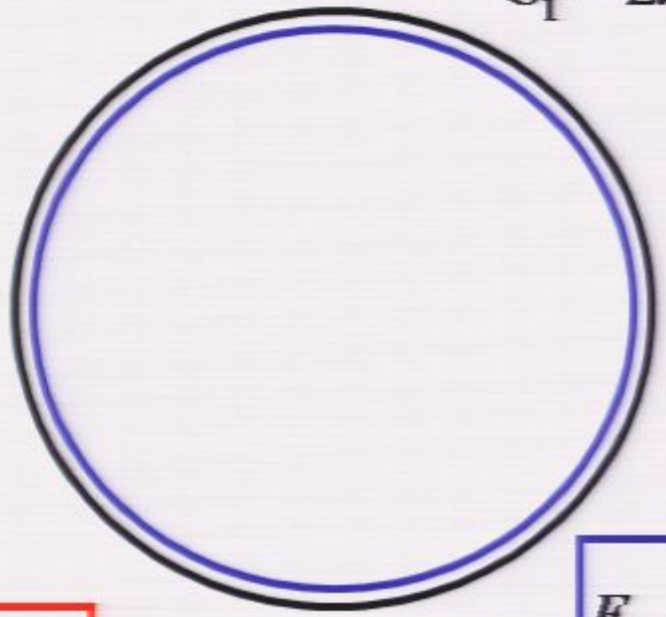
$$C_1 = 2\pi R$$

$$C_2 = \frac{2\pi \ell_s^2}{R}$$

String winding modes!!

$$E_w = mTC$$

$$= m \frac{1}{2\pi \ell_s^2} 2\pi R$$



$E_p = \frac{n}{R}$

$E_w = m \frac{R}{\ell_s^2}$

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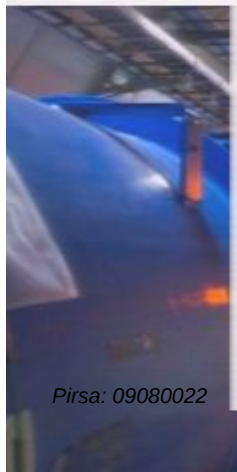
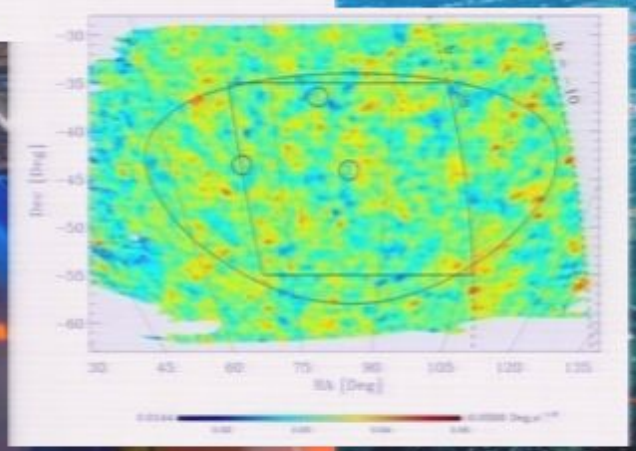
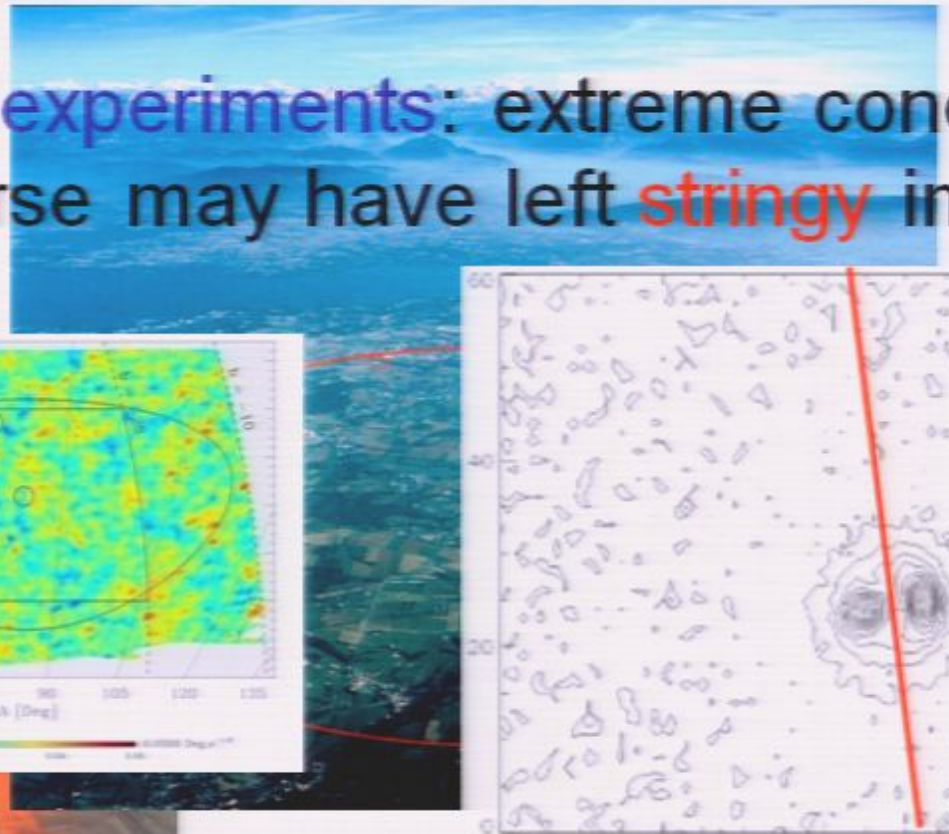
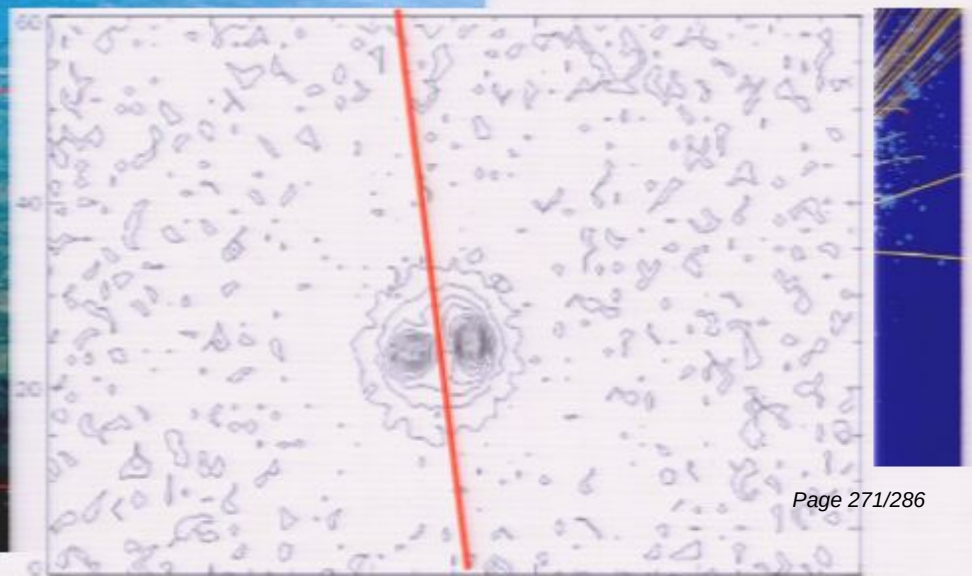


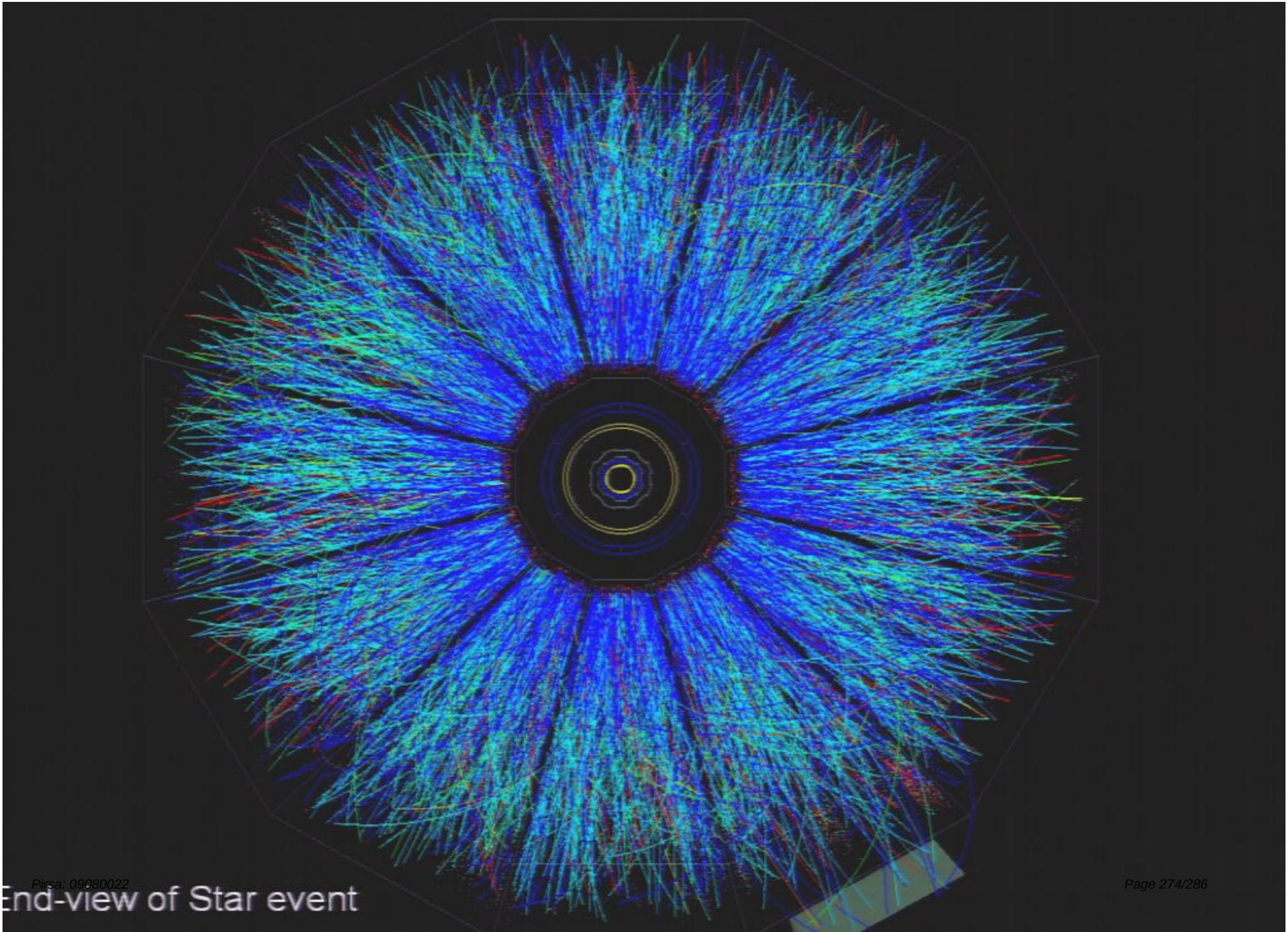


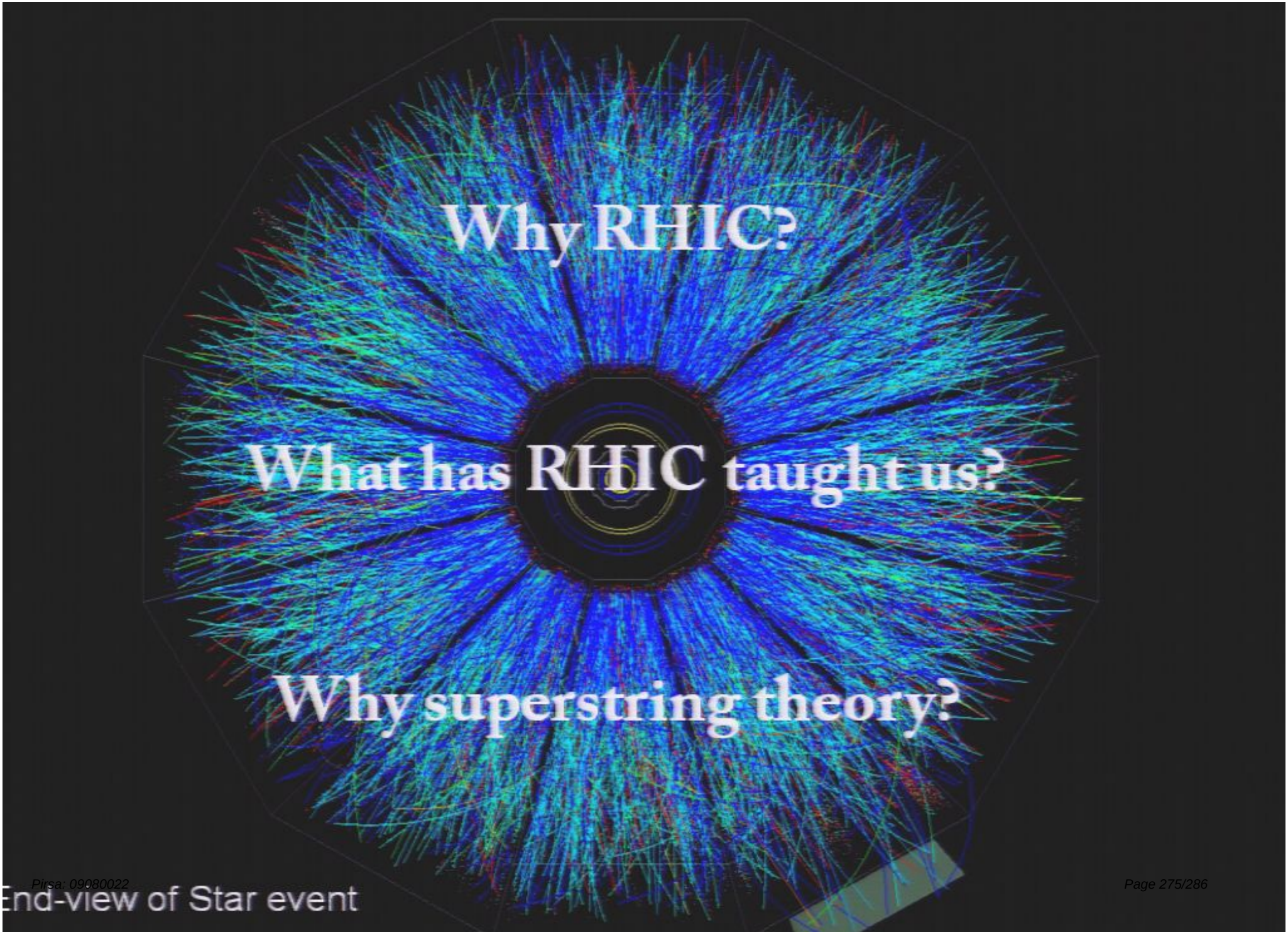




String theory: a rich source of new ideas

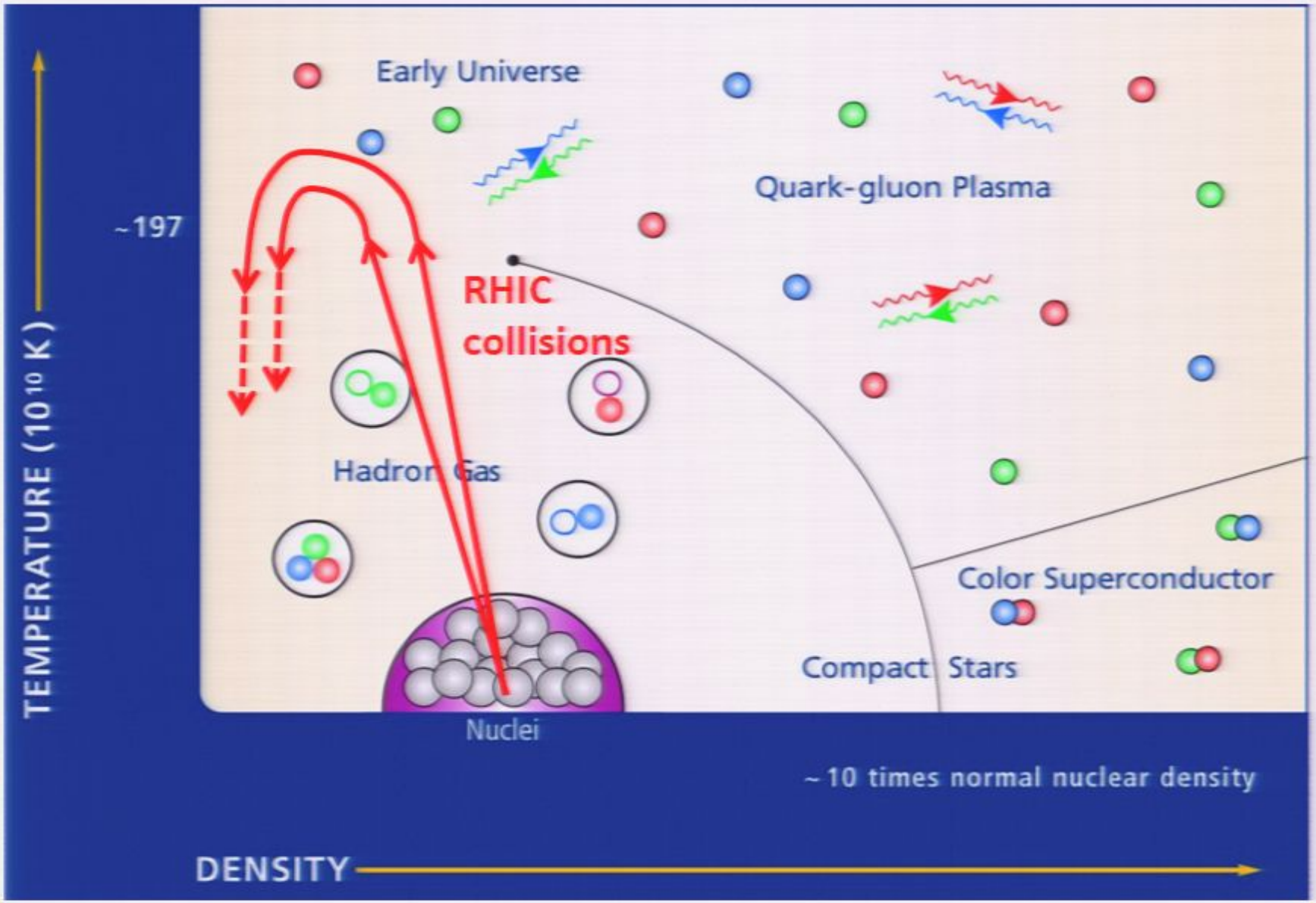
Traffic
Map
Satellite
Hybrid
RHIC
relativistic heavy ion collider
Brookhaven National Laboratory
200 m


End-view of Star event

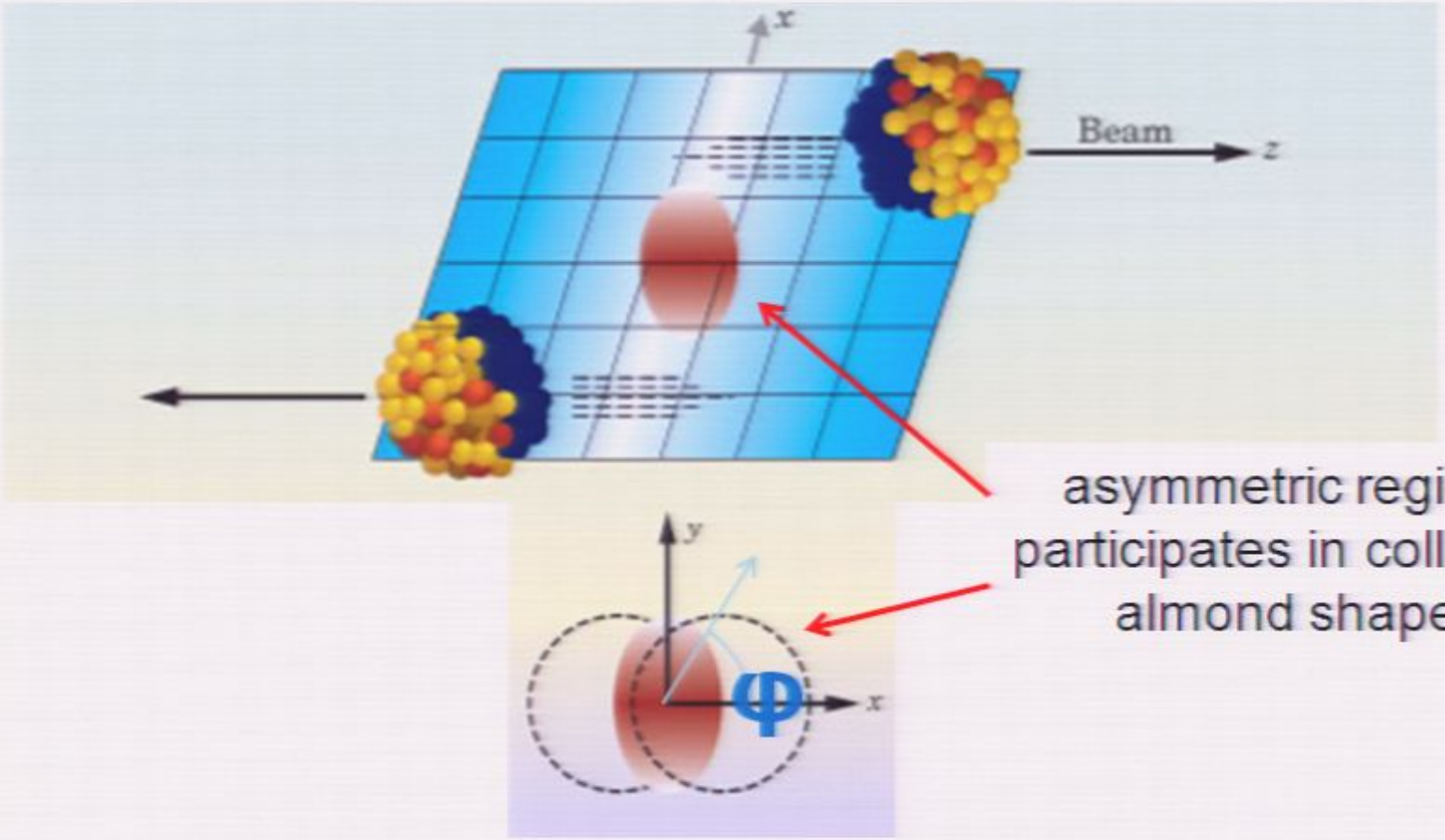


End-view of Star event

QCD Phase Diagram (according to theorists):



Elliptic flow: consider collision which is not head-on



asymmetric region participates in collision; almond shape

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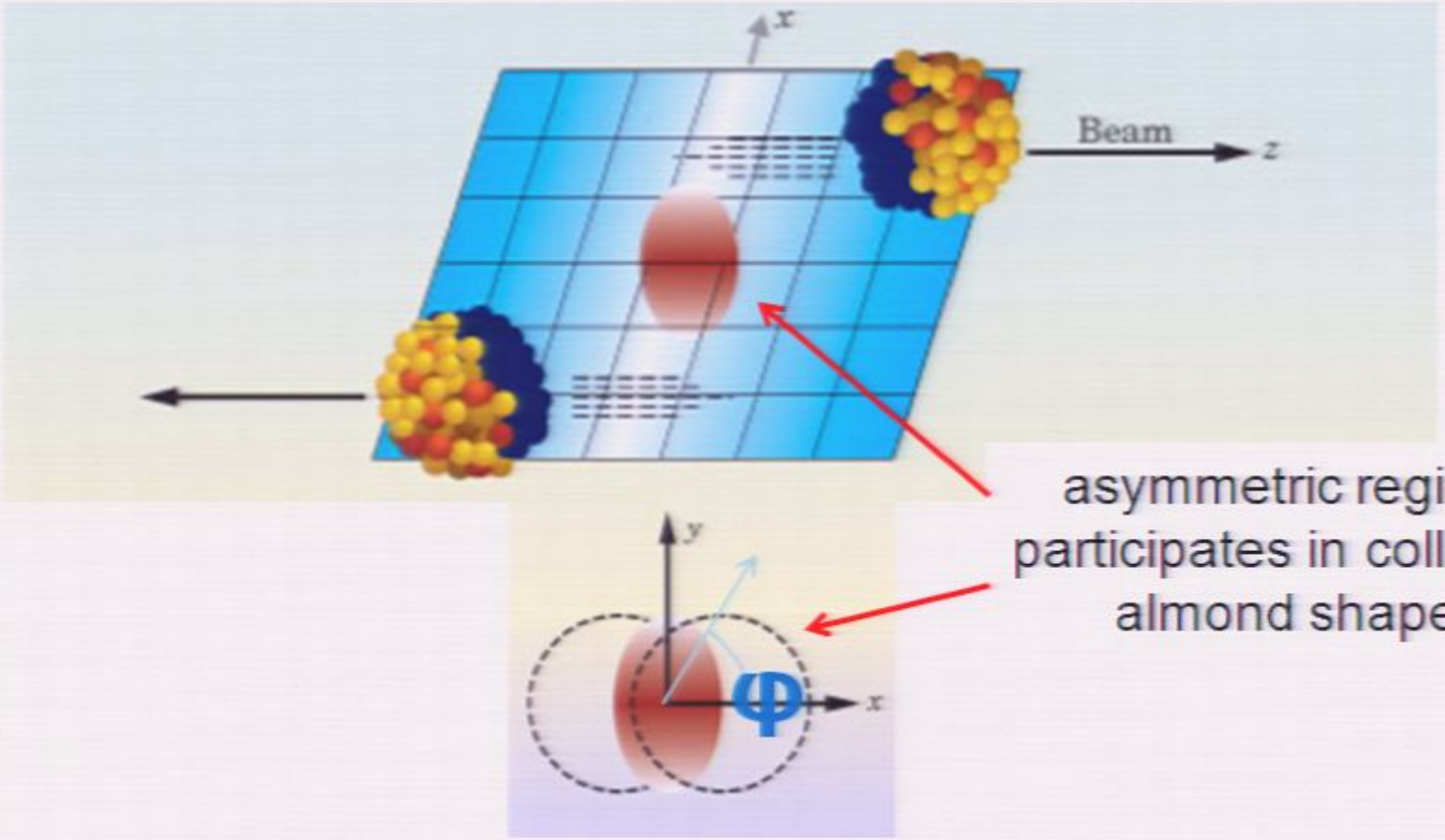

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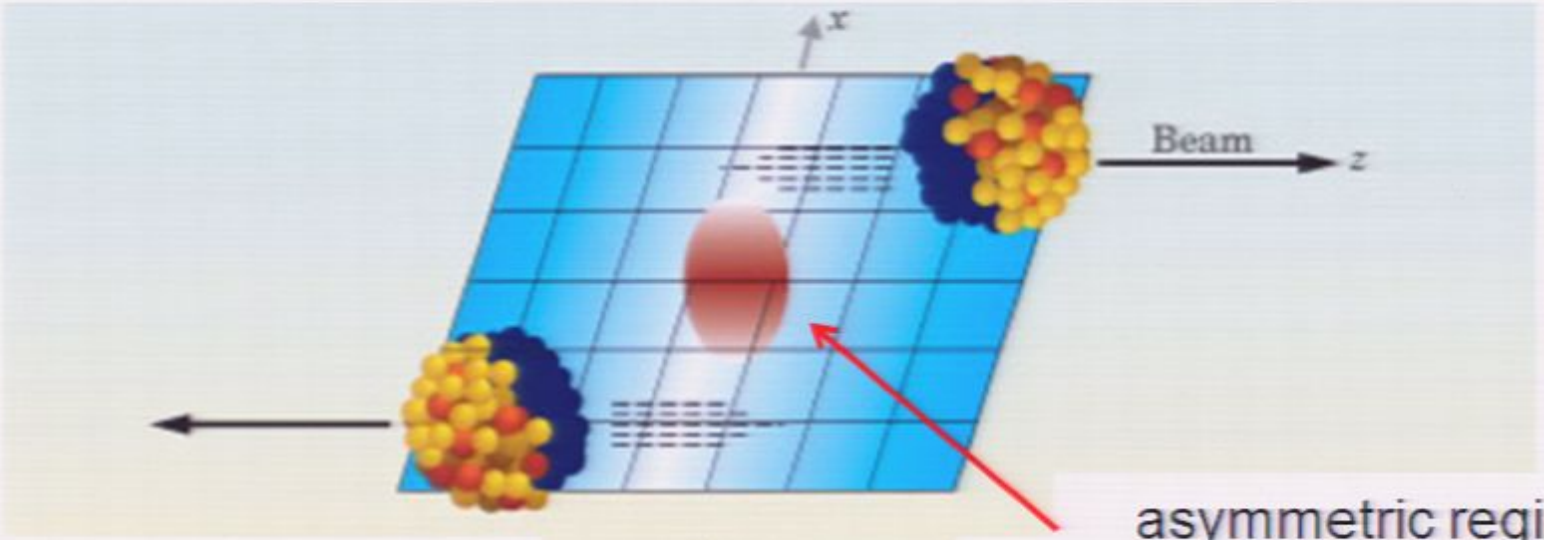

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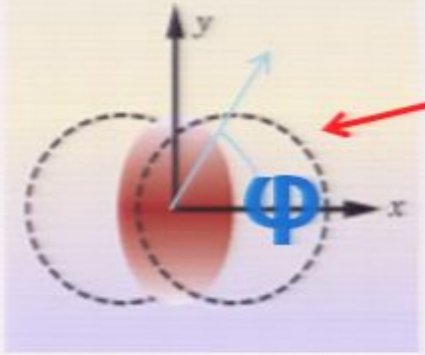

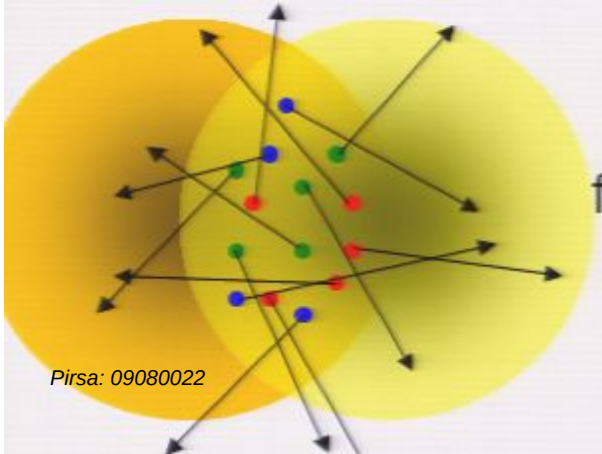

free-streaming particles emerge uniformly in φ

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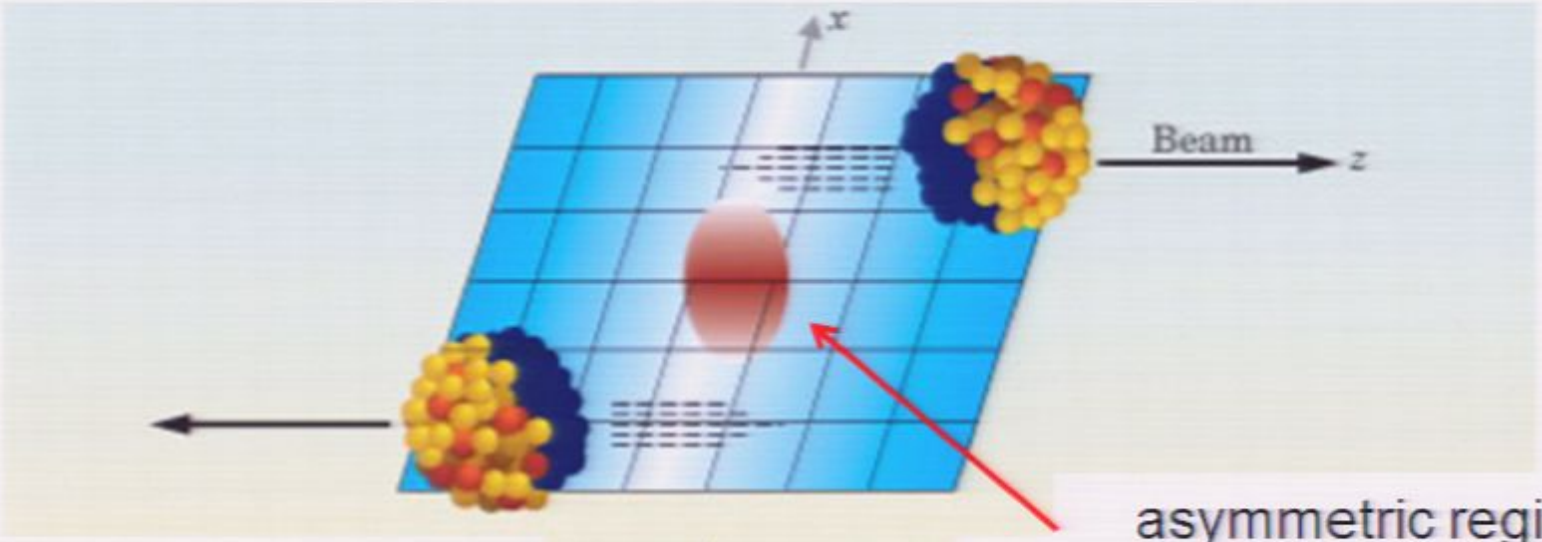

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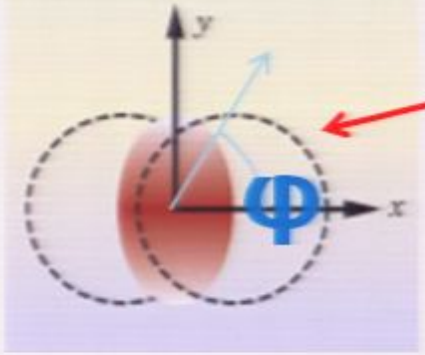
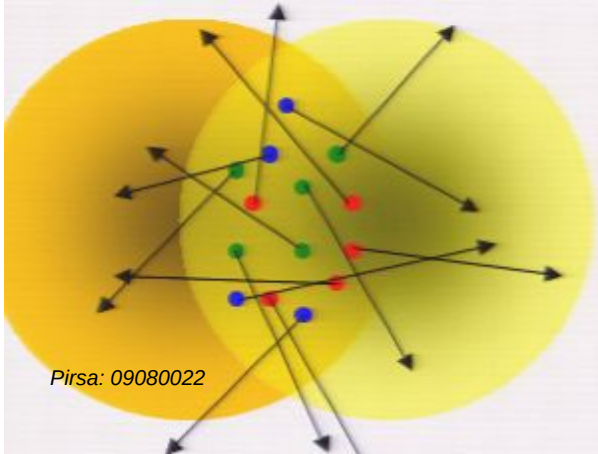
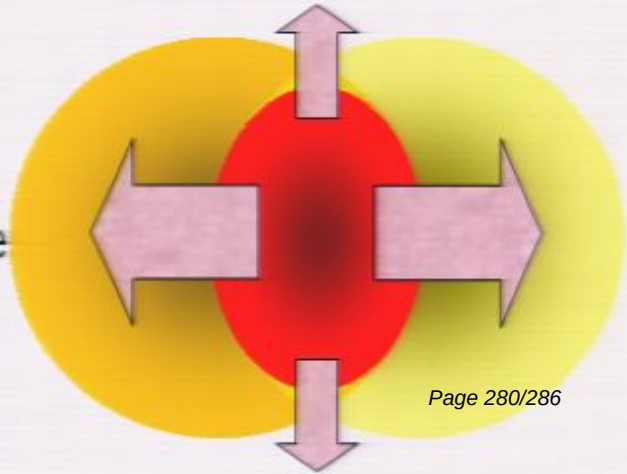




Collective flow: pressure gradients generate nonuniform distribution

$$v_2 \sim \langle \cos 2\phi \rangle \neq 0$$



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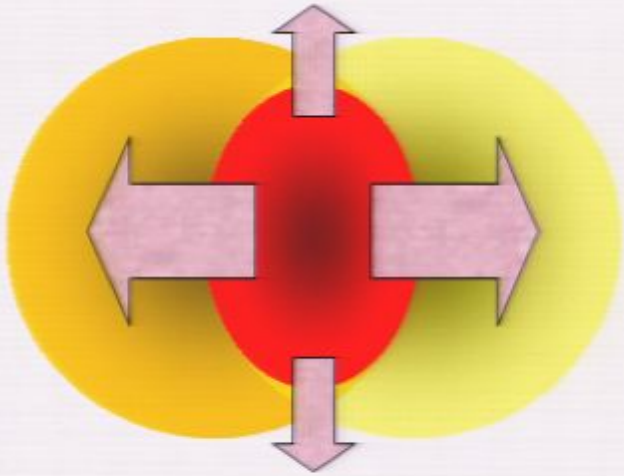

→ fluid behaviour

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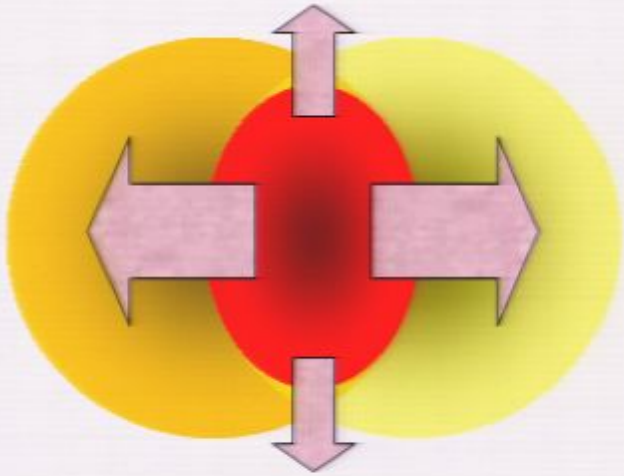

→ "**near ideal** fluid"

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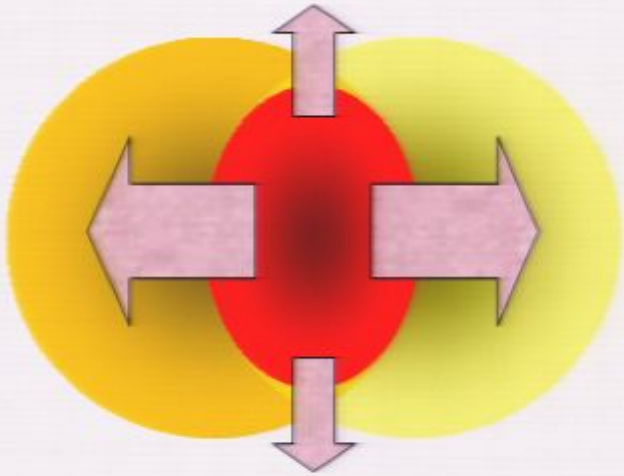

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Data also indicates Shear Viscosity η is small!

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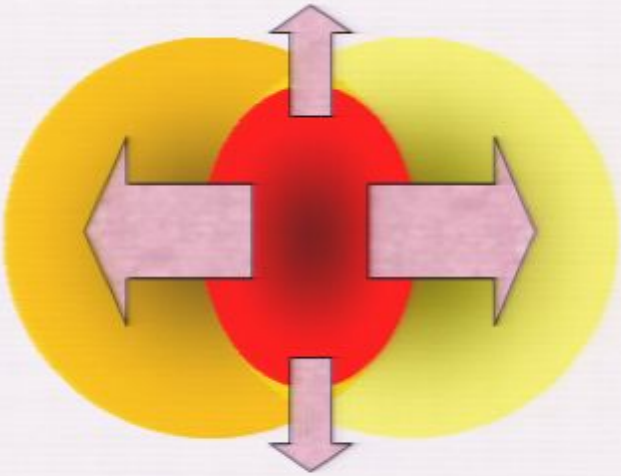

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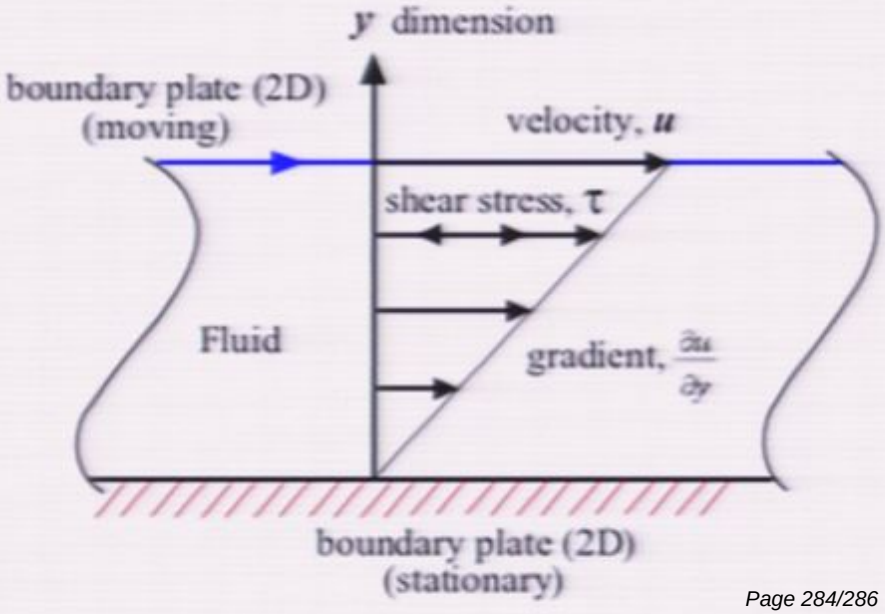
$$\tau = \eta \frac{\partial u}{\partial y}$$



large shear viscosity would even out flow and produce uniform distribution

Surprise: Just above critical temperature, quark-gluon plasma behaves like a **near ideal fluid** with:

$$\eta/s \simeq .08 - .16$$

Theoretical challenge: **both** perturbative analytic and computer techniques fail for strong-coupling dynamics!

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Surprise 2: using techniques emerging from string theory, Kovtun, Son & Starinets found:

$$\frac{\eta}{s} = \frac{1}{4\pi} \sim 0.08 \quad \textbf{!!}$$