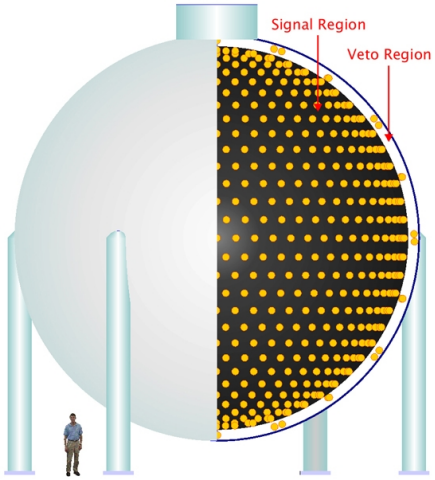
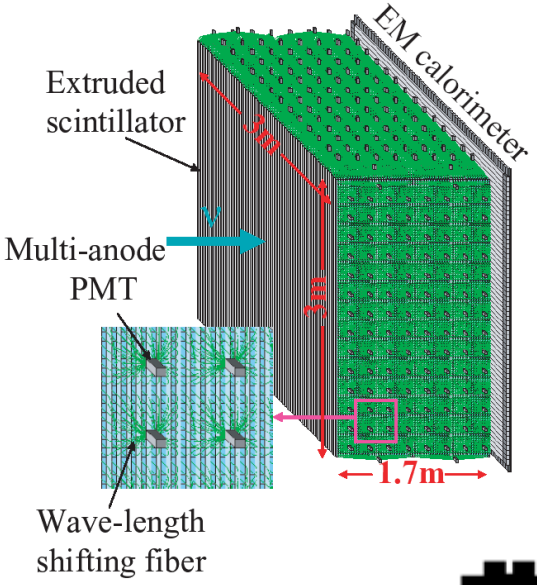
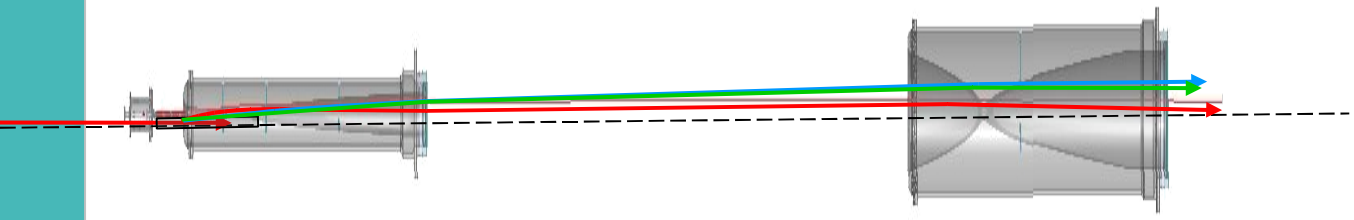
A Study of the NuMI Beam in the SciBooNE detector



Javier Duarte
MIT
April APS Meeting
Session D11
April 12, 2008

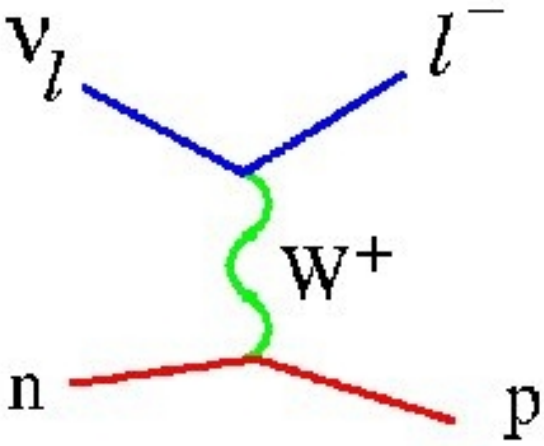




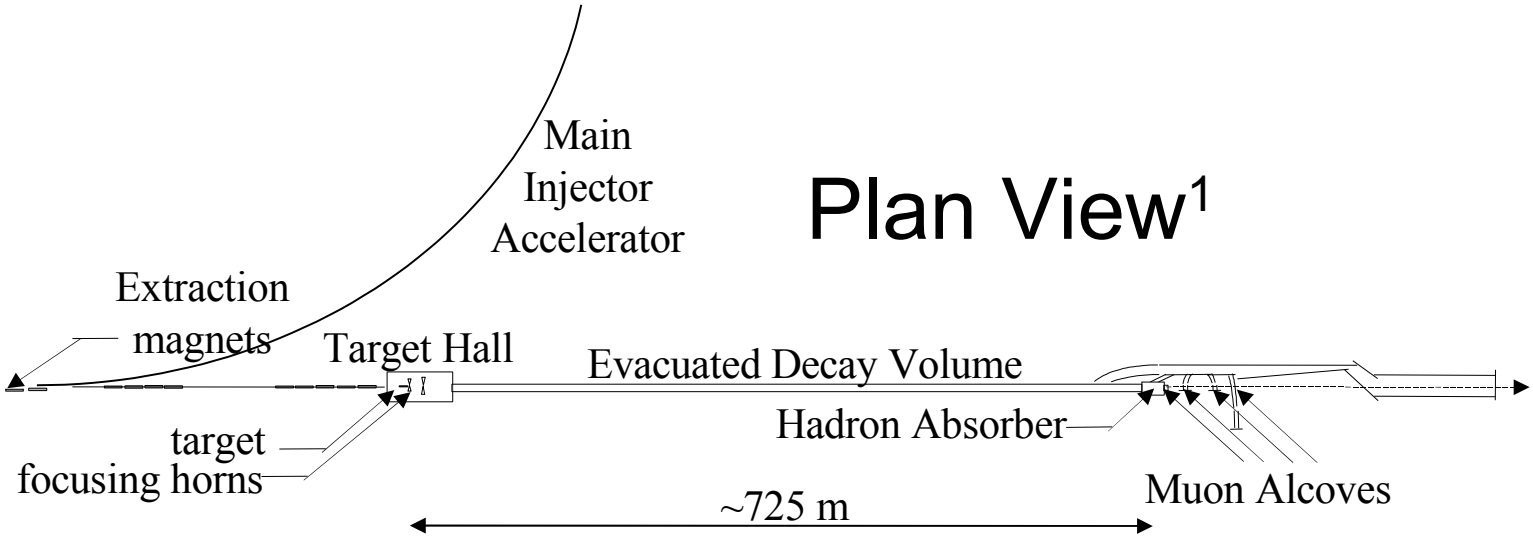
Outline

- Calculation of Event Rates

- Analysis of Event Rates



Neutrinos at the Main Injector Beam



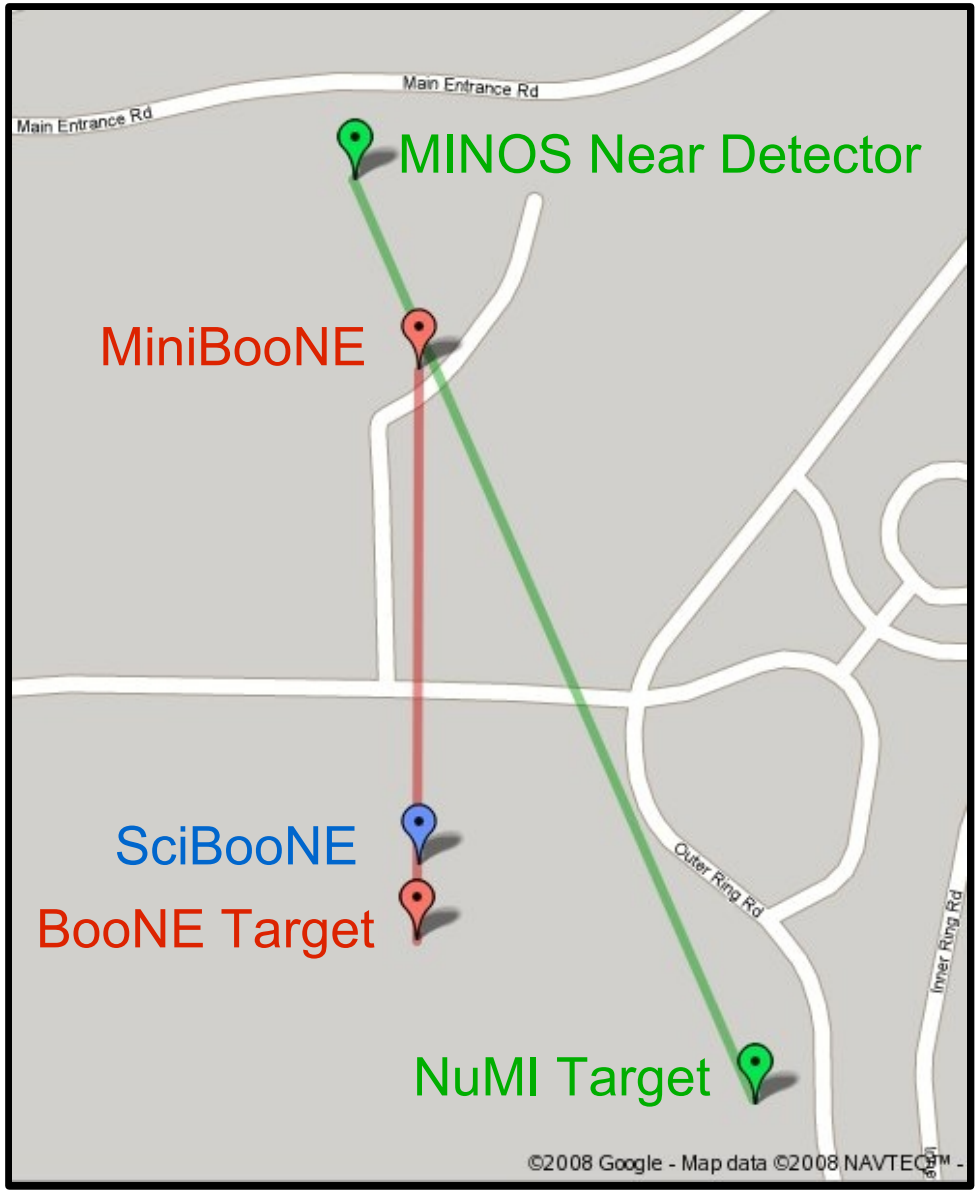
- 120 GeV proton beam from Main Injector at Fermilab
- Pions and kaons (π^+'s, K^+'s) are produced at the graphite target
- Two magnetic horns focus secondary particles of along the direction of MINOS
- Secondaries decay into neutrinos along the pipeline
- Hadron absorber and muon shield filter out other particles
- As of July 2007, NuMI had received ~ 3.29 x 10^{20} Protons on Target (P.O.T.)

1. S. Kopp 2007 NuInt presentation, "The NuMI facility"

Positions and Geometry

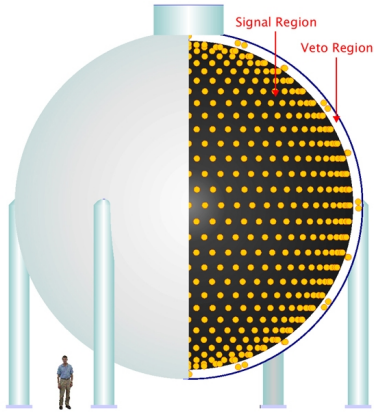
Off-axis angle
- to SciBooNE is 543 mrad
- to MiniBooNE is 111 mrad

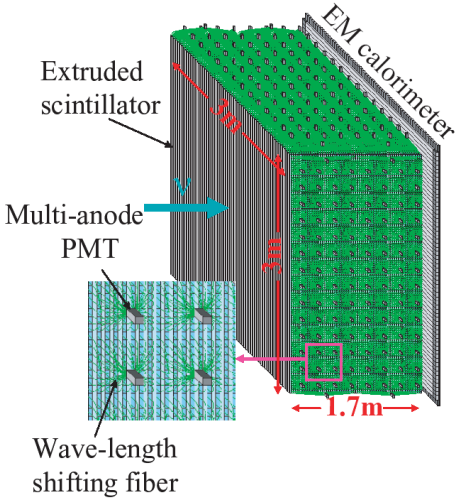
Distance from NuMI target
- to SciBooNE is 396 m
- to MiniBooNE is 749 m



Limitations of the Study

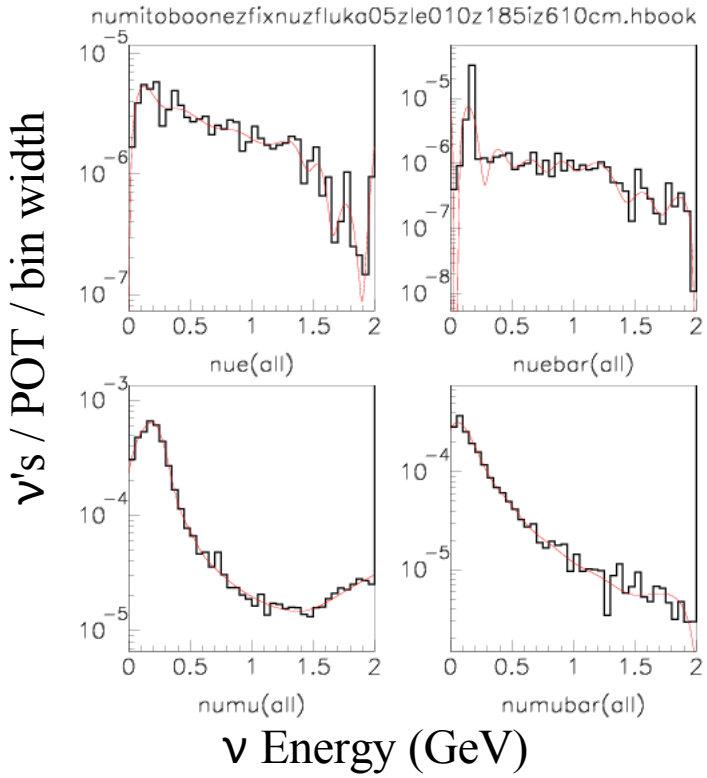
- Simplifications were used instead of SciBooNE Monte Carlo
- Detector efficiency is not included
- SciBooNE is approximated as a sphere (like MiniBooNE) rather than a rectangular prism
- Simulated tonnage is ~13 tons, whereas the actual fiducial tonnage is ~9 tons



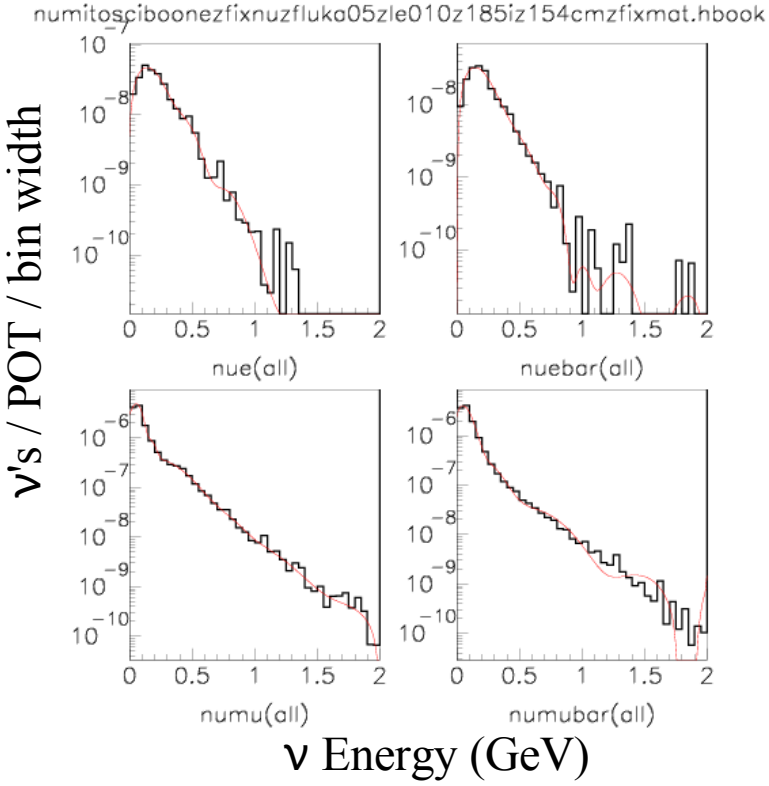


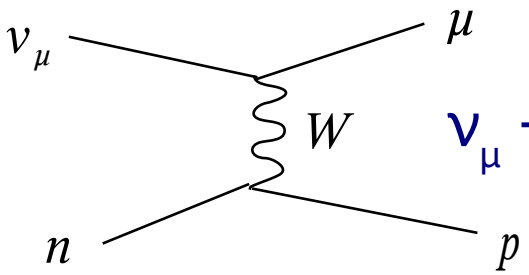
NuMI Beam Fluxes and Event Rates

MiniBooNE



SciBooNE





$\nu_\mu + n \longrightarrow \mu^- + p$

Charged Current Quasi-Elastic (CCQE) events expected: **328**

Event rates generated for 6×10^{20} POT

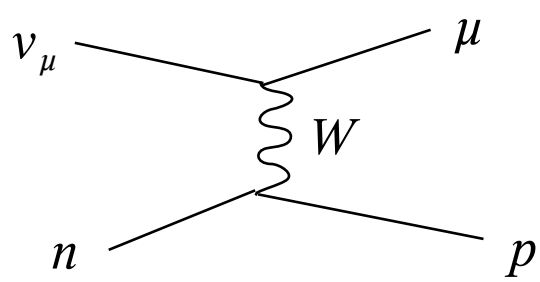
CCQE Events

All kinematics are determined from 2 observables: muon energy, E_μ and muon scattering angle, θ_μ

Energy of the neutrino E_ν and 4-momentum transfer Q^2 can be reconstructed by these 2 observables as follows:

$$E_\nu = \frac{2(M - E_B)E_\mu - (E_B^2 - 2ME_B + m_\mu^2 + \Delta M^2)}{2[(M - E_B) - E_\mu + p_\mu \cos\theta_\mu]}$$

$$Q^2 = -q^2 = -m_\mu^2 + 2E_\nu(E_\mu - p_\mu \cos\theta_\mu)$$



$\nu_\mu + n \longrightarrow \mu^- + p$

Nuclear Model

MiniBooNE made a measurement of muon neutrino quasi-elastic scattering on Carbon

Nuclear effects are important because the neutron in MiniBooNE CCQE scattering is bound in a Carbon atom

To calculate bound cross sections, a Fermi gas model is used:

$$(W_{\mu\nu})_{ab} = \int_{Elo}^{Ehi} f(\vec{k}, \vec{q}, w)\, T_{\mu\nu}\, dE \quad \text{(hadronic tensor)}$$

$$Ehi = \sqrt{(p_F^2 + M_n^2)}$$

$$Elo = \sqrt{(p_F^2 + M_p^2)} - w + E_B$$

3 parameters are especially important to control nuclear effect of Carbon:

P_F = 220 MeV : Fermi momentum

E_B = 34 MeV : binding energy

M_A = 1.03 GeV : axial mass

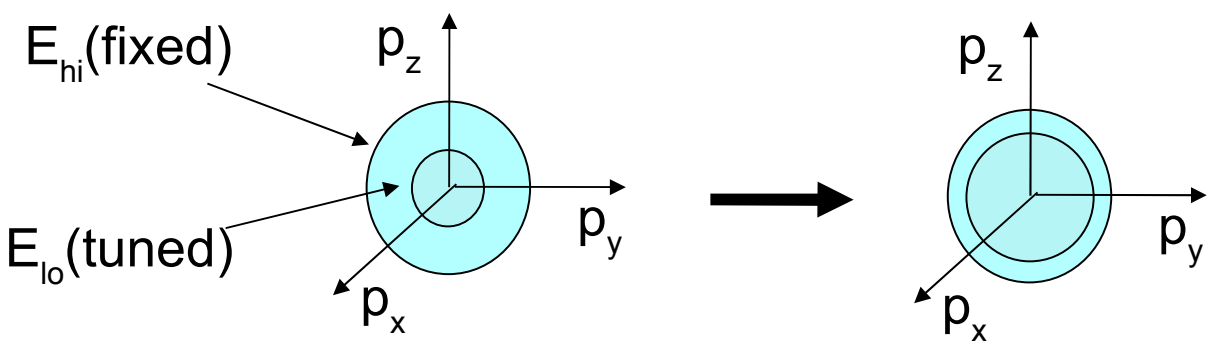
MiniBooNE Monte Carlo Tuning‡

The data-MC discrepancy is marked by: (1) data deficit at low Q^2 and (2) data excess at high Q^2

Pauli blocking parameter "kappa" : κ

$$\text{Elo} = \kappa\left(\sqrt{(p_F^2 + M^2)} - w + E_B\right)$$

To enhance the Pauli blocking at low Q^2, the MiniBooNE collaboration introduced a new parameter κ, a scale factor of the lower bound of nucleon sea that controls the size of nucleon phase space

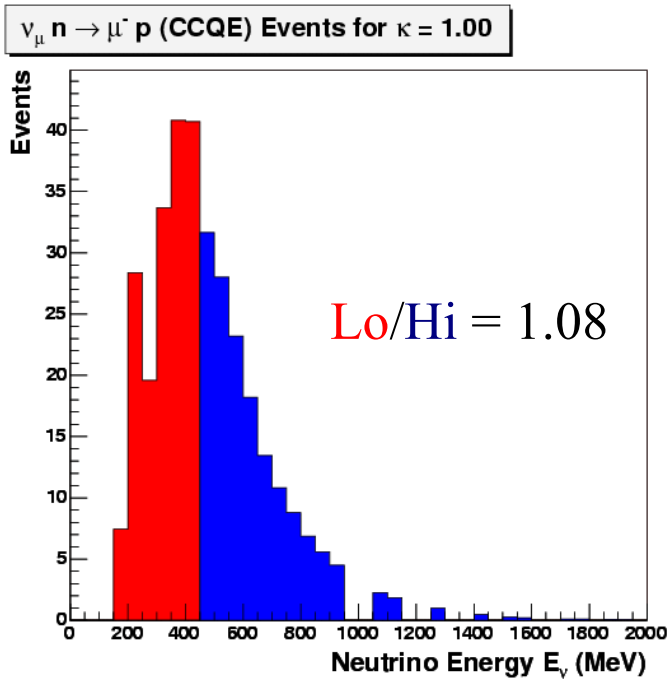


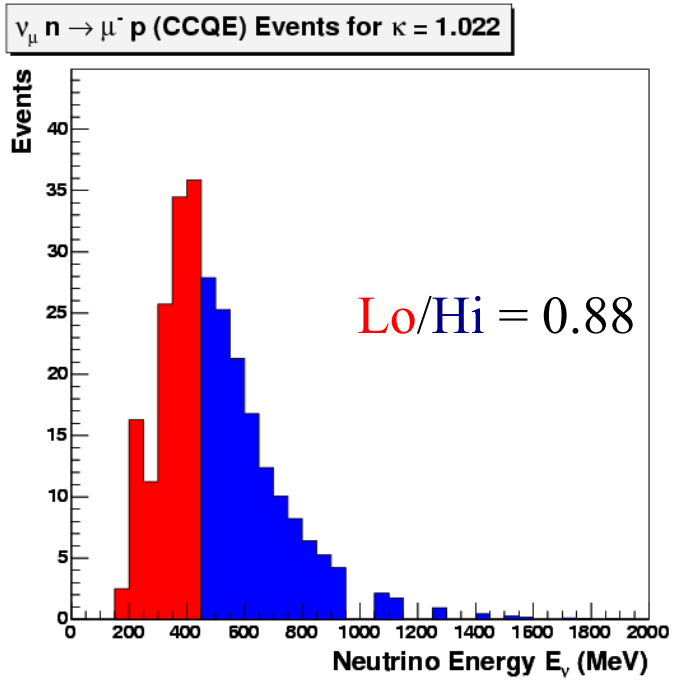
This modification gives significant effect only in the low Q^2 region

‡ A.A. Aguilar-Arevalo *et al.*, arXiv:0706.0926 (Phys. Rev. Lett. 100, 032301 (2008)).

Effect of κ and Lo-E to Hi-E Ratio

- Muon neutrino CCQE event rates for κ = 1.00: 328
  κ = 1.022: 270
- Ratio of low energy events to high energy events (with the cut-off at 450 MeV) may be measured instead of absolute events
- Relatively independent of absolute flux normaliztion
- 19% change in Lo/Hi ratio by changing κ parameter by 2.2%





Analysis of CCQE Event Rates

- Setting $\kappa = 1.022$ describes the smaller cross section observed in the MiniBooNE data at low Q^2
- Geometric Acceptance: only events in which μ is captured in SciBar (1.7 m x 3 m x 3 m)
  - This eliminates the "SciBar as a sphere" simplification
  - Fiducial tonnage corrected to ~9 tons
- Summary:

CCQE events	$\kappa = 1.00$	$\kappa = 1.022$
Sphere	328	270
Prism	123	87

  - Free off-axis NuMI beam in SciBooNE
  - 87 CCQE events expected for 6×10^{20} POT
  - Calculated how well MiniBooNE low energy effect could be detected
    - Given statistics, it would be tough measurement

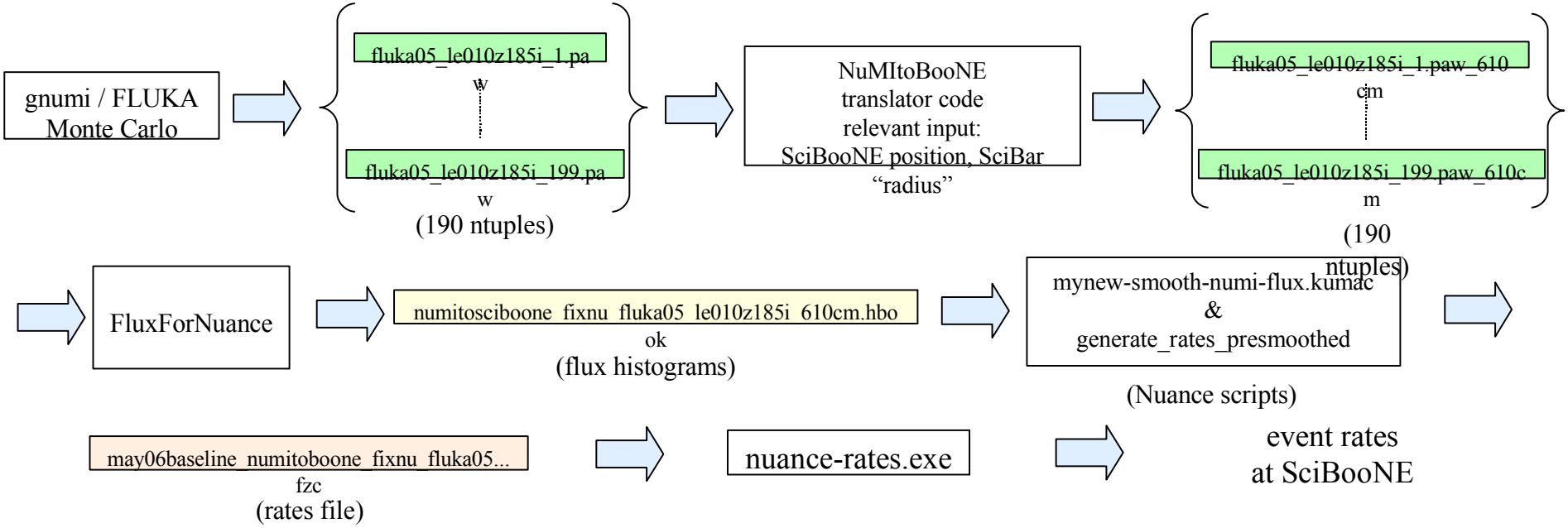
BACK UP

Processing Chain: From gnumi to nuance-rates

MINOS collaborators Zarko Pavlovic and Sacha Kopp provided 190 gnumi v.19 Monte Carlo output ntuple files

These 190 gnumi ntuples were converted by M. Wilking's translator code NuMItoBooNE with SciBar's position and size as input

FluxForNuance takes the translated ntuples and generates the flux histograms needed by nuance-rates to produce rates files



Event Rates for SciBooNE

Neutrino Type	Total Events	CC	NC
ν_μ	581	381	200
$\overline{\nu}_\mu$	143	85	57
ν_e	28	20	8
$\overline{\nu}_e$	7	5	2

NOTE: 'CC' includes quasi-elastic scattering, resonant 1 π production, multi-π, etc.

$\nu_\mu + n \longrightarrow \mu^- + p$ (CCQE) events expected: 328

These event rates were generated for 6 x 10^{20} P.O.T., the expected number for 2 years of running

The detector is assumed to be a sphere of radius of 154 cm, filled with mineral oil (CH_2)

With the density of mineral oil, $\rho_{CH2} = 0.855$ g/cm^2, the detector is assumed to have a tonnage of 13.08 tons.

MiniBooNE CCQE Fit Results‡

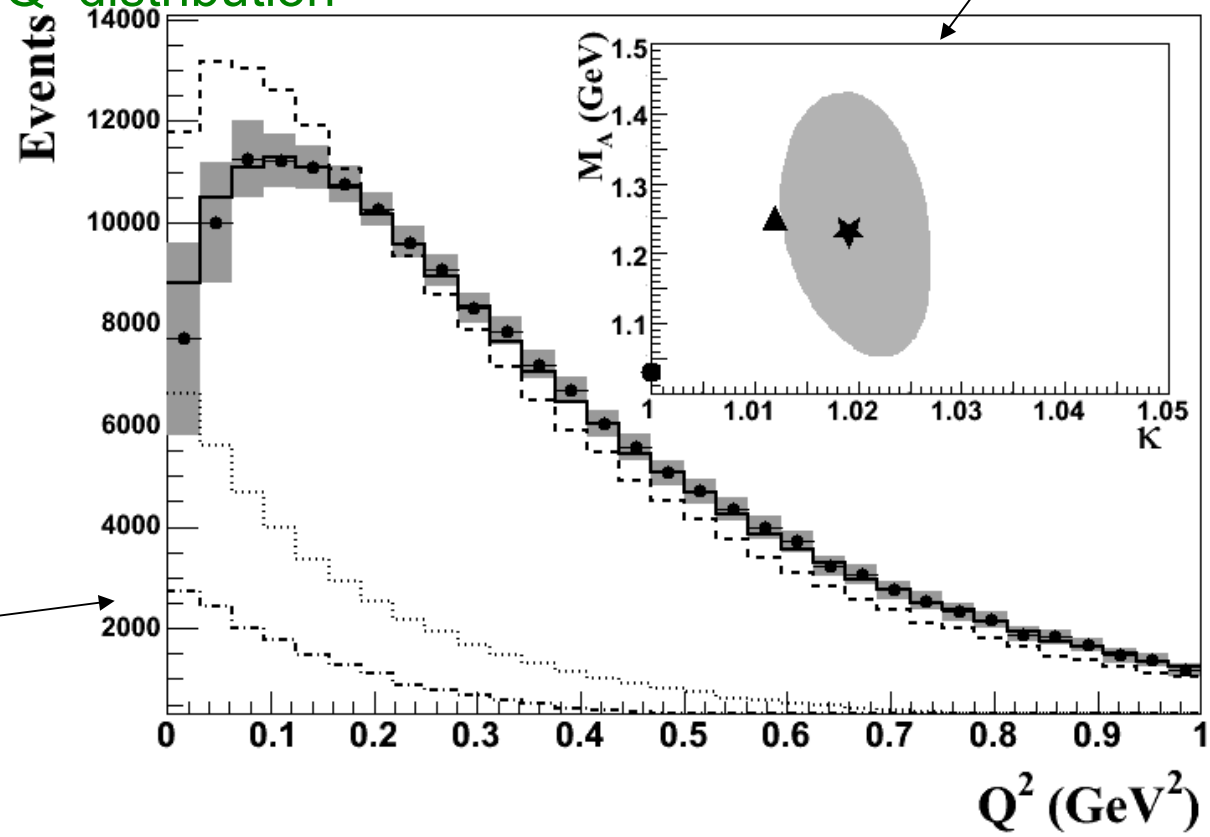
M_A - κ fit result

$M_A = 1.23 \pm 0.20$(stat+sys)

$\kappa = 1.019 \pm 0.011$(stat+sys)

circle: before fit
star: after fit with 1-sigma contour
triangle: bkgd shape uncertainty

Q^2 distribution



dots : data with error bar
dashed line : MC before fit
solid line : MC after fit
dotted line : background
dash-dotted :CCQE-like bkgd

‡ T. Katori 2007 NuInt Presentation, 'Charged Current Interaction measurements in MiniBooNE'