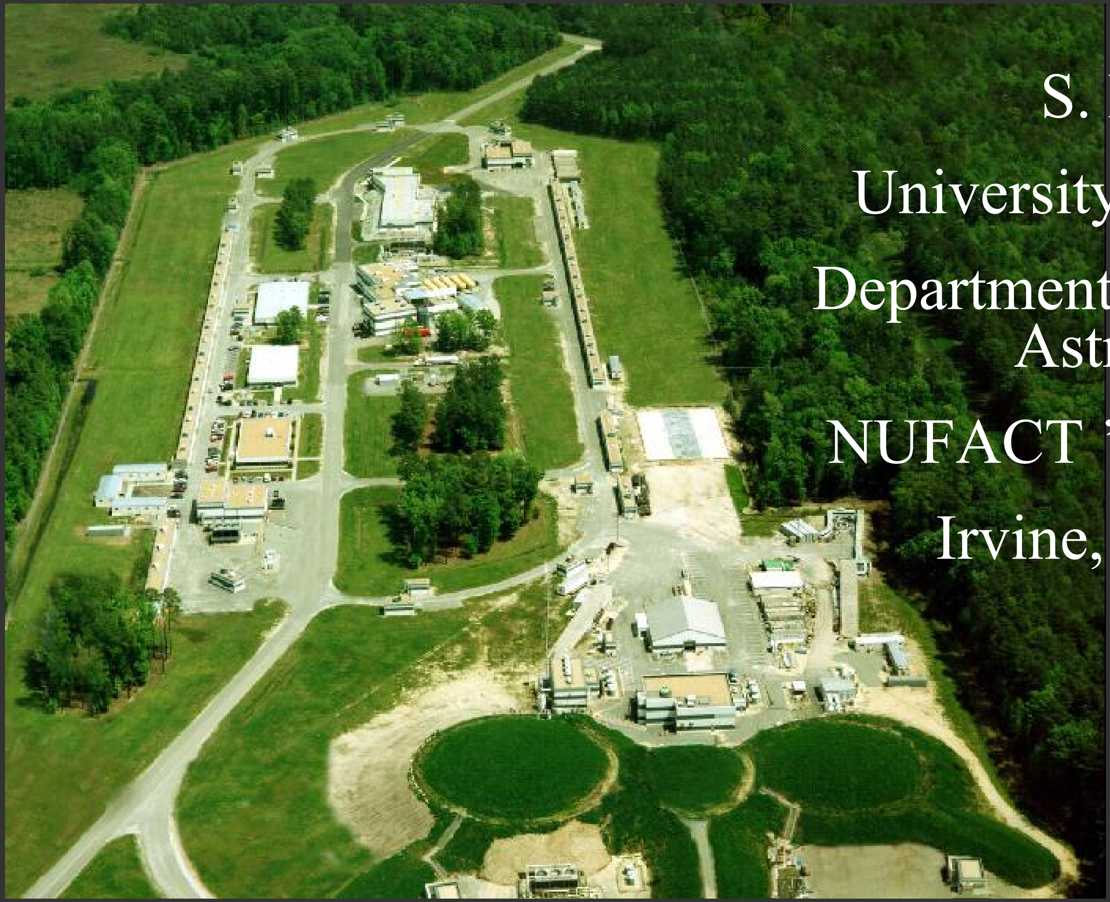
Recent Electron Scattering Results from Jefferson Laboratory



S. Manly

University of Rochester

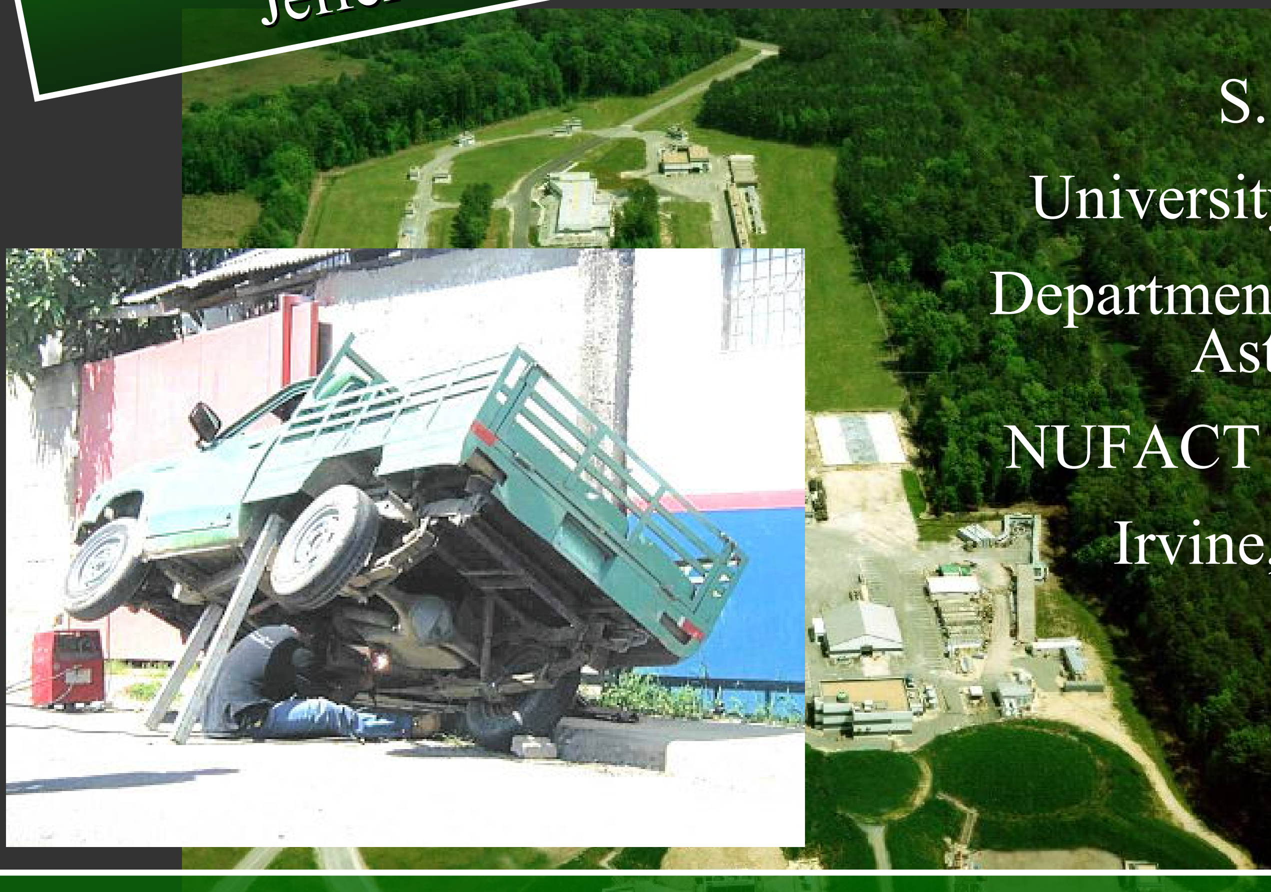
Department of Physics and Astronomy

NUFACT '06, Aug. 2006

Irvine, California

Recent Electron Scattering Results from Jefferson Laboratory

Update on several electron scattering experiments at Jefferson Lab relevant for ν program



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JUPITER – Jlab Unified Program to Investigate nuclear Targets and Electroproduction of Resonances

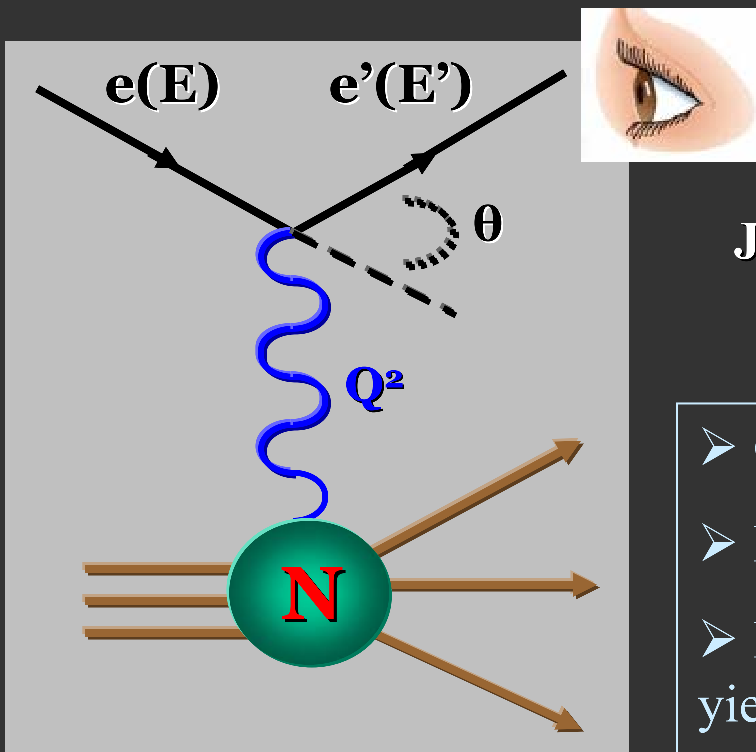
Wait a minute … we don’t care about no stinkin’ electrons!

Sure you do! …

- High statistics
- Control over initial energy and interaction point – gives kinematic constraints and ability to optimize detector
- Neutrino cross section can be written as a vector piece and an axial vector piece. Can get the vector piece from electron elastic electron-nucleon form factors using CVC
- Nuclear effects on final state should be similar … the eA data can constrain models used to quantify nuclear effects and resonance production in ν physics

Inclusive measurements

Detect e- only in final state

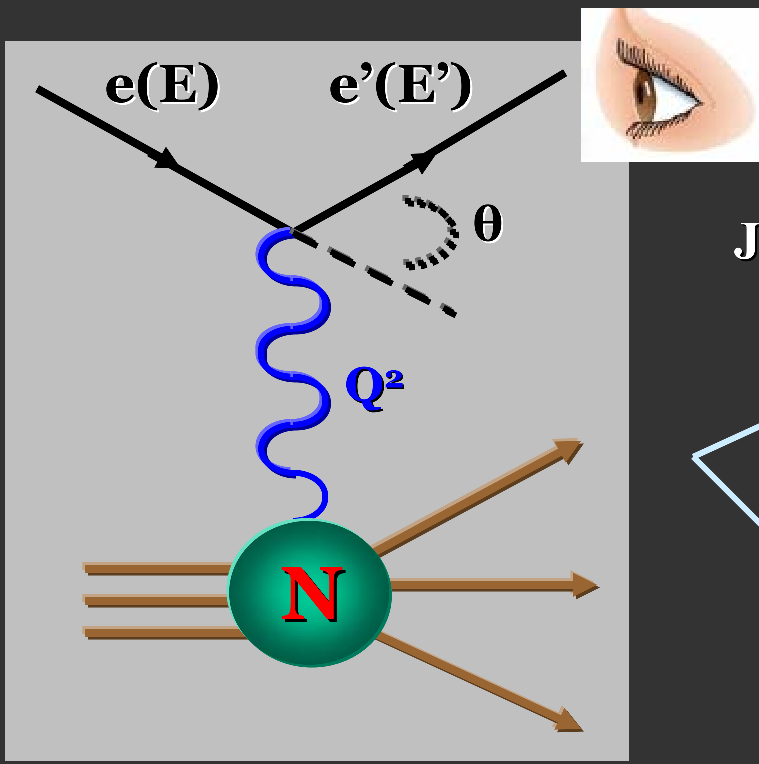


JLab E94-110, E02-109, E04-001, E06-009

- Completed
- Proton L/T separated SF's in resonance region
- Duality works, i.e., extrapolated DIS SF's yield what is observed by averaging out the resonance structure

Inclusive measurements

Detect e- only in final state



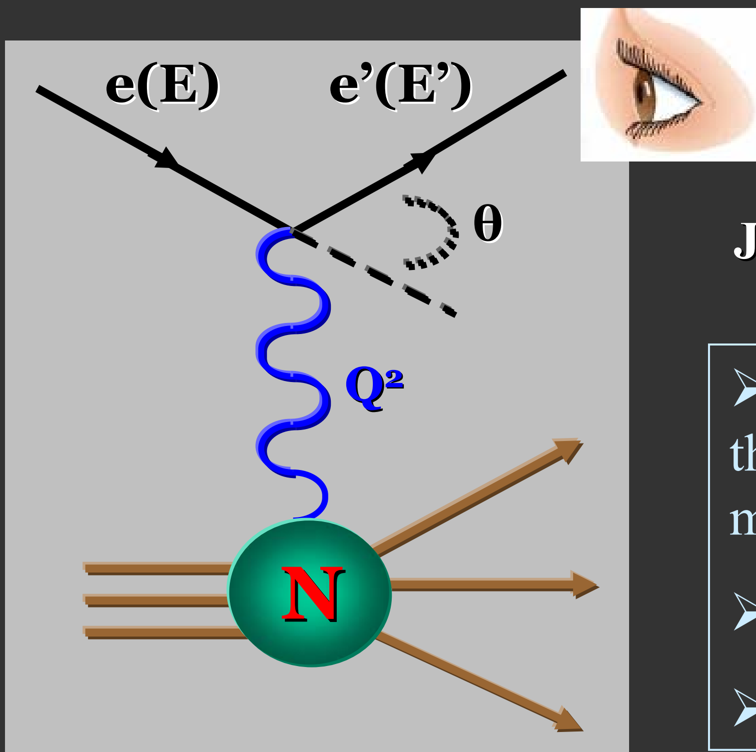
$0.3<Q^2<2\ GeV^2$ *$Q^2<4.5\ GeV^2$*

JLab E94-110, E02-109, E04-001, E06-009

- L/T sep. SF's on Deuterium in the resonance region and beyond (gets at the neutron)
- Already much data in hand
- Expect to run in April '07

Inclusive measurements

Detect e- only in final state

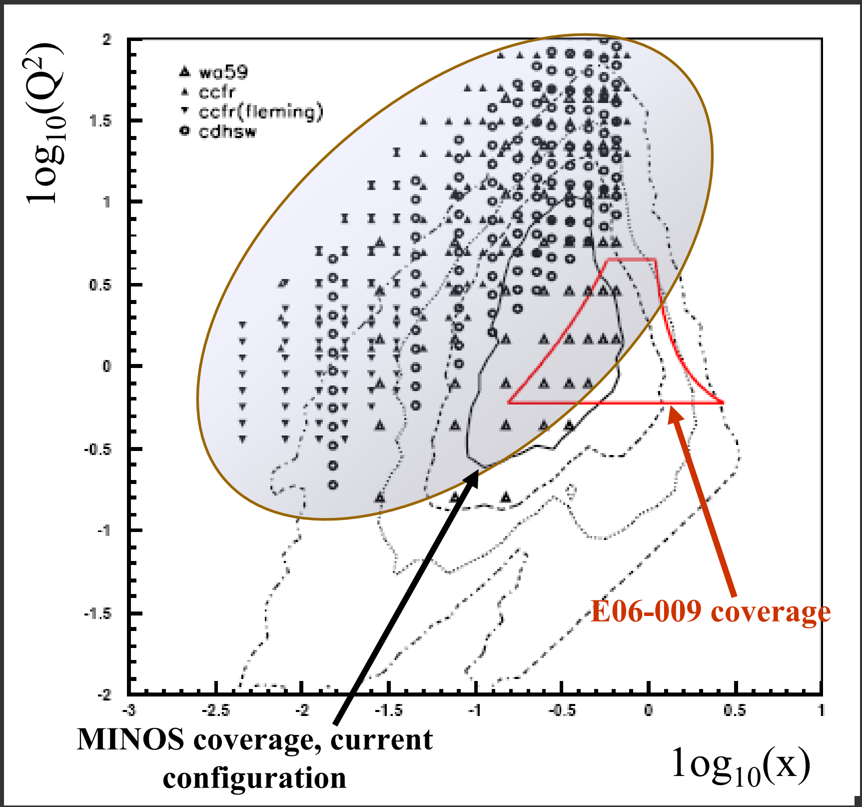


JLab E94-110, E02-109, E04-001, E06-009

- L/T sep. cross sections and SF's on nuclei in the resonance region and cross section measurement on nuclei at low Q^2
- H, D, C, Al, Fe
- Ran in Jan '05, preliminary results ready

Inclusive measurements

JLab E94-110, E02-109, E04-001, E06-009



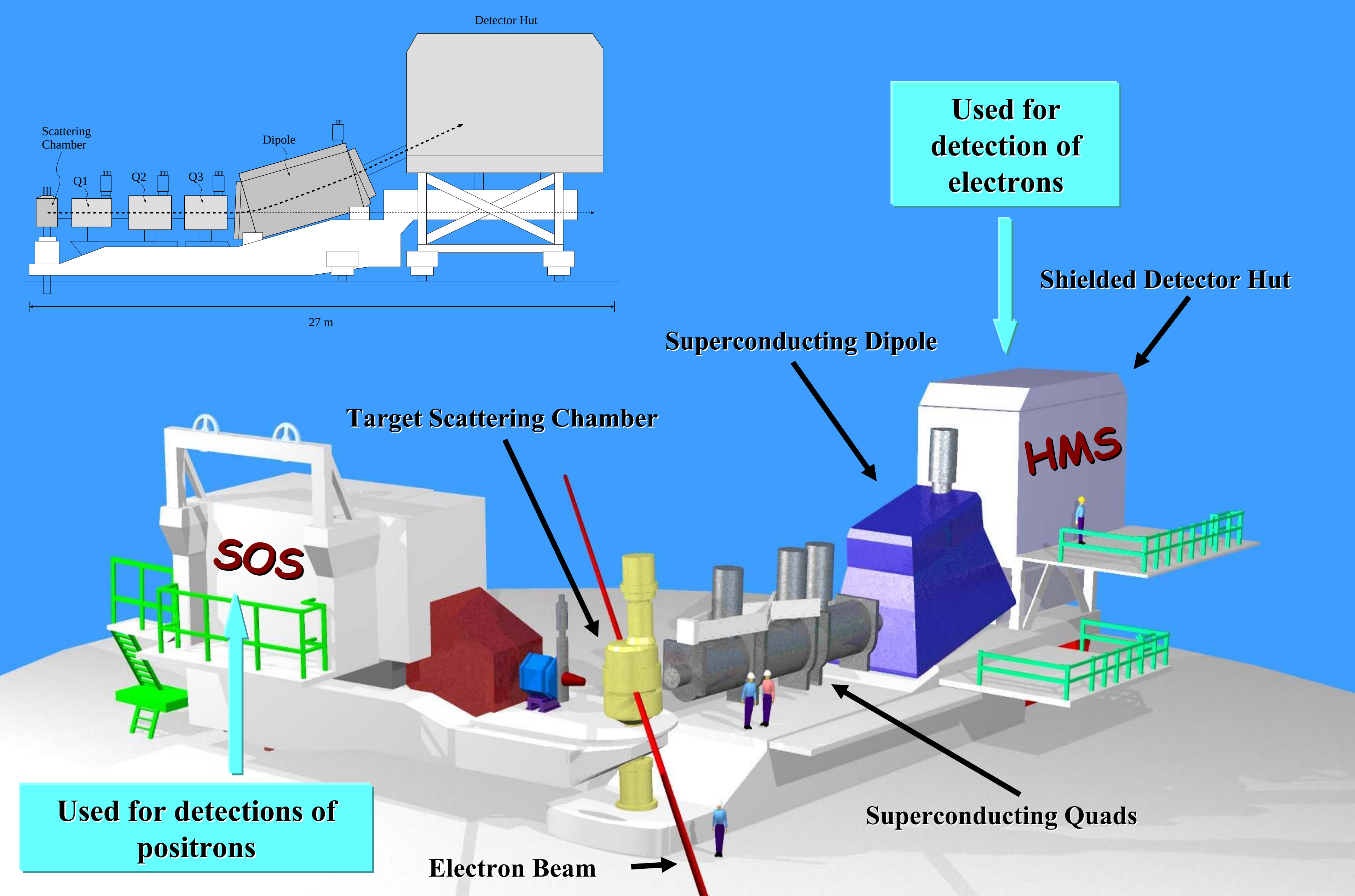
From H. Gallager in proposal for E06-009

Collectively these expts get at -

- Proton and neutron vector form factors
- Quark-hadron duality
- Nuclear effects on structure functions

Neutrino structure function measurements, MINOS coverage and coverage of E06-009, these measurements help us build a cross section model in region of relevance

Jlab Hall C



Detector Hut
Scattering Chamber
Dipole
Q1
Q2
Q3
27 m
Used for detection of electrons
Shielded Detector Hut
Superconducting Dipole
Target Scattering Chamber
HMS
SOS
Superconducting Quads
Used for detections of positrons
Electron Beam

e - N scattering formalism

Born Approximation

$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T\left(x, Q^2\right) + \varepsilon\sigma_L\left(x, Q^2\right)\right]$$

σ_T (σ_L) is the Transverse (Longitudinal) virtual photon Cross Section

$$\Gamma = \frac{\alpha E'\left(W^2 - M_p^{\ 2}\right)}{2\pi Q^2 M_p E\left(1-\varepsilon\right)}$$

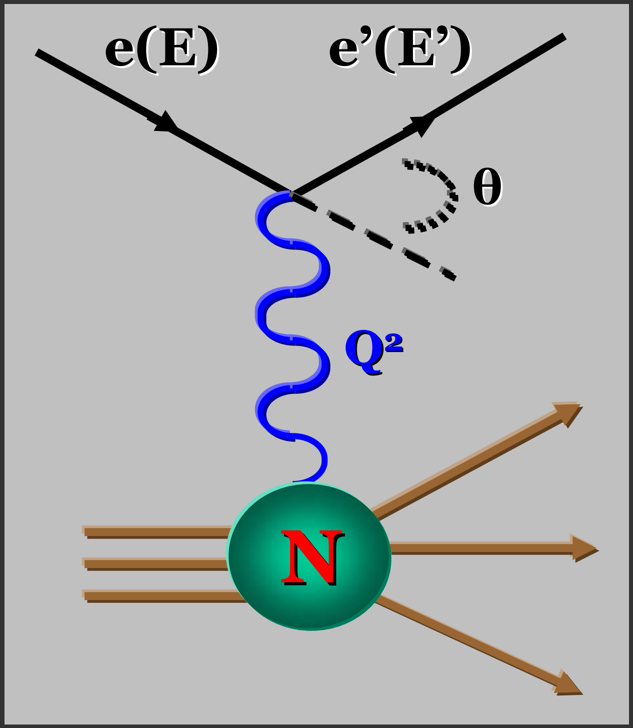
Transverse virtual photon flux

M_p - mass of the Proton

$$\varepsilon = \left[1 + 2\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2\frac{\theta}{2}\right]^{-1}$$

Virtual photon polarization parameter

$$\nu = E - E'$$



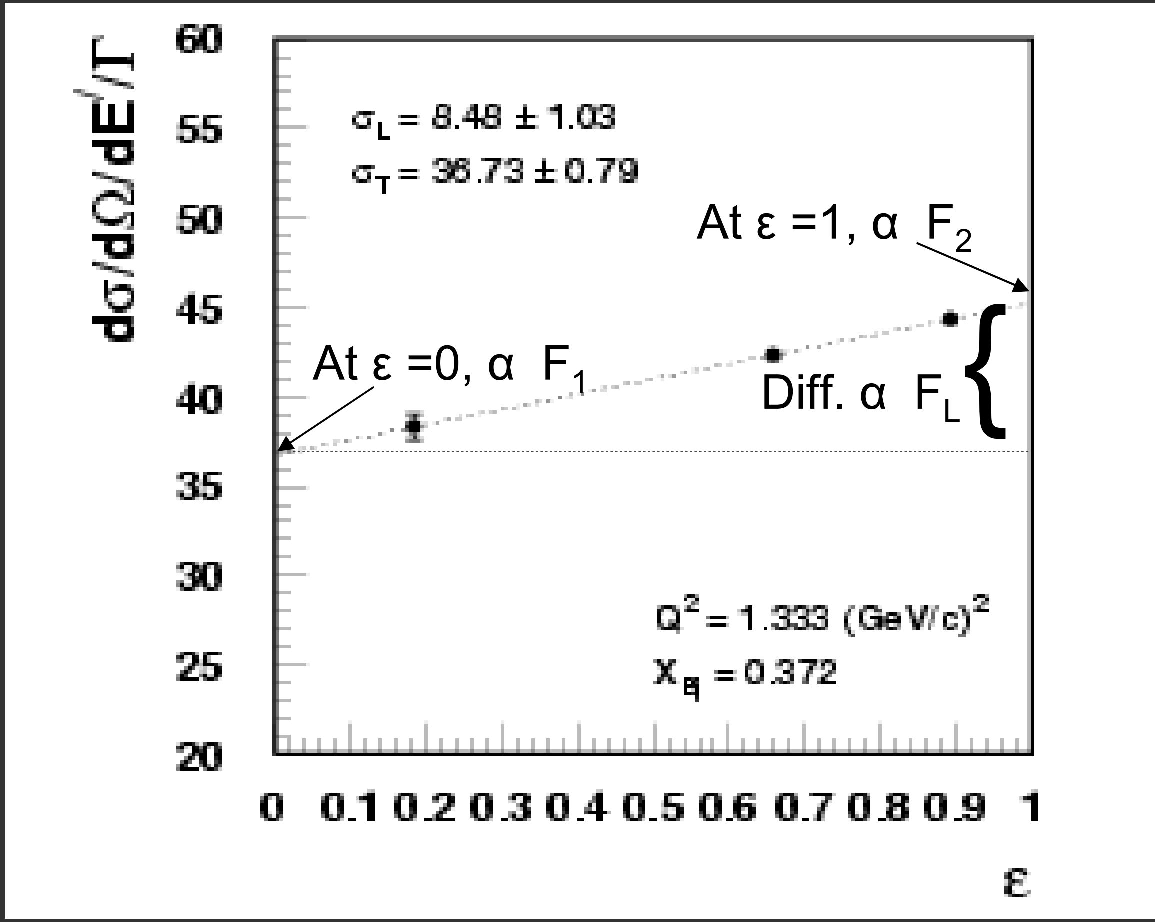
V. Tvaskis

Rosenbluth Separation

Reduced cross-section

$$\frac{1}{\Gamma}\frac{d\sigma}{d\Omega dE'} = \sigma_T\left(x,Q^2\right) + \varepsilon\sigma_L\left(x,Q^2\right)$$

- While keeping W^2 and Q^2 fixed, we plot the reduced cross-section vs ε
- Linear fit yields:
  σ_L = Slope
  σ_T = Intercept



Kinematic Coverage for E02-109 and E04-001

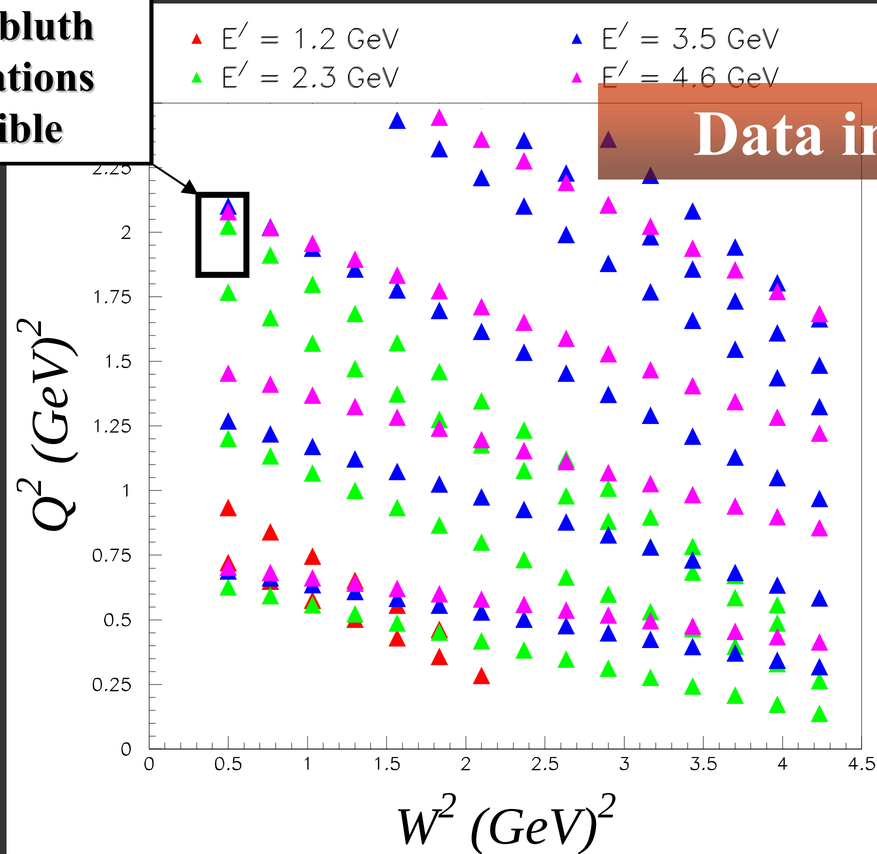
Rosenbluth Separation Data

- Targets: D, C, Al, Fe , and some H for crosschecks
- Projected final Uncertainties estimated at 1.6 % pt-pt.

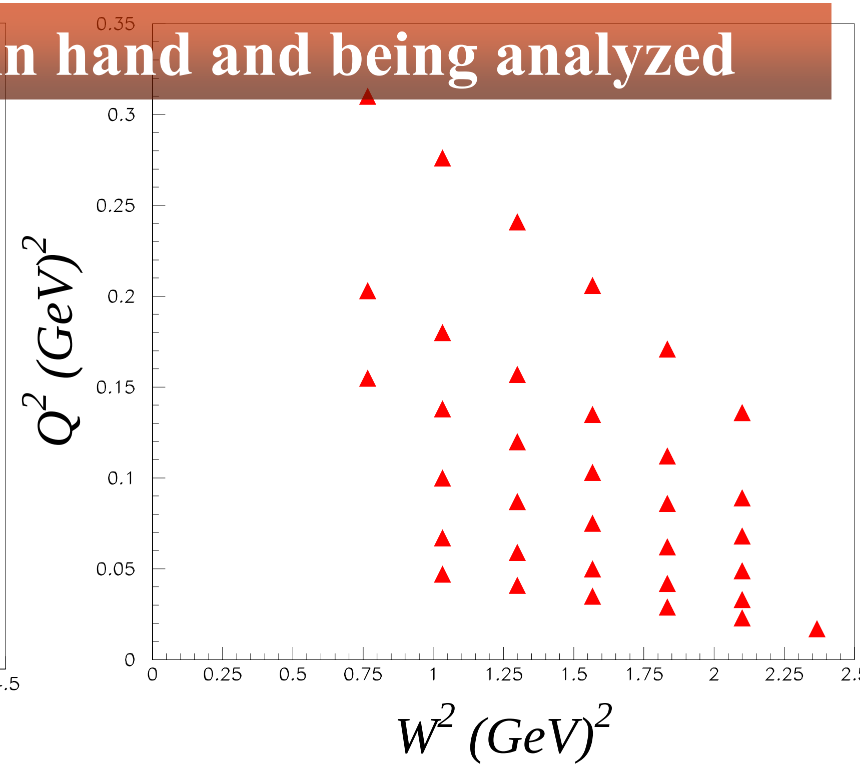
Low Q^2 data for ν modeling

- Targets: H,D, C, Al
- Projected final Uncertainties estimated at ~3 - 8%
  (Much larger RCs and rates)

Rosenbluth separations possible



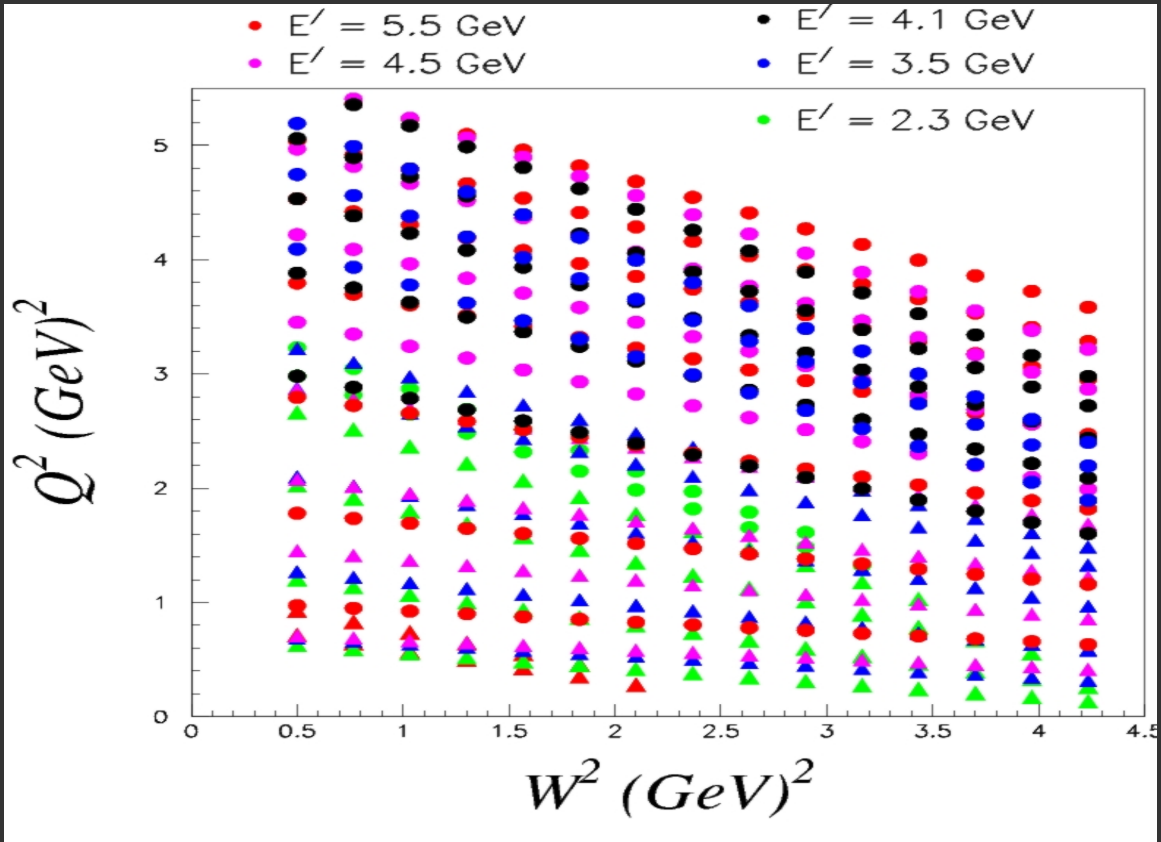
Data in hand and being analyzed



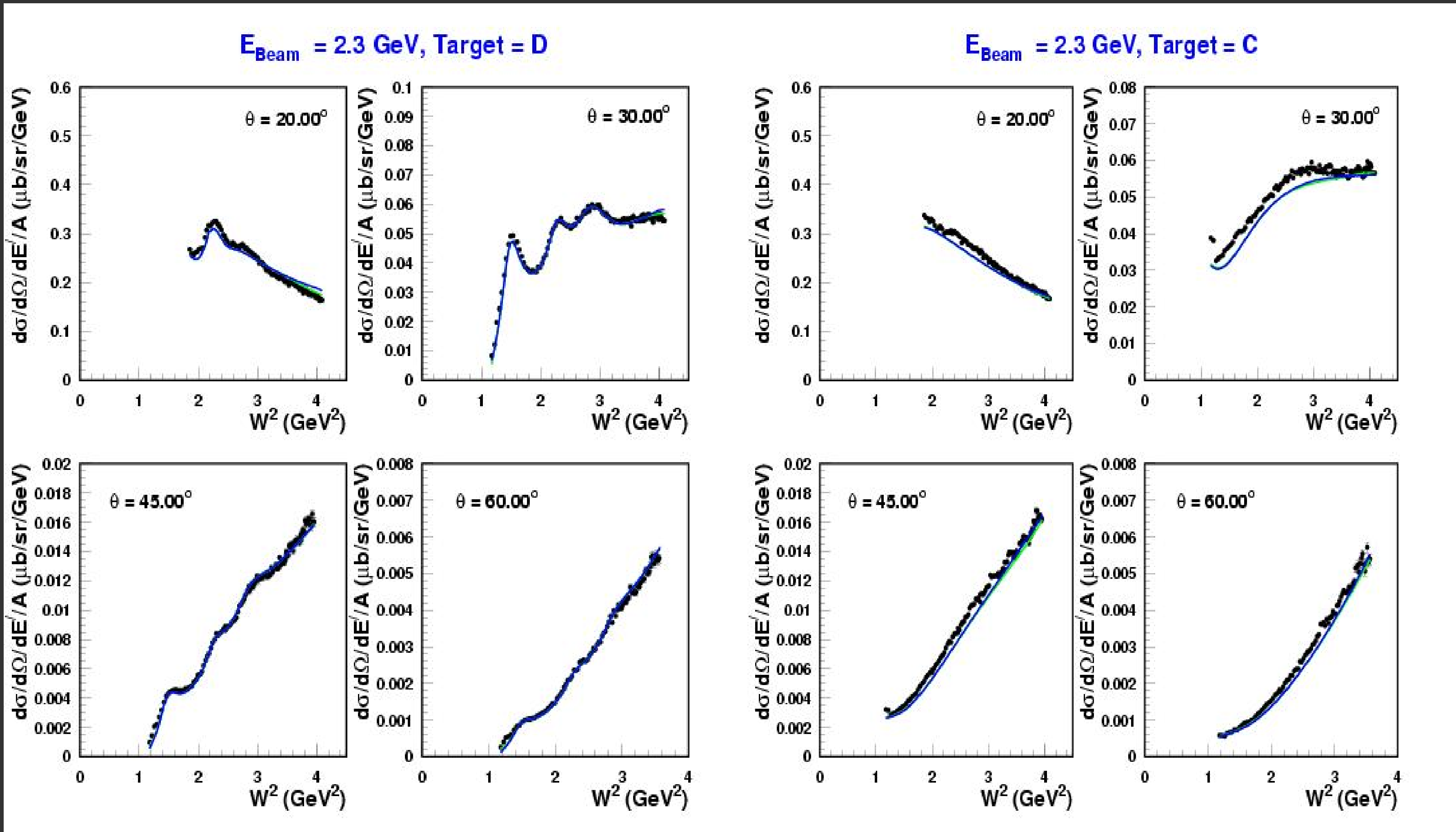
L/T Separated Structure Functions on Nuclei (JLab E02-109, E04-001 and E06-009)

- L/T Separation Data: Targets: D, C, Al, Fe
  - Final uncertainties 1.6 % pt-pt in ε (2% normalization)

Includes approved future running



Preliminary cross section results exist

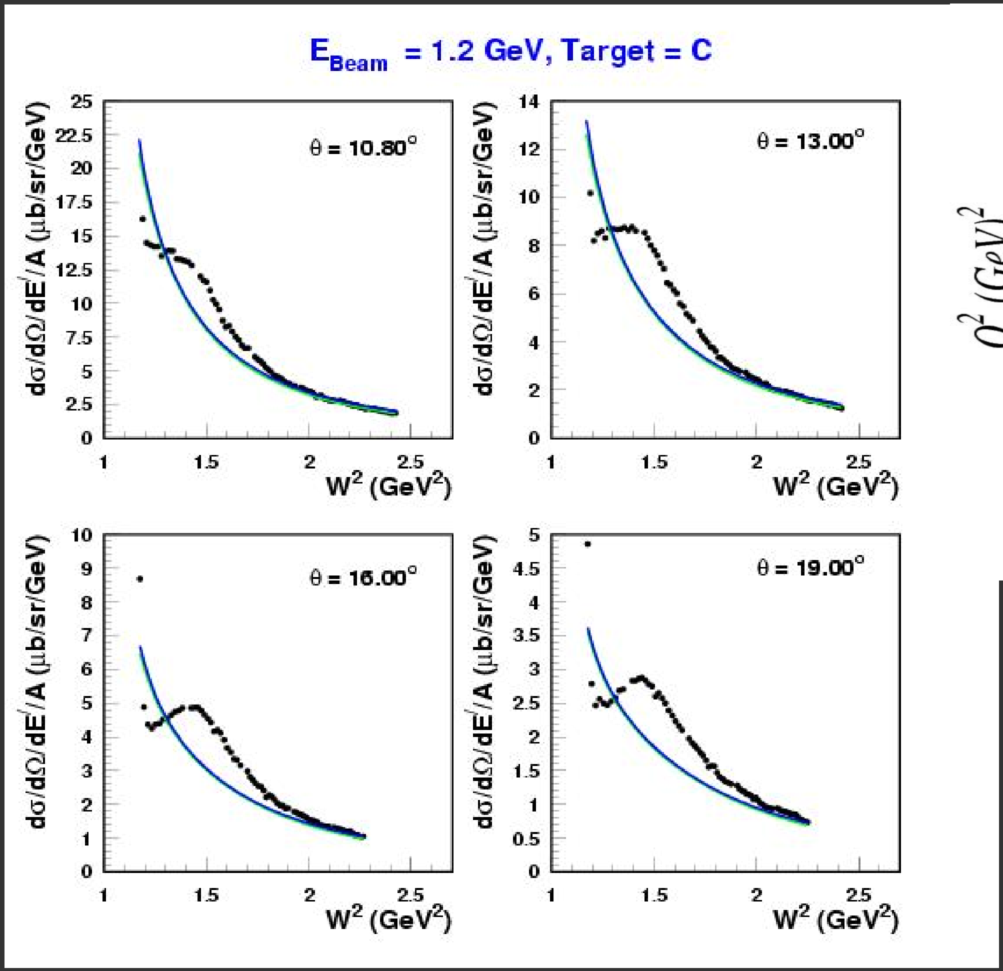


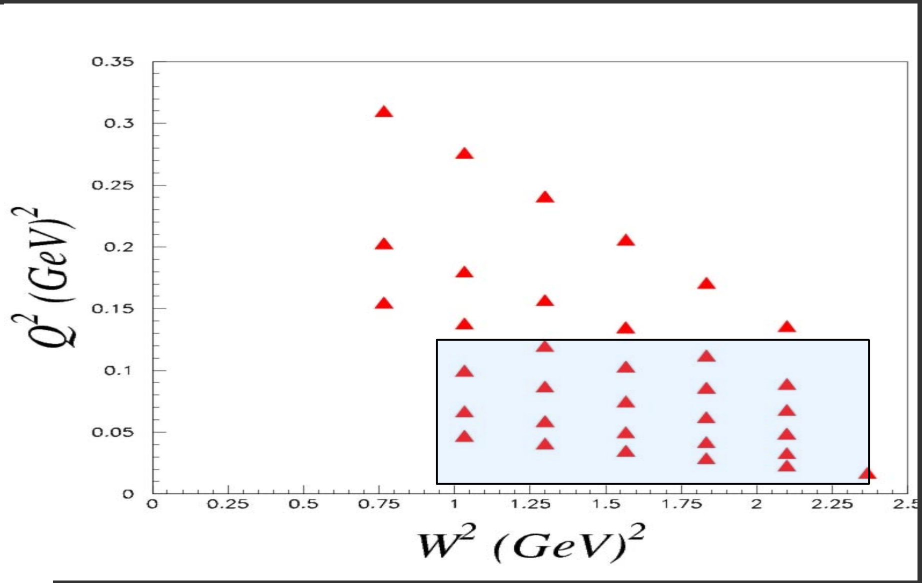
- ➢ **Error bars are statistical only.**
- ➢ **Only inelastic data shown.**

Deuterium: Fits to previous JLab & SLAC res. region data.

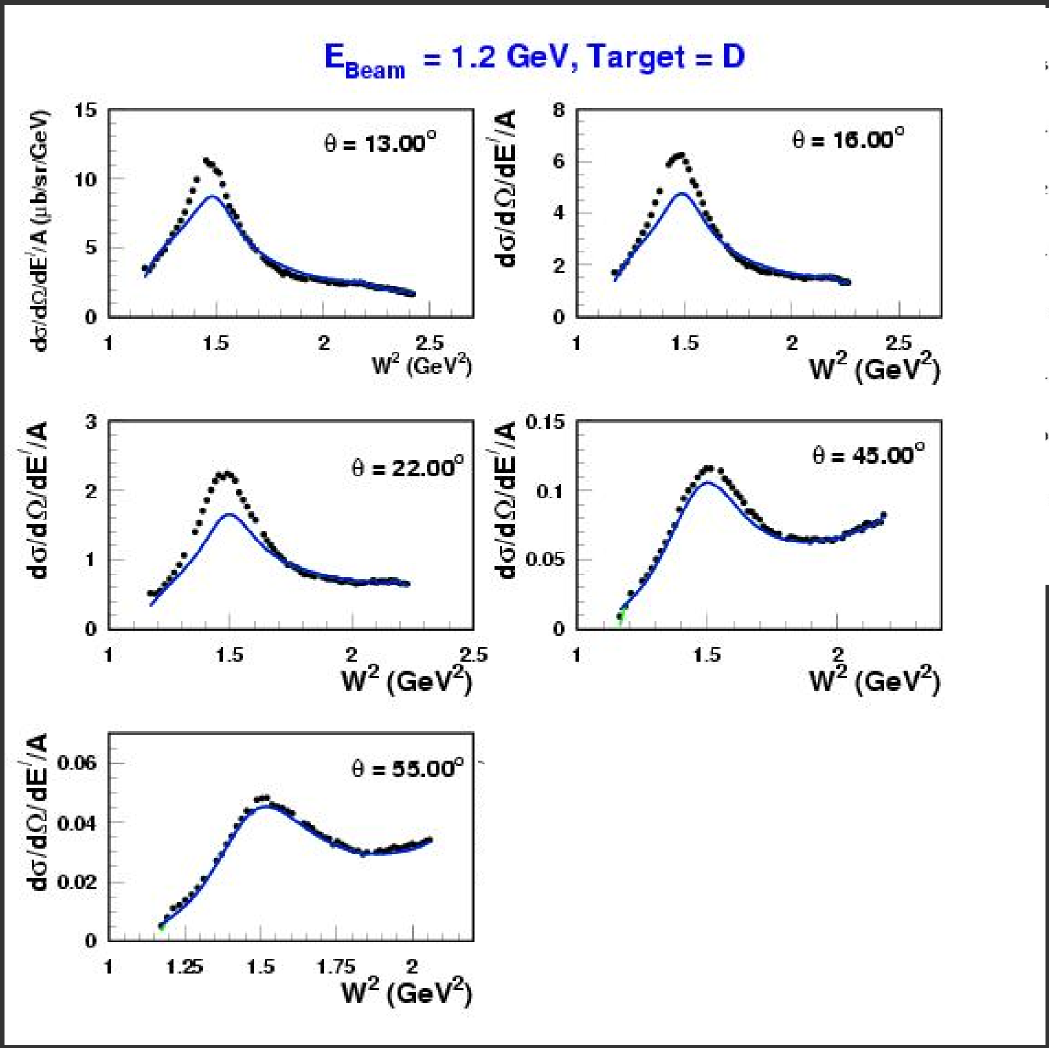
Heavy targets: fits to DIS data (F_2 & R).

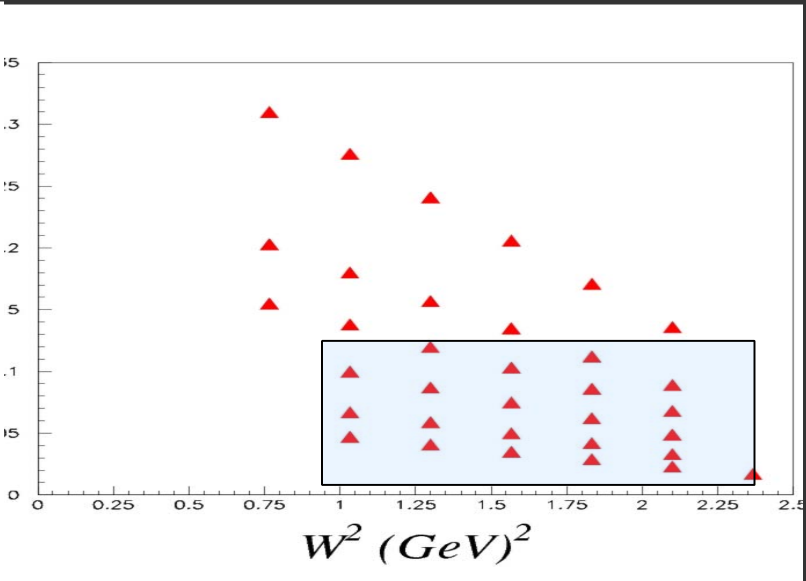
Preliminary results at low Q^2





Preliminary results at low Q^2



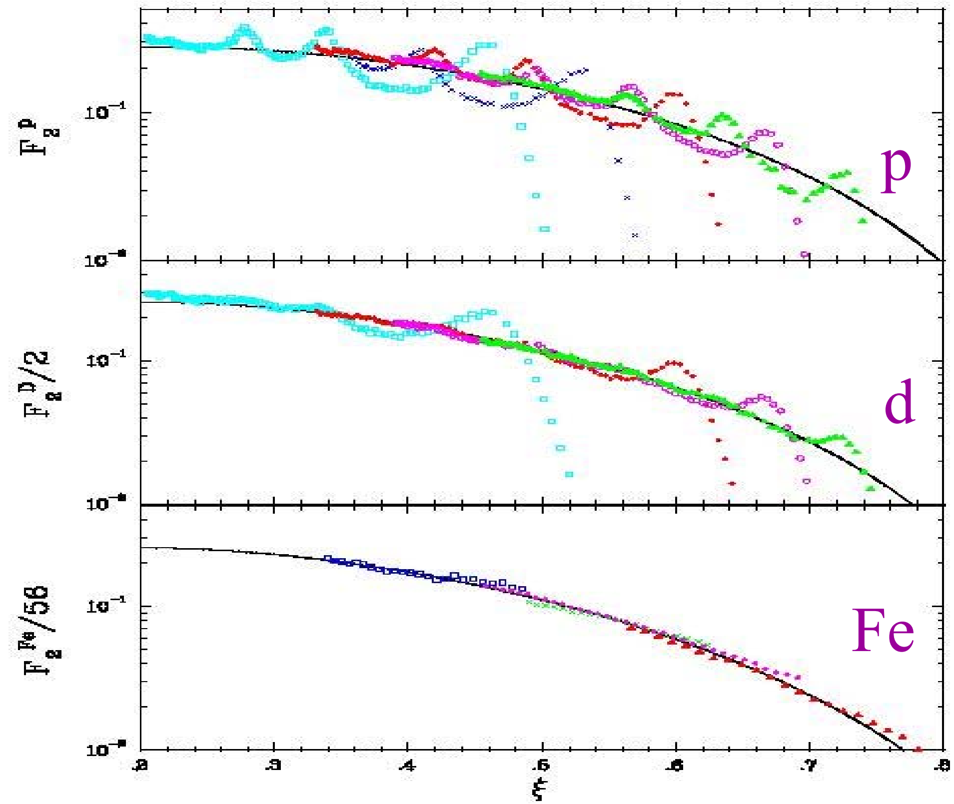


Even for deuterium, we need better models at low Q^2

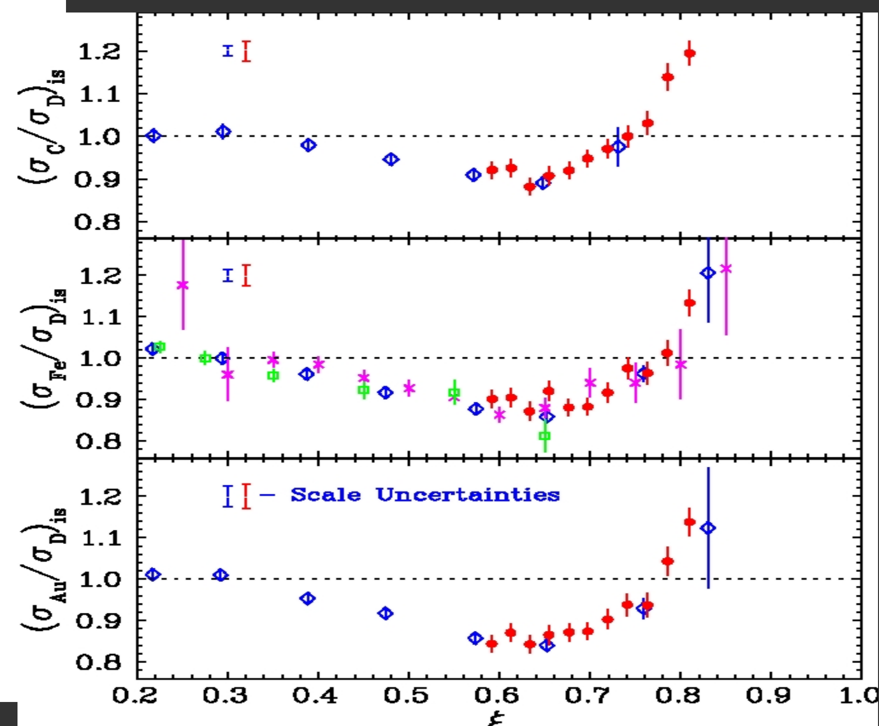
Nuclear Structure Functions

Arrington, Keppel, Ent, Niculescu PRC73:045206 (2006)
Arrington, Keppel, Ent, Mammei, Niculescu PRC73: 035205, 2006

- **Nuclear structure functions follow a single curve – *shallow Q^2 dependence, x-scaling*.**
- **In nuclei the averaging is nearly accomplished by Fermi motion.**
- **No low Q^2 or L/T data.**

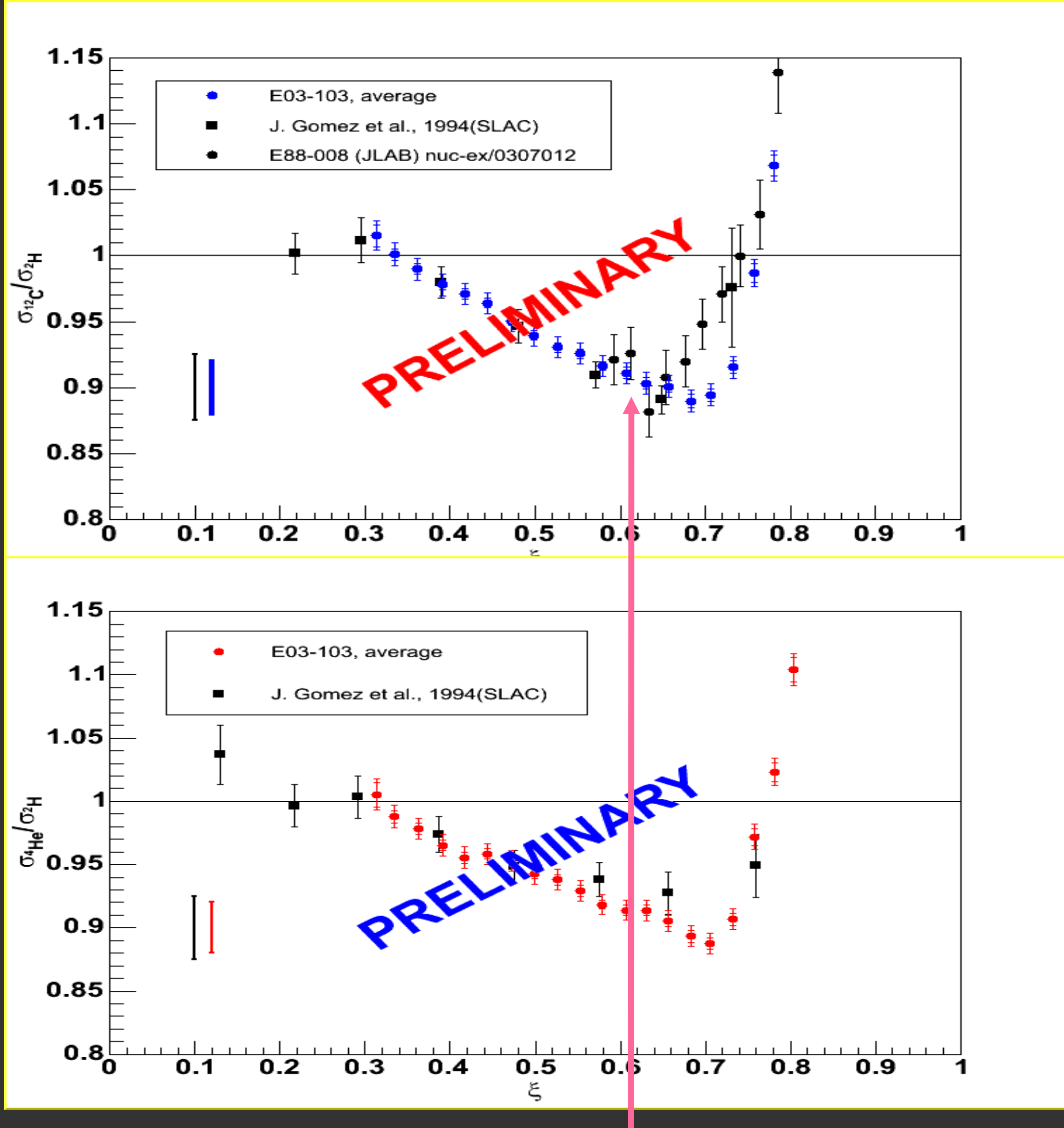


$$\xi = 2x[1 + (1 + 4M^2x^2/Q^2)^{1/2}]$$



New data: Jlab E03-103 – *EMC in light nuclei*

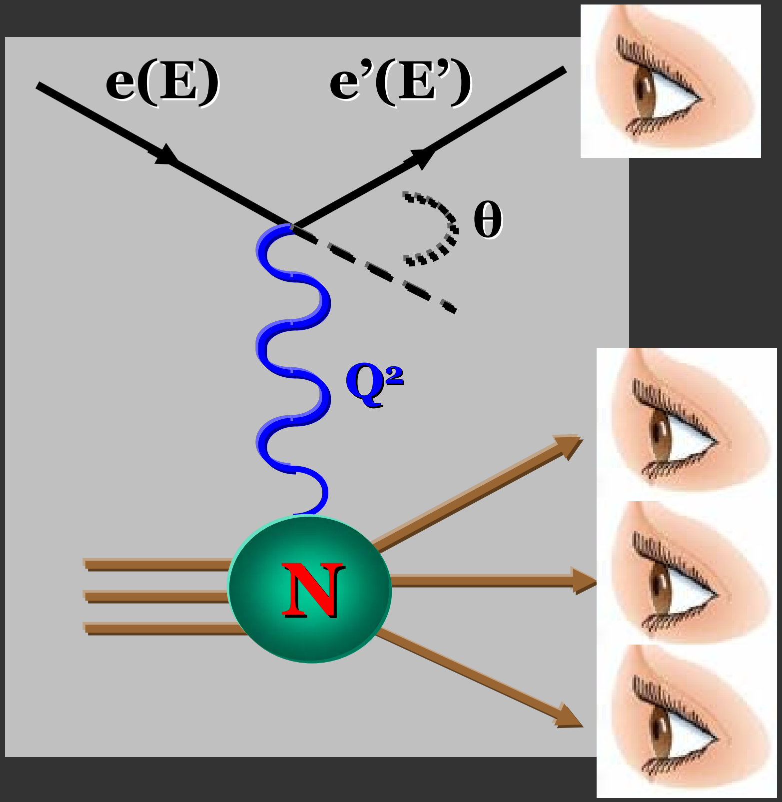
- Ran Fall 2004 in Hall C (Arrington, spokesman).
- Provides precision data on nuclear SFs/ nuclear modifications in light nuclei.
- Large kinematic coverage to study x and Q^2 dependences.
- EMC effect is the same in resonance region as in DIS.
- Data will provide precision data on A-dependence of EMC effect => help distinguish models of EMC
- Can determine Q^2 at which duality in EMC breaks down.



$W^2 \sim 4\ GeV^2$

Exclusive measurements

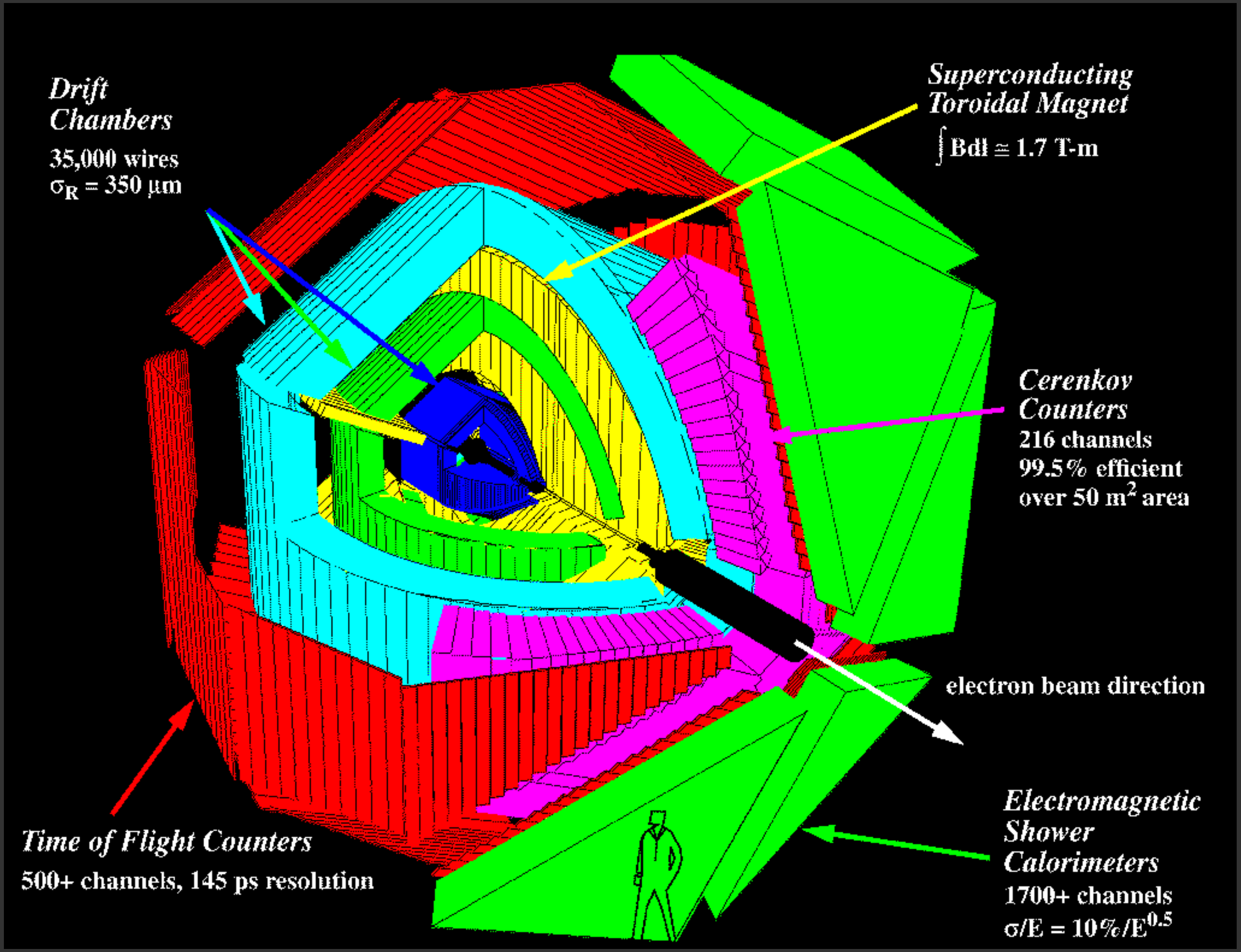
Detect all (most) particles in final state



JLab Hall B, CLAS detector

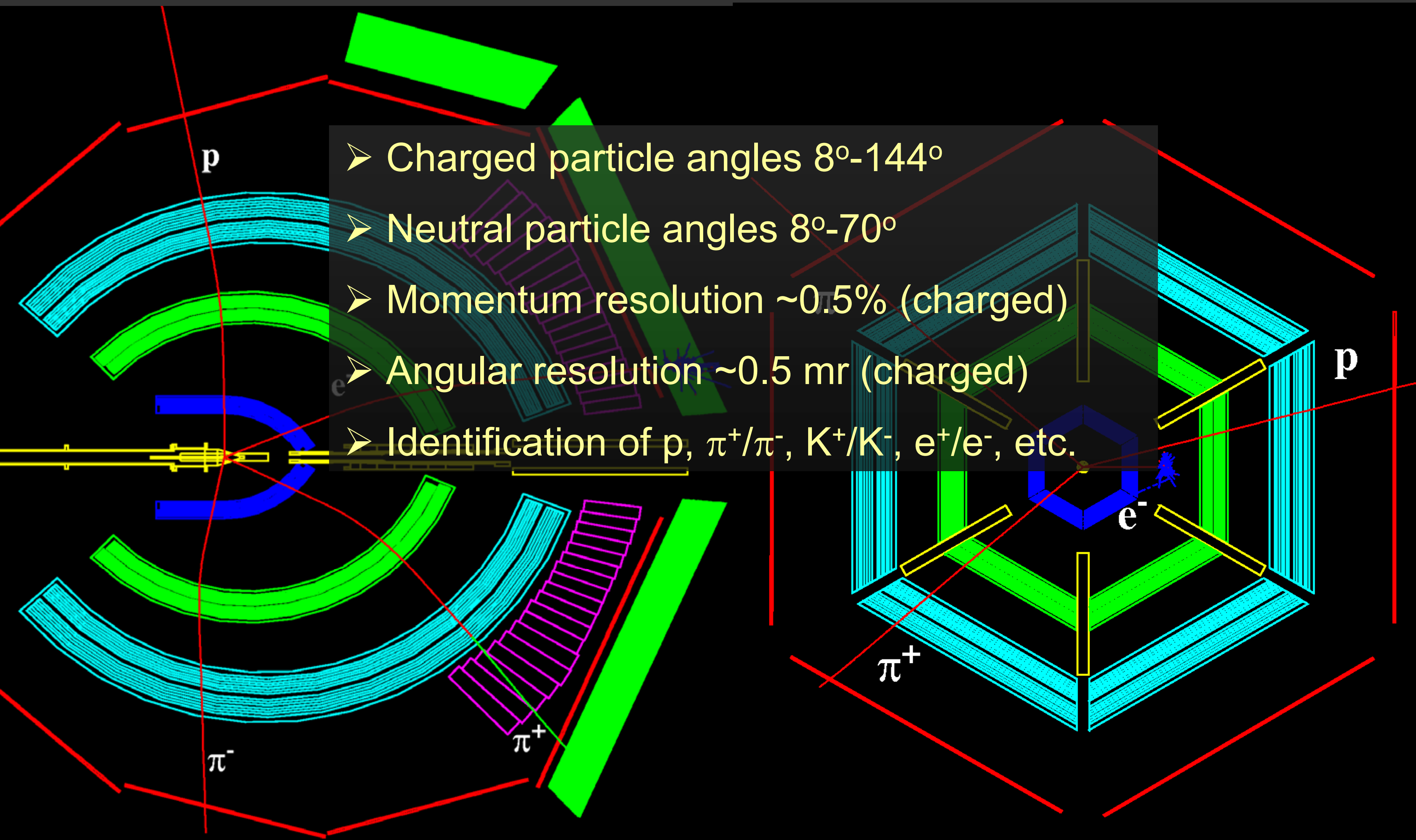
- Large acceptance
- Started taking data in 1997
- Wide variety of run conditions: e-/γ beams, 0.5<E<6 GeV (polarized), ^{1,2}H, ^{3,4}He, ^{12}C, ^{56}Fe, etc.

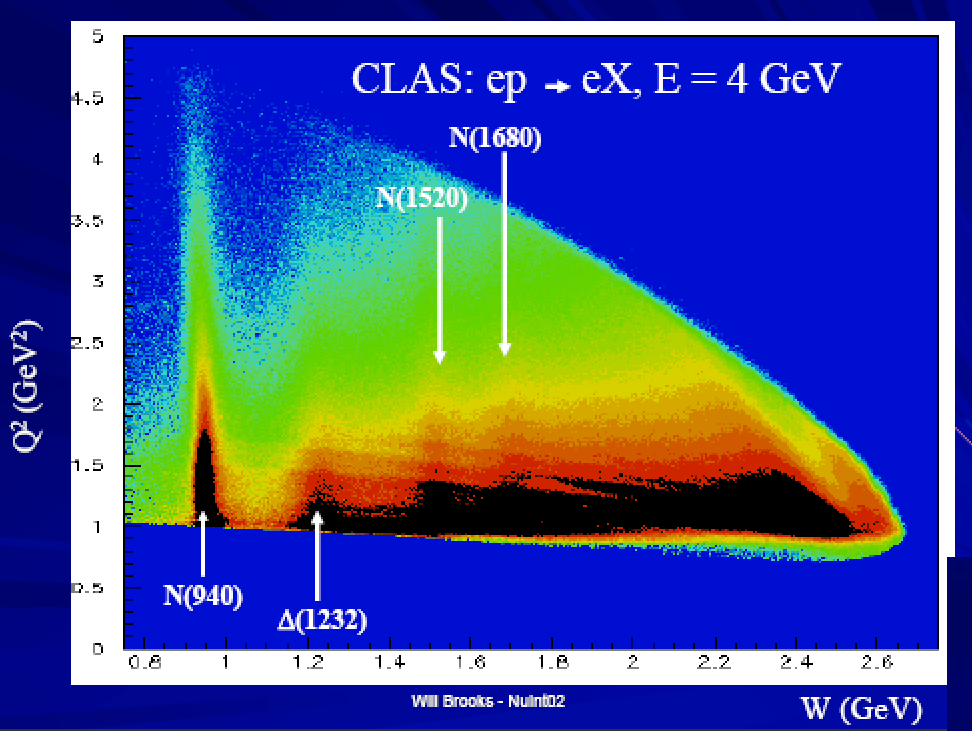
CLAS: CEBAF Large Acceptance Spectrometer (Hall B)

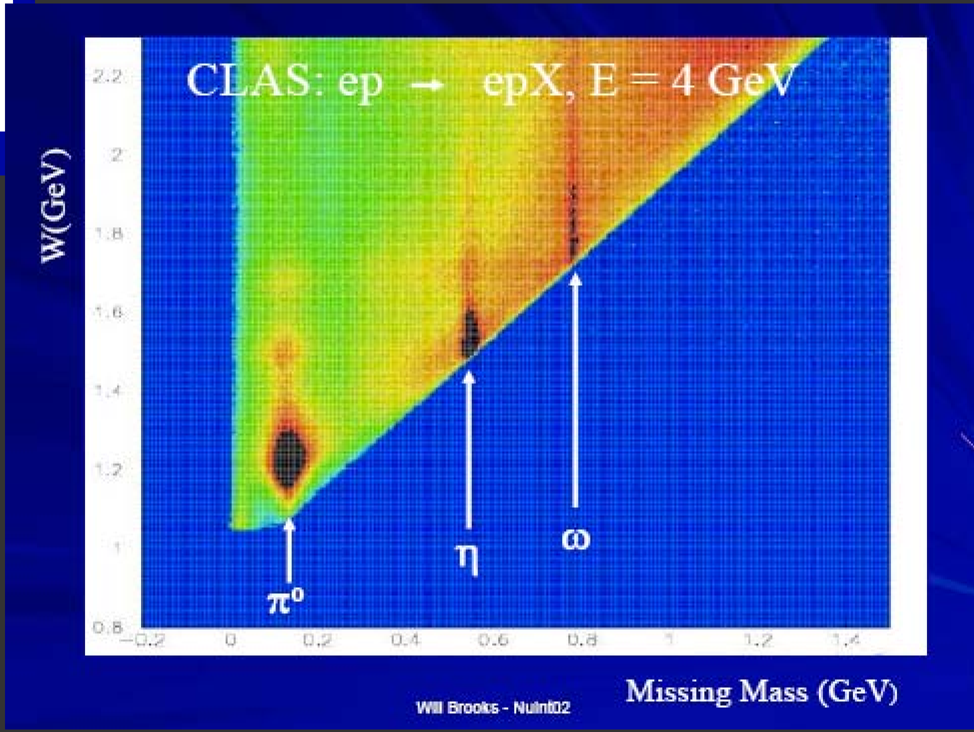


CLAS Single Event Display

- Charged particle angles 8°-144°
- Neutral particle angles 8°-70°
- Momentum resolution ~0.5% (charged)
- Angular resolution ~0.5 mr (charged)
- Identification of p, π^+/π^-, K^+/K^-, e^+/e^-, etc.




CLAS: ep → eX, E = 4 GeV
N(1680)
N(1520)
N(940)
Δ(1232)
Q² (GeV²)
W (GeV)
Will Brooks - NuInt02


CLAS: ep → epX, E = 4 GeV
W(GeV)
π⁰
η
ω
Missing Mass (GeV)
Will Brooks - NuInt02

Exclusive measurements for the ν program at CLAS

(SM, R. Bradford and undergrads: Dave Sher, Ian Kleckner, Jennifer Cano)

Examples of measurements:

- Momentum distributions for protons and charged pions in 1-π and 2-π events (E, Q^2, A=H,C,Fe)
- ep → epπ^o → epπ^+ below 2π threshold
- π^o/π^+ ratio as function of W and Q^2

Allows neutrino MC tuners to take into account nuclear effects like transparency and absorption in a brute force way. They can look at data for vector part and appropriate Q^2 only.

How often do you see proton from QE event? (Affects Evis and event categorization.)

How often do you lose a pion in a resonance or inelastic event? (Affects Evis and event categorization)

Neutral and charged pions look different in ν detectors. Need to understand A dependence.

The reconstructed neutrino energy is a critical quantity for neutrino expts. Tune models with CLAS measurements.

Coherent π^o production background for electron neutrinos. How often does charge exchange happen? Is there an A dependence?

Exclusive measurements for the ν program at CLAS

(SM, R. Bradford and undergrads: Dave Sher, Ian Kleckner, Jennifer Cano)

Are we living a fantasy? We'll see.
$ limited at the moment.

Examples of measurements

- Momentum dist
pions in 1-π and 2
- ep → epπ° → e
- π°/π⁺ ratio as fu

Allows neutrino MC tuners to take into
uclear effects like transparency
otion in a brute force way. They
ok at data for vector part and
appropriate Q^2 only.

ou see proton from QE event?
s and event categorization.)

u lose a pion in a resonance or
nt? (Affects Evis and event
categorization)

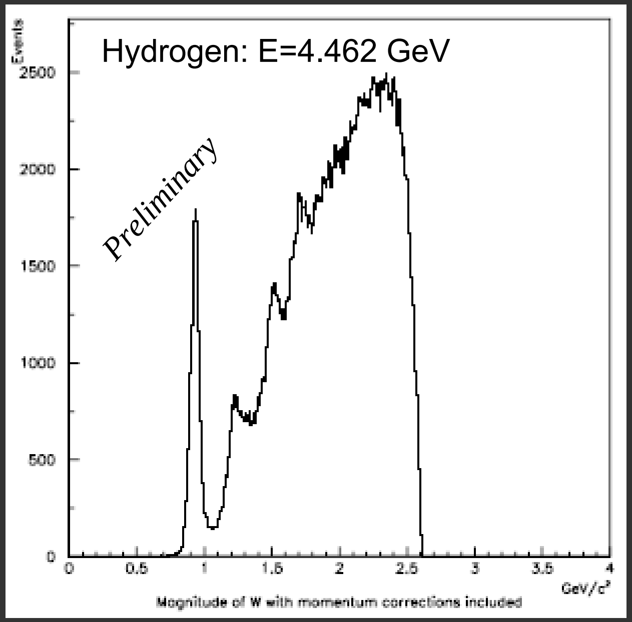
Neutral and charged
detectors. Need to u

The reconstructed n
quantity for neutrino
CLAS m

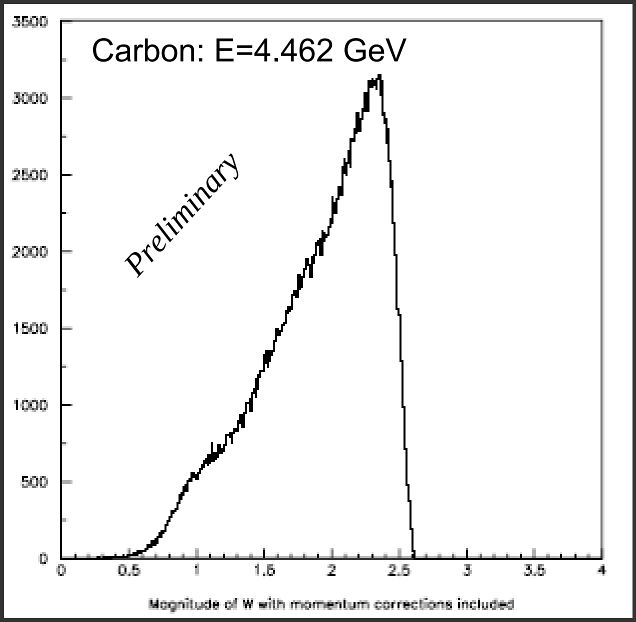
background for electron
oes charge exchange
n A dependence?

W distributions

hydrogen



carbon

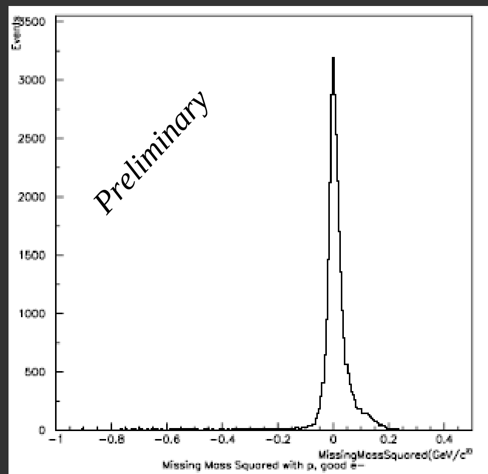


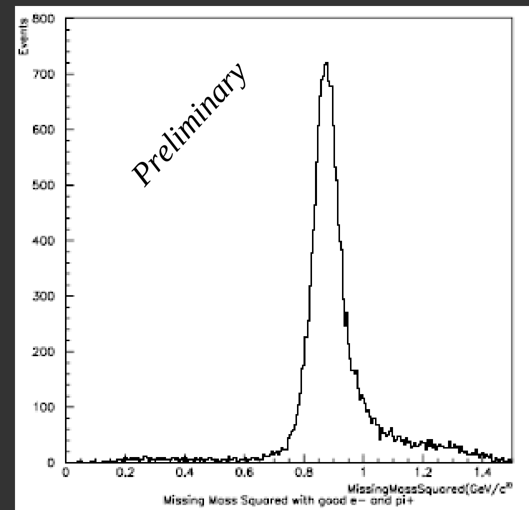
Missing mass squared in Δ(1232) resonance region

e-p

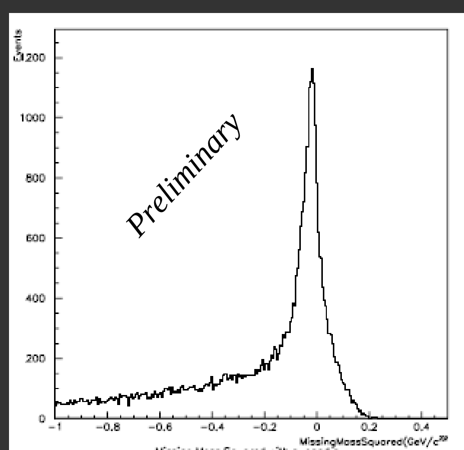
e-pi

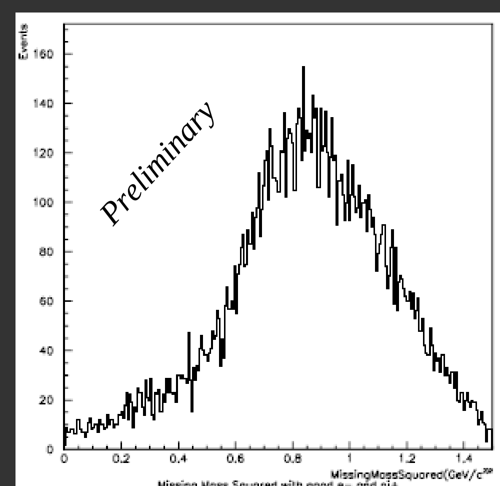
hydrogen





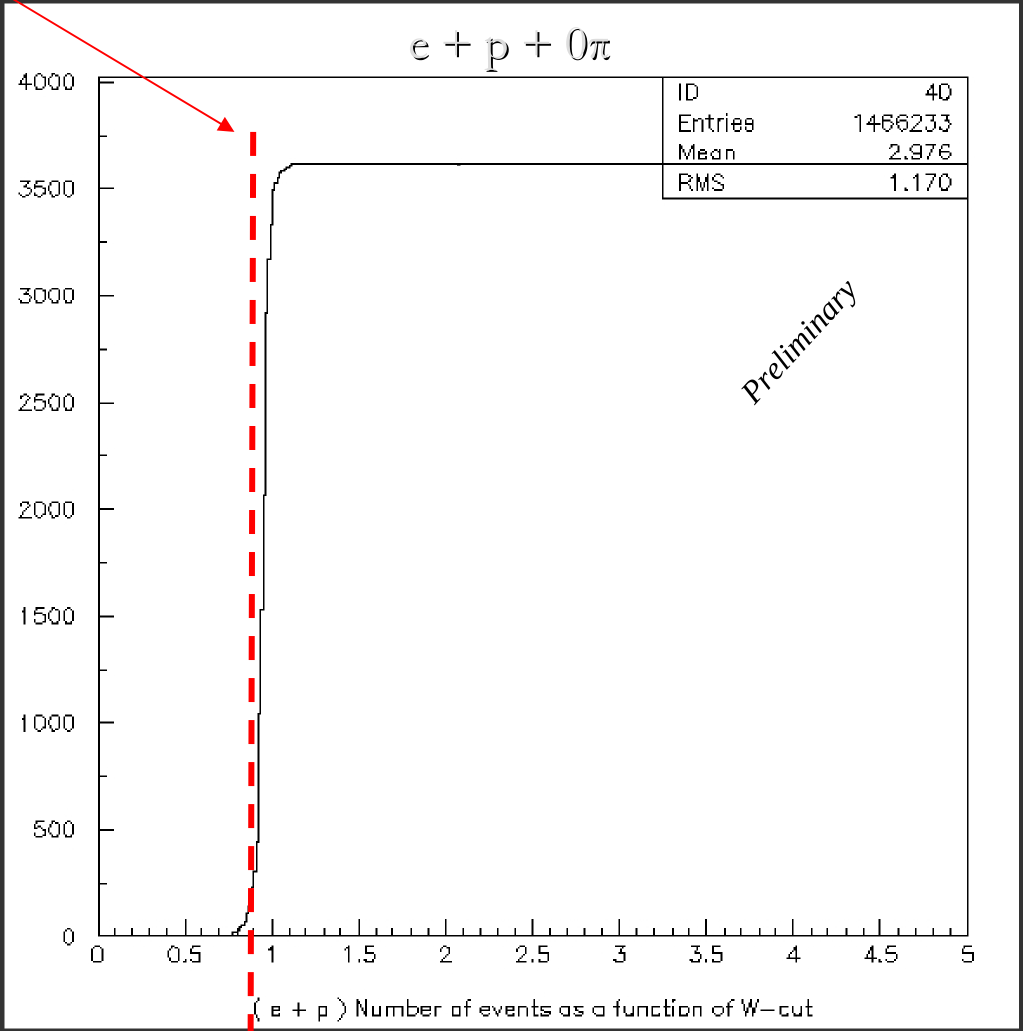
carbon

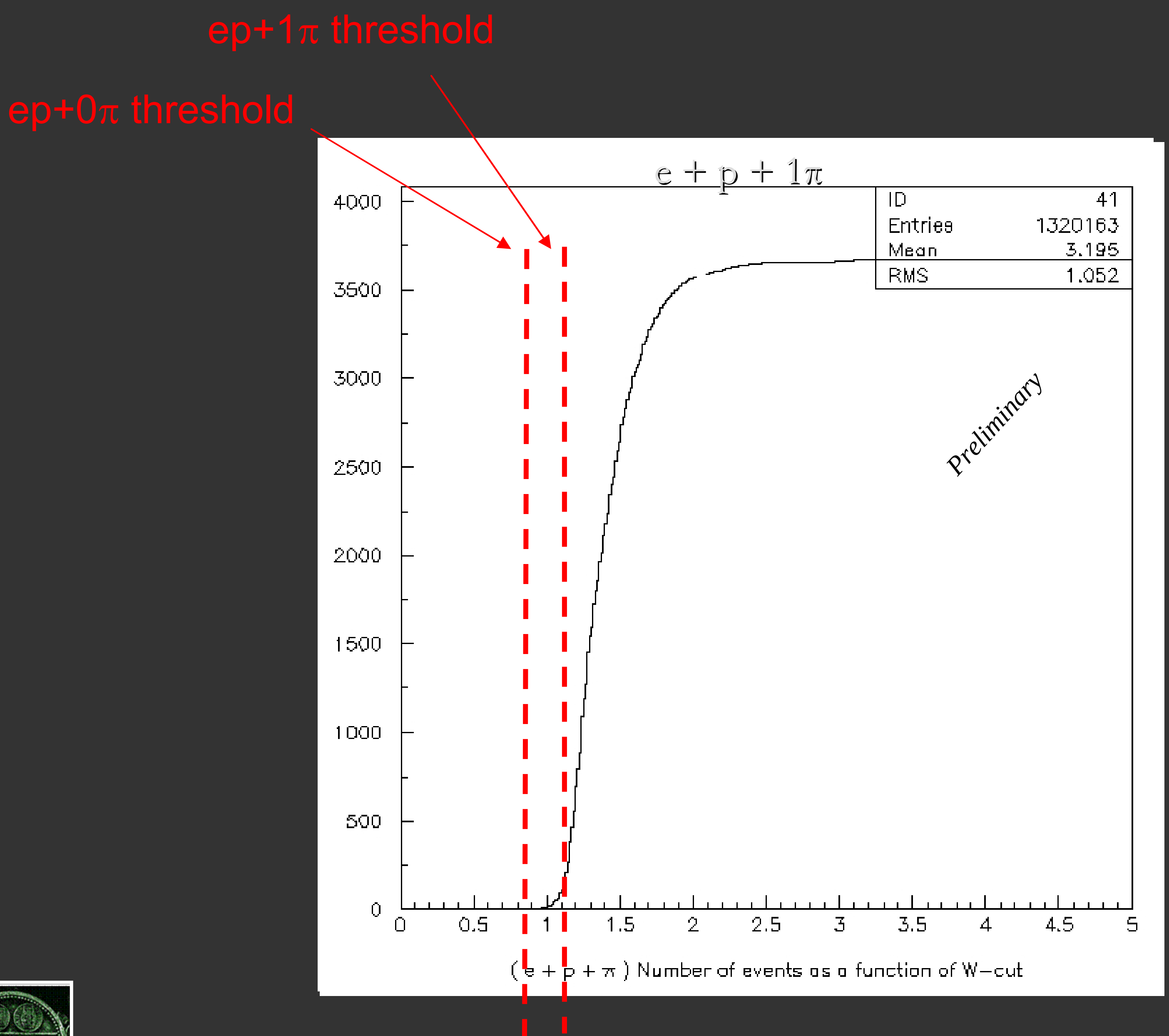


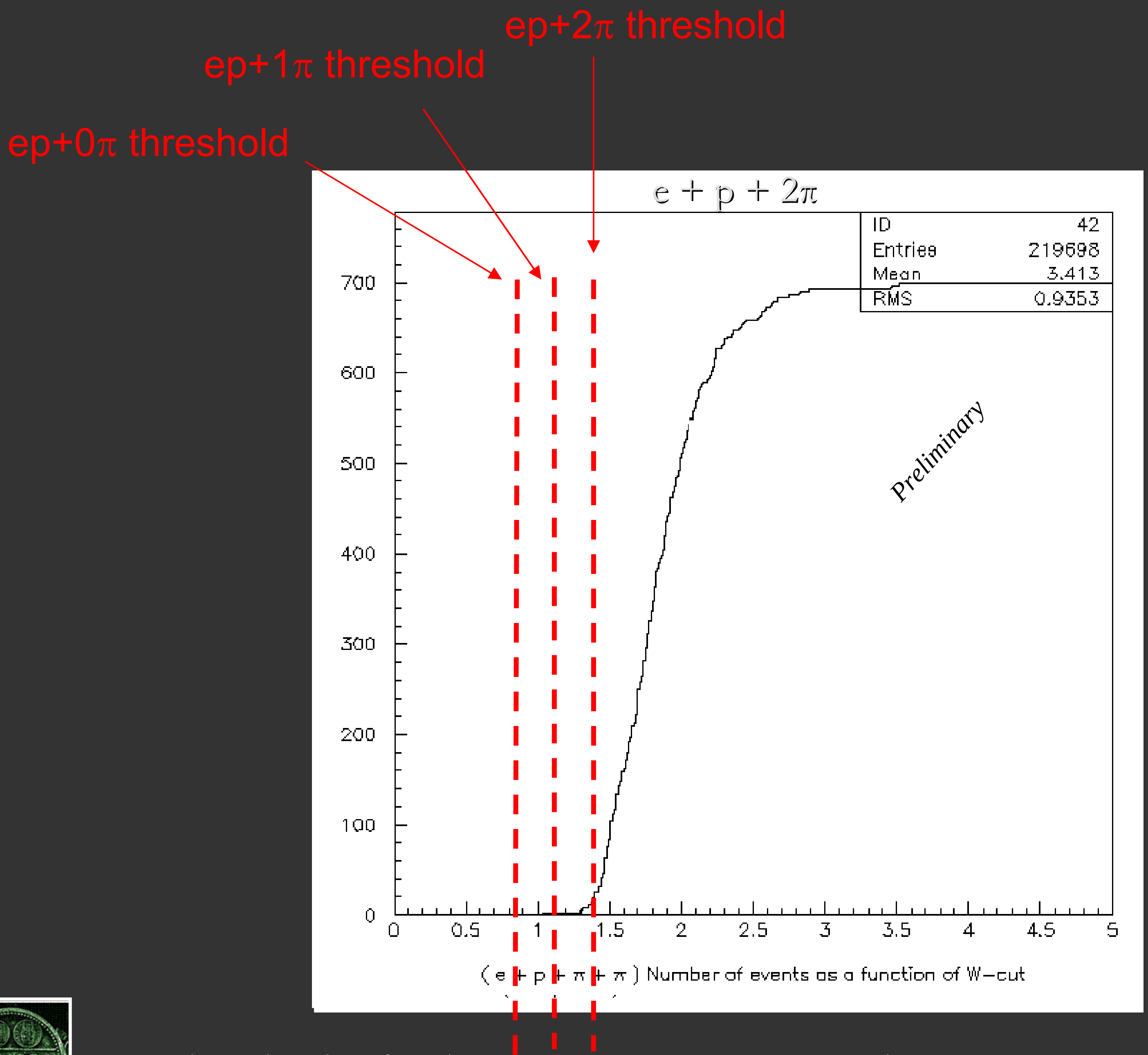


Can we use thresholds in W to isolate topologies?

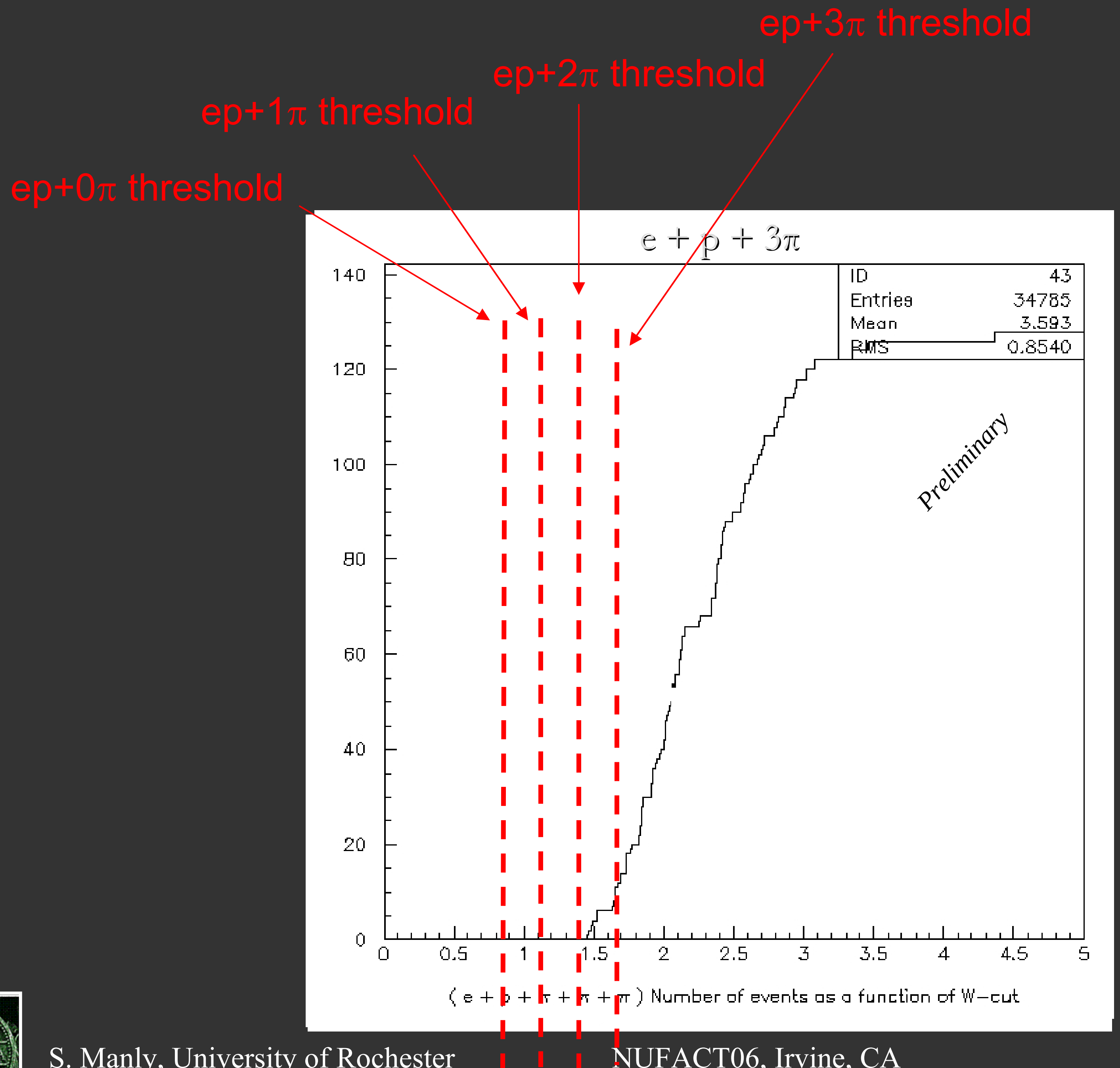
ep+0π threshold




ep+1π threshold
ep+0π threshold
e + p + 1π
ID 41
Entries 1320163
Mean 3.195
RMS 1.052
Preliminary
4000
3500
3000
2500
2000
1500
1000
500
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
(e + p + π) Number of events as a function of W–cut



ep+2π threshold
ep+1π threshold
ep+0π threshold
e + p + 2π
ID 42
Entries 219698
Mean 3.413
RMS 0.9353
Preliminary
0
100
200
300
400
500
600
700
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
(e + p + π + π) Number of events as a function of W−cut

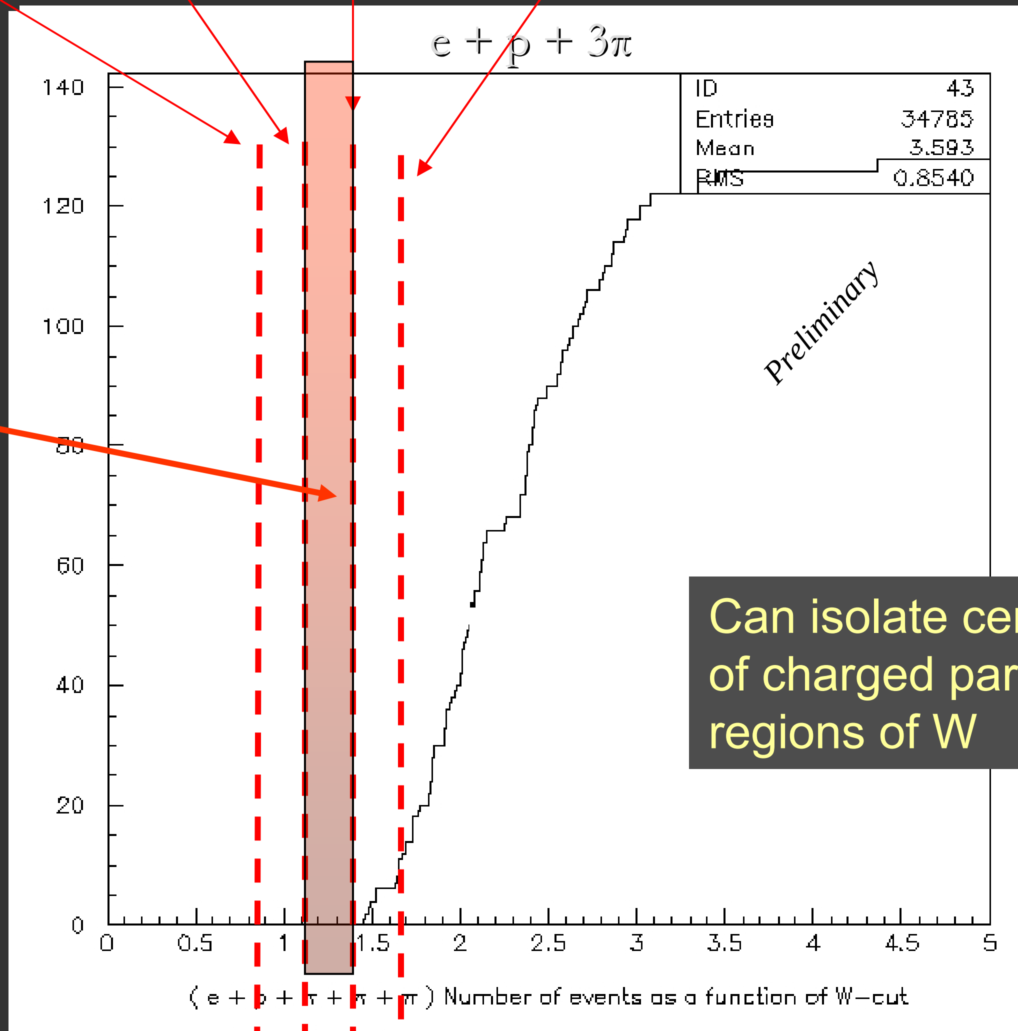

ep+3π threshold
ep+2π threshold
ep+1π threshold
ep+0π threshold
e + p + 3π
ID 43
Entries 34785
Mean 3.593
RMS 0.8540
Preliminary
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Number of events as a function of W−cut

ep+3π threshold

ep+2π threshold

ep+1π threshold

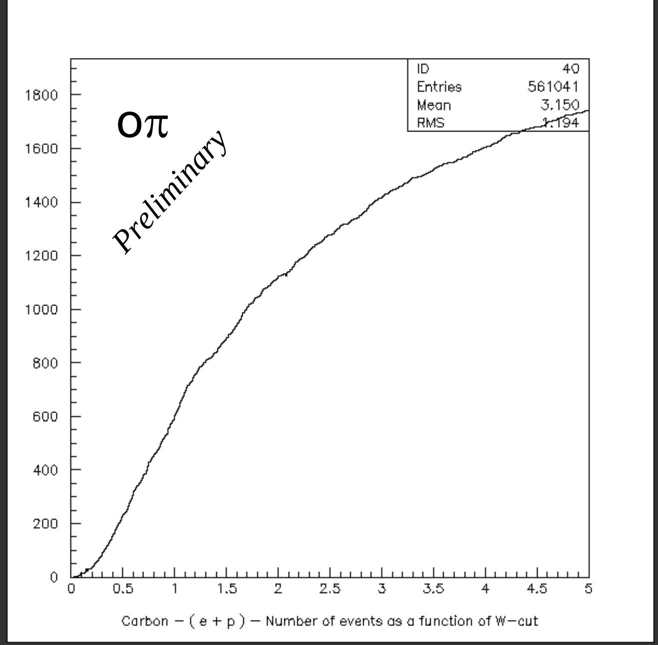
ep+0π threshold



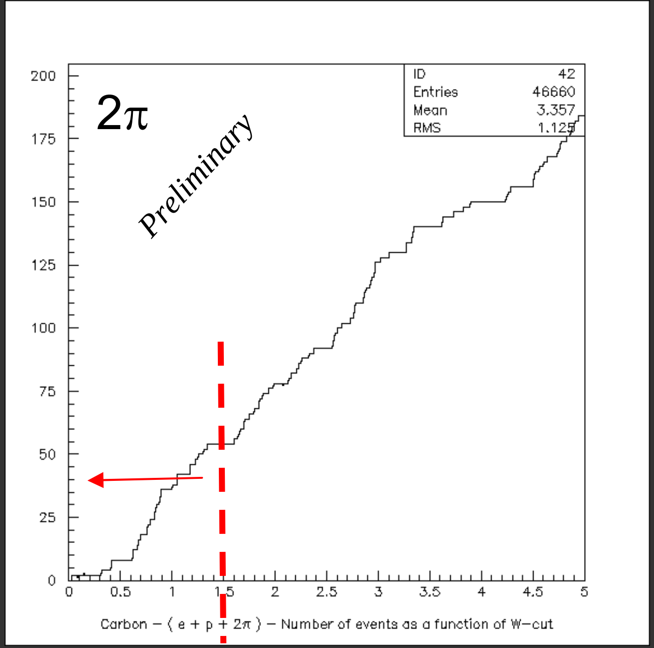
epπ with little/no missing mass in this region of W

Can isolate certain topologies of charged particles in small regions of W

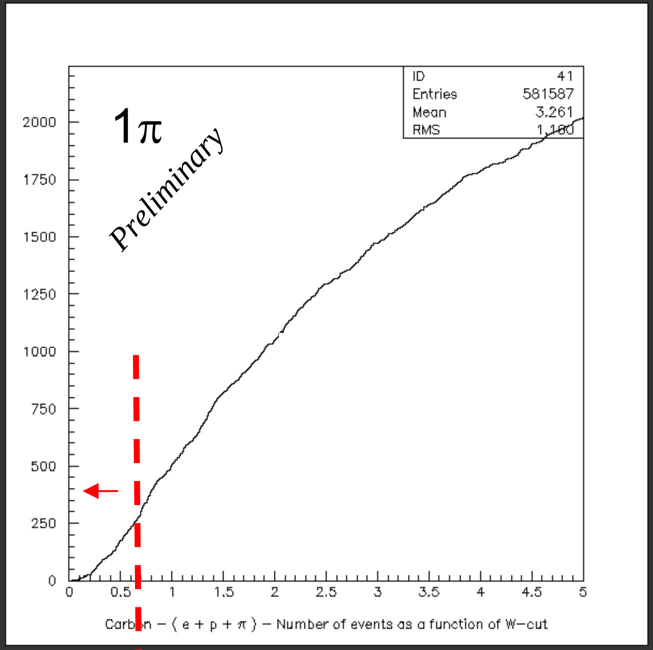
Carbon



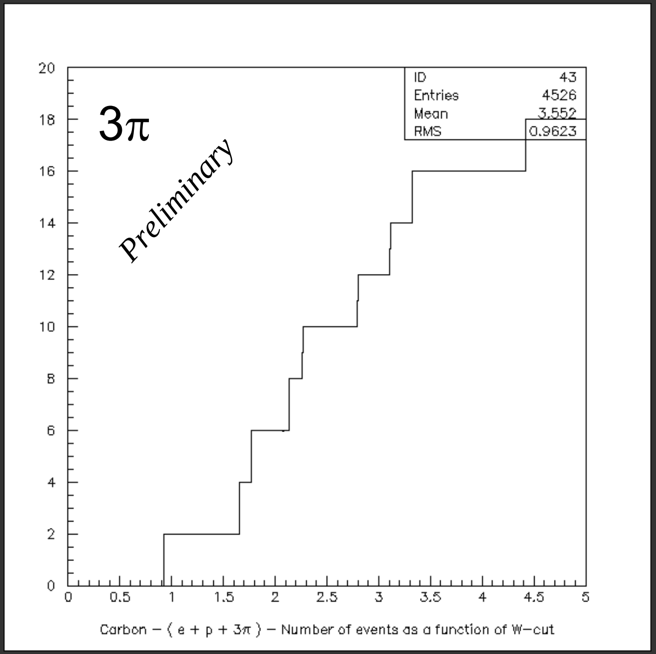
0π
Preliminary
ID 40
Entries 561041
Mean 3.150
RMS 1.194
Carbon – (e + p) – Number of events as a function of W–cut



2π
Preliminary
ID 42
Entries 46660
Mean 3.357
RMS 1.125
Carbon – (e + p + 2π) – Number of events as a function of W–cut



1π
Preliminary
ID 41
Entries 581587
Mean 3.261
RMS 1.180
Carbon – (e + p + π) – Number of events as a function of W–cut

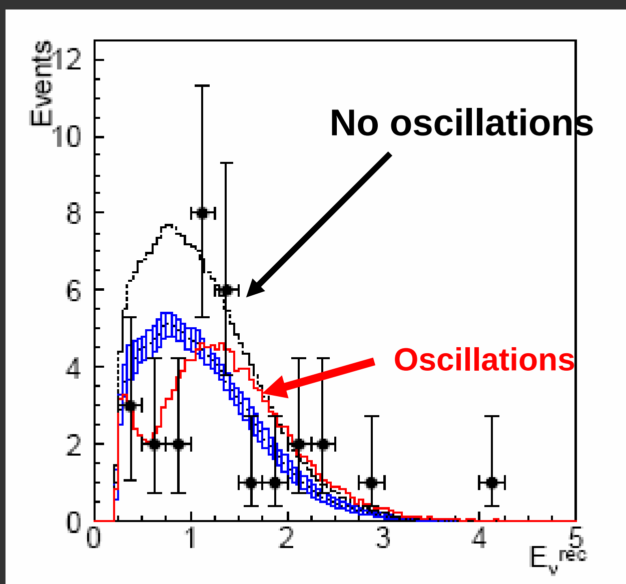


3π
Preliminary
ID 43
Entries 4526
Mean 3.552
RMS 0.9623
Carbon – (e + p + 3π) – Number of events as a function of W–cut

Exclusive measurements for the ν program at CLAS

Neutral and charged pions look different in ν detectors.

E_ν is a critical quantity. Tune models that can be used in ν expts.



i.e., K2K result, E_ν is important

K2K Collaboration, hep-ex/0212007.

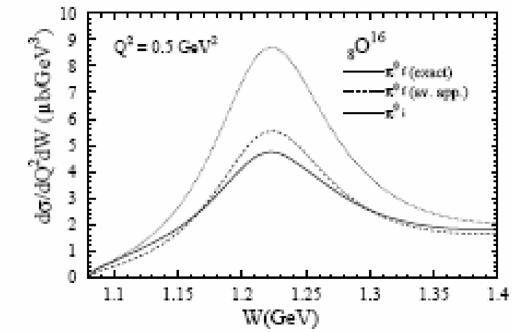


Figure 1. Electroproduction for π^0 on Oxygen target.

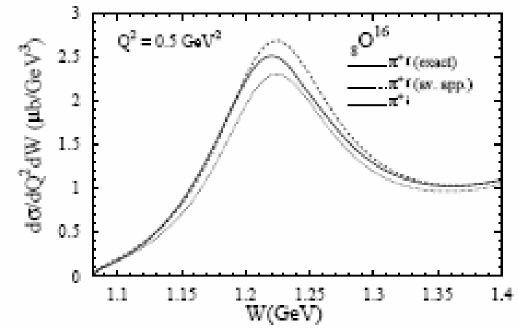


Figure 2. Electroproduction for π^+ on Oxygen target.

Paschos, Schienbein, Yu, hep-ph/0408148

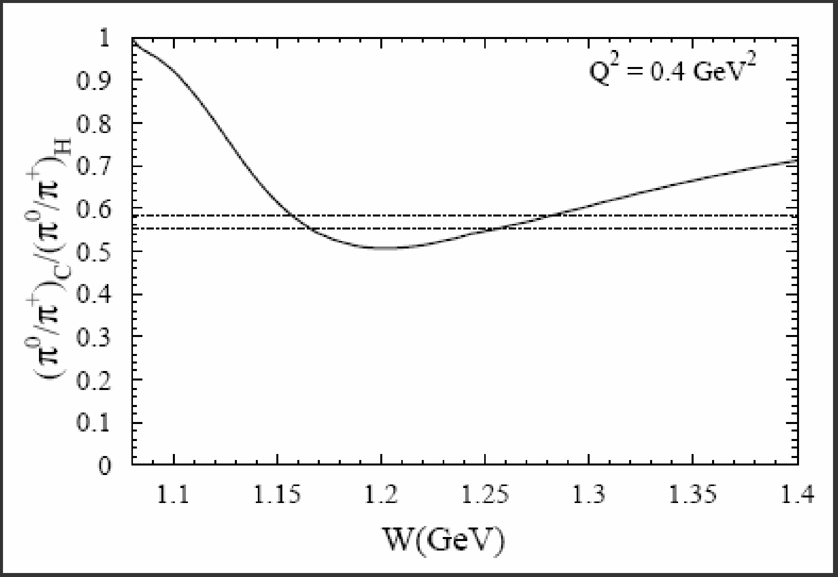
ANP model calculations

$$\frac{\left[\dfrac{\pi^o}{\pi^+}\right]_{hydrogen}}{\left[\dfrac{\pi^o}{\pi^+}\right]_{carbon}}$$

Fermi smearing and radiative corrections ~cancel

$\pi^o\pi^+$ acceptance differences ~cancel

Fermi smearing and radiative corrections ~cancel



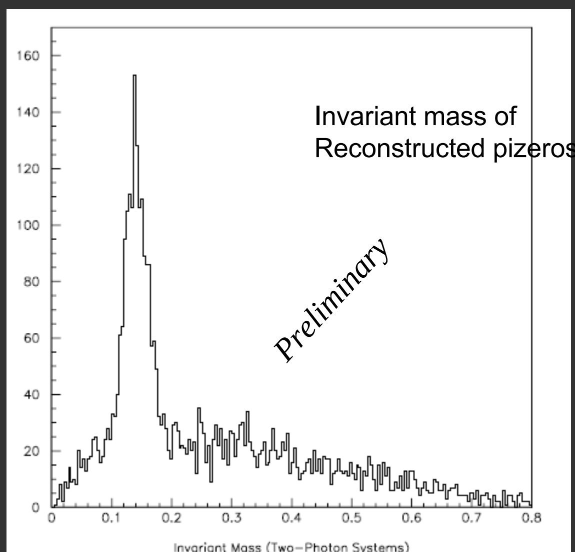
ANP model preliminary result: private communication from I. Schienbein, E Paschos, J. Yu

$$\frac{\left[\frac{\pi^o}{\pi^+}\right]_{hydrogen}}{\left[\frac{\pi^o}{\pi^+}\right]_{carbon}}$$

Fermi smearing and radiative corrections ~cancel

$\pi^o \pi^+$ acceptance differences ~cancel

Fermi smearing and radiative corrections ~cancel

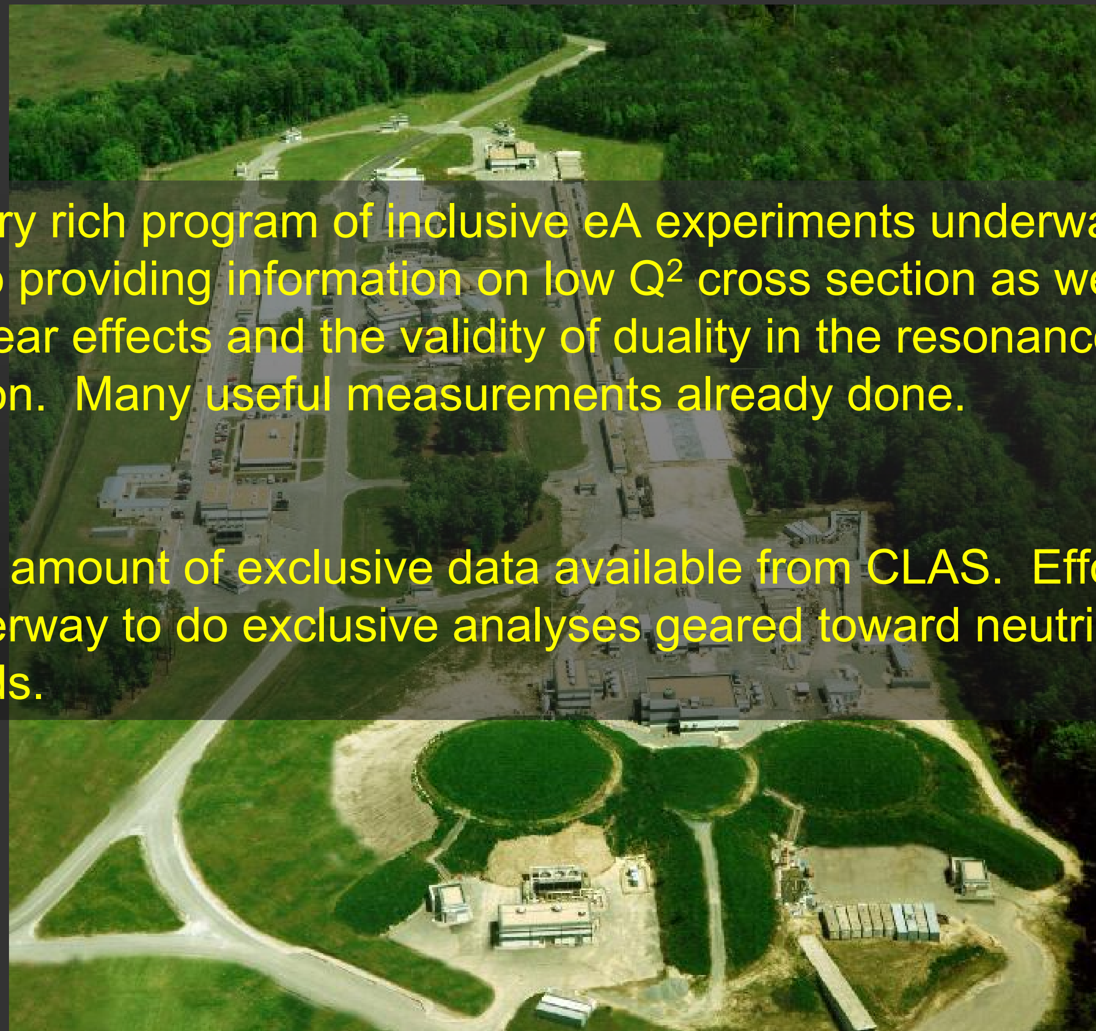


Can do direct detection of π^o's

Double ratio sensitive to slight variations in detector behavior between the C and H runs

… stay tuned.

Conclusions



A very rich program of inclusive eA experiments underway at JLab providing information on low Q^2 cross section as well as nuclear effects and the validity of duality in the resonance region. Many useful measurements already done.

Vast amount of exclusive data available from CLAS. Effort underway to do exclusive analyses geared toward neutrino needs.

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