Bonnie Fleming
Yale University
GS Cryodet Workshop
March 13, 2006

Neutrino Events in a Liquid Argon detector on the NuMI Neutrino Beamline

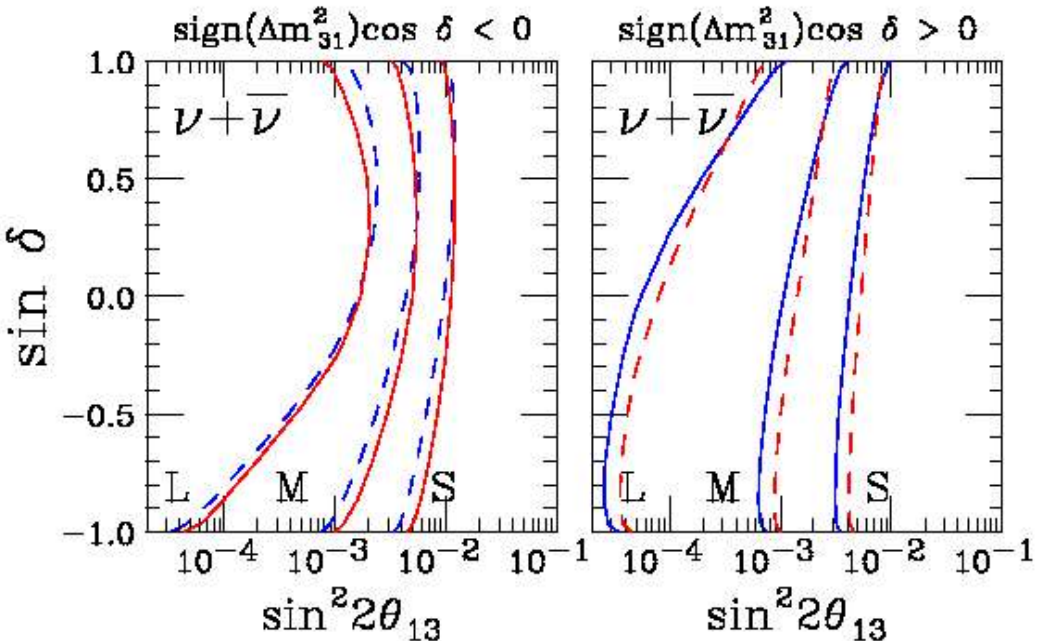
- Motivation
- NuMI neutrino beam
- Seeing neutrinos from NuMI

0.5-5 GeV neutrino energy regime is the region of interest for long baseline ν_e appearance searchs

0ff-axis beams: 1st and 2nd oscillation maxima

Wide-band neutrino beams (VLBNO)

LAr detectors ameliorate the statistics limitations and background rejection capabilites of conventional detectors



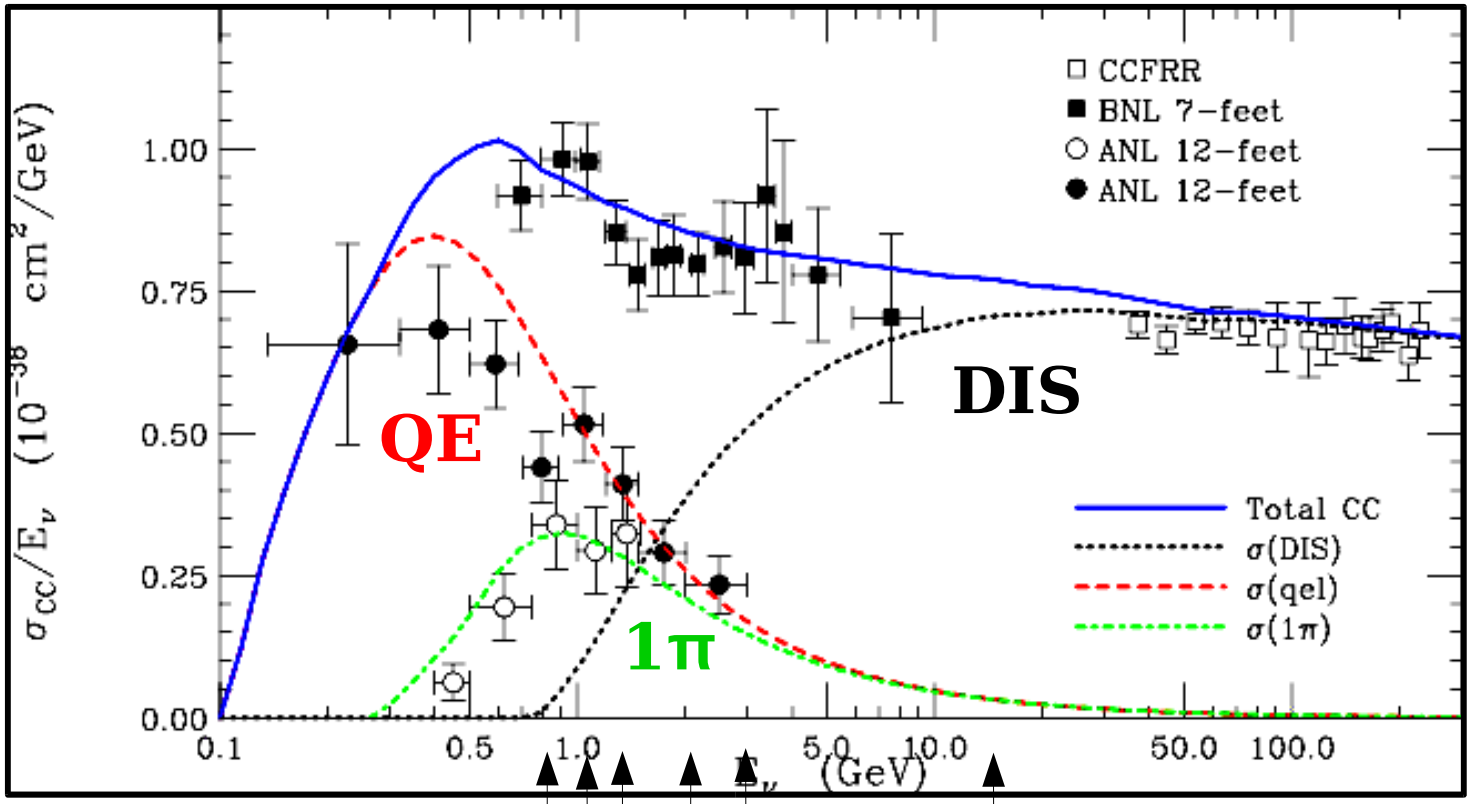
hep-ph/0505202

S=small:
30 kton NOvA
8 kton LArTPC

M=Medium
30 kton NOvA x5
40 kton LArTPC

etc.....

Low Energy Neutrino Interactions....



MiniBooNE

T2K

K2K

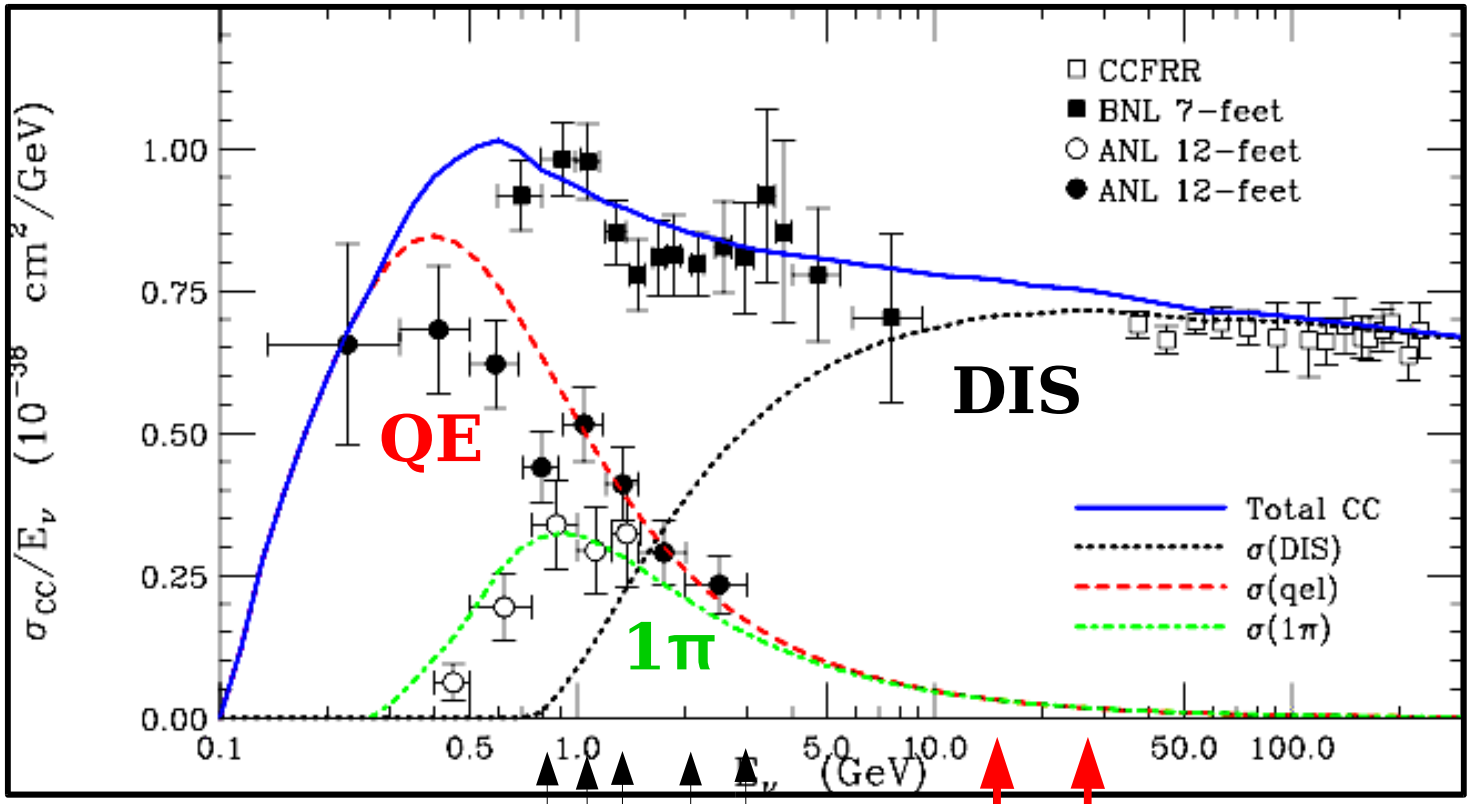
NuMI off-axis

NuMI on-axis

CNGS

Running and future beams

Low Energy Neutrino Interactions....



MiniBooNE

T2K

K2K

NuMI off-axis

NuMI on-axis

CNGS

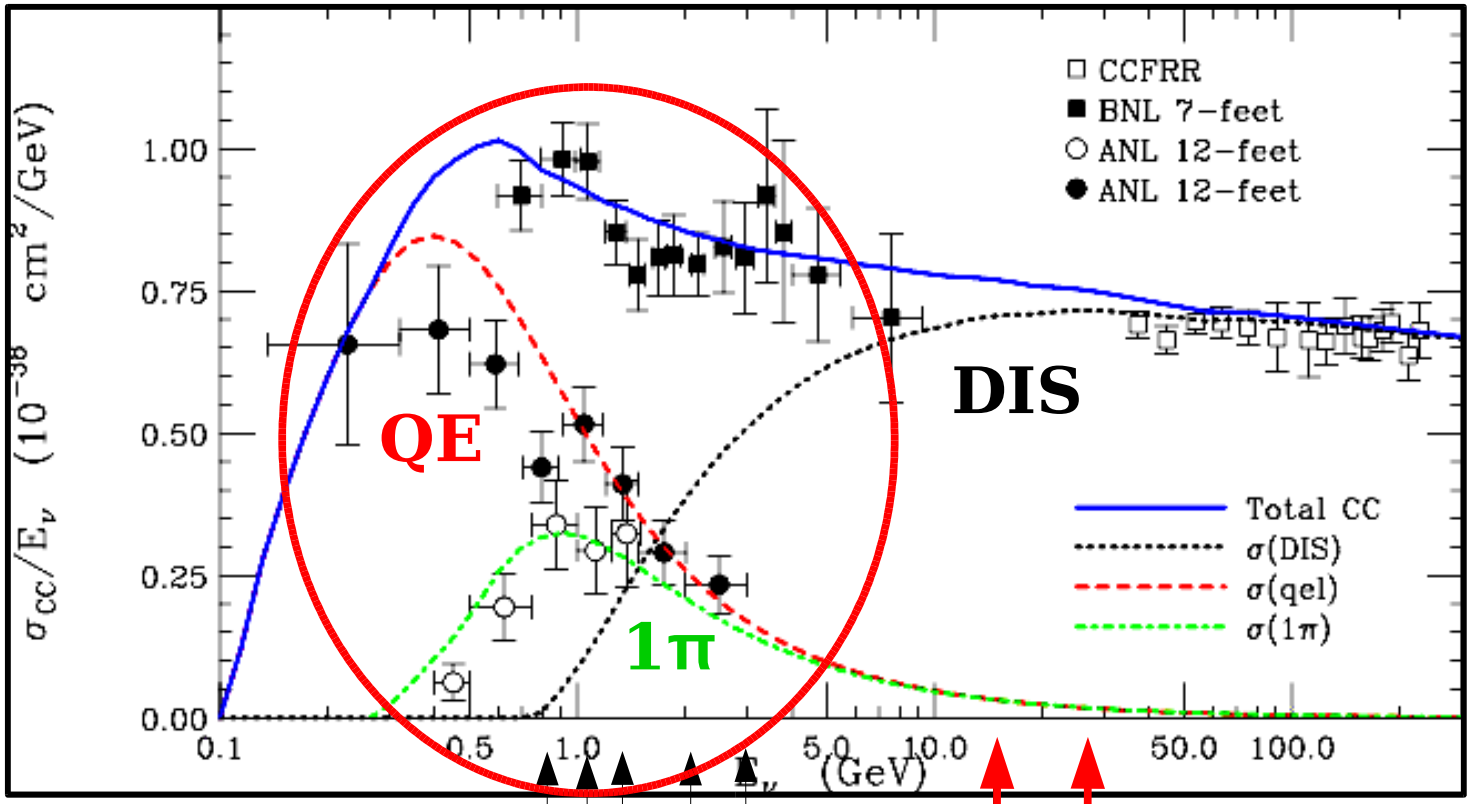
T600

50 lt

Running and future beams

LAr neutrino data

Low Energy Neutrino Interactions....



MiniBooNE

T2K

K2K

NuMI off-axis

NuMI on-axis

CNGS

T600

50 lt

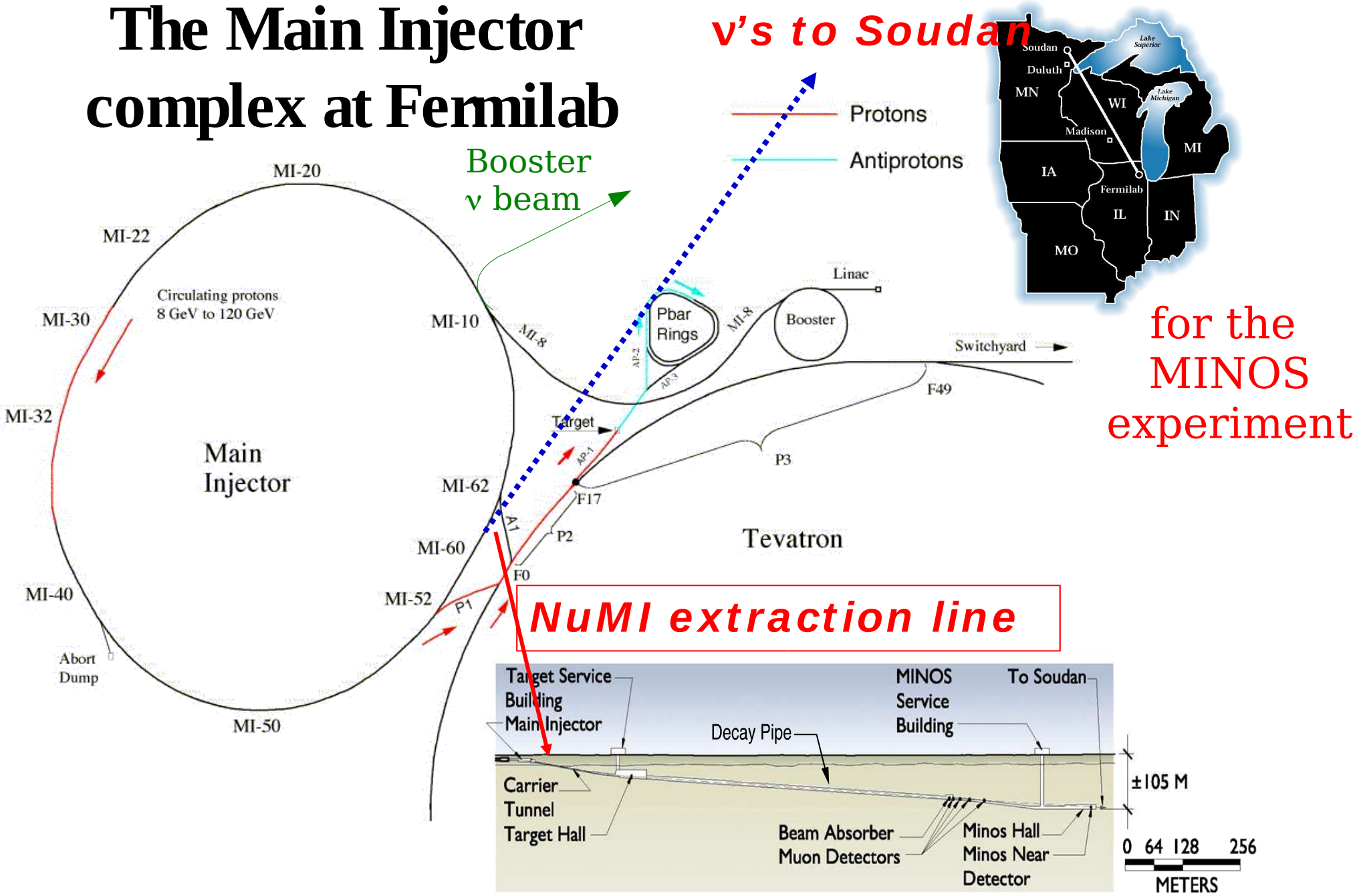
Running and future beams

LAr neutrino data

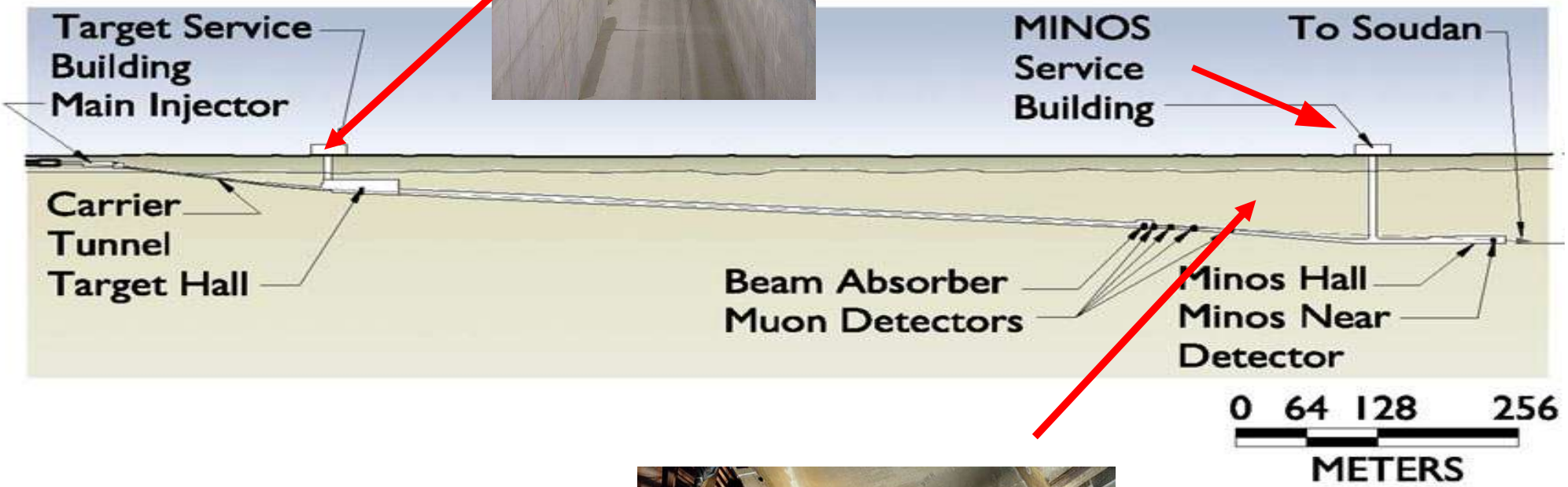
higher energy low statistics

Neutrinos from the NuMI beam at Fermilab

The Main Injector complex at Fermilab



NuMI beam-line

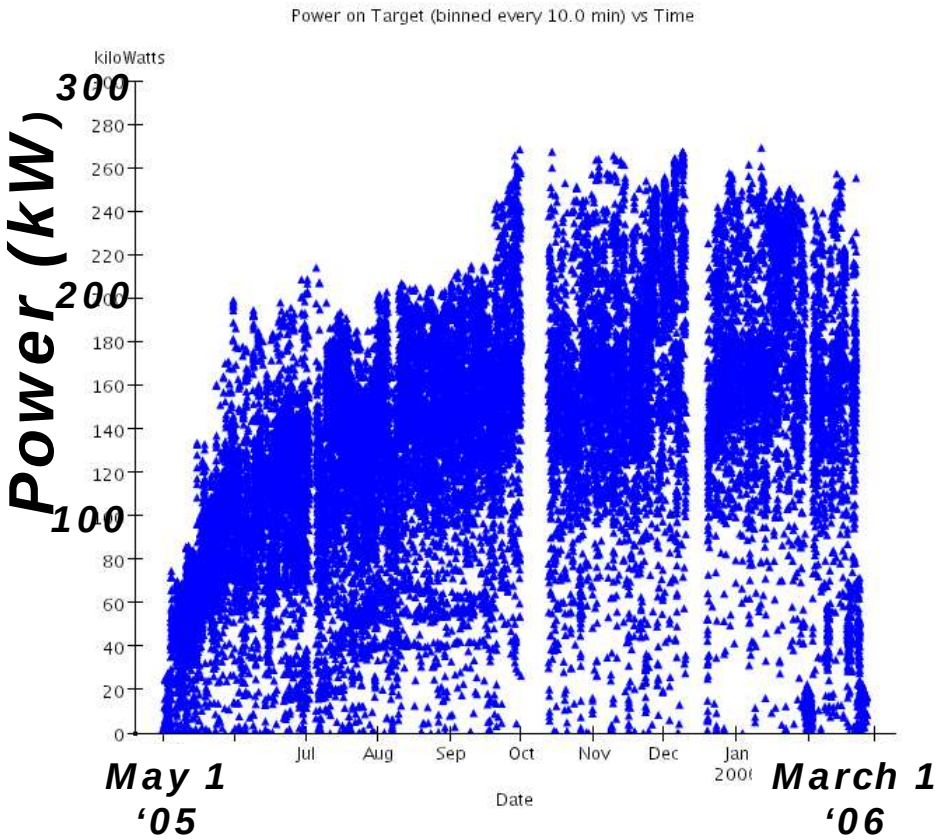


NuMI performance

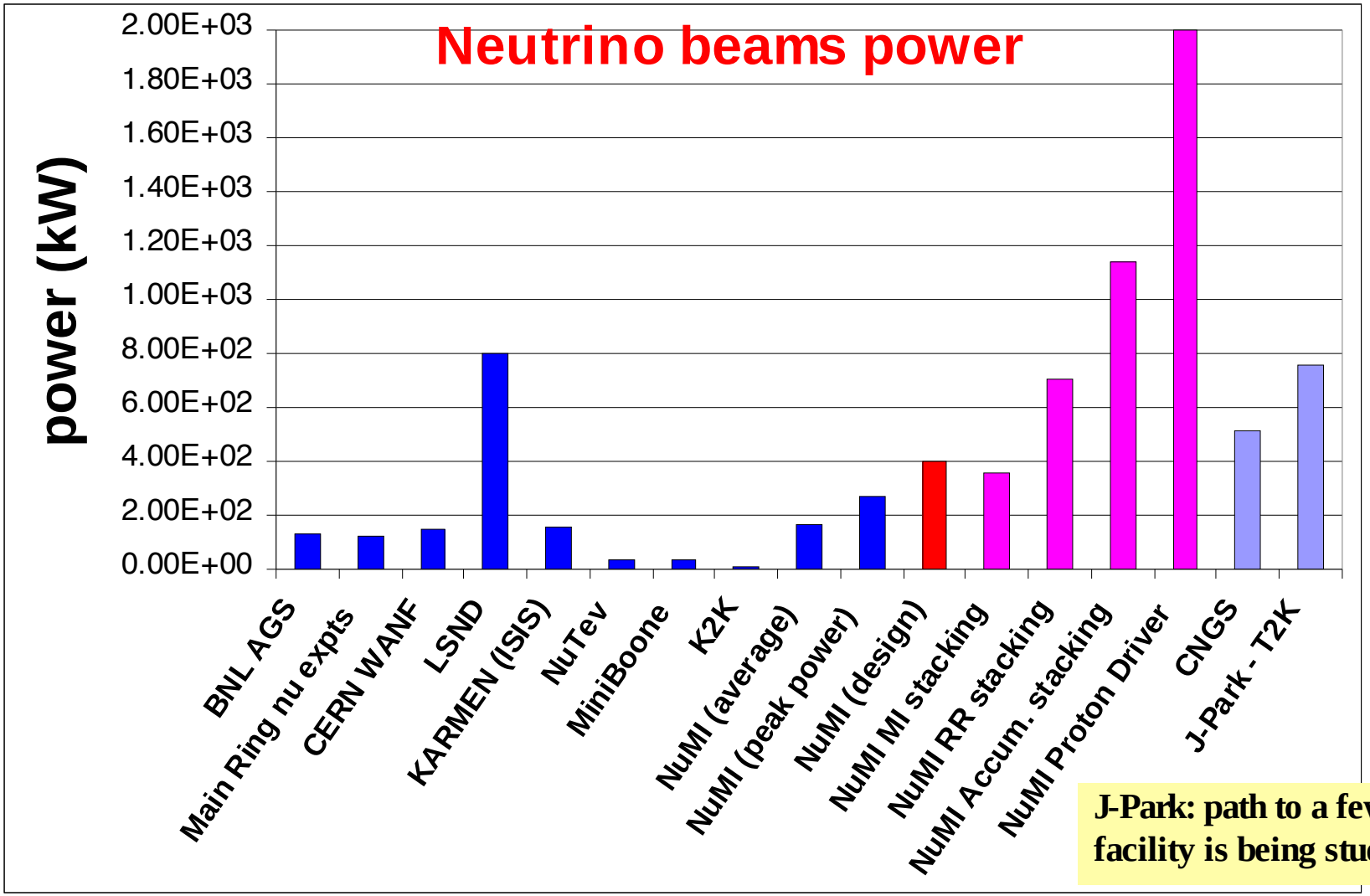
average power of 165 kW in the last few months

reached a max beam power of 270 kW down the NuMI line (stably for ~ ½ hour)

reached a peak intensity of 3×10^{13} ppp on the NuMI target

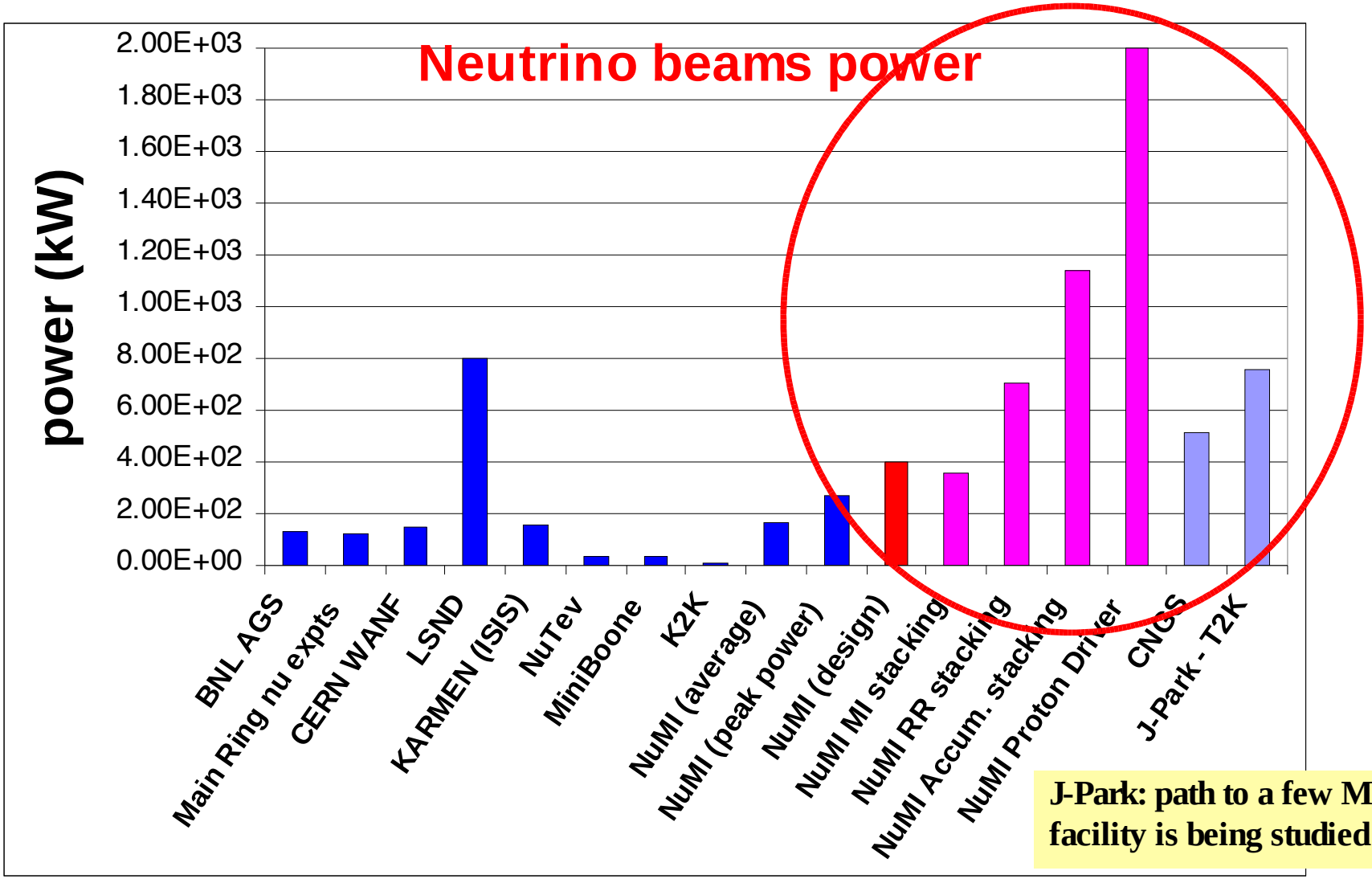


Performance comparison....



J-Park: path to a few MW facility is being studied

Performance comparison....



J-Park: path to a few MW facility is being studied

Upgradeable to higher intensities

long-term viability of this beamline for neutrino physics

Neutrino beams for extensions to MINOS

Intensity increases:

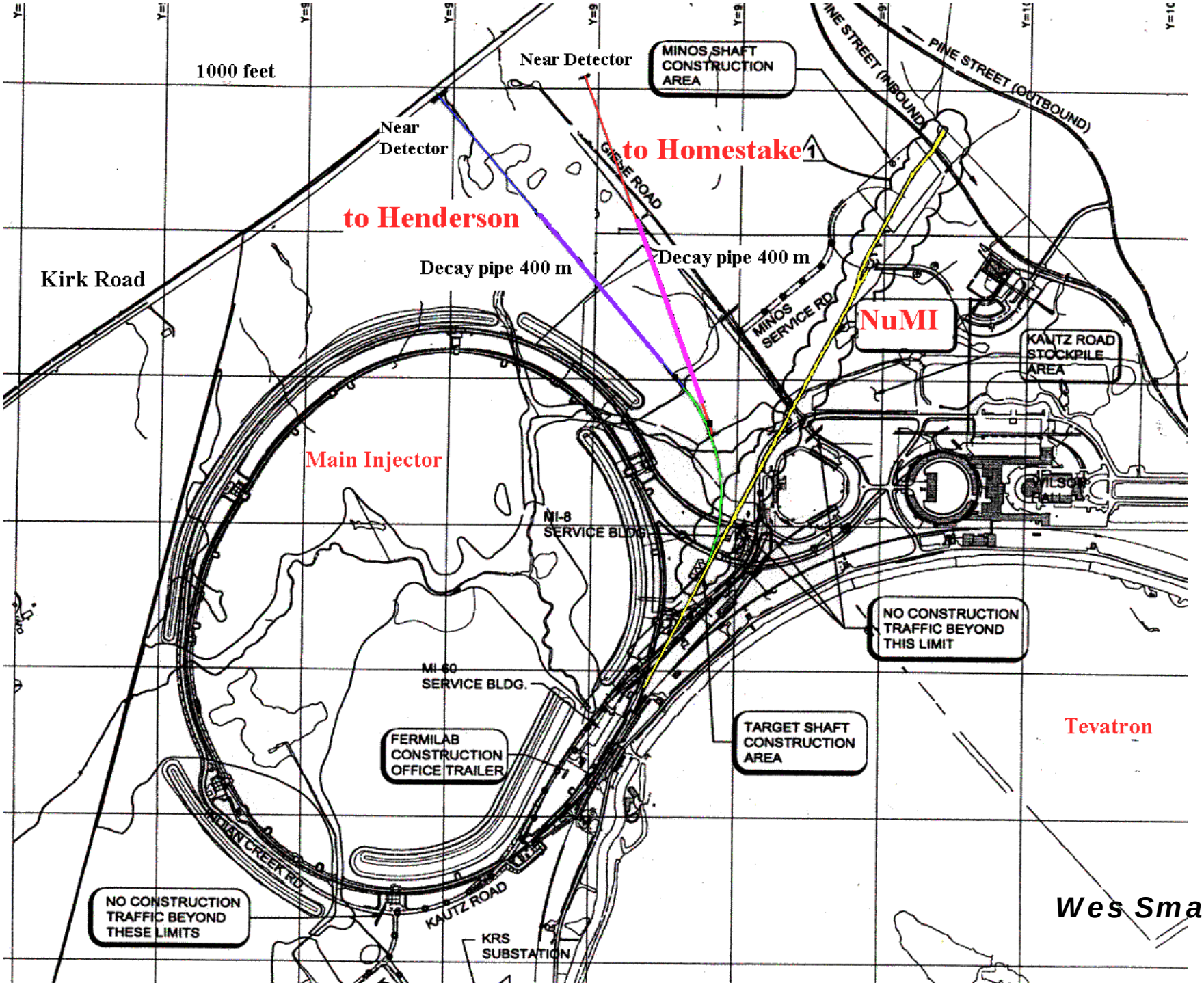
- slip stacking in Main Injector
- Booster batch storage in the recycler
- Shortening of main injector cycle time
  - timing modifications
  - extraction energy modifications
- Further understanding of beam losses

Neutrino beams towards a DUSEL site

Intensity upgrades above/PD + new beamline

W. Smart

	Latitude	Longitude	Vertical angle from FNAL (deg)	Distance from FNAL (km)
Homestake	44.35	-103.77	-5.84	1289
Henderson	39.76	-105.84	-6.66	1495


1000 feet
Near Detector
MINOS SHAFT CONSTRUCTION AREA
PINE STREET (INBOUND)
PINE STREET (OUTBOUND)
Near Detector
to Homestake
GIESE ROAD
to Henderson
Decay pipe 400 m
Decay pipe 400 m
Kirk Road
MINOS SERVICE RD
NuMI
KAUTZ ROAD STOCKPILE AREA
Main Injector
MI-8 SERVICE BLDG.
NO CONSTRUCTION TRAFFIC BEYOND THIS LIMIT
MI-60 SERVICE BLDG.
FERMILAB CONSTRUCTION OFFICE TRAILER
TARGET SHAFT CONSTRUCTION AREA
Tevatron
INDIAN CREEK RD
KAUTZ ROAD
NO CONSTRUCTION TRAFFIC BEYOND THESE LIMITS
KRS SUBSTATION

Wes Smart

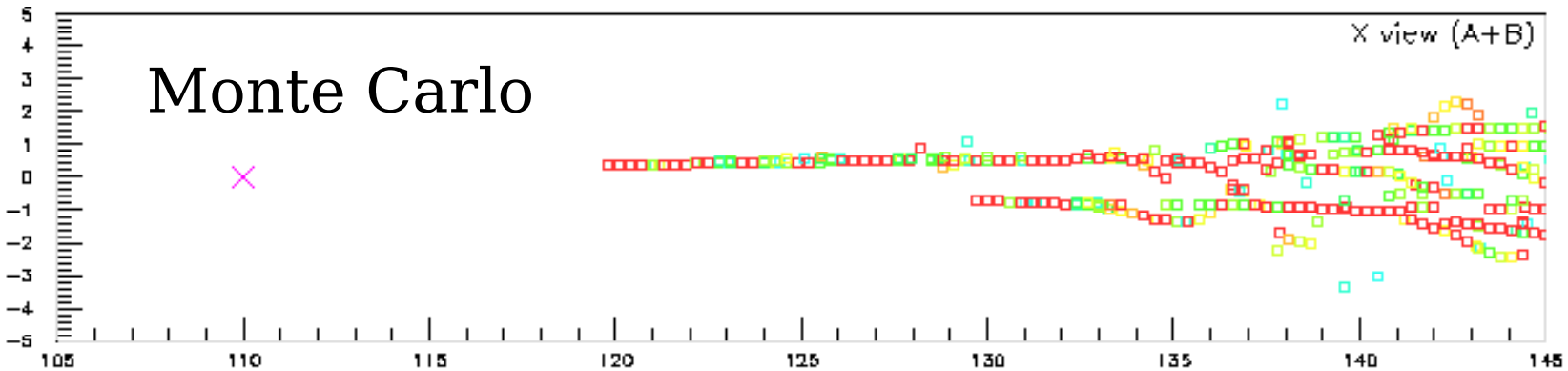
Seeing Neutrinos at NuMI..

Seeing Neutrinos at NuMI..

Why bother?

Efficiencies and mis-ID estimates are extremely promising!

$\pi^0 \rightarrow \gamma\gamma$ identified by two trackes emerging from displaced vertex, coupled with e^+e^- dE/dx shower deposition

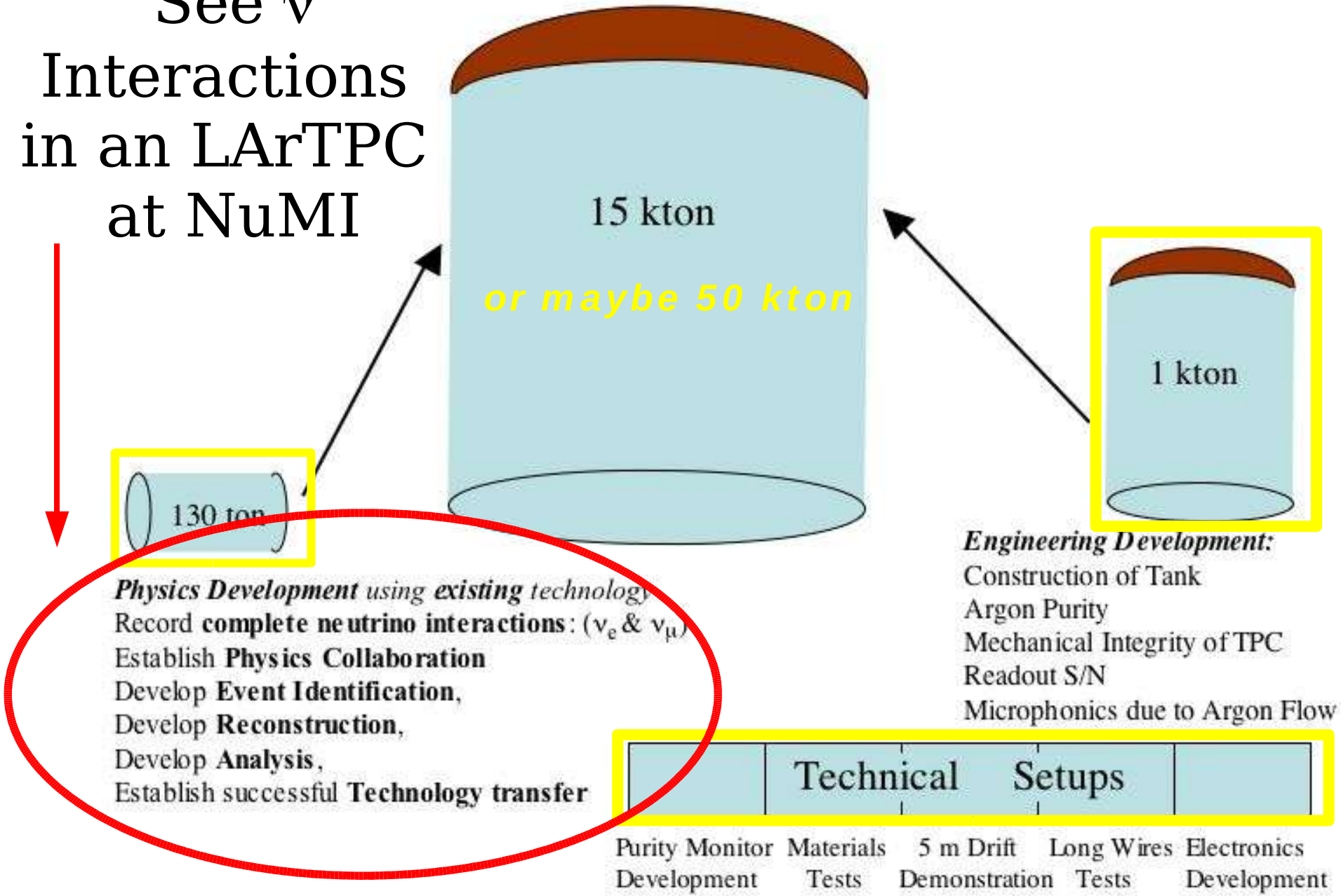


Need a sizable sample of e's and π^0's from neutrino interactions at 2 GeV....

- How bad is mis-ID?
- How good is ν_e efficiency?
- How small are backgrounds from other channels?
- Are cosmic backgrounds a problem?
- How good is energy resolution?
- What about angular resolution?

Physics R&D

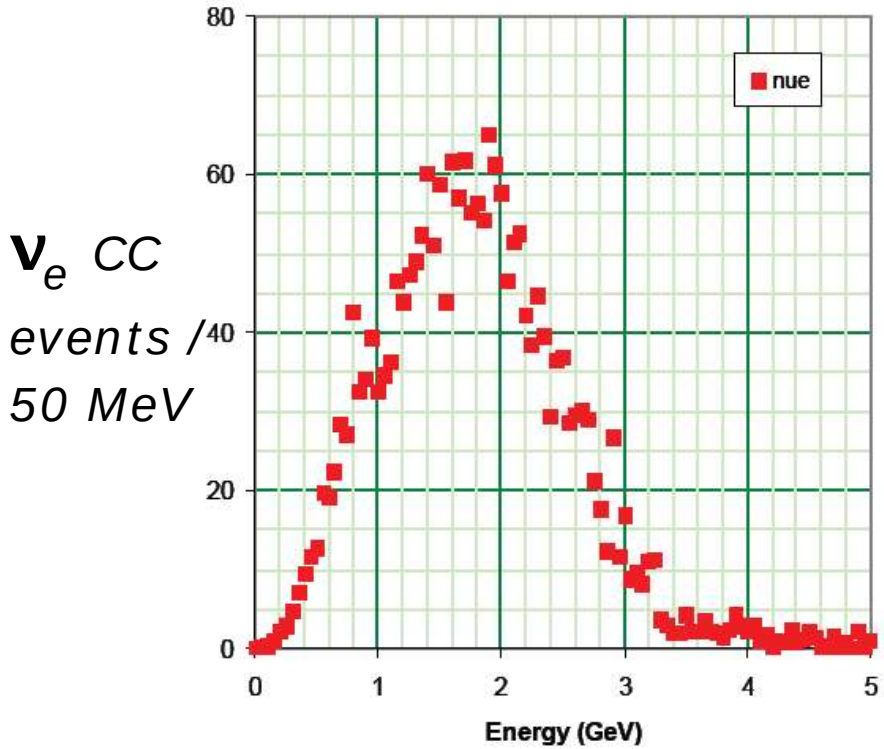
See ν Interactions in an LArTPC at NuMI



2 GeV off-axis NuMI beam

Electron Neutrinos in MINOS Surface Building

From the NOvA Proposal March 15, 2005



- *The charged current ν_e event spectrum in the MINOS surface building.*
- *The ν_e event spectrum peaks just below 2 GeV.*
- *There are ~2,000 ν_e events shown here for 6.5E20 POT and the 20.4 ton fiducial mass NOvA near detector.*

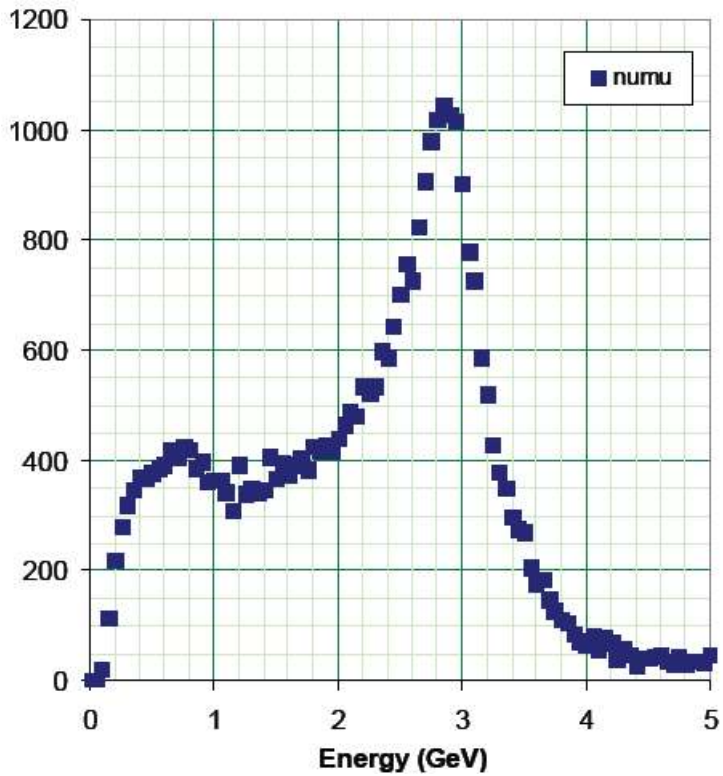
NuMI is presently providing ~2E20 POT per year.

- ***a 50 ton (fid. vol) LAr TPC detector will see ~1600 ν_e events/year***

Muon Neutrinos in MINOS Surface Building

From the NOvA Proposal March 15, 2005

ν_μ *CC events / 50 MeV*

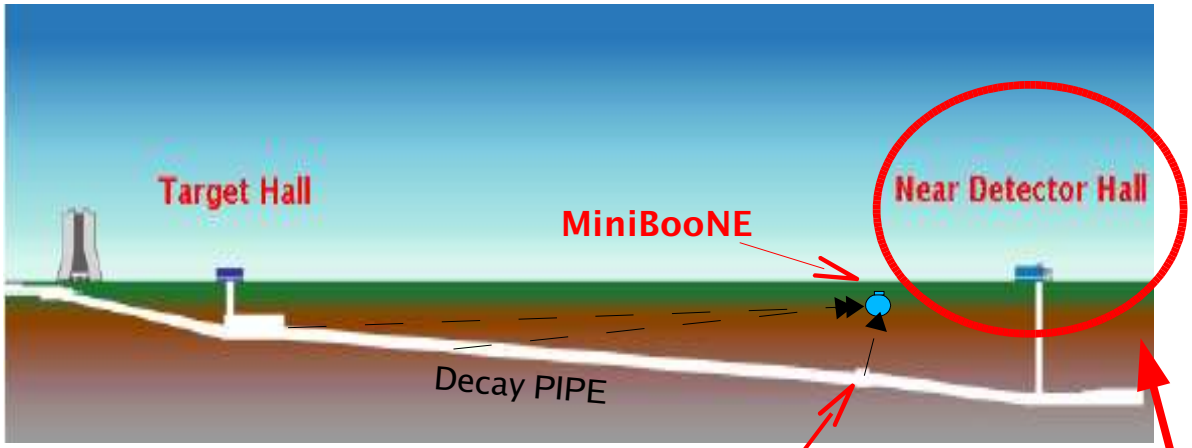


- *Same assumptions as previous slide, except this shows ~15,000 muon neutrinos.*
- *The* ν_μ *peak at ~2.8 GeV is from Kaon decay.*

- ***a 50 ton (fid. vol.) LArTPC detector will see ~34000 νCC events/year***

Experiments seeing off-axis neutrino beams at FNAL are already a reality!

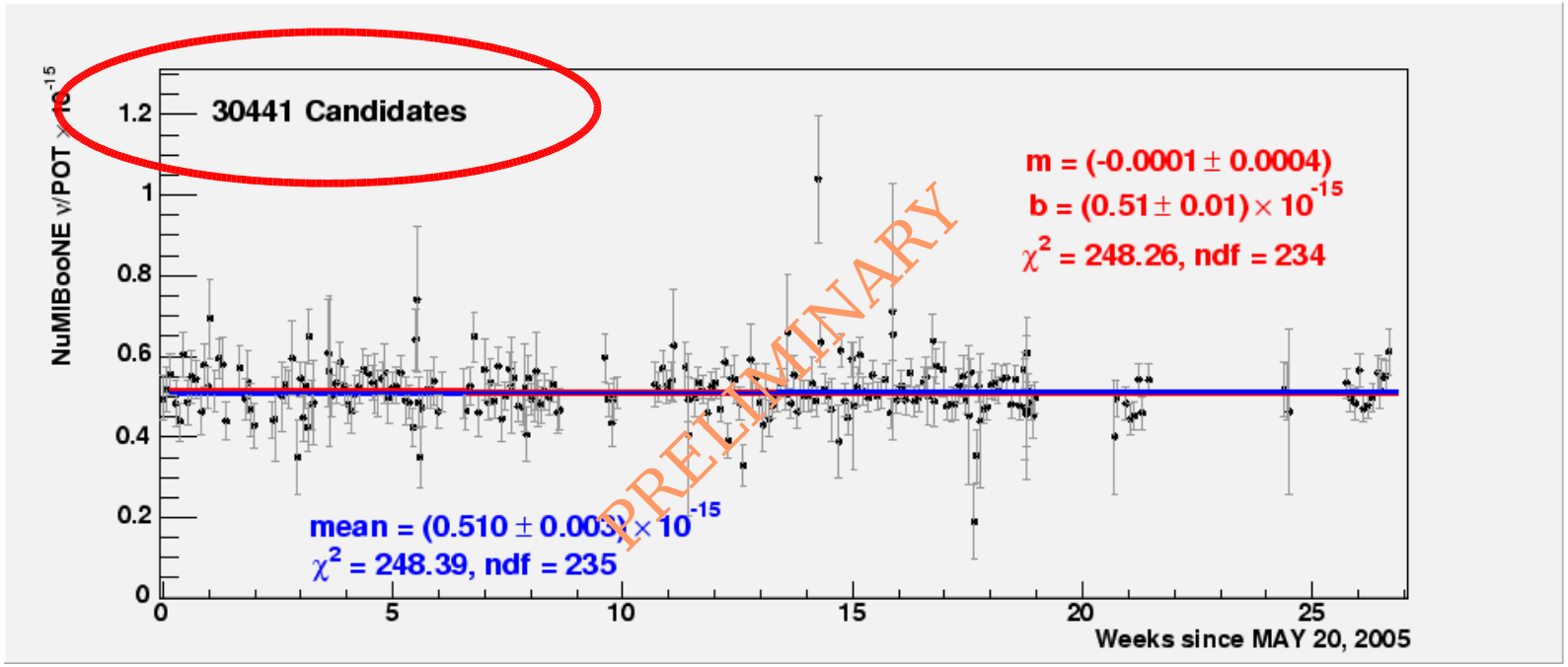
Neutrino beams are big! MiniBooNE sees NuMI beam!



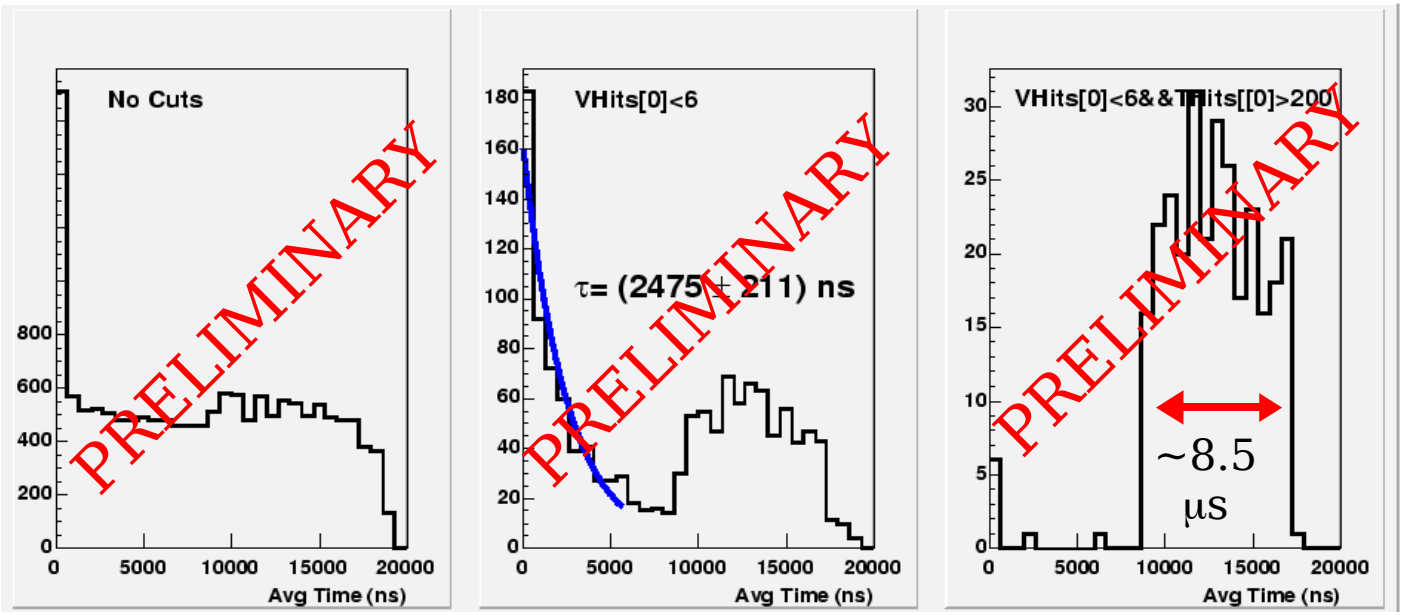
NuMI beam line

Absorber (Beam

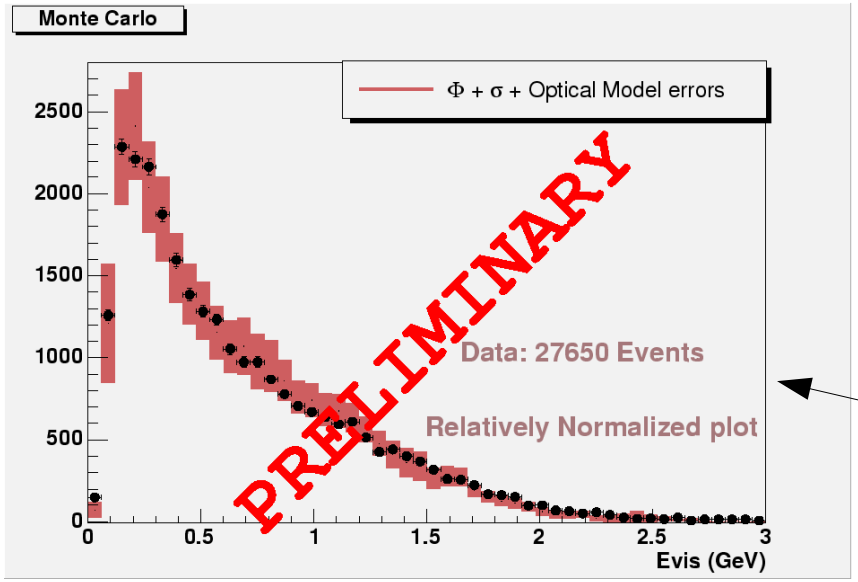
plenty of real estate here



Simple cuts -> Neutrinos hitting MiniBooNE



width of beam pulse
from Main Injector to NuMI



Already beginning to
understand off-axis
NuMI beam using
MiniBooNE

What can we learn beyond Physics R&D?

Ingredients for precision, low energy, neutrino cross section measurements

- High intensity beams → high event rates

- Minimize flux uncertainties
  - 15-20% in the past → 5% expected by MiniBooNE and less by MINOS/MINERvA

reduced statistical errors

- Minimize background contamination
  - low energy neutrino spectrum (below DIS turn-on and with small high energy tail)
  - fine-grained detector →good final state separation -- K2K SciBar measurements

reduced systematic errors

What can we learn beyond Physics R&D?

Ingredients for precision, low energy, neutrino cross section measurements

- High intensity beams → high event rates

- Minimize flux uncertainties
  - 15-20% in the past → 5% expected by MiniBooNE and less by MINOS/MINERvA

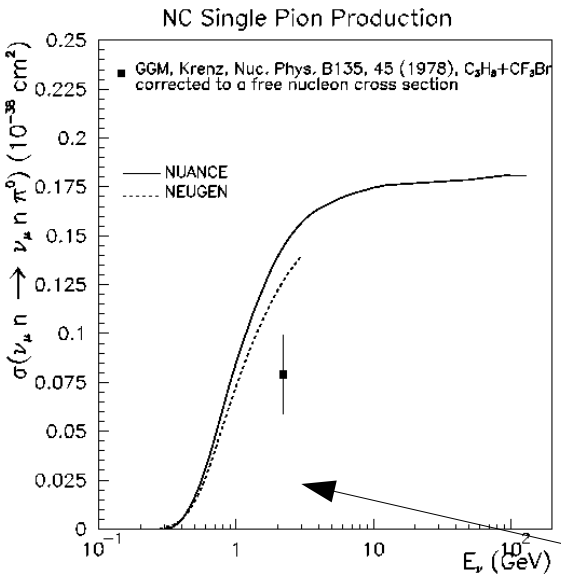
reduced statistical errors

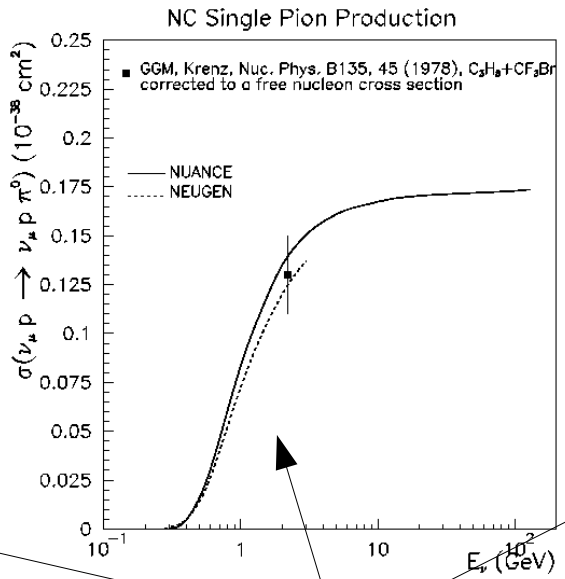
- Minimize background contamination
  - low energy neutrino spectrum (below DIS turn-on and with small high energy tail)
  - fine-grained detector →good final state separation -- K2K SciBar measurements

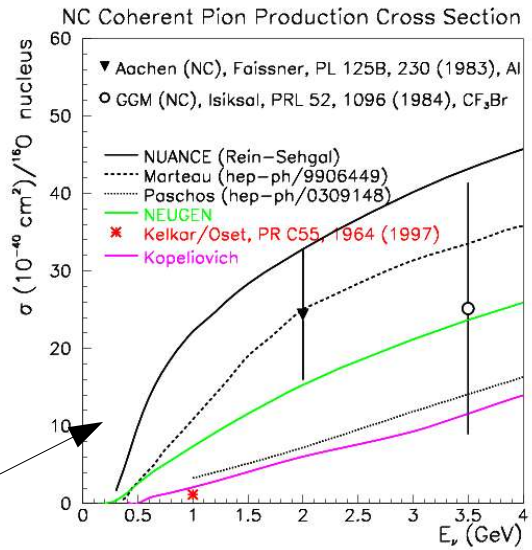
reduced systematic errors

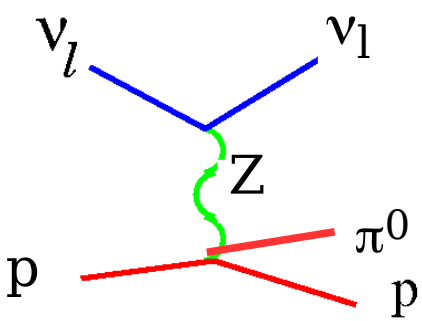
LArTPC running in a high intensity, low energy neutrino beam brings together all of these components for the first time!

Neutral current π^0 production: least known cross section at low energies!









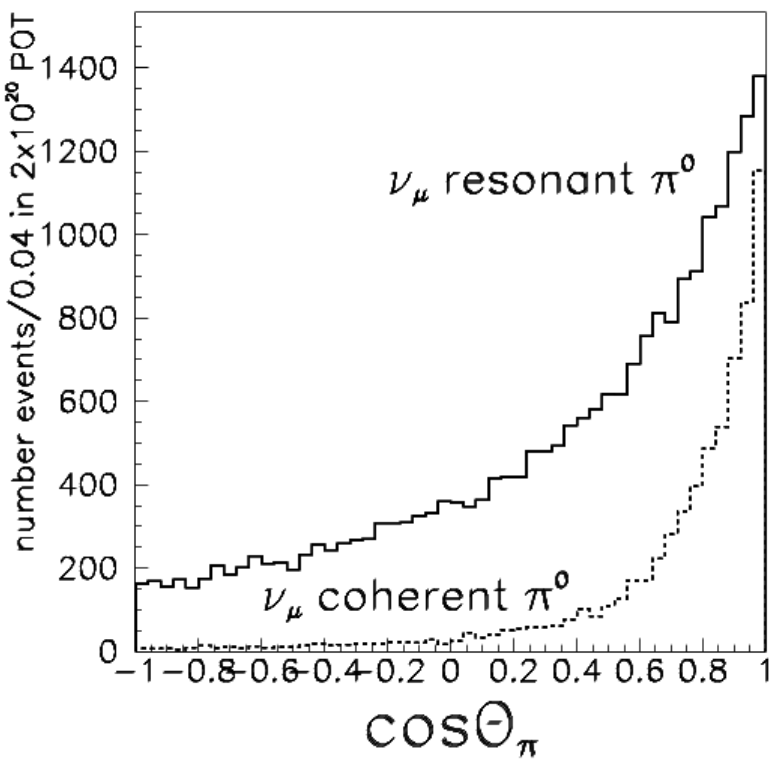
No data below 2 GeV

Lack of data and conflicting predictions →experiments assume 100% uncertainty

→ need fine-grained detector to distinguish π^0s from ν_es

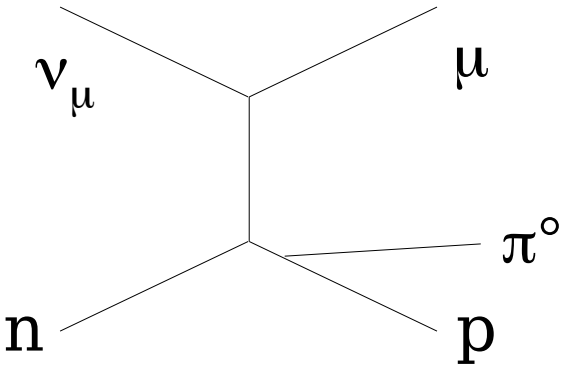
Both rate and kinematics of π°s are not well known...
→ different contributions from resonant and coherent

Fine-grained detectors can take
advantage of shape of contributions in extracting data



Comparisons to
less dominant channels
can also help unfold
resonant vs. coherent

CCπ°→ ~5% events



Resonant only!

Need fine-grained, high statistics data set

What do you gain from higher statistics?
Cross Section measurements!

Basis of Existing QE σ Knowledge

$< E_\nu >$	Exp	Mode	Target	Year	# QE events
0.7 GeV	ANL	ν	D_2	1973	166
0.5 GeV	ANL	ν	D_2	1977	600
2 GeV	CERN	ν	C_3H_8	1979	26
2 GeV	GGM	ν	C_3H_8	1979	622
0.5 GeV	ANL	ν	D_2	1981	1737
1.6 GeV	BNL	ν	D_2	1981	1138
5-200 GeV	FNAL	ν	D_2	1983	362
6 7 GeV	SKAT	ν	CF_3Br	1988	464
9 GeV	SKAT	ν	CF_3Br	1990	540
54 GeV	BEBC	ν	D_2	1990	552
1.6 GeV	FNAL	ν	D_2	1990	2538
5-7 GeV	SKAT	ν	CF_3Br	1992	1465
2 GeV	GGM	$\bar{\nu}$	$C_3H_8CF_3Br$	1979	766
1.3 GeV	BNL	$\bar{\nu}$	H_2	1980	13
16 GeV	FNAL	$\bar{\nu}$	NeH_2	1984	405
6-7 GeV	SKAT	$\bar{\nu}$	CF_3Br	1988	52
9 GeV	SKAT	$\bar{\nu}$	CF_3Br	1990	159
5-7 GeV	SKAT	$\bar{\nu}$	CF_3Br	1992	256

MiniBooNE (~800 MeV):
100 K (after cuts)
K2K(~1.2 GeV):
SciFi: 10K
SciBar:24K
1kt: 30K
T600(~17 GeV):
2900/kton/year

Existing data on fine-grained detectors is minimal!

Conclusions

Physics R&D program for 2 GeV ν interactions in LArTPCs in the running NuMI neutrino beam!

Record and reconstruct complete neutrino interactions (ν_e and π^0) in the 0.5-5 GeV range of interest for future long baseline ν_e searches

→ ***no existing data!***

Continue to:

- *Develop event identification*
- *Develop reconstruction*
- *Develop analysis*
- *Test bed for R&D*

Help to establish international physics collaboration!