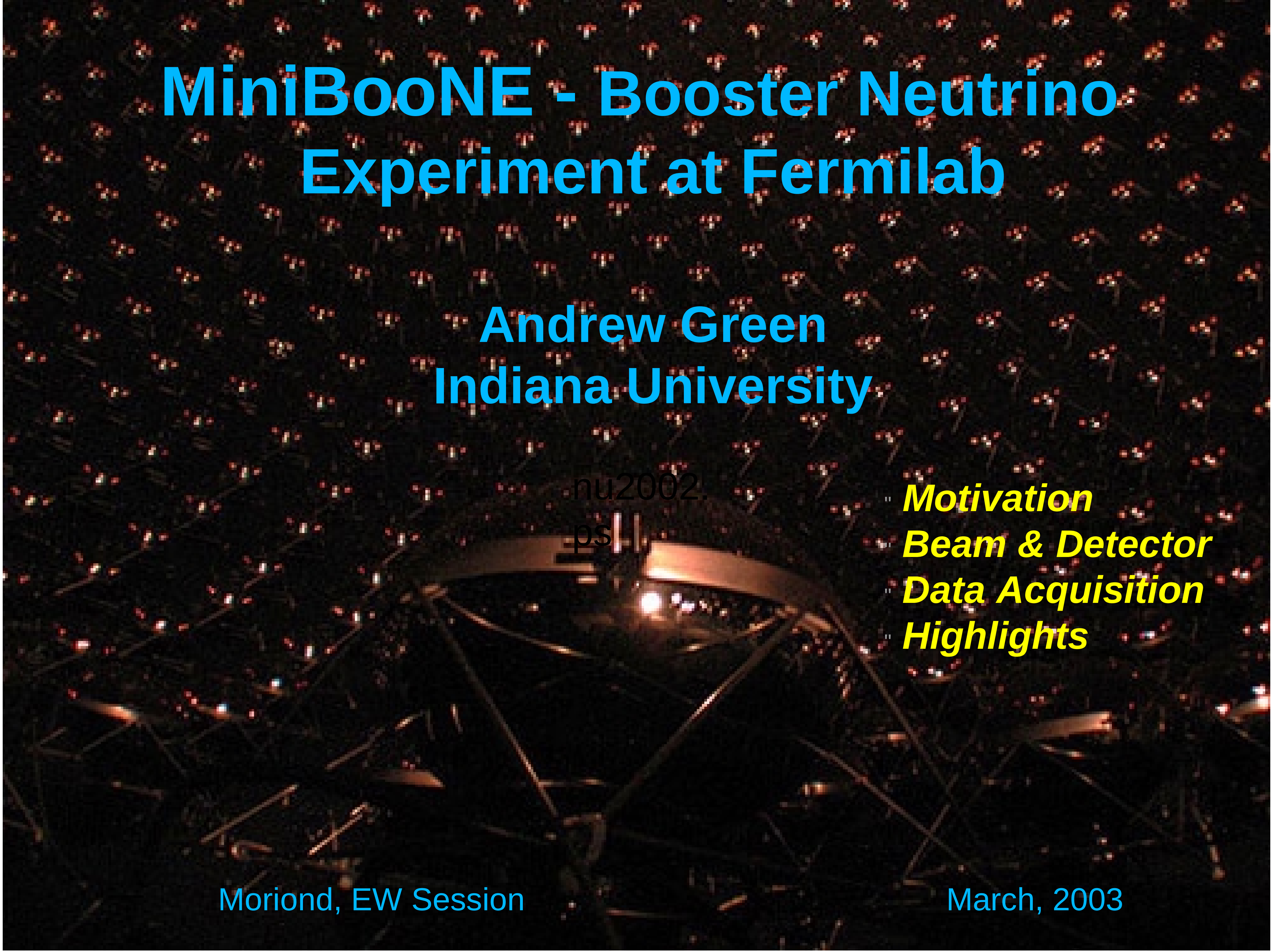


MiniBooNE - Booster Neutrino Experiment at Fermilab

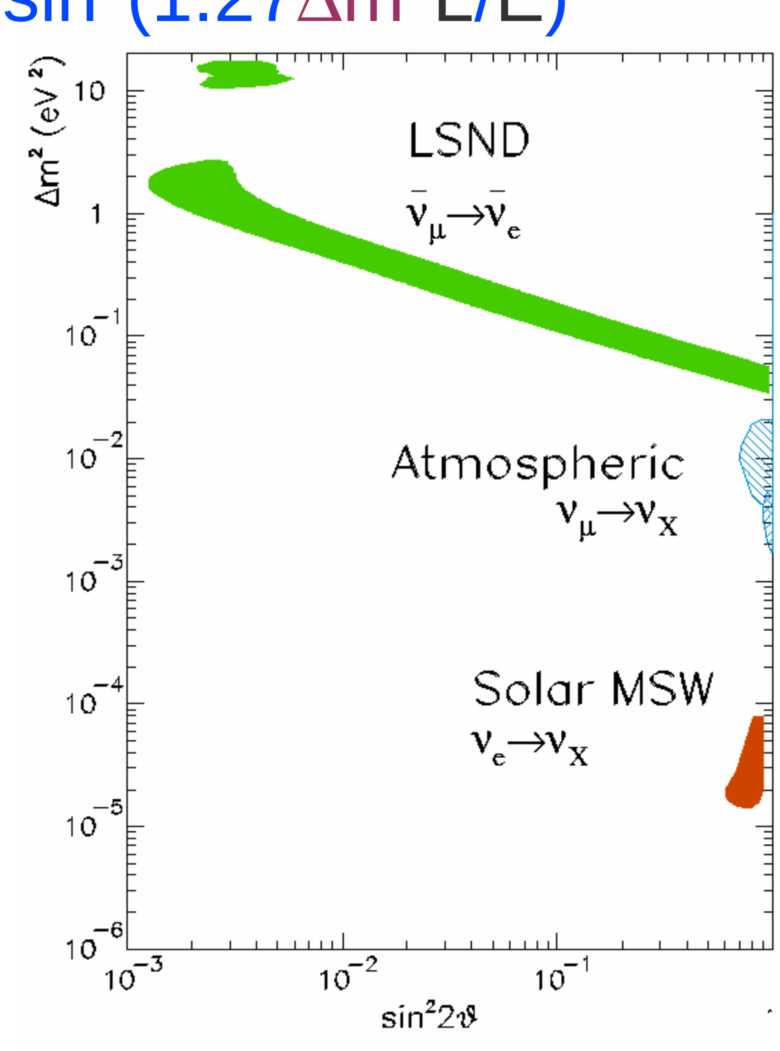
Andrew Green
Indiana University

nu2002.
ps

- ***Motivation***
- ***Beam & Detector***
- ***Data Acquisition***
- ***Highlights***

Current ν Oscillation Measurements

$P_{osc} = \sin^2 2\theta \, \sin^2(1.27\Delta m^2 L/E)$



Well-established measurements:

***Solar** $\Delta m^2 \sim 10^{-(4\sim5)}$ eV^2 from $\nu_e \longrightarrow \nu_x$*

Atmospheric $\Delta m^2 \sim 3\text{x}10^3 \text{eV}^2$ from $\nu_\mu \longrightarrow \nu_x$

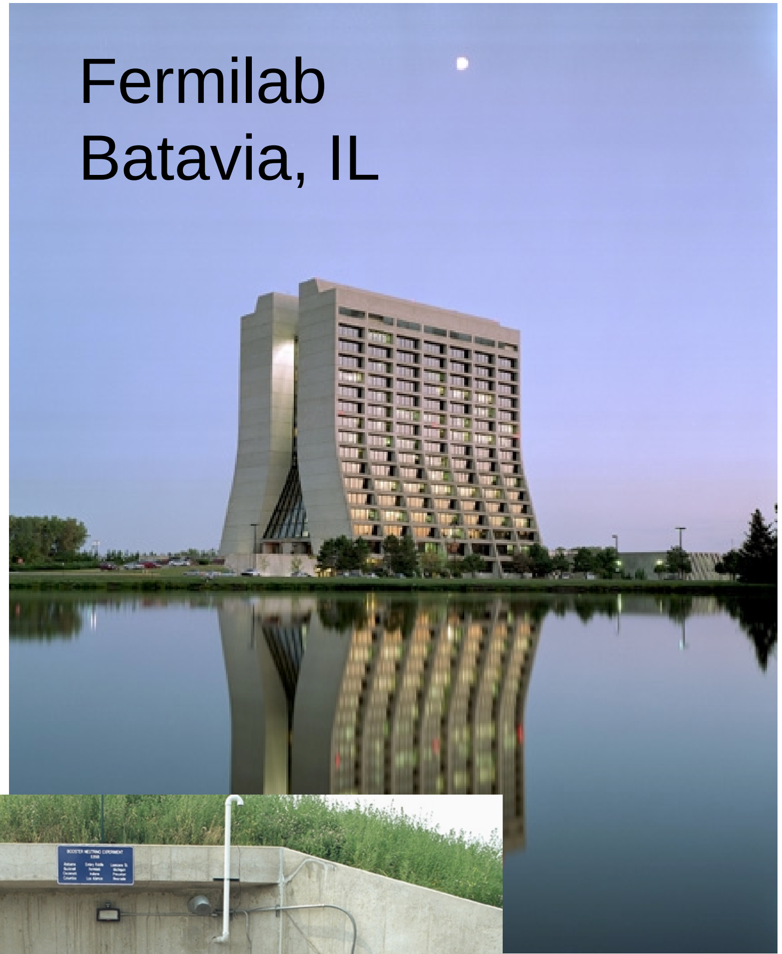
Needs Confirmation:

LSND $\Delta m^2 \sim 10^{-(0 \sim 1)}$ eV^2 from $\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$

***Introduces 3** Δm^2 values inconsistent with 3 neutrino families!!*

Enter MiniBooNE...

Goal: Verify or rule out the LSND signal.



Main Advantages over LSND:

- L/E same, but L, E ~ 10x larger
- 10x higher statistics.
- Better background understanding
- Larger detector volume.
- Cosmic ray hodoscope above.
- Better detector calibration
- Lower beam duty factor (lower background from cosmics)

The BooNE Collaboration

62 Scientists from 13 institutions

2 undergraduate universities
9 graduate universities
2 U.S. laboratories

Y. Liu, I Stancu
University of Alabama, Tuscaloosa, AL 35487

S. Koutsoliotas
Bucknell University, Lewisburg, PA 17837

E. Church, C. Green, G. J. VanDalen
University of California, Riverside, CA 92521

E. Hawker, R. A. Johnson, J. L. Raaf
University of Cincinnati, Cincinnati, OH 45221

T. Hart, E. D. Zimmerman
University of Colorado, Boulder, CO 80309

J. M. Conrad, J. Link, J. Monroe, M. H. Shaevitz, M. Sorel, G. P. Zeller
Columbia University, Nevis Labs, Irvington, NY 10533

D. Smith
Embry Riddle Aeronautical University, Prescott, AZ 86301

C. Bhat, S. J. Brice, B. C. Brown, L. Bugel, B. T. Fleming, R. Ford, F. G. Garcia, P. Kasper, T. Kobilarcik, I. Kourbanis, A. Malensek, W. Marsh, P. Martin, F. Mills, C. Moore, P. Nienaber, E. Prebys, A. Russell, P. Spentzouris, R. Stefanski, T. Williams
Fermi National Accelerator Laboratory, Batavia, IL 60510

D. C. Cox, A Green, H. -O. Meyer, R. Tayloe
Indiana University, Bloomington, IN 47405

G. T. Garvey, W. C. Louis, G. A. McGregor, G. B. Mills, V. Sandberg, B. Sapp,
R. Schirato, R. Van de Water, D. H. White
Los Alamos National Laboratory, Los Alamos, NM 87545

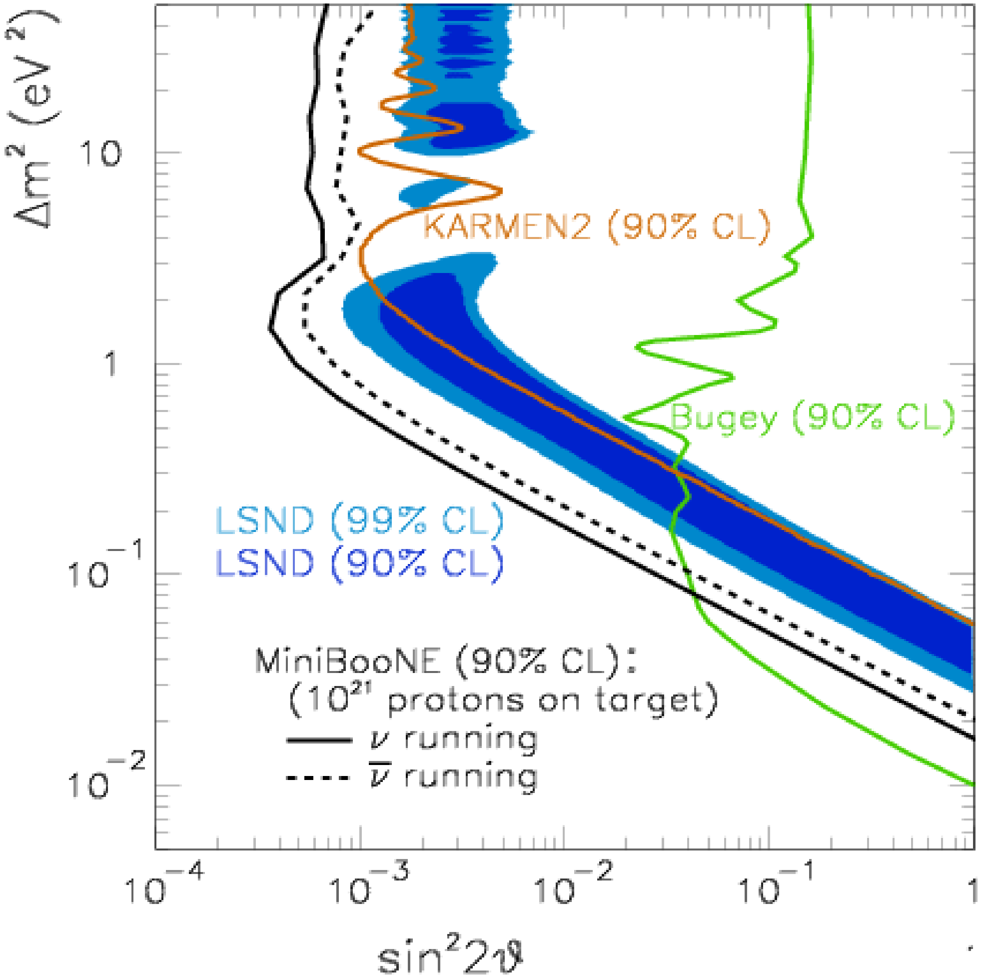
R. Imlay, W. Metcalf, M. Sung, M. O. Wascko
Louisiana State University, Baton Rouge, LA 70803

J. Cao, Y. Liu, B. P. Roe
University of Michigan, Ann Arbor, MI 48109

A. O. Bazarko, P. D. Meyers, R. B. Patterson, F. C. Shoemaker
Princeton University, Princeton, NJ 08544

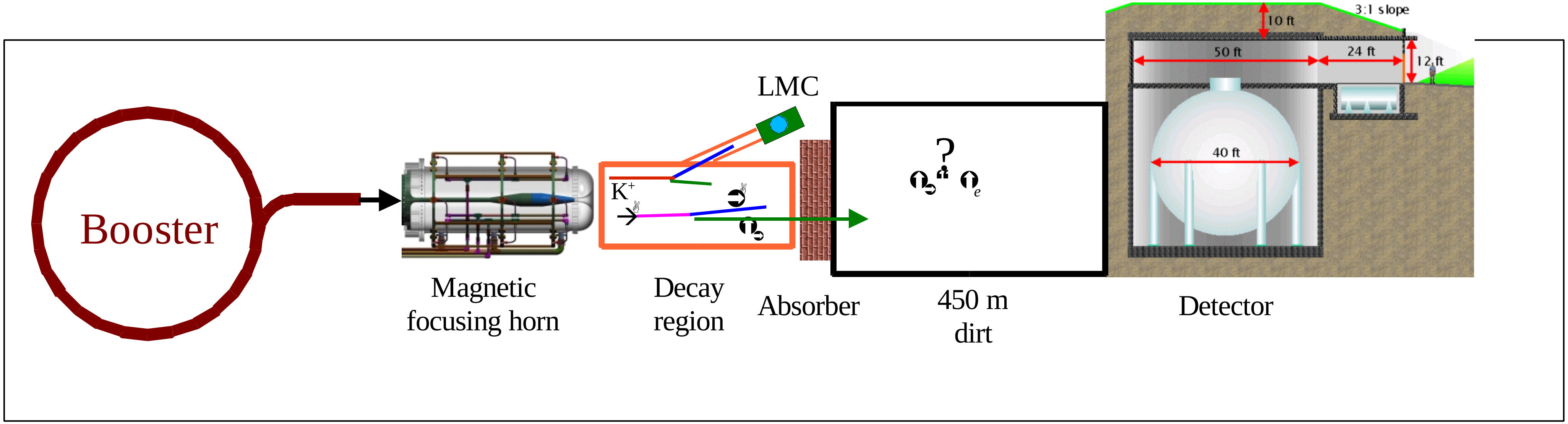
Sensitivity Goal

MiniBooNE at 1-2 yrs of full intensity



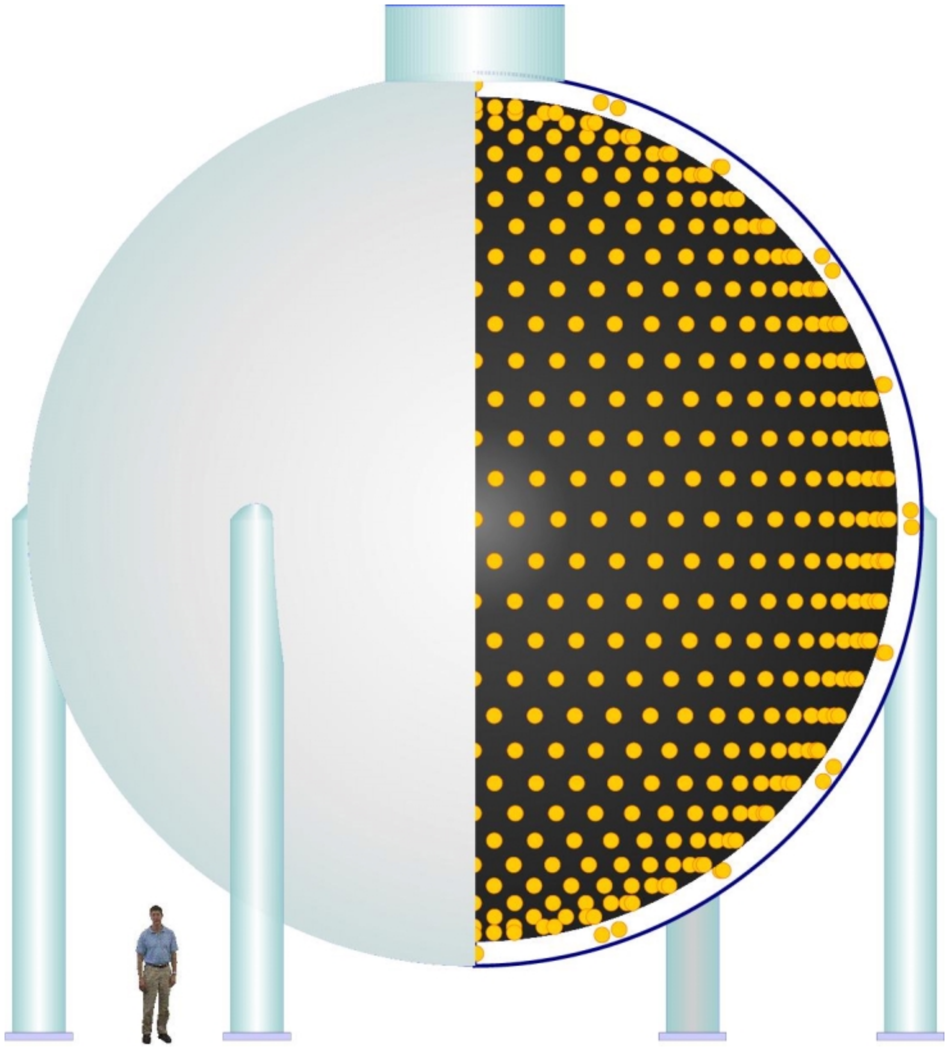
- With 1×10^{21} protons on target, MiniBooNE will cover the LSND signal region at the 5σ level.
- **Fill area is highest likelihood region of LSND's *affirmative result.***
- **Lines indicate *proposed exclusion region.***

The neutrino beam



- Primary beam of 8 GeV protons from Booster
- Beryllium target produces secondary beam of pions and kaons
- Horn focuses charged particles toward detector
- The Little Muon Counter cross-checks the beam flux and measures ν_e background from K decays
- Variable decay length of 50/25 m
- Potential $\bar{\nu}$ running mode

MiniBooNE Detector



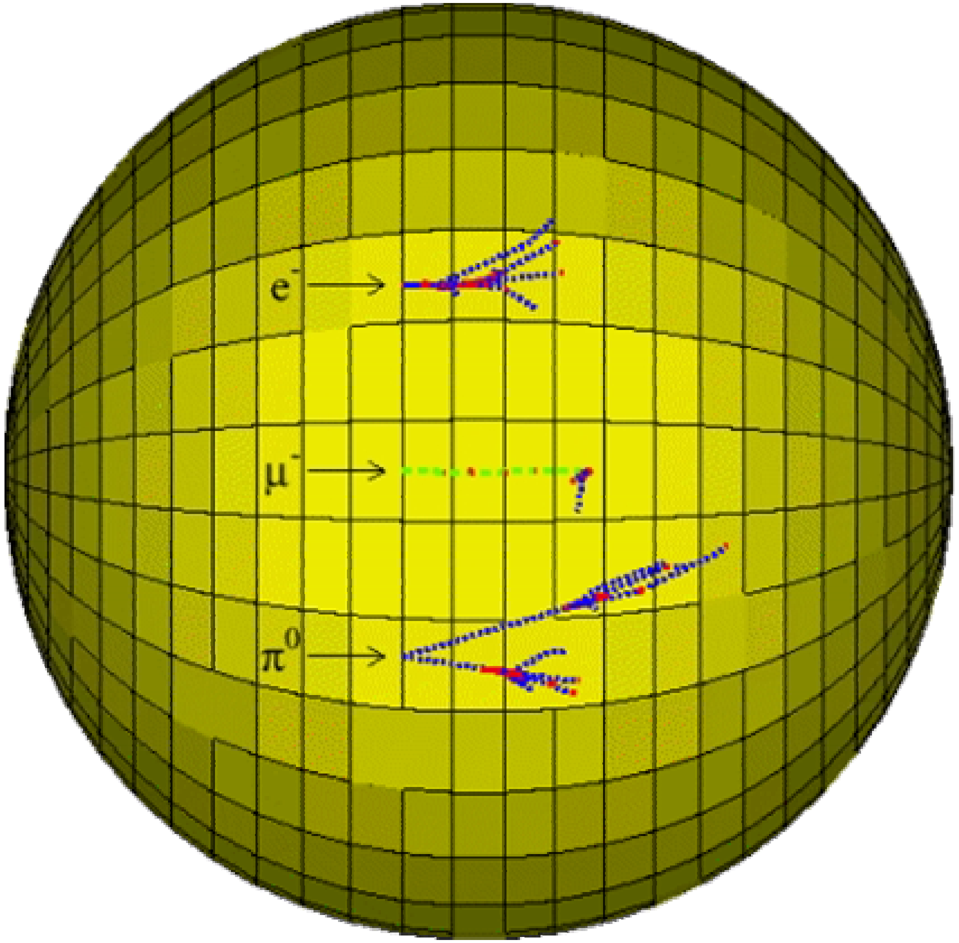
- Built to detect Cherenkov light
- 12 meter (40') diameter sphere
- 250,000 gallons of white mineral oil
  - 807 tons, 445 tons fiducial
- Optically isolated inner region lined
  - with 1280 PMTs (10% coverage)
- Veto region with 240 PMTs
- Custom front-end electronics

All new DAQ software

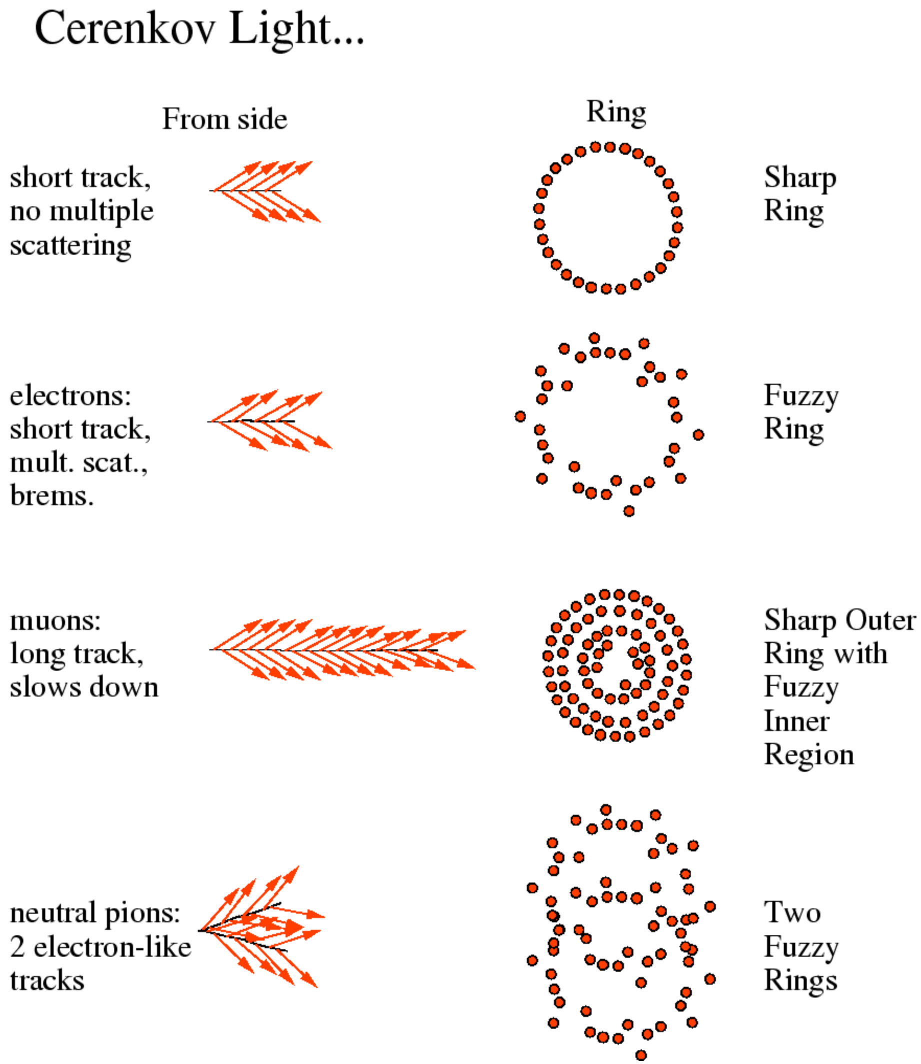
Main Data Acquisition System

- PMT Charges (Q) and times (T) are digitized every 100ns ...info kept for 205μs (about 10x longer than needed) in a circular buffer for each channel.
- The trigger captures a time window (stored in the circular buffer) of Q & T data based on:
  - External input pulses: "protons to MiniBooNE," calibration, strobe signals
  - Detector info: A few Nhit thresholds for Main & Veto
- PMT & Trigger data from VME crates are colated, monitored, and shipped.
- Other data streams: beam, horn, off-axis muon detector (LMC), beam pulse digitizer, slow monitoring.

Particle ID

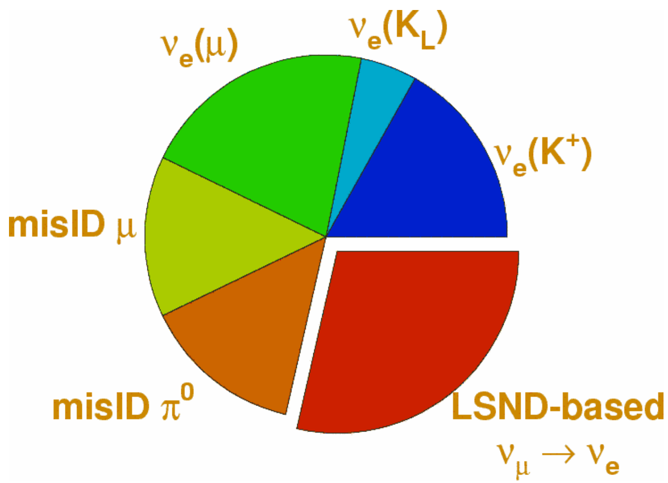


e-
μ-
π0



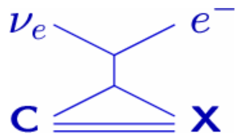
Cerenkov Light...
From side
Ring
short track, no multiple scattering
Sharp Ring
electrons: short track, mult. scat., brems.
Fuzzy Ring
muons: long track, slows down
Sharp Outer Ring with Fuzzy Inner Region
neutral pions: 2 electron-like tracks
Two Fuzzy Rings

Estimates of the MiniBooNE Signal

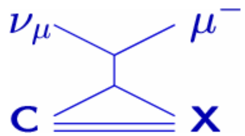


- ~500k ν_μC CC events
- ~50K ν_μC NC

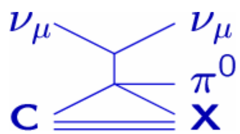
Intrinsic ν_e background: 1,500 events



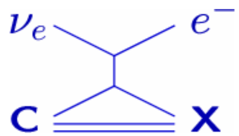
μ mis-ID background: 500 events



π^0 mis-ID background: 500 events



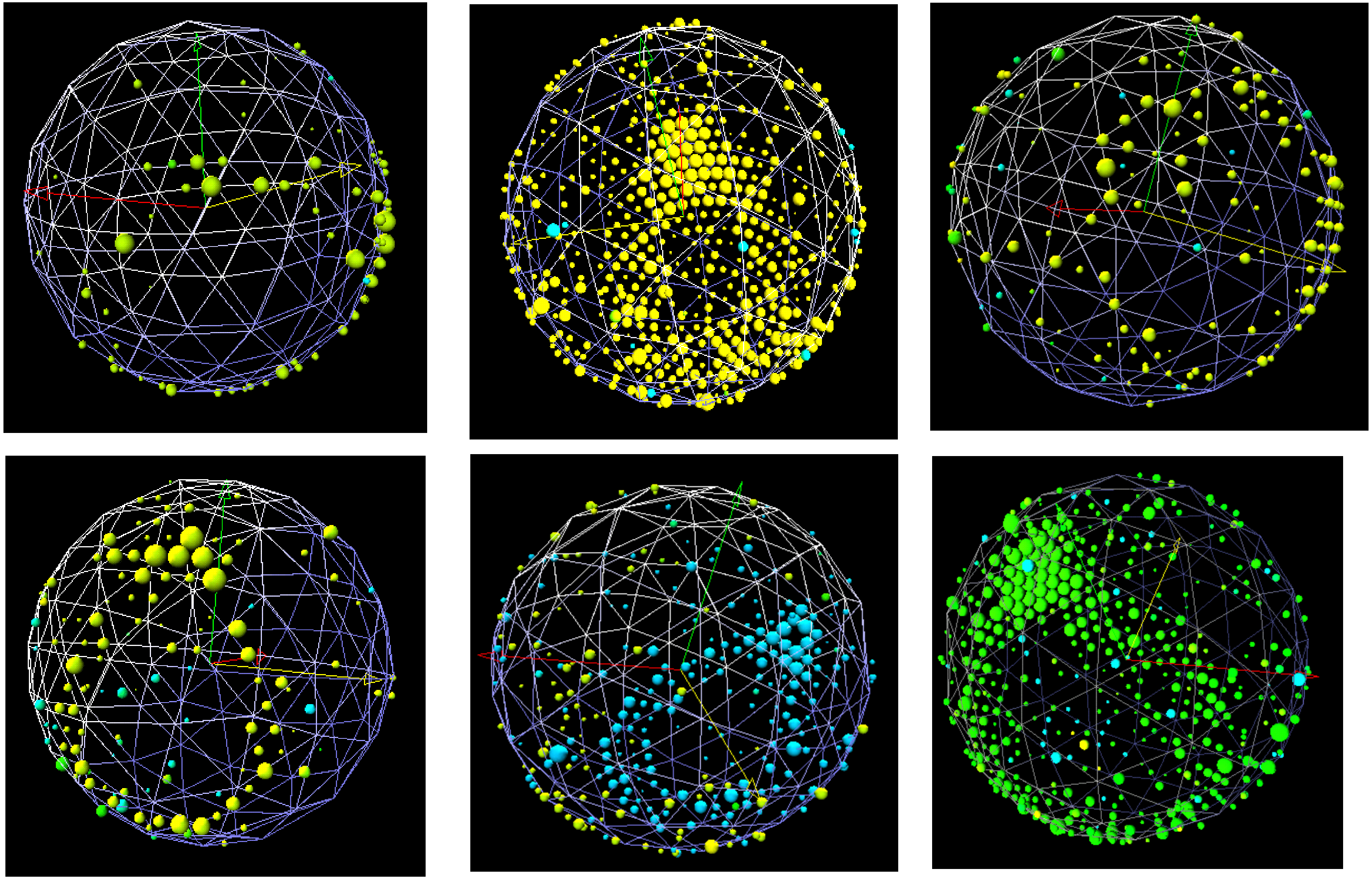
LSND-based $\nu_\mu \rightarrow \nu_e$: 1,000 events



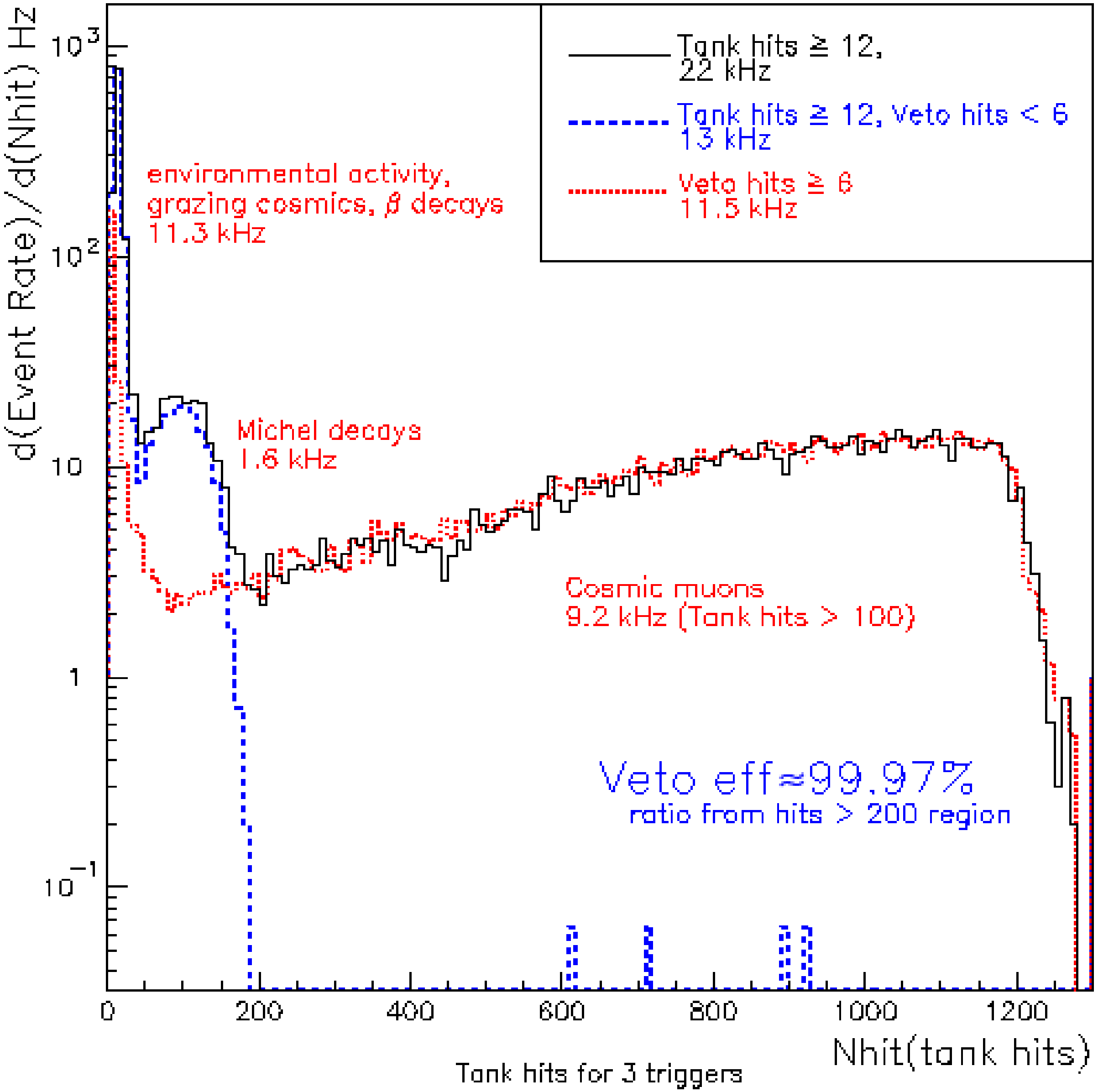
Status Highlights

- Cosmic & calibration data-taking since Dec 2001
  - "Michel"-electron data ($\mu \rightarrow e\ \nu_\mu$) from cosmics: endpoint used to get partial energy calib.
- Beam data began Sept 2002
  - Beam ν data: ~40k ν events collected so far (loose cuts).
  - π^0 peak seen: preliminary, but encouraging!

Event Displays: Gallery of Rings



Cosmics, and other things



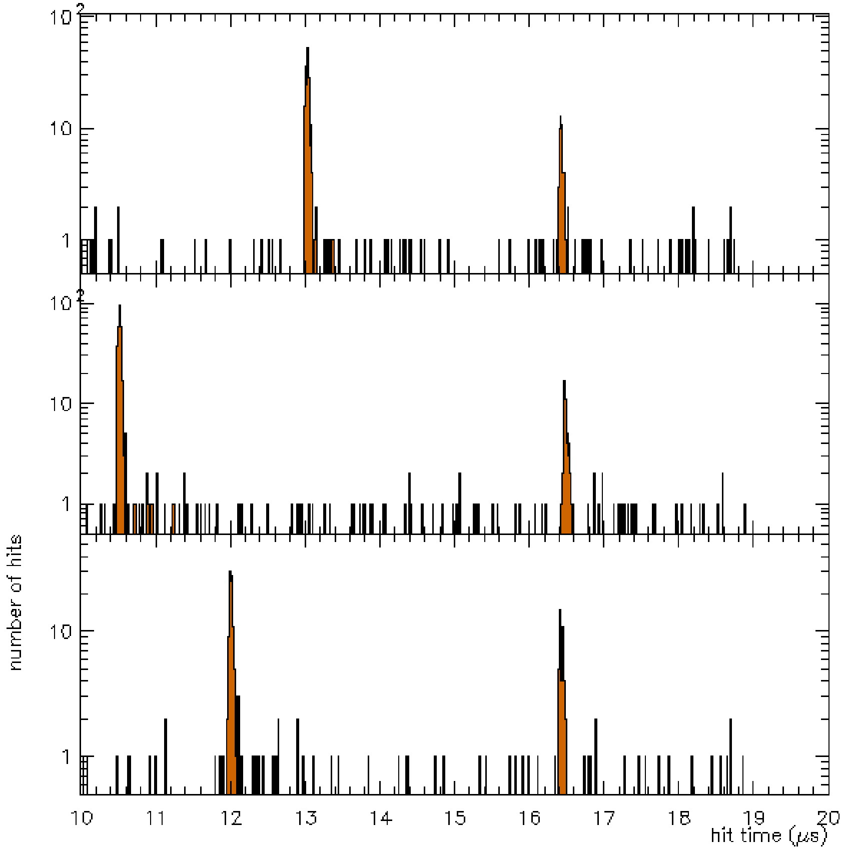
- **Tank** is inner region (1280 tubes)
- **Veto** is optically isolated outer region (240 tubes)

- Cosmics enter outer veto region first
  - **Rate consistent with known measurement.**
  - **Check of veto efficiency**
- Michel electrons decay from cosmic muons
  - **Important tool for calibration**
  - **Well-understood.**

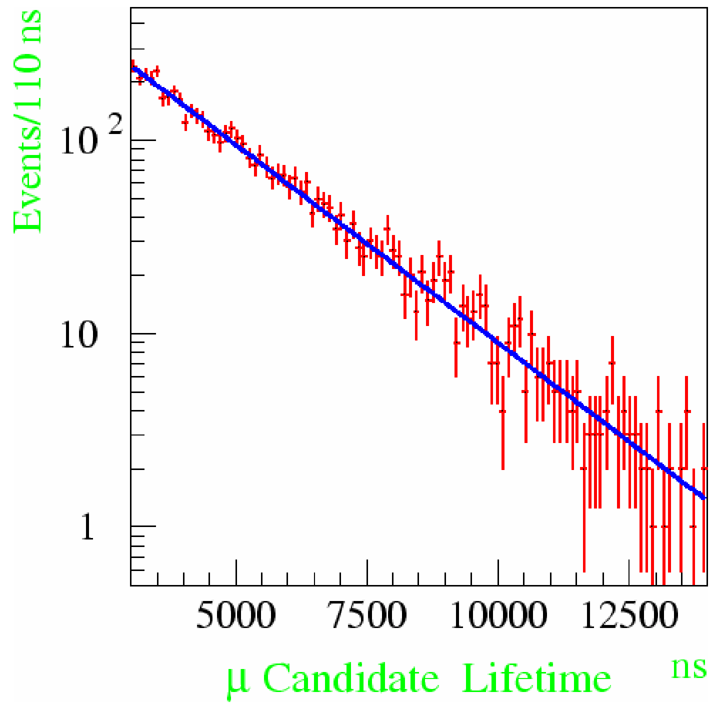
Michel Data

Hit times for 3 "Michel" events

Number of hits/time



PMT hit time (μs)

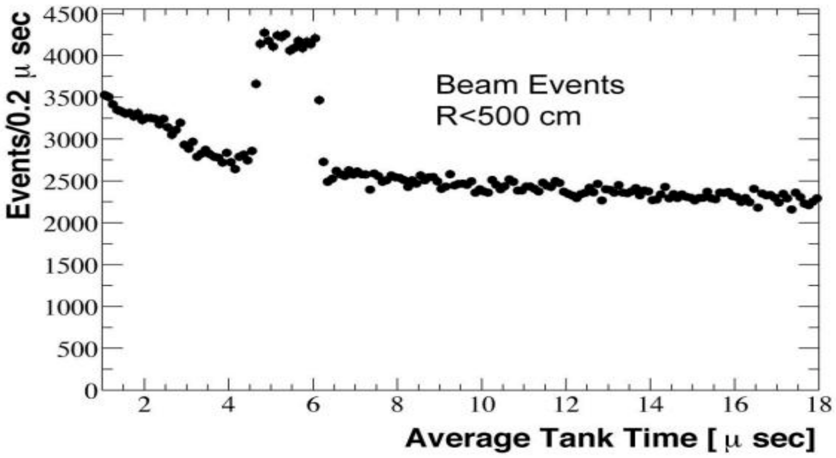


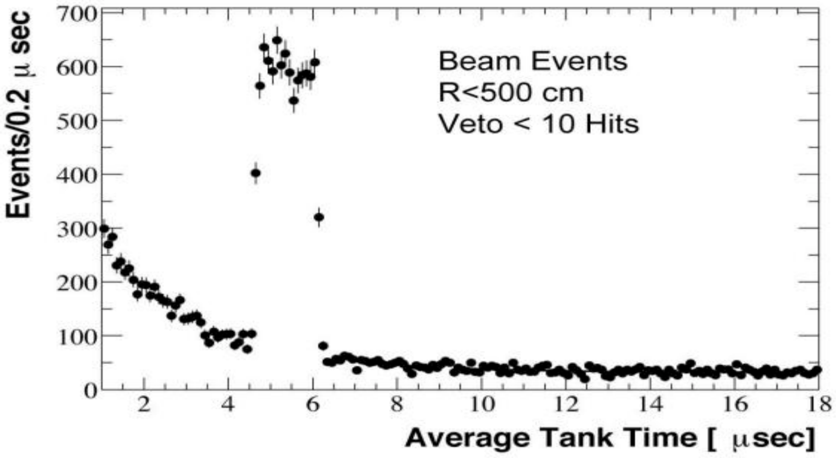
Fit lifetime: 2.12 ± 0.05 μs

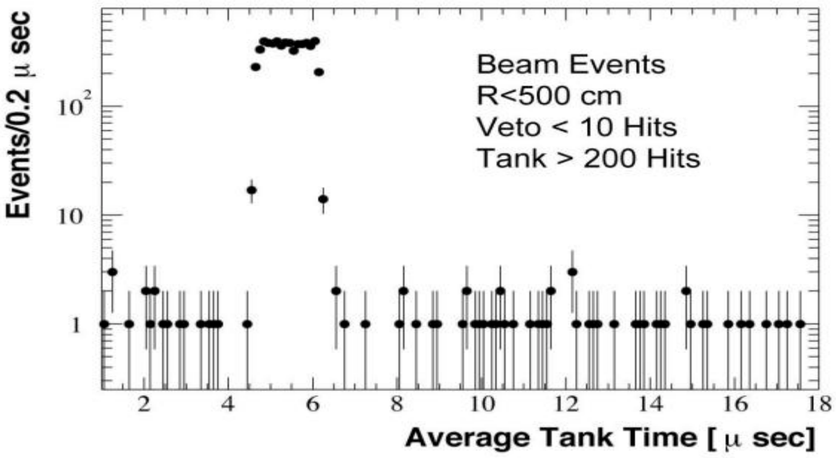
Expected < 2.2 μs due to μ^- capture on ^{12}C.

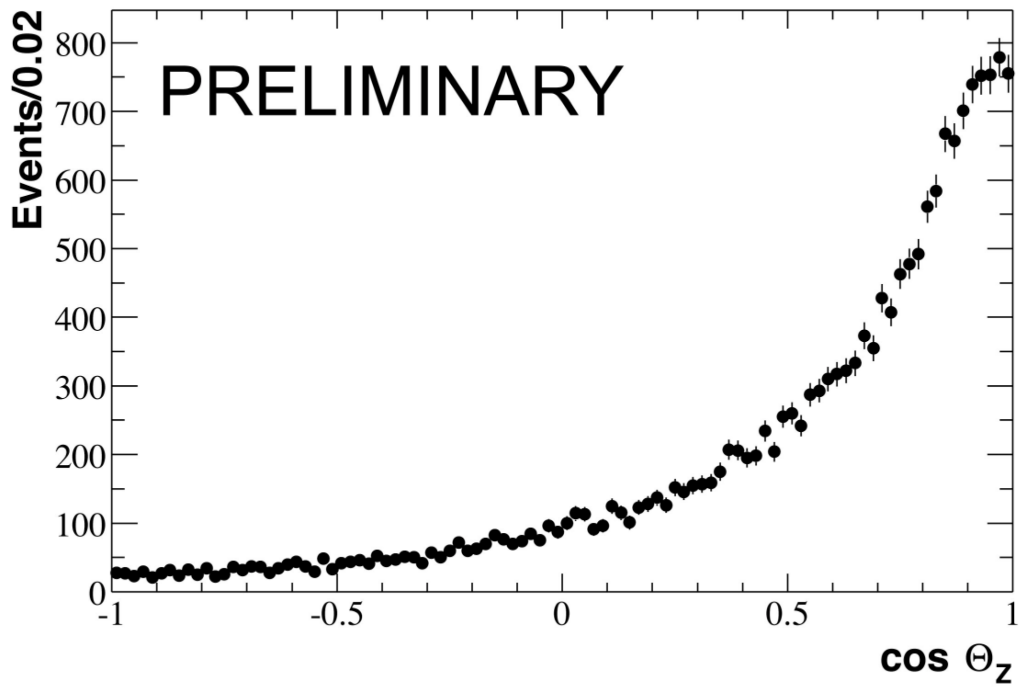
Neutrino candidates

Simple cuts:
- Fiducial R < 5m
- Tank hits > 200
- Veto hits < 6



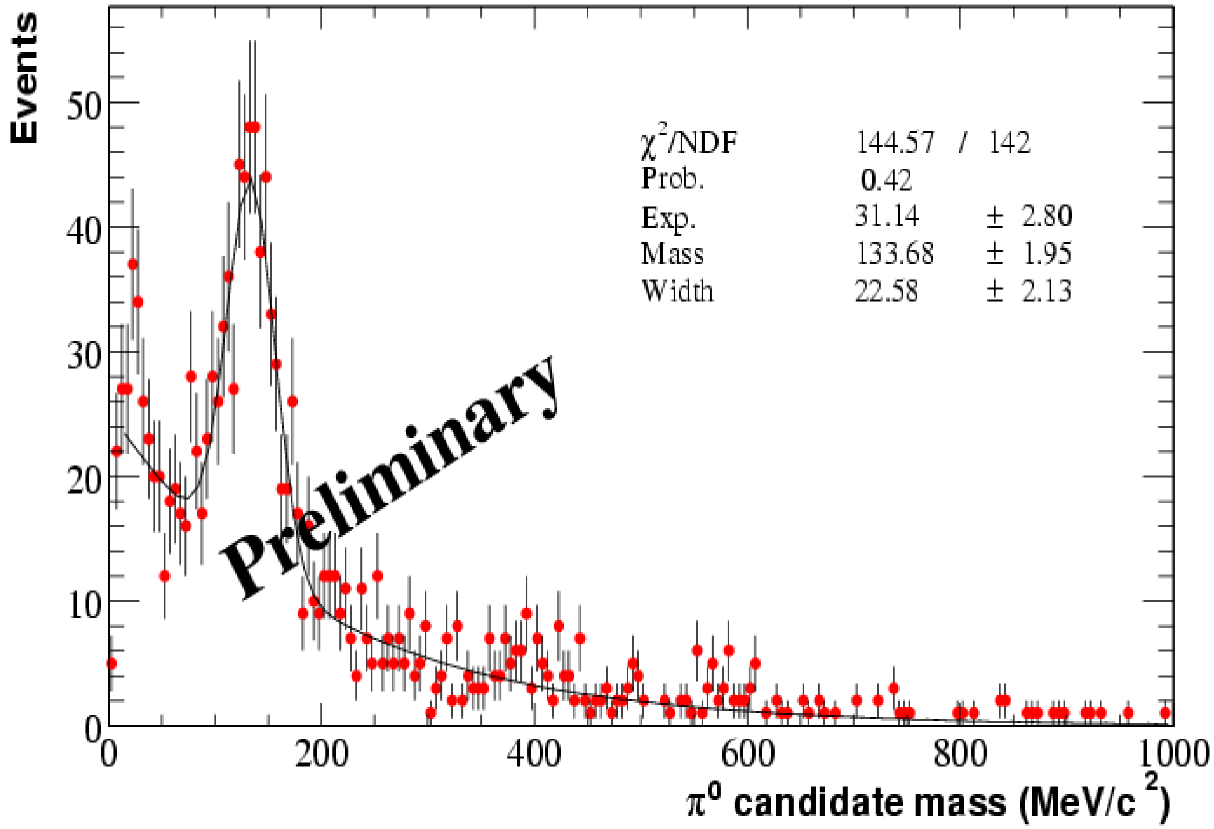




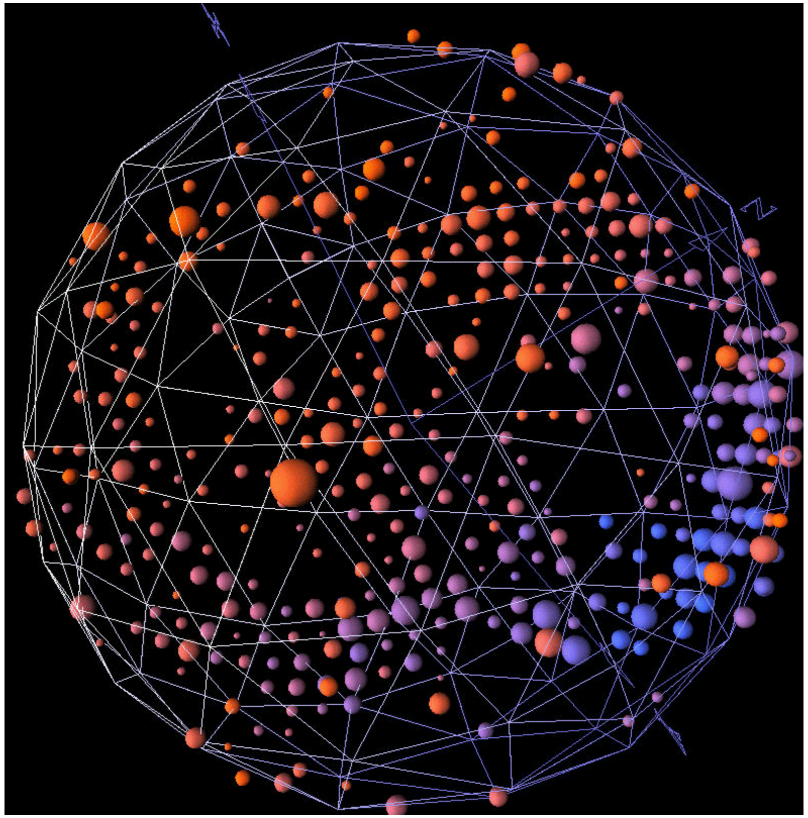


π^0 Mass Peak

Select: beam ν candidates with two good rings



Example π^0 candidate



Summary

- MiniBooNE will confirm or rule out the LSND result.
- The detector is fully operational and taking ν-beam data.
- We understand our cosmic & michel data
- We see neutrinos.
- We see a π^0 peak in the neutrino data.

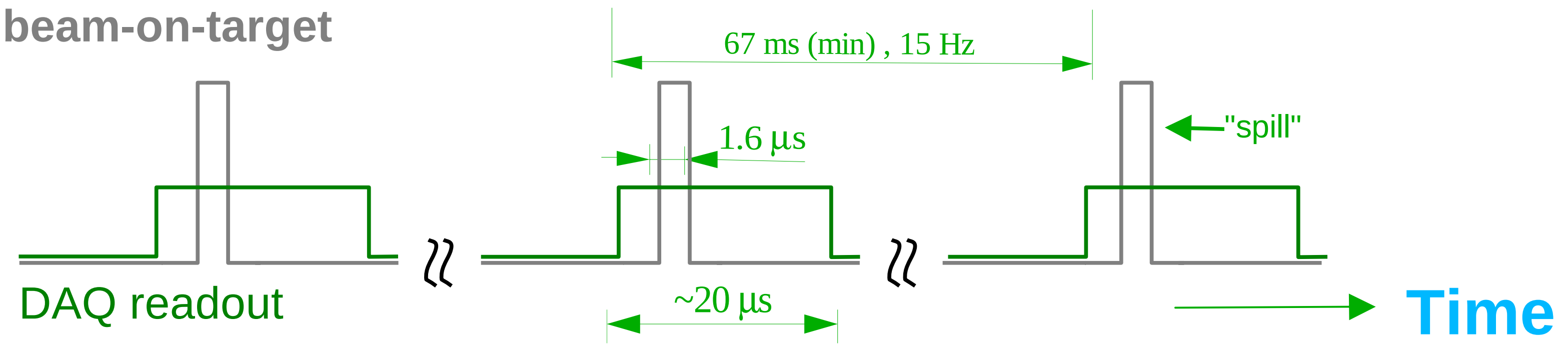
End of Presentation.
Backup slides follow...

MiniBooNE Standard Trigger Set — February 1, 2003

Trigger Name	*Ave. Data Rate (Hz)*	*Prescale*	*Description*	*Event Window Size (μs)*
Signal & Background Triggers				
Beam	2-5	1	Protons to MiniBooNE from Booster	19.2
Beam γ	~ 0.1	1	Hits $\geq$ 10 tank, $<$ 4 veto; $<$ 1ms after "ν"; cosmic h/o	3.2
Beam β	~ 0.3	1	Hits $\geq$ 24 tank, $<$ 4 veto; $<$ 30ms after "ν"; cosmic h/o	3.2
Strobe	2.0	1	Random window in time	19.2
Strobe γ	0.1	1	Hits $\geq$ 10 tank, $<$ 4 veto; $<$ 1ms after "ν"; cosmic h/o	3.2
Strobe β	0.3	1	Hits $\geq$ 24 tank, $<$ 4 veto; $<$ 30ms after "ν"; cosmic h/o	3.2
Michel	1.2	600	Cosmic followed by "electron"	19.2
Supernova	10.9	1	Hits $\geq$ 60 tank, $<$ 6 veto; cosmic h/o	3.2
Tank	0.4	90000	Hits $\geq$ 10 tank	19.2
Veto	0.4	5000	Hits $\geq$ 6 veto	19.2
Calibration Triggers				
Laser	1.0	1	Pulsed at fixed time within event	9.6
Fake beam	~ 0.5	1	Laser in time w/ Booster; no p's to M'BooNE	9.6
Cube	1.1	1	Decay in cube; hits $\geq$ 100 tank	12.8
Tracker	0.7	170	4-plane coincidence of top μ-tracker	12.8
	$\sim$23 Hz			

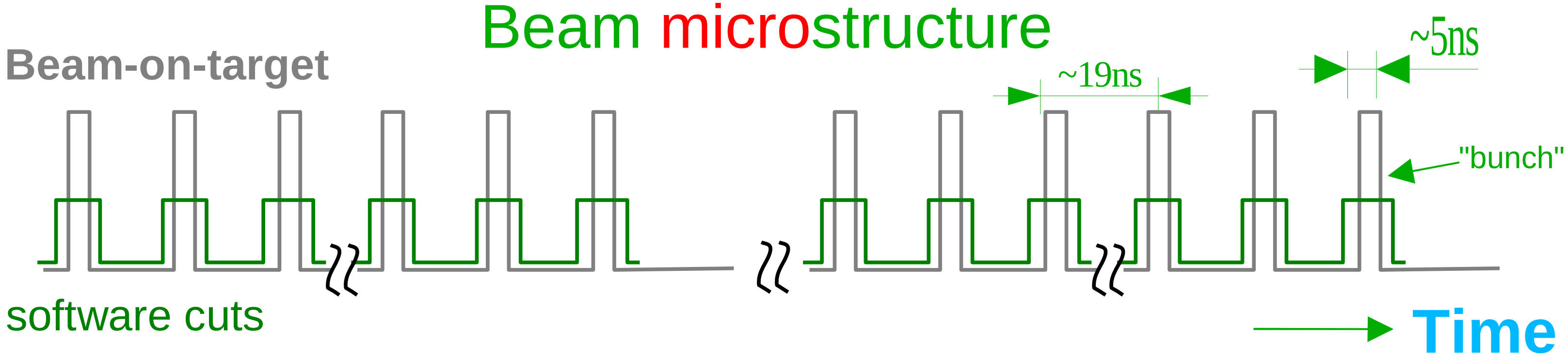
Neutrino Beam/Event Timing

Beam macrostructure



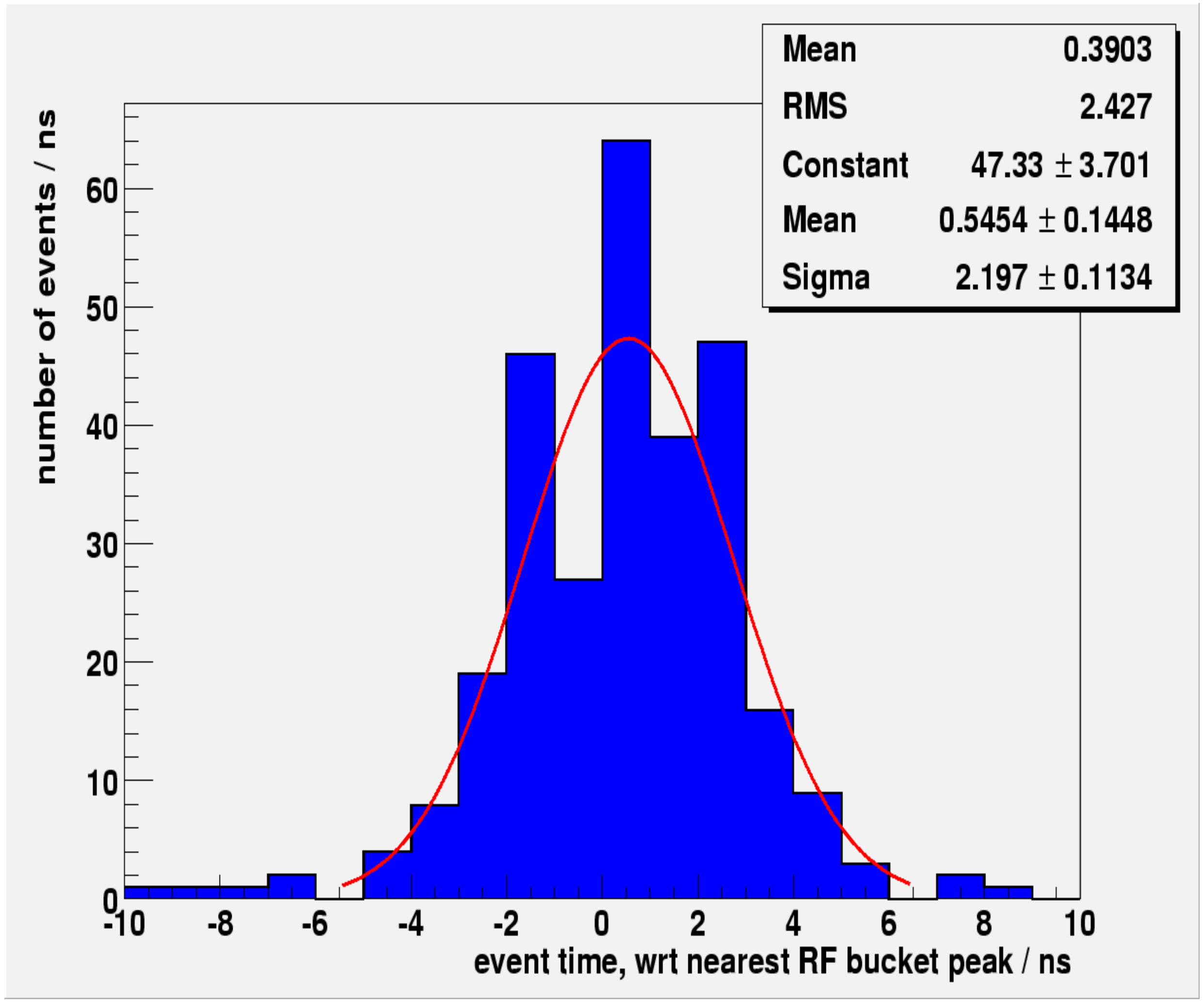
- DAQ readout started with "booster extract" signal

Beam microstructure



- A cut is determined from beam microstructure digitized at target.
- Reduces "out -of-time" backgrounds

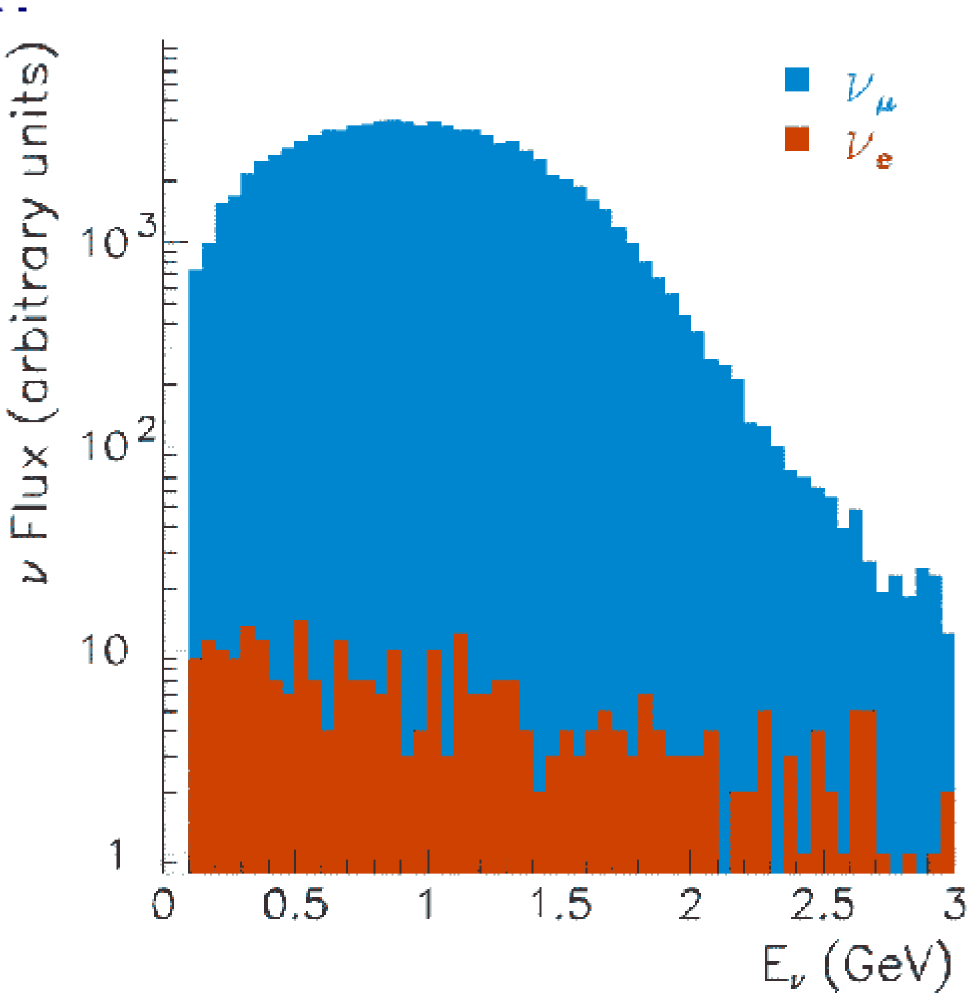
ν -Candidate Timing Relative to proton bunches.



- ν candidates in the detector line up well with a Booster proton bunch.
- This greatly reduces external backgrounds.

Beam Composition

- Protons on Be:
  - $p + Be \rightarrow \pi^+, K^+, K^0_L$
- Yield a high flux of ν_μ:
  - $\pi^+ \rightarrow \mu^+ \nu_\mu$
  - $K^+ \rightarrow \mu^+ \nu_\mu$, $K^0_L \rightarrow \pi^+ \mu^- \nu_\mu$
- With a low background of ν_e:
  - $\mu^+ \rightarrow e^+ \nu_e \nu_\mu$
  - $K^+ \rightarrow \pi^0 e^+ \nu_e$, $K^0_L \rightarrow \pi^+ e^- \nu_e$



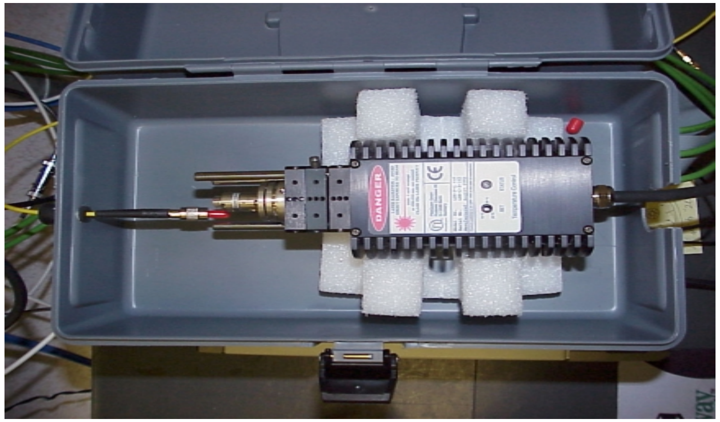
Getting to know the flux:
- Detailed simulations
- HARP measurements
- ν_μ–Carbon charged current σ
- 50m & 25m decay region (μ background)
- Off-axis muon counter, LMC (K background)

Auxiliary Data

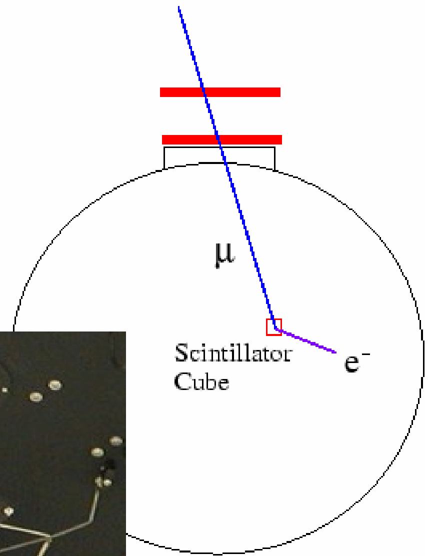
- Proton beam structure digitizer (reduce beam duty cycle).
- Little Muon Counter (LMC) data (understand some backgrounds)
- Beam Data (understand prot. flux for each event):
  - MiniBooNE beamline
    - Slow data -> Magnet currents
    - Fast data (synch with proton pulse) -> Target multiwire detectors, beam position monitors, toroid (measures proton intensities)
  - Horn & Target
    - Horn current
    - Temperature of the target
    - 90° monitor (beam on target?)

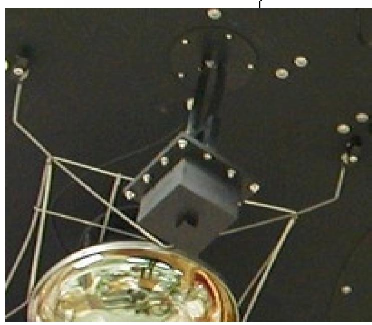
Calibration

- PMT charges and times calibrated using laser and 4 flasks ludox.



- Trajectories of michel decays understood using muon tracking system and 7 scintillator cubes.





Calibration Sources

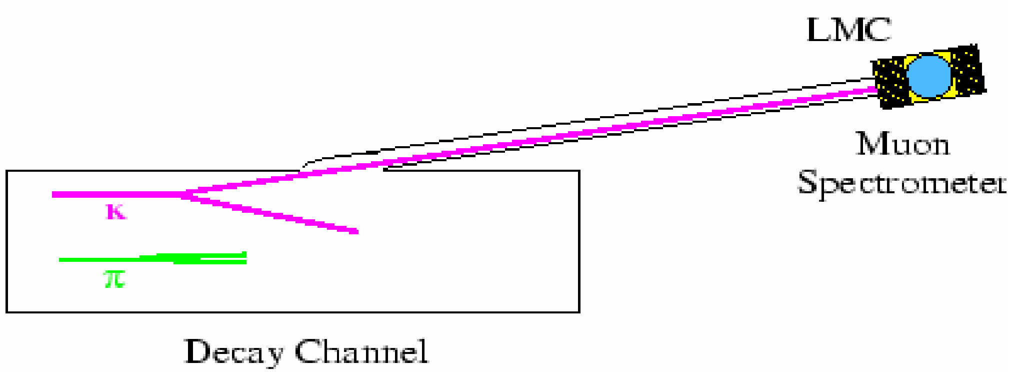
- Cosmic Michel data
  - Energy calibration
  - Develop electron cuts
- Laser data
  - PMT charge & time
  - Detailed PMT hit structure
- Muon hodoscope, scintillator cubes (7)
  - Precise michel trajectory through the detector correlate to PMT data

Background measurements in the beamline

Varying the length of the decay region from 50m to 25m :

- An oscillation signal would go down by factor of 2.
- Background ν_e rate (μ decay) would go down by a factor of 4.
- ν_e 's from decay of short-lived sources not affected.

Little Muon Counter: A spectrometer which exploits the wide-angle decays of the Kaon, and will get the μ energy distribution to constrain the ν_e production rate from Kaons.

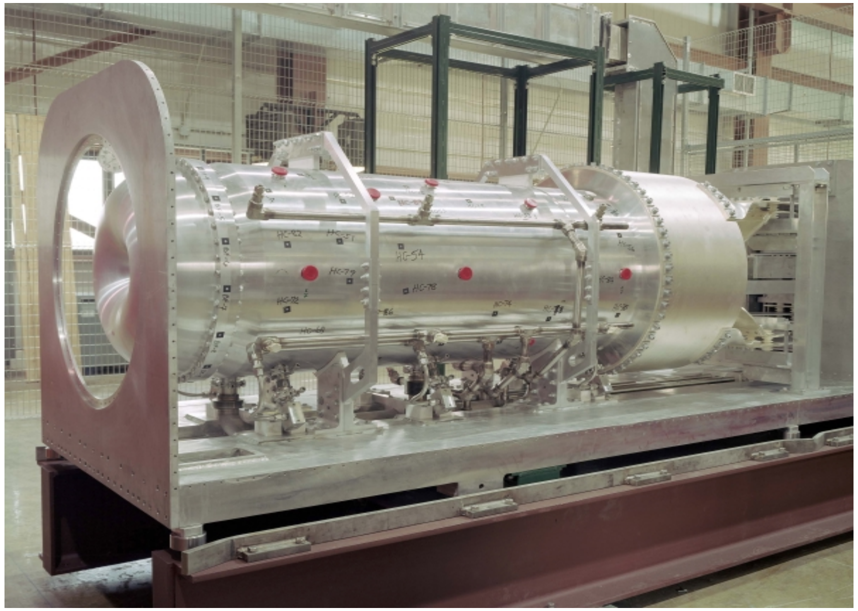


Fermilab Booster

- Supplies 8 GeV protons to the lab
- **Currently supplying to collider programs (Run II) & MiniBooNE without affecting Run II luminosity.**
- **Operating at record intensities** of ~5 x 10^{12} protons/pulse,
- **Goal average pulse rate to MiniBooNE is 5 Hz, currently at ~3Hz.**
- **Rate is mostly limited by radiation losses which are gradually being addressed.**

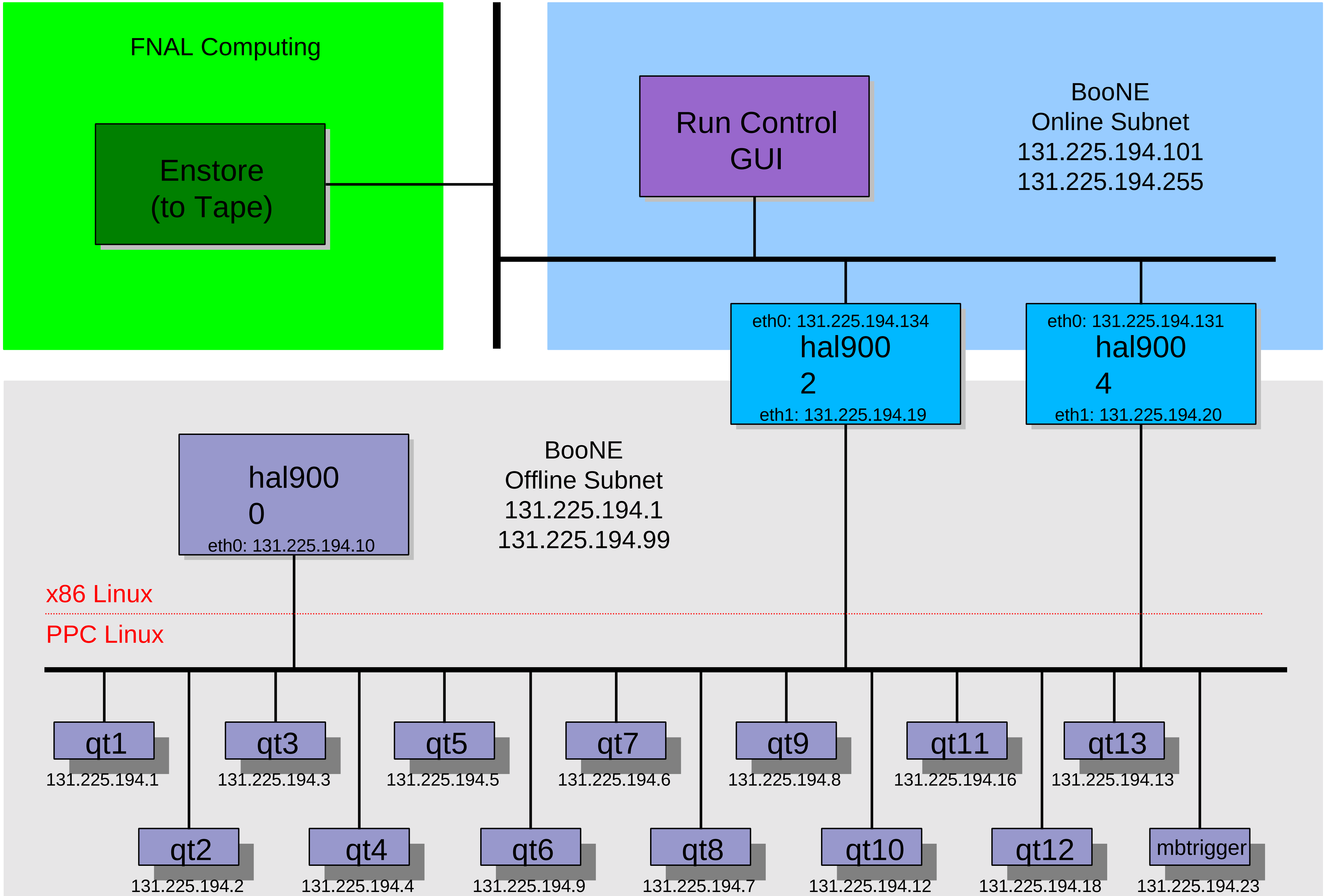
Target & Horn

- 170 kA, 140 μs waveform, 5 Hz average rate (15 Hz burst rate).
- Life expectancy is 200 M pulses, and tested with 11 M.
- Installed & running with beam since early September.
- H_2O cooled 1 liter/sec (2.4 kW heat load).



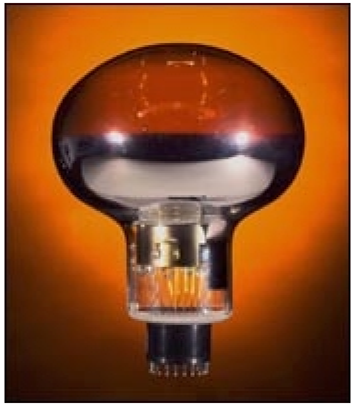
- Beryllium target, 71 cm long.
- Resides on the horn axis of symmetry.
- Air cooled -> air temperature correlates to beam on target.

DAQ Overview



Supernova "Trigger"

- 200 $\nu_e\, p \rightarrow e^+\, n$ events for a Milky Way supernova at 10 kpc.
- Trigger: 15 μs holdoff from cosmics & no hits in veto region.
- ^{12}B decay background peaked at lower energy, cosmic ray background peaked at higher energy (M. K. Sharp, J. F. Beacom, J. Formaggio, **hep-ph/0205035)**



MiniBooNE Photomultiplier Tubes

Why they will not implode.

Calculations show:

1. Energy release from a single tube imploding is an order of magnitude less than SuperKamiokande single tube.
2. Pressure in shock wave is less than half of the SuperK shock pressure at a depth where SK tubes survived.

Tests at SuperK showed no chain reaction at depth of 5 m.

SNO tests with 8" tubes with closer spacing and greater depth than MiniBooNE produced no chain reaction.

Goal

- Make a high intensity nearly pure ν_μ beam of known spectrum and flux.
- Build a mineral oil detector to analyze the beam ν's.
- Ask: Do we see a ν_e spectrum in addition to that expected in the beam?
- If so, measure the oscillation probability of

$$\nu_\mu \longrightarrow \nu_e$$

- In addition, make other measurements.

Neutrino Oscillations

$$P_{osc} = \sin^2 2\theta \, \sin^2(1.27 \Delta m^2 L/E)$$

Oscillations depend on 2 *experimental* parameters

L: distance from the neutrino source to the detector (km)
E: energy of the neutrinos (GeV)

... and 2 *intrinsic* parameters

Δm^2: $m_2^2 - m_1^2$
$\sin^2 2\theta$: θ is the mixing angle between
the two flavors in question

The Δm^2 and $\sin^2 2\theta$ accessible to neutrino oscillation experiments are set by L, E, and the neutrino intensity available.