Fermilab: The Next Decade and Beyond

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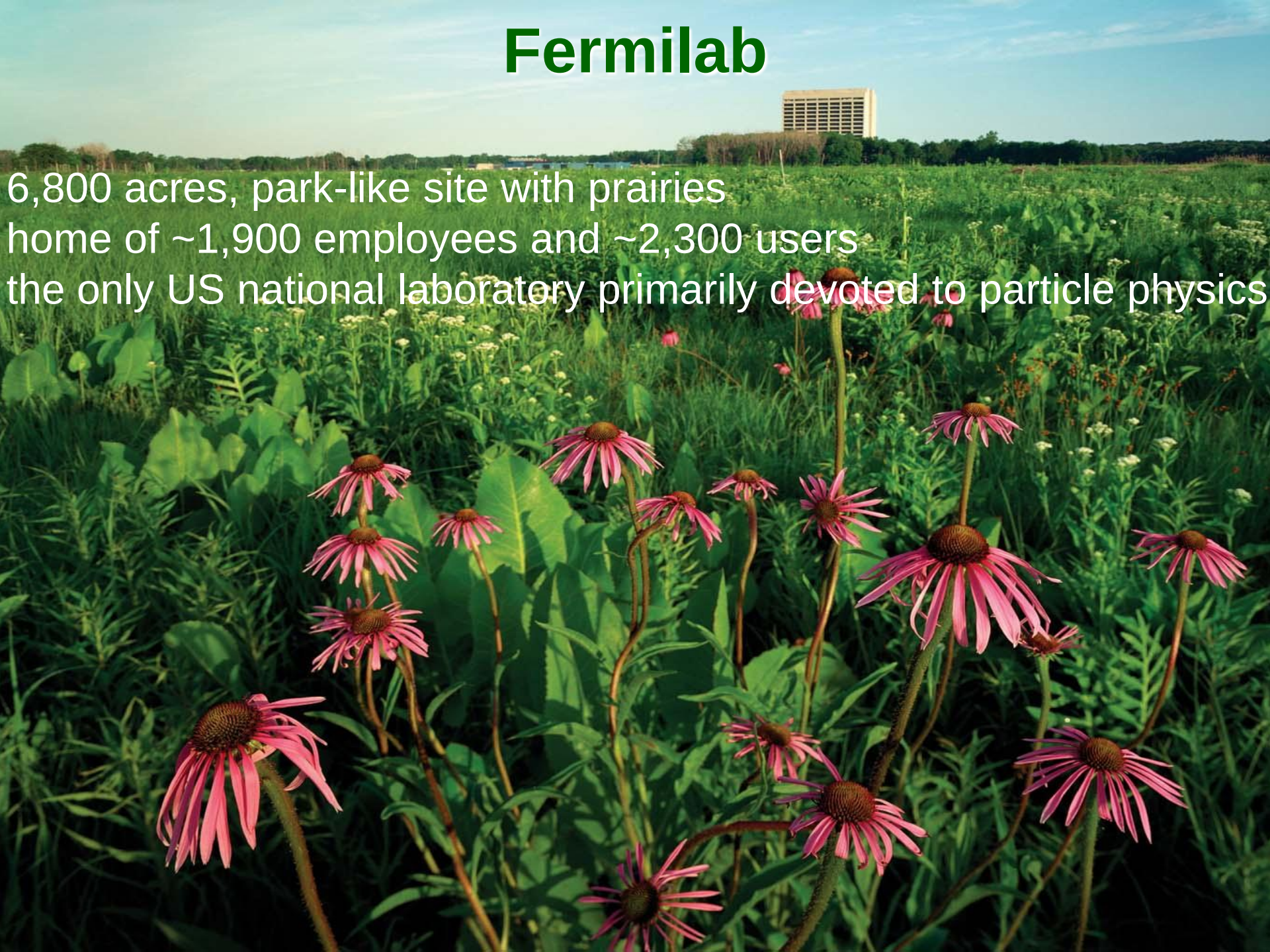
Deputy Director, Fermilab
The University of Chicago

Excellence in Detectors and Instrumentation Technologies
February 13 – 24, 2012, Fermilab

Fermilab



6,800 acres, park-like site with prairies
home of ~1,900 employees and ~2,300 users
the only US national laboratory primarily devoted to particle physics

Particle Physics

What is the universe made of?
What holds it together?
Where did we come from?

Elementary Particles and Small Distance and Early Universe

Early universe: high temperature T

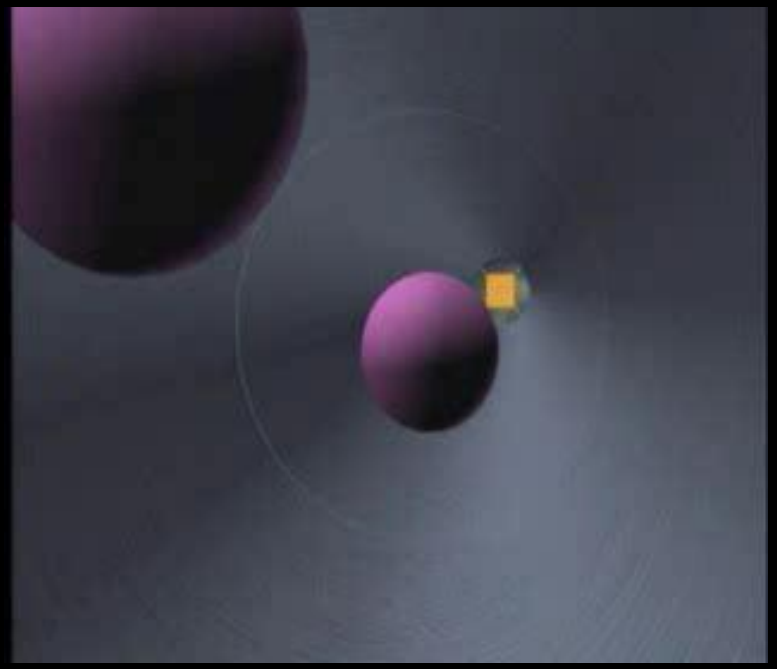
High energy $E = kT$

High momentum $p = E/c$

Small distance $x = \hbar/p$

Early universe: elementary particles play important roles

Accelerators are ultimate microscopes.
Accelerators create exotic-particle beams.



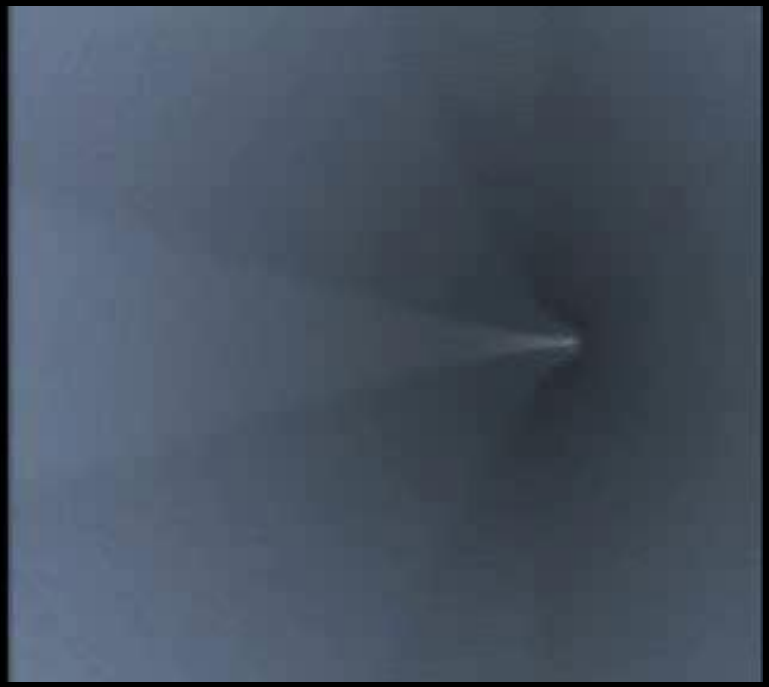
proton accelerator

kaon
pion → muon + neutrino
…..

anti-proton

Accelerators are ultimate microscopes.
Accelerators create exotic-particle beams.

They make particles last seen
in the earliest moments of the universe.



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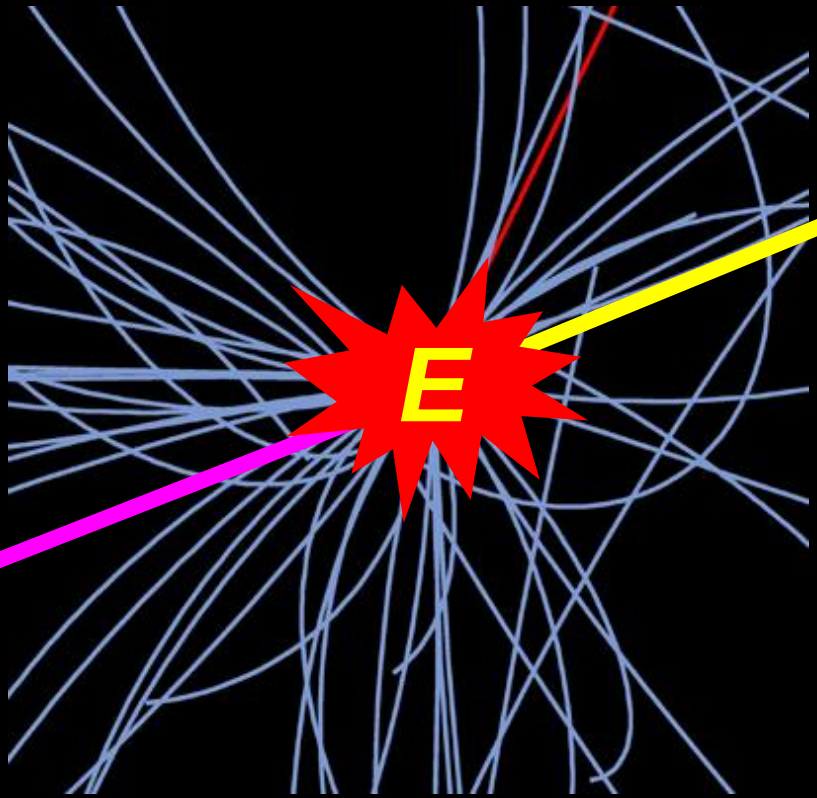
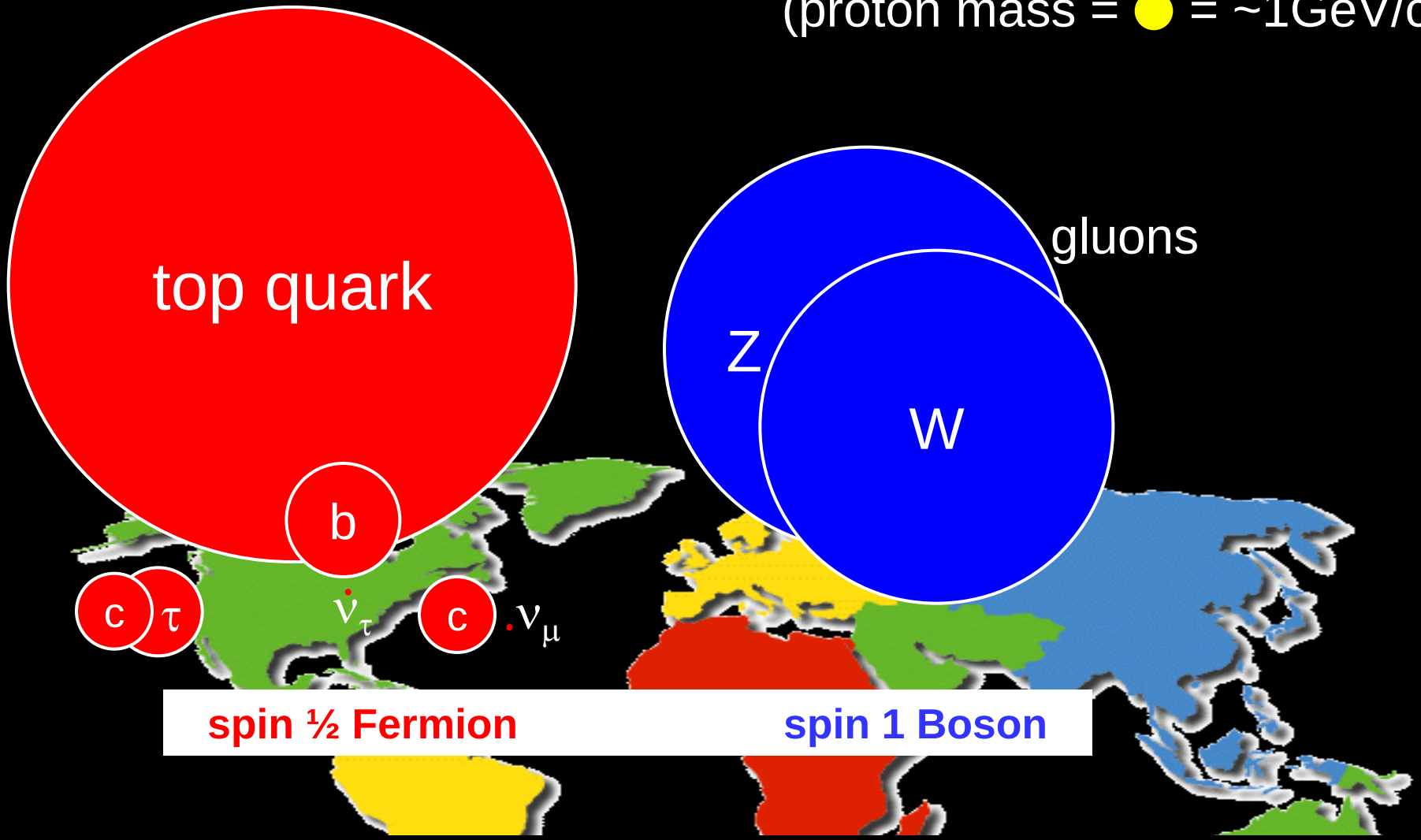


anti particle

particle

$E = Mc^2$

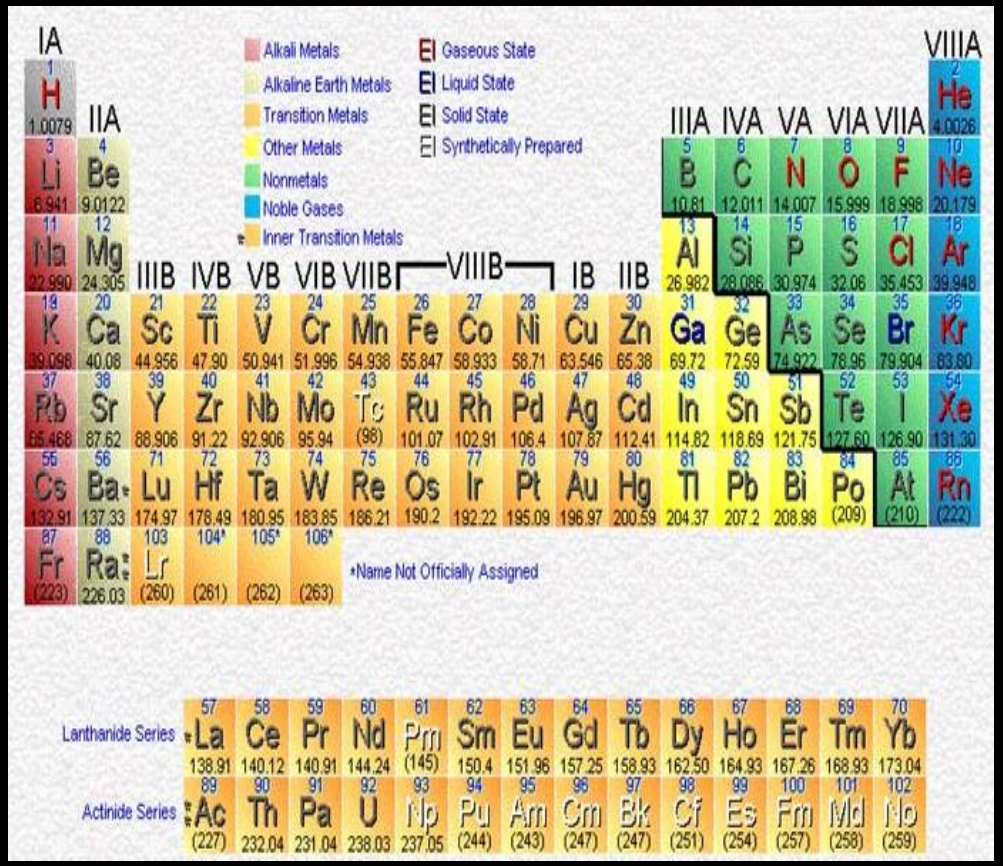
(proton mass = ● = ~1GeV/c^2)



Accelerators (colliders, intense beams) playing crucial roles in discovering new particles and interactions between particles, and understanding their properties

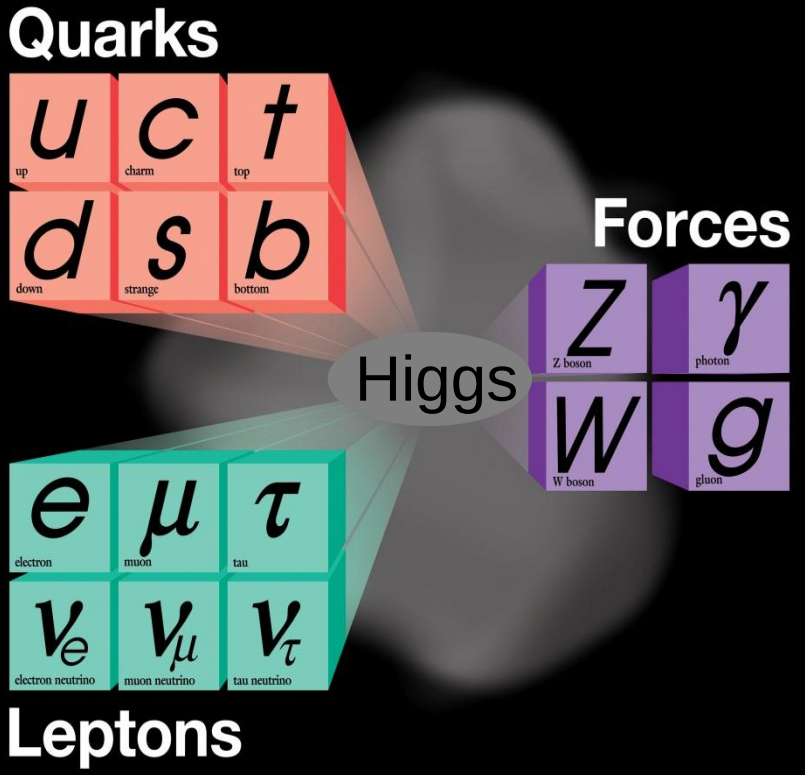
Accomplishment of the 19th Century

Periodic Table of Elements



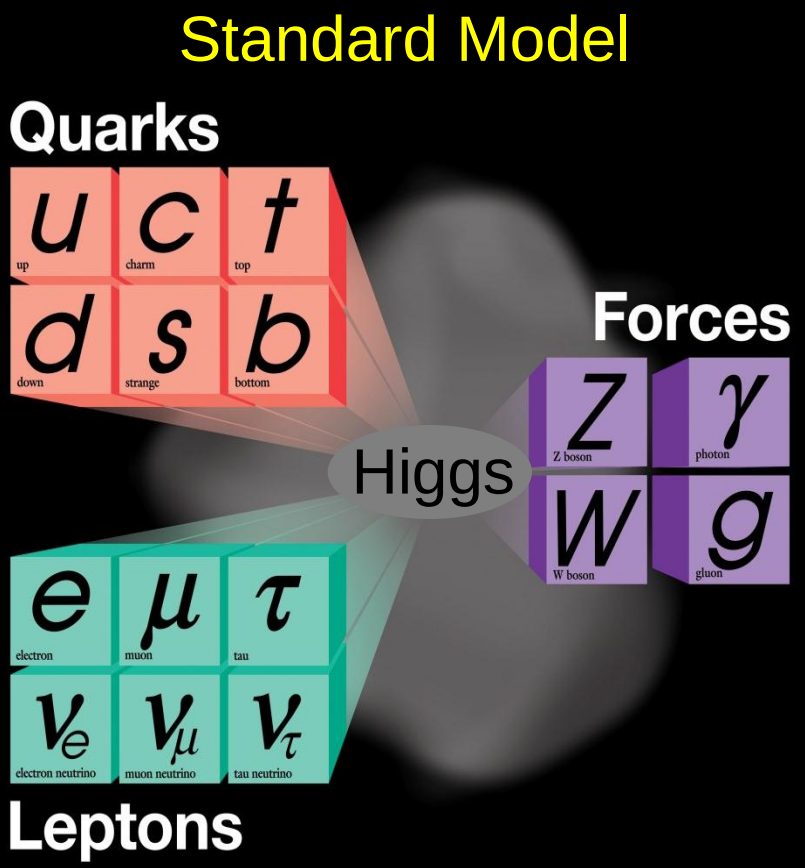
Accomplishment of the 20th Century

Table of Elementary Particles
Standard Model



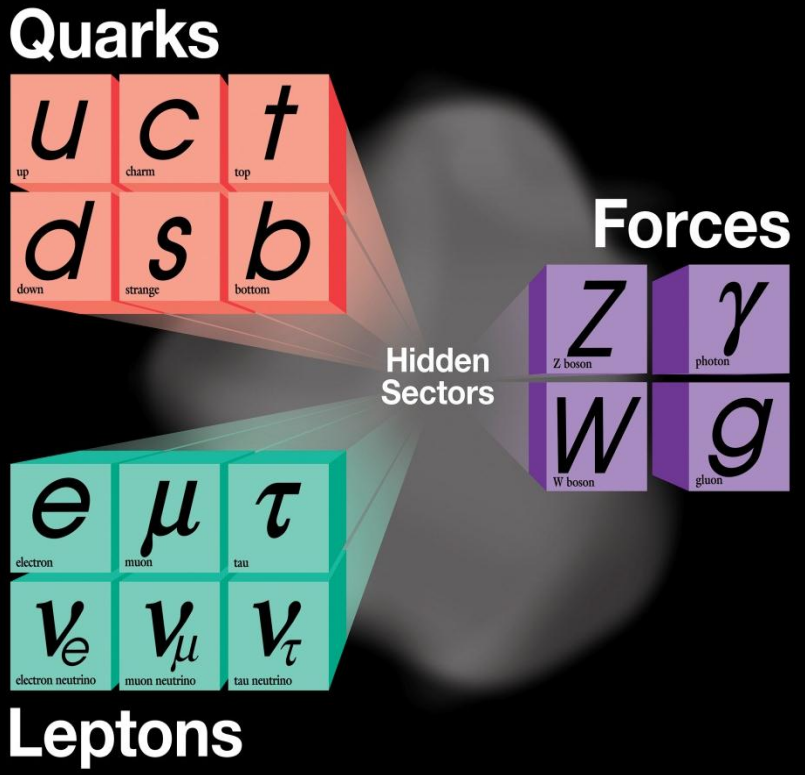
The triumphs……

- The present theory is a remarkable intellectual construction
- Particle experimental results beautifully fit in this framework
- BUT, Standard Model is not good enough, new physics is required.



..... and the mysteries

- Why?
- Why?
- Why?



Particle Physics

What is the universe made of?
What holds it together?
Where did we come from?

Primitive Thinker

21st Century Questions in Particle Physics

- Origin of mass for elementary particles?
- Where did all antimatter go?
- What do neutrinos tell us?
- Do charged leptons oscillate?
- Why three families of quarks and leptons?
- Do all forces become one?
- Extra dimensions?
- Will protons ever decay?
- Supersymmetry or other new symmetries?
- What is dark matter?
- What is dark energy?

Evolved Thinker

How do we make progress?

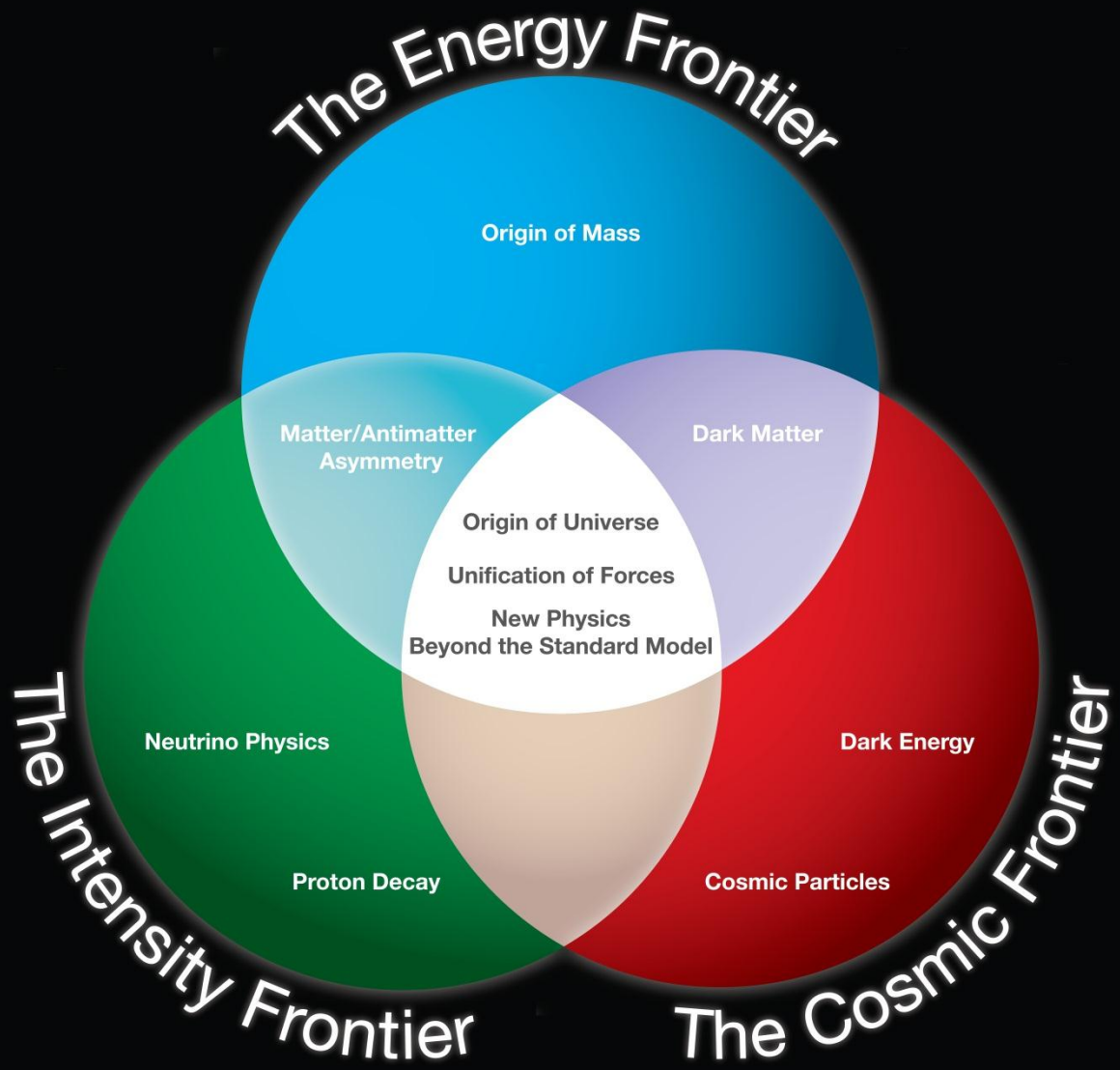
Go to:

Highest energies
Shortest distances
Earliest moments of the Universe

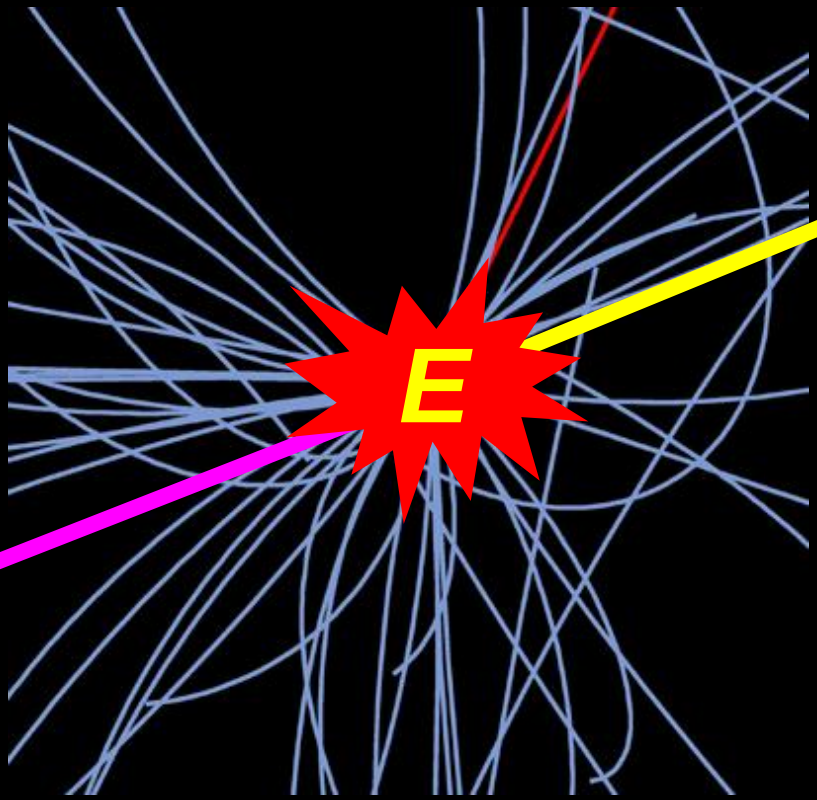
Reveal laws of nature: ~complete and ~elegant

Answer the questions and understand our origin

Tools for the Future



Energy Frontier



anti particle

particle

$E = Mc^2$

a few TeV

Intensity Frontier

Discover the nature of massive known & NEW particles indirectly by intense beams of charged leptons and quarks

Quantum Fluctuation

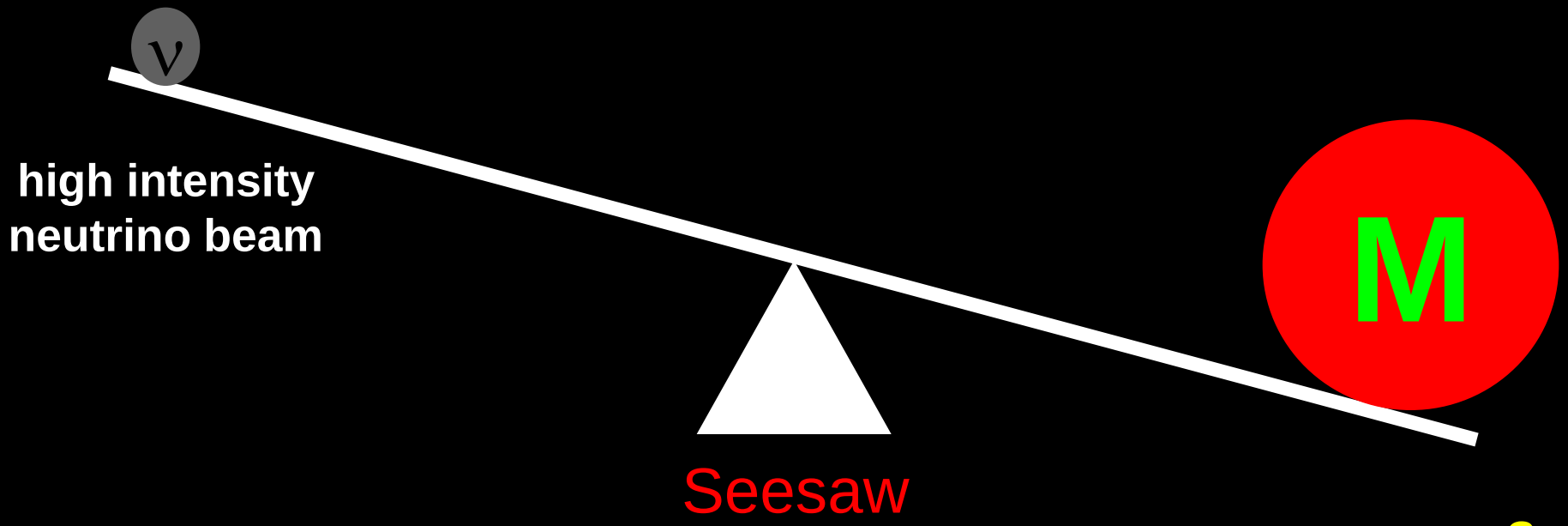
Uncertainty Principle

$E = Mc^2$

~10^4 TeV

Intensity Frontier

Probe even more massive NEW particles
by intense neutrino beams

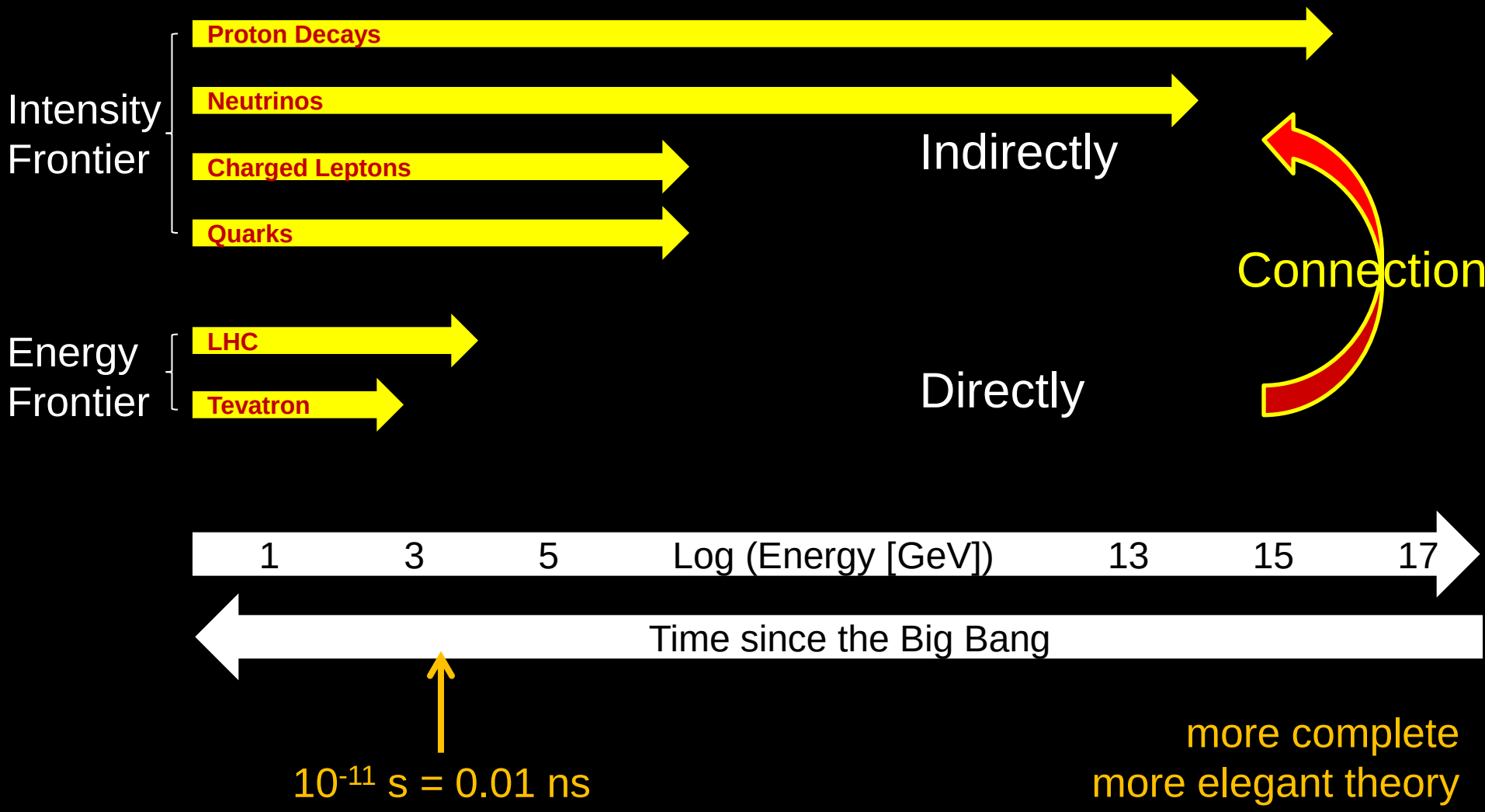


$m_\nu \times m_N \sim (m_{quark})^2$

$E = Mc^2$

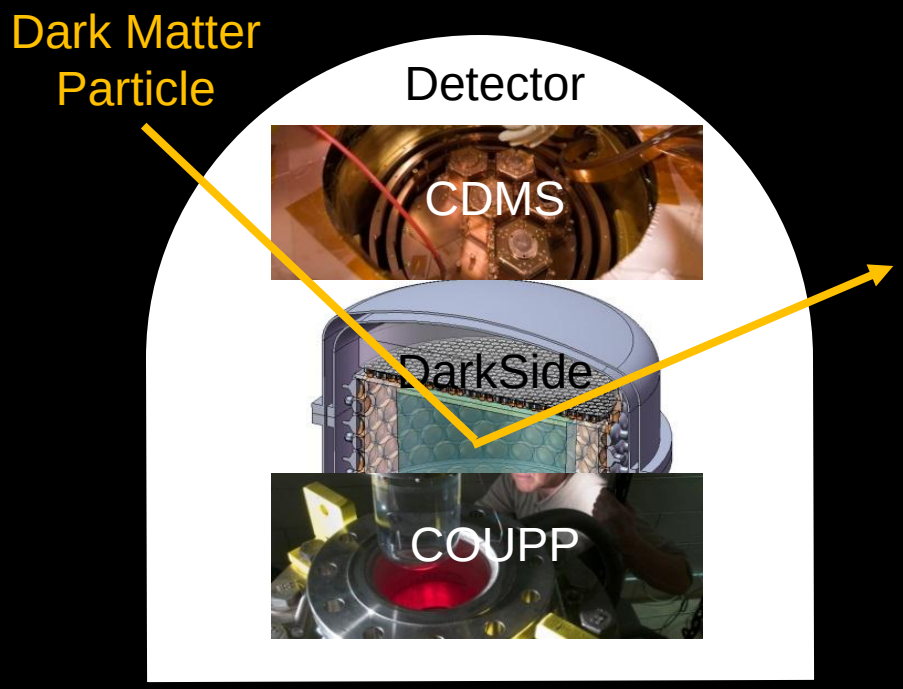
$\sim 10^{12}$ TeV

Experimental reach (model dependent)



Cosmic Frontier at Fermilab

Dark Matter Detector

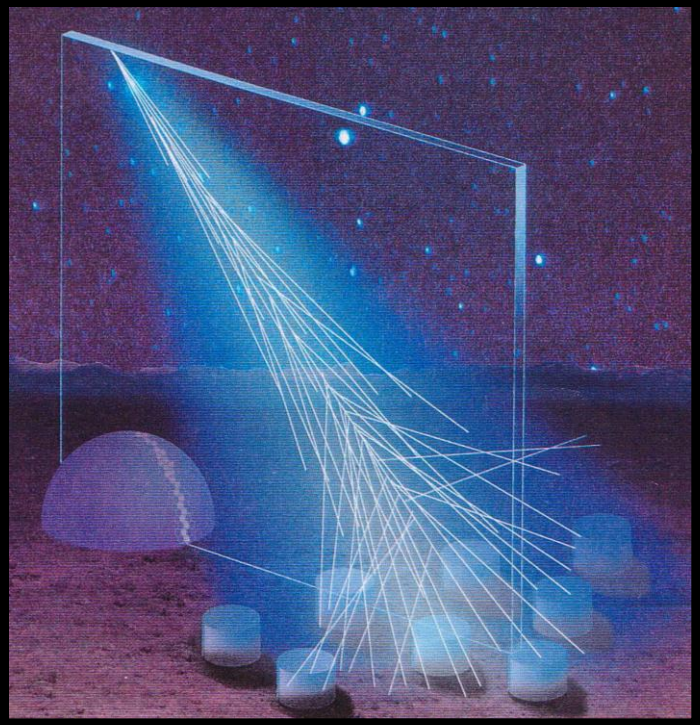


Detectors
in underground facilities

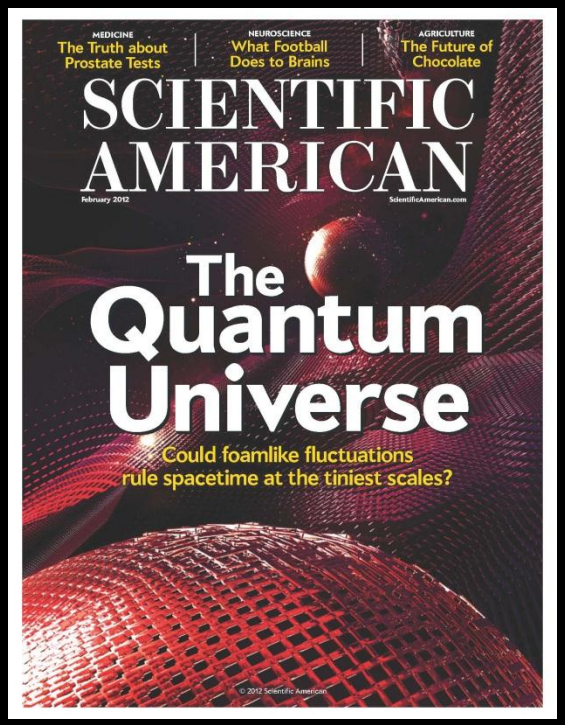
Dark Energy Camera

Cosmic Frontier at Fermilab

Exploring
Highest Cosmic Ray Particles
(Auger)



Exploring
Quantum Space-time
(Fermilab Holometer)



Energy Frontier at Fermilab

Remote Control Room at Fermilab

Fermilab★

★CERN

Tevatron

$p\bar{p}$: 2 TeV

LHC

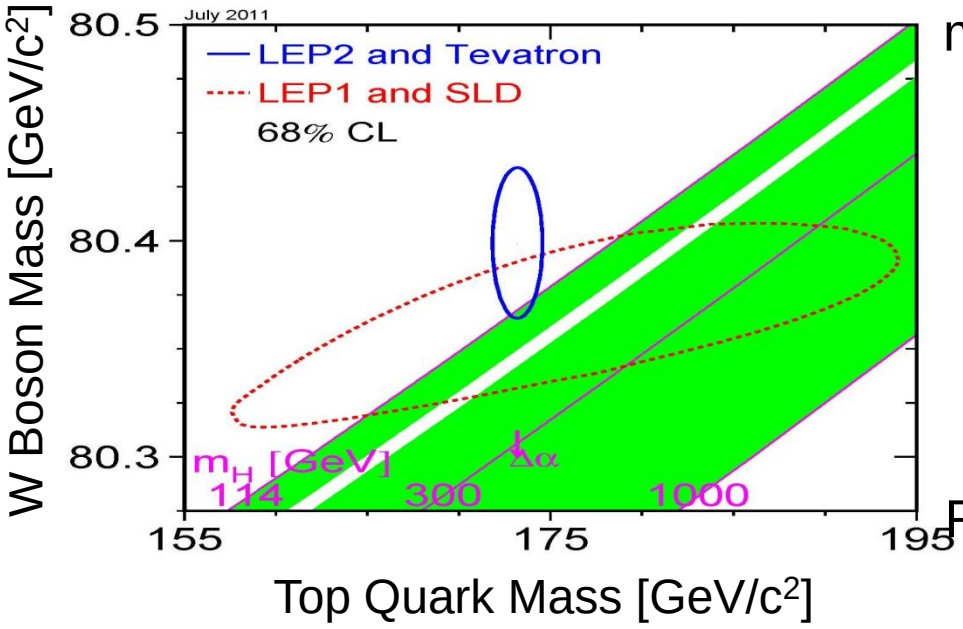
pp: 7 TeV → 14 TeV

(energy decision)

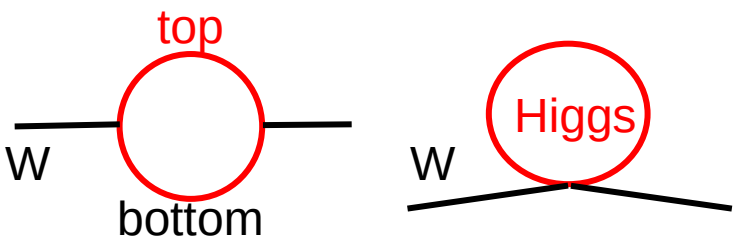
Lepton Collider

(ILC, Muon Collider)

Origin of Mass: Higgs Boson



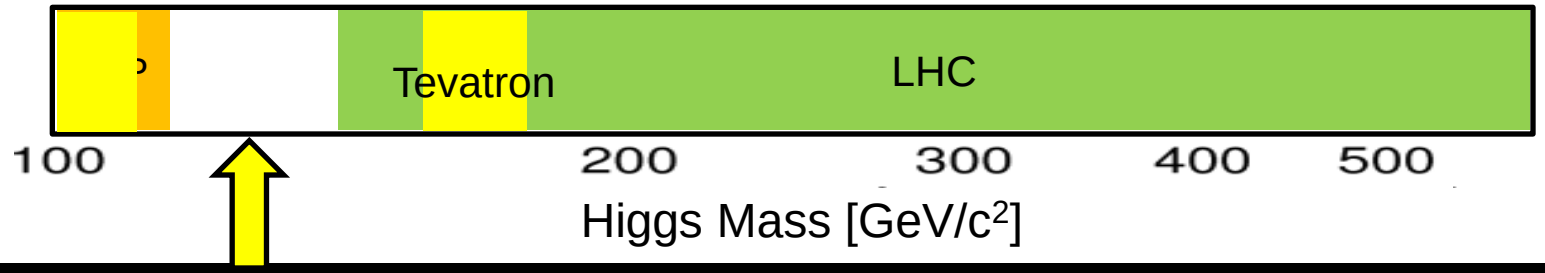
m_{Higgs} prediction from m_W, m_{top} meas.s



$m_{Higgs} < 145$ GeV/c² at 95%CL

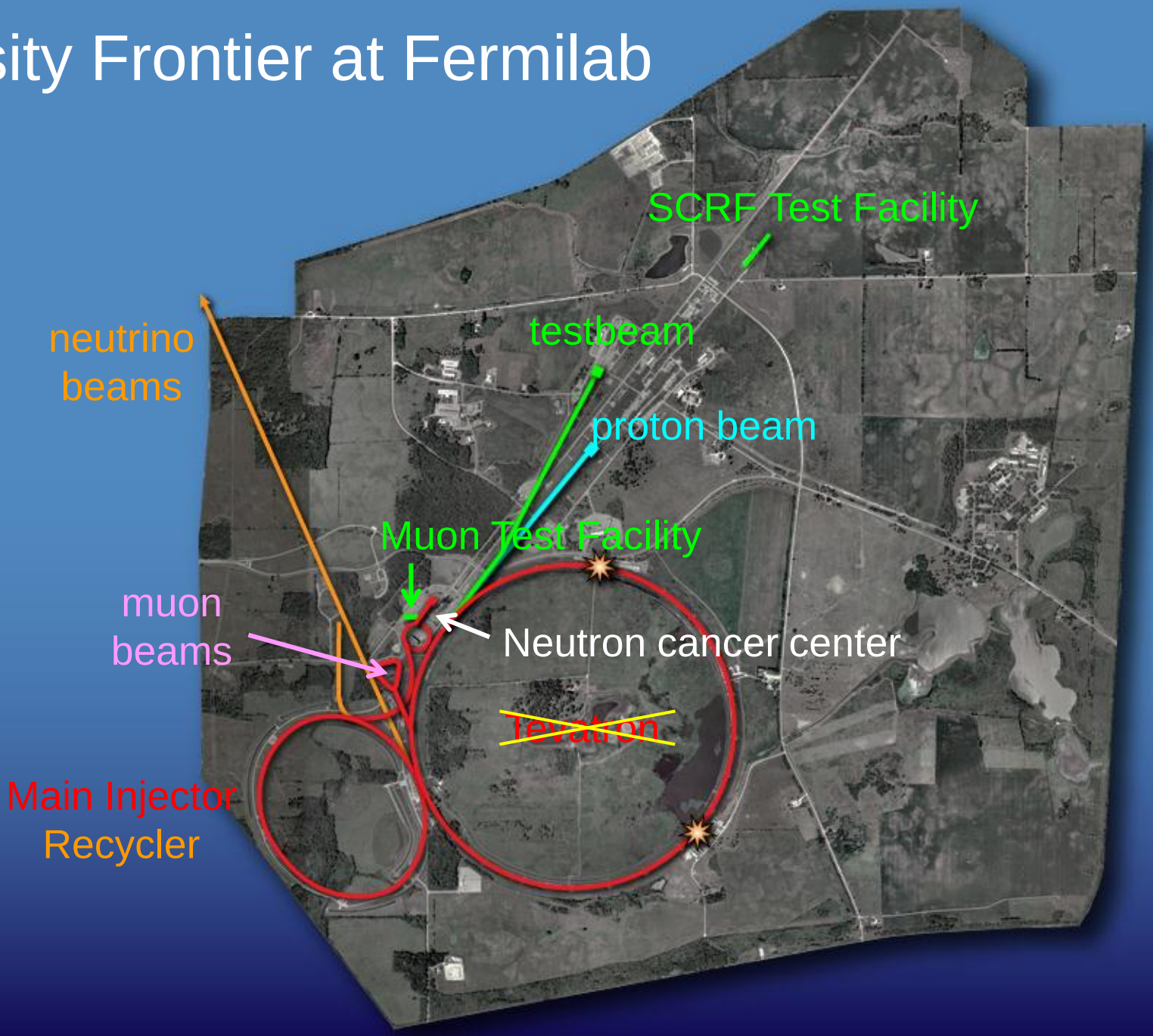
Results still coming out from Tevatron

Excluded by direct searches at 95%CL

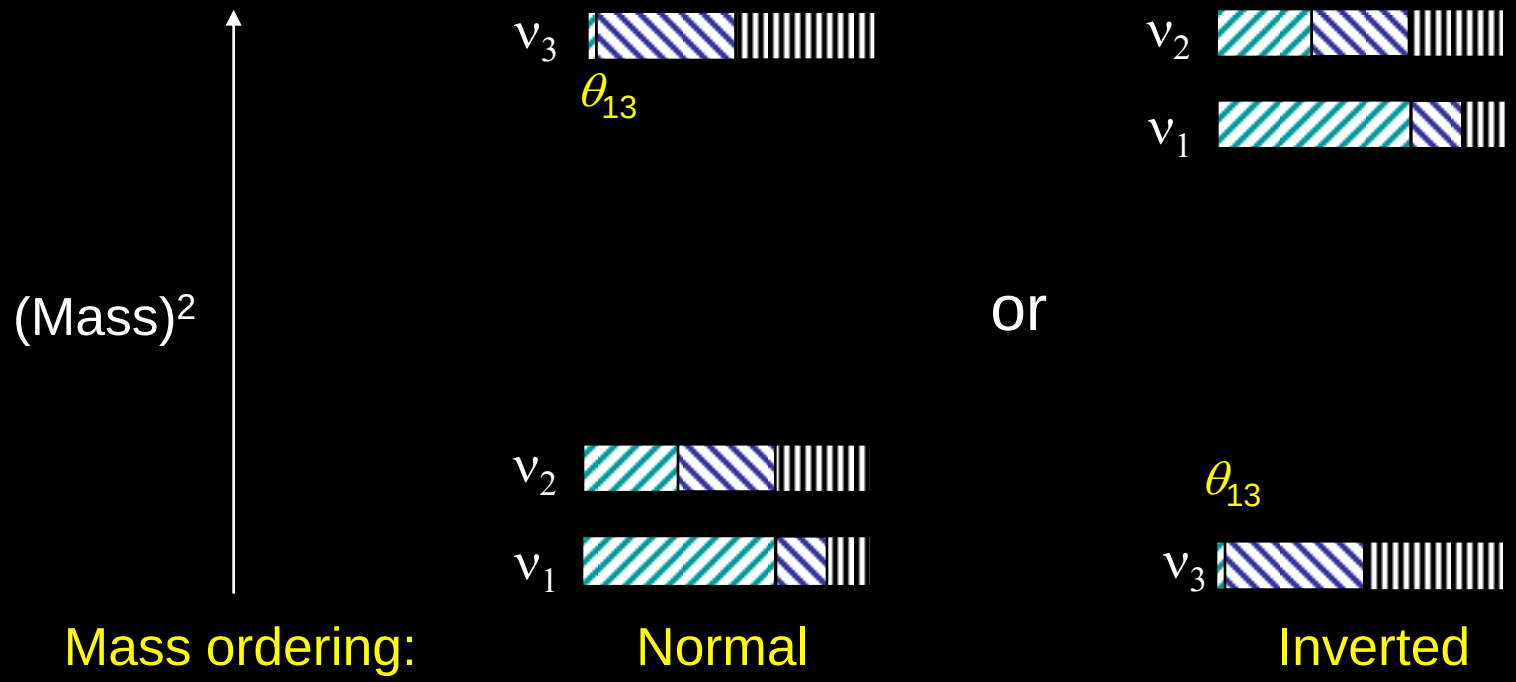


Higgs → 2 photos at LHC
Higgs → 2 bottom quarks at Tevatron
Stay tuned this year!

Intensity Frontier at Fermilab



Neutrinos: known unknowns

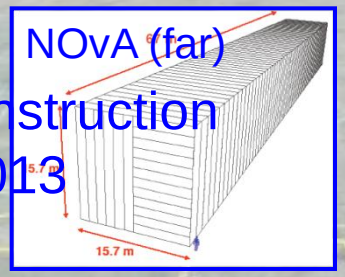


$\nu = \overline{\nu}$?

Matter – Antimatter Asymmetry

unknown unknowns

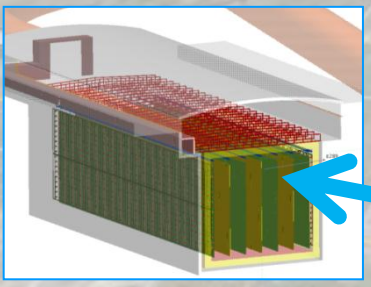
Intensity Frontier at Fermilab: Neutrinos



under construction
Online 2013
(700 kW)

Operating
since 2005
(350 kW)

Far detector

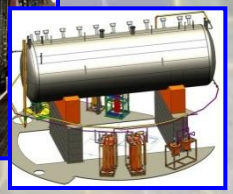


Proton decay
Supernovae neutrinos

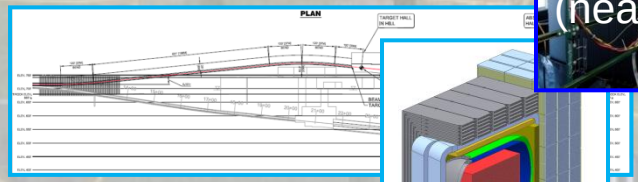
Goal: operating in 2020s

LBNE under development
700 kW → 2.3 MW (Project X)
1300 km

735 km
810 km



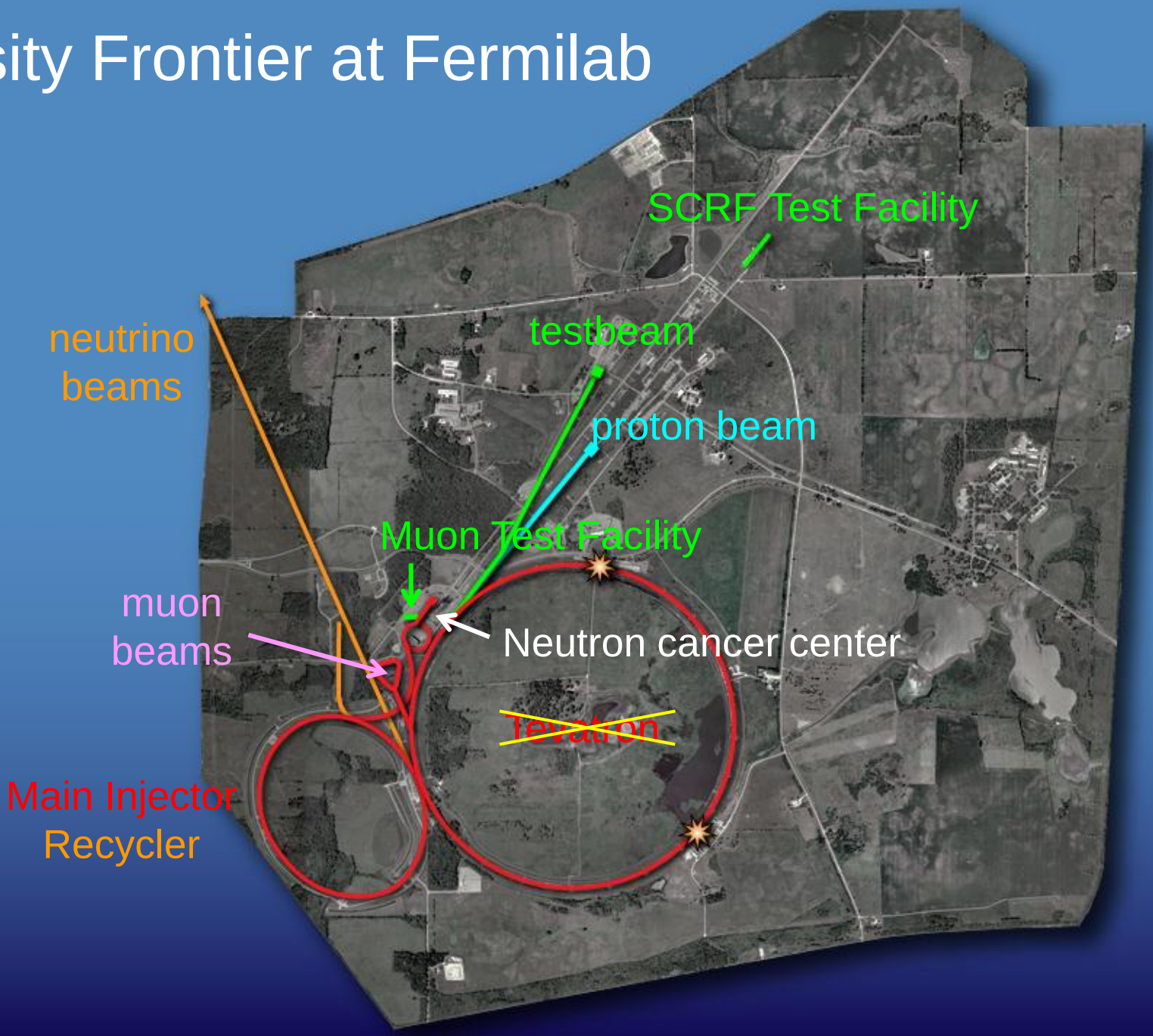
MicroBooNE



Beamline

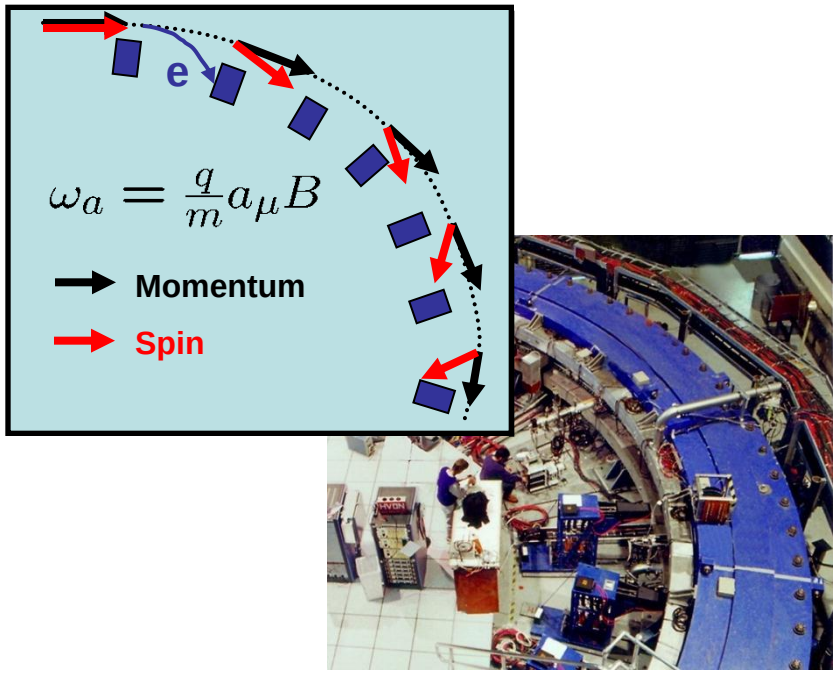
Near detector

Intensity Frontier at Fermilab

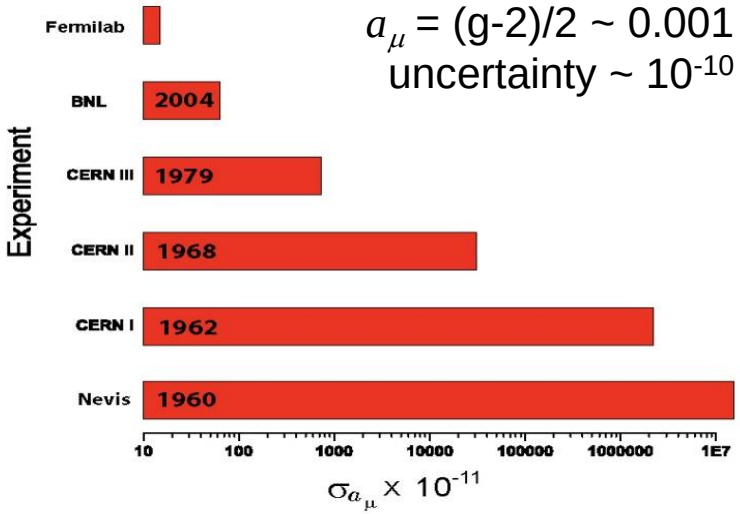


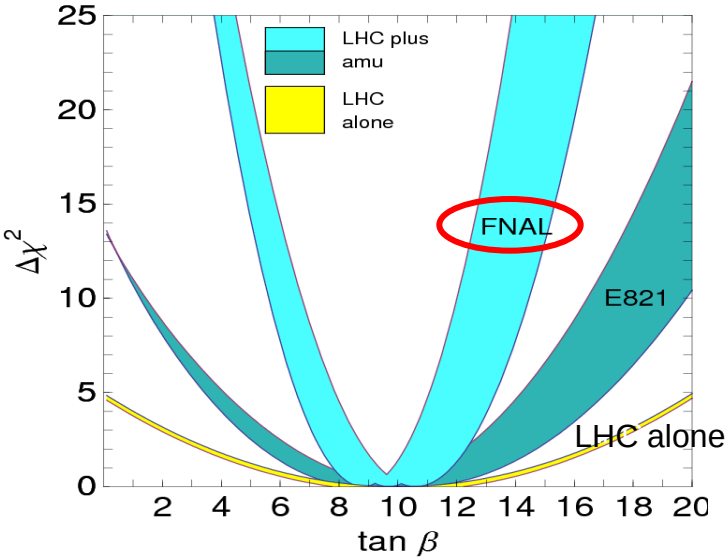
Intensity Frontier at Fermilab: muon g-2

Anomalous magnetic moment



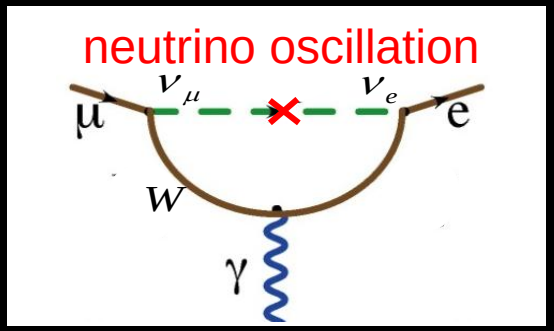
a_μ = (g-2)/2 ~ 0.001
uncertainty ~ 10^{-10}





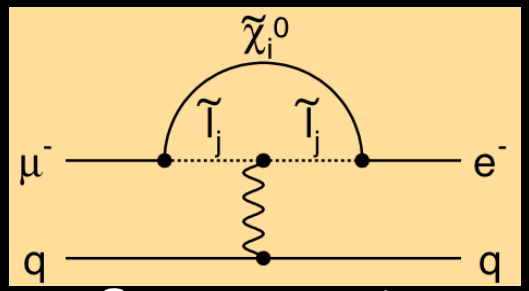
Intensity Frontier at Fermilab: $\mu \rightarrow$ e conversion

- Negligible rate in the SM: < 10^{-54}

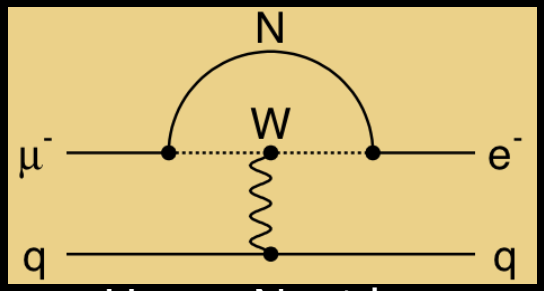


- Measurable rate with new physics contributions: ~ 10^{-15}

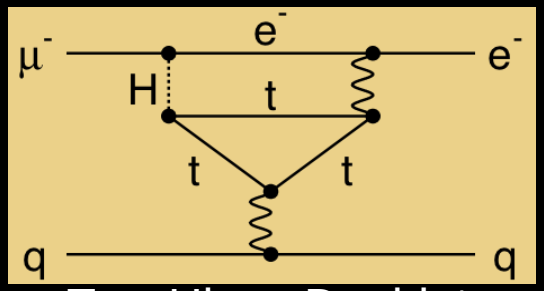
Loops



Supersymmetry

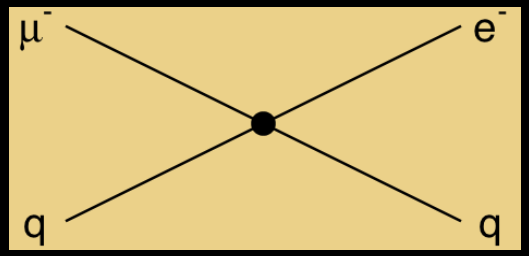


Heavy Neutrinos

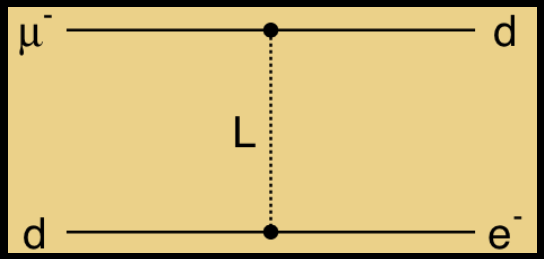


Two Higgs Doublets

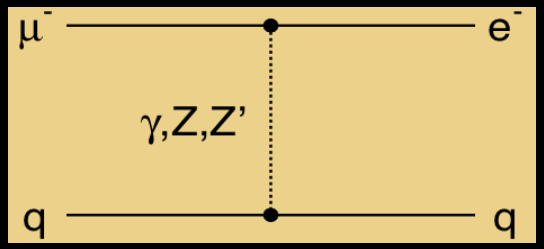
Contact Terms



Compositeness

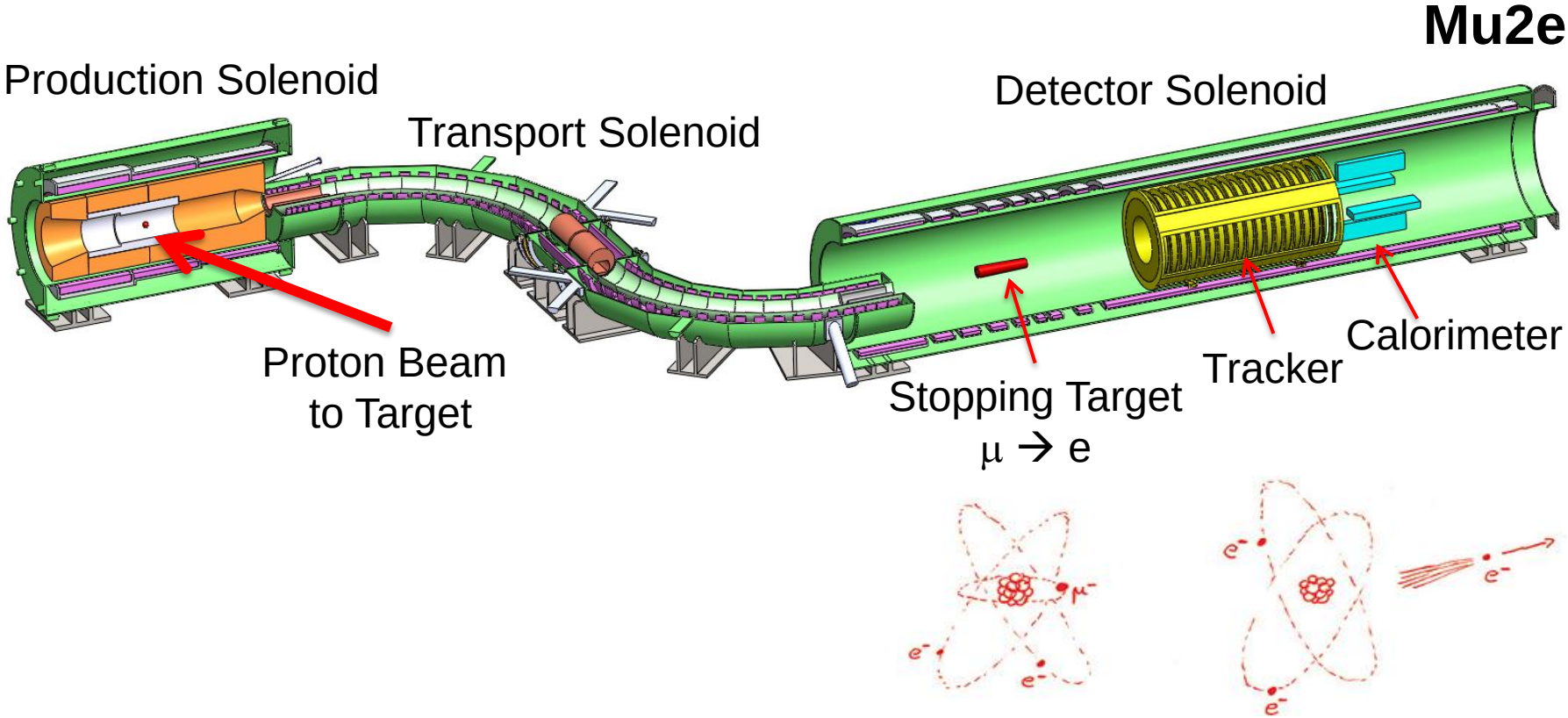


Leptoquarks



New Heavy Bosons / Anomalous Couplings

Intensity Frontier at Fermilab: $\mu \rightarrow$ e conversion



Conversion of a muon into an electron in the field of a nucleus:

Mu2e experimental rate sensitivity: 10^{-16} – 10^{-17}

Mu2e has discovery sensitivity to many new physics models

Project X

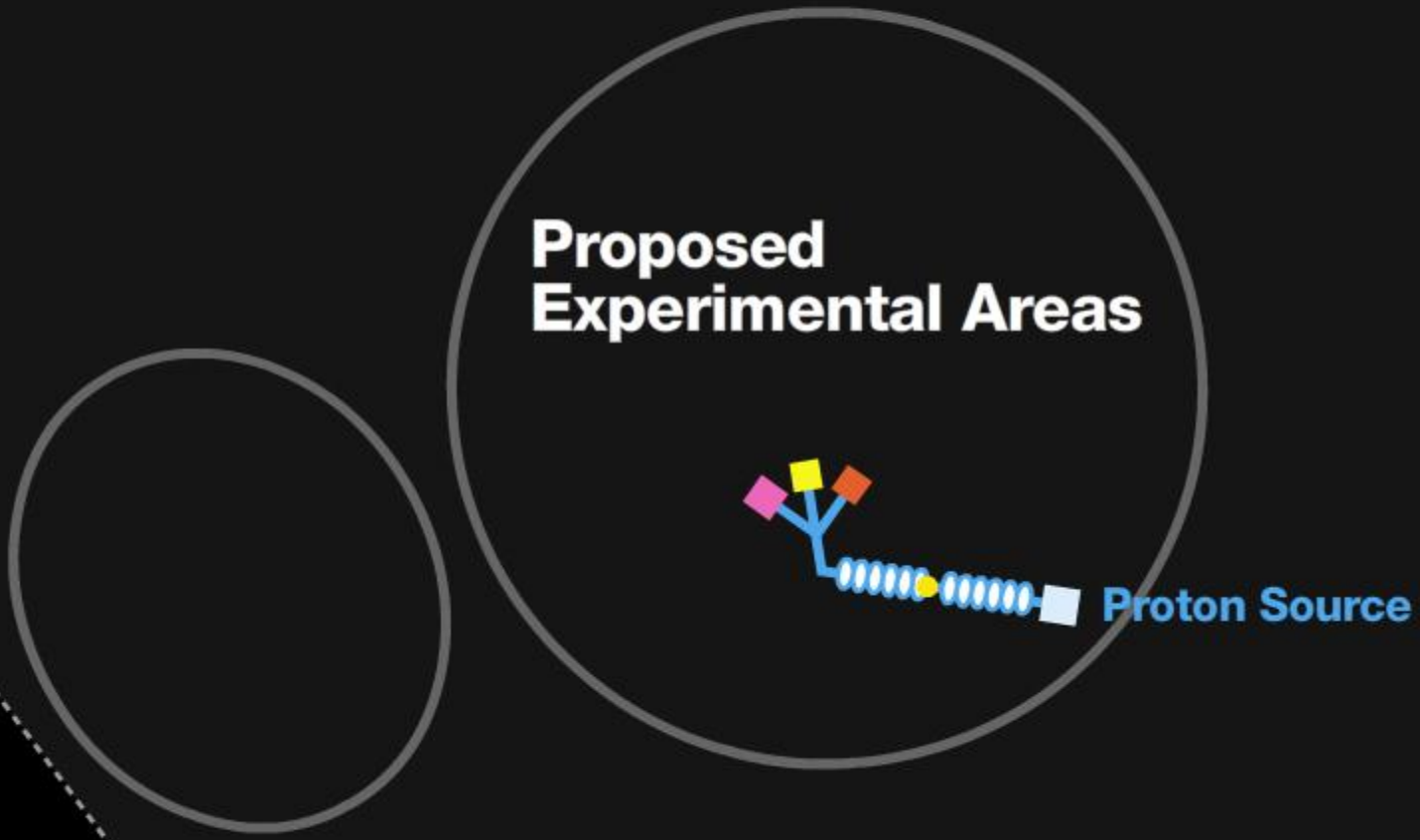
will be the world's most powerful proton source

will make the world's most powerful beams of neutrinos, muons, kaons and nuclei to explore new physics in unprecedented breadth and depth

will establish a versatile technical foundation for future accelerators

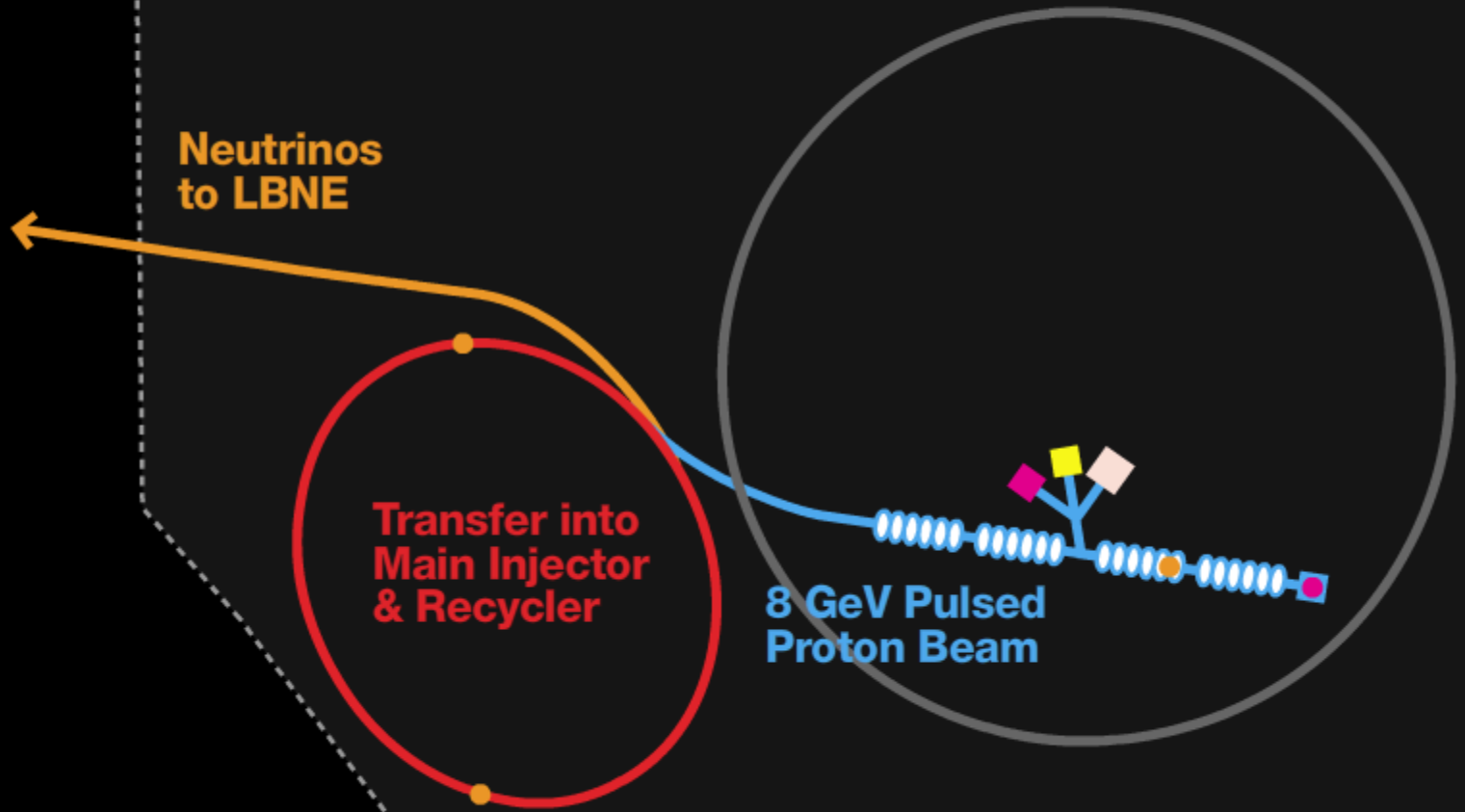
Project X: Low-energy Program

Highest-intensity proton accelerator in the world



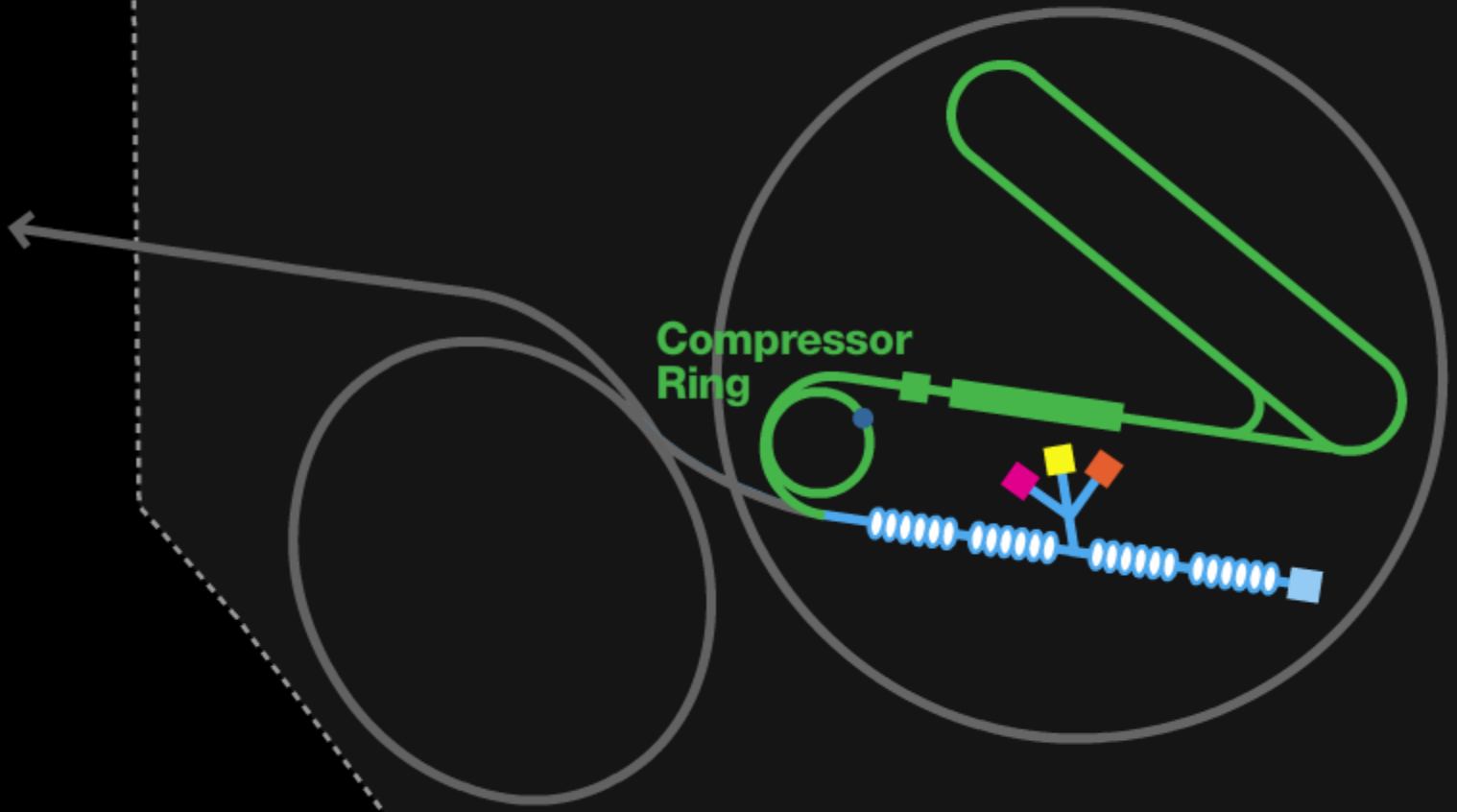
Project X: High-energy Program

More beam for high-intensity neutrino experiments



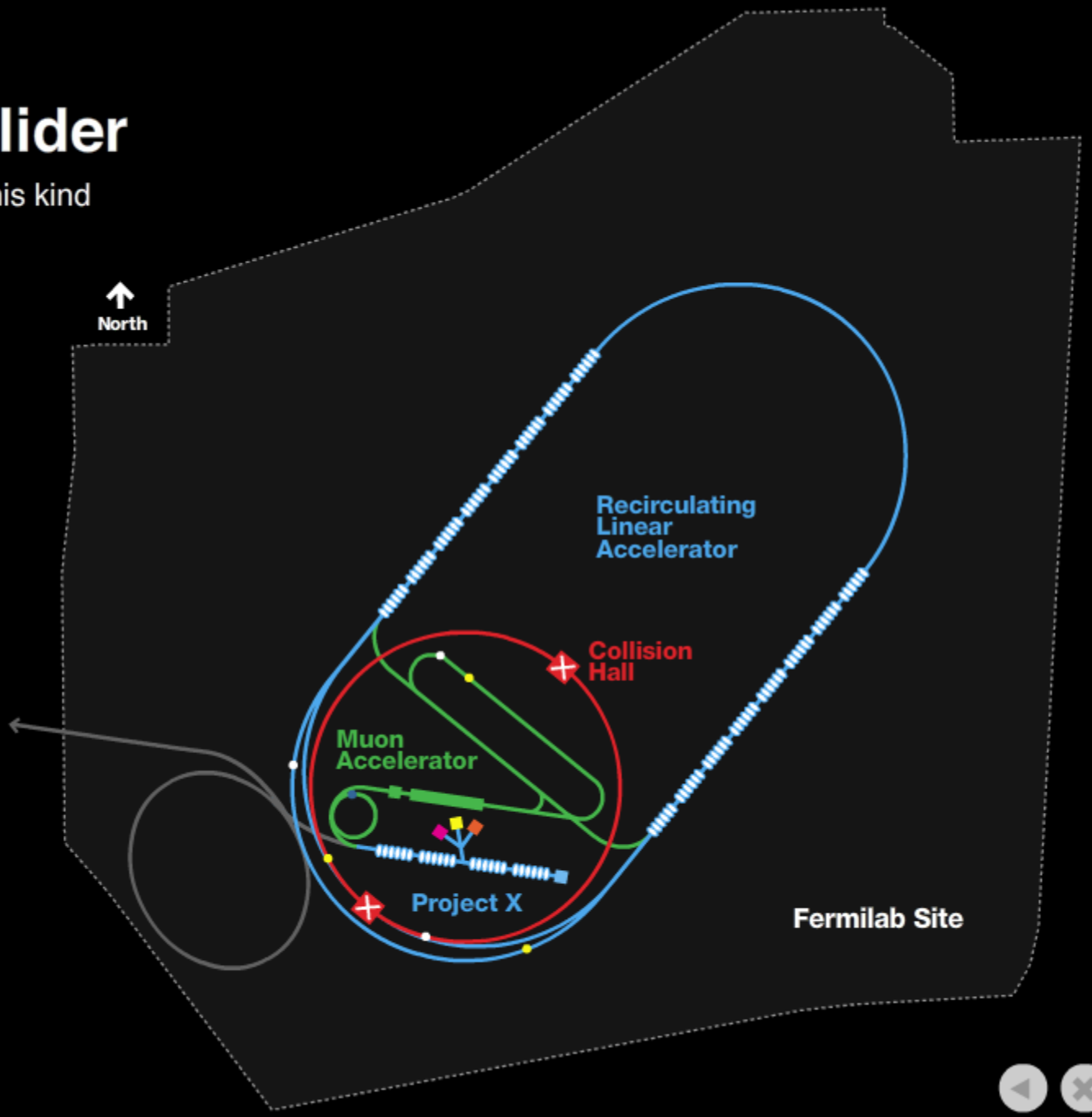
Muon Beamline & Neutrino Factory

Highest-intensity muon and neutrino source in the world



Muon Collider

The first collider of this kind



The Intensity Frontier and the big questions

Origin of mass for elementary particles?

Why is matter dominant?

What do neutrinos tell us?

Do charged leptons oscillate?

Why three families of quarks and leptons?

Do the forces unify?

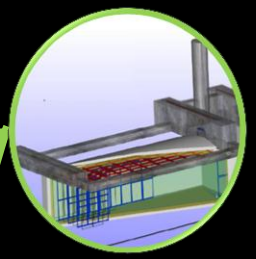
Will protons every decay?

Supersymmetry or other new symmetries?

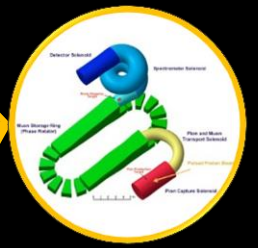
Extra dimensions?

What is dark matter?

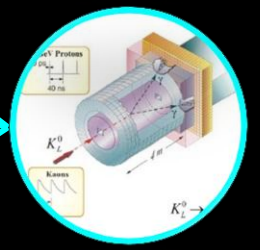
What is dark energy?



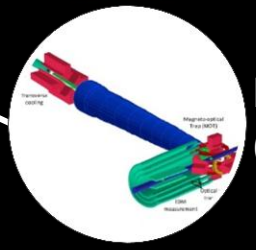
neutrinos



muons

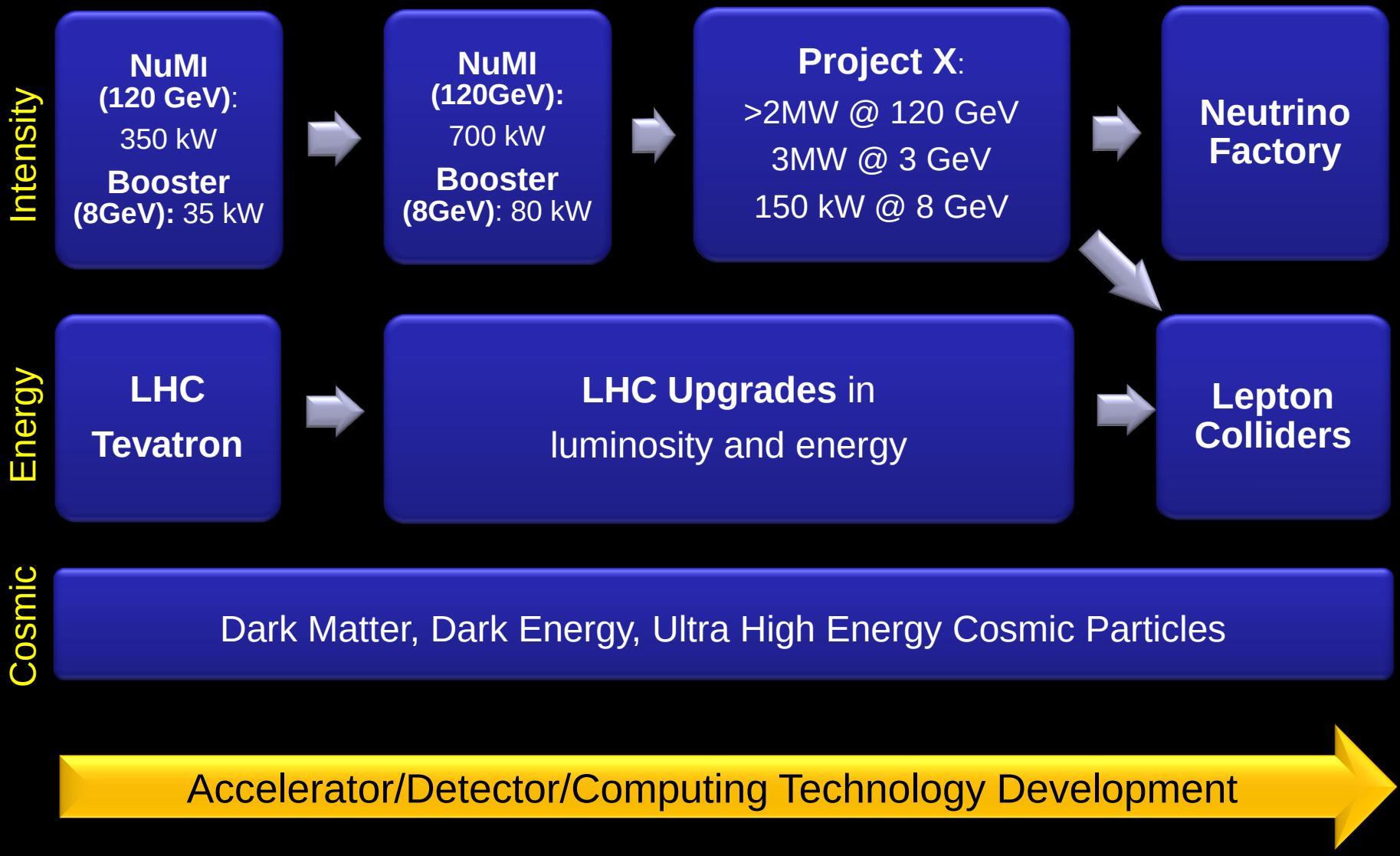


kaons



Nuclei
(EDMs..)

Fermilab Program



Vision of Fermilab

- Fermilab is going after the most exciting questions in particle physics, questions about the nature and future of our universe.

- Fermilab continues to operate most of its existing accelerators with enhanced capabilities and next generation experiments (2010s)

- Fermilab will build new accelerators and experiments for the future (2020s and beyond)