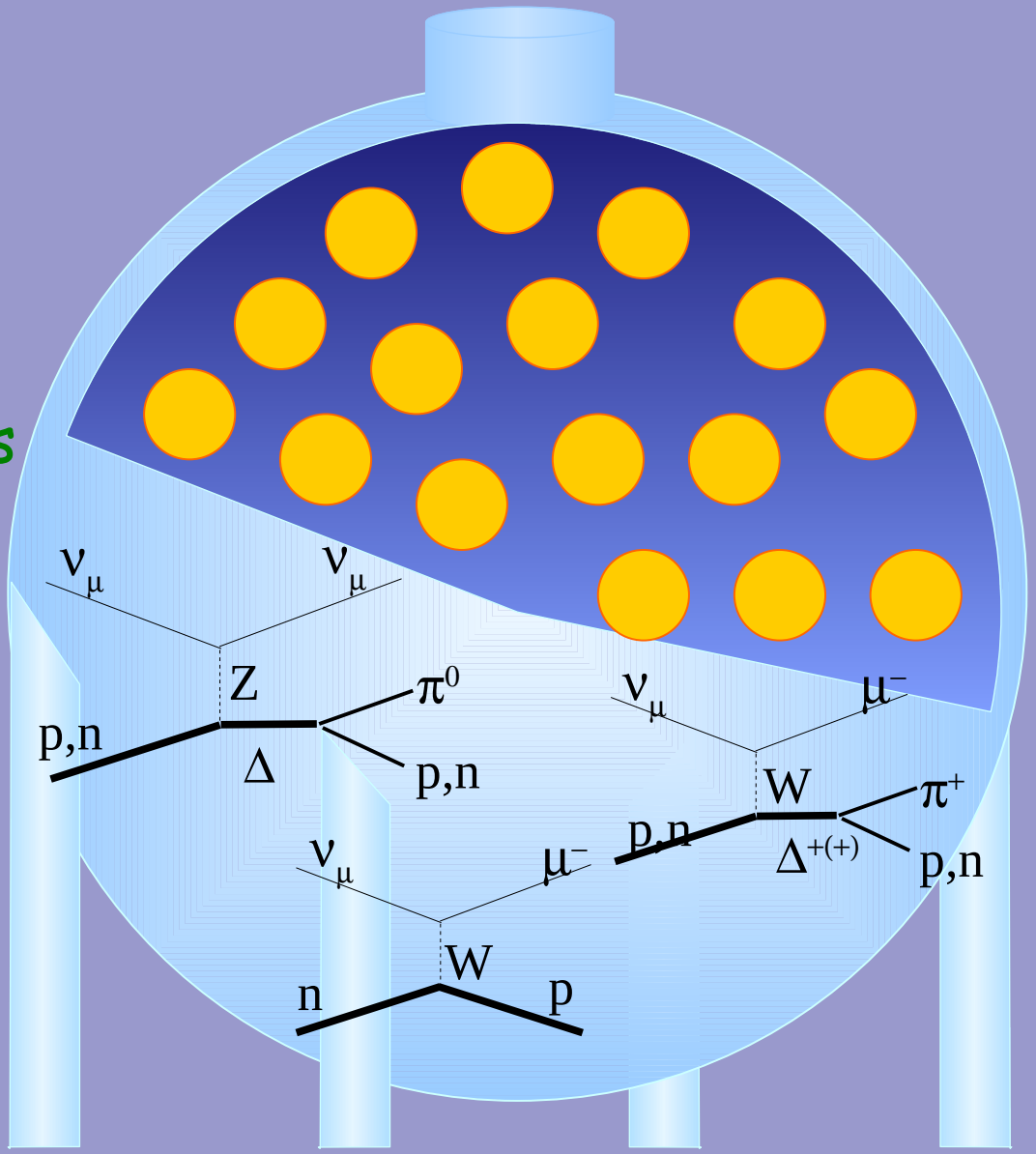
Measuring Neutrino Interactions with MiniBooNE

Outline:

- overview
- experiment
  - ν beam, detector, analysis
- ν reactions and rates
- overview of MiniBooNE measurements
- antineutrino running



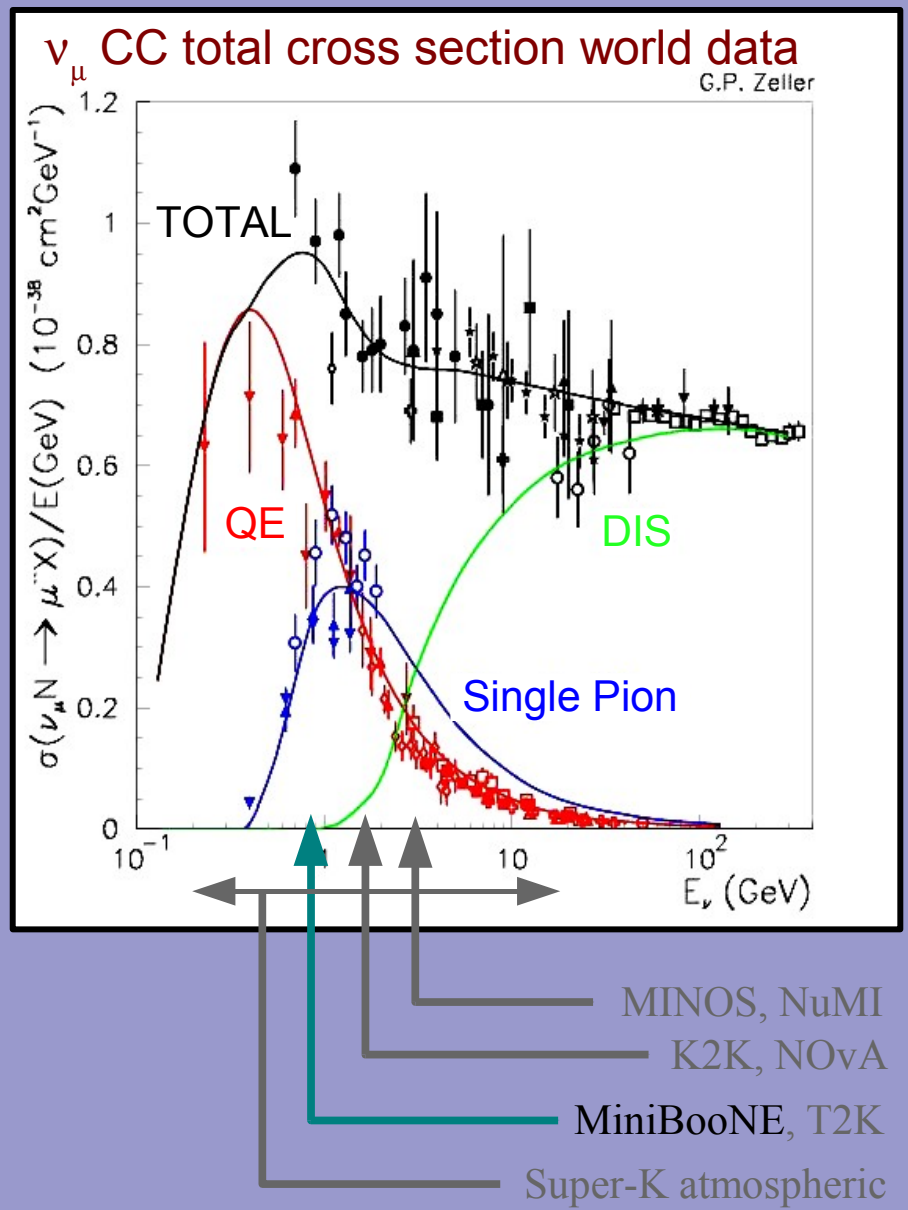
Neutrino Interactions with MiniBooNE

- The main goal of MiniBooNE (MB) is a $\nu_\mu \rightarrow \nu_e$ search

- High rates and good particle ID also allow accurate measurements of neutrino interactions

- Important to understand these interactions, both for the physics and to extract oscillation parameters.

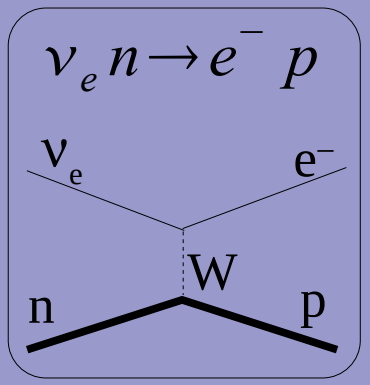
- Especially at E_ν~1 GeV



Neutrino interactions and oscillations

- For example, in recent results on $\nu_\mu \rightarrow \nu_e$ search from MiniBooNE...
  (arXiv:0704.1500v2 [hep-ex], to be published in PRL)
- Crucial to measure ν_μ , ν_e interactions from a variety of processes:
  - ν_μ CCQE: provides cross section for ν_e CCQE, constrains ν_μ flux, background for oscillations
  - ν_μ NCπ^0: measured in data, background for oscillations
  - ν_μ CCπ^+: provides understanding of Δ production and therefore input to $\Delta \rightarrow N\gamma$ background for oscillations
- and understand/predict energy, angle, etc distributions.

oscillation signal reaction:



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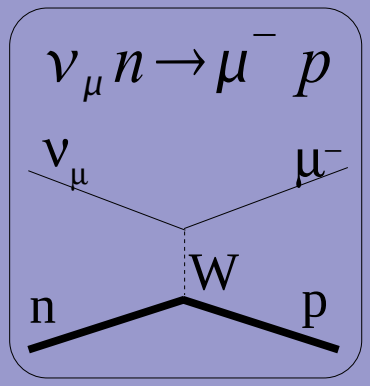

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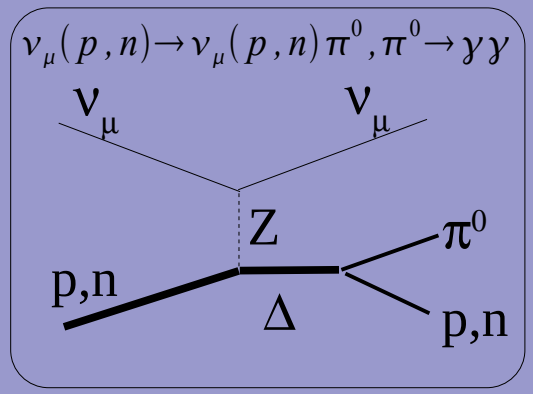


Neutrino interactions and oscillations

- Need to understand/model the underlying physics (for ν interactions on Carbon). E.g.:

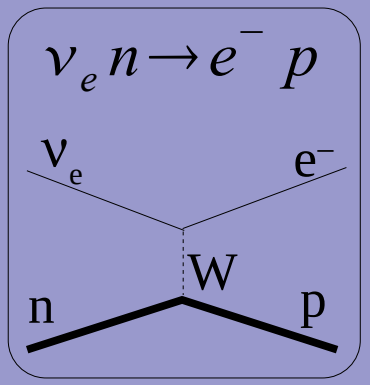
  ν_μ CCQE: nucleon momentum distributions and form factors

  ν_μ NCπ^0: Δ form factors, resonant/coherent contributions

  ν_μ CCπ^+: " " " " "

- In addition, this physics just plain interesting....!

oscillation signal reaction:



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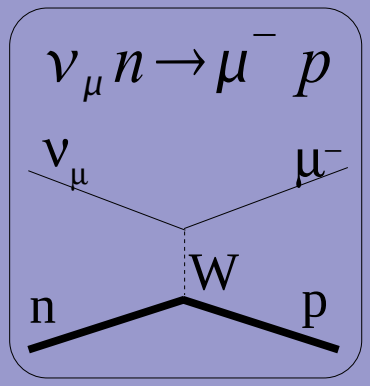

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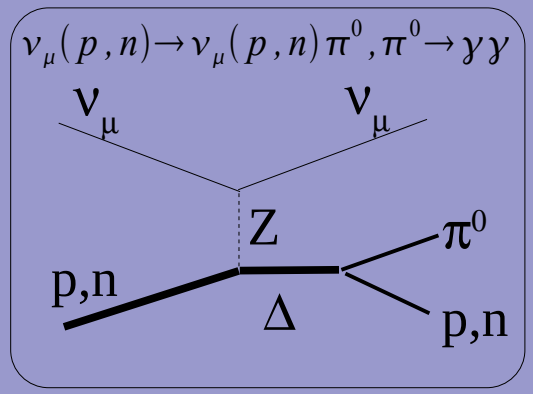
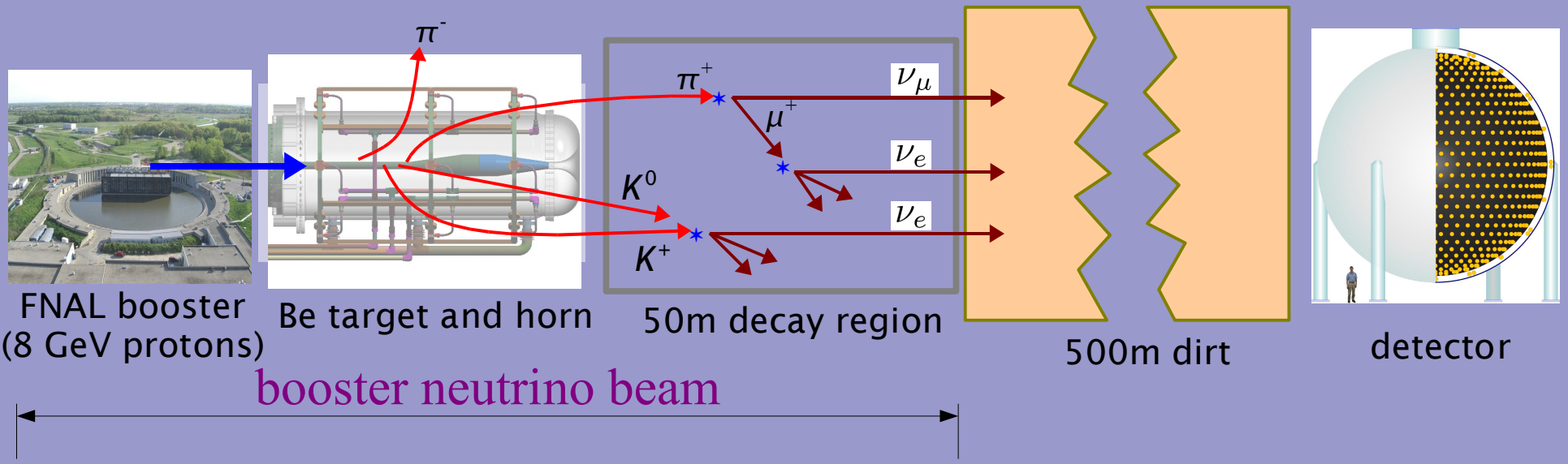


The MiniBooNE experiment



MiniBooNE ν beam

- proton beam from 8 GeV booster accel (at Fermilab)

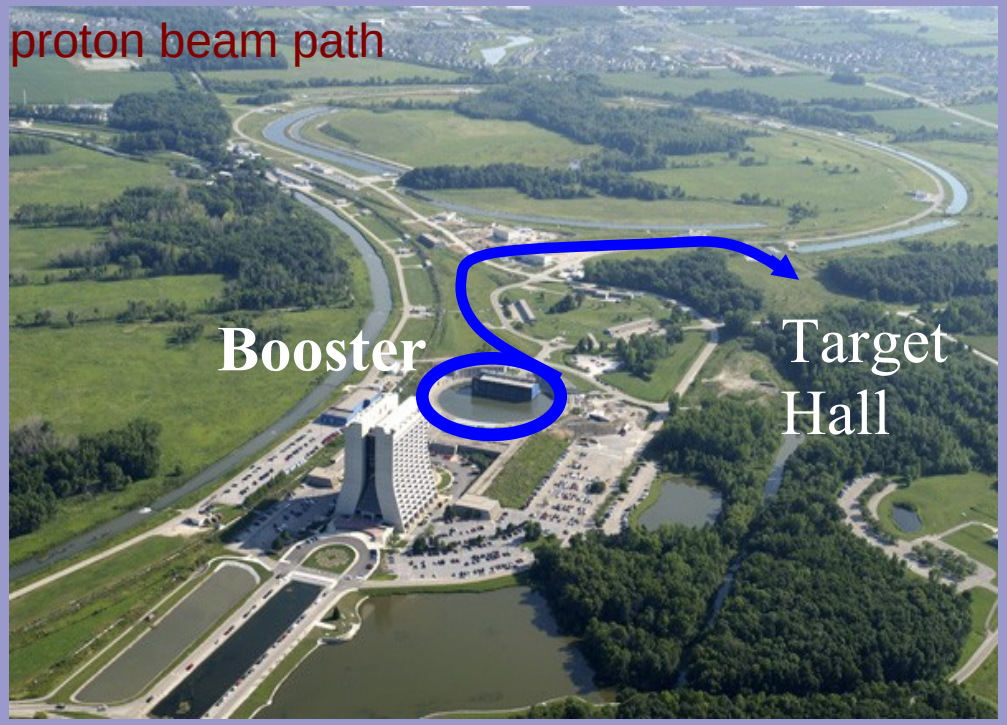
- Delivered to a 1.7 λ Be target

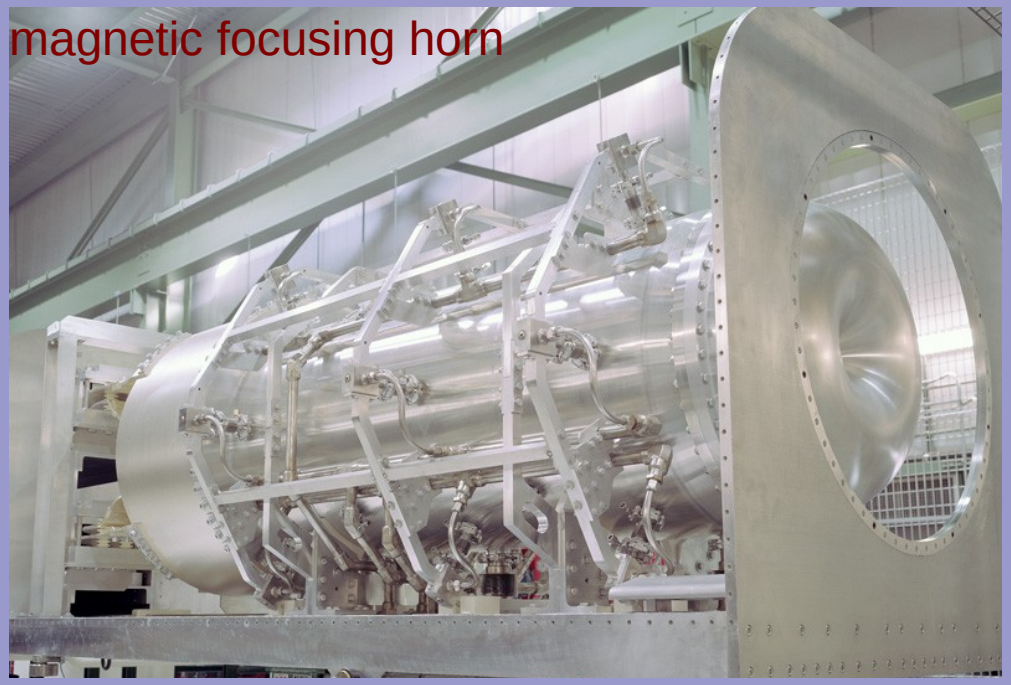
- within a magnetic horn pulsing with beam spill @ 170 kA

- 4 $\times 10^{12}$ protons per 1.6 μs pulse delivered at up to 5 Hz.

- $(5.58 \pm 0.12) \times 10^{20}$ POT collected in neutrino mode, 2003-2005

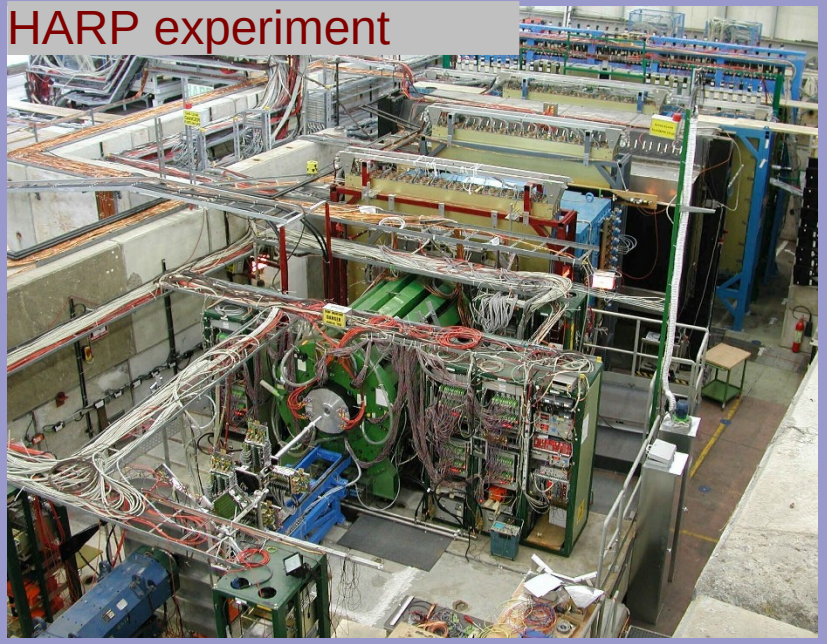
(POT="protons-on-target")





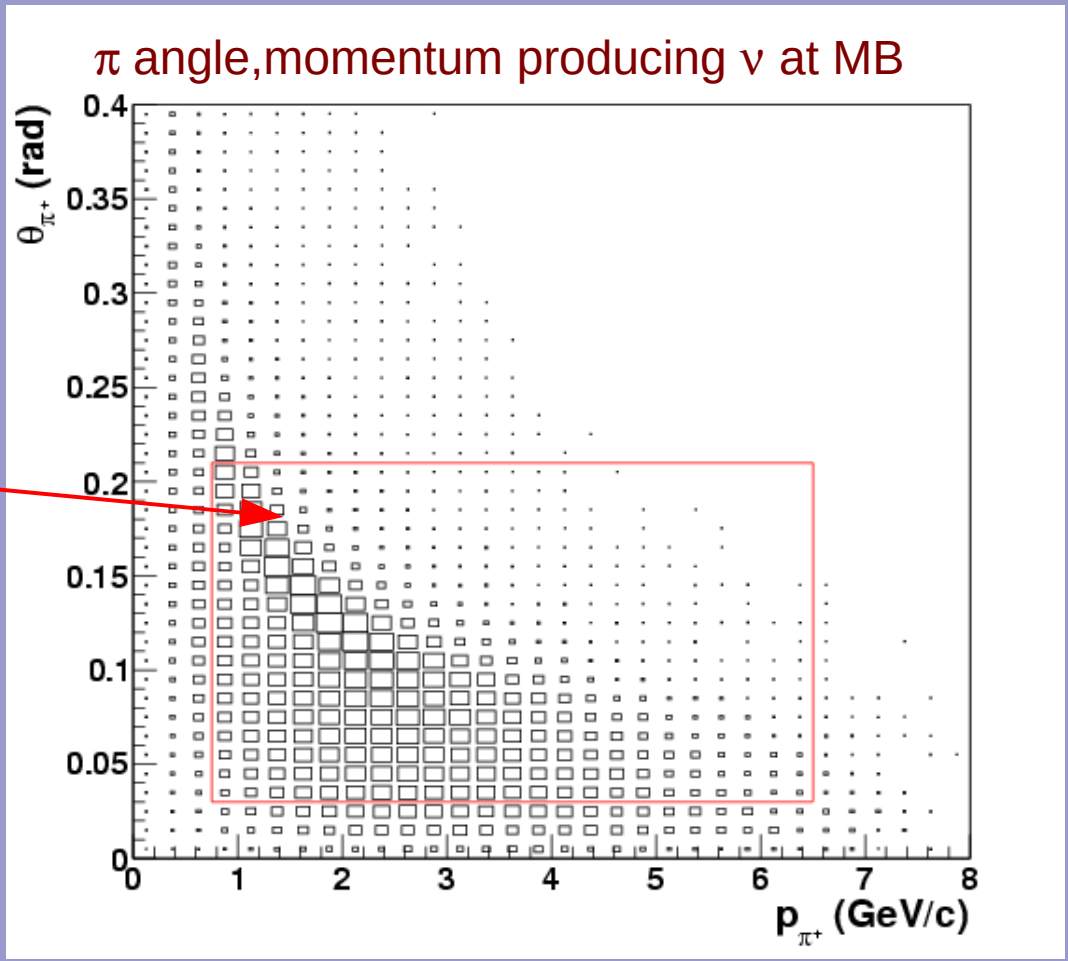
MiniBooNE ν beam: flux from pions

HARP experiment



- pion production in p,Be at 8.9 GeV/c from HARP experiment at CERN (arXiv:hep-ex/0702024v1)

- kinematics of pions are well-covered by HARP (80.8% of flux with HARP coverage)



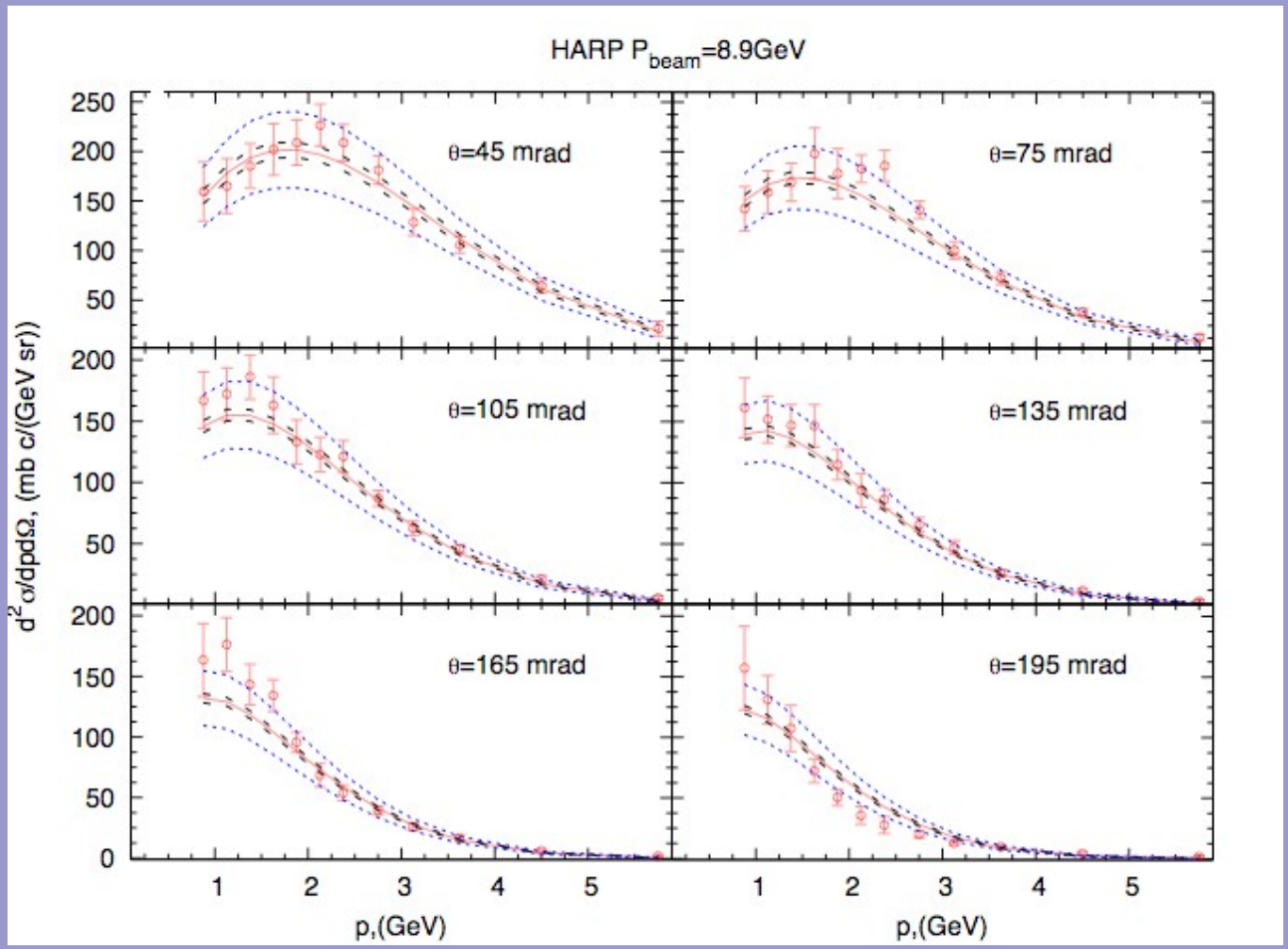
MiniBooNE ν beam: flux from pions

- pion production in p,Be at 8GeV/c from HARP

Data are fit to a "Sanford-Wang" parameterization.
- points: data
- red line: fit
- blue lines: error band

- BNL910 p,BE data at p=6.4,12.3 GeV/c used also in fits

- similar proceedure for kaons



(HARP data, arXiv:hep-ex/0702024v1)

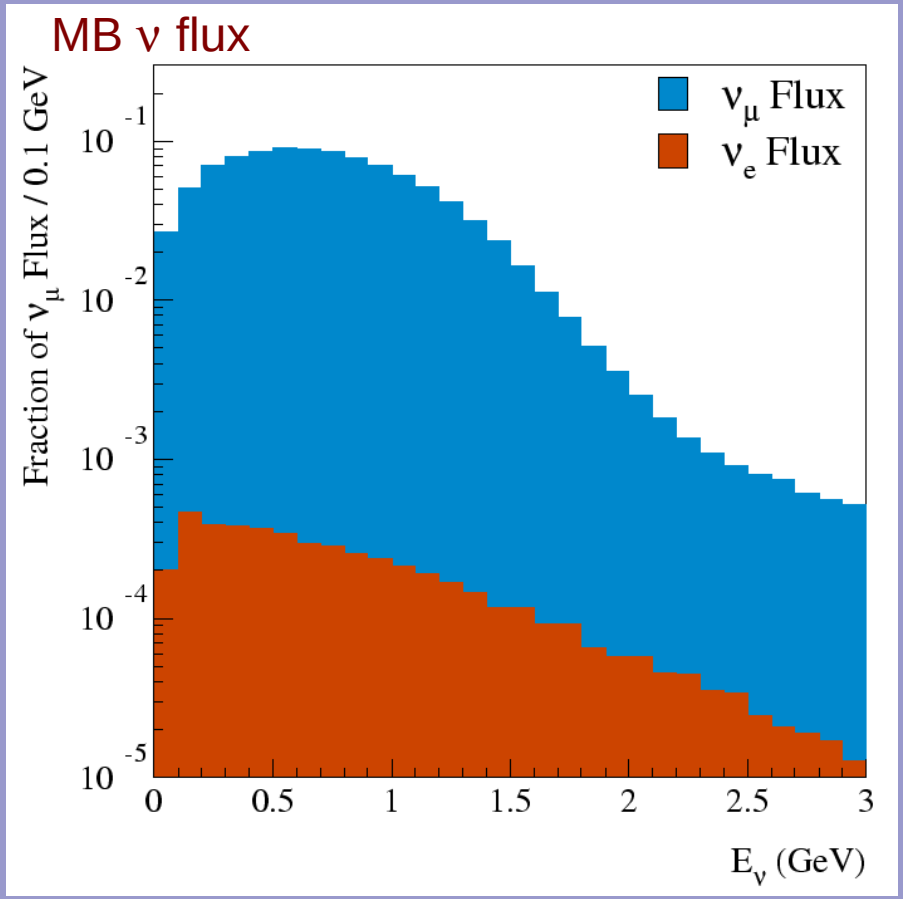
MiniBooNE beam: total ν flux

GEANT4 simulation use to predict flux at detector, includes:

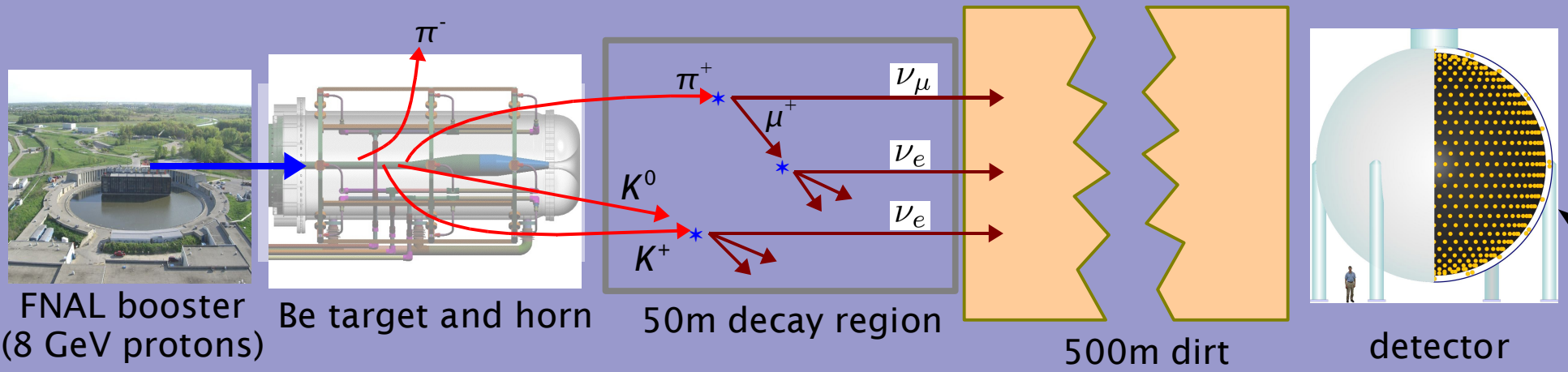
- pi, K production data
- proton interactions (primary, 2ndary)
- horn/decay pipe geometry

- mean energy ~ 800MeV
- 99% of flux from <2.5GeV
- 98% of CCQE interactions from ν_μ due to π decays
- ν_e/ν_μ = 0.5%
- 6% $\bar{\nu}$ contamination

- ~15% error on flux normalization
- energy-correlated errors calculated



The MiniBooNE experiment



MiniBooNE detector

MiniBooNE Detector

- 541 meters from target
- 12 meter diameter sphere
- 800 tons mineral oil (CH_2)
- 3 m overburden
- includes 35 cm "veto region"
- viewed by 1280 8" PMTs (10% coverage) + 240 veto
- Simulated with a GEANT3 Monte Carlo program

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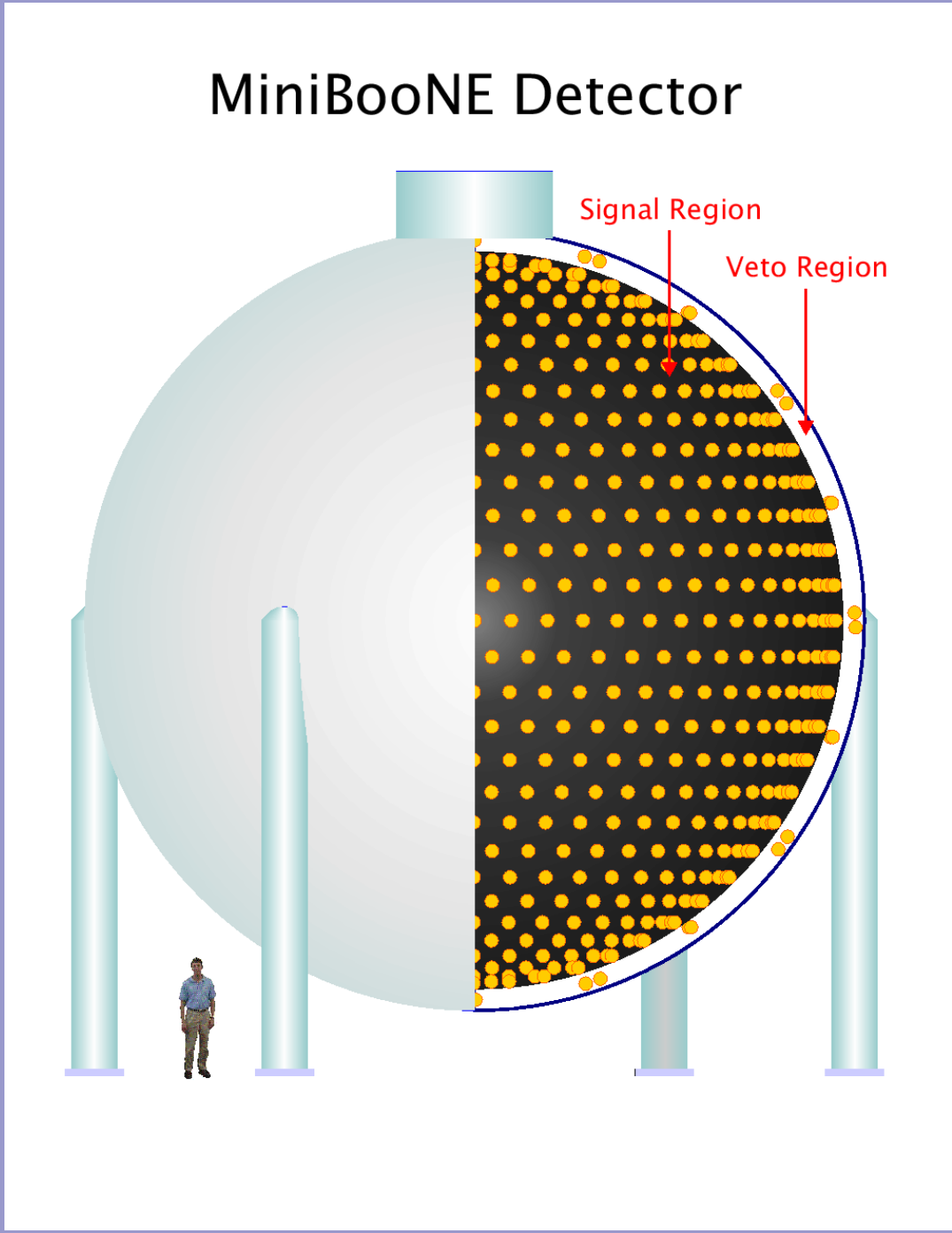

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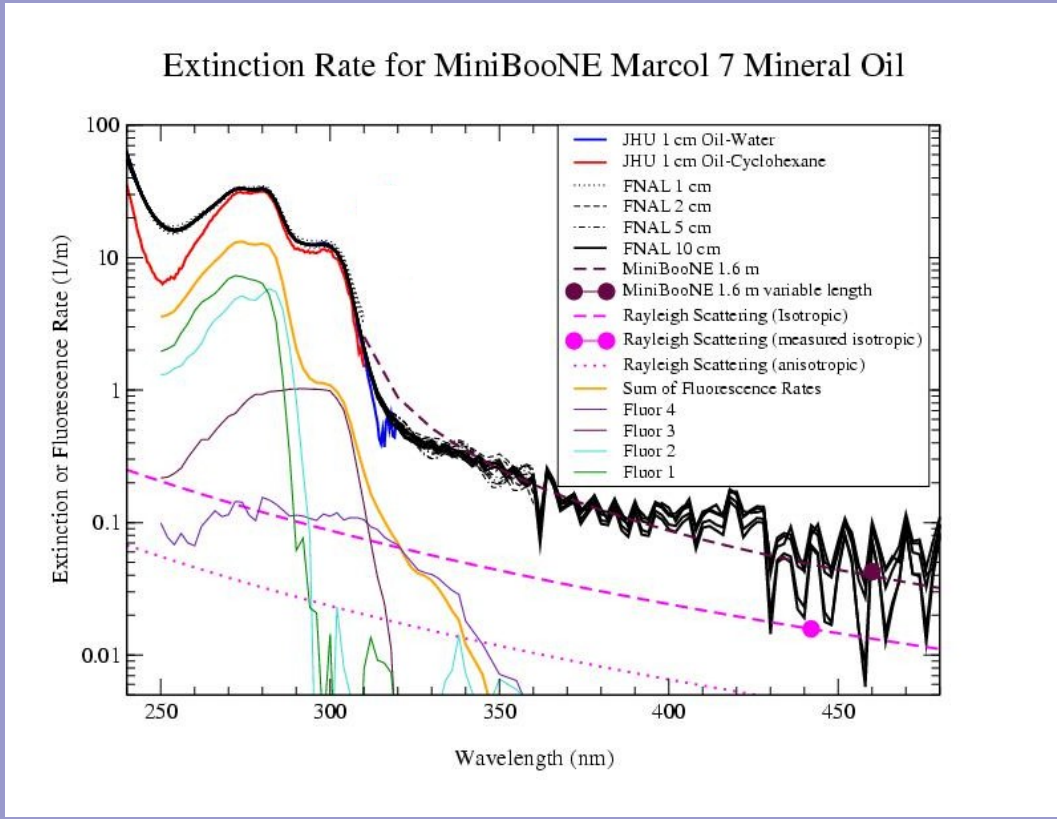
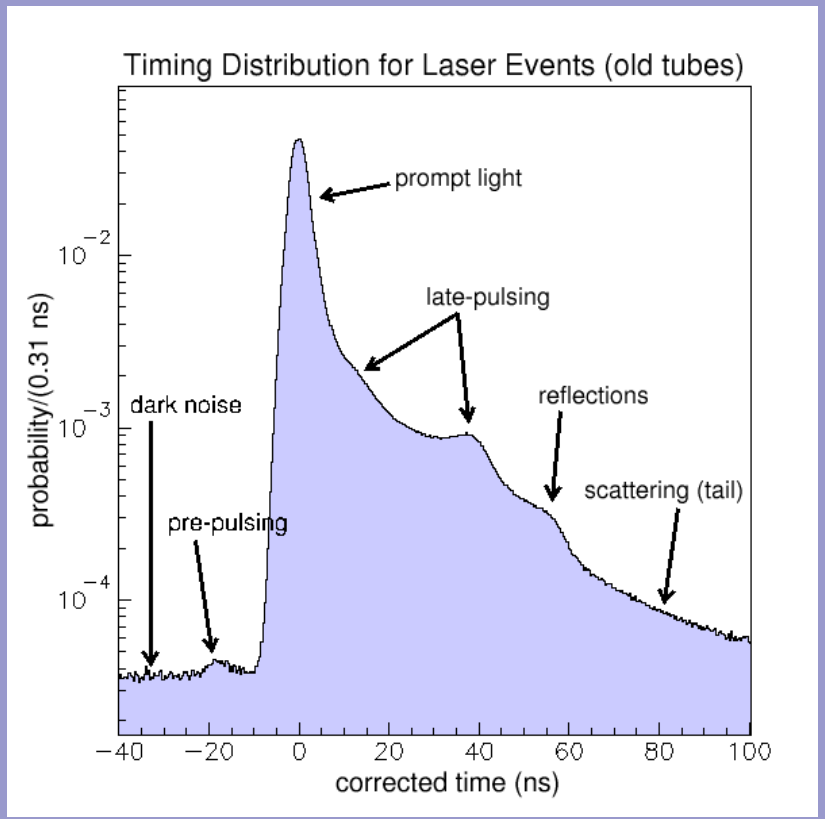
PMT

Detector: light propagation and simulation

- detailed "optical model" of detector has been developed...
- ...guided by internal/external measurements
- Attenuation length: >20 m @ 400 nm
- both prompt (Cerenkov), late light (scintillation, fluorescence) modeled
- detected prompt:late light is ~3:1 for β~1

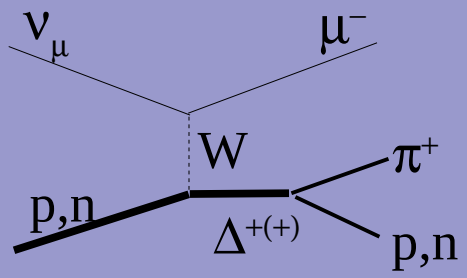


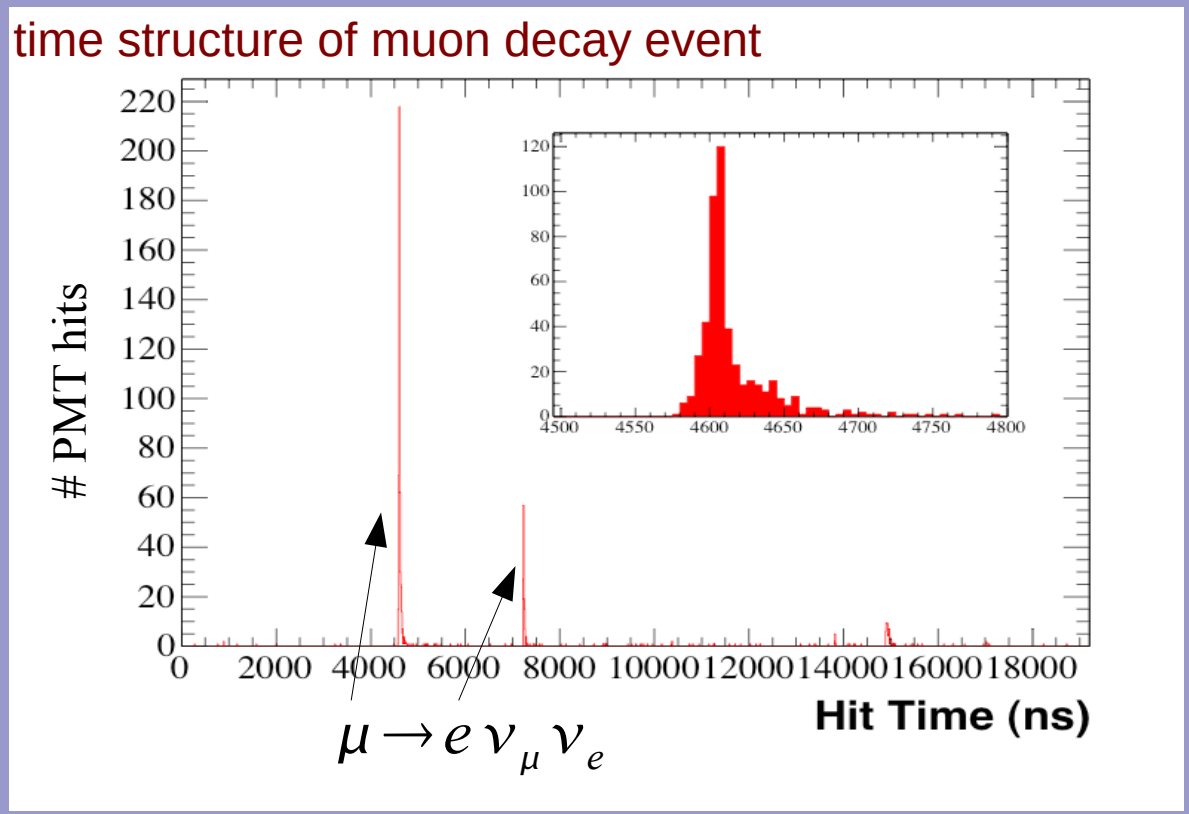


Detector: trigger and "subevents"

- main "beam" trigger:
  - readout all hits (above low threshold) in 19.2 μs window around ~1.6 μs beam spill
- essentially no trigger bias
- allows decays of muon and pions to be detected with high efficiency

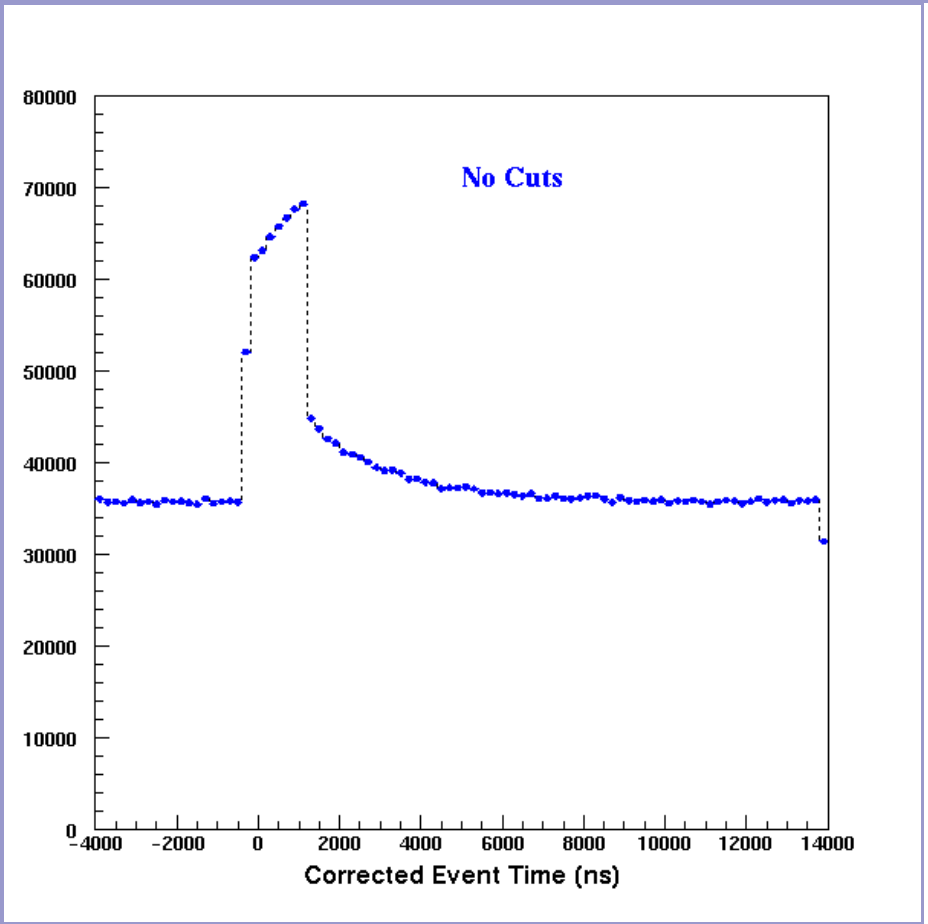
- "subevents" are then split up within this window
- then subevent structure may be used as a powerful cut to select event types
- e.g. $CC\pi^+$ typically has 3 subevents

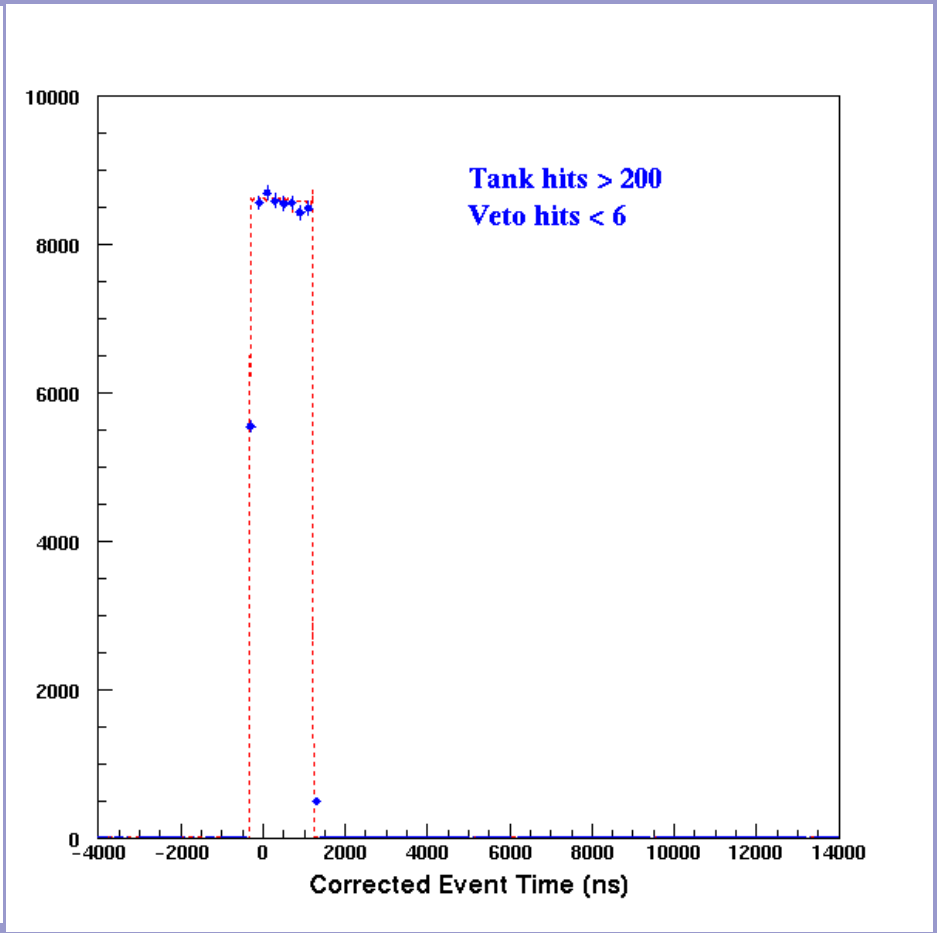




Detector: event time structure

- 1.6μs beam spill within 19.2μs trigger window
- ν events easily seen with simple cuts
- low duty-ratio => low beam-unrelated background

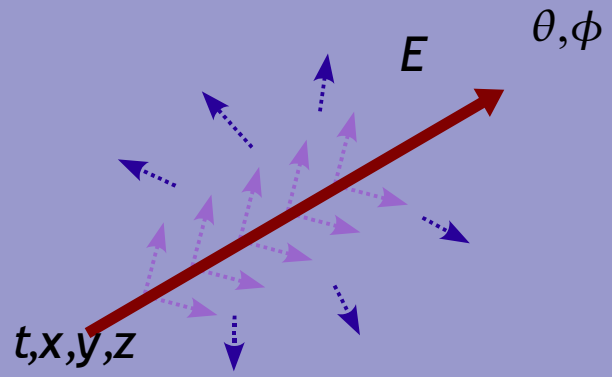




ν Events in MiniBooNE

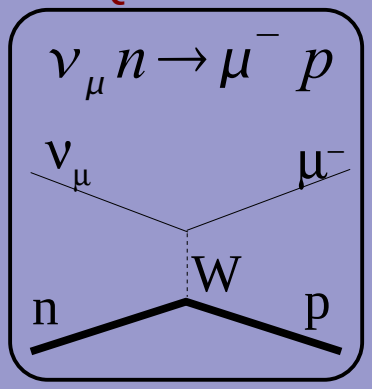
- ν interaction products create (directed, prompt) Cerenkov light and (isotropic, delayed) scintillation light

- pattern and timing of the light collected by PMTs allows for identification of events (and position, direction, energy measurement)

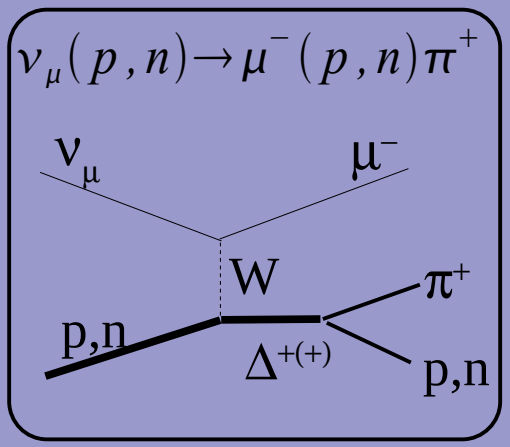


- muon energy/angle resolution ~7%/5° at 300 MeV

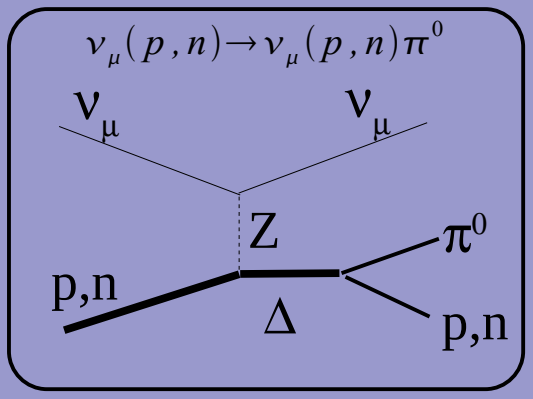
CCQE:



CCπ^+:



NC π^0:



ν Events in MiniBooNE

Muons

Sharp, clear rings

Long, straight tracks

Electrons

Fuzzy rings

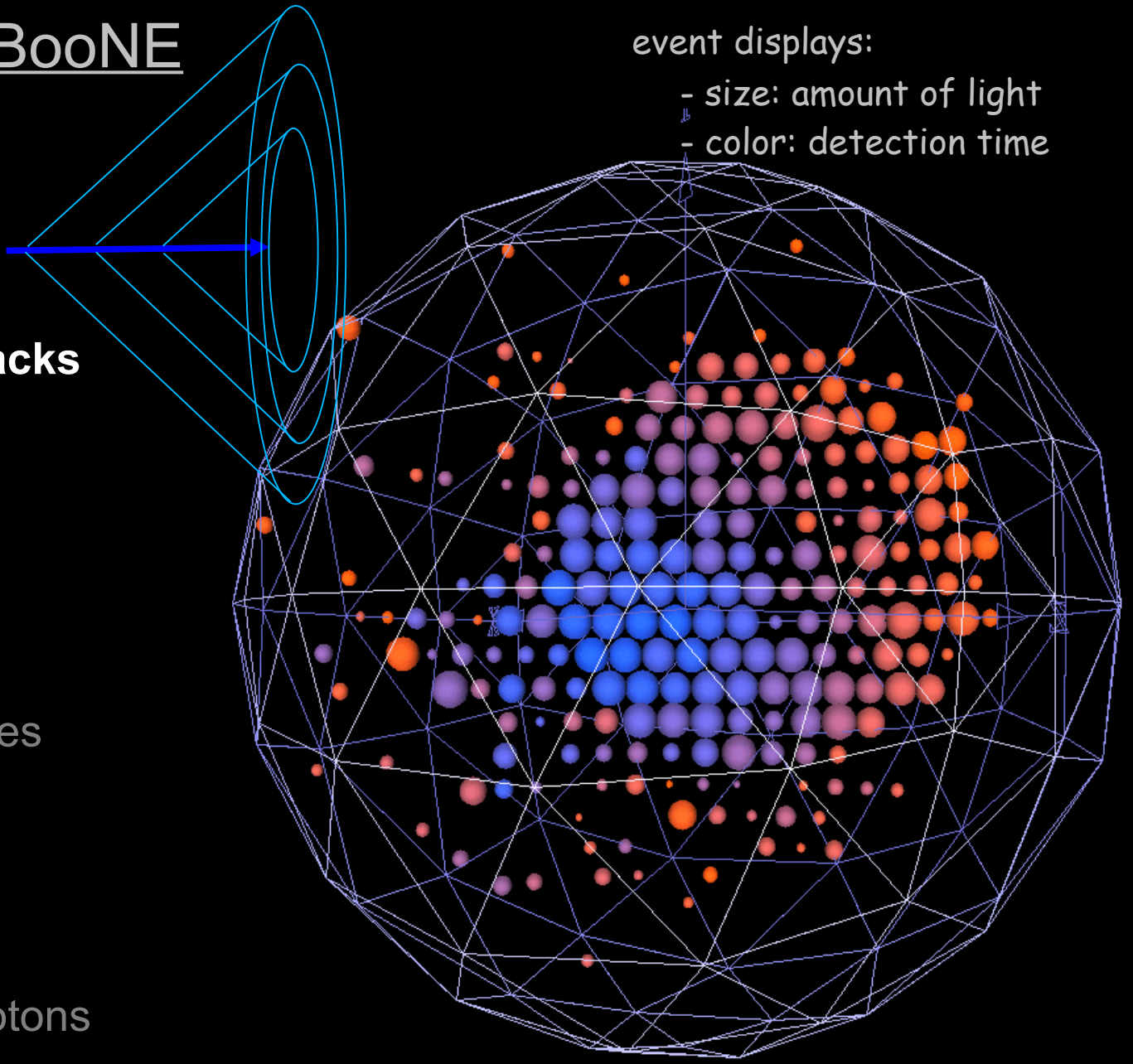
Multiple scattering

Radiative processes

Neutral Pions

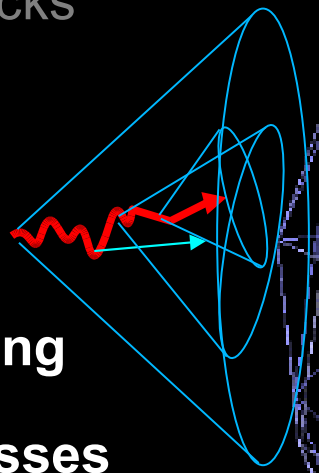
Double rings

Decays to two photons

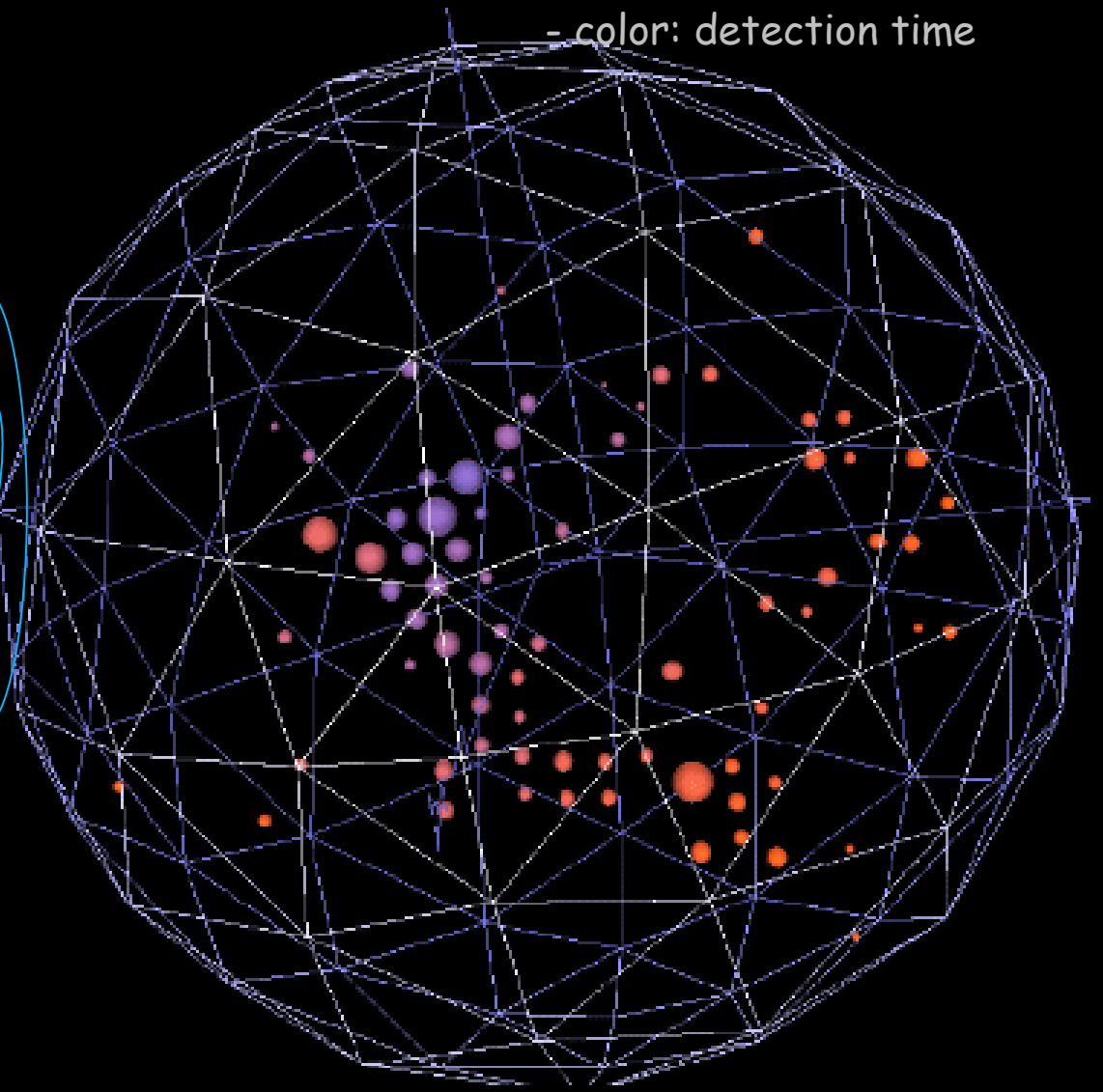


ν Events in MiniBooNE

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

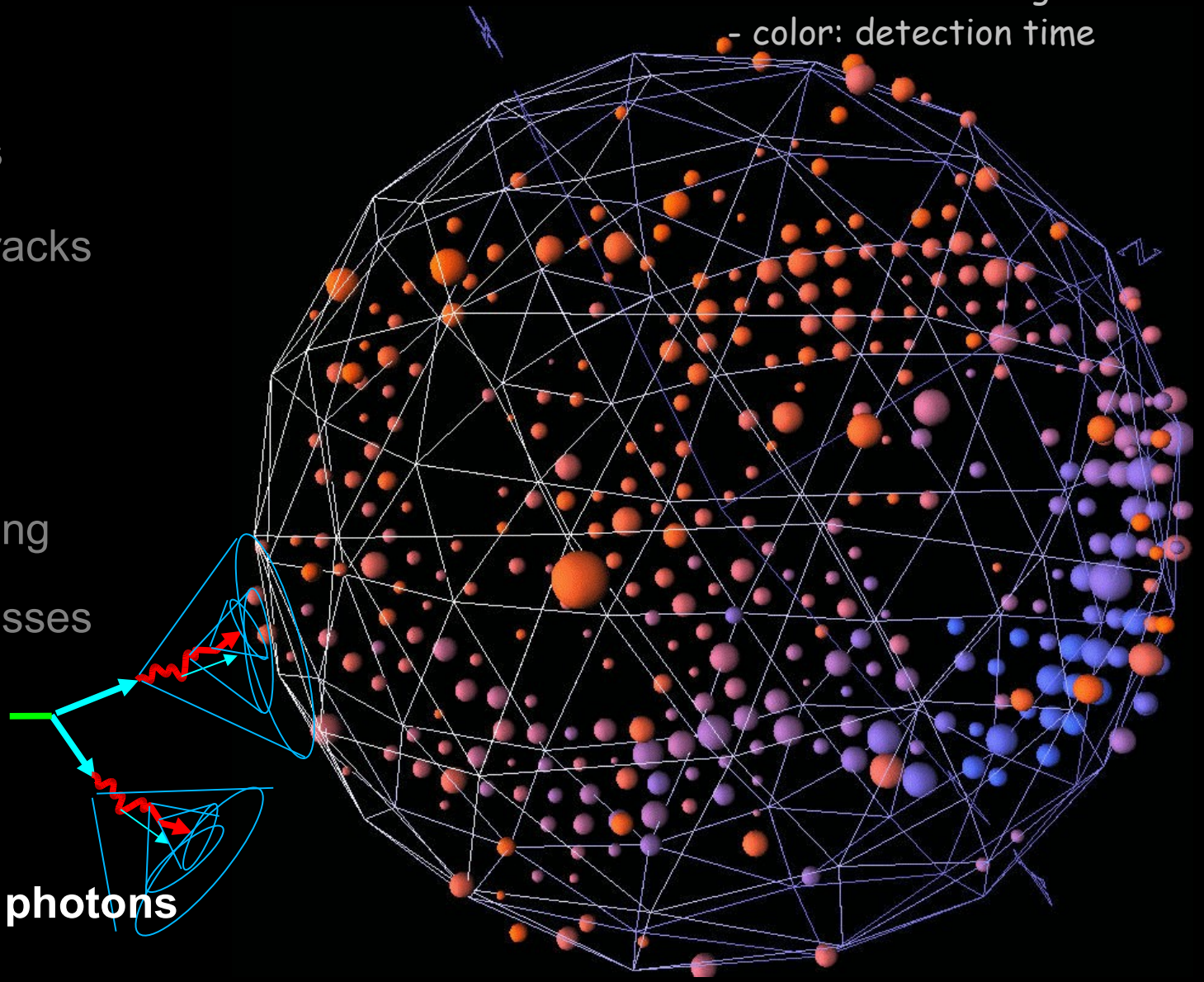


event displays:
- size: amount of light
- color: detection time



ν Events in MiniBooNE

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

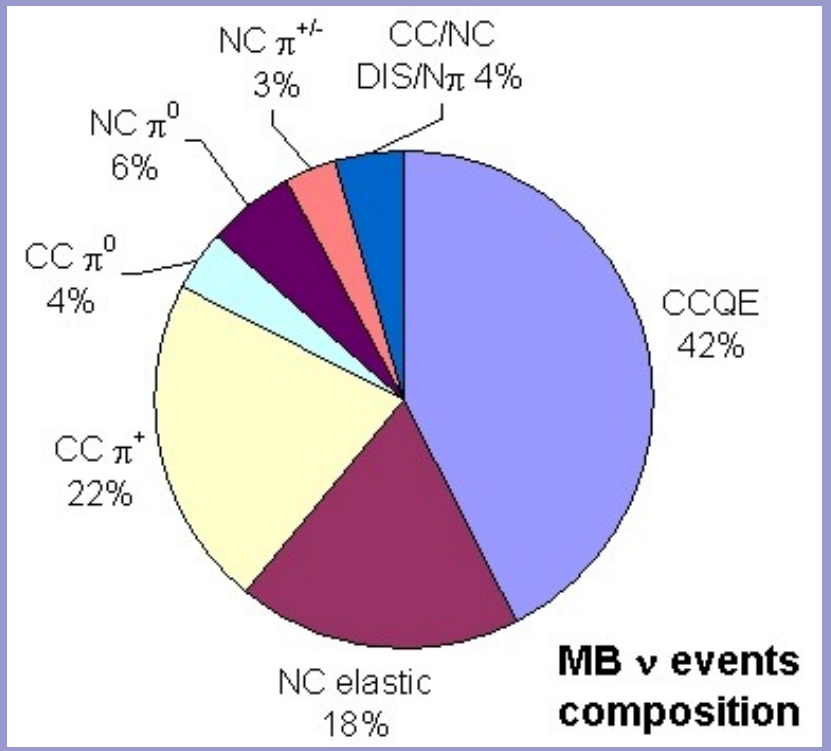


MiniBooNE ν Event Rates

ν events currently "on-tape" :
- predicted by ν interaction MC*
- 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

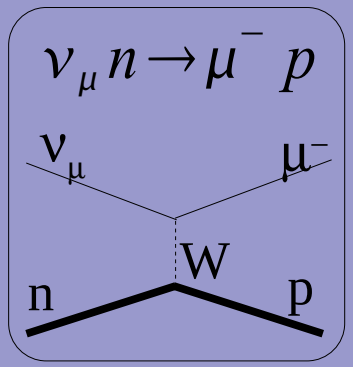


*MB ν interaction MC:
v3 NUANCE code with:
- Smith-Moniz Fermi Gas
- (non-dipole) vector form factors from Bradford et al
- Rein-Sehgal resonant/coherent 1π
- Bodek-Yang DIS

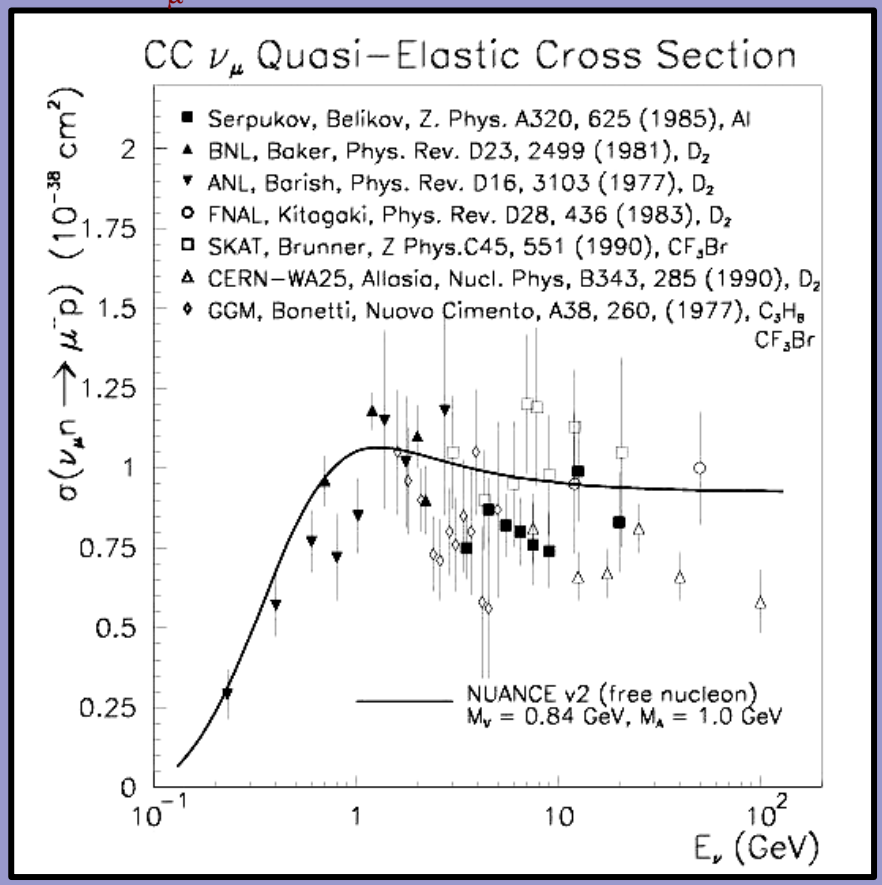
These (record-sized!) event samples allow cross section measurements with excellent statistical precision.

Charged-Current Quasielastic Scattering (CCQE)

- highest-rate reaction channel in MiniBooNE
- for oscillations: provides check of the ν_μ flux, measurement of ν_e CCQE
- Need to understand this process on nuclear target (C)
- existing data consists of small samples and (at low E) on D_2
- Teppei Katori, Indiana U., Session 5, Thurs.
  - extraction of model parameters from Q^2 distribution (paper soon!)
- Ultimate goals for CCQE:
  - differential cross section
  - investigation/implementation of modern models

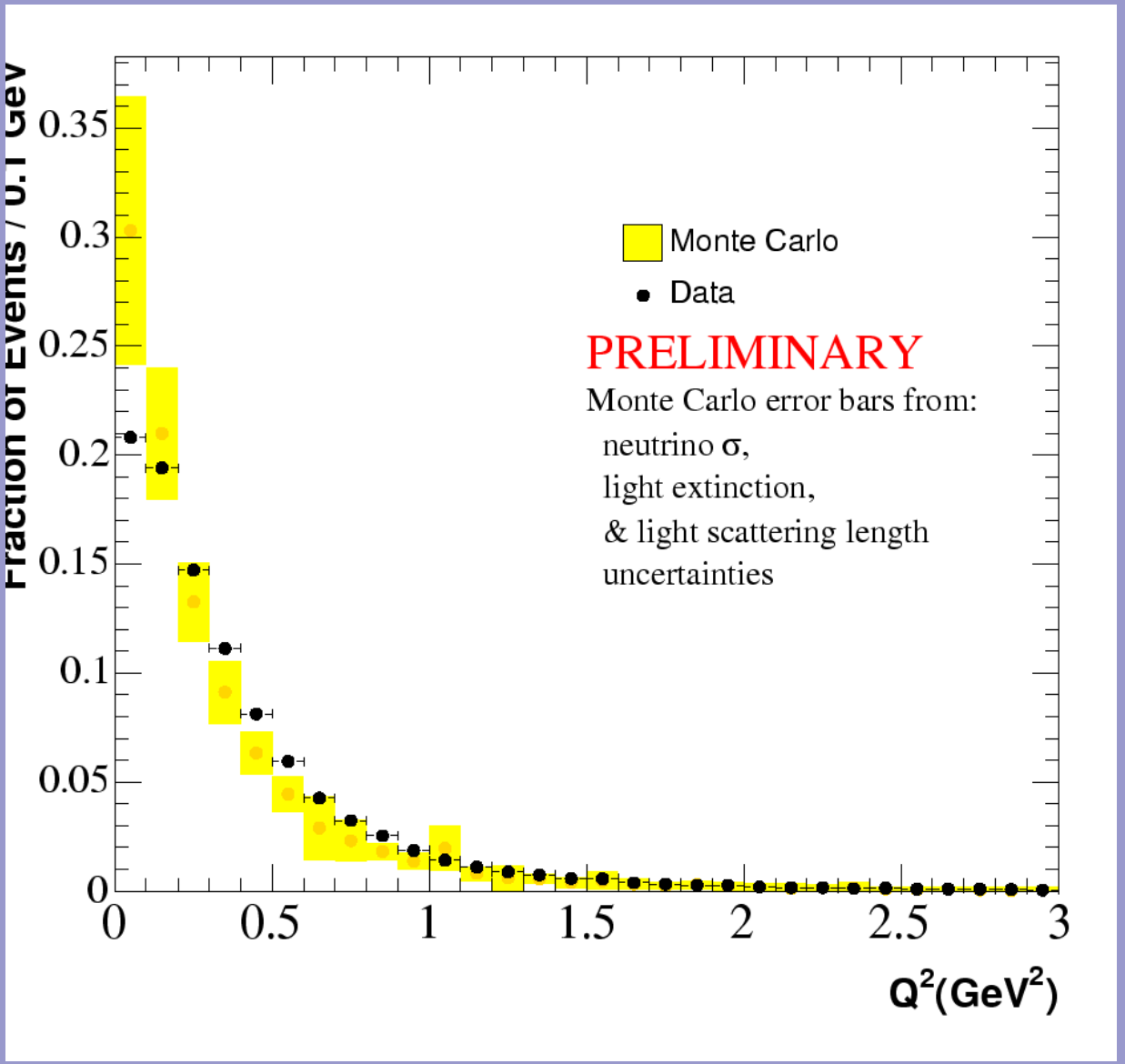


ν_μ CCQE cross section world data



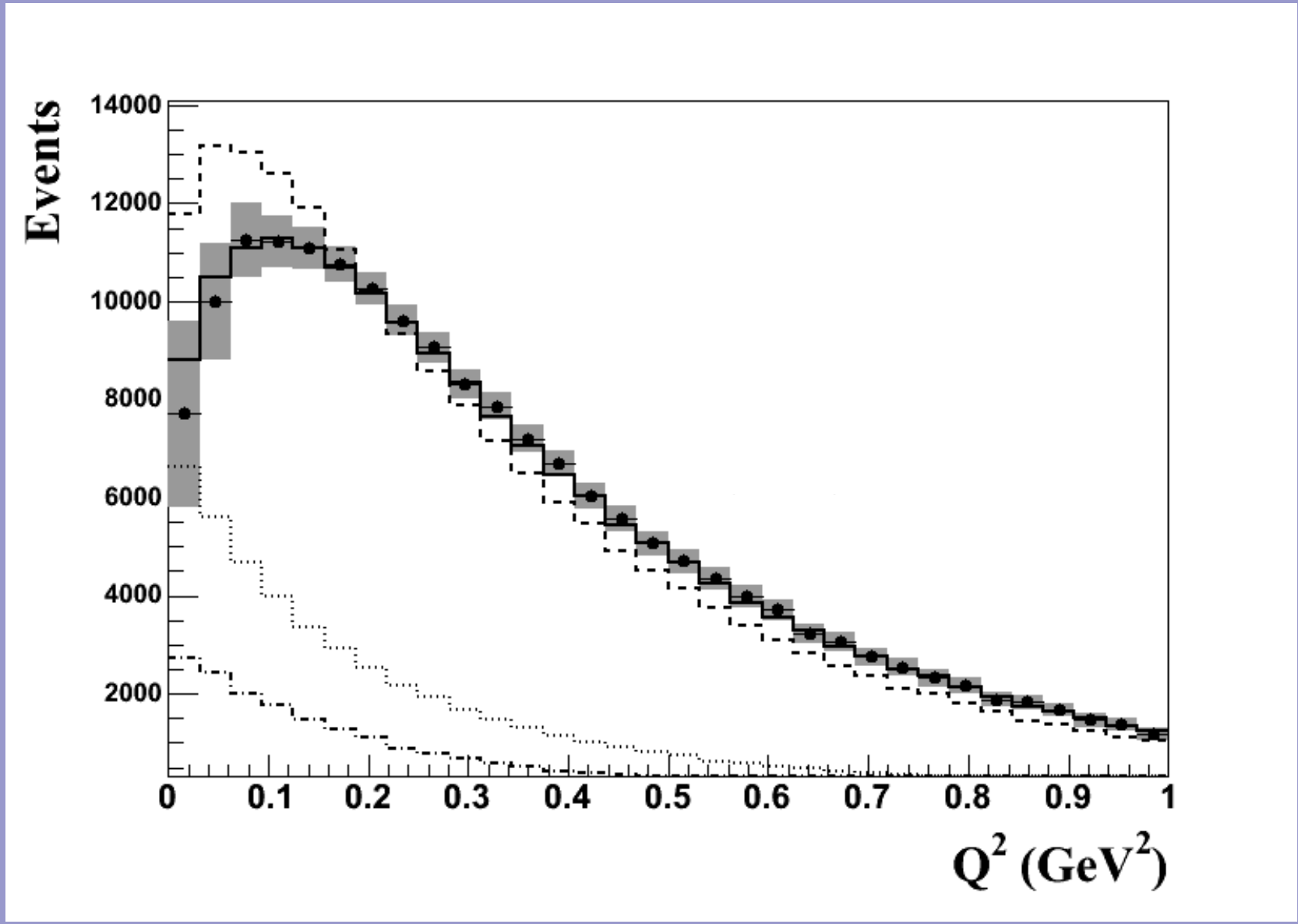
Charged-Current Quasielastic Scattering (CCQE)

- previous MB result, from NuInt05



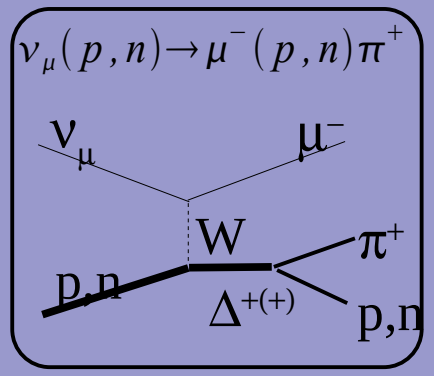
Charged-Current Quasielastic Scattering (CCQE)

- new MB result, will be shown tomorrow

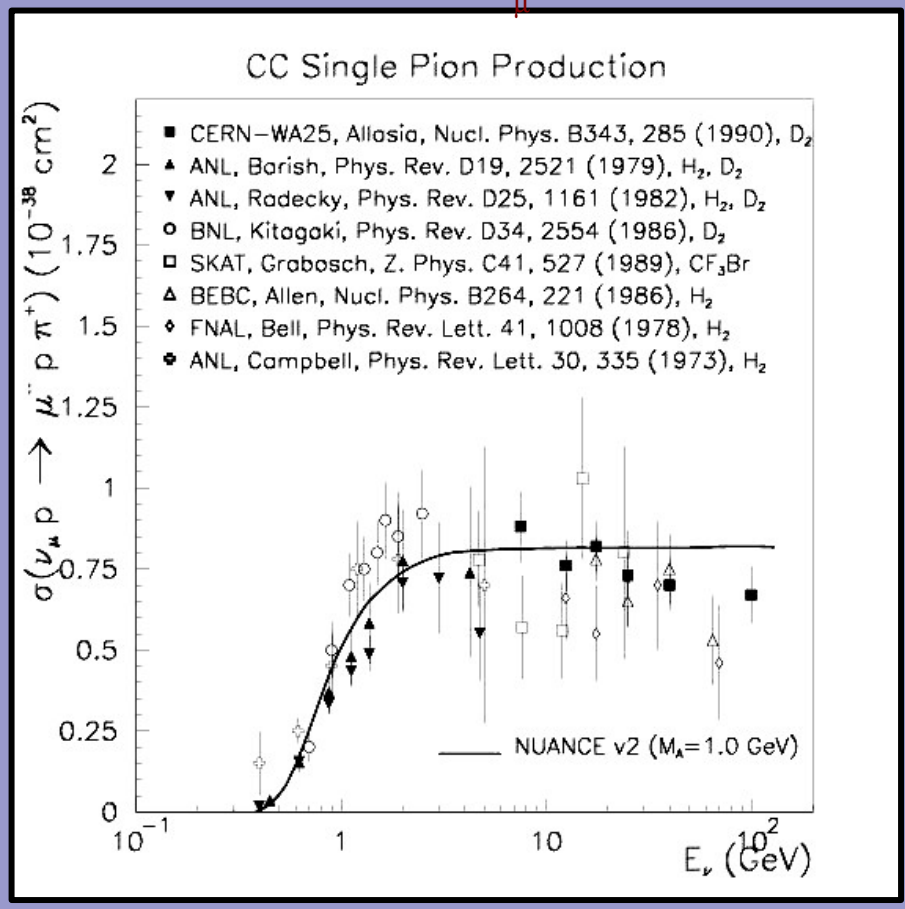


Charged-Current $1\pi^+$ Production (CC π^+)

- 2nd highest-rate reaction channel in MiniBooNE
- largest background for ν_μ CCQE
- coherent CC π^+ is interesting subject, K2K sets limit (hep-ex/0506008)
- existing data is sparse
- Bonnie Fleming, Yale U. Session 6, Friday
  - kinematic distributions and comparison with model
- Ultimate goals:
  - $CC\pi^+/CCQE$ ratio
  - $M_A(1\pi)$ extraction
  - differential cross section
  - coherent contribution

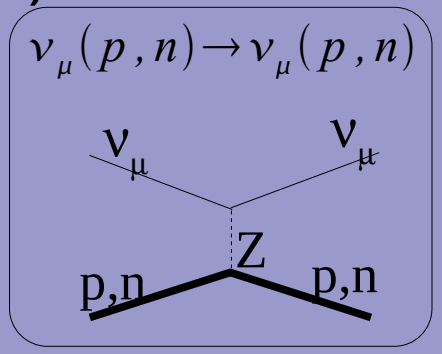


ν_μ CCπ^+ world data



Neutral-Current Elastic scattering (NC elastic)

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

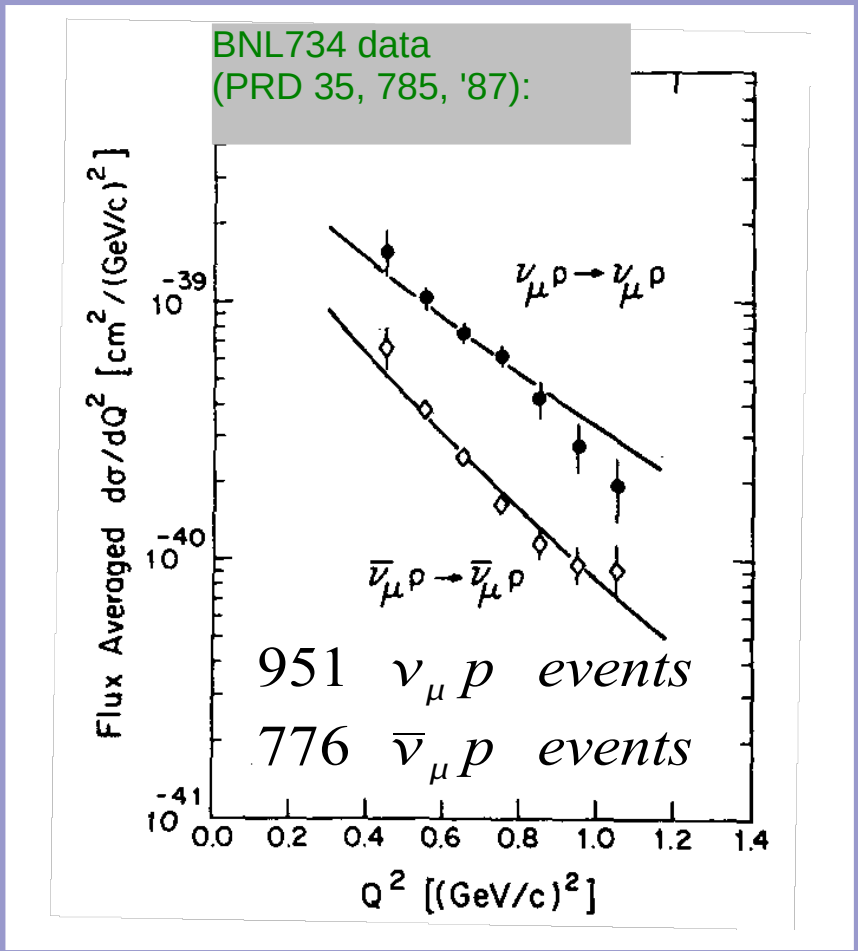


- Chris Cox, Indiana U.

Session 5, Thursday

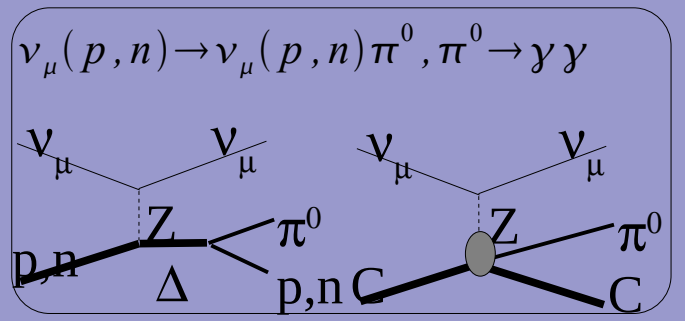
- (preliminary) differential cross section

- Ultimate goals:
  - differential cross section
  - NCelastic/CCQE ratio

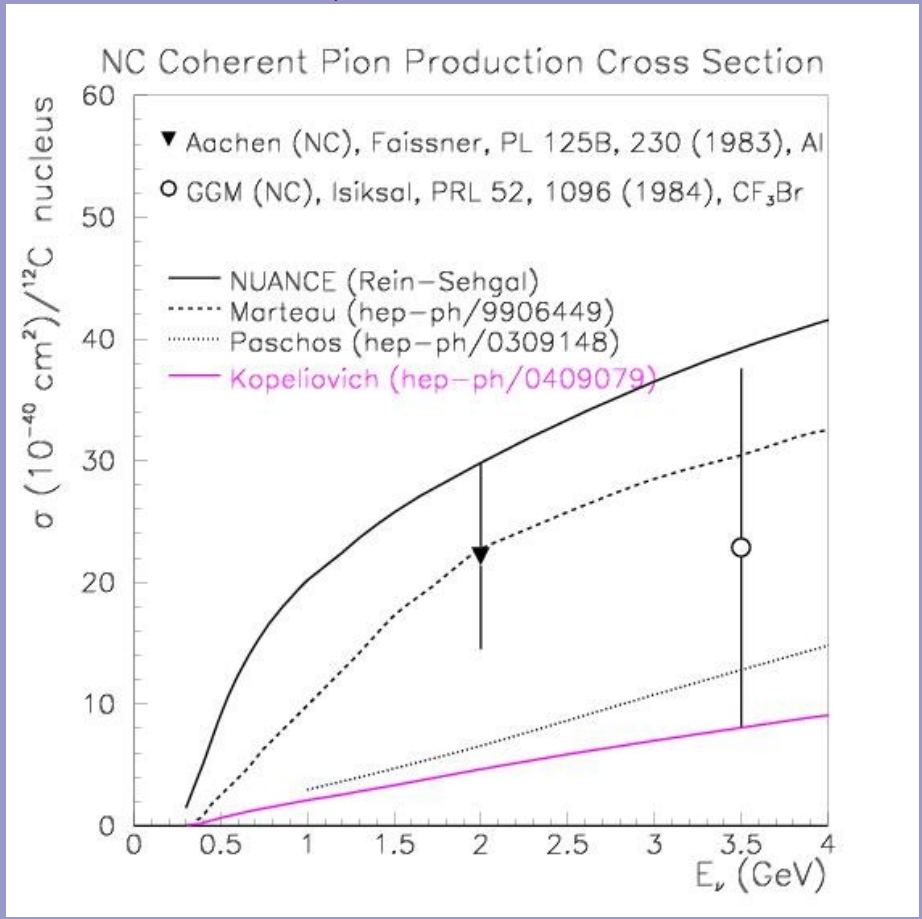


Neutral-Current π^0 Production (NCπ^0)

- (very) important oscillation background
- both resonant and coherent channels contribute (coherent predicted to be ~5-20%)
- coherent dominated by axial current, therefore, not constrained with e-scattering data
- very little existing ν data



ν_μ coherent NCπ^0 world data



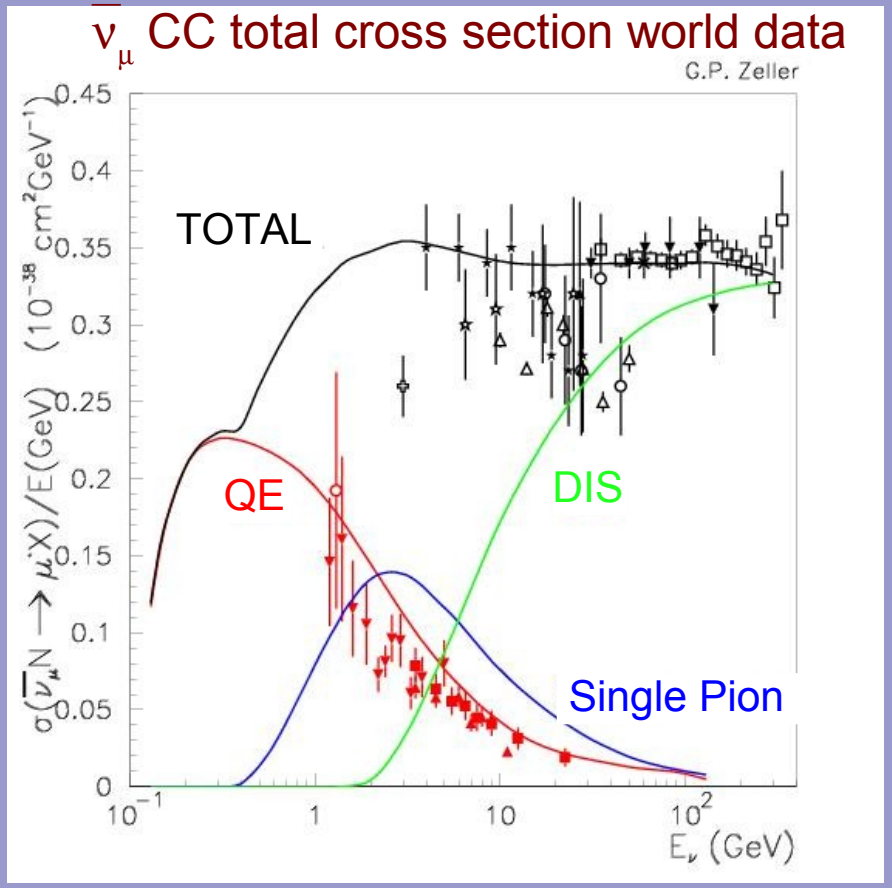
- Jon Link, Virgina Tech U., Session 6, Friday
  - coherent fraction
  - pi0 rate measurement
- Ultimate goals:
  - differential cross section
  - CCπ^0 analysis (underway)

Antineutrino Scattering with MiniBooNE

- interesting physics,
- an important test of ν results,
- a (limited) $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ search

- no existing $\bar{\nu}$ data below E_ν = 1GeV

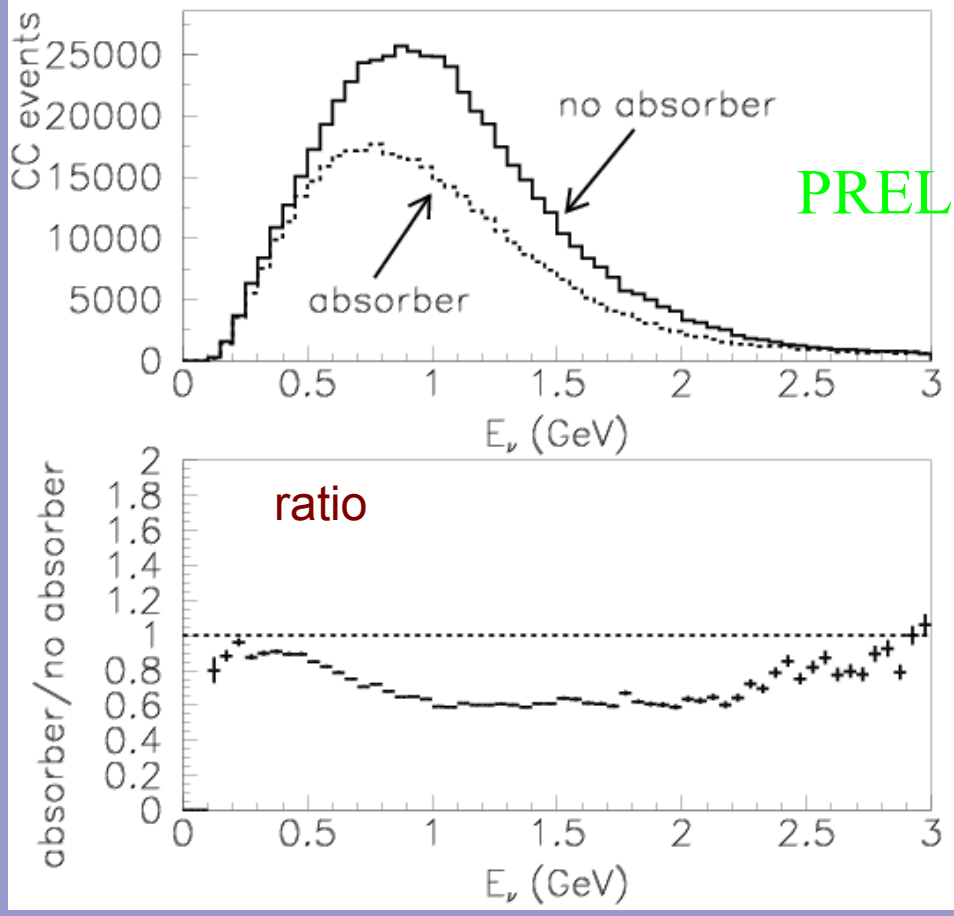
- MiniBooNE started $\bar{\nu}$ run in Jan, '06
  - 1.5E20 POT collected
  - problem with absorber plates at 25m in 50m decay tunnel
  - fixed! and back running in April '07, 0.3E20POT obtained since then
  - continue running to obtain total of (2-2.5)E20POT



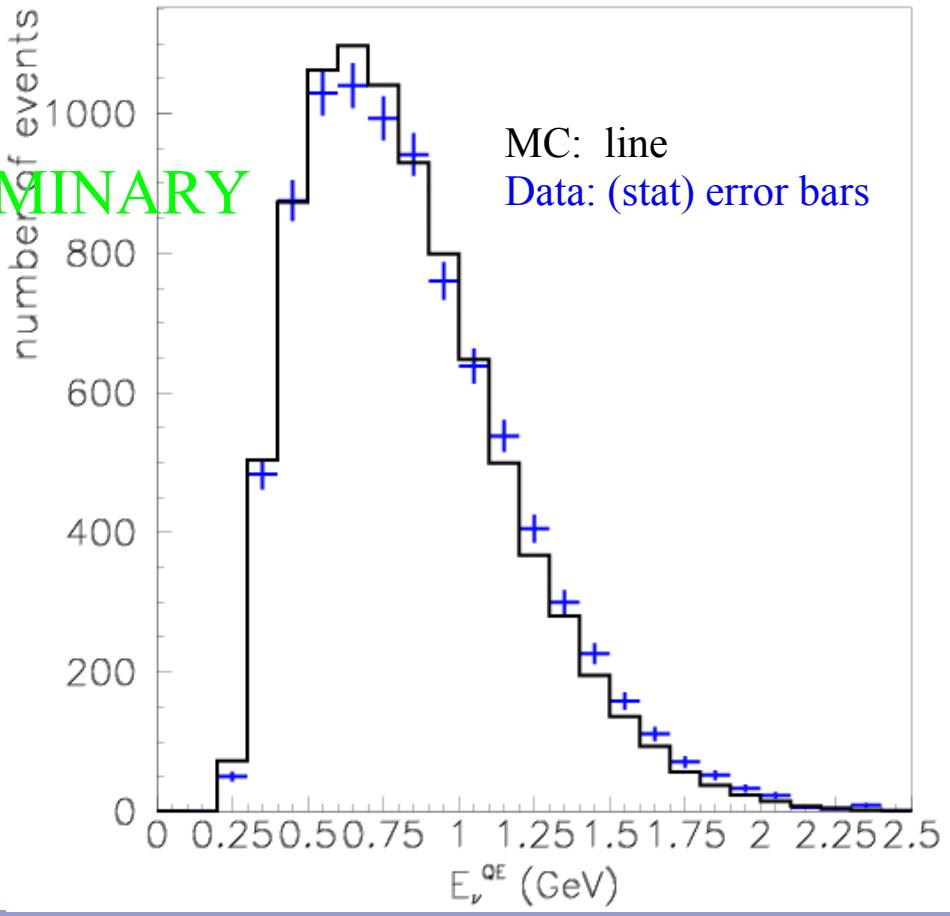
MiniBooNE Antineutrino Run

- flux/event distributions with absorber plates in understood
- all data may be used for analyses

event rates with/without absorber plates



E_ν distribution for antineutrino run



PRELIMINARY

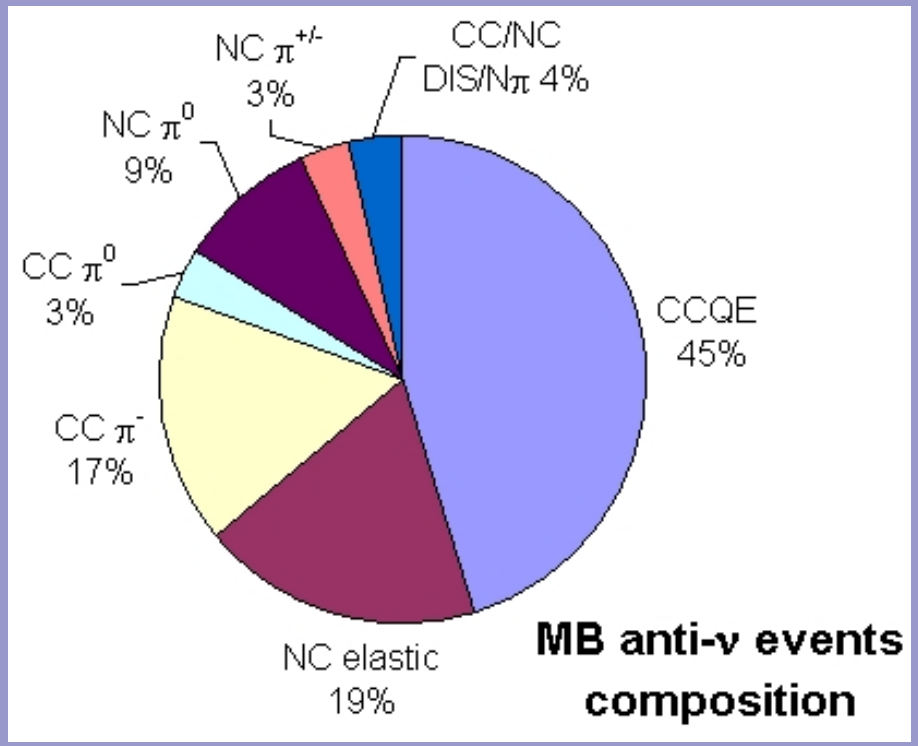
Antineutrino Scattering with MiniBooNE

$\bar{\nu}$ events expected:

- 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



1.8E20 POT collected so far...

Antineutrino Scattering with MiniBooNE

Topics investigated:

- M_A and differential cross sections in $\bar{\nu}$ quasielastic data
- joint analysis of ν/ $\bar{\nu}$ QE data to measure interference term
- coherent π^0 fraction and π^0 differential cross section in $\bar{\nu}$ data
- measurement of wrong-sign neutrino contamination (from QE muon angle, CC π^+ in $\bar{\nu}$ data, and muon lifetimes)

- Van Nguyen, Columbia U. Poster Session, Friday
  - NCπ^0 distributions
- Teppei Katori, Session 5, Thursday
  - $\bar{\nu}$ CCQE events
- Bonnie Fleming, Session 6, Friday
  - $\bar{\nu}$ (+ "wrong-sign) CCπ^+ events

Summary

- MiniBooNE has collected a large ν -scattering data set (~800k events) at E_ν~1GeV region, will enable increased understanding of ν interactions

- Many new results reported over next days, dont miss them!

- Ultimate goals included model-independent cross section extraction, necessary for development and testing of more accurate, sophisticated models of these processes.

- MiniBooNE antineutrino running has commenced.
First look at results here!

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