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Quo Vadis, MiniBooNE?

- Context
  - ν oscillation landscape
  - LSND
    - Implications
    - What if the signal is confirmed?
- Latest MiniBooNE news
  - Beam and Booster performance
  - Detector performance
    - calibration sources
    - optical modeling of the oil
    - detected neutrino rate vs. time
  - Neutrino data
    - flux, cross section progress
- Updated Oscillation Sensitivity based on measured neutrino rates during first year of data

New physics?

Getting better all the time

Rock steady

Many answers for many questions

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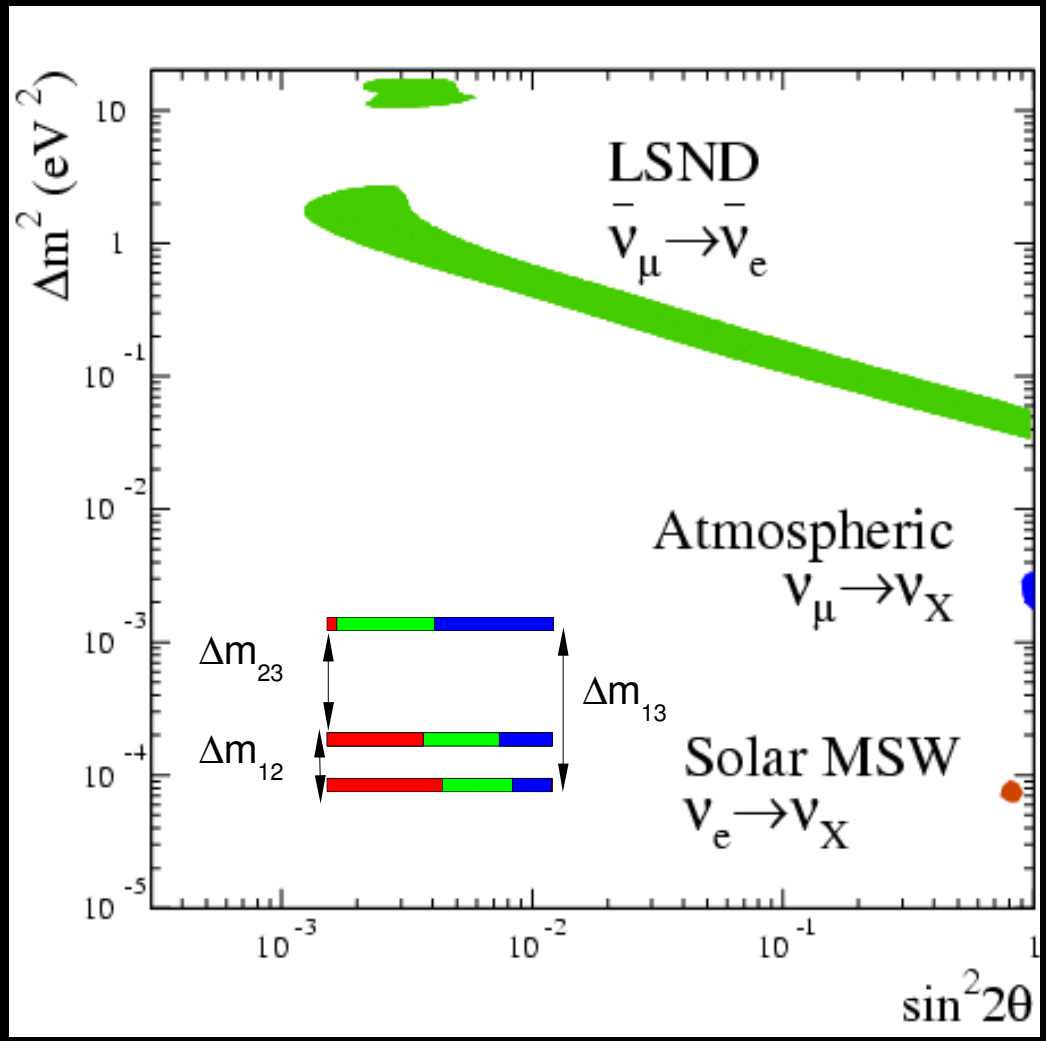
Motivation: 3 Δm^2 regions

- The 3 oscillation regions are incompatible with 3 standard model neutrinos
  - $10^{-5}+10^{-3} \neq 1$ (Solar+Atmospheric ≠ LSND)
  - Solar neutrino oscillations
    - Homestake, SAGE, GALLEX, GNO, Kamiokande
    - SNO
    - KamLAND
  - Atmospheric oscillation
    - first hints: IMB,Kamiokande
    - confirmed by Super-K
    - also seen by SOUDAN2, MACRO, K2K
  - LSND
    - Yet unconfirmed



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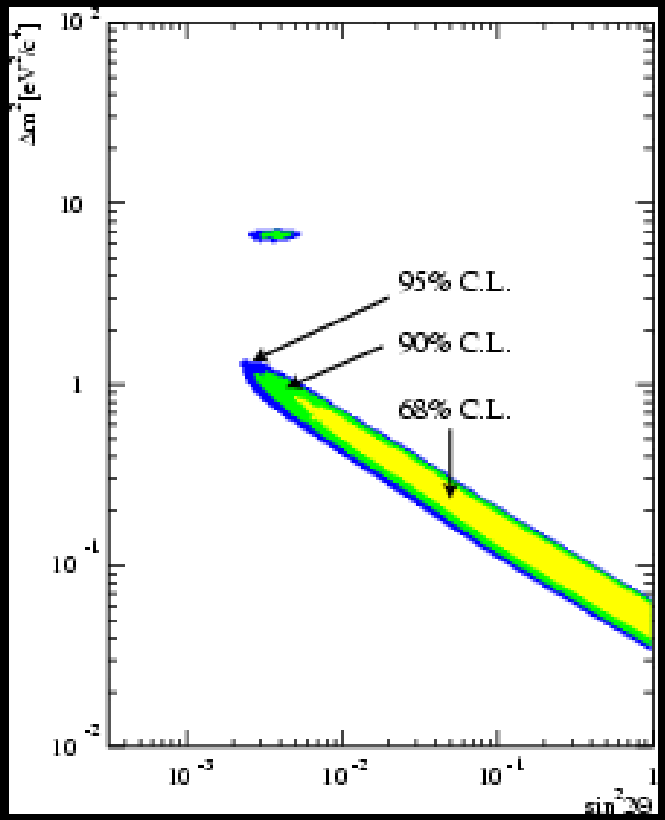
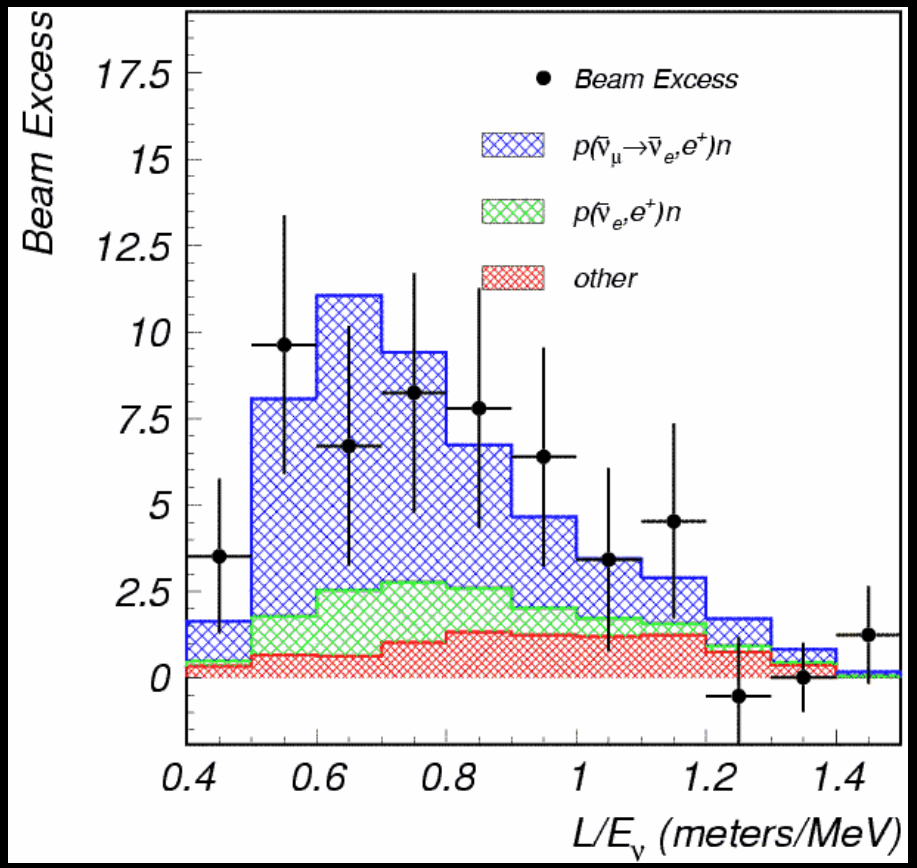
The LSND signal

- $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation probability:
  0.264±0.067±0.045%
- KARMEN2 and LSND collaborators performed joint analysis on both data sets - allowed regions remain!



hep-ex/0203023

3.8σ excess!



hep-ex/0104049

- High statistical significance - not easily ruled out

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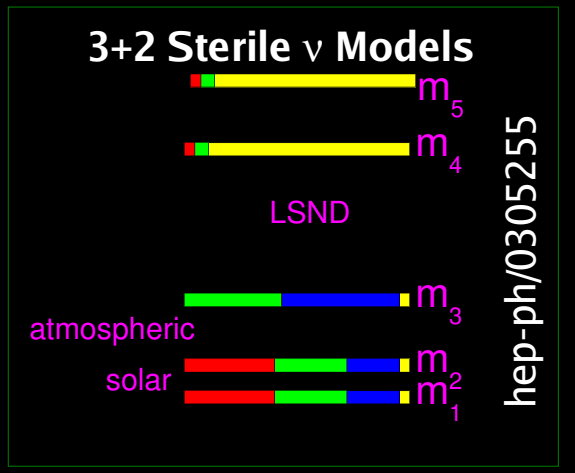
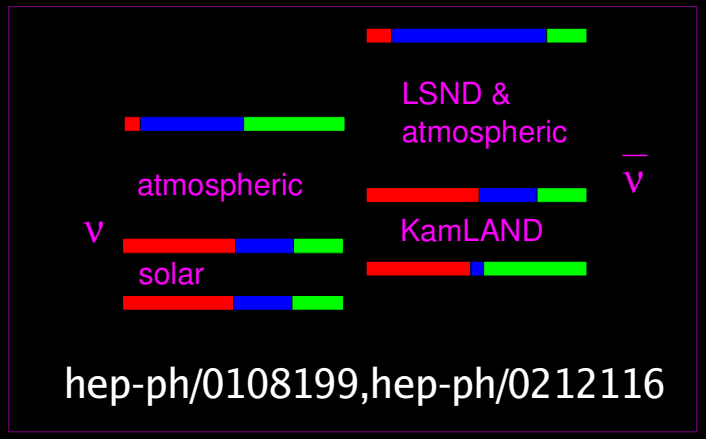
Interpreting LSND

- Not oscillations?
  - Anomalous muon decay: Ruled out by KARMEN2 at 90%CL (hep-ex/0302017)
- If it is oscillations, it indicates
  new physics beyond the standard model
- Sterile Neutrinos
  - (No weak coupling ⇐ invis. Z width)
  - 2+2 models (not quite?) ruled out
  - 3+1 models disfavored
  - 3+n models wide open (n>1)
- CPT Violation
  - ν, $\bar{\nu}$ have different masses and mix separately
- Mass varying neutrinos (astro-ph/0309800)
- MiniBooNE can confirm or exclude LSND w/ 1E21 POT

Neutrino key: ν_e ν_μ ν_τ ν_s





The LSND signal has inspired fresh, new ideas.

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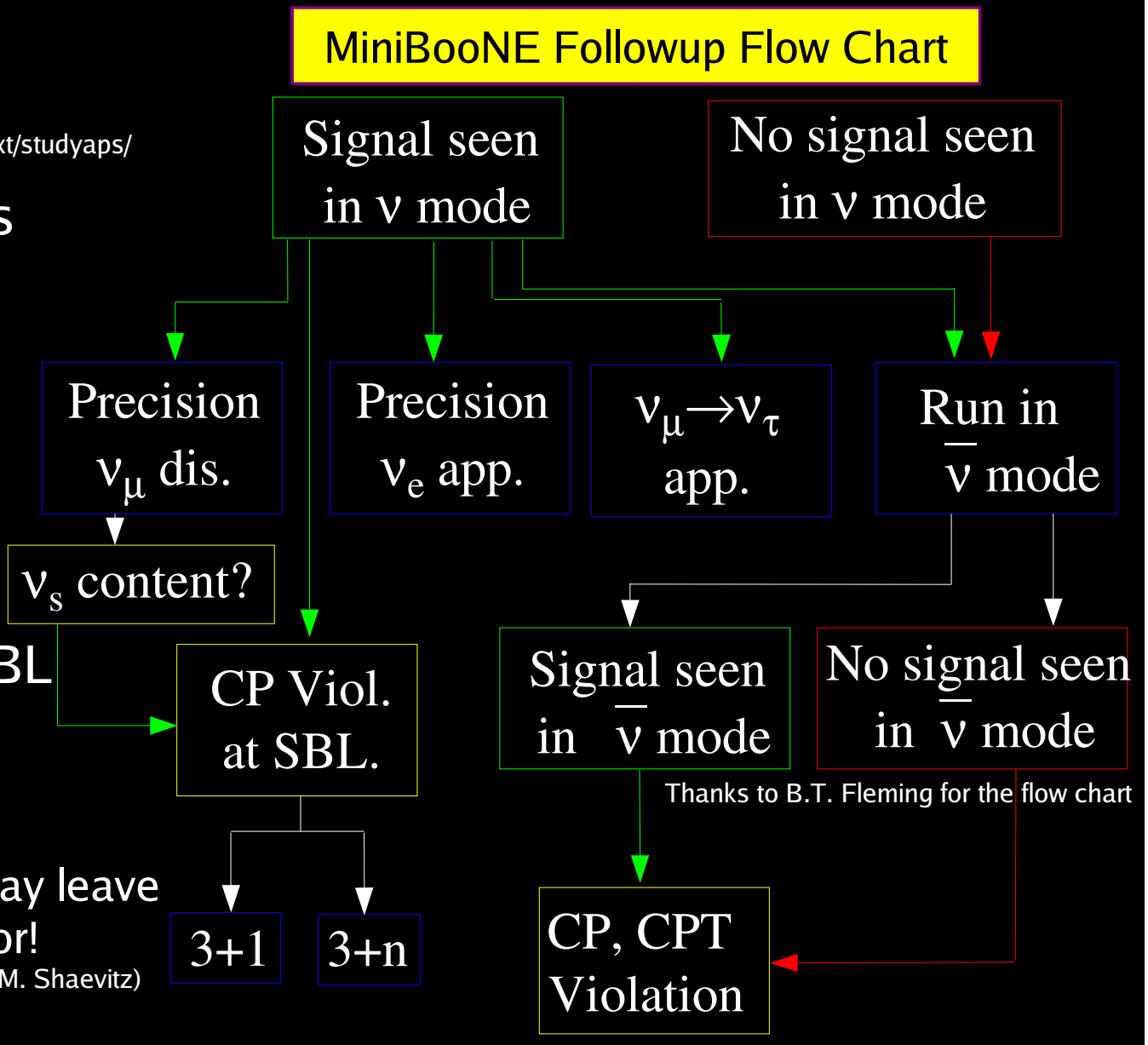
If LSND is Confirmed...

- APS Neutrino Study
  - Charge:
    http://www.hep.anl.gov/NDK/hypertext/studyaps/
- New SBL experiments proposed:
  - FINeSSE
  - MINERvA
  - T2K Near
- LSND oscillations important for future SBL
  - LSND signal might be background for NovA
  - Failure to exclude it may leave a large systematic error!
    (preliminary studies by J.M. Conrad, M. Shaevitz)



Thanks to B.T. Fleming for the flow chart

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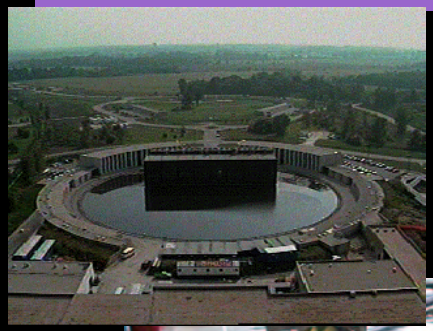
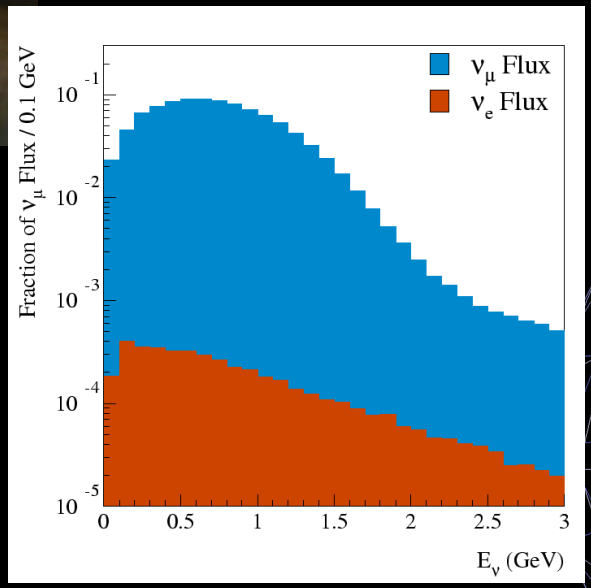
MiniBooNE Overview

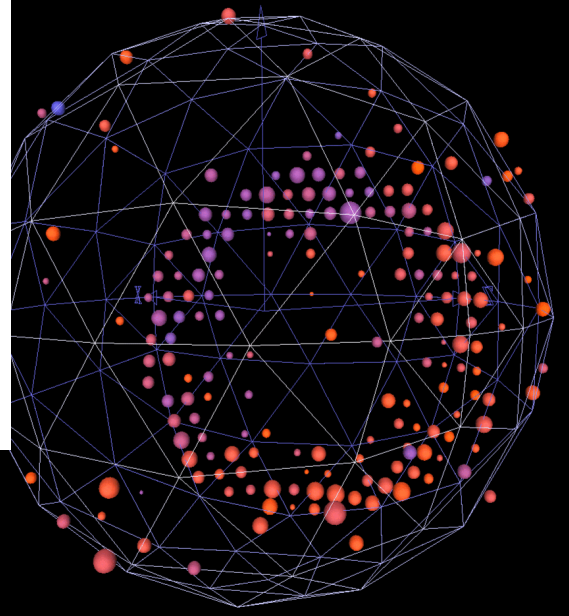


- 8 GeV protons from Booster
- Beryllium target

- Magnetic horn to focus mesons
  - Over 76M pulses - a world record!
  - Reversible polarity - $\overline{\nu}$ mode

- 50 m decay region
  - >99% pure ν_μ, $\overline{\nu}_\mu$ beam
- ~500 m dirt
  - $\nu_\mu \rightarrow \nu_e$?
- 800 ton mineral oil detector
  - 1520 PMTs (1280+240 veto)





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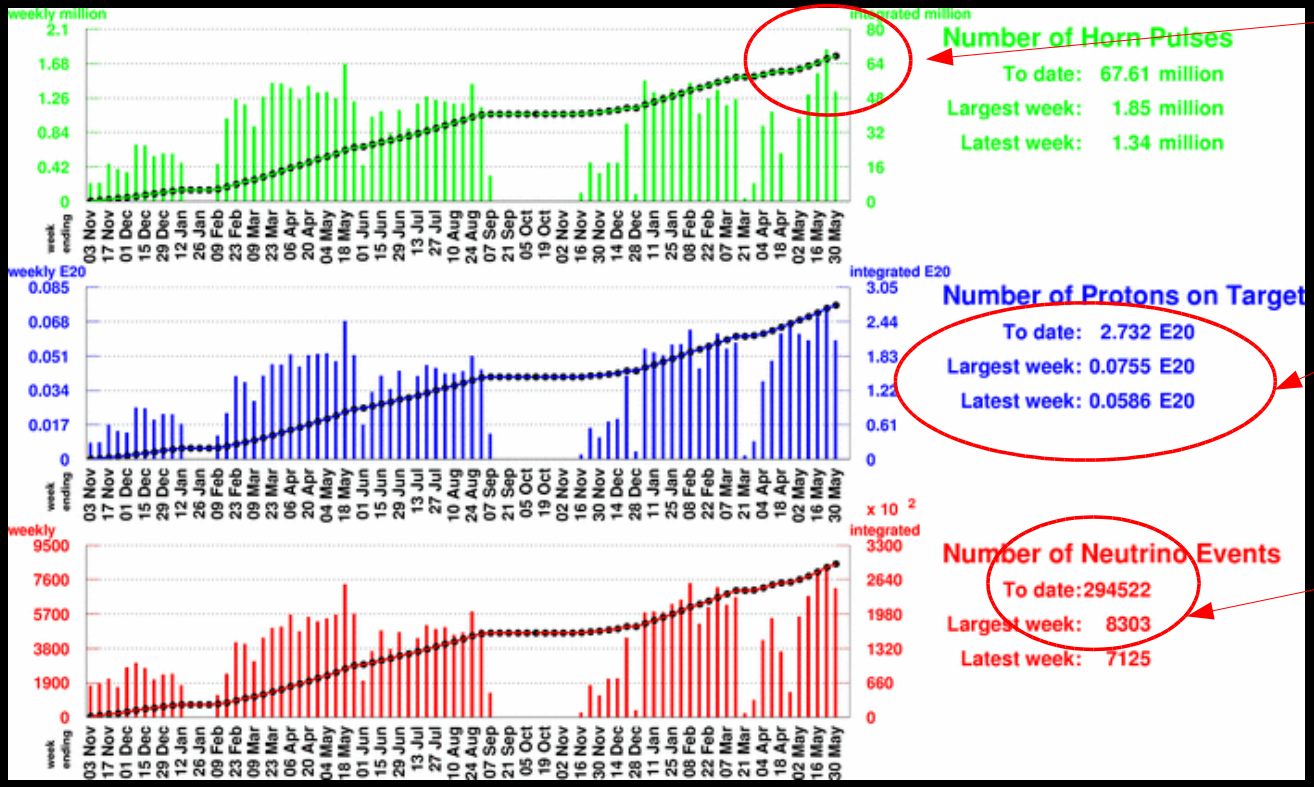
Beam Performance

- MiniBooNE Design request (proposal):
  - 5Hz × 5E12ppp × 88% ≈ 8E16p/hr → 0.13E20 p/week
  - getting closer all the time: recently at 60%!



http://www-boone.fnal.gov/publicpages/progress_monitor.html

Recent upturn in this slope bodes well!

Setting new records

Already the largest data set at these energies - ever!

Many thanks to Accelerator Division for getting us here!

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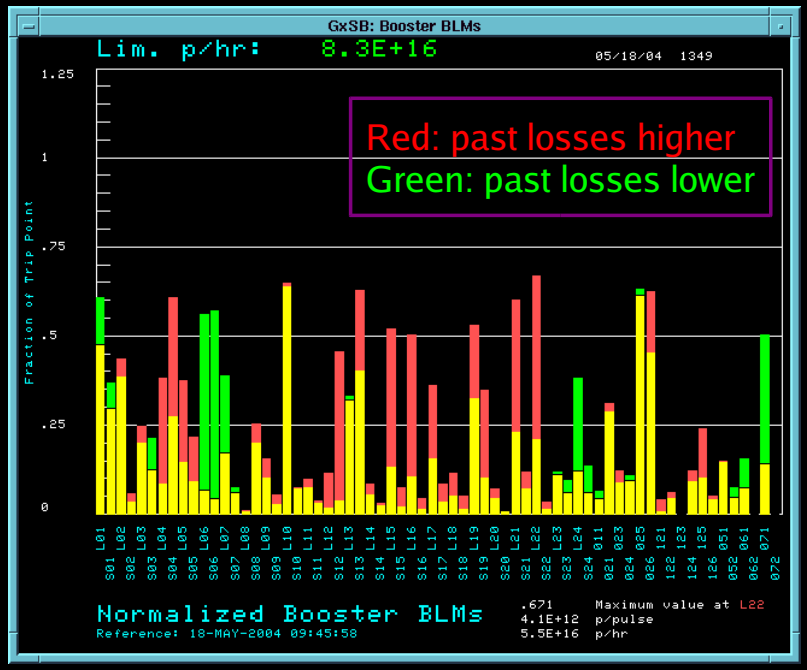
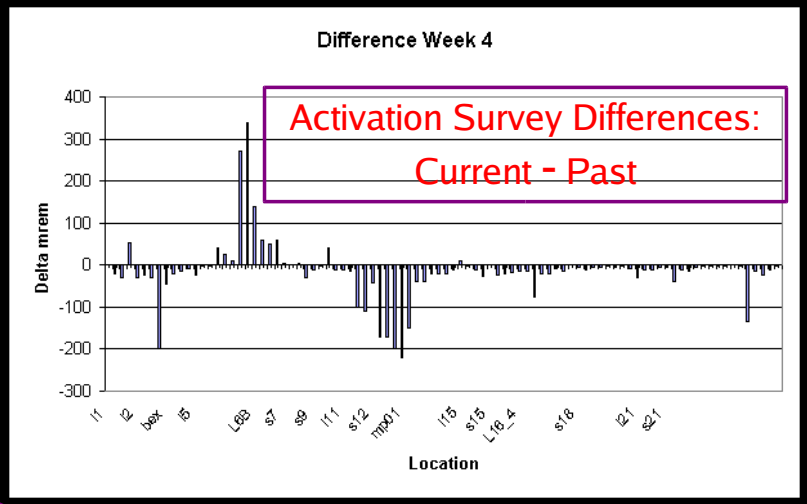
Booster performance

- Many factors contribute to improvements in the Booster
- Operation issues, tuning, etc.
  - Efficiency is up
  - Energy loss per proton is down
  - Thank you to the operators!
- Activation decreasing in high maintenance areas
- Collimation System Installed
- MiniBooNE has made a big investment in the Booster
  - Many collaborators contribute
  - University groups built two new RF cavities





See Ami Choi's poster!

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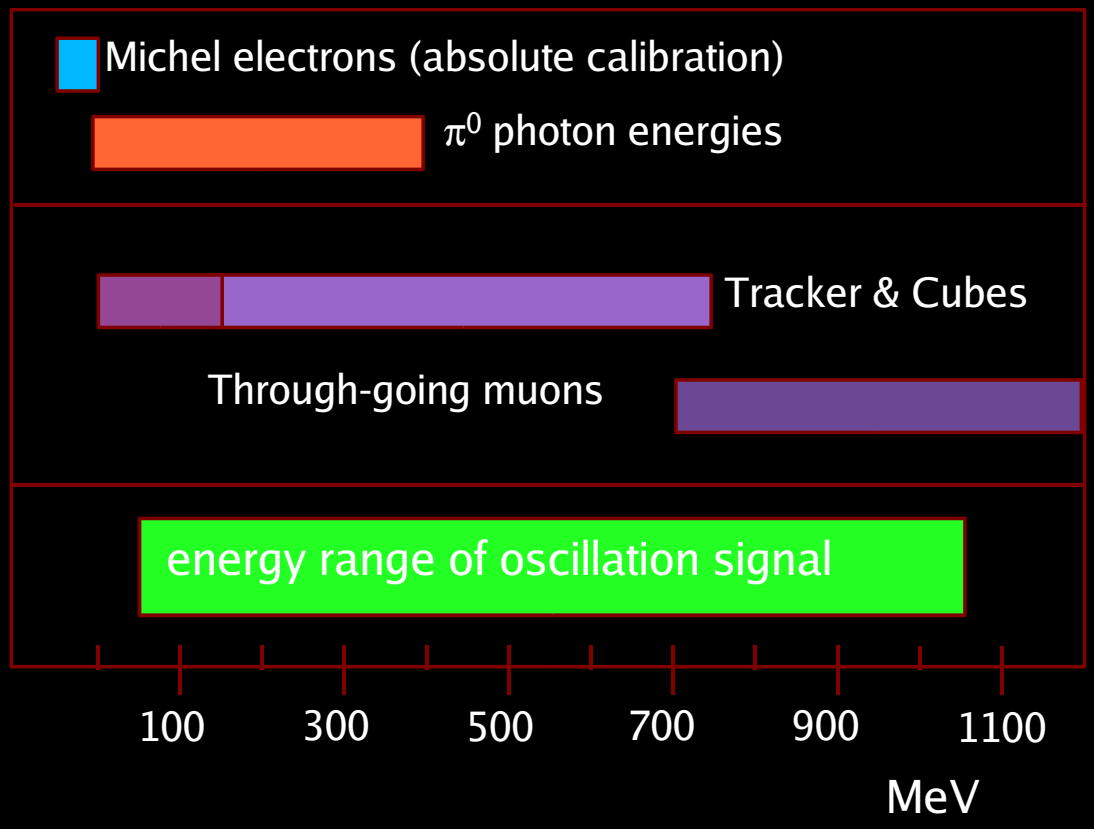
Detector Calibration



- Many calibration sources
- PMTs calibrated with laser system
- Calibration data samples that span oscillation signal energy range
- Electron data samples
  - Michel electrons
  - π^0 photons
- Cosmic Muons
  - Stopping, through-going

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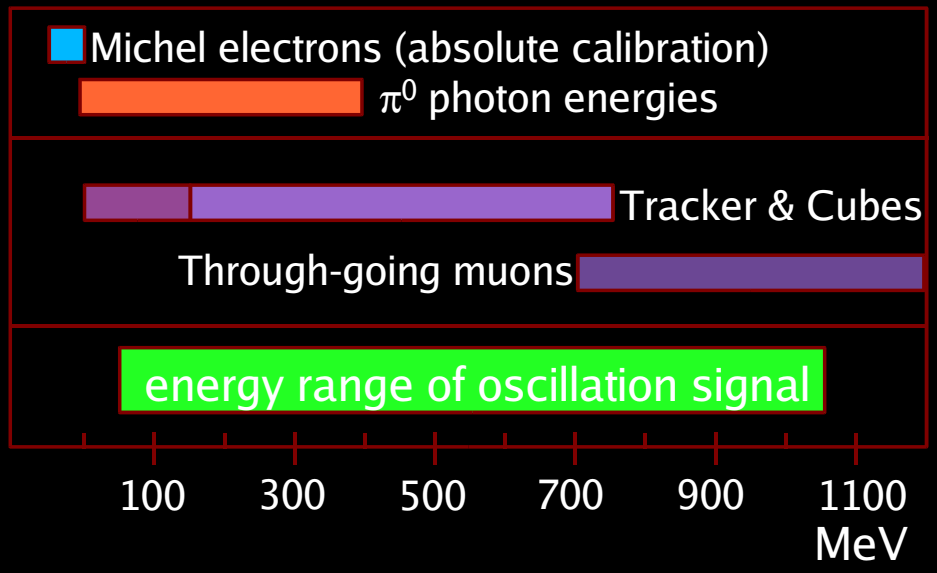
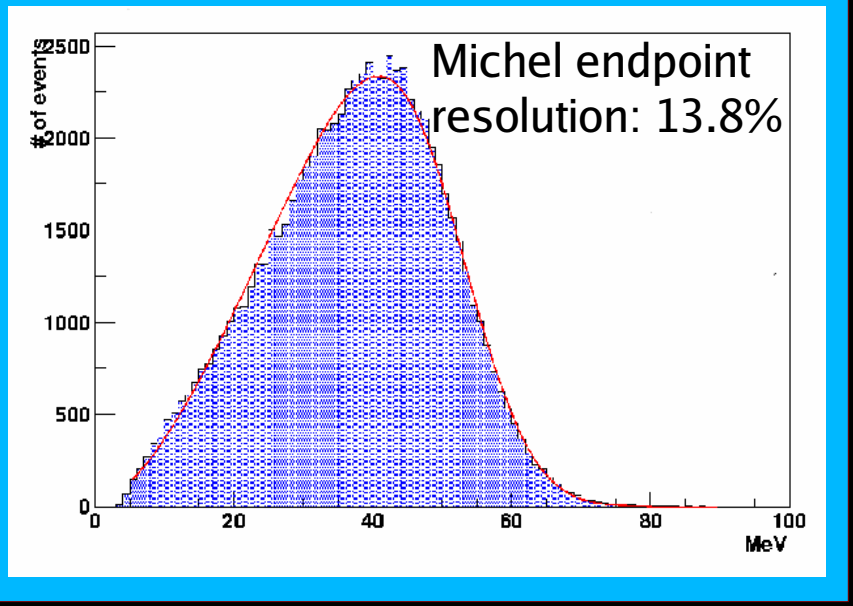
Detector Calibration





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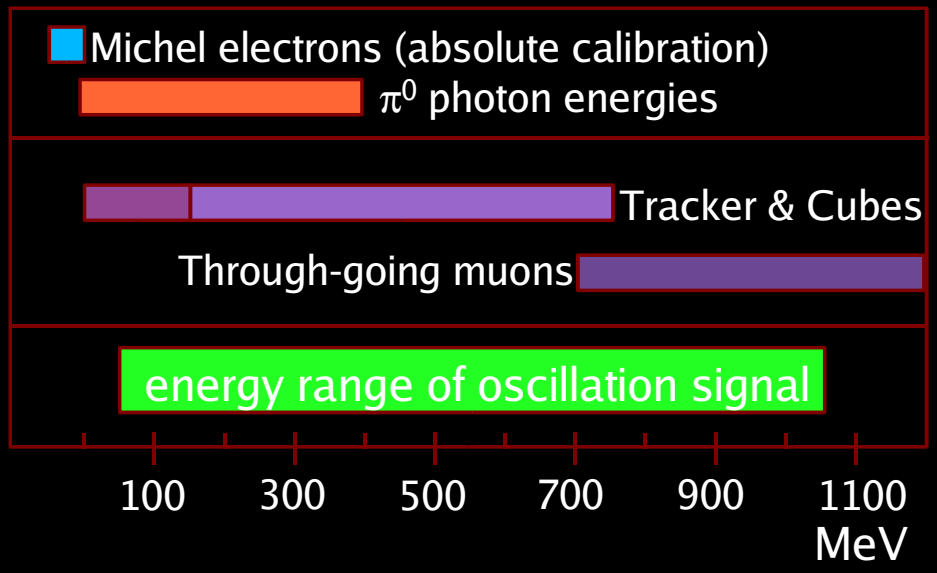
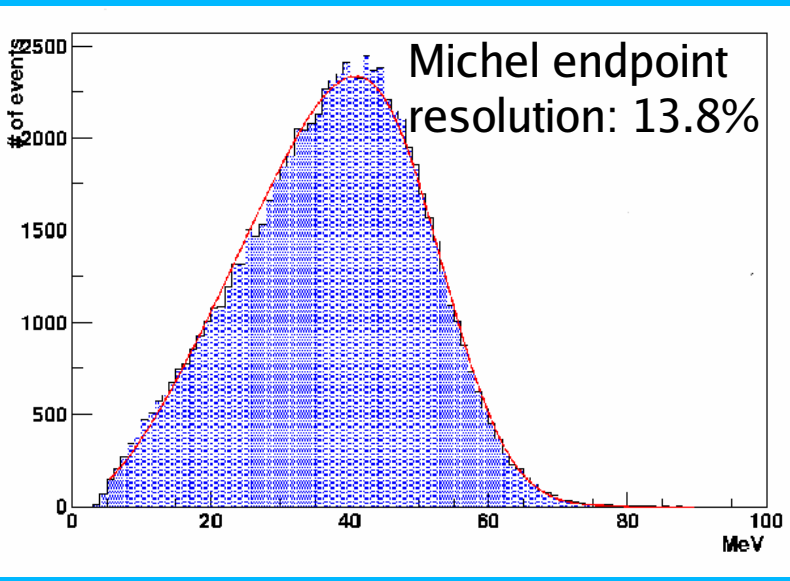
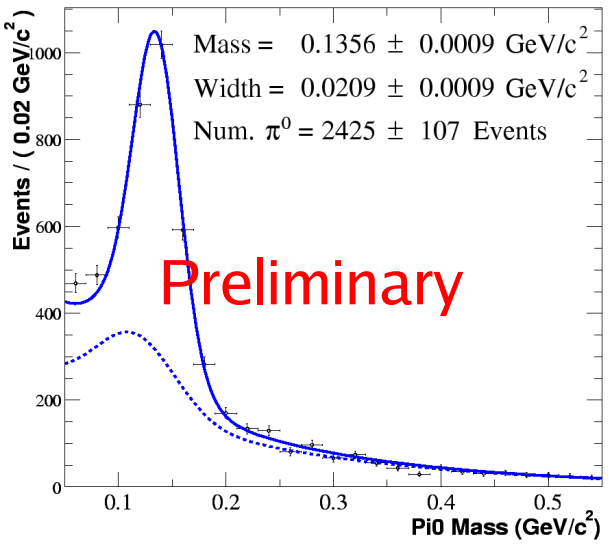
Detector Calibration







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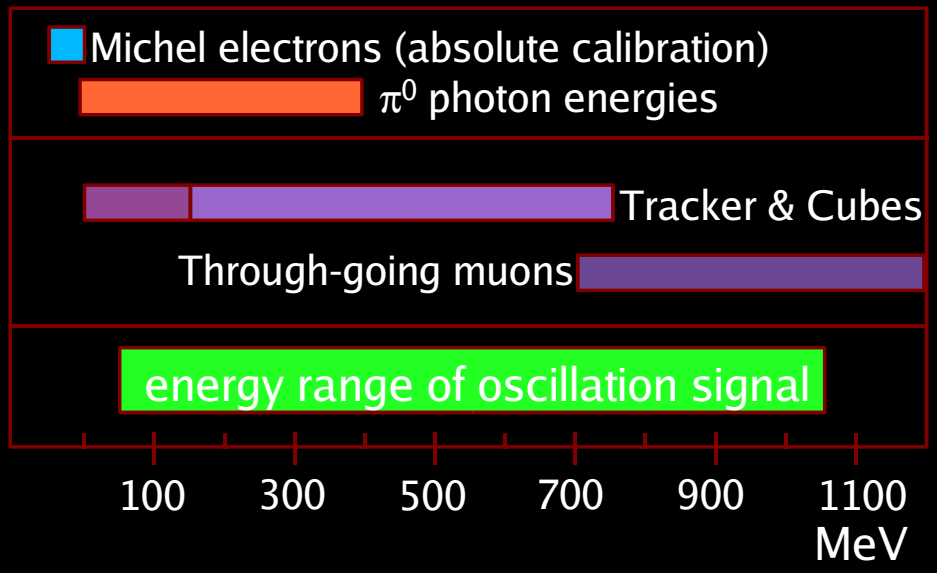
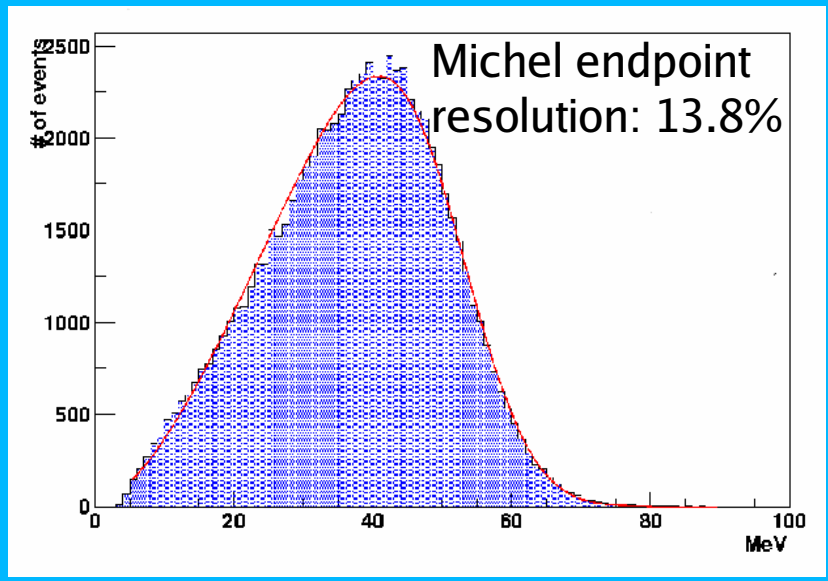
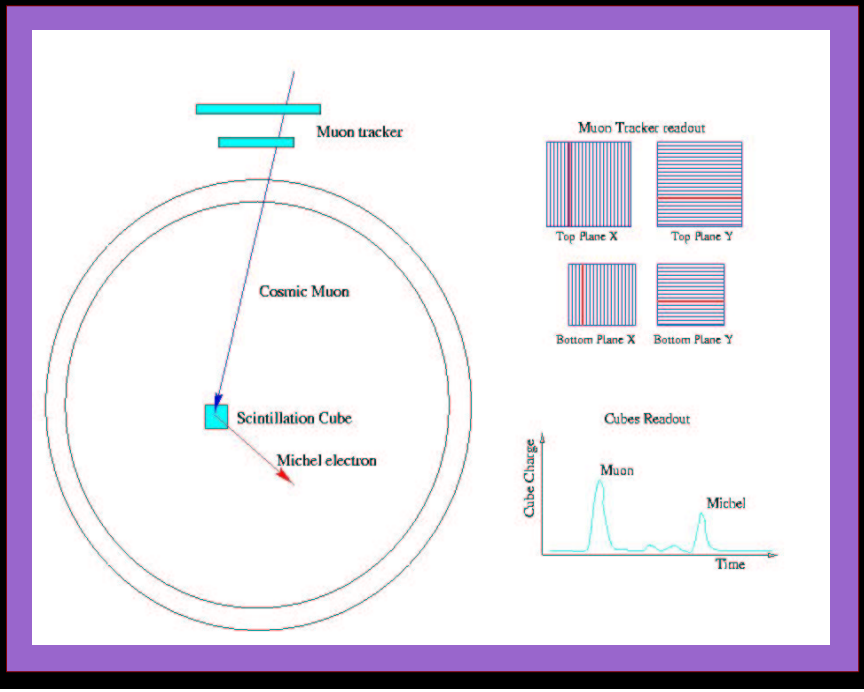
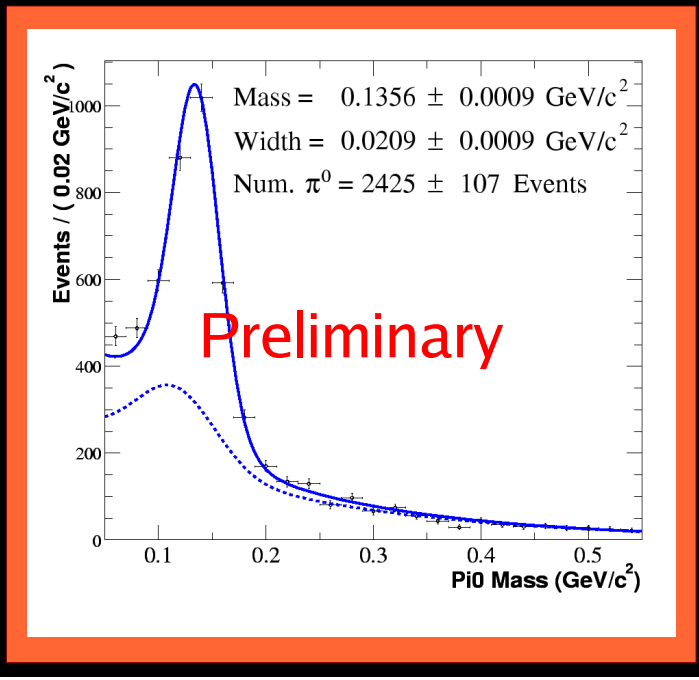
Detector Calibration









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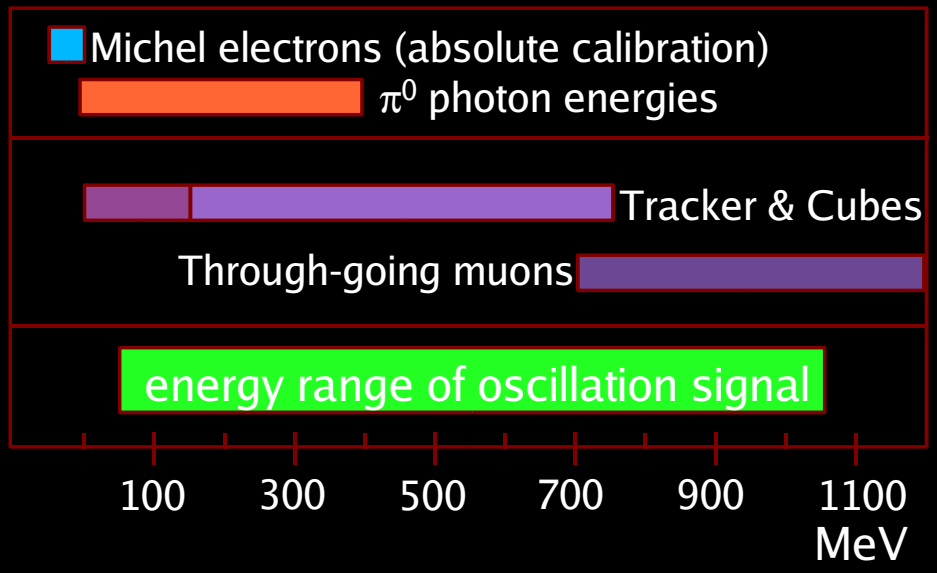
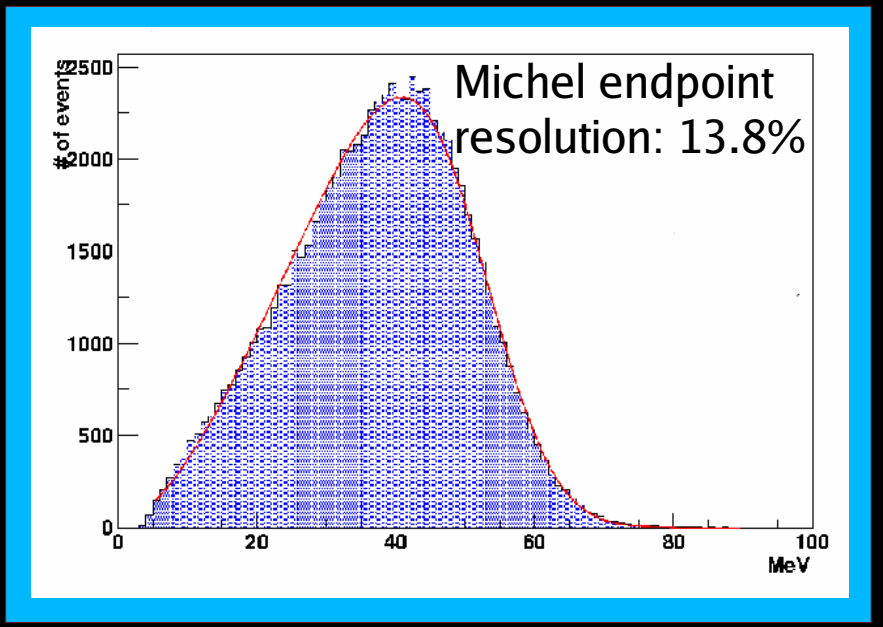
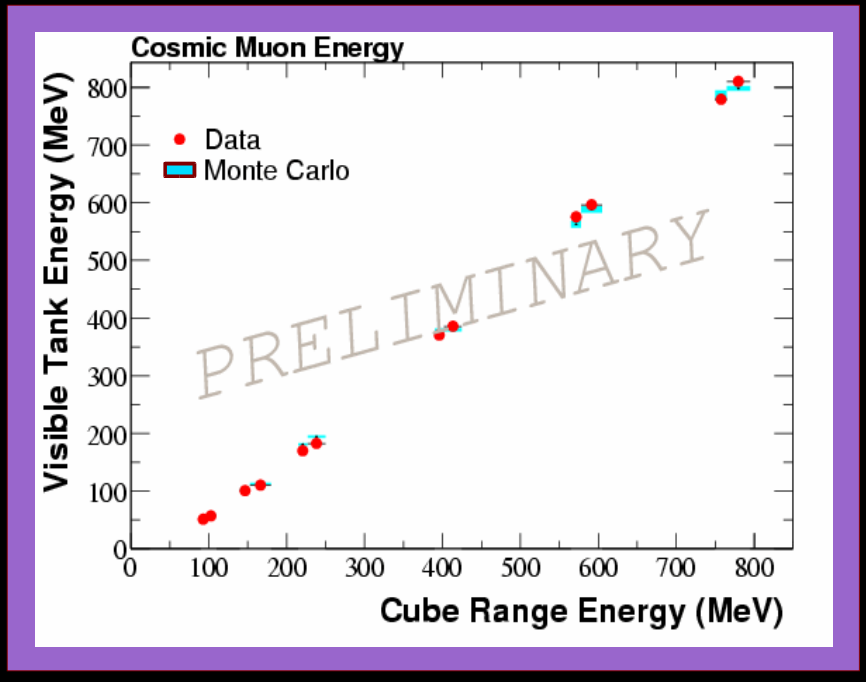
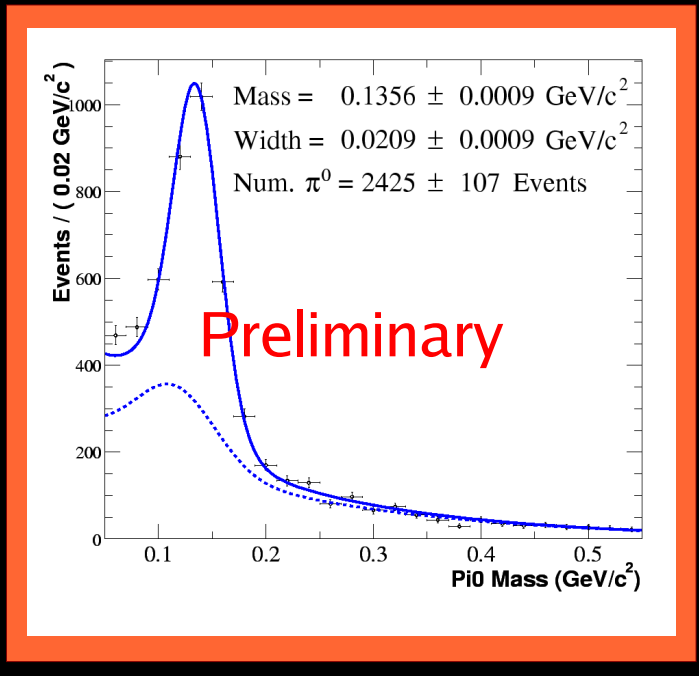
Detector is Calibrated









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Optics of Mineral Oil

Creation

- Čerenkov light
  - proportional to β
- Scintillation
  - dE/dx
  - time delay

Propagation

- Scattering (Rayleigh)
  - prompt
  - $1+\cos^2\theta$
  - λ^4
- Fluorescence
  - isotropic
  - time delay
  - spectrum
- Absorption

In Situ

- Michel electrons
- Cosmic muons
- Laser: diffuse light
- Laser: pencil beam

Ex Situ

- Scintillation (IUCF) w/p^+
- Scintillation (FNAL) w/μ
  - repeated w/p^+ (IUCF)
- Goniometry (Princeton)
- Fluorescence spectroscopy (FNAL)
- Time resolved spectroscopy (JHU)
- Attenuation (FNAL)
  - multiple devices

Work in progress...

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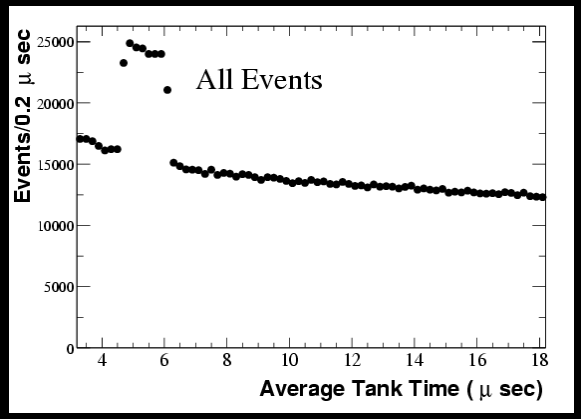
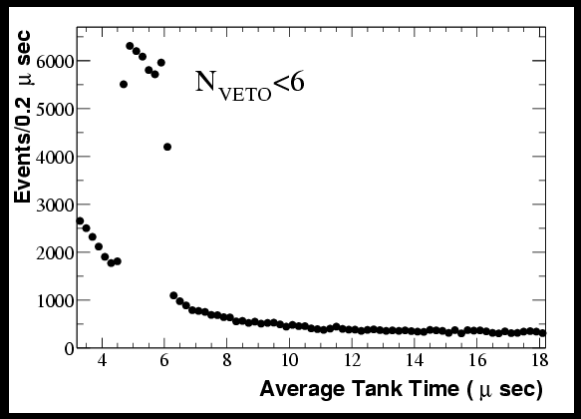
Neutrino Data

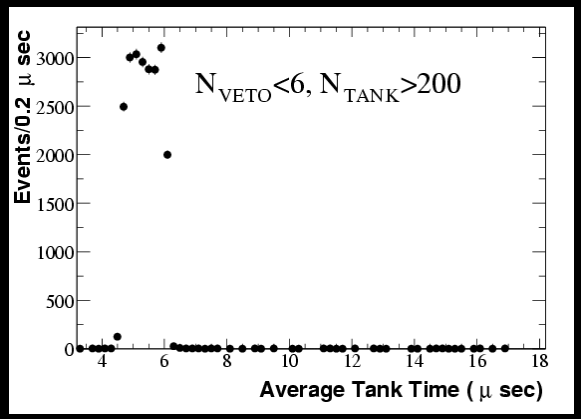
- Neutrino Candidate Cuts
  - <6 veto PMT hits
  - >200 tank PMT hits
- Beam spill (1.6μs) is clearly evident in all
  - simple cuts kill non-beam backgrounds



Beam and Cosmic BG



Beam and Michels



Beam only

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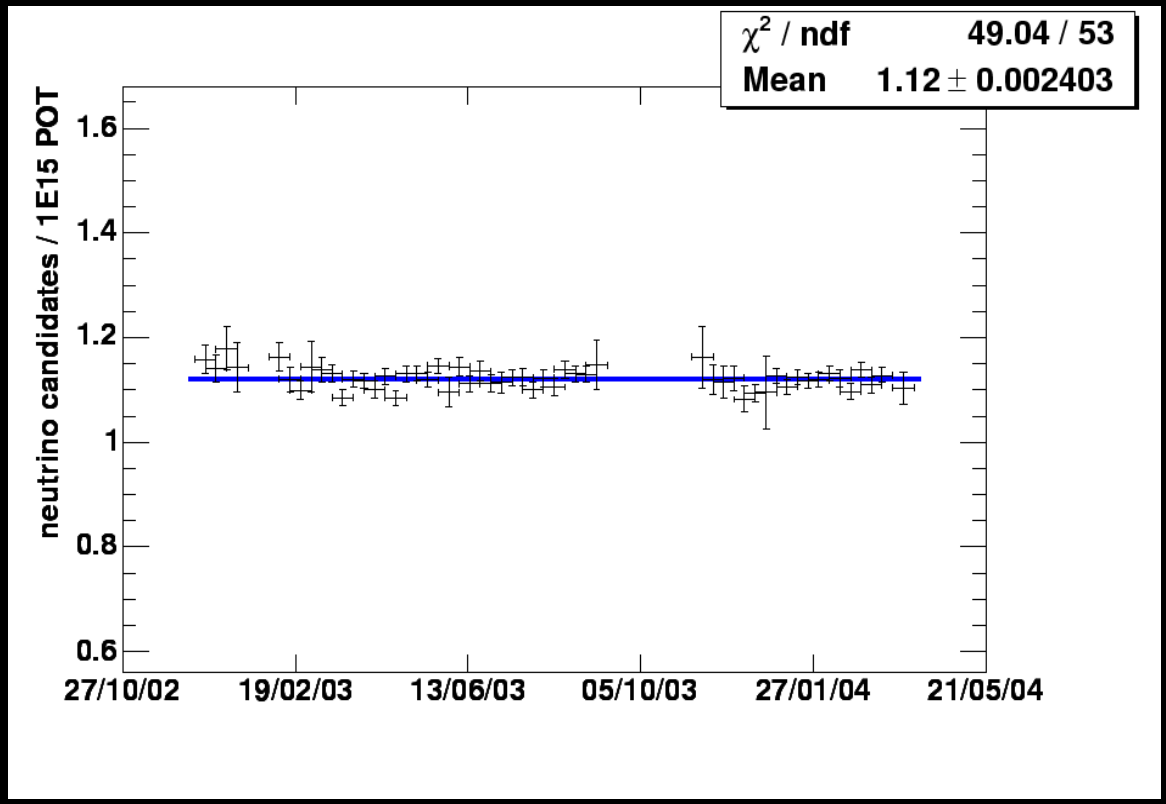
Neutrino Data

- Measured rate of neutrino candidates
  - Neutrino candidates≡
    - >200 tank hits
    - <6 veto hits
- Constant rate over time
  - χ^2/d.o.f. = 49/53
- Tests performance of:
  - Tank DAQ
  - ACNET DAQ
  - Calibration stability
  - Data processing chain



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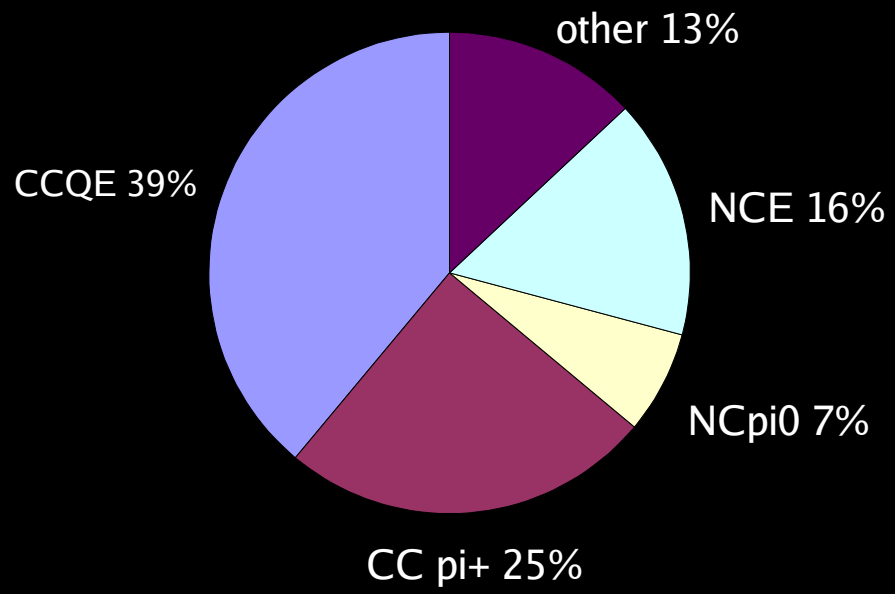
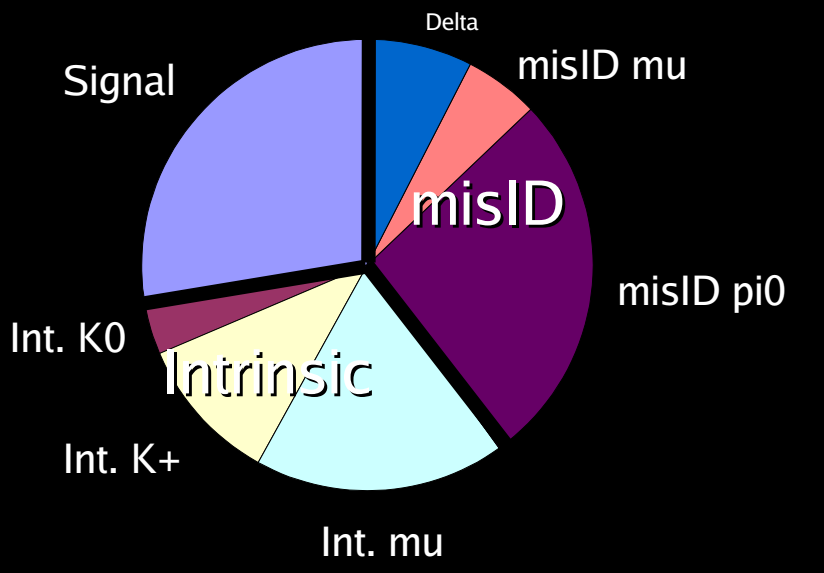
ν Event Rates



- ν_μ Event Analyses
- CCQE
  - Eν distribution
  - Q^2 reconstruction
- NC π^0
  - coherent fraction

- ν_e Appearance Analysis, 1E21
- Expect to see ~1080 ν_e CC QE
  - 300 oscillation signal events
  - 350 Intrinsic ν_e in beam
    - K^+, K^0, μ decay
  - 430 misID events
    - μ, π^0,Δ



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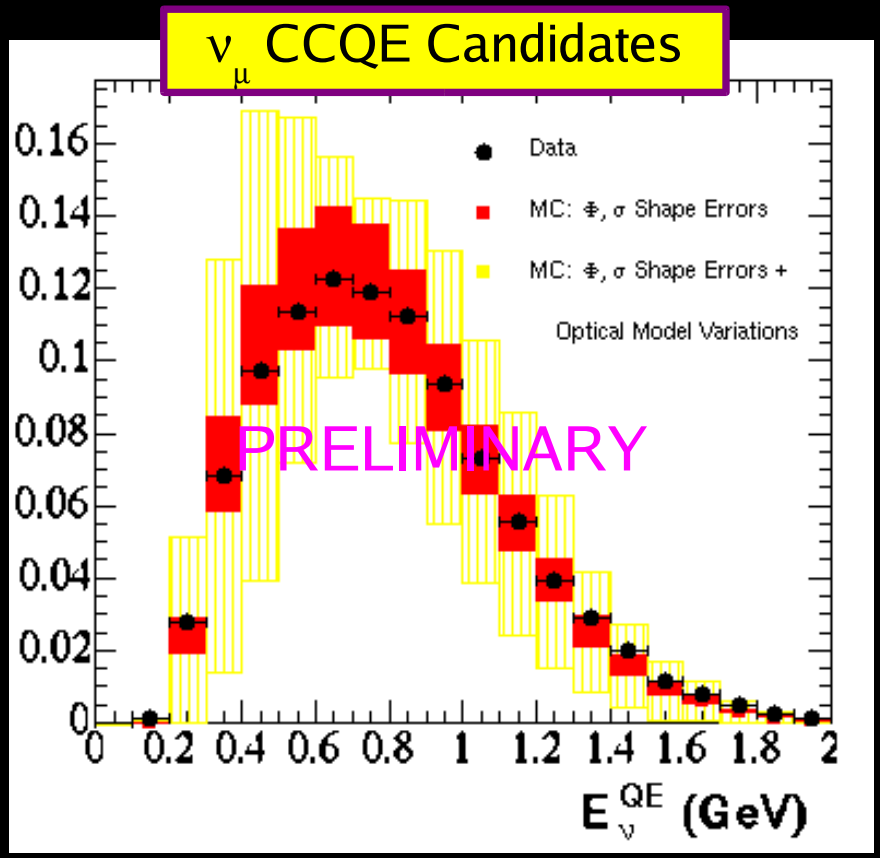
Understanding the flux

- External pion production measurements
  - E910 (M'BooNE analysis by Jon Link)
    - Beryllium target
    - 6.4GeV/c, 12.3GeV/c, 17.5 GeV/c
  - HARP
    - MiniBooNE target slugs
      - 5%, 50%, 100% λ
    - 8GeV protons
- Fit pion production data with Sanford-Wang model
- Calculate ν_μ flux at detector, and compare to data

$$E_\nu^{QE} = \frac{1}{2}\,\frac{2\,M_p E_\mu - m_\mu^2}{M_p - E_\mu + \sqrt{(E_\mu^2 - m_\mu^2)}\,\cos\theta_\mu}$$



- Measure:
  - muon energy: ±10%
  - muon direction ±45mrad
- Neutrino energy res.: 15-20%

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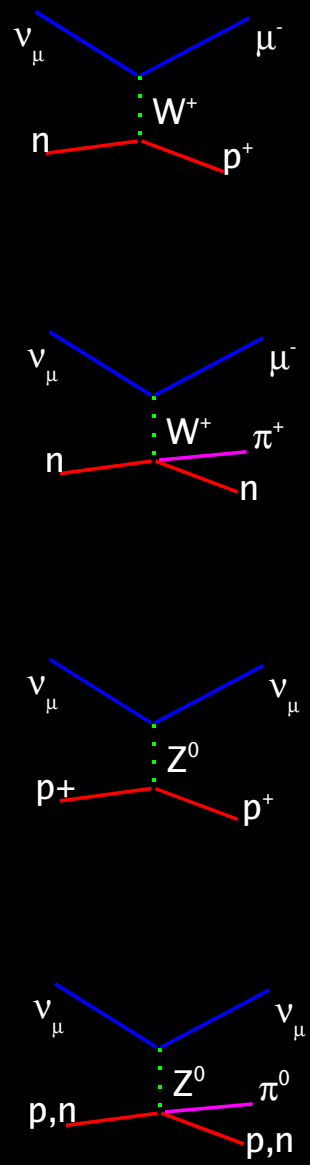
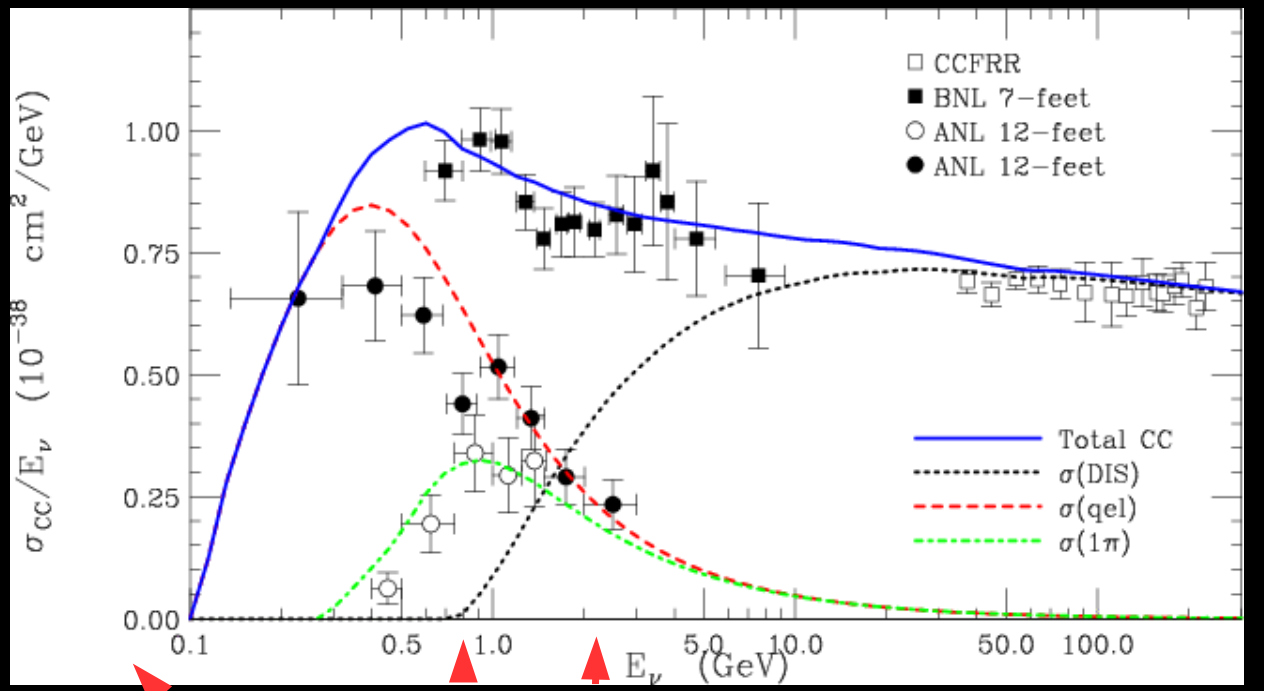
Understanding Cross Sections 1

- >290,000 neutrino events and counting!
  - 113k CCQE
  - 72k CC $1\pi^{\pm}$
  - 46k NC E
  - 20k NC π^0



P. Lipari, Nucl. Phys. Proc. Suppl. 112, 274 (2002) (NuInt01)



LSND

MiniBooNE

K2K

Super-K atmospheric νs

Range of NuMI Possibilities

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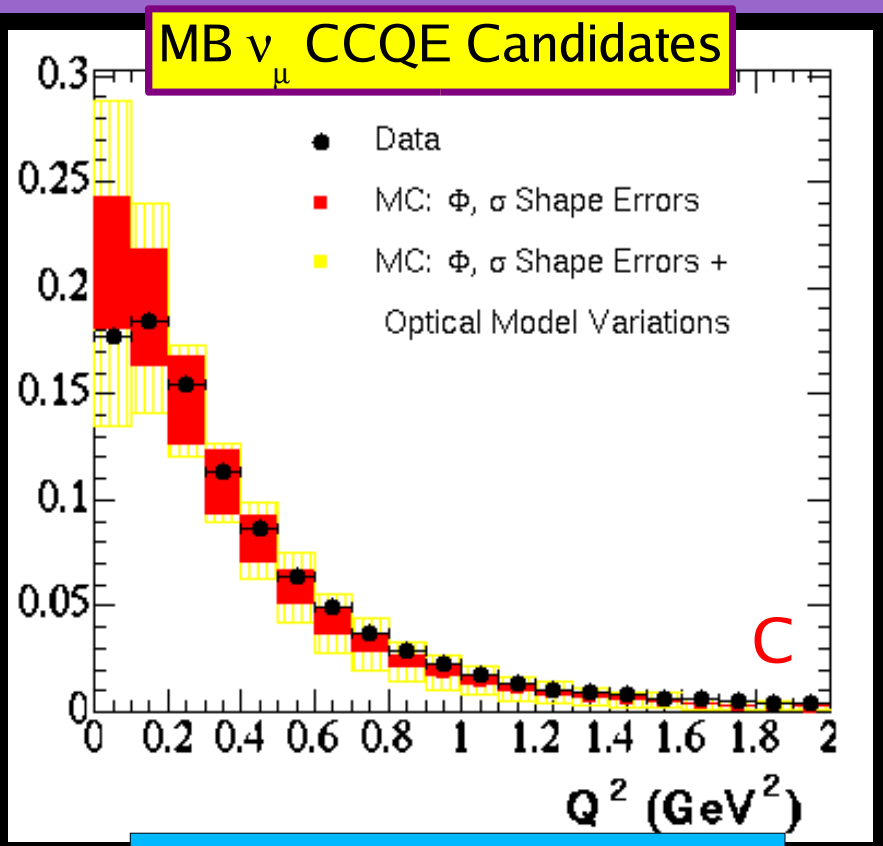
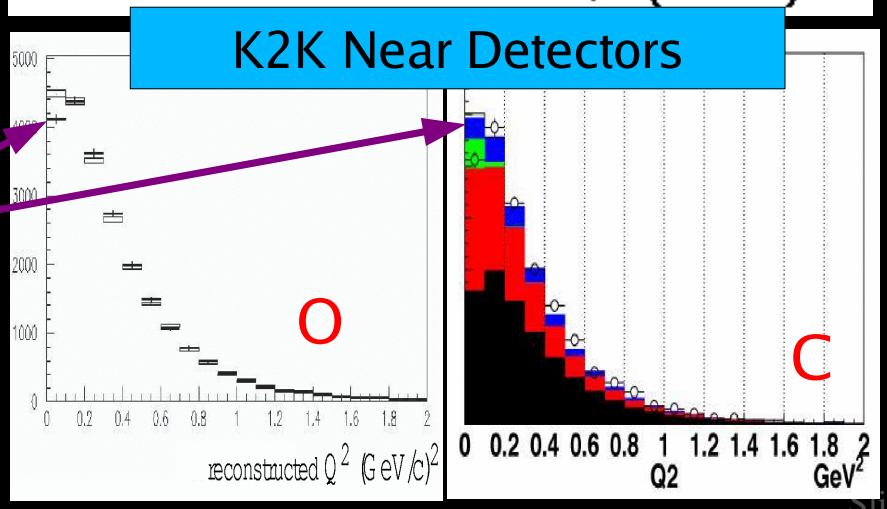
Cross Sections 2

- Nuclear effects important at MiniBooNE neutrino energies
  - Pauli blocking and simple nuclear effects included in NUANCE MC - neutrino simulation used by MiniBooNE
  - Reduction in low Q^2 rate previously observed by BEBC comparing Ne to D data sets
    P. Allport et al., Phys. Lett. B232, 417 (1989)
- Observed reduction exceeds Pauli blocking prediction
  - Nuclear shadowing?
  - Also observed by K2K near detectors
  - Generated much interest at NuInt04 in March





Rik Gran, NuInt04

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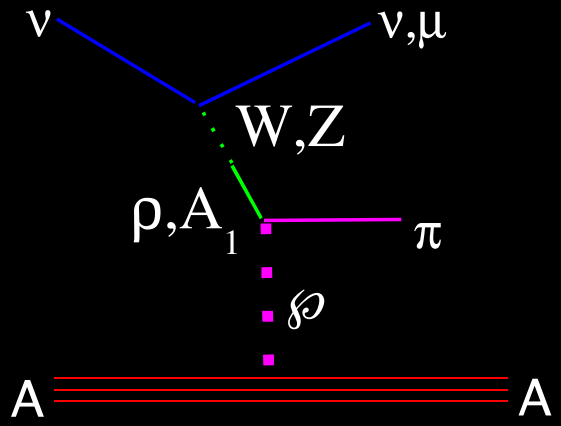
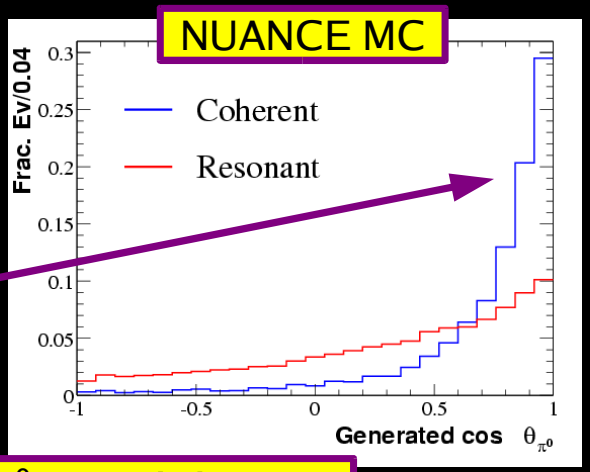
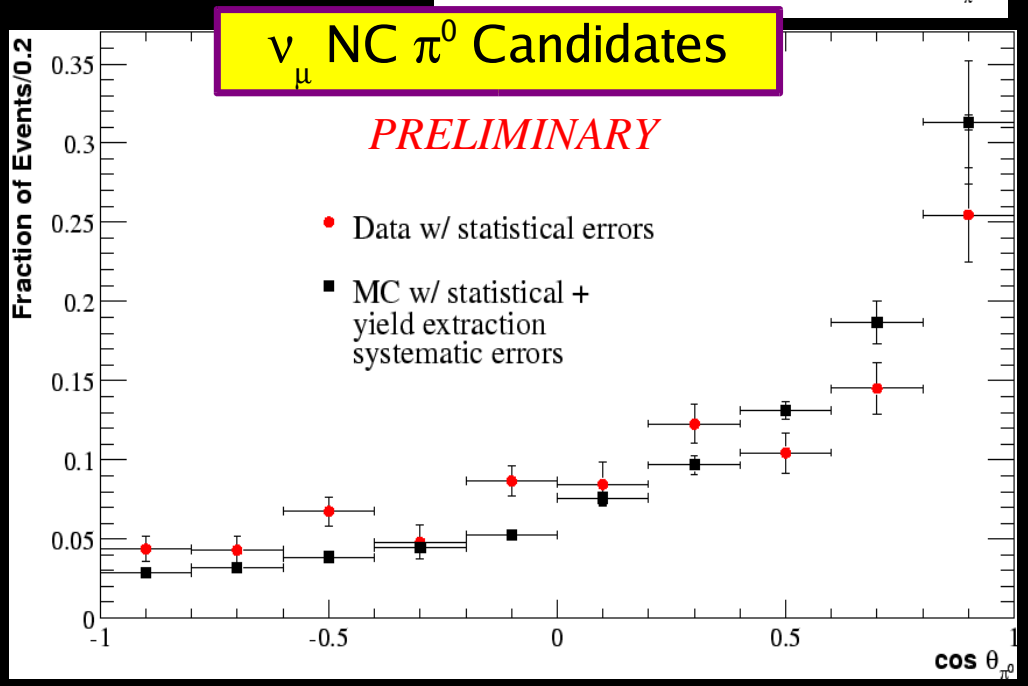
Cross Sections 3

- NC π^0: important background for MiniBooNE $\nu_\mu \rightarrow \nu_e$
- Coherent/resonant ratio?
- Coherent: ν scatters w/ whole nucleus
  - diffractive scattering, forward-peaked
  - NUANCE predicts ~20% of $\sigma(\nu_\mu N \rightarrow X\pi^0)$ at 1 GeV
  - competing models differ by 20X!
- No data published below 2 GeV
  - K2K near dets also have data







- Super-K: needed for $\nu_\mu \rightarrow \nu_s$ vs. $\nu_\mu \rightarrow \nu_\tau$

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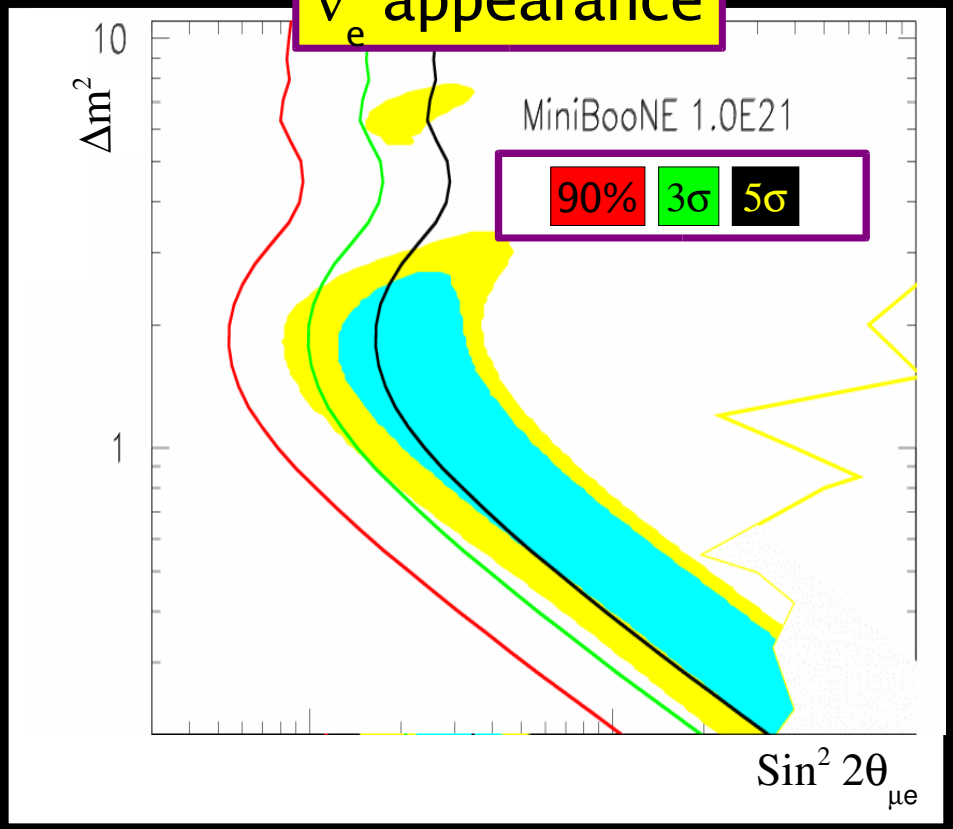
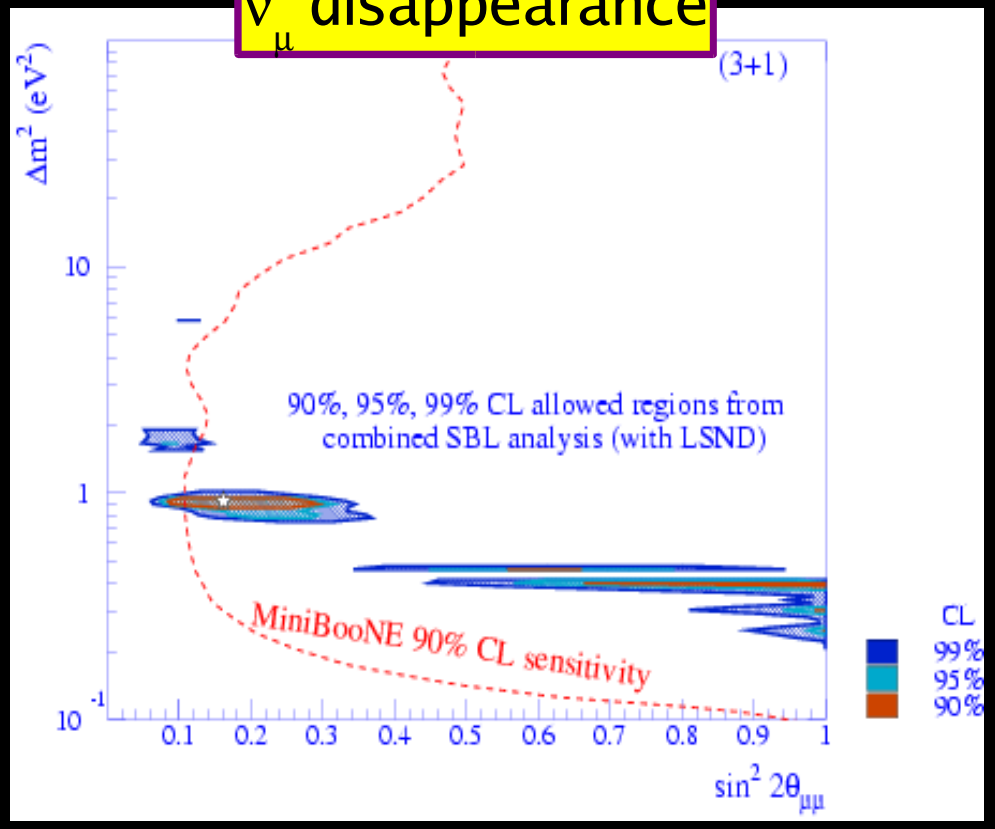
Oscillation Sensitivity

- Updated sensitivity based on measured rates in first year of data

ν_e appearance



ν_μ disappearance



www-boone.fnal.gov/publicpages/news.html

Many thanks to JR.Monroe and M.Sorel for the plot

- Can exclude LSND at high statistical level only with 1E21 POT
- Sensitivity is statistics limited until >2E21 POT

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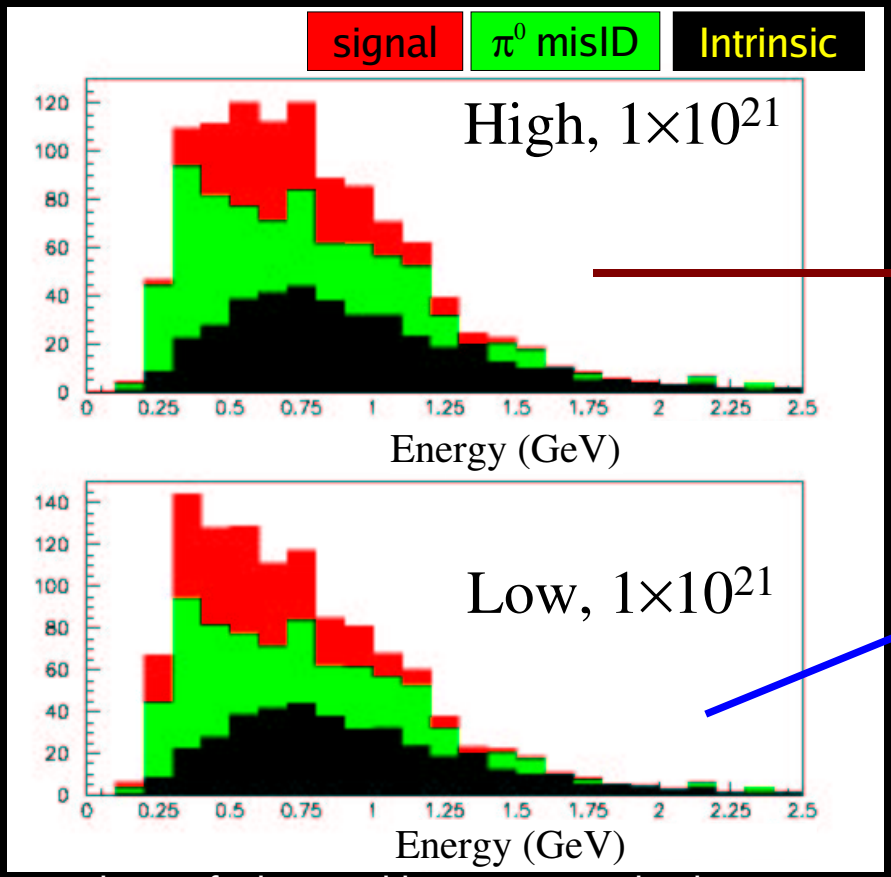
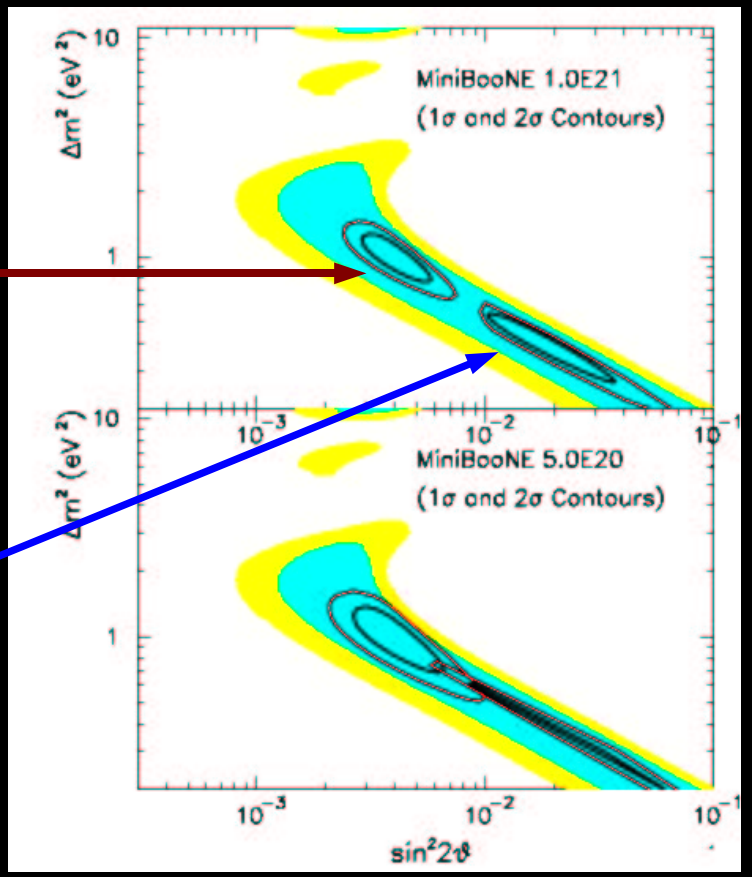
Measuring Δm^2





www-boone.fnal.gov/publicpages/news.html

- Can differentiate high and low Δm^2 regions with 1E21 POT
- High vs. low Δm^2 is important for near future experiments

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Conclusions

- MiniBooNE data have already generated much interest in ν community
- Booster improvements continue
  - Collimators may provide at least 30% more improvement
- HARP results will finalize flux predictions
  - pion and kaon rates
- Tank energy calibrations indicate good reconstruction, resolution
- Optical model being pursued vigorously
  - Parameters, uncertainties will soon incorporate vast program of measurements
- Analysis work proceeding well
- High statistics will allow important low energy cross section measurements
- Will be fully ready to open $\nu_\mu \rightarrow \nu_e$ box with 1E21 POT
- Looking forward to $\overline{\nu}$ running!