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Antineutrino Running at MiniBooNE

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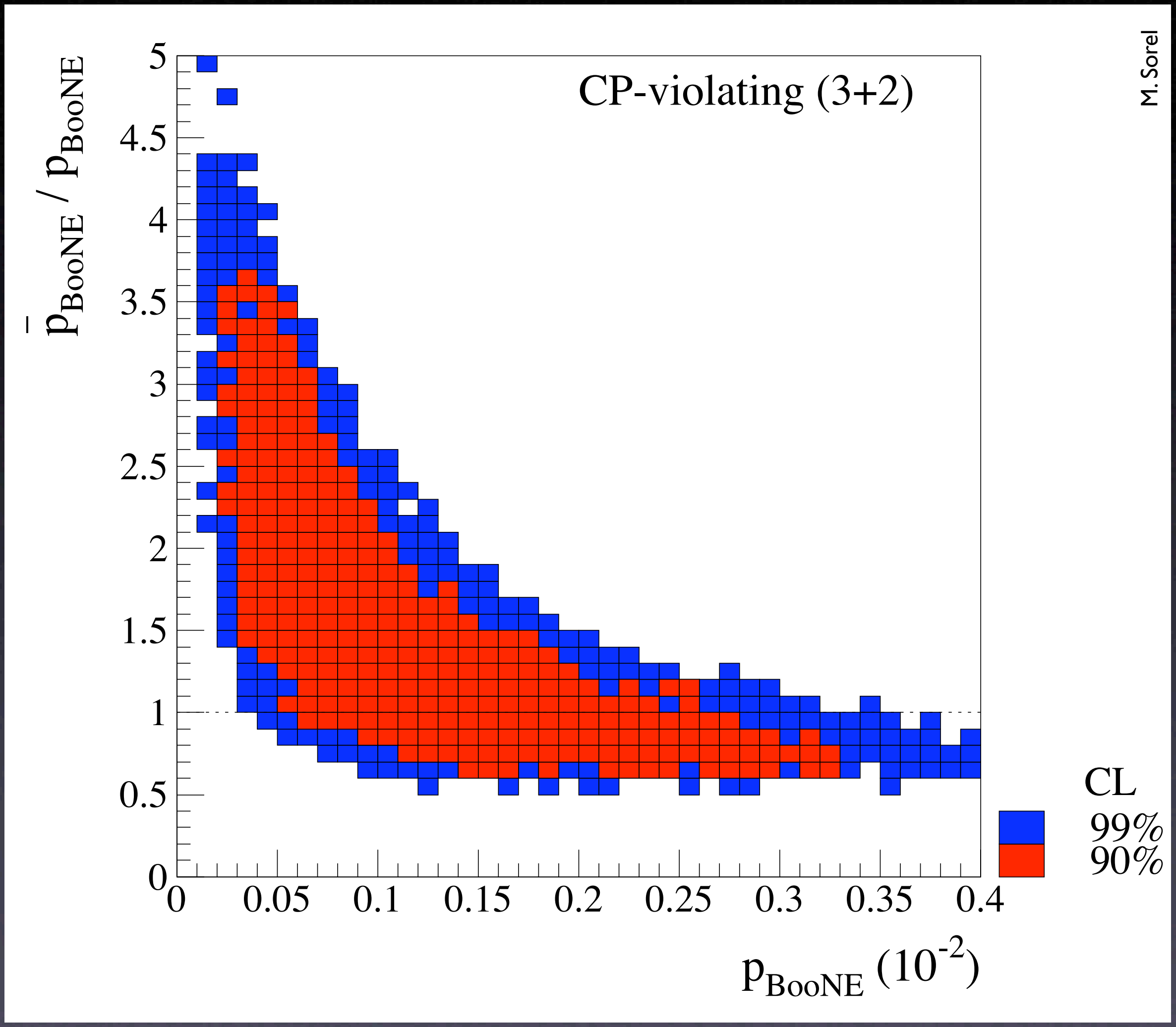
Motivation

- $\bar{\nu}$ running is a subject of much interest
- CP violation in ν sector
- Difference in oscillation probabilities for $\nu, \bar{\nu}$
- Major experimental obstacles:
  - $\bar{\nu}$ cross sections not well known
  - wrong sign backgrounds
    - ν in a $\bar{\nu}$ beam

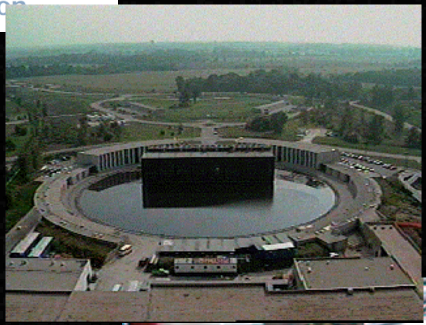


Asymmetry of $\bar{\nu}$,ν oscillation probabilities in MiniBooNE versus ν oscillation prob.

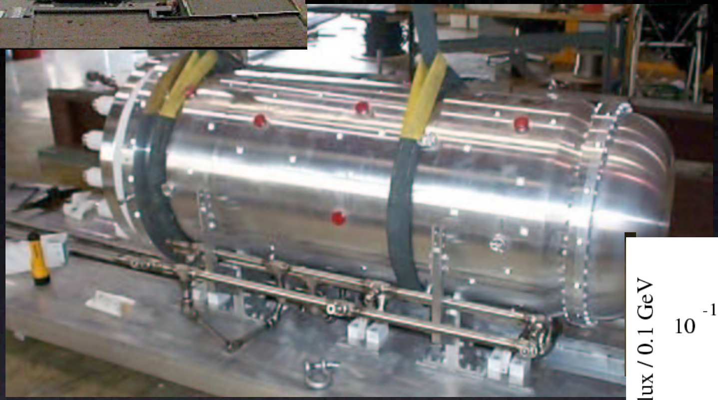
Outline

- MiniBooNE antineutrino running
  - First Data!
  - Wrong Sign Backgrounds
- Physics Goals for first year
  - Cross section physics
  - Oscillations
- The future of the BNB: SciBooNE

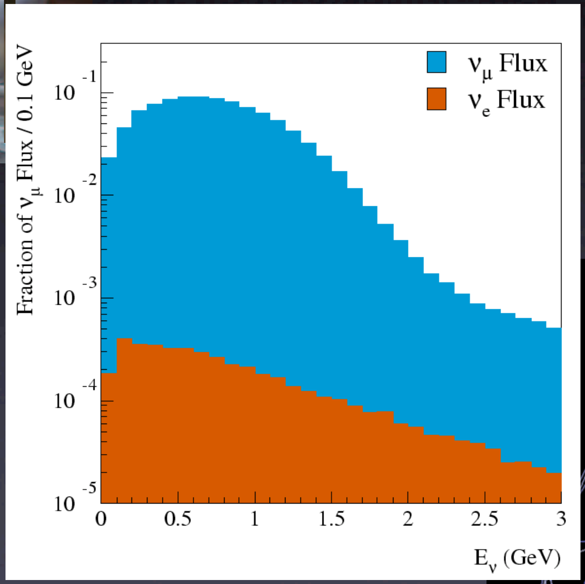
Images of the MiniBooNE horn



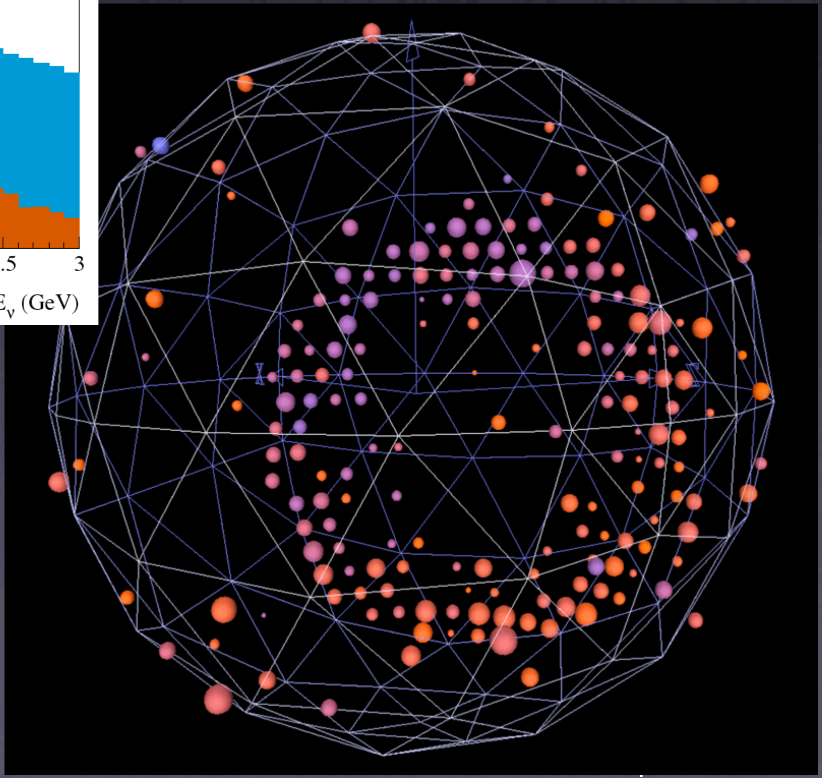
Extract 8 GeV protons from Fermilab Booster
1.7 λ beryllium target (HARP results soon!)



Reversible magnetic horn
Focusses mesons of specific charge
Allows antineutrino running!

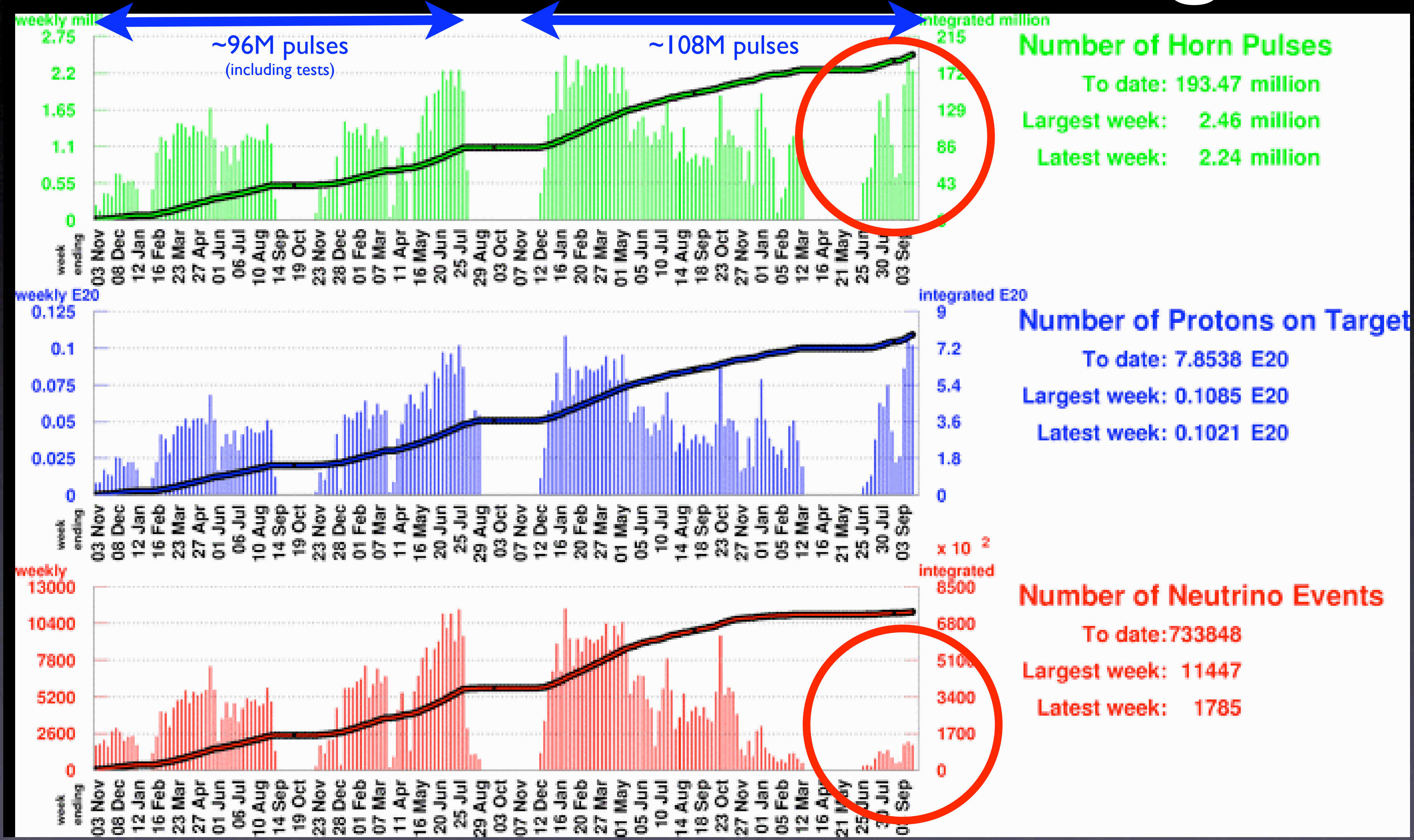


50 m decay region
>99% muon neutrinos
both ν and $\bar{\nu}$
490 m dirt
800 ton CH_2 detector
1520 PMTs
1280 in main tank
240 in veto region



Switched horn polarity in Jan, 2006
About 0.8e20 POT so far!

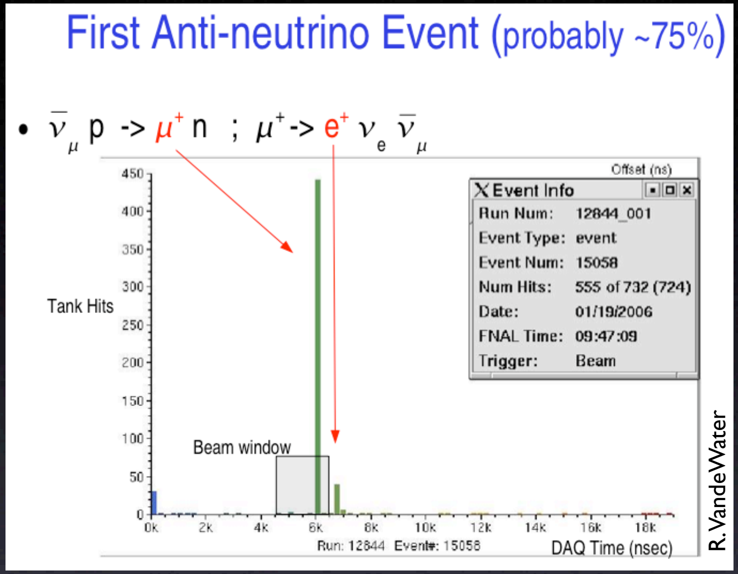
MiniBooNE $\bar{\nu}$ Running

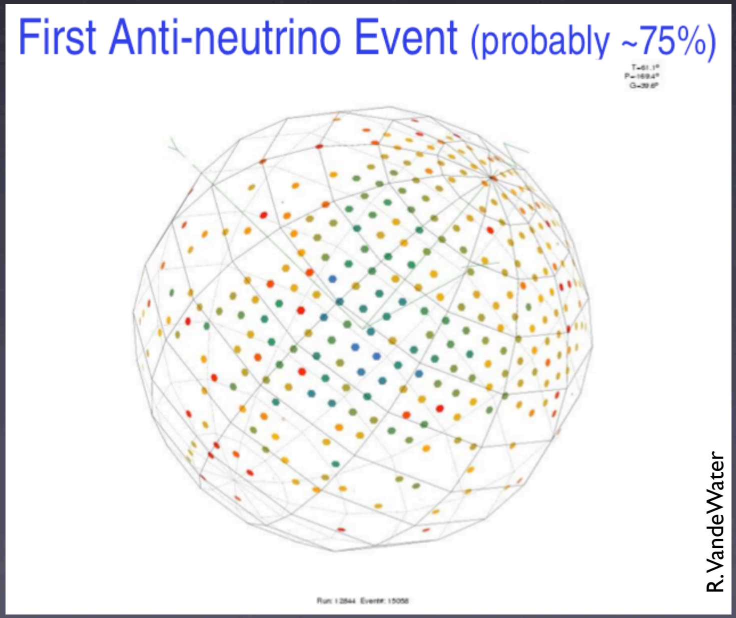


- Antineutrino data means fewer events per POT
- Note also: a horn world record!

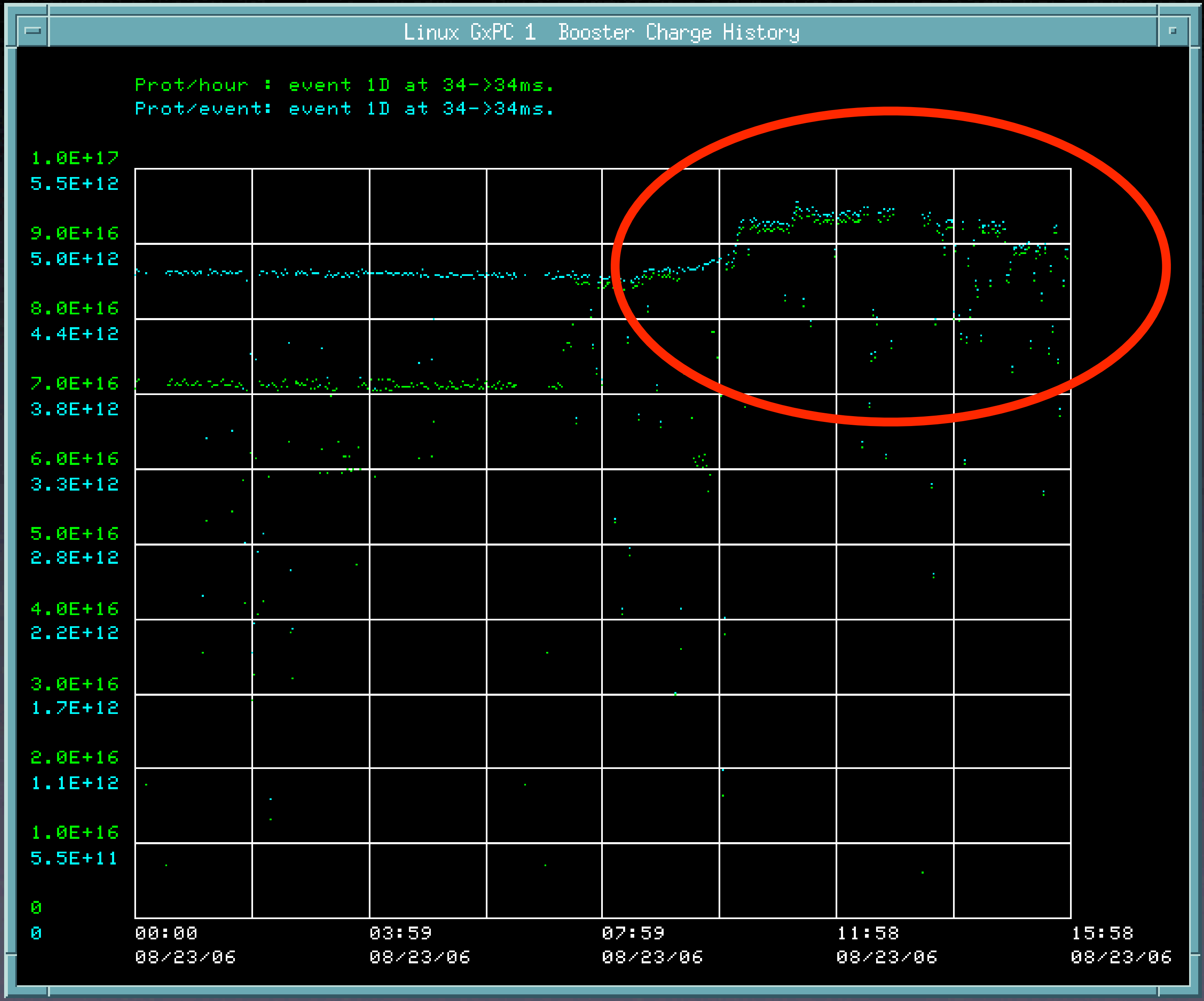
Horn Polarity Change

- Ran special reduced current runs for several weeks before polarity change
- Power supply polarity switch began Jan 9
- Expected to take two weeks
  - $\bar{\nu}$ run started Jan 19!
- "Changeover went flawlessly" - R. Van de Water





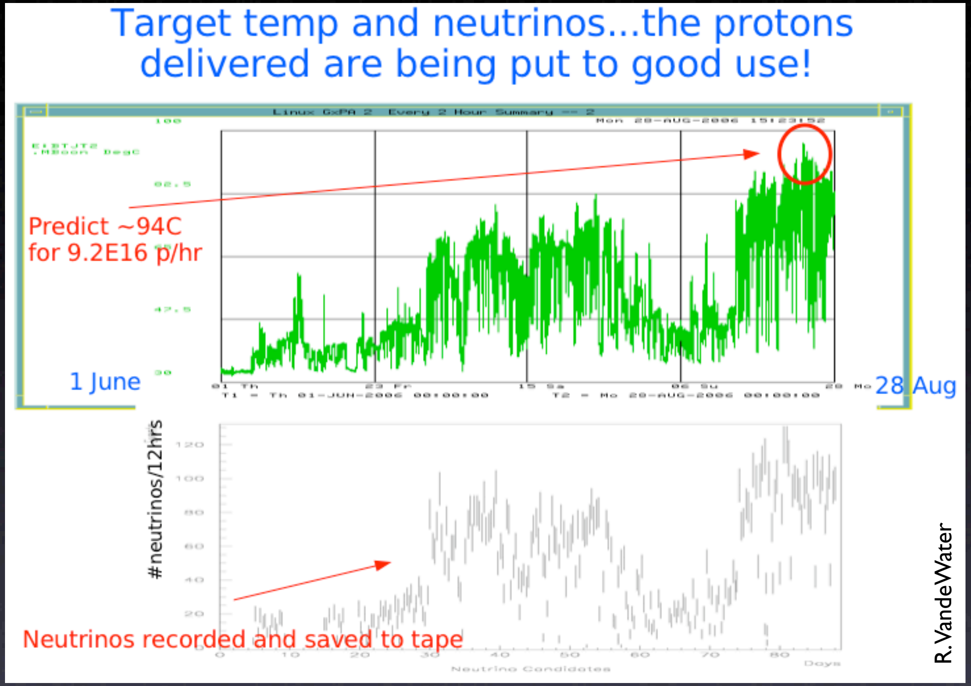
Booster Performance

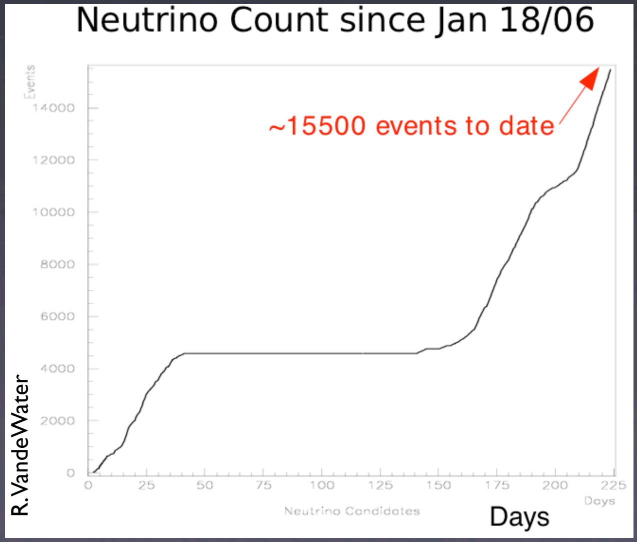


A new record!

Beam Performance

- A 35 year old machine has been pushed to run 20 times more output while keeping the losses at the same level
  - *Amazing!*
- But it's more than just one good week
- Great performance throughout the run has allowed MiniBooNE to amass the world's largest $\bar{\nu}$ data set at these energies





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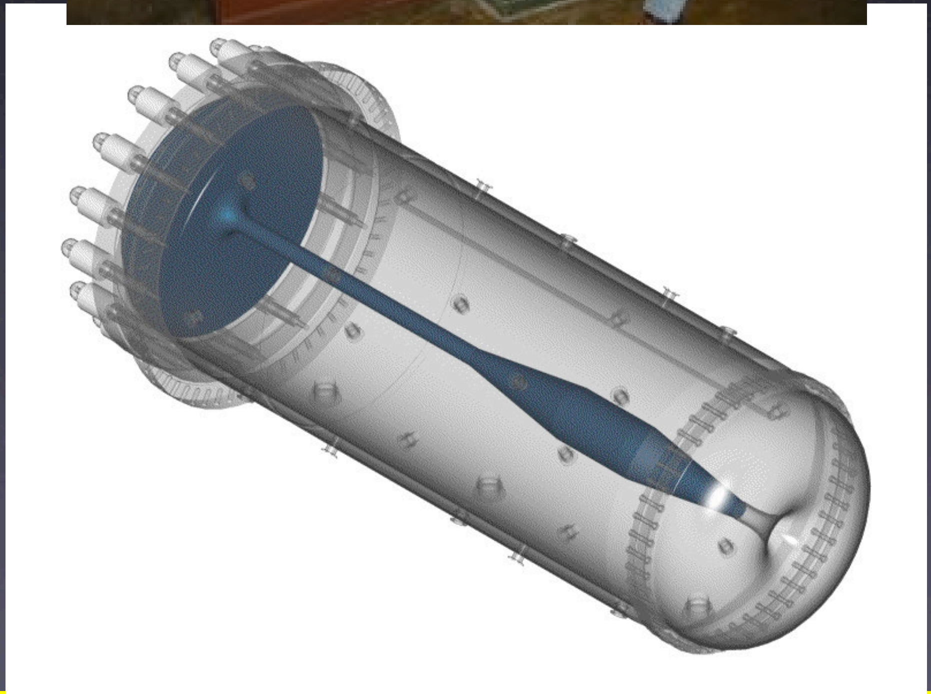
Outline

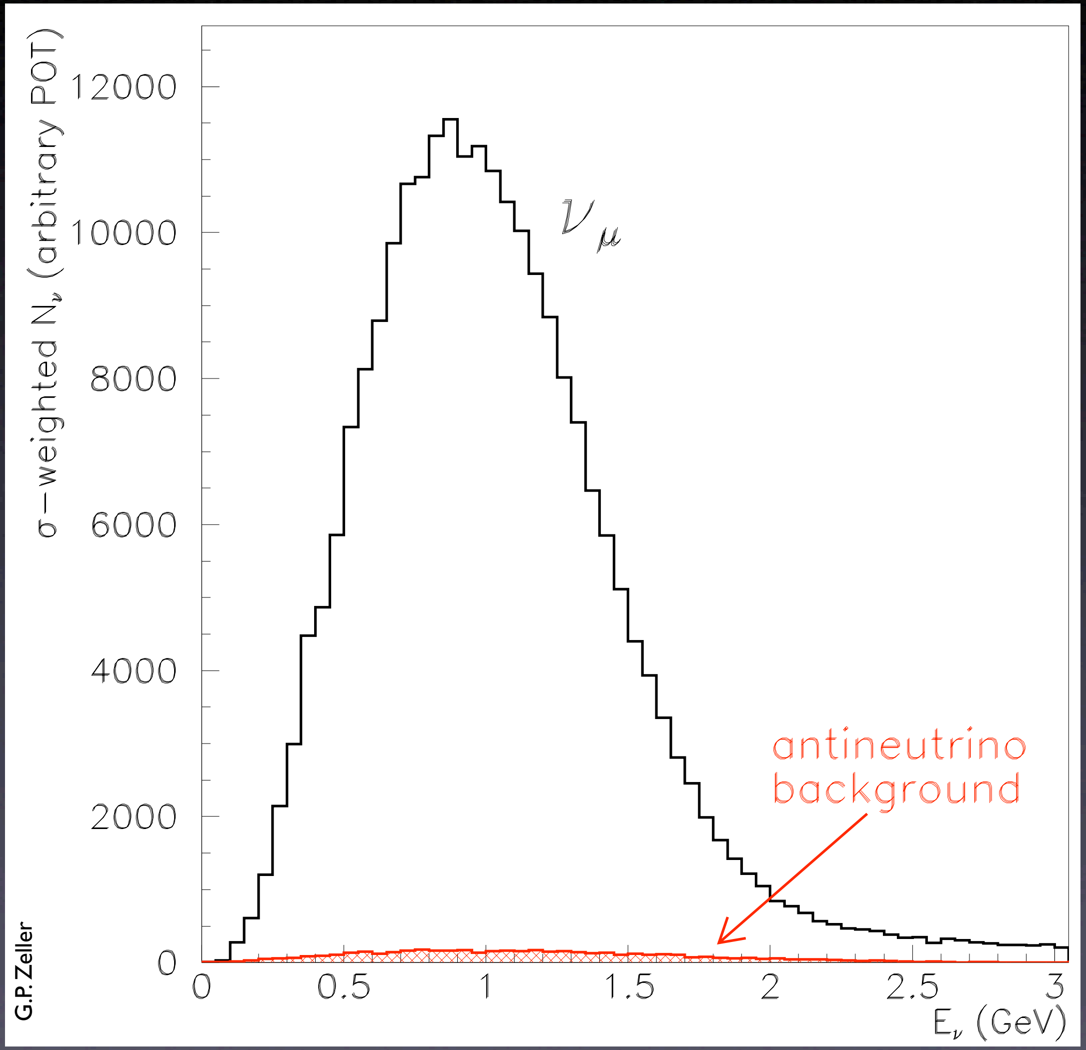
- MiniBooNE antineutrino running
  - First Data!
  - *Wrong Sign Backgrounds*
- Physics Goals for first year
  - Cross section physics
  - Oscillations
- The future of the BNB: SciBooNE



Images of the MiniBooNE horn

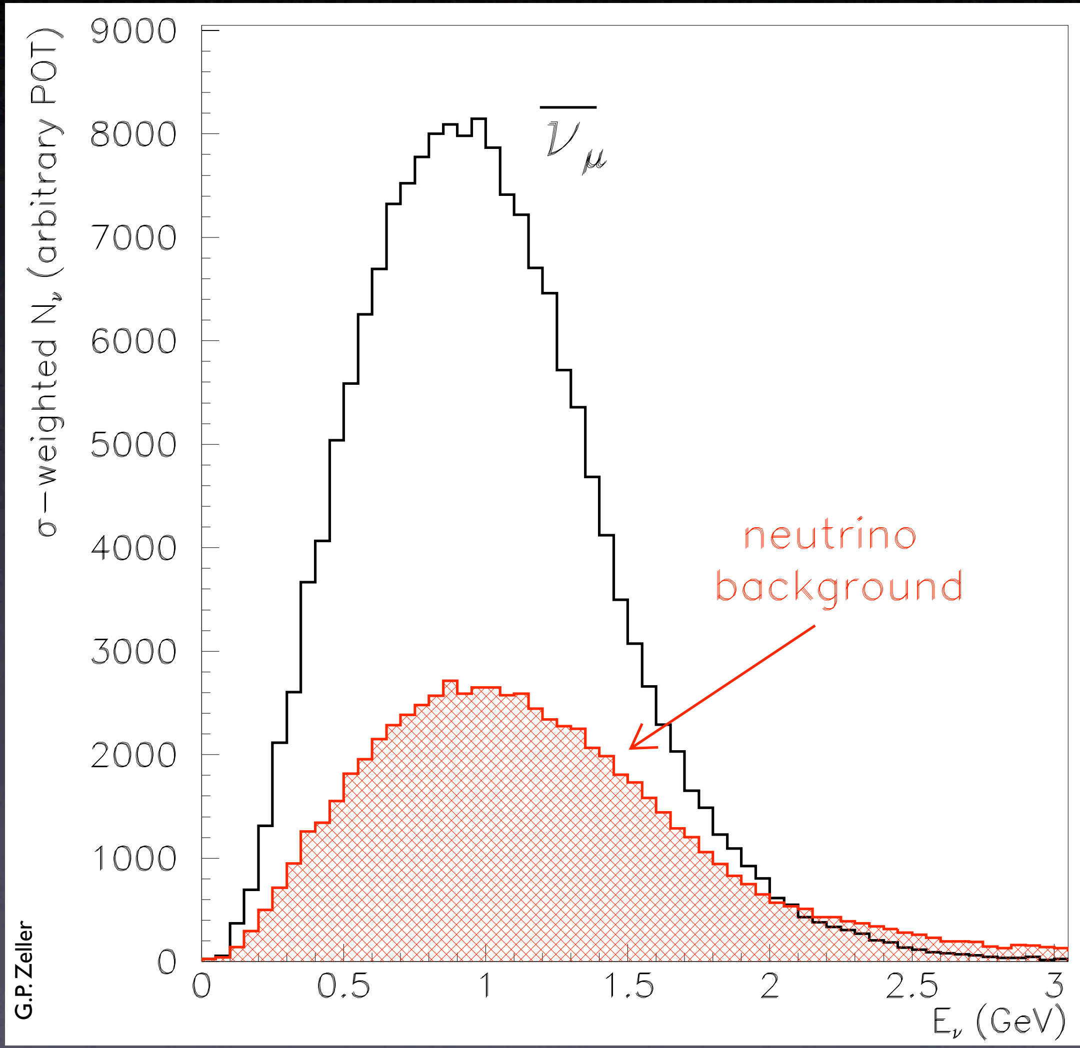
Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (~30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+
- Need a way to extract the WS BGs!



Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (~30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+ (event by event)
- Need a way to extract the WS BGs!

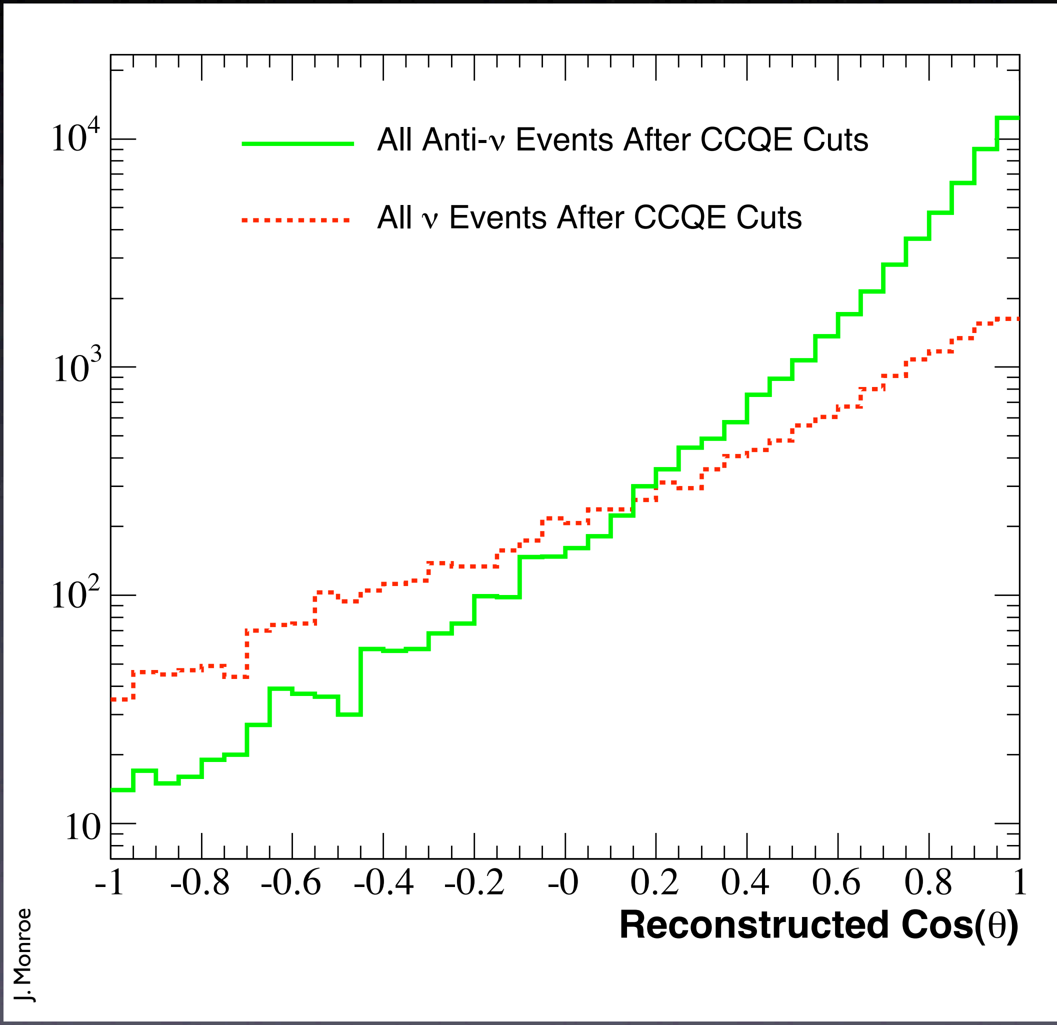


Constraining WS BGs

- MiniBooNE has developed three methods of constraining the overall fraction of ν, $\bar{\nu}$
  - μ direction
  - μ lifetime
  - $CC\pi^+$ event selection
- Independent constraints
- Sensitive to total WS fraction
  - Not sensitive to energy spectrum of WS events

WS BG Constraints: μ Directions

- Softer Q^2 spectrum for antineutrino events means more forward-peaked μ
- Reconstruction has little effect on this constraint
- WS fraction can be measured to 7% with reconstructed angles
- Can also use Q^2 distributions
  - Similar precision
    - Stronger constraint?
  - Poorer resolution
  - Larger uncertainties



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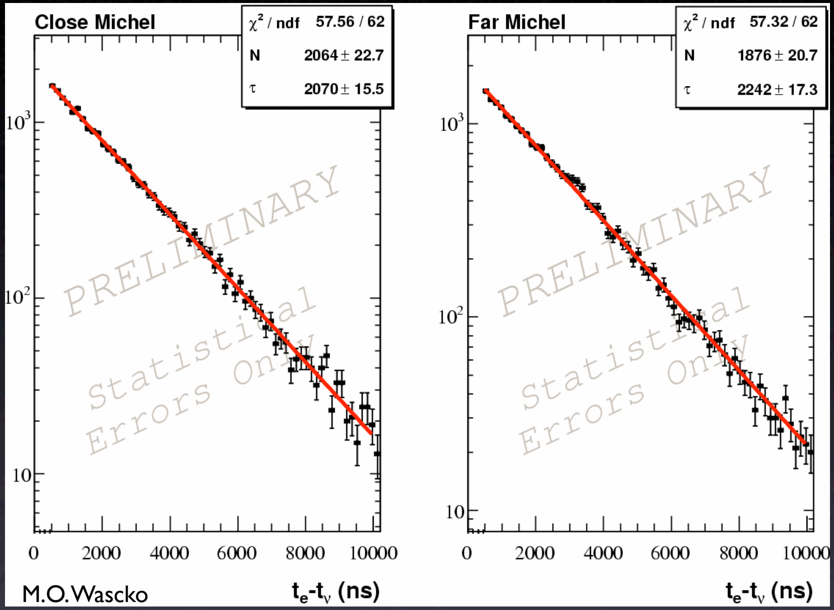
WS BG Constraints:
$CC\pi^+$ Selection

- Use CCπ+ event selection:
- Tag $\nu_\mu N \rightarrow \mu^- \pi^+ N$ events with two Michel electrons
- π- captured by carbon, do not decay
  - Cannot tag $\bar{\nu}_\mu N \rightarrow \mu^+ \pi^- N$ events: only 1 Michel
- Two Michel sample is 85% pure WS
- Constrain WS fraction with 15% uncertainty

Neutrino type	# before cuts	# after cuts
ν_μ (WS)	30,539	2,525
$\bar{\nu}_\mu$ (RS)	71,547	461
Total	102,086	2,986

WS BG Constraints: μ Lifetime

- Use muon decay rate in mineral oil to constrain WS BGs
- 8% μ- capture probability on carbon
  - $\tau_{\mu-}$=2.026μs, $\tau_{\mu+}$=2.197μs
- Can extract WS contribution with 30% uncertainty
- Independent of kinematics and reconstruction



μ^- lifetime μ^+ lifetime

Comparison of muon lifetimes from CC1π^+ data sample

WS BG Constraints: Summary

Measurement	WS uncertainty	resultant $\bar{\nu}_\mu$ σ error
$\cos\vartheta_\mu$	7%	2%
$CC1\pi^+$	15%	5%
μ Lifetimes	30%	9%

Note: not much sensitivity to WS energy spectrum!

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Status of $\bar{\nu}_\mu$ σs

- Very few data, especially at low energy
- Not much understanding of nuclear targets

- $\bar{\nu}_\mu$ CCQE
  - ~1700 events
- $\bar{\nu}_\mu$ NCπ^0
  - Only one (1) measurement ever.

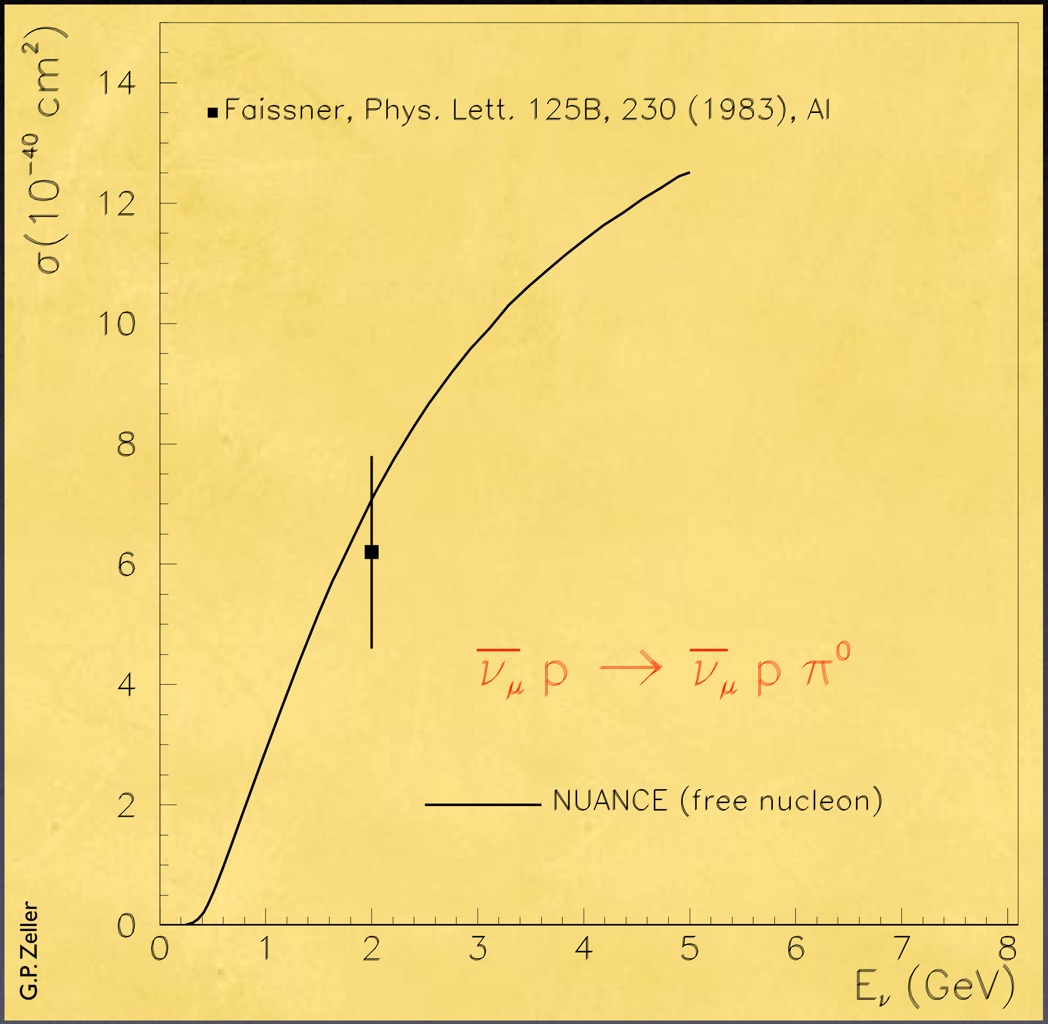
- Look at past measurements, then MiniBooNE data and expectations

$\bar{\nu}_\mu$ CC QE Scattering

<E>	Experiment	target	date	#QE evts
2 GeV	Gargamelle	$C_3H_8CF_3Br$	1979	766
1.3 GeV	BNL	H_2	1980	13
16 GeV	FNAL	NeH_2	1984	405
6-7 GeV	SKAT	CF_3Br	1988	92
9 GeV	SKAT	CF_3Br	1990	159
5-7 GeV	SKAT	CF_3Br	1992	256
				1691

$\bar{\nu}_\mu$ NC π^0

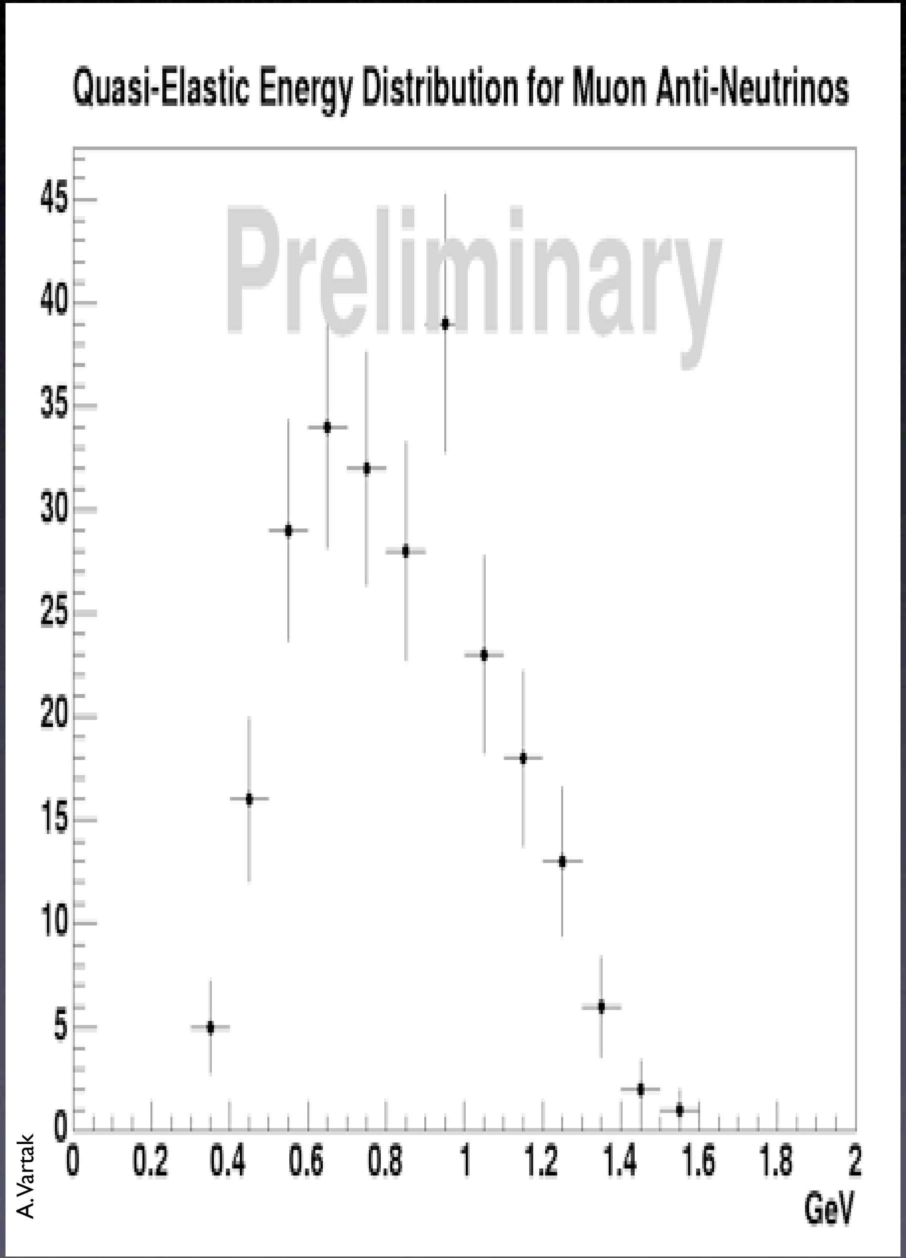
- Only one measurement of $\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu N \pi^0 N$ to date[1]
    - 25% uncertainty at 2 GeV
- Important for $\bar{\nu}_e$ appearance searches
- Coherent production more apparent in antineutrino scattering



[1] This appeared as a footnote in Faissner et al., Phys. Lett. 125B, 230 (1983)

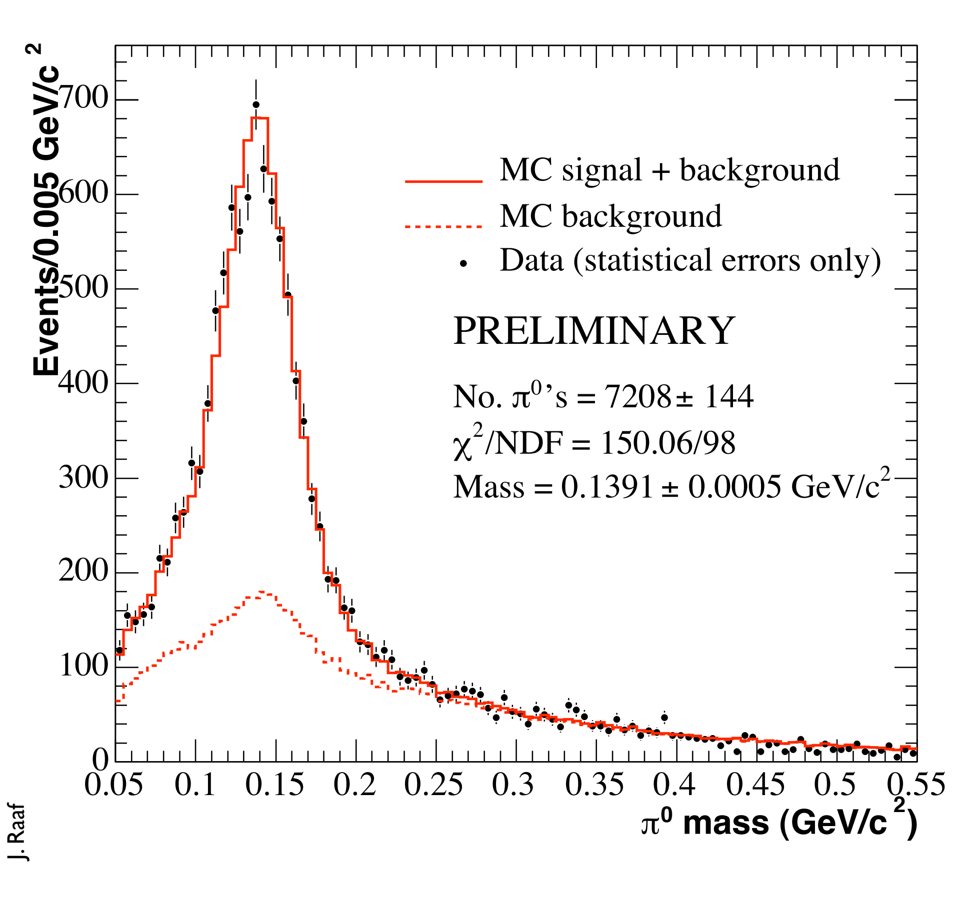
$\bar{\nu}_\mu$ CC QE: MiniBooNE

- MiniBooNE has collected 0.8E20 POT to date in $\bar{\nu}$ mode
  - >15,000 events!
- Preliminary look at data with early subset of 5000 events
  - cf. 1700!
- The world's first $\bar{\nu}_\mu$ events below 1 GeV!



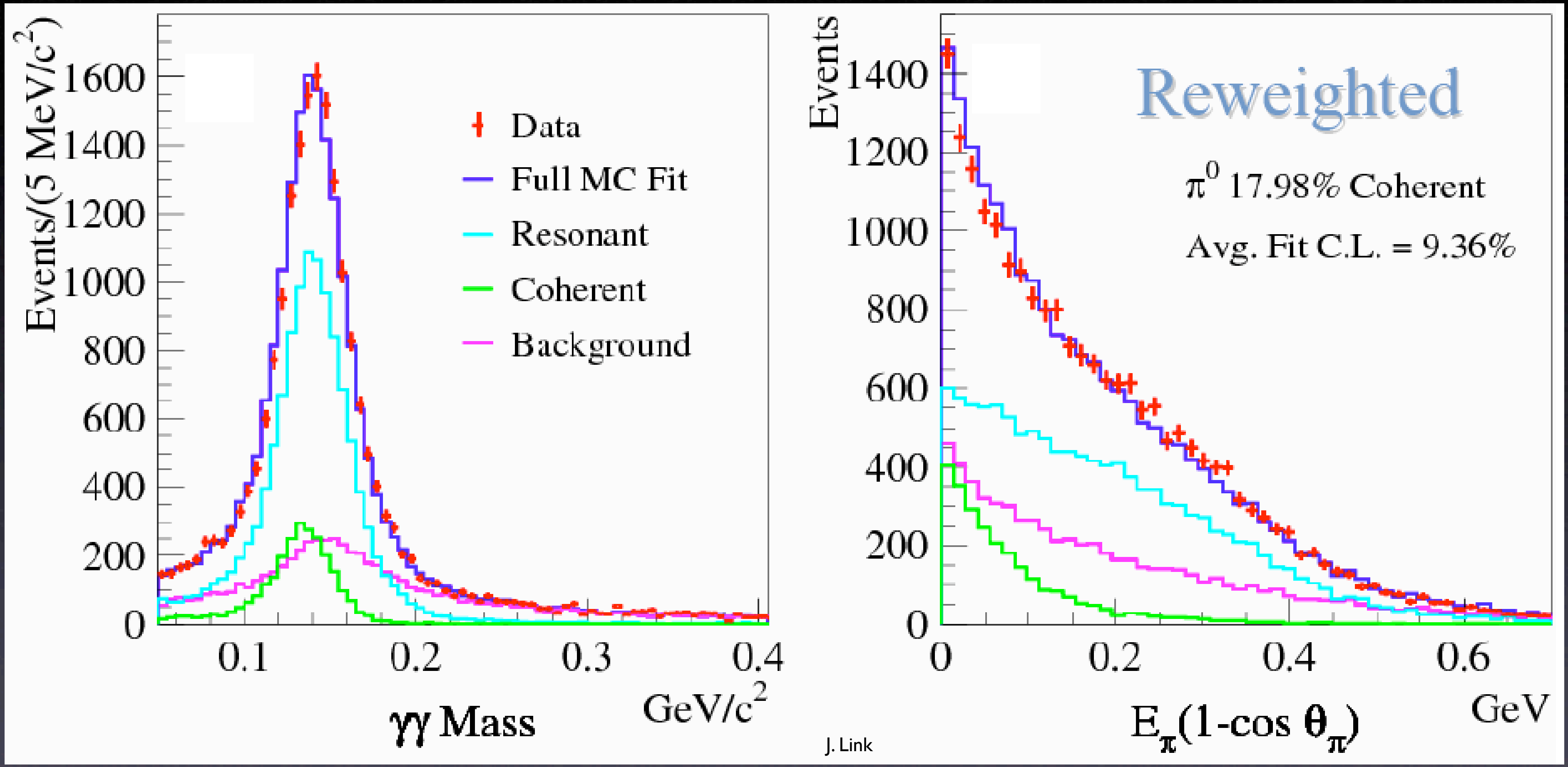
$\bar{\nu}_\mu$ NC π^0

- Expect >5000 $\bar{\nu}_\mu$ NC π^0 events within fiducial volume for 2E20 POT
- MiniBooNE's event selection requires:
  - Tank (>200) & veto (<6) PMT hit cuts
  - Two-ring reconstruction
    - m_{π^0}>50 MeV/c^2
- Application of event selection should yield
  - 1650 resonant events
  - 1640 coherent events (Rein & Sehgal)
  - ~1000 WS events



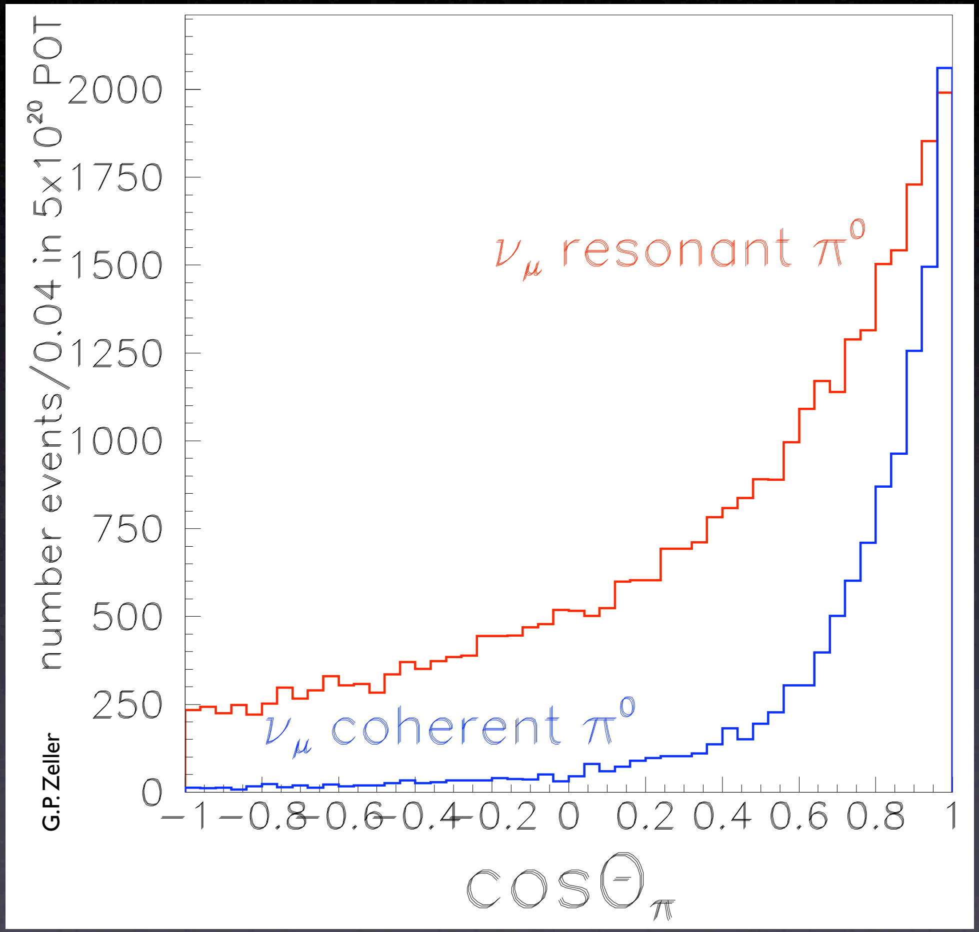
Reconstructed π^0 mass

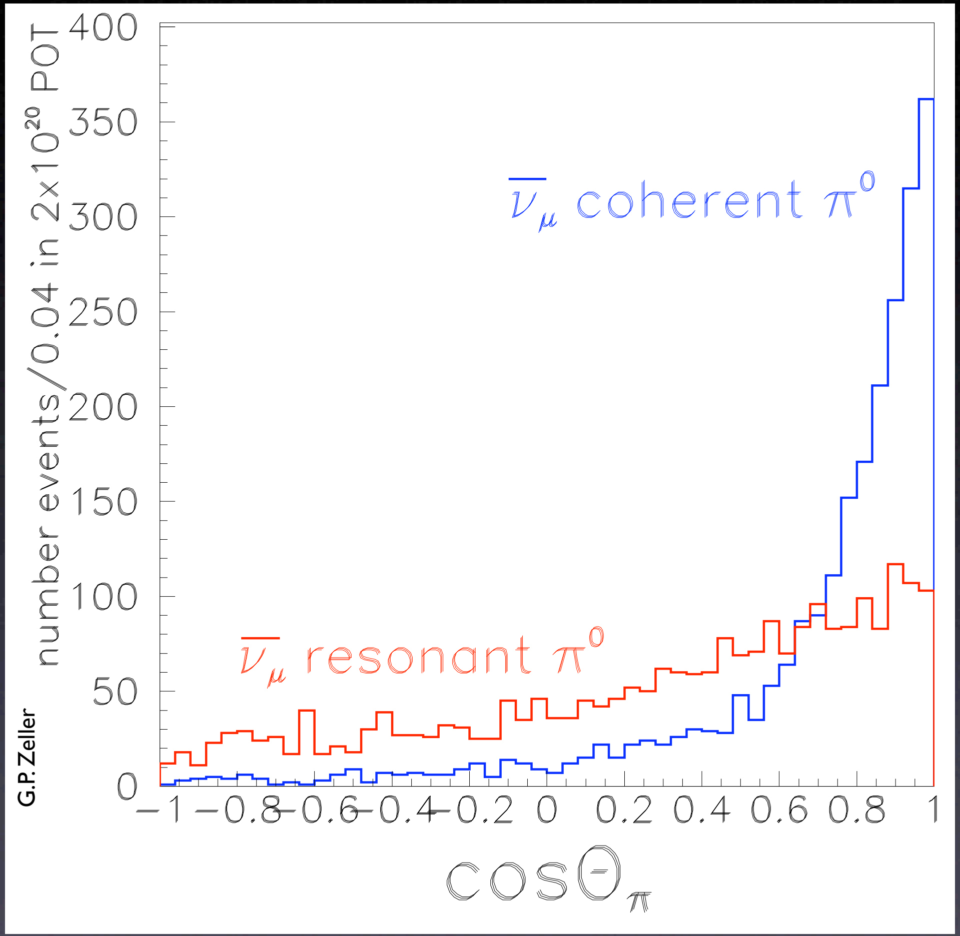
cf. ν_μ NC π^0



- Recent improvements in π0 reconstruction algorithm allow better extraction of coherent fraction in neutrino data
  - ~18%

Coherent NC π⁰





- Coherent production in $\bar{\nu}$ mode should be obvious!
- Given the K2K coherent CC1π search, MiniBooNE's $\bar{\nu}$ NCπ^0 search should be very interesting!

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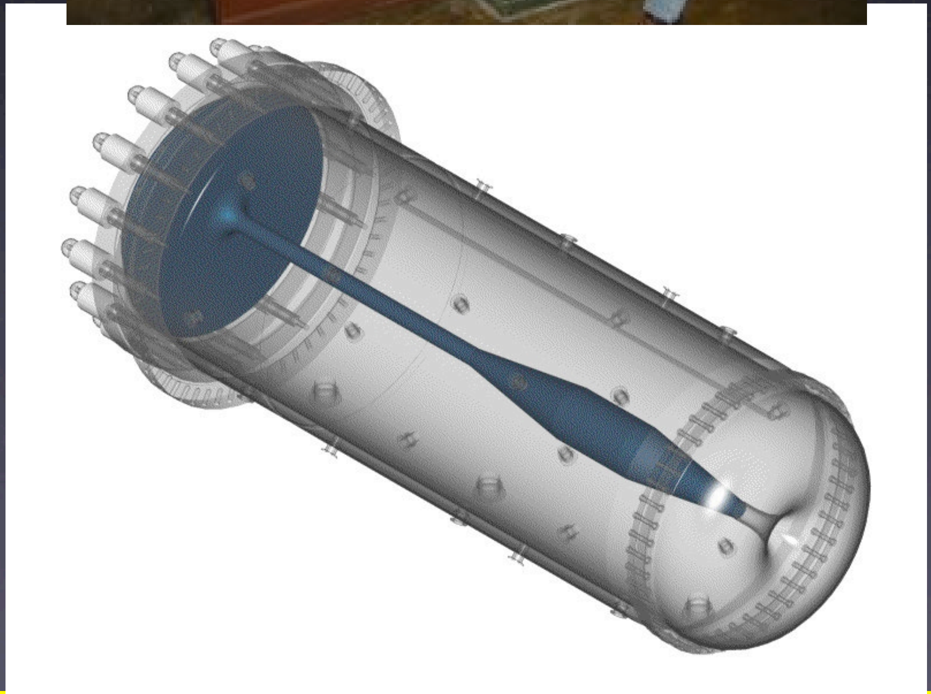
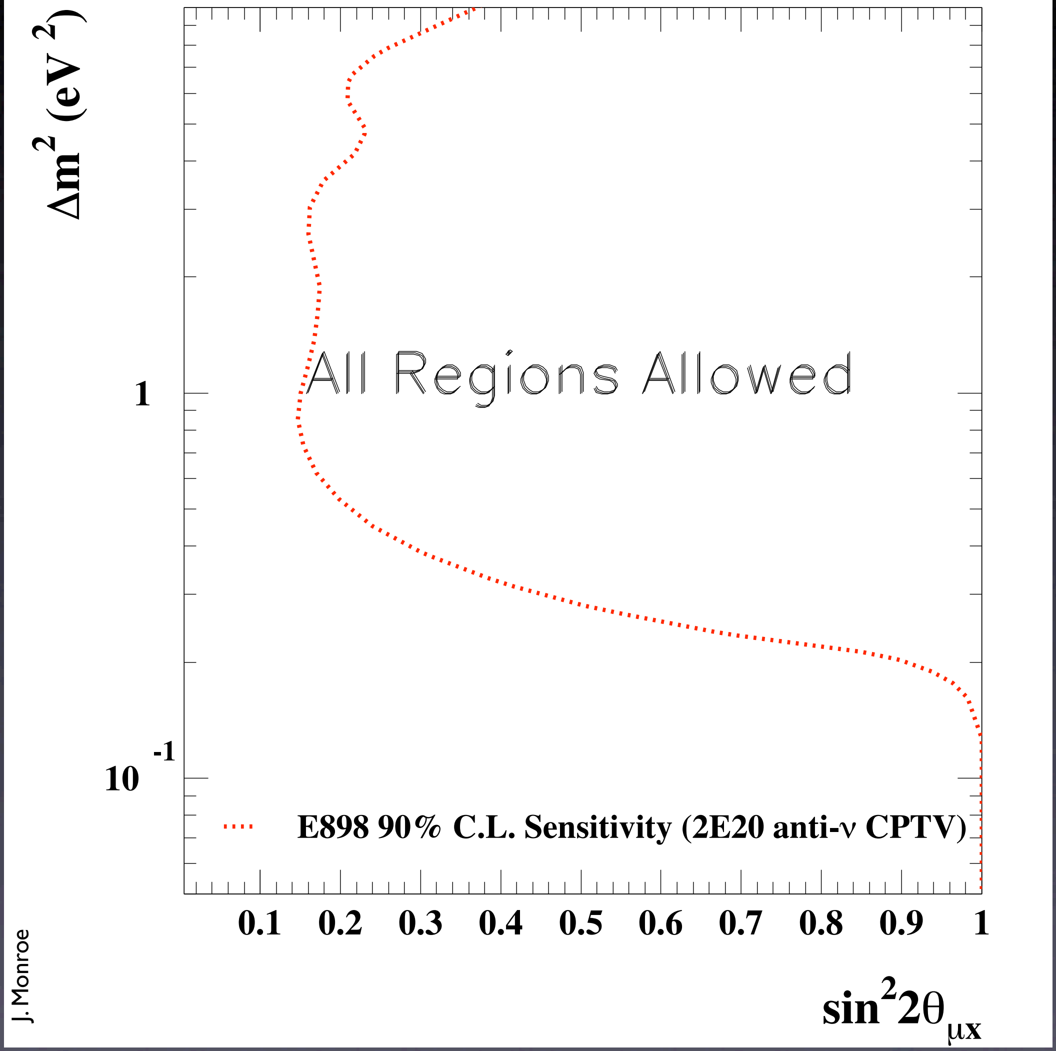


Images of the MiniBooNE horn

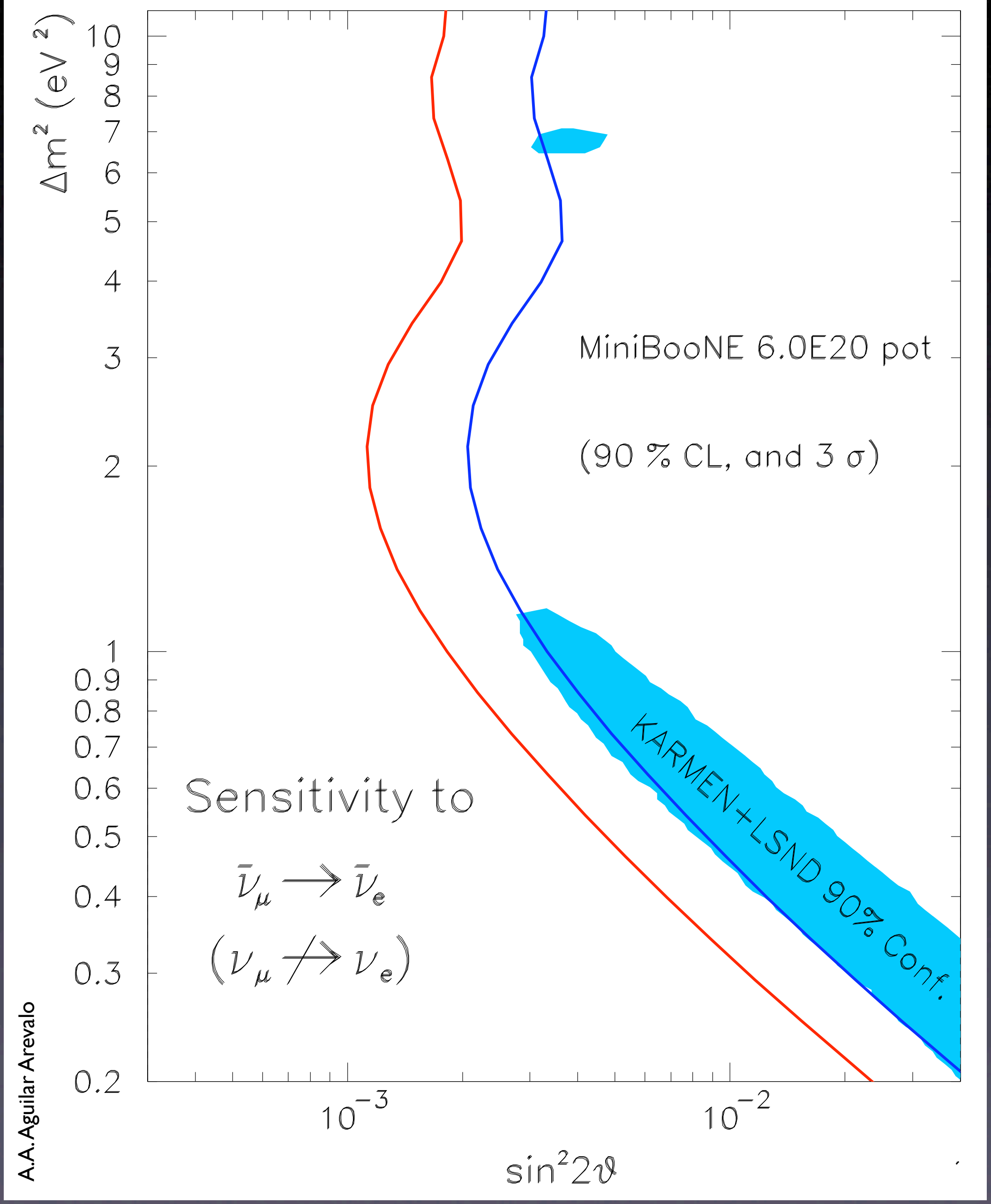
$\bar{\nu}_\mu$ Disappearance

- Oscillation appearance searches are sensitive to CPV, but not CPTV
  - Need disappearance search as well to distinguish between CPV and CPTV
- MiniBooNE can perform both searches
- Shown: CPT violating case
  - ν_μ do not oscillate, but $\bar{\nu}_\mu$ do oscillate
- Note: no published limits on CPTV ν_μ disappearance



$\bar{\nu}_e$ Appearance

- Recall, LSND oscillations were seen in antineutrinos
  - $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - True confirmation can only be made with antineutrino running!
- Shown: appearance sensitivity region for antineutrino oscillations in the case of no oscillations in neutrinos
  - Compare to LSND-KARMEN joint analysis allowed region
- Statistics limited!



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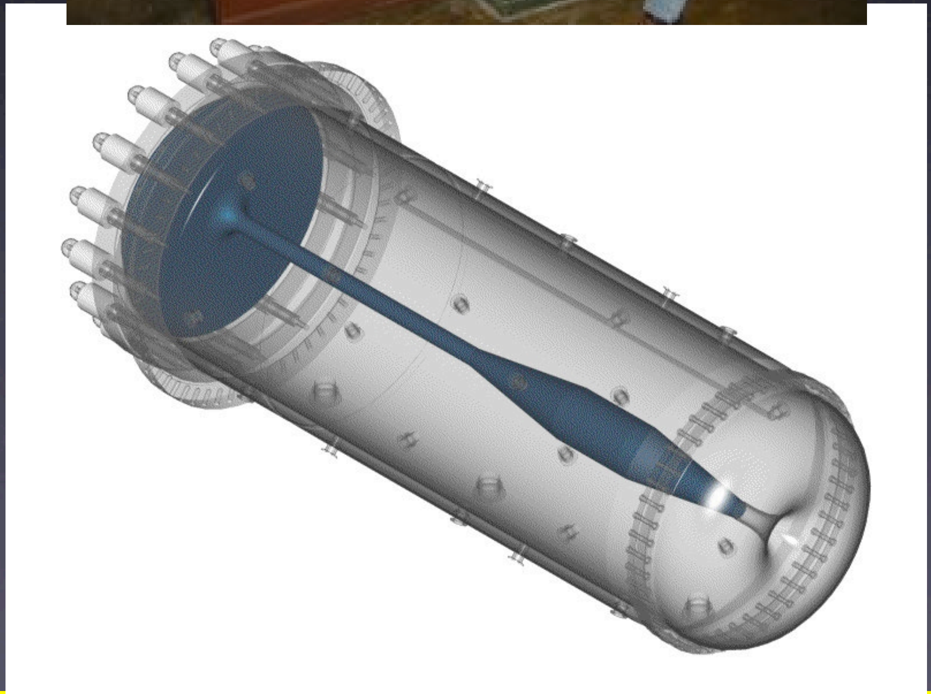

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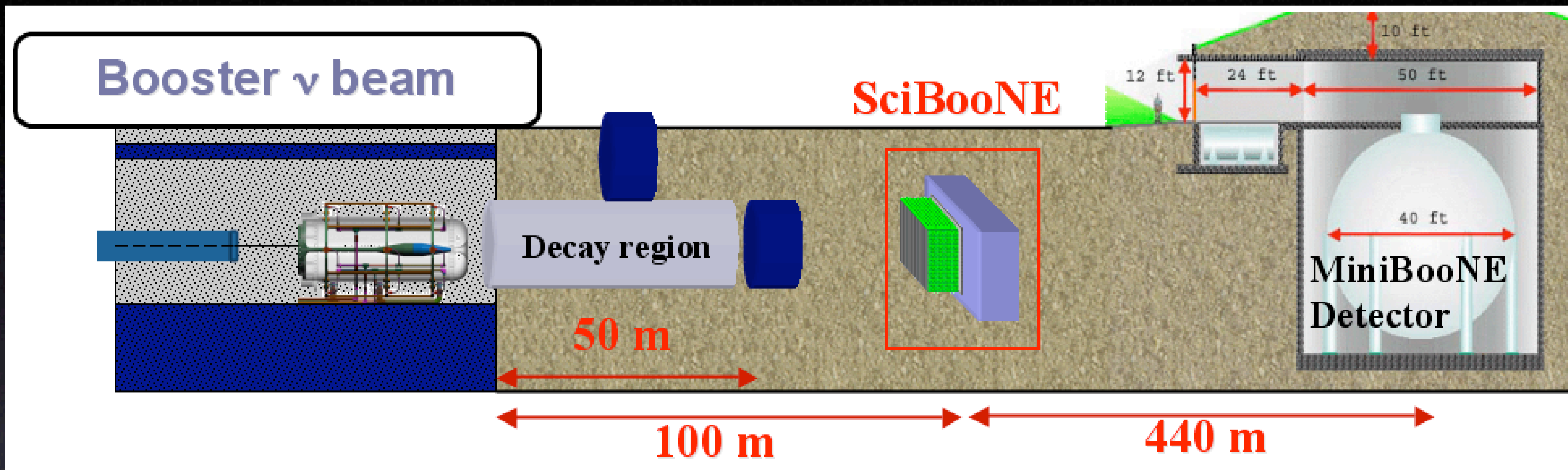
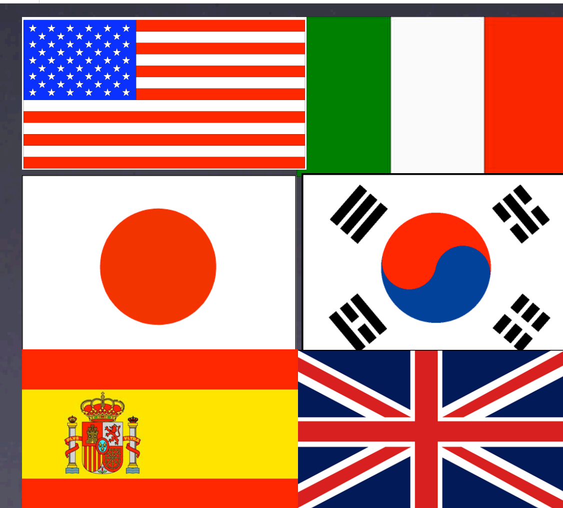
The Future: SciBooNE



Fermilab E-954



Spokespeople:
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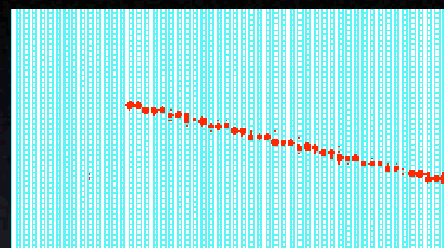
$\bar{\nu}_\mu$ WS Constraints

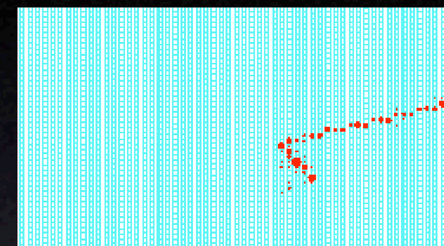
Right Sign



$\bar{\nu} + p \rightarrow \mu^+ + n$

$\bar{\nu}$ QE: ~80%

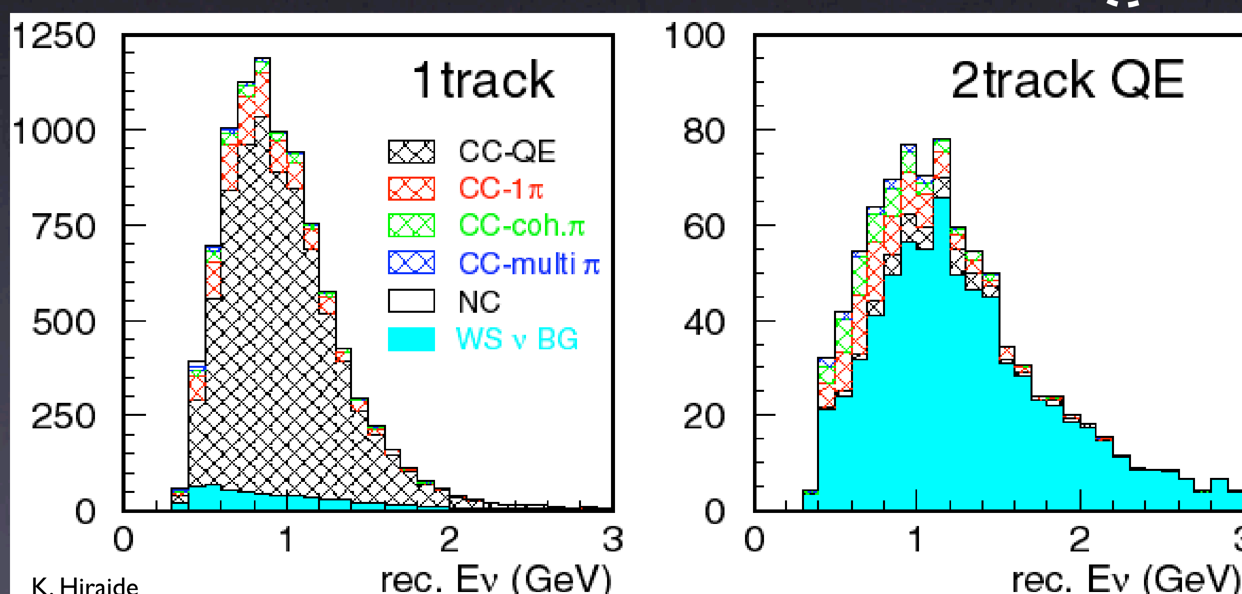
ν BG: ~7%



Wrong Sign

$\nu + n \rightarrow \mu^- + p$

ν QE: ~80%



- MiniBooNE: ~15% uncertainty on WS BG in 4 bins (0-1.5 GeV)
- SciBooNE: ~7.5% stat. err. in 2 track sample in 4 bins (0-1.5 GeV)

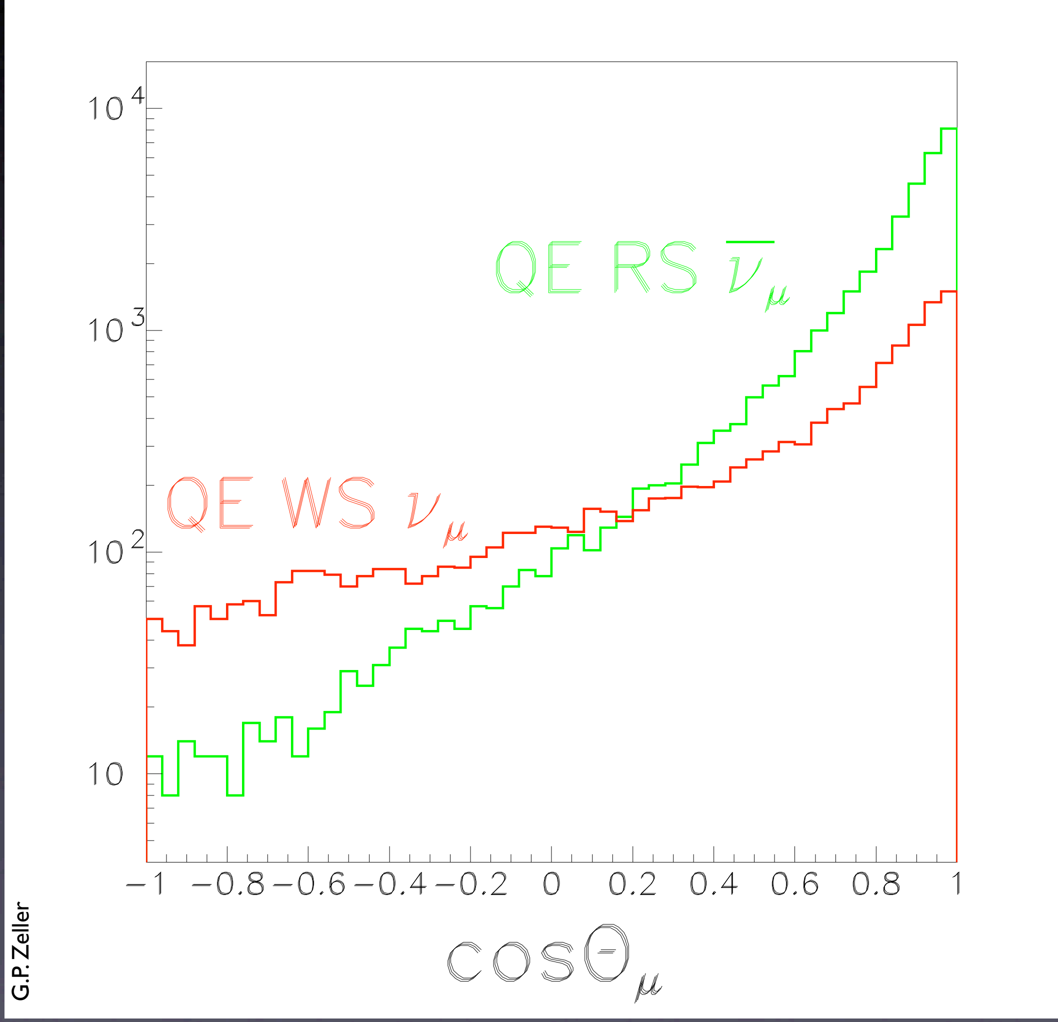
Conclusions

- MiniBooNE began running in antineutrino mode in January 2006
  - Already the world's largest data set at these energies!
  - Opening up the antineutrino cross section landscape with first $\bar{\nu}$ data
- We have developed several novel techniques to constrain the overall level of WS BGs
- New $\bar{\nu}$ cross section measurements coming
- SciBooNE will bring enhanced $\bar{\nu}$ cross section capabilities to the BNB in 2007
- Sensitivity to antineutrino oscillations will require more data!

Backups

WS BG Constraints: μ Direction

- Softer Q^2 spectrum for antineutrino events means more forward-peaked μ
- Can fit angular distribution shape and extract RS/WS fractions
- Using generated muon directions, can extract WS fraction with 5% uncertainty



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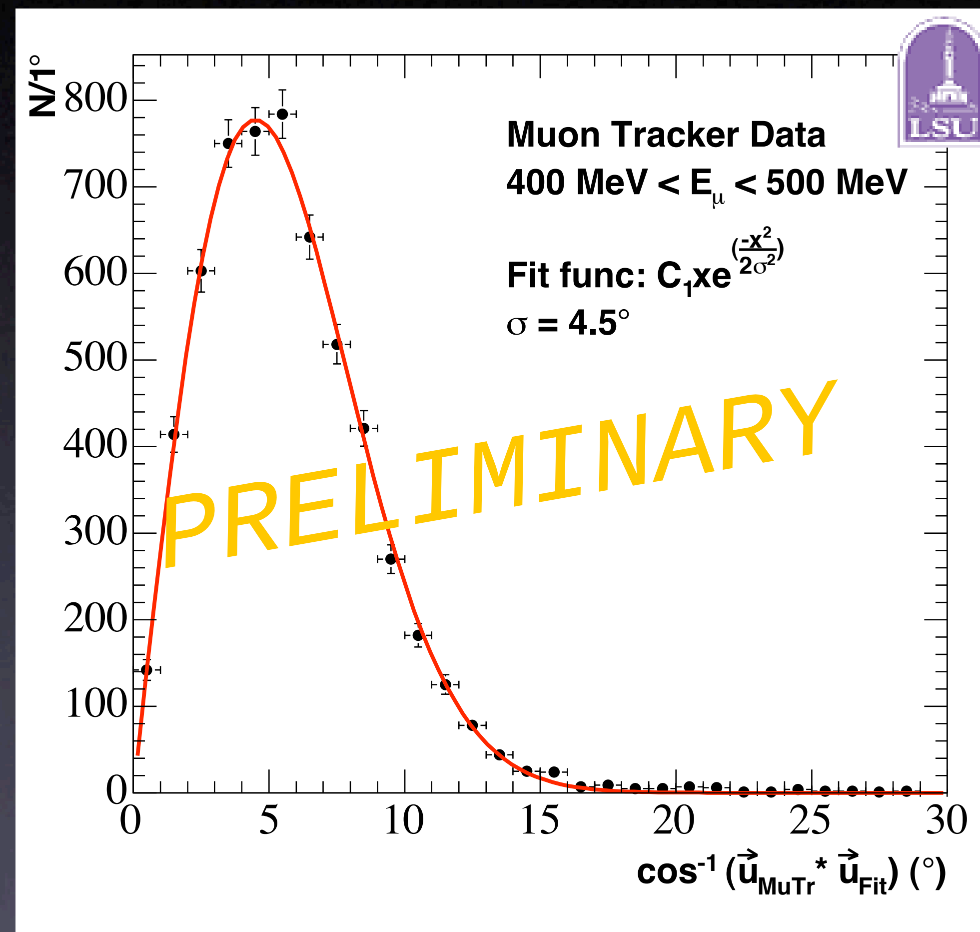
WS BG Constraints:
μ Direction

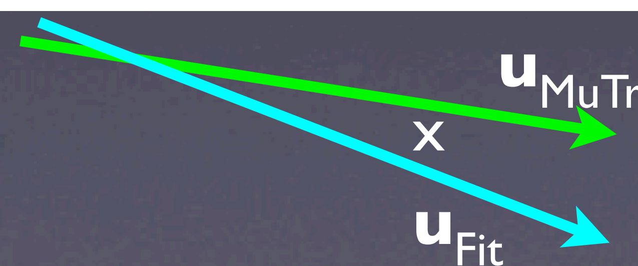
- MiniBooNE has very good angular reconstruction
- Tested with cosmic muon calibration system
- Fit distribution of

$$\cos^{-1}(\vec{u}_{MuTr} \cdot \vec{u}_{Fit})$$

$$xe^{-x^2/2\sigma^2}$$

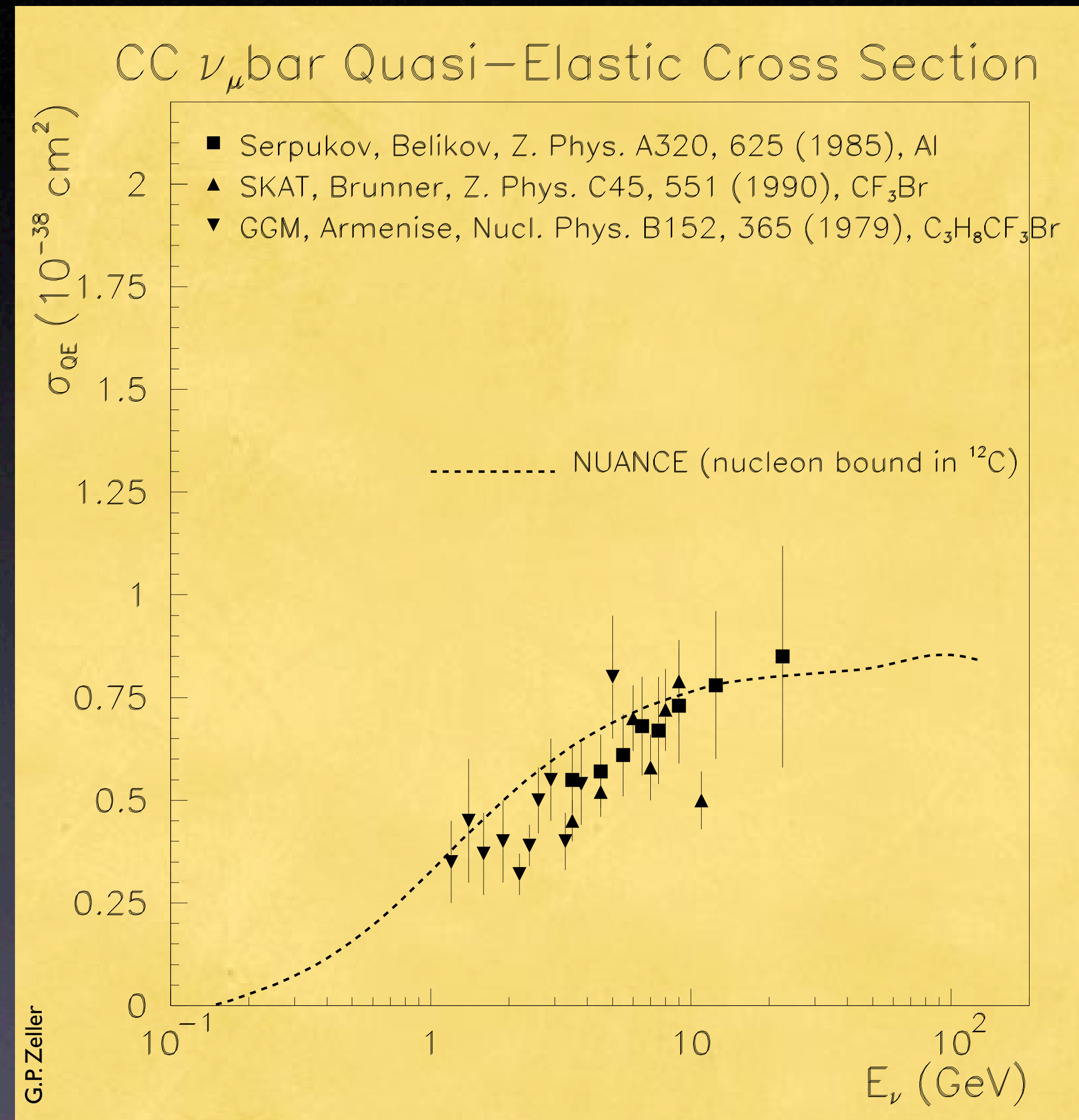
- (projection of a 2D Gaussian)
- Extract intrinsic resolution of muon tracker
- Angular resolution = 4.0°

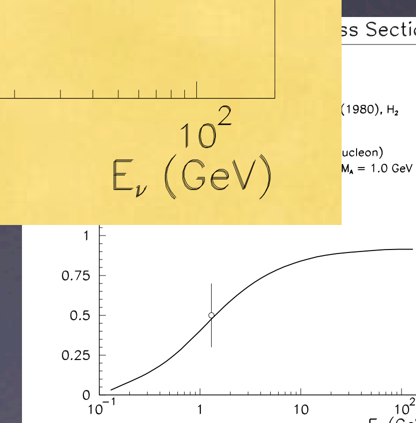




$\bar{\nu}_\mu$ CC QE Scattering

- Few $\bar{\nu}_\mu$ QE measurements
- None below 1 GeV
- MiniBooNE expects ~40,000 events before cuts for 2E20 POT





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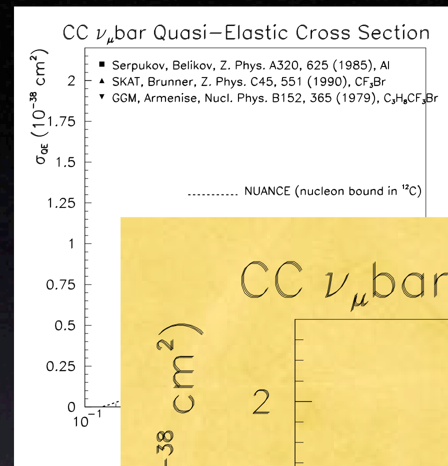

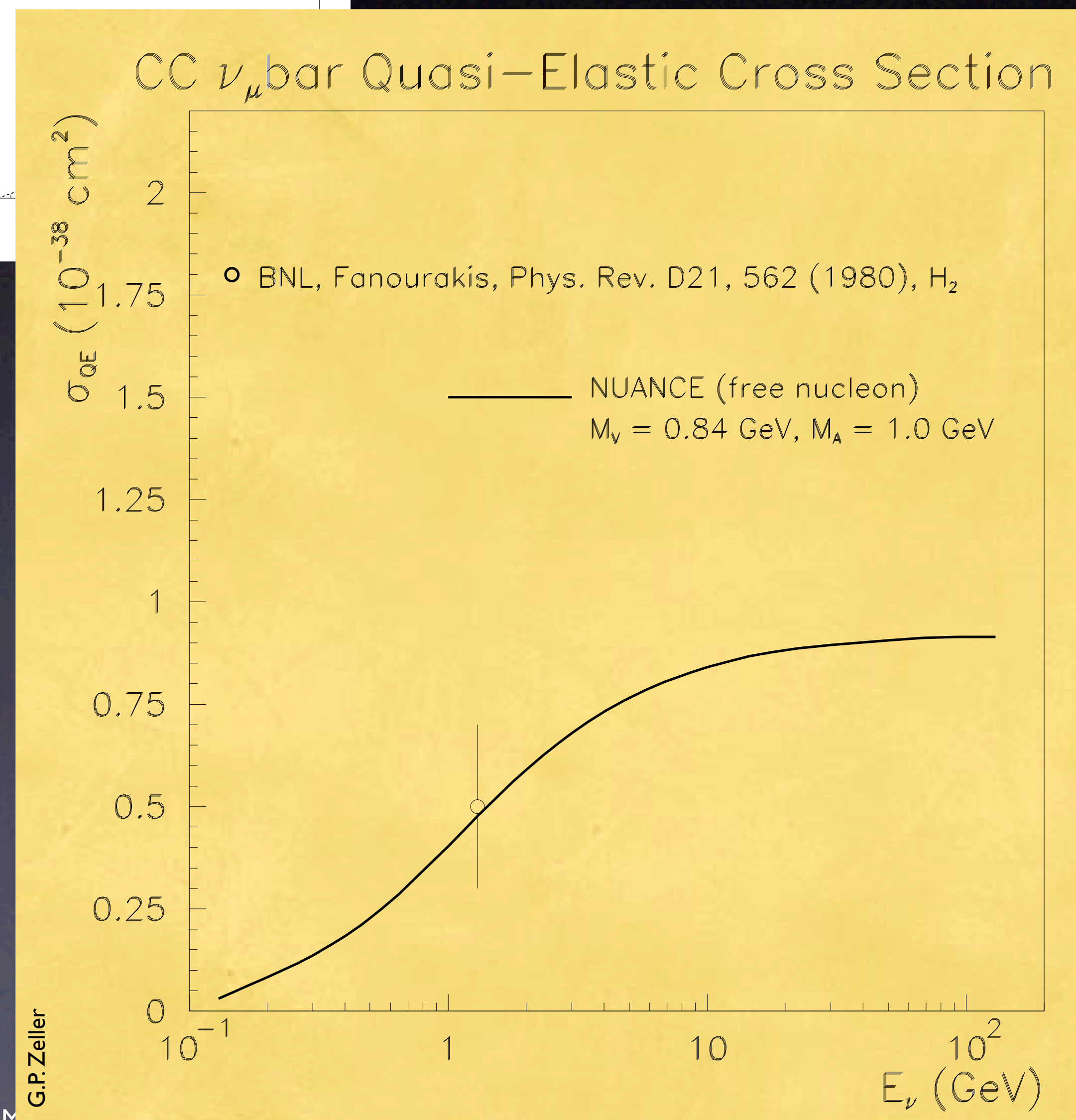

CCπ^- Events

<E>	Experiment	target	date	#CCπ^- evts
1.5 GeV	Gargamelle	$C_3H_8CF_3Br$	1979	282
5-70 GeV	FNAL	H_2	1980	247
5-200 GeV	BEBC	D_2	1983	300
25 GeV	BEBC	H_2	1986	375
7 GeV	SKAT	CF_3Br	1989	120
				1324

$\bar{\nu}_\mu$ CC QE Scattering

- Expect ~32,000 $\bar{\nu}_\mu$ CC QE interactions within fiducial volume for 2E20 POT
- MiniBooNE's current CC QE event selection:
  - Tank (>100) & veto (<6) PMT hit cuts
  - Fisher discriminant cut on event topology parameters
    - Select single, μ-like ring
- Using CC QE event selection, expect ~19,000 events
  - 75% pure QE (30% of those are WS)
  - May be improved with further refinements for $\bar{\nu}_\mu$
- Using WS constraints, expect to measure $\bar{\nu}_\mu$ CC QE cross section with ~20% uncertainty