Plans for superbeams in US

Young-Kee Kim

Fermilab / Univ. of Chicago

October 1-3, 2009

European Strategy for Future Neutrino Physics

Particle Physics

- Global enterprise
- Many laboratories have changed missions. A few principle particle physics laboratories in the world
- Important and healthy to maintain expertise, long term stability, and support in all three regions, and to engage the world wide community
- More coordination and collaboration

US Particle Physics Today

- National Laboratories
  - Fermilab
    - Single mission – particle physics
  - Other laboratories: SLAC, BNL, LBNL, ANL, LANL, …
    - Multi missions including particle physics
    - Particle physics is not the primary mission
- Universities

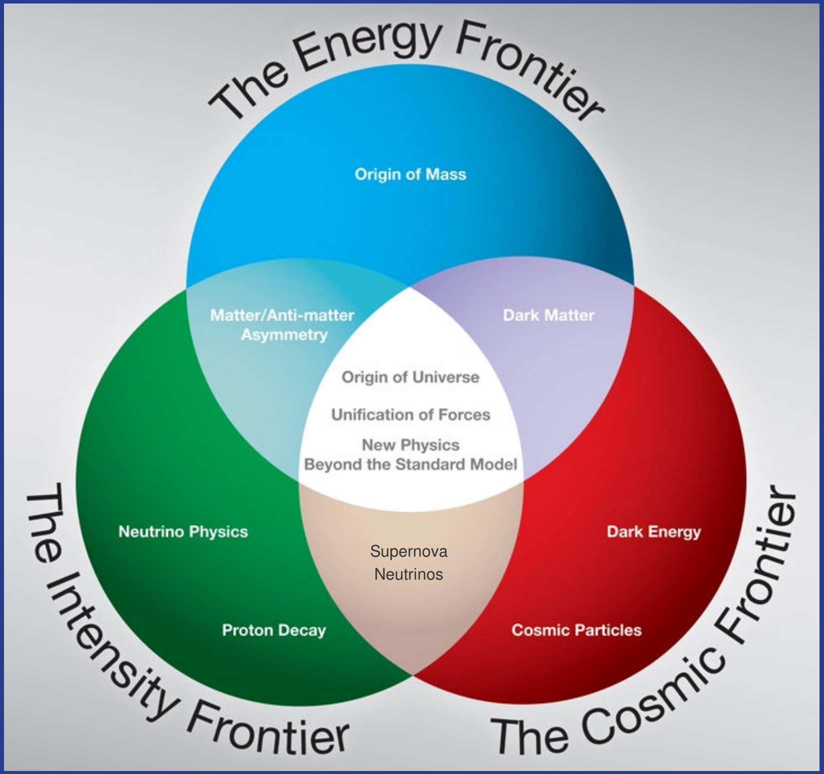
- We need to maintain expertise and uniqueness in laboratories and universities

US Particle Physics Today

- Current and Future "Large" Projects in US (not too large: smaller than global projects)
  - Located at Fermilab
  - National Projects with International partnership / collaboration
    - e.g. Project X: multi-MW proton accelerator
      - R&D MOUs established so far
        - US: ANL, BNL, Cornell, Fermilab, LBNL, ORNL/SNS/ MSU, TJNAF, SLAC, ILC/ART
        - Non US (International participation via in-kinds contributions): India
        - Collaborating with more institutions and countries

Particle Physics at the Three Frontiers

Endorsed by the US Particle Physics Community

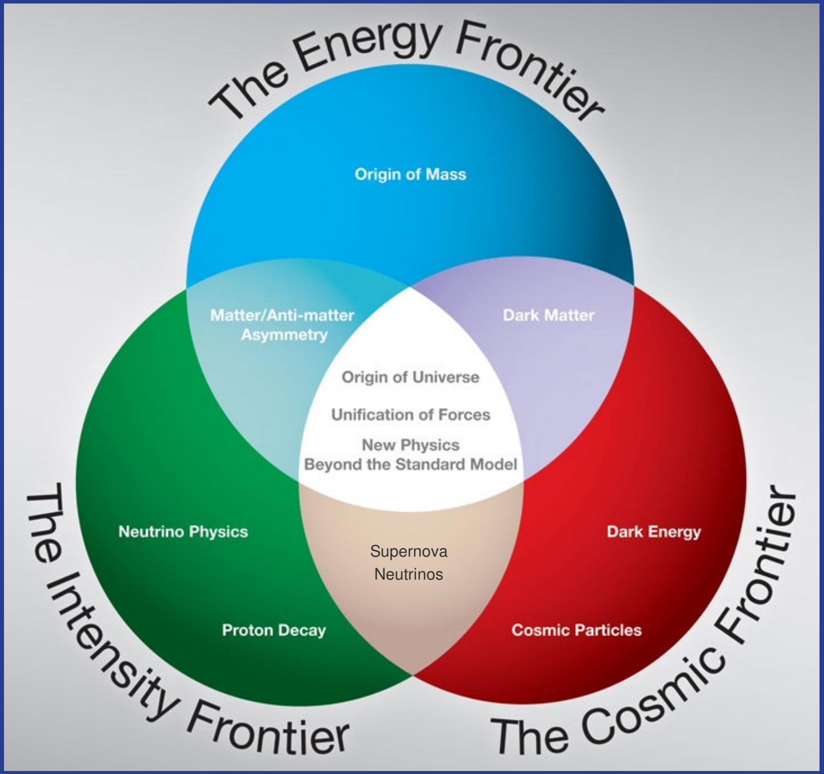


P5 (Particle Physics Project Prioritization Panel) Report

Fermilab Programs at Three Frontiers (Now)

Hadron Colliders:
Tevatron
LHC

Neutrinos



Dark Matter,
Dark Energy,
UHE Particles
from Space

http://www.fnal.gov/pub/science/frontiers/

Fermilab Programs at Three Frontiers (Now)

Hadron Colliders:
Tevatron
LHC

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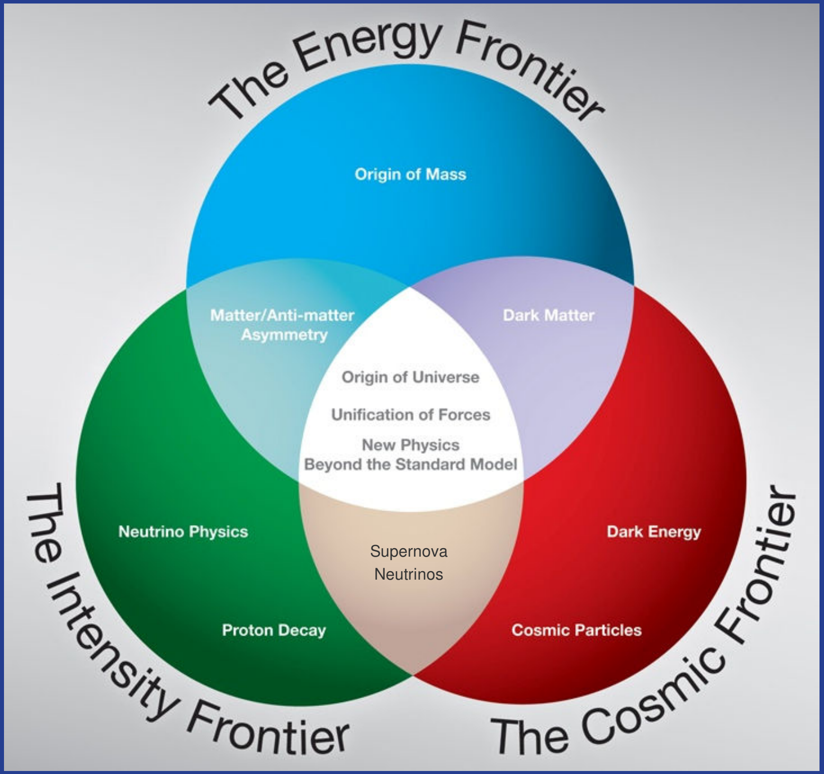

Dark Matter,
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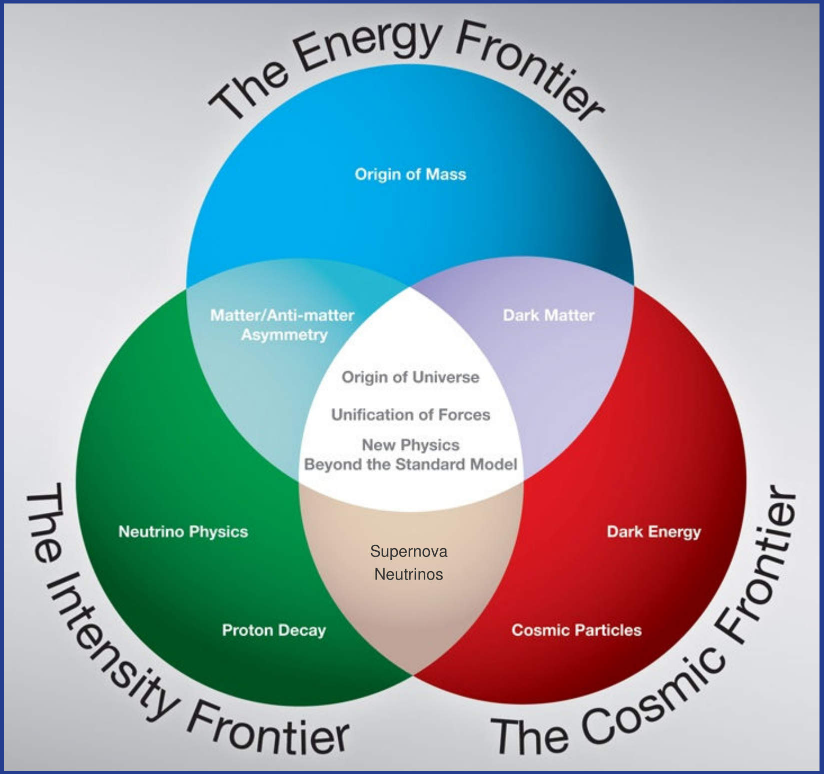
http://www.fnal.gov/pub/science/frontiers/

Fermilab Programs at Three Frontiers (Future)

Hadron Colliders:

LHC

Neutrinos
Rare Processes / Precision Meas.s



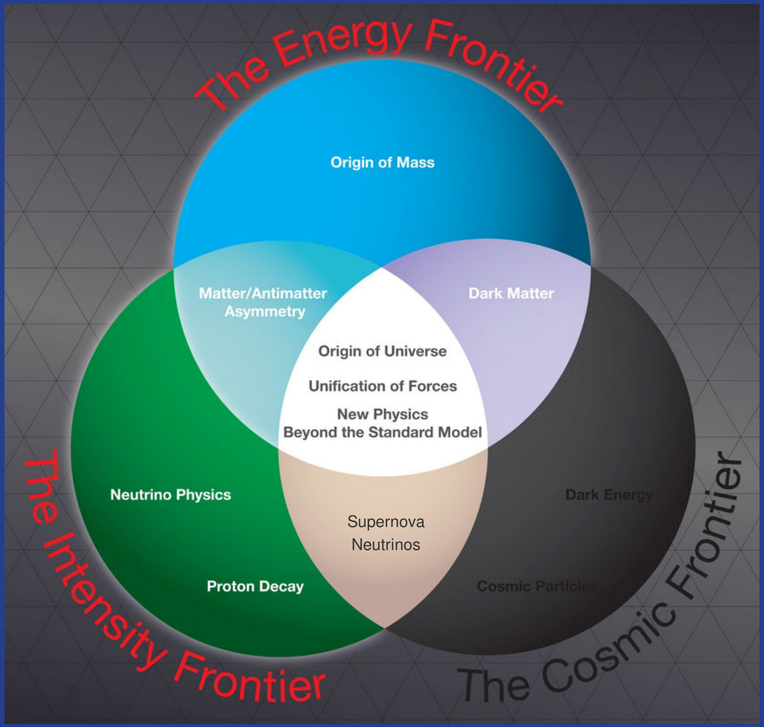
Lepton Colliders:
Sub-TeV: ILC
Multi-TeV: μ Collider (CLIC)

Dark Matter,
Dark Energy,
UHE Particles from Space

http://www.fnal.gov/pub/science/frontiers/

US Accelerator-based Programs

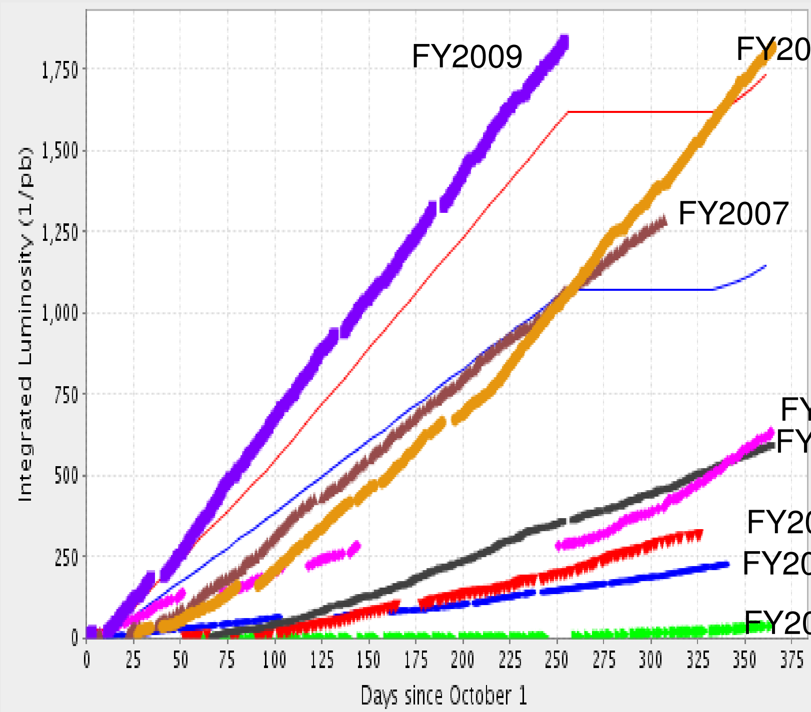
Energy-Intensity Integrated Program: Today operates the world's highest energy collider & highest power ν beam

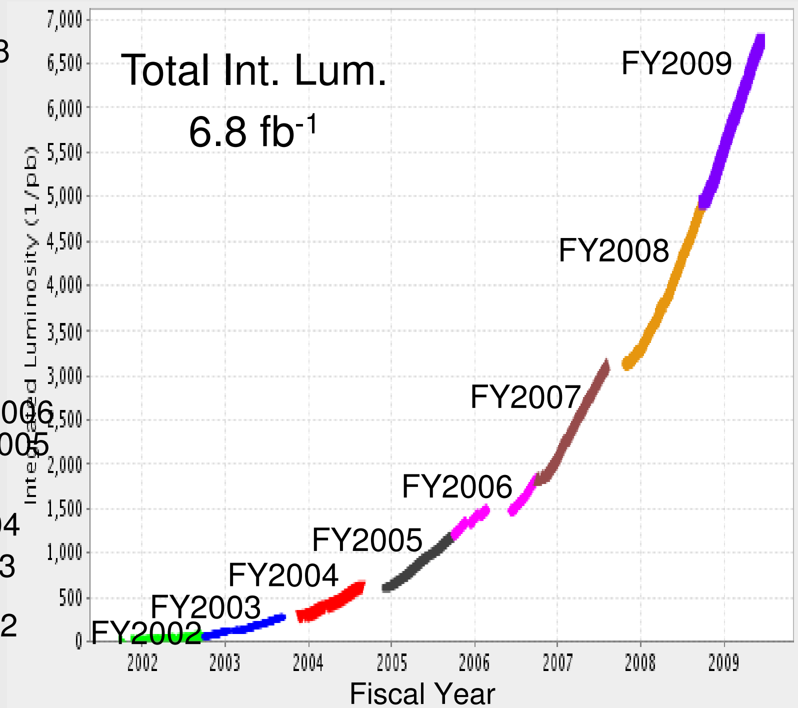


Future: Integrated plan for the Energy & Intensity Frontier

The Energy Frontier: The Tevatron

Progress: the Tevatron

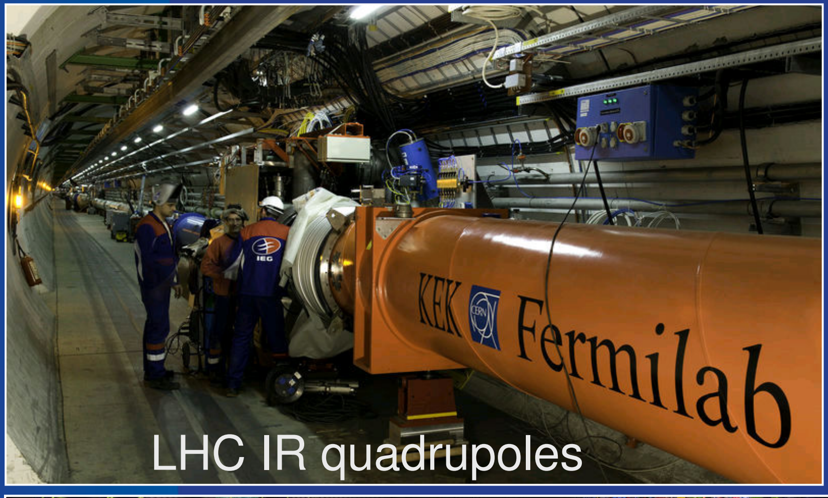


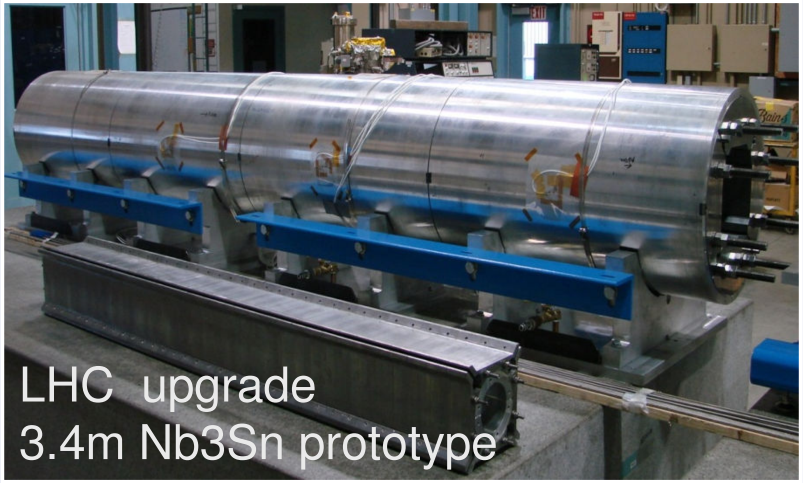


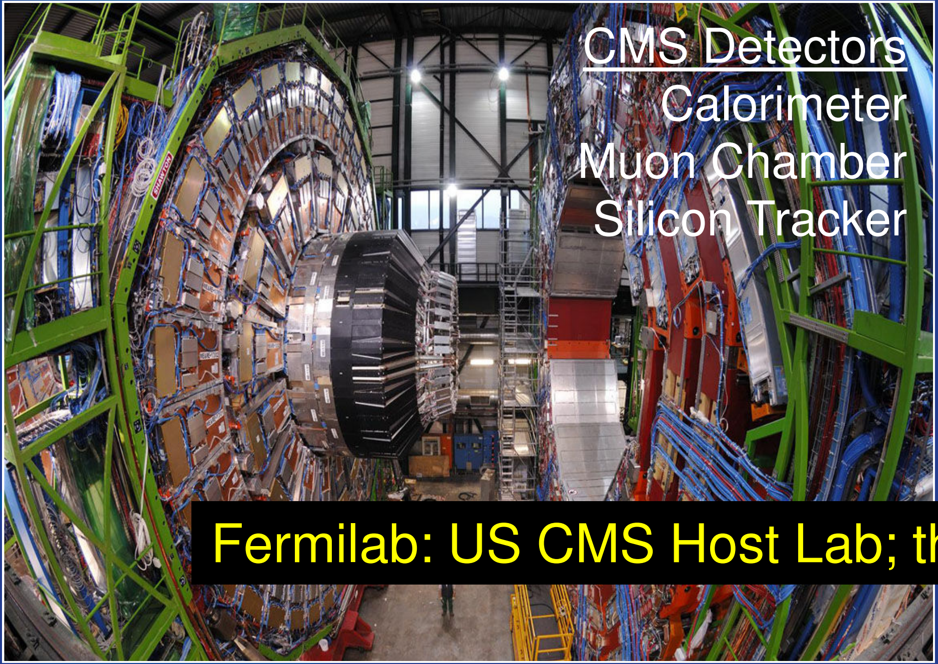
~100 publications / year, ~60 Ph.D.s / year

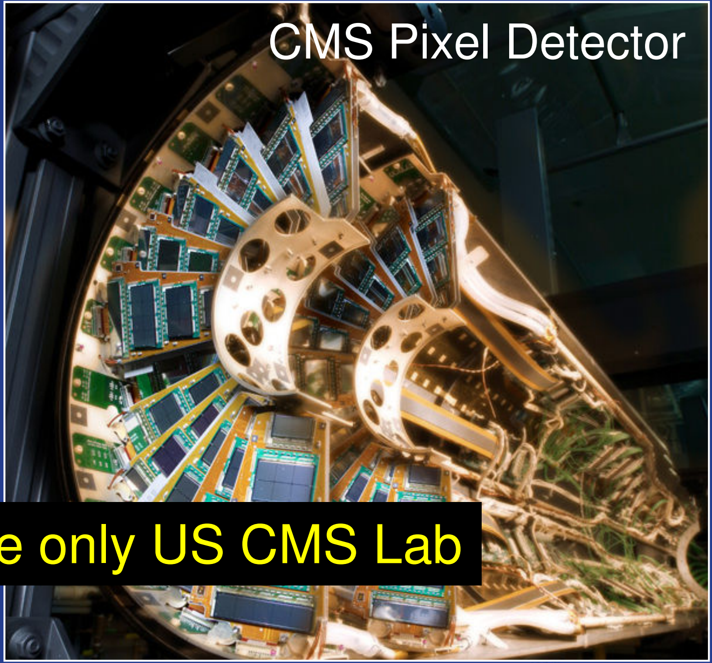
Plan to run through FY2011: nearly double the luminosity

Fermilab and LHC:
Accelerator and Detector Design/Engineering/Construction and Upgrades



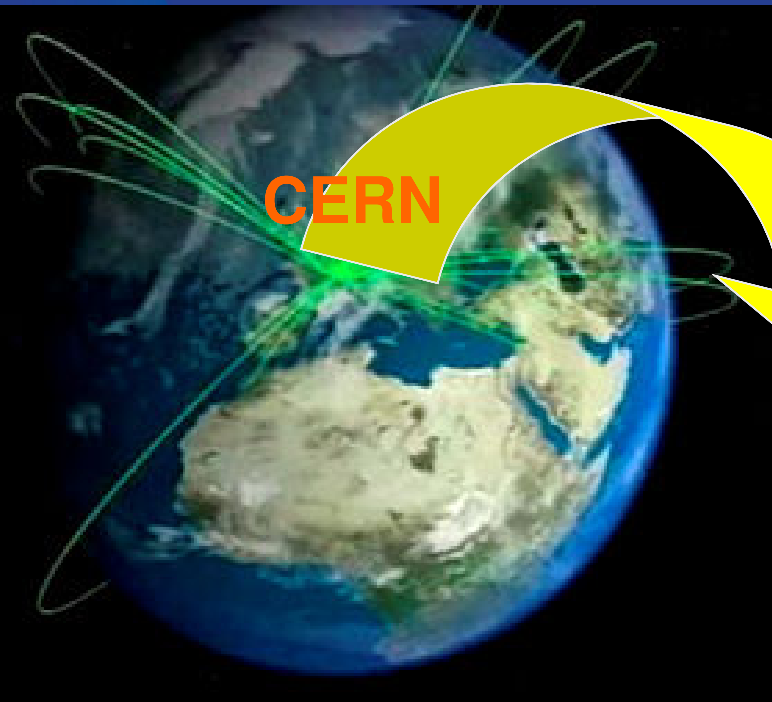






Fermilab: US CMS Host Lab; the only US CMS Lab

Fermilab and LHC



US CMS Host Lab; the only US CMS Lab

CMS Tier-1 Computing Center
LHC Physics Center
Support US CMS Community

To make being at Fermilab as good as being at CERN.
Requires critical mass (~100 Fermilab + University Scientists at Fermilab).

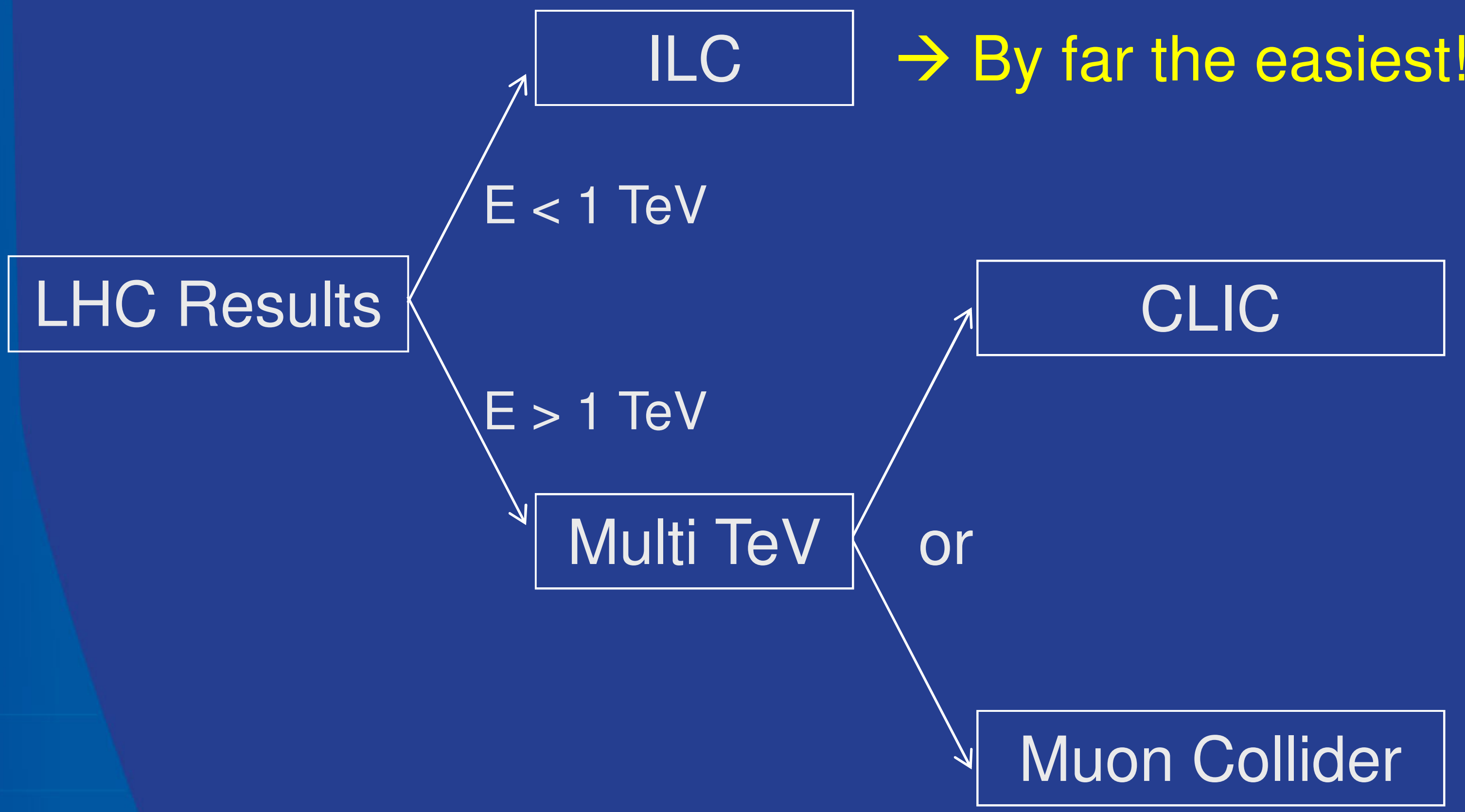
Supporting the LHC Community

CERN-Fermilab Hadron Collider Physics Summer School

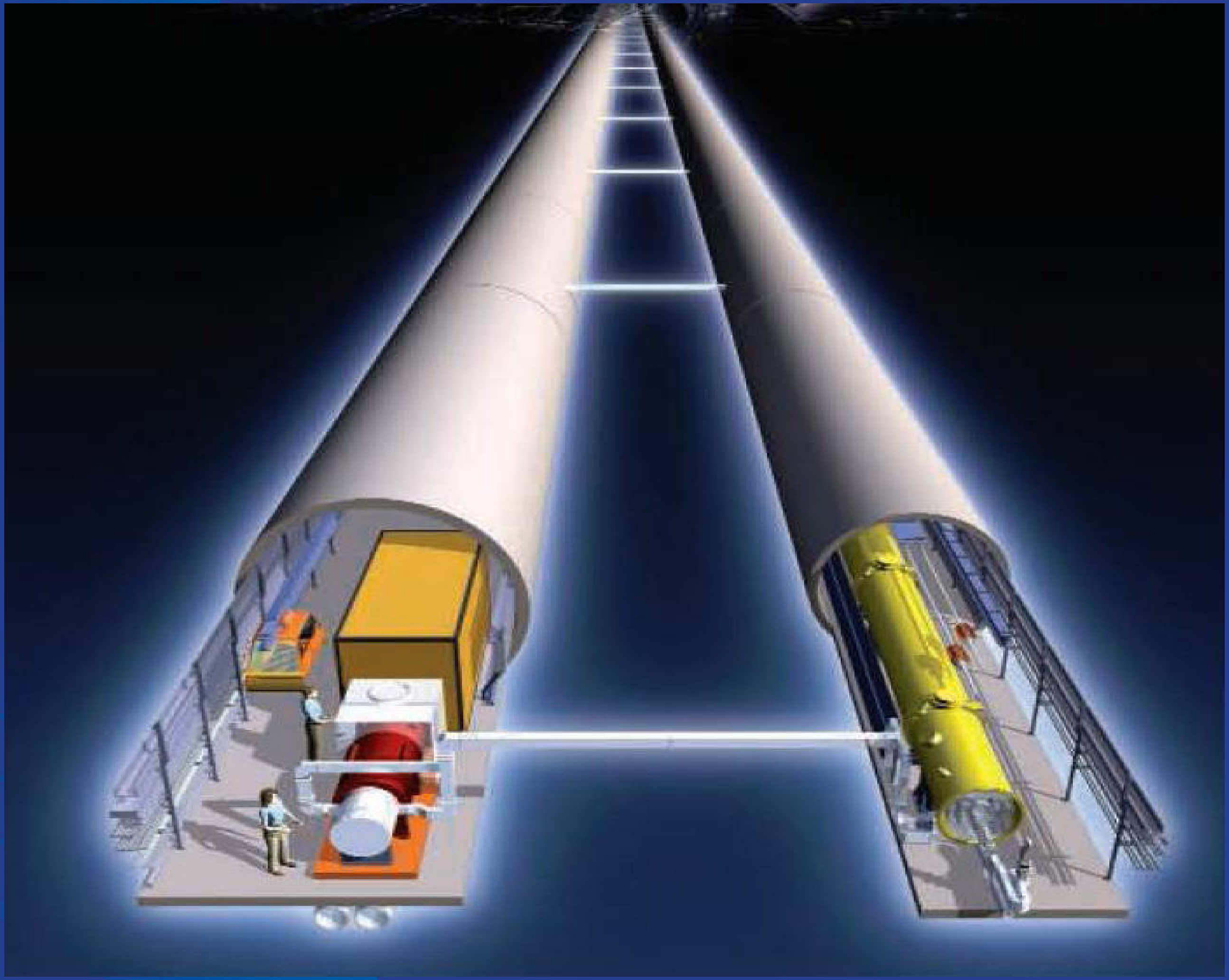
1st	Fermilab	August 9-18, 2006
2nd	CERN	June 6-15, 2007
3rd	Fermilab	August 12-22, 2008
4th	CERN	June 8-17, 2009

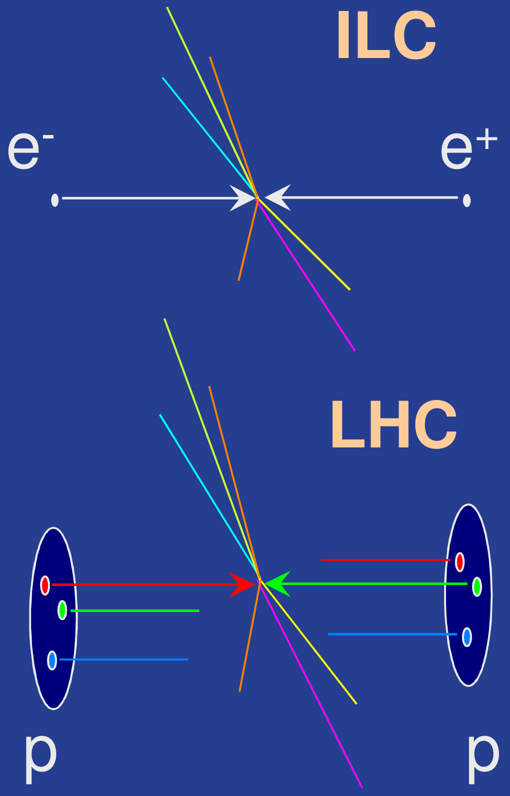
Fermilab

Lepton Colliders beyond LHC



International Linear Collider (ILC)





Multi-TeV Lepton Colliders

- Muon Collider Approach: Fermilab's Focus
  - Based on a secondary beam: we have experience basing colliders on antiprotons. For μ's we must do it in 20 msec.
  - Advantages: narrow energy spread (no beamstrahlung) and small physical footprint (no synchrotron radiation)
  - No new methods of acceleration, but new method of deceleration!: muon cooling
- CLIC Approach: CERN's Focus
  - Advantages: stable particles, polarization
  - Two-beam accelerator scheme
- Physics/detector: ILC-CLIC-Muon Collider Synergy
  - Identify benchmark processes and determine realistic detector configuration (workshop at Fermilab: Nov.10-12)

Muon Collider Conceptual Layout

http://www.fnal.gov/pub/muon_collider/

Project X
Accelerate hydrogen ions to 8 GeV using SRF technology.

Compressor Ring
Reduce size of beam.

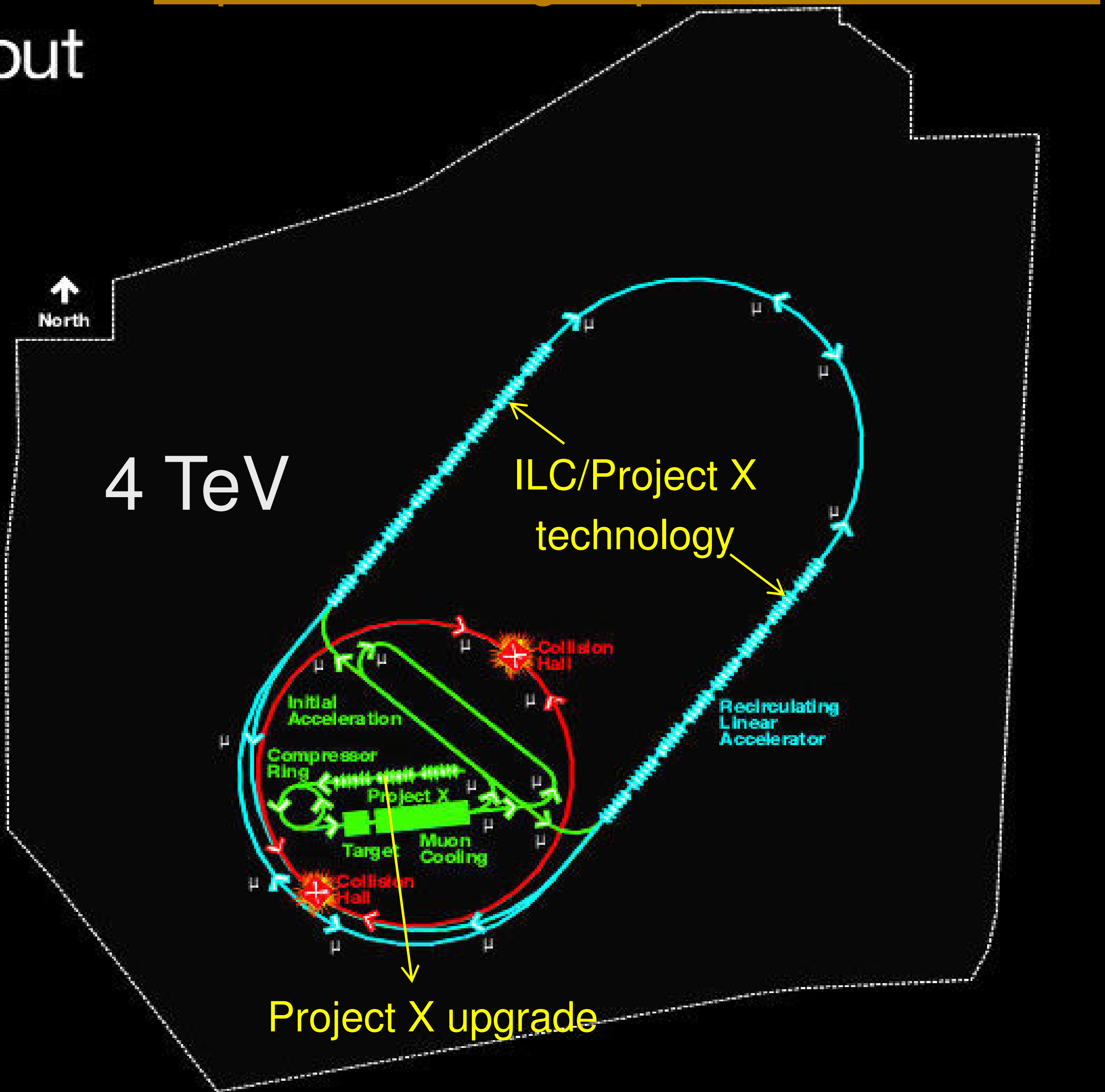
Target
Collisions lead to muons with energy of about 200 MeV.

Muon Cooling
Reduce the transverse motion of the muons and create a tight beam.

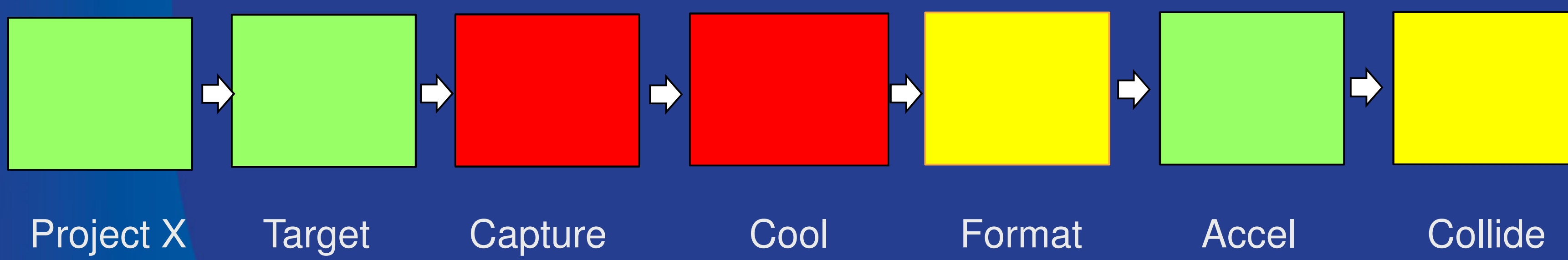
Initial Acceleration
In a dozen turns, accelerate muons to 20 GeV.

Recirculating Linear Accelerator
In a number of turns, accelerate muons up to 2 TeV using SRF technology.

Collider Ring
Located 100 meters underground. Muons live long enough to make about 1000 turns.

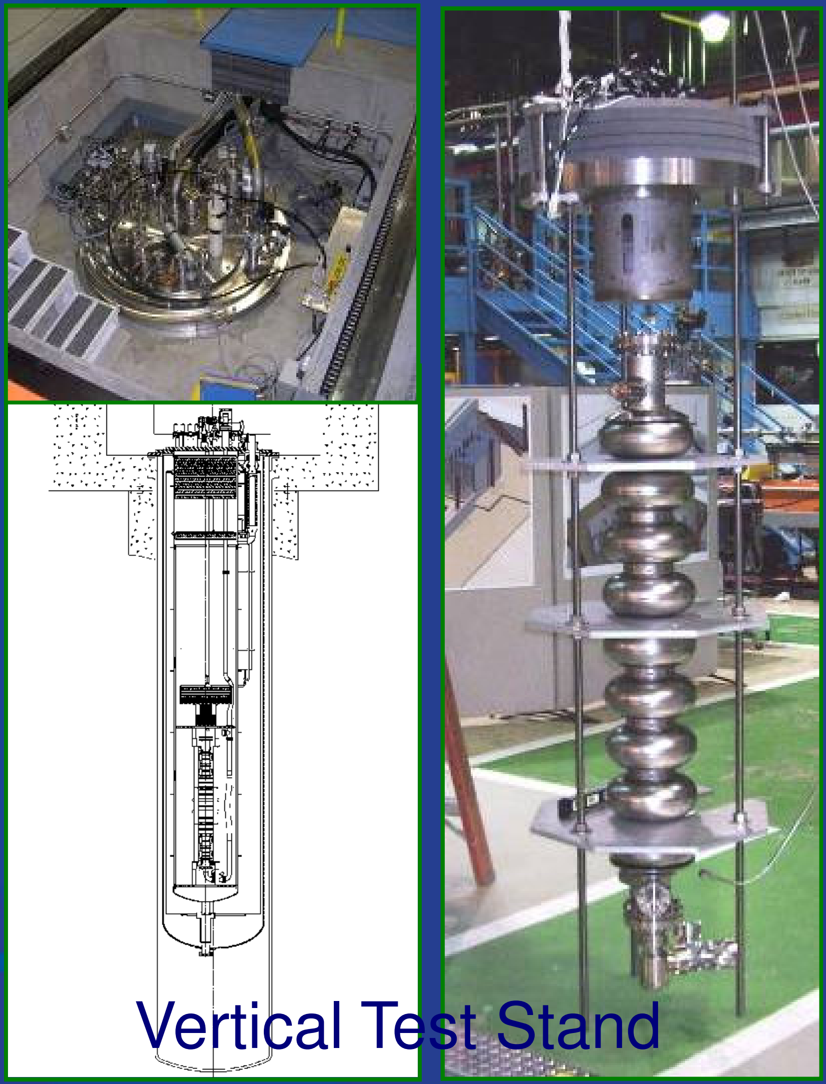


Muon collider functional layout



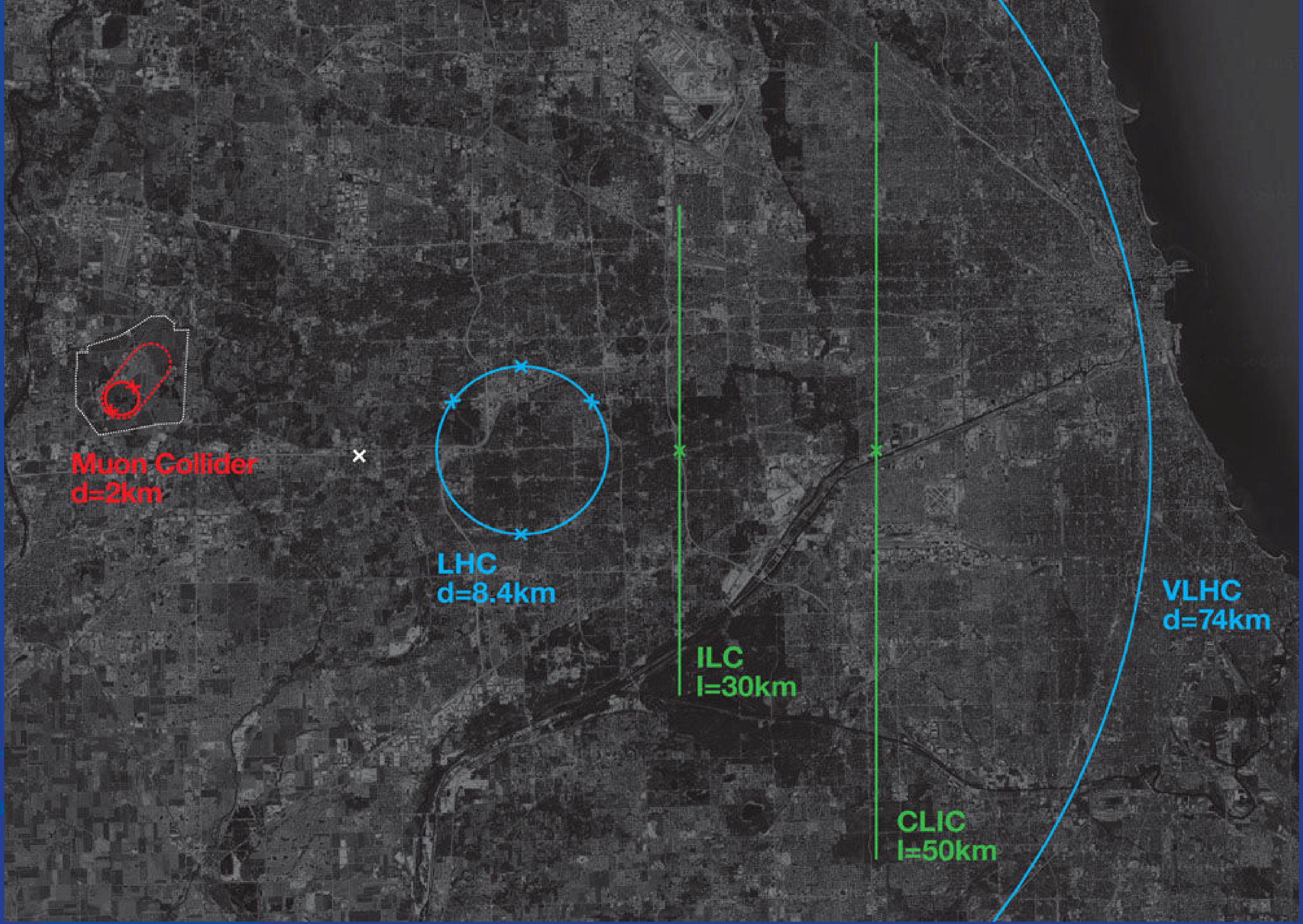
Color indicates degree of needed R&D (difficulty) and demonstration

ILC / Project X technology at Fermilab



Comparison of Particle Colliders

To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.



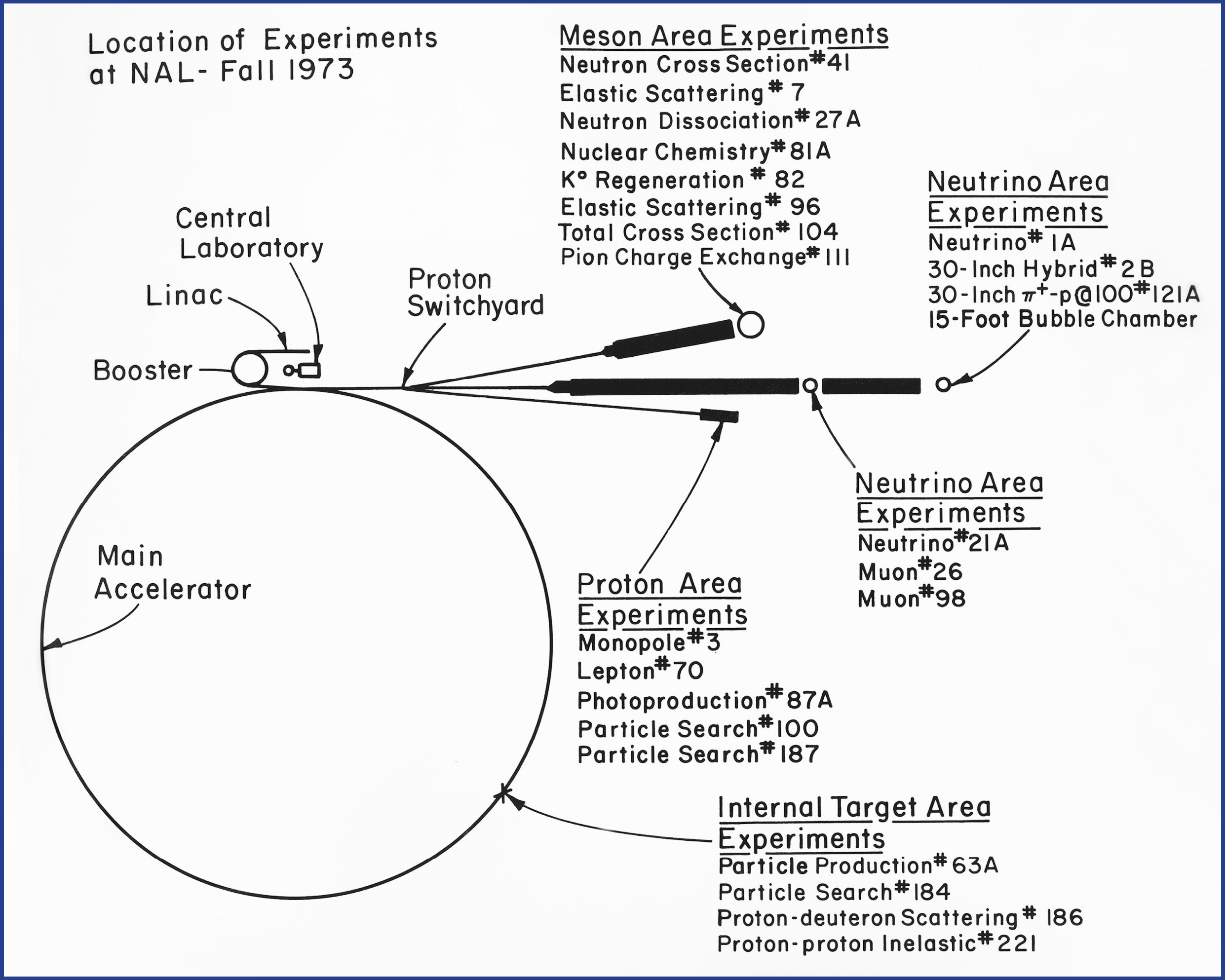
International Neutrino Summer School

Merging various neutrino schools into one coherent school

Rotating in three regions

1^{st}	Fermilab	July 6-18, 2009
2^{nd}	KEK	2010
3^{rd}	Europe	2011

Neutrinos at Fermilab have a long history



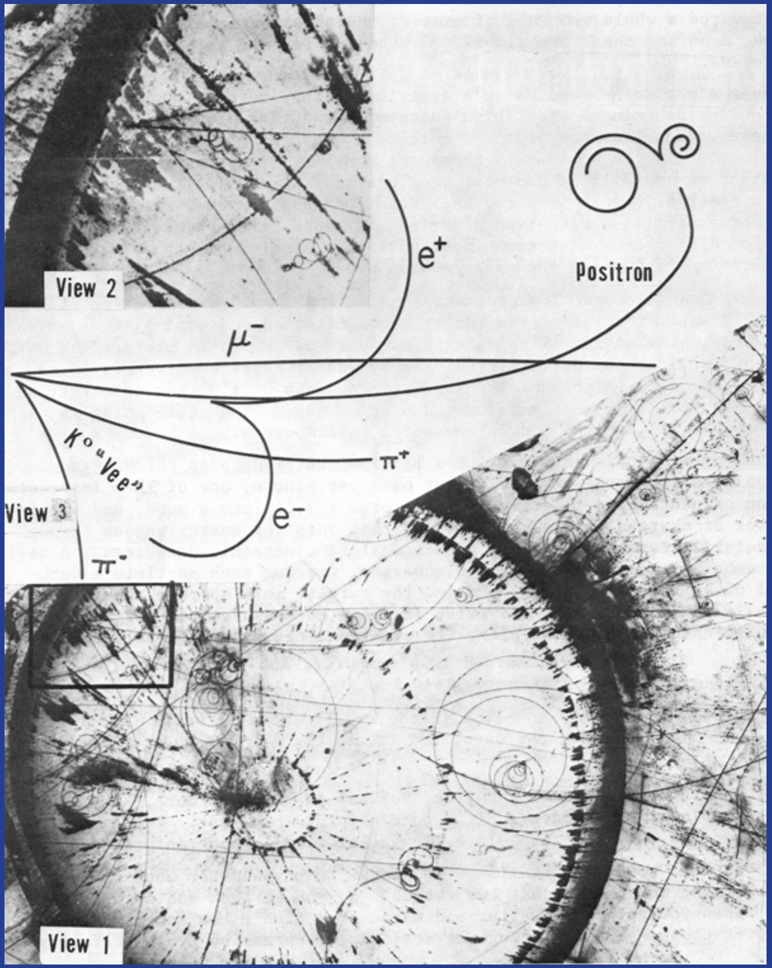
Beginning with Neutrino E-1A [proposed 15 Apr 1970, approved 1 Oct 1970, completed 30 June 1975], 21A (CCFR),….815 (NuTeV), 872 (DONUT), ….

Fermilab

Neutrinos at Fermilab have a long history

Active program with:

- horn-focused beams,
- quad-focused beams, and prompt beams;
- calorimeters,
- emulsions,
- bubble chambers,
- …

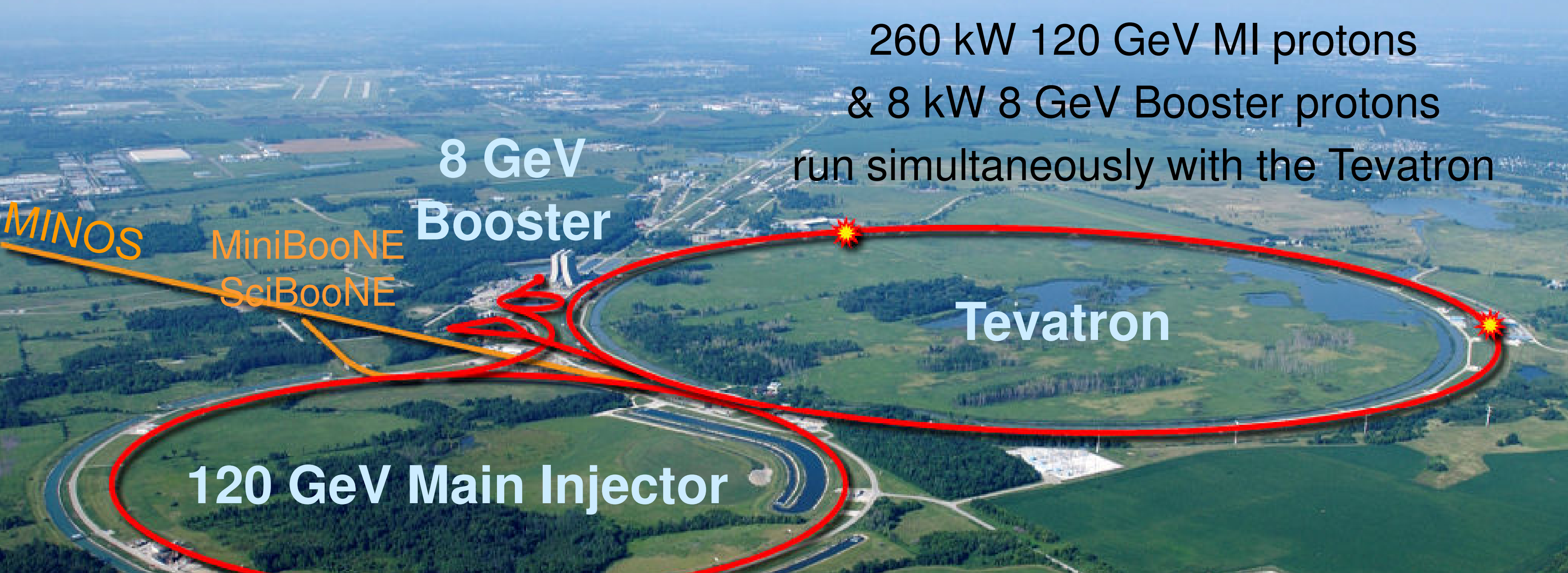


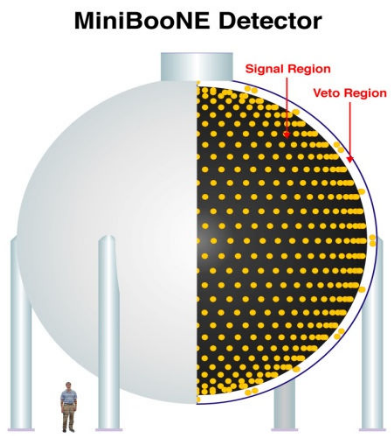
Measurements of:

- cross sections,
- electroweak scattering,
- structure functions,
- charm production,
- di-muon production,
- tau neutrino observatin,
- neutrino oscillations,
- …

The Intensity Frontier: Neutrinos

260 kW 120 GeV MI protons
& 8 kW 8 GeV Booster protons
run simultaneously with the Tevatron





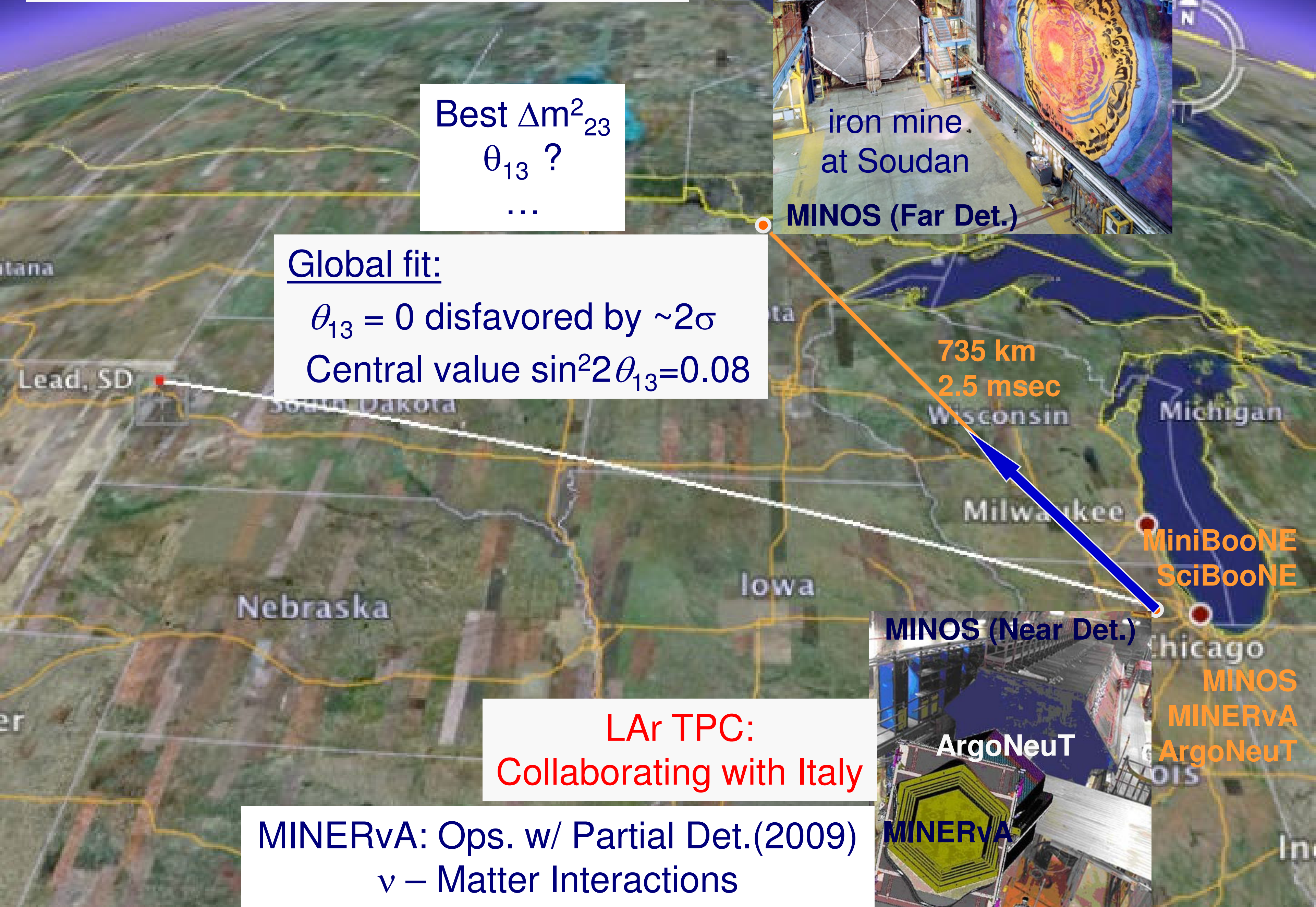
Neutrino beam from 8 GeV Booster

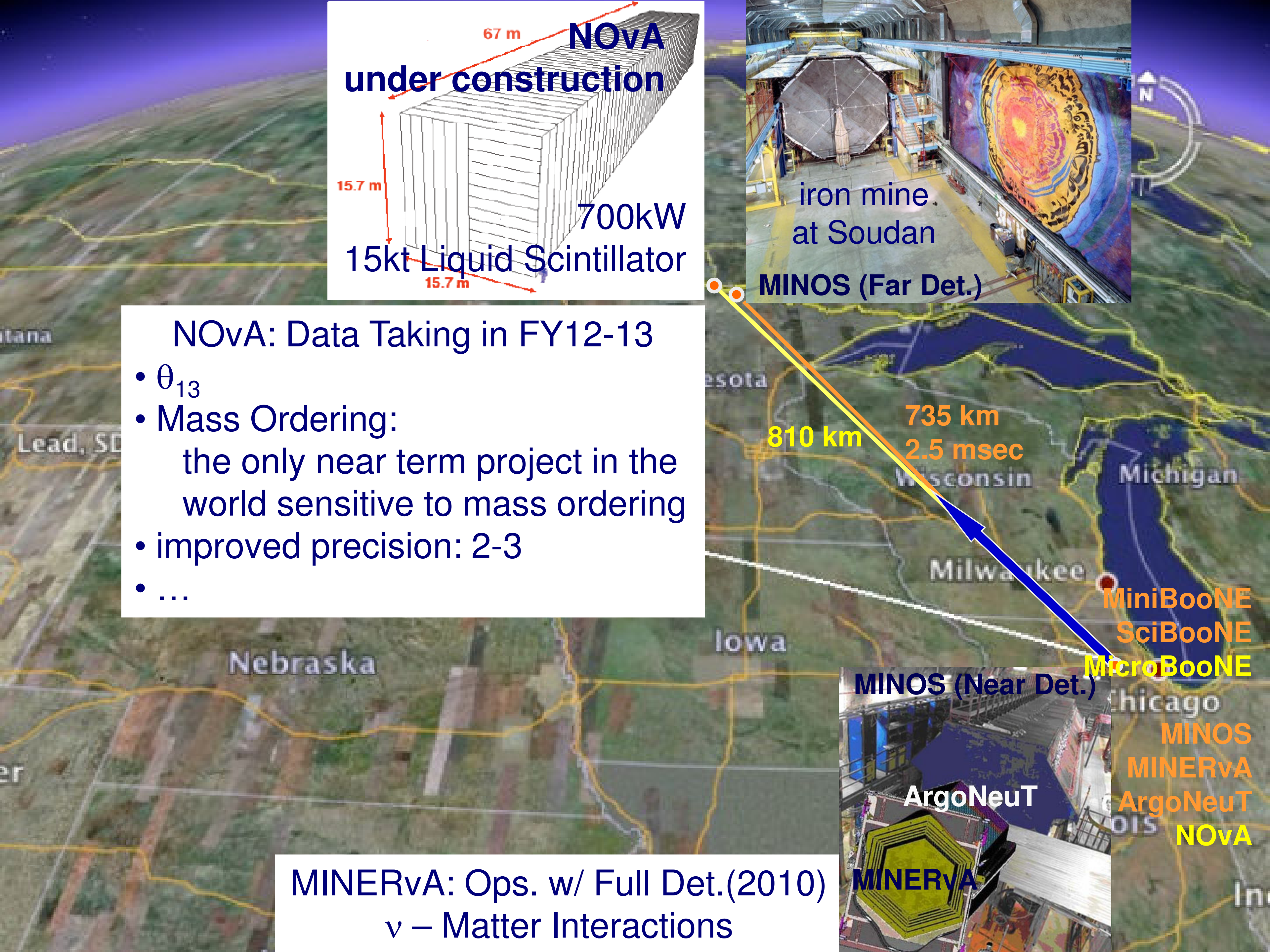
MiniBooNE: Excludes "4th gen." ν
Low Eng Excess in ν, Now running anti-ν

SciBooNE: ν – Matter Interactions

MicroBooNE: 170 ton LAr TPC (approved by Lab)

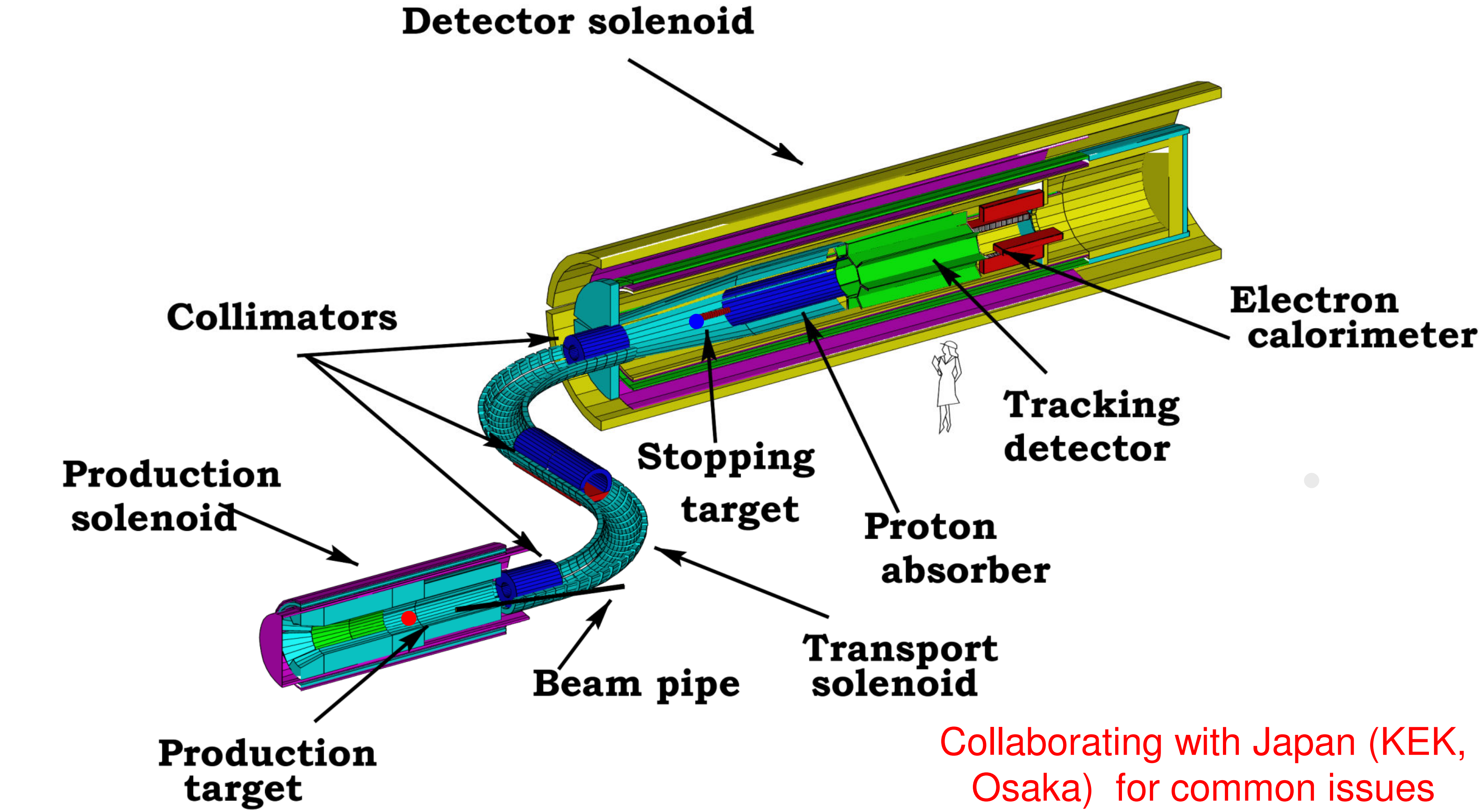
Neutrino beam from 120 GeV MI





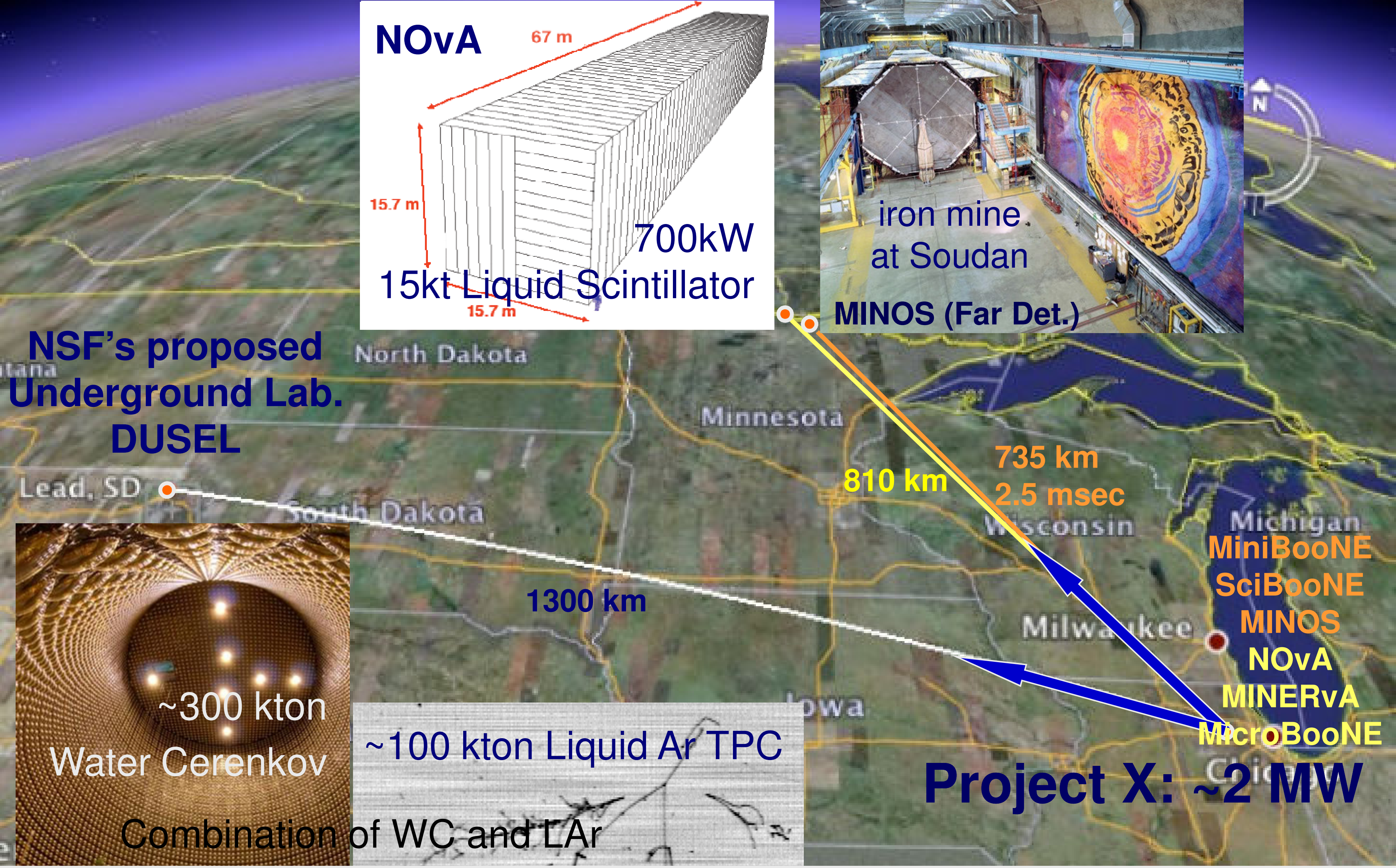
NOvA
under construction
67 m
15.7 m
15.7 m
700kW
15kt Liquid Scintillator
iron mine
at Soudan
MINOS (Far Det.)
NOvA: Data Taking in FY12-13
• θ_{13}
• Mass Ordering:
the only near term project in the world sensitive to mass ordering
• improved precision: 2-3
• …
810 km
735 km
2.5 msec
Wisconsin
Michigan
Milwaukee
Lead, SD
Iowa
Nebraska
MiniBooNE
SciBooNE
MicroBooNE
MINOS (Near Det.)
Chicago
MINOS
MINERvA
ArgoNeuT
NOvA
ArgoNeuT
MINERvA
MINERvA: Ops. w/ Full Det.(2010)
ν – Matter Interactions

Muon to e Conversion ($\mu N \rightarrow eN$)



Collaborating with Japan (KEK, Osaka) for common issues

Muon g-2, $K^+ \rightarrow \pi^+\nu\nu$ (1000 events) under consideration

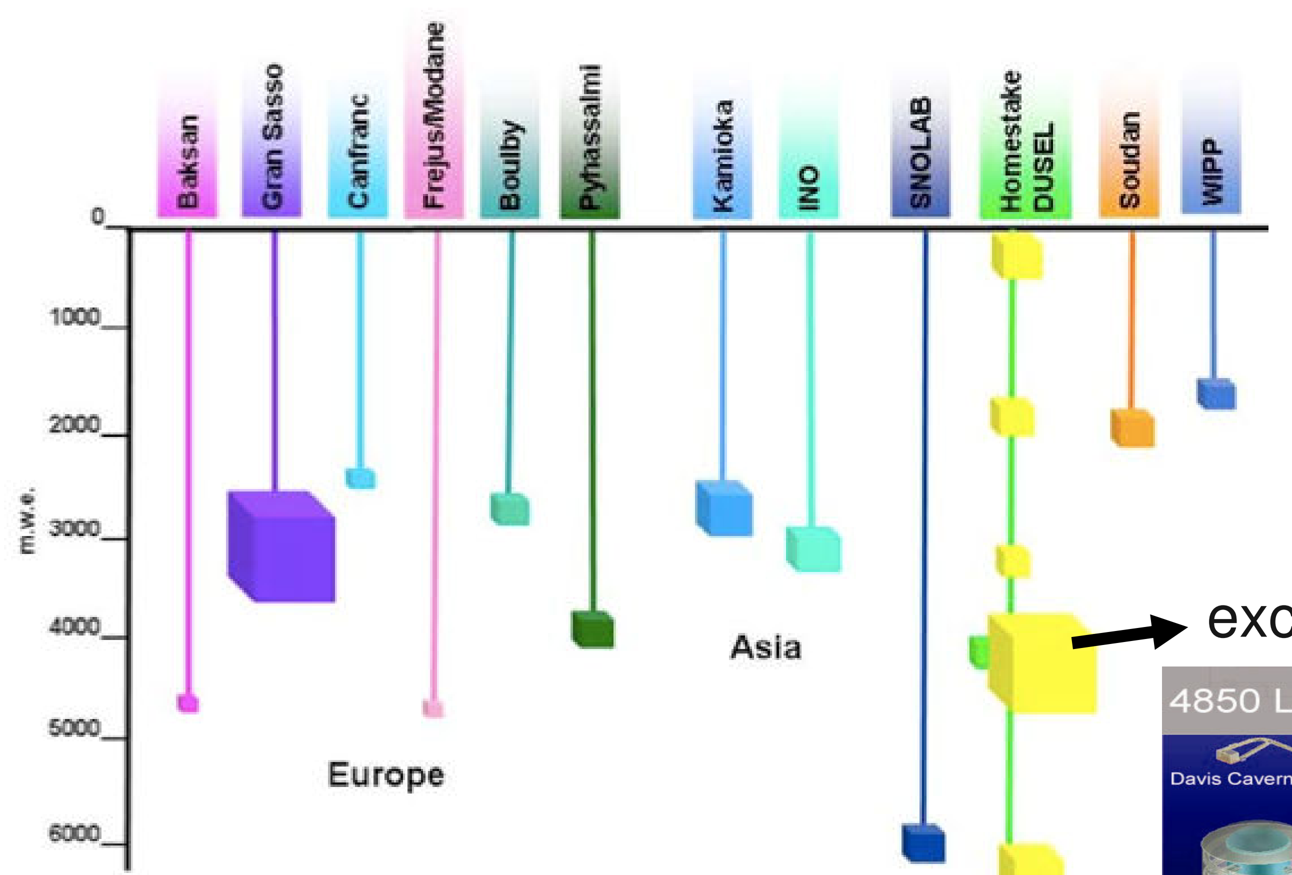


Matter – Antimatter Asymmetry with Neutrinos

Proton Decay

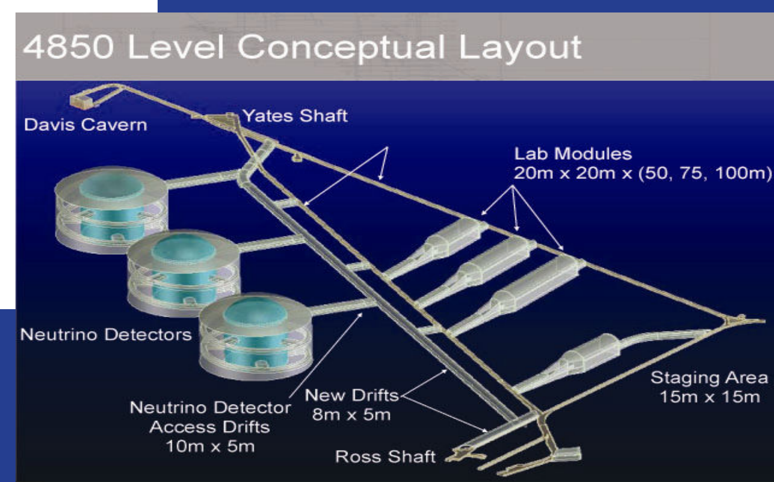
Supernovae Neutrinos

The Intensity Frontier: Fermilab → DUSEL Option



Existing + Potential Underground Lab.s

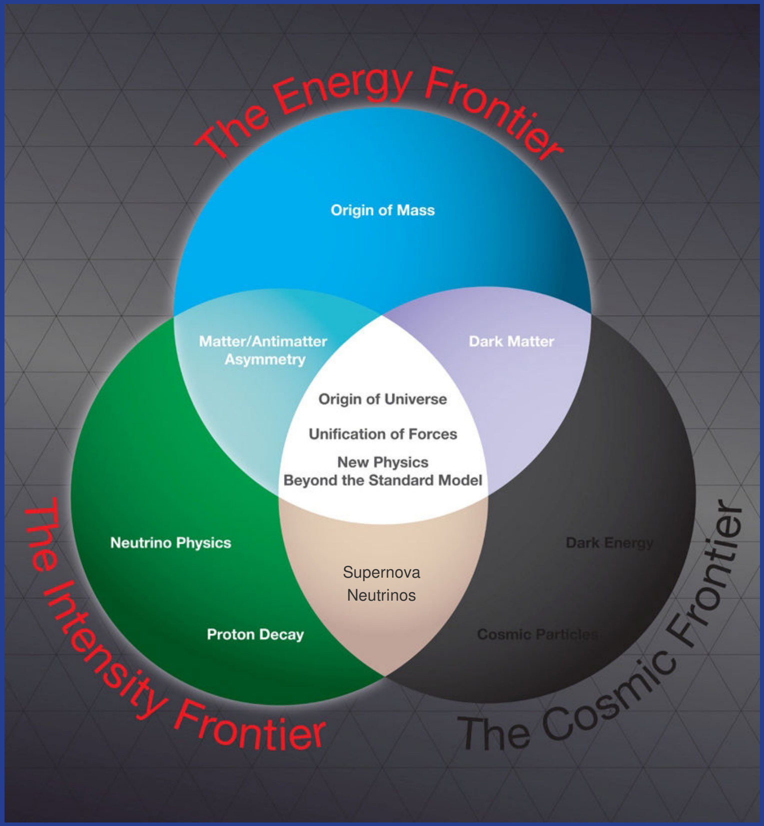
excluding the big cavern



Project X: intense proton accelerator

http://www.fnal.gov/pub/projectx/

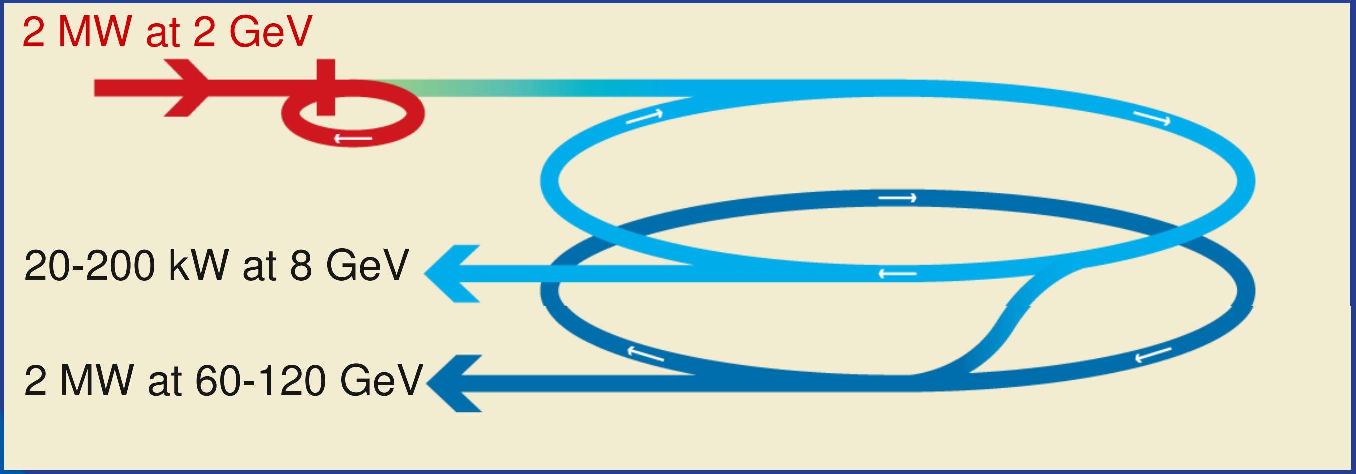
- The intensity frontier answers fundamental questions
- Project X is the key
- Project X can lead us back to the energy frontier



Fermilab

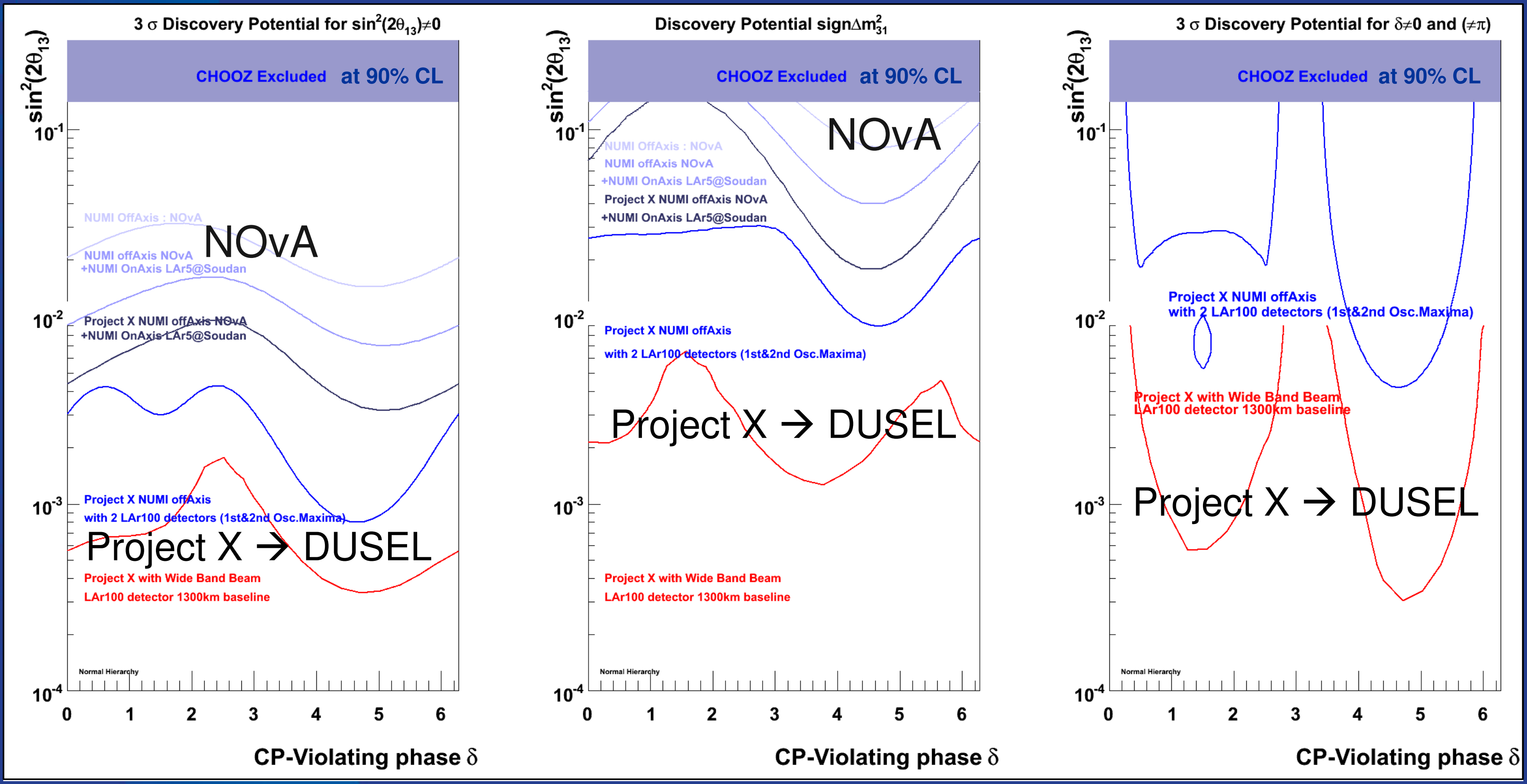
Evolution of Project X: 3 Simultaneous Beams

- 2 MW CW (continuous pulses at 325 MHz) 2 GeV protons
  - rare processes and precision measurements
  - flexible time patterns and pulse intensities
- 20 – 200 kW 8 GeV protons
  - rare processes and precision measurements
- 2 MW 60 – 120 GeV protons (to Homestake) for neutrinos



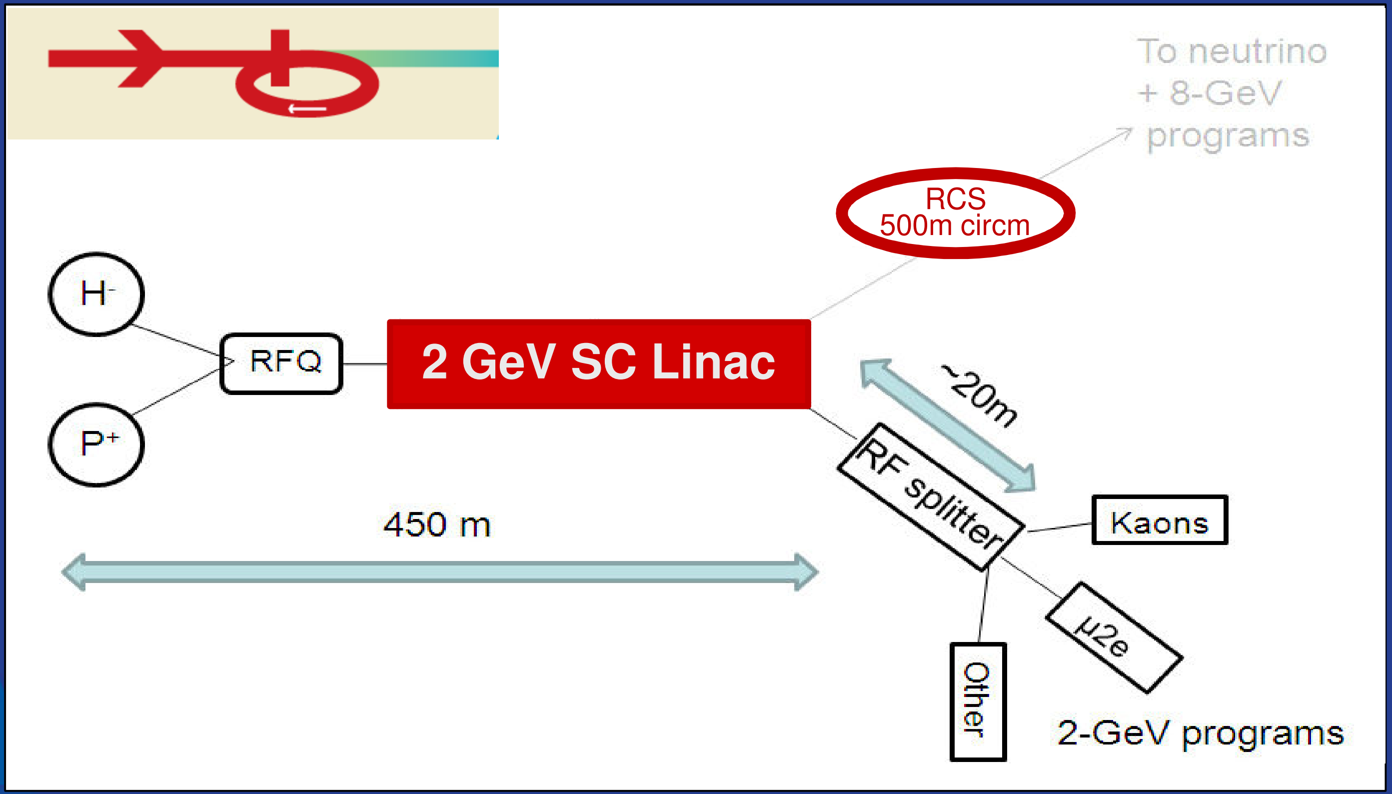
The 3σ reach (2 MW, 100 kton LAr TPC)

$\sin^2 2\theta_{13}$ | Mass Hierarchy | CP Violation



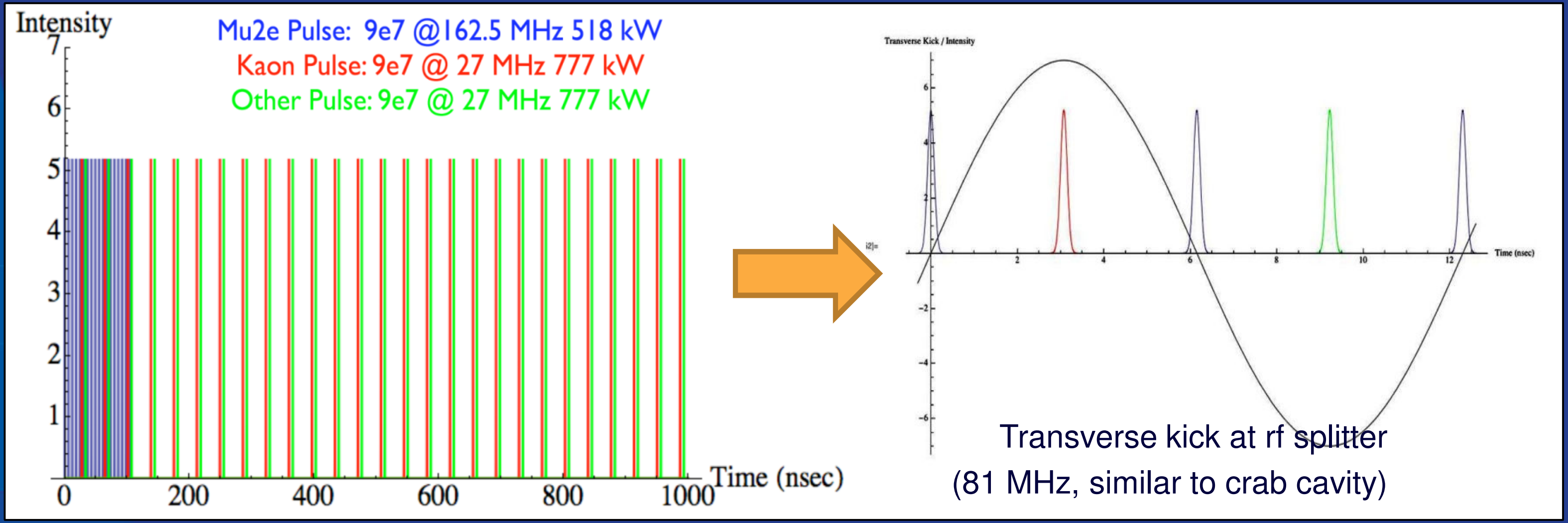
Project X and 2 GeV beams

- Great potential for rare processes comes from 2 MW continuous beam. Intensity experiments need continuous beam: pile up is the main limitation in pulsed beams



Flexible bunch format

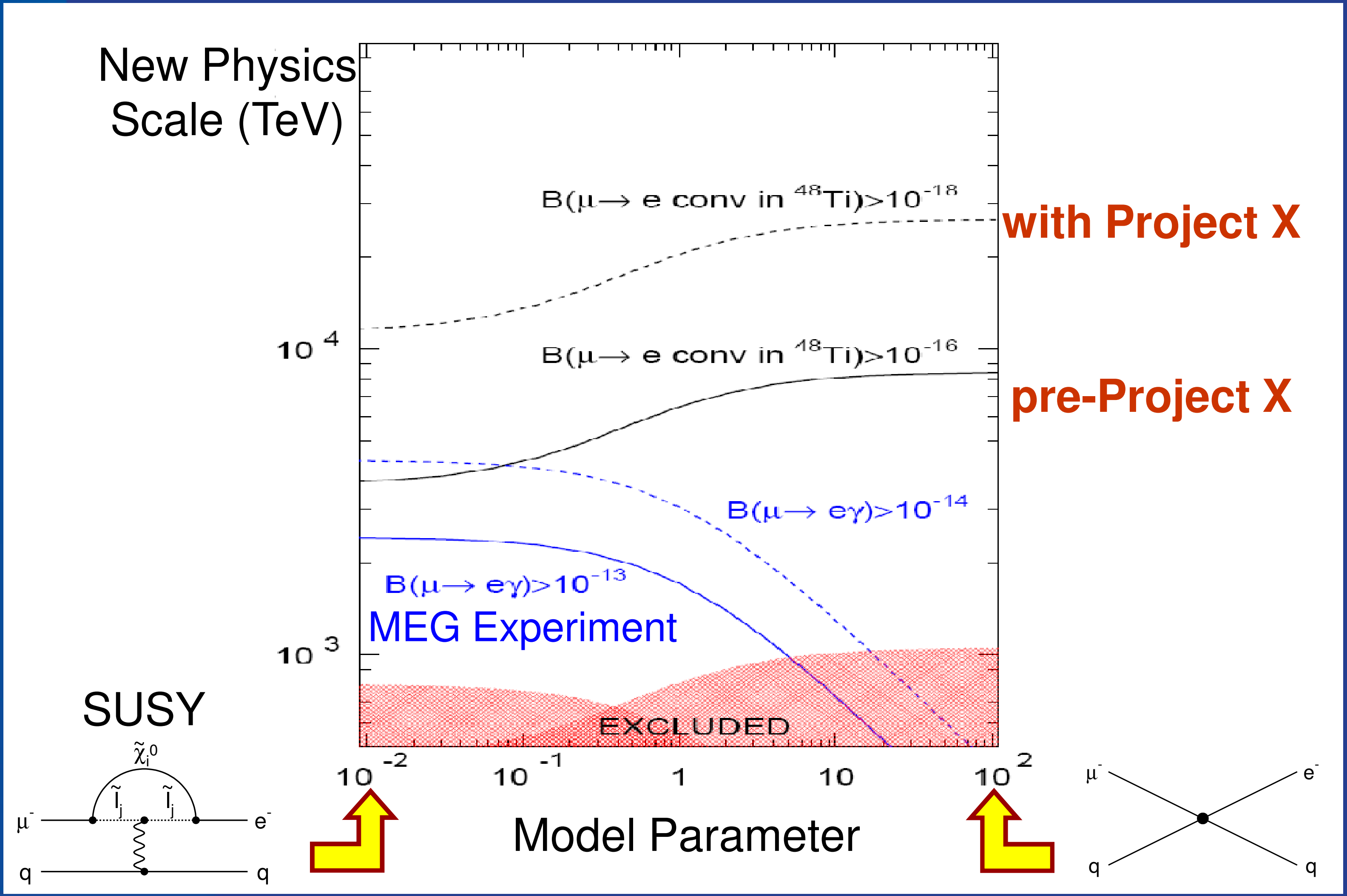
- Variable H- ion source provides current 1 to 10 mA DC
- Variable bunch formats:
  1. Ion source at 1 mA, no beam chopping: 1.9×10^7 protons per bunch at 325 MHz rate
  2. Ion source at 10 mA, 90% beam chopping: 1.9×10^8 protons per bunch at 32.5 MHz rate (1 mA ave current)
  3. Bunch-by-bunch chopping example (ion source at 4.7 mA), chopping and rf splitting for 3 experiments



Other applications

- Nuclear Physics
  - Can drive an ISOL target for Nuclear Physics applications. Totally complementary program for nuclear EDMs and fundamental experiments on atomic traps just with ISOL target
- Muon Spin Rotation
  - Currently done in Rikken, PSI and TRIUMF
  - Would produce the most intense muon beams available, including, polarization and monochromatization

Mu2e can probe 10^3 – 10^4 TeV



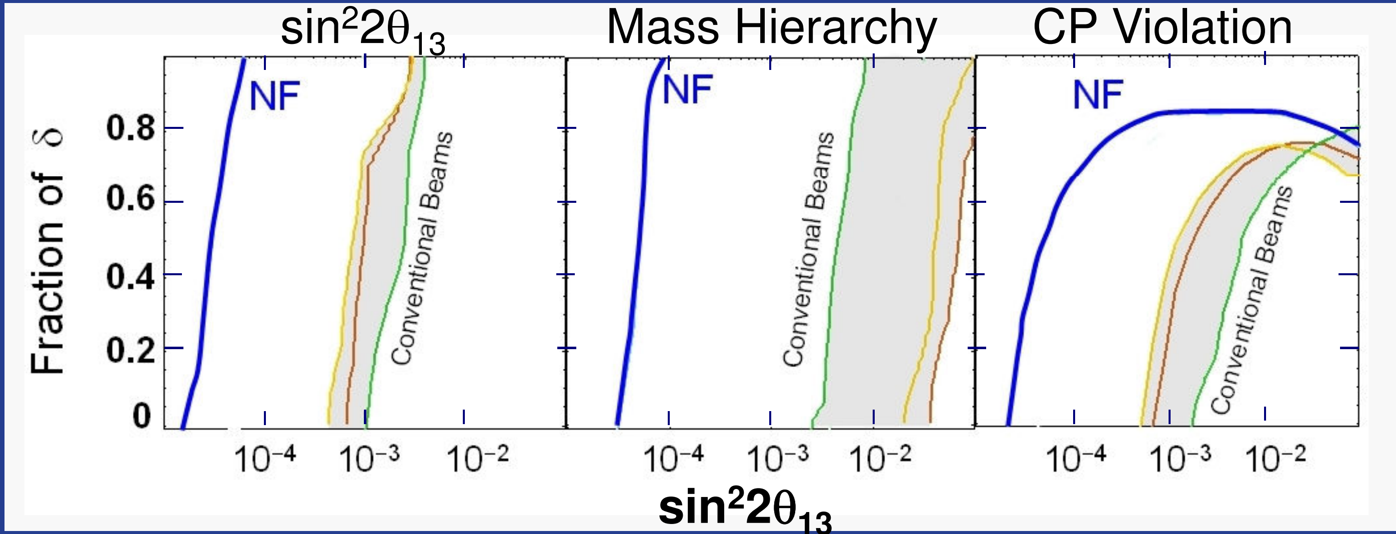
Muon experiments

- Next generation $\mu \rightarrow e$ conversion experiment, new techniques for higher sensitivity and/or other nuclei.
- $\mu \rightarrow 3e$
- Next generation (g-2) if motivated by theory, next round, LHC
- Other:
  - μ edm.
  - $\mu^{+}e^{-} \rightarrow \mu^{-}e^{+}$
  - $\mu^{-}A \rightarrow \mu^{+}A'$
- Systematic study of radiative μ capture on nuclei.

Evolution of ν Program: Neutrino Factory

International Design Study

- If $\sin^2 2\theta_{13}$ is small
  - Choose a NF energy of 25 GeV & a very long baseline (e.g. ~3000km) – up to ~ x100 improvement in sensitivity compared to a superbeam

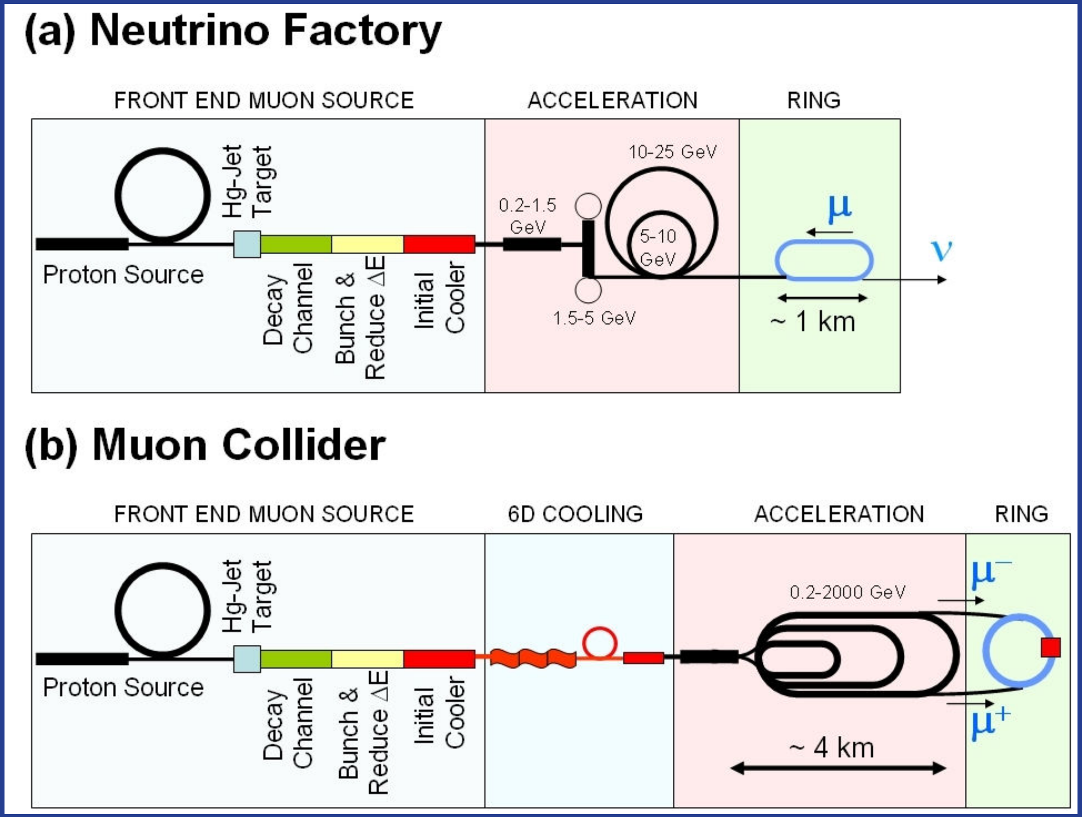


- If θ_{13} is large (>.005)
  - A 4 GeV NF aimed at Homestake gives clean reach into CP violation, mass hierarchy and any unusual features

Fermilab

Neutrino Factory and Muon Collider

- Muon Colliders & Neutrino Factories require similar, & potentially identical, muon sources:



US Strategy: Project X

- Would be a fantastic machine at the intensity frontier for neutrino, kaon and muon beams
  - Provide a powerful beam of neutrinos to the Homestake site
  - Provide intense proton beams for muon, kaon, low energy neutrino physics and other possible applications
    - without affecting the neutrino program
    - flexible time patterns / pulse intensities (different expt.s)
- Would develop to serve as the front end of future facilities like a neutrino factory and/or a muon collider
- Would develop / exercise the technologies to position US to host (or contribute to one elsewhere) a global facility at the energy frontier (ILC / muon collider)

US Strategy

Detector Synergy:
ILC/CLIC/μ Collider

Energy Frontier

Tevatron — (LHC) — ILC / μ Collider

protons

technology injector

Intensity Frontier

NuMI (260kW) Booster → NuMI (700kW) → **Project X** → injector → ν Factory

2 MW (120GeV) for ν
+ 2MW(2GeV) + 200kW(8GeV)

MINOS
MiniBooNE
SciBooNE
ArgoNeuT

NOvA
MINERvA
MicroBooNE

1300km baseline ν
WC / LAr
(+Proton Decay,..)

Mu2e
μ g-2
K^+

Mu2e II
μ g-2 II
(K^0/K_L, K^+) II
EDM (μ, Λ, Σ^+) II
Nuclear Physics
….

time →

Workshops / Collab. Meeting at Fermilab

Fall 2009

- Project X collaboration meeting
  - September 11-12, 2009
- Applications of High Intensity Proton Accelerators
  - October 19-21
- Physics with a High Intensity Proton Source
  - pre-Project X and post-Project X
  - November 9-10
- Muon Collider physics/det./machine background
  - November 10-12

Advantages of 2 Gev kaons

- Intense beams and significant cross sections
- Great timing resolution (10-20 psec)
- One in about 1000 proton interactions produces a kaon
- In five years: accelerate a mole of protons!

2.1 GeV Tp