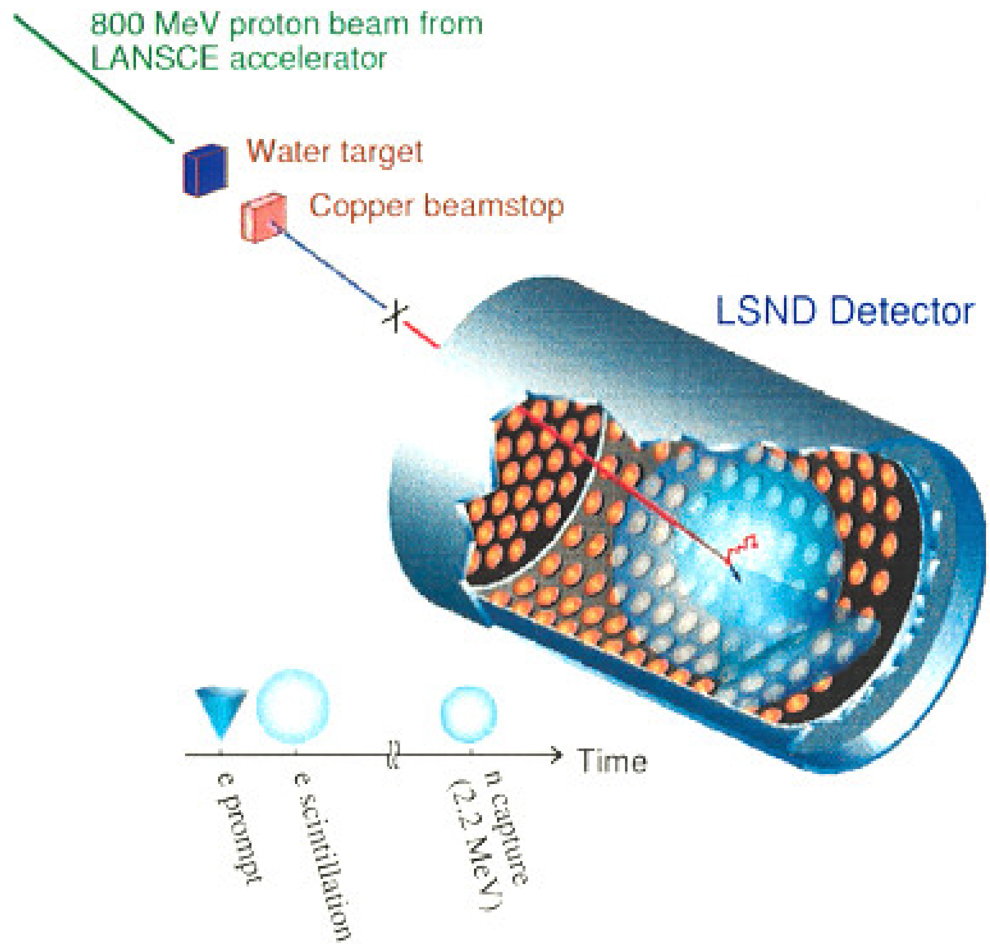
MiniBooNE Progress Report

MOTIVATION - LSND
OVERVIEW
    CIVIL LAYOUT
    SCHEMATIC
        BOOSTER
        BEAMLINE & HORN
INTRINSIC BACKGROUND
DETECTOR
TRIGGER & TIMING
EVENTS
OSCILLATIONS
OTHER PHYSICS
SUMMARY

Investigating the LSND result

LSND:

- searched for $\bar{\nu}_e$ in $\bar{\nu}_\mu$ beam
- 3.8σ excess over background



$\bar{\nu}_e$ events over background:

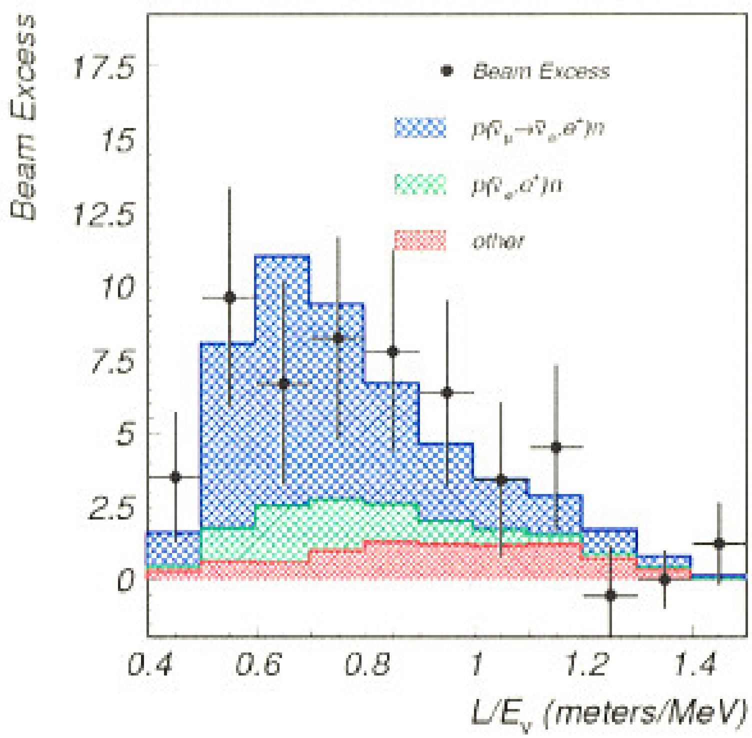
$87.9 \pm 22.4 \pm 6.0$

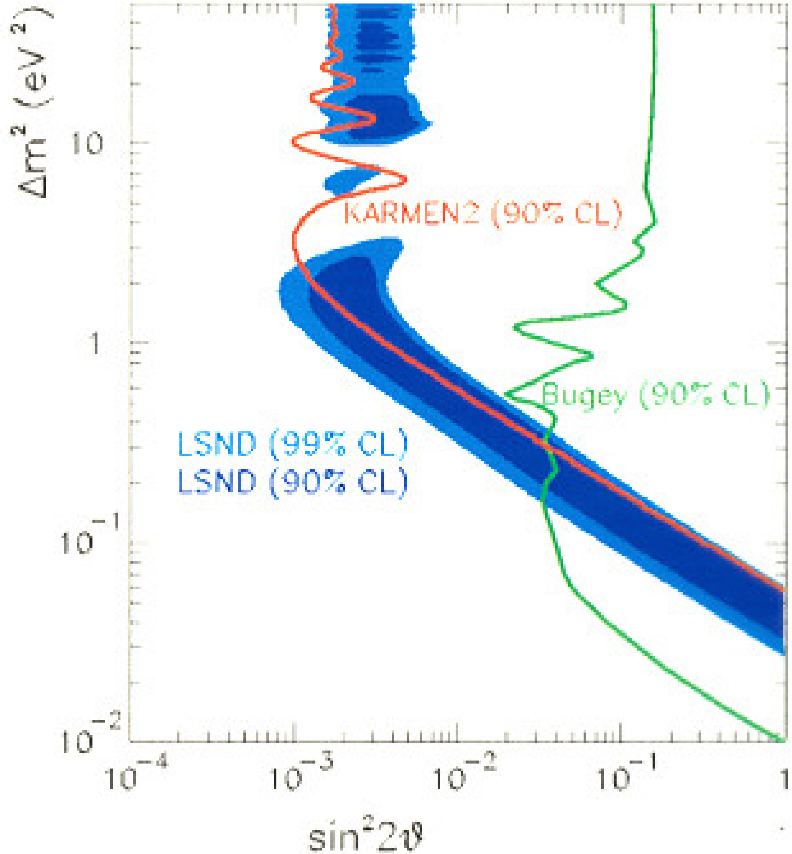
oscillation probability:

$(0.264 \pm 0.067 \pm 0.045)\%$

Phys. Rev. D **64**, 112007 (2001)

The LSND result:





- taking atmospheric, solar, reactor, and LSND results together...
  - one or more experiments is not seeing oscillations, *or*
  - there are more than 3 neutrinos, *or*
  - CPT is not a good symmetry, *or*
  - ?

G. Barenboim, L. Borissov, and J. Lykken, hep-ph/0212116

To check LSND, you want...

- similar L/E_ν
- different systematics
- higher statistics

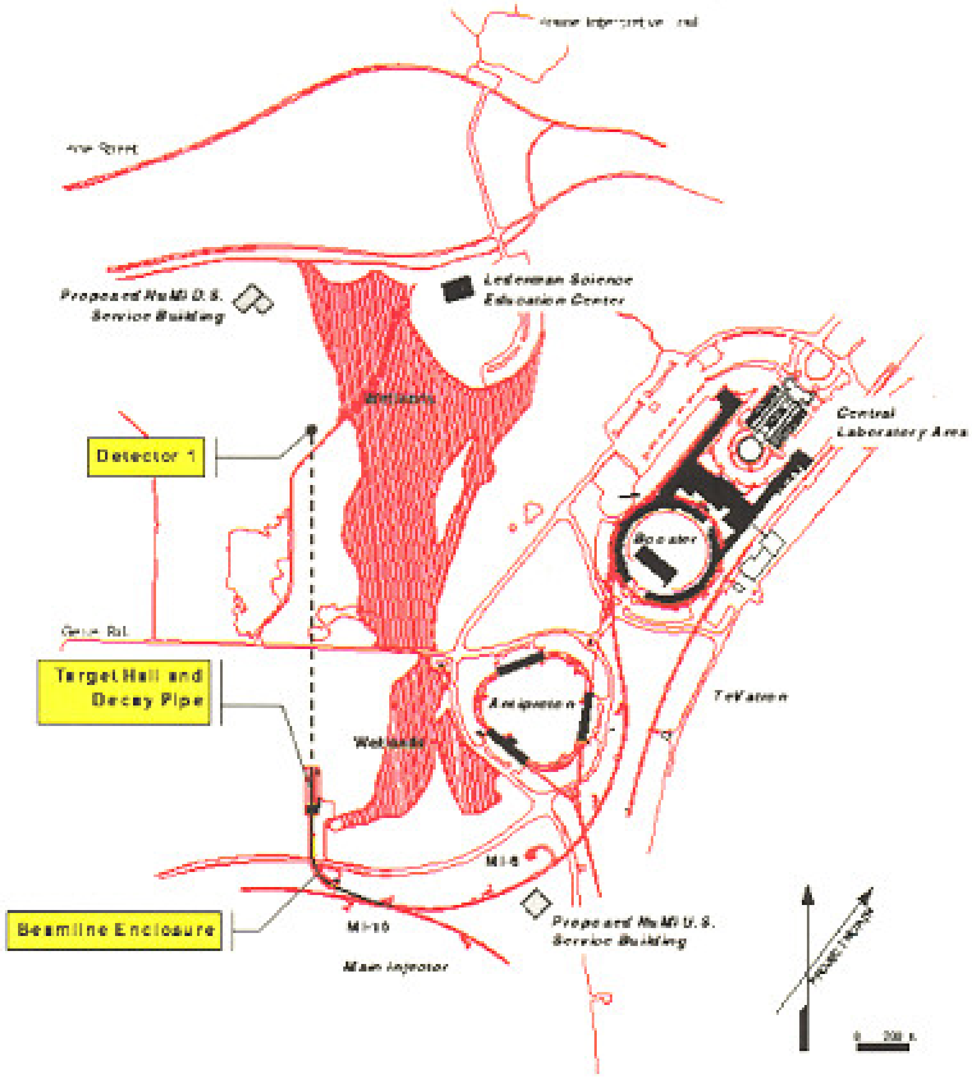
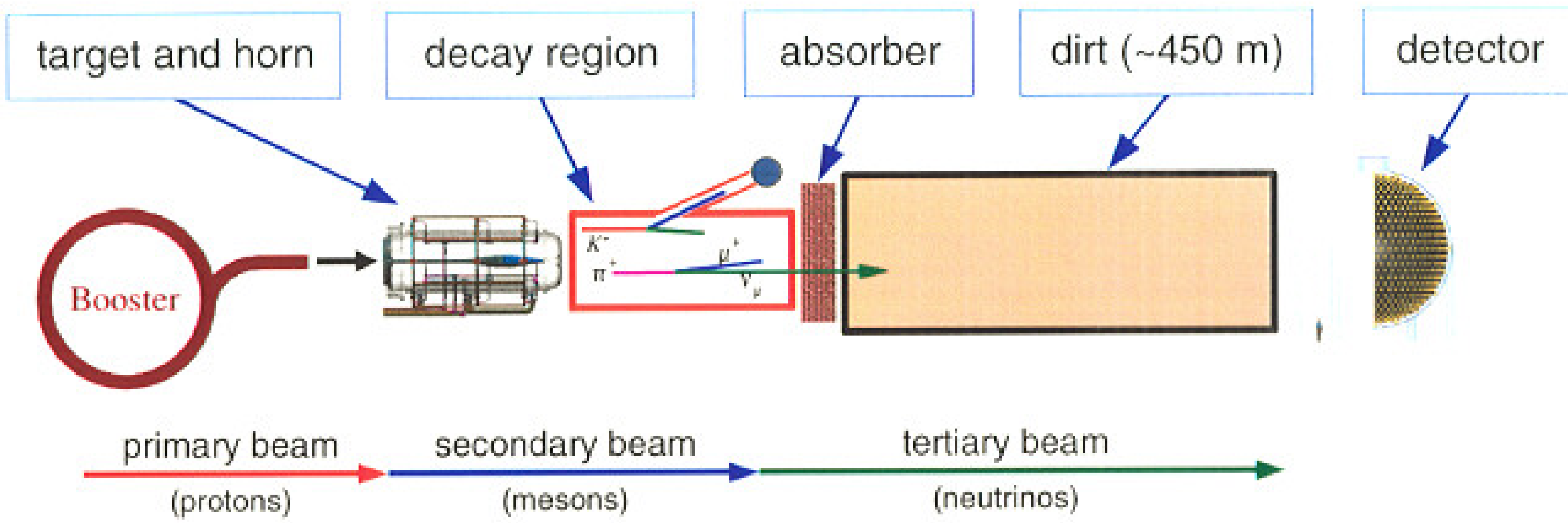


Figure 1.   A schematic view of the 8 GeV Fixed Target Beamline and the MiniBooNE detector.

MiniBooNE



primary beam

- 8 GeV protons from FNAL Booster
- through MiniBooNE beamline

secondary beam

- mesons produced at beryllium target
- magnetic horn focuses these down 50 m decay pipe

tertiary beam

- neutrinos from meson decay
- 450 m path through dirt to detector

$\nu_\mu \rightarrow \nu_e$ search

$$L_{\text{MiniBooNE}} \sim 10\, L_{\text{LSND}}$$

$$E_{\text{MiniBooNE}} \sim 10\, E_{\text{LSND}}$$

- different signal
- different backgrounds

$\Rightarrow$ *different systematics*

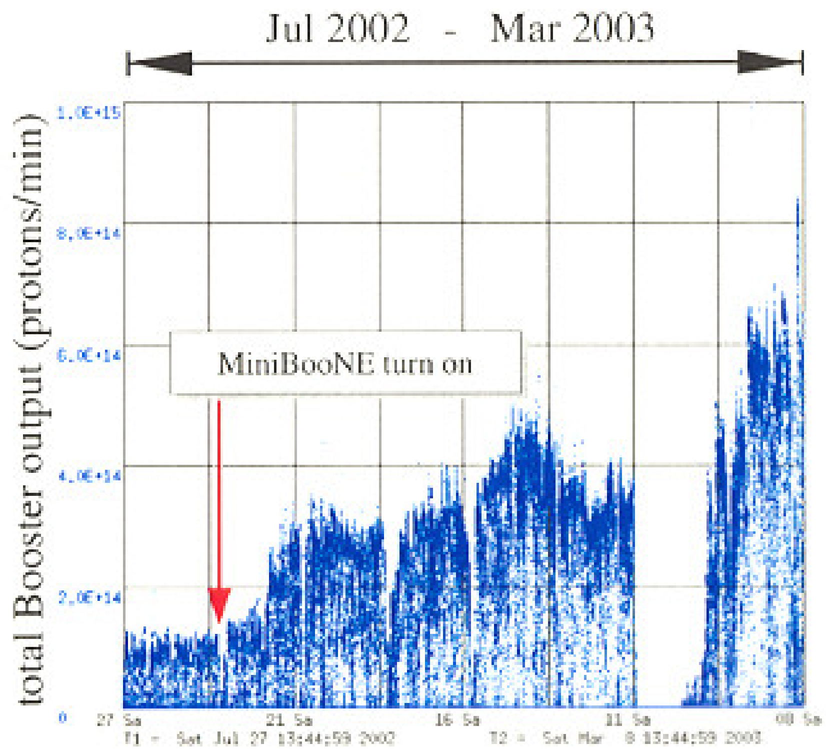
Booster performance

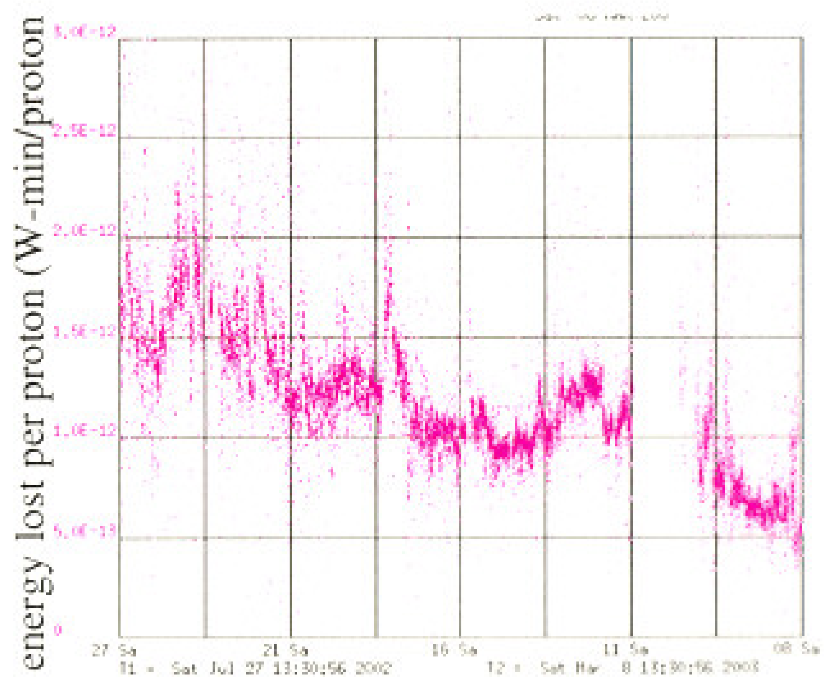
- Booster has never worked this hard

- steady increase
  - careful tuning
  - optimizing pulse rate / pulse intensity
  - hardware changes

- need factor of ~2-3 to reach total of 10^{21} protons on target

- further improvements coming
  - collimator project (underway)
  - large-aperture RF cavities





BOOSTER INTEGRATED INTENSITY

YEAR	INTENSITY (1E19 PROTONS)
1973	
1974	1.48
1975	1.95
1976	2.33
1977	3.00
1978	2.51
1979	3.25
1980	1.36
1981	2.00
1982	2.24
1983	.00307
1984	.131
1985	.608
1986	.152
1987	1.31
1988	.737
1989	.557
1990	.501
1991	.725
1992	1.07
1993	.971
1994	1.36
1995	1.68
1996	.871
1997	1.133

3.2 E20

Σ = 3.2 E20

Mini-BooNE Primary Beam - Overview

Primary Beam Momentum- 8.9 GeV/c

Spill length 1.6 microseconds

Intensity - $5x10^{12}$ ppp Rep rate 15 Hz(5 Hz Beam) $2x10^{7}$ seconds/yr

$\int$ Protons = 5×10^{20} p/year

Invariant Emittance 20 Pi (~10 Pi at 4E12)

Beam Half Size (95%) < 3.5mm [2.0mm achieved]

Autotune and Power Supply Stability

Beam Position and Stability < 1mm

Targeting Angle and Stability < 4.6 microradian

FERMILAB INTENSE BEAMS

Historical Program and Present Demands

Not only protons/pulse but almost continuous beam

Oth order: Well Designed Beamline

Measurements - Apertures

1st order: Are you really ready for beam- R. Ducar

Are you losing beam anyhow - J. Anderson

2nd order: Can you do better on the next pulse -

T. Kobilarcik

INITIAL OPERATION OF THE FERMILAB MINIBOONE BEAMLINE*

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J. Monroe, Columbia University, N.Y, N.Y

Abstract

The MiniBooNE neutrino experiment is projected to take more intensity in a single year than was delivered during the seventeen years of running the Fixed Target Program. The experiment will require almost continuous running (18,000 pulses/hour) at full intensity (5E12 protons per pulse). In order to safely handle this intensity various measures have been instituted. The design of the beamline ensures sufficient clearance between the beam and apertures. A MiniBooNE Beam Permit System has been installed that is able to check various digital and analogue information against nominal values on a pulse by pulse basis. An automated total beam loss monitoring system (electronic berm) measures any beam loss between the beginning and end of the line. An automated correction system (Autotune) finds and corrects minor beam wandering. A description of the beamline design and relevant instrumentation is given.

INITIAL DESIGN

The first consideration in the design of the very high intensity proton beamline was to make the size of the beam pipe large with respect to the size of the beam. Figure 1 shows the beam envelope and the apertures along the beamline. There were two major obstacles to achieving this goal. First, the beamline passes underneath an existing service building. Typically, a FODO channel is used to keep the beam tightly focused, but in this case the beam had to pass through a 43 m. berm pipe. The second consideration was that for a tight focus, the beam should be large in the final focus quadrupoles. Using elements with large apertures (6-3-120 dipoles, LEP trims, and LEP quadrupoles) ameliorated both problems.

OPTICS MEASUREMENTS AND COMPARISON TO THEORY

Dipole measurements

To measure the quadrupole gradients, each dipole trim magnet was varied, and the change in beam position at each BPM was recorded. The optics program TRANSPORT was used to find the quadrupole gradients that gave the best fit to the data. Figure 2 shows a representative trajectory.

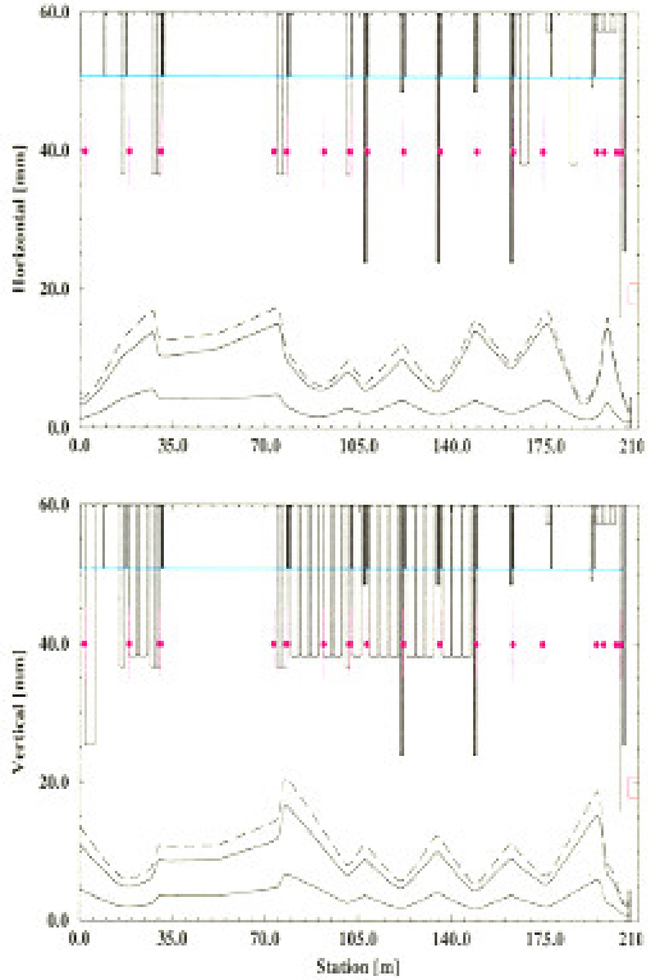


Figure 1. Beam envelope and apertures. The lower beam envelope is the one sigma and the two upper traces are the 95% and 99% with momentum folded in. The assumed emittances were 20 PI and a dp/p of .1%. The line indicates the total loss monitor coverage and the dots indicate the location of individual loss monitors.

Beam Profile Measurements

To measure the input lattice parameters, each profile monitor was inserted into the beam, one at a time to reduce scattering, and the beam size was recorded.

*Operated by Universities Research Association, Inc. under contract number DE-AC02-76CH03000 with United States Department of Energy.

TRANSPORT was used to vary the initial beam parameters to find the best fit to the measured profiles. The calculated beam sizes are compared with the measured profiles in Figure (3).

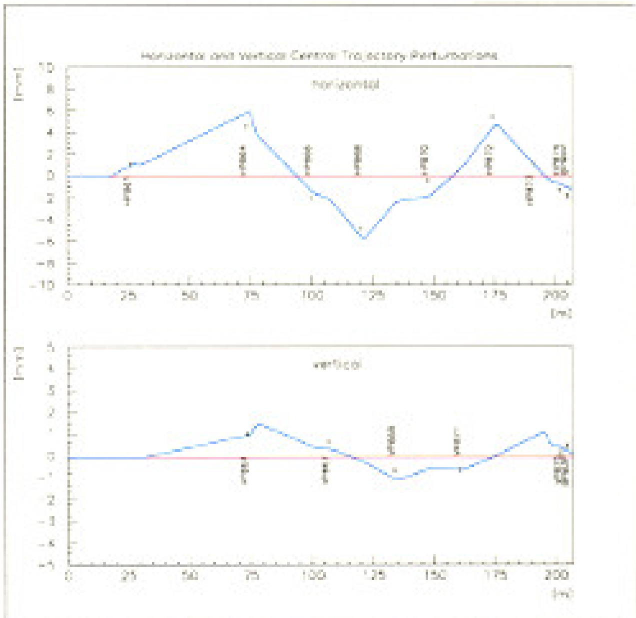


Figure 2. Example horizontal and vertical dipole changes

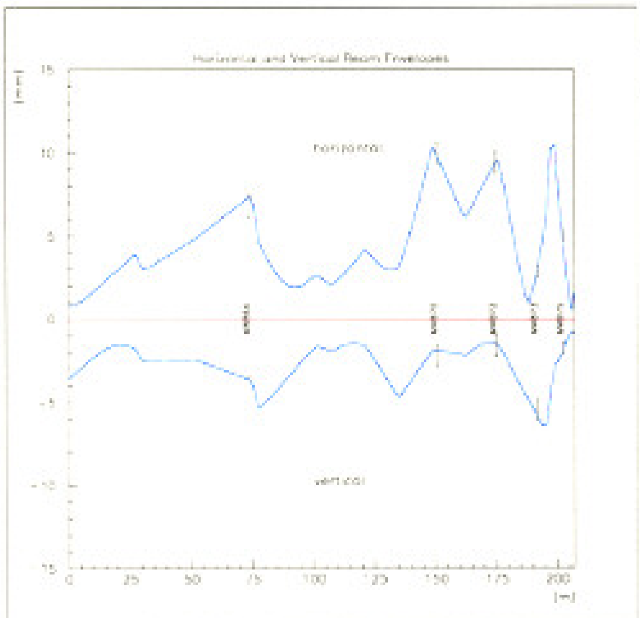


Figure 3. Beam sizes compared to prediction

Dispersion Measurements

To measure the dispersion, three foils of different thicknesses were inserted into the beam, one at a time, at the same location. For a given foil thickness, the energy loss, and hence the momentum change caused by the foil, is known. The changes in positions at the downstream BPMs were recorded for each foil to make a direct measurement of dx/(dp/p). The measurement was modeled in TRANSPORT and the comparison between the measured data and predicted dispersion wave is shown in Figure (4), with the error bars indicating the spread in measurements from the three foils

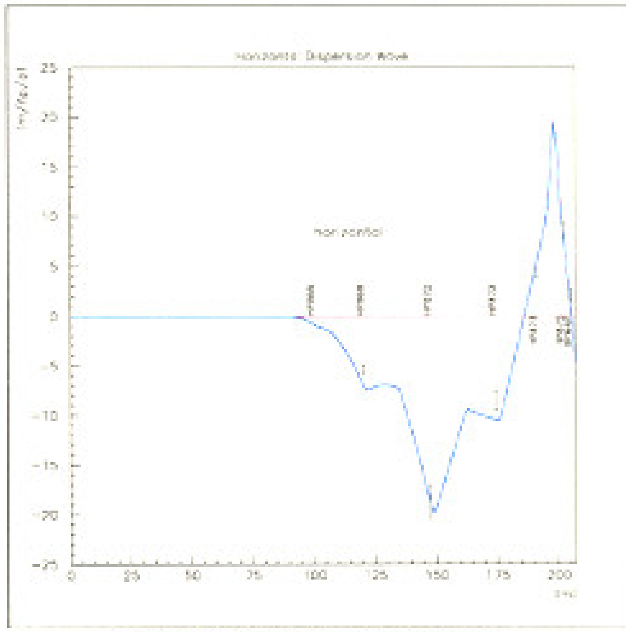


Figure 4. Dispersion measurements

Local Bumps and Target Mults

Local bumps were developed to perform aperture scans during commissioning. Nominal beam positions were defined by centering the beam in the apertures. Position and angle mults were developed for target scans, and were used in conjunction with a 90 degree monitor to center the beam on target.

AUTOTUNE

An automatic beamline correction program, Autotune, was developed to aid in keeping the proton beam on the nominal trajectory [1]. The procedure of the program is as follows: for every trim magnet in the beamline, the current is changed by a small amount and the change in position at every BPM is measured. The measurements are used to solve the linear equations relating the change in current to the change in position. The trim magnets and BPMs are chosen such that the matrix can be inverted. Once the transfer matrix is found, Autotune finds the trim currents needed to correct deviations of the beam from the nominal trajectory.

BEAM PERMIT SYSTEM

Beam Permit Systems have long been implemented for various accelerators and beamlines at Fermilab, with inputs generally in the class of simple go/no-go status. The new MiniBooNE Beam Permit System hardware consists of a supervisory micro-controller sampling multiple analogue and digital inputs in accord with programmed state logic and delays sensitive to accelerator clocks. Limits or allowable ranges are downloaded to the micro-controller via the Accelerator Controls Network (ACNET). Sampled results are compared to these limits, and out of limit inputs effect a trip of the beam permit system, thereby preventing transfer of beam until the limit situation is corrected. Up to eight different sampling times are accommodated, with the process of sampling, determination, and trip taking less than 100 microseconds.

The Beam Permit System, currently in use, successfully prevents beam transport when monitored conditions are not proper, and inhibits repetitive transport of beam when beam losses or other conditions are abnormal. Monitored quantities include analogue representations of magnet power supply ramped outputs, sampled both before and during beam extraction to the MiniBooNE beamline, and all of the beamline loss monitors (with different signal time constants), which are sampled immediately after beam transport. There is complete coverage of the beamline with long loss monitors and spot coverage with short loss monitors (shown as the dots in Figure 1). Loss monitor readings taken during the dispersion measurements (described above) also demonstrated that the total loss monitor trip points are set to a level corresponding to a 0.02% beam loss.

E-BERM

To minimize air and groundwater activation and radiation in areas outside the overburden, a total beam loss monitoring system termed an Electronic Berm (E-Berm) was developed. The E-Berm, shown in Figure 5, consists of two Pearson 3100 toroids, associated integrating electronics, a resistive wall monitor, and a comparator module, used in conjunction with two toroid calibration modules. The toroids are located at the beginning and end of the beamline. The comparator module calculates the difference between the two toroids for each pulse, and for the sum of the previous ten pulses. The instantaneous and integrated losses are designed to be output to the radiation safety interlock system, which automatically inhibits the next beam pulse if the per-pulse losses are greater than 6%, or if the average losses are greater than 2%.

In addition to the total beamline losses, the E-Berm checks for other abnormal conditions on each pulse. The timing of the toroid signal in the integrator gate is verified to be within an acceptable envelope by comparison with the timing signal from a nearby resistive wall monitor. The beam-off readings of the two toroid integrators are also measured and checked against a reasonable interval, to guard against integrator failure. Finally, the relative calibration of the toroids is measured for each beam pulse. The calibration sequence consists of a series of 10 current pulses that are sent through a toroid calibration loop and read back through an integrator. The calibration occurs simultaneously for both toroids, over the full dynamic range (0.5E11 to 5E12 protons per pulse) of the beam intensity. A linear regression is performed on the measured and ideal values of the integrated toroid output in the calibration module. Gain and pedestal corrections are obtained for each toroid, and are compared with an acceptable range. If any of the monitored quantities are abnormal, the system is designed to trip the radiation safety interlock system.

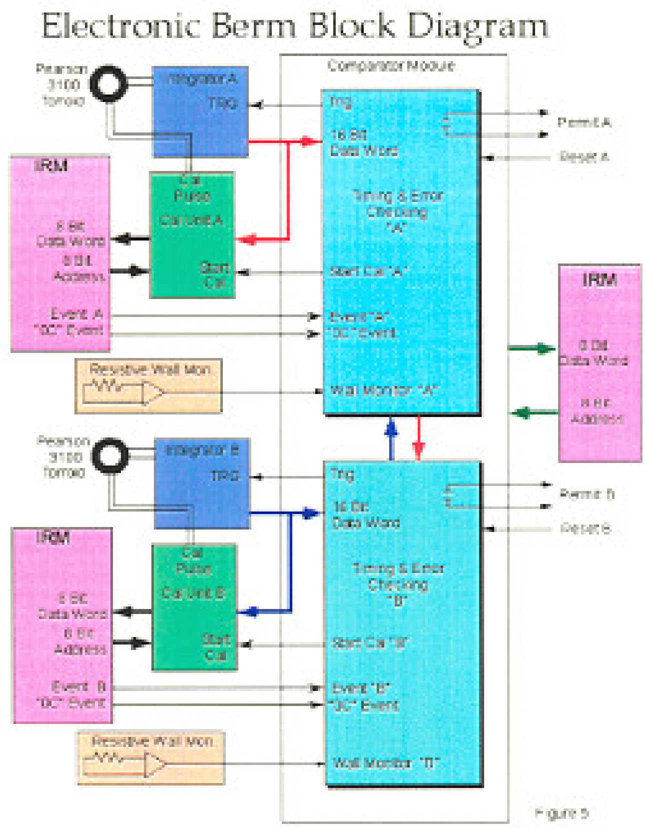


Figure 5

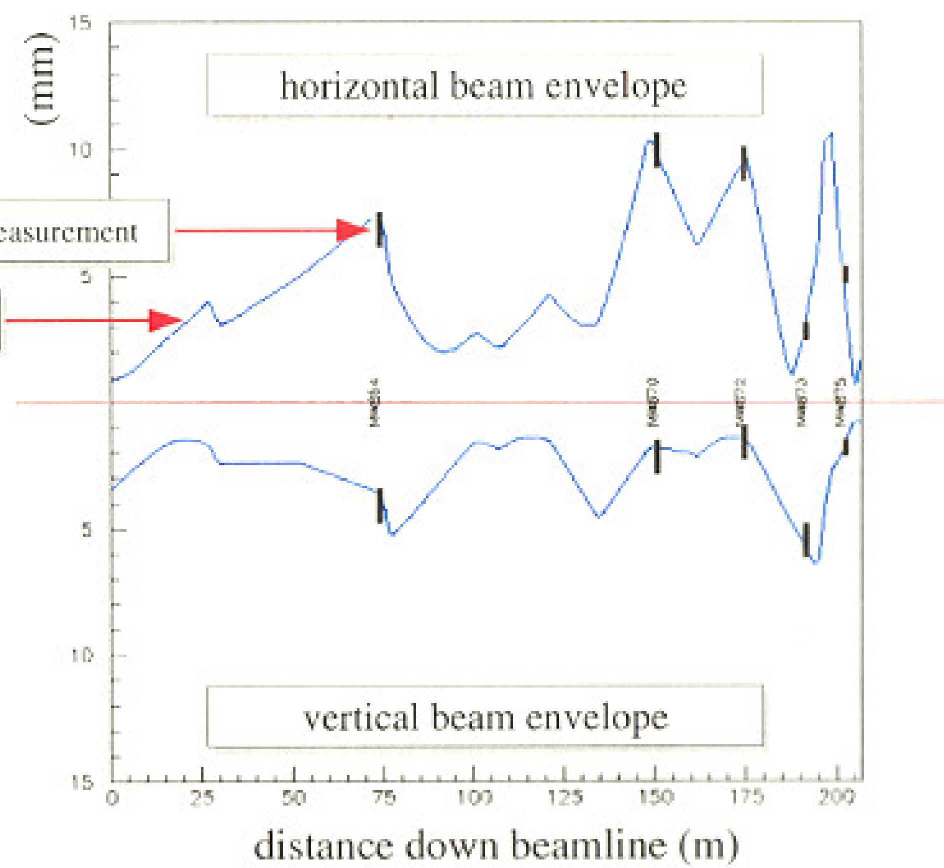
CONCLUSION

The beamline has worked very well. The limitation on MiniBooNE intensity has been Booster losses; however up to 60% of the design intensity has been transported to the target with minimal losses until the final horn protection collimator. The highest contact reading before the final focus region is less than 10 millirem/hour. The highest contact reading in the final focus region is 200 millirem/hour on the horn protection collimator.

REFERENCES

[1] T. Kobilarcik, J. DeVoy, C. Moore, "Automatic Beamline correction", This Conference

Beamline and horn



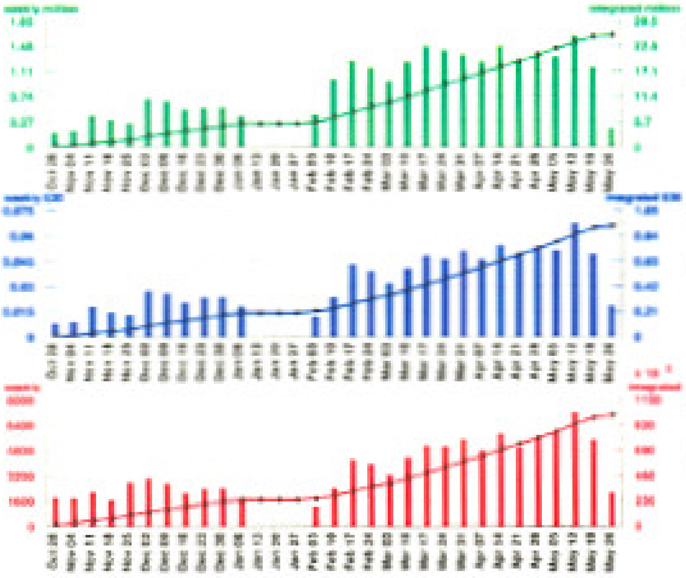
- 8 GeV MiniBooNE transport line
  - first beam in final configuration: Aug 24, 2002
  - optics understood very well

- Horn
  - increases neutrino flux ~7x
  - 170 kA , 143 μs pulses @ 5 Hz
  - has performed flawlessly, with >20M pulses *in situ*

Booster Neutrino Experiment

about BooNE | about neutrinos | virtual tour | BooNE at work | Fermilab at work | PPD home page

Progress in Delivering Beam to MiniBooNE



Number of Horn Pulses

To date: 25.22 million

Largest week: 1.63 million

Latest week: 0.27 million

Number of Protons on Target

To date: 0.8232 E20

Largest week: 0.0671 E20

Latest week: 0.0183 E20

Number of Neutrino Events

To date: 101119

Largest week: 7182

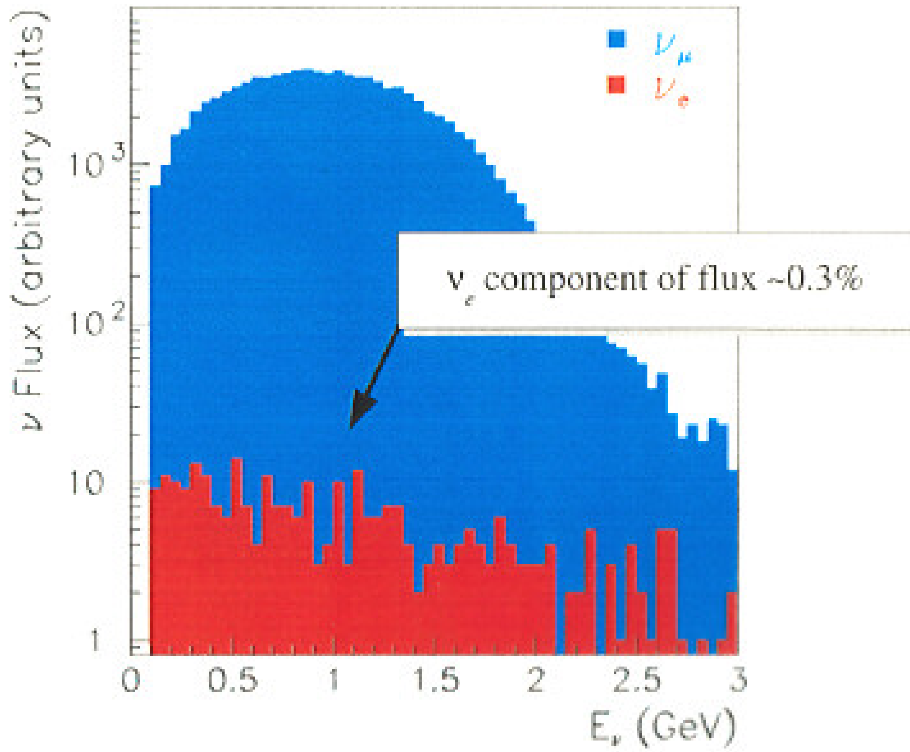
Latest week: 2143

Intrinsic ν_e in the beam

- a major background for the appearance experiment
- sources:

$$\pi^+ / K^+ \to \mu^+ \nu_\mu$$
$$\hookrightarrow e^+ \bar{\nu}_\mu \nu_e$$
$$K^+ / K_L^0 \to \pi\, e\, \nu_e$$

- tackle this background with
  - half-million ν_μ interactions in the detector
  - HARP experiment (CERN)
  - E910 (Brookhaven)
  - "little muon counter"
  - 25 m / 50 m decay length option



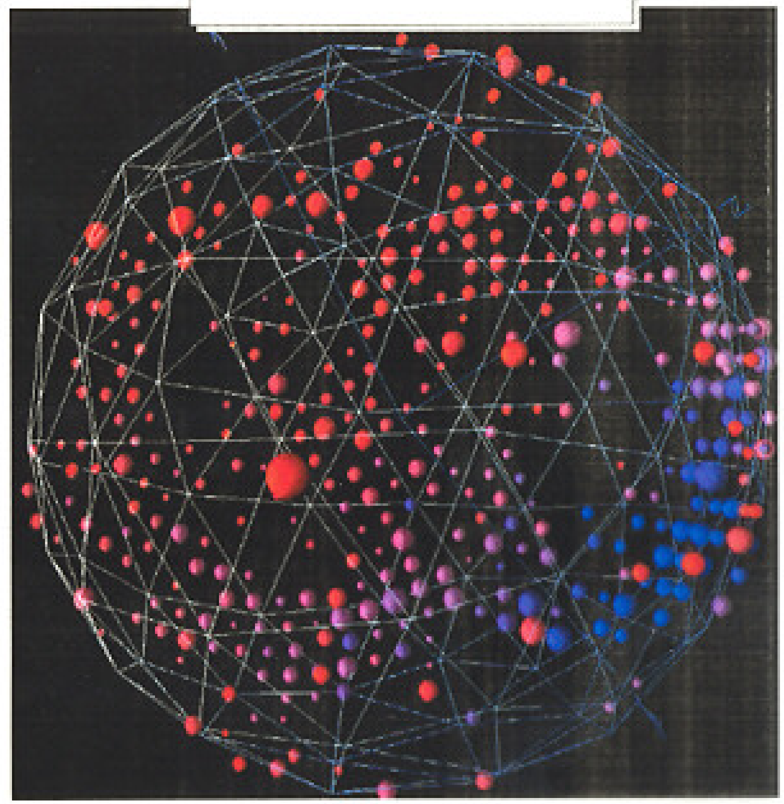

HARP experiment at CERN

π^0 background

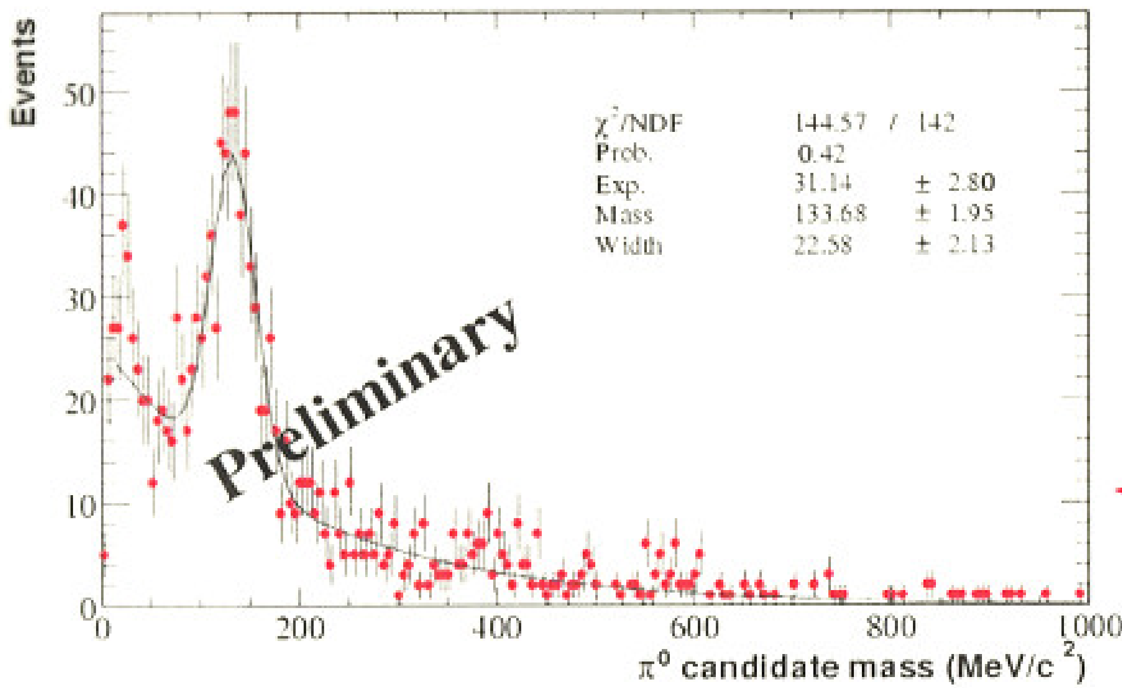
$\nu_\mu C \to \nu_\mu X \pi^0$

- $\pi^0 \to \gamma\gamma$ can mimic an e^-
  - escaping γ
  - "asymmetric" decays
  - ring overlap
- π^0 events are useful calibration sources

π^0 candidate event



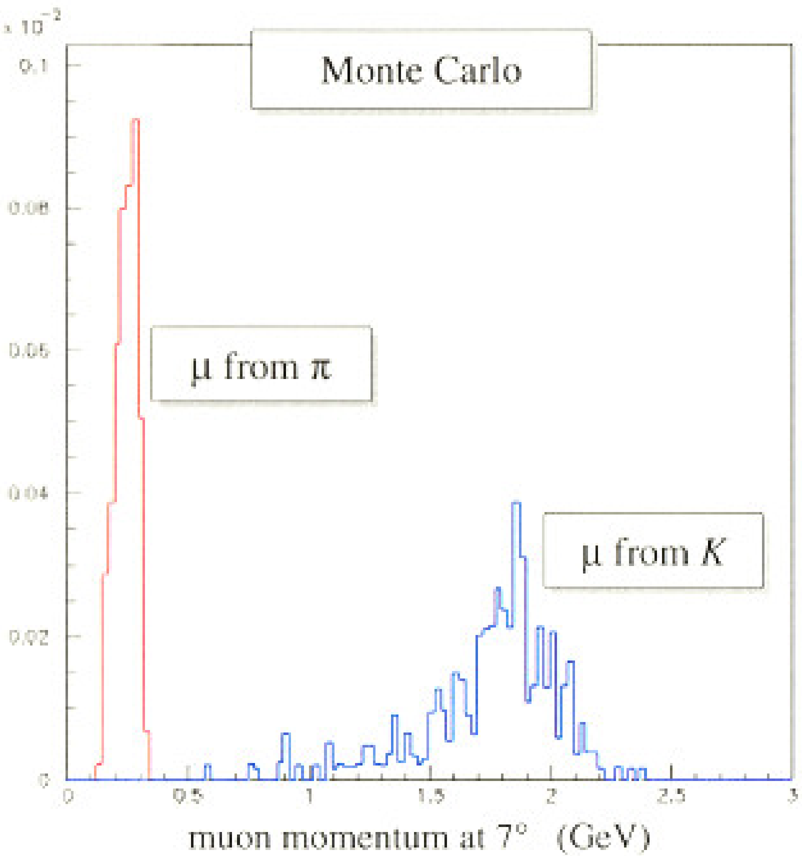
- high-energy electron-like tracks (can check electron reconstruction)

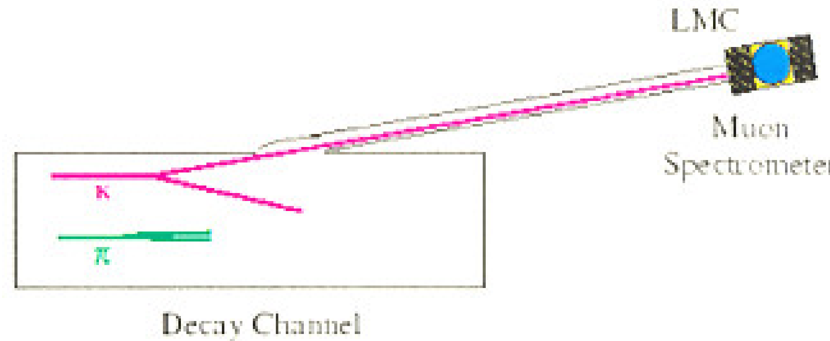


the π^0 peak stands out with minimal cuts

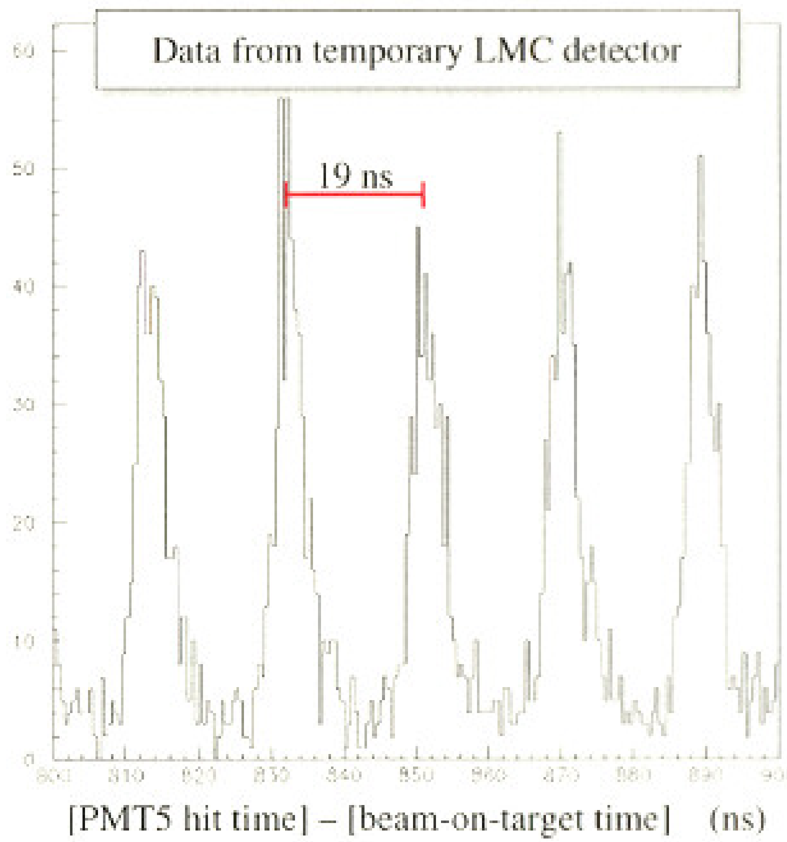
Little muon counter

- K decays produce more wide-angle muons than π decays
- LMC: off-axis (7°) muon spectrometer
- scintillator fiber tracker
- clean separation of muon parentage

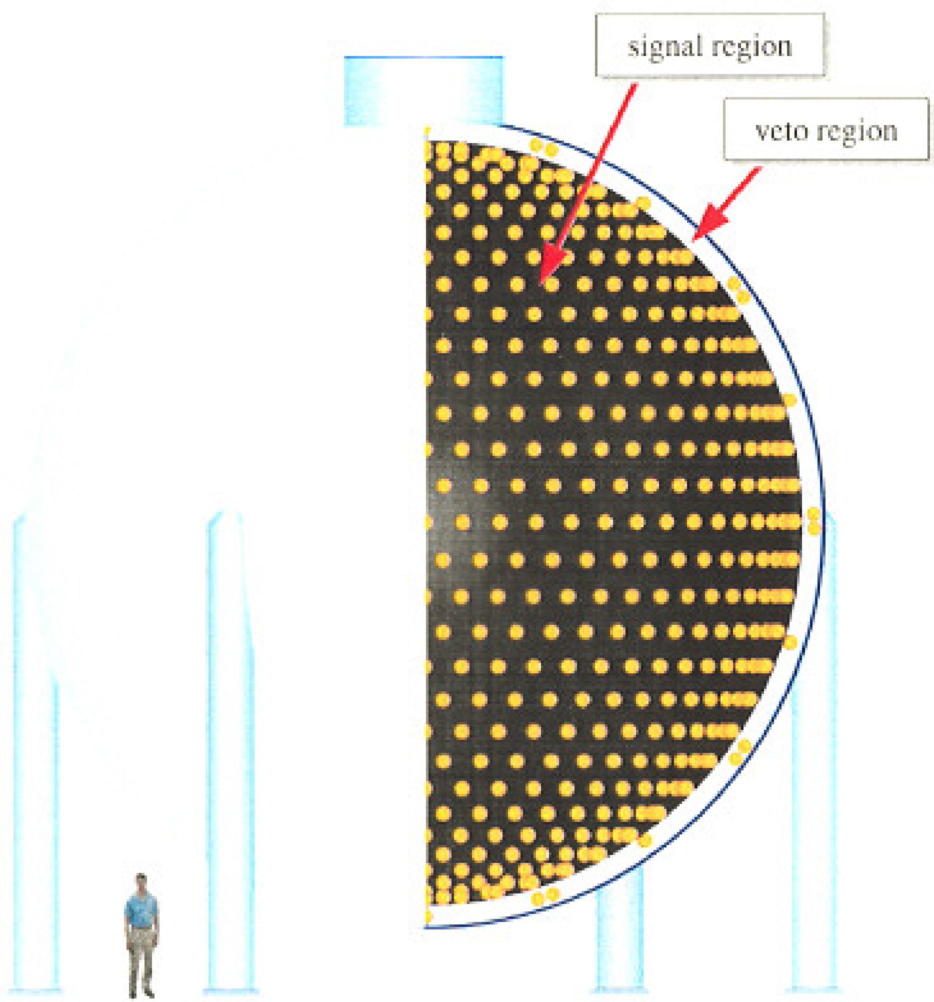


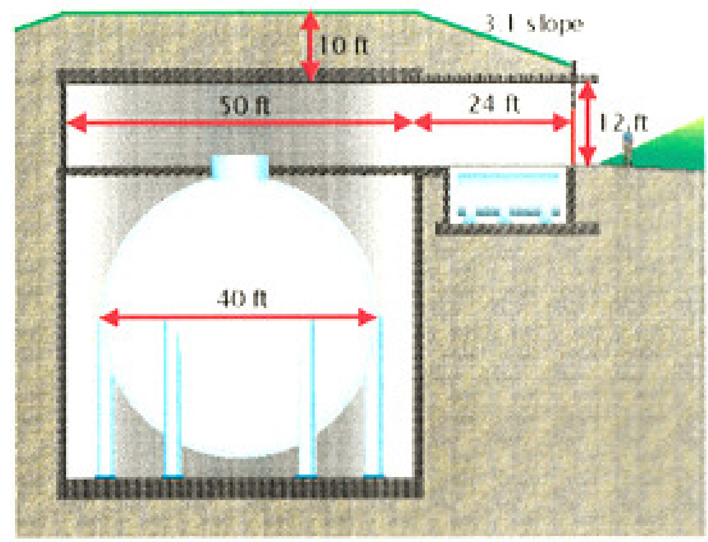


- temporary LMC detector (scintillator paddles):
  - shows that data acquisition is working
  - 53 MHz beam RF structure seen



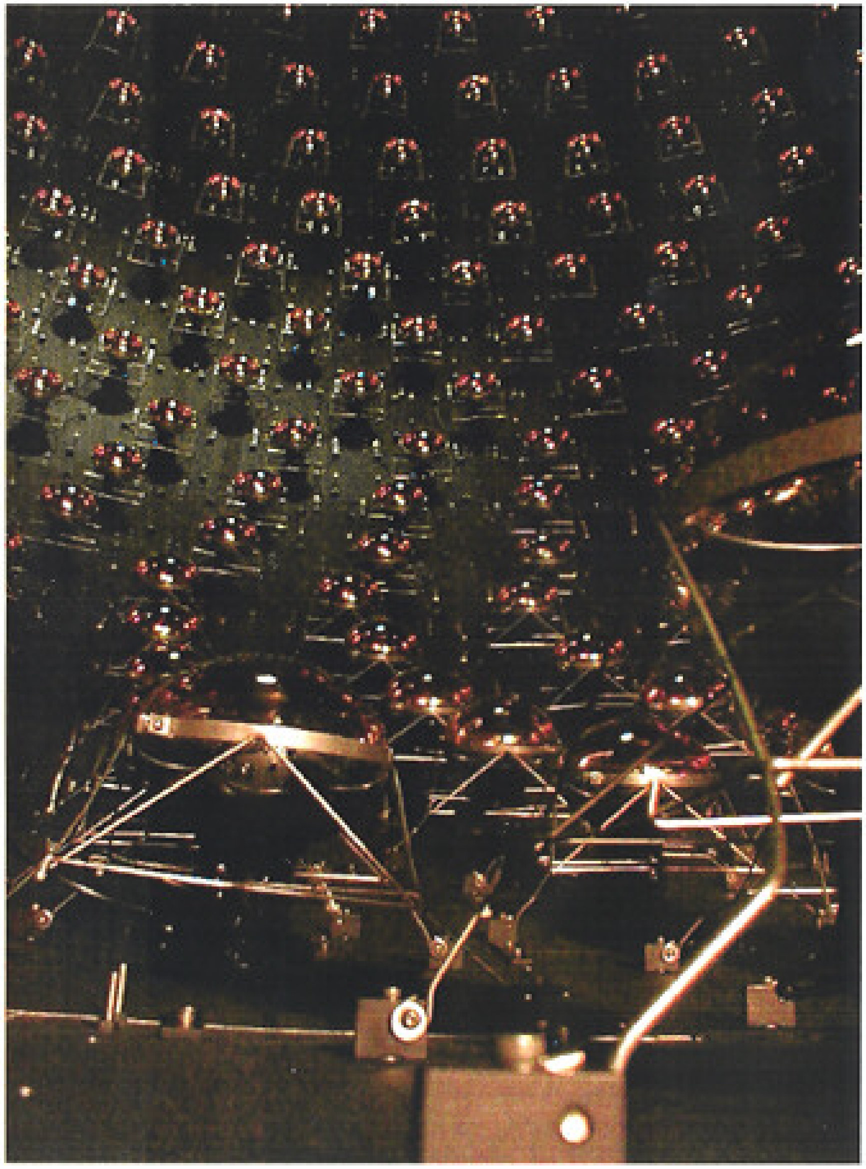
The MiniBooNE detector





- 40 ft diameter sphere
- 800 tons of mineral oil
- 1280 8-inch phototubes in signal region (10% coverage)
- 240 8-inch phototubes in veto region

some views...

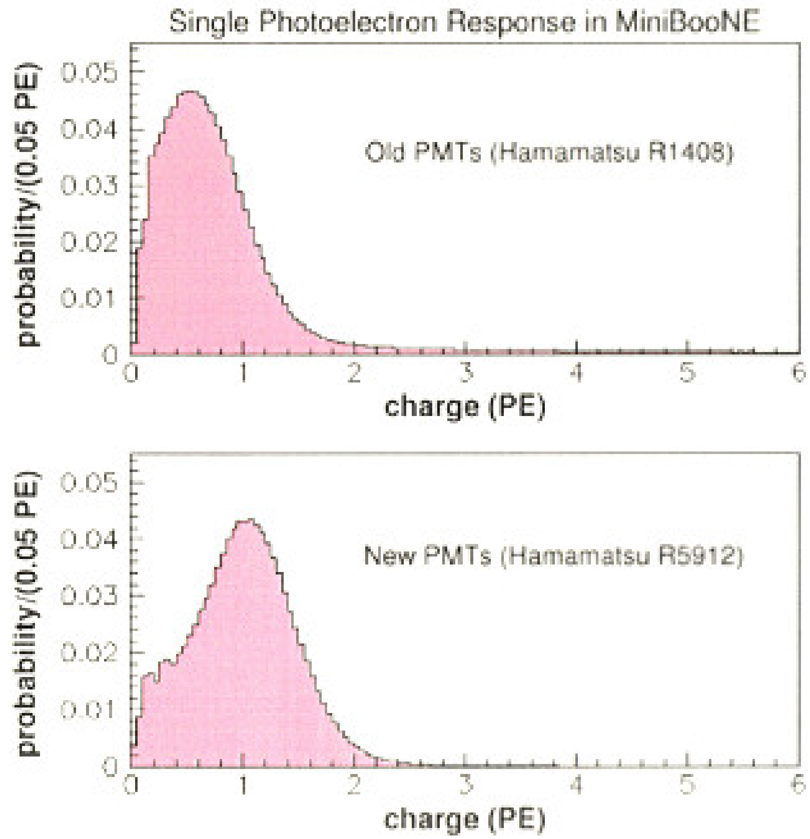


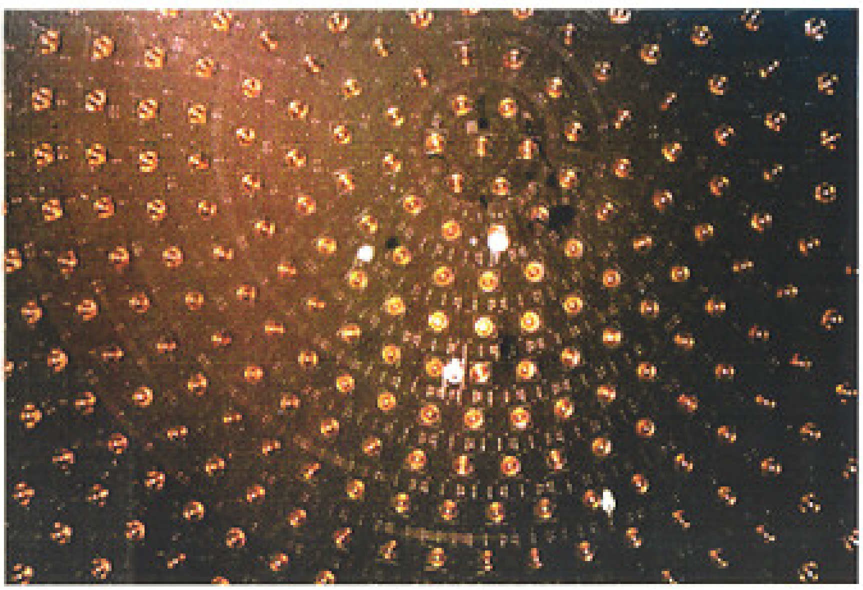
Understanding the detector

Laser flasks

- Ludox®-filled round flasks
- fed by optical fiber from laser
- four flasks distributed about detector

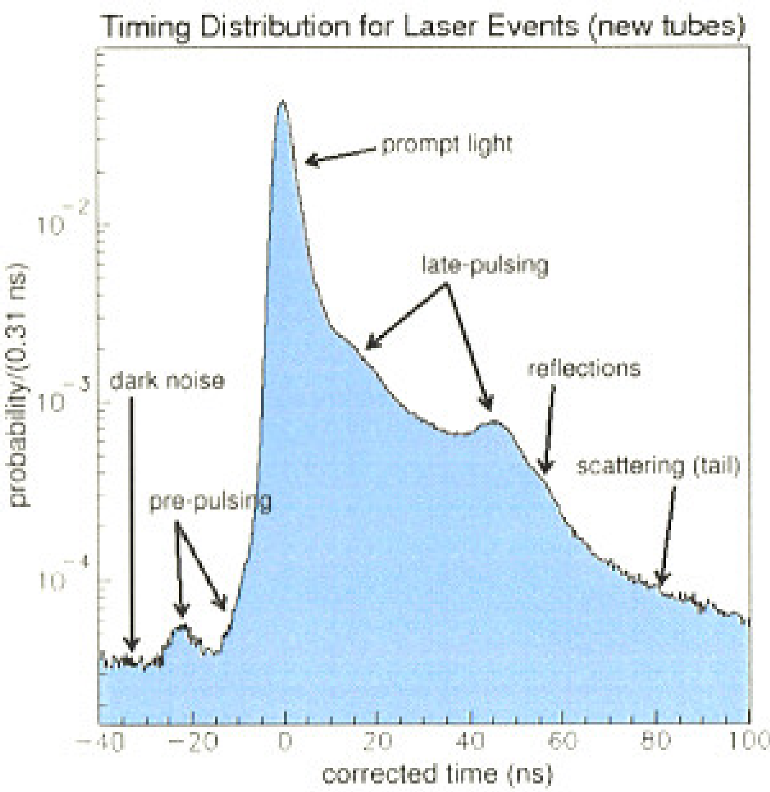
- attenuation length measurements
- charge response of phototubes

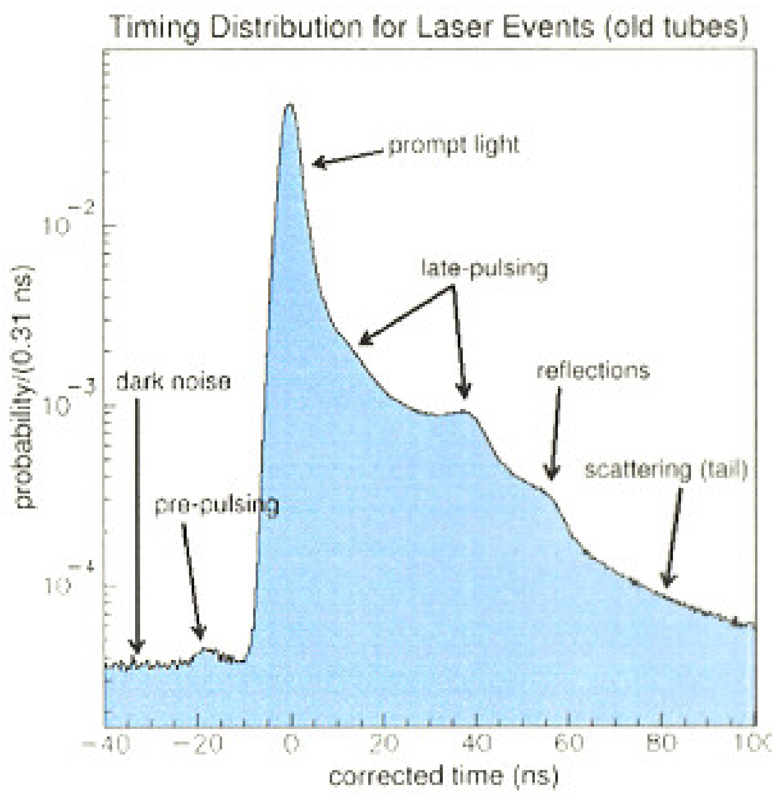




Laser flasks (cont'd)

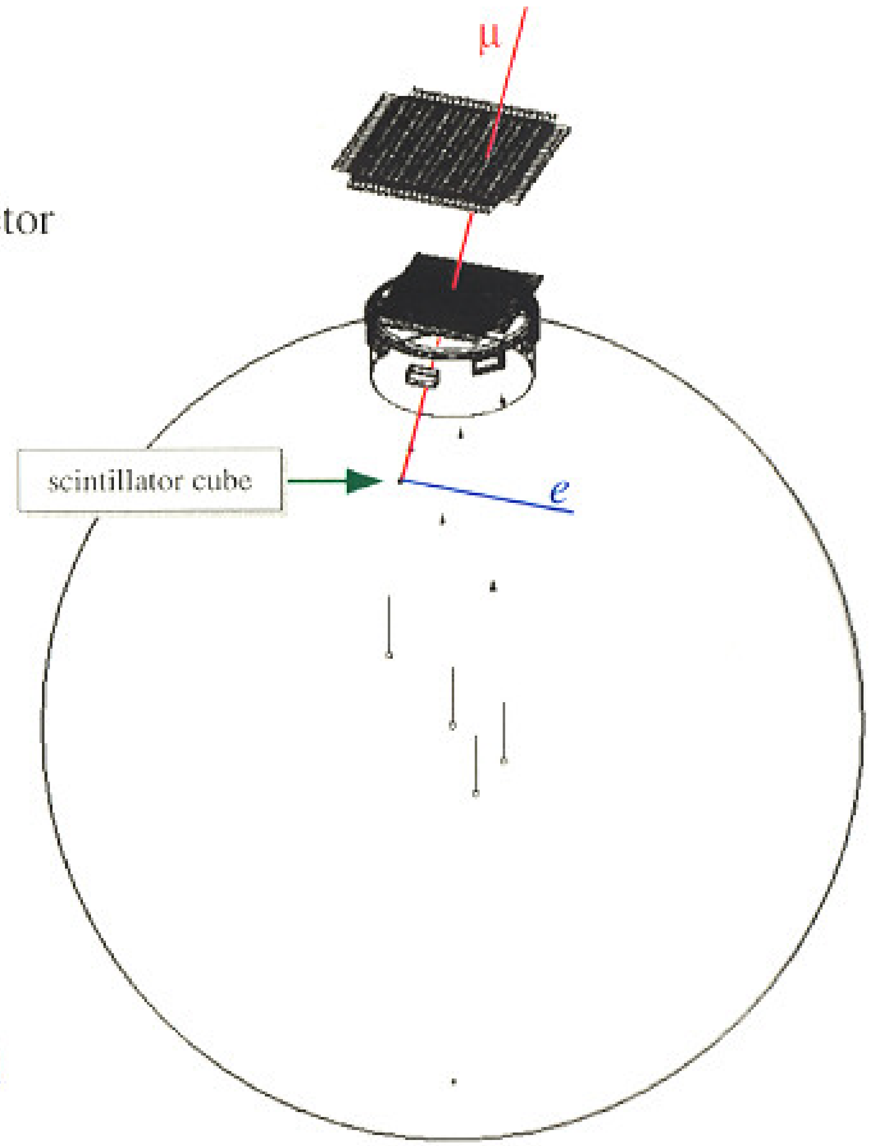
- time response of tubes (resolution, slewing, etc.)
  - time resolutions from data: 1.2 ns (new tubes), 1.7 ns (old tubes)
  - in agreement with benchtop measurements / tube specifications
  - important for reconstruction and particle ID
- global properties of detector/phototube time response:





Muon tracker plus scintillator cubes

- seven enclosed cubes of scintillator in detector volume
- tracker/cube combination provides
  - muons with known pathlength
  - electrons with known vertex

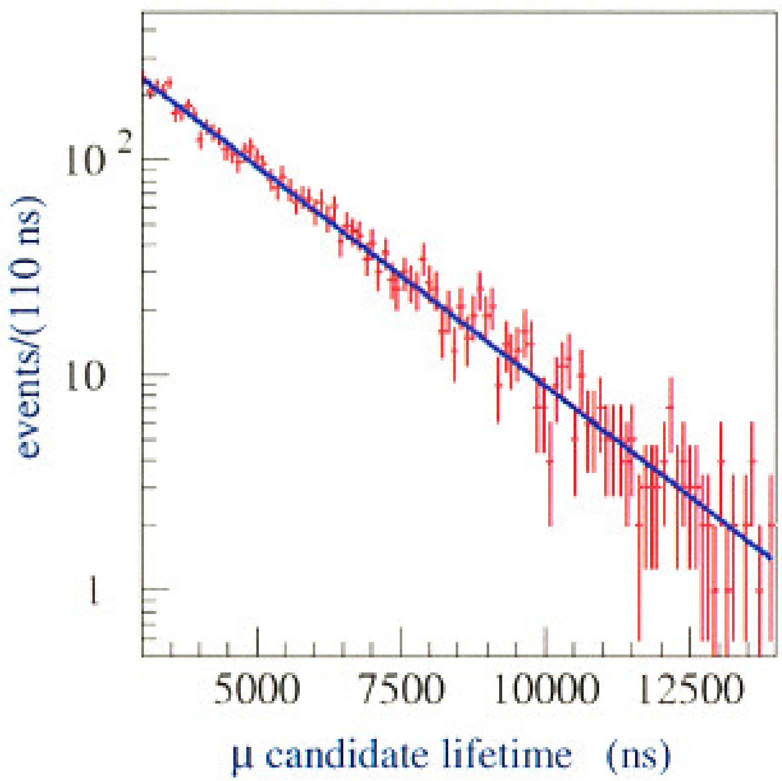


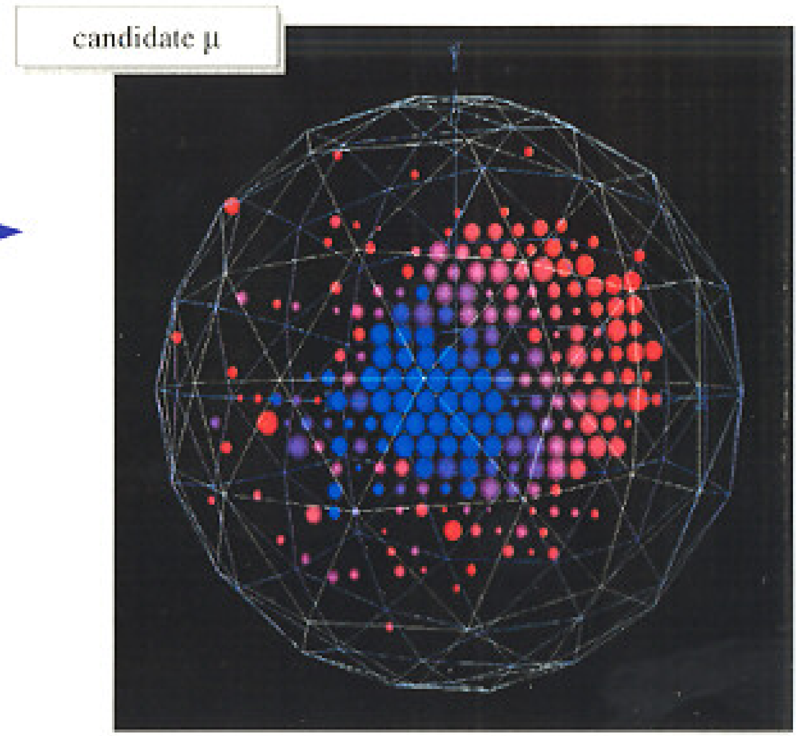
Michel electrons throughout detector

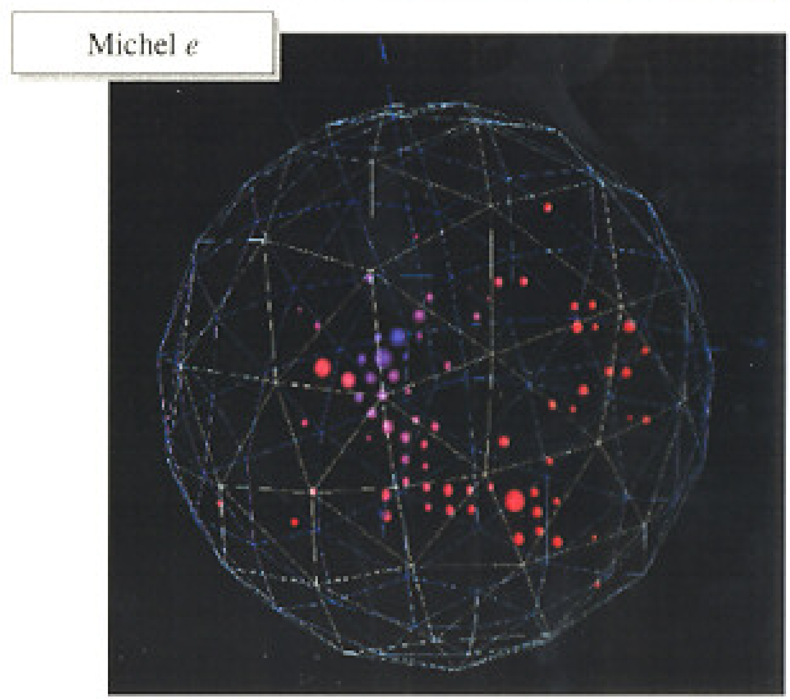
- plentiful source from cosmics and beam-induced muons
  - get energy scale and resolution at Michel endpoint
  - beam-on v. beam-off calibration check
  - electron particle ID

Michel electrons (cont'd)

- candidate muon and subsequent Michel electron →
- cosmic muon lifetime in oil
  - measured: $\tau = 2.12 \pm 0.05\ \mu s$
  - expected: $\tau = 2.13\ \mu s$ (8% μ^- capture)







color=time size=charge

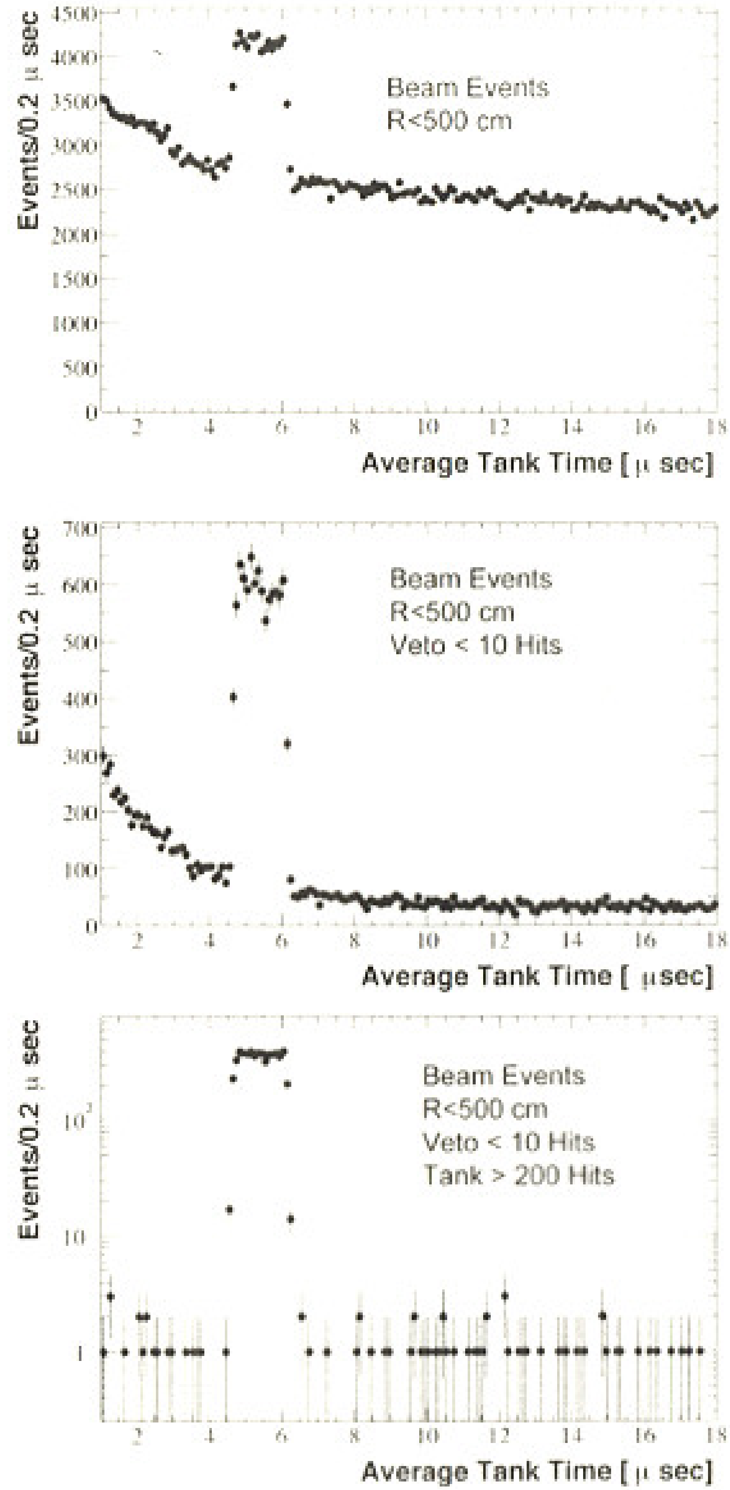
Coarse beam timing

- beam comes in spills @ 5 Hz
- each spill: ~82 buckets separated by 19 ns

  ⇒ ~1.6 μs spill

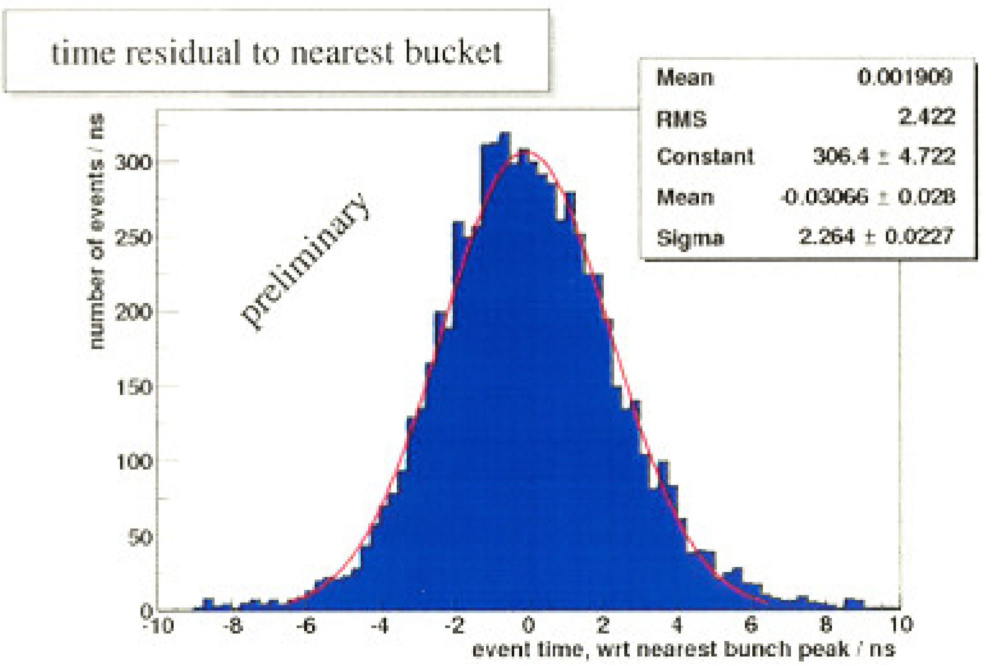
- trigger on signal from Booster; read out for 19.2 μs
- no high level analysis needed to see neutrino events over background!
- and...

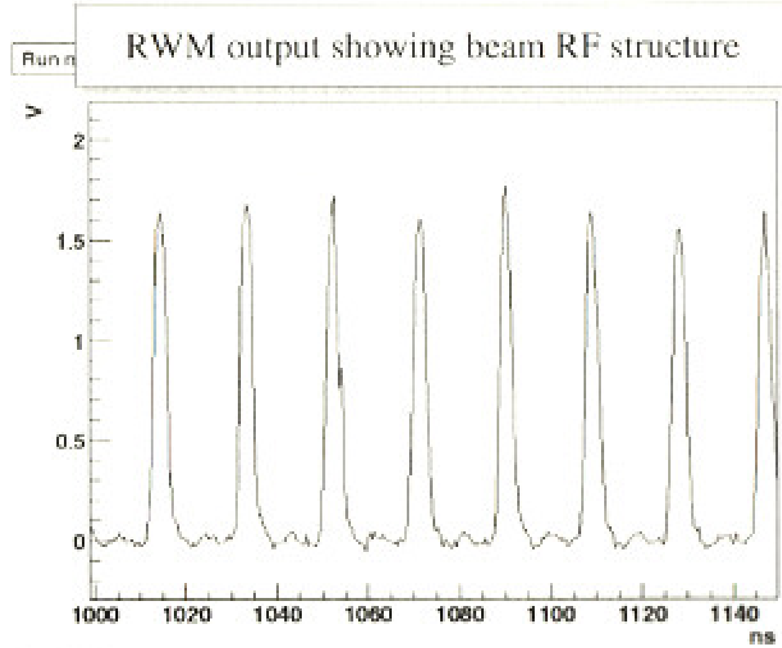
Adding a few simple cuts reduces the non-beam background to ~10^{-3}.



Fine beam timing

- resistive wall monitor (RWM) near target
- RWM signal discriminated, sent to detector DAQ
- with reconstructed neutrino event, can
  - determine event time (from start of spill)
  - adjust for vertex
  - find time to nearest RF bucket

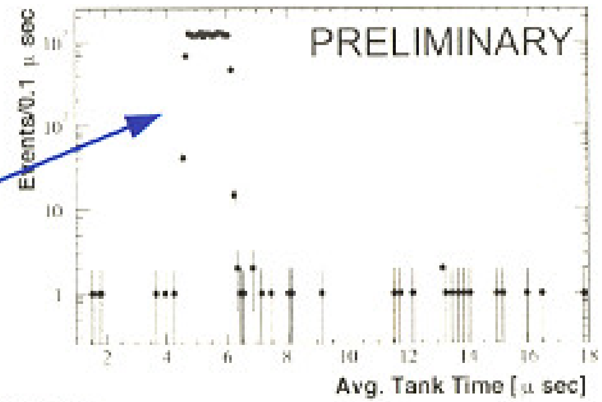




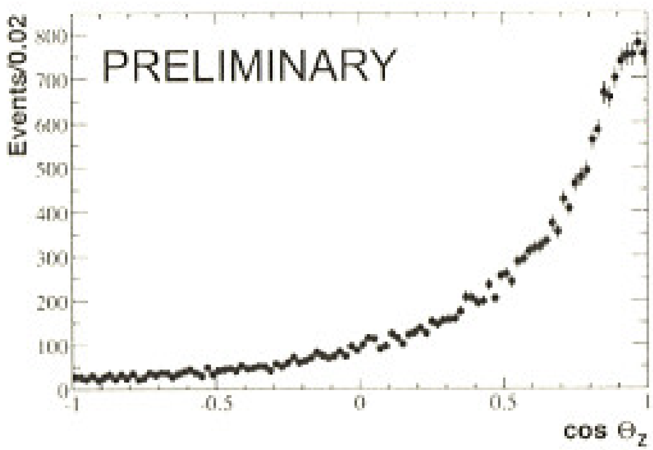
We can measure the Booster bucket structure with neutrinos in the detector.

Neutrino events

- look at these events

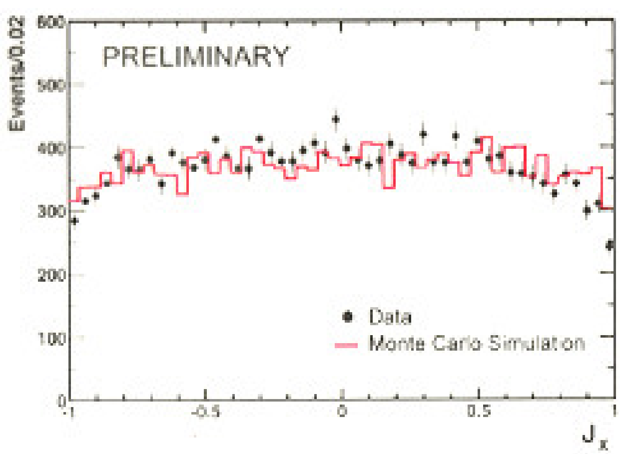


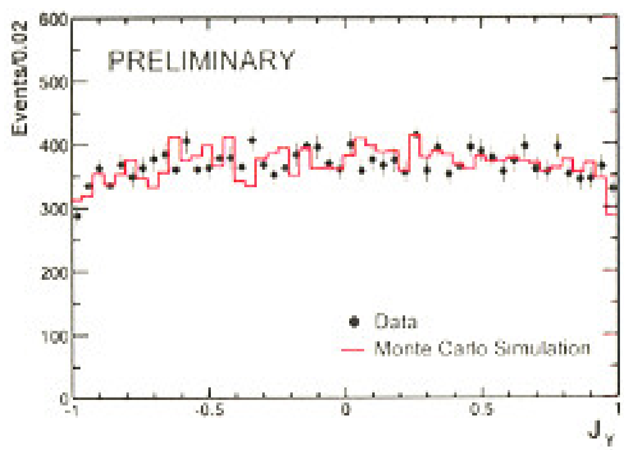
- track direction ⇒ these are beam events:

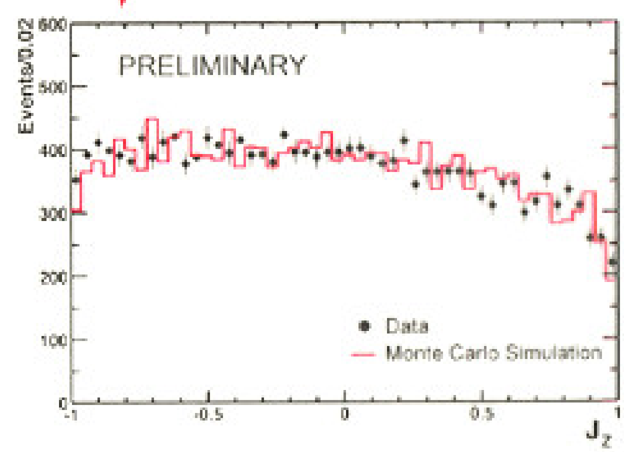


reconstructed track direction
w.r.t. neutrino beam direction

event vertex (in "reduced" coordinates)







The collaboration

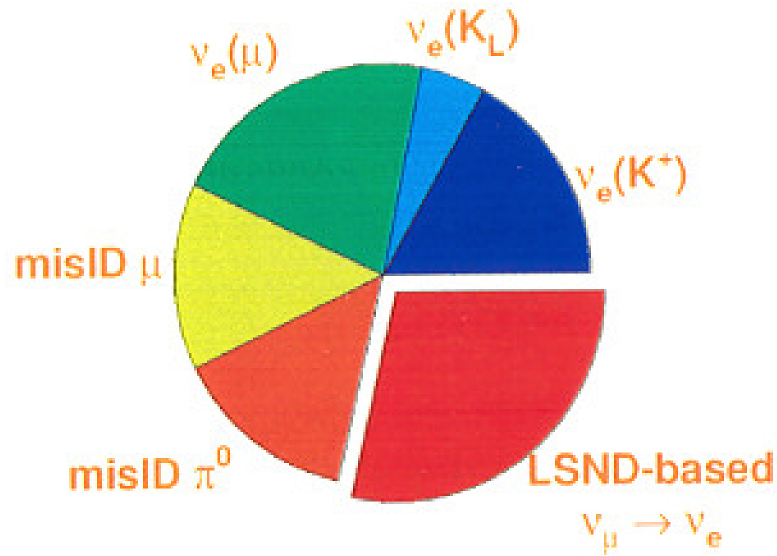
~60 scientists

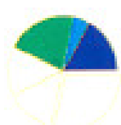
13 institutions

University of Alabama
Bucknell University
University of California, Riverside
University of Cincinnati
University of Colorado
Columbia University
Embry Riddle Aeronautical University
Fermi National Accelerator Laboratory
Indiana University
Los Alamos National Laboratory
Louisiana State University
University of Michigan
Princeton University

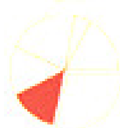
Returning to oscillations

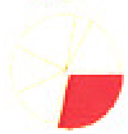
backgrounds and signal (preliminary estimates)

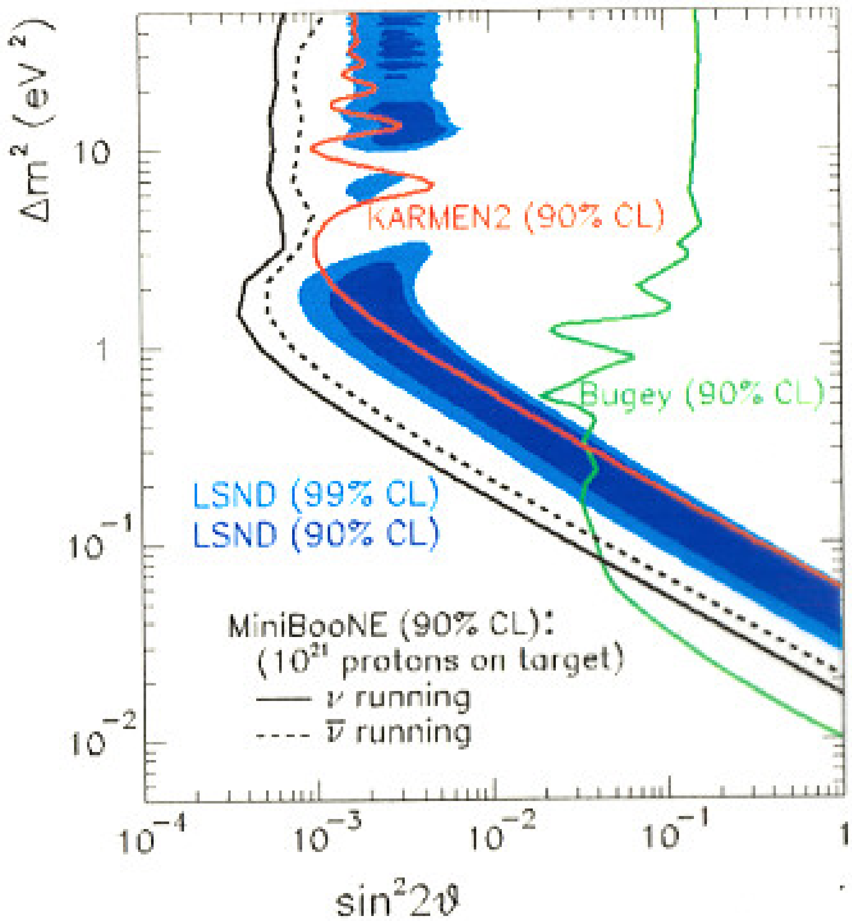


 1,500 intrinsic ν_e

 500 μ mis-ID

 500 π^0 mis-ID

 1,000 LSND-based $\nu_\mu \rightarrow \nu_e$ signal



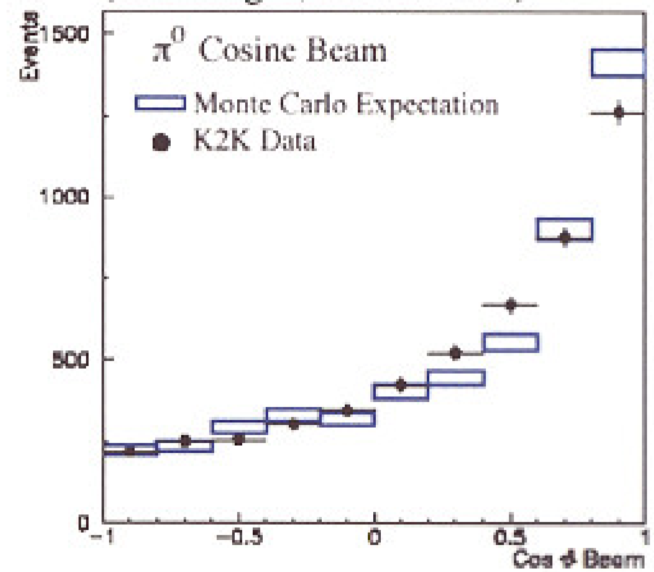
- cover entire LSND allowed region at >5σ
- updated estimates coming
- currently expect results in 2005

Other physics

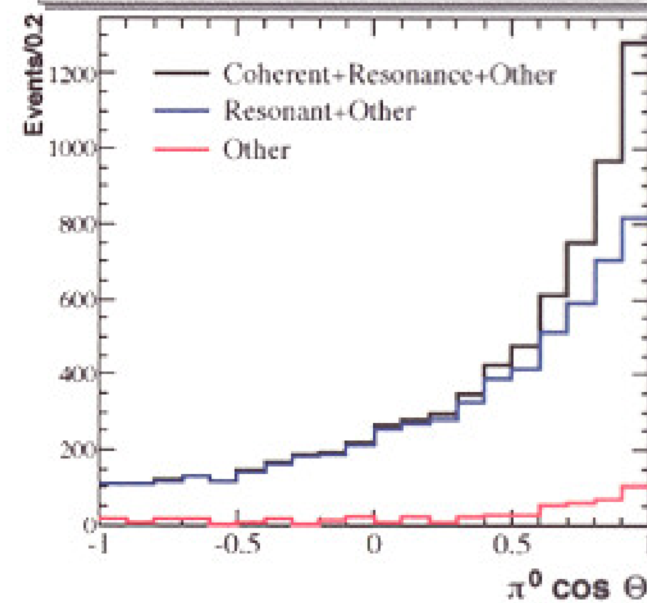
ν_e appearance search is primary purpose, but MiniBooNE can do a lot more...

- ν_μ disappearance
- cross sections, etc.
  - coherent π^0 production (relevant for SuperK sterile ν limits)
  - single K production
  - NC elastic scattering, measurement of Δs
  - μ^- capture
- exotics
  - Q^0 Karmen timing anomaly
    S. Case, S. Koutsoliotas, and M. L. Novak, Phys Rev **D65**, 077701 (2002)
  - neutrino magnetic moment
  - supernova watch

(C. Mauger, NUINT '01)



π^0 angular distribution in MiniBooNE (Monte Carlo)



SUMMARY

STEADILY TAKING DATA, ~10% of 1E21 p.o.t

BOOSTER IMPROVEMENTS THIS SUMMER => FACTOR OF 2?

DETECTOR IS WORKING WELL

SOME PHYSICS RESULTS LATER THIS YEAR

APPEARANCE RESULTS IN 2005

LEARNING HOW TO HANDLE INTENSE BEAMS
ON OUR WAY TO SUPERBEAMS