The Project X Physics Study

R. Tschirhart
Fermilab

June 29th 2012

U.S. DEPARTMENT OF ENERGY

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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)

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)

PXPS Overview*

- The 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.

*(https://indico.fnal.gov/conferenceDisplay.py?confId=5276)

2012 PXPS Deliverables

- Brainstorming, work!
- Succinct summary (<5pages) of physics opportunities for each stage.
- Outline and roadmap of work required for Project X to reach science goals for each stage in the following thrusts:
  - **-Experiment concept development**
  - **-Detector R&D**
  - **-Theory development**

PXPS Meeting Scope

- 217 registrants
- 213 presentations
- 2 days of plenary, 4 days of parallel, 2 days of summary.
- Both vigorous and stimulating discussions.

  (heat & light)
- Mean residency of registrants was 2-3 days, ~500 researcher-days on the Project-X research program. Instantaneous population of 75-100.

Planning for planning…

June 2012 Physics Study:
June 14th-22nd

Summer 2012 through Spring 2013:

Continue to evolve existing white papers into a comprehensive staged program with compelling physics at each stage.

October 11th-13th 2012: CPM2012

US particle physics community planning meeting at Fermilab preparing for CSS2013, summer 2013.

"Community Summer Study" (CSS2013)

July 29th – August 10th

[cf Lepton-Photon 6/24-6/29; DPF 8/11-8/17.]

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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.

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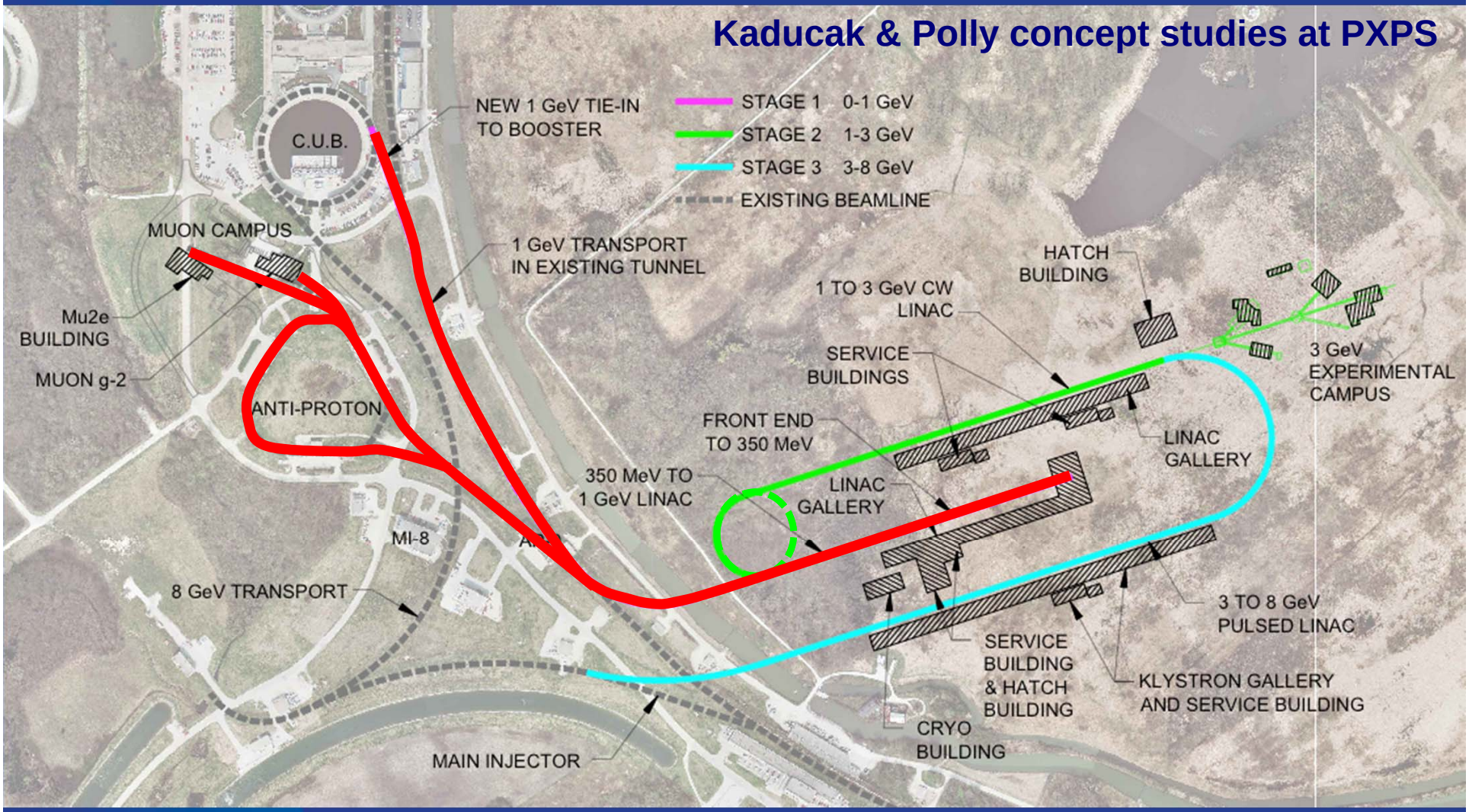
Kaducak & Polly concept studies at PXPS



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

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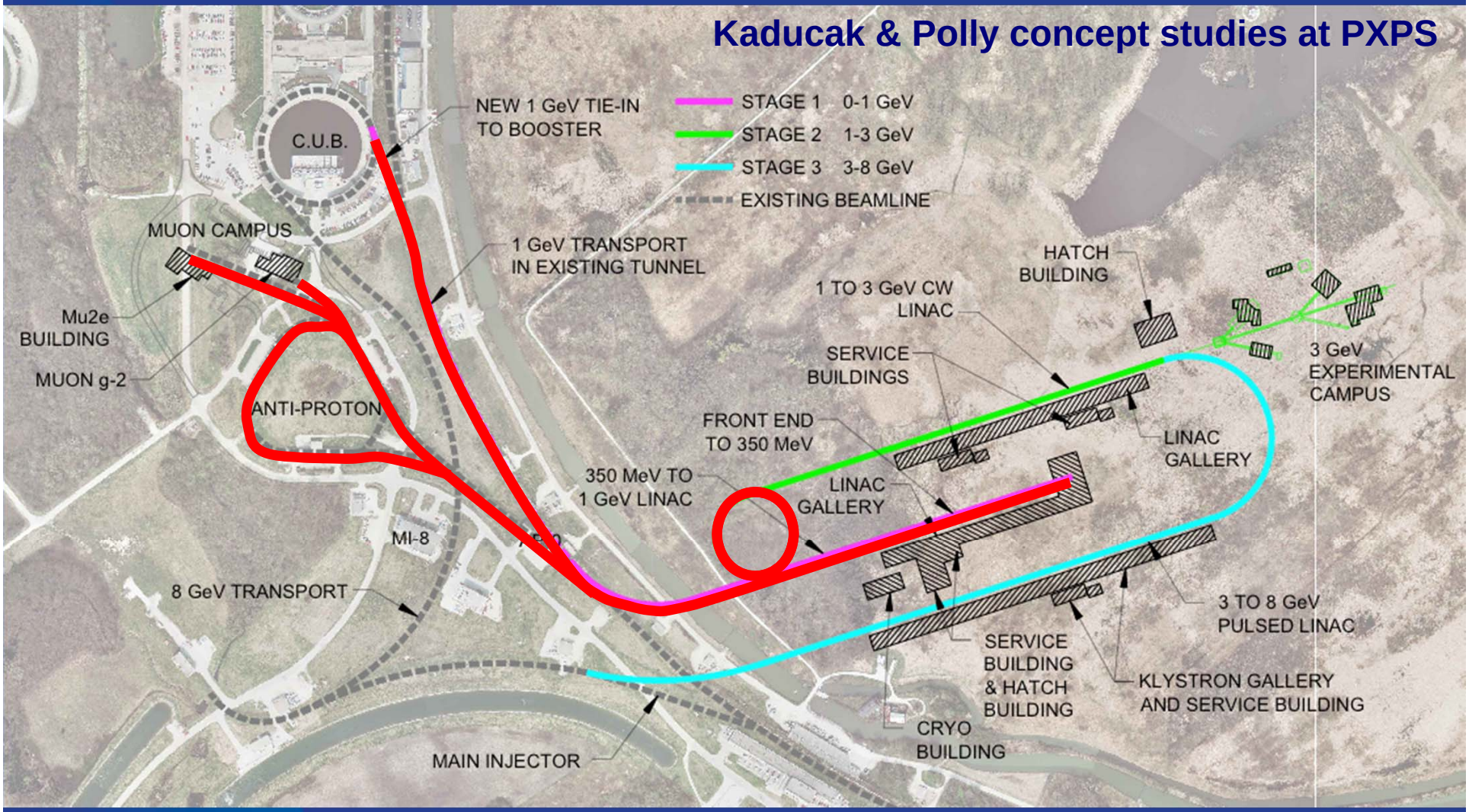
Kaducak & Polly concept studies at PXPS



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

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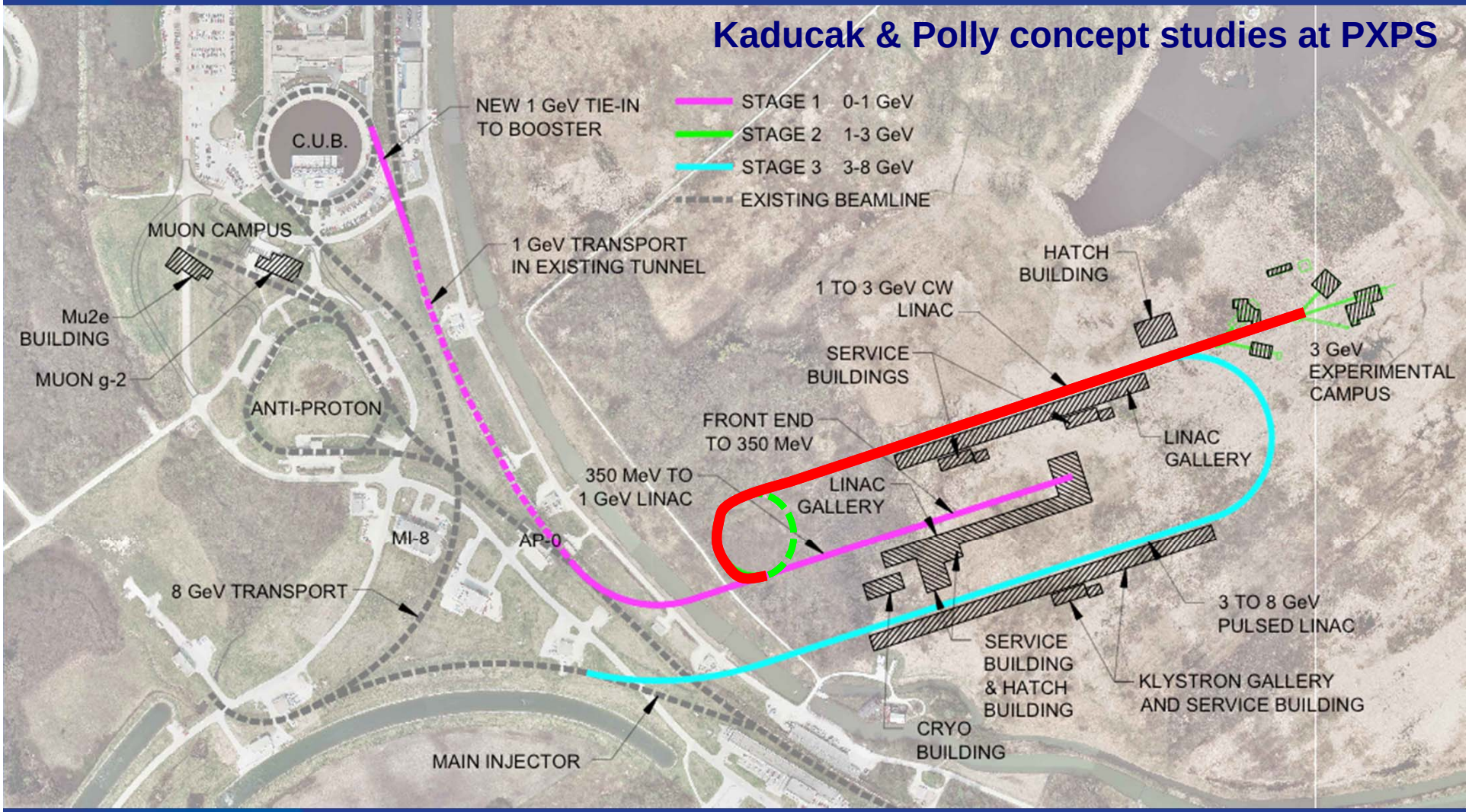
Kaducak & Polly concept studies at PXPS



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.

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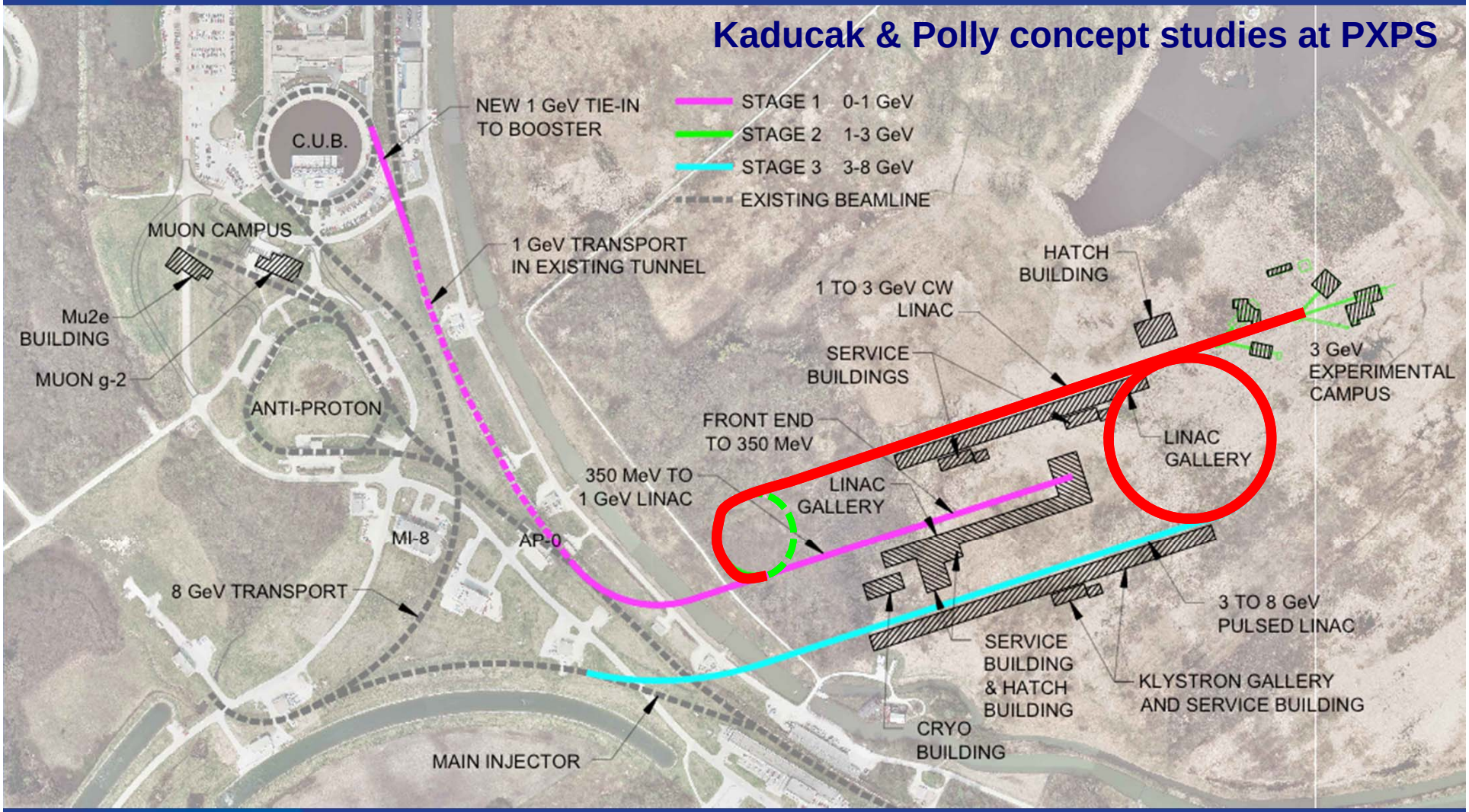
Kaducak & Polly concept studies at PXPS



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

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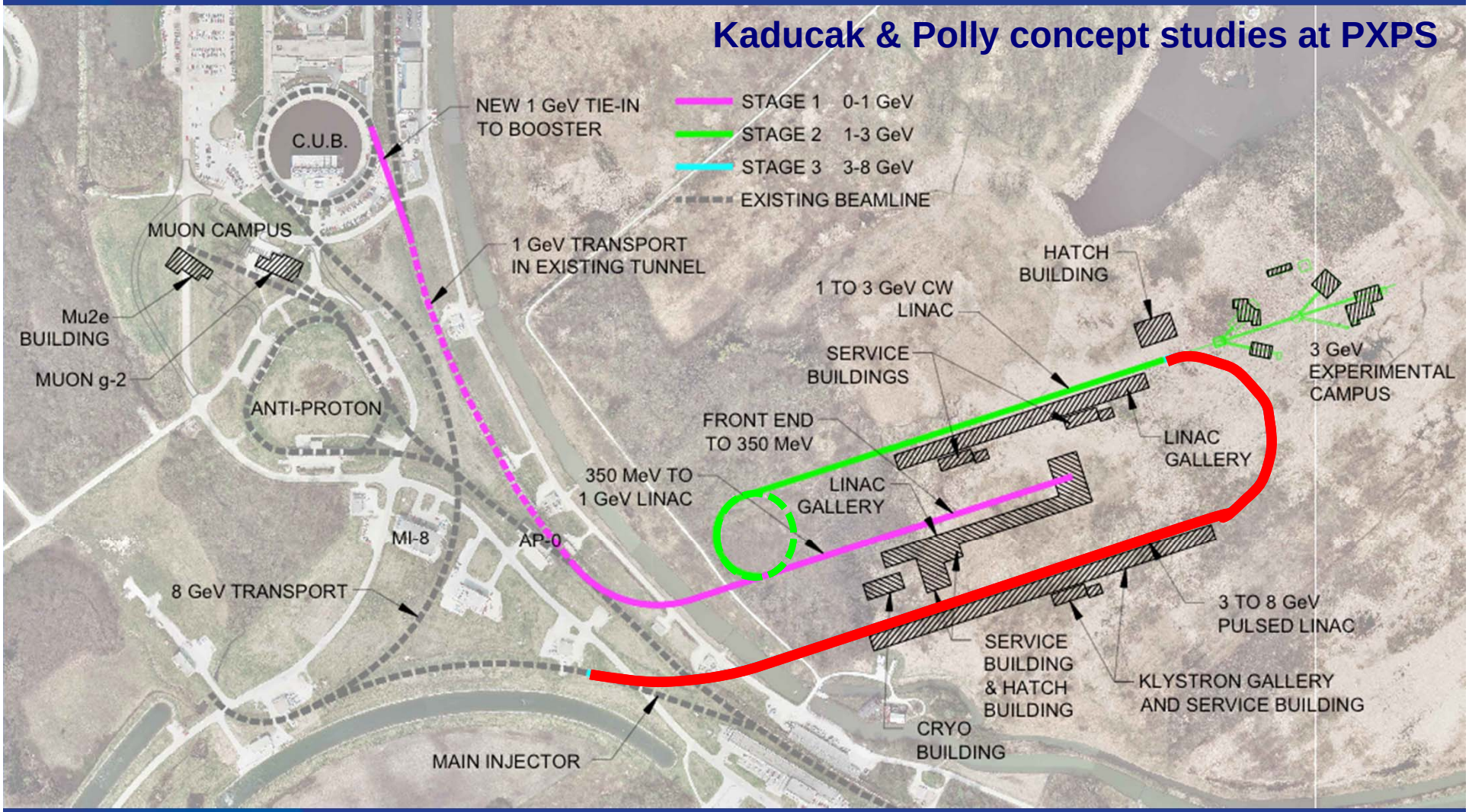
Kaducak & Polly concept studies at PXPS



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

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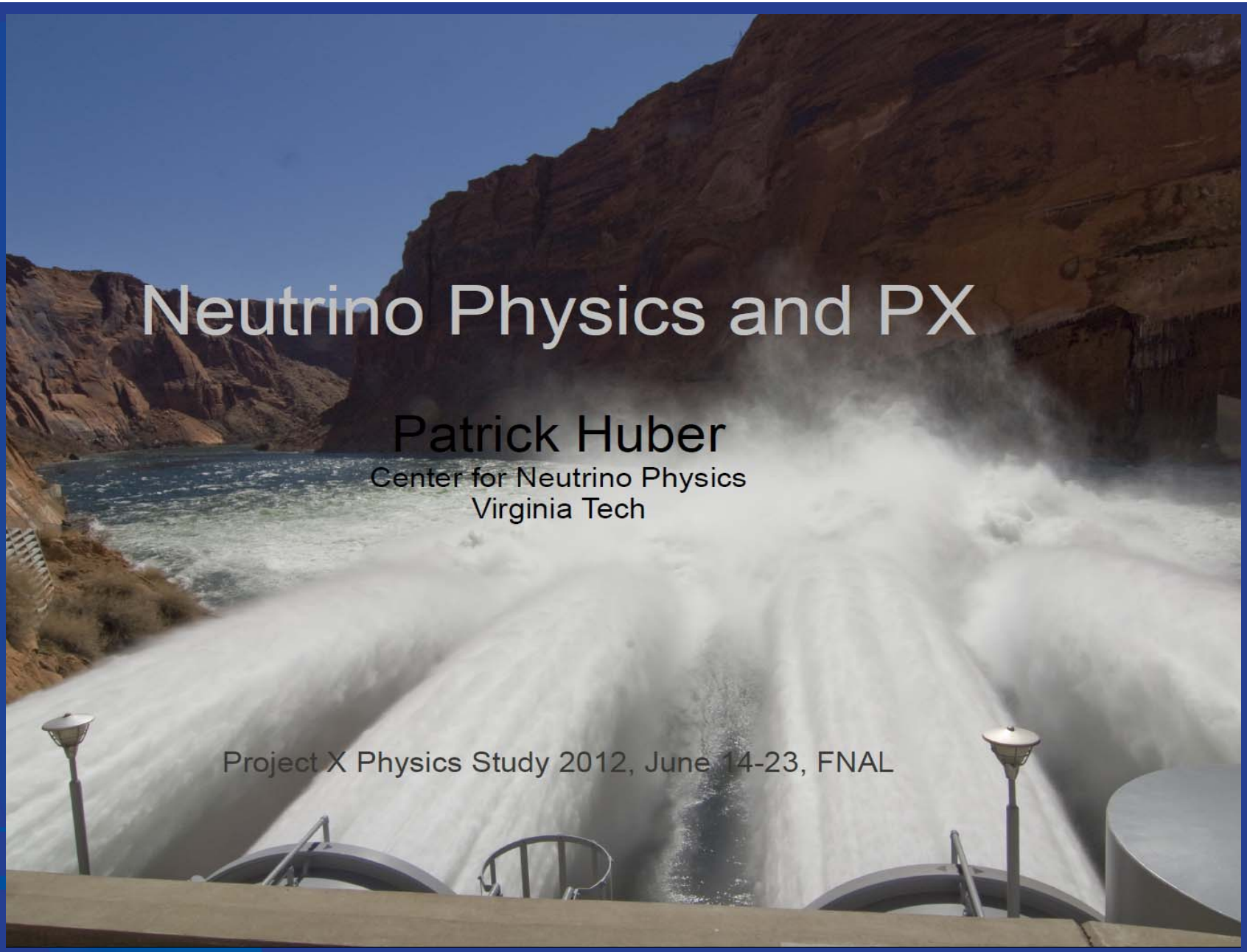


Neutrino Physics and PX

Patrick Huber
Center for Neutrino Physics
Virginia Tech

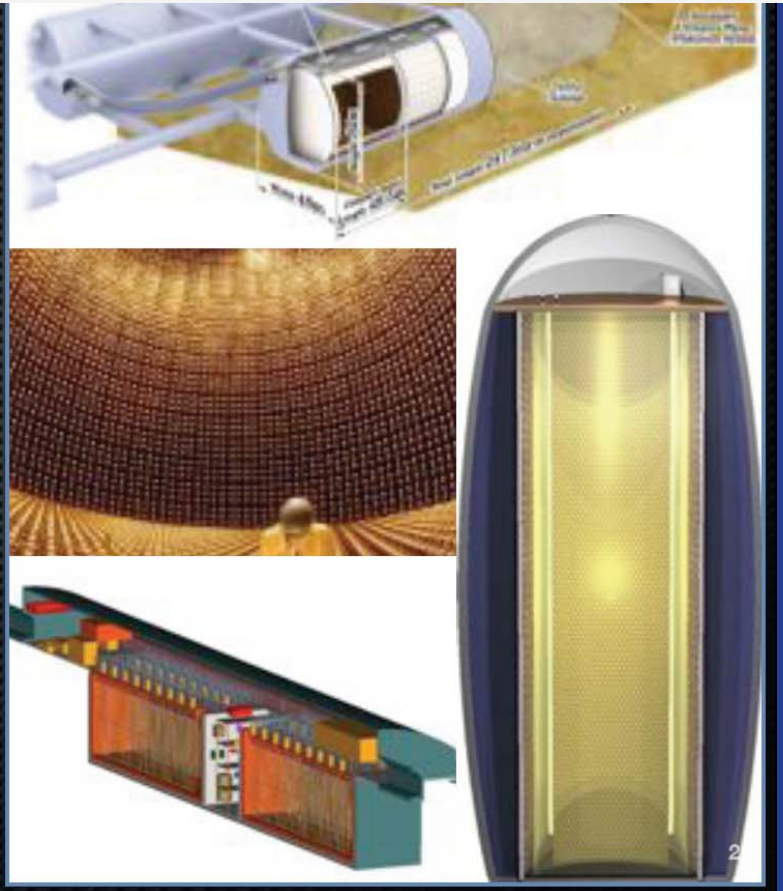
Project X Physics Study 2012, June 14-23, FNAL

Next generation long-baseline

Liquid Argon Operations on the Surface??

detectors to reach the sensitivities needed to measure CP violation, the mass hierarchy, the θ_{23} octant and non-standard interactions.
(See P. Huber's talk)

- One or several **large detectors,** can provide the mass required to the next generation of long-baseline experiments.
- A challenge will be instrumenting the **very large surfaces/volumes**.
- A second challenge will be making **multi-purpose detectors** to enable a broader physics program.



M. Sanchez - ISU/ANL

Mayly Sanchez PXPS

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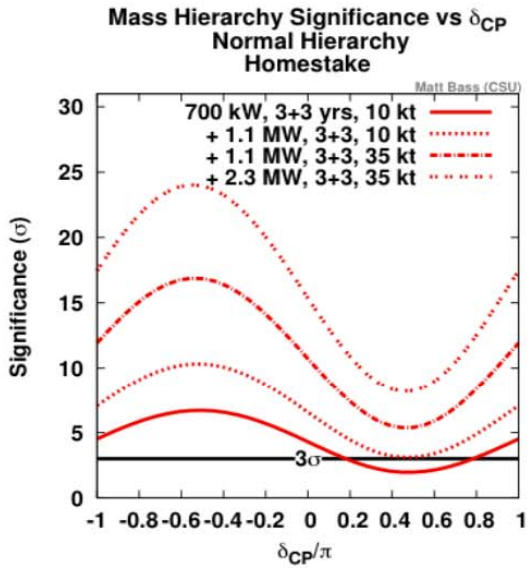
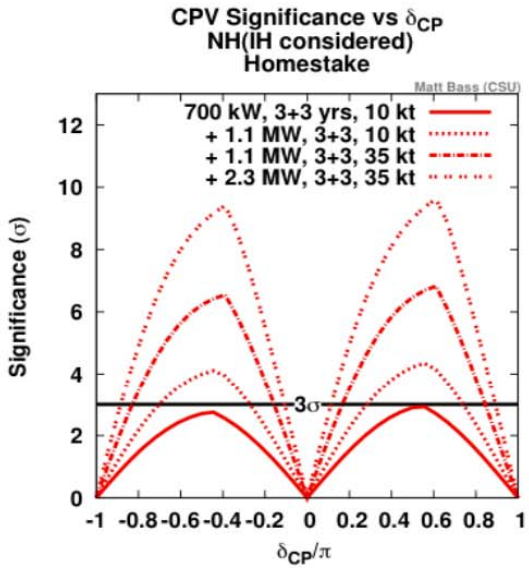
LBNE Phase 2 + Project X Stage 1





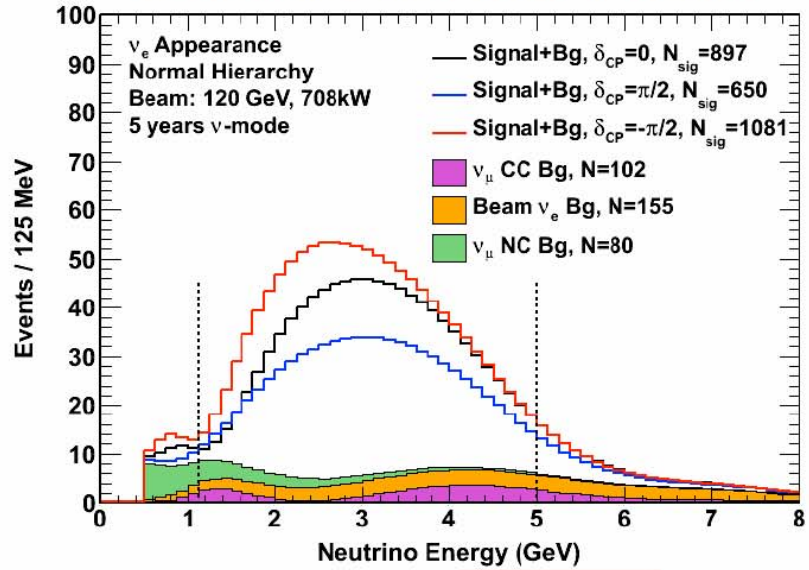
- Stage 1 of PX increases the MI beam power to MW range
- LBNE/Homestake Phase 2 + PX Phase 1 = **Discovery (>5σ) CPV**

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:

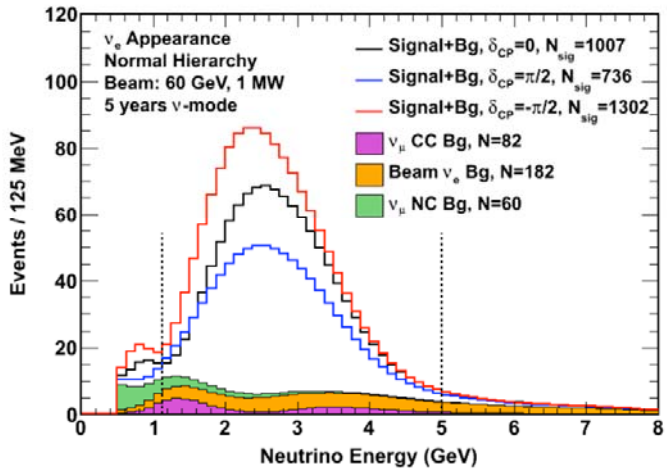
$$\frac{N_{-\pi/2} - N_{\pi/2}}{\sqrt{B}} = 23.5$$

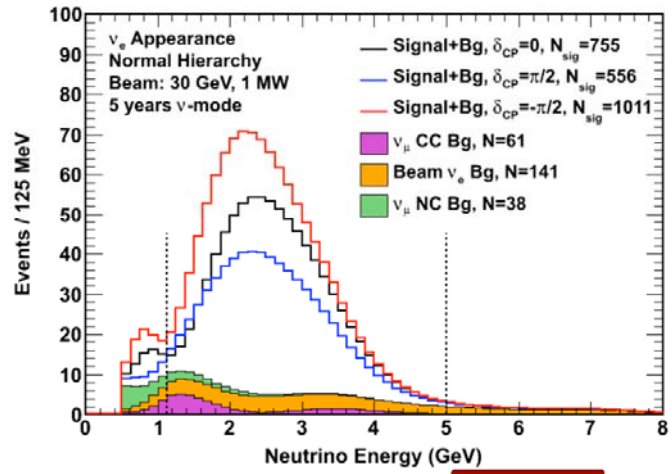
Standard 120 GeV 700kW



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

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

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

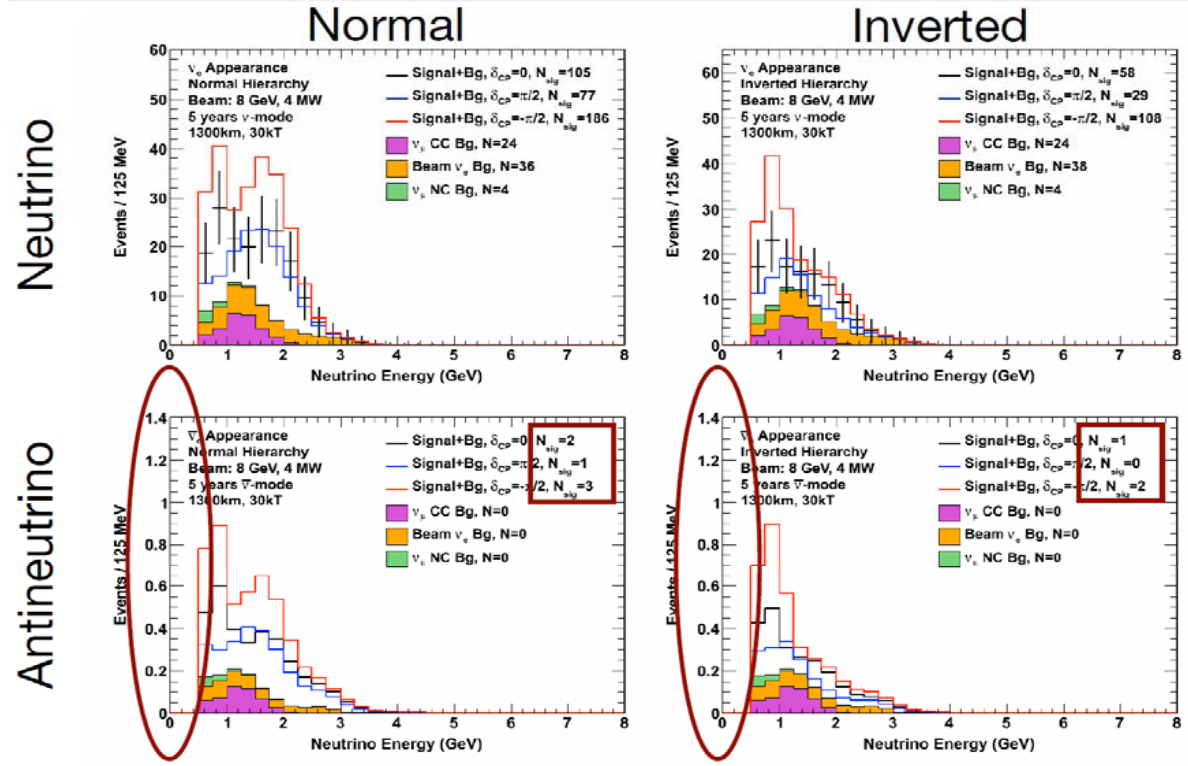
δ_{CP}	N	N_{second}	N_{first}	$N/\sqrt{B}$	$N_{second}/\sqrt{B}$	$N_{first}/\sqrt{B}$
0	755	30	716	48.74	4.93	55.08
$\pi/2$	556	11	538	35.89	1.81	41.38
$-\pi/2$	1011	51	951	65.26	8.38	73.15

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

- 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

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

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

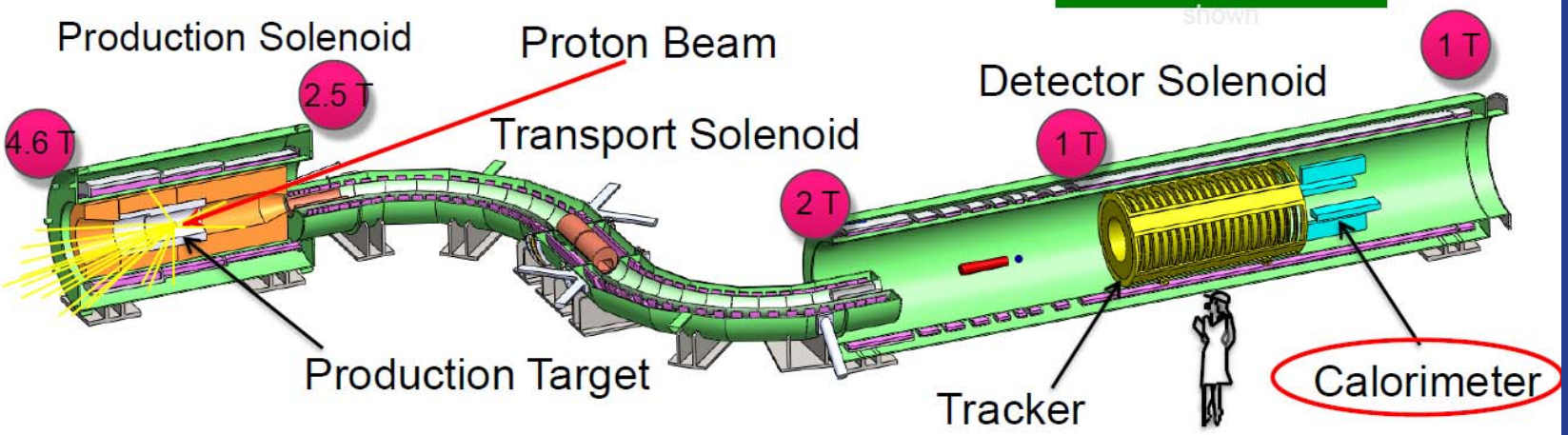
Production Solenoid
- Production target
- Graded field

- 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

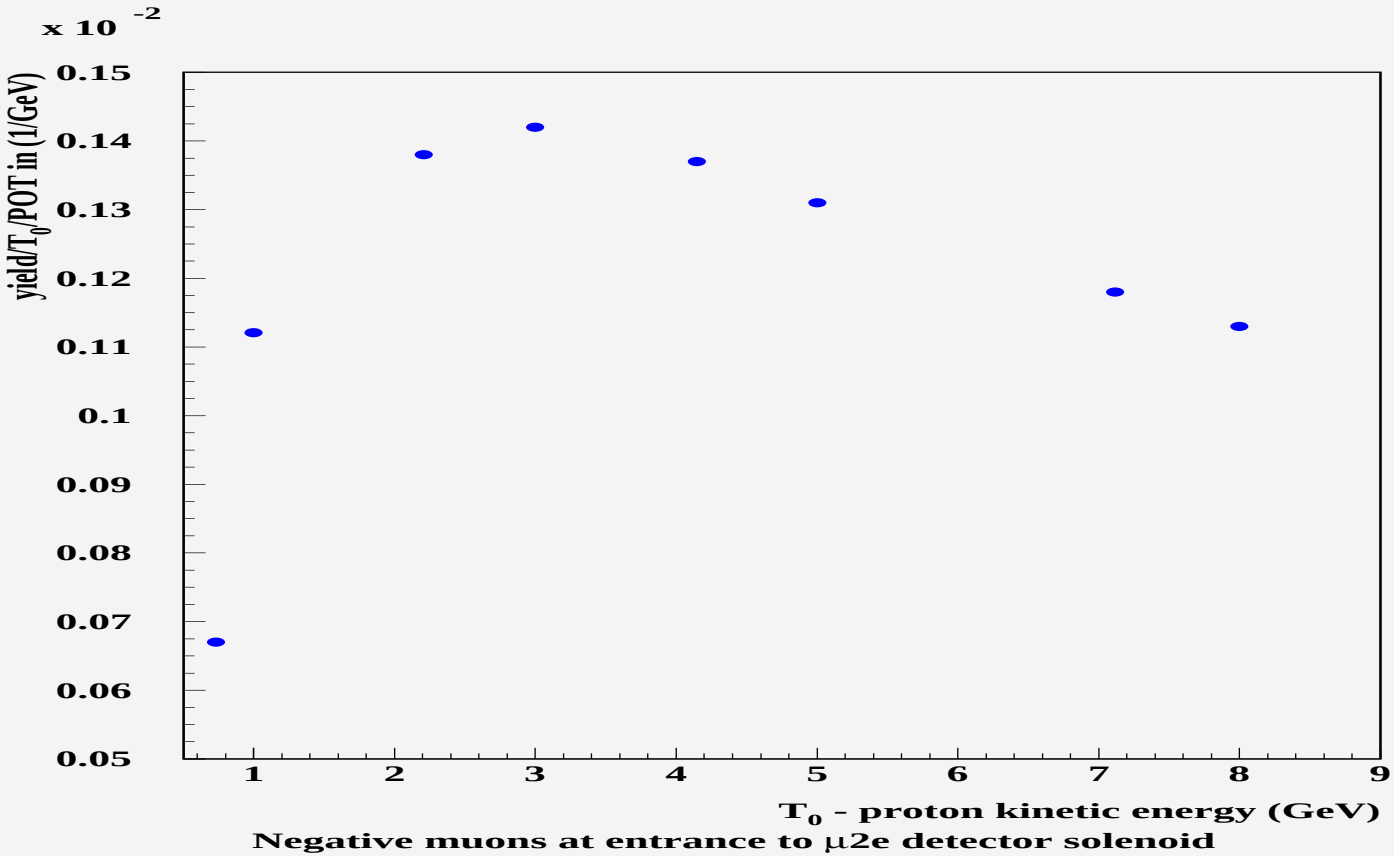
Transport Solenoid
- Collimation system selects muon charge and momentum range
- Pbar window in middle of central collimator

Cosmic Ray Veto not shown



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

Yield / Watt



S. Striganov et al, work in progress

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A Few of the opportunities for growth identified at the PXPS

- Driving the Mu2e experiment with 1 GeV beam: Issues identified.
- Common target station for n-nbar and n-edm experiments may be plausible. "cold-neutron facility"
- Importance of 1000 event $K_L \rightarrow \pi^0 \nu\nu$ amplified.
- Importance of 60 GeV Main-Injector running at Stage 2 quantified, value of 8 GeV drive beam in Stage-4 explored.

Opportunities for pruning identified at the PXPS

- Pursuing a pion Decay-at-Rest (DAR) experiment with Stage-1 will not compete or distinguish from Osc-SNS at the SNS.
- Pursuing the use of PXIE to drive an “IsoDAR” type experiment* (~1 kTon IBD detector) near or on the surface does not appear feasible.
- Pursuing a <100 event sensitivity experiment for $K_L \rightarrow \pi^0 \nu\nu$.

***arXiv:1205.4419v1 May 2012**

Challenges to developing the Project X Research Program

- Communicating plausible schedules
- Relationship with LBNE
- Developing a smooth interface with the program this decade
- Building partnerships between funding agencies & offices

Research program priorities for the coming year

- Complete the concept study of LBNE/Project-X staging interplay.
- Concept study of scheme to drive Mu2e with 1 GeV proton beam.
- Guest and visitor support to develop 1-GeV spallation target designs to drive next generation cold-neutron experiments.
- Continued effort on developing high power targetry.
- Continued outreach into the community