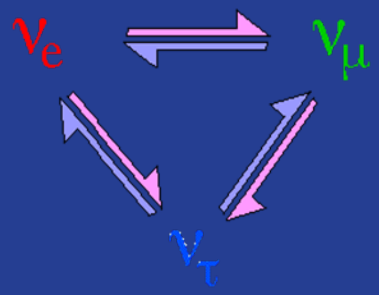
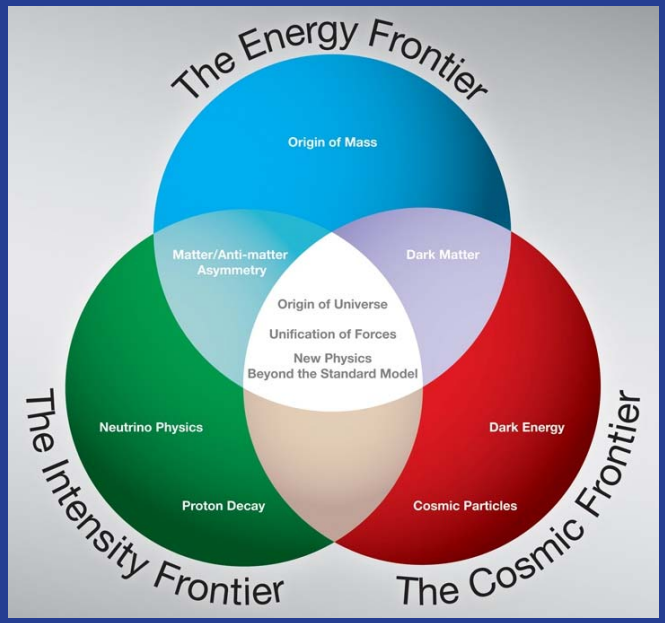
Neutrino Projects at the Intensity Frontier





Young-Kee Kim
Fermilab and University of Chicago

22nd Rencontres de Blois, July 19, 2010

U.S. DEPARTMENT OF ENERGY

Fermilab

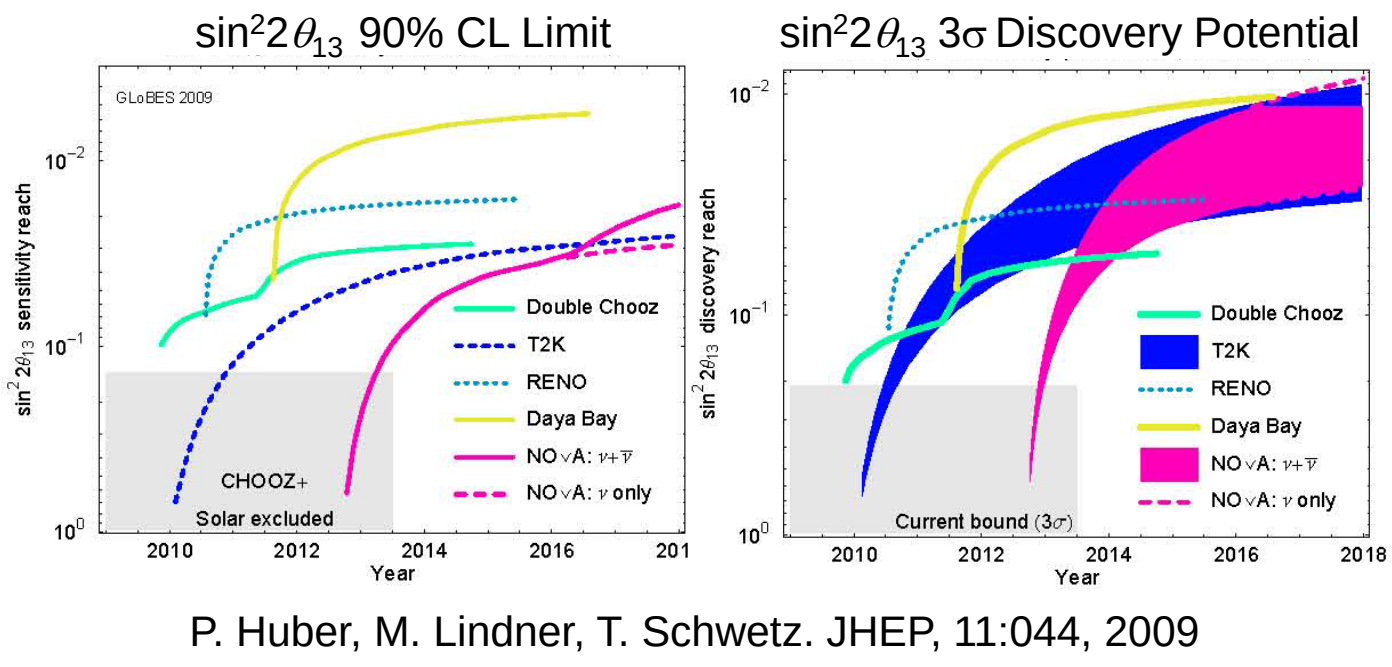
In this session

- Neutrino Physics
  - Boris Kayser (Fermilab)
  - Belen Gavela (Madrid)
- Neutrino Mixing (experiments)
  - Current and Short-term prospects by Stan Wojcicki (Stanford)

→ Longer-term prospects

Short-Term Prospects on Mixing

- Present & near future expt.s seek to measure θ_{13}:

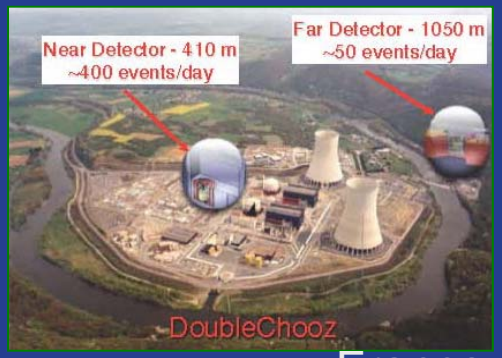


P. Huber, M. Lindner, T. Schwetz. JHEP, 11:044, 2009

- Sensitivity plateau of ~10^{-2} reached in ~2016

Reactor Neutrinos

South Korea



France

China

Accelerator-Based Neutrinos

Fermilab → Soudan (735km)

Fermilab → Ash river(810km)

300 kW (now)

→ 700 kW (being upgraded)

CERN → Gran Sasso (732km)

J-PARC → Kamioka (295km)

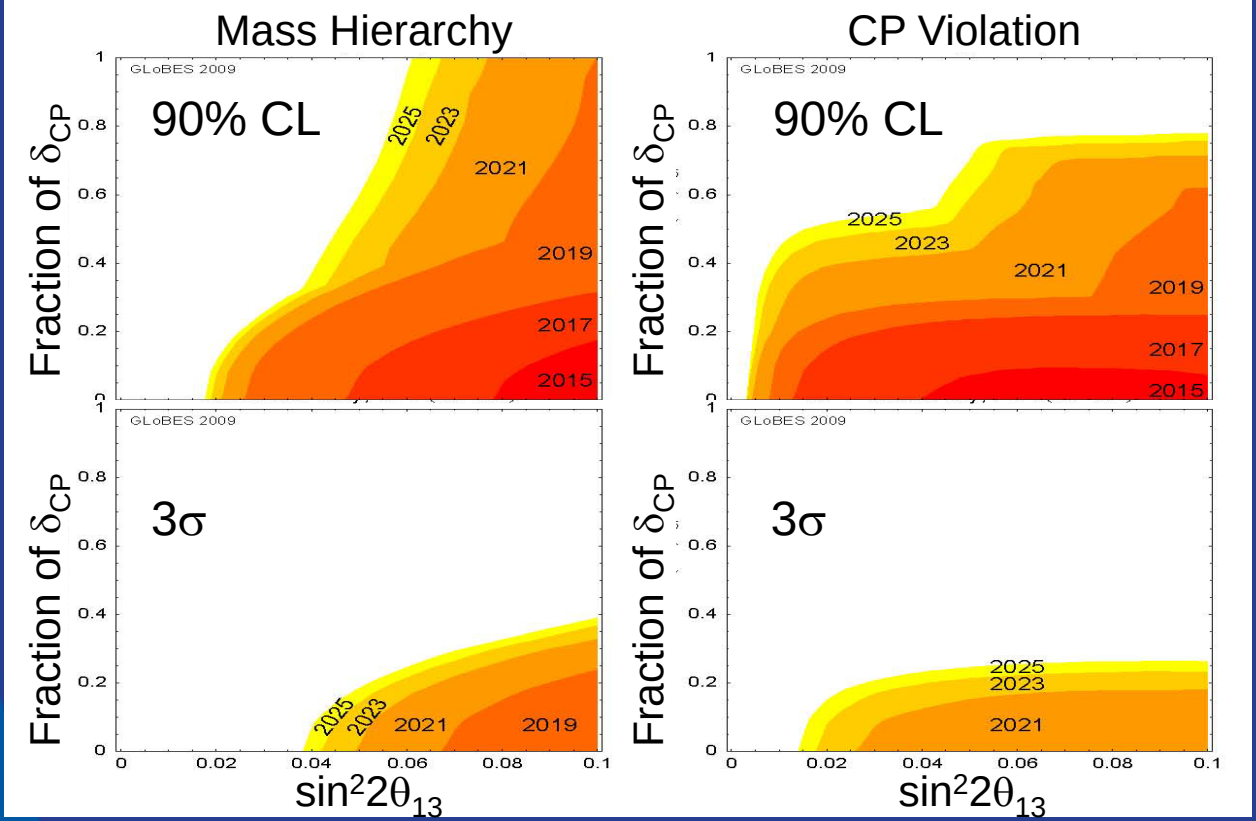
~50 kW (now) → 400 kW

→ 750 kW (to be upgraded)

Fermilab

Future Prospects without New Facilities

Assumed modest upgrades to the T2K and NOvA setups



(P. Huber, M. Lindner, T. Schwetz. JHEP, 11:044, 2009)

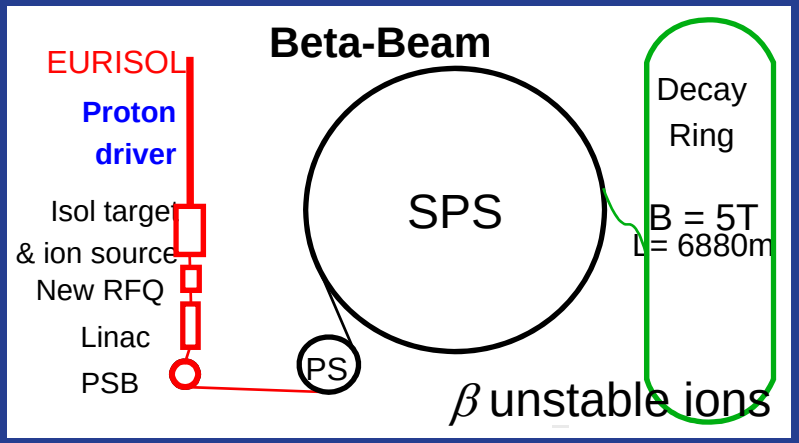
→ Establish facility with discovery potential for ~full para. space & very small $\sin^2 2\theta_{13}$

In addition, precision on the SνM parameters & flexibility for physics beyond SνM

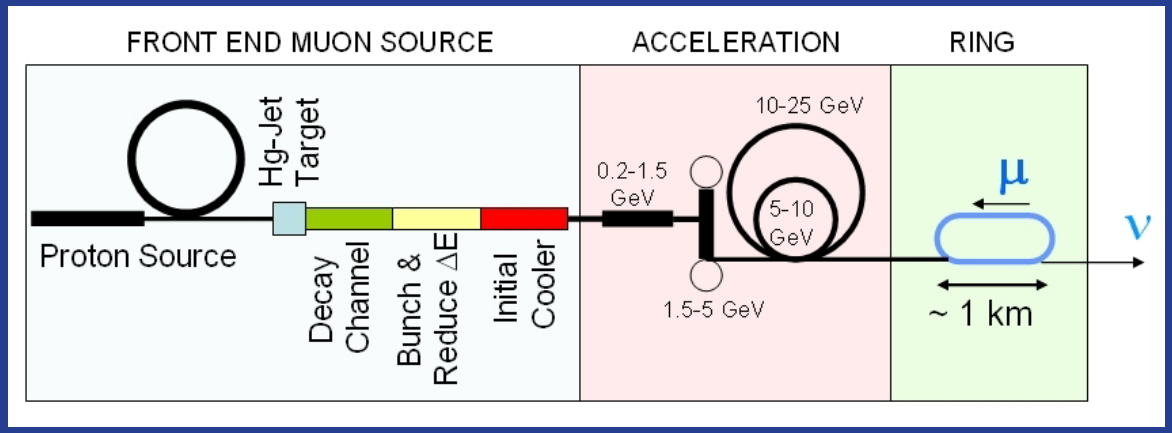
Accelerators (intensity/quality) + Detectors (distance/size/technology)

Future Neutrino Source – Options

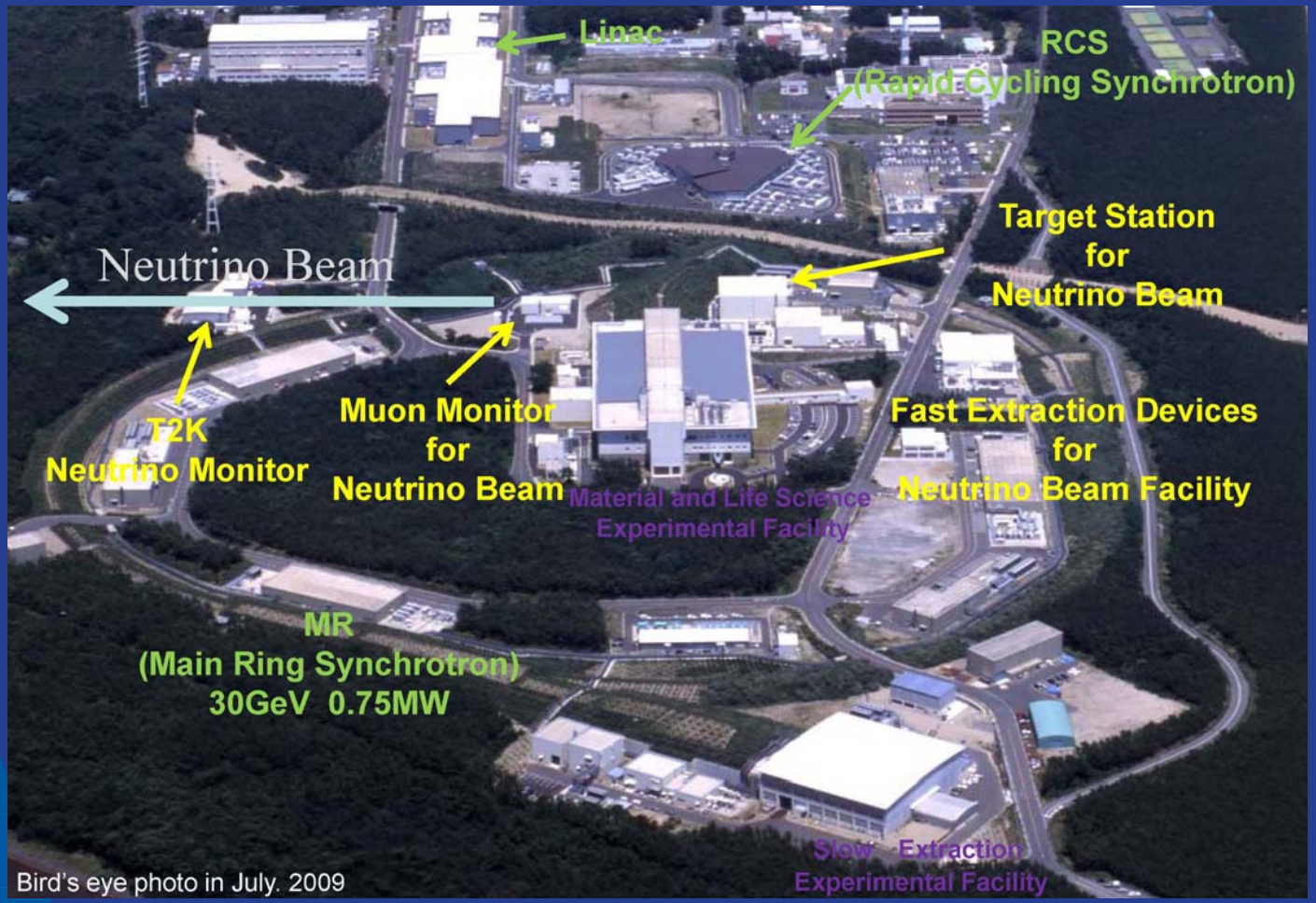
- Super-beam: multi MW proton driver (ν_μ, $\bar{\nu}_\mu$)
  - SPL II at CERN
  - Project X at Fermilab
  - J-PARC II
- Beta-beam (ν_e, $\bar{\nu}_e$)
- Neutrino Factory
  - All channels potentially possible



Stored $\mu^- \to e^- \nu_\mu \bar{\nu}_e$	
Disappearance	**Appearance**
$\bar{\nu}_e \to \bar{\nu}_e \to e^+$	$\bar{\nu}_e \to \bar{\nu}_\mu \to \mu^+$ $\bar{\nu}_e \to \bar{\nu}_\tau \to \tau^+$
$\nu_\mu \to \nu_\mu \to \mu^-$	$\nu_\mu \to \nu_e \to e^-$ $\nu_\mu \to \nu_\tau \to \tau^-$



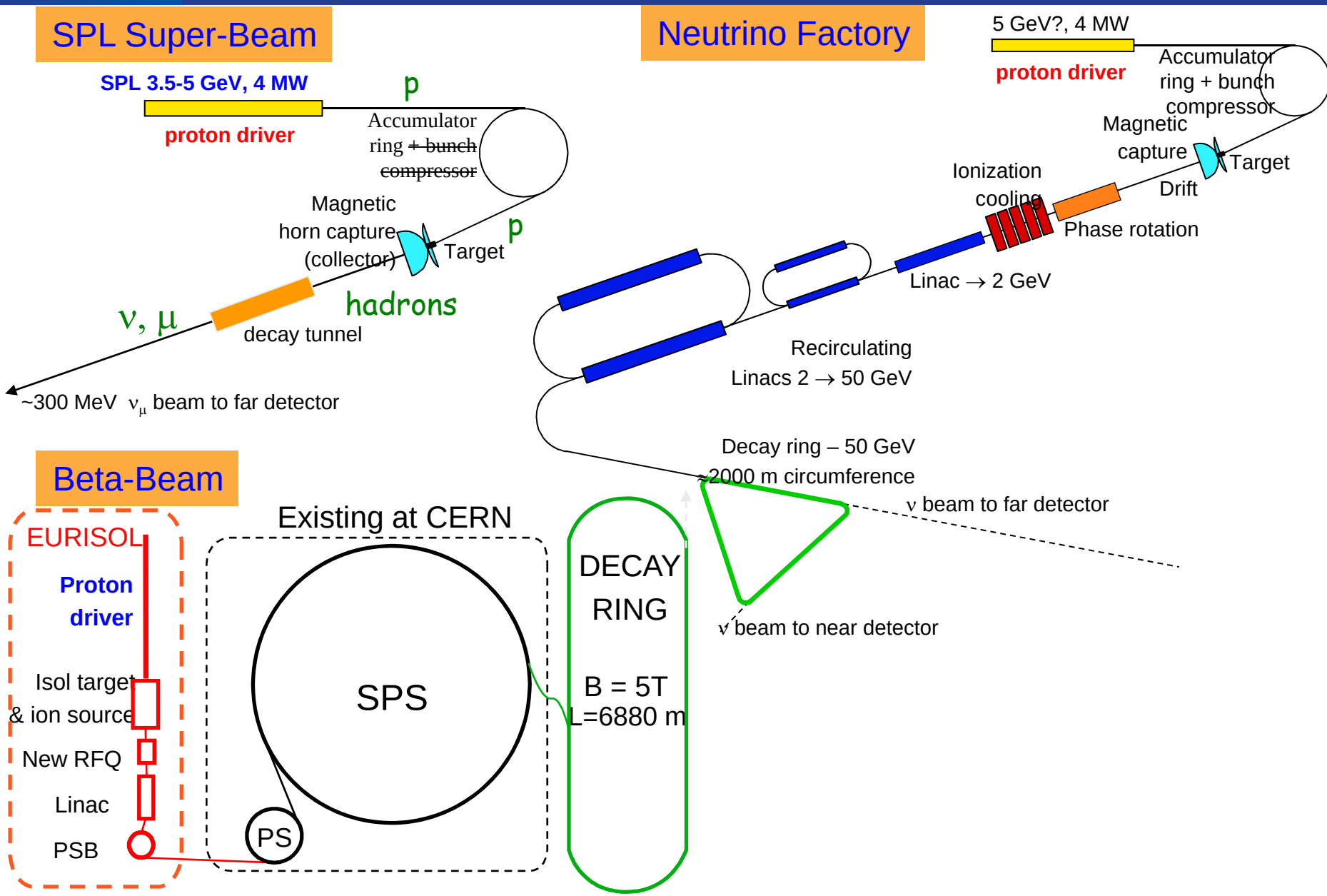
Neutrino Beams in Asia: J-PARC II



J-PARC: ~50 kW (now) → 400 kW → 750 kW (to be upgraded)

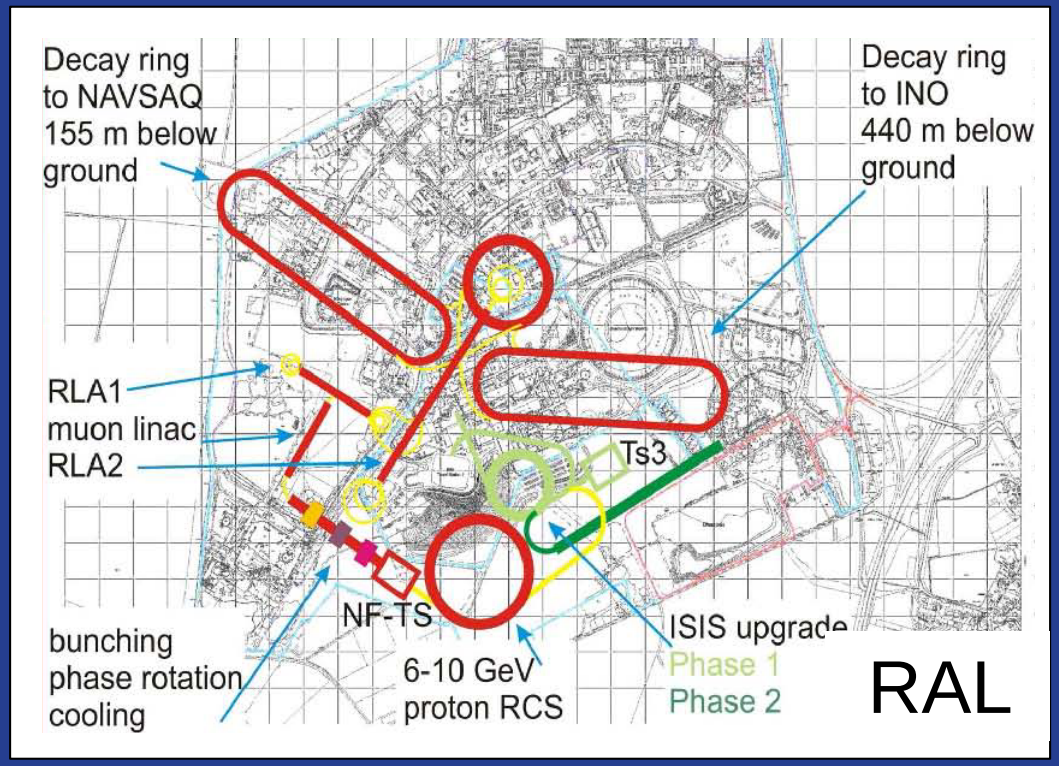
J-PARC II: ~1.66 MW

Neutrino Beams in Europe: CERN



Neutrino Beams in Europe: RAL

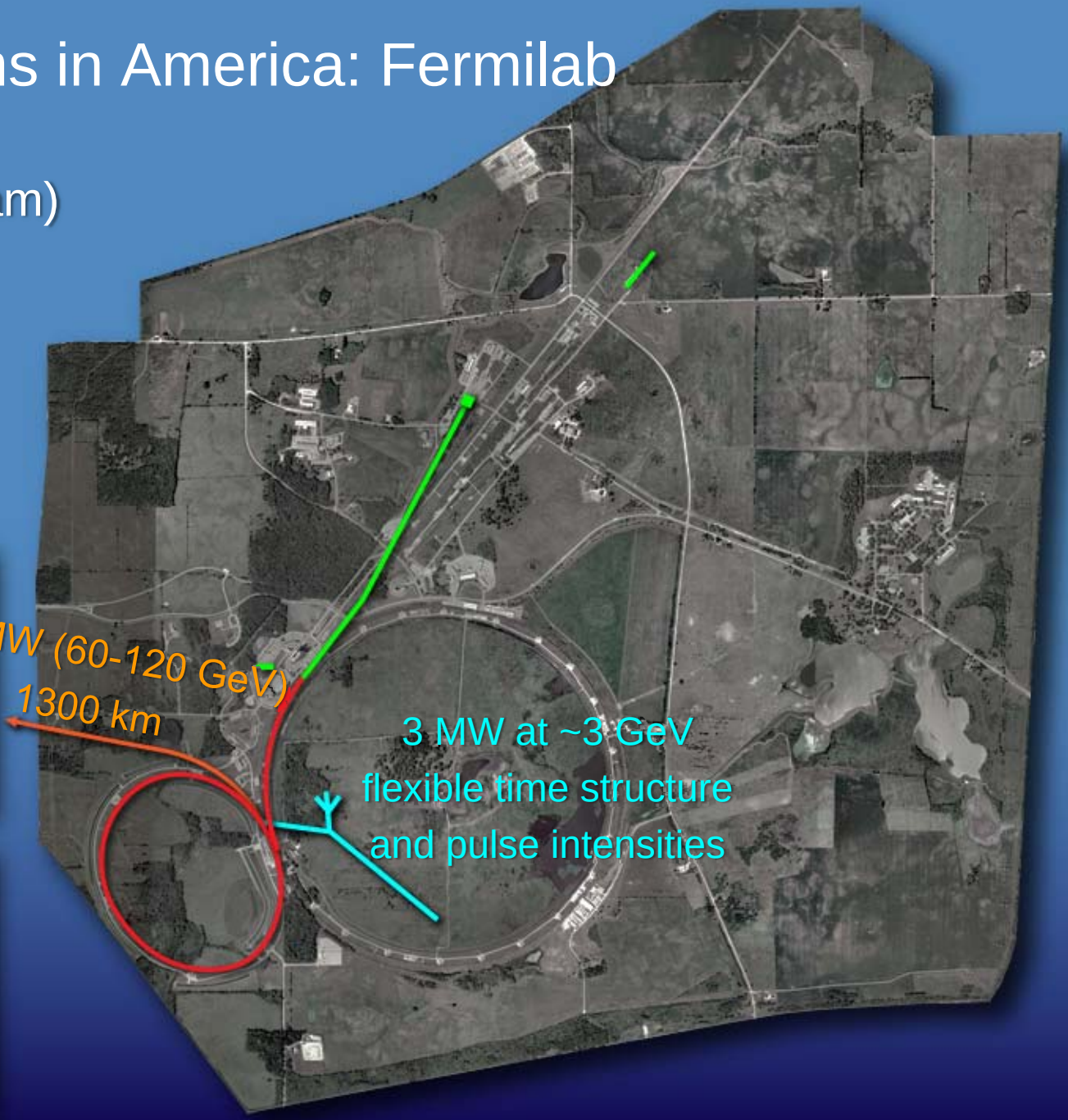
Neutrino Factory Footprint



Neutrino Beams in America: Fermilab

Project X (Super-beam)

Neutrino physics
Muon physics
Kaon physics
Nuclear physics
"simultaneously"



Neutrino Beams in America: Fermilab

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

Compressor Ring
Reduce size of beam.

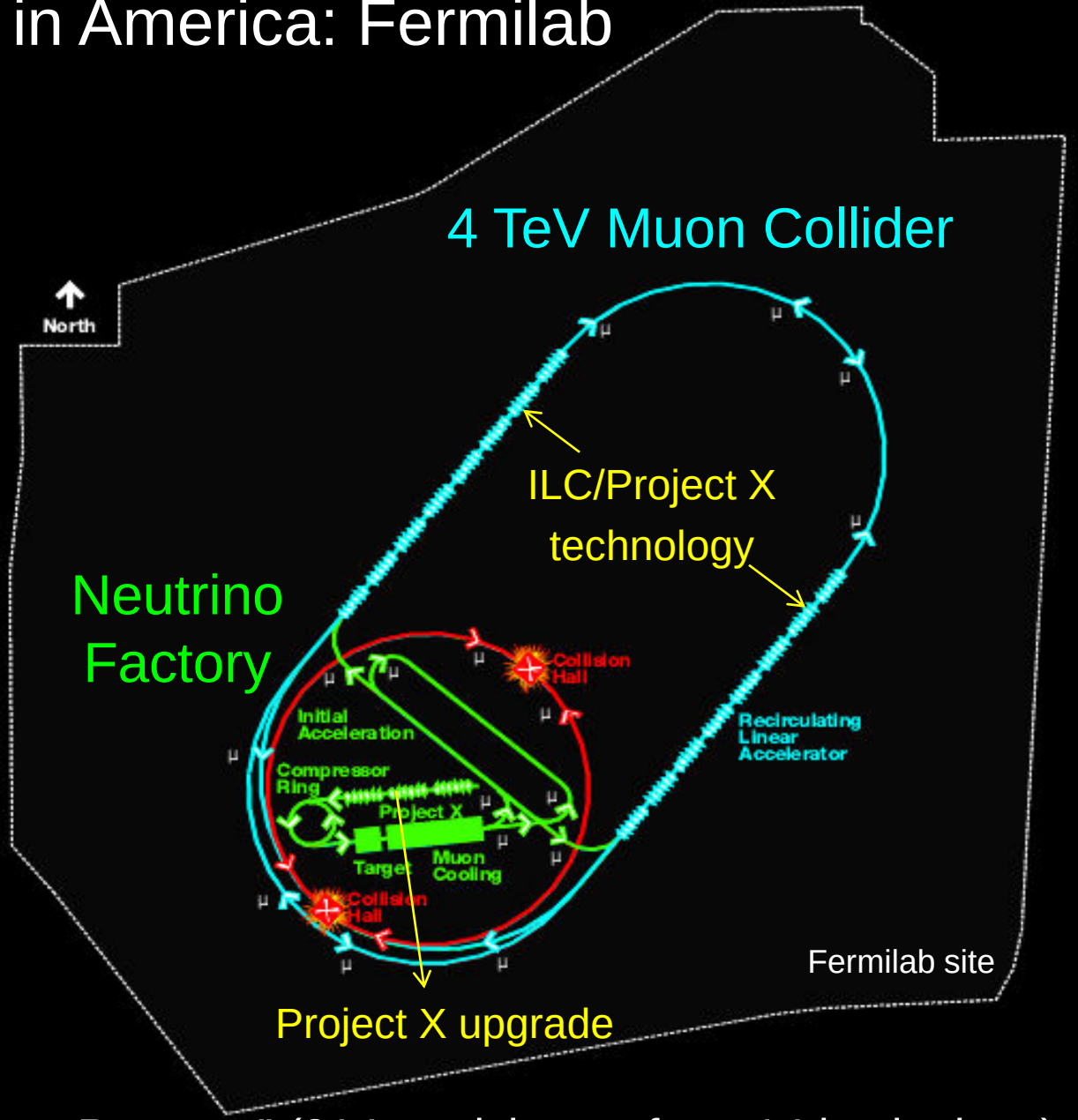
Target
Collisions lead to muons with energy of about 200 MeV.

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.

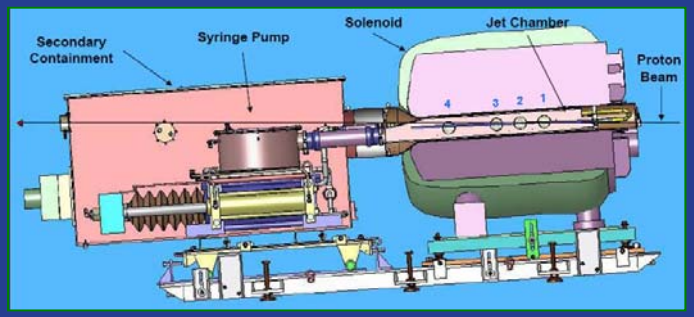


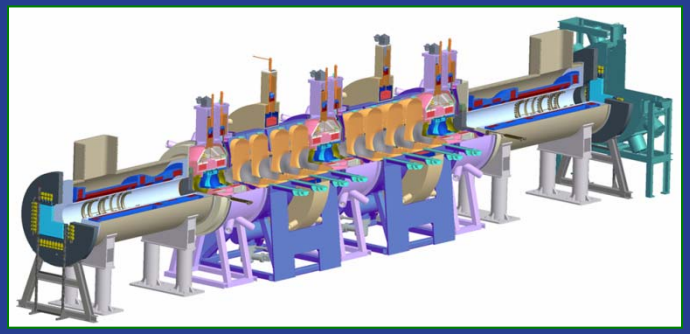
US: “Muon Accelerator Program” (214 participants from 14 institutions)

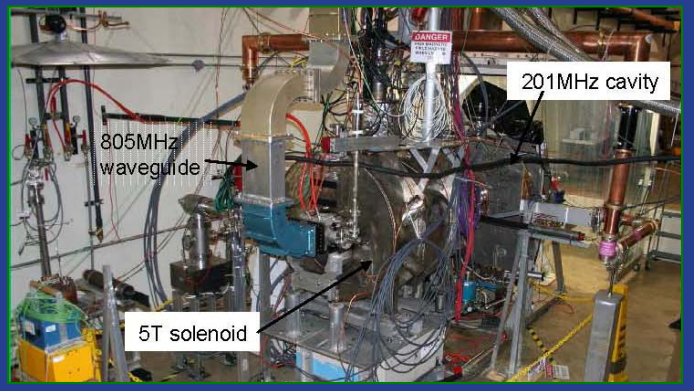
Towards Neutrino Factory

Current Activity – Prototyping

- MERIT at CERN
  - very successful US – Europe collaboration to successfully demonstrate the feasibility of a Hg jet target for a high power beam.
- MICE at RAL
  - will be the first demsonstration of muon ionisation cooling, critical for neutirno factory and muon collider. First data taking next year and final results ~2014
- MuCOOL at Fermilab
  - tesitng various components of cooling channel, a most important one being the behaviour of RFcavities in a magnetic field





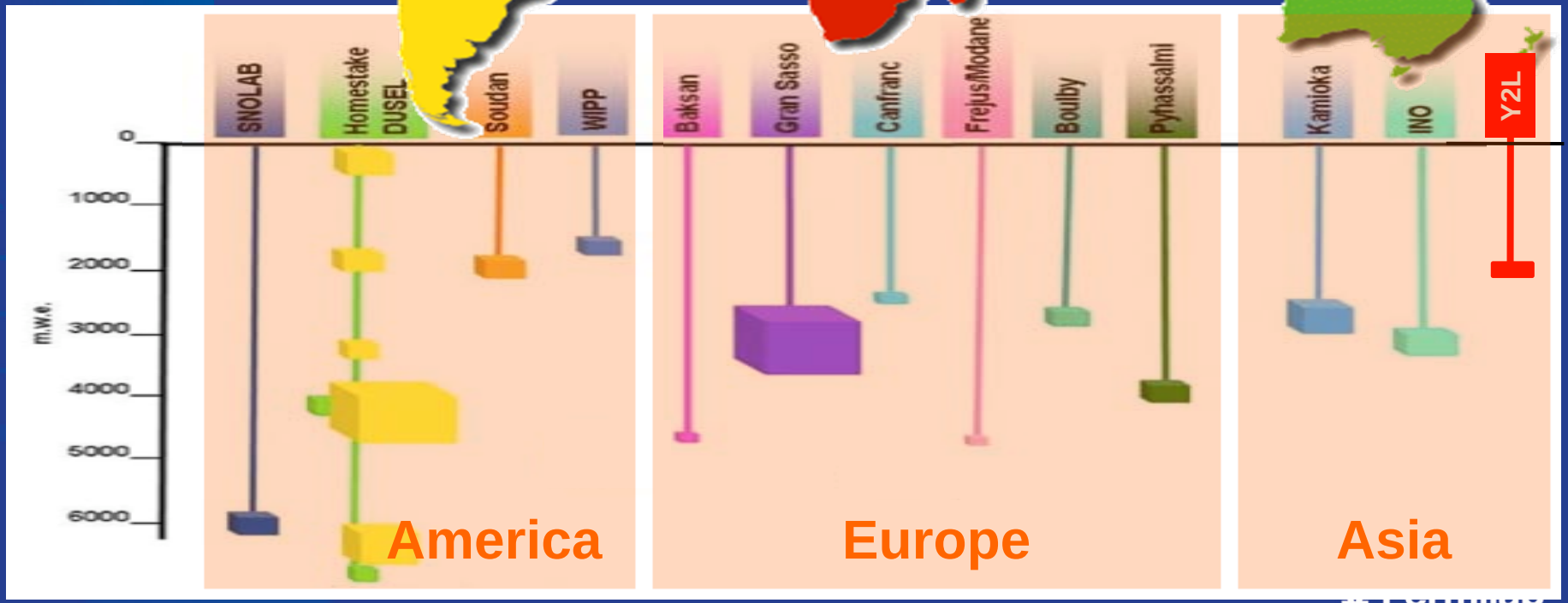


Neutrino Factory Community

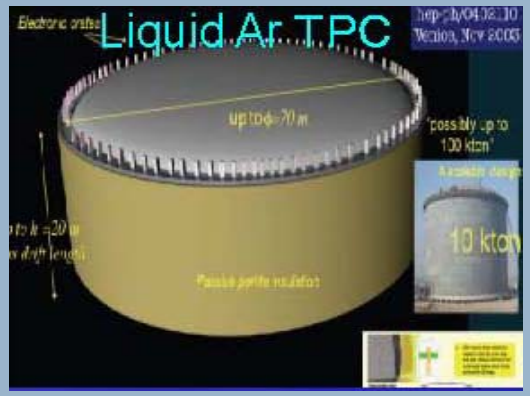
- International Design Study for the Neutrino Factory (IDS-NF) collaboration – Reference Design Report ~2013 representing the engineering phase
- Also NFMCC collaboration, MC Task force, MAP collaboration, EUROnu collaboration, …

Existing & Potential Underground Laboratories

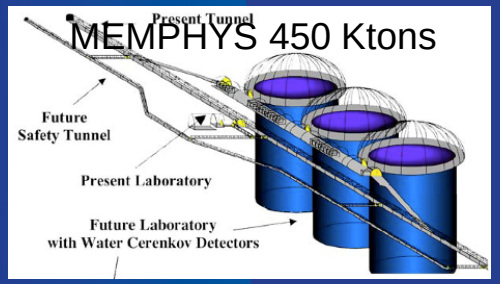
for neutrinos, proton decays, dark matter searches

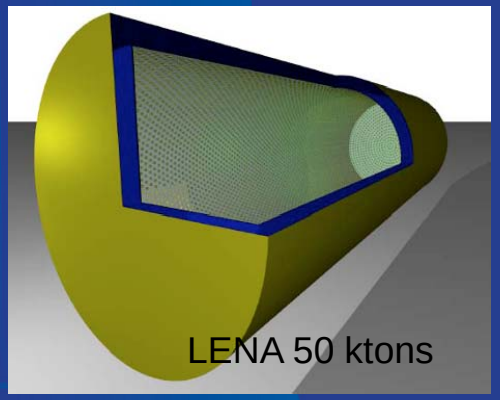


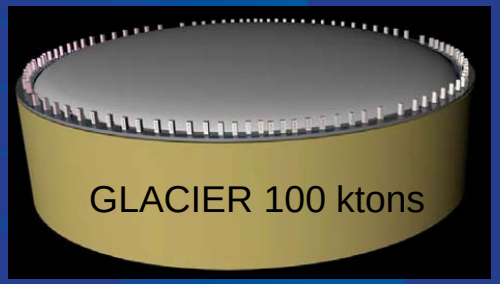
Asia: 3 sites under consideration

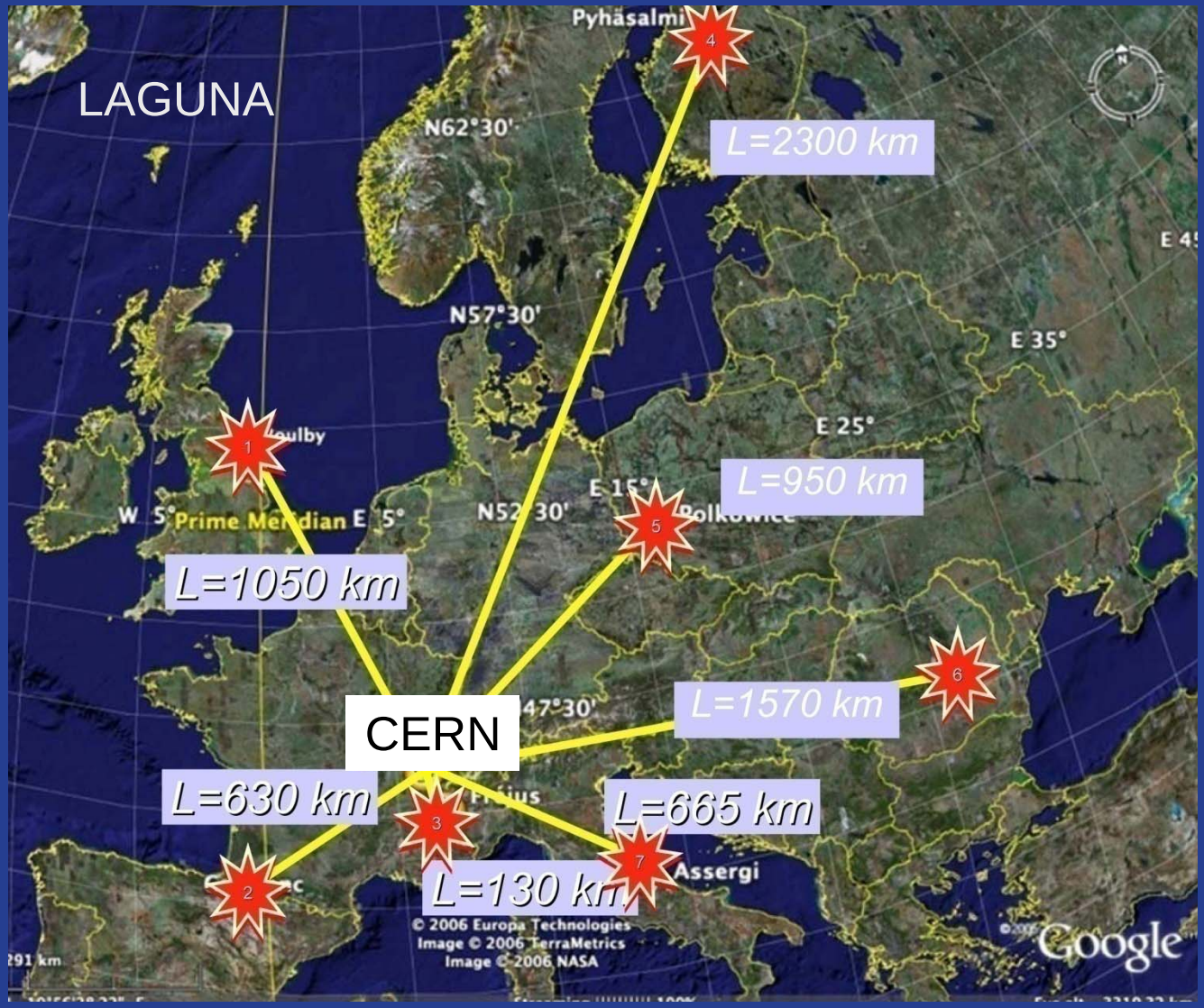


Europe: 6 sites under consideration







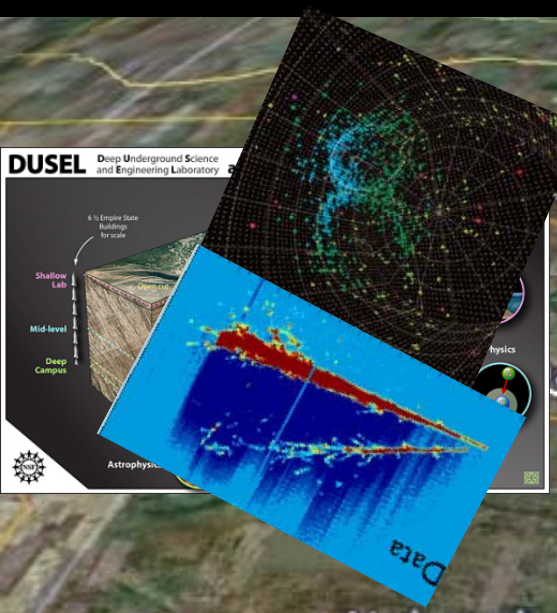


America: site selected (DUSEL)

Long Baseline Neutrino Experiment

Neutrinos, Proton Decays, Neutrino Astrophysics, …

(DOE – NSF Joint Project)



LBNE collaboration:
262 Scientists and Engineers
from 59 Institutions / 4 countries
And still growing !

1300 km

New Neutrino Beam at Fermilab…
…Directed towards NSF's proposed DUSEL

Precision Near Detector on the Fermilab site

Far Detector Options:

- 2 x 100 kT fiducial WC
- 100 kT fiducial WC + 17 kT fiducial LAr TPC

DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD

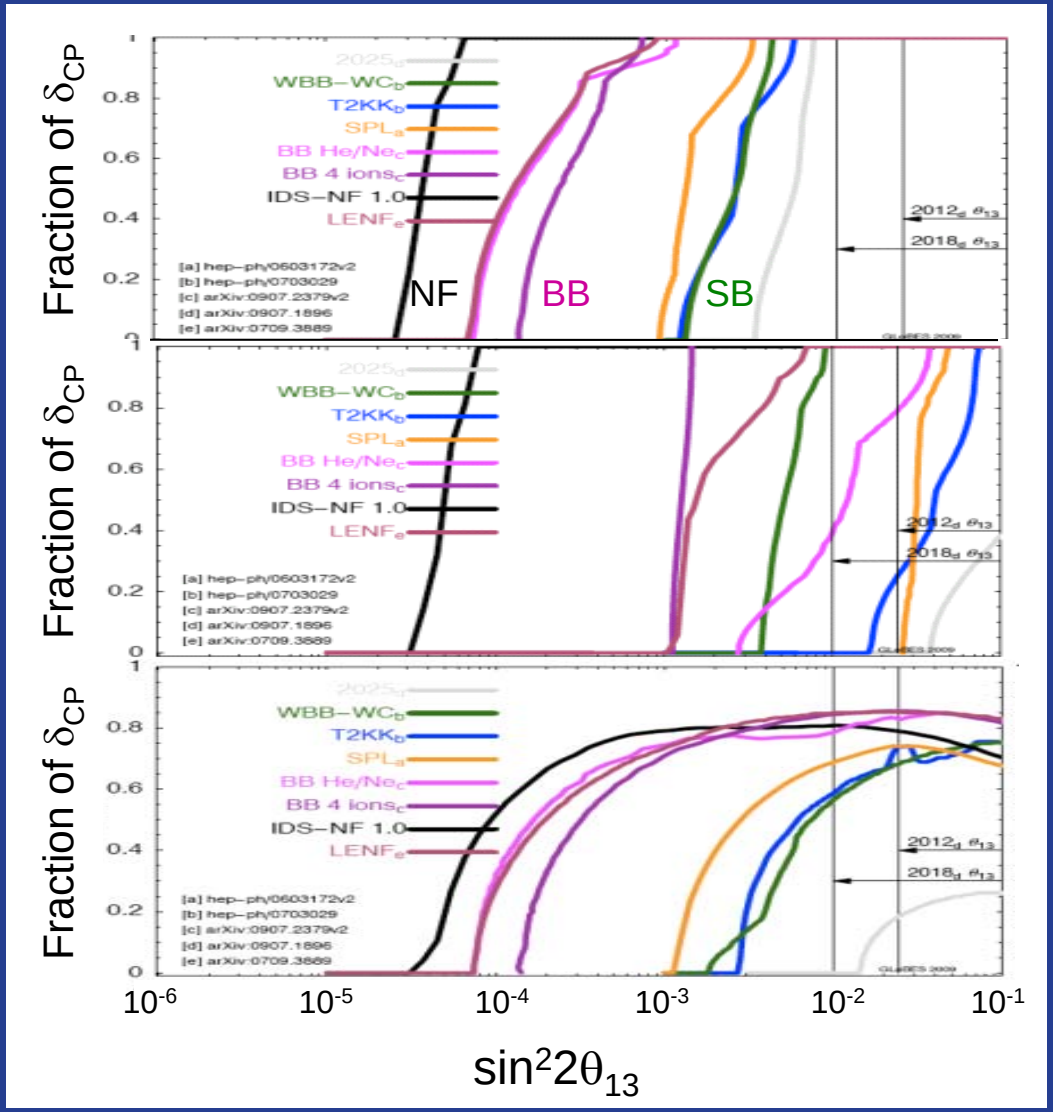
Ray Davis's Experiment

Longer-Term Prospects: 3σ Sensitivity

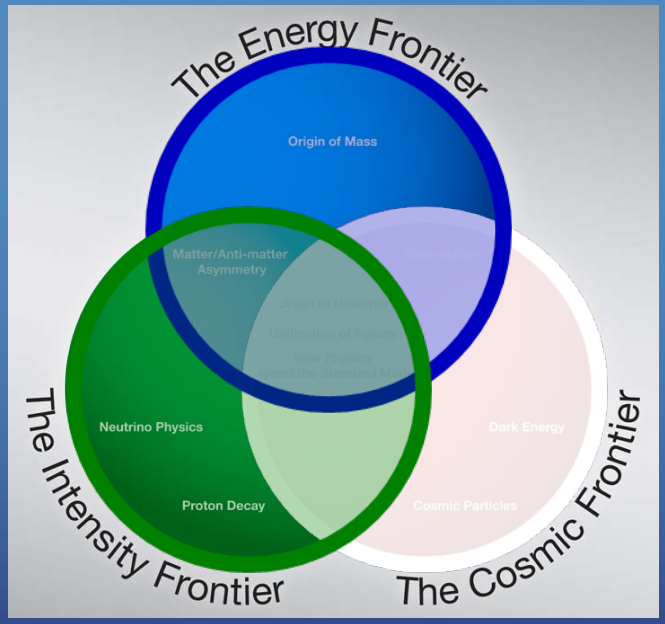
$\sin^2 2\theta_{13}$

Mass Hierarchy

CP Violation



Accelerator-based programs at Fermilab Now and Future



Cockroft-Walton

Linac

Booster

Main Injector

Tevatron

Antiproton

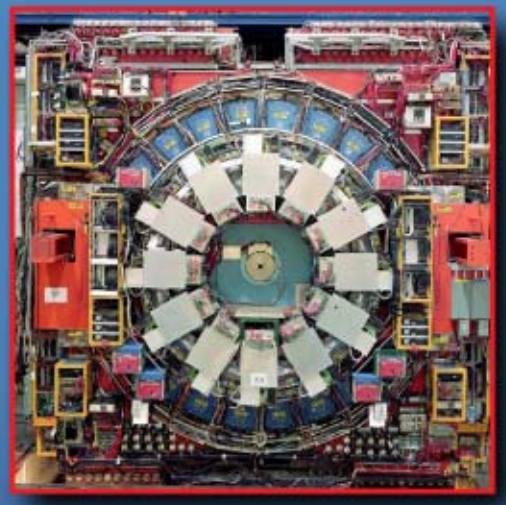
Production &
Accumulation

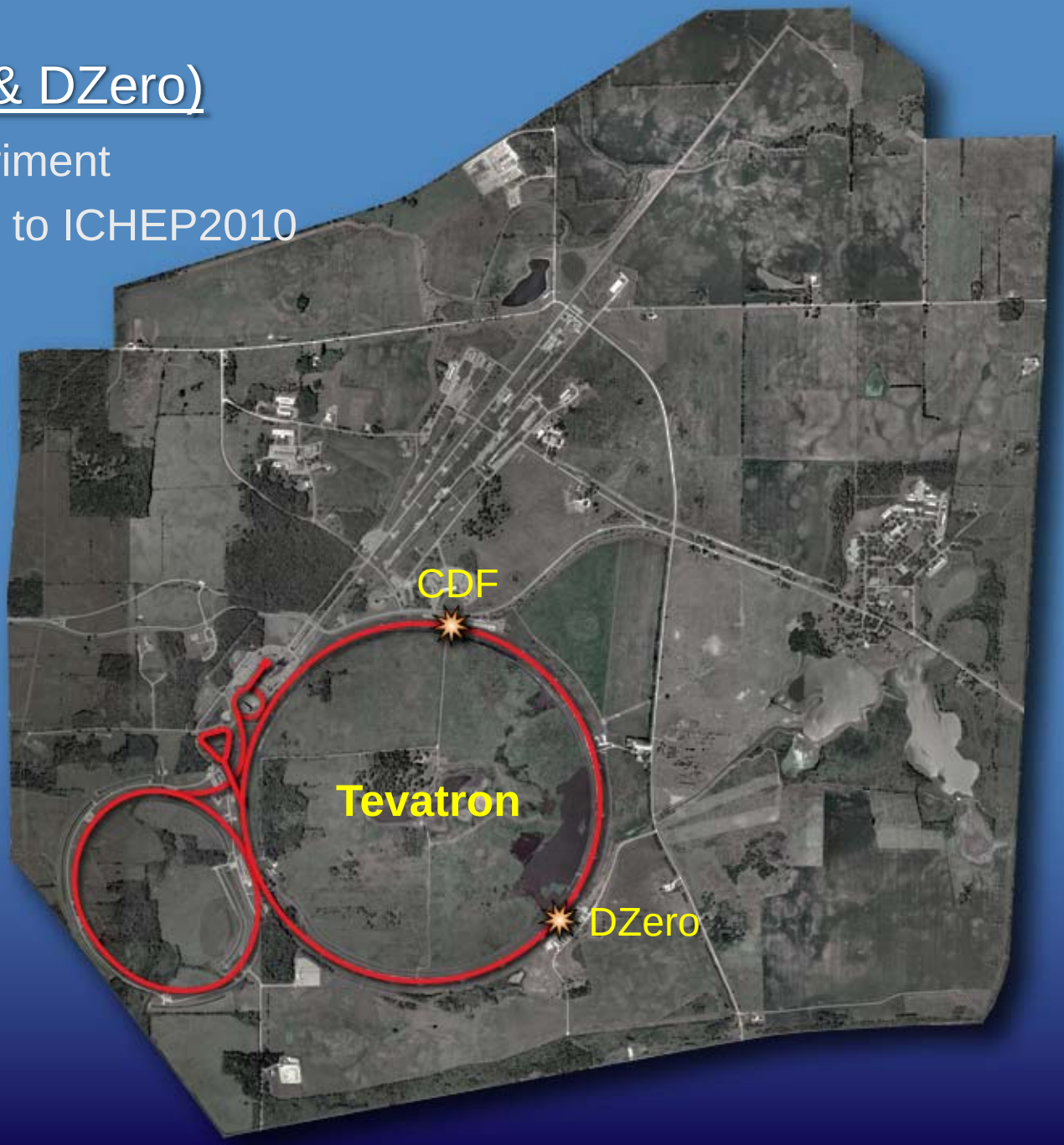
Storage Ring
(Recycler)

Tevatron (CDF & DZero)

> 9 fb^{-1} / experiment

152 abstracts submitted to ICHEP2010





ν's from Main Injector

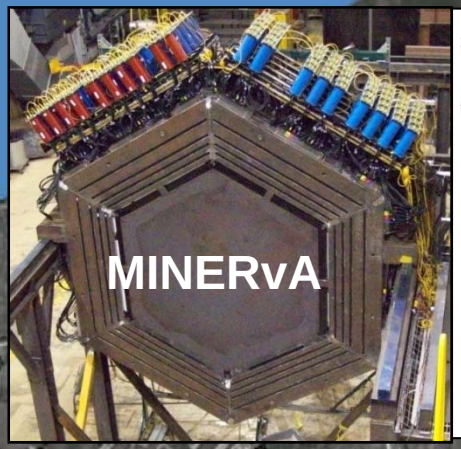
MINOS (on-axis)

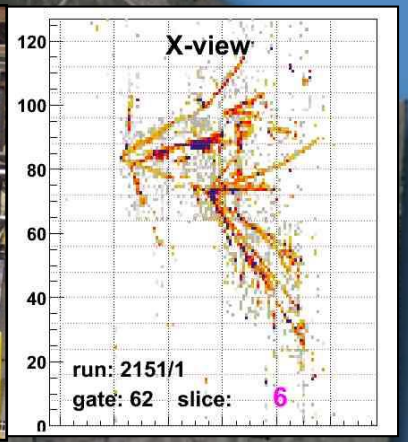
MINERvA since Mar. 2010

NOvA (near detector)

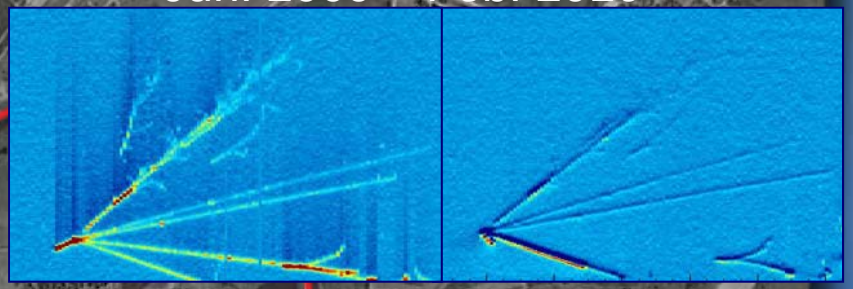
735 km

300 kW





ArgoNeuT (0.3 ton LAr TPC)
Jun. 2009 – Feb. 2010

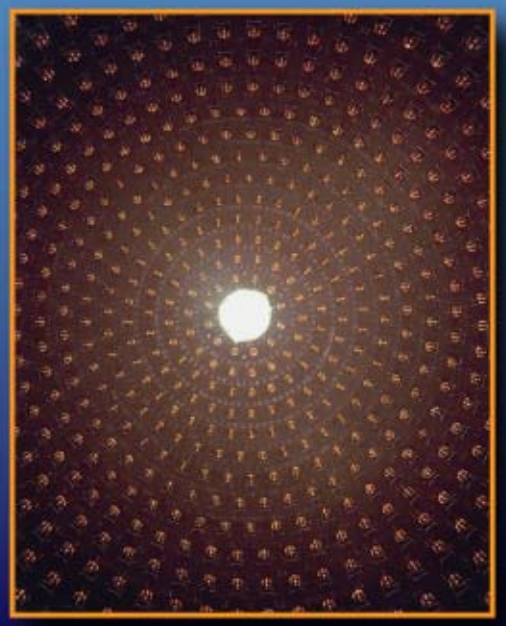


* ICARUS at Gran Sasso
(600 ton LAr TPC)
Taking data since May 2010

ν's from Booster

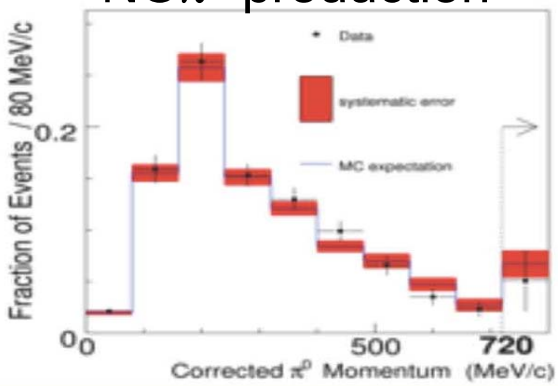
MiniBooNE

SciBooNE (Jun.2007 – Aug.2008)

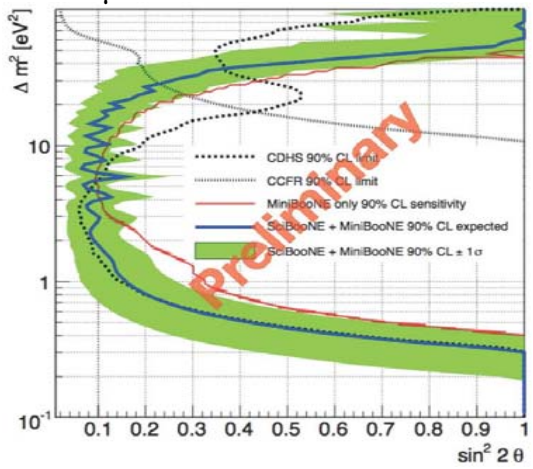


SciBooNE

NCπ^0 production



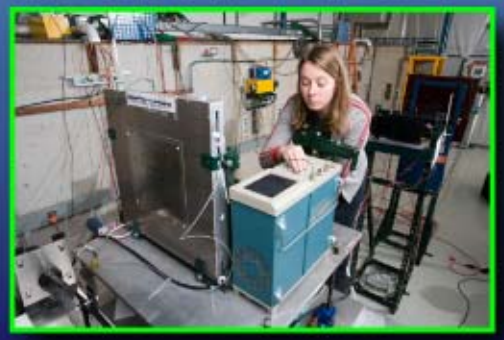
ν_μ disappearance



Testbeam

for Detector Development

supporting the international community



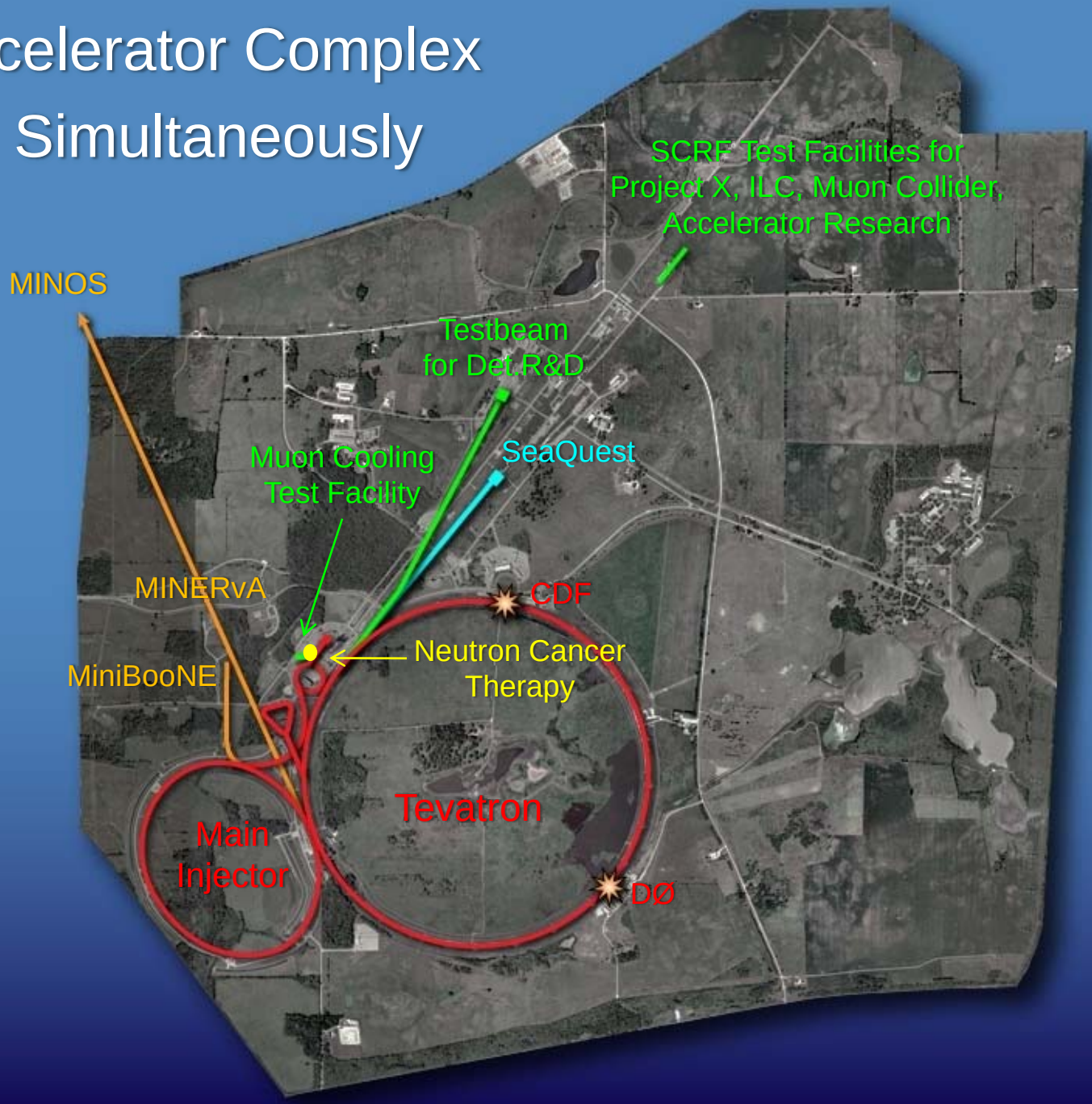
Test Facility for Accelerator Development

Super Conducting RF Technology

Test Facility for Muon Cooling (MuCOOL)

SeaQuest

Fermilab Accelerator Complex Operating Simultaneously



Accelerator Shutdown

March 2012 – February 2013

for installation/commissioning of neutrino beam upgrade

(300 kW → 700 kW)

NOvA Detector Construction & Installation

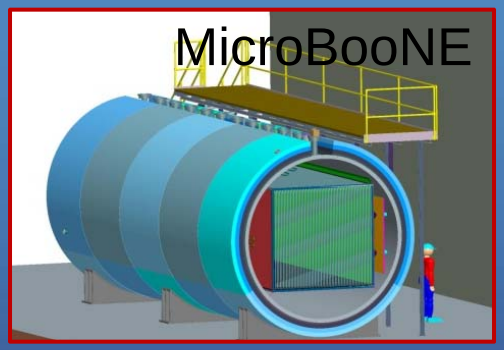
Plan: MicroBooNE Detector Construction & Installation

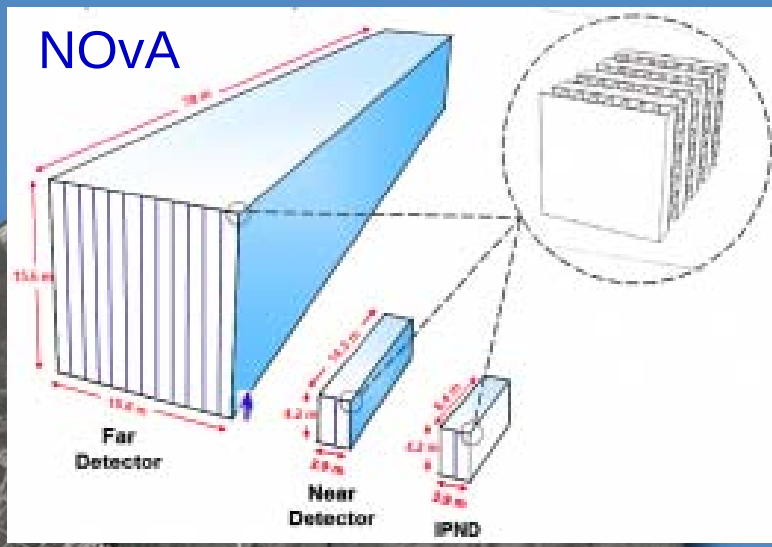
Neutrinos

NOvA (off-axis)

MINERvA

MicroBooNE (170 ton LAr)





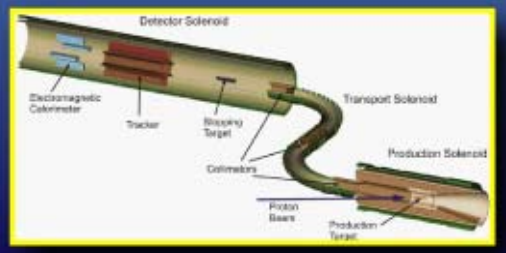
Neutrinos

LBNE (DOE Stage-1 approval)

Muons

Mu2e (DOE Stage-1 approval)

Muon g-2 (Being reviewed by DOE)



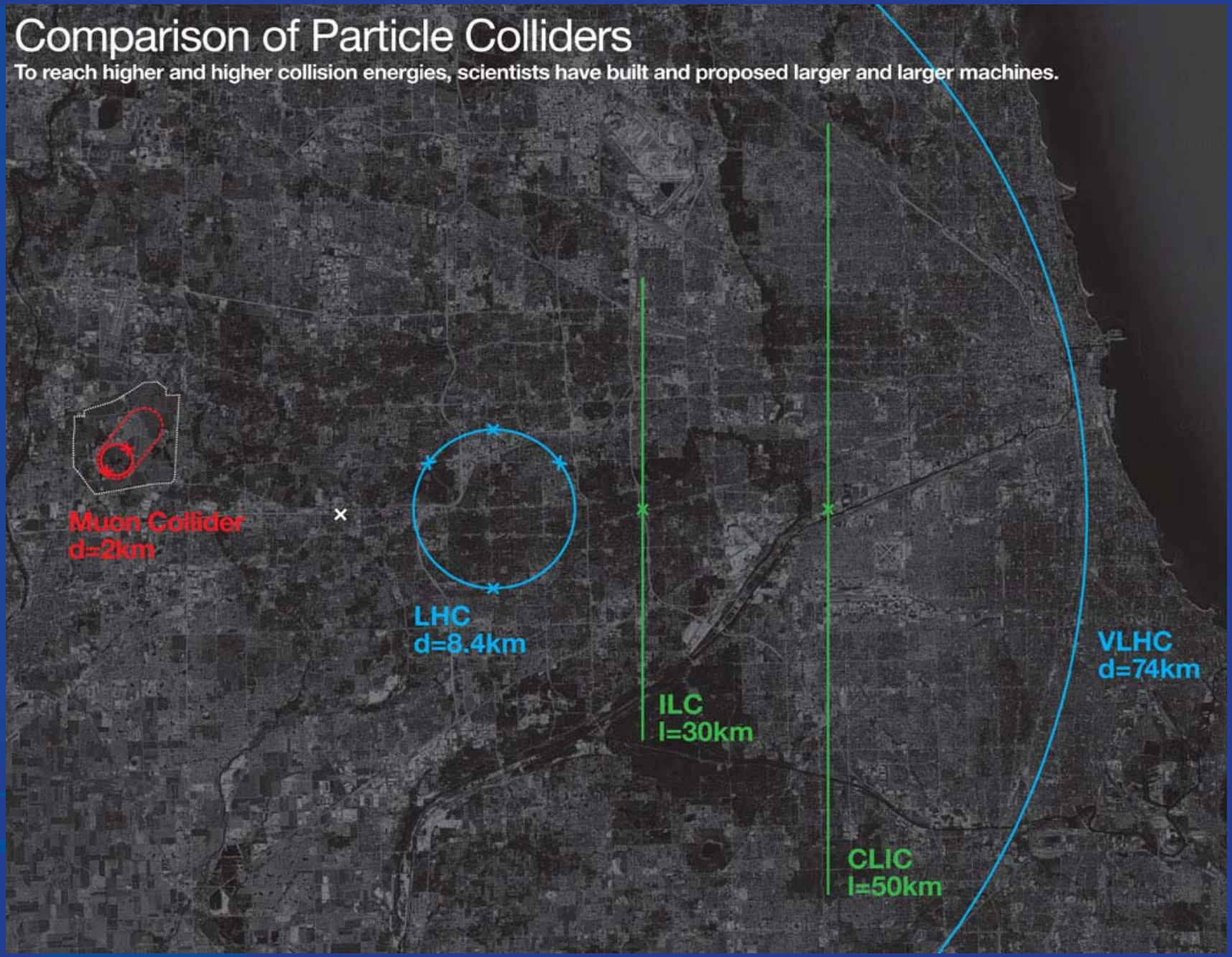
810 km
700 kW

700 kW
1300 km

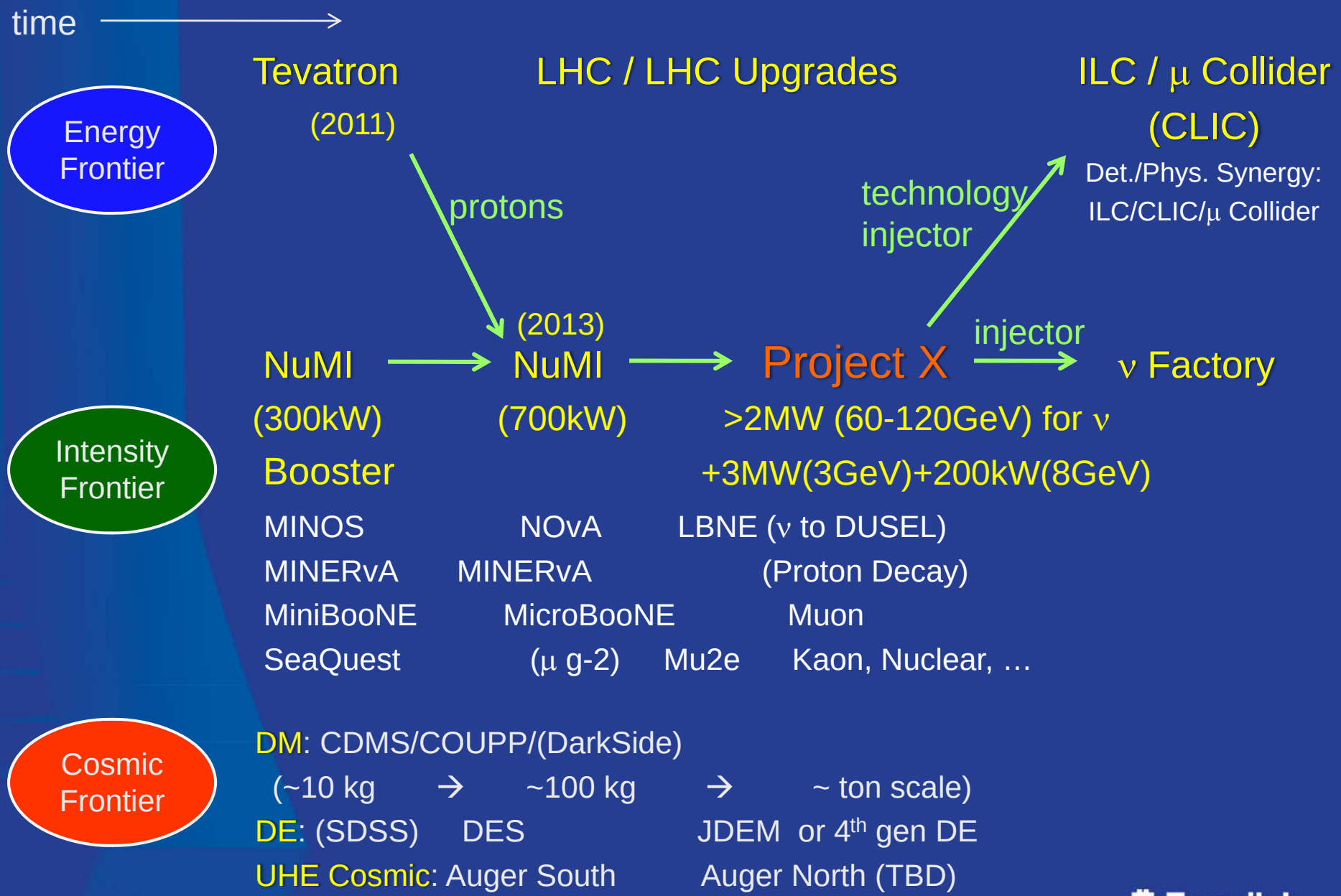
Kaons

$K^+ \rightarrow \pi^+ \nu\nu$

(200 SM events / year !! But, …)

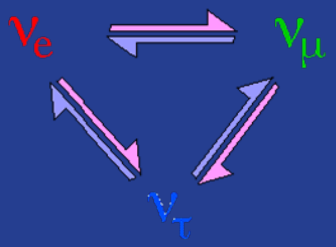

Comparison of Particle Colliders
To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.
Muon Collider
d=2km
LHC
d=8.4km
ILC
l=30km
CLIC
l=50km
VLHC
d=74km

Fermilab Strategic Plan at the Three Frontiers



Fermilab

Closing Remarks



- Neutrinos
  - The properties of the neutrino provide a unique window on physics beyond the SM.
  - Discoveries so far produced much excitement
  - Excitement growing, near future experiments seeking to measure θ_{13}(primarily), mass hierarchy, anti-ν properties,...
- Long-term vision
  - Establish facility with CP and mass hierarchy discovery potential for ~full parameter space & very small $\sin^2 2\theta_{13}$, and precision on the SνM parameters & flexibility for new physics → Accelerators, Detectors
  - Much progress made
  - Short-term experiments will play a critical role optimizing / directing the longer-term projects