Project-X

ICHEP , July 24, 2010

R.Tschirhart
FNAL

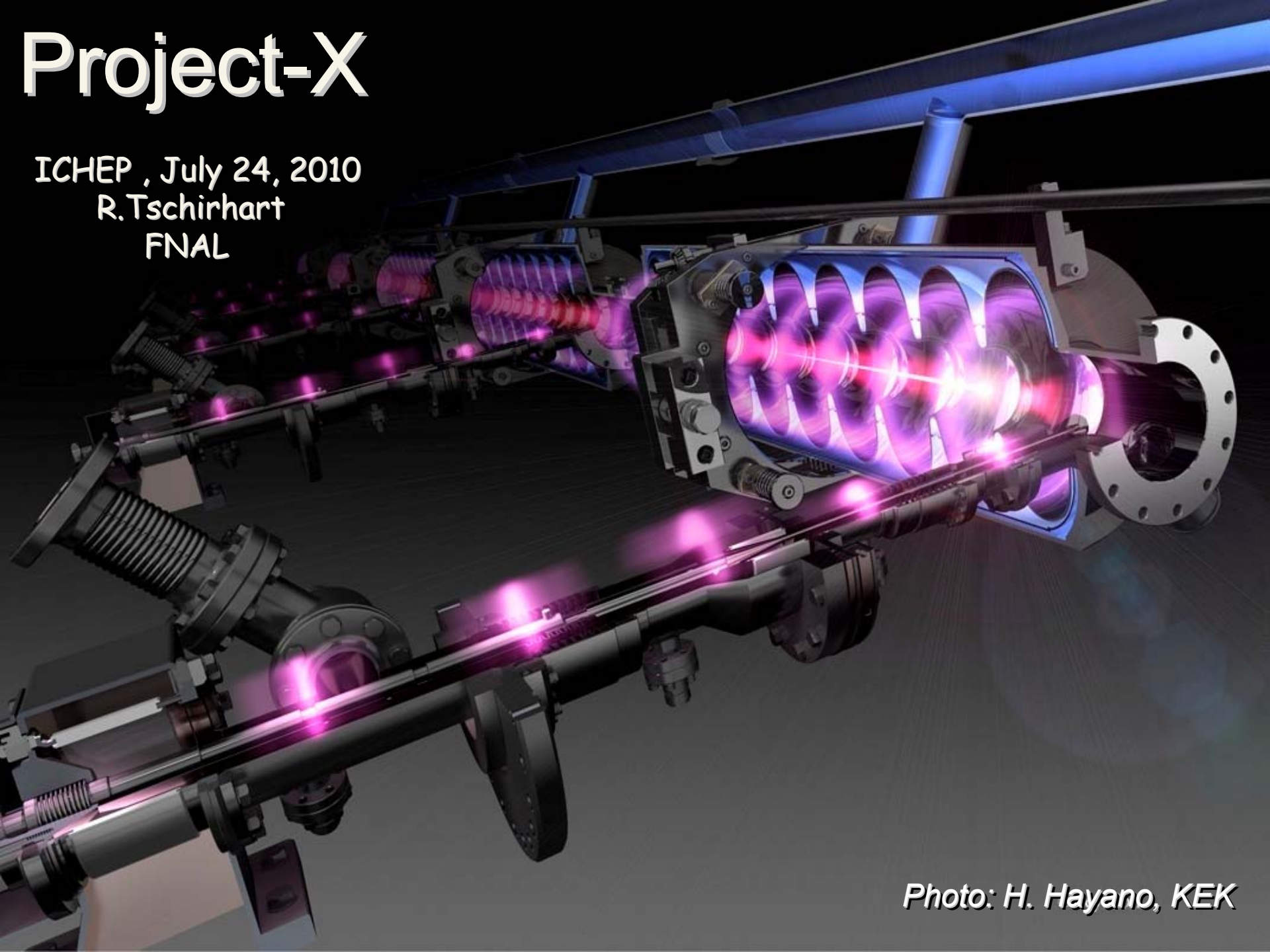
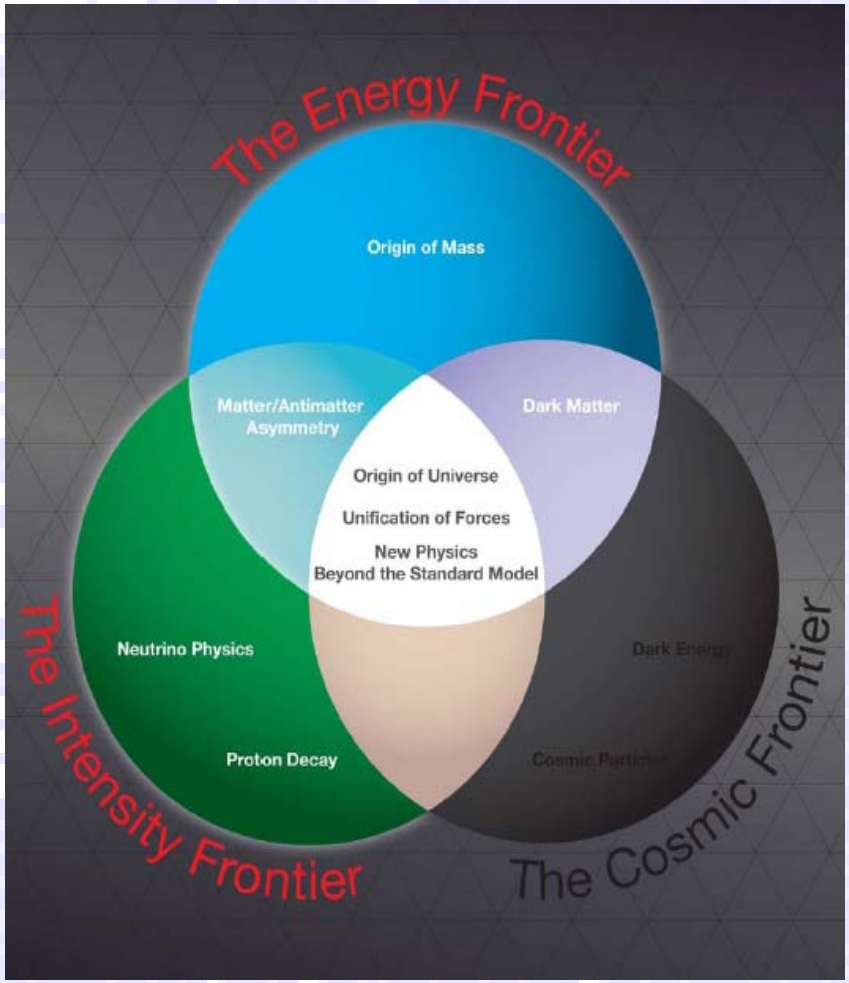


Photo: H. Hayano, KEK

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:***

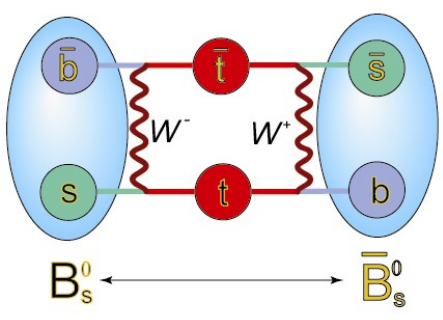
  These could include world leading experiments searching for muon-to-electron conversion, nuclear and neutron electron dipole moments (edms), and world-leading precision measurements of ultra-rare kaon decays.

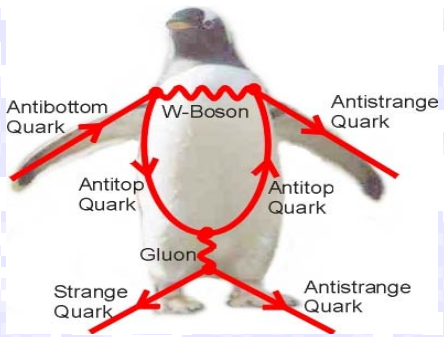
- ***Platform for evolution to a Neutrino Factory and Muon Collider***

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??

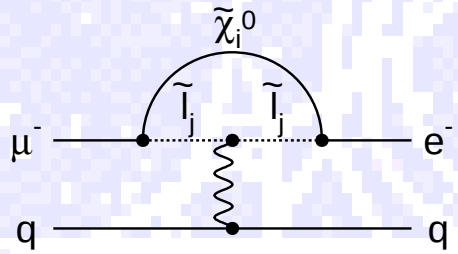


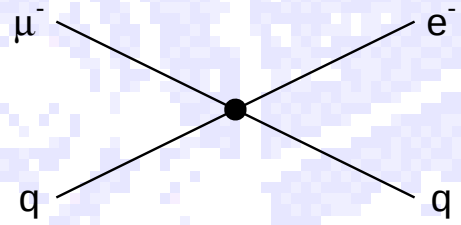


Deepest Probe of the Flavor Probem: Ultra-rare Muon Experiments at Project-X

Supersymmetry

Predictions at 10^{-15}



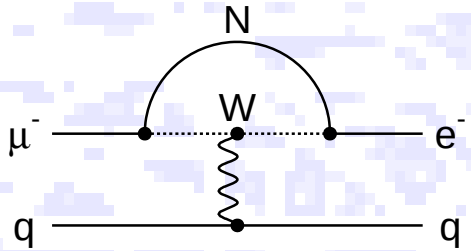


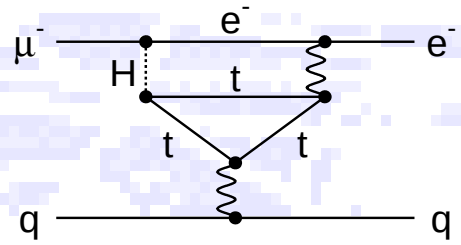
Compositeness

$\Lambda_C = 3000$ TeV

Heavy Neutrinos

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



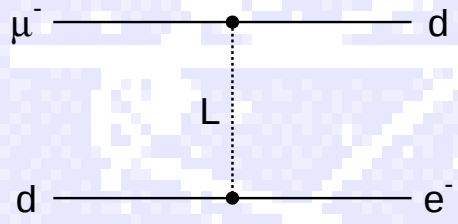


Second Higgs doublet

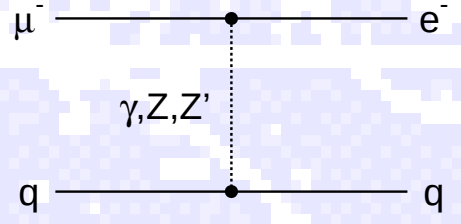
$g_{H_{\mu e}} = 10^{-4} \times g_{H_{\mu\mu}}$

Leptoquarks

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



After W. Marciano

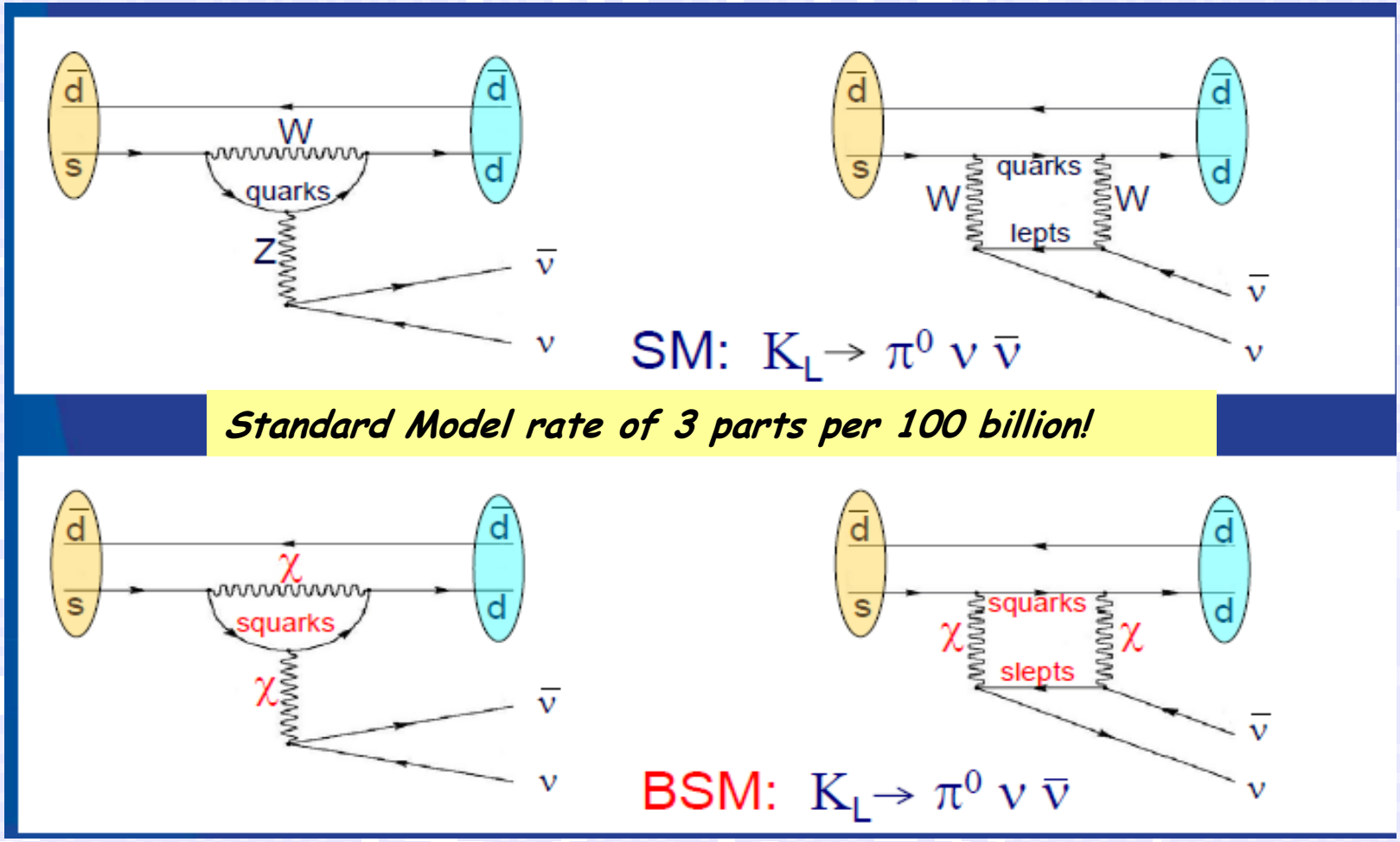


Heavy Z', Anomalous Z coupling

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

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

The Window of Ultra-rare Kaon Decays in Project X

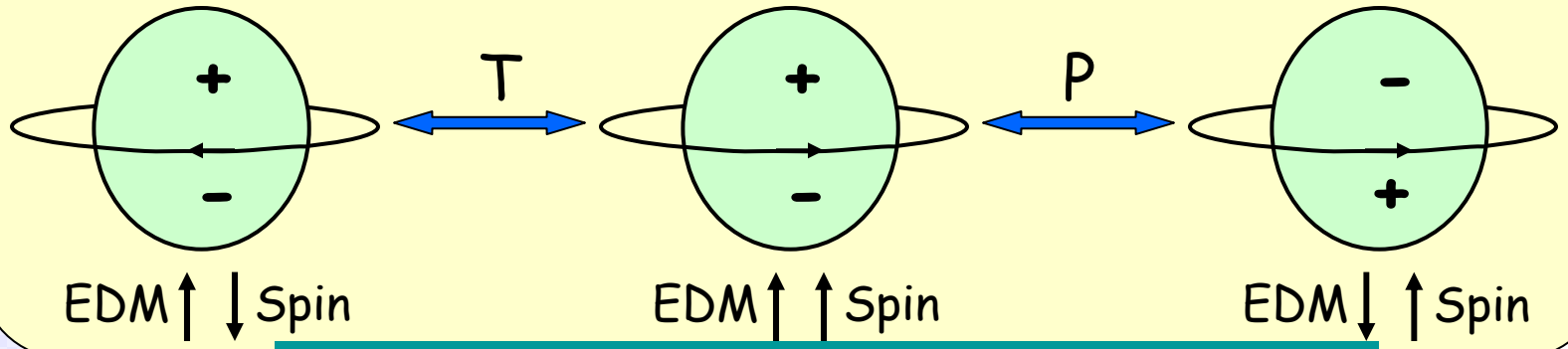


Standard Model rate of 3 parts per 100 billion!

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!

Neutron → Quark EDM

Diamagnetic Atoms (Hg, Xe, Ra, Rn) → Quark Chromo-EDM

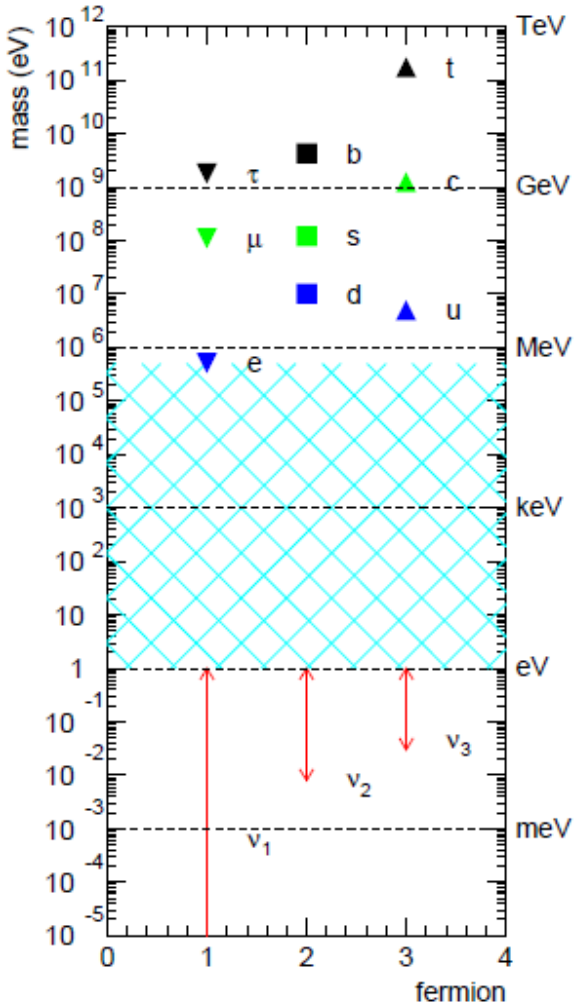
Paramagnetic Atoms (Tl, Fr) Molecules (PbO) → Electron EDM

Quark EDM, Quark Chromo-EDM, Electron EDM → Physics beyond the Standard Model: SUSY, Strings …

Guy Savard, ANL

What are Neutrinos Telling Us?

André de Gouvêa — Northwestern



What We Are Trying To Understand:

⇐ NEUTRINOS HAVE TINY MASSES

⇓ LEPTON MIXING IS "WEIRD" ⇓

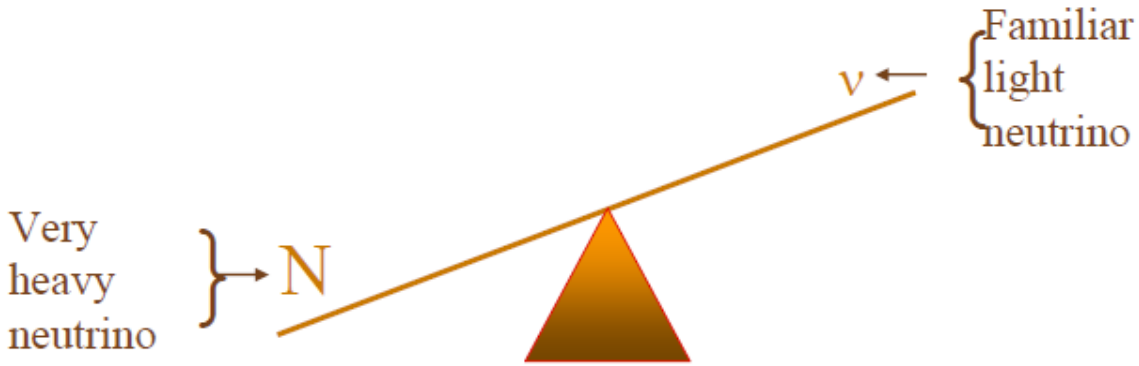
$$V_{MNS} \sim \begin{pmatrix} 0.8 & 0.5 & 0.2 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} \qquad V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.001 \\ 0.2 & 1 & 0.01 \\ 0.001 & 0.01 & 1 \end{pmatrix}$$

What Does It Mean?

Andre de Gouvea

Leveraging to the Unification Scale

See-Saw Mechanism



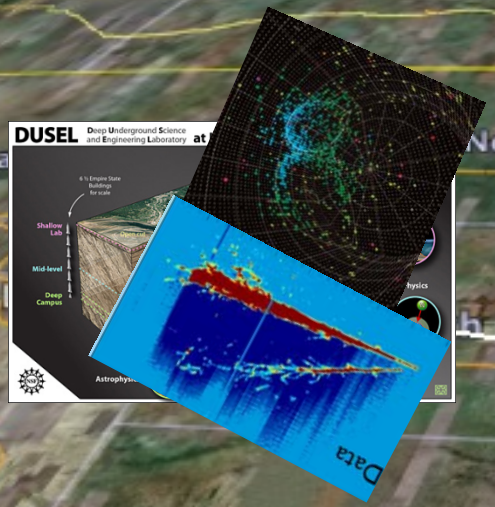
Mass(N) ~ 10^{15} GeV

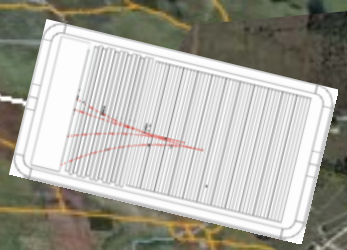
The strong, EM, and weak forces unify at ~ 10^{16} GeV

Unification? Leptogenisis?

Boris Kayser

Long Baseline Neutrino Experiment





New Neutrino Beam at Fermilab…

…Directed towards NSF's proposed DUSEL

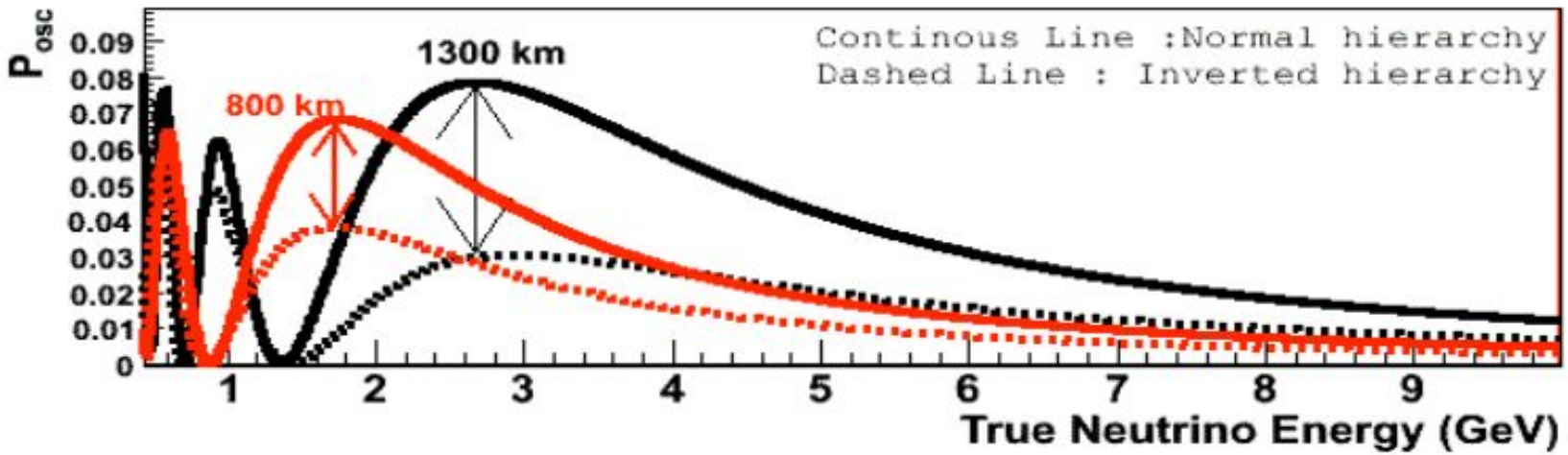
Precision Near Detector on the Fermilab site

100 kT fiducial volume Water Cherenkov Far Detector

17 kT fiducial volume Liquid Argon TPC Far Detector

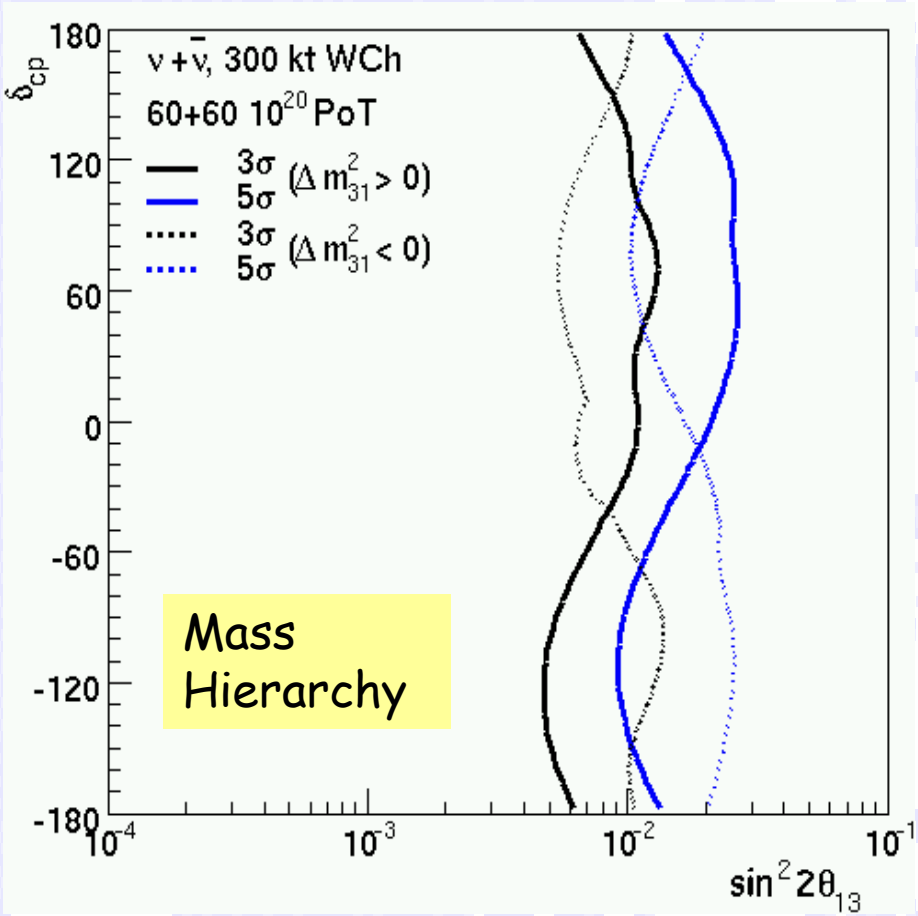
Why DUSEL?

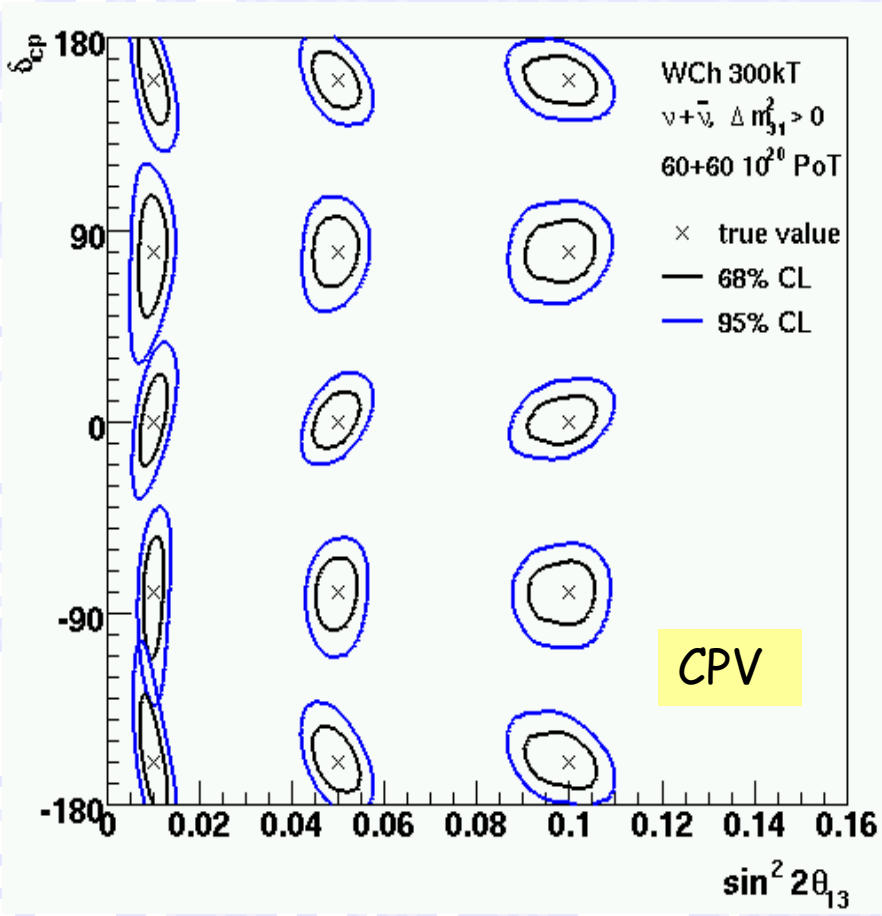
- 1300 km distance is a good compromise of mass-hierarchy and CP violation sensitivities
- Deep underground site allows rich physics program in addition to LB neutrinos



Bob Svoboda, 4th PXP Workshop

DUSEL LBNE Sensitivities

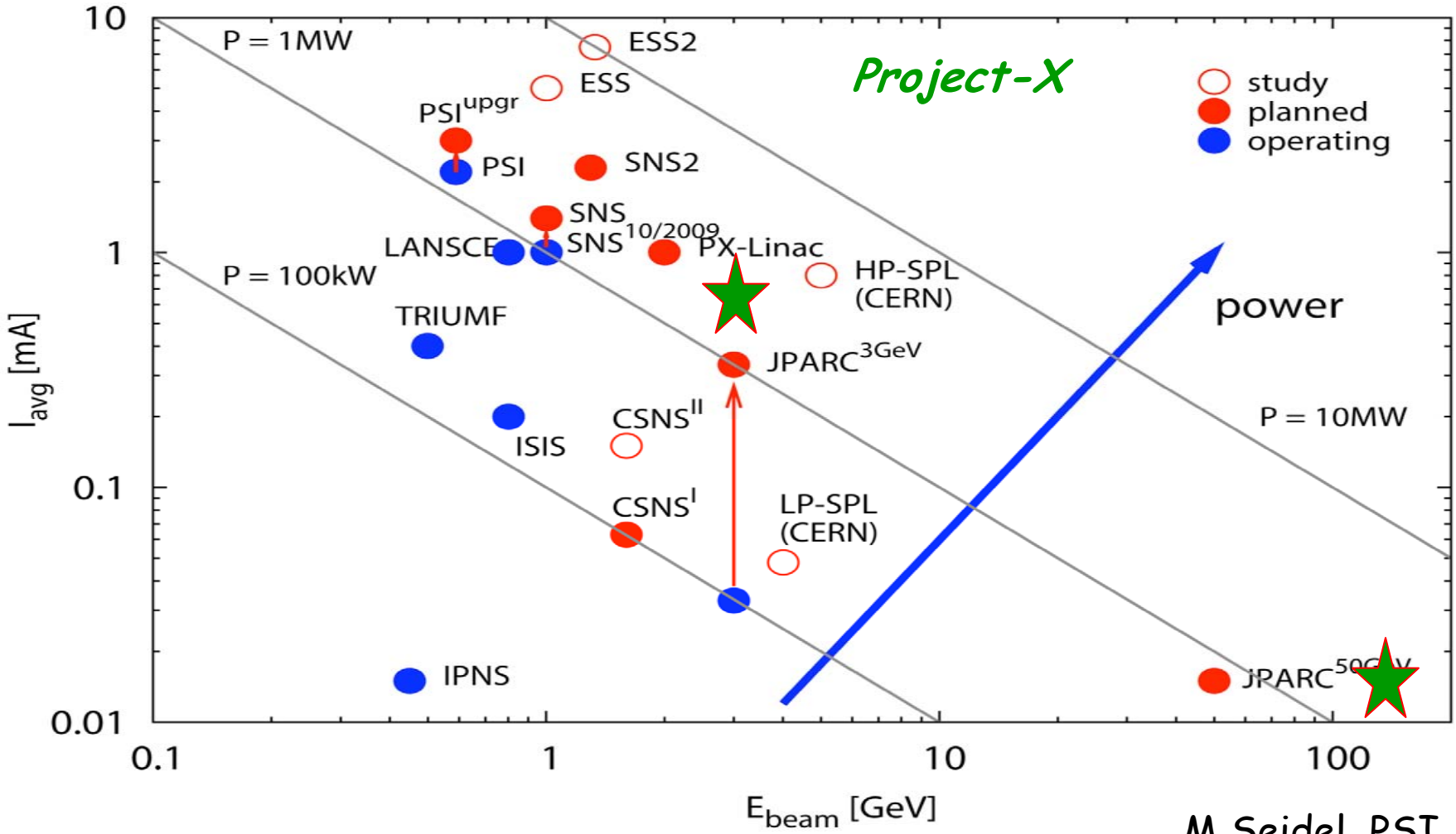




Sensitivities for (300 kT H_2O)×(2 MW)×(3+3 ν/ν̄ years)

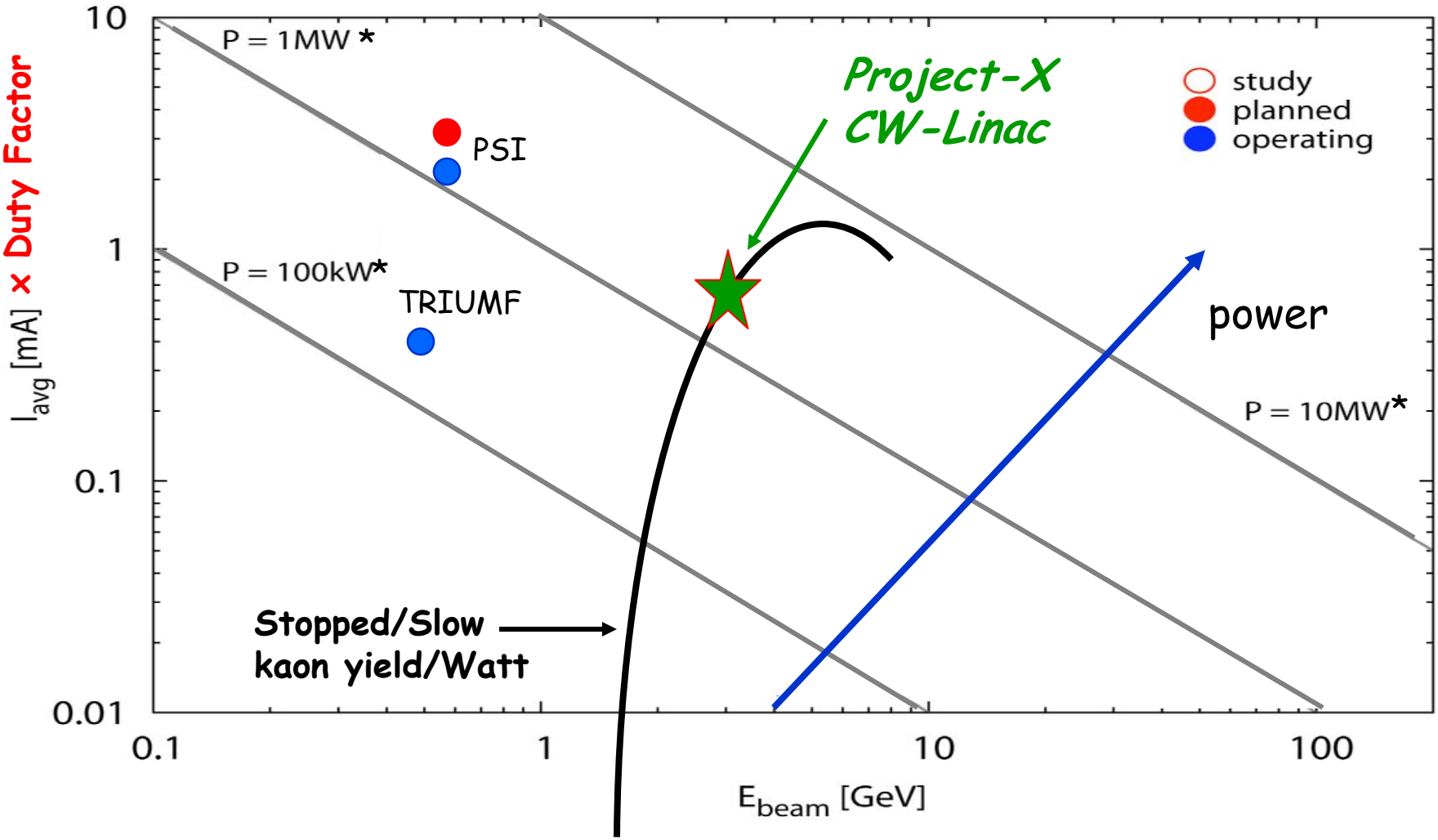
Bob Svoboda, 4th PXP Workshop

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



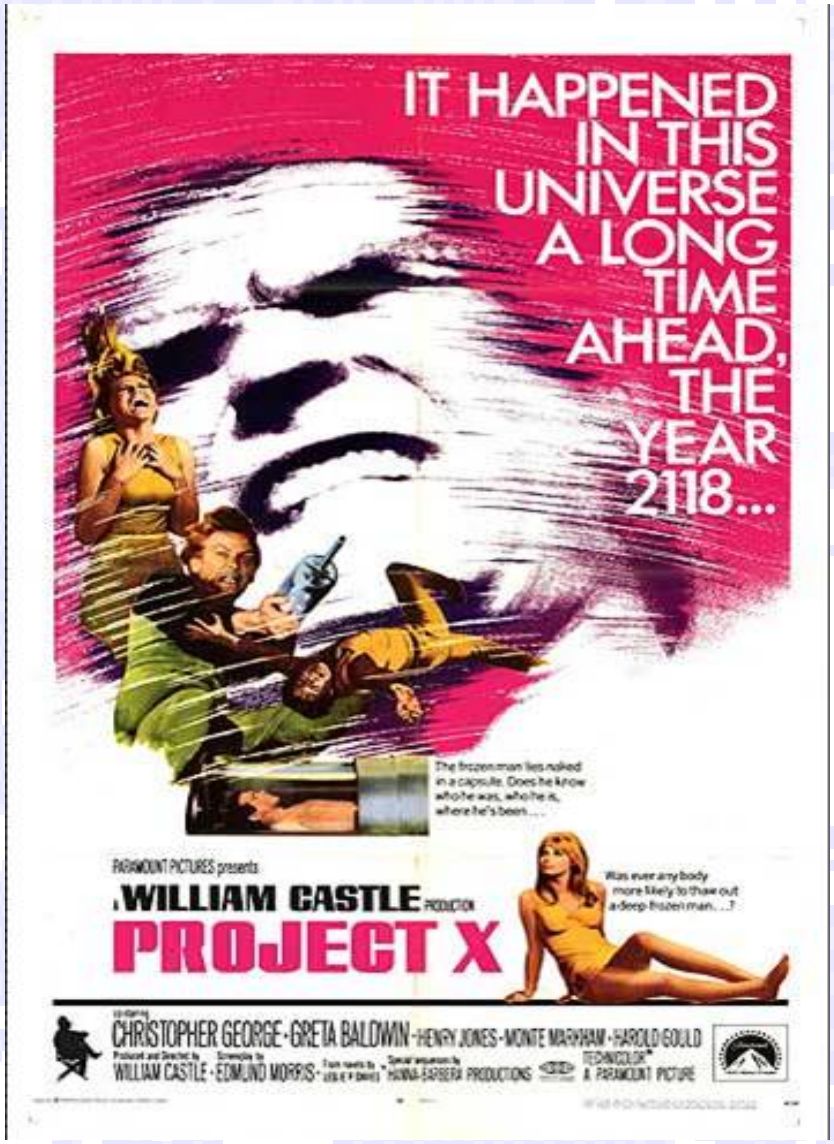
M Seidel, PSI

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



* Beam power x Duty Factor

Project-X, What it's not…



Project-X Accelerator Performance Goals

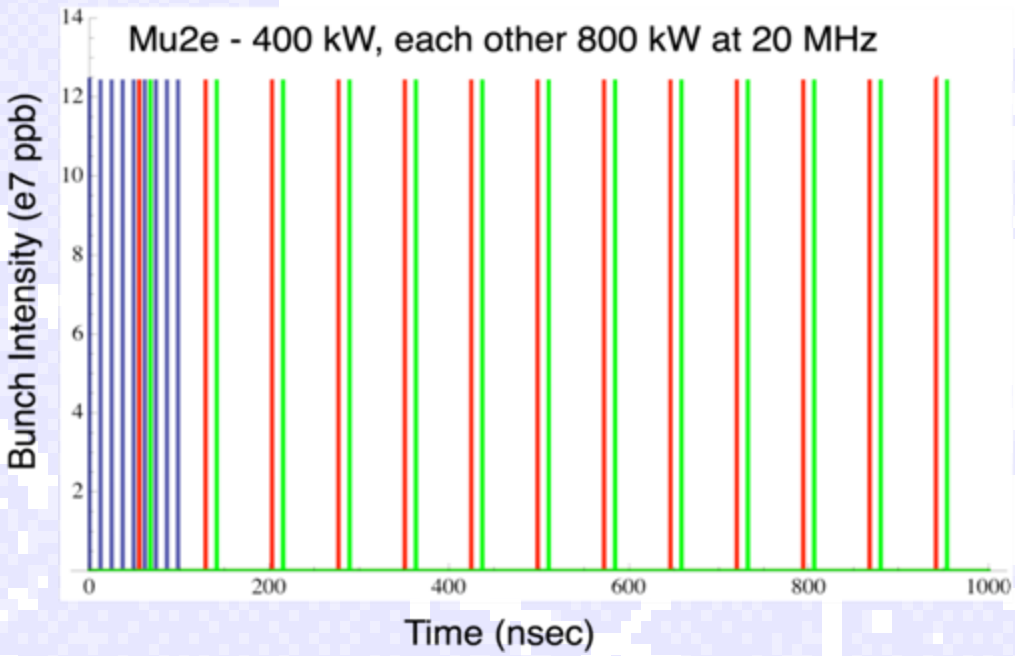
CW Linac		
Particle Type	H^-	
Beam Kinetic Energy	3.0	GeV
Average Beam Current	1	mA
Linac pulse rate	CW	
Beam Power	3000	kW
Beam Power to 3 GeV program	2870	kW
RCS/Pulsed Linac		
Particle Type	protons/H^-	
Beam Kinetic Energy	8.0	GeV
Pulse rate	10	Hz
Pulse Width	0.002/4.3	msec
Cycles to MI	6	
Particles 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

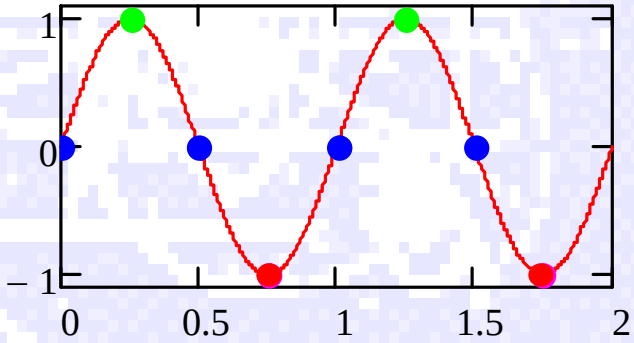
simultaneous

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

1 μsec period at 3 GeV

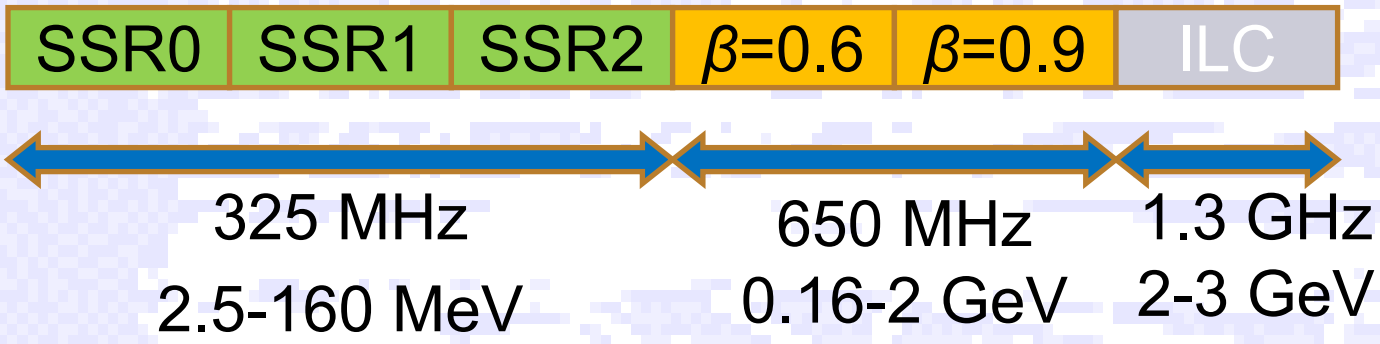
mu2e pulse (9e7) 162.5 MHz, 100 nsec	600 kW
Kaon pulse (9e7) 27 MHz	1200 kW
Nuclear pulse (9e7) 27 MHz	1200 kW





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

"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 (δt~20psec) 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.
- The intrinsic properties of this SCRF CW Linac enables the physics rather than fighting with it. Excellent beam power scaling.

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

Neutrino Physics:

- **Mass Hierarchy**
- **CP violation**

Day-1 Experiments

- **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.

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

Day-1 Experiment

Muon Physics:

- **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…

Day-1 Experiments

Kaon Physics:

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

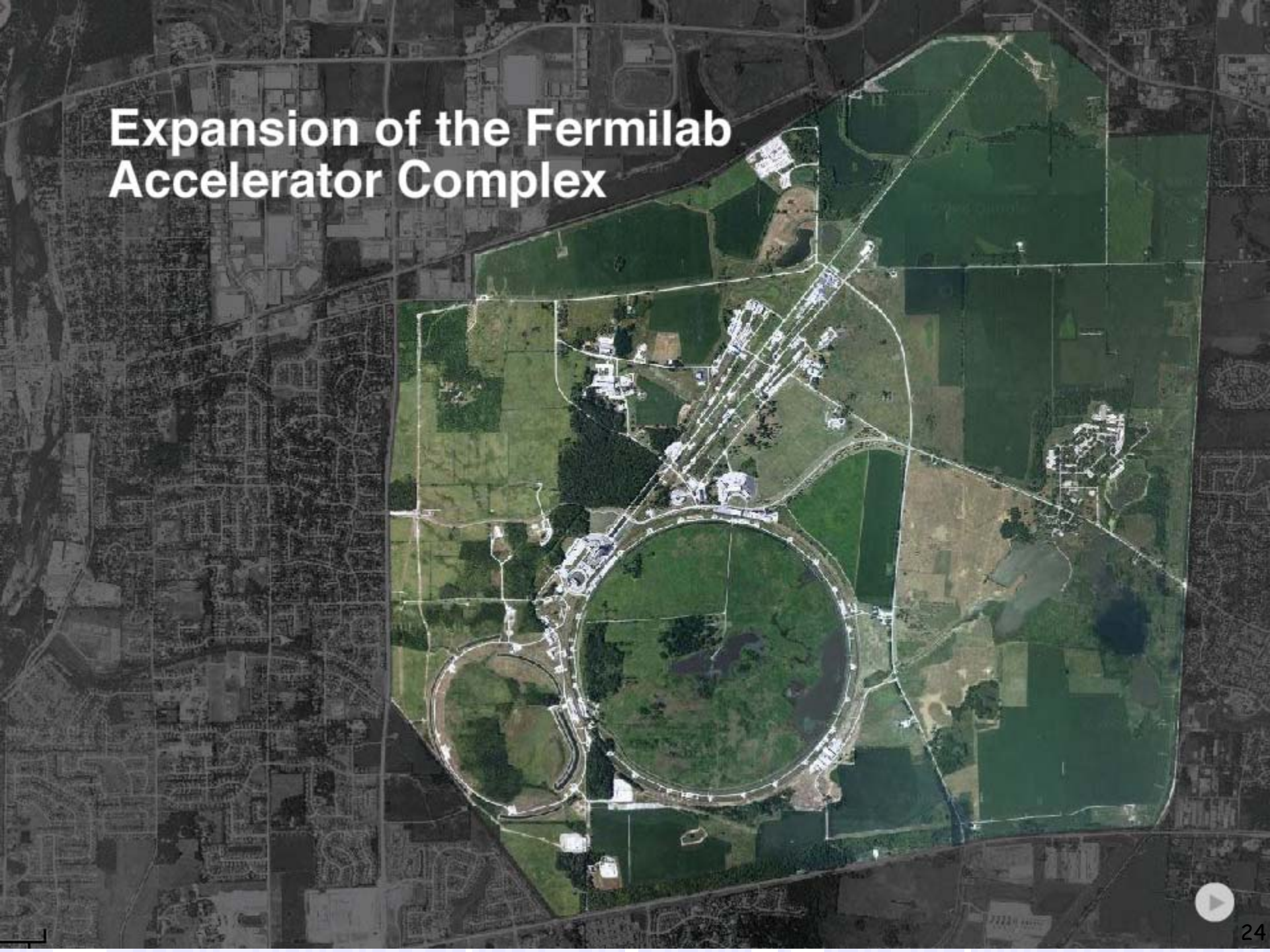
Nuclear Enabled Particle Physics:

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

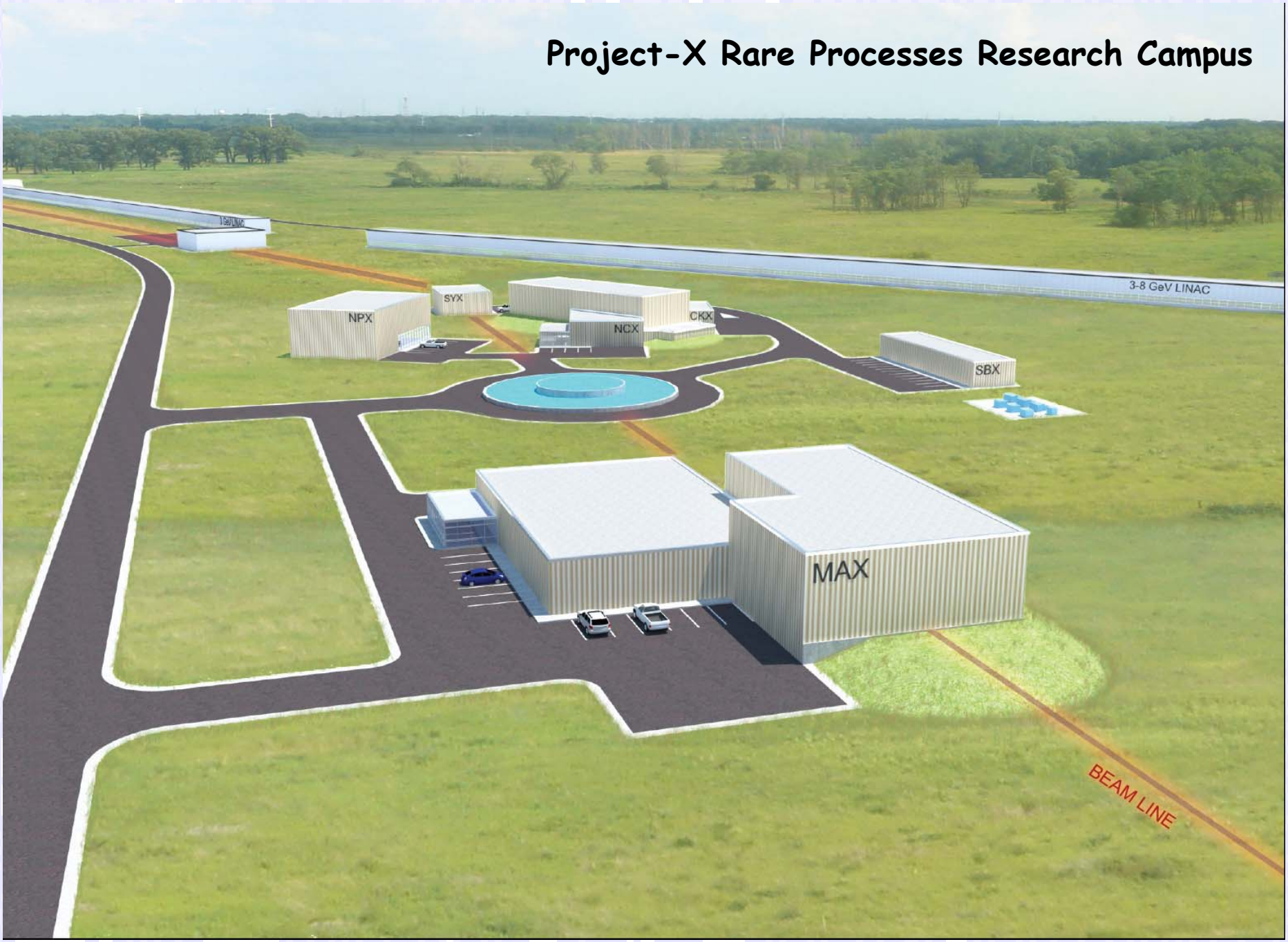
Baryons Physics:

- $pp \rightarrow \bar{\Sigma}^{+} K^{0} p^{+}$; $\Sigma^{+} \rightarrow p^{+} \mu^{+} \mu^{-}$ (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 (~$25M/year) on Super Conducting RF accelerator technology supporting Project-X.

Earliest construction start of 2015, operations in 2020.