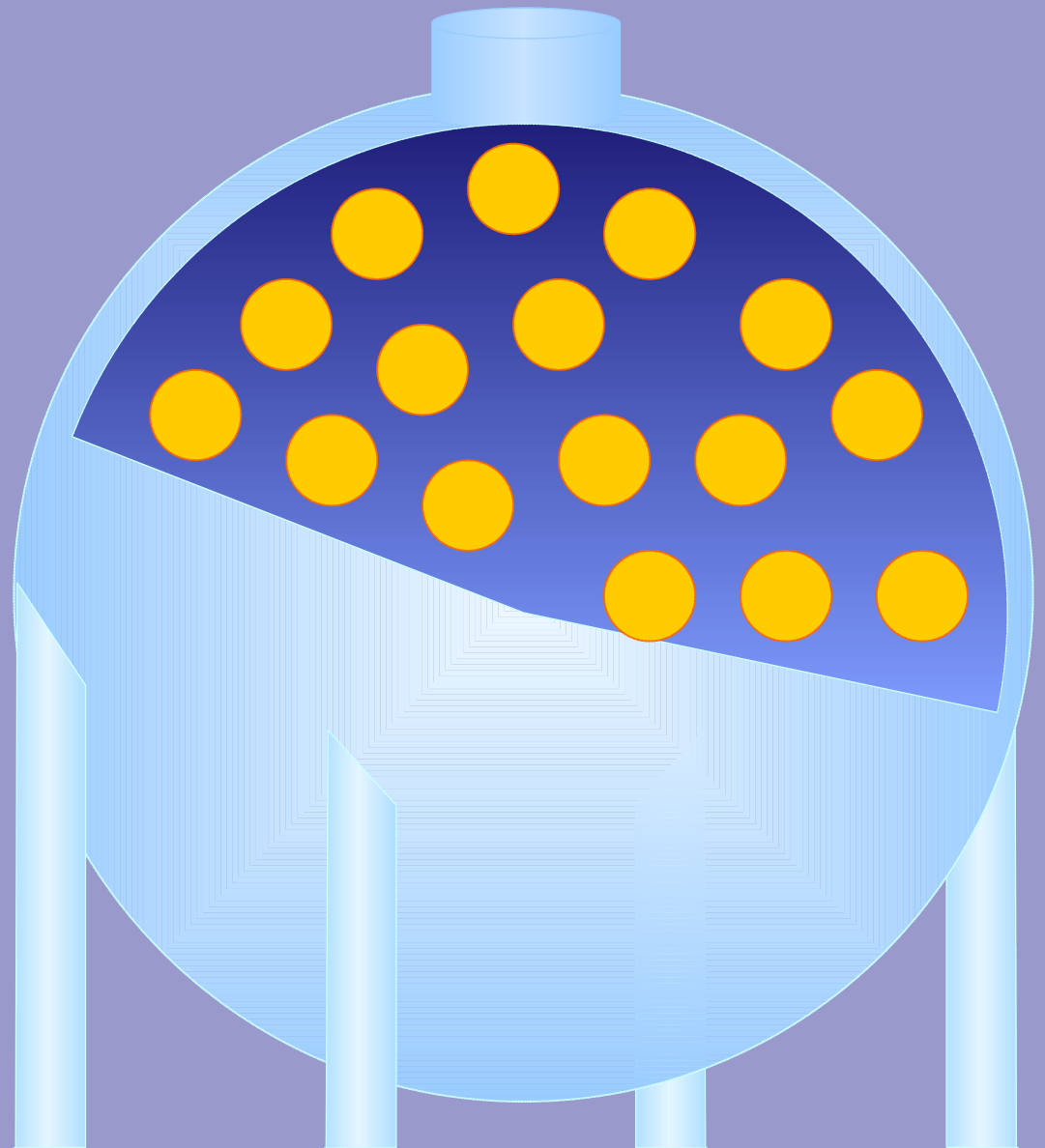


Neutrino Cross Section Measurements with MiniBooNE

Outline:

- overview
- neutrino reaction channels
and event totals
- CC channels,
preliminary results
- NC channels,
(new) preliminary results
- antineutrino running

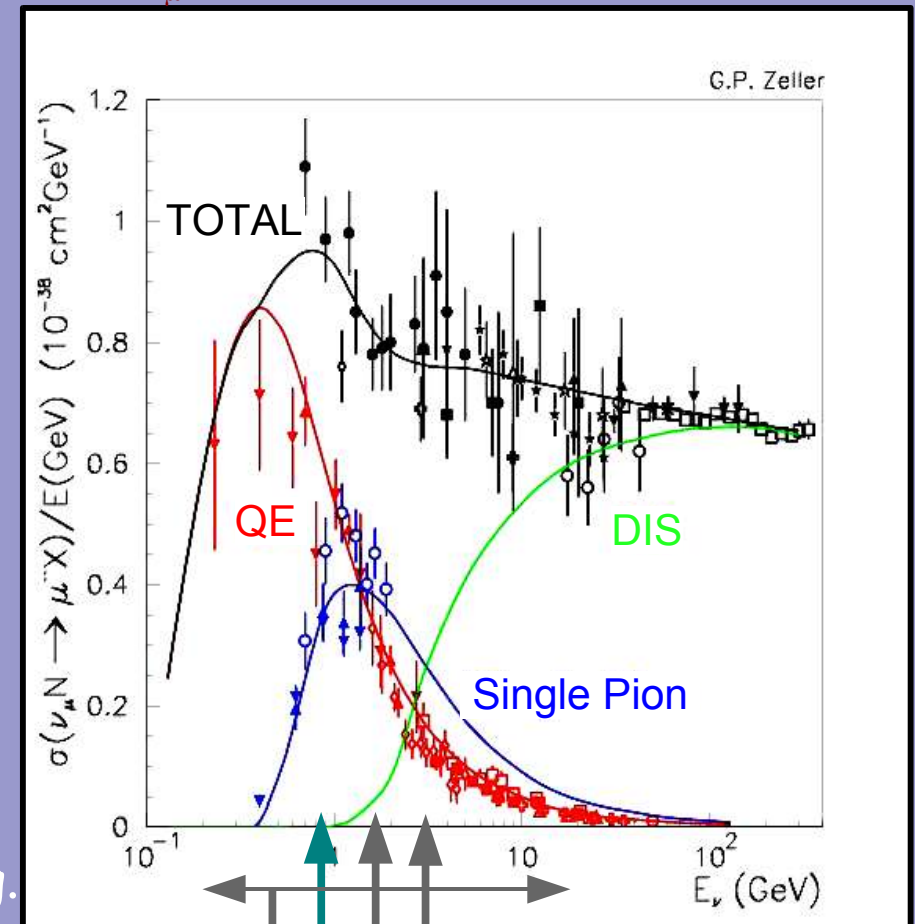


Neutrino Cross Sections

- The main goal of MiniBooNE (MB) is a $\nu_\mu \rightarrow \nu_e$ search
(B. Fleming, next session)
- High rates and good particle ID also allow accurate cross section measurements.
- Important for MB and other oscillation experiments especially at $E_\nu \sim 1$ GeV
- where data is somewhat sparse
- In addition, the physics addressed in these measurements is quite interesting.

E.g. Does the ν "see" the same nucleus/nucleons as does the e or p ?

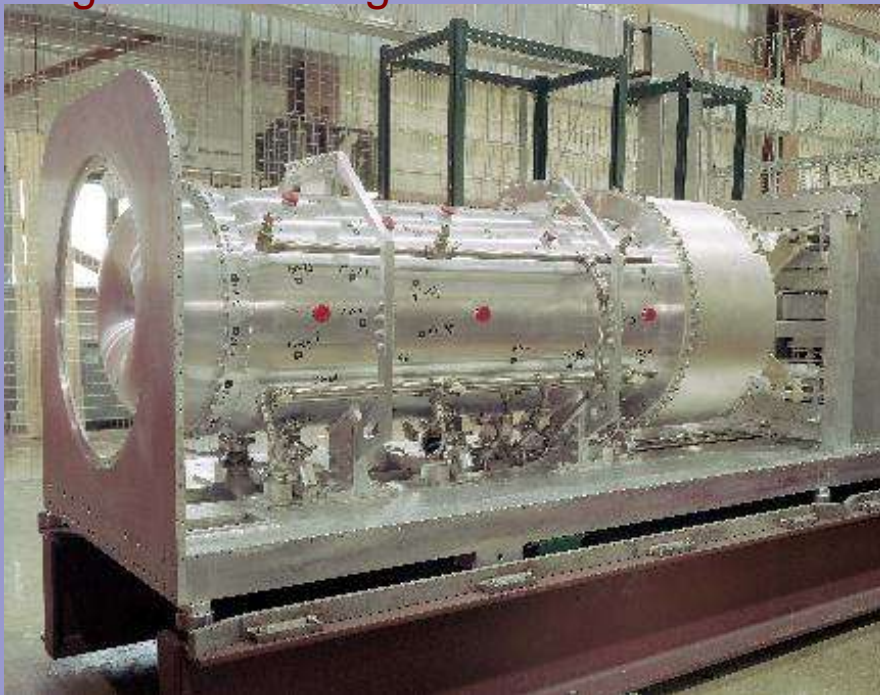
ν_μ CC total cross section world data



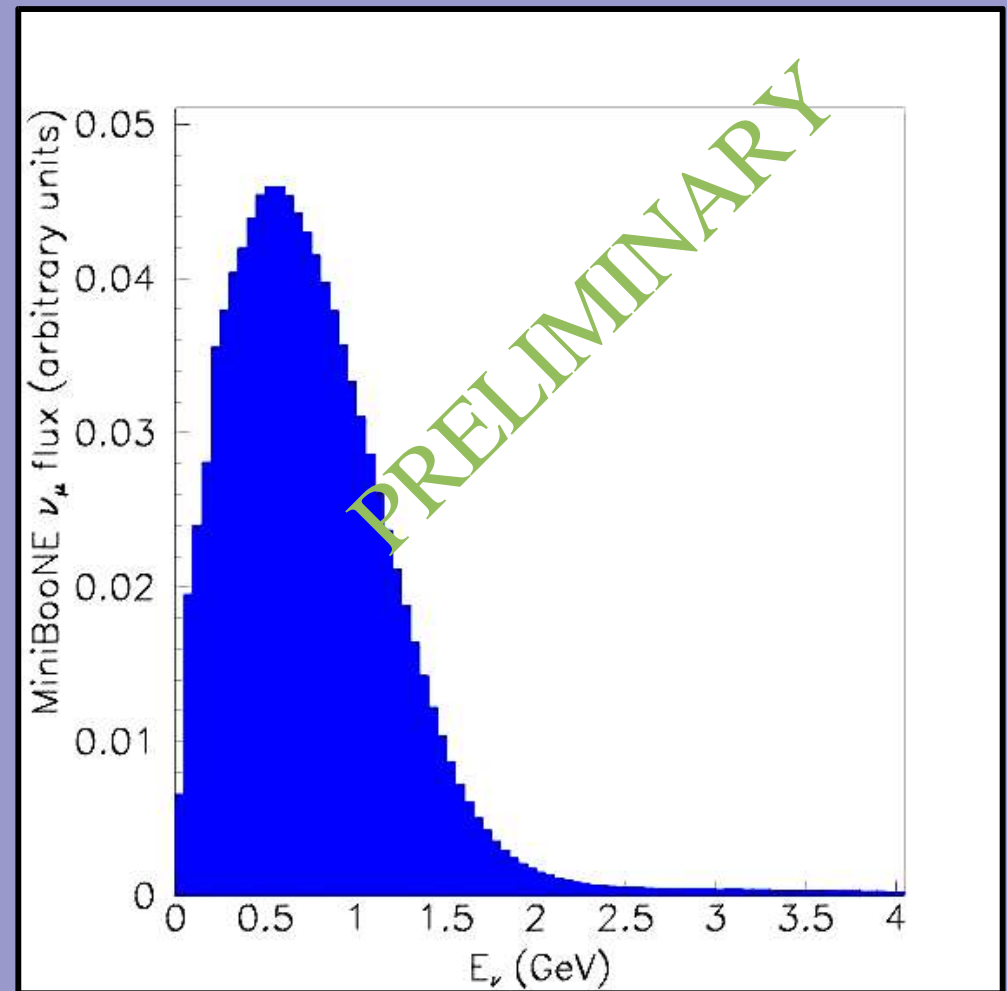
MiniBooNE ν Beam and Flux

- "horn-focussed" beam using 8 GeV protons on Be
- >99% ν_μ , mainly via $\pi^+ \rightarrow \mu^+ \nu_\mu$
- $\langle E_\nu \rangle \sim 0.7$ GeV
- small high energy tail \Rightarrow low background from high multiplicity reactions

magnetic focusing horn



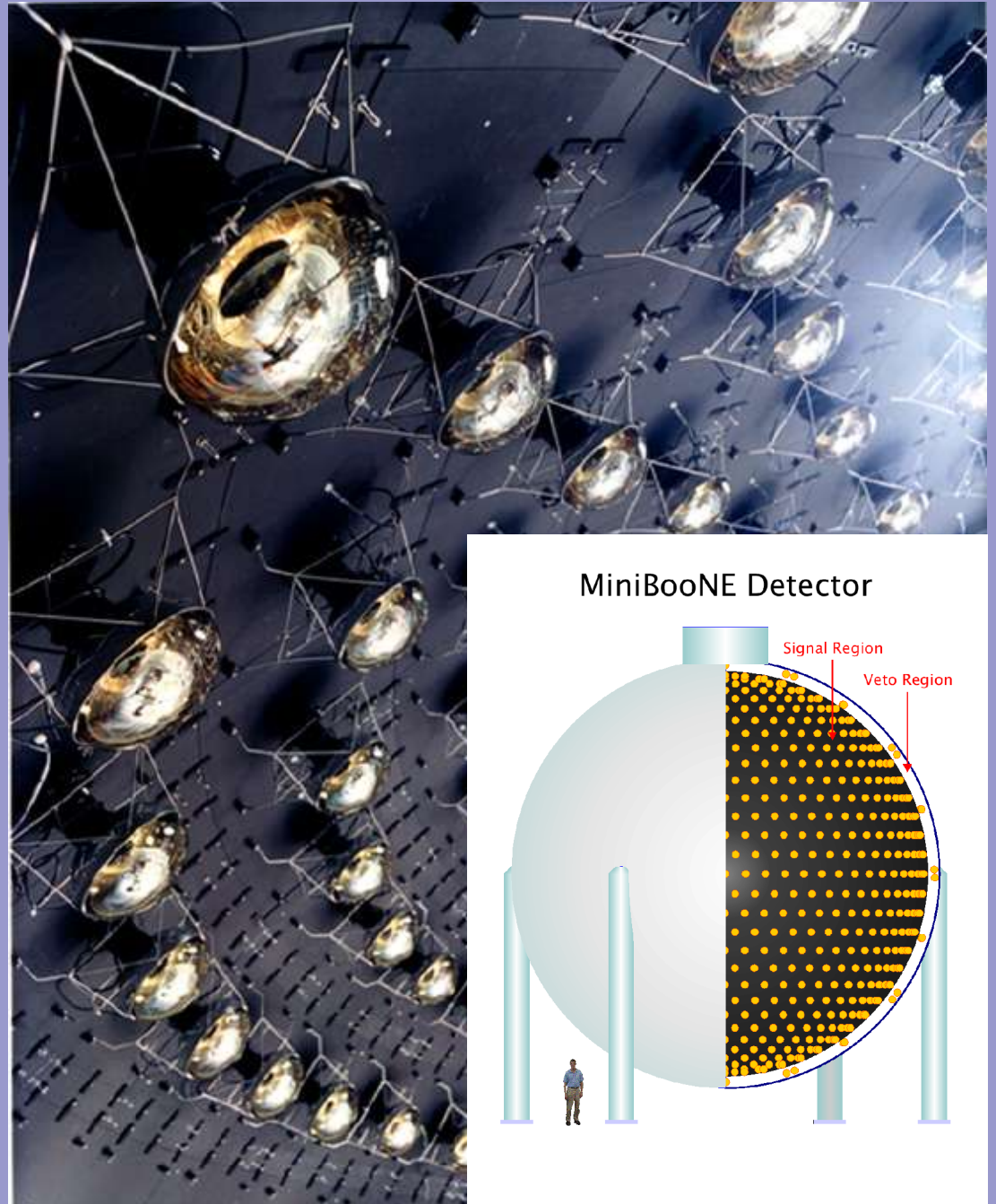
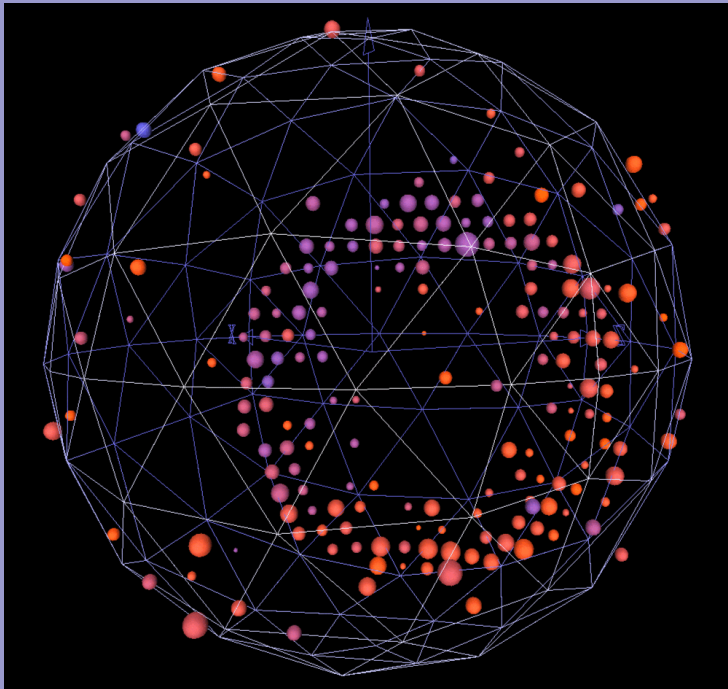
MB ν flux



MiniBooNE Detector

- 800 tons mineral oil (CH_2)
- viewed by 1280 8" PMTs (10% coverage) + veto
- Particle ID via Cerenkov (ring pattern) and scintillation light

muon event in MiniBooNE



MiniBooNE Event Rates

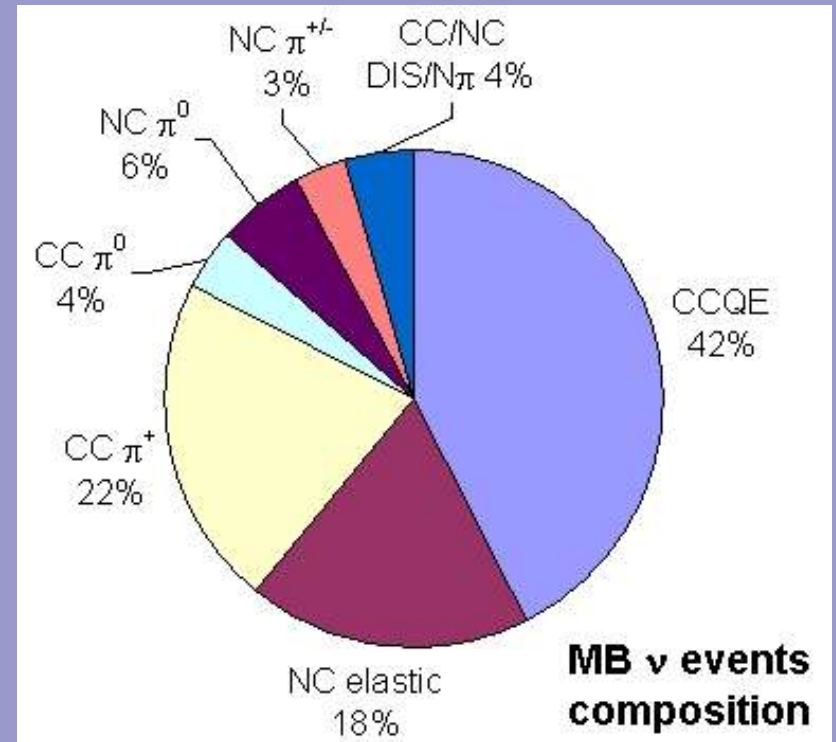
ν events currently "on-tape" :

- predicted by ν interaction MC*
- from $5.7E20$ "protons-on-target" (POT)
- with fiducial radius of 500cm
- before cuts

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" =
charged current
"NC" =
neutral current

These event samples allow cross section measurements with excellent statistics and demand high systematic precision.

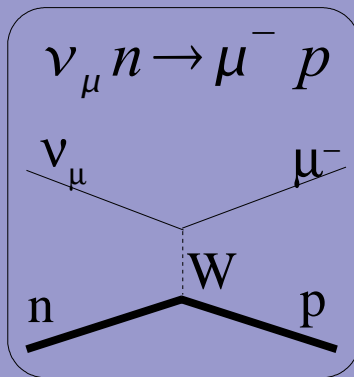


*MB ν interaction MC:

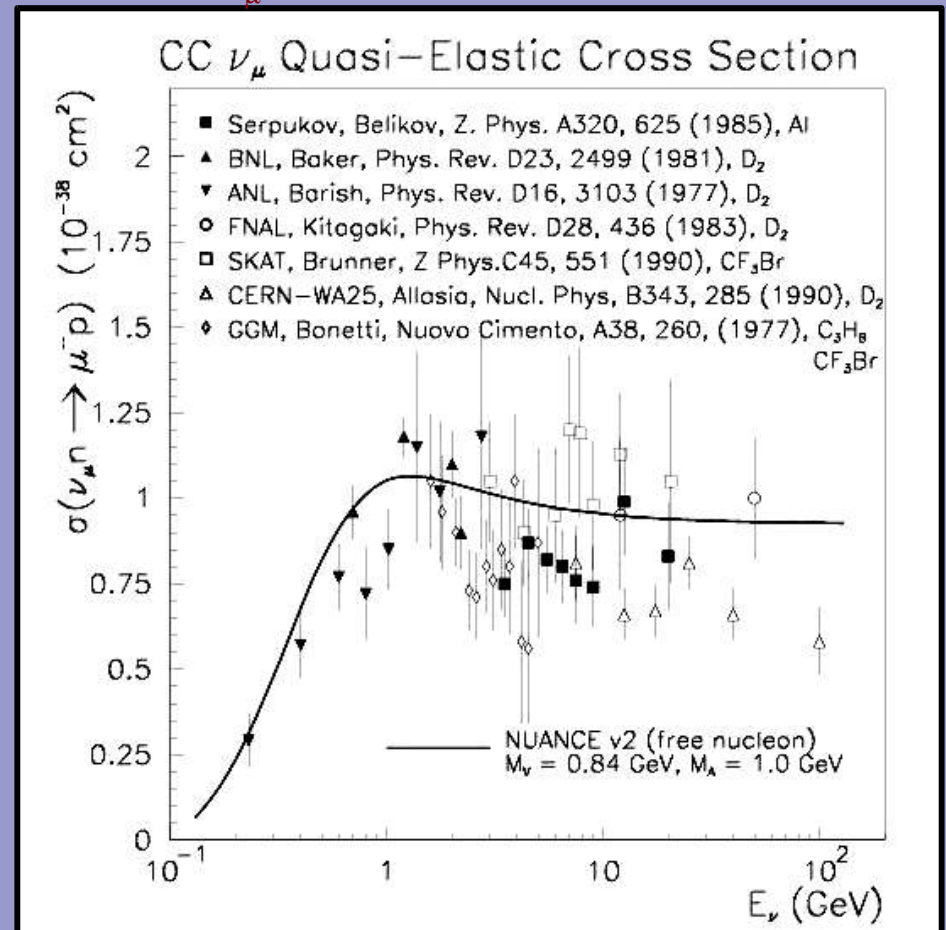
- NUANCE code with:
 - Smith-Moniz Fermi Gas
 - Rein-Sehgal 1π
 - Bodek-Yang DIS

Charged-Current Quasielastic Scattering (CCQE)

- highest-rate reaction channel in MiniBooNE
- ν_μ CCQE provides a cross check of the ν_μ flux
- ν_e CCQE is the oscillation signal channel
- Need to understand this process on nuclear target (C)
- existing data consists of small samples and (at low energies) on D_2



ν_μ CCQE cross section world data



Charged-Current Quasielastic Scattering...

MB preliminary ν_μ CCQE results (hep-ex/0602050) :

- from $\sim 1/2$ of current ν data set (3.2E20 POT)
- $\sim 60k$ events with $\sim 80\%$ purity

- data/MC disagreement interesting...

- similar to that seen by K2K

- has since been largely solved with adjustments to

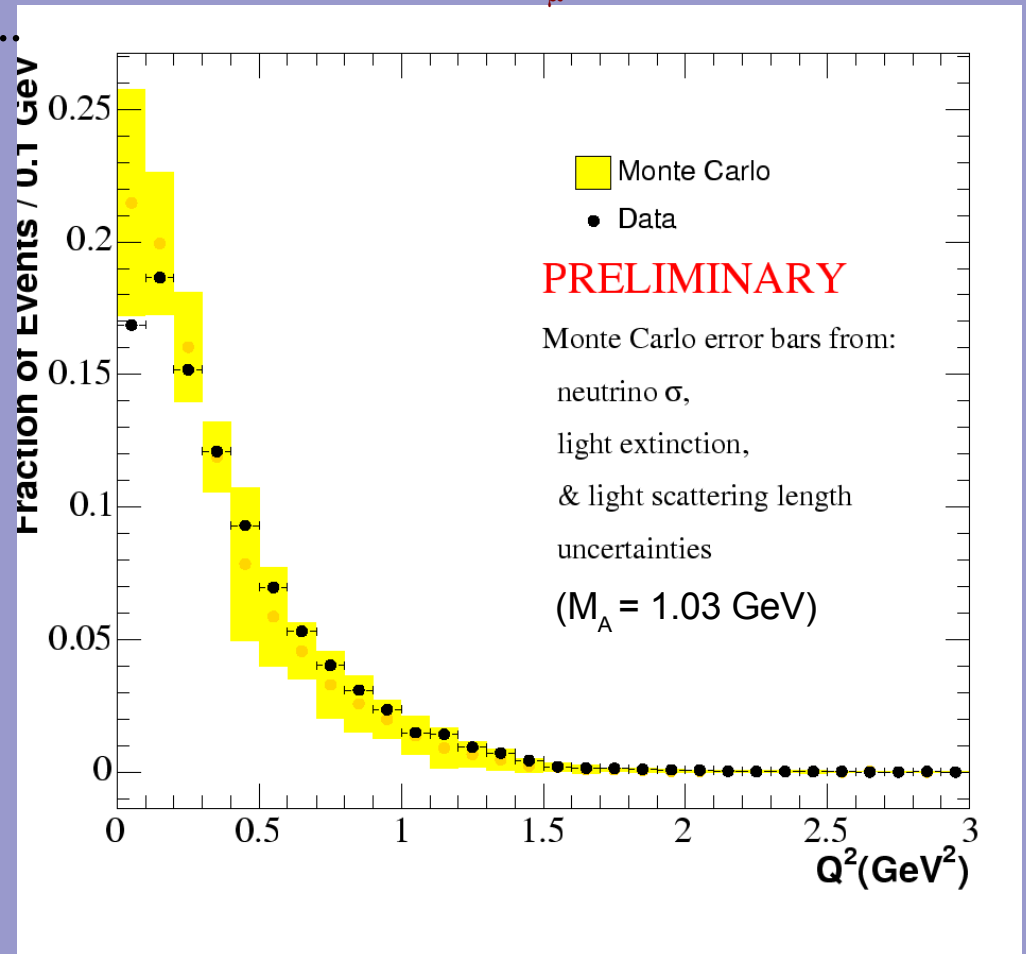
- axial form-factor (M_A)

- nuclear model

- area of current effort

- Another processing of this data is currently being performed with full data set and improved MC/event reconstruction. ... stay tuned.

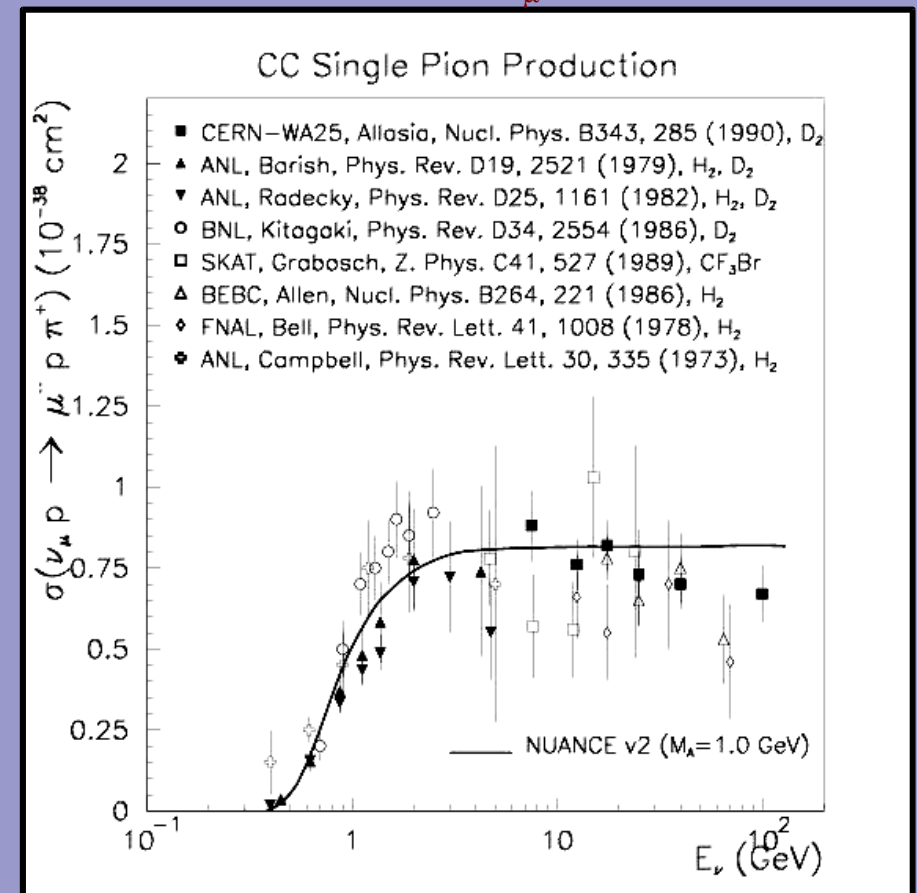
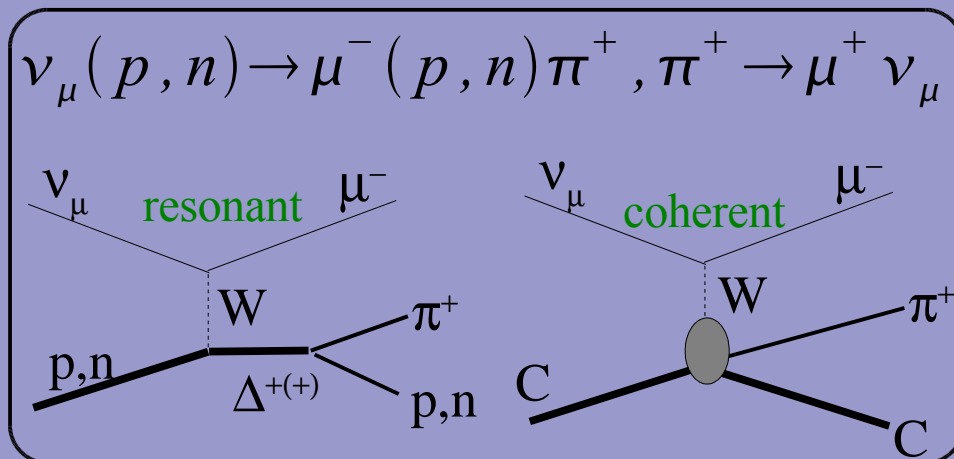
MB ν_μ CCQE Q^2 distribution



Charged-Current $1\pi^+$ Production ($\text{CC } \pi^+$)

- 2nd highest-rate reaction channel in MiniBooNE
- largest background for ν_μ CCQE
- provides measurement of Δ production
(and $\Delta \rightarrow N \gamma$ background in $\nu_\mu \rightarrow \nu_e$ search)
- coherent $\text{CC } \pi^+$ is interesting subject,
K2K sets limit (hep-ex/0506008)
- existing data is sparse

ν_μ $\text{CC}\pi^+$ world data



Charged-Current $1\pi^+$ Production...

MB preliminary ν_μ CC π^+ results ([hep-ex/0602050](https://arxiv.org/abs/hep-ex/0602050)):

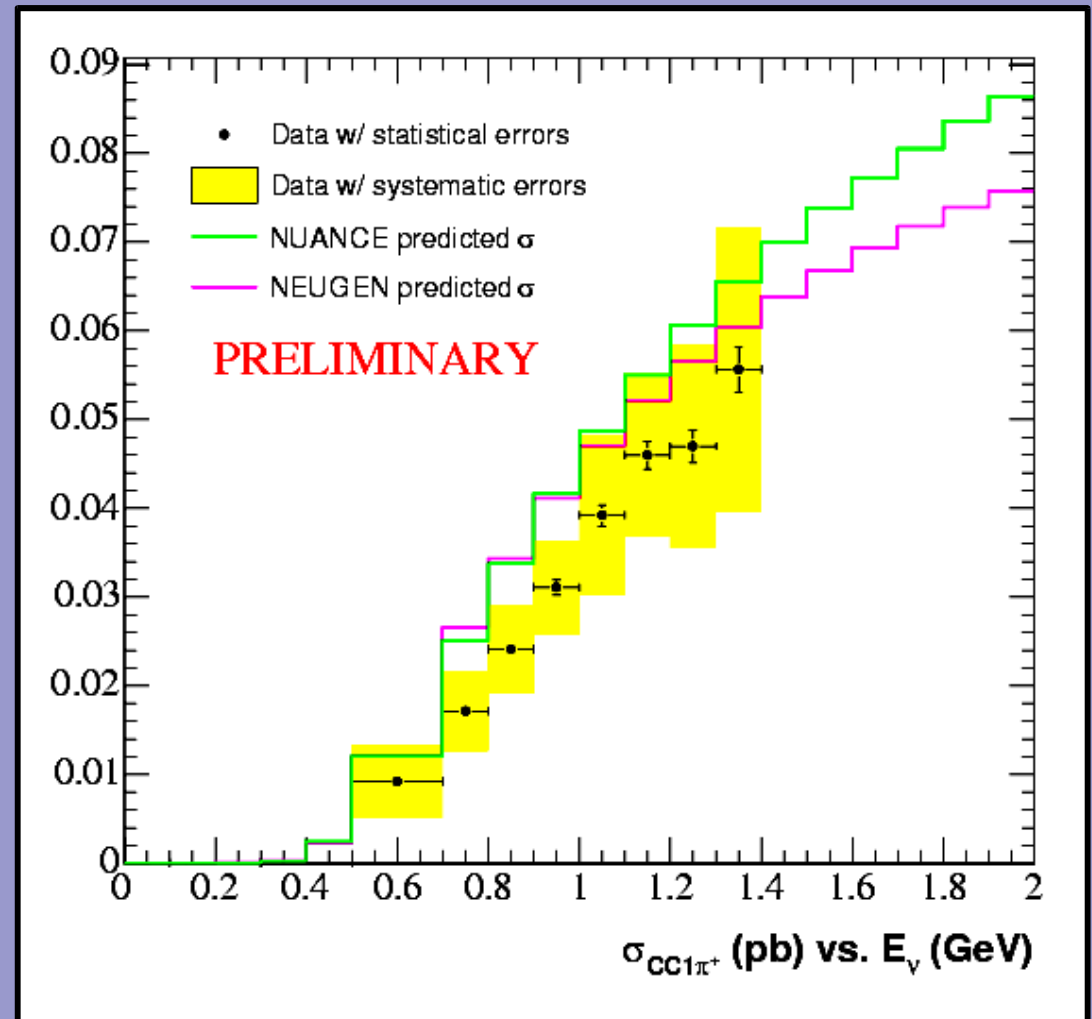
- from $\sim 1/2$ of current ν data set (3.2E20 POT)
- $\sim 40k$ events with $\sim 80\%$ purity

- $CC\pi^+/CCQE$ ratio:

1st measurement on a
nuclear target at low-E

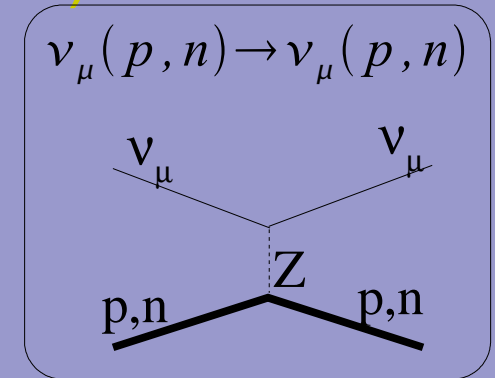
- combining this with
predicted CCQE cross section
yields $CC\pi^+$ cross section

$CC\pi^+$ cross section



Neutral-Current Elastic scattering (NC elastic)

- NC probe of the nucleus/nucleon
- unlike CC channels, sensitive to isoscalar component of nucleon (strange quarks)



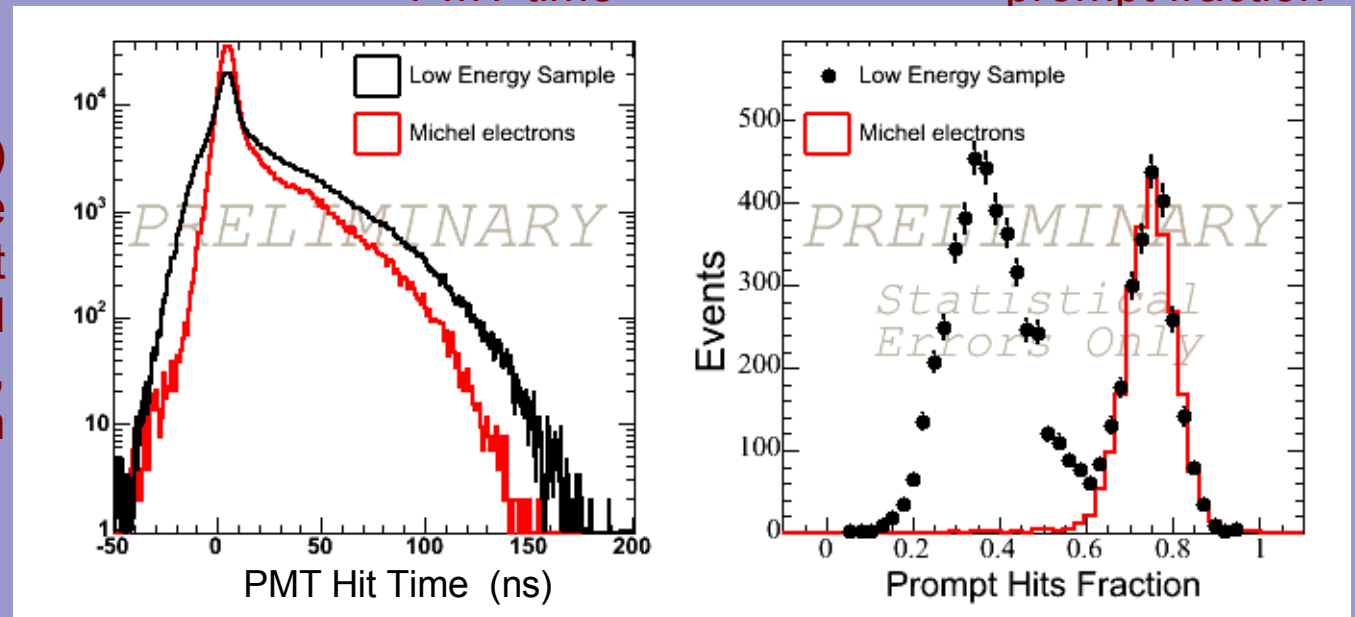
NC elastic event selection:

- low multiplicity (proton scintillation only)
- no μ -decay
- proton-likelihood high (low prompt hits fraction)

PMT time

prompt fraction

NC elastic (low energy)
sample before
proton-likelihood cut
(includes Michel
electrons),
relative normalization



Neutral-Current Elastic scattering...

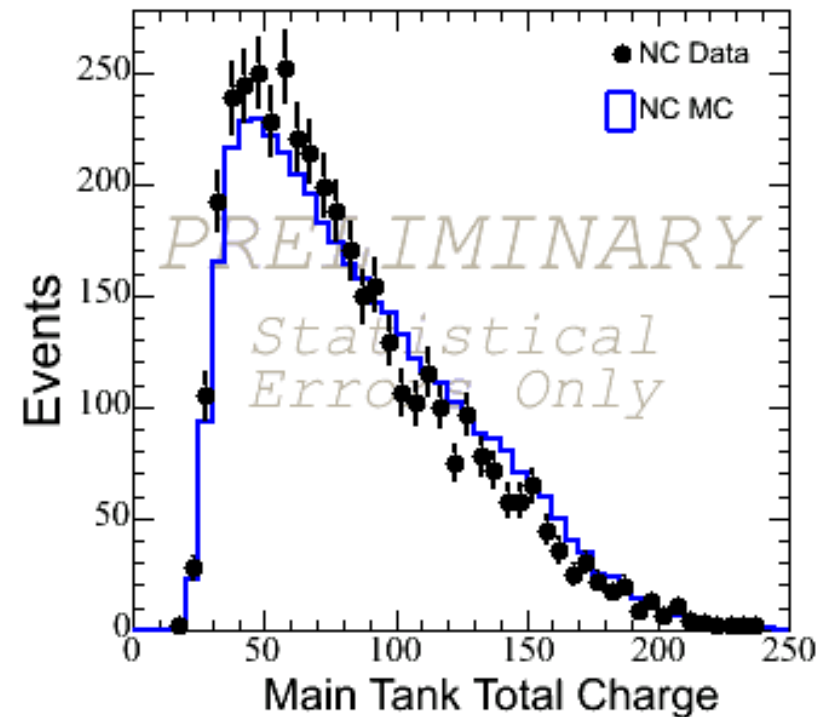
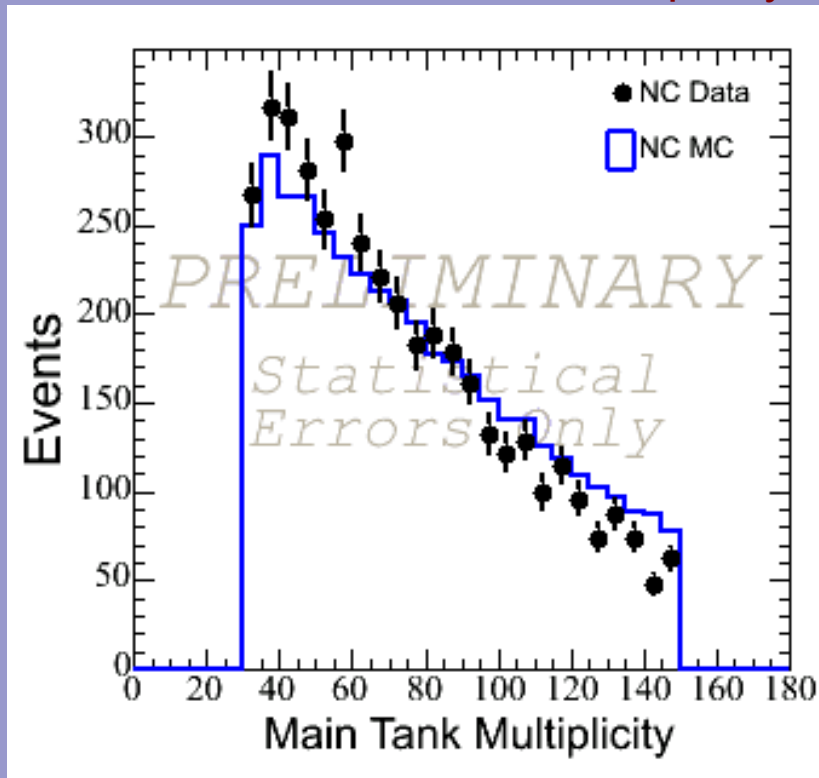
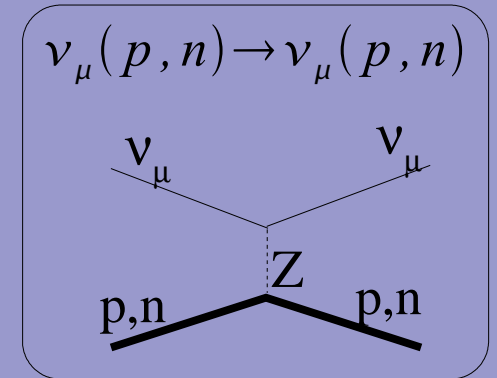
MB preliminary NC elastic results:

- from $\sim 1/10$ of ν data ($0.6E20$ POT)
- ~ 4000 events, with $\sim 80\%$ purity

NC elastic sample
after proton-likelihood cut
(relative normalization)

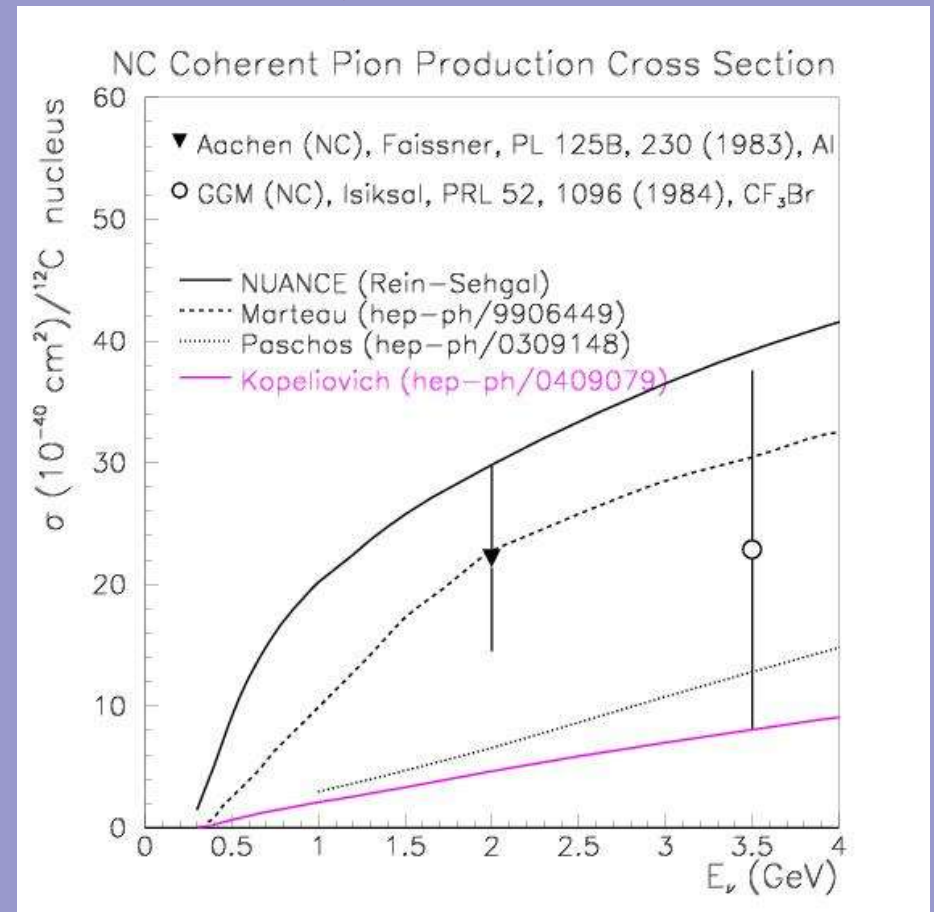
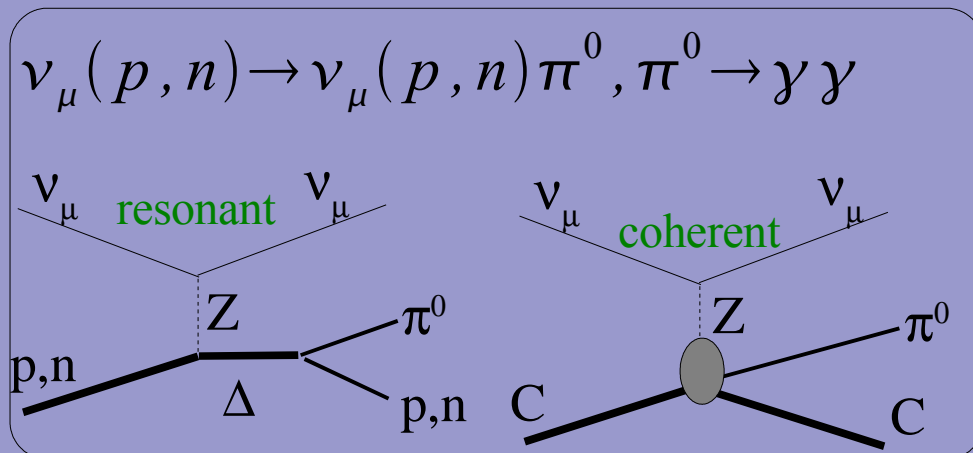
PMT multiplicity

PMT total charge



Neutral-Current π^0 Production ($\text{NC}\pi^0$)

- important background for MB (and other's) ν_e appearance search
- both resonant and coherent channels contribute (coherent predicted to be ~5-20%)
- coherent dominated by axial current, therefore, ν_μ coherent $\text{NC}\pi^0$ world data not constrained with e-scattering data
- very little existing ν data
- coherent production results in forward-going π^0



Neutral-Current π^0 Production...

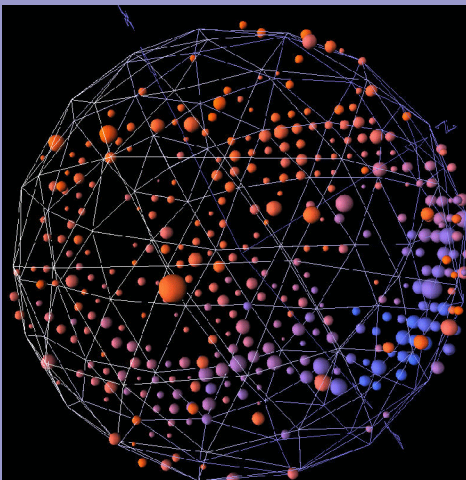
NC π^0 event selection:

- no μ -decay
- π^0 -likelihood high (2 rings)

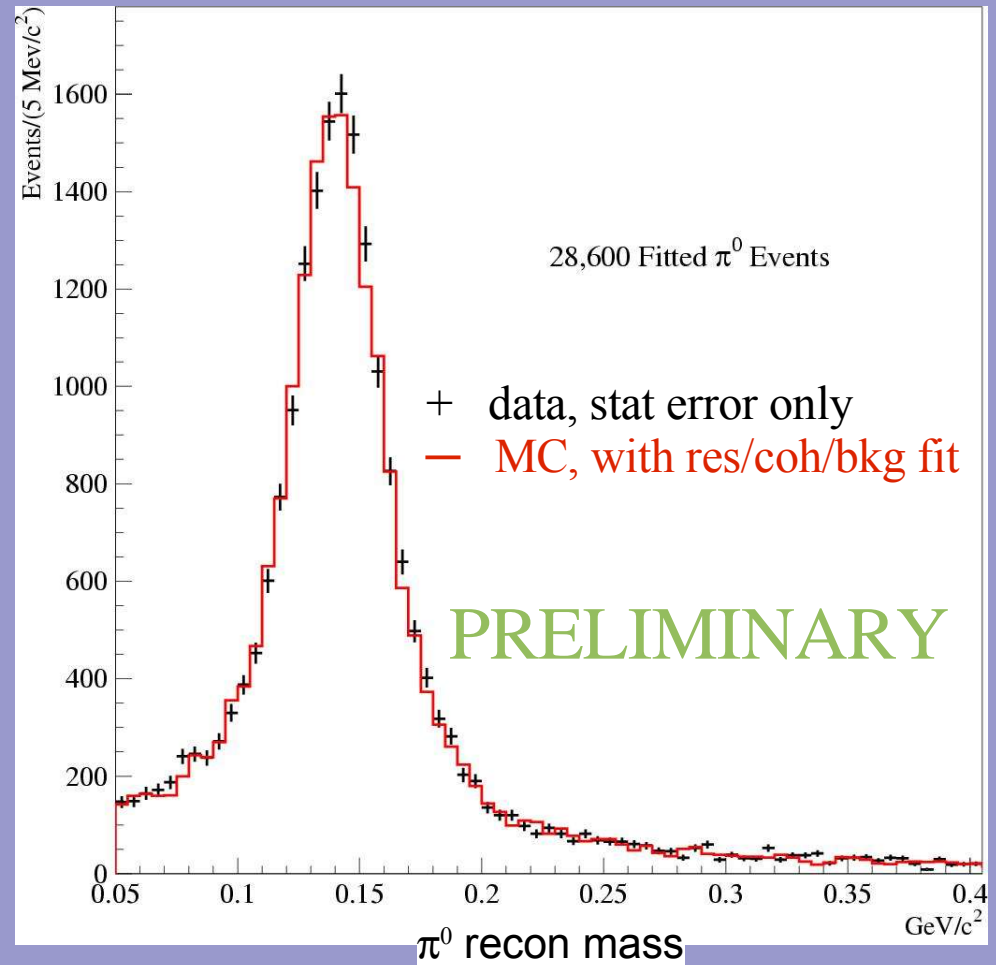
MB preliminary NC π^0 results:

- from entire ν data set (5.7E20 POT)
- ~29k NC π^0 (a record sample size)
- with ~90% purity
- good data/MC agreement
(after fit to coherent fraction)

π^0 candidate
event



reconstructed π^0 -mass distribution

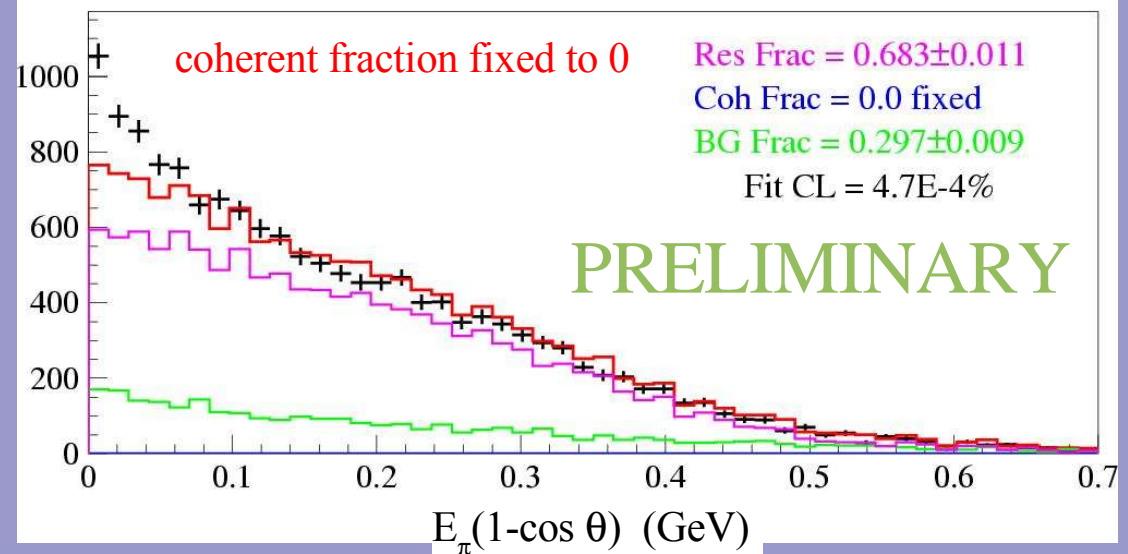
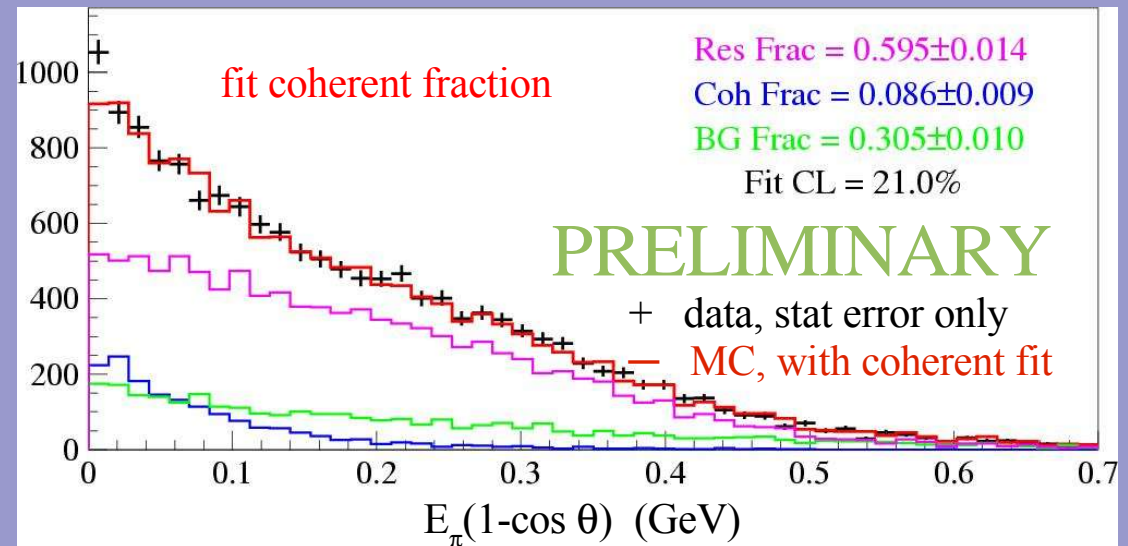


Neutral-Current π^0 Production...

NC π^0 coherent fraction:

- fit to resonant, background, coherent fraction
- data strongly disfavors zero coherent fraction
- interesting in light of recent K2K CC π^+ coherent results

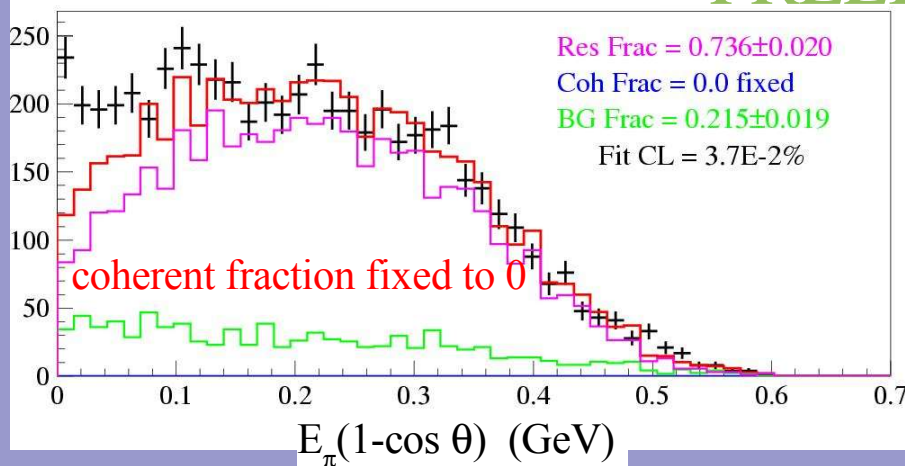
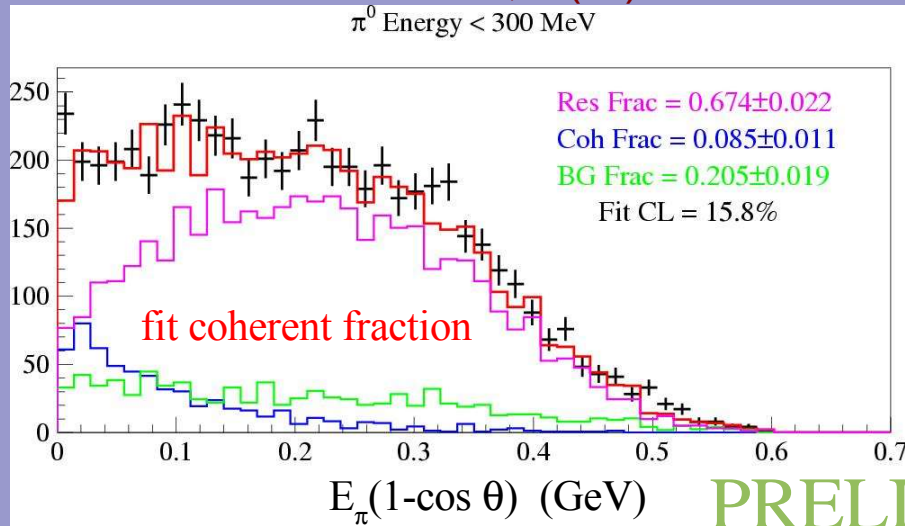
π^0 coherent fraction fits



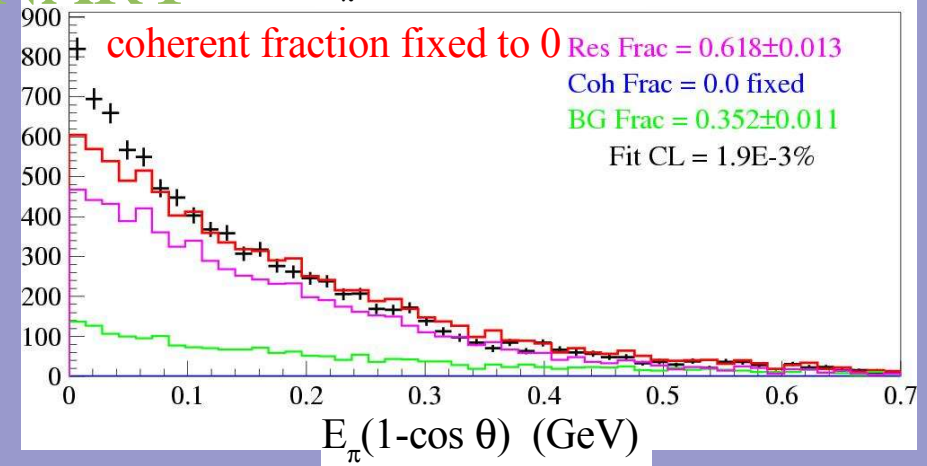
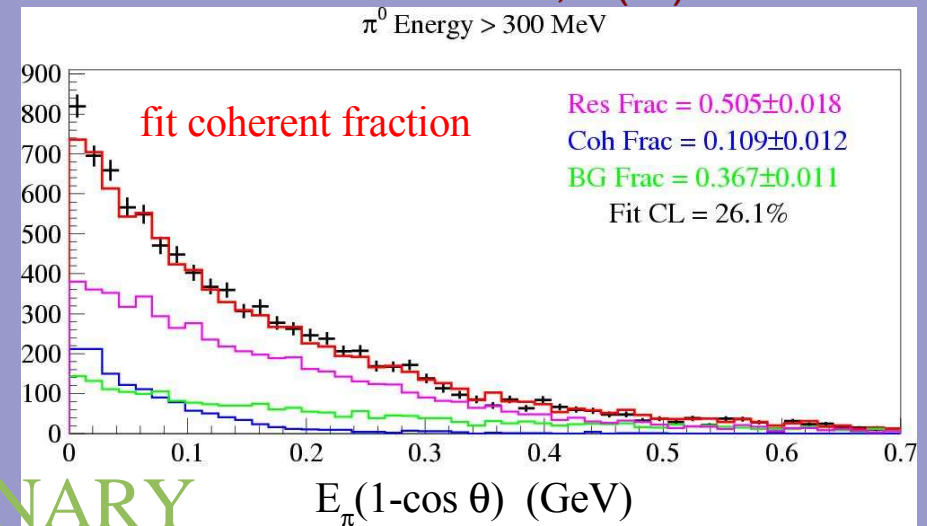
Neutral-Current π^0 Production...

- angular distribution of NC π^0 resonant/coherent components vary differently with energy due to different production mechanism
- the MB data support this as seen in fits at low/high π^0 energy

π^0 coh. fraction fits, $E(\pi^0) < 300 \text{ MeV}$



π^0 coh. fraction fits, $E(\pi^0) > 300 \text{ MeV}$



PRELIMINARY

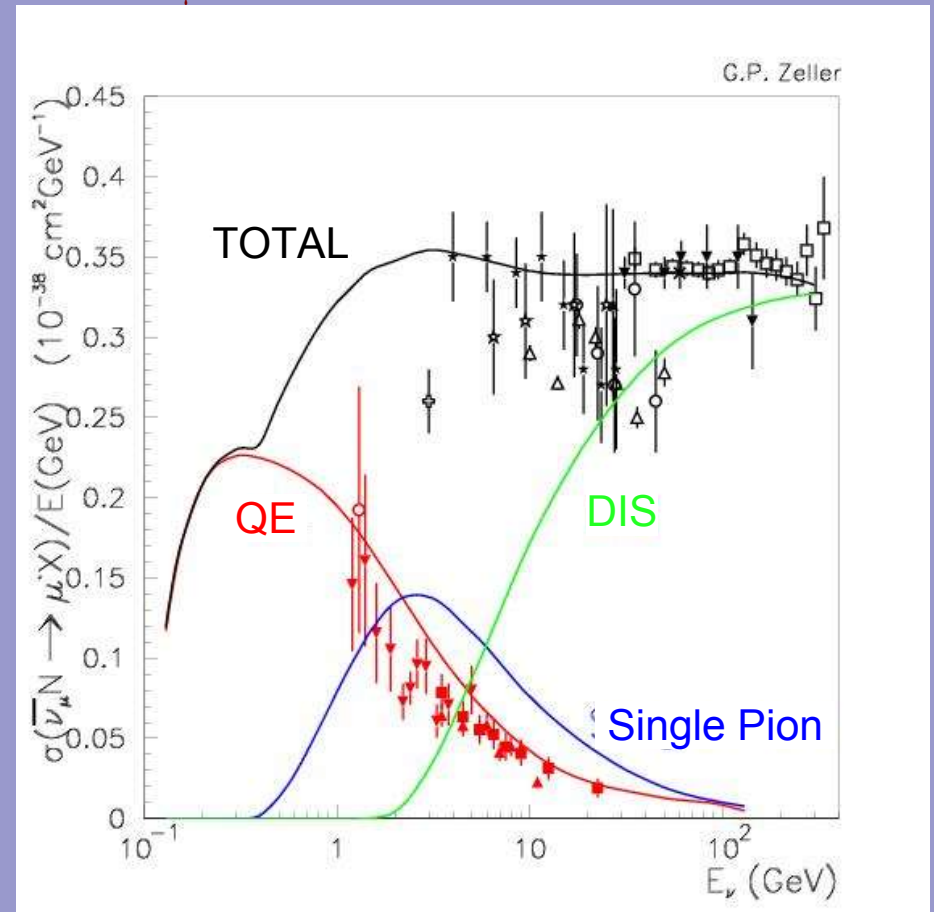
Additional MB ν Channels under Investigation

- $CC\pi^0$ ($\nu_\mu n \rightarrow \mu^- p \pi^0$) :
 - resonant only, no coherent contribution
 - requires 3-ring fit
- νe elastic ($\nu_\mu e \rightarrow \nu_\mu e$) :
 - well-known cross section, possible normalization channel
 - very small cross section
- $CC N_{gs}$ ($\nu_\mu C \rightarrow \mu^- N_{gs}$) :
 - well-known cross section, possible normalization channel
 - requires ID of N_{gs} β -decay
- CC inclusive ($\nu_\mu p \rightarrow \mu^- X$)
 - interesting for theory comparisons
 - any event with muon

Antineutrino Scattering

- MiniBooNE started $\bar{\nu}$ running in Jan, '06
- will enable $\bar{\nu}$ cross section measurements, an important systematic test of ν results
- with a longer (not yet approved) run, a $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ search
- no $\bar{\nu}$ data below $E_\nu = 1\text{GeV}$

$\bar{\nu}_\mu$ CC total cross section world data



Antineutrino Scattering with MiniBooNE

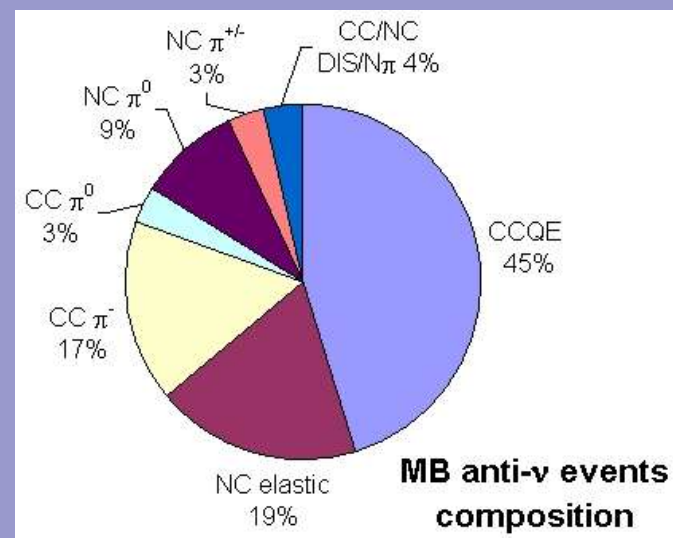
$\bar{\nu}$ events expected in next year:

- from 2E20 "protons-on-target" (POT)
- with fiducial radius of 500cm
- before cuts
- ν event (wrong-sign) contribution not included

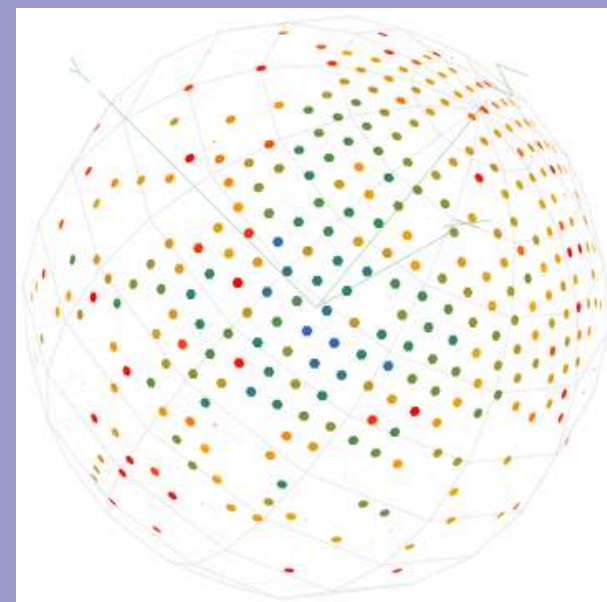
$\bar{\nu}$ channel	events
all channels	54k
CC quasielastic	24k
NC elastic	10k
CC π^-	8.9k
CC π^0	1.7k
NC π^0	4.9k
NC $\pi^{+/-}$	1.8k

"CC" =
charged current
"NC" =
neutral current

0.2E20 POT collected so far...



first MB $\bar{\nu}$ event



Summary

- MiniBooNE has collected a large ν -scattering data set ($\sim 800k$ events) at $E_\nu \sim 1\text{GeV}$ region, will enable
 - high precision oscillation search for MB (and other exps)
 - increased understanding of ν interactions
- Reported preliminary results for $CCQE$, $CC\pi^+$, NC elastic, NC π^0 .
- MiniBooNE antineutrino running has commenced.

The many contributions from MB collaborators for this talk are gratefully acknowledged!

