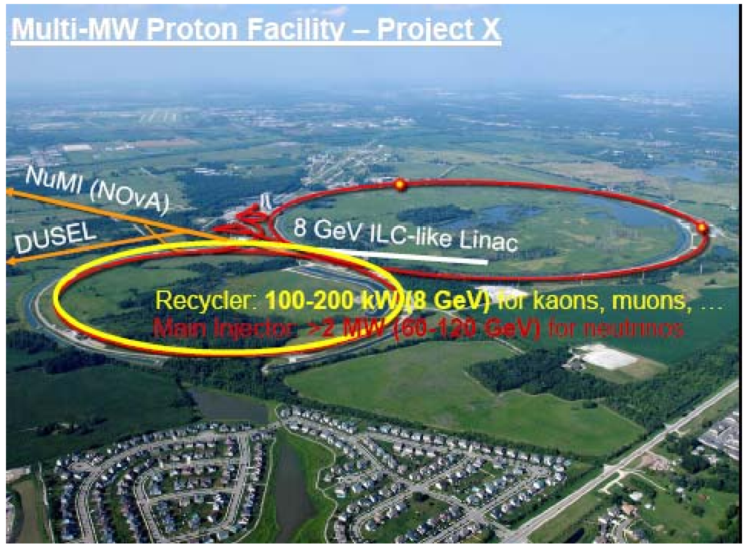
Intensity Frontier Prospects at Fermilab



Douglas Bryman
University of British Columbia
JSPS Fellow

Energy Frontier

Tevatron → LHC; TeV Energy Scale

New Physics

High Mass Scales?

Precision Frontier

Flavor Physics

DARK Matter Frontier

↓

COSMOLOGICAL EVOLUTION, BBN

Rare Decays and CP violation

Symmetry Violation

LEPTOGENESIS?

NEUTRINO PHYSICS

Intensity Frontier Focus

* Neutrino Physics: Oscillations:
  $\sin\theta_{13}$ (if it's large enough);
  intense beams to DUESL;
  CP Violation; scattering

* Muon Physics: μe Conversion $<10^{-17}$; $g-2\,(20x)$
* Rare K Physics: $K^{+}\rightarrow\pi^{+}\nu\bar{\nu}$ and $K_{L}^{0}\rightarrow\pi^{0}\nu\bar{\nu}$

Other Topics:

* $\bar{p}$ Physics: QCD, searches for new physics using hyperons
  and charmed mesons, antihydrogen.
* Charm Mixing and CP Violation at the Tevatron;
  D-mixing, 70K events/yr.

Intensity Frontier at Fermilab: Now and in the Future

Now:

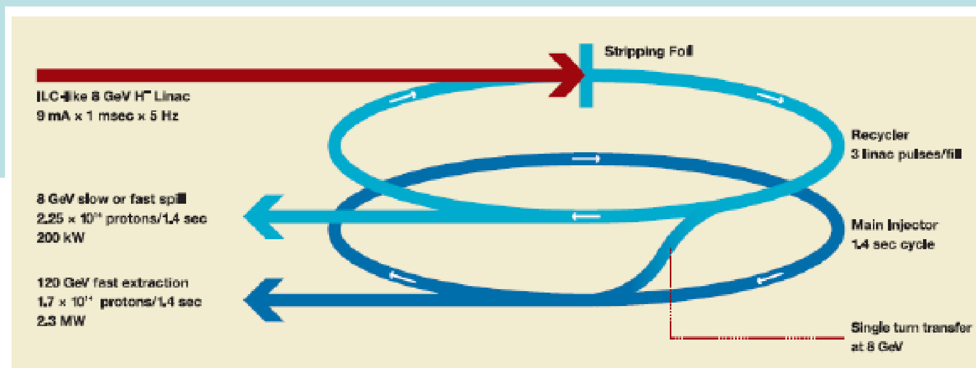
Main Injector Neutrino Program (MINOS,Miniboone,Minerva,NOVA)

8 GeV Booster: Proposals Mu2E (10^{-16}), g-2 (4x), ...

Tevatron Stretcher: $K \rightarrow \pi\nu\bar{\nu}\,? + \ldots$

Future:

Project X



Tevatron Stretcher

Mike Syphers

- Tevatron can be use as a stretcher for providing 120 GeV beams to the existing Fermilab switch yard.
- MI: 120 GeV, 1.33 s cycle time, 2 pulses->Tevatron
- 100 Tp could be stored in the Tevatron for slow extraction using resonant extraction.
- 10% of the available beam would produce 70 kW with a **duty factor of 95%** over a 27.6 s cycle time.

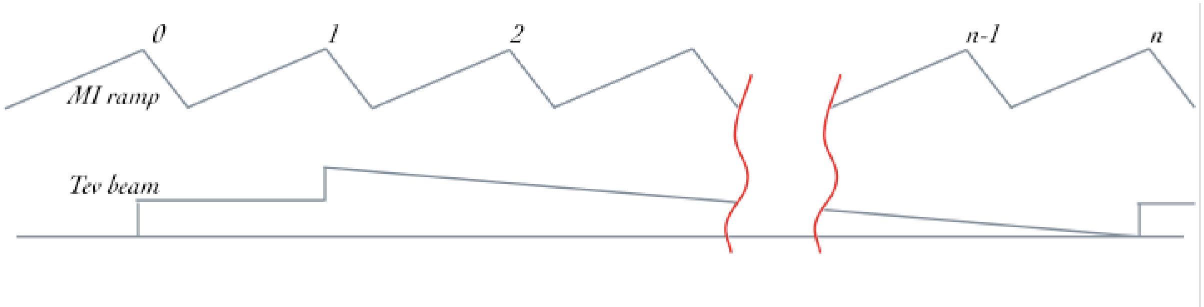


Figure 2. Main Injector energy ramps (top curve) and Tevatron beam intensity (bottom curve). Out of *n*, beam is injected over two cycles, and spilled for *n*-1.

Project X – which one?

Collage Stolen from Jonathon Bagger

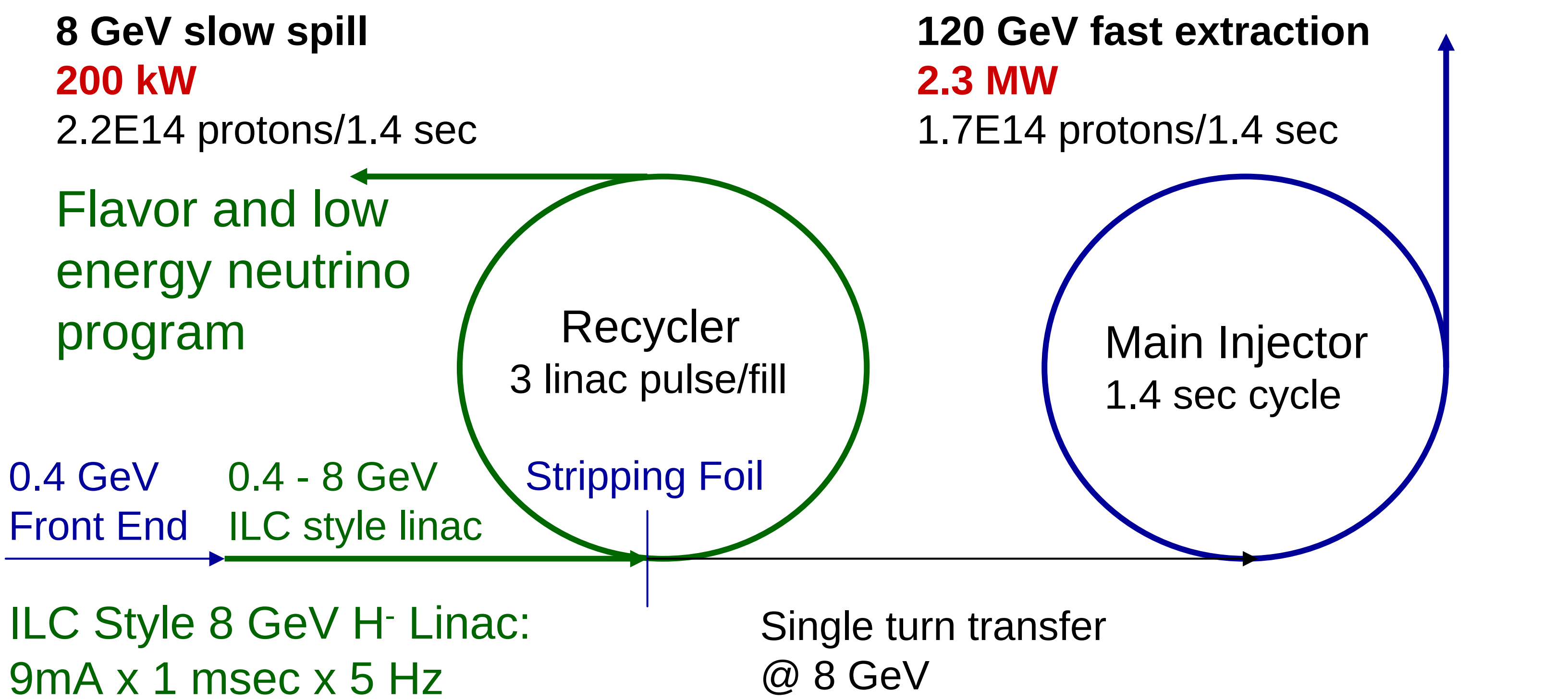
PROJECT X: Search for the Chosen One: An on-line spiritual community that shares personal supernatural experiences.

Steve Holmes
APT seminar 2008

Project X Facility Overview

Project X is a high intensity proton facility aimed at supporting a world leading program in neutrinos and rare decays.

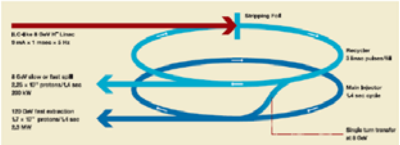
NOνA initially,
DUSEL later?



Project X

Initial Configuration
Performance Goals

Linac		
Particle Type	H^-	
Beam Kinetic Energy	8.0	GeV
Particles per pulse	1.6×10^{14}	
Linac pulse rate	2.5	Hz
Beam Power	500	kW
Recycler		
Particle Type	protons	
Beam Kinetic Energy	8.0	GeV
Cycle time	1.4	sec
Particles per cycle to MI	1.6×10^{14}	
Particles per cycle to 8 GeV program	1.6×10^{14}	
Beam Power to 8 GeV program	360	kW
Main Injector		
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.4	sec
Particles per cycle	1.6×10^{14}	
Beam Power at 120 GeV	2100	kW



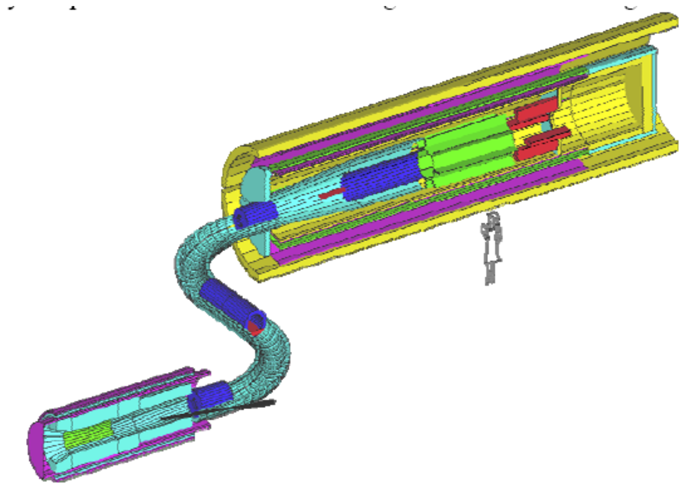
Project X Accelerator Summary

- The Project X design concept supports a long term future for Fermilab based on world leading facilities at the:
  - Energy Frontier
  - Intensity Frontier
- Design concept exists for a facility with >2 MW beam power at 120 GeV, simultaneous with 200 kW at 8 GeV.
  - Major sub-system performance goals established
  - Supports world class program in neutrino physics and rare processes
- Design provides flexibility to support a long-term future for accelerator based physics at Fermilab
  - Potential upgrade paths to mulit-MW at 8 GeV exist
  - Design aligned with needs of ILC technology development
  - Design concept supports future development of muon facilities

8 GeV

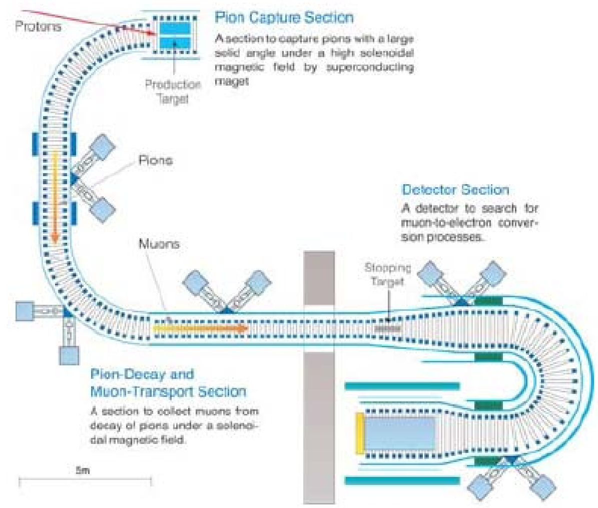
Proposals: $\mu^- N \to e^- N$ at 10^{-16}

Lobashov (1980): Solenoid Pion Collector; flux x 1000.



BNL MECO $\to$ *Mu2E*

$\mu \to$ e Conversion at Fermilab



$\mu \to$ e Conversion

COMET at JPARC

- **Singles experiment mitigates high rates.**
- **Background (decay-in-orbit) known and calculable.**
- **High resolution detector feasible.**
- **Possible improvement x 10^4**

$K^+ \to \pi^+ \nu \bar{\nu}$ and $K_L^0 \to \pi^0 \nu \bar{\nu}$ Possibilities at Fermilab

MI+Tevatron Stretcher and Project X

Requirements:

- High intensity, high duty factor
- Low energy K+ beams.
- Pulsed beams for Neutral K TOF
- Exploit advances in instrumentation

Goals and opportunities:

>1000 events attainable in 3-5 years:

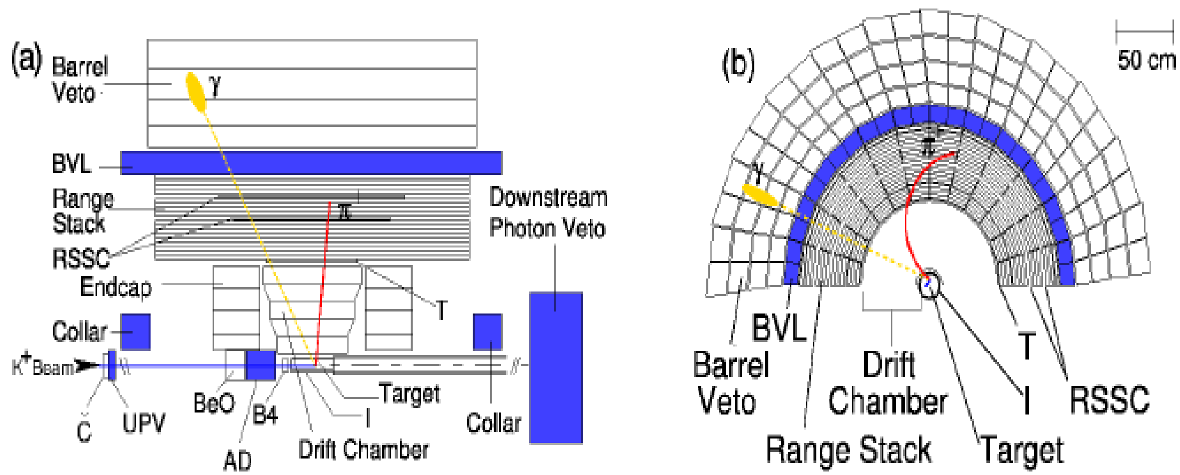
<3% precision, comparable to theory

New opportunity: $K^+ \to \pi^+ \nu \bar{\nu}$ at Fermilab/Tevatron Strecher:

Stopped K technique: 1000 events!

Principal Improvement: Lower P_k ~450 MeV/c

Only modest upgrades to the methods of E949 needed.



- **4-5 x higher stop efficiency at low momentum**
- **Improved Acceptance (x5)**
- **Reduced randoms and accidental spoiling of events (photon veto) due to low momentum.**

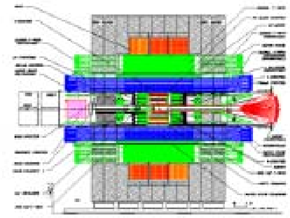
Assumptions and Issues for a new $K^+ \to \pi^+ \nu\bar{\nu}$ Measurement at Fermilab

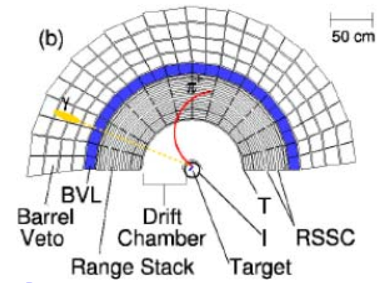
- **New high acceptance short Kaon beam** (E949):
  14.6 (19) **m**; 18 (12) **msr**; **400-550** (710) **MeV/c**
  2 x total acceptance relative to LESB3 at the AGS;
  4-5 x efficiency for stopping kaons
- **Detector Improvements.** Finer segmentation of RS (4-10x) for suppression of muon background; new electronics, DAQ improvements.
  >5 x acceptance of E949.
- **Reduced Accidental losses** from photon veto hits due to low momentum.

Net gain: >200 SM events/yr (100 x E949). *Proven technique.*

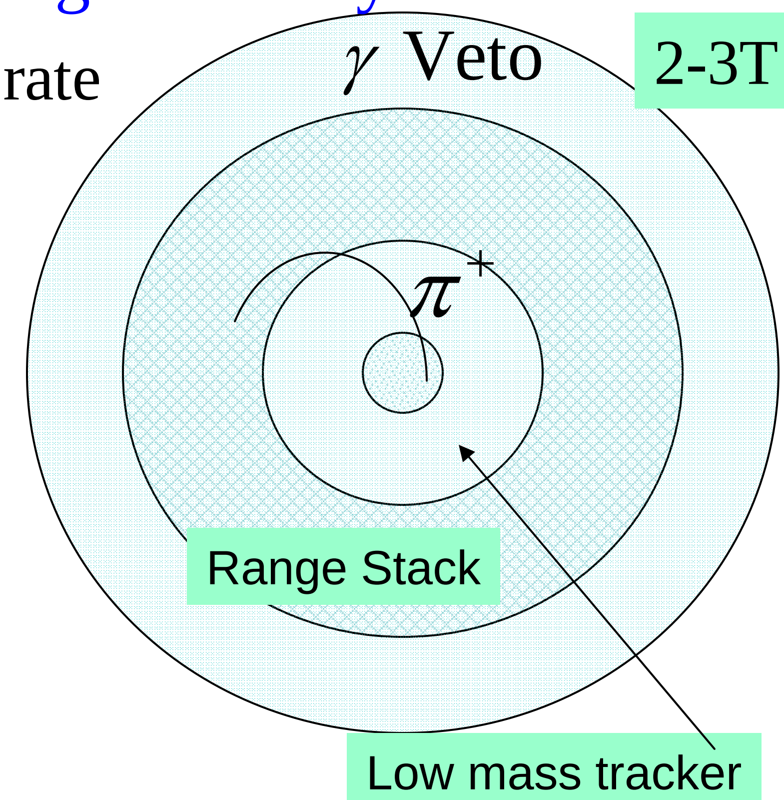
Compact High Field System for $K^+ \to \pi^+ \nu \bar{\nu}$

Major Improvement of E949
Techniques for Project X





- Low P_K ~400 MeV/c for high stopping efficiency
- Sci-Fi target and range stack for high rate $\pi \to \mu \to e$ measurements
- High acceptance and precise momentum measurement to suppress $K^+ \to \pi^+ \pi^0, K^+ \to \mu^+ \nu$ backgrounds
- "Ideal" homogeneous photon veto e.g. LXe 20 X_0

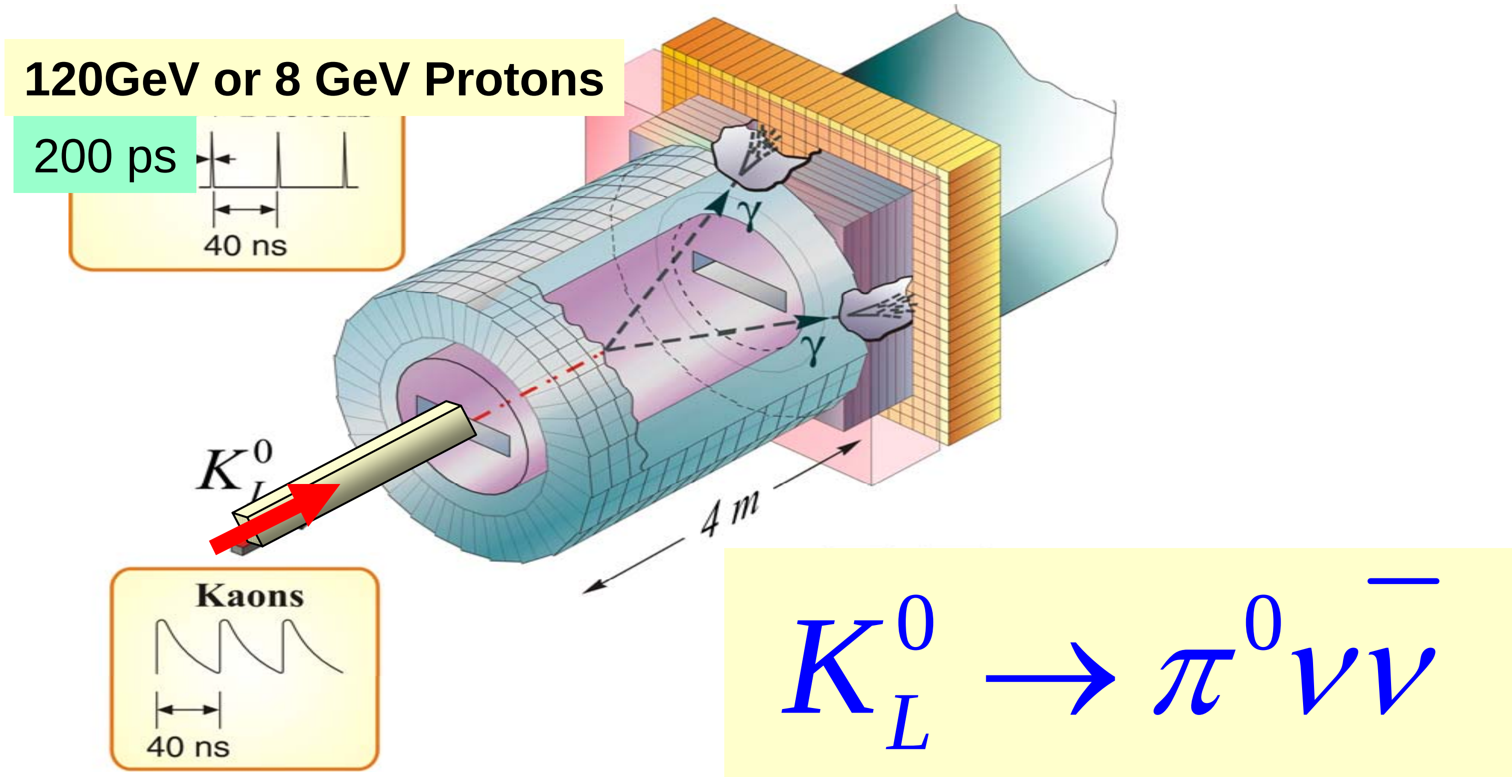


$K^+ \to \pi^+ \nu \bar{\nu}$	**FNAL** **“Booster” (20 kW)**	**FNAL** **Tevatron Stretcher 12%MI**	**FNAL** **Project-X**
Events/yr*	40	200	325
Events/5yr	200	1000	1600
Precision**	**8**	**3.6**	**3**

Estimates based on extrapolation of BNL E949.

***** Includes separate estimates of backgrounds in Regions I (10%) and 2 (75%)*.**

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



- Use TOF to work in the K_L^0 c.m. system
- Identify main 2-body background $K_L^0 \to \pi^0 \pi^0$
- Reconstruct $\pi^0 \to \gamma\gamma$ decays with pointing calorimeter
- 4π solid angle photon and charged particle vetos

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

High intensity of Project X is ideal for the TOF-based K_L experiment.

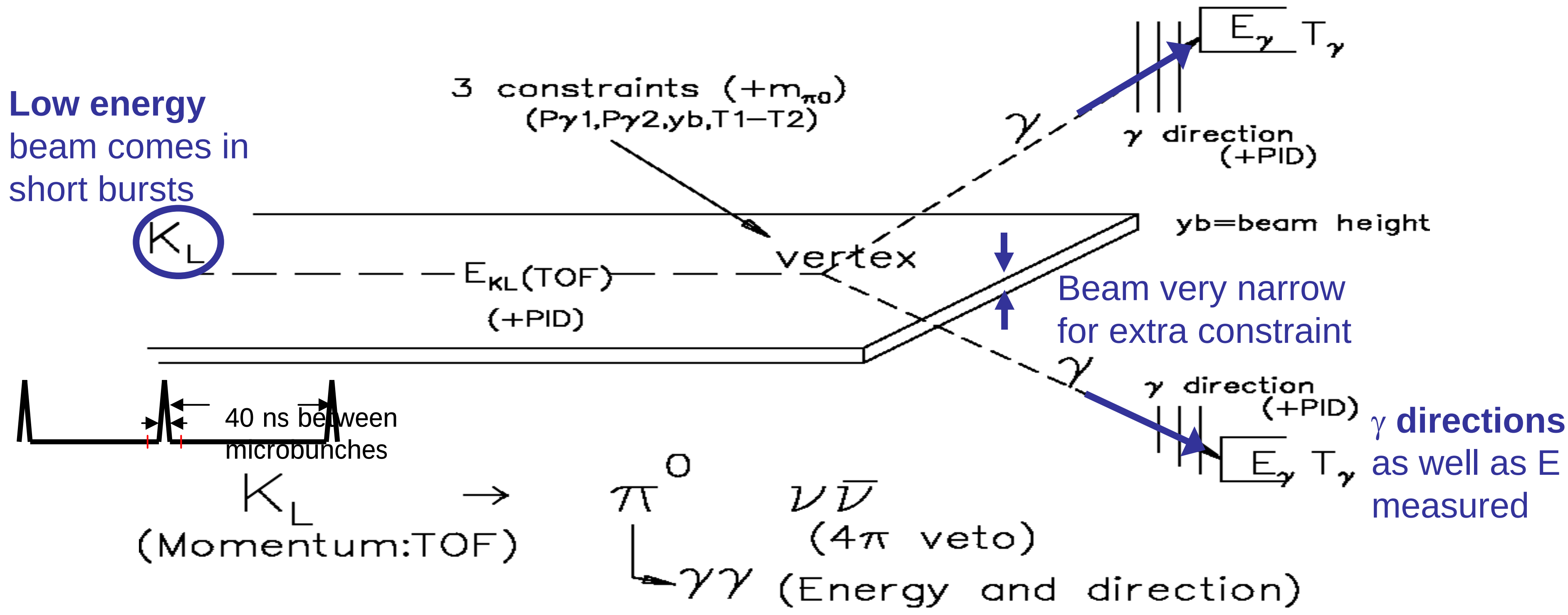
- Small aperture, symmetric beam - makes for simpler, higher acceptance detector
- Exploit advances in instrumentation

- 300 events/year at 1st stage of Project X; 3% precision possible after 5 years.
- 5 times higher intensity could be used to get ~900 events/year
- **Similar possibilities may be available with the MI+Tevatron Stretcher approach**

TOF-based experiment

Intense source of protons (e.g. J-PARC, Project X) allows

a low energy approach to studying $K^+ \to \pi^+ \nu\bar{\nu}$ (à la KOPIO)



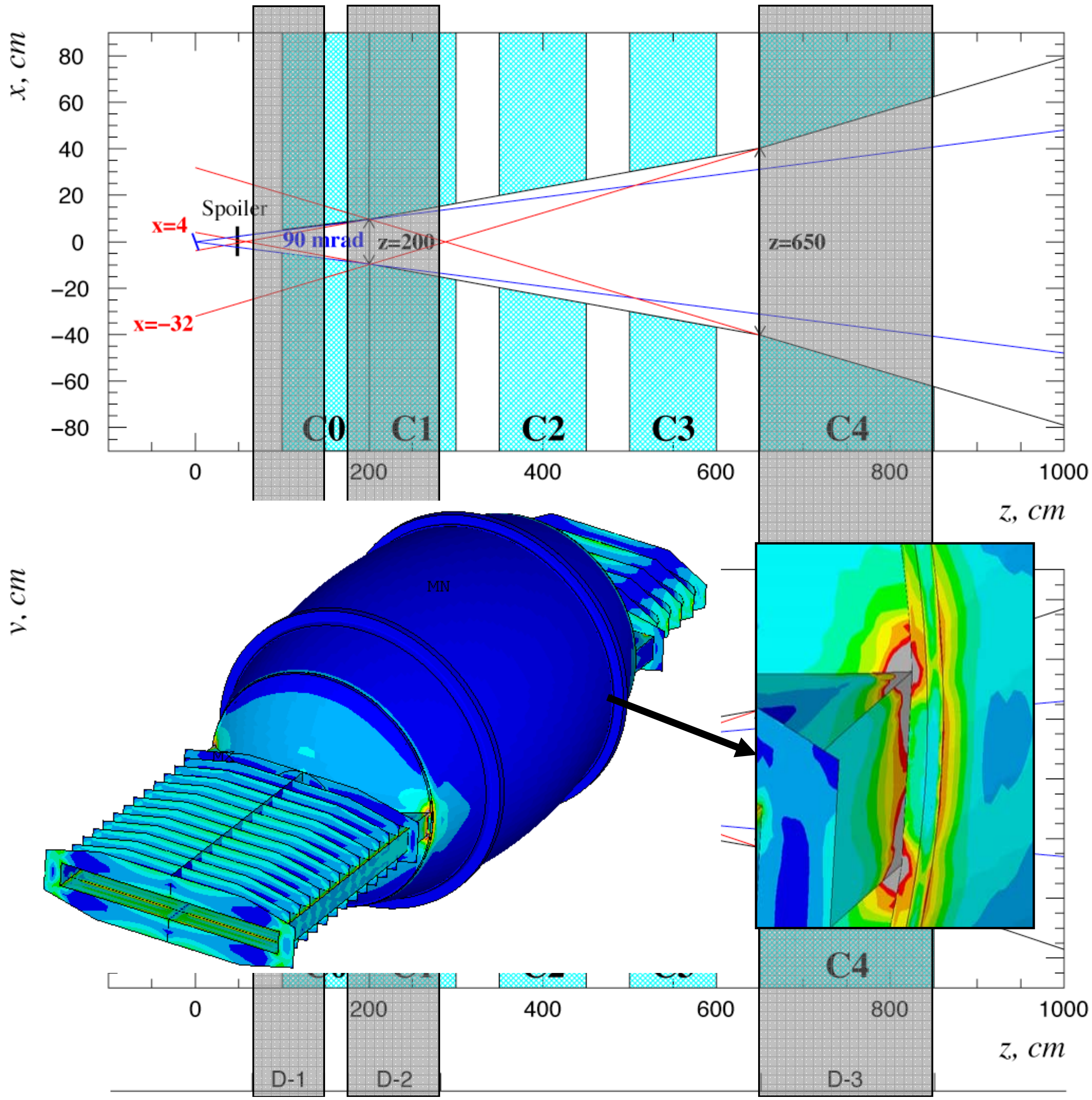
A major issue in the KOPIO design was the very wide beam.

KOPIO Challenge #1: Beamline

- Complex, costly series of collimators

- 3 large sweeping magnets

- Plenty of aperture for particles created upstream to reach fiducial region
- “Difficult” vacuum vessel



L. Littenberg

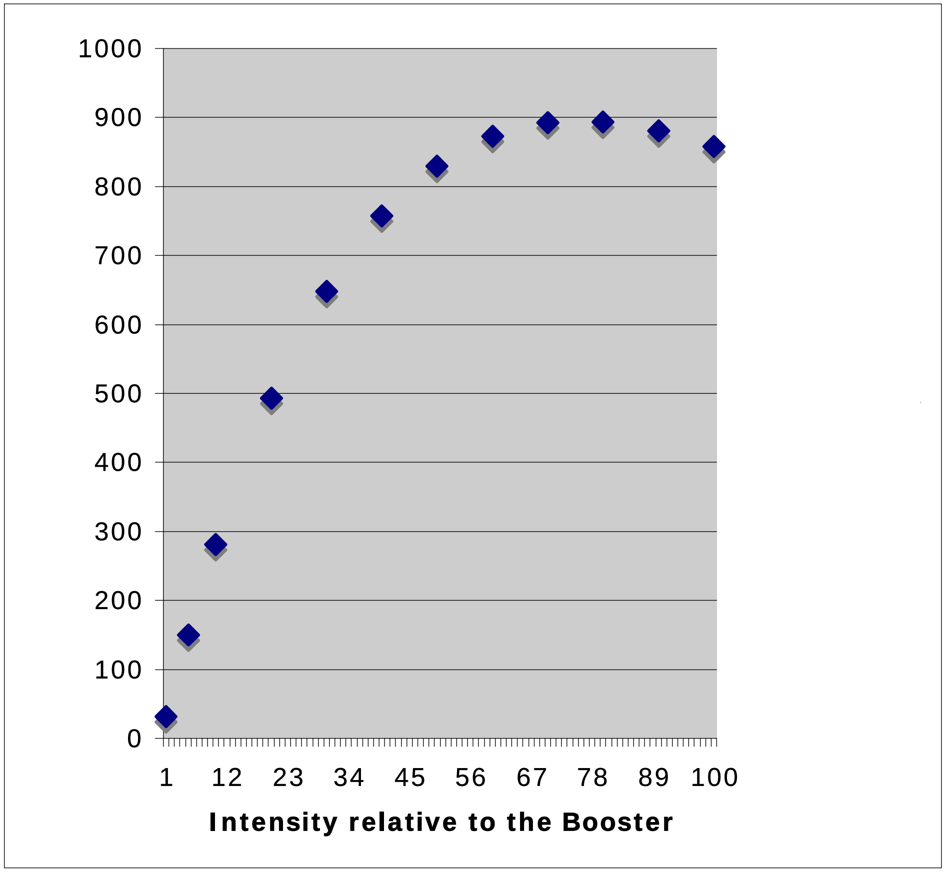
Small Beam: Many Advantages

- “Difficult” vacuum vessel disappears
- Geometric acceptance increases since horizontal plane accessible
- Beamline simpler, cheaper, better
- Upstream background disappears, so do some types of background in the fiducial volume
- Same micro-bunch event spoilage disappears
- Random vetoes much reduced
- Extra kinematic constraint increases S/B
- Beam veto probably unnecessary
- Beam spoiler probably unnecessary
  - Gives 72% more kaons/proton
  - Much reduced neutron spreading
- Detector can be symmetrized, geometric acceptance increased

L. Littenberg

Sensitivity of Small Beam Exp.

- At 1st stage Project-X, 300 equivalent events per year
- Can get to 900 equivalent events per year using 60% of 2nd stage Project-X
- Experiment might even be improved beyond this…



Kaon Experiment Issues

- Details of schemes for delivering ~100% duty factor.
- Uncertainties in low energy K production cross-sections at 8 GeV and 120 GeV.
- Micro-bunching and neutrons at 120 GeV production.
- Dual targeting for charged and neutral experiments appears feasible but needs examination.
- Some detector technology R&D would be valuable.
- Further development of CKM parameters (from theory and B physics) needed for 3% measurements.

Summary

* Fermilab has great potential for contributing to the intensity frontier:

Neutrino Physics -- oscillation phemomenolgy

Muon (mue Conversion, g-2) and Kaon Rare Decays ($K \rightarrow \pi\nu\bar{\nu}$)

* Significant work can be done with existing facilities:

MI, Booster and MI+Tevatron Strecher

* Project X promises to provide extraordinary opportunities for
  new physics discovery

Acknowledgements

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