Conventional neutrino experiments

Heidi Schellman
P5
February 21, 2008

Conventional neutrino experiments @FNAL

	Fiducial mass	Energy	POT, x	Technology	Status	Goal
DONuT	0.3 T	20-300 GeV	0.03	Emulsion	complete	τ neutrino
NuTeV	680 T	20-300 GeV	0.03	Iron/Scint	complete	θ_w, DIS, charm
MiniBooNE	440 T	0.3-2 GeV	10	Mineral Oil	running	σ, anomaly
SciBooNE	10 T	0.3-2 GeV	2	Scintillator	running	σ, QE, Coh
MINOS near	100 T	1-20 GeV	25	Iron/Scint.	running	σ, QE, Coh, DIS
Minerva	5T	1-20 GeV	15	Scintillator	2010	σ, QE, Coh, excl., A dep., DIS
MicroBoone	50 T	0.3-2 GeV	6	Liquid Argon	Proposal	σ, QE, Coh, low E excess
HiResMNu	7.4T	1-20 GeV	120	magnetic tracker		θ_W, σ, excl.
NuSonG	3000 T	20-300 GeV	2	Glass	EOI	θ_W, DIS, A dep.

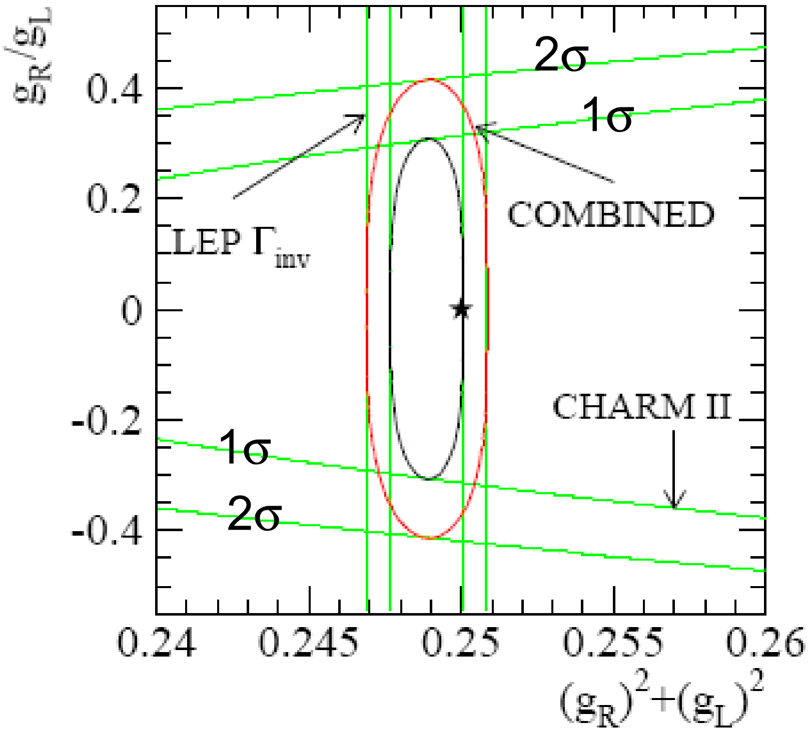
Why do more conventional neutrino experiments

- We should do it
    - Discovery requires a firm foundation, we need the best neutrino cross sections, PDF’s, and standard model parameters to get the most out of oscillation experiments and the LHC.
    - We don’t know what is out there – 2 orders of magnitude more luminosity in relatively unexplored (but clean) channels with much better detectors.
- We can do it
    - Neutrino Oscillation experiments have driven neutrino beam intensities up by factors of a hundred
    - Moore’s law has made fine segmentation possible
    - New detector technologies

- What have we done for you lately?

Standard Model parameters

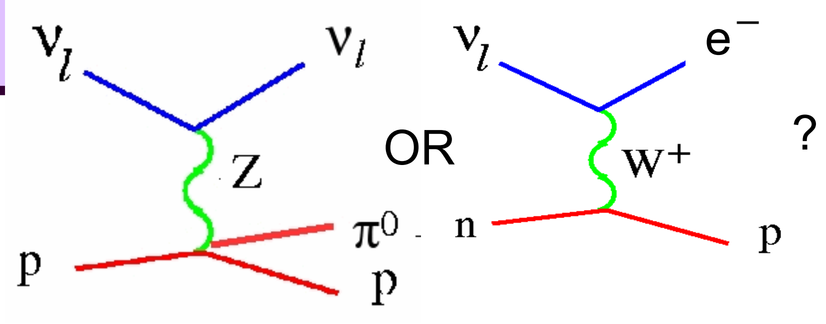
- Weak mixing parameters
  - $\sin^2\theta_w$ in neutrino sector (g_R^ν is only constrained by neutrino experiments) ⇨
  - V_{cd} (CHORUS)
- QCD
  - $\alpha_s(Q^2)$ (NuTeV xF_3)
  - Parton distributions, including unique sensitivity to q/qbar difference



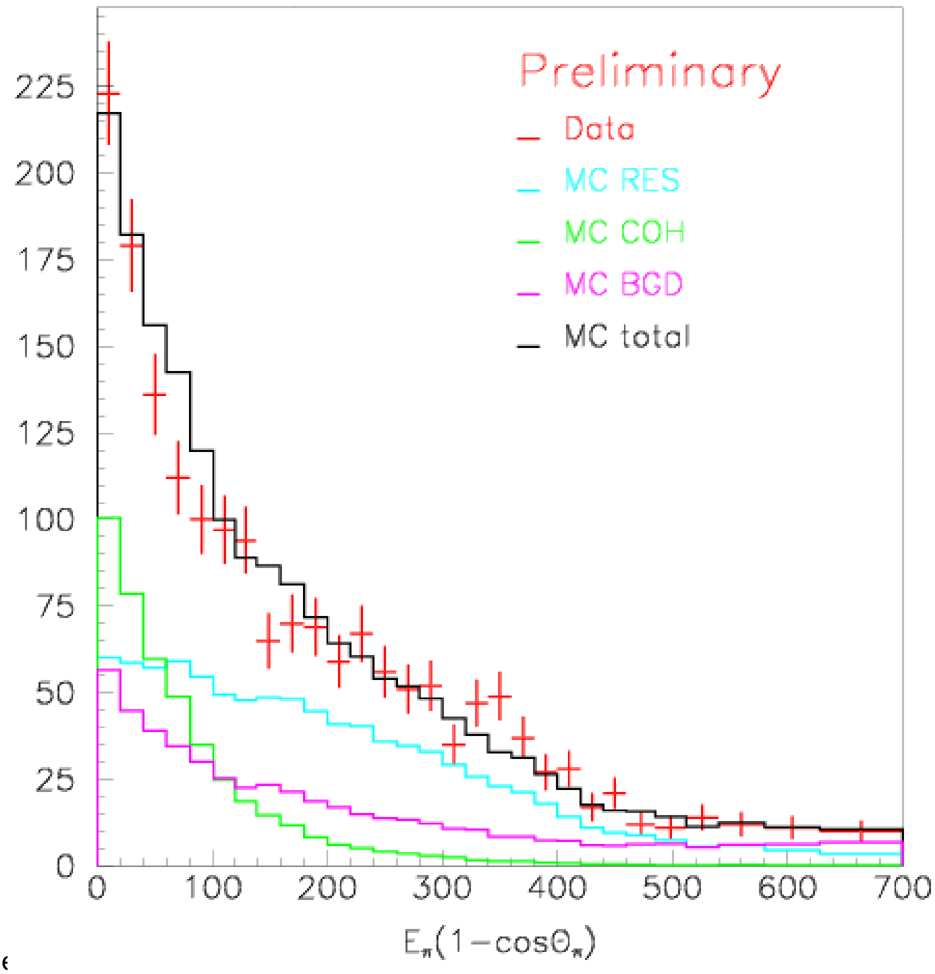
Current (1990's) neutrino experiments are still the standard for these measurements (check the PDG)

Low energy inclusive and exclusive cross sections

- π^0 NC important for oscillation experiments



MiniBoone Coherent π^0 measurement

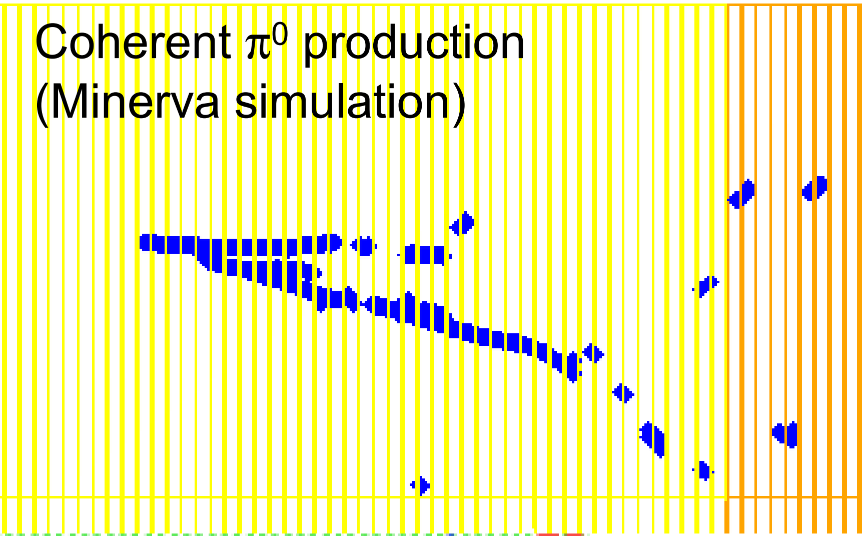


The intensity revolution

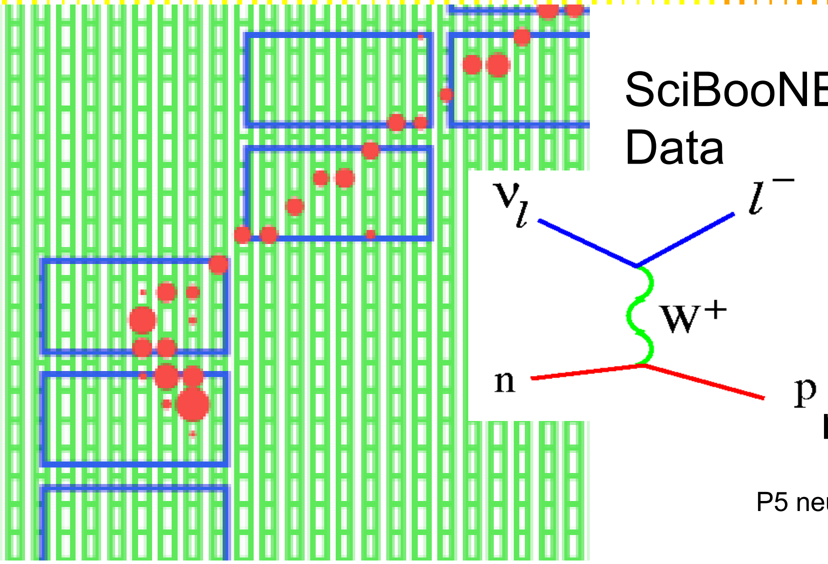
- The NUMI beam-line delivers 3×10^{20} protons/year - every year
- (NuTeV saw 3×10^{18} pot in 1997 –alternating with the collider)
- Improvements
  - the main injector
  - can run all the time
  - better machine instrumentation
  - TeVatron also has a decade of upgrades
- Future
  - NuMI upgrades →Project X !!
  - Tevatron?

Detector revolutions

Fine scintillator readout

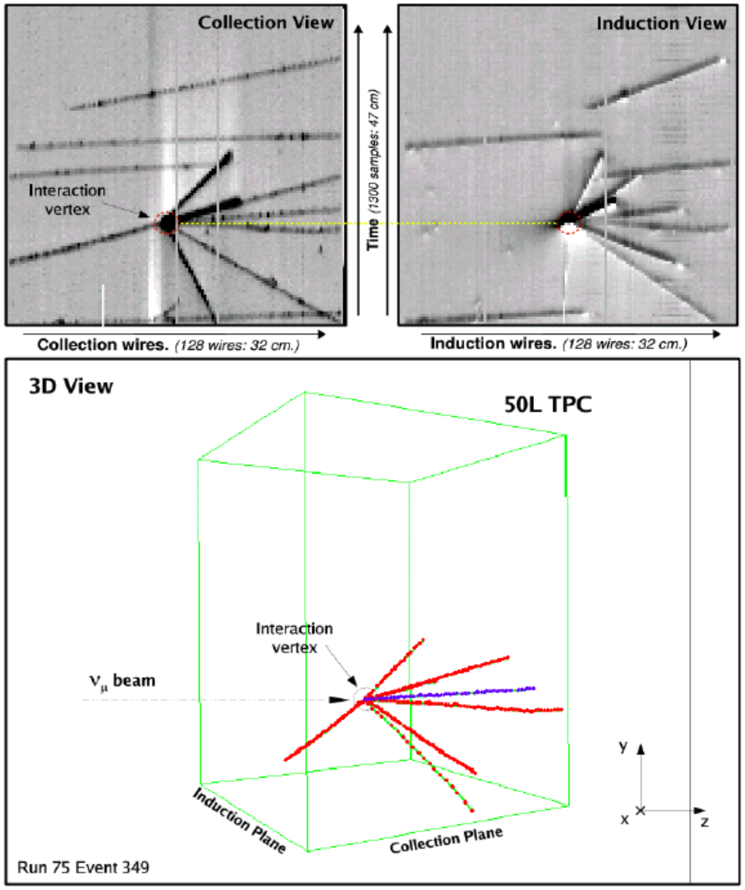


Coherent π^0 production (Minerva simulation)



SciBooNE Data

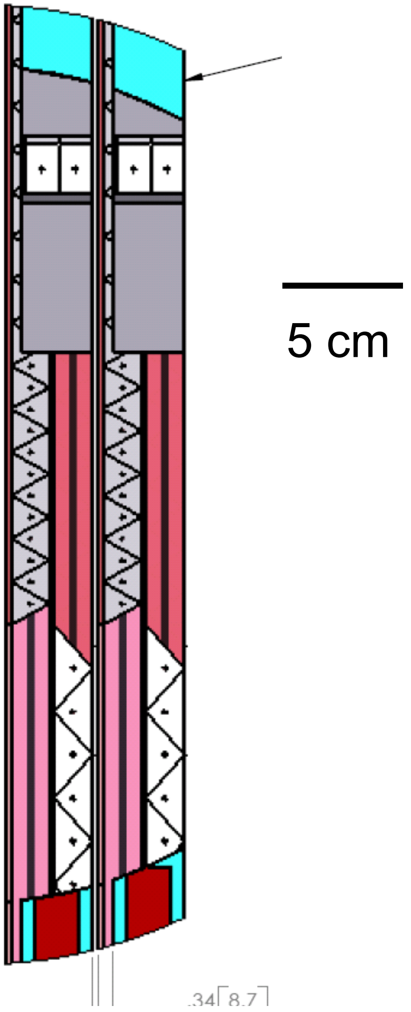
Liquid Argon TPC

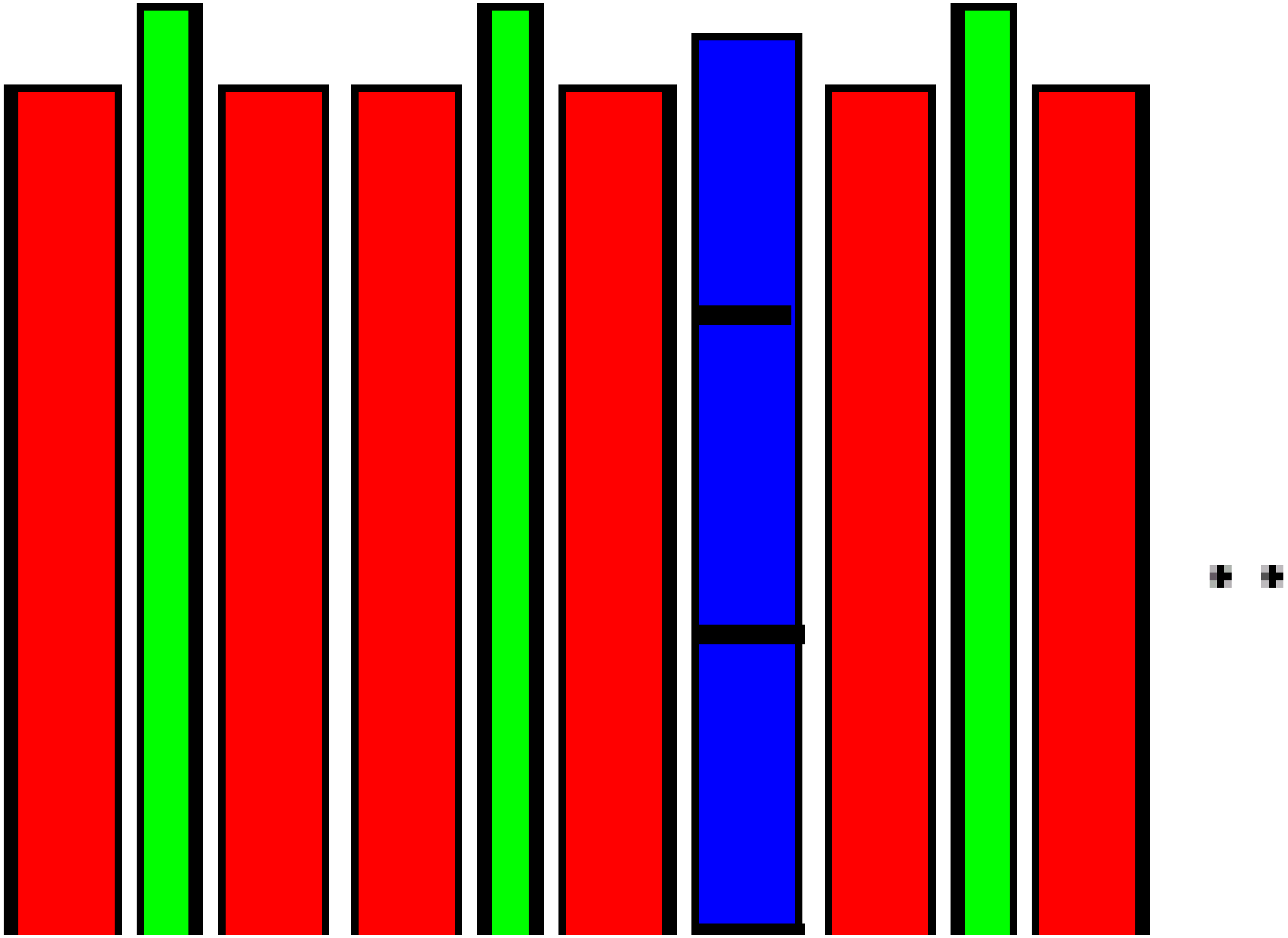


neutrino event in 50 ℓ prototype at CERN

MINERvA compared to NuTeV

Moore's law for electronics 800 channels → 32,000 for less $





Two strategies for using the intensity revolution for conventional neutrino measurements

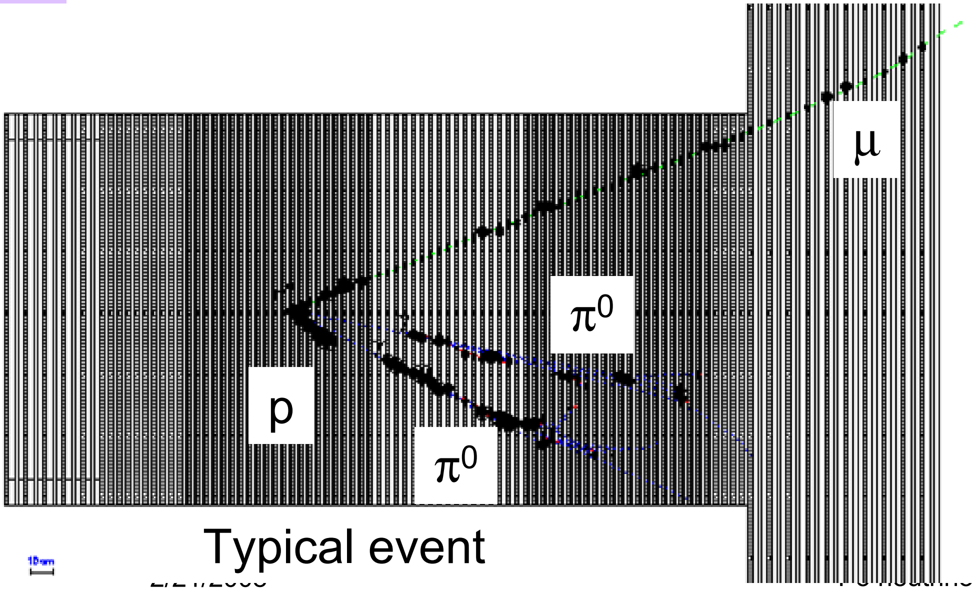
- Build much better but smaller fine grained detectors to study interactions in detail – and still have more events!
  - SciBooNE and MINERvA - scintillator
  - MicroBooNE – Liquid Argon TPC
  - HiResMnu – Magnetic tracker

- Build better bigger detector and shoot for 50x the luminosity of the PDG level experiments
  - NuSonG – TeVatron sign selected beam
  - possible tau neutrino factory using a TeVatron beam dump, 1000 DONuT's
  - others?

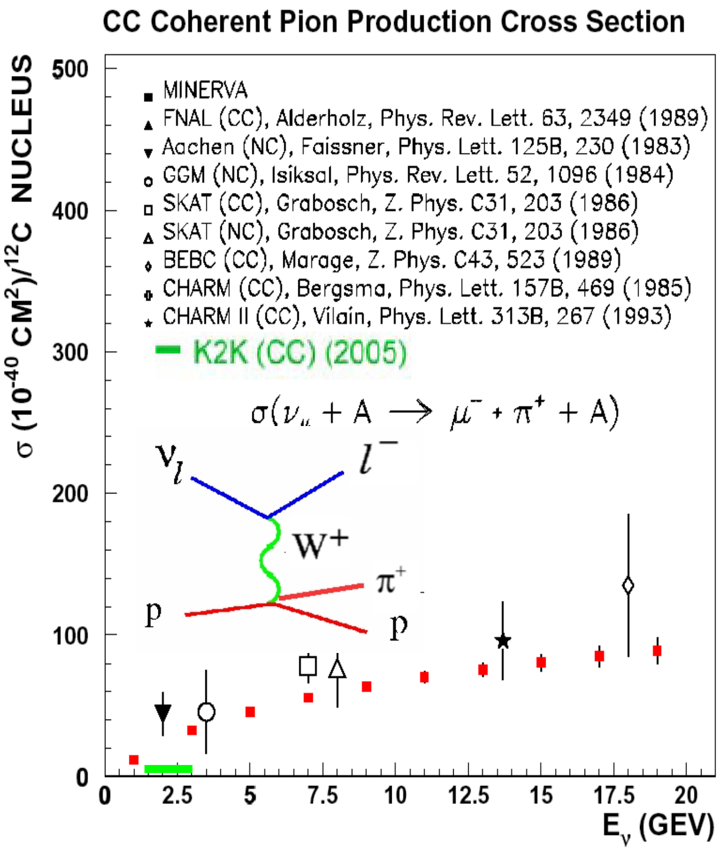
Detailed measurements

Example MINERvA 4 year run

8.6 M ν events in CH
1.4 M ν events in C
2.9 M ν events in Fe
2.9 M ν events in Pb

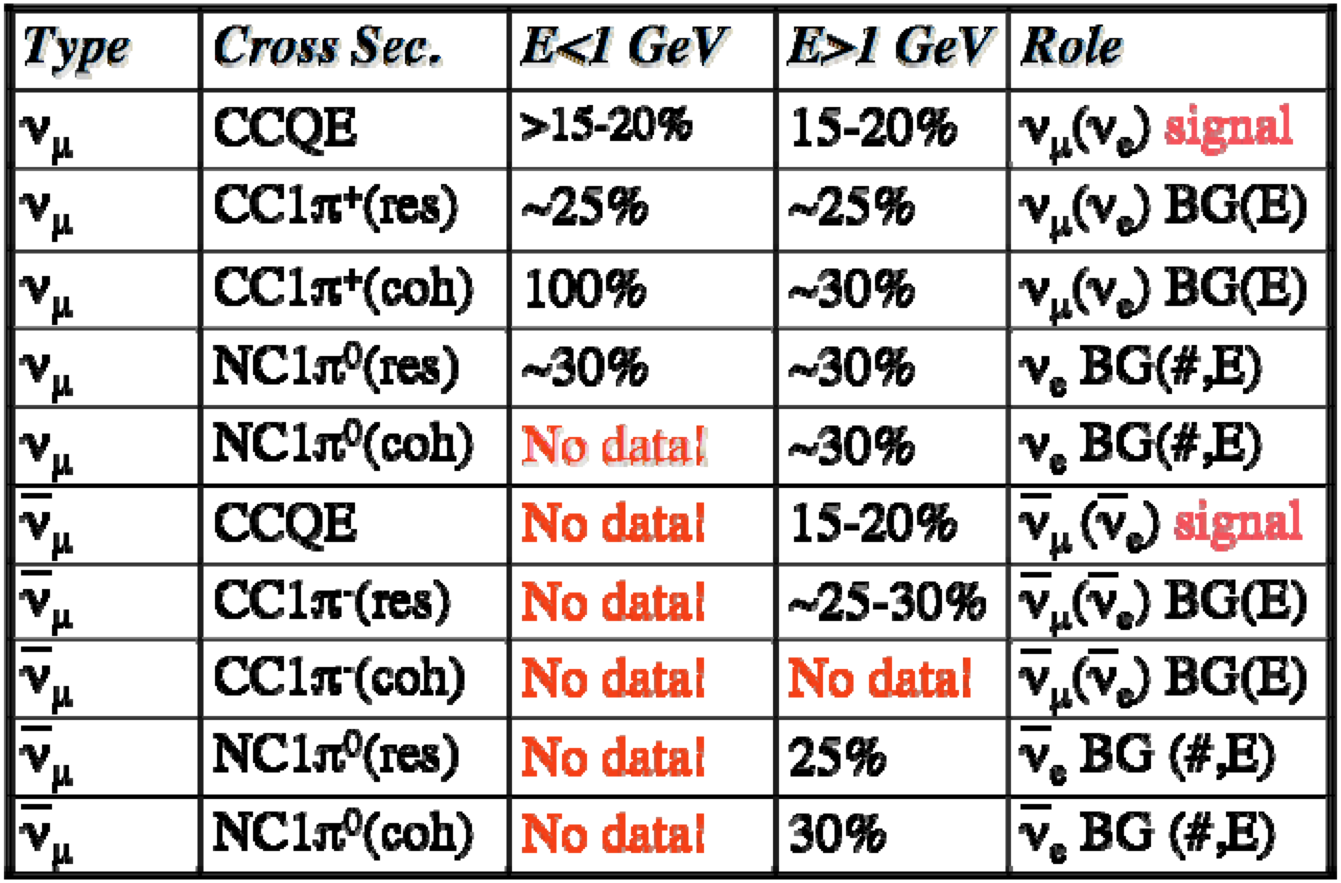


Typical event



Current world samples are ~ 10^5 events

Present knowledge of neutrino cross sections

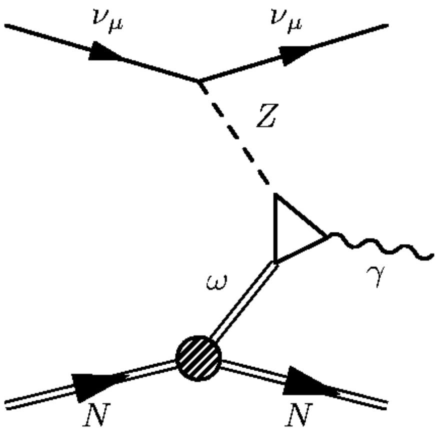


Type	*Cross Sec.*	*E<1 GeV*	*E>1 GeV*	*Role*
ν_μ	CCQE	>15-20%	15-20%	$\nu_\mu(\nu_e)$ signal
ν_μ	CC1π^+(res)	~25%	~25%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	CC1π^+(coh)	100%	~30%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	NC1π^0(res)	~30%	~30%	ν_e BG(#,E)
ν_μ	NC1π^0(coh)	No data!	~30%	ν_e BG(#,E)
$\bar{\nu}_\mu$	CCQE	No data!	15-20%	$\bar{\nu}_\mu(\bar{\nu}_e)$ signal
$\bar{\nu}_\mu$	CC1π^-(res)	No data!	~25-30%	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	CC1π^-(coh)	No data!	No data!	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	NC1π^0(res)	No data!	25%	$\bar{\nu}_e$ BG (#,E)
$\bar{\nu}_\mu$	NC1π^0(coh)	No data!	30%	$\bar{\nu}_e$ BG (#,E)

SciBooNE and MINERvA will these reduce errors to 5-10%

Detailed measurements

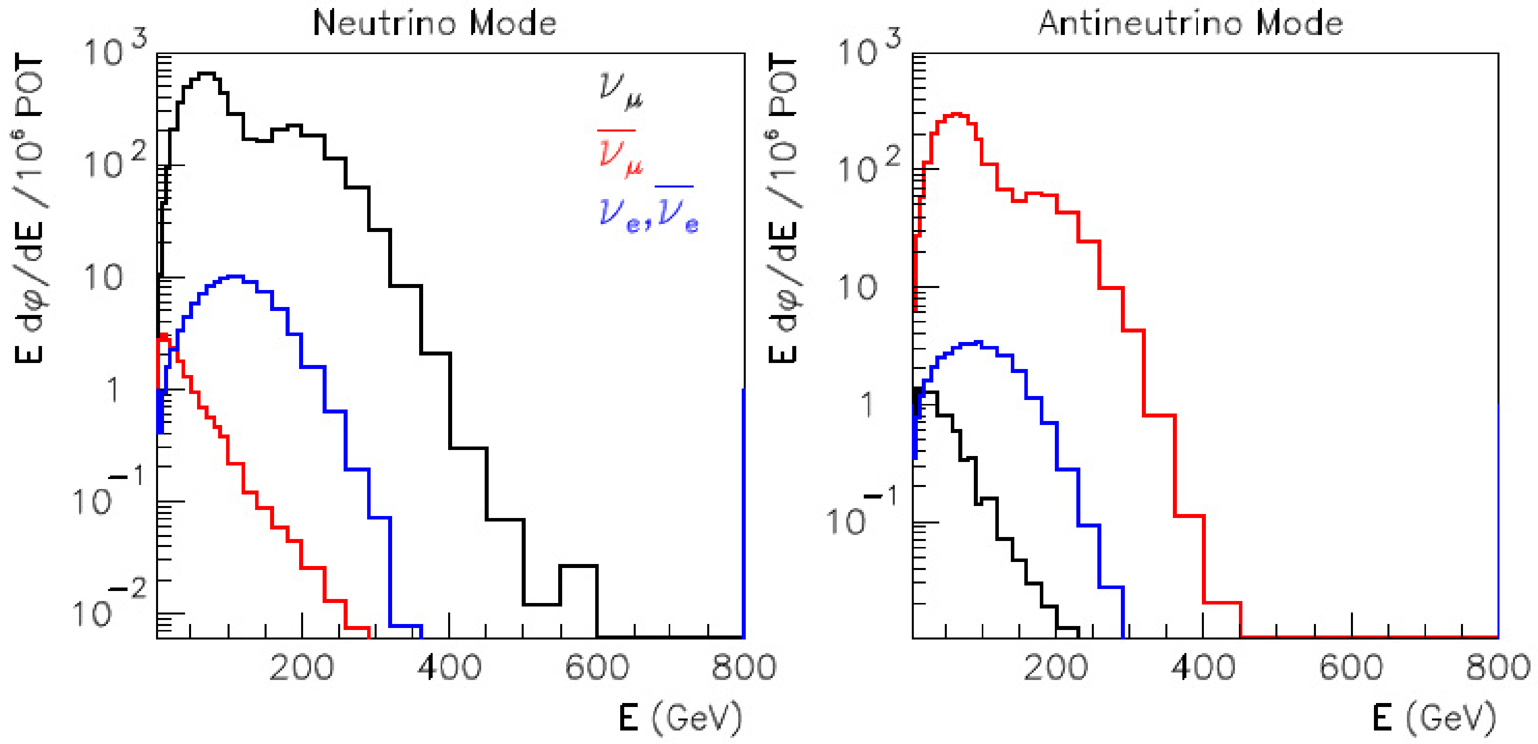
- Necessary physics
  - backgrounds and references for oscillations
- New physics - with 10-100 times more
  - Anomalies
  - Non-standard neutrino interactions
  - ??
- Complementary physics
  - Similar kinematics to JLab experiments
  - Finally have sufficient detail in the final state and enough statistics to make useful comparisons of νp and ep scattering.



High Luminosity - Example

- Proposed neutrino program at the TeVatron
  - raise protons/batch by x3
  - shorten ramp time
  - run for 5 years
- Example: NuSonG:
  - Build a segmented 3-4 kT fiducial volume modern detector with low A
  - Result, 100 times the data of any previous experiment in a better detector
- Note:
  - The accelerator exists!
  - Neutrino detectors are “transparent” – you can run many in the same beamline

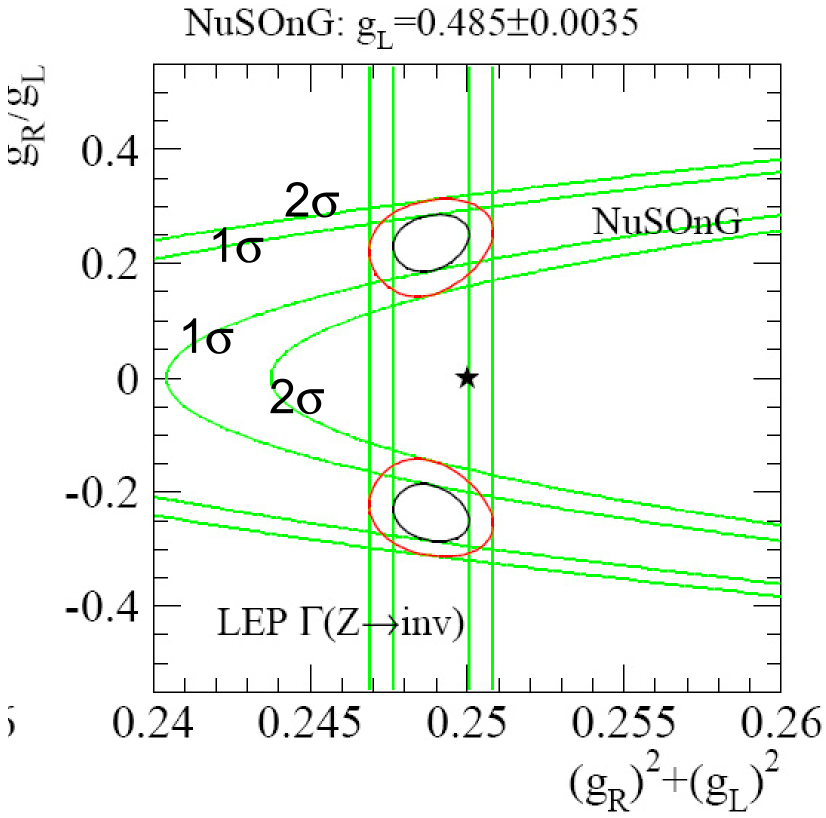
Clean sign separation in a neutrino beam



NuSonG $\nu_e e \rightarrow \nu_e e$

- ~5 years of running =
- 50 times previous experiments
- ~1G DIS events
- 75K $\nu_e e \rightarrow \nu_e e$
- 7 K anti-$\nu_e e \rightarrow$ anti-$\nu_e e$
- measure ρ and $\sin^2\theta_w$
- 700K $\nu_\mu e \rightarrow \nu_e \mu$ for clean flux measurements

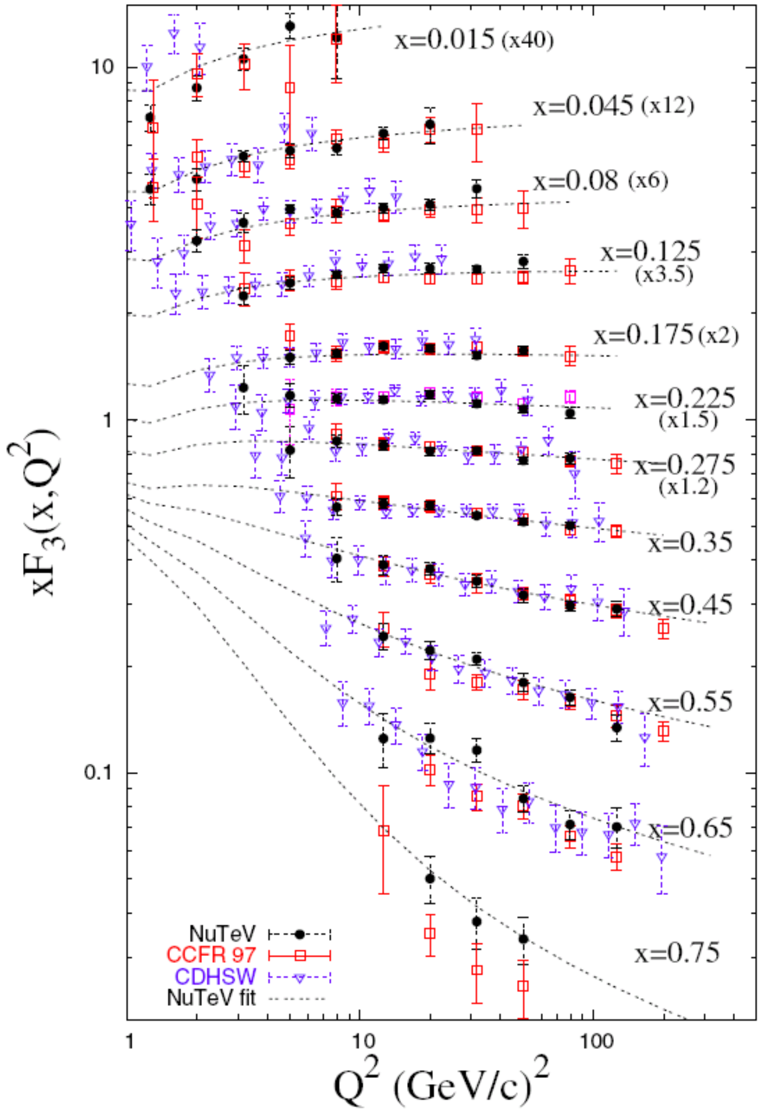
new physics scenario



Structure functions

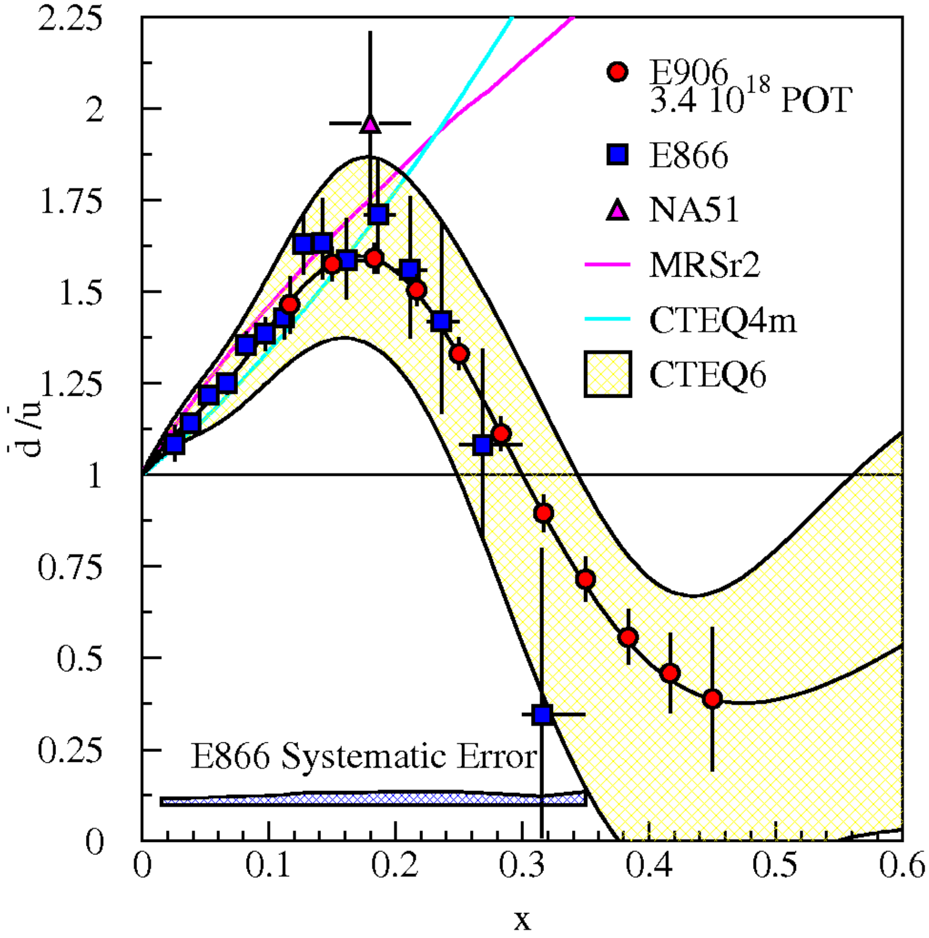
- $F_2(x)$ - $xF_3(x)$ measures the anti-quarks
- Evolution constrains α_s and the gluon
- Caveat – nuclear effects need to be understood – measure A dependence using a fraction of the fiducial mass
- Data from Hera and precision neutrino experiments will provide unbiased reference inputs into LHC physics when we reach the precision stage.

Current status of xF_3
NuSonG adds ~ 100 x



And a related experiment E906

- Approved by FNAL PAC for a run at 120 GeV
- Measure the anti-quark d/u ratio in pp Drell-Yan scattering
- Very important for LHC! The dominant errors on the Z cross sections at the LHC are currently best constrained by fixed target Drell-Yan.



Conclusions

- Fixed Target Neutrino Programs provide:
  - crucial measurements to support discovery experiments
  - potential for discoveries themselves
  - measurements which coordinate with the Nuclear Community

- There are three future opportunities in the US
  - ☑ Continued running of the Fermilab 8 GeV line
  - ☑ Running on Long Baseline lines (NuMI, DUSEL)
  - ☐ A Tev-based Program

- These opportunities belong on the HEP roadmap

References

- MINOS
  - http://www-numi.fnal.gov/
- MiniBoone
  - http://www-boone.fnal.gov/
- SciBoone
  - http://www-sciboone.fnal.gov/
- MINERvA
  - http://minerva-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=700
- MicroBoone
  - http://www-microboone.fnal.gov/
- HiResMnu
  - http://www.fnal.gov/directorate/Longrange/Steering_Public/FERMI08_Petti.pdf
- NuSonG
  - http://www-nusong.fnal.gov/
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2222
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2849