Project-X

ICHEP , July 24, 2010
R.Tschirhart
Fermilab

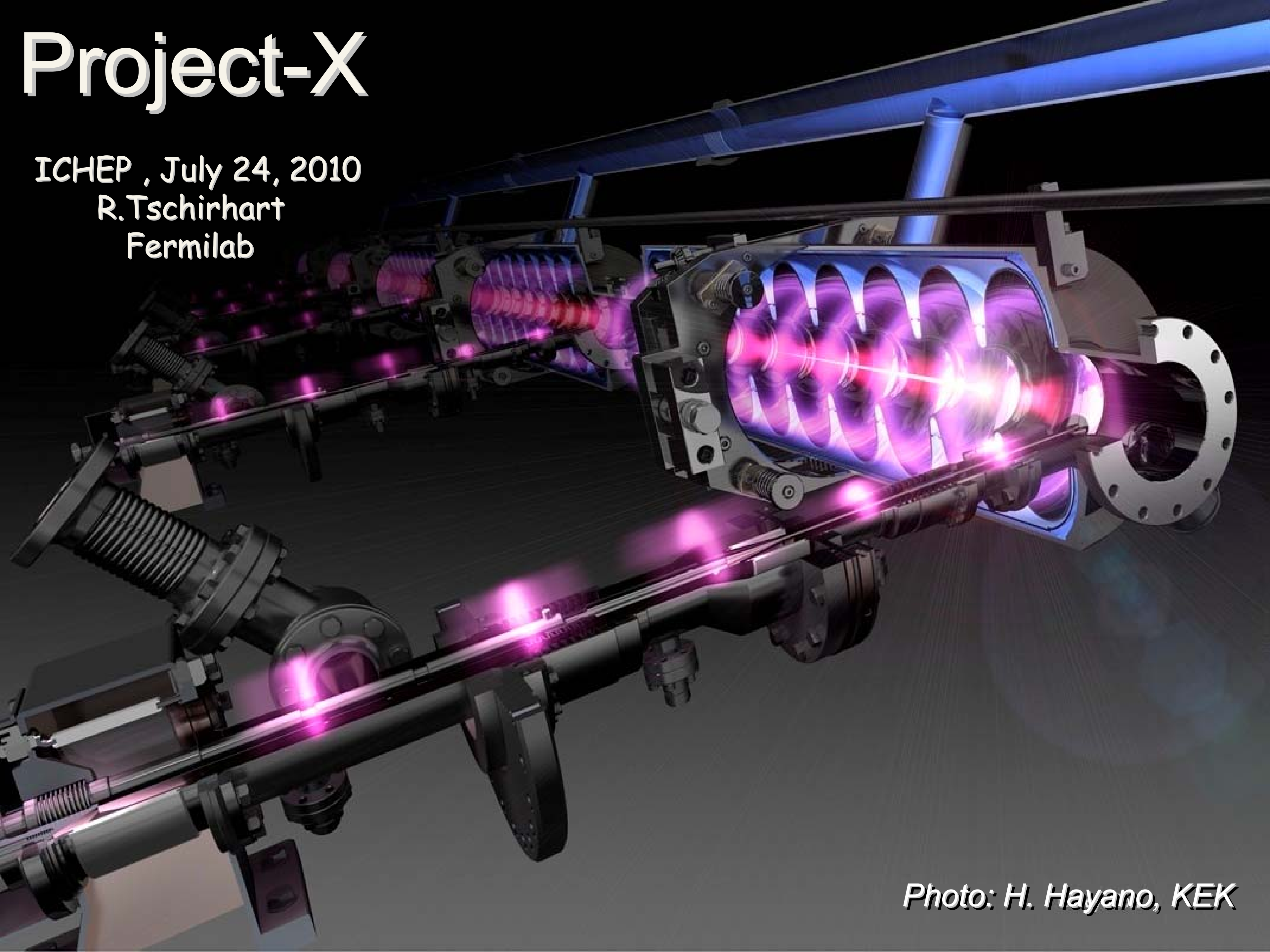
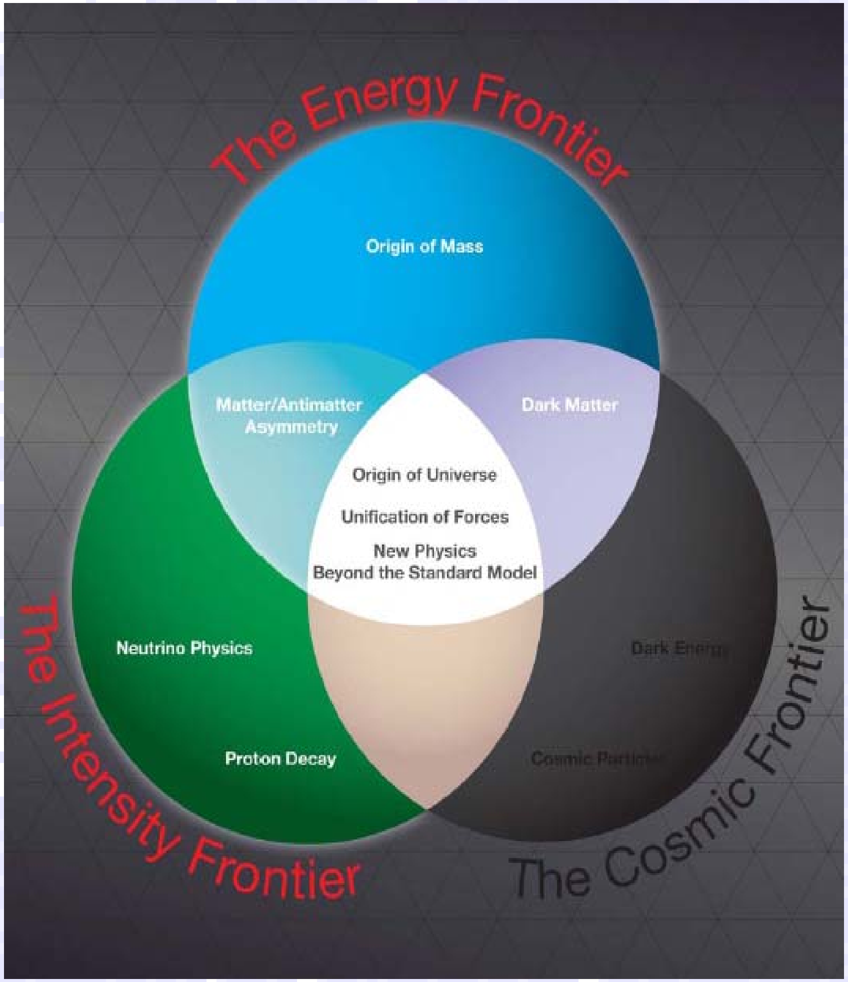


Photo: H. Hayano, KEK

The Promise of the Intensity Frontier

Project-X will drive next generation experiments in rare processes neutrino physics that explore:

- ***The origin of the universe***
- ***Unification of Forces***
- ***New Physics Beyond the Standard Model.***



The Project-X Research Program

- ***Long baseline neutrino oscillation experiments:***

  Driven by a high-power proton source with proton energies between 50 and 120 GeV that would produce intense neutrino beams directed toward massive detectors at a distant deep underground laboratory.

- ***Kaon, muon, nuclei & neutron precision experiments driven by high intensity proton beams running simultaneously with the neutrino program:***

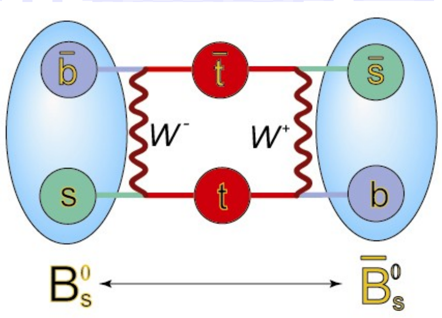
  These could include world leading experiments searching for muon-to-electron conversion, nuclear and neutron electron dipole moments (edms), and world-leading precision measurements of ultra-rare kaon decays.

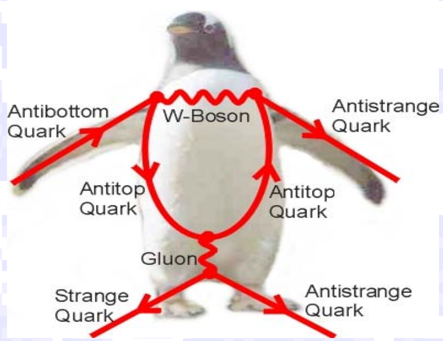
- ***Platform for evolution to a Neutrino Factory and Muon Collider***

Detailed Discussion: Project X website

Kaon, Muon and EDM Experiments Deeply Attack the Flavor Problem

Why don't we see the *Terascale Physics we expect* affecting the flavor physics we study today??

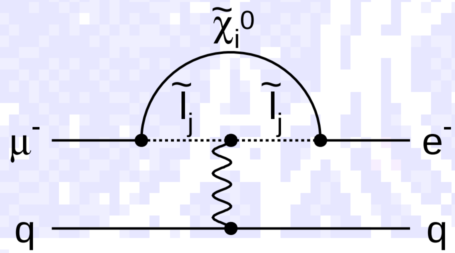


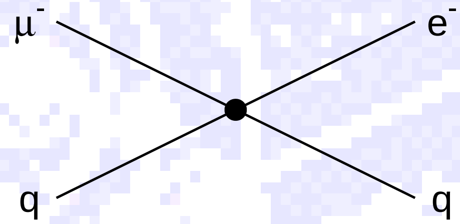


Deepest Probe of the Flavor Probem: Ultra-rare Muon Experiments at Project-X

Supersymmetry

Predictions at 10^{-15}



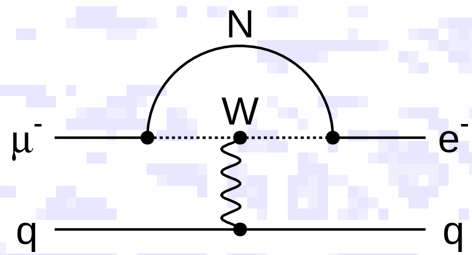


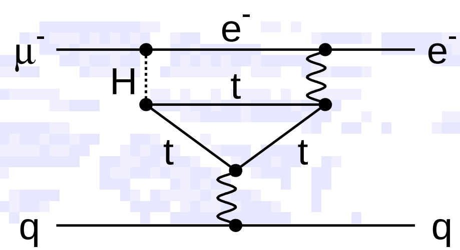
Compositeness

$\Lambda_C = 3000$ TeV

Heavy Neutrinos

$|U_{\mu N}^* U_{eN}|^2 = 8 \times 10^{-13}$



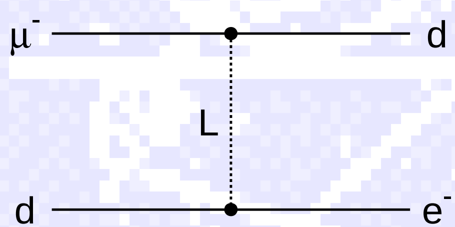


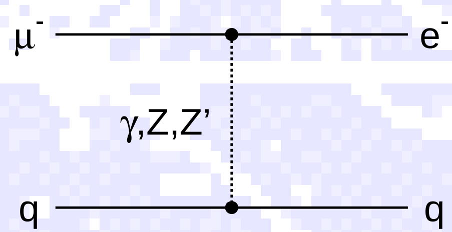
Second Higgs doublet

$g_{H_{\mu e}} = 10^{-4} \times g_{H_{\mu\mu}}$

Leptoquarks

$M_L = 3000\sqrt{\lambda_{\mu d}\lambda_{ed}}$ TeV/c^2





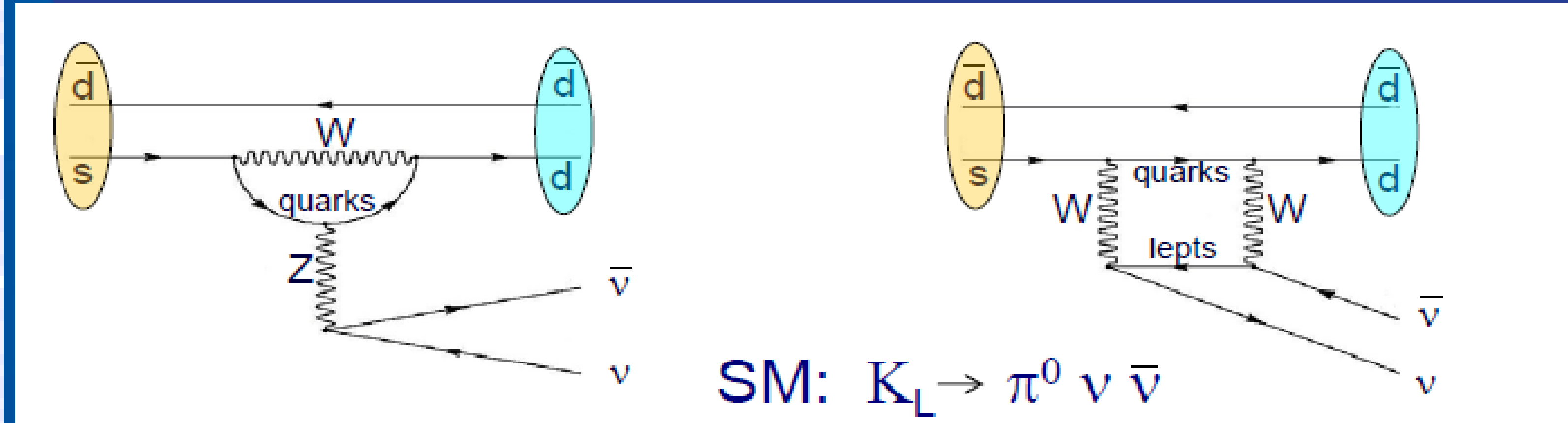
Heavy Z', Anomalous Z coupling

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

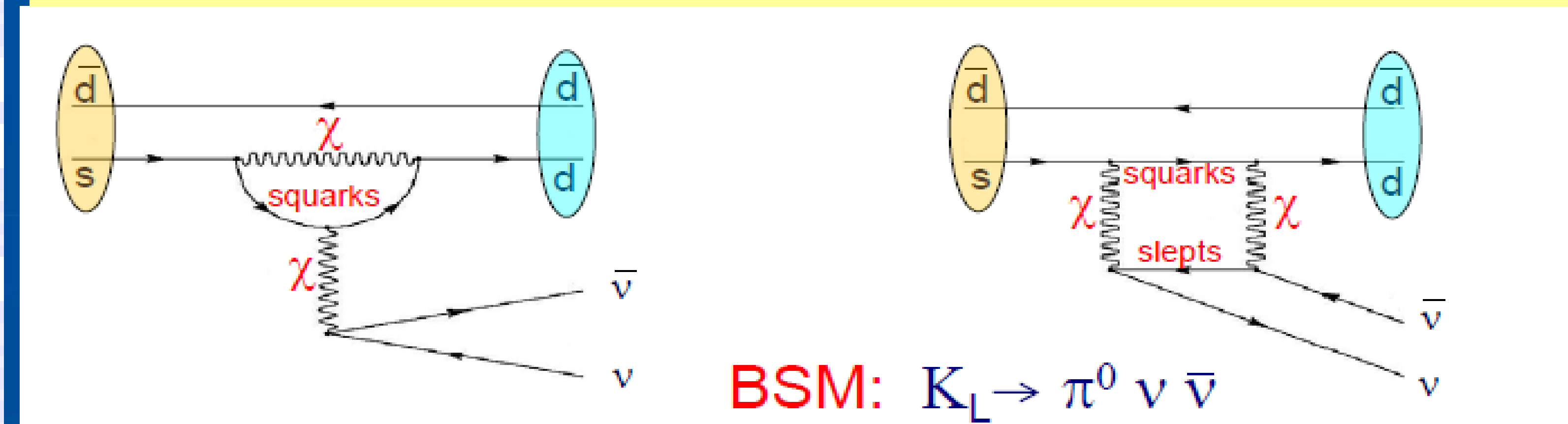
$B(Z \to \mu e) < 10^{-17}$

After W. Marciano

The Window of Ultra-rare Kaon Decays in Project X



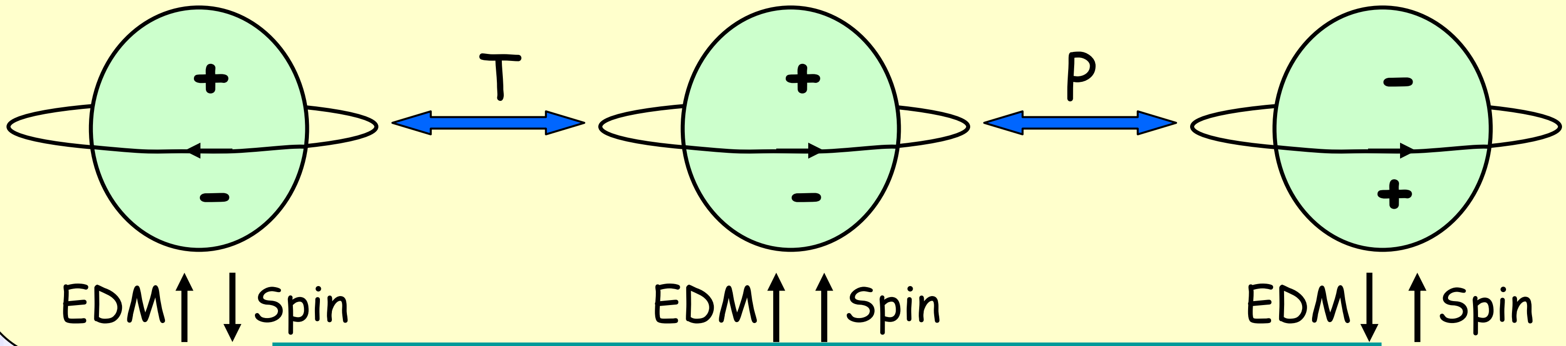
Standard Model rate of 3 parts per 100 billion, known to < 3% precision



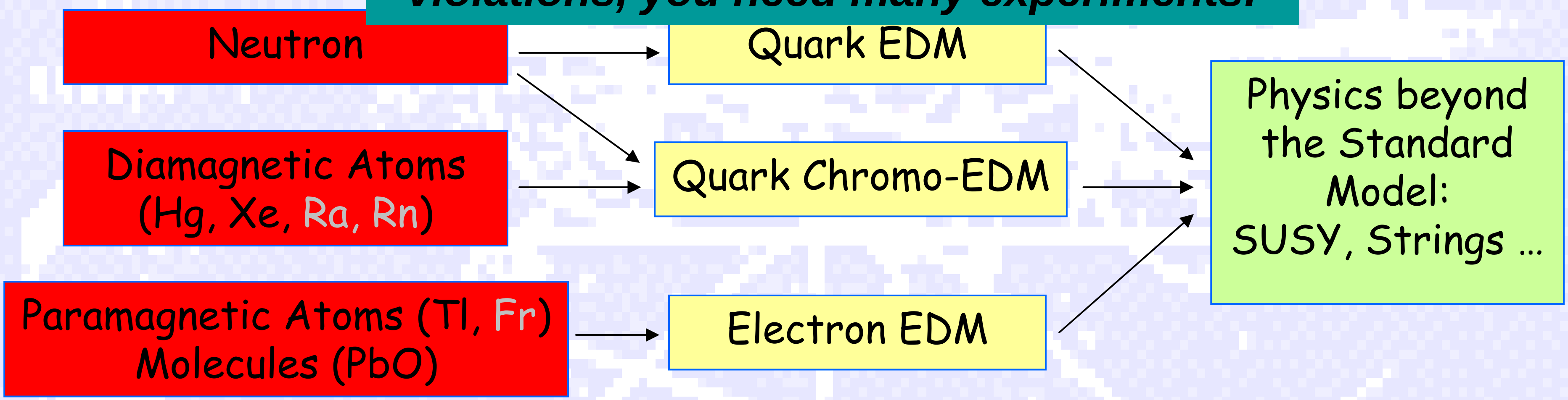
BSM particles within loops can increase the rate by x10 with respect to SM.

The Quest for Electric Dipole Moments

A permanent EDM violates both time-reversal symmetry and parity

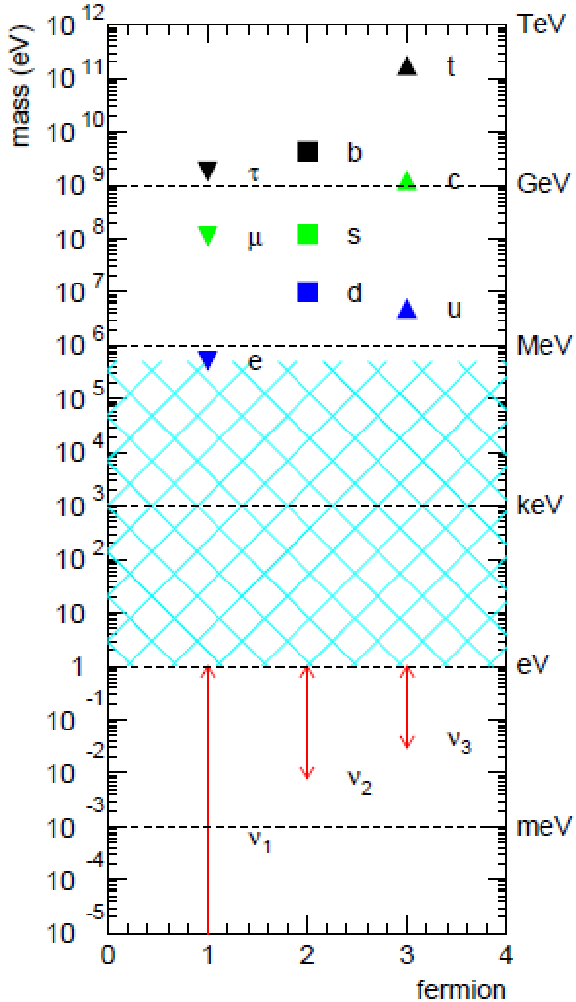


To understand the origin of the symmetry violations, you need many experiments!



Guy Savard, ANL

What are Neutrinos Telling Us?



What We Are Trying To Understand:

⇐ NEUTRINOS HAVE TINY MASSES

⇓ LEPTON MIXING IS "WEIRD" ⇓

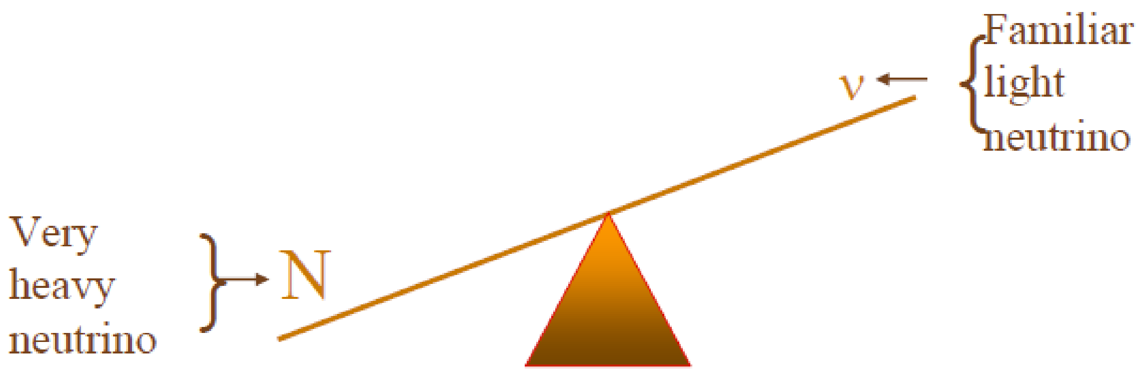
$$V_{MNS} \sim \begin{pmatrix} 0.8 & 0.5 & 0.2 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} \qquad V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.001 \\ 0.2 & 1 & 0.01 \\ 0.001 & 0.01 & 1 \end{pmatrix}$$

What Does It Mean?

Andre de Gouvea

Leveraging to the Unification Scale

See-Saw Mechanism



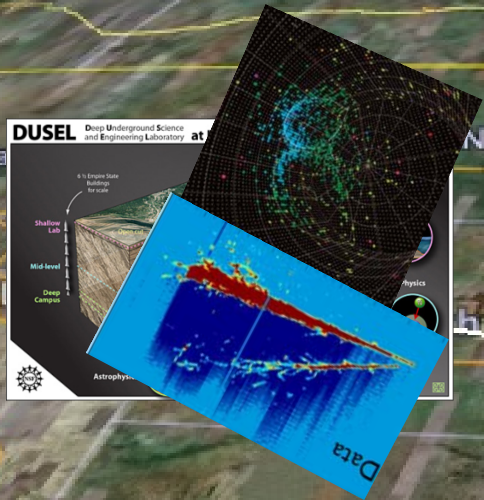
Mass(N) ~ 10^{15} GeV

The strong, EM, and weak forces unify at ~ 10^{16} GeV

Unification? Leptogenisis?

Boris Kayser

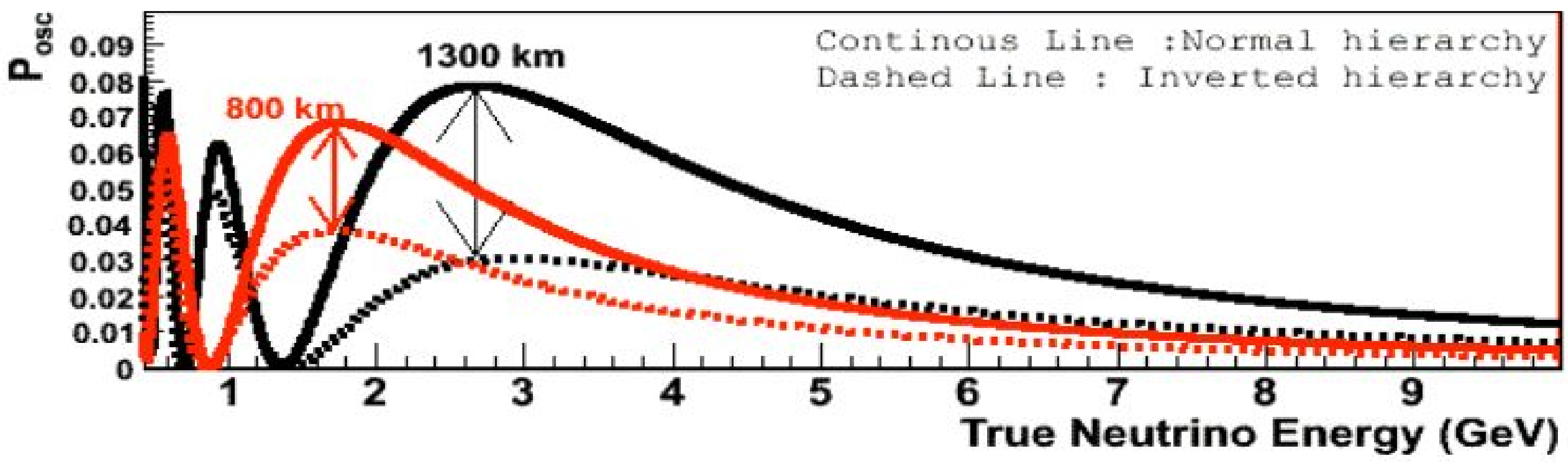
Long Baseline Neutrino Experiment



- New Neutrino Beam at Fermilab…
- …Directed towards NSF's proposed DUSEL
- Precision Near Detector on the Fermilab site
- 100 kT fiducial volume Water Cherenkov Far Detector
- 17 kT fiducial volume Liquid Argon TPC Far Detector

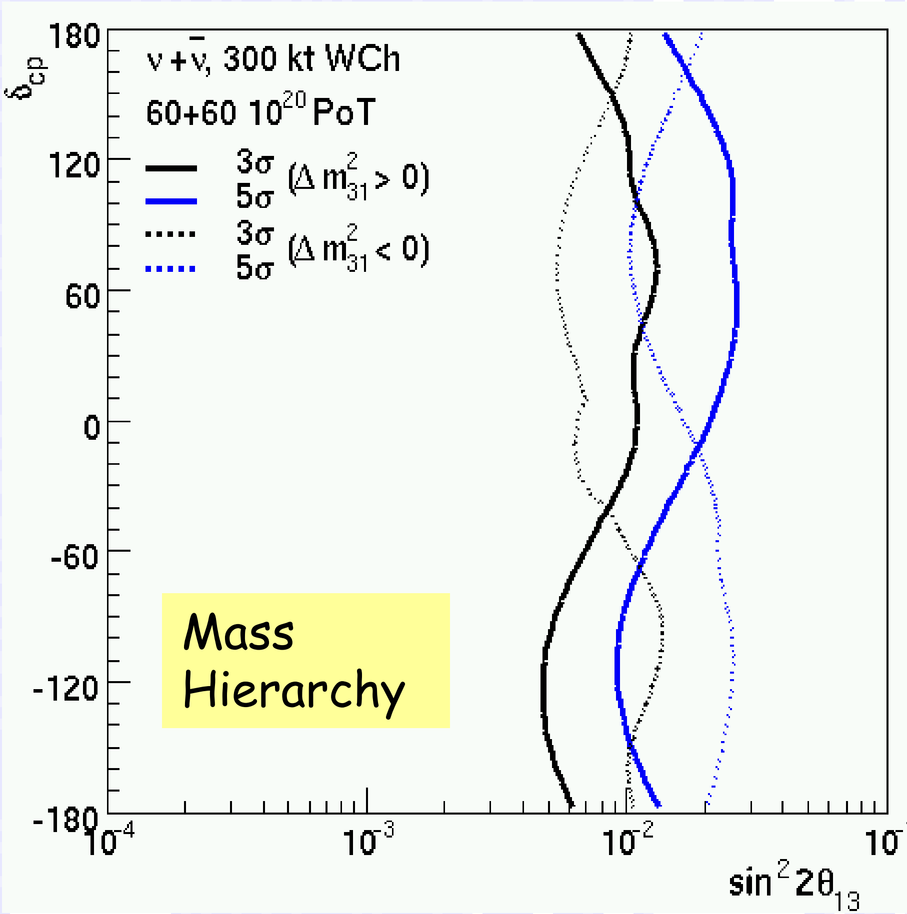
Why DUSEL?

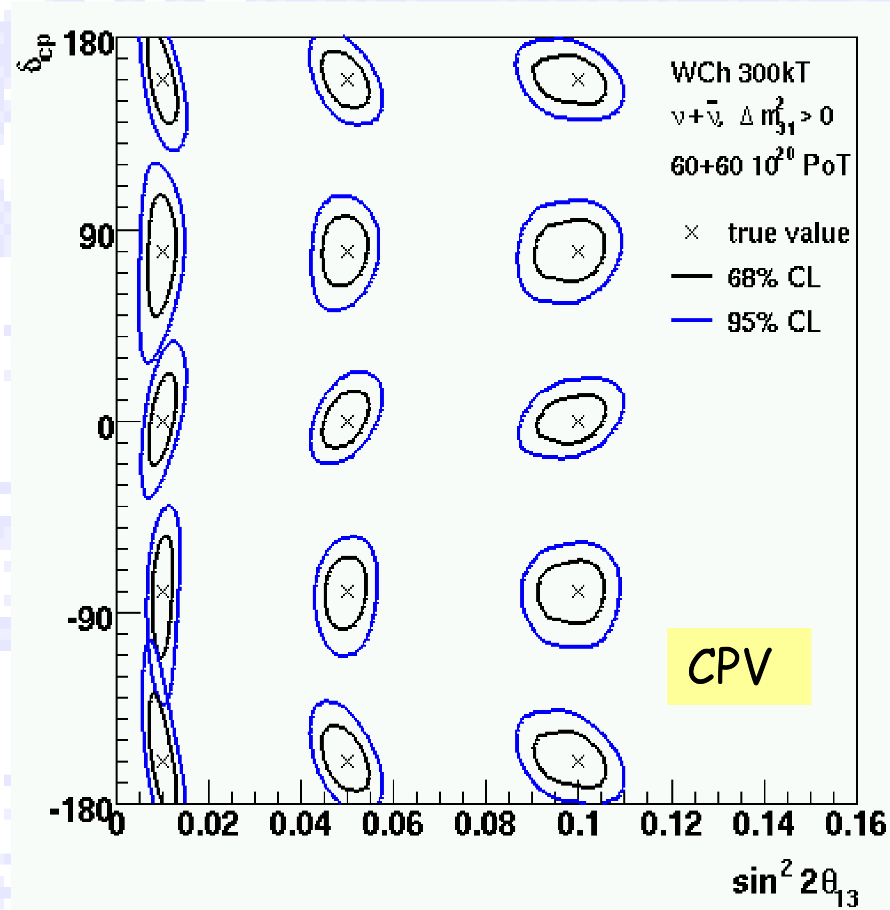
- 1300 km distance is a good compromise of mass-hierarchy and CP violation sensitivities
- Deep underground site allows rich physics program in addition to LB neutrinos



Bob Svoboda, 4th PXP Workshop

DUSEL LBNE Sensitivities

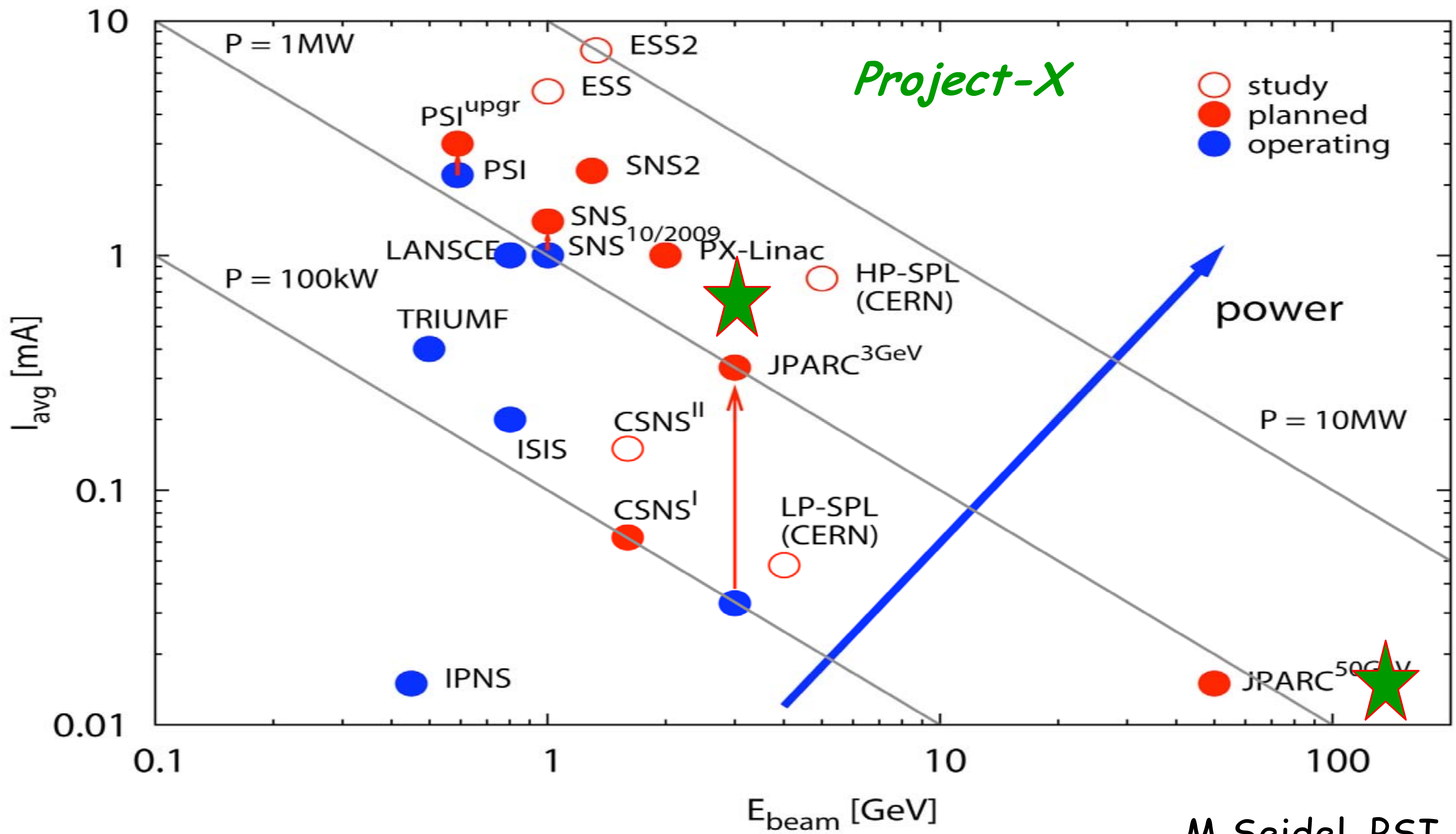




Sensitivities for (300 kT H_2O)×(2 MW)×(3+3 ν/ν̄ years)

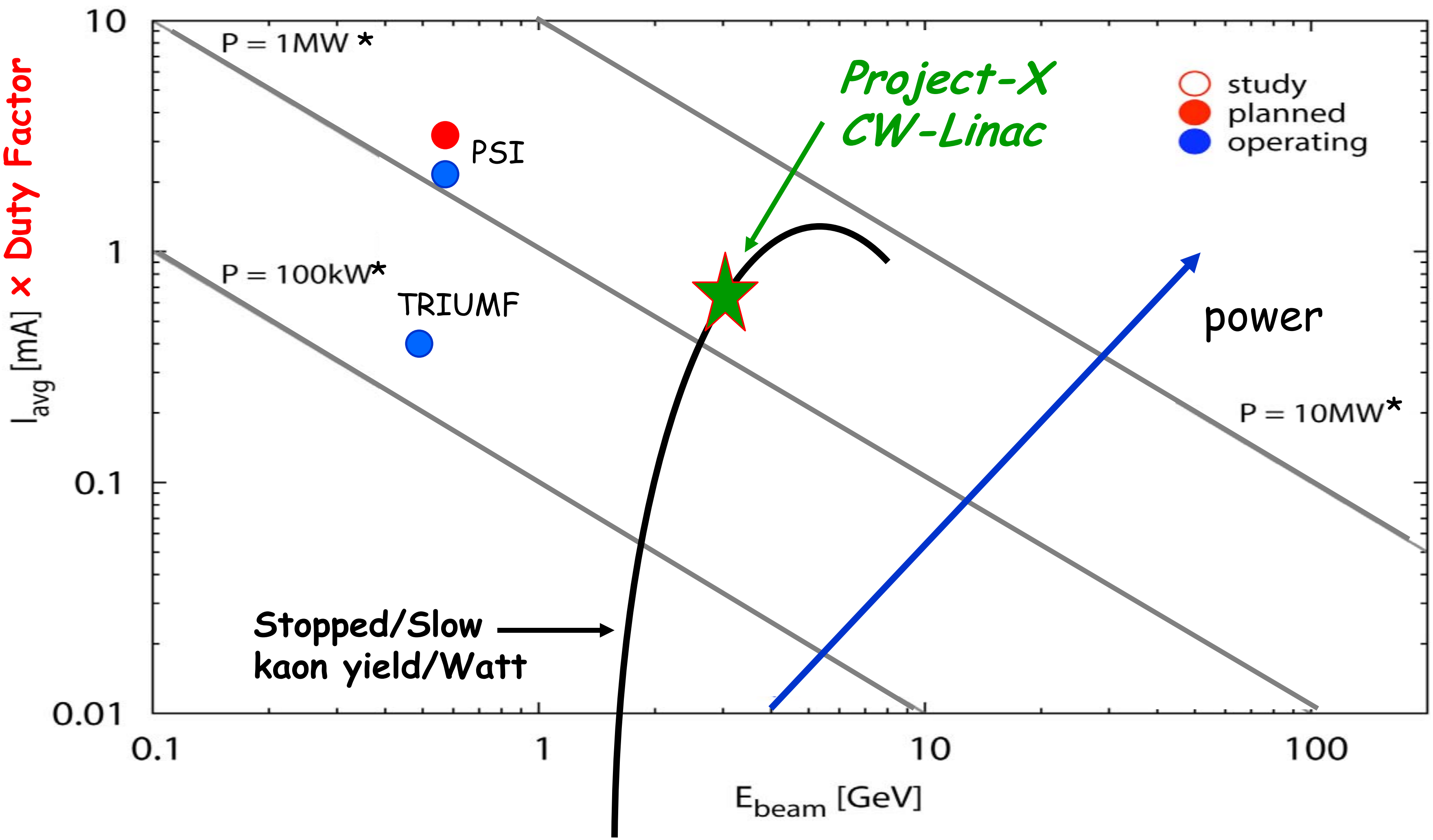
Bob Svoboda, 4th PXP Workshop

This Science has attracted Competition: The Proton Source Landscape This Decade...



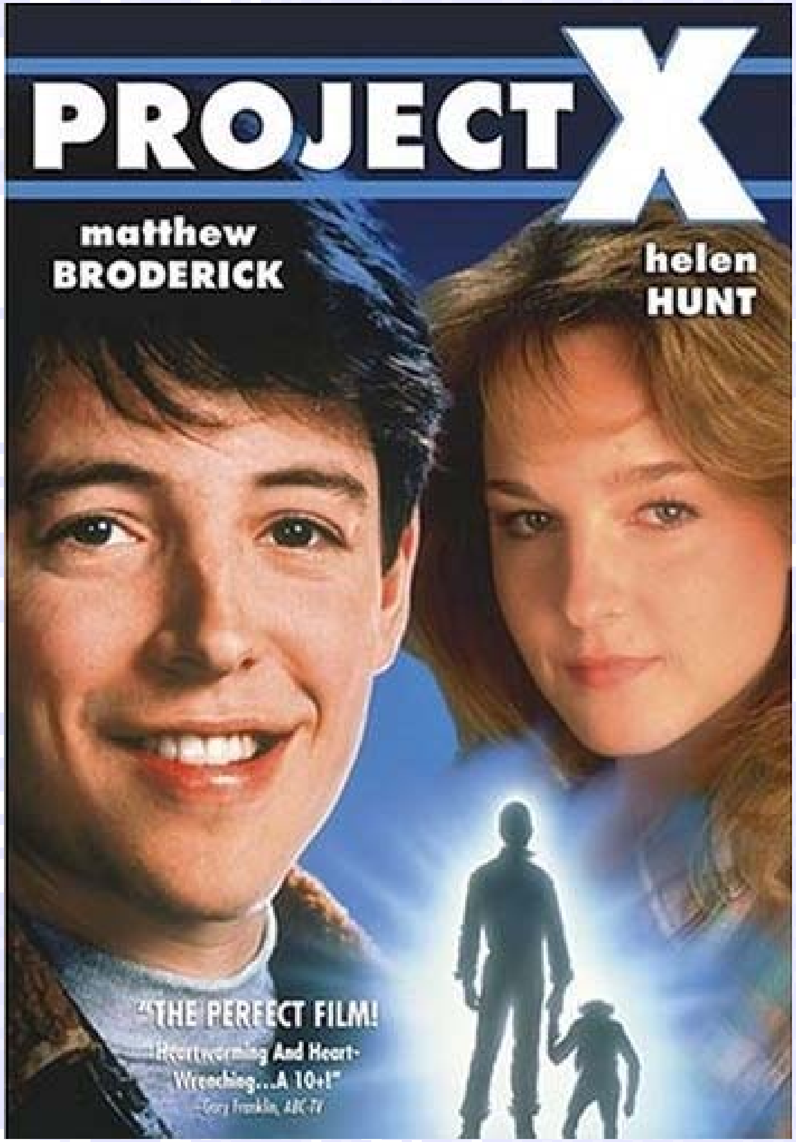
M Seidel, PSI

The High Duty Factor Proton Source Landscape This Decade...



* Beam power × Duty Factor

Project-X, What it's not…



Project-X Accelerator Performance Goals

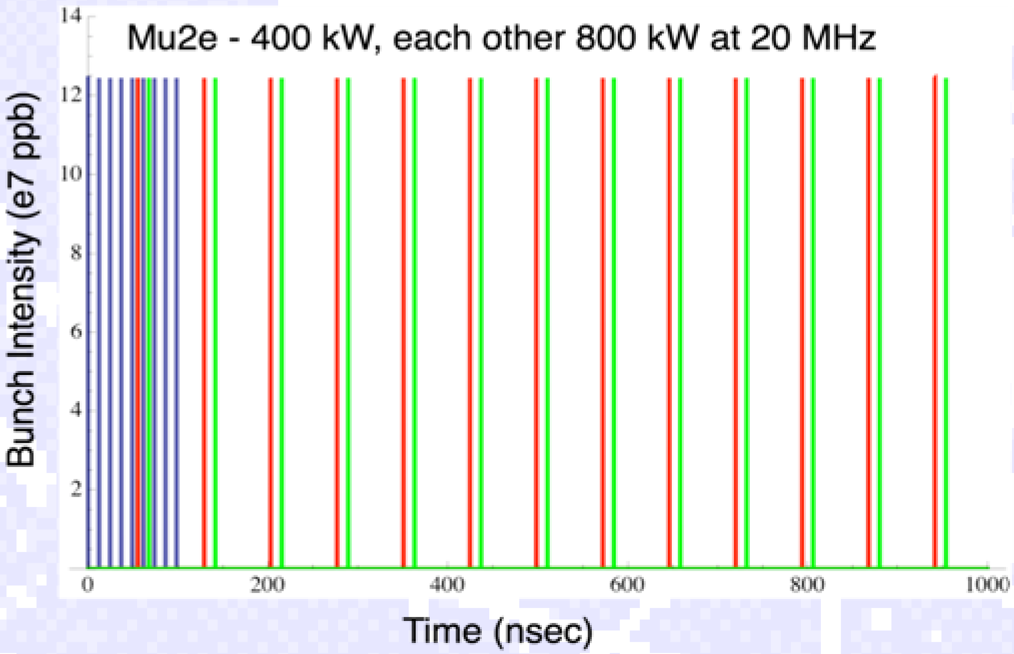
CW Linac		
Particle Type	H^-	
Beam Kinetic Energy	3.0	GeV
Average Beam Current	1	mA
Linac pulse rate	CW	
Beam Power	3000	kW
Beam Power to 3 GeV program	2870	kW
RCS/Pulsed Linac		
Particle Type	protons/H^-	
Beam Kinetic Energy	8.0	GeV
Pulse rate	10	Hz
Pulse Width	0.002/4.3	msec
Cycles to MI	6	
Particles per cycle to Recycler	2.6×10^{13}	
Beam Power to 8 GeV program	200	kW
Main Injector/Recycler		
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.4	sec
Particles per cycle	1.6×10^{14}	
Beam Power at 120 GeV	2200	kW

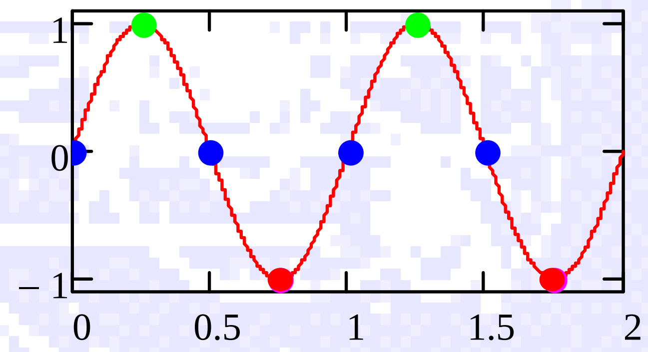
simultaneous

3 GeV Super-conducting CW Linac: High Power and High Duty Factor

1 μsec period at 3 GeV

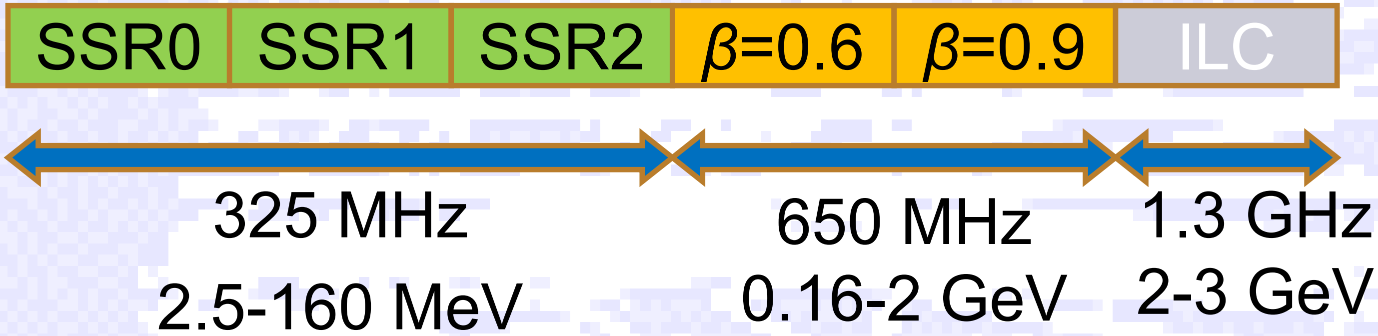
mu2e pulse (9e7) 162.5 MHz, 100 nsec	600 kW
Kaon pulse (9e7) 27 MHz	1200 kW
Nuclear pulse (9e7) 27 MHz	1200 kW





Separation scheme with traverse kicker ala JLAB.

SC CW Linac Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
SSR0 (β_G=0.11)	325	2.5-10	26 /26/1	SSR, solenoid
SSR1 (β_G=0.22)	325	10-32	18 /18/ 2	SSR, solenoid
SSR2 (β_G=0.4)	325	32-160	44 /24/ 4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-520	42 /21/ 7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	520-2000	96 /12/12	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	2000-3000	64 / 8/ 8	9-cell elliptical, quad

"Continuous Wave" (CW) Linac for Rare Processes…

- Beam extraction challenge is finessed.
- Duty factor is very high.
- The high frequency bandwidth intrinsic to a Linac can be exploited to generate excellent time resolution ($\delta t \sim 20 psec$) crucial to survival in a high intensity environment.
- JLAB has demonstrated that beam can be cleanly multiplexed between many targets with minimal losses. These "touchless" RF beam multiplexers are enabled by the high linac bandwidth.
- Excellent beam power scaling.

An Incomplete Menu of World Class Research Targets Enabled by Project-X

Neutrino Physics:

- Mass Hierarchy
- CP violation
- Precision measurement of the θ_{23} (atmospheric mixing). Maximal??
- Anomalous interactions, e.g. $\nu_\mu \rightarrow \nu_\tau$ probed with target emulsions (Madrid Neutrino NSI Workshop, Dec 2009)
- Search for sterile neutrinos, CP & CPT violating effects in next generation $\nu_e, \bar{\nu}_e \rightarrow X$ experiments.
- Next generation precision cross section measurements.

Day-1 Experiments

An Incomplete Menu of World Class Research Targets Enabled by Project-X. continued…

Muon Physics:

Day-1 Experiment

- Next generation muon-to-electron conversion experiment, new techniques for higher sensitivity and/or other nuclei.
- Next generation $(g\text{-}2)_\mu$ if motivated by next round, theory, LHC. New techniques proposed to JPARC that are beam-power hungry…
- μ edm
- $\mu \rightarrow 3e$
- $\mu^+ e^- \rightarrow \mu^- e^+$
- $\mu^- A \rightarrow \mu^+ A'$; $\mu^- A \rightarrow e^+ A'$; $\mu^- e^- (A) \rightarrow e^- e^- (A)$
- Systematic study of radiative muon capture on nuclei.

An Incomplete Menu of World Class Research Targets Enabled by Project-X. continued…

Kaon Physics:

Day-1 Experiments

- $K^+ \to \pi^+\nu\bar{\nu}$: >1000 events, Precision rate and form factor.
- $K_L \to \pi^0\nu\bar{\nu}$: 1000 events, enabled by high flux & precision TOF.
- $K^+ \to \pi^0\mu^+\nu$: Measurement of T-violating muon polarization.
- $K^+ \to (\pi,\mu)^+\nu_X$: Search for anomalous heavy neutrinos.
- $K_L \to \pi^0 e^+ e^-$: <10% measurement of CP violating amplitude.
- $K_L \to \pi^0\mu^+\mu^-$: <10% measurement of CP violating amplitude.
- $K^0 \to X$: Precision study of a pure K^0 interferometer: Reaching out to the Plank scale ($\Delta m_K/m_K \sim 1/m_P$)
- $K^0, K^+ \to LFV$: Next generation Lepton Flavor Violation experiments

…and more

An Incomplete Menu of World Class Research Targets Enabled by Project-X. continued…

Day-1 Experiment

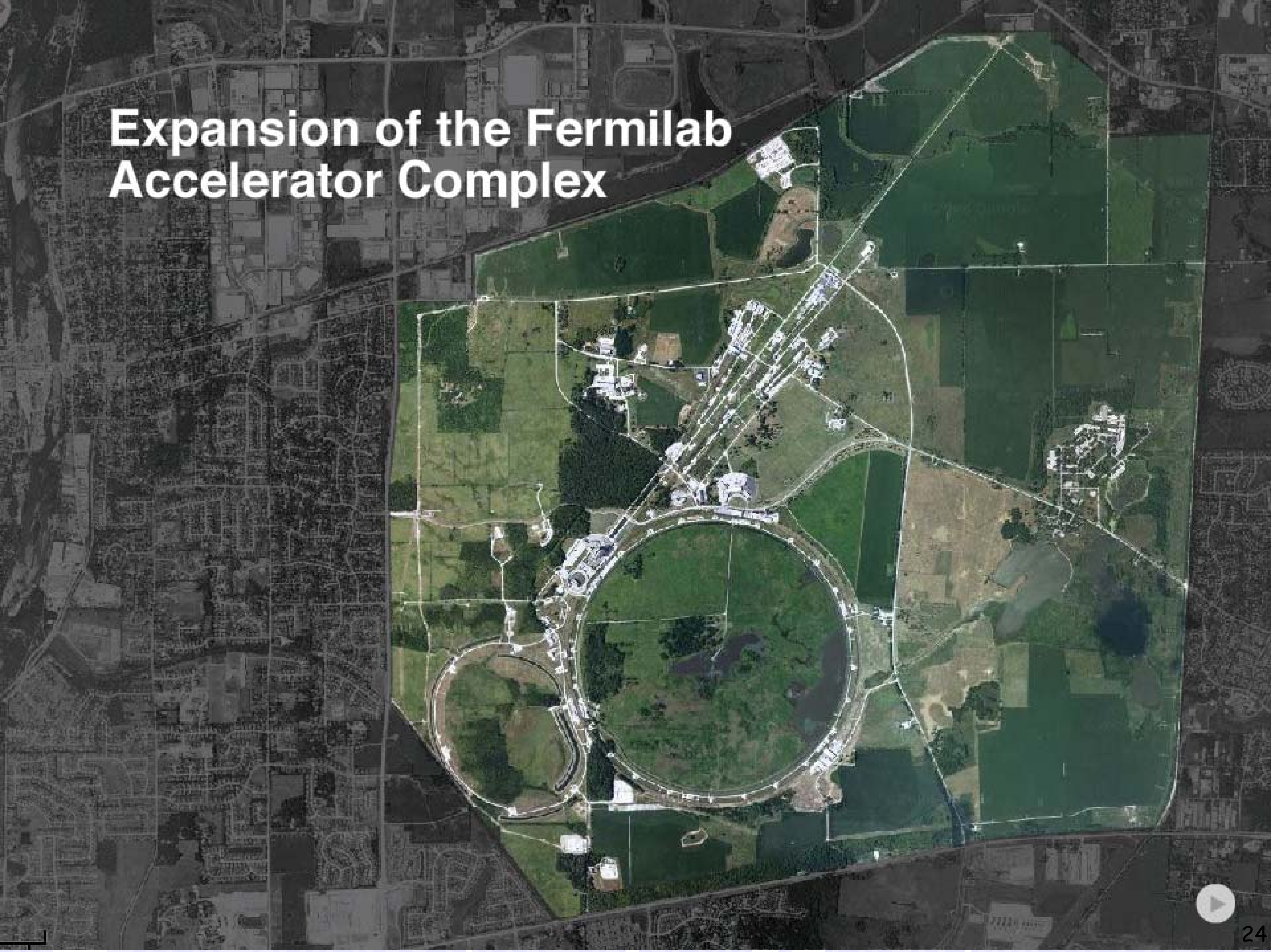
Nuclear Enabled Particle Physics:

- Production of Ra, Rd, Fr isotopes for nuclear edm experiments that are uniquely sensitive to Quark-Chromo and electron EDM's.

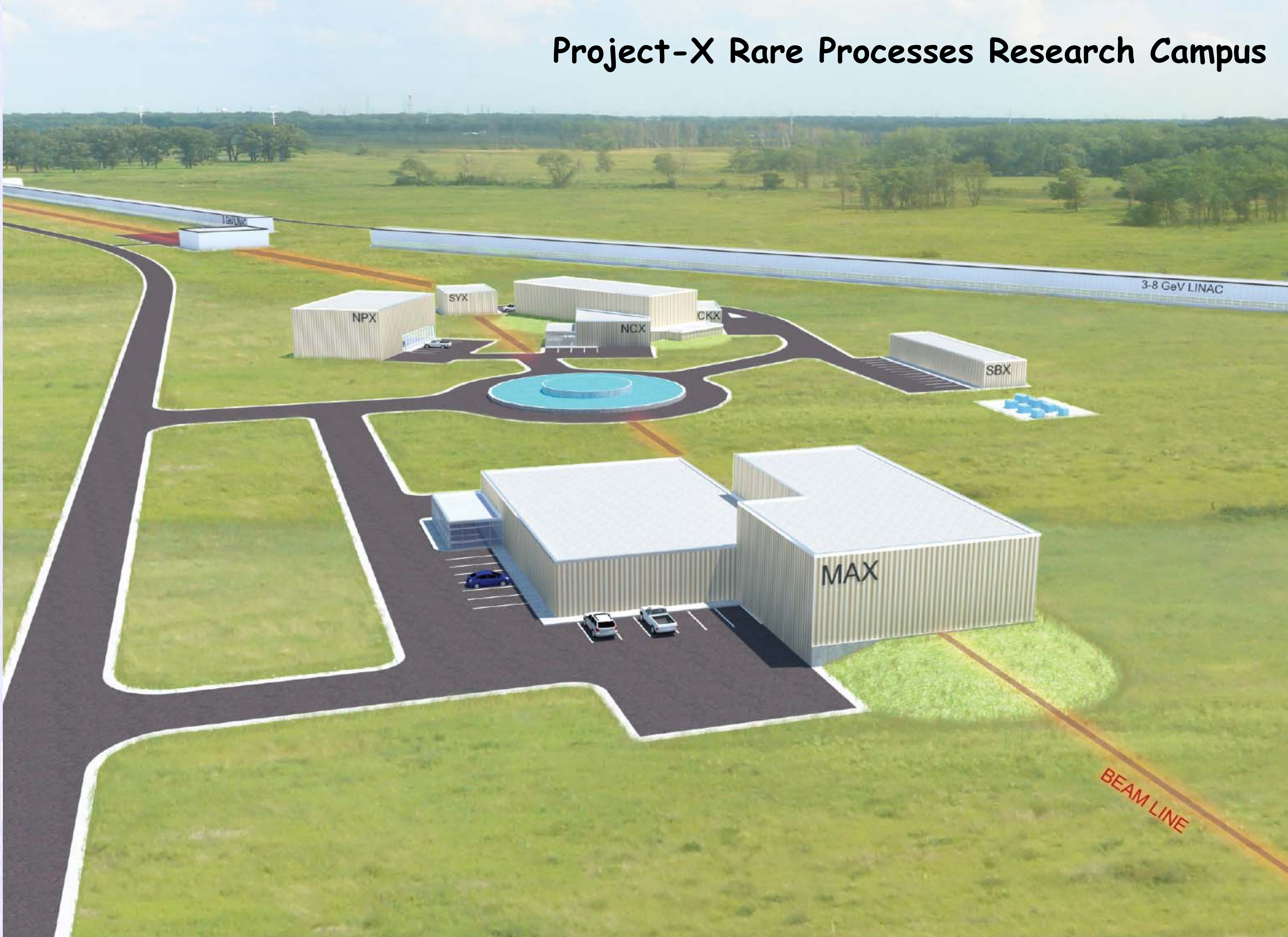
Baryons Physics:

- pp $\rightarrow \bar{\Sigma}^{+} K^{0} p^{+}$; $\Sigma^{+} \rightarrow p^{+} \mu^{+} \mu^{-}$ (HyperCP anomaly, and other rare Σ^{+} decays)
- pp $\rightarrow K^{+} \Lambda^{0} p^{+}$; Λ^{0} ultra rare decays
- $\Lambda^{0} \leftrightarrow \Lambda^{0}$ oscillations (Project-X operates below anti-baryon threshold)
- Neutron EDMs

Expansion of the Fermilab Accelerator Complex



Project-X Rare Processes Research Campus



Summary

Project-X is a next generation high intensity proton source that can deliver:

Neutrinos: An after-burner for LBNE that reduces the tyranny of (Detector-Mass **x** Running-time) by **x3**, and a foundation for a Neutrino Factory.

Rare Processes: Game-changing beam power and timing flexibility that can support a broad range of particle physics experiments.

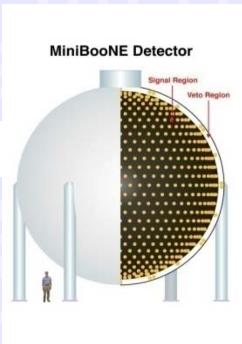
Lepton Collider: A platform for Muon Collider development.

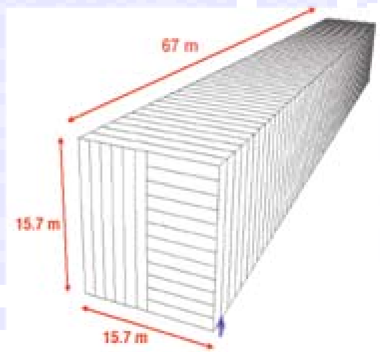
Prospects: International collaboration formed, ongoing substantial US (DOE) investments in R&D (Project-X + SRF + ILC) on Super Conducting RF accelerator technology supporting Project-X.

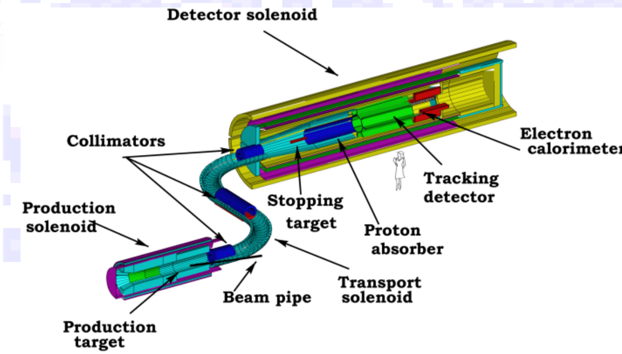
Earliest construction start of 2015, operations in 2020.

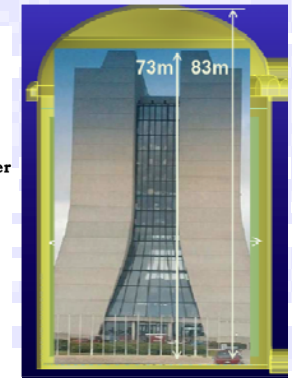
Spare Slides

Intensity Frontier Strategy & Timeline





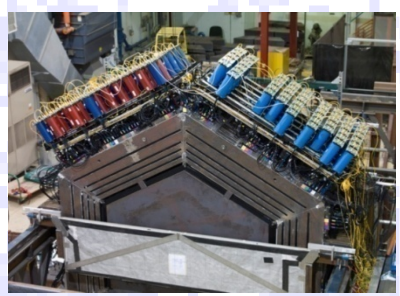


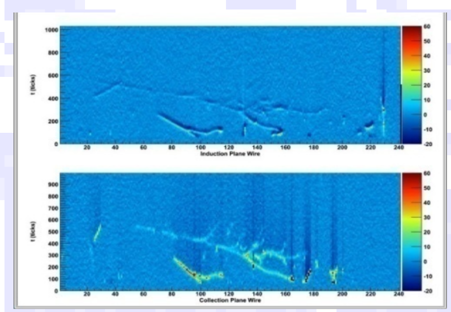


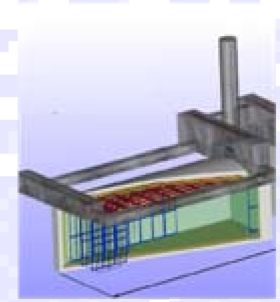
Intensity

Now – 2013	2013 – 2016	2016 – 2019	2019 – 2022
MINOS MiniBooNE MINERvA SeaQuest	NOvA MicroBooNE g-2? SeaQuest	LBNE Mu2e	Project X+LBNE μ, K, nuclear, … ν Factory ??

Now 2013 2016 2019 2022







Beam Requirements for a World Leading Rare Processes Program

	Proton Energy (kinetic)	Beam Power	Beam Timing
Rare Muon decays	2-3 GeV	>500 kW	1 kHz – 160 MHz
(g-2) measurement	8 GeV	20-50 kW	30- 100 Hz.
Rare Kaon decays	2.6 – 4 GeV	>500 kW	20 – 160 MHz. (<50 psec pings)
Precision K^0 studies	2.6 – 3 GeV	> 200kW (100μA internal target)	20 – 160 MHz. (<50 psec pings)
Neutron and exotic nuclei EDMs	1.5-2.5 GeV	>500 kW	> 100 Hz

High Duty-Factor Proton Beams
Why is this important to Rare Processes?

- Experiments that reconstruct an "event" to a particular time from sub-detector elements are intrinsically vulnerable to making mistakes at high instantaneous intensity (I). The probability of making a mistake is proportional to $I^2 \times \delta t$, where δt is the event resolving time.

- Searching for rare processes requires high intensity.

- Controlling backgrounds means minimizing the instantaneous rate and maximizing the time resolution performance of the experiment.

- This is a common problem for Run-II, LHC, Mu2e, High-School class reunions, etc.

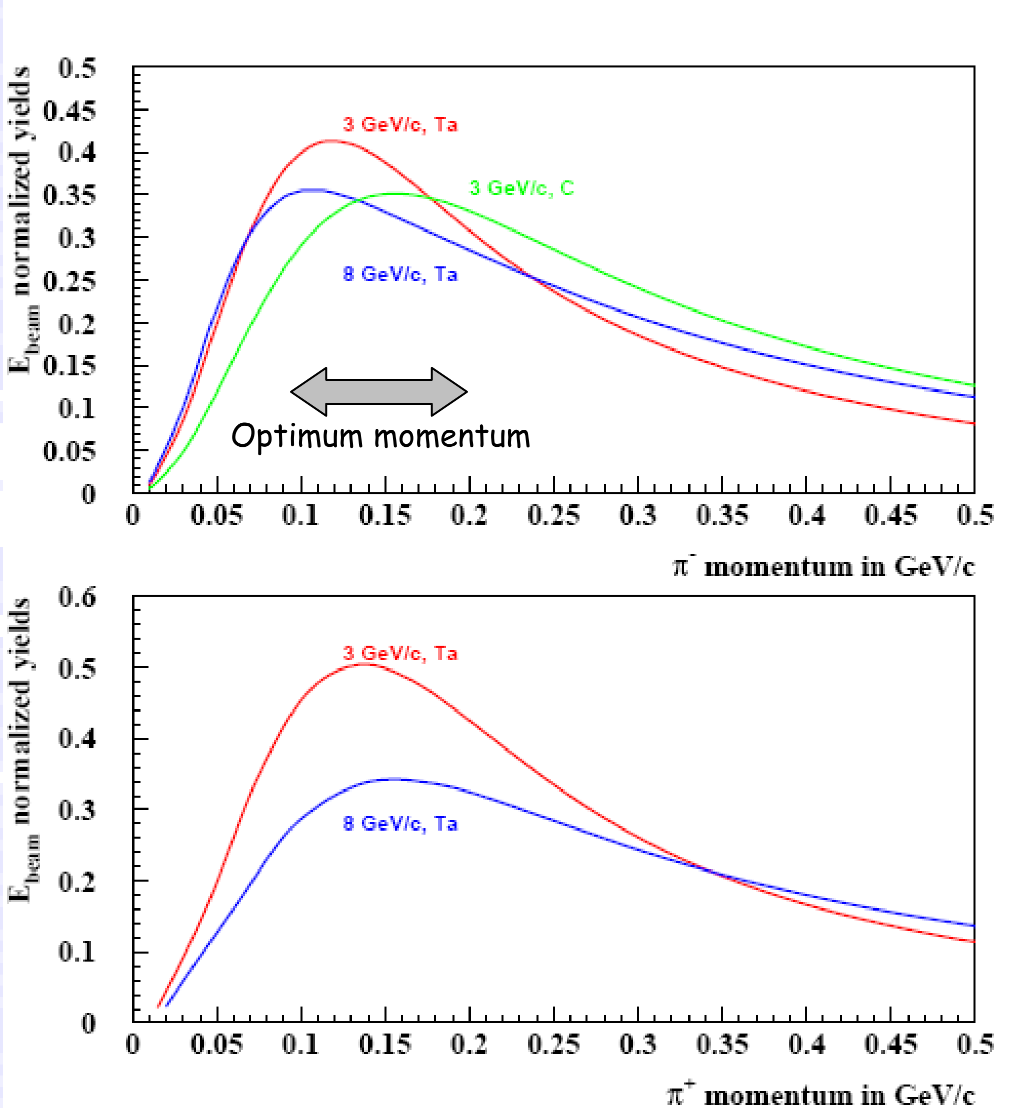
Slow Extracted Beam: The Standard Tool to Drive Ultra Rare Decay Experiments

- Techniques developed in the late 1960's to "slow spill" beam from a synchrotron.
- Technique operates at the edge of stability---Betatron oscillations are induced which interact with material in the beam (wire septum) to eject particles from the storage ring beam phase space.
- Technique limited by septum heating & damage, beam losses, and space charge induced instabilities. Works better at higher energies where the beam-power/charge ratio is more favorable.
- Performance milestones:

  Tevatron 800 GeV FT: 64 kW of SEB in 1997.
  BNL AGS 24 GeV beam, 50-70 kW of SEB.

- JPARC Goal: 300 kW of SEB someday, a few kW within reach now.

What is the optimum energy for producing low-energy muons?



LAQGSM/MARS simulation validated with HARP data

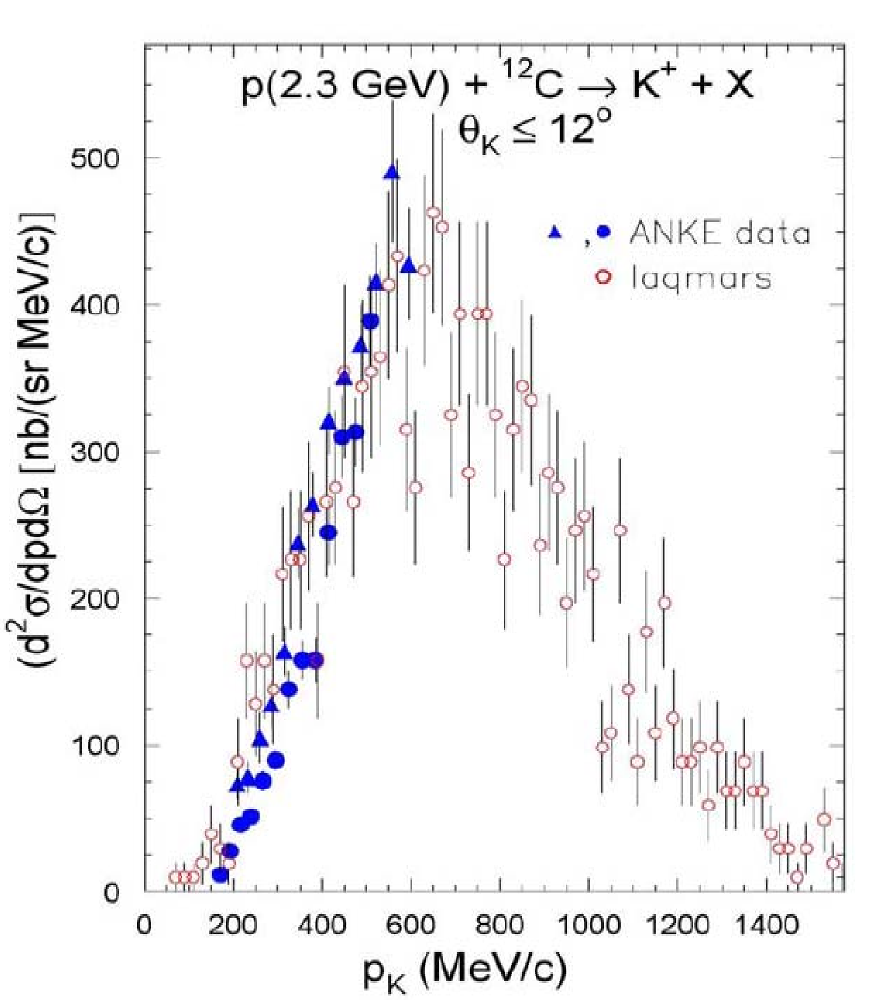
Sensitivity of Kaon Physics Today

- CERN NA62: 100×10^{-12} measurement sensitivity of $K^+ \to e^+\nu$
- Fermilab KTeV: 20×10^{-12} measurement sensitivity of $K_L \to \mu\mu ee$
- Fermilab KTeV: 20×10^{-12} search sensitivity for $K_L \to \pi\mu e$, $\pi\pi\mu e$
- BNL E949: 20×10^{-12} measurement sensitivity of $K^+ \to \pi^+\nu\bar{\nu}$
- BNL E871: 1×10^{-12} measurement sensitivity of $K_L \to e^+e^-$
- BNL E871: 1×10^{-12} search sensitivity for $K_L \to \mu e$

Probing new physics above a 10 TeV scale with 20-50 kW of protons.

Next goal: 1000-event $\pi\nu\nu$ **experiments...10^{-14} sensitivity**.

Validating Simulation Tools…



- Los Alamos + MARS simulation suite (LAQGSM + MARS15) is now a state of the art tool set to simulate the challenging region between 1-4 GeV/c proton beam momentum.

[Gudima, Mokhov, Striganov]

- Validated against the high quality data sets from COSY.

- Data shown: Buscher et al (2004) ANKE experiment at COSY, absolutely normalized.

Kaon Yields at Constant Beam Power

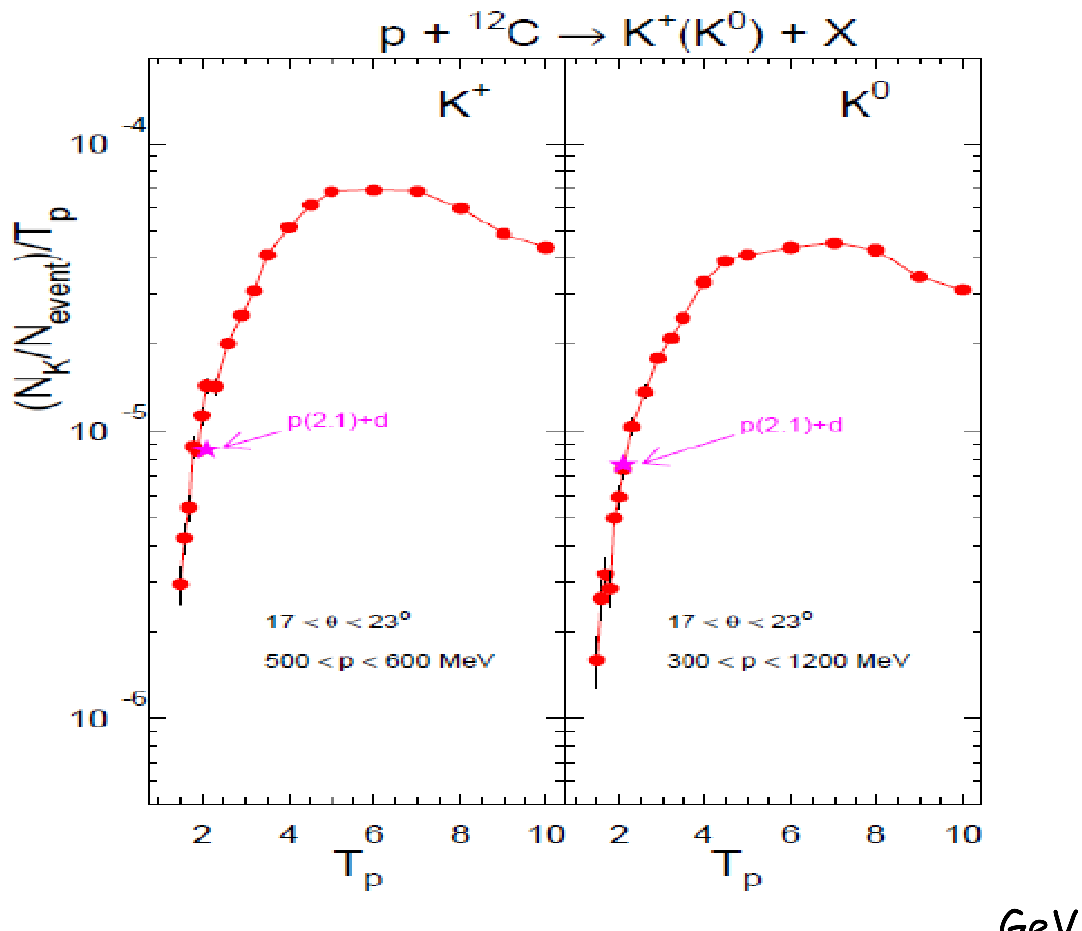
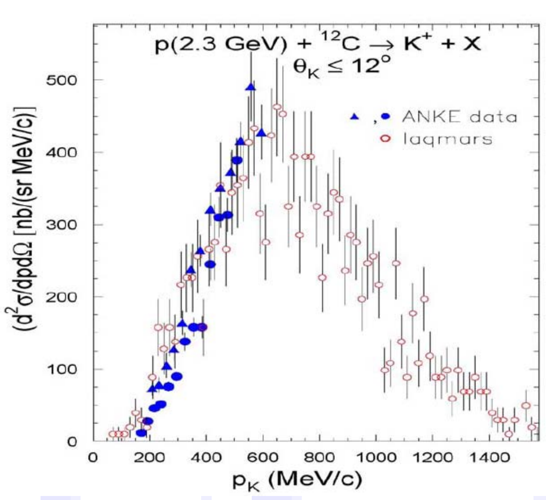


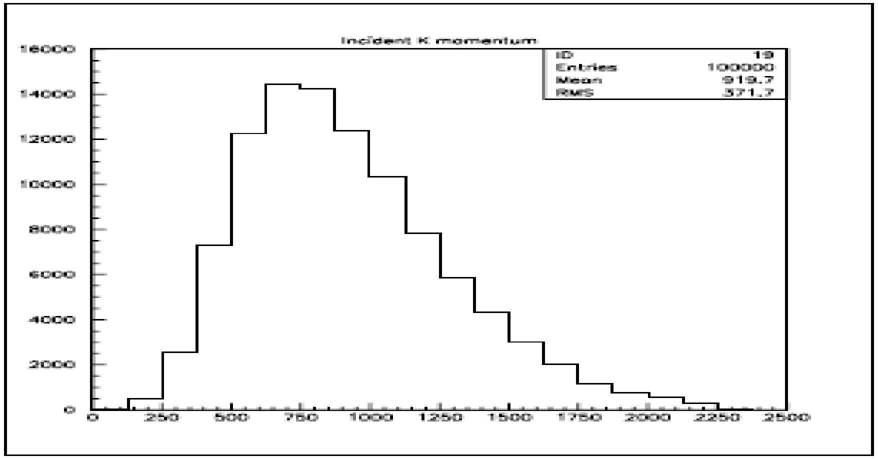
Figure 17: The K → πνν experiment (3.2.3.1 and 3.2.3.2) K$^+$ and K$_L$ yields at constant beam-power as a function of T$_p$ (GeV).

Optimum yield for IC2 kaon experiments is 4-8 GeV. Minimum for next round of experiments is 2.6 GeV.

From: Project-X Research Program

KOPIO-AGS and Project-X kaon momentum spectra comparison



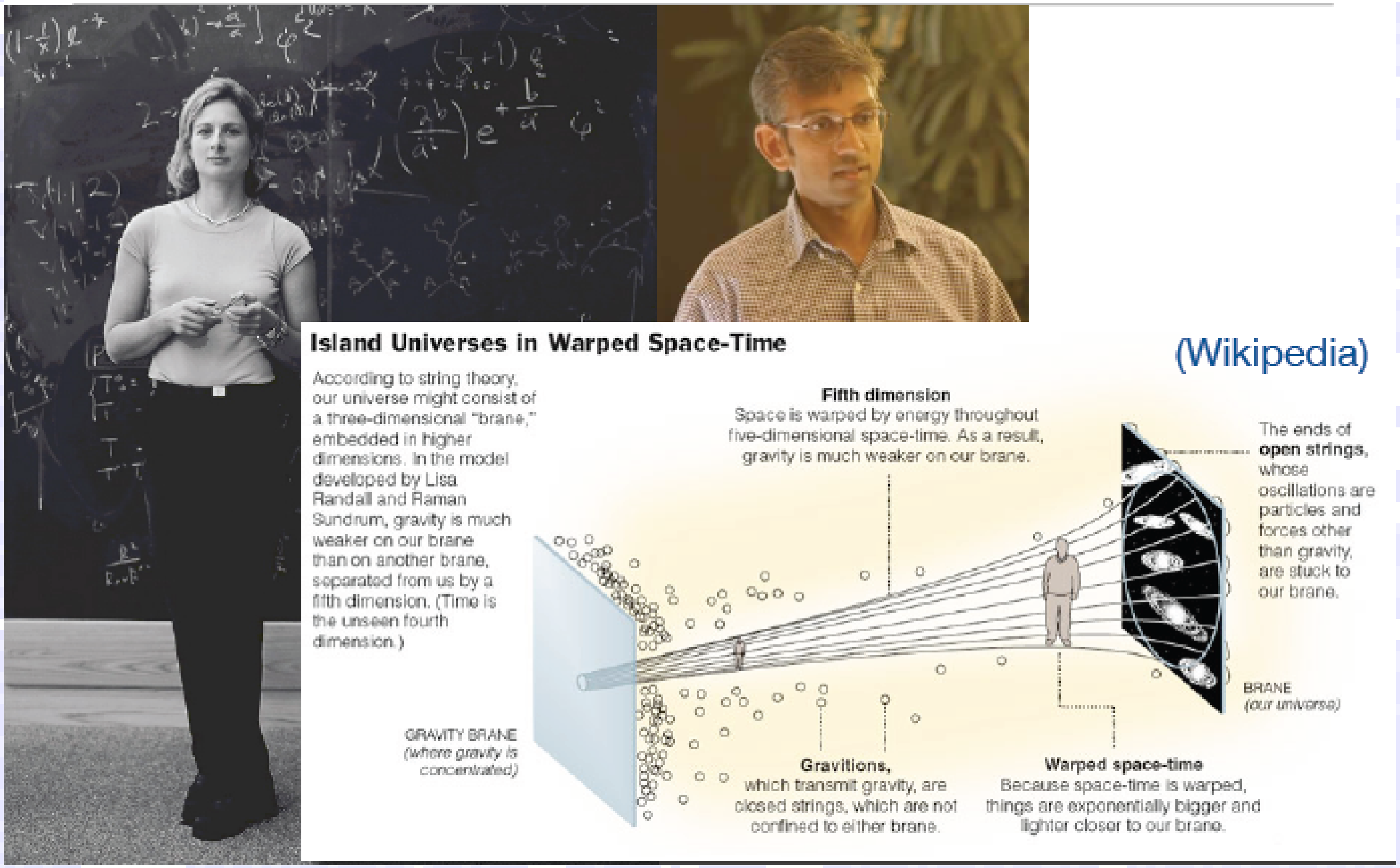


KOPIO Proposal

Figure 13: K_L^0 spectrum incident on KOPIO decay volume.

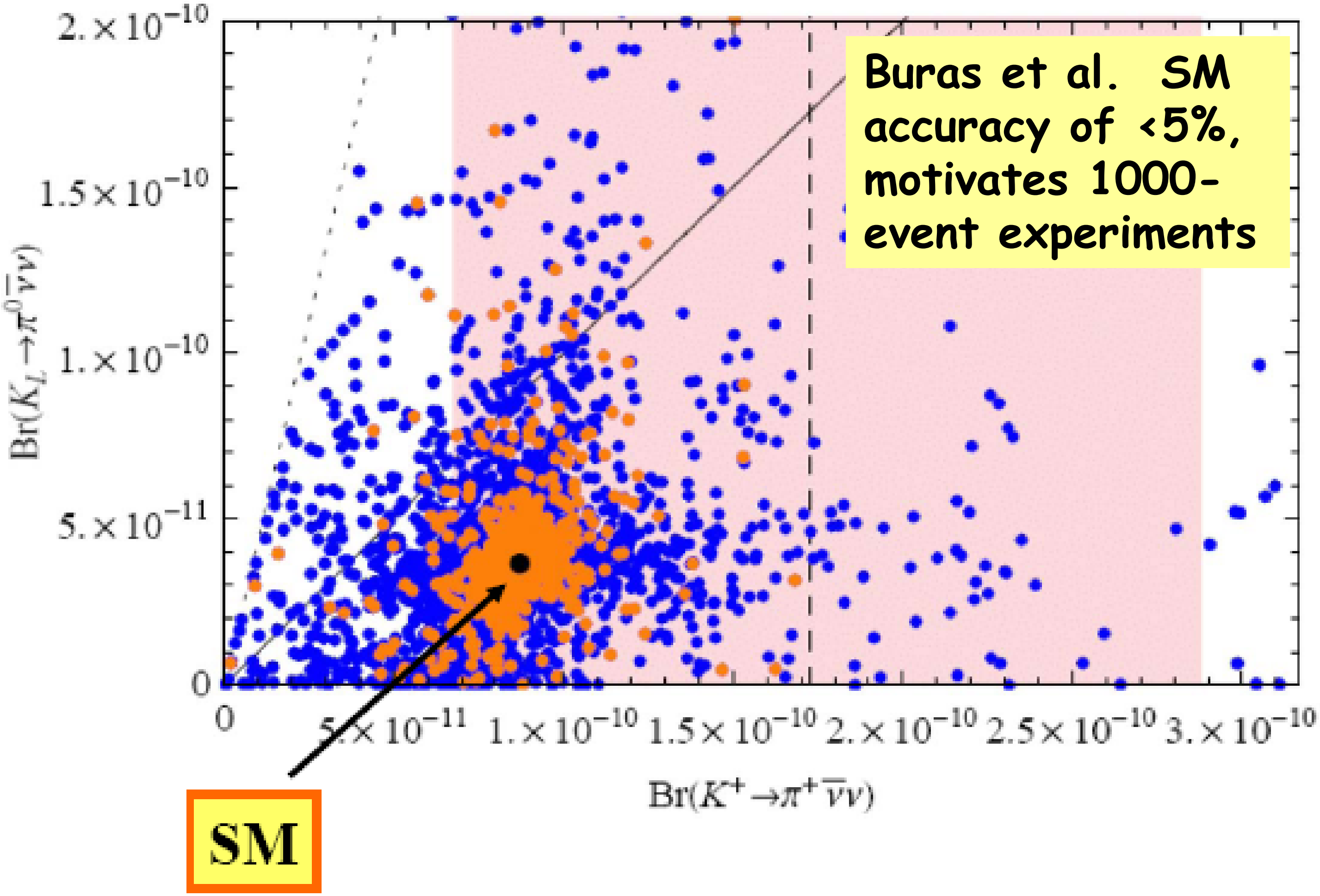
Rates sensitive to other BSMs: Warped Extra Dimensions as a Theory of Flavor??

The Randall-Sundrum (RS) idea



$K_L \to \pi^0 \nu\bar{\nu}$ vs. $K^+ \to \pi^+ \nu\bar{\nu}$ (RS)

(Up to Factor 3 and 2 Enhancements)



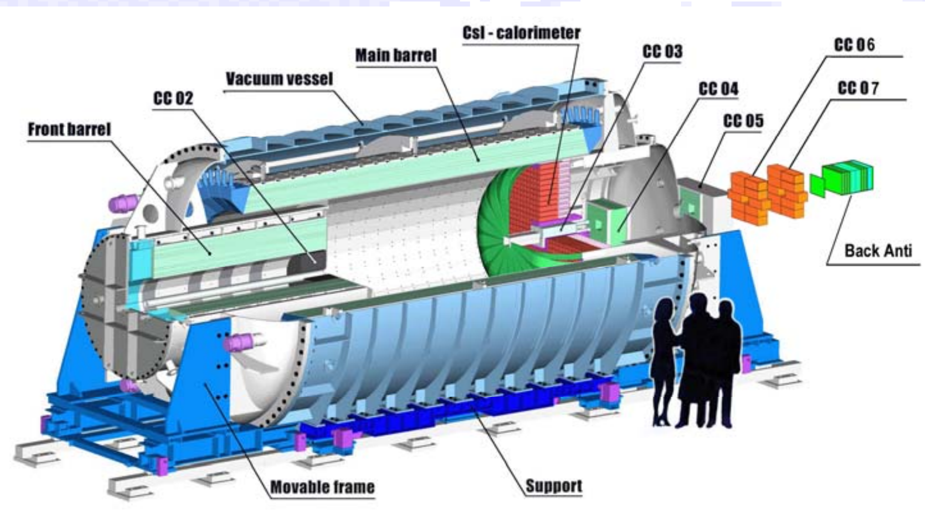
Effect of Warped Extra Dimension Models on Branching Fractions

$K_L \rightarrow \pi^0 \nu\nu$ Experimental Challenge: "Nothing-in nothing out"

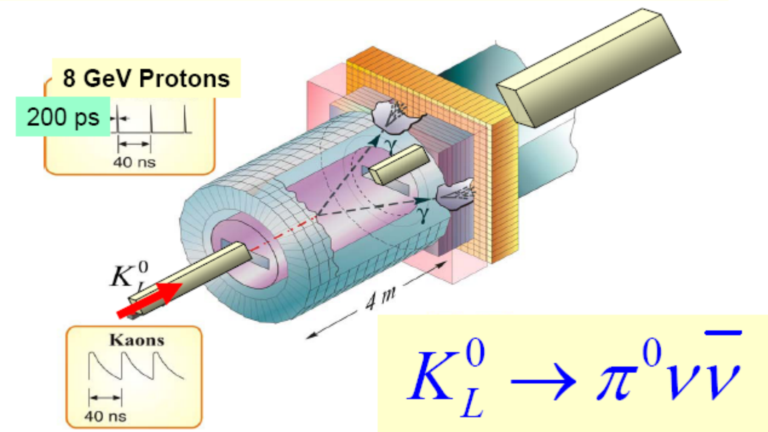
- KEK/JPARC approach emphasizes high acceptance for the two decay photons while vetoing everything else:

A hermetic "bottle" approach.

- The original KOPIO concept measures the kaon momentum and photon direction…Good! But costs detector acceptance and requires a large beam to compensate. Project-X Flux can get back to small kaon beam!



Another $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ Experiment Concept



- Use TOF to work in the K_L^0 c.m. system
- Identify main 2-body background $K_L^0 \rightarrow \pi^0 \pi^0$
- Reconstruct $\pi^0 \rightarrow \gamma\gamma$ decays with pointing calorimeter
- 4π solid angle photon and charged particle vetos

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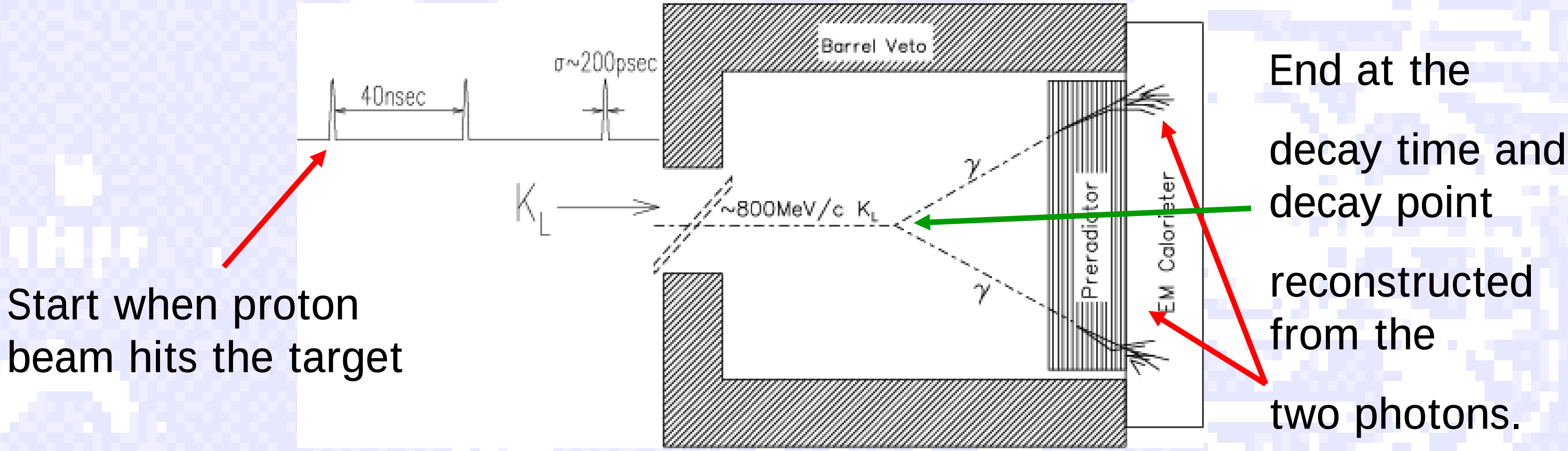
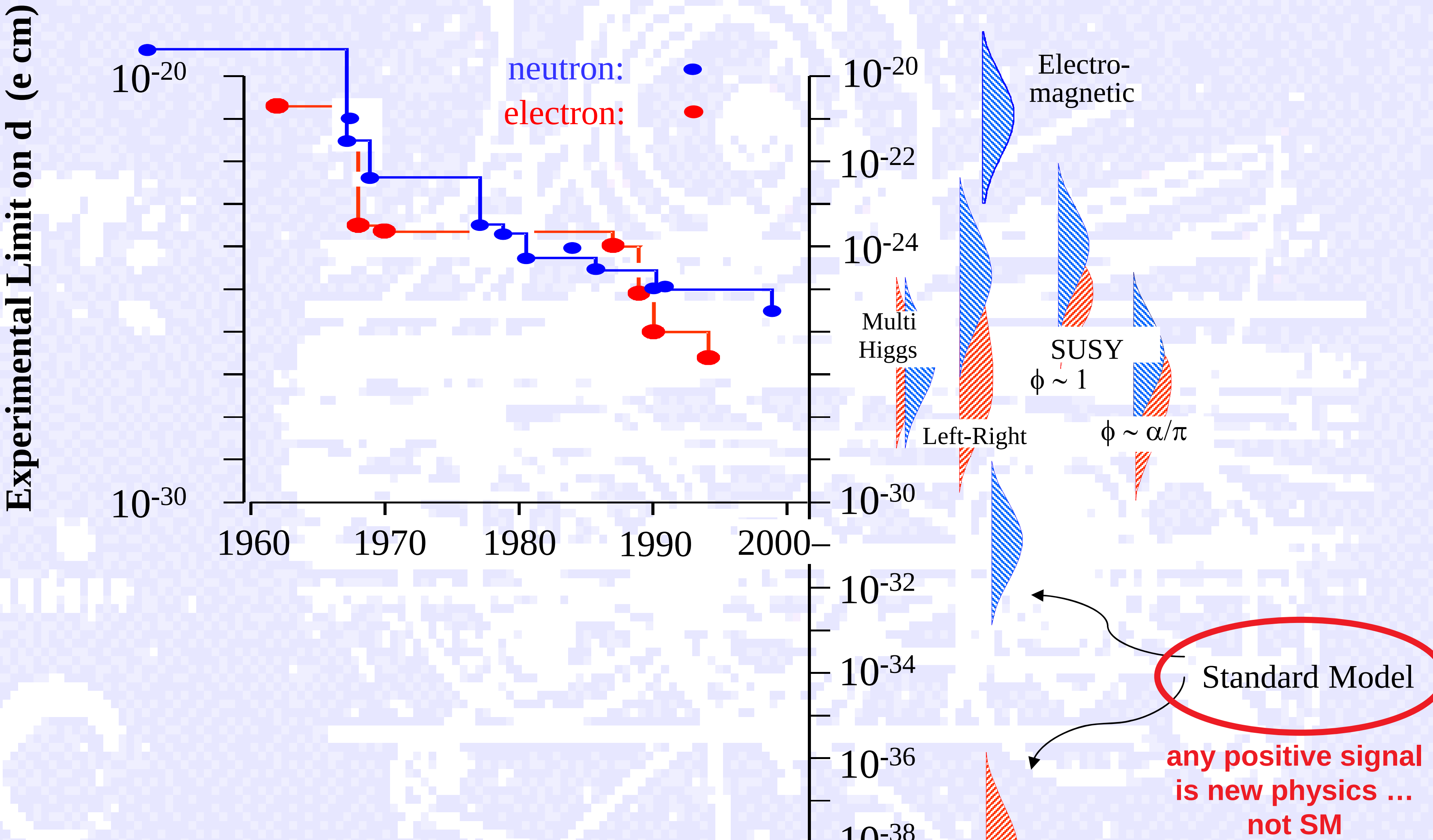
KOPIO inspired: Micro-bunch the beam, TOF determines K_L momentum.

Fully reconstruct the neutral Kaon in $K_L \rightarrow \pi^0 \nu \bar{\nu}$ measuring the Kaon momentum by time-of-flight.



Timing uncertainty due to microbunch width should not dominate the measurement of the kaon momentum; requires RMS width < 200ps. CW linac pulse timing of less than 50ps is intrinsic.

EDM measurements: BSM slayers



Updated from Barr: Int. J. Mod Phys. A8 208 (1993)

any positive signal is new physics … not SM

Guy Savard, ANL

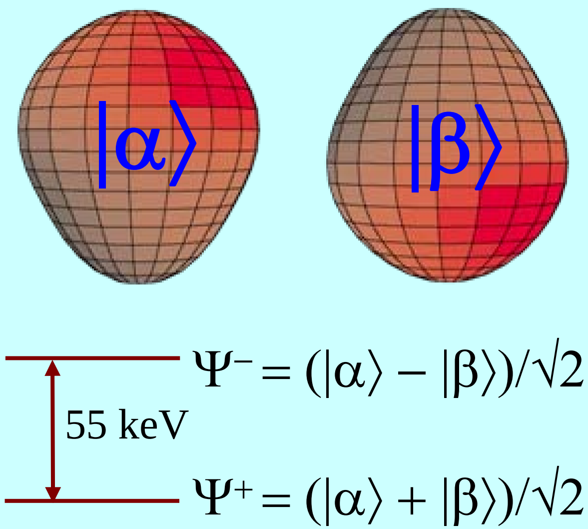
Enhanced EDM of ^{225}Ra

Enhancement mechanisms:

- Large intrinsic Schiff moment due to octupole deformation;
- Closely spaced parity doublet;
- Relativistic atomic structure.

Haxton & Henley (1983)
Auerbach, Flambaum & Spevak (1996)
Engel, Friar & Hayes (2000)

Parity doublet



$$\Psi^- = (|\alpha\rangle - |\beta\rangle)/\sqrt{2}$$

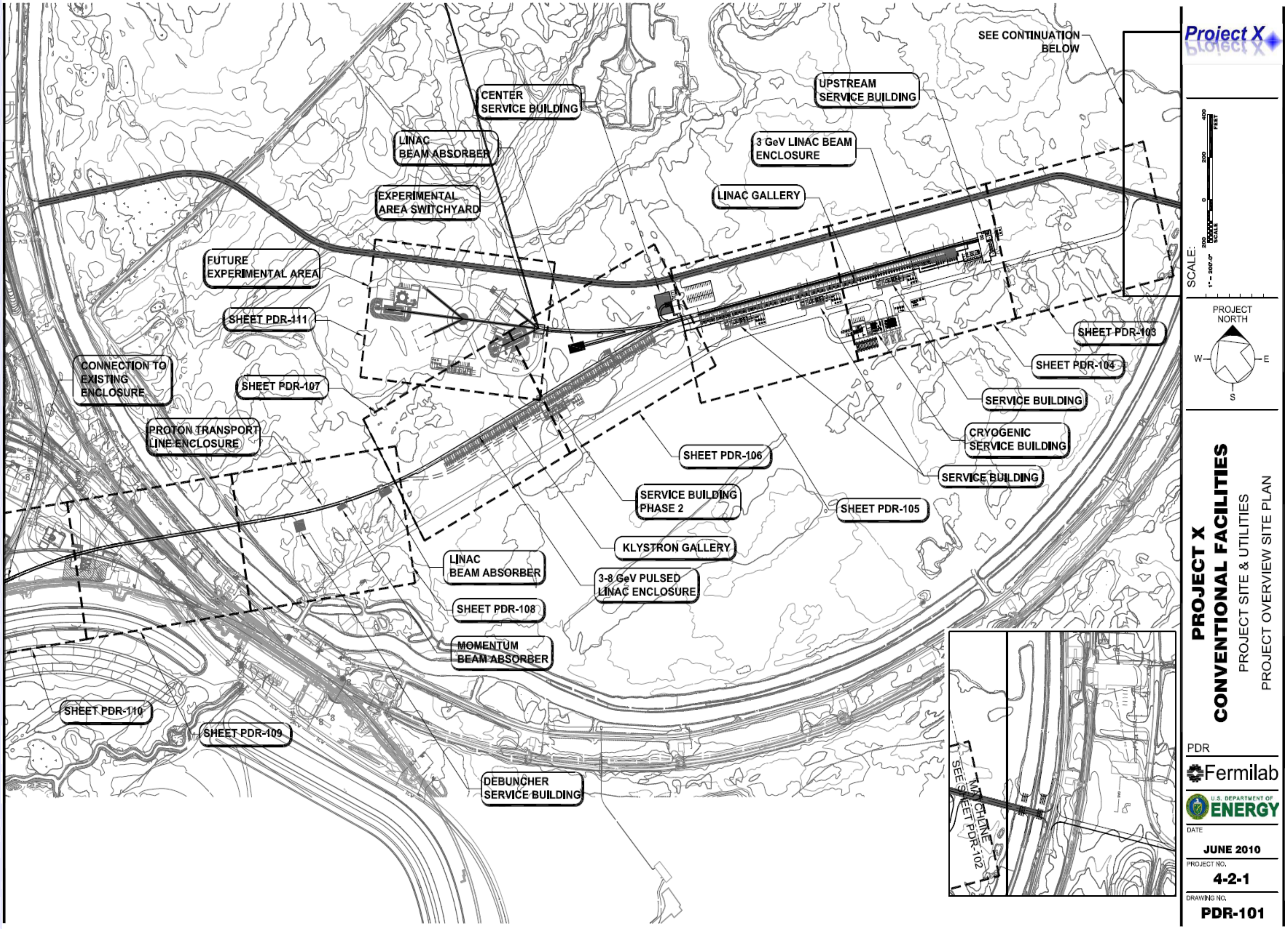
$$\Psi^+ = (|\alpha\rangle + |\beta\rangle)/\sqrt{2}$$

Enhancement Factor: EDM (^{225}Ra) / EDM (^{199}Hg)

Skyrme Model	Isoscalar	Isovector	Isotensor
SkM*	1500	900	1500
SkO'	450	240	600

Schiff moment of ^{199}Hg, de Jesus & Engel, PRC (2005)
Schiff moment of ^{225}Ra, Dobaczewski & Engel, PRL (2005)

Guy Savard, ANL



Project X
SEE CONTINUATION BELOW
CENTER SERVICE BUILDING
UPSTREAM SERVICE BUILDING
LINAC BEAM ABSORBER
3 GeV LINAC BEAM ENCLOSURE
EXPERIMENTAL AREA SWITCHYARD
LINAC GALLERY
FUTURE EXPERIMENTAL AREA
SHEET PDR-111
SHEET PDR-103
CONNECTION TO EXISTING ENCLOSURE
SHEET PDR-107
SHEET PDR-104
SERVICE BUILDING
PROTON TRANSPORT LINE ENCLOSURE
CRYOGENIC SERVICE BUILDING
SHEET PDR-106
SERVICE BUILDING
SERVICE BUILDING PHASE 2
SHEET PDR-105
KLYSTRON GALLERY
LINAC BEAM ABSORBER
3-8 GeV PULSED LINAC ENCLOSURE
SHEET PDR-108
MOMENTUM BEAM ABSORBER
SHEET PDR-110
SHEET PDR-109
DEBUNCHER SERVICE BUILDING
MATCHLINE SEE SHEET PDR-102
SCALE: 1" = 200'-0"
PROJECT NORTH
W
E
S
PROJECT X
CONVENTIONAL FACILITIES
PROJECT SITE & UTILITIES
PROJECT OVERVIEW SITE PLAN
PDR
Fermilab
U.S. DEPARTMENT OF ENERGY
DATE
JUNE 2010
PROJECT NO.
4-2-1
DRAWING NO.
PDR-101