Near Detector Physics Working Group

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MINOS Collaboration Meeting

January 2004

Cambridge

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Jan 2004

Outline

- Idiot's guide to ND Physics
- Neutrino Energy Calibration
- Mock Data Challenge Goals
- Non-Oscillation Physics: Coherent Production
- NEUGEN Readiness
- MINOS Neutrino Interaction Experts Group?

Our Job in a Nutshell

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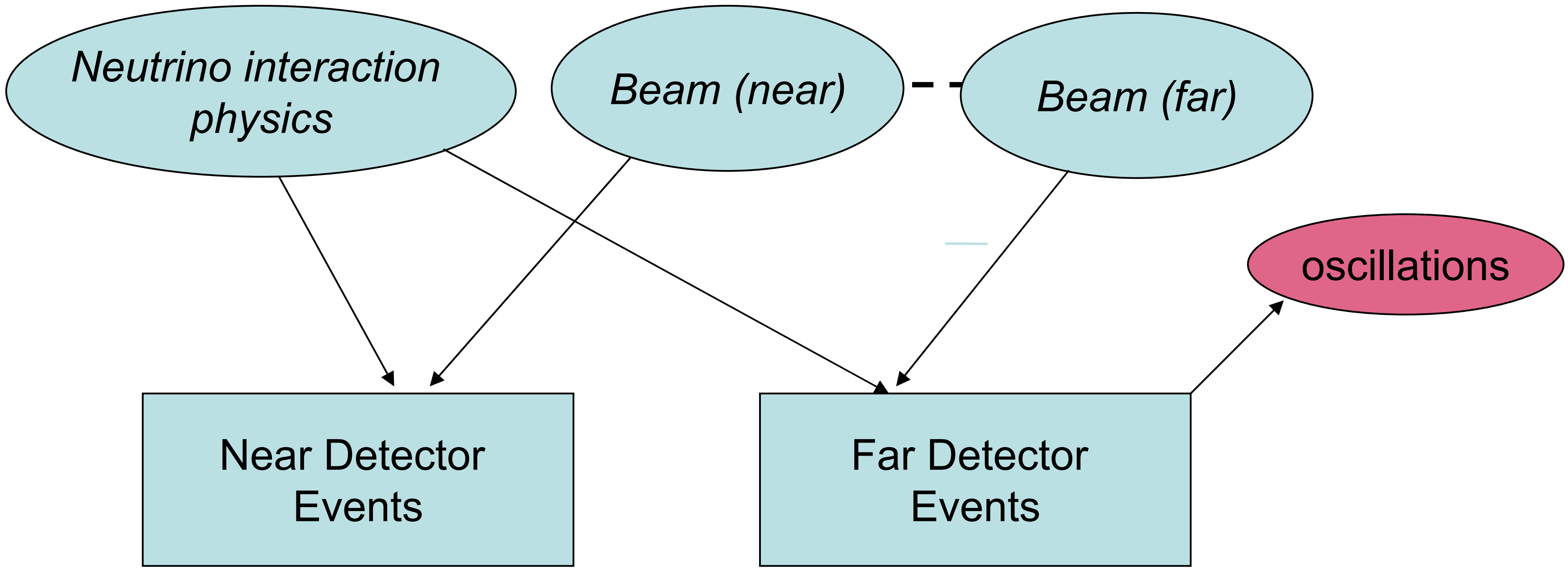

The job of the near detector physics analyses is to use near detector events and our knowledge of the detector responses near and far to predict what we should be measuring in the far detector with no oscillations.

Can think of the task as constraining uncertainties in the neutrino interaction and beam models (and evaluating how the residual uncertainties affect predictions).

Goal is to reduce as much as possible model dependence in extracting signal.

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Mock Data Challenge

- Get our hands dirty with “real” near detector data
- Provide feedback to the reconstruction / software groups
- Demonstrate that our analysis strategies makes sense
- Verify that we’re on the same page as the oscillation groups
- Is there anything we’re forgetting?
- Understand in more detail the interaction between reconstruction, calibration, and near/far physics comparisons.
- Explore degeneracies in the description of near detector data
- Will special runs (horns off, modified currents) be needed?
- An effort like this is the next logical step for our group.
- Will require significant effort over the next 6 months.

Mock Data Challenge

- We have been working with several assumptions
  - A goal of the collaboration will be to understand the near detector data as quickly as possible.
    - That we want to have our analysis strategies planned out before we get data (end 2004).
    - That we want our tools (generators, reconstruction) ready when we get first data (end 2004).
  - That our existing models will not be able to describe the near detector data.

If we are going to stick to these goals, a mock data challenge on a short timescale is “critical path”.

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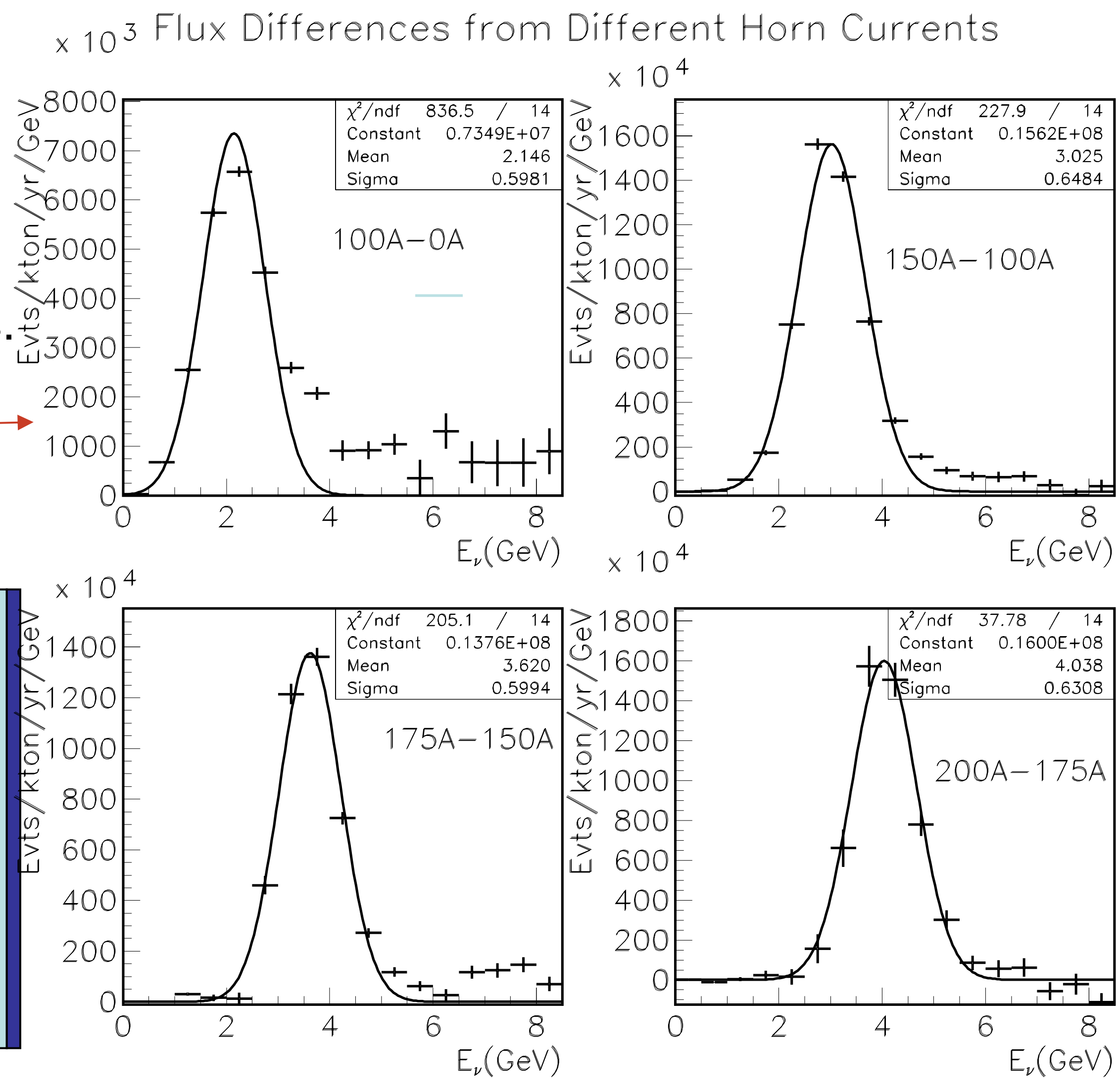
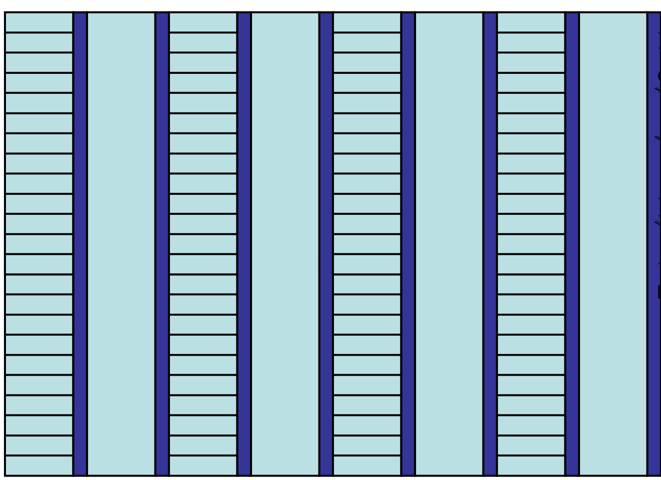
Mock Data Challenge

Required to evaluate the necessity of various options we have investigated over the past year which would require resources or specific run plans.

Pseudo-NBB



Fine grained near detector:



Neutrino Energy Calibration

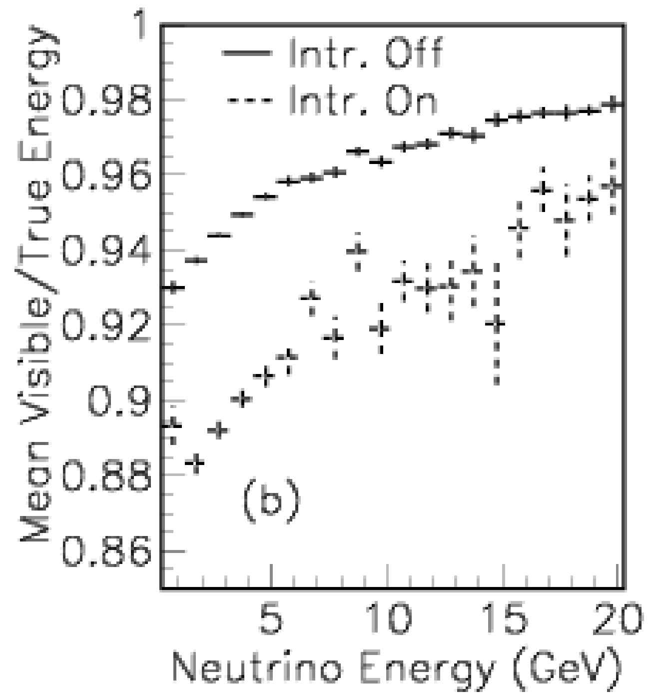
(D. Harris – NuMI 948)

One place where model dependencies inevitably occur is in the determination of the neutrino energy from the visible hadronic energy (MEU) in the detector.

Doesn't cancel in near/far comparisons as E_ν is coupled to Δm^2.

Visible energy is not the same as total energy for a number of reasons:

- π+ leave only KE, some get absorbed
- π^0's deposit all energy in calorimeter
- Nuclear binding energy
- Intranuclear scattering absorbs energy, affecting multiplicities and charge ratio



The models related to hadronization in the low invariant mass region and intranuclear scattering at these energies have substantial uncertainties.

It remains to be seen how well MINOS ND data can constrain these models.

ν Energy Calibration

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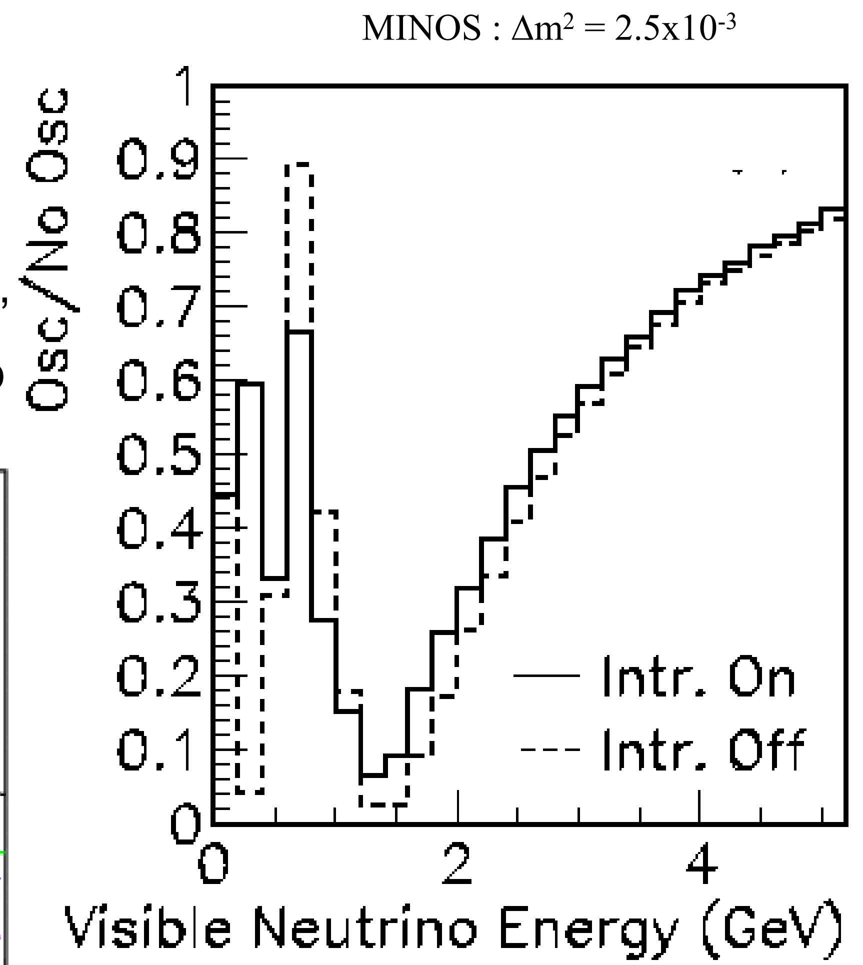
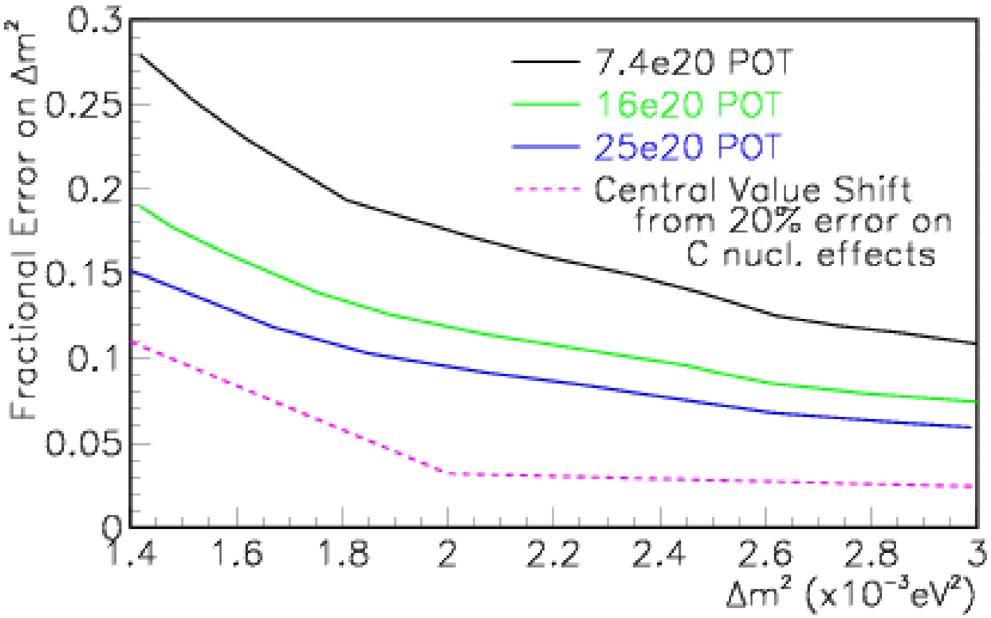
Change the “energy loss” by 20% of itself and examine the shift in Δm^2. Optimistic for MINOS alone.

K2K and miniBoone data aren’t much help
CLAS data?
Designer beam runs – NBB as “ν test beam”
Minerva measures multiplicties on C, Fe, Pb





NEUGEN Readiness

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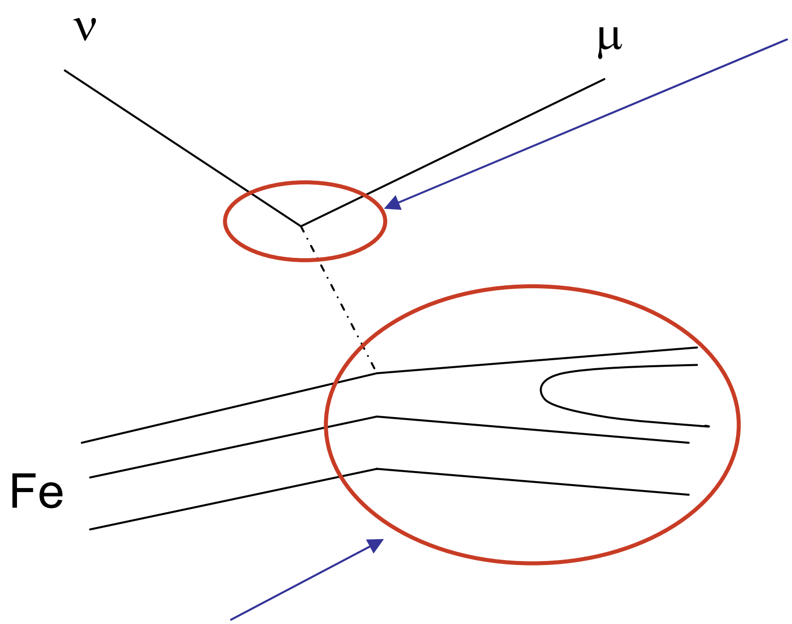

Lepton kinematics (inclusive predictions):

Free nucleons: QEL, RES, DIS scattering
Q: How well does the Rein-Seghal model describe the resonance region? What is the best method for combing DIS and resonance contributions for W<2 GeV?

Nucleus: Fermi motion, Pauli blocking, binding effects, EMC effect, shadowing. Spectral functions.

Hadronic System:
Free nucleons: hadronization scheme for low invariant mass DIS, validity of R-S resonance model.

Nucleus: intranuclear scattering of produced hadrons, consequent changes to multiplicites, charge ratios, visible energy.

NEUGEN Readiness

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The NuMI WBB exposes a large kinematic range, overlapping to a large degree JLAB and other earlier electron scattering experiments.

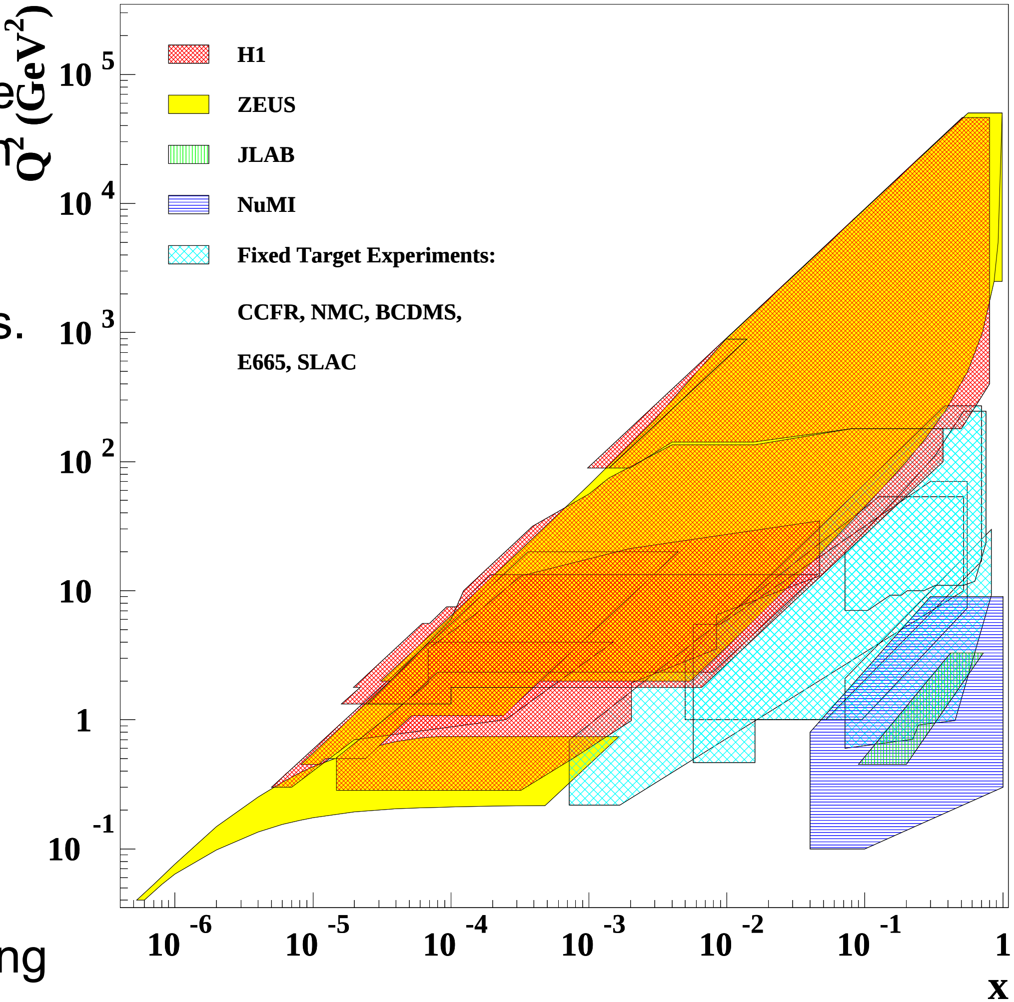
Mainly inclusive and coincidence expts.

Important areas that still need work:
Extension of intranuclear scattering model to NuMI energies.

Charm production.

Spectral Functions (almost done in collaboration with Omar Benhar).

Validating Rein-Seghal and Bodek-Yang models.



NEUGEN: miniBoone

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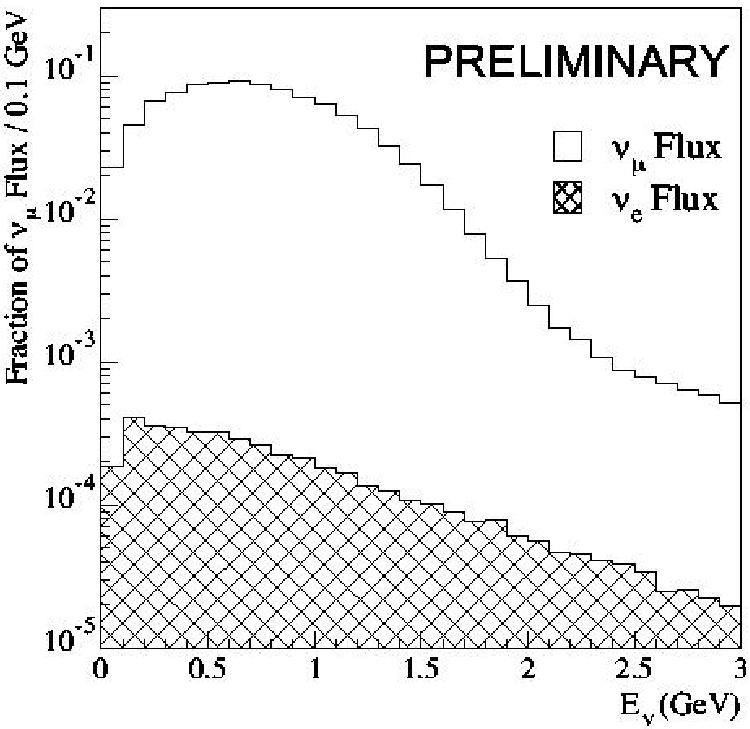
- The miniBoone Experiment has asked to use NEUGEN for comparisons with their data
- NUANCE is their official generator – NEUGEN/NUANCE comparisons come for free
- Files and code have been provided
- Comparisons within a few months
- Test low energy ν-C simulations – particularly NC backgrounds to ν_e appearance
- Excellent working relationship with the miniBoone cross section group.

Figures from H. Tanaka WIN03 Talk - All to be considered preliminary



Similar energy spectrum to off-axis

NEUGEN: miniBoone

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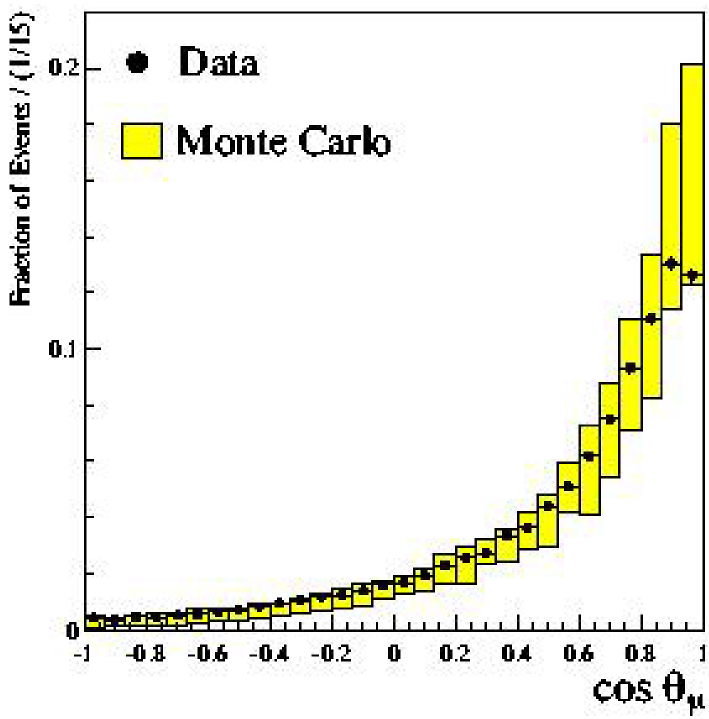
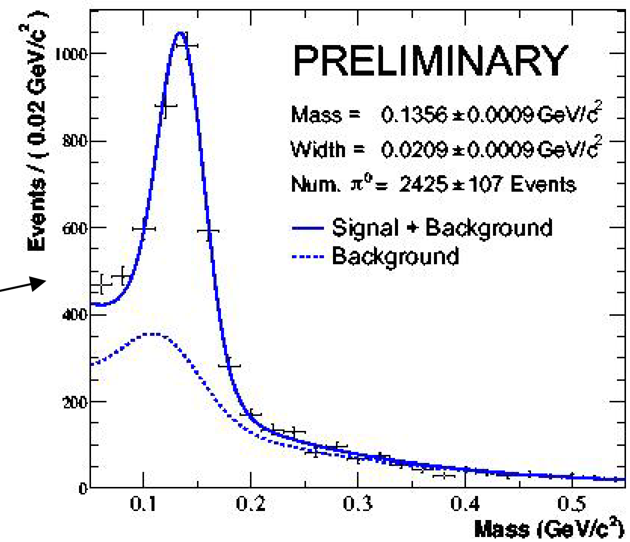
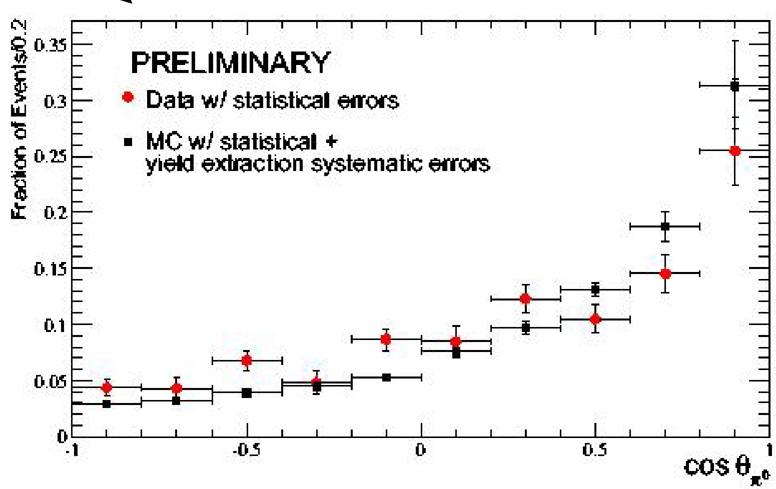


ν_μ CC interactions – quasielastic primarily

π^o





NEUGEN Readiness

- NEUGEN / NUANCE comparisons are underway
- NEUGEN / miniBoone comparisons as well
- Plans to do NEUGEN / ANL bubble chamber comparisons at Tufts
- Highly Desirable (volunteers – suggestions?)
  - NEUGEN / K2K comparisons
  - NEUGEN / BEBC bubble chamber comparisons
  - Satisfy QCD sum rules!

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NEUGEN Readiness

- The C++ frontier has been pushed to NEUGEN's doorstep.
- Making NEUGEN and NULOOK accessible from the offline framework.
- NEUGEN wrapper and appropriate analysis code.
  - e.g. Event reweighting for changes in model parameters.

Will be required in some form for the mock data challenge. Just ideas at this point (mainly Costas).

Non-Oscillation Physics: Coherent Pion Production

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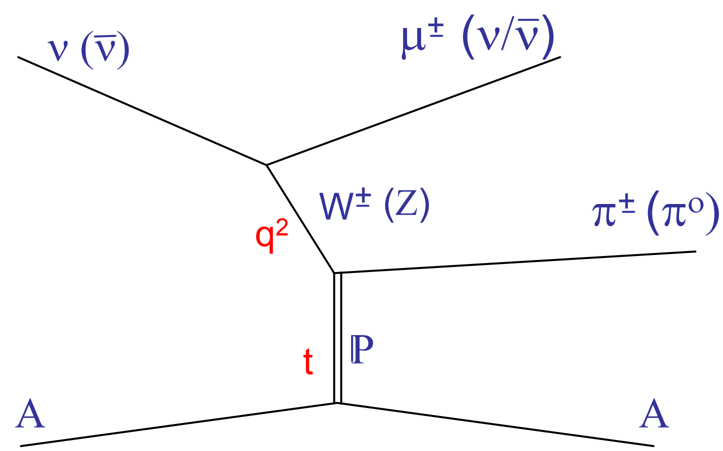
Coherence requires:
$t = (q - p_\pi)^2 < 1/R^2$
Where R is the size of the nucleus

$\nu A \rightarrow \nu \pi^+ \mu^-$
$\nu A \rightarrow \nu \pi^o \nu$



PCAC prediction starting from Adler's relation (q^2=0). Assumptions about the q^2 dependence, and the treatment of the pion-nucleus scattering. Other calculations based on VMD treatment. Characterized by a small energy transfer to the nucleus, forward going π.

From the Rein-Seghal model:

1. Purely axial
2. $d\sigma(CC) = 2\, d\sigma(NC)$
3. $\sigma(A) \sim A^{1/3}$

Piketty and Stodolosky, Nucl. Phys B15 (1970) 571.
Rein and Seghal, Nucl. Phys **B223** (1983) 29.
Belkov and Kopeliovich, Sovt. J Nucl Phys 46 (1987) 499.
Paschos and Kartavtsev (2003), hep-ph/0309148.

Data to date has not been precise enough to discriminate between several very different models…

Non-Oscillation Physics: Coherent Pion Production

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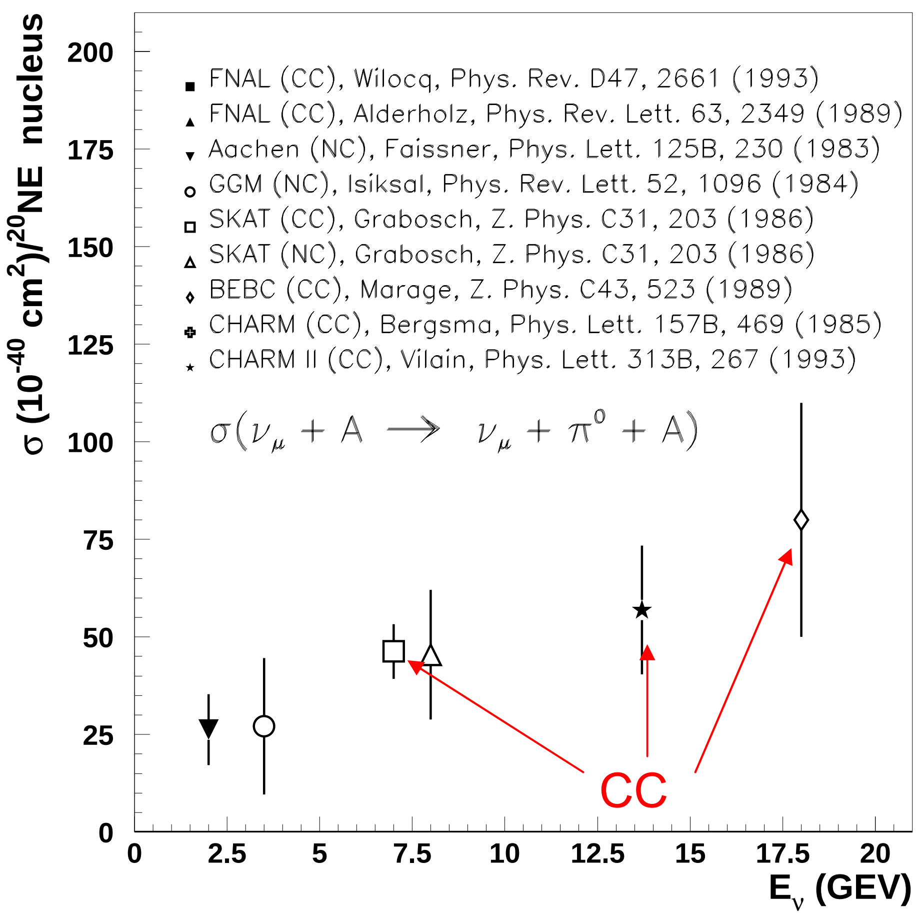
Experimental signature:

CC events: μ/π tracks (with no extra vertex activity), low t. Main backgrounds are from quasi-elastic and Δ production, which have different kinematics and lower energy hadronic tracks.

NC: single pion with no additional detector activity, closer to the beam direction than resonance and DIS contributions.

Expt	CC/NC	E	<A>	Signal
Aachen-Padova	NC	2	27	360
Gargamelle	NC	2	30	101
CHARM	NC	20-30	20	715
CHARM II	CC	20-30	20	1379
BEBC	CC	5-100	20	158
SKAT	CC(NC)	3-20	30	71(14)
FNAL 15'	NC	2-100	20	28
FNAL E180	CC	10-100	20	61
FNAL E632	CC	10-100	20	52

NC Coherent Pion Production Cross Section



(Sam Zeller)

Non-Oscillation Physics: Coherent Pion Production

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CC events / ton / 10^{20} POT= 300 (LE), 890 (ME), 5300 (HE).

CC channel offers the best prospects for a physics study of the coherent reaction. Would also be the first measurement off a target with A>30.

Backgrounds come from other low multiplicity CC reactions where only a single Pion is visible.

Analysis based on:
Topological cuts: requiring the event to have only two tracks, one muon and one pion. No extra activity around the vertex. A challenge in MINOS.

Kinematic cuts: reconstruction of event kinematics dominated by the pion energy resolution → MINOS should not be too bad in this regard.

Would be a useful measurement, as this process is an important background for $\nu_\mu \rightarrow \nu_e$ searches.

ν Interaction Experts Group?

- A main goal of our working group is to understand the near detector data as quickly as possible.
- The expectation is that when data arrives, our MC will not correctly describe it (certainly the experience of K2K and miniBoone).
- Enormous expertise within this collaboration on many aspects of neutrino scattering physics - but diffuse. Need to know who to talk to.
- Would it be worthwhile to have a consultative body that pulls together these experts but can also draw on expertise from others outside the collaboration?
- Would in particular provide a means to get input from theorists (who are much more interested in our problems now than 5 years ago).

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NuINT 2004

- Third International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region
- March 17-21, INFN Gran Sasso Laboratory
- Very useful conference series that brings together both experimentalists and theorists from nuclear and particle communities.
- One focus of this year's meeting will be on understanding K2K / miniBoone data and MC descriptions (NEUGEN, NUANCE, NEUT…)

more info at: http://nuint04.lngs.infn.it

Conclusions

- Major advances in the last 3 months in near detector Monte Carlo and reconstruction (Robert, Nathaniel, Jim, Niki, Costas).
- We are excited about the mock data challenge and expect to learn a lot from it.
- Efforts to systematically collect data from previous experiments has received a big boost with the involvement of the Durham database group.
- Still numerous areas where NEUGEN needs to do better to be ready for beam. Volunteers are required!
- Establishing a group that would allow us to pull together MINOS expertise on neutrino interaction physics as well as outside expertise might be useful.

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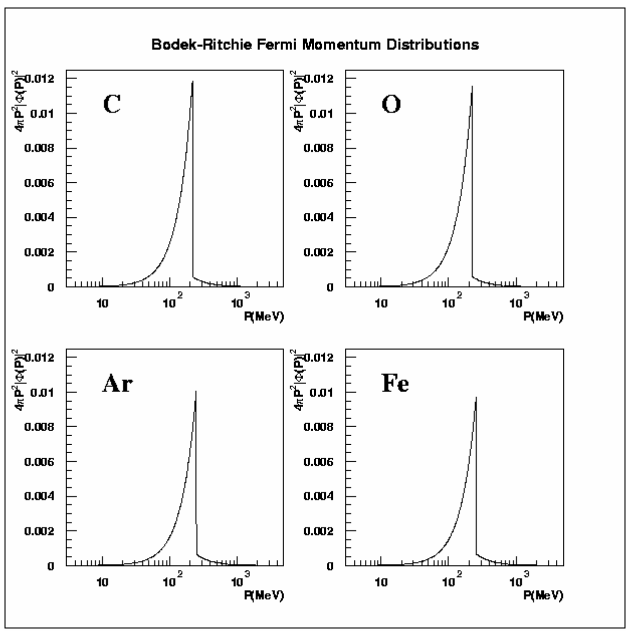
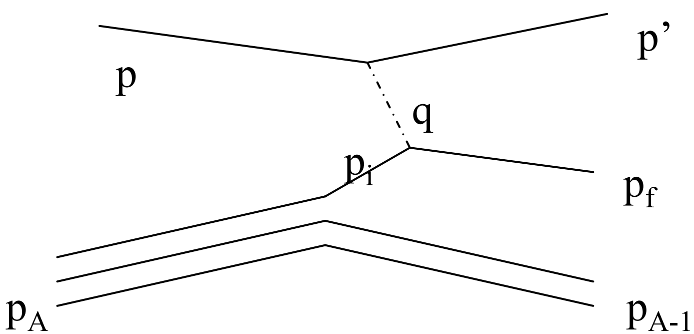
Spectral Functions

A major improvement to the handling of kinematics for low energy ν scattering:

Improvements in the simulations as a result of collaboration with:
- nuclear theorists (Omar Benhar)
- nuclear experiment (JLab)
- particle experiment (Jorge +)

Select a nucleon momentum from the Bodek-Ritchie distribution (basically a Fermi Gas distribution $n(p) \sim p^2\,dp$ for $p<k_F$) with a small tail beyond the Fermi momentum.





(Fe^{56}) (Mn^{55})

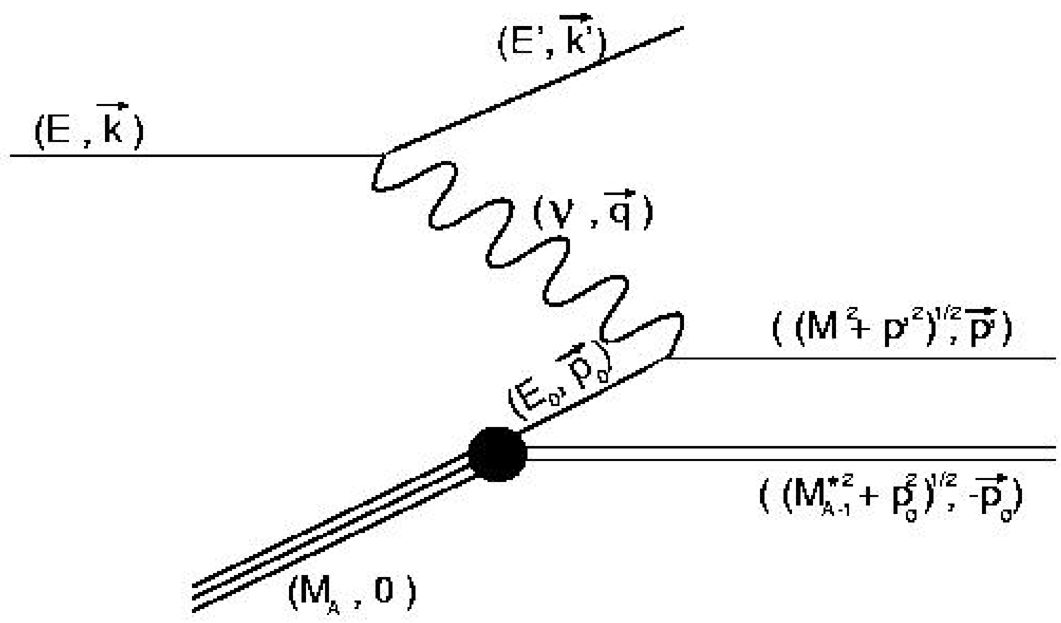
Old Way

on-shell: $p_{A-1} = (\vec{p}_s, \mathrm{Sqrt}(\vec{p}_s^{\,2} + M_{A-1}^2))$

off-shell: $p_i = (-\vec{p}_s, M_A - \mathrm{Sqrt}(\vec{p}_s^{\,2} + M_{A-1}^2))$

Plane Wave Impulse Approximation

- The total energy and momentum of the boson is absorbed by one nucleon
- The struck nucleon leaves the nucleus without interacting
- The struck nucleon may be represented by a plane wave



(Fig. from J. Arrington thesis)

Spectral Functions

O. Benhar et al. Nucl Phys A579 (1994) 493, and talks at NuINT.

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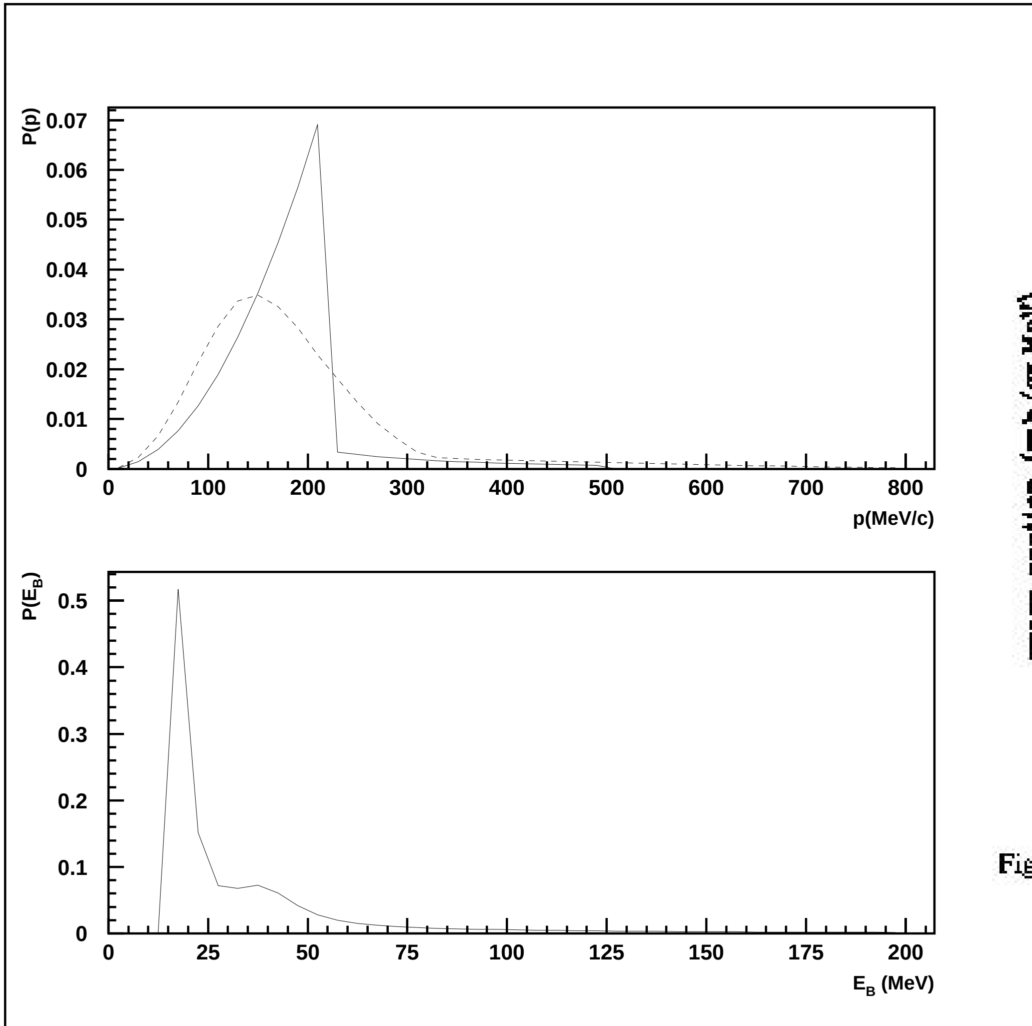

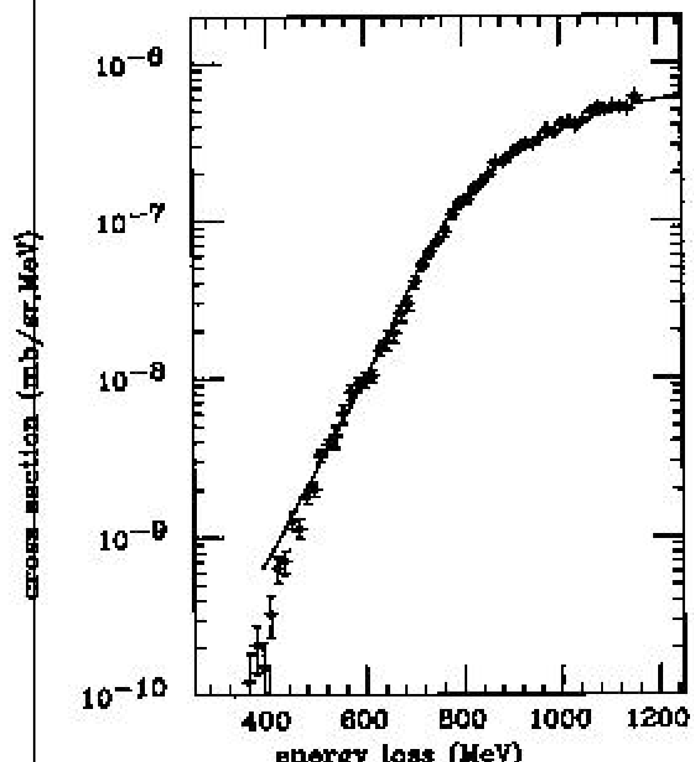

Fig. 11. Inclusive cross sections for ^{56}Fe for 3.6 GeV and 25°.