Particle Physics and Fermilab

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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?

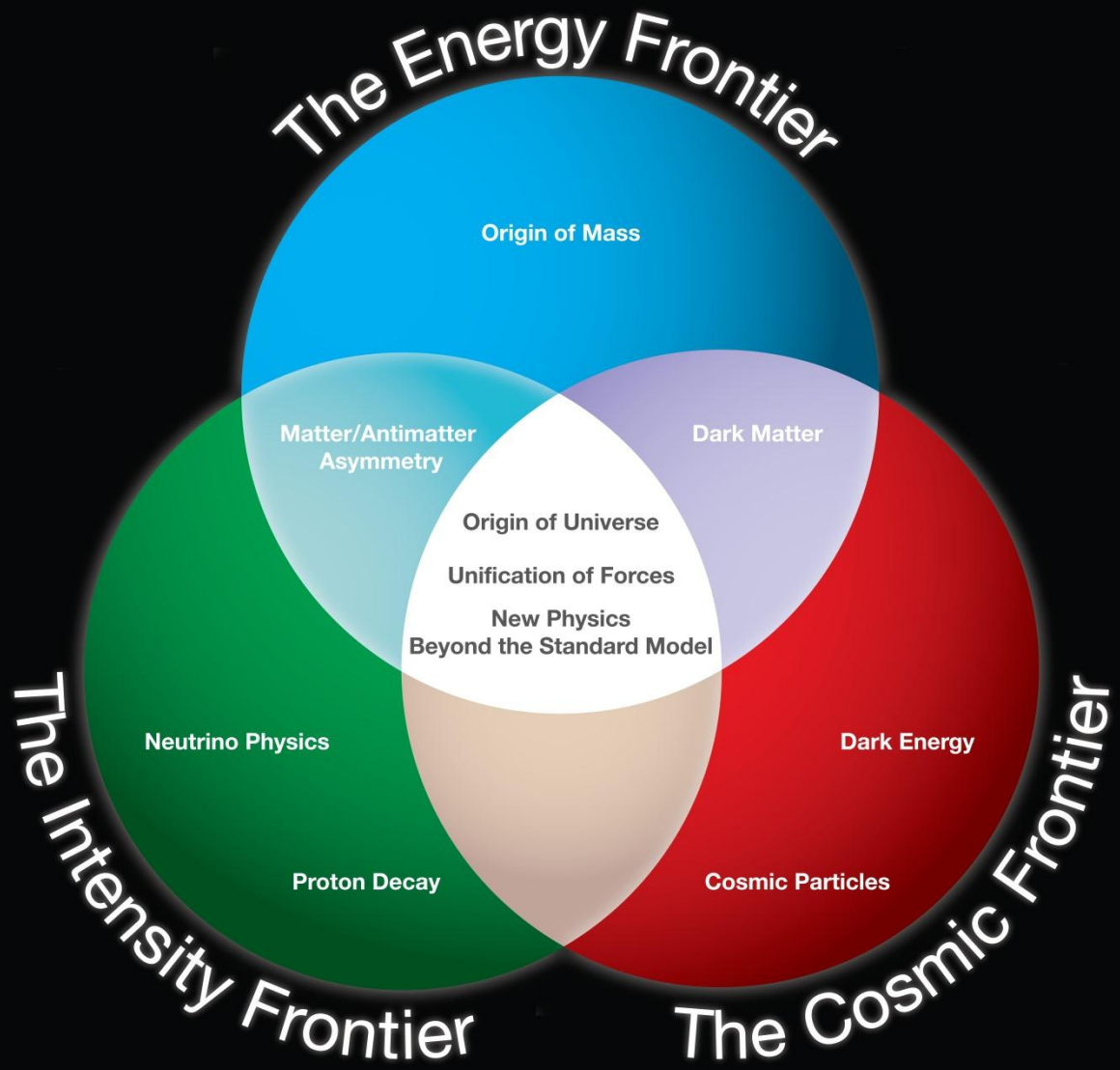
Go to:

Highest energies
Shortest distances
Earliest moments of the Universe

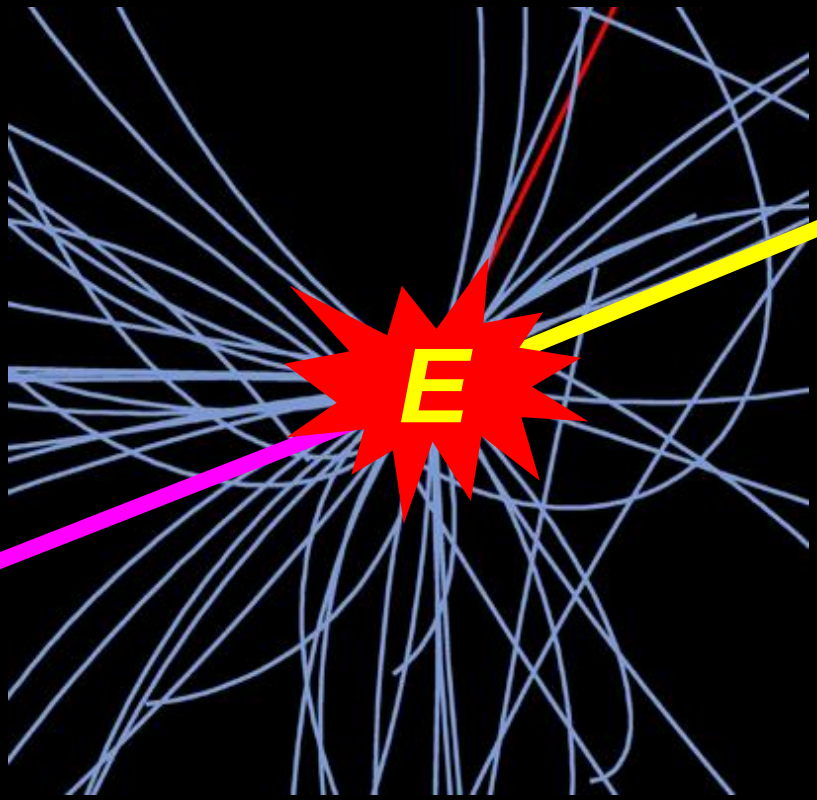
Reveal laws of nature: ~complete and ~elegant

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

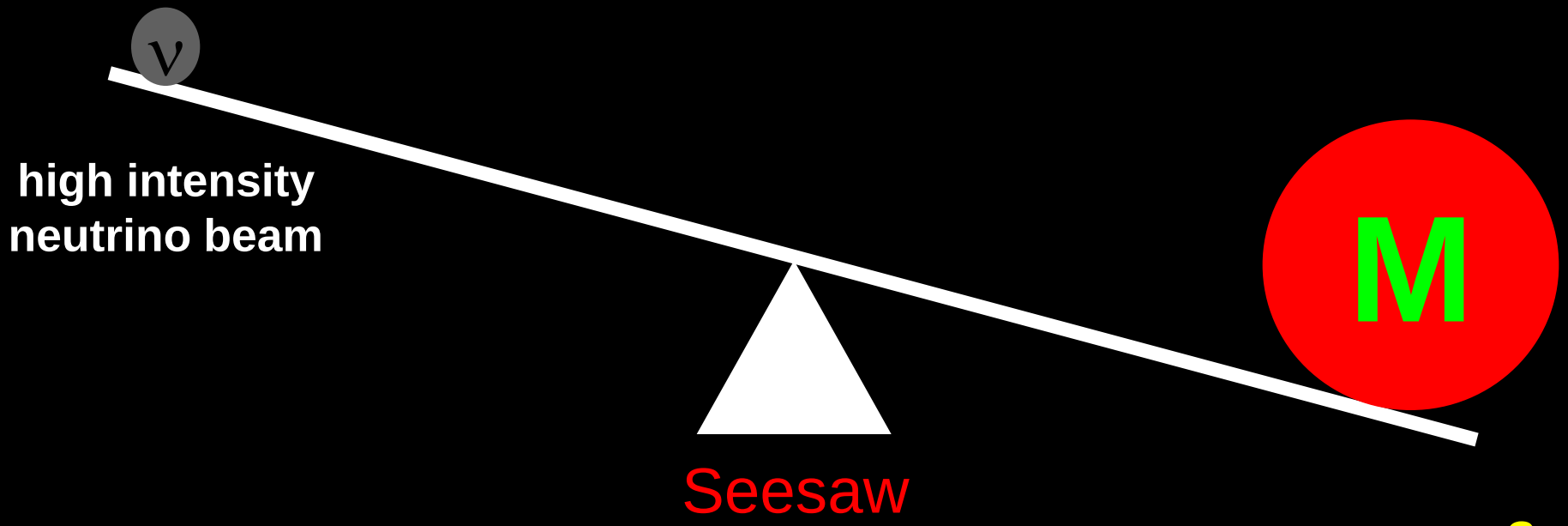
Uncertainty Principle

$E = Mc^2$

~10^4 TeV

Intensity Frontier

Probe even more massive NEW particles
by intense neutrino beams

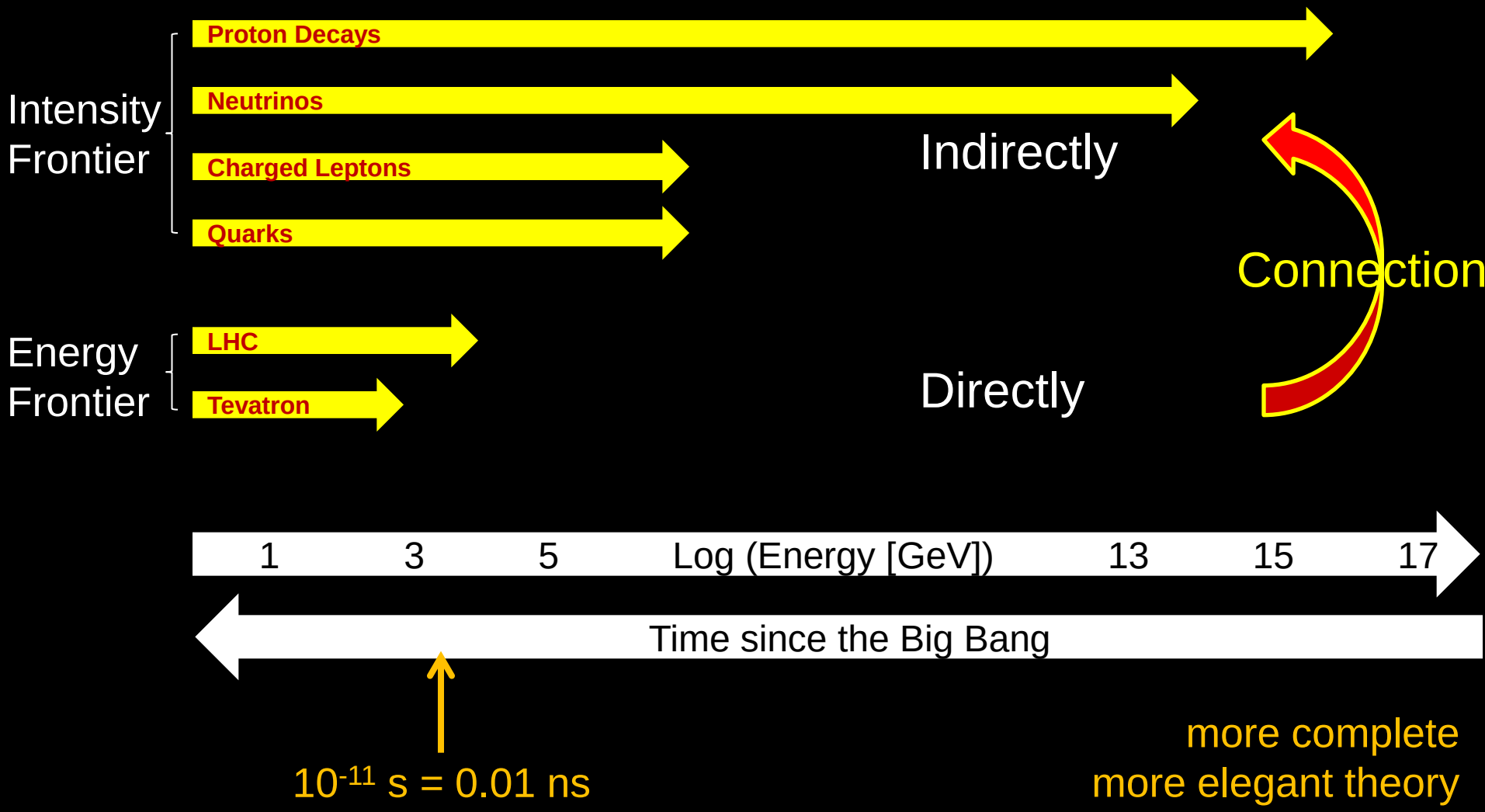


$m_\nu \times m_N \sim (m_{quark})^2$

$E = Mc^2$

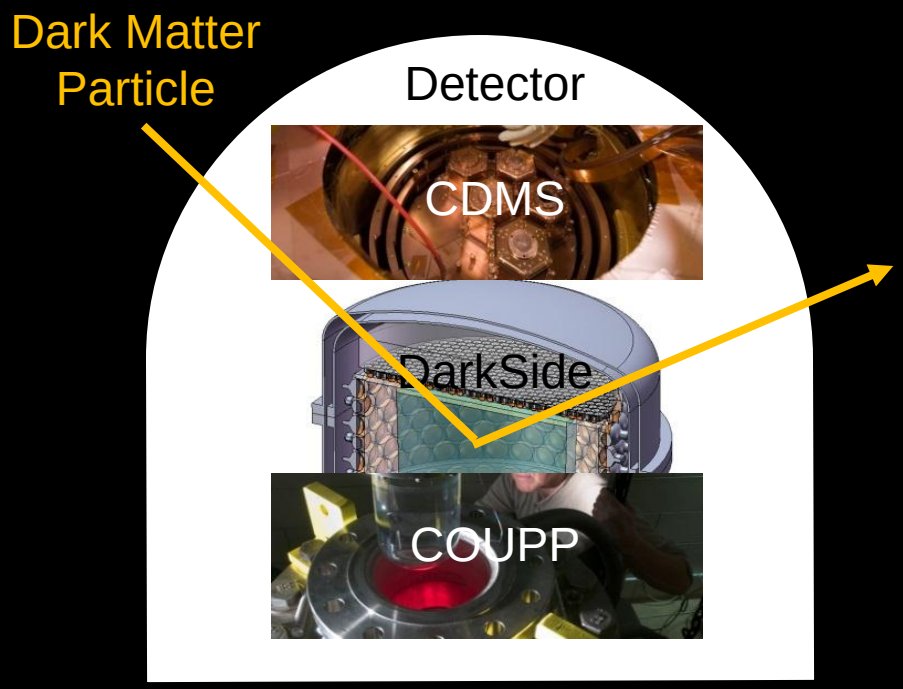
$\sim 10^{12}$ TeV

Experimental reach (model dependent)



Cosmic Frontier at Fermilab

Dark Matter Detector

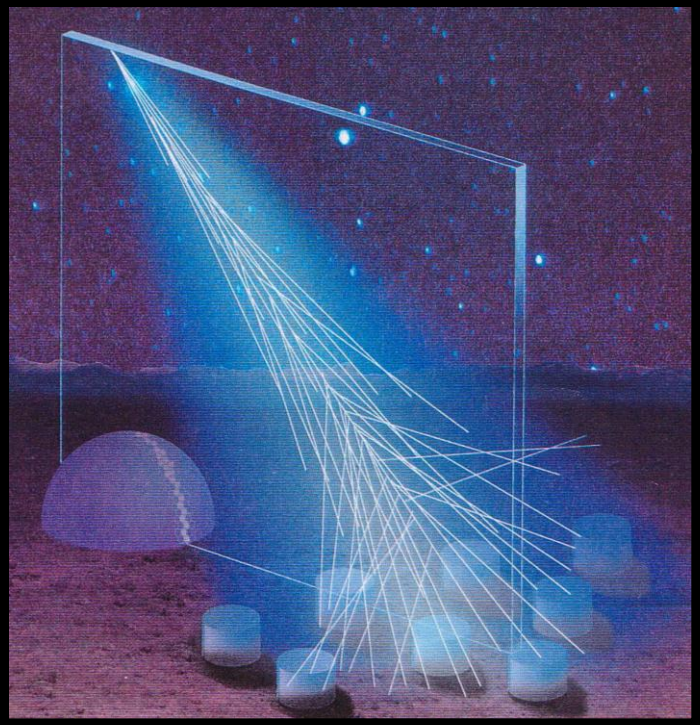


Detectors
in underground facilities

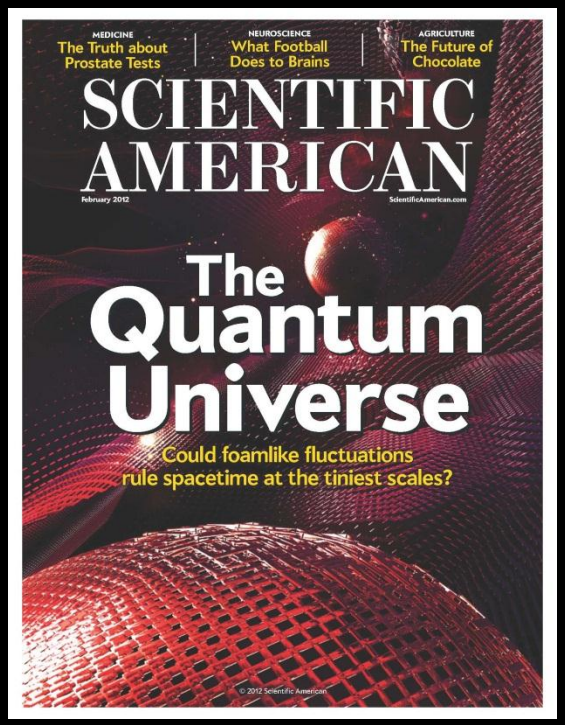
Dark Energy Camera

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

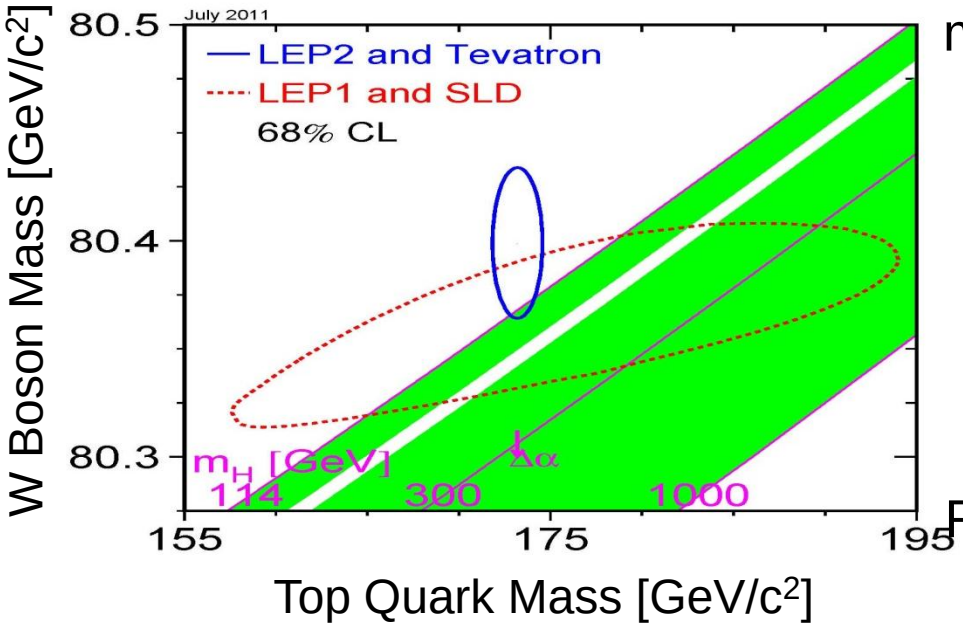
(energy decision)

Lepton Collider

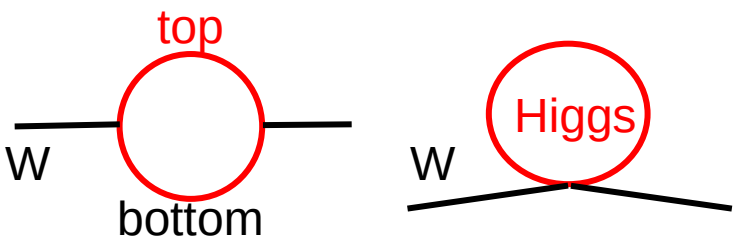
(ILC, Muon Collider)

Hadron Collider

Origin of Mass: Higgs Boson



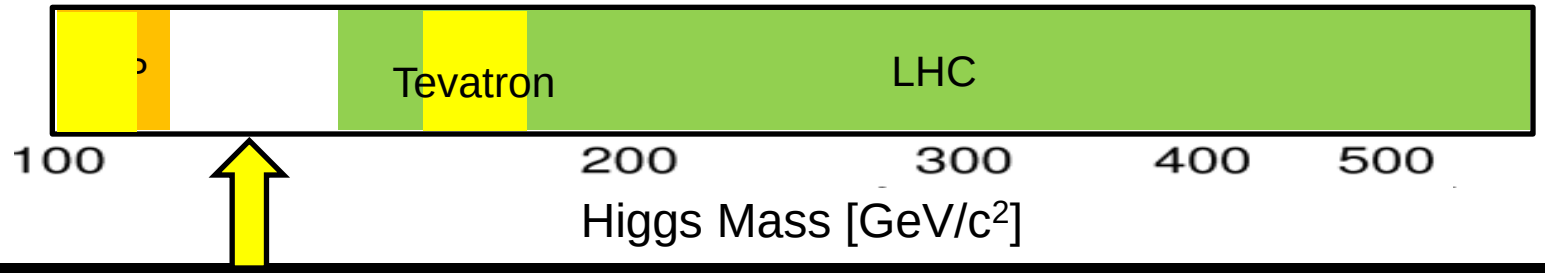
m_{Higgs} prediction from m_W, m_{top} meas.s



$m_{Higgs} < 145$ GeV/c² at 95%CL

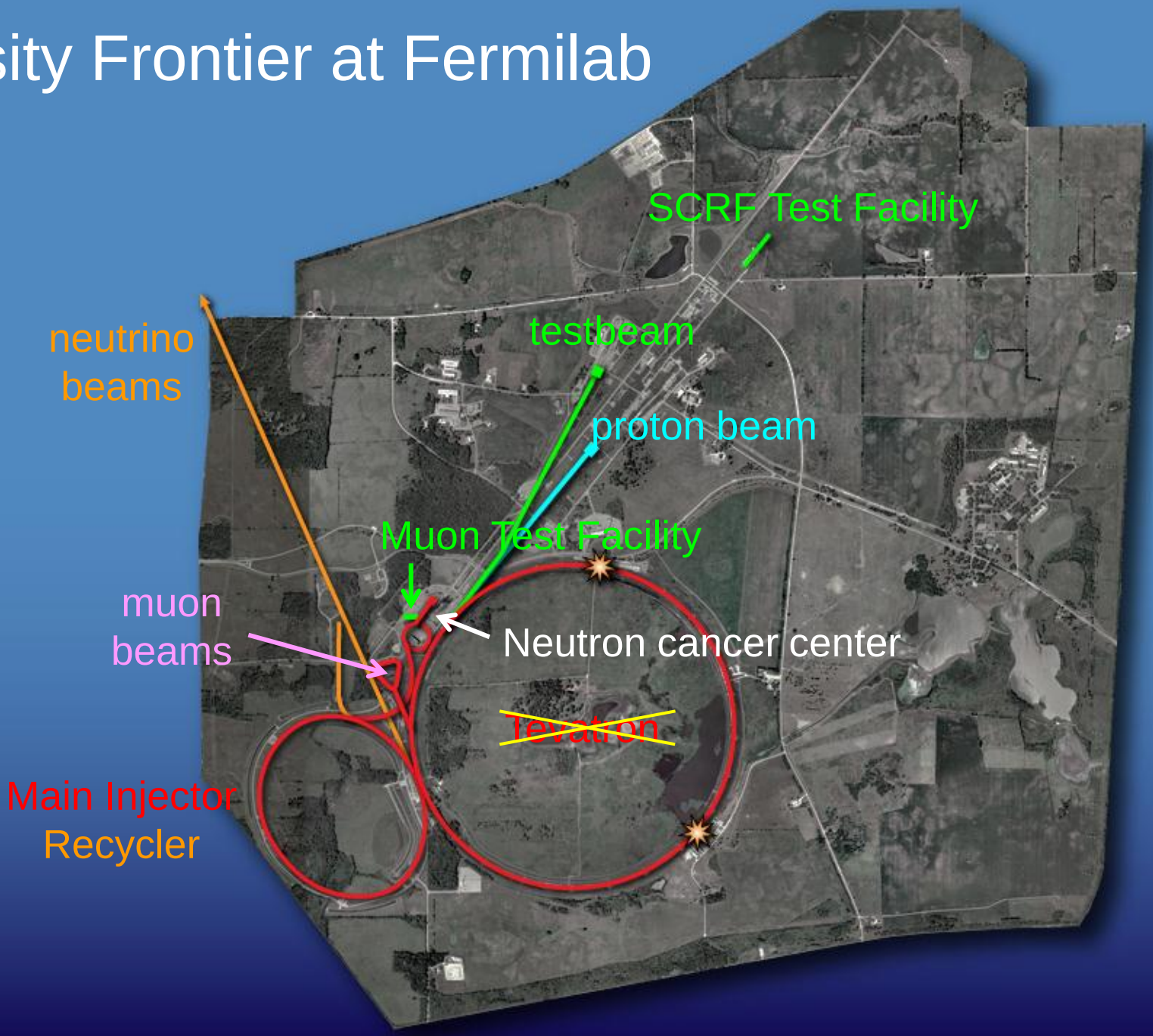
Results still coming out from Tevatron

Excluded by direct searches at 95%CL

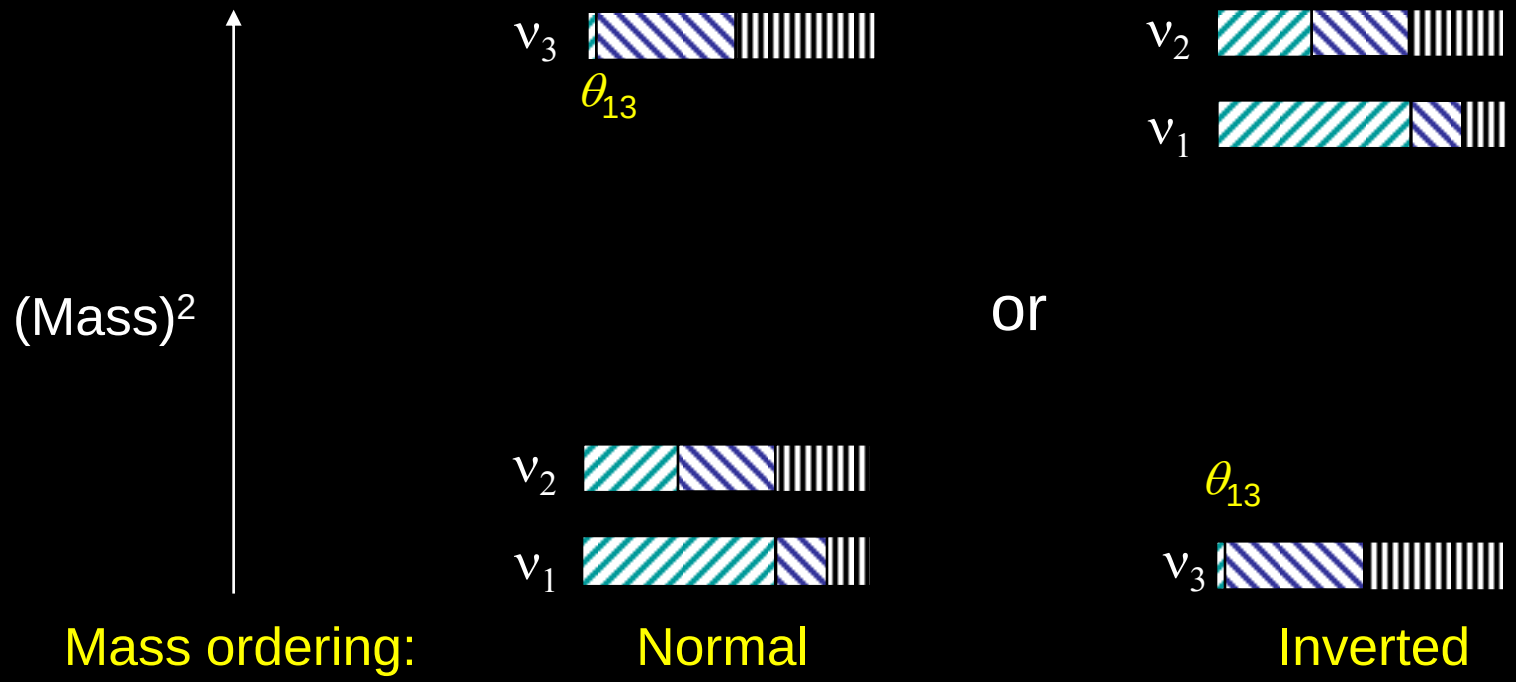


Higgs → 2 photos at LHC
Higgs → 2 bottom quarks at Tevatron
Stay tuned this year!

Intensity Frontier at Fermilab



Neutrinos: known unknowns

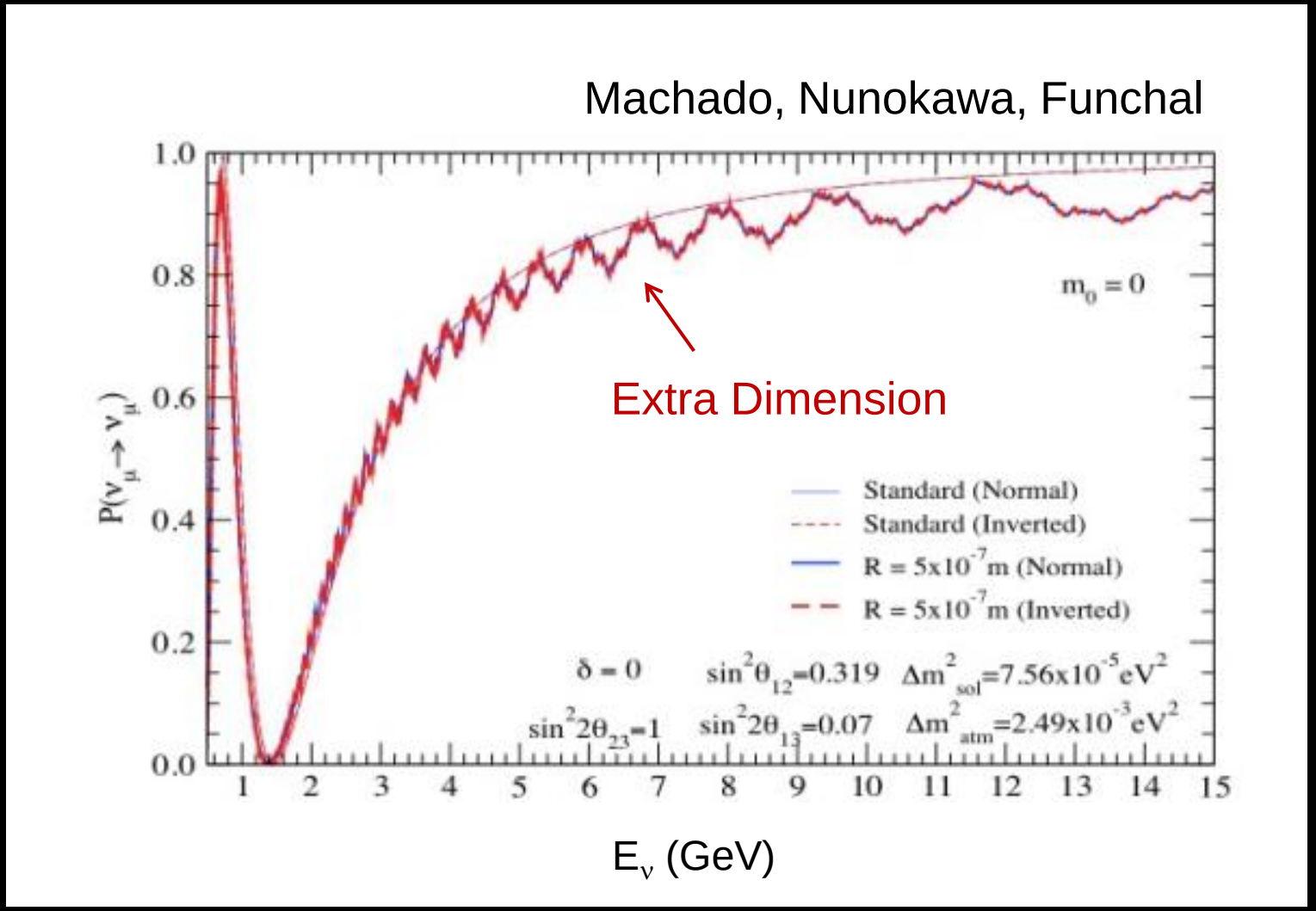


$\nu = \overline{\nu}$?

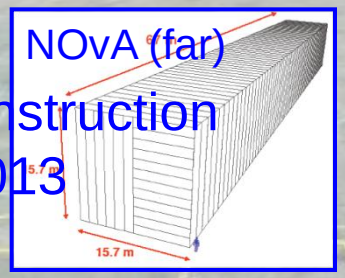
Matter – Antimatter Asymmetry

unknown unknowns

Exploring unknown unknowns in neutrino oscillation

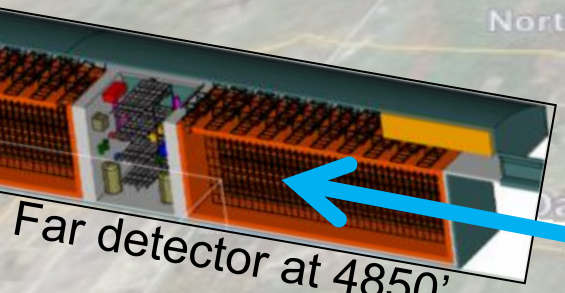


Intensity Frontier at Fermilab: Neutrinos



under construction
Online 2013
(700 kW)

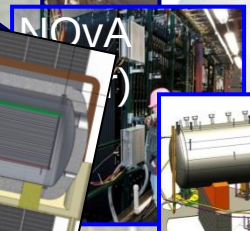
Operating
since 2005
(350 kW)

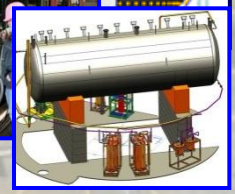


Far detector at 4850'

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

735 km
810 km





Near detector

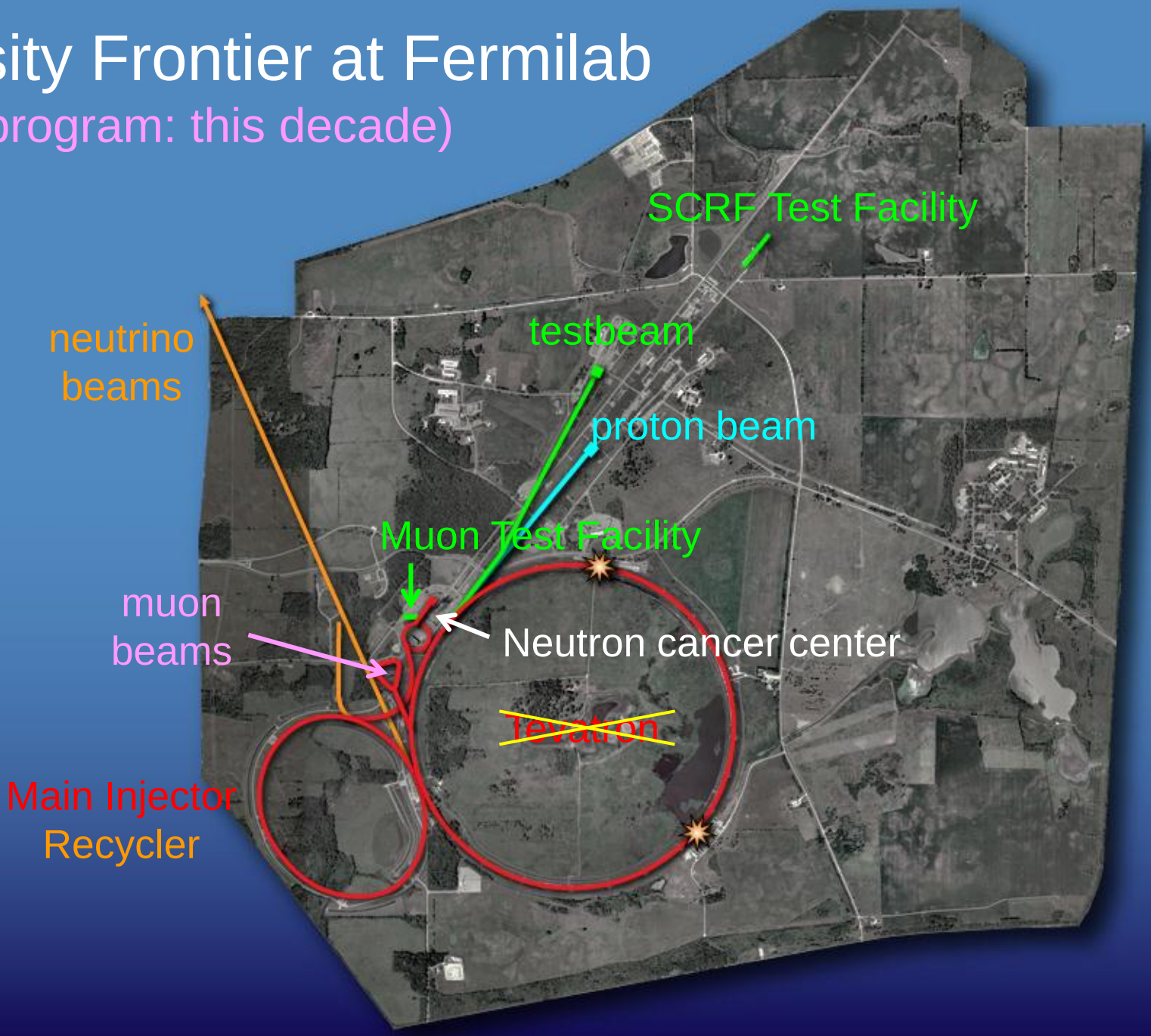
MicroBooNE

Proton decay
Supernovae neutrinos

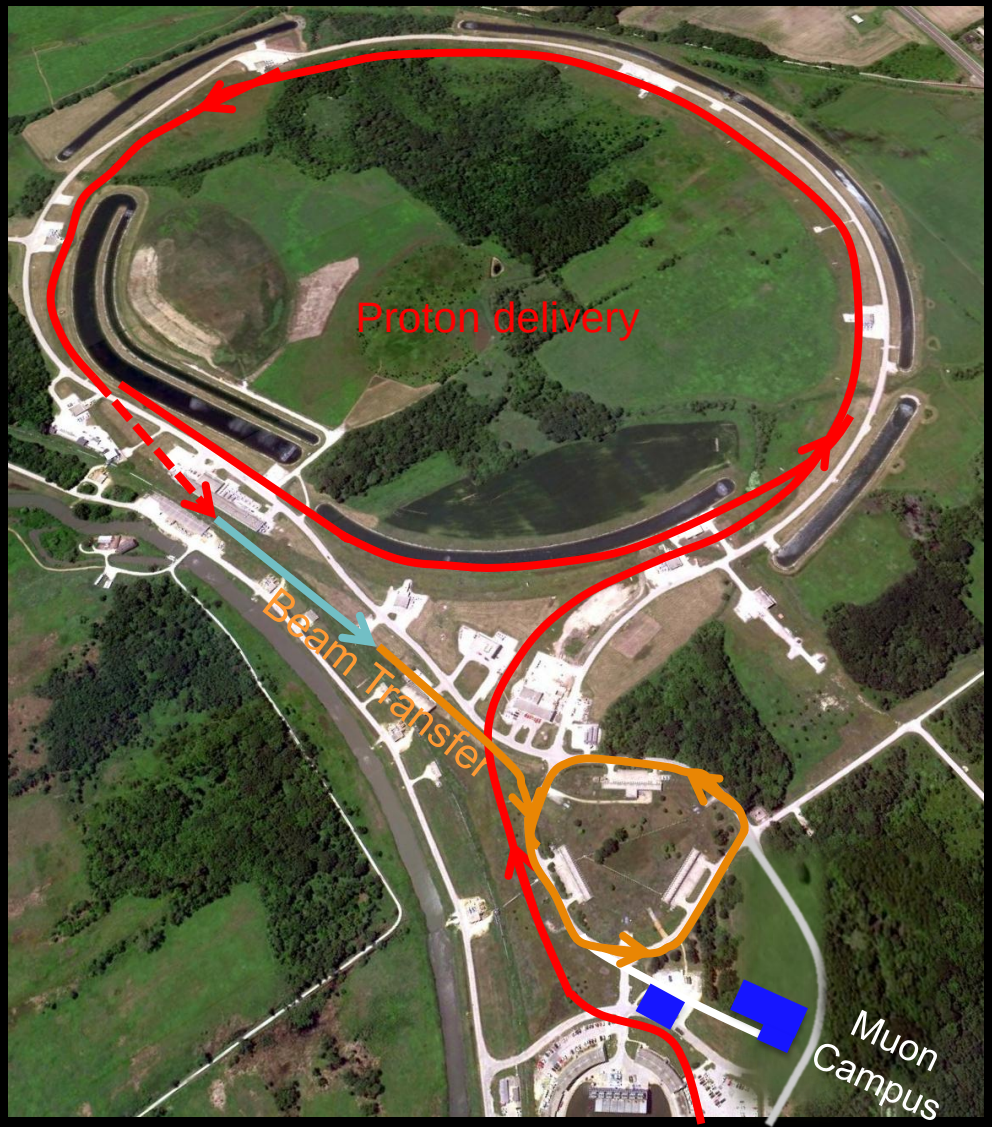
Goal: operating in 2020s

Intensity Frontier at Fermilab

(muon program: this decade)

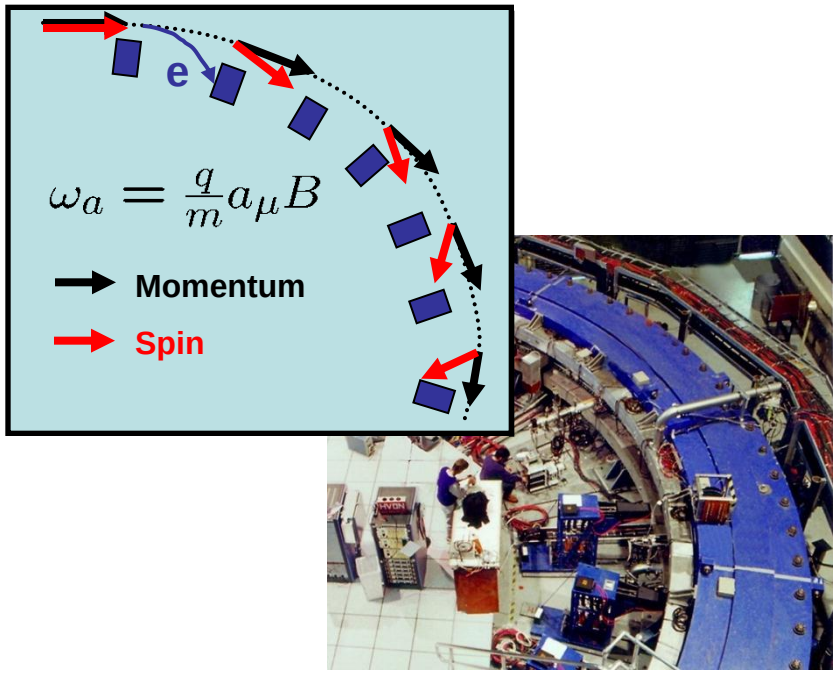


Intensity Frontier at Fermilab: Muon Campus (this decade)

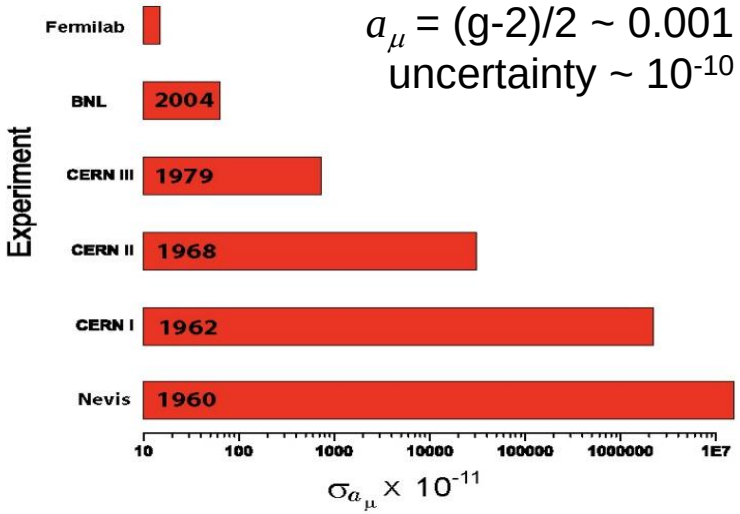


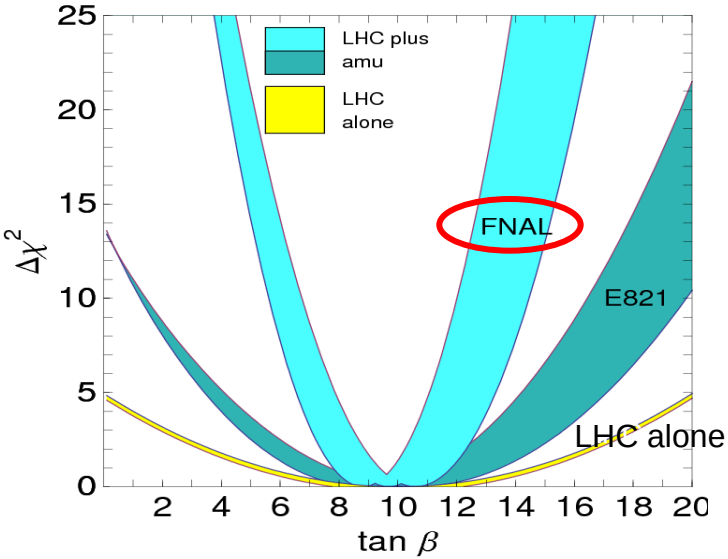
Intensity Frontier at Fermilab: muon g-2

Anomalous magnetic moment



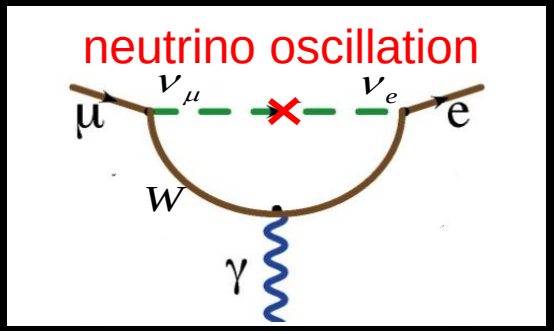
a_μ = (g-2)/2 ~ 0.001
uncertainty ~ 10^{-10}





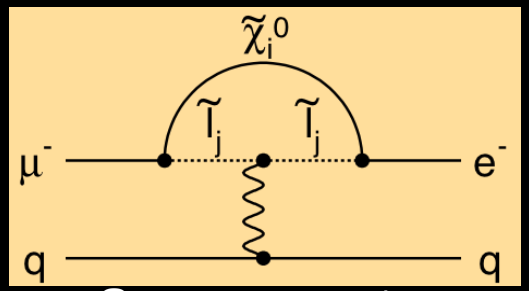
Intensity Frontier at Fermilab: $\mu \rightarrow$ e conversion

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

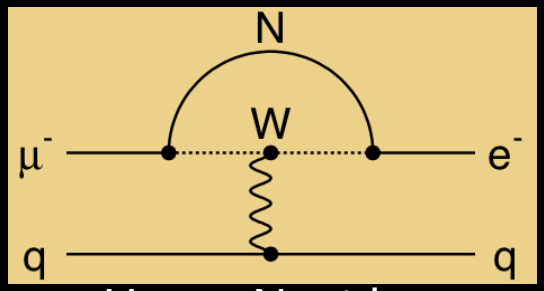


- Measurable rate with new physics contributions: ~ 10^{-15}

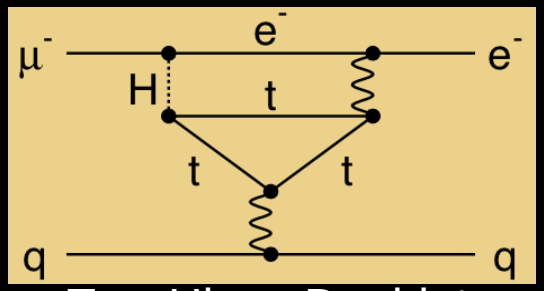
Loops



Supersymmetry

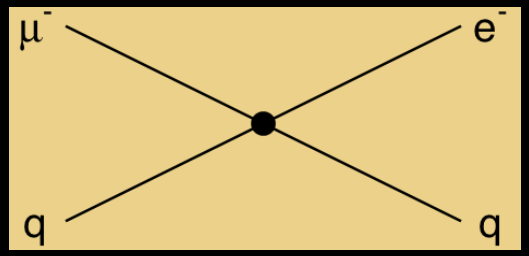


Heavy Neutrinos

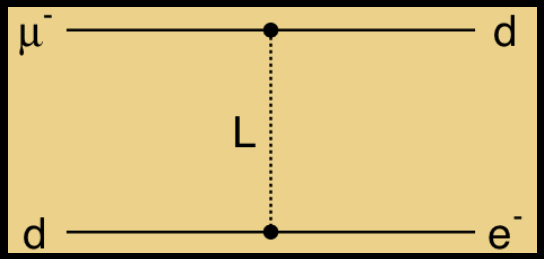


Two Higgs Doublets

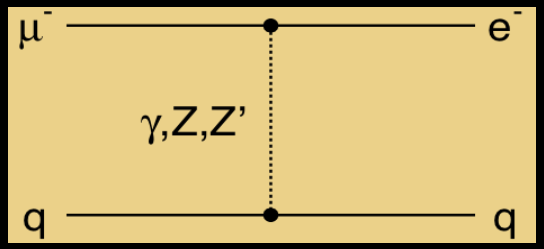
Contact Terms



Compositeness

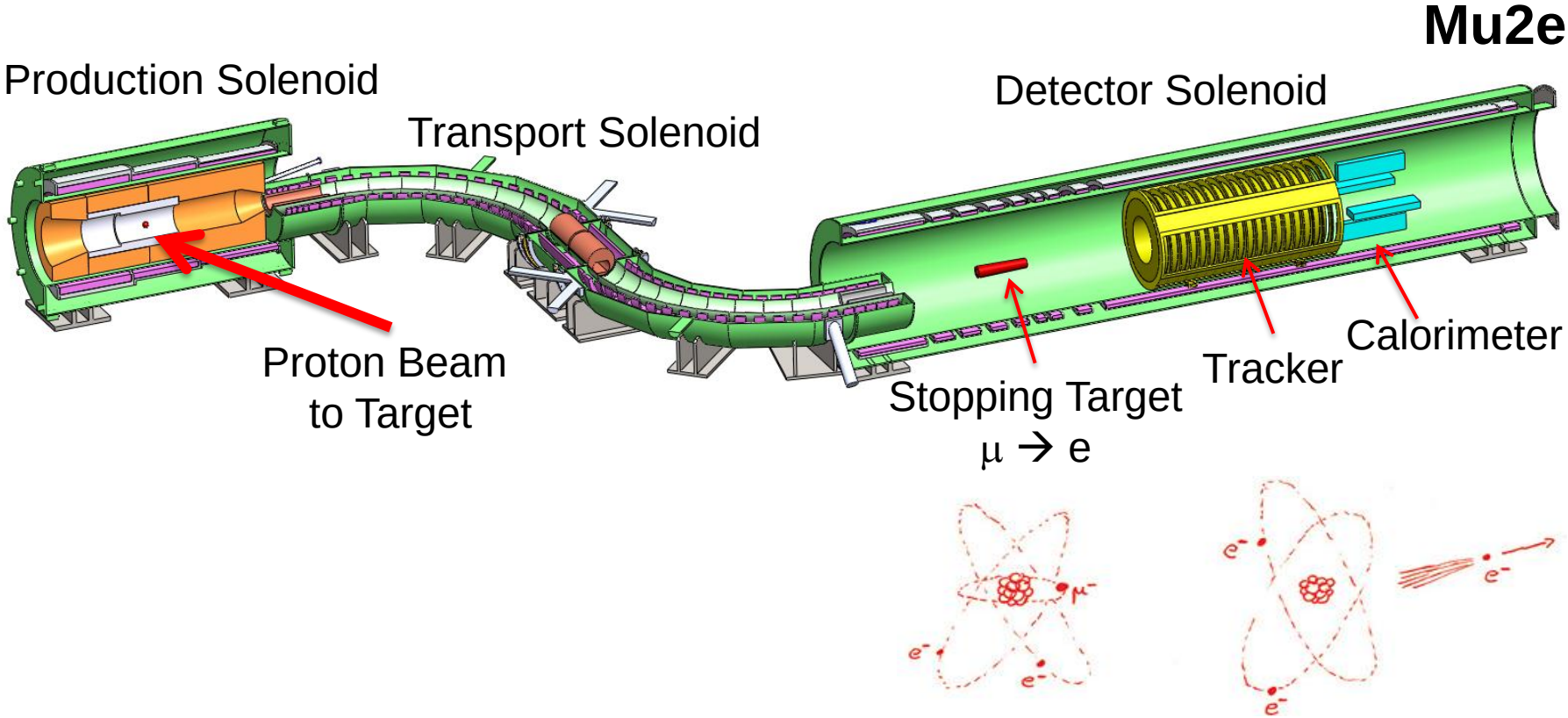


Leptoquarks



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

Intensity Frontier at Fermilab

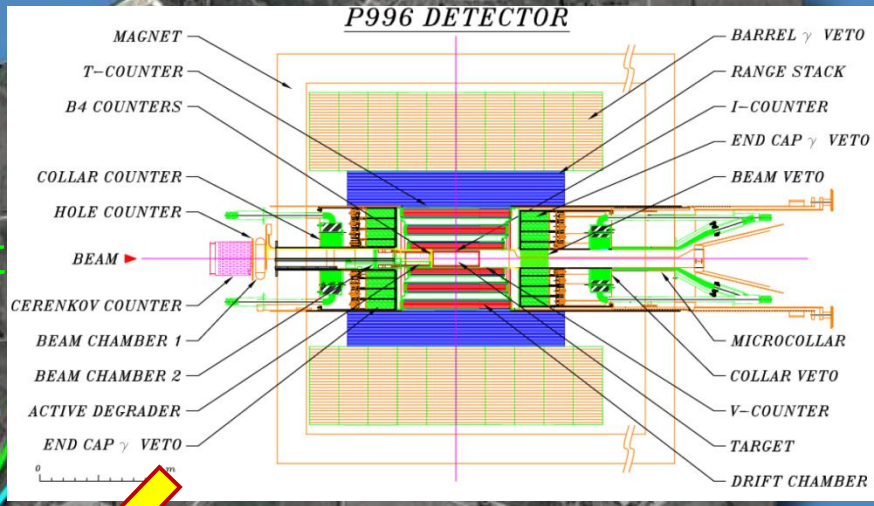
Kaon beam (if an opportunity arises)

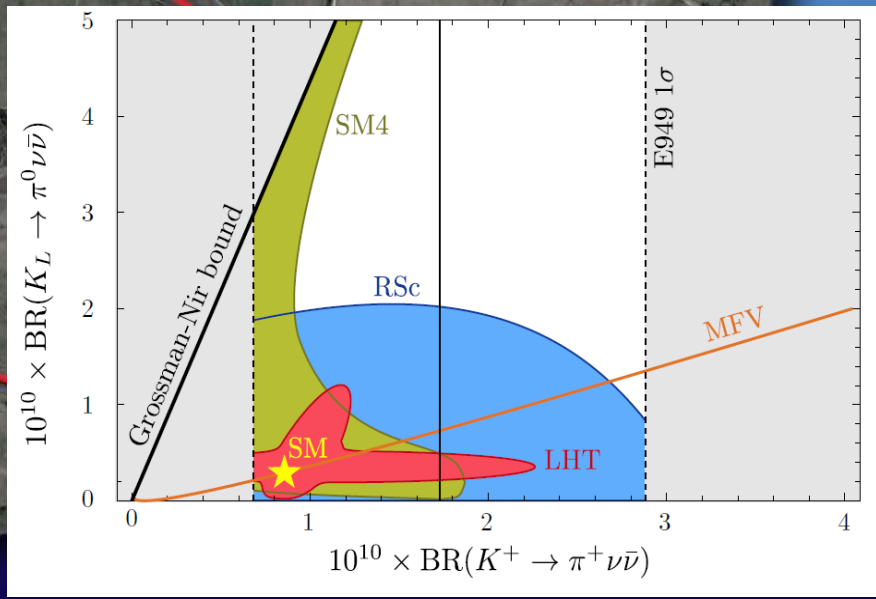
neutrino beams

muon beams

Main Injector

Recycler





$K^+ \rightarrow \pi^+ \nu\nu$ rate in SM ~ 10^{-10}

Project X

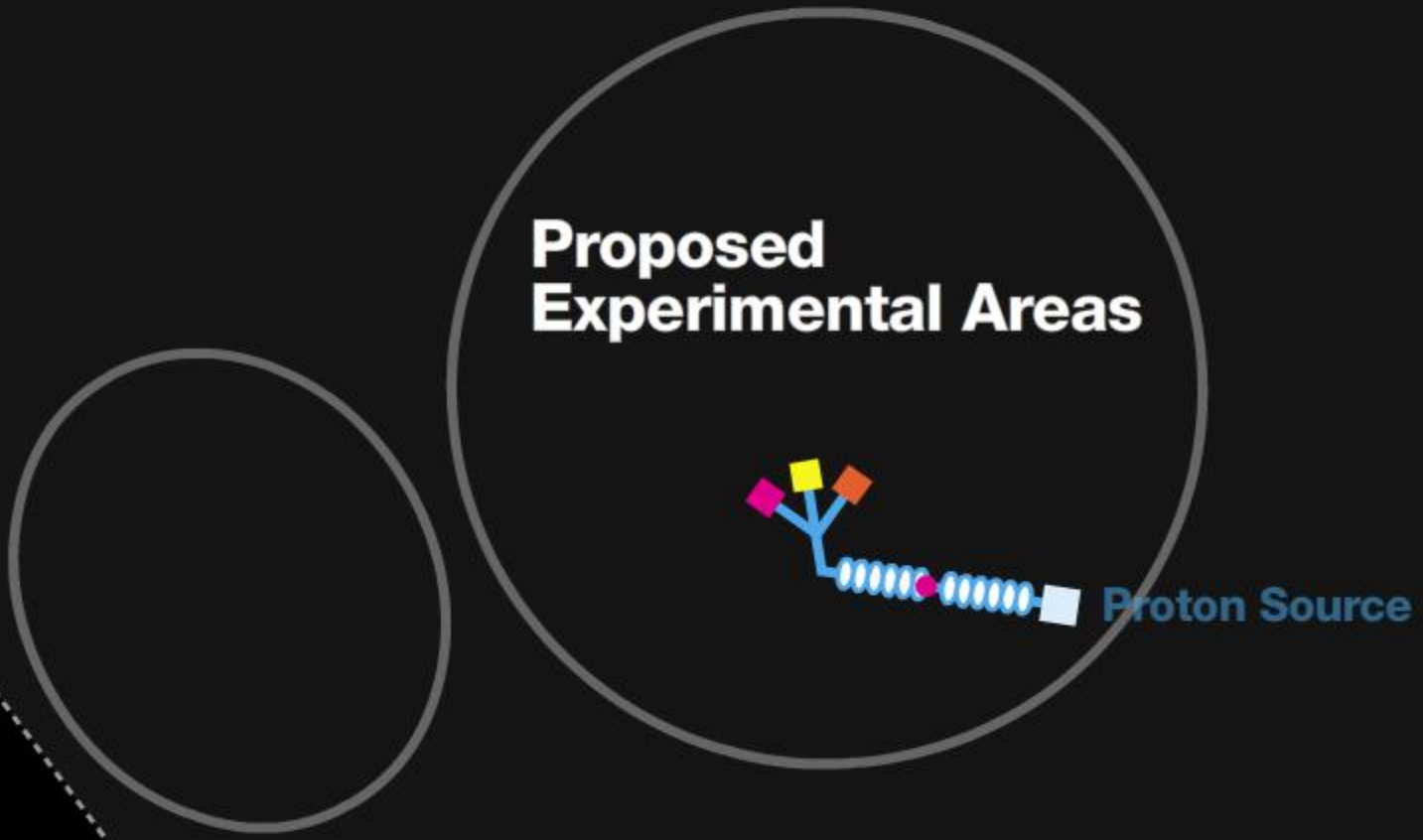
will be the world's most powerful (> 5 MW)
and flexible (162 MHz) proton source

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

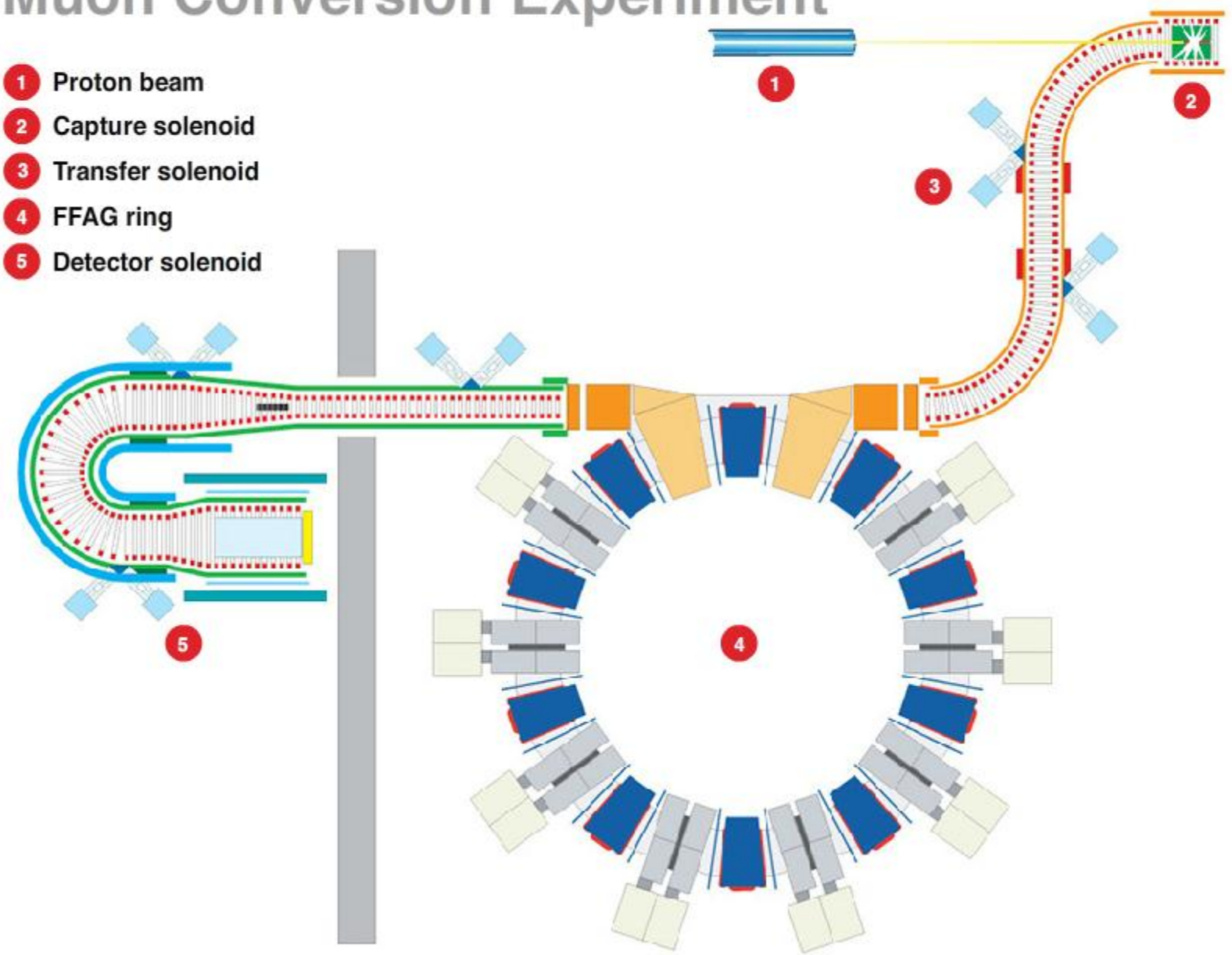
Project X: Low-energy Program

Highest-intensity proton accelerator in the world

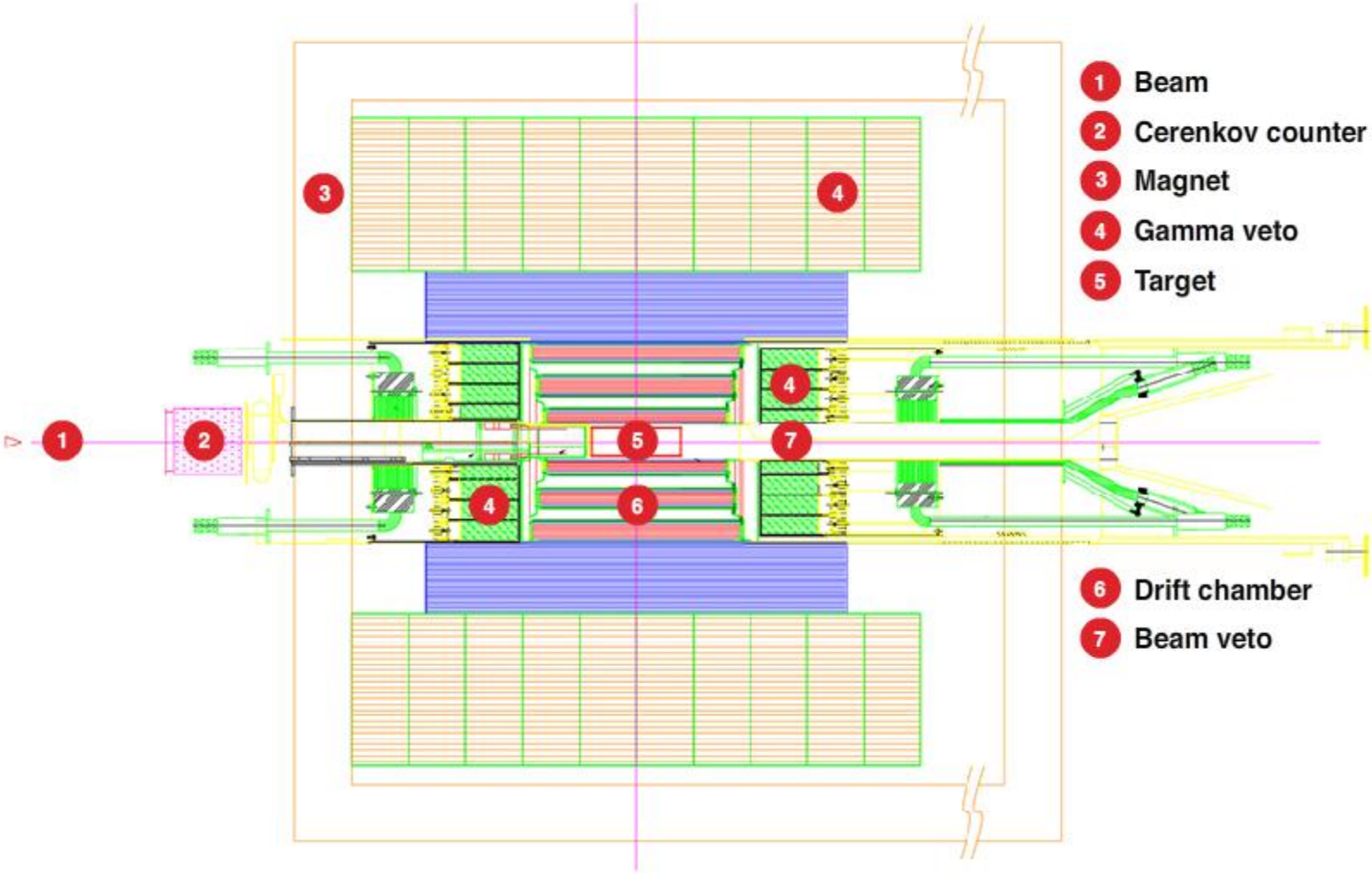


Muon Conversion Experiment

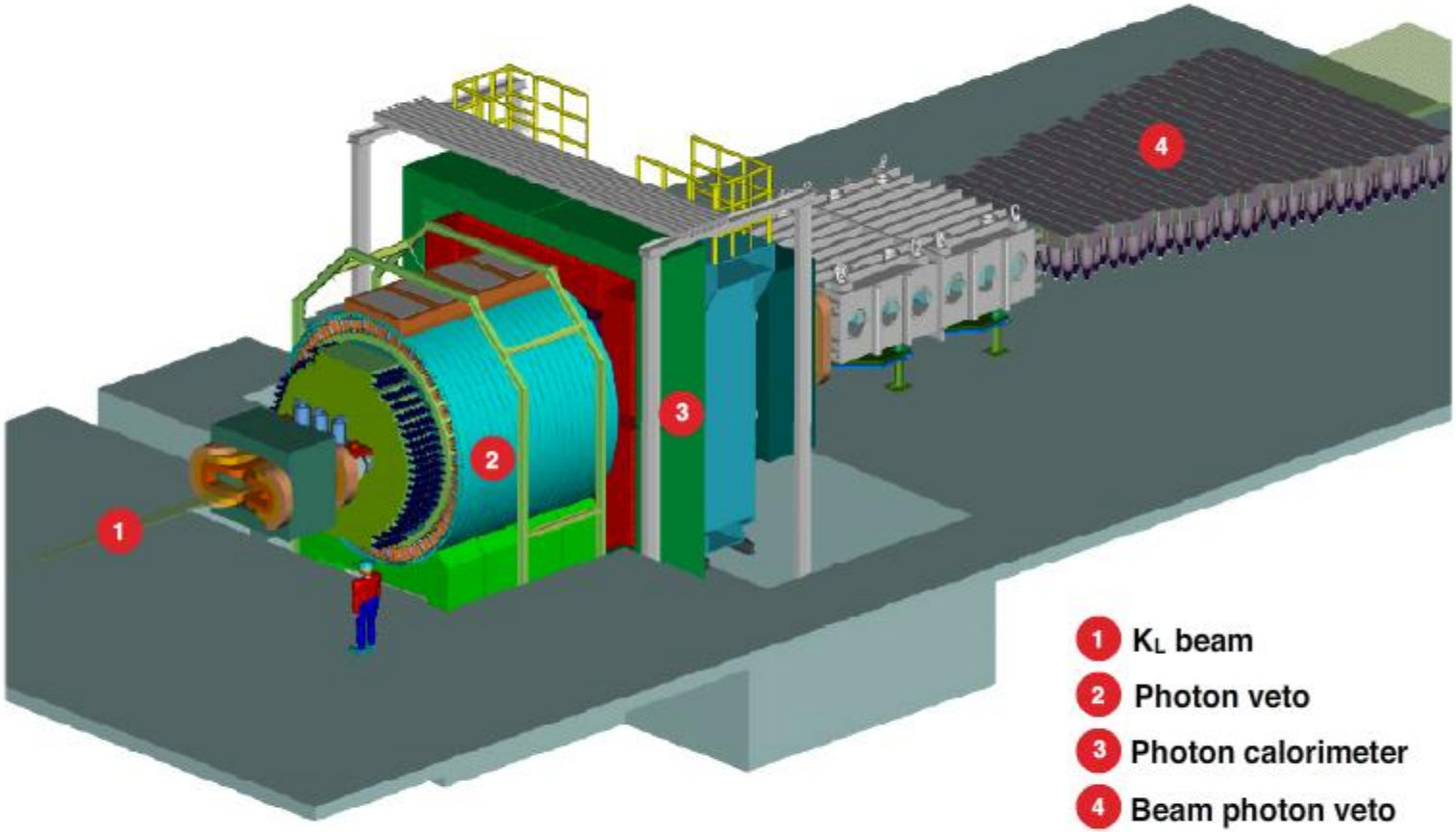
1. Proton beam
2. Capture solenoid
3. Transfer solenoid
4. FFAG ring
5. Detector solenoid



$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ Experiment

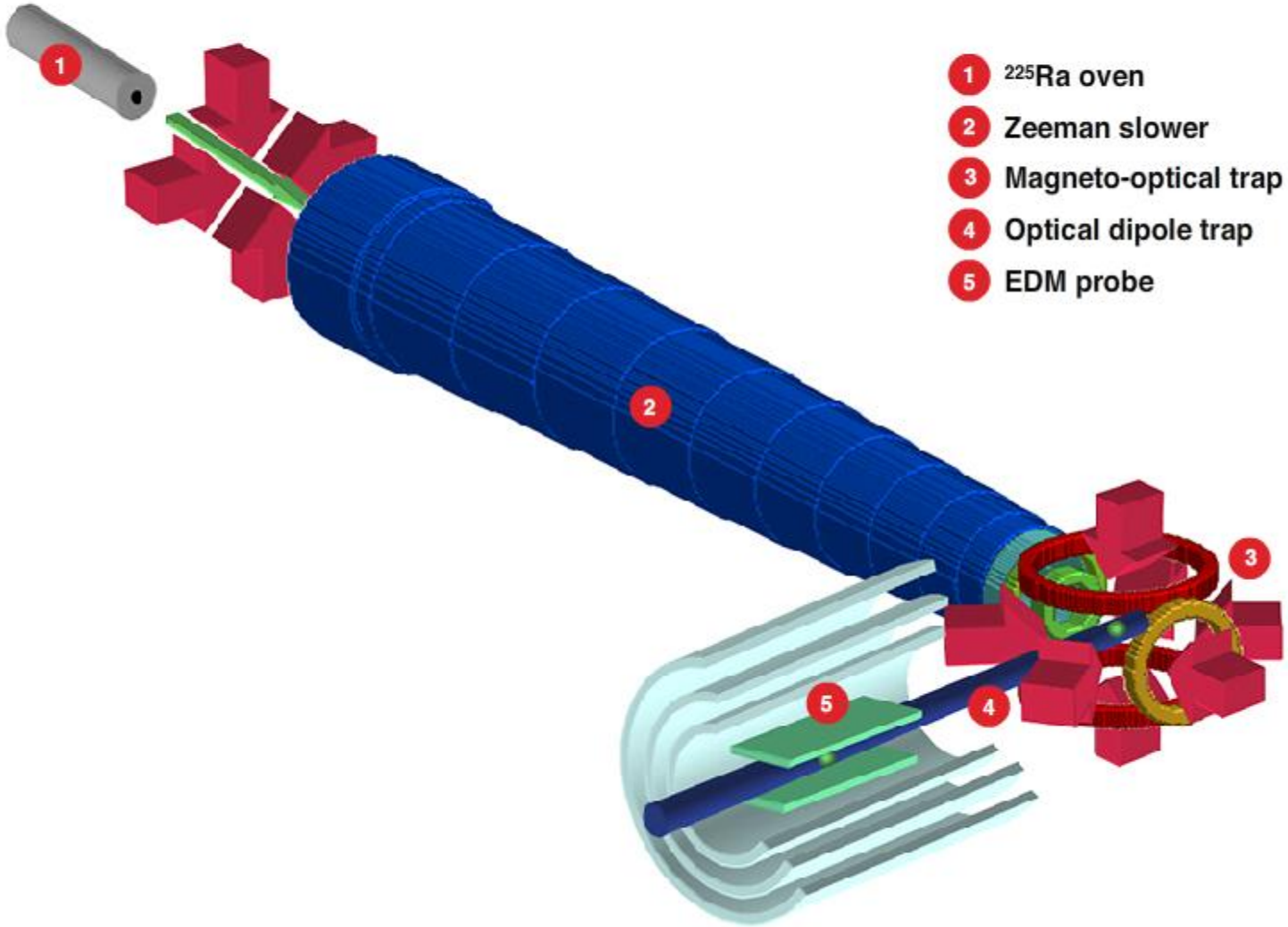


$K_L \rightarrow \pi^0 \nu\bar{\nu}$ Experiment



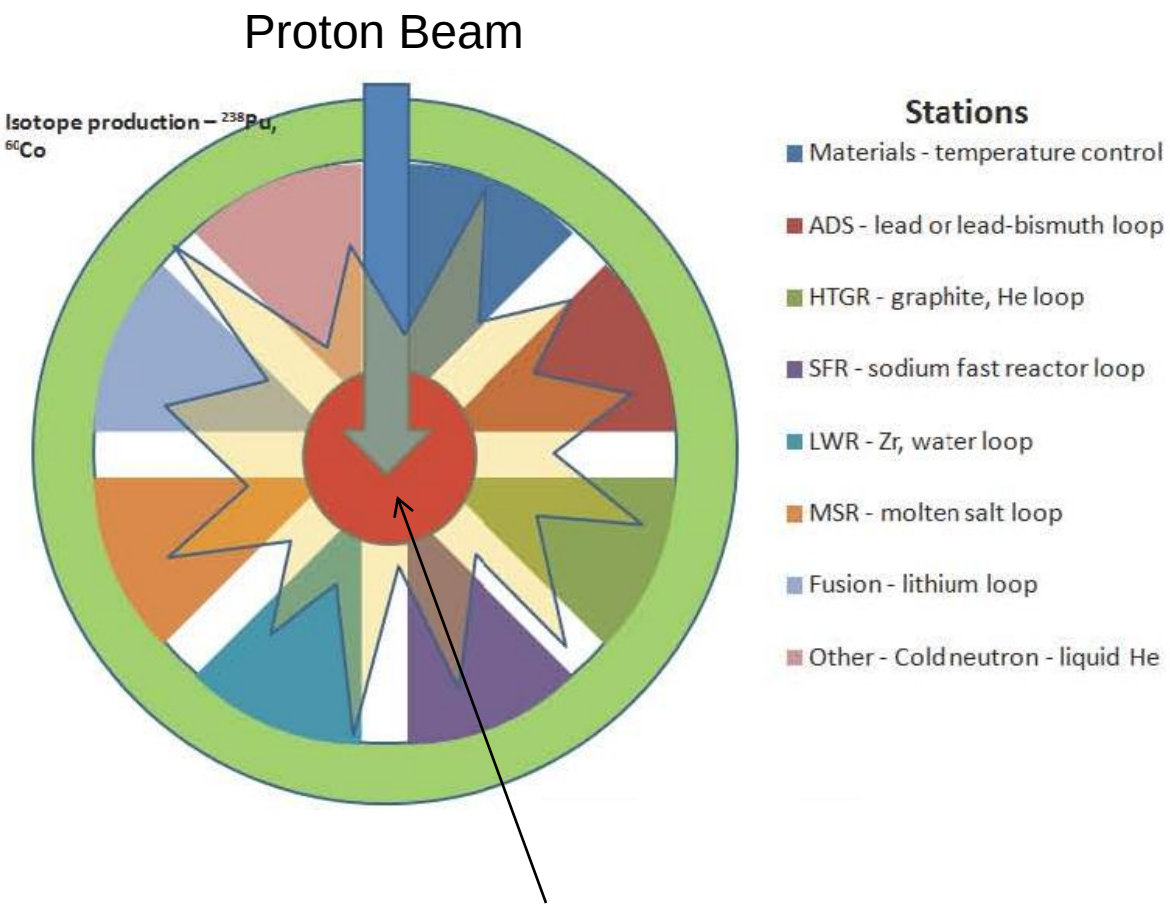
1. K_L beam
2. Photon veto
3. Photon calorimeter
4. Beam photon veto

Electric Dipole Moment Search



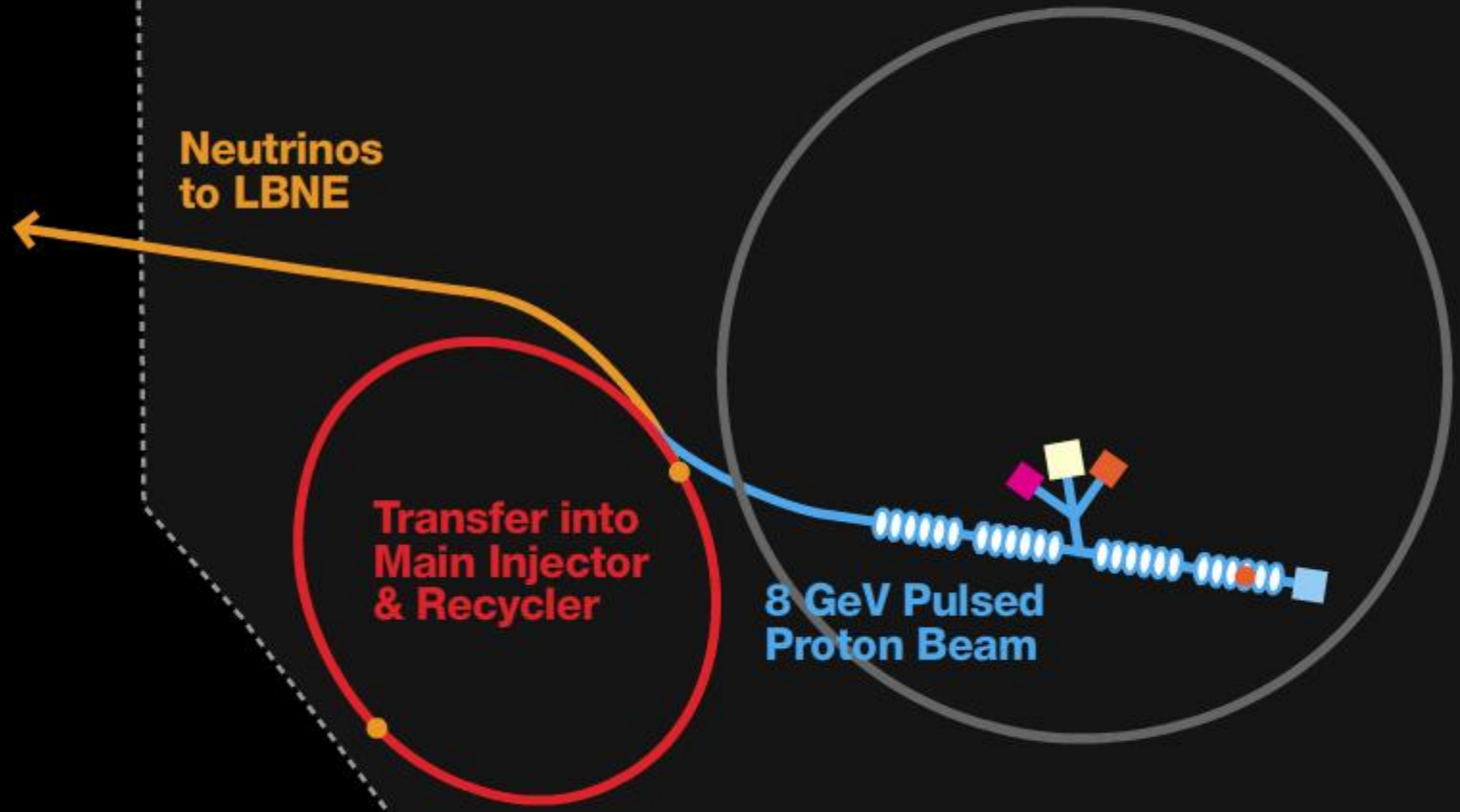
1. ^{225}Ra oven
2. Zeeman slower
3. Magneto-optical trap
4. Optical dipole trap
5. EDM probe

Nuclear Energy Station Concept



Project X: High-energy Program

More beam for high-intensity neutrino experiments



The Project X 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?

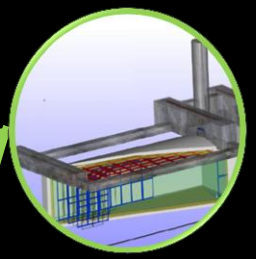
Will protons every decay?

Supersymmetry or other new symmetries?

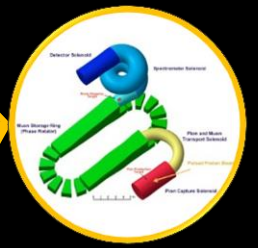
Extra dimensions?

What is dark matter?

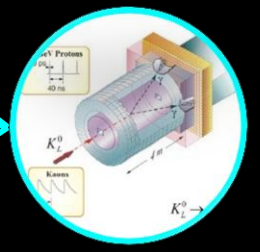
What is dark energy?



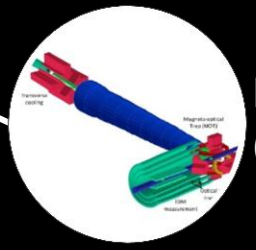
neutrinos



muons



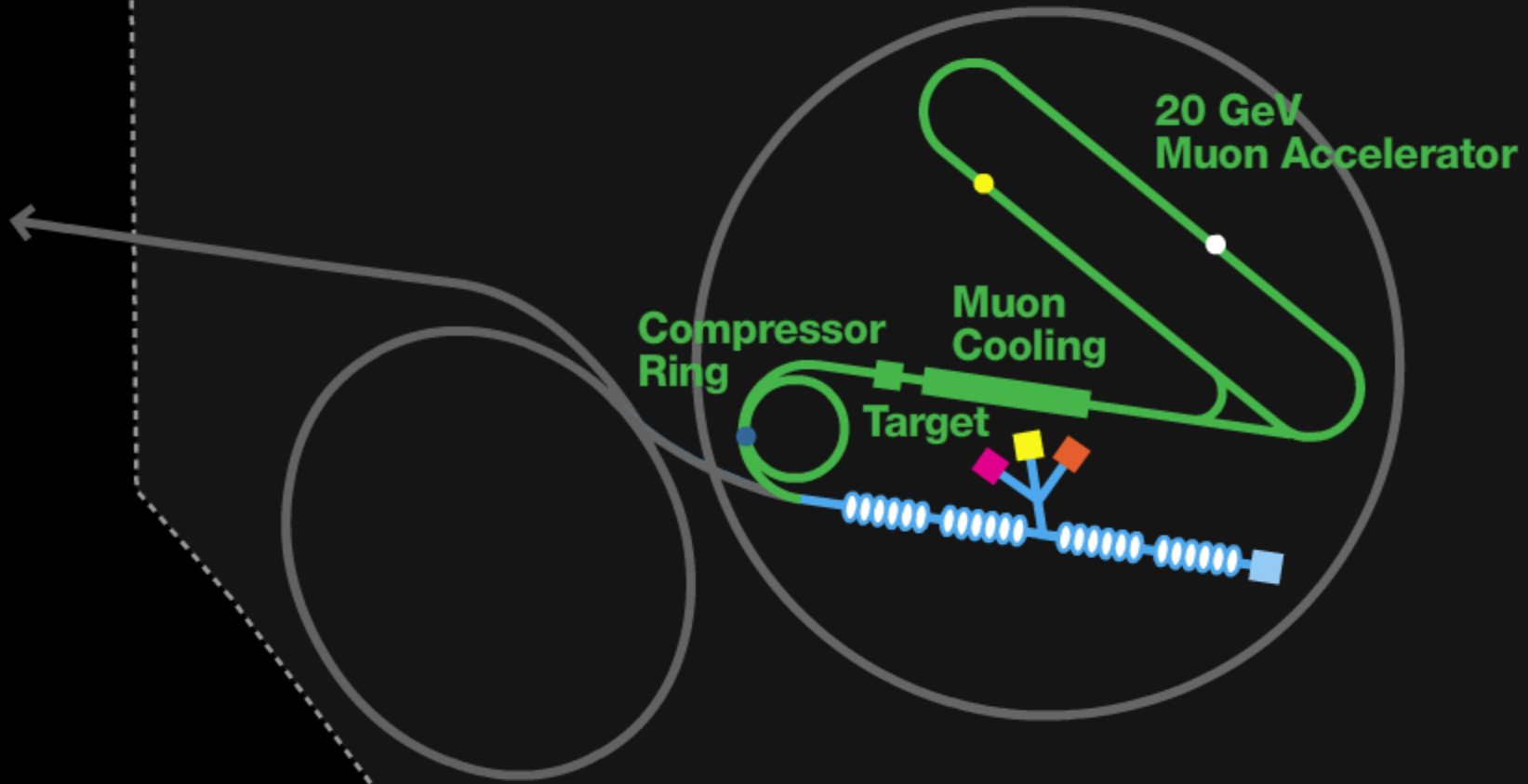
kaons



Nuclei
(EDMs..)

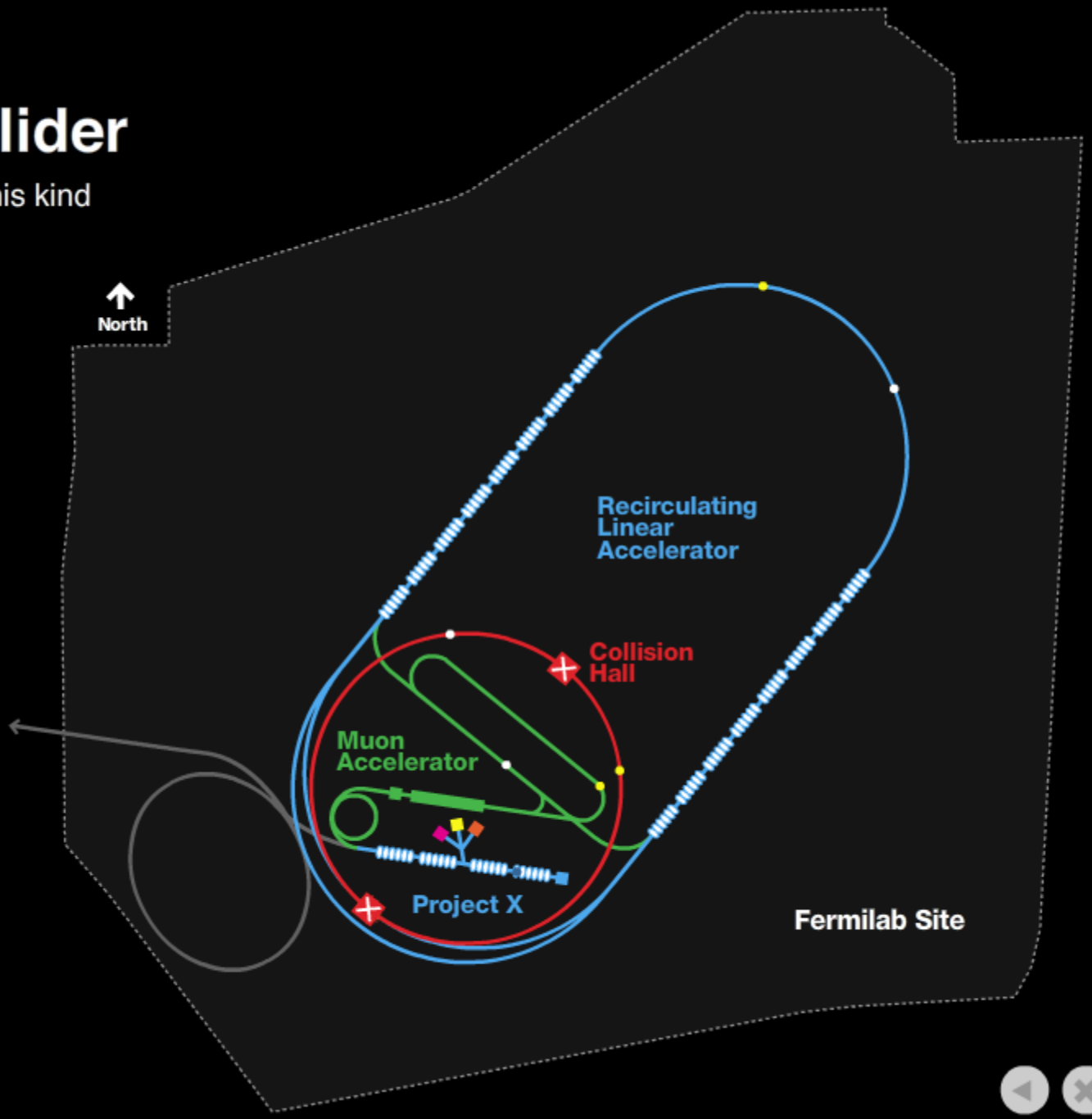
Muon Beamline & Neutrino Factory

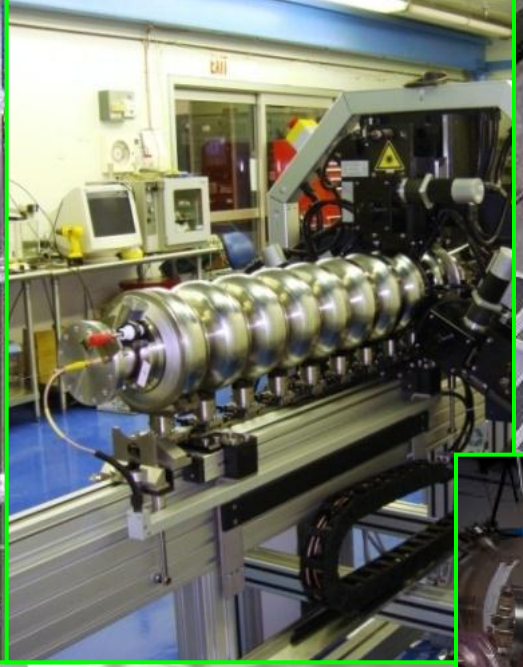
Highest-intensity muon and neutrino source in the world

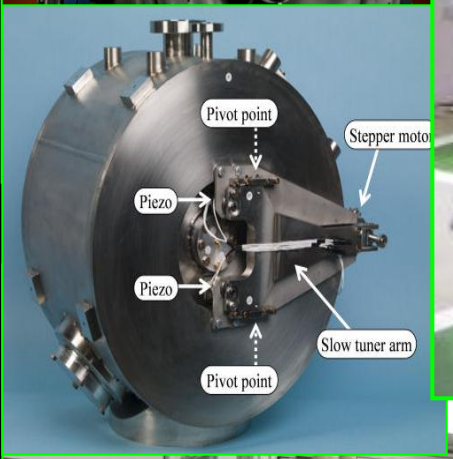


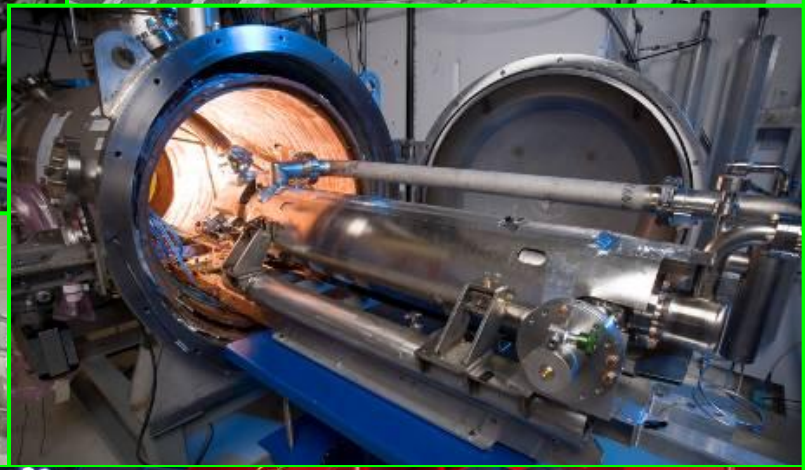
Muon Collider

The first collider of this kind



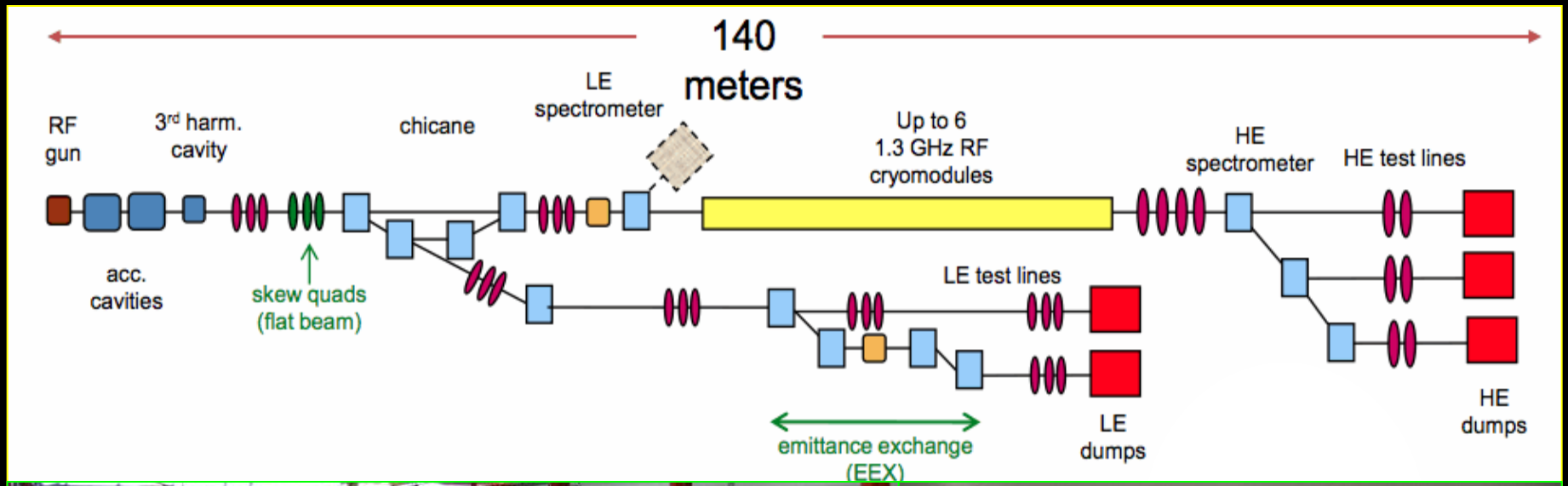






Project X and Lepton Collider Development Facilities at Fermilab

Accelerator System Test / Research Facility

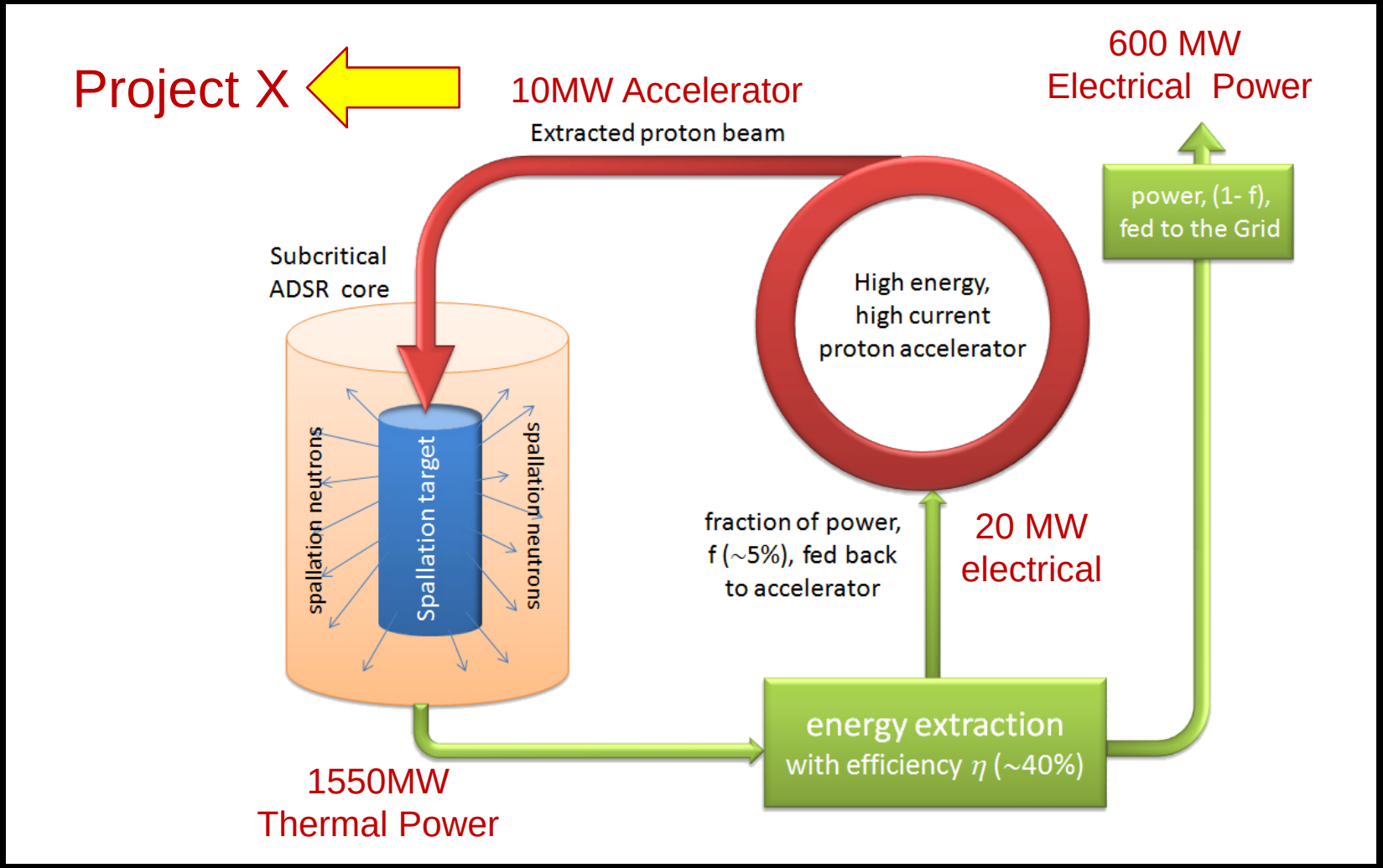


Illinois Accelerator Research Center

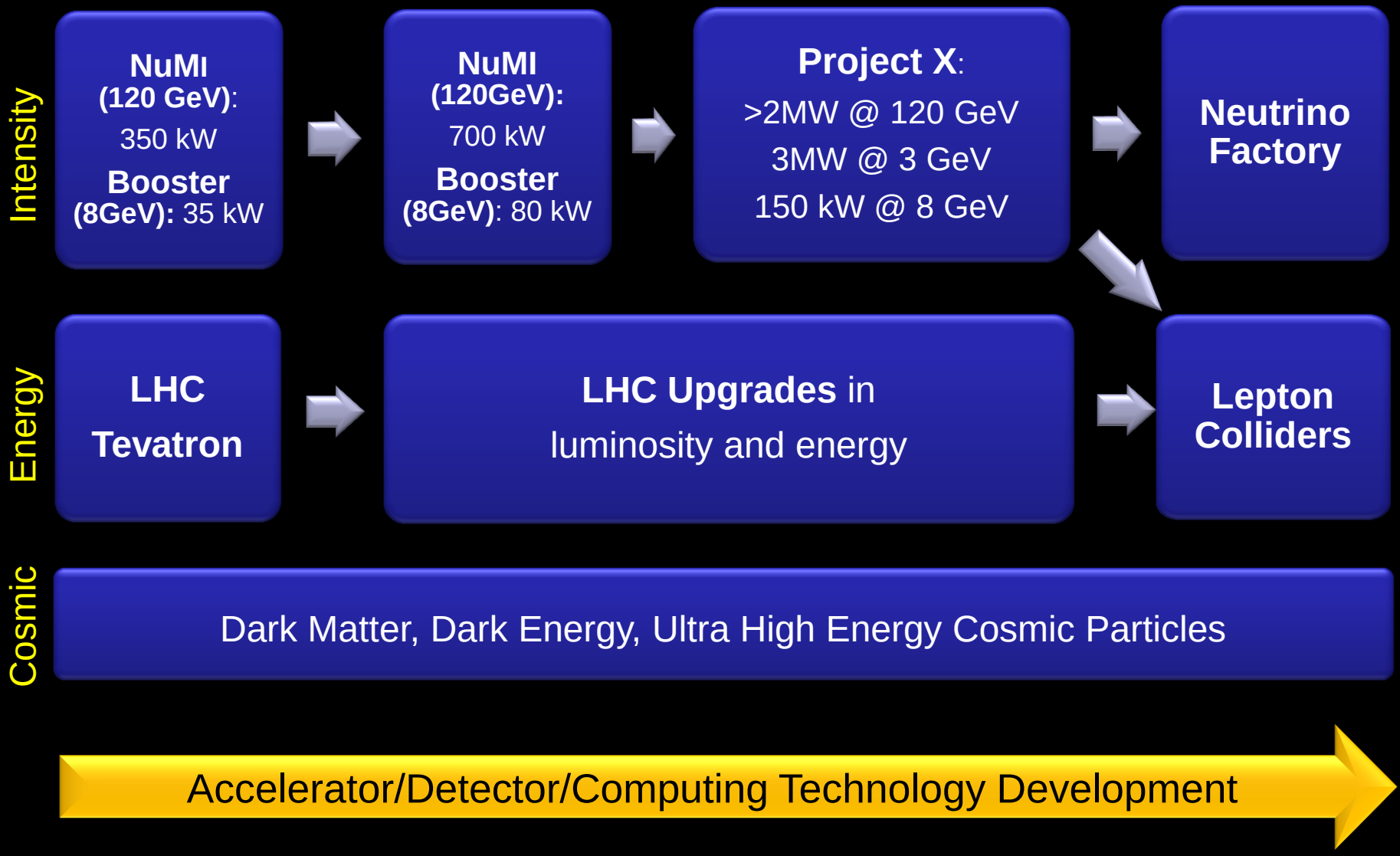
Accelerator: science, technology, education, partnerships with industry

Project X and Accelerator Driven Subcritical Reactor

Nuclear waste transmutation / Energy sources



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)