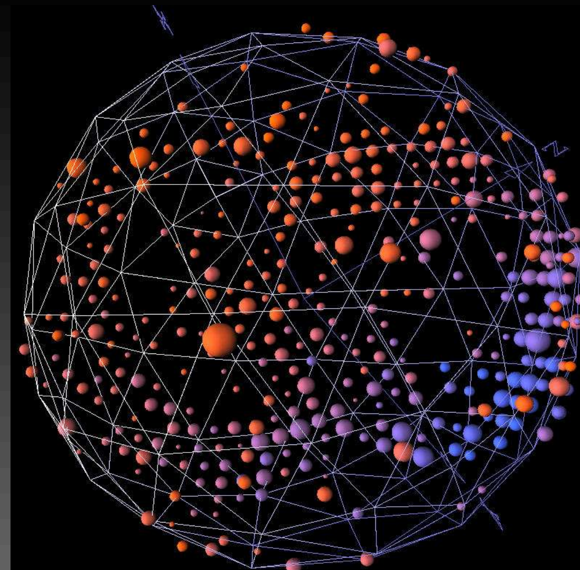
Status of

MiniB  NE

Booster Neutrino Experiment

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7th International Workshop on Neutrino Factories and Superbeams

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Laboratori Nazionali di Frascati, Frascati, Italy

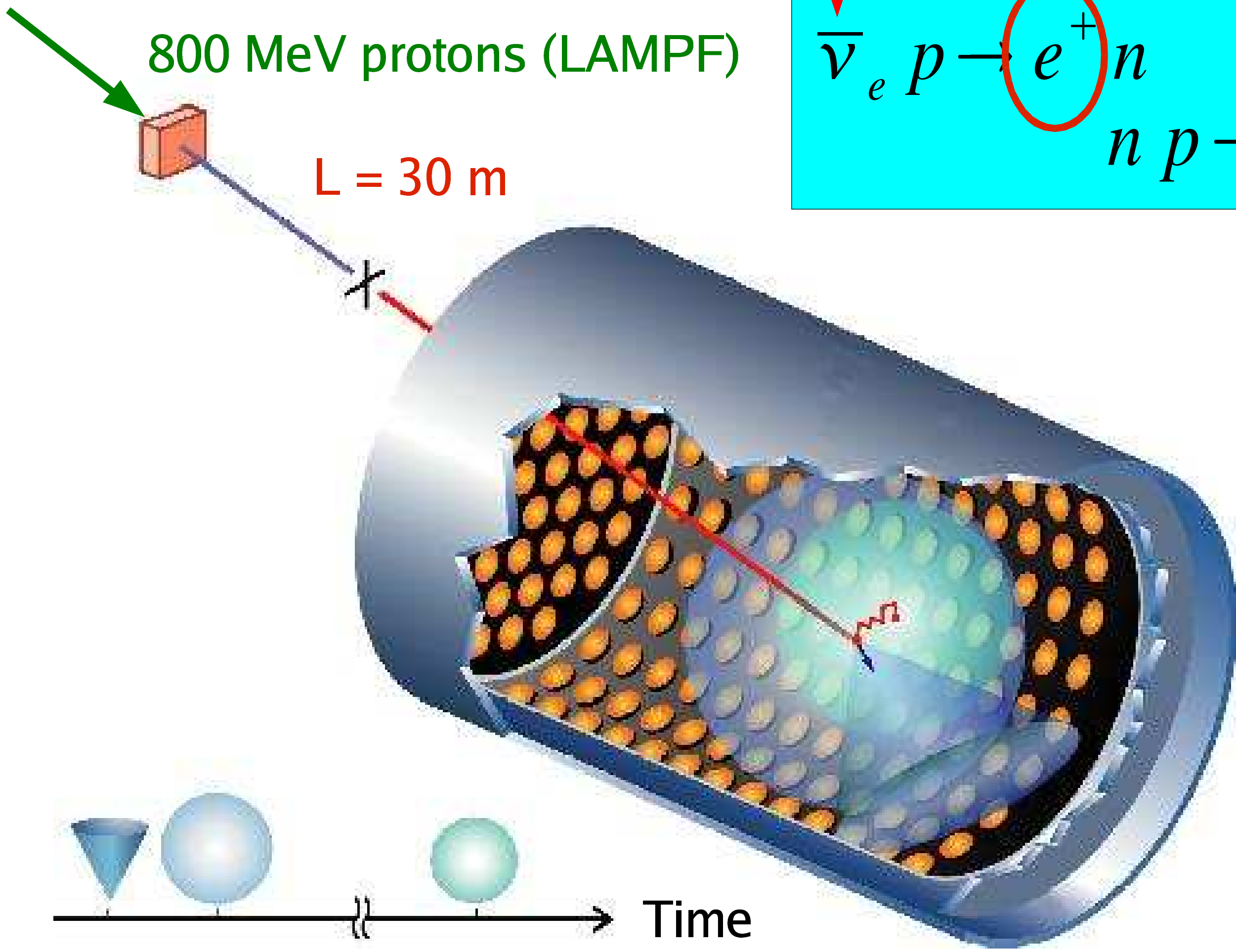
The LSND Experiment

Los Alamos, 1993-1998

- Decay at rest: $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

$$\bar{\nu}_e \, p \rightarrow e^+ n$$
$$n \, p \rightarrow d \gamma$$

L/E ≈ 0.75



T = 186 μs

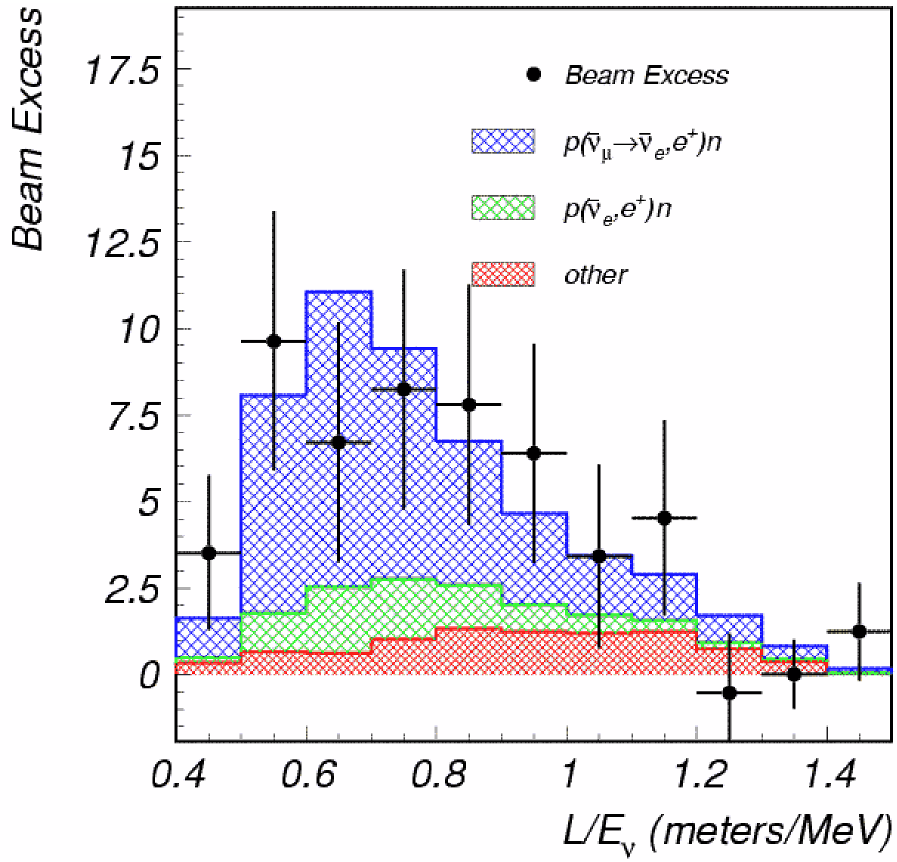
167 tons of
liquid scintillator

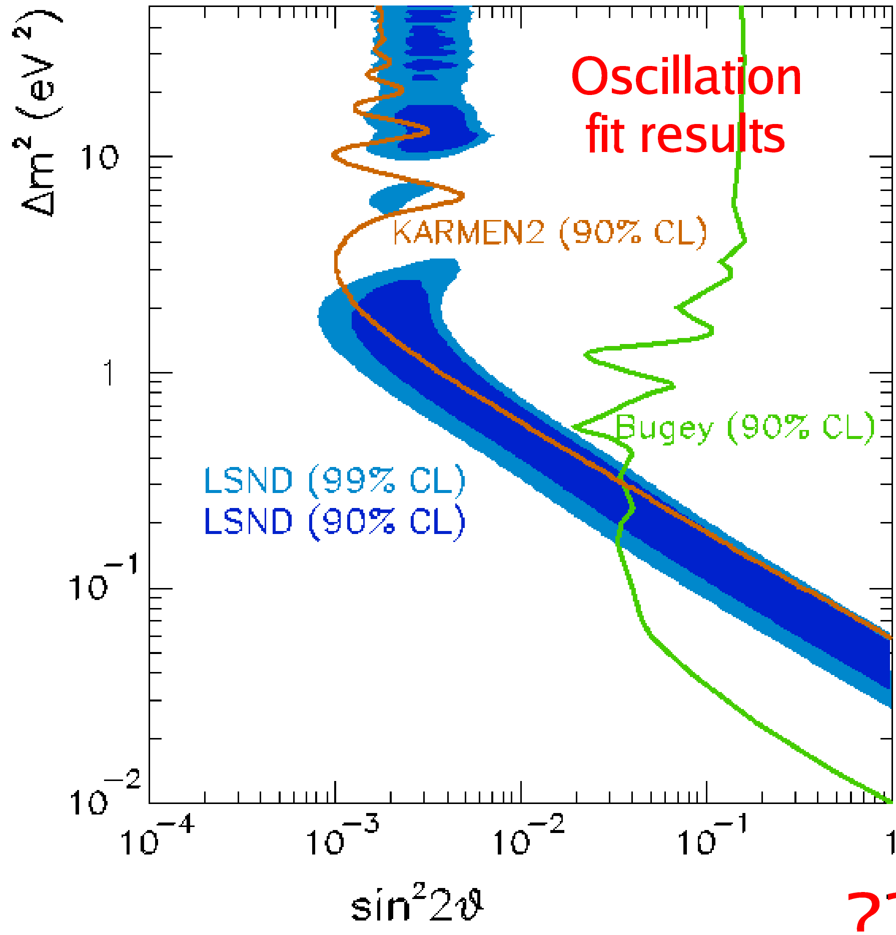
1220 PMTs

$$\nu_e C \rightarrow e^- X$$

- Decay in flight: $\pi^+ \rightarrow \mu^+ \nu_\mu$

The LSND Signal





- Signal above background:

  87.9 ± 22.4 ± 6.0 events

  ~ 4σ evidence for ν oscillations

- KARMEN-2 cannot confirm/dismiss LSND! (statistically consistent - joint analysis)

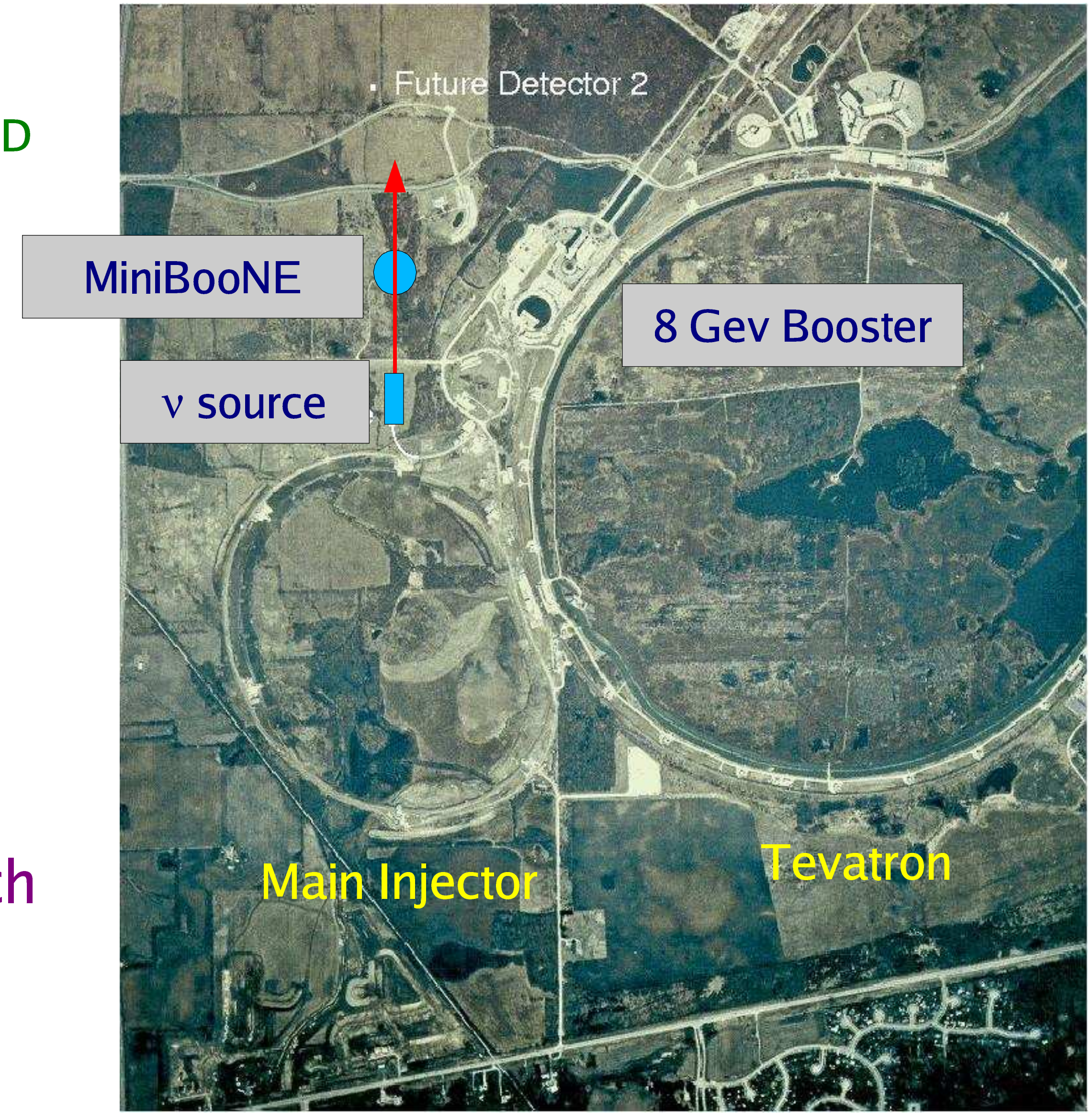
??

$$\Delta m_3^2 = \Delta m_1^2 + \Delta m_2^2$$

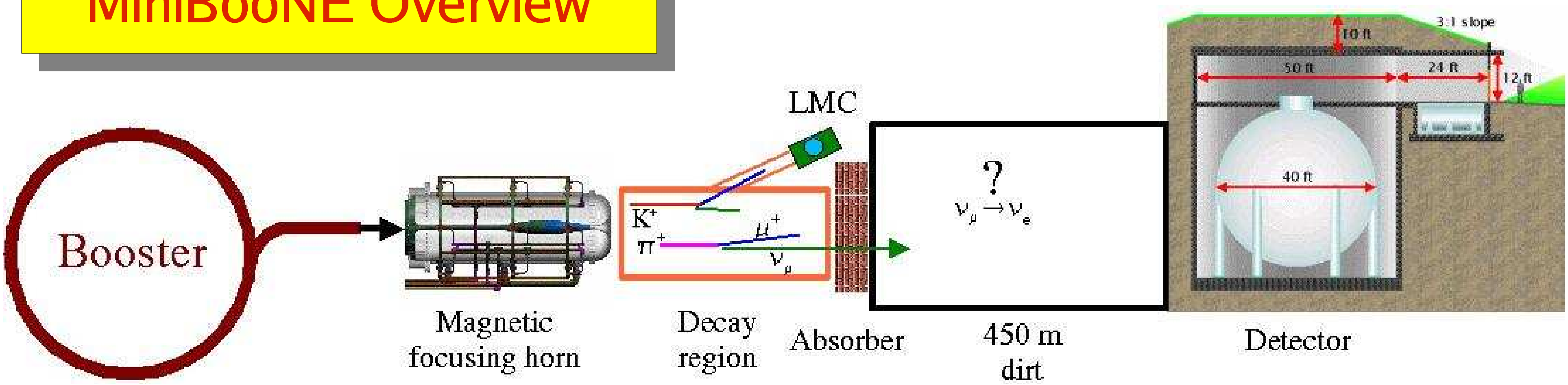
The Booster Neutrino Experiment

Goal: confirm or dismiss the LSND signal

- **High statistics**
  10 times more events than LSND
- **Higher significance**
  - 5σ over LSND region as a counting experiment
  - more significant if energy dependence included
- **Different systematics**
  - 10 times higher beam energy
  - different event signature
  - different backgrounds
- $\nu_\mu \rightarrow \nu_e$ appearance search
- First phase: MiniBooNE
  (single detector)



MiniBooNE Overview



Primary beam (protons) → Secondary beam (mesons) → Tertiary beam (neutrinos)

- 8 GeV protons from the FNAL booster ...
- on a Be target, produce π^+ (and K^+) ...
- π^+ are focused via the neutrino "horn"...
- π^+ decay ($\pi^+ \rightarrow \mu^+\nu_\mu$) in 50 m pipe ...
- yielding intense source of ν_μ (average energy ~ 800 MeV) ...
- neutrinos detected in Cherenkov detector (450 m away)

The Neutrino Flux

- Protons on Be:

  $p + Be \rightarrow \pi^{+}, K^{+}, K^{0}_{L}$

- Yield a high flux of ν_μ:

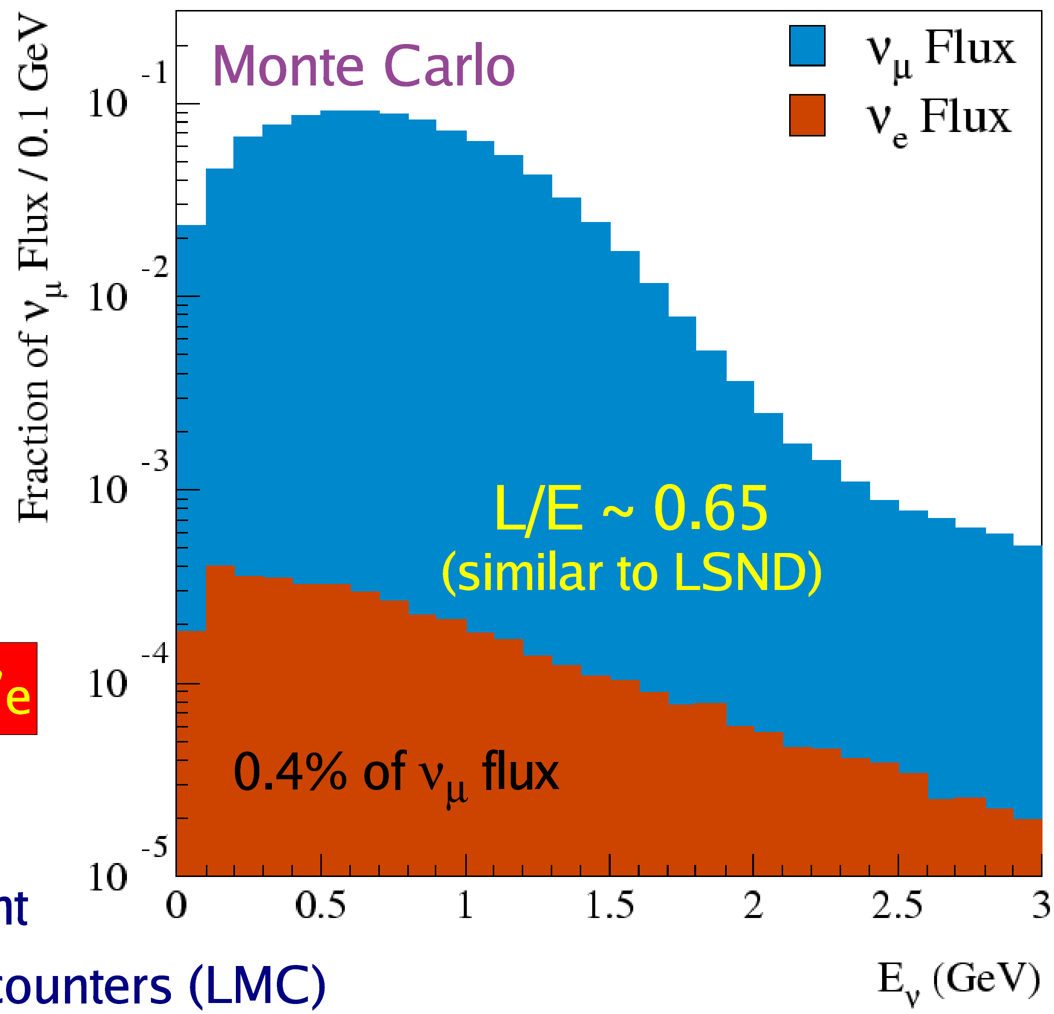
  $\pi^{+} \rightarrow \mu^{+} \nu_\mu$

  $K^{+} \rightarrow \mu^{+} \nu_\mu$, $K^{0}_{L} \rightarrow \pi^{+} \mu^{-} \nu_\mu$

- With a low background of ν_e:

  $\mu^{+} \rightarrow e^{+} \nu_e \nu_\mu$

  $K^{+} \rightarrow \pi^{0} e^{+} \nu_e$, $K^{0}_{L} \rightarrow \pi^{+} e^{-} \nu_e$



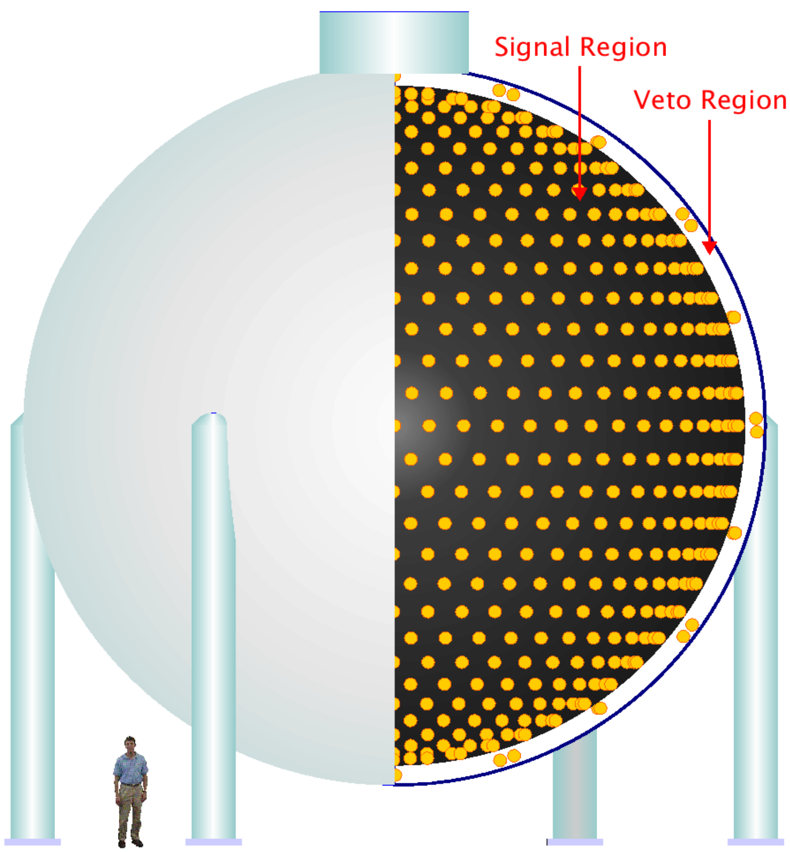
- Flux estimate is important...
  - ν_μ C charged-current measurement
  - secondary absorbers, little muon counters (LMC)

The MiniBooNE Detector

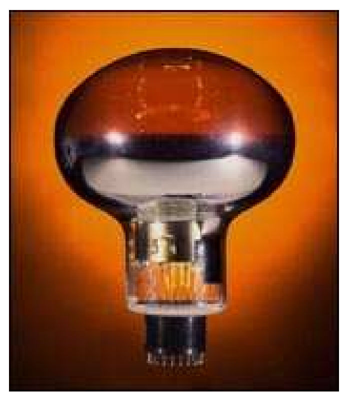
- Fully operational since May 2002
- 12 m diameter spherical tank
- Volume: 800/445 tons (total/fiducial)
- 950,000 liters of pure mineral oil

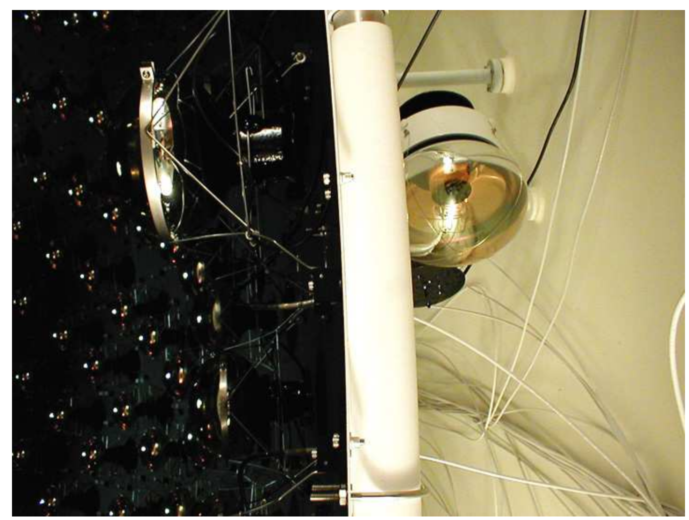
  (ρ = 0.836 g/cm^3, n = 1.46)
- 1280 PMTs (10% coverage)
- 240 PMTs active veto

MiniBooNE Detector

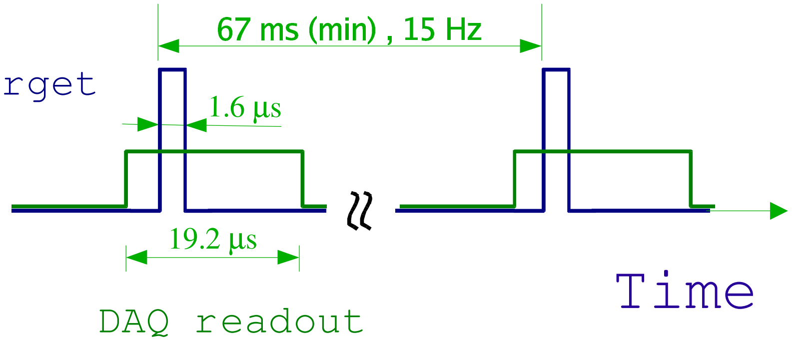


330 new PMTs (R5912)
1190 old PMTs (R1408)





Neutrino Events



- Charge (Q) and time (T) digitized every 100 ns for each PMT channel (kept for 205 μs)
- DAQ readout started with ``booster extract" signal

- No high level analysis needed to see ν events
- Backgrounds: cosmic muons + decay electrons
- Simple cuts reduce non-beam bkgd to 10^{-3}

Current trigger rate ~ 11 Hz
Typical DAQ live-time ~ 99% (beam ON)

600k neutrino events after 5.66E+20 POT!

Neutrino Events (II)

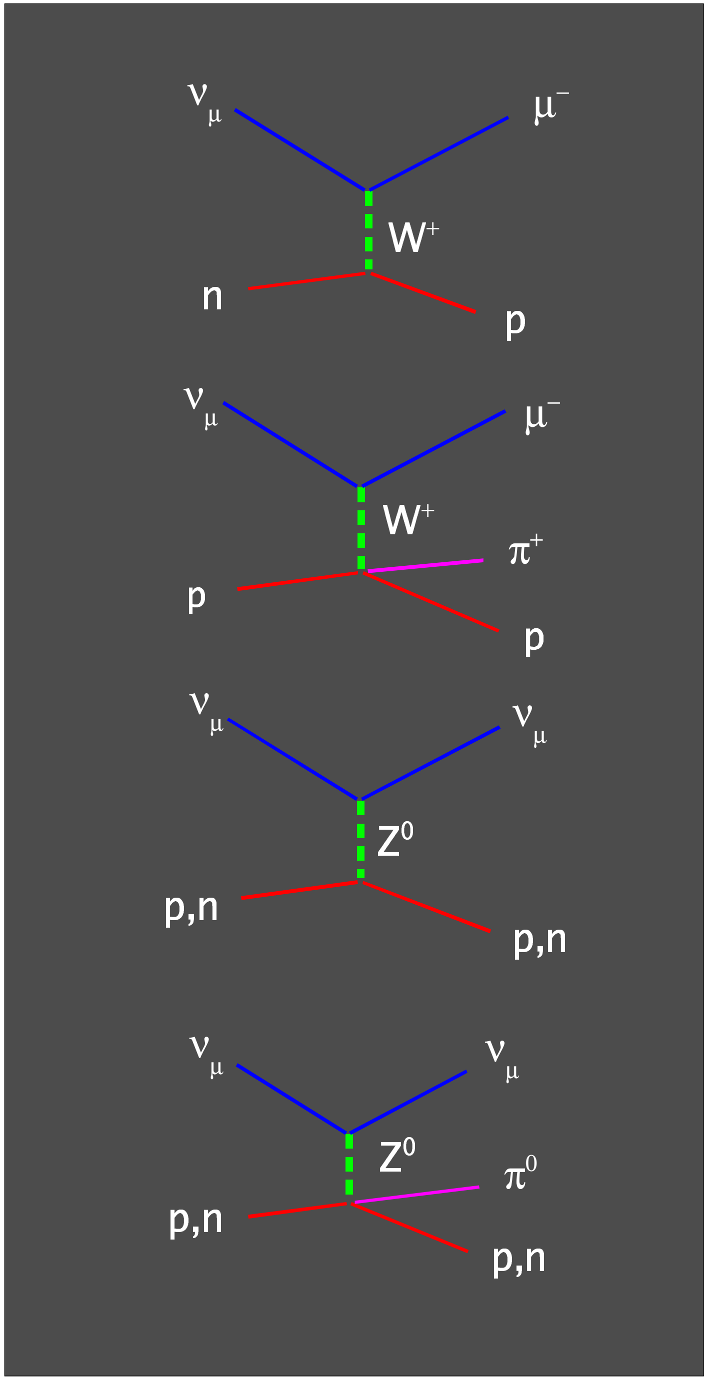
What are these 600k beam-induced events?

~ 240k (40%) CCQE events (see JM's talk)
potentially dangerous...

~ 150k (25%) CC single $\pi^{\pm}$ events (JM)
not dangerous (topology)

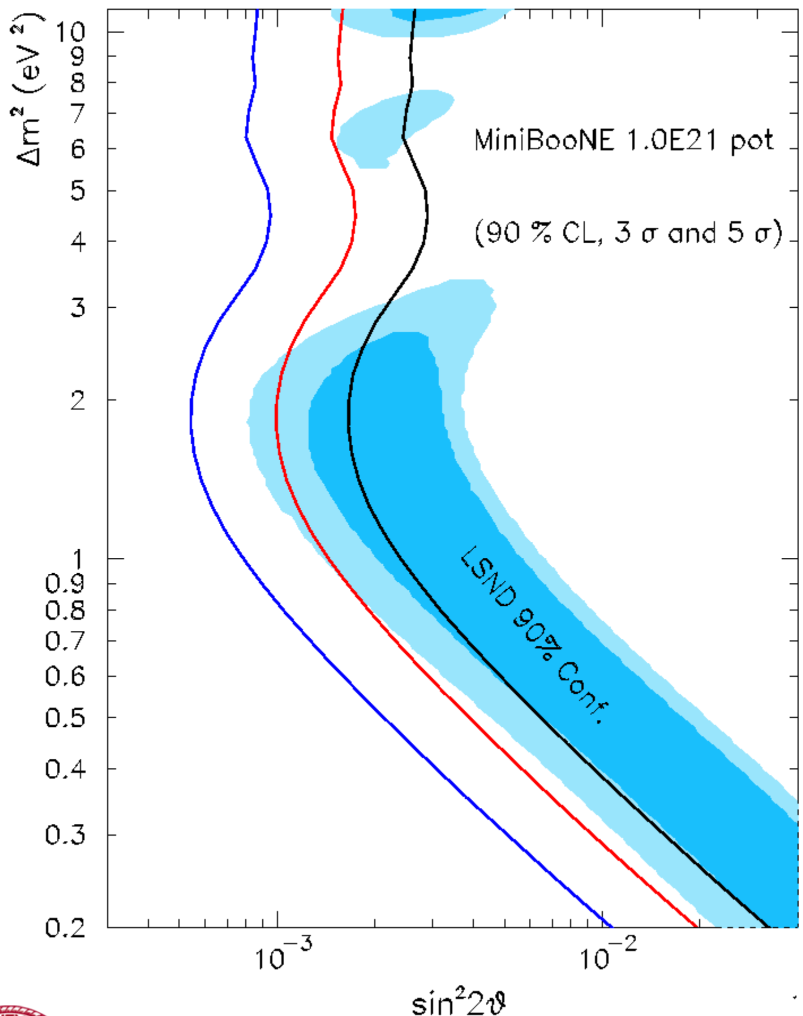
~ 95k (16%) NC elastic scattering events
not dangerous (energy, SCI dominated)

~ 42k (7%) NC π^0 events (JM)
potentially dangerous...

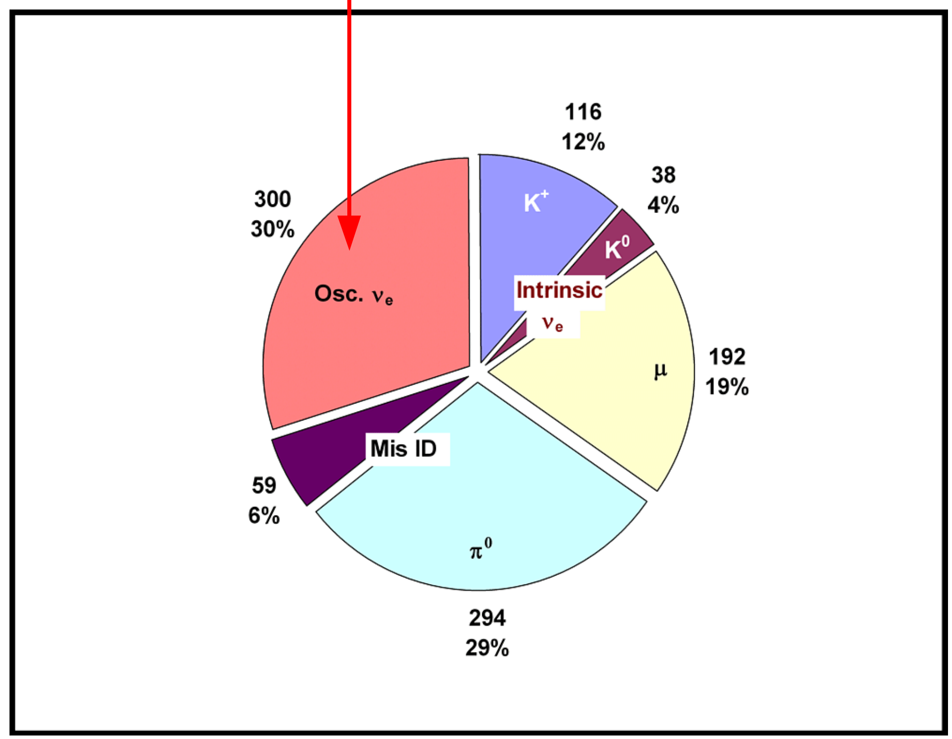


MiniBooNE Sensitivity to Neutrino Oscillations

Assuming 1E+21 POT:



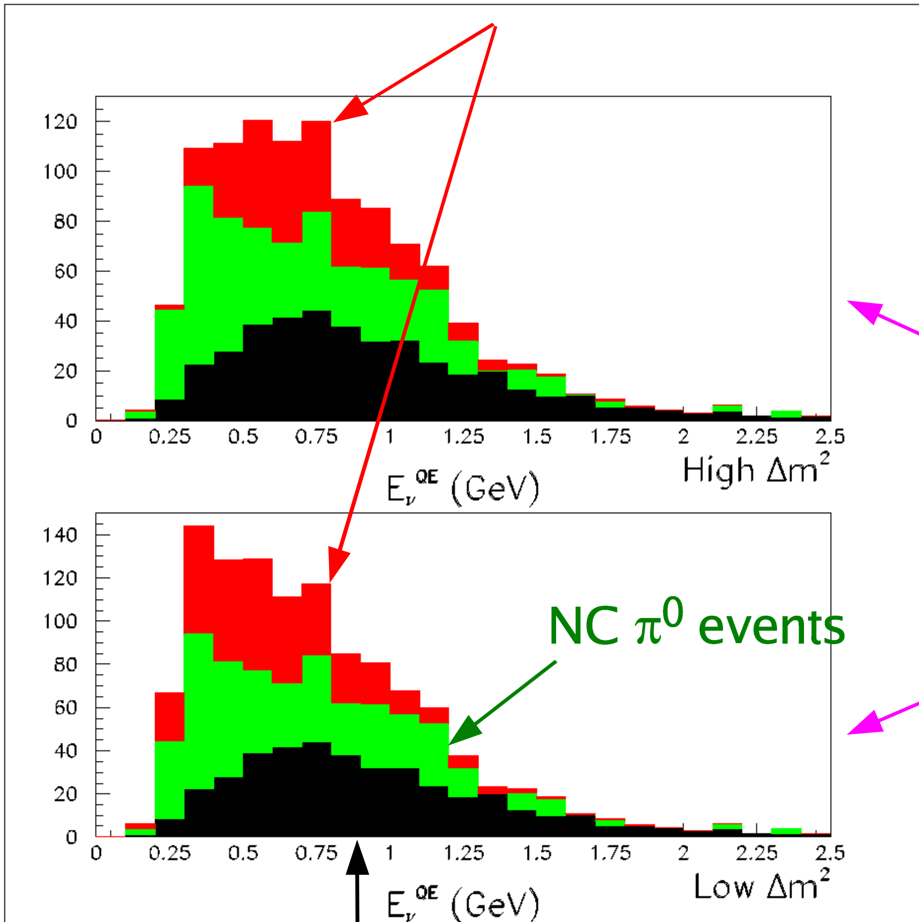
Number can differ by 20% between the low and high Δm^2 regions...



MiniBooNE Sensitivity to Δm^2

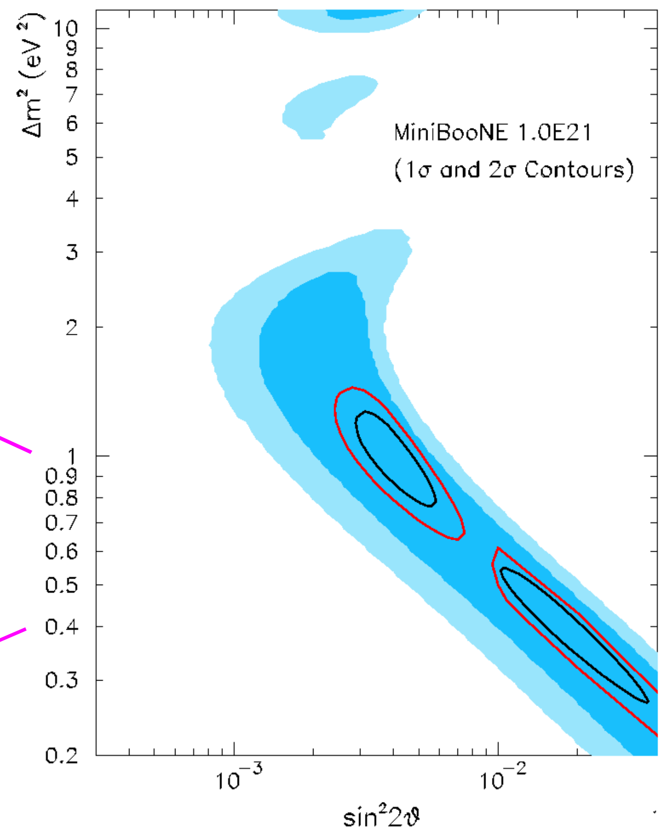
Assuming 1E+21 POT:

Oscillation events



NC π^0 events

Intrinsic ν_e background



How do we get there?

The Road to $\nu_\mu \rightarrow \nu_e$ Oscillations Analysis

- Blind ν_e appearance analysis:

  We can see ALL of the info on SOME events...

  or

  We can see SOME of the info on ALL events...

  but

  We cannot see ALL of the info on ALL events!

Early physics: other analyses before the $\nu_\mu \rightarrow \nu_e$ appearance

- interesting in their own right
- relevant to other experiments
- necessary for the $\nu_\mu \rightarrow \nu_e$ search

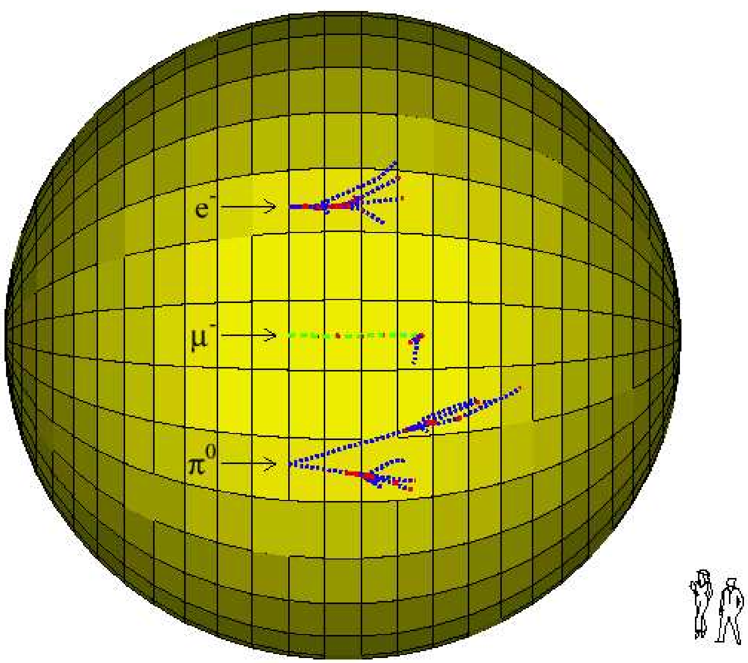
  checks the data/MC agreement (optical properties, etc.)

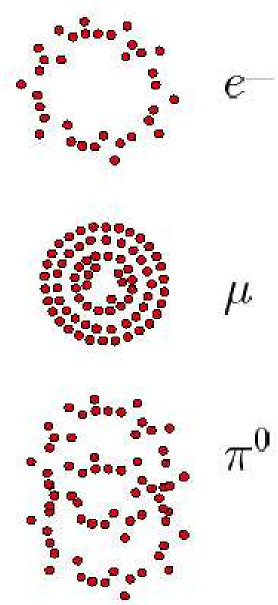
  checks the reliability of the reconstruction/PID algorithms

  progress in understanding backgrounds

MiniBooNE Reconstruction & Particle Identification

- Maximum likelihood (q,t) event reconstruction
- PID based on track extent, ring sharpness, prompt/late light ratio, ...
- Artificial neural networks & boosted decision trees



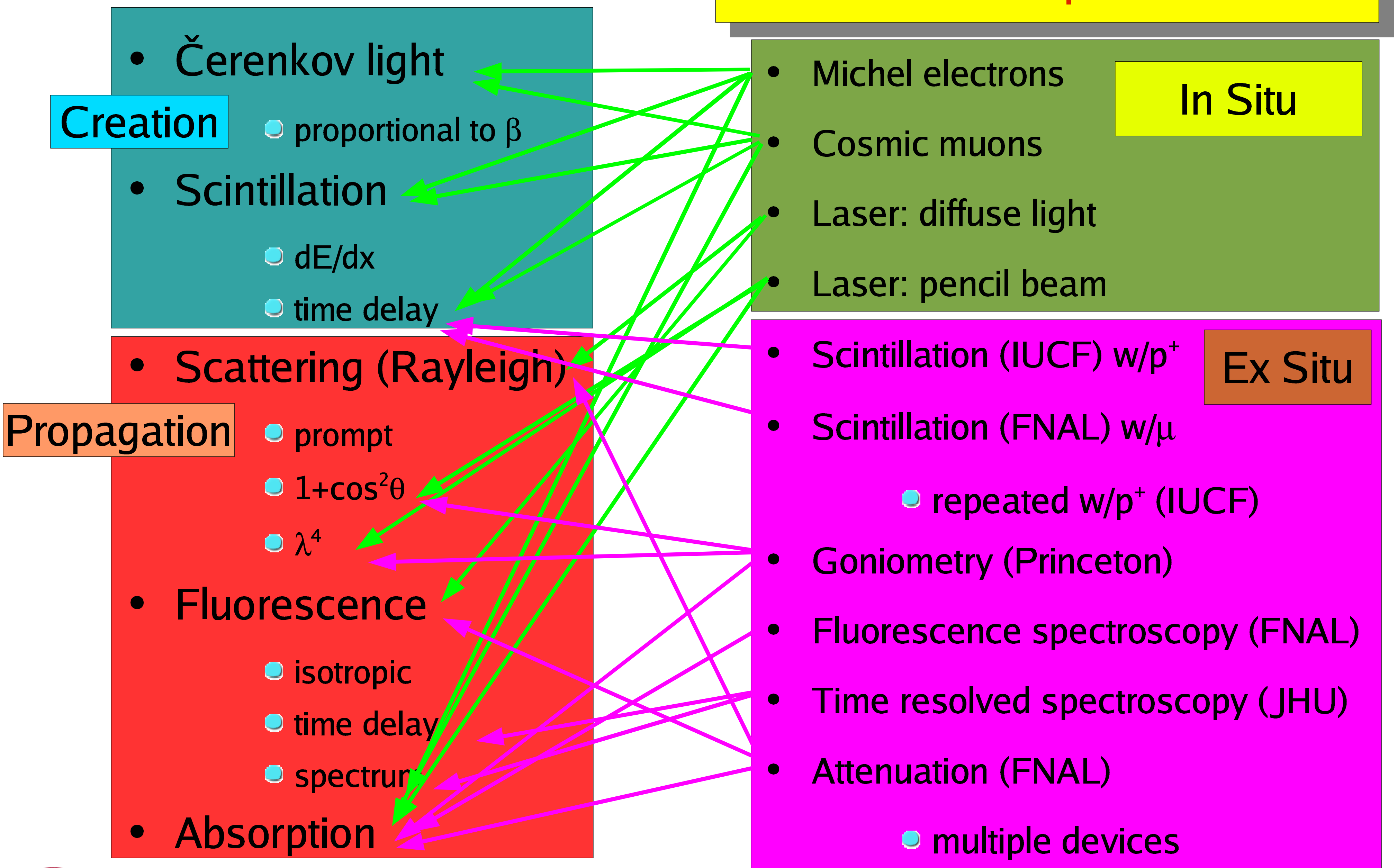


short tracks, multiple scattering (fuzzy ring)

long tracks, sharp outer ring

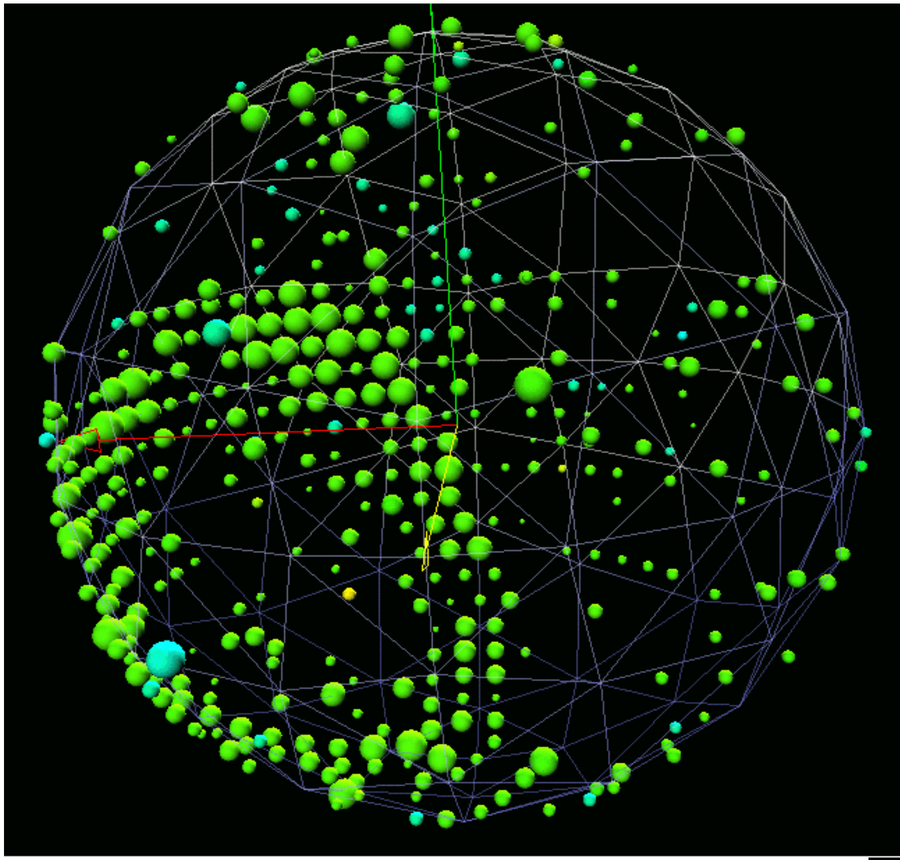
2 e-like tracks, 2 fuzzy rings

MiniBooNE Optical Model

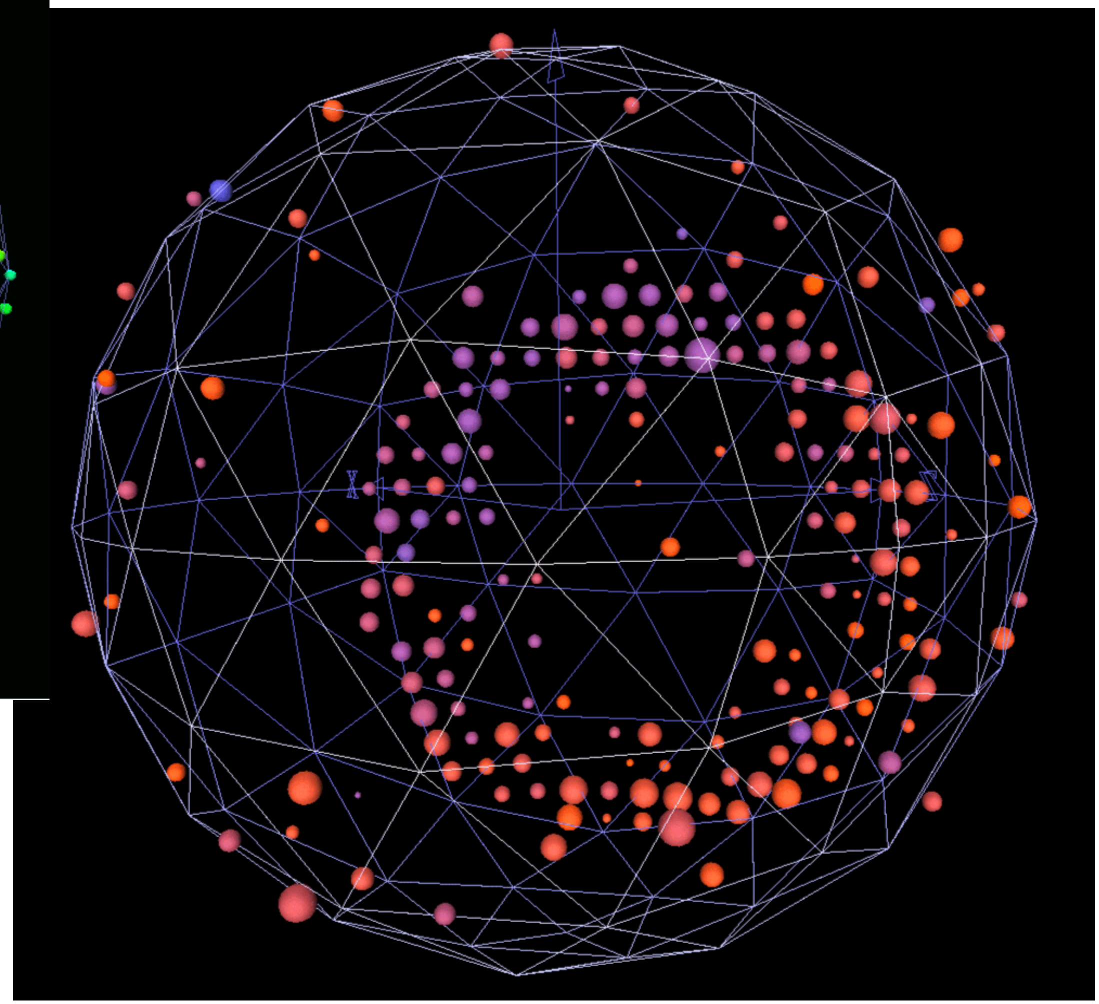


MiniBooNE Muon Events

Cosmic-ray muon event



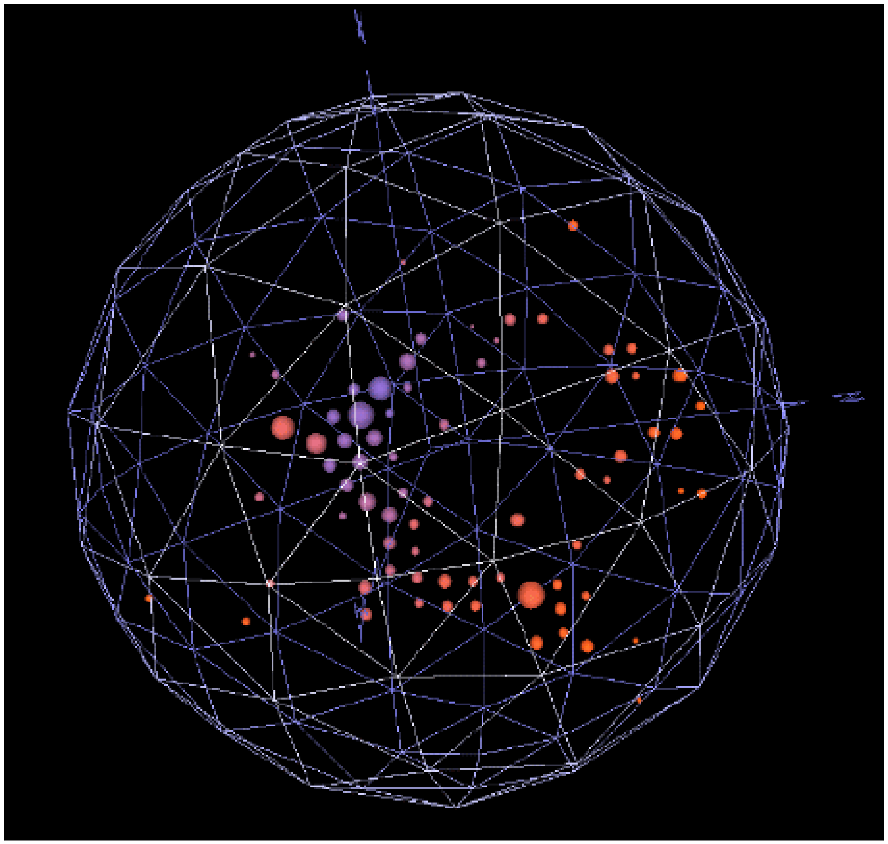
Beam-induced muon event



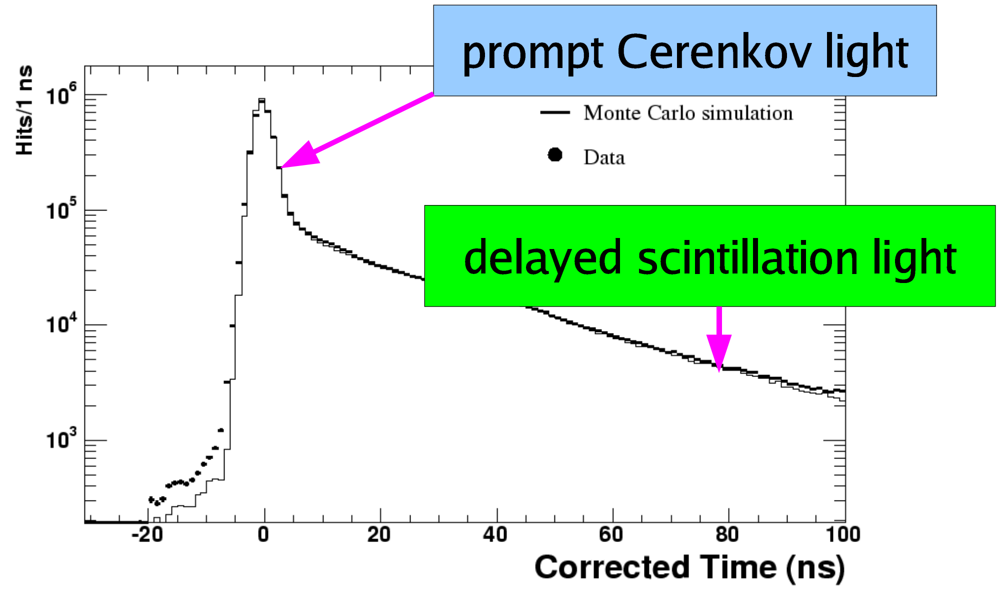
Size = charge, Colour = time

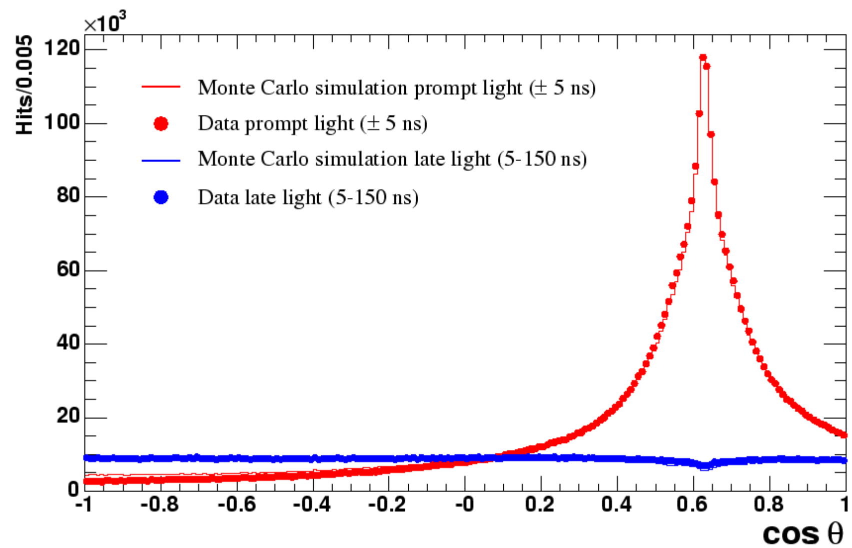
Michel Electron Events

Provide invaluable calibration source & data/MC comparison data set



(decays of stopped CR muons)

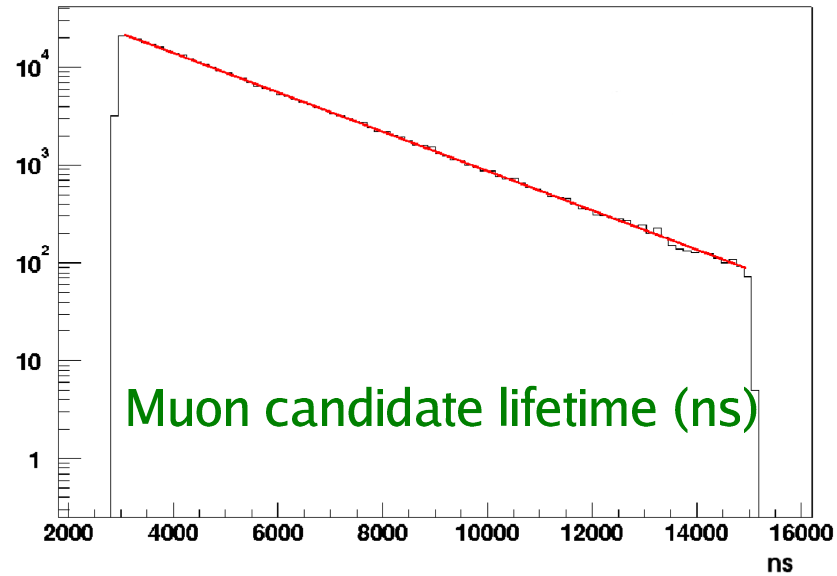


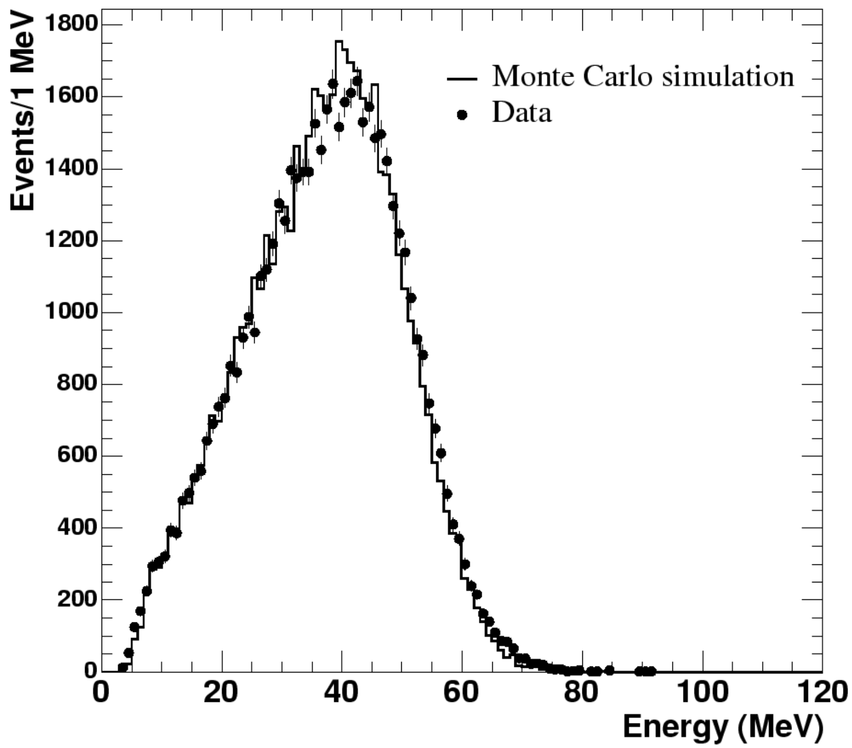


θ = angle between reconstructed event direction and hit PMT

Michel Electron Events (II)

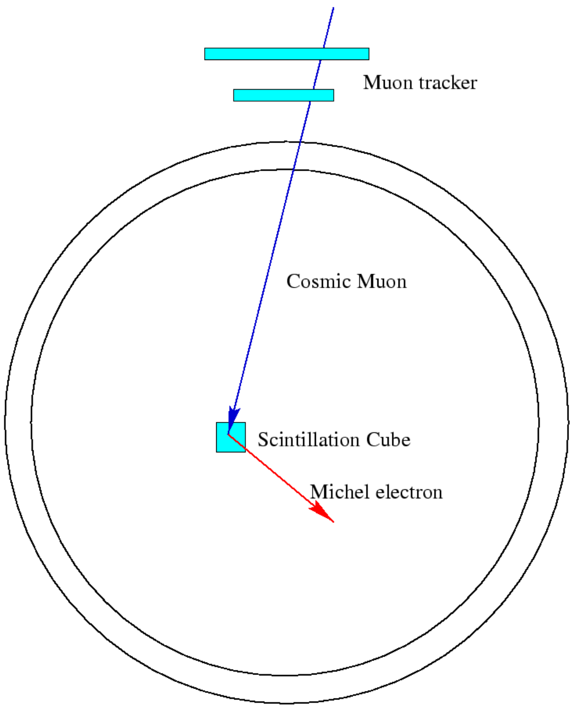
- Cosmic muon lifetime in oil
  measured: $\tau = 2.15 \pm 0.02\ \mu s$
  expected: $\tau = 2.13\ \mu s$
  (8% μ^- capture)

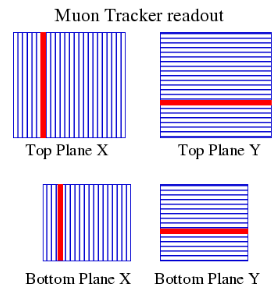


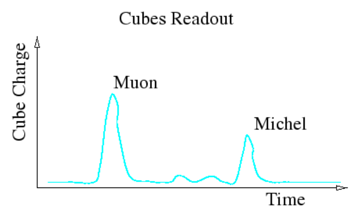


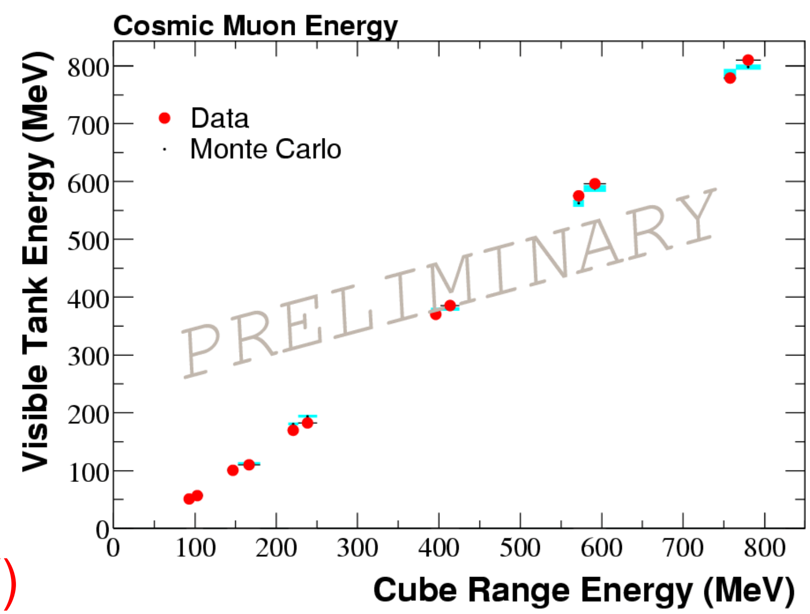
- Sets the electron energy scale
- Energy resolution @ the Michel spectrum endpoint (53 MeV): 15% (visible charge)
- Energy resolution: 11% using fitted CER and SCI fluxes

The Muon Tracker and Scintillator Cubes



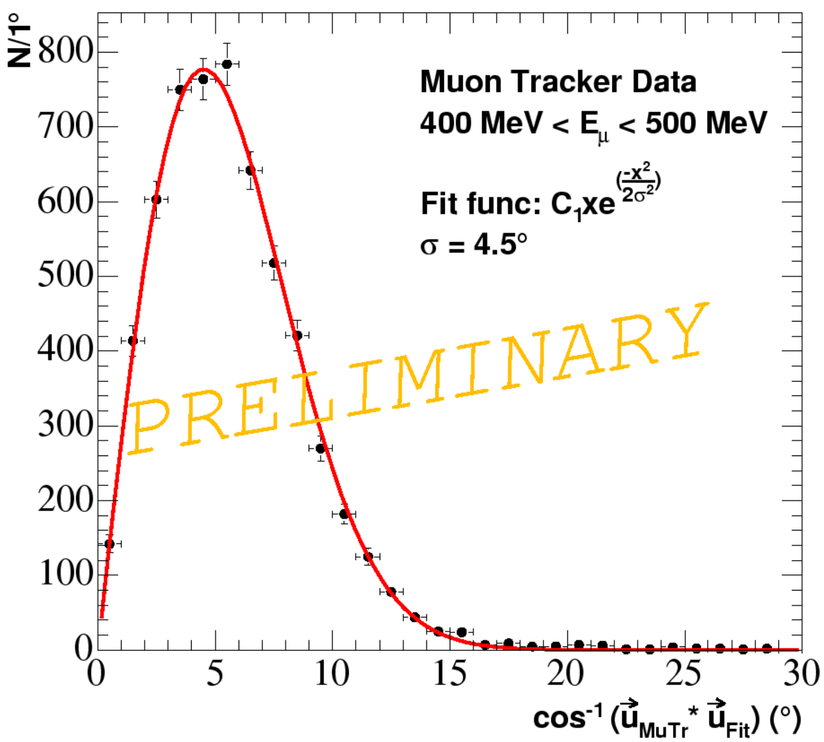


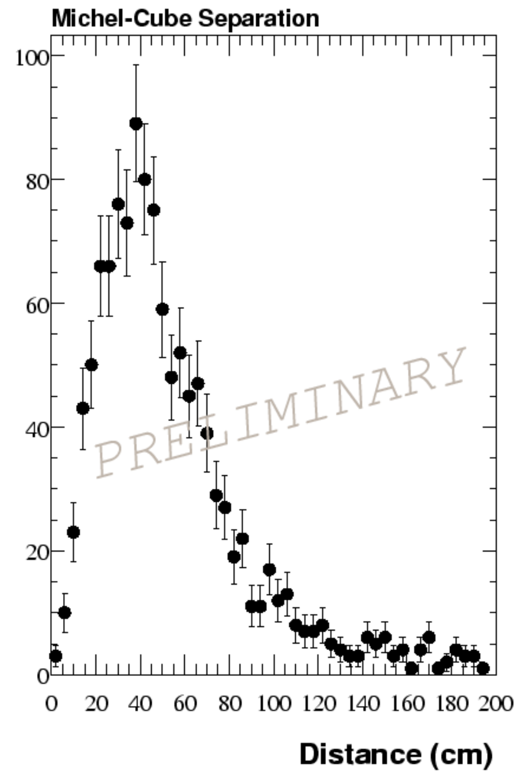


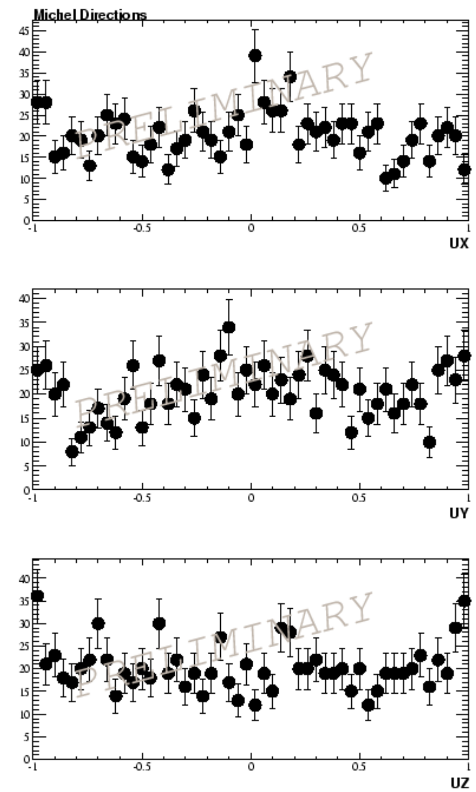


- Muon tracker above the tank: 2 (x,y) planes
- 7 optically isolated SCI cubes in the tank
- Muons with known trajectory: reco checks
- Range for energy calibration (up to 800 MeV)

The Muon Tracker and Scintillator Cubes (II)

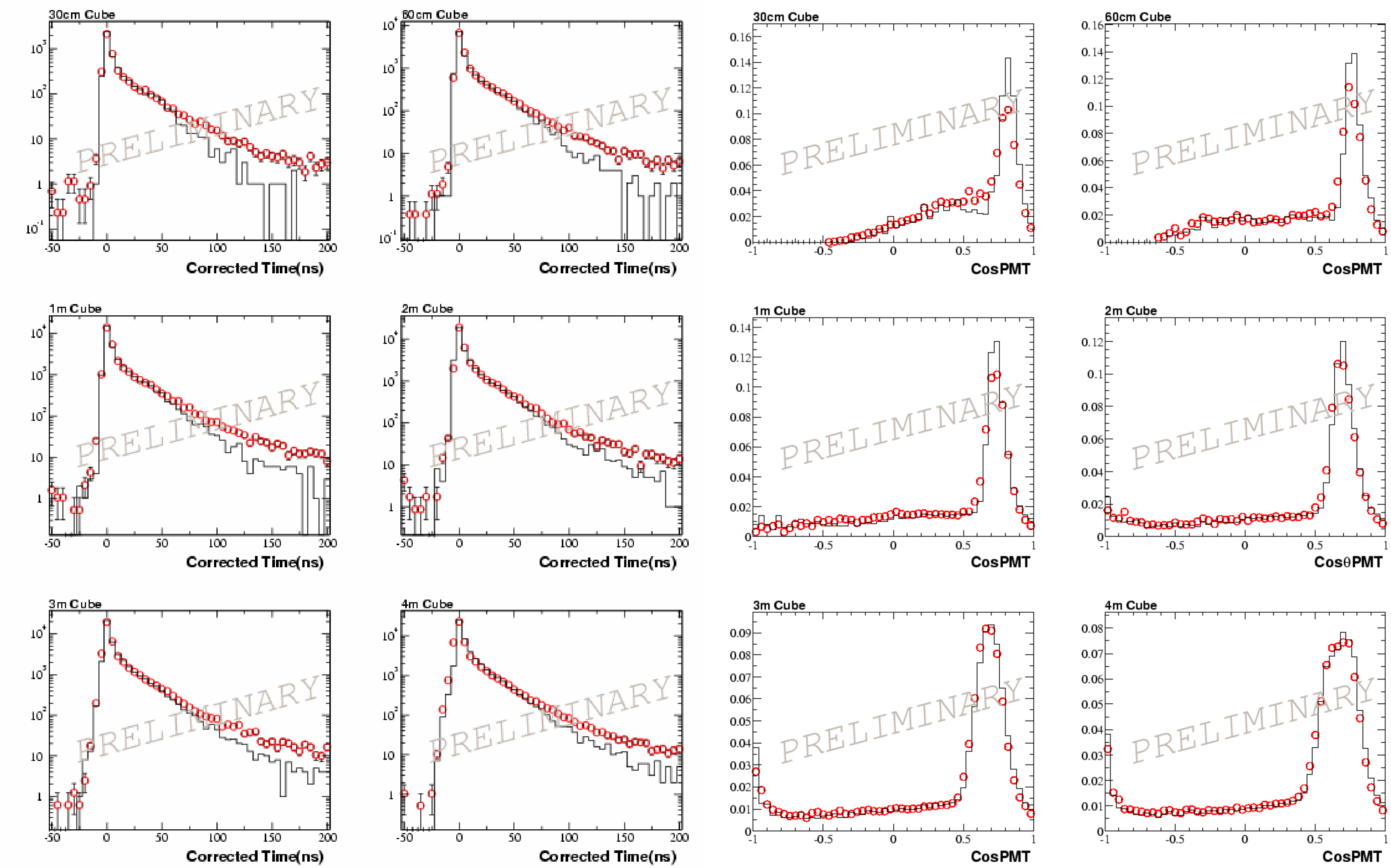






- Angular resolution (tracker/fit) = 4.5 degrees
- Muon tracker intrinsic resolution = 2.0 degrees
- Fitter resolution = 4.0 degrees (consistent with MC simulations)
- Electron position resolution = 40 cm (consistent with MC simulations)

The Muon Tracker and Scintillator Cubes (III)

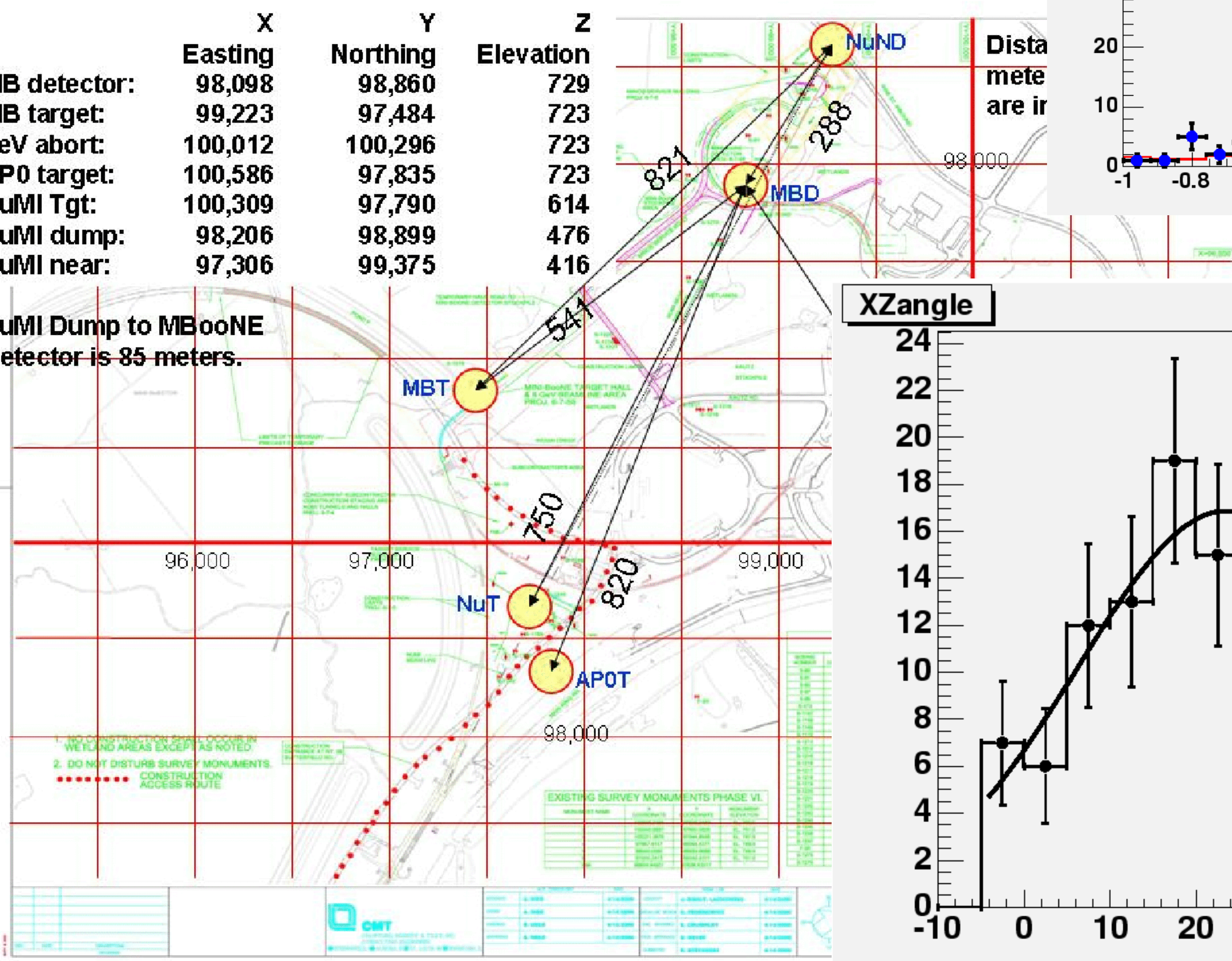


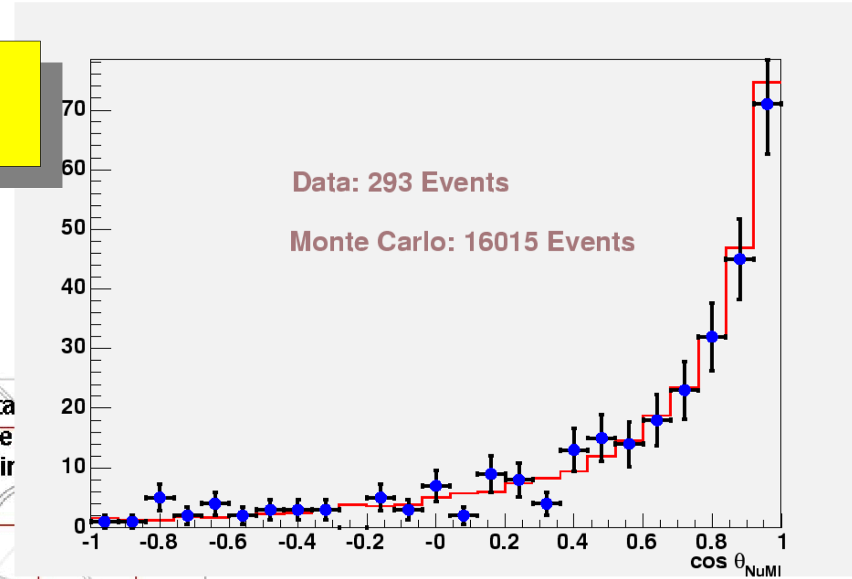
The NuMI Events: Muons + HEE

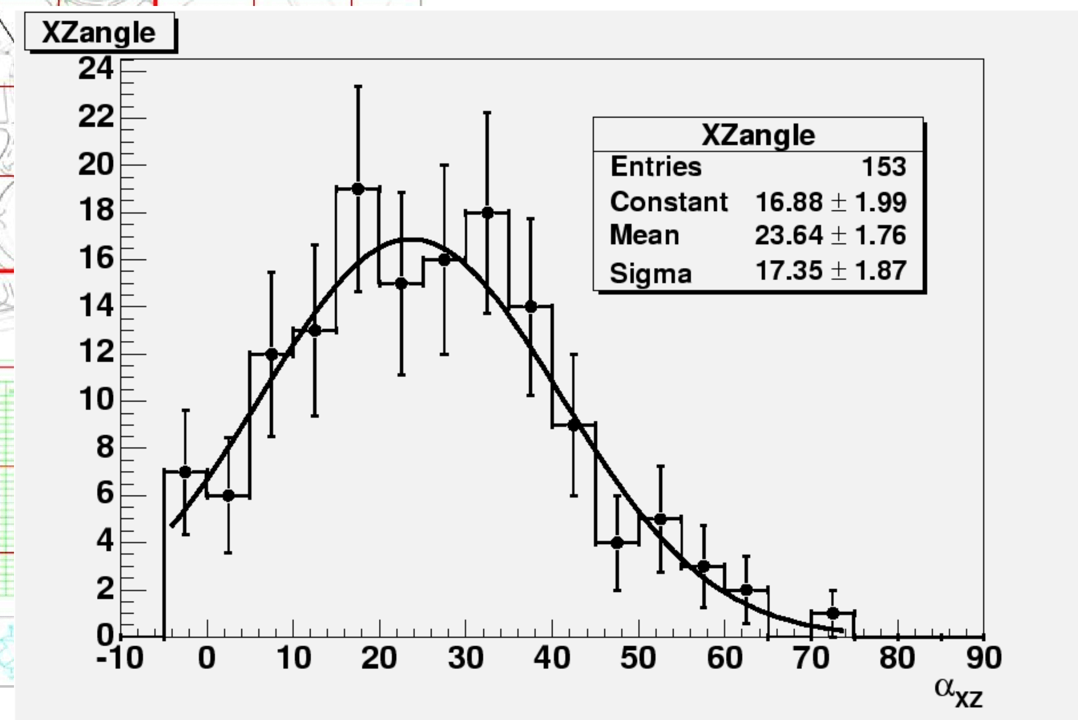
Quite interesting for PID studies too…

	X Easting	Y Northing	Z Elevation
MB detector:	98,098	98,860	729
MB target:	99,223	97,484	723
TeV abort:	100,012	100,296	723
AP0 target:	100,586	97,835	723
NuMI Tgt:	100,309	97,790	614
NuMI dump:	98,206	98,899	476
NuMI near:	97,306	99,375	416

NuMI Dump to MBooNE Detector is 85 meters.

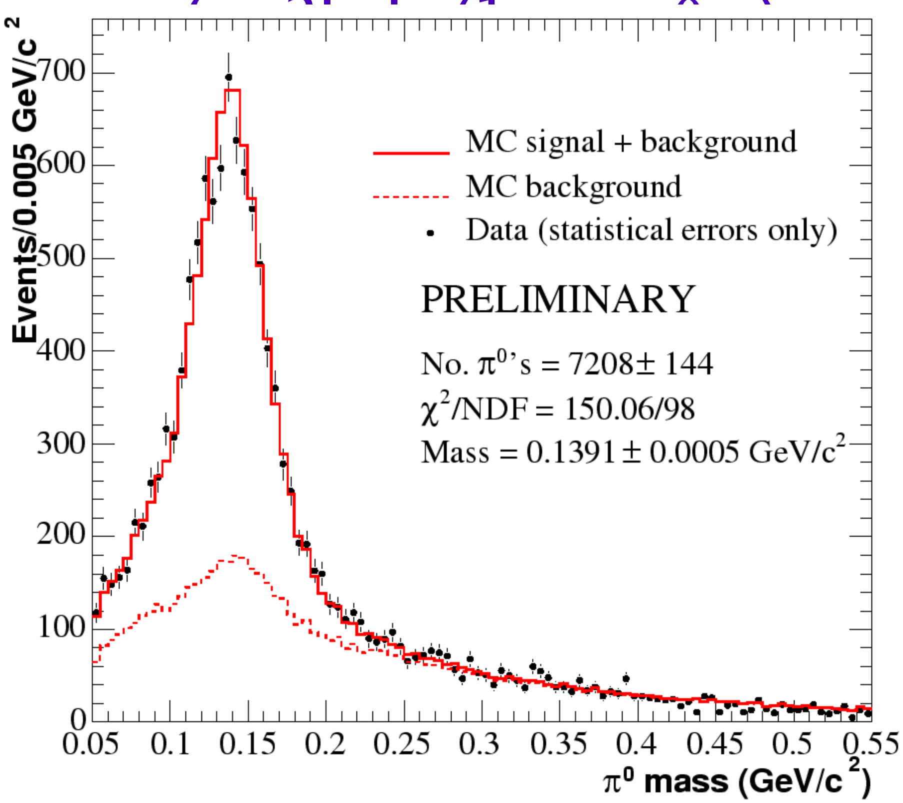


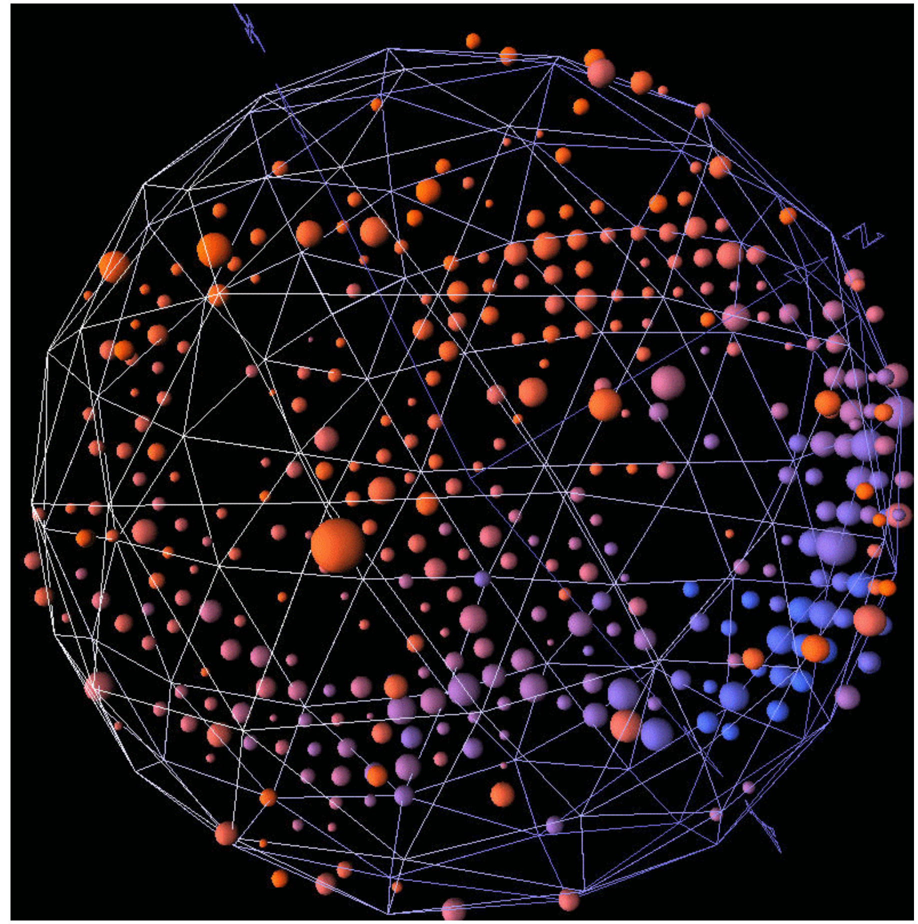




NC π^0 Production

- All events undergo a π^0 fit
  (tedious 14 variables fit)





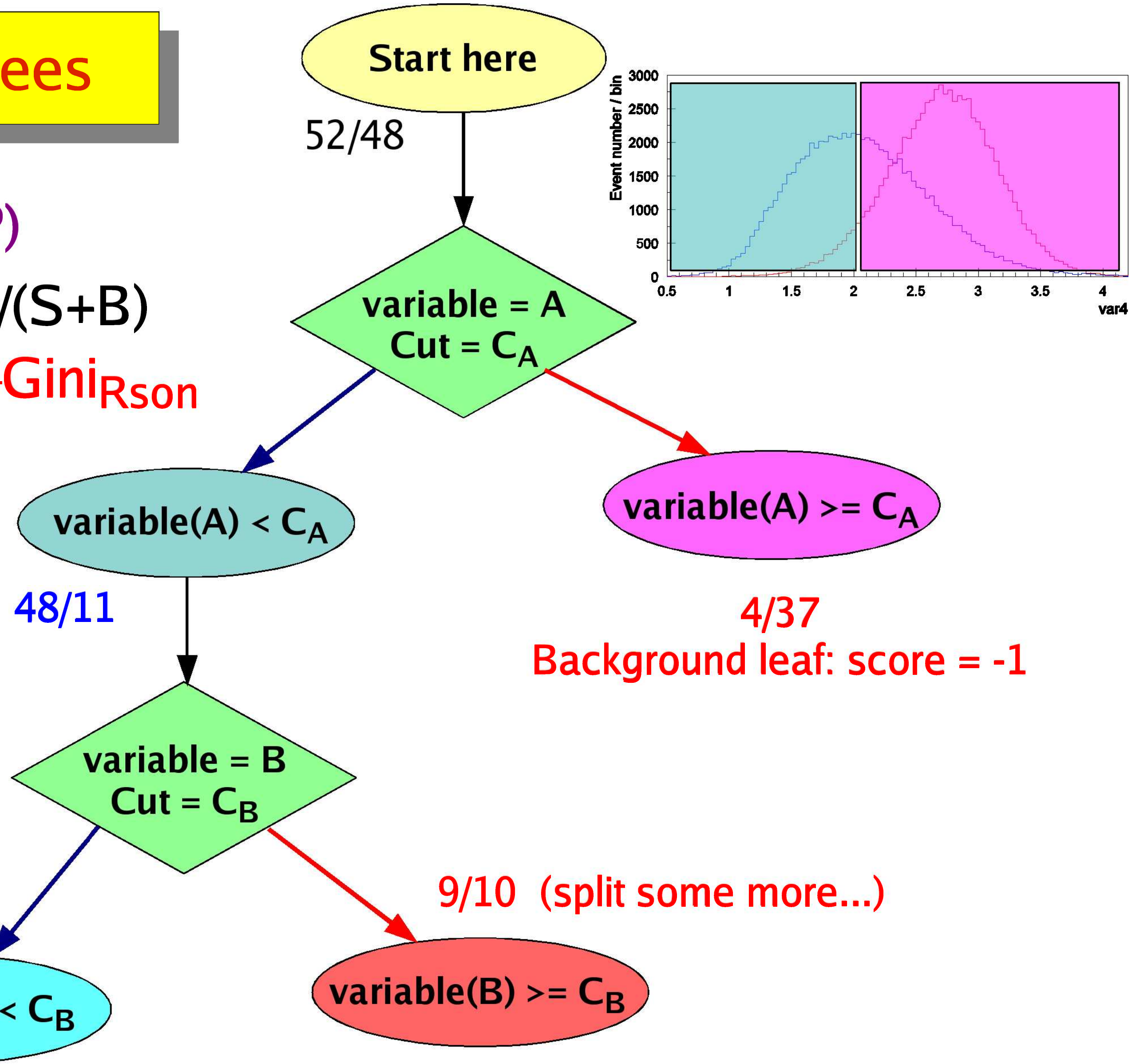
- Event selection:
  - no decay electrons
  - $N_{tank} > 200$, $N_{veto} < 6$
  - E_1 and $E_2 > 40$ MeV
- Checks electron E scale

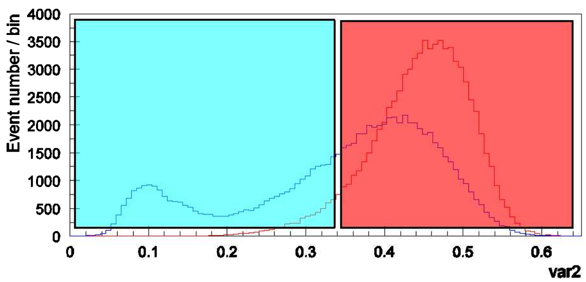
Boosted Decision Trees

$Gini_{node} = W_{tot} * P * (1-P)$

P = (weighted) purity = S/(S+B)

MAX: $Gini_{father} - Gini_{Lson} - Gini_{Rson}$

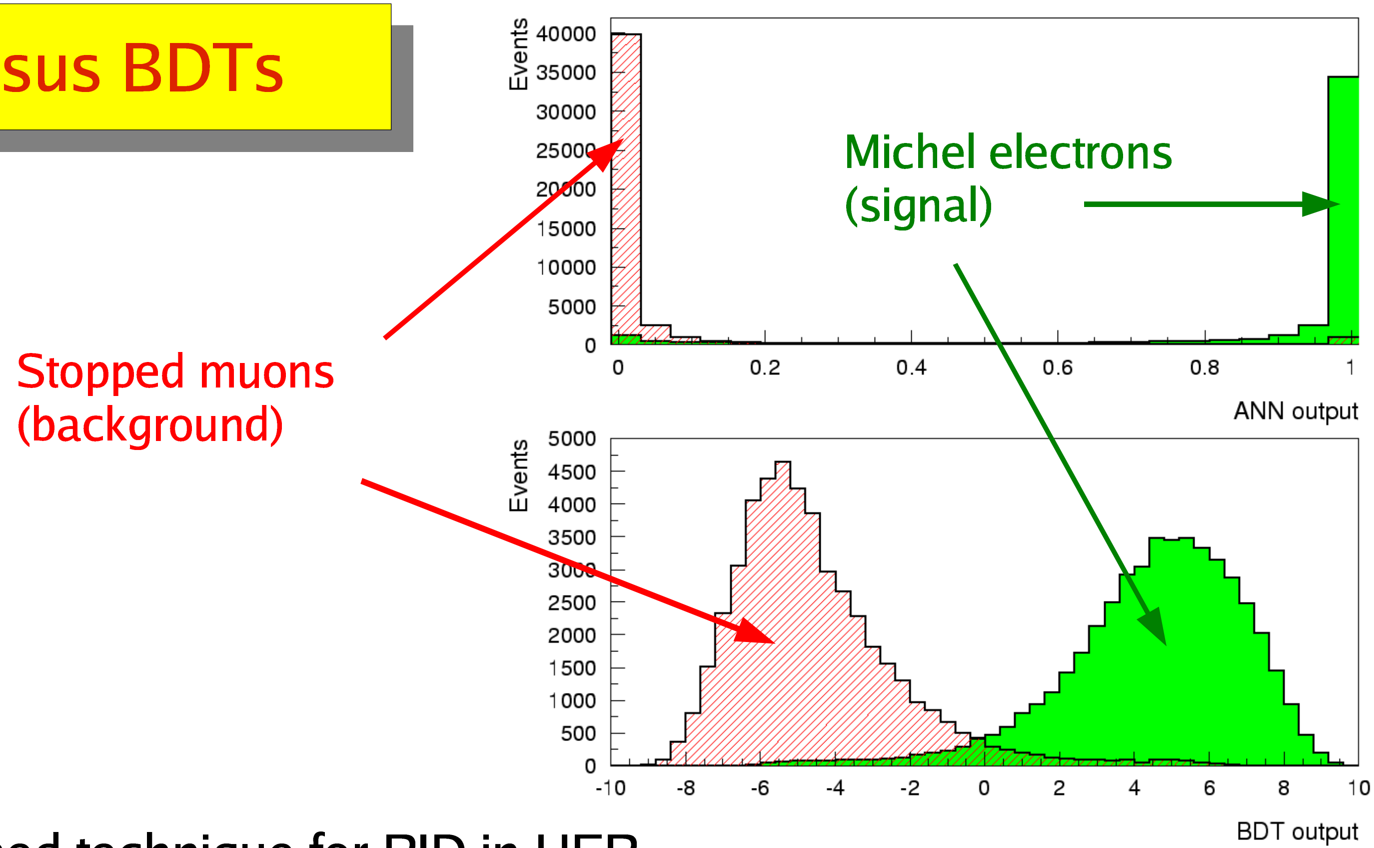




39/1
Signal leaf: score = +1

Boosting: Follow misclassified events increase weights & build a new tree...

PID: ANNs versus BDTs

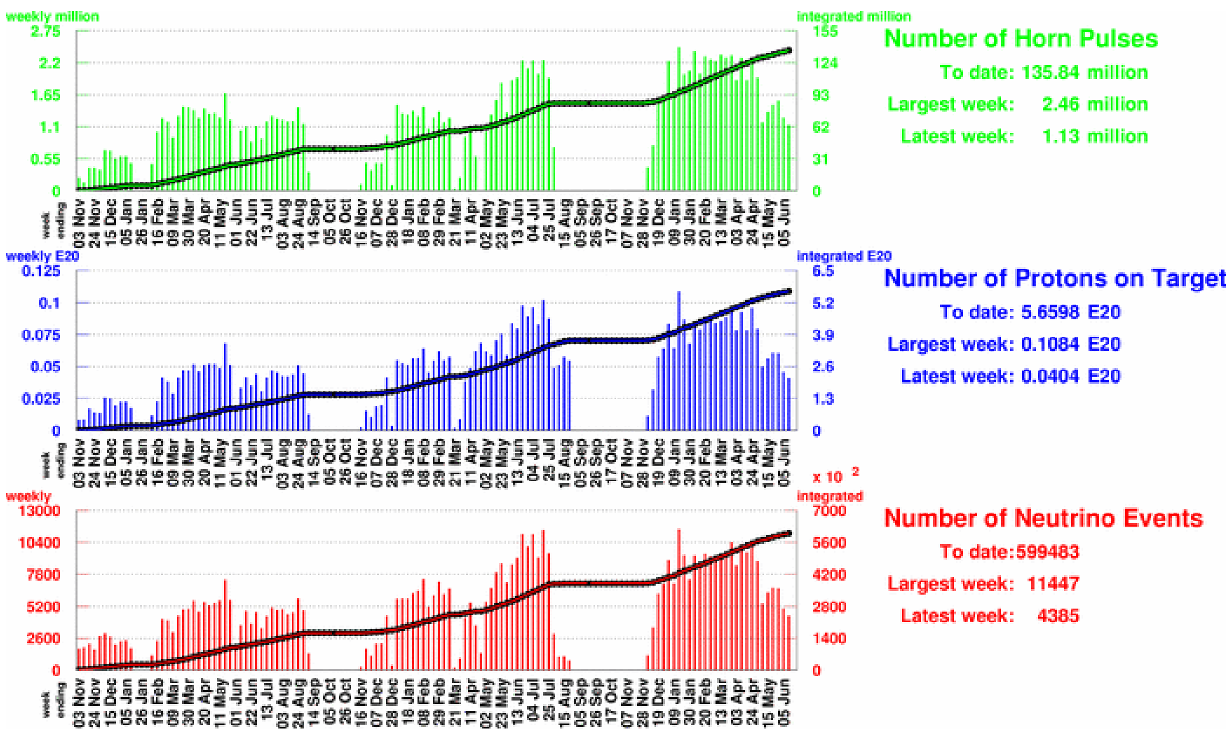


- ANNs:
  - relatively established technique for PID in HEP
  - very effective for small number of input variables
  - quite tedious to train (many parameters... art)

- BDTs:
  - can easily handle large numbers of input variables
  - relatively easy to train
  - invariant under monotonous variable transformations

Conclusions

- MiniBooNE running steadily & smoothly
- Currently: 5.66e+20 POT and 600k ν events
- Should accumulate about 6.67e+20 POT (2/3), i.e. 700k ν events



- We have accumulated large control data sets (MC tuning)
- Detector & reco/PID algorithms are working well
- First samples of neutrino physics (see JM + MW talks)...

Stay tuned...