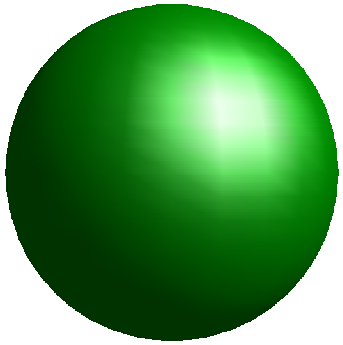


MiniBooNE:
Not Just a ν_e Appearance Oscillation Experiment

1. Motivation
2. Beam and Detector Status
3. Fun Physics from MiniBooNE *this year*!

Motivation: LSND Anomaly

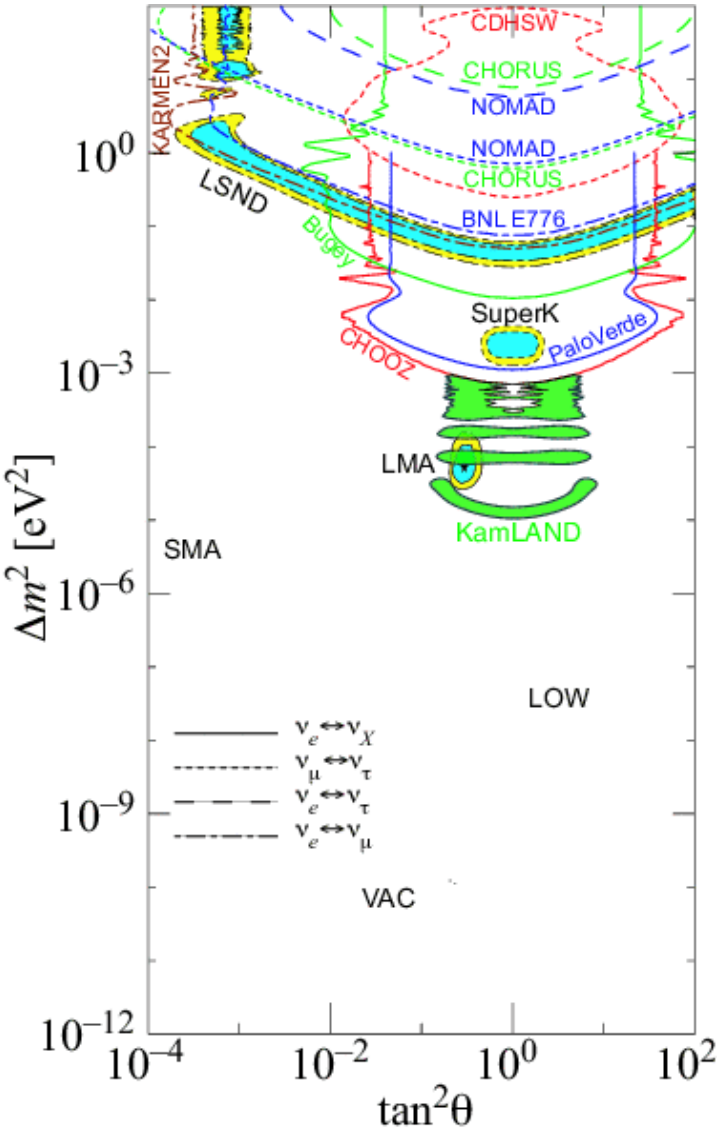
- **ν oscillation signals:**

  ***Atmospheric*: $\Delta m^2 \sim 10^{-3}$ eV^2**
  (Super-K, K, ...)

  ***Solar*: $\Delta m^2 \sim 10^{-5}$ eV^2**
  (SNO, KamLAND, ...)

  ***Accelerator*: $\Delta m^2 \sim 10^{0}$ eV^2**
  (LSND)

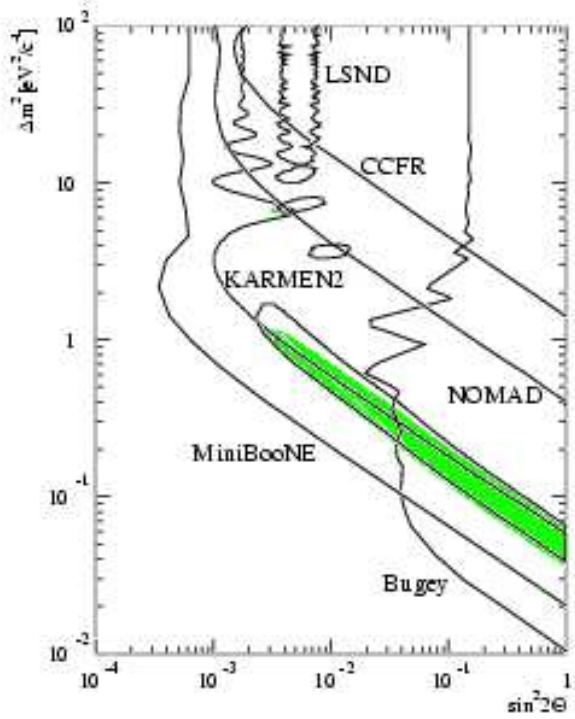
3 νs allow only 2 independent values of Δm^2

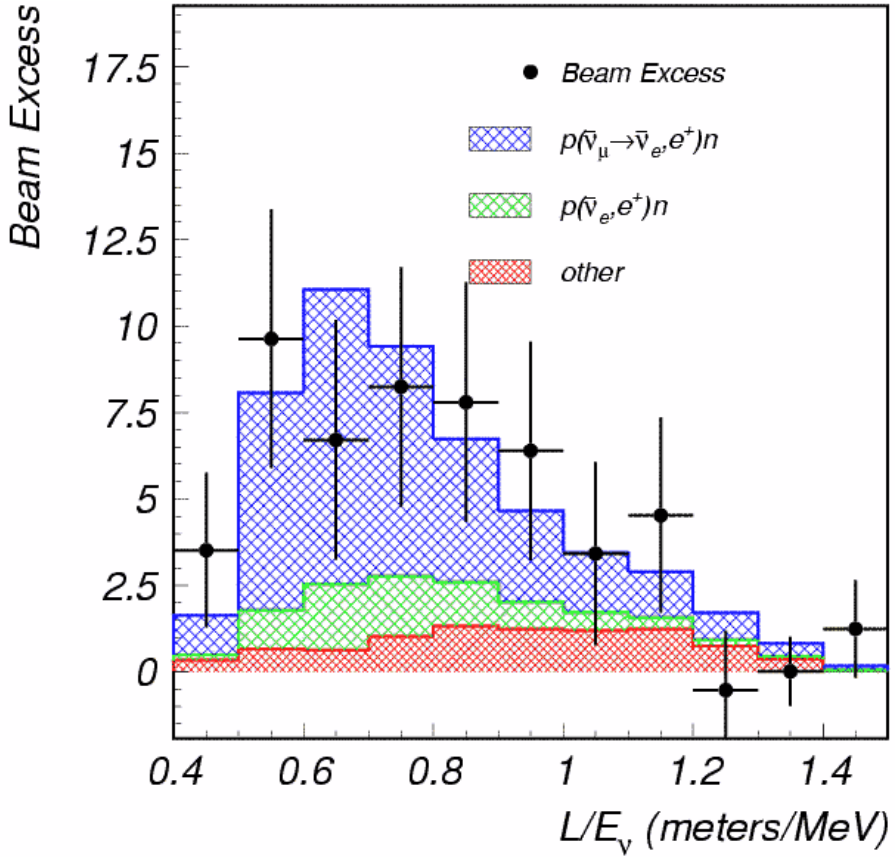


- **What to do?**
  1. Some experiment is wrong
  2. Add more neutrinos: 1, 2, 3 ...
  3. Violate CPT

Motivation: LSND Anomaly

- ***Excess*** ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, ***appearance):*** 87.9 ± 22.4 ± 6.0
- ***Oscillation probability:***
  (0.264 ± 0.067 ± 0.045)% (DAR)
  (0.10 ± 0.16 ± 0.04)% (DIF)
- **3.8 σ statistical significance of excess,**
  3.3 σ significance of oscillation hypothesis





Combined analysis with KARMEN2 gives large allowed region. Confirmation is crucial!
Enter MiniBooNE ●●●

MiniBooNE: Collaboration

The BooNE Collaboration

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University of Alabama

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Bucknell University

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University of California, Riverside

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Columbia University

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Embry Riddle Aeronautical University

L.Bartoszek, C.Bhat, S.J.Brice, B.C.Brown, D.A.Finley, 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.D.Russell, P.Spentzouris, R.Stefanski, T.Williams
Fermi National Accelerator Laboratory

D.C.Cox, J.A.Green, H.Meyer, R.Tayloe
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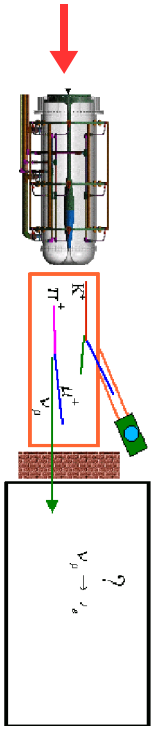
J.Cao, Y.Liu, B.P.Roe
University of Michigan

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

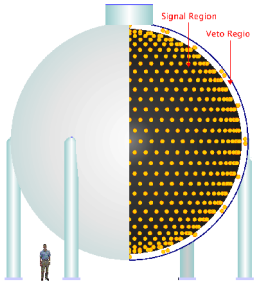
~60 scientists + students
13 institutions
1 goal

Confirm or refute LSND ($\nu_\mu \rightarrow \nu_e$)

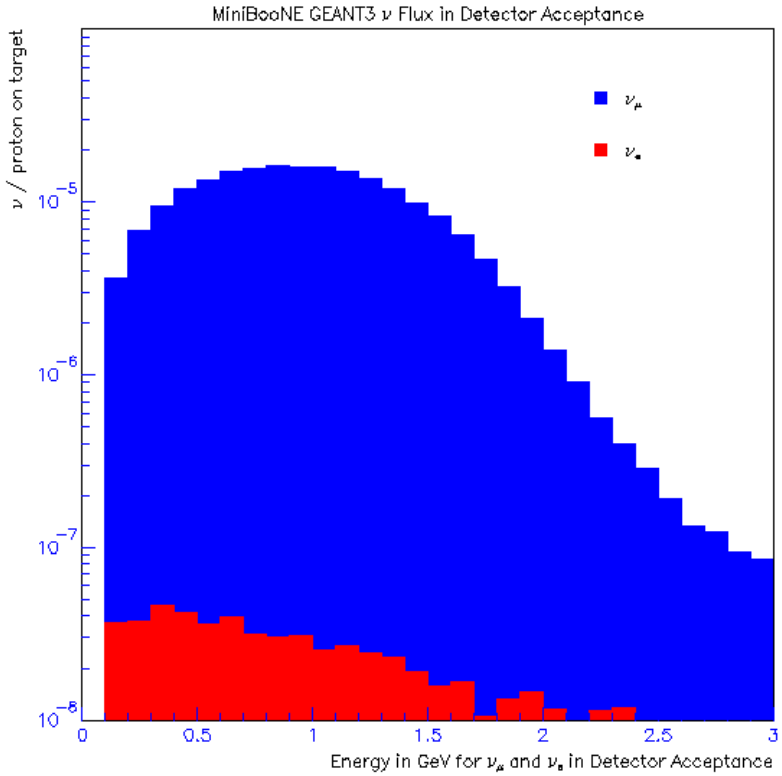
MiniBooNE Status: Beam and Detector



MiniBooNE Detector



- ***Protons:*** 4E12 protons per 1.6 μs pulse, at a rate of 3 - 4 Hz. *(see Terry Hart's talk)*
- ***Mesons:*** produced in p-Be collisions, + signs focused in horn. 50m decay region.
- ***Neutrinos:*** 450 m soil berm before the detector hall. Intrinsic ν_e flux = 0.3 - 0.5% x ν_μ flux.
- ***Detector:*** 1280 PMTs, 250,000 gallons of mineral oil, Cherenkov and scintillation light. 240 PMTs in optically isolated veto region. *(see Chris Green's talk)*



- Beam background ν_es from:

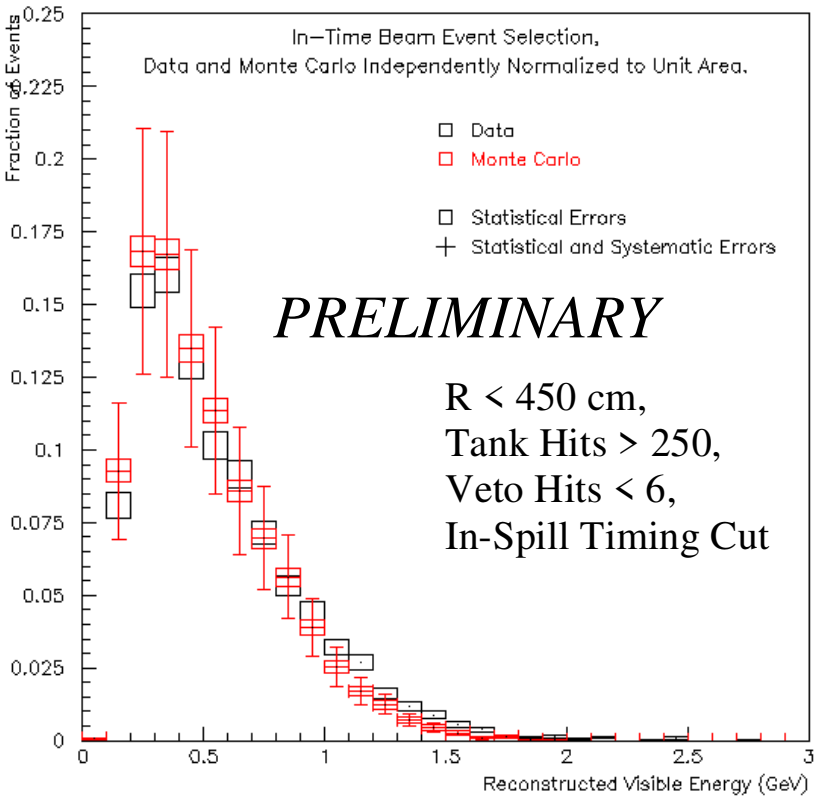
$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	(99.99% B.R.)
$K^+ \rightarrow \pi^0 e^+ \nu_e$	(5% B.R.)
$K^0_L \rightarrow \pi^\pm e^\pm \nu_e$	(39% B.R.)

MiniBooNE Status: Calibration

Many calibration sources ...

- **Laser + Flasks:** PMT gains, timing resolution, vertex reconstruction cross-check
- **Michel Electrons**: low energy (50 MeV) scale and resolution, electron particle ID
- **π^0 mass peak**: energy scale and resolution at medium energy (135 MeV), reconstruction
- **FNAL Debuncher (ν_e's):** electron particle ID at high energy (GeV), expect ~50 total
- **Cosmic Rays + Tracker + Cubes (ν_μ's)**: energy scale and resolution at high (GeV) energy and track reconstruction cross-check

- Unit-area normalized visible energy distributions: (<50% Charged Current Quasi-Elastic)



Updated systematic errors coming soon to an experiment near you...

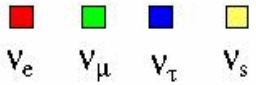
Fun physics from MiniBooNE this year

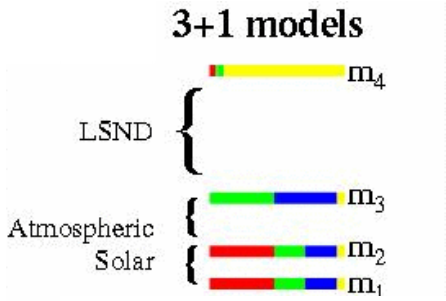
Lots of interesting physics on the road to the ν_e appearance result...

- 1. ν_μ **Disappearance**, discrimination among models?
- 2. **Test CPT invariance** with $\bar{\nu}_\mu$ oscillations (may even be possible in ν running!)
- 3. **Cross Sections**
  - 3a. Coherent π^0 production (relevent for SuperK sterile limits)
  - 3b. Single K production (relevant for proton decay searches)
  - 3c. μ^- capture
  - 3d. ^{12}B (2x discrepancy between experimental results)
  - 3e. NC elastic, measurement of Δs
- 4. **Exotic Particle Searches**
  - 4a. Q^0 Karmen timing anomaly (*Case,Koutsoliotas,Novak* ***Phys.Rev.D65****,077701,2002)*
  - 4b. νs from gamma ray bursts

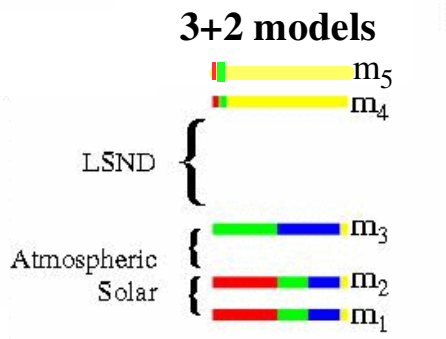
ν_μ Disappearance: discrimination among models (?)

- ***To accommodate all three oscillation signals,*** one needs 3 independent Δm^2 values...
  - → add sterile ν(s) *or* invoke ~~CPT~~ *or* ?

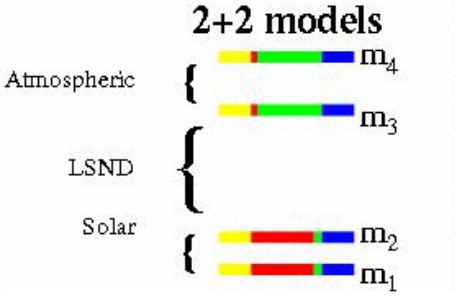




- ***Disappearance can be large at MiniBooNE***, $A_{disappear} \sim 4U^2_{\mu 4}(1-U^2_{\mu 4})$
  - → for viable 3+1 models:
    $\Delta m^2_4 = 19.0\ eV^2$, $U_{e4} = 0.12$, $U_{\mu 4} = 0.23$, $A_{disappear} \sim 0.20$
    $\Delta m^2_4 = 0.91\ eV^2$, $U_{e4} = 0.14$, $U_{\mu 4} = 0.20$, $A_{disappear} \sim 0.15$
    $\Delta m^2_4 = 0.47\ eV^2$, $U_{e4} = 0.12$, $U_{\mu 4} = 0.40$, $A_{disappear} \sim 0.58$
  - → for one viable 3+2 model:
    (more parameters) $A_{disappear} \sim 0.20$
    (M. Sorel, in preparation)

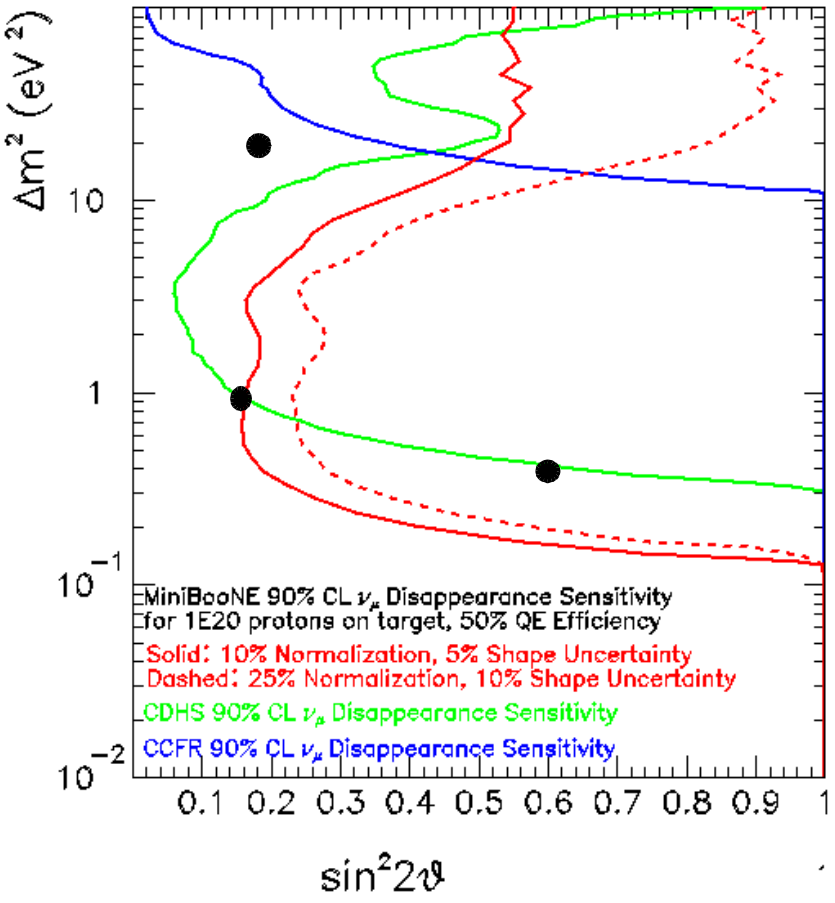


- ***2+2 models may still be viable ...***
  if so, MiniBooNE could have sensitivity for $0.1 < \Delta m^2 <$ few eV^2



ν_μ Disappearance: Projected 3+1 Sensitivity

- ***Projected MiniBooNE 90% C.L. Sensitivity*** by August '03:
  - -1E20 protons on target
  - -50% charged current quasi-elastic selection efficiency
  - -25% energy resolution below 1 GeV, 15% above
- Analysis is systematics dominated.
- Energy distribution shape uncertainty much more important than overall normalization error.
  Goal: 5 to 10% energy distribution shape uncertainty.
- We have sensitivity to some 3+1 allowed regions!
  - $\Delta m^2 = 19.0\ eV^2$
  - $\Delta m^2 = 0.91\ eV^2$
  - $\Delta m^2 = 0.47\ eV^2$

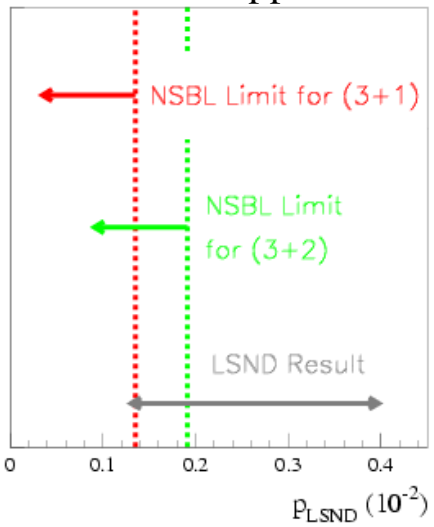


ν_μ Disappearance: 3+2 Model

- ***Constraints on 3+2 models from SBL experiments***
  Null Results:
  - -Bugey and CHOOZ ($\bar{\nu}_e \rightarrow \bar{\nu}_x$)
  - -CCFR and CDHS ($\nu_\mu \rightarrow \nu_x$)
  - -KARMEN ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)

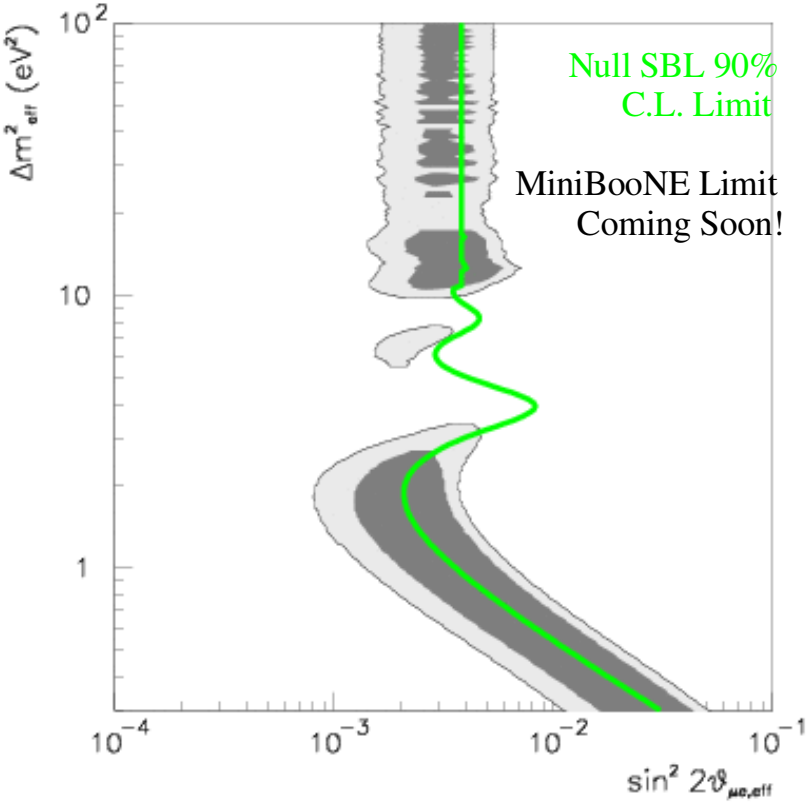
- Method: perform a combined χ^2 analysis of the null SBL experiments to derive upper limit on LSND oscillation probability with Δm^2_4, Δm^2_5 , $(\Delta m^2_5 - \Delta m^2_4) \neq 0$. *(M. Sorel)*

- Is the null SBL upper limit consistent with the LSND result?



$p_{LSND} = \langle P_{LSND}(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \rangle$ averaged over LSND L/E

3+2 Null SBL 90% C.L. limit has large overlap with LSND allowed region!



For the purpose of plotting allowed regions, define an effective mixing angle and δm^2.

$$\langle P_{LSND} \rangle_{(L/E)} \equiv \sin^2 2(\theta_{\mu,e})^{effective} \langle \sin^2(1.27(\delta m^2)^{effective} L/E) \rangle_{LSND}$$

$\bar{\nu}_\mu$ Disappearance: CPT Violation

- In CPT violating models, $m_\nu \neq m_{\bar{\nu}}$
  (Barenboim, Borissov, Lykken, Smirnov hep-ph/0108199)

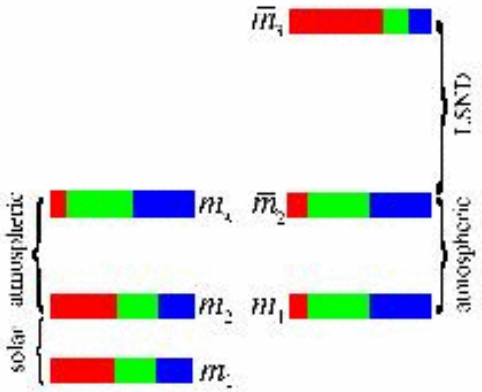
- Since KamLAND,

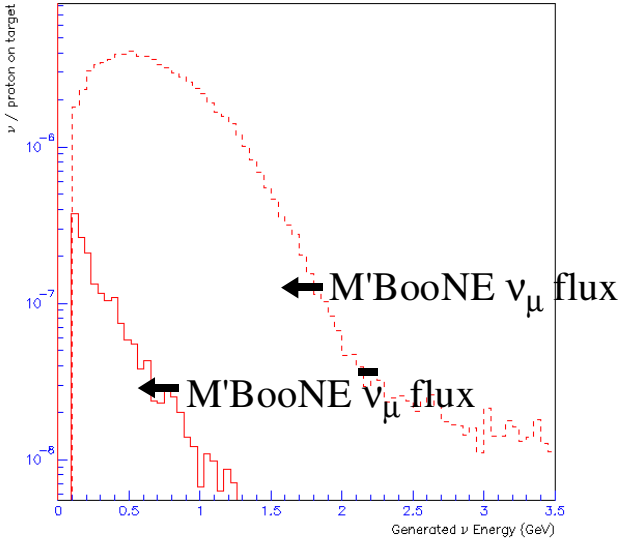
$$P(\bar{\nu}_\mu \to \bar{\nu}_\mu) \approx 1 - \sin^2 2\bar{\theta}_{23} \sin^2 \frac{\delta m^2_{LSND} L}{4E}$$

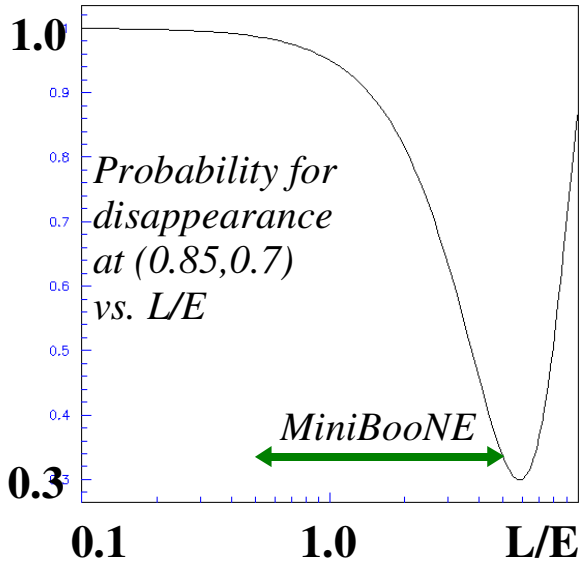
  with $0.4 < \sin^2 2\bar{\theta}_{23} < 0.9$ for $\Delta m^2 < 1\text{eV}^2$. *LARGE!*
  (Barenboim, Borissov, Lykken hep-ph/0212116)

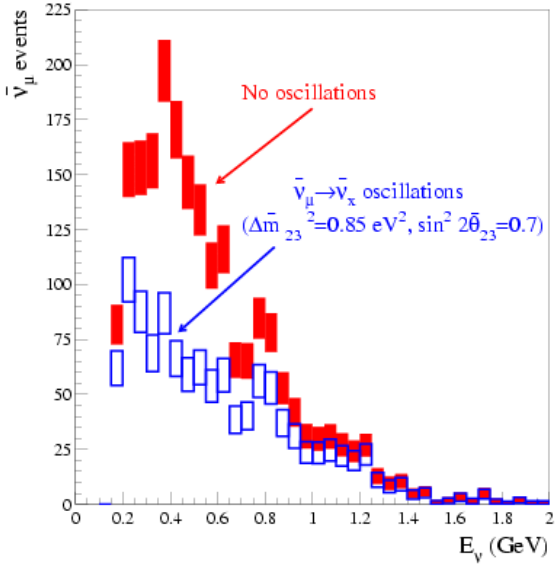
- ***Running γ trigger to identify $\bar{\nu}_\mu$s with n capture γ (2.2 MeV) now.***

CPT violating models



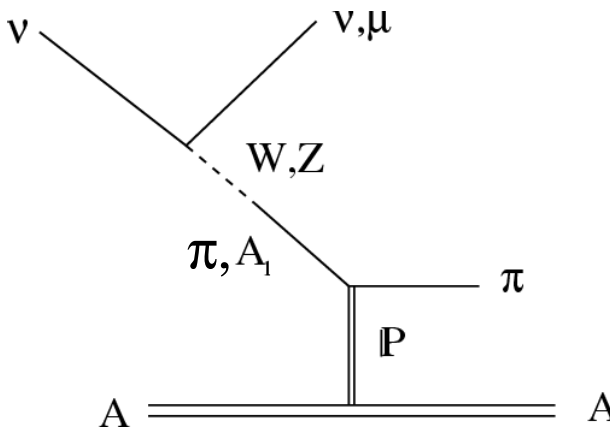


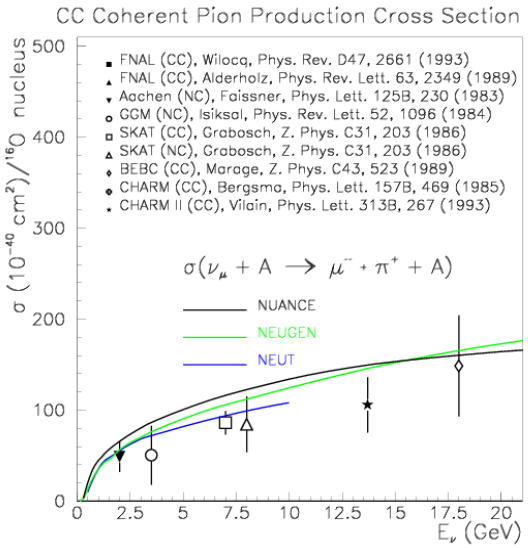




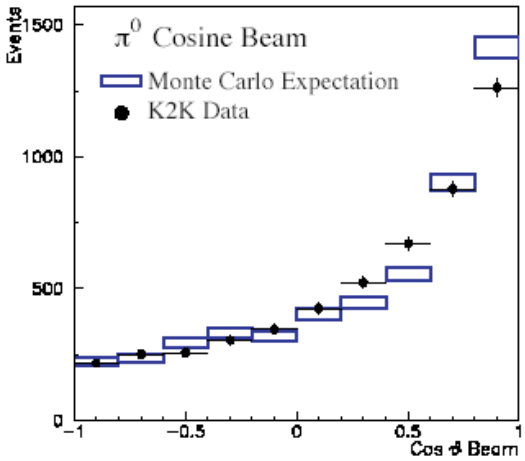
Cross Sections: Coherent π^0 Production

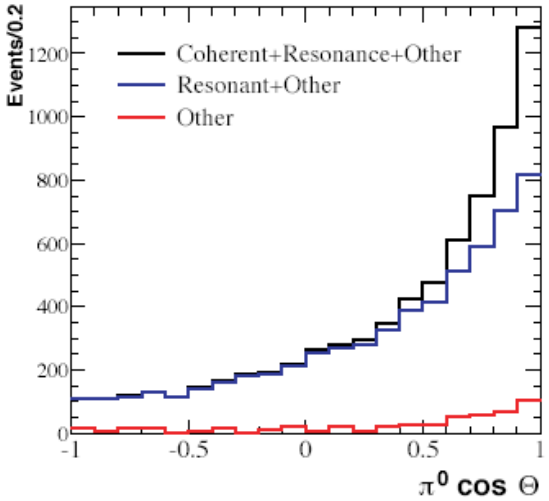
- ***Mechanism***: scatter from entire nucleus
  - -NC: $\nu_\mu A \rightarrow \nu_\mu A \pi^0$
  - -CC: $\nu_\mu A \rightarrow \mu^- A \pi^+$
- ***Distinct kinematics***:
  - -Negligible energy transfer (low q^2)
  - -Forward scattered π
- Theoretical models exist, but, coherent rate has 100% error.
- Impacts atmospheric oscillations to sterile states since NC rate + cross- section bounds sterile content of disappearance.
- NC Coherent π^0 production is 20% of total π^0 production, background to ν_e appearance.
- ***MiniBooNE should be able to see it!***
  10x more events than K2K near detector.
  Can select coherent production events with π angular distribution.





(C. Mauger, NUINT '01)





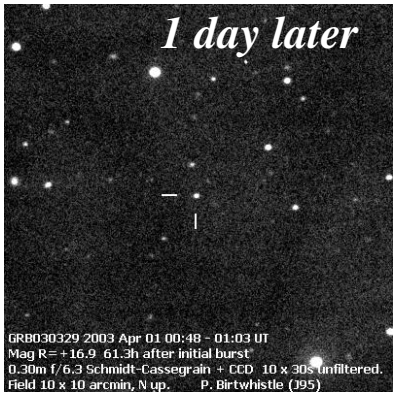
Exotics Searches: GRB Neutrinos

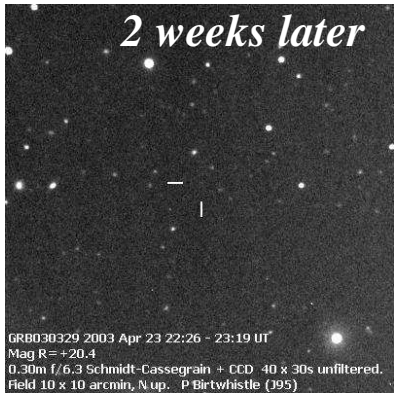
- ***Top 1% Brightest Gamma Ray Burst,***
  GRB030329 occurred March 29, 2003
  = SN2003dh (supernova) in Leo,
  2 billion LY away (z = 0.17).

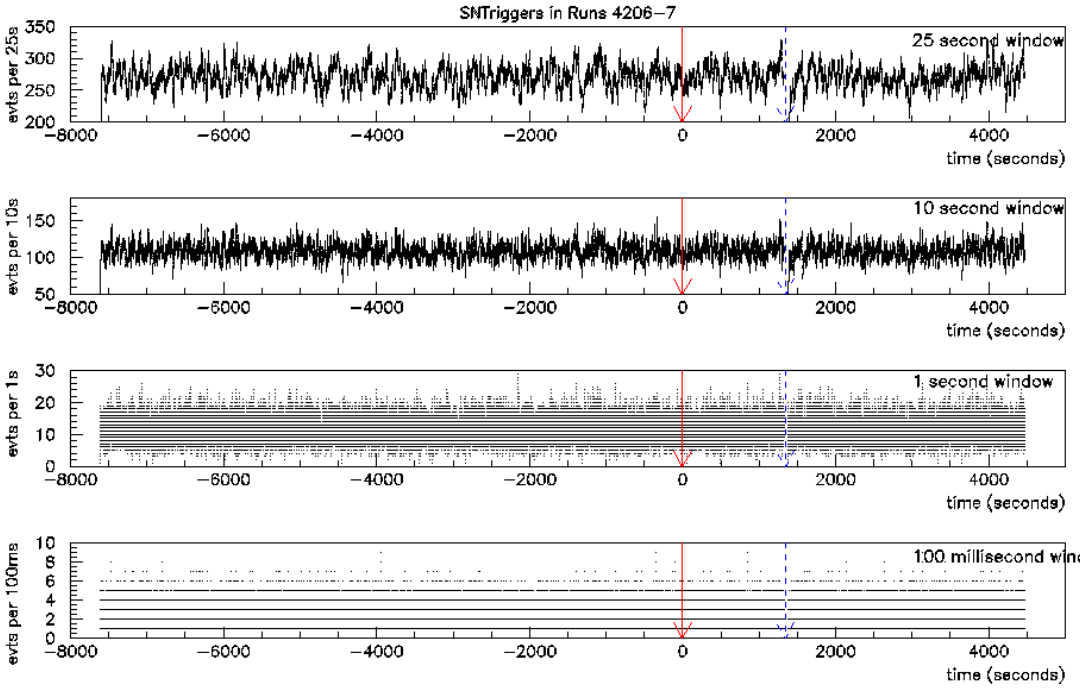
- ***Can MiniBooNE possibly see it?***
  "typical" supernova at 10kPc = 200 ν events
  (Sharp, Beacom, Formaggio ***Phys.Rev.D66****:013012,200*
  typical SN at 2E9 LY = 4.5E-8 ν events.
  But, we looked anyway.
  (M. O. Wascko, in preparation)

- ***MiniBooNE Supernova Trigger***:
  -Tank Hits > 60
  -Veto Hits < 4
  -15 μs holdoff after CR event
  -priority = 3

  We may not have discovered νs from GRB, but we are supernova live (and ready for SNEWS)!

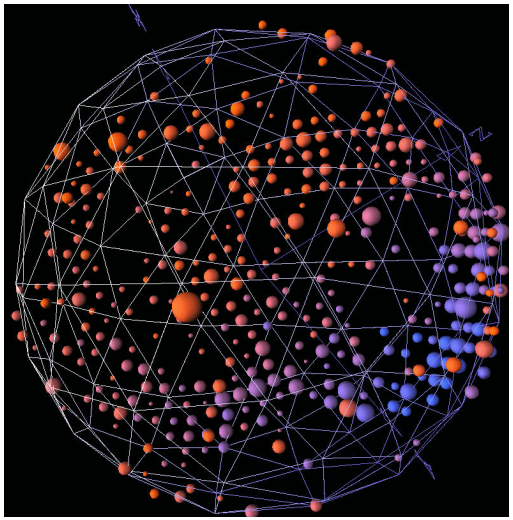


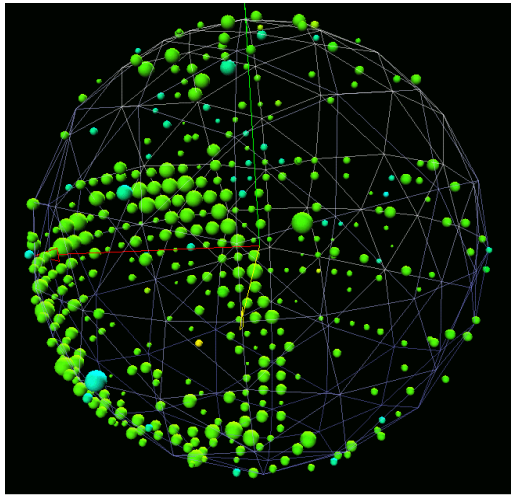




MiniBooNE: Status and Outlook

- ***6.85E19 protons on target to date (7% of goal)!***
- ***All*** calibration systems on line,
  initial Q,T calibrations almost complete
- ***Hope*** to be at full proton intensity by fall '03
- ***Plan:*** complete 1st round of MC tuning this summer
  produce 1st updated systematic errors this summer
  priorities for summer '03:
  - -external measurements (π,K production),
  - -detector optical model,
  - -energy scale and resolution,
  - -absolute CCQE flux normalization.
- ***Goal:*** 1st Cross-sections and exotics measurements,
  preliminary ν_μ disappearance measurement





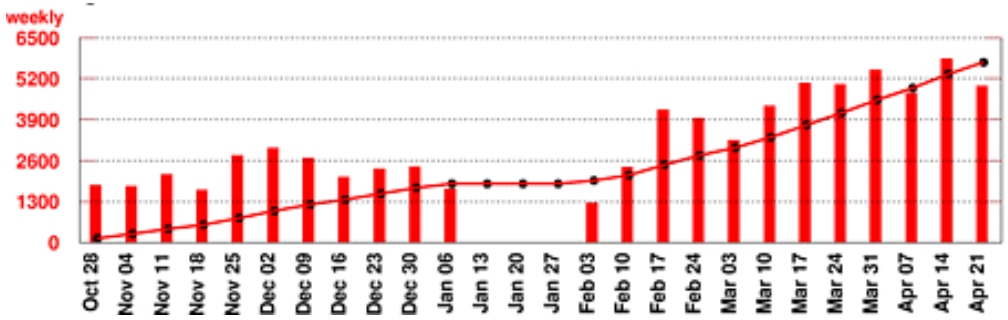
Fall '03,
Stay Tuned ...

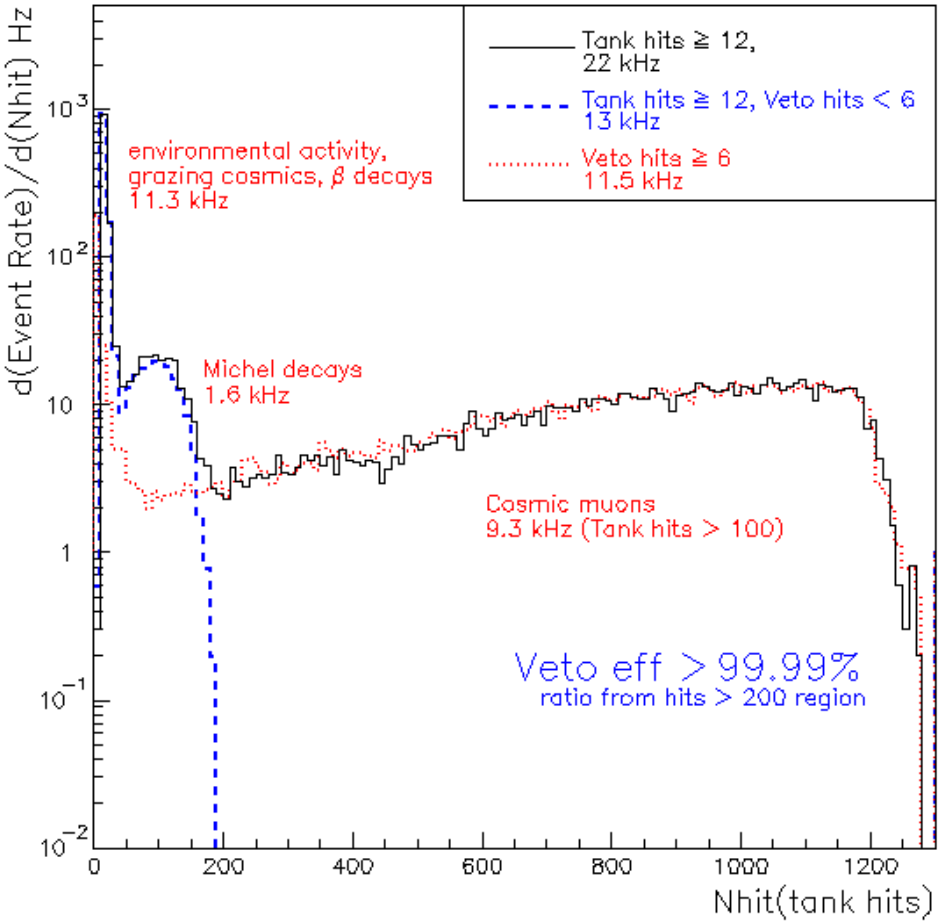
MiniBooNE Status: **Data Collection**

- ***Trigger "to tape" Rate:*** **total: 22 Hz**
  Laser (Calibration): 1 Hz
  Cosmic Rays + Tracker (Calibration): 1.5 Hz
  Michel Electrons (Calibration): 1 Hz
  Strobe (Calibration): 2 Hz
  Supernova (We can hope): 11 Hz
  Beam: 2.5 Hz

- ***Protons:*** Total to date: 6.85E19

- ***Beam Neutrino Candidates:*** Selected with tank hits > 200, veto hits < 6, in time with the beam spill. Total to date: 74,881

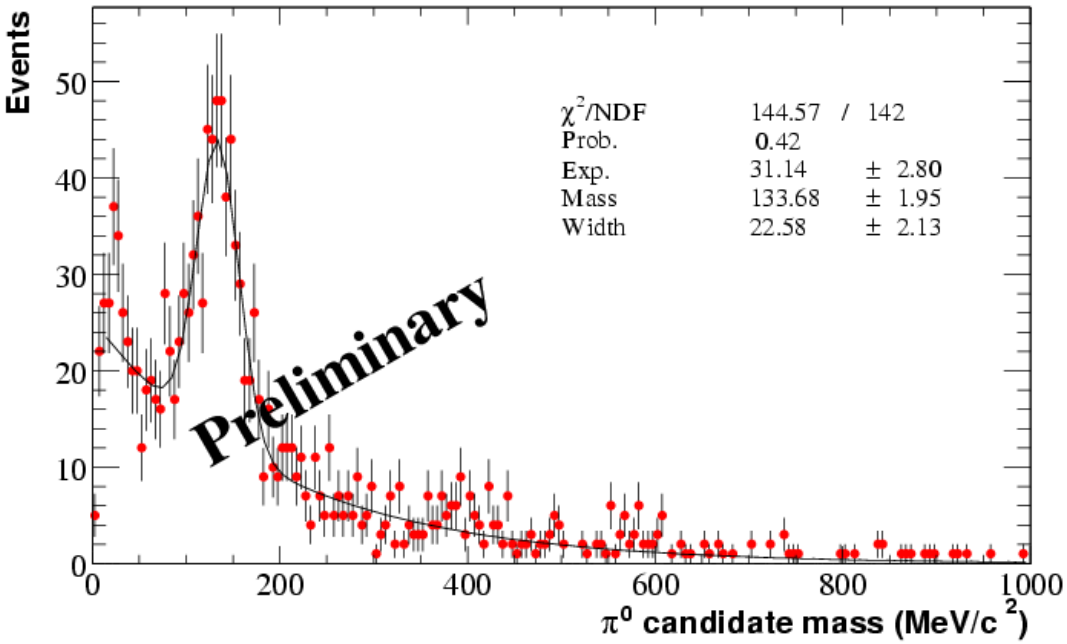




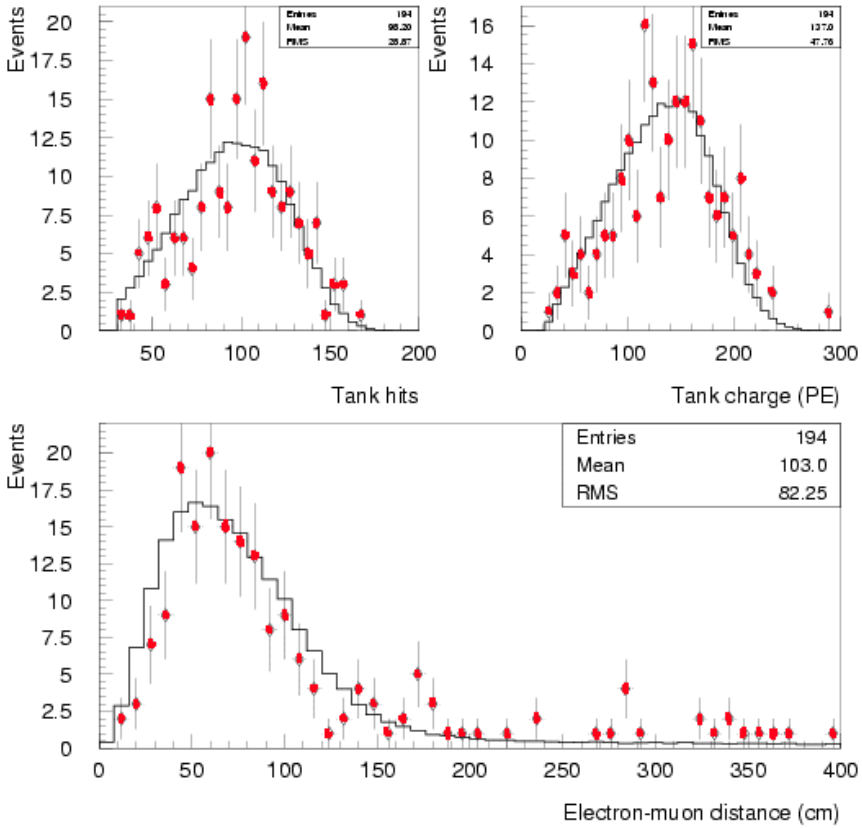
MiniBooNE Status: **Calibration**

Energy scale and resolution calibration status:

- We reconstruct the endpoint of the michel electron spectrum with 15% resolution. Michel endpoint sets energy scale of MC.
- We reconstruct the π^0 mass peak to be 134 MeV.



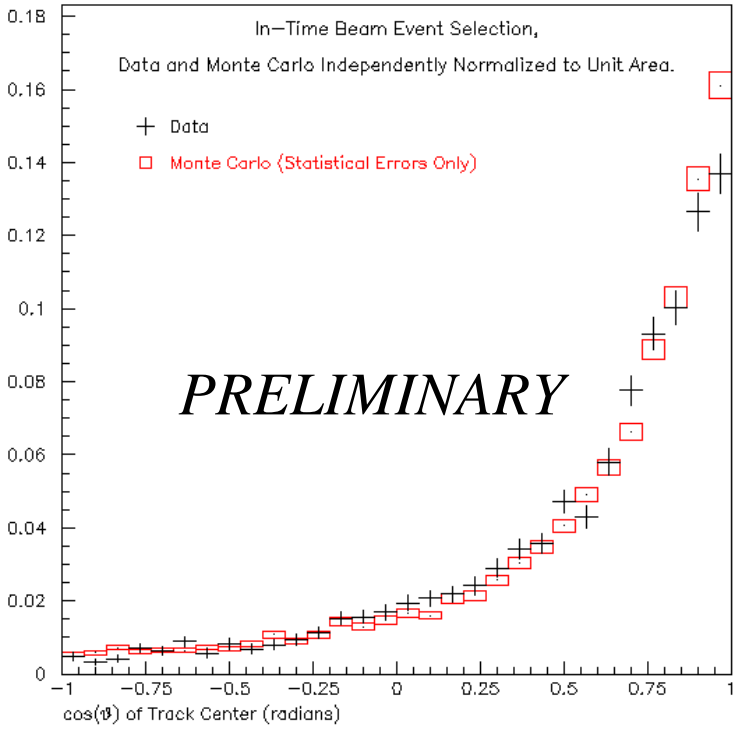
- We reconstruct michel electrons from beam-induced muons and cosmic ray muons the same way, and there is good agreement in charge and tracking distributions.



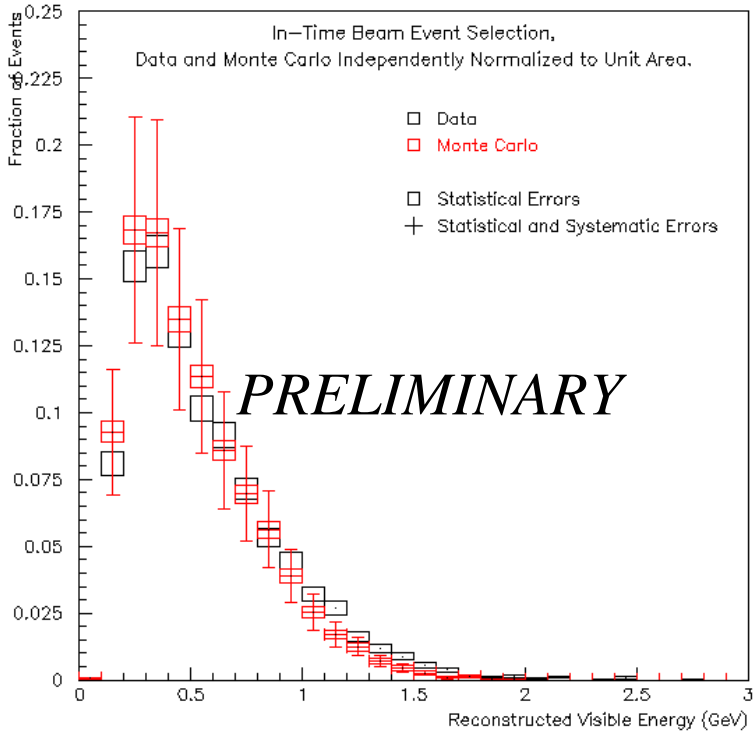
MiniBooNE Status: MC / Data Comparison

In-Time Beam Event Selection:
R < 450 cm, Tank Hits > 250, Veto Hits < 6, In-Beam-Spill Timing Cut
(<50% Charged Current Quasi-Elastic)

- Muon angle with respect to the beam direction:



- Unit-area normalized visible energy distributions:



Systematic errors coming soon to an experiment near you...