

Project X Research Program

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Representing the Collaboration Coordination Committee for Project-X Physics

July 29th , 2011

Research begins with people!



Dr. Kalam in April with Fermilab Scientists of Indian origin.

Project-X

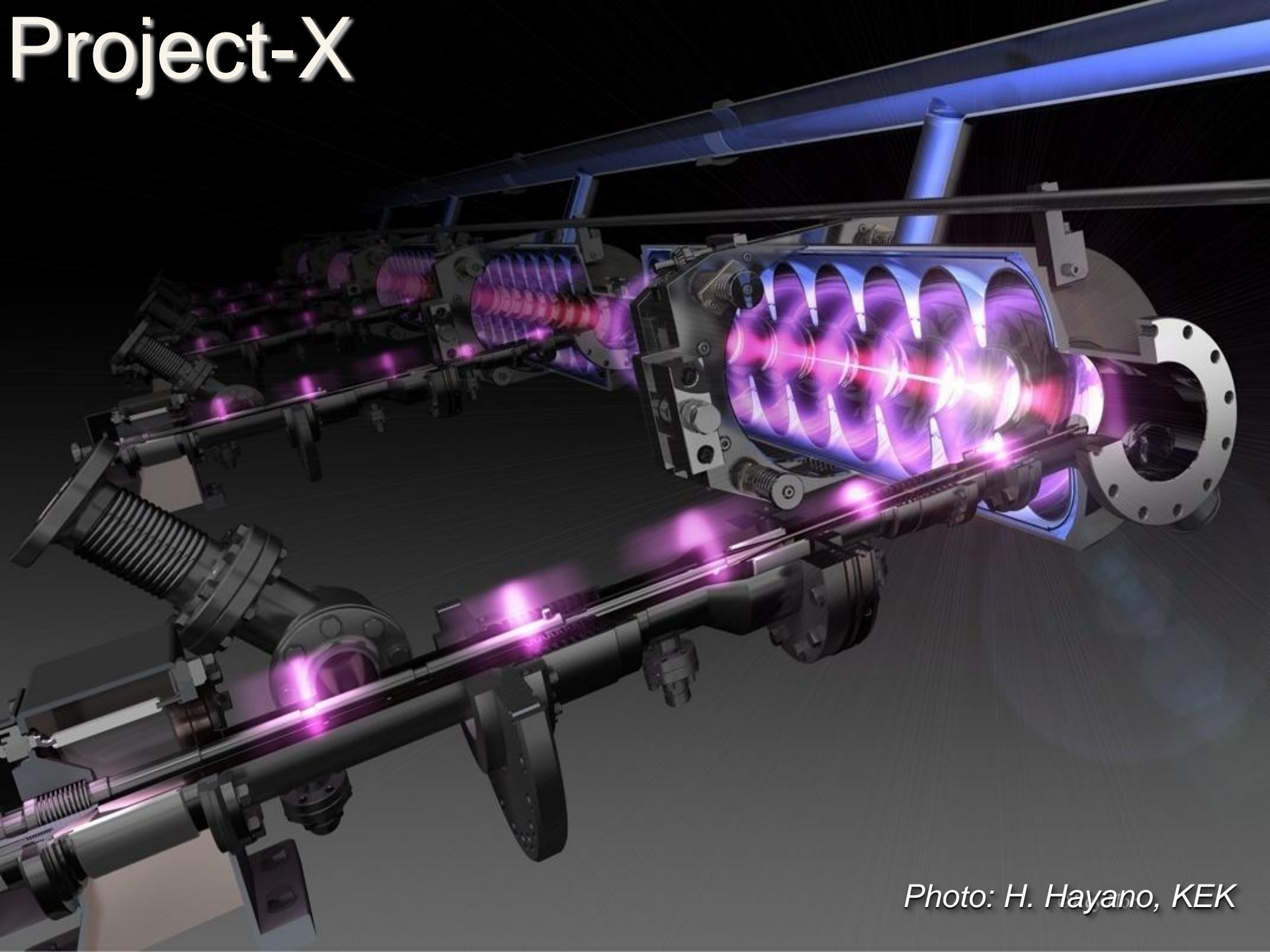


Photo: H. Hayano, KEK

Project-Y: Origins...

- **The Origin of Mass:**

How do massless chiral fermions become matter particles?
(buzzword: "Higgs")

- **The Origin of Matter:**

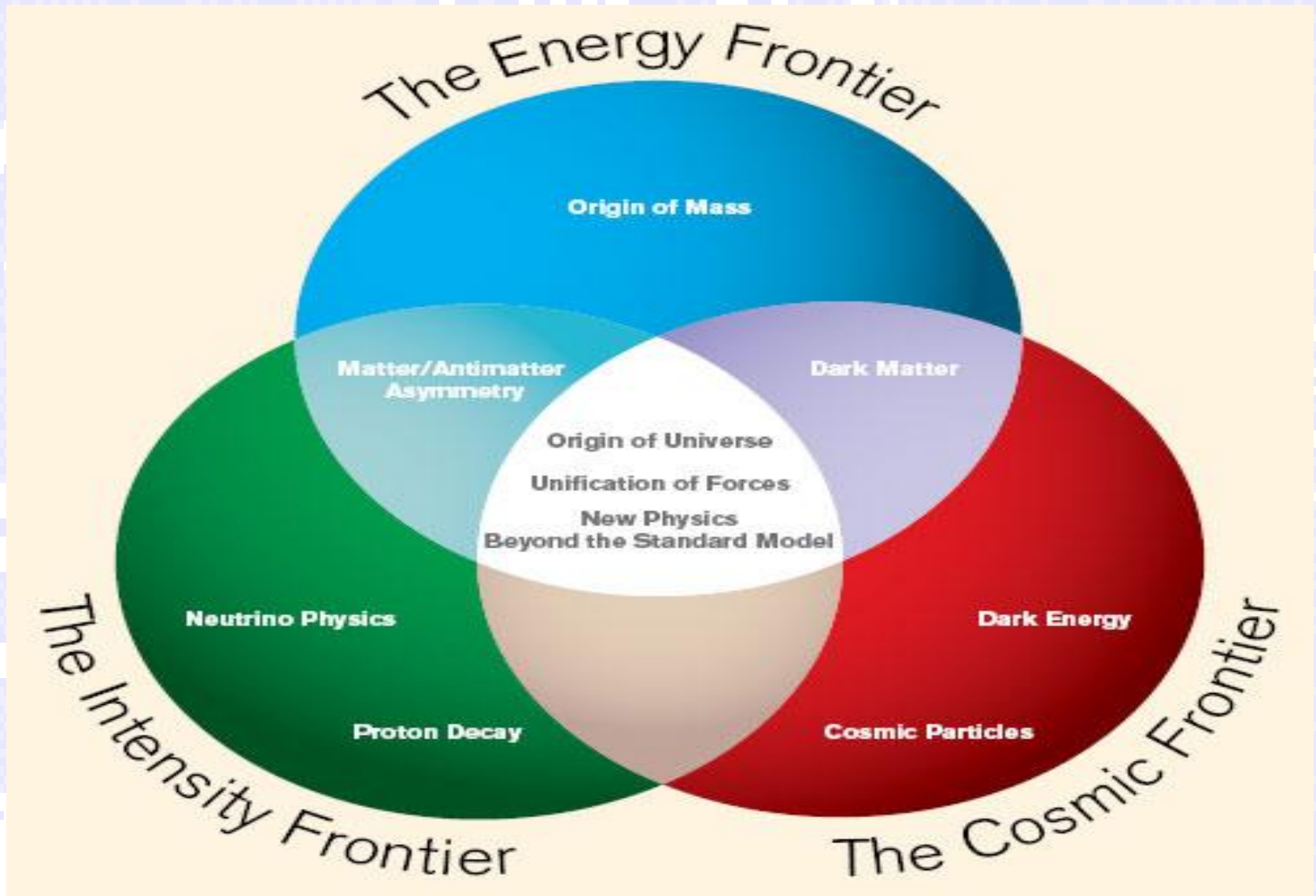
Why are there so many different kinds of matter particles with different properties?
(buzzword: "Flavor")

- **The Origin of the Universe:**

Where did matter come from in the first place and why didn't it all annihilate with antimatter?
(buzzwords: "Baryogenesis", "Leptogenesis")

Joe Lykken

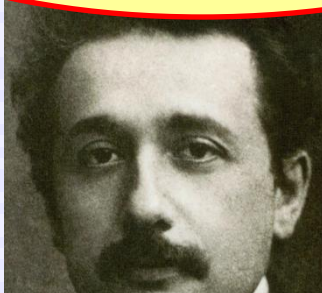
An integrated approach to direct and indirect and probes in science...



The Energy Frontier exploits Einstein's mass-energy relation, $E=mc^2$. The Intensity Frontier exploits Heisenberg's uncertainty principle, $\Delta E\Delta t \gtrsim \hbar/2$

$$E=mc^2$$

appearance of **real**
new particles

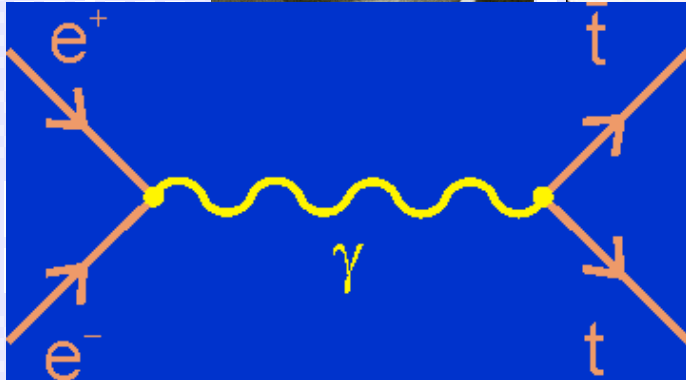


$$\Delta E\Delta t \gtrsim \hbar$$

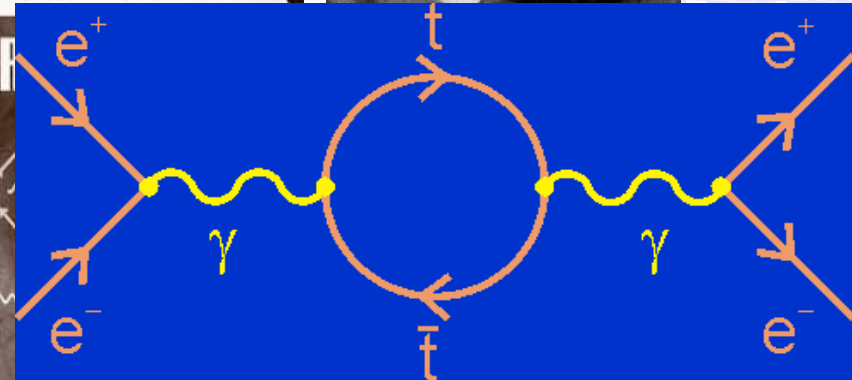
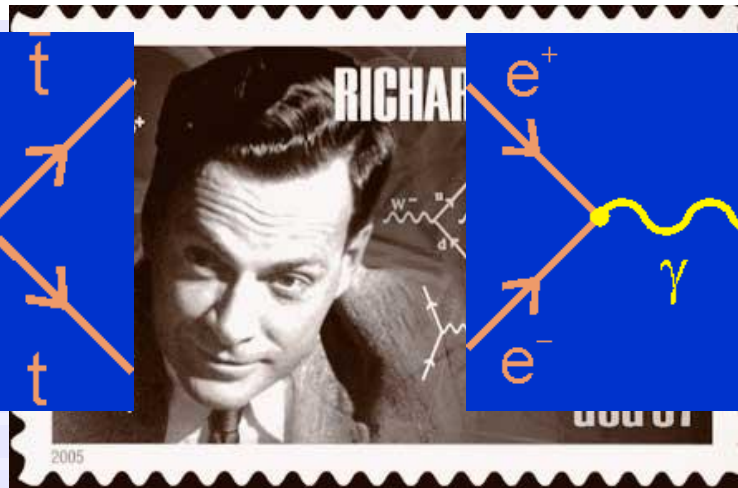
appearance of **virtual**
new particles



Feynman's tools



High energy crucial



High intensity crucial

The Project-X Research Program

- ***Neutrino oscillation experiments***

- A high-power proton source with proton energies between 8 and 120 GeV would produce intense neutrino beams directed toward near detectors on the Fermilab site and massive detectors at distant underground laboratories.

- ***Kaon, muon, nuclei & neutron precision experiments***

- 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***

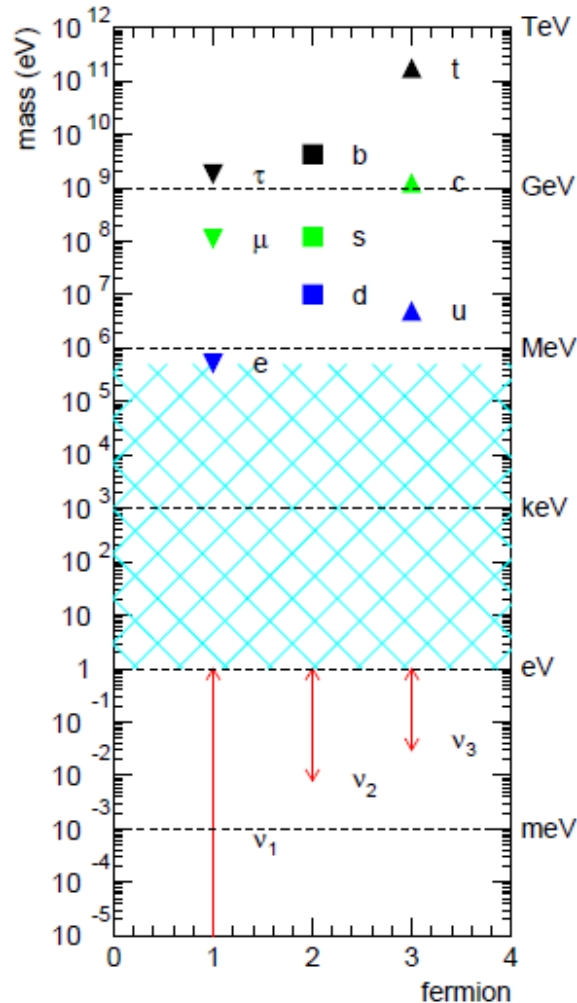
- Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.

- ***Nuclear Energy Applications***

- Accelerator, spallation, target and transmutation technology demonstration which could investigate and develop accelerator technologies important to the design of future nuclear waste transmutation systems and future thorium fuel-cycle power systems.

Detailed Discussion: [Project X website](#)

What are Neutrinos Telling Us?



What We Are Trying To Understand:

⇐ NEUTRINOS HAVE TINY MASSES

⇓ LEPTON MIXING IS “WEIRD” ⇓

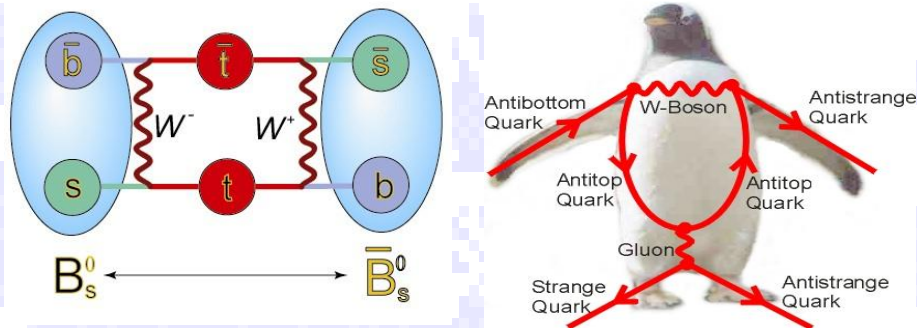
$$V_{MNS} \sim \begin{pmatrix} 0.8 & 0.5 & 0.2 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

$$V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.001 \\ 0.2 & 1 & 0.01 \\ 0.001 & 0.01 & 1 \end{pmatrix}$$

What Does It Mean?

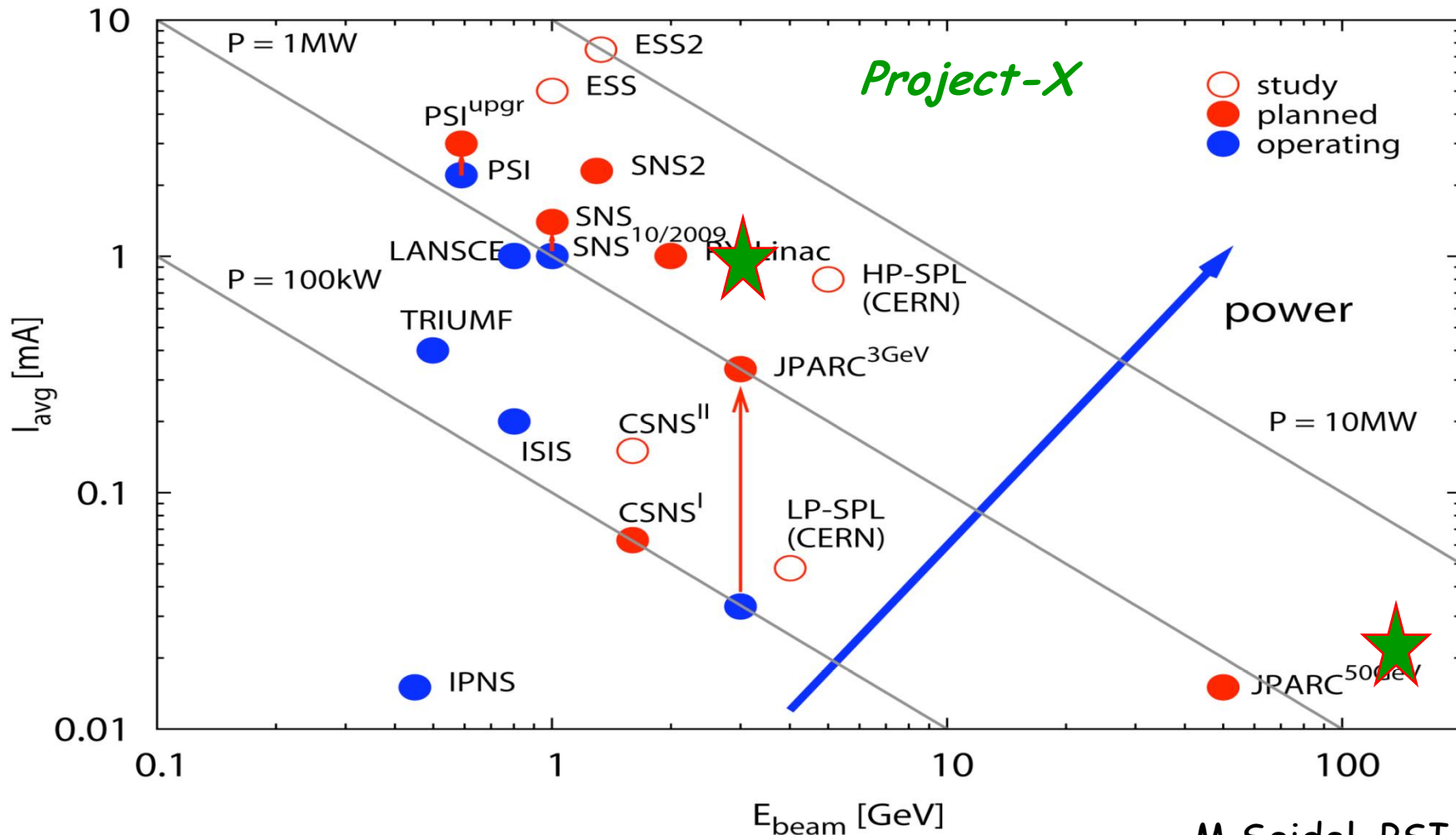
Kaon, Muon and EDM Experiments Deeply Attack the "Flavor Problem"

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



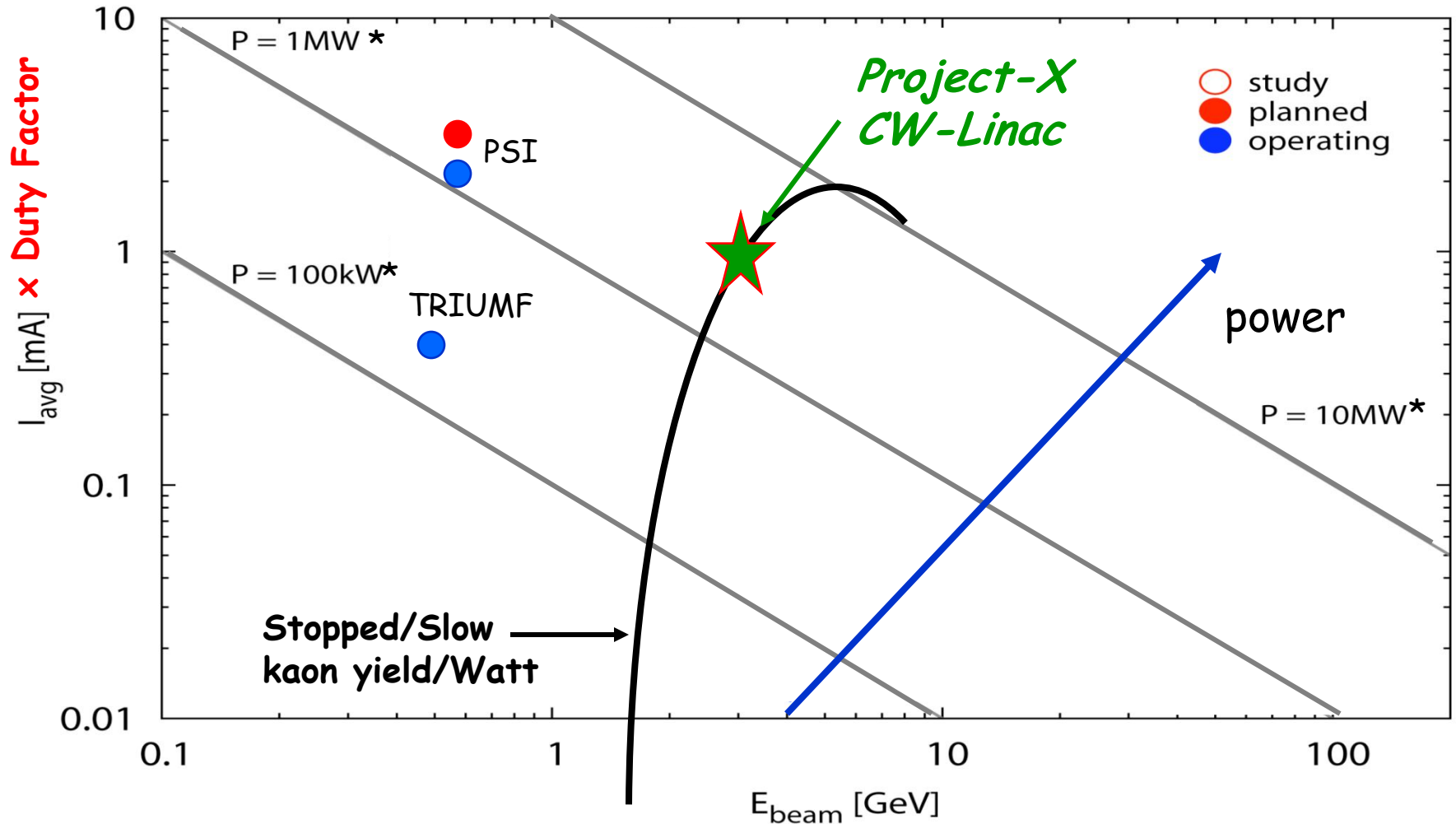
e.g. D0 2μ charge asymmetry arXiv:1106.6308

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



M Seidel, PSI

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

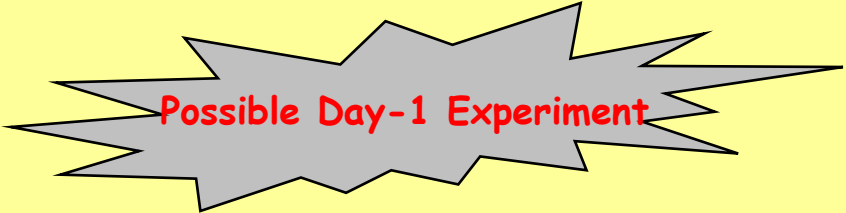


* Beam power \times **Duty Factor**

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

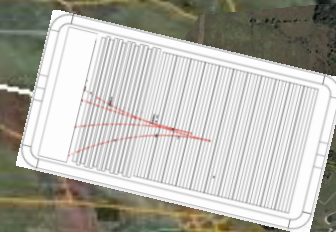
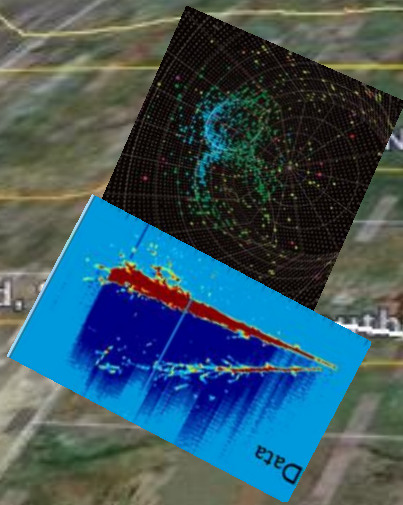
Neutrino Physics:

- **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....x3 beam power @ 120 GeV, x10-x20 power @ 8 GeV.
- Next generation precision cross section measurements.



Possible Day-1 Experiment

Long Baseline Neutrino Experiment



New Neutrino Beam at Fermilab...
...directed towards a precision near detector and a massive far detector.

Image NASA

© 2008 Tele Atlas

Image © 2008 TerraMetrics

© 2008 Europa Technologies

Missouri

Google

Project-X and LBNE...

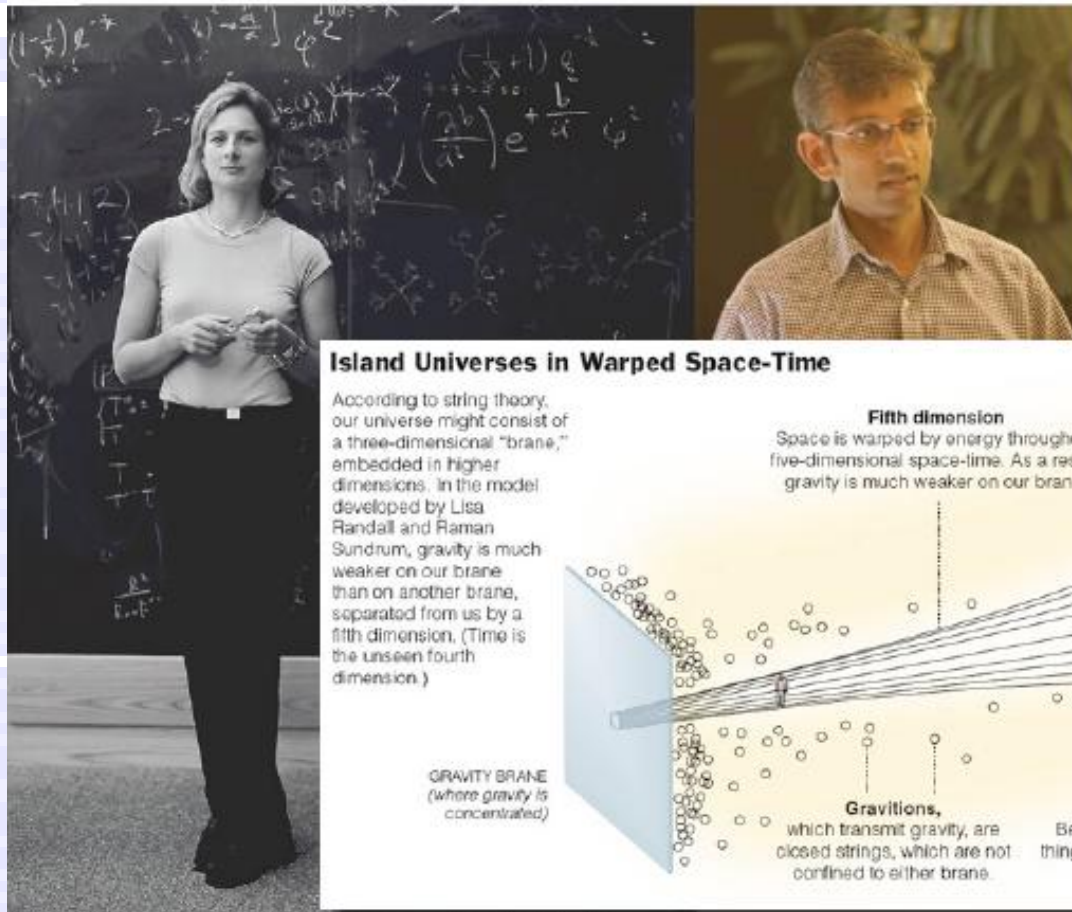
- Project-X makes LBNE a much better experiment! The recent US National Research Council (NRC) report recognized this:

" The long-baseline neutrino oscillation experiment would provide a great advance in the study of neutrino properties, particularly when coupled with a neutrino beam produced at Fermilab using a new high-intensity proton source under development. "

- The NRC also recognized that the principal consideration for LBNE is Beam-Power x Detector-Mass.

Rare processes sensitive to new physics... Warped Extra Dimensions as a Theory of Flavor??

The Randall-Sundrum (RS) idea



Island Universes in Warped Space-Time

According to string theory, our universe might consist of a three-dimensional "brane," embedded in higher dimensions. In the model developed by Lisa Randall and Raman Sundrum, gravity is much weaker on our brane than on another brane, separated from us by a fifth dimension. (Time is the unseen fourth dimension.)

GRAVITY BRANE
(where gravity is concentrated)

Fifth dimension
Space is warped by energy throughout five-dimensional space-time. As a result, gravity is much weaker on our brane.

Gravitons,
which transmit gravity, are closed strings, which are not confined to either brane.

Warped space-time
Because space-time is warped, things are exponentially bigger and lighter closer to our brane.


BRANE
(our universe)

The ends of **open strings**, whose oscillations are particles and forces other than gravity, are stuck to our brane.

(Wikipedia)

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

Muon Physics:



Possible Day-1 Experiment

- Next generation muon-to-electron conversion experiment, new techniques for higher sensitivity and/or other nuclei.
- Next generation $(g-2)_\mu$ 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.

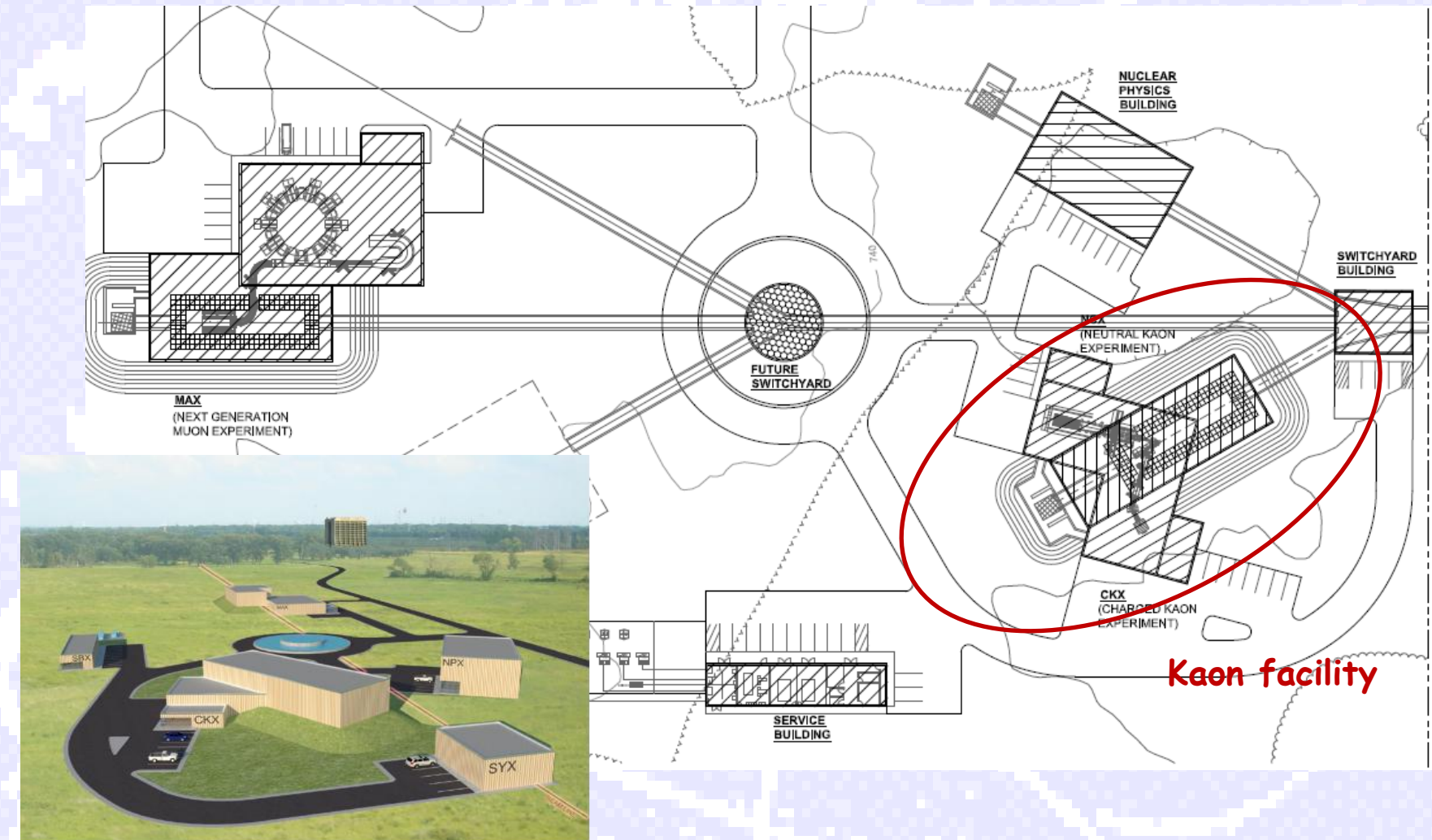
An Incomplete Menu of World Class Research Targets Enabled by Project-X. continued...

Kaon Physics:

Possible Day-1 Experiments

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$: >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.
- $K^+ \rightarrow (\pi, \mu)^+ \nu_\chi$: Search for anomalous heavy neutrinos.
- $K_L \rightarrow \pi^0 e^+ e^-$: <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

Project-X High-Intensity Campus



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

Possible Day-1 Experiment

Nuclear Enabled Particle Physics:

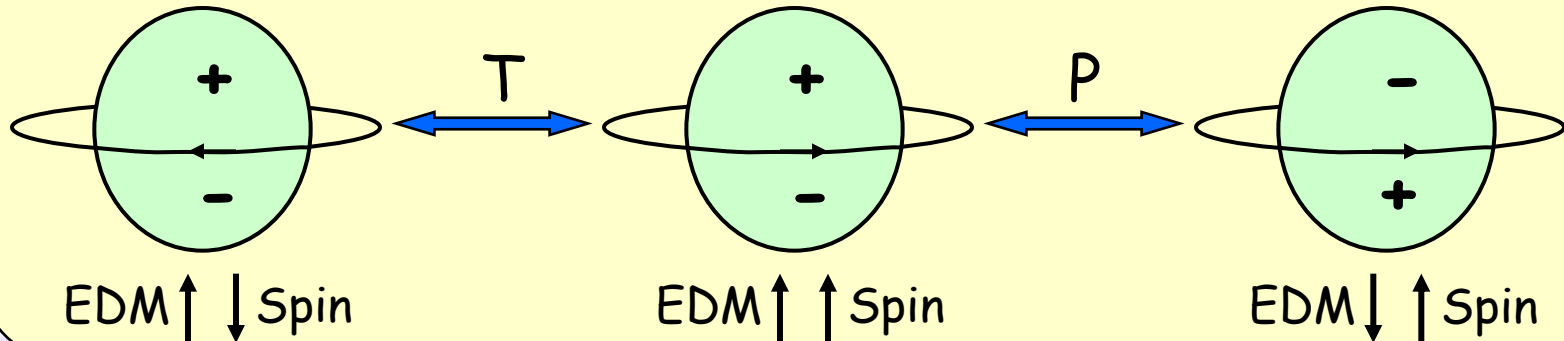
- Production of Ra, Rd, Fr isotopes for nuclear edm experiments that are uniquely sensitive to Quark-Chromo and electron EDM's.

Baryon 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
- neutron - antineutron oscillations
- $\Lambda^0 \leftrightarrow \bar{\Lambda}^0$ oscillations (Project-X operates below anti-baryon threshold)
- neutron EDMs

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

Physics beyond
the Standard
Model:
SUSY, Strings ...

Paramagnetic Atoms (Tl, Fr)
Molecules (PbO)

Electron EDM

Guy Savard, ANL

Efforts toward building the Indian-US Research Collaboration

- **A solid foundation at Fermilab:** D0 collaboration, MINOS and MINOS+ collaborations, MIPP collaboration and now the Long Baseline Neutrino Experiment (LBNE).
- **January 2011:** Focus meeting for Project-X research, formation of the Collaboration Coordination Committee for Project-X Physics (C3P2)

Indian side: Professor Dugad (TIFR), Professor Roy (IUAC),
Dr. Mohanakrishnan (IGCAR)

US side: Dr. Mishra, Dr. Plunkett, Dr. Tschirhart (Fermilab)

- **March 2011 - June 2011:** 5-year proposals developed for the Project-X research program, exciting opportunities for further collaboration on rare processes, nuclear physics, and detector R&D.

Research Program Budget in the 12th and 13th Budget Proposals

Sub-Projects	12 th Plan (Rs. Crores)	13 th Plan (Rs. Crores)
Indian Infrastructure and Manpower Development	100	50
Neutrino Physics	150	100
Particle Production and Hyper Nuclei Experiments	60	30
Nuclear Physics	75	75
Rare Decay	25	25
Nuclear Energy	100	100
Detector	100	100

~\$125M

~\$100M

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 \times Running-time) by $\times 3$, 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.

Energy Studies: A laboratory to develop enabling technologies.

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

Now Excellent near-term opportunities for collaborating on the research program!