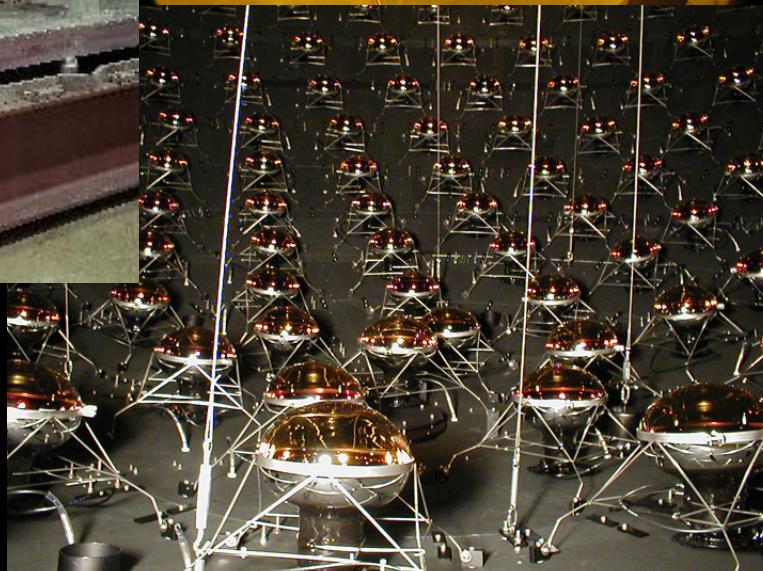
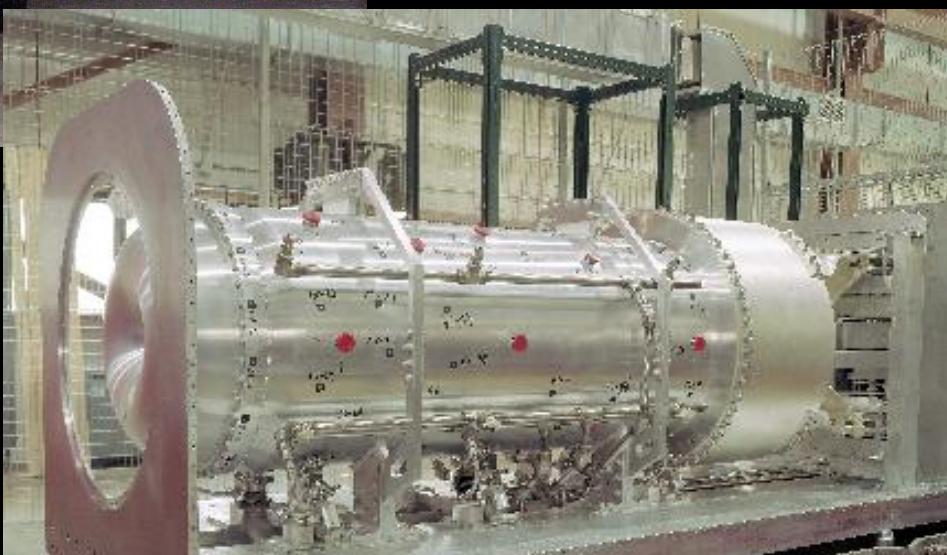
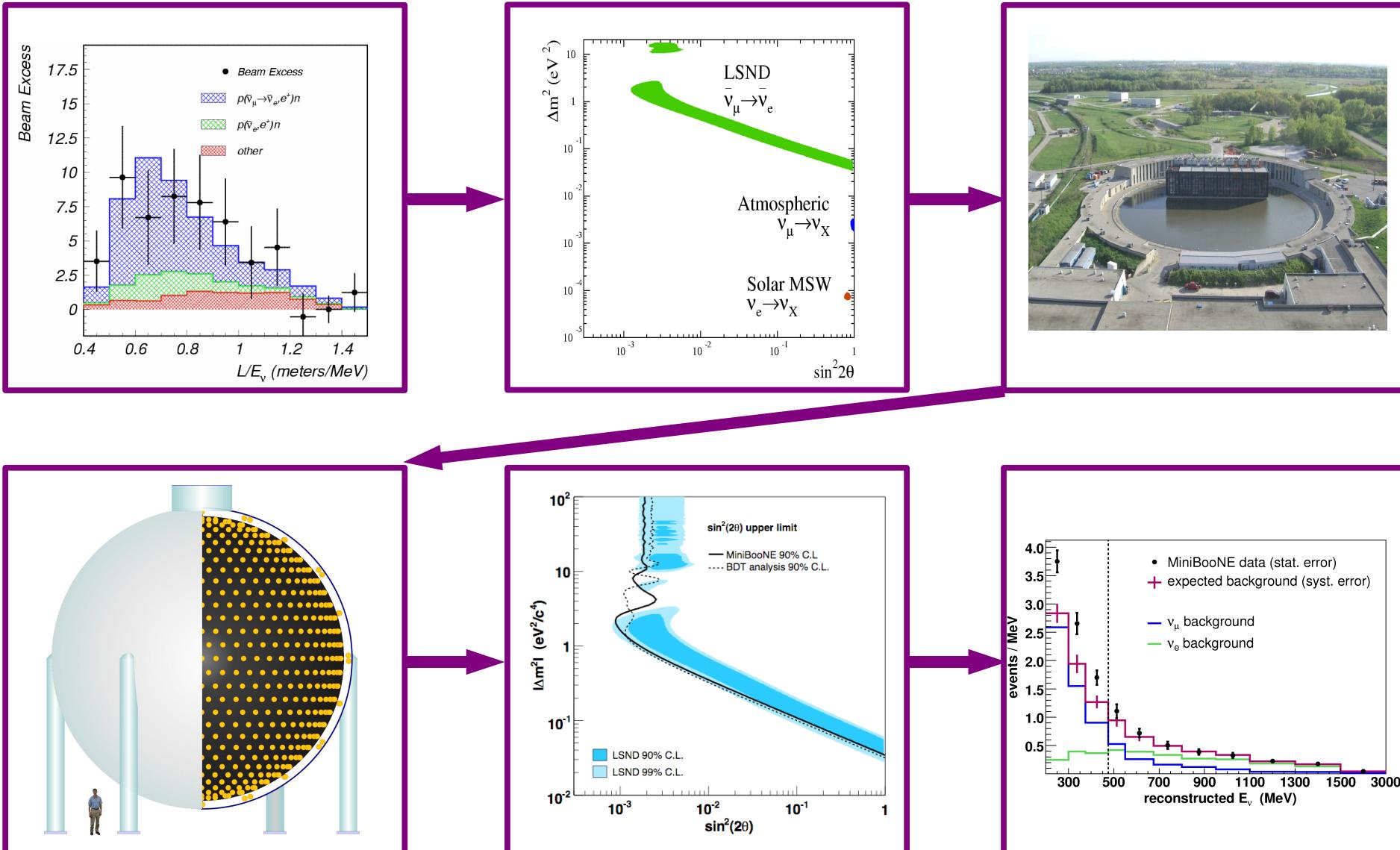


Neutrino Interactions in MiniBooNE

Chris Polly, University of Illinois



Most are familiar with ν oscillations in MB...

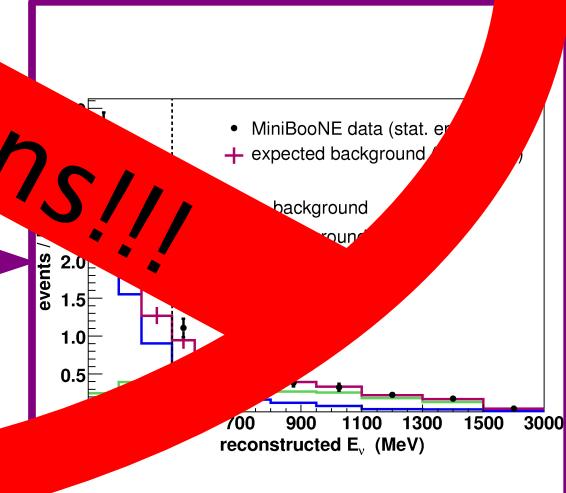
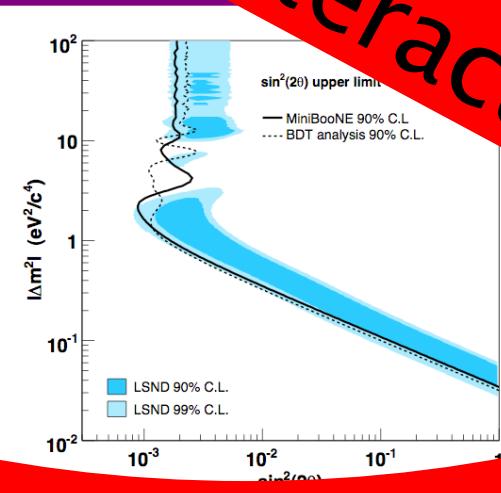
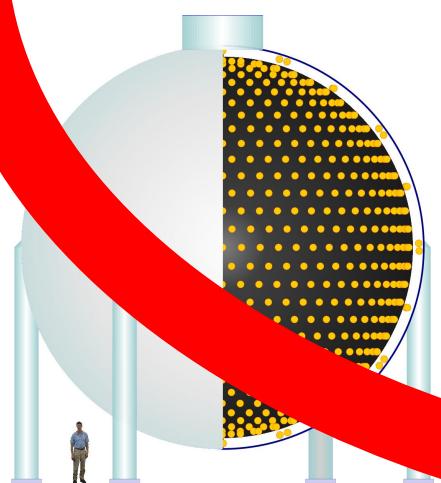
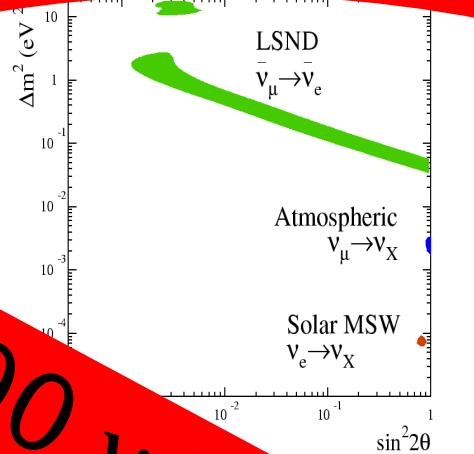
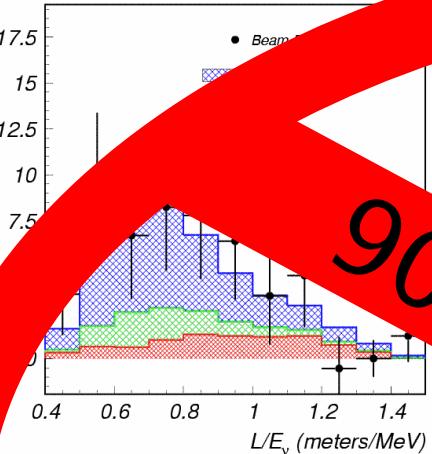


* Talks this AM by R. Van de Water,
Z. Djurcic, and later by Z. Pavlovic



Forget that for now and think...

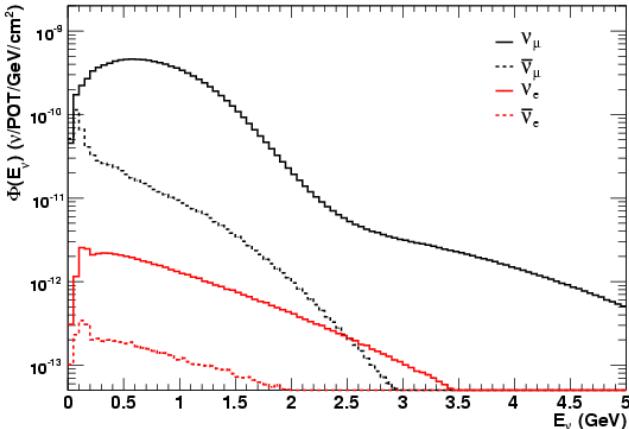
Beam Excess



900,000 ν interactions!!!

Wouldn't Pauli be proud of how far we have come?

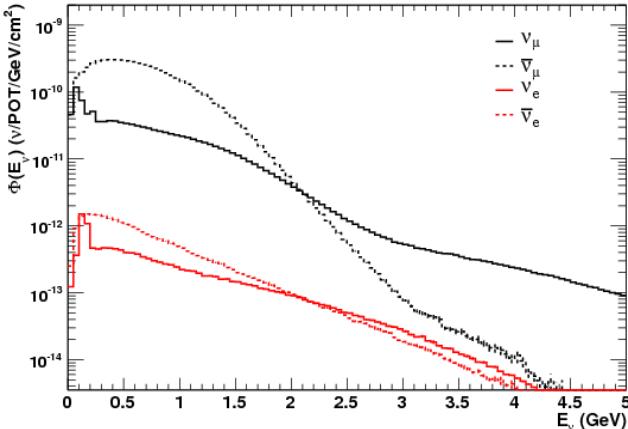
ν mode flux (focus π^+)



ν channel	events*
all channels	810k
CC quasielastic	340k
NC elastic	150k
CC π^+	180k
CC π^0	30k
NC π^0	48k
NC $\pi^{+/-}$	27k
CC/NC DIS, multi- π	35k

6e20 POT (ν mode)

$\bar{\nu}$ mode flux (focus π^-)



$\bar{\nu}$ channel	events*
all channels	81k
CC quasielastic	36k
NC elastic	15k
CC π^-	13k
CC π^0	2.6k
NC π^0	7.4k
NC $\pi^{+/-}$	2.7k
CC/NC DIS, multi- π	2.9k

3e20 POT ($\bar{\nu}$ mode)

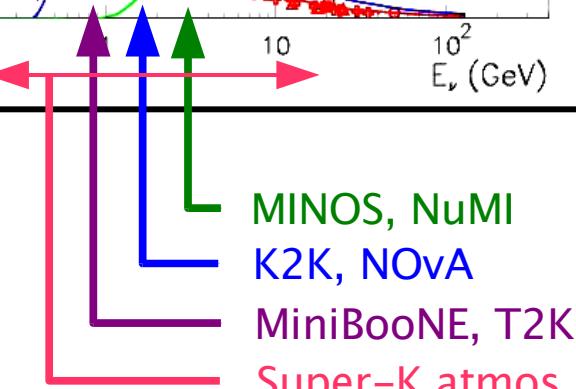
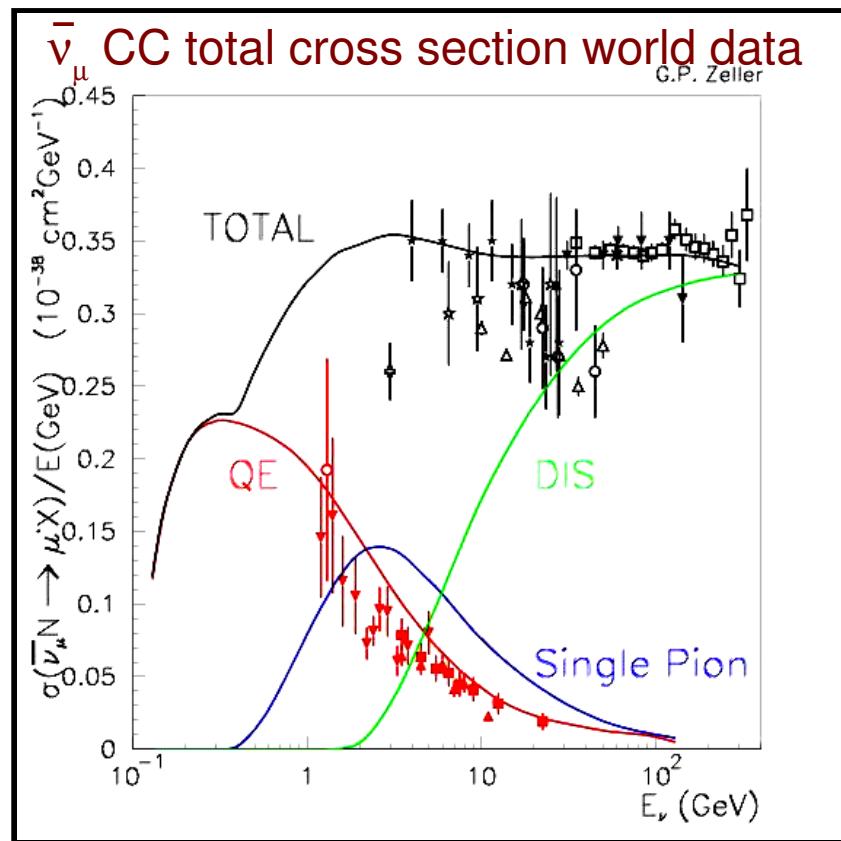
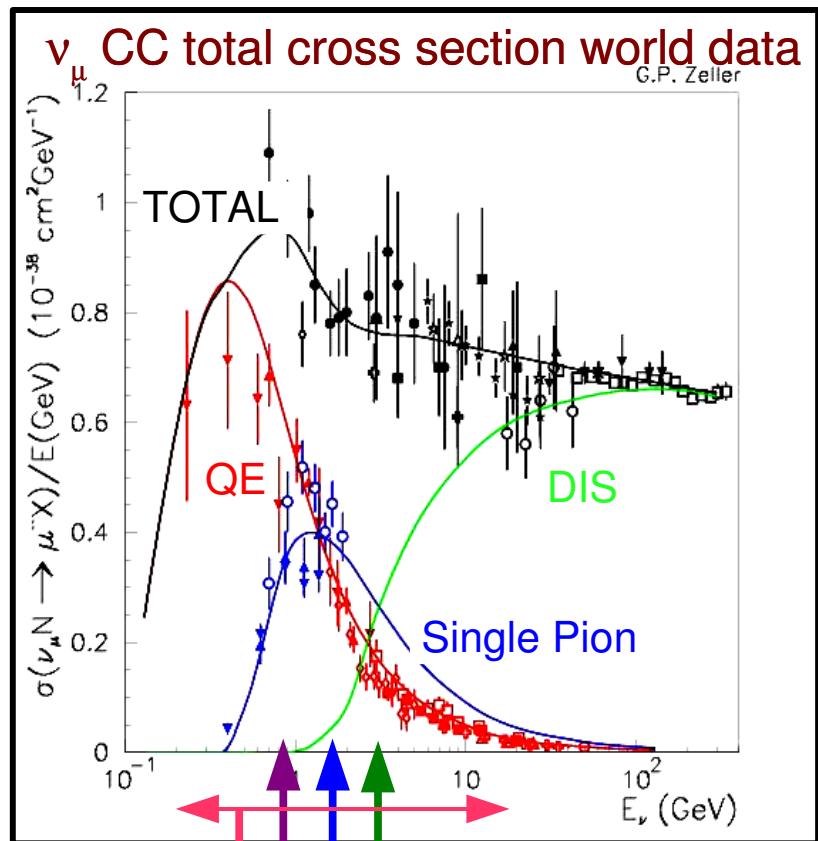
*Event rates (flux x xsec) after 500cm fiducial volume cut, but before other cuts



"I have done something very bad today by proposing a particle that cannot be detected; it is something no theorist should ever do."
W. Pauli 1929



Data is sparse at these important energies (~ 1 GeV)



- ➊ Relevant region for precision osc expts (esp. T2K), transition from QE to single π
- ➋ Charged-current data 20–30 yrs old, low event rate bubble chamber data
- ➌ Status of NC xsecs measurements even worse

ν_μ CCQE events

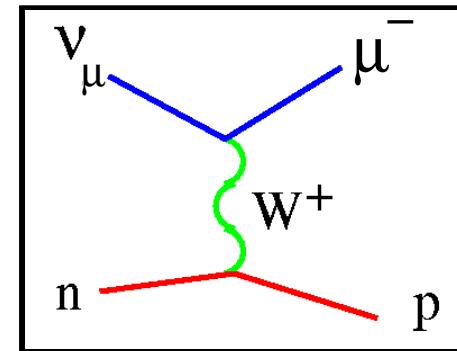
- Oscillation significance

- Golden channel by which MB constrains flux x xsec errors in ν_e CCQE appearance search
- Signal channel for disappearance experiments measuring $\nu_\mu \rightarrow \nu_x$

- Cross-section significance

- Used to probe nuclear structure
- Tool to measure axial form factors

$$F_A(Q^2) = \frac{g_A}{(1+Q^2/M_A^2)^2}$$



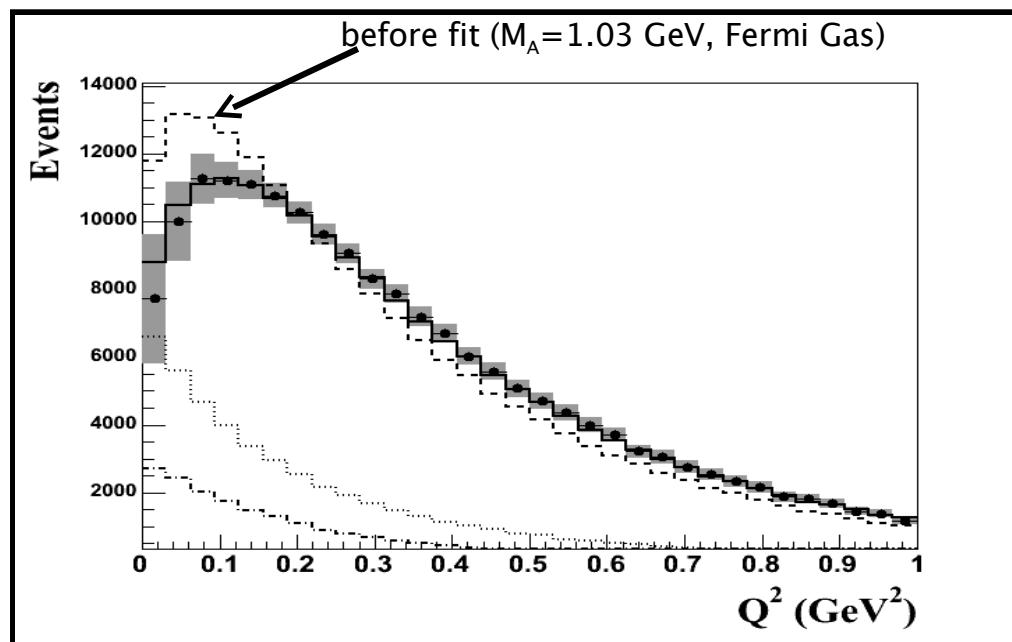
ν_μ CCQE Q^2 distribution

- Extracting M_A

- Can be done via normalization since M_A enters in overall cross-section
- Can be done using shape in Q^2

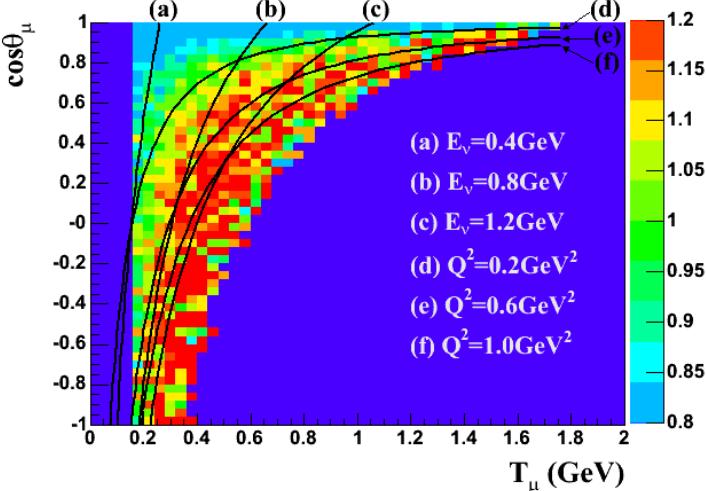
- MiniBooNE does the latter, and also fits for a parameter κ (Pauli blocking par)

- $M_A = 1.23 \pm 0.20$ GeV
- $\kappa = 1.019 \pm 0.011$

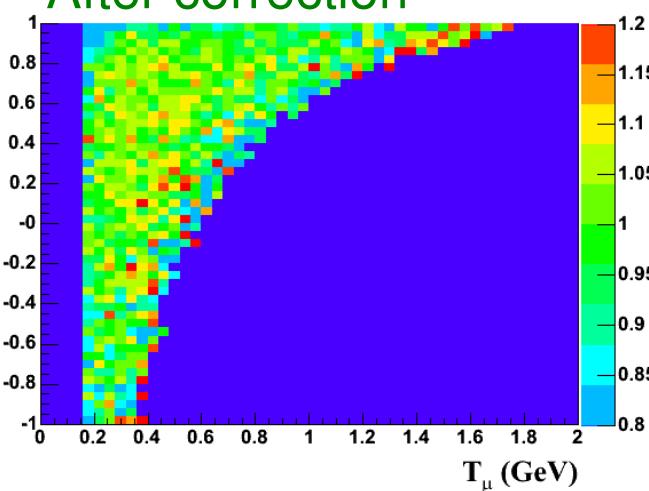


ν_μ CCQE events

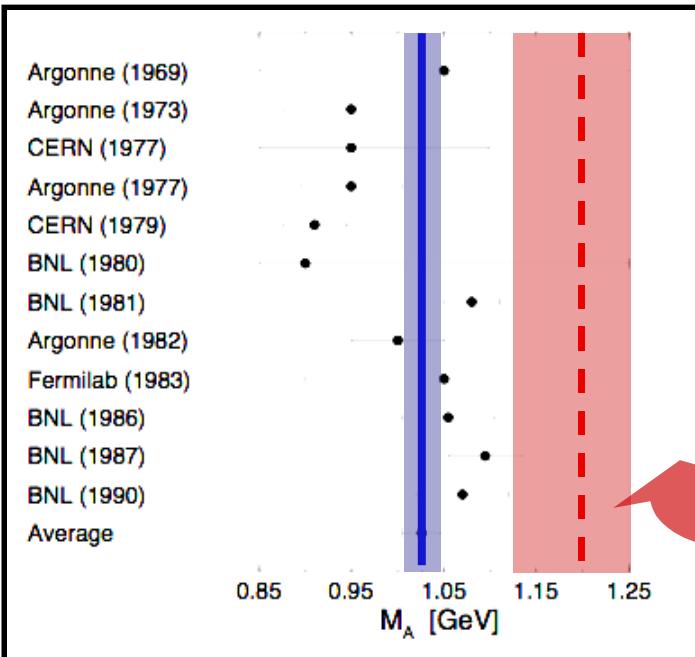
Before correction



After correction



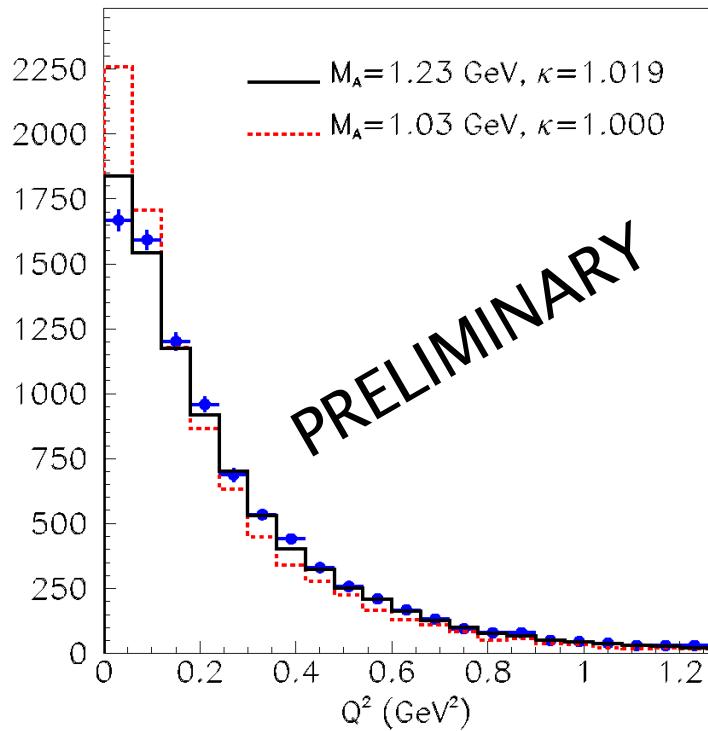
198,000 events
after cuts!



- High MB stats allow 2d kinematic plots
- All modern M_A extractions on nuclear targets (C and O) finding similar results

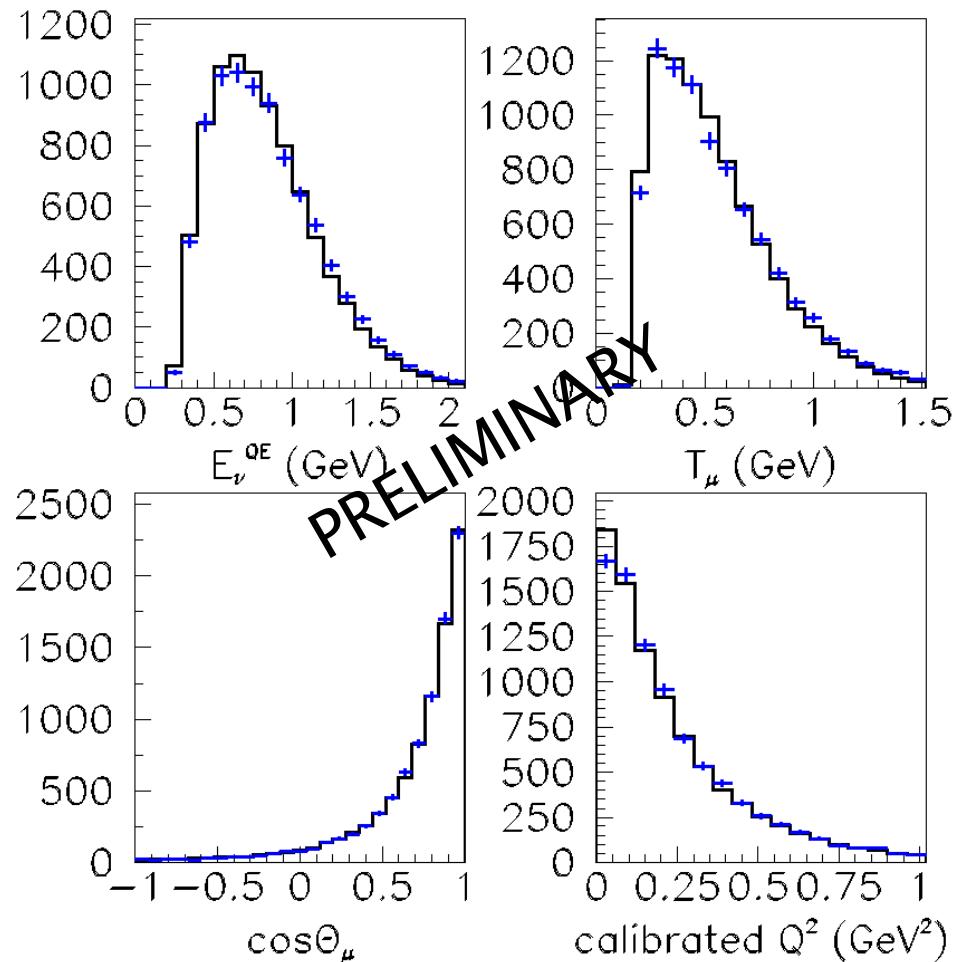
- K2K SciFi (^{16}O , $Q^2 > 0.2$)
Phys. Rev. D74, 052002 (2006)
 $M_A = 1.20 \pm 0.12 \text{ GeV}$
- K2K SciBar (^{12}C , $Q^2 > 0.2$)
 $M_A = 1.14 \pm 0.11 \text{ GeV}$
- MiniBooNE (^{12}C , $Q^2 > 0.25$)
Phys. Rev. Lett. 100, 032301(2008)
 $M_A = 1.25 \pm 0.12 \text{ GeV}$

$\bar{\nu}_\mu$ CCQE events



- ➊ Apply M_A, κ extracted from ν data
- ➋ Good agreement in Q^2
- ➌ Similarly good agreement in other kinematic variables

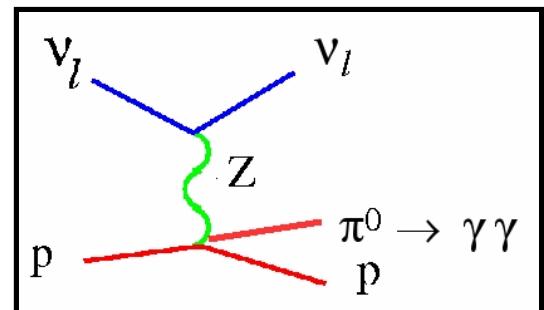
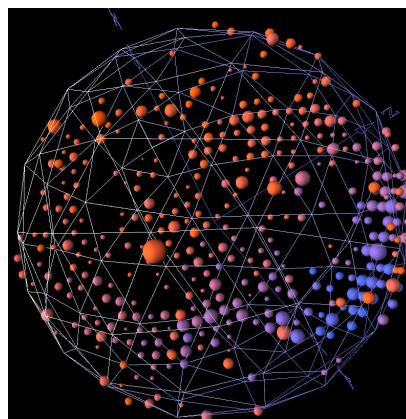
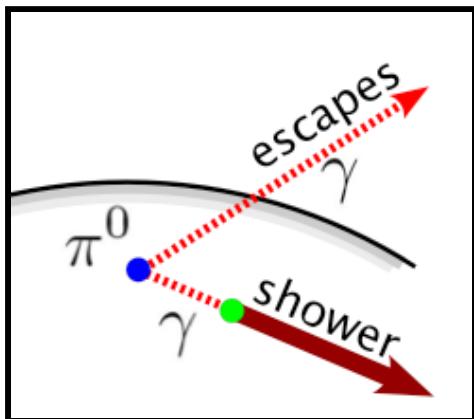
$\bar{\nu}_\mu p \rightarrow \mu^+ n$



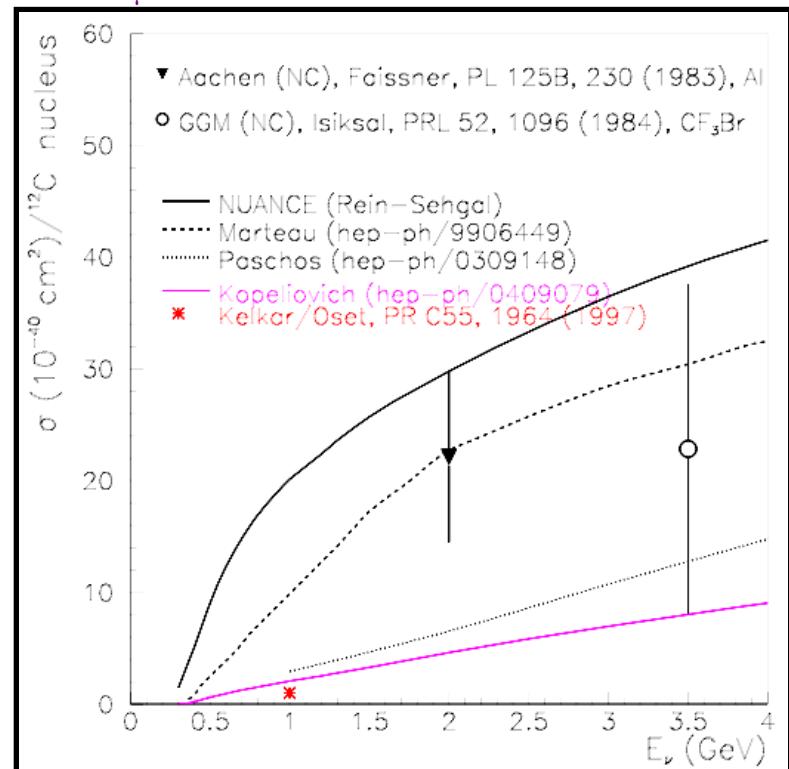
ν_μ NC π^0 events

Oscillation significance

- Important measurement for *in situ* MB constraint on NC π^0 bkg
- Generally important bkg for appearance measurements $\nu_\mu \rightarrow \nu_e$
- Bkg when only 1 γ found
 - Both γ 's too close to resolve
 - Asymmetric decay leaves one γ below threshold
 - One γ escapes



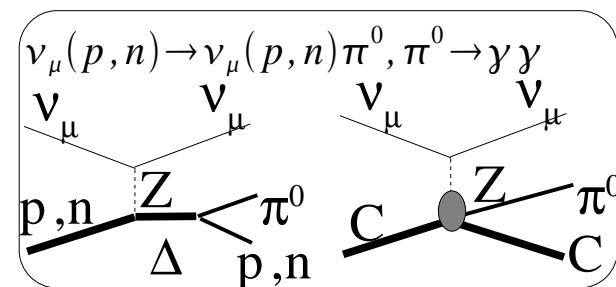
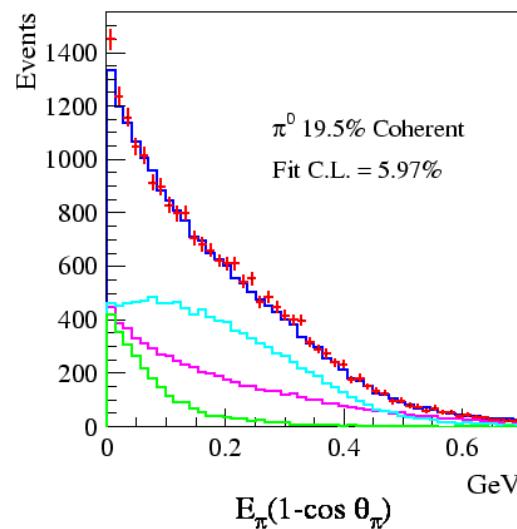
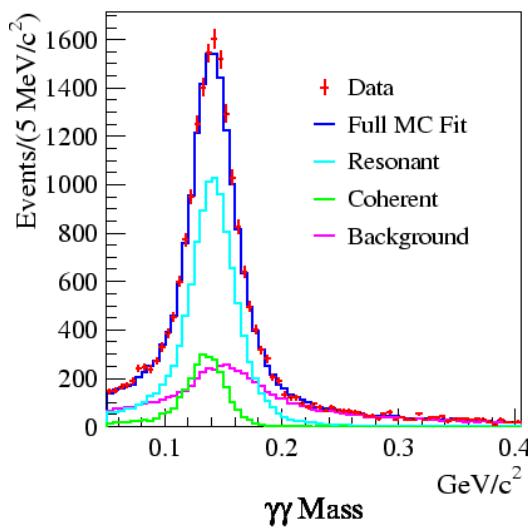
ν_μ coherent NC π^0 world data



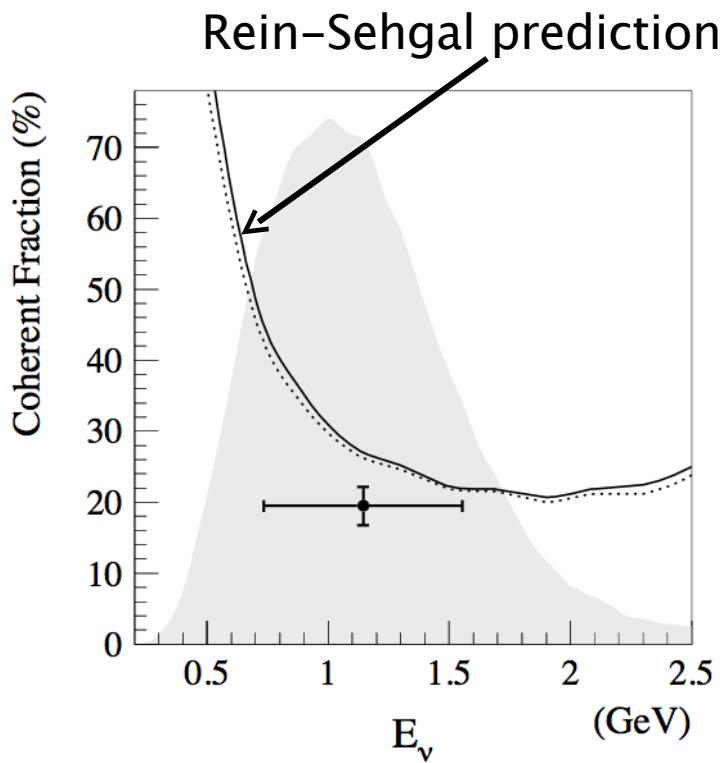
Cross-section significance

- Understanding resonant and coherent production
- VERY little historical data in this E range
 - NO data for ν or anti- ν production below 2 GeV

ν_μ NC π^0 events

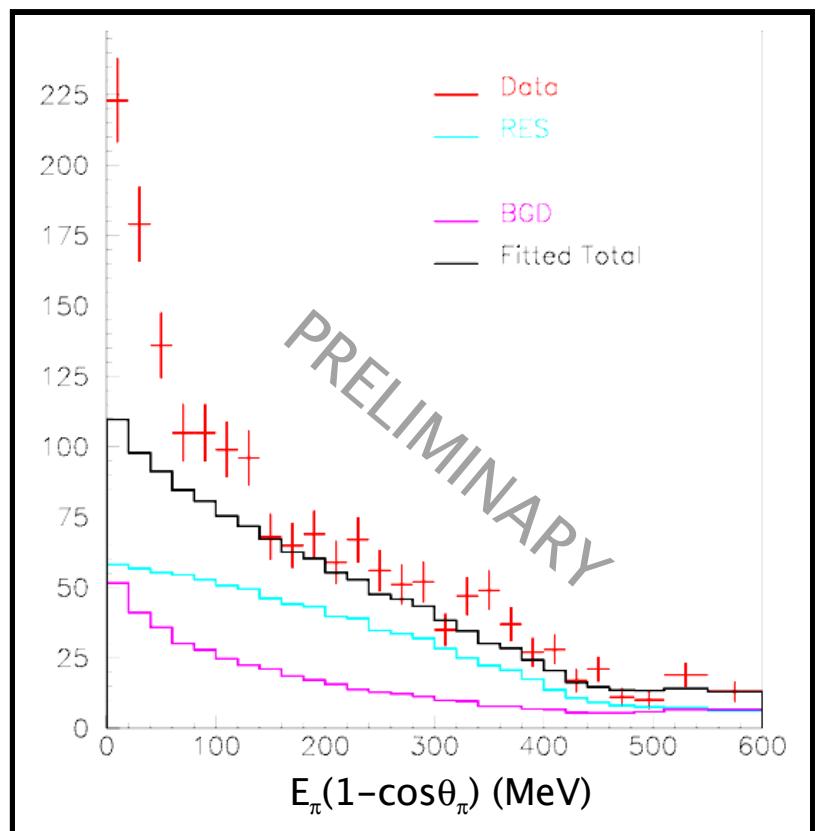
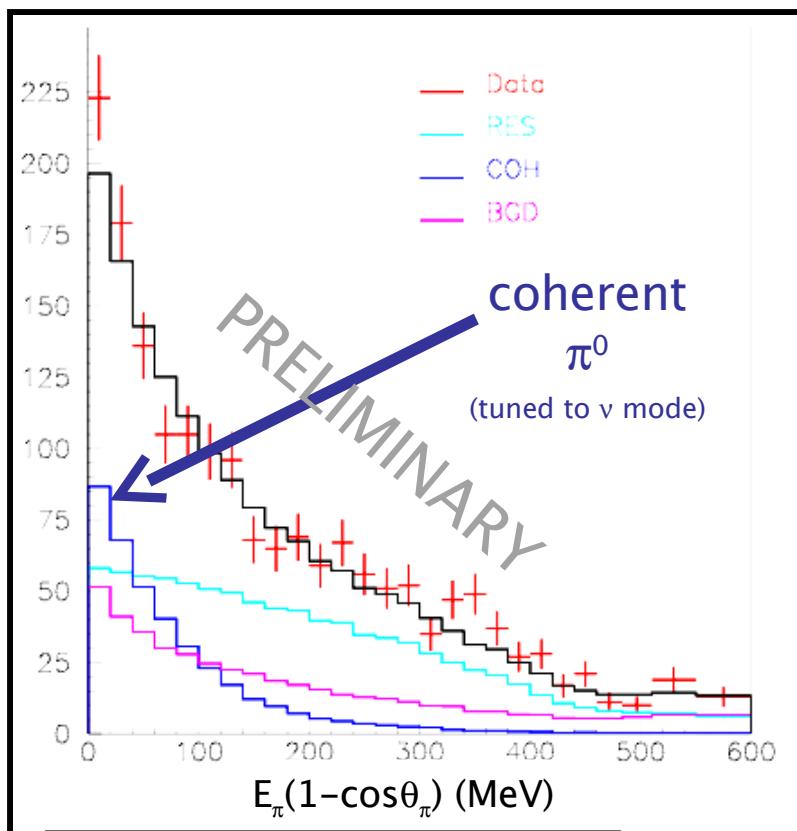


- MB reweights MC prediction in bins of pion momentum \rightarrow perfect kinematic agreement
- Clear difference in res/coh kinematics
- Fit to coh/res fraction yields a $[19.5 \pm 1.1(\text{stat}) \pm 2.5(\text{syst})]\%$, much lower than Rein-Sehgal prediction



$\bar{\nu}_\mu$ NC π^0 events

- First anti- ν measurement at 1 GeV...1750 events
- Same level of coherent production as observed in ν mode



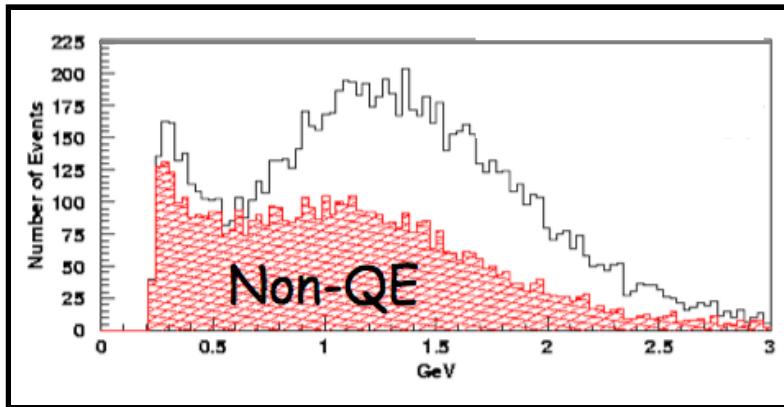
(prediction if no coherent π^0 contribution)

ν_μ CC π^+ events

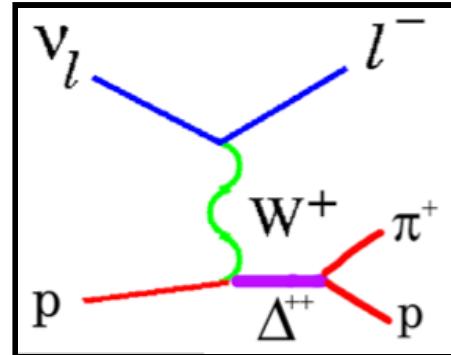
Oscillation significance

- Dominant bkg for ν_μ CCQE disappearance experiments $\nu_\mu \rightarrow \nu_x$
 - π^+ can absorb in struck nucleus
 - Results in mis-reconstruction of nm energy
 - Distorts E spectrum and extraction of osc parameters
 - Would like to know ratio Ccp+/CCQE ratio to 5%

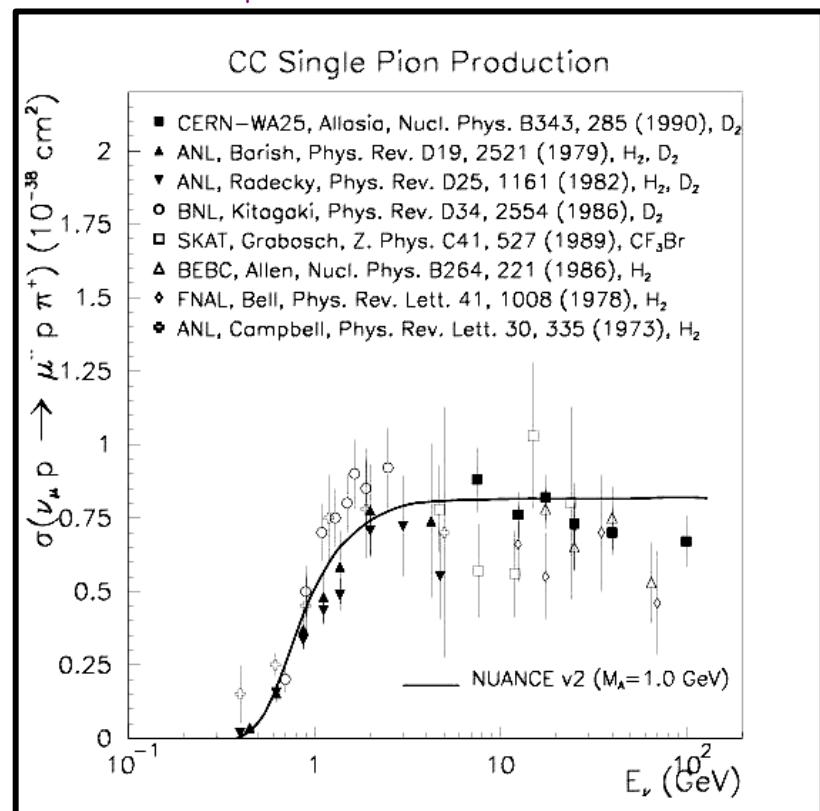
* Talk this AM by S. Linden



(C. Walter, NuInt07)



ν_μ CC π^+ world data



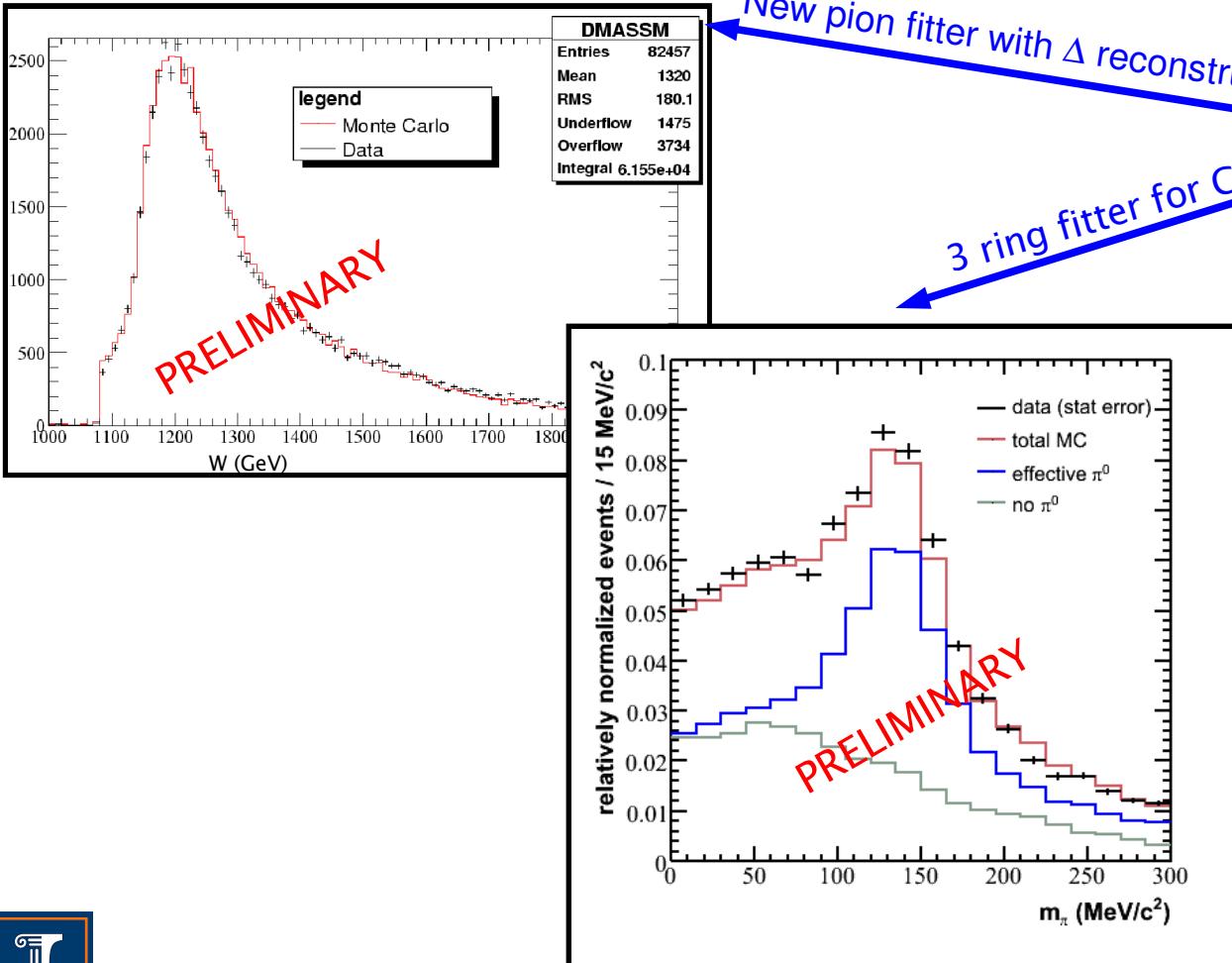
Cross-section significance

- Curious absence of coh. component (K2K & SciBooNE)
- Need more work to understand kinematics

* Next talk by J. Nowak

Other on-going efforts....

- Too many cross-section analyses to talk about in 10 minutes... good problem to have...only discussed RED flagged channels
- Lot's of other exciting developments!!



v channel	events*
all channels	810k
CC quasielastic	340k
NC elastic	150k
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CC π^0	30k
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CC π^0	2.6k
NC π^0	7.4k
NC $\pi^{+/-}$	2.7k
CC/NC DIS, multi- π	2.9k

Current and upcoming cross-section papers

For info on MiniBooNE relevant to cross-sections see

- Measurement of Muon Neutrino Quasi-Elastic Scattering on Carbon, PRL 100, 032310 (2008)
- First Observation of Coherent π^0 Production in Neutrino Nucleus Interactions with $E_n < 2$ GeV, Phys Lett B. 664, 41 (2008)
- The Neutrino Flux Prediction at MiniBooNE, Accepted by PRD [arXiv:0806:1449]
- The MiniBooNE Detector, Submitted to NIM A [arXiv:0806.4201]

Cross-section analyses on the immediate horizon

- CC π^+ /CCQE ratio measurement
- NC π^0 coherent/resonant fraction for anti- ν
- Differential cross sections
 - CCQE
 - NC elastic
 - NC π^0
 - CC π^+
 - CC π^0

NC elastic..1st differential xsec

