The Project-X Research Program

- ***Neutrino long-baseline and short-baseline 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 and other rare muon processes, nuclear and neutron electron dipole moments (edms) & fundamental physics, 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.

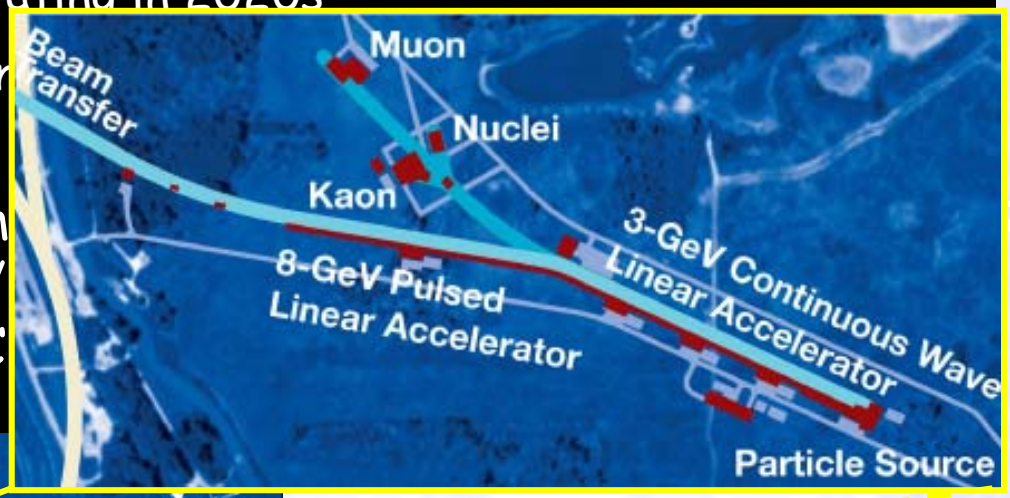
Detailed Discussion: Project-X website

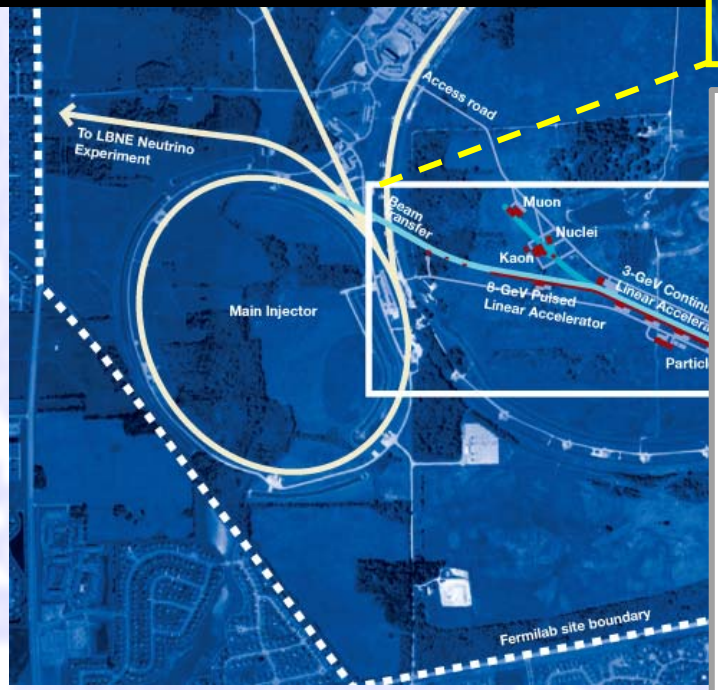
Project X: 5 MW Proton Accelerator

Construction later this decade, operating in 2020s

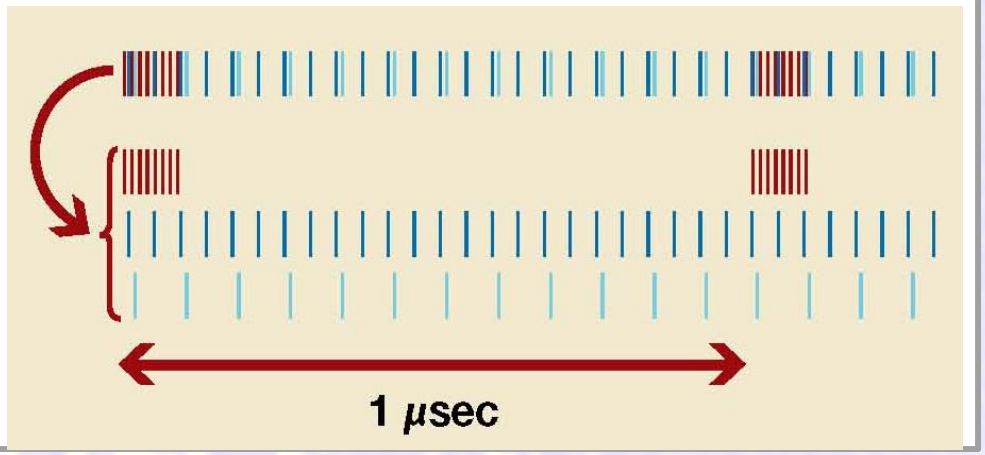
US National project with internation

MOUs for R&D
- US: ANL, BNL, Cornell, Ferm
- India: BARC/Mumbai, IUAC/
- Additional collaboration with C





Unique feature of *Project X*: flexible beam structure



Project-X High-Intensity Campus

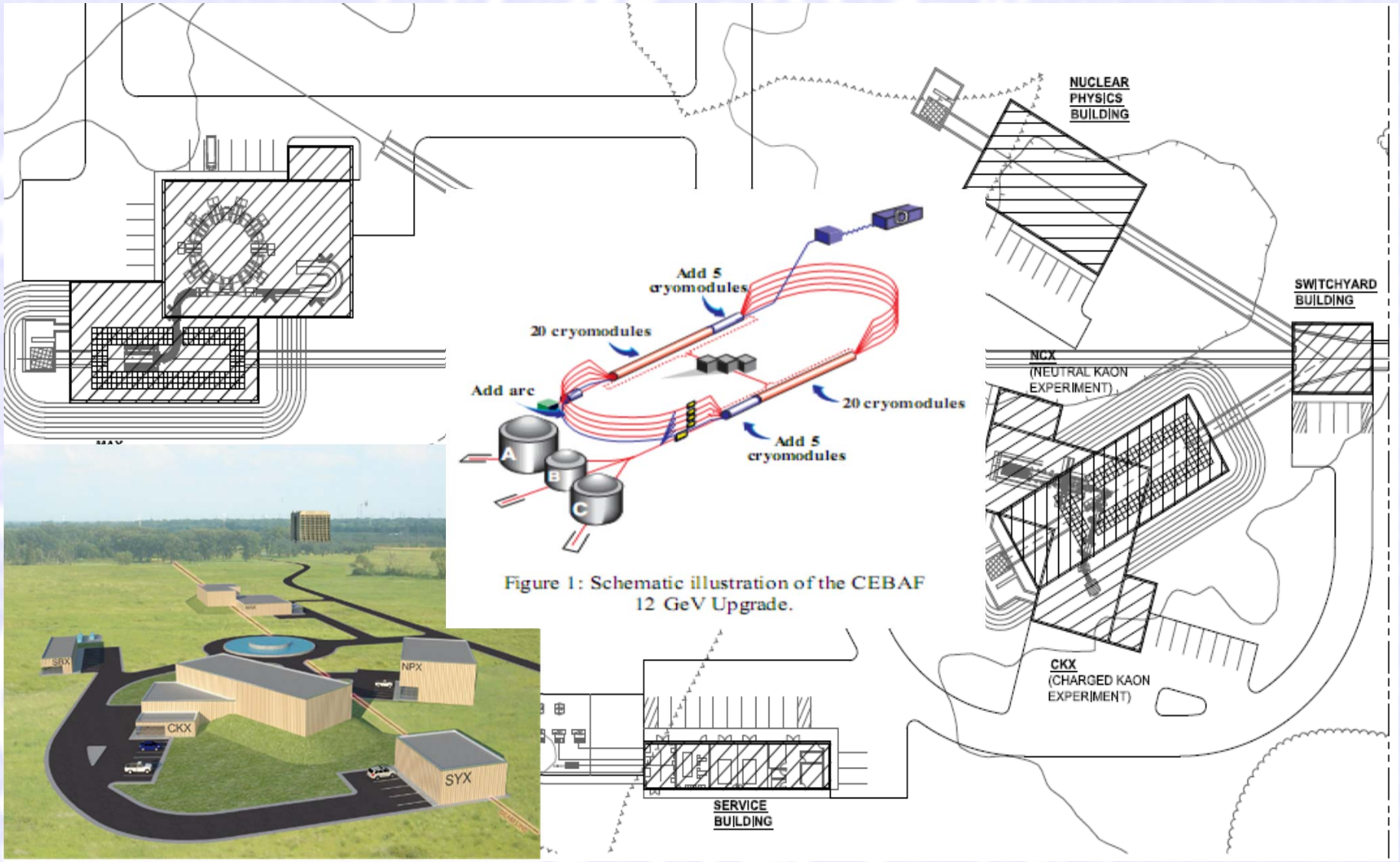


Figure 1: Schematic illustration of the CEBAF 12 GeV Upgrade.

Project-X Beam Parameters provided to IFW chairs

Project X (2022-202X)

120 GeV Fast Spill

120 GeV Beam Power	2400	kW
Protons per pulse	1.6×10^{14}	
Pulse length	9.5	μsec
Number of bunches	504	
Bunch spacing	18.9	nsec
Bunch length (FWHM)	2	nsec
Pulse repetition rate	1/1.3	Hz

8 GeV Fast Spill*

8 GeV Beam Power	190	kW
Protons per pulse	2.7×10^{13}	
Pulse length	4.3	msec
Bunch spacing	6.2	nsec
Bunch length (FWHM)	20	psec
Pulse repetition rate	7/1.3	Hz

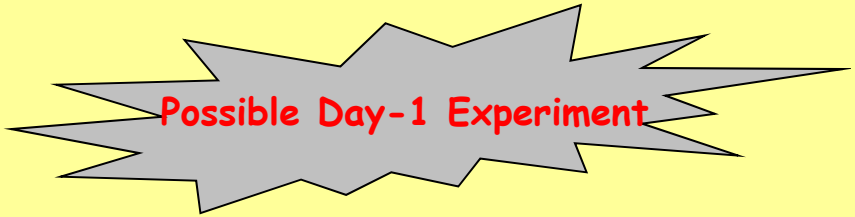
Project-X Beam Parameters provided to IFW chairs

3 GeV Slow Spill

3 GeV Beam Power	2900	kW
Bunch Structure	Programmable*	
Protons per bunch (Max)	1.9×10^{8}	
Bunch spacing	6.2	nsec
Bunch length (FWHM)	40	psec
Pulse repetition rate	CW*	

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.
- Search for sterile neutrinos, CP & CPT violating effects in next generation $\nu_e, \overline{\nu}_e \rightarrow X$ experiments….x3 beam power @ 120 GeV, **x10-x20 power @ 8 GeV**.
- Next generation precision cross section measurements.

Project X at the neutrino working group Monday Oct 24th

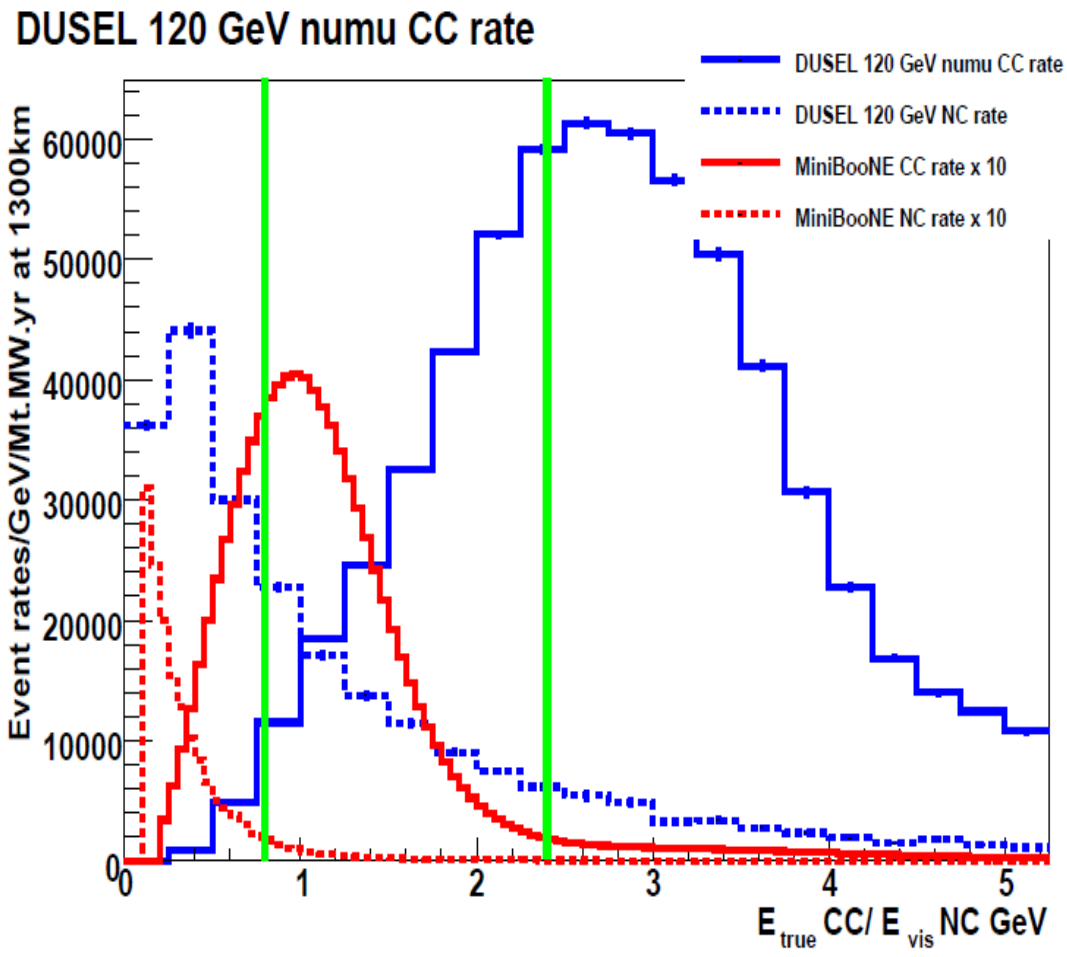
- Well represented, good understanding of Project X capability, many creative ideas to exploit beam power.
- Some confusion about available 8 GeV beam power in the Project-X design. This is 190 kW for coincident 120 GeV MI running at 2300 kW, and progressively less (down to 50kW) for coincident MI running at 60 GeV.
- There is growing interest in 8 GeV beam power. The Intensity Frontier Workshop should survey community interest and the Project-X can respond with consideration of an 8 GeV beam power upgrade.
- A ongoing task-force (Muon Collider task force) has developed a concept for 4000kW at 8 GeV which could greatly benefit LBNE. This is currently not in the Project X scope.

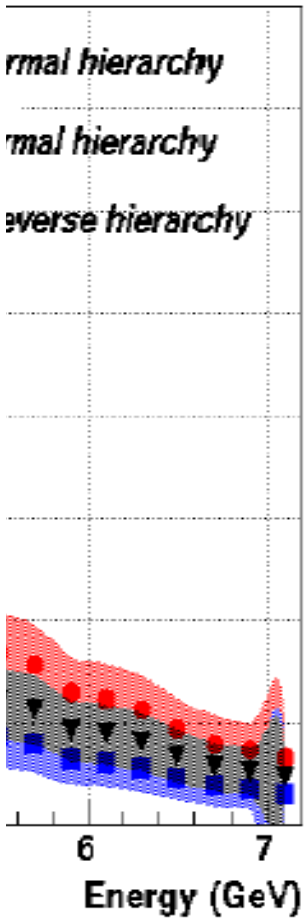
Can we use "excess" 8 GeV pulsed power to drive LBNE as well??

LBNE Physics and Beam Designs
AHIPA Workshop, 10/10/09

Mary Bishai, Brookhaven National Lab

October 20, 2009





A wide-band beam at 1300km

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 $(g\text{-}2)_\mu$ 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:

Possible 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.
- $K^0 \to \pi^0 e^+ e^-$: <10% measurement of CP violating amplitude.
- $K^0 \to \pi^0 \mu^+ \mu^-$: <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…

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, some of a long list:

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

US Nuclear Physics Facilities Allied With This Research Program

Some examples….

- SNS fundamental physics beam-line (nEDM experiment)
- ORNL, LBNL: source of relevant isotopes (eg ^{225}Rn)
- JLAB: Dark photons searches.
- Facility for Rare Isotope Beams (FRIB, 2020 operations): No ISOL capability within current scope. Conceptual designs exist for ISOL upgrades, must share directly with radioactive beam base program.

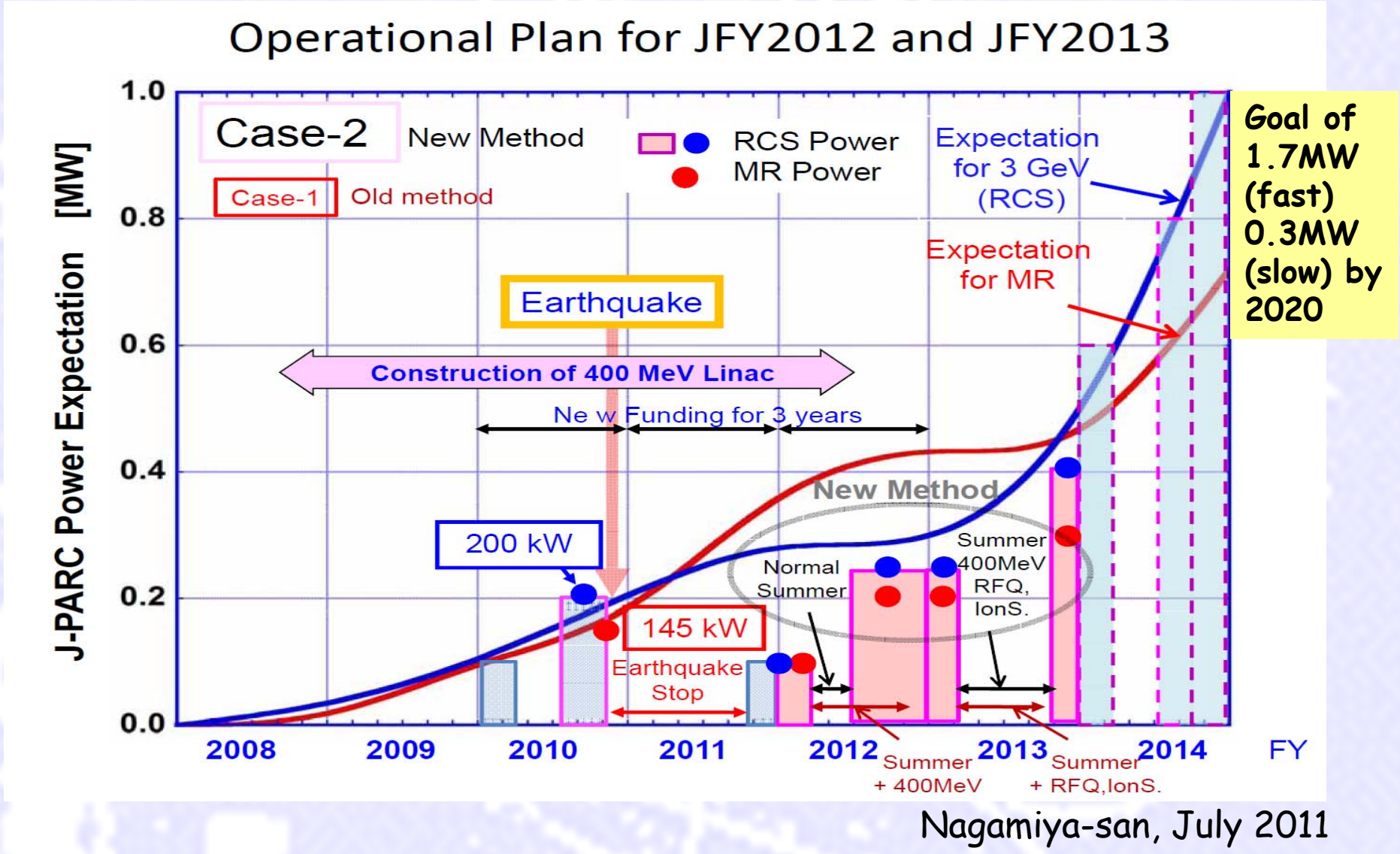
How will this landscape be incorporated into the IFW report?

Some of the World-wide Facilities Competing for the Project-X Research Program

- Neutrinos: CERN, JPARC
- Rare processes: CERN, JPARC, PSI,JLAB
- Neutron edms, n-nbar:
  Institut Laue-Langevin, (ILL) ; Paul Scherrer Institute (PSI)
- ISOL facilities: Many world-wide. Very active field.

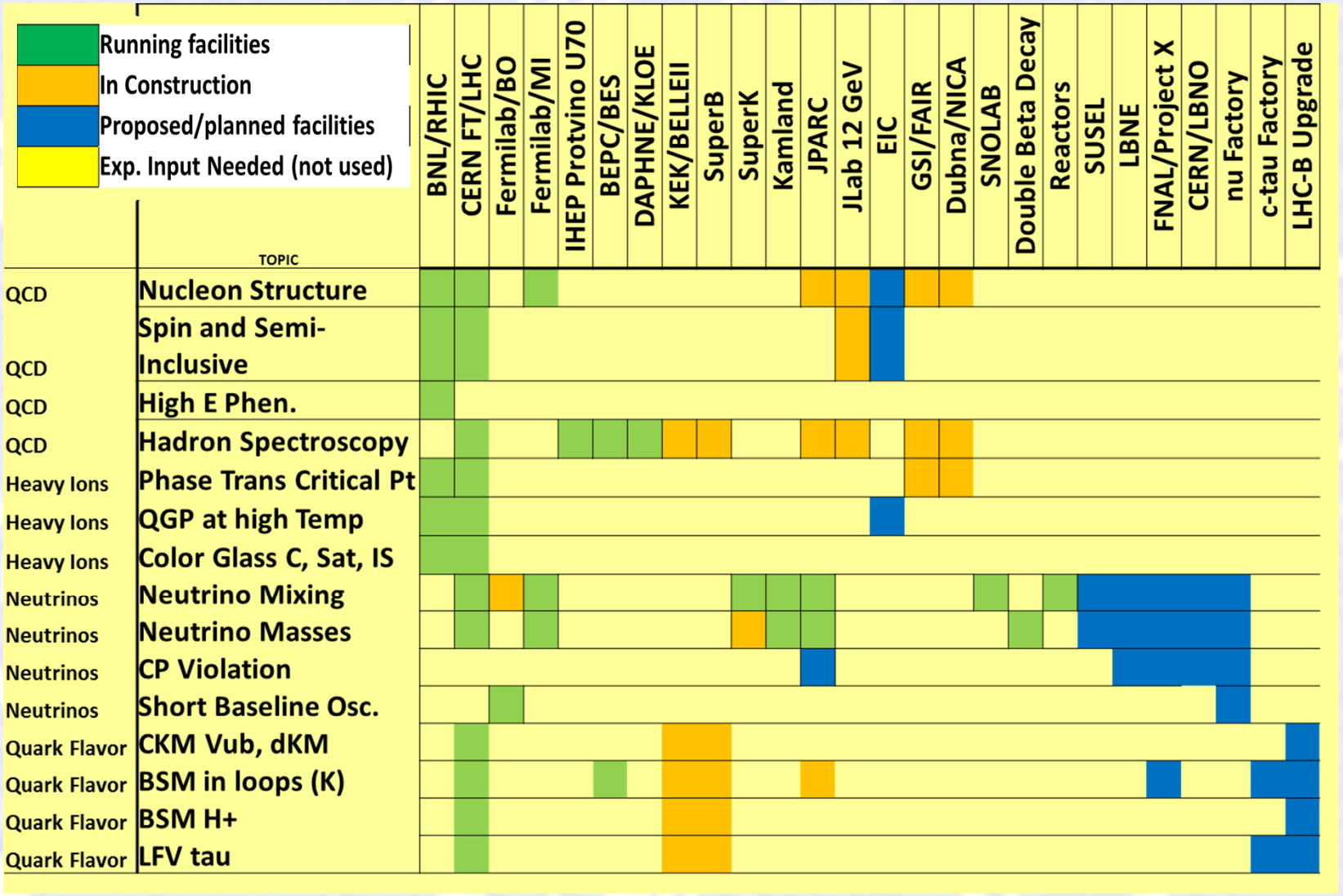
How will this landscape be incorporated into the IFW report?

JPARC plan post earthquake



Nagamiya-san, July 2011

ICFA Seminar Intensity Frontier Matrix October 2011



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ICFA Seminar Precision Intensity Frontier Matrix October 2011

						University labs & reactors
T-Violation	EDM PSI	EDM PSI	EDM BNL, COSY, FNAL, J-PARC, PSI, RCNP, SNS, TRIUMF			EDM, nnpd
Charged lepton flavor violation	MFVD PSI	MFVD FNAL, J-PARC	MFVD FNAL, J-PARC, PSI, RCNP			
New flavor conserving interactions		g-2 FNAL, J-PARC	g-2 FNAL, J-PARC	Qweak J-LAB	PVES, g-2 J-LAB, MAMI, Super(KEK)B, BINP	g-2
New charged current interactions	nnpd J-PARC, LANL, PSI	nnpd	nnpd PSI, SNS, TRIUMF			nnpd
Bound state QED, CPT	exat CERN, PSI	exat CERN, PSI	exat CERN, J-PARC, PSI			atoms and ions
Other exotic interactions	DPA CERN			DPA DESY, J-LAB, MAMI	DPA DESY, J-LAB, MAMI	DPA

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>40 Intensity & Precision Frontier facilities world-wide pursuing particle physics science and closely aligned nuclear physics science.

ICFA Seminar Energy Frontier Matrix October 2011

Topic/Facility	RHIC	Tevatron	LHC	LHC High Lum.	Linear Collider <500 GeV	LHeC	Linear Collider > 500 GeV	LHC High Energy	μ-Collider
QCD/EW Meas.									
Higgs									
SUSY									
Other BSM									
QGP Prop High T									
Color Glass C, Sat, IS									

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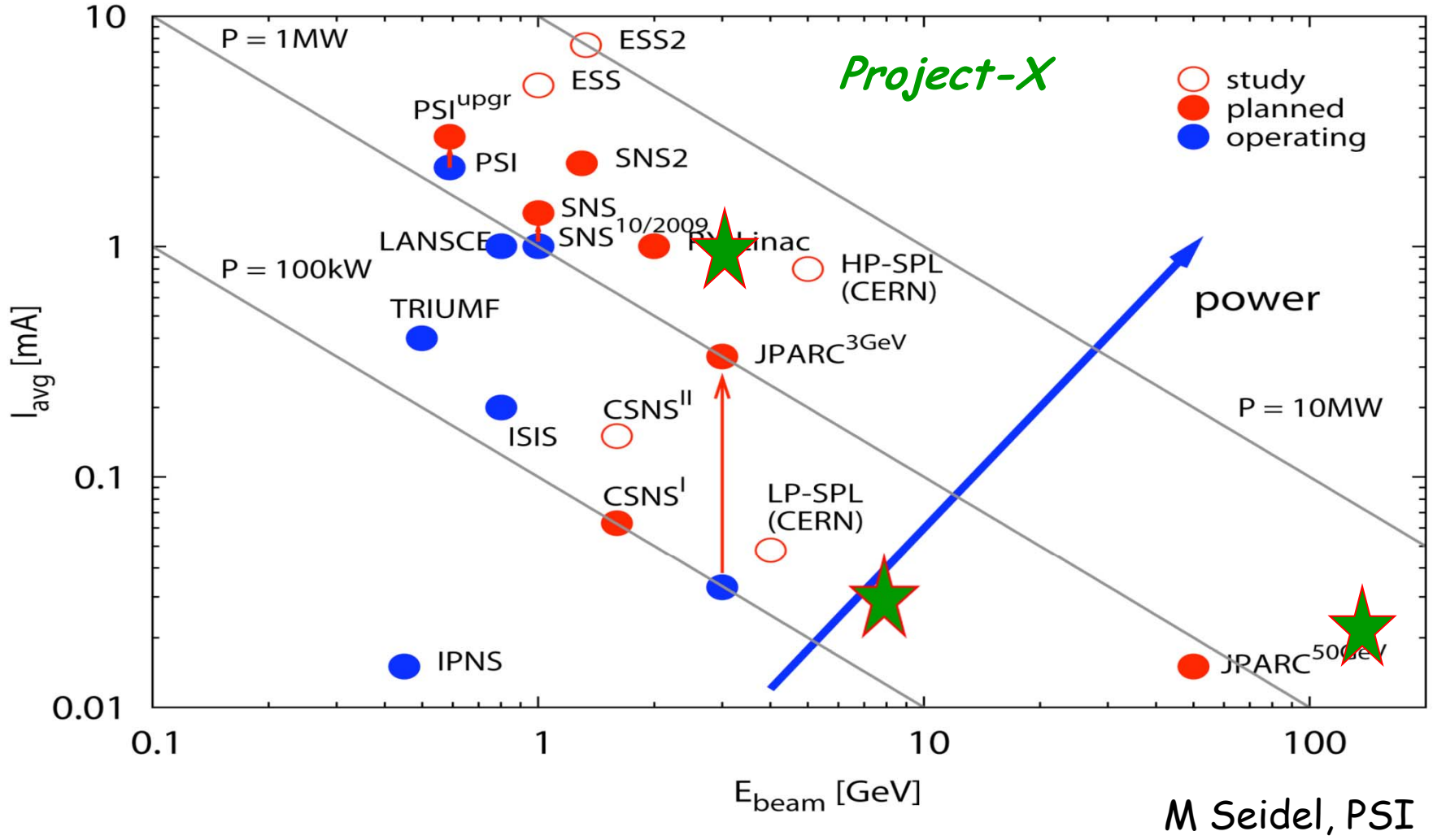
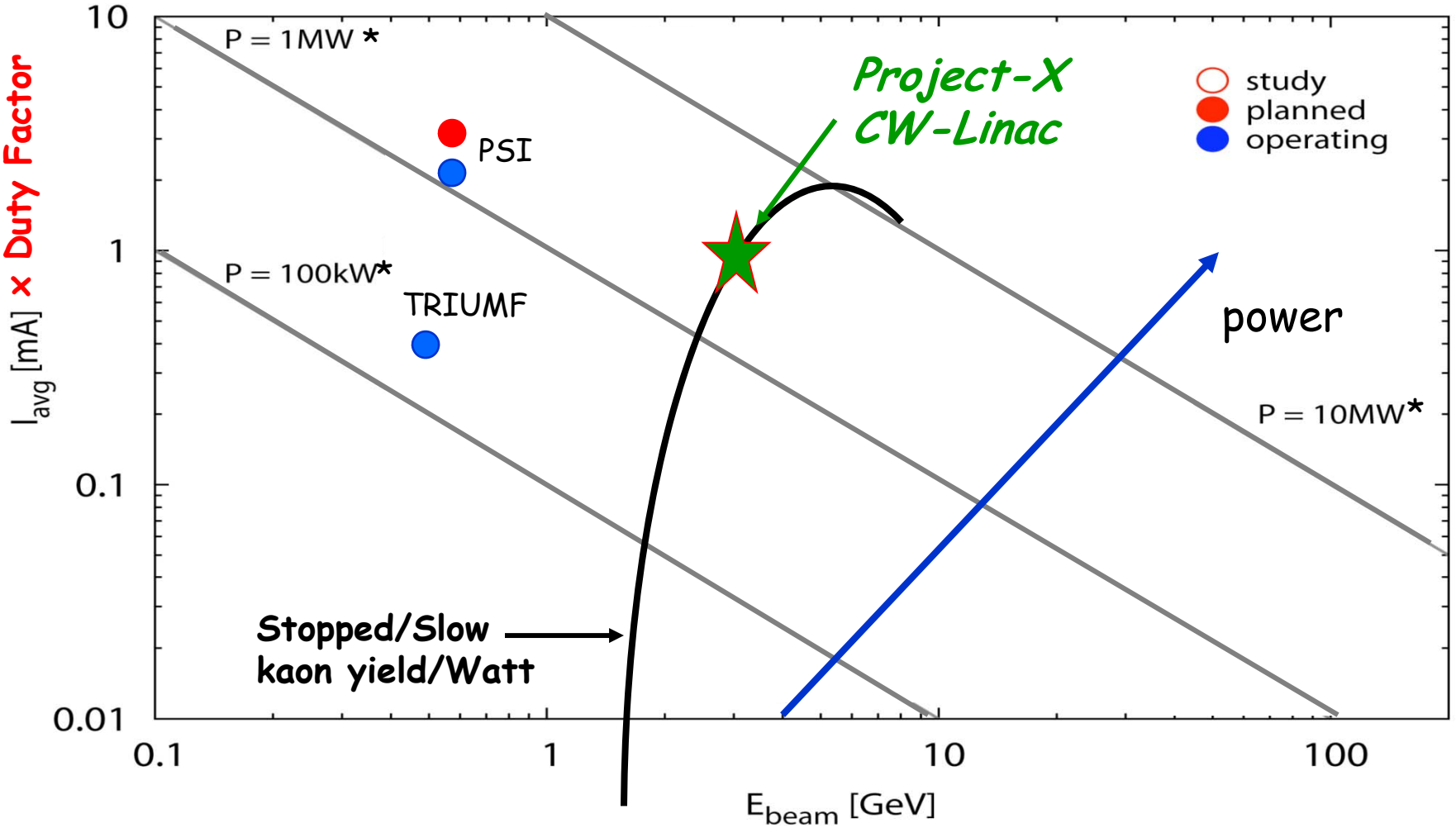
Spare Slides

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



M Seidel, PSI

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



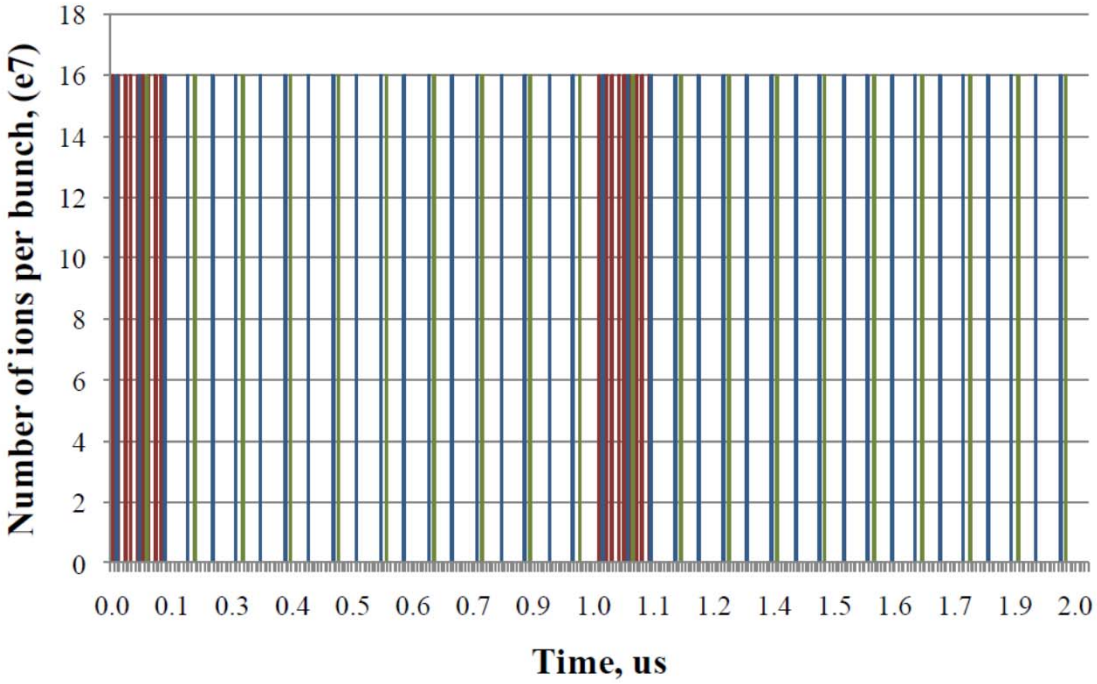
* Beam power x Duty Factor

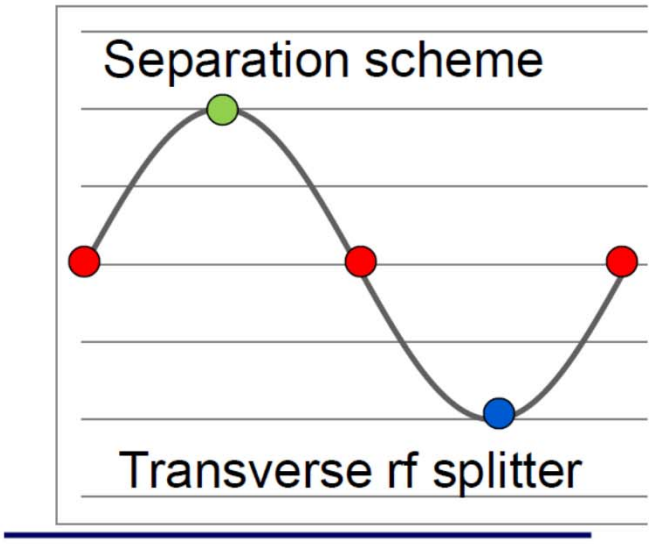
Chopping and splitting for 3-GeV experiments

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

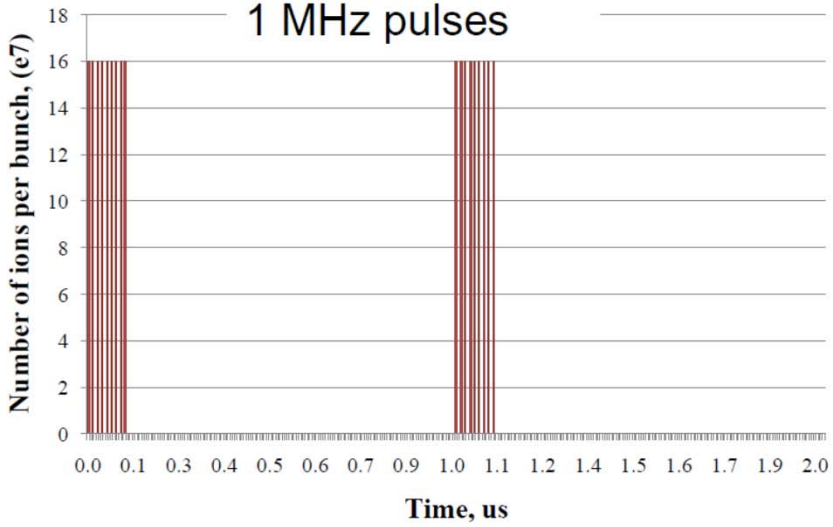
Ion source and RFQ operate at 4.2 mA
75% of bunches are chopped at 2.5 MeV after RFQ

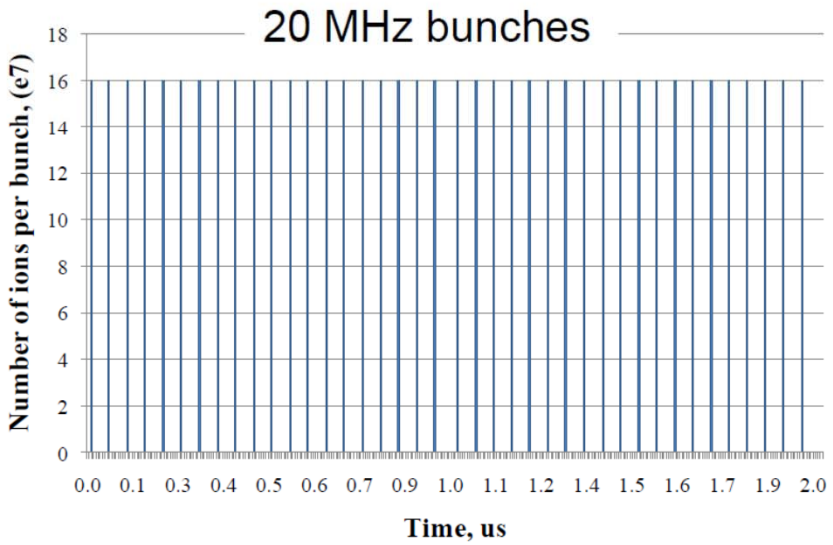


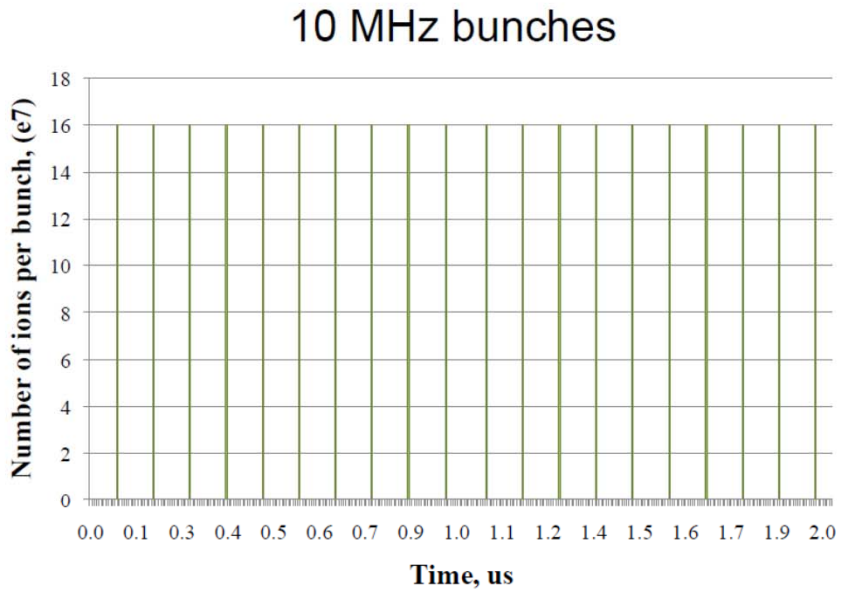


Nagaitsev, Telluride

Beam after splitter







Nagaitsev, Telluride