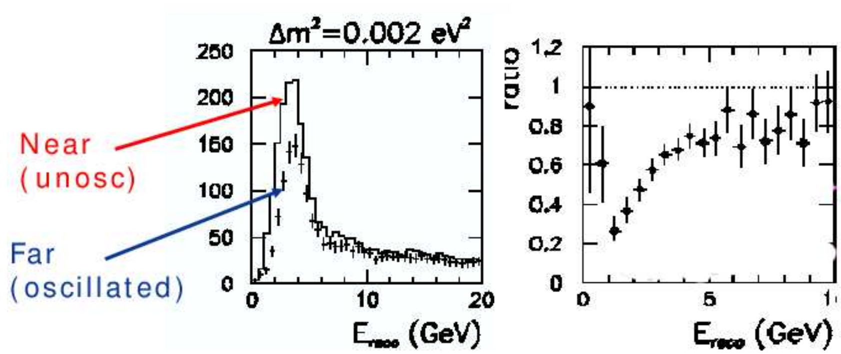
MINERνA *High-Statistics Neutrino Scattering using a Fine-grained Detector*

D. Naples
University of Pittsburgh

- Motivation
- MINERνA Physics Overview
- MINERνA and Oscillations
- MINERνA Detector and Status (H. Budd)

Motivation for MINERνA

▷*Oscillation Measurements*



- Measure the ratio of far/near
  - ▷ See the dip region of E$<$3 GeV
- Oscillation probability depends on E_ν
  ▷▷ Experiments measure: E_{VIS}
  - ▷ E_{VIS} depends on Flux, Cross section, and detector response.

Complications and Realities:

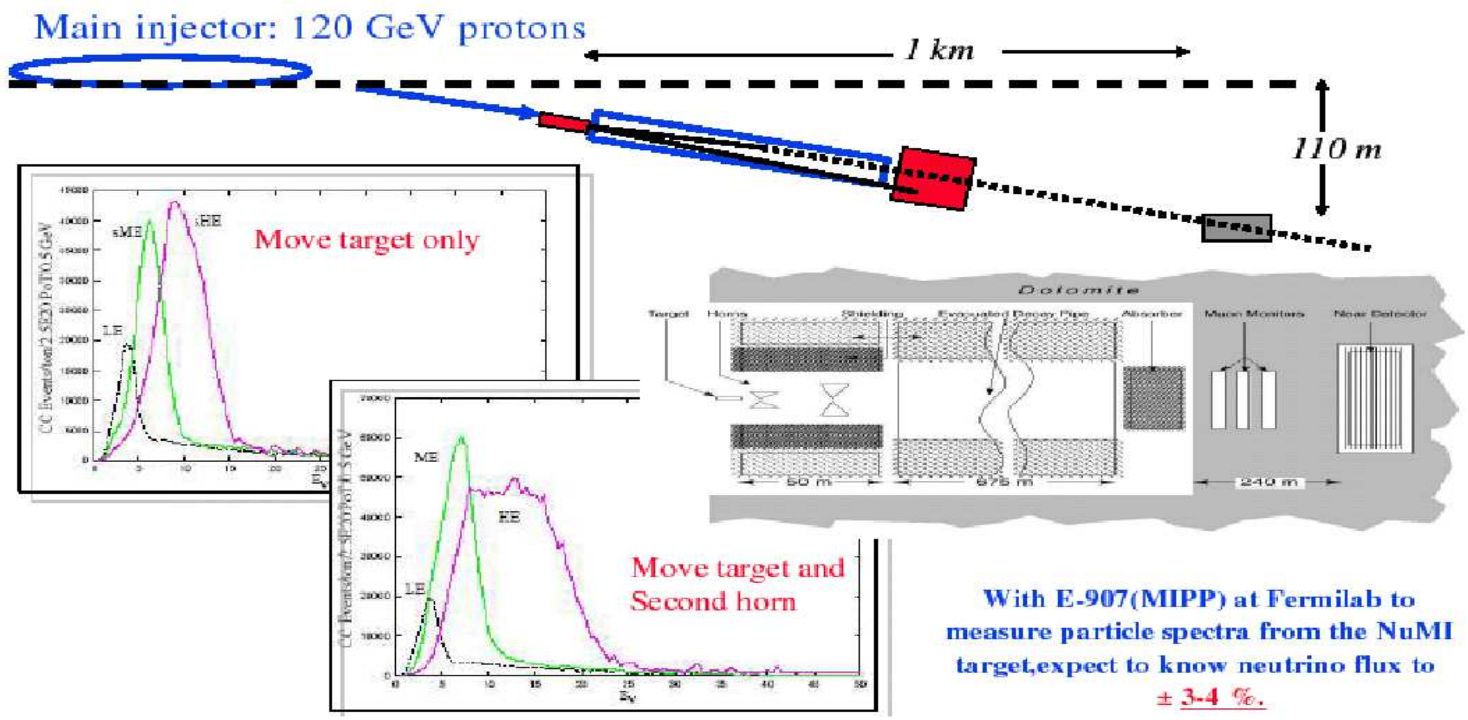
- Near/Far fluxes are different ▷ Cross Section does not cancel in the ratio.
- Low energy cross section not well understood.
  - ▷ Little data available (Bubble chambers circa 1980) with large stat. and sys. uncertainties.
  - ▷ Data up to A=27; Not applicable to heavy targets (Minos: Fe)
    - ▷ Must use untested models to incorporate nuclear effects.

▷ ***Intrinsic interest in low energy neutrino interaction phenomonology.***

MINERνA ▷ Put fine grained detector in high-rate neutrino beam (NuMI) *measure precisely low energy neutrino cross sections.*

MINERνA Experiment Features

- Fine-grained fully-active detector *allows exclusive final state measurements.* (Next talk ▷ H. Budd)
  - ▷ Good tracking capabilities and particle-ID.
- High-Rate NuMI beam - high statistical precision.



MINERνA Collaboration

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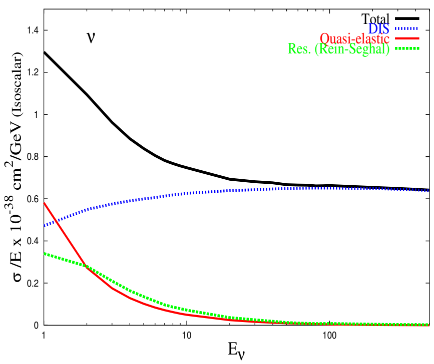
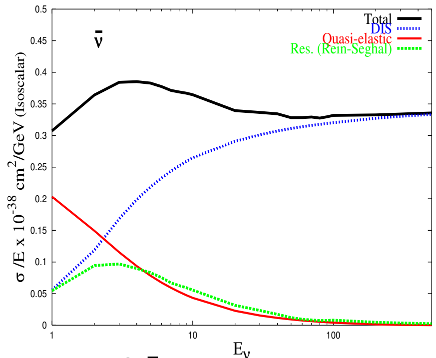
(HEP Nuclear Theory)

Overview of Low Energy Neutrino Scattering





Three contributions to the cross section.:

$\sigma_{\mathrm{TOT}} = \sigma_{\mathrm{QE}} + \sigma_{\mathrm{RES}} + \sigma_{\mathrm{DIS}}$

- **Quasi-elastic**
  $\nu(\overline{\nu})\, n(p) \longrightarrow \mu^-(\mu^+)\, p(n)$

$$\frac{d\sigma}{dQ^2} = \frac{M^2 G^2 \cos^2\theta_c}{8\pi E^2}\left[A(Q^2) \mp B(Q^2)\frac{(s-u)}{M^2} + C(Q^2)\frac{(s-u)^2}{M^4}\right]$$

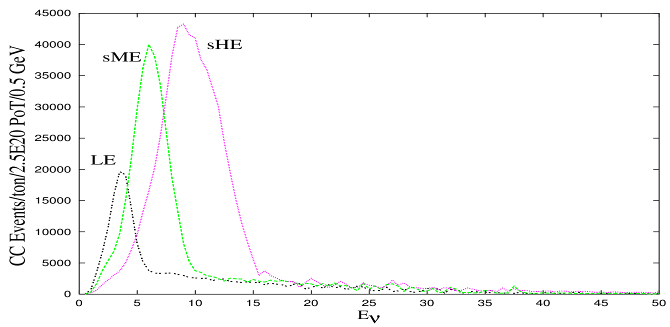
$A(Q^2)$, $B(Q^2)$, $C(Q^2)$ depend on nucleon form factors; s, u Mandelstam vars.

- **Resonance** $\nu N \longrightarrow \mu N^*$
  Inelastic, Low-multiplicity final states, $\nu_\mu p(n) \longrightarrow \mu^- \pi^+ p(n)$, $\nu_\mu n \longrightarrow \mu^- \pi^o p$
  Excited baryon resonances decays (Rein Seghal, Ann. Phys **133**, p.79 1981).

- **Deep Inelastic (DIS)** $\nu N \longrightarrow \mu X$
  $$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dx\,dy} = \frac{G_F^2 M E}{\pi}\left[\frac{y^2}{2} 2xF_1(x,Q^2) + (1-y)F_2(x,Q^2) \pm \left(y - \frac{y^2}{2}\right) xF_3(x,Q^2)\right].$$

MINERνA Event Rates

- High-rate well understood NuMI beams: LE, sME, sHE.
- Parastic running with Minos



Process	CC/ton	NC/ton
Elastic	103 K	42 K
Resonance	196 K	70 K
Transition	210 K	65 K
DIS	420 K	125 K
Coherent	8.3 K	4.2 K
Total (ν)	940 K	288 K

- Fiducial target 3-5tC, 1t Fe, 1t Pb
- 4 year run 9×10^{20} PoT.

Summary of MINERνA physics topics.

- Quasi-elastic νN scattering
- Resonance scattering
- Coherent Pion Production
- DIS Low Q^2
- Nuclear Effects in νN

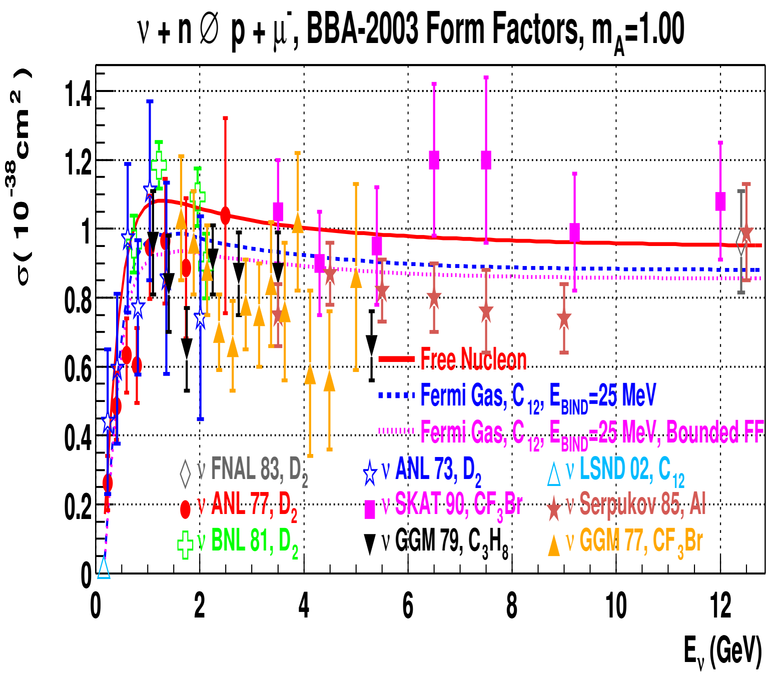
Quasi-Elastic Scattering

$\nu\ n \rightarrow \mu^-\ p$

- ▷ Dominates E_ν <1 GeV.
- Low Q^2: 1 track (μ) + low activity at vertex
  - ▷ Requires fine granularity at vertex

.

- High Q^2 2 tracks, one μ + Id proton track
  - ▷ Fine granularity: dE/dx measurement for proton Id.
- Current uncertainties 20%

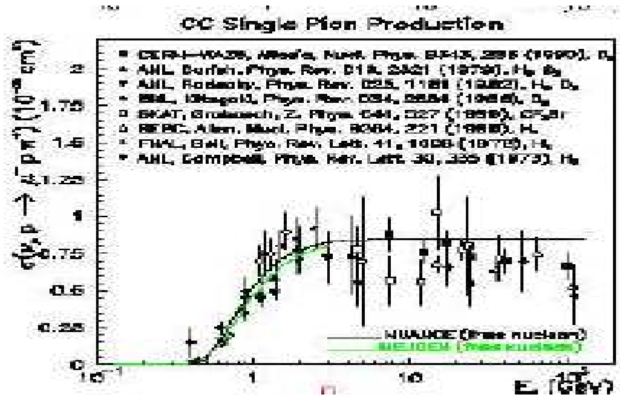


MINERνA will improve by $\sim 4\times$ (details: see next talk)

- Miniboone and K2K are also adding new information.
- MINERνA : Higher energy and Q^2.
  - ▷ Can see proton track.

Resonance Production

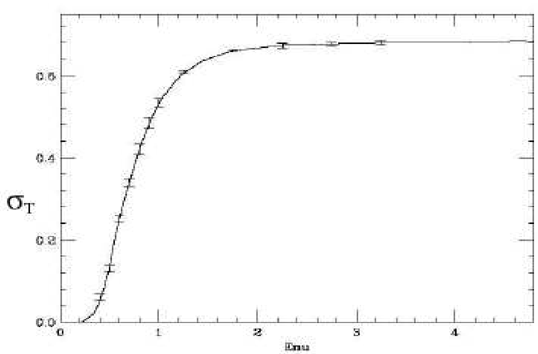
- Comparable to QE at $\sim$ 1 GeV.
- Inelastic, low-multiplicity final states.
  $\nu_\mu p \rightarrow \mu^- \Delta^{++} \rightarrow \mu^- p\pi^+$
- Need ability to reconstruct exclusive final states.
  - ▷ Requires good single-track reconstruction
  - ▷ *for both charged and neutral pions.*
- MINERνA sample: 1M events , 450K 1π.
  Uncertainty reduced 40% $\rightarrow$ 5-10%

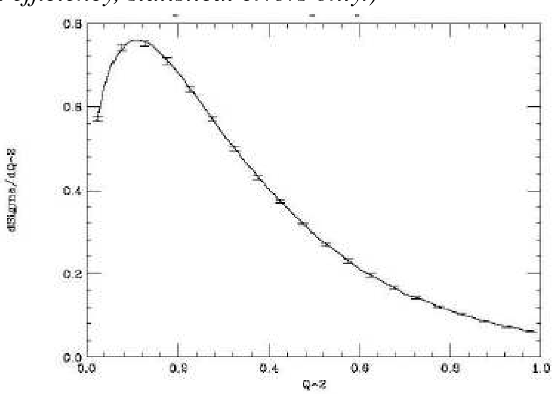


G. Zeller NuInt04

Δ^{++} Cross section and $\frac{d\sigma}{dQ^2}$

(MINERνA sensitivity: assumes 50% detection efficiency, statistical errors only.)





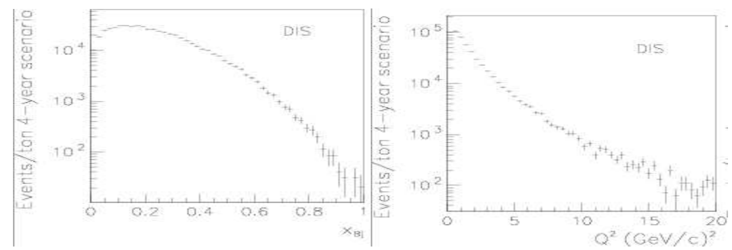
Deep Inelastic Scattering

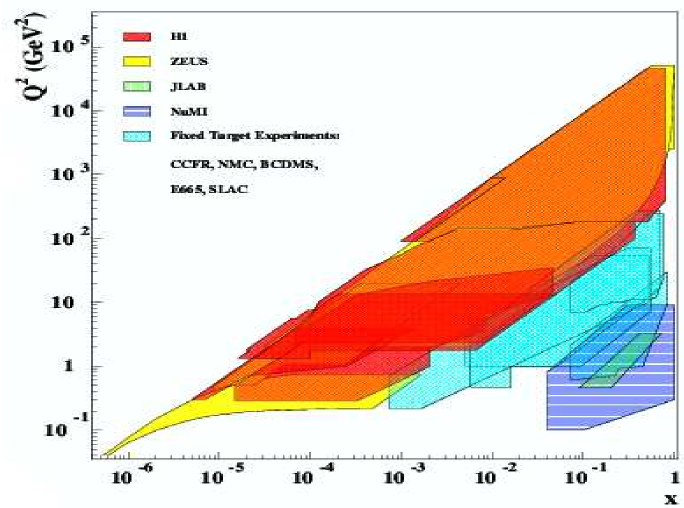
$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dx\,dy} = \frac{G_F^2 ME}{\pi}\left[\frac{y^2}{2}2xF_1(x,Q^2) + (1-y)F_2(x,Q^2) \pm \left(y - \frac{y^2}{2}\right)xF_3(x,Q^2)\right].$$

- Largest MINERνA data sample: 1.2M.
- Investigate transition region: low multiplicity final states DIS/Resonance.
- Extract Structure Functions from fits to y dependence of differential cross section.
- High-x Low Q^2.
  - ▷ New kinematic region for νN Structure Functions.
- $\overline{\nu}$ running: reverse horn currents.

	CC $\overline{\nu}_\mu$	CC ν_μ
LErev	26 K	34 K
MErev	56 K	10 K
HErev	75 K	13 K

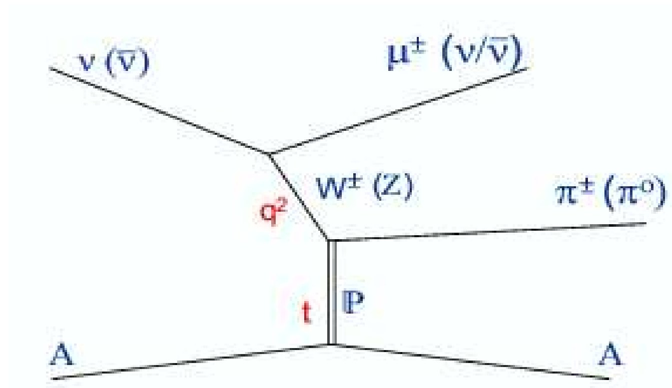
CC Events/10^{20} PoT/ton





Coherent Pion Production

- CC: $\nu A \longrightarrow \mu^- \pi^+ A$
  - ▷ Two charged tracks: μ^-, forward π^+, no vertex activity.
  - ▷ Small $t = (q - p_\pi)^2$
- NC: $\nu A \longrightarrow \nu \pi^o A$
- *Important background for ν_e appearance measurements.*
  - ▷ Single forward π^o



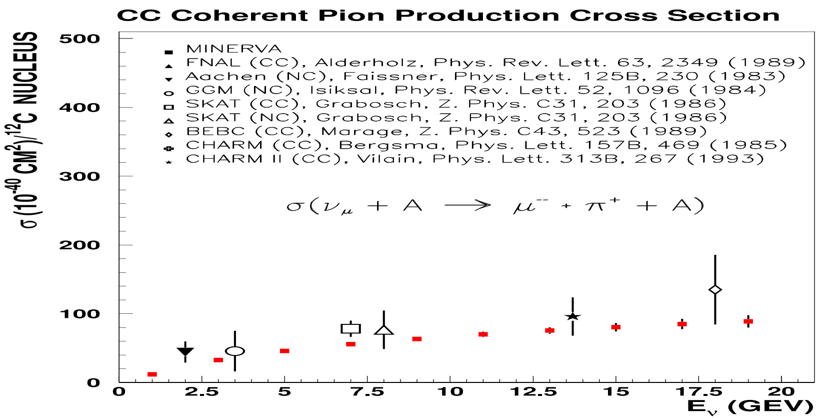
Expt	CC/NC	E	<A>	Signal
Aachen-Padova	NC	2	27	360
Gargamelle	NC	2	30	101
CHARM	NC	20-30	20	715
CHARMII	NC	20-30	20	1379
BEBC	CC	5-100	20	158
SKAT	CC/(NC)	3.0 - 20.	30	71(14)
FNAL 15'	NC	2.0-100.	20	28
FNAL E180	CC	10.-100.	20	61
FNAL E632	CC	10.-100.	20	52
MINERvA	**CC**	**2.0 - 10.(**	**12**	**5000**

MINERνA NC 3200

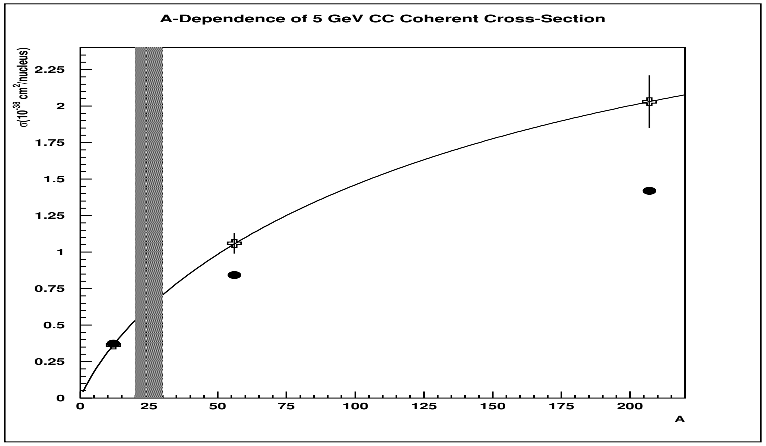
- High-statistics samples for both CC and NC processes
- Requires good charged-π and π^o tracking resolution and reconstruction efficiency.

Coherent Pion Production (Cont'd)

- CC-Efficiency: 30-40%
- Background rejection 1000:1
- NC-Efficiency: $\sim$40%

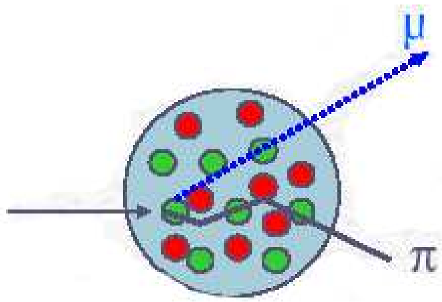


- First measurement of A-dependence : *wide A range.*
  - ▷ Distinguish between models.

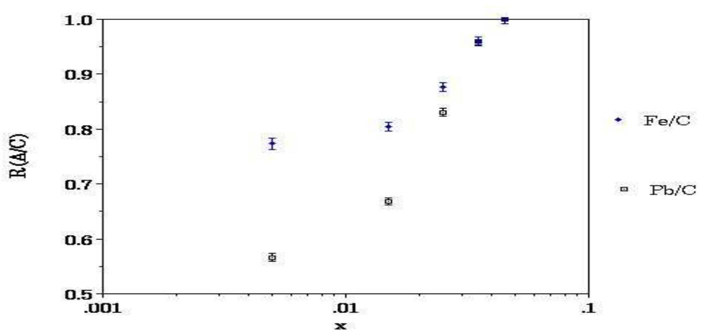


Nuclear Effects

- Final State interactions
  - ▷ Intranuclear rescattering
    - ⋆ Energy loss and/or absorption.
    - ⋆ Change in direction.



- Modification of pdfs in nuclear medium.
  - ▷ Measured only in charged-lepton scattering.
  - ▷ Shadowing region $(x < 0.1)$: expect difference due to axial-vector current.
  - ▷ High-x region $(0.2 < x < 0.7)$, EMC mechanism not fully understood.



prediction from S. A. Kulagin, [arXiv:hep-ph/9812532] w/MINERνA statistical errors.

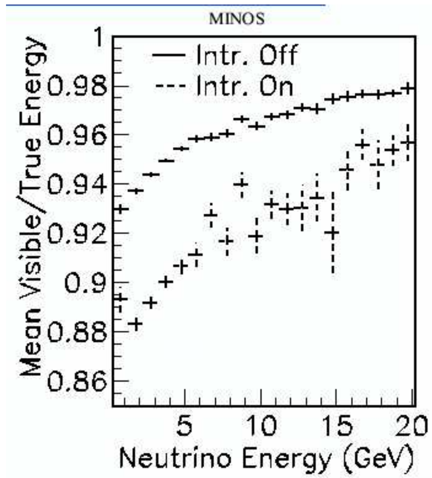
▷ Minerva can perform first measurement with high-A and high-statistics.

- ▷ Nuclear Targets Carbon, Fe and Pb.

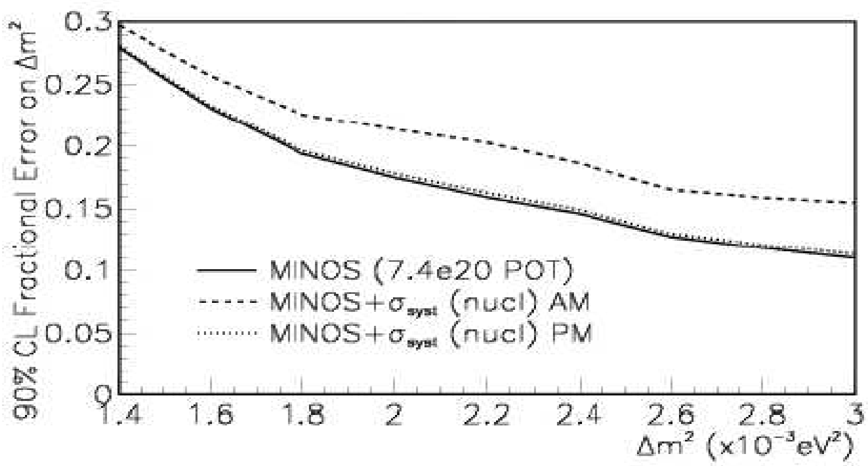
MINERνA Effect on Oscillation Measurements

Case Study I: MINOS

- Minos Iron calorimeter: Modeling of nuclear effects among the largest systematics.
- Reconstruct E_ν from $E_{\rm VIS}$
  - ▷ Intranuclear rescattering: Energy loss and/or absorption of outgoing particles.
  - ▷ *Changes measured visible energy spectrum.*
    - ⋆ Translates to shift in Far/Near 'dip' location⇒ Δm^2



- MINERνA can measure ratio of visible energy distribution on different nuclear targets Fe, Pb, C.
- Constrain pion absorption,intranuclear rescattering models.



MINERνA Effect on Oscillation Measurements (Cont'd)

Case Study II: Noνa

- Main Issue: ▷ Backgrounds to ν_e signal.
  - ▷ NC: energetic π^o's in shower
  - ▷ ν_μ-CC: high-y, + π^o in shower.
  - ▷ Beam ν_e

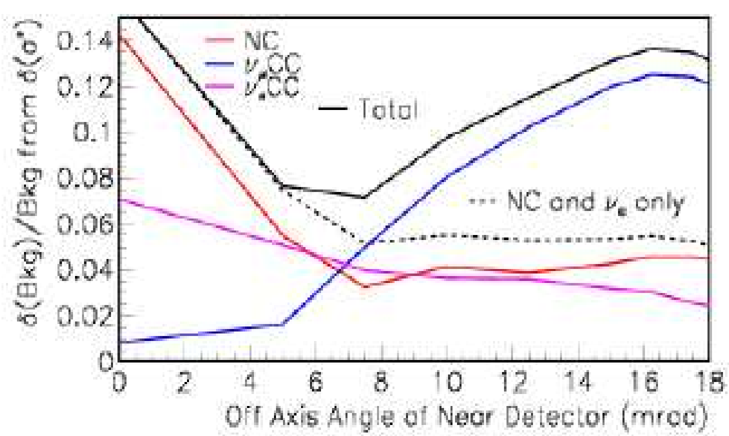
▷▷Uncertainties in background predictions dominate Noνa's ν_e appearance sensitivity.

Estimated Cross section uncertainties

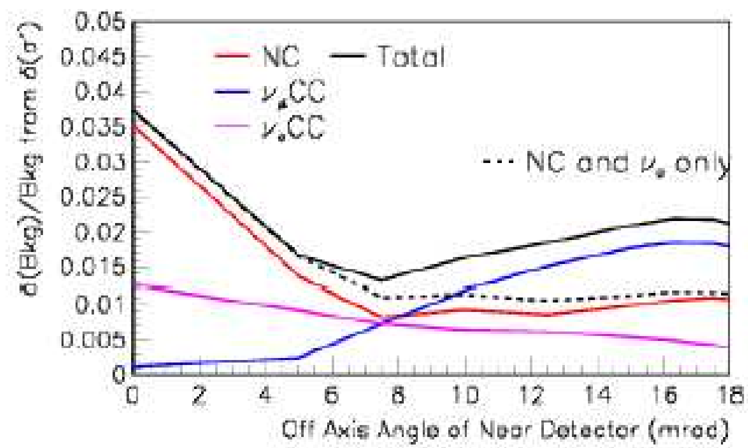
Process	Current	After MINERνA
QE	20%	5%
Res	40%	5/10%(CC/NC)
DIS	20%	5%
Coh	100%	20%

Fractional uncertainty in background predictions:

Before



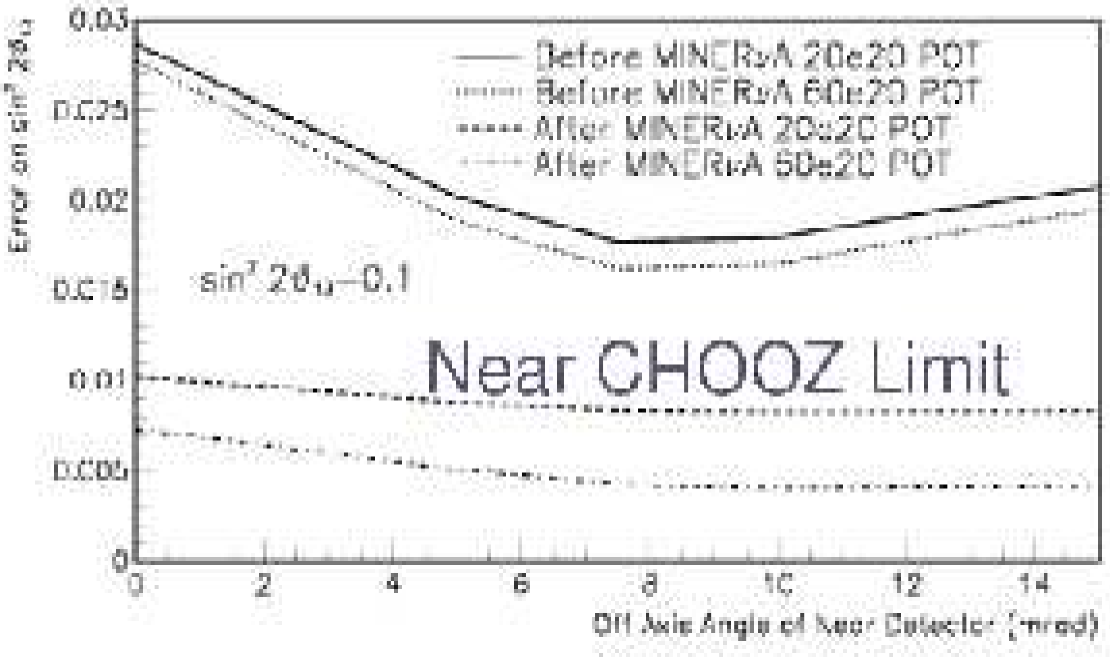
After



Background uncertainty decreases by factor of 4.

MINERνA Effect on Oscillation Measurements (Cont'd)

Effect of reducing cross section uncertainties on Noνa sensitivity:



Without MINERνA :

- Even at "minimum" systematic error $\rightarrow$ systematics are comparable to statistical error in Noνa.
- Without MINERνA : *Noνa could be systematics dominated.*

Summary

- MINERνA will precisely measure neutrino interactions with a fine-grained, high-resolution, ν detector using the high flux NuMI beam.
  - Improve knowledge of
    - Neutrino cross sections at low energy, Low Q^2.
    - A-Dependence in neutrino interactions (three targets C, Fe, Pb)
  - This will be important to minimize systematics errors in oscillation experiments.

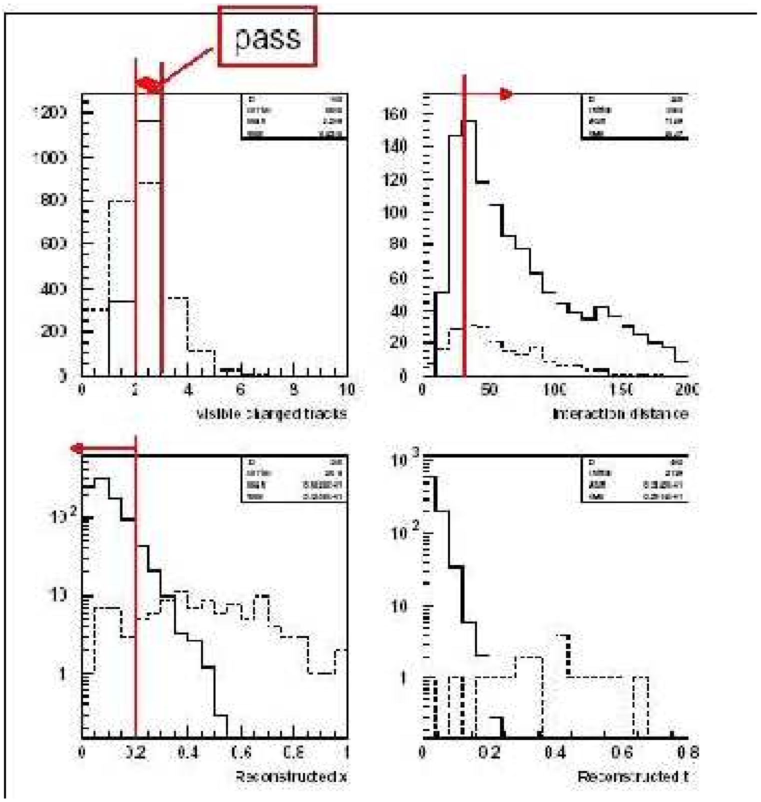
Stay tuned for H.Budd's talk : Detector and MINERνA Status.

MINERνA Run Scenario

Scenario for PoT per year ($\times 10^{20}$)							
year	total PoT	LE	sME	sHE	LErev	MErev	HErev
2006	3.0	3.0	0.0	0.0	0.0	0.0	0.0
2007	4.0	3.0	0.7	0.3	0.0	0.0	0.0
2008	4.0	0.0	0.0	0.0	2.5	1.0	0.5
2009	4.0	1.0	0.5	0.5	0.5	0.5	1.0
Total	15.0	7.0	1.2	0.8	3.0	1.5	1.5

Table 1: Hypothetical proton luminosity scenario for a four-year run.

CC Coherent Pion Analysis



	Signal	Background
	5000	10000
2 Visible Charged Tracks	3856	3693
π/n <500 MeV	3124	3360
Track separation	2420	500
x<0.2	2223	100
t<0.2	2223	19
p_{π}> 600 MeV	1721	12
Fudge factor factor	(0.65)	-
Normalized	5004	4400

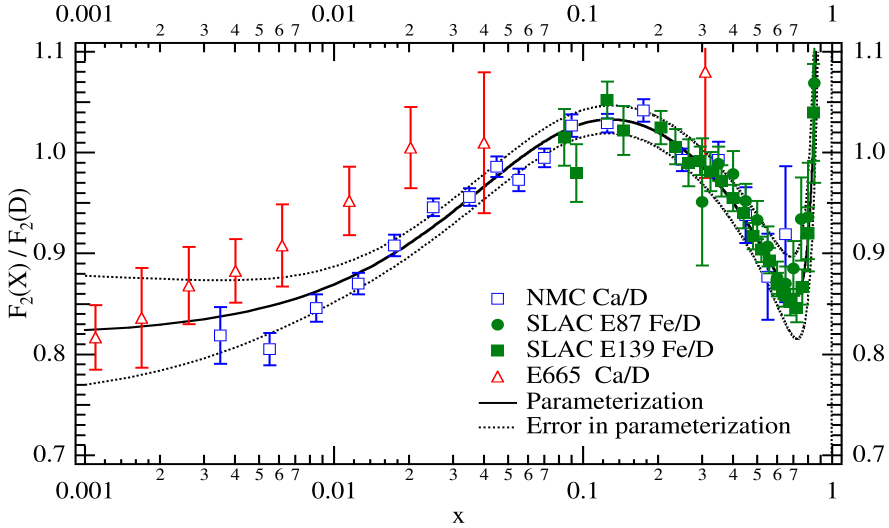
Signal/Noise CC $5004/4400$

Signal/Noise NC ∼2

⋆ 'fudge factor' : unrealistic tracking.

Nuclear Effects

Nuclear effects in charged-lepton scattering.

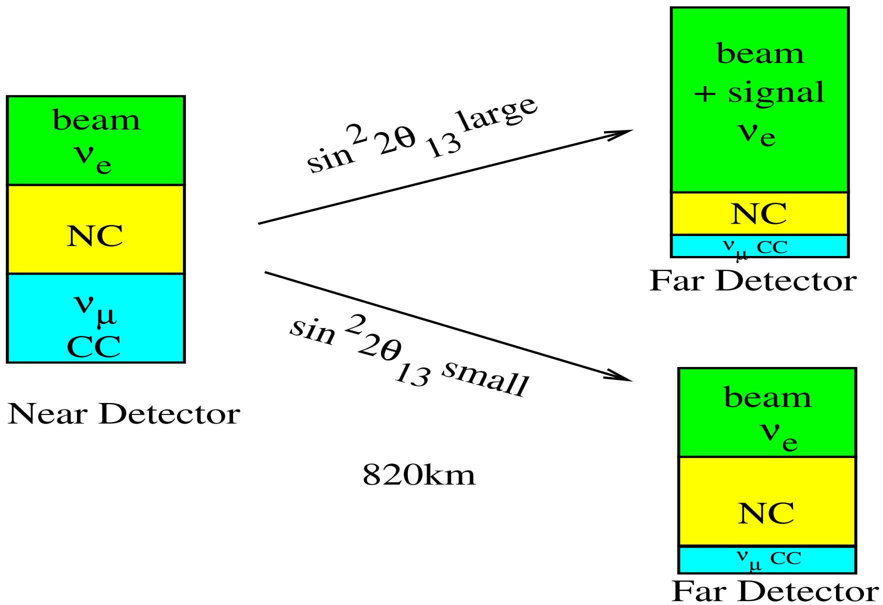


Cross Sections Uncertainties by Background & Process

Process	Statistics	QE	RES	COH	DIS
$\delta\sigma/\sigma$		20%	40%	100%	20%
Signal ν_e	175 ($\sin^2 2\theta_{13} = 0.1$)	55%	35%	n/I	10%
NC	15.4	0	50%	20%	30%
$\nu_\mu CC$	3.6	0	65%	n/I	35%
Beamν_e	19.1	50%	40%	n/I	10%

List of the signal and background processes than can contribute events in the NOνa far detector, for a 50kton detector located 12km from the NuMI axis, 820km from Fermilab, assuming a Δm^2 of $2.5 \times 10^{-3} eV^2$. Also given are the cross section uncertainties on those processes before MINERνA runs.

Noνa Oscillation Scenarios



- Either case: ν_μ-CC very different Near vs Far. $\Rightarrow$ Cross section systematics don't cancel!
- Near detector measures *sum* of backgrounds, not each component.
- Without MINERνA : even at "minimum" systematic error $\longrightarrow$ systematics are comparable to statistical error.