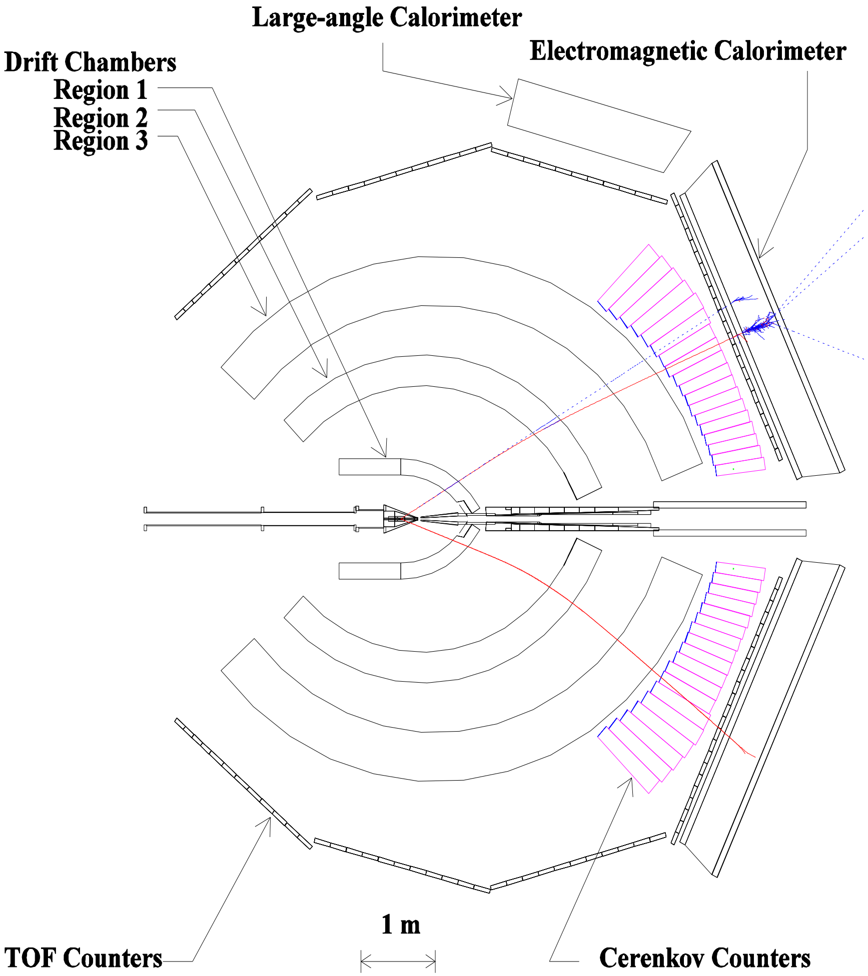
eA pion production at CLAS aimed at neutrinos



S. Manly & Hyupwoo Lee

University of Rochester

Department of Physics and Astronomy

NUINT 2011

Dehradun, India

Representing the CLAS (EG-2) collaboration

Motivation

I thought this here was a neutrino conference.

NUINT - 2011
Seventh International Workshop on
Neutrino-Nucleus Interactions in the Few-GeV Region
March 7th - 11th, 2011
Dehradun, Uttarakhand (India)

George is right! $\nu \neq e^-$

Inconsistent footers in talk, will need to straighten out

Motivation – why eA?

- **High statistics.**
- **Control over initial energy and interaction point – gives kinematic constraints and ability to optimize detector.**
- **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.**
- **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. (Hall C)**

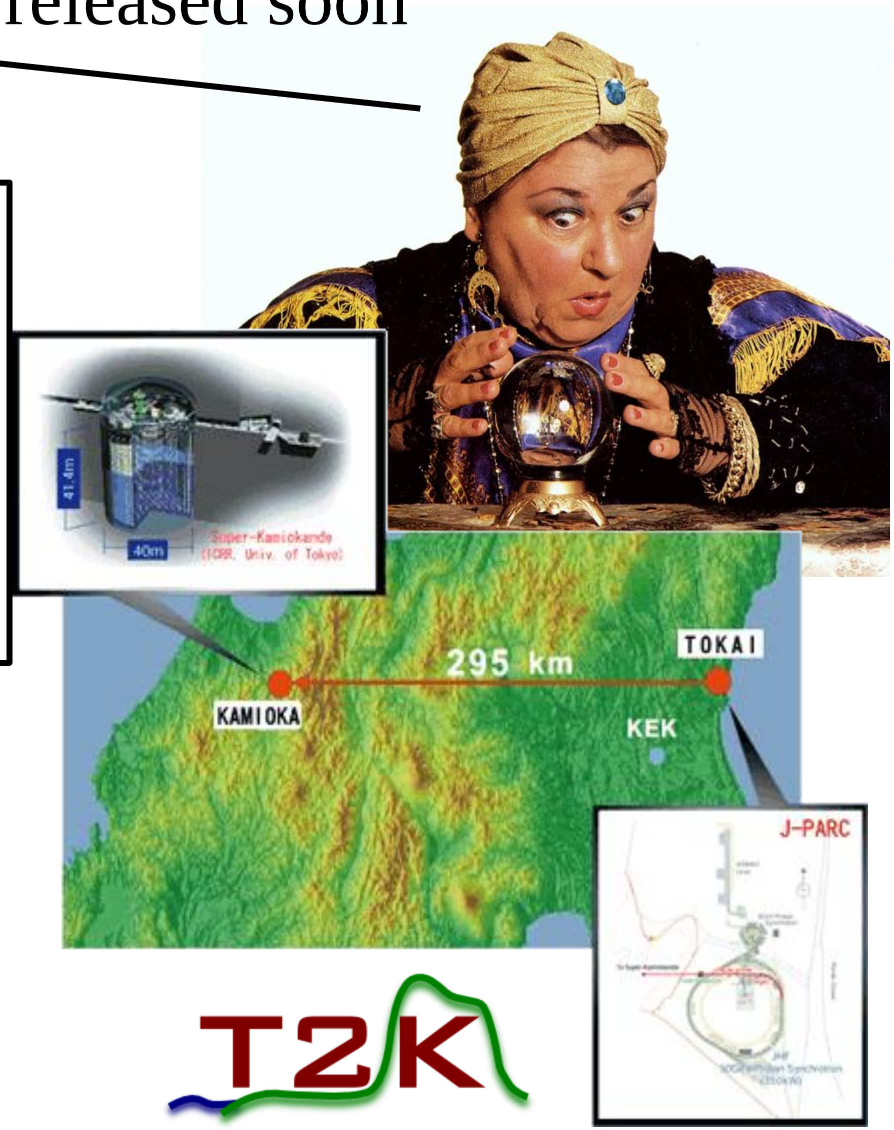
Provide a point of comparison for the nuclear part of neutrino generators

Is information from eA potentially useful?

This section still needs work

T2K – First results to be released soon

I see … I see … the beam error will be the largest systematic error with FSI coming in second.



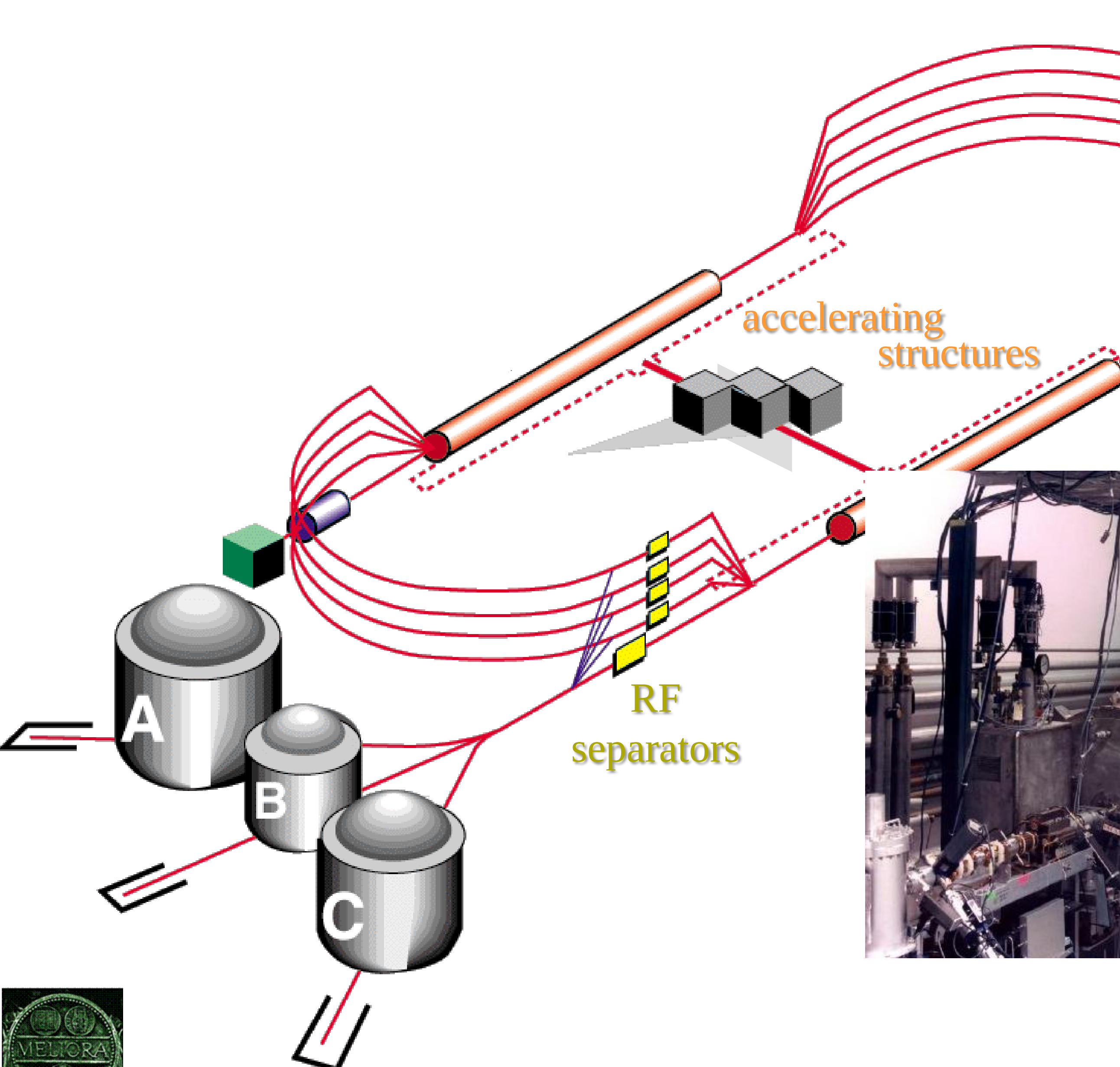
... work on FSI effects ... cross checking the prediction of the implemented FSI models on the available pion-nucleon scattering and photoproduction data for light nuclei like carbon and aluminum to secure better understanding of systematics for moving from carbon in ND280 to oxygen in SK

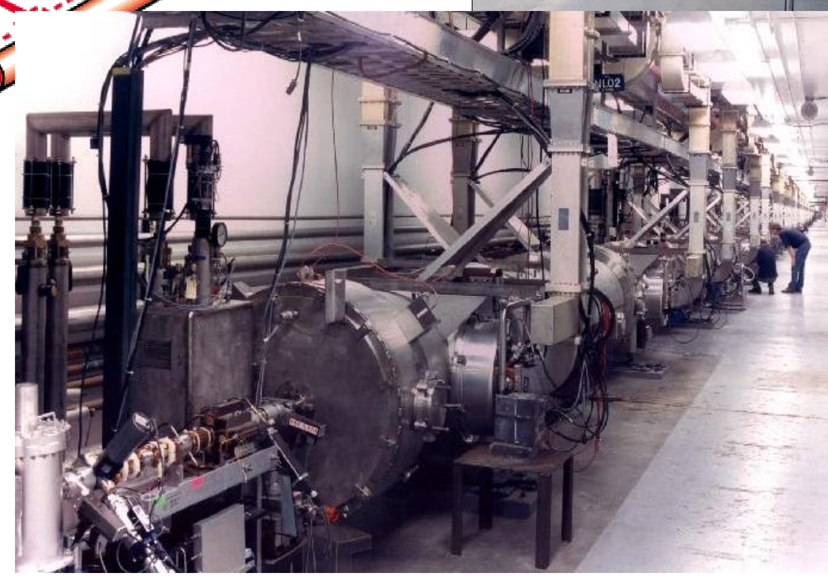
Private communication – S. Boyd, J. Sobczyk

Significant uncertainties exist in the modeling of neutrino-induced hadronization for neutrinos in the few-GeV energy range. In the energy range of T2K, possibly the most important hadronization uncertainty is that in the assignment of pion kinematics for Nπ hadronic states coming from non-resonance processes.

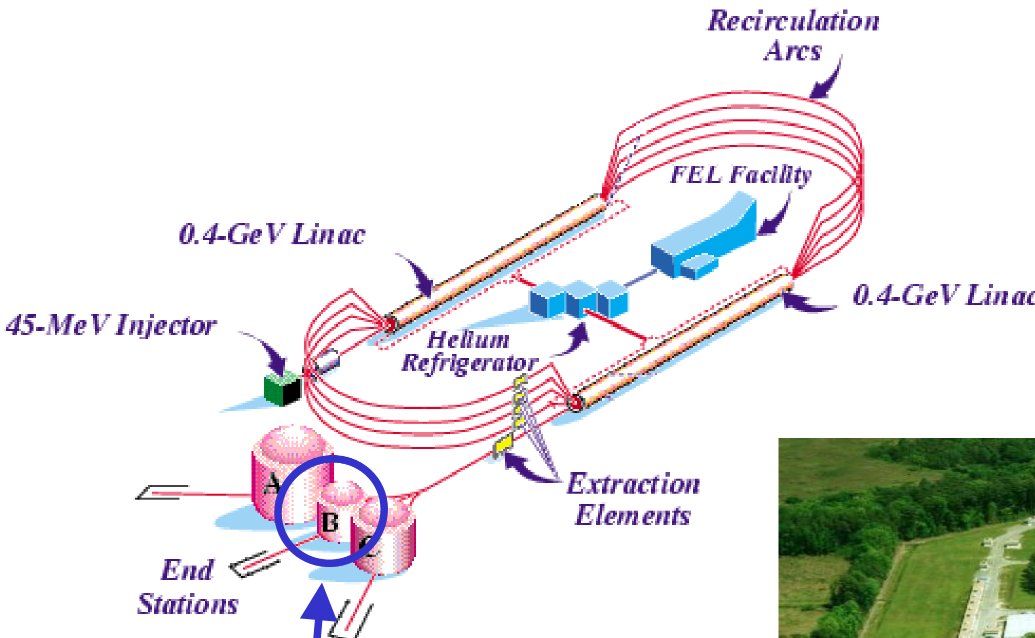
Private communication – C. Andreopoulos

CEBAF Continuous Electron Beam Accelerator Facility



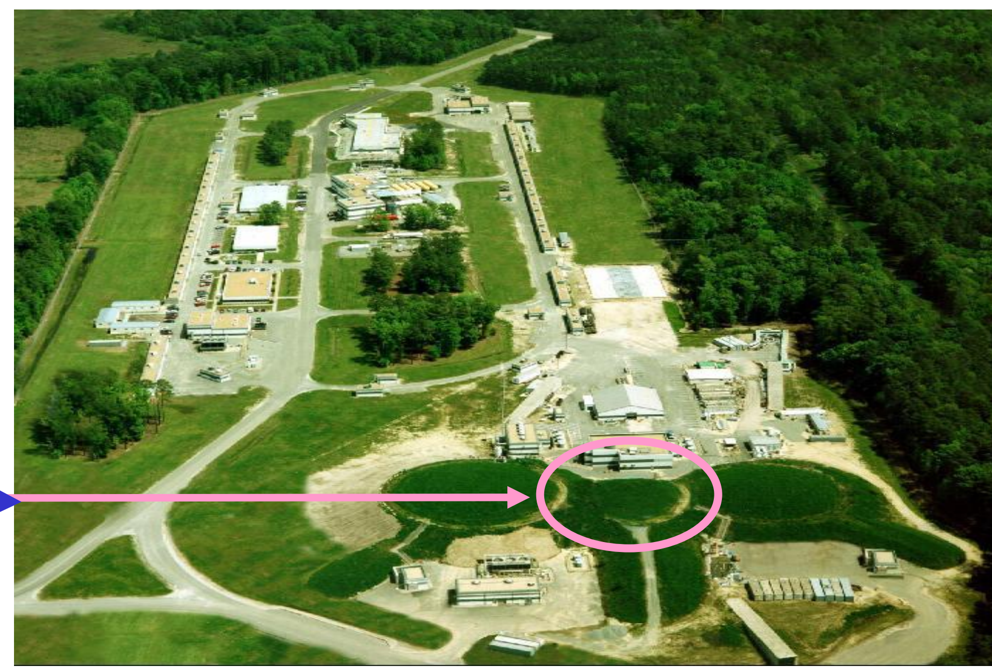


Jefferson Lab (Newport News, Virginia)



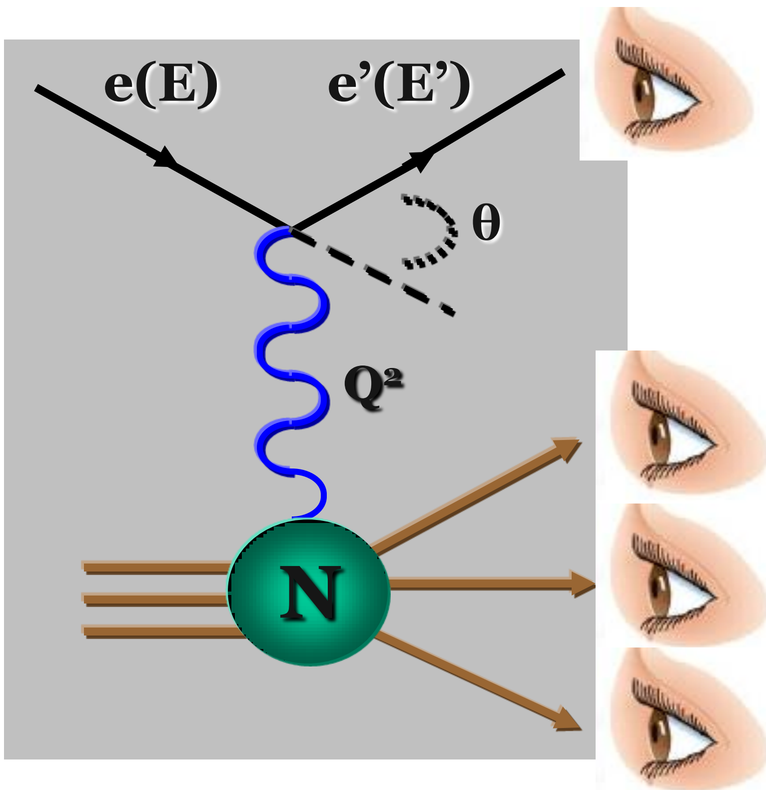
E_{max} ~ 6 GeV
I_{max} ~ 200 μA
Duty Factor ~ 100%
σ_E/E ~ 2.5 10^{-5}
Beam P ~ 80%

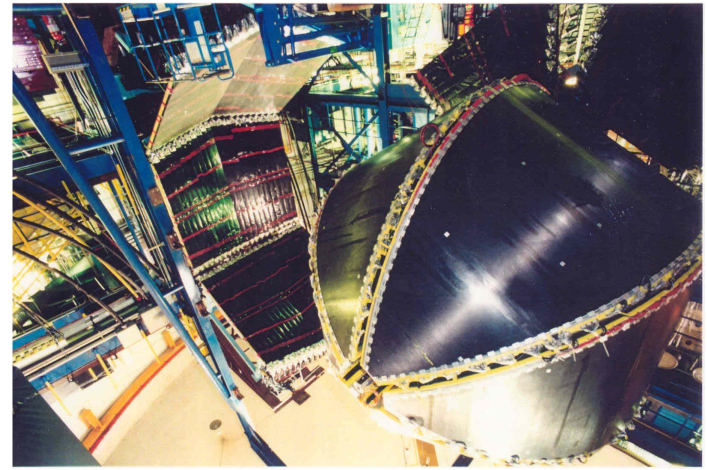
CLAS



Exclusive measurements

Detect all (most) particles in final state

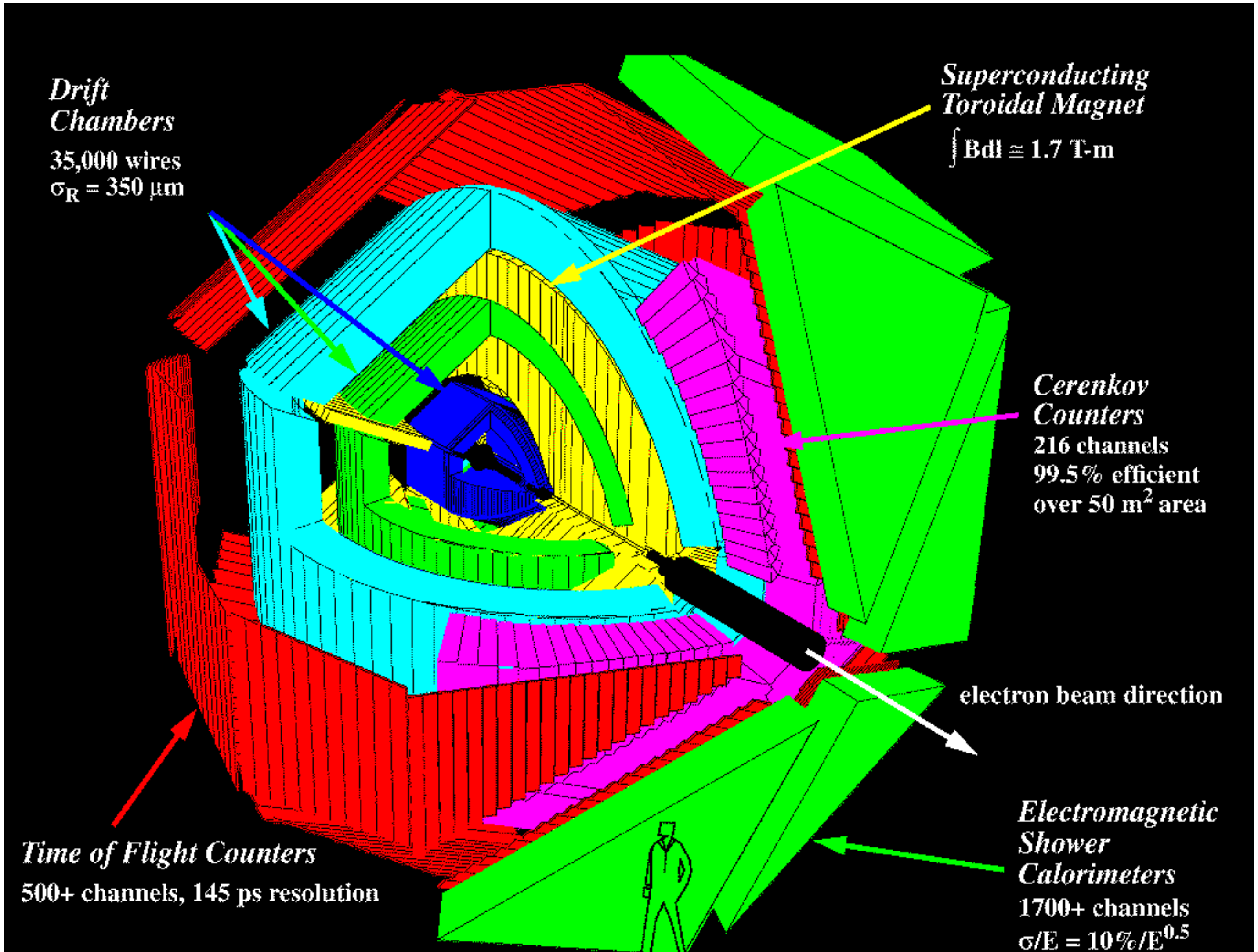




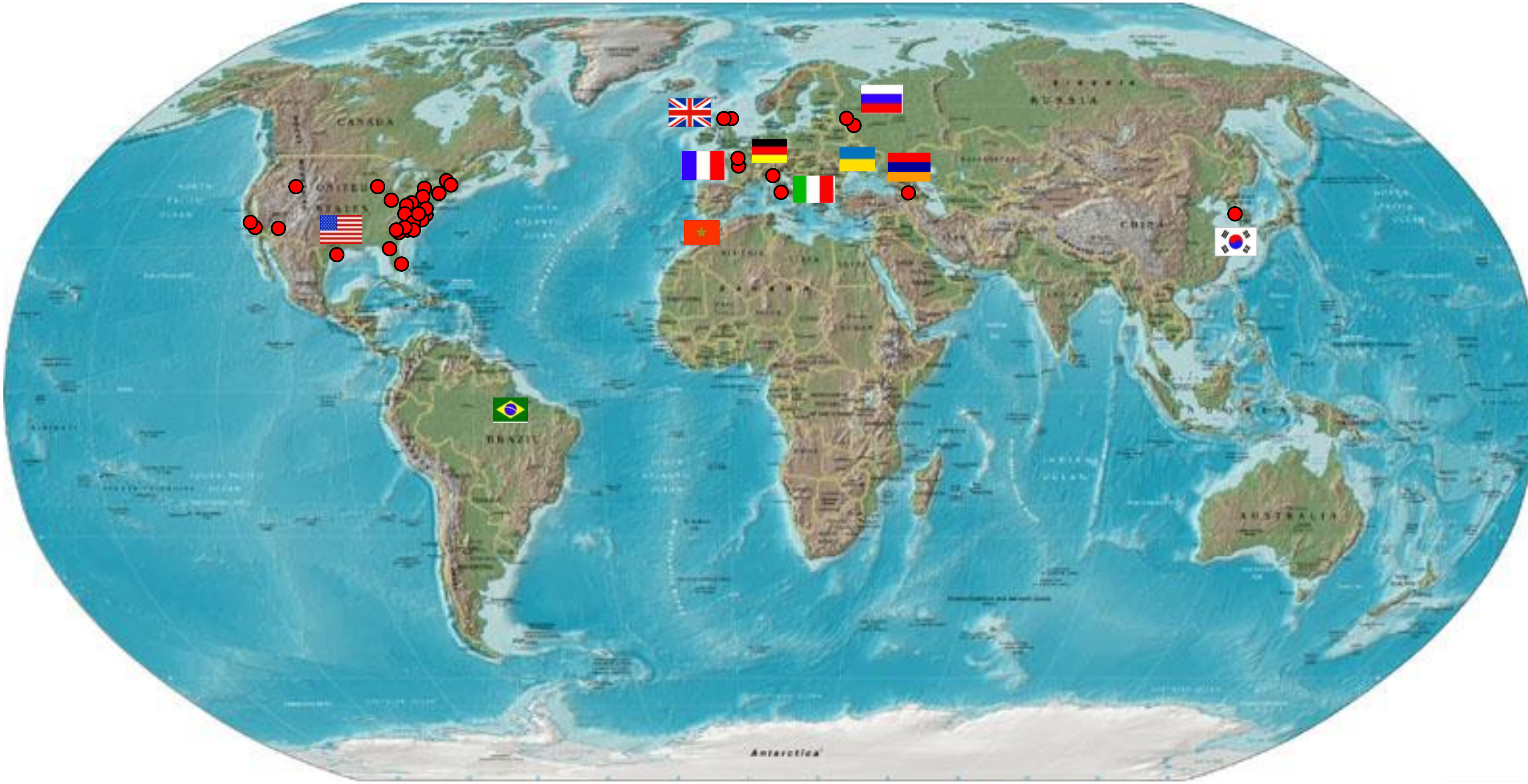
JLab Hall B, CLAS detector

- 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)



The CLAS Collaboration



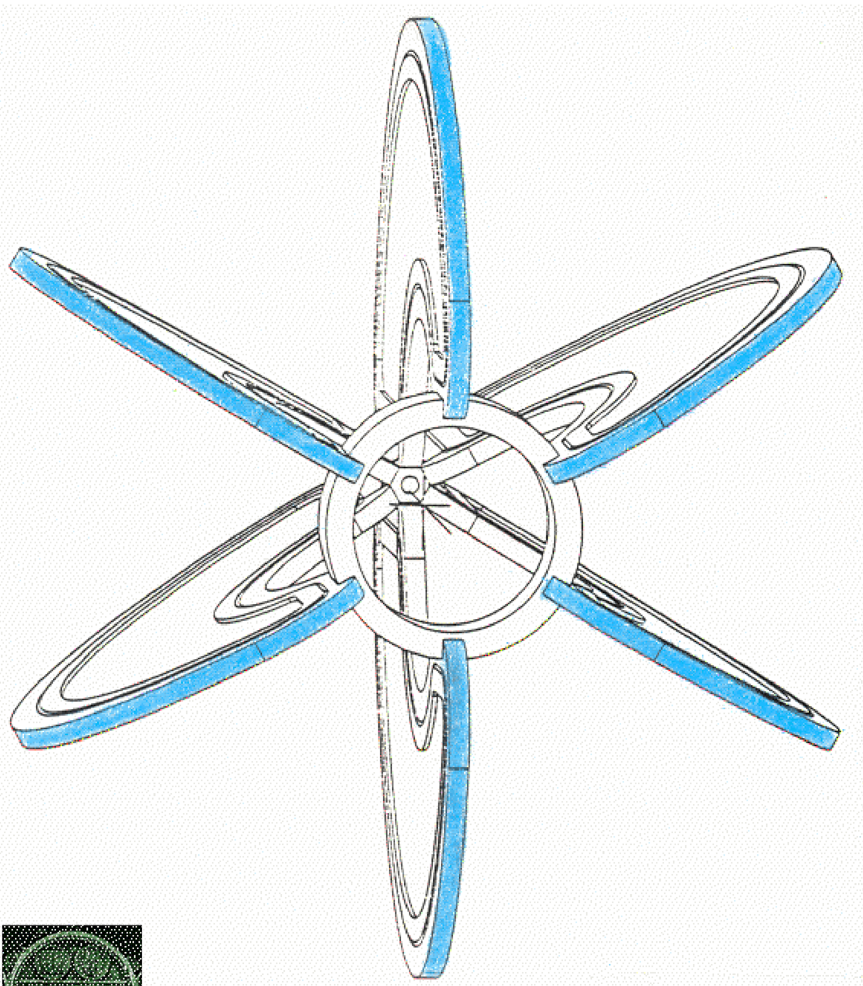
Arizona State University, Tempe, AZ
University of California, Los Angeles, CA
California State University, Dominguez Hills, CA
Carnegie Mellon University, Pittsburgh, PA
Catholic University of America
CEA-Saclay, Gif-sur-Yvette, France
Christopher Newport University, Newport News, VA
University of Connecticut, Storrs, CT
Edinburgh University, Edinburgh, UK
Florida International University, Miami, FL
Florida State University, Tallahassee, FL
George Washington University, Washington, DC
University of Glasgow, Glasgow, UK

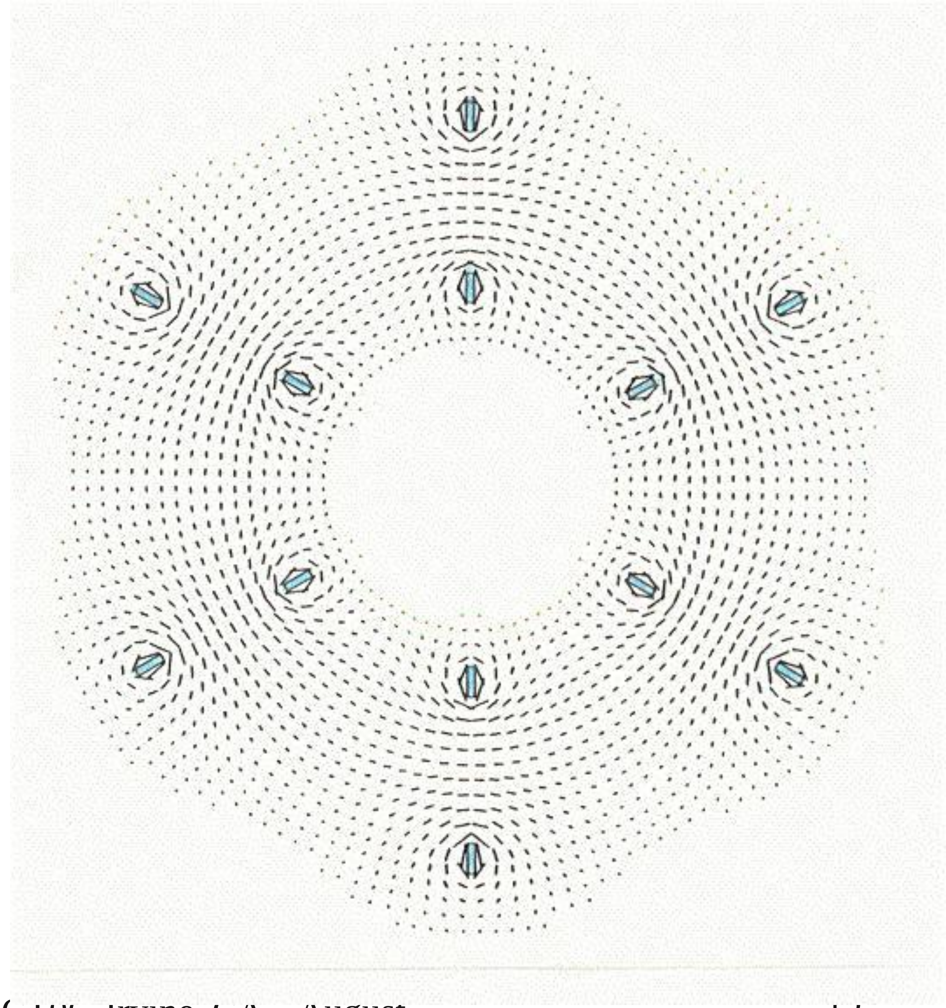
Idaho State University, Pocatello, Idaho
INFN, Laboratori Nazionali di Frascati, Frascati, Italy
INFN, Sezione di Genova, Genova, Italy
Institut de Physique Nucléaire, Orsay, France
ITEP, Moscow, Russia
James Madison University, Harrisonburg, VA
Kyungpook University, Daegu, South Korea
University of Massachusetts, Amherst, MA
Moscow State University, Moscow, Russia
University of New Hampshire, Durham, NH
Norfolk State University, Norfolk, VA
Ohio University, Athens, OH
Old Dominion University, Norfolk, VA

Rensselaer Polytechnic Institute, Troy, NY
Rice University, Houston, TX
University of Richmond, Richmond, VA
University of South Carolina, Columbia, SC
Thomas Jefferson National Accelerator Facility, Newport News, VA
Union College, Schenectady, NY
Virginia Polytechnic Institute, Blacksburg, VA
University of Virginia, Charlottesville, VA
College of William and Mary, Williamsburg, VA
Yerevan Institute of Physics, Yerevan, Armenia
Brazil, Germany, Morocco and Ukraine,
as well as other institutions in France and in the USA,
have individuals or groups involved with CLAS,
but with no formal collaboration at this stage.

Super-conducting toroidal magnet with six kidney-shaped coils

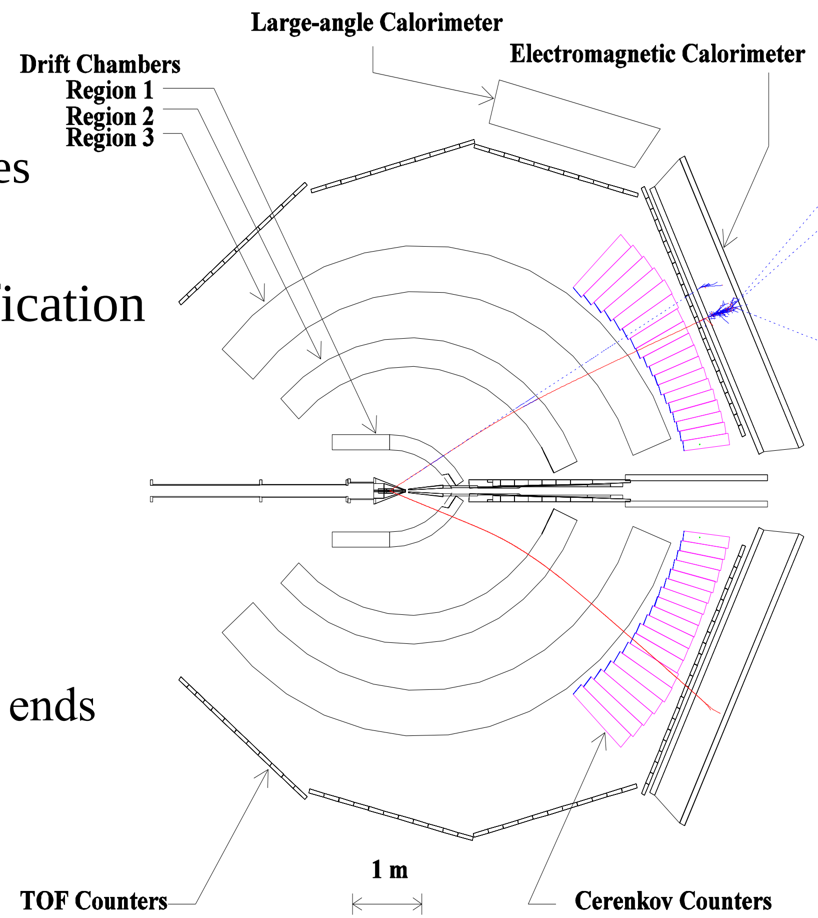
5 m diameter, 5 m long, 5 M-Amp-turns, max. field 2 Tesla



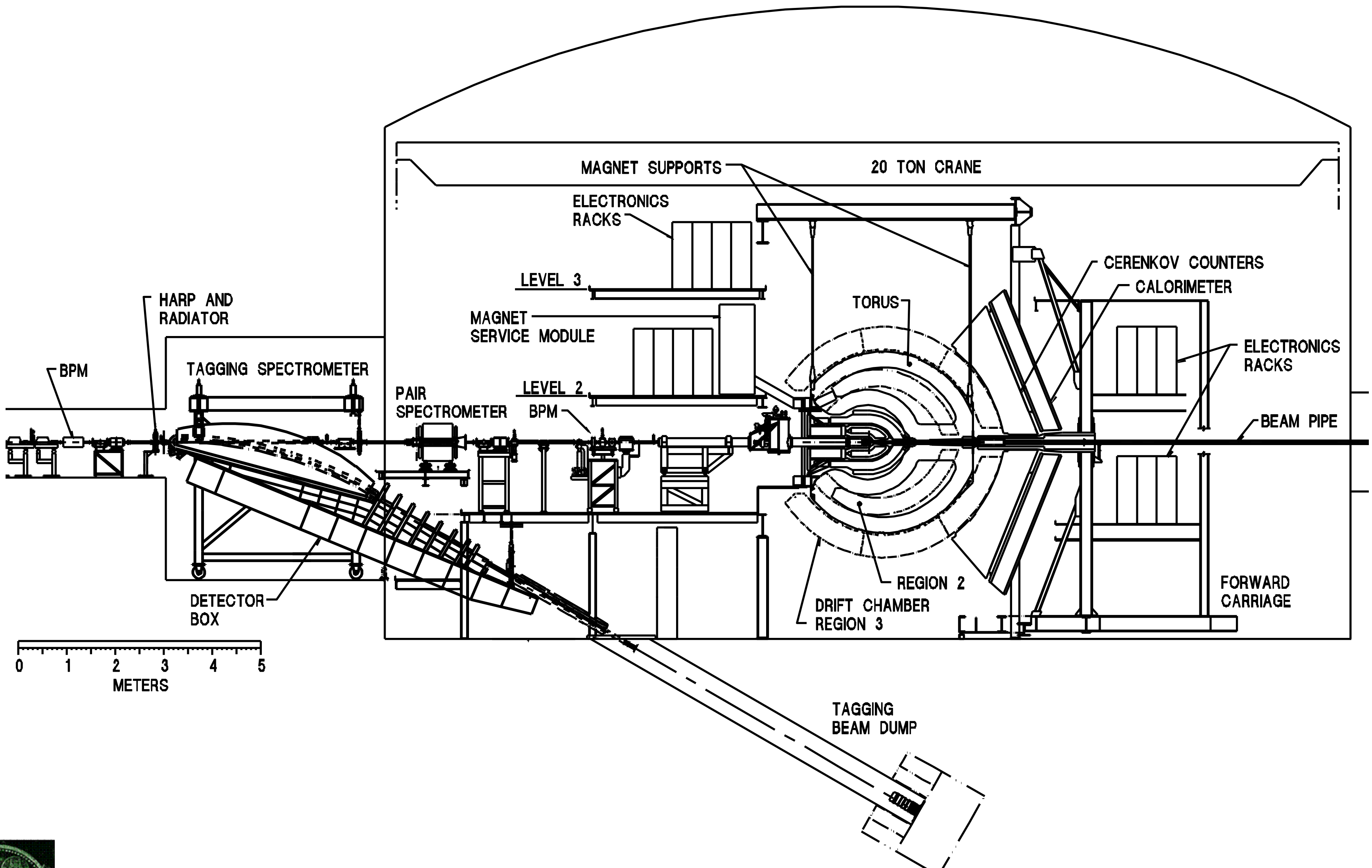


CLAS Components

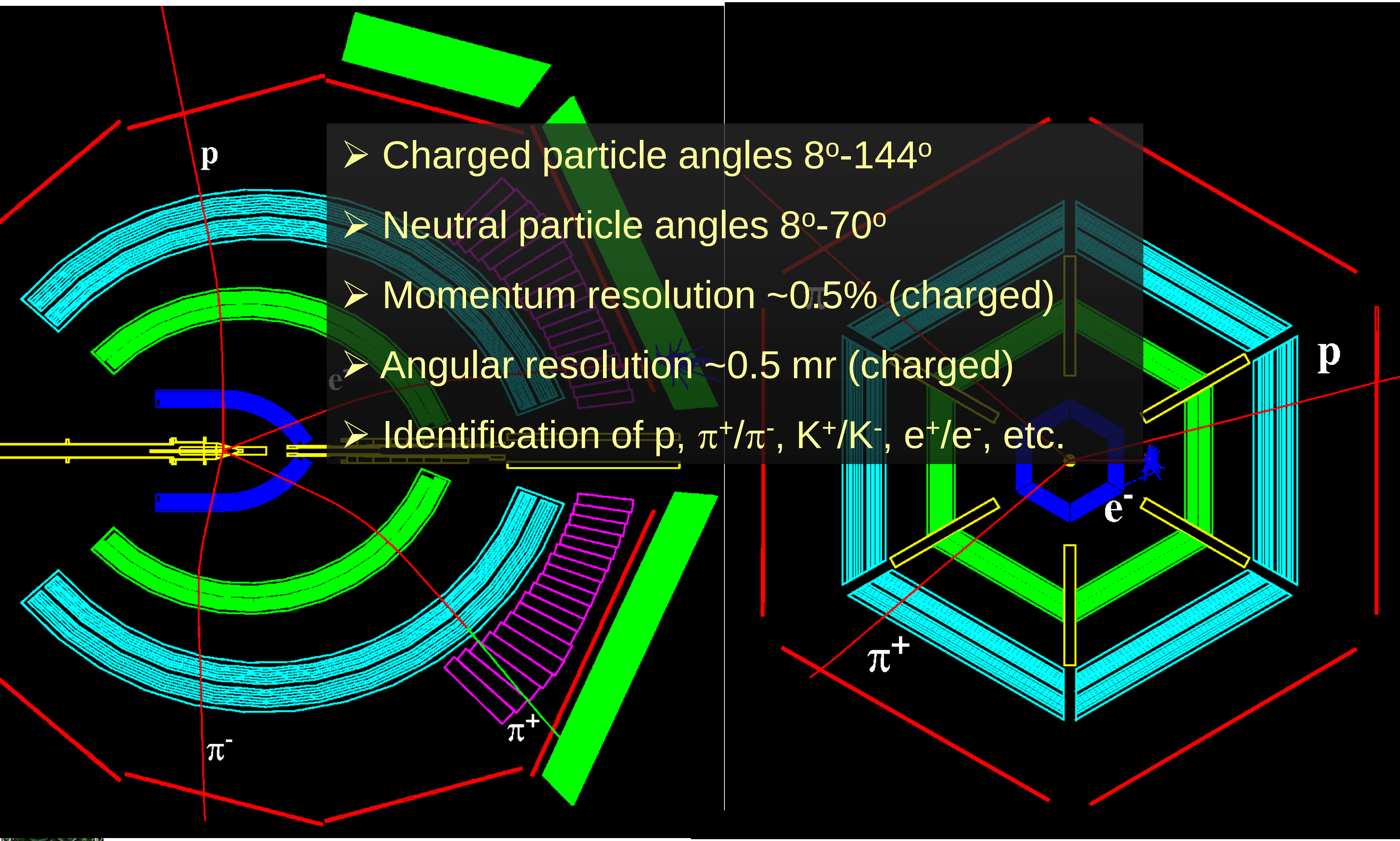
- Charged particle tracking in six independent sectors
  - 3 drift chamber packages per sector
  - 34 layers (axial and stereo)
  - drift time recorded from 35,000 sense wires
- Threshold Cerenkov counters for e identification
  - C_4F_{10} gas radiator
  - focusing mirror system
  - 250 PMT's, time and charge recorded
- Scintillation time-of-flight counters
  - 5 cm thick scintillator with PMT's at both ends
  - 600 PMT's, time and charge recorded



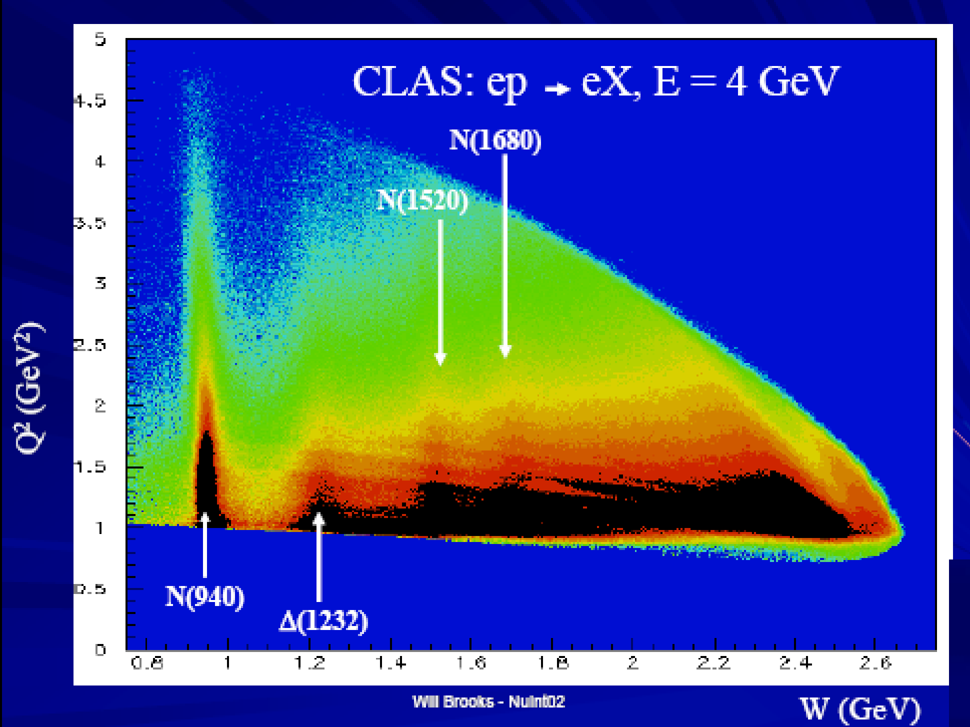
Hall B Side View



CLAS Single Event Display

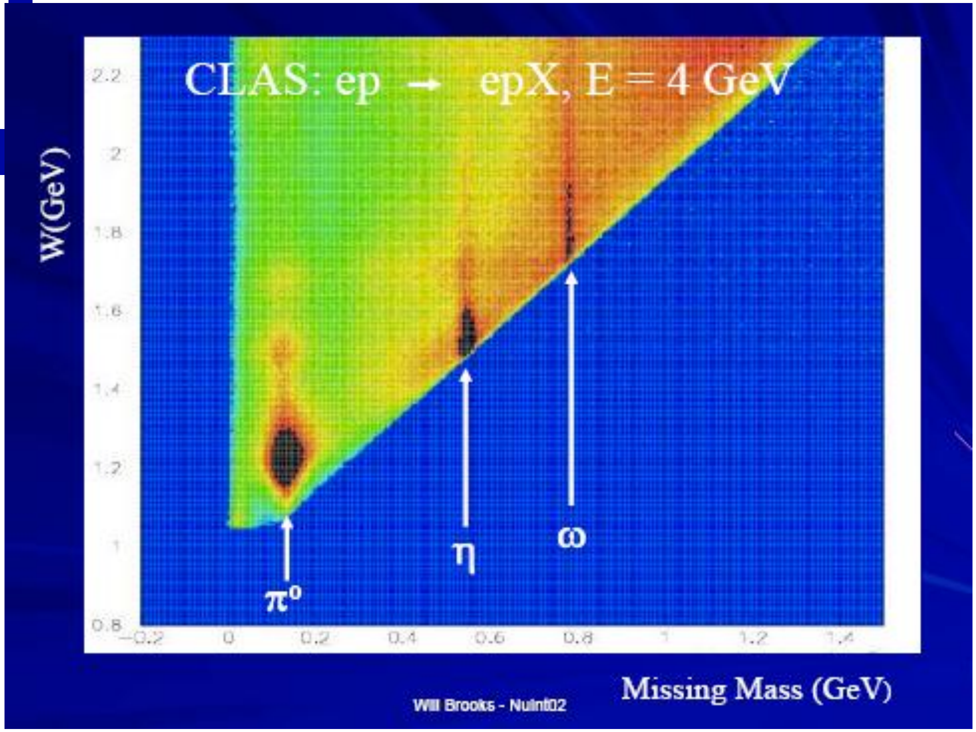


- Charged particle angles 8º-144º
- Neutral particle angles 8º-70º
- Momentum resolution ~0.5% (charged)
- Angular resolution ~0.5 mr (charged)
- Identification of p, π^+/π^-, K^+/K^-, e^+/e^-, etc.



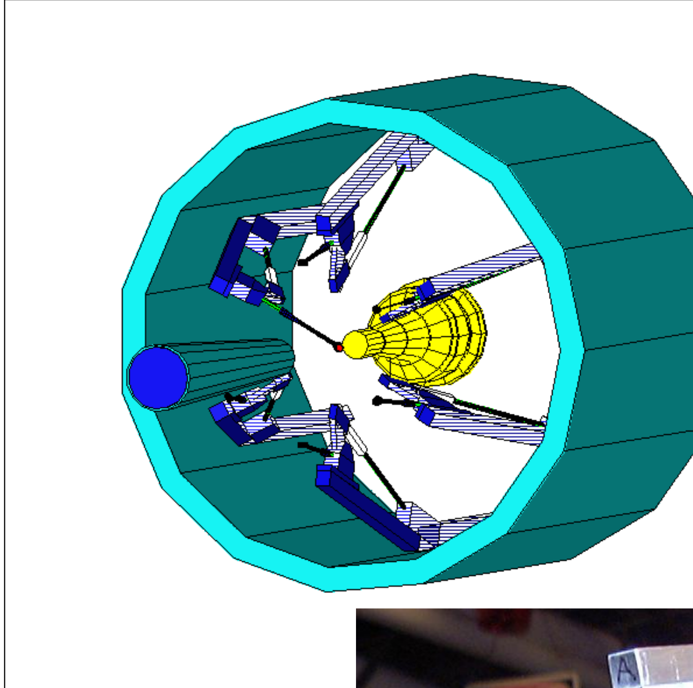
From Will Brooks at NUINT02

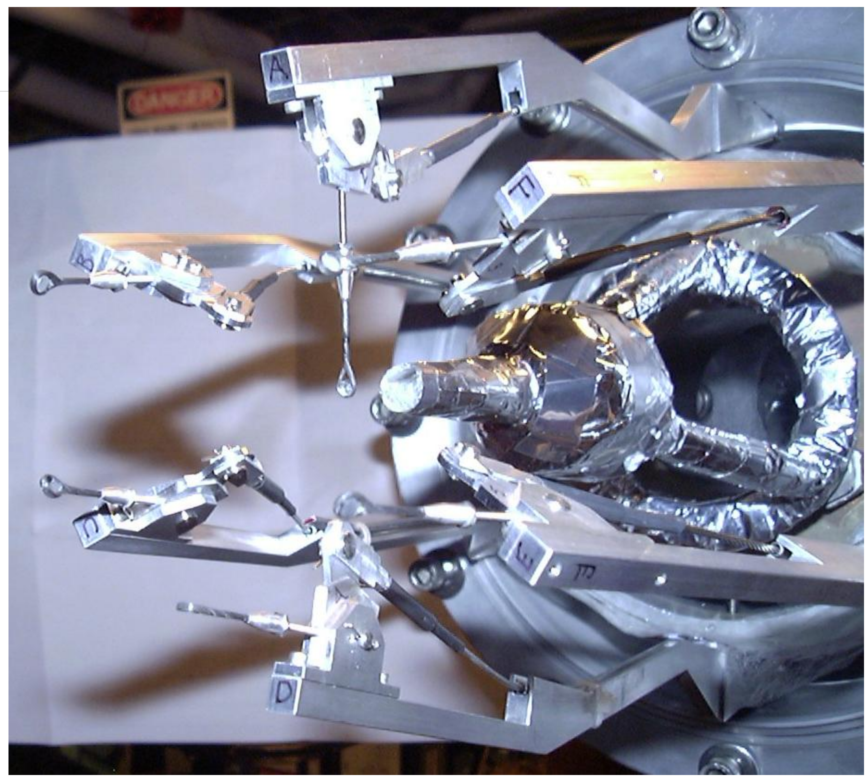
H target with Ebeam = 4 GeV illustrates the power of CLAS



- CLAS - International collaboration 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.
- EG2 running period for JLab experiments E02-104 (Quark propagation through cold QCD matter) and E02-110 (Q2 dependence of nuclear transparency for incoherent rho electroproduction)
- deuterium, carbon, lead, tin, iron, aluminum
- 3 running periods: Sept. 2003, Dec. 2003 and Jan. 2004

CLAS EG2
Targets





- *Two* targets in the beam simultaneously
- 2 cm LD2, upstream
- Solid target downstream
- Six solid targets:

  -Carbon

  -Aluminum (2 thicknesses)

  -Iron

  -Tin

  -Lead

GENIE eA

Using GENIE version 2.5.1 in eA mode
with Q^2>0.5

Costas Andreopoulos (thanks Costas!): GENIE eA mode is a "straightforward adaptation of the neutrino generator"

- Use charged lepton predictions of cross-section models: Rein-Sehgal, Bodek-Yang, etc.
- Transition region handled as in neutrino mode.
- Nuclear model (Bodek-Ritchie, Fermi-Gas) same as in neutrino mode.
- Intranuclear cascade (INTRANUKE) same as in neutrino mode.
- Small modifications to take into account probe charge for hadronization model and resonance event generation.
- In-medium effects to hadronization same as in neutrino mode.

GENIE eA

Generates

Events for

Neutrino

Interaction

Experiments

Generates

Events for

~~Neutrino~~ Electron

Interaction

Experiments

GEEIE ?

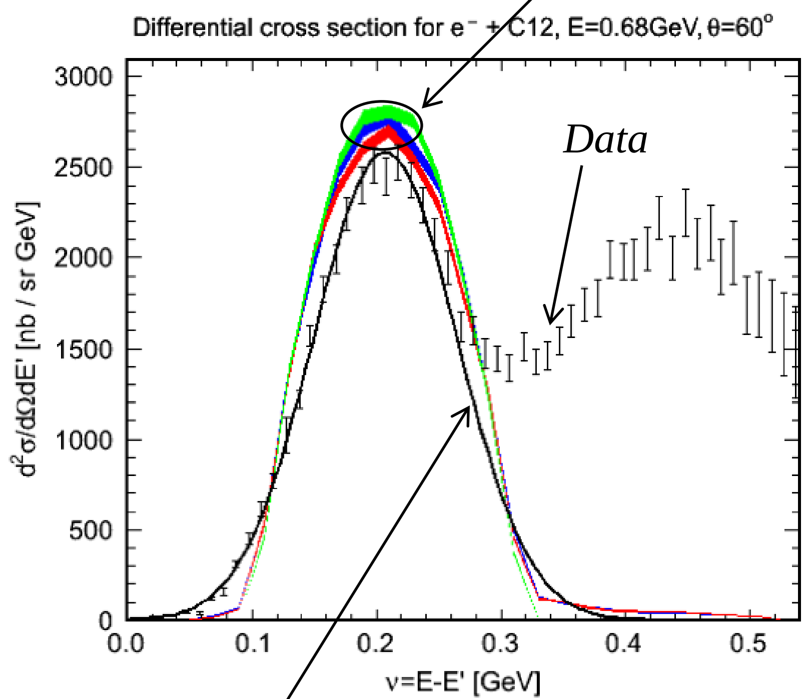
I prefer GENIE eA

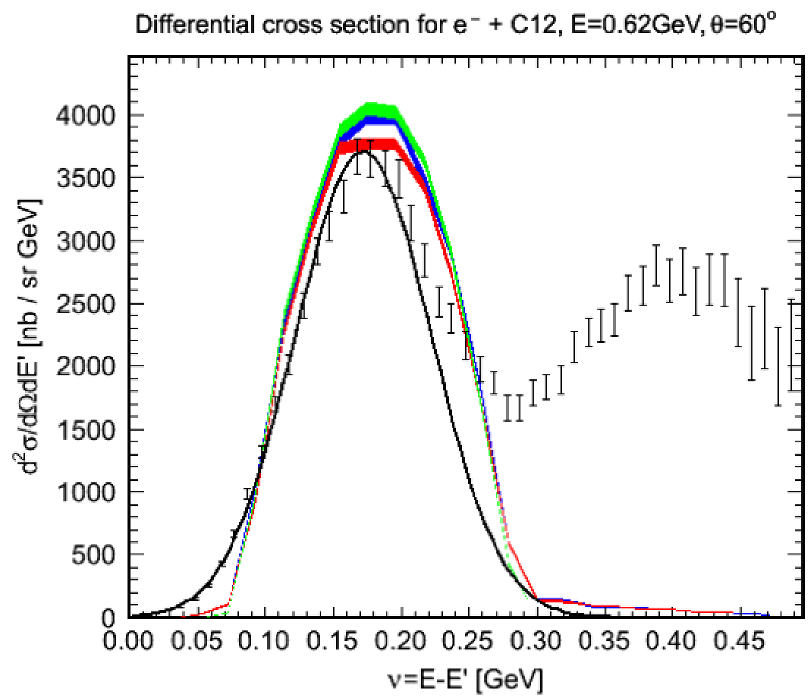
GENIE eA validation

GENIE eA with different Fermi gas models (red is default)

Reference for data

Data





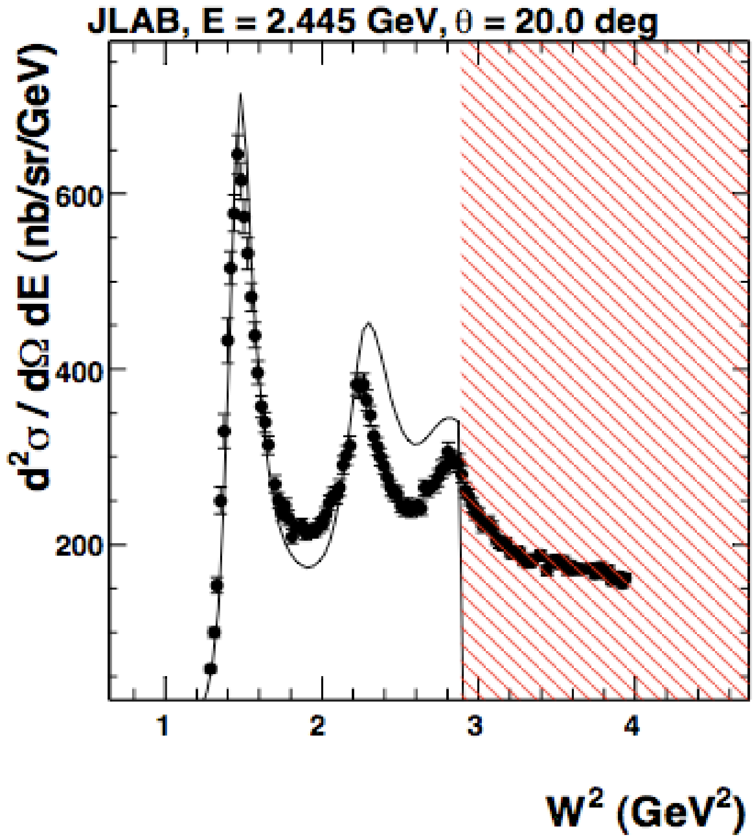
Gaussian fit to data

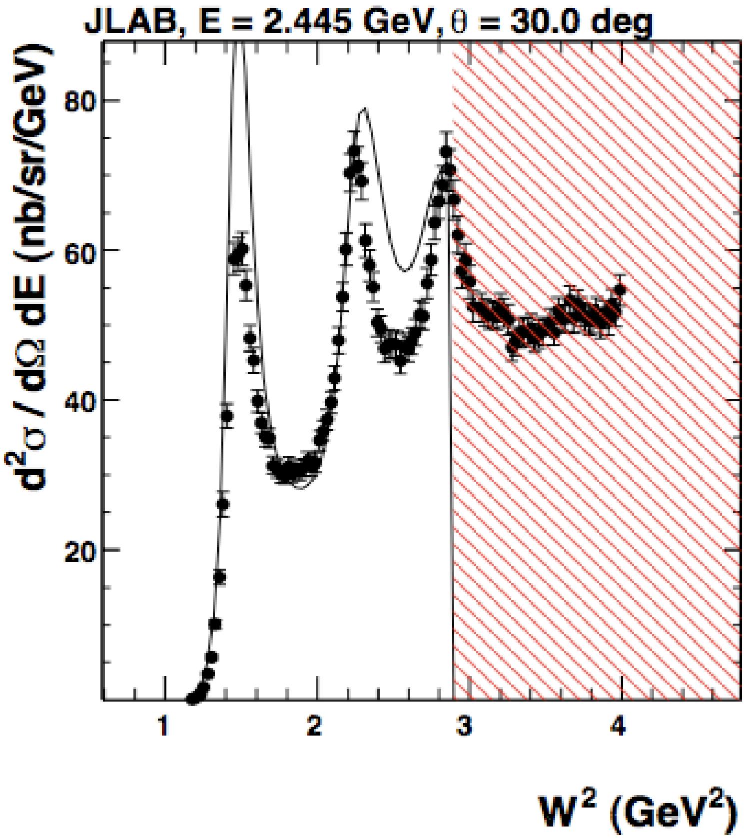
-From C. Andreopoulos

Comparison with electron quasi-elastic scattering data

GENIE eA validation

Reference for data





-From C. Andreopoulos

Comparison with electron scattering resonance data

Samples

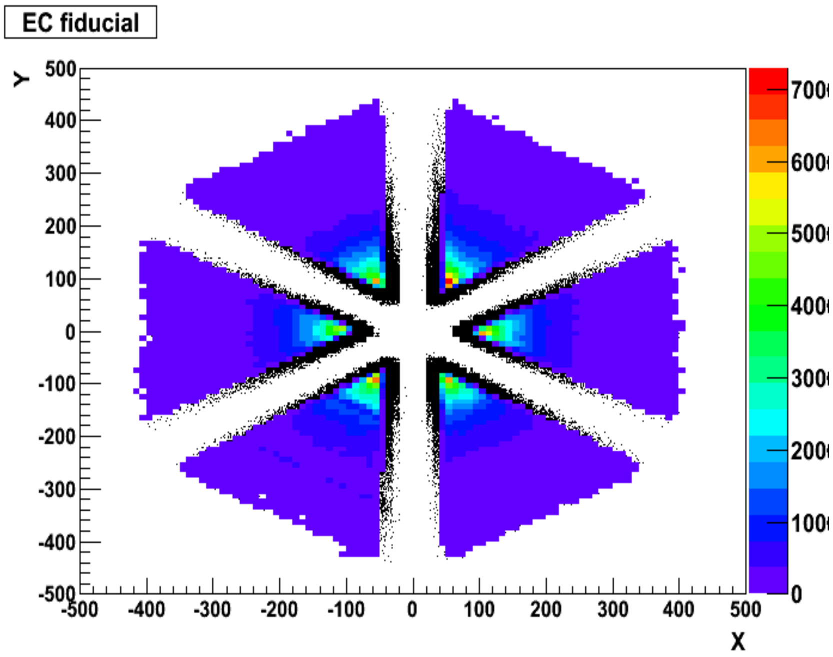
EG-2 data sample size:

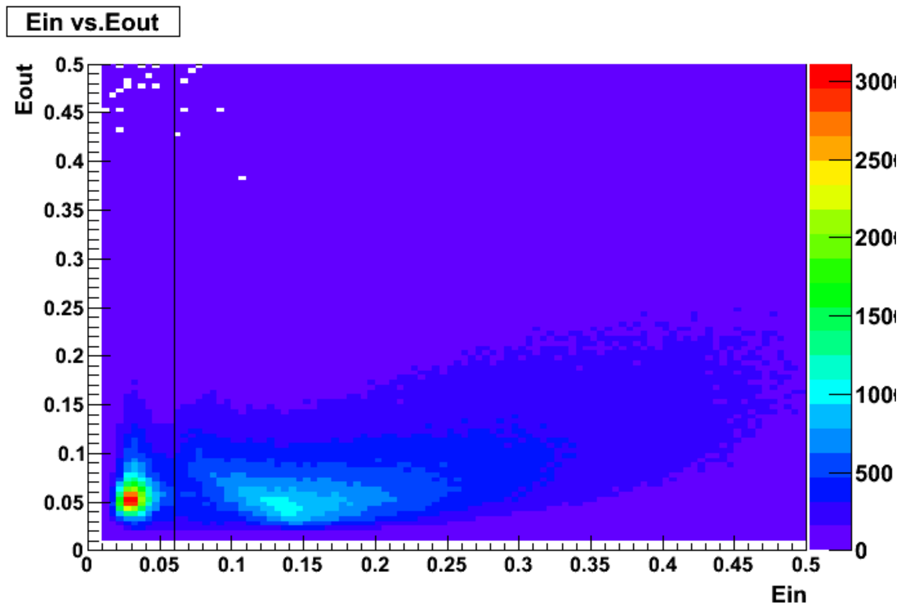
Deuterium + Carbon raw events	1,127,814,448
Deuterium (e^- and 1 $\pi^\pm$)	10,871,245
Carbon (e^- and 1 $\pi^\pm$)	8,397,162

Simulated sample size (Genie MC):

Deuterium generated events	100,000,000
Carbon generated events	100,000,000
Deuterium (e^- and 1 $\pi^\pm$)	33,685,862
Carbon (e^- and 1 $\pi^\pm$)	33,370,187

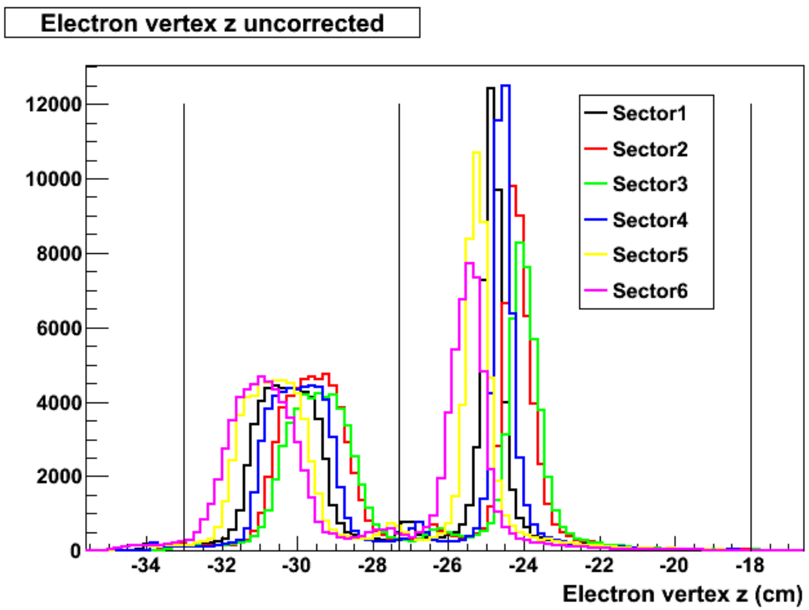
Analysis cuts

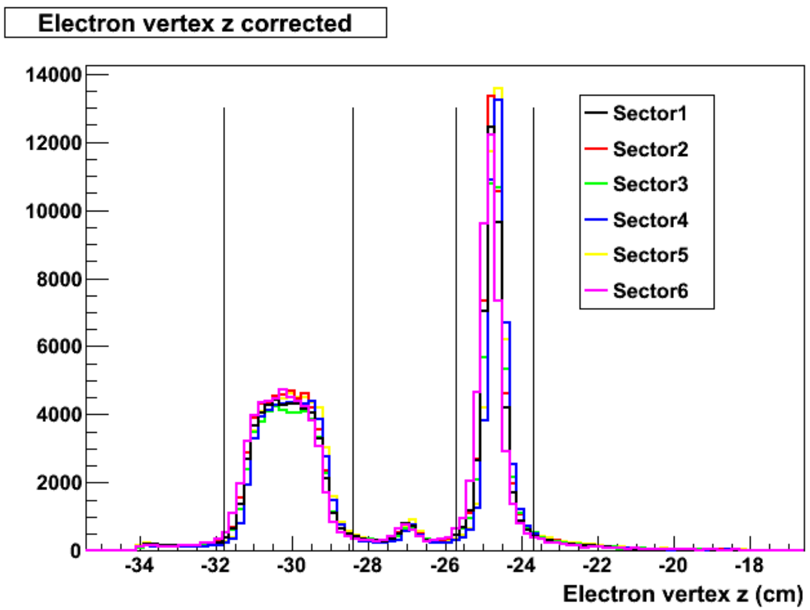




Calorimetric fiducial and ID cuts on outgoing e^-

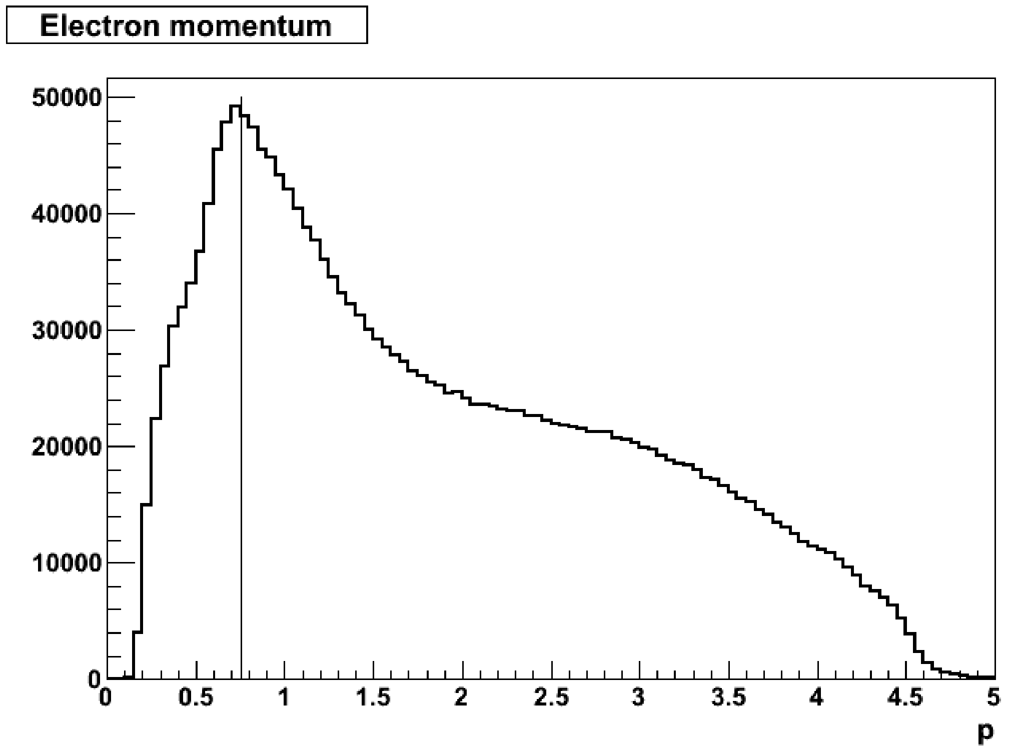
Analysis cuts





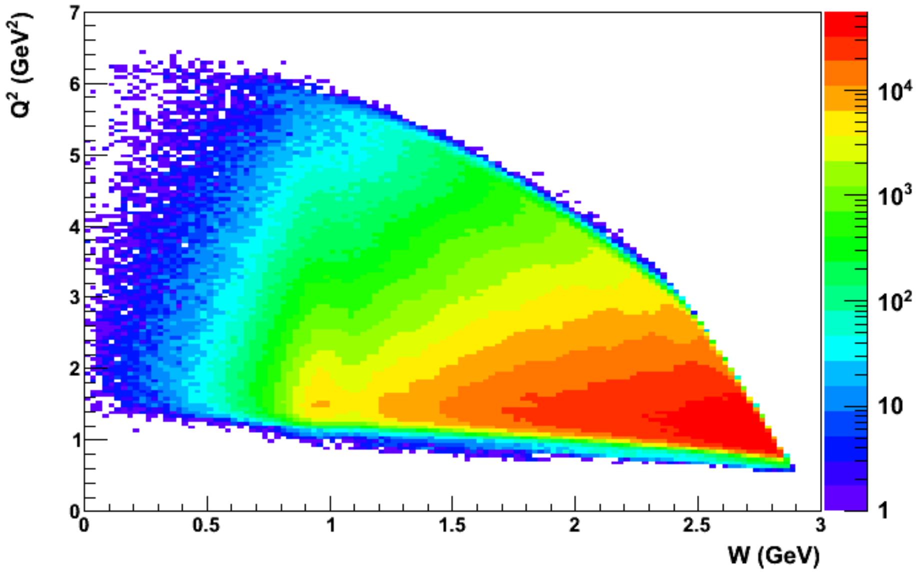
Beam offset requires sector-by-sector z vertex correction

Analysis cuts

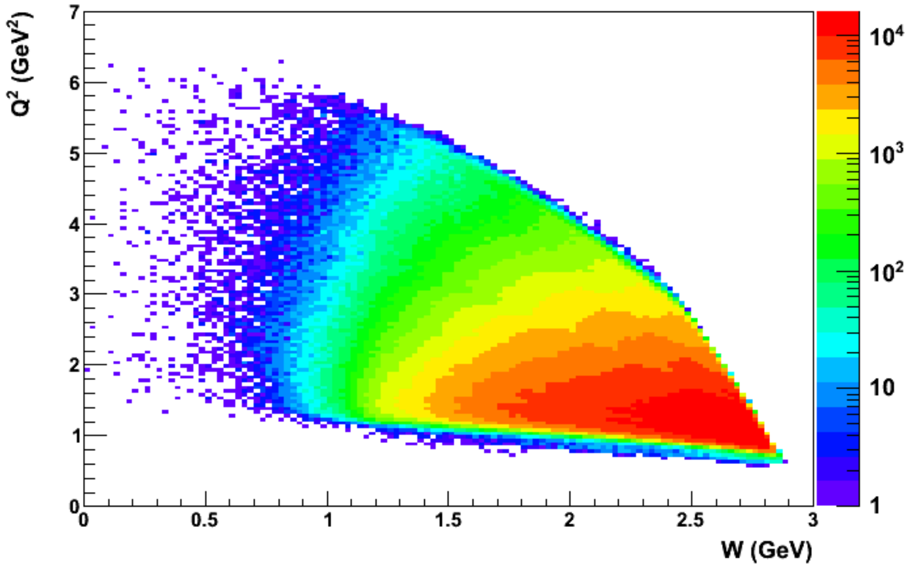


Momentum of outgoing e-: p>0.75 GeV or y<0.85
Removes bias due to electromagnetic energy threshold in trigger.
Also reduces sensitivity to radiative effects.

Sample W versus Q^2 on deuterium target



No requirement of single reconstructed $\pi^{\pm}$



Require single reconstructed $\pi^{\pm}$

Caveats

- All results shown here are preliminary
- These results have not yet passed through the full CLAS collaboration physics result approval process
- The errors shown are statistical only
- Systematic errors are under investigation
- Expectation/goal is to hold the systematic errors to <10%

Cross-sections

- In process of producing absolute differential cross-section measurements

- Results shown here are shape comparisons of
  - Non-acceptance corrected data to GENIE+CLAS detector simulation+EG2 target geometry
  - Acceptance corrected data to simulated events from GENIE

- Check on cross-section for data vs. GENIE

	Data cross-section (nb) (acceptance corrected, no radiative corrections, $Q^2>1$, $y<0.85$, single $\pi^{\pm}$)	GENIE cross-section (nb) (No QEL, $Q^2>1$, $y<0.85$, single $\pi^{\pm}$)
Deuterium	28.6	25.0
Carbon	169.2	150.6

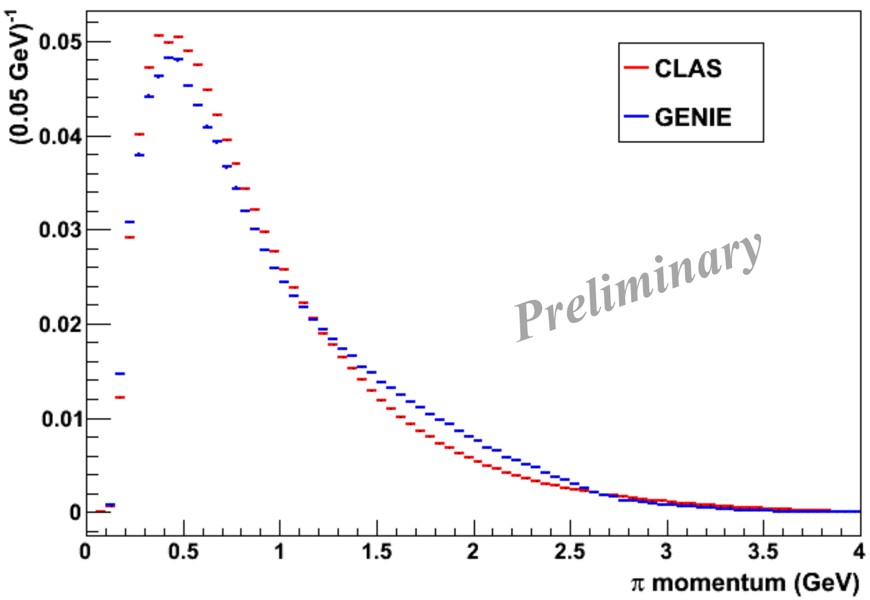
Preliminary

Data-MC comparison
(no acceptance corrections)

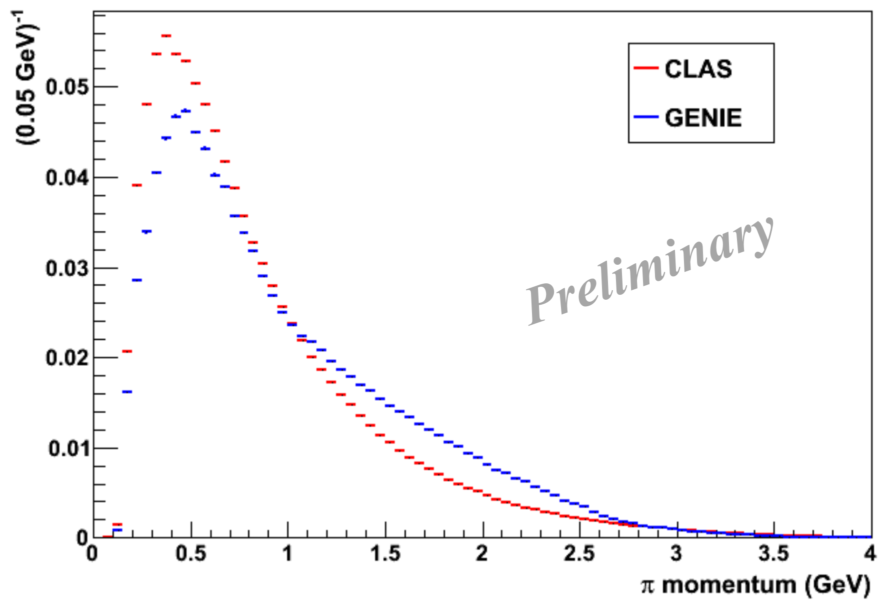
➢ GENIE events run through CLAS detector simulation (GSIM) with EG2 target geometry and same analysis chain as data

➢ Require single $\pi^{\pm}$ reconstructed

Deuterium



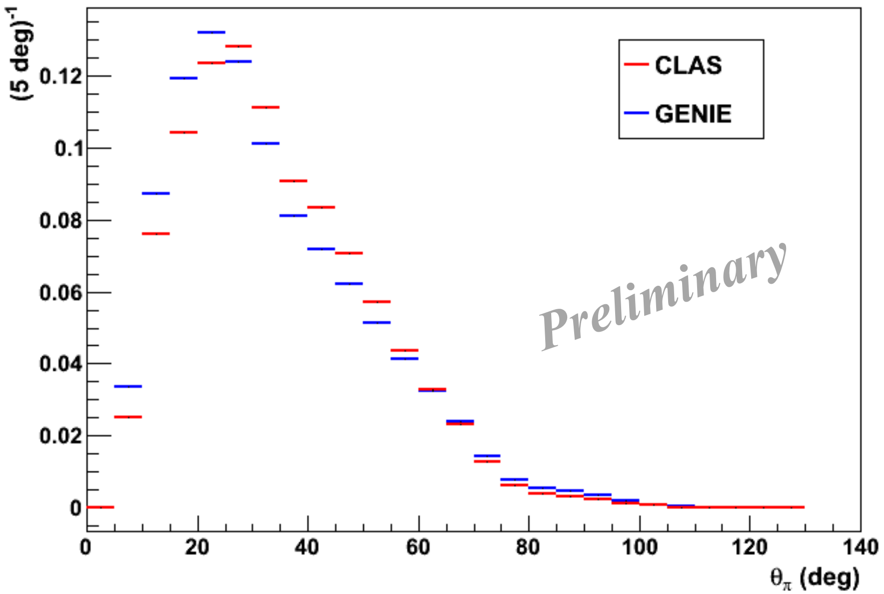
Carbon



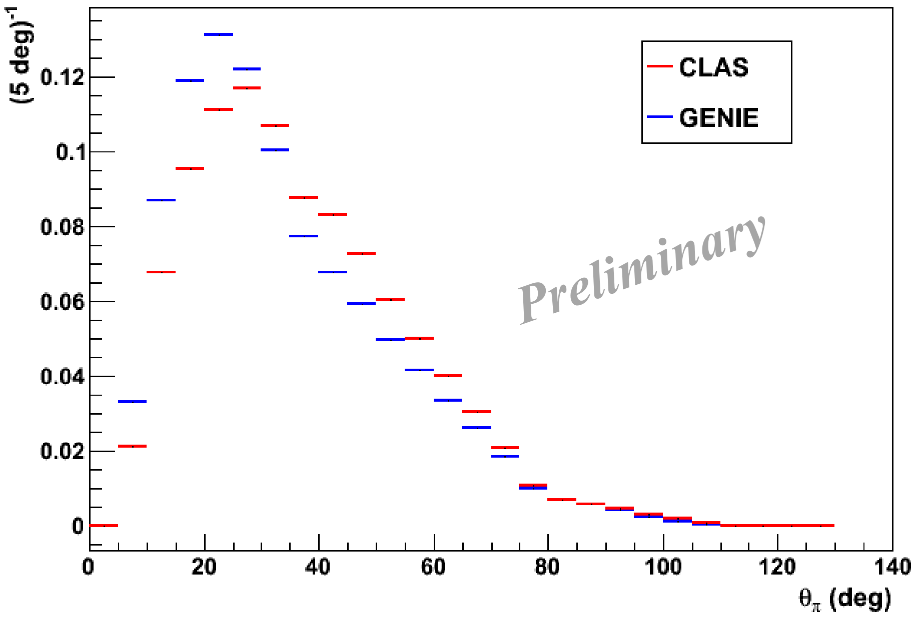
Momentum of π in the lab frame

Data-MC comparison
(no acceptance corrections)

Deuterium



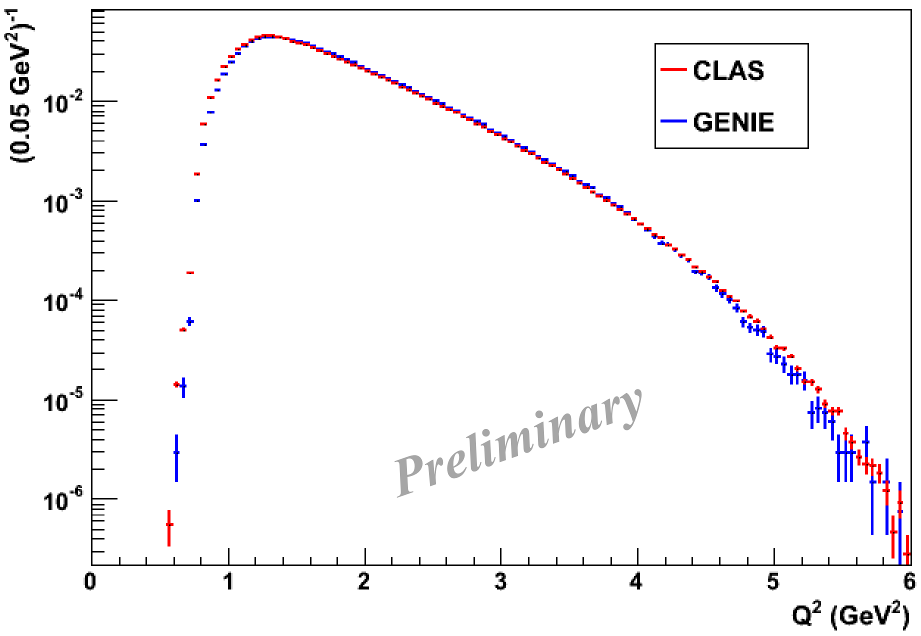
Carbon



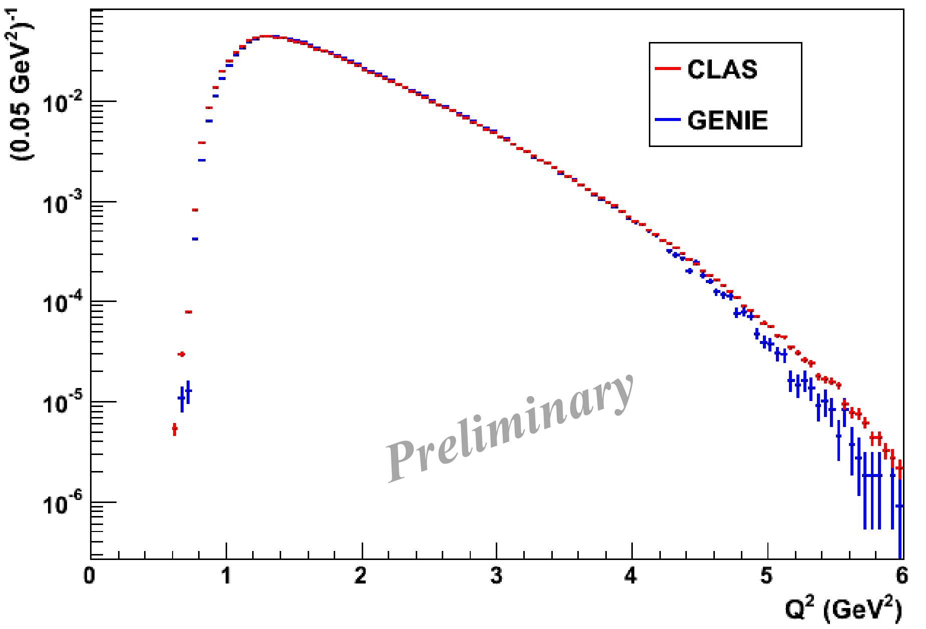
Angle of π with respect to the beam direction

Data-MC comparison
(no acceptance corrections)

Deuterium



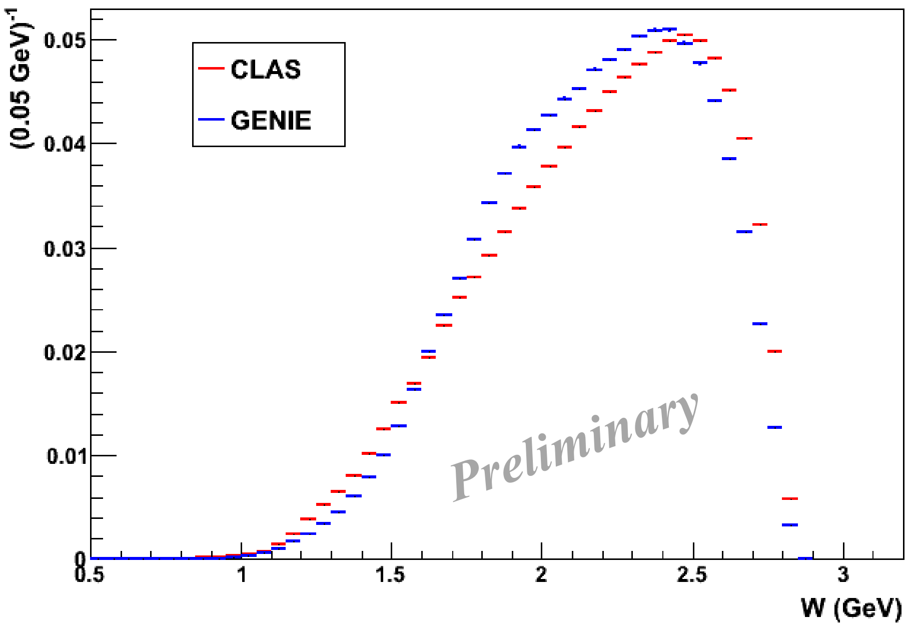
Carbon



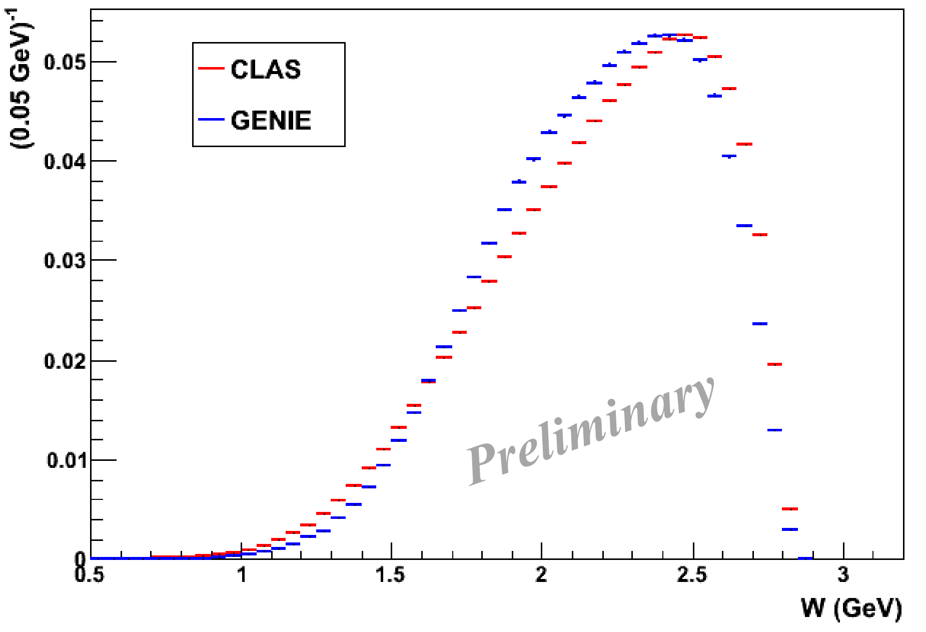
Q^2 distribution

Data-MC comparison
(no acceptance corrections)

Deuterium



Carbon



W distribution

Acceptance corrections

- Use GENIE MC samples to calculate acceptance

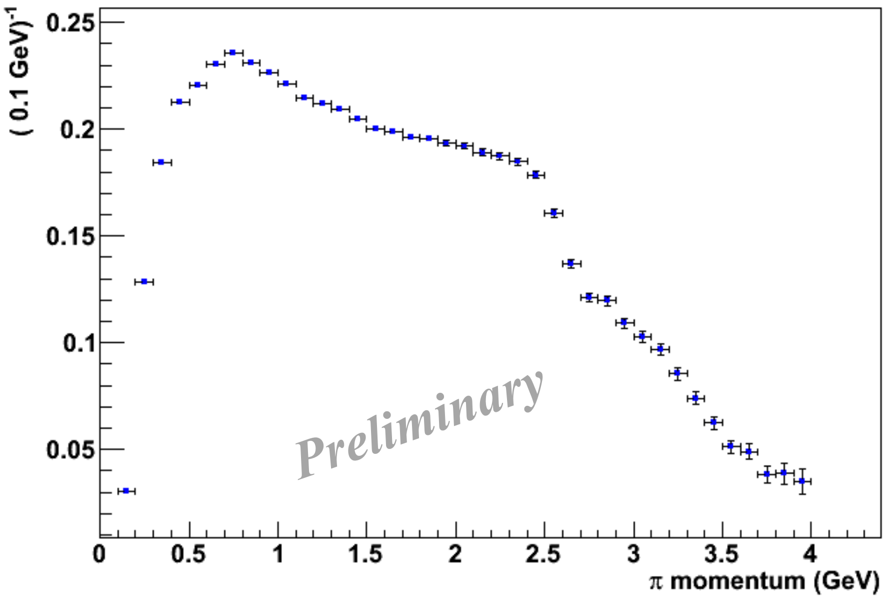
$$\text{acceptance}_{\text{bin}} = \left(\frac{\text{Events reconstructed}}{\text{Events generated}} \right)_{bin}$$

- Require single $\pi^{\pm}$ reconstructed, will need to study feed-down from higher multiplicity events.

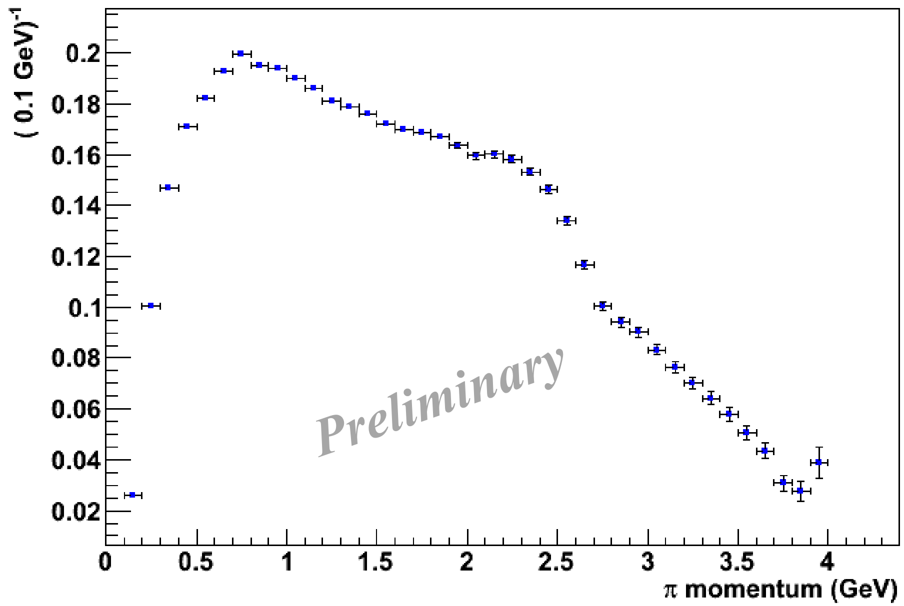
- Estimate single $\pi^{\pm}$ sample to originate from *** percent single $\pi^{\pm}$ with most of the rest originated from multiple π events.
- Non-acceptance corrected GENIE distributions look very similar to the data distributions – reasonable to use the GENIE samples for the acceptance corrections.

Acceptance corrections

Deuterium



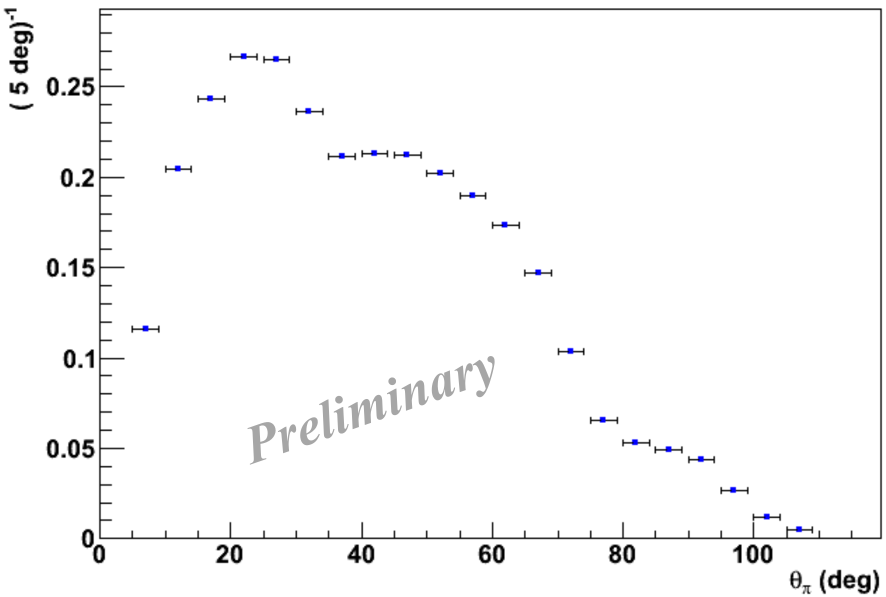
Carbon



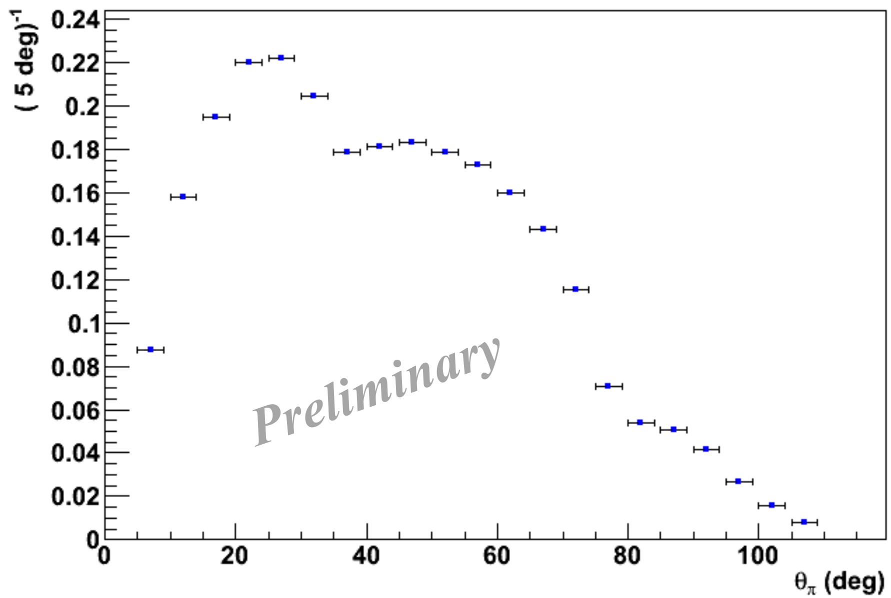
Acceptance as a function of momentum of π in the lab frame

Acceptance corrections

Deuterium



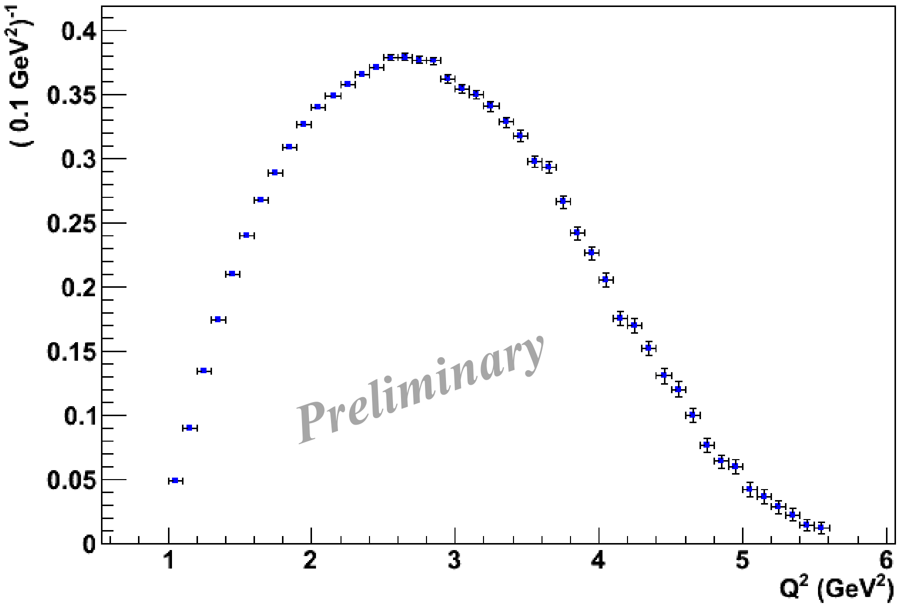
Carbon



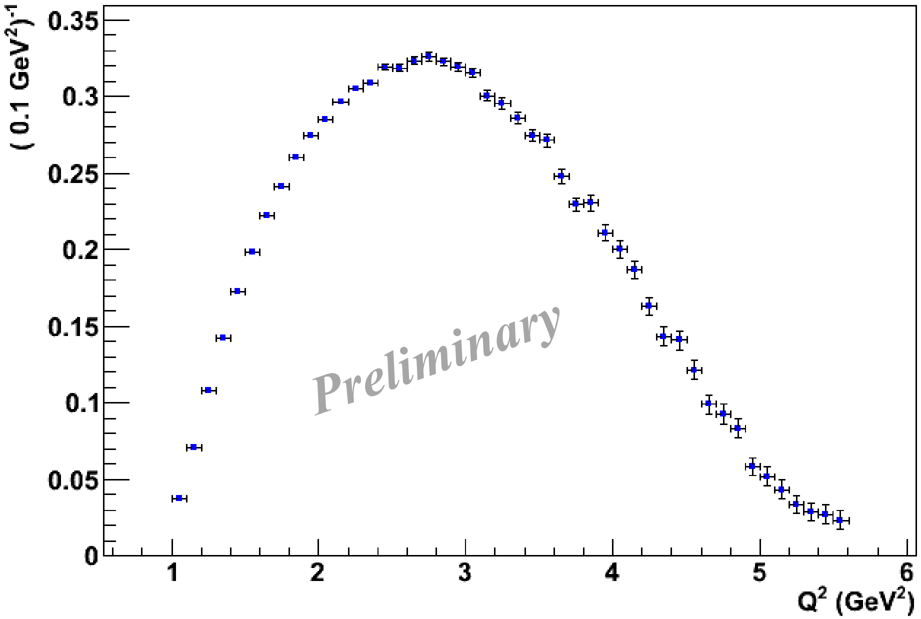
Acceptance as a function of angle of π with respect to the beam direction

Acceptance corrections

Deuterium



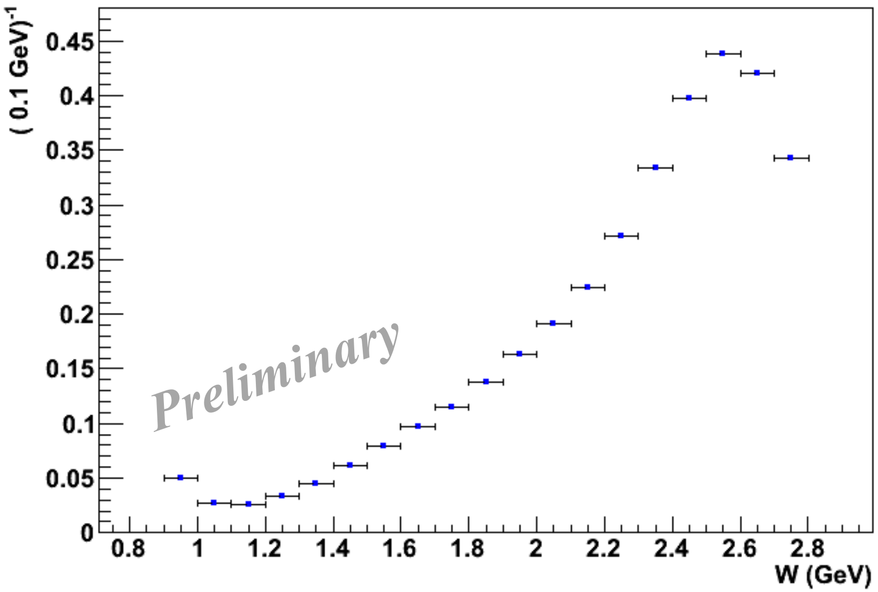
Carbon



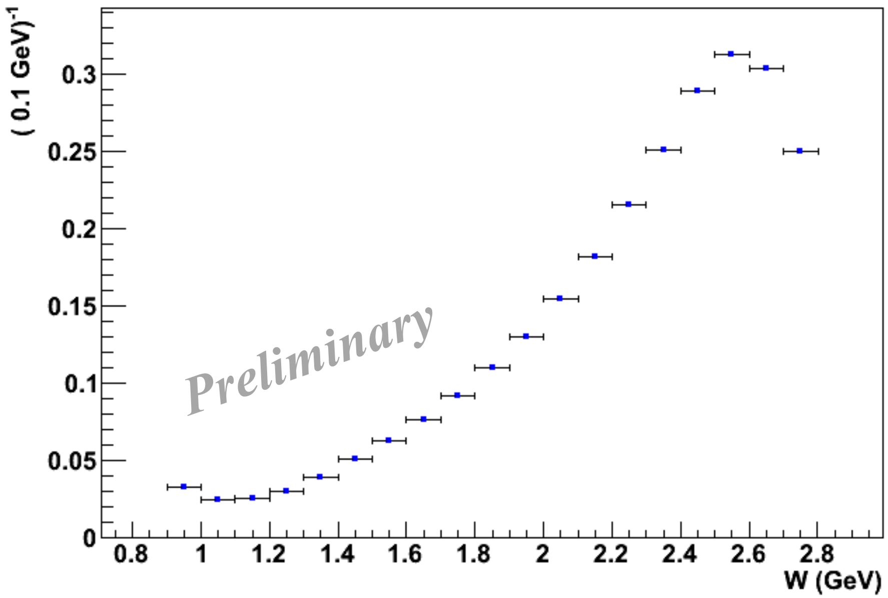
Acceptance as a function of Q^2

Acceptance corrections

Deuterium



Carbon



Acceptance as a function of W

Radiative corrections

- Not included on data presented here. Planning to use/testing HAPRAD code (http://www.jlab.org/RC/)

  I. Askushevich, N. Shumeiko, A. Soroko, Radiative effects in the processes of hadron electroproduction, Eur. Phys. J. C 10, 681-687 (1999).

- Developed to calculate the QED radiative corrections to the semi-inclusive unpolarized five-dimensional cross section

$$\frac{d^5\sigma}{dx\,dy\,dz\,dp_t^2\,d\theta_h}$$

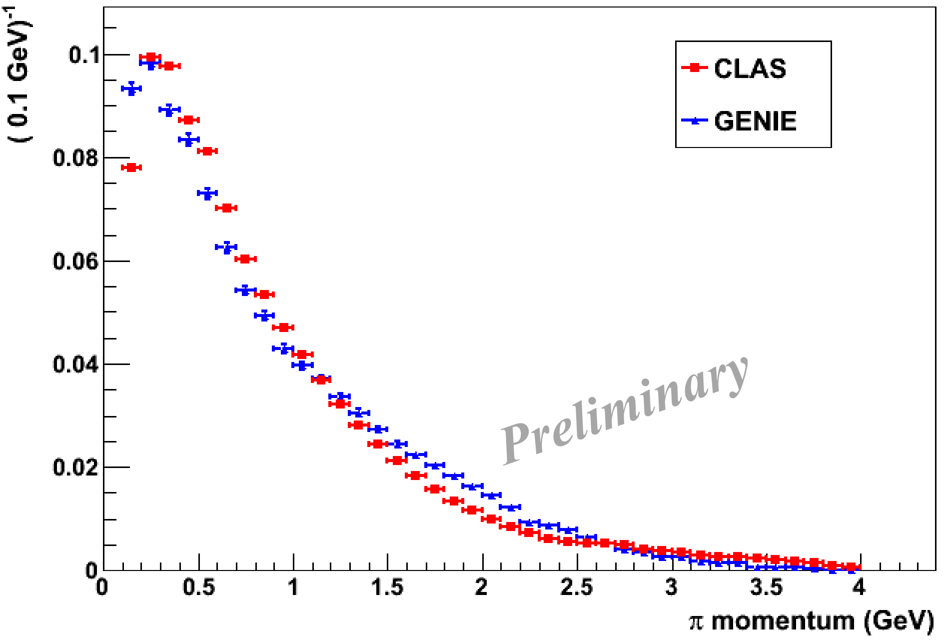
- Similarity of shapes of GENIE/data means we can use GENIE events to develop/study the radiative corrections.

- Expecting the $y<0.85$ cut will minimize effect of radiative corrections.

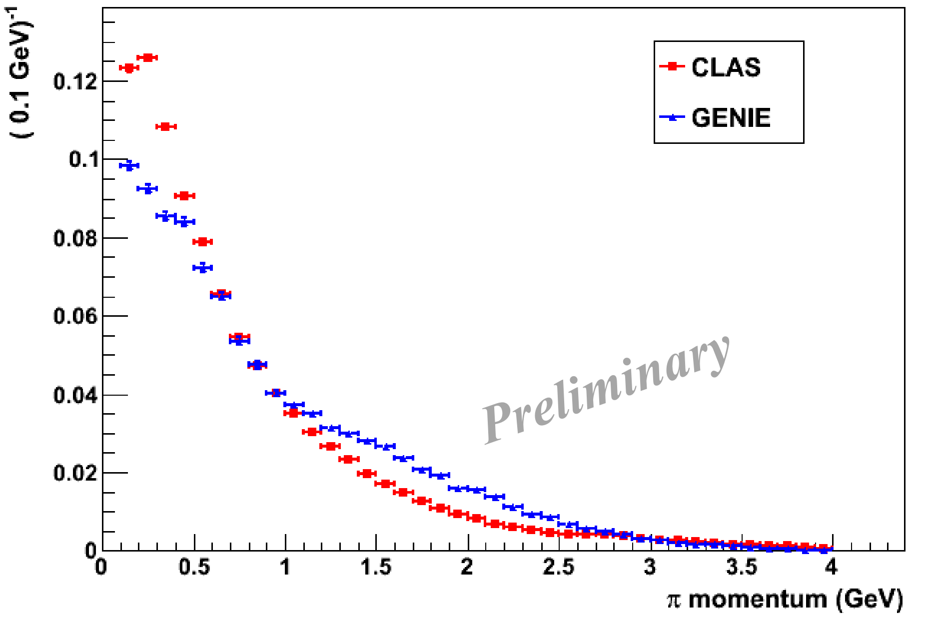
Data-MC comparison

(Acceptance corrected, statistical errors only, no radiative corrections)

Deuterium



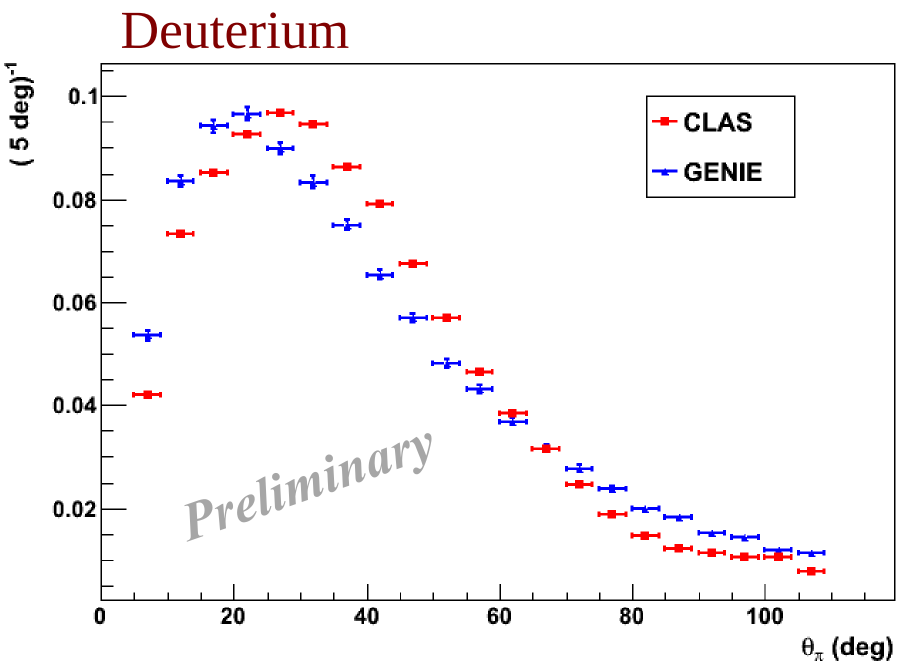
Carbon

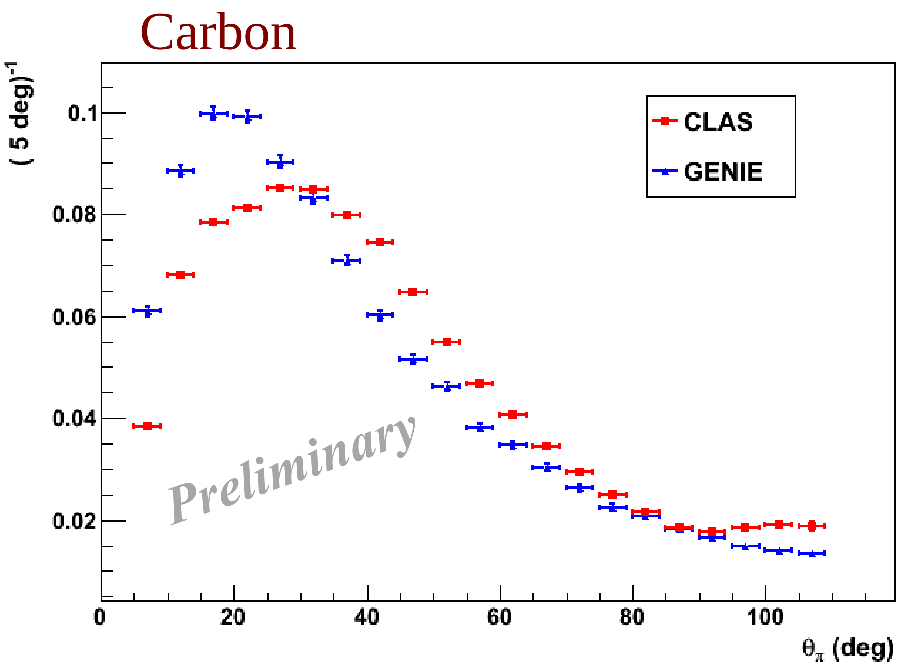


Momentum of π in the lab frame

Data-MC comparison

(Acceptance corrected, statistical errors only, no radiative corrections)



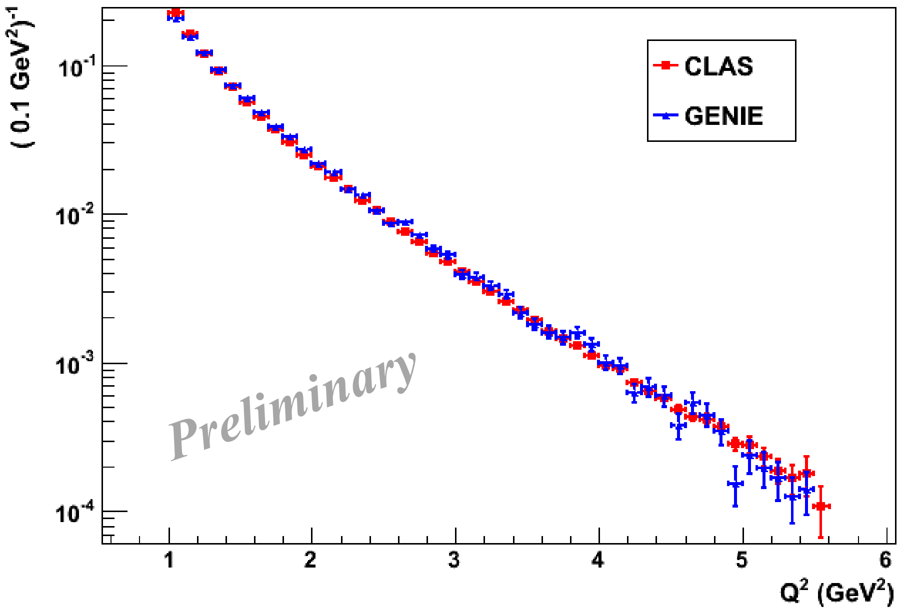


Angle of π with respect to the beam direction

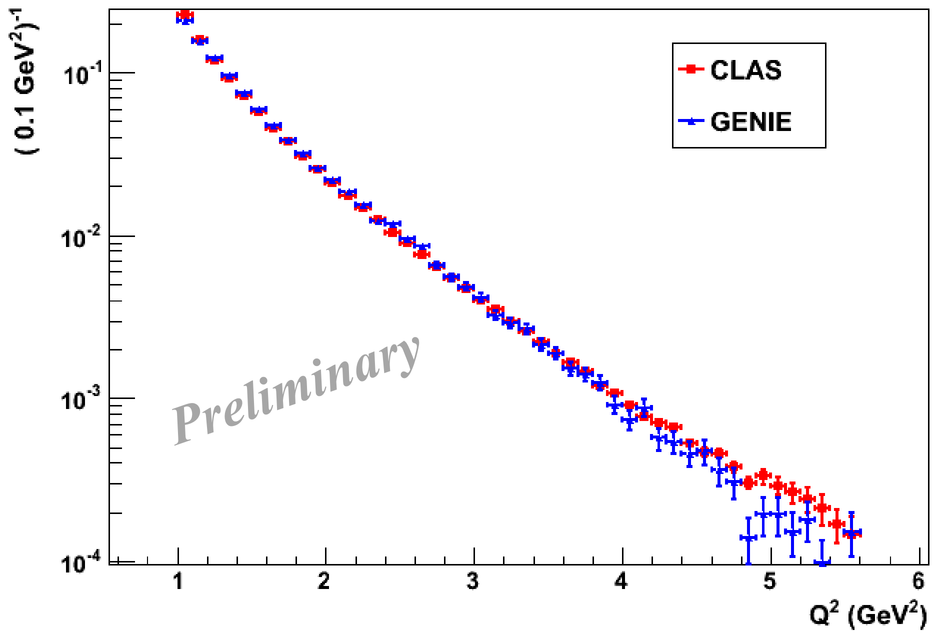
Data-MC comparison

(Acceptance corrected, statistical errors only, no radiative corrections)

Deuterium



Carbon

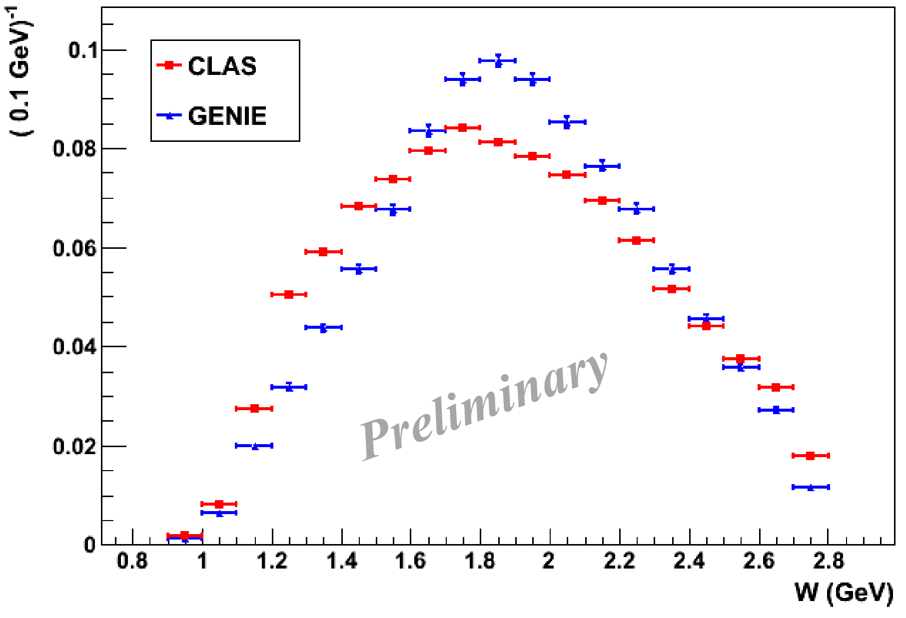


Q^2 distribution

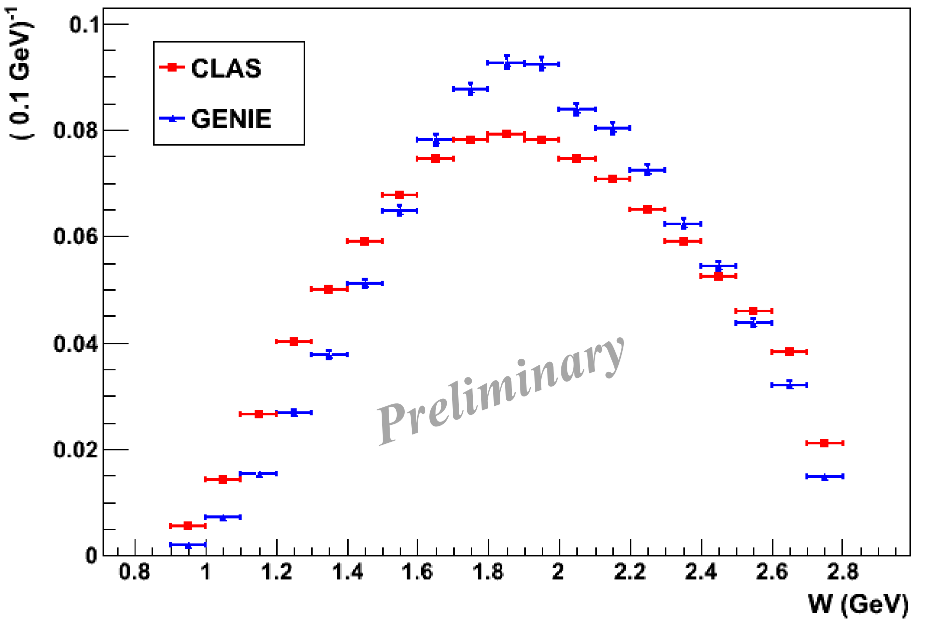
Data-MC comparison

(Acceptance corrected, statistical errors only, no radiative corrections)

Deuterium



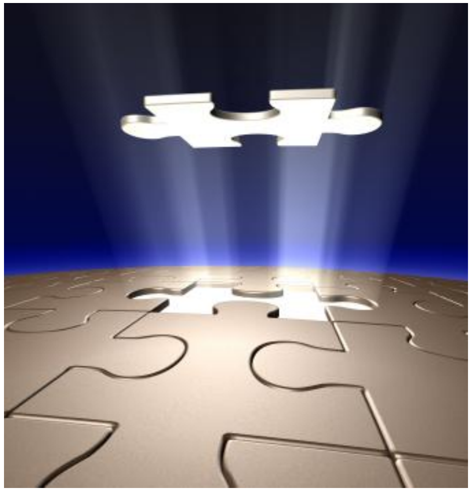
Carbon



W distribution

Still to do

- Explore doing more differential analysis.
- Radiative corrections.
- Correction for higher multiplicity events feeding down.
- Systematic error analysis. Goal is <10%.
- Plan to analyze Fe and Pb in addition to the C and ^{2}H.



High precision neutrino results are a product of many pieces carefully fit together

- CLAS/EG2 is making significant progress toward releasing precision $\pi^{\pm}$ production cross-sections on different nuclei in a region of phase space relevant for the current precision neutrino physics program. We hope for final results to be released in the next year.

- Preliminary comparisons with GENIE are quite good, though there is some room for tuning.

Thank you to the organizers for inviting us to show this work and for what is surely to be a fine workshop.