Project-X
Staging Strategy

R. Tschirhart

Nov 28th 2012

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 & 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***

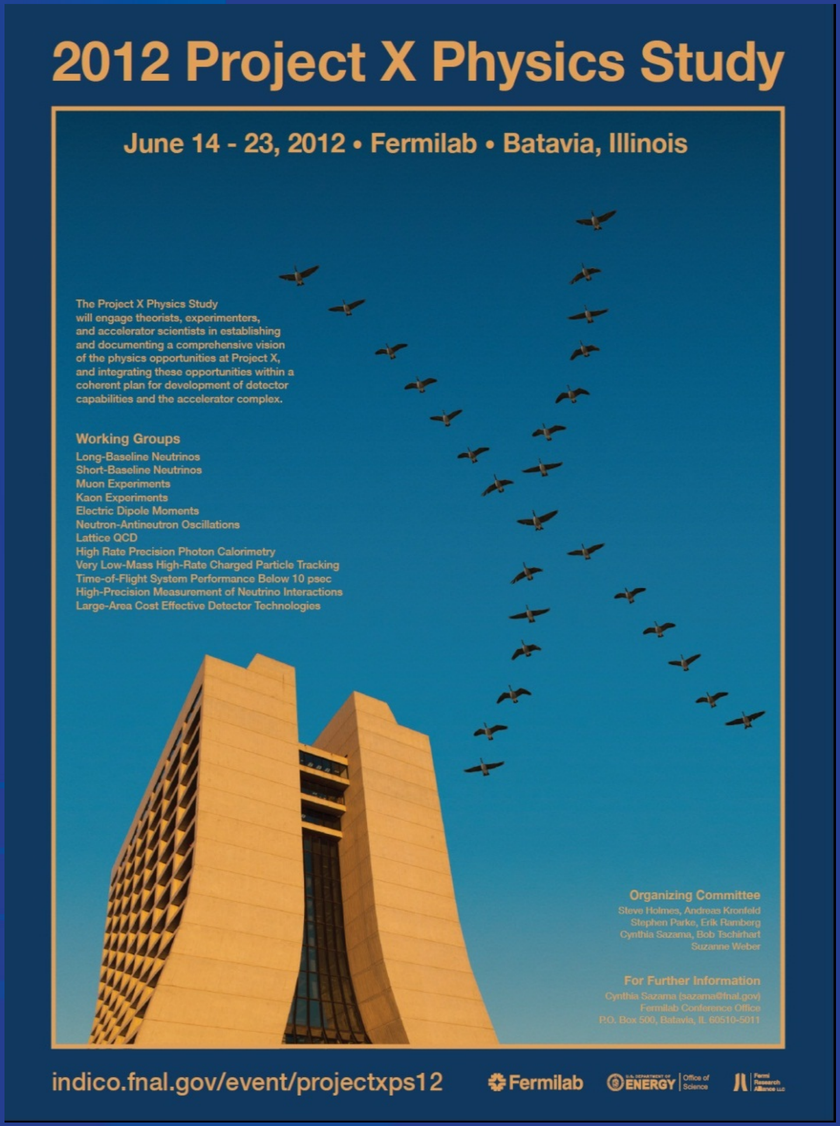
Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.

- ***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

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



2012 Project X Physics Study

June 14 - 23, 2012 • Fermilab • Batavia, Illinois

The Project X Physics Study will engage theorists, experimenters, and accelerator scientists in establishing and documenting a comprehensive vision of the physics opportunities at Project X, and integrating these opportunities within a coherent plan for development of detector capabilities and the accelerator complex.

Working Groups

Long-Baseline Neutrinos
Short-Baseline Neutrinos
Muon Experiments
Kaon Experiments
Electric Dipole Moments
Neutron-Antineutron Oscillations
Lattice QCD
High Rate Precision Photon Calorimetry
Very Low-Mass High-Rate Charged Particle Tracking
Time-of-Flight System Performance Below 10 psec
High-Precision Measurement of Neutrino Interactions
Large-Area Cost Effective Detector Technologies

Organizing Committee

Steve Holmes, Andreas Kronfeld
Stephen Parke, Erik Ramberg
Cynthia Sazama, Bob Tschirhart
Suzanne Weber

For Further Information

Cynthia Sazama (sazama@fnal.gov)
Fermilab Conference Office
P.O. Box 500, Batavia, IL 60510-5011

indico.fnal.gov/event/projectxps12

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↔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.

Since PXPS, Development of Stage-1 Research Program

Physics Opportunities with Stage 1 of Project X

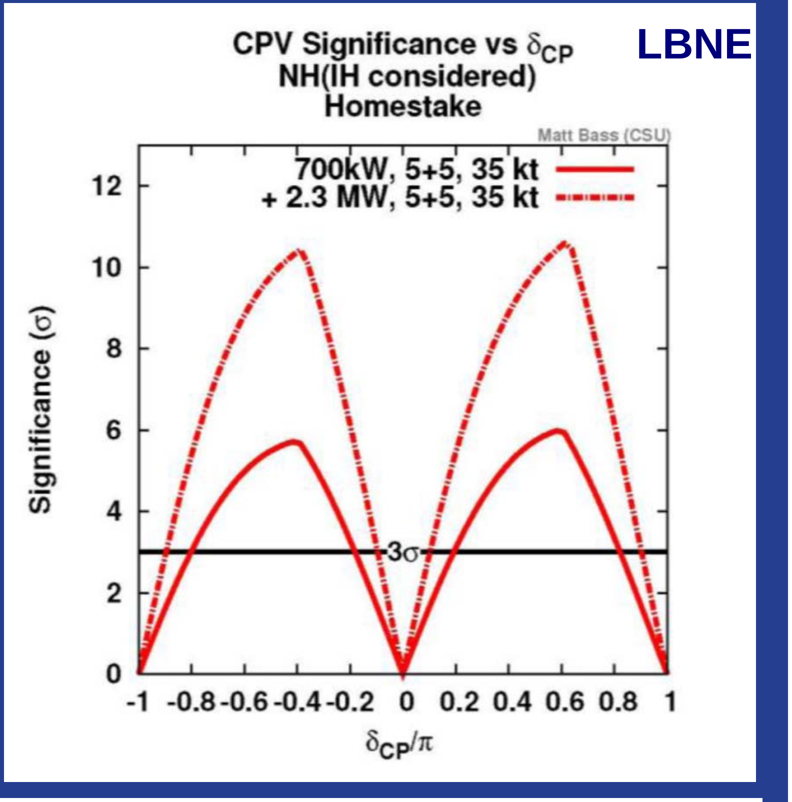
Wolfgang Altmannshofer, Marcela Carena, Patrick Fox, Stuart Henderson,
Stephen Holmes, Young-Kee Kim, Joachim Kopp, Andreas Kronfeld,
Joseph Lykken, Chris Quigg, and Robert Tschirhart

August 2012

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

CP violation research opportunities with Stage-1:

- Neutrinos: 70% increase in LBNE 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!



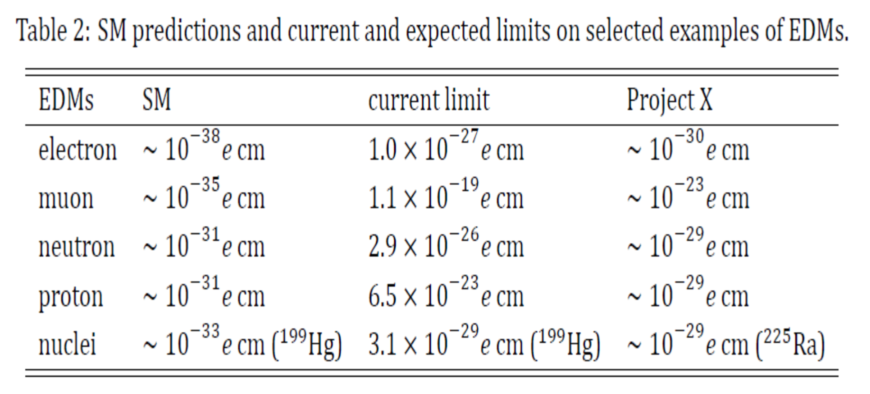


Table 2: SM predictions and current and expected limits on selected examples of EDMs.

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

Stage-1

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

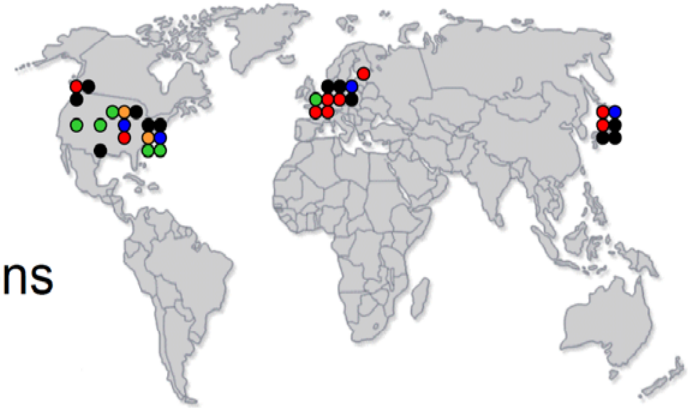
~50

- 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

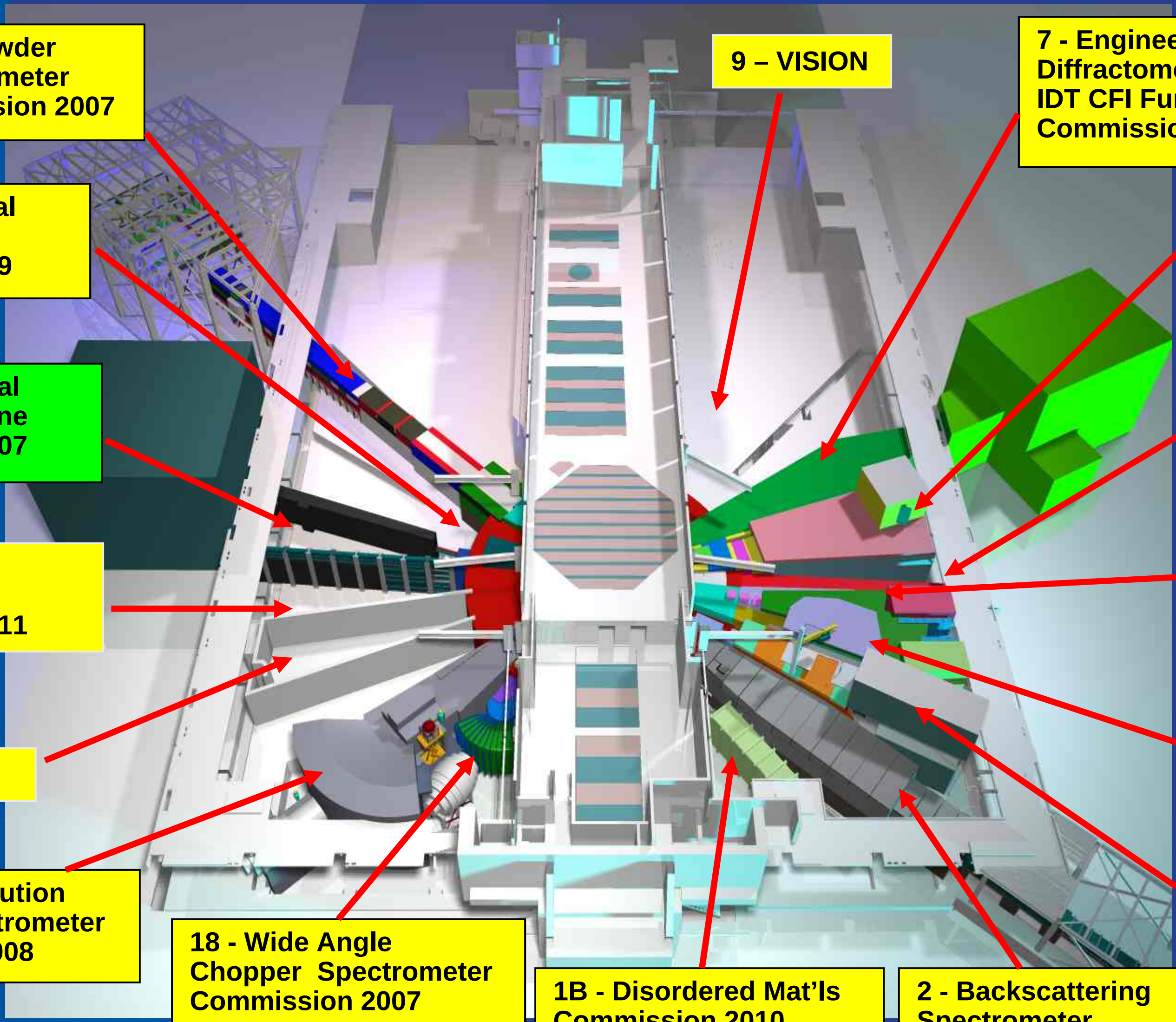
Solids

~10

- GGG@Indiana
- ferroelectrics@Yale

Courtesy Klaus Kirch
CIPANP 2012

Beamline 13 Has Been Allocated for Nuclear Physics at SNS



11A - Powder Diffractometer Commission 2007

9 – VISION

7 - Engineering Diffractometer IDT CFI Funded Commission 2008

12 - Single Crystal Diffractometer Commission 2009

6 - SANS Commission 2007

13 - Fundamental Physics Beamline Commission 2007

5 - Cold Neutron Chopper Spectrometer Commission 2007

4B - Liquids Reflectometer Commission 2006

14B - Hybrid Spectrometer Commission 2011

4A - Magnetism Reflectometer Commission 2006

15 – Spin Echo

3 - High Pressure Diffractometer Commission 2008

17 - High Resolution Chopper Spectrometer Commission 2008

18 - Wide Angle Chopper Spectrometer Commission 2007

1B - Disordered Mat'ls Commission 2010

2 - Backscattering Spectrometer Commission 2006

Courtesy
Geoff Greene

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.

Neutrino research opportunities with Stage-1:

- 70% increase in LBNE statistics for hierarchy, precision oscillation measurements.

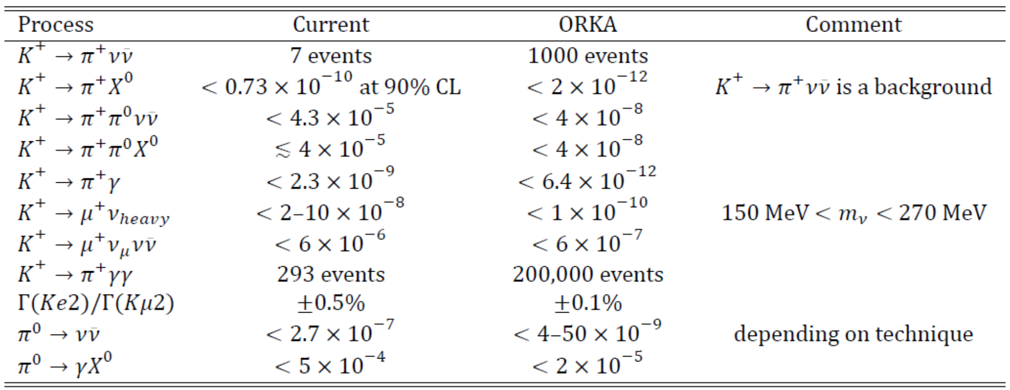
- 70% increase in statistics for short baseline experiments driven be the Main Injector (e.g. nuSTORM).

- X2-3 increase in 8 GeV beam power for short baseline experiments.

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

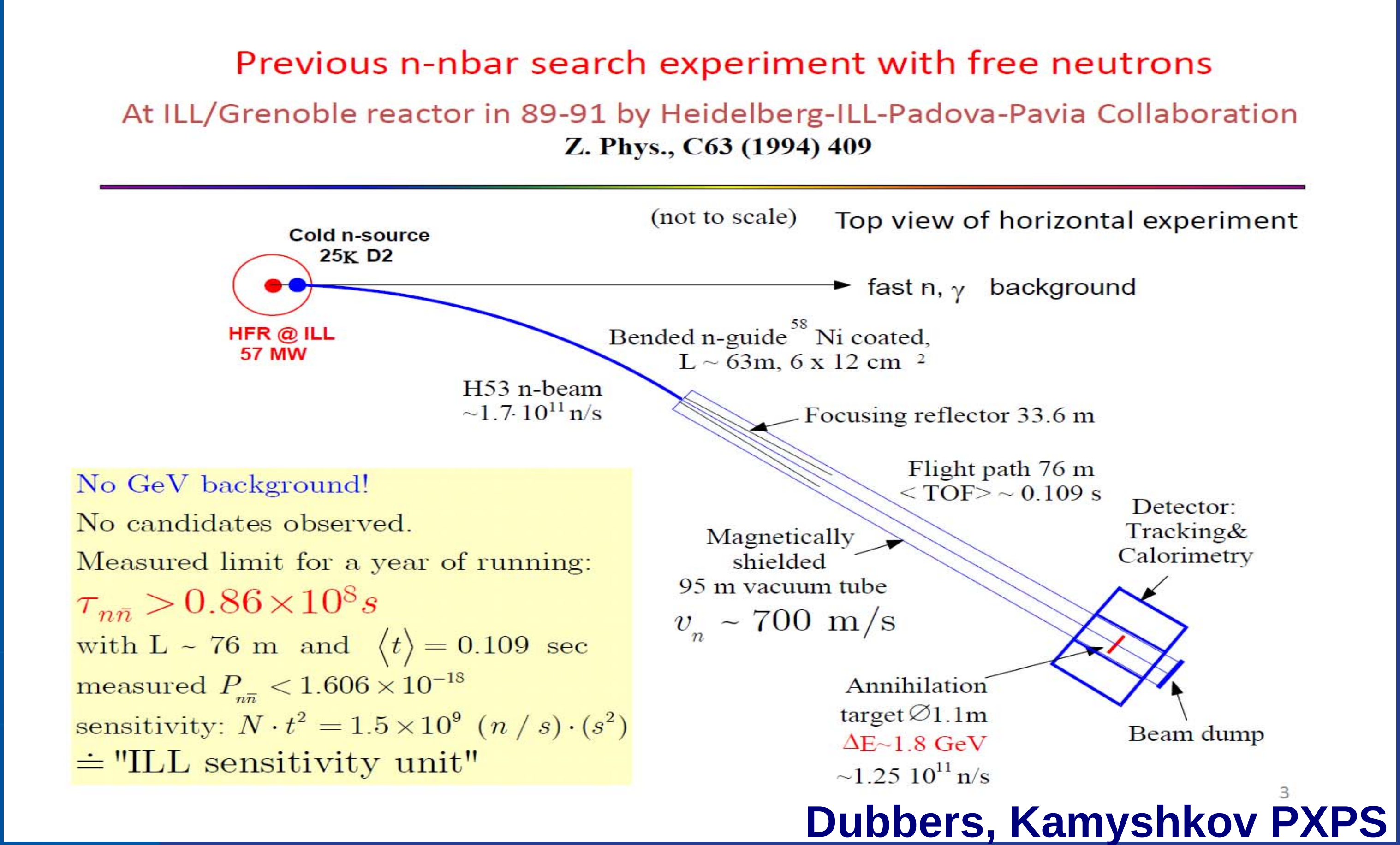
- x10 improvement in mu2e sensitivity. Platform for next generation rare muon decay experiments such as $\mu \rightarrow 3e$.

- 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



Previous n-nbar search experiment with free neutrons

At ILL/Grenoble reactor in 89-91 by Heidelberg-ILL-Padova-Pavia Collaboration

Z. Phys., C63 (1994) 409

No GeV background!

No candidates observed.

Measured limit for a year of running:

$\tau_{n\bar{n}} > 0.86 \times 10^{8} s$

with L ~ 76 m and $\langle t \rangle = 0.109$ sec

measured $P_{n\bar{n}} < 1.606 \times 10^{-18}$

sensitivity: $N \cdot t^2 = 1.5 \times 10^9 \ (n / s) \cdot (s^2)$

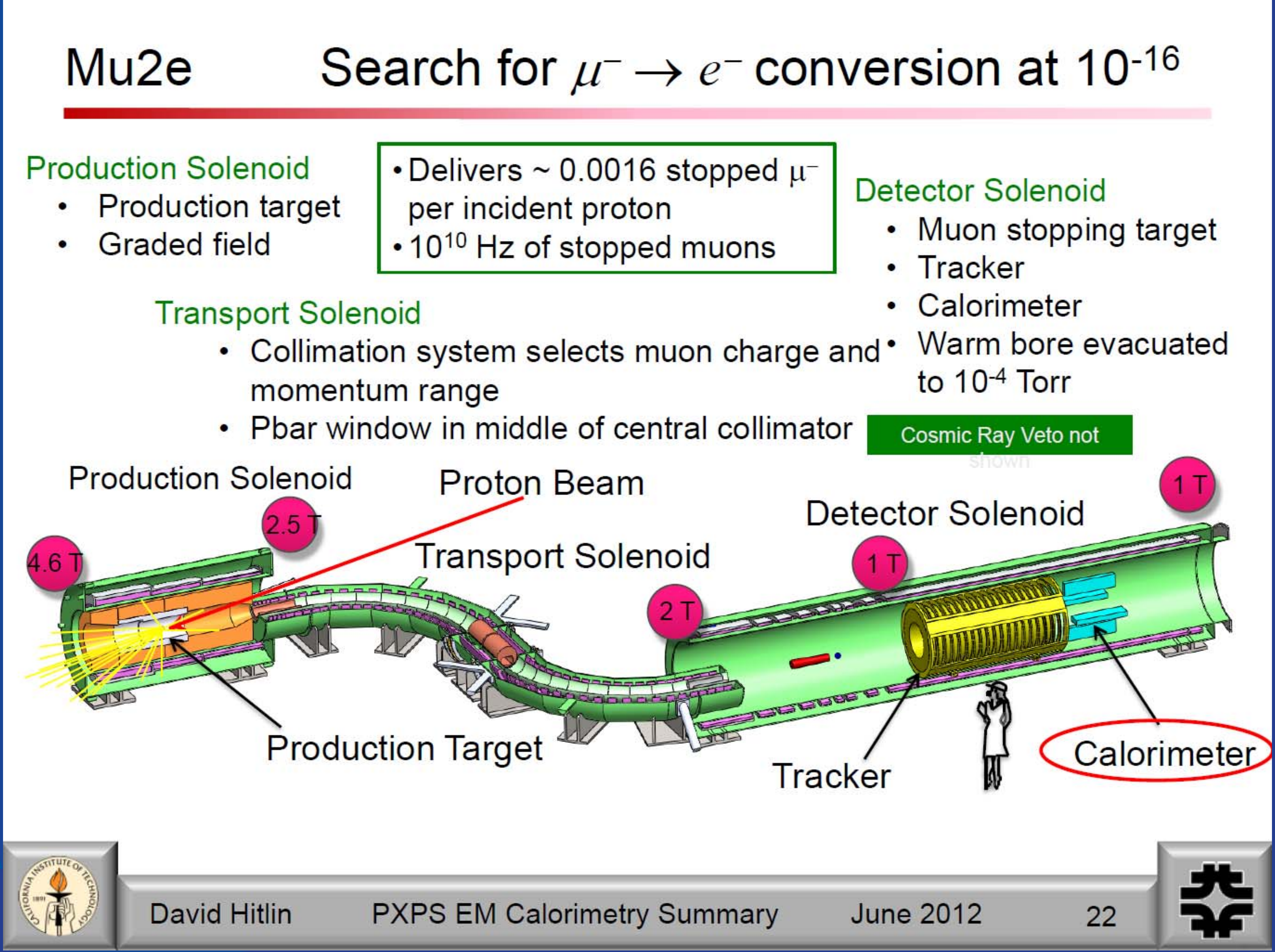
$\doteq$ "ILL sensitivity unit"

Dubbers, Kamyshkov PXPS

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

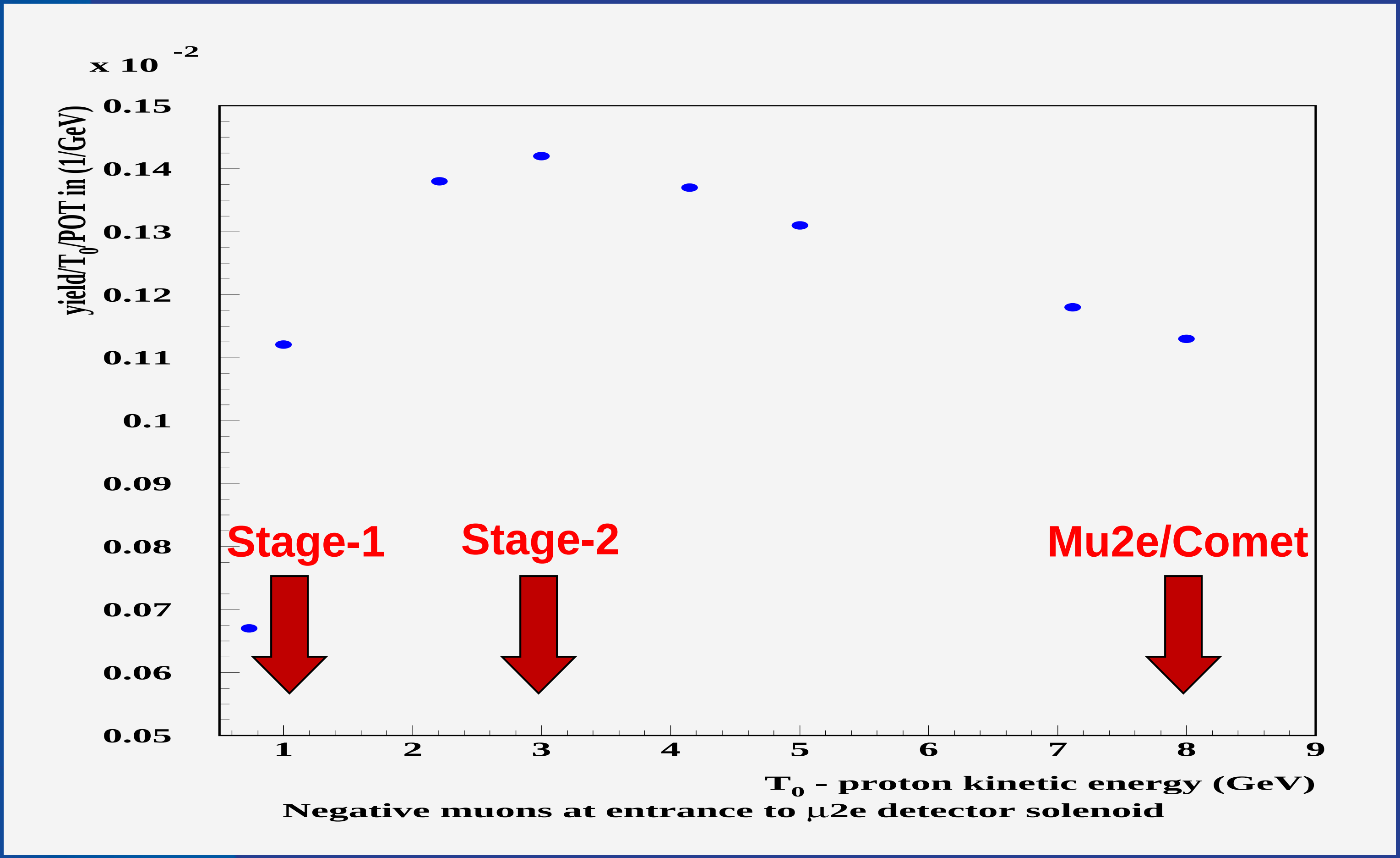
Transport Solenoid
- Collimation system selects muon charge and momentum range
- Pbar window in middle of central collimator

Cosmic Ray Veto not shown

David Hitlin PXPS EM Calorimetry Summary June 2012 22

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

Issues That a Next-Generation Conversion Experiment must face…

- Target systems. High-Z stationary targets do not scale well with power.
- Radiation damage: Production Solenoid, Readout systems (e.g. SiPMs).
- Readout speed, rate robustness.
- Spectrometer resolution…much better than 100 keV/c??
- Spectrometer calibration: Internal (Michel edge, πe2)?
  External (electron injection)?
- Background Rejection!

Opportunities with Project –X to meet these Challenges

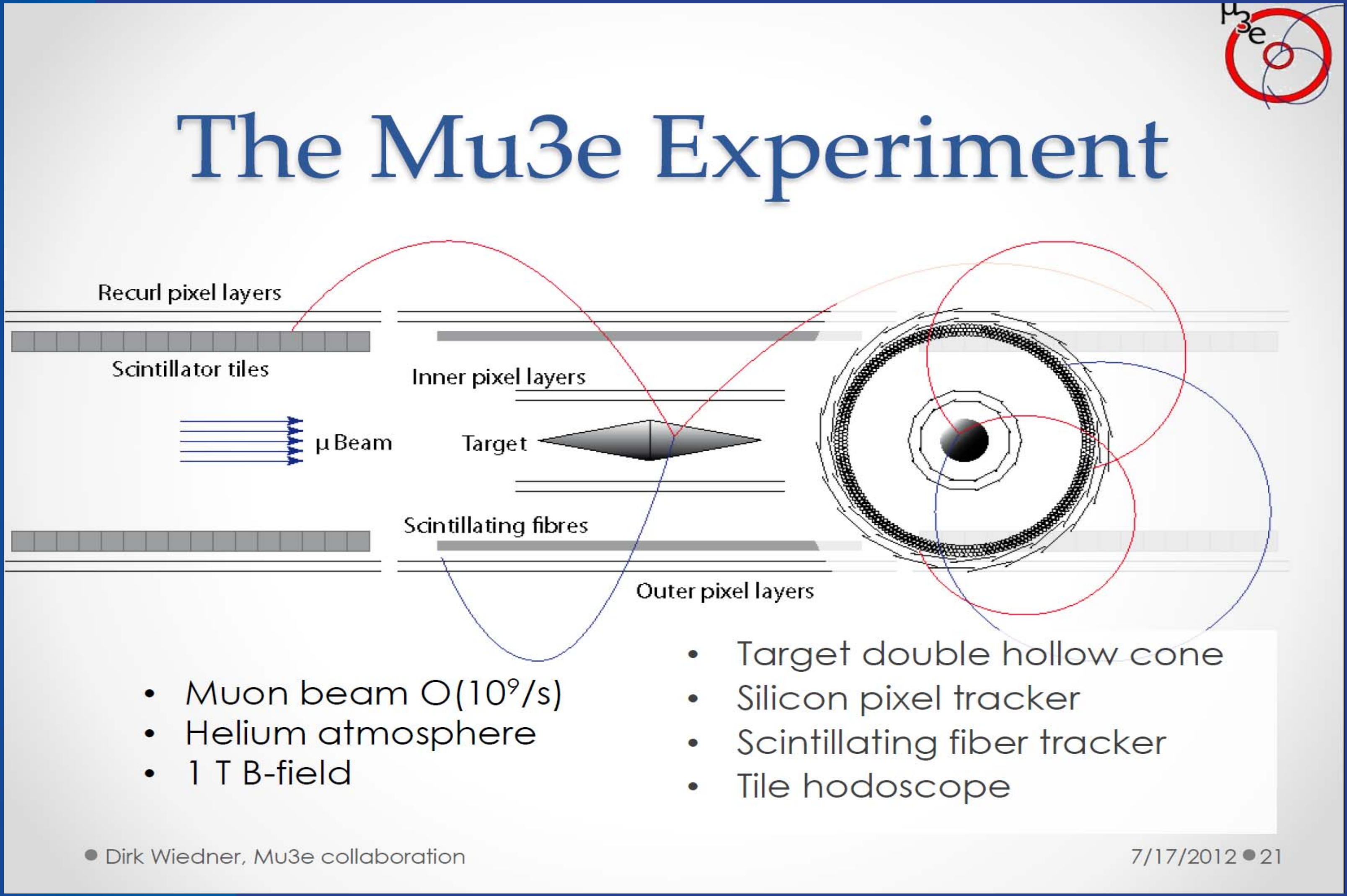
- Much better proton pulse timing. ~10 nsec as compared to 200 nsec (Mu2e, COMET) for the same power level, <100 nsec at 1 MWatt!. Radiative Pion Capture background much reduced.

- No anti-proton background.

- High power can mean fewer stopping target foils, possibly colder beams.

- Can realize optimum cold-muon-yield/driver-power

0.1% X_0 per layer, 100 psec track timing…



The Mu3e Experiment

- Muon beam O(10^9/s)
- Helium atmosphere
- 1 T B-field

- Target double hollow cone
- Silicon pixel tracker
- Scintillating fiber tracker
- Tile hodoscope

Dirk Wiedner, Mu3e collaboration

7/17/2012 21

Dirk Wiedner, Mu3e Initiative at PSI

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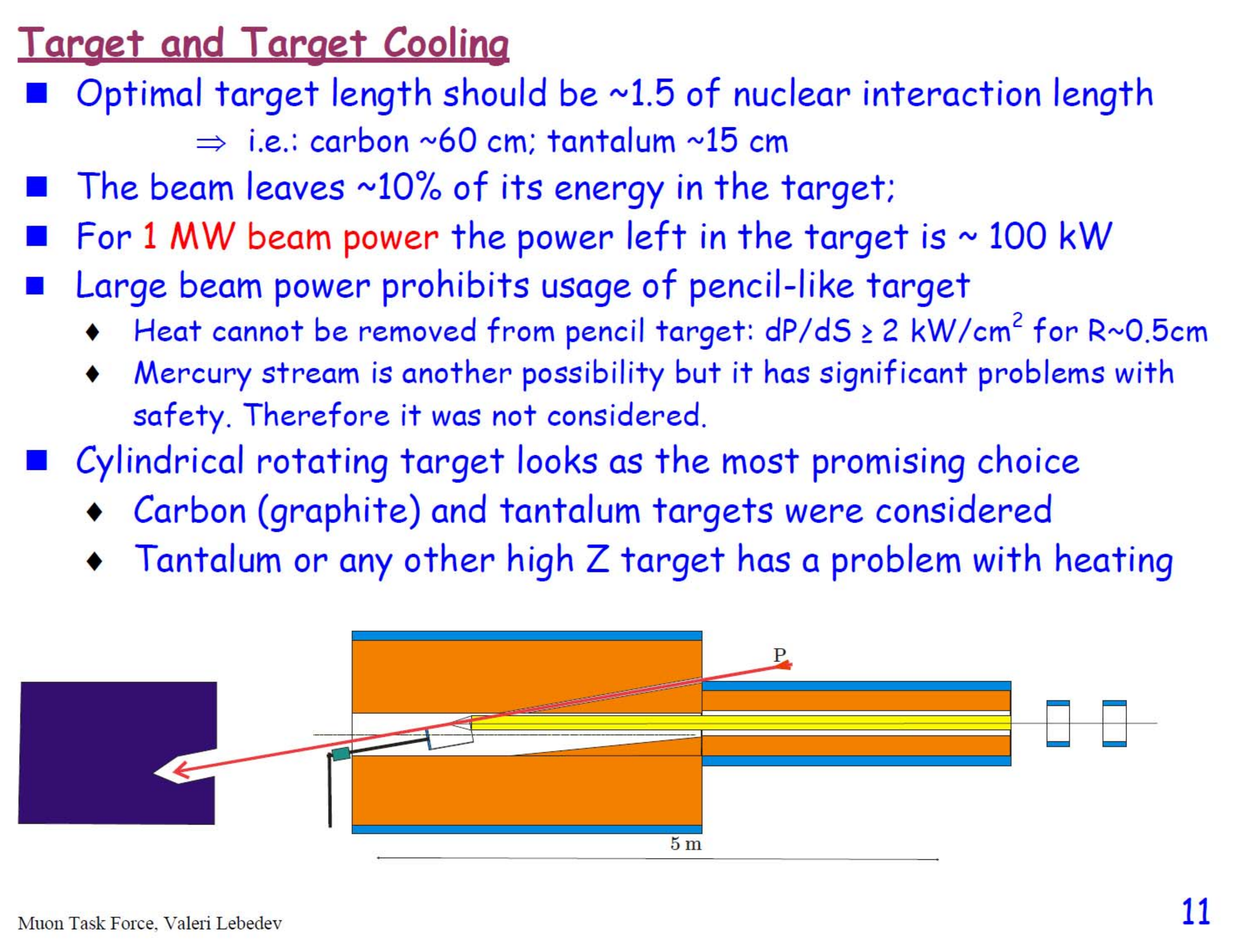
** Operating point in range depends on MI injector slow-spill duty factor (df) for kaon program.

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: $dP/dS \geq 2\ \mathrm{kW/cm^2}$ 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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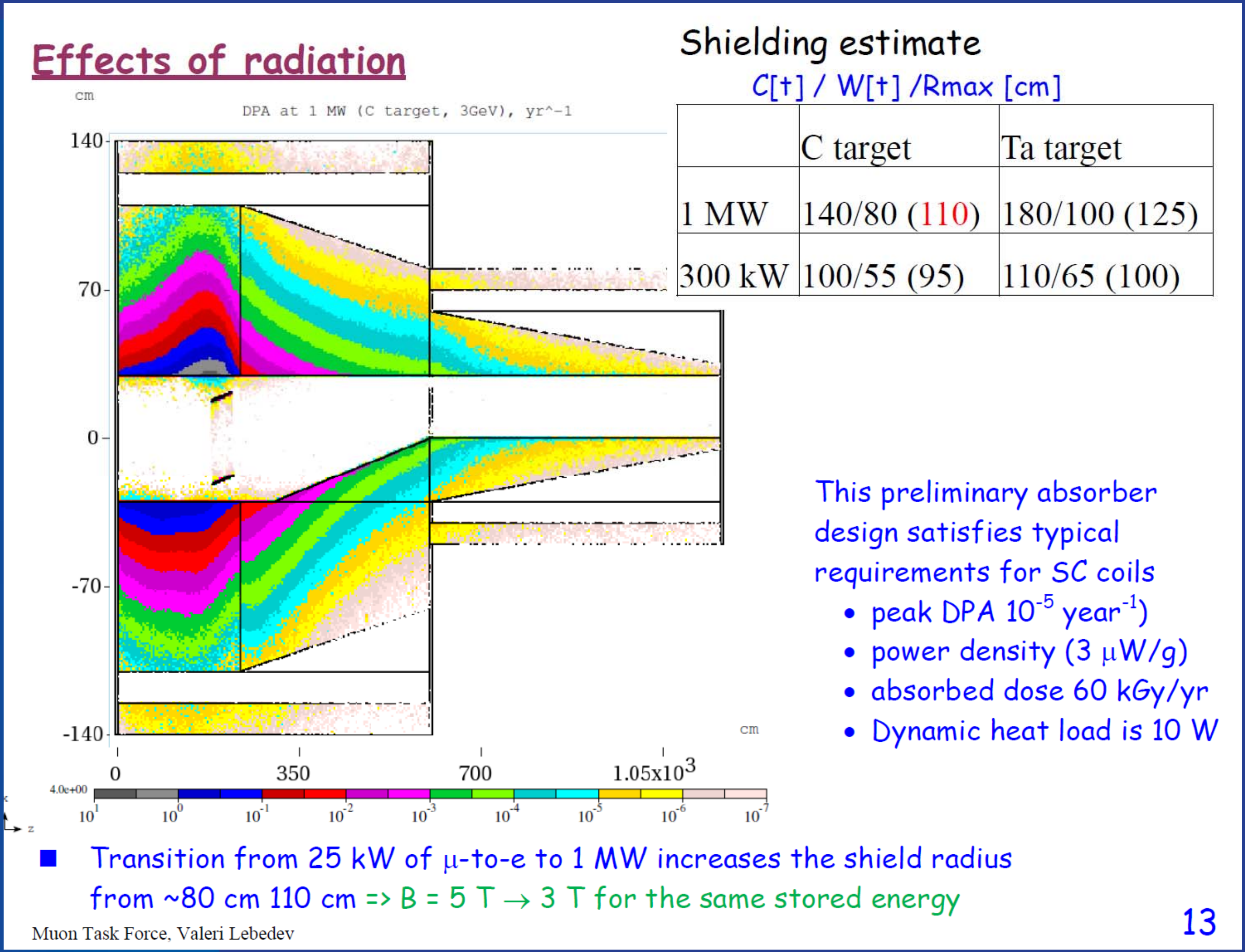
V. Lebedev, Fermilab AAC 2011



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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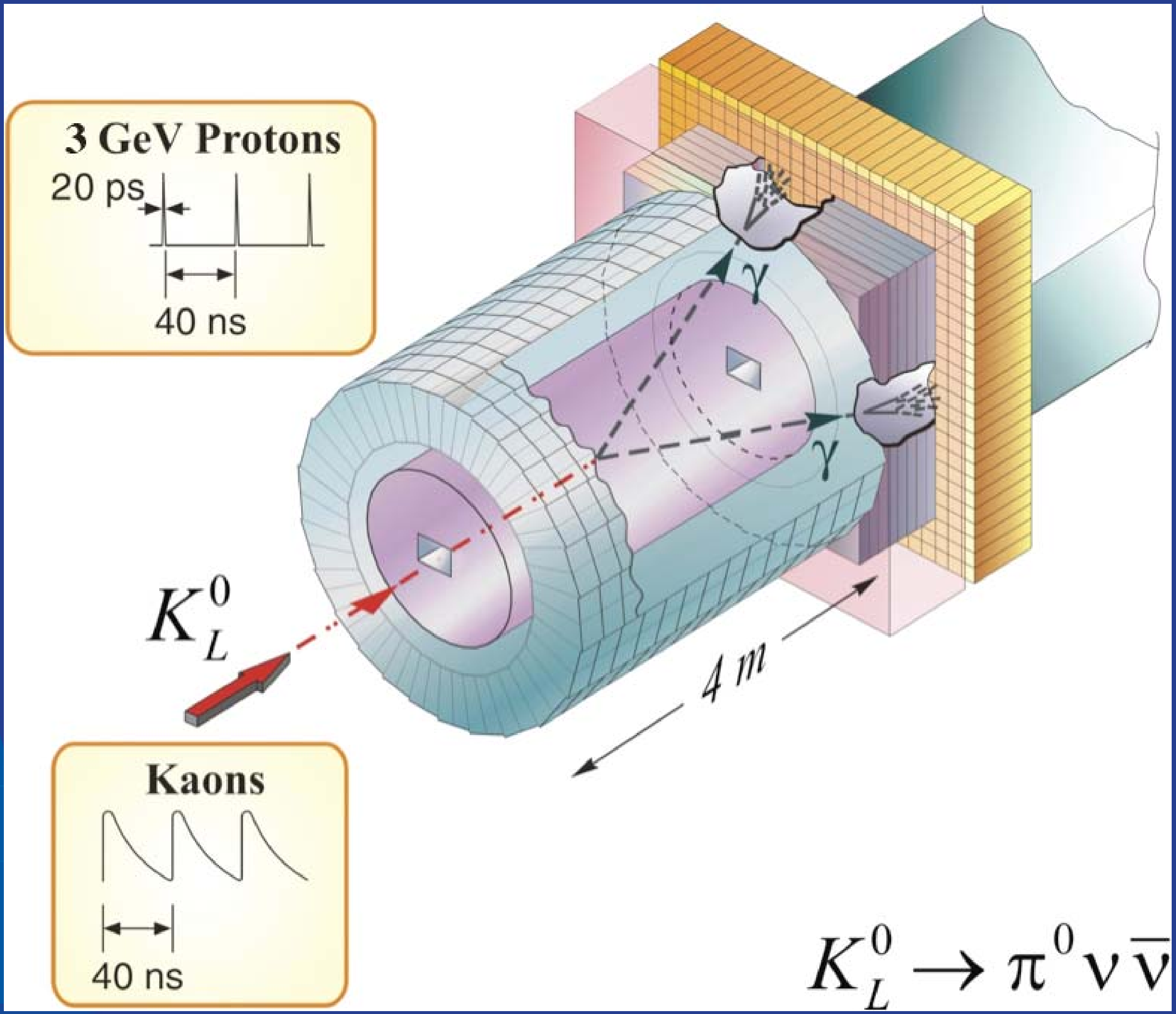
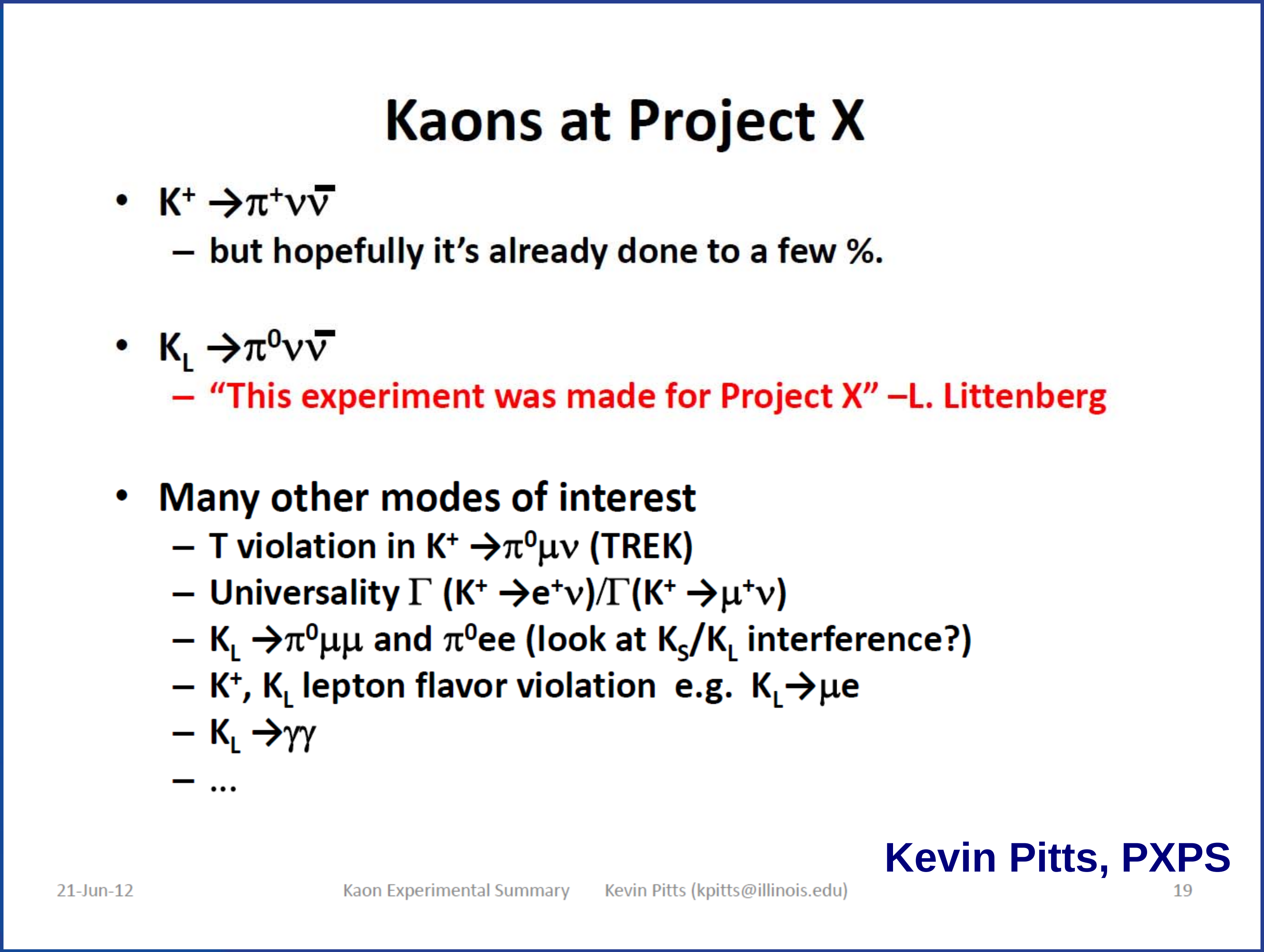
V. Lebedev, Fermilab AAC 2011

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



$K_L^0 \to \pi^0 \nu \bar{\nu}$

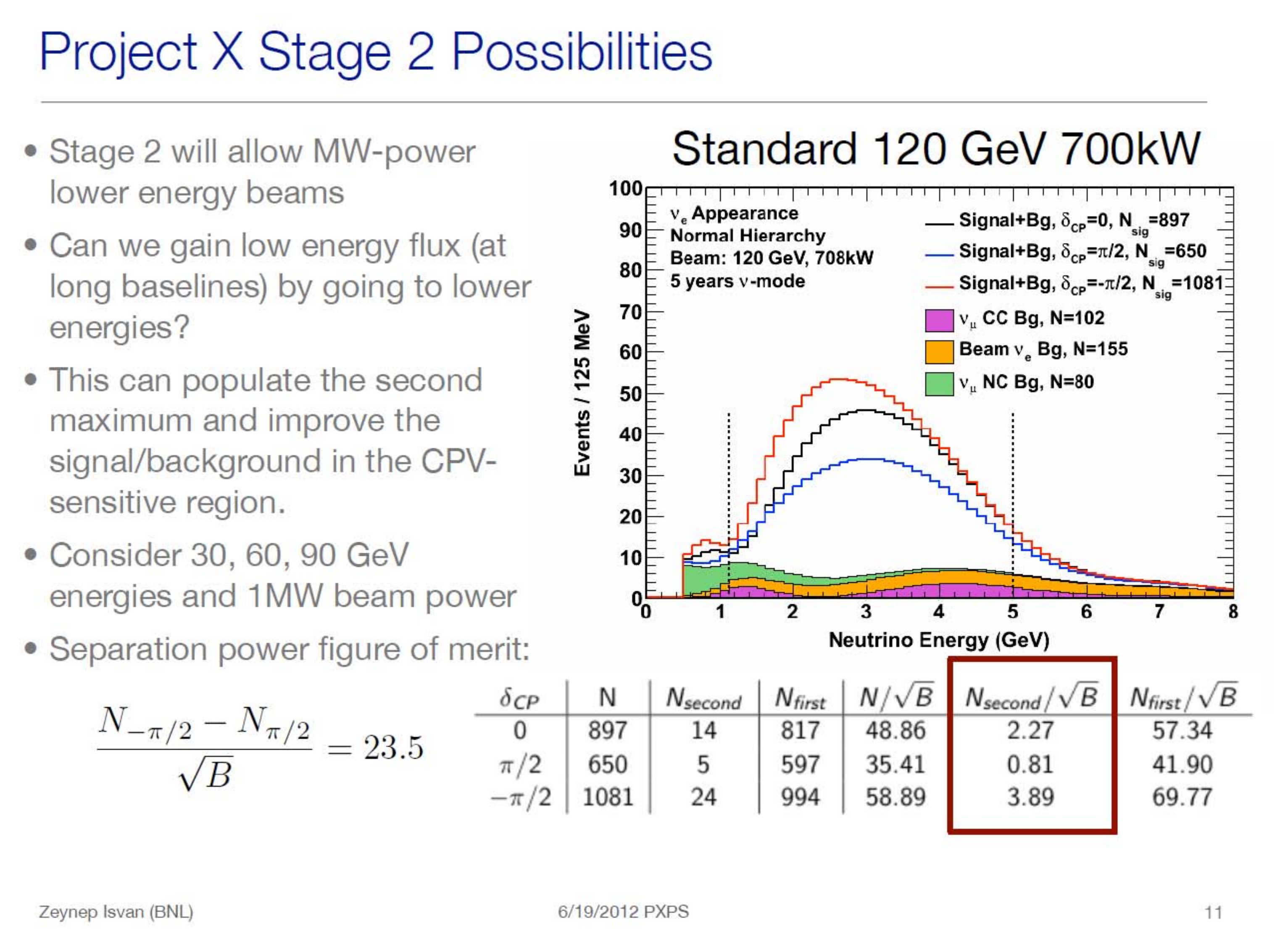


Kaons at Project X

- $K^+ \rightarrow \pi^+ \nu\bar{\nu}$
  - but hopefully it's already done to a few %.
- $K_L \rightarrow \pi^0 \nu\bar{\nu}$
  - "This experiment was made for Project X" –L. Littenberg
- Many other modes of interest
  - T violation in $K^+ \rightarrow \pi^0 \mu\nu$ (TREK)
  - Universality $\Gamma(K^+ \rightarrow e^+\nu)/\Gamma(K^+ \rightarrow \mu^+\nu)$
  - $K_L \rightarrow \pi^0 \mu\mu$ and $\pi^0 ee$ (look at K_S/K_L interference?)
  - K^+, K_L lepton flavor violation e.g. $K_L \rightarrow \mu e$
  - $K_L \rightarrow \gamma\gamma$
  - …

21-Jun-12 Kaon Experimental Summary Kevin Pitts (kpitts@illinois.edu) 19

Kevin Pitts, PXPS



Project X Stage 2 Possibilities

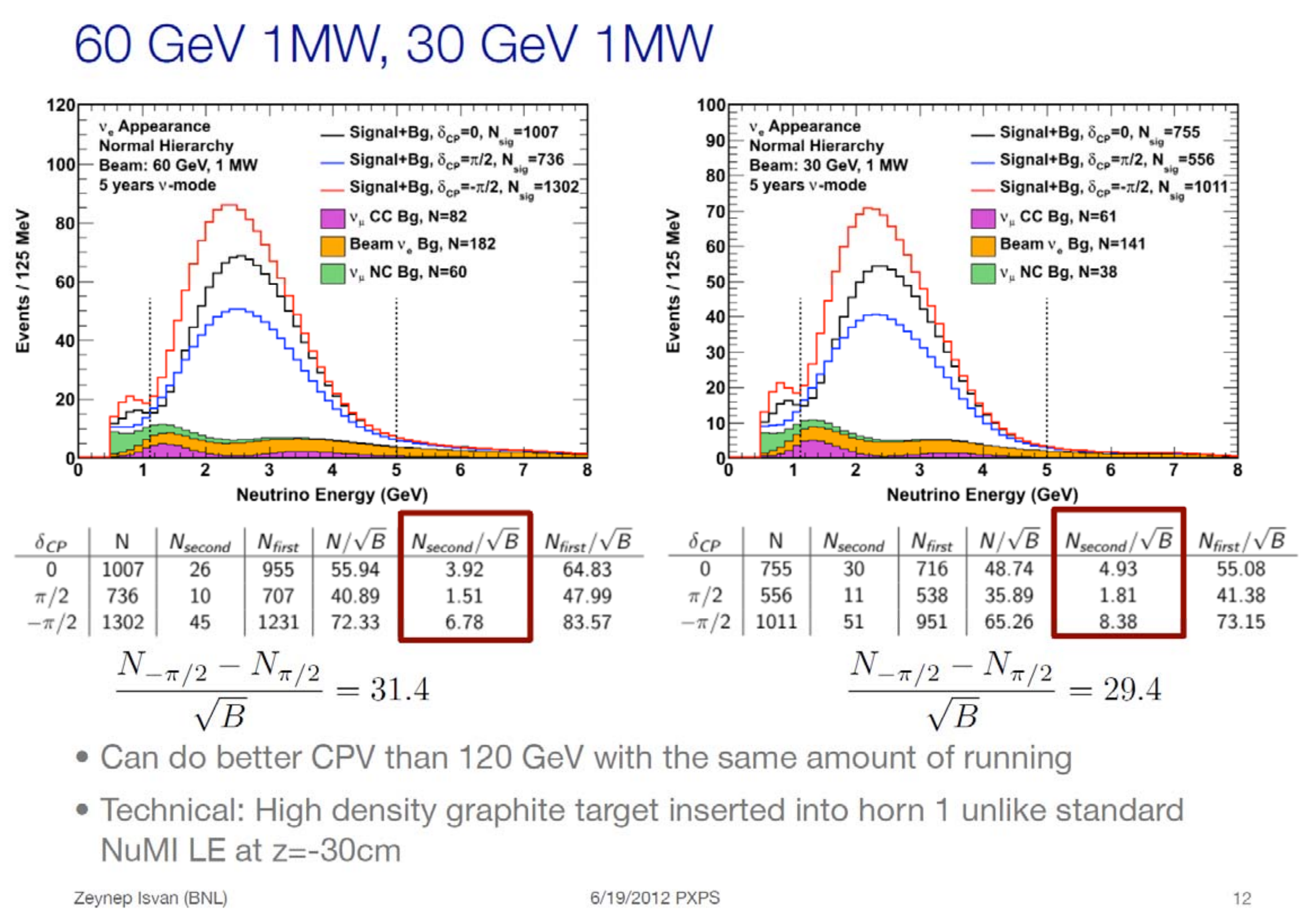
- Stage 2 will allow MW-power lower energy beams
- Can we gain low energy flux (at long baselines) by going to lower energies?
- This can populate the second maximum and improve the signal/background in the CPV-sensitive region.
- Consider 30, 60, 90 GeV energies and 1MW beam power
- Separation power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

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

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

Zeynep Isvan (BNL) 6/19/2012 PXPS 11

Zeynep Isvan (BNL) PXPS



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

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

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

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

- 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

Zeynep Isvan (BNL) PXPS

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

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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 →

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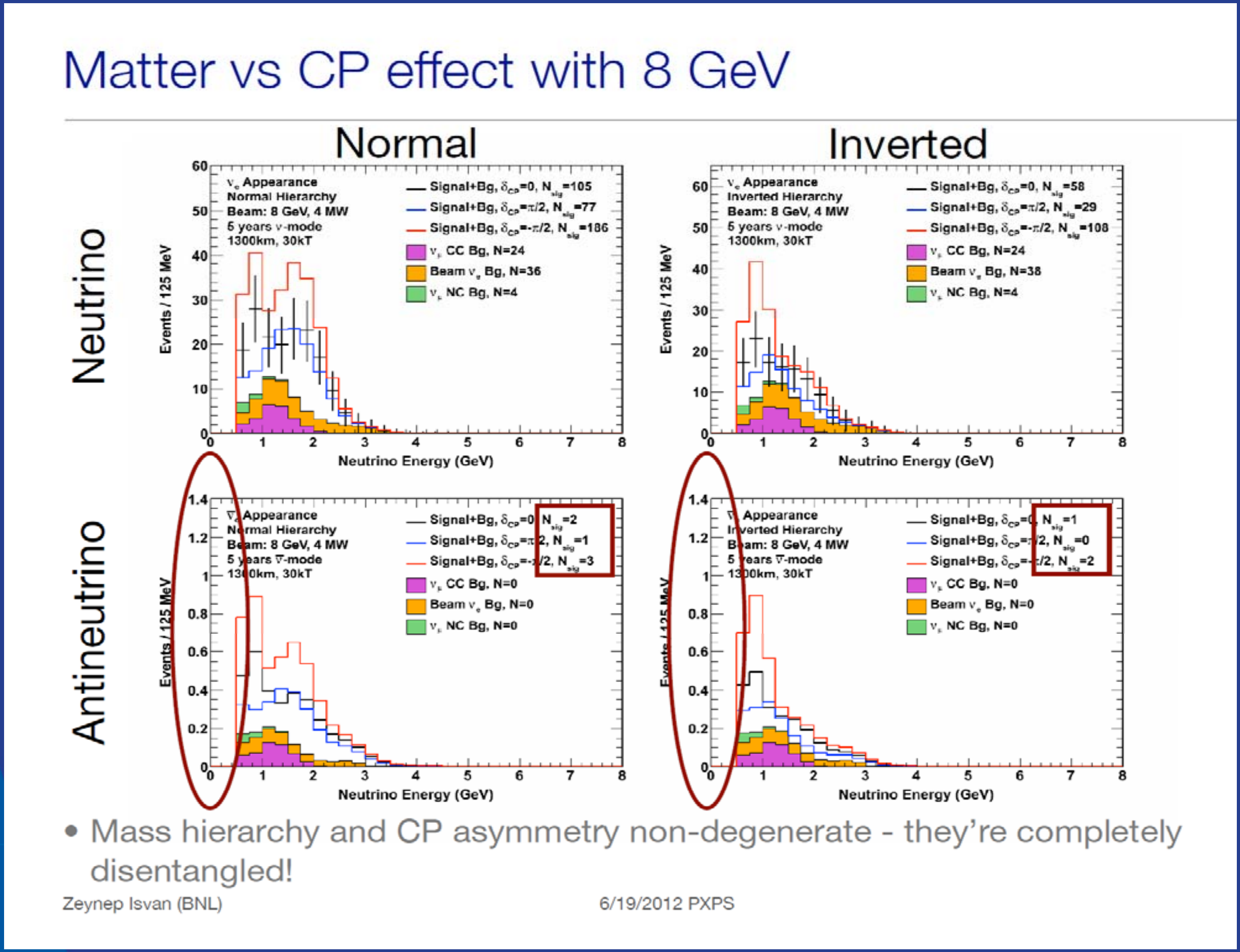
Science Enabled with Stage-4 (Beyond RDR)

- 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

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

Zeynep Isvan (BNL)

6/19/2012 PXPS

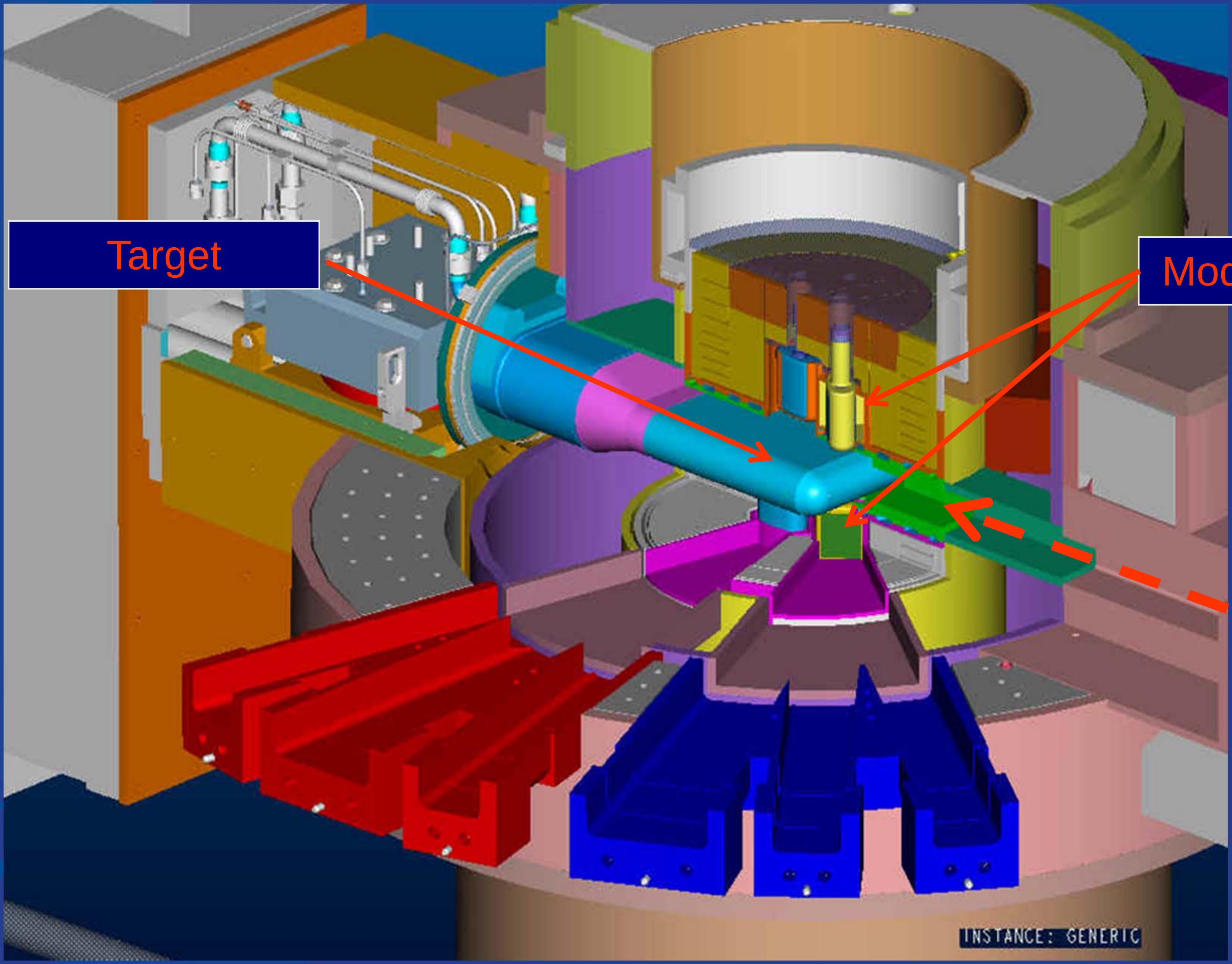
Zeynep Isvan (BNL) PXPS

Summary

- Project X has clearly defined stages in scientific reach, with each successive stage adding a compelling increment to the research program.
- Stage-1 of Project X can host a program of world class experiments, with “Day-1” experiments inherited from the investments being made this decade in advance of Project-X operations.

Spare Slides

ORNL SNS Spallation target



Courtesy Geoff Greene

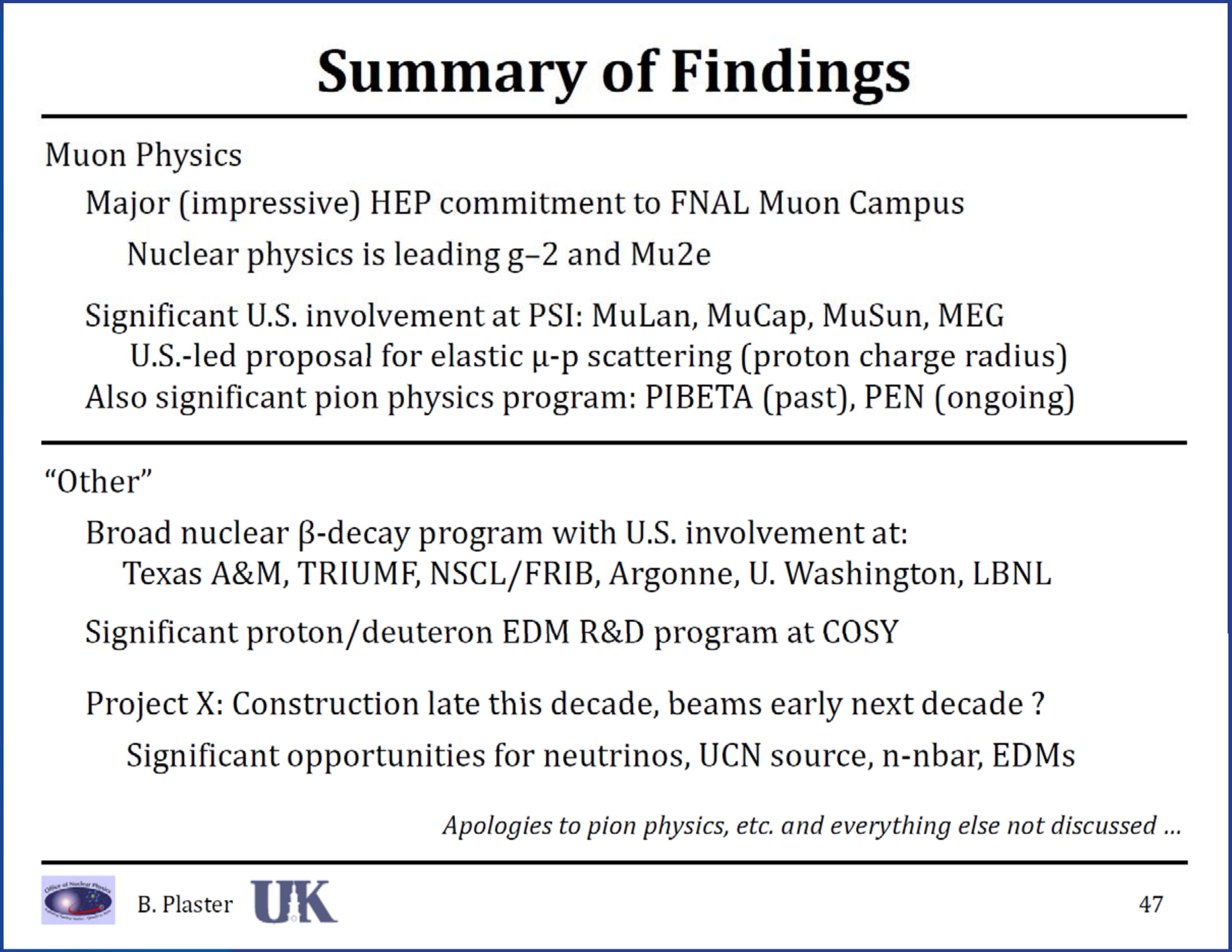
A spallation target facility dedicated to particle physics

- The pursuit of edms induced by physics beyond the Standard Model has been a long term interest of US science agencies: NIST, NSF, DOE/NP*, DOE/HEP…***this is core particle physics.***
- Project X presents an opportunity for a spallation target facility optimized for particle physics: ISOL production of edm-enhanced isotopes and ultra-cold neutrons for edm research, n-nbar oscillations, etc.
- Leaders in the nuclear physics community are intrigued.
- The spallation facility is excellent leadership-share opportunity for our Indian colleagues in accelerator science and particle physics, ***and for our field to learn new techniques (e.g. AMO).***
- Much infrastructure can be shared with energy and materials technology development.

*http://science.energy.gov/~/media/np/nsac/pdf/docs/NSAC_NeutronReport.pdf

Since PXPS: Interaction with the NP/NSAC Fundamental Symmetries and Neutrinos working group August 10th & 11th

- Investment in Fermilab muon program highlighted.
- Project X Stage-1 capability document submitted to workshop. Recognition of Project X opportunities.
- Recognized value of cooperation with OHEP on selected projects.



Summary of Findings

Muon Physics

- Major (impressive) HEP commitment to FNAL Muon Campus
  - Nuclear physics is leading g–2 and Mu2e
- Significant U.S. involvement at PSI: MuLan, MuCap, MuSun, MEG
  - U.S.-led proposal for elastic μ-p scattering (proton charge radius)
- Also significant pion physics program: PIBETA (past), PEN (ongoing)

“Other”

- Broad nuclear β-decay program with U.S. involvement at:
  - Texas A&M, TRIUMF, NSCL/FRIB, Argonne, U. Washington, LBNL
- Significant proton/deuteron EDM R&D program at COSY
- Project X: Construction late this decade, beams early next decade ?
  - Significant opportunities for neutrinos, UCN source, n-nbar, EDMs

Apologies to pion physics, etc. and everything else not discussed …

B. Plaster

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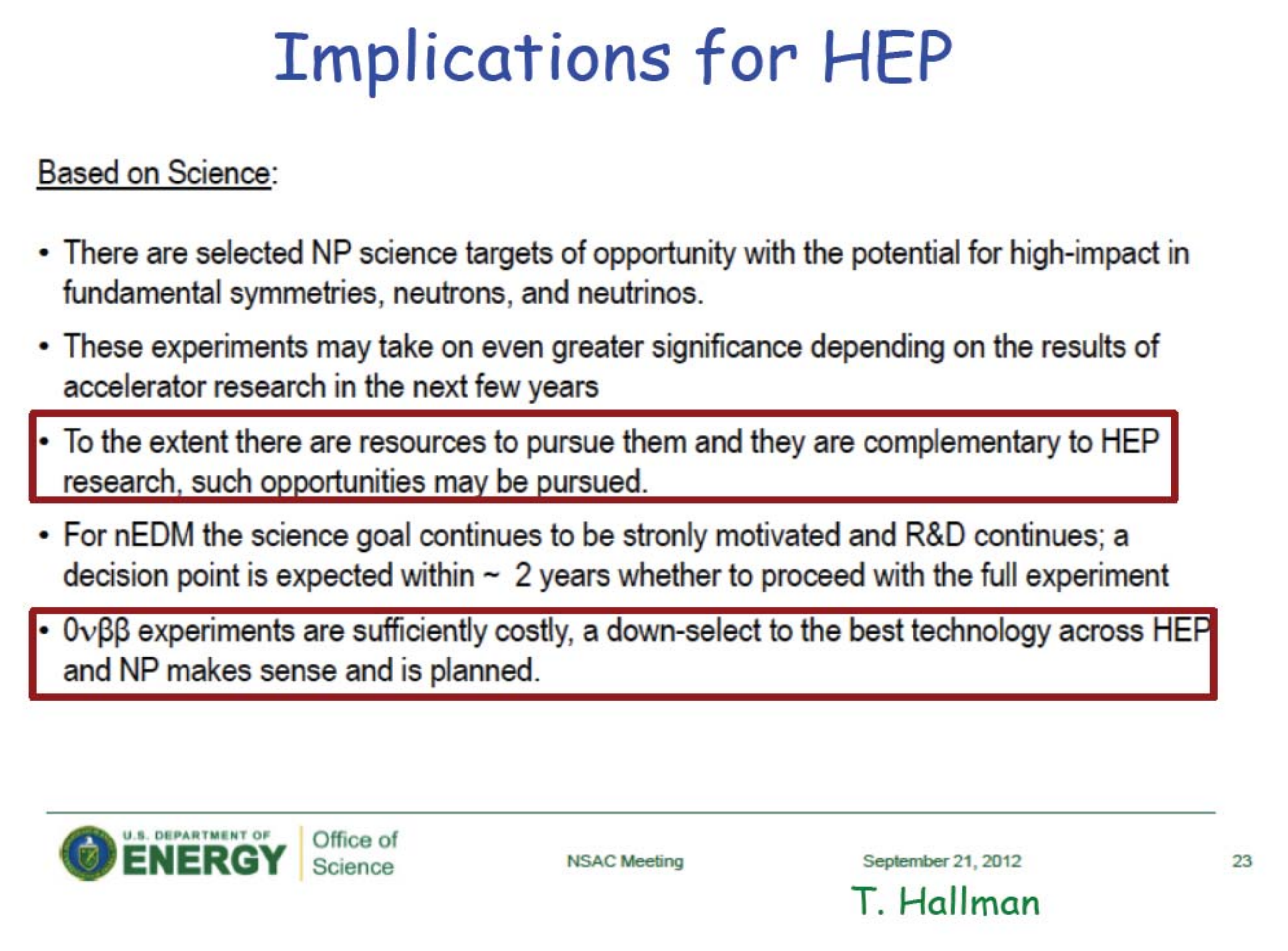
Brad Plaster, Fun-Sym August 11th

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 strony 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.