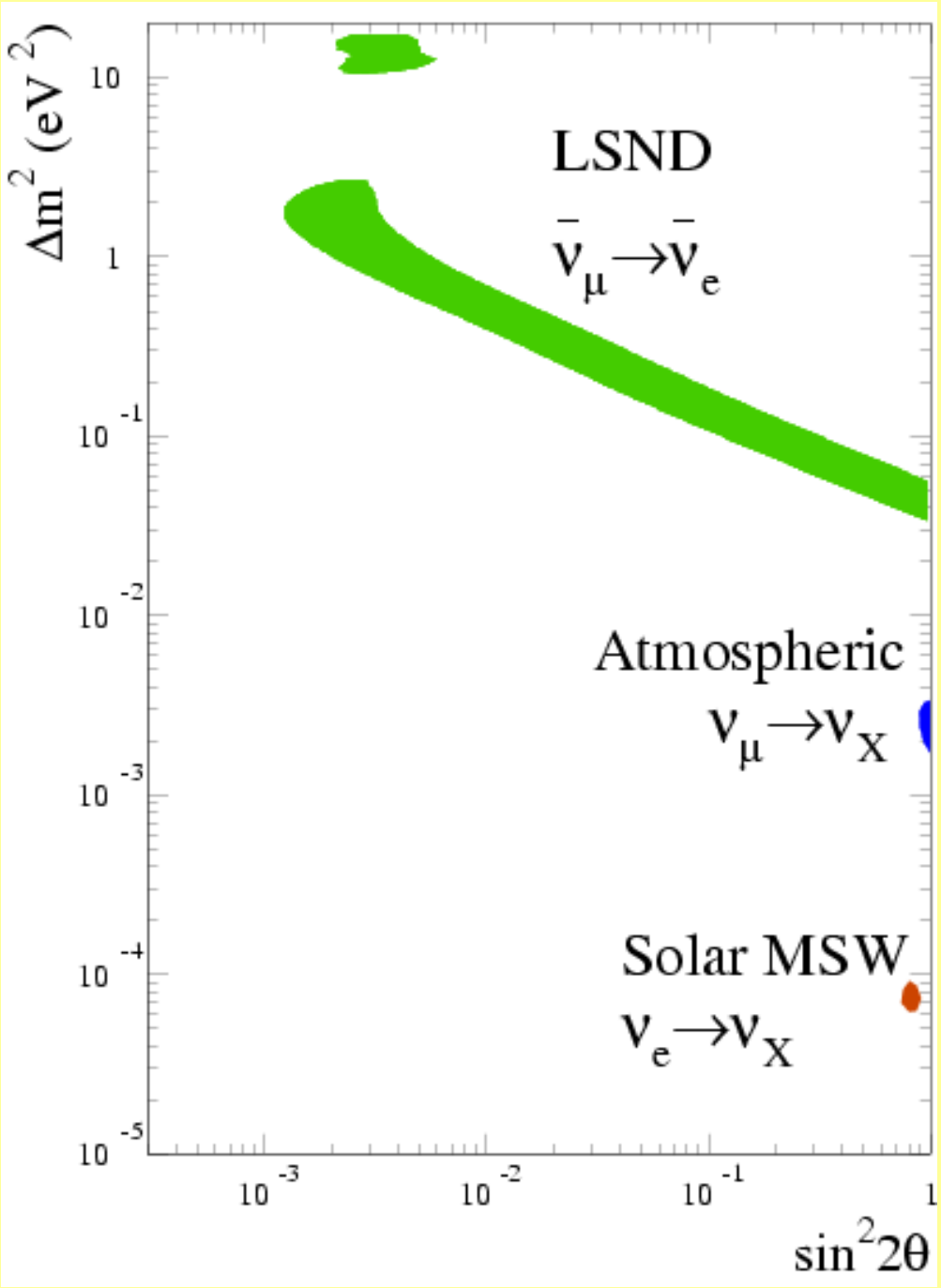
MiniBooNE Presentation to the FNAL PAC

(November 11, 2004)

- Louis — Current Status of MiniBooNE
- Conrad — Run Plan for FY06

Current State of Neutrino Oscillation Evidence

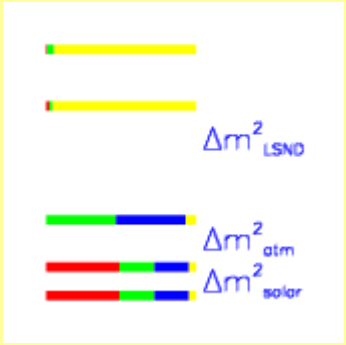


Expt.	Type	Δm^2 (eV^2)	$\sin^2 2\theta$
LSND	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	~1	~3×10^{-3}
Atm.	$\nu_\mu \rightarrow \nu_\tau$	~2×10^{-3}	~1
Solar	$\nu_e \rightarrow \nu_{\mu,\tau}$	~8×10^{-5}	~0.8

If MiniBooNE Confirms LSND ⇒Physics Beyond the Standard Model & Connections with Astrophysics!

For example:

3+2 Sterile Neutrinos Sorel, Conrad, & Shaevitz (hep-ph/0305255)



Explain Pulsar Kicks?

Explain R-Process in Supernovae?

Sterile Neutrinos Explain Dark Matter?

MaVaNs & 3+1 Sterile Neutrino Kaplan, Nelson, & Weiner (hep-ph/0401099)

Explain Dark Energy?

CPT Violation & 3+1 Sterile Neutrino Barger, Marfatia, & Whisnant (hep-ph/0308299)

Explain Baryon Asymmetry in the Universe?

Quantum Decoherence Barenboim & Mavromatos (hep-ph/0406035)

Lorentz Violation Kostelecky & Mewes (hep-ph/0406255)

Lepton-Number Violation is no Longer a Viable Explanation of the LSND Excess!

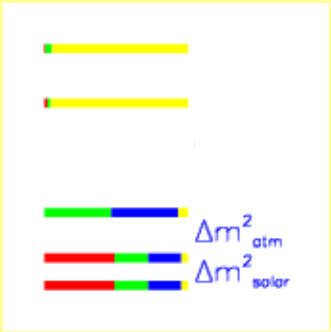
TWIST has published a stringent limit on a (ρ=0) component in muon decay $\Rightarrow$

$$(\rho - 0.75) = 0.00080 \pm 0.00044_{stat} \pm 0.00093_{syst} \pm 0.00023_{theor}$$

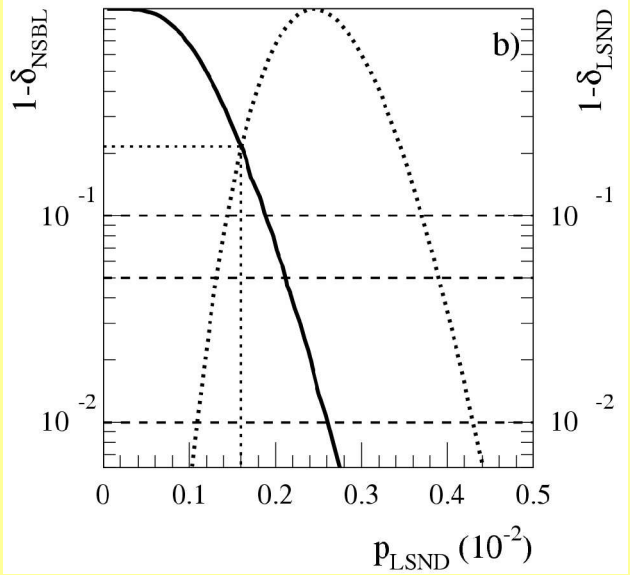
(Musser *et al.* hep-ex/0409063)

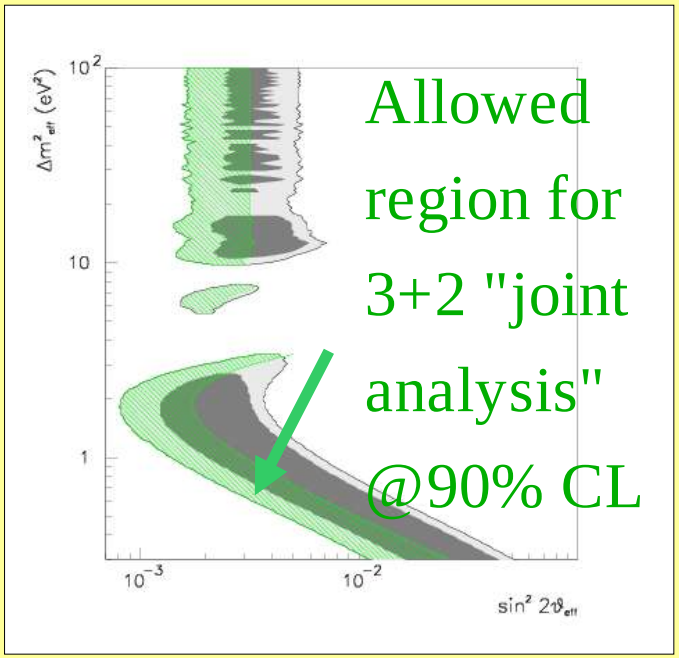
Therefore, $\mu^+ \rightarrow e^+ \bar{\nu}_e \nu_\mu$ does not explain LSND (which was the only scenario that MiniBooNE could not address)

The best fits to LSND come from models with 2 or more sterile neutrinos with similar-magnitude Δm^2's



Compatibility Level = 30%

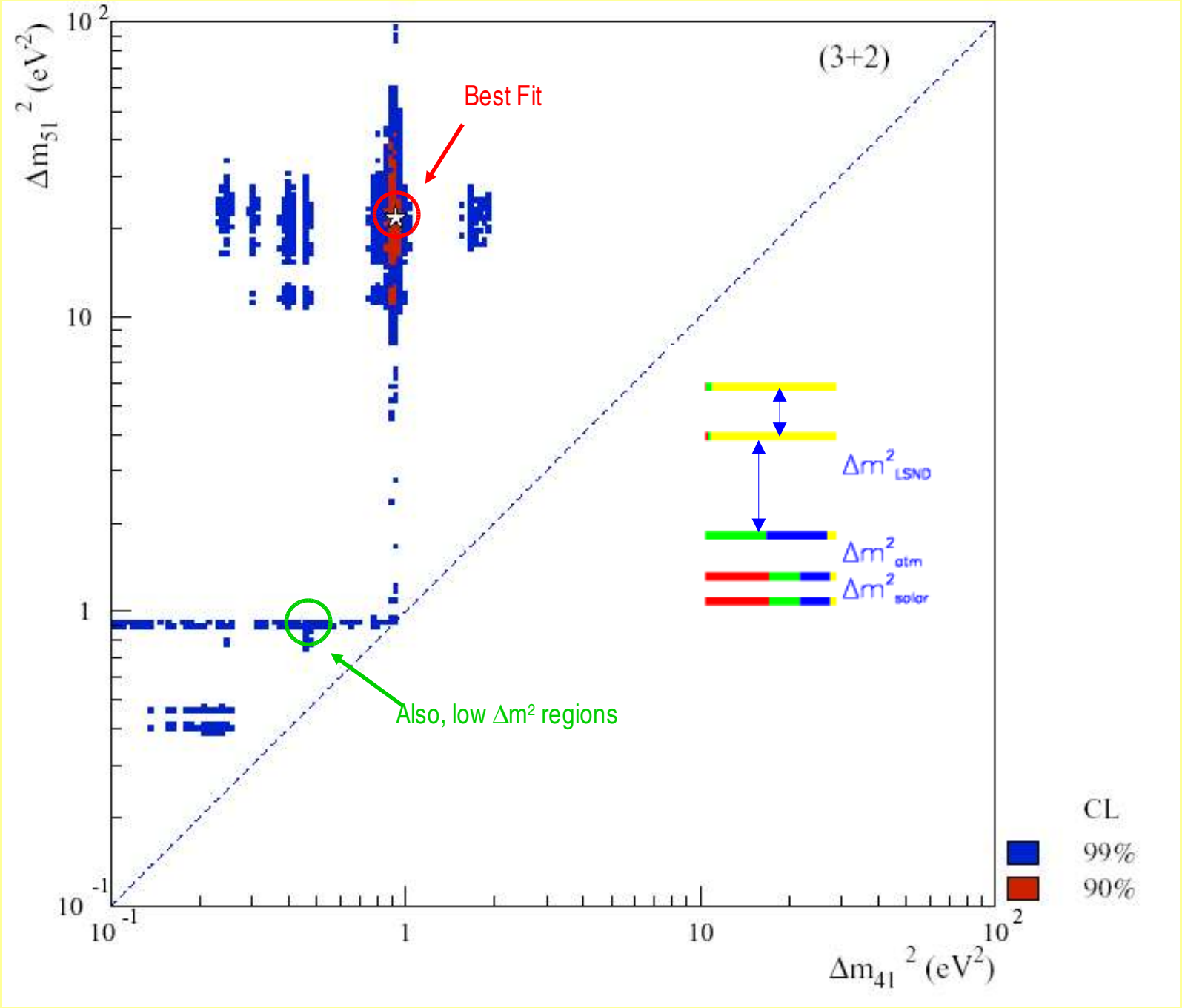




Best Fit: Δm_{41}^2=0.92 eV^2 , U_{e4}=0.121 , $U_{\mu 4}$=0.204 , Δm_{51}^2=22 eV^2 , U_{e5}=0.036 , $U_{\mu 4}$=0.224

Two similar-magnitude Δm^2's can lead to CP violation

3+2 Model Fits



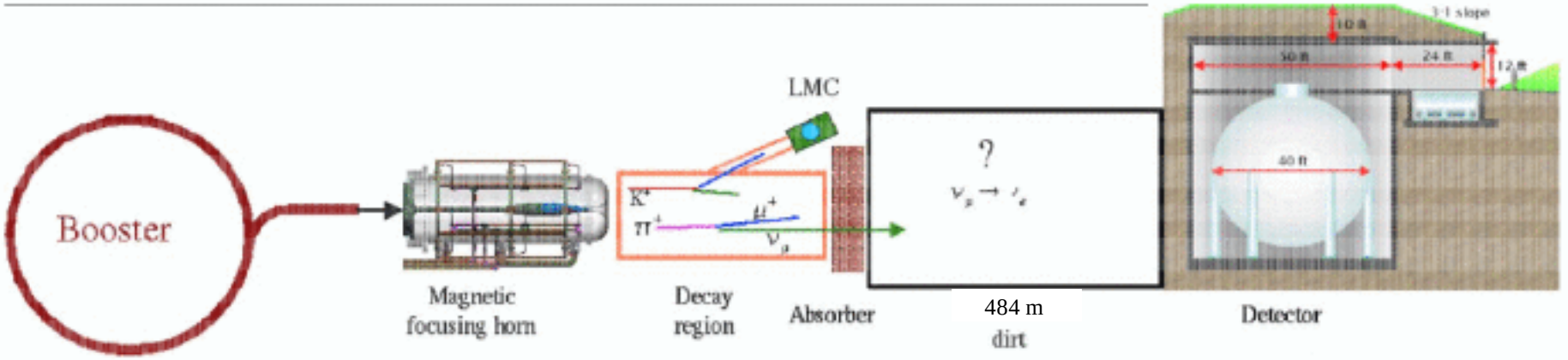
Addendum to the MiniBooNE Run Plan: MiniBooNE Physics in 2006

October 28, 2004

A. A. Aguilar-Arevalo[5], A. O. Bazarko[12], C. Bhat[7], S. J. Brice[7], B. C. Brown[7], L. Bugel[5], J. Cao[11], J. M. Conrad[5], D. Cox[8], A. Curioni[15], D. A. Finley[7], B. T. Fleming[15], R. Ford[7], F. G. Garcia[7], G. T. Garvey[9], A. Green[8], C. Green[9], T. Hart[4], E. Hawker[14], R. Imlay[10], R. A. Johnson[3], P. Kasper[7], T. Katori[8], T. Kobilarcik[7], I. Kourbanis[7], S. Koutsoliotas[2], J. M. Link[5], Y. Liu[1], Y. Liu[11], W. C. Louis[9], W. Marsh[7], K. B. McConnel[5], G. McGregor[9], S. McKenney[9], W. Metcalf[10], H. O. Meyer[8], P. D. Meyers[12], G. B. Mills[9], J. Monroe[5], C. Moore[7], R. H. Nelson[4], P. Nienaber[13], S. A. Ouedraogo[10], R. B. Patterson[12], E. Prebys[7], J. L. Raaf[3], H. Ray[9], B. P. Roe[11], A. D. Russell[7], V. Sandberg[9], B. Sapp[9], R. Schirato[9], D. Schmitz[5], M. H. Shaevitz[5], F. C. Shoemaker[12], D. Smith[6], M. Sorel[5], P. Spentzouris[7], I. Stancu[1], R. Stefanski[7], M. Sung[10], H. A. Tanaka[12], R. Tayloe[8], R. Van de Water[9], M. O. Wascko[10], N. L. Walbridge[9], D. H. White[9], M. Wilking[4], H. J. Yang[11], G. P. Zeller[5], E. D. Zimmerman[4]

[1] *University of Alabama*
[2] *Bucknell University*
[3] *University of Cincinnati*
[4] *University of Colorado*
[5] *Columbia University*
[6] *Embry Riddle Aeronautical University*
[7] *Fermi National Accelerator Laboratory*
[8] *Indiana University*
[9] *Los Alamos National Laboratory*
[10] *Louisiana State University*
[11] *University of Michigan*
[12] *Princeton University*
[13] *St. Mary's University of Minnesota*
[14] *Western Illinois University*
[15] *Yale University*

MiniBooNE - A Definitive Test of the LSND Evidence for ν Oscillations

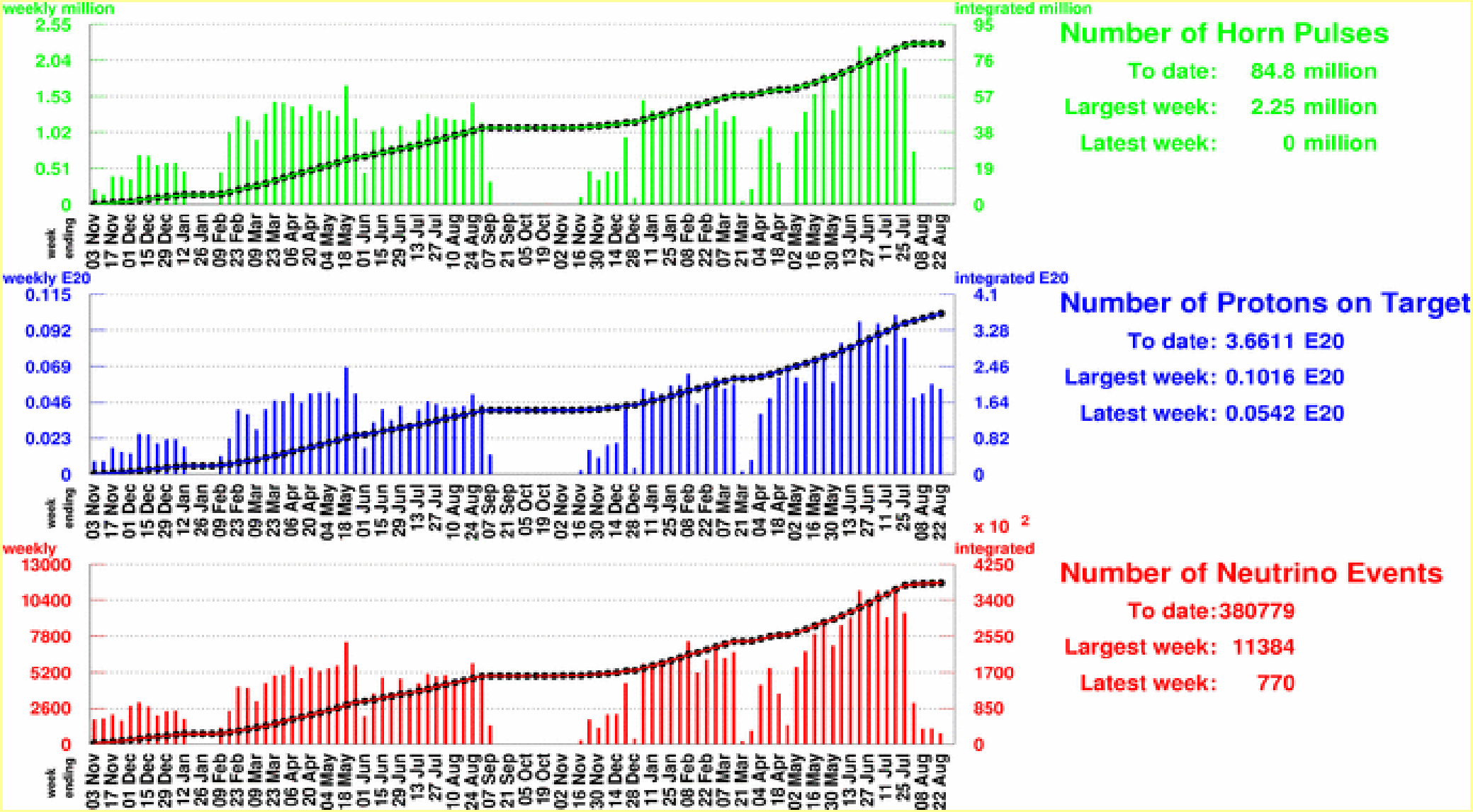


- Booster - 8 GeV proton beam (5 x 10^{20} POT/y)
- Target - 71 cm Be
- Horn - 5 Hz, 170 kA, 143 μs, 2.5 kV, 10^{8} pulses/y
- Decay Pipe - 50 m (adjustable to 25 m)
- Neutrino Distance - ~ 0.5 km
- $\langle E_\nu \rangle$ ~ 1 GeV
- (ν_e / ν_μ) ~ 0.005
- Detector - 40' diameter spherical tank
- Mass - 800 (450) tons of mineral oil
- PMTs - 1280 detector + 240 veto, 8" diameter

MiniBooNE Highlights

- MiniBooNE has collected ~380K neutrino events from 3.66E20 POT
- Experiment is working well (>99% livetime & 99% of PMT channels working well)
- Clearly reconstructing CCQE, CCPI+, NCPI0, & NCEL events
- Focussing horn has been replaced during fall shutdown! First horn set a world record of 96M pulses (previous record set at BNL with 13M pulses)
- Beam is scheduled to resume by end of month

MiniBooNE Operations



Number of Horn Pulses

To date: 84.8 million

Largest week: 2.25 million

Latest week: 0 million

Number of Protons on Target

To date: 3.6611 E20

Largest week: 0.1016 E20

Latest week: 0.0542 E20

Number of Neutrino Events

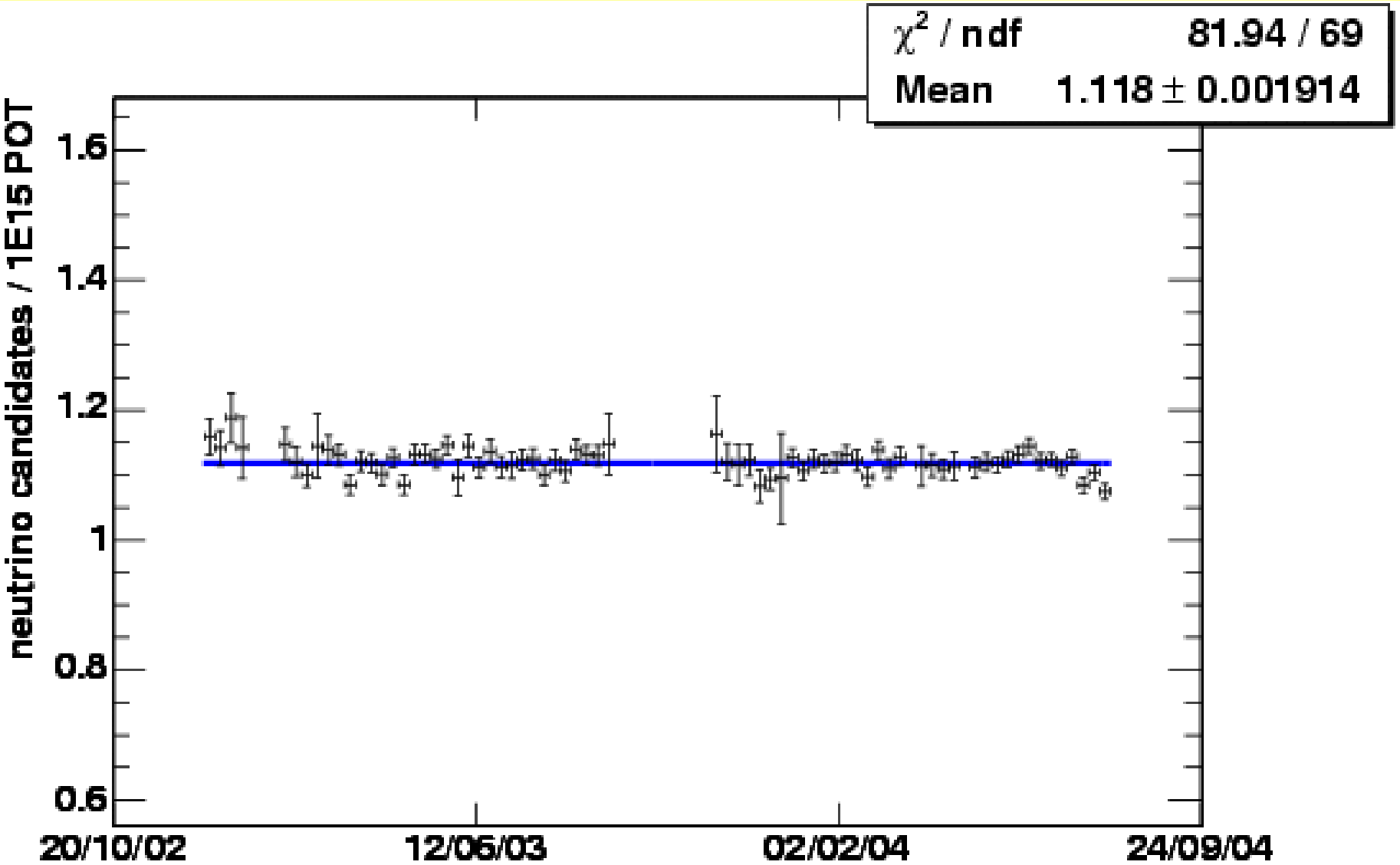
To date: 380779

Largest week: 11384

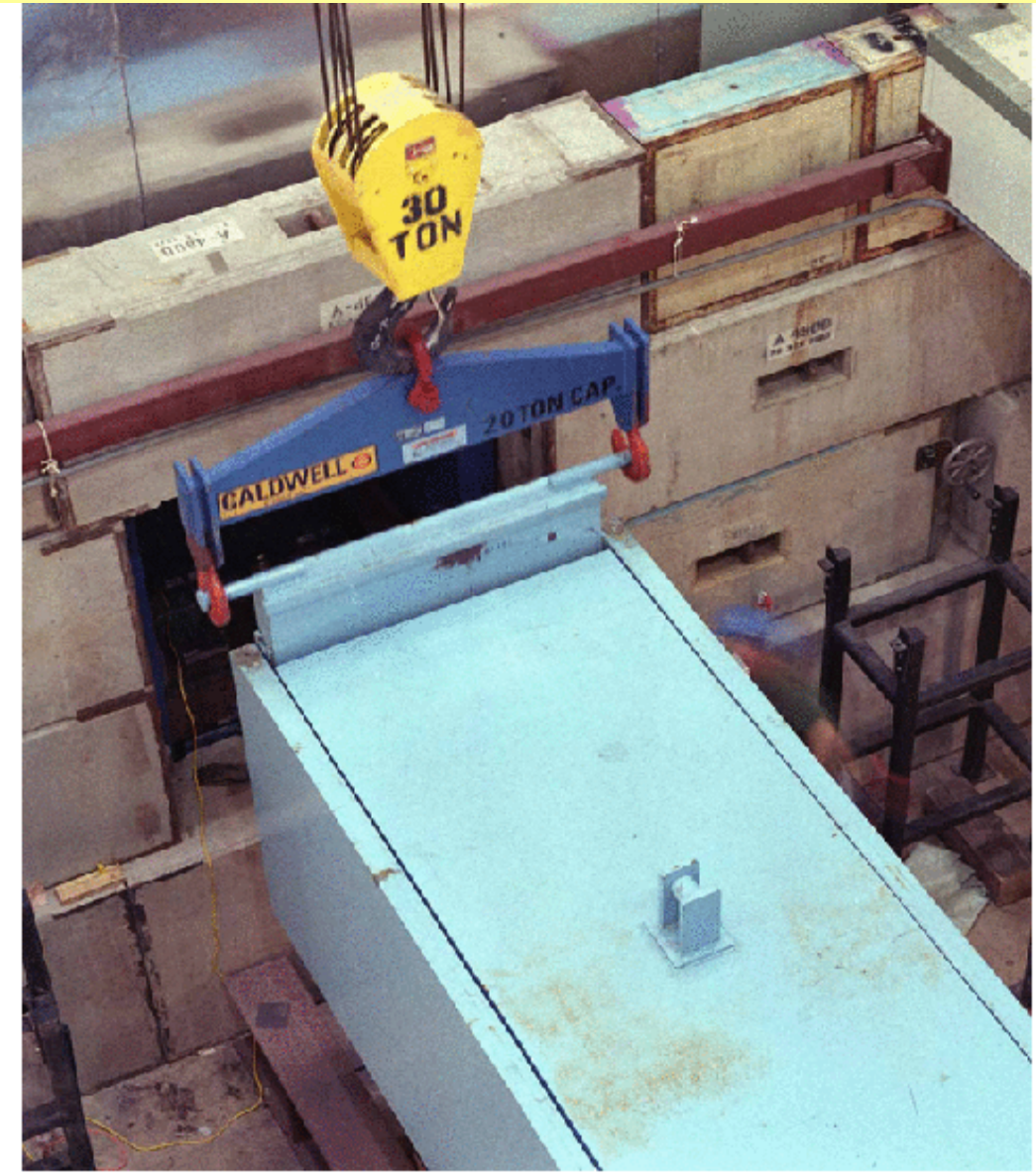
Latest week: 770

Neutrino Events Per POT Is Stable!

Tank Hits>200 & Veto Hits<6



MiniBooNE Horn Replacement



First MiniBooNE horn set a world record of 96M pulses!

Second horn is installed.

Reqs are out for 3rd horn.

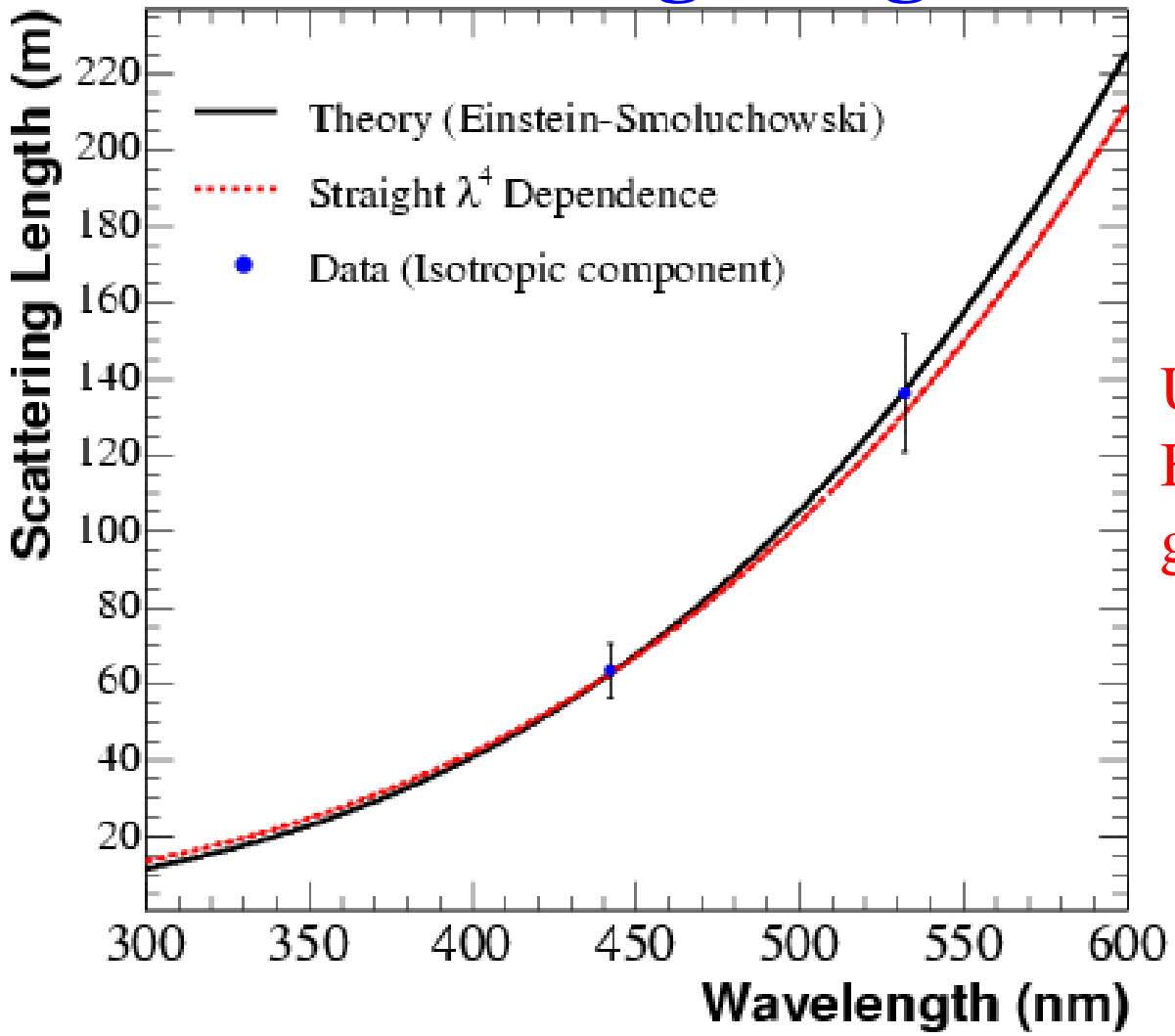
Thanks to Fermilab for full support in replacing horn!

Progress in Completing Analysis

- Detector Monte Carlo – Oil Optical Model
- Beam Monte Carlo – Neutrino Flux from E910 & HARP
- Cross Section Estimation – Using NUANCE

These 3 areas represent the 3 main contributions to the Error Matrix!

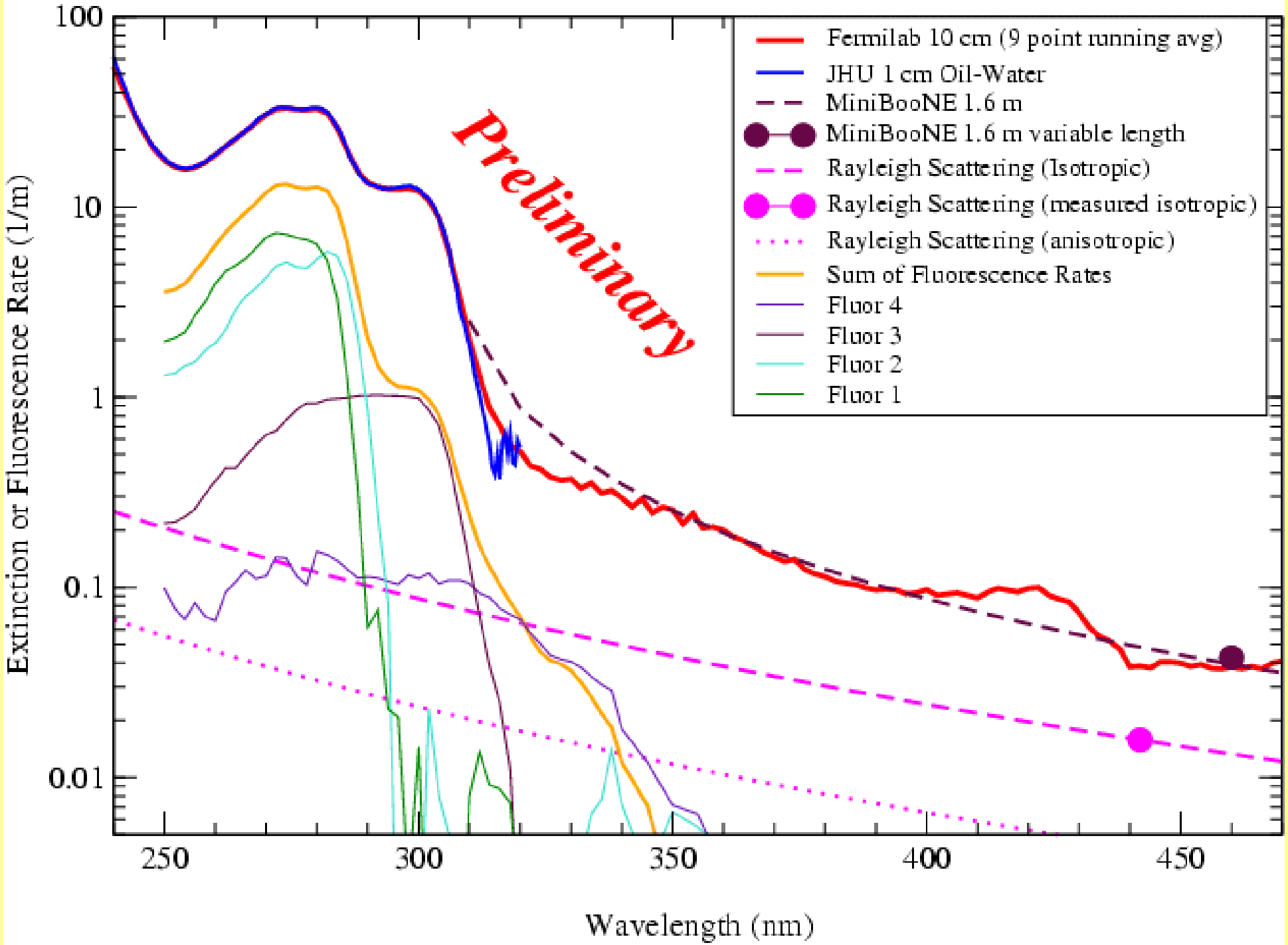
Mineral Oil Scattering Length (TN#144)



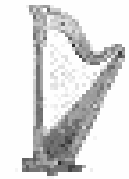
Using BNL BIS-200 goniometer

Figure 4: Comparison of theoretical prediction (solid line) for the Rayleigh scattering length due to isotropic density fluctuations (Equation 1) versus wavelength, pure λ^{-4} dependence (dashed line), and the measured scattering lengths at 442 nm and 532 nm (blue points). The λ^{-4} is normalized by matching the scattering length at 442 nm to Equation 1 and differs from the theoretical prediction in that it does not account for variations in the index of refraction with wavelength. Uncertainties in the theoretical prediction are not shown.

Extinction Rate for MiniBooNE Marcol 7 Mineral Oil

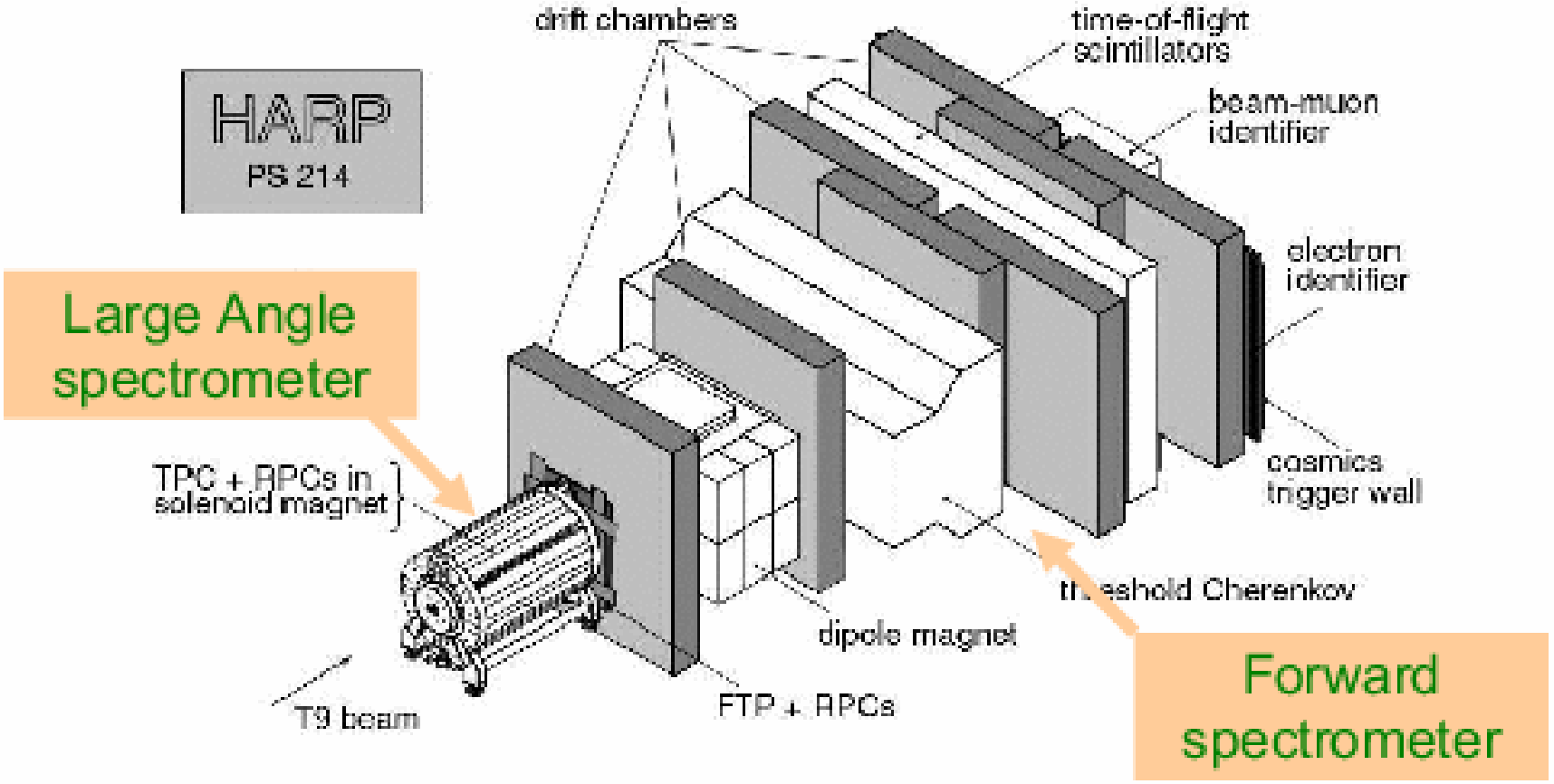


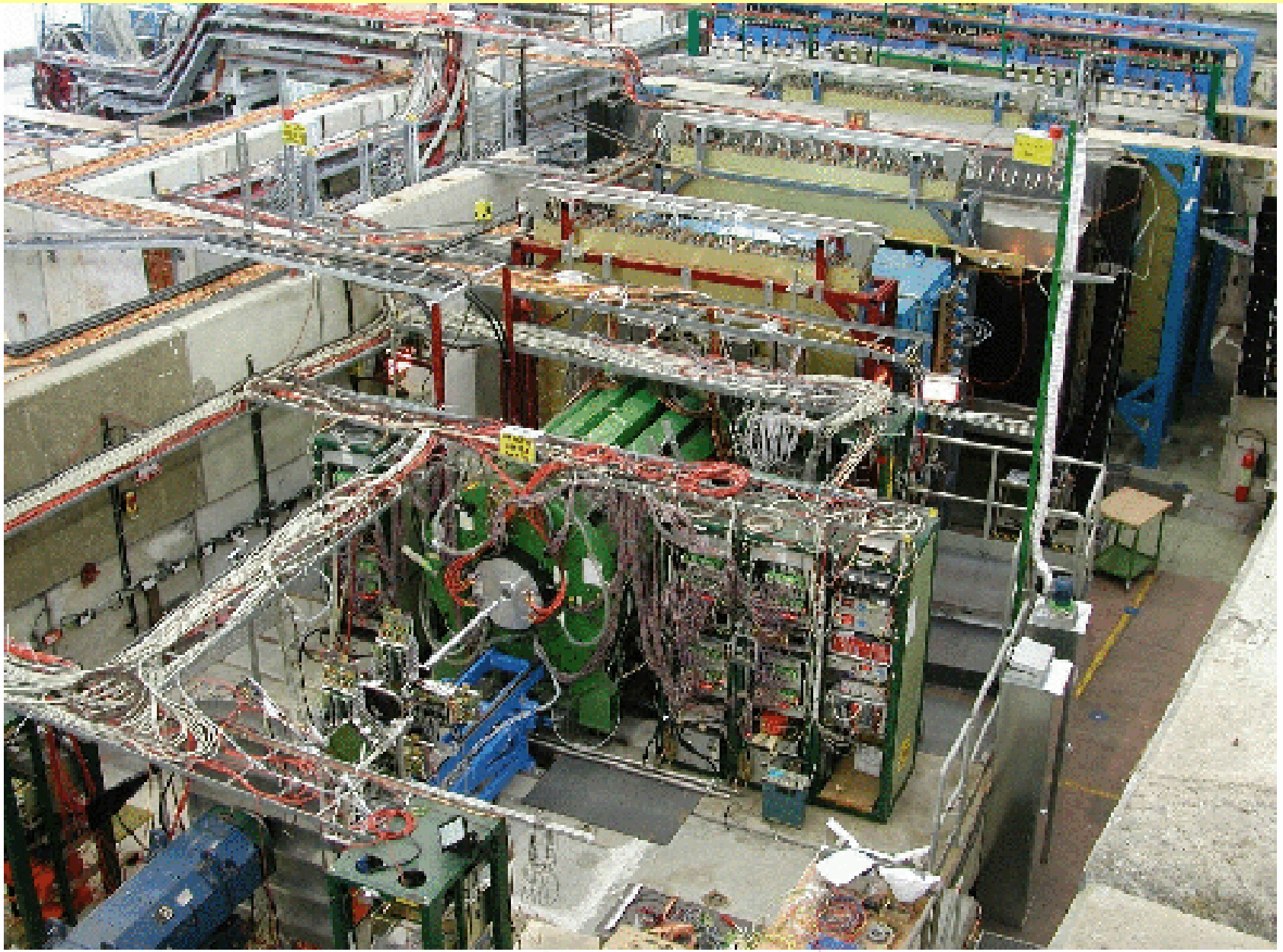
Determining Neutrino Flux with HARP Data



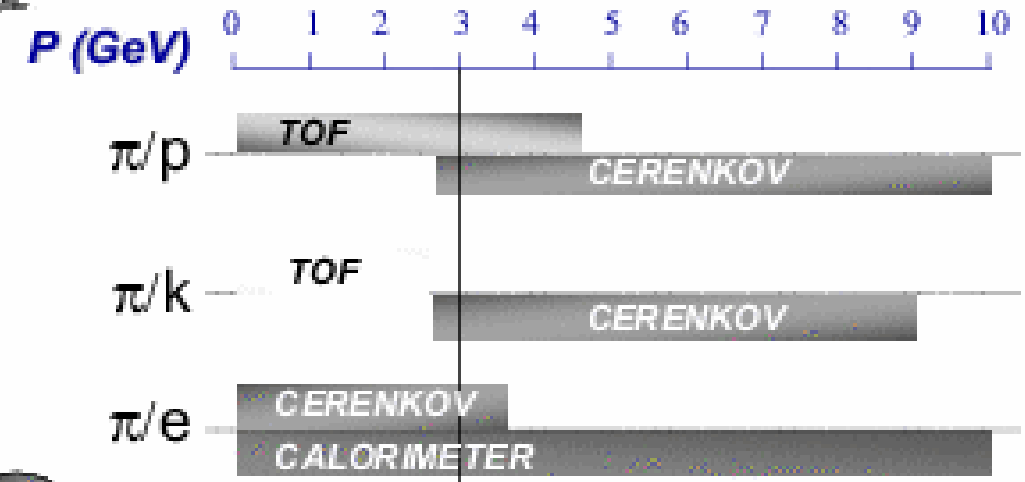
Detector layout

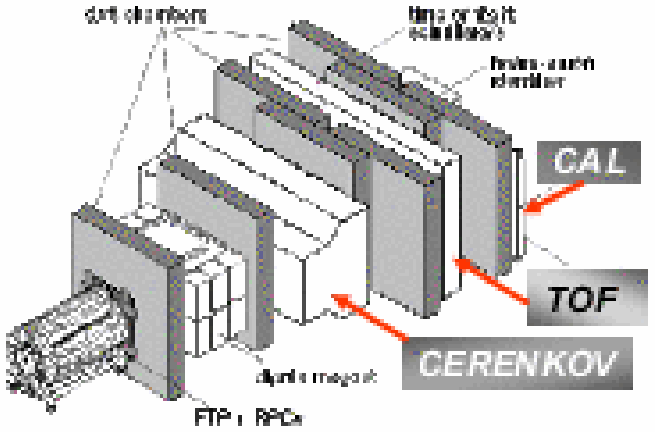
HARP
PS 214



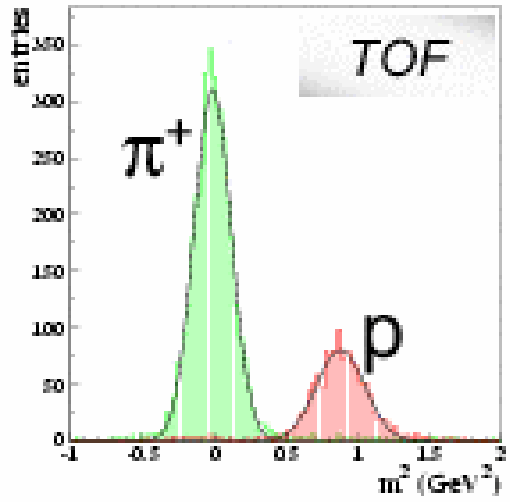


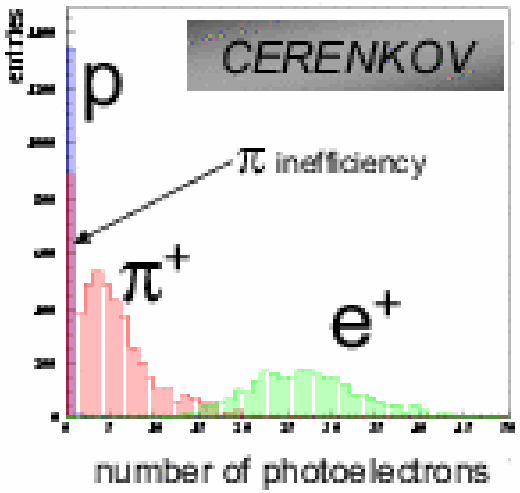
Particle identification

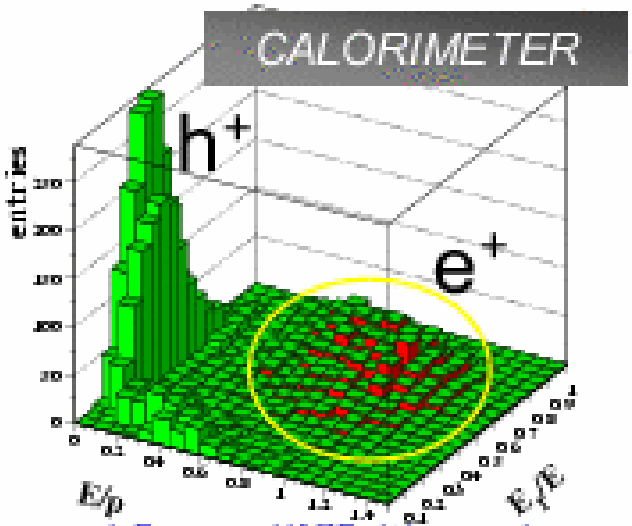




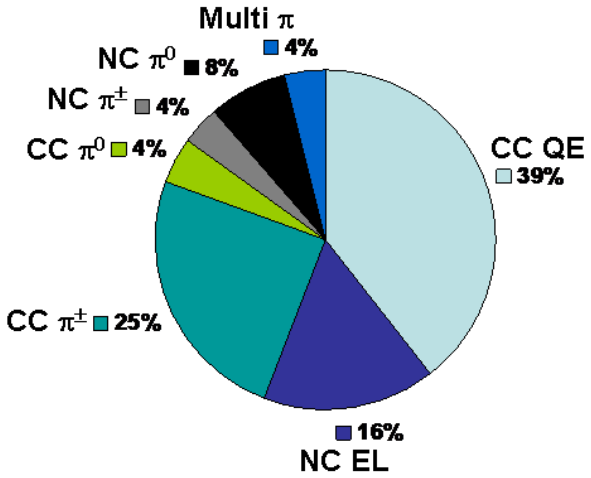
data — ***3 GeV/c beam particles***



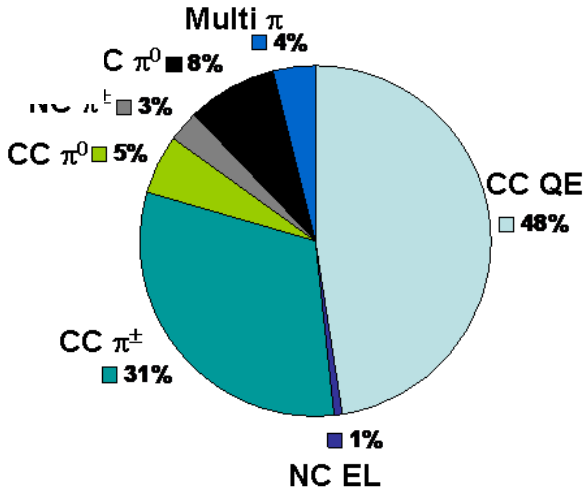




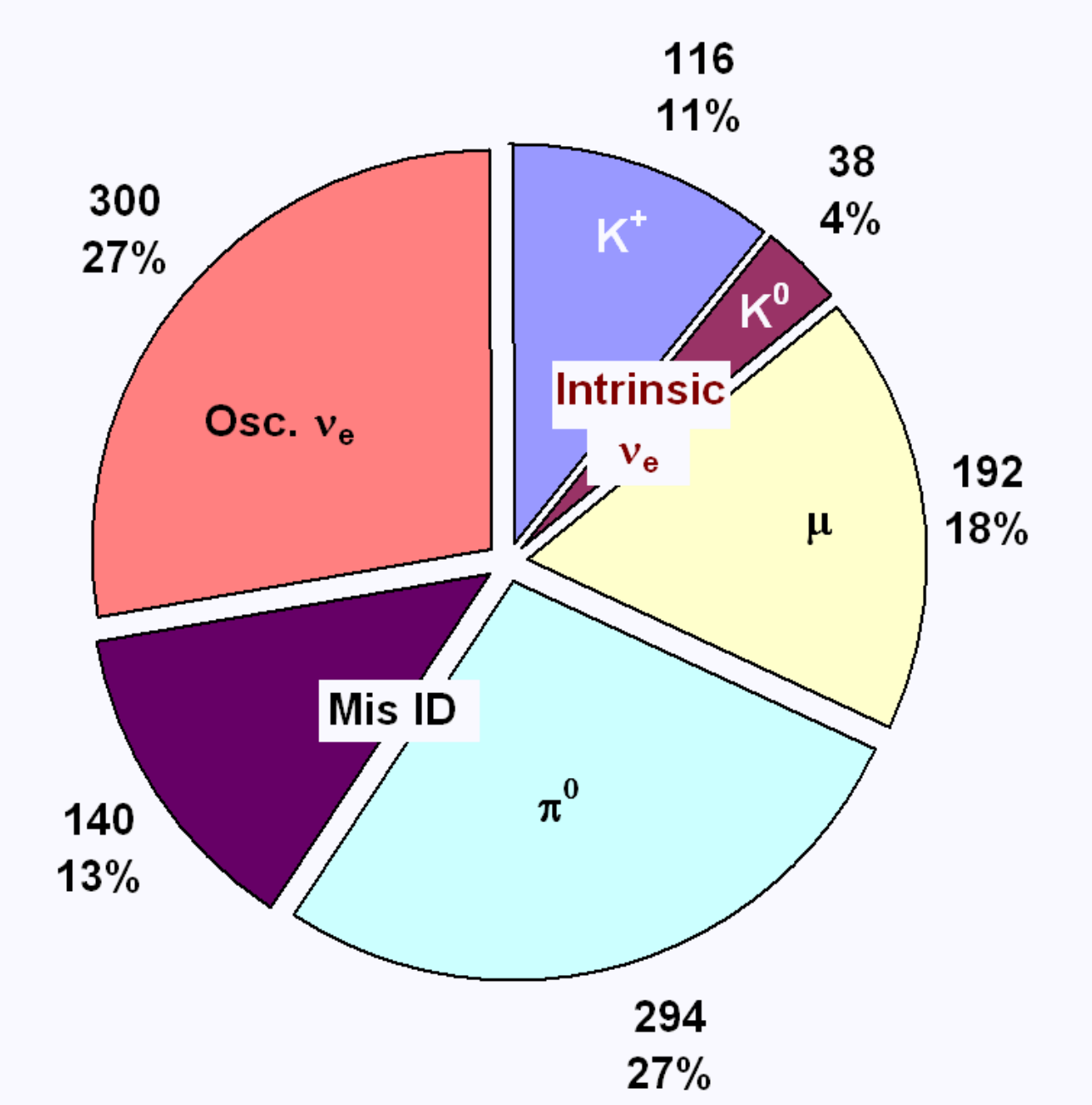
Generated Events from NUANCE



Events with >200 Tank Hits & <6 Veto Hits



Events After PID Selection

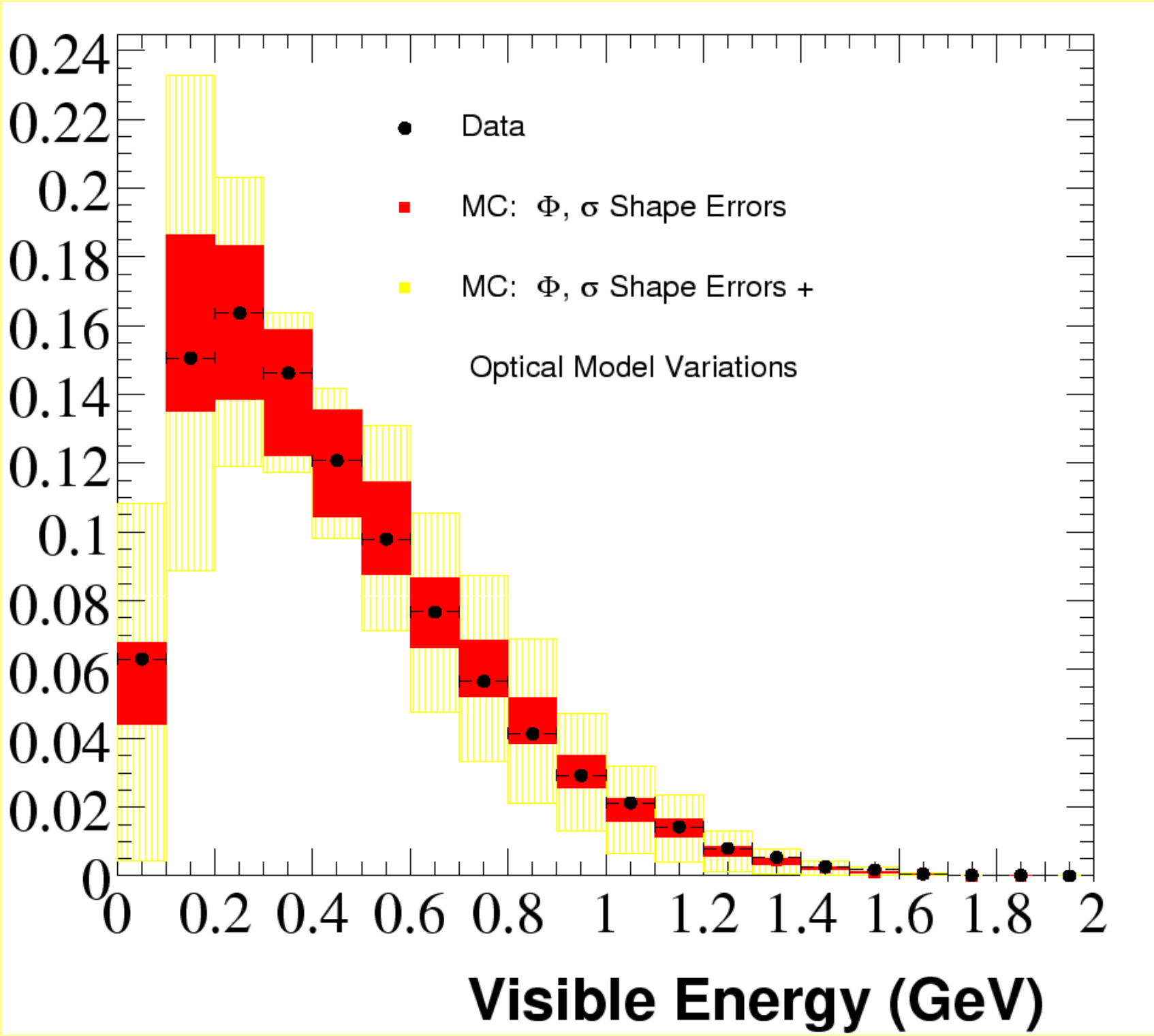


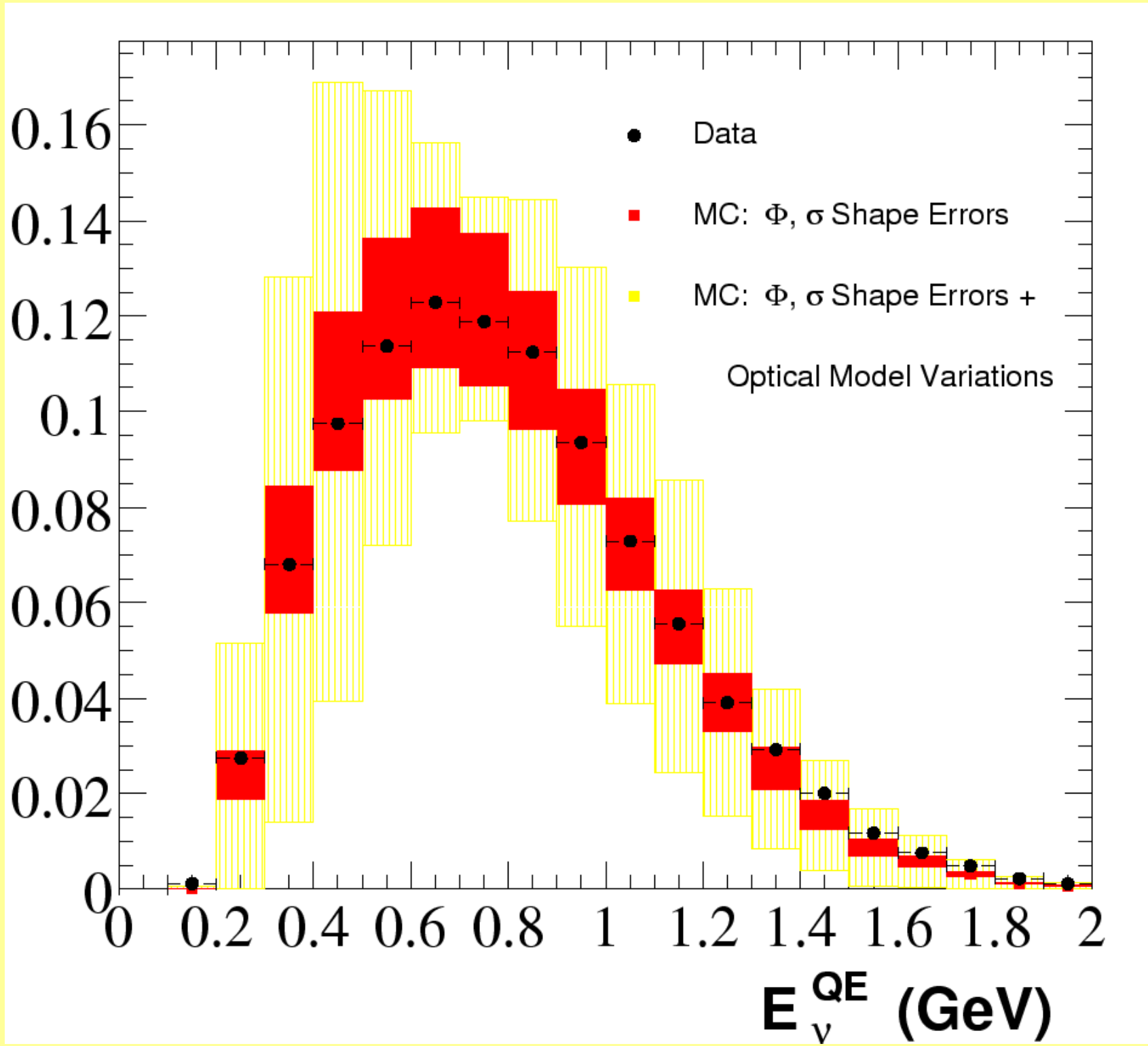
I. CC QE Events $\nu_\mu C \rightarrow \mu^- p C^*$

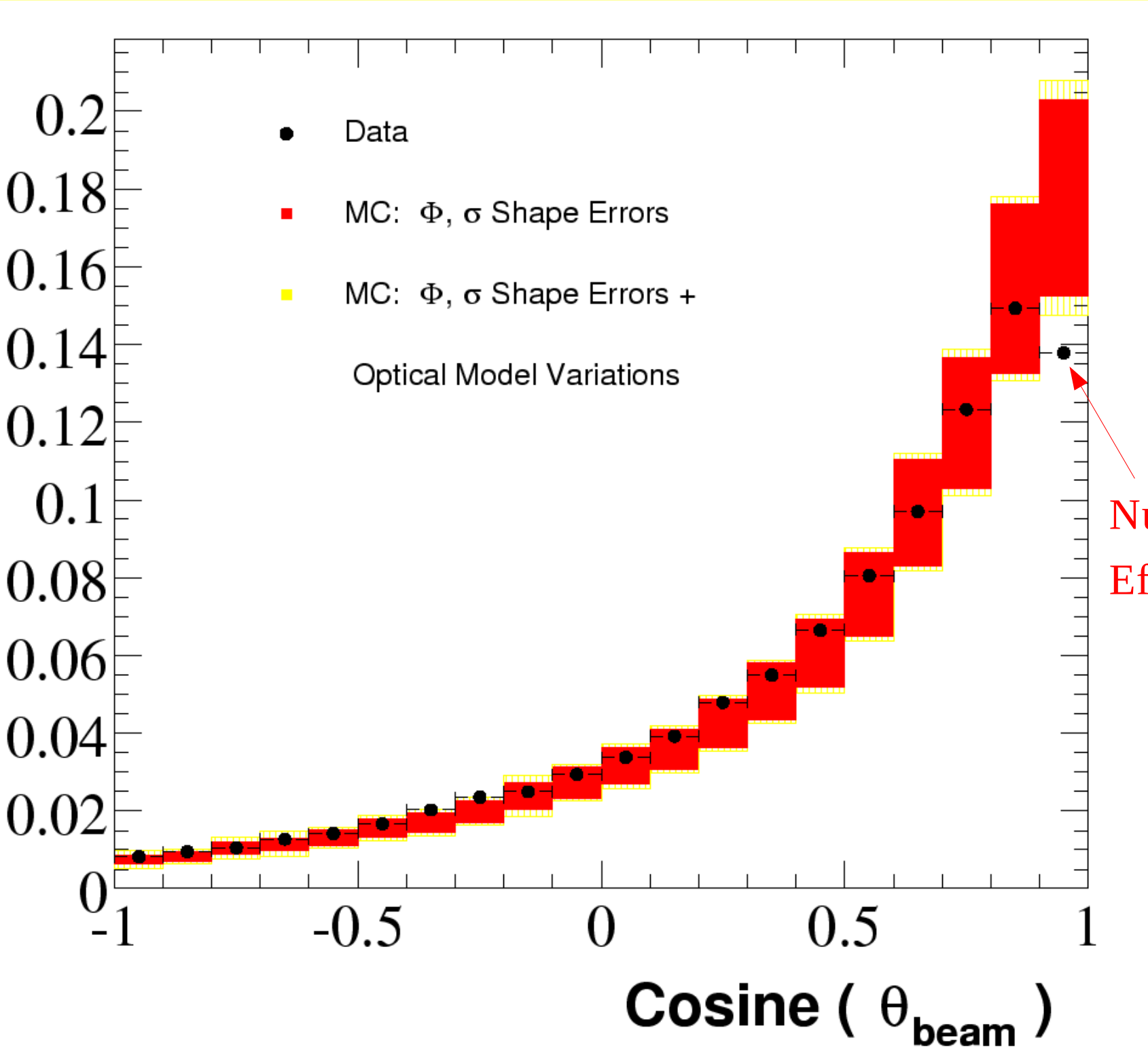
Important for ν_μ Disappearance

Important for ν_e Appearance

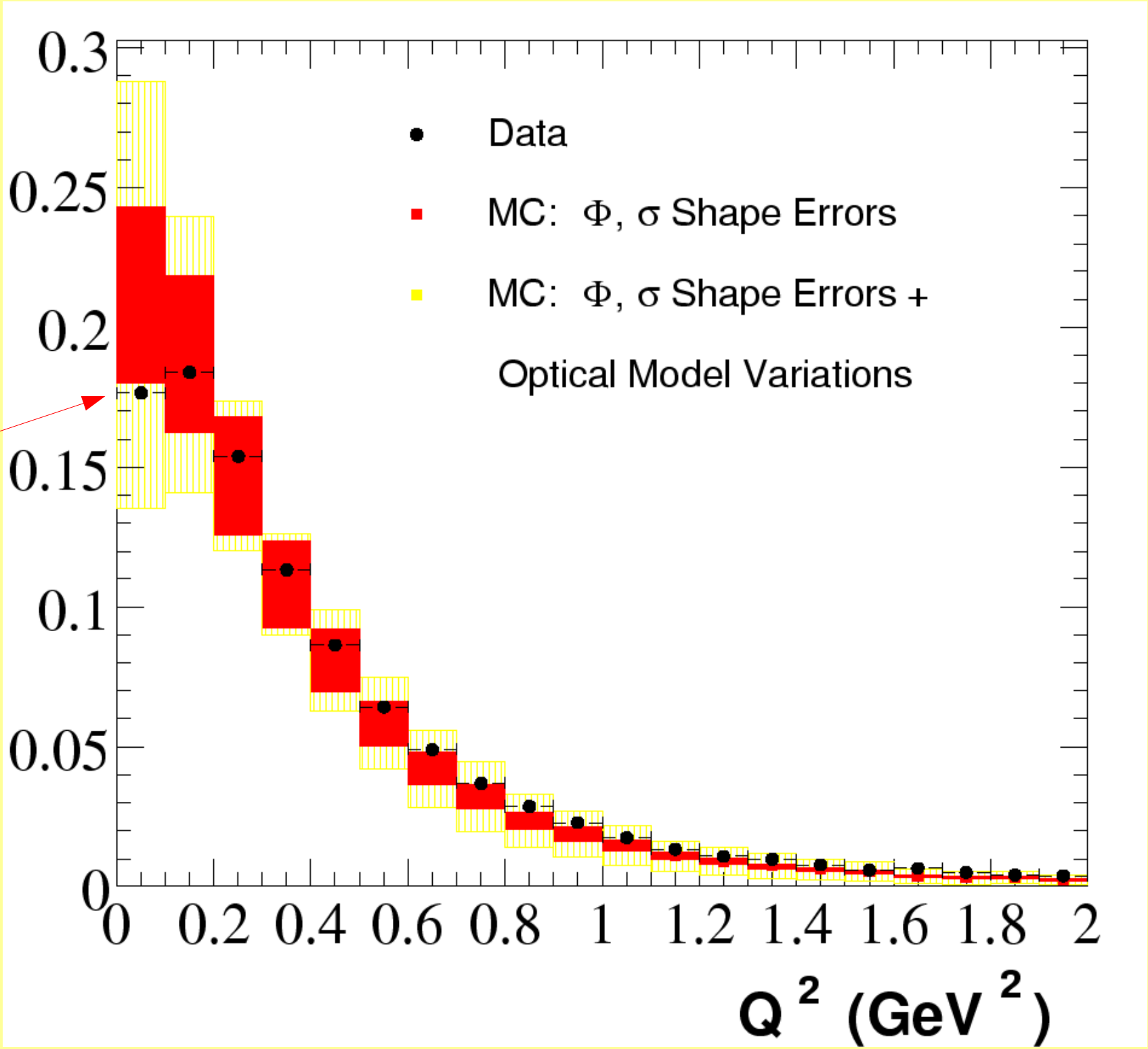
Selection: Single ring event, consistent with a muon


Data
MC: Φ, σ Shape Errors
MC: Φ, σ Shape Errors +
Optical Model Variations
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
Visible Energy (GeV)


Data
MC: Φ, σ Shape Errors
MC: Φ, σ Shape Errors +
Optical Model Variations
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
E ν QE (GeV)


Data
MC: Φ, σ Shape Errors
MC: Φ, σ Shape Errors +
Optical Model Variations
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-1
-0.5
0
0.5
1
Cosine (θbeam)
Nuclear
Effects?!

Nuclear Effects?!

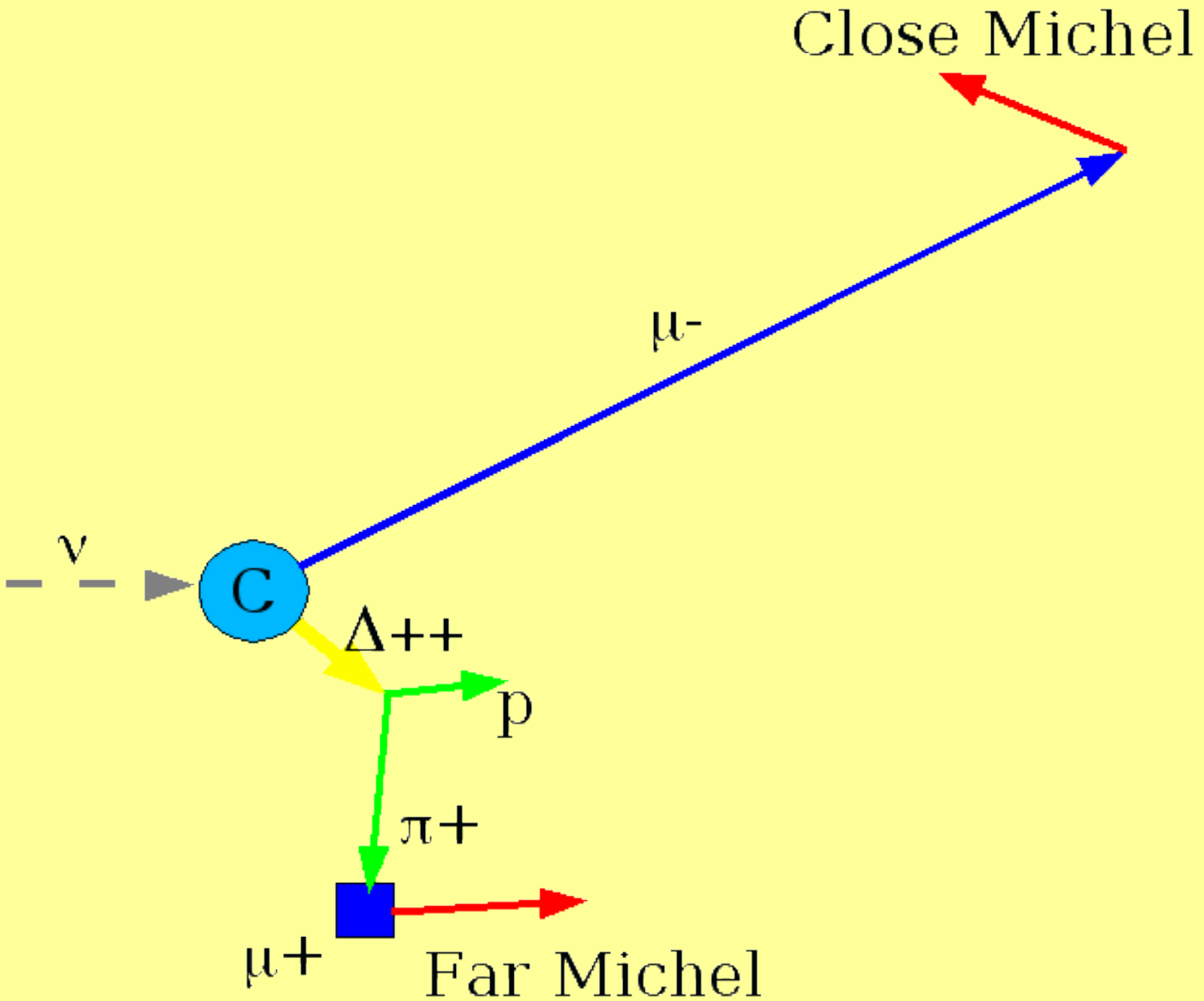


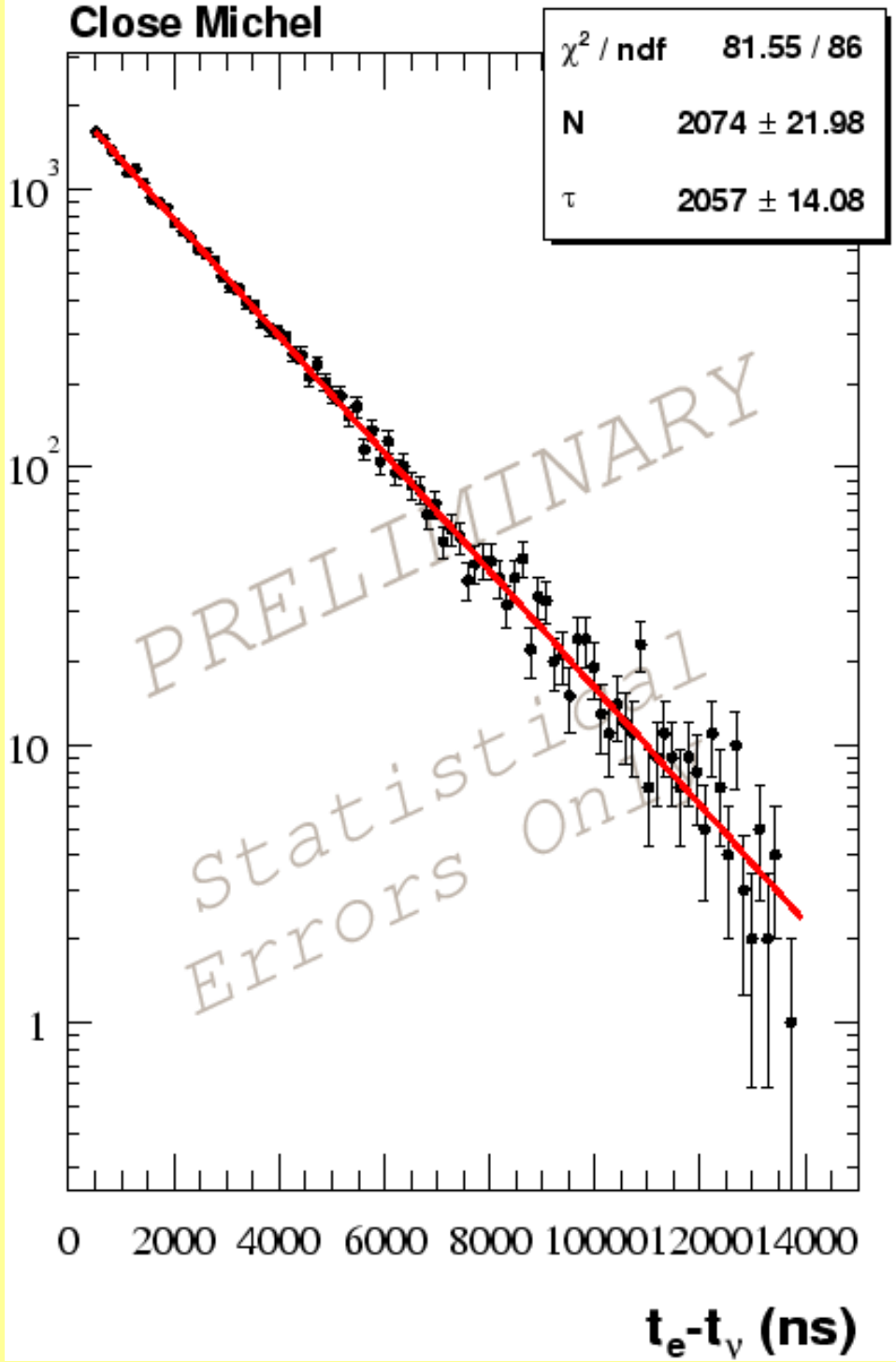
II. CC π^+ Events $\quad \nu_\mu C \rightarrow \mu^- \pi^+ X$

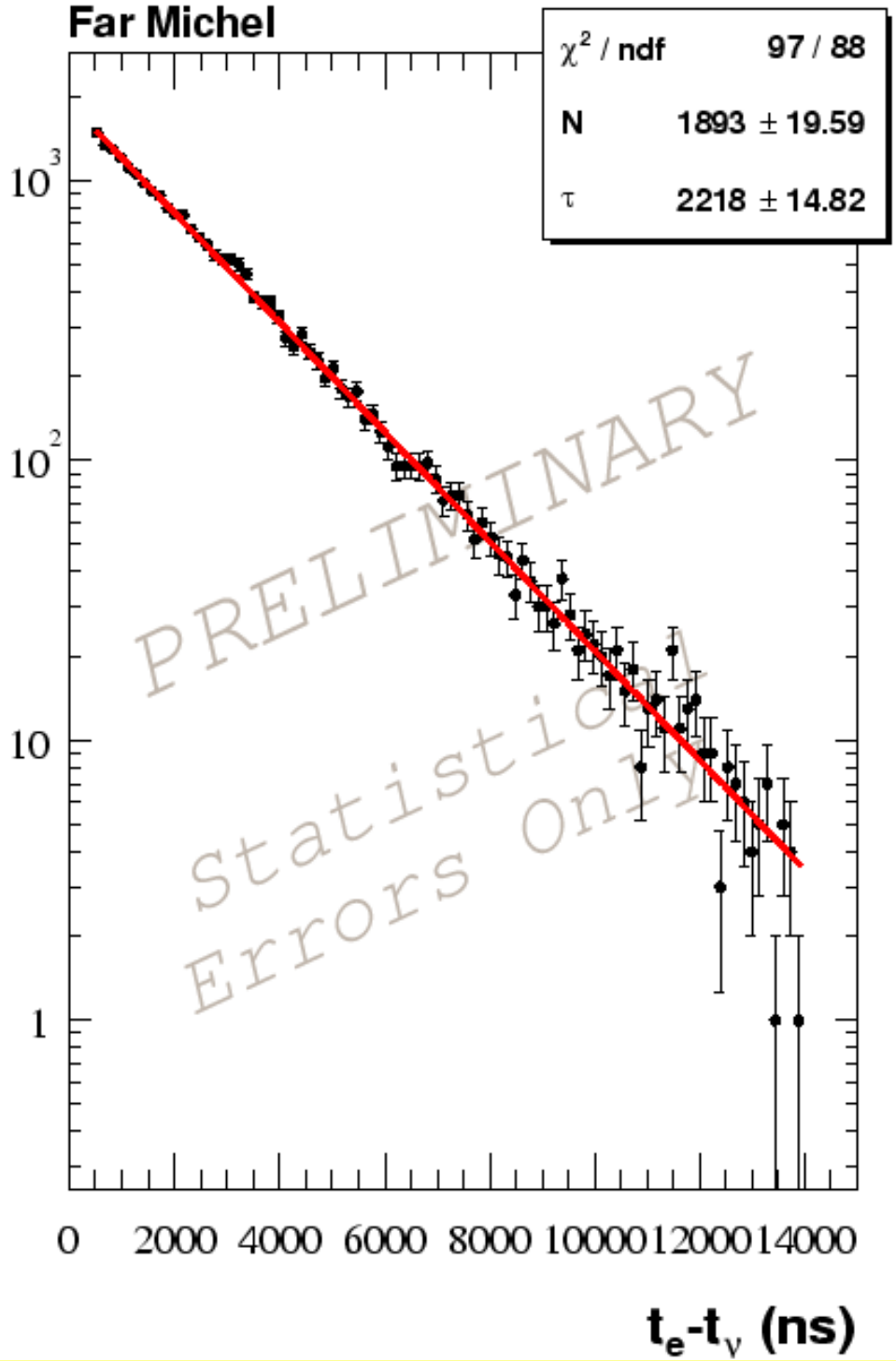
Not Well Measured at Low Energies

Important for Checking Cross Section Estimates

Selection: Double-ring event with 2 Michel-electrons


Close Michel
μ-
ν
C
Δ++
p
π+
μ+
Far Michel


Close Michel
χ^2 / ndf 81.55 / 86
N 2074 ± 21.98
τ 2057 ± 14.08
PRELIMINARY
Statistical Errors Only
10^3
10^2
10
1
0 2000 4000 6000 8000 10000 12000 14000
t_e-t_ν (ns)


Far Michel
χ^2 / ndf 97 / 88
N 1893 ± 19.59
τ 2218 ± 14.82
PRELIMINARY
Statistical Errors Only
10^3
10^2
10
1
0 2000 4000 6000 8000 10000 12000 14000
t_e-t_ν (ns)

III. NC π^0 Events $\nu_\mu C \rightarrow \nu_\mu \pi^0 C^*$

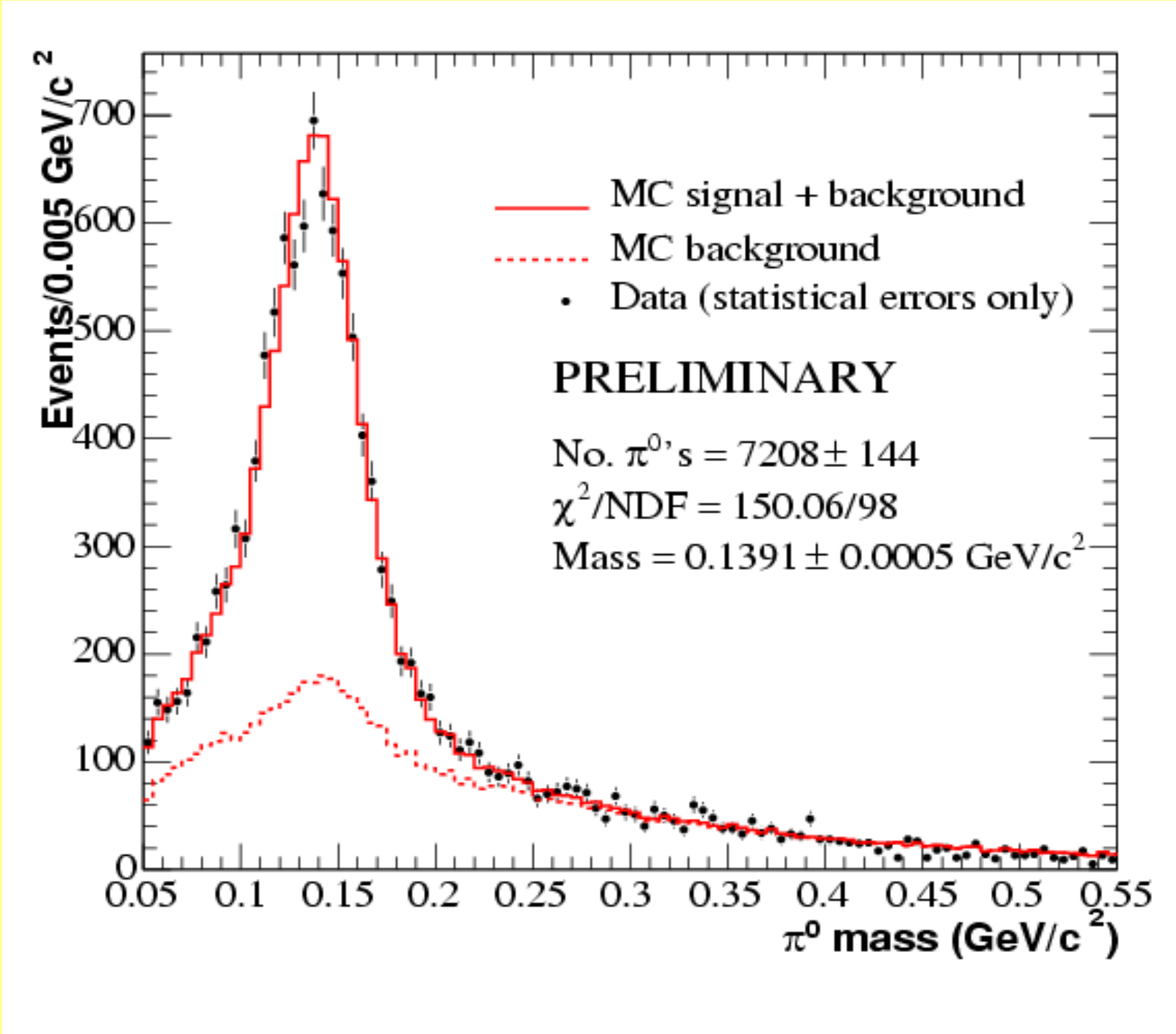
Contributions from:

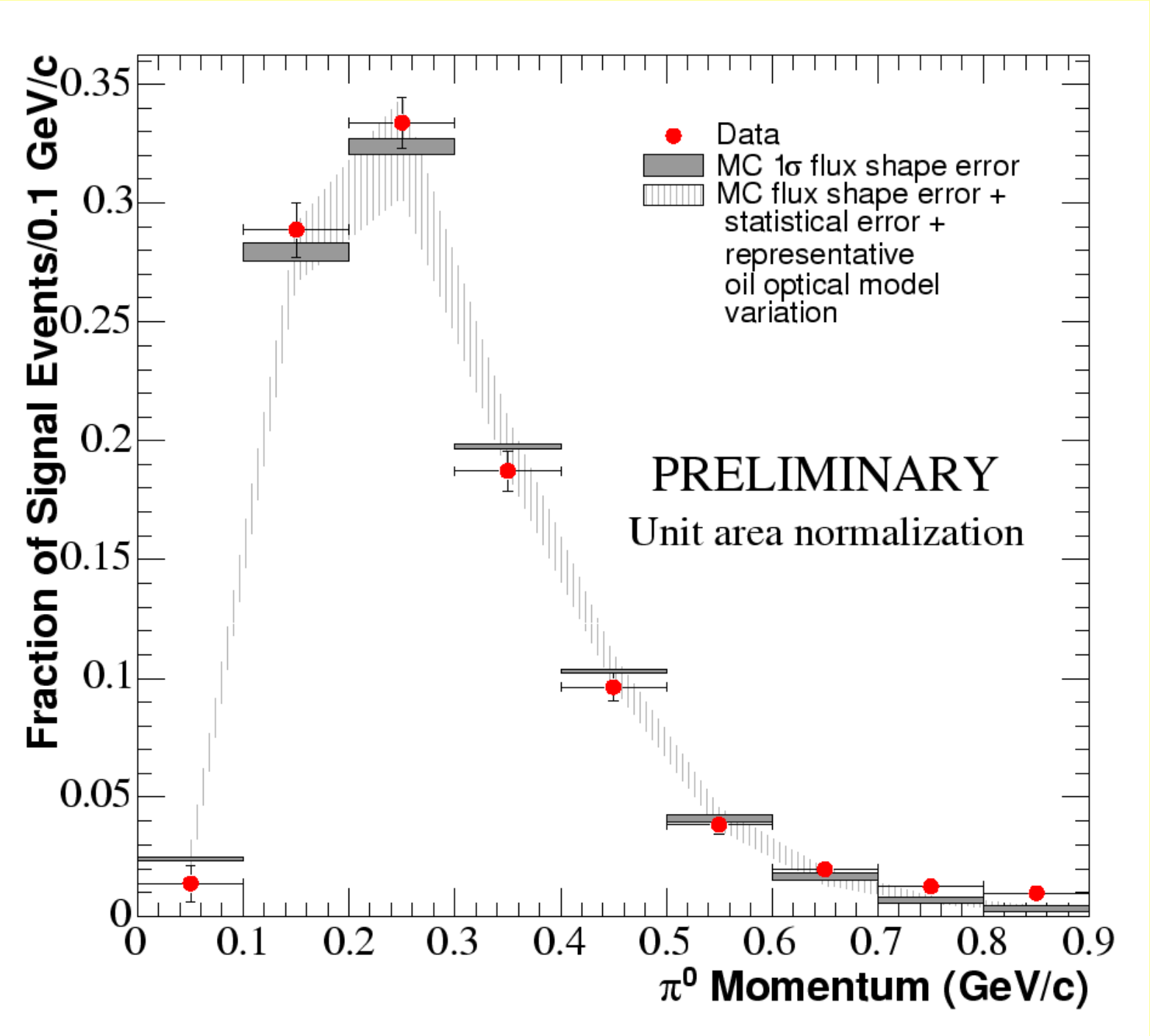
Resonance Production

Coherent Production

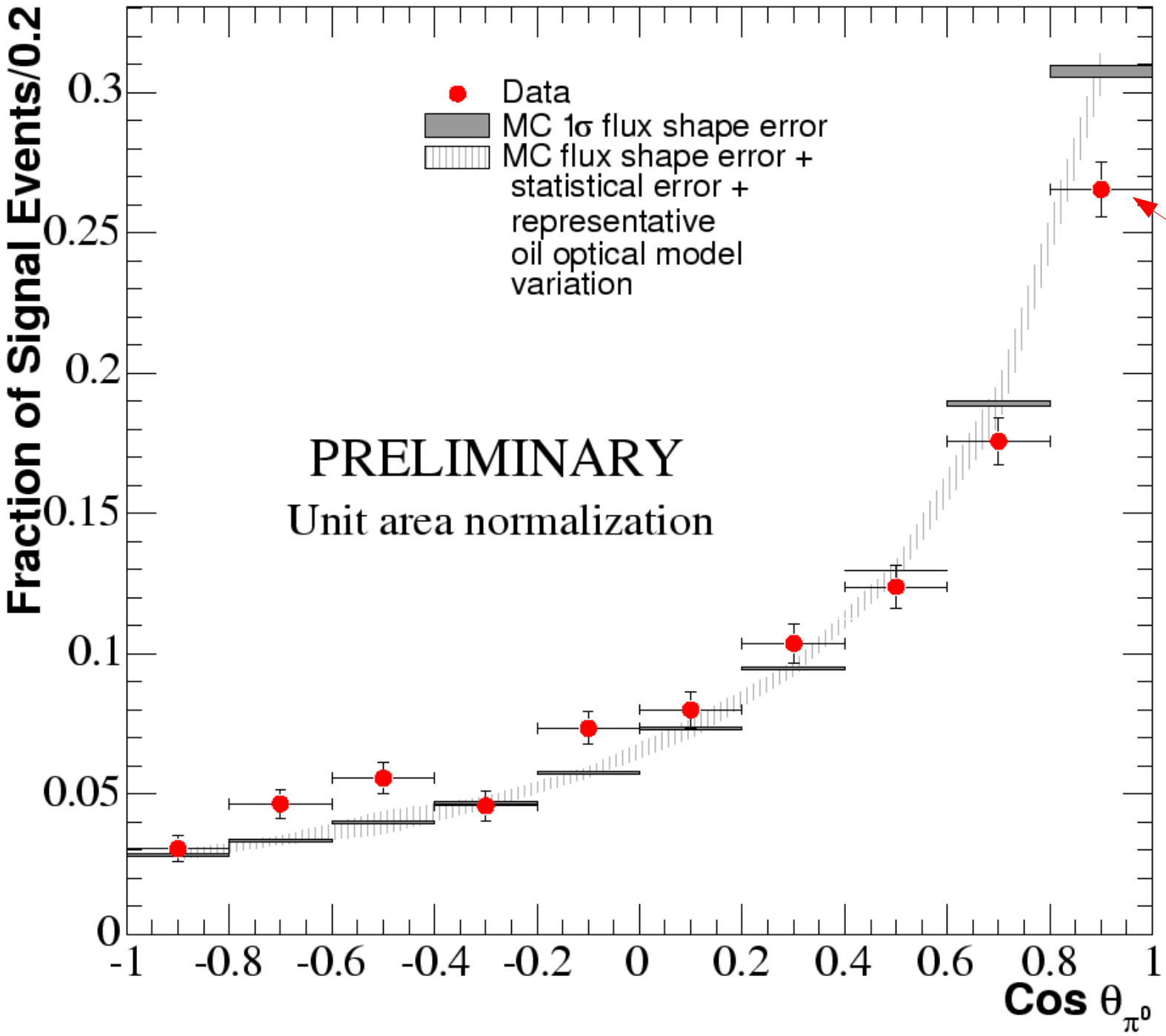
Selection: 2 rings with >40 MeV per ring

MiniBooNE NCπ^0 Reconstruction





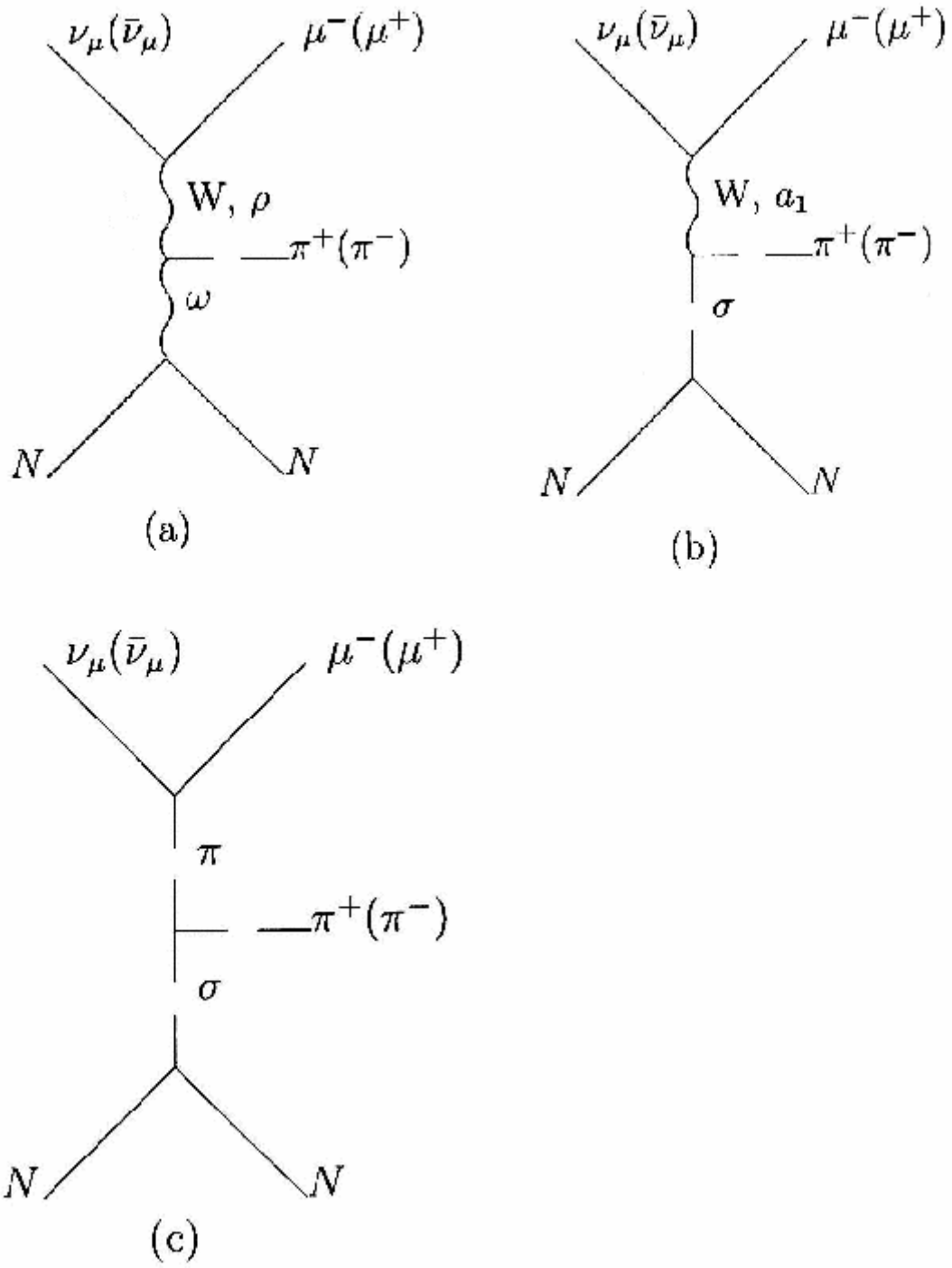
Data: Fit invariant mass in each p bin to extract signal events.



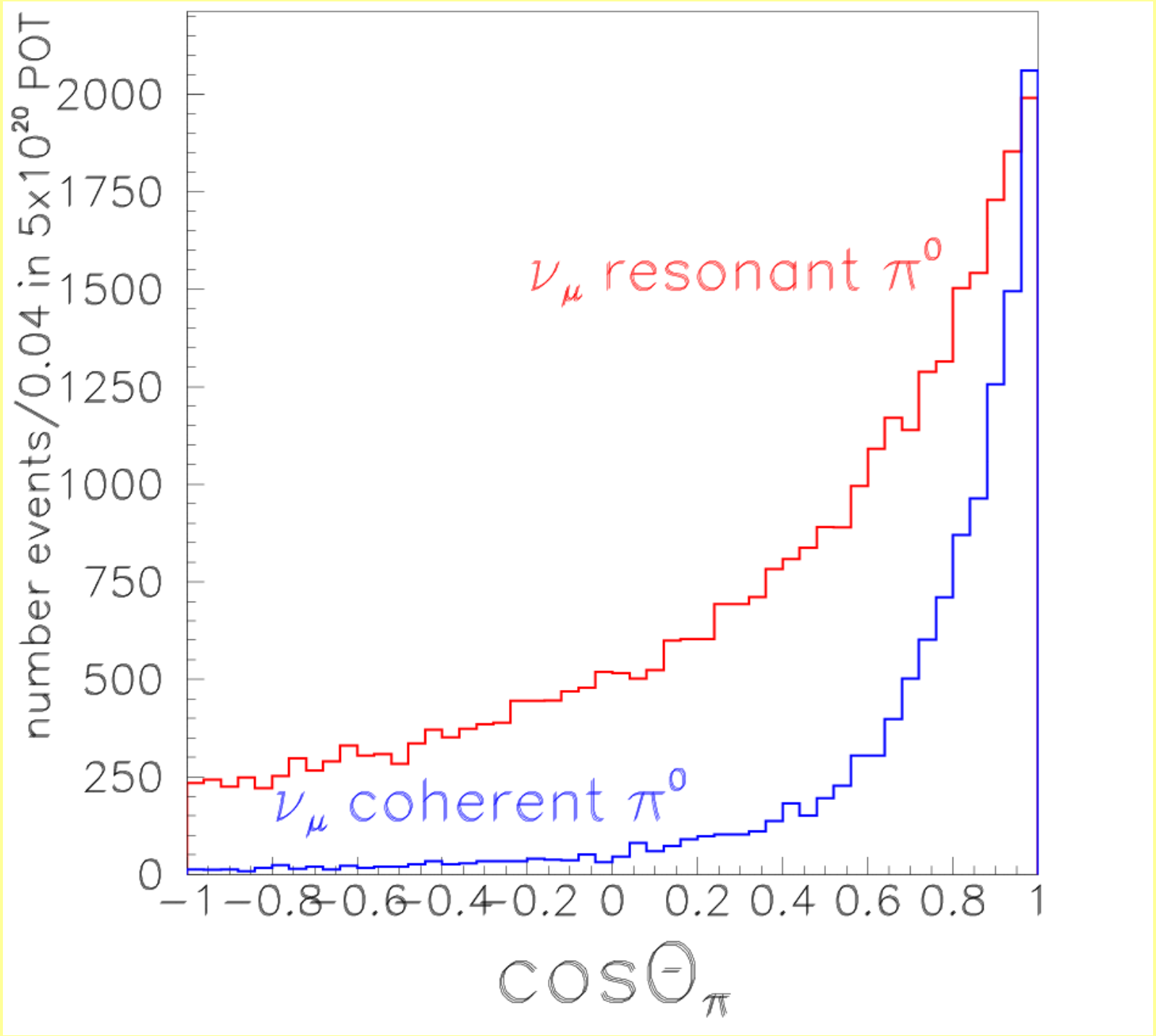
Coherent Production?!

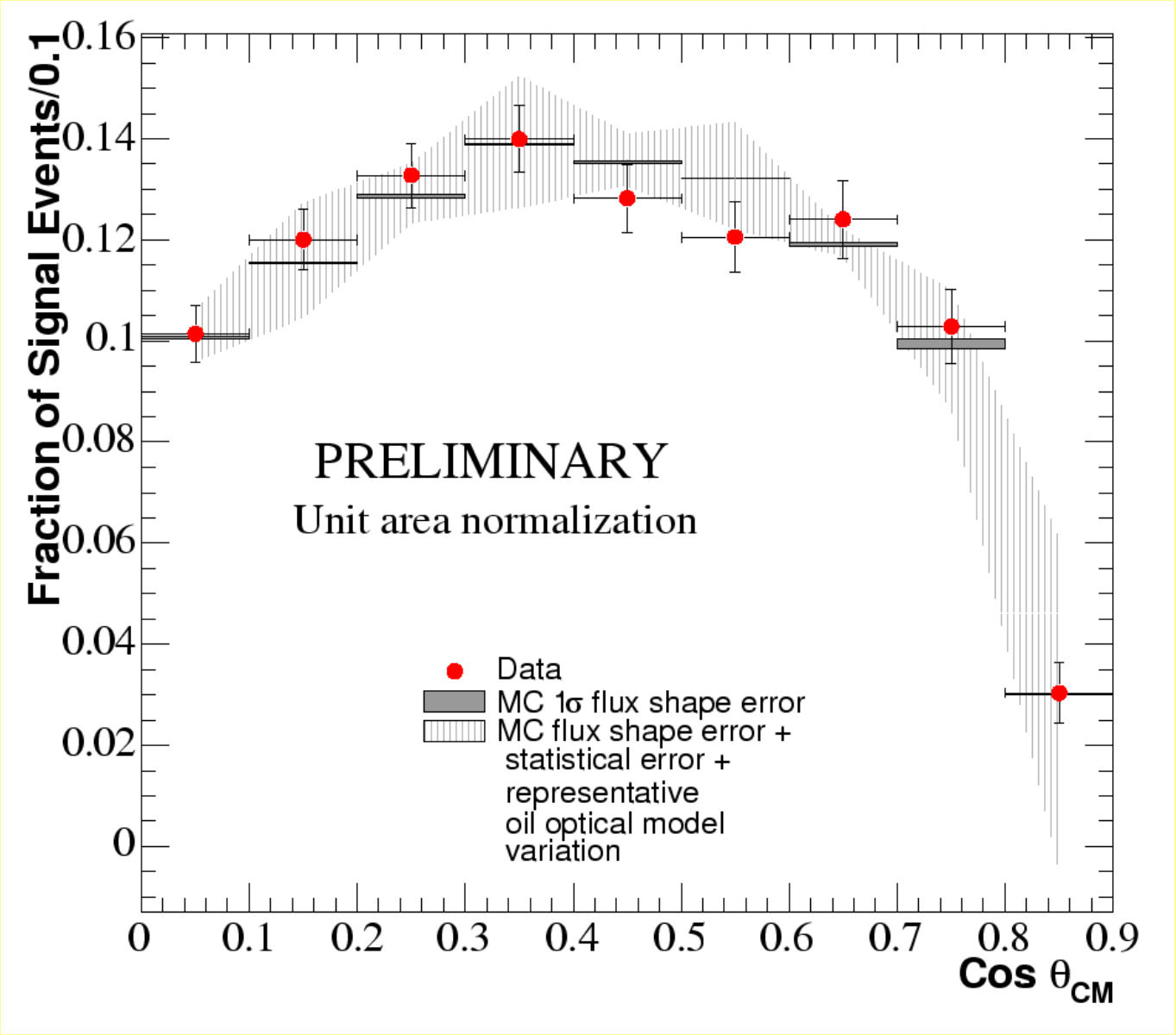
Coherent π^0 Production

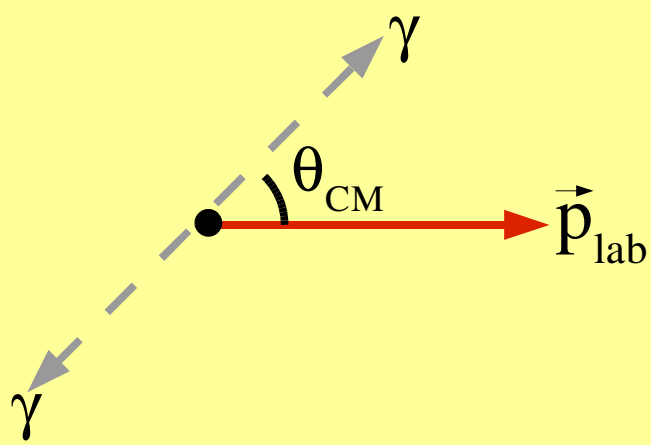
Paschos & Kartavtsev (hep-ph/0309148) predict a much smaller cross section than Rein & Sehgal (Nucl. Phys. B223 (1983) 29)



Coherent/Resonant Separation







π^0 decays isotropically

distribution flat for π^0

IV. $\nu_\mu \rightarrow \nu_e$ *Oscillations:* $\nu_e C \rightarrow e^- p C^*$

Blind Analysis is Working!

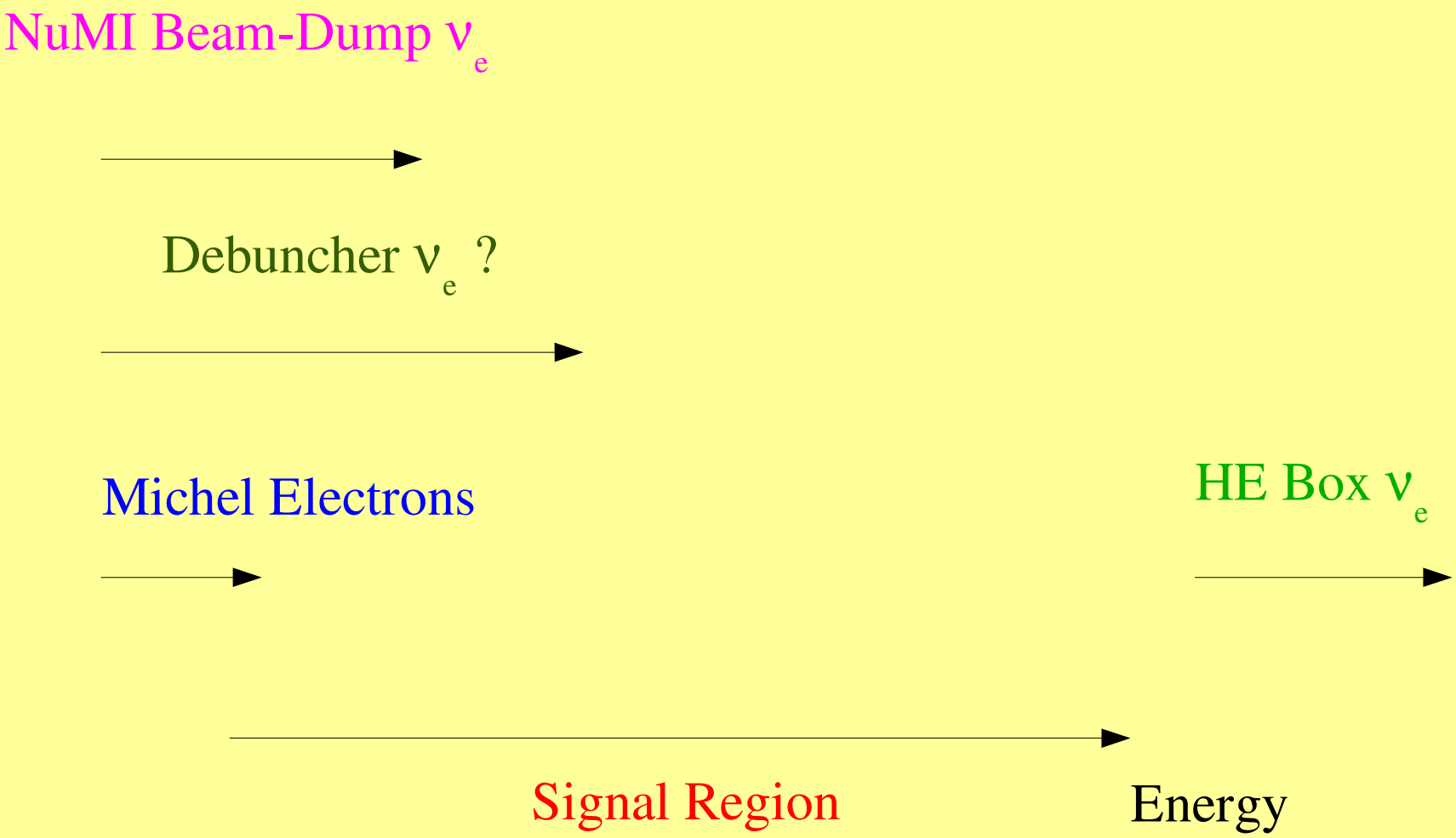
Obtaining good agreement between data & MC

Considering both ANNs & Boosted Decision Trees

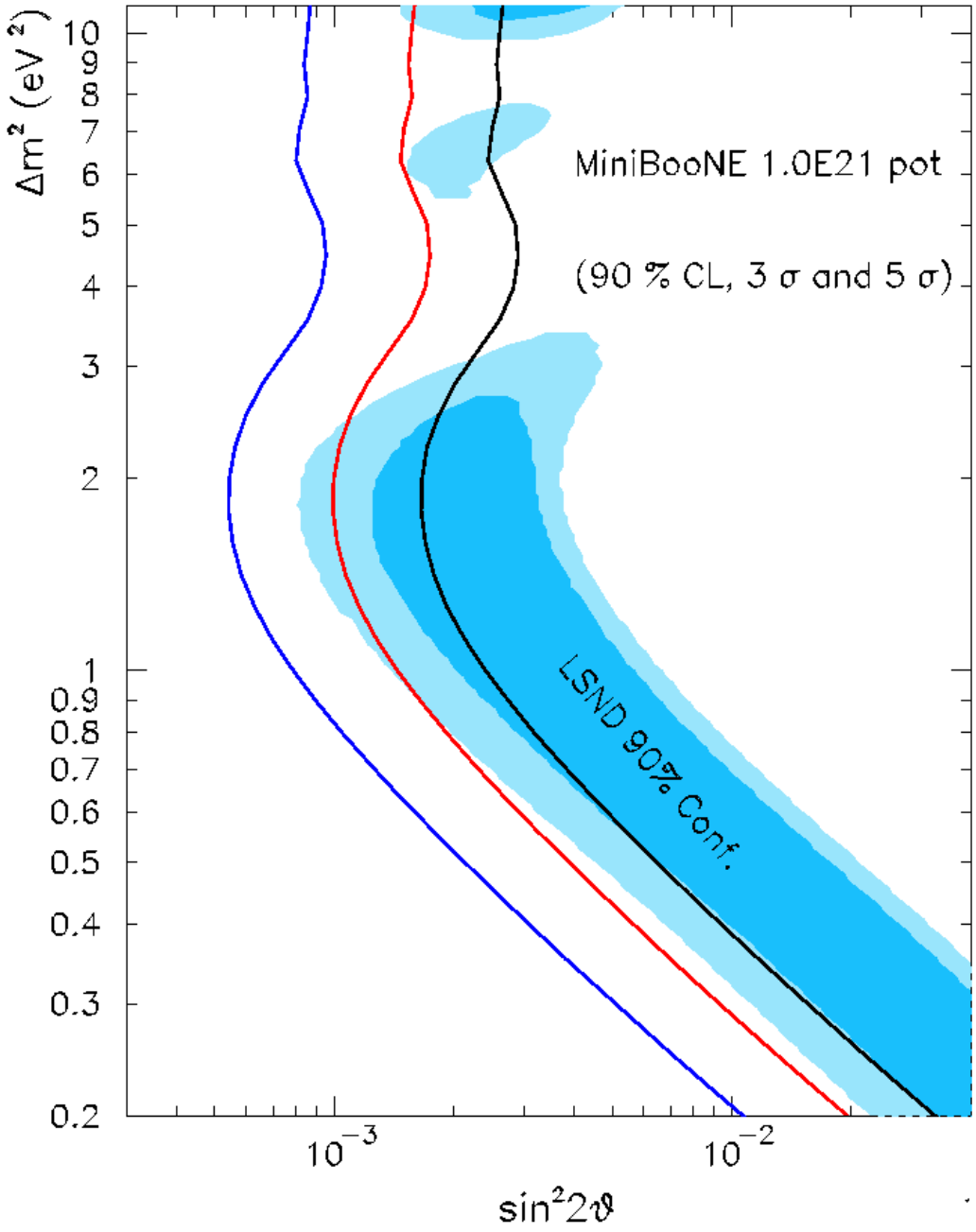
PID with Boosted Decision Trees

- MiniBooNE has a deceptively large amount of information & Boosted Decision Trees are tailor-made for MiniBooNE particle identification!
- See physics/0408124 (Roe, Yang, Zhu, Liu, Stancu, McGregor) for a discussion of Boosted Decision Trees, which appear to give better performance than ANN

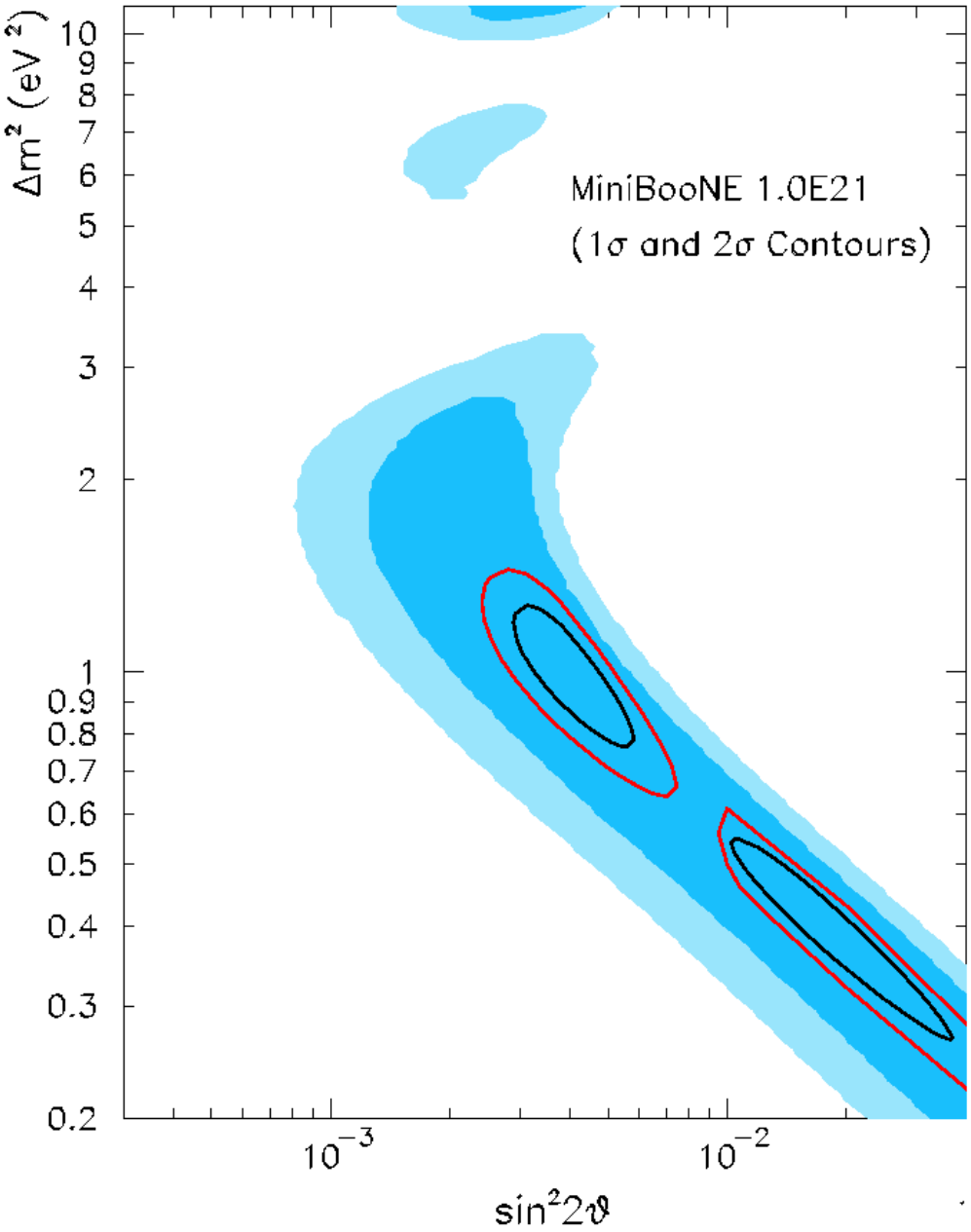
Sources for Electron Calibration



Expected MiniBooNE Sensitivity



Measurement of Oscillations



Schedule

- Take data until August 2005 Shutdown (>5E20 POT)
- Complete Analysis (Good agreement between data & MC: flux, cross sections, detector MC)
- Open Box in early autumn (?) & Present Results
- Run Antineutrinos (and/or Neutrinos) in 2006
- If MiniBooNE Confirms LSND $\Rightarrow$ Physics Beyond the Standard Model! Begin Design & Construction of a 2nd Detector at a Different Distance