The Future of DIS by Neutrino Beams

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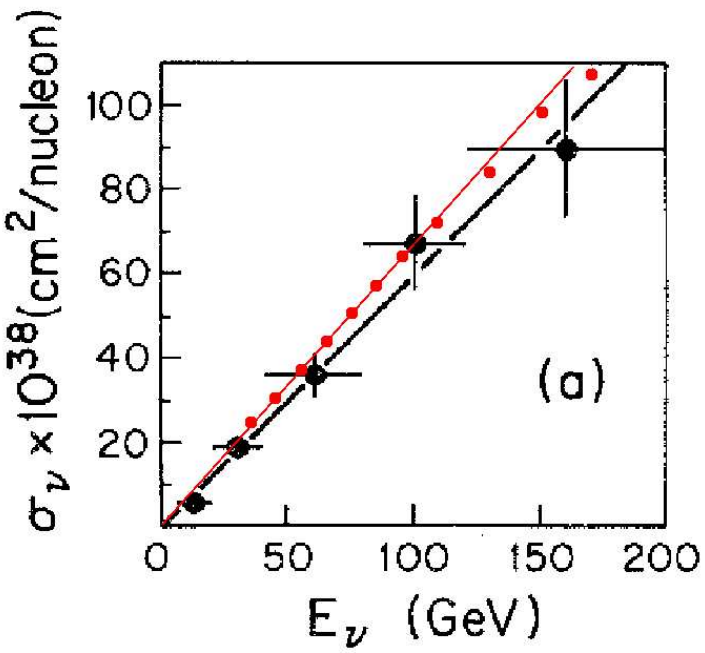
Neutrino Deep Inelastic Scattering

- ν DIS only via weak interaction
  - Low rate $\Rightarrow$ massive detectors and/or intense beams
  - Neutrinos "taste" quark flavor
- Access to $xF_3^{\nu N}$ and $xF_3^{\bar{\nu} N}$
  - Average $xF_3^{\nu N}$ and $xF_3^{\bar{\nu} N}$ sensitive to valence pdfs
  - ΔxF_3 sensitive to strange and charm pdfs
- Charm production provides direct look at strange pdf



FNAL E-001 and E-815 cross sections

Part I: Settling the Books on Past $\nu - N$ DIS

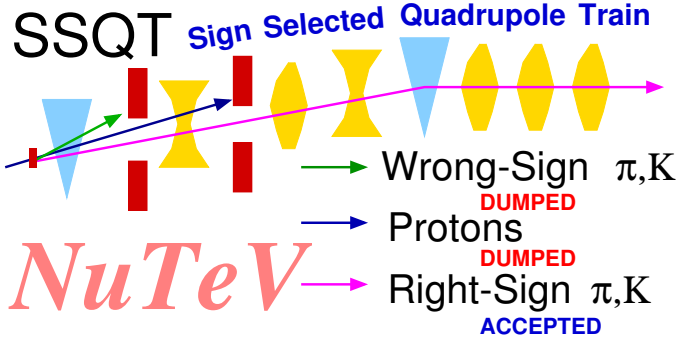
Good things are still to come from experiments past!

- NuTeV
  - Ran in 1996-97 at FNAL
  - Final NLO strange asymmetry
  - Preliminary NLO QCD SF fits
- CHORUS & NOMAD
  - Ran in 1995-98 at CERN
  - Pb cross section results (CHORUS)
  - Expecting charm production/dimuon and cross section results in the near future

NuTeV

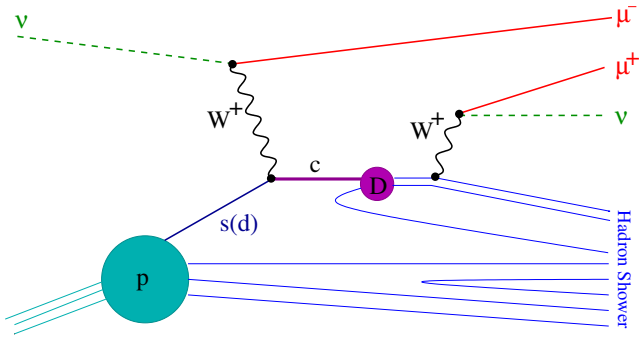
- 690 ton iron sampling calorimeter
  followed by magnetized muon spectrometer
- SSQT $\Rightarrow$ pure sign selected beams
  - 99.9% pure ν and 99.7% pure $\overline{\nu}$
- Continuous calibration by π/K, μ, e beams
- $3.15 \times 10^{18} POT$ with $\langle E_\nu \rangle \sim 120$ GeV
- NuTeV $\sin^2\theta_W$:
  - $0.22773 \pm 0.00135(st) \pm 0.00093(sy)$

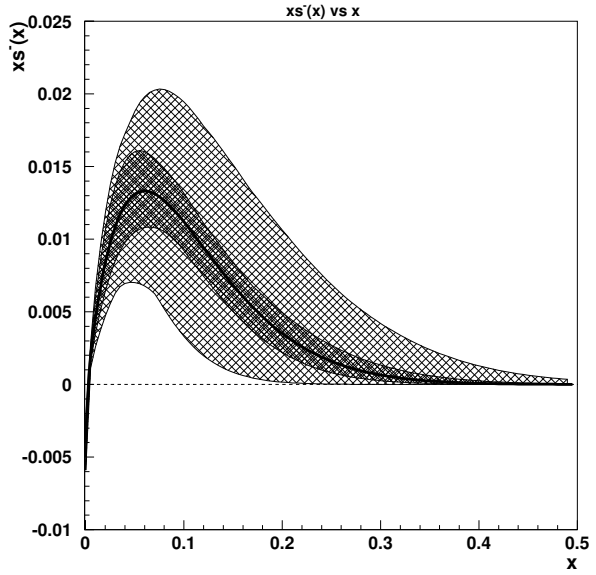
    Zeller et al: PRL 88 (2002) 091802)
  - 3 σ above world average
  - http://home.fnal.gov/~gzeller/nutev.html



NuTeV Final NLO Dimuon Analysis Results

- $\nu - N$ DIS charm production uniquely sensitive to strange sea $\Longrightarrow$
- NuTeV sign selected beam allowed independent look at $s(x)$ vs $\overline{s}(x)$
- Complete NLO modeling of dimuon cross section and acceptance
- $xs(x) - x\overline{s}(x)$ positive $\Longrightarrow$
  - Not large enough to eliminate "NuTeV $\sin^2\theta_W$ anomaly"
- Pdf groups working to include data in fits
- See SF session talk





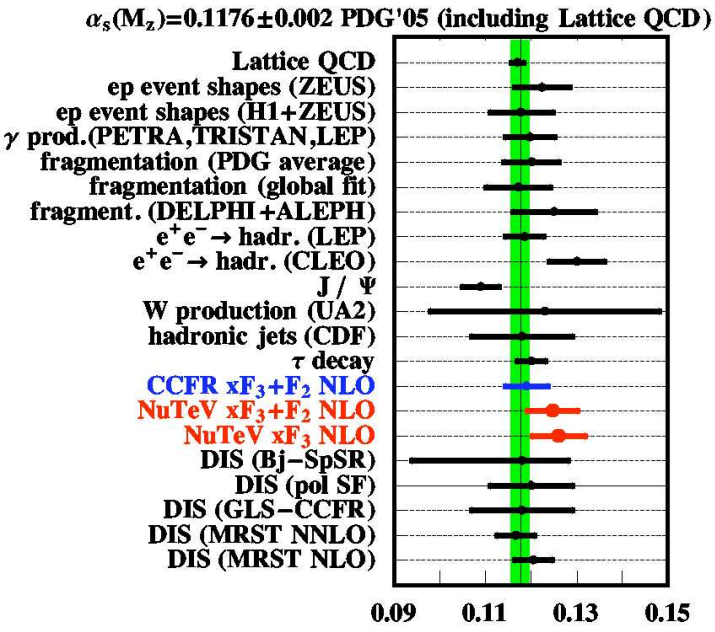
Preliminary NuTeV NLO QCD Structure Function Fits

- Preliminary extraction of $\Lambda_{QCD}^{(n_f=4)}$
- First $\nu - N$ DIS measurement of Λ_{QCD} including full NLO treatment of charm production
  - ACOT massive scheme (F. Olness, S. Kretzer)
- Performed NLO fits to xF3 alone, and combined F2 and xF3
- Fits use full correlation matrix, data from NuTeVpack (M. Tzanov et al, hep-ex/0509010)

NuTeV preliminary $\Lambda_{QCD}^{(n_f=4)}$:

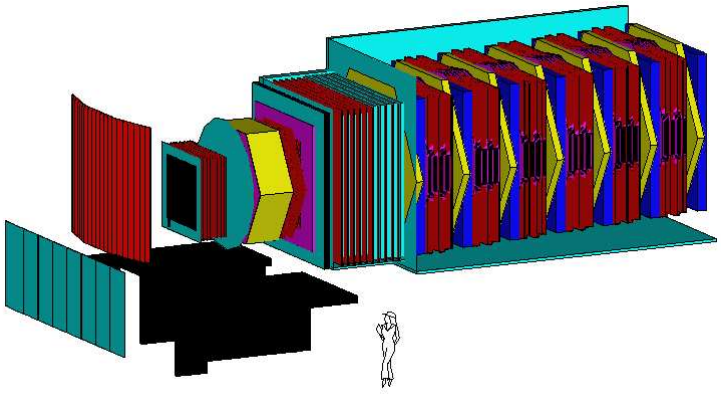
Nonsinglet: $488 \pm 59(stat+sys) \pm 112(th)$ MeV

NS+S: $458 \pm 41(stat+sys) \pm 104(th)$ MeV

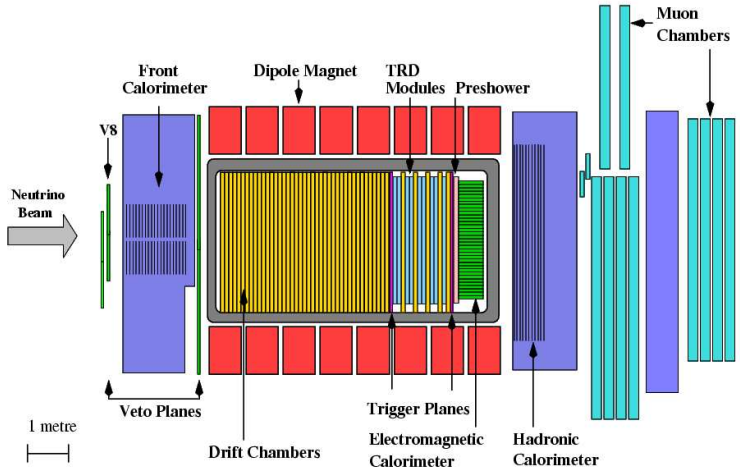


(Preliminary, V. Radescu)

CHORUS & NOMAD



The CHORUS detector

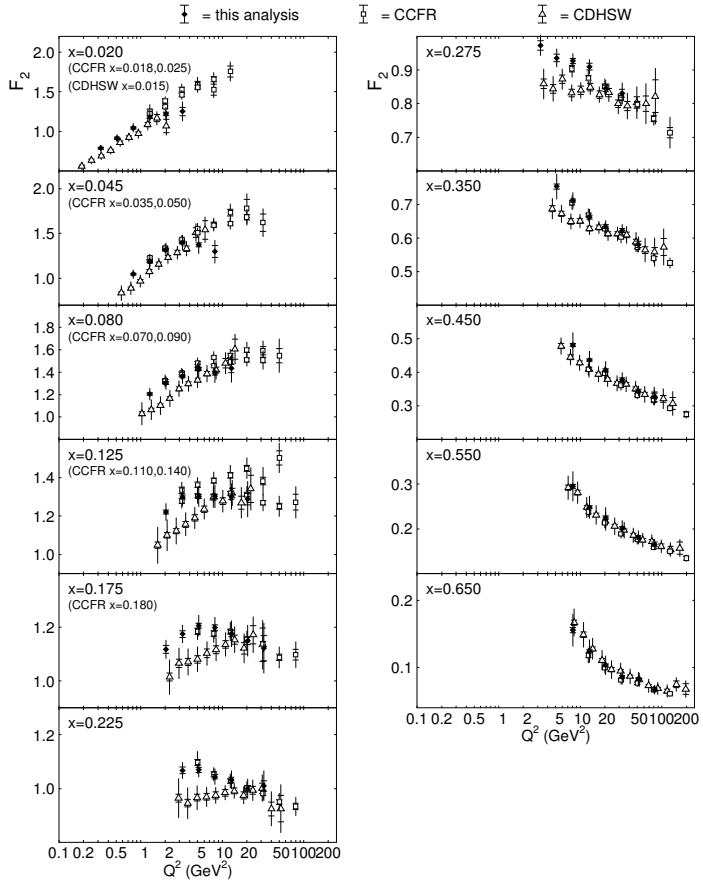


The NOMAD detector

- Fine grained detectors designed to observe $\nu_\mu \to \nu_\tau$ oscillations
- Ran from 1995-98, $\sim 5 \times 10^{19}$ POT, $\langle E_\nu \rangle = 27$ GeV
- Horn focused beam from CERN SPS, mostly ν, some $\overline{\nu}$.
- Charm production and cross section results in the near future!

CHORUS ν Pb Cross Section Measurement

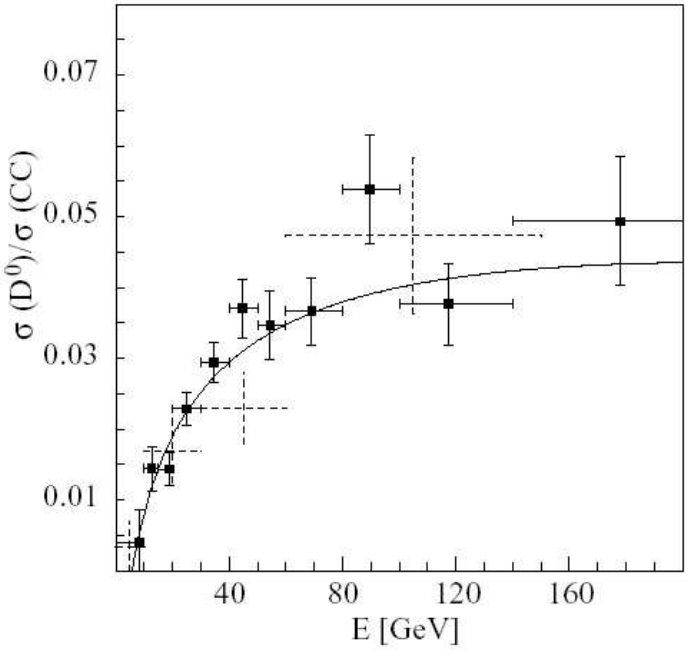
- Began run with emulsion target
- Switched to nuclear targets in 1998
- New ν on lead cross section, F_2 shown $\Longrightarrow$
- $10 \leq E_\nu \leq 200$ GeV
- 932,257 ν and 162,958 $\overline{\nu}$ events
- F_2 Favors CCFR over CDHSW
- Comparison with NuTeV/CCFR high x more subtle
  - Lead vs iron nuclear correction dependent
  - Systematics larger at high x



(G. Onengut et al. Phys.Lett. B. 632, (2006) 65-75)

CHORUS Charm Production Measurements

- Measurement of ν D^0 production cross section this past year $\Longrightarrow$
- Coming this year:
  - Total ν and $\overline{\nu}$ charm production cross section
    - Seperately for both NC and CC
    - As well as by prong multiplicity
    - First time measurement!
  - Associated charm production for both NC and CC

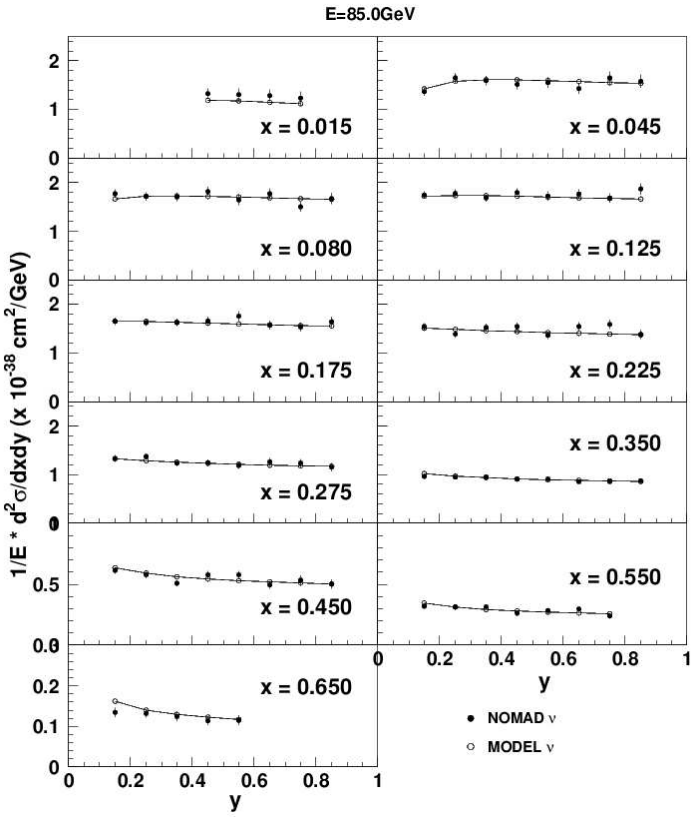


(G. Onengut et al. Phys.Lett. B. 613, (2005) 105-117)

CHORUS results at: http://choruswww.cern.ch/Publications/papers.html

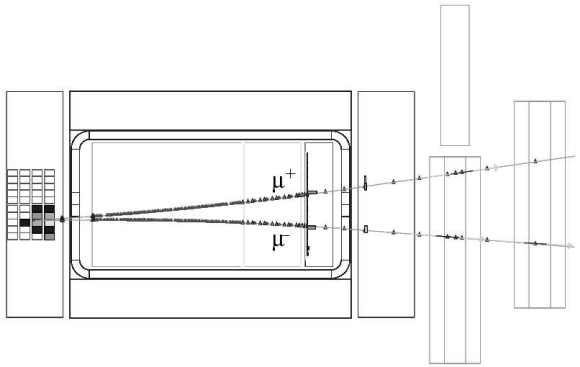
The NOMAD Cross Section Measurement

- First inclusive cross section mm't on carbon target at relatively large Q^2
- 750k ν events, $6 \leq E_\nu \leq 300$ GeV
  - Detector μ ID, $E_\mu > 2.5$ GeV
  - $E_{HAD} > 3$ GeV, $Q^2 > 1$ GeV^2
- Cross section measurement from interactions in front iron calorimeter also possible
  - Almost 10$\times$ carbon statistics

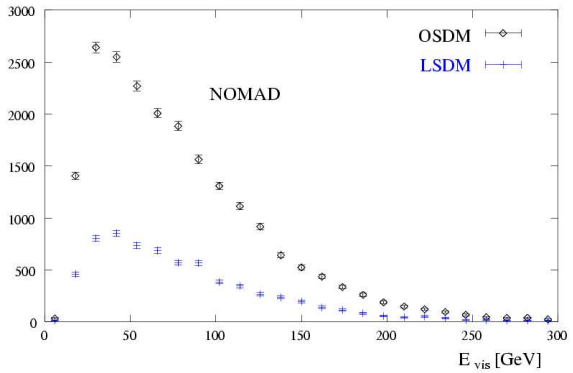


(Preliminary – courtesy R. Petti)

NOMAD Dimuons



A NOMAD dimuon event



Opposite and same-sign dimuon $E\nu$ distributions

- 14k opposite sign dimuon events from front iron calorimeter.
- Measure $R_{\mu^-\mu^+} \equiv \frac{\sigma(\nu N \to \mu^-\mu^+ X)}{\sigma(\nu N \to \mu^- X)}$
  - NLO strange sea, charm production parameter measurement
  - Data near charm threshold

    $\Rightarrow$ high m_c sensitivity

NOMAD results at: http://nomad-info.web.cern.ch/nomad-info/Public/PUBLICATIONS/public_pub.html

A Transition Period for $\nu - N$ Experiments

- NuTeV last of dedicated EW/DIS ν experiments
  - Produced many DIS measurements
  - As well as ν oscillations measurements
- Next came NOMAD & CHORUS
  - Designed as ν oscillation experiments
  - Produced many DIS results
- Last results from "old guard" still to come!
- We're transitioning into the ν oscillation era
  - Lower beam energies, but higher intensities
  - Chance to revist neglected regions of phase space
  - Many interesting DIS possibilities!

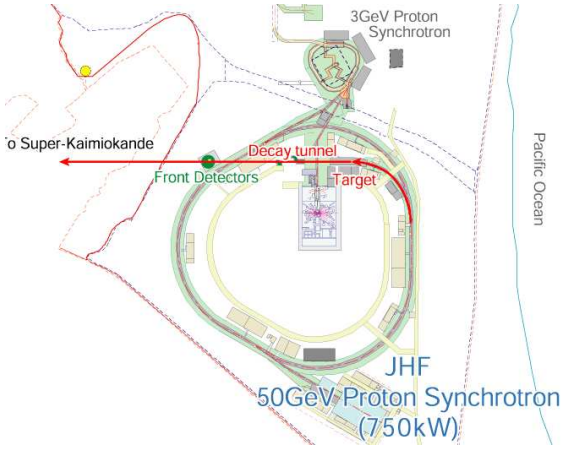
Part II: DIS Opportunities in the ν-Oscillation Era

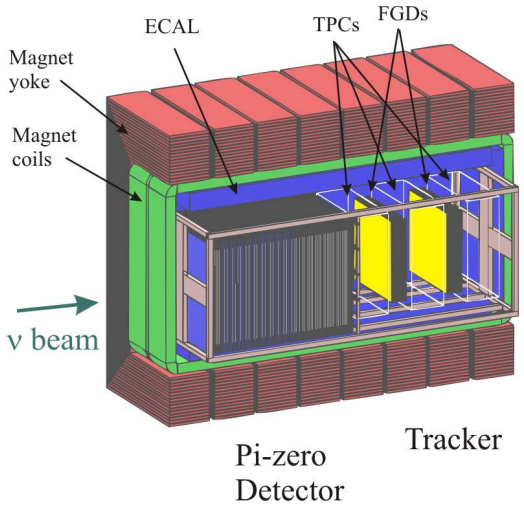
3 ν facilities are running, or will be soon:

- JPARC: High intensity neutrino beam to service T2K experiment
- CNGS: Higher energy neutrino beam from CERN to Gran Sasso
- NuMI: Fermilab Main Injector neutrino beam

JPARC

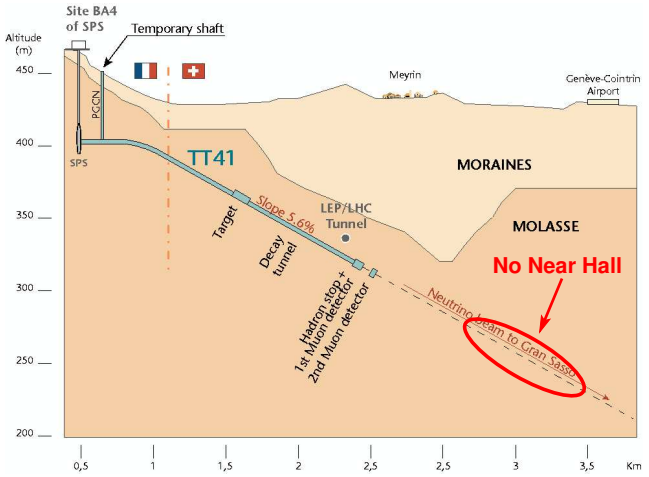
- JPARC ν beam to serve T2K
- High power beam, turn on in 2009
- Off axis, $\langle E_\nu \rangle \sim 700$ MeV
- Proposed near detector "ND280" ⇘
  - Off axis, fine grained detector
  - To measure ν_μ, ν_e fluxes for T2K
  - π^0 production rates
  - Characteristics of processes expected to be misreconstructed at Super-K



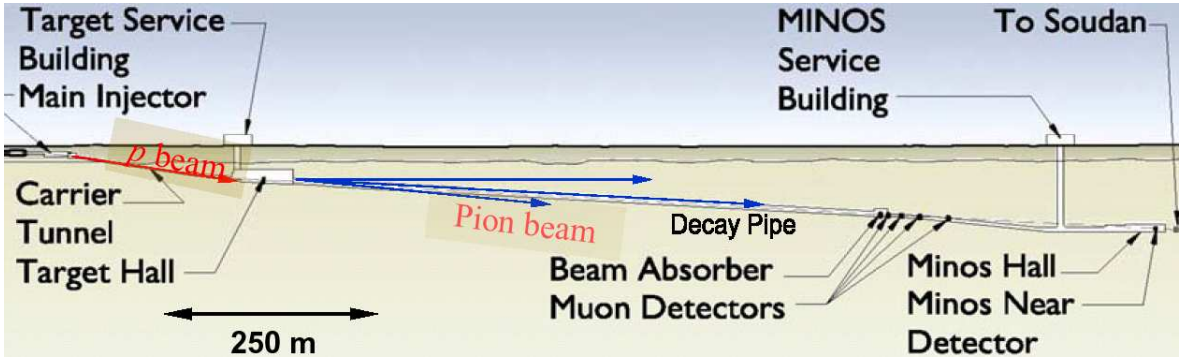


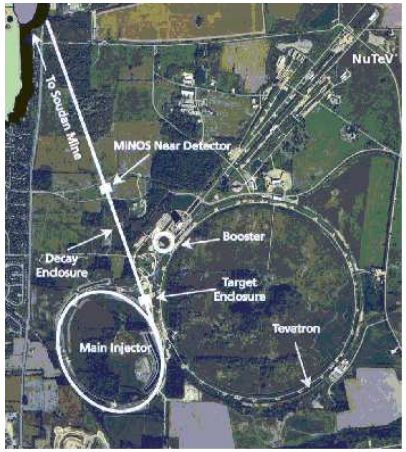
CNGS

- Beam turn on expected this summer!
- SPS-generated ν beam to serve ICARUS and OPERA
- ν_τ appearance experiments
  - Higher energy, $\langle E_\nu \rangle \sim 17$ GeV
  - 4.5×10^{19} POT/year expected
  - High resolution far detectors
  - But no near detector hall
  - Similar beam to "old" SPS beam, NOMAD, CHORUS measurements will serve as "near detectors"

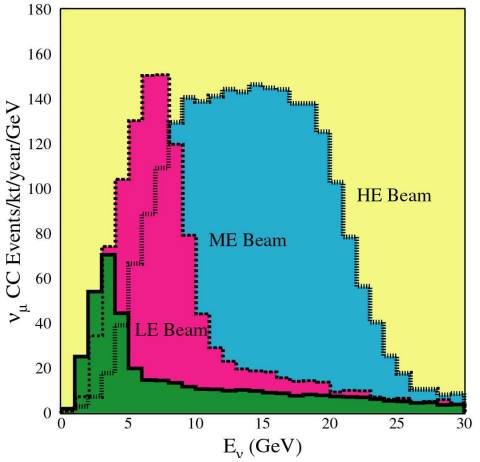


NuMI





- 120 GeV protons impact graphite target
- Initial intensity 2.5×10^{20} POT/year
- Started running at end of 2004
- Three possible energy tunes (on axis) $\Longrightarrow$
  - $E_{\nu-LE}$ = 1-3 GeV, $E_{\nu-ME}$ = 3-8 GeV, $E_{\nu-HE}$ = 8-20 GeV
  - Moving position of target and horns



The NuMI Physics Program

- MINOS
  - Long baseline ν_μ disappearance oscillation experiment
  - To reduce systematics have both far and near detectors
  - Data taking began in January 2005

- MINERνA
  - Fine grained detector in front of MINOS near detector
  - Precise measurements of cross sections, DIS
  - Expected to begin running in mid 2009

- NOνA
  - Long baseline off-axis ν_e appearance osc. experiment
  - Both far and near detectors, simple near detector
  - Expected to begin running in 2011

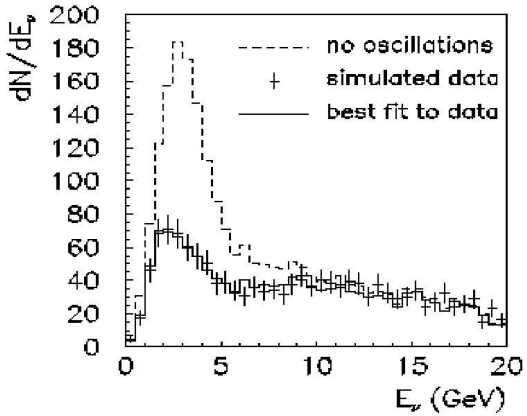
MINOS and MINERνA data will record lots of ν DIS data!

The MINOS Experiment

- First priority to demonstrate oscillation behavior
- Precise measurement of Δm^2_{23}
- Search for $\nu_\mu \rightarrow \nu_e$ oscillations

To do this:

- Multi-energy, high intensity NuMI beam
- Two similar detectors, one far one near.
- Both magnetized iron + scintillator based tracking calorimeters (B field is a first for ν-osc)
  - 5.4 kT far detector in Soudan, Minnesota
  - 1 kT near detector in NuMI beam at Fermilab
- First NuMI beam results announced on March 30: http://www-numi.fnal.gov/talks/results06.html

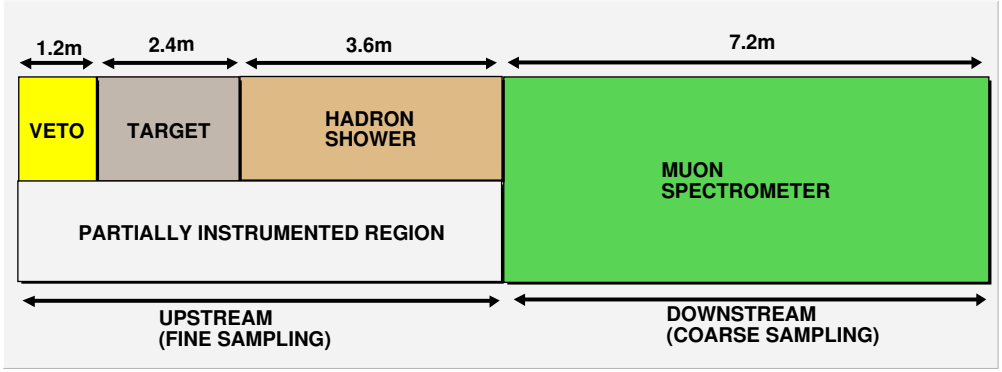


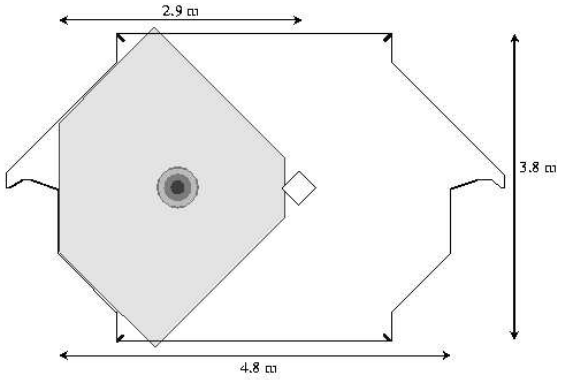
$E\nu$ distribution in far detector

Large sample of DIS events already recorded in MINOS near detector!

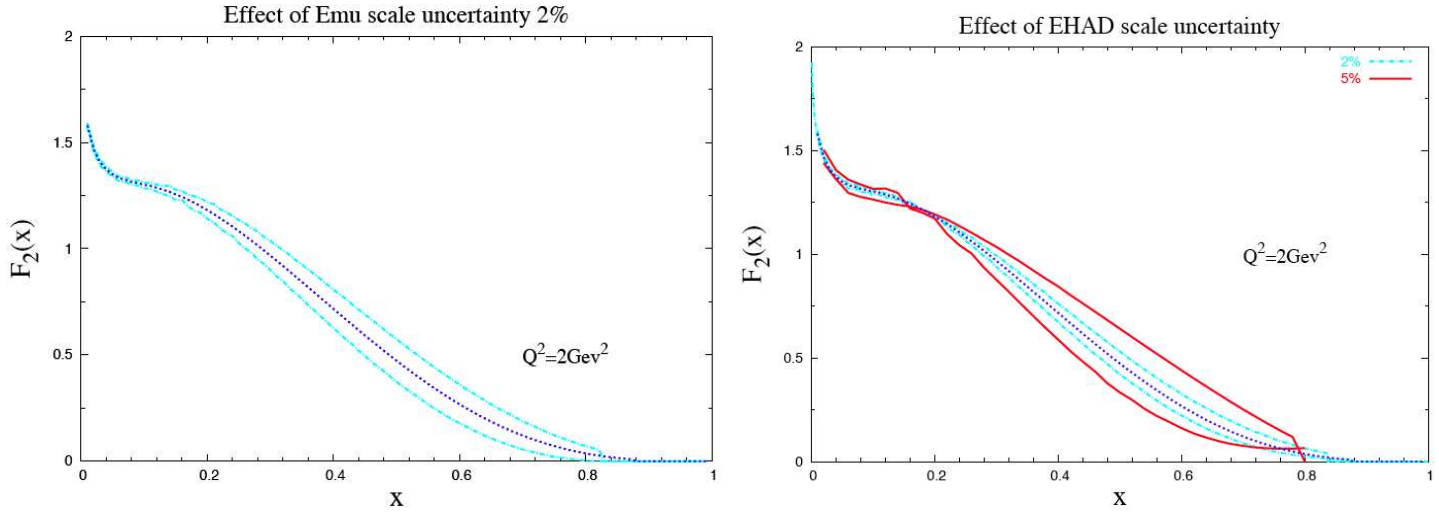
The MINOS Near Detector

- Asymmetric, wide section centered on beam
- Field coil passes through center
- 282 planes, 153 instrumented
- Arrays of 4 × 1 cm extruded scintillator strips
- Forward section instrumented every plane
- Back (spectrometer) every 5th plane



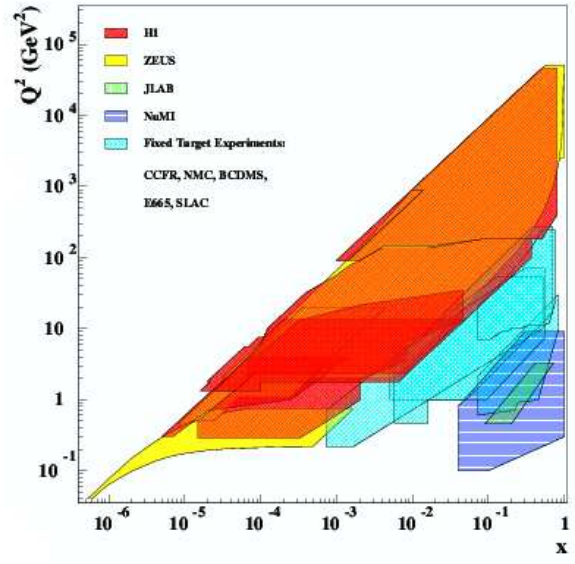


Expected MINOS Systematics

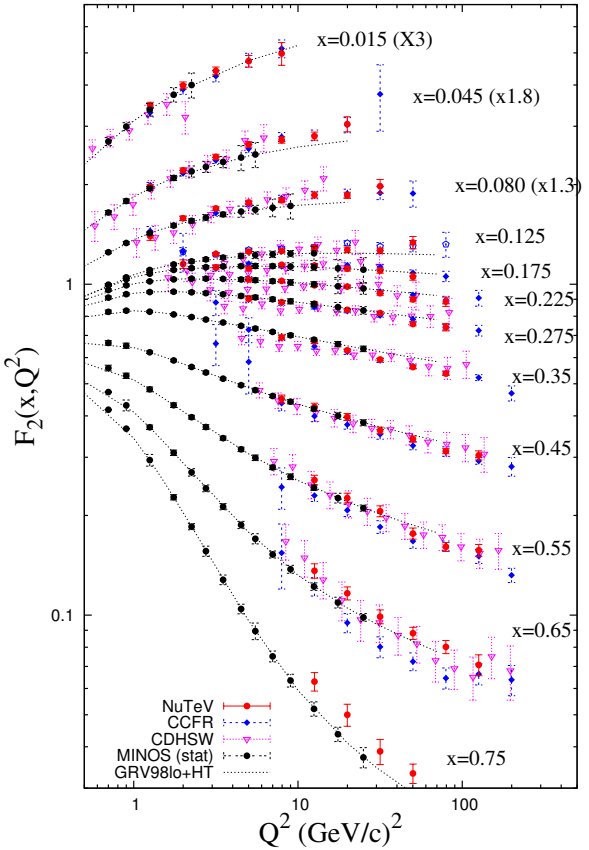


- MINOS energy scale uncertainties will dominate the statistical errors.
- NuTeV solved this with dedicated calibration beams
  - 0.47% hadronic energy scale, 0.7% muon energy scale
- No calibration beam into the NuMI near hall $\Longrightarrow$ larger uncertainties

DIS in MINOS



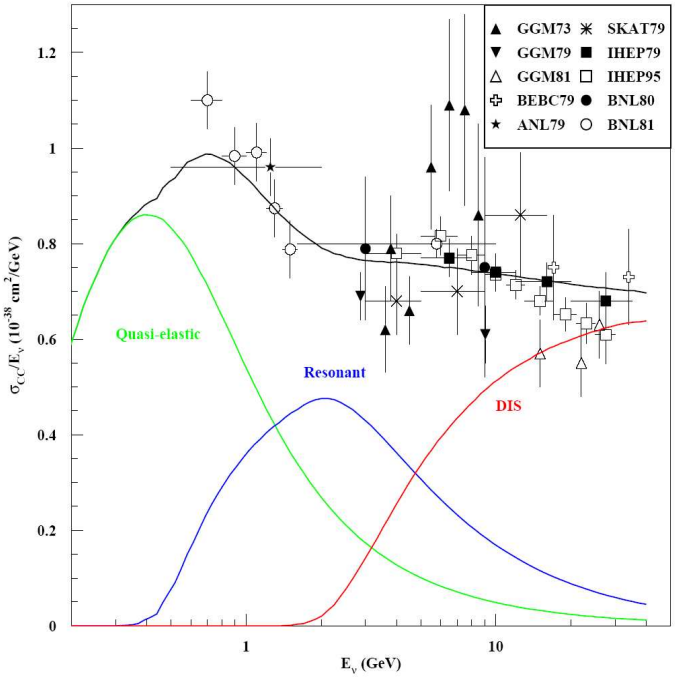
- New region of phase space opens up:
  low Q^2, high x
- Very high statistics:
  $\sim$ 6M ν CC, $\sim$ 0.9 $\overline{\nu}$
  (compare to 1M ν, 0.3M $\overline{\nu}$ from NuTeV)



predicted MINOS points, pink, stat errs only

Revisiting Low E_ν...

- The low energy scale of ν-oscillations has allowed (forced ?) us to revisit low energy $\nu - N$ scattering.
- Ancient cross section measurements lack required accuracy $\Longrightarrow$
  - Example: uncertainty in NC π^0 production causes trouble for next generation of ν_e appearance experiments.
- Transition into ν DIS is not well understood
- Minimal data available for understanding neutrino nuclear corrections.
  Are they different from charged leptons?

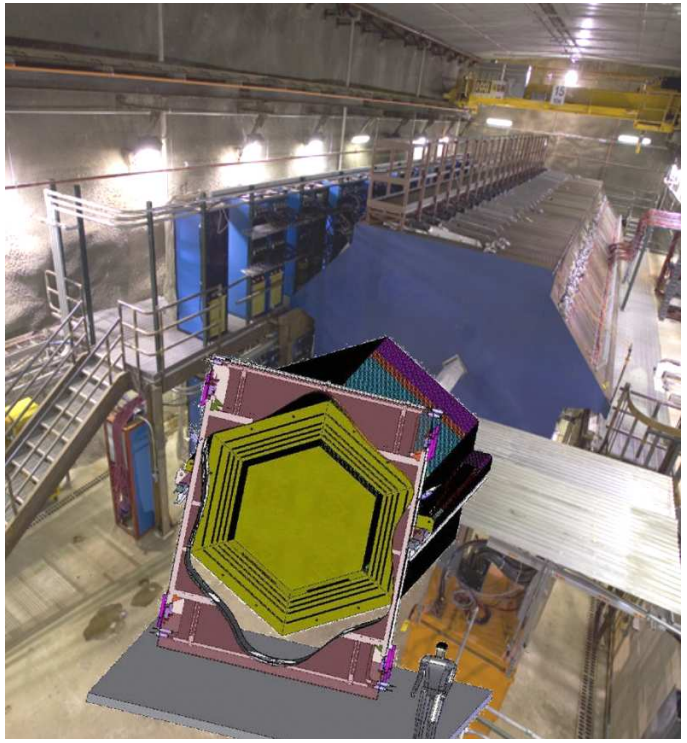


(NEUGEN predicted curves with data points)

$\Longrightarrow$ need new precise cross section measurements from different nuclear targets!

Enter MINERνA...

- Placed upstream of MINOS near detector
  - Using MINOS N.D. as μ spectrometer
- An amalgam of tested detector technology
  - Scintillator strip based active core
  - Wrapped in EM, hadronic calorimeters
  - Carbon, iron, lead nuclear targets
- Has Stage 1 approval, FNAL E-938
- Expected turn on in 2009, $\geq$ 4 year run
- To straddle MINOS & NOνA runs
  - MINOS: low E_ν, NOνA: medium E_ν

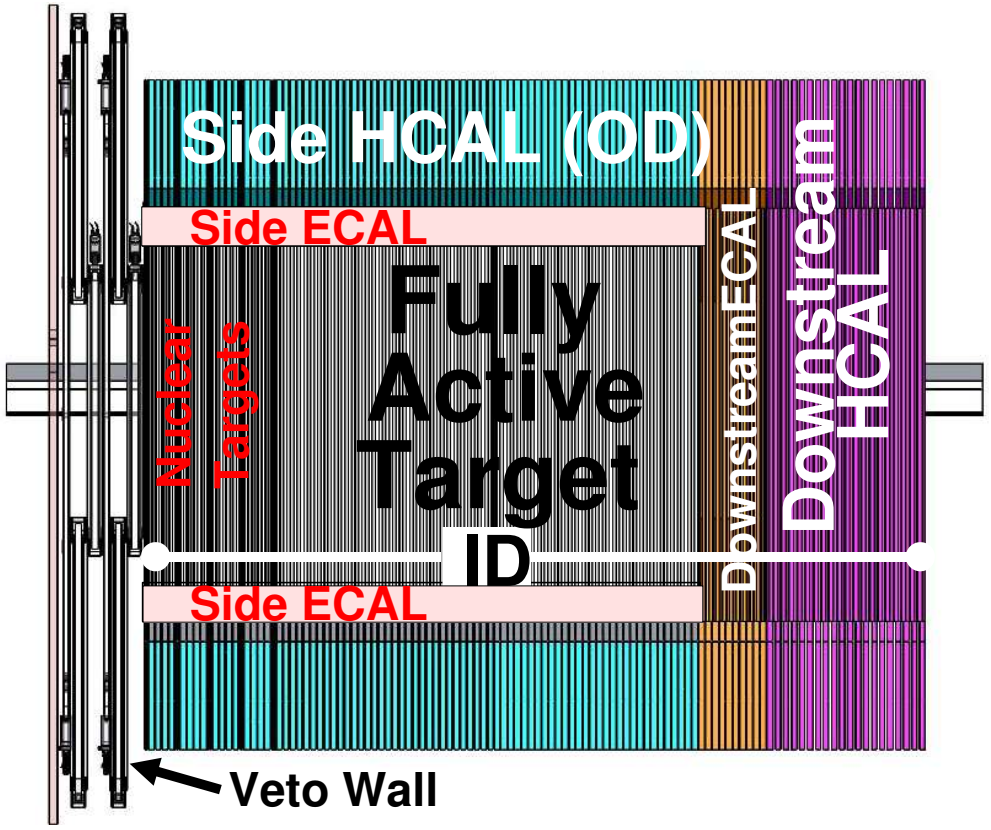


MINERνA Physics & Event Samples

- Quasi-elastic scattering ($\nu_\mu N \to \mu^- P$) (0.8M events)
- Resonance production (1.6 M events)
- Resonance production $\Longrightarrow$ DIS transition region (2 M events)
- Deep Inelastic Scattering (4.1 M events)
  - Structure functions and high x pdfs
- Nuclear Effects, npdfs (8.6M CH, 1.5M C, 1.5M Fe, 1.5M Pb events)
- Exclusive strange and charm production ($>$ 230k fully reconstructed)
- Coherent pion production (85k CC, 37k NC events)
- Generalized parton distributions ($\sim$ 10k events)

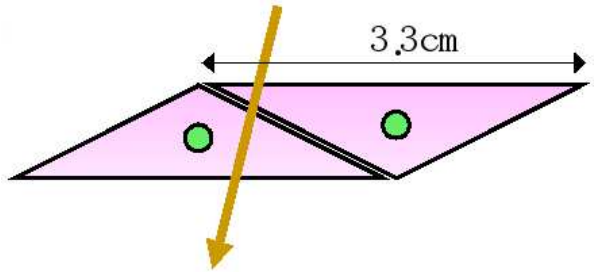
The MINERνA Detector

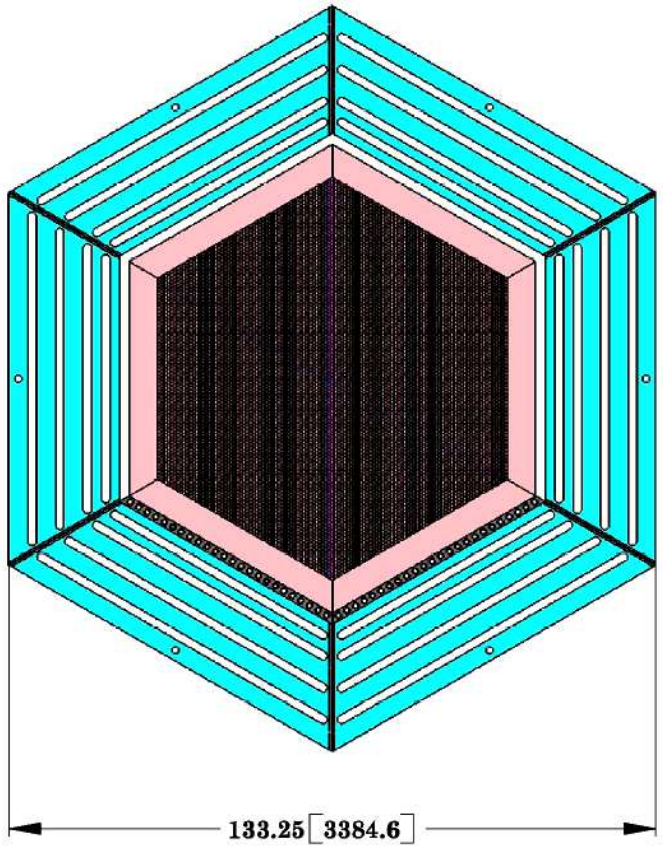
- Sandwiched layers hang like file folders, then secured together
- Active target composed of arrays of triangular scintillator bars
- Target encased in calorimeters
- Nuclear targets in front, sandwiched between scintillator planes
- 5.2 meters long, 8.3 ton active target, 3.7 tons nuclear targets



Active Target Plane

- Hexagonal scintillator planes (U, V views)
- Inner detector fully active scint. strips
- Lead washers around outside of target
- 1 module = 1 stack of XUXV planes
- Triangular scintillator profile for finer resolution through light sharing ($\sigma \sim 3$mm)
- 128 scintillator strips per I.D. plane
- 8 rectangular strips in each of 6 towers in calorimeter

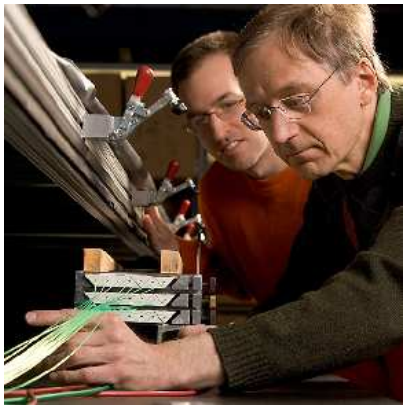




MINERνA: Towards a real detector and data running

2006 Vertical slice test

- MINERνA has functioning multi-layer scintillator array, taking CR data



2007 Finish constructing 20% tracking prototype

- To develop detector construction and event reconstruction techniques

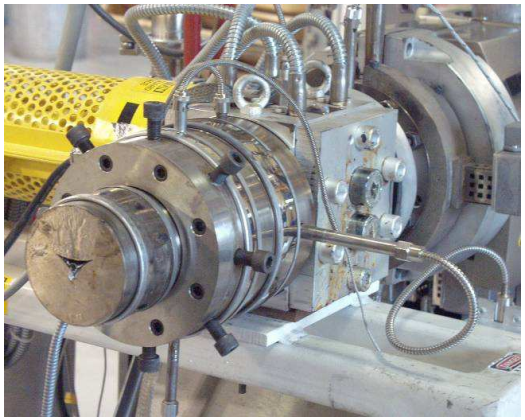
2008 Construction should be underway of final detector

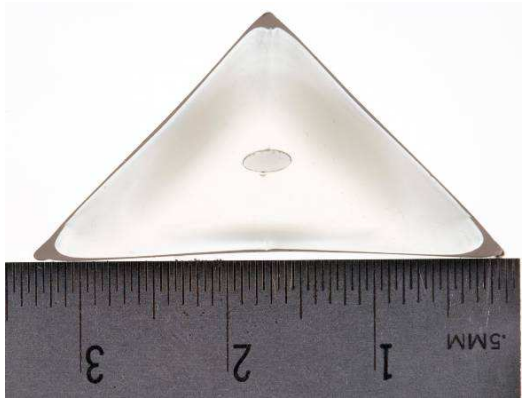
- Cosmic Ray studies with 20% prototype
- Testbeam run

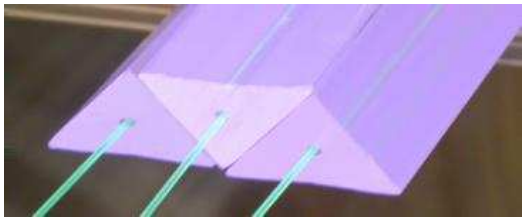
2009 Completing detector construction, installation

- Mid 2009 MINERνA hopes to be taking data!

Towards a real detector – Scintillator prototyping



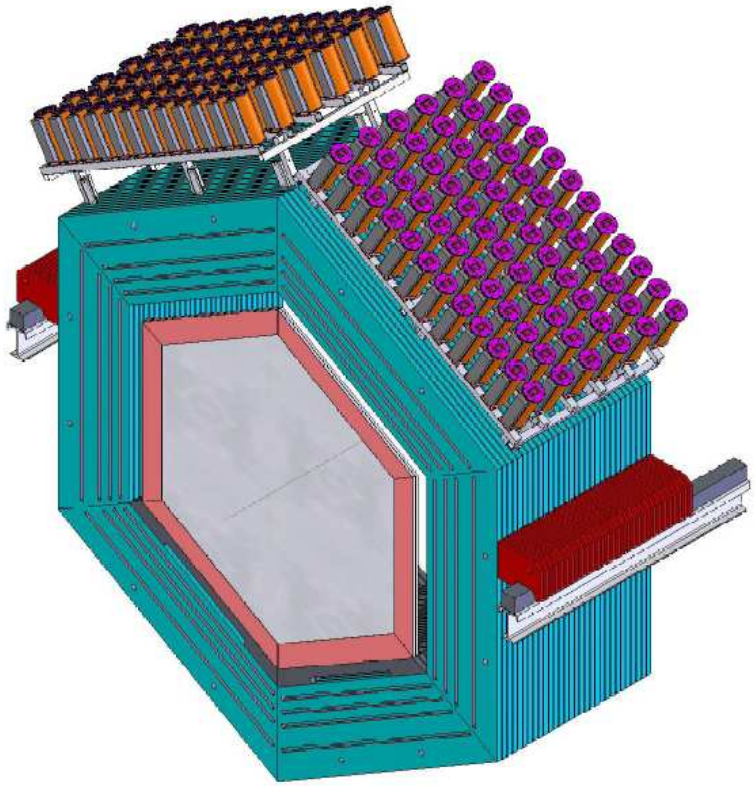




- Scintillator bars are extruded plastic, glued-in WLS fibers through the middle.
- MINERνA has working extruder, able to produce prototypes for testing.
- Studied attenuation and light yield of WLS fibers, flexibility, light loss
- Now using prototype scintillators and fibers in vertical slice test setup to test light yield, position and timing resolution.

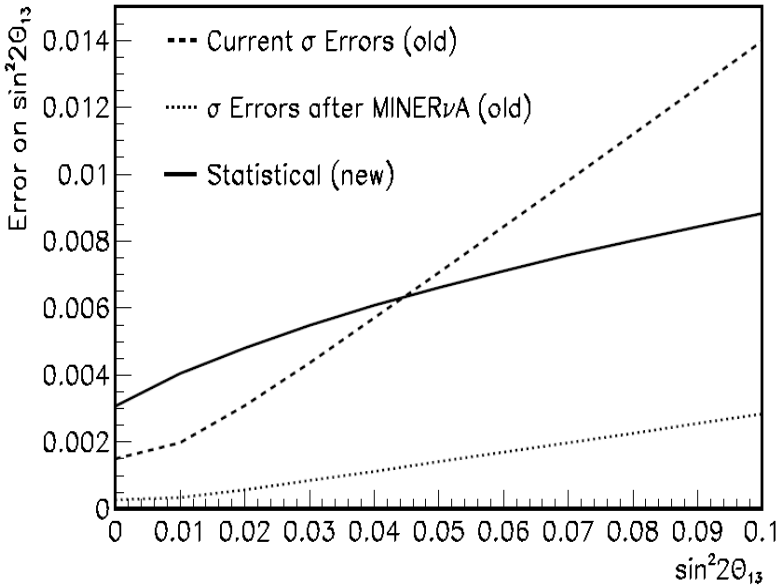
Towards a real detector II – 20% Prototype

- Approx. 20% of full detector
- Full EM Pb calorimeter
- To be used for the following tests:
  - Scintillator spacing uniformity
  - Inter-plane spacing uniformity
  - Determining how close planes should be stacked
  - How to perform repairs / replace electronics
- Installation to start in late 2007
- Cosmic ray data taking in 2008



Example: Effect of MINERνA on NOνA

Process	$\frac{\delta\sigma}{\sigma}$ now	$\frac{\delta\sigma}{\sigma}$ post-MINERνA
QE	20%	5%
Resonant	40%	5% (CC), 10% (NC)
Coh. π	100%	5% (CC), 20% (NC)
DIS	20%	5% (CC), 10% (NC)



- NOνA could be limited by cross section uncertainties without MINERνA measurements
- Note improvement in knowledge of DIS cross sections

Summary

- There have been and will continue to be many interesting $\nu - DIS$ results
- Still expect new results from NuTeV, NOMAD, & CHORUS
- Data taking has begun with MINOS, huge DIS data sample expected
  - Low Q^2, high x cross section
- MINERνA expected to come online in 2009
  - Many precise cross section measurements on a variety of nuclear targets
  - Detector development is proceeding
  - Vertical slice test this year
  - Construction of 20% prototype next year
  - Detector construction and installation in 2008-9

Thanks To:

The Conference Organizers

- and -

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Roberto Petti

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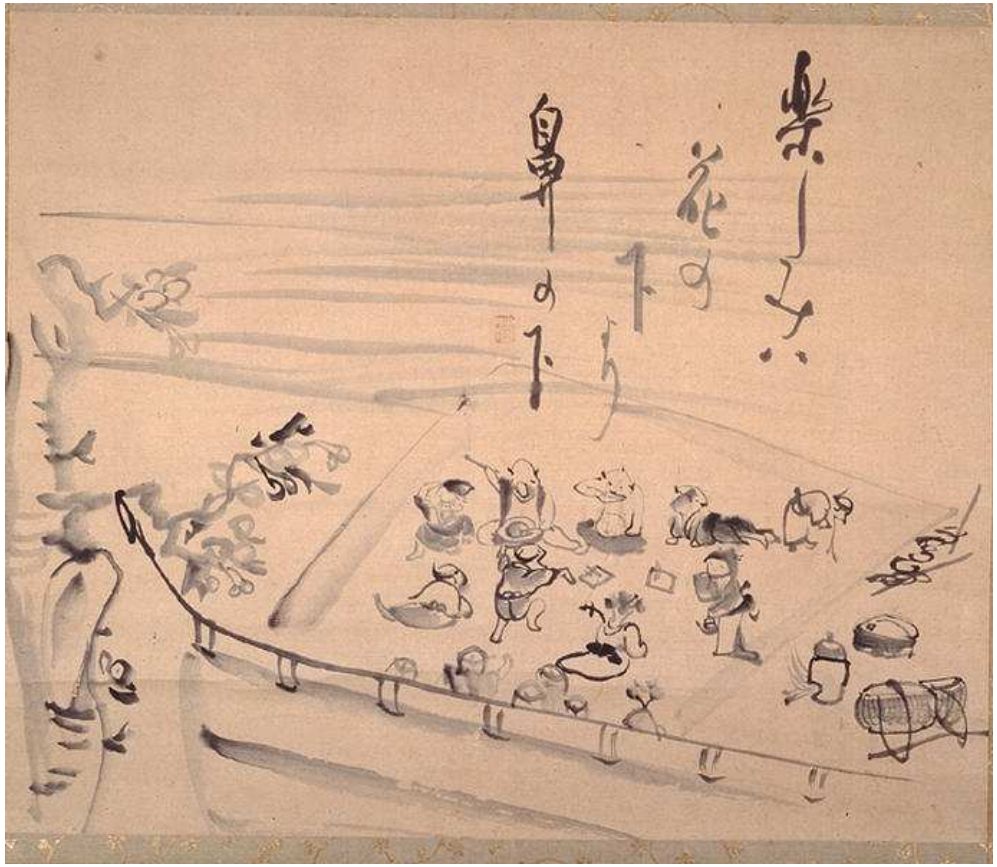

The DIS 1806 Conference