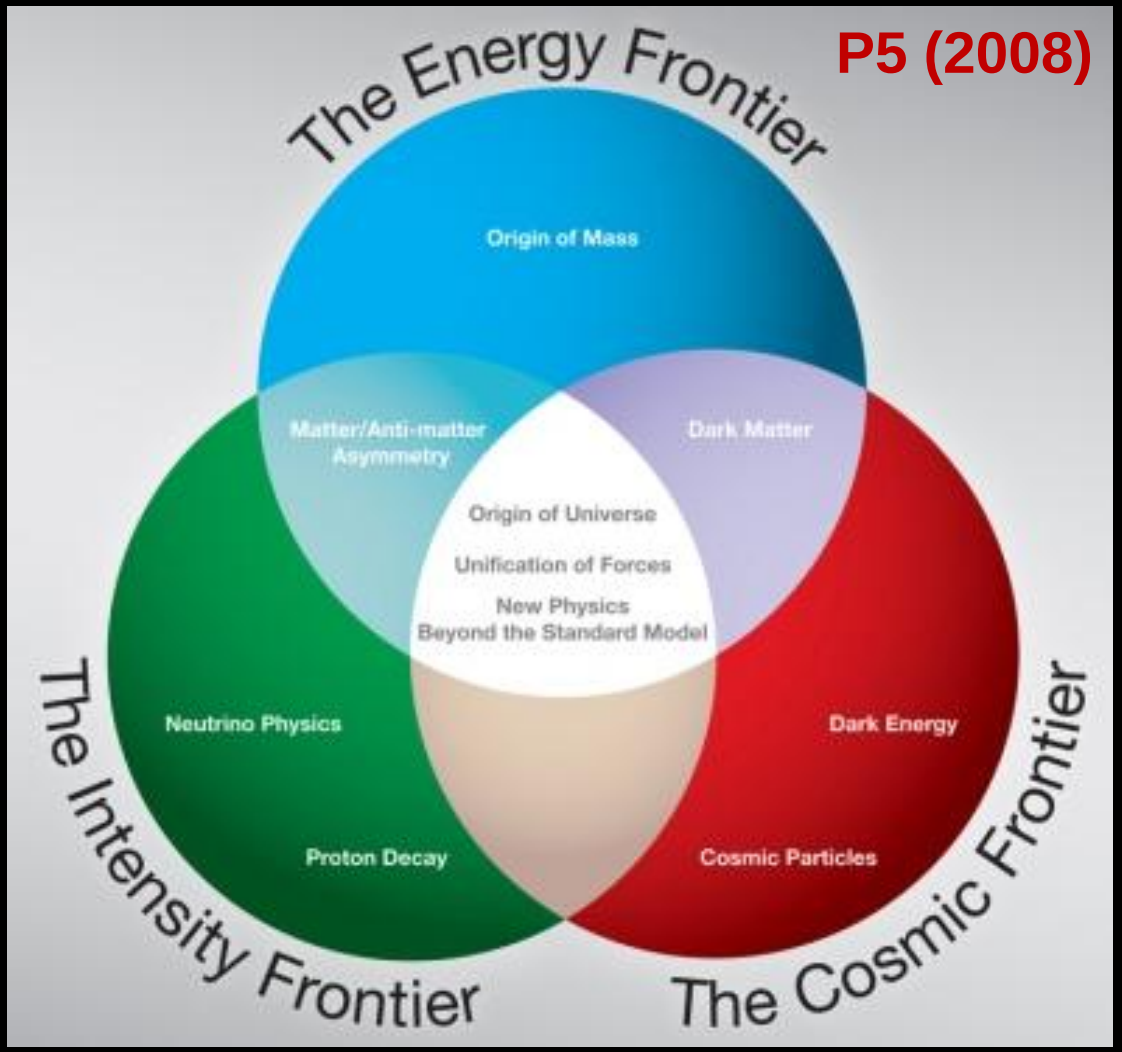
Fermilab: Now and Future

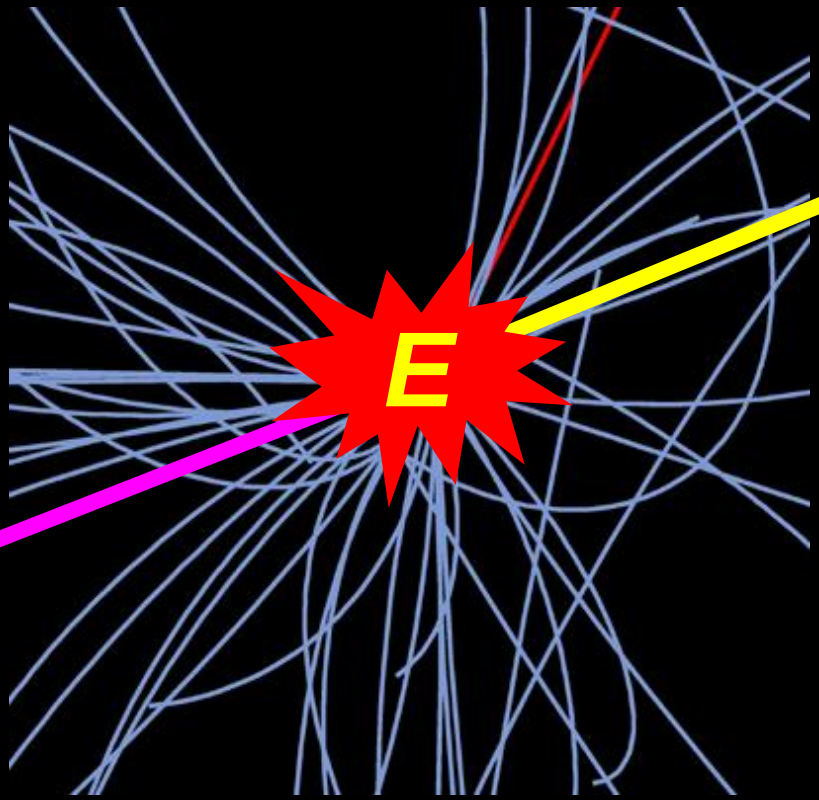
Young-Kee Kim
Fermilab and the University of Chicago

Phenomenology 2010 Symposium
May 10 – 12, 2010
University of Wisconsin, Madison

21st Century Questions in Particle Physics
The Three Frontiers

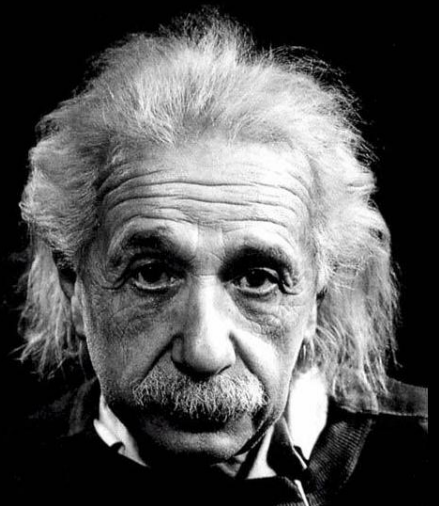


Energy Frontier Accelerators



anti particle

particle



$E = Mc^2$

Energy Frontier Accelerators

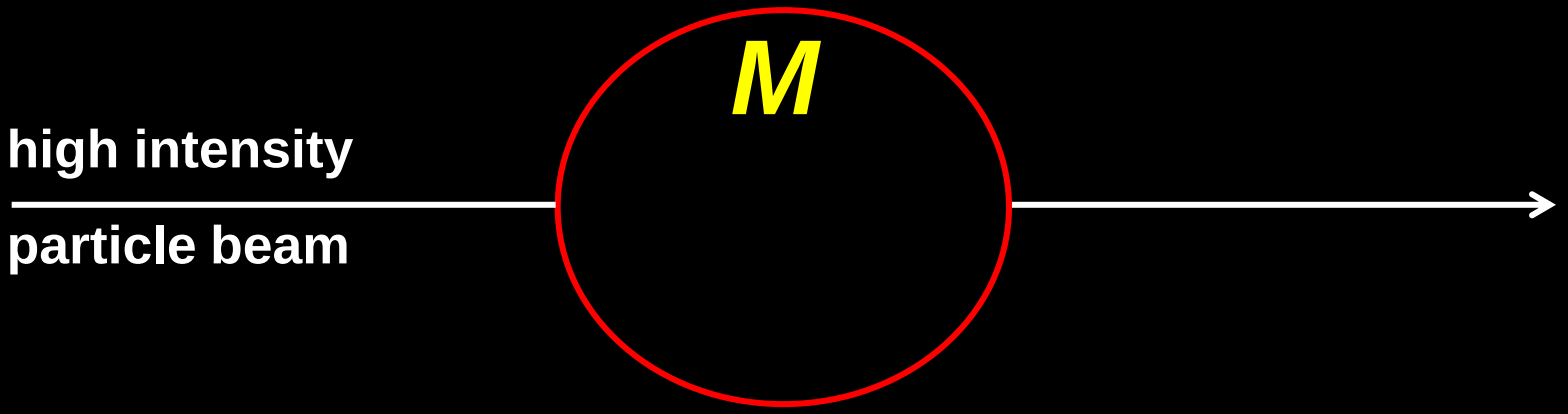
Tevatron

LHC

Lepton Collider

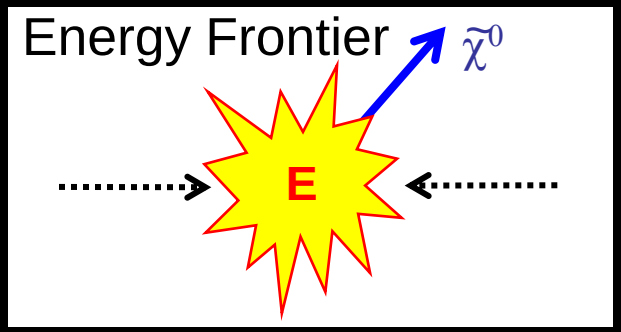
(energy, technology, site to be determined)

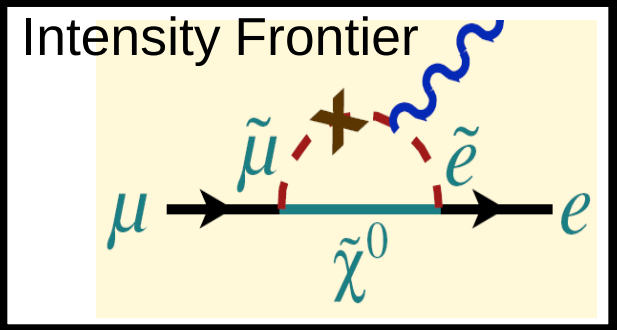
Intensity Frontier Accelerators (μ, K, C, B, nuclei)



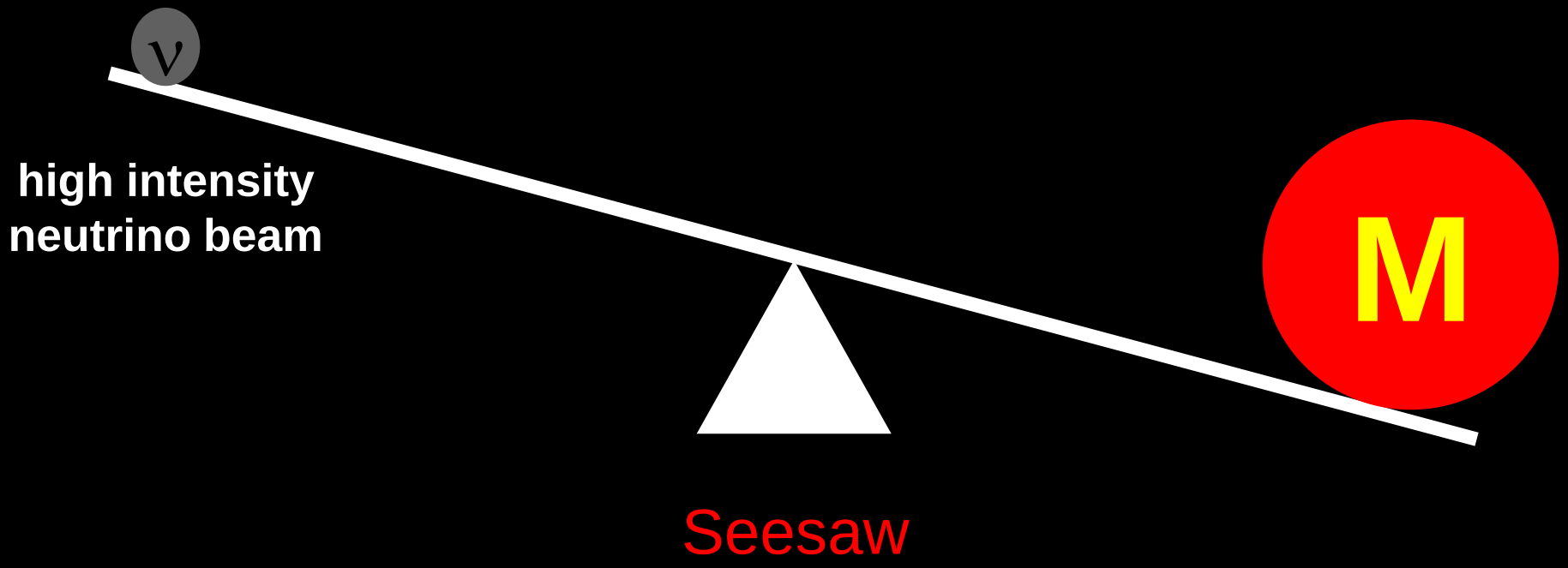
Quantum Fluctuation

Interplay: Energy – Intensity Frontiers





Intensity Frontier Accelerators (neutrinos)



Intensity Frontier Accelerators (neutrinos)

International Neutrino Summer School since 2009:
2009 at Fermilab, 2010 at KEK, 2011 in Europe, ……

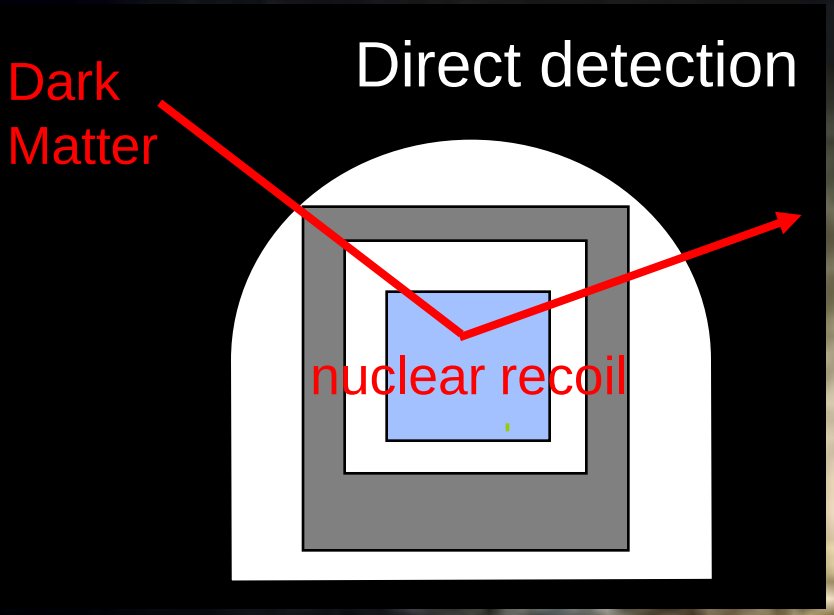
Fermilab → Soudan Mine
735 km
300 → 700 kW

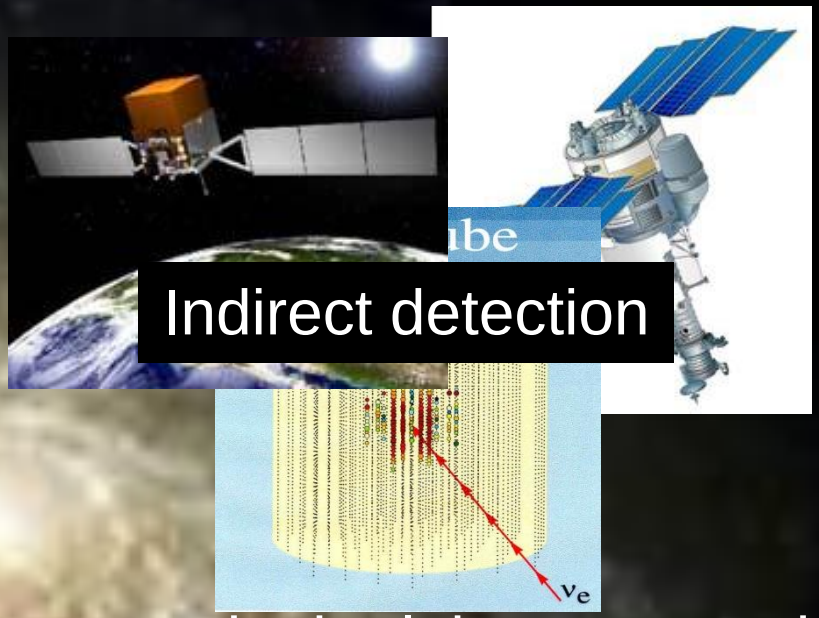
CERN → Gran Sasso
732 km

KEK → Kamiokande
295 km
30 → 100 → 750 kW

Towards longer distance (>1200km) & higher power (~2MW)

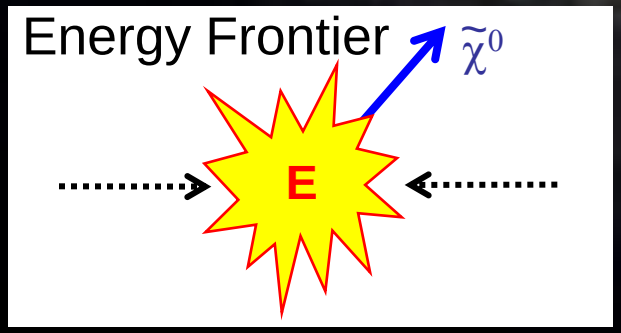
Cosmic Frontier: Dark Matter

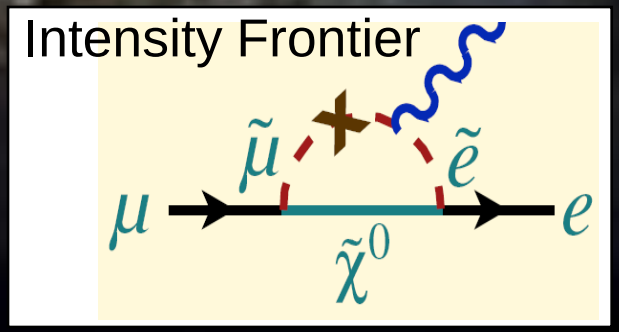




Accelerators can produce dark matter in the laboratory and understand exactly what it is.

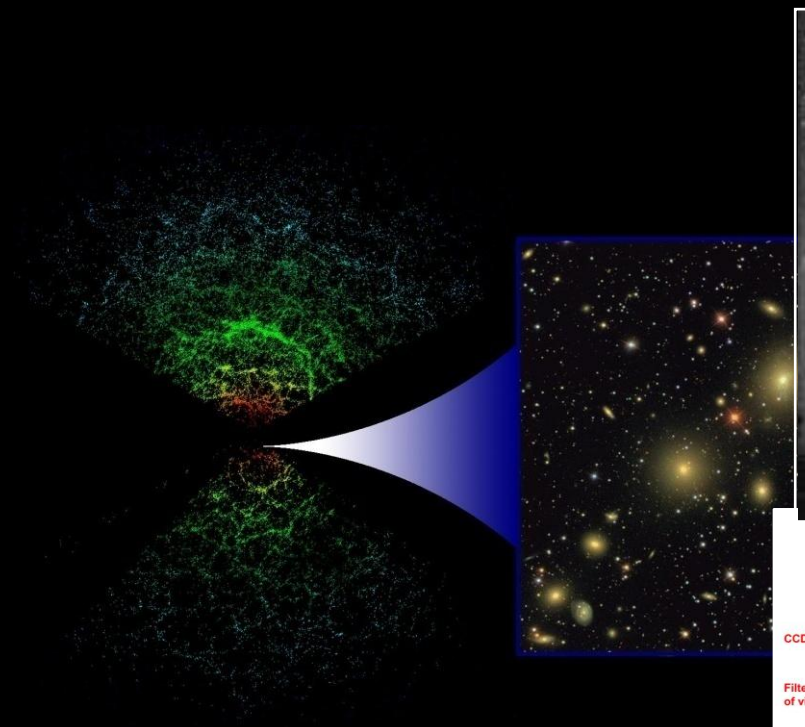
Interplay: Energy – Intensity – Cosmic Frontiers

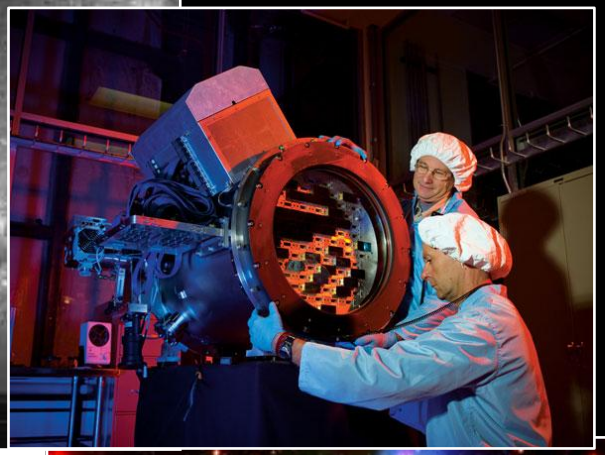


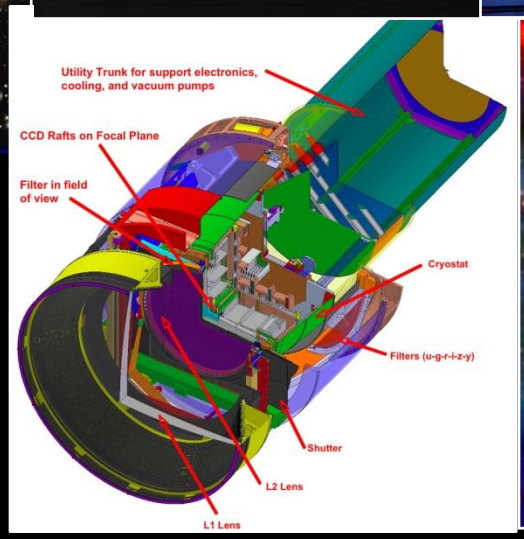


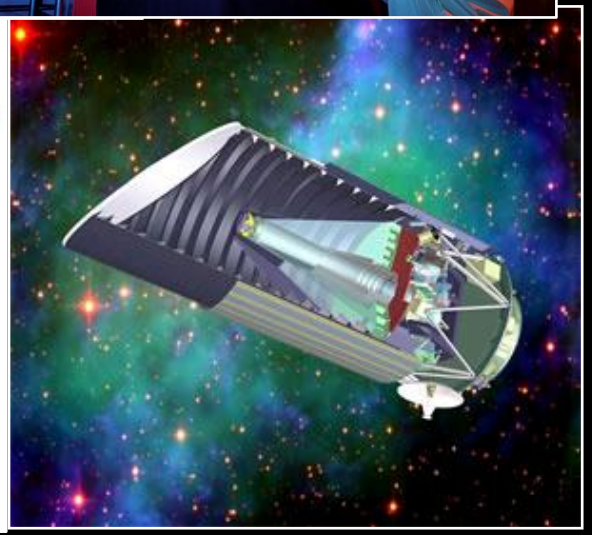
Cosmic Frontier: Dark Energy

Telescopes (ground, space)





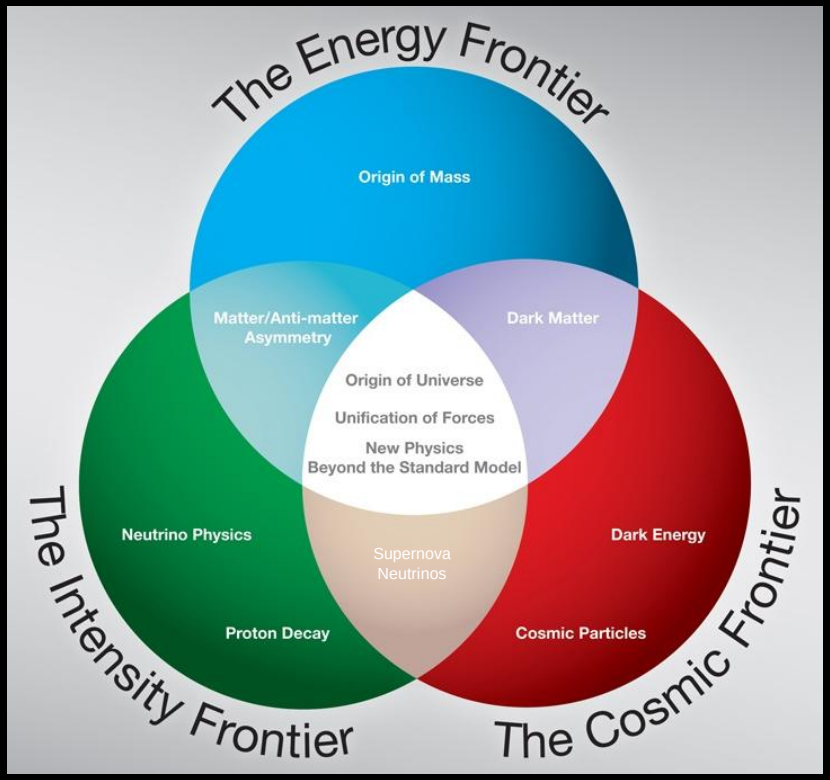




Fermilab Programs at Three Frontiers (Today)

Hadron Colliders:
Tevatron
LHC

Neutrinos



Dark Matter
Dark Energy
UHE Cosmic Rays

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

LHC (Construction/Commissioning/Operations/Physics/Upgrades)

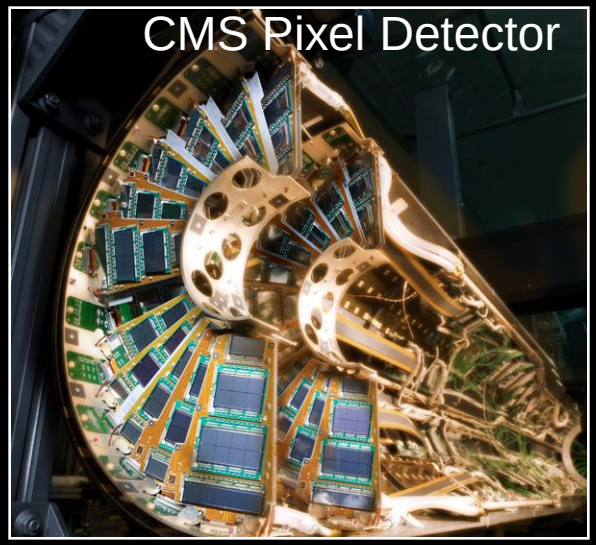
Accelerators

LHC IR quadrupoles

LHC upgrade
3.4m Nb3Sn prototype

Detectors/Computing


CMS Calorimeter
Muon Chamber
Silicon Tracker


CMS Pixel Detector

Operations/Physics


Remote Operations Center

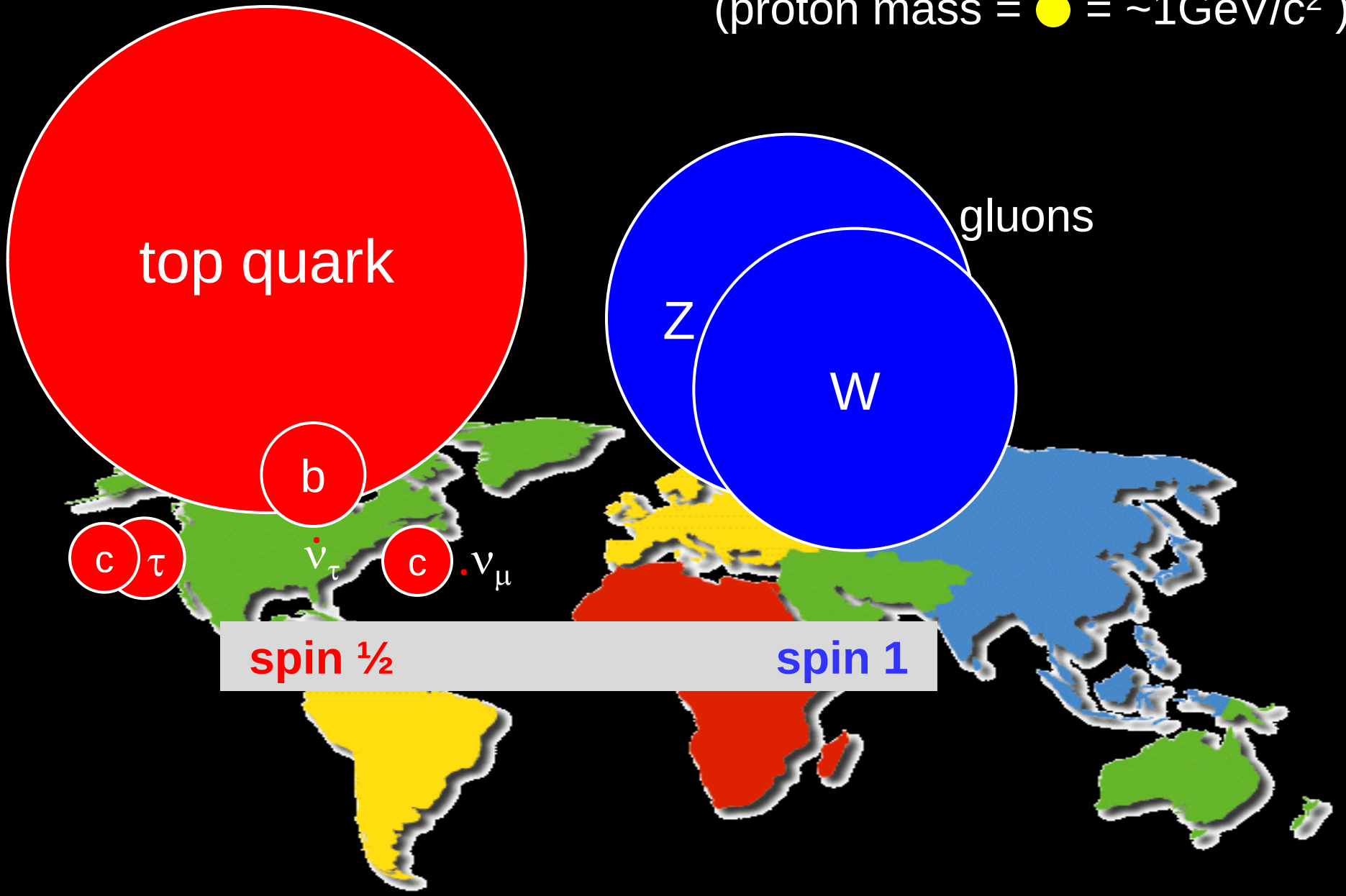
LHC Physics Center
CMS Tier-1 Computing Center
US CMS Host Laboratory


German vs. US+UK

Final: Italy+France+Spain
vs. rest of the world

CERN-Fermilab Summer School since 2006

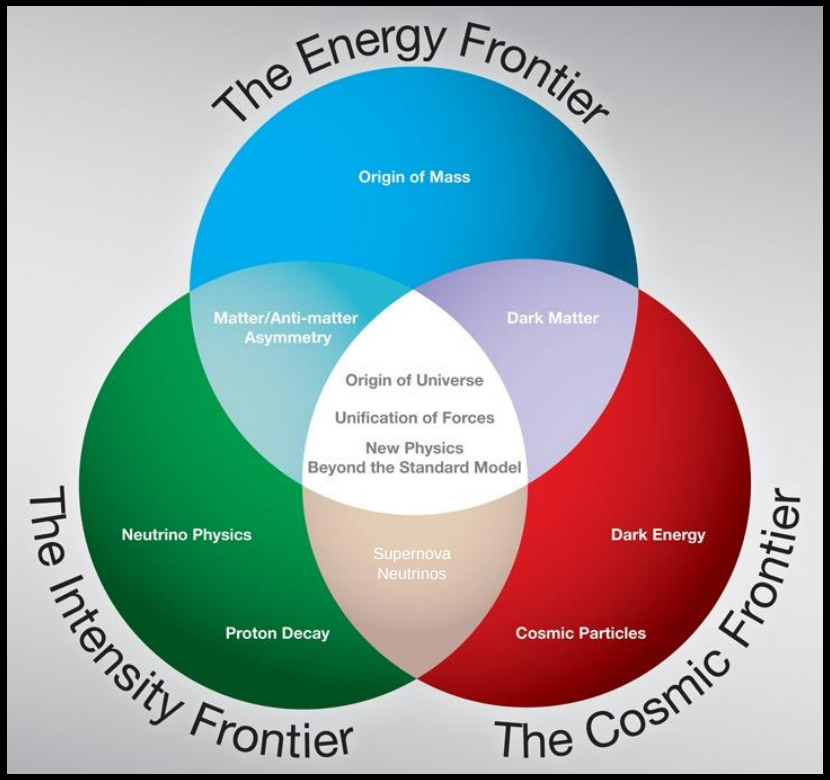
(proton mass = ● = ~1GeV/c^2)



Fermilab Programs at Three Frontiers (Future)

Hadron Colliders:
LHC

Neutrinos
Muons



Dark Matter
Dark Energy
UHE Cosmic Rays
New Initiatives

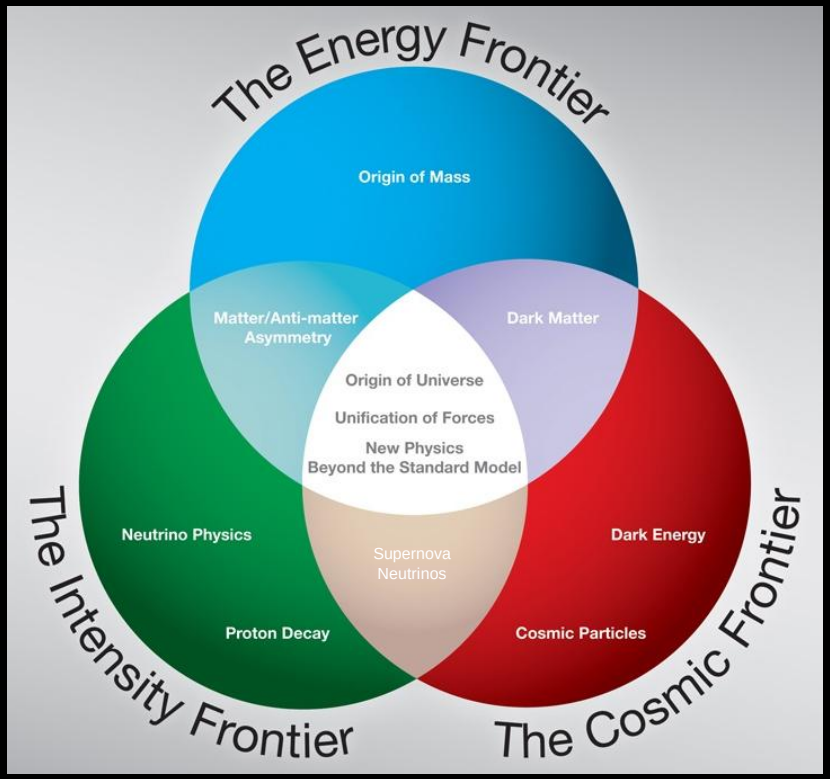
http://www.fnal.gov/pub/science/frontiers/

Fermilab Programs at Three Frontiers (Future)

Hadron Colliders:
LHC

Project X:
Neutrinos
Muons
Kaons
Nuclei

Neutrino Factory



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

Dark Matter
Dark Energy
New Initiatives

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

Tour of Accelerator Complex at Fermilab

Cockroft-Walton

Linac

Booster

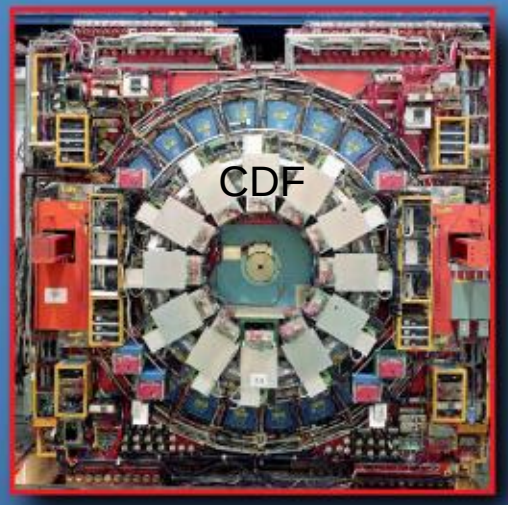
Main Injector

Tevatron

Antiproton

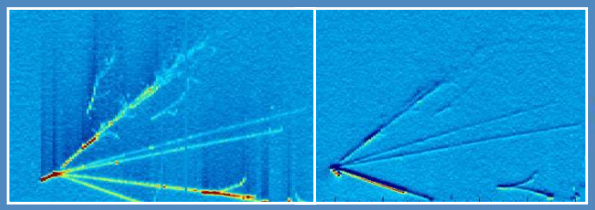
Tevatron

CDF and DZero



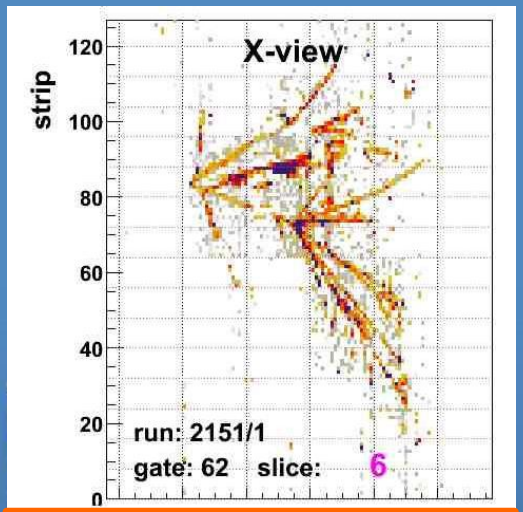
ν's from Main Injector

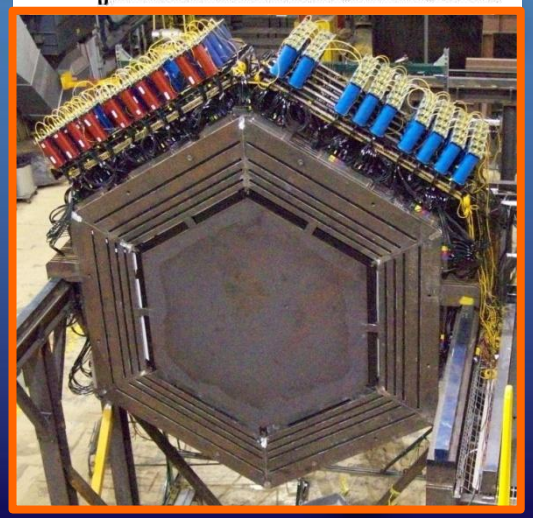
MINOS (on-axis)
ArgoNeuT (LAr TPC)



ν's from Main Injector

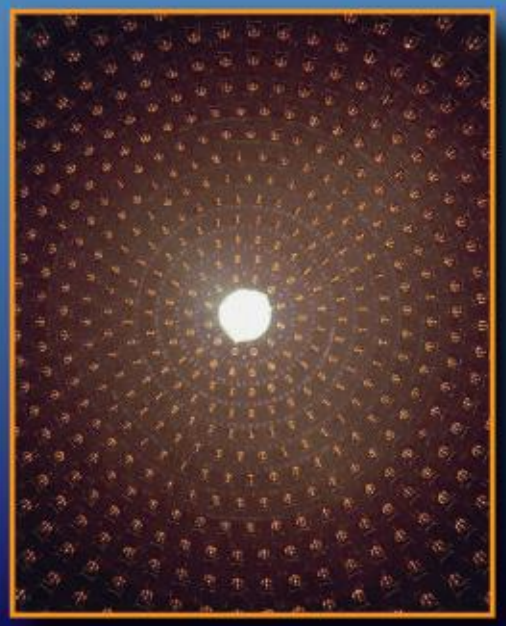
MINOS (on-axis)
ArgoNeuT (LAr TPC)
MINERvA



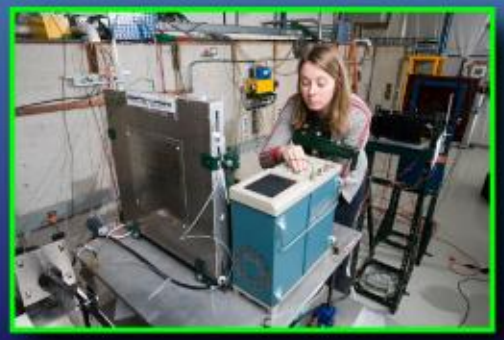


ν's from Booster

MiniBooNE
(SciBooNE)



Beam for Detector Development



Test Facility for Accelerator Development

Super Conducting RF Technology

Test Facility for
Muon Cooling
(MuCOOL)

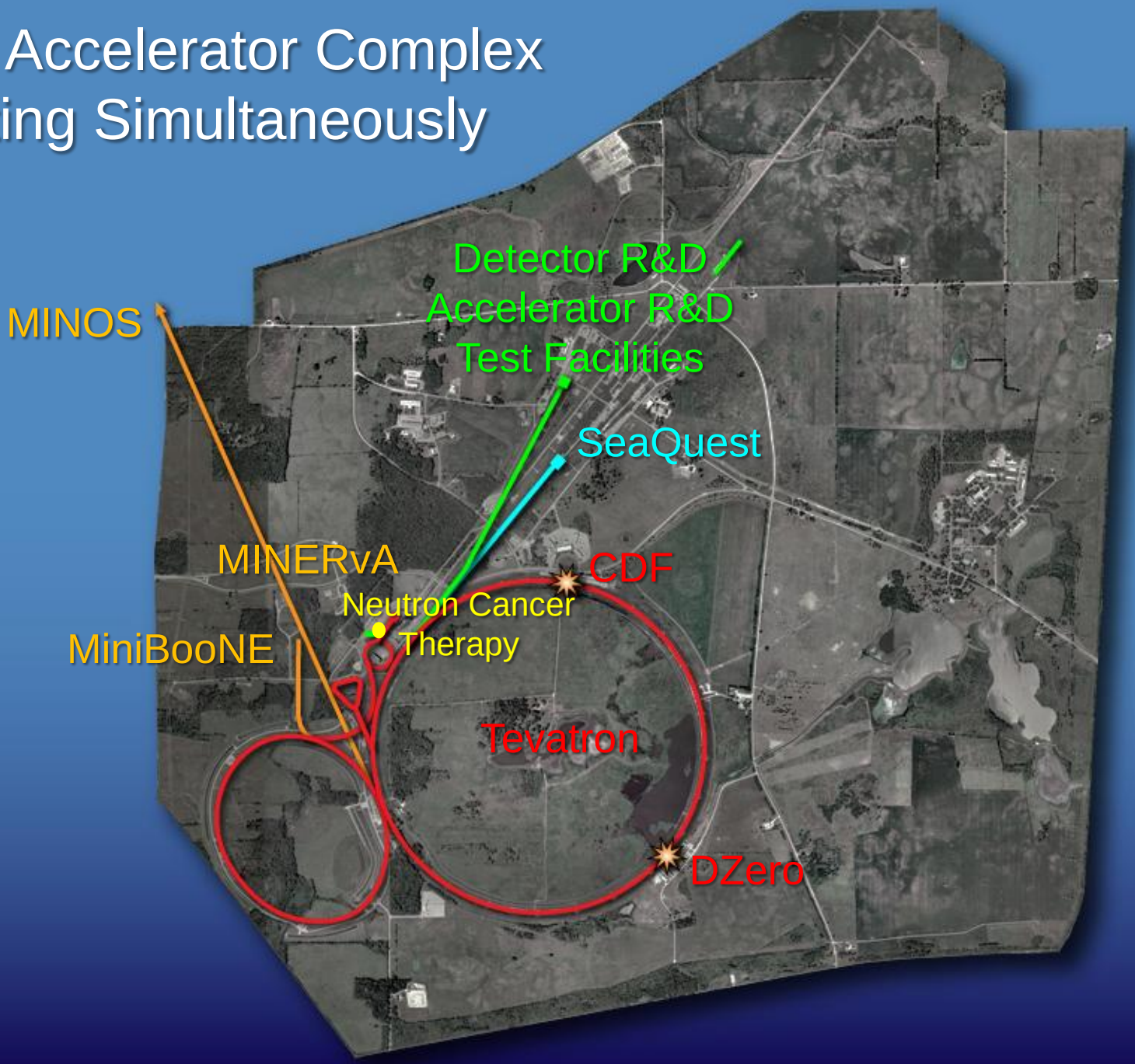
Proton

SeaQuest

Neutron Cancer Therapy

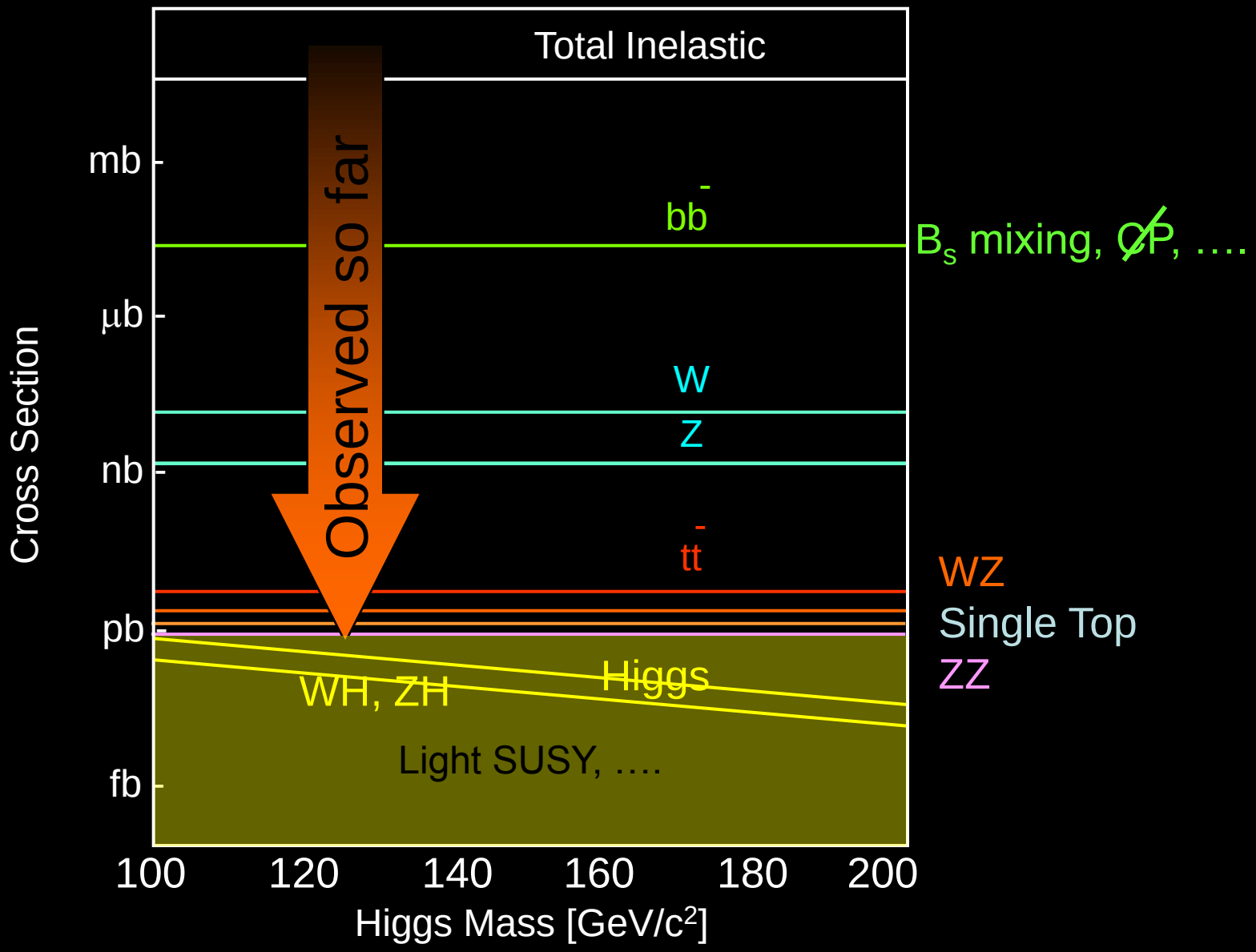
Patient treatments since 1976

Fermilab Accelerator Complex Operating Simultaneously



Physics at the Tevatron

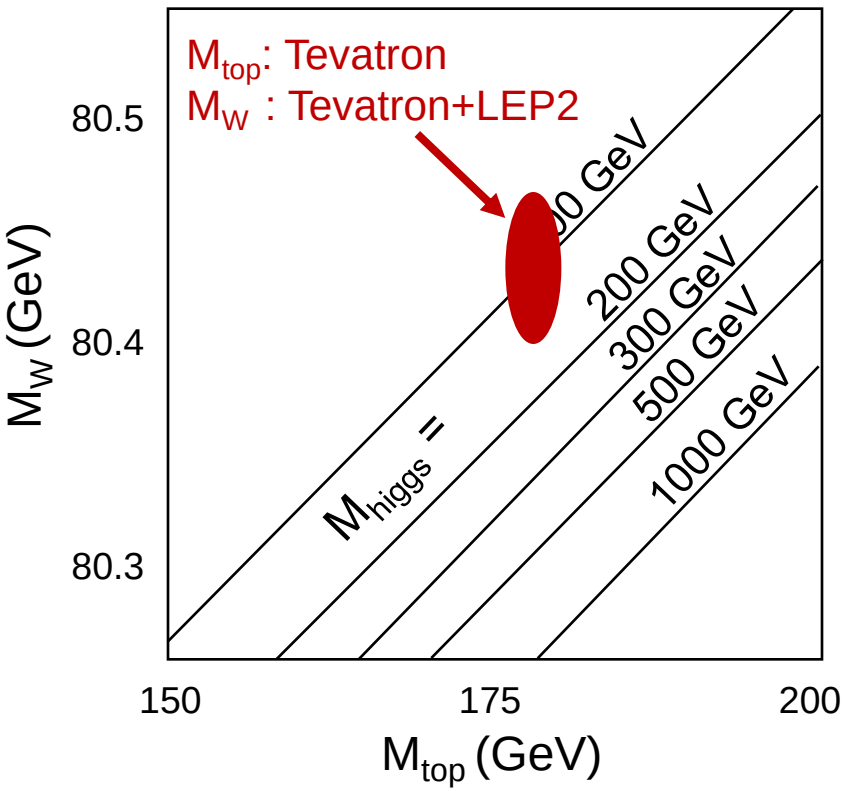
(per year: ~100 publications, ~60 Ph.D.s)



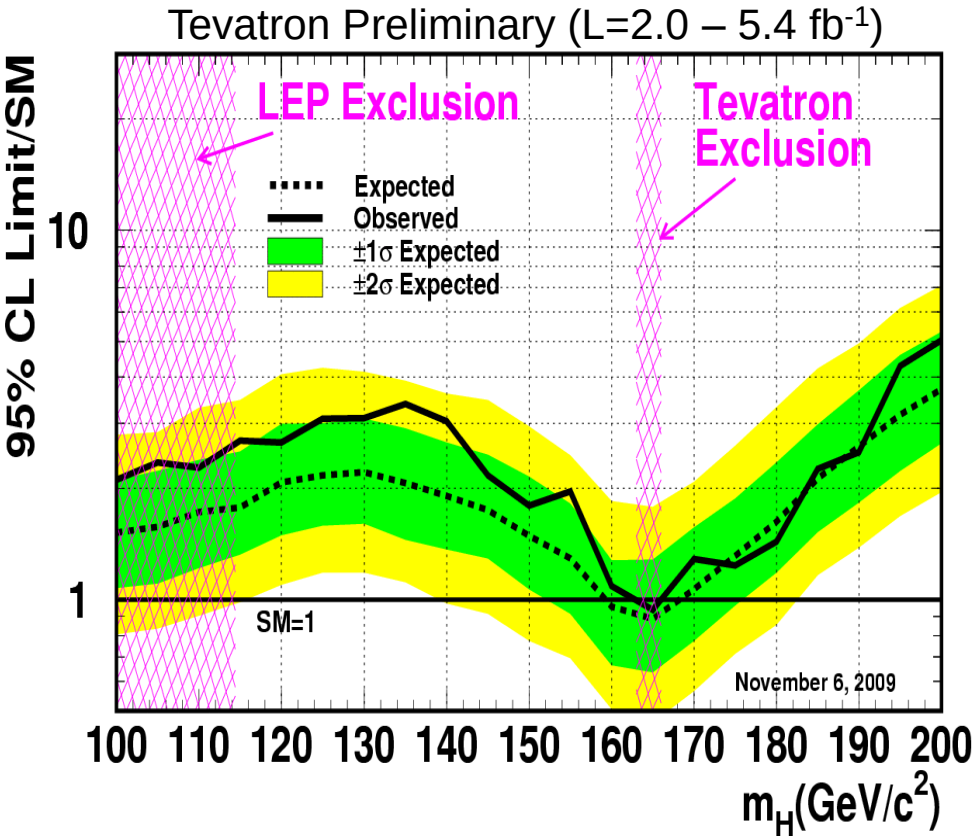
Some highlights from the past

Tevatron SM Higgs

Predict Higgs Mass



Search for Higgs



$m_H = 87^{+35}_{-26}$ GeV

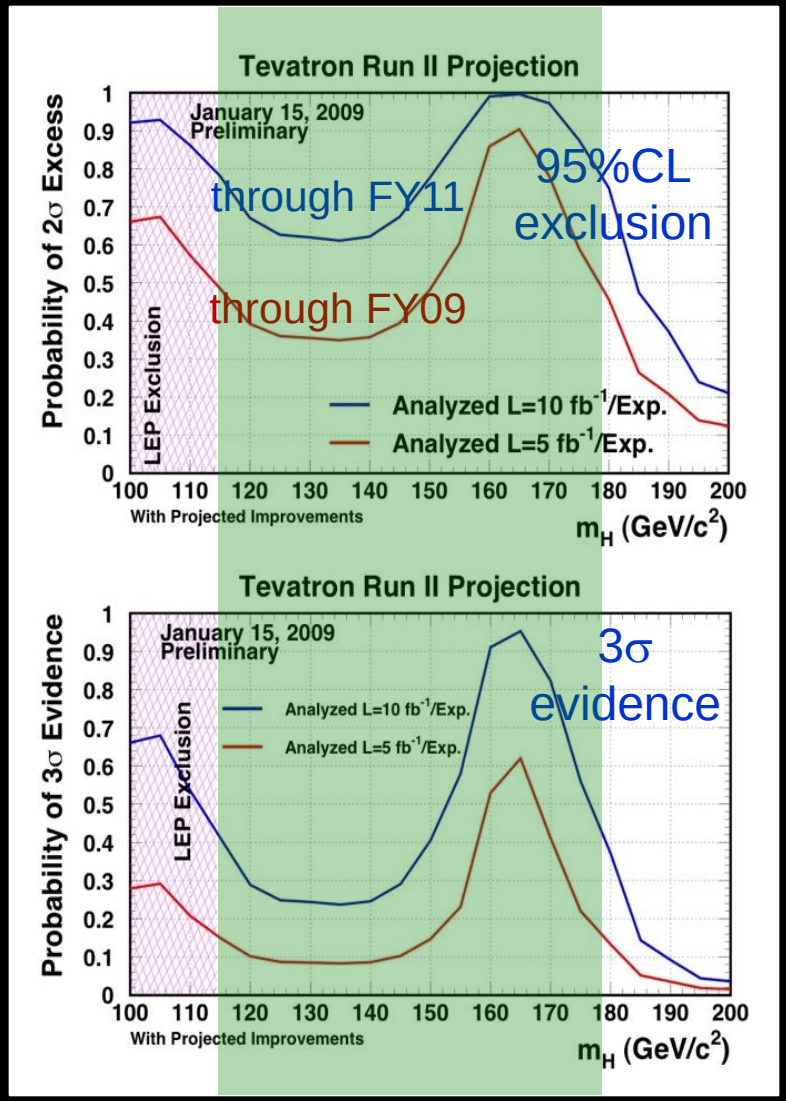
(m_{top} = 173.1 ± 1.3 GeV)

and some luck

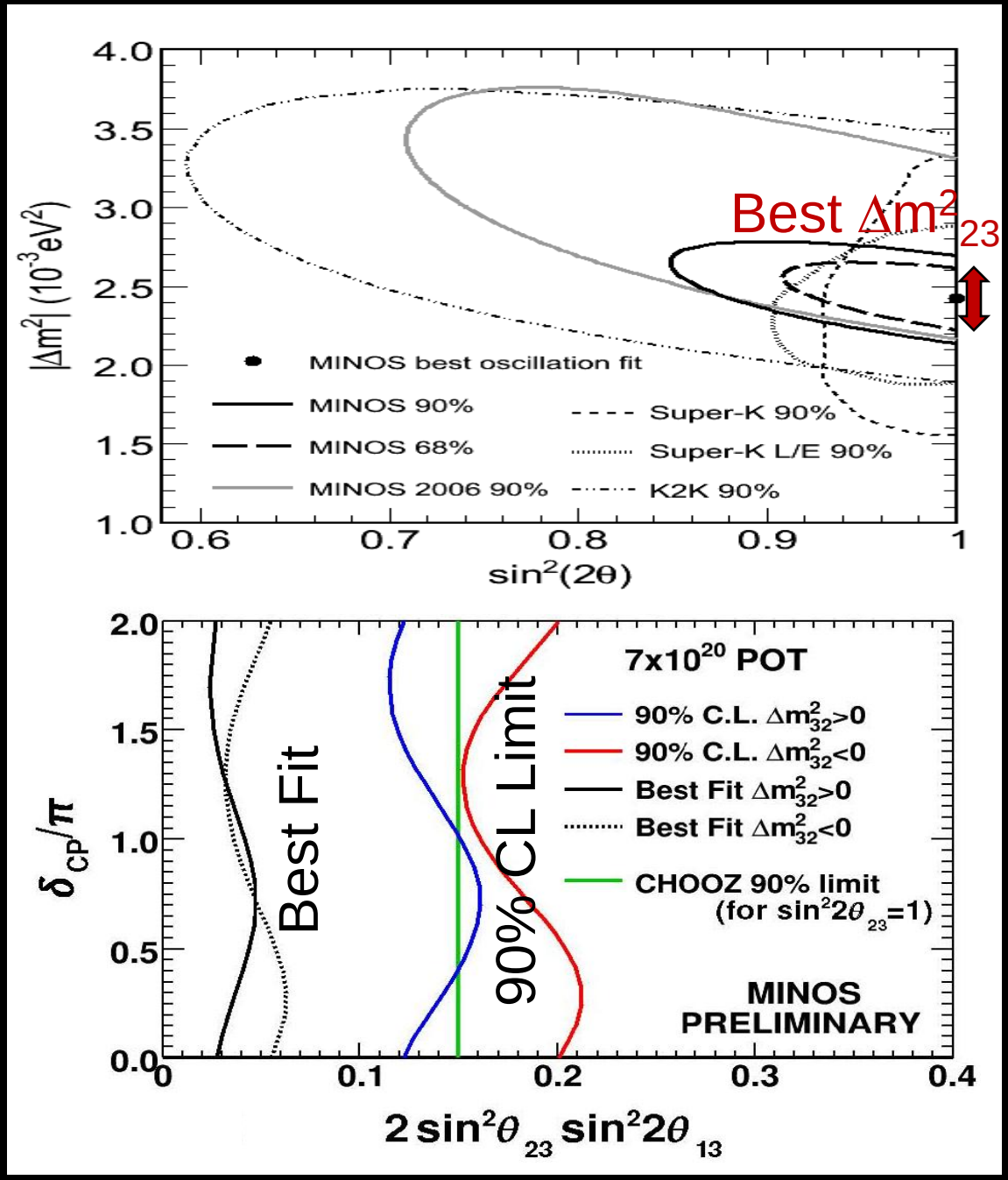
Higgs reach with continued analysis improvement

running through FY09 (red) FY11(blue)

Favored mass region



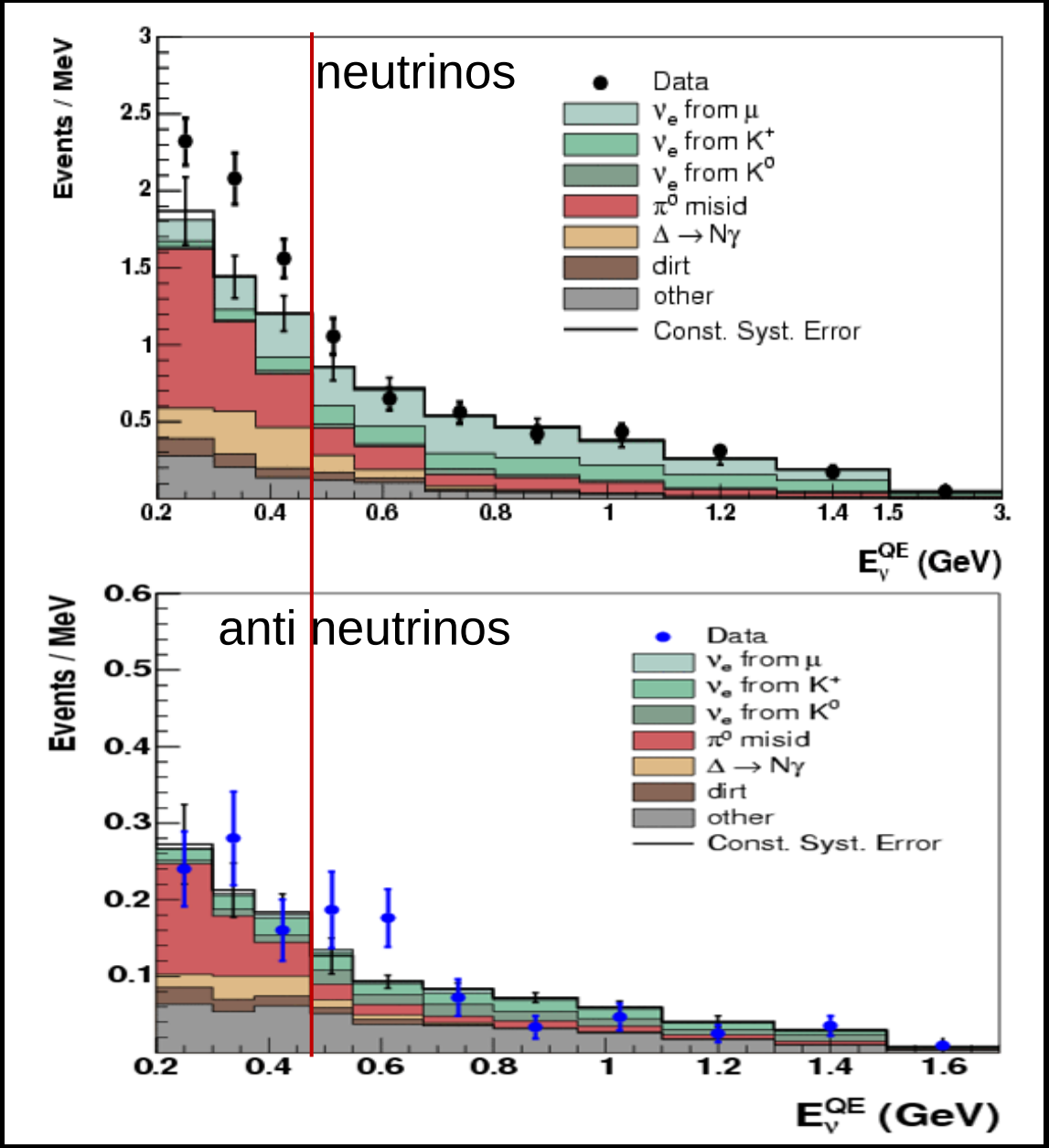
MINOS


Best Δm^2_{23}
$|\Delta m^2|$ (10^{-3}eV^2)
$\sin^2(2\theta)$
MINOS best oscillation fit
MINOS 90%
MINOS 68%
MINOS 2006 90%
Super-K 90%
Super-K L/E 90%
K2K 90%
δ_{CP}/π
Best Fit
90% CL Limit
7×10^{20} POT
90% C.L. $\Delta m^2_{32}>0$
90% C.L. $\Delta m^2_{32}<0$
Best Fit $\Delta m^2_{32}>0$
Best Fit $\Delta m^2_{32}<0$
CHOOZ 90% limit
(for $\sin^2 2\theta_{23}=1$)
MINOS
PRELIMINARY
$2\sin^2\theta_{23}\sin^2 2\theta_{13}$

MiniBooNE

neutrinos
vs.
antineutrinos

at
MiniBooNE
MINOS



Accelerator Shutdown
March 2012 – February 2013
to upgrade neutrino beam from Main Injector
(300 kW → 700 kW)

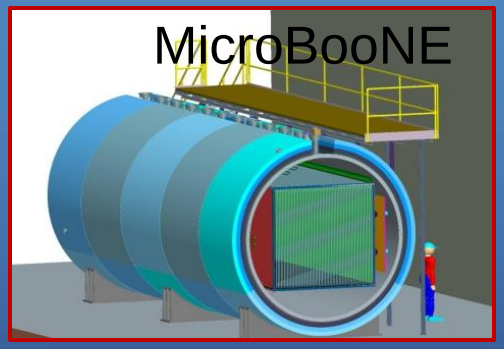
NOvA Detector Construction & Installation
Plan: MicroBooNE Detector Construction & Installation

Neutrinos

NOvA (off-axis)

MINERvA

MicroBooNE (LAr)



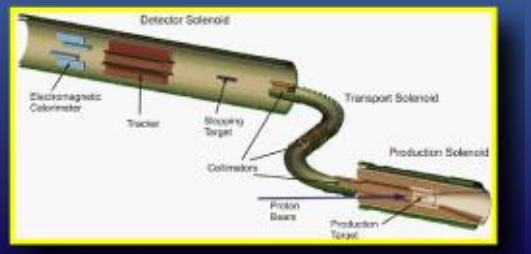
Neutrinos

LBNE: beam to DUSEL + Proton Decay
(DOE 1st stage approval)

Muons

Mu2e
(DOE 1st stage approval)

Muon g-2
(will be reviewed by DOE)

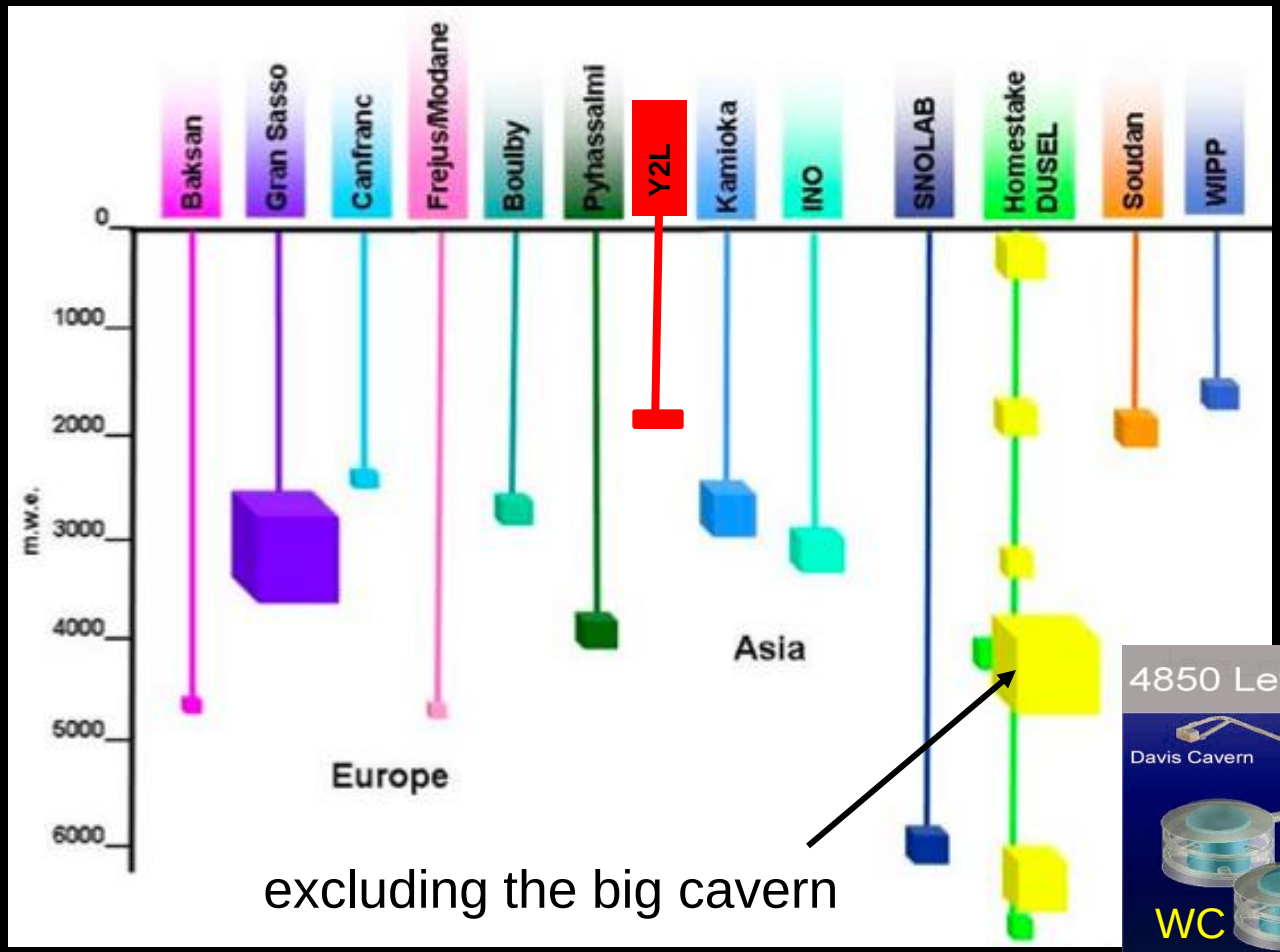


700 kW
1300 km

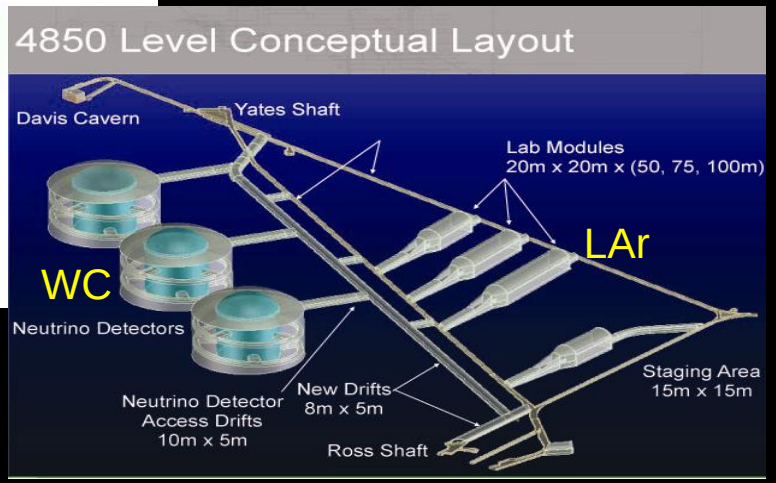
Kaons

$K^+ \rightarrow \pi^+ \nu\nu$
(under consideration)

Existing and Potential Underground Laboratories for Neutrinos / Proton Decays and Dark Matter Searches



excluding the big cavern



DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD

Ray Davis's Experiment

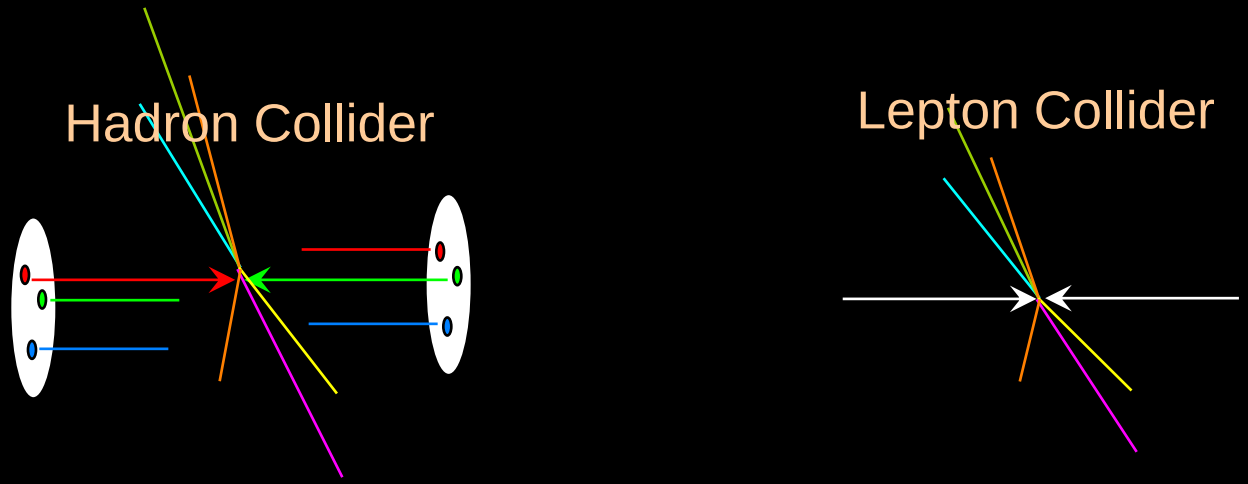
Project X

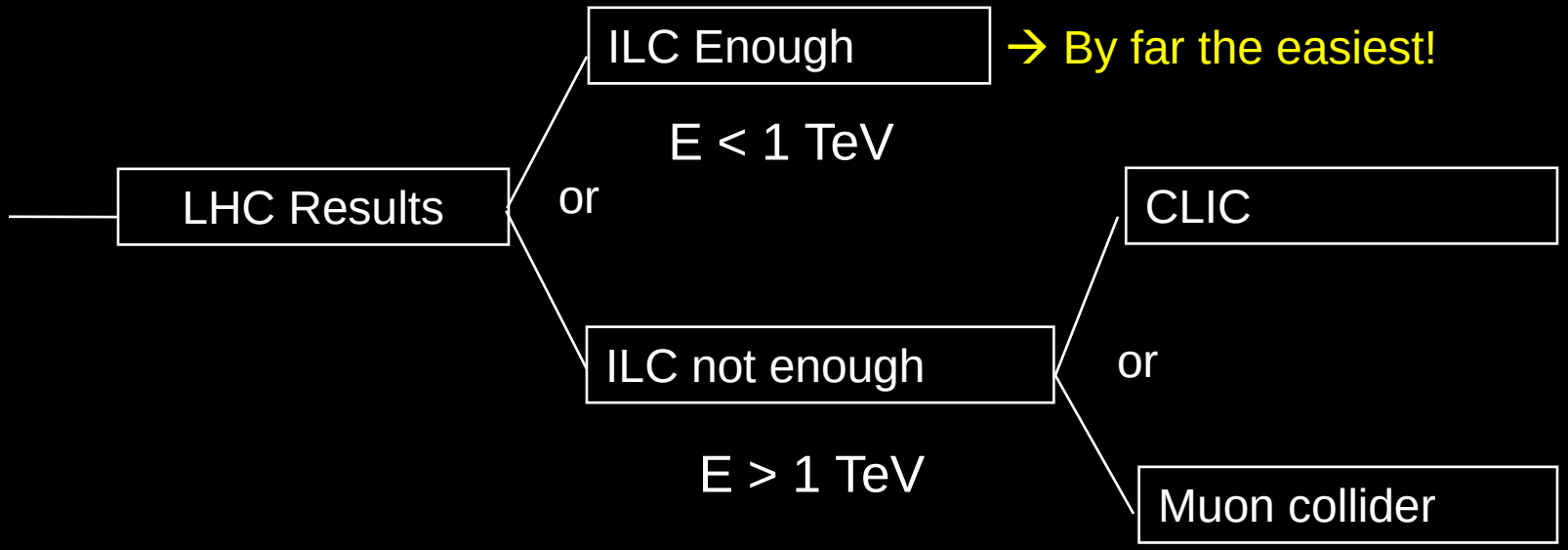
Neutrino physics
Muon physics
Kaon physics
Nuclear physics

"simultaneouly"

from Project X to Lepton Collider / Neutrino Factory

Energy Frontier beyond LHC: Lepton Collider

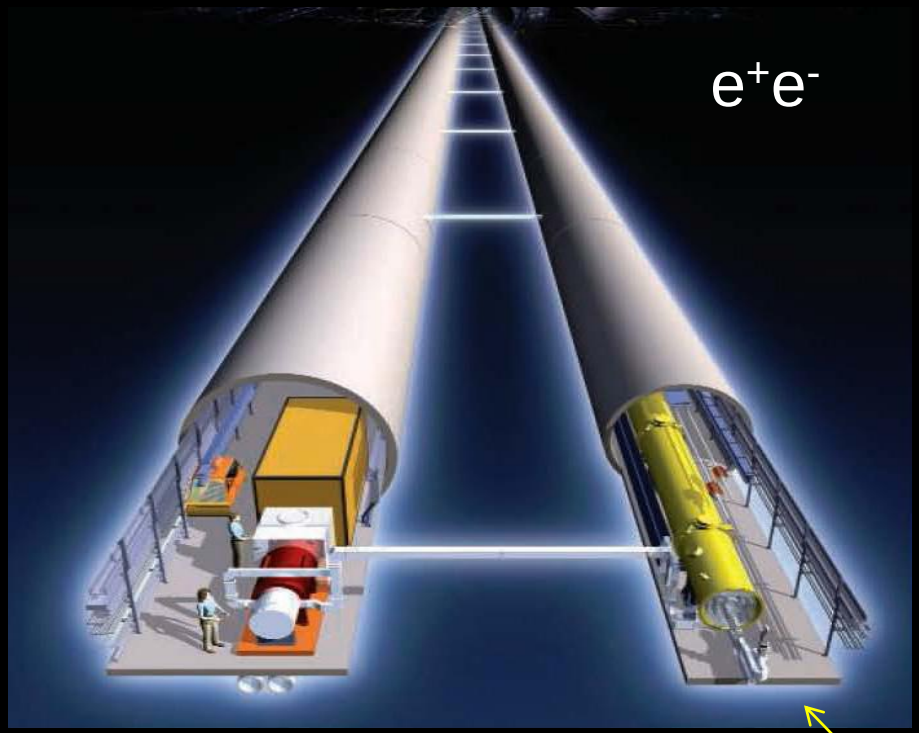


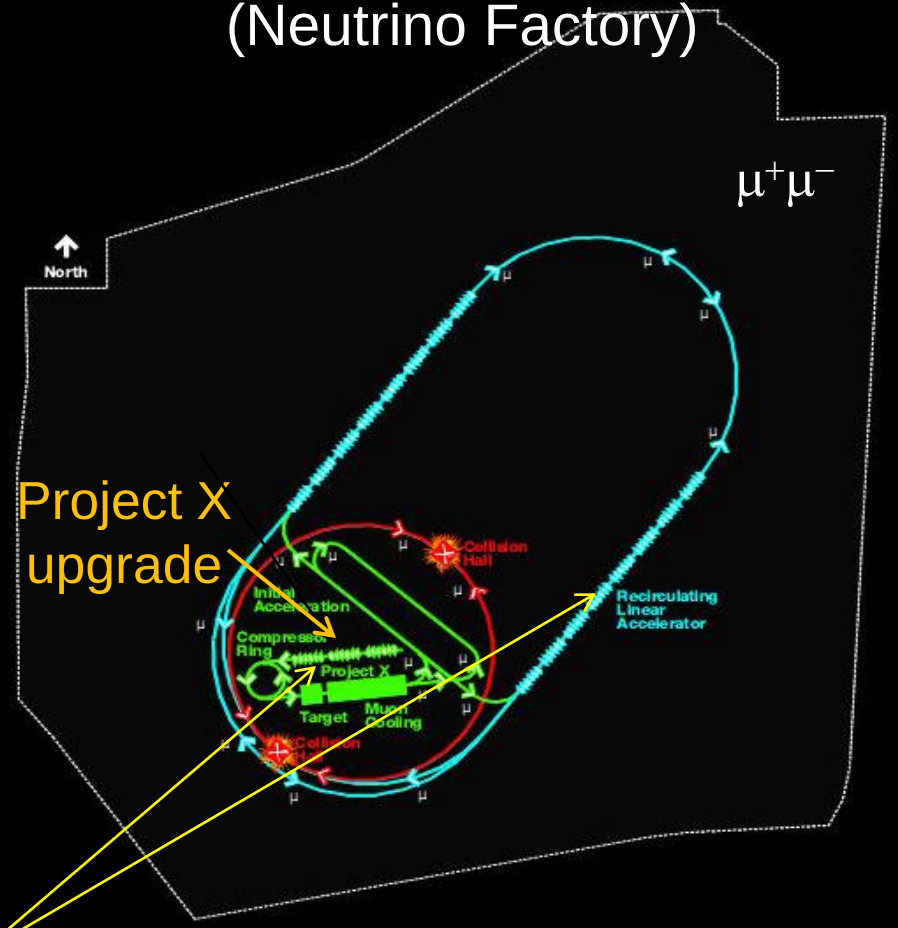


from Project X to Lepton Collider / Neutrino Factory

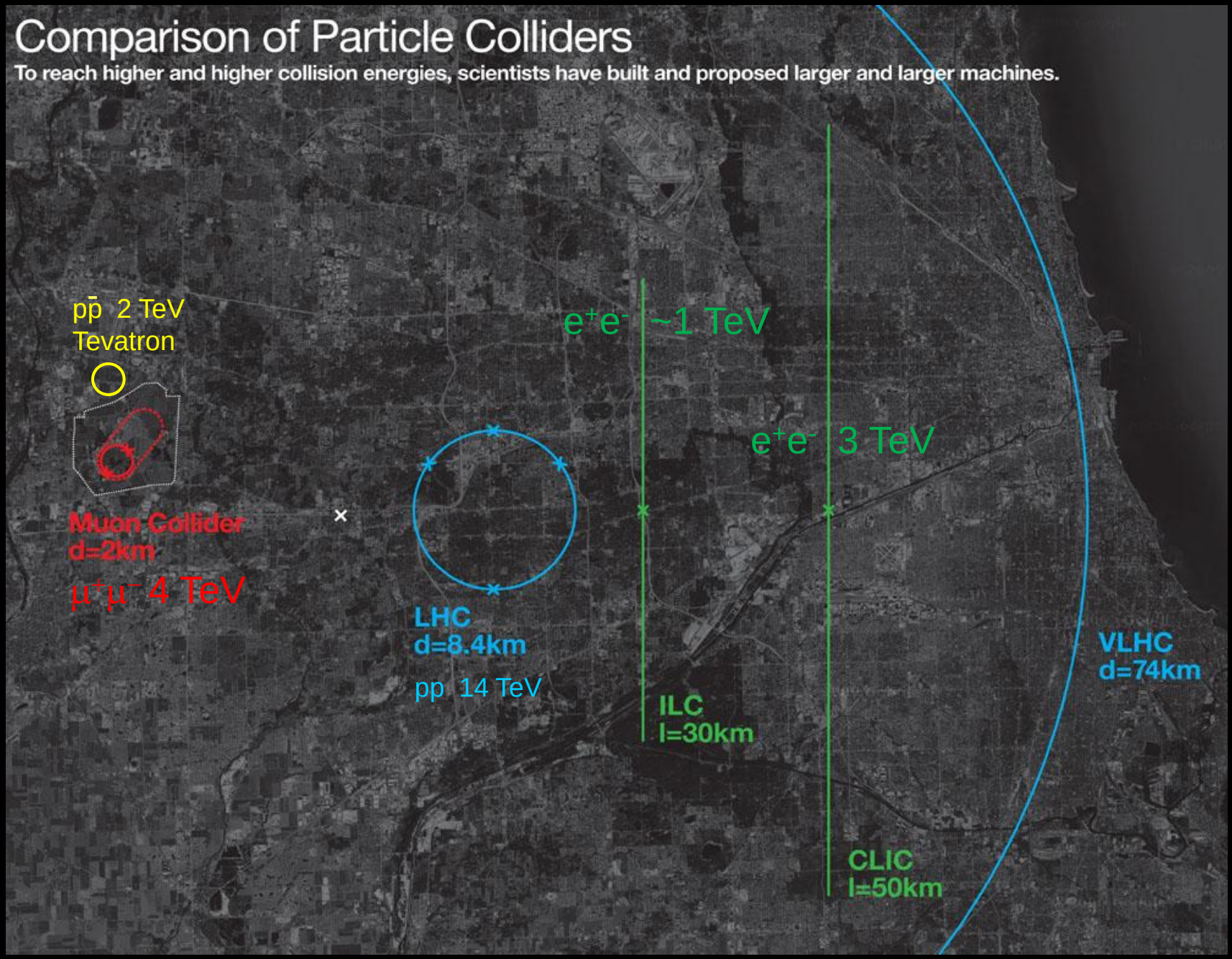
0.5 – 1 TeV Linear Collider

4 TeV Muon Collider
(Neutrino Factory)

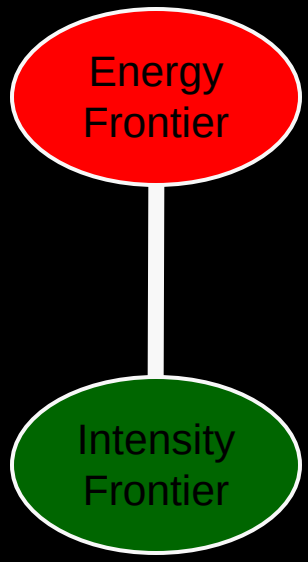




Superconducting RF Technology for
Project X, ILC, Muon Collider, Neutrino Factory


Comparison of Particle Colliders
To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.
p$\bar{p}$ 2 TeV
Tevatron
Muon Collider
d=2km
$\mu^+\mu^-$ 4 TeV
LHC
d=8.4km
pp 14 TeV
e^+e^- ~1 TeV
ILC
l=30km
e^+e^- 3 TeV
CLIC
l=50km
VLHC
d=74km

Fermilab/US Strategy



Detector Synergy:
ILC/CLIC/μ Collider

Tevatron (LHC) ILC / μ Collider

protons

technology injector

NuMI (300kW) → NuMI (700kW) → **Project X** injector → ν Factory

Booster

2 MW (120GeV) for ν
+ 2MW(3GeV) + 200kW(8GeV)

MINOS NOvA 1300km baseline ν
MiniBooNE MicroBooNE WC / LAr
MINERvA MINERvA (+Proton Decay,..)
(SciBooNE) Mu2e Mu2e II
(ArgoNeuT) (μ g-2) μ g-2 II
(K⁺) K^0/K_L, K^+ II
EDM, μ, Λ, Σ^+ II
Nuclear Physics
....

time →

Cosmic Frontier: Dark Matter Searches – Now

CDMS (4 kg)
Low temp. Ge / Si crystals

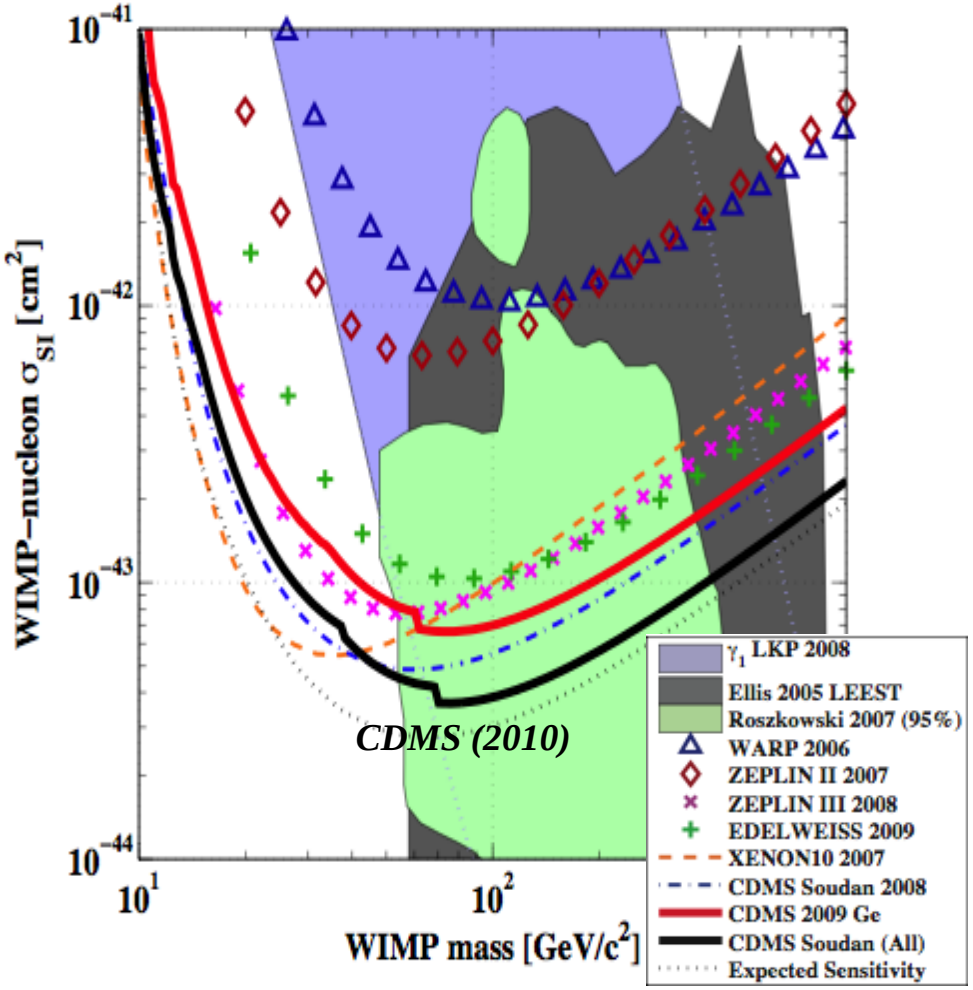
MINOS Far Det
(Soudan Mine)

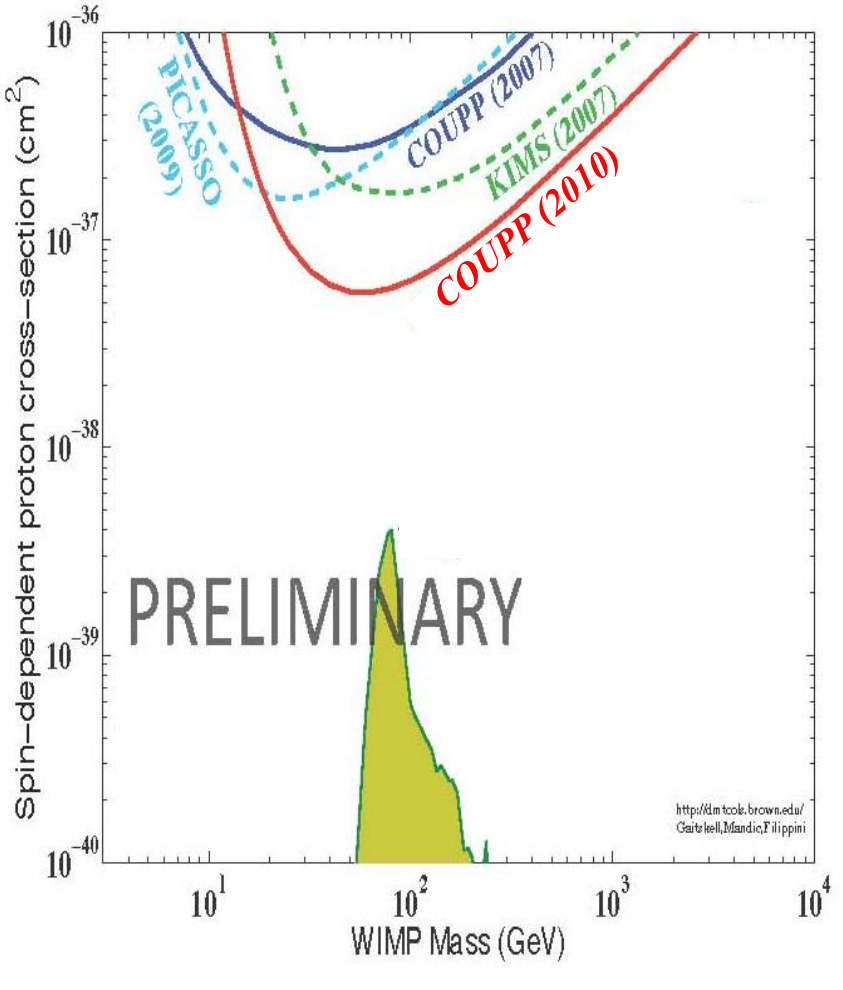
Lead, SD

MINOS
Near Det

COUPP (2 kg / 1 liter)
Room temp CF_3I Bubble Chamber

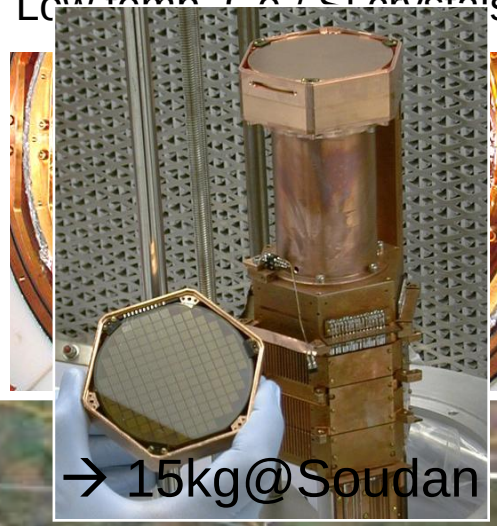
Cosmic Frontier: Dark Matter Searches - Now





Cosmic Frontier: Dark Matter Searches – Future

CDMS (4 kg)
Low temp. Ge / Si crystals



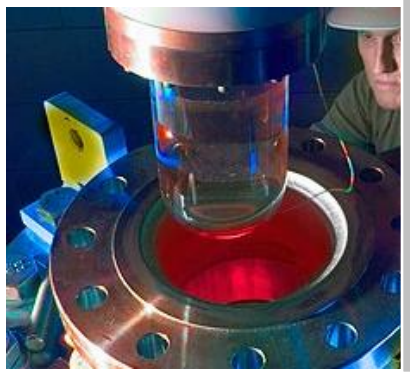
→ 15kg@Soudan

→ 100kg @SNOLAB

MINOS Far Det
(Soudan Mine)

~1ton@DUSEL
Technology:
CDMS,
COUPP,
or Dark Side

COUPP (2 kg
Room temp CF_3I Bub



→ 60kg@SNO

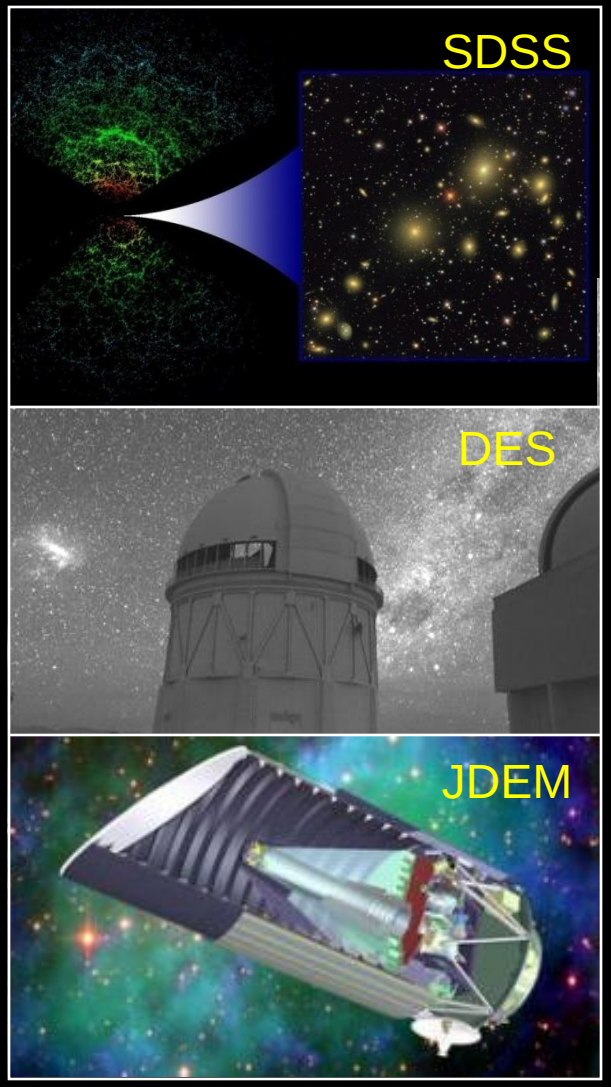
Dark Side:
Depleted Argon Cryogenic
Scintillation and Ionization

Cosmic Frontier: Probing Dark Energy

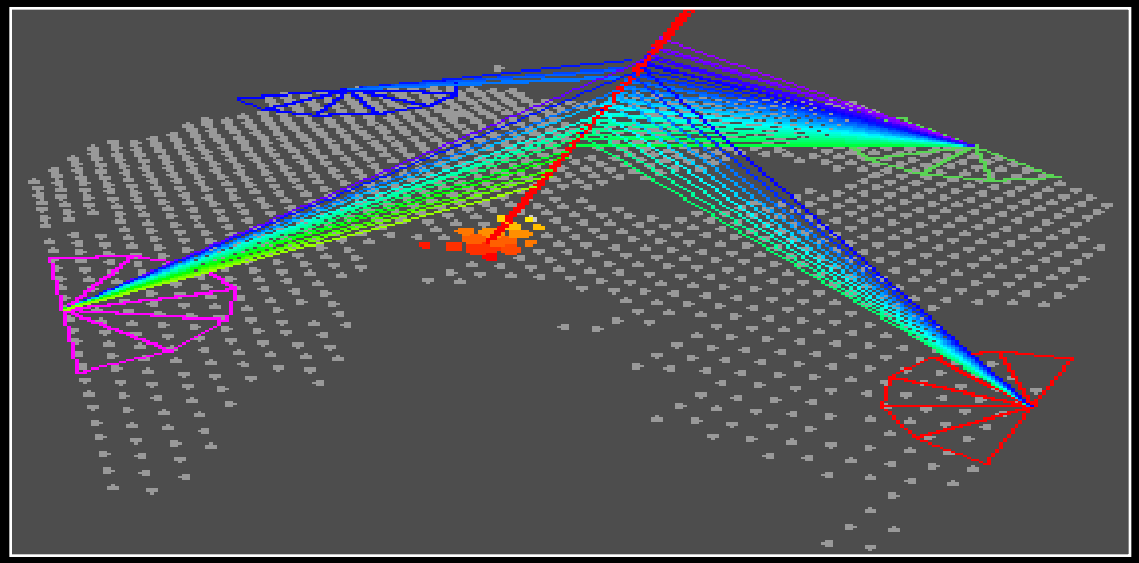
1. SDSS (Sloan Digital Sky Survey)
   - 2.5 meter telescope in New Mexico
   - Ranks as the facility with the highest impact in astronomy for the 3rd year in a row.
   - Power spectrum of galaxies constrain dark energy density parameter.

2. DES (Dark Energy Survey)
   - 4 meter telescope in Chile
   - DES Camera under construction
   - Operation: 2011 – 2016

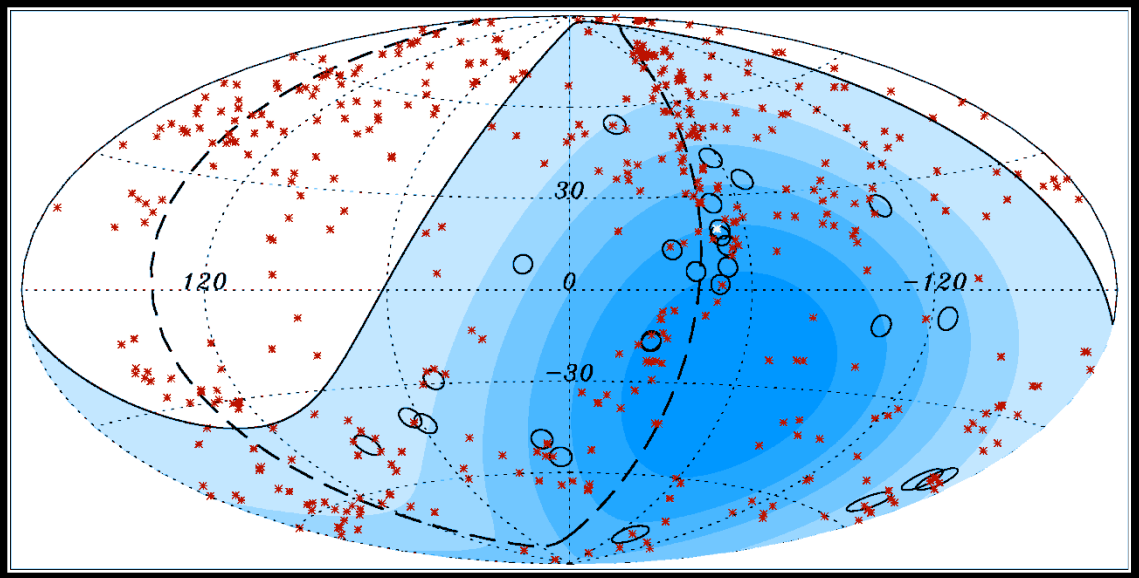
3. JDEM (Joint Dark Energy Mission)
   - Space telescope
   - Fermilab Goal: Science Operation Center



Cosmic Frontier: High Energy Particles from Space



Auger Observatory studies ultra-high energy cosmic rays.



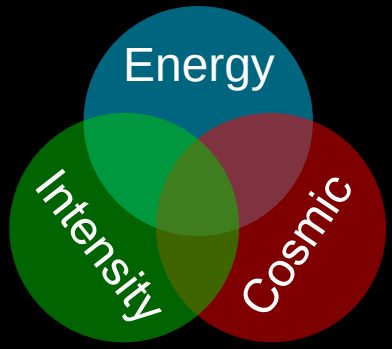
o – Cosmic rays with E > 57,000,000 TeV

Correlation

x – Active Galactic Nuclei

Closing Remarks

- Compelling Questions in Particle Physics
  - Require three interrelated frontiers
    - The Energy Frontier
    - The Intensity Frontier
    - The Cosmic Frontier



- Fermilab
  - a balanced program at the three interrelated frontiers
  - Project X (intense proton source)
    - Intensity Frontier Facility (broad physics program)
    - A path back to the Energy Frontier
      - ILC technology
      - Front end of a muon collider (and/or ν factory), Acceleration technology for a muon collider