The IDS Neutrino Factory Near Detector: Status and Plans

5th Neutrino Factory International Design Study Meeting
Fermilab - April, 2010

Jorge G. Morfín, Fermilab
Roumen Tsenov, St. Kliment Ohridski Univ. of Sofia

Immediate Goals of the Near Detector Work

From Paul Soler's summary at Mumbai

IDR work for the Near Detector

- Conclude IMD measurement to determine neutrino flux
- Conclude work on extrapolation near detector flux to far detector
- Start on charm (and tau) analysis
- Define preliminary detector parameters
- Will not be able to do estimates of cross-section measurement errors yet nor any other ND physics

What Are the Objectives for this Meeting

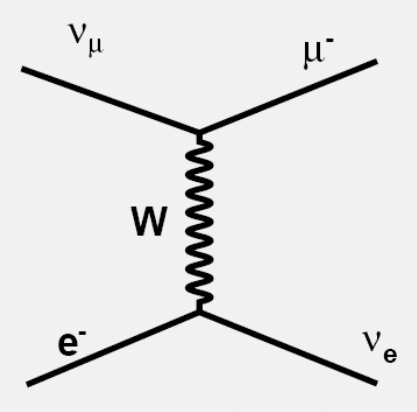
- Update from Roumen on simulations for neutrino flux determination.
  - Presentation by A. Laing on flux measurement extrapolation– DPS4
- Emphasis on "other' near detector physics.
- **Joint IDS/LBNE near detector and R&D sessions to**
  - **review LBNE near detector design alternatives**
  - **Consider a collaborative IDS/LBNE R&D effort.**
- **Consider one of the LBNE near detector designs as candidate for an IDS Near Detector baseline?** We will hear about another design from Roumen.
- Formation of an IDS Near Detector group with regular meetings and distributed responsibilities.

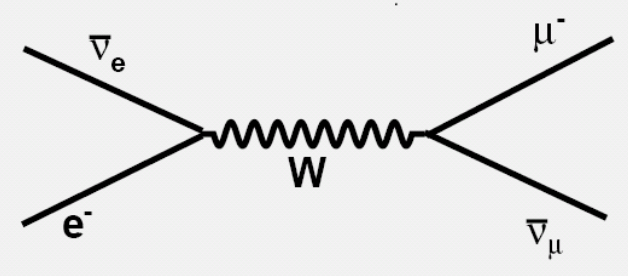
Measurement of the ϕ_ν with a Near Detector

R. Tsenov

Quasi elastic scattering off electrons can be used to measure the flux, because its absolute cross-section can be calculated theoretically with enough confidence. The two processes of interest for neutrinos from μ^- decays are:

$$\nu_\mu + e^- \rightarrow \nu_e + \mu^- \qquad \overline{\nu_e} + e^- \rightarrow \overline{\nu_\mu} + \mu^-$$





Example Near Detector Parameters

R. Tsenov

Position: 100 m after the straight section end
Material: polystyrene (ρ = 1.032 g/cm^3)
Size: radius 1.5 m, length = 10 m.

Detector resolutions:

	$\delta\theta_\mu$ (mrad)	$\delta\, p_\mu/p_\mu$ (%)	$\delta E/E$ (%) [hadron energy]
Poor :	**1.0**	**10**	**10**
Medium:	**0.5**	**5**	**5**
Best :	**0.1**	**1**	**1**

Preliminary Conclusions from Roumen

- We need good measurement of recoil (hadronic) energy down to few tens of MeV;
- θ_μ *and* $E_\mu * \theta^2_\mu$ have equivalent discriminating power;
- It's not clear yet if the uncertainty of the flux measurement could be made less than a few % → depends on extrapolation of the inclusive cross-section to $\theta \rightarrow 0$.

Update from Roumen in Parallel Session

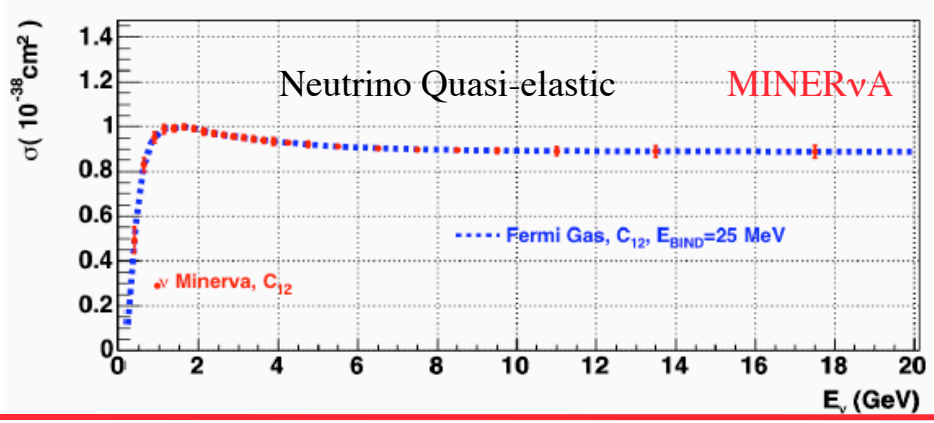
"Other" Near Detector Physics

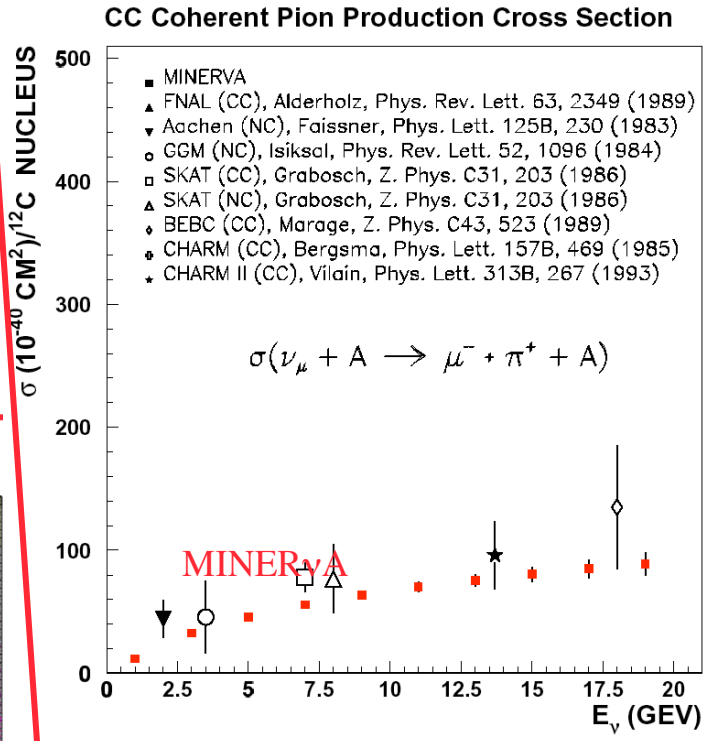
- To achieve the kind of accuracy we want on the neutrino flux measurement, we will have constructed a detector ideally suited for advanced studies of neutrino-nucleus interactions – the "other" physics.
- This in turn can be grouped into standard processes:
  - **Quasi-elastic**
  - **Resonance Production**
  - **Transition: Resonance to DIS**
  - **DIS, Structure Functions. and high-x PDFs**
  - **Coherent Pion Production**
  - **Strange and Charm Particle Production**
  - **Generalized Parton Distributions**
  - **Nuclear Effects**
- and more exotic…
  - NSI such as the measurement of ν_τ in the near detector

Where will we be at the time of NF – ND

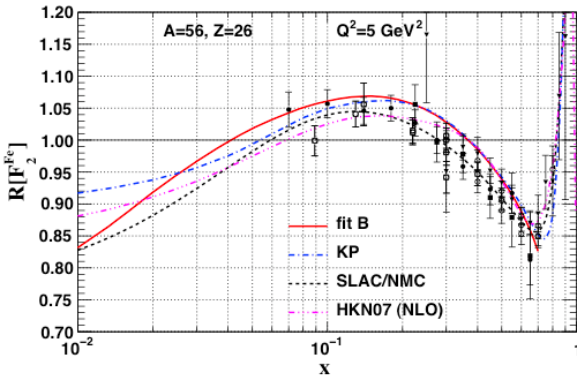
Dominated by systematics: Mainly Flux Errors

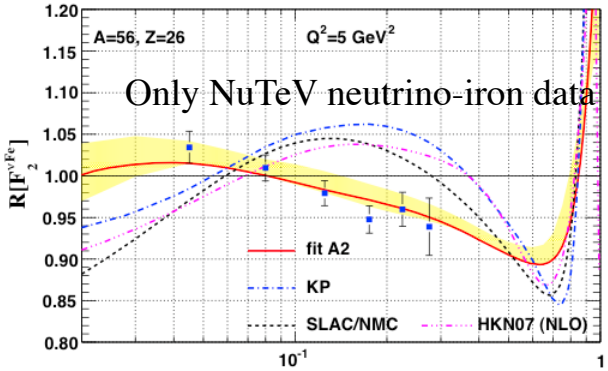
- The neutrino factory experiments will occur after MINERvA and LBNE will have taken and analyzed their data. Examples:





Neutrino Nuclear Effects





- Combined many charged lepton data sets on many different nuclei
- MINERvA provides **<u>He, C, Fe, Pb</u>**

Neutrino-nucleus Scattering Physics at NF-ND

post MINERνA and LBNE

- Take advantage of much-increased knowledge of the flux:
  - absolute cross-sections
- Take advantage of much-increased event rate:
  - use of H_2 and D_2 targets as well as higher A,
  - study of rare topologies,
  - high-x phenomena …..
- Take advantage of extended kinematic coverage:
  - study lower-x phenomena at reasonable Q^2,
  - extended reach in Q^2
- Certainly to be other benefits…

Requirements for the NF - Near Detector

- Need high resolution (low-Z) target for accurate measurement of angles of muons for flux determination and resolution of hadronic final states for cross section measurements.
- Need good identification and accurate momentum measurement of the muon – a magnetic field with muon identification.
- Very good hadron energy determination for flux and cross section measurements.
- Need excellent vertex resolution for charm production and ν_τ detection for indications of NSI.

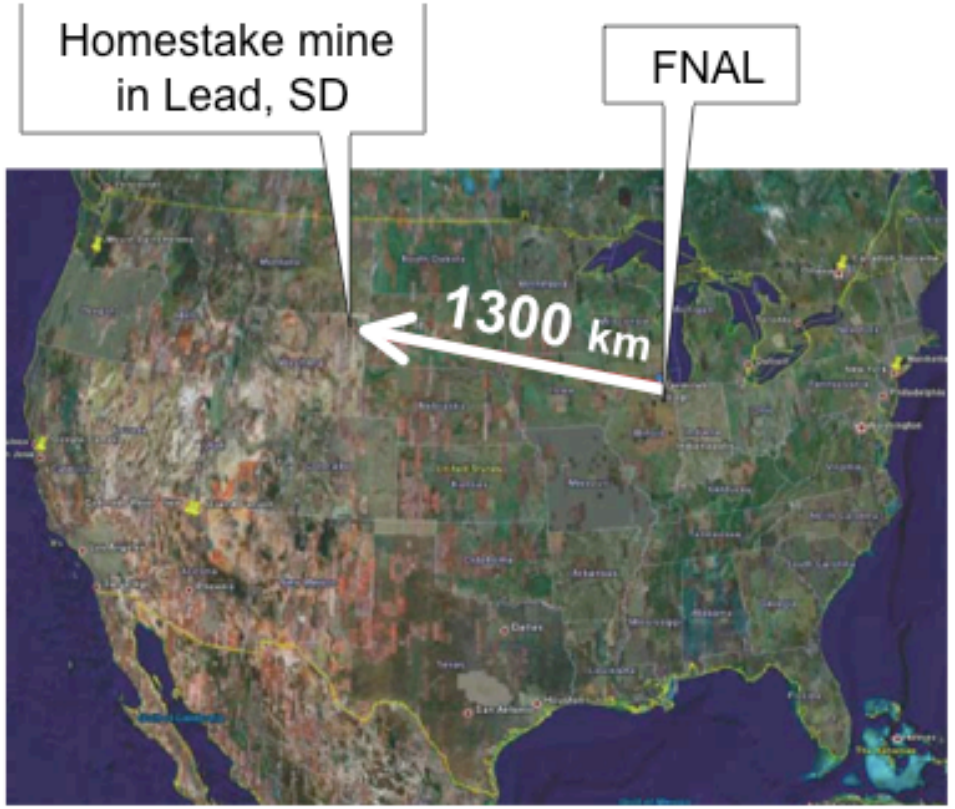
- … somehow this sounds vaguely familiar

  (enter stage right….. **LBNE**)

LBNE (Long Baseline Neutrino Experiment)

- idea is to send intense ν, $\overline{\nu}$ beams from Fermilab
- long baseline (1300 km)
- very massive detectors (100's kton) in a deep underground laboratory

  - water Cerenkov
  - liquid Argon TPC



new beam → long baseline → large detectors → big project
→ potential big payoff !

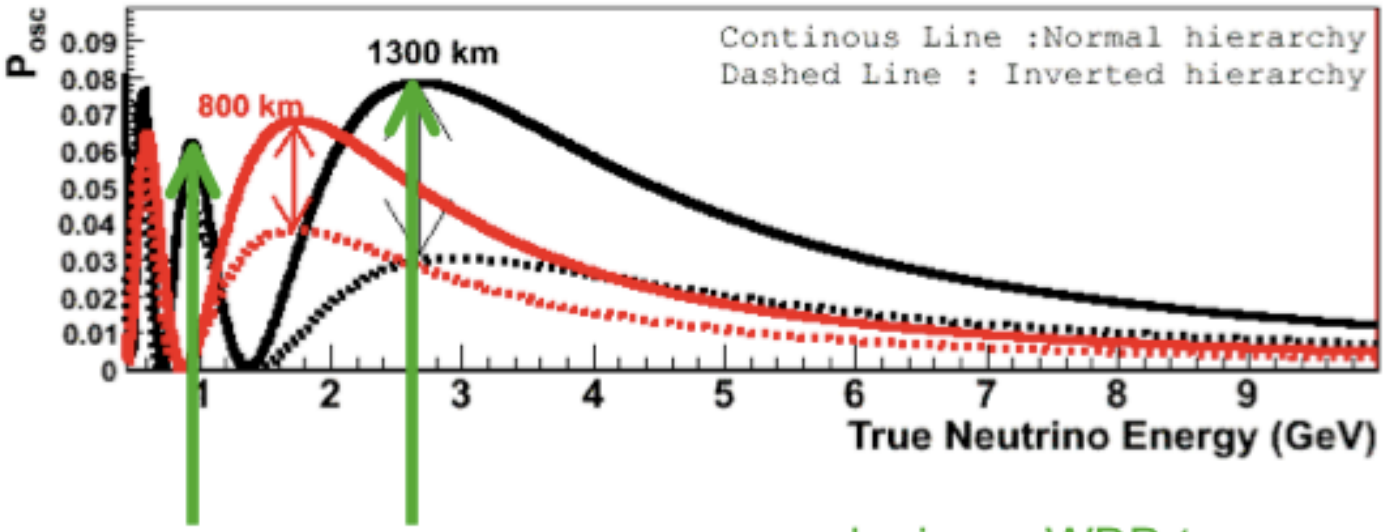
LBNE Physics in One slide!

Physics and Far Detector Ideas – R. Svoboda, Detector PS4 tomorrow

- so can measure θ_{13}, mass hierarchy, δ_{CP}
- long baseline and small $\nu_\mu \rightarrow \nu_e$ probability, requires:

(1) intense beam
(2) massive far detectors

(to provide sufficient event rates ideally ~100's ν_e events/yr)



0.8 GeV 2.7 GeV

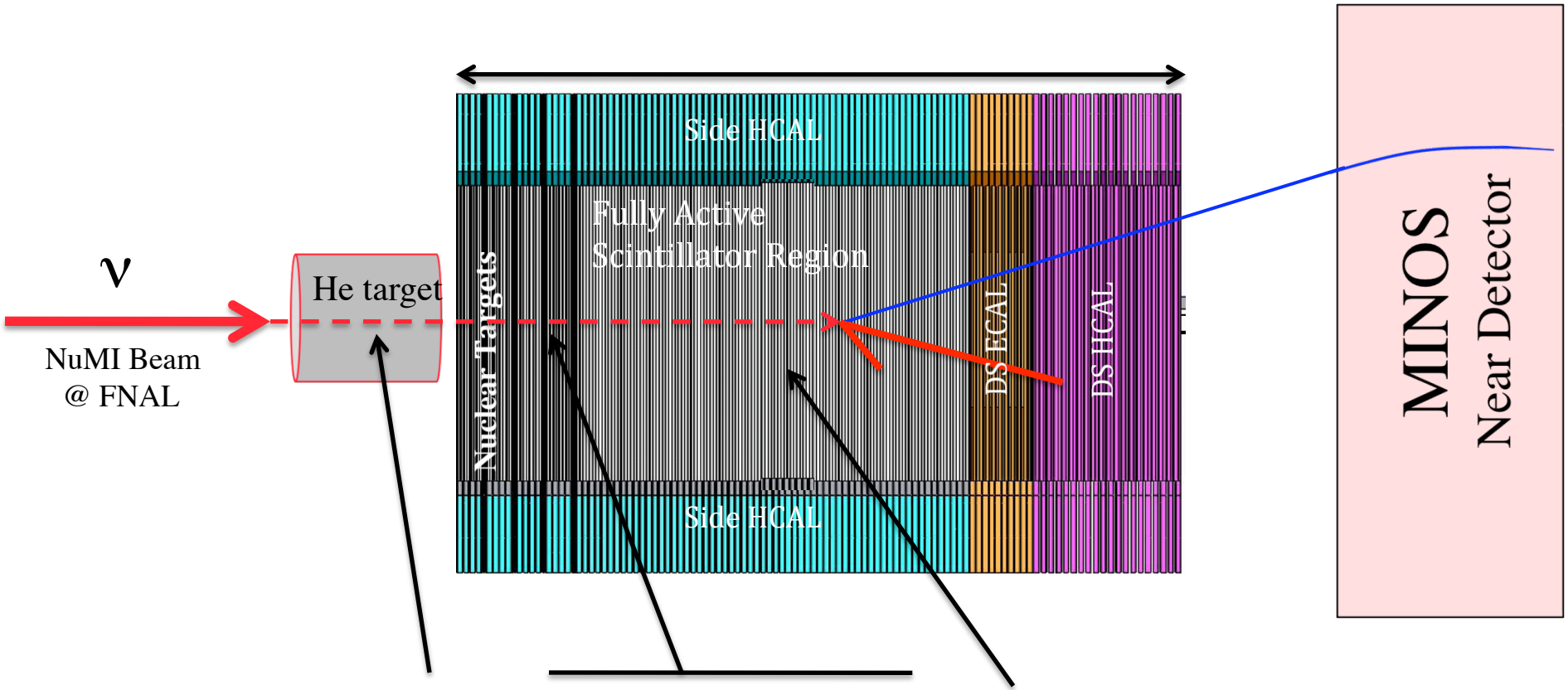
design a WBB to cover
1st and 2nd oscillation maxima

Requirements for an LBNE Near Detector

- Tasks of the LBNE Near Detector:
  - establishing the neutrino fluxes at the "source" in both flavor and energy with high confidence by utilizing sufficiently well-known reactions
  - measuring the yields as a function of energy of the process to be used at the FD to investigate CP violation
  - Uncover and quantify any background processes that could interfere with the signal at the FD that is not adequately incorporated in the simulation of the FD response.
- Consequent Near Detector Questions currently being addressed:
  - What is the required mass and material of the ND
  - What, if any, is the required strength and extent of a magnetic field at the ND?
  - What is the required granularity/sampling and position resolution of the ND?
- LBNE is currently considering two near detector alternatives.

LBNE ND1: MINERνA Detector Concepts

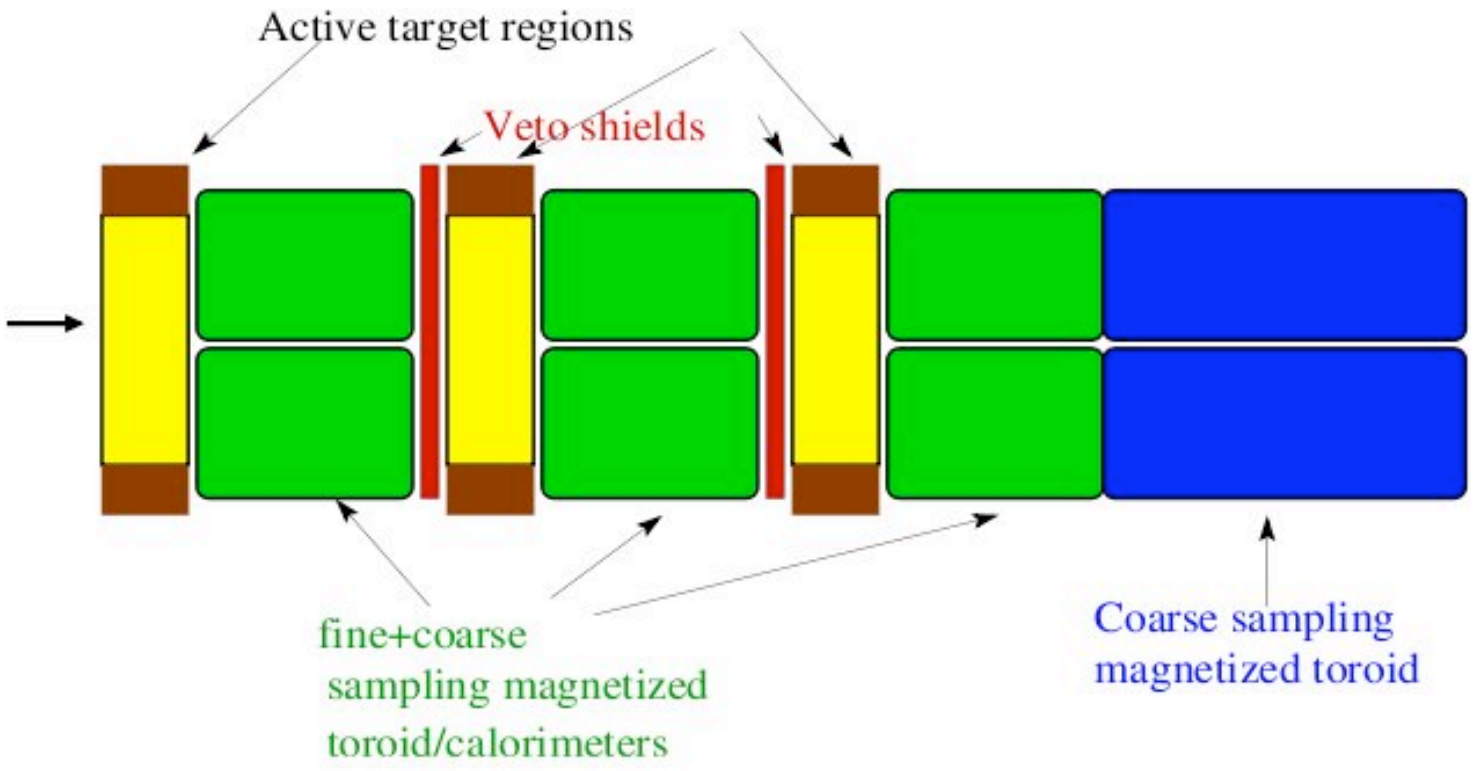
Finely segmented, fully active scintillator tracking region surrounded by ECAL and HCAL,



nuclear targets **(He, C, Fe, Pb, H_2O, CH)**

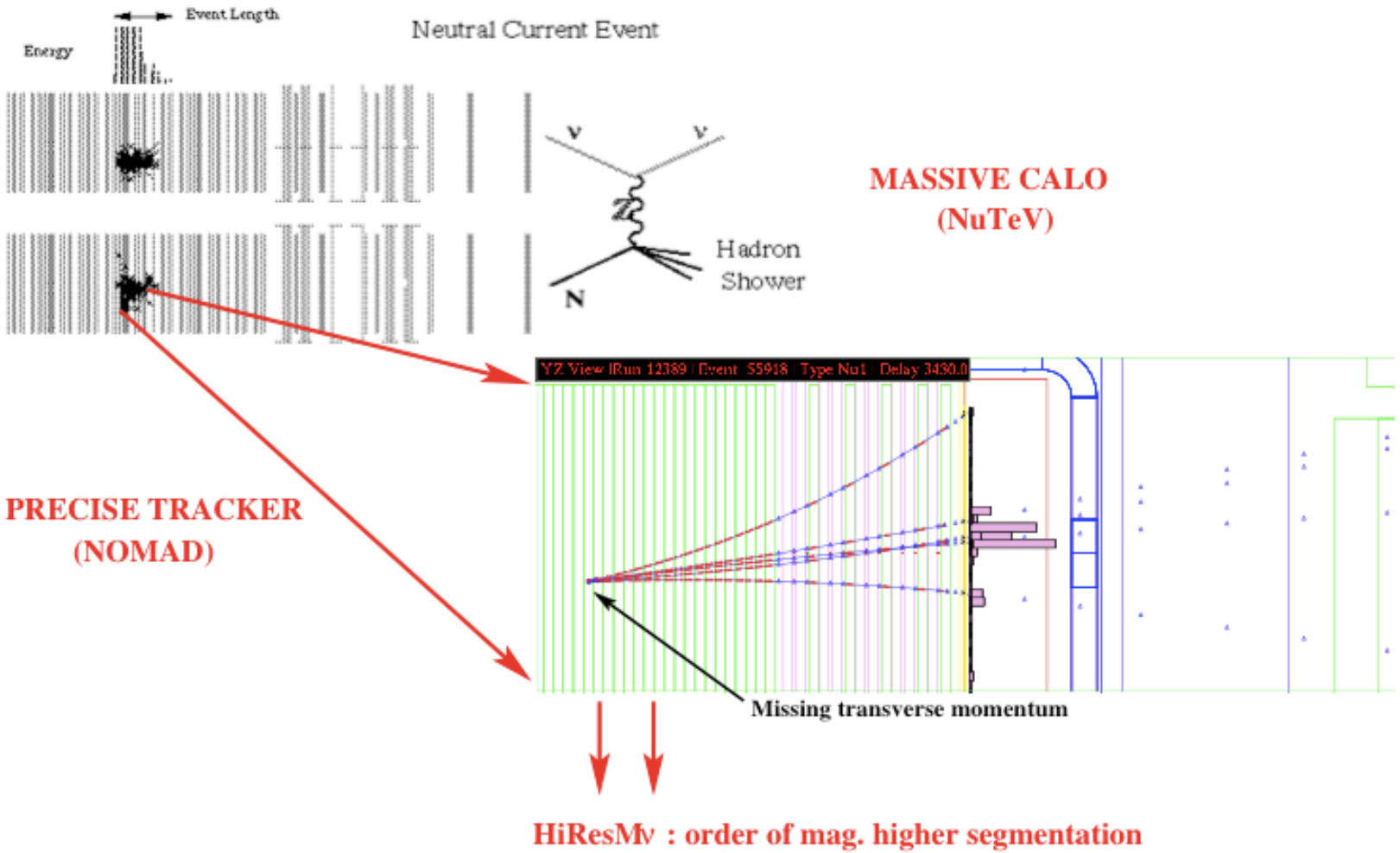
Hybrid Design based on MINERνA concept

Bob Bradford (U of Rochester) – Detector session PS3 tomorrow AM



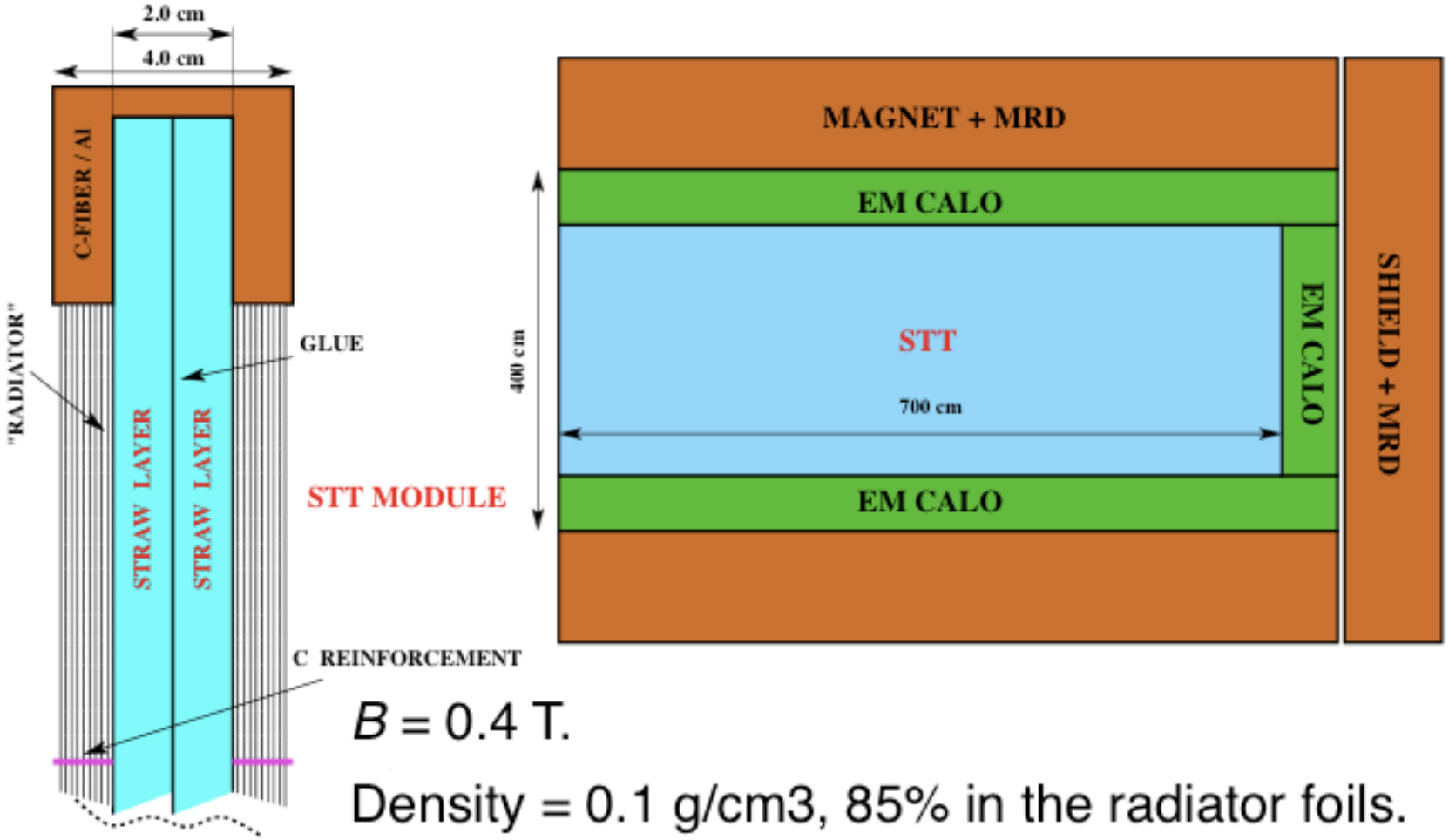
- Downstream of the entire group of 3 is a coarser muon ranger for the highest energy muons.

LBNE ND2: High Resolution STT Concepts



Overall Design and STT Concept

Sanjib Mishra (U South Carolina) – Detector session PS3 tomorrow AM



$B = 0.4$ T.

Density = 0.1 g/cm3, 85% in the radiator foils.

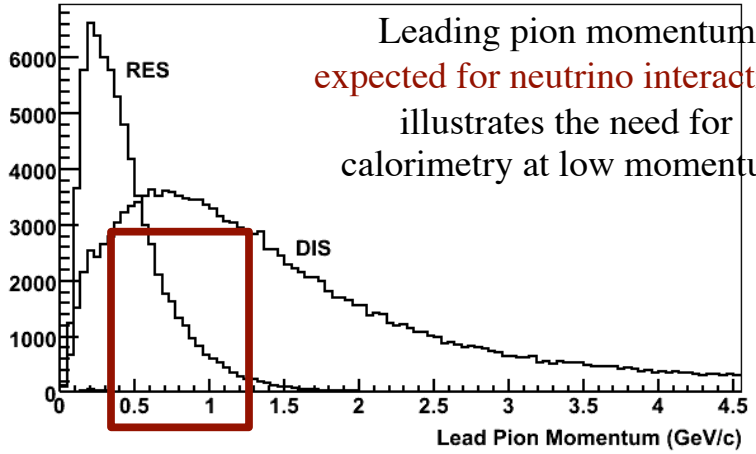
dE/dx for π, K ID, transition radiation for $e^{\pm}$ ID.

A Common IDS/LBNE R&D Program?

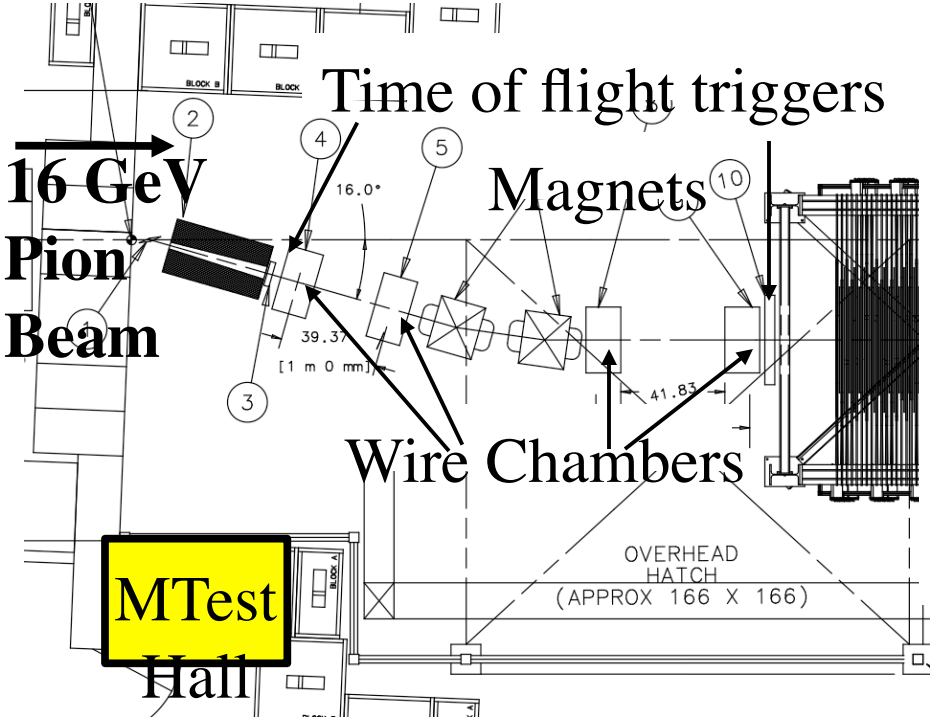
- An R&D concept called "MINERνA-Prime" has been discussed at several meetings starting around the time of NuFact09:
  - Using MINERνA–style scintillator extrusions
  - With SiPM readout
  - Placed in a magnetic field at CERN
  - Collaborators from Europe and the US
- Have had one phone-meeting discussion concerning a combined LBNE and MINERνA-Prime R&D program.
- Is it a reasonable idea, to save time and funds, to collaborate on joint R&D? Is it practical, do the time scales for LBNE and IDS-NF encourage such collaboration?
- Joint IDS/LBNE R&D session tomorrow afternoon to discuss the concept.

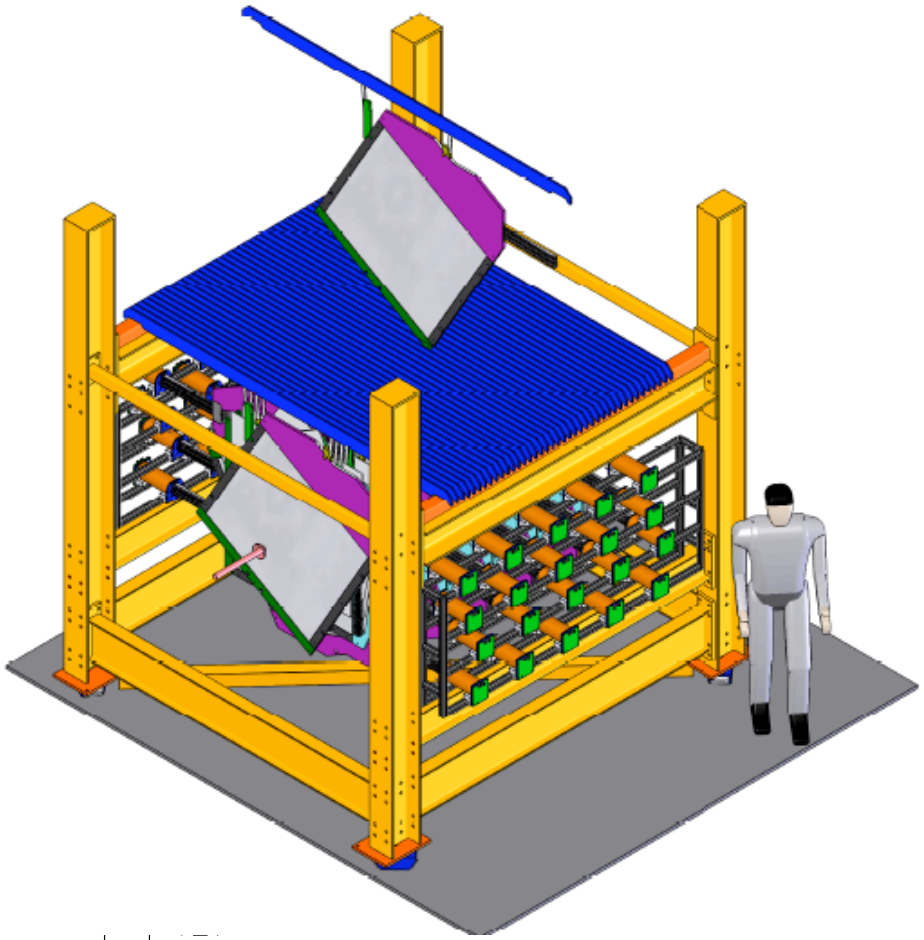
MINERνA Test Beam Effort

New Low-E Fermilab Test Beam



Leading pion momentum expected for neutrino interactions illustrates the need for calorimetry at low momentum





IDS-Near Detector Group

- In the beginning and essentially until now, the near detector group was mainly Roumen Tsenov + Yordan Karadzhov + ?.
- By joining the near detector group, I've increased the membership by a sizable fraction. This is not a reasonable situation.
- Roumen and I will now form a near detector group with "regular" meetings and a membership consisting of those:
  1. Interested in understanding/measuring the neutrino flux
  2. Wanting to study conventional neutrino-nucleus interactions
  3. Interested in looking for NSI
  4. Wanting to design/construct a near detector able to accomplish 1 – 3
- We will start recruiting within the IDS-NF structure.
- Could go outside the established IDS-NF to recruit others who are interested in near detector physics and could join IDS-NF.

Summary

- The IDS-NF near detector effort is entering a new phase.
- In addition to the primary motive for a near detector, determining the flux, more attention can now be directed to important secondary efforts such as neutrino-nucleus scattering physics and the search for non-standard interactions.
- By reviewing what LBNE is considering for near detector alternatives, we could have several candidate detectors for an IDS-NF near detector baseline.
- We should seriously consider how we could benefit from forming a joint IDS/LBNE R&D effort leading to the technology necessary for our near and far detectors.
- The formation of a near detector group, drawing on several diverse interests, is a goal for the immediate future.