A Rare Opportunity, the Mu2e Experiment

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Fermilab

21-March-2012

Topics I'll Cover Today

- What is High Energy Physics?
- What is a muon?
- What is "Mu2e"?

  … and how does it work?

  … and why is it important?

Preamble

What is Science?

What is Science?

- Evidence based

For first few millenia

- There were no scientists… only "Natural Philosophers"

Birth of Modern Science

- Galileo Galilei insists that scientific conclusions must be based on experimental evidence

Galileo Galilei, 1636

What is Science?

- Evidence based

What is Science?

- Evidence based
- Curiosity driven

What is High Energy Physics?

What is High Energy Physics?

It is a branch of science

What is the goal of High Energy Physics?

Identify the fundamental particles

…and the forces that govern their interactions

What is the goal of High Energy Physics?

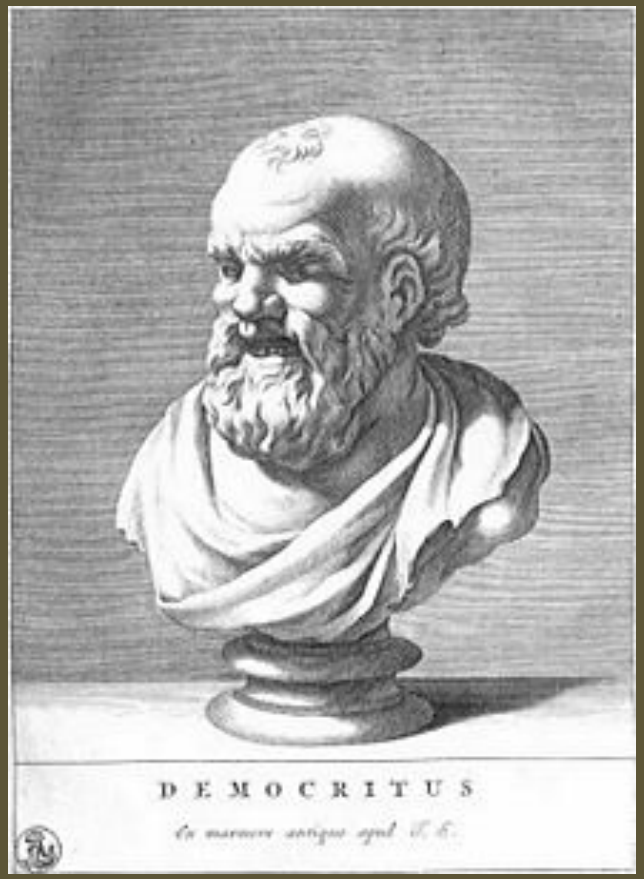
What are things made of?

Why do they behave the way they do?

Our first guess…

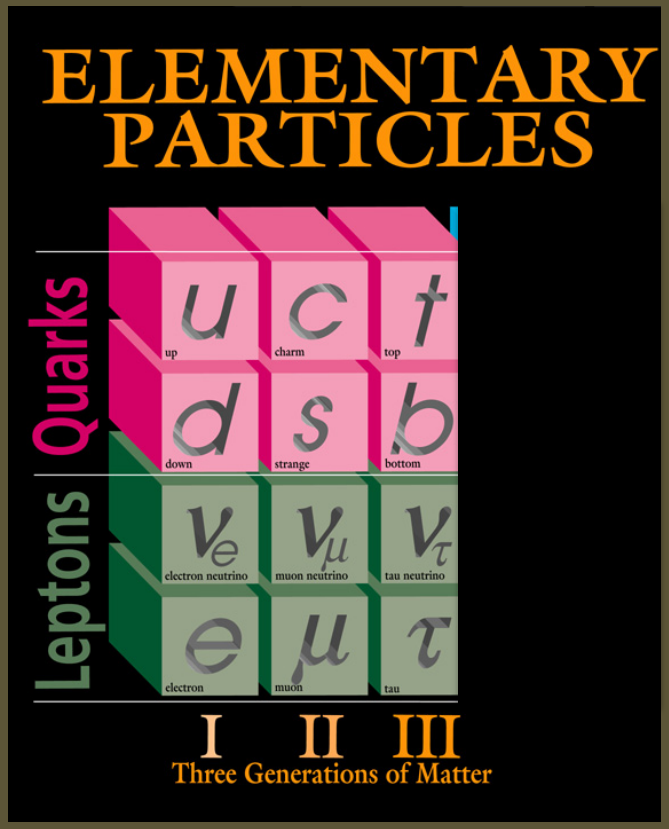
earth, wind, fire, water

A couple thousand years later…



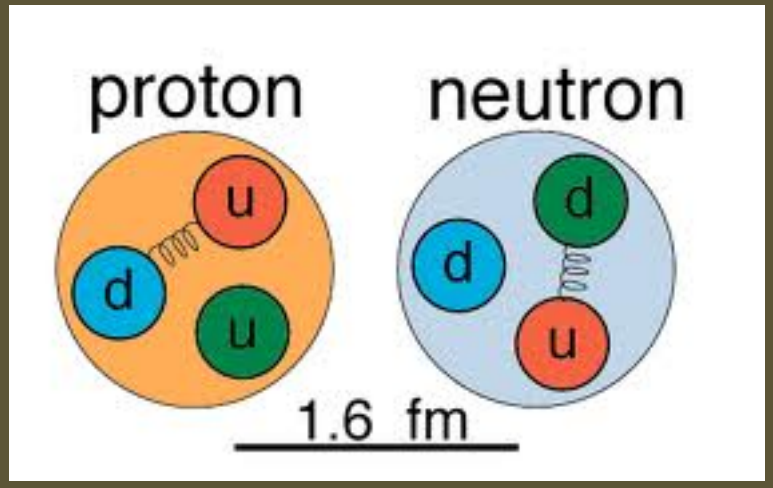
Postulated that all things are made of “atoms”

Today



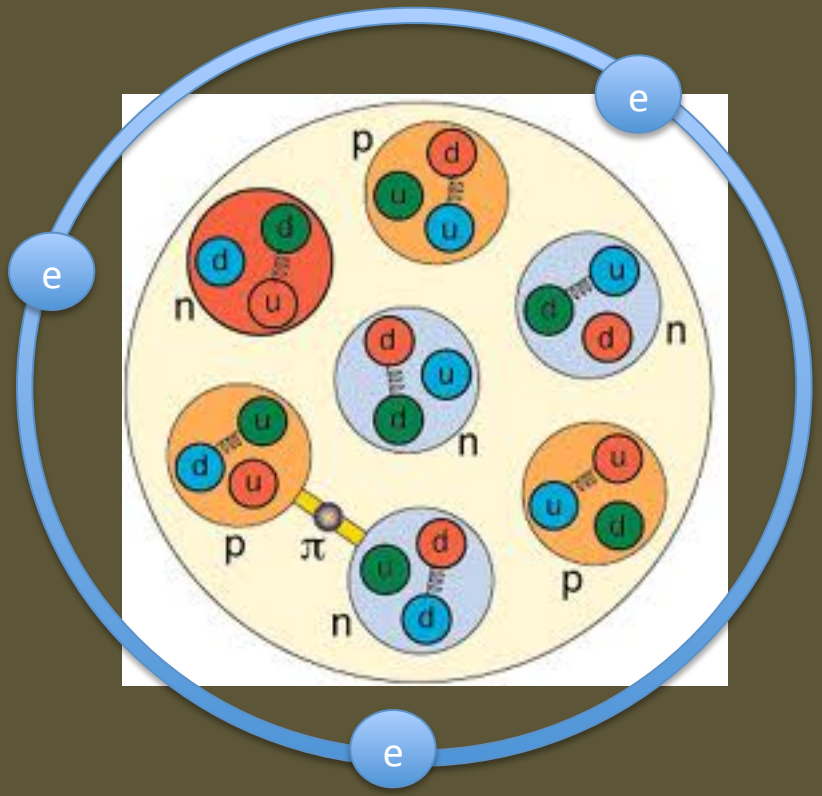
The fundamental particles

From Quarks to Cosmos



At its most basic level, everything we see is made of quarks and electrons

From Quarks to Cosmos



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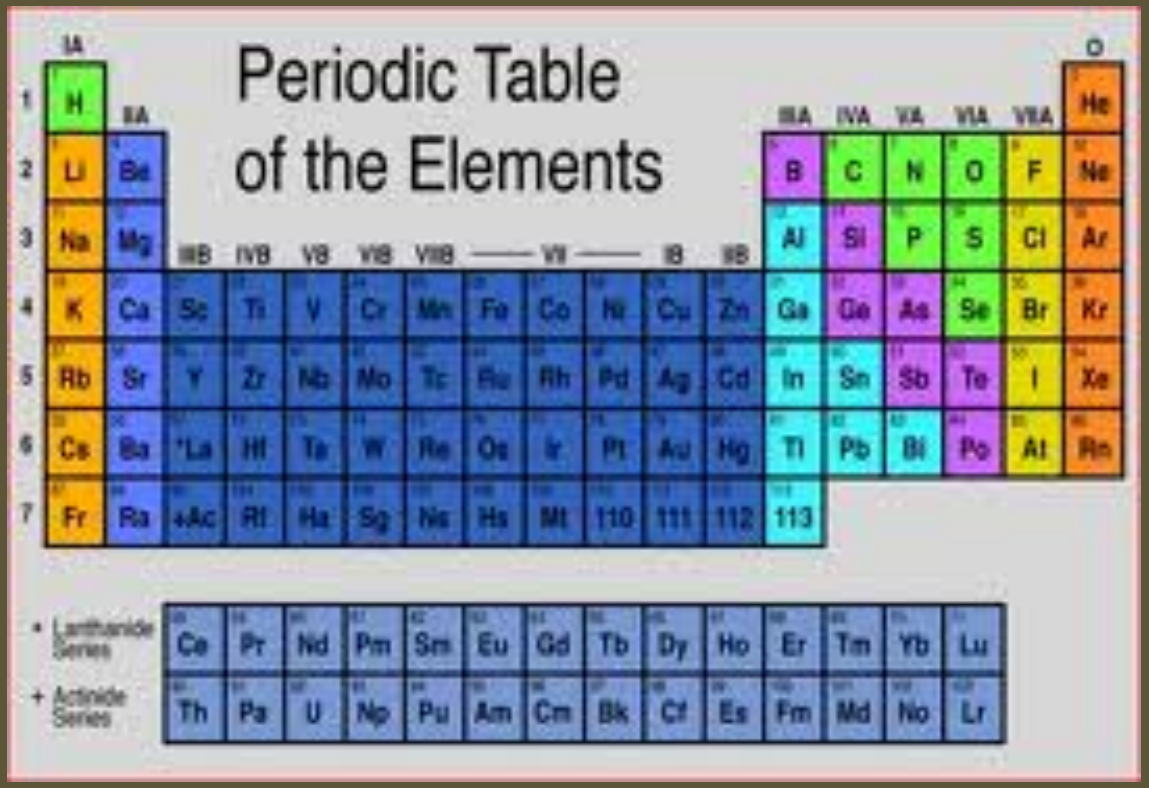


At its most basic level, everything we see is made of quarks and electrons

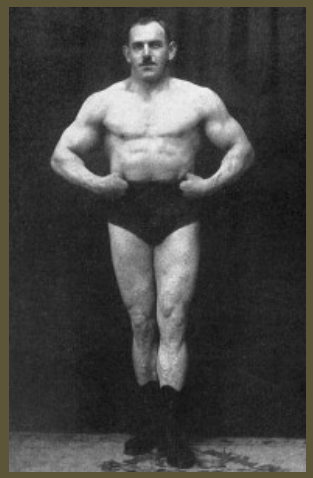
From Quarks to Cosmos

At its most basic level, everything we see is made of quarks and electrons

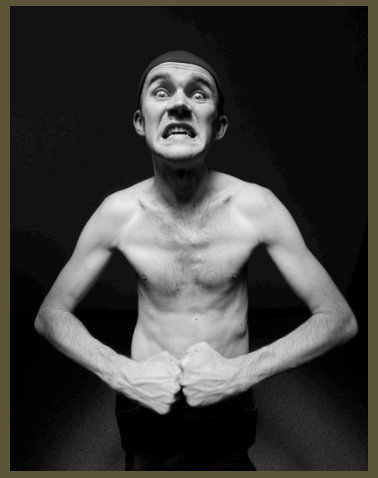
Today

electromagnetic

strong



weak



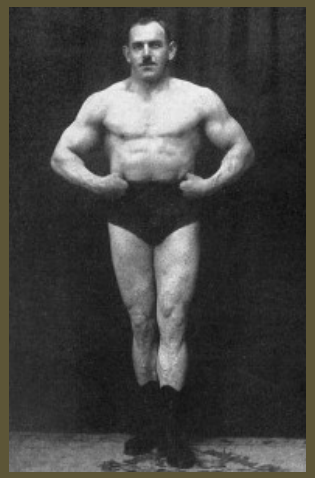
The forces that govern their interactions

Today

electromagnetic

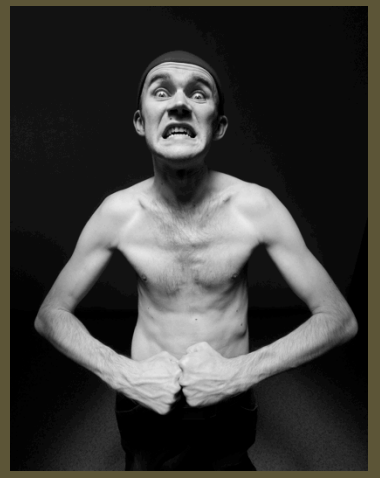
γ

strong



g

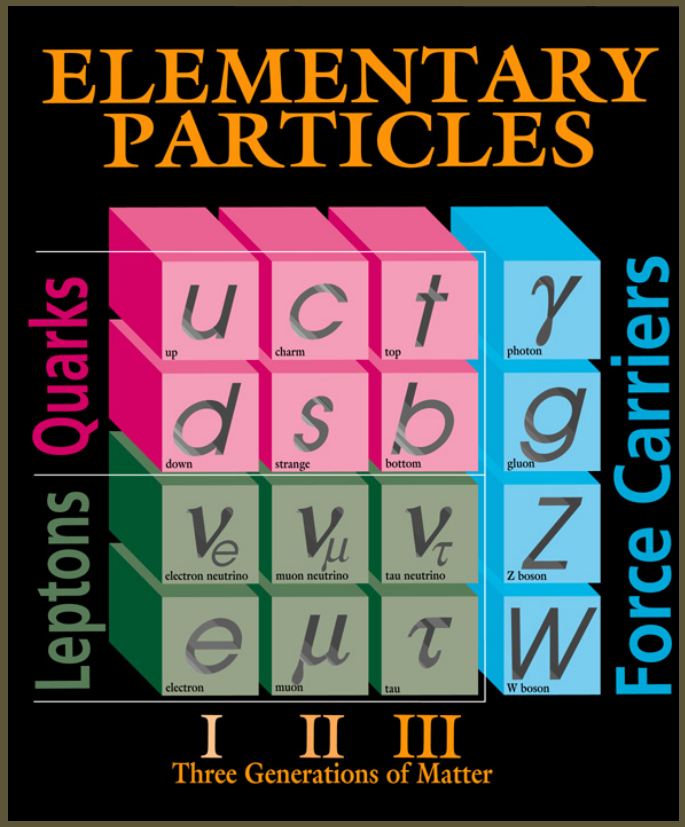
weak



W, Z

The forces that govern their interactions

Today



The Standard Model

Standard Model Evidence

- Discovery of the γ

Standard Model Evidence

- Discovery of the γ
- Discovery of the nucleus

Standard Model Evidence

- Discovery of the γ
- Discovery of the nucleus
- Discovery of the μ

Standard Model Evidence

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Standard Model Evidence

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- Discovery of anti-matter

Standard Model Evidence

- Discovery of the γ
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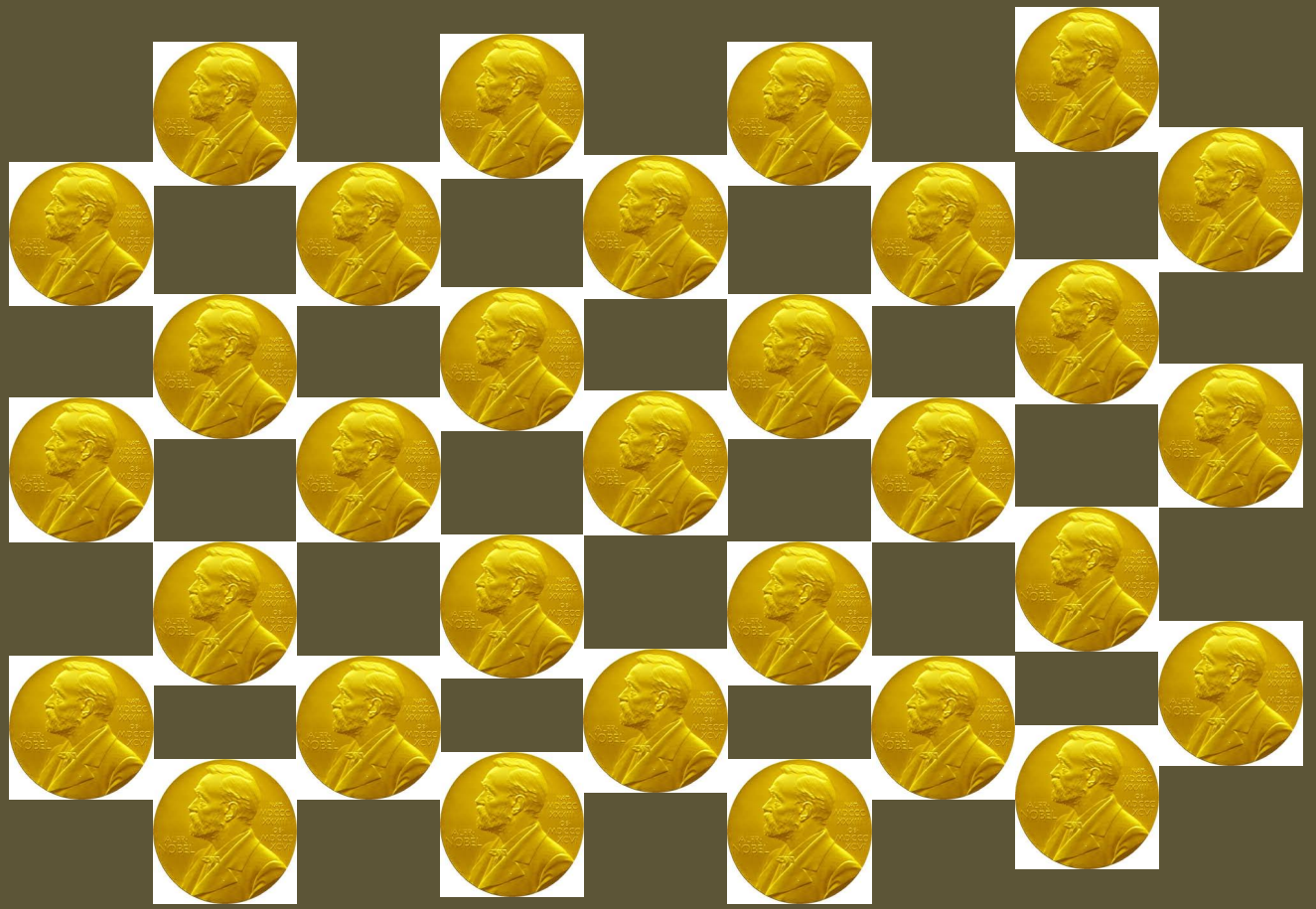
- Discovery of anti-matter
- Discovery of W & Z

Standard Model Evidence

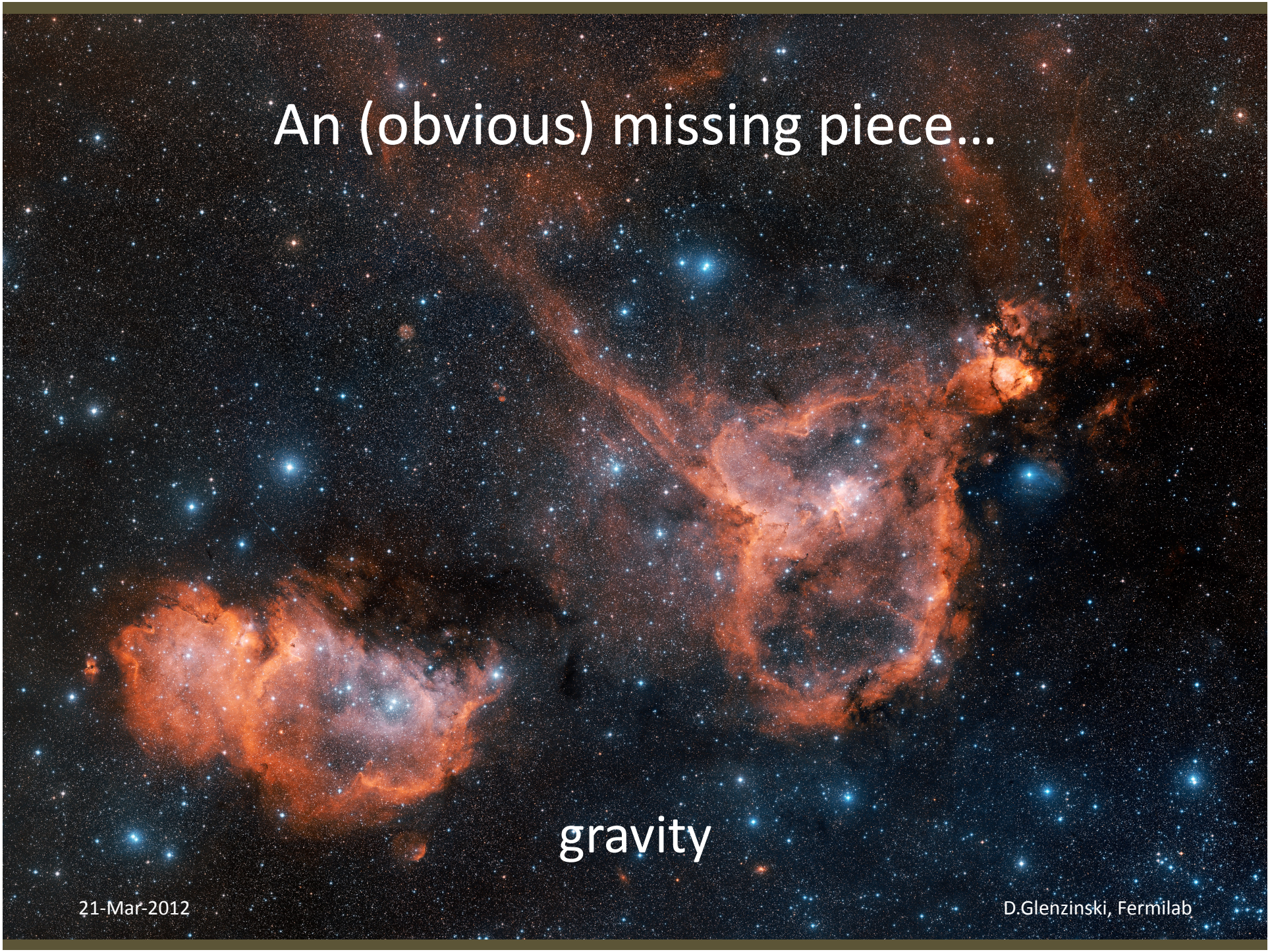


… and 1000s of additional experimental results

But there is a catch

We know the Standard Model is incomplete

An (obvious) missing piece…

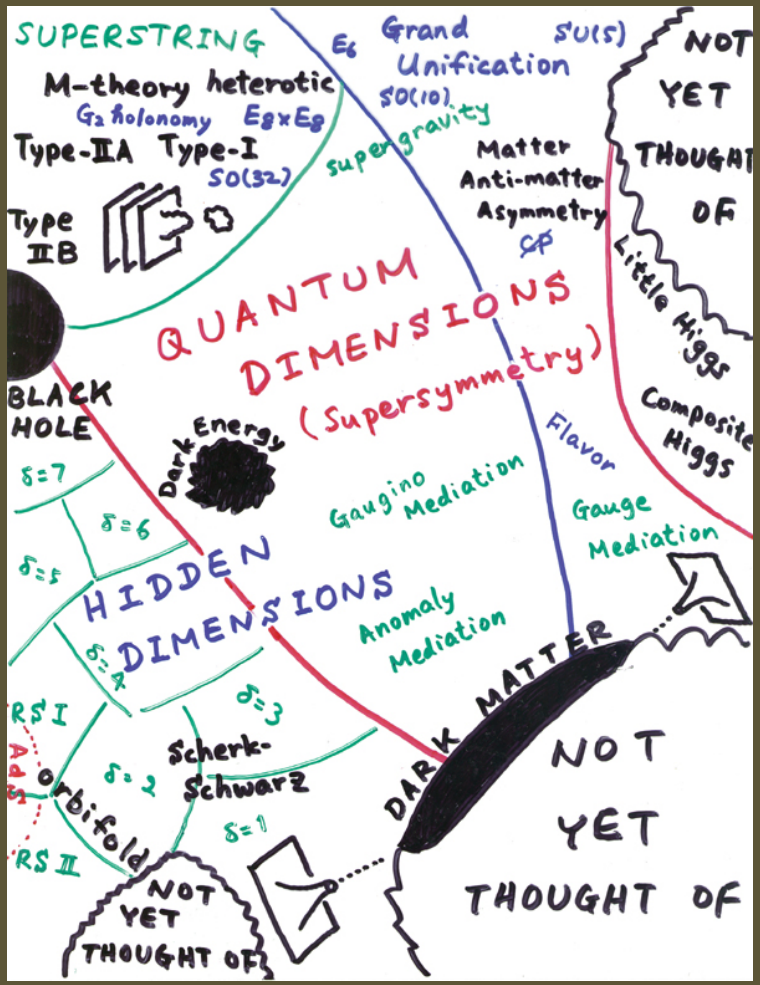


gravity

There is a catch

Standard Model only describes 5% of Universe

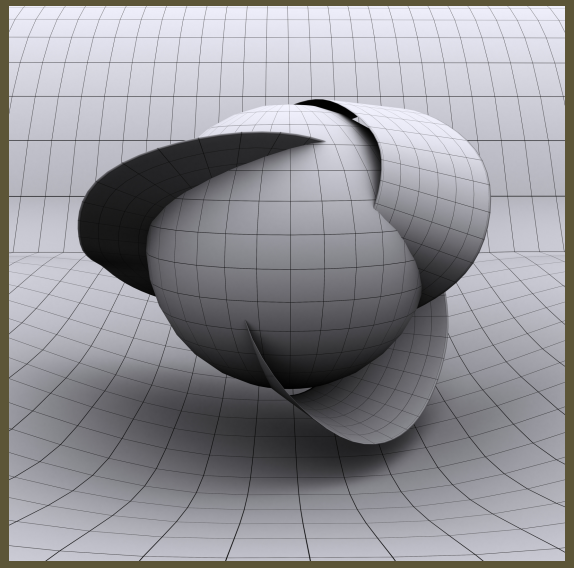
Possibilities

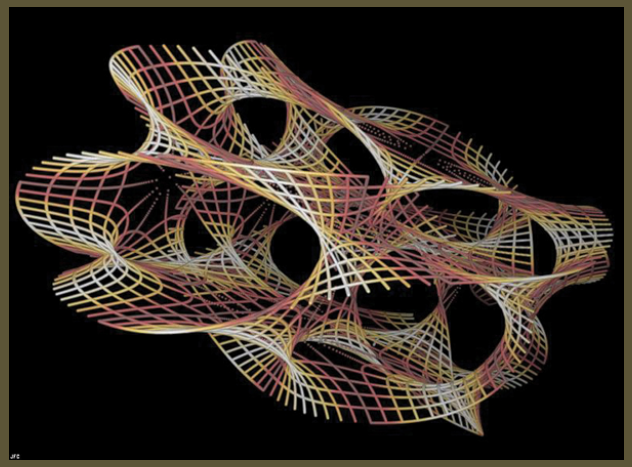


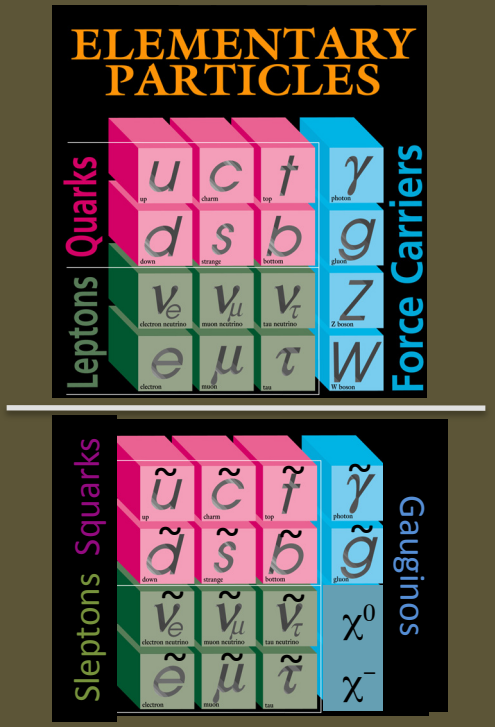
We have lots of ideas of what a more complete theory might look like…

but we don't know which one (if any) is correct.

In the future







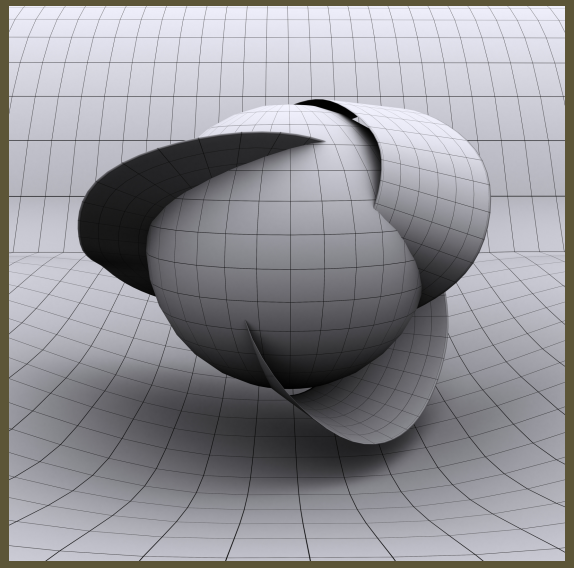
Extra Dimensions

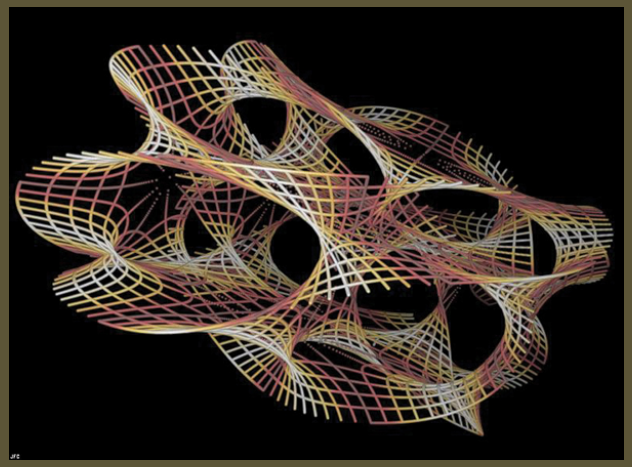
Super Strings

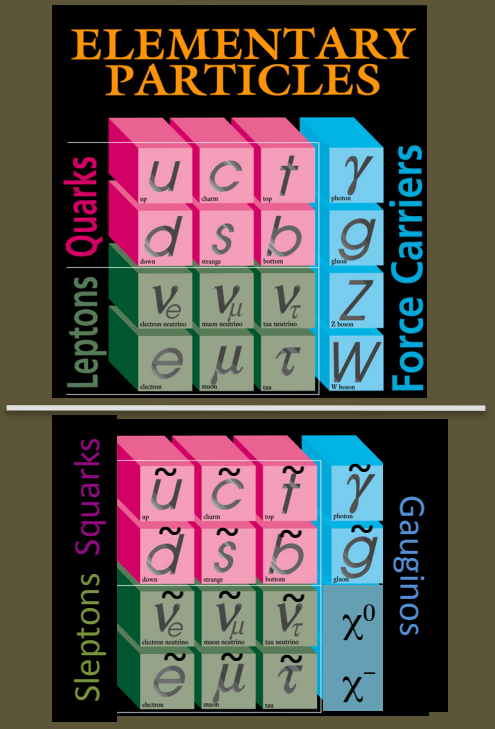
Super Symmetry

Our picture of HEP may well be very different.

In the future







Extra Dimensions

Super Strings

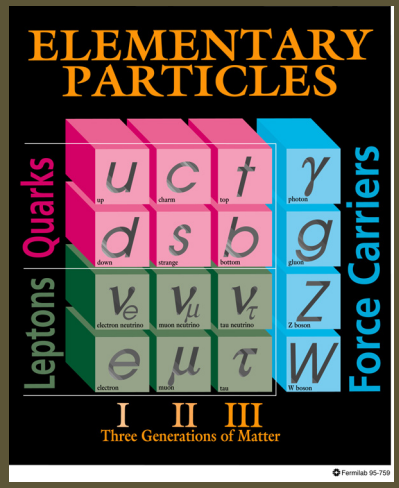
Super Symmetry

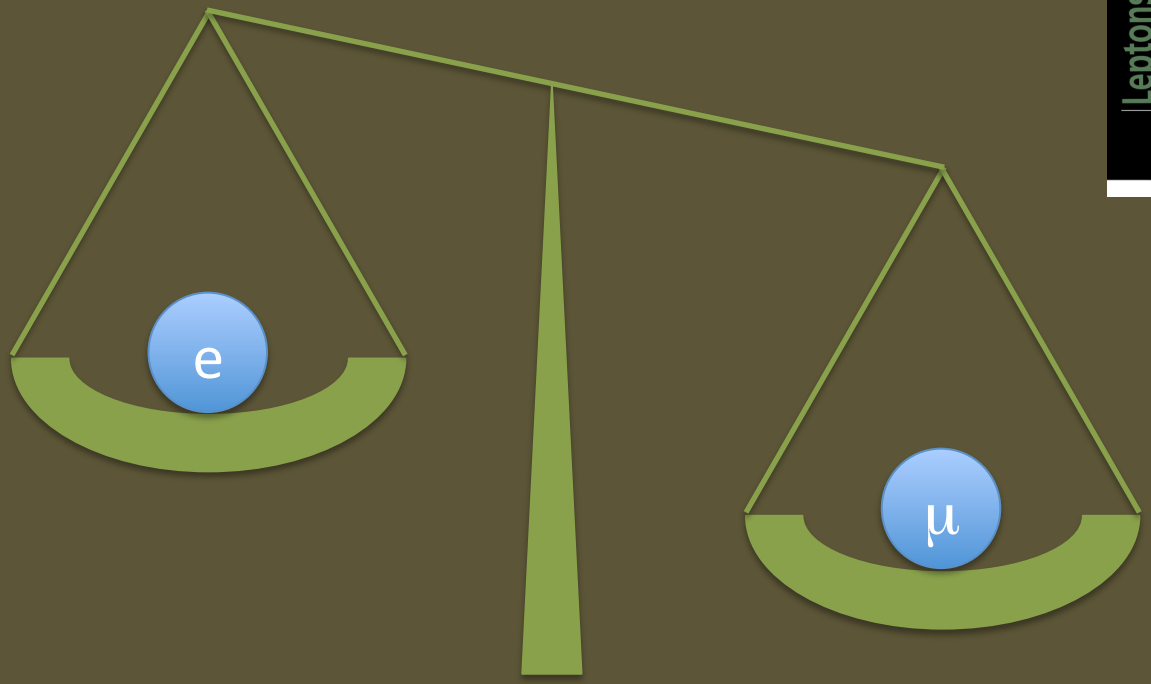
Our picture of HEP may well be very different.

We need experiments (like Mu2e) to point the way.

What is a muon?

What is a muon?





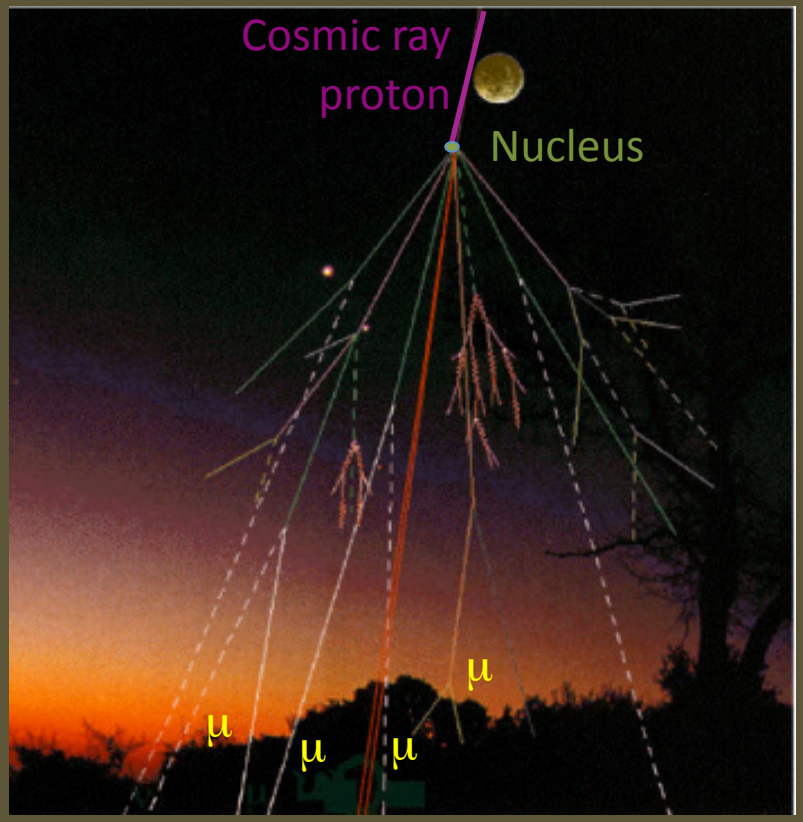
Very much like an electron… but heavier

What is a muon?

discovered in 1936 using cosmic rays

(they are streaming through us now)

What is a muon?

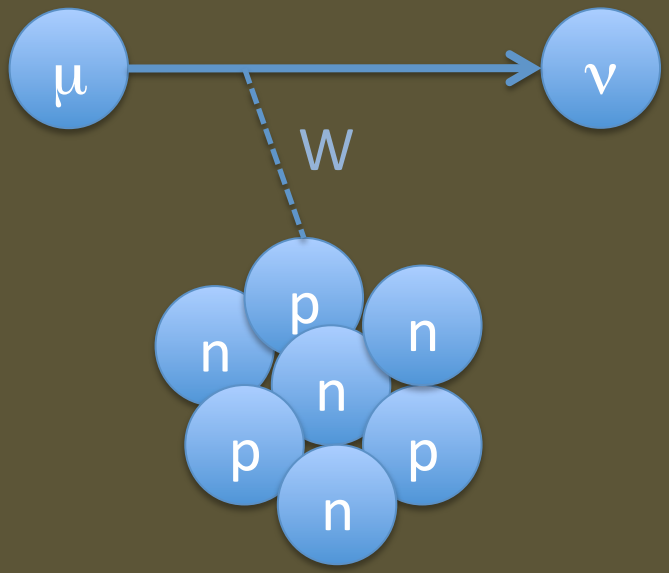


discovered in 1936 using cosmic rays

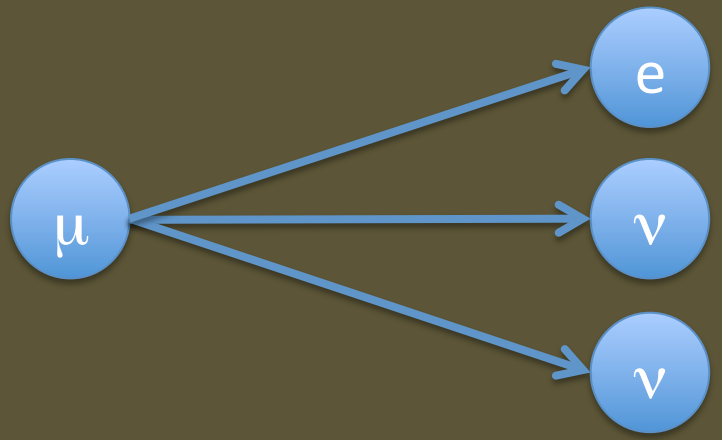
(they are streaming through us now)

What is a muon?

- μs have only ever been observed to do one of two things…



1) Interact with a nucleus to produce a ν



2) Decay into an electron and two ν

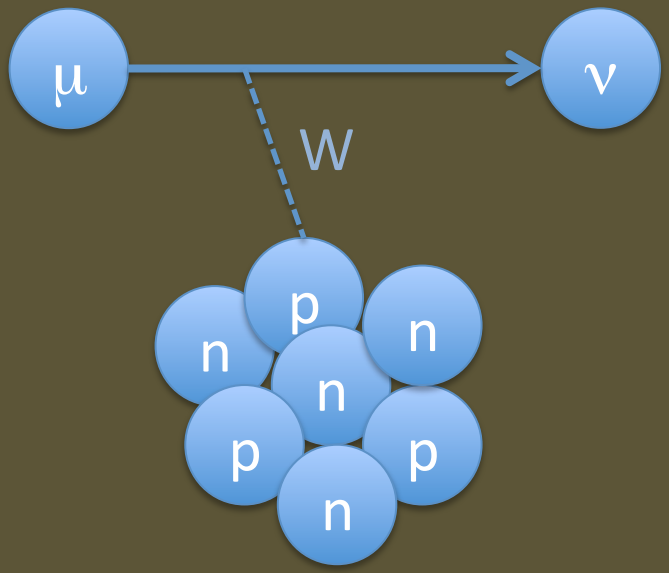
What is “Mu2e”?

What is “Mu2e”?

- A high energy physics experiment
- Uses μ_s to look for a very rare process

What is Mu2e?

- μs have only ever been observed to do one of two things…



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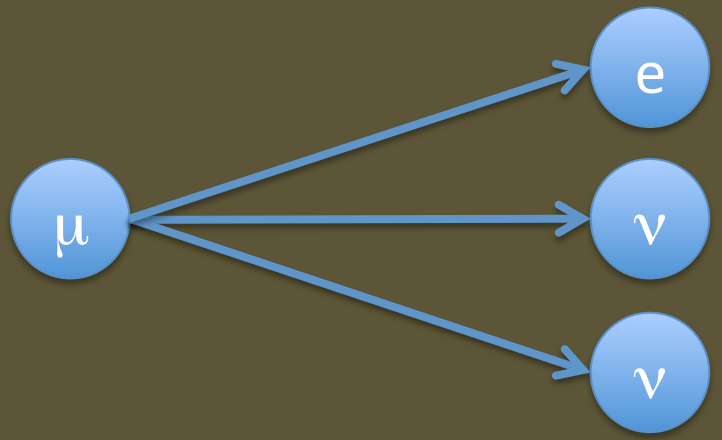
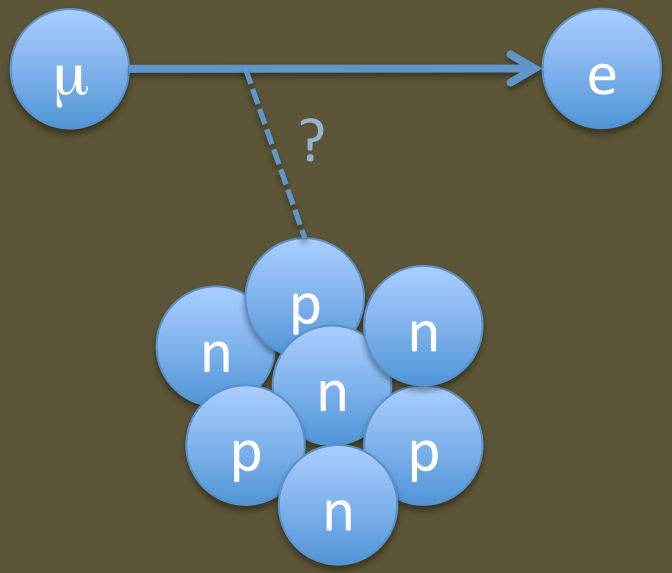


2) Decay into an electron and two ν

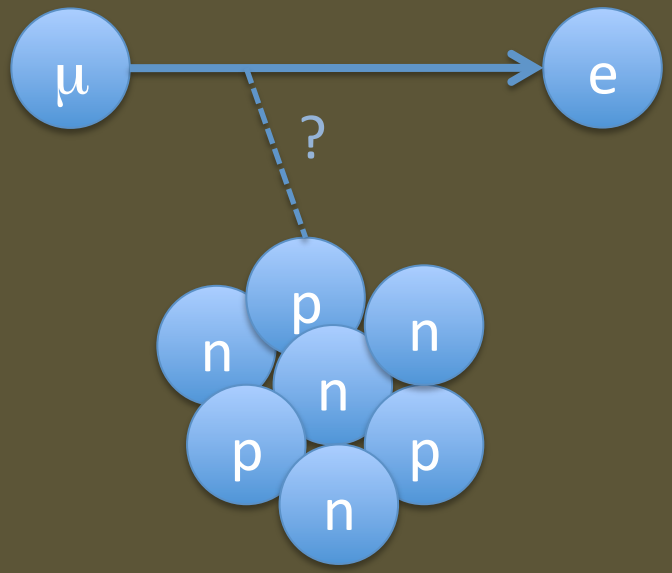
What is Mu2e?

- Mu2e is looking for evidence of a 3rd thing…



3) Interact with a nucleus to produce an electron

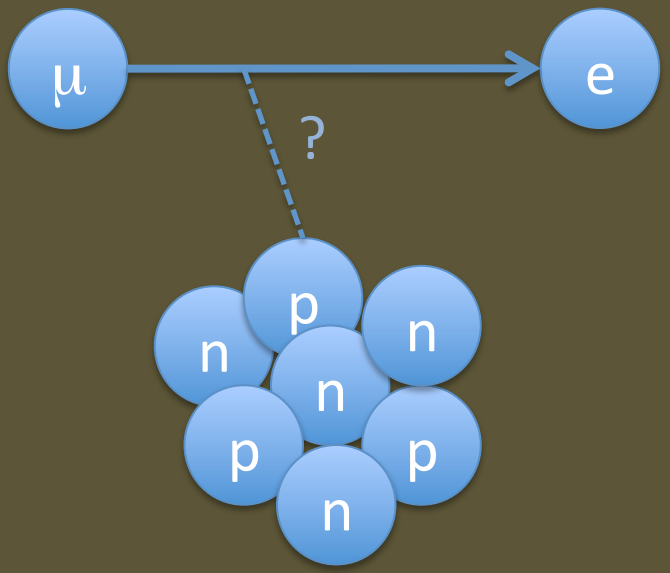
Why is Mu2e important?

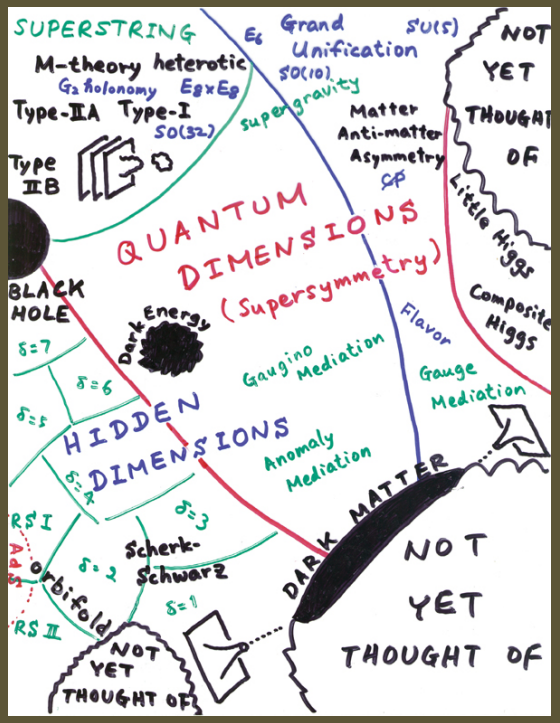


There are many ways this process can occur…

but *none* of them are in the Standard Model!

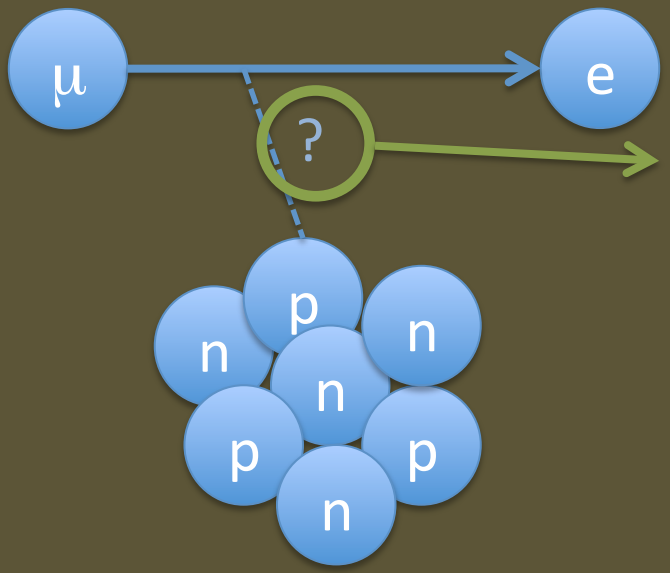
Why is Mu2e important?

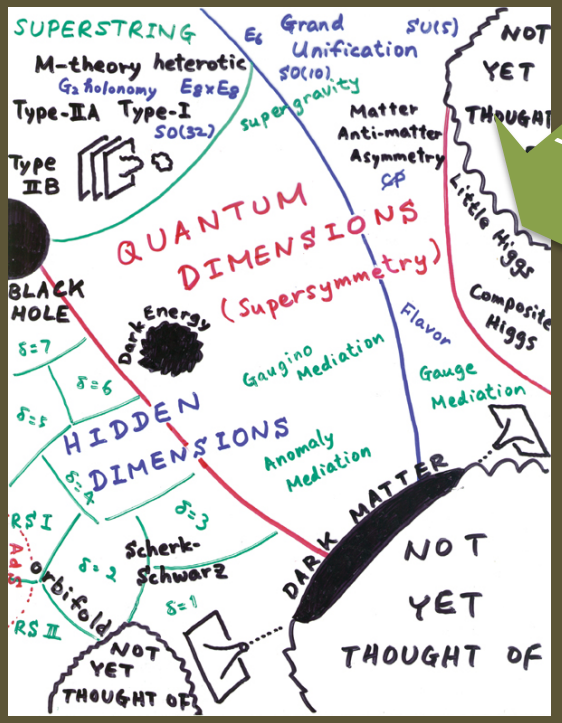




So, by measuring the rate of the μN→eN process we can test these new theories

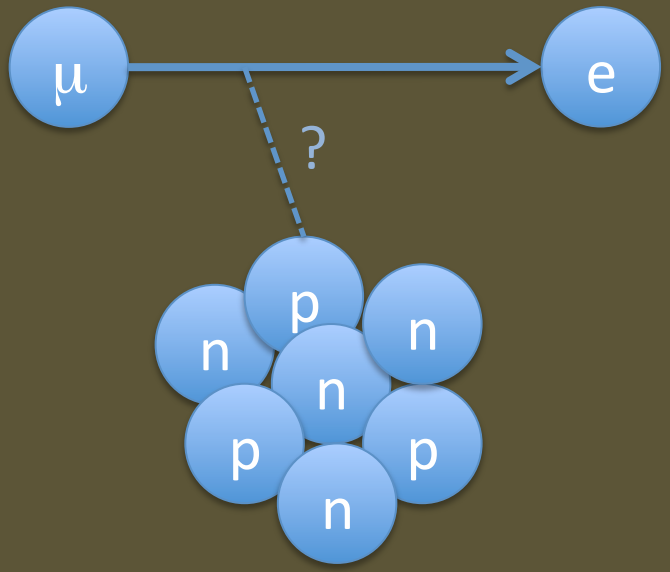
Why is Mu2e important?

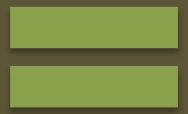


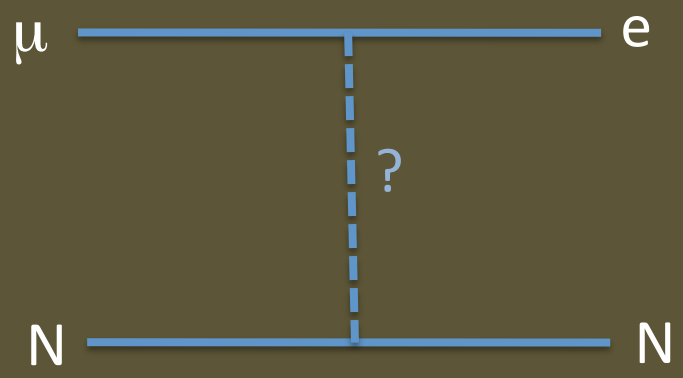


The rate tells you something about the question mark in the figure, which in turn depends on the details of the new theory

Why is Mu2e important?







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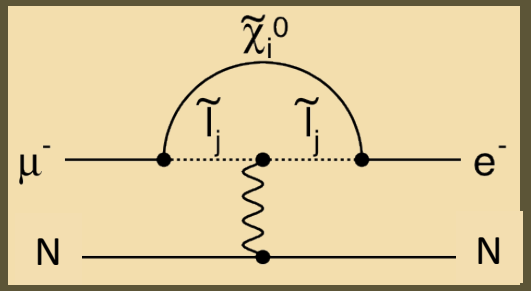
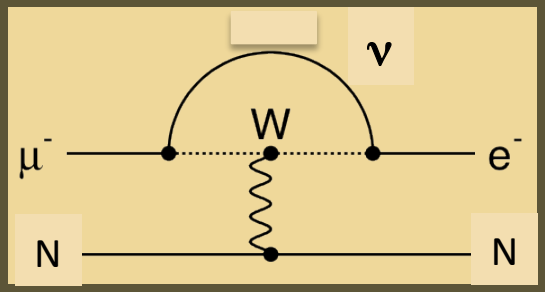
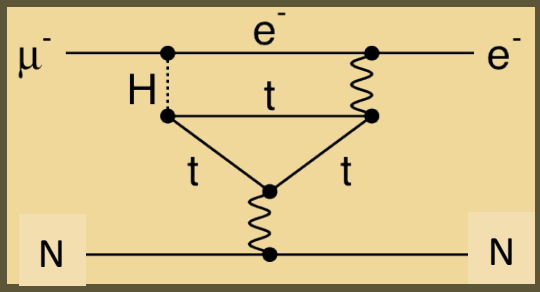


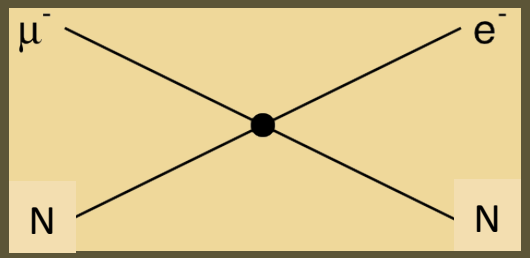
Supersymmetry



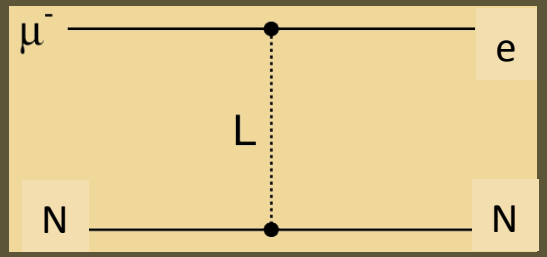
Heavy Neutrinos



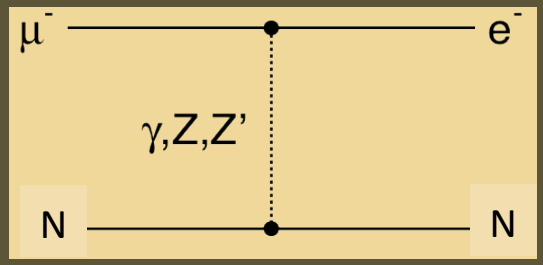
Two Higgs Doublets



Preons



Leptoquarks



New Heavy Bosons
New Forces

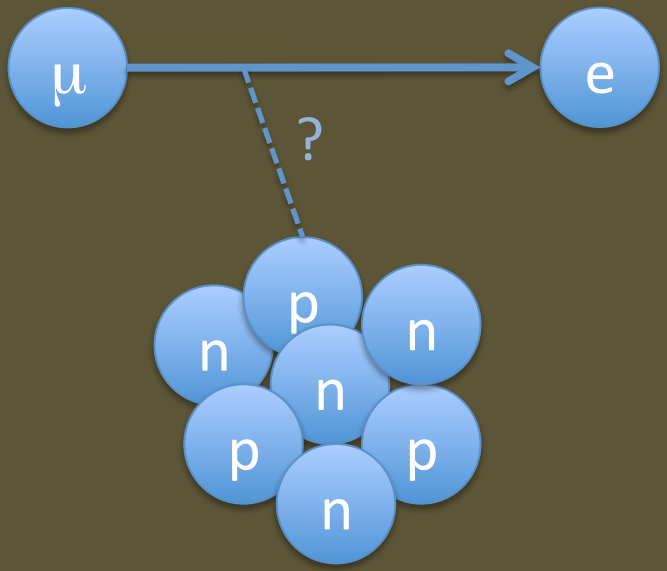
because Mu2e will be sensitive to many theories of "physics beyond the Standard Model"

Physicist Speak Decoded

"sensitive to physics beyond the Standard Model"

"can make Major Discovery"

Why is Mu2e important?



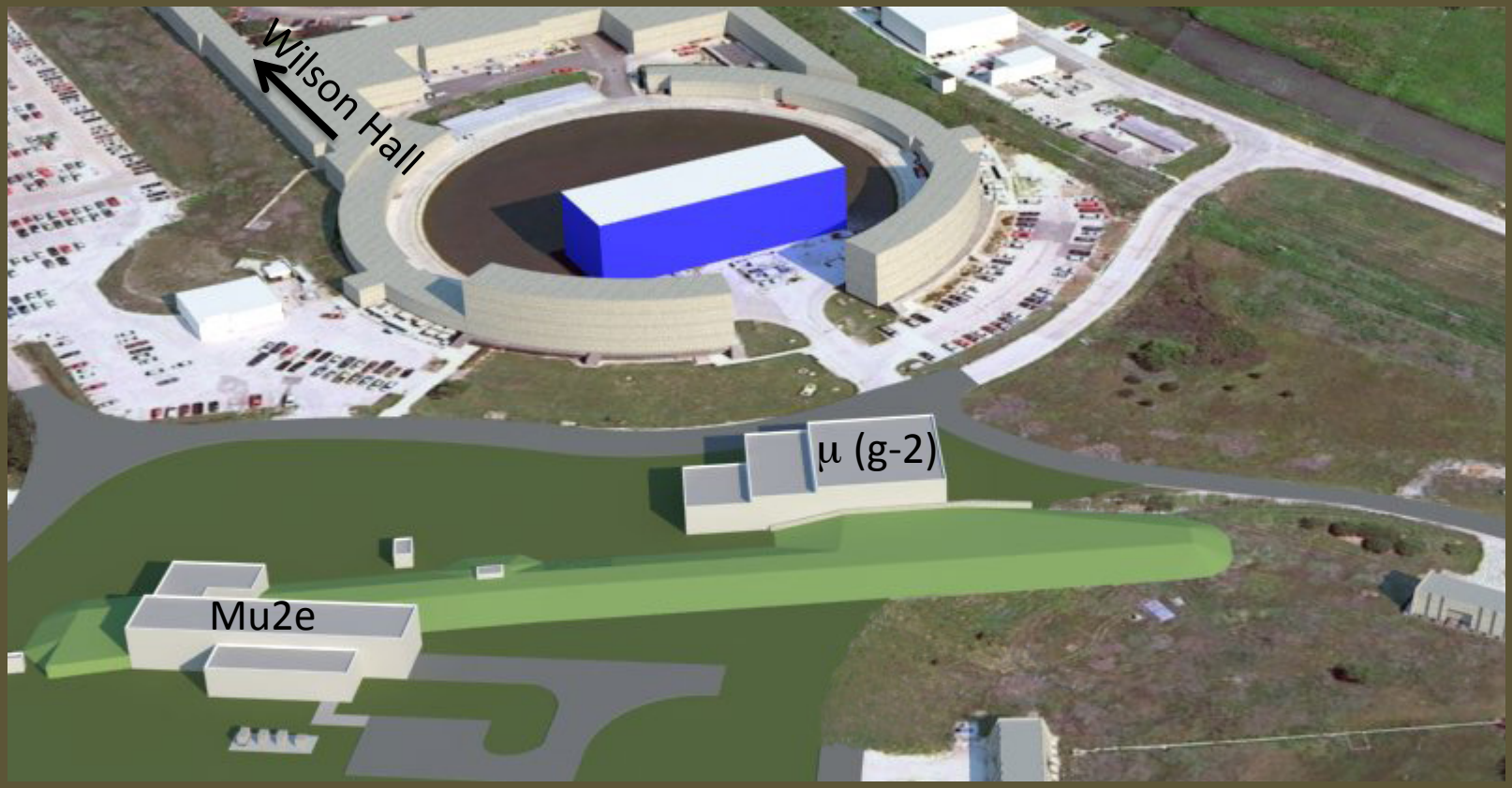
because Mu2e is poised to make a major discovery

How does Mu2e work?

How does Mu2e work?

Mu2e will recycle some of the accelerator components used by the Tevatron to make anti-protons and instead make μs

How does Mu2e work?



Mu2e will be located at a new “Muon Campus”

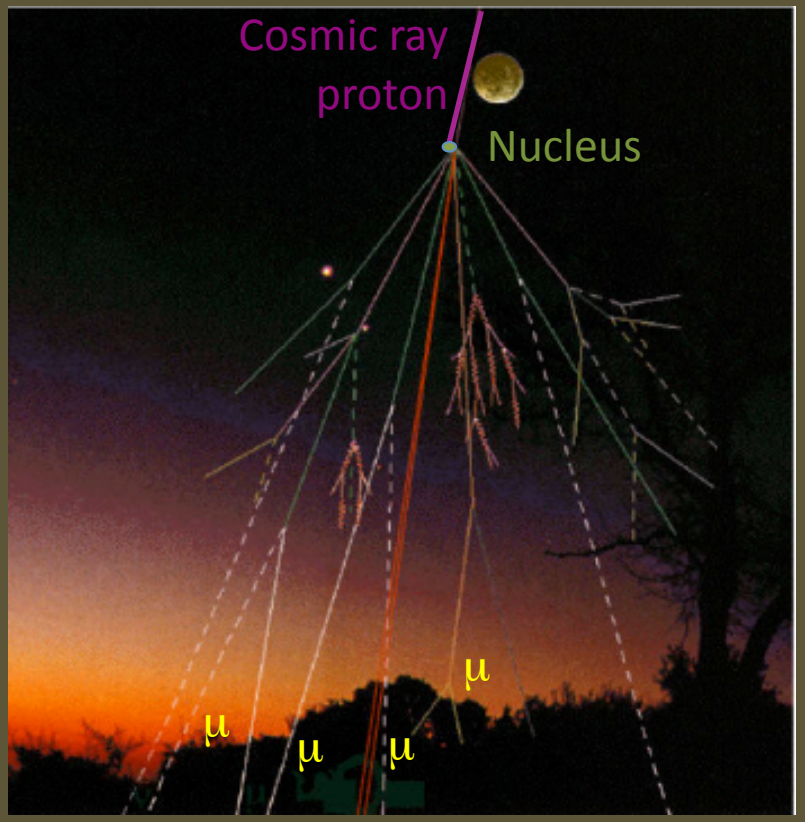
Mu2e Building

Graphic of proposed Mu2e detector hall

How does Mu2e work?

1) Make lots of μs
2) Stop them near nuclei
3) Look for electrons

Making μs

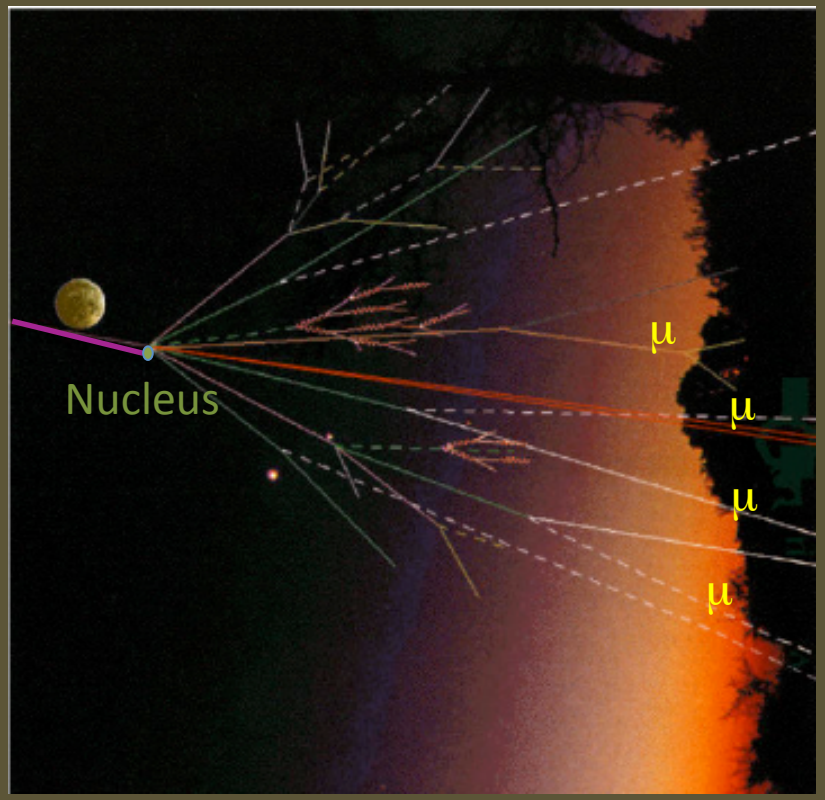


smash protons on nuclei, collect the debris

(just like cosmic rays)

Making μs

Cosmic ray proton

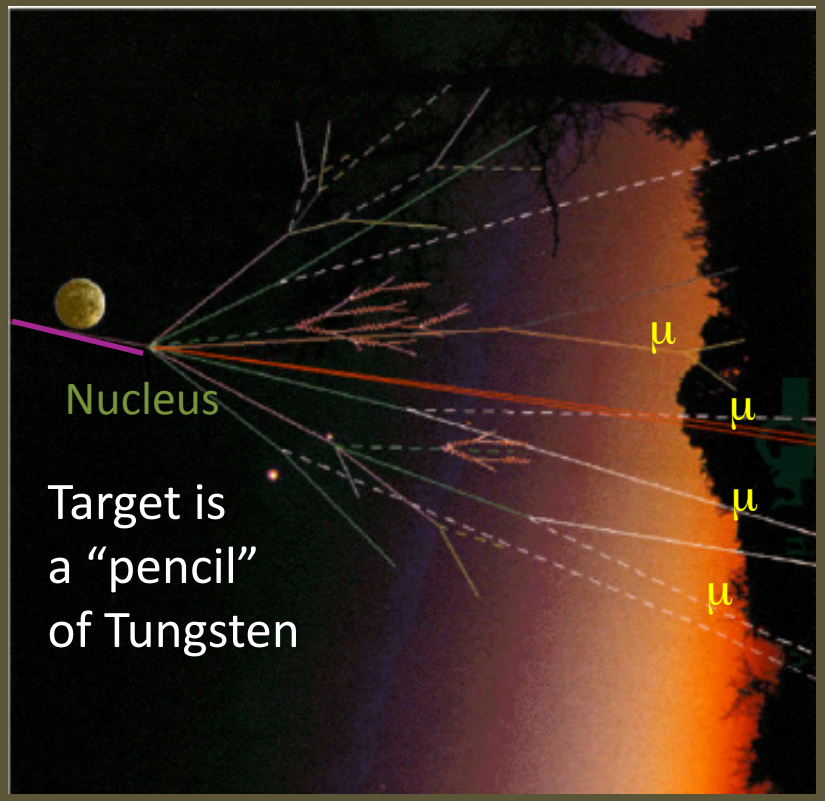


smash protons on nuclei, collect the debris

(just like cosmic rays)

Making μs

Protons from Booster
- 8 GeV kinetic energy
- 99.4% speed of light
- 667,000,000 mph



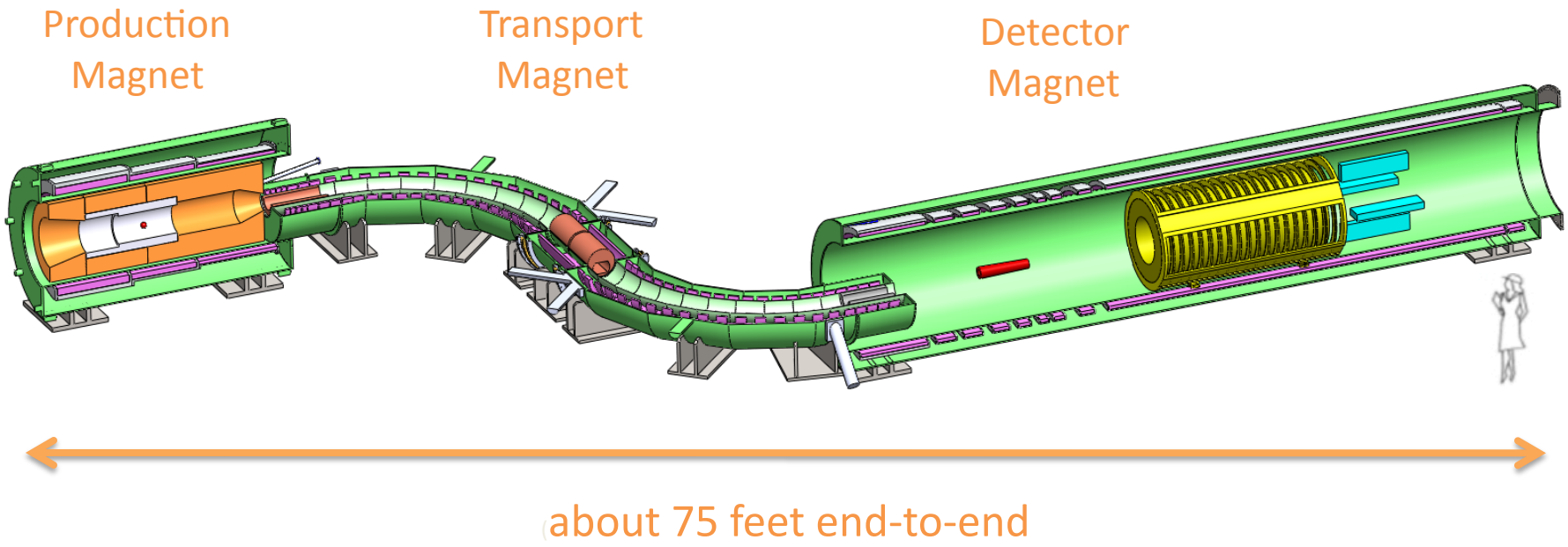
The debris eventually decays, often to μs

Use magnets to collect the μs

smash protons on nuclei, collect the debris

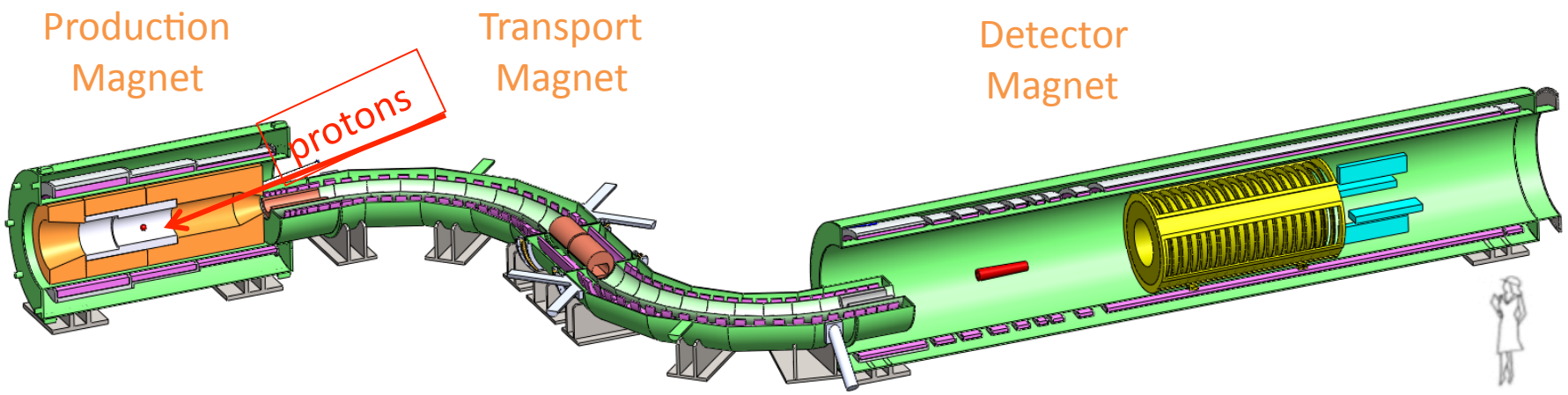
(just like cosmic rays)

Mu2e Apparatus



- Mu2e will consist of 3 magnet systems

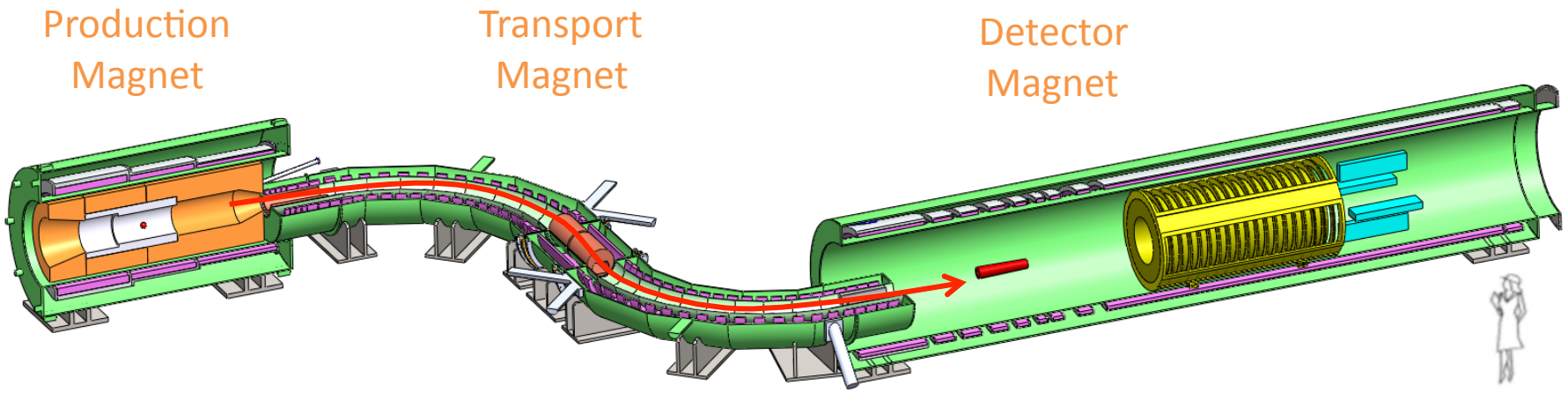
Mu2e Apparatus



Production Magnet:
this is where the μs get made

- Mu2e will consist of 3 magnet systems

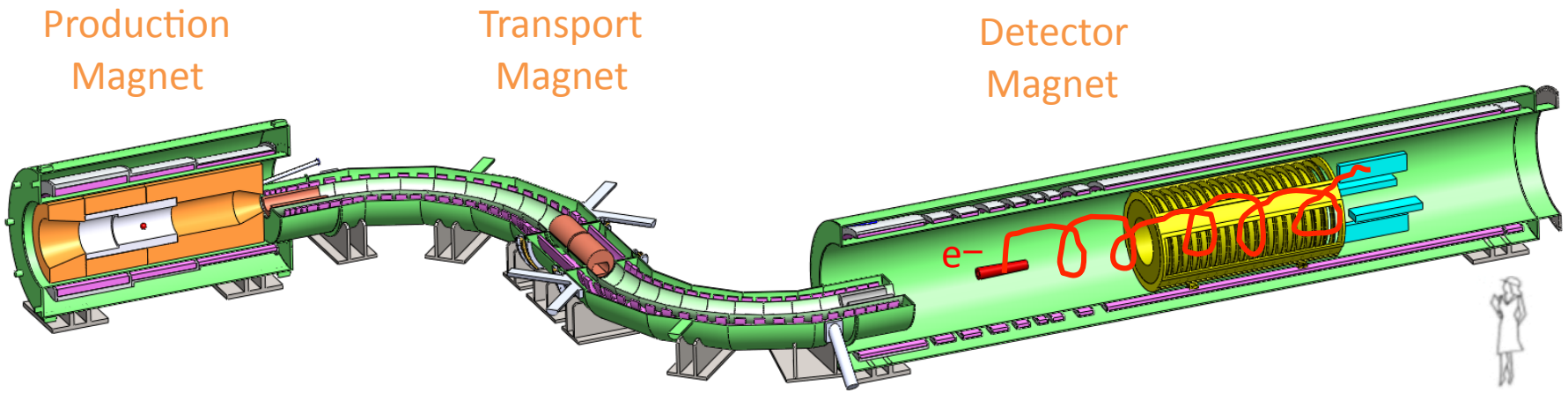
Mu2e Apparatus



Transport Magnet:
"carries" the μs to the Detector Magnet

- Mu2e will consist of 3 magnet systems

Mu2e Apparatus



Detector Magnet:
this is where we look for evidence μN→eN

- Mu2e will consist of 3 magnet systems

Some Mu2e numbers

- Every 1 second Mu2e will
  - Send 8,000,000,000,000 protons to the Production Magnet
  - Send 26,000,000,000 μs through the Transport Magnet
  - Stop 13,000,000,000, μs in the Detector Magnet
- By the time Mu2e is done, about 1,000,000,000,000,000,000 stopped μs

Some Perspective

1,000,000,000,000,000,000

= number of stopped Mu2e muons

= number of grains of sand on earth

Why so many?

- The new theories predict that the rate of $\mu N \rightarrow eN$ will occur at most

$$\frac{1}{1{,}000{,}000{,}000{,}000{,}000}$$

- This is a very very very very very very very very small rate… so you need a lot of μs to observe and measure it.

What is the status of Mu2e?

- Mu2e is currently in the Conceptual Design phase
- Mu2e hopes to break ground on the building within the next few years
- Mu2e plans to begin taking data by the end of this decade

The end is nigh

Summary

- High Energy Physics aims to answer two simple questions
  - What are the fundamental particles of nature?
  - What forces govern their interactions?
- We have a pretty good answer, the Standard Model

Summary

- High Energy Physics is at a crossroads
  - We know that the Standard Model is incomplete
  - We have lots of ideas about what a more complete model might look like
  - … but we have no idea which is the right one

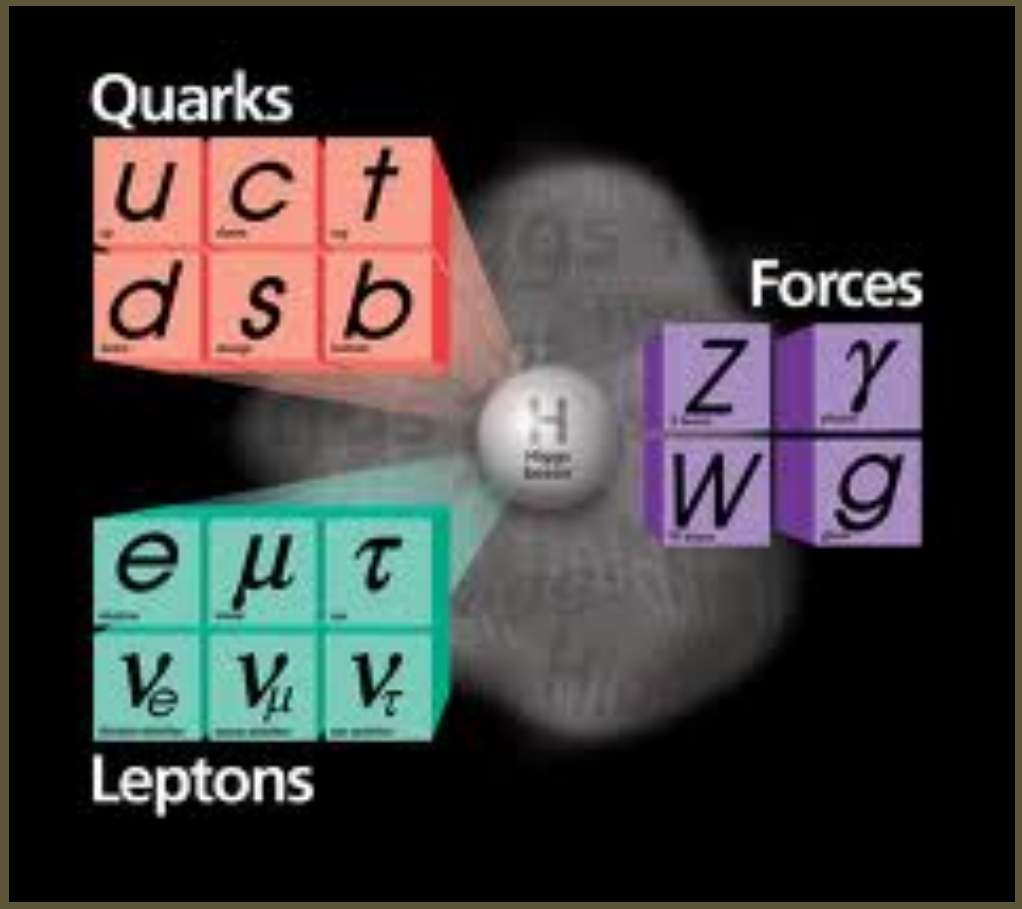
Summary

Fermilab's Mu2e experiment is important because it is designed to discover which direction is the right one

Thank You!

Additional Slides

Standard Model



Higgs boson gives mass to the quarks and leptons
(has not been verified experimentally)

Discoveries

What	When	Who	How
electron	1897	Thompson	cathodes
anti-electron	1932	Anderson	Cosmic rays
muon	1936	Anderson/Neddermeyer	Cosmic rays
tau	1975	Perl	SLAC ee→em
nu_e	1956	Cowan, Reines	nu+p → e + n
nu_mu	1962	Lederman,Steinberger,Schwartz	BNL, pion decay
nu_tau	2000	DONUT Collaboration	Fermilab
u, d, s quarks	1968	Breidenbach, Freidman, Kendall	SLAC, DIS
c quark	1974	Richter, Ting	BNL, SLAC
b quark	1977	Lederman	Fermilab
t quark	1995	CDF, D0 Collaborations	Fermilab
photon	1905	Einstein	Theory work
gluon	1978	PLUTO Collaboration	DESY
W & Z bosons	1983	Rubbia, Van de Meer	CERN