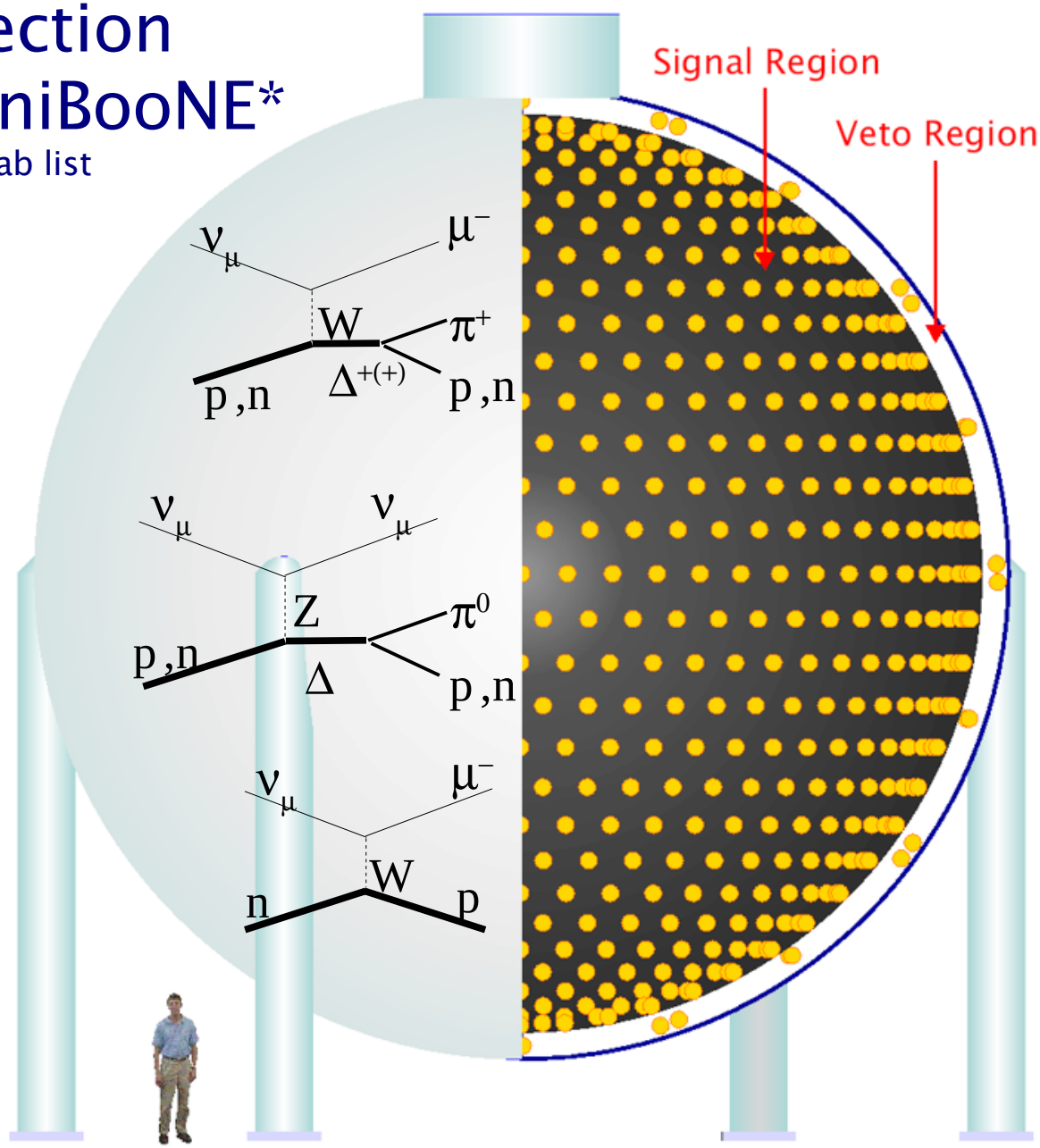
Neutrino cross-section measurements in MiniBooNE*

*see plenary MB talk for collab list

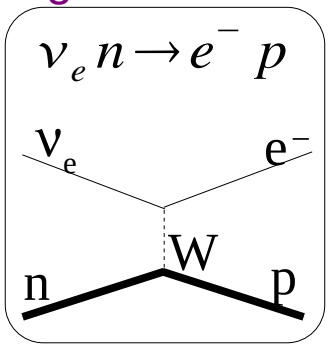
- Outline:
  - Cross-sections in MB
  - Flux prediction
  - Event selection
  - X-sec examples
    - CC QE
    - CC π^+
    - NC π^0
    - NC elastic
  - Anti-neutrinos in MB
  - Conclusions



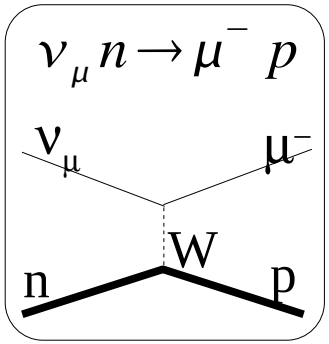
Why measure cross-sections in MiniBooNE?

- Internal MB oscillation analysis reasons:
  - Need ν_μ CCQE measurement to constrain flux x xsec errors
  - Need to know ν_μ CCQE and NC π^0 absolute rates to finalize background predictions in signal region (shown below)

signal:



background:



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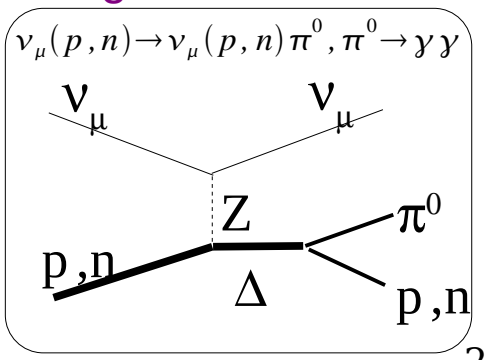
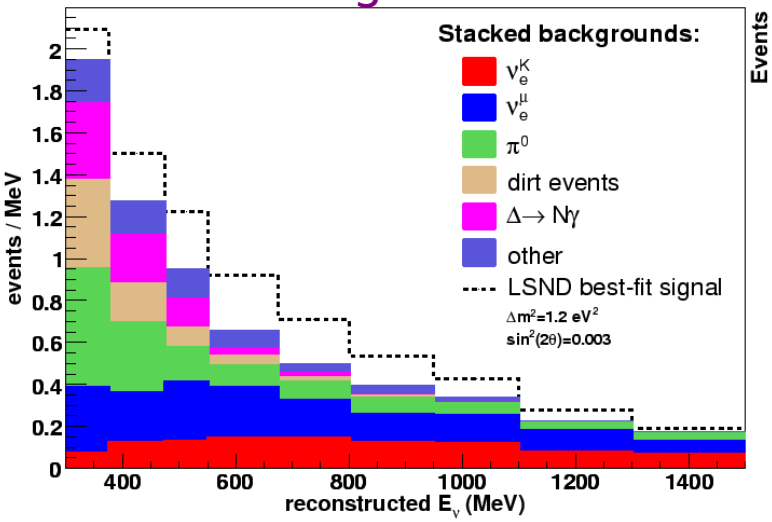
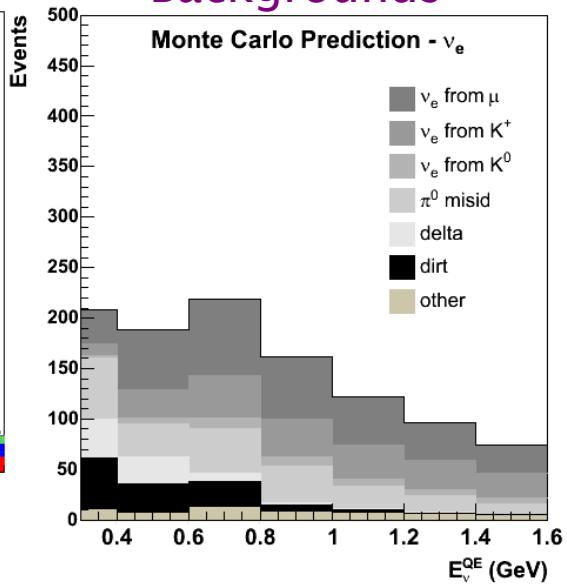


Track-Based Likelihood Backgrounds

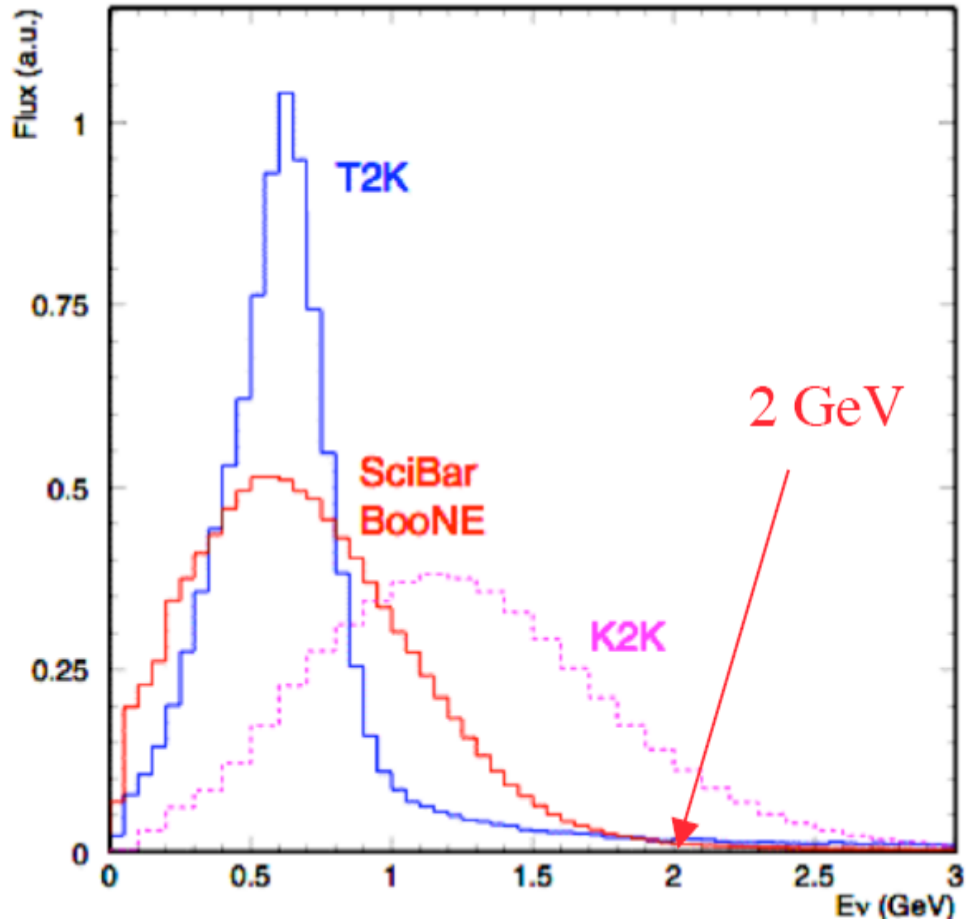


Boosted Decision Tree Backgrounds



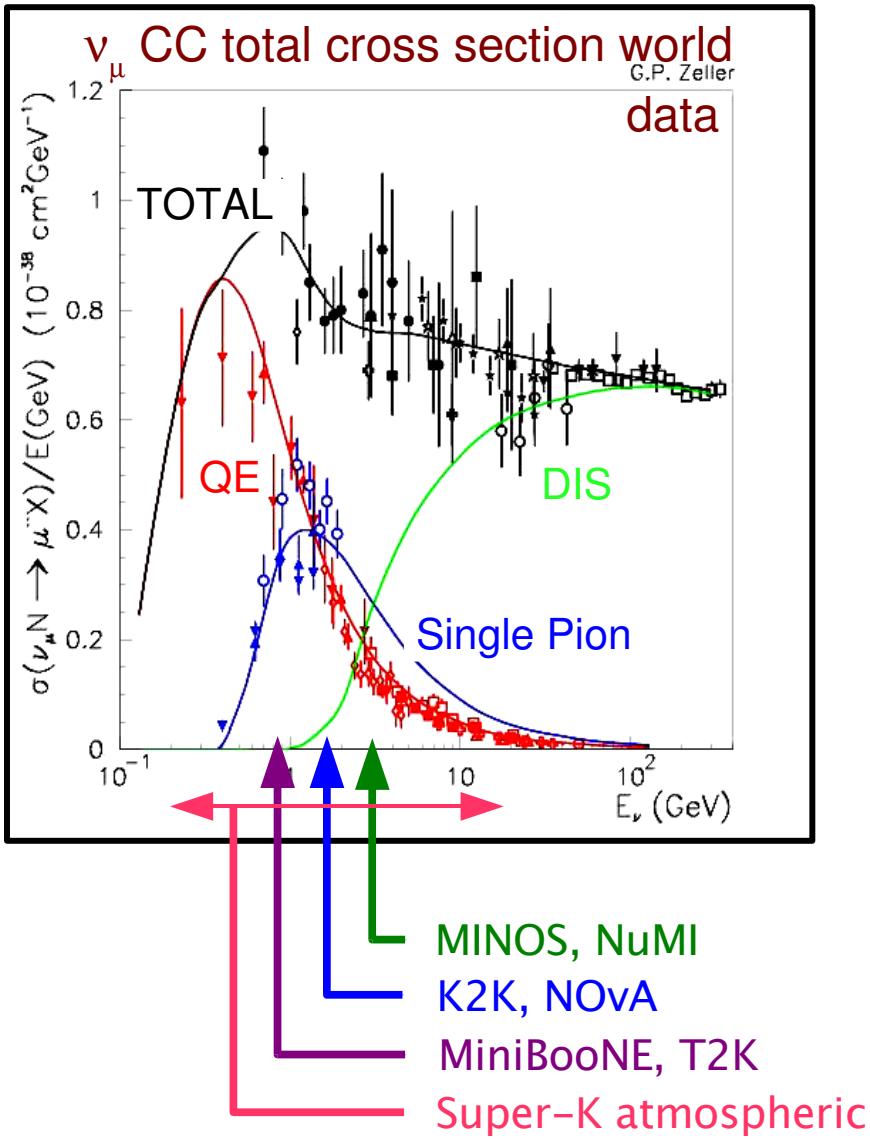
Why measure cross-sections in MiniBooNE?

- Generally needed by all osc experiments
  - ν_e appearance: Mis-identified ν_μ CCQE and NC π^0 are a common problem
  - ν_μ disappearance: Non-QE events can distort E spectrum in region of osc dip.
  - See C. Walter talk from NuInt07
- The average neutrino energy in MB is very close to T2K.



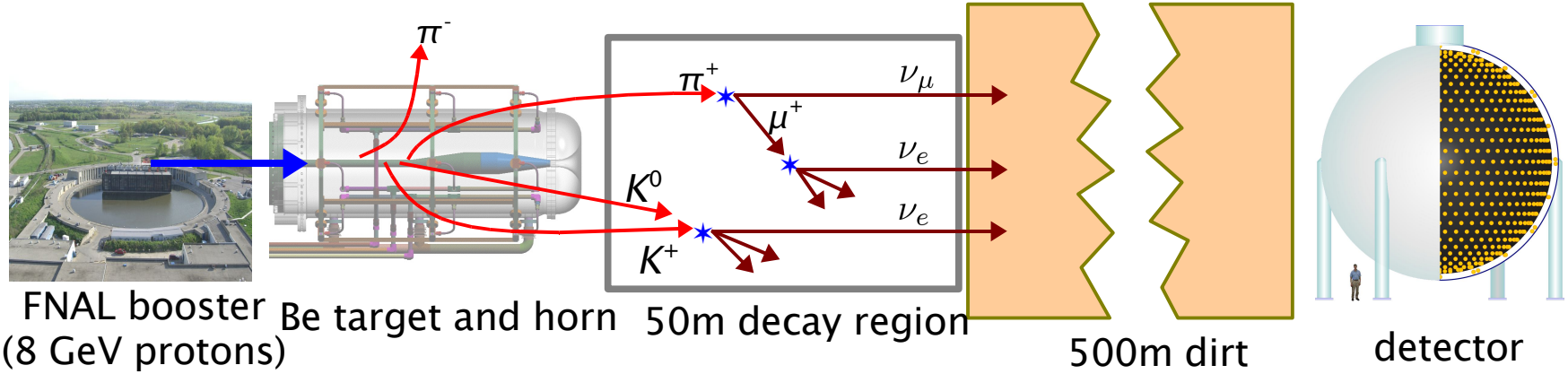
What makes x-sections interesting in MB?

- Existing world data can be pretty sparse down at 800 MeV
- The cross-section physics itself is very interesting
  - low Q^2 behavior observed in ν_μ CCQE and CCπ^+ channels
  - spectral functions, form factors, nuclear modeling
  - resonant/coherent π^0 ratio
  - NC/CC ratio (can obtain Δs)
- Interest evident by the presentations here and at NuInt, along with the impressive compendium of current papers shown in J. Morfin's talk.

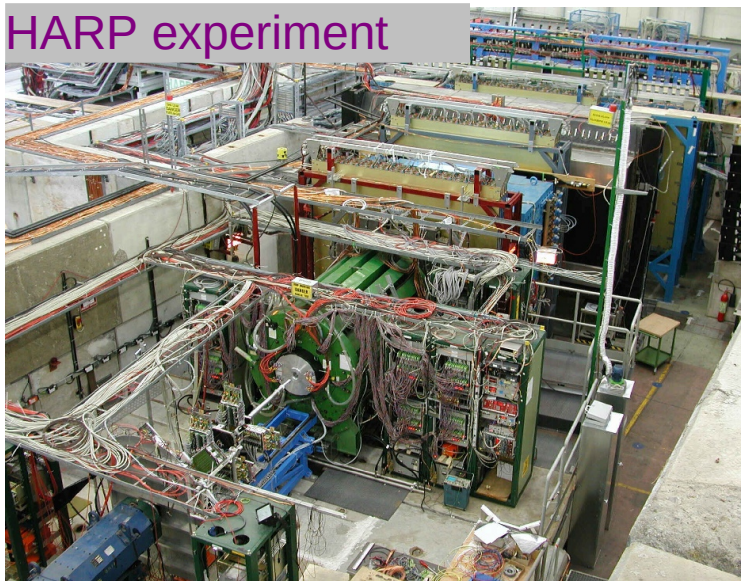


Strengths and limitations of MB xsec's

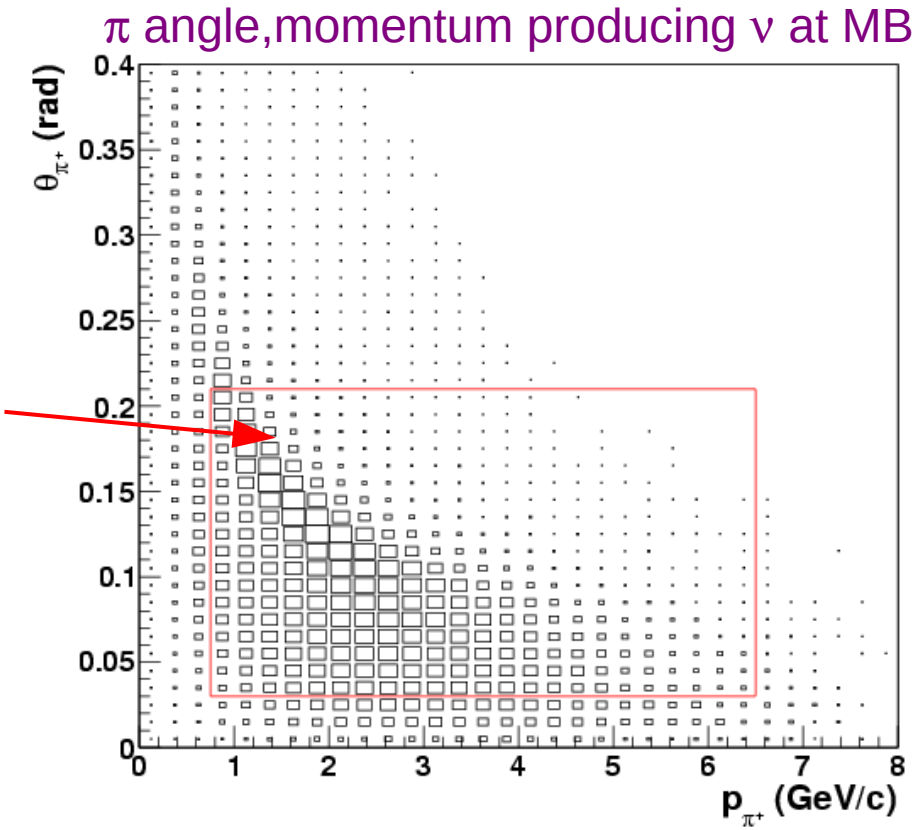
- Extremely well understood detector and cross-section models that have been tuned for a very demanding oscillation analysis
  - Evident in the "out-of-the-box" agreement in anti-neutrino analyses, i.e. see Van Nguyen's next talk
- Rigorous systematic error treatment established in such a way that it can be applied turn-the-crank to almost any analysis
- Statistics (probably our biggest strength)
  - double-differential xsec
  - detailed 2d kinematics
  - relative xsecs to 5%
- Limitations
  - Not a fine-grained detector (but now we have SciBooNE, K. Hiraide)
  - Absolute xsec limited by 16% flux error



Where does the flux error come from?

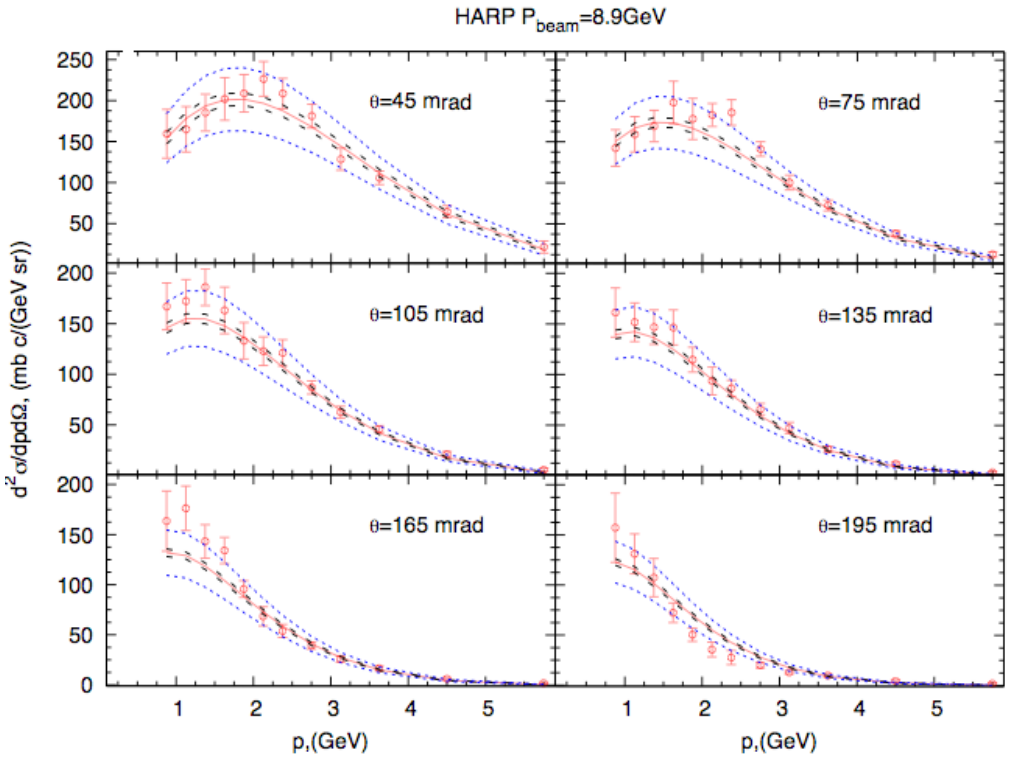


- Overall error is about 16.5%
  - 15% from Sanford-Wang fit to HARP production data
  - 7% from targeting, horn focusing, skin depth, secondary interactions



- About 81% of MiniBooNE flux covered by HARP measurement

Can the flux error be reduced?

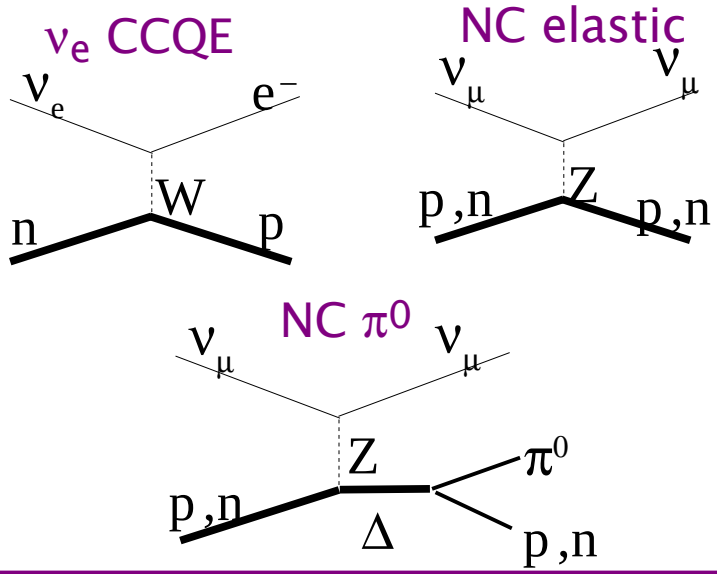


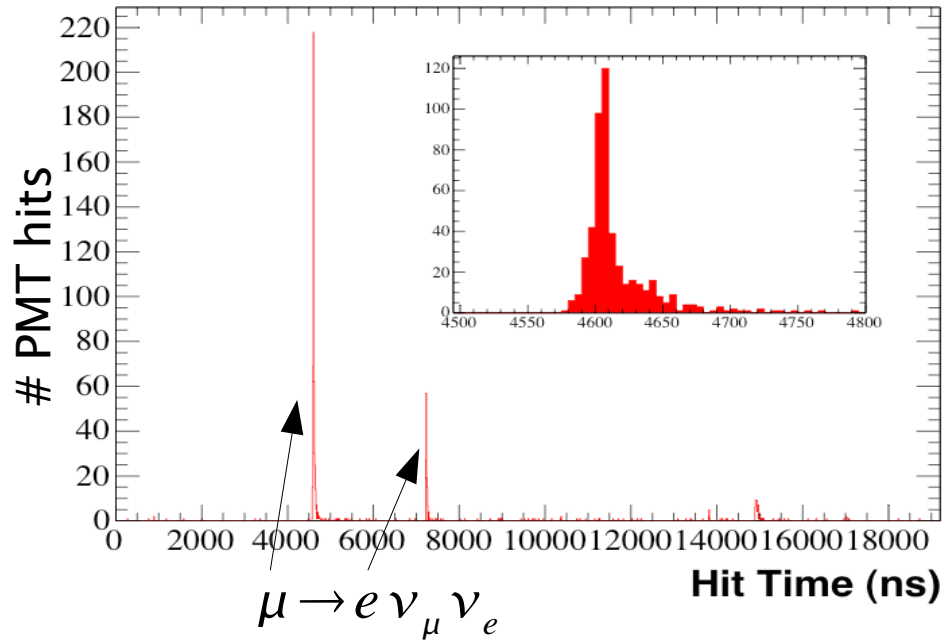
- In principle, underlying HARP errors are ~8%
- 15% error from SW fit arises from tension in the fit (poor χ^2)
- Have been looking into modified SW or directly using HARP data via an interpolation scheme
- Will still have an extrapolation error due to incomplete coverage, but we might see the flux error reduced by a few %.

- Other approach: work backwards from a known cross-section
  - ν_e-electron elastic scattering (stats are very low, probably nothing here)
  - N_{12} ground state (not ruled out as a possibility)
  - Any other suggestions along these lines are welcome

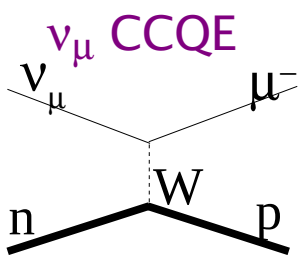
Identifying cross-section channels via subevents

1 subevent

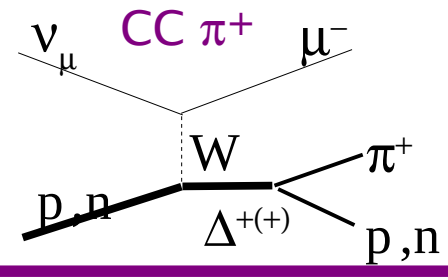




2 subevent



3 subevent



- Muon capture, charge exchange, and pion absorption can change sub-event structure, but in general decay electron tagging helps purity

Is the ring μ-like?

Muons

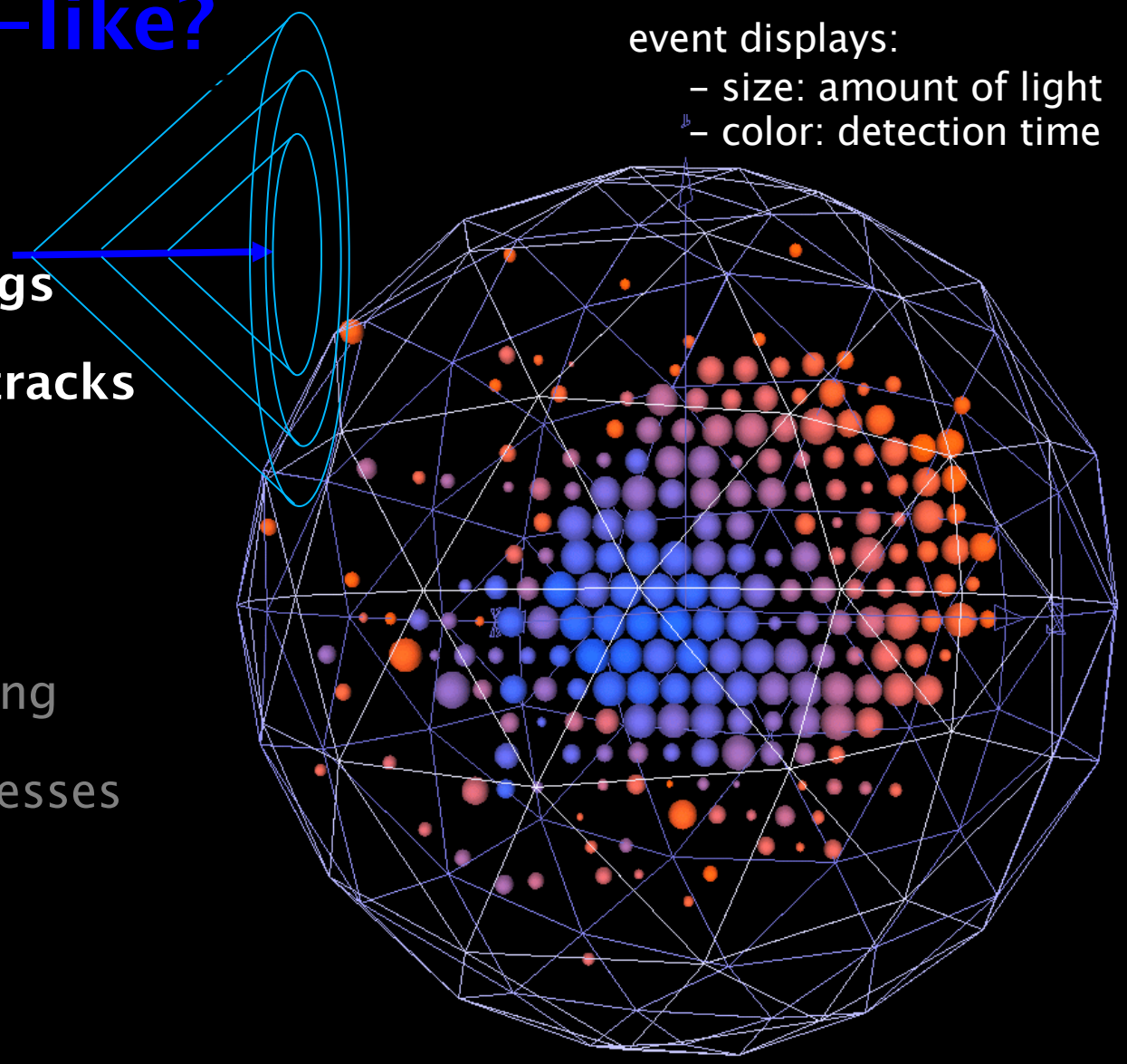
- **Sharp, clear rings**
- **Long, straight tracks**

Electrons

- Fuzzy rings
- Multiple scattering
  - Radiative processes

Neutral Pions

- Double rings
- Decays to two photons



Is the ring e-like?

event displays:
- size: amount of light
- color: detection time

Muons

Sharp, clear rings

Long, straight tracks

Electrons

Fuzzy rings

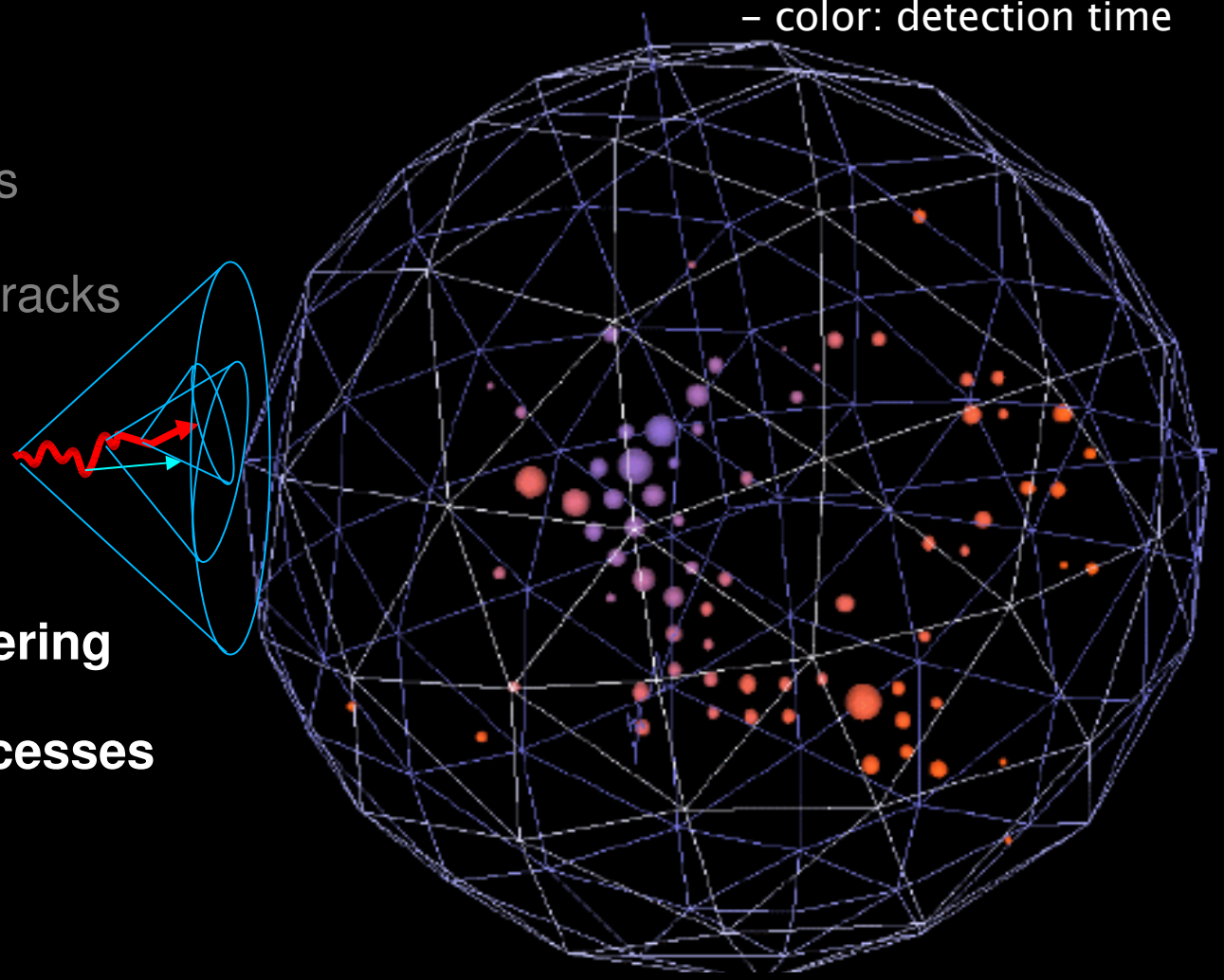
Multiple scattering

Radiative processes

Neutral Pions

Double rings

Decays to two photons



How many rings?

event displays:
- size: amount of light
- color: detection time

Muons

Sharp, clear rings

Long, straight tracks

Electrons

Fuzzy rings

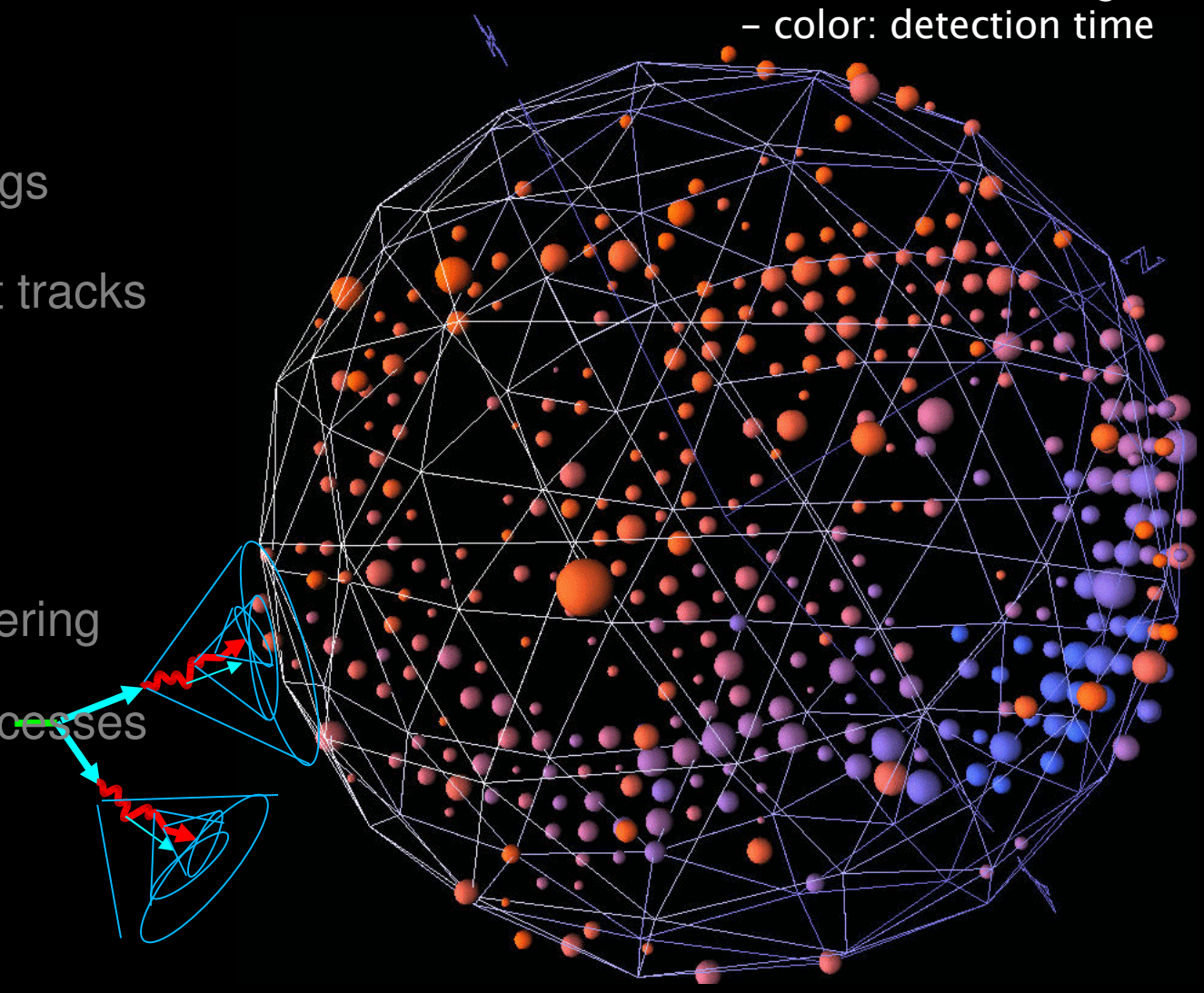
Multiple scattering

Radiative processes

Neutral Pions

Double rings

Decays to two photons



How much Cerenkov?

Muons

Sharp, clear rings

Long, straight tracks

Electrons

Fuzzy rings

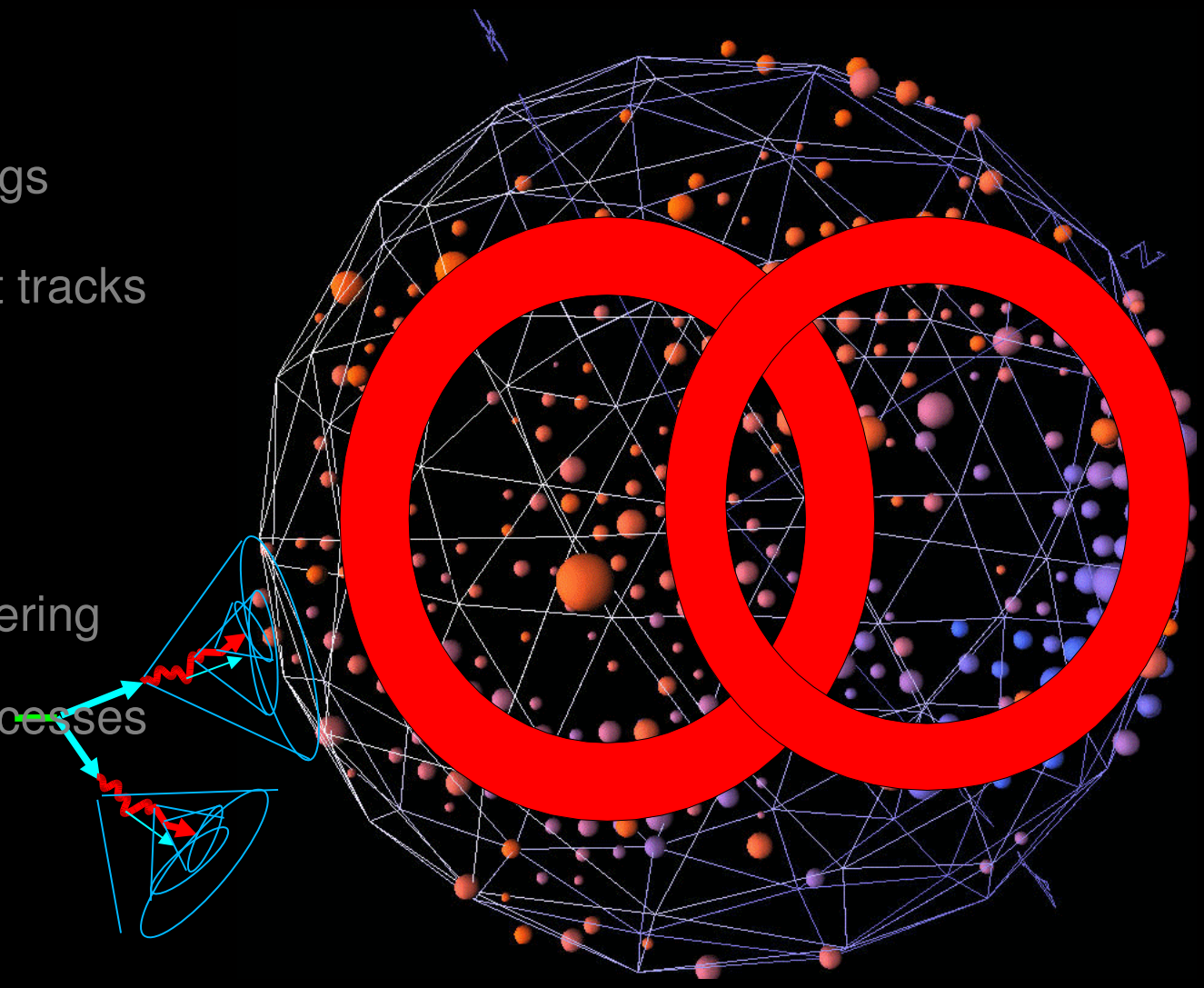
Multiple scattering

Radiative processes

Neutral Pions

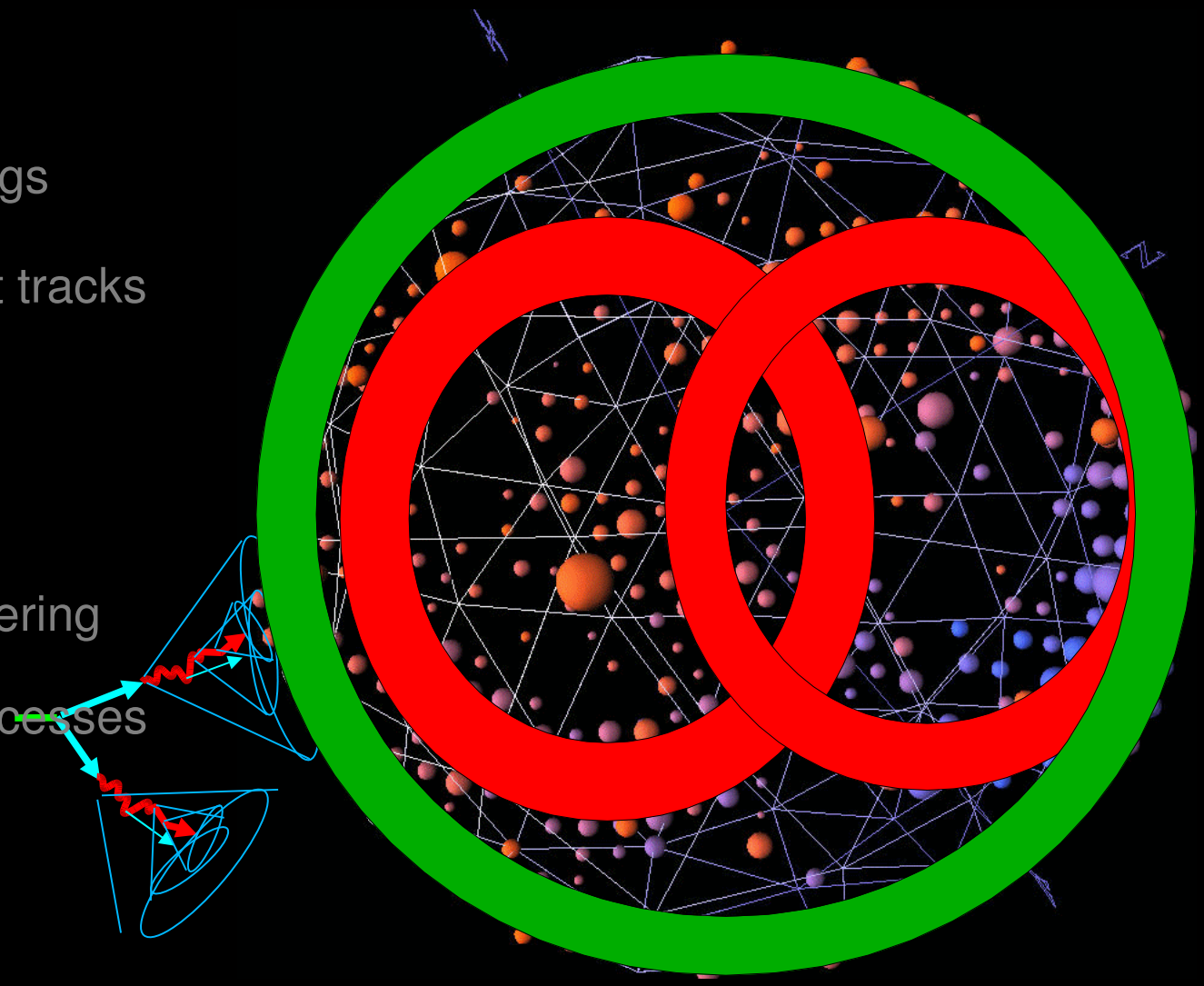
Double rings

Decays to two photons

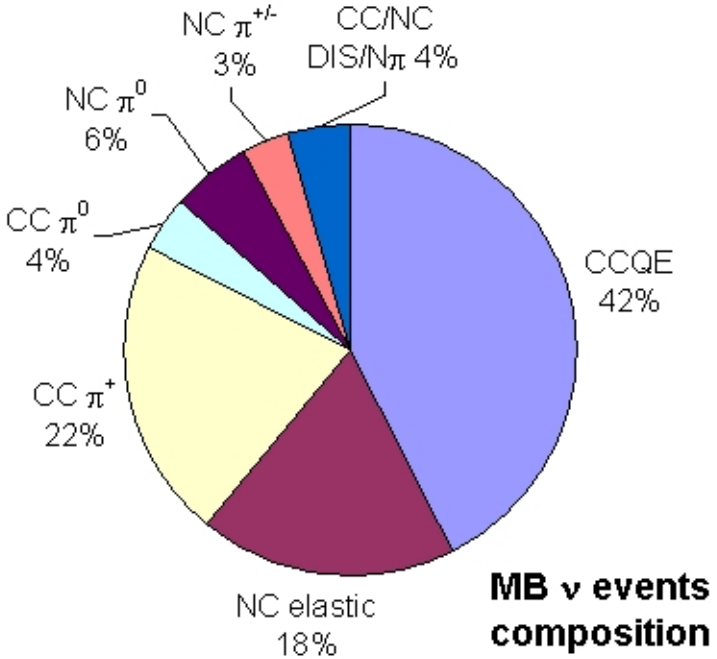


How much Cerenkov vs isotropic?

- Muons
  - Sharp, clear rings
    - Long, straight tracks
- Electrons
  - Fuzzy rings
    - Multiple scattering
    - Radiative processes
- **Neutral Pions**
  - **Double rings**
    - **Decays to two photons**



Neutrino mode (focus π^+) xsec overview



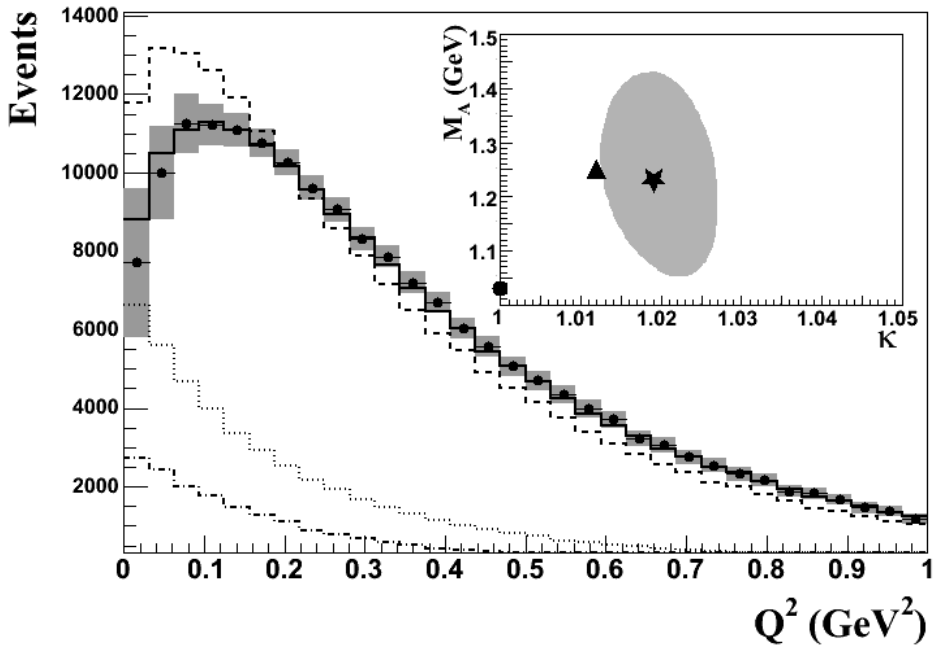
*MB ν interaction MC:
v3 NUANCE code with:
- Smith-Moniz Fermi Gas
- (non-dipole) vector form factors from Bradford et al
- Rein-Sehgal resonant/coherent 1π
- Bodek-Yang DIS

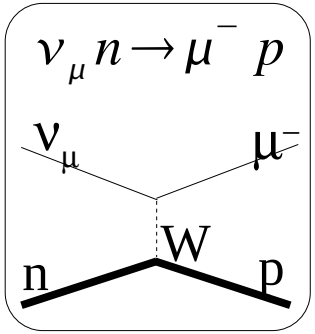
Event rates after for ~6 x 1020 POT on tape, after 500cm fiducial volume cut, but before other cuts are applied

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

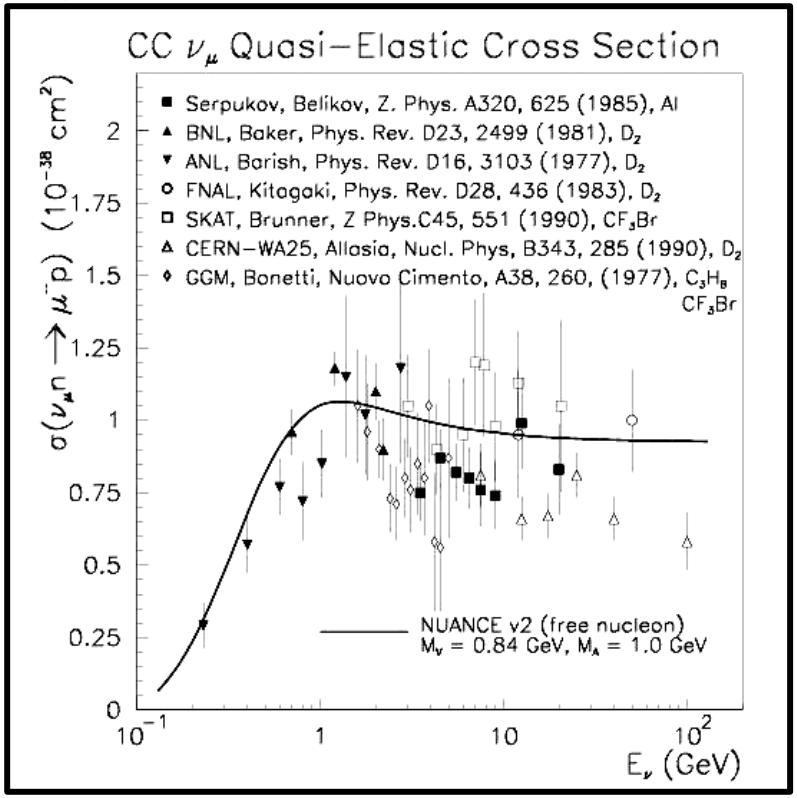
ν_μ CCQE Channel

ν_μ CCQE Q^2 distribution (hep-ex/0706.0926)





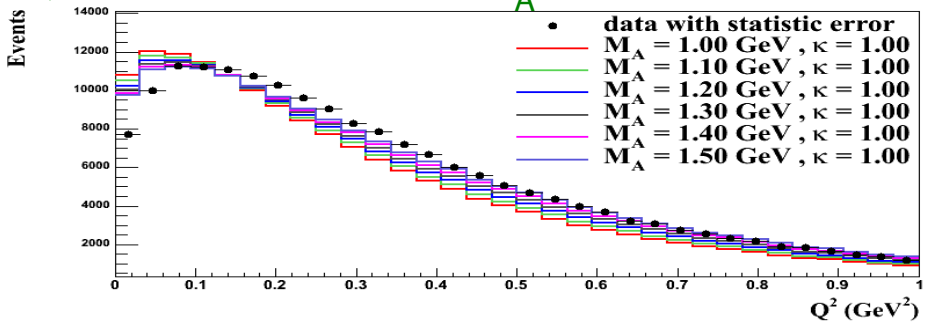
ν_μ CCQE cross section world data



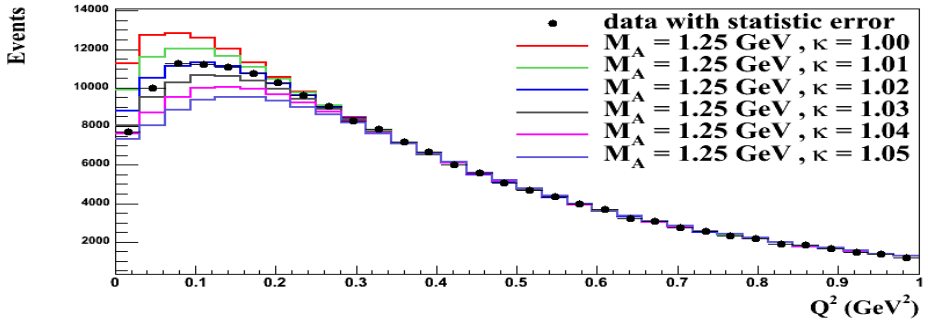
- 'Golden channel' for normalizing flux X xsec in oscillation analysis
- "198,000 events, x10 larger than all past experiments combined", S. Zeller
- "Modified Fermi gas allows simulation of low Q^2 for first time", S. Zeller

ν_μ CCQE Channel

Q^2 distribution with M_A variation

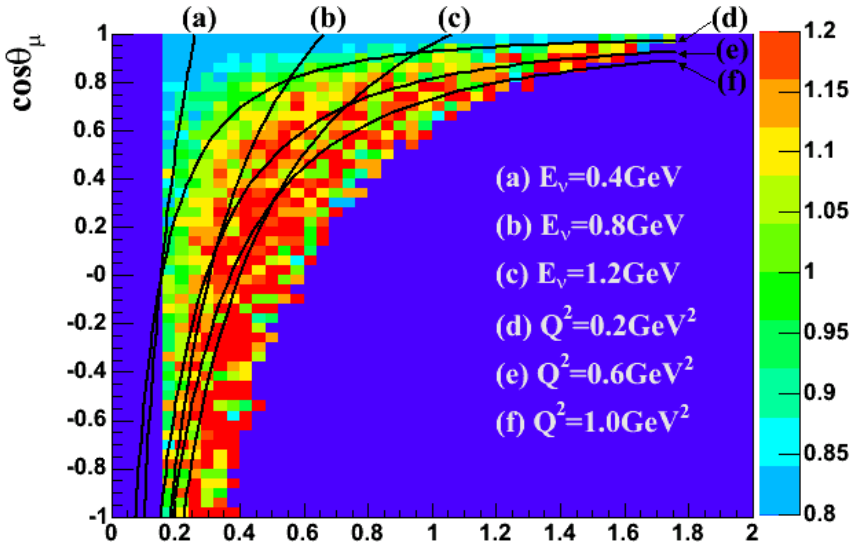


Q^2 distribution with κ variation

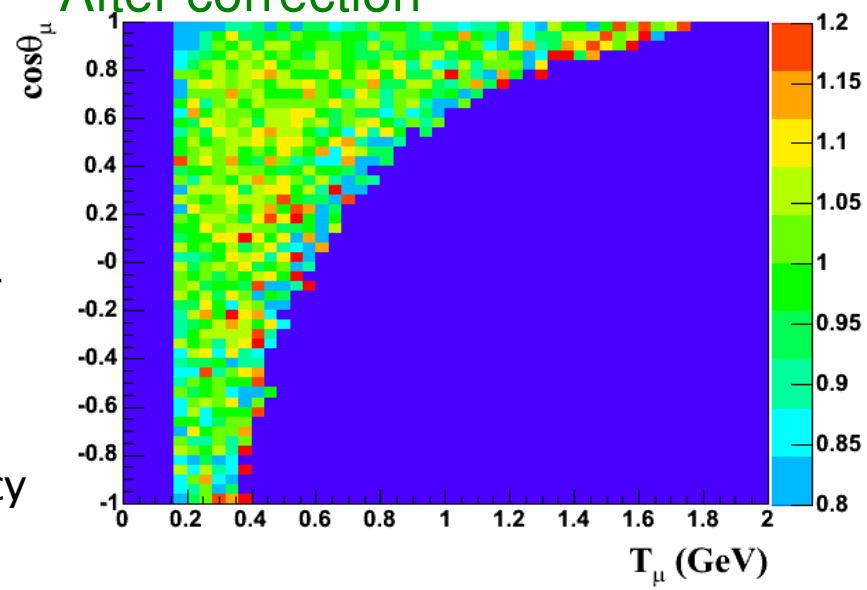


- Individual variations of M_A and κ shown ↑
- "First time we have had the stats to show these detailed 2d kinematic plots", S. Zeller
- Sometimes asked how we know tuning did not remove a ν_μ disappearance signal? Answer in the 2d plot before corr, deficiency follows constant Q^2 contours (not E_ν)

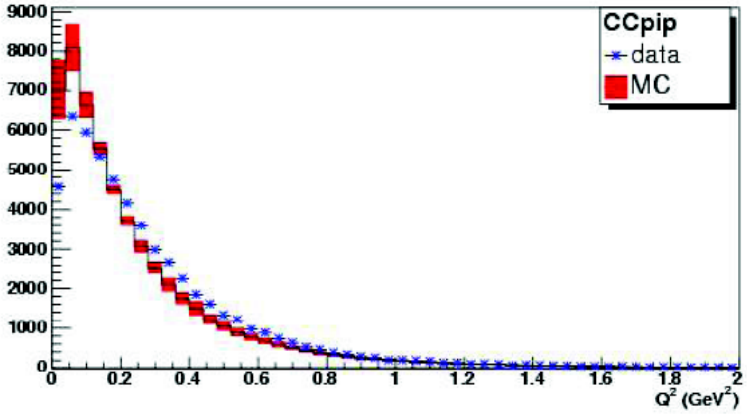
Before correction

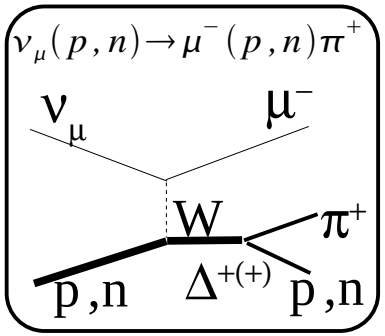


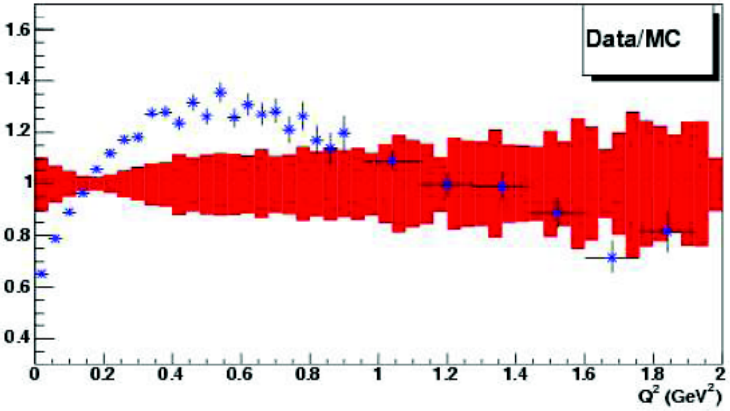
After correction



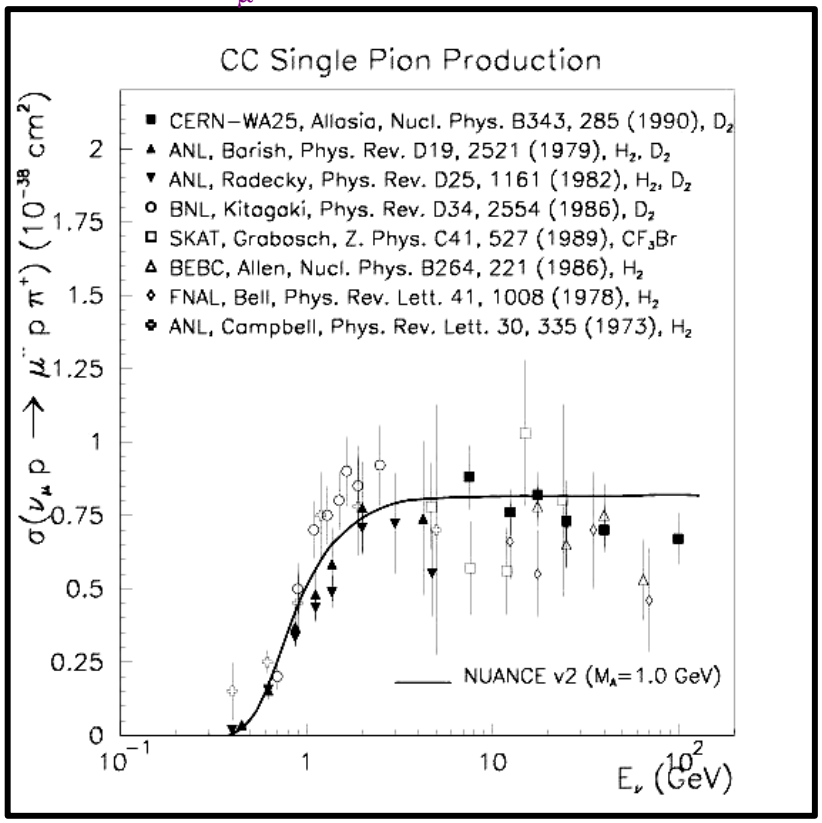
CC π^+ Channel





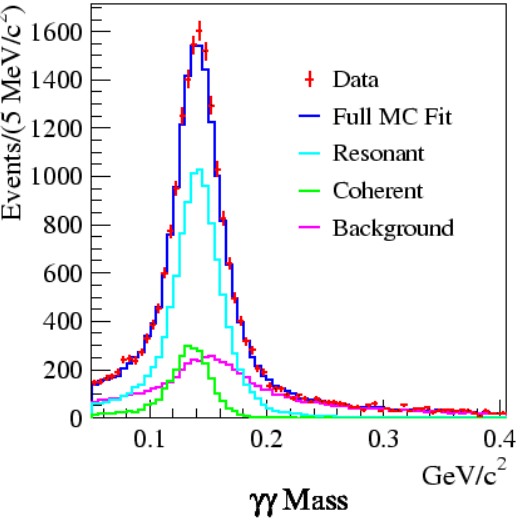


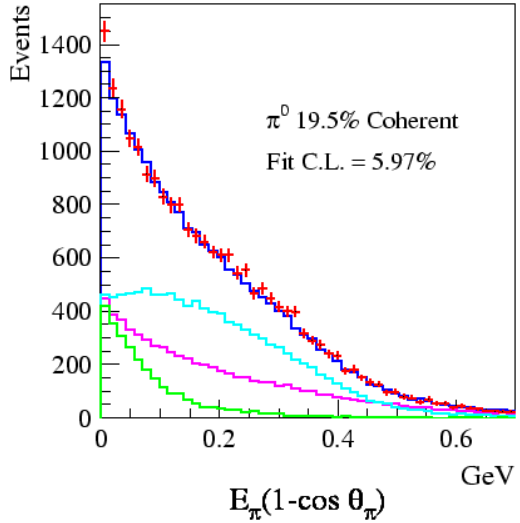
ν_μ CCπ^+ world data

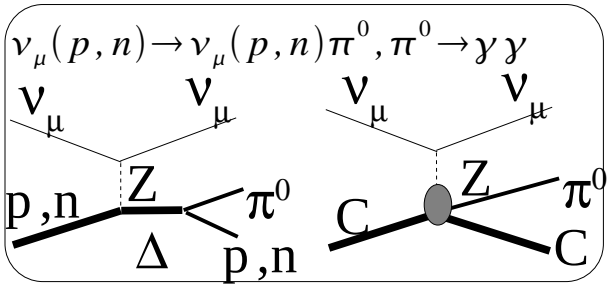


- "71,000 events, also X10 increase in stats over all prior experiments", S. Zeller
- See a similar problem in Q^2 (along with other expts)...not unlike ν_μ CCQE
- Impacts osc analysis via bkg contribution to ν_μ CCQE constraint.

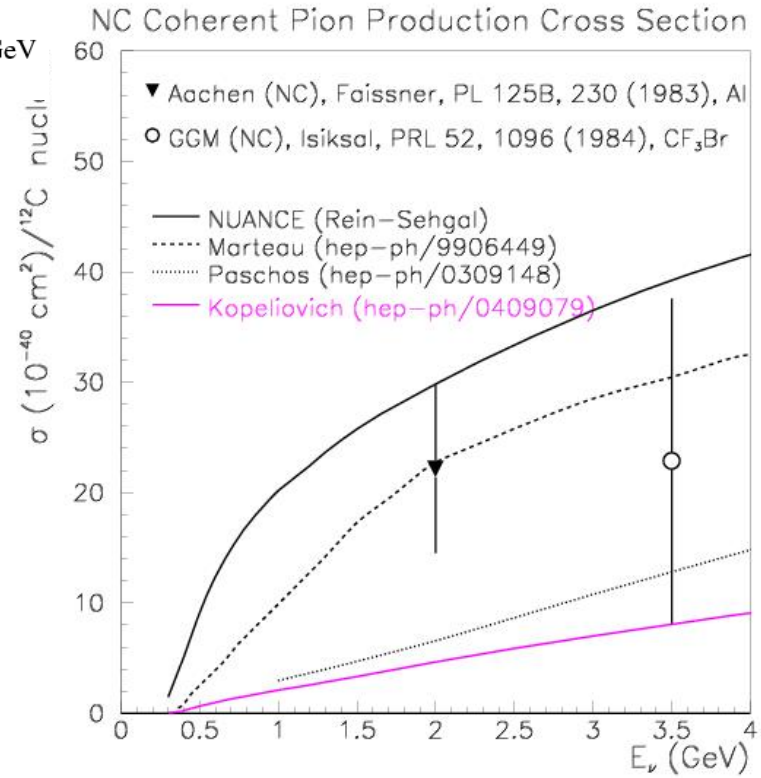
NC π^0 Channel





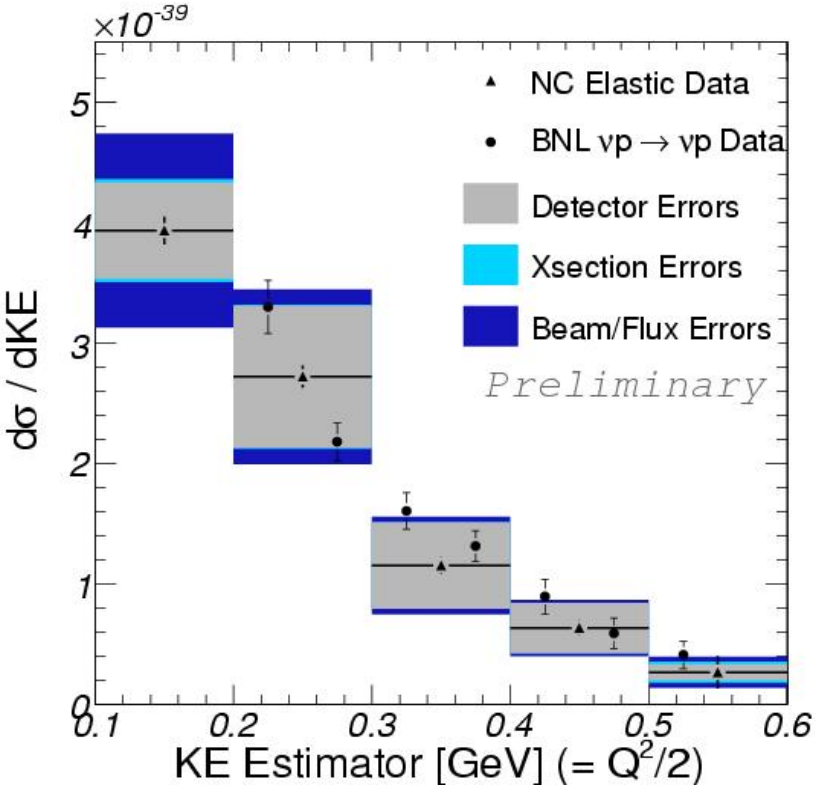


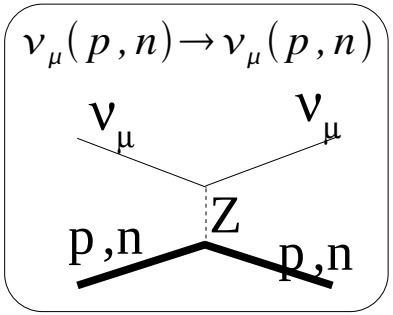
ν_μ coherent NC π^0 world data

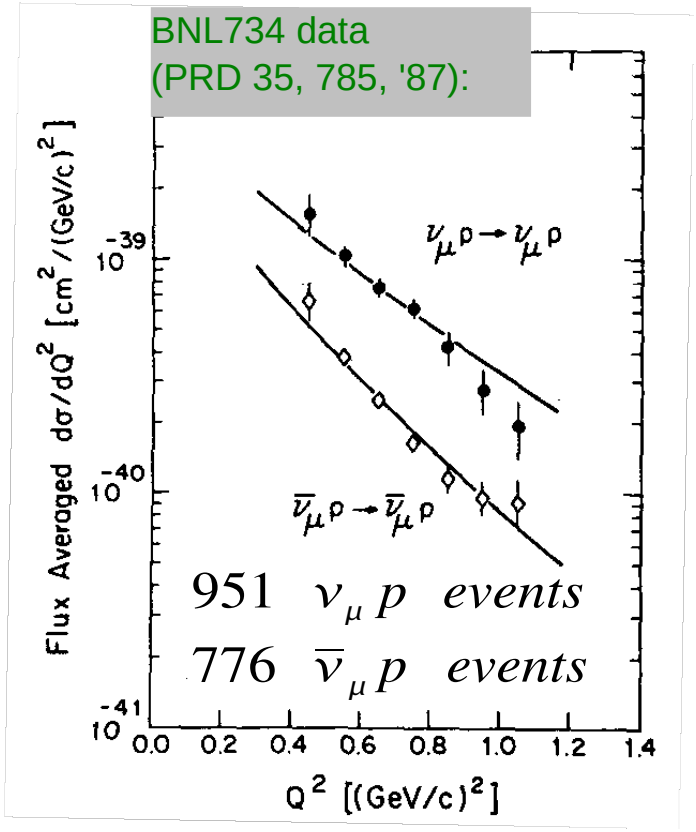


- Most important mis-id background for osc analysis...see CP or K. Mahn prior talks for description of MC tuning in p_π bins
- "Able to obtain a 99% pure effective π^0 sample, and extract flux integrated rate measurement with an 8.8% error", S. Zeller
- "Fit to resonant/coherent fraction yields a [19.5 ± 1.1(stat) ± 2.5(syst)]% coh fraction, x1.5 lower than Rein-Sehgal", S. Zeller

NC elastic

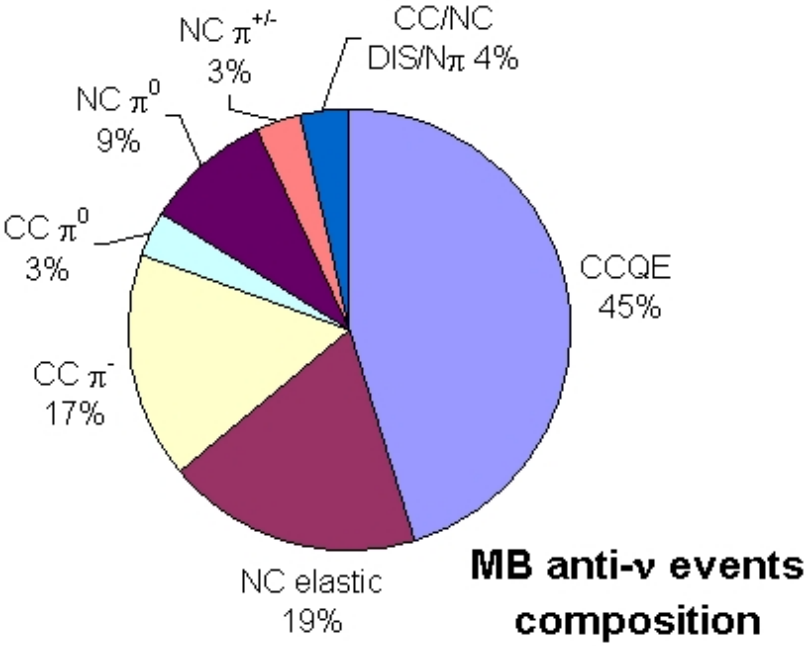


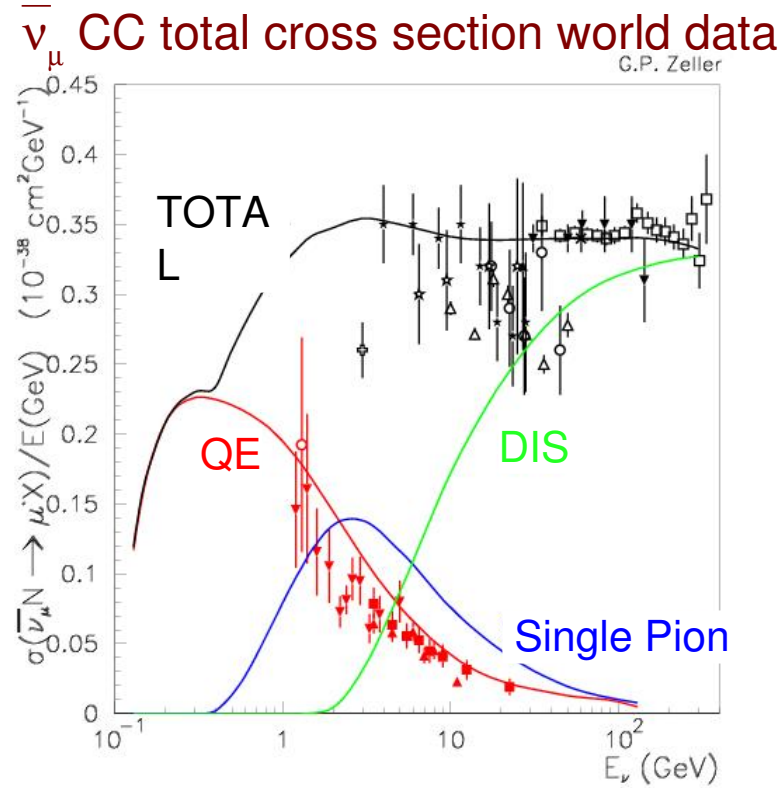




- Sample was important to osc analysis because it allowed a fairly clean measurement of OM scintillation amplitudes below the Cerenkov threshold
- "First absolute differential cross-section measurement from MiniBooNE", S. Zeller

Anti-neutrino (focus π^-) mode

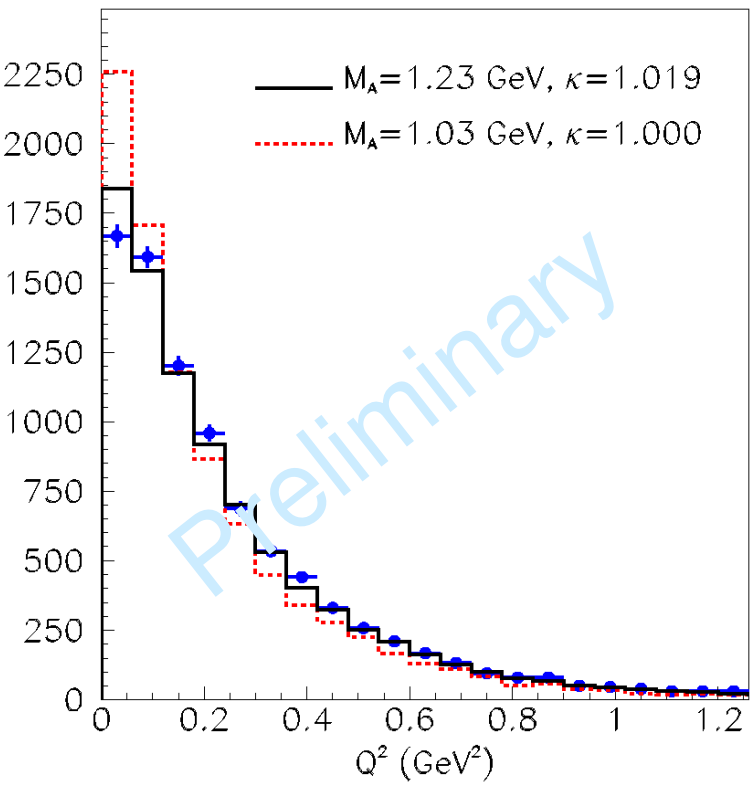


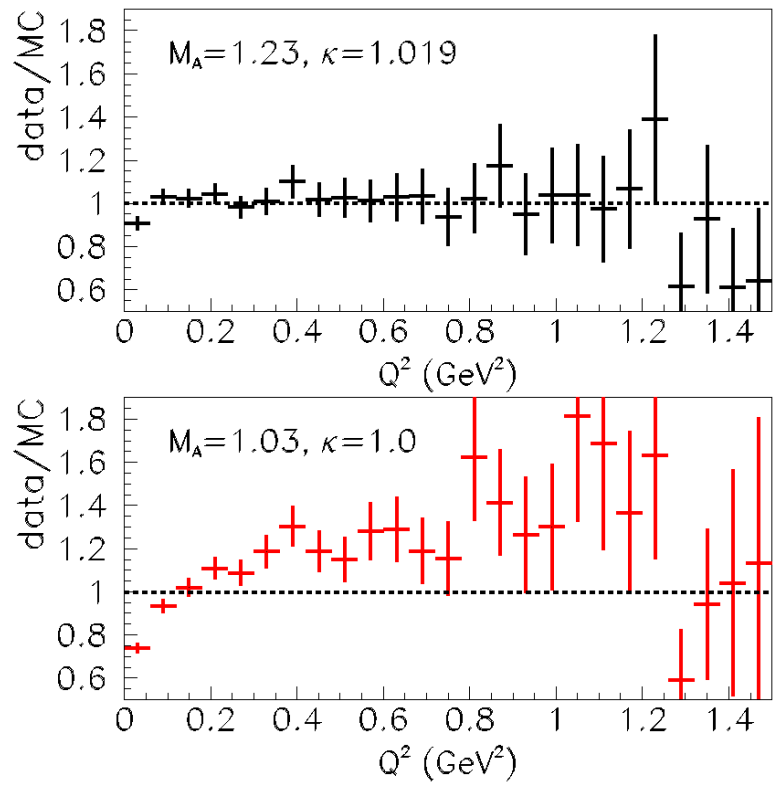


$\bar{\nu}$ channel	events
all channels	54k
CC quasielastic	24k
NC elastic	10k
CC π^-	8.9k
CC π^0	1.7k
NC π^0	4.9k
NC $\pi^{+/-}$	1.8k
CC/NC DIS, multi-π	1.9k

- Can see how sparse the world data is at low Eν
- Event rates are after 500 cm fiducial volume cuts but before otherr cuts
- 30% wrong-sign events not included in table

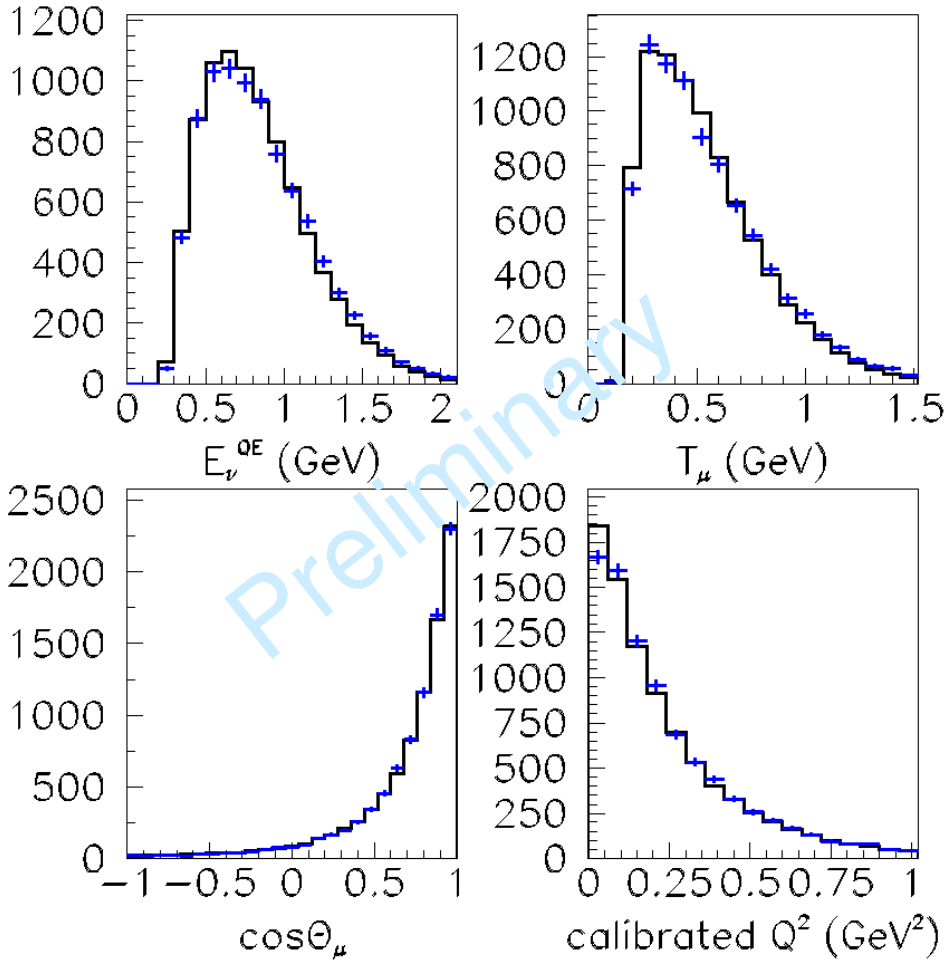
ν_μ CCQE in anti-neutrino mode





- Can see that the Q2 behavior agreement is quite good with the same Fermi gas parameters (no further tuning)

ν_μ CCQE in anti-neutrino mode



- Good agreement in other kinematic variables as well

Other on-going efforts...

- Re-examining systematic errors to see where gains might be still be had for all of the analyses
- Working on developing some more sophisticated reconstructions
  - proton fitter (measure hadronic energy via isotropic light)
  - CC π^+ fitter (SAA with 2 rings adding to the complication)
  - CC π^0 fitter (3-ring fitter)
- Would be great if any of these fitters gave a better resolution for E_ν
- Several other channels being worked besides what was discussed in this talk
- Working on updating the CC π^+ / ν_μ CCQE ratio.
- Stay tuned for V. Nguyen who will be updating us next on NC π^0 events in anti-neutrino mode...