Project-X

March 2012
R.Tschirhart
Fermilab

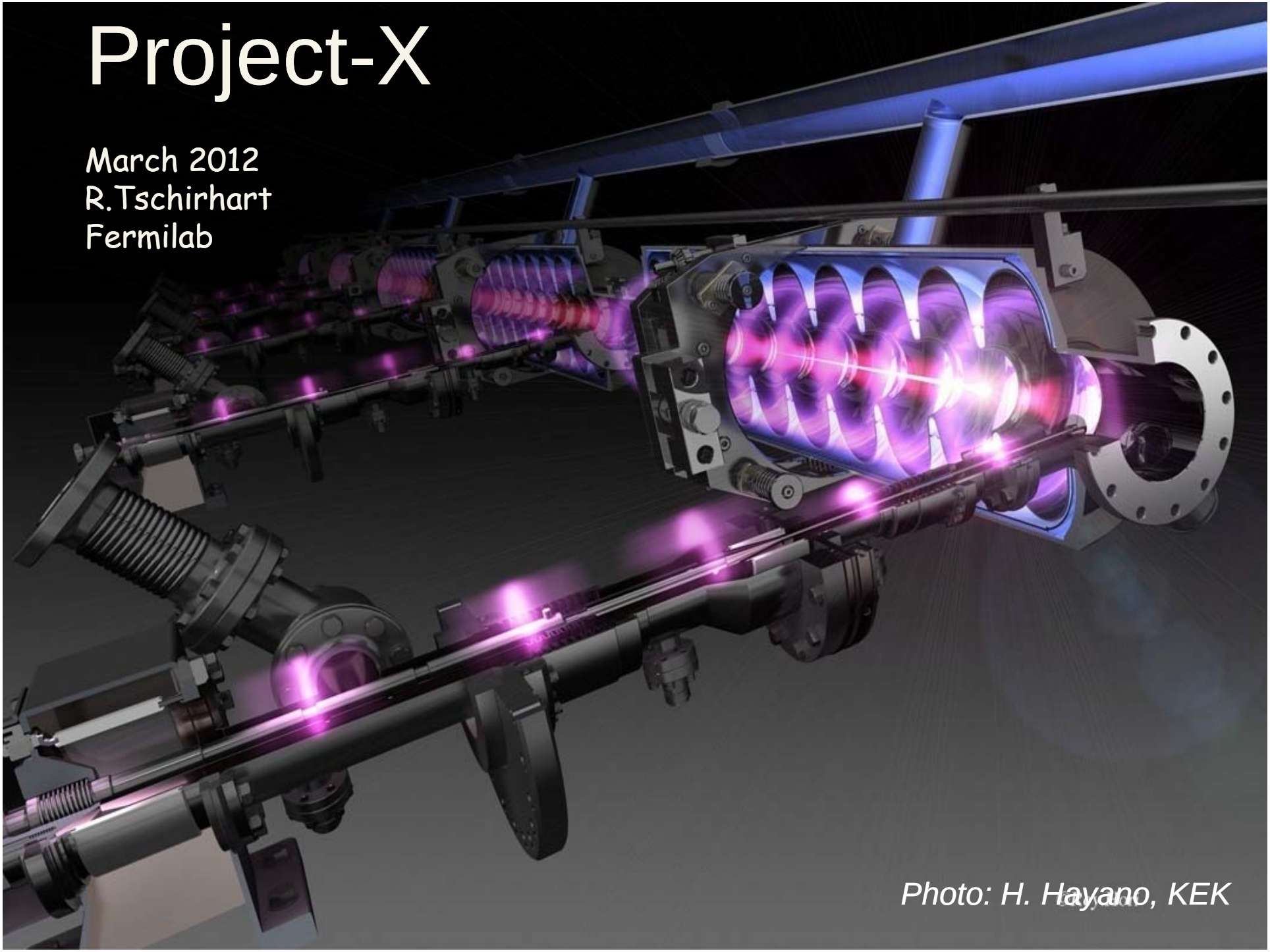


Photo: H. Hayano, KEK

The Project-X Research Program

- ***Neutrino oscillation experiments***
- A high-power proton source with proton energies between 8 (3) and 120 GeV would produce intense neutrino beams directed toward near detectors on the Fermilab site and massive detectors at distant underground laboratories.

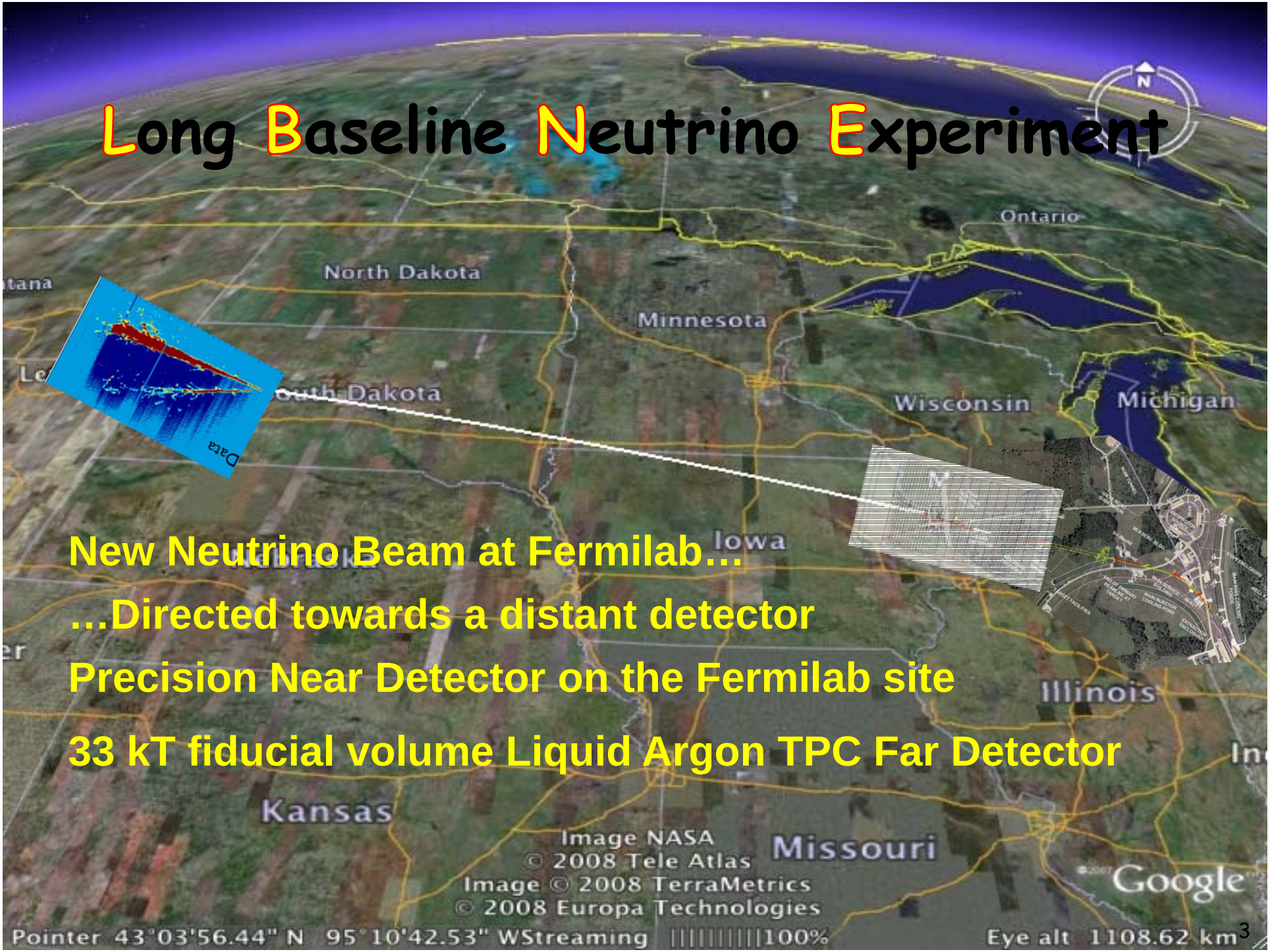
- ***Kaon, muon, nuclei & neutron precision experiments***
- These could include world leading experiments searching for muon-to-electron conversion, nuclear and neutron electron dipole moments (edms), precision measurement of neutron properties and world-leading precision measurements of ultra-rare 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

Long Baseline Neutrino Experiment



New Neutrino Beam at Fermilab…

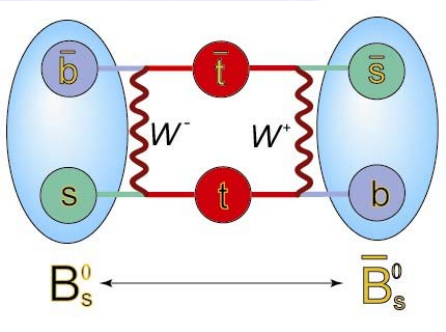
…Directed towards a distant detector

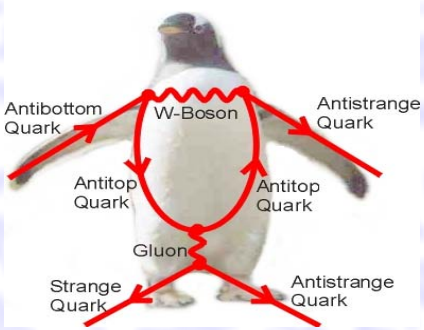
Precision Near Detector on the Fermilab site

33 kT fiducial volume Liquid Argon TPC Far Detector

EDM, Kaon and Muon Experiments Deeply Attack the Flavor Problem

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





"n-EDM has killed more theories than any other single experiment"

-J.M. Pendlebury, Review of Particle Electric Dipole Moments

EDMs: New CPV?

In units of e cm, selected EDM limits are:

Particle	EDM limit	System	SM Prediction	New Physics
e	10.5×10^{-28}	YbF	10^{-38}	10^{-27}
μ	1.1×10^{-19}	rest frame E	10^{-35}	10^{-22}
τ	3.1×10^{-16}	$e^+e^- \to \tau^+\tau^-\gamma$	10^{-34}	10^{-20}
p	6.5×10^{-23}	TlF molecule	10^{-31}	10^{-26}
n	2.9×10^{-26}	UCN	10^{-31}	10^{-26}
^{199}Hg	3.1×10^{-29}	atom cell	10^{-33}	10^{-28}

- *SM "background" well below new CPV expectations*
- *New expts: 10^2 to 10^3 more sensitive*

A non-exhaustive list:

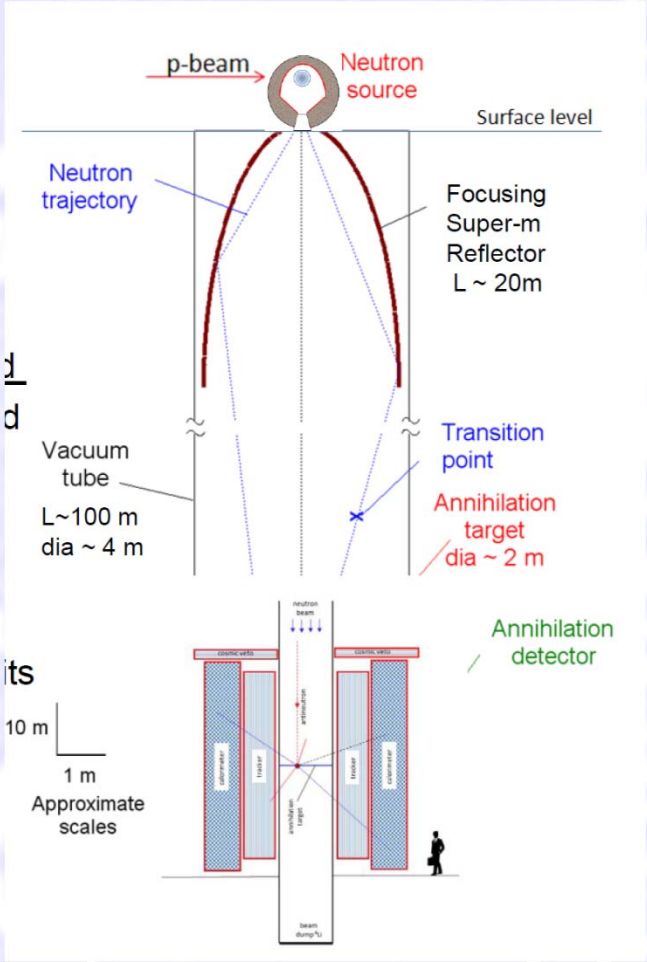
Leptonic EDMs		Hadronic EDMs	
System	Group	System	Group
Cs (trapped)	Penn St.	n (UCN)	SNS
Cs (trapped)	Texas	n (UCN)	ILL
Cs (fountain)	LBNL	n (UCN)	PSI
YbF (beam)	Imperial	n (UCN)	Munich
PbO (cell)	Yale	^{199}Hg (cell)	Seattle
HBr^+ (trapped)	JILA	^{129}Xe (liquid)	Princeton
PbF (trapped)	Oklahoma	^{225}Ra (trapped)	Argonne
GdIG (solid)	Amherst	^{213,225}Ra (trapped)	KVI
GGG (solid)	Yale/Indiana	^{223}Rn (trapped)	TRIUMF
muon (ring)	J-PARC	Proton (ring)	BNL

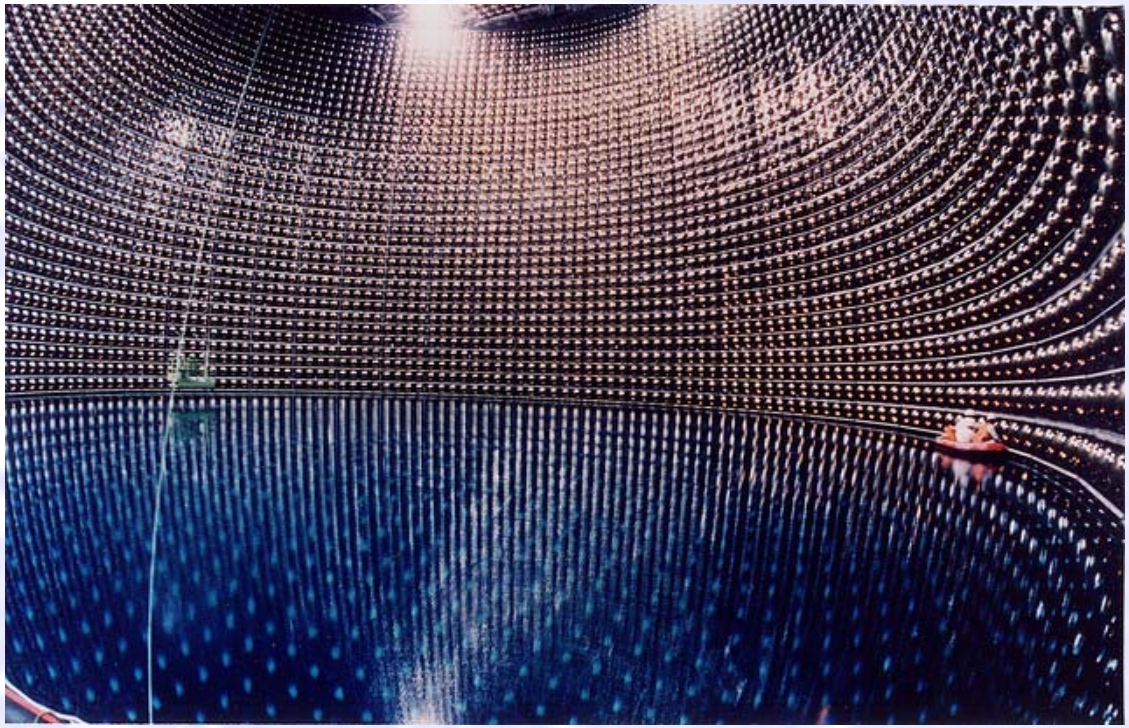
+ TRIUMF

+ COSY (deuteron)

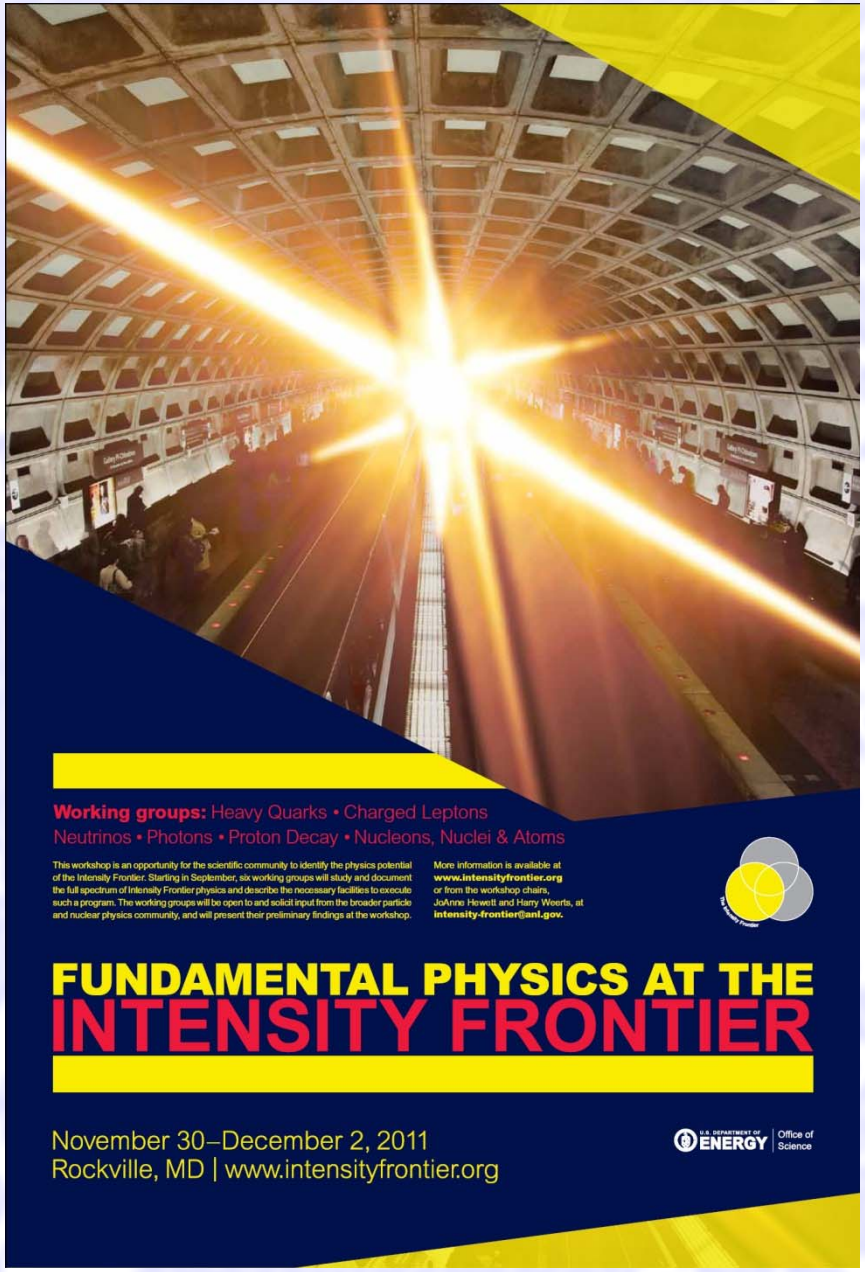
M. Ramsey-Musolf, Intensity Frontier Workshop (http://www.intensityfrontier.org/)

neutron-antineutron oscillations: Potentially deeper reach with a spallation source than watching 25kT of H_2O…





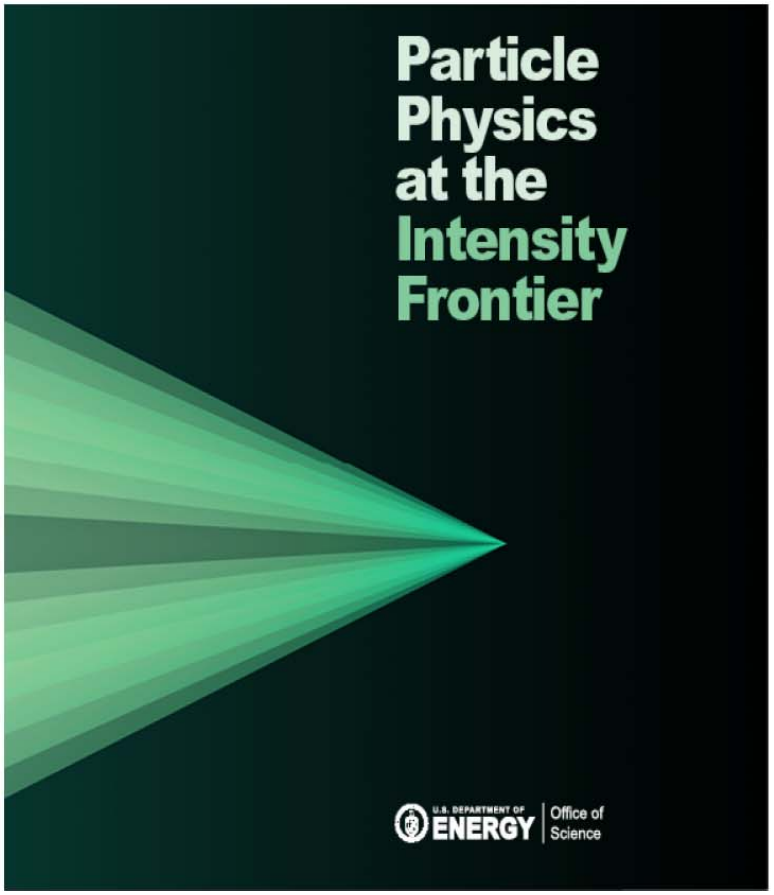
Y. Kamyshkov (http://www.intensityfrontier.org/)



- 500+ Attendees
- Five very active working groups:
- Charged leptons
- Heavy Quarks
- Hidden Sector
- Neutrinos
- Nucleons/Nuclei/Atoms
- Proton Decay
- DOE OHEP listened…

(http://www.intensityfrontier.org/)

Vision for Program Development



Dr. Jim Siegrist, Associate Director
Office of High Energy Physics
Office of Science, U.S. Department of Energy

- Our domestic program is the world leader in 'Intensity Frontier' area, and we need to increase investments there, while keeping a balance with the other frontiers
- Community is engaged on further developing the science case on all 3 frontiers – we need a healthy portfolio of construction ideas supported by compelling science drivers at achievable budget levels
  - Will need more help from the community here; see also talks tomorrow
- Our program will deliver science now, in the near term, and in the long term on all 3 frontiers

5

In the absence of new facilities enabling new experiments…

From Hitoshi Murayama , ICFA October 2011

New facilities drive the Synergy between Experimental Frontiers to directly confront theory…

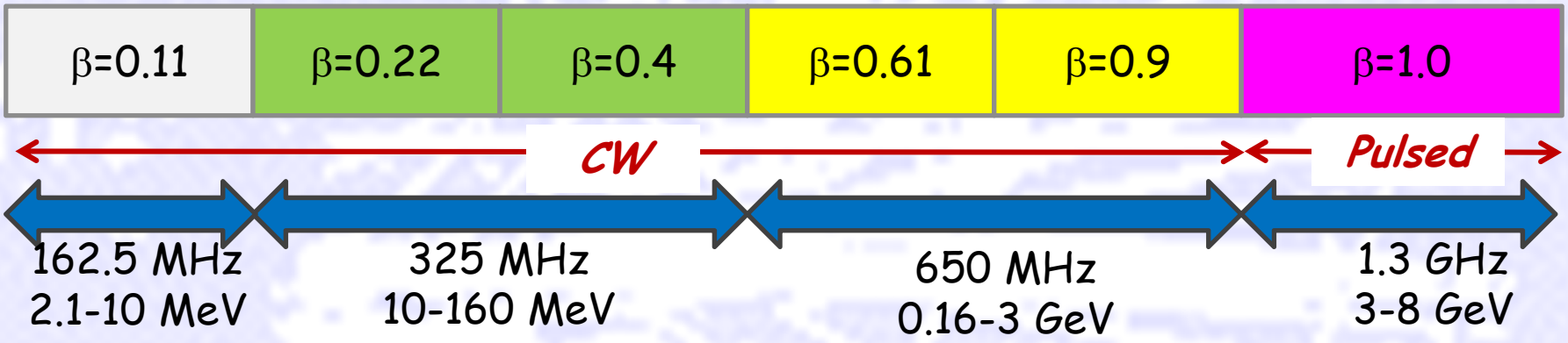
Modified from Hitoshi Murayama , ICFA October 2011

Project-X Accelerator Functional Requirements

CW Linac		
Particle Type	H^-	
Beam Kinetic Energy	1.0-3.0	GeV
Average Beam Current	1	mA
Linac pulse rate	CW	
Beam Power @ 3 GeV	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	190	kW
Main Injector/Recycler		
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.3	sec
Particles per cycle	1.6×10^{14}	
Beam Power at 120 GeV	2200	kW

simultaneous

Project X SRF Linac Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
HWR (β_G=0.1)	162.5	2.1-10	9/6/1	HWR, solenoid
SSR1 (β_G=0.22)	325	10-42	16/18/ 2	SSR, solenoid
SSR2 (β_G=0.47)	325	42-160	36/20/4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-460	42 /14/7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	460-3000	152/19/19	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

Courtesy S. Holmes

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

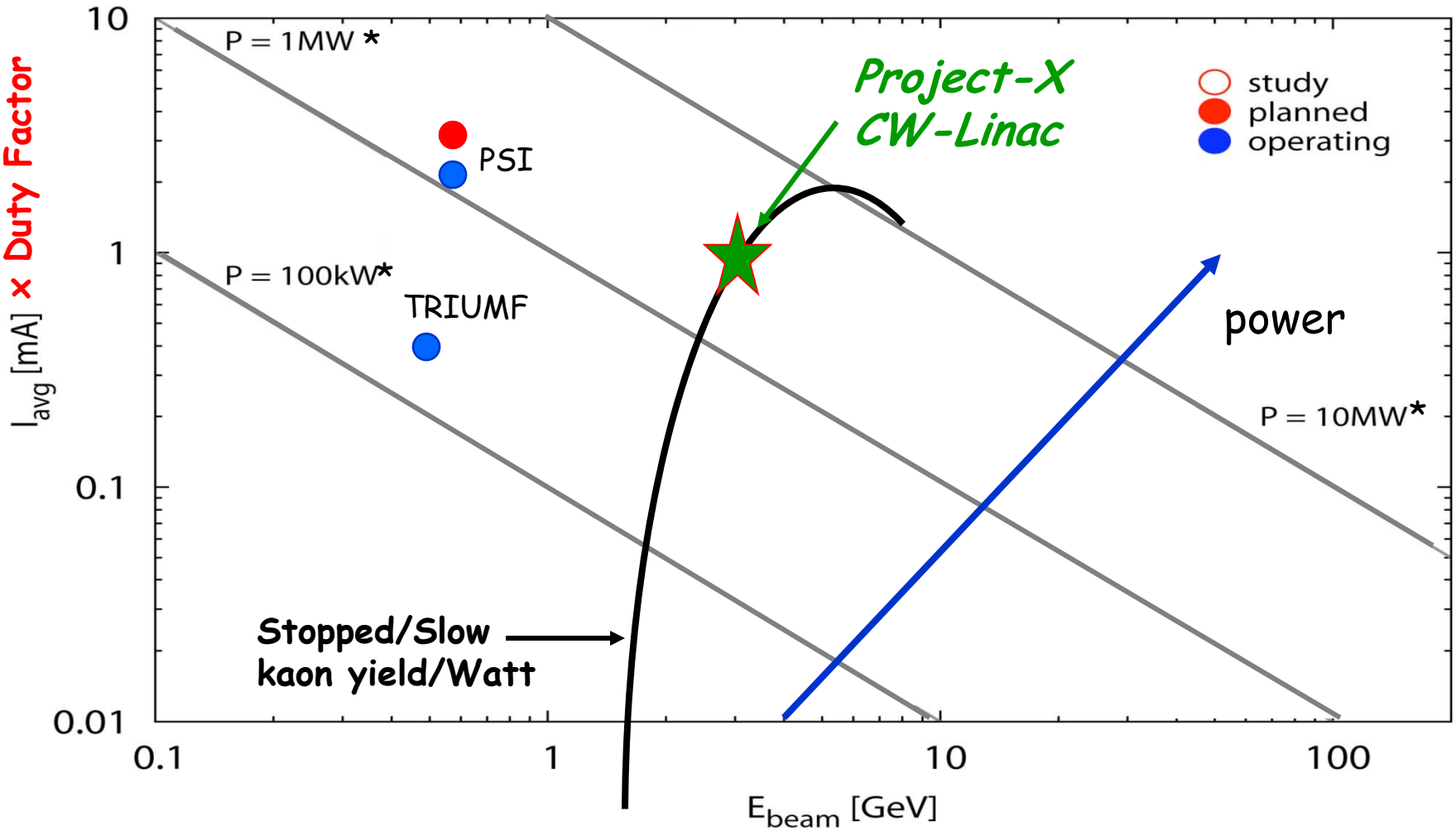
- Pulsed machines driving neutrino horns:
  SPS (0.5 MW), Main Injector (0.3 MW now, 0.7 MW for Nova),
  JPARC (plan for 1.7 MW)

- Cyclotrons and synchrotrons driving muon programs
  PSI (1.3 MW, 600 MeV), JPARC RCS (0.1-0.3 MW)

- Synchrotrons driving kaon physics programs.
  SPS (0.015 MW), JPARC (goal of >0.1 MW), Tevatron (0.1 MW)

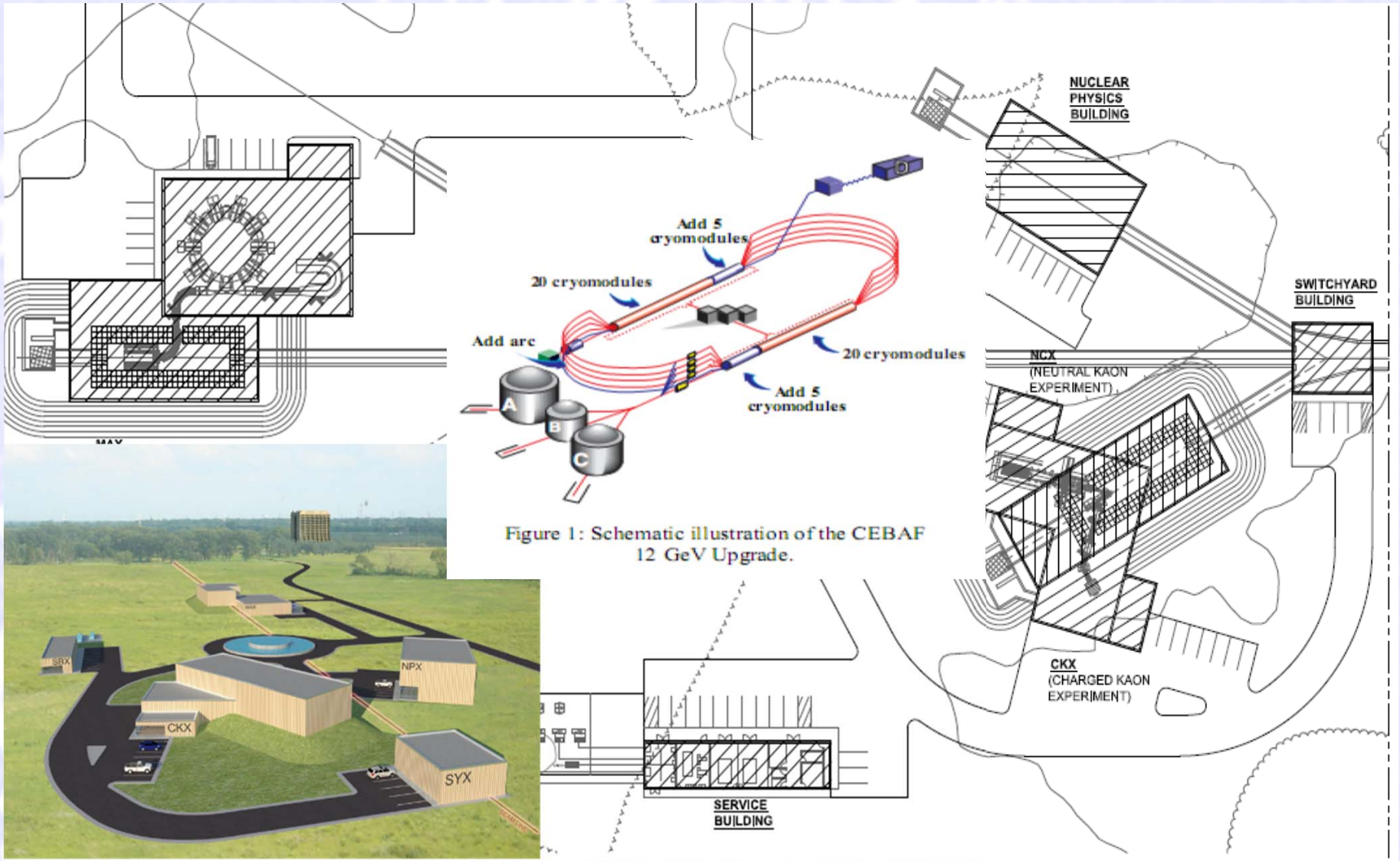
- Linear machines driving nuclear and neutron programs:
  SNS, LANL, FRIB….not providing CW light-nuclei beams.

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



* Beam power x Duty Factor

Project X Research Campus

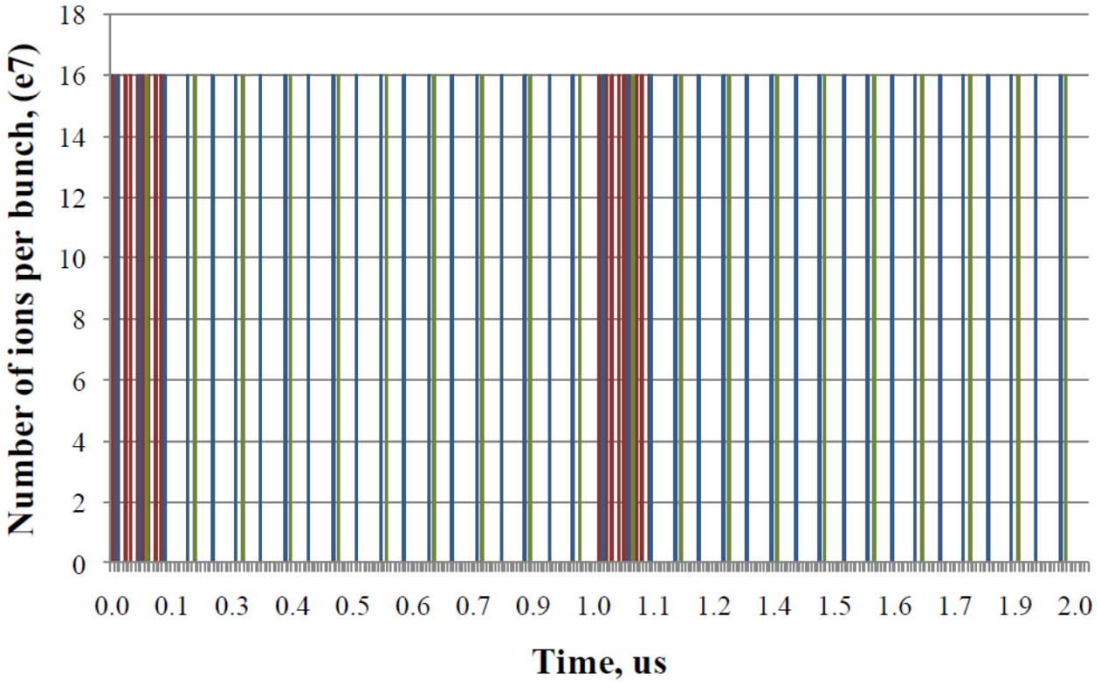


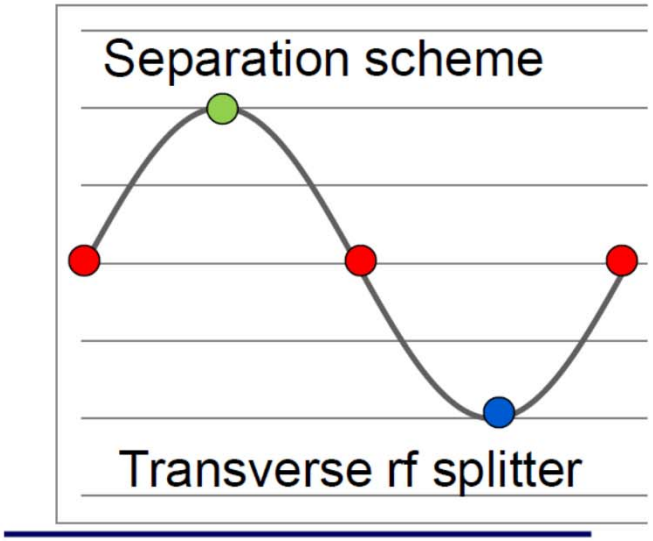
Chopping and splitting for 3-GeV experiments

1 μsec period at 3 GeV

Muon pulses (16e7) 81.25 MHz, 100 nsec at 1 MHz	700 kW
Kaon pulses (16e7) 20.3 MHz	1540 kW
Nuclear pulses (16e7) 10.15 MHz	770 kW

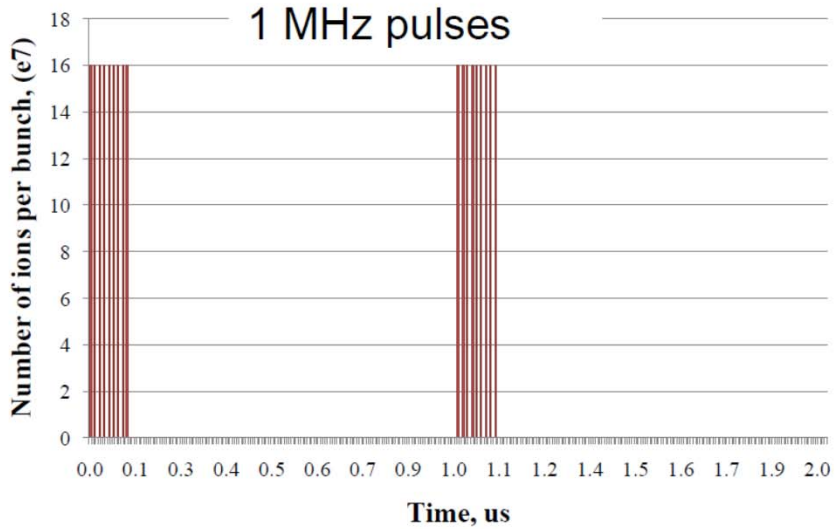
Ion source and RFQ operate at 4.2 mA
75% of bunches are chopped at 2.5 MeV after RFQ

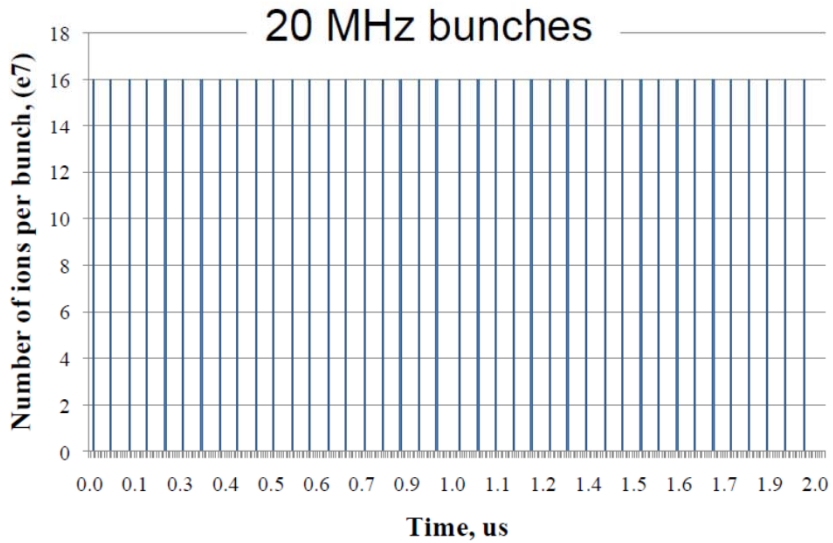


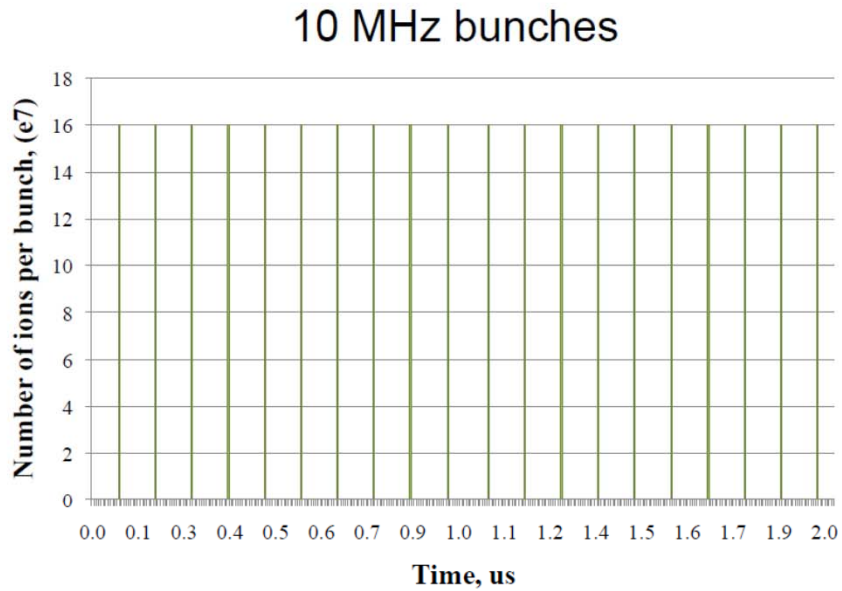


Courtesy of Nagaitsev

Beam after splitter







The "PXIE" R&D project develops the LEBT & MEBT technology to validate this opportunity.

Courtesy of Nagaitsev

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

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

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

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.
- $K^+ \rightarrow (\pi,\mu)^+\nu_x$: Search for anomalous heavy neutrinos.
- $K^0 \rightarrow \pi^0e^+e^-$: <10% measurement of CP violating amplitude.
- $K^0 \rightarrow \pi^0\mu^+\mu^-$: <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

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. Production of Very-cold and Ultra-cold neutrons for EDM and n-nbar.**

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

Example Power Staging for the Research Program

Prioject X Campaign

Program:	Stage-0: Proton Improvement Plan	Stage-1: 1 GeV CW Linac driving Booster & Muon, EDM programs	Stage-2: Upgrade to 3 GeV CW Linac (MI>70 GeV)	Stage-3: Project X RDR (MI>60GeV)	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2300 kW	2300-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-40 kW* + 0-90 kW**	0-40 kW*	85 kW	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	85 kW	1000 kW
1-3 GeV Muon program	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1100 kW	1100 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
# Programs:	4	8	8	8	8
Total* power (mean):	660 kW	1950 kW	4230 kW	5490 kW	11300kW

* Operating point in range depends on MI energy for neutrinos.

** Operating point in range is depends on MI injector slow-spill duty factor (df) for kaon program.

The Mega-Watt Jungle…

Apologies to Jurassic Park and Hitoshi Murayama , ICFA October 2011

A Few High Power Target Issues…

- Modelling of beam energy deposition
- Modelling of secondary particle production
- Modelling of target material response using FEA codes
- Target cooling or replacement
- Activation and radiation damage everywhere
- Thermal shock
- Target lifetime
- Particle capture, moderation and delivery
- Beam windows
- Target station design, inc. shielding, RH, licensing, etc
- Diagnostics in high radiation environments
- Demanding environmental and safety requirements

Courtesy Patrick Hurh and the UKHPT/STFC

Project X Research Program Milestones…

- June 2012 Physics Study.

- Summer 2012 through Spring 2013:

Evolve existing white papers into comprehensive program.

- October 2012:

US particle physics town meeting preparing for "Snowmass", summer 2013.

- Snowmass, summer 2013:

Event to develop US strategies.

Goals of the this Forum

- Identify key spallation targetry & beamline technical issues that must be addressed for next generation:

Atomic EDM, neutron-EDM, and neutron-anti-neutron experiments.

- Identify roadmap elements toward next generation designs:

- Conceptual
- Engineering
- Simulation

- 2012 goals: Update white paper accordingly, establish roadmap.

Miscellaneous Announcements

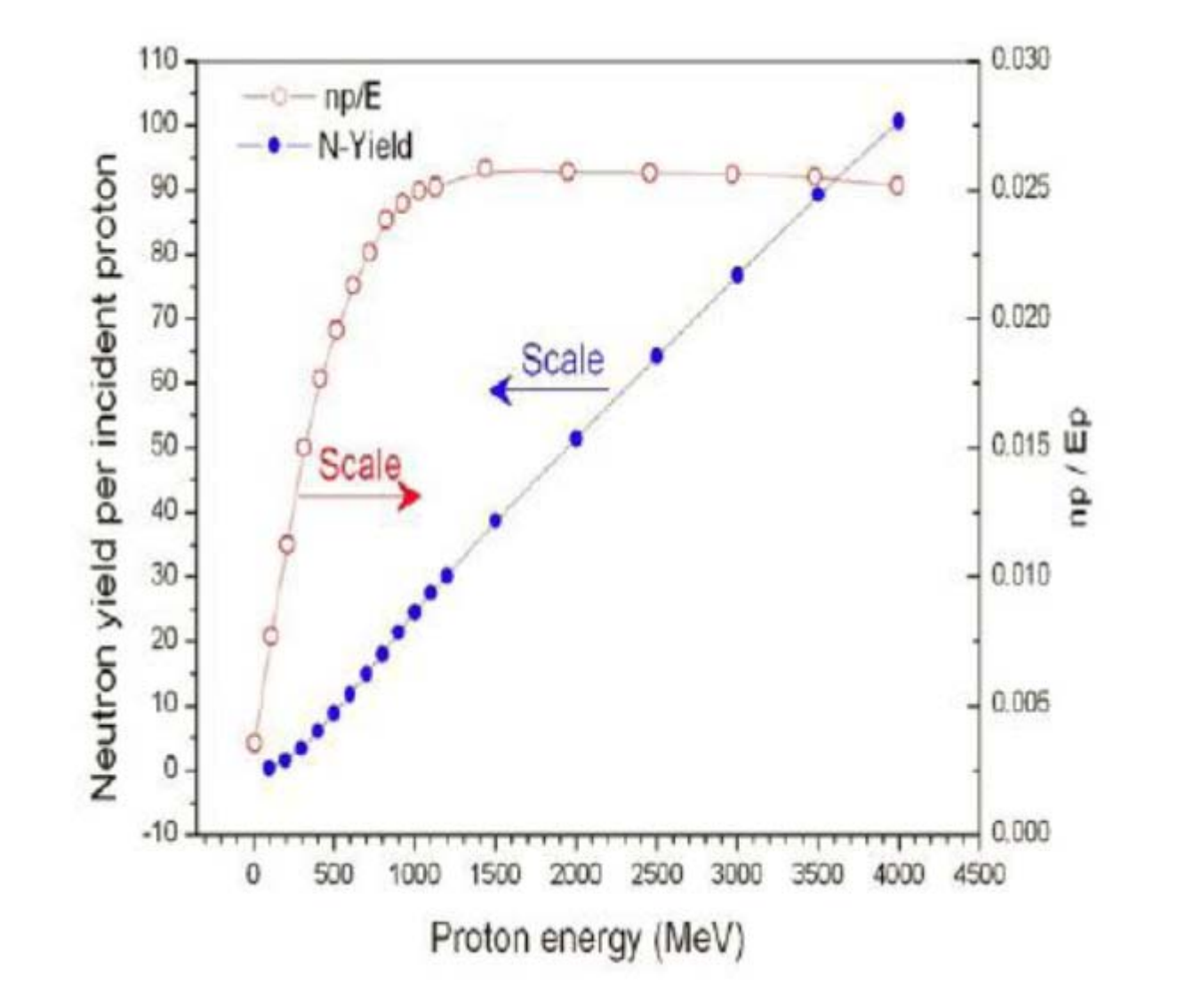
- Photo op @ 12:30a in atrium.

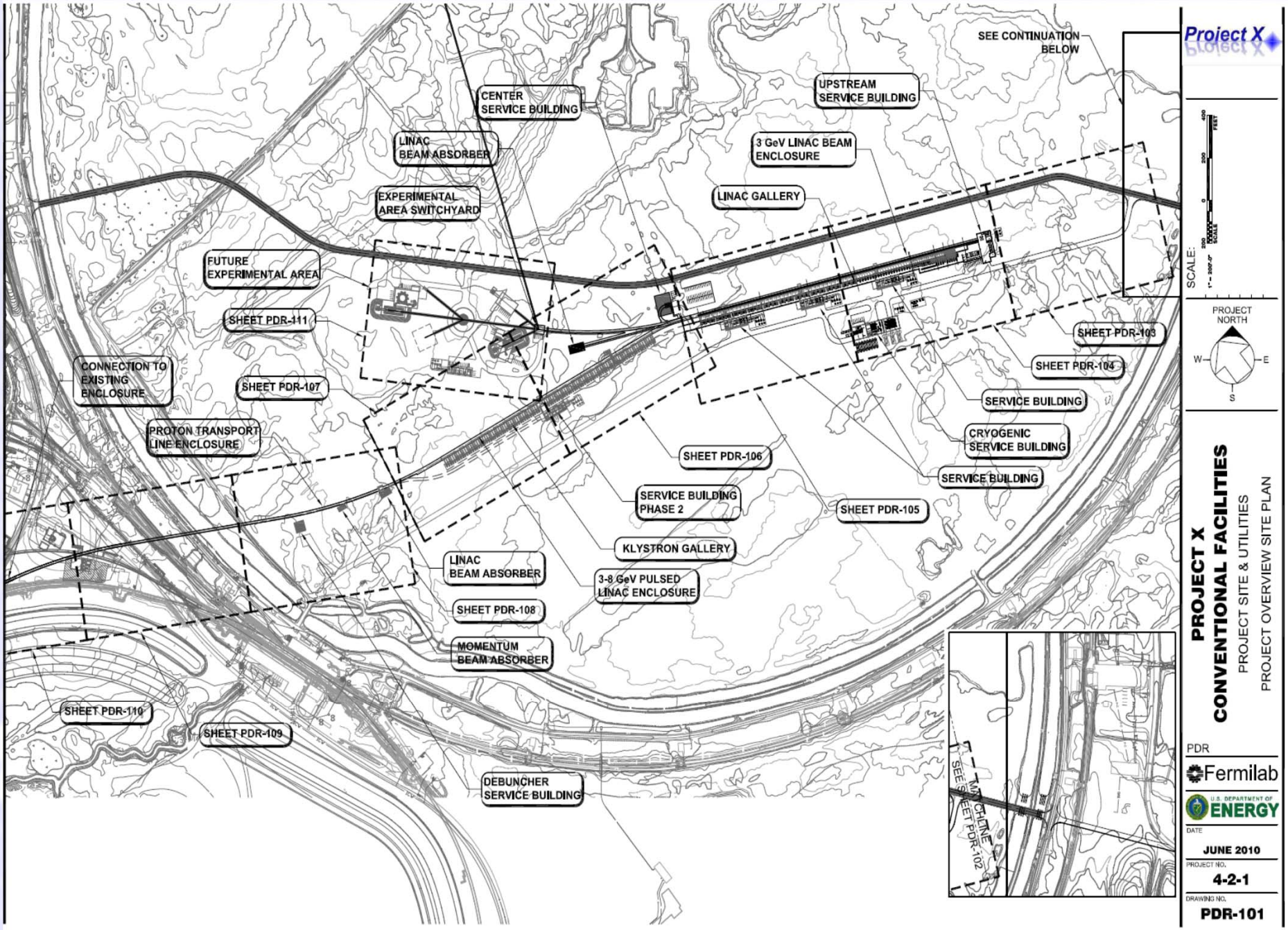
- For those joining dinner this evening (Monday March 19th):

  Cooper's Hawk Winery & Restaurant 7:30pm.

  1740 Freedom Drive
  Naperville, IL 60563

Optimum Energy for ADS R&D




SEE CONTINUATION BELOW
UPSTREAM SERVICE BUILDING
CENTER SERVICE BUILDING
LINAC BEAM ABSORBER
3 GeV LINAC BEAM ENCLOSURE
EXPERIMENTAL AREA SWITCHYARD
LINAC GALLERY
FUTURE EXPERIMENTAL AREA
SHEET PDR-111
SHEET PDR-103
SHEET PDR-104
CONNECTION TO EXISTING ENCLOSURE
SHEET PDR-107
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
TWO CHIME
SEE SHEET PDR-102
Project X
SCALE:
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PROJECT X
CONVENTIONAL FACILITIES
PROJECT SITE & UTILITIES
PROJECT OVERVIEW SITE PLAN
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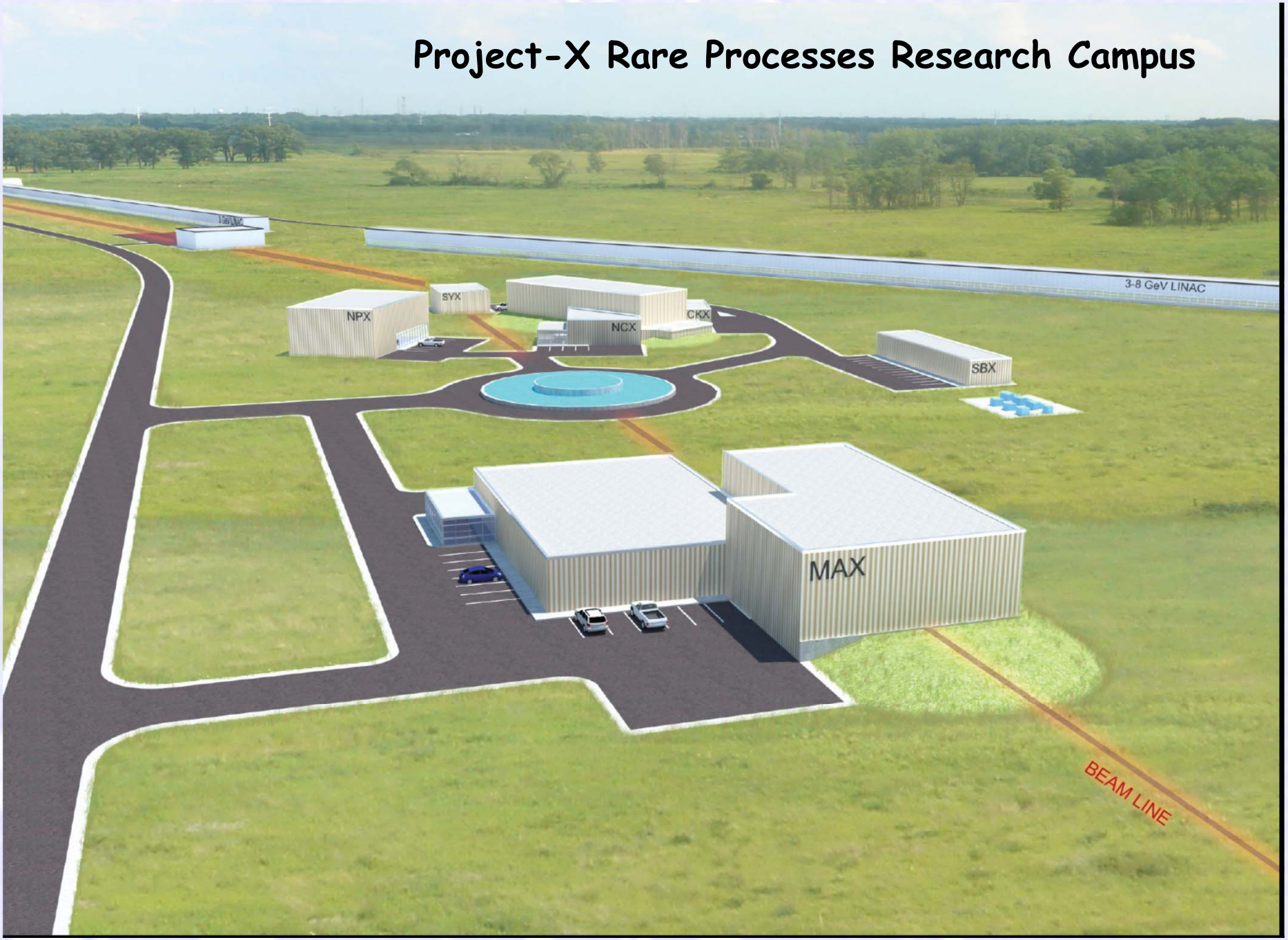
Project-X Rare Processes Research Campus