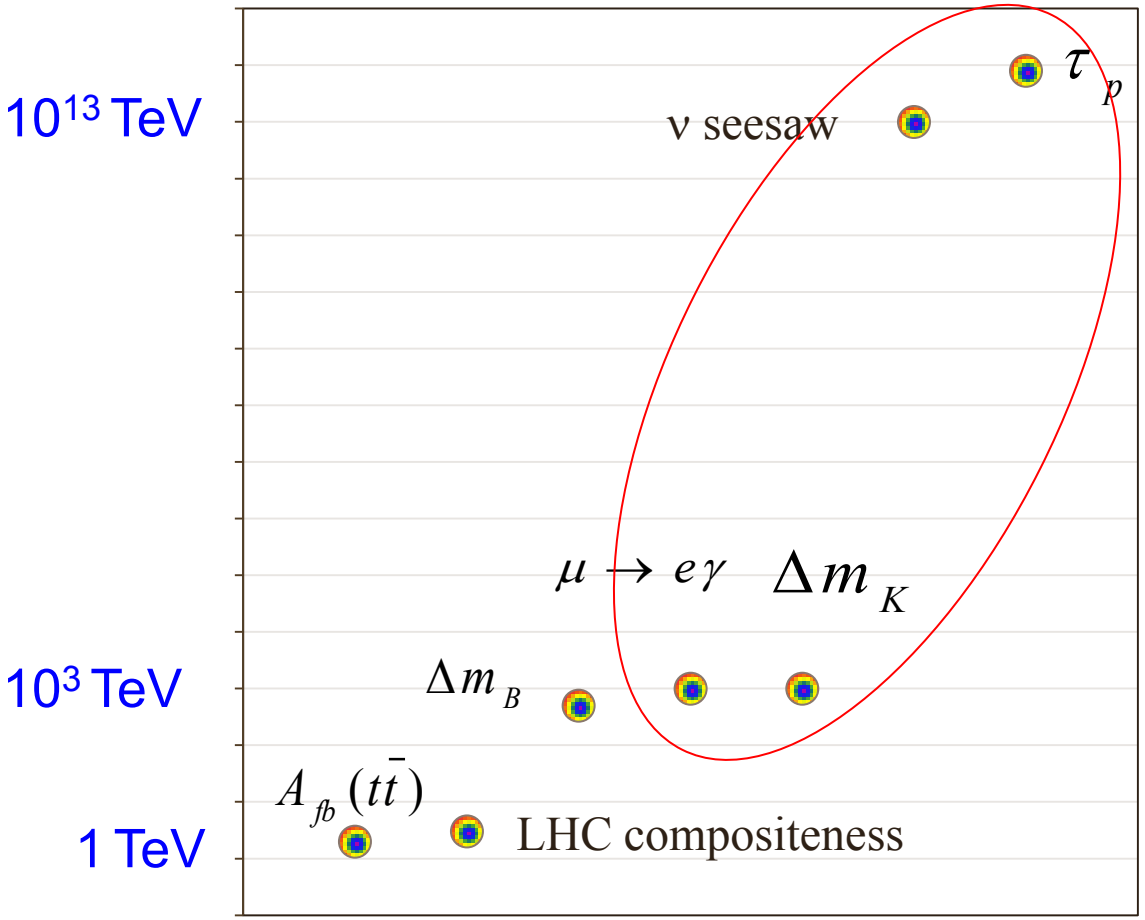
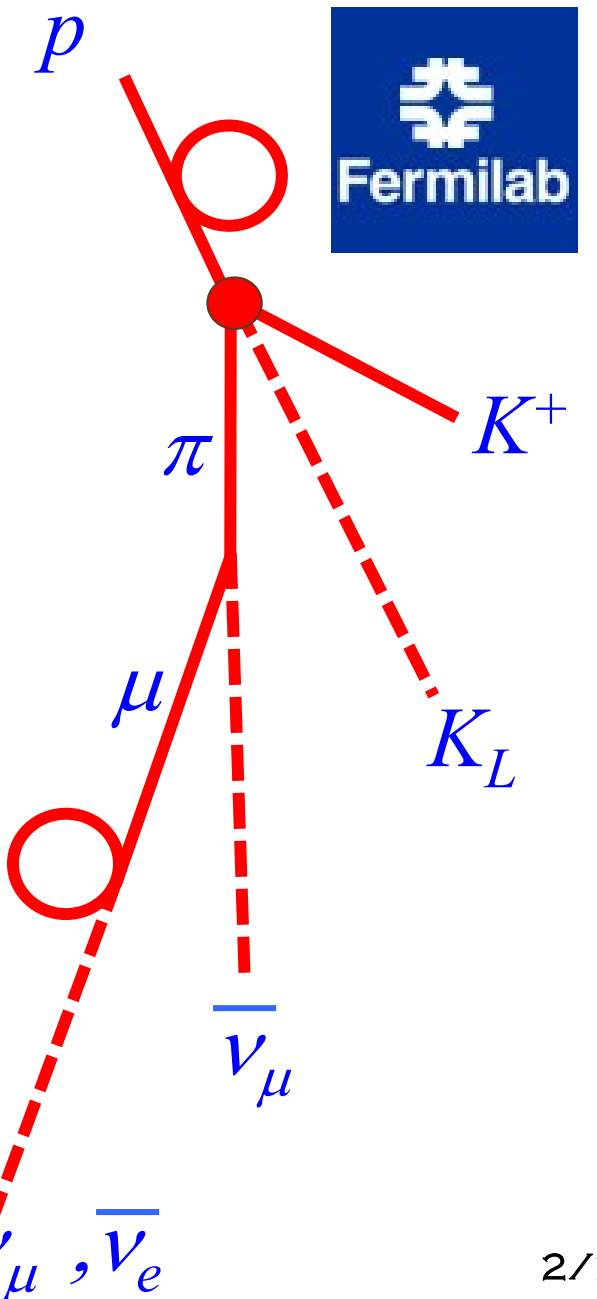
Brendan Casey , Fermilab, FPCP2011

Future Fermilab Flavor Physics Program

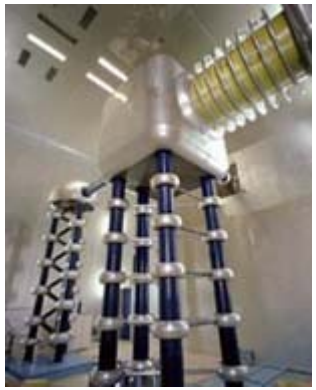
Probing the highest energies

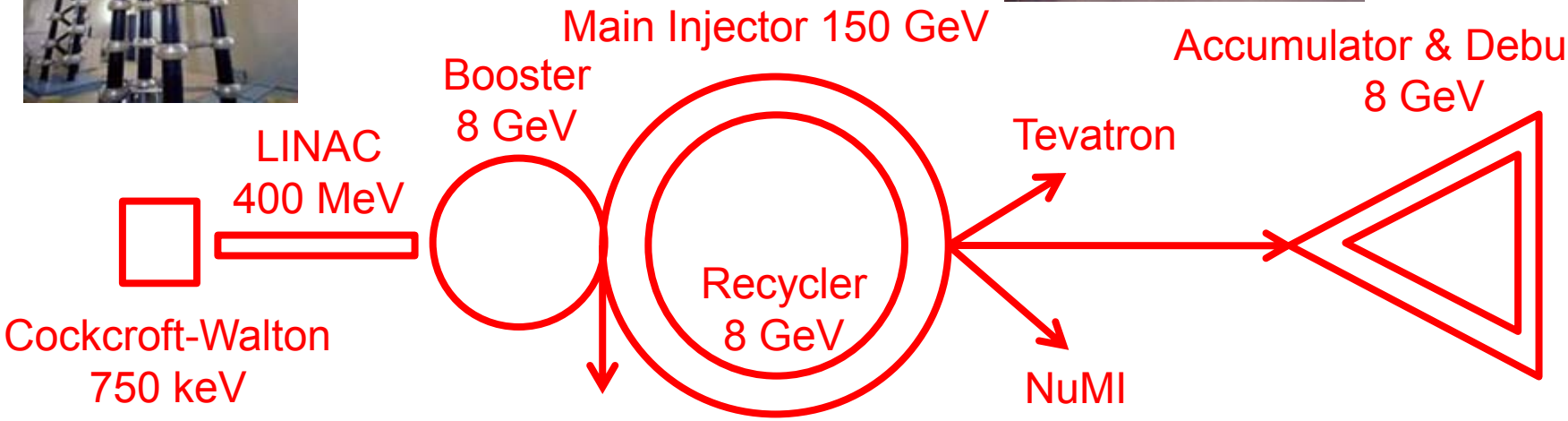
New Physics Energy Scale, Λ_{NP}





Current Rings/Accelerators

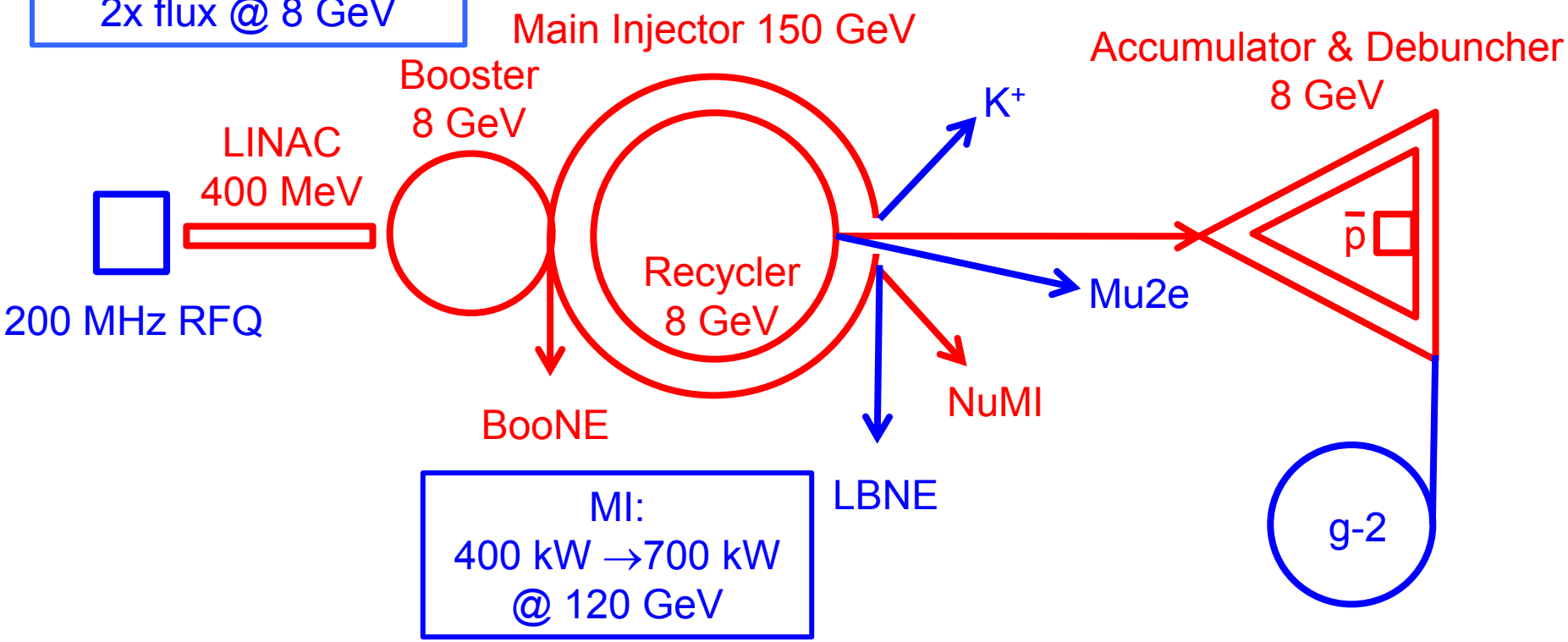




Upgrades for experiments this decade

Major proton source accelerator improvement project for increased beam power and reliability for next 15 years of operation

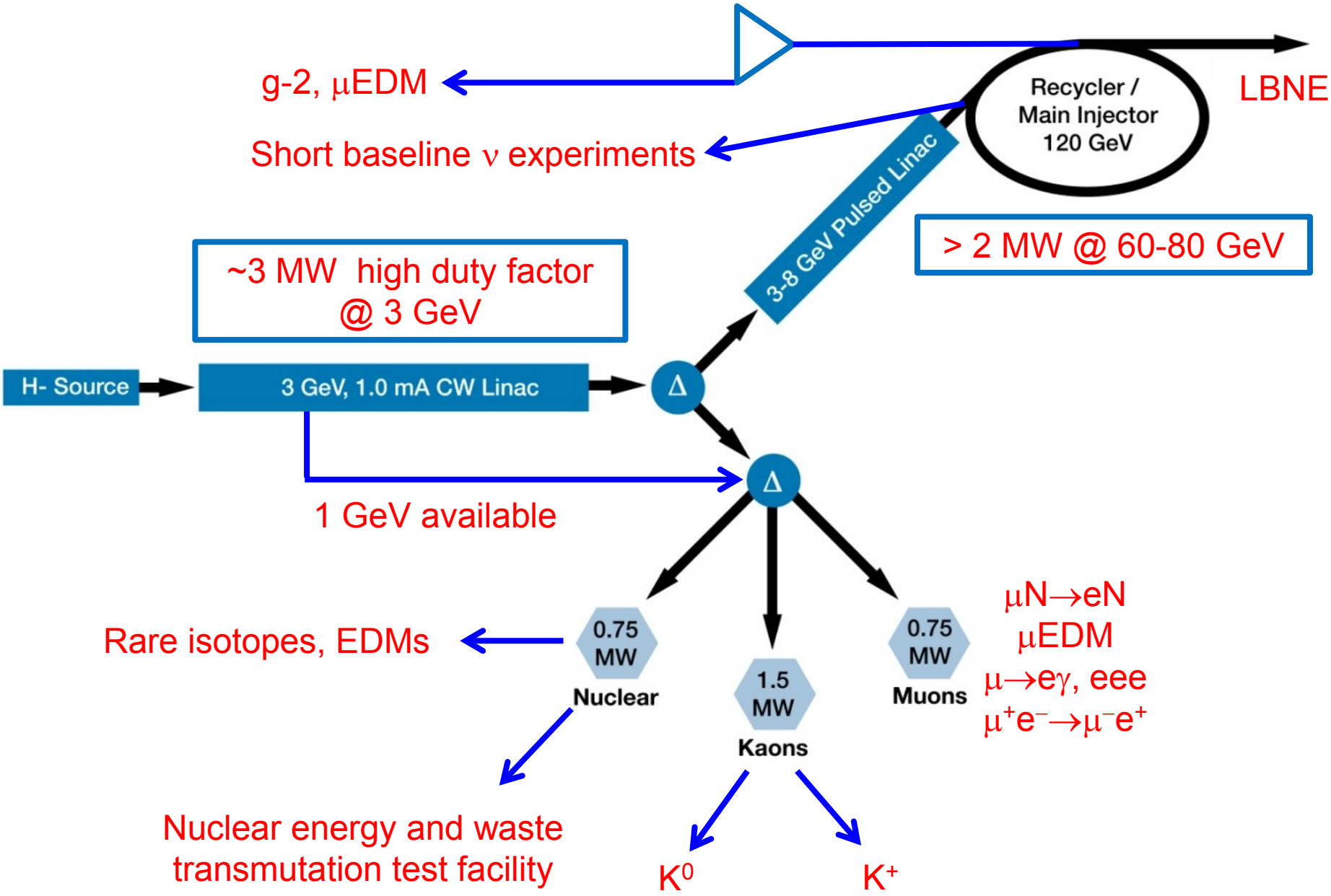
Booster:
7 Hz → 15 Hz
2x flux @ 8 GeV



MI:
400 kW →700 kW
@ 120 GeV

Next generation muon, Kaon, and neutrino experiments

Upgrades for Experiments next decade



Neutrino Beamlines

Fermilab

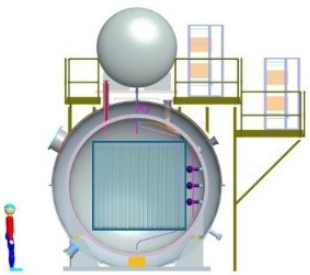
ν factory
???
+
upgrades

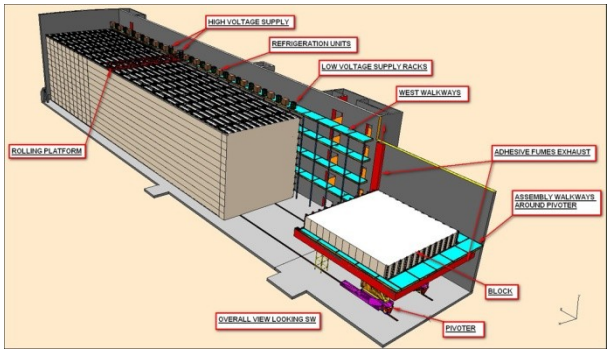
Local
MiniBooNE
MicroBooNE
MINERvA
SBNE

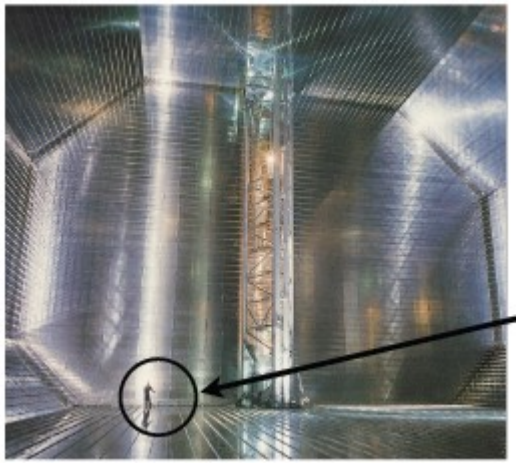
South Dakota
wide band
1300k
LBNE
+
upgrades

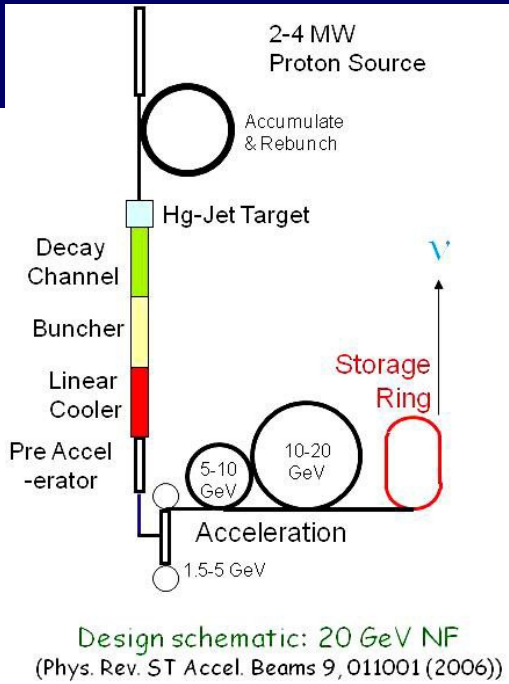
Minnesota
on axis
735 km
MINOS
+
upgrades

Minnesota
off axis
810km
NOvA
+
upgrades







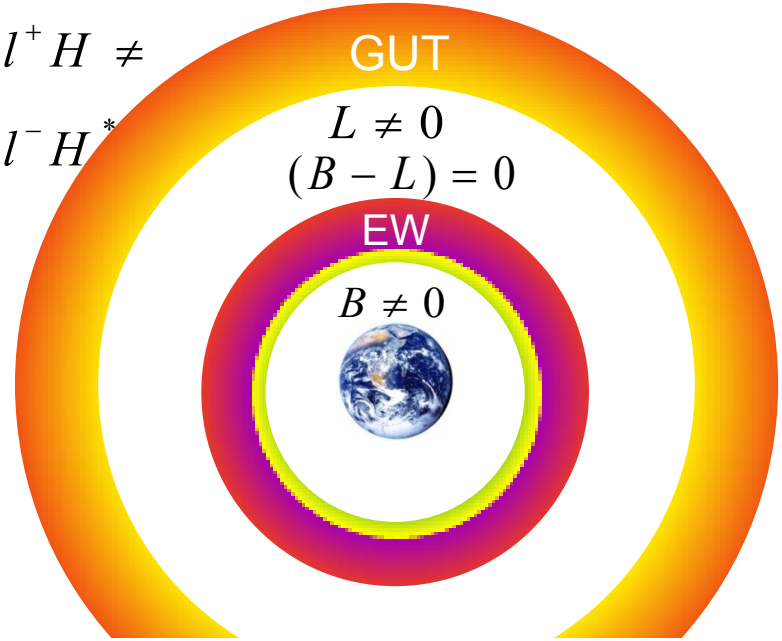


Design schematic: 20 GeV NF
(Phys. Rev. ST Accel. Beams 9, 011001 (2006))

Leptogenesis

- "Archeological evidence:"
  Murayama hep-ph/0208005
  - No electroweak baryogenesis
  - CPV in light, left ν
  - Lepton number violation
- What info do we need to do these experiments?

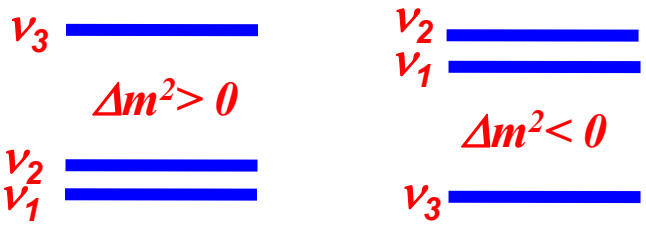
$$N_R \rightarrow l^+ H \neq$$
$$N_R \rightarrow l^- H^*$$

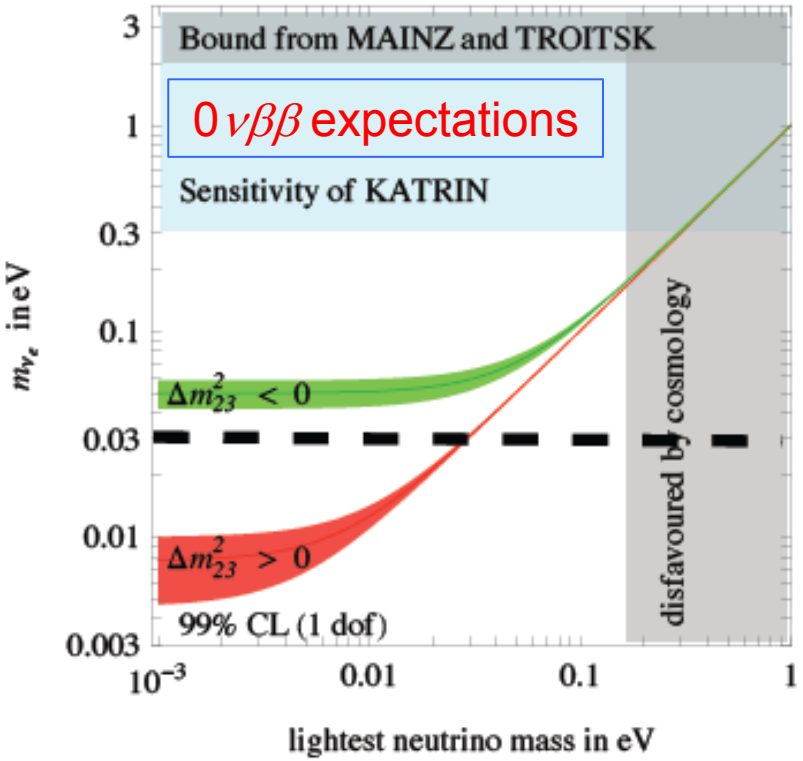


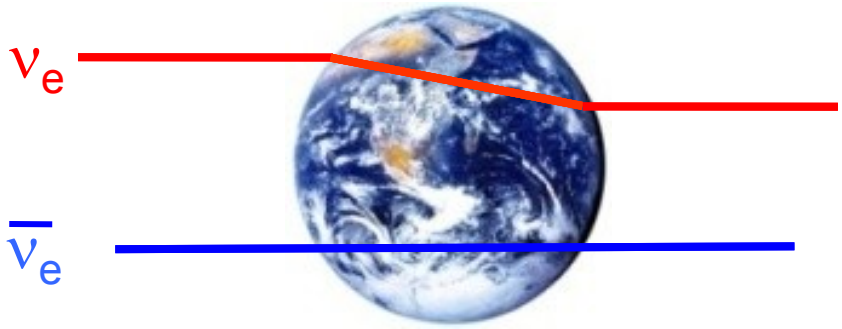
Need to know θ_{13}

$$\text{PMN} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix}$$

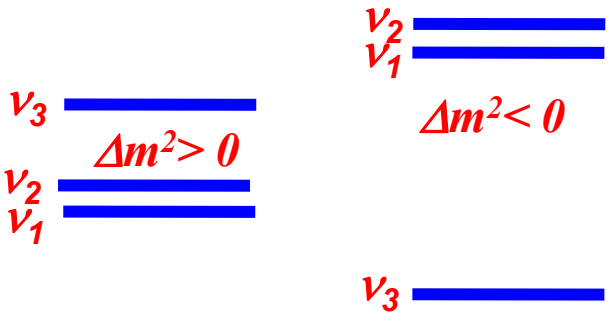
Need to know mass hierarchy



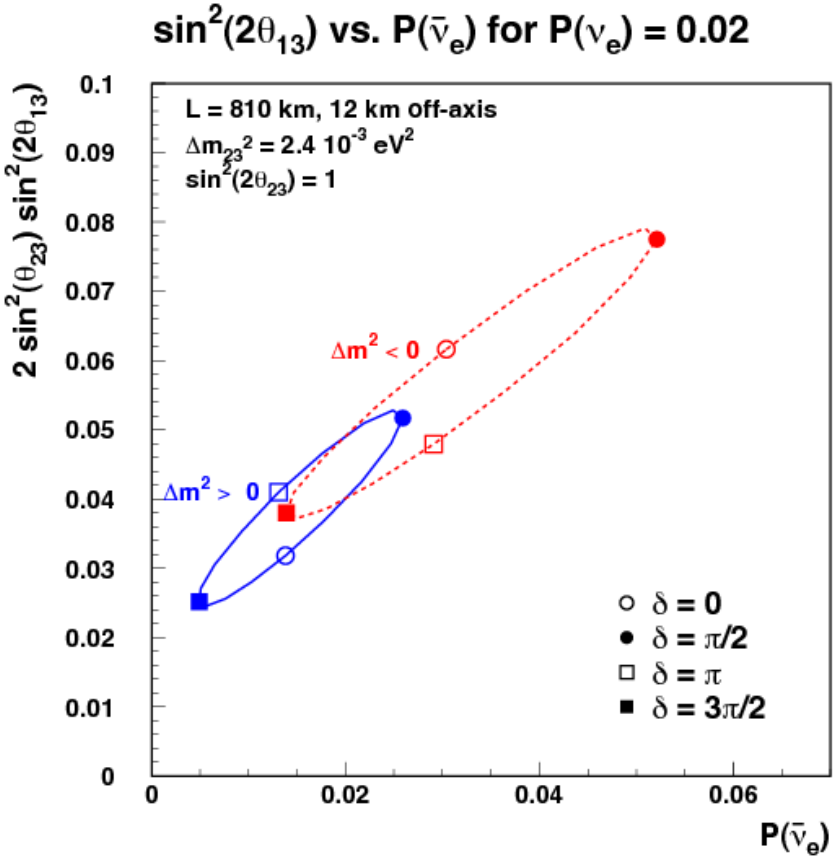


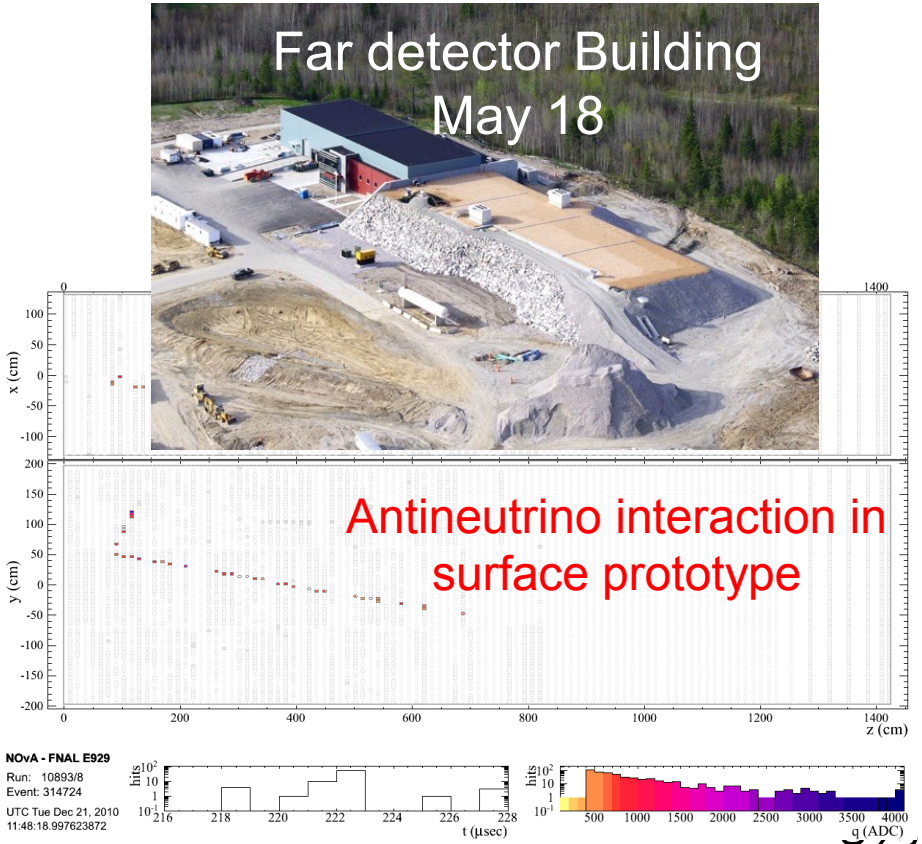


Effective mass



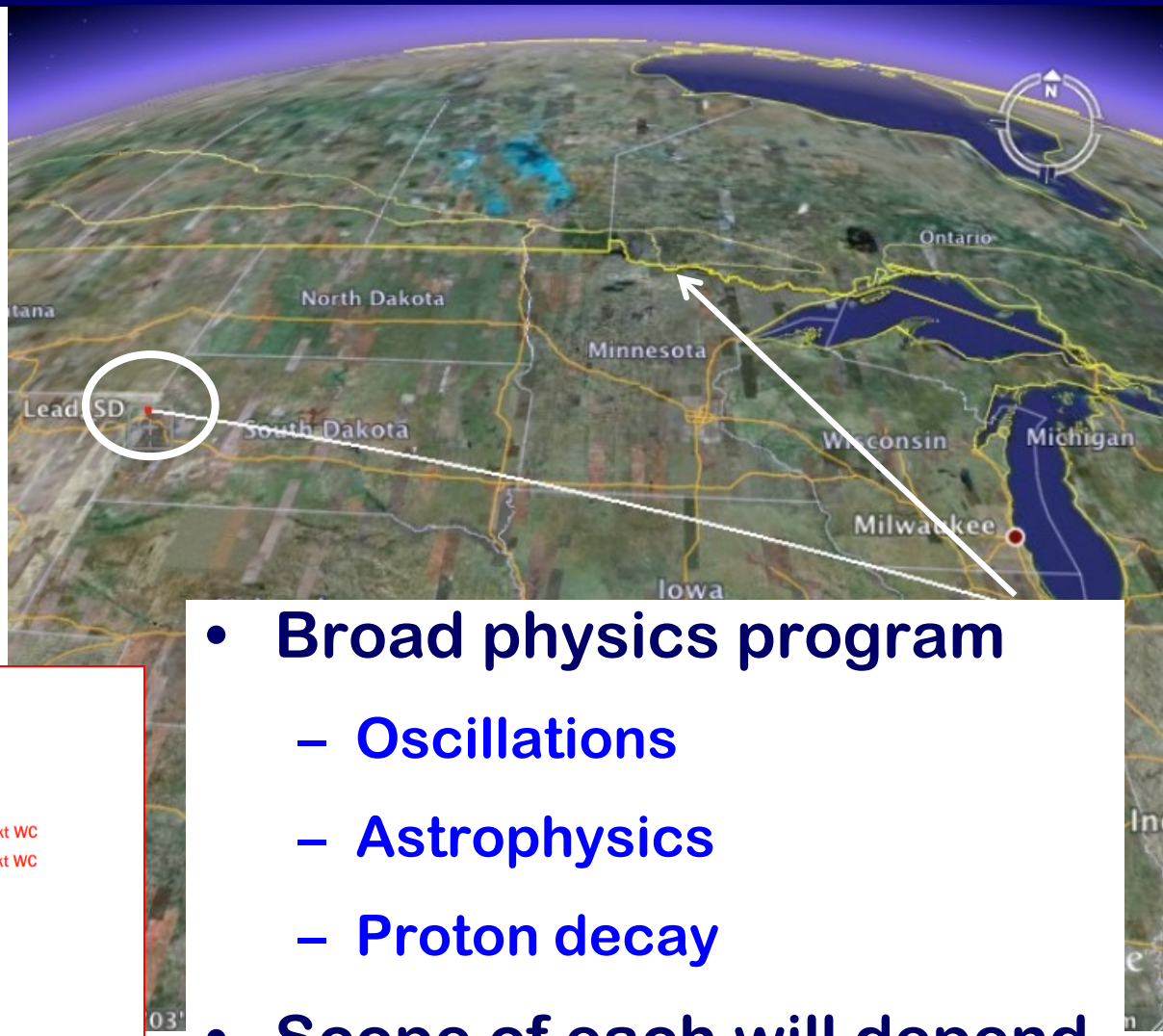
Oscillation frequency increases or decreases depending on hierarchy



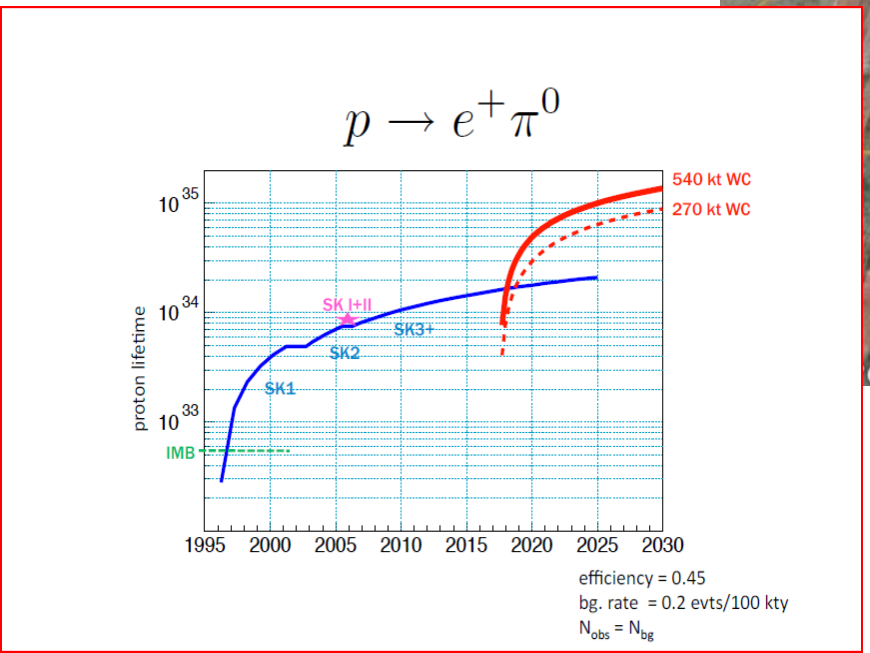


LBNE

- Longer baseline
  - 810→1300km
- Larger detector
  - 2 x 100 kt Water
  - 2 x 17 kt Liquid Ar
- Next generation θ_{13}, CPV experiments

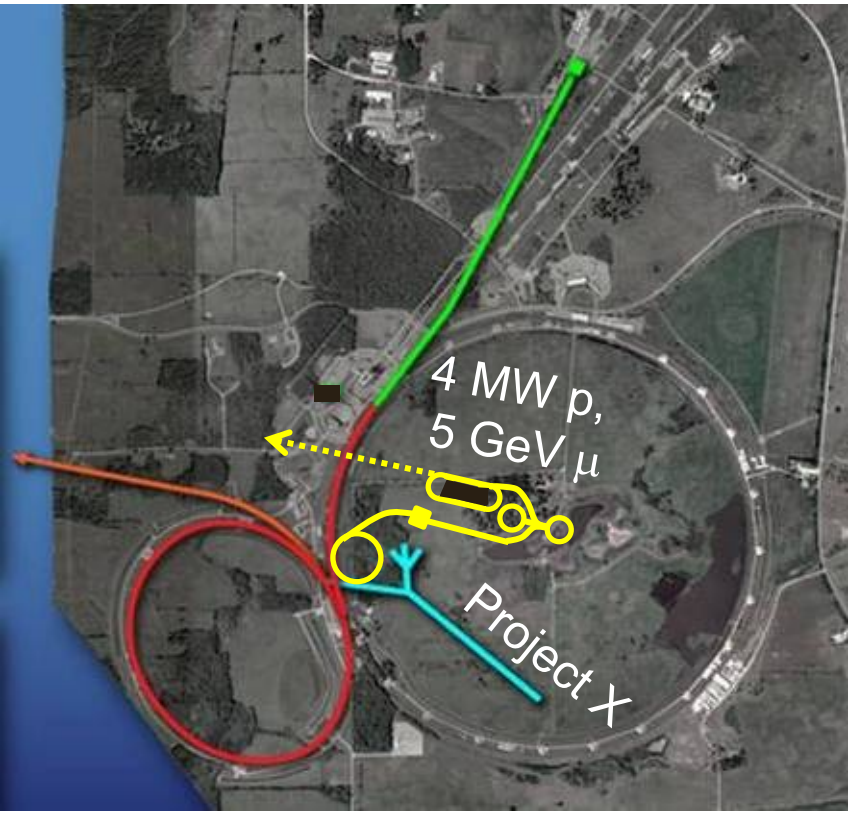


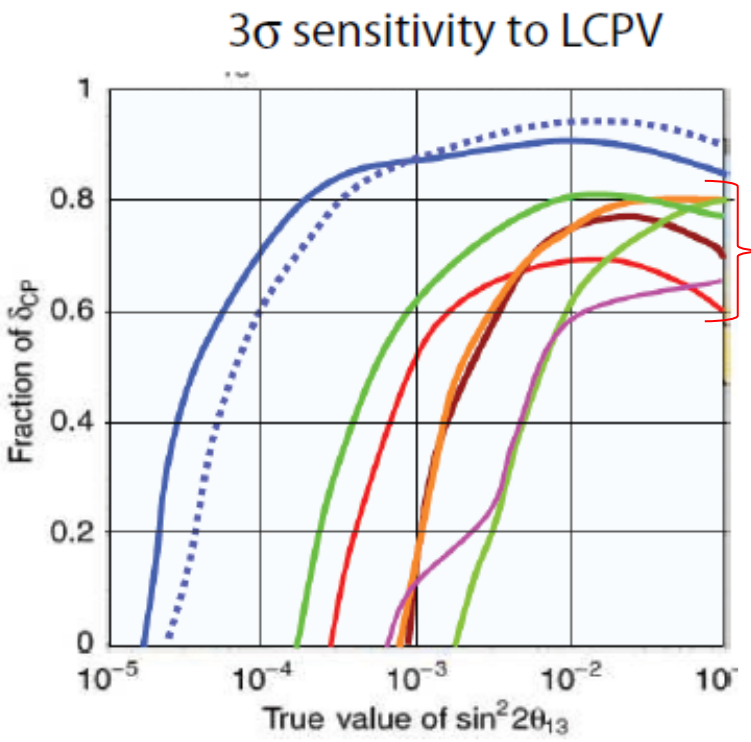
- Broad physics program
  - Oscillations
  - Astrophysics
  - Proton decay
- Scope of each will depend on detector choice

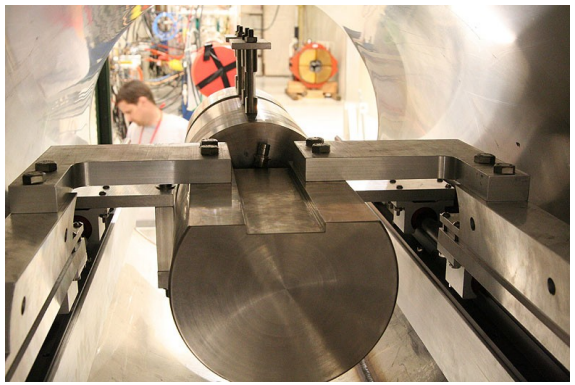


ν-FACTORY

Ultimate and perhaps necessary reach comes from muon storage ring





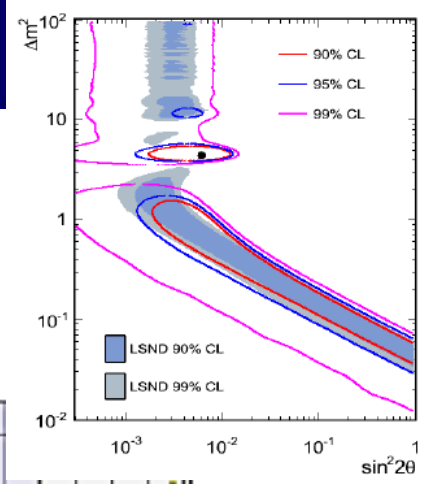


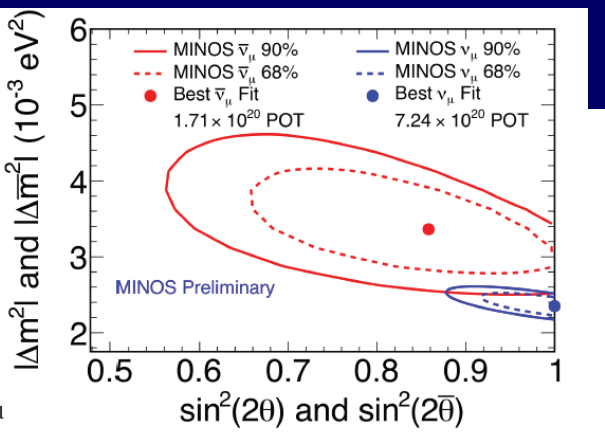
MuCool test area at Fermilab First beam delivered Feb 2011

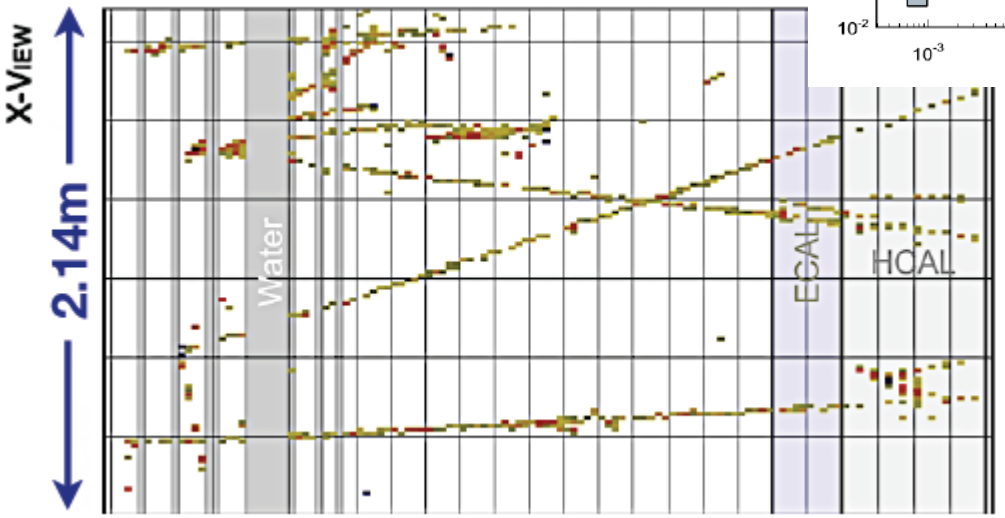
Muon acceleration program (MAP) formed to unify US funded R&D and prove feasibility of muon collider in the next few years

And much more

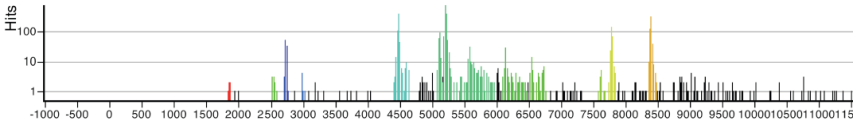
Address anomalies with MicroBooNE, MINOS+



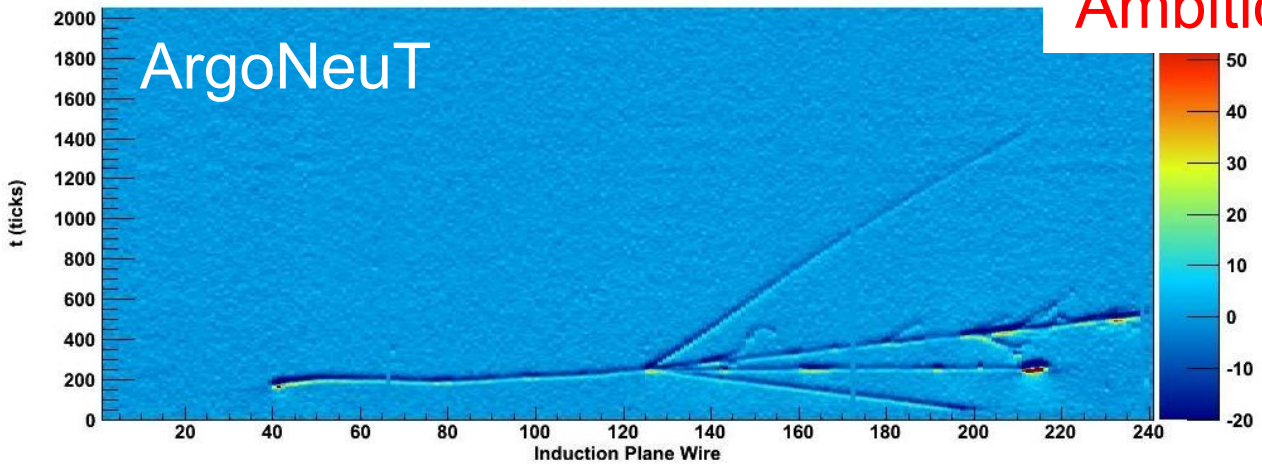


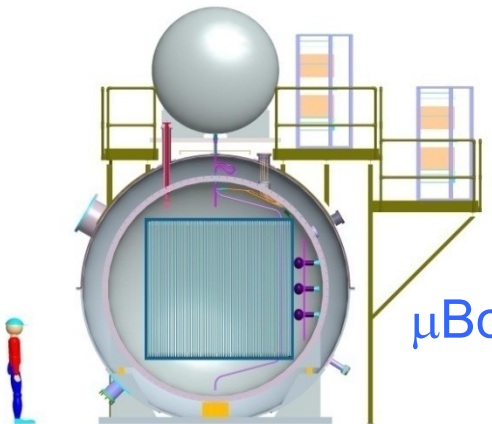


Precision cross section measurements with MINERvA



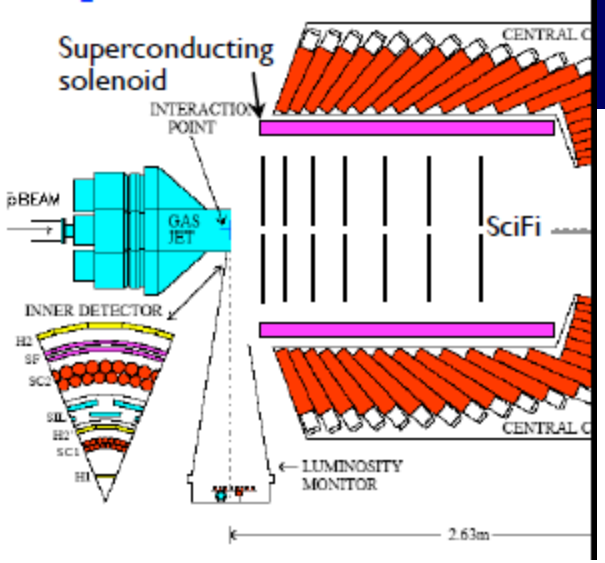
Ambitious LAr R&D program



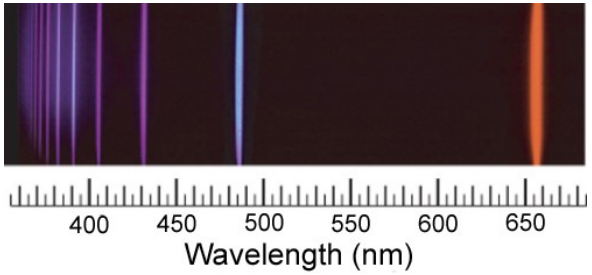


Antiprotons

World's greatest antimatter factory



Charm, hyperon, exotics



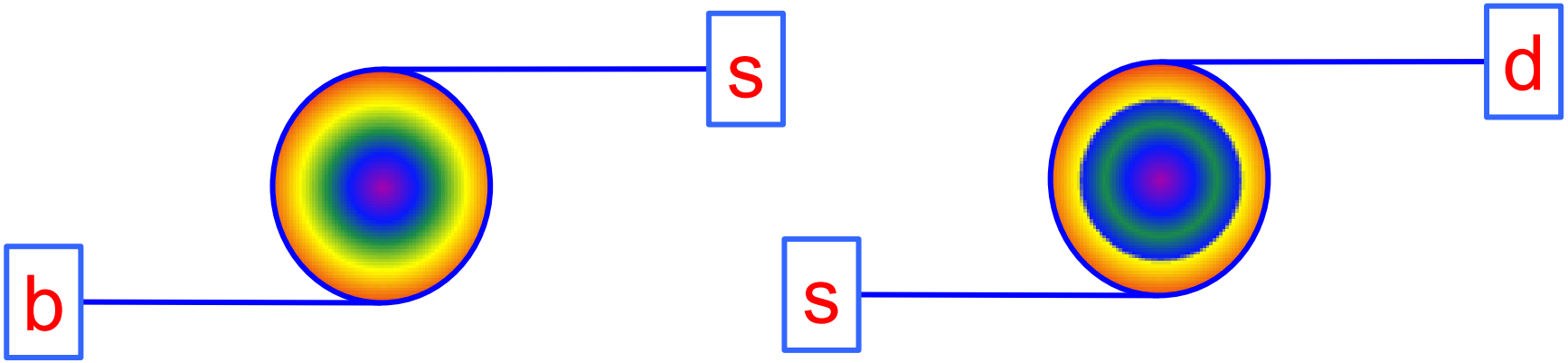
Anti Hydrogen

Anti Gravity

Will be repurposed for muon production but there is still interesting physics that may be unique to this facility

Kaons

Same motivation for FCNC B and K programs



Difference is the size of the SM 'background'

B mesons: $V_{ts} \approx \lambda^2$ *or* $V_{td} \approx \lambda^3$ *or* $V_{ub} \approx \lambda^3$

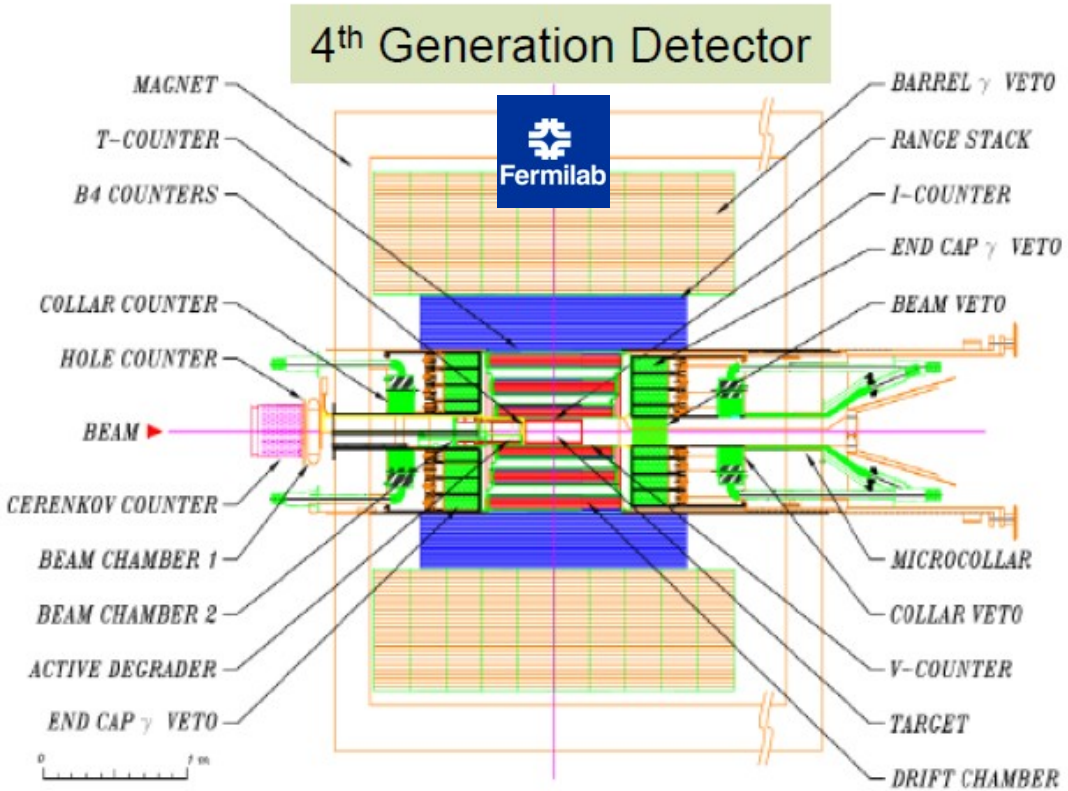
Kaons: $V_{ts}^* V_{td} \approx \lambda^5$

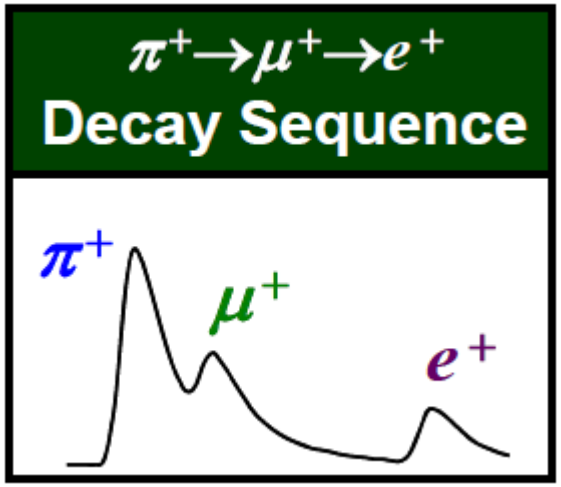
$$b \to s\gamma : 3 \times 10^{-4} \qquad K^+ \to \pi^+ \nu\bar{\nu} : 7.8 \times 10^{-11}$$

$$B_s \to \mu\mu : 3 \times 10^{-9} \qquad K^0 \to \pi^0 \nu\bar{\nu} : 2.4 \times 10^{-11}$$

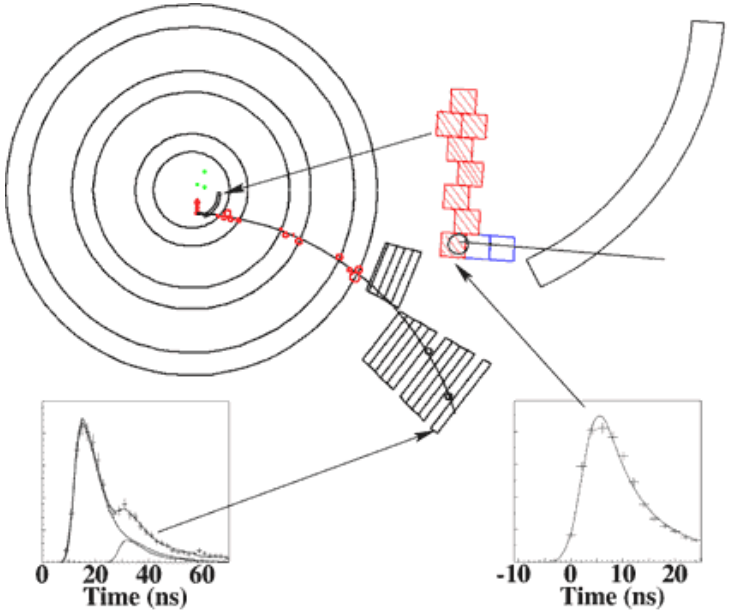
Generic couplings: Kaons win, flavor specific: need both

1st 2nd 3rd generation at BNL
= 7 event data sample





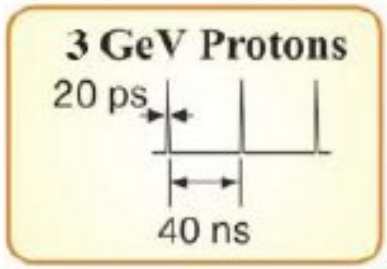
BNL E787 event display



Can get hundreds of evts per year starting with beam from Main Injector and continuing with Project X

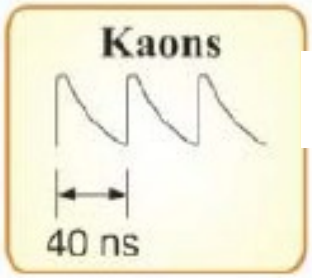
$K^0 \to \pi^0 \nu\nu$

Pico-bunches

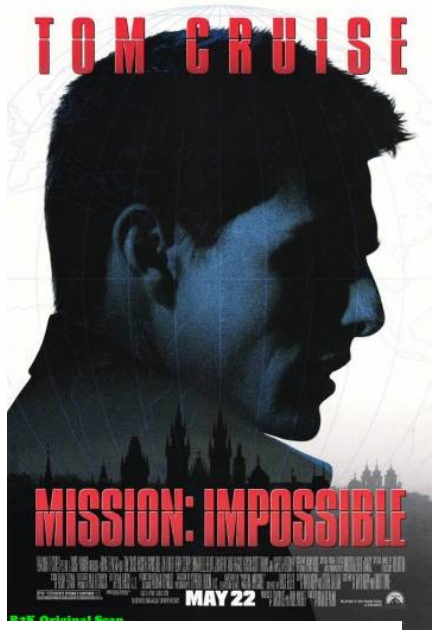


Pointing

Pencil beam K_L^0



Plus a lot more



200 evt/yr possible with Project X

Generic couplings: Kaons win, flavor specific: need both

Other Kaon measurements

$K^+ \to \pi^0 \mu^+ \nu$ (Transverse Polarization -T violation)

$K^+ \to e^+ \nu / K^+ \to \mu^+ \nu$ (Universality, LFV, Pseudoscalars...)

$K^+ \to \mu^+ \nu_H$ (Heavy neutrinos)

$K_L^0 \to \pi^0 ee / \pi^0 \mu\mu$ (CP Violation)

$K_L^0, K^+ \to LFV$ *e.g.* $K_L^0 \to \mu e$

K^0 Interferometry (Plank scale physics)

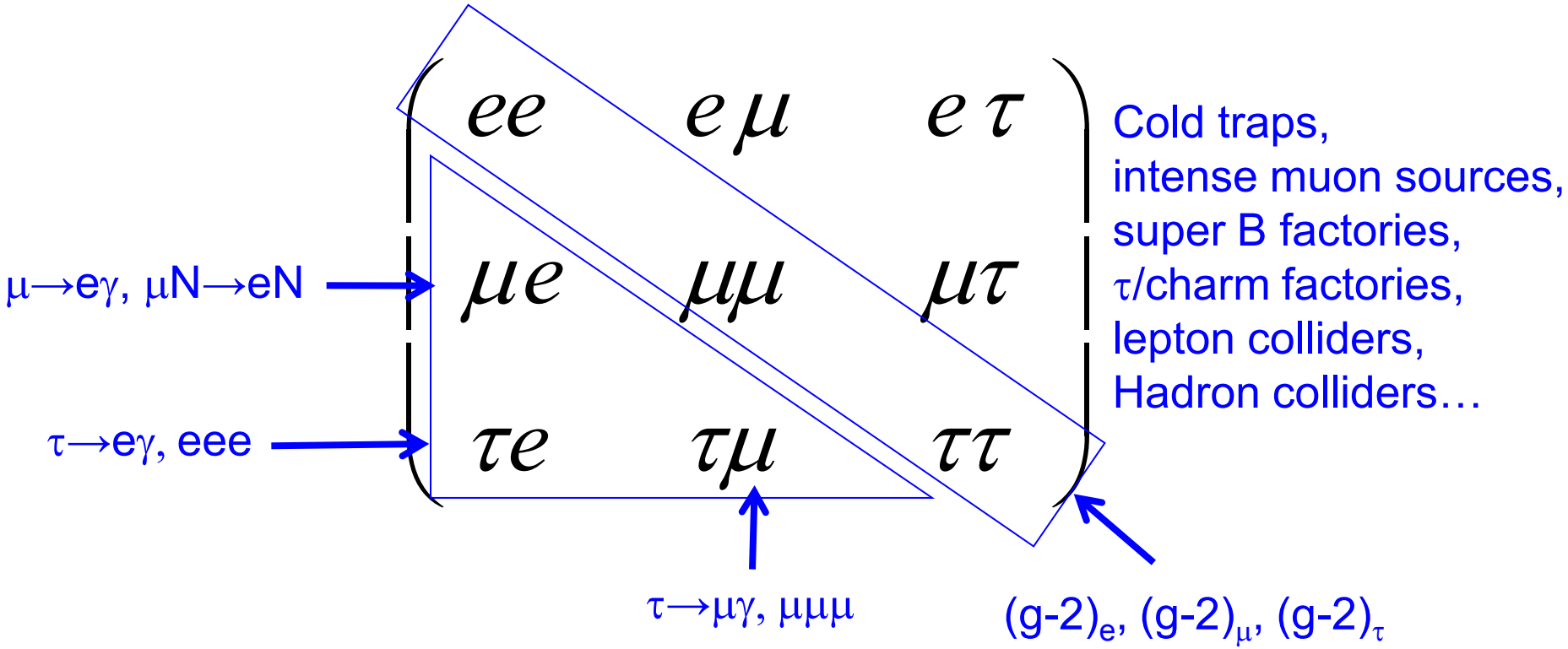
$K \to \pi l \nu$ ... (Universality, Chiral PT)

Enormous data sets + multipurpose detectors = lots of physics

Charged lepton flavor program

An observation of charged lepton flavor violation expected in the next decade implies existence of a new mixing matrix.

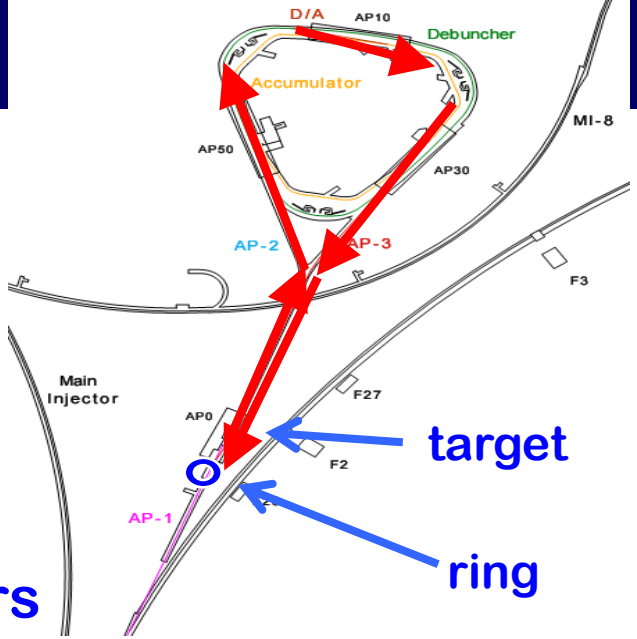
Expect same as quarks, neutrinos: multi-decade program to determine 4 parameters of the matrix



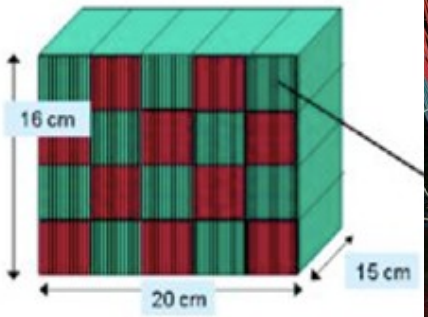
CP violation: lepton EDM measurements

G-2

- Follow up of BNL experiment but better:
  - Reuse the storage ring
  - 10x longer decay channel
  - Segmented calorimeters
  - Tracking
  - >20x statistics, >2x less systematics
- Coupled with a world wide program to interpret the measurement



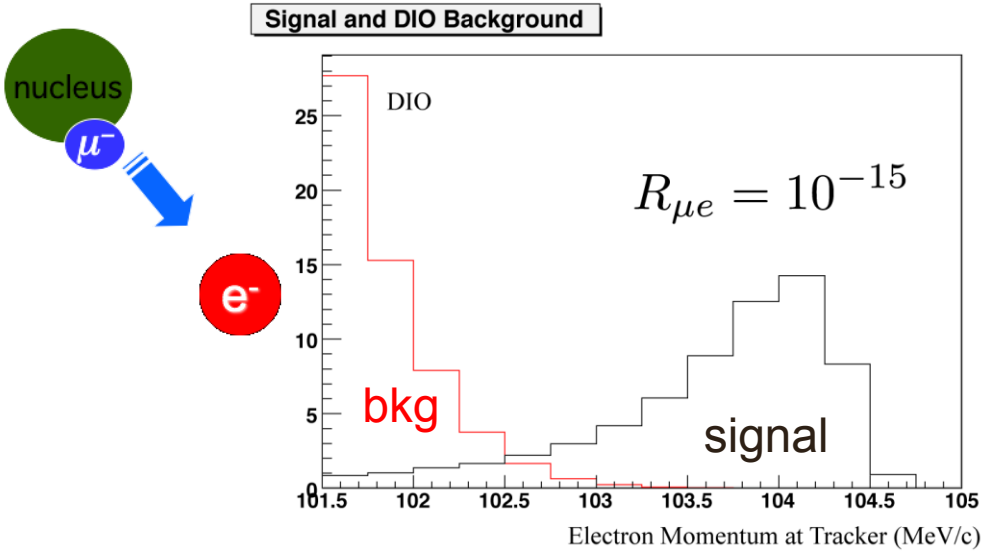
Pbar complex

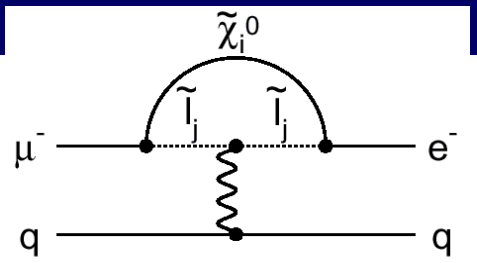


USQCD

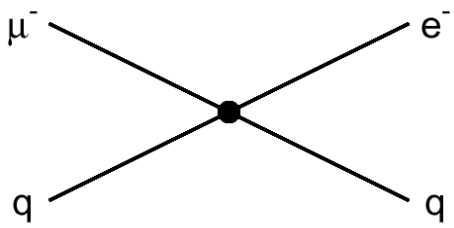
US Lattice Quantum Chromodynamics

Direct conversion of a muon into an electron

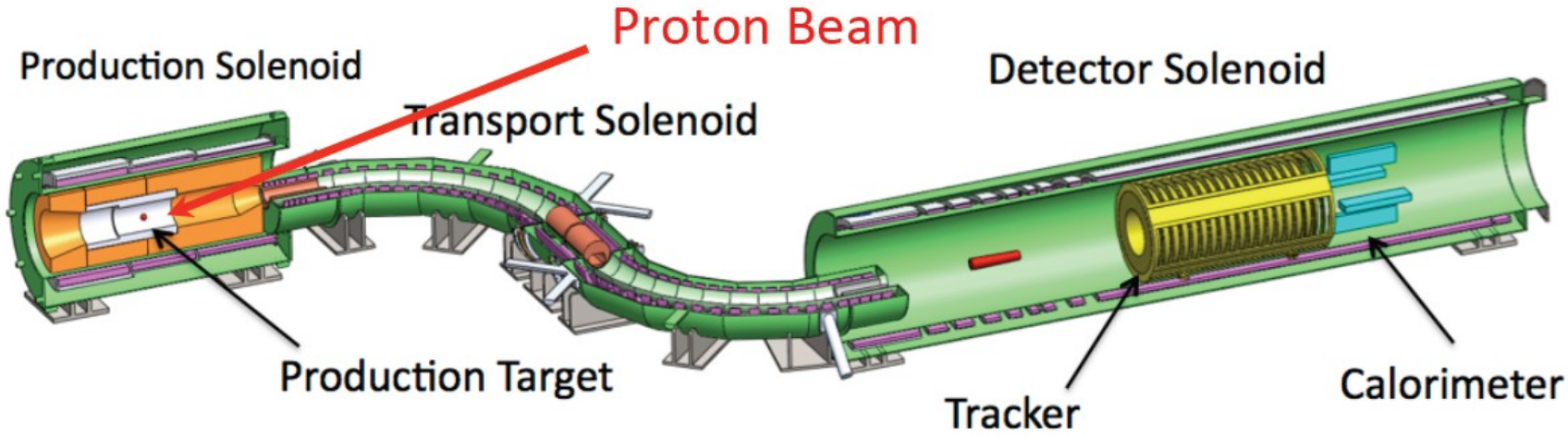




Diagrams in common with $\mu \to e\gamma$



Diagrams not accessible to $\mu \to e\gamma$



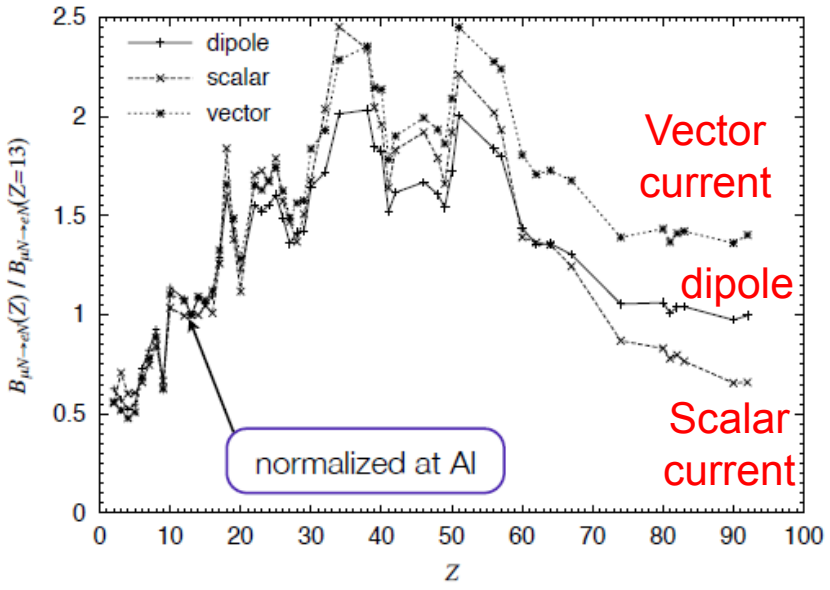
Mu2e goal: 3 x10^{-17} wrt capture (Λ_{NP}~10^4 TeV)

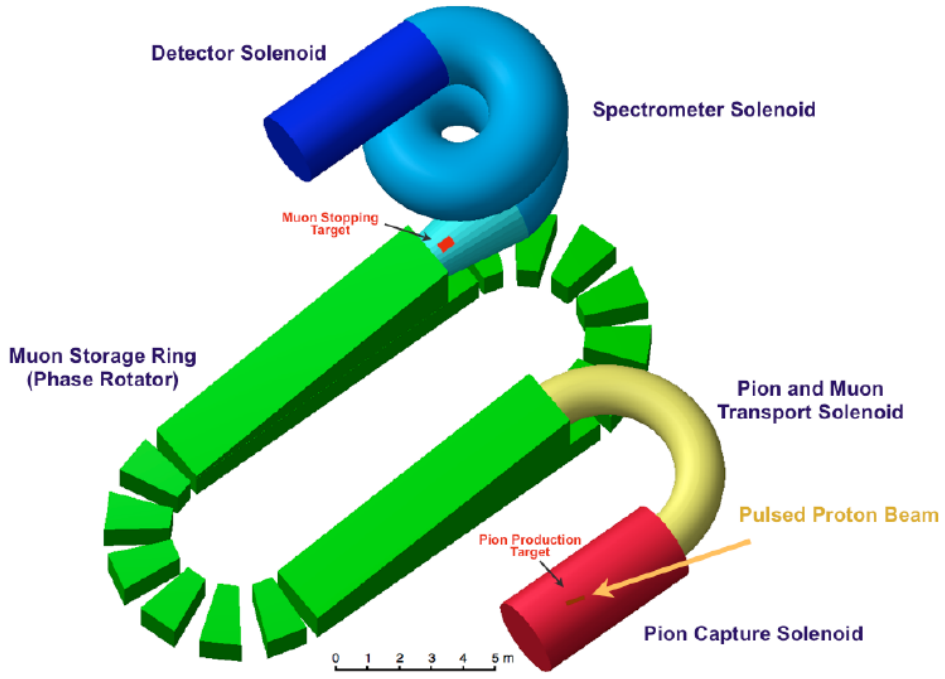
$\mu \rightarrow e$ WITH PROJECT X

Option 1: LFV established → design for precision measurements / properties

Option 2: LFV not established → design for maximum sensitivity
3 x 10^{-19} possible with Project X beam power

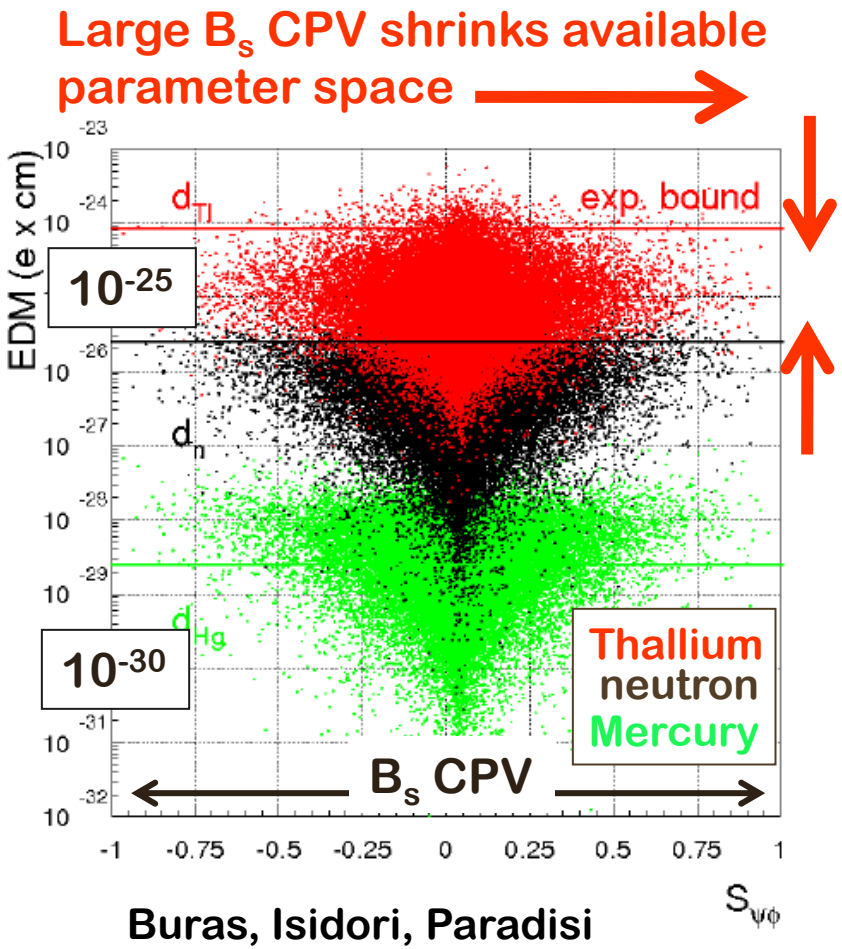
Conversion rate vrs target Z





EDMs

MFV + 1 new phase + Bs CPV = EDM

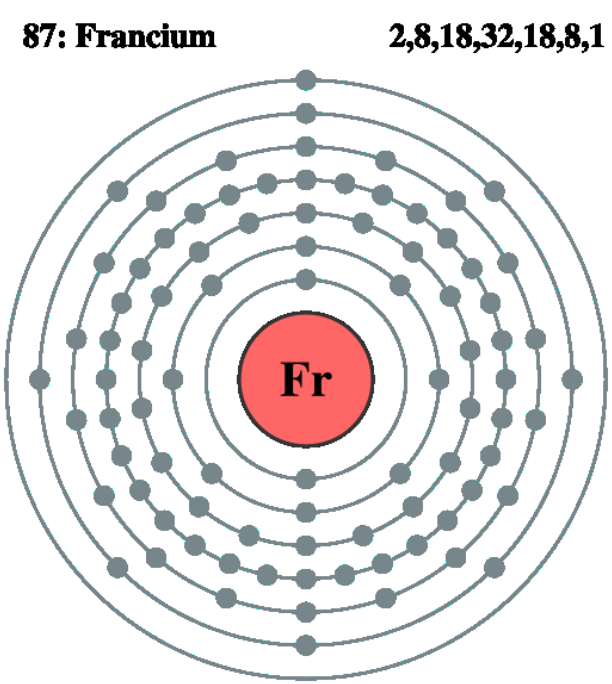


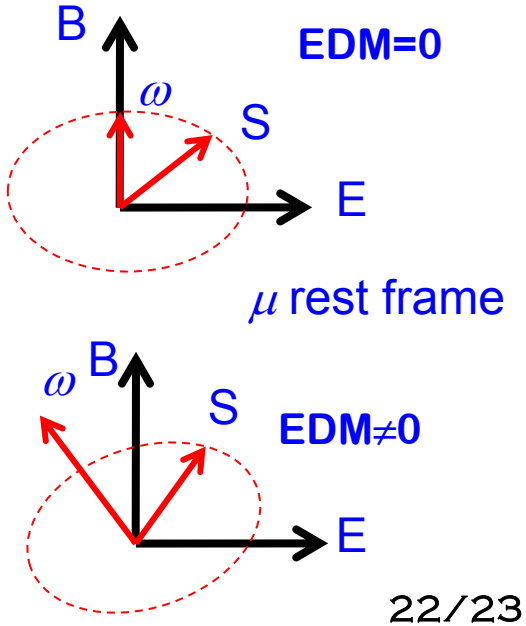
Buras, Isidori, Paradisi
arXiv:1007.5291

EDMs this decade ?!?!

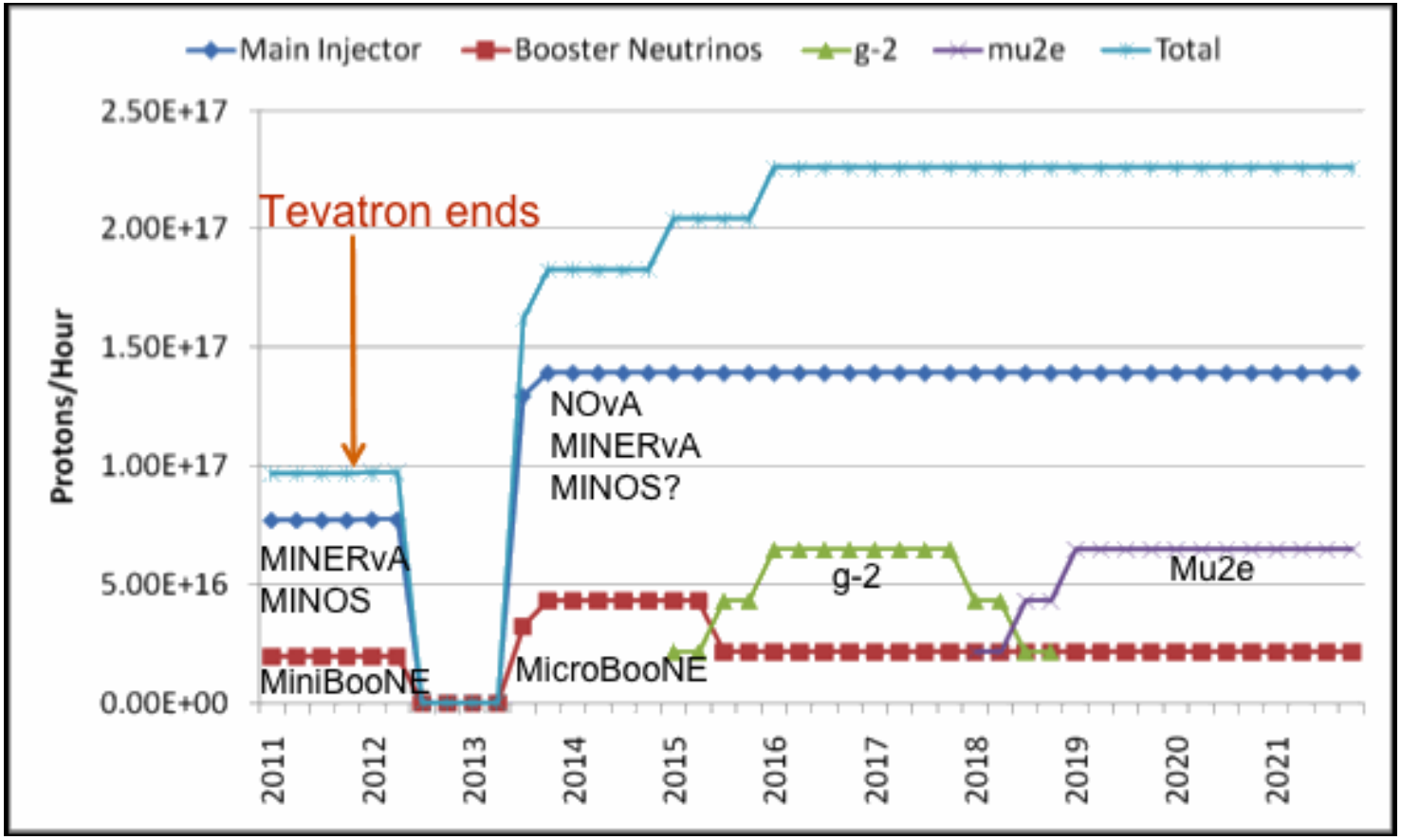
EDMs

- e EDM:
  - Can amplify signal using high Z Alkali metals
    - Outer electron is in s-wave: size of electron becomes size of atom.
    - Factor ~1000 enhancement for Francium
  - Project X nuclear physics facility: copious production of desired heavy isotopes
- μ EDM:
  - EDM tilts precession plane of muons in a storage ring
    - Factor 100 improvement possible with New g-2 experiment
    - Extra factor 10000 possible with dedicated storage ring in Project X muon facility





Near term timeline



Conclusions

- Fermilab is planning a diverse neutrino and targeted rare process program that covers many of the most important low energy observables
- In several cases, Fermilab is the best place to perform these experiments
  - Beam power + duty factor
  - In many, it is the only place to perform these measurements to high precision due to unique features of Project X
- The program will play an integral role in interpreting LHC results, will push the envelope in precision detector technology, and will provide unique opportunities to grad students and post docs.