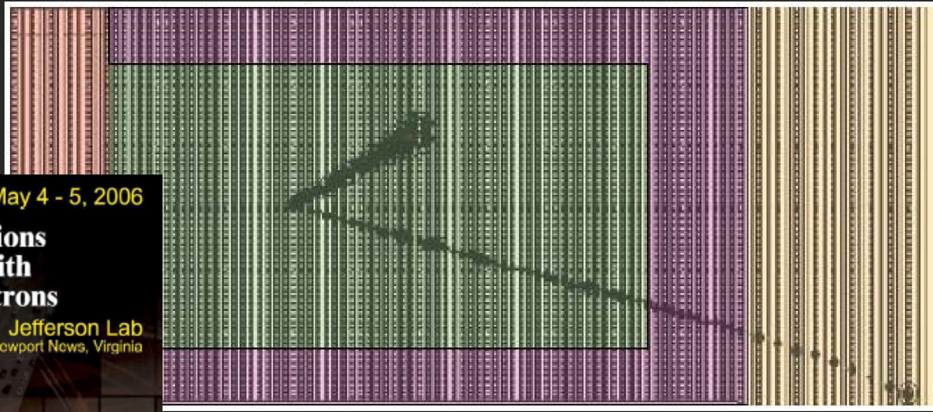
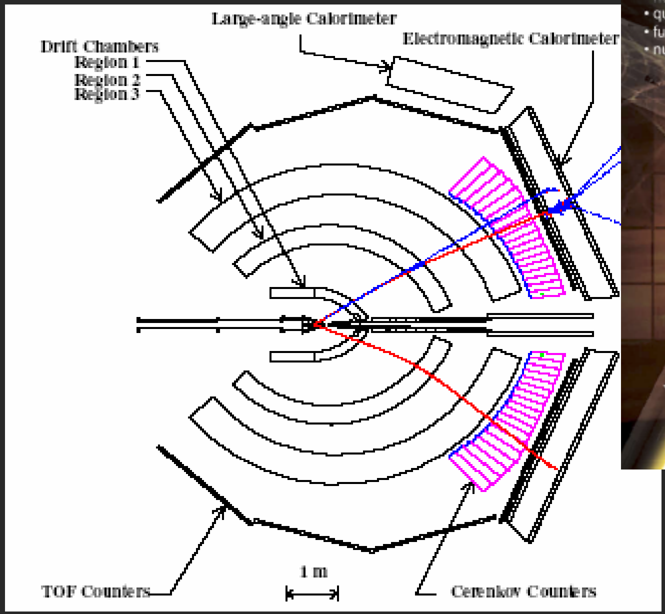
Multi-pion production - status and issues in Hall B

Evolving project



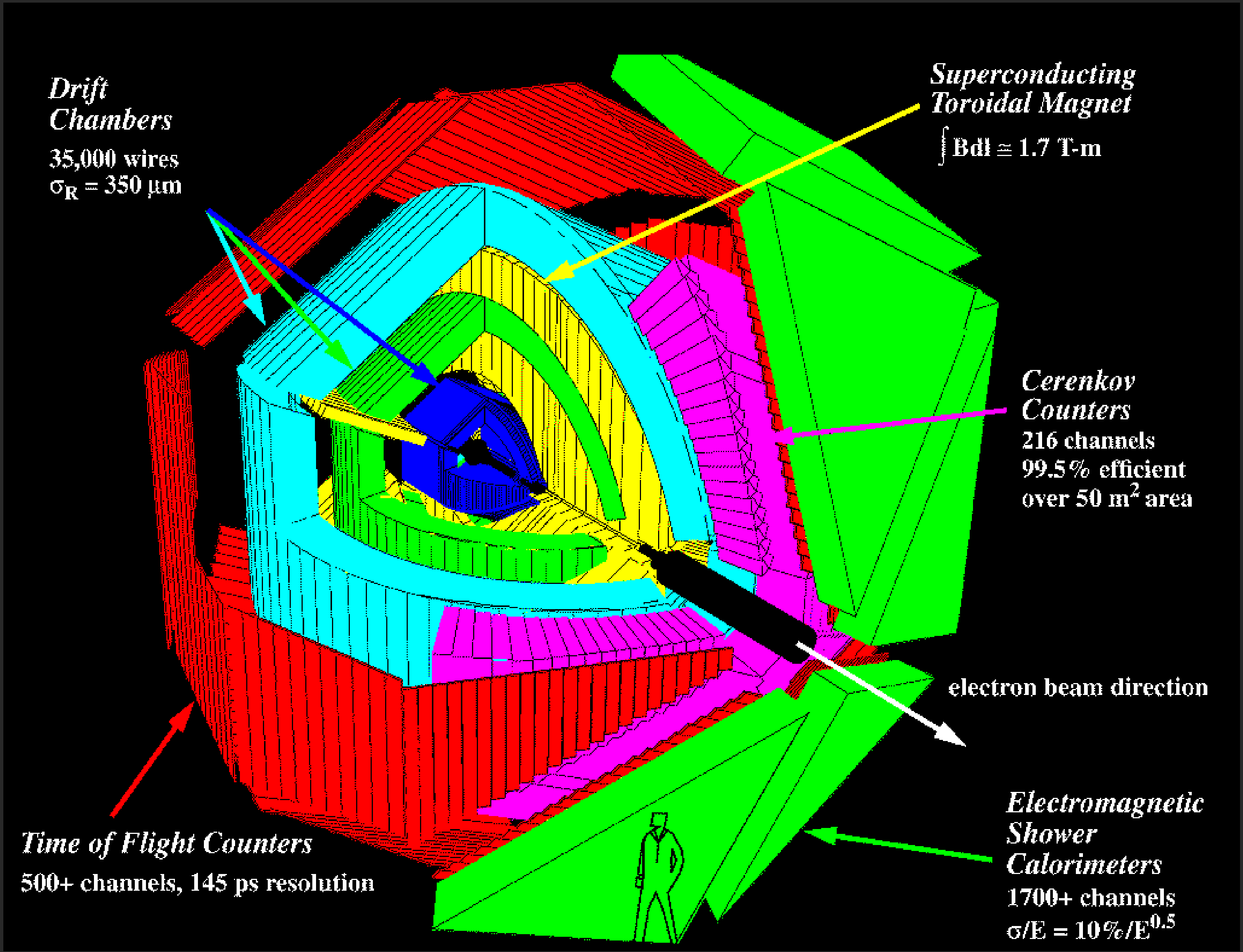
MINERνA event display



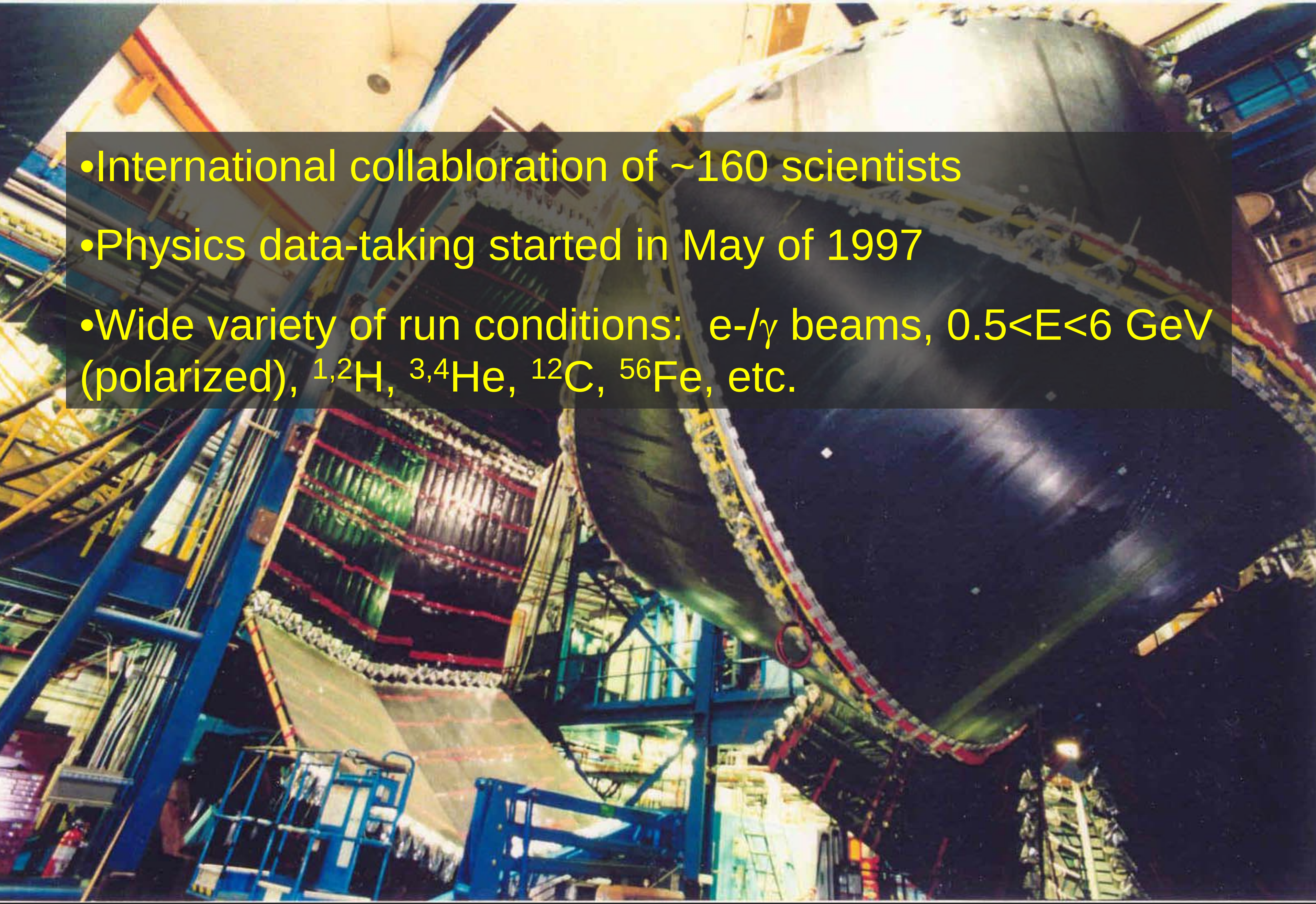
CLAS event display

S.Manly, R.Bradford, I. Kleckner, D. Sher
University of Rochester

CLAS: CEBAF Large Acceptance Spectrometer (Hall B)

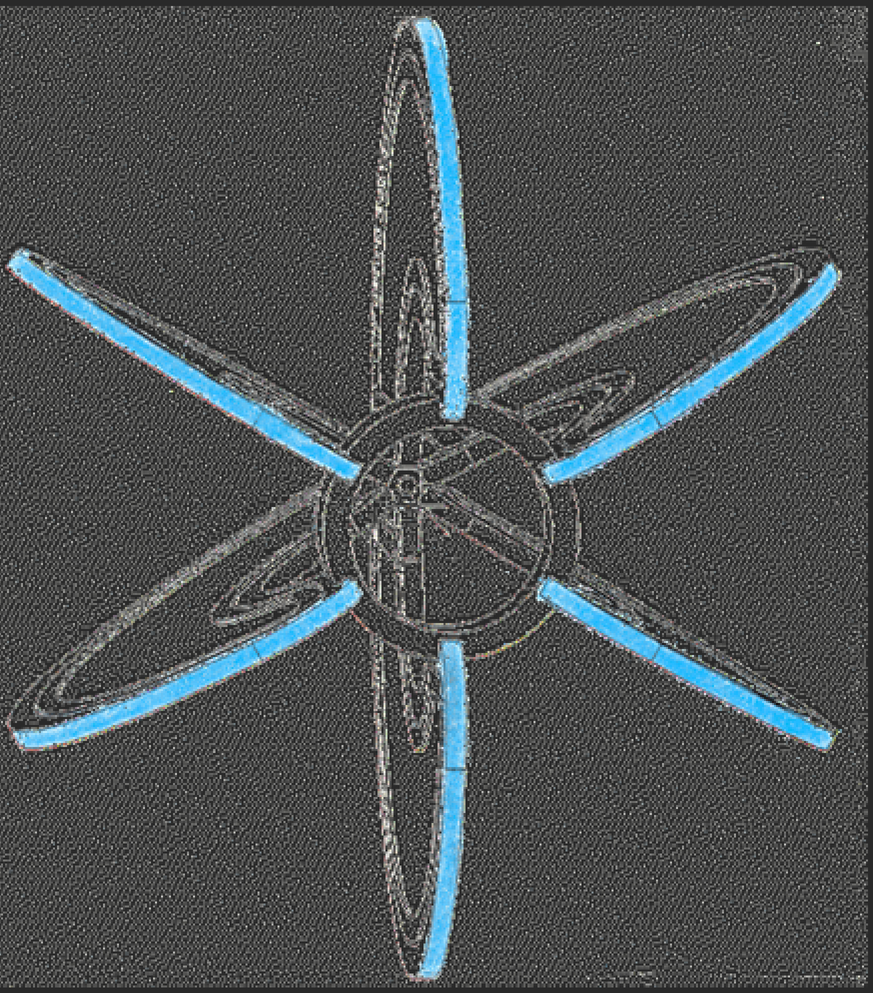


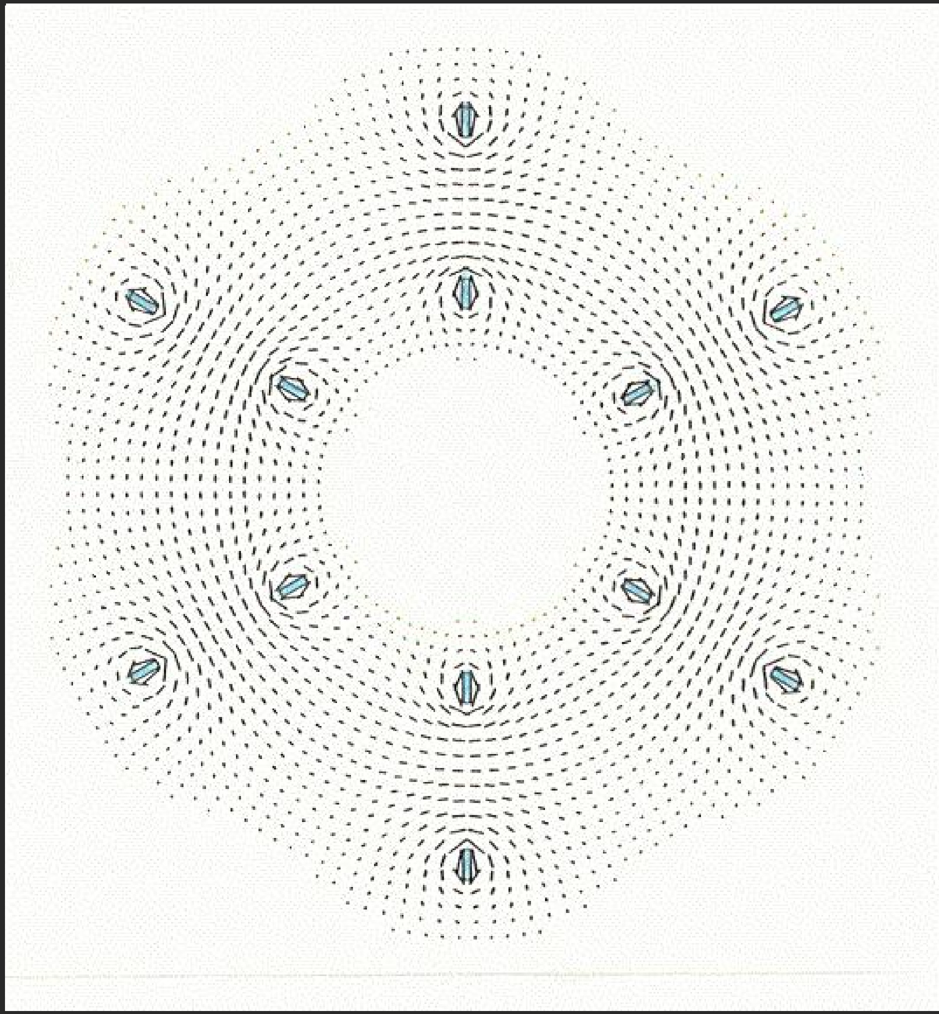
- International collabloration of ~160 scientists
- Physics data-taking started in May of 1997
- Wide variety of run conditions: e-/γ beams, $0.5<E<6$ GeV (polarized), ^{1,2}H, ^{3,4}He, ^{12}C, ^{56}Fe, etc.



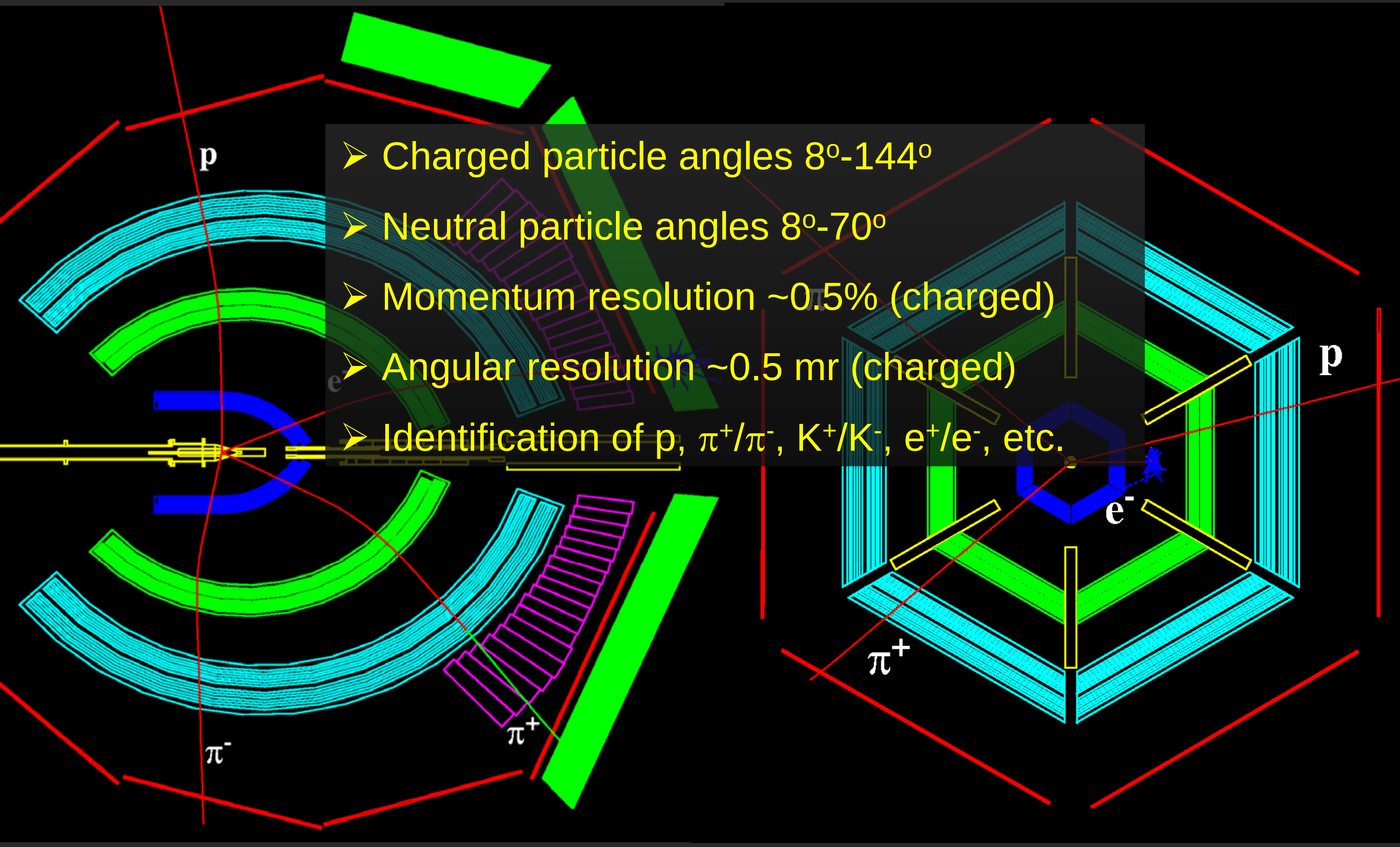
Super-conducting toroidal magnet with six kidney-shaped coils

5 m diameter, 5 m long, 5 M-Amp-turns, max. field 2 Tesla

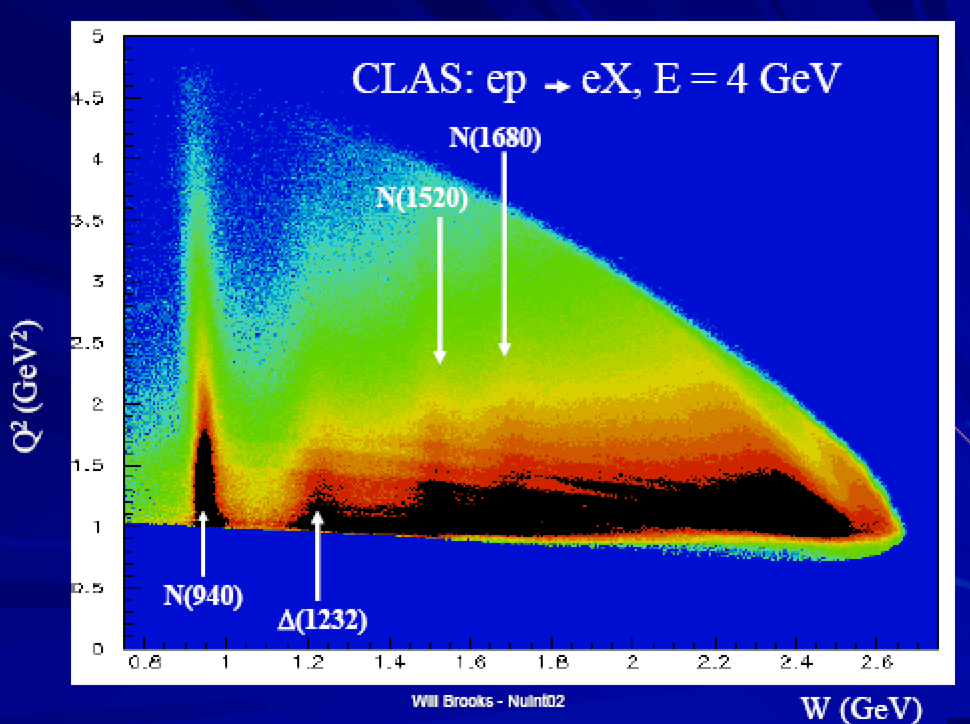


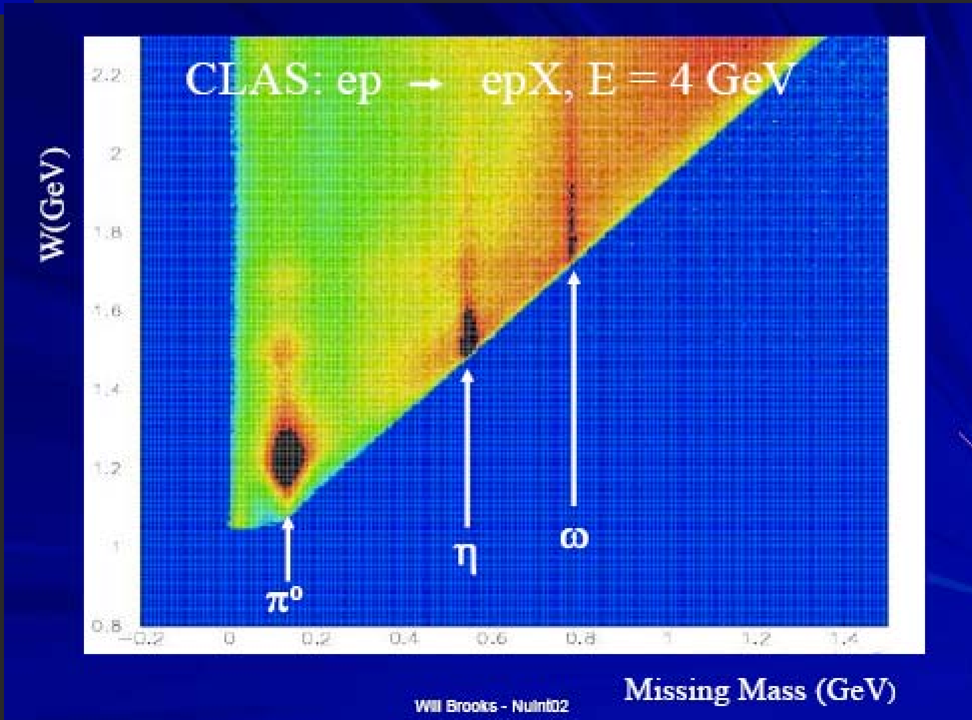


CLAS Single Event Display



- 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

Jupiter: JLab Unified Program to Investigate Nuclear Targets and Electroproduction of Resonances

Hall B part of JUPITER program: look at exclusive final states in eA data in hydrogen and nuclear targets (C and Fe). Produce results useful for tuning MC models used in current and next-generation νA experiments

Bob Bradford

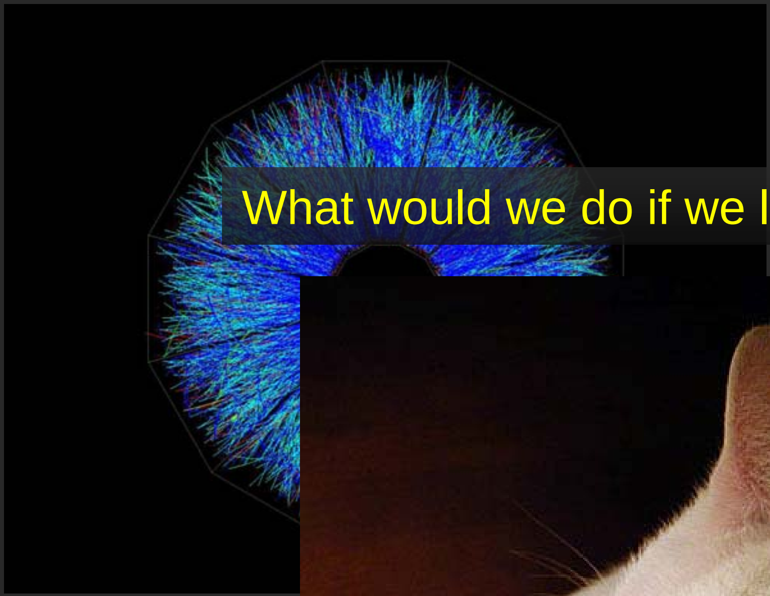
Jennifer Cano (Univ. Virginia undergraduate, summer 2006)

Ian Kleckner (UR undergraduate)

Steve Manly

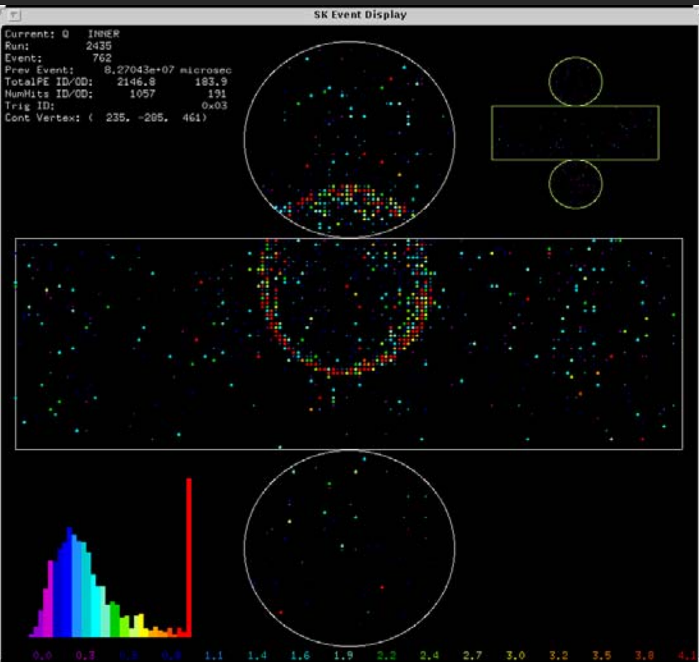
David Sher (John's Hopkins undergraduate, summer 2005)

Coming from RHIC, this has to be easy …



What would we do if we lived in a fantasy world?

Neutrino interaction ID and energy reconstruction



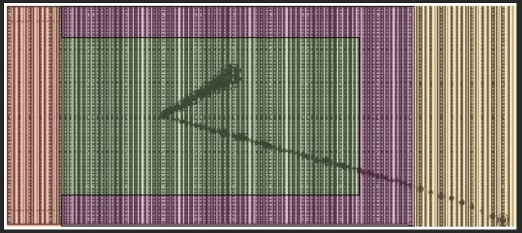
SuperK

Cerenkov

$$E_\nu = \frac{m_N E\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

For QE/E, with source known

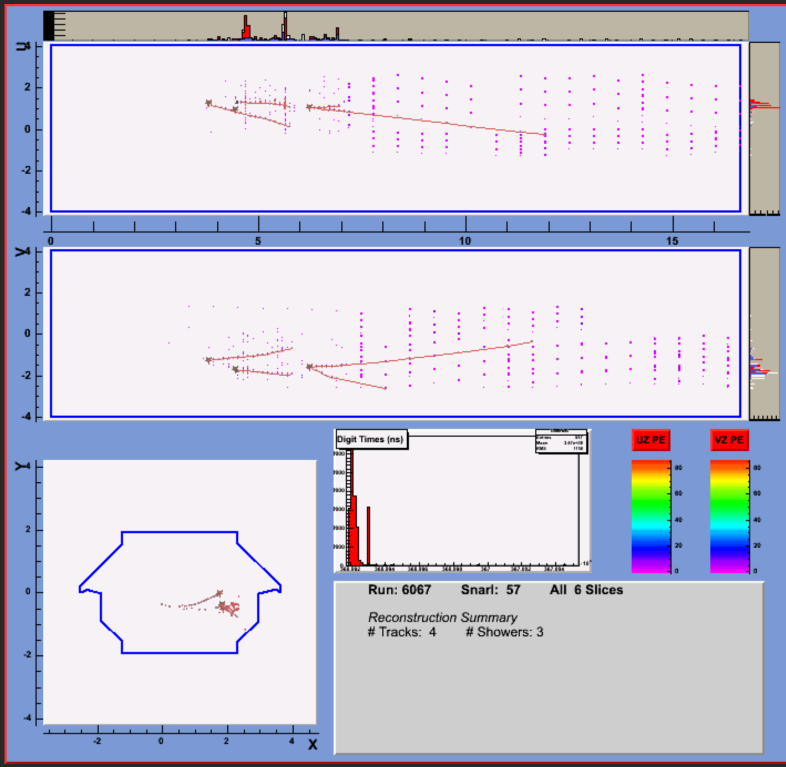
MINERνA

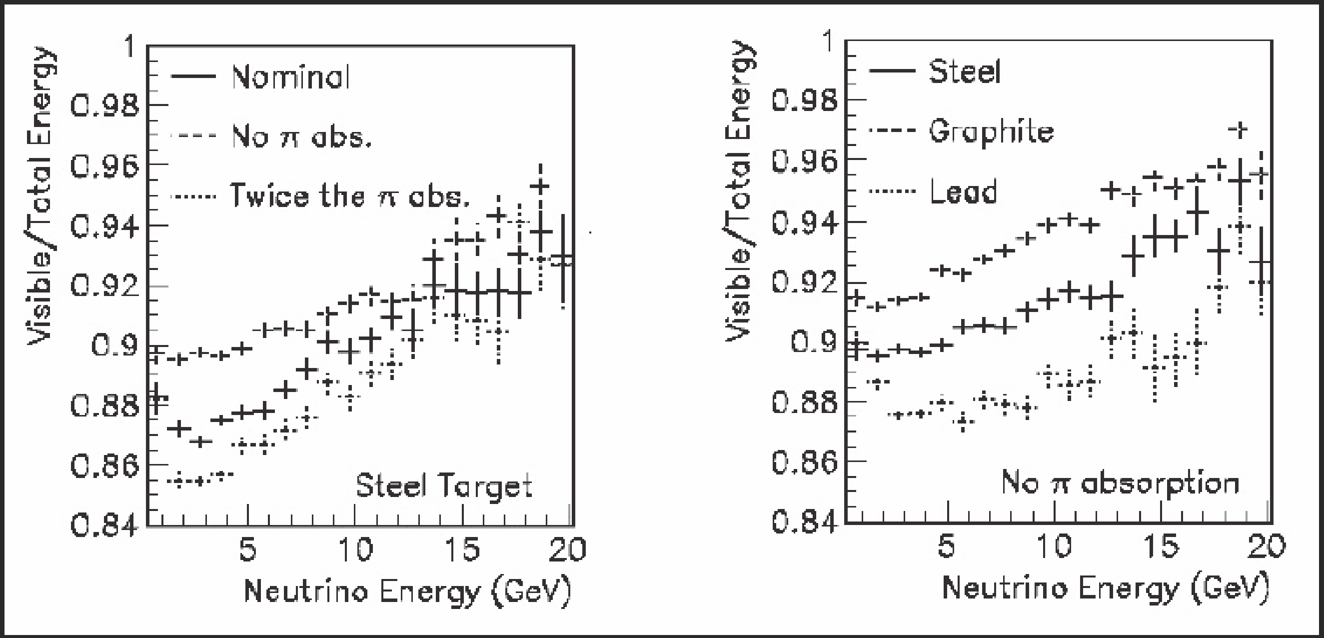


Calorimetric

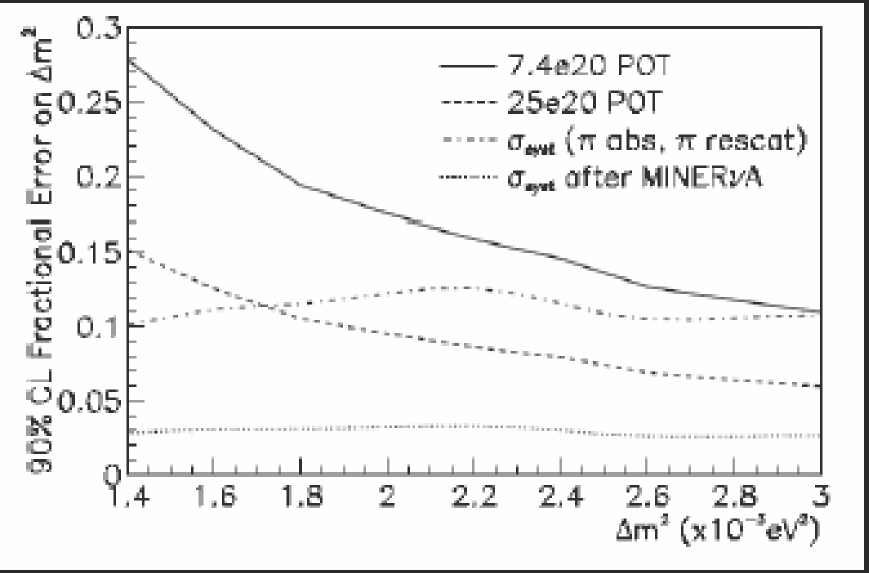
Sampling fraction varies

MINOS





Estimates for MINOS-like detector



D. Harris et al., hep-ex/0410005

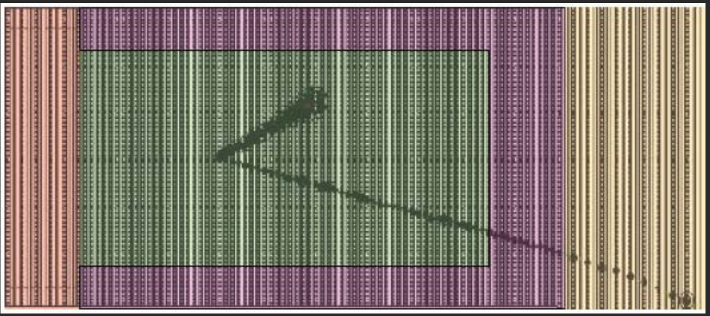
Momentum distributions for charged pions in 1-π and 2- π events (E, Q^2, A=H,C,Fe)

Momentum and angular distributions for charged protons in 0,1,2-π events (E, Q^2, A=H,C,Fe)

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/elastic event? (Affects E_{vis} and event categorization.)

How often do you lose a pion in a resonance or inelastic event? (Affects E_{vis} and event categorization)



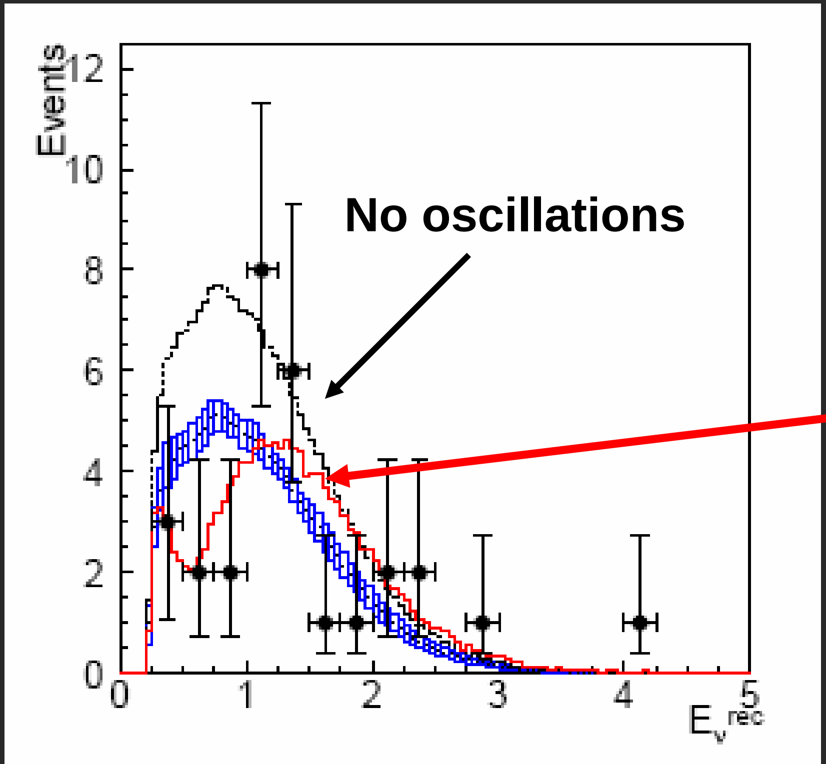
MINERνA event display

π^o / π^+ ratio, π^- / π^+ ratio (E, q^2, A)

E_{vis} vs. W

Neutral and charged pions look different in ν detectors.

The reconstructed neutrino energy is a critical quantity for neutrino expts. They can tune MC's with CLAS results presented appropriately.



i.e., K2K result, E_ν is important

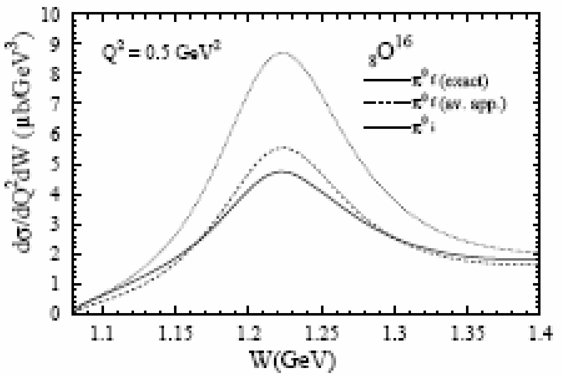


Figure 1. Electroproduction for π^0 on Oxygen target.

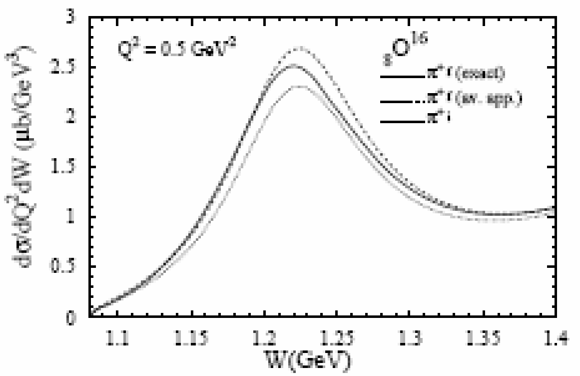


Figure 2. Electroproduction for π^+ on Oxygen target.

- Dotted line is x-section without nuclear corrections
- Broken-line curve is the x-section including nuclear corrections with averaging approximation
- Solid line is x-section with exact transport problem (no averaging)

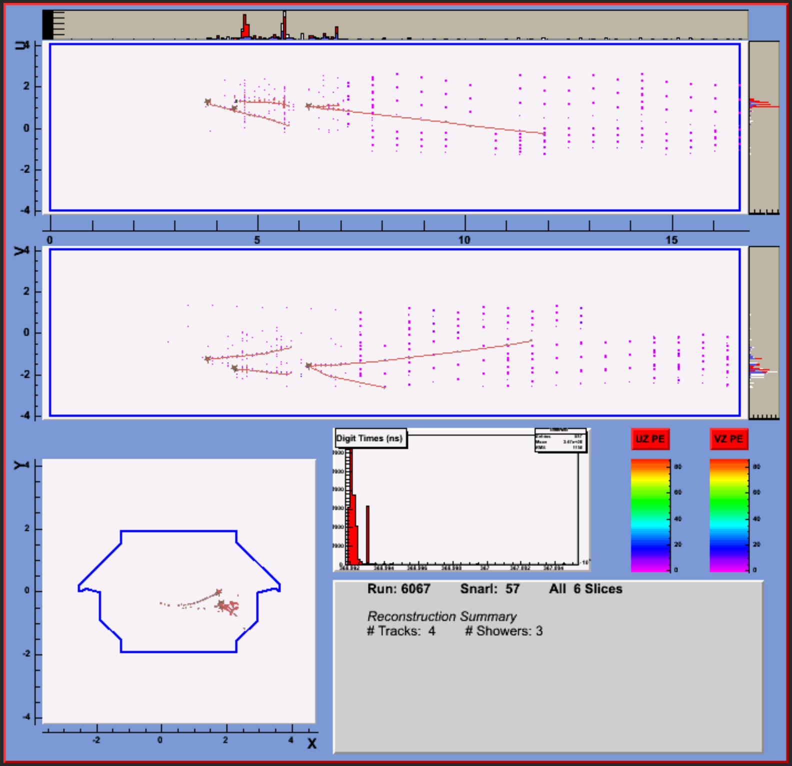
Would be nice to test/tune the model to best extent possible on electroproduction …

Paschos, Schienbein, Yu, hep-ph/0408148

ANP model calculations

ep → epπ^o → epπ^+ below 2π threshold

Coherent neutral pion production background needs to be understood in neutrino experiments. Pizeros can mimic electron neutrinos. How often does charge exchange happen? Is there an A dependence?



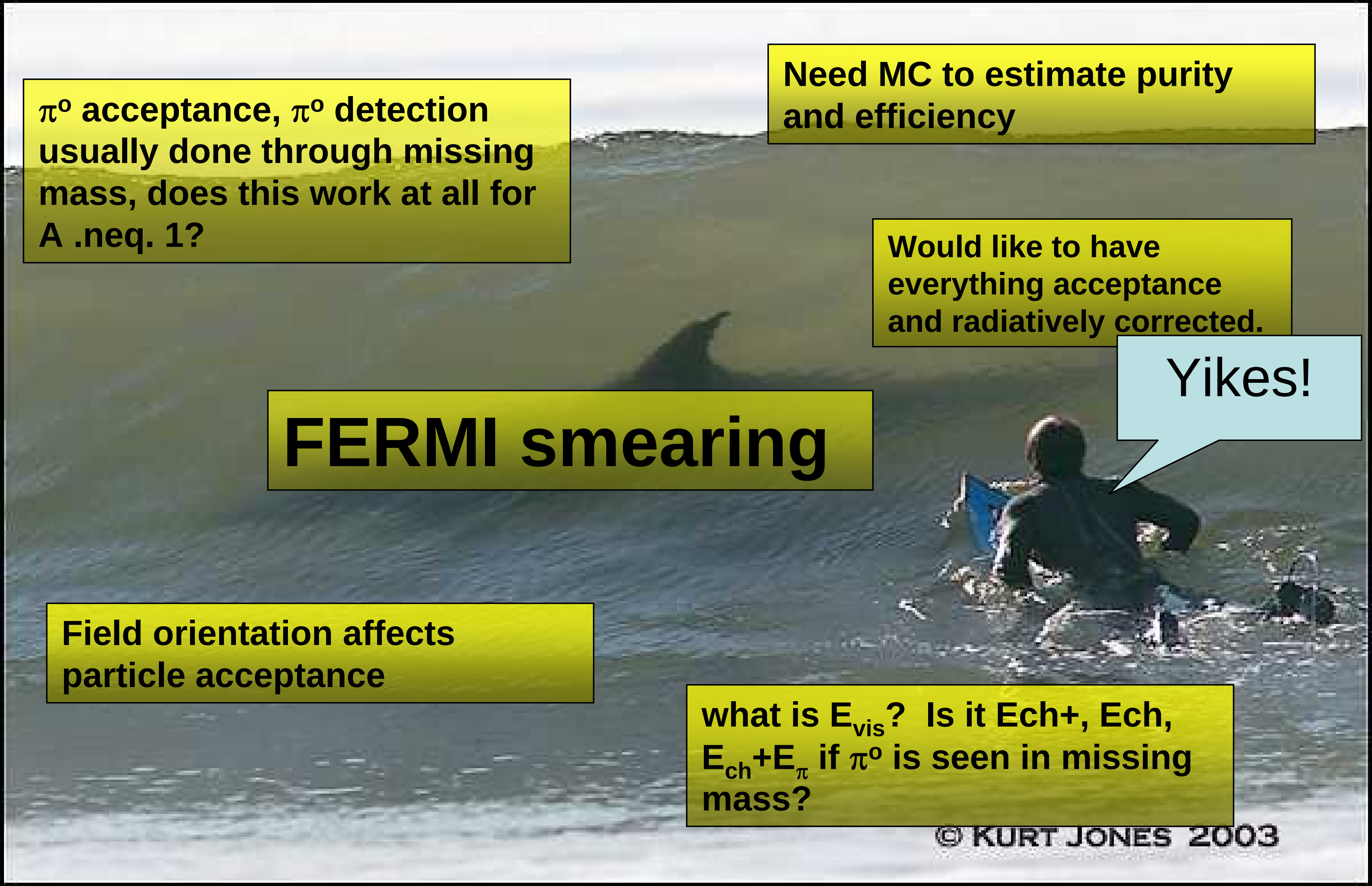
Identify events with specific resonances, in, say $p\pi$

Look at single π yields $d^5\sigma/d\Omega' dE' d\Omega^*$

π Integrated $d\sigma/dw$, $d\sigma/dq^2$ for each resonance

Helpful for model builders trying to understand the resonance region (Paschos).

Okay … time for a reality check.


Need MC to estimate purity and efficiency
π^o acceptance, π^o detection usually done through missing mass, does this work at all for A .neq. 1?
Would like to have everything acceptance and radiatively corrected.
Yikes!
FERMI smearing
Field orientation affects particle acceptance
what is E_{vis}? Is it Ech+, Ech, $E_{ch}+E_{\pi}$ if π^o is seen in missing mass?
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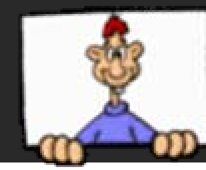
Hydrogen data from Run e1c, E=4.462 GeV

Carbon data from Run e2a, E=4.462 GeV



Our first look at the data

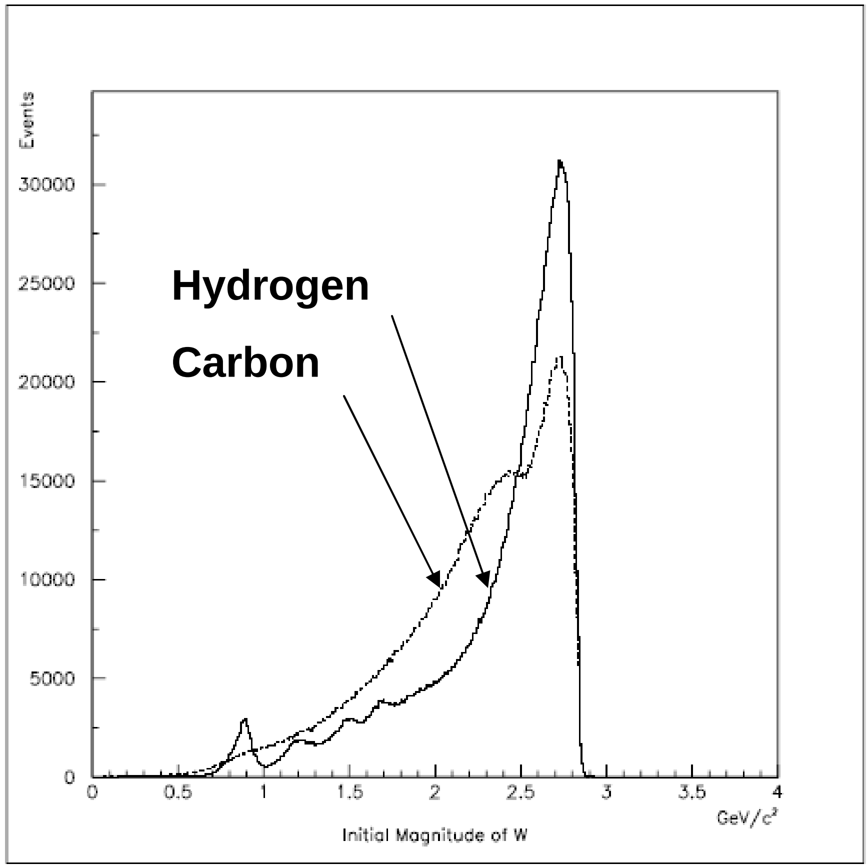


Figure 1. Initial Magnitude of Hadronic Mass W. Hydrogen solid line, carbon dotted line.

Raw W distribution using SEB group and CLAS software for initial particle ID (H from run 17746, C from run 018018)

Cleaning up the electrons

Sampling fraction cut, E/p be near 1 for electron hypothesis

Demand 60 MeV in inner electromagnetic calorimeter

Demand electrons lose no more than 20% of initial energy, y<0.8

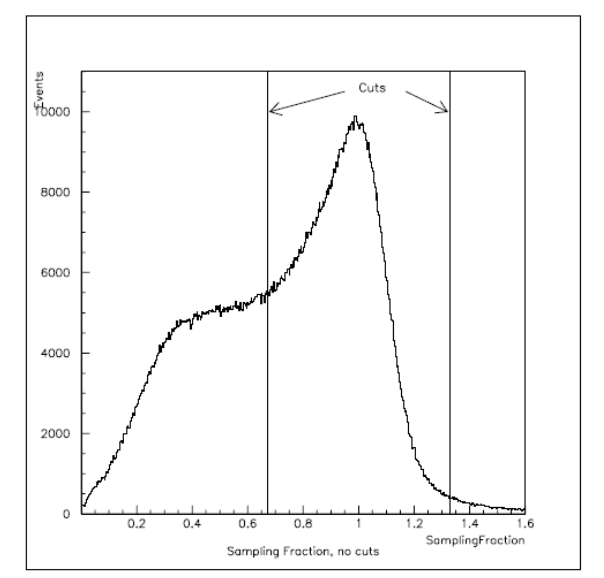
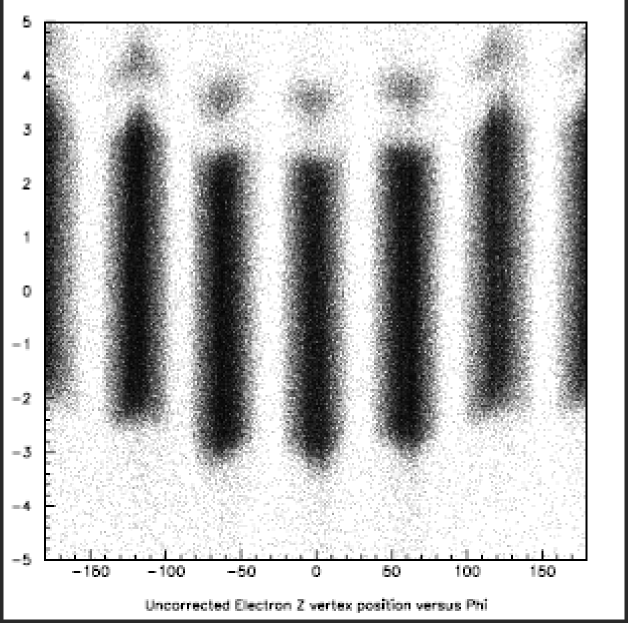
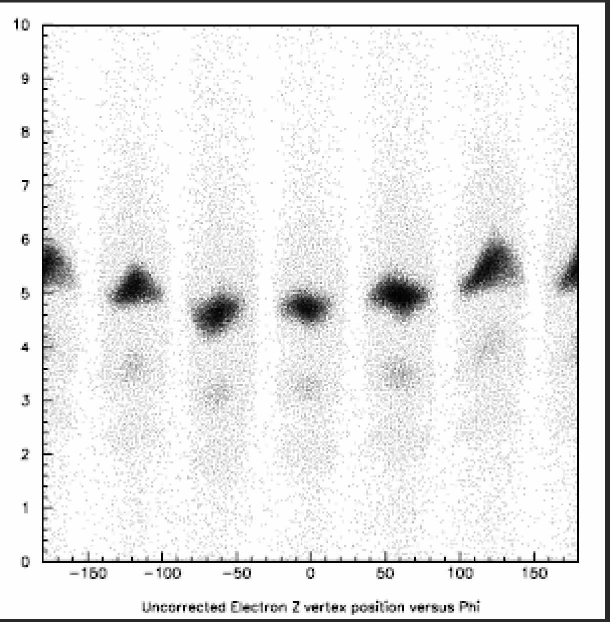
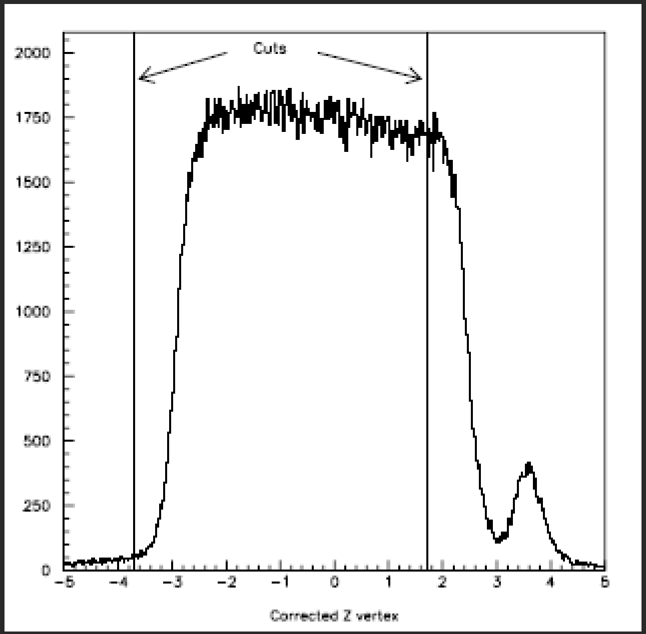


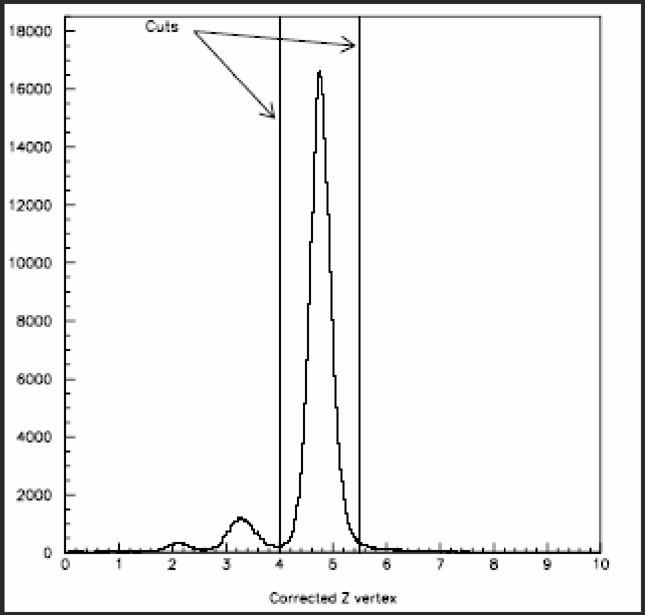
Figure 2. Sampling fraction for hydrogen data. Cuts indicated by vertical lines.

Uncorrected z vertex distributions







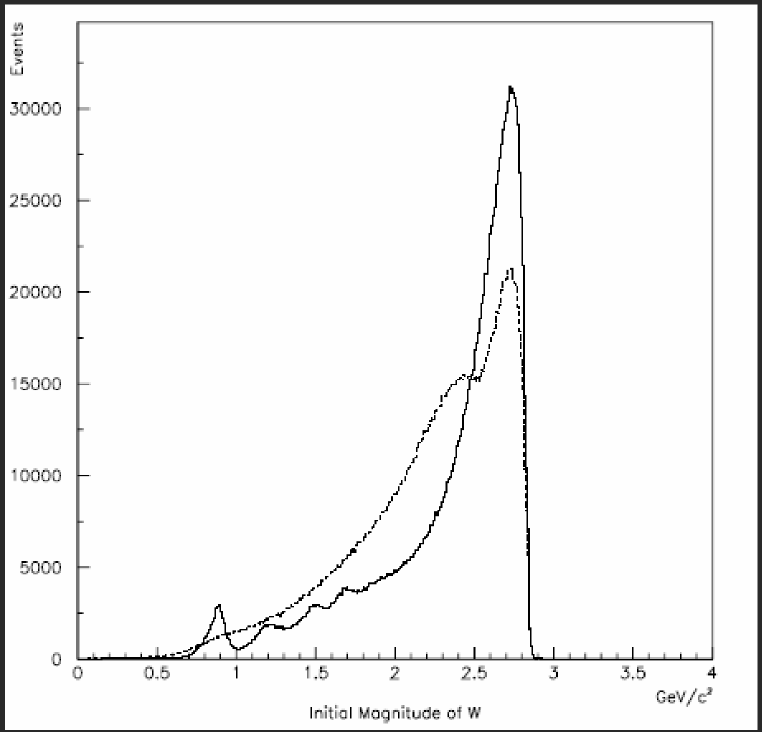


carbon

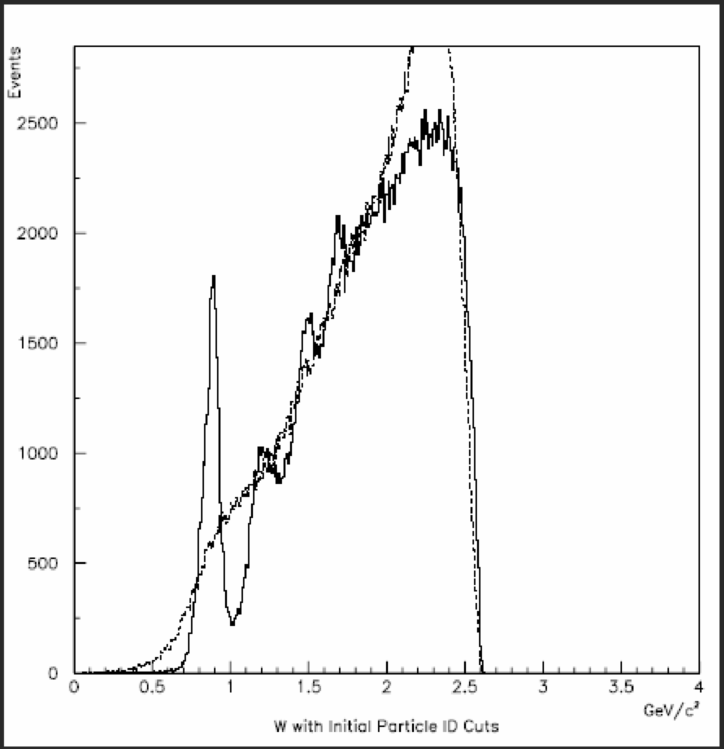
Hydrogen

Follows cuts done in Carman and Raue, "Hyperon Electroproduction in CLAS"

Cleaning up the electrons



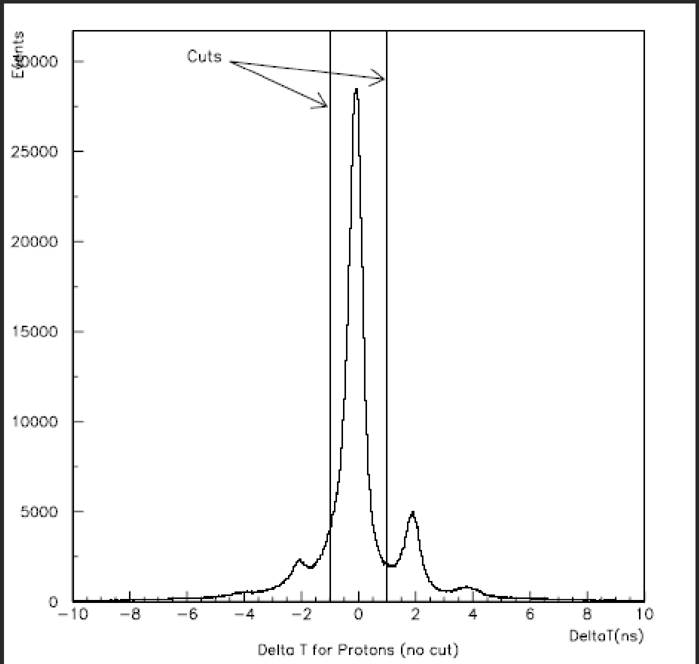
Raw data

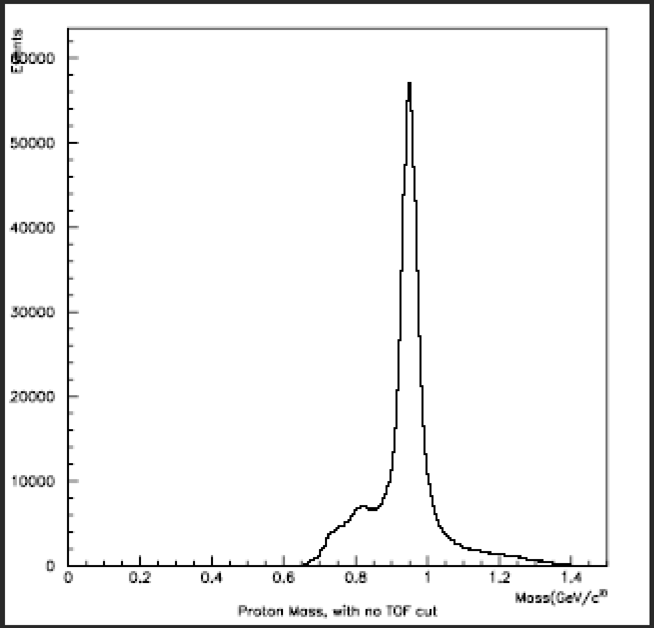


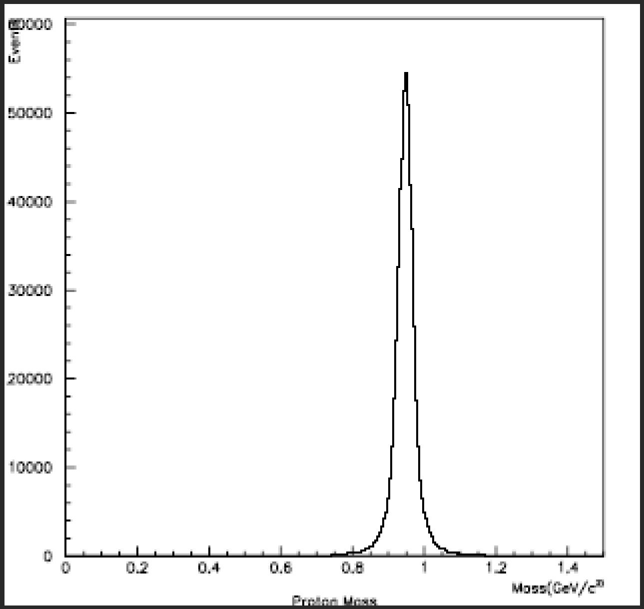
With sampling fraction cut, mass cut, Z-vertex cut, EC-fiducial cuts, y<0.8.

Cleaning up the hadrons

Time-of-flight cuts for protons in hydrogen target data

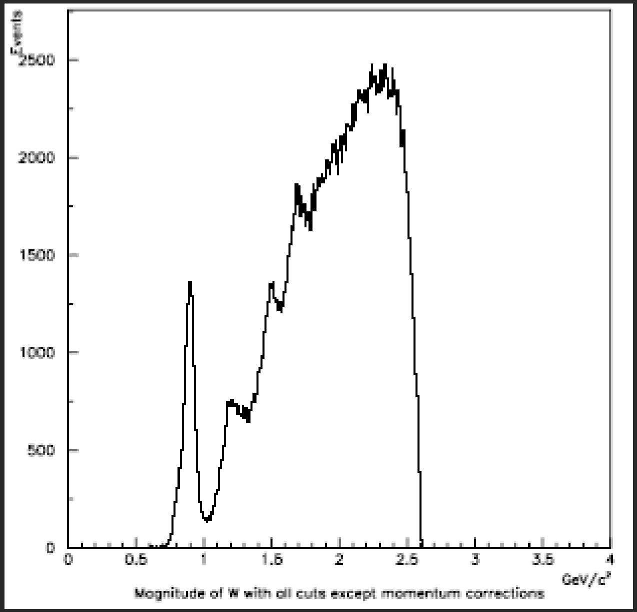




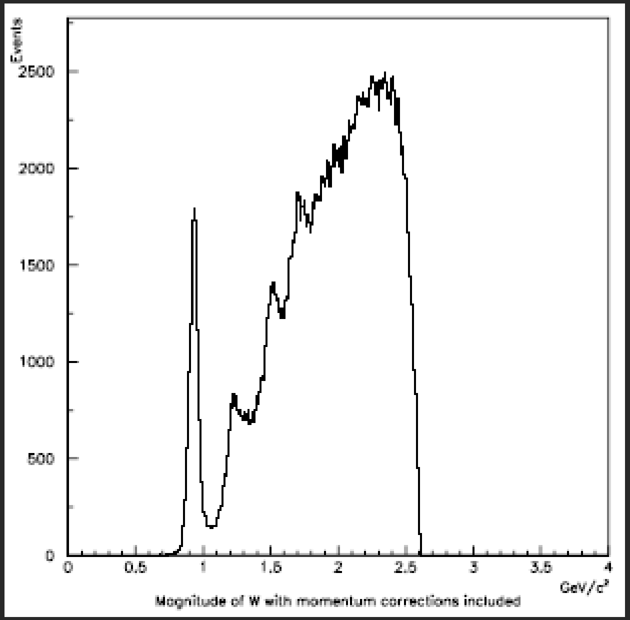


Momentum corrections –

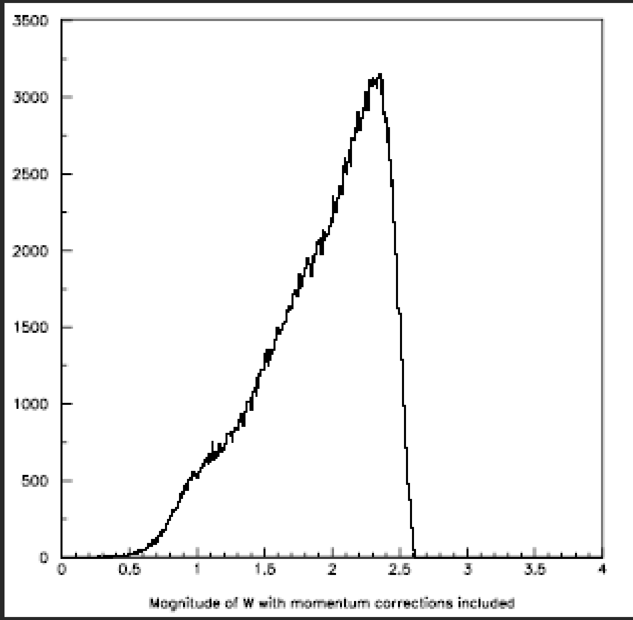
Use PittsMomCorr (for e1c H data), also applied to our e2a carbon data



hydrogen



carbon

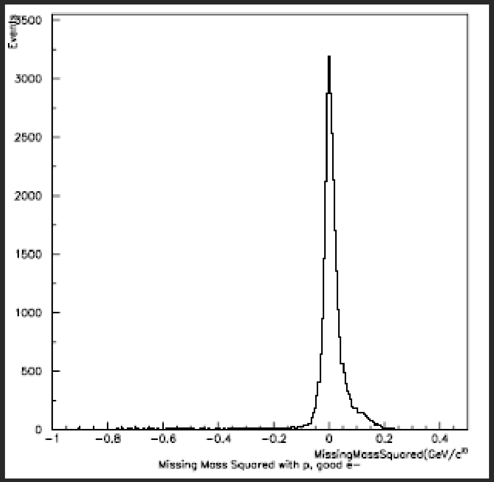


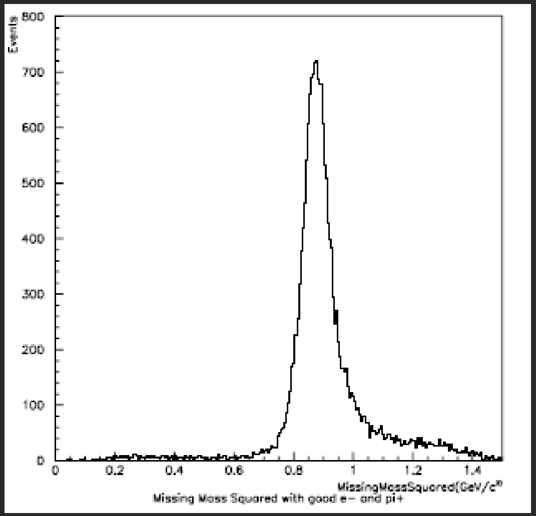
Missing mass squared in Δ(1232) resonance region

e-p

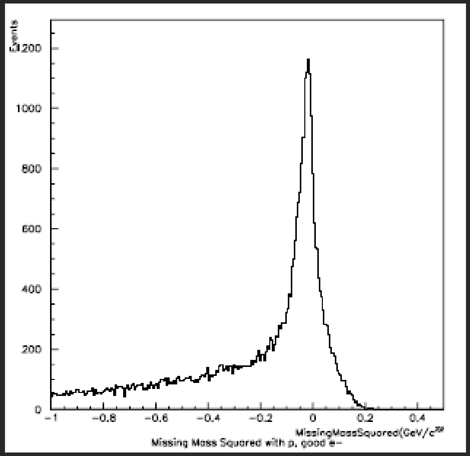
e-pi

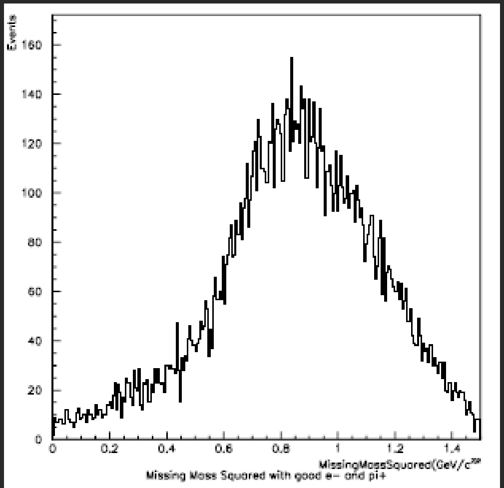
hydrogen



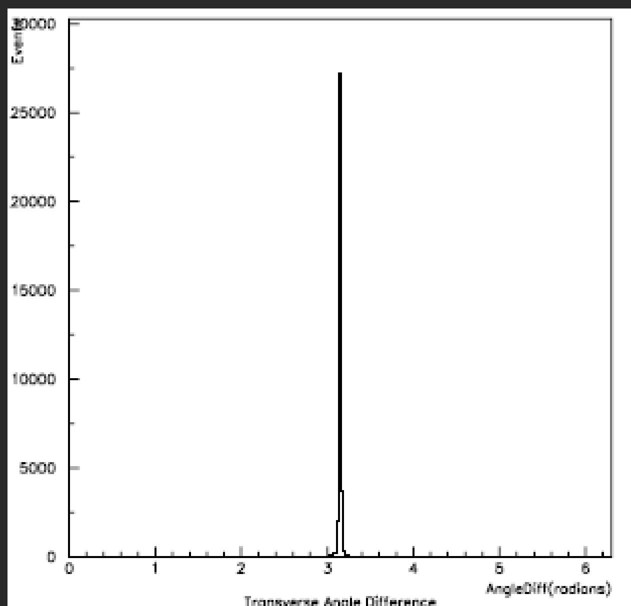


carbon

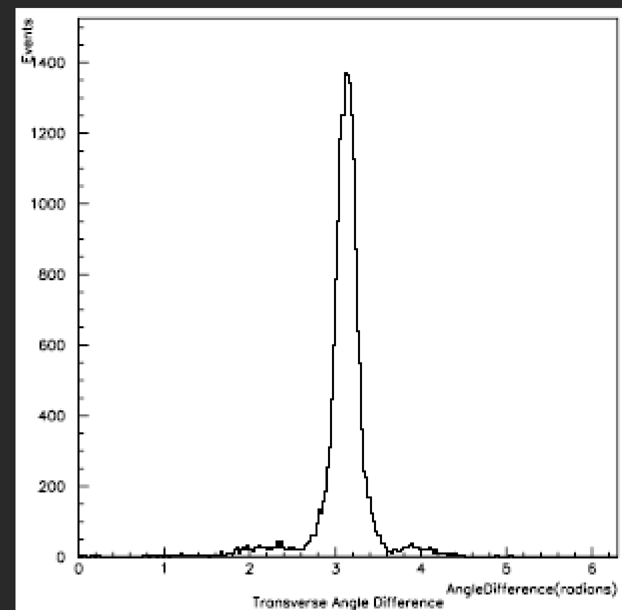




Events in the elastic region – transverse opening angle between the e- and proton

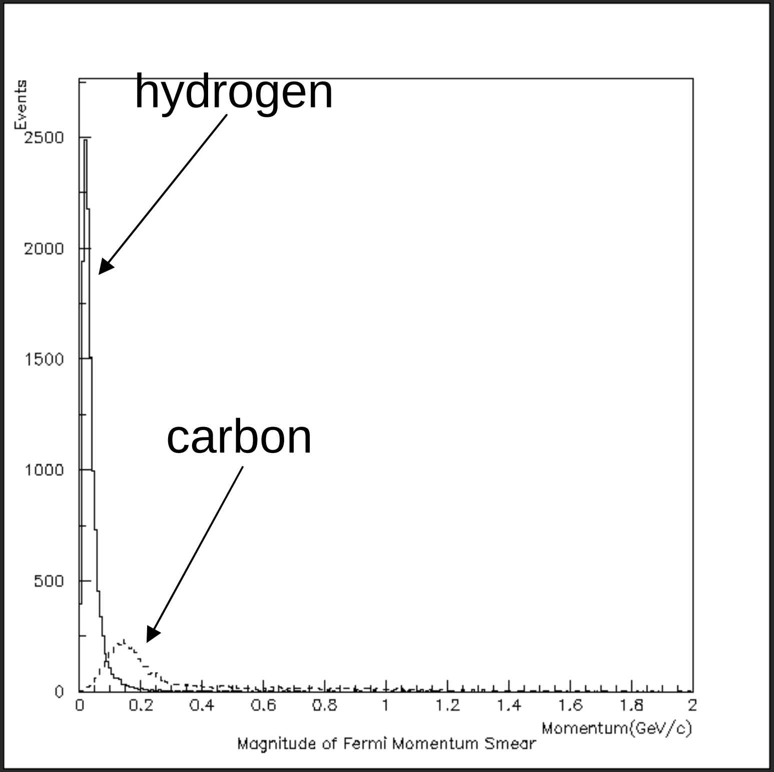


hydrogen



carbon

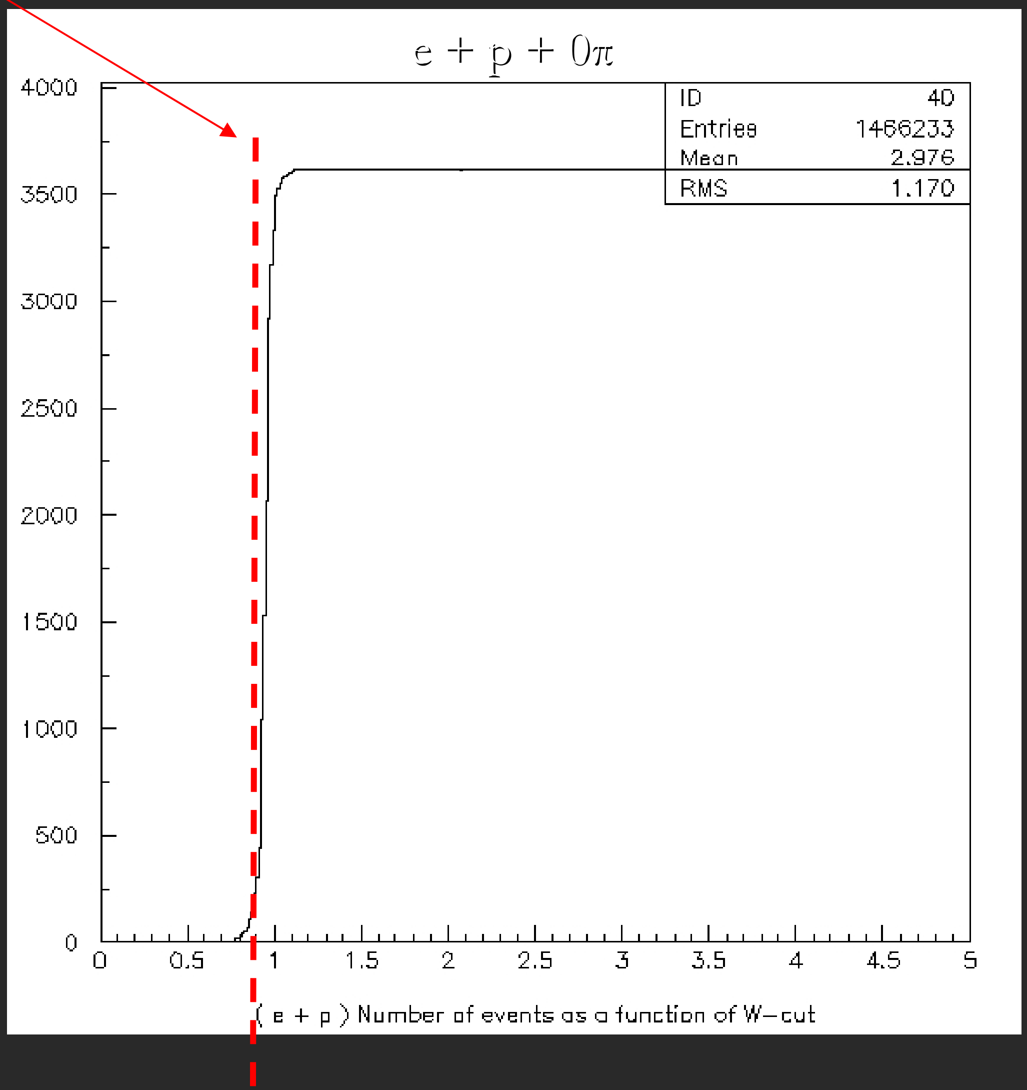
Know incoming e- four-vector and outgoing e- and p four-vectors, calculate magnitude of incoming p momentum due to Fermi smearing

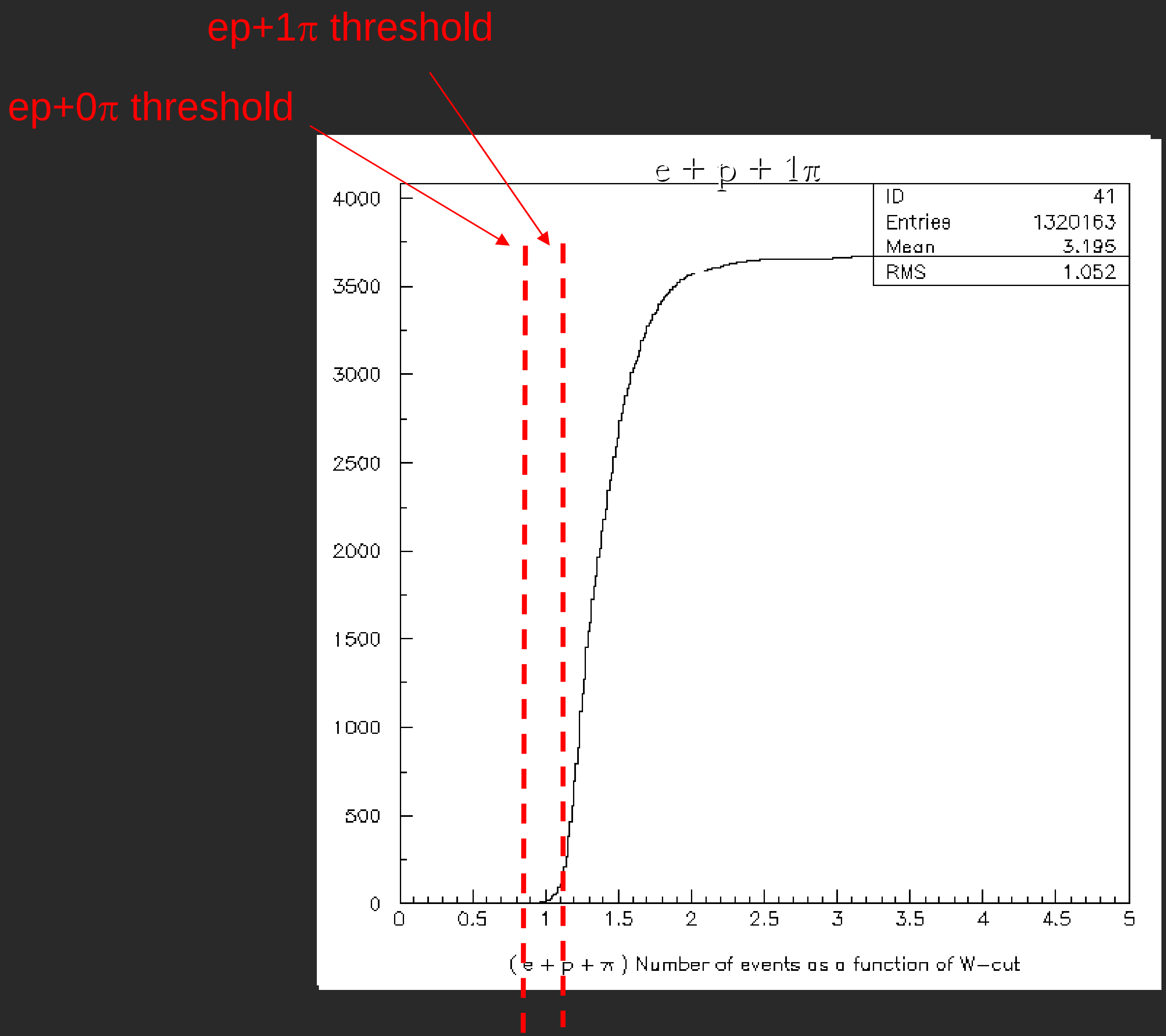


Can use momentum and energy conservation and try to correct for Fermi smear on event-by-event basis. Sort of works but imperfect due to off-shell kinematics.

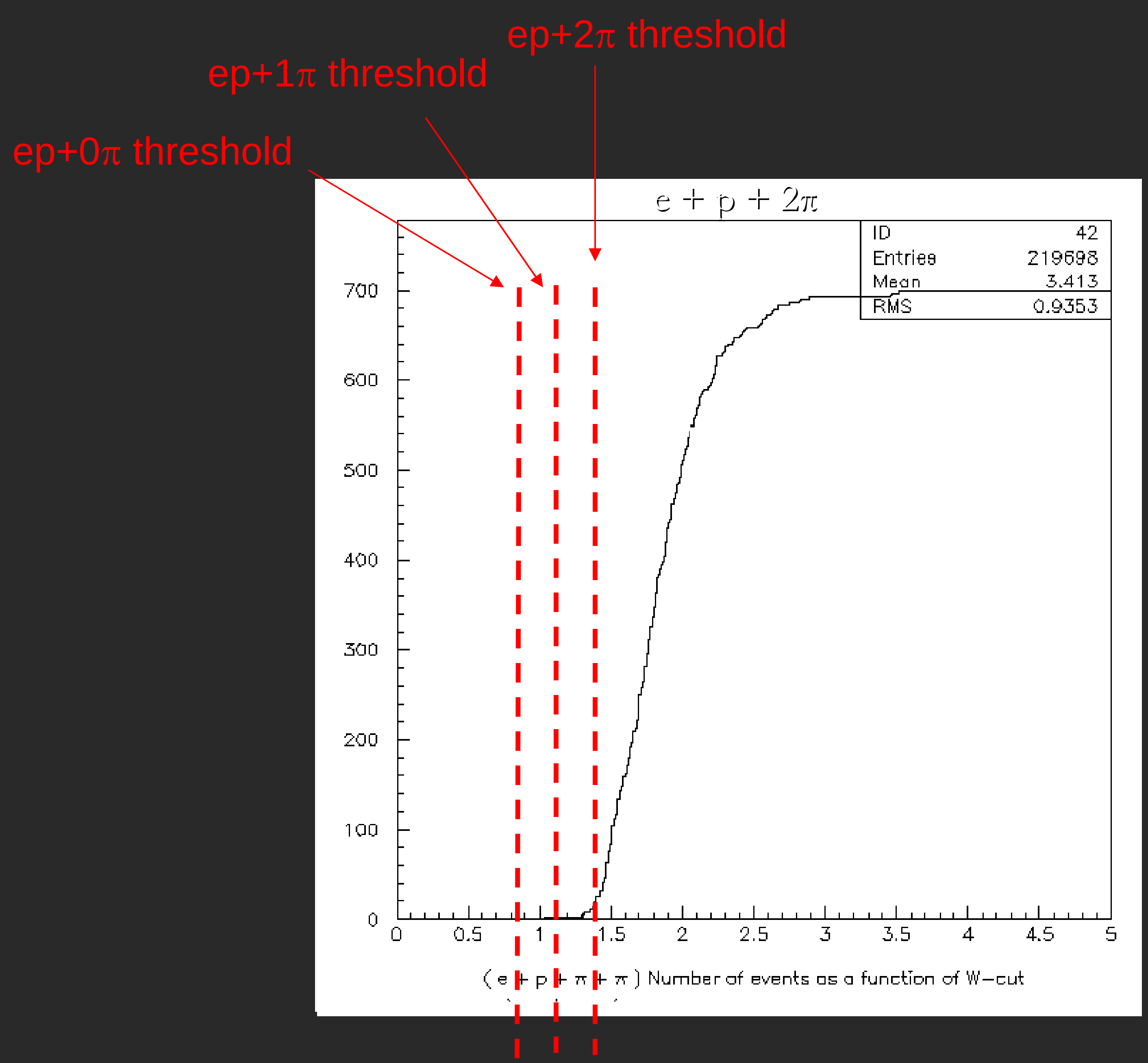
Can we use thresholds in W?

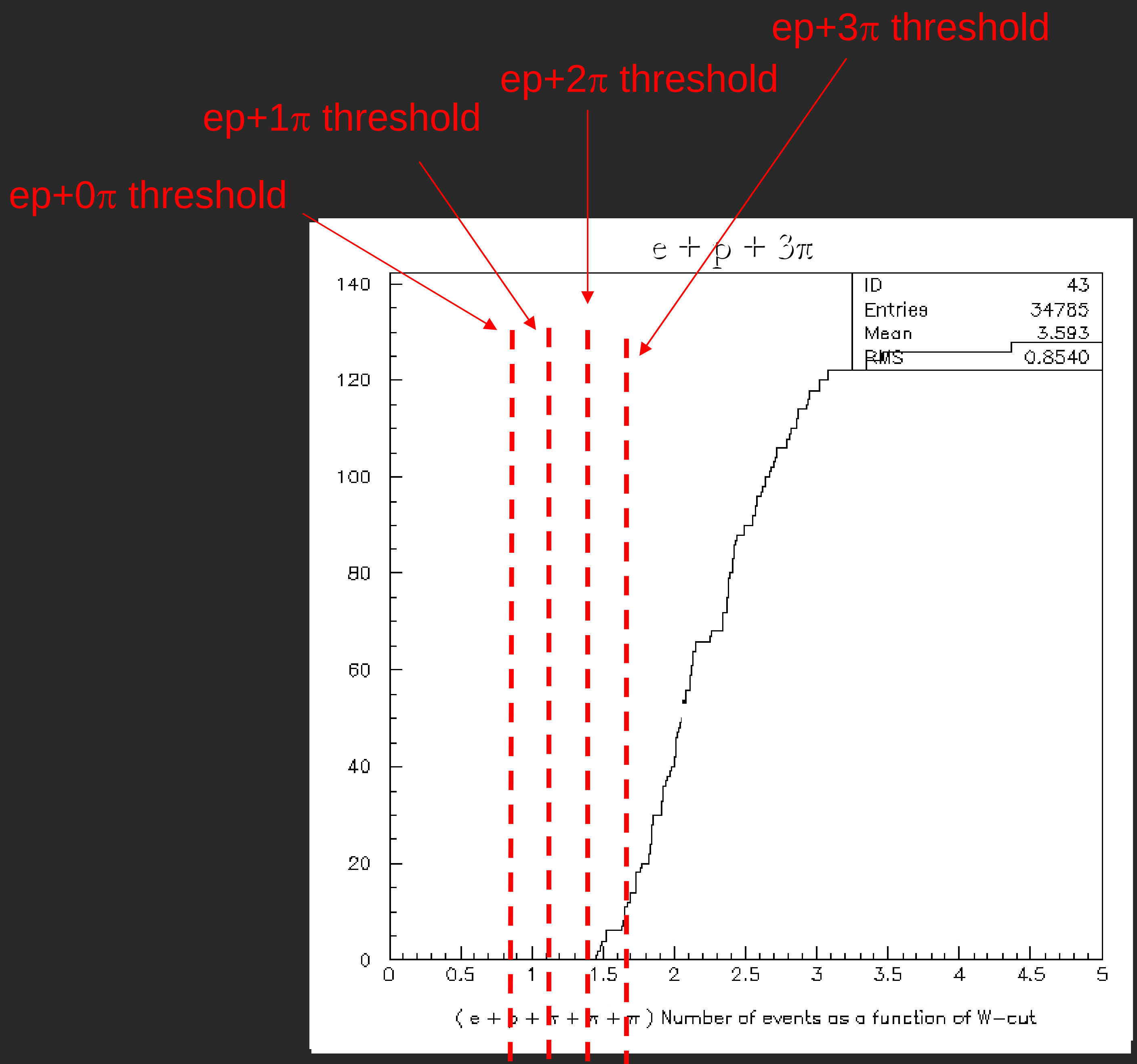
ep+0π threshold





ep+1π threshold
ep+0π threshold
e + p + 1π
ID 41
Entries 1320163
Mean 3.195
RMS 1.052
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
700
600
500
400
300
200
100
0
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

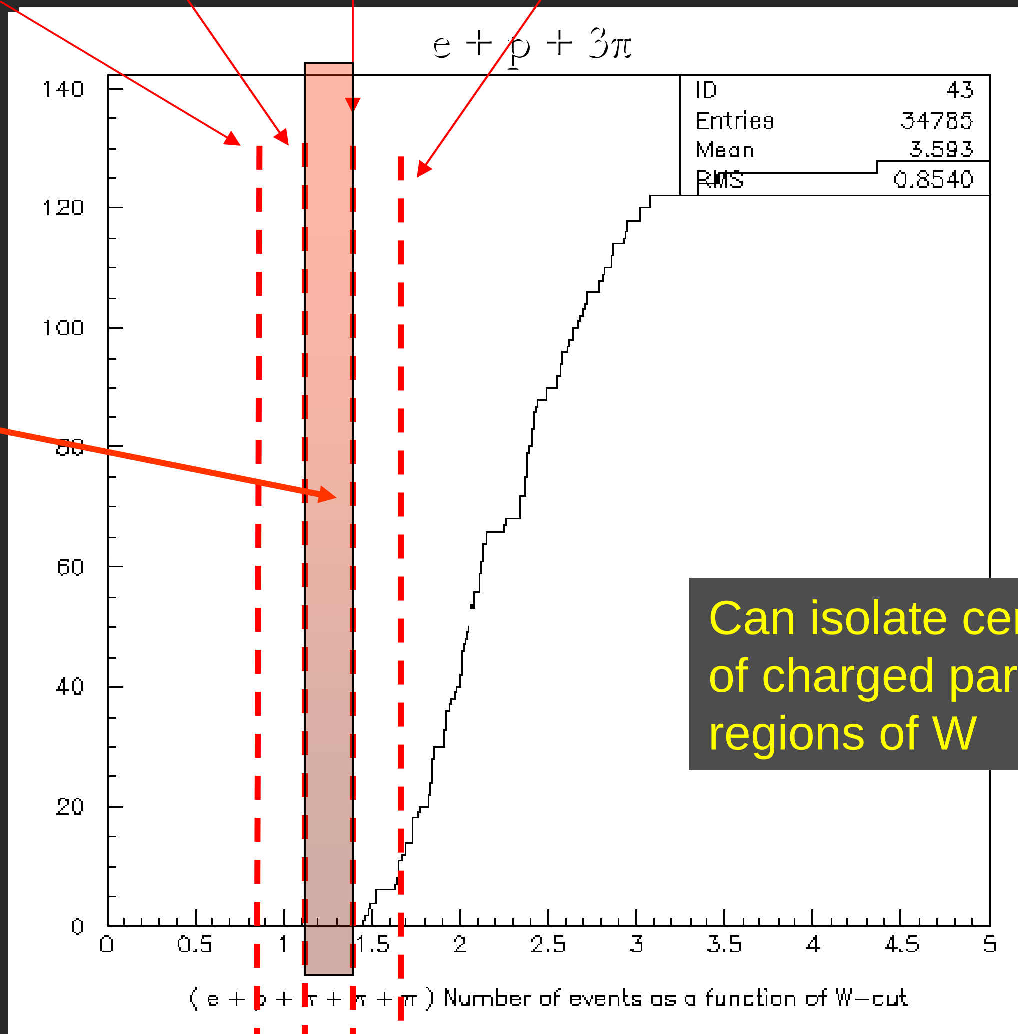

ep+3π threshold
ep+2π threshold
ep+1π threshold
ep+0π threshold
e + p + 3π
ID 43
Entries 34785
Mean 3.593
RMS 0.8540
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
(e + p + π + π + π) Number of events as a function of W−cut

ep+3π threshold

ep+2π threshold

ep+1π threshold

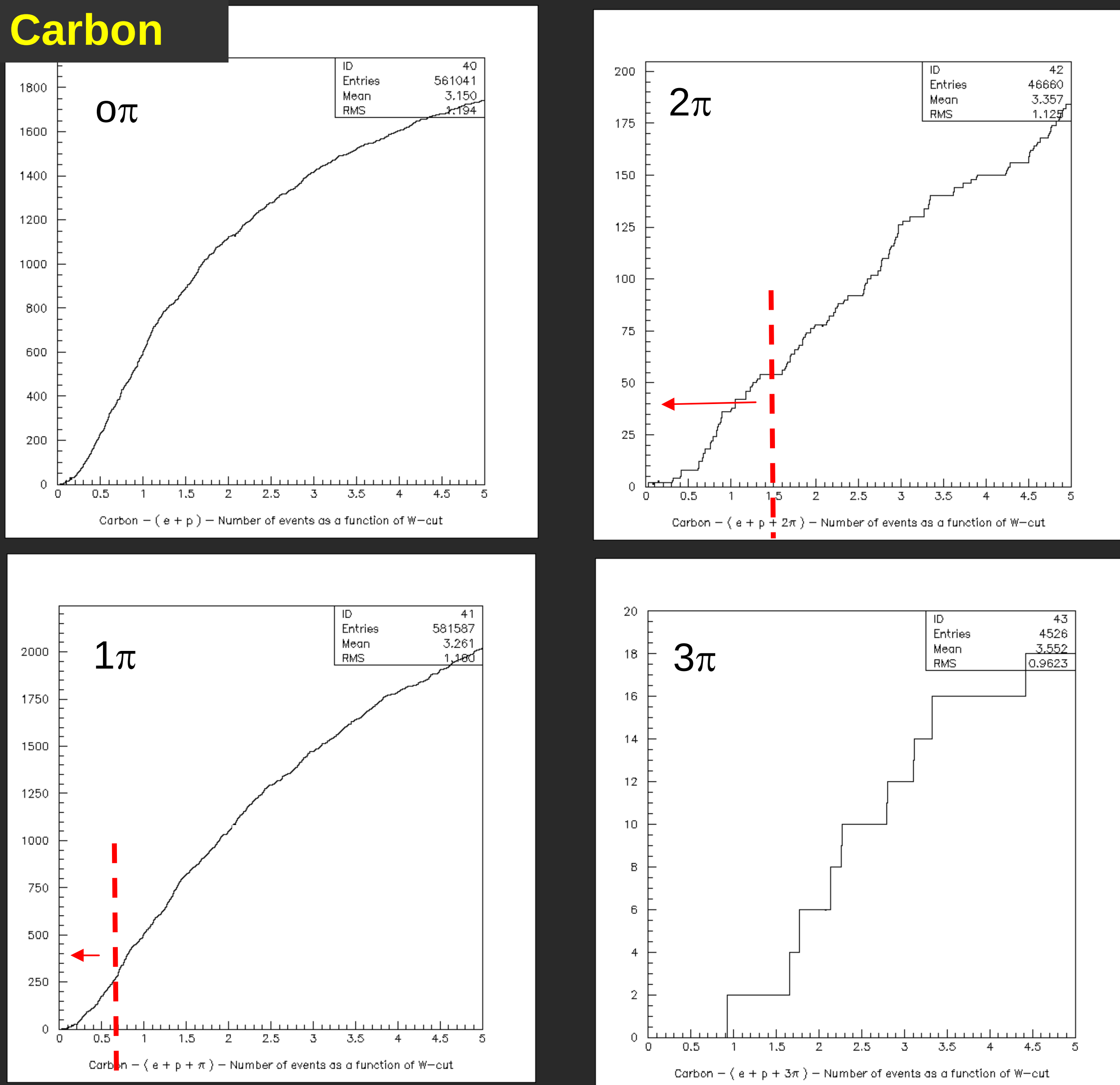
ep+0π threshold



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
ID 40
Entries 561041
Mean 3.150
RMS 1.194
Carbon – (e + p) – Number of events as a function of W–cut
2π
ID 42
Entries 46660
Mean 3.357
RMS 1.125
Carbon – (e + p + 2π) – Number of events as a function of W–cut
1π
ID 41
Entries 581587
Mean 3.261
RMS 1.160
Carbon – (e + p + π) – Number of events as a function of W–cut
3π
ID 43
Entries 4526
Mean 3.552
RMS 0.9623
Carbon – (e + p + 3π) – Number of events as a function of W–cut

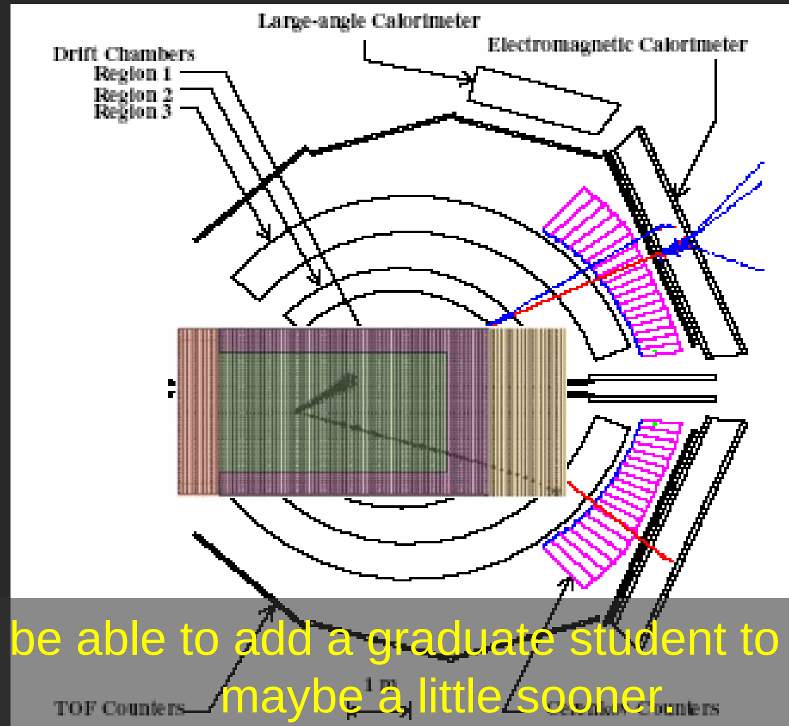
Near future

Fermi smearing and radiative corrections ~cancel

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

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

Fermi smearing and radiative corrections ~cancel



Expect to be able to add a graduate student to effort by 2007, maybe a little sooner.

This summer … pizeros

MC, radiative corrections

Able to isolate topologies in eA in narrow regions of W

Open to suggestions for tricks to pull out resonances

Open to suggestions for useful observations that are realistic about the difficulty of identifying topologies and resonances