

Title: A Night with Nobel - The Origin of Mass and the Feebleness of Gravity

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Abstract: Einstein's famous equation $E=mc^2$ asserts that energy and mass are different aspects of the same reality. It is usually associated with the idea that small amounts of mass can be converted into large amounts of energy. For fundamental physics, however, the more important idea is just the opposite. Researchers want to explain how mass itself arises, by explaining it in terms of more basic concepts. In this lecture targeted for a general audience, Prof. Wilczek will explain how this goal can, to a remarkable extent, be achieved. He will also discuss some of the consequences - an explanation of why gravity is so feeble - and suggestions for new physical phenomena at the Large Hadron Collider (LHC) in Geneva. Prof. Wilczek is a distinguished scientist and lecturer. He is the author of *Fantastic Realities: 49 Mind Journeys* and a trip to Stockholm and co-author of *Longing for the Harmonies*. In addition to many distinguished memberships and affiliations, he is a member of Perimeter Institute's Scientific Advisory Committee. <kw> </kw>



Photo: Judith Knight Photography

**Prof. Frank
Wilczek**
*MIT and 2004 Nobel
Laureate*

***The Origin of
Mass and the
Feebleness of
Gravity***

The Origin of Mass

Mass Without Mass?

Mass Without Mass?

Not in Newtonian mechanics!

Mass Without Mass?

Not in Newtonian mechanics!

Einstein's second law: $m = E/c^2$

What Matters for Matter

What Matters for Matter

mass is mostly in atomic nuclei

What Matters for Matter

mass is mostly in atomic nuclei

nuclei are made from protons and neutrons

What Matters for Matter

protons and neutrons are made from
quarks and gluons

What Matters for Matter

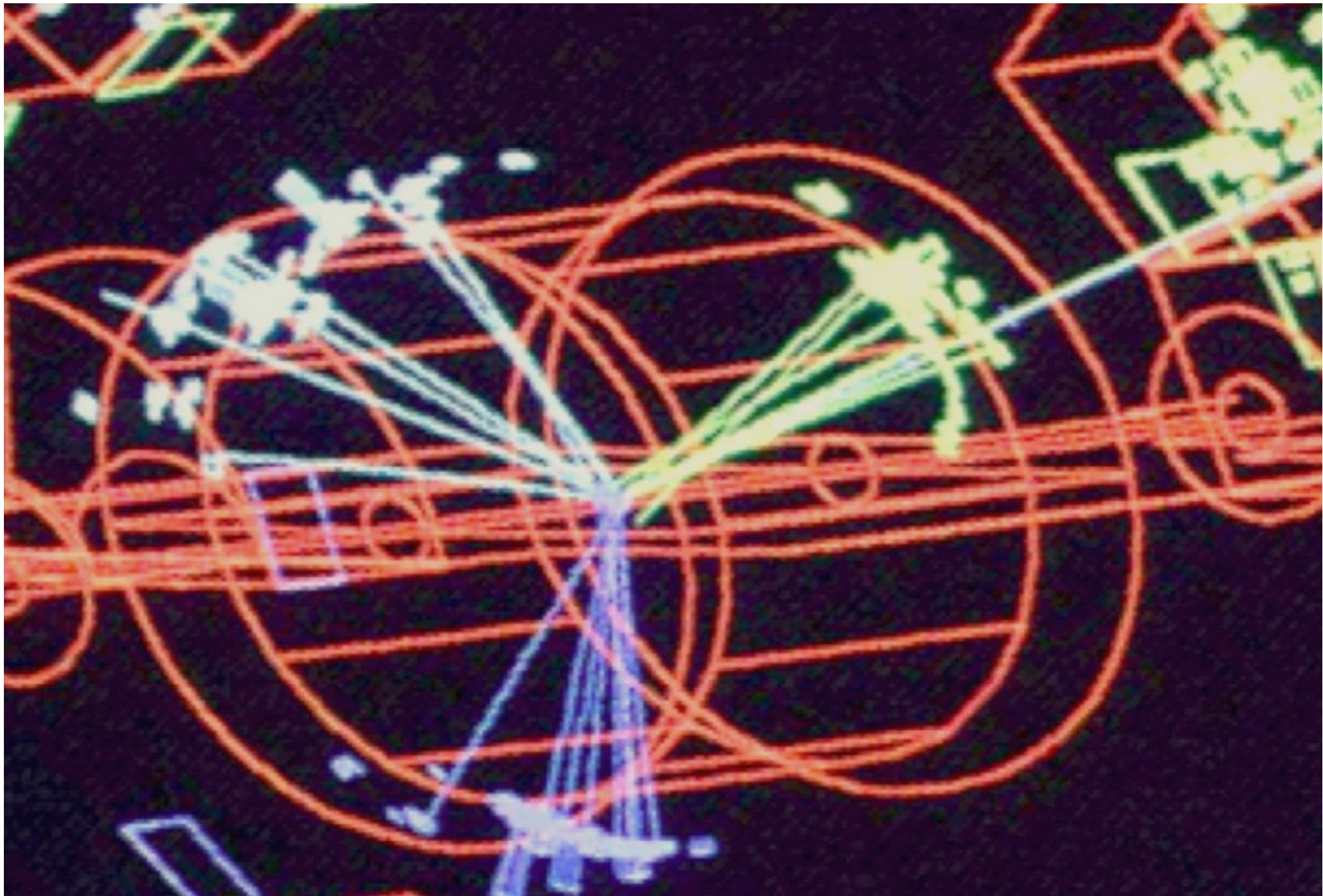
protons and neutrons are made from
quarks and gluons

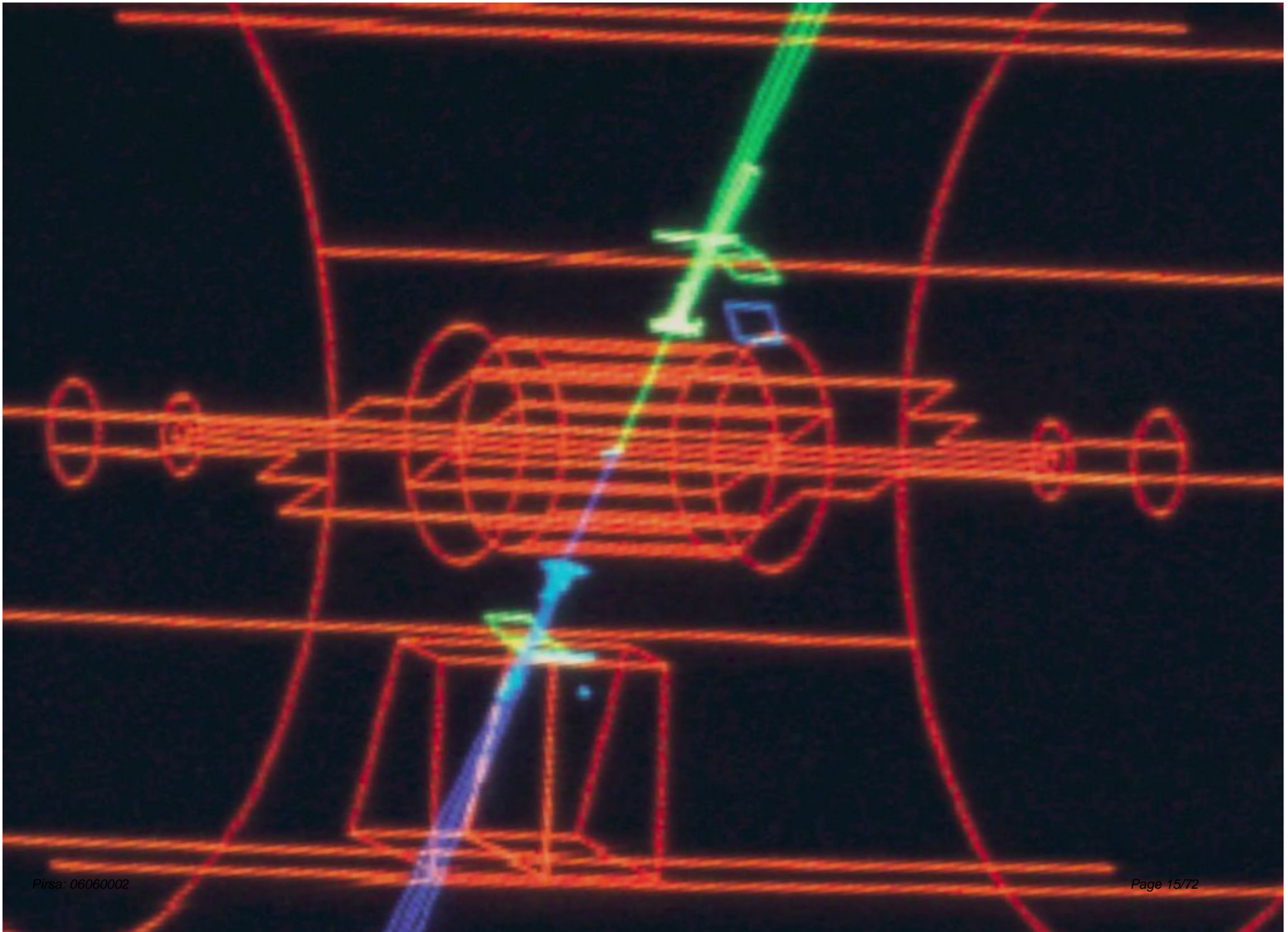
we have a marvelous theory for quarks and gluons

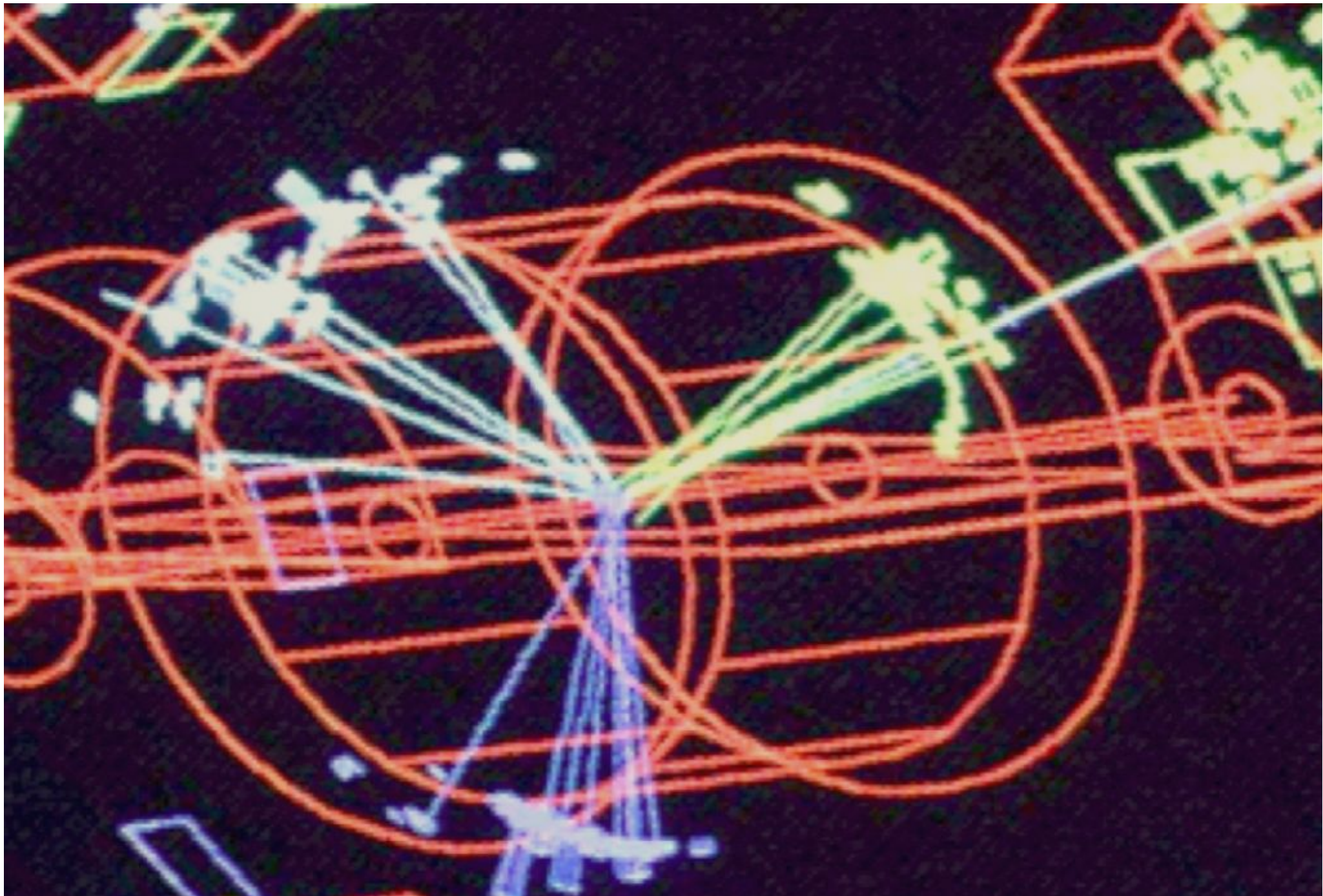
How Do We Know?

How Do We Know?

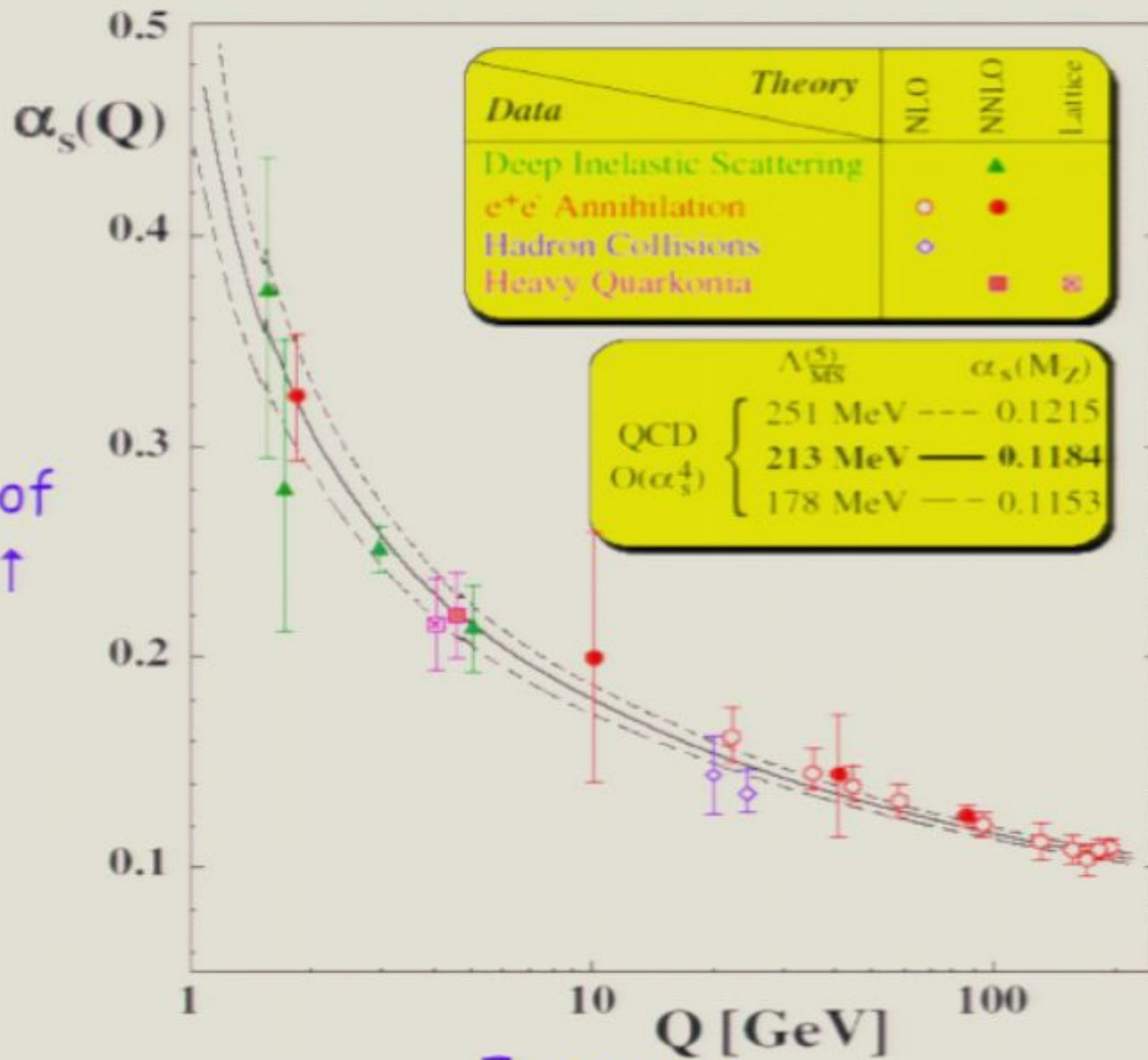
Aren't quarks and gluons elusive, ghostly things?







Strength of
Coupling \uparrow



Energy \rightarrow
 \leftarrow Distance

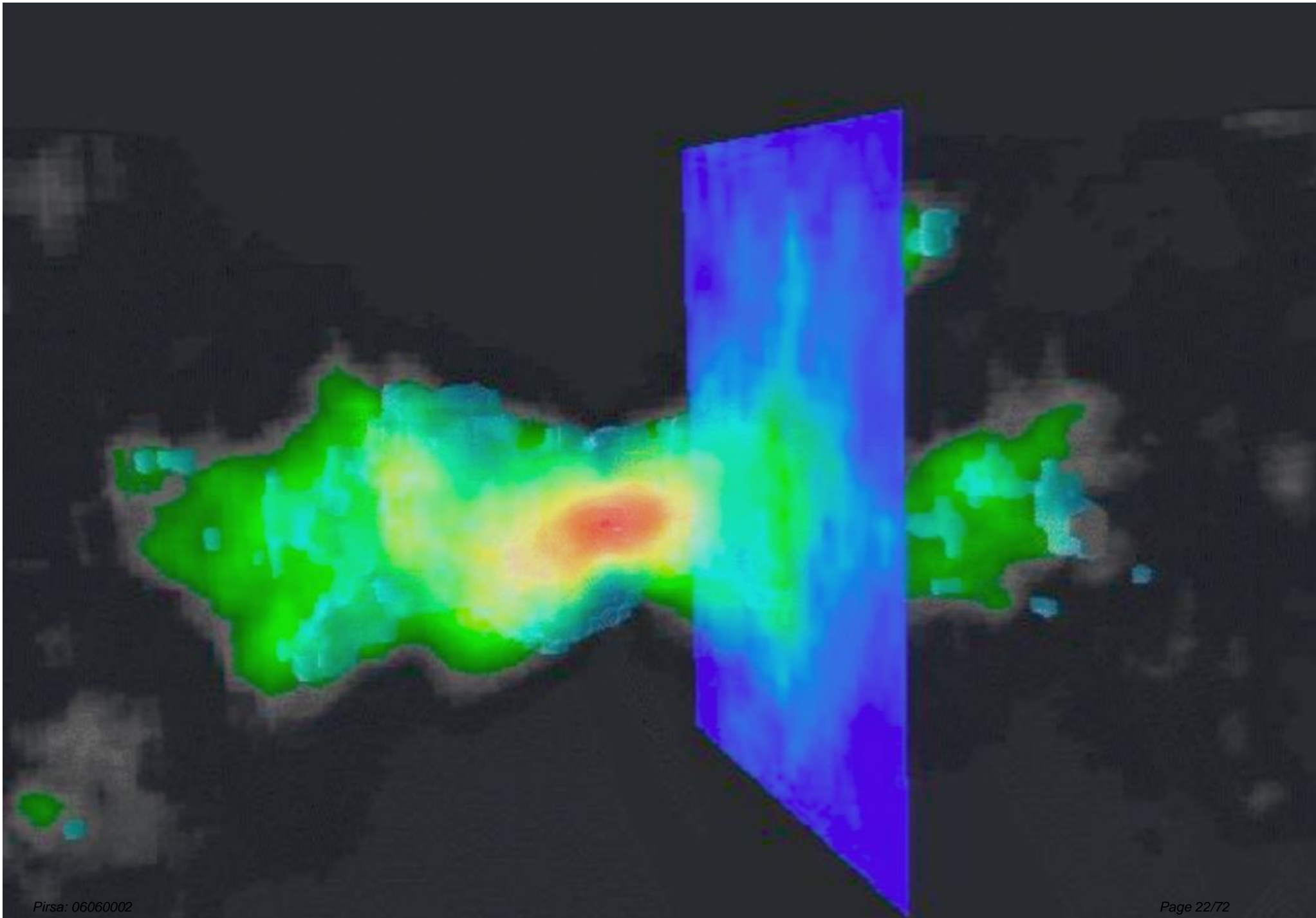
How does it happen?

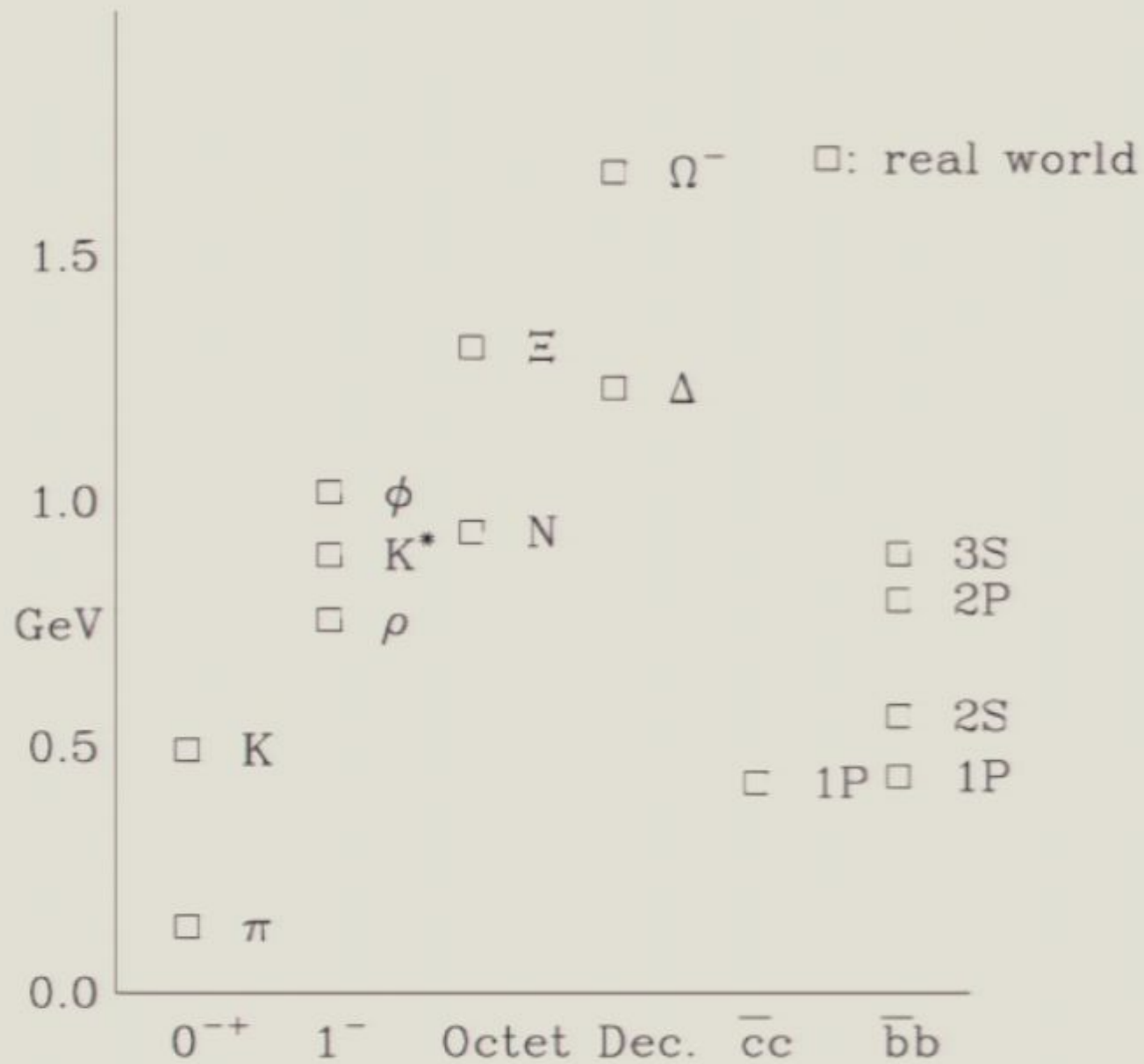
How does it happen?

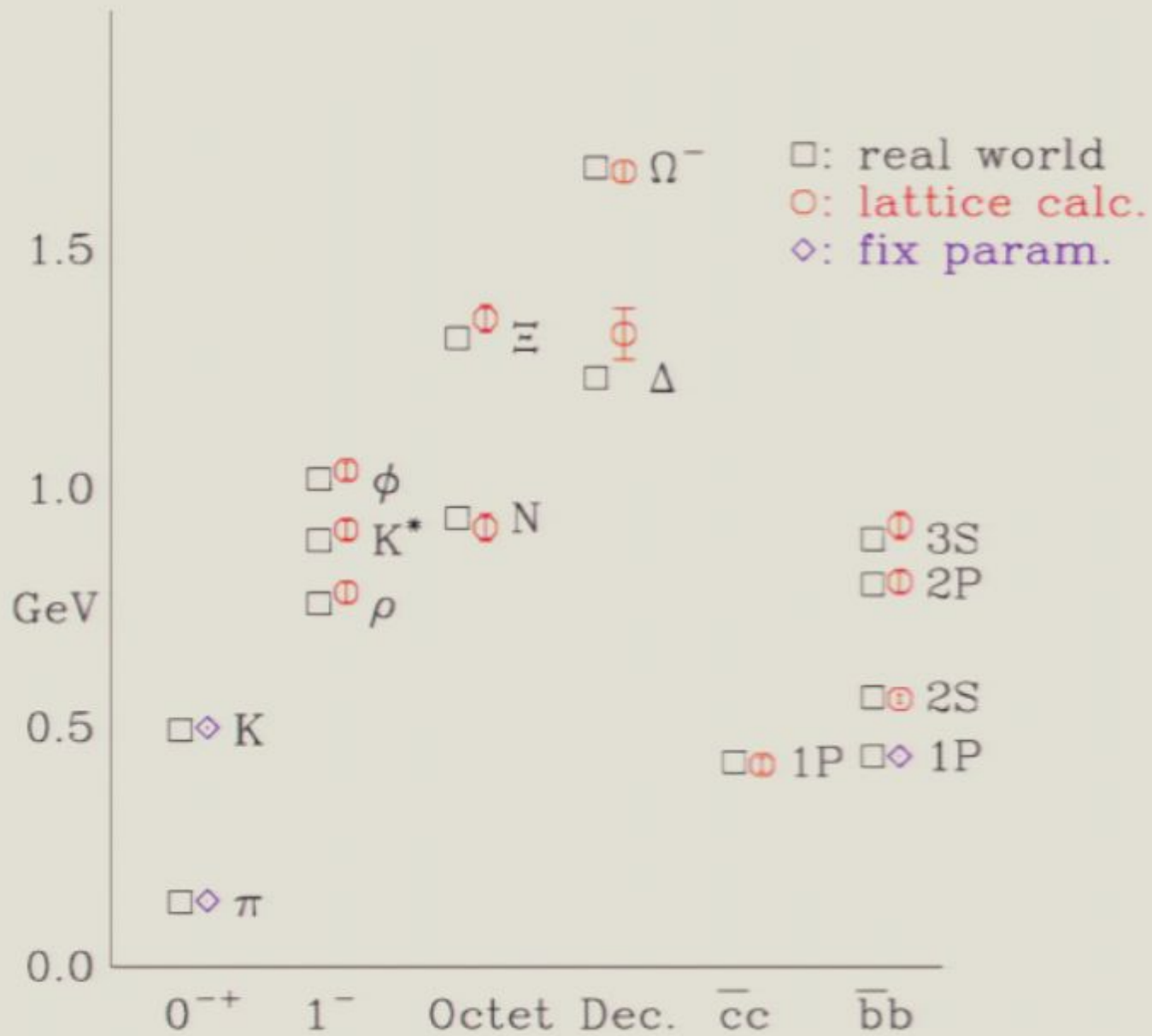
We learn that what appears to us
as empty space is in reality a wildly
dynamical medium.

Can we really make heavy nucleons from nearly massless quarks and strictly massless gluons (and nothing else)??

The different particles we observe must correspond to the vibration-patterns that occur in this dynamical Void, when it is disturbed in various ways.







Ingredients of QCD*

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massless gluons

Ingredients of QCD*

massless gluons

massless u, d quarks

Ingredients of QCD*

massless gluons

massless u, d quarks

nothing else

Ingredients of QCD*

massless gluons

massless u, d quarks

nothing else

*(Lite)

Ingredients of QCD*

massless gluons: this is automatic, and exact

massless u, d quarks

nothing else

*(Lite)

Ingredients of QCD*

massless gluons: this is automatic, and exact

massless u, d quarks: this is a slight idealization

nothing else

*(Lite)

Ingredients of QCD*

massless gluons: this is automatic, and exact

massless u, d quarks: this is a slight idealization

nothing else: also a slight idealization

*(Lite)

The Origin Of Mass

(Most)
The Origin Of Mass

(Most) The Origin Of [^]Mass

Quark Charges Generate Costly Disturbances, That We'd
Better Cancel

(Most) The Origin Of [^]Mass

Quark Charges Generate Costly Disturbances, That We'd
Better Cancel

But They're Wavy, and Resist Precise Localization

(Most) The Origin Of [^]Mass

Stable Patterns of Equilibrium:
"The Highest form of Musicality"

Waxing Poetic

Waxing Poetic

$$m = E/c^2 = h\nu/c^2 \Leftrightarrow \nu = mc^2/h$$

Waxing Poetic

$$m = E/c^2 = h\nu/c^2 \Leftrightarrow \nu = mc^2/h$$

"Music of the Spheres" \rightarrow Music of the Void

The Feebleness of Gravity

Gravity is Feeble!

Gravity is Feeble!

Force Comparisons

Gravity is Feeble!

Force Comparisons

Mass Comparison

Pythagoras' Vision, Planck's Units

Pythagoras' Vision, Planck's Units

c, G, h as "Honorary Numbers"

Pythagoras' Vision, Planck's Units

c, G, h as "Honorary Numbers"

c, G, h as a Basis of Units

Redefining the Question

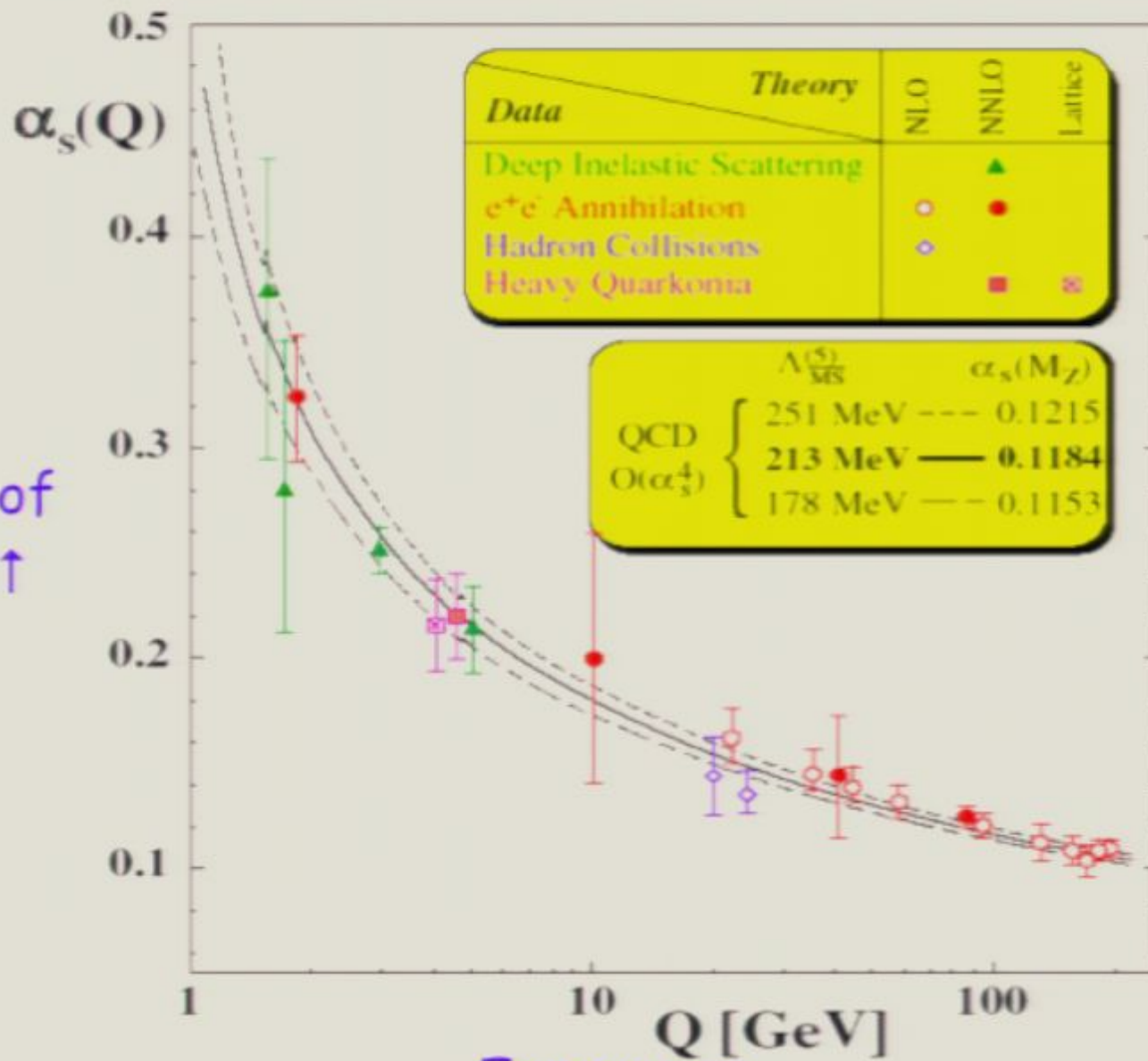
Gravity "is what it is"

The Answer

The Answer

You must walk before you run!

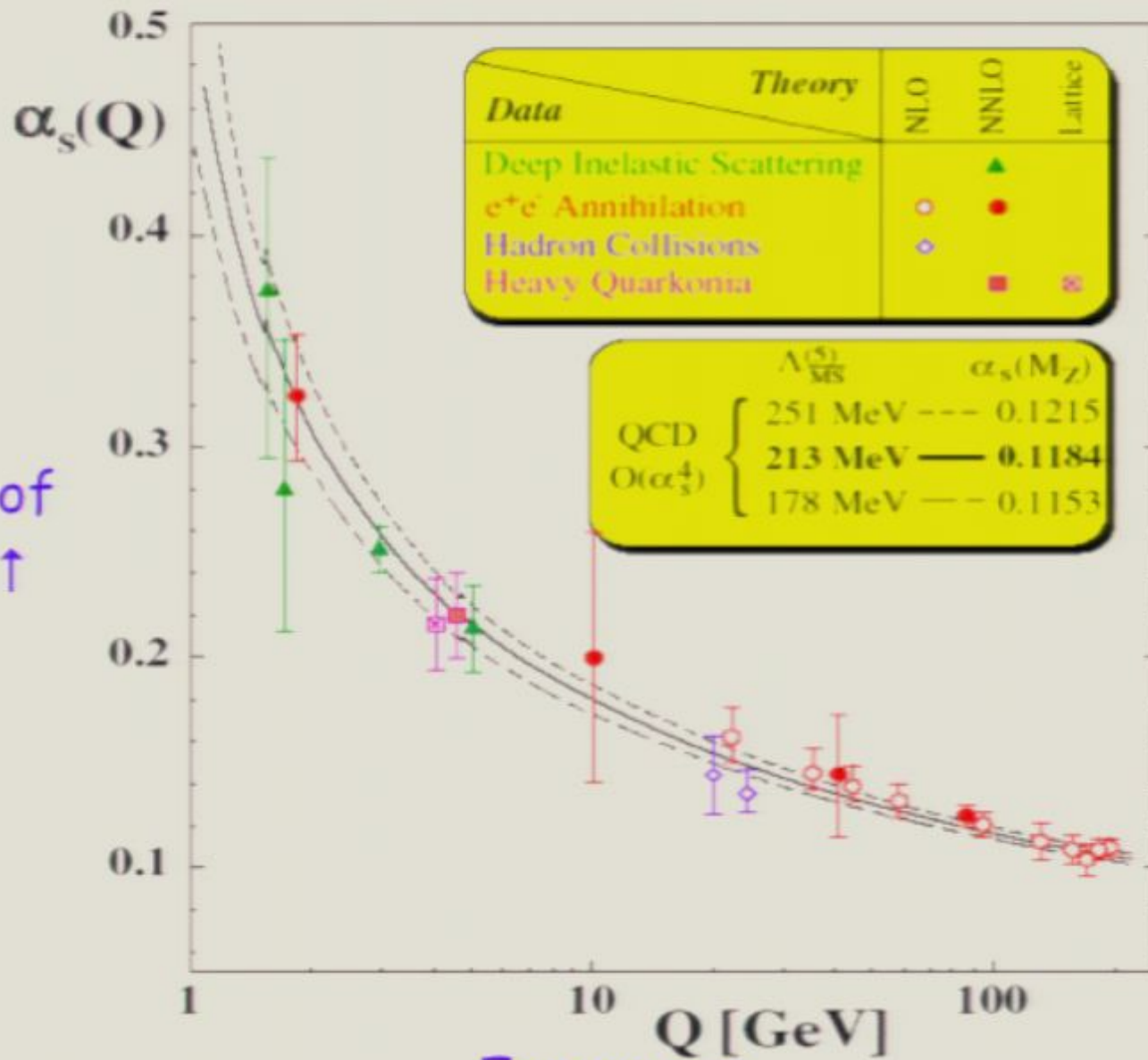
Strength of
Coupling \uparrow



Energy \rightarrow
 \leftarrow Distance

Is It Right?

Strength of
Coupling ↑



Energy →
← Distance

Is It Right?

$$\begin{pmatrix} u & u & u \\ d & d & d \end{pmatrix}^L_{1/6}$$

$$\begin{pmatrix} \nu \\ e \end{pmatrix}^L_{-1/2}$$

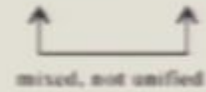
$$\begin{pmatrix} u & u & u \end{pmatrix}^R_{2/3}$$

$$\begin{pmatrix} d & d & d \end{pmatrix}^R_{-1/3}$$

$$(e)^R_{-1}$$

No ν^R

SU(3) x SU(2) x U(1)



	R	W	B	G	P
u	+	-	-	+	-
u	-	+	-	+	-
u	-	-	+	+	-
d	+	-	-	-	+
d	-	+	-	-	+
d	-	-	+	-	+
u^c	-	+	+	-	-
u^c	+	-	+	-	-
u^c	+	+	-	-	-
d^c	-	+	+	+	+
d^c	+	-	+	+	+
d^c	+	+	-	+	+
ν	+	+	+	+	-
e	+	+	+	-	+
e^c	-	-	-	+	+
N	-	-	-	-	-

$$\begin{pmatrix} u & u & u \\ d & d & d \end{pmatrix}^L_{1/6}$$

$$\begin{pmatrix} \nu \\ e \end{pmatrix}^L_{-1/2}$$

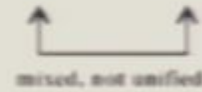
$$\begin{pmatrix} u & u & u \end{pmatrix}^R_{2/3}$$

$$\begin{pmatrix} d & d & d \end{pmatrix}^R_{-1/3}$$

$$(e)^R_{-1}$$

No ν^R

SU(3) x SU(2) x U(1)



	R	W	B	G	P
u	+	-	-	+	-
u	-	+	-	+	-
u	-	-	+	+	-
d	+	-	-	-	+
d	-	+	-	-	+
d	-	-	+	-	+
u^c	-	+	+	-	-
u^c	+	-	+	-	-
u^c	+	+	-	-	-
d^c	-	+	+	+	+
d^c	+	-	+	+	+
d^c	+	+	-	+	+
v	+	+	+	+	-
e	+	+	+	-	+
e^c	-	-	-	+	+
N	-	-	-	-	-

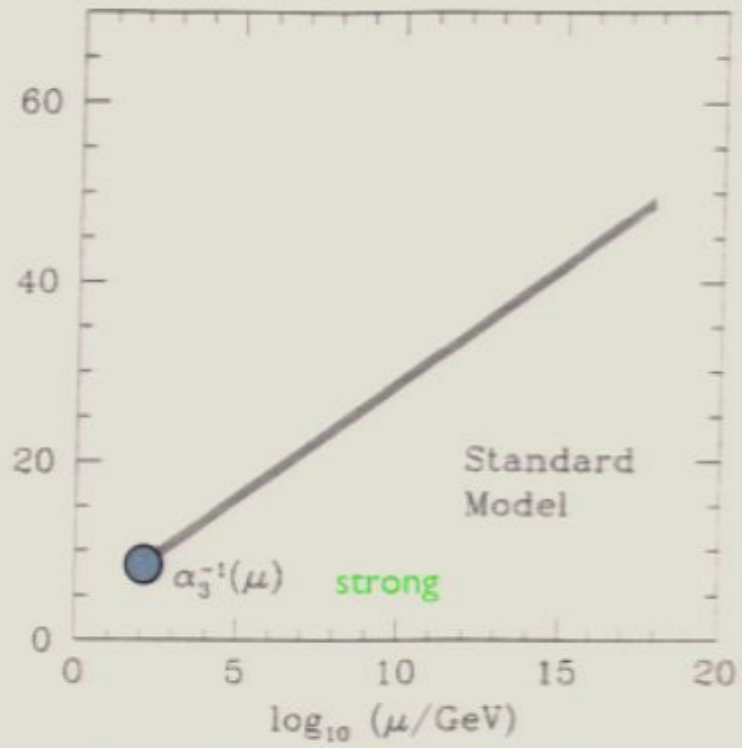
↑
inverse
coupling
strength

● electric

● weak

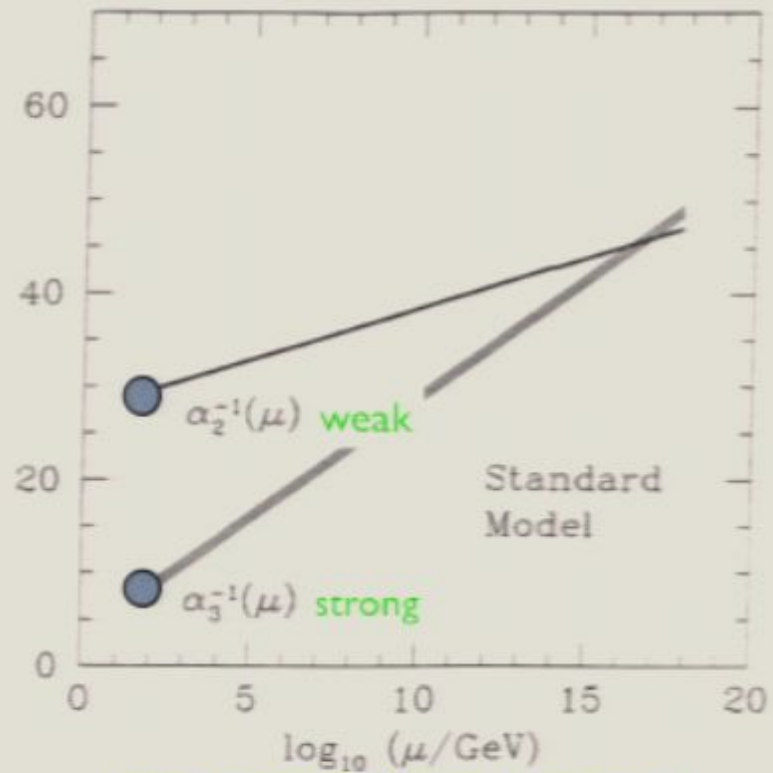
● strong

↑
inverse
coupling
strength

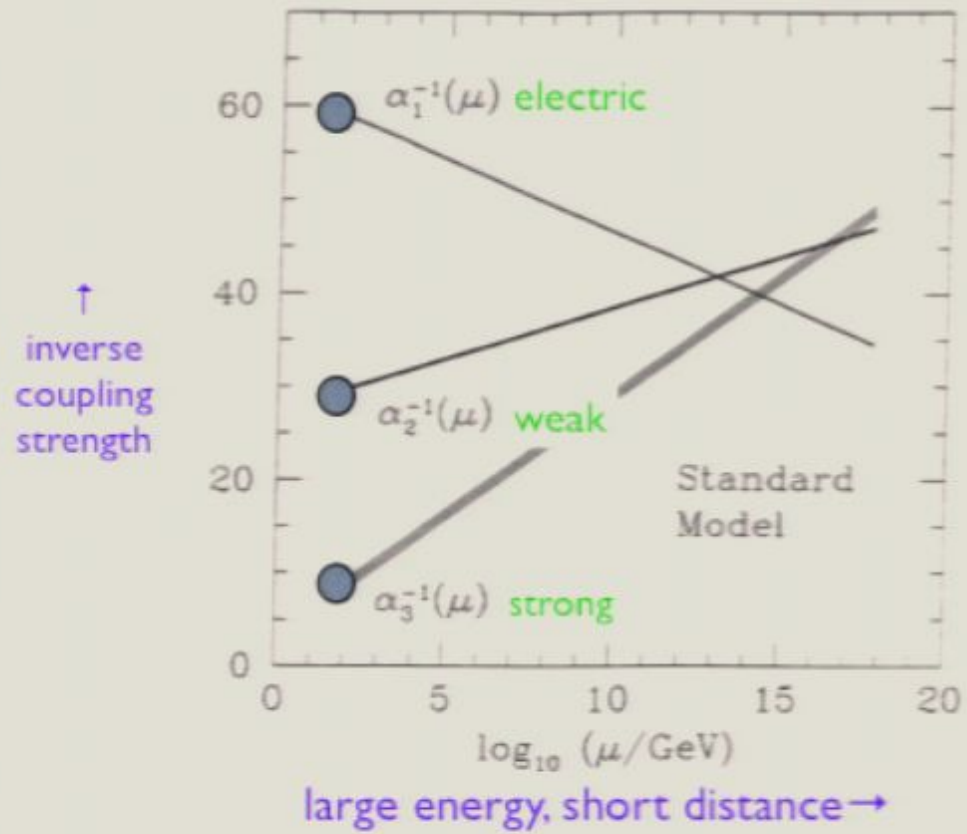


large energy, short distance →

↑
inverse
coupling
strength

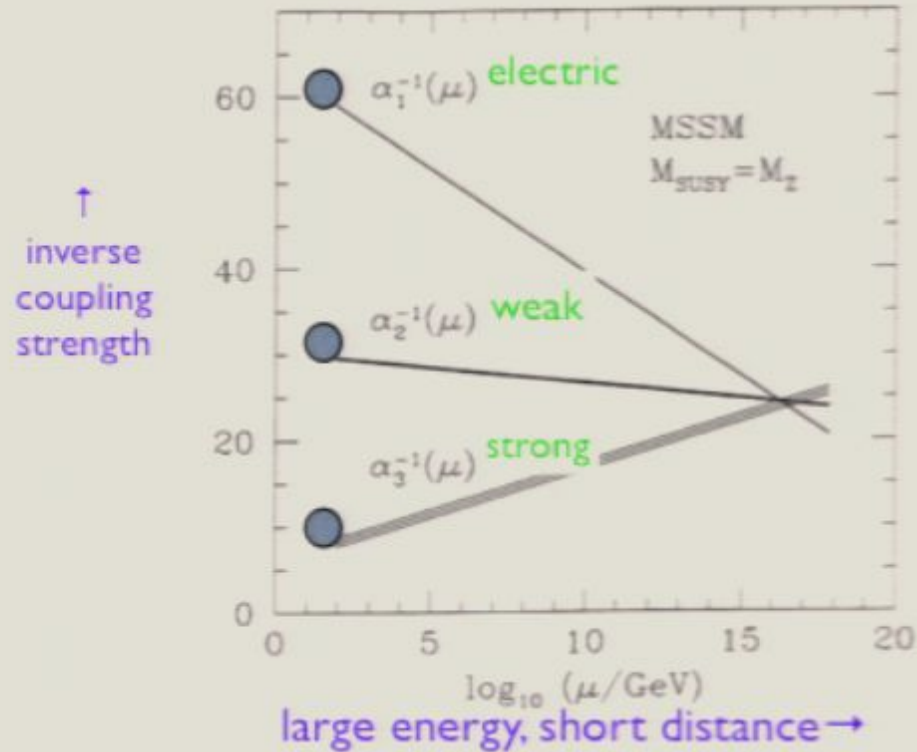


large energy, short distance →

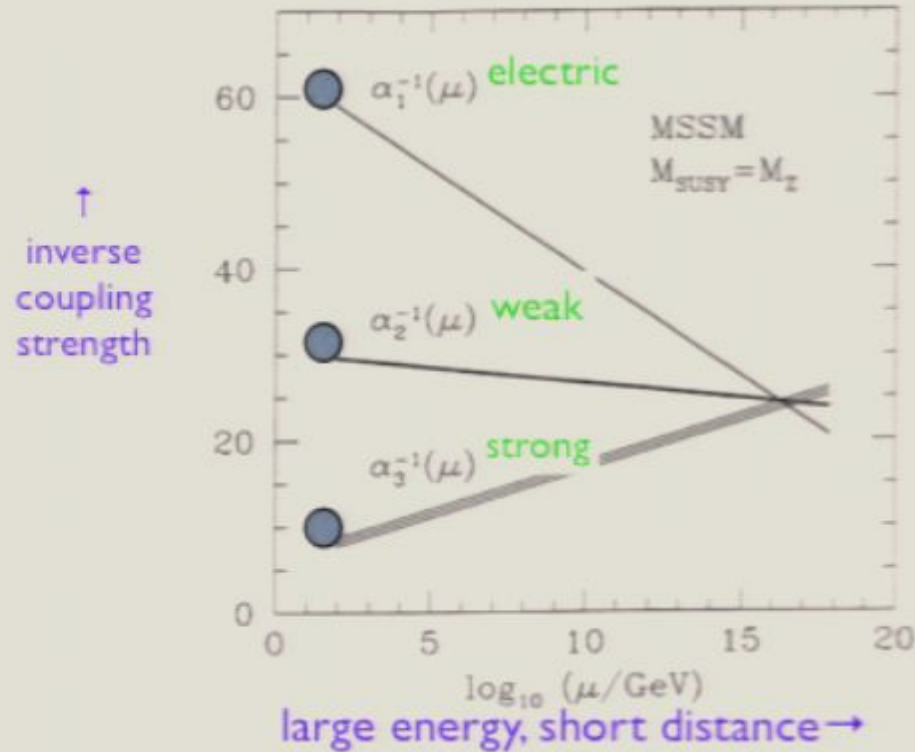


Now Add SUSY:

Now Add SUSY:



Now Add SUSY:



Gravity Fits,
Too! (Roughly)

These ideas have experimental
consequences ...

These ideas have experimental
consequences ...

a new world of particles

These ideas have experimental
consequences ...

a new world of particles

a candidate "dark substance"





-- verdicts will be coming in soon!

