

Project-X

IFW, Rockville Md, Dec 1st 2011

R. Tschirhart
Fermilab

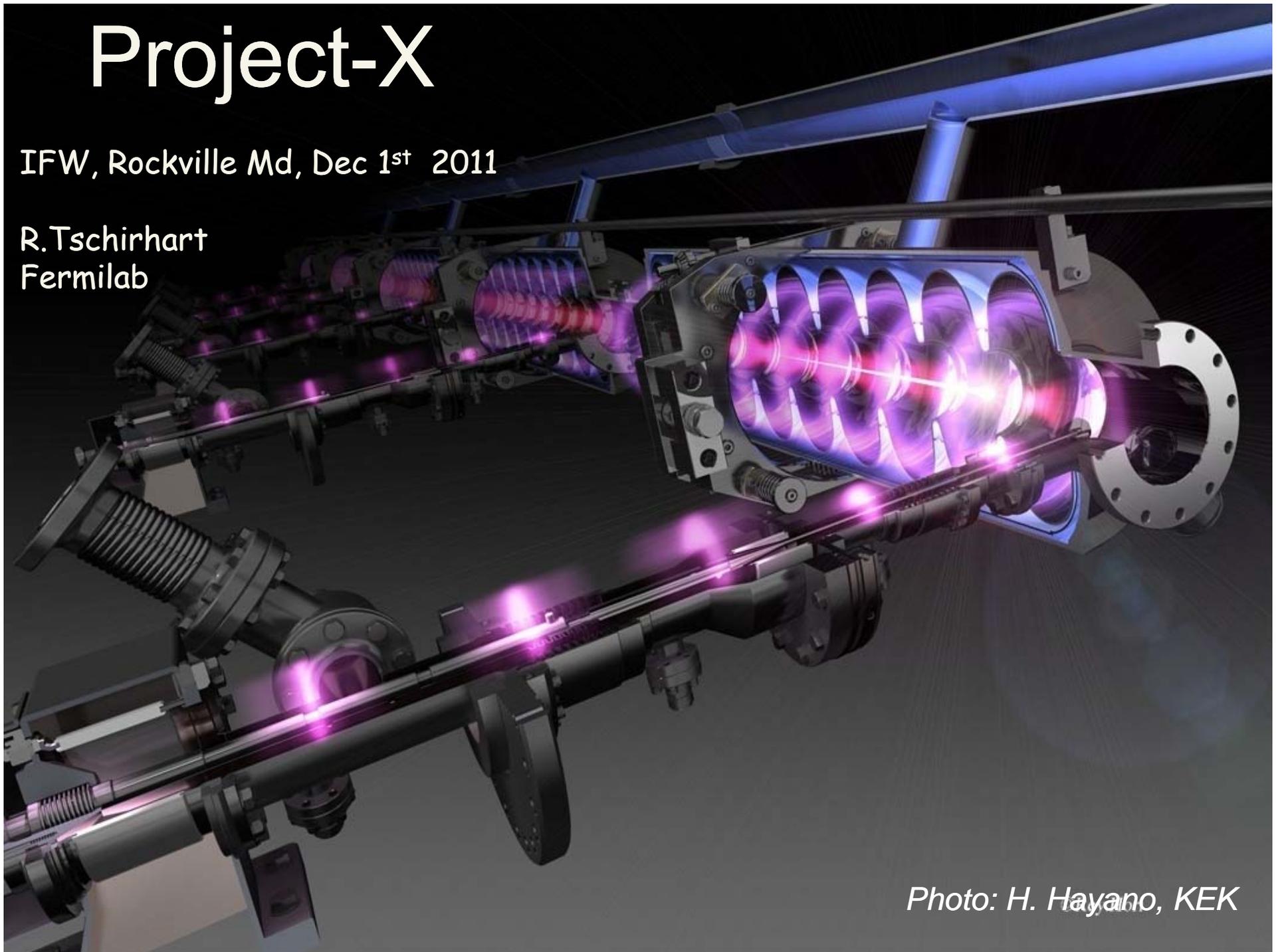


Photo: H. Hayano, KEK

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***

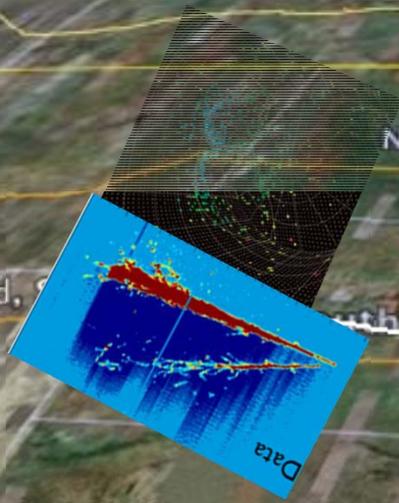
- Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.

- ***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

200 kT fiducial volume Water Cherenkov Far Detector

33 kT fiducial volume Liquid Argon TPC Far Detector

Image NASA
© 2008 Tele Atlas

Image © 2008 TerraMetrics
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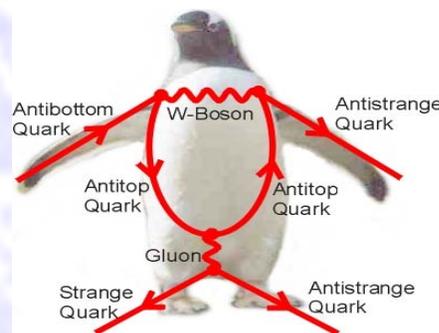
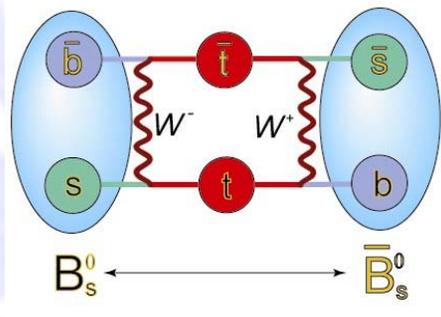
Google

Pointer 43°03'56.44" N 95°10'42.53" W Streaming ||||| 100%

Eye alt 1108.62 km³

Kaon, Muon and EDM Experiments Deeply Attack the Flavor Problem

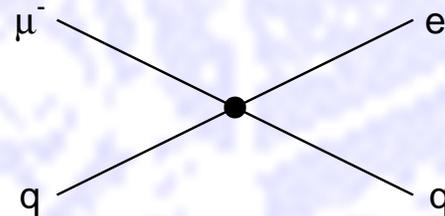
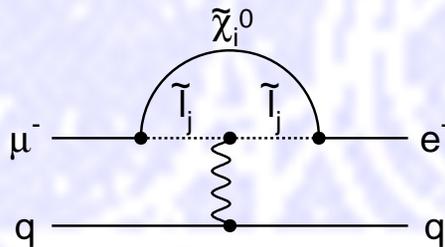
Why don't we see the *Terascale Physics we expect* affecting the flavor physics we study today??



Deepest Probe of the Flavor Problem: muon-to-electron Conversion Expt at Project-X

Supersymmetry

Predictions at 10^{-15}

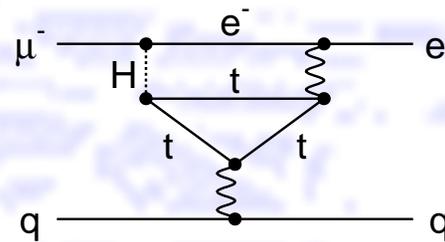
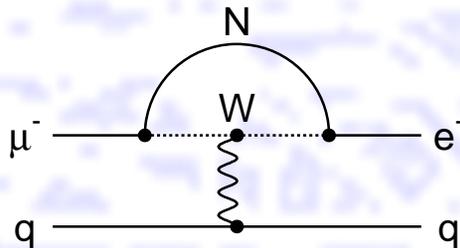


Compositeness

$$\Lambda_C = 3000 \text{ TeV}$$

Heavy Neutrinos

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

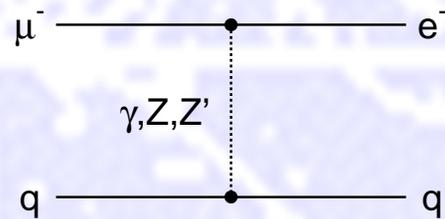
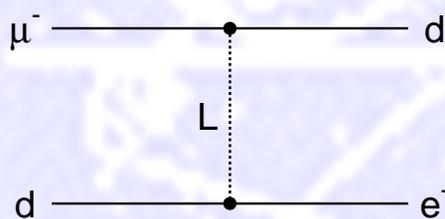


Second Higgs doublet

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

Leptoquarks

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



Heavy Z',
Anomalous Z
coupling

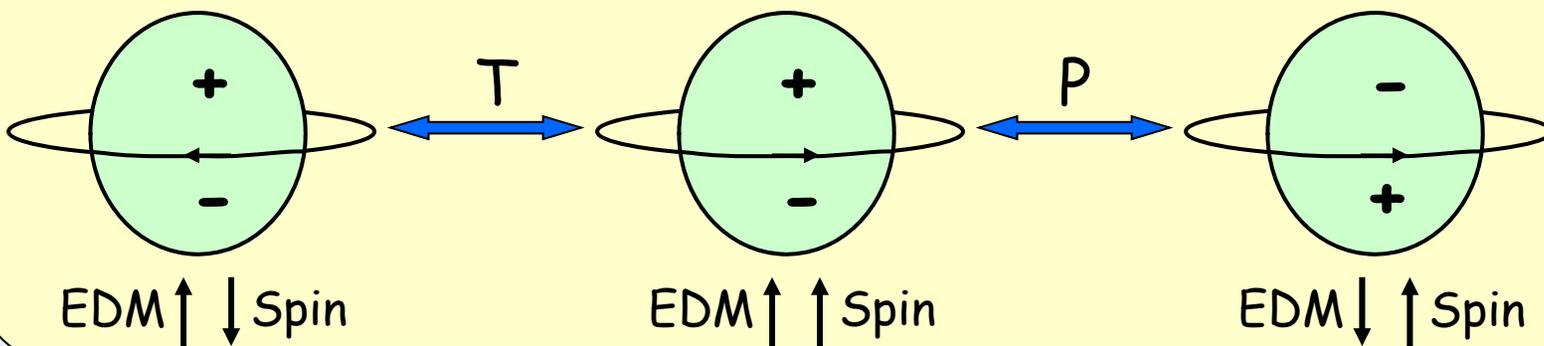
$$M_{Z'} = 3000 \text{ TeV}/c^2$$

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

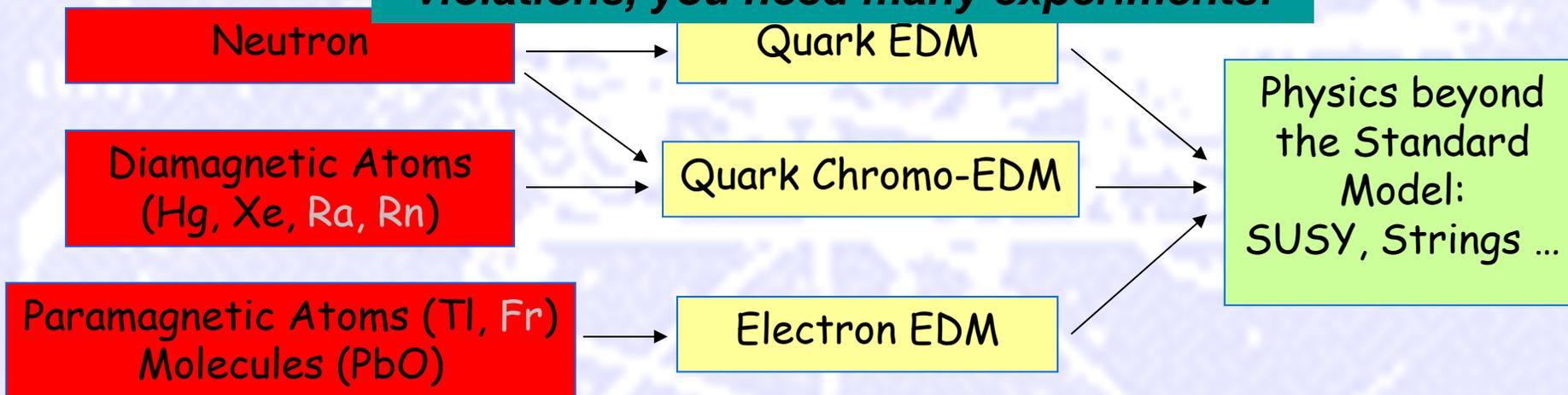
After W. Marciano

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!

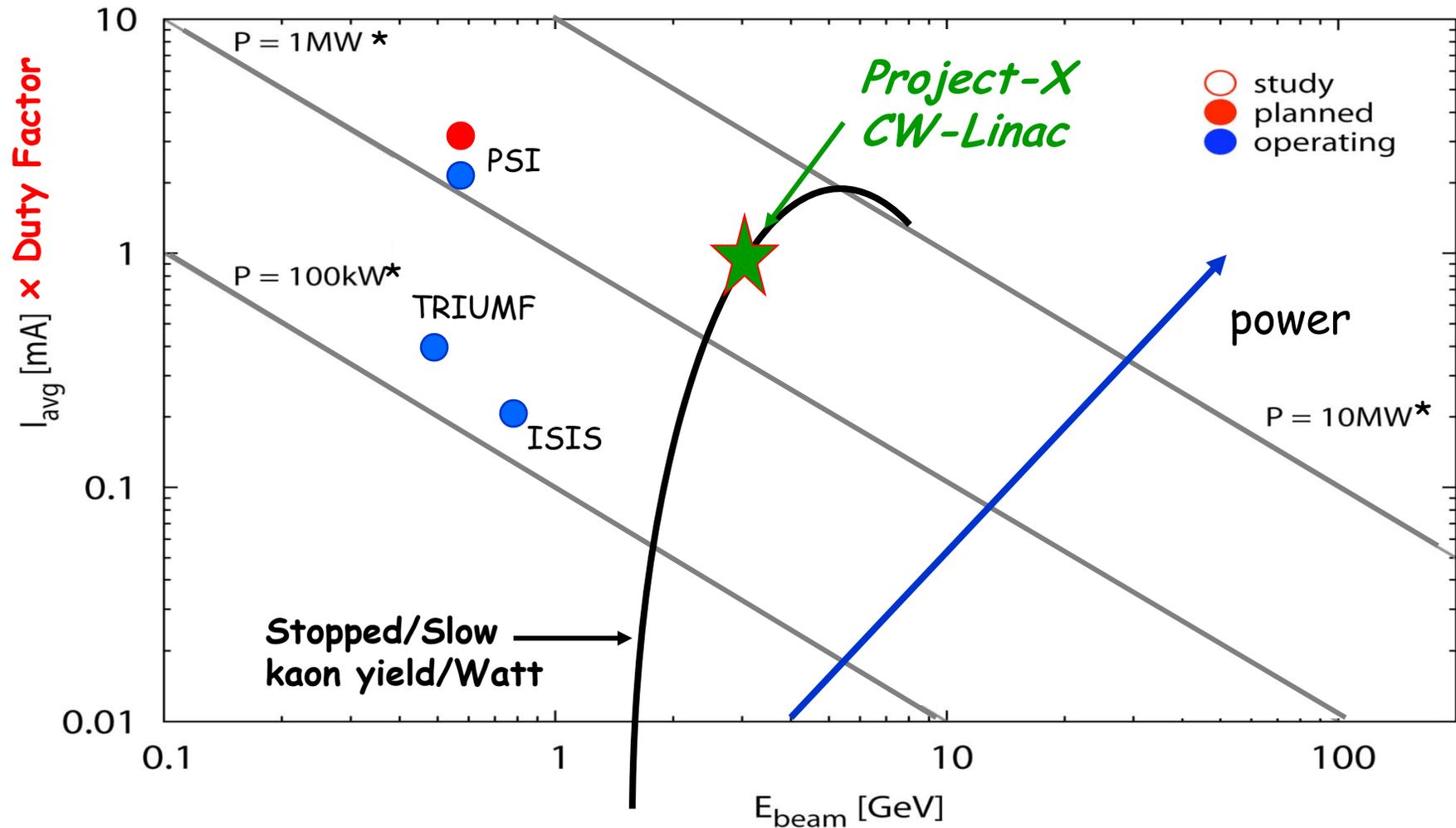


Guy Savard, ANL

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 \times Duty Factor

Project-X Accelerator Functional Requirements

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

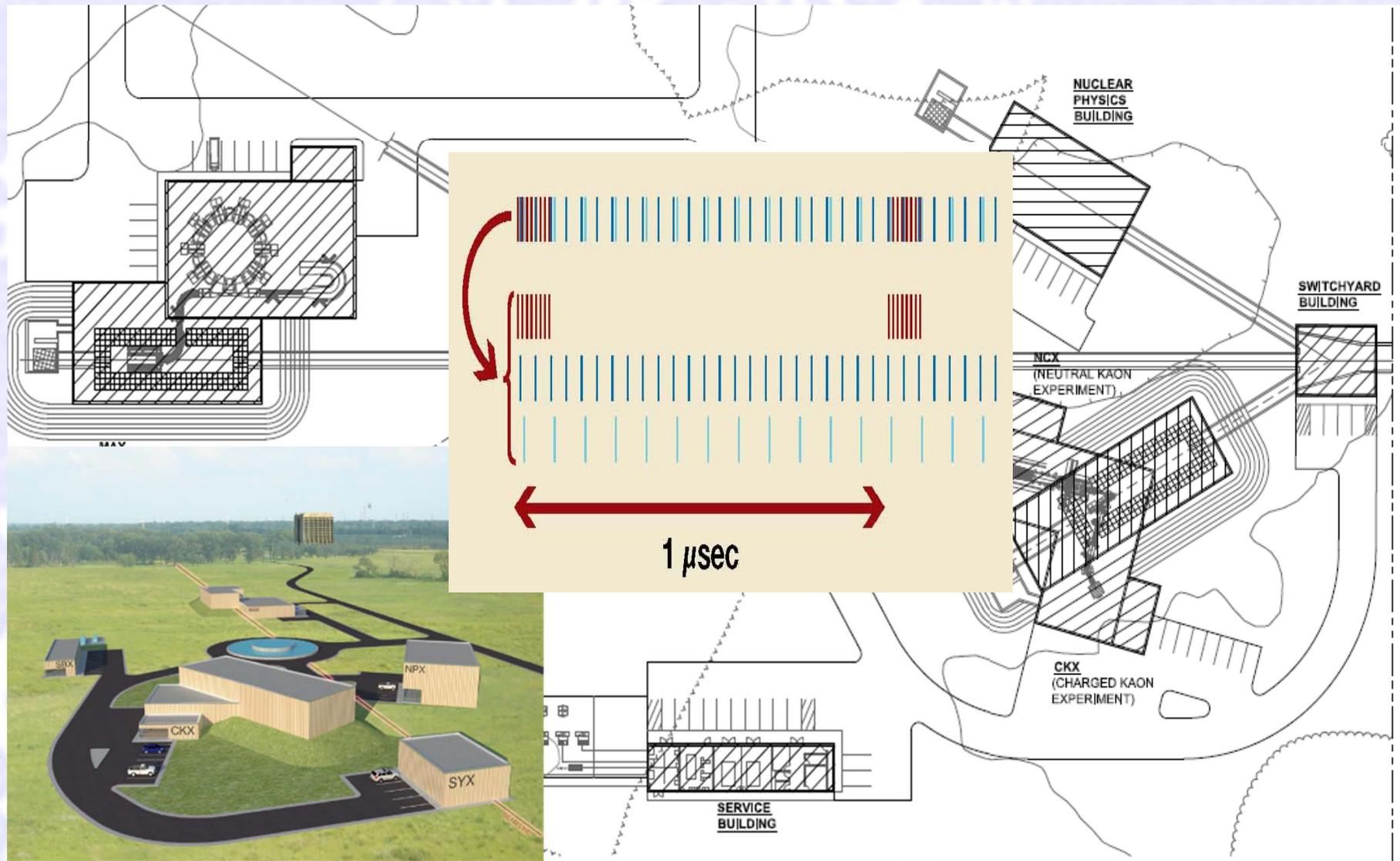
Particle Type	protons/H ⁻	
Beam Kinetic Energy	8.0	GeV
Pulse rate	10	Hz
Pulse Width	0.002/4.3	msec
Cycles to MI	6	
Particles per cycle to Recycler	2.6×10^{13}	
Beam Power to 8 GeV program	190	kW

Main Injector/Recycler

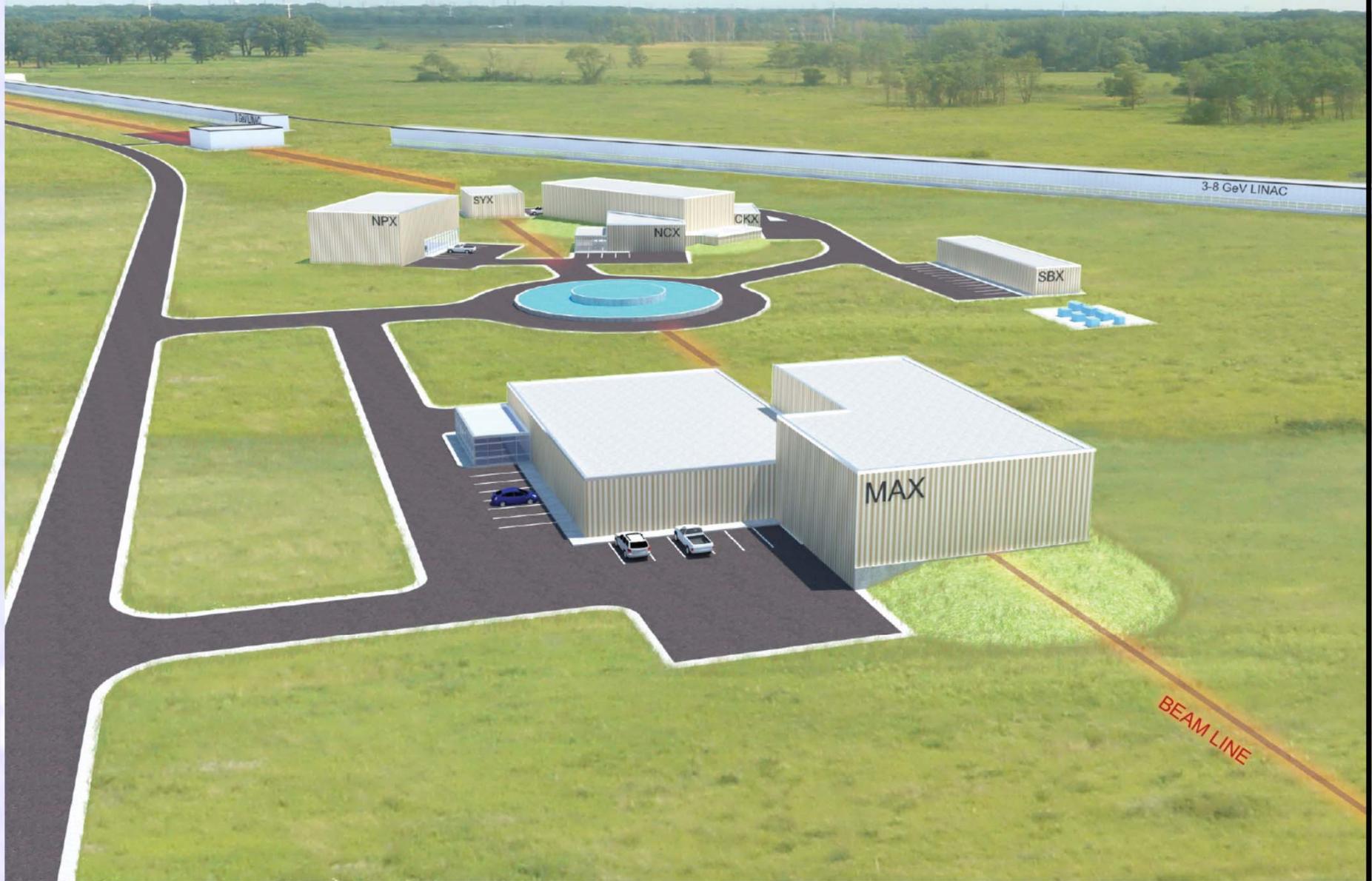
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.3	sec
Particles per cycle	1.6×10^{14}	
Beam Power at 120 GeV	2200	kW

simultaneous

Project-X High-Intensity Campus



Project-X Rare Processes Research Campus



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

Muon Physics:

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

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.
- $K^0 \rightarrow \pi^0 e^+ e^-$: <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.

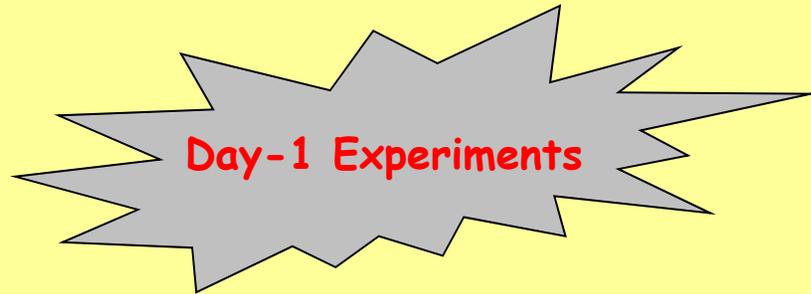
Baryon Physics:

- $pp \rightarrow \bar{\Sigma}^+ K^0 p^+$; $\Sigma^+ \rightarrow p^+ \mu^+ \mu^-$ (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

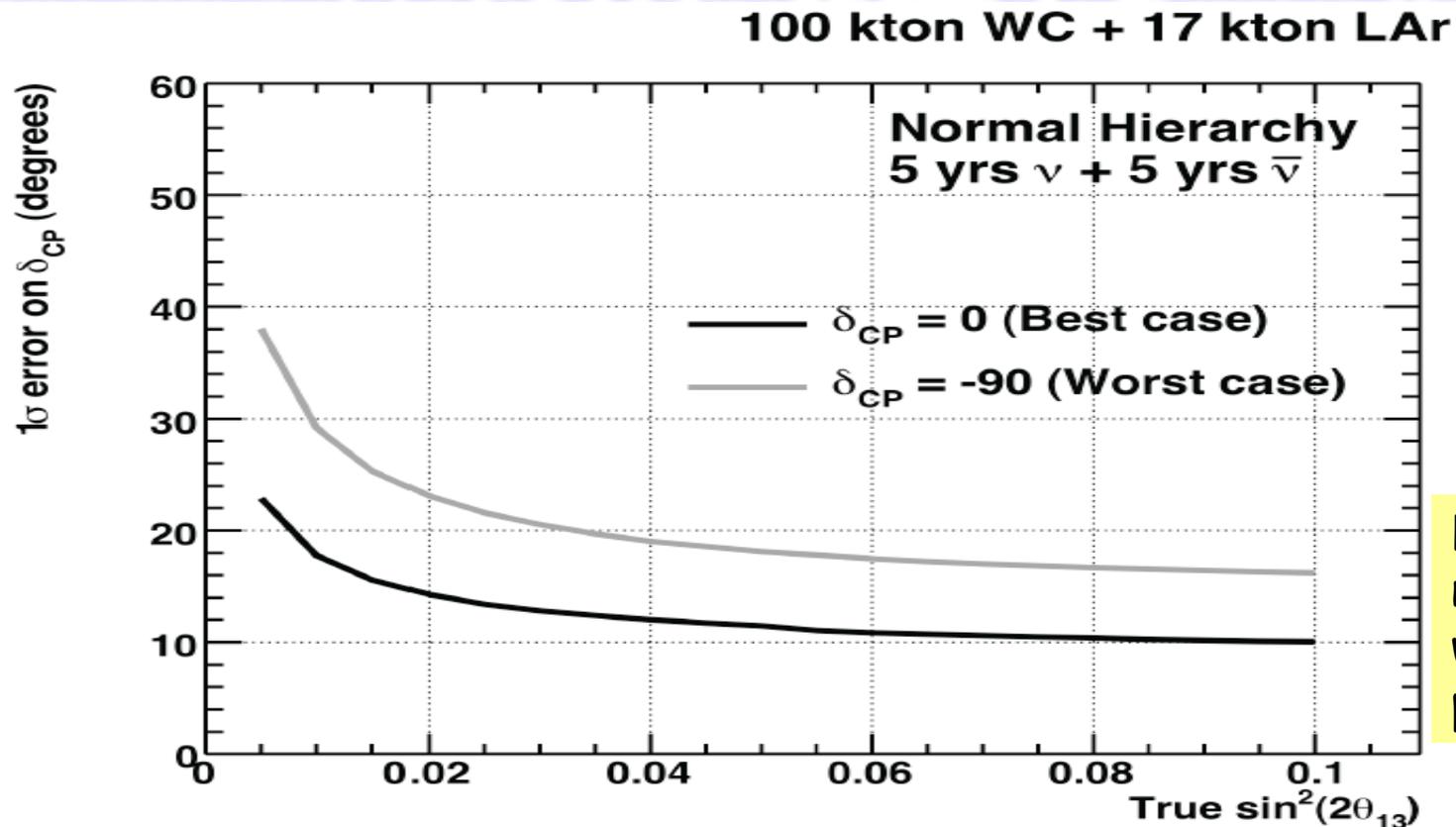
An Incomplete Menu of World Class Research Targets Enabled by Project-X

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.



Pursuing next-generation neutrino parameters is beam-power hungry: Project-X Triples LBNE (Power x Mass) Reach



From the neutrino white paper

Figure 3: Plot showing 1 sigma error (in degrees) on δ_{CP} at an LBNE far detector complex composed of a 100-kT water Cherenkov detector and a 17-kT liquid argon detector. The exposure assumes a 700-kW proton beam. [Plot courtesy of Lisa Whitehead, Brookhaven National Laboratory]

Future Detector 2 ■

Short-Baseline Neutrino Workshop

12-14 May 2011

Fermilab

Neutrino Source I

Local Organizing Committee:

Zelimir Djuracic (ANL)
Bonnie Fleming (Yale)
Bill Louis (LANL)
Geoff Mills (LANL)
Zarko Pavlovic (LANL)
Chris Polly (FNAL)
Richard Van de Water (LANL)
Sam Zeller (FNAL)

Scientific Advisory Committee:

Gerry Garvey (LANL)
Carlo Giunti (Torino)
Terry Goldman (LANL)
Young-Kee Kim (FNAL)
Bill Marciano (BNL)
Mark Messier (Indiana)
Jorge Morfin (FNAL)
Mike Shaevitz (Columbia)
Bob Svoboda (UC Davis)
Stan Wojcicki (Stanford)

Supported by Fermi National Accelerator Laboratory and Los Alamos National Laboratory

The workshop will cover recent short-baseline neutrino results, theoretical interpretations, future neutrino facilities, and future short baseline neutrino experiments. The goal of the workshop will be to discuss future facilities and experiments that can be built at Fermilab and elsewhere to explore short-baseline neutrino physics (including neutrino oscillations, CP violation, sterile neutrinos, axion searches, cross sections, etc.).

<https://indico.fnal.gov/event/sbnw2011>

Project-X Opportunities

- Follow leads on 3+N sterile neutrinos:

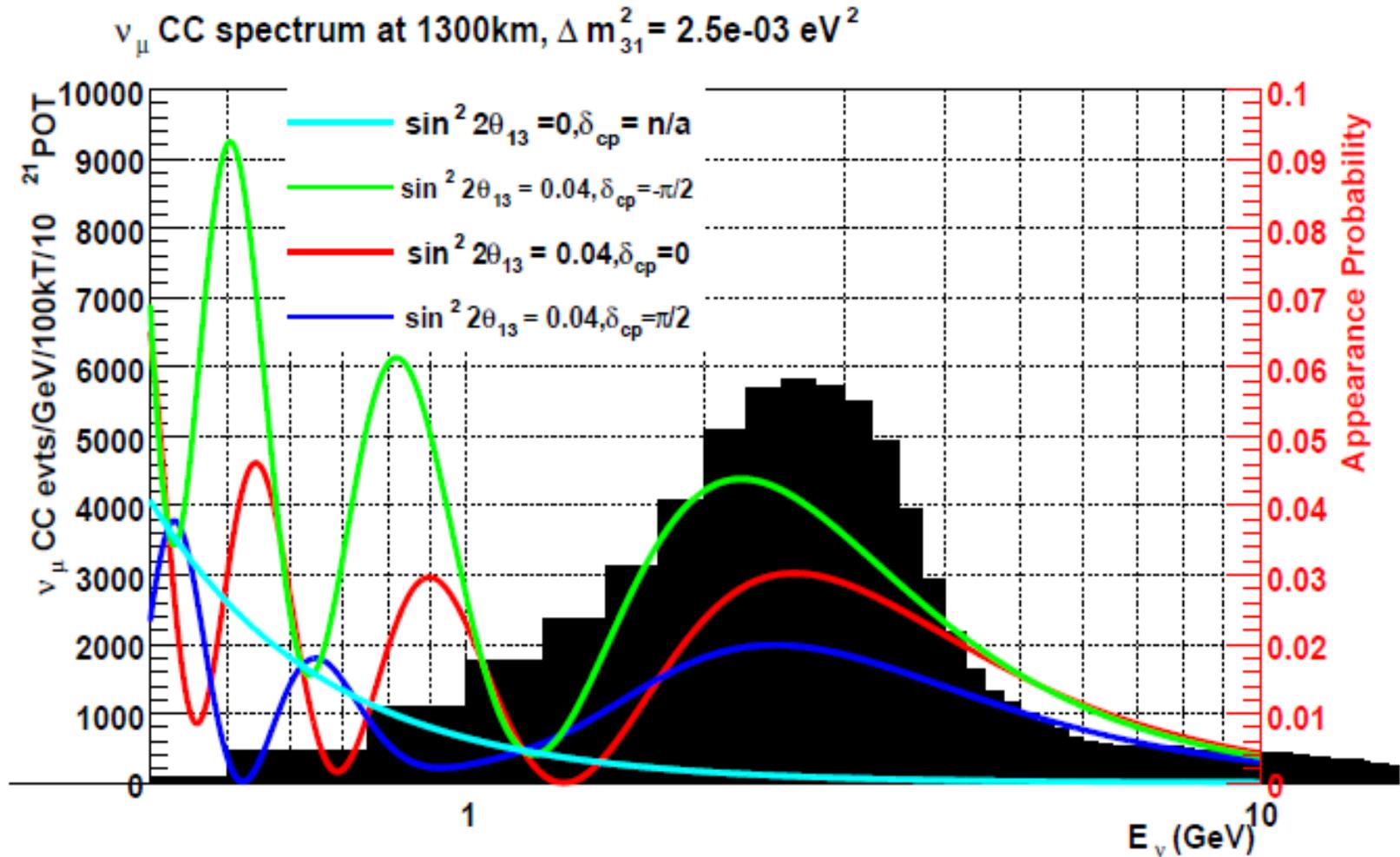
190 kW 8-GeV beam power
1000 kW class 3-GeV DIF driver

Higher 8-GeV beam power??

- Beam dump exotics search
- Precision neutrino cross sections
- Flux measurements with H/D₂

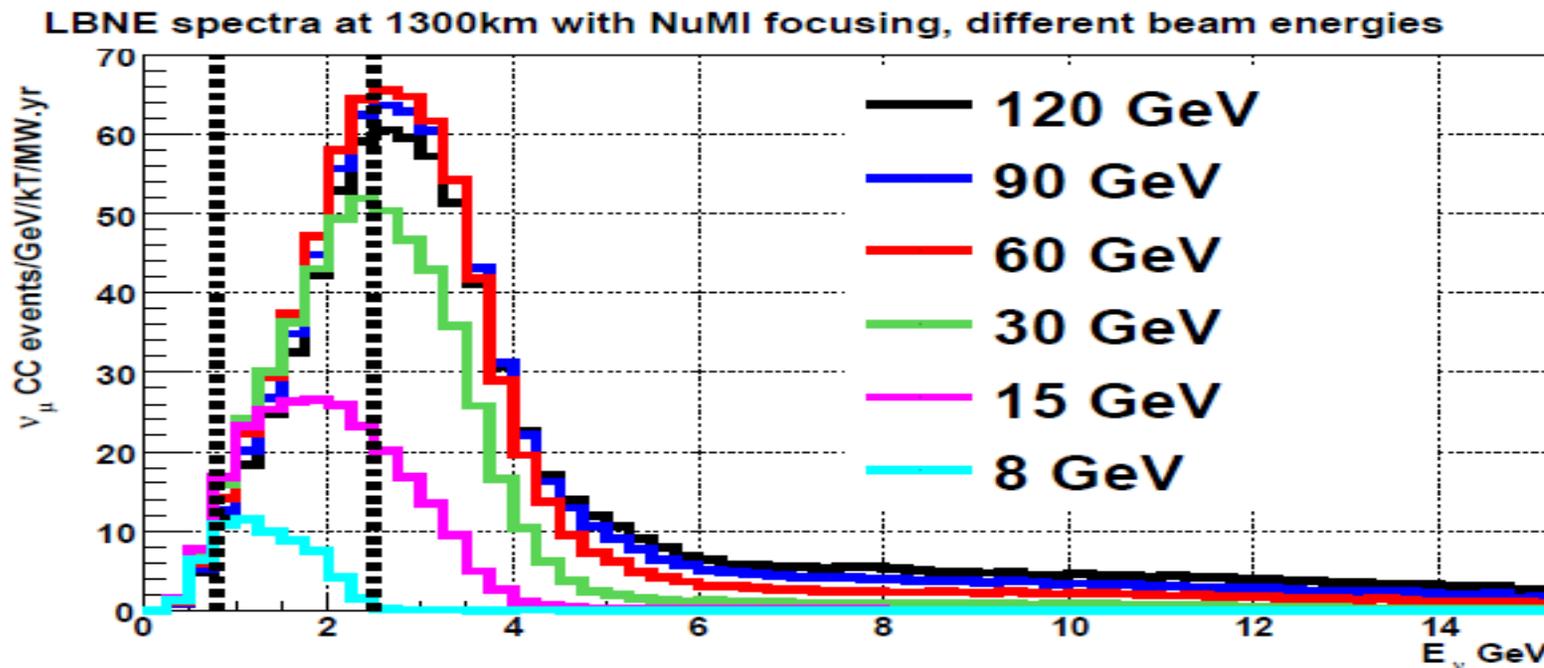
SBNW11 Summary : R. Van de Water (LANL)

Tuning the LBNE spectrum



Mary Bishai, Neutrino Working Group meeting October 24th, 2011

- A task force (K. Gollwitzer) to develop a path from Project-X to a Neutrino-Factory/Muon-Collider has recently reported a concept to raise available 8 GeV beam power from 190kW to 4000kW! This path re-uses 75% of the Project-X facility.
- The joint reach of simultaneous 2MW@60 GeV and 4MW@8 GeV is very interesting. This idea has been long been considered (D Michael) and more recently by Mary Bishai and Jeff Nelson.



Mary Bishai, Neutrino Working Group meeting October 24th, 2011

Impact of Project X on LBNE

Mary Bishai (LBNE collaboration) Brookhaven National Laboratory

Intro

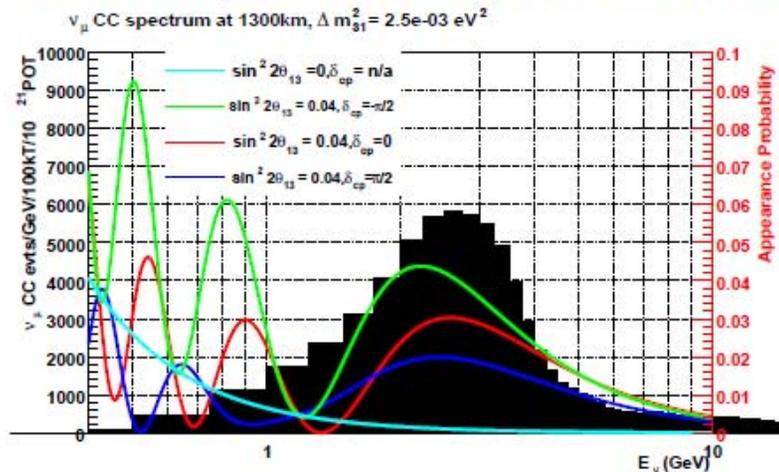
LBNE Beams

LBNE Detectors

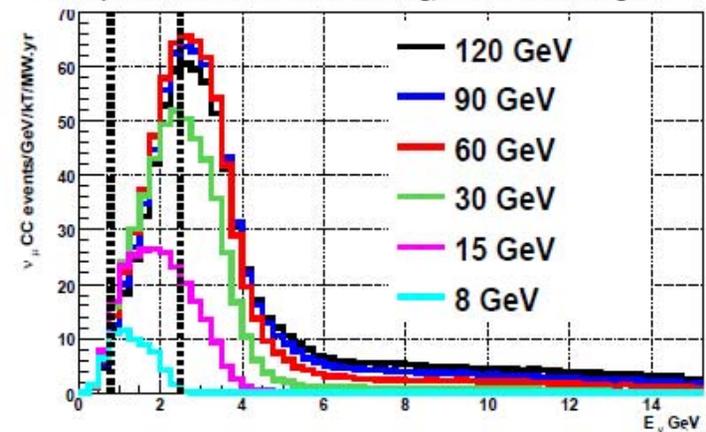
Beam Physics with Project X

Summary

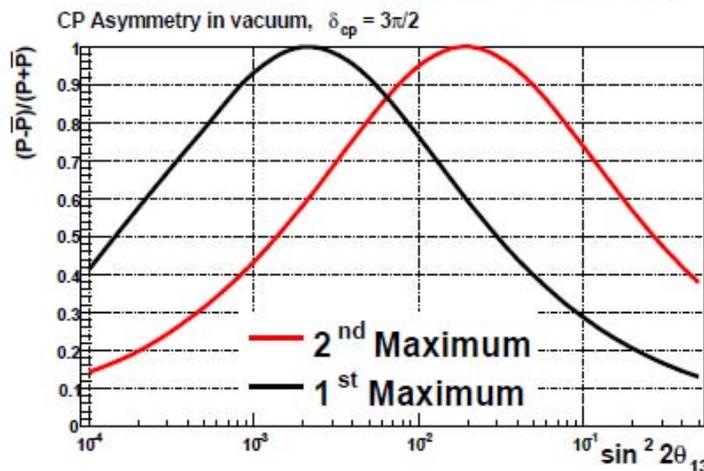
Wide-band beam to cover BOTH oscillation maxima for best CP Violation/Mass Hierarchy sensitivity



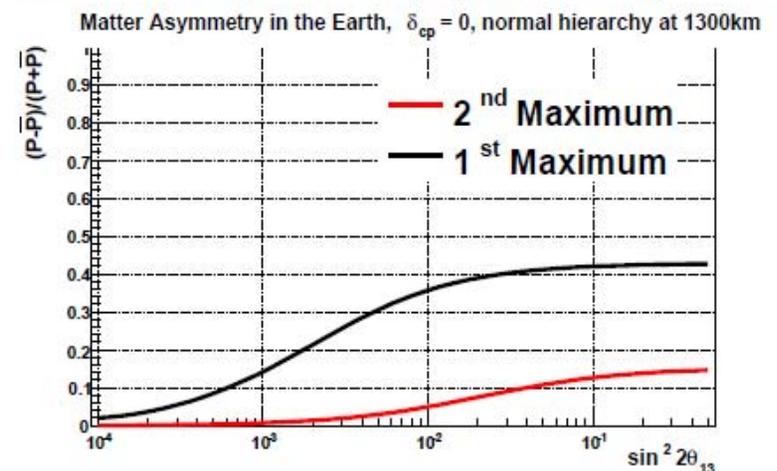
LBNE spectra at 1300km with NuMI focusing, different beam energies



CP Asymmetry (vacuum)



Matter Asymmetry (no CPV)



Mary Bishai, Neutrino Working Group meeting October 24th, 2011

Neutrinos, Project-X and you...

- Project-X will reduce the tyranny in long-baseline experiments of (Beam-Power \times Detector-Mass) by $\times 3$.
- Many opportunities for high power short-baseline experiments exist for 3-8 GeV beam power. More development is needed, directions will depend on how the 3+N sterile-neutrino saga unfolds.
- Development of Project-X includes consideration of a 4MW proton driver at 8 GeV for a neutrino factory and Muon Collider.

A beam power path to consider for long-baseline experiments:

700kW at 120 GeV this decade.

>2000kW at 60-120 GeV in the Project X era (2022+)

>2000kW at 60-120 GeV and 4000kW at 8-GeV on the NF/MC road.

Spare Slides

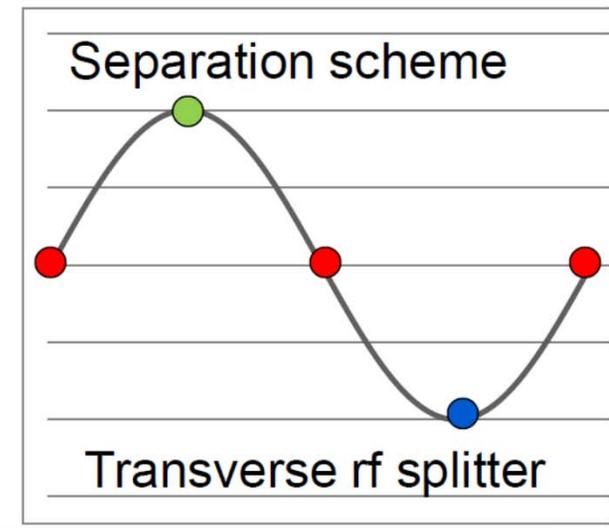
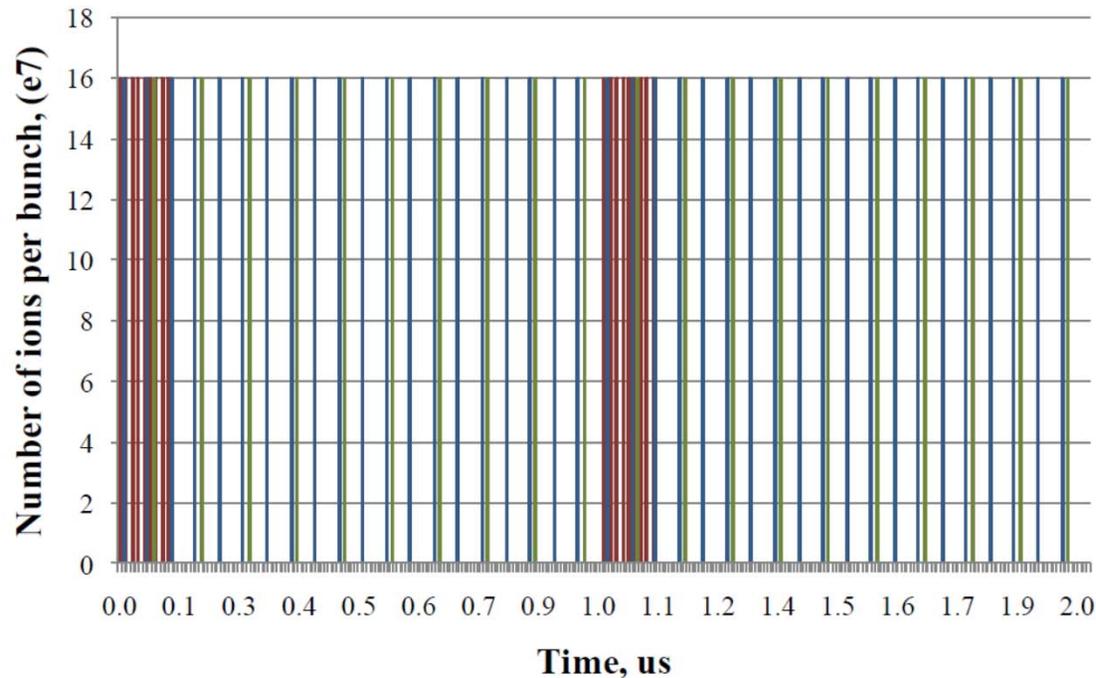
Chopping and splitting for 3-GeV experiments



1 μ sec 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

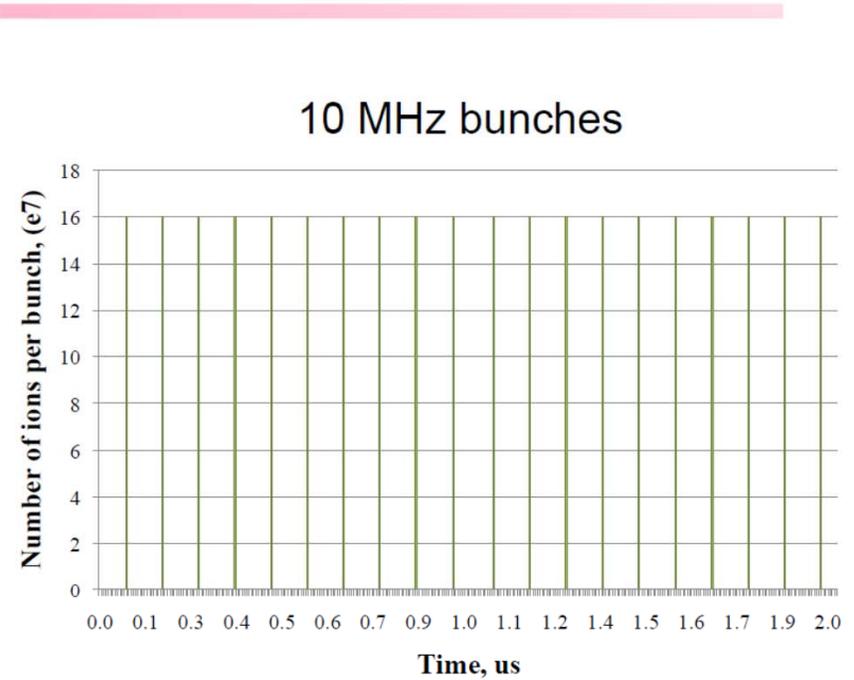
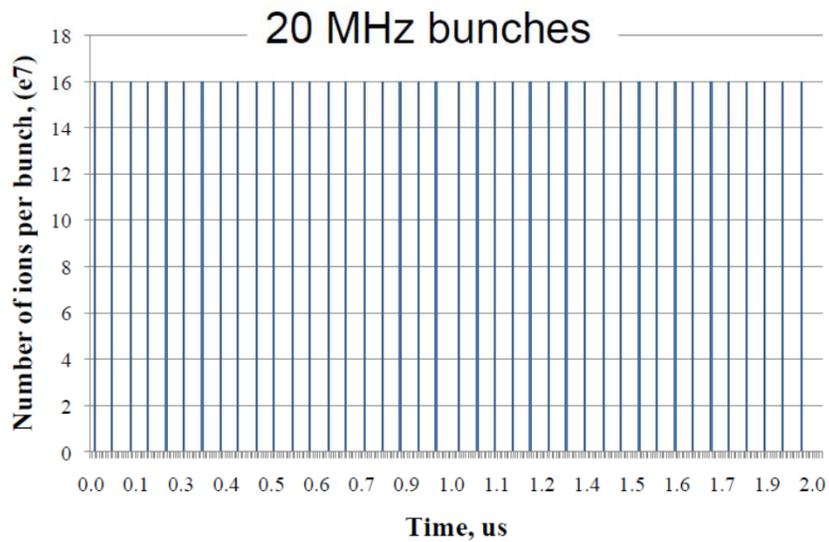
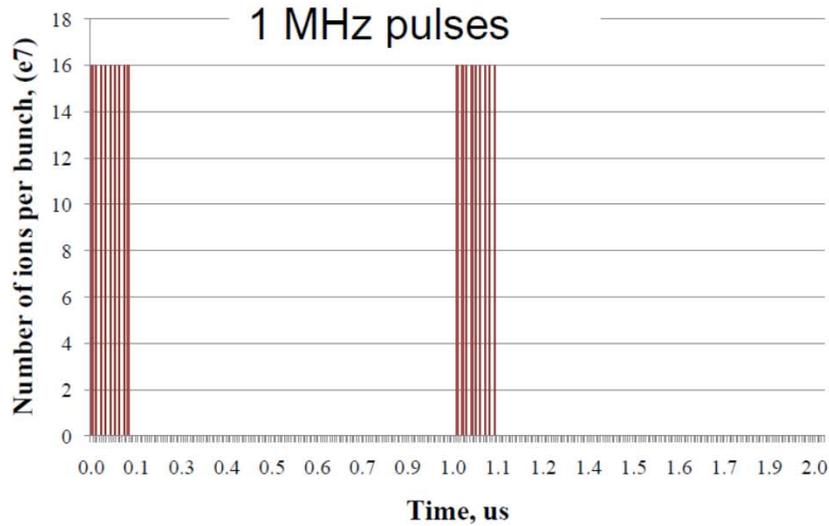
Ion source and RFQ operate at 4.2 mA
75% of bunches are chopped at 2.5 MeV after RFQ



Courtesy of Nagaitsev

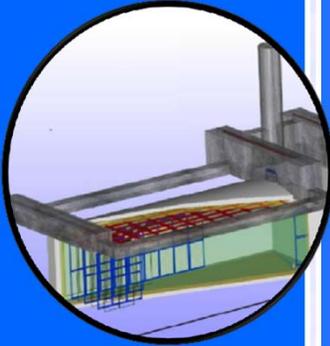


Beam after splitter



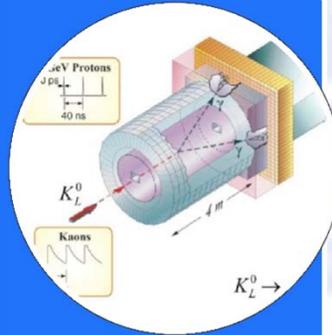
Courtesy of Nagaitsev

Project X: new experiments



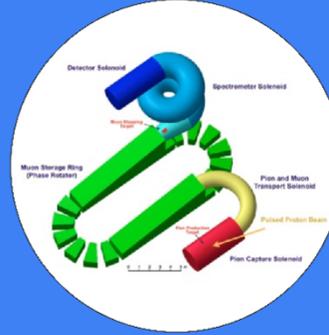
Neutrinos

- Matter-antimatter asymmetry
- Neutrino mass spectrum
- Neutrino-antineutrino differences
- Anomalous interactions
- Proton decay
- SuperNova bursts



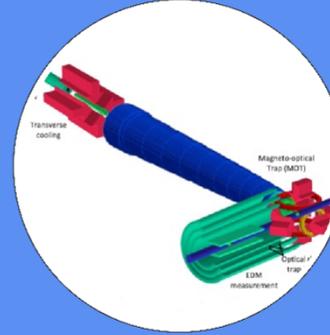
Kaons

- Physics beyond the Standard Model
- Elucidation of LHC discoveries
- Two to three orders of magnitude increase in sensitivity



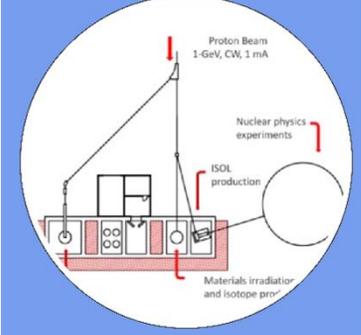
Muons

- Oscillation in charged leptons
- Physics beyond the Standard Model
- Elucidation of LHC physics
- Sensitive to energy/mass scales three orders of magnitude beyond LHC



Nuclei

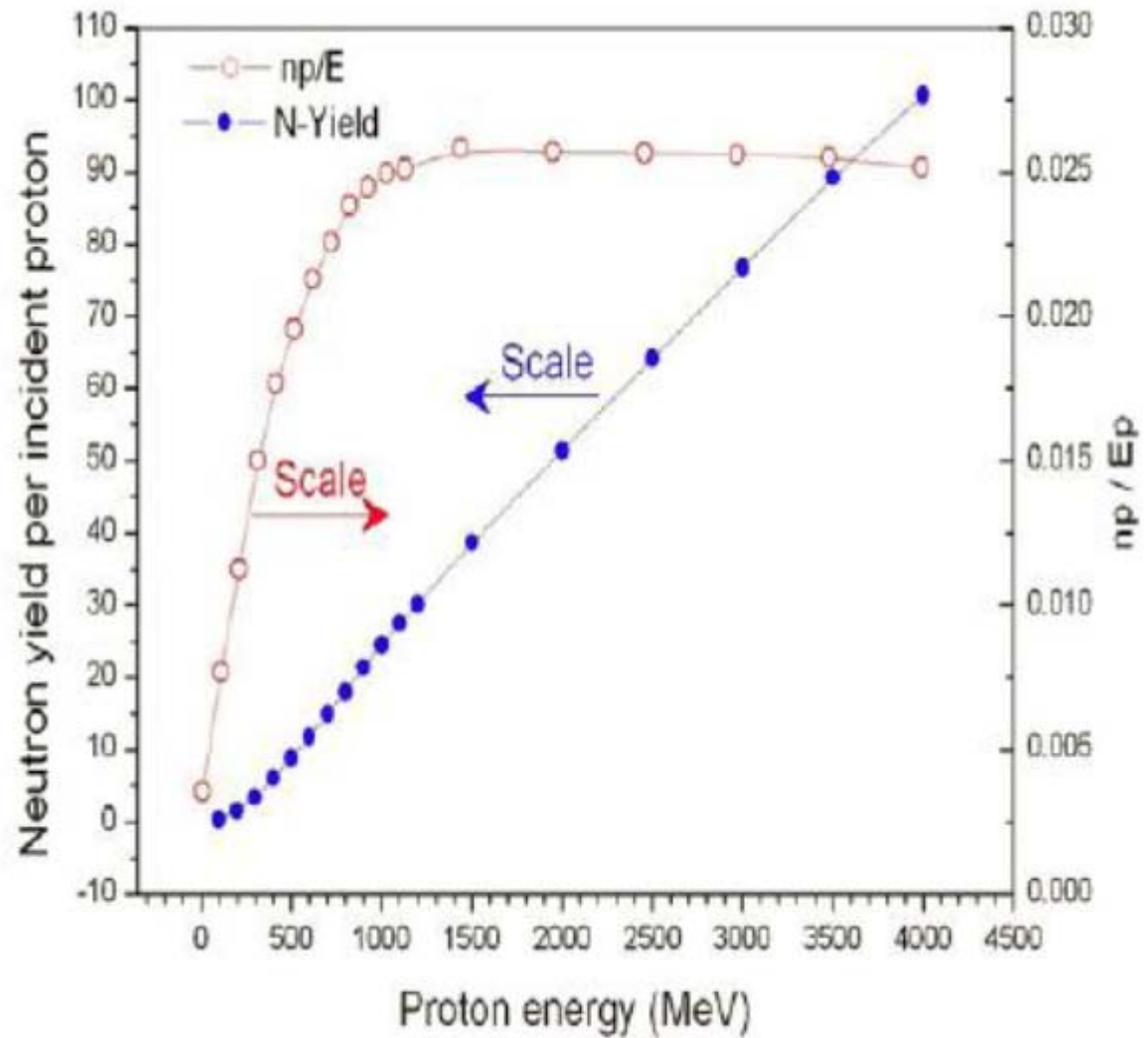
- New generation of symmetry-test experiments
- Electric Dipole Moments
- Three or more orders of magnitude increase in Francium, Radium, Actinium isotopes



Energy Applications

- Transmutation experiments with nuclear waste
- Spallation target configurations
- Materials test under high irradiation
- Neutron fluxes relevant to ADS

Optimum Energy for ADS R&D



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.

Kaon Yields at Constant Beam Power

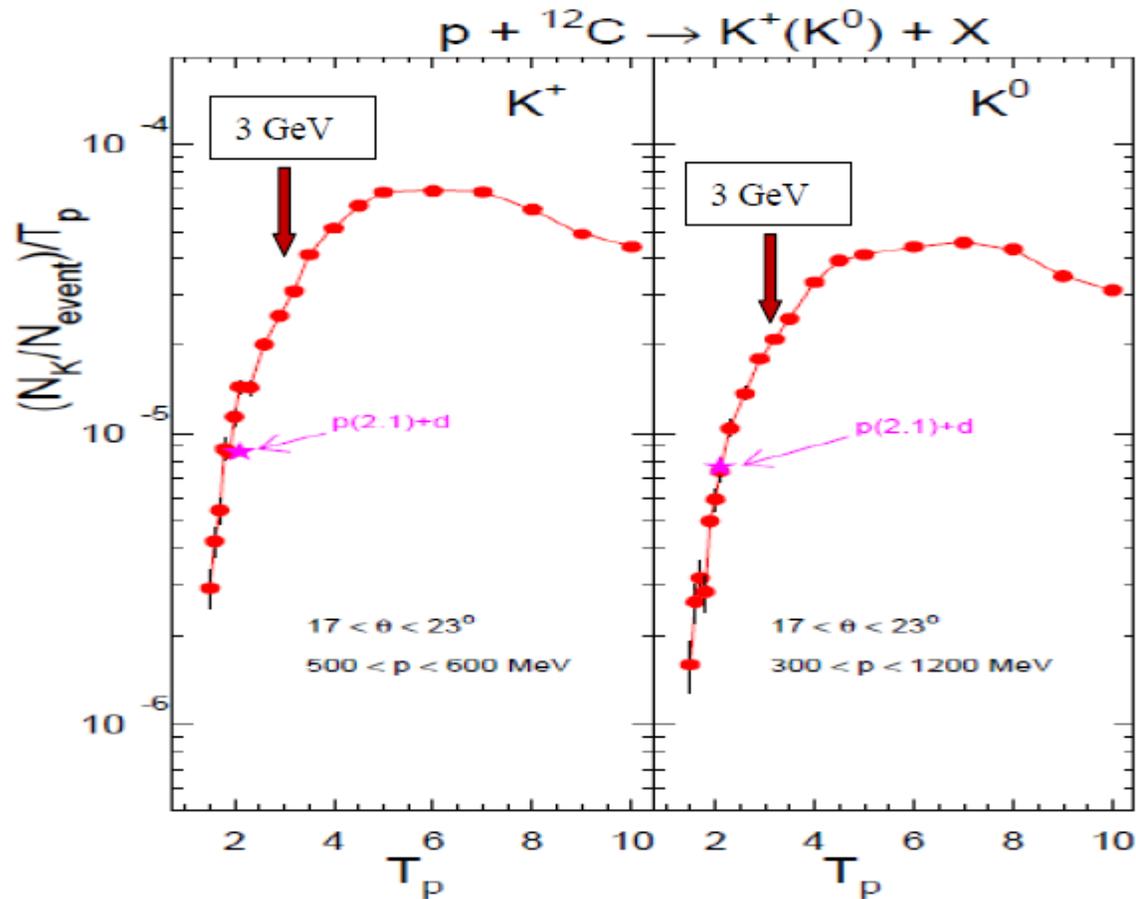
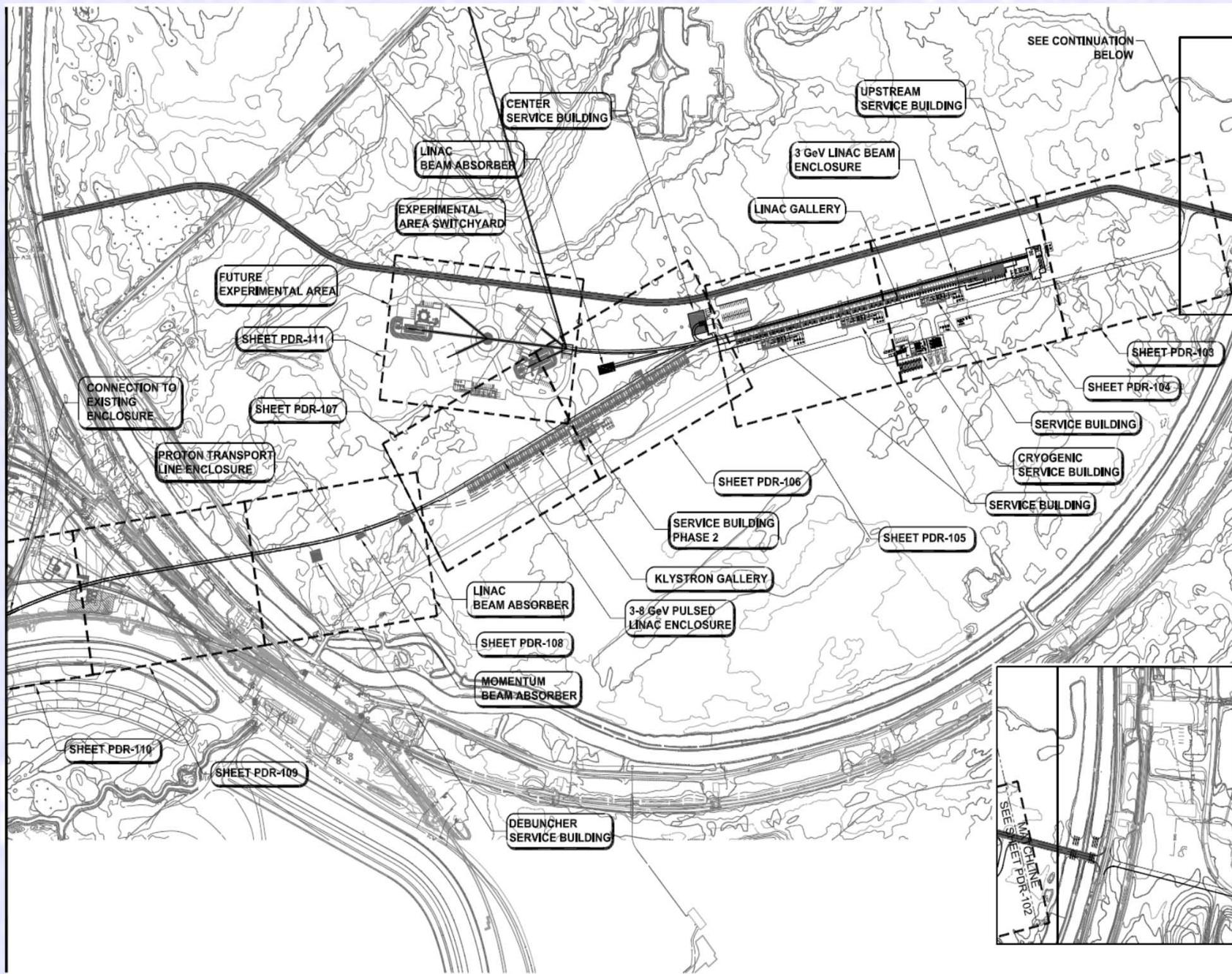
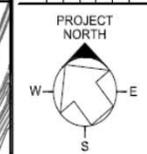


Figure 2: The estimated (LAQGSM/MARS15) kaon yield at constant beam power (yield/ T_p) for experimentally optimal angular and energy regions as a function of T_p (GeV).



Project X
SLOSH X



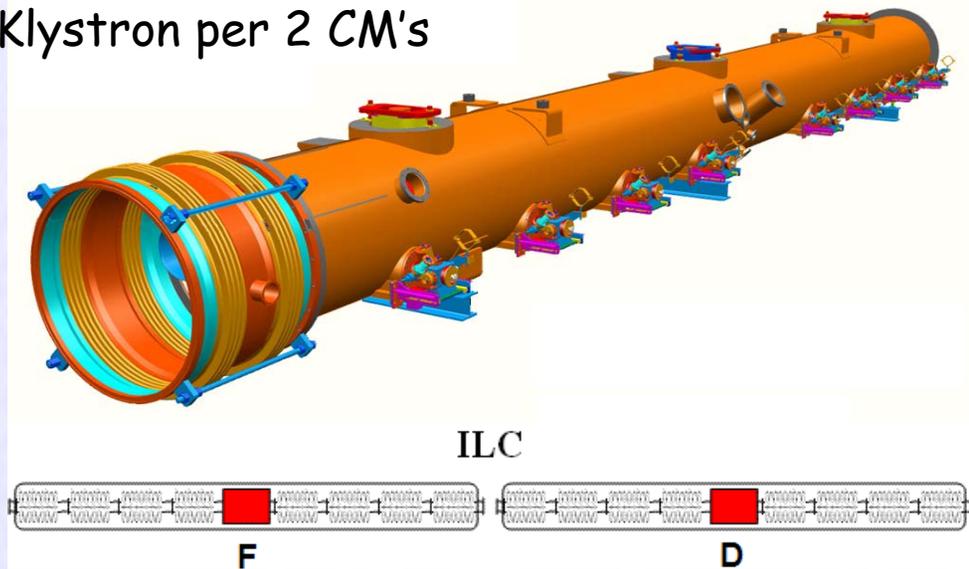
PROJECT X
CONVENTIONAL FACILITIES
PROJECT SITE & UTILITIES
PROJECT OVERVIEW SITE PLAN

PDR
 Fermilab
 U.S. DEPARTMENT OF ENERGY
 DATE: **JUNE 2010**
 PROJECT NO.: **4-2-1**
 DRAWING NO.: **PDR-101**

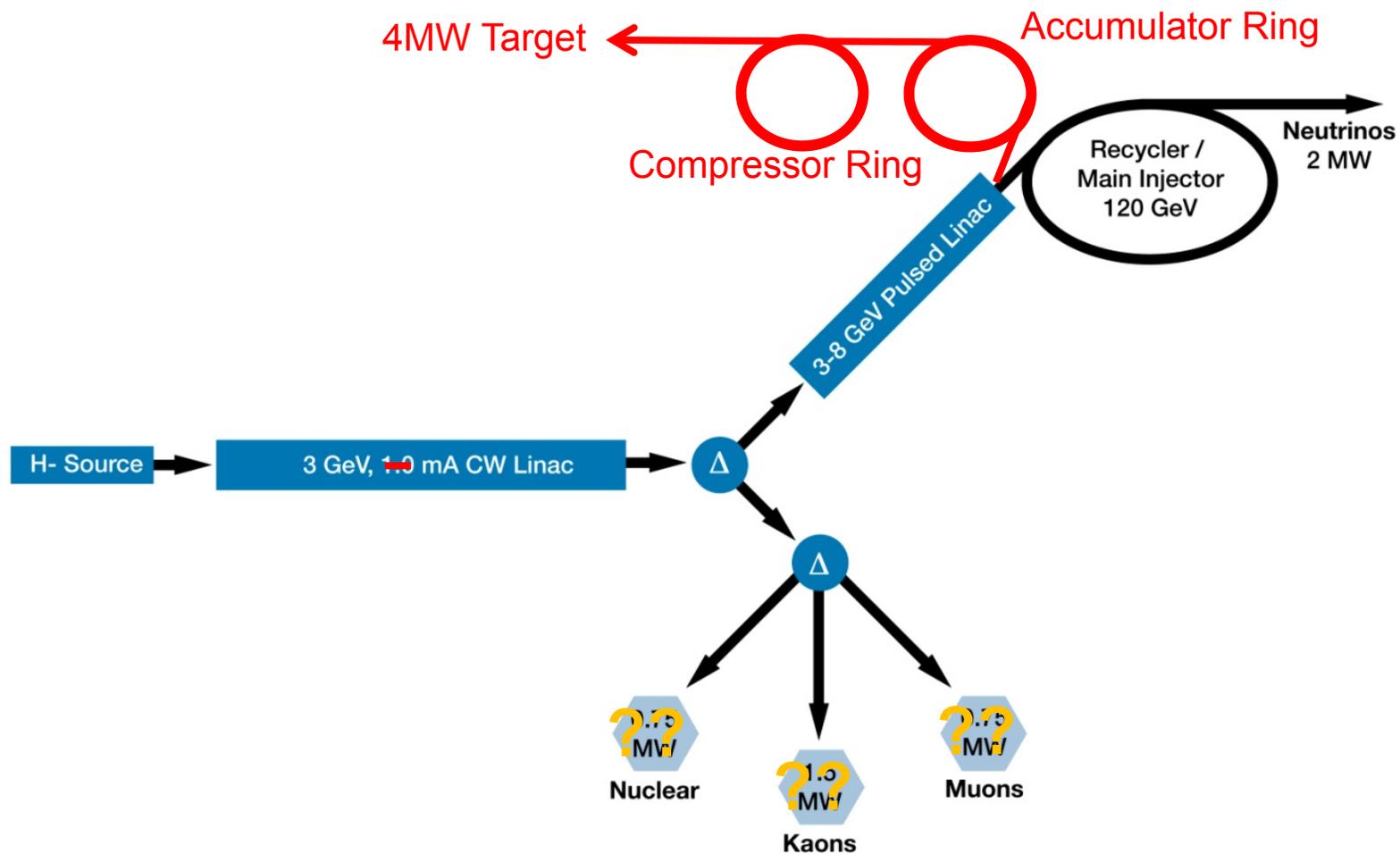


3 - 8 GeV acceleration

- Pulsed linac based on the ILC technology
 - ✓ 1.3 GHz, 25 MV/m gradient, $\leq 5\%$ duty cycle
 - ✓ considering 8-30 ms pulse length
 - ✓ ~250 cavities (28 ILC-type cryomodules) needed.
 - ✓ Simple FODO lattice
 - ✓ 1 Klystron per 2 CM's



MAP Layout based upon Project X



Project X Upgrade Proton Driver - 3

Pulsed Linac

1.3GHz SRF

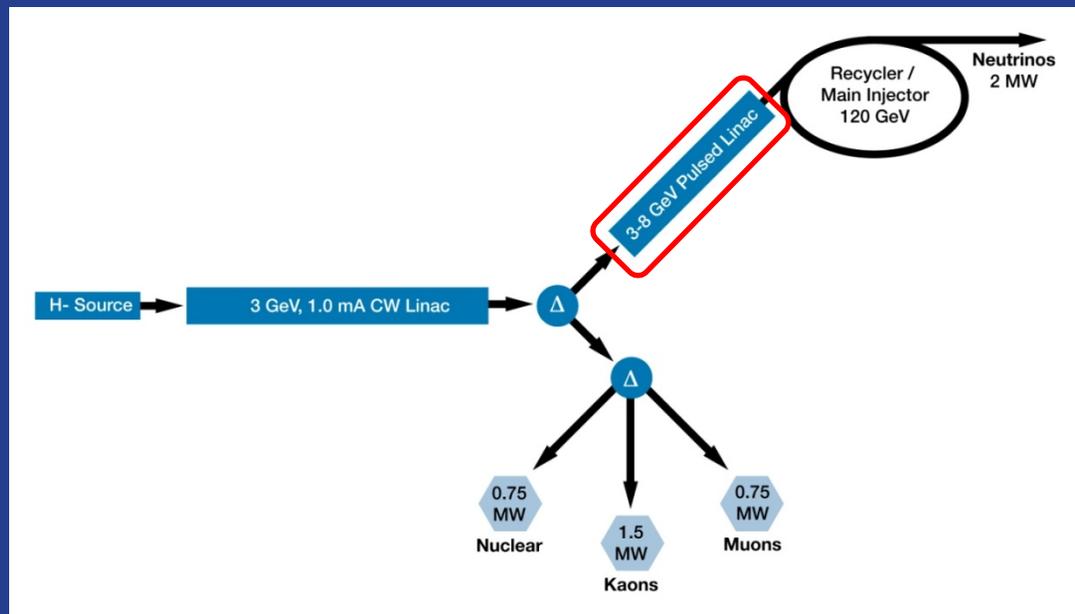
3-8 GeV

10% 5% duty factor at 10Hz 15Hz

More RF power

Upgrade of couplers

More cryo capacity



Rings' Concepts & Concerns

- Simple numbers to start

- $T_{\text{rev}} \sim 800 \text{ ns}$
- $f_{\text{rf}} \sim 10 \text{ MHz}$
- $h = 8$
- Injection scheme
 - $\sim 50 \text{ ns}$ beam ON followed by $\sim 50 \text{ ns}$ NO beam



- Evolution of design

- Increase of circumference ($\sim 300\text{m}$)
- Space for RF and Injection/Extraction components
- Several designs and will settle on one

- Concerns

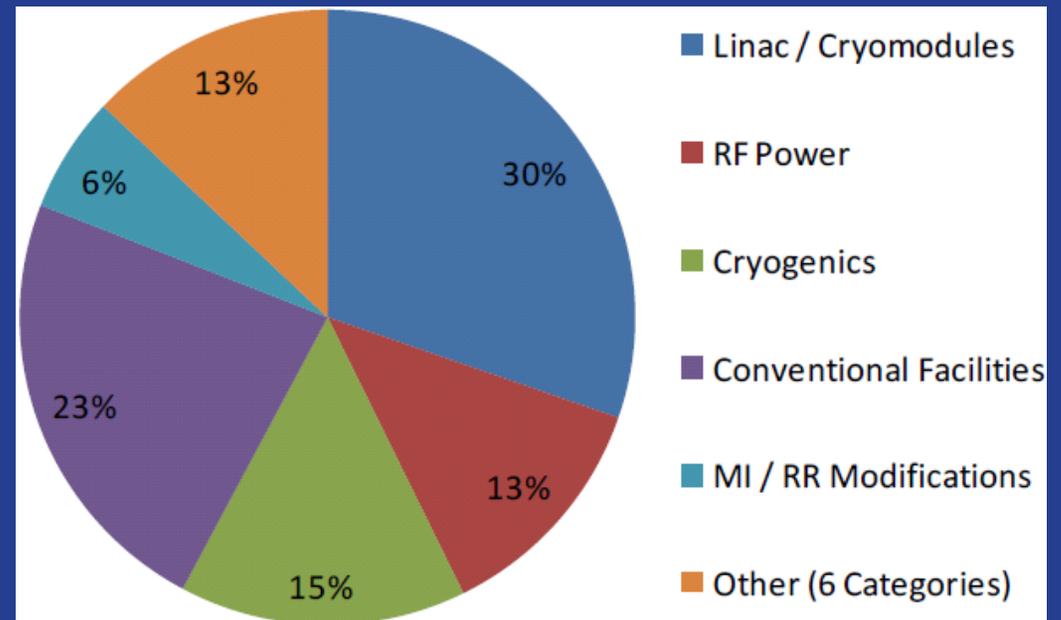
- Injection: Stripping
- Instabilities
- Beam size in Compressor Ring after bunch rotation

Ring Concern: Injection/Stripping

- Stationary foil will not survive
- Solutions are being investigated by other groups; will have to keep informed of progress
 - Will need to build upon Project X R&D for stripping at 8 GeV in to Recycler/Main Injector
 - Rotating foils
 - Laser
- Should not forget about un-stripped beam ($\sim 1\%$) needs to be “absorbed”

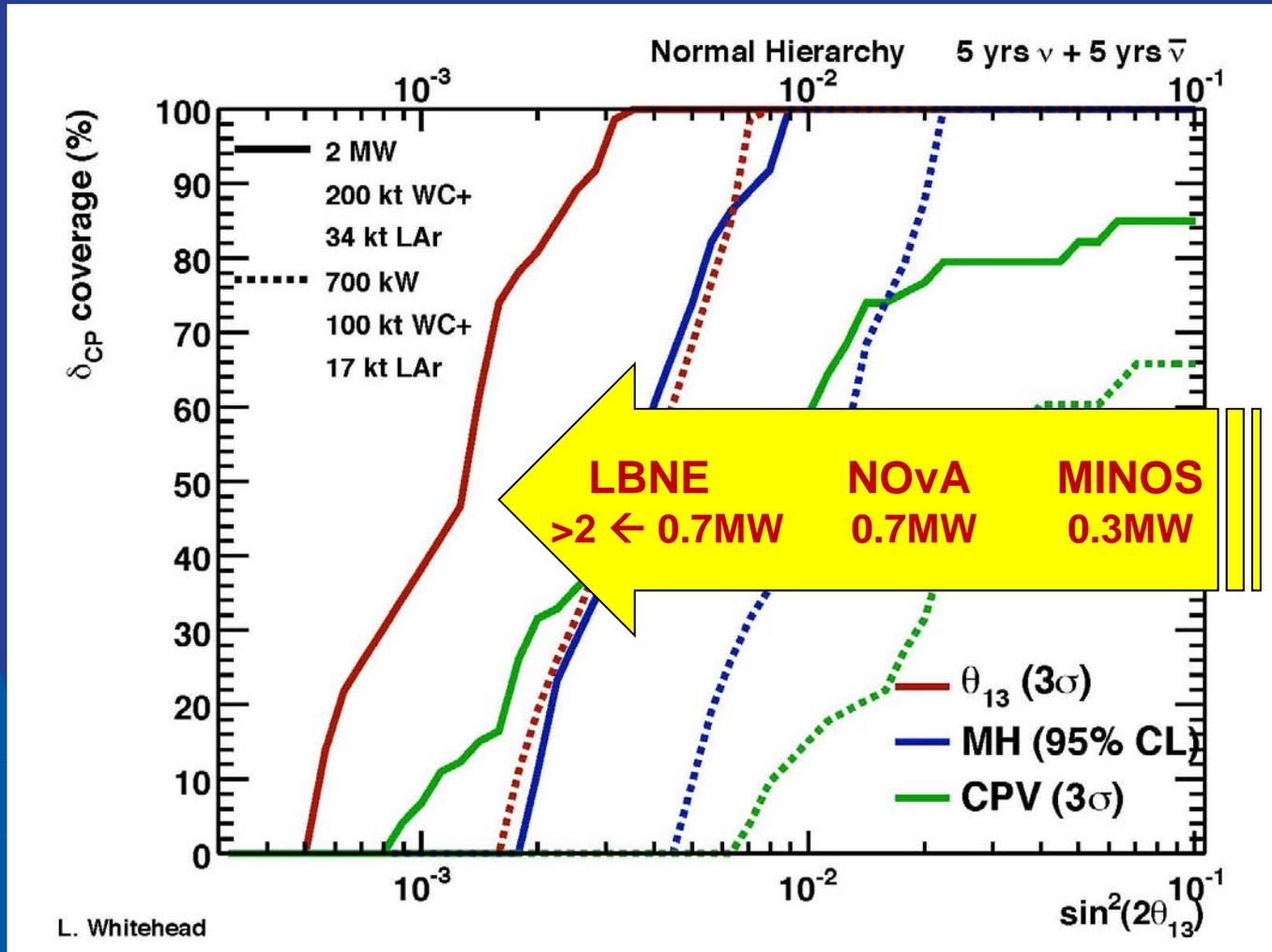
Project X Upgrade Proton Driver - 4

- Conventional facilities
 - More water cooling
 - Building space
 - More cryo capacity
 - More Klystrons



- An upgrade re-uses >75% of RDR cost

Evolution of Neutrino Sensitivities



Impact of
Project X on
LBNE

Mary Bishai
(LBNE
collaboration)
Brookhaven
National
Laboratory

Intro

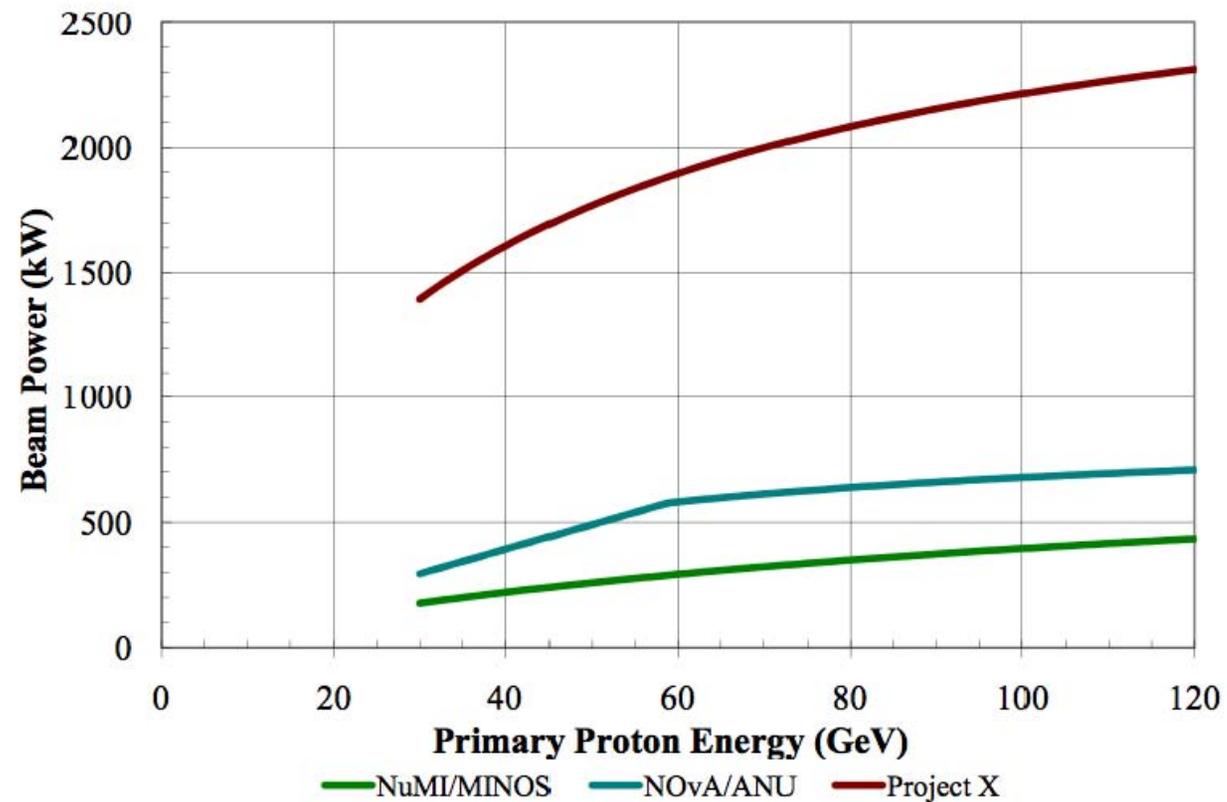
LBNE Beams

LBNE
Detectors

Beam Physics
with Project X

Summary

With Project X:

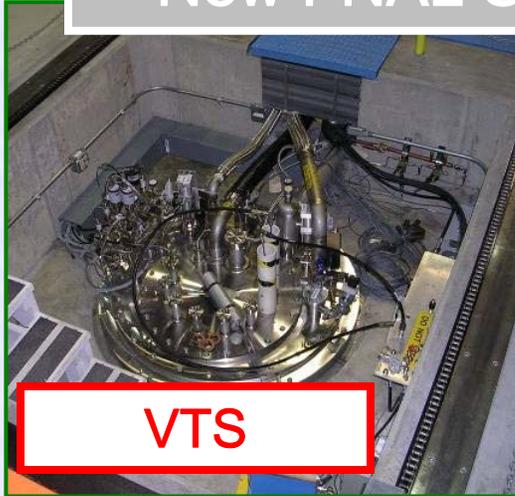


New FNAL SRF infrastructure



VTS

VTS



Cavity tuning machine



HTS



String Assembly



MP9 Clean Room



Final Assembly

December 2011

VTS2 Dewar



R. Tschirhart - IFW



New Vacuum Oven for 1300 MHz

ANL/ FNAL cavity processing infrastructure



EP tool for 1300 MHz at ANL



New EP tool for ¼ wave and 650 MHz cavities at ANL



HPR and clean Rooms
December 2011



New EP tool at FNAL



New Vacuum Oven for 650 MHz + SSR

Industrial Capabilities--AES



- BCP and EP Tools for 1300 MHz 9-cell or 650 MHz 5-cell. (commissioning)
- HPR up to 1000 lb structures. (commissioned)
- BCP up to 1000 lb. structures. (commissioned)
- Clean Room Area is planned in the future

Also developing capability at Roark-Niowave,
PAVAC

Integrated SRF Schedule - Infrastructure

U.S. Fiscal Year	2008	FY09	FY10	FY11	FY12	FY13	FY14	FY15	
ANL/FNAL cavity handling upgrades	Omnibus Delay				650	Upgrade Complete			
650 MHz VTS-1 Upgrade					650	Upgrade Complete			
CAF CM Assembly Upgrade		1300	Upgrade Complete			325	Upgrade Complete	650	Upgrade Complete
650 MHz dressing CAF Upgrade						650 MHz	Upgrade Complete		
VTS 2 & 3 Upgrade			VTS2/3 Procure		VTS 2	VTS3	VTS 2/3 Complete		
HTS 2 cryostat				Design		Procure India		HTS2 Complete	
HTS 2 cave, cryo dist				Design	Procure				
NML Injector & BL			Design	Procure		Install & commission		NML Beam ava	
NML Refrigerator				Design	Procurement		install & commissio	NML 500 W superfluid F	
NML Cryo Distribution System								CDS Complete	
NML SLAC Refrigerator				Design SLAC Ref Interface (as req'd)	refurbish	Install & commission	SLAC Refrig Oper		
CMTF CM Test Stand (1.3 GHz)						Procure India		1.3 CMTS Complete	
650 MHz CM Test Stand						Procure India		650 CMTS Complete	
CMTF Cryo Distribution System						Procure India		CMTF Dist Complete	
MDB Spoke Test Facility 2k Upgrade					325	325 HTS complete			Des/add 4th Refrig
325 MHz CM Test Stand @ NML							Procure FNAL		325 CM TS Complete
AES 1300-650 EP / 325 BCP facility				Design	Procurement		EP/BCP ready		
JLAB VTS cryo upgrade			JLab Upg Des	Procure		Upgrade Complete			
ANL EP/BCP Upgrade			ANL 1300 EP ready Oper	Design 650 EP	Procure	650 EP Ready			

Shows only remaining items, many completed items are now not shown (VTS-1, HTS, STF, CAF)

Integrated SRF Schedule - Cryomodules

U.S. Fiscal Year	2008	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	
1.3 GHz										
CM1 (Type III+)		Omnibus Delay	CM fab	Install CM	CM1 Test	Rework?	?			
CM2 (Type III+)		Omnibus Delay	Order Cav & CM Parts	Process & VTS/Dress/HTS	CM fab swap	swap?				
CM3 (Type IV)			Design	Order Cav & CM Parts		CM fab	install	ILC S2 test	also supports AAR	
CM4 (Type 2/5/8 ILC or PX)						CM fab				
CM5 (Type 2/5/8 ILC or PX)							CM fab	test in CMTF	swap? PX RF	
CM6 (Type 2/5/8 ILC or PX)							CM fab	test in CMTF	swap? Unit test	
NML Extension Building			Design	Construction						
NML Beam					Move injector/install beam components				Beam Available to RF Unit test except during installation periods	
CMTF Building			Design	Construction						
650 MHz									Project X construc	
Single Cell Design & Prototype				Prototypes	Process & VTS					
LE 650 five cell Design & Prototype					Industry Prototypes (4)		Industry Prototypes (10)	Process & VTS/Dress/HTS	LE 650 ready	
HE 650 five cell Design & Prototype				Industry Prototypes (2+ 2)	Process & Test (ANL/FNAL)	Industry Prototypes (10)	Process & VTS/Dress/HTS	HE 650 ready		
HE_650_CM1				Concept Design	Design	Order 650 CM Parts		650 CM Ass'y	HE 650 CM Test	
325 MHz										
SSR1 Design & Prototype			Procurement (14 in progress)		Process & VTS/Dress/STF	SSR1 ready	Process & VTS/Dress/STF			
SSR2 Design & Prototype					Design	Prototype(2)	Process & VTS/Dress/STF	SSR2 ready		
CM325_SSR1_proto CM				Concept Design	Design	Order 325 CM Parts	Process & Test (as required)	325 CM Ass'y	Test @ PXIE	
162.5 MHz										
					Design	Proto cavities	Process & Test (as required)	Order cav & CM Parts	162 CM Ass'y	HWR CM Test @ PXIE