

Title: Particle Physics: Expanding Our Perimeter

Date: Jan 30, 2014 03:50 PM

URL: <http://pirsa.org/14010113>

Abstract:

THE BIG THREE

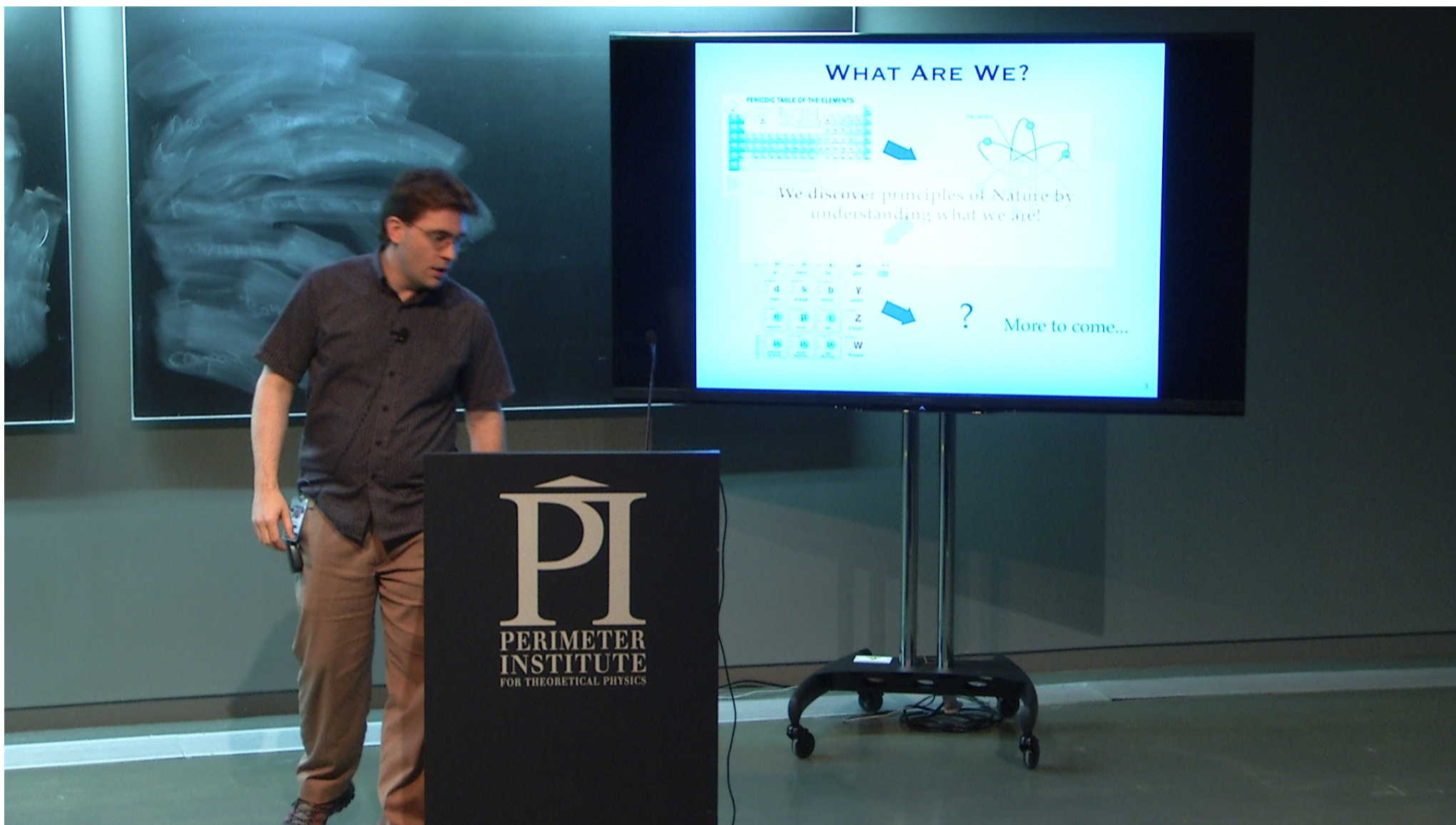
2

THE BIG THREE

What are we?

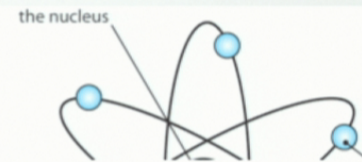
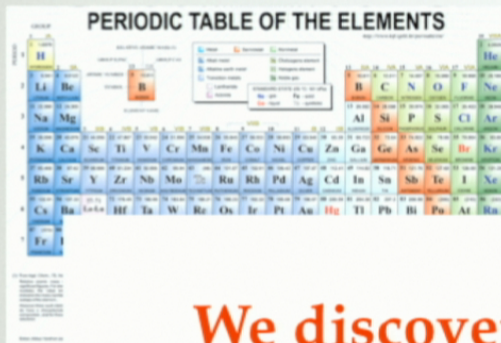
Where did we come from?

Are we alone?



WHAT ARE WE?

PERIODIC TABLE OF THE ELEMENTS



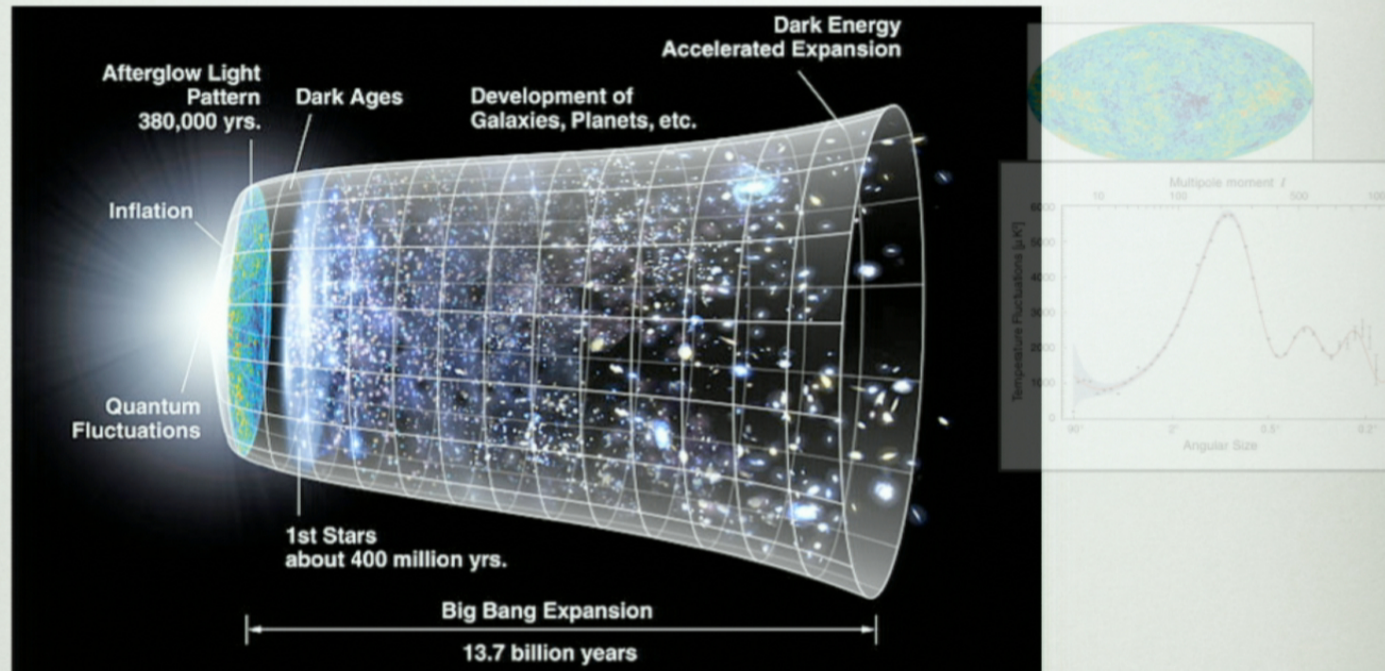
We discover principles of Nature by understanding what we are!

| | | | | | |
|--------------|--|--|--|--|---|
| QUARKS | up +2/3 MeV/c ² 2/3 | charm +1.27 MeV/c ² 2/3 | top +173.1 GeV/c ² 2/3 | gluon 0 | Higgs boson +125.1 GeV/c ² 0 |
| | down -1/3 MeV/c ² -1/3 | strange +95 MeV/c ² -1/3 | bottom +4.18 GeV/c ² -1/3 | photon 0 | |
| | electron 0.511 MeV/c ² -1 | muon 105.7 MeV/c ² -1 | tau 1.777 GeV/c ² -1 | Z boson 91.2 GeV/c ² 0 | |
| LEPTONS | electron neutrino +0.2 eV/c ² 0 | muon neutrino +0.17 MeV/c ² 0 | tau neutrino +1.8 MeV/c ² 0 | W boson 80.4 GeV/c ² ±1 | |
| GAUGE BOSONS | | | | | |

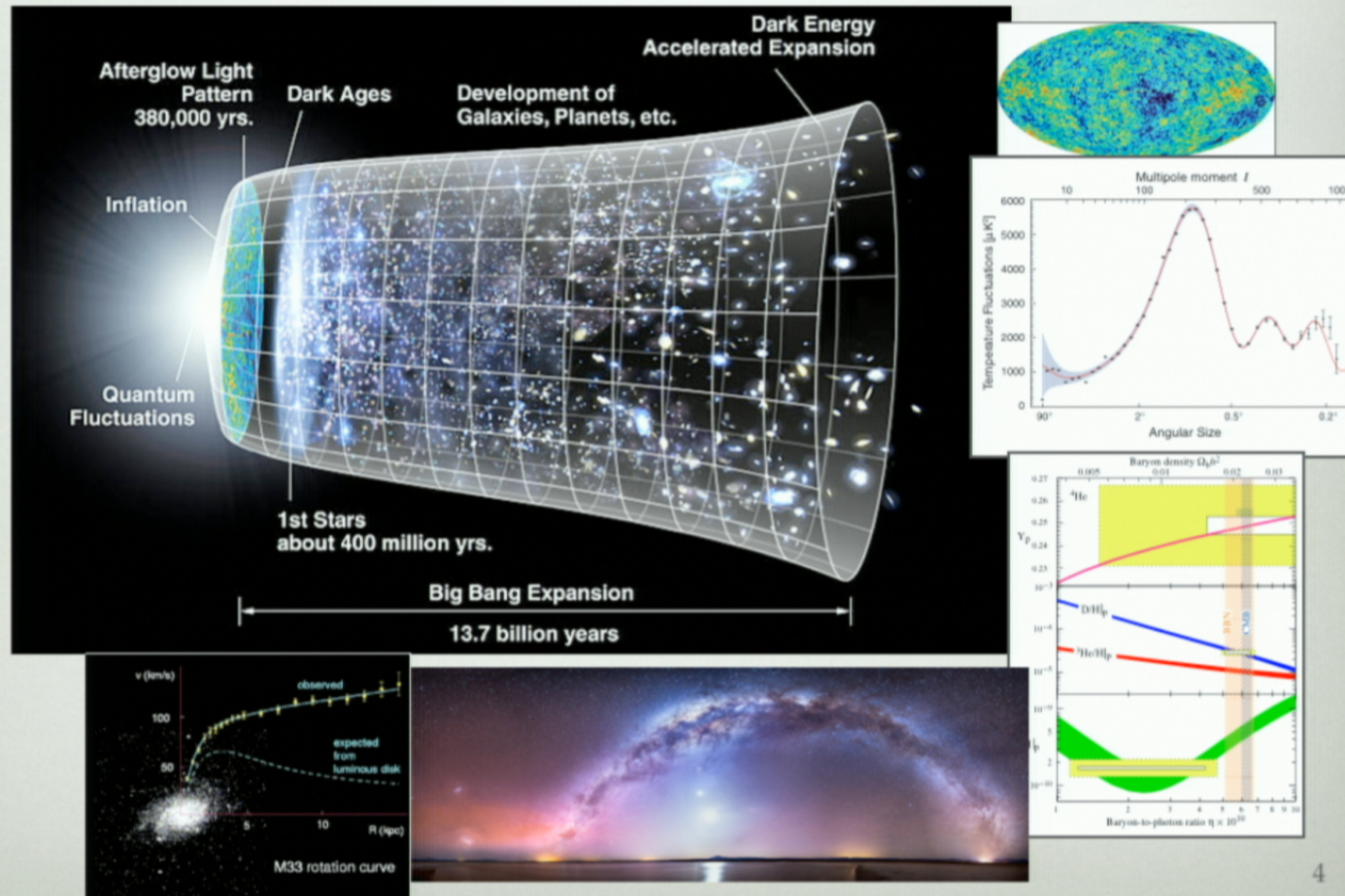
?

More to come...

WHERE DID WE COME FROM?



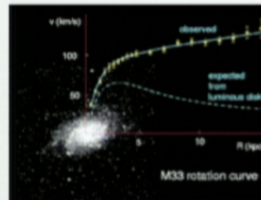
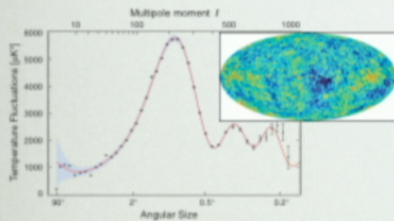
WHERE DID WE COME FROM?



ARE WE ALONE?

No!

The wealth of evidence for dark matter & dark energy



What is it?
Why is it there?
How does it work?

Where do the baryons come from?

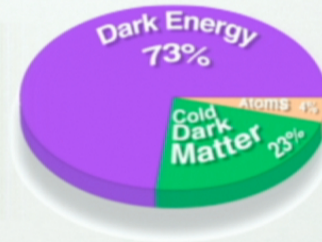
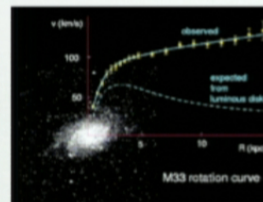
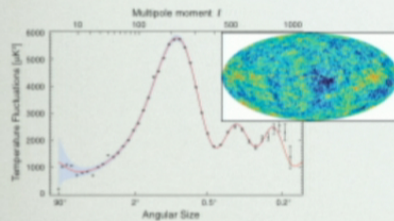
Origin of neutrino masses?

New phenomena associated with known forces at ultra-high or -low energy?

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What is it?
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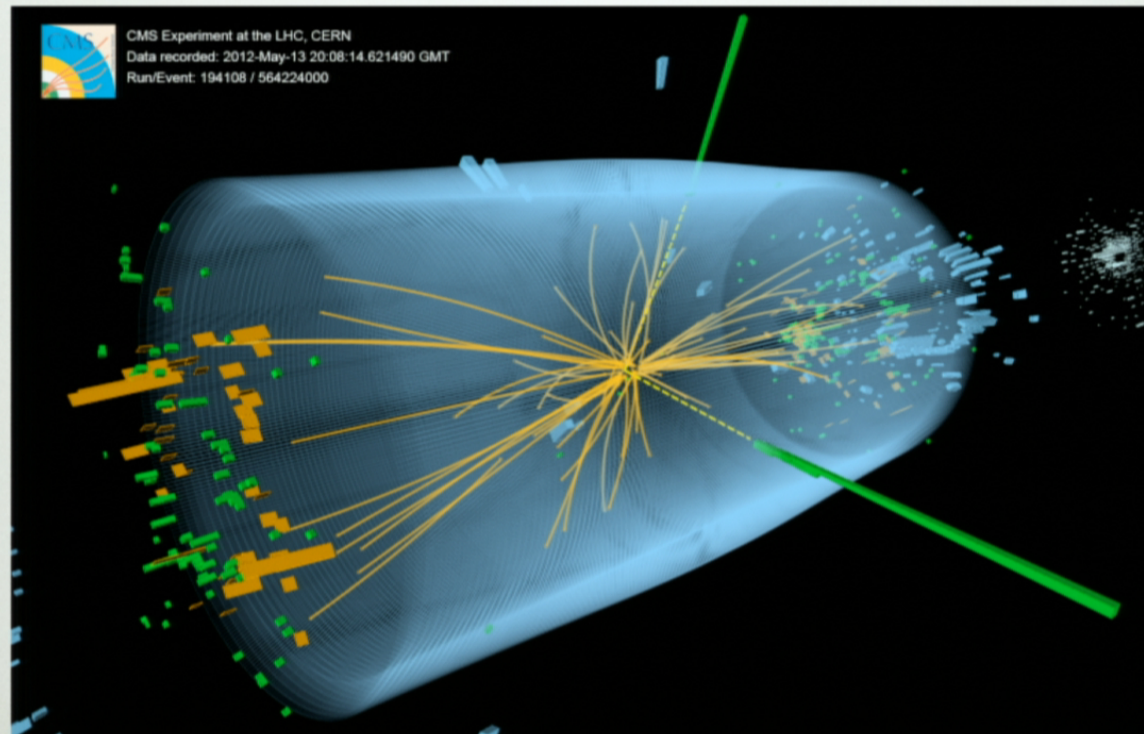
Where do the baryons come from?

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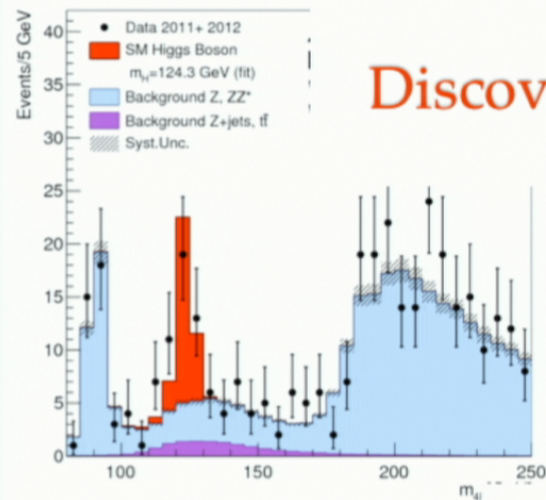
PARTICLE PHYSICS IN THE NEWS

LHC used to explore the smallest length scales to date

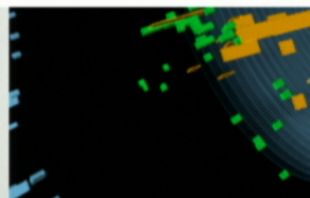
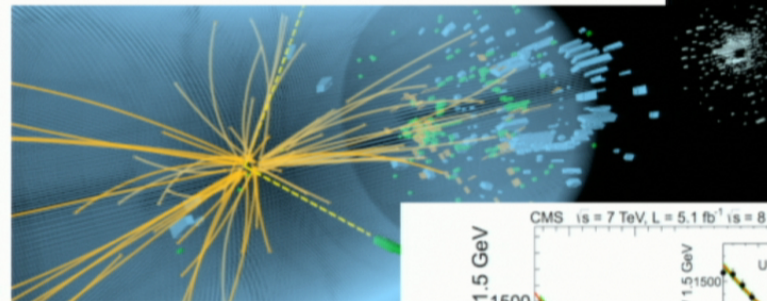


PARTICLE PHYSICS IN THE NEWS

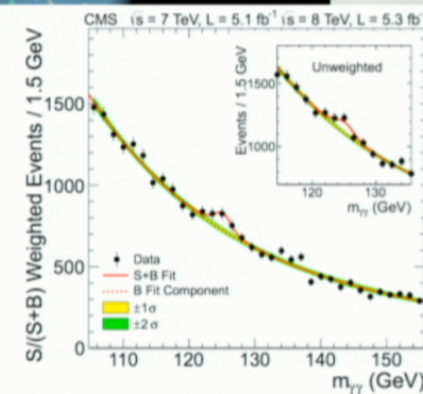
LHC used to explore the smallest length scales to date



Discovery of a Higgs particle!



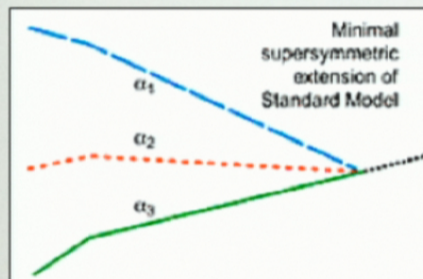
Nobel Prize



PARTICLE PHYSICS AT THE ENERGY FRONTIER

Much more to explore, beyond the Higgs

- Explanation of large hierarchies of scales?
- Unification?



LHC has tested most predictive form of naturalness —
and it is wrong!

Is it just approximate?

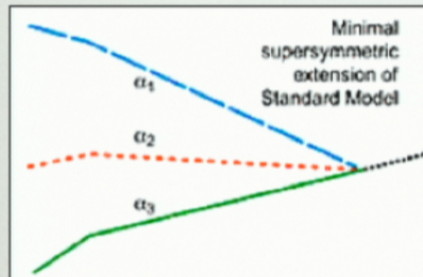
Are we missing some important principle?

- Enough structure to address other puzzles?

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7

PARTICLE PHYSICS AT THE ENERGY FRONTIER

Much more to explore, beyond the Higgs

This is the type of transformative physics we are after!

Where discoveries can

- ... Turn a now-standard paradigm on its head
- ... Open up a completely new field of exploration
- ... Confirm an untested picture of Nature (e.g. the Higgs)

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and it is wrong!

Is it just approximate?

Are we missing some important principle?

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PARTICLE PHYSICS AT THE ENERGY FRONTIER
Much more to explore, beyond the Higgs

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Where discrepancies can

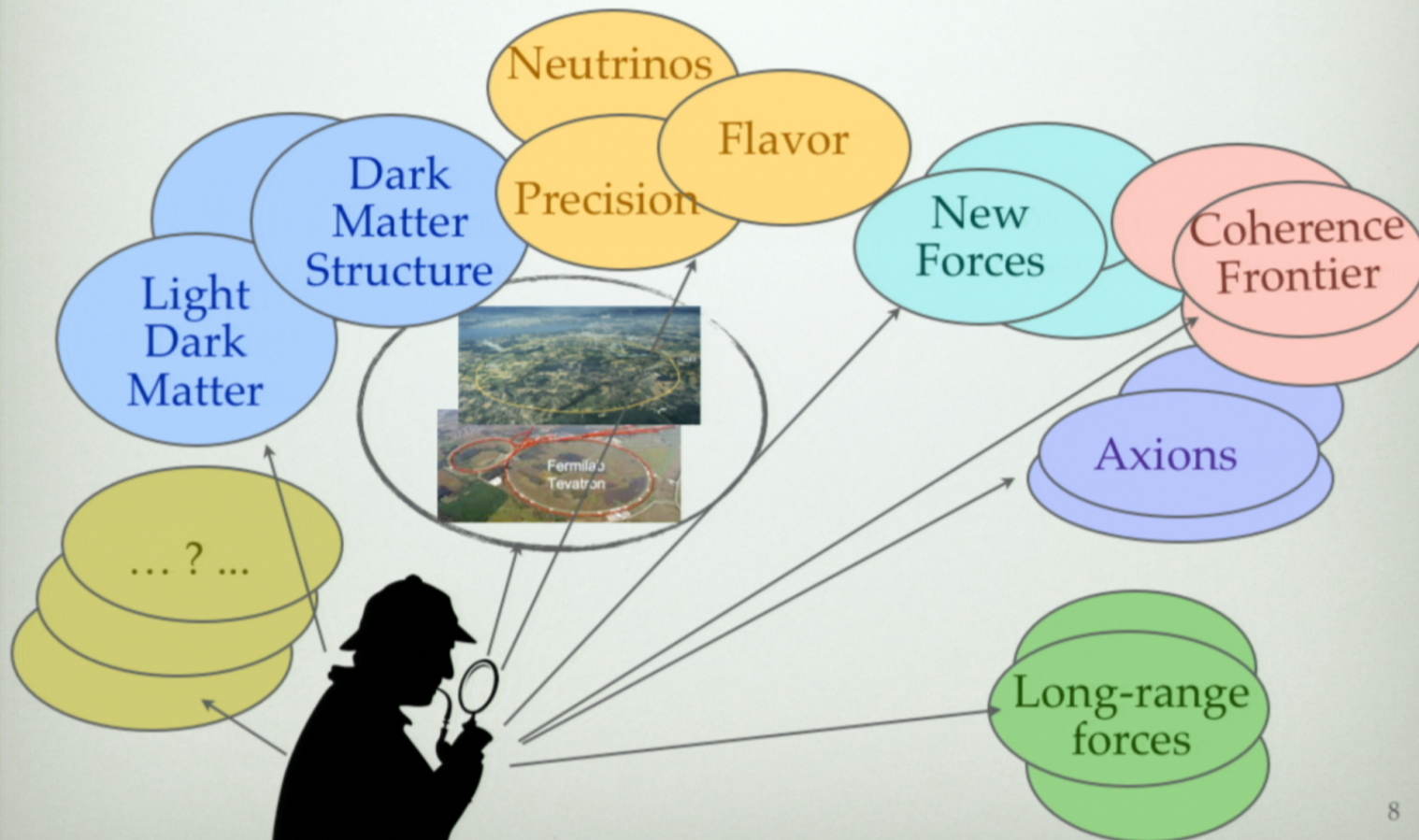
- There is new standard paradigm on its feet!
- Open up a completely new field of exploration
- Confine an untested picture of Nature to the edge!

LHC has tested most predictive forms of naturalness — and it is wrong!

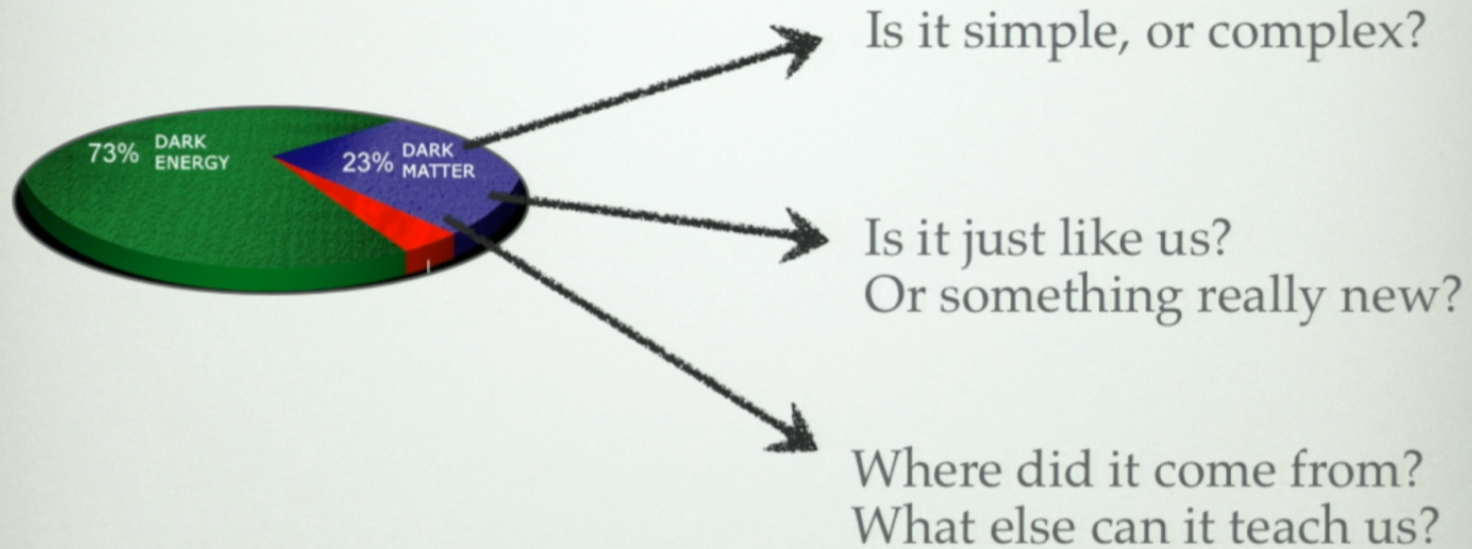
Is it just approximate?

Are we missing some important principle?

EXPANDING OUR PERIMETER **BEYOND** THE ENERGY FRONTIER



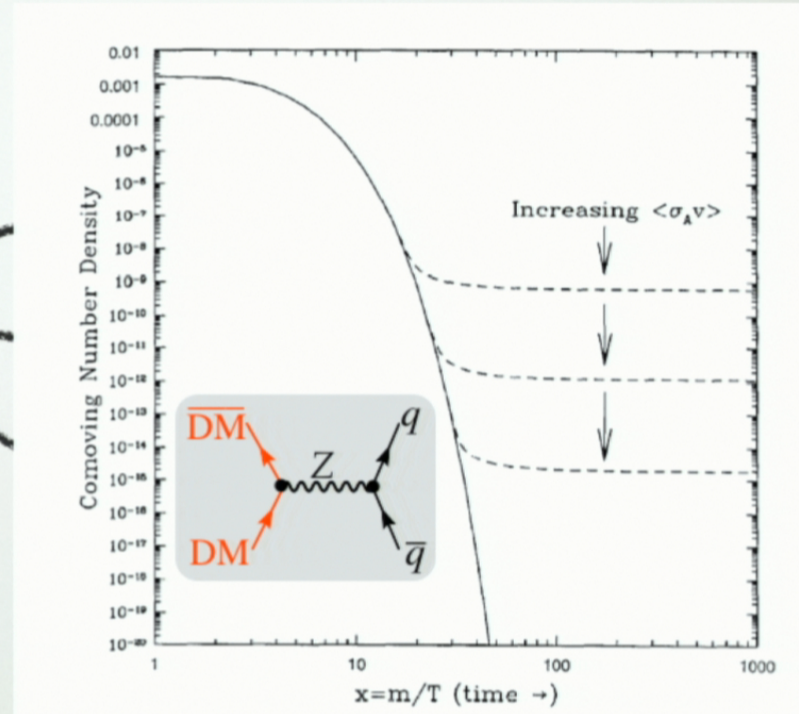
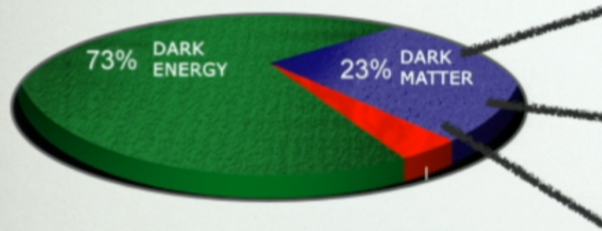
THE DARK MATTER FRONTIER



All evidence for dark matter is from gravitational effects –
we know almost nothing about other interactions

14

THE DARK MATTER FRONTIER



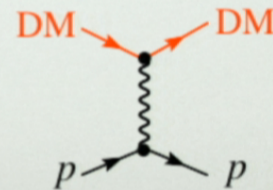
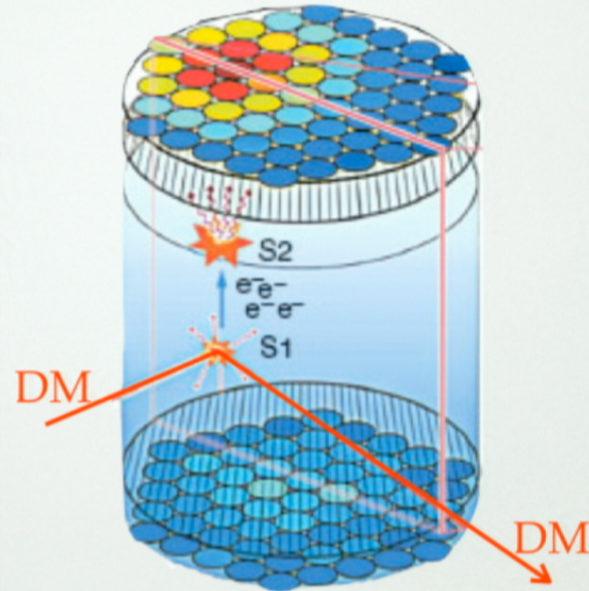
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B4

HUNTING DARK MATTER

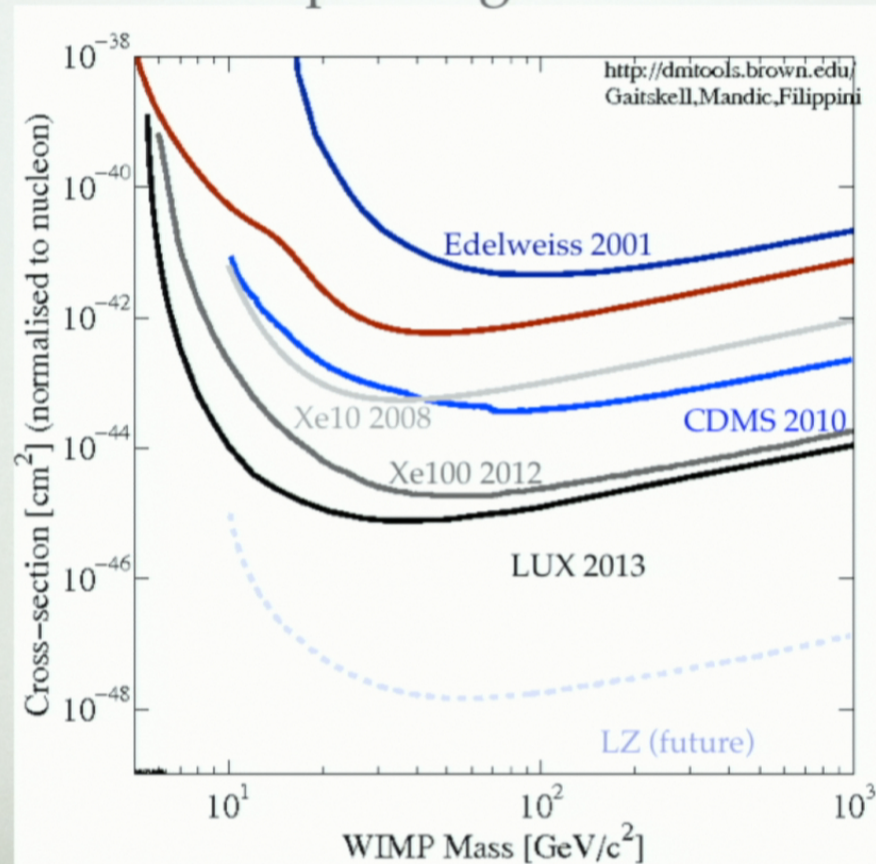
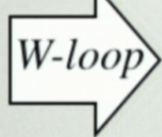
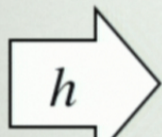


Deep underground
dark matter detectors



HUNTING DARK MATTER

Dark matter searches straining the “just like us” paradigm



STRUCTURE-FUL DARK MATTER

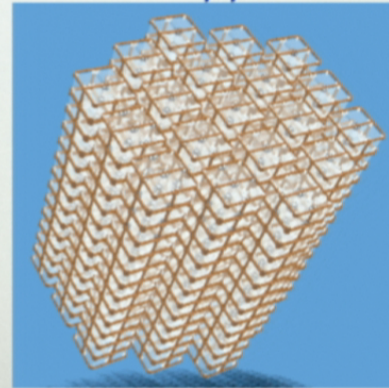
What if interactions can only
up/down-scatter DM ?

Look for the decay!

[Maxim, Itay, Neal W.]



CUORE ($0\nu\beta\beta$ detector)



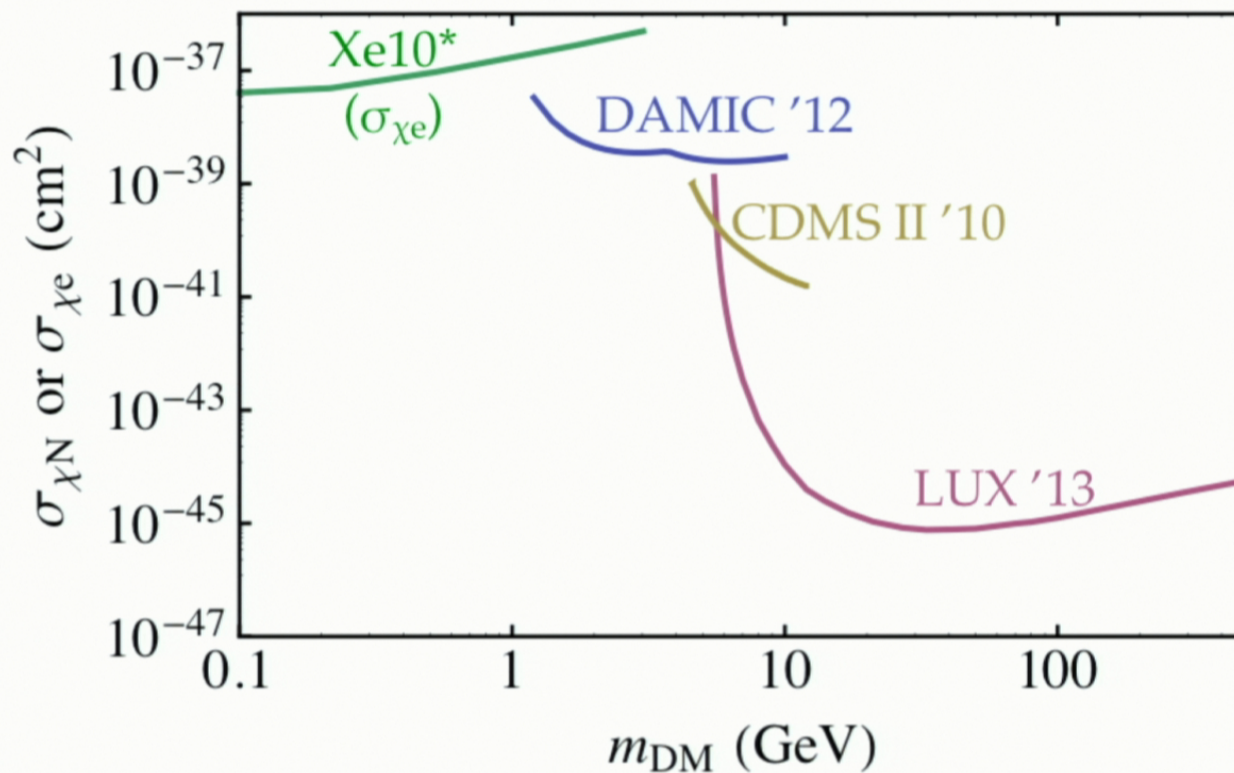
Lead
shield

=

DM
exciter

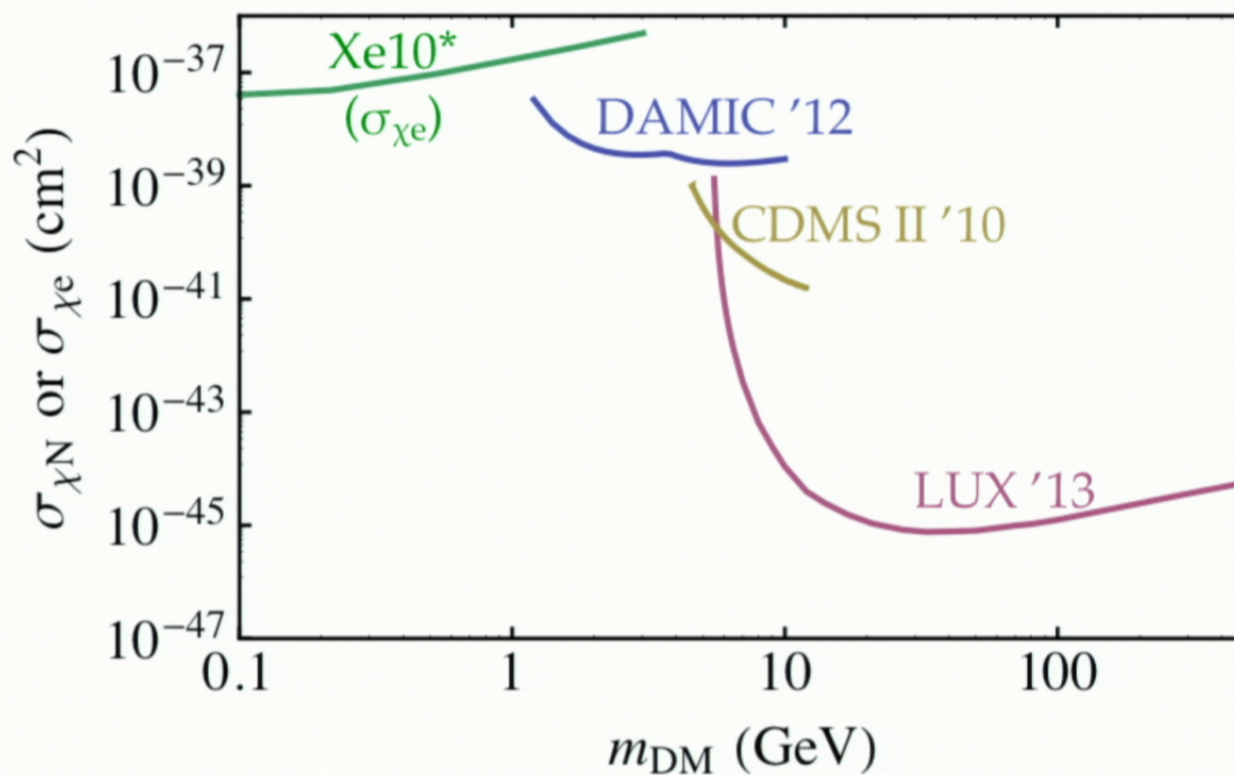
HUNTING DARK MATTER

How sensitive are current searches to DM scattering through a new force?



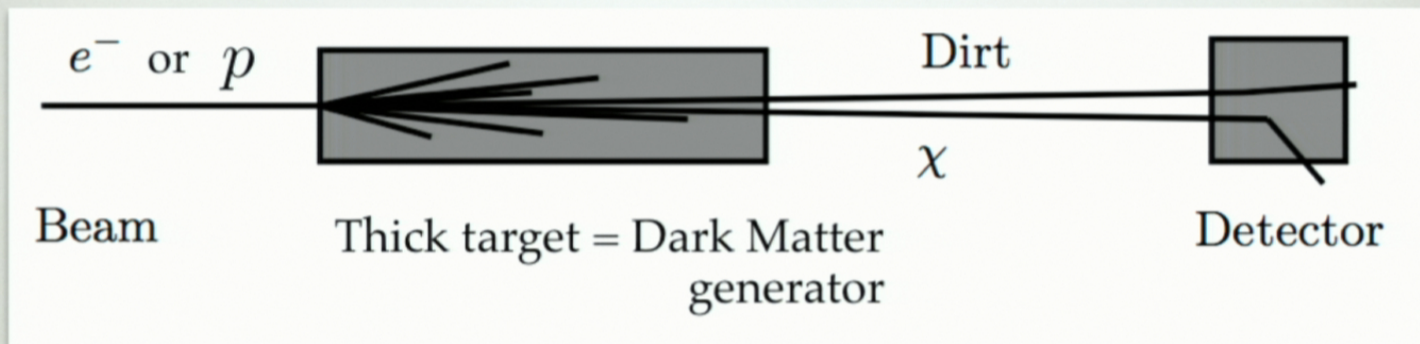
HUNTING DARK MATTER

How sensitive are current searches to DM scattering through a new force?



HUNTING DARK MATTER

Make it directly in high intensity beams

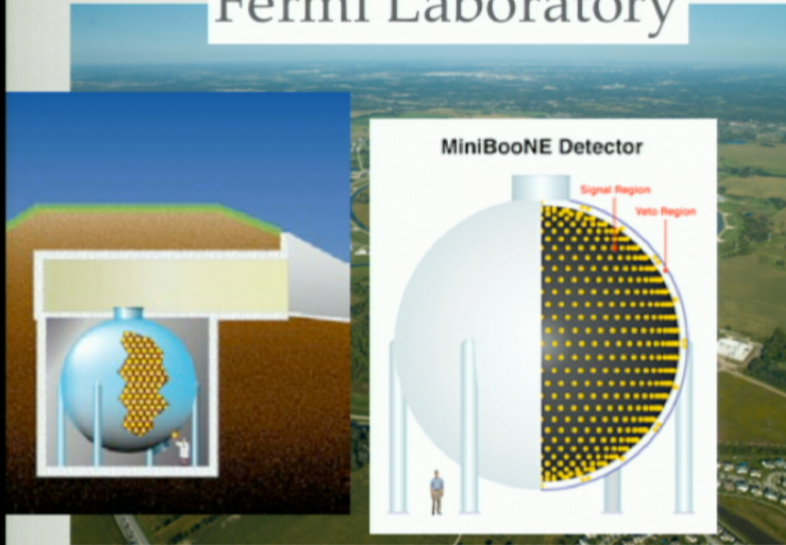


Dark matter comes out with large energy
 \Rightarrow energy from scattering is visible in detector

Brand new idea, using existing detectors (+ beam)

HUNTING DARK MATTER

Fermi Laboratory



Jefferson Laboratory



Can use existing high intensity beams and detectors.

EXPANDING OUR PERIMETER IN THE HUNT FOR DARK MATTER

What can dark matter teach us?

The basic questions are key: Is Dark Matter simple or complex? Like us, or a window into something new?

The “simple & like us” paradigm is under strain

Other options call for creative new experiments

Pursuing all these directions – and finding more new ones
– is the surest path towards learning from dark matter!

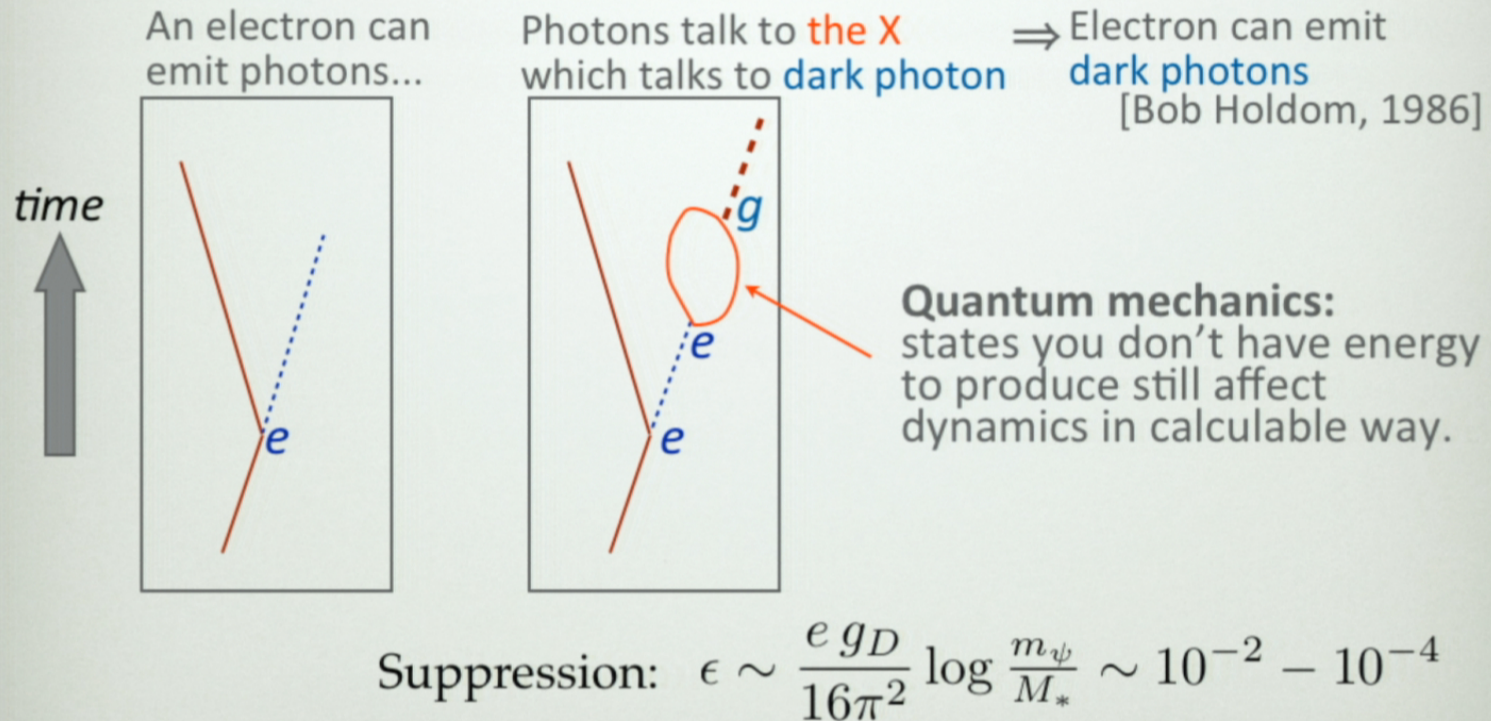
OLD & NEW FORCES

| Forces Matter | EM | Weak | Strong | New force? |
|--------------------------------|-----------|-------------|---------------|-----------------------|
| Electron | ✓ | ✓ | — | — |
| Neutrino | — | ✓ | — | — |
| Quarks | ✓ | ✓ | ✓ | — |

So far, we have found the three forces under which the stuff we're made of is charged

... any other forces will be harder to find

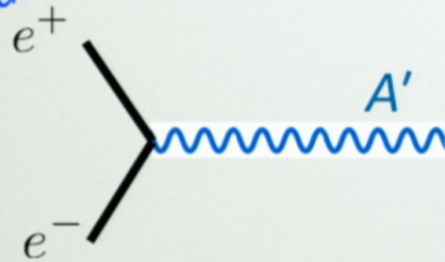
NEW FORCES & QUANTUM MECHANICS



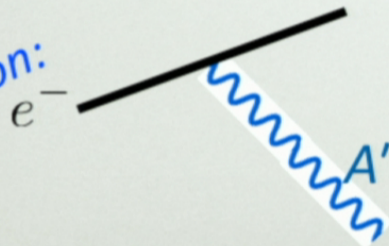
NEW FORCES: THE BASIC PICTURE

Production
(like ordinary
radiation of light, but
suppressed by ϵ)

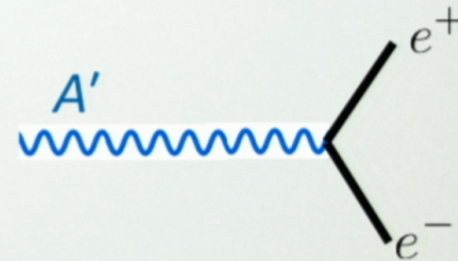
Annihilation:



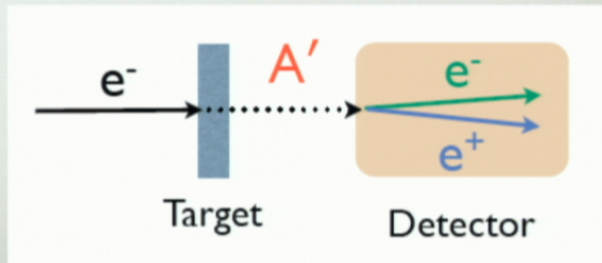
Radiation:



Decay



Put it together:



THE “PORTALS”

Searches can be organized around a small number of interactions allowed by Standard Model symmetries

Higgs Portal $\epsilon_h |h|^2 |\phi|^2$ exotic rare Higgs decays?

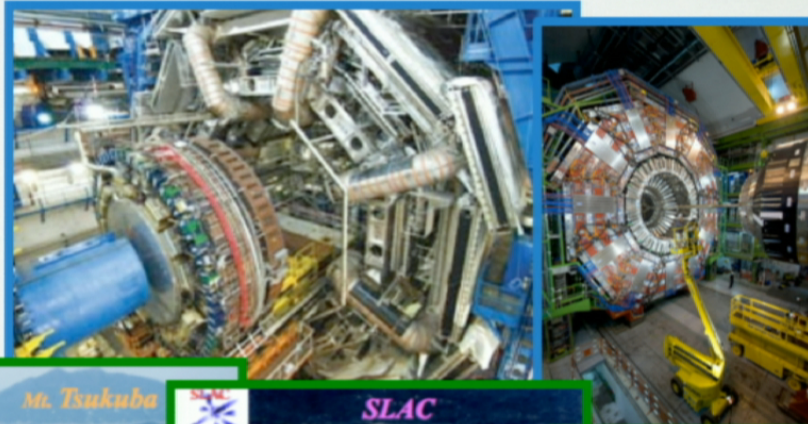
Neutrino Portal $\epsilon_\nu (hL)\psi$ not-so-sterile neutrinos?

Vector Portal $\frac{1}{2}\epsilon_Y F_{\mu\nu}^Y F'^{\mu\nu}$ **kinetic mixing?**

Axion Portal $\frac{1}{f_a} a F_{\mu\nu} \tilde{F}^{\mu\nu}$ axion-like particles?

An Array of Opportunities for Discovery!

High-energy
colliders



High
intensity
colliders

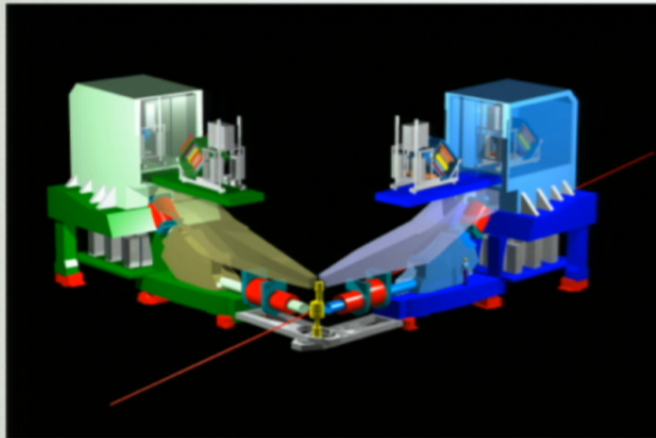


Fixed
Target

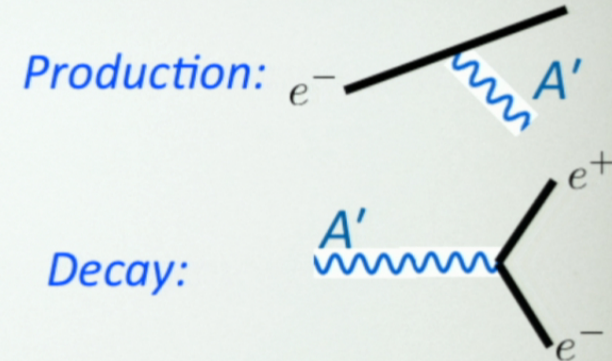


25

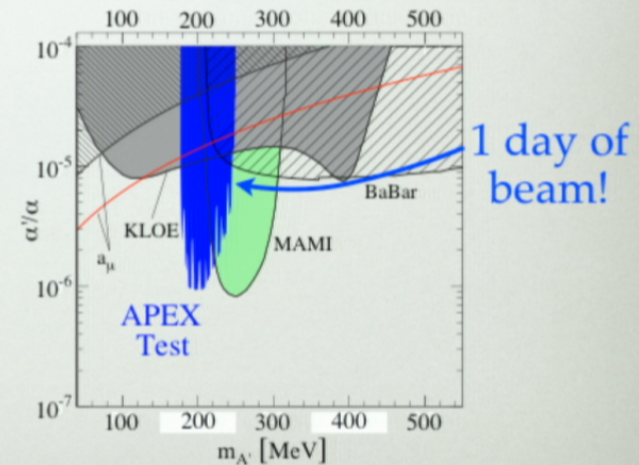
APEX



Pioneering search for new forces via resonances

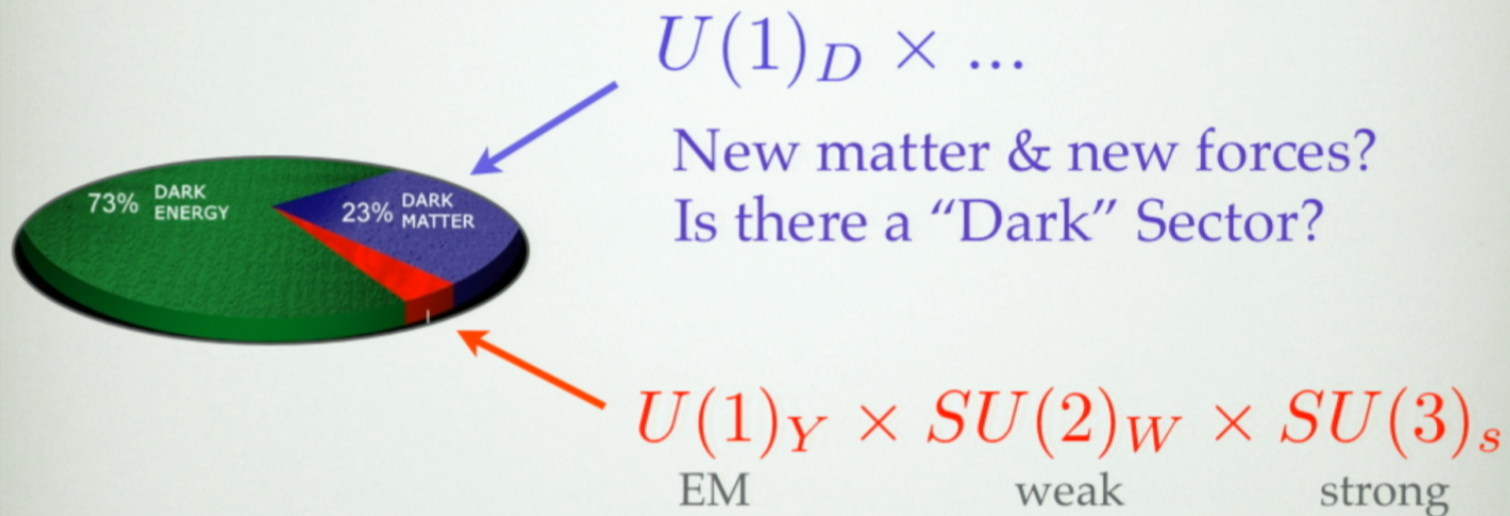


Test run PRL 2011



...full run ~2016

BIG PHYSICS FROM WEAK FORCES



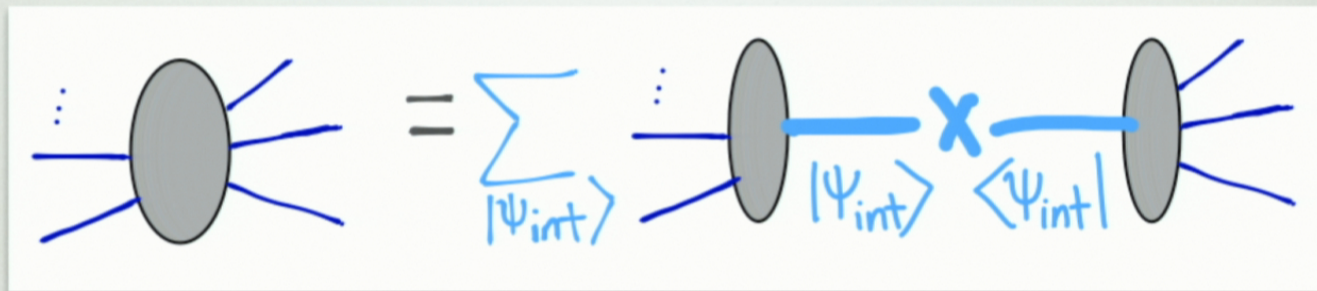
We can estimate the strength of possible new forces, and look for them with targeted small-scale experiments.

If we find a sector associated with new forces, it would open a new window on unification, naturalness, and many other big-picture questions about Nature.

IMAGINATION WITH A STRAITJACKET

Two **well-tested** principles restrict any explanation of long-range forces:

Quantum Mechanics \Rightarrow unitary scattering



relates complex amplitudes to simple ones

IMAGINATION WITH A STRAITJACKET

Mediator

helicity 0

helicity 1

helicity 2

helicity ≥ 3

Force (up to γ factors)

v -independent $1/r^2$ *<— not found in Nature!*

linear in v (E & B)

quadratic in v

— inconsistent —

IMAGINATION WITH A STRAITJACKET

Mediator

helicity 0

helicity 1

helicity 2

helicity ≥ 3

helicities mix
(continuous spin)

Force (up to γ factors)

v -independent $1/r^2$ *<— not found in Nature!*

linear in v (E & B)

quadratic in v

— inconsistent —

unknown!

\vdots
 $\text{—} | 2\rangle$
 $\text{—} | 1\rangle$
 $\text{—} | 0\rangle$
 $\text{—} | -1\rangle$
 $\text{—} | -2\rangle$
 \vdots

CLOSING THOUGHTS

- Particle Physics is in the midst of breakthroughs!
- New generation of opportunities to explore Nature is in view, and is being led by PI

