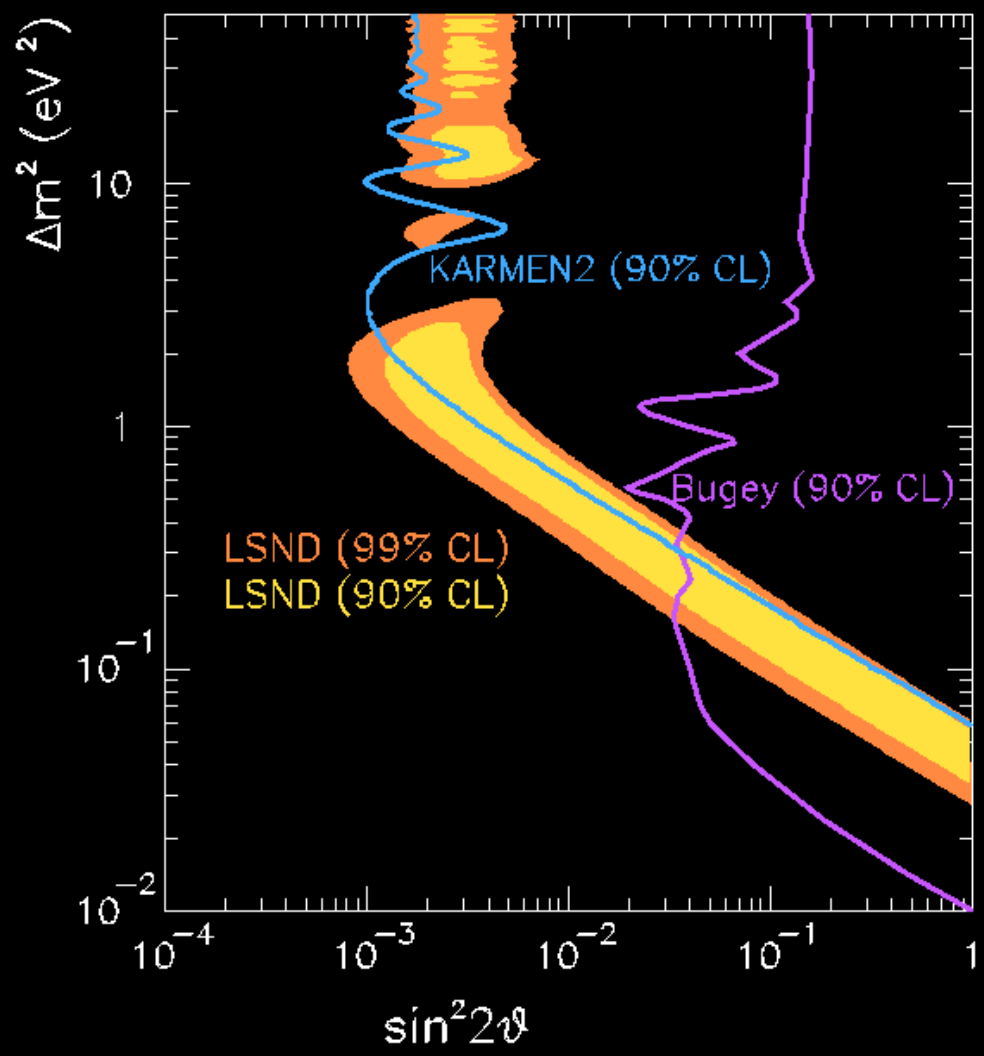
Update on MiniBooNE's Neutrino Oscillation Result

Morgan Wascko
Imperial College London

Verifying LSND

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{12} \sin^2(1.27\Delta m^2_{12}\frac{L}{E})$$



- LSND interpreted as 2 ν oscillation
- Verification requires same (L/E) and high statistics
  - Different systematics
- MiniBooNE chose higher L and E
- Strategy: search for ν_e excess in ν_μ beam

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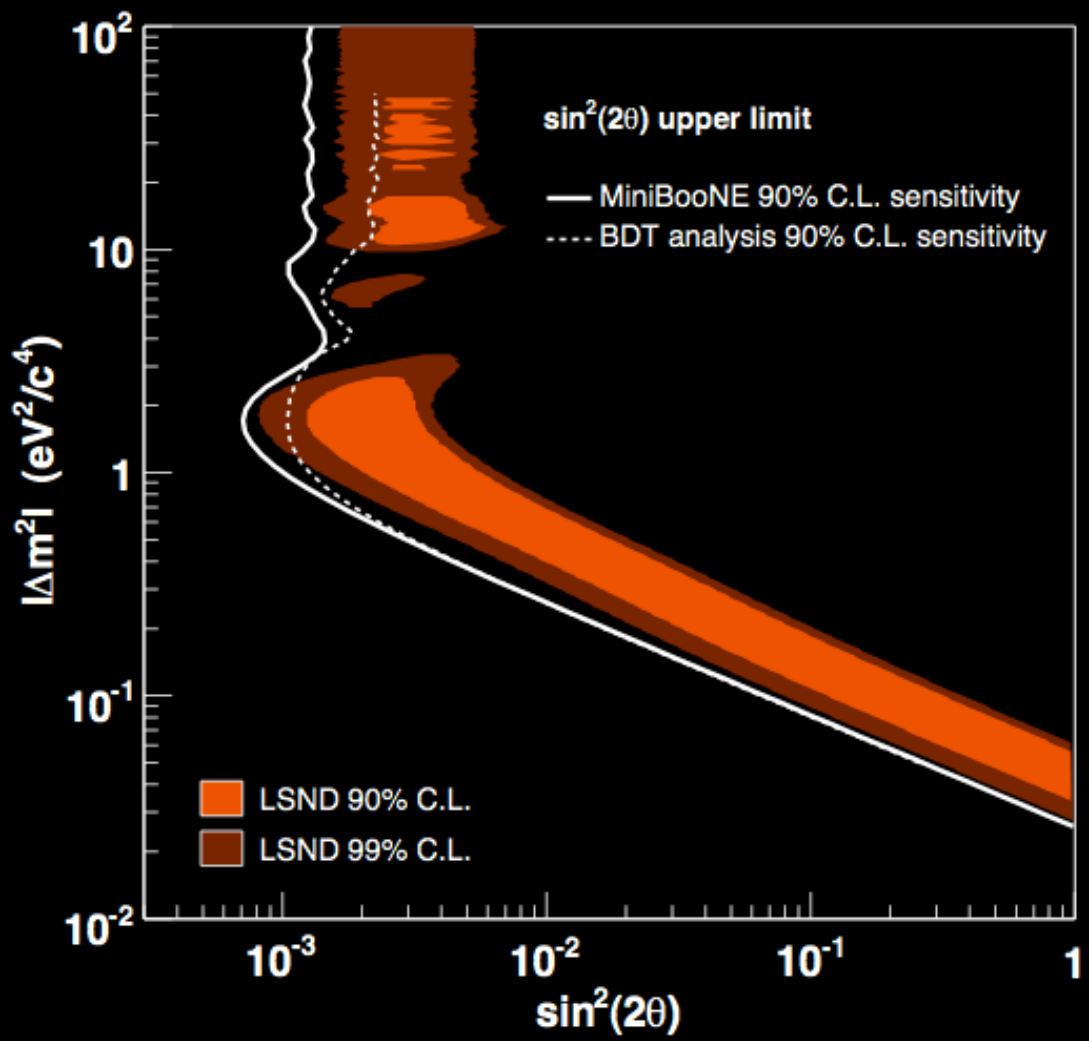

MiniBooNE Sensitivity

- LSND interpreted as 2 ν oscillation
- Verification requires same (L/E) and high statistics
  - Different systematics
- MiniBooNE chose higher L and E
- Strategy: search for ν_e excess in ν_μ beam

MiniBooNE Collaboration

A. A. Aguilar-Arevalo[5], A. O. Bazarko[12], S. J. Brice[7], B. C. Brown[7], L. Bugel[5], J. Cao[11], L. Coney[5], J. M. Conrad[5], D. C. Cox[8], A. Curioni[16], Z. Djurcic[5], D. A. Finley[7], B. T. Fleming[16], R. Ford[7], F. G. Garcia[7], G. T. Garvey[9], J. A. Green[8,9], C. Green[7,9], T. L. Hart[4], E. Hawker[15], R. Imlay[10], R. A. Johnson[3], P. Kasper[7], T. Katori[8], T. Kobilarcik[7], I. Kourbanis[7], S. Koutsoliotas[2], E. M. Laird[12], J. M. Link[14], Y. Liu[11], Y. Liu[1], W. C. Louis[9], K. B. M. Mahn[5], W. Marsh[7], P. S. Martin[7], G. McGregor[9], W. Metcalf[10], P. D. Meyers[12], F. Mills[7], G. B. Mills[9], J. Monroe[5], C. D. Moore[7], R. H. Nelson[4], P. Nienaber[13], S. Ouedraogo[10], R. B. Patterson[12], D. Perevalov[1], C. C. Polly[8], E. Prebys[7], J. L. Raaf[3], H. Ray[9], B. P. Roe[11], A. D. Russell[7], V. Sandberg[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. J. Stefanski[7], M. Sung[10], H. A. Tanaka[12], R. Tayloe[8], M. Tzanov[4], M. O. Wascko[10], R. Van de Water[9], D. H. White[9], M. J. Wilking[4], H. J. Yang[11], G. P. Zeller[5], E. D. Zimmerman[4]

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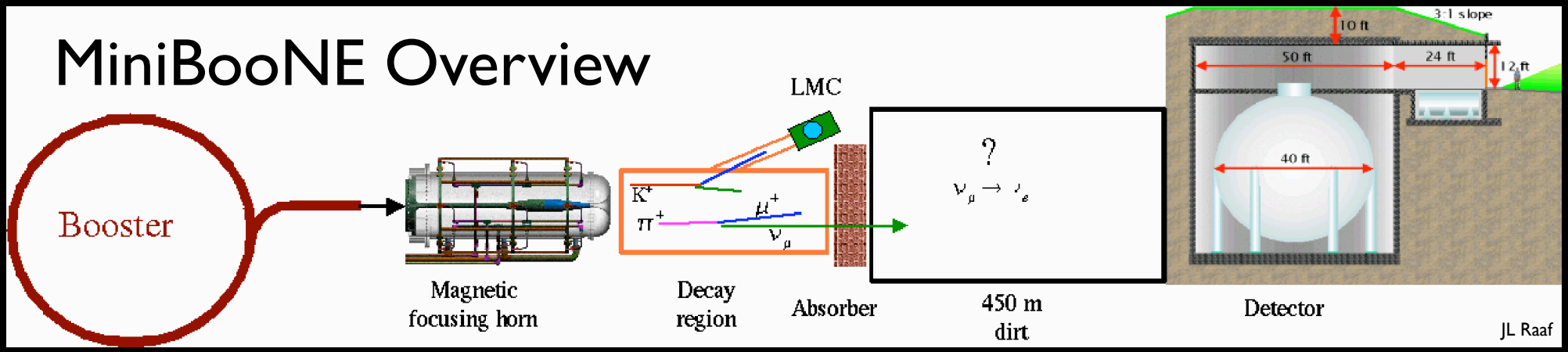
[16] *Yale University, New Haven, CT 06520*

Fermilab Visual Media Services

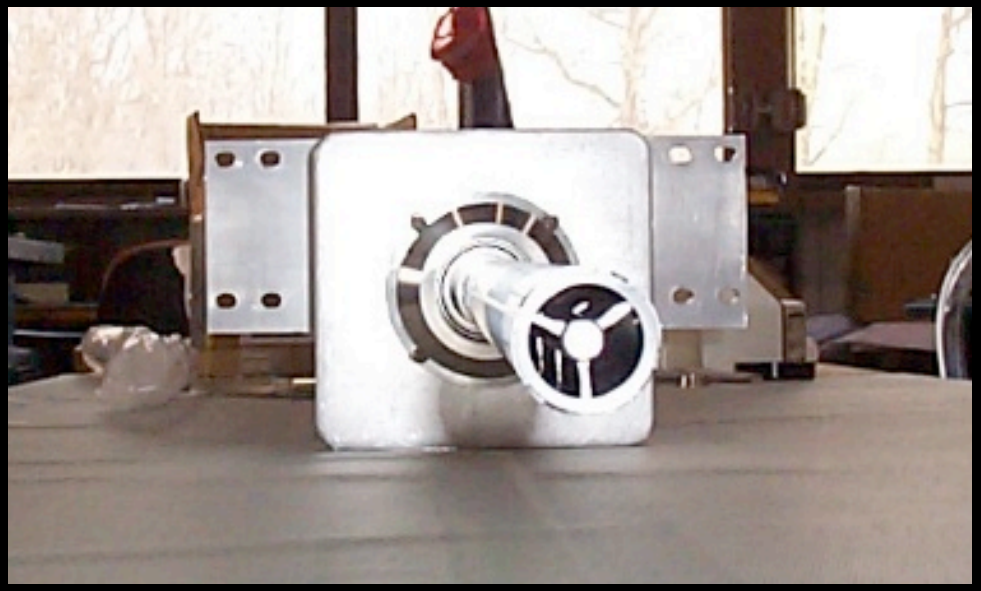
Our task: Dead reckon the background estimates and uncertainties with just one detector.

Overview

Fermilab Visual Media Services

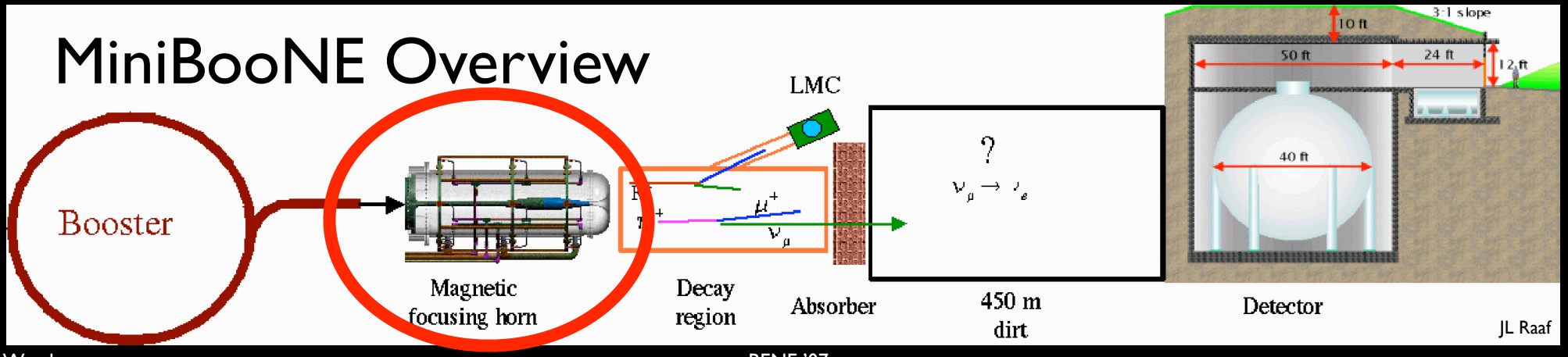

MiniBooNE Overview
Booster
Magnetic focusing horn
LMC
K^+
π^+
μ^+
ν_μ
Decay region
Absorber
?
$\nu_\mu \rightarrow \nu_e$
450 m dirt
3:1 slope
10 ft
50 ft
24 ft
12 ft
40 ft
Detector
JL Raaf

Target & Horn

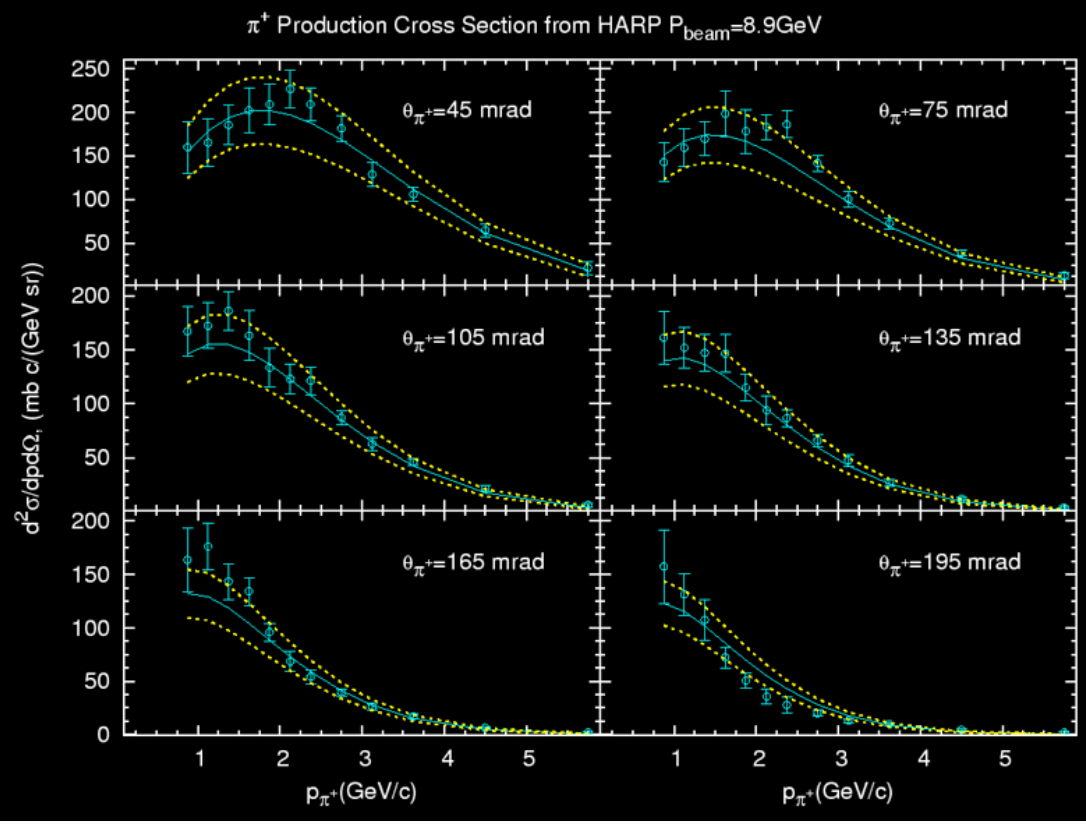


Main components of Booster Neutrino Beam (BNB)

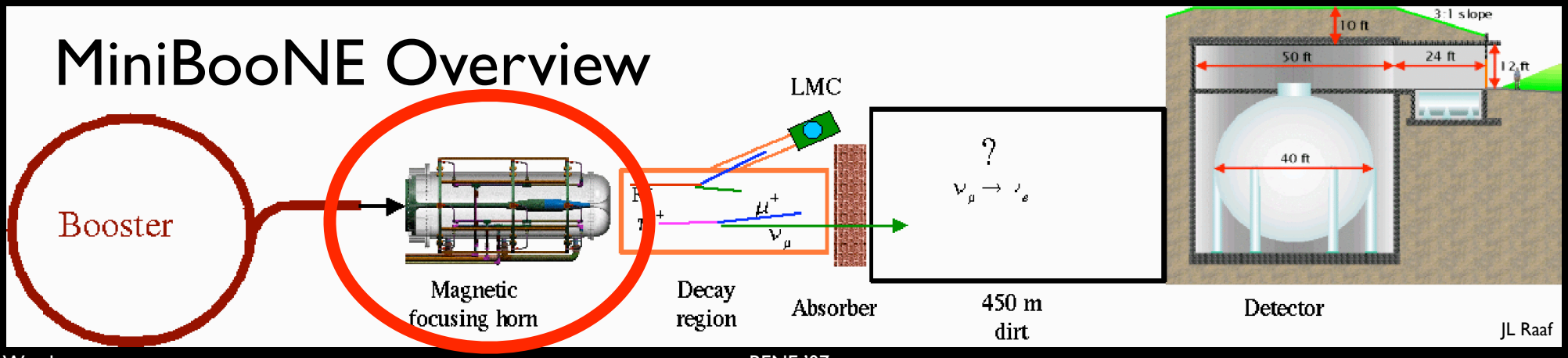
(96M and 146M+ pulses)



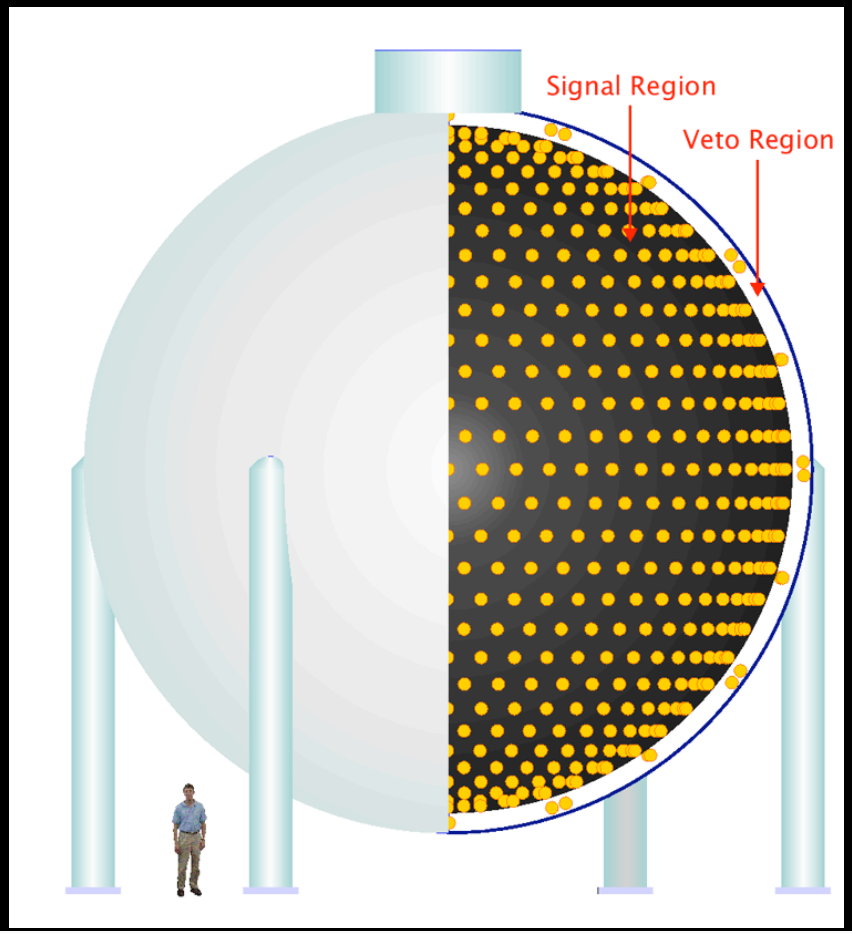
Meson Production

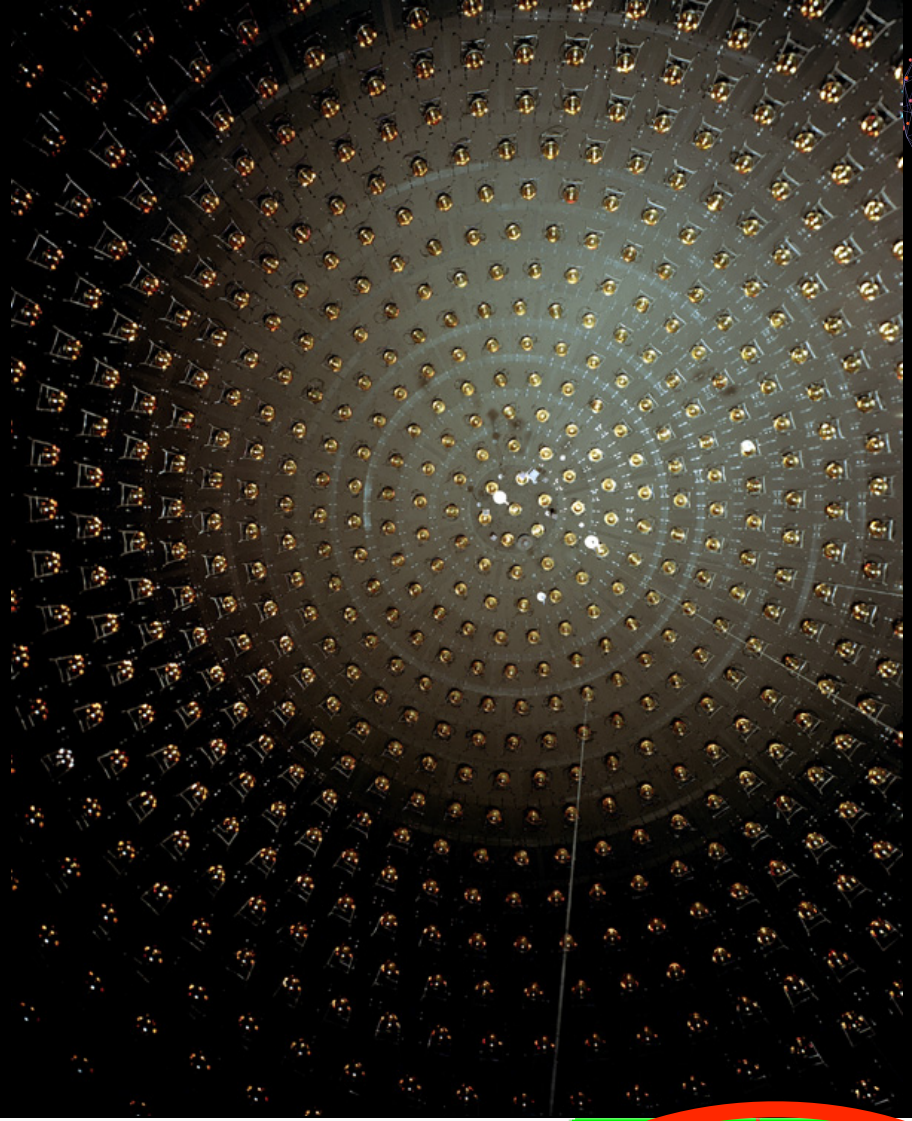


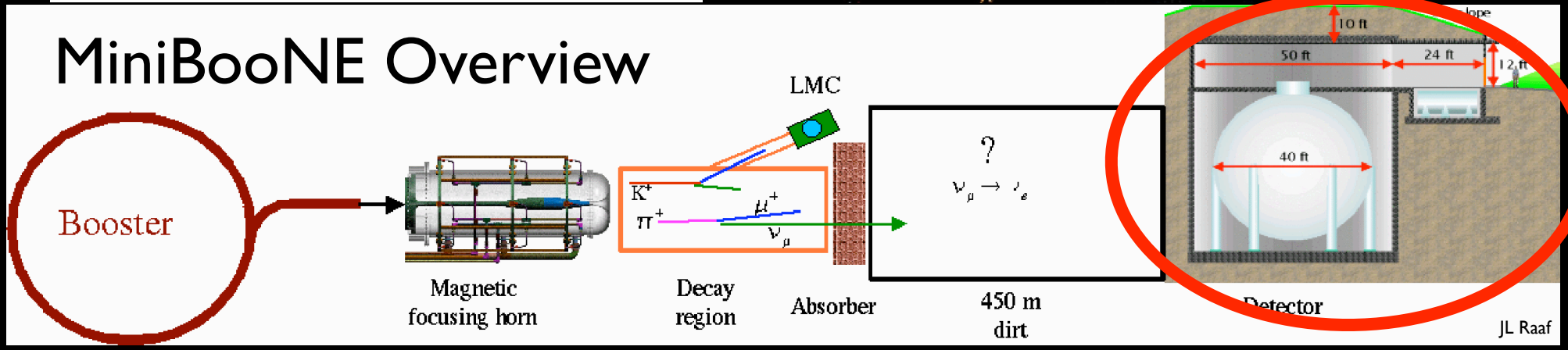
- External meson production data
  - HARP data (CERN)
- Parametrisation of cross-sections
  - Sanford-Wang for pions
  - Feynman scaling for kaons



Detector


Signal Region
Veto Region

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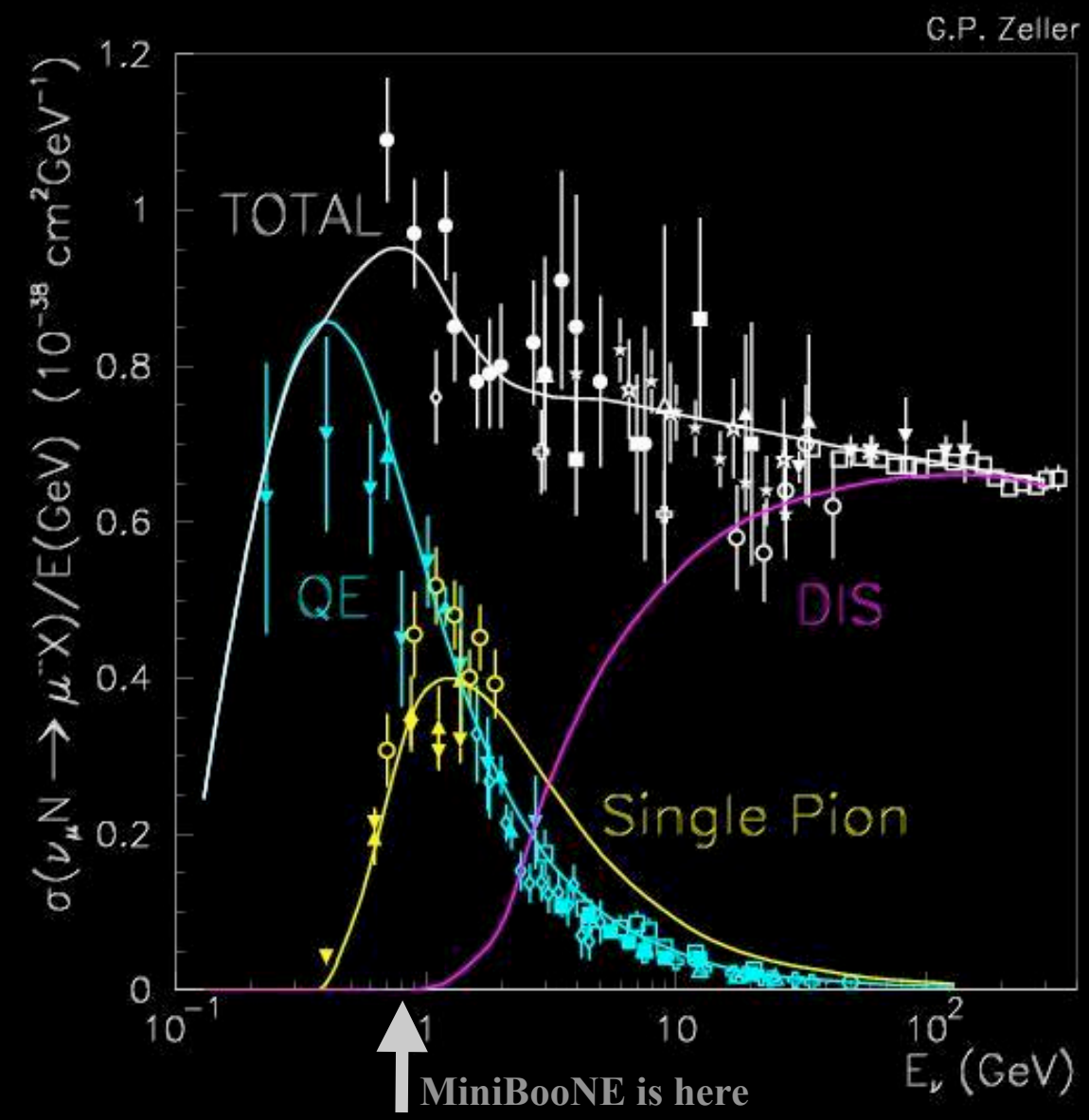
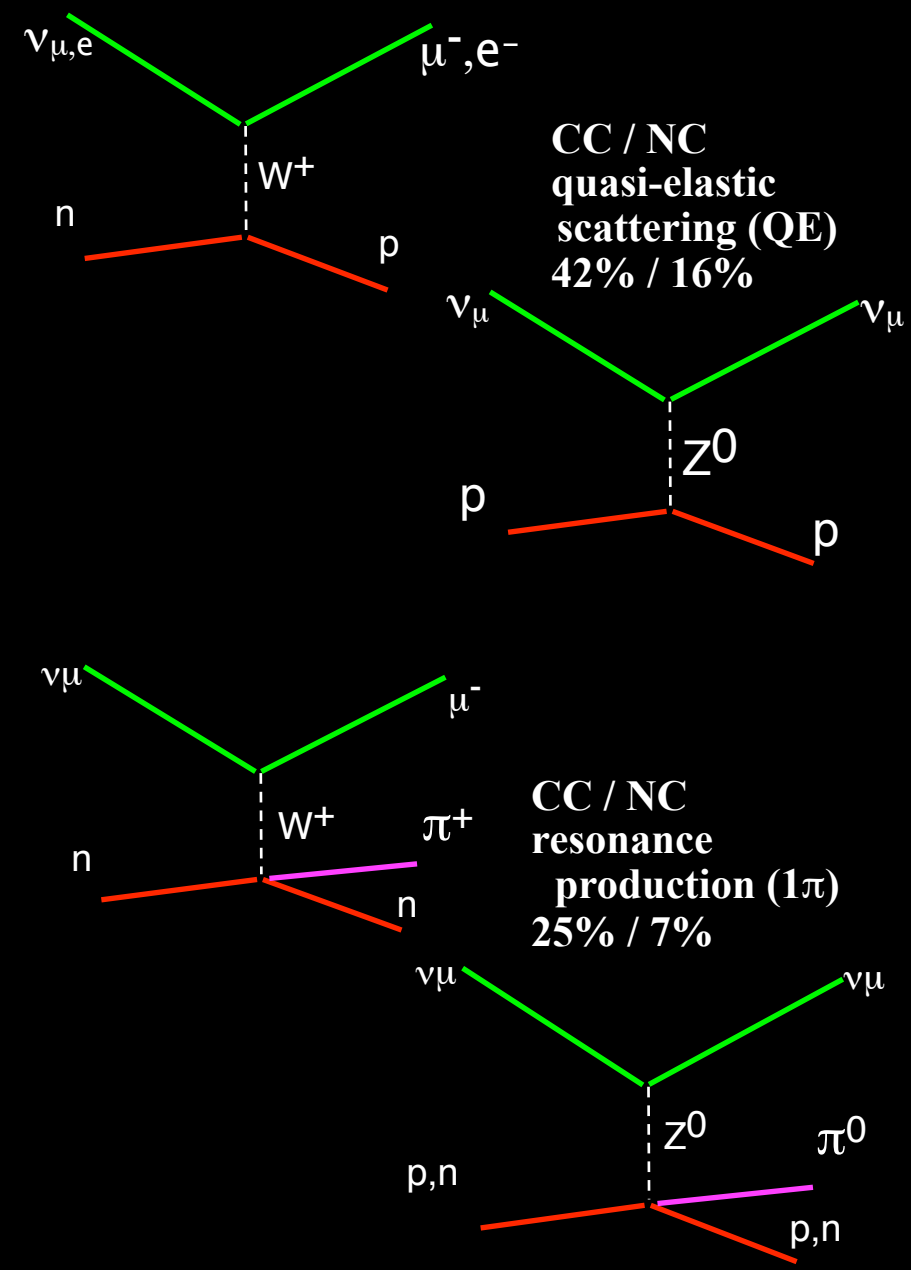
Detector
JL Raaf

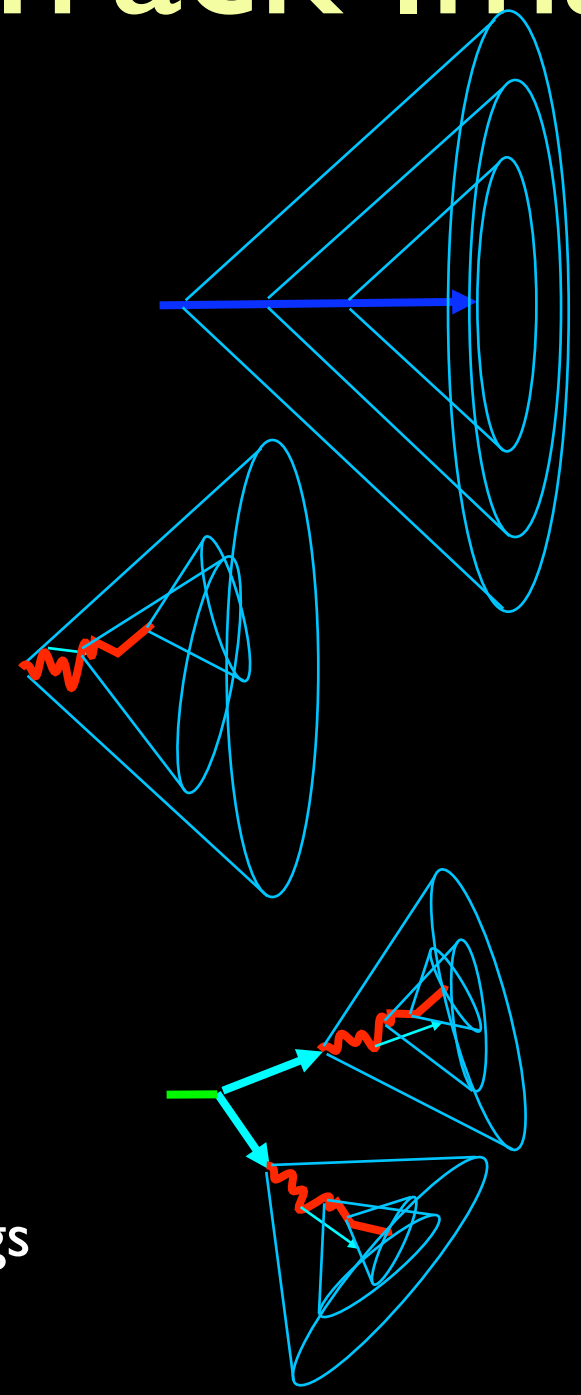
Neutrino Interactions

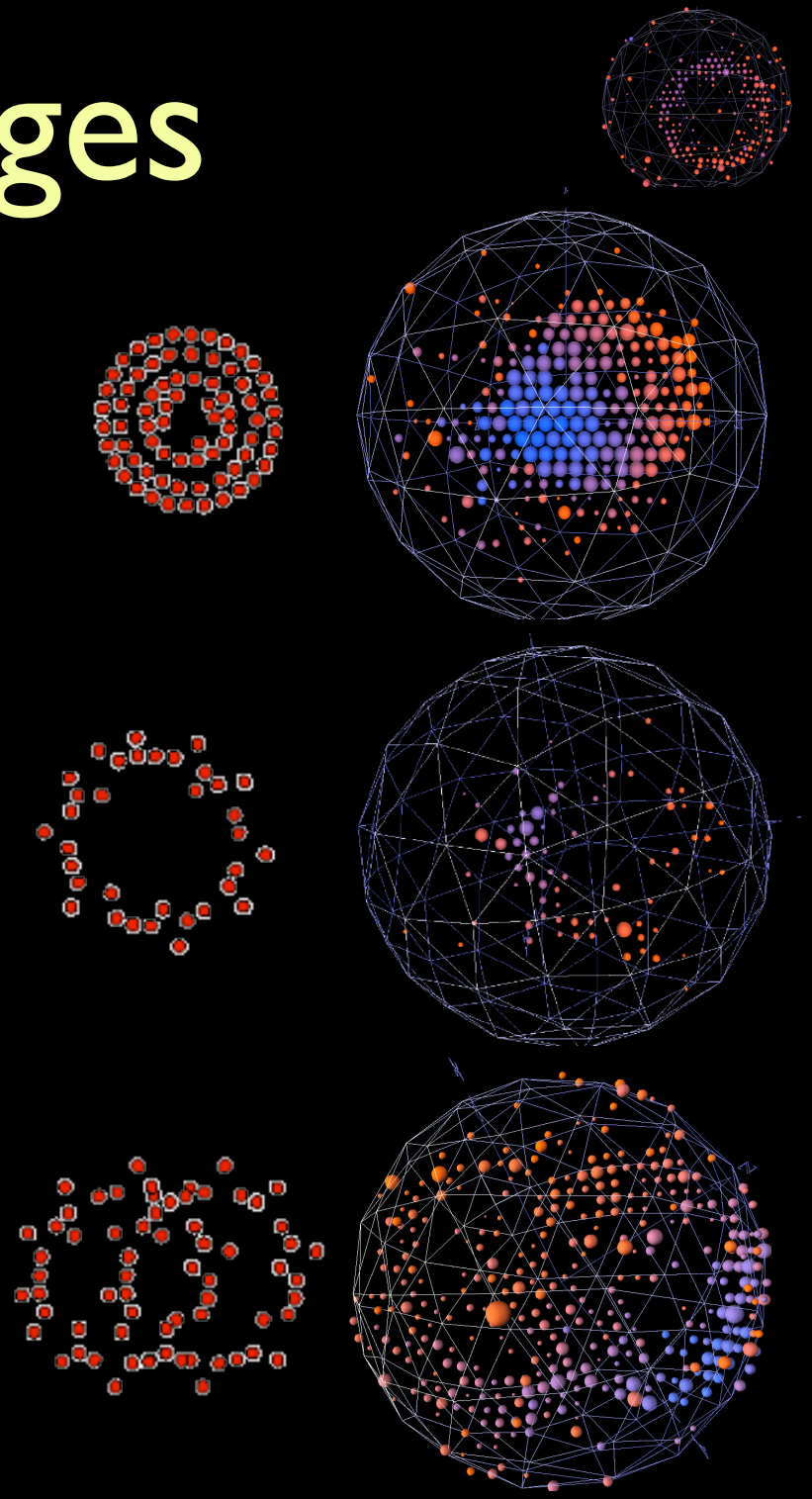




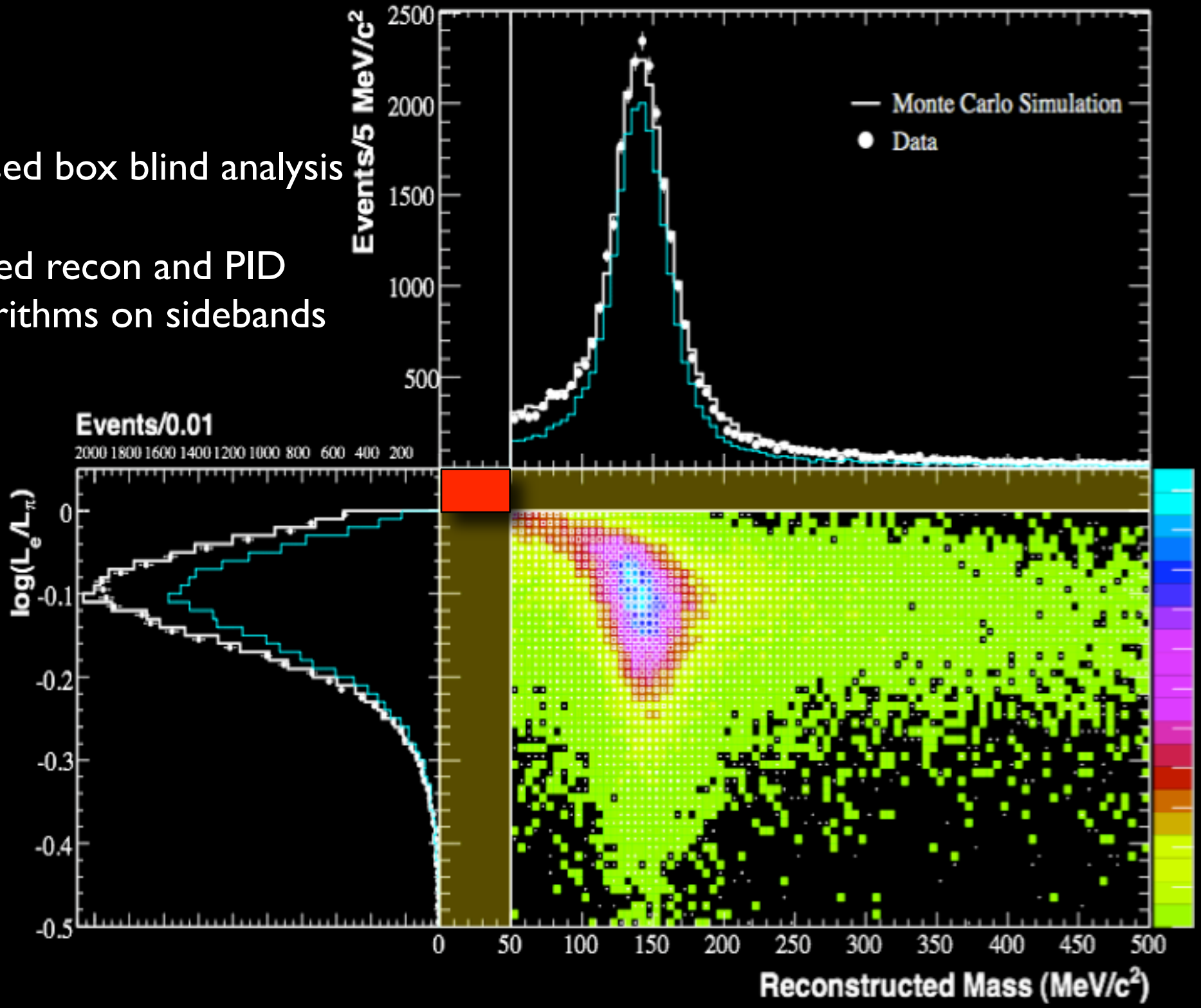
Track Images

- Muons
  - full rings
- Electrons
  - fuzzy rings
- Neutral pions
  - double rings





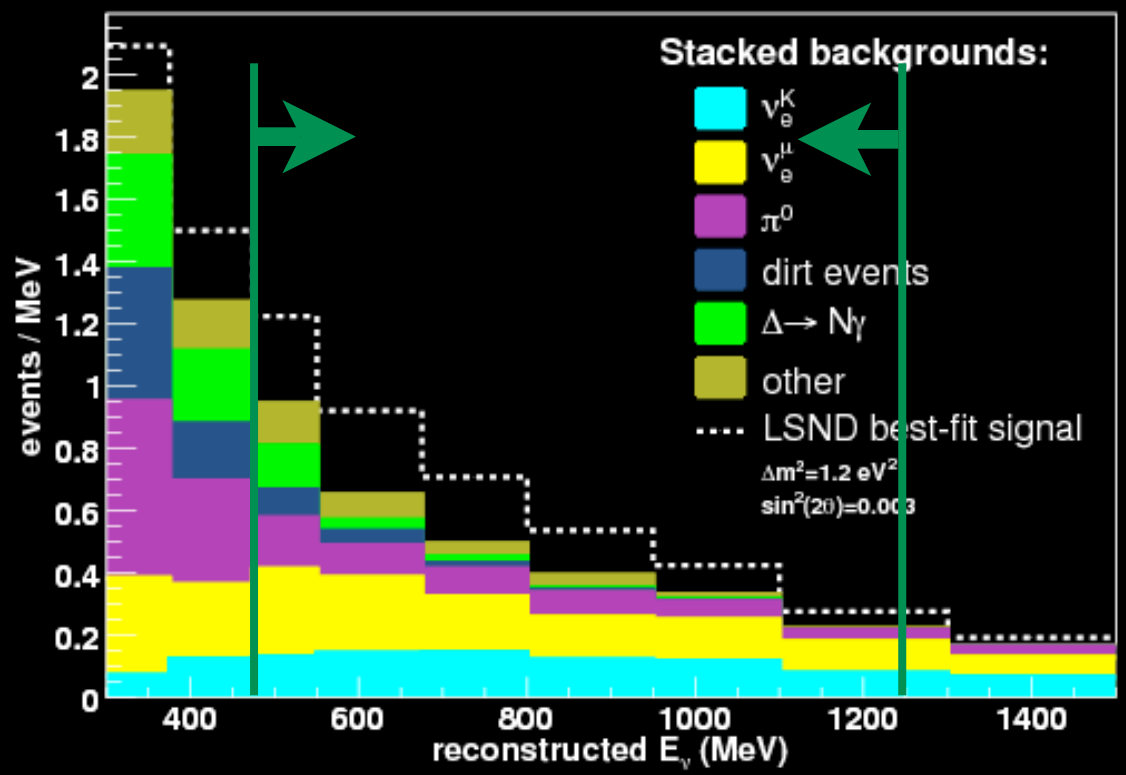
- Closed box blind analysis
- Tested recon and PID algorithms on sidebands



Signal & Background

475-1250 MeV	
ν_e(μ decay)	132
ν_e(K decay)	94
Radiative Δ	20
NCπ^0	62
Dirt	17
Other	33
Total	*358*
Signal	*163*

Predicted ν_e energy distribution

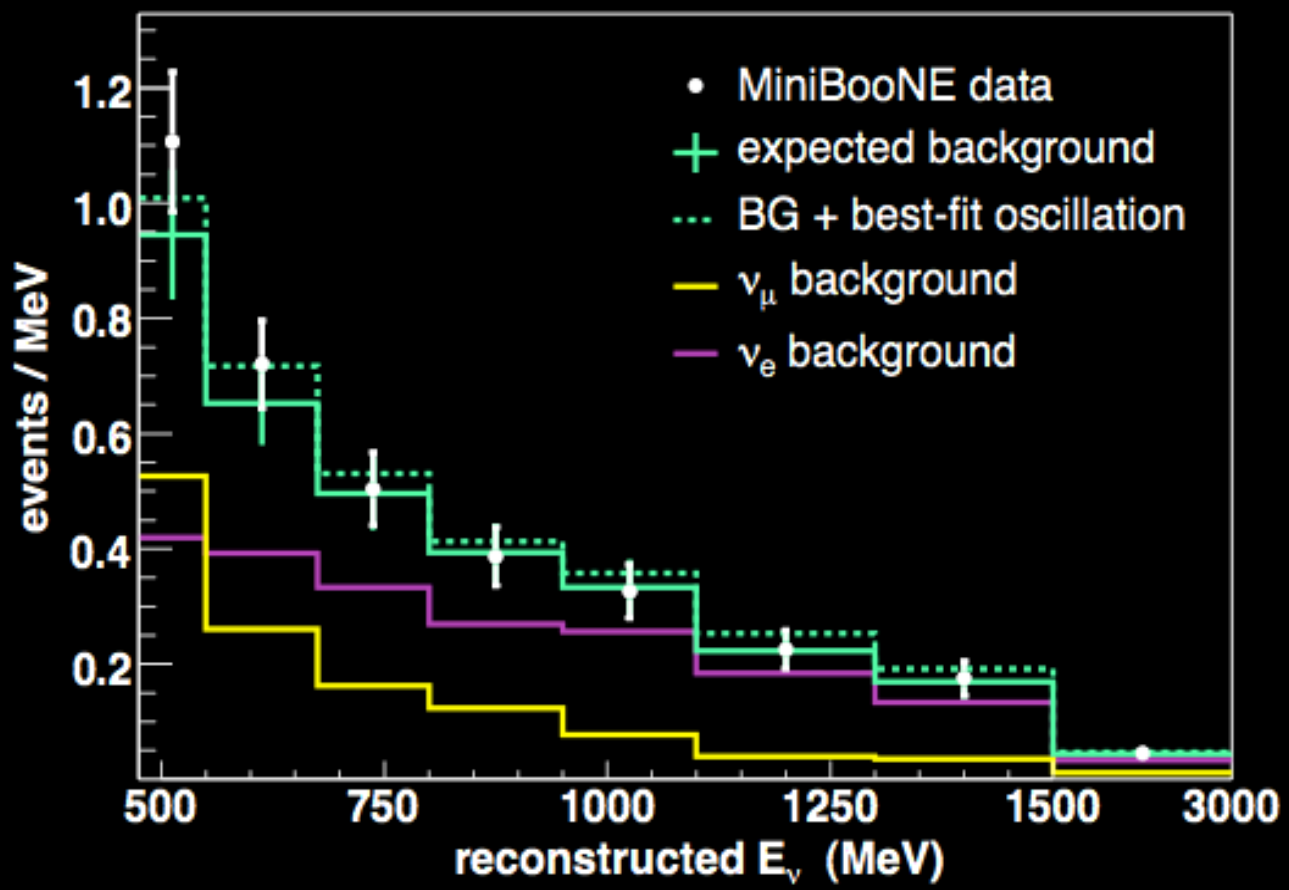


Uncertainties

	source	***uncertainty (%)***
√	Flux from π^+/μ^+ decay	6.2
√	Flux from K^+ decay	3.3
√	Flux from K^0 decay	1.5
	Target and beam models	2.8
√	ν-cross section	12.3
	NC π^0 yield	1.8
	External interactions	0.8
√	Optical model	6.1
	Electronics & DAQ model	7.5
	constrained total	9.6

Note:
"total" is **not** the quadrature sum-- errors are further reduced by constraints from ν_μ data

Opened box!

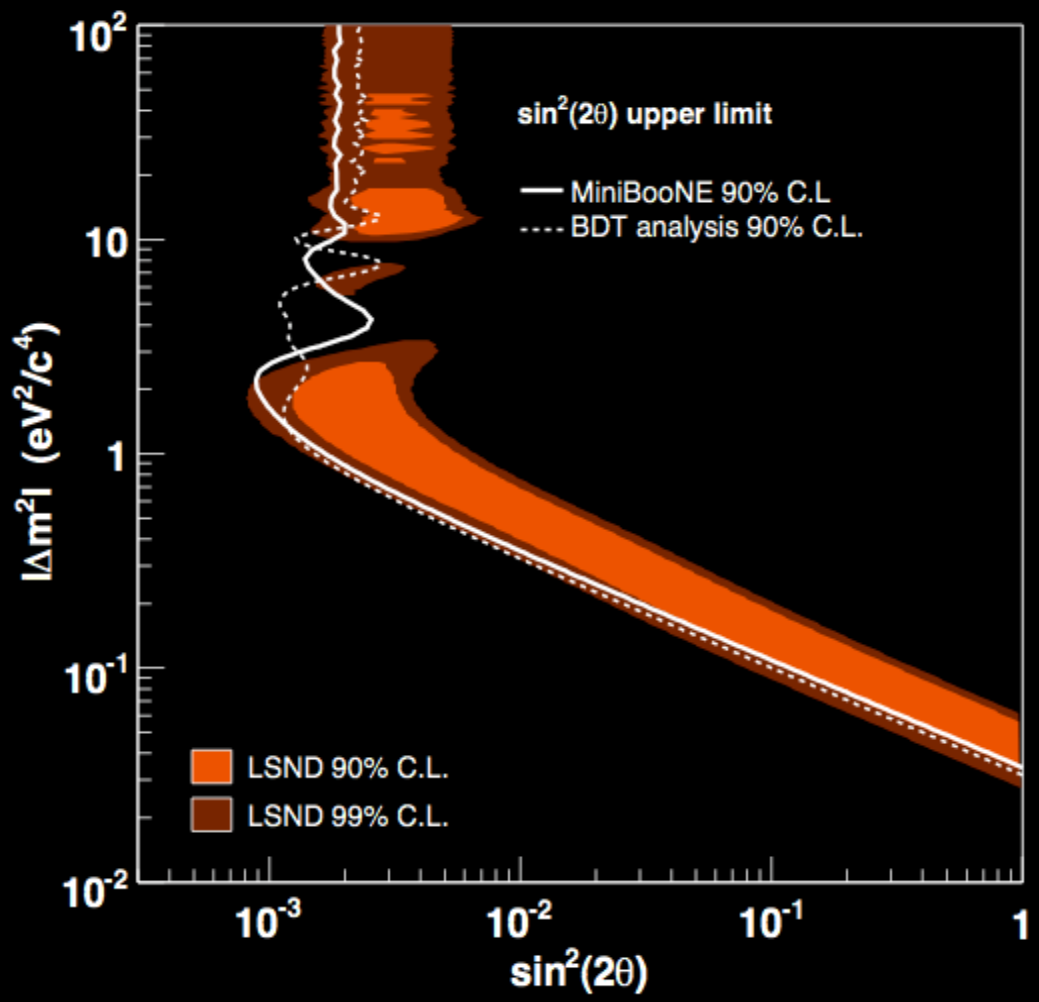


- Counting Experiment (475-1250 MeV)
- Expect 358 ± 19(stat) ± 35(sys)
- Observe 380
- Significance 0.55 σ

Exclusion Curve

- No evidence for $\nu_\mu \rightarrow \nu_e$ 2ν appearance only oscillations
- Independent second analysis finds similar result
- Incompatible with LSND at 98% CL
  - cf. KARMEN2 compatible at 64%

MiniBooNE First Result



What Does It Mean?

- With the blind analysis, we have asked the question:

Do ν_μs oscillate directly to ν_es with $\Delta m^2 \sim 1 eV^2$, ala LSND?

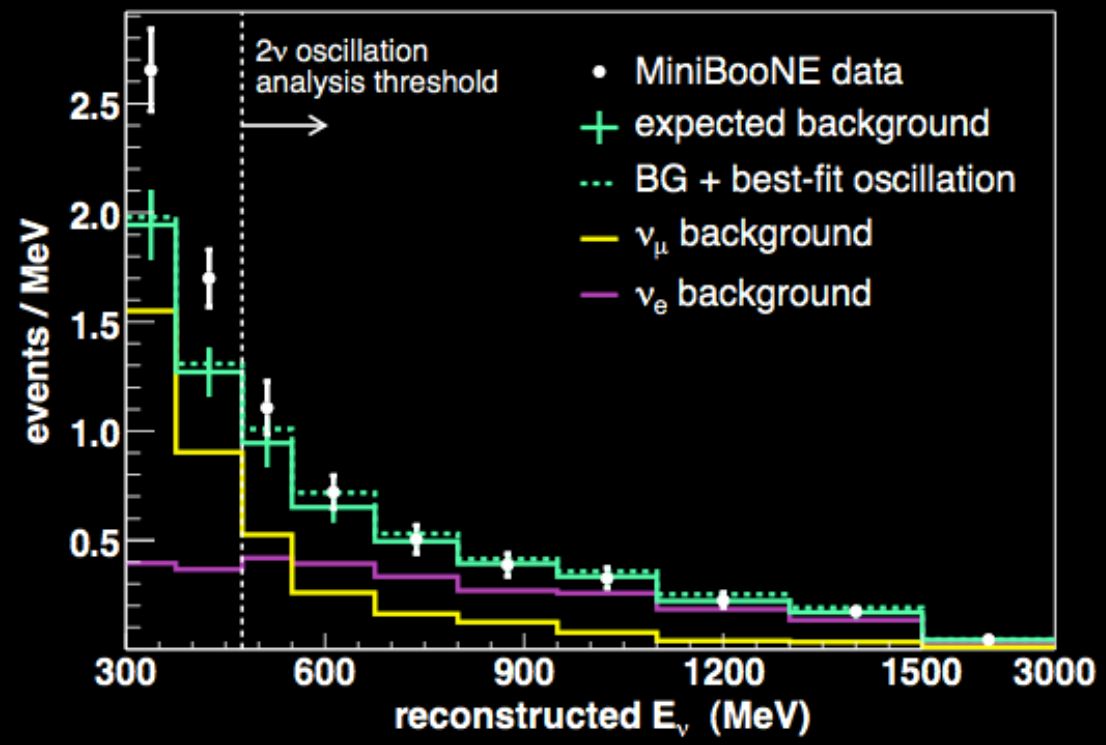
- We have a clear answer:

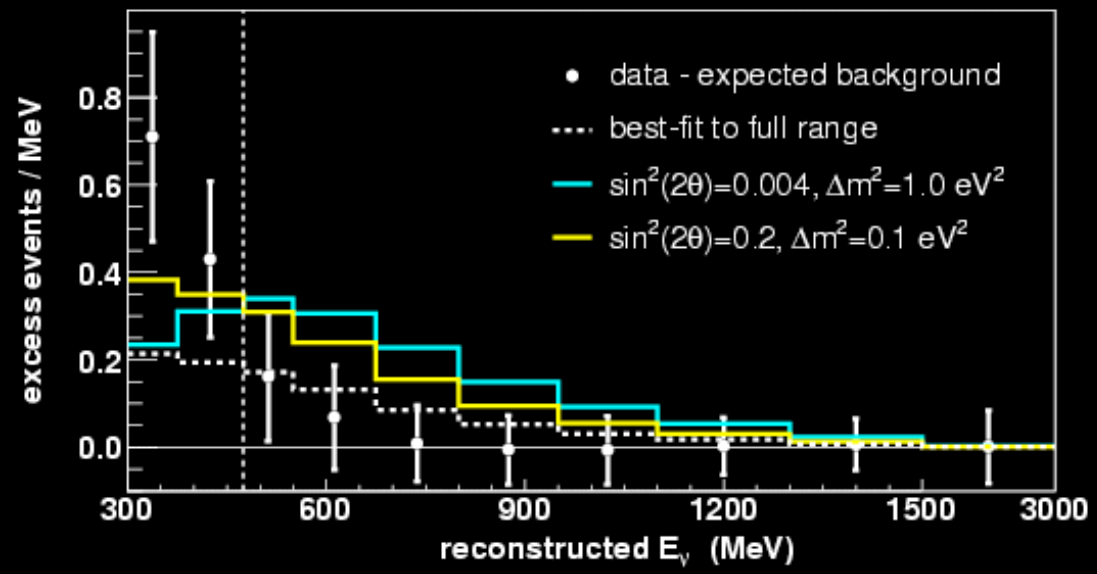
NO

More work yet to do...

At lower energy...

- Lowering the energy threshold reveals ν_e excess
- Excess not consistent with LSND signal
- Currently under investigation





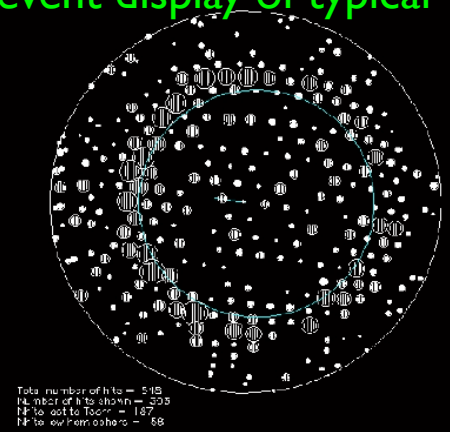
Low E checklist

- Data integrity checks
- Double check background calculations
- New backgrounds?
  - (i.e. not considered in original analysis)
  - N.B. If this is a background it may be relevant for other experiments searching for $\nu_\mu \rightarrow \nu_e$
- New physics?
- Looking at new/more data

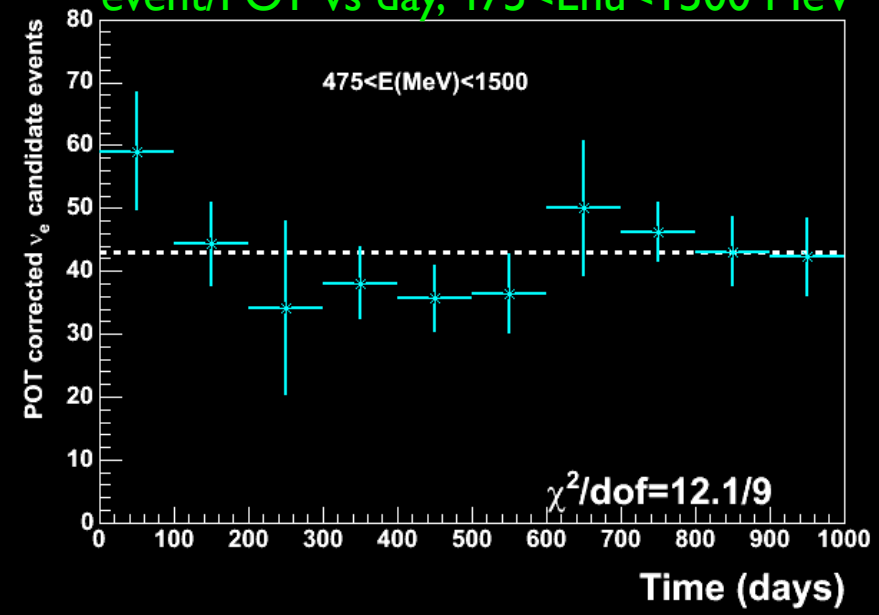
Integrity checks

- Detector anomalies: none found
  - Example: time distribution of ν_e events is flat
- Hand scanned all events: nothing pathological found

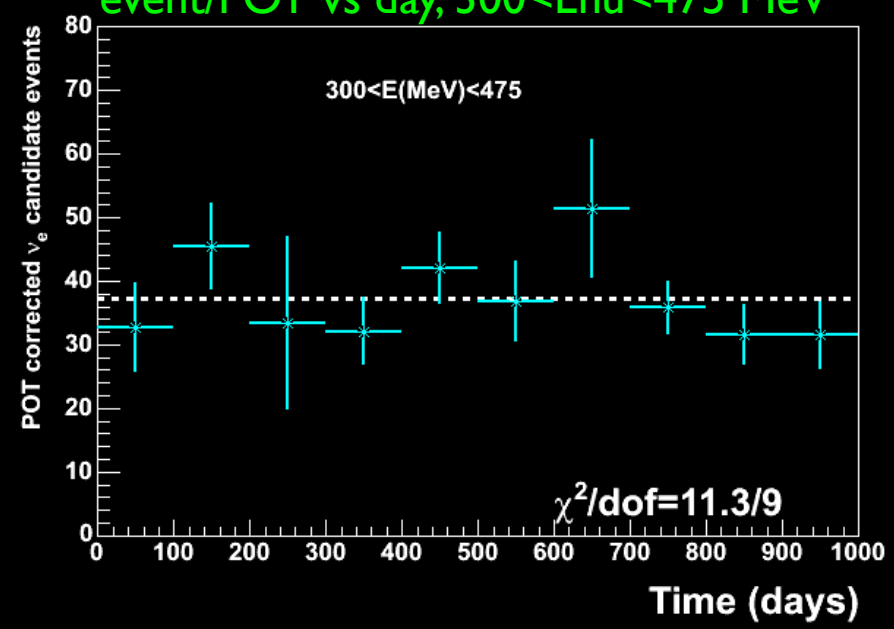
event display of typical ν_e



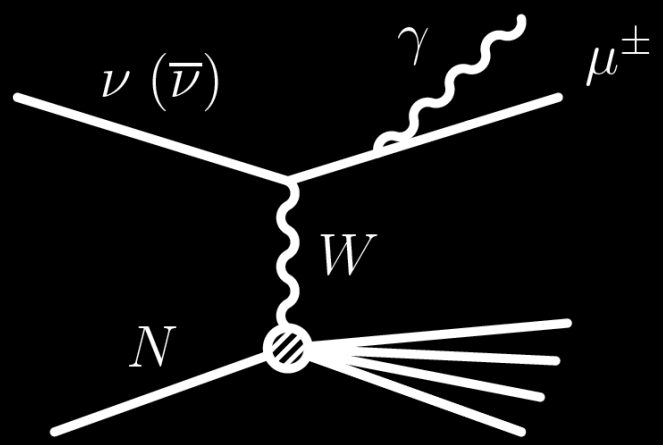
event/POT vs day, 475<Enu<1500 MeV



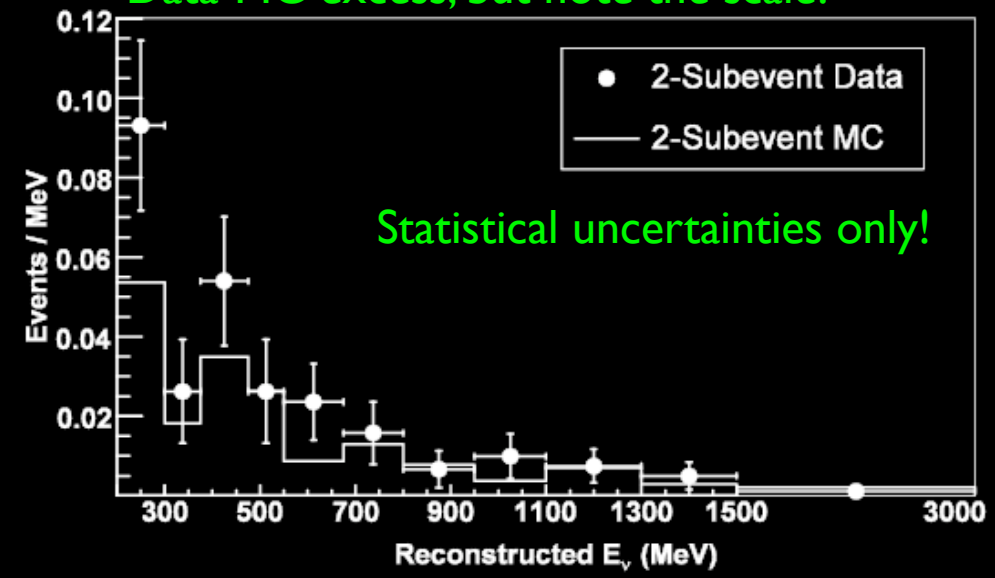
event/POT vs day, 300<Enu<475 MeV



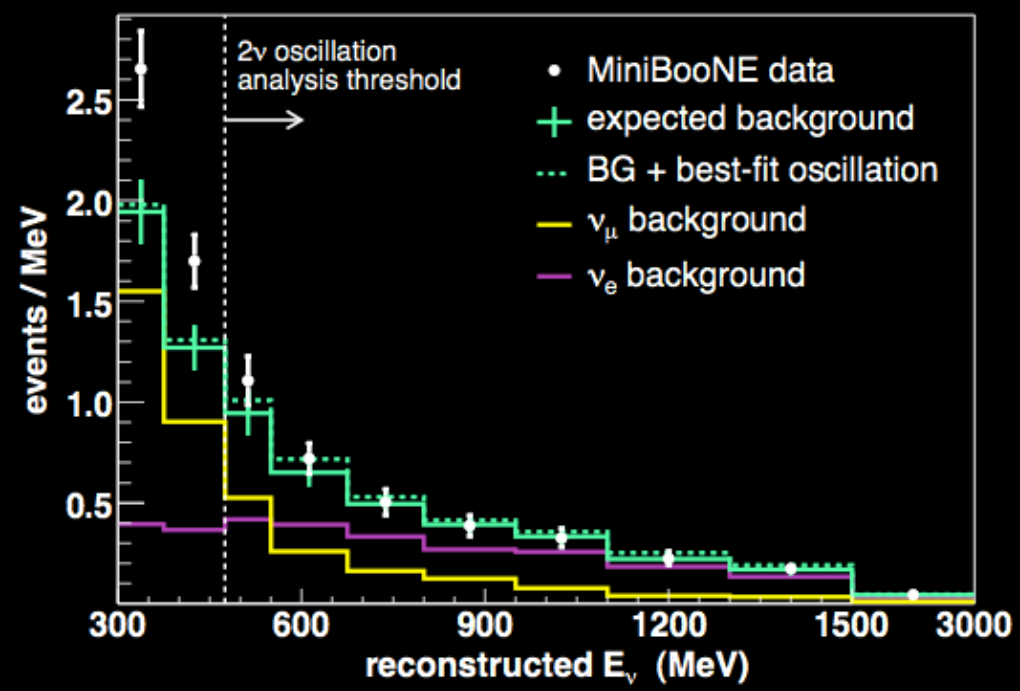
Muon Internal Brem



Data-MC excess, but note the scale!

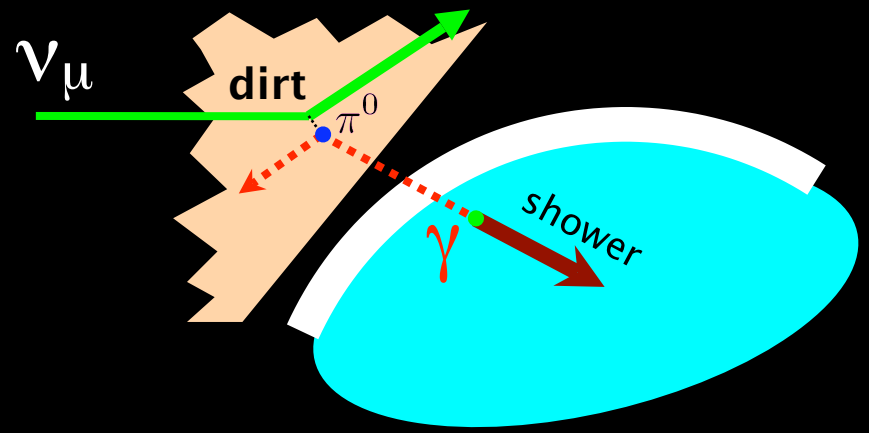


- Apply recon and PID to clean muon CCQE events
- Directly measure rate of final state muon ν_e backgrounds

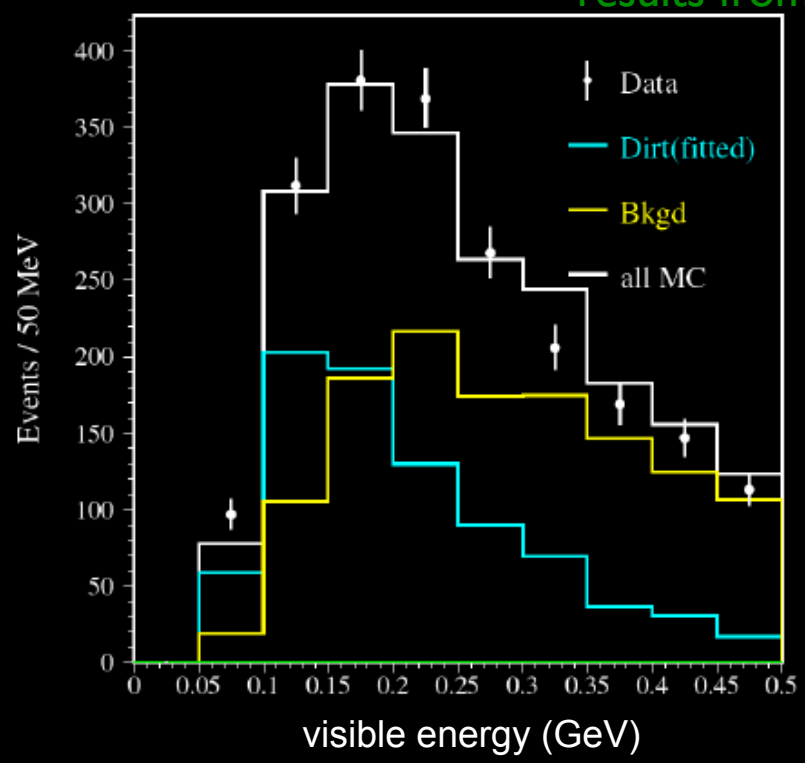


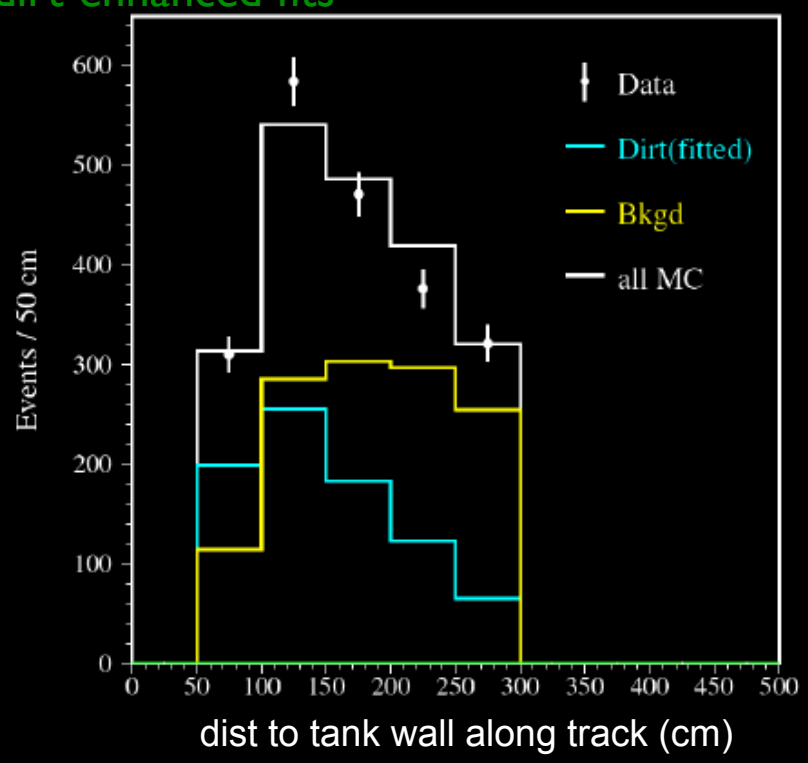
"Dirt" Backgrounds

- before box-opening, fit yielded
  - meas/pred = 1.00±0.15
- fit in different (open) sample yields
  - meas/pred = 1.08±0.12



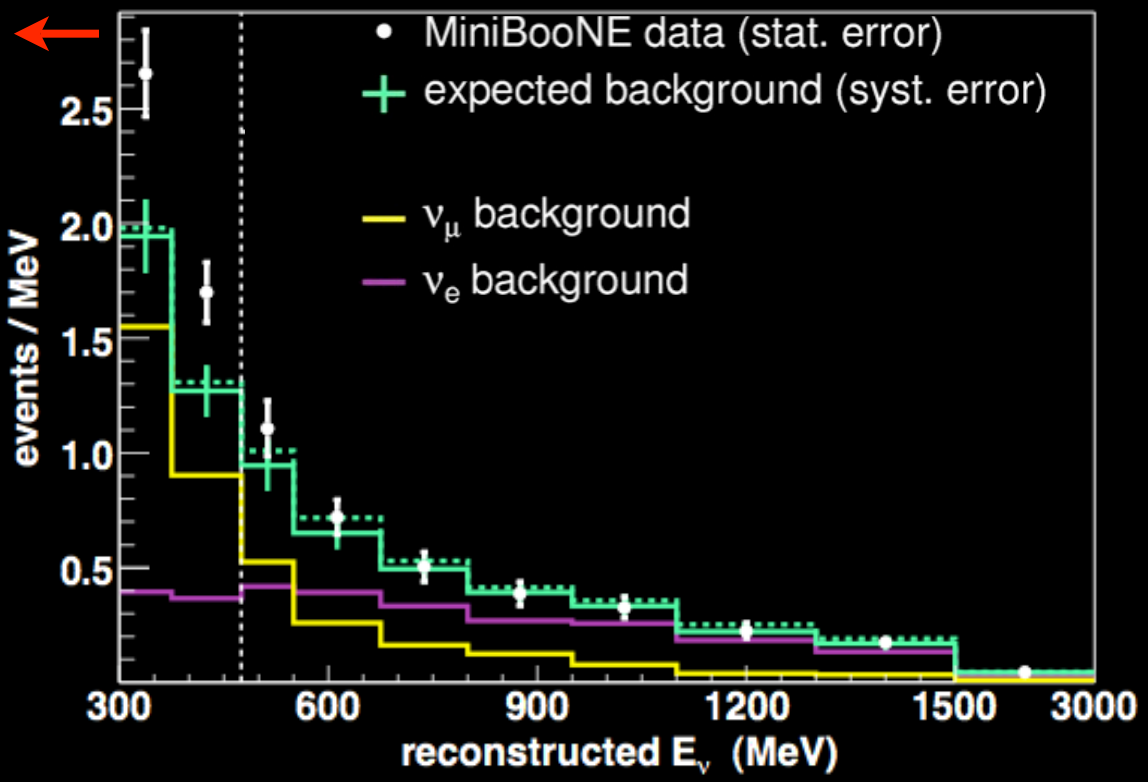
results from dirt-enhanced fits





Lower energy threshold

- More data should help
- Extended threshold to lower energy
  - required extension of systematics
- Excess persists below 300 MeV
- New bin is even more dominated by mis-ID ν_μ



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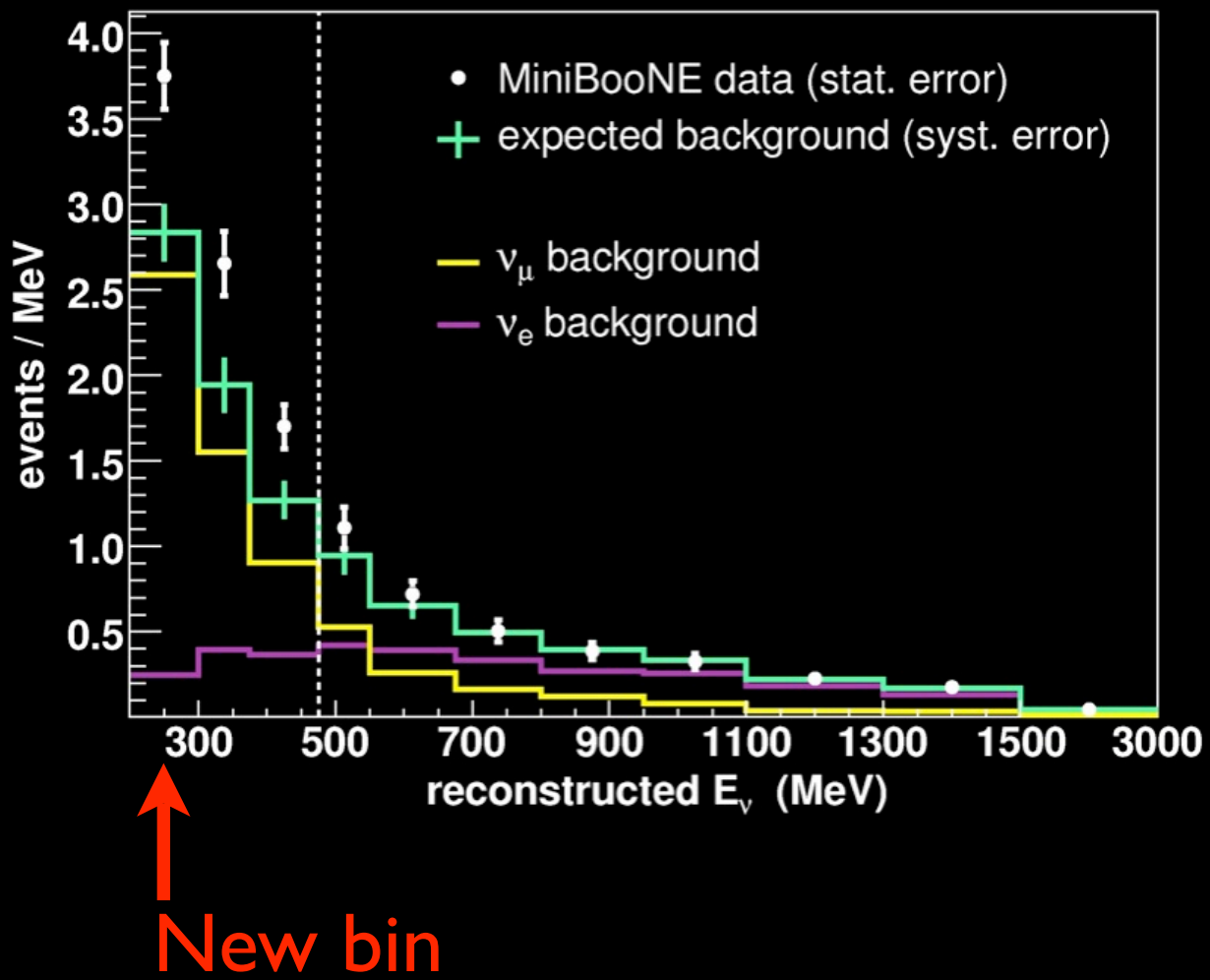
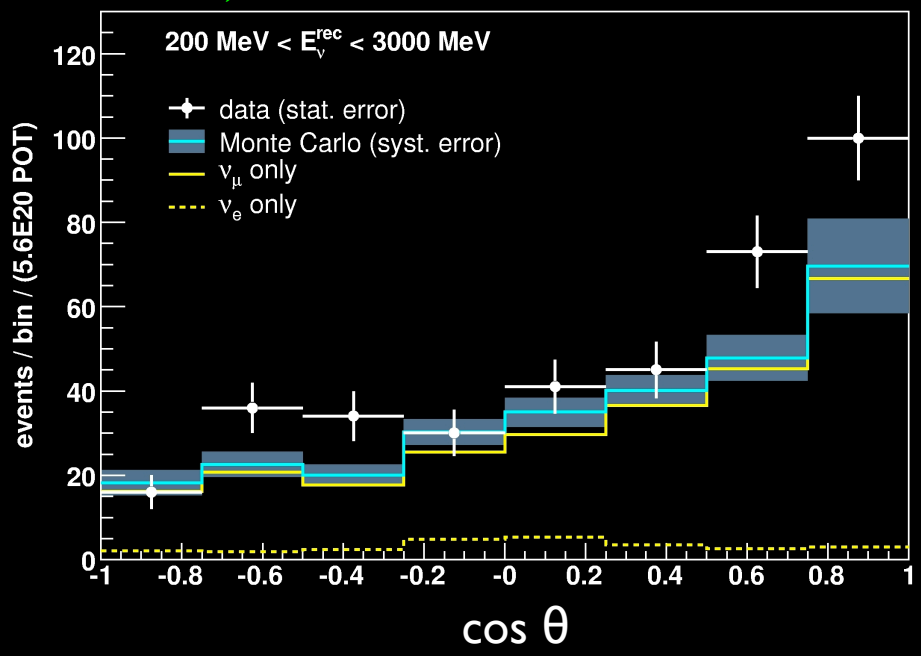


Background Breakdown

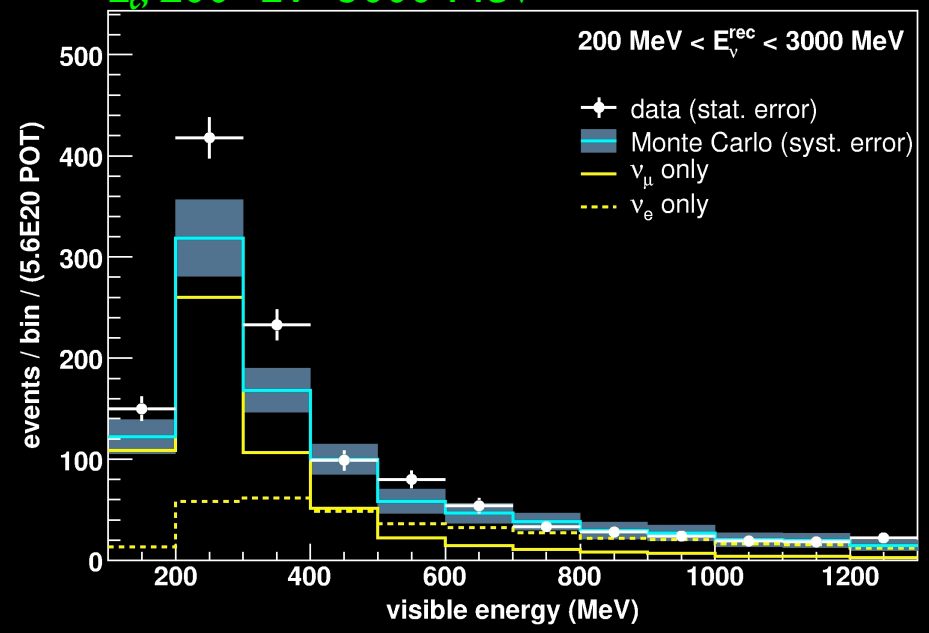
	reconstructed ν energy bin (MeV)		
	200-300	300-475	475-1250
total BG	**284±25**	**274±21**	**358±35**
ν_e *intrinsic*	26	67	229
ν_μ *induced*	258	207	129
NC π^0	*115*	*76*	*62*
NC $\Delta \rightarrow N\gamma$	*20*	*51*	*20*
Dirt	*99*	*50*	*17*
other	*24*	*30*	*30*
DATA	**375±19**	**369±19**	**380±19**

Visible Energy & Angles

cos θ , 200<Eν<3000 MeV



E_ℓ, 200<Eν<3000 MeV

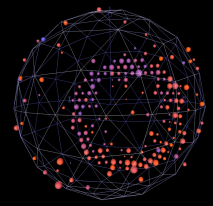


- Recall: two-body kinematics allow ν energy reconstruction from E_{lepton} and θ_{lepton}

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

- no anomalies in these distributions

E_ℓ & θ_ℓ in E_ν bins



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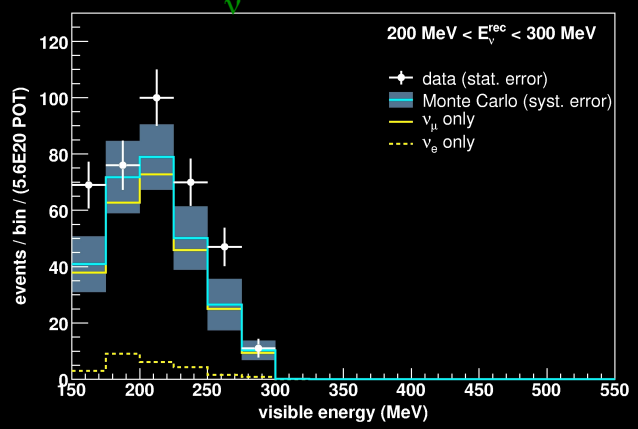
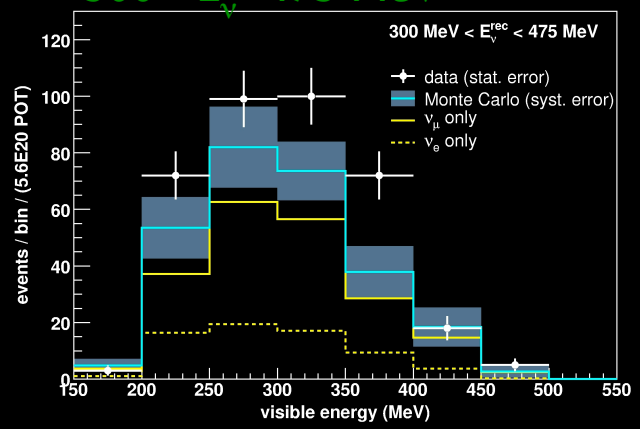


300 <E_ν <475 MeV



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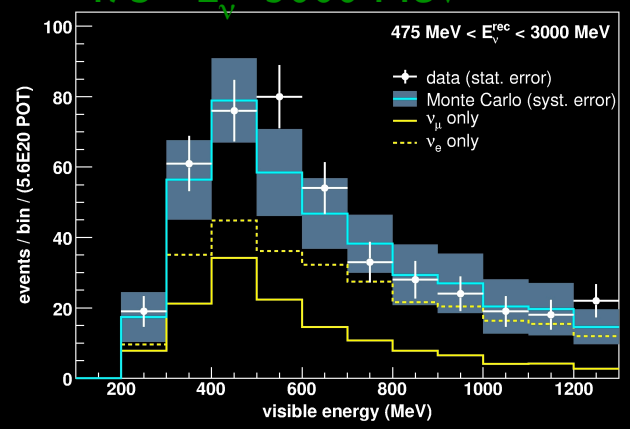

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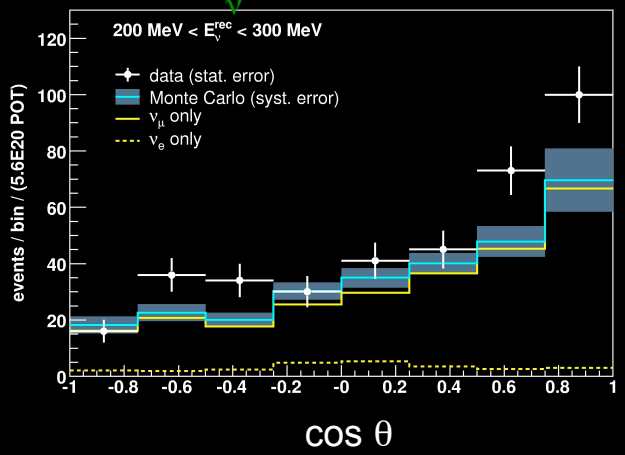

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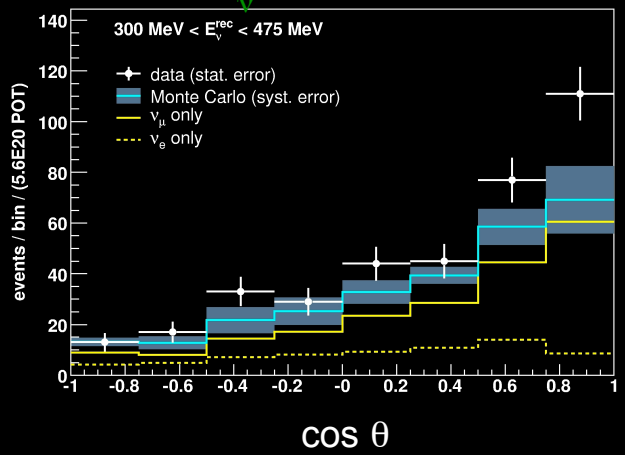

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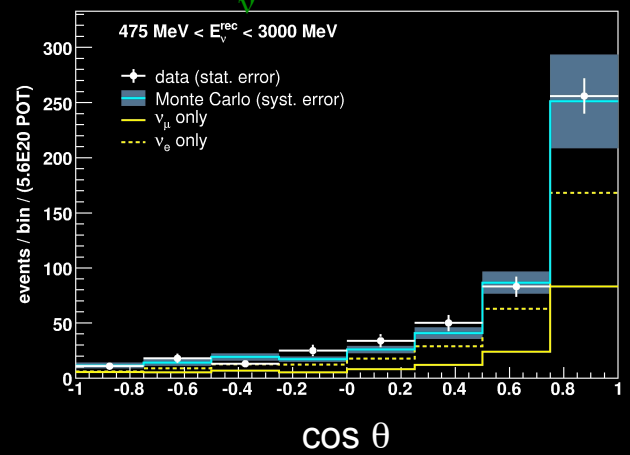


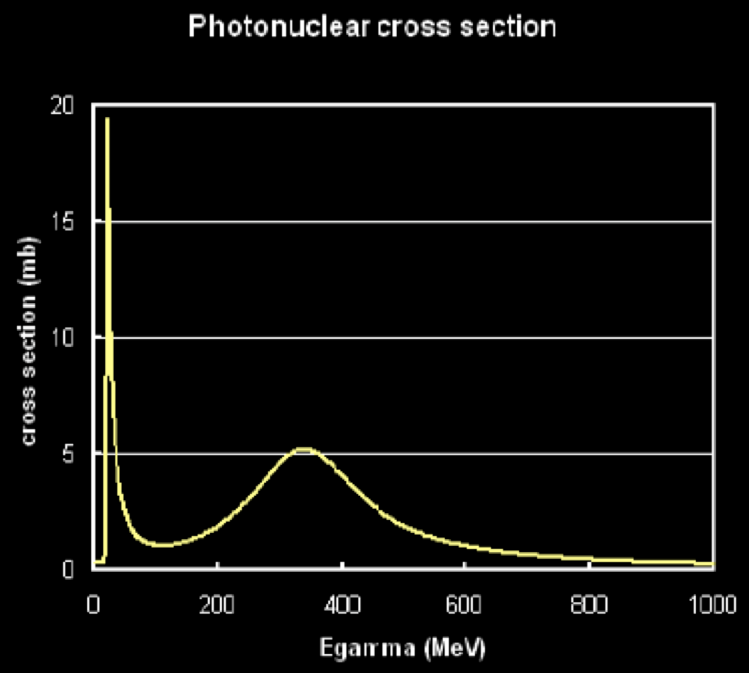
Excess distributed among E_ℓ, $\cos\theta_\ell$ bins

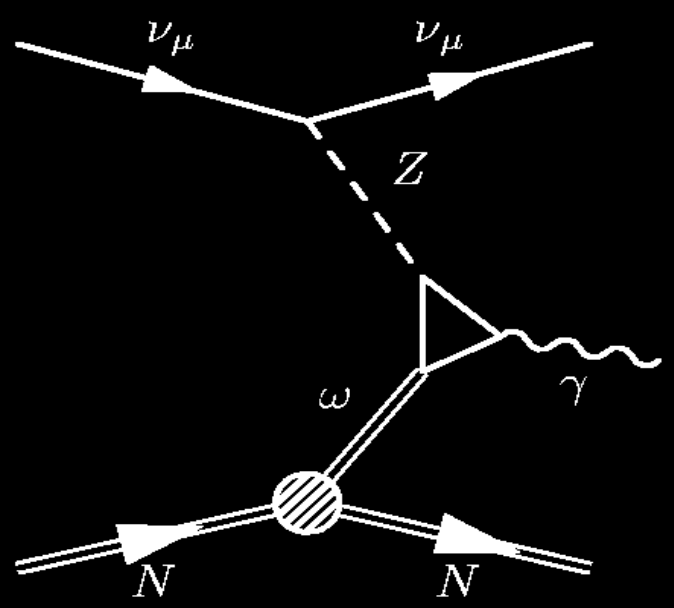
At higher energy, data are well-described by predicted background

New BG? Physics?

Difficulty distinguishing single photons from electrons

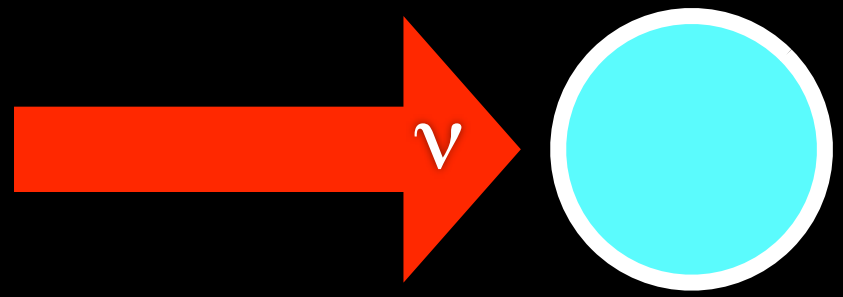
- Photo-nuclear absorption
  - Can produce low energy "ν_e" events
  - No effect on E_ν>475 MeV
- Anomaly-mediated photon production
  - arXiv:0708.1281[hep-ex]
- Both under active investigation



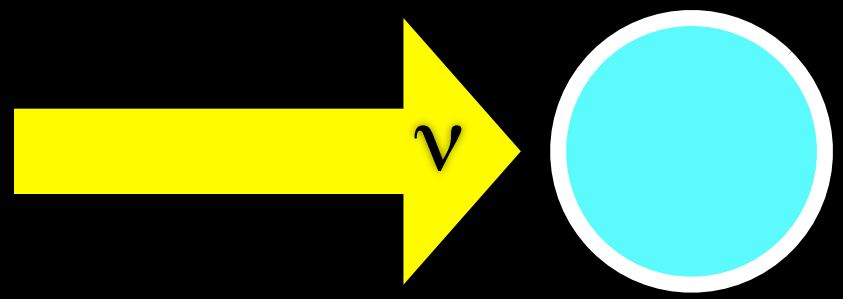


More data should help!

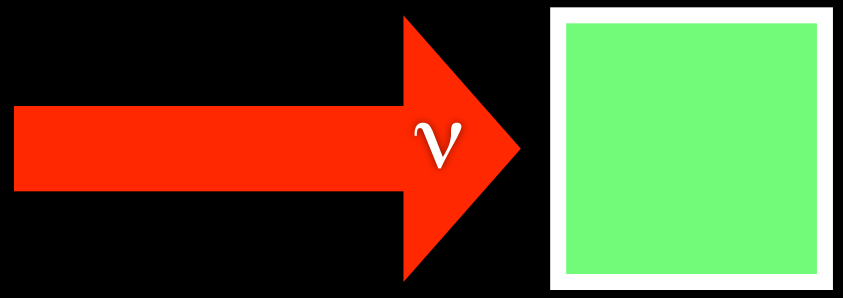
- Double check everything in MiniBooNE



- Same detector with different beam ⇒NuMI

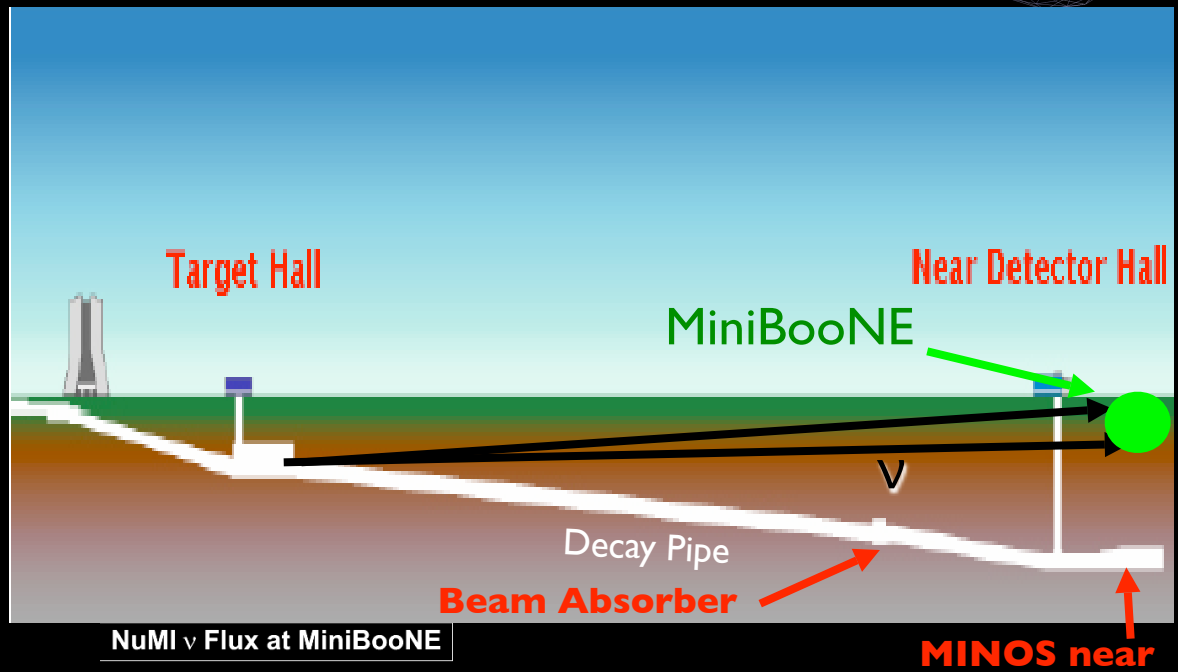


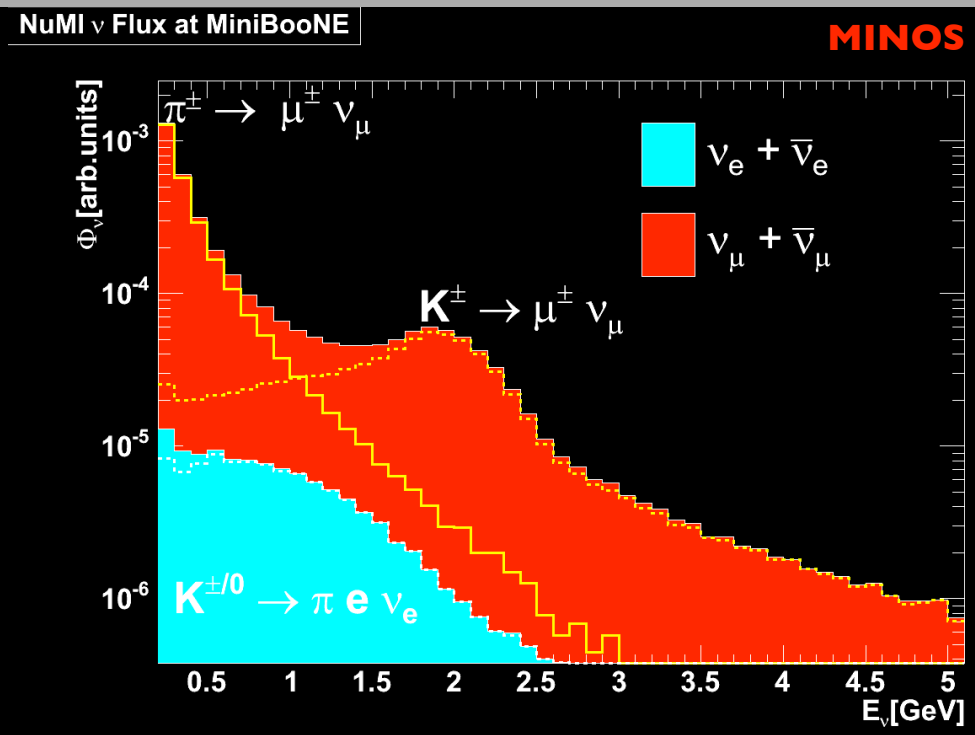
- Same beam with different detector ⇒SciBooNE



Same Det. Diff. Beam

- MiniBooNE can see neutrinos from the NuMI beam
- Off-axis beam
  - 110 mrad
- Enriched ν_e sample
  - Very different energy for ν_μ components
- Results coming soon!

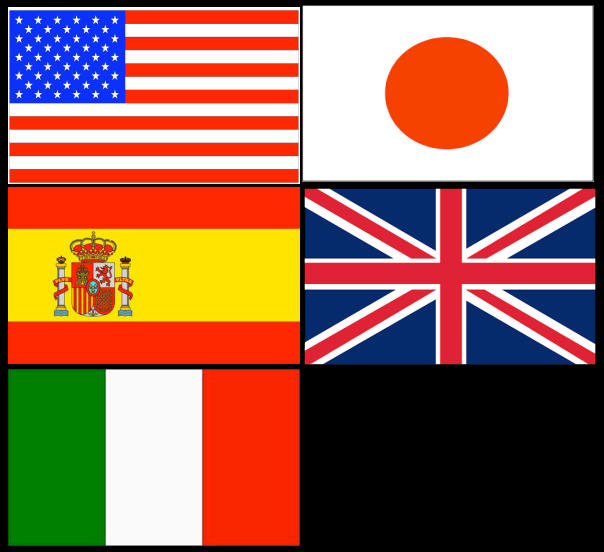




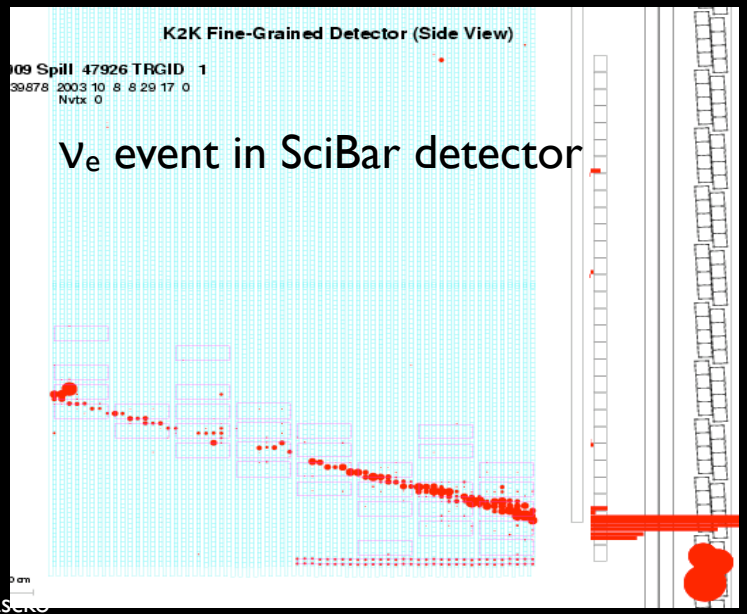
Same Beam Diff. Det.

SciBooNE

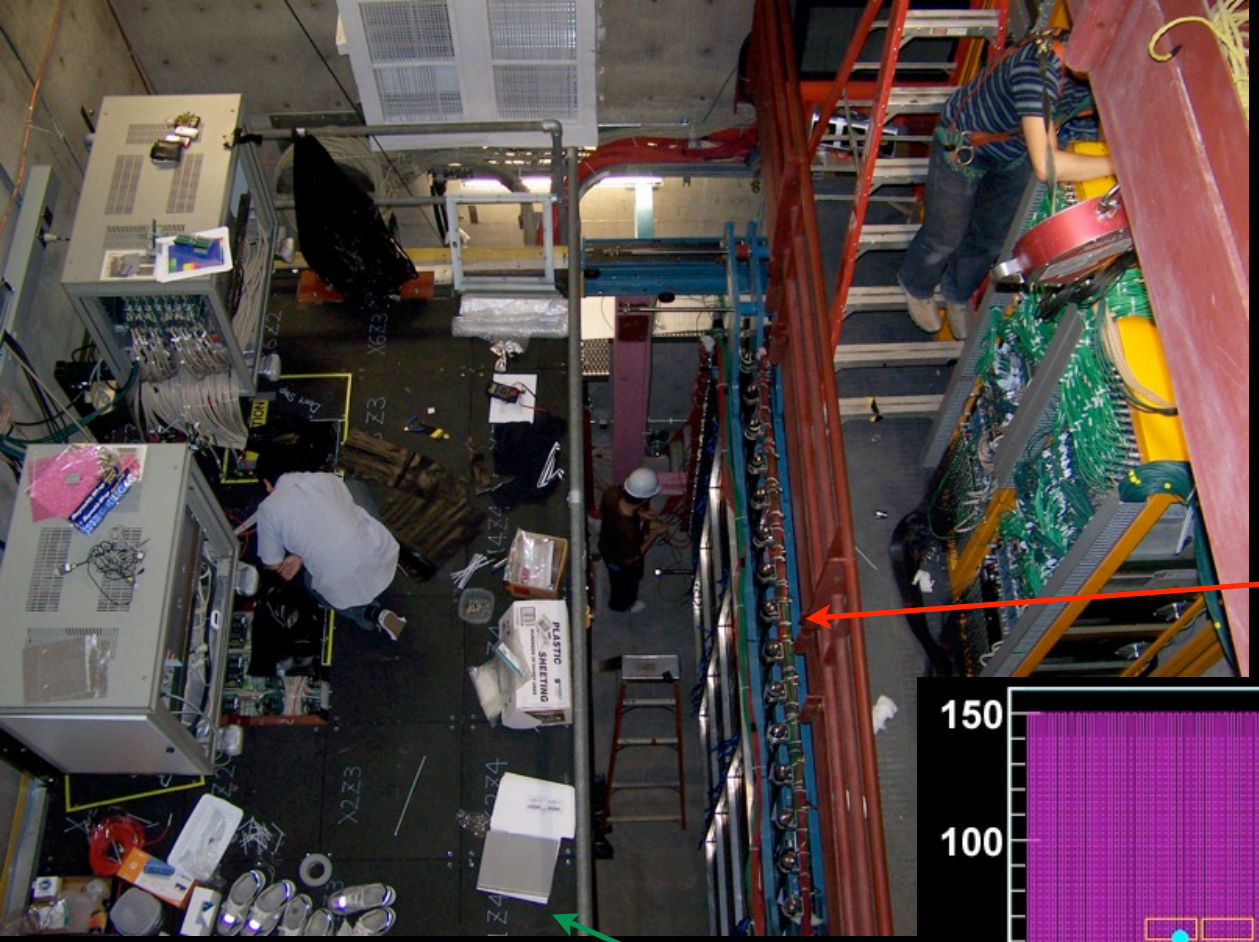
- New experiment at Fermilab
- Near Detector in BNB
- Better at distinguishing photons from electrons
  - Check MiniBooNE's background estimates



Spokespeople:
T. Nakaya, Kyoto University
M.O. Wascko, Imperial College

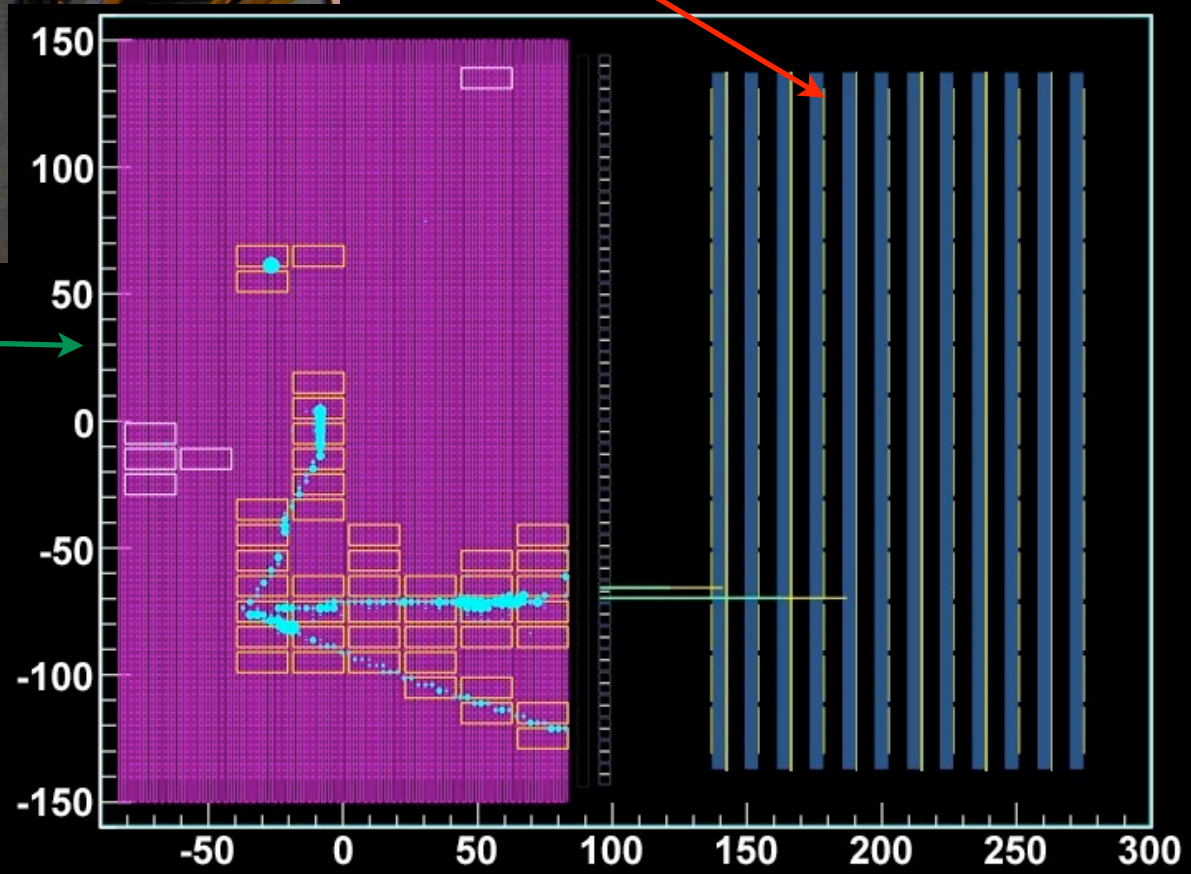


SciBooNE



- *Data run started this summer*

Muon Range Detector

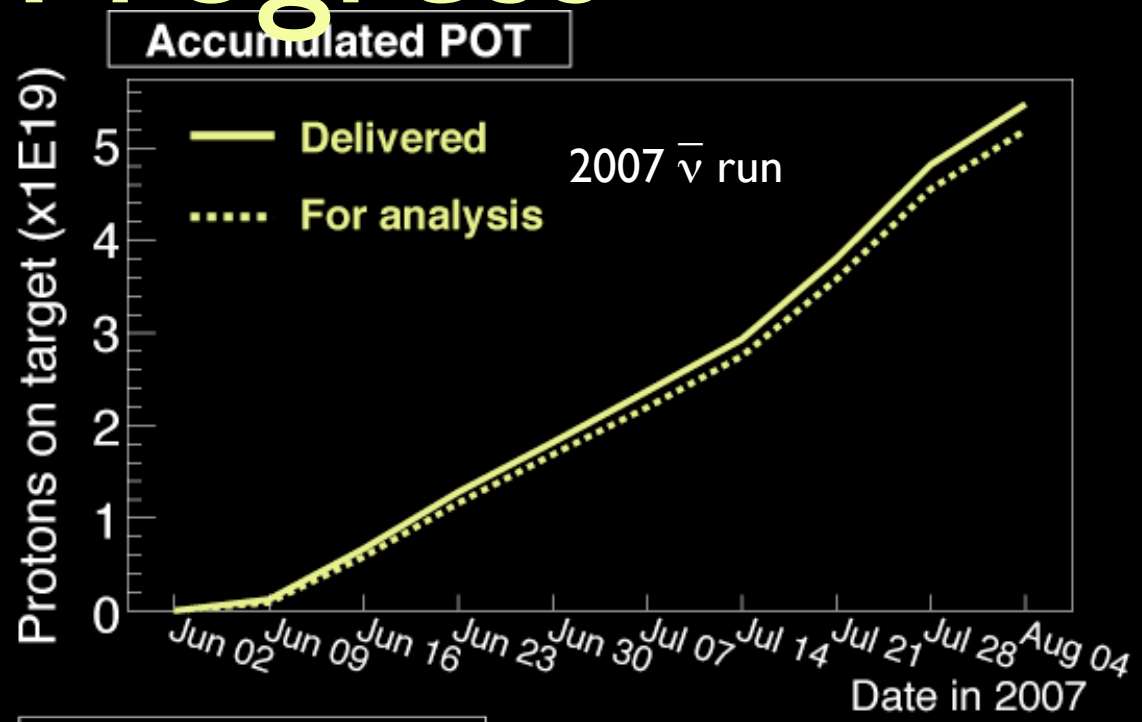


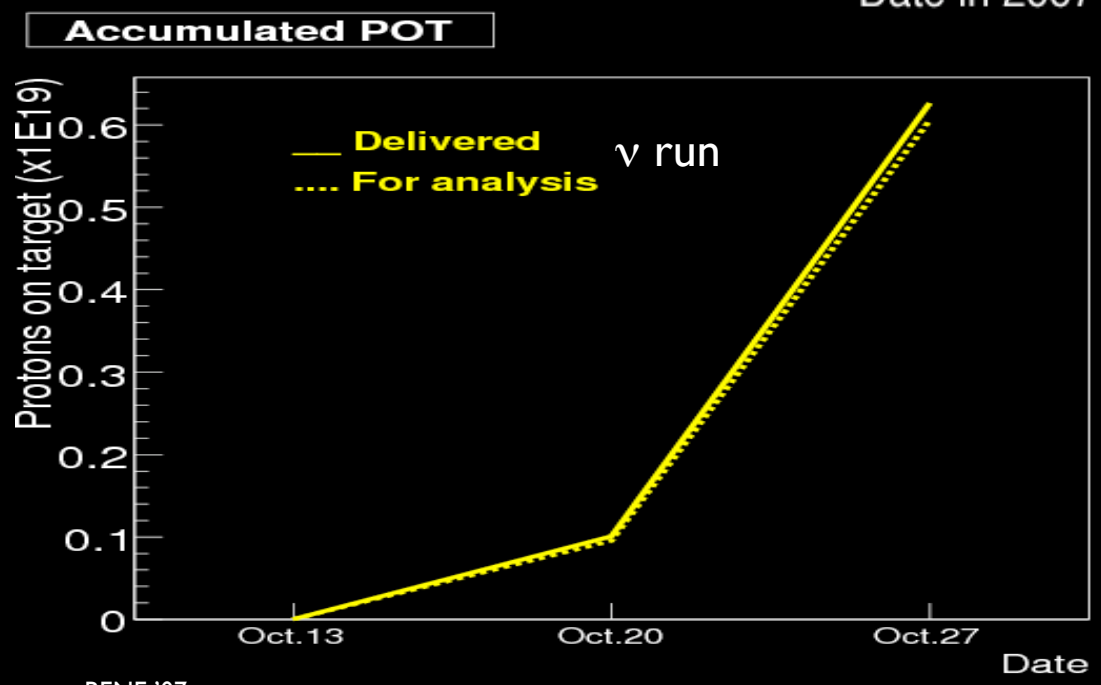
SciBar/EC Detectors

- *Now taking data (as I speak!)*

Data Progress

- Expect 2.0e20 POT total
  - 1.0e20 neutrino
  - 1.0e20 antineutrino
- Collected 0.54e20 POT antineutrinos already
- Now running in neutrino mode
  - Only 1 dead channel in 14,336+256+362





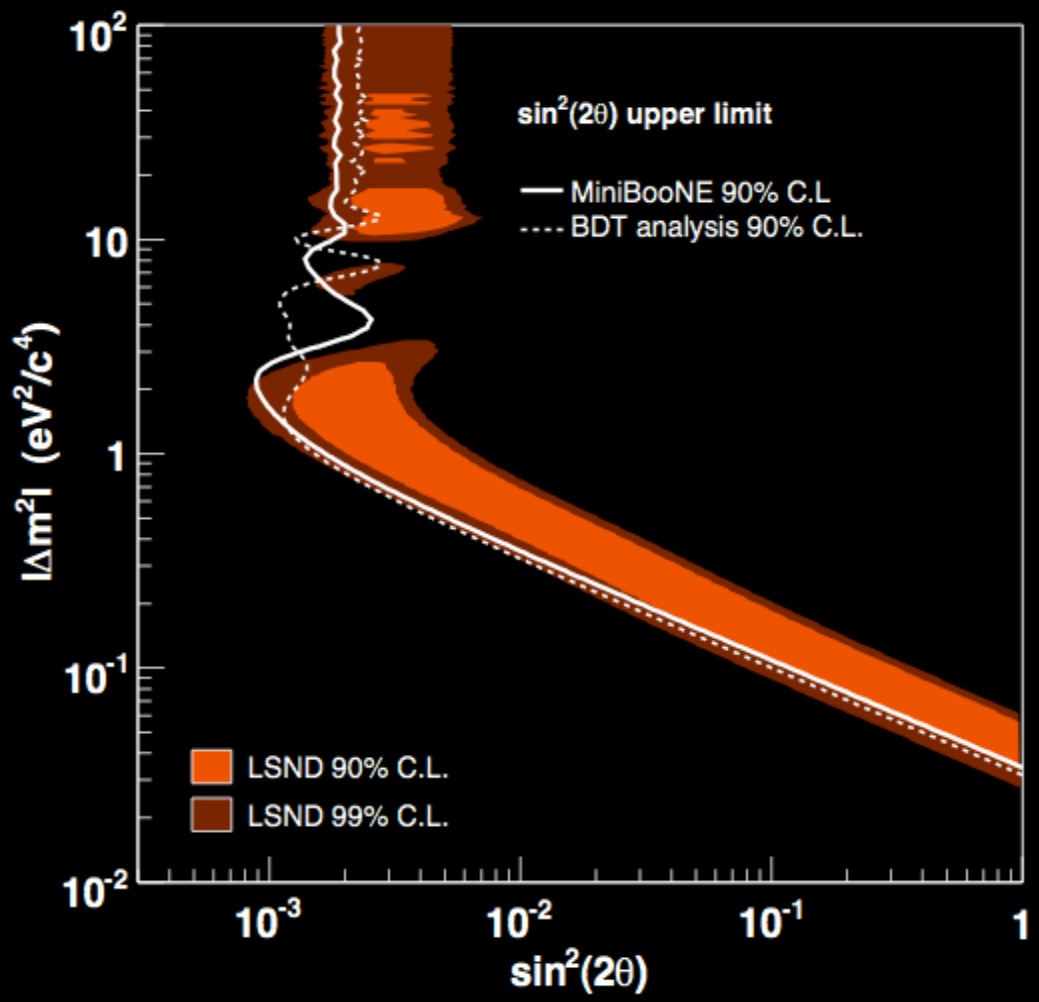
What's Next?

- MiniBooNE is publishing more papers:
  - Neutrino cross section measurements
  - Joint analysis of MiniBooNE, LSND and KARMEN data
  - More exotic oscillation analyses
    - ν_e disappearance
      - Laveder & Giunti (arXiv:0707.4593)
    - 2 or 3 sterile neutrinos with CP violation
      - Maltoni & Schwetz (hep-ph/07050107)
        - MiniBooNE analysis coming soon
- Results of NuMI-MB analysis very soon
  - Fermilab "Wine & Cheese" Seminar before end of the year
- MiniBooNE is pursuing $\bar{\nu}_e$ appearance search now

Summary

- MiniBooNE observes no evidence for $\nu_\mu \rightarrow \nu_e$ 2ν oscillations
- Incompatible with LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation signal at 98% CL
- Low energy excess under investigation
  - More data coming soon

MiniBooNE First Result

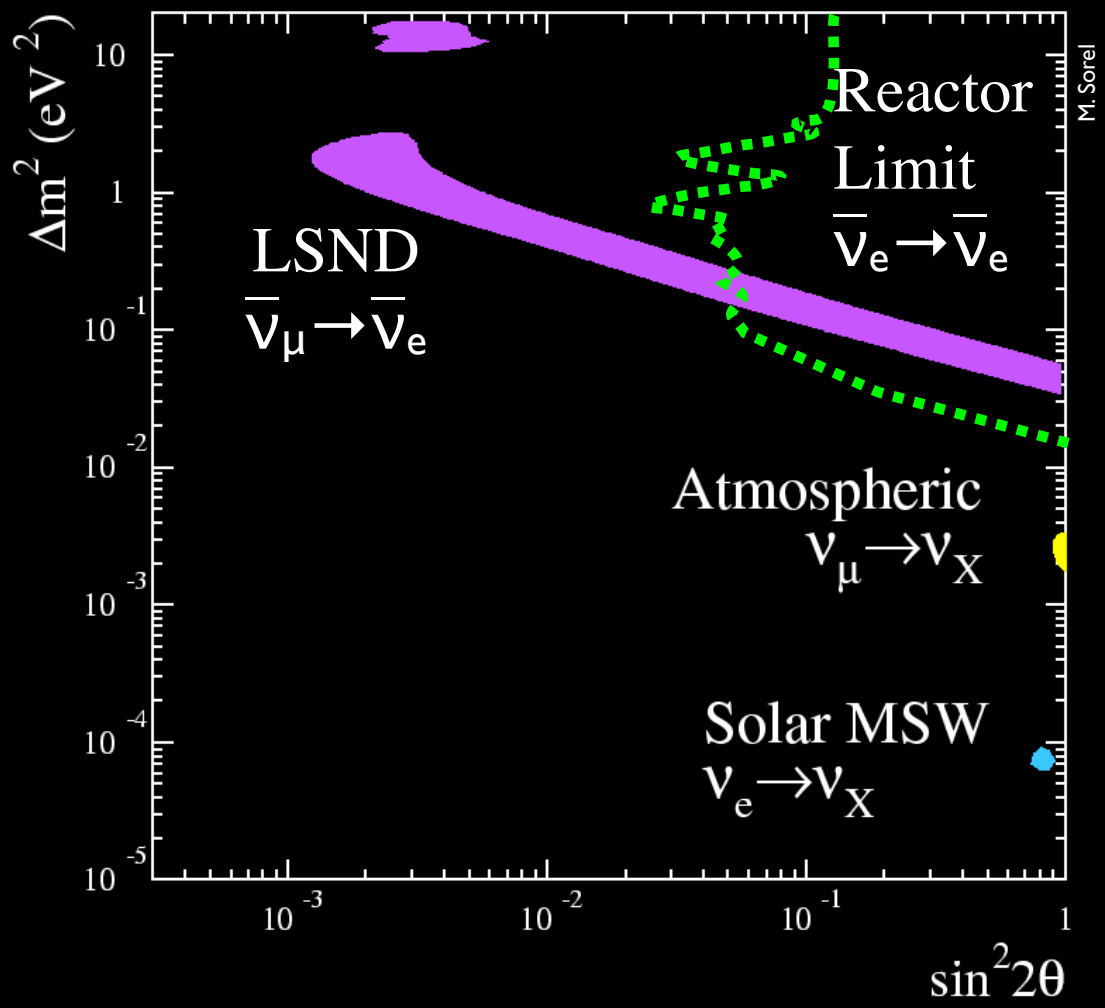


Phys.Rev.Lett. 98, 231801 (2007)
arXiv:0704.1500 [hep-ex]

Backup slides

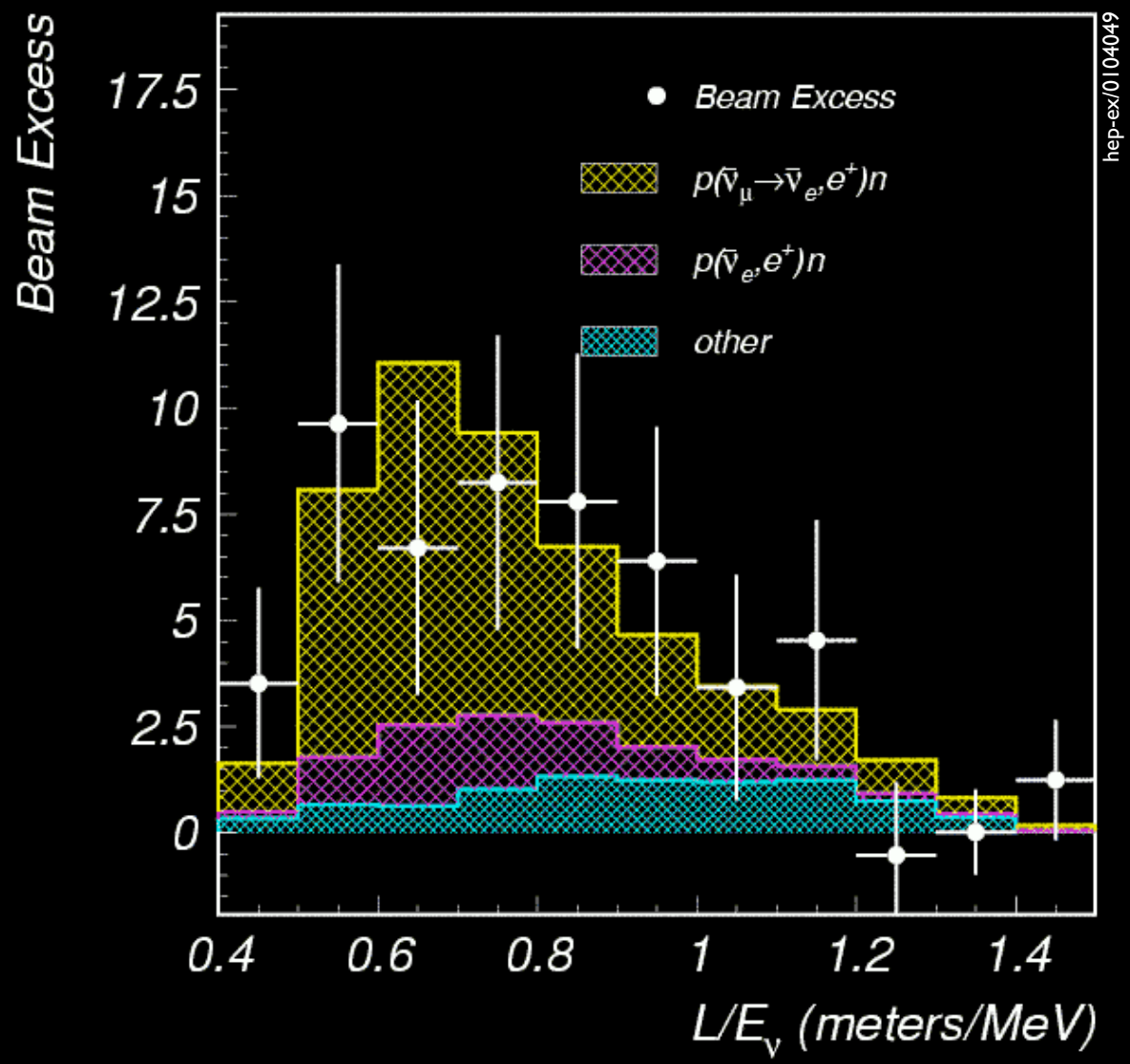
Motivation

- Three different neutrino oscillation signals
- Three independent Δm^2
- Problem:
  We only need two!
- Explanation requires physics well beyond the standard model
- Is it true?



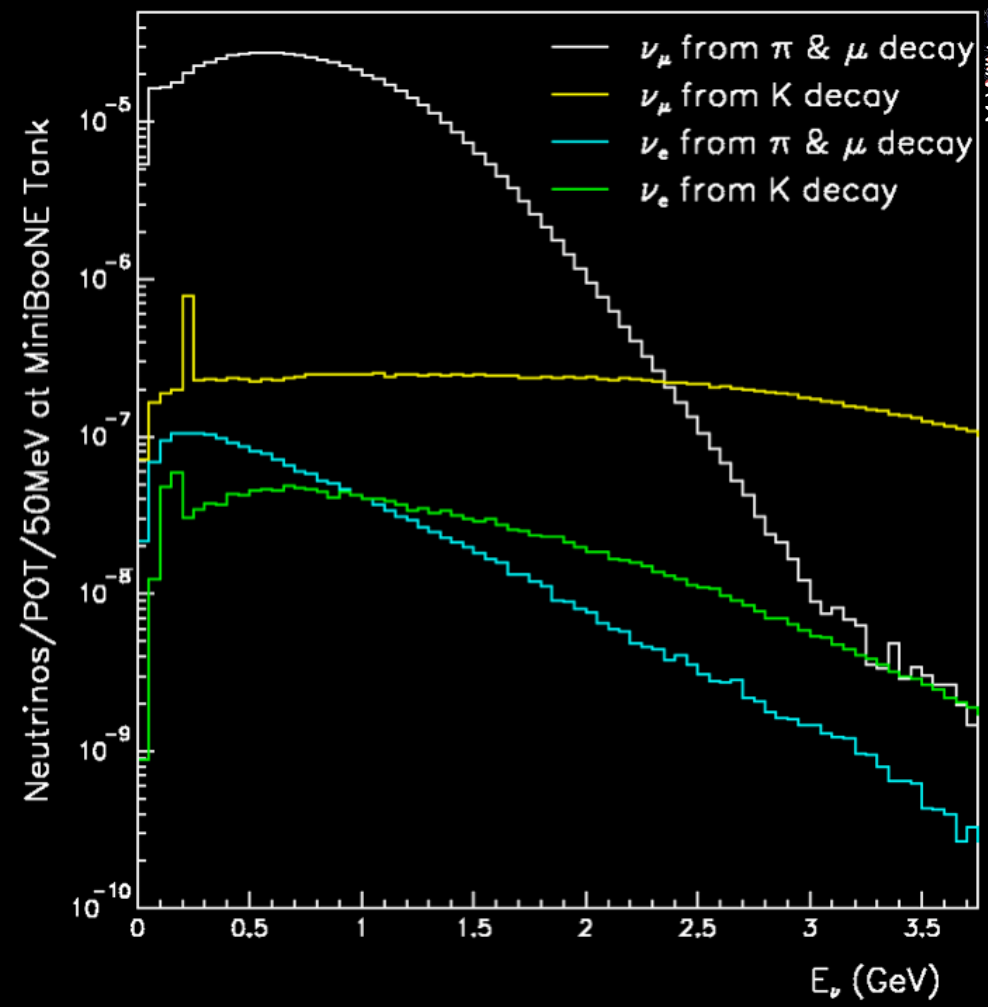
LSND Signal

- Clean experimental signature
  - Stopped pion neutrino source
  - Delayed coincidence detection signal
- excess: 87.9 ± 22.4 ± 6.0
- Interpreted as 2 ν oscillation
- $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = 0.26\%$

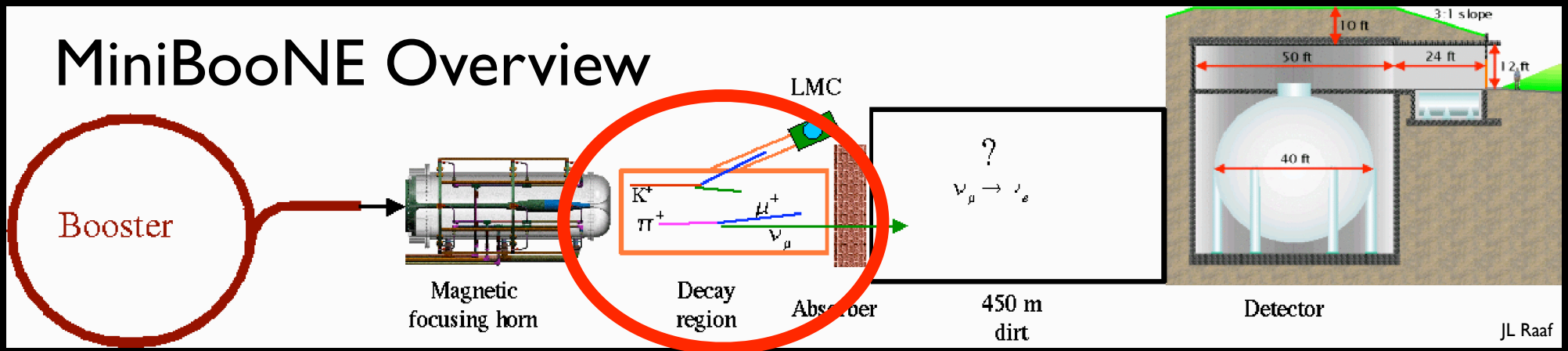


ν Flux

- 99.5% pure muon flavour
- 0.5% intrinsic ν_e
- Constrain ν_e content with ν_μ measurements

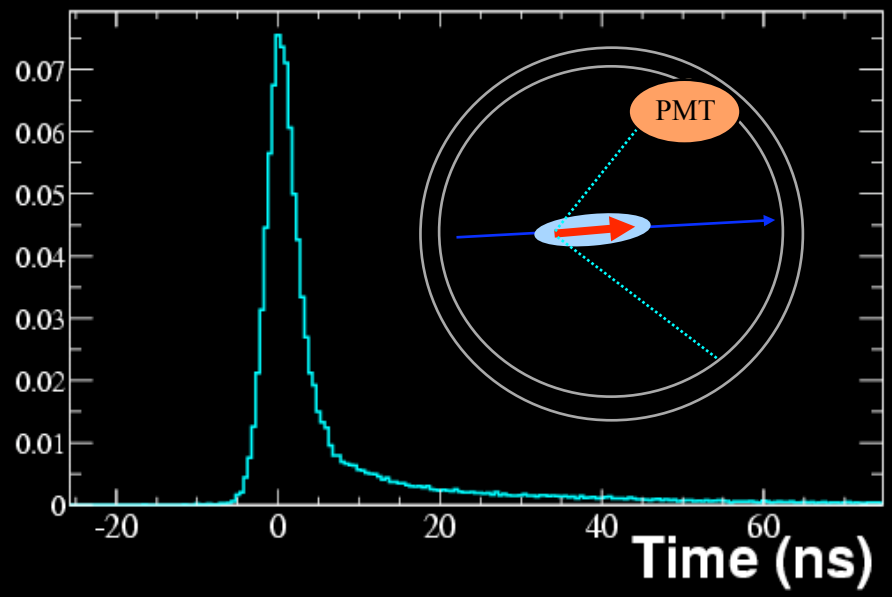


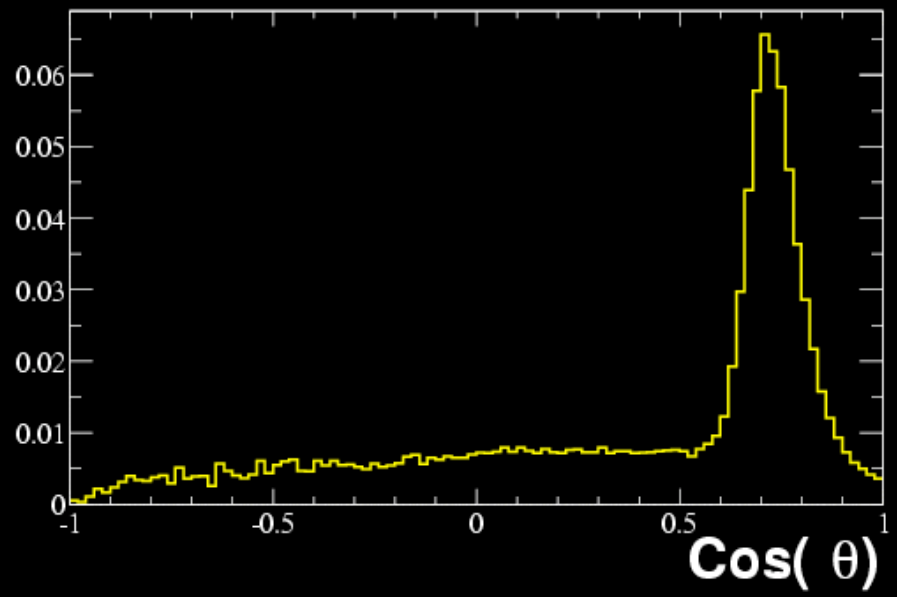
M. Wilking



Track Reconstruction

Charged particles produce Cherenkov and scintillation light in oil





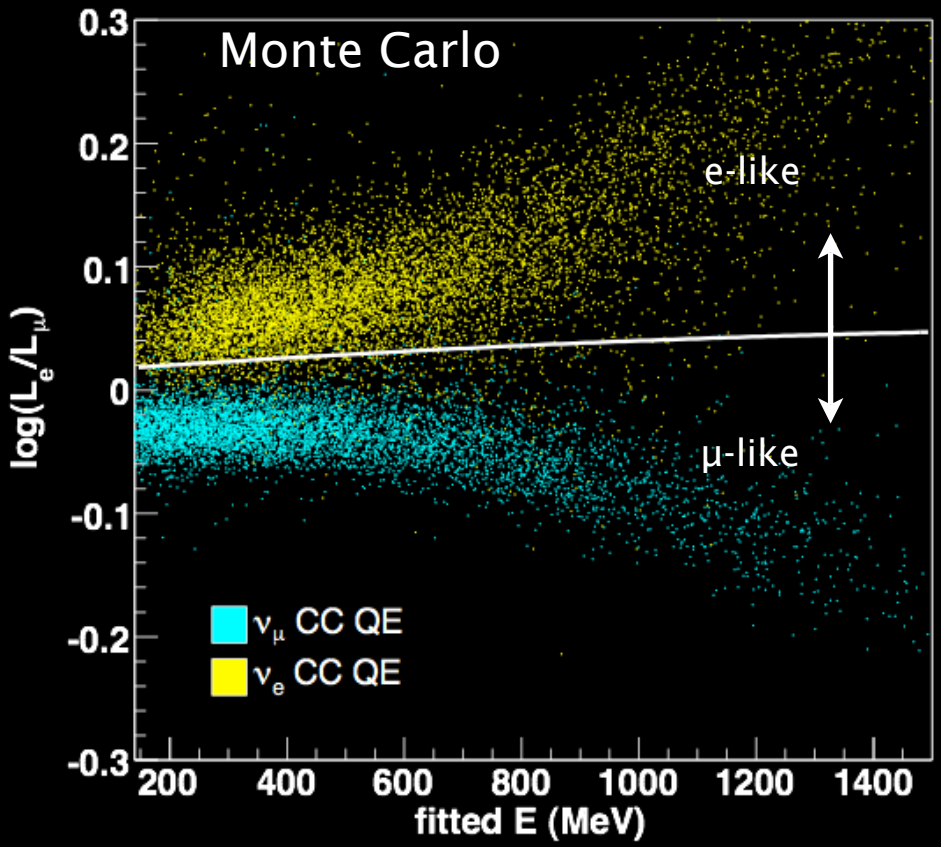
PMTs collect photons, record t,Q

Reconstruct tracks by fitting time and angular distributions

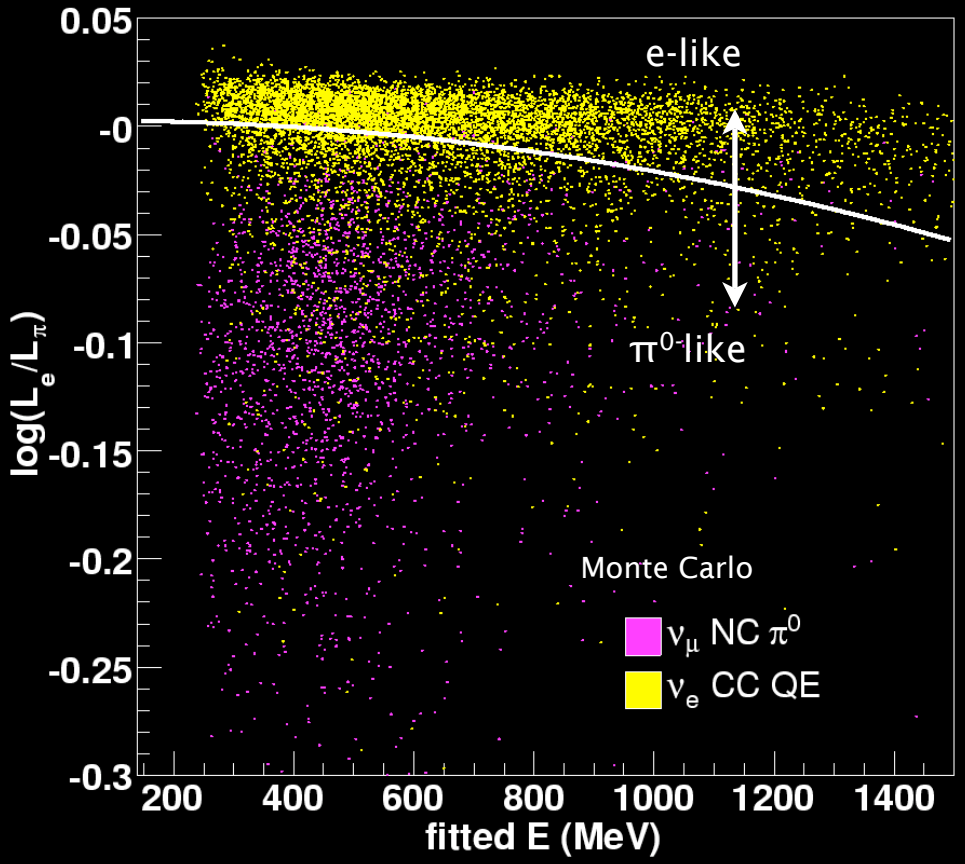
Find position, direction, energy

Particle Identification

Reconstruct under 3 possible hypotheses: μ-like, e-like, π^0-like

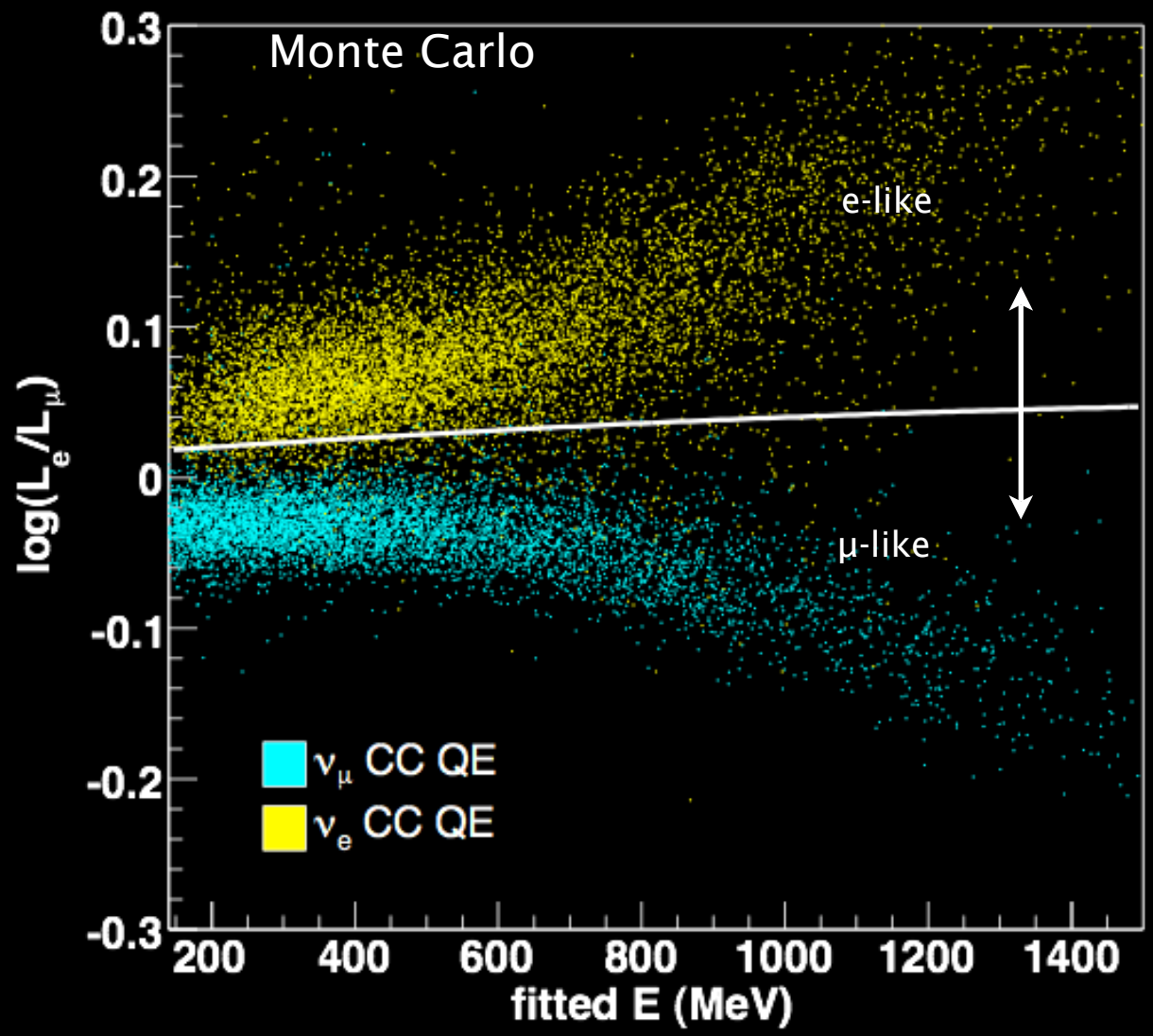


Reconstruction produces likelihoods for the three hypotheses



ν_e particle ID cuts on likelihood ratios

cuts chosen to maximise sensitivity to $\nu_\mu \rightarrow \nu_e$ oscillation

Particle Identification

- Reconstruct under 3 possible hypotheses: μ-like, e-like, π^0-like
- ν_e particle ID cuts on likelihood ratios
- cuts chosen to maximise sensitivity to $\nu_\mu \rightarrow \nu_e$ oscillation