Project-X

R.Tschirhart - Fermilab

Dec 11th, 2012

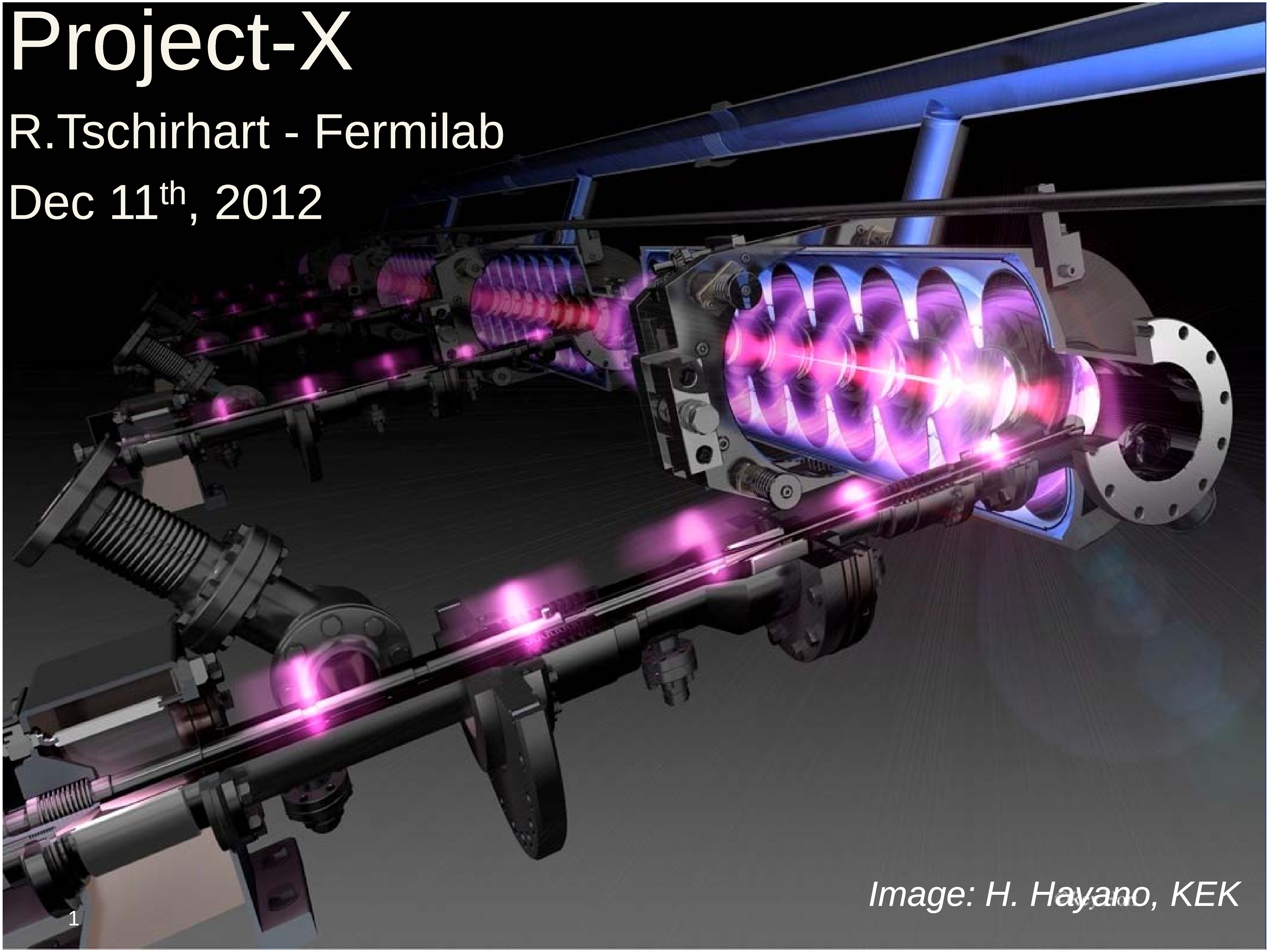


Image: H. Hayano, KEK

Project-X:

- Evolution of the existing Fermilab accelerator complex with the revolution in Super-Conducting RF Technology.

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

The Project-X Research Program

- ***Neutrino experiments***

A high-power proton source with proton energies between 1 and 120 GeV would produce intense neutrino sources and beams illuminating near detectors on the Fermilab site and massive detectors at distant underground laboratories.

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

These could include world leading experiments searching for lepton flavor violation in muons, atomic, muon, nuclear and nucleon electron dipole moments (edms), precision measurement of neutron properties (e.g. n,nbar oscillations) and world-leading precision measurements of ultra-rare kaon decays.

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

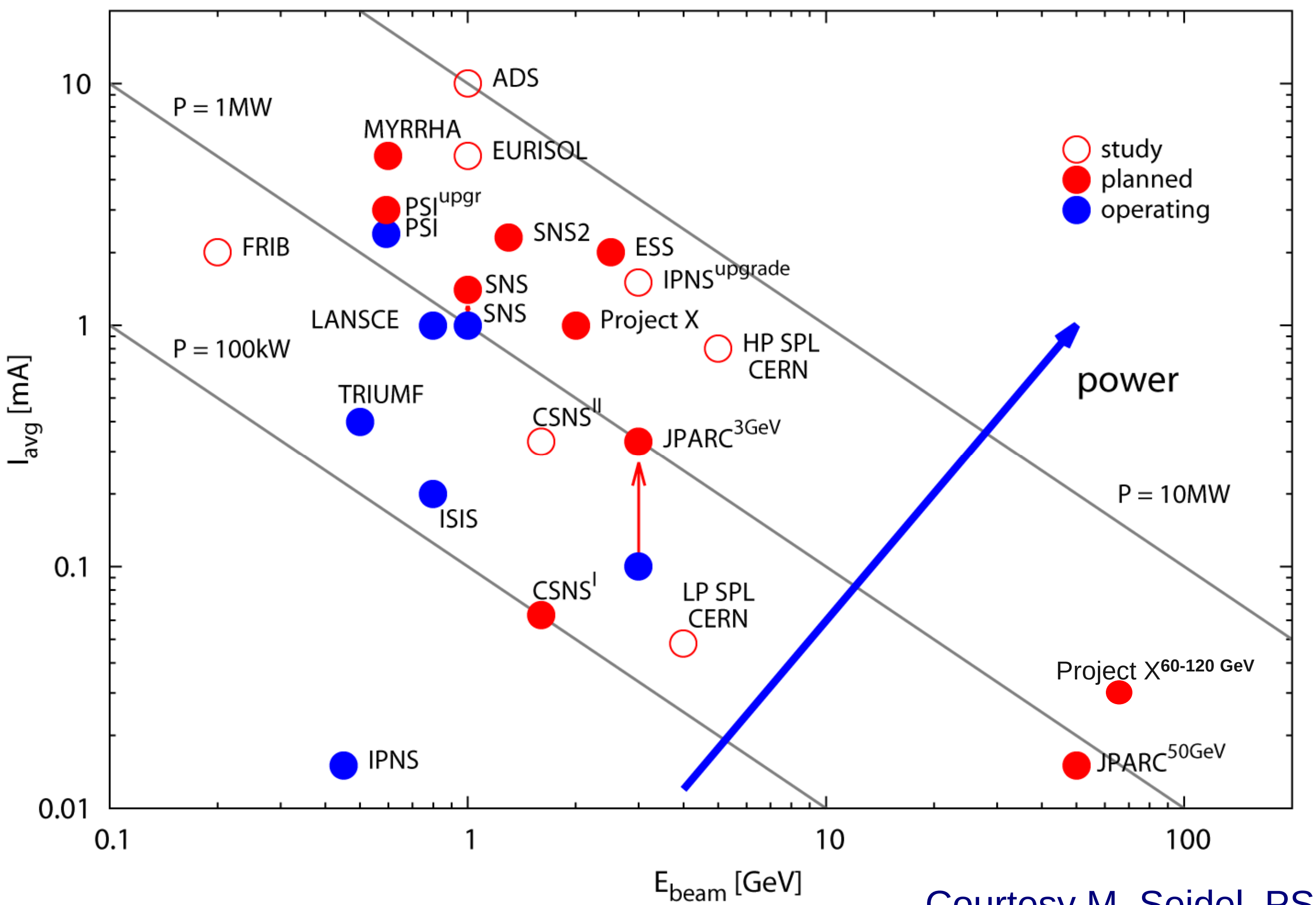
Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.

- ***Material Science and Nuclear Energy Applications***

Accelerator, spallation, target and transmutation technology demonstrations which could investigate and develop accelerator technologies important to the design of future nuclear waste transmutation systems and future thorium fuel-cycle power systems. Possible applications of muon Spin Resonance techniques (muSR). as a sensitive probes of the magnetic structure of materials .

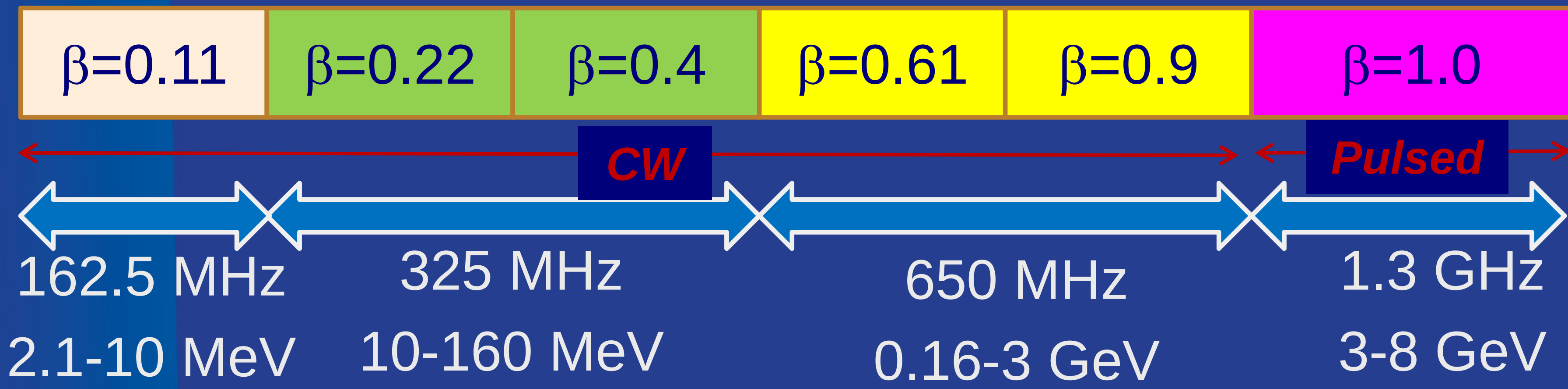
Detailed discussion on Project X website

Beam Power is the Gateway…



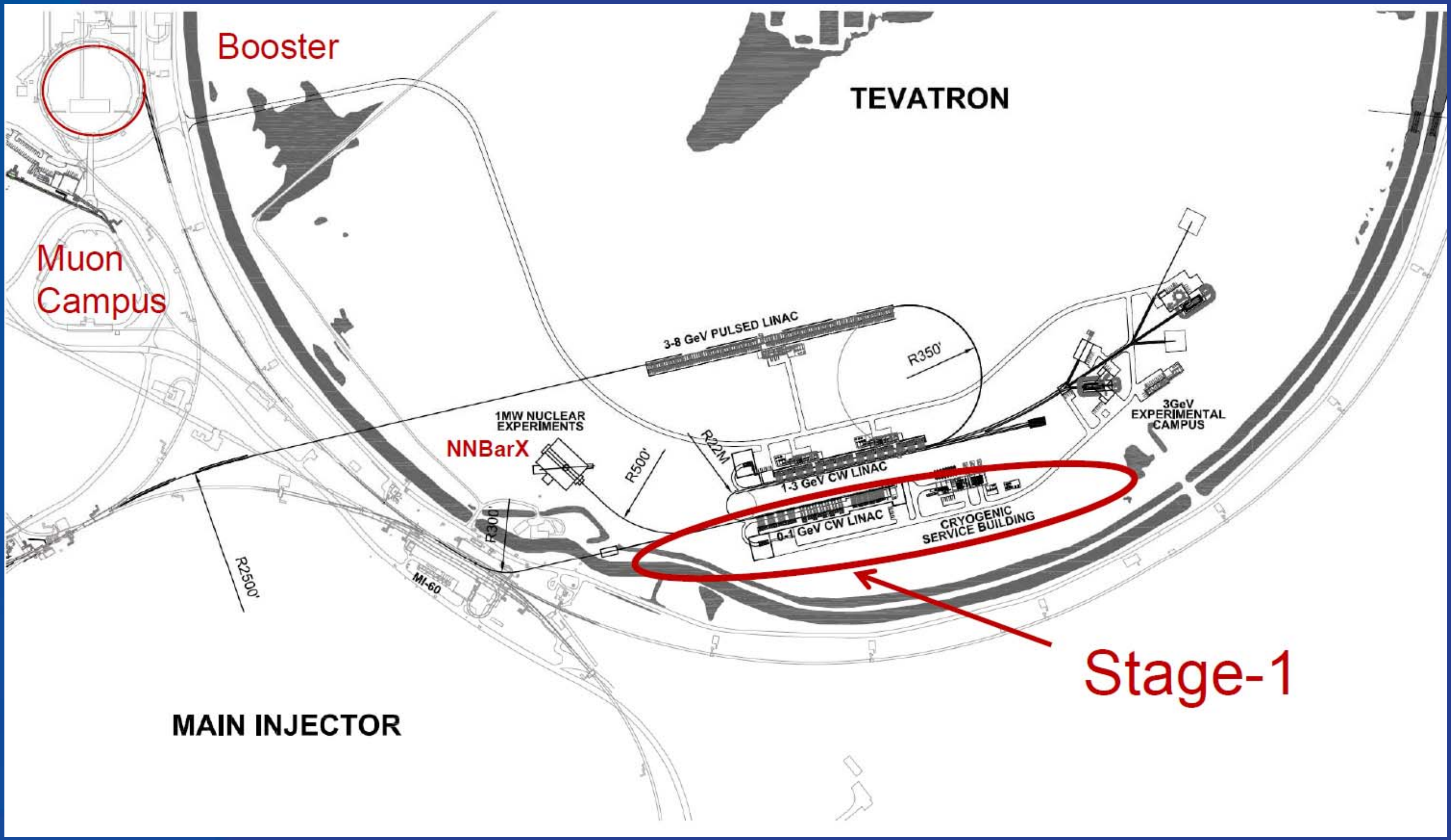
Courtesy M. Seidel, PSI

Project X SRF Linac Technology Map

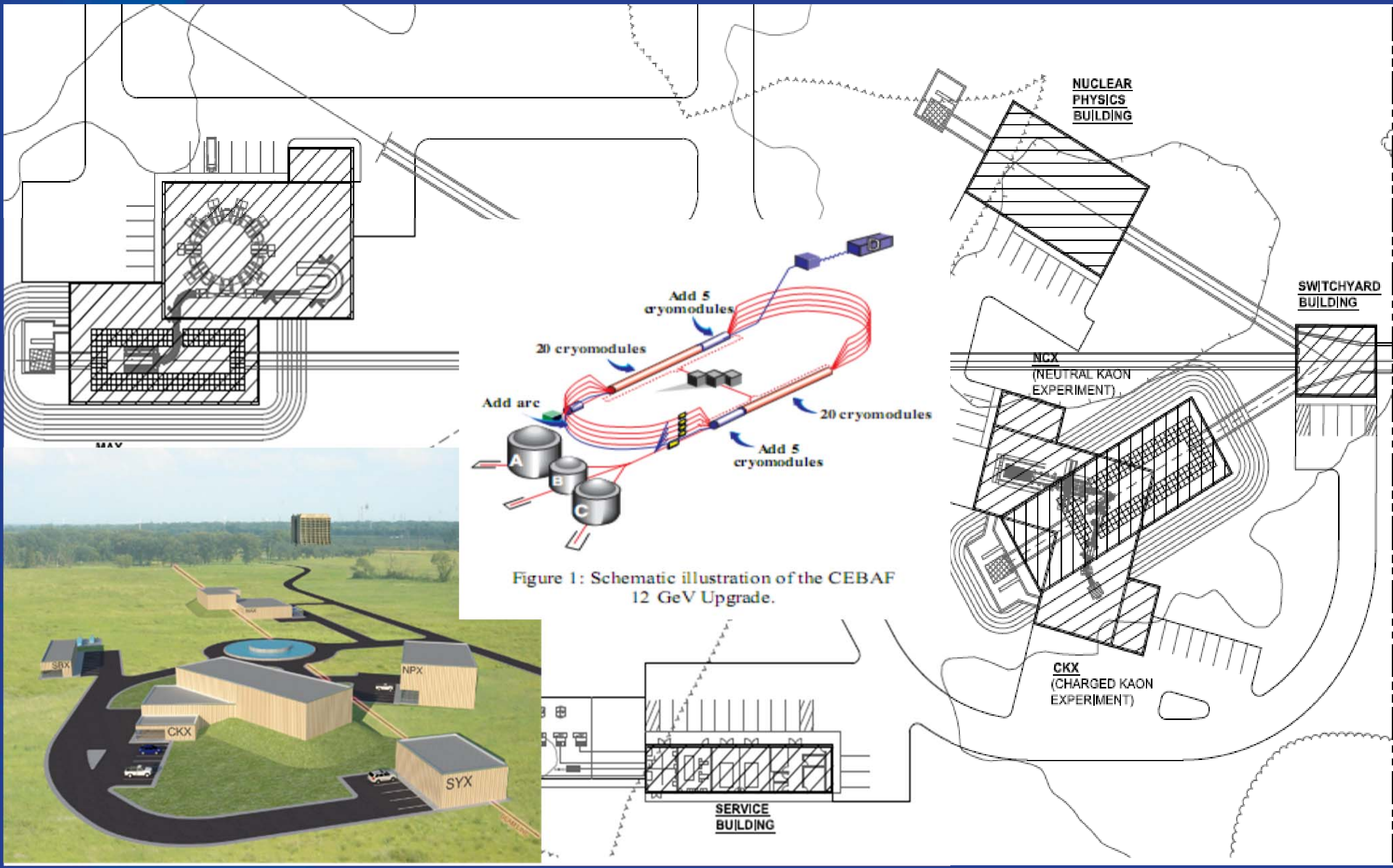


Section	Freq	Energy (MeV)	Cav/mag/CM	Type
HWR (β_G=0.1)	162.5	2.1-10	9/6/1	HWR, solenoid
SSR1 (β_G=0.22)	325	10-42	16/18/ 2	SSR, solenoid
SSR2 (β_G=0.47)	325	42-160	36/20/4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-460	42 /14/7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	460-3000	152/19/19	5-cell elliptical,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

Evolution of the Fermilab Accelerator Complex…



Project-X Stage-2 High-Intensity Campus



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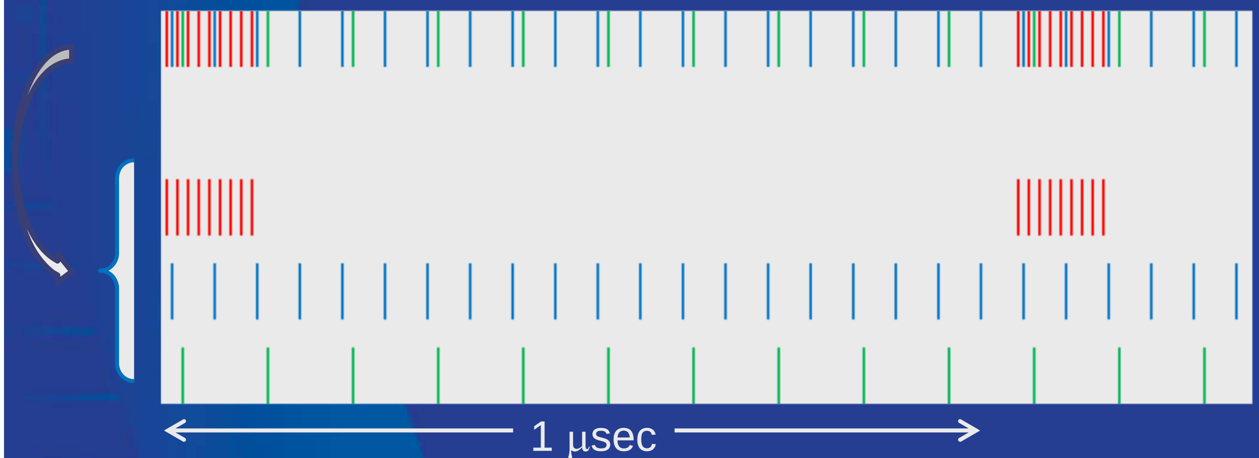
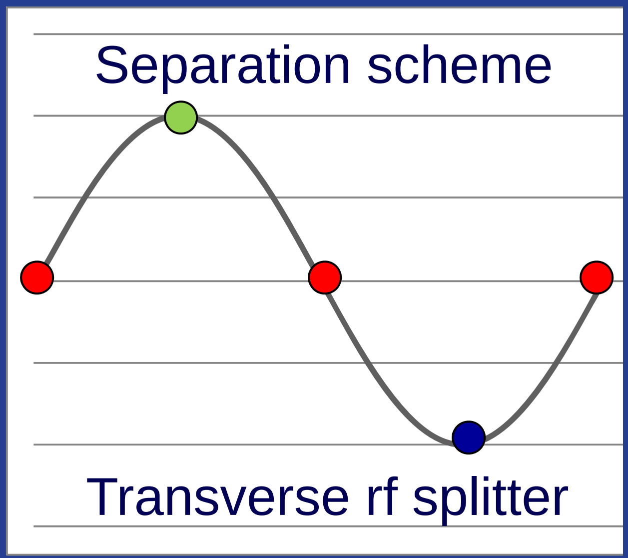
Operating Scenario for High Power Campus

1 μsec period at 3 GeV

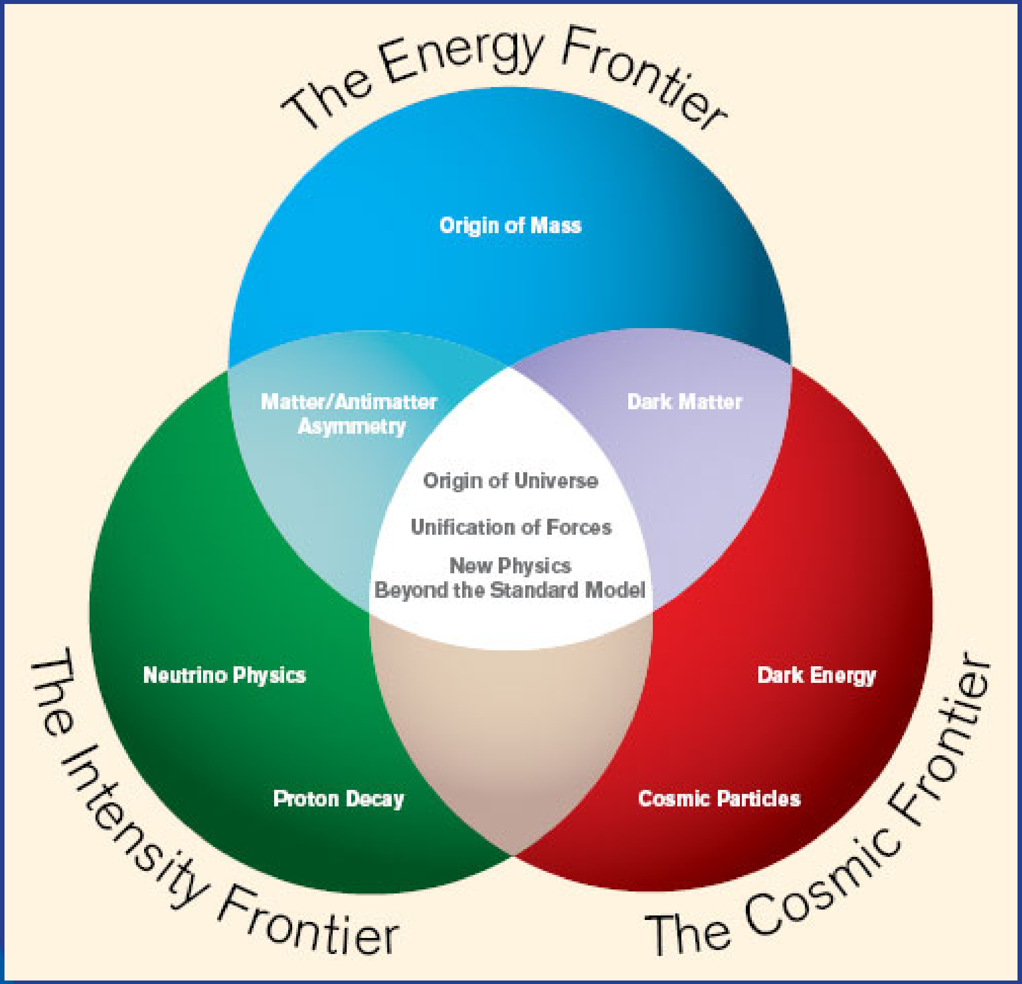
Muon pulses (12e7) 162.5 MHz, 80 nsec	700 kW
Kaon pulses (12e7) 27 MHz	1540 kW
Nuclear pulses (12e7) 13.5 MHz	770 kW

Ion source and RFQ operate at 4.4 mA; 77% of bunches are chopped @ 2.1 MeV $\Rightarrow$ maintain 1 mA over 1 μsec



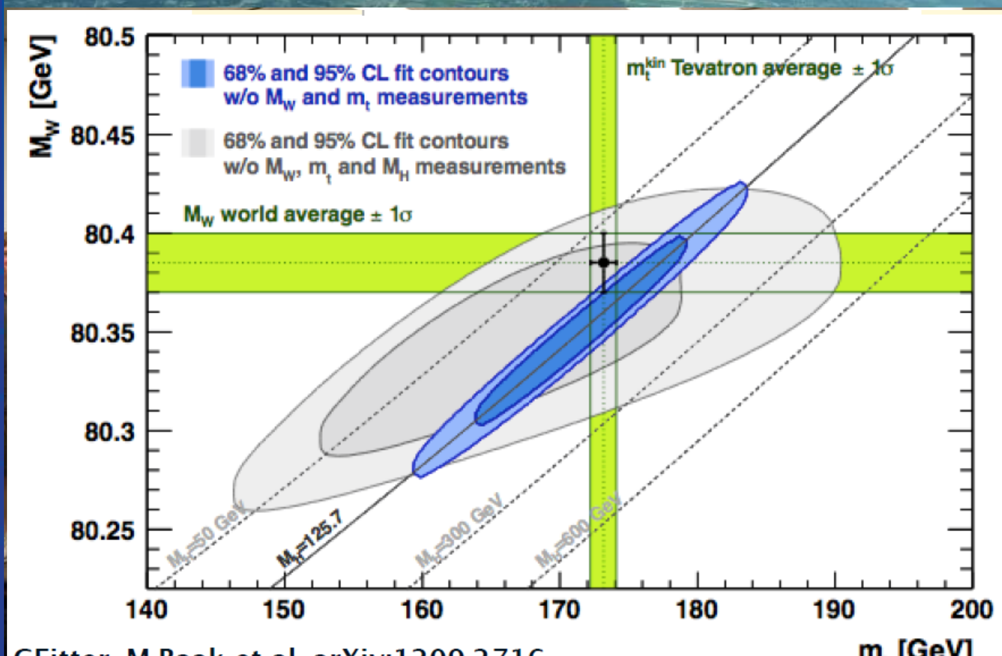


Guiding Principles in Particle Physics…

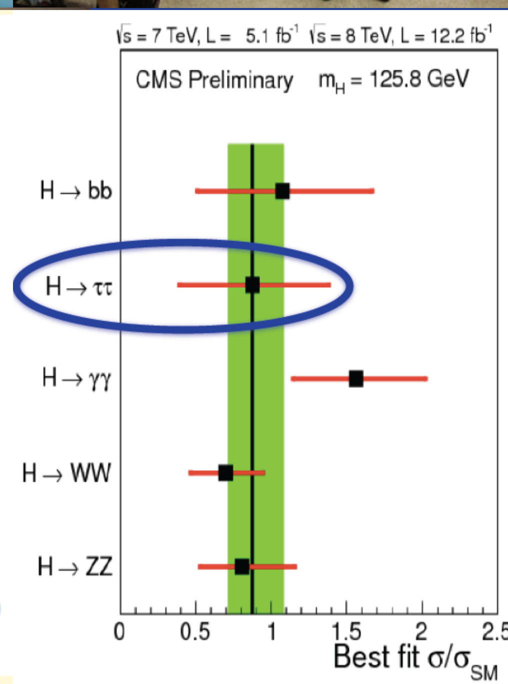


Leading the Energy Frontier..
The Large Hadron Collider at CERN in Europe

CERN,
July 4th 2012



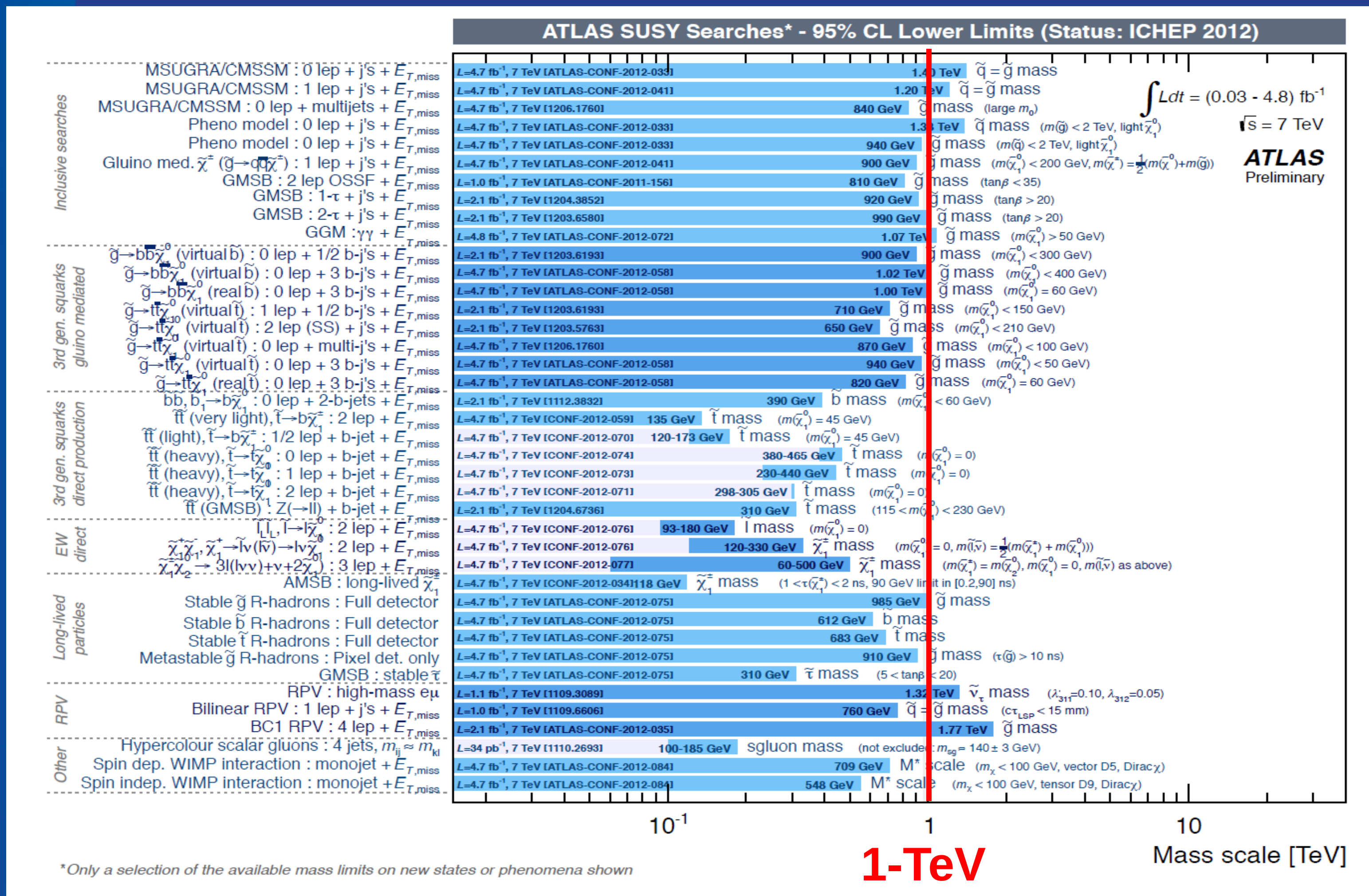
GFitter, M.Baak et al, arXiv:1209.2716



Mangano,
HCP 2012
Kyoto, Nov 2012.

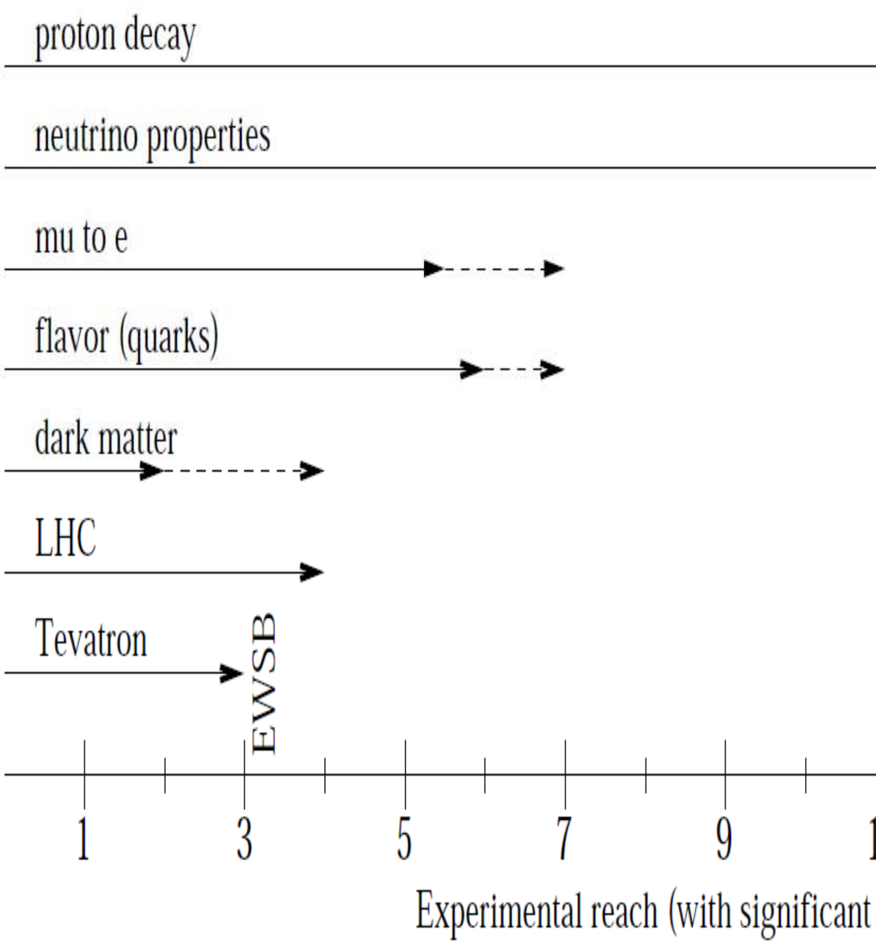
Direct Challenges from the Energy Frontier to Models Beyond the Standard Model

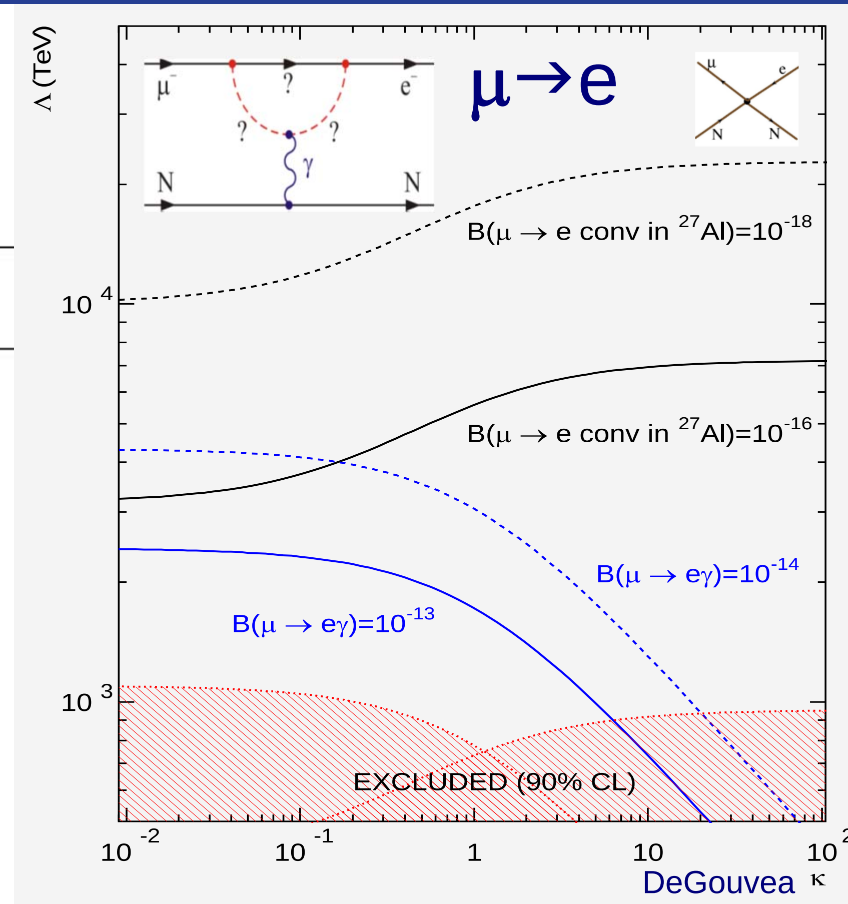
New Physics



ATLAS@ICHEP - July 2012, Courtesy A. Parker

Indirect Challenges from the Intensity Frontier…

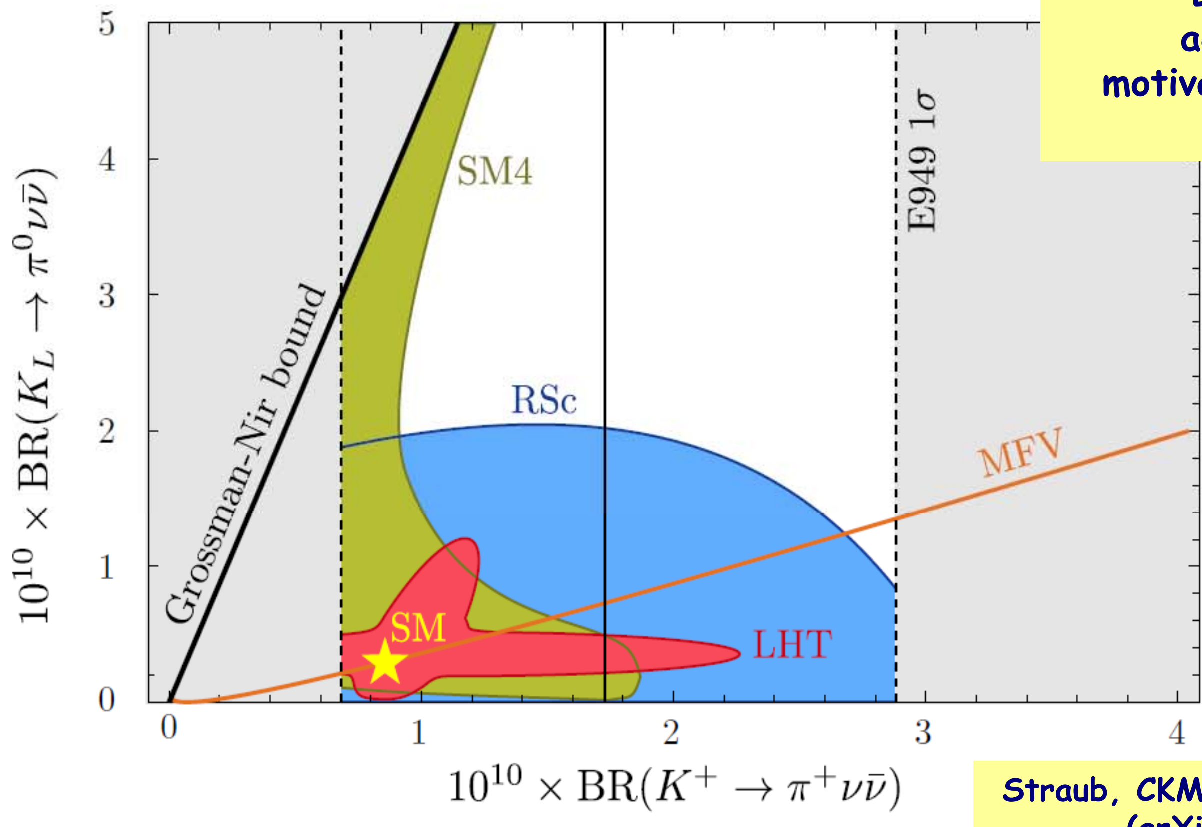




Y. Grossman, Z. Ligeti, Project X Physics Study (PXPS)

Rare processes can dissect new physics…
e.g. Warped Extra Dimensions as a Theory of Flavor??

Buras et al. SM accuracy of <5%, motivates 1000-event experiments



Straub, CKM 2010 workshop (arXiv:1012.3893v2)

Figure 1: Correlation between the branching ratios of $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ in MFV and three concrete NP models. The gray area is ruled out experimentally or model-independently by the GN bound. The SM point is marked by a star.

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CP violation research opportunities

- Neutrinos: > x3 increase in LBNE neutrino statistics.
- Proton-EDM, x10^6 reach, *new capability*
- Muon-EDM, x10^4 reach, *new capability*
- Neutron EDM, x10^2-10^3 reach
- Atomic EDMs. x10^3-10^4 reach, goal of surpassing Hg!

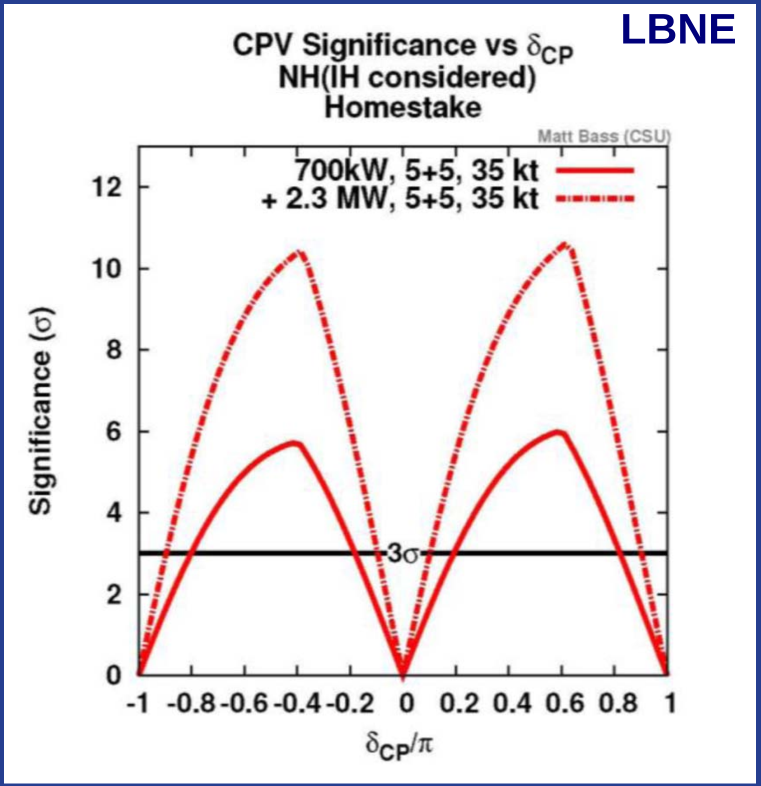


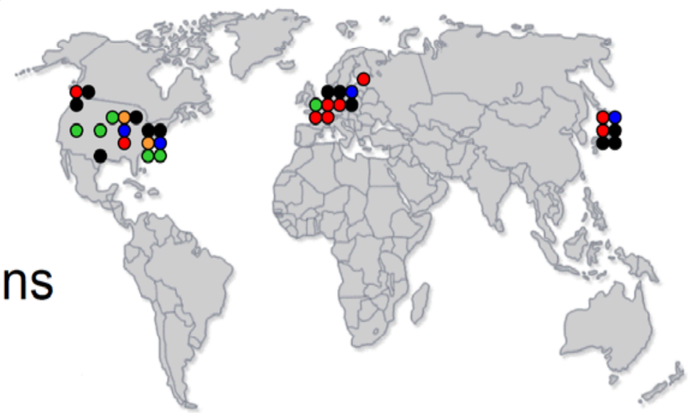
Table 2: SM predictions and current and expected limits on selected examples of EDMs.

EDMs	SM	current limit	Project X
electron	$\sim 10^{-38}$ e cm	1.0×10^{-27} e cm	$\sim 10^{-30}$ e cm
muon	$\sim 10^{-35}$ e cm	1.1×10^{-19} e cm	$\sim 10^{-23}$ e cm
neutron	$\sim 10^{-31}$ e cm	2.9×10^{-26} e cm	$\sim 10^{-29}$ e cm
proton	$\sim 10^{-31}$ e cm	6.5×10^{-23} e cm	$\sim 10^{-29}$ e cm
nuclei	$\sim 10^{-33}$ e cm (^{199}Hg)	3.1×10^{-29} e cm (^{199}Hg)	$\sim 10^{-29}$ e cm (^{225}Ra)

EDM Research Worldwide…

Rough estimate of numbers of researchers, in total ~500 (with some overlap)

- **Neutrons** (~200)
  - @ILL
  - @ILL,@PNPI
  - @PSI
  - @FRM-2
  - @RCNP,@TRIUMF
  - @SNS
  - @J-PARC
- **Molecules** (~50)
  - YbF@Imperial
  - PbO@Yale
  - ThO@Harvard
  - HfF+@JILA
  - WC@UMich
  - PbF@Oklahoma
- **Atoms** (~100)
  - Hg@UWash
  - Xe@Princeton
  - Xe@TokyoTech
  - Xe@TUM
  - Xe@Mainz
  - Cs@Penn
  - Cs@Texas
  - Fr@RCNP/CYRIC
  - Rn@TRIUMF
  - Ra@ANL
  - Ra@KVI
  - Yb@Kyoto



- **Ions-Muons** (~200)
  - @BNL
  - @FZJ
  - @FNAL
  - @JPARC
- **Solids** (~10)
  - GGG@Indiana
  - ferroelectrics@Yale

Courtesy Klaus Kirch CIPANP 2012

Summary of the The Project X Physics Study June 14th-22nd

220 participants

Summaries for experimental concepts and required detector R&D. Will serve as basis for research program white papers.

Staging introduced, Stage-1 program clarified. Scope increments discussed:

proton-edm, decay-at-rest neutrino sources.

Project X detector R&D proposals submitted to OHEP as part of the comparative review process.

PX Physics Study Conveners for Experimental Concepts and Sensitivities

Neutrinos:

Andre de Gouvea (Northwestern University), Patrick Huber (Virginia Tech) , Geoff Mills (LANL)
Ko Nishikawa (University of Chicago/FNAL), Steve Geer (FNAL)

Muon Experiments:

Bob Bernstein (Fermilab), Graham Kribs, (University of Oregon)

Kaon Experiments:

Kevin Pitts (University of Illinois UC), Vincenzo Cirigliano (LANL)

EDMs:

Tim Chupp (University of Michigan) , Susan Gardner (University of Kentucky), Zheng-Tian Lu (ANL)

n-nbar oscillations:

Chris Quigg (FNAL), Albert Young (North Carolina State University)

Hadron physics:

Stephen Godfrey (Carleton University), Paul Reimer (ANL)

PX Physics Study Conveners for Enabling Technologies and Techniques

High rate Precision Photon Calorimetry:
David Hitlin (Caltech), Milind Diwan (BNL)

Very Low-Mass High-Rate Charged Particle Tracking:
Ron Lipton (FNAL), Jack Ritchie (University of Texas, Austin)

Time-of-Flight System Performance below 10 psec:
Mike Albrow (FNAL), Bob Wagner (ANL)

High Precision Measurement of Neutrino Interactions:
Kevin McFarland (Rochester University), Jonghee Yoo (FNAL), Rex Tayloe (University of Indiana)

Large Area Cost Effective (LACE) Detector Technologies:

Mayly Sanchez (Iowa State University), Yury Kamyshkov (University of Tennessee)

Lattice QCD:
Ruth Van de Water (BNL), Tom Blum (University of Connecticut)

Example Research Program, definitive space of accelerator parameters on PXPS Indico site

← Project X Campaign →

Program:	Onset of NOvA operations in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RDR	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2450 kW	2450-4000 kW
8 GeV Neutrinos	15 kW +0-50kW**	0-42 kW* + 0-90 kW**	0-84 kW*	0-172 kW*	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	0-172 kW*	1000 kW
1-3 GeV Muon program, e.g. Mu2e-2	-----	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	1870 kW	1870 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
# Programs:	4	8	8	8	8
Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

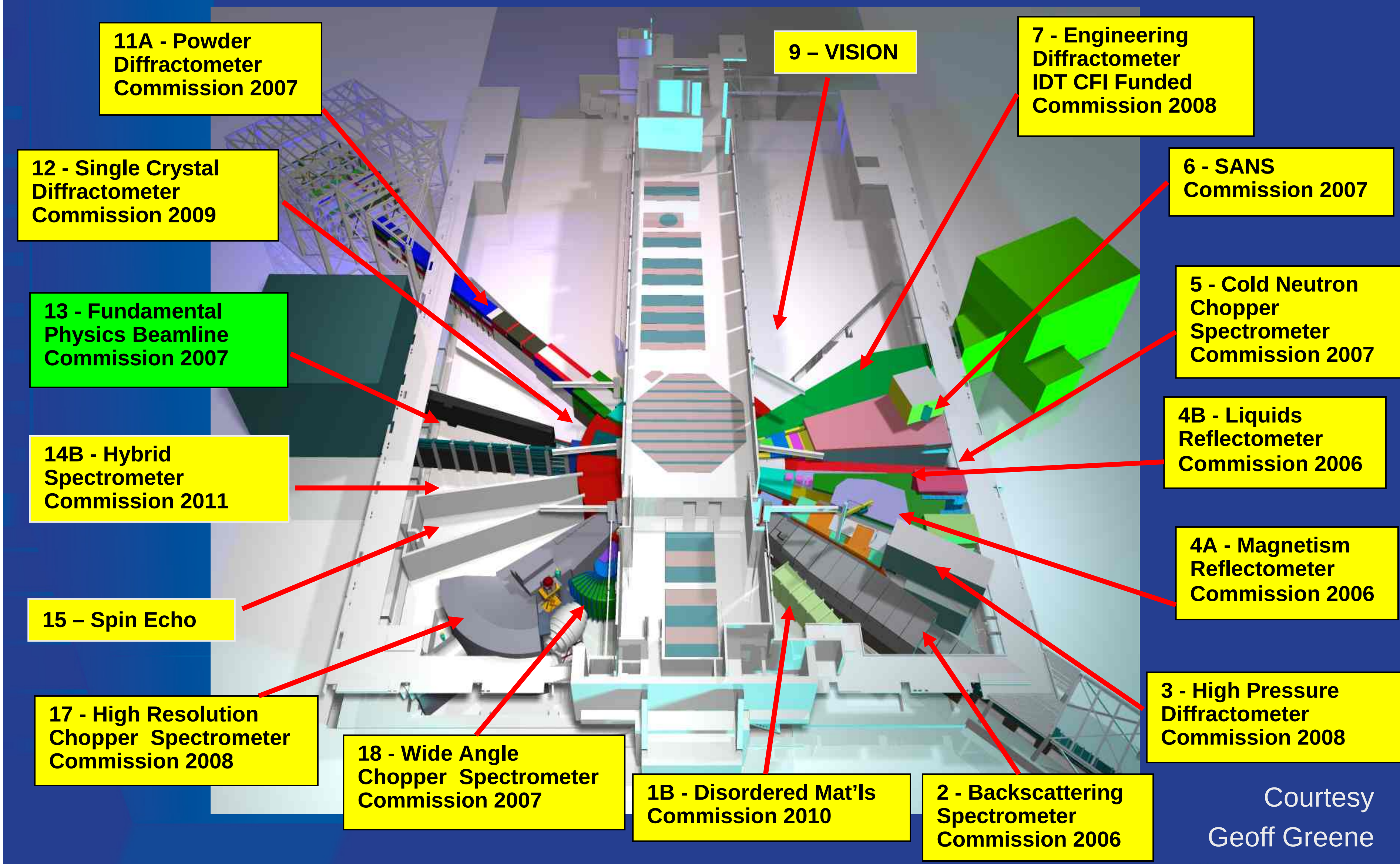
* Operating point in range depends on MI energy for neutrinos.

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

Stage-1 Accelerator Resources:

- Promotes the Main Injector (MI) to a Mega-Watt class machine for neutrinos, and increases the potential beam power for other medium power MI experiments (e.g. ORKA, nu-STORM).
- Unshackles the $\mu \rightarrow e$ (Mu2e) experiment from the Booster complex: Potentially increases sensitivity of Mu2e by x10 - x100 with 1-GeV CW drive beam.
- High power spallation target optimized for ultra-cold neutron and atomic-edm particle physics experiments and neutron $\leftrightarrow$ anti-neutron oscillation experiments.
- Capability to drive polarized protons to a proton-edm experiment.
- Increases the available integrated 8 GeV power for other experiments (e.g. short-baseline neutrinos) from the Booster complex by liberating Mu2e.

Beamline 13 Has Been Allocated for Nuclear Physics at SNS



Courtesy Geoff Greene

Since PXPS, Development of Stage-1 Research Program

Physics Opportunities with Stage 1 of Project X

Wolfgang Altmannshofer, Marcela Carena, Patrick Fox, Stuart Henderson, Stephen Holmes, Young-Kee Kim, Joachim Kopp, Andreas Kronfeld, Joseph Lykken, Chris Quigg, and Robert Tschirhart

August 2012

* http://www.fnal.gov/directorate/lbne_reconfiguration/

PAC Feedback Regarding the Proton EDM Expression of Interest.

- "…This experiment represents an exciting opportunity for Fermilab."
- "…The PAC recommends that Fermilab and Brookhaven management work together, and with potential international partners, to find a way for critical R&D for this promising experiment to proceed."
- This experiment requires 236 MeV/c polarized protons of modest intensity, injection every 20-60 minutes.

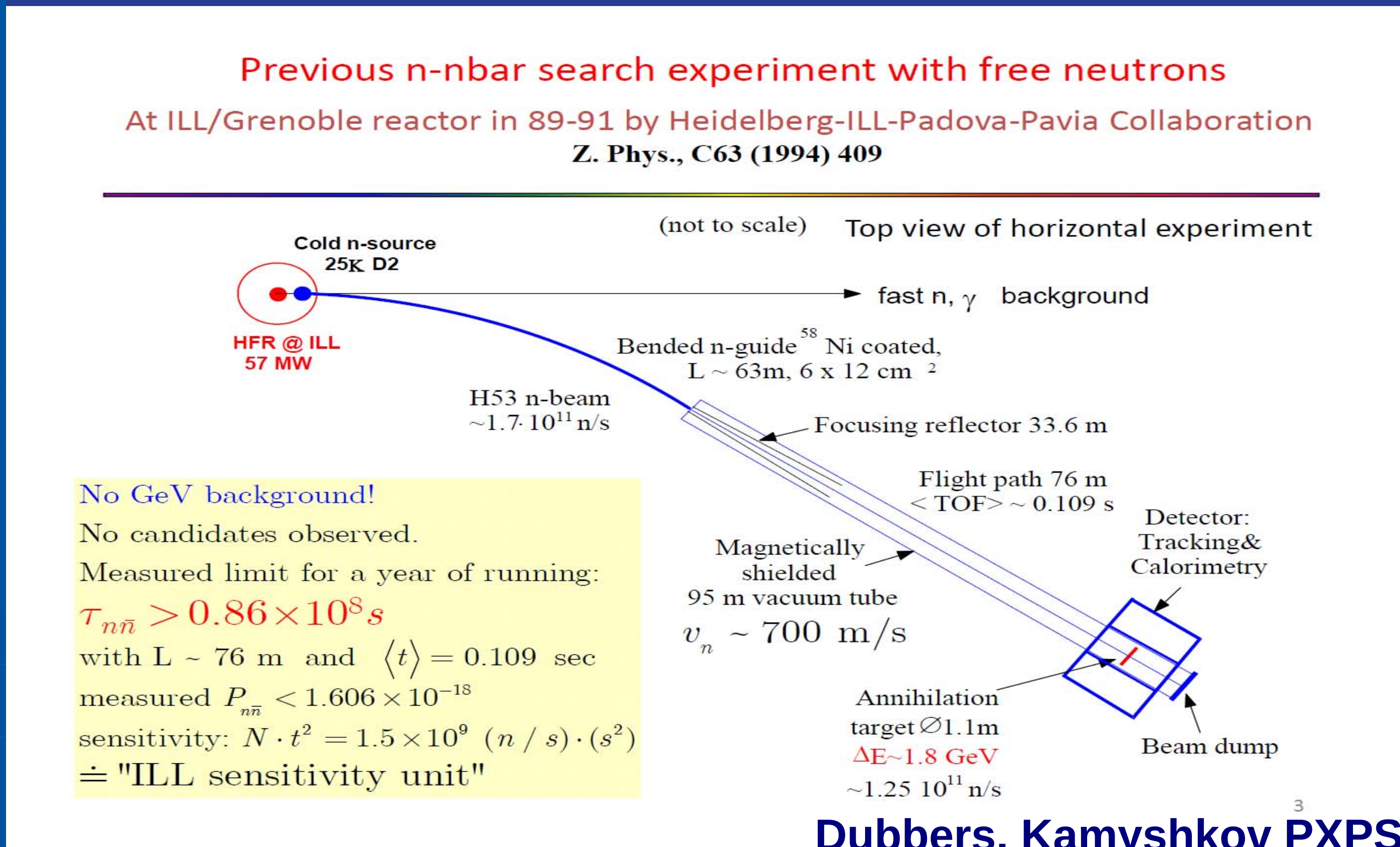
Rare Processes Research Probing far Beyond the TeV scale with Stage-1

- x10 improvement in mu2e sensitivity. Platform for next generation rare muon decay experiments such as $\mu \rightarrow 3e$.

- x100 improvement in $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ sensitivity, many other rare K^+ modes.

Process	Current	ORKA	Comment
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$	7 events	1000 events	
$K^+ \rightarrow \pi^+ X^0$	$< 0.73 \times 10^{-10}$ at 90% CL	$< 2 \times 10^{-12}$	$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ is a background
$K^+ \rightarrow \pi^+ \pi^0 \nu\bar{\nu}$	$< 4.3 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \rightarrow \pi^+ \pi^0 X^0$	$\lesssim 4 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \rightarrow \pi^+ \gamma$	$< 2.3 \times 10^{-9}$	$< 6.4 \times 10^{-12}$	
$K^+ \rightarrow \mu^+ \nu_{heavy}$	$< 2\text{–}10 \times 10^{-8}$	$< 1 \times 10^{-10}$	150 MeV $< m_\nu <$ 270 MeV
$K^+ \rightarrow \mu^+ \nu_\mu \nu\bar{\nu}$	$< 6 \times 10^{-6}$	$< 6 \times 10^{-7}$	
$K^+ \rightarrow \pi^+ \gamma\gamma$	293 events	200,000 events	
$\Gamma(Ke2)/\Gamma(K\mu2)$	$\pm 0.5\%$	$\pm 0.1\%$	
$\pi^0 \rightarrow \nu\bar{\nu}$	$< 2.7 \times 10^{-7}$	$< 4\text{–}50 \times 10^{-9}$	depending on technique
$\pi^0 \rightarrow \gamma X^0$	$< 5 \times 10^{-4}$	$< 2 \times 10^{-5}$	

Stage-1 presents an opportunity to increase n-nbar search sensitivity by > x20



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PAC Feedback Regarding the $n \leftrightarrow \bar{n}$ Expression of Interest.

- "…The observation of n↔nbar oscillation would be a major breakthrough in particle physics, providing evidence for baryon number violation, which is needed to explain the observed baryon asymmetry of the Universe."

- "…The PAC recommends that R&D be supported, when possible, for the design of the spallation target, and for the overall optimization of the experiment, to bring it to the level required for a proposal to be prepared. The NNbarX experiment would be an interesting addition to the wider physics program involving neutrons at the first stage of Project-X."

Broader Impacts Research with Stage-1

- Energy applications: Material studies, transmutation science, accelerator reliability. DOE SC/NE workshop January 2013.
- Materials science with muon Spin Rotation (muSR): very-low energy (<4 MeV) stopping μ^+ that are sensitive probes of the magnetic properties of materials. Several facilities world-wide, no US facilities. Sucessful Project X muSR forum October 17th-19th.

Mu2e Search for $\mu^- \rightarrow e^-$ conversion at 10^{-16}

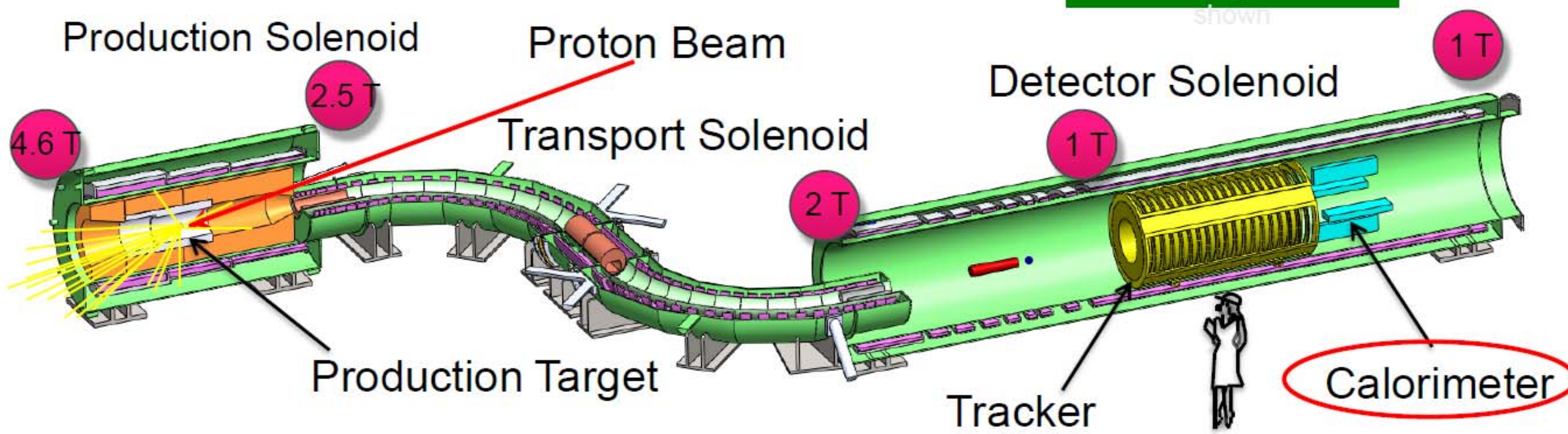
Production Solenoid
- Production target
- Graded field

- Delivers ~ 0.0016 stopped μ^- per incident proton
- 10^{10} Hz of stopped muons

Detector Solenoid
- Muon stopping target
- Tracker
- Calorimeter
- Warm bore evacuated to 10^{-4} Torr

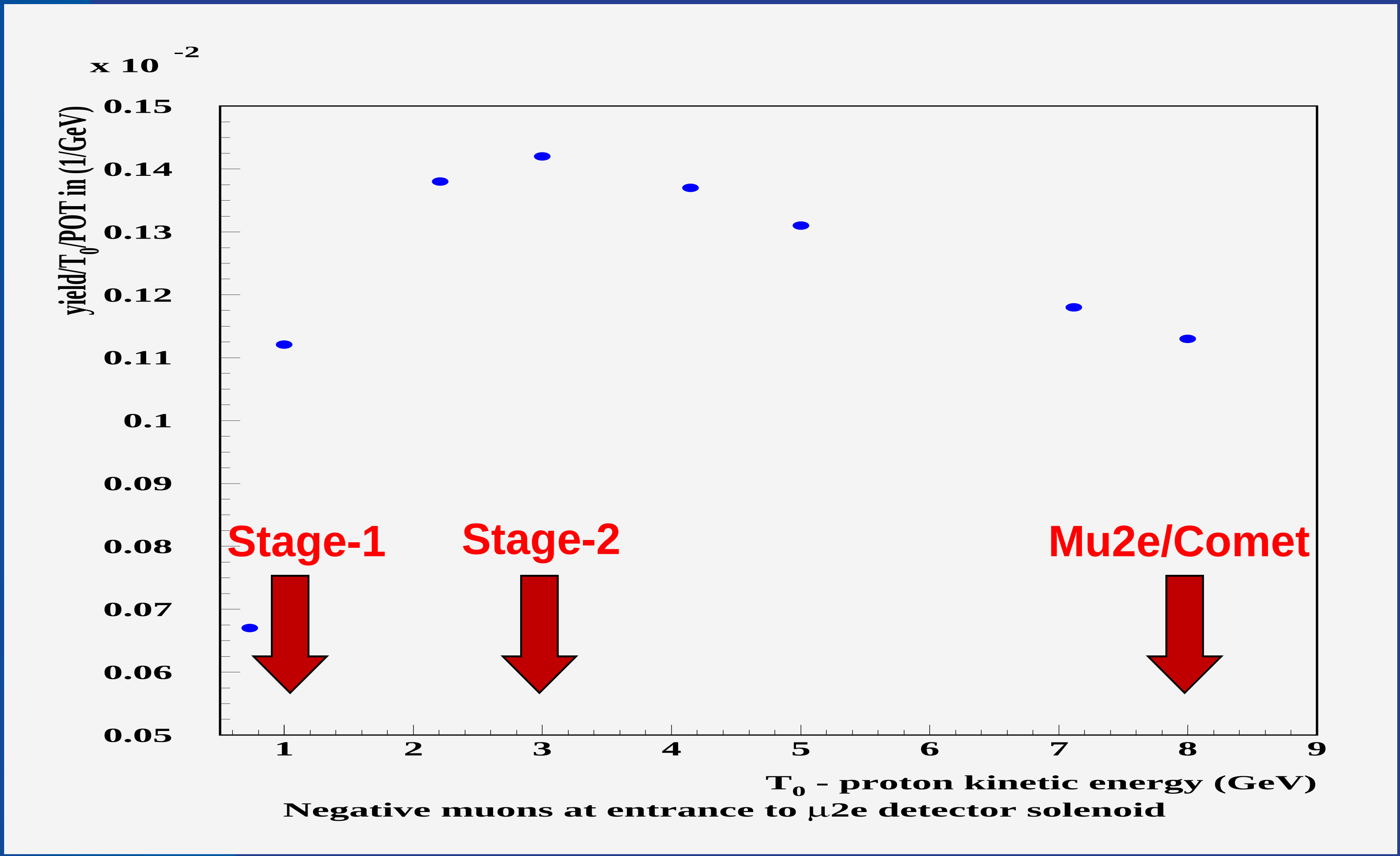
Transport Solenoid
- Collimation system selects muon charge and momentum range
- Pbar window in middle of central collimator

Cosmic Ray Veto not shown



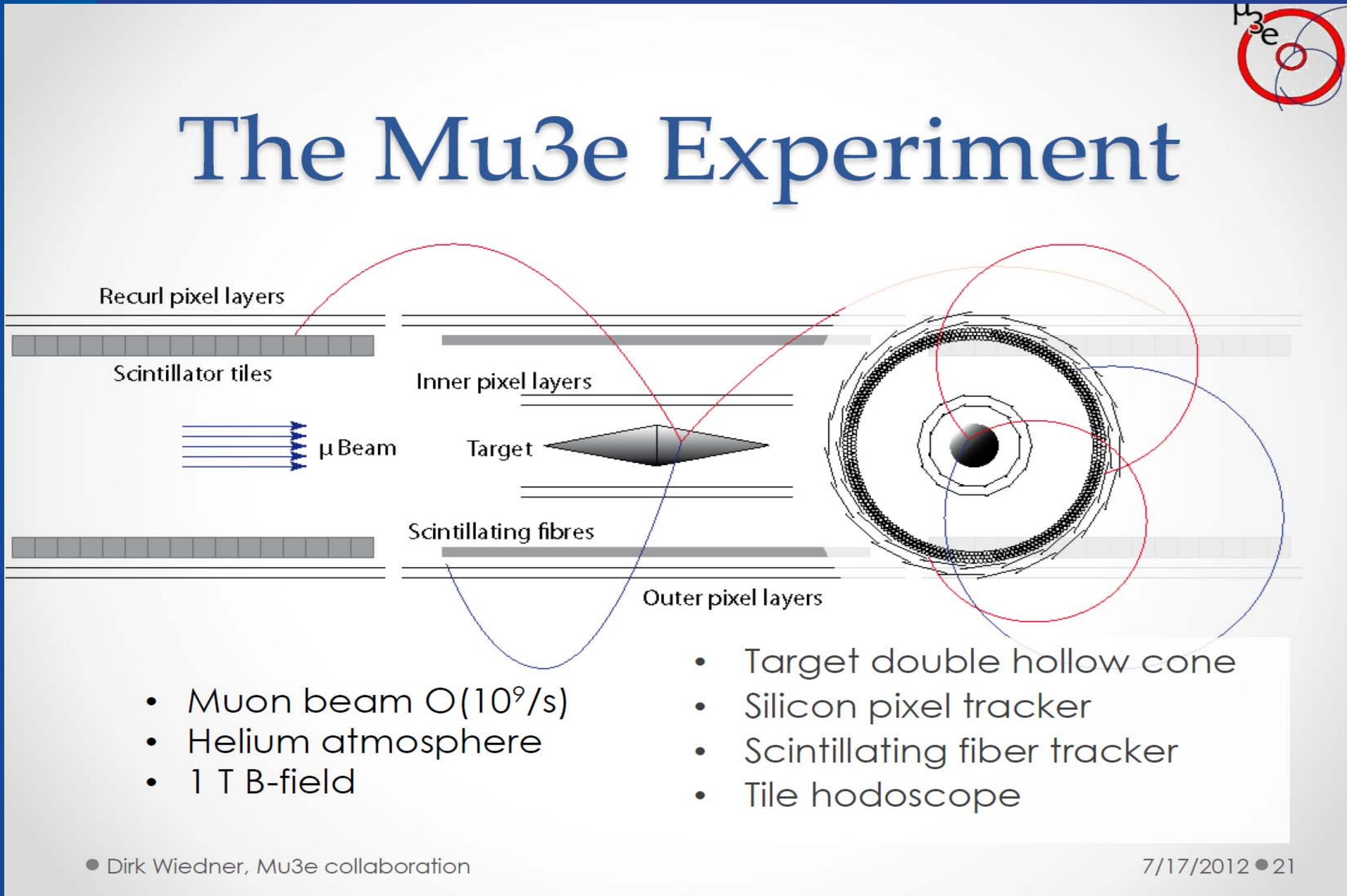
What is the optimum proton beam energy to drive a MELC/MECO/Comet-Mu2E experiment?

Yield / Watt



S. Striganov et al PXPS, work in progress

0.1% X_0 per layer, 100 psec track timing…



Dirk Wiedner, Mu3e Initiative at PSI

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

Science Enabled with Stage-2

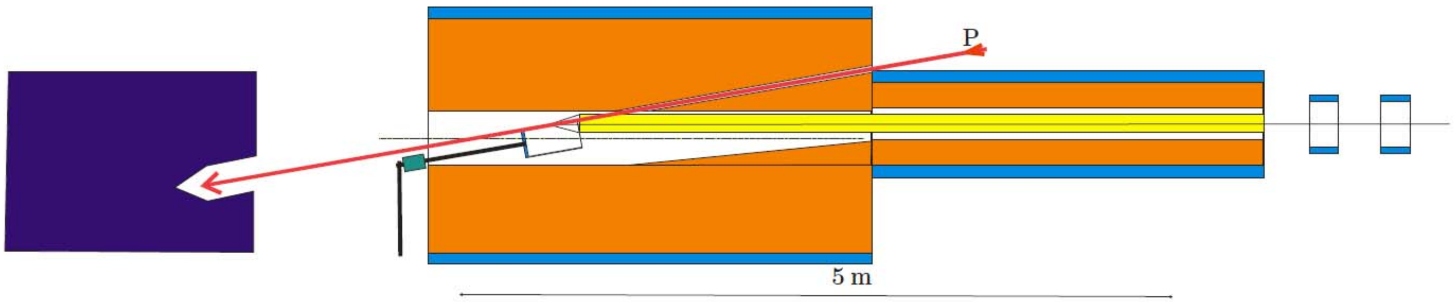
- World leading kaon physics program: Megawatt power (x10 over competing facilities) can drive multiple experiments.

- World class muon physics program: Mu2e descendant migrates to a higher power campus. Megawatt power for conversion experiments (x10 over competing $\mu \rightarrow e$ facilities), opportunities for major next steps in other channels (e.g. $\mu \rightarrow 3e$, others).

- Maintains Main Injector beam power at lower energies (e.g. 60 GeV) enhancing the neutrino spectrum for long baseline experiments.

Target and Target Cooling

- Optimal target length should be ~1.5 of nuclear interaction length
  - ⇒ i.e.: carbon ~60 cm; tantalum ~15 cm
- The beam leaves ~10% of its energy in the target;
- For 1 MW beam power the power left in the target is ~ 100 kW
- Large beam power prohibits usage of pencil-like target
  - Heat cannot be removed from pencil target: $dP/dS \geq 2$ kW/cm^2 for R~0.5cm
  - Mercury stream is another possibility but it has significant problems with safety. Therefore it was not considered.
- Cylindrical rotating target looks as the most promising choice
  - Carbon (graphite) and tantalum targets were considered
  - Tantalum or any other high Z target has a problem with heating



Muon Task Force, Valeri Lebedev

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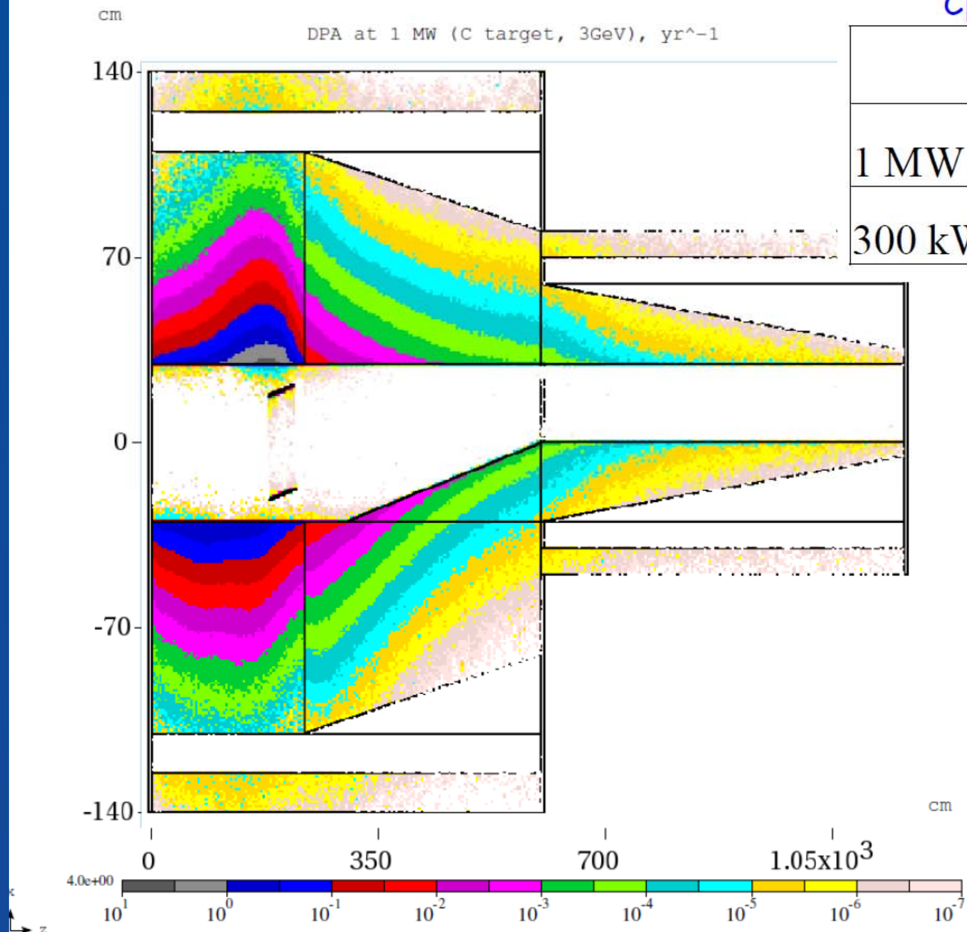
V. Lebedev, Fermilab AAC 2011

Effects of radiation



Shielding estimate

C[t] / W[t] /Rmax [cm]

	C target	Ta target
1 MW	140/80 (110)	180/100 (125)
300 kW	100/55 (95)	110/65 (100)

This preliminary absorber design satisfies typical requirements for SC coils

- peak DPA 10^{-5} year^{-1})
- power density (3 μW/g)
- absorbed dose 60 kGy/yr
- Dynamic heat load is 10 W

- Transition from 25 kW of μ-to-e to 1 MW increases the shield radius from ~80 cm 110 cm => B = 5 T → 3 T for the same stored energy

Muon Task Force, Valeri Lebedev

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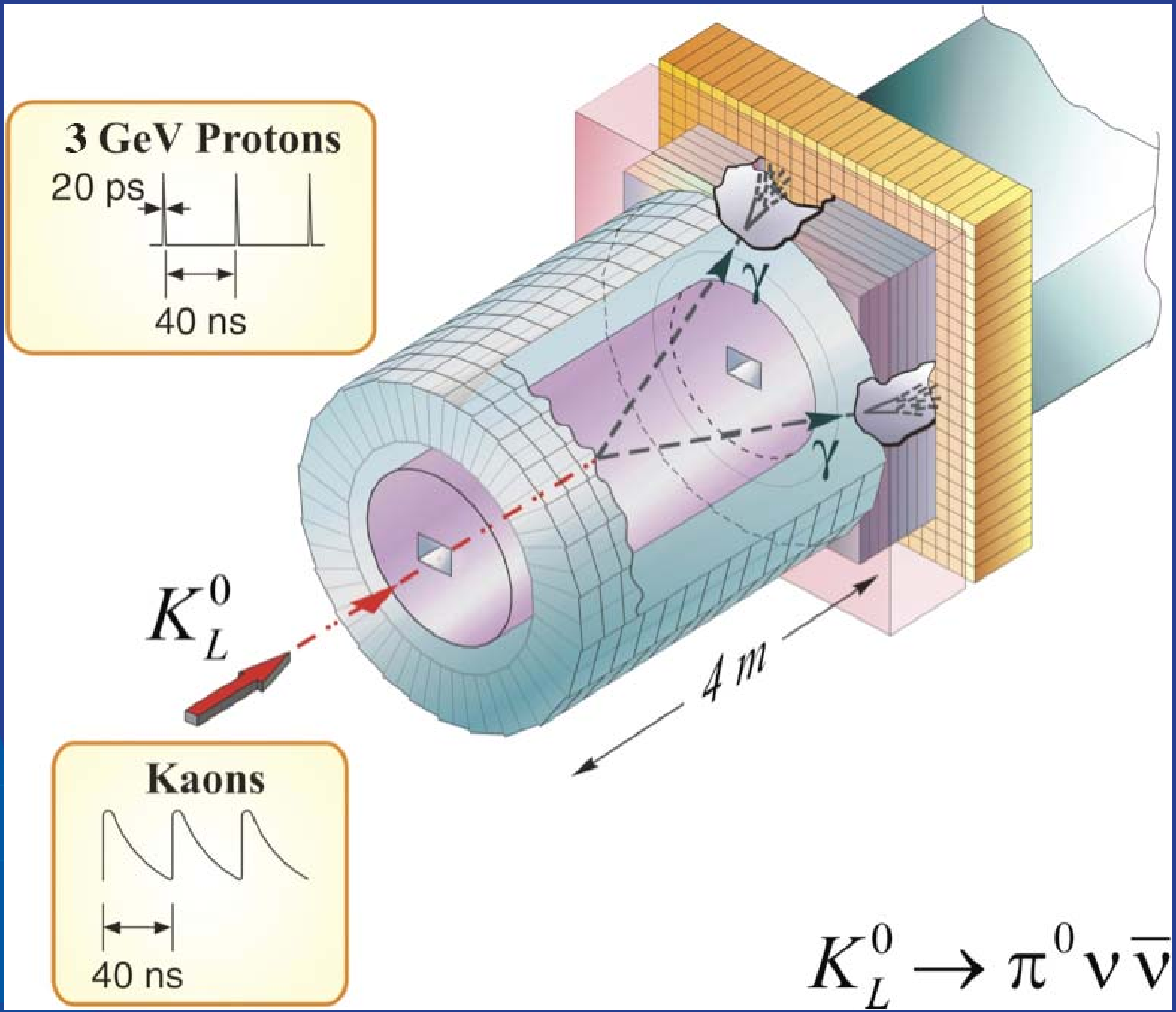
V. Lebedev, Fermilab AAC 2011

"Nothing in, nothing out…" Next generation photon measurements crucial.



Kaons at Project X

- $K^+ \to \pi^+ \nu \bar{\nu}$
  - but hopefully it's already done to a few %.

- $K_L \to \pi^0 \nu \bar{\nu}$
  - "This experiment was made for Project X" –L. Littenberg

- Many other modes of interest
  - T violation in $K^+ \to \pi^0 \mu \nu$ (TREK)
  - Universality $\Gamma(K^+ \to e^+ \nu)/\Gamma(K^+ \to \mu^+ \nu)$
  - $K_L \to \pi^0 \mu\mu$ and $\pi^0 ee$ (look at K_S/K_L interference?)
  - K^+, K_L lepton flavor violation e.g. $K_L \to \mu e$
  - $K_L \to \gamma\gamma$
  - ...

Kevin Pitts, PXPS

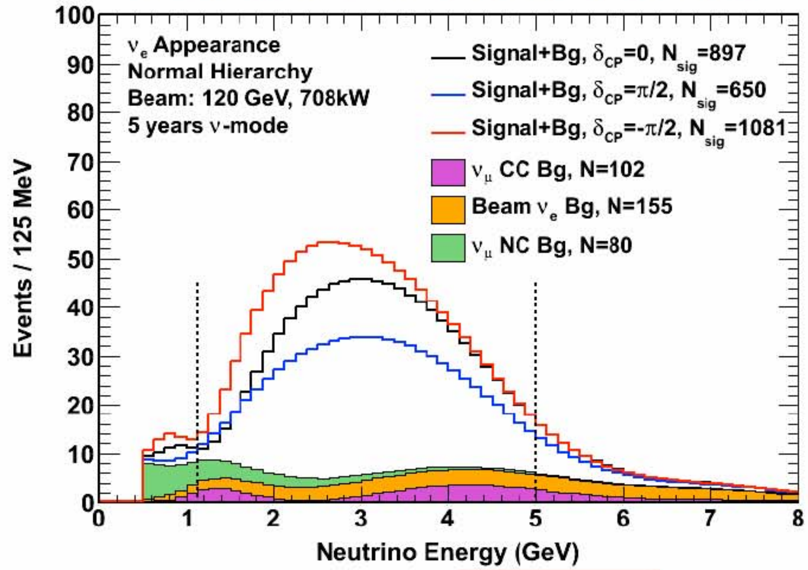
Project X Stage 2 Possibilities

LBNE

- Stage 2 will allow MW-power lower energy beams
- Can we gain low energy flux (at long baselines) by going to lower energies?
- This can populate the second maximum and improve the signal/background in the CPV-sensitive region.
- Consider 30, 60, 90 GeV energies and 1MW beam power
- Separation power figure of merit:

$$\frac{N_{-\pi/2} - N_{\pi/2}}{\sqrt{B}} = 23.5$$

Standard 120 GeV 700kW



δ_{CP}	N	N_{second}	N_{first}	$N/\sqrt{B}$	$N_{second}/\sqrt{B}$	$N_{first}/\sqrt{B}$
0	897	14	817	48.86	2.27	57.34
$\pi/2$	650	5	597	35.41	0.81	41.90
$-\pi/2$	1081	24	994	58.89	3.89	69.77

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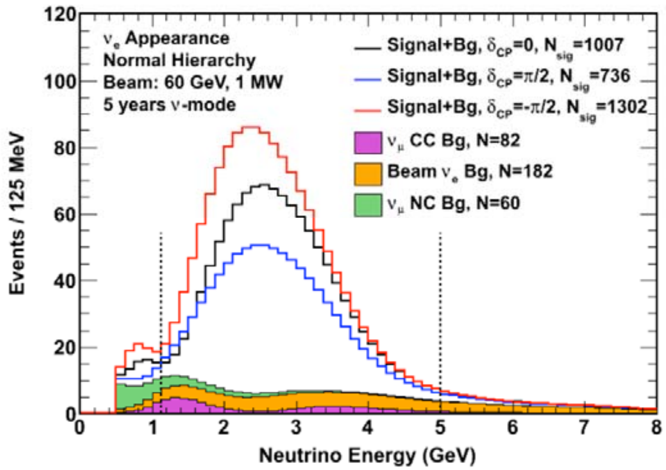
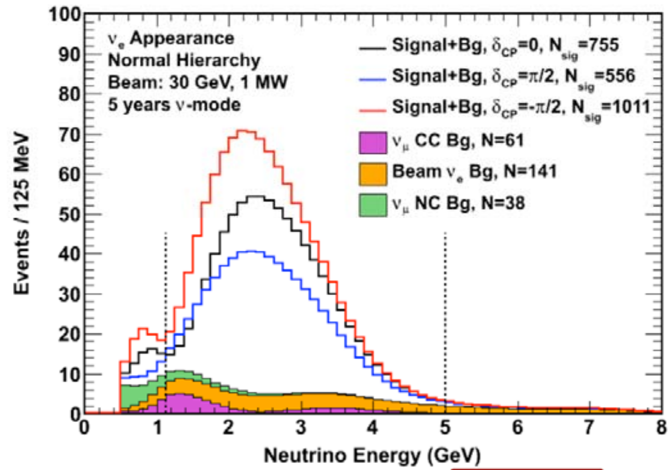
LBNE

60 GeV 1MW, 30 GeV 1MW





δ_{CP}	N	N_{second}	N_{first}	$N/\sqrt{B}$	$N_{second}/\sqrt{B}$	$N_{first}/\sqrt{B}$
0	1007	26	955	55.94	3.92	64.83
$\pi/2$	736	10	707	40.89	1.51	47.99
$-\pi/2$	1302	45	1231	72.33	6.78	83.57

$$\frac{N_{-\pi/2} - N_{\pi/2}}{\sqrt{B}} = 31.4$$

δ_{CP}	N	N_{second}	N_{first}	$N/\sqrt{B}$	$N_{second}/\sqrt{B}$	$N_{first}/\sqrt{B}$
0	755	30	716	48.74	4.93	55.08
$\pi/2$	556	11	538	35.89	1.81	41.38
$-\pi/2$	1011	51	951	65.26	8.38	73.15

$$\frac{N_{-\pi/2} - N_{\pi/2}}{\sqrt{B}} = 29.4$$

- Can do better CPV than 120 GeV with the same amount of running
- Technical: High density graphite target inserted into horn 1 unlike standard NuMI LE at z=-30cm

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Example Research Program, definitive space of accelerator parameters on PXPS Indico site

← Project X Campaign →

Program:	Onset of NOvA operations in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RDR	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2450 kW	2450-4000 kW
8 GeV Neutrinos	15 kW +0-50kW**	0-42 kW* + 0-90 kW**	0-84 kW*	0-172 kW*	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	0-172 kW*	1000 kW
1-3 GeV Muon program, e.g. Mu2e-2	-----	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	1870 kW	1870 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
# Programs:	4	8	8	8	8
Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

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

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

Science Enabled with Stage-3 (RDR)

- Main Injector power upgrade to >2 Mega Watts for 60-120 GeV beam, doubling power to long baseline Main Injector Neutrinos and Main Injector near-detector neutrino physics.

- 8 GeV beam power for experiments is doubled to now x10 the MiniBooNE era, which will support a new generation of short-baseline neutrino physics.

Example Research Program, definitive space of accelerator parameters on PXPS Indico site

← Project X Campaign →

Program:	Onset of NOvA operations in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RDR	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
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Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
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Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

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

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

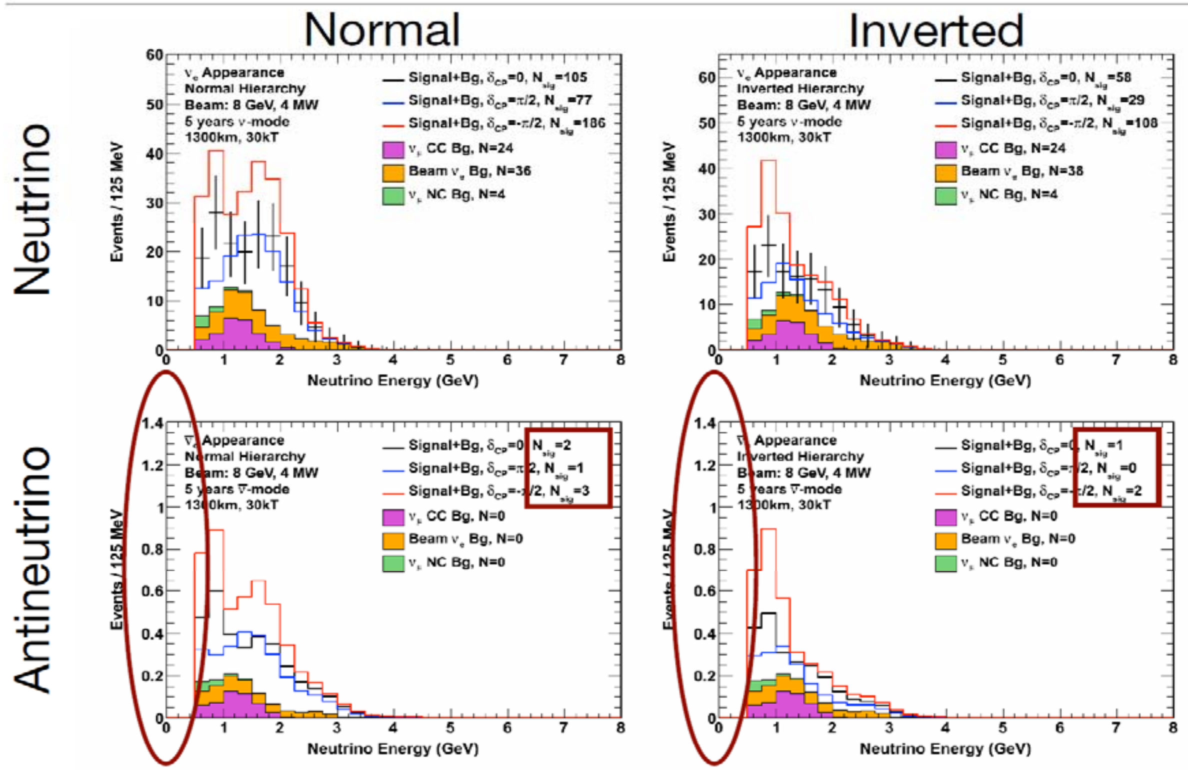
Science Enabled with Stage-4 (Beyond RDR)

- 4000kW @ 8 GeV and 4000kW at 60 GeV for the ultimate super beams.
- Double super-beam technique can tune illumination of the first and second maxima of long-baseline experiments of very massive next generation long-baseline detectors.
- Driver for an extremely powerful muon storage ring neutrino source, ultimately leading to a neutrino factory as motivated by the physics.

Stage-4: LBL physics with 8 GeV beam!

Matter vs CP effect with 8 GeV

LBNE



- Mass hierarchy and CP asymmetry non-degenerate - they're completely disentangled!

Zeynep Isvan (BNL) 6/19/2012 PXPS

Zeynep Isvan (BNL) PXPS

Project X Preparations for Snowmass

http://www.snowmass2013.org/
Minnesota

U.S. DEPARTMENT OF ENERGY

Fermilab

What is Snowmass About?

- Sponsored by the APS Division of Particles and Fields …***not*** the DOE.
- Community strategic planning for the 2020-2030 era.
- Message from the funding agencies: ***Not*** a process to re-consider Projects that are currently within the Critical Decision process.
- Snowmass output will be input to the Particle Physics Projects Prioritization Panel (P5) which will recommend programs in the context of budget scenarios.

Boundary Conditions

- "Physics comes first." However there are important real-world considerations.
- Note that a 'brute force' approach that seeks to spend vast sums in order to build some facility/physics capability simply will not work in today's fiscal environment. This has been empirically demonstrated.
  - Most recently, via our discussions on LBNE, we have confirmed that single project expenditures must be somewhat smaller than $1B per stage.
- CSS2013 participants are encouraged to think about whatever physics you think is most relevant and important to progress in HEP, but the effort you put in should be tempered with a realistic assessment of funding possibilities.
  - Many ideas can be staged to provide new physics capability at each step, but some cannot.
- Projects that build upon previous investments either scientifically or through recycling of infrastructure are generally well received.
- A plan that can produce a steady flow of scientific results is also highly desirable/required.

Presentation to HEPAP Dec 5th 2012 by Jim Siegrist, Associate Director, Office of High Energy Physics

21

SNOWMASS WORKING GROUPS

- Energy Frontier
- Intensity Frontier
- Cosmic Frontier
- Frontier Capabilities
- Instrumentation Frontier
- Computing Frontier
- Education and Outreach

Intensity Frontier group charge:

Conveners: JoAnne Hewett (SLAC), Harry Weerts (Argonne)

The Intensity Frontier working group is charged with summarizing the current state of knowledge and identifying the most promising future opportunities at the intensity frontier. Topics are described under the working groups.

Frontier Capabilities Group

Conveners: William Barletta (MIT), Murdock Gilchriese (LBNL)

Frontier Facilities will assess the existing and proposed capabilities of two distinct classes of experimental capabilities for high energy physics broadly understood, namely, those provided by accelerator-based facilities and those provided by detector facilities distinct from accelerators. We expect the evaluations to be performed with two principal groups that will operate independently: Accelerator Facilities and Non-accelerator Facilities.

Accelerator Sub-Groups in the Frontier Capabilities Group

- Energy Frontier Hadron Colliders
- Energy Frontier Lepton and Gamma Colliders
- High Intensity Secondary Beams Driven by Protons
- High Intensity Electron and Photon Beams
- Electron-ion Colliders
- Accelerator Technology Test-beds and Test Beams

CSS 2013 Engagement Plan: Accelerator Reference Design Report*

- Accelerator Reference Design Report (RDR) will be prepared for distribution to the community in at the Fermilab Users Meeting June 12th 2013. The RDR will include:

  -Staging plan, capability of each stage.

  -Some information on cost drivers and scaling.

*Editor: S. Holmes

CSS 2013 Engagement Plan: Research Program Report*

- Research program opportunities report will be prepared for distribution be prepared for distribution to the community at the Fermilab Users Meeting June 12th 2013. This report will include:

  - Experimental concepts and physics reach opportunities of each stage.

  - Evolution of existing white papers, work at the Project X Physics Study, a URA funded theory study group (C. Quigg P.I.) and PX/CSS Intensity Frontier meetings April 24th-27th 2013.

*Editors: A. Kronfeld, R.T.

PX Physics Study Conveners for Experimental Concepts and Sensitivities

Neutrinos:

Andre de Gouvea (Northwestern University), Patrick Huber (Virginia Tech) , Geoff Mills (LANL)
Ko Nishikawa (University of Chicago/FNAL), Steve Geer (FNAL)

Muon Experiments:

Bob Bernstein (Fermilab), Graham Kribs, (University of Oregon)

Kaon Experiments:

Kevin Pitts (University of Illinois UC), Vincenzo Cirigliano (LANL)

EDMs:

Tim Chupp (University of Michigan) , Susan Gardner (University of Kentucky), Zheng-Tian Lu (ANL)

n-nbar oscillations:

Chris Quigg (FNAL), Albert Young (North Carolina State University)

Hadron physics:

Stephen Godfrey (Carleton University), Paul Reimer (ANL)

CSS 2013 Engagement Plan: Necessary Detector R&D Report*

- A report on Detector R&D required to develop the research program opportunities will be prepared for distribution to the community at the Fermilab Users Meeting June 12th 2013. This report will include:

  - R&D necessary for each stage.

  - Coordination with the DPF Coordination Panel for Advanced Detectors (CPAD) and connections to other scientific and technical disciplines. Meetings at ANL in January, Boulder Co. in the spring.

*Editors: E. Ramberg, R.T.

PX Physics Study Conveners for Enabling Technologies and Techniques

High rate Precision Photon Calorimetry:

David Hitlin (Caltech), Milind Diwan (BNL)

Very Low-Mass High-Rate Charged Particle Tracking:

Ron Lipton (FNAL), Jack Ritchie (University of Texas, Austin)

Time-of-Flight System Performance below 10 psec:

Mike Albrow (FNAL), Bob Wagner (ANL)

High Precision Measurement of Neutrino Interactions:

Kevin McFarland (Rochester University), Jonghee Yoo (FNAL), Rex Tayloe (University of Indiana)

Large Area Cost Effective (LACE) Detector Technologies:

Mayly Sanchez (Iowa State University), Yury Kamyshkov (University of Tennessee)

Lattice QCD:

Ruth Van de Water (BNL), Tom Blum (University of Connecticut)

CSS 2013 Engagement Plan: Broader Impacts Report*

- A report on the broader impacts of Project-X will be prepared for distribution to the community at the Fermilab Users Meeting June 12th 2013. This report will include:

  - Energy and material irradiation applications working closely with our DOE NE colleagues at ANL, LANL and PNNL and our Indian collaborators.

  - muon Spin Rotation applications.

*Editors: TBD

Summary

- Project-X is a staged evolution of the best assets of the Fermilab accelerator complex with the revolution in super-conducting RF technology.

- Each Stage of Project-X will raise many boats of the Intensity Frontier in particle physics, with a program scope of more than 20 world-leading particle physics experiments and an associated robust user community.

- Stage-1 of Project X can host a program of world class experiments, with "Day-1" experiments inherited from the investments being made now in advance of Project-X operations which could commence at the close of this decade.

Spare Slides

DOE NP view of fundamental symmetries

Implications for HEP

Based on Science:

- There are selected NP science targets of opportunity with the potential for high-impact in fundamental symmetries, neutrons, and neutrinos.
- These experiments may take on even greater significance depending on the results of accelerator research in the next few years
- To the extent there are resources to pursue them and they are complementary to HEP research, such opportunities may be pursued.
- For nEDM the science goal continues to be stronly motivated and R&D continues; a decision point is expected within ~ 2 years whether to proceed with the full experiment
- $0\nu\beta\beta$ experiments are sufficiently costly, a down-select to the best technology across HEP and NP makes sense and is planned.

U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   September 21, 2012   23

T. Hallman

T. Hallman, NP Associate Director Sept 21st, NSAC.

Recent interaction with the European Strategy for Particle Physics*

- "Opportunities for Collaboration at Fermilab: Input to the European Strategy for Particle Physics, 2012"
  Submitted by P. Oddone

- "Opportunities for Collaboration in the Design and Development of the Project-X Accelerator Complex and Research Program."
  Submitted by S. Holmes & R.T.

- "Americas: Vision, Status &Strategy"
  Presented by A. Lankford,
  High Energy Physics Advisory Panel chair

*(http://espp2012.ifj.edu.pl/)

Intensity Frontier – Strategy

Project X – Overview

Unique facility with a 3 MW at 3 GeV continuous-wave (CW) linac.

Principal characteristics:

- **Increases Fermilab low-energy proton flux by *x*100 with flexible timing patterns, ideal for rare decay experiments**
- **Experiments run simultaneously at 3 GeV, 8 GeV, & 60-120 GeV at high power**
- **Delivers 2+ MW to LBNE**
- **Design consistent with serving as front end for neu factory or muon collider**

Capable of a rich physics menu with neutrinos, kaons, muons, nuclei

Centerpiece of a world-leading Intensity Frontier program

R&D in progress

Lankford, Krakow, September 13, 2012 42

A. Lankford, High Energy Physics Advisory Panel chair
@ ESPP Sept 2012

Project X – Phased approach

Project X can be broken down into 3 phases, each about 1/3 of the cost.

- **Phase 1: Up to 1 GeV**
  Retires old linac, increases neutrino flux *x*1.7, enhances existing Mu2e by *x*10, starts EDM, nuclear-physics and nuclear-materials studies
- **Phase 2: Up to 3 GeV**
  Starts powerful Intensity Frontier experiments with kaons and feeds short baseline neutrino programs
- **Phase 3: Up to 8 GeV**
  Multiplies power to LBNE by *x*3, multiplies power at 8 GeV several fold for short baseline neutrino program

First phase could be 2^nd phase of LBNE.

Decision on when to start later in decade.

A. Lankford, ESPP Sept 2012

U.S. at the Intensity Frontier - Summary

Vision: Implement comprehensive program to understand **neutrino mixing.**
Deliver much improved limits (measurements?) of **charged lepton mixing** and **hidden sector phenomena**

Status:

Neutrinos

Broad, world-class neutrino program already in progress at Fermilab
New facilities are under construction for near term

Planned program of **major projects**:

long baseline neutrino experiment – **LBNE** (CD-1 planned by end 2012)
lepton number violation experiment – **Mu2e** (CD-1 approved July 2012)
muon anomalous magnet moment experiment – **g-2**

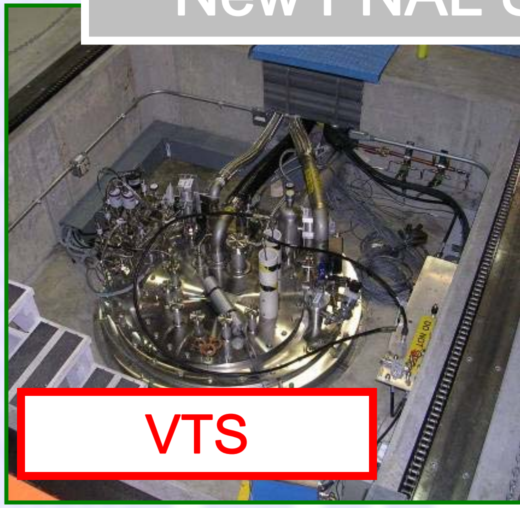
R&D for next generation multi-MW proton accelerator – **Project X**

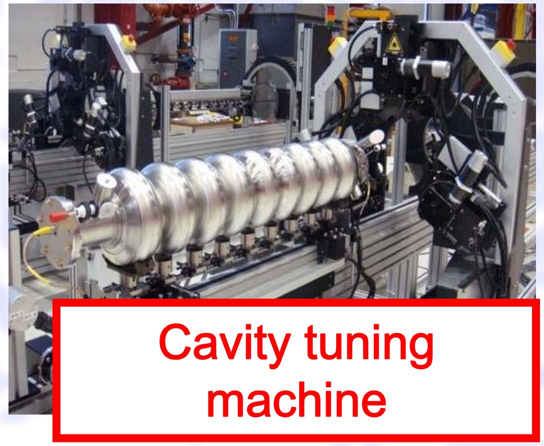
Strategy:

Devote Fermilab accelerator complex to advantage of worldwide community
Develop LBNE to its full potential: underground, detector mass, flux
Construct Project X to feed rich, world-leading IF program w/ nu's, mu's, K's

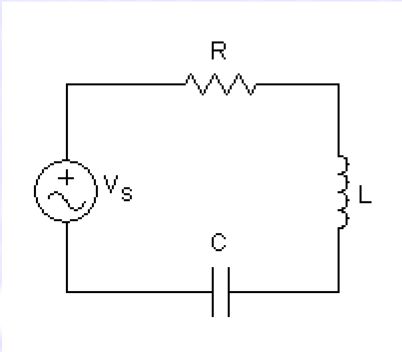
A. Lankford, ESPP Sept 2012

New FNAL SRF infrastructure

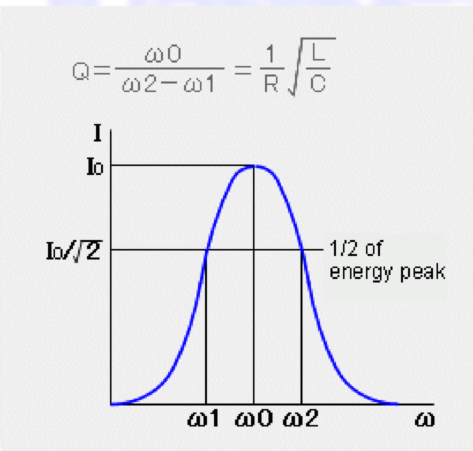


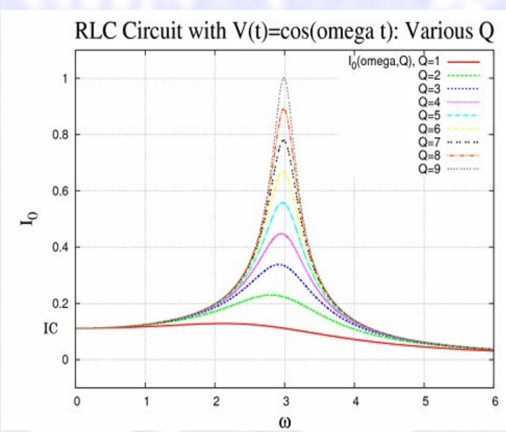


Illinois Accelerator Research Center



$$Q = 2\pi \times \frac{\textbf{Energy-Stored}}{\textbf{Energy-Lost-per-Cycle}}$$

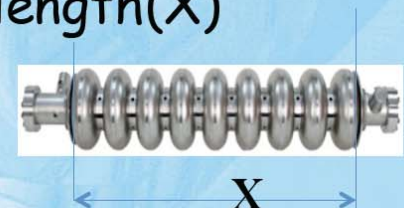




Typical Parameters for 1.3GHz 9 cell ILC/Tesla cavities

- Cavity frequency (F) VS. cavity length(X)

  $\Delta F/\Delta x$ ~300 Hz/um;



- Slow tuner range (DF &DX):

  ΔF ~500 kHz == Δx ~+/-1 mm

- Cavity bandwidth ($F_{1/2}$ at Q_L~$3*10^6$)

  $F_{1/2}$~400 Hz;

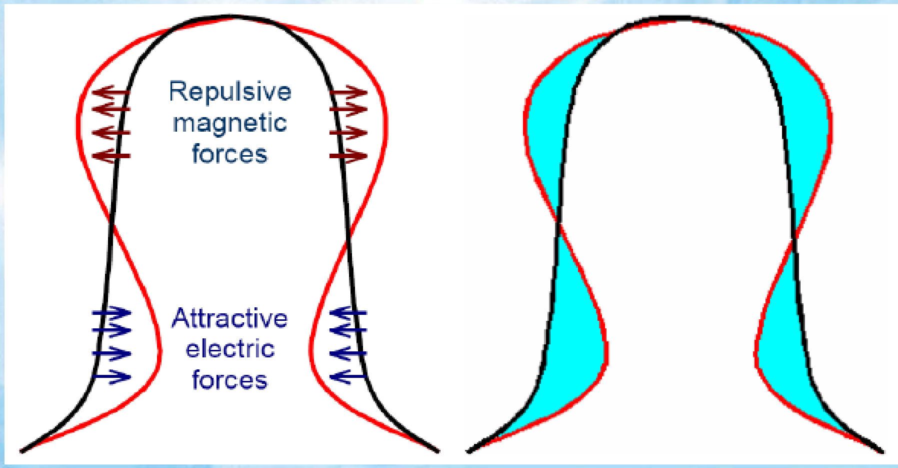
- Requirements to slow tuner to tune cavity within +/-10Hz to nominal value (1.3GHz) limit hysterezis of mechanical system

  +/-30 nm;

Courtesy of Yuriy Pischalnikov

Resonance Control in SCRF Cavities

- SCRF cavities are designed with thin walls to maximize heat transfer to liquid He bath
- The thin walls lack stiffness making the cavities susceptible to mechanical oscillations
- Longitudinal oscillations can change the resonance frequency of the cavity
- Oscillations can be excited
  - Deterministically (**Lorentz Force**)
  - Non-Deterministically (Microphonics)



Courtesy of Yuriy Pischalnikov

Piezoelectrical actuators

PIEZOELECTRIC ACTUATORS

- ***Commercially available from multiple sources***
- ***Typically used at room temperature (stroke~50µm for 50mm long Piezostack at RT)***
- ***Work at cryogenic temperatures with reduced stroke (6-10% of RT stroke ~ 4-5µm at 4K)***
- ***Deliver high forces ~5000N for 10*10mm² cross-section***
- ***Low voltage (150-200V) actuators used for fast tuner***
- ***~10uF for stack 10*10*50mm (at RT) and 10% at LiqHe***
- ***Actuator of main choice at many labs for detuning compensation studies***
- ***Piezo can work as a sensor***
- ***Widely used in different industrial applications (diesel engine , etc...)***

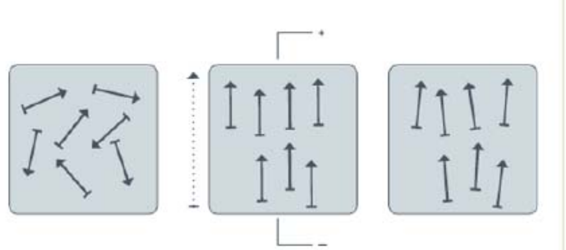


Fig.2 Electric dipoles in piezoelectric materials before, during and after poling.

Stacked multilayer piezoelectric actuators are made of two or several linear actuators glued together. The purpose of the stacking is to obtain more displacement than can be achieved by a single linear actuator.

Courtesy of Yuriy Pischalnikov