Rare Processes

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Fermilab Institutional Review
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U.S. DEPARTMENT OF ENERGY

Fermilab

Experiments at overlapping frontiers

Goal:

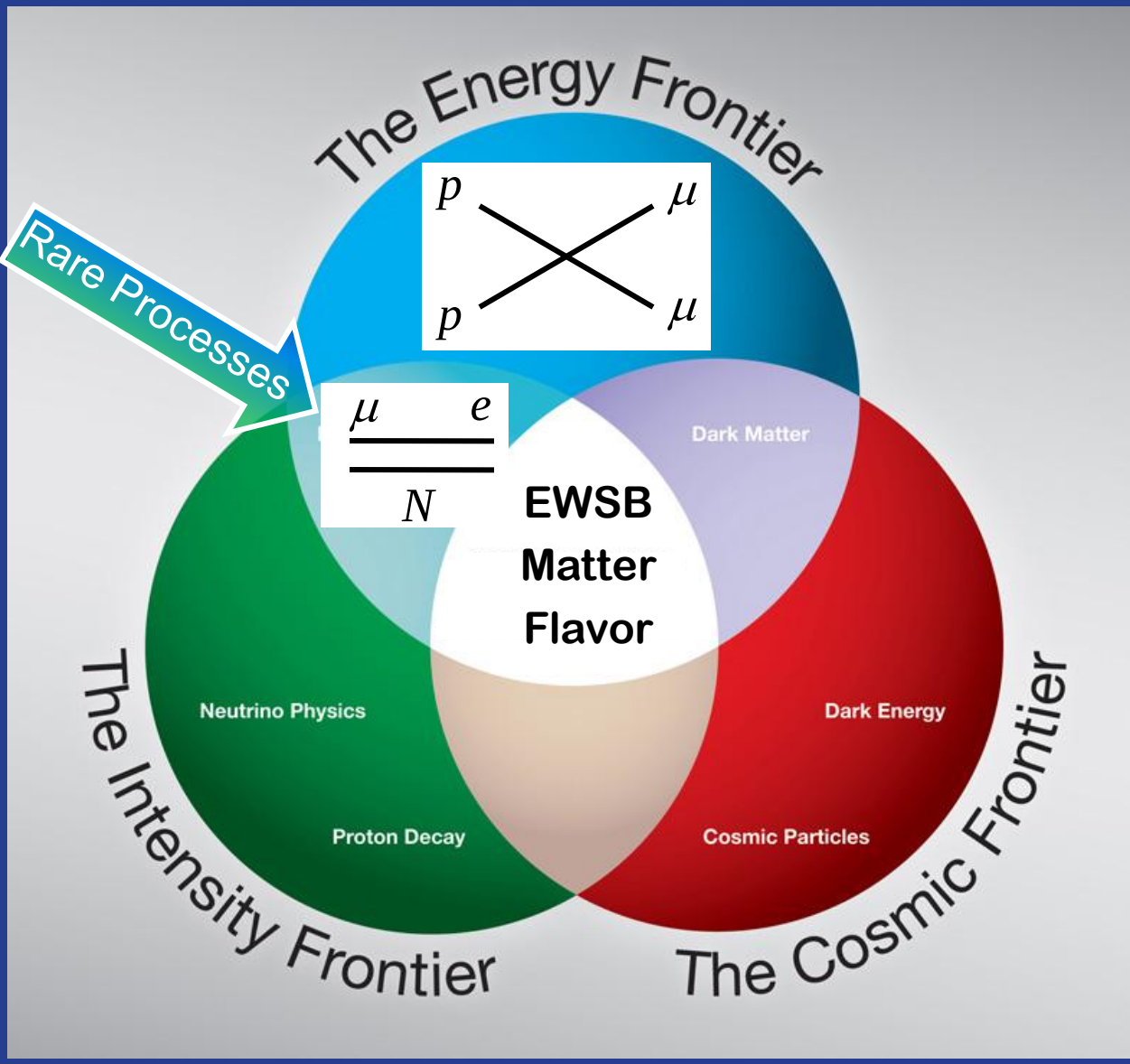
- discover new phenomena in rare processes

How:

- by probing LHC energies through virtual interactions

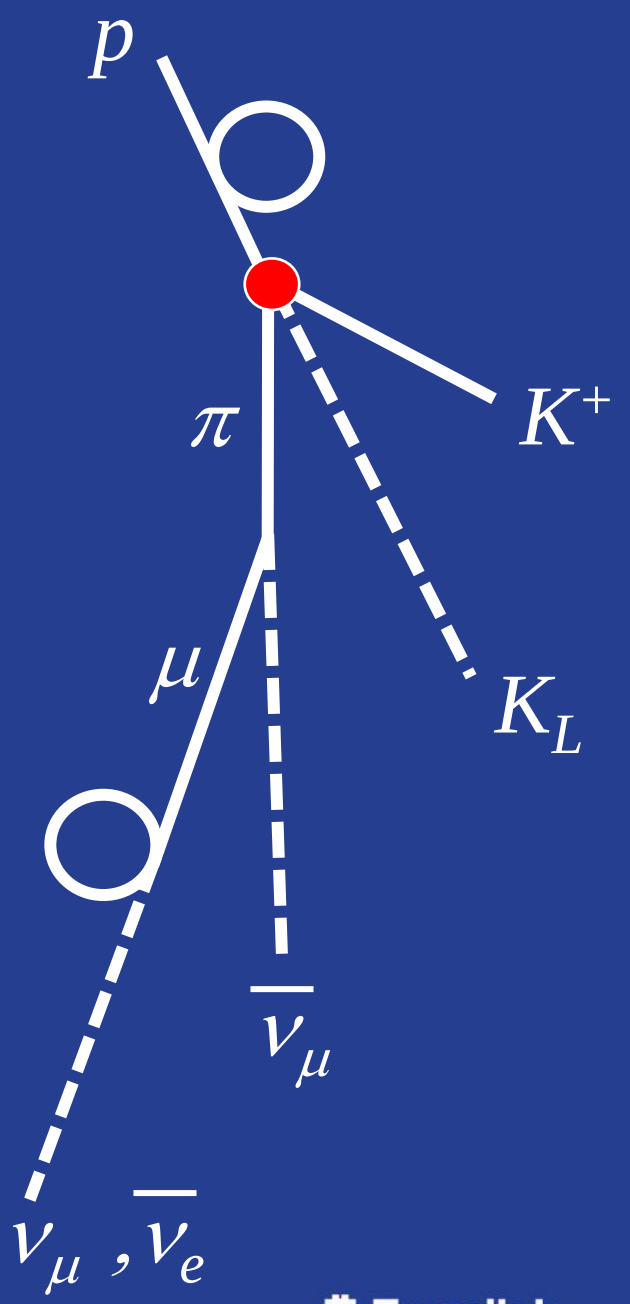
Prize:

- understand new physics associated with electroweak symmetry breaking, matter, and flavor



Rare Processes @ Fermilab

- Large, clean samples of Kaons and muons available from secondary beams
  - Modest reconfiguration of existing complex enables world leading program
- Beam tailored for each experiment
- Simultaneous running of multiple experiments
- Ultimate and unmatched sensitivities possible with Project X 3 GeV program



Rare Process Experiments and Initiatives

Experiment	Location	Status
SeaQuest	MI	Running this summer
Muon g-2	pbar	Equivalent CD1 review this fall
Mu2e	pbar	CD1 review this summer
$K^+ \to \pi^+ \nu\bar{\nu}$	MI	Updated proposal in preparation
$K^+ \to \pi^+ \nu\bar{\nu}$	Project X	White paper
$K^0 \to \pi^0 \nu\bar{\nu}$	Project X	White paper
$\mu N \to eN$	Project X	White paper
Rare isotope EDMs	Project X	White paper
μ EDM	Project X	White paper
$\mu \to e\gamma$, $\mu \to eee$, muonium…	Project X	White paper

Rare Process Collaborations

Many exist from last generation experiments at other Labs. Brings large, new user base to Fermilab

Leading roles played by Fermilab Scientists in every Fermilab Division

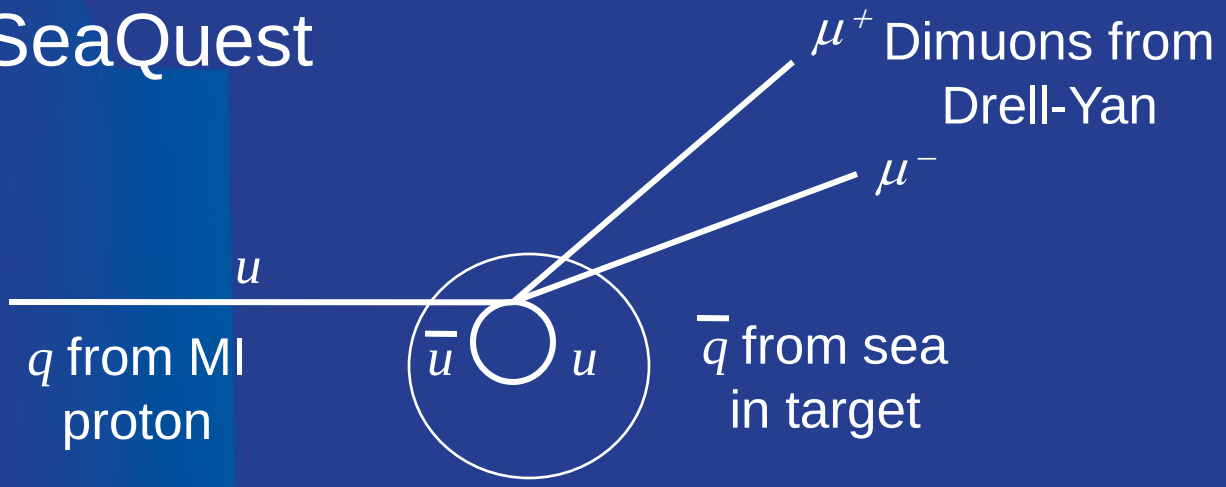
Several scientists transitioning from Tevatron. Some examples:

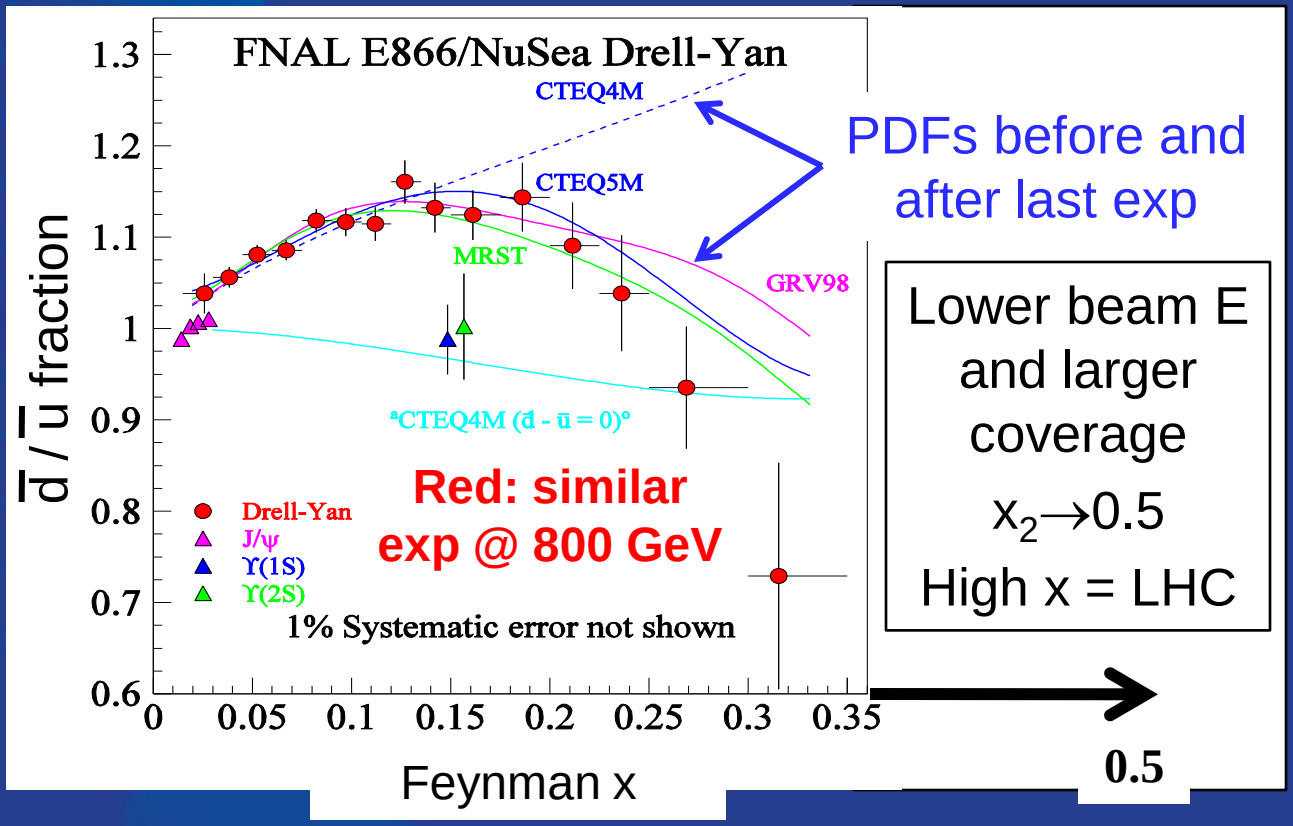
Mandy Rominsky
Fermilab Reaserch Associate
D0 New Pheno+ g-2

Craig Group
Fermilab Associate Scientist
Joint appointment w UVA
CDF Higgs + Mu2e

Leah Welty-Reiger
URA Visiting Scholar from Northwestern
D0 Higgs + g-2

SeaQuest





PDFs before and after last exp

Lower beam E and larger coverage

$x_2 \rightarrow 0.5$

High x = LHC

Significant funding from DOE nuclear

Detector installed

Initial physics before 2012 shutdown

High stats running after shutdown

Fermilab Kaon Program

- FCNCs highly motivated by all new physics models

- Extensively studied in B decay
  - >10 x current data sets expected this decade
- Kaon advantage:
  - Rates go as (Cabbibo angle)^5 versus (Cabbibo angle)^3 in B physics
    - Universal effects: Kaons win
    - Flavor specific effects: need both

	$\Lambda_{New\ Physics}$
$b \to s$: $V_{tb}^* V_{ts} \approx \lambda^2$	100 TeV
$b \to d$: $V_{tb}^* V_{td} \approx \lambda^3$	500 TeV
$s \to d$: $V_{ts}^* V_{td} \approx \lambda^5$	1000 TeV

Isidori, Nir, Perez 2010

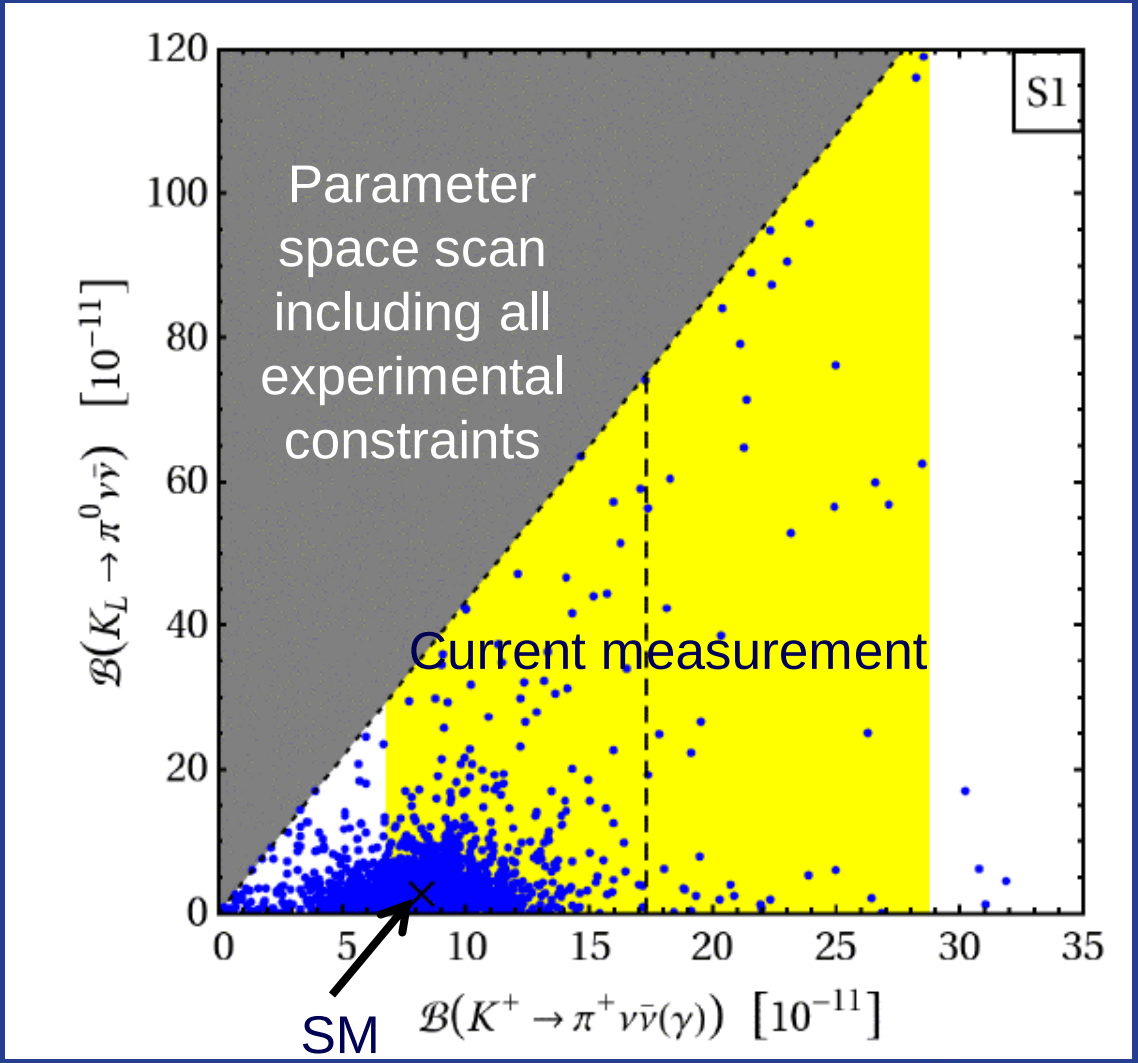
$\lambda = \sin\theta_C = 0.226(1)$

Example: warped extra dimensions

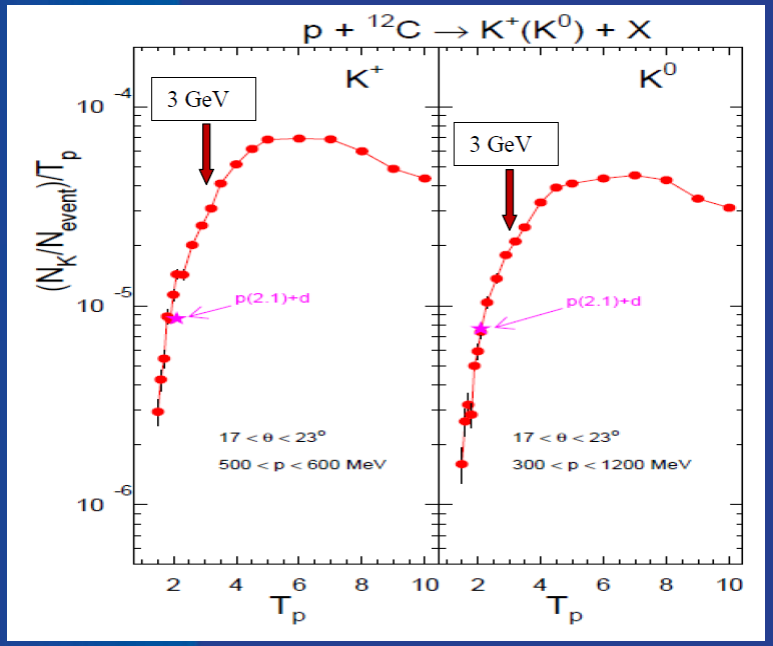
Bauer, Casagrande, Haisch, Neubert JHEP 1009:014 (2010)

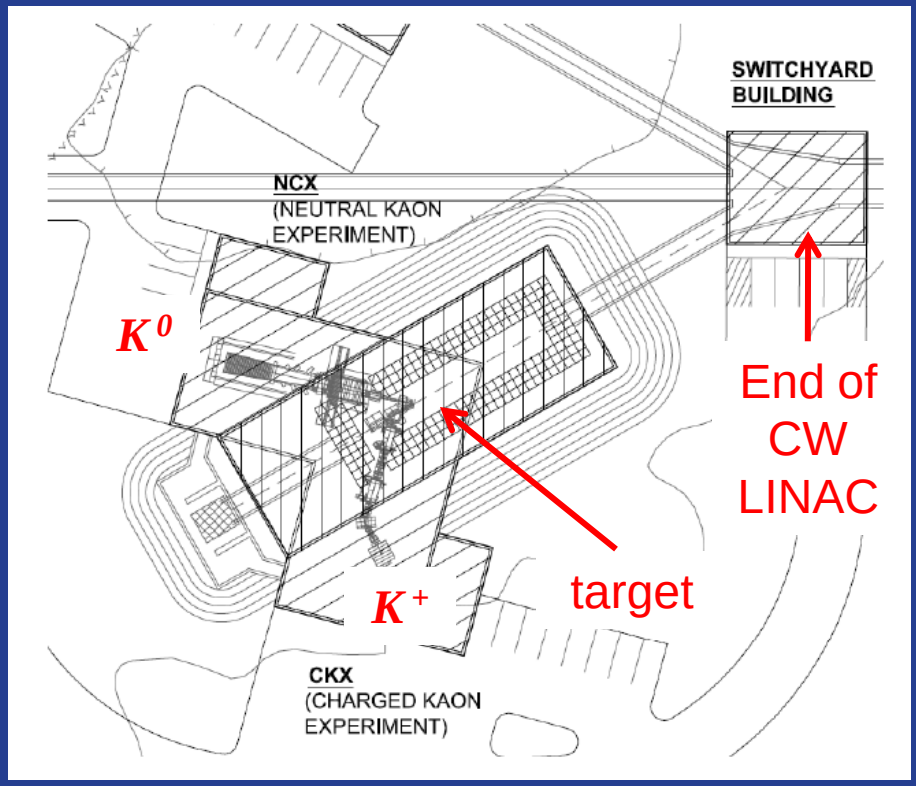
Exhaustive study of effects of warped extra dimensions on low energy observables

Unique regions of the theory probed with the $K \to \pi \nu\bar{\nu}$ channels



Project X Kaon Campus



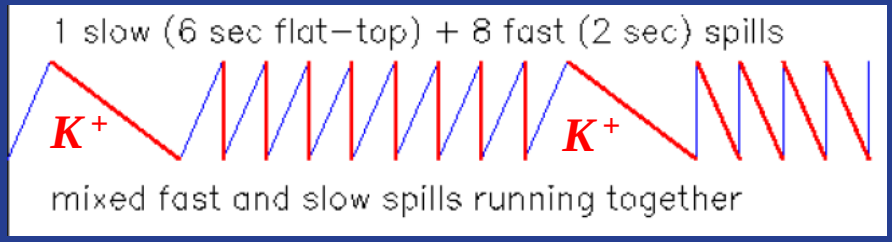


3 GeV beam energy close to ideal for Kaon production

Campus designed to use same target for K^+ and K^0 experiment → simultaneous running

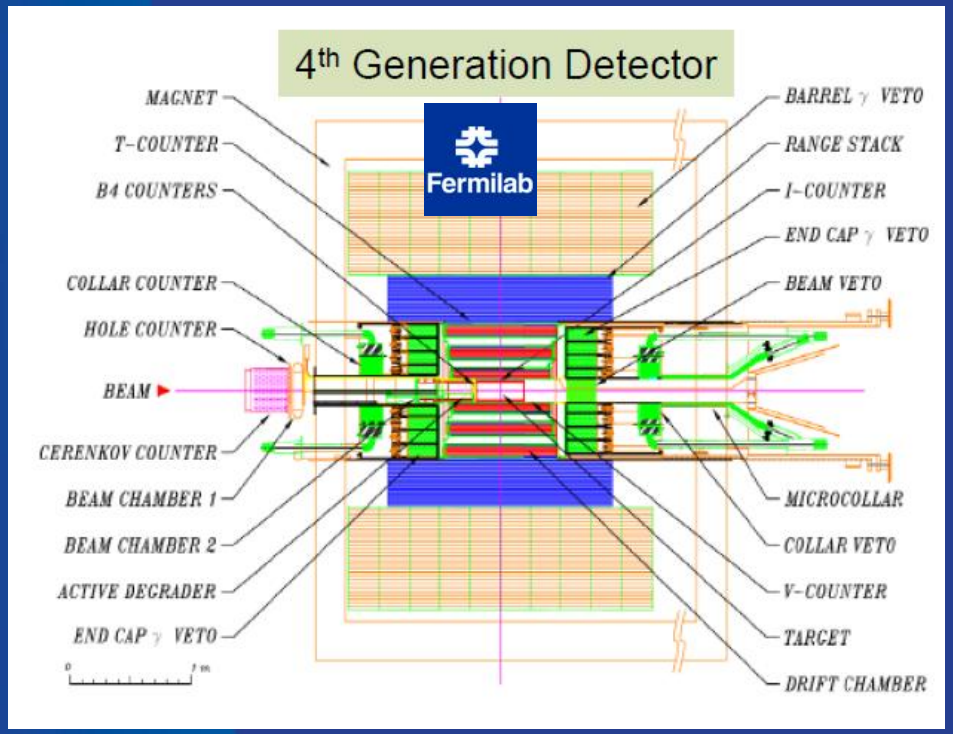
MI Option

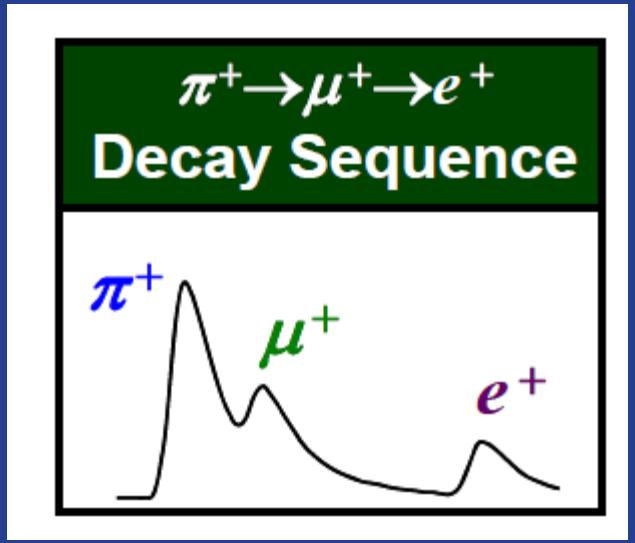
After several years of NOvA, MI can add slow spill cycles to feed the K^+ experiment and jumpstart the program



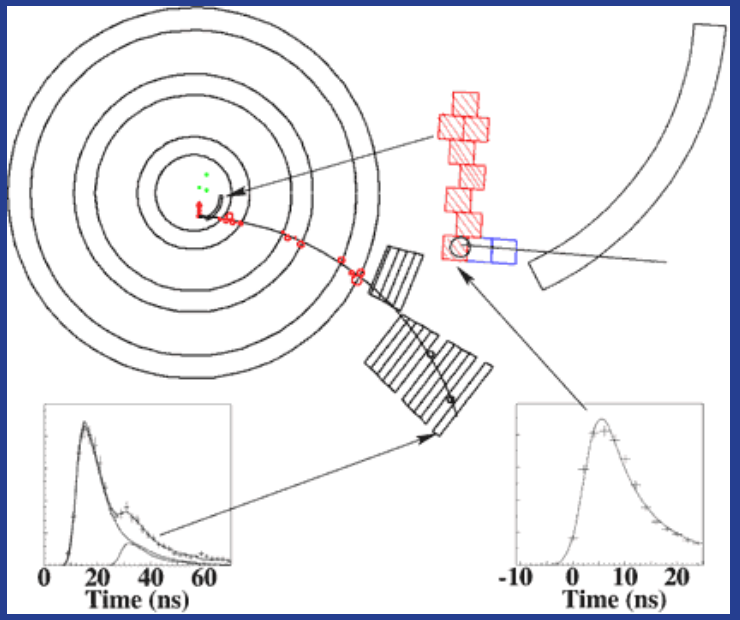
$K^+ \to \pi^+ \nu\bar{\nu}$

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





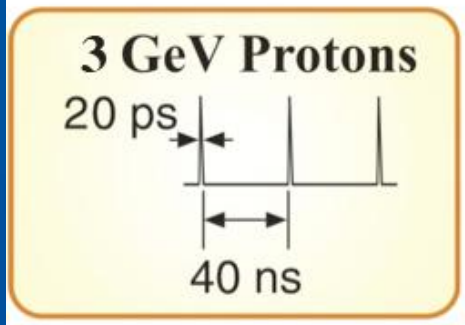
BNL E787 event display



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

$K^0 \to \pi^0 \nu\bar{\nu}$

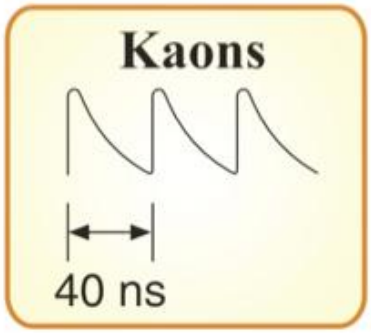
Pico-bunches



Pencil beam

K_L^0

Pointing



200 events per year possible with Project X

Probably only facility where a precision measurement is possible

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

Fermilab Charged Lepton Program

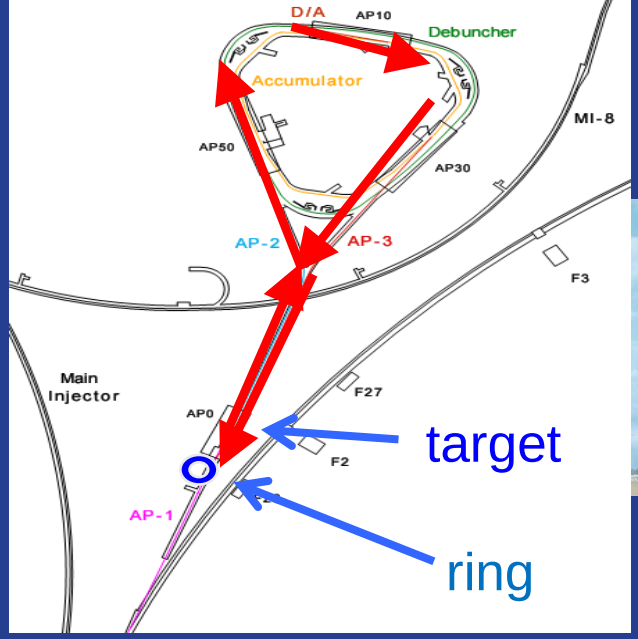
- CLFV$\rightarrow$ new mixing matrix
  - Multi-decade program to determine 4 free parameters

$$\begin{pmatrix} ee & e\mu & e\tau \\ \mu e & \mu\mu & \mu\tau \\ \tau e & \tau\mu & \tau\tau \end{pmatrix}$$

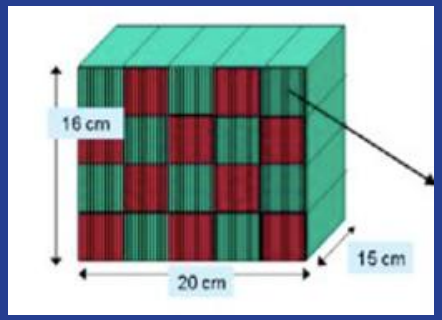
- Flavor conserving
  - Muon g-2
- Flavor violating
  - Mu2e
  - Next generation Mu2e @ Project X
  - $\mu \rightarrow e\gamma$, $\mu \rightarrow e\,ee$, $\mu^+e^- \rightarrow e^+\mu^-$ also being considered @ Project X
- CP violating
  - e EDM with rare isotopes
  - μ EDM storage ring experiments

Kick starting the program: The new g-2 experiment

- 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

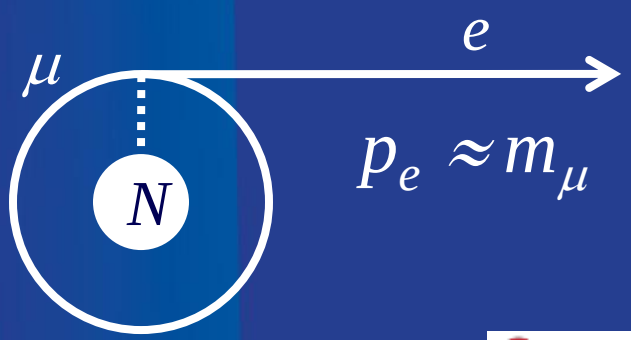


Pbar complex



USQCD US Lattice Quantum Chromodynamics

Discovering Lepton Flavor Violation



Best chance for an unambiguous, background free discovery is the $\mu N \rightarrow eN$ process

Experimental advantage:

Monocromatic e above Michel endpoint

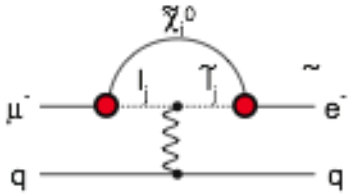
Theoretical advantage:

unique sensitivity to several mechanisms of flavor violation

From Marciano:

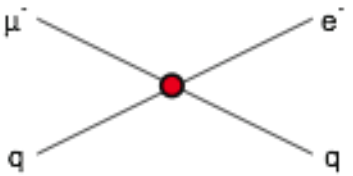
Supersymmetry

rate ~ 10^{-15}



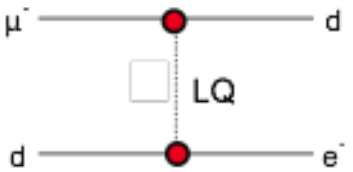
Compositeness

Λ_c ~ 3000 TeV



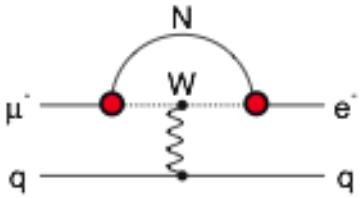
Leptoquark

M_{LQ} = 3000 $(\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/c^2



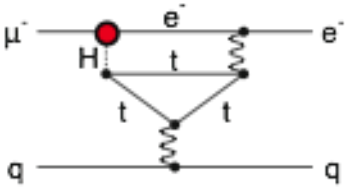
Heavy Neutrinos

$|U_{\mu N}U_{eN}|^2$ ~ 8×10^{-13}



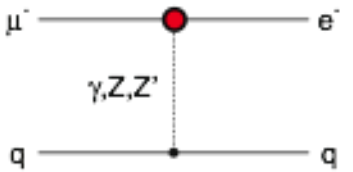
Second Higgs Doublet

$g(H_{\mu e})$ ~ $10^{-4} g(H_{\mu\mu})$

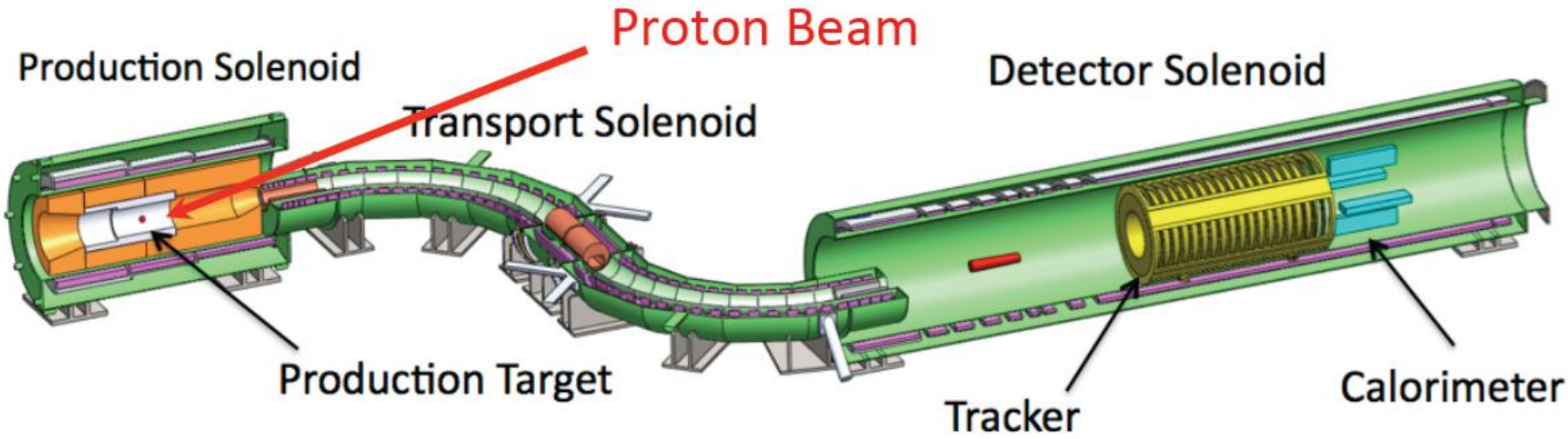


Heavy Z' Anomal. Z Coupling

$M_{Z'}$ = 3000 TeV/c^2



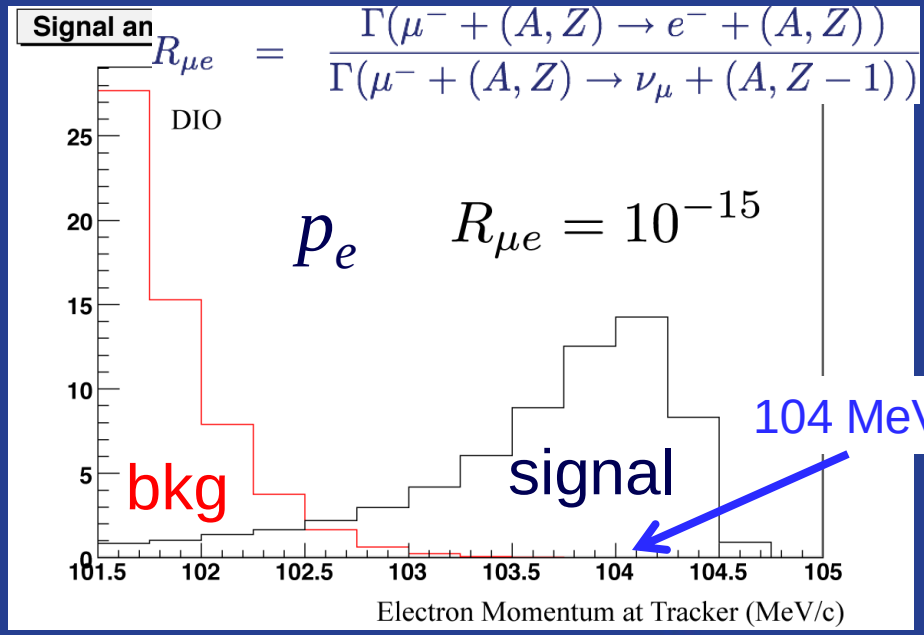
Mu2e



Expectation for a SUSY inspired rate →

Sensitivity with booster based experiment = 3 x 10^{-17} (10^{4} TeV)

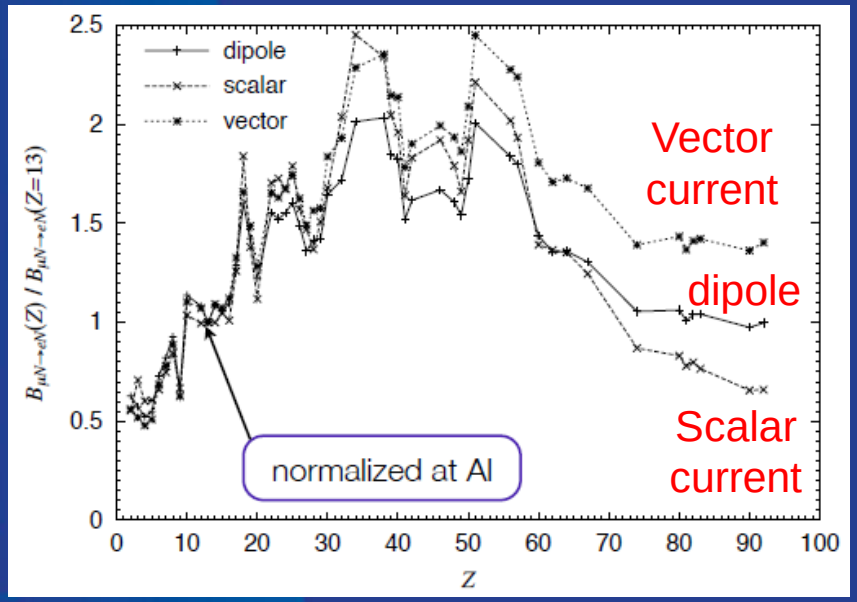
Sensitivity of 3 x 10^{-19} possible with Project X



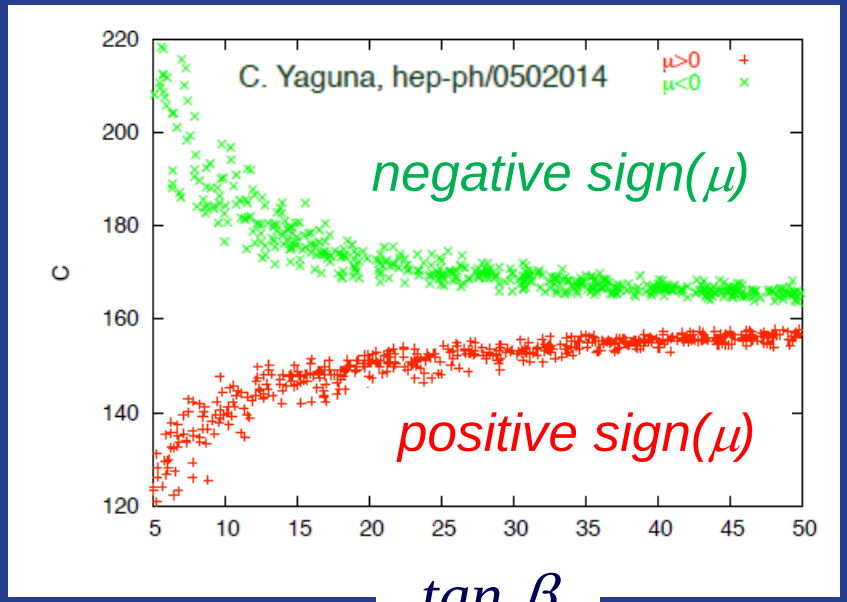
Beyond Discovery

Once lepton flavor violation is discovered, Project X would allow a diverse , precision LFV program to disentangle underlying physics

Conversion rate vrs target Z for $\mu N \rightarrow eN$



Ratio of $\mu \rightarrow e\gamma$ / $\mu N \rightarrow eN$

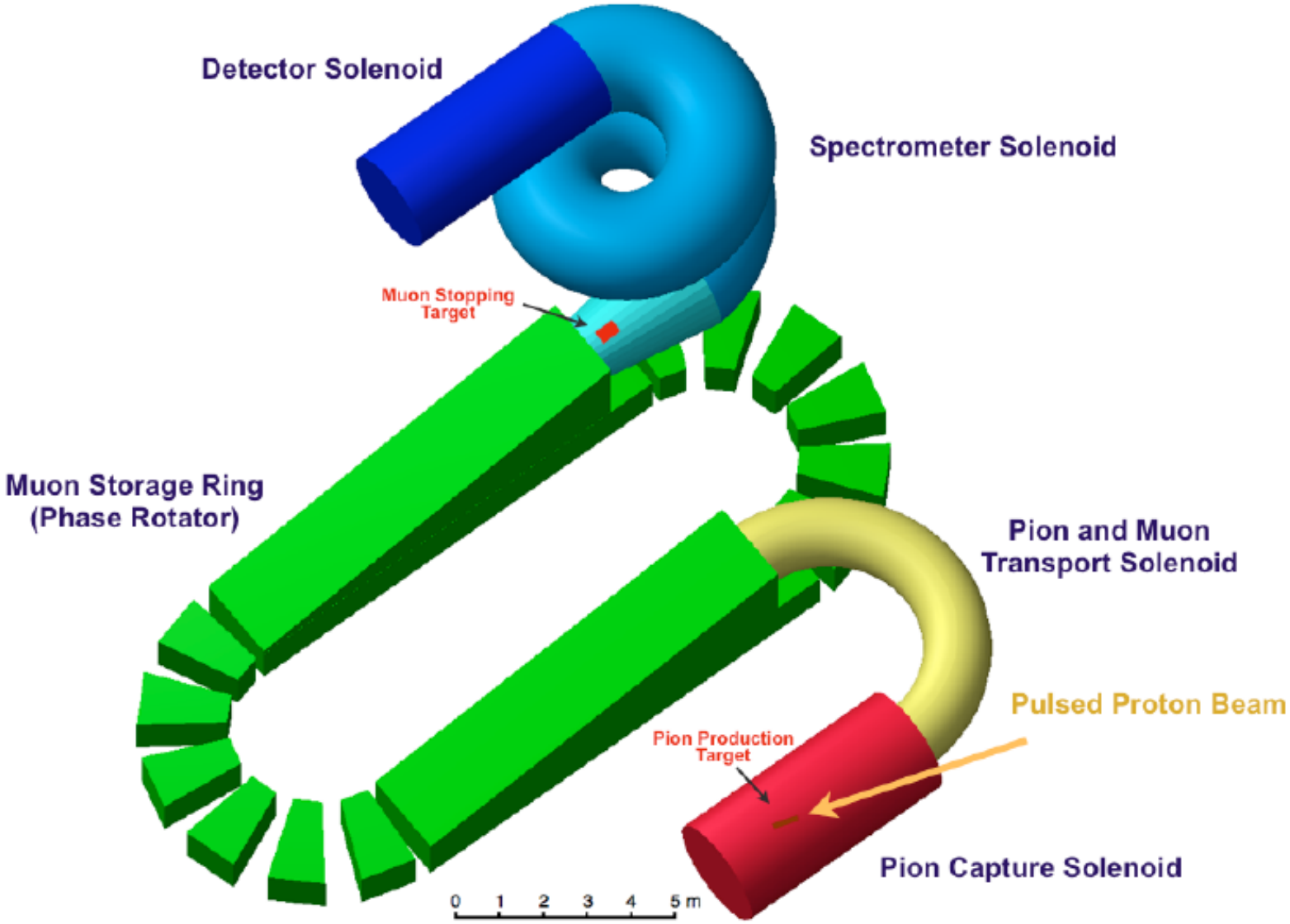


SUSY: $B(\mu \rightarrow e\gamma) \approx 100 \quad B(\mu \rightarrow eee)$

Little Higgs: $B(\mu \rightarrow e\gamma) \approx B(\mu \rightarrow eee)$

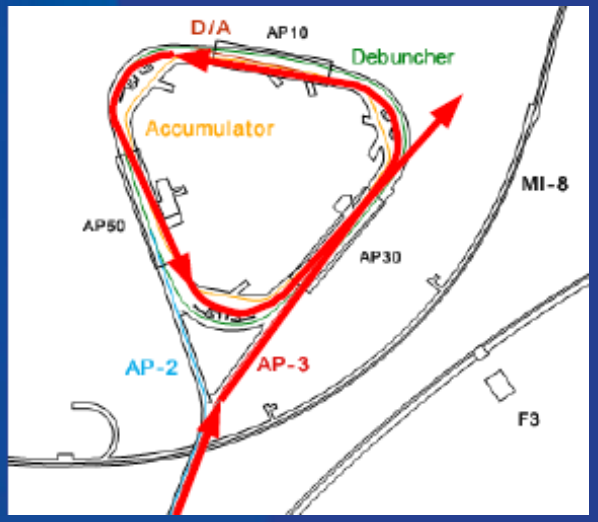
$\Delta F=2$: $\mu^- e^+ \rightarrow e^- \mu^+$

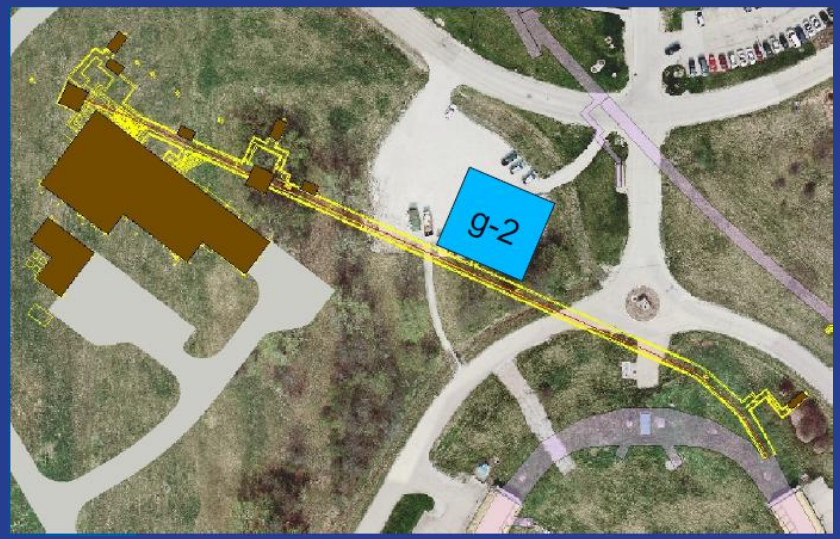
$\mu \rightarrow e$ with Project X



Optimizing the near term muon program

- Fermilab, DOE capitalizing on opportunity provided by g-2
- Challenges:
  - Best use of existing rings, common infrastructure
  - Ability to change quickly between g-2 and Mu2e configurations
  - Smooth transition into Project X era
- New AD Associate Division Head for g-2+Mu2e appointed
- Scientists in all divisions + collaborators actively participating



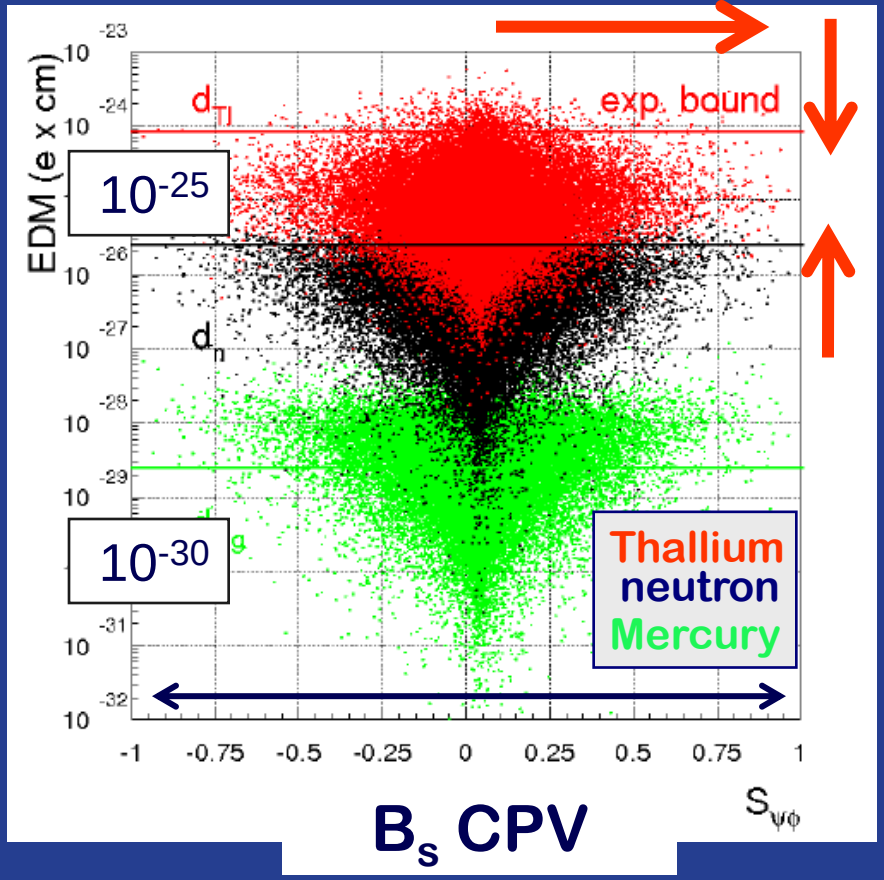


EDMs with Project X

EDMs are an excellent candidate for CPV needed to make baryogenesis work

If the Tevatron indications of large CPV in B_s mixing are confirmed, EDMs could be around the corner.

Large B_s CPV shrinks available parameter space

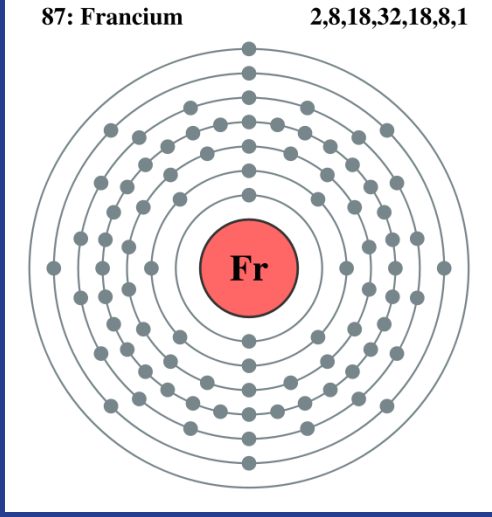


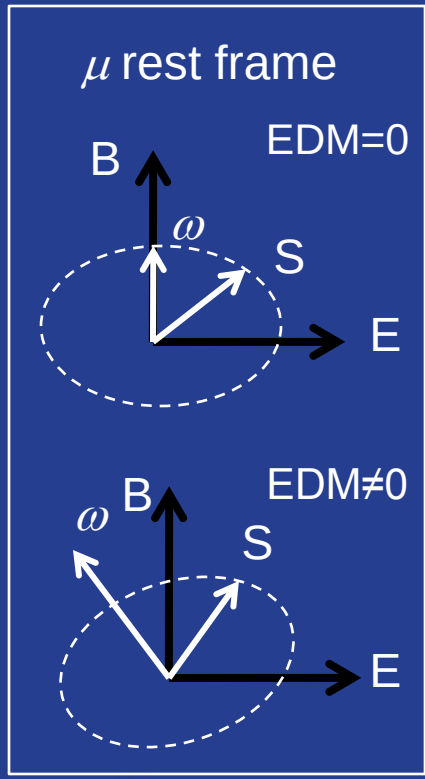
Buras, Isidori, Paradisi
arXiv:1007.5291

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





Conclusions

- Fermilab is planning a targeted rare process program that covers arguably the most important intensity frontier measurements
- In all cases, Fermilab is the best place to perform these experiments
  - 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 produce an outstanding crop of graduate students