PX Stage 1 Physics Case: Preparations for Snowmass

http://www.snowmass2013.org/
Minnesota

R. Tschirhart
Fermilab

Oct 15th 2012

U.S. DEPARTMENT OF ENERGY

Fermilab

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.

Instrumentation frontier charge:

Conveners: Marcel Demarteau (ANL),
Howard Nicholson (Mt. Holyoke), Ron Lipton (Fermilab)

The task of this group is to provide an evaluation of the Detector R&D program being carried out in support of the High Energy Physics science mission, to determine if the existing program meets the science needs of the Energy, Intensity, and Cosmic Frontiers, and to suggest a program to strengthen the field. This group supports the other frontier groups and at the same time identifies and advocates new technologies that have the potential for significant breakthrough in science reach.

Education and Outreach charge:

Conveners: Marge Bardeen (Fermilab),
Dan Cronin-Hennessy (U of M)

How can we build support for and develop understanding of particle physics?

- The questions we want to answer
- Our history and record of accomplishment
- The impact of our research, our tools and our people on society
- The nature of discovery science in general

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

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.

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)

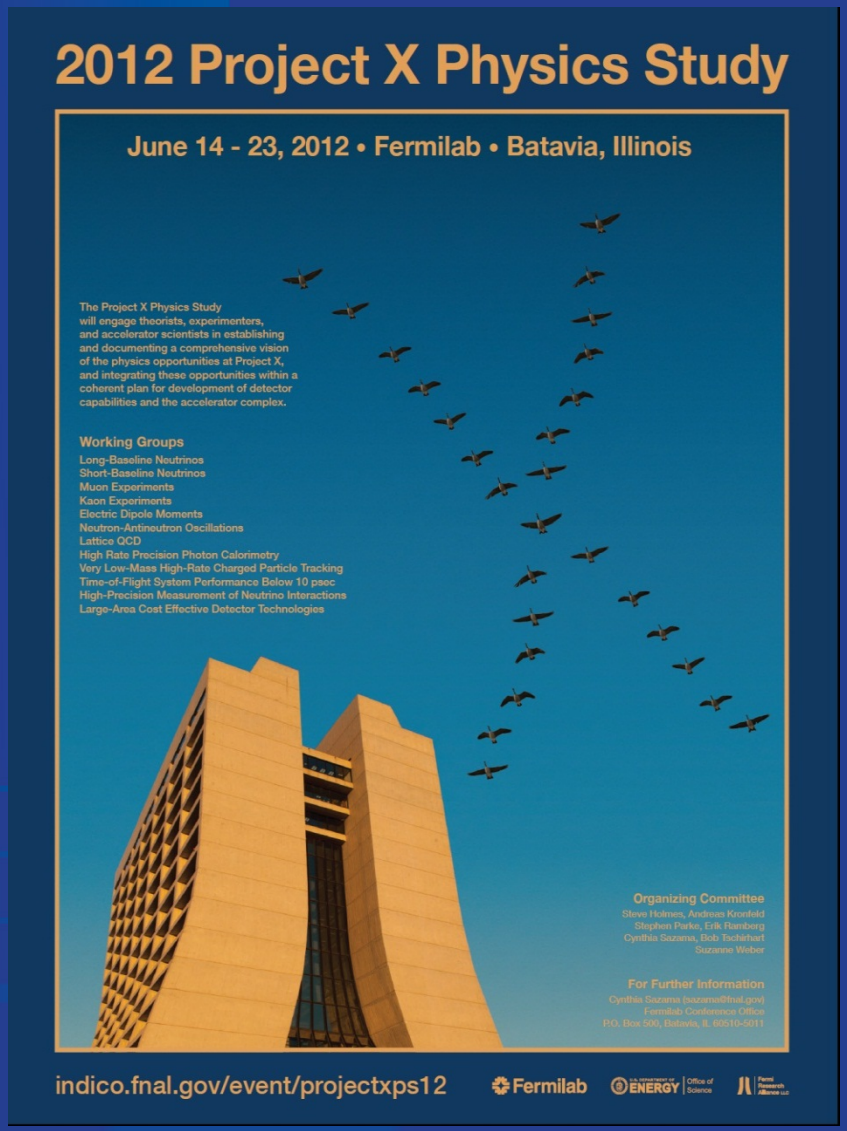
Large Area Cost Effective (LACE) Detector Technologies:

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

Lattice QCD:

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

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



220 participants

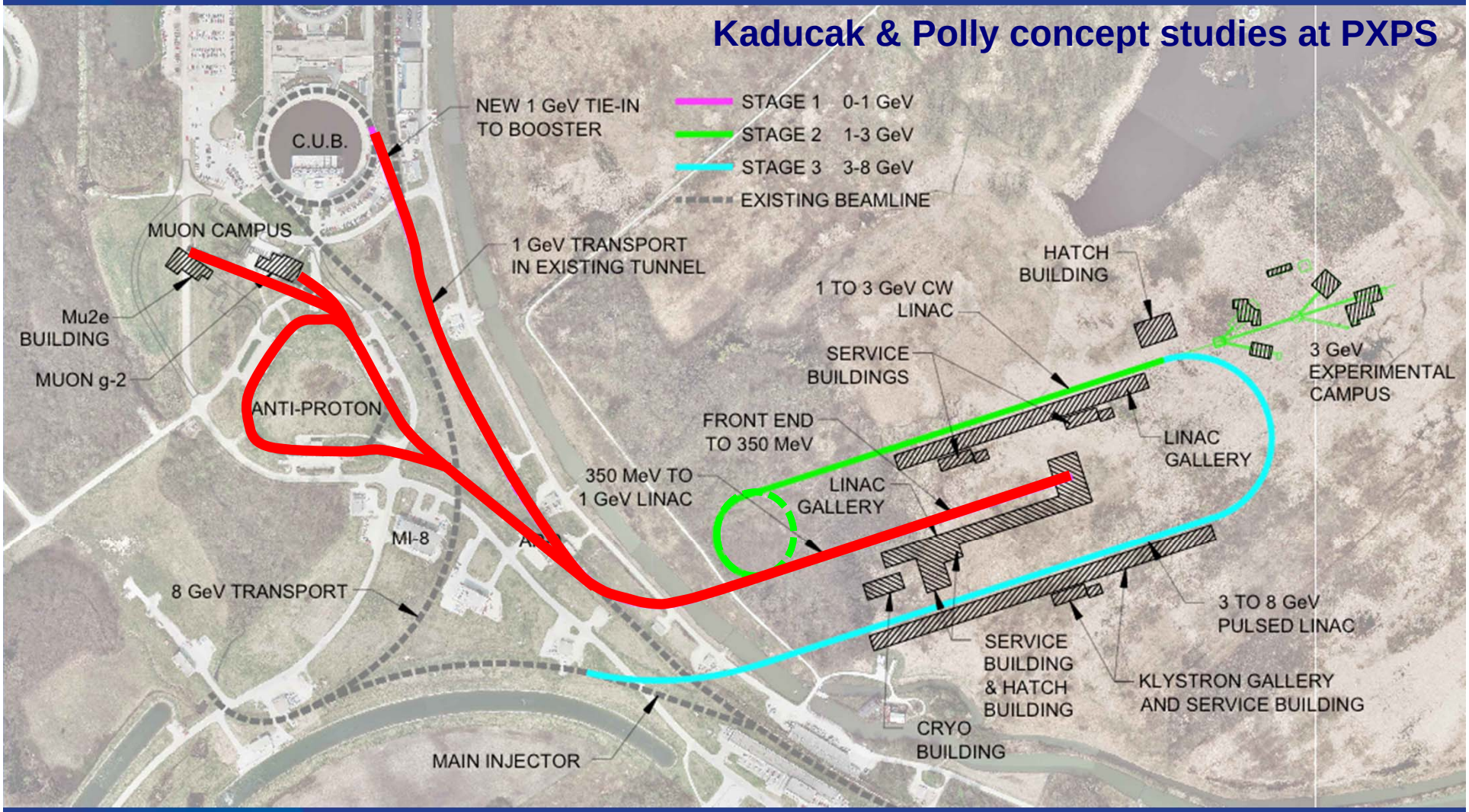
Summaries for experimental concepts and required detector R&D. Will serve as basis for research program white papers.

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

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

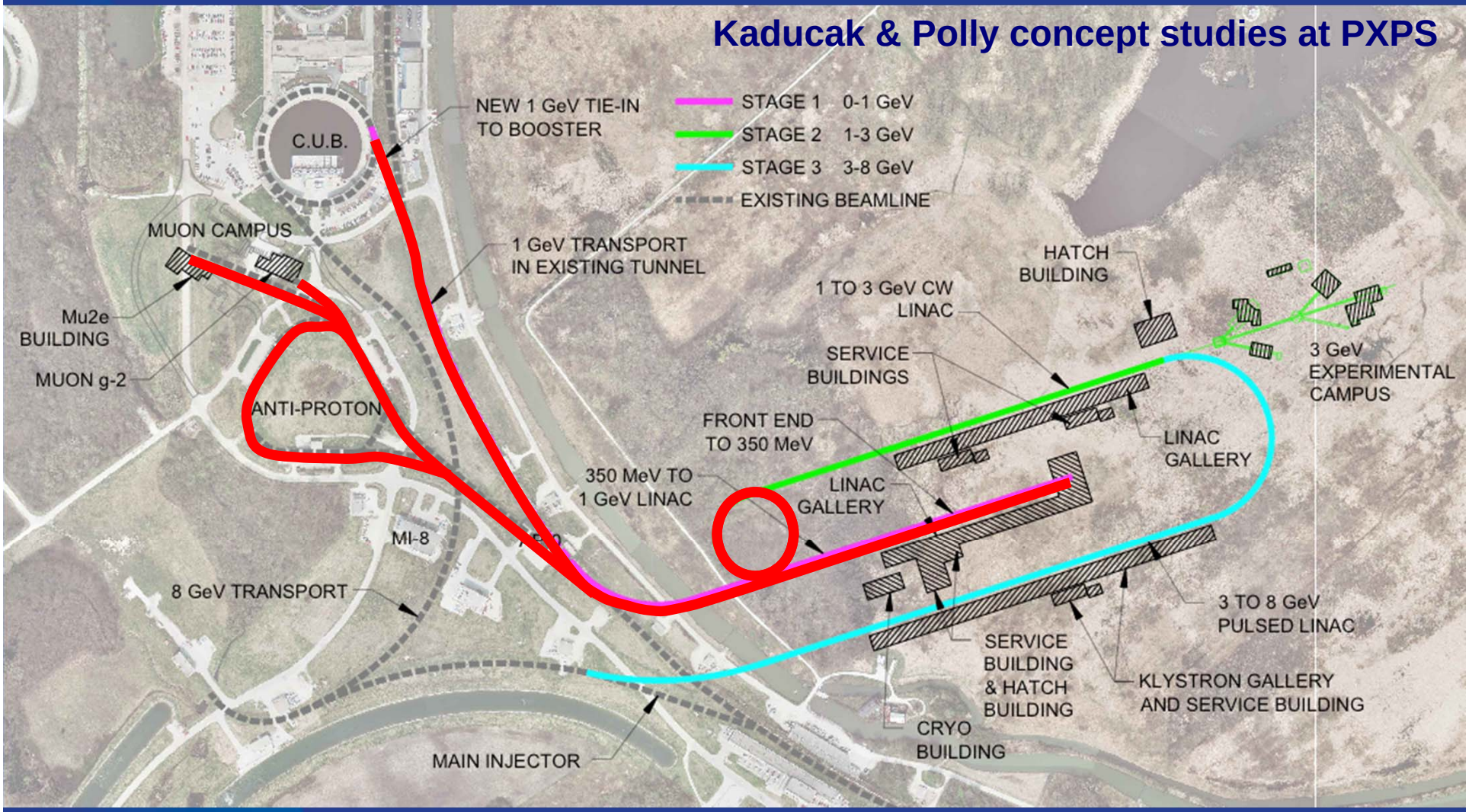
Project X detector R&D proposals submitted to OHEP as part of the comparative review process.

Kaducak & Polly concept studies at PXPS



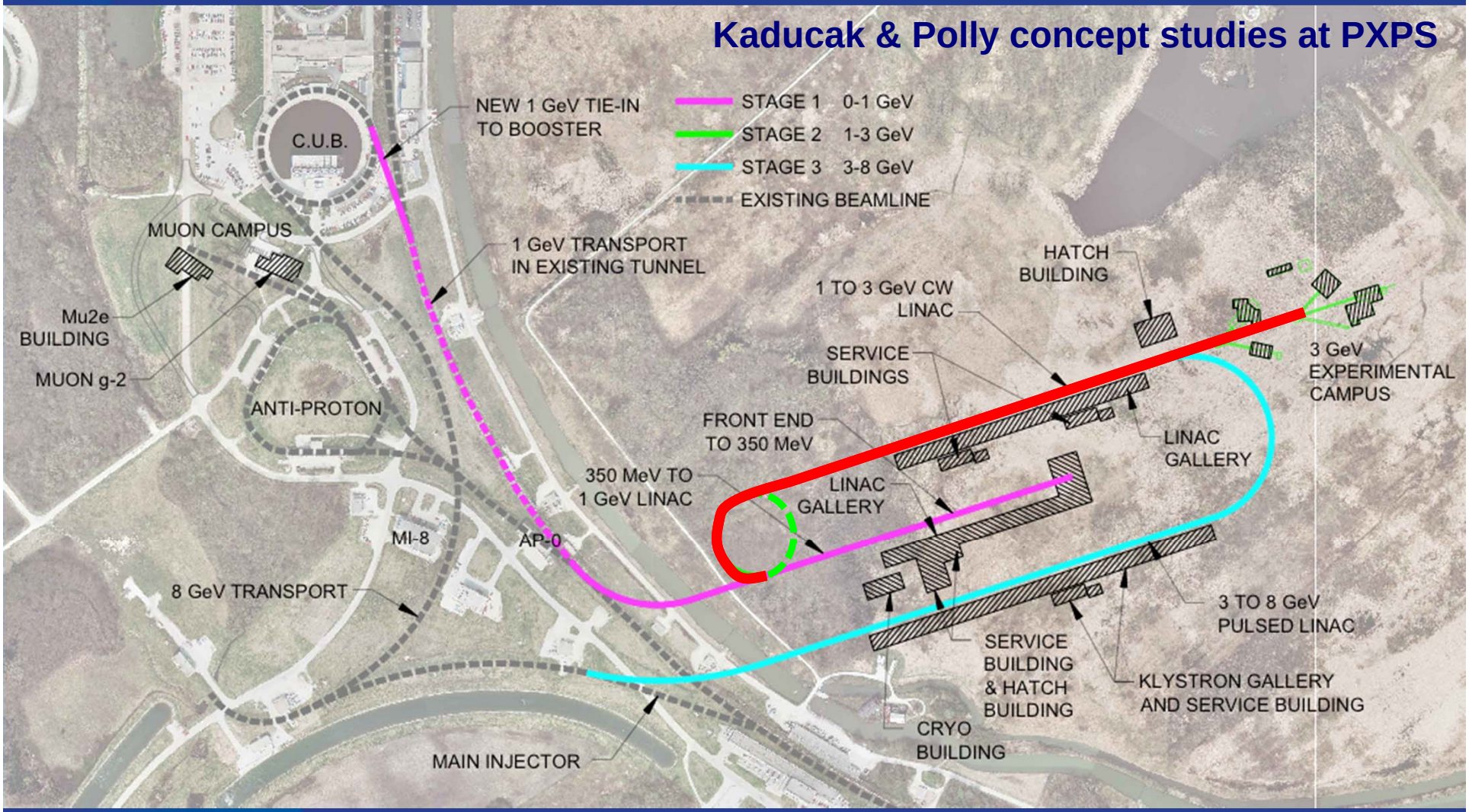
Stage 1: CW Linac (1 GeV, 1 mA) feeds Booster allowing 60-70% more beam at 8 and 120 GeV. 900 kW of CW beam remains at 1 GeV, and can be used in combination with existing AP0, former anti-proton rings, and new Muon Campus

Kaducak & Polly concept studies at PXPS



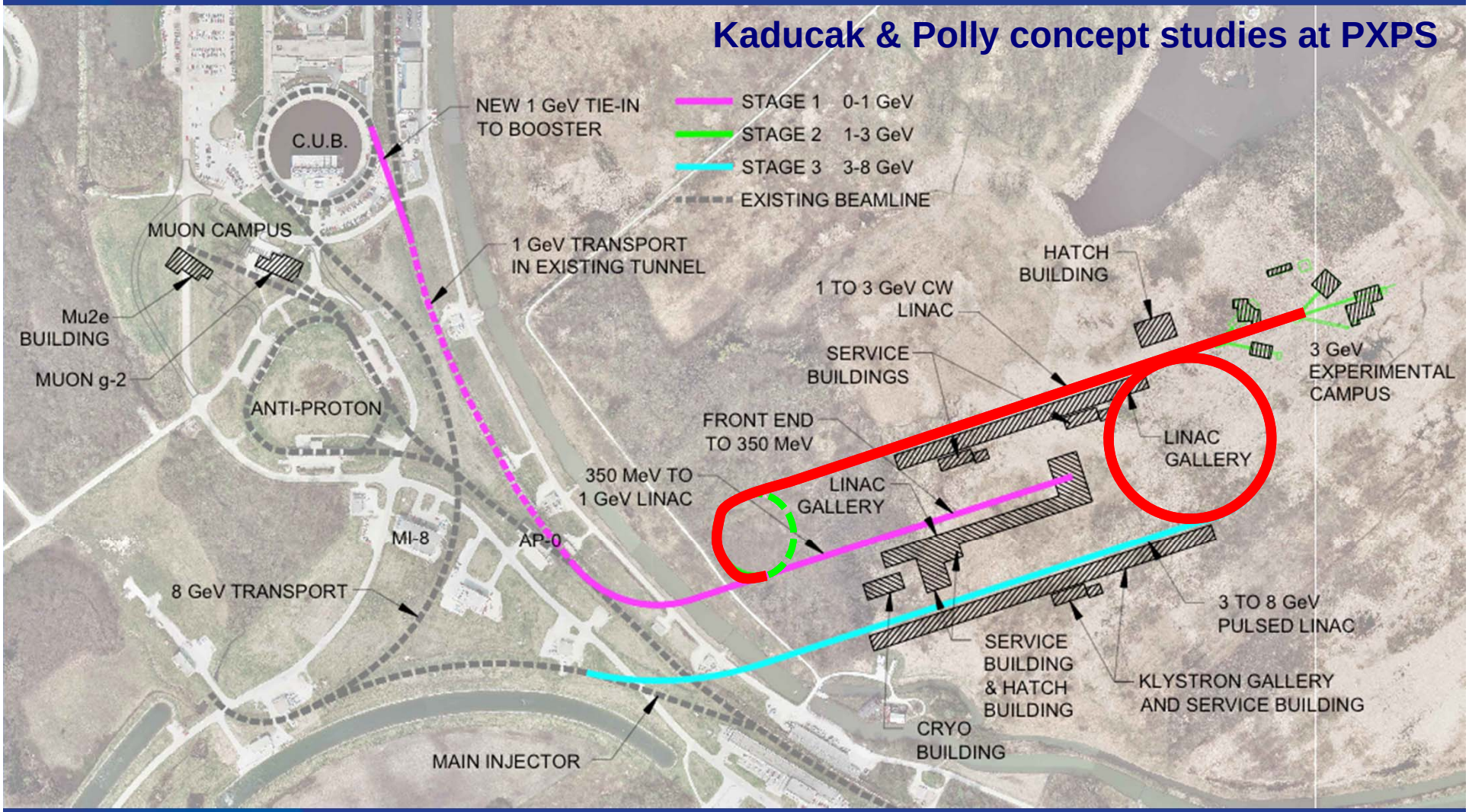
Stage 1a: A compressor ring allows non-CW experiments to be mounted in the existing 1 GeV experimental areas.

Kaducak & Polly concept studies at PXPS



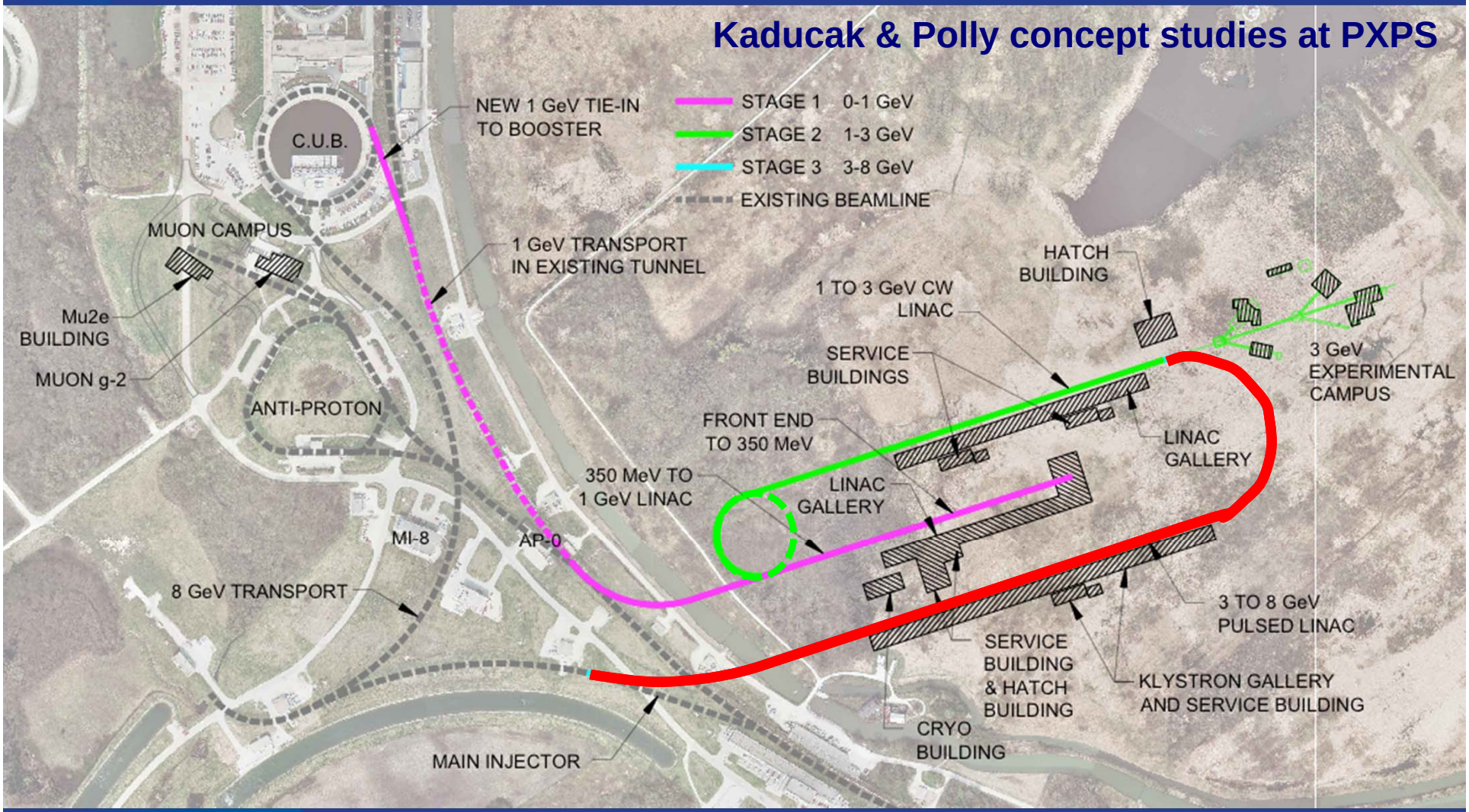
Stage 2: CW linac for 1 to 3 GeV constructed to feed new 3 MW experimental campus. Reuses first 180˚ of 1 GeV bunching ring for transport.

Kaducak & Polly concept studies at PXPS



Stage 2a: A compressor ring allows non-CW experiments to be mounted in the 3 GeV experimental areas.

Kaducak & Polly concept studies at PXPS



Stage 3: Pulsed linac constructed to feed Recycler. Reuses first 180˚ of 3 GeV bunching ring for transport.

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.

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!

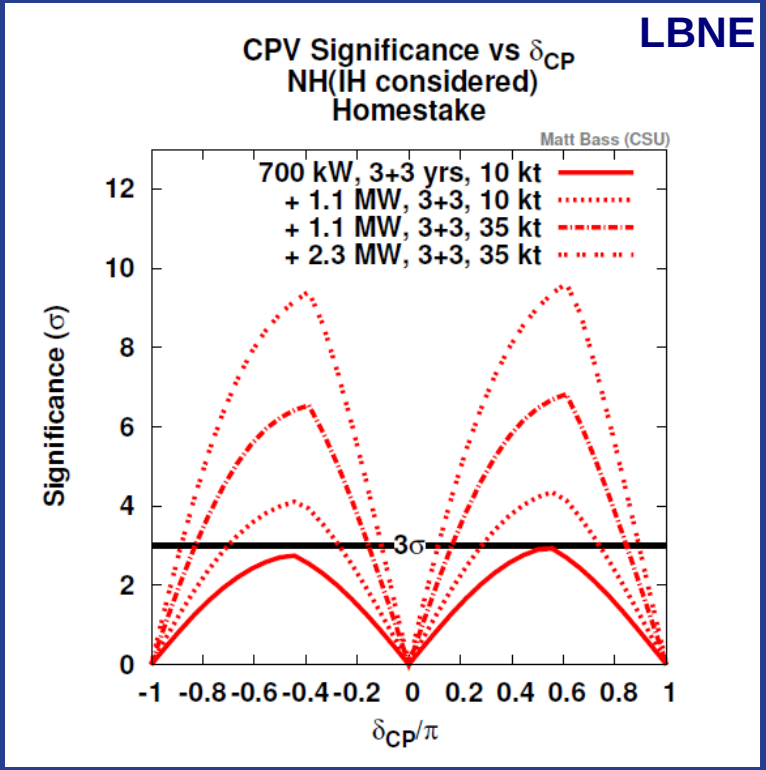


Table 2: SM predictions and current and expected limits on selected examples of EDMs.

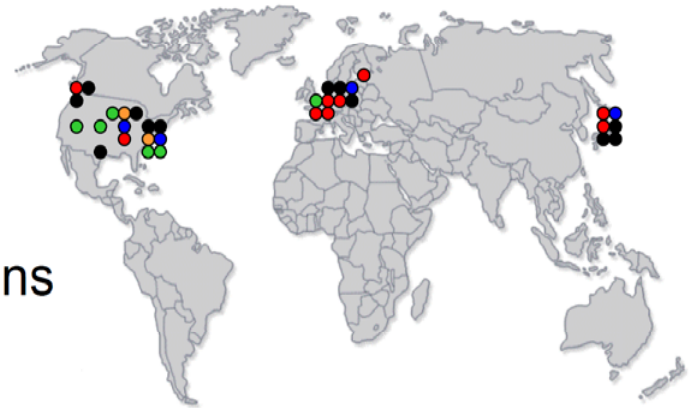
EDMs	SM	current limit	Project X
electron	$\sim 10^{-38}$ e cm	1.0×10^{-27} e cm	$\sim 10^{-30}$ e cm
muon	$\sim 10^{-35}$ e cm	1.1×10^{-19} e cm	$\sim 10^{-23}$ e cm
neutron	$\sim 10^{-31}$ e cm	2.9×10^{-26} e cm	$\sim 10^{-29}$ e cm
proton	$\sim 10^{-31}$ e cm	6.5×10^{-23} e cm	$\sim 10^{-29}$ e cm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

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

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).
- x3 increase in 8 GeV beam power for short baseline experiments.

Baryon number violation research opportunities with Stage-1

- n-nbar oscillations with free neutron techniques, sensitivity reach beyond Super-K which is background limited.

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
$K^+ \rightarrow \pi^+ \pi^0 \nu\nu$	$< 4.3 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \rightarrow \pi^+ \pi^0 X^0$	$\lesssim 4 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \rightarrow \pi^+ \gamma$	$< 2.3 \times 10^{-9}$	$< 6.4 \times 10^{-12}$	
$K^+ \rightarrow \mu^+ \nu_{heavy}$	$< 2\text{–}10 \times 10^{-8}$	$< 1 \times 10^{-10}$	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	
$\Gamma(Ke2)/\Gamma(K\mu 2)$	$\pm 0.5\%$	$\pm 0.1\%$	
$\pi^0 \rightarrow \nu\bar{\nu}$	$< 2.7 \times 10^{-7}$	$< 4\text{–}50 \times 10^{-9}$	depending on technique
$\pi^0 \rightarrow \gamma X^0$	$< 5 \times 10^{-4}$	$< 2 \times 10^{-5}$	

Broader Impacts Research with Stage-1

- Energy applications: Material studies, transmutation science, accelerator reliability. DOE SC/NE workshop early 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. Project X muSR forum October 17th-19th.

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"

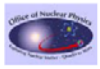
Broad nuclear β-decay program with U.S. involvement at:
Texas A&M, TRIUMF, NSCL/FRIB, Argonne, U. Washington, LBNL

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 UK

47

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 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.

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

Since PXPS: Interaction with the LBNE Reconfiguration enterprise*


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/

Since PXPS: 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.

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

CSS 2013 Engagement Plan: Accelerator Reference Design Report

- Accelerator Reference Design Report (RDR) will be prepared for distribution to the community in June 2013. The RDR will include:

  -Staging plan, capability of each stage.

  -Some information on cost drivers and scaling.

CSS 2013 Engagement Plan: Research Program Report

- Research program opportunities report will be prepared for distribution to the community in June 2013. This report will include:

  - Experimental concepts and physics reach opportunities of each stage.

  - Will evolve from existing white papers, work at the Project X Physics Study, and and a URA funded theory study group.

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 in June 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.

CSS 2013 Engagement Plan: Broader Impacts Report

- A report on the broader impacts of Project X including:

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

  - Possibly muon Spin Rotation applications, pending discussions later this week.

Schedule

- Broader applications forums and workshops Oct 2012 (muSR) January 2013 (Energy & Materials).
- May/June 2013: Meeting at Fermilab to review Project X draft materials for Snowmass. This meeting will be coordinated with an Intensity Frontier CSS 2013 preparatory meeting.
- June 2013: Post and distribute Project X Snowmass materials.

Summary

- Project X staging and the stage-1 research program is now fairly clear, and community engagement is growing.
- Coordination and interaction with DOE NP is important and should continue through Snowmass.
- We will deliver Project X materials that define the research and broader impacts landscape for Snowmass.

Facilities: Cold vs. Ultracold Neutrons

"Cold Neutrons"
~50 μeV – ~25 meV

↓

Moderation of Flux From Reactor / Spallation Source

↓

Transported Along Guides
Pros: High Rates

↓

Hadronic PV, β-decay, Interferometry, n-nbar

"Ultracold Neutrons"
< 350 neV

"UCN"

↓

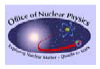
Downscattering of (Cold) Neutron Flux in Moderator "Source"

↓

Stored in Bottles or Magnetic Traps
Pros: Systematics

↓

nEDM, β-decay, Gravity/Exotic Forces

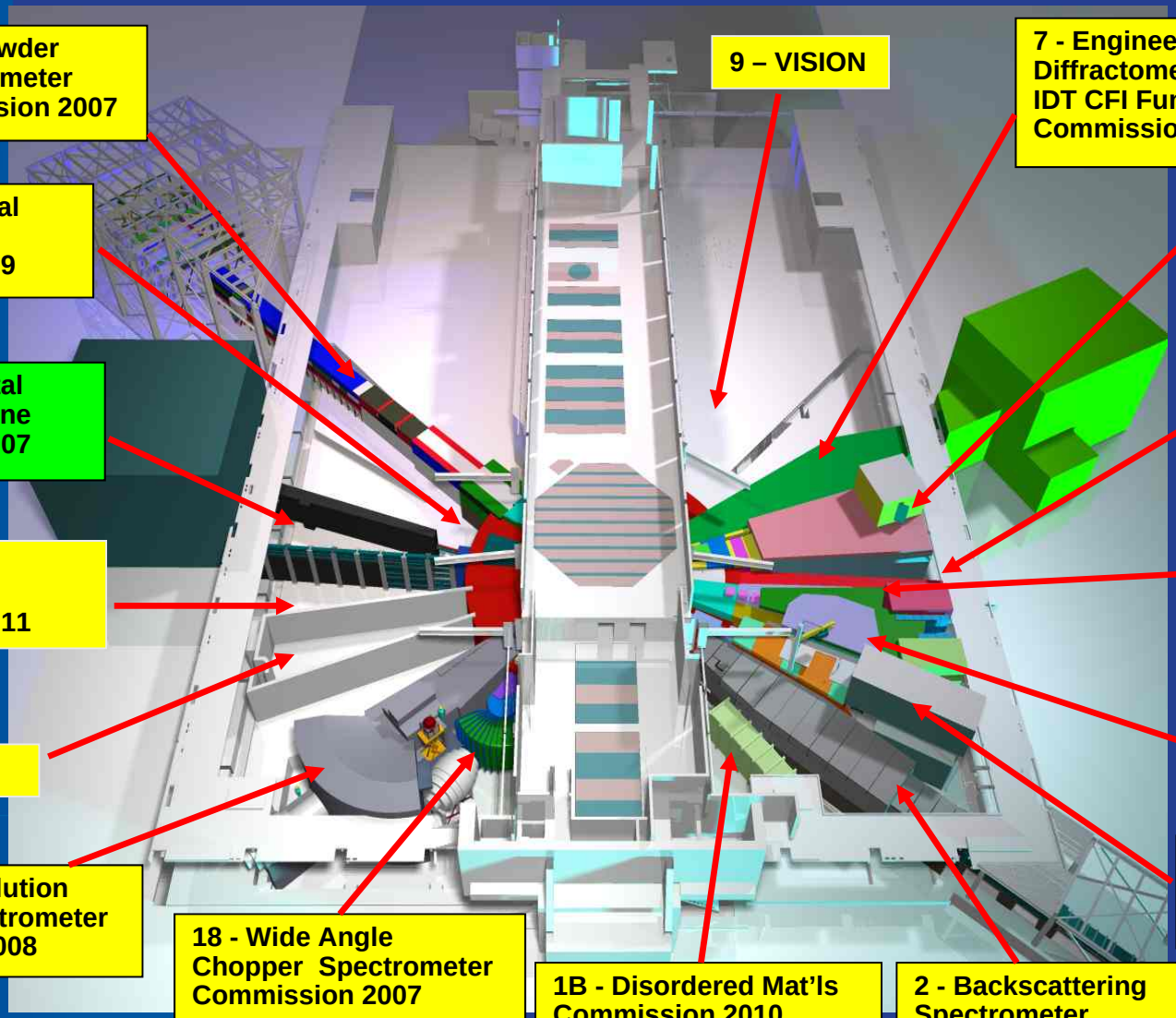


B. Plaster UK

4

Brad Plaster, Fun-Sym August 11th

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

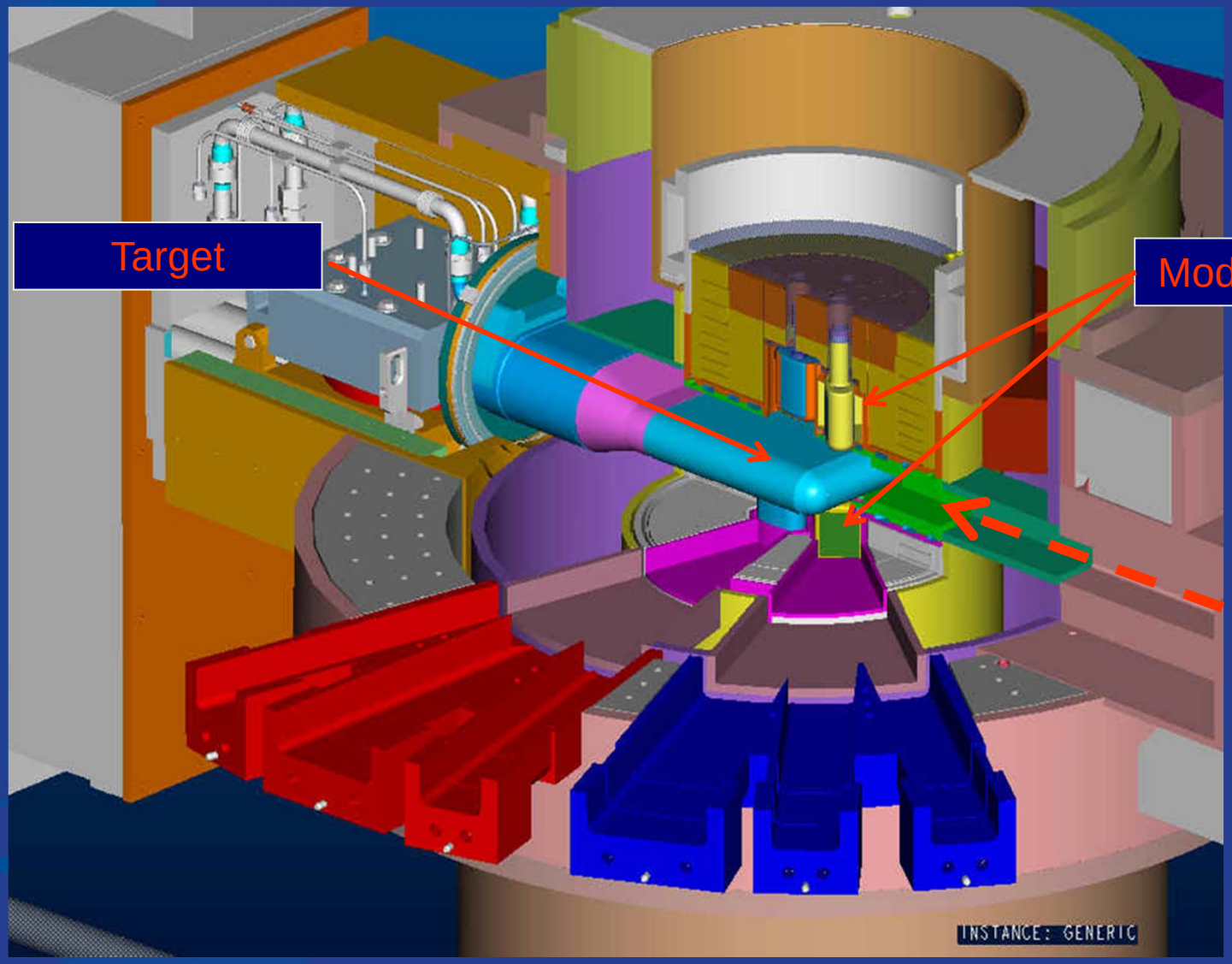
18 - Wide Angle Chopper Spectrometer Commission 2007

1B - Disordered Mat'ls Commission 2010

2 - Backscattering Spectrometer Commission 2006

Courtesy
Geoff Greene

ORNL SNS Spallation target



Courtesy Geoff Greene

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, 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 2nd 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

Lankford, Krakow, September 13, 2012 46

A. Lankford, ESPP Sept 2012