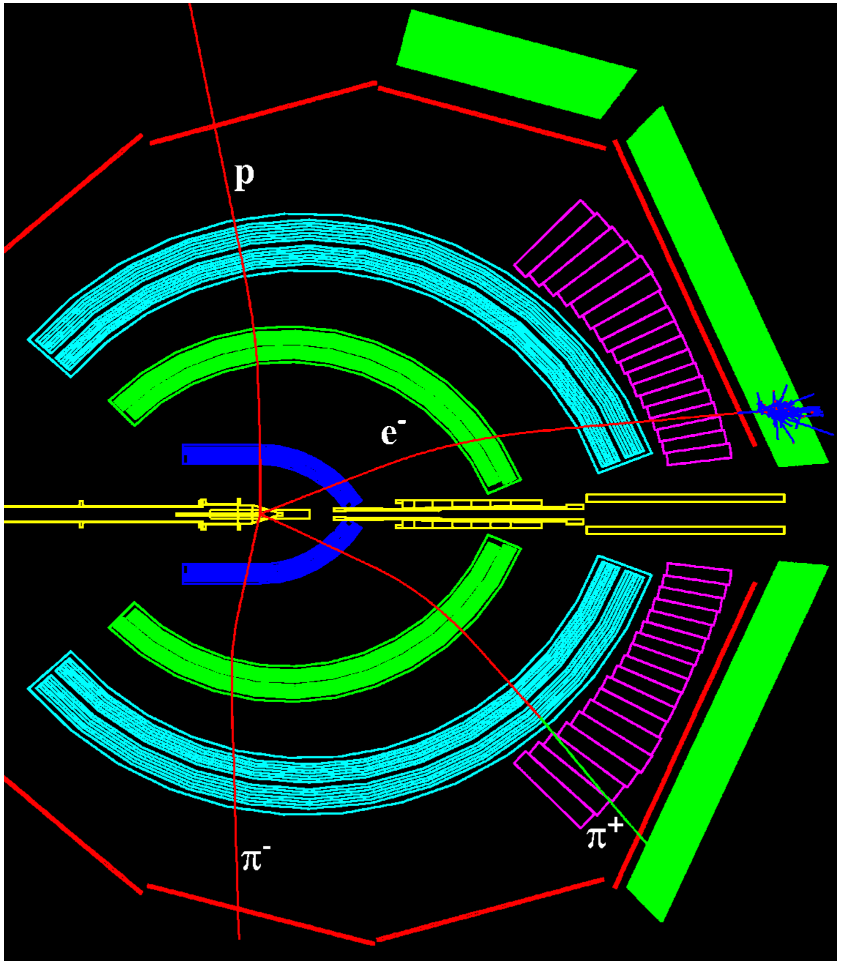
eA pion production at CLAS aimed at neutrinos



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Department of Physics and Astronomy

NUFACT 2013

August 19-24, 2013

Beijing, China

Representing the CLAS (EG-2) collaboration

Motivation – why eA?

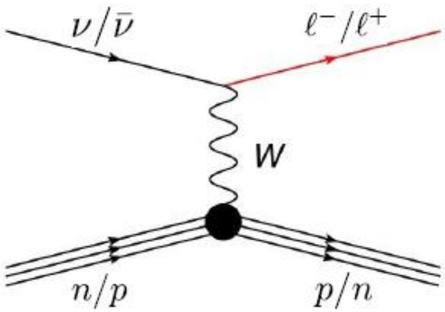
- ➢ High statistics.
- ➢ Control over initial energy and interaction point – gives kinematic constraints and ability to optimize detector.

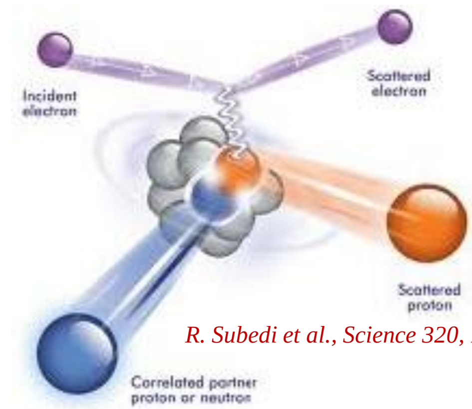
Summary slide from talk by Costas Andreopolos at NUINT 2009
"Electron scattering data and its use in constraining neutrino models"

- Electron (and muon) scattering data provide a wealth of information about the **nucleon and nuclear structure** and **in-medium modifications**
    - *Nucleon Elastic Form Factors*
    - *PDFs, R, d/u, …*
    - *Resonances & QE → DIS transition, Non-Resonance Backgrounds*
    - *Nucleon momentum distributions and binding energies*
    - *Nuclear charge distributions, energy levels, ...*
    - *N-N correlations*
    - *Medium modifications*
        - *EMC effect, ...*
        - *Effects on hadronization: Landau-Pomeranchuck-Migdal and Cronin effects*
    - *...*

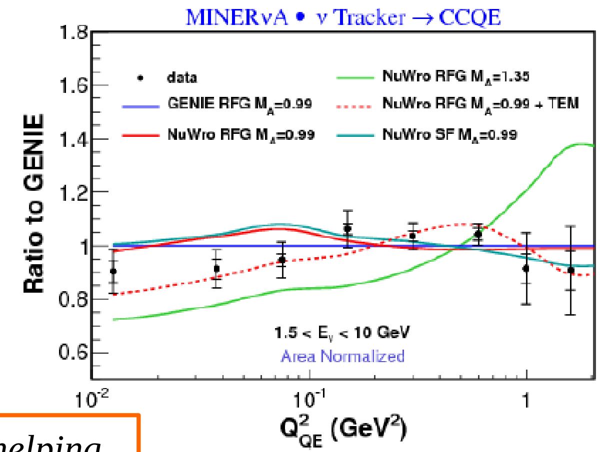
This information has been central in building comprehensive picture of neutrino interactions in the ~few GeV energy range

Why eA? – Discussions at NUFACT



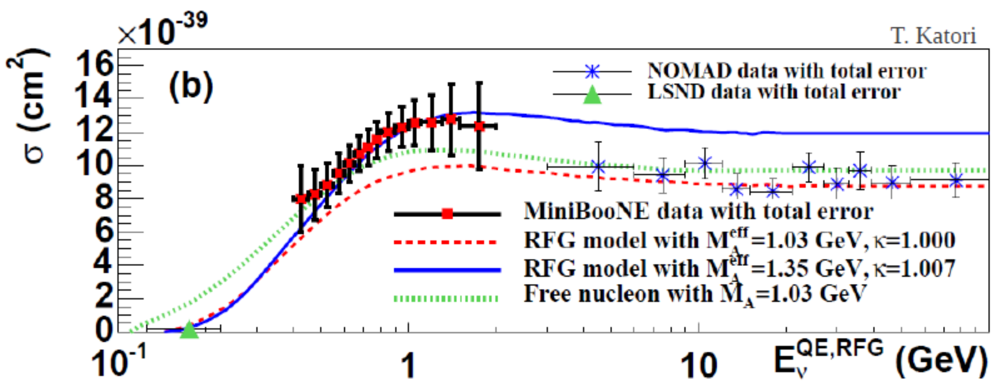


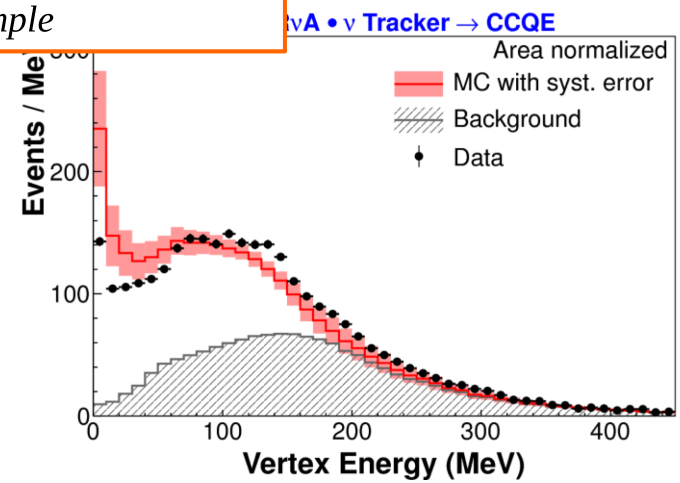
R. Subedi et al., Science 320, 1476 (2008)



Much of the conversation here at NUFACT regarding oscillations/cross sections has centered around the fact that interactions are on nuclei rather than nucleons

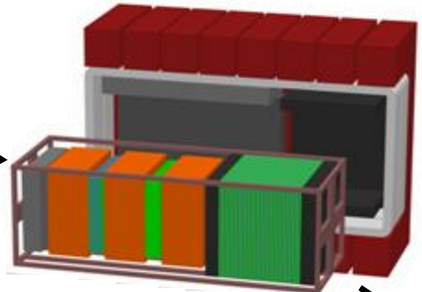
Input from eA has been important in helping us understand the potential effects of SRC and MEC, for example



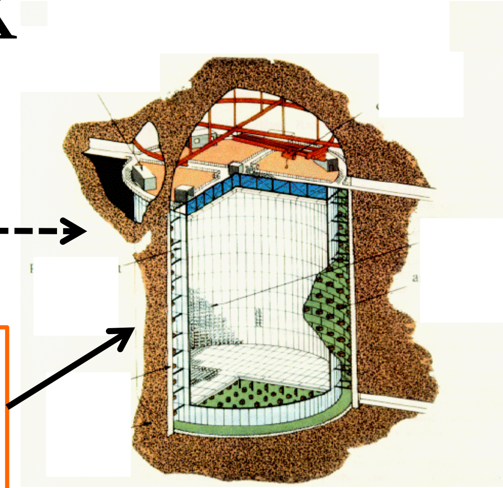


Why eA? – This work

Neutrino beam



Long baseline

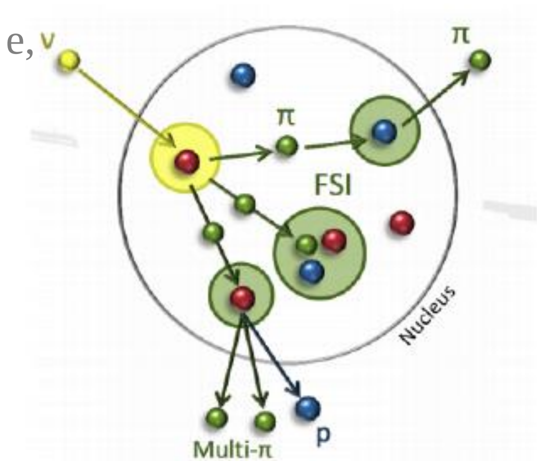


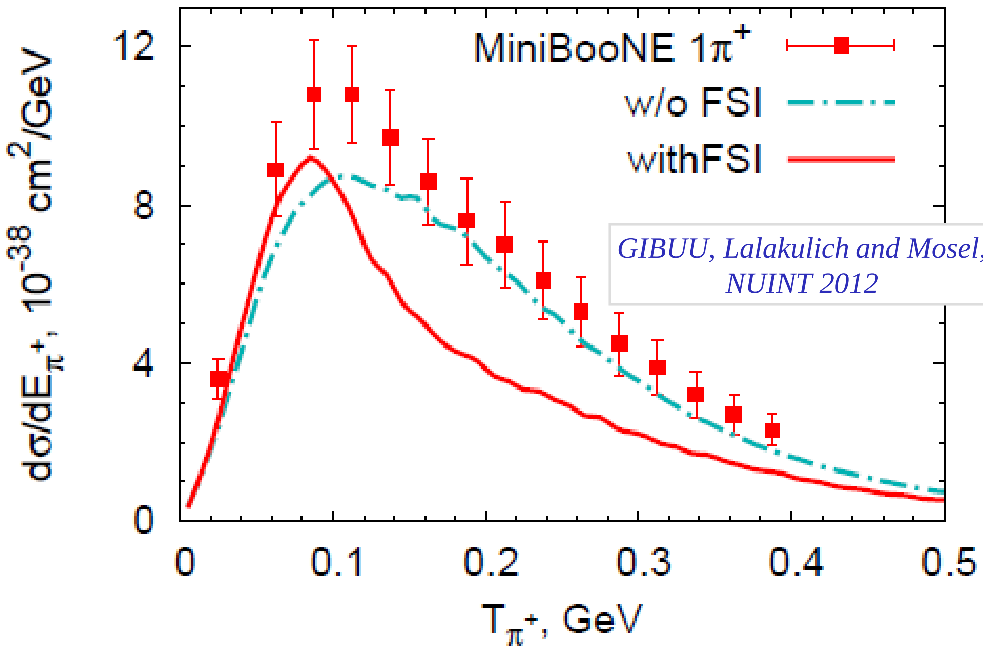
Measure flux and backgrounds in near detector and propagate to far detector and the uncertainties "cancel out"

Cross-sections, nuclear effects and backgrounds don't cancel simply/completely, even in the limit of identical detectors.

Model

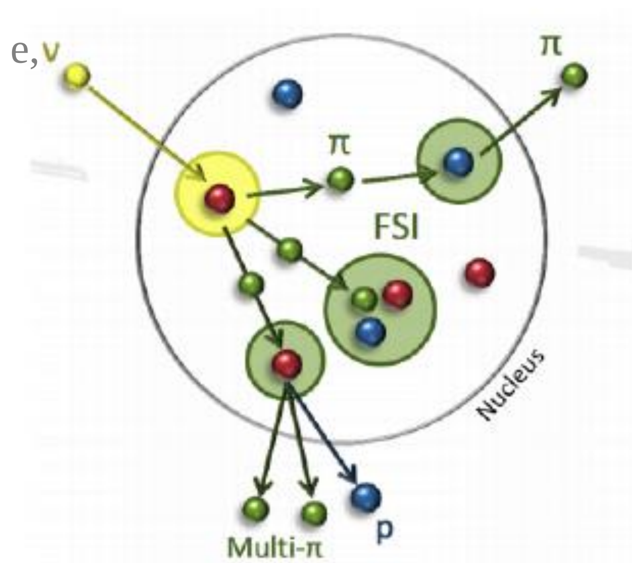
Even more important if near and far detectors are not the same material



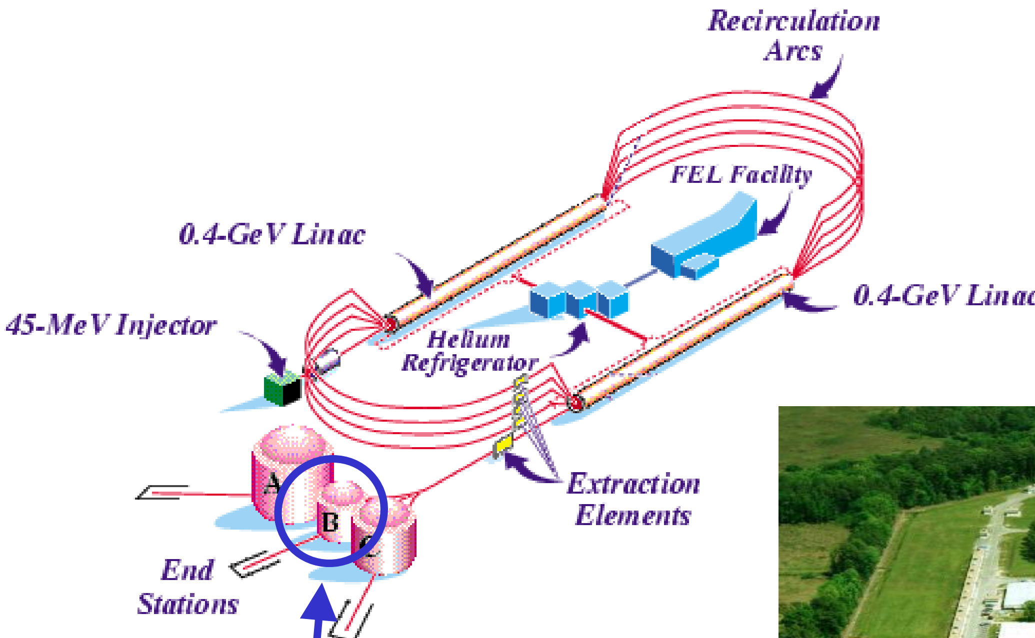


Why eA? – This work

This work aims to produce high statistics, multidimensional, differential, charged pion production measurements on different nuclei. The hope is that this will be useful for learning about and tuning models for FSI.

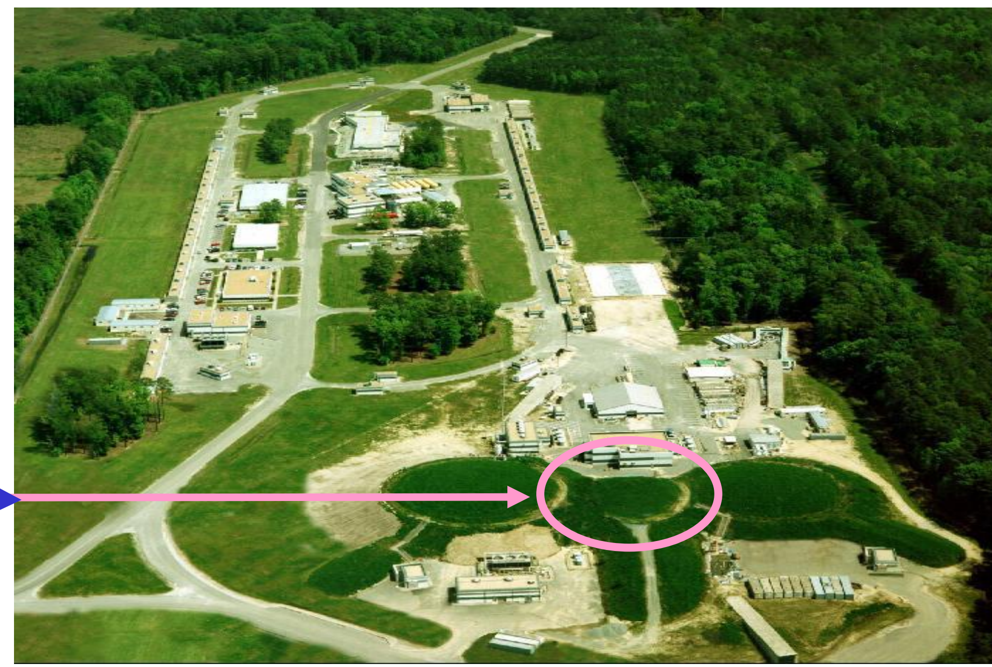


Jefferson Lab (Newport News, Virginia)



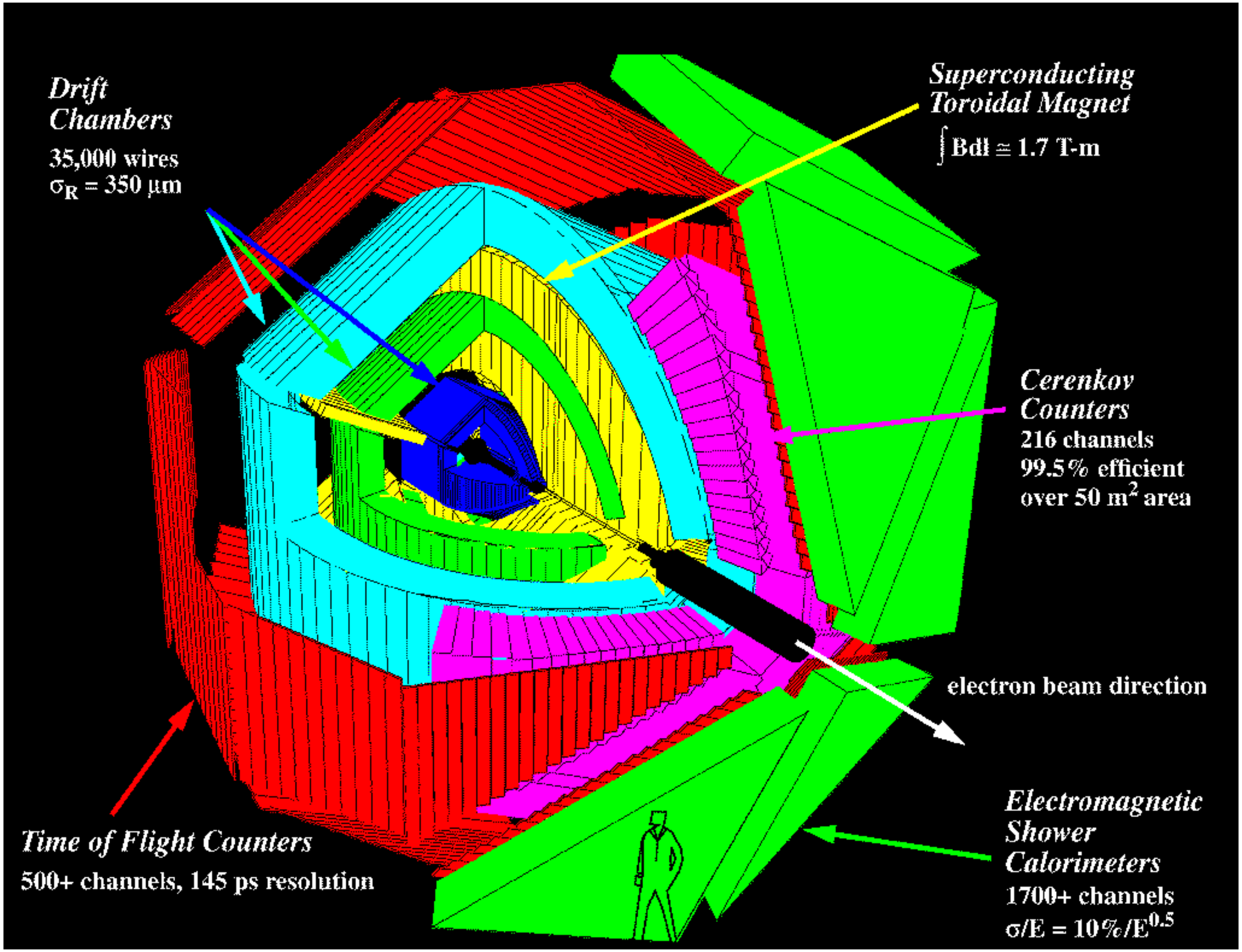
E_{max} ~ 6 GeV
I_{max} ~ 200 μA
Duty Factor ~ 100%
σ_E/E ~ 2.5 10^{-5}
Beam P ~ 80%

12 GeV upgrade underway

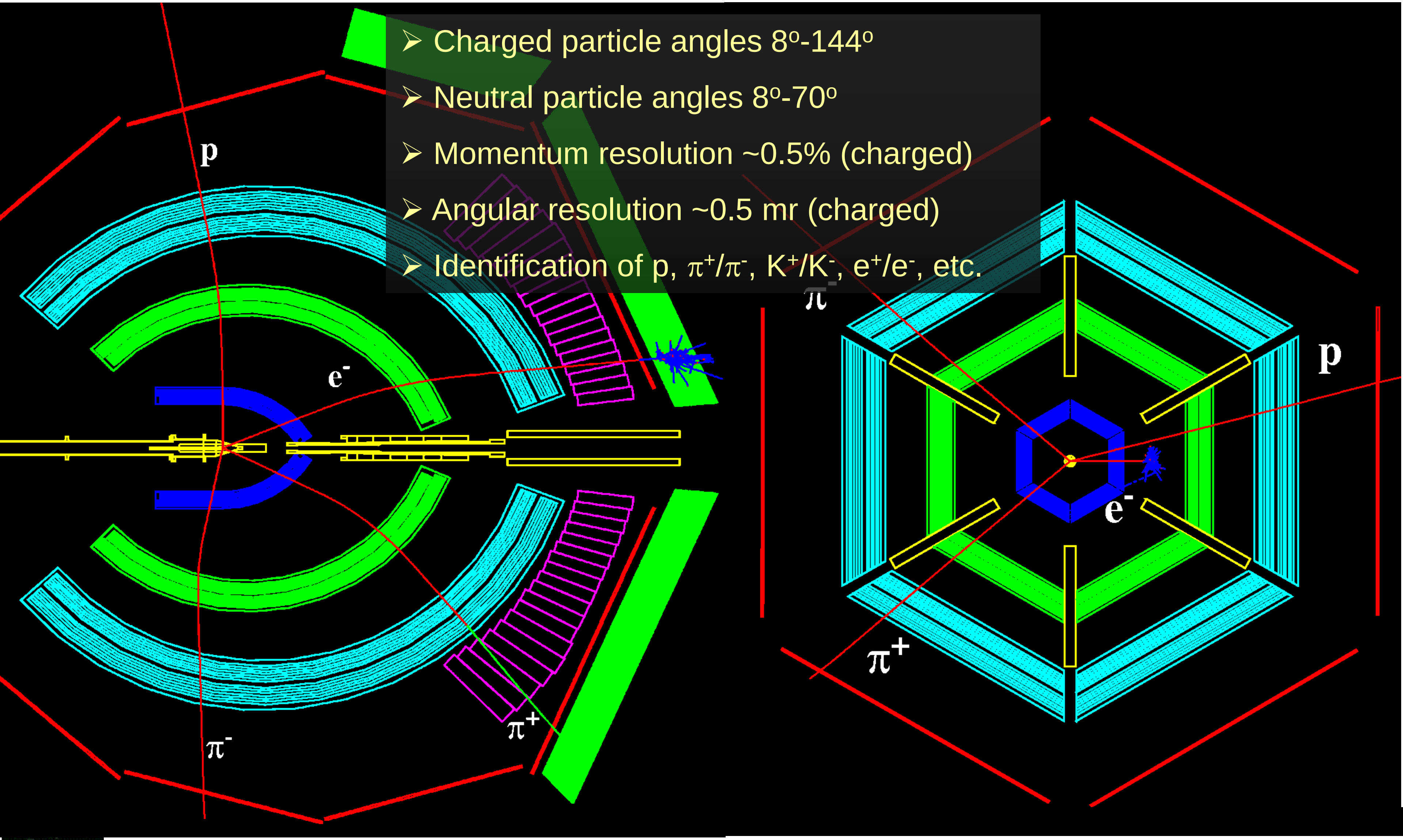


CLAS

CLAS: CEBAF Large Acceptance Spectrometer (Hall B)

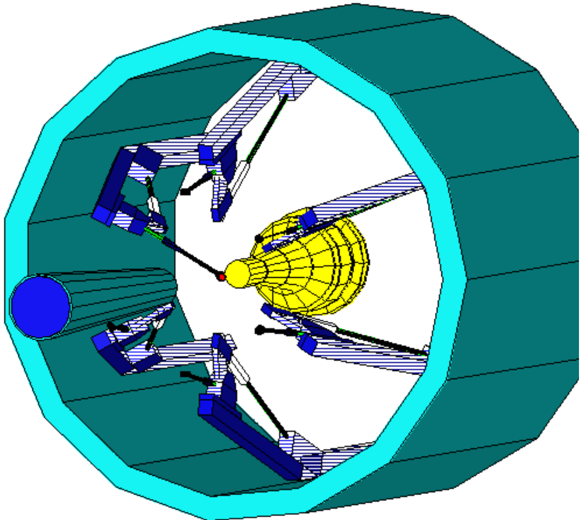


CLAS Single Event Display

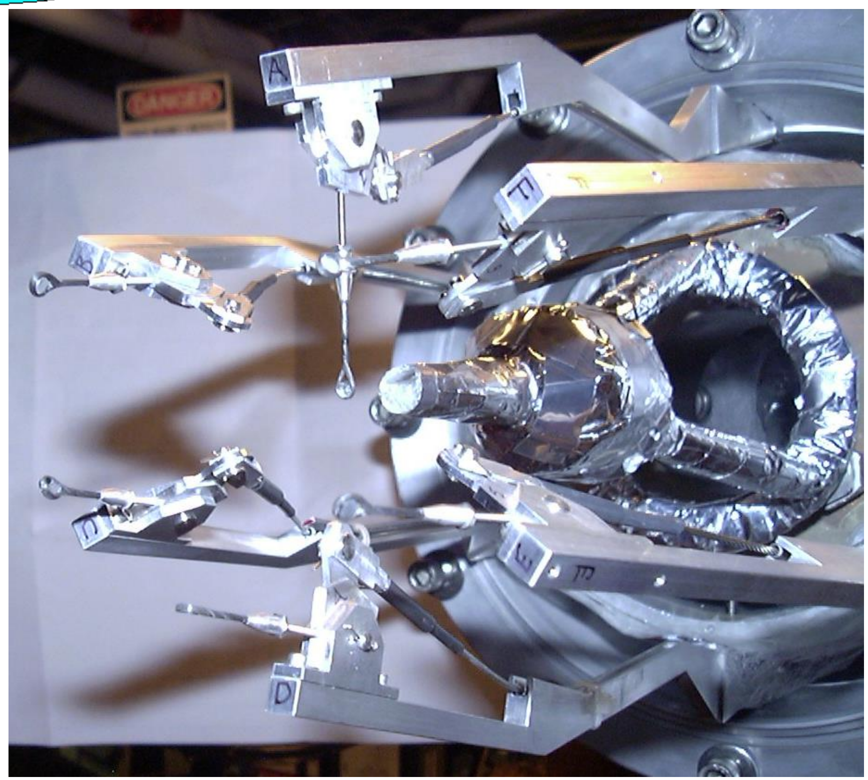


- Charged particle angles 8°-144°
- Neutral particle angles 8°-70°
- Momentum resolution ~0.5% (charged)
- Angular resolution ~0.5 mr (charged)
- Identification of p, π^+/π^-, K^+/K^-, e^+/e^-, etc.

- CLAS - International collaboration of ~230 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 (Q^2 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 $Q^2 > 0.5$ for acceptance calculations and comparison

C. Andreopoulos: 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/hA) 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.

Samples

EG-2 data sample size (E_{beam}=5.015 GeV):

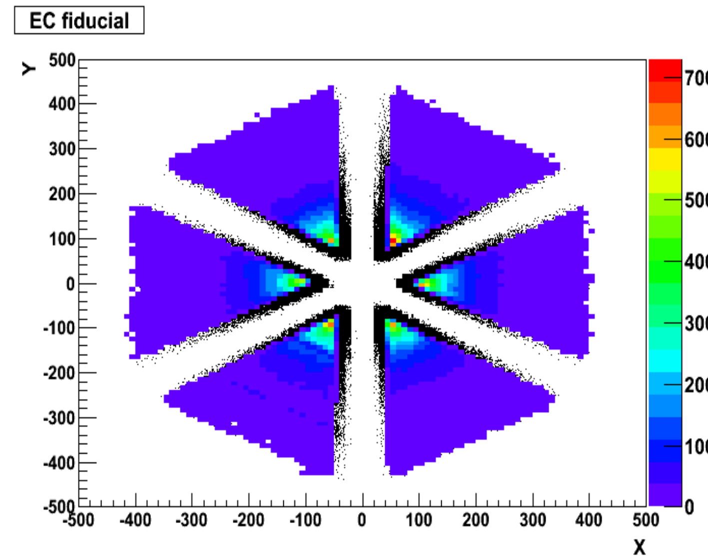
Deuterium + C/Fe/Pb raw events	1.1/2.2/1.5 ($\times 10^9$)
D2/C/Fe/Pb events passing all cuts	28.1/5.0/7.6/2.5 ($\times 10^6$)

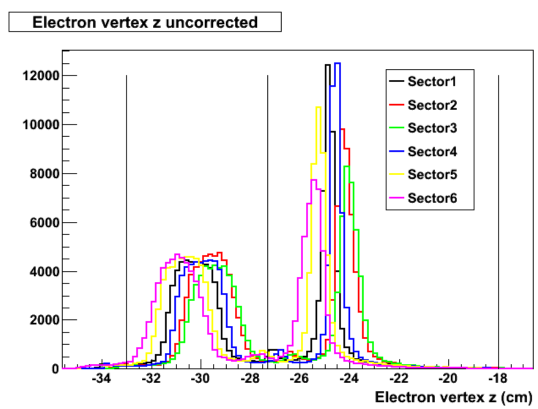
Simulated sample size (Genie MC + detector simulation):

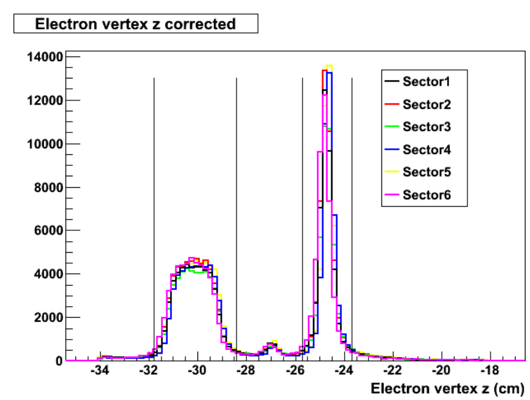
D2/C/Fe/Pb generated events	(4)$\times$1.0$\times 10^8$
D2/C/Fe/Pb events passing all cuts	7.9/6.4/5.5/4.8 ($\times 10^6$)

Analysis cuts

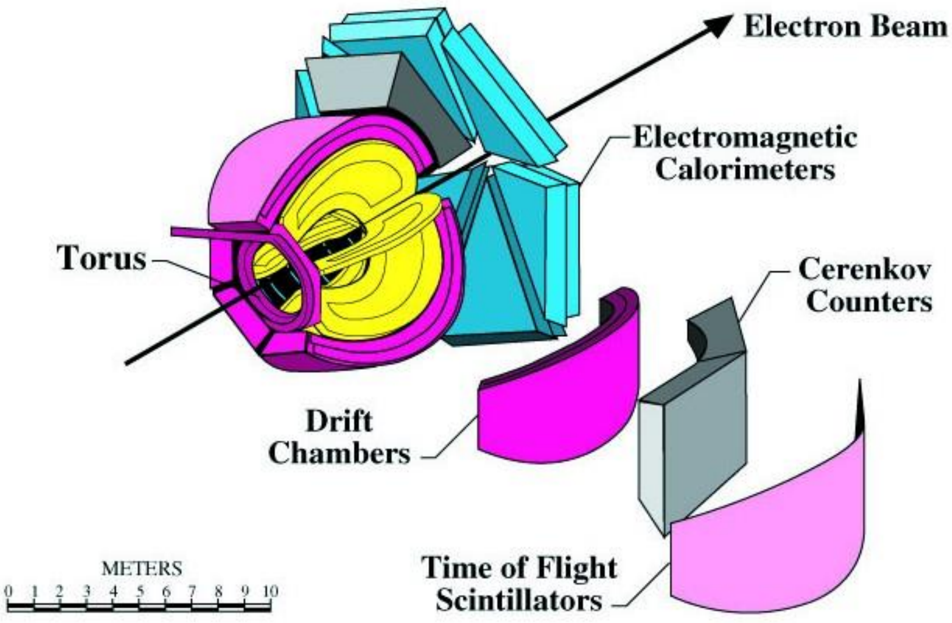
- Demand electron enter calorimeter safely away from edges
- Demand energy deposit as function of depth in ECAL be uneven
- Adjust vertex Z position for sector-by-sector beam offset
- Demand momentum of outgoing e-: $p>0.64$ GeV (or $y<0.872$) (removes bias due to electromagnetic energy threshold in trigger)
- Implement "relatively" easy to model cuts in W, Q^2, θ for the electron and p_π, θ_π for the pion



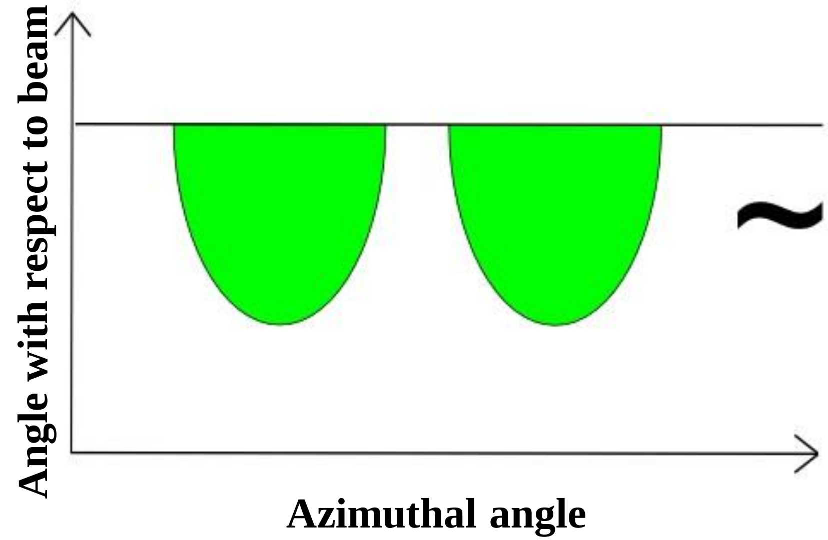




Fiducial volume complications

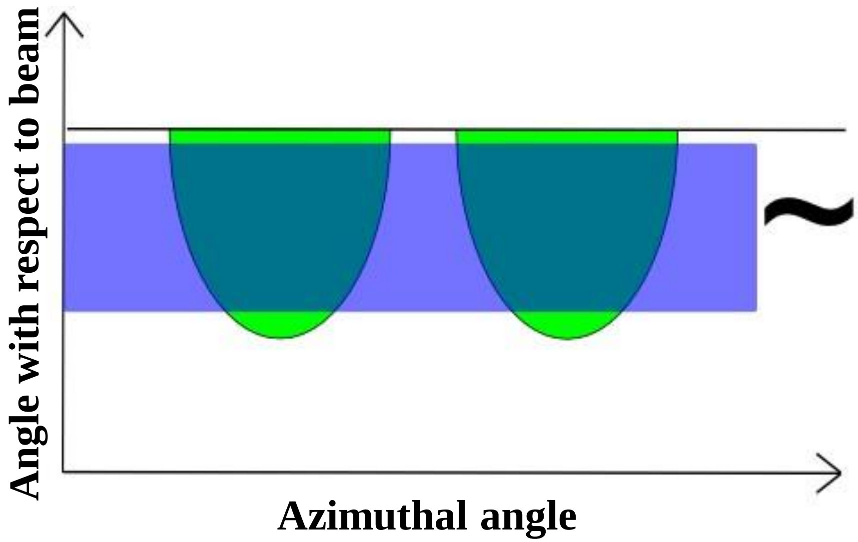


Six azimuthal regions of angular acceptance that are a function of θ, p, charge

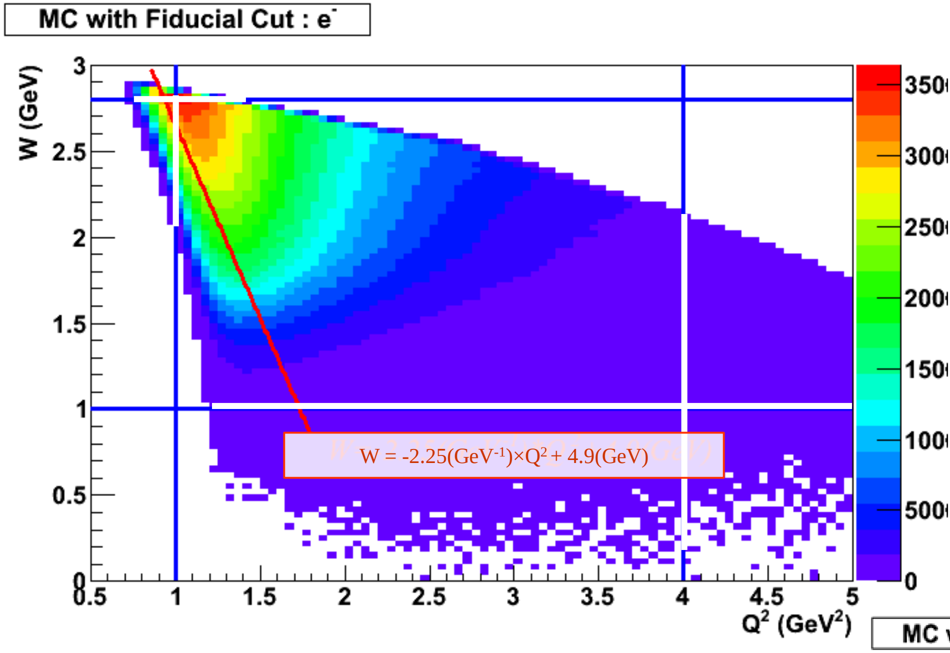


➢ The optimal fiducial regions for the detector are not conveniently modeled for comparison to calculations

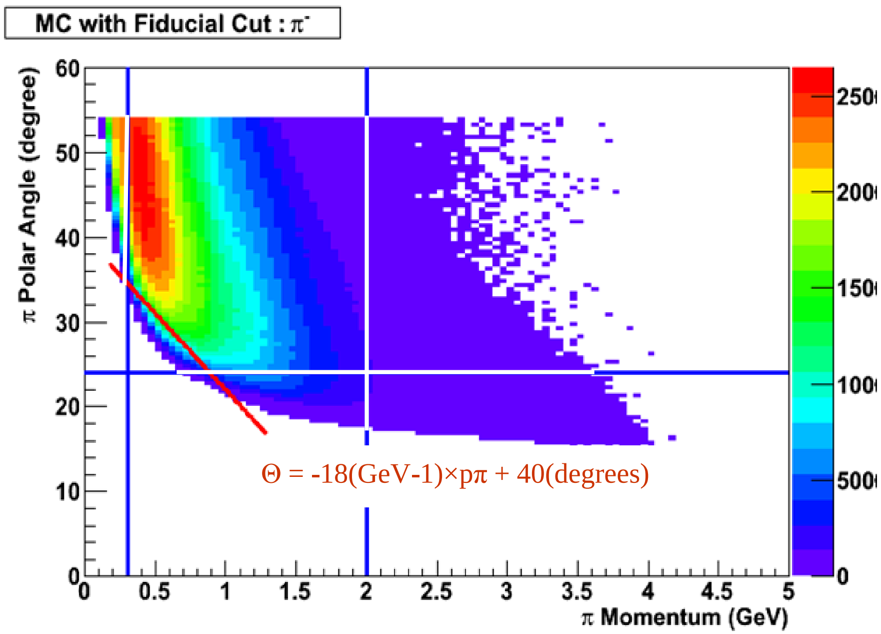
Fiducial volume complications



- Report results with geometric correction to be azimuthally symmetric
- Implement “relatively” easy to model cuts in W, Q^2, θ for the electron and p_π, θ_π for the pion



For e^-
- $y>0.872$
- $1GeV^2<Q^2<4\ GeV^2$
- $1\ GeV<W<2.8\ GeV$
- red line shown



For π^- (π^+ has distinct but similar cuts)
- $0.3<p_\pi<2$
- $24^o<\theta_\pi<54^o$
- red line shown

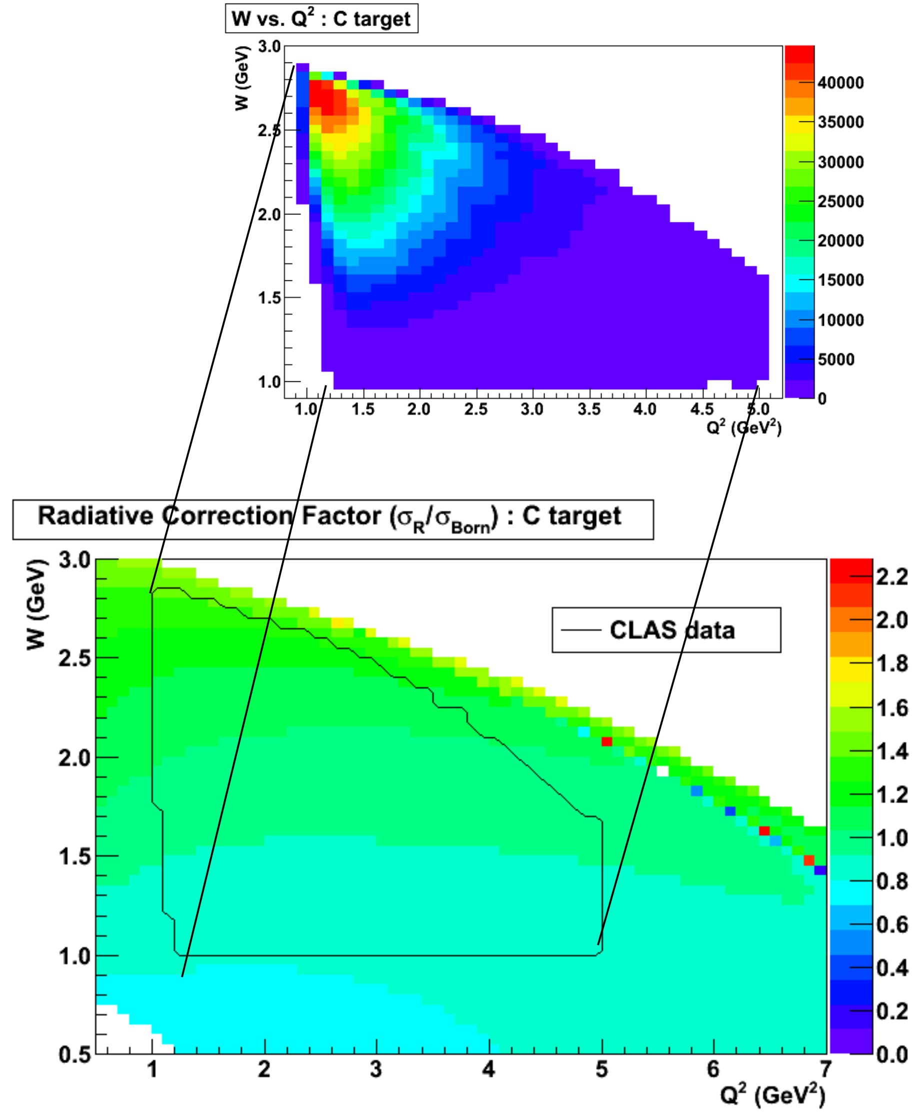
Radiative corrections

➢ Use "externals_all" routine designed for EG1-DVCS experiment (P. Bosted, EG1-DVCS technical note 5, 2010)

➢ Calculate differential cross sections (W, Q^2) with and without QED radiative effects in the process.

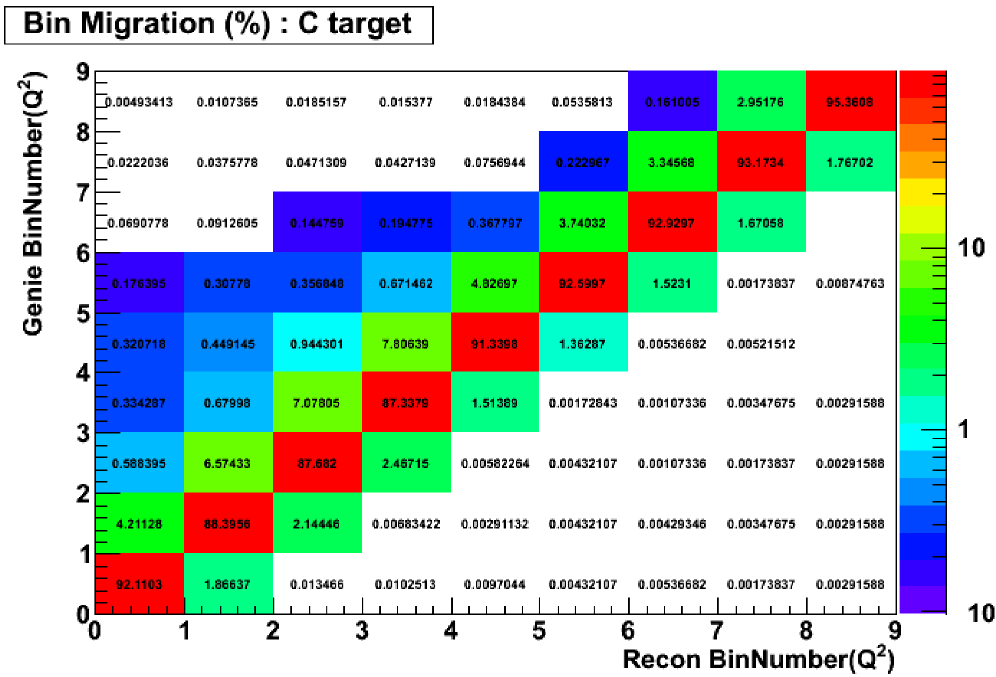
➢ Remove (quasi-)elastic contribution (since we demand a pion be present)

➢ Only consider leptonic side (in neutrinos we don't typically worry about the radiative corrections on the hadronic side)



Acceptance and bin migration

- Work in 4-dimensional space (W, Q^2, p_π, θ_π)
- Multi-dimensional acceptance correction and bin migration correction from MC (<10%, typically smaller)
- Non-acceptance corrected GENIE distributions look very similar to the data distributions – reasonable to use the GENIE samples for the acceptance corrections.
- Require at least one $\pi^\pm$ reconstructed, take leading pion as the analysis pion
- MC indicates single $\pi^\pm$ sample to originate from ~40% percent single $\pi^\pm$ with most of the rest from multiple π events.
- Missing mass analysis improves single-π purity with a big loss in statistics. Not using for current results.

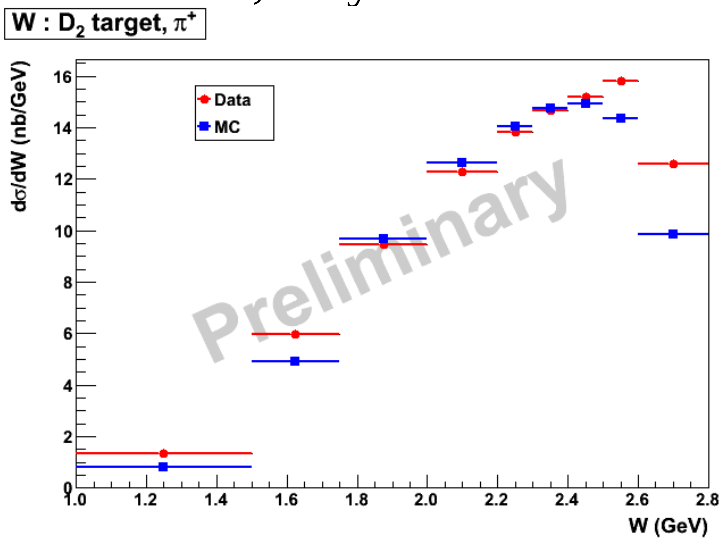


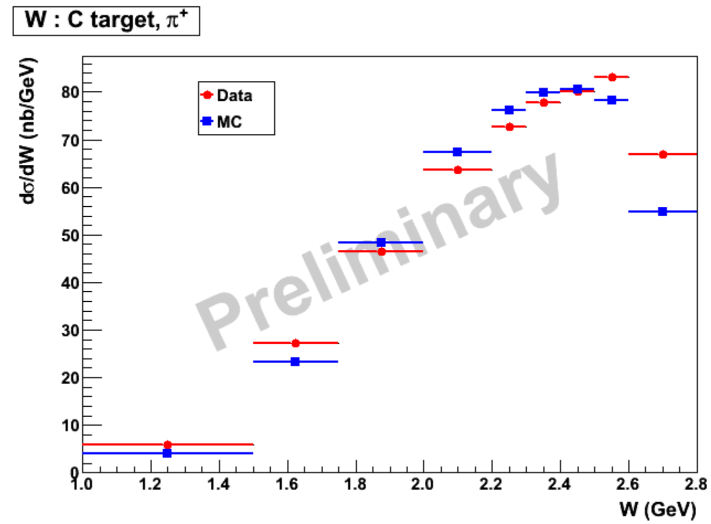
Caveats

- All results shown here are preliminary
- The errors shown are statistical only
- Systematic errors are under investigation
- Expectation/goal is to hold the systematic errors to <10%
- Vast amount of differential data. Only sampling shown here.
- Ask if you want to see preliminary result on something I do not have time to show here.

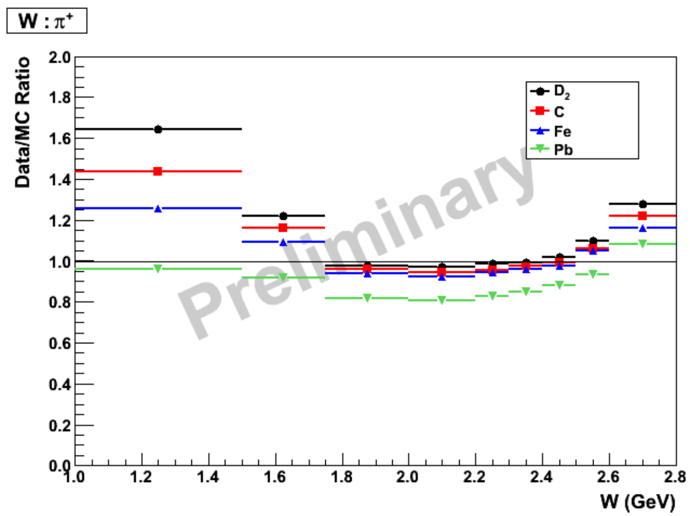
Data-MC comparison

(Comparison friendly fiducial region, corrected for acceptance and radiative effects, only statistical errors shown , three variables integrated over)





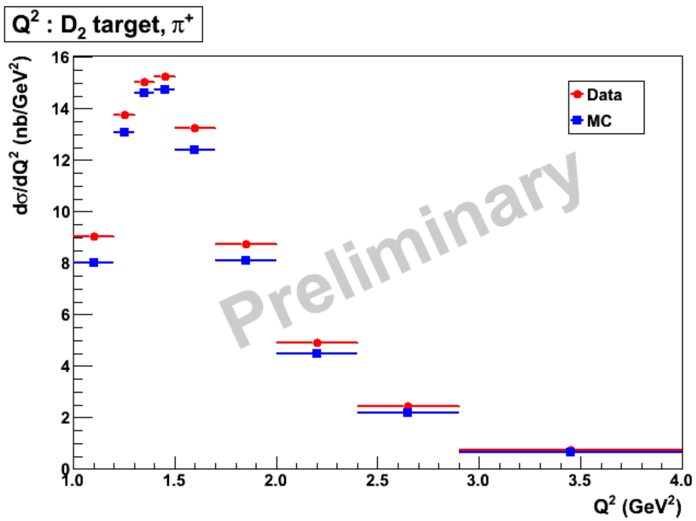
W, π^+

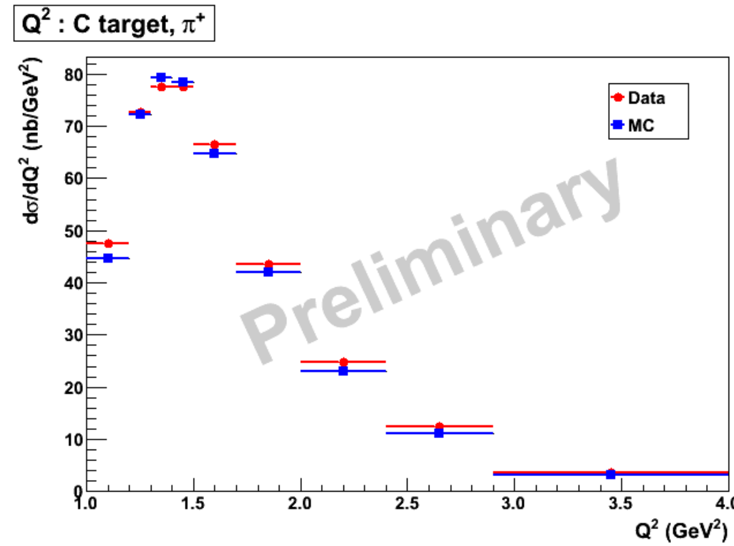


Data/MC ratio, all targets

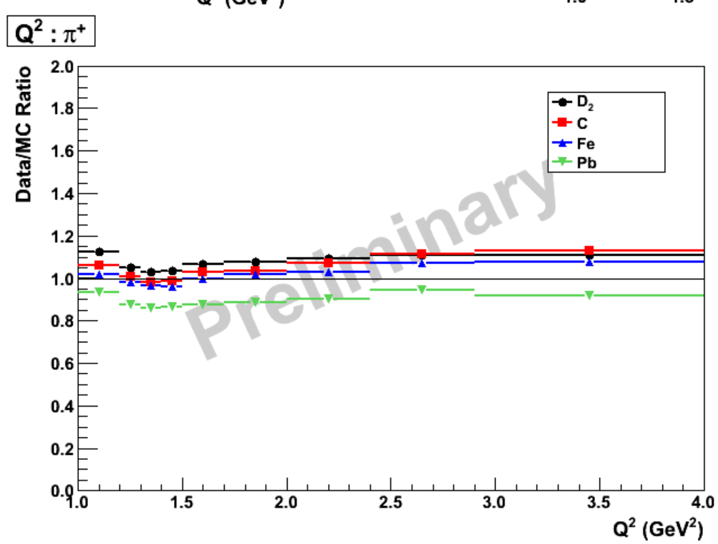
Data-MC comparison

(Comparison friendly fiducial region, corrected for acceptance and radiative effects, only statistical errors shown , three variables integrated over)





Q^2, π^+



Data/MC ratio, all targets

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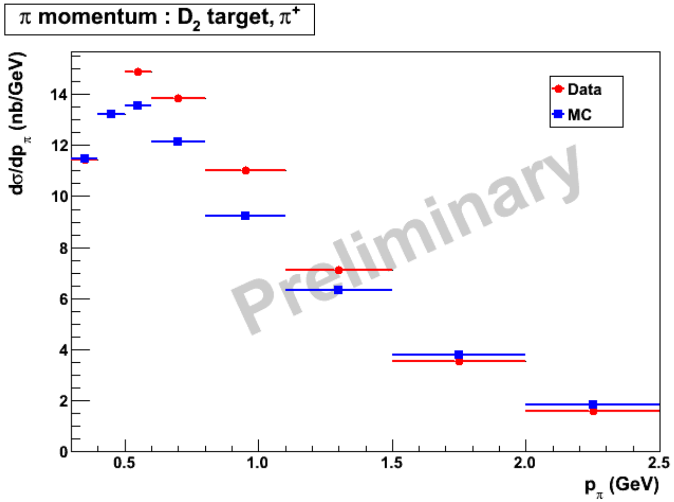
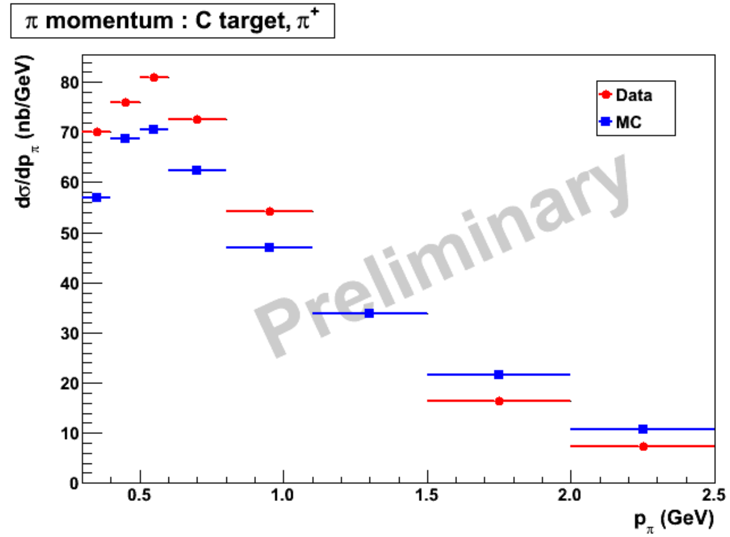
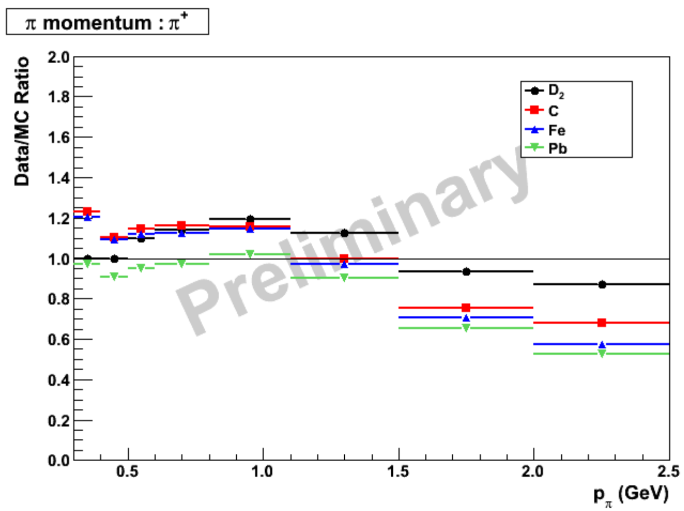




p_π, π^+



Data/MC ratio, all targets

Data-MC comparison

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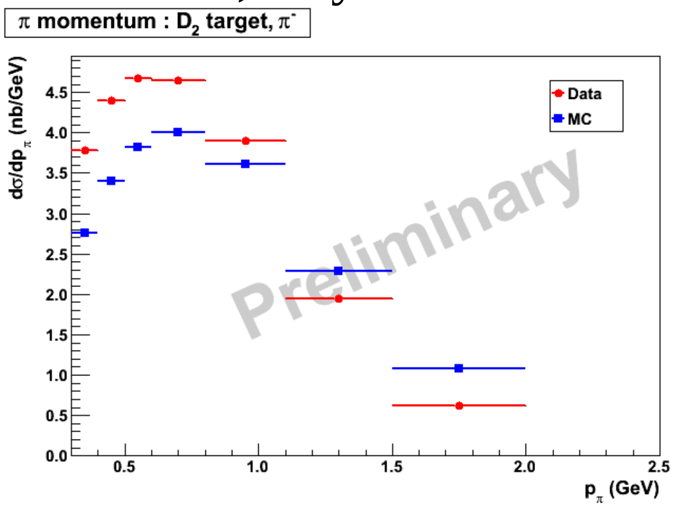
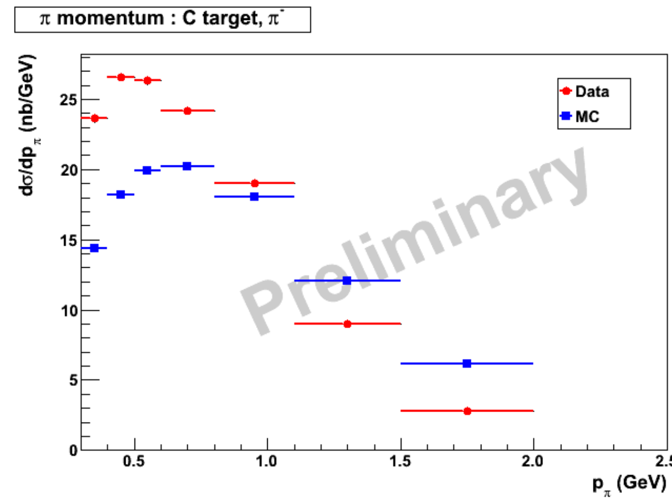
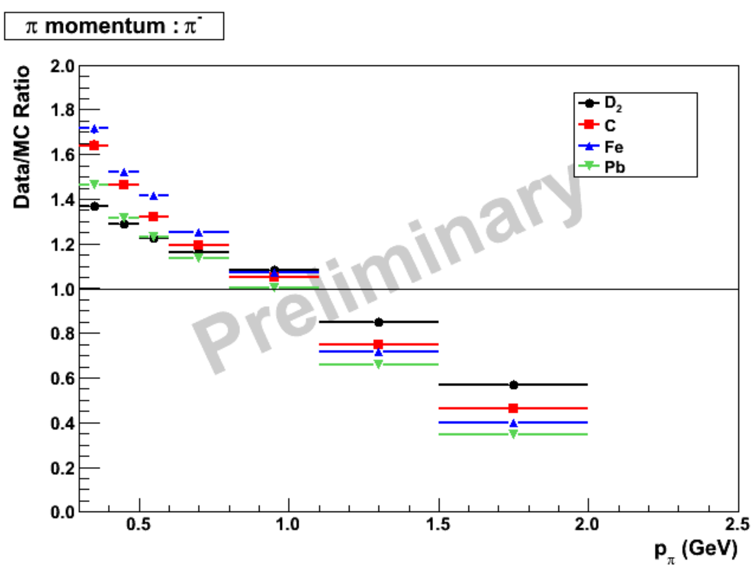




p_π, π^-



Data/MC ratio, all targets

Data-MC comparison

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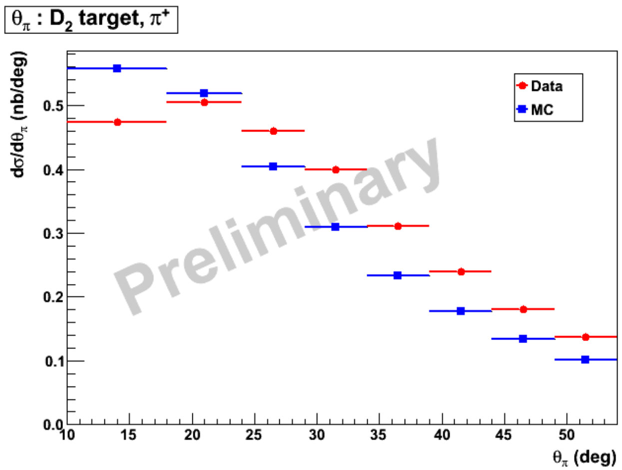
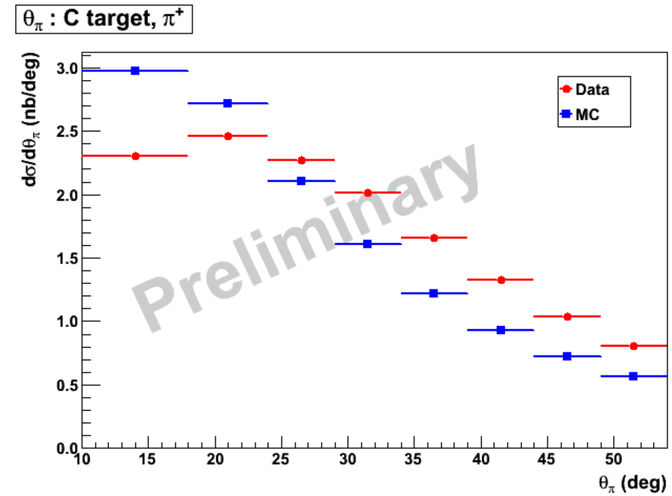
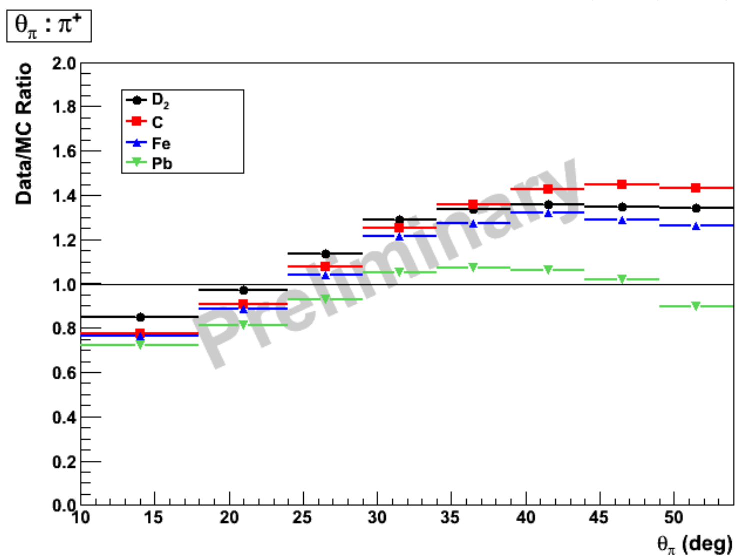
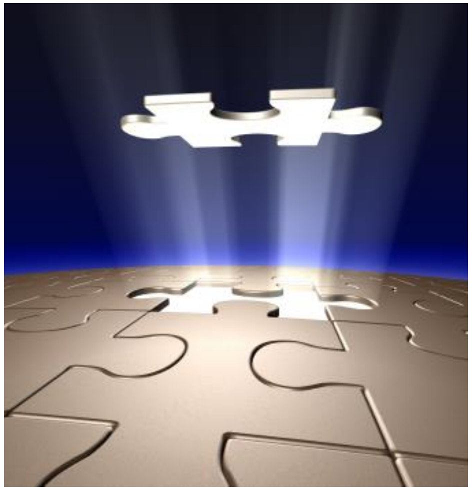




θ_π, π^+



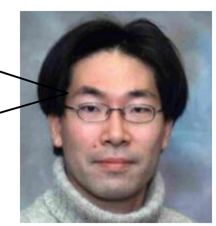
Data/MC ratio, all targets



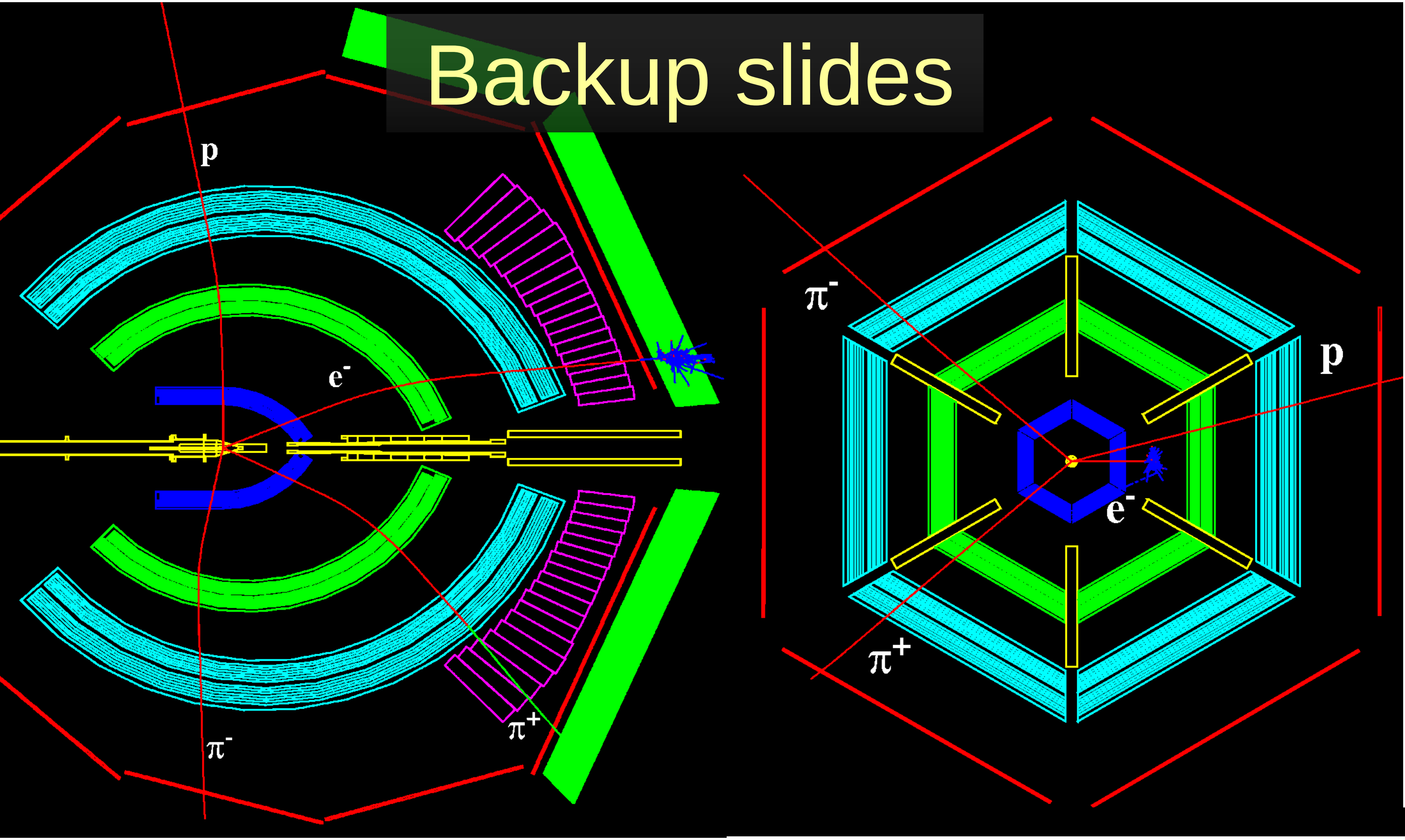
High precision neutrino results are a product of many pieces carefully fit together

- ➢CLAS/EG2 is making significant progress toward releasing multi-dimensional 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.

Let’s finish this up. I need to graduate!



Backup slides

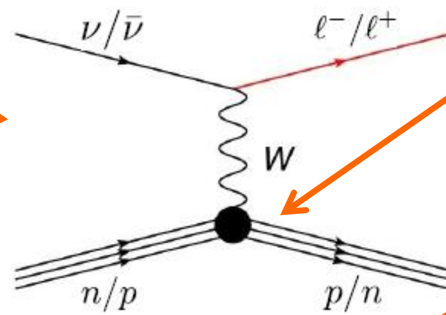


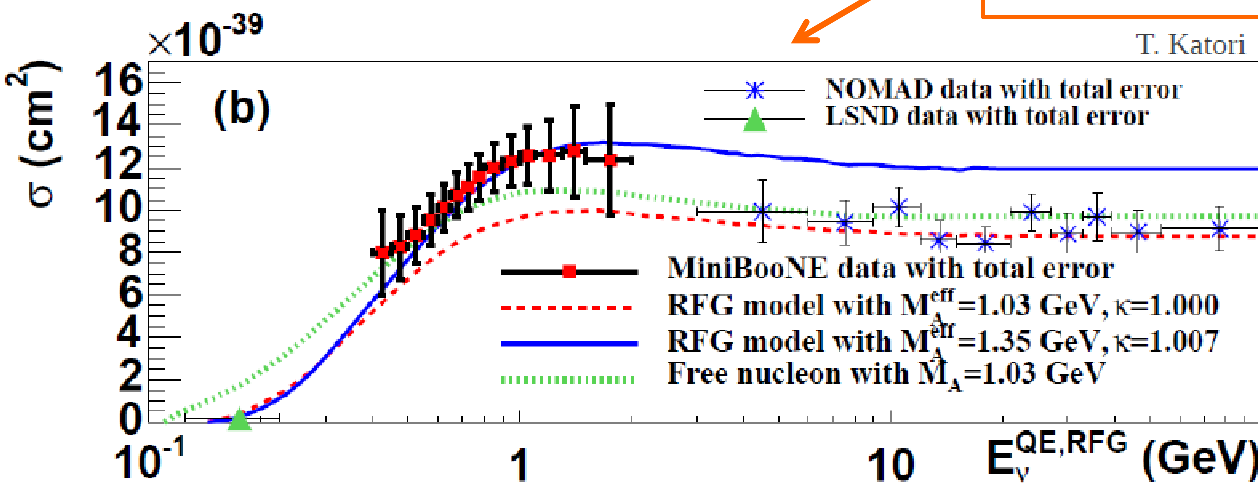
Motivation – why eA?

Assume quasielastic kinematics to determine E_ν

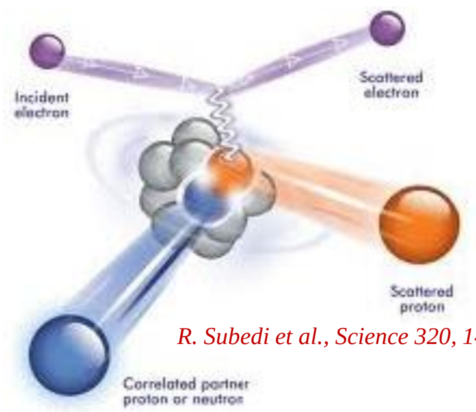
Not a free nucleon in general

Well-known "disagreement" calls into question the completeness of our model, perhaps need meson exchange currents and nucleon correlations



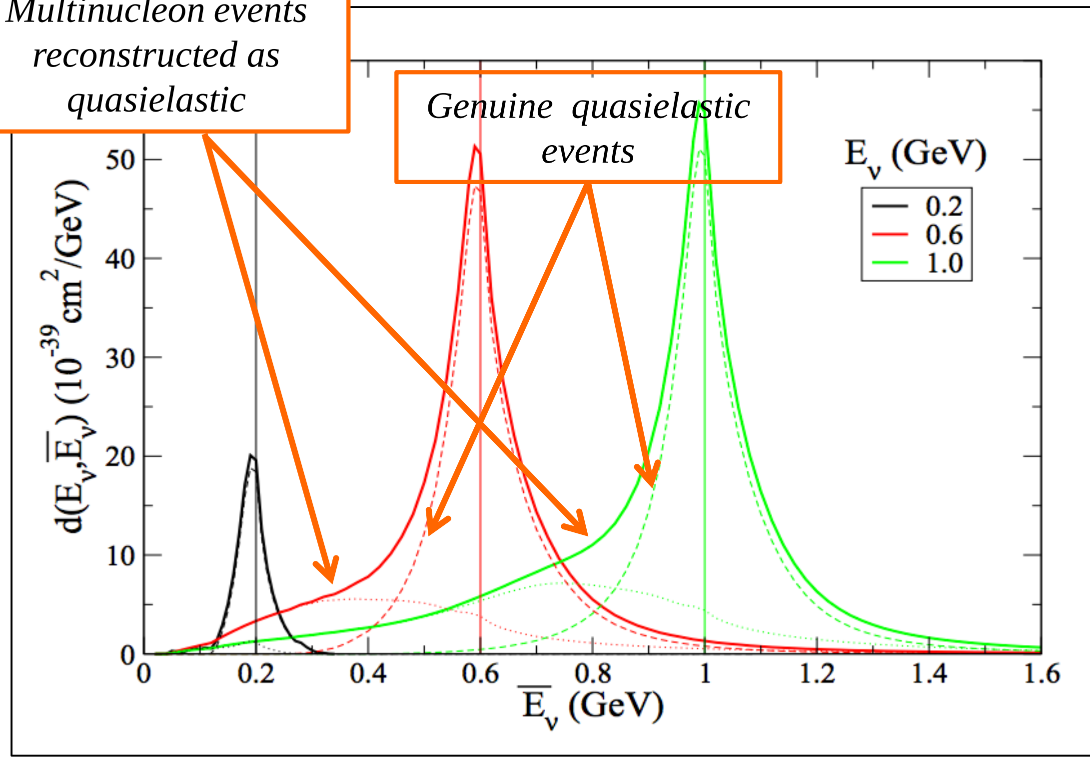


Motivation – why eA?



R. Subedi et al., Science 320, 1476 (2008)

Short-range correlations between nucleons might change the kinematics and affect ability to identify/reconstruct quasielastic events



Martini et al. arXiv:1211.1523

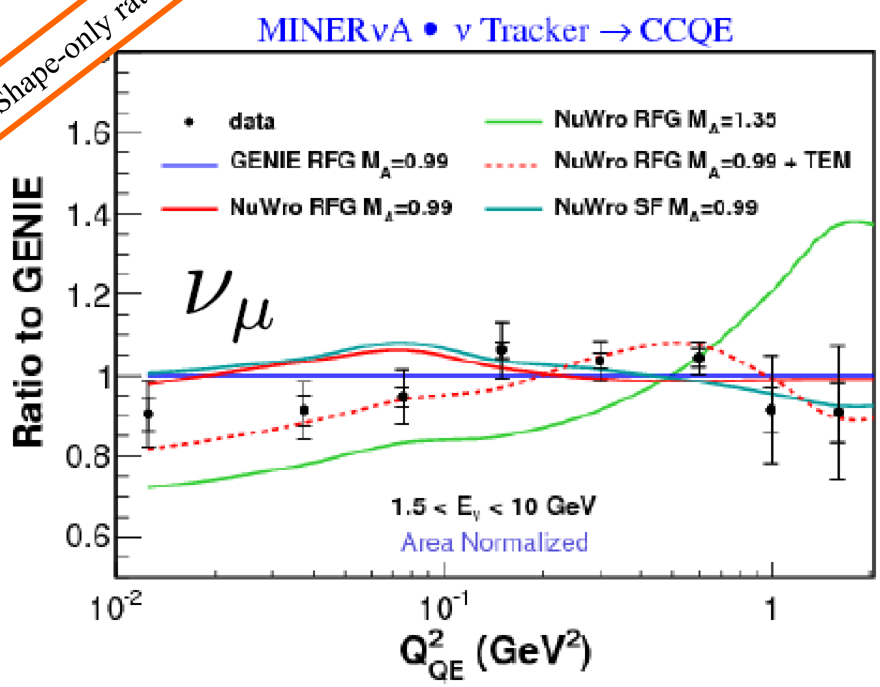
Also:
J. Sobczyk arXiv:1201.3673,
Lalakulich et al. arXiv:1208.367
Nieves et al. arXiv:1204:5404

Motivation – why eA?

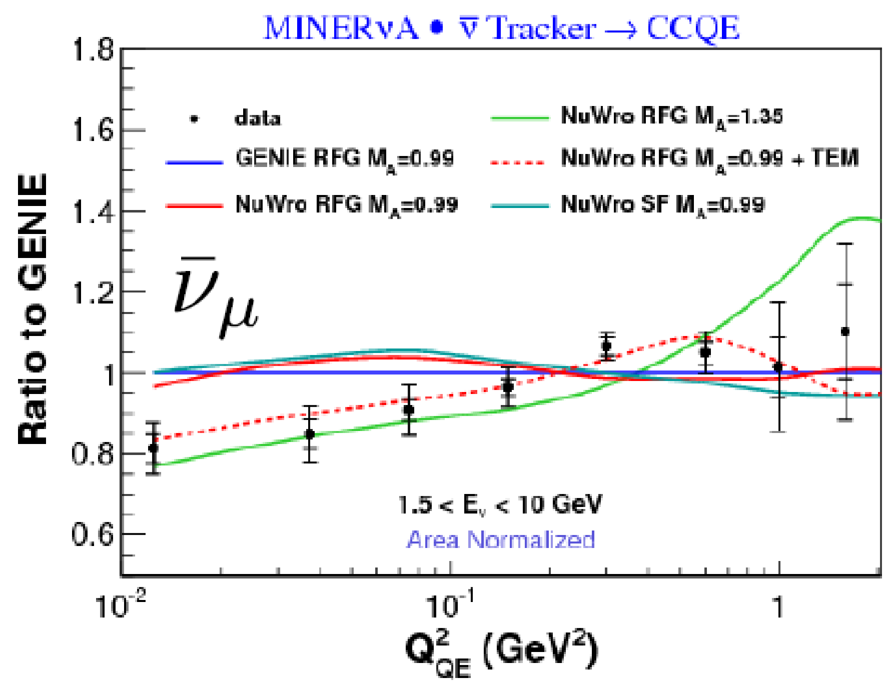
M_A = 1.35 best fit to MiniBooNE data — Phys.Rev.Lett. 100, 032301 (2008)
TEM empirical model based on electron scattering data — Eur. Phys. J. C 71, 1726 (2011)
GENIE independent nucleons in mean field — Nucl.Instrum.Meth. A 614:87-104 (2010)
SF more realistic nucleon momentum-energy relation — Nucl.Phys. A579, 493 (1994)

Shape-only ratio

G.A. Fiorentini et al., PRL 111, 022502 (2013)

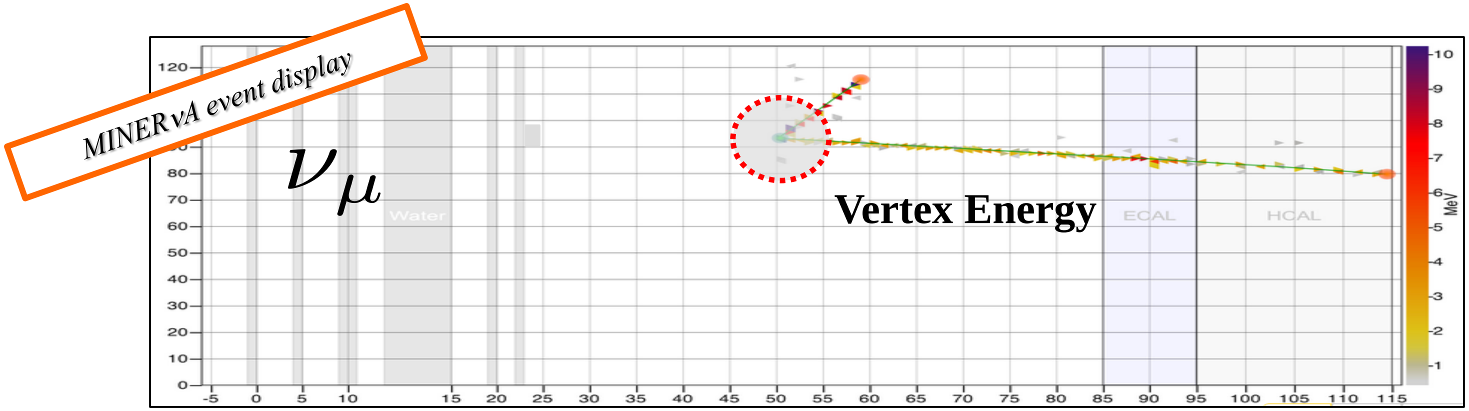


L. Fields et al., PRL 111, 022501 (2013)

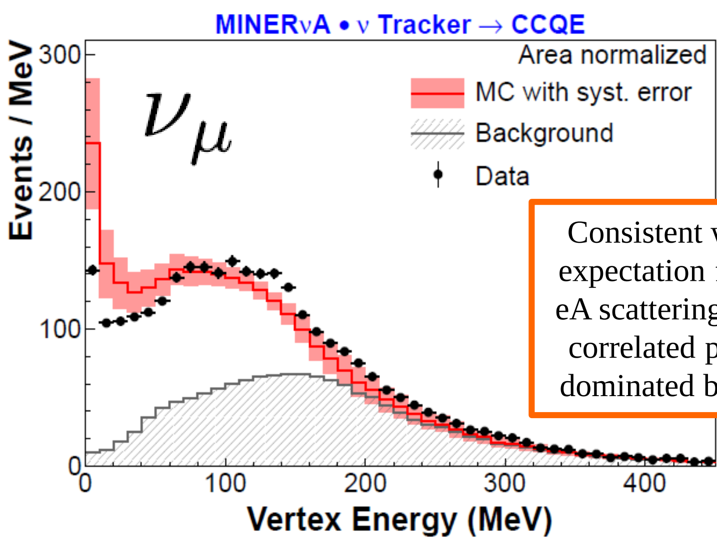


TEM: emperical, adjust magnetic form factors of bound nucleons to reproduce enhancement in the transverse cross-section in eA scattering attributed to meson exchange currents in the nucleus

Motivation – why eA?

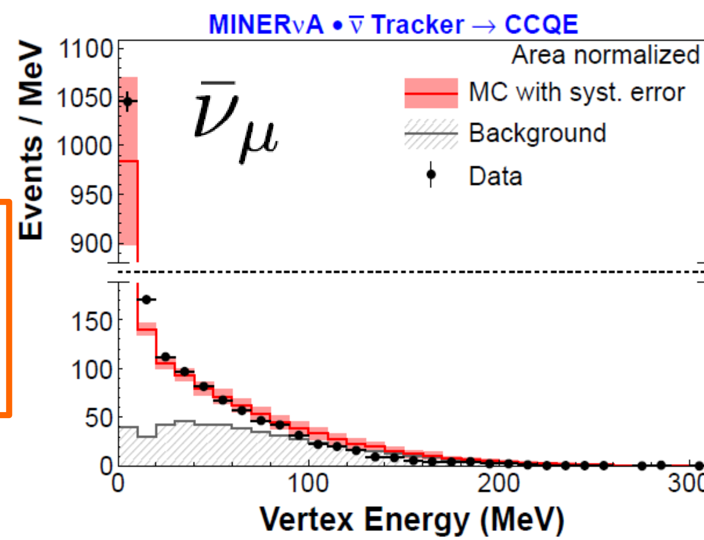


G.A. Fiorentini et al., PRL 111, 022502 (2013)

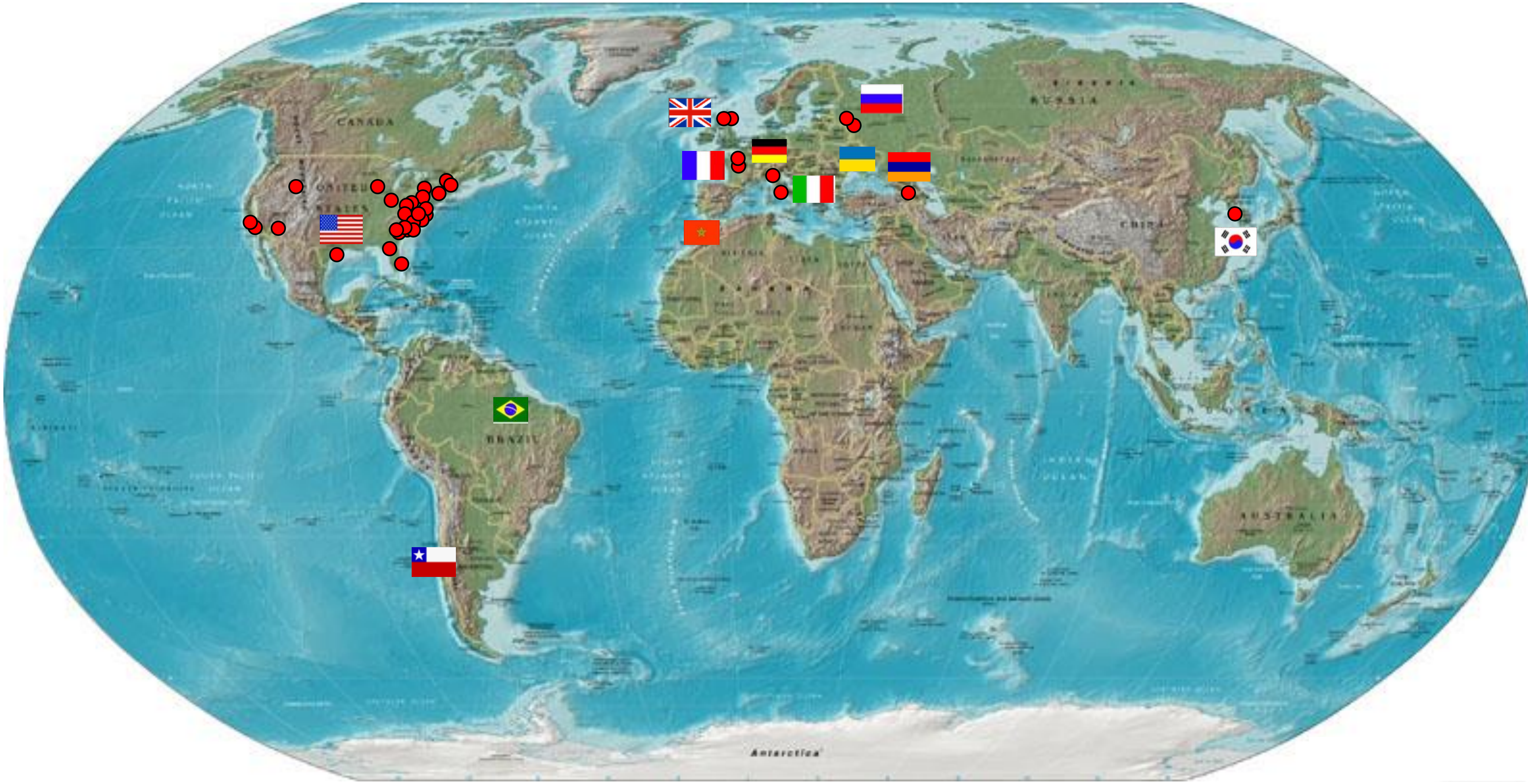


Consistent with expectation from eA scattering that correlated pairs dominated by np

L. Fields et al., PRL 111, 022501 (2013)



The CLAS Collaboration

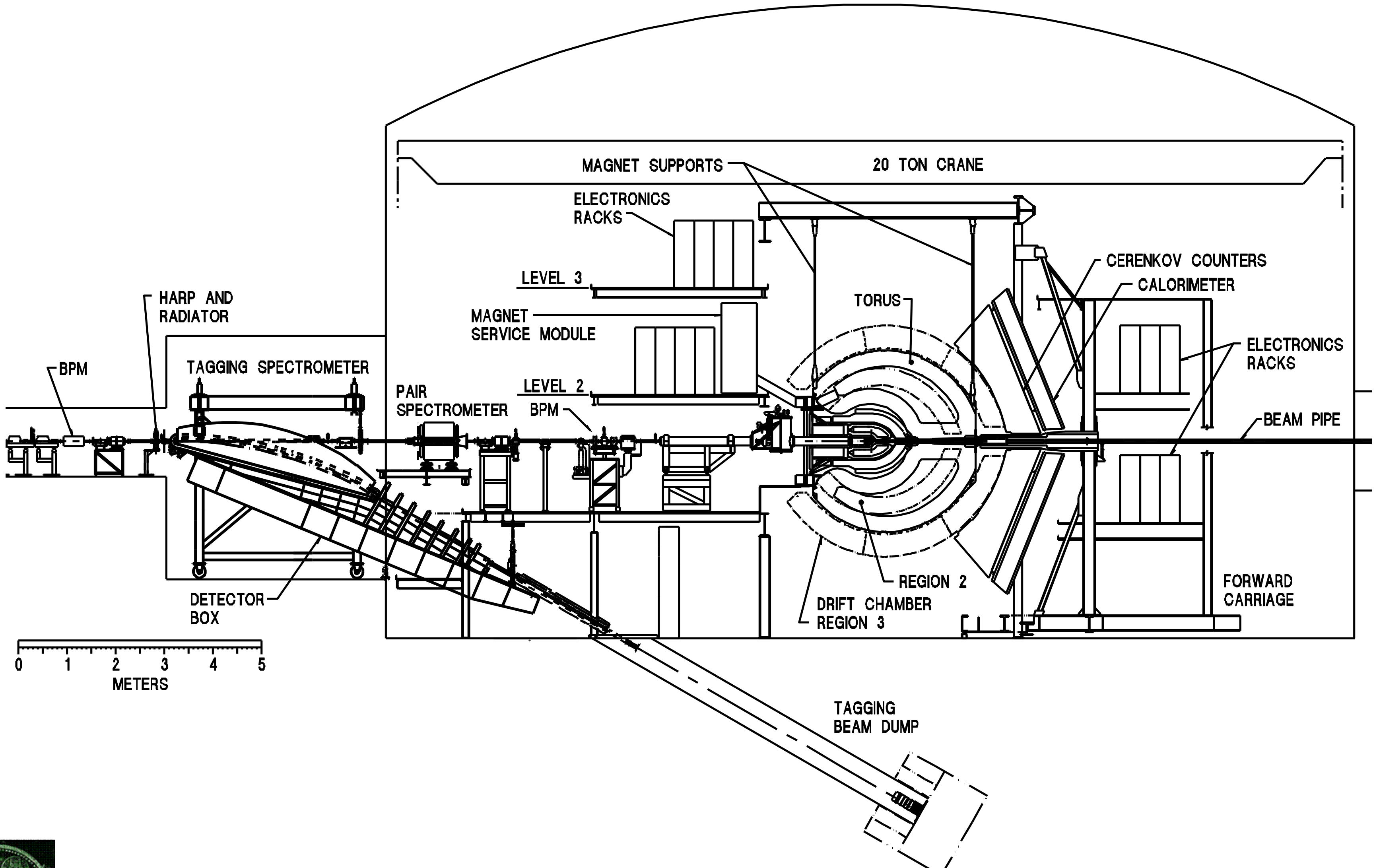


Arizona State University, Tempe, AZ
University of California, Los Angeles, CA
California State University, Dominguez Hills, CA
Carnegie Mellon University, Pittsburgh, PA
Catholic University of America
CEA-Saclay, Gif-sur-Yvette, France
Christopher Newport University, Newport News, VA
University of Connecticut, 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

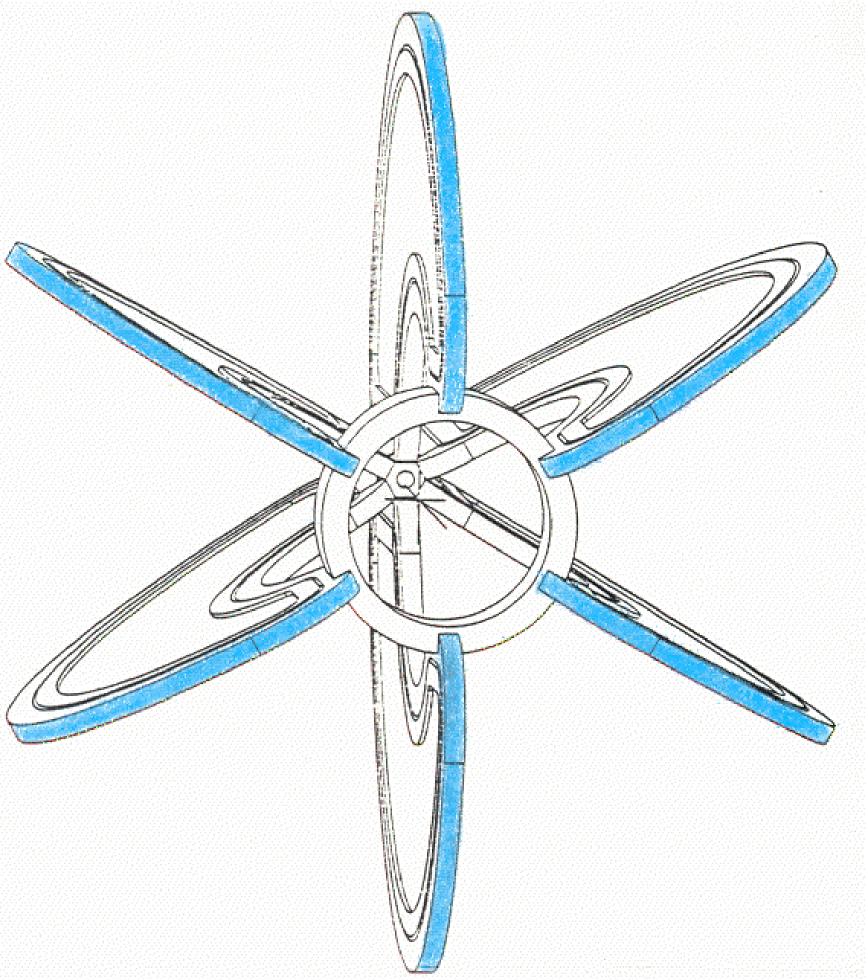
Rensselaer Polytechnic Institute, Troy, NY
Rice University, Houston, TX
University of Richmond, Richmond, VA
University of South Carolina, Columbia, SC
Thomas Jefferson National Accelerator Facility, Newport News, VA
Union College, Schenectady, NY
Virginia Polytechnic Institute, Blacksburg, VA
University 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.

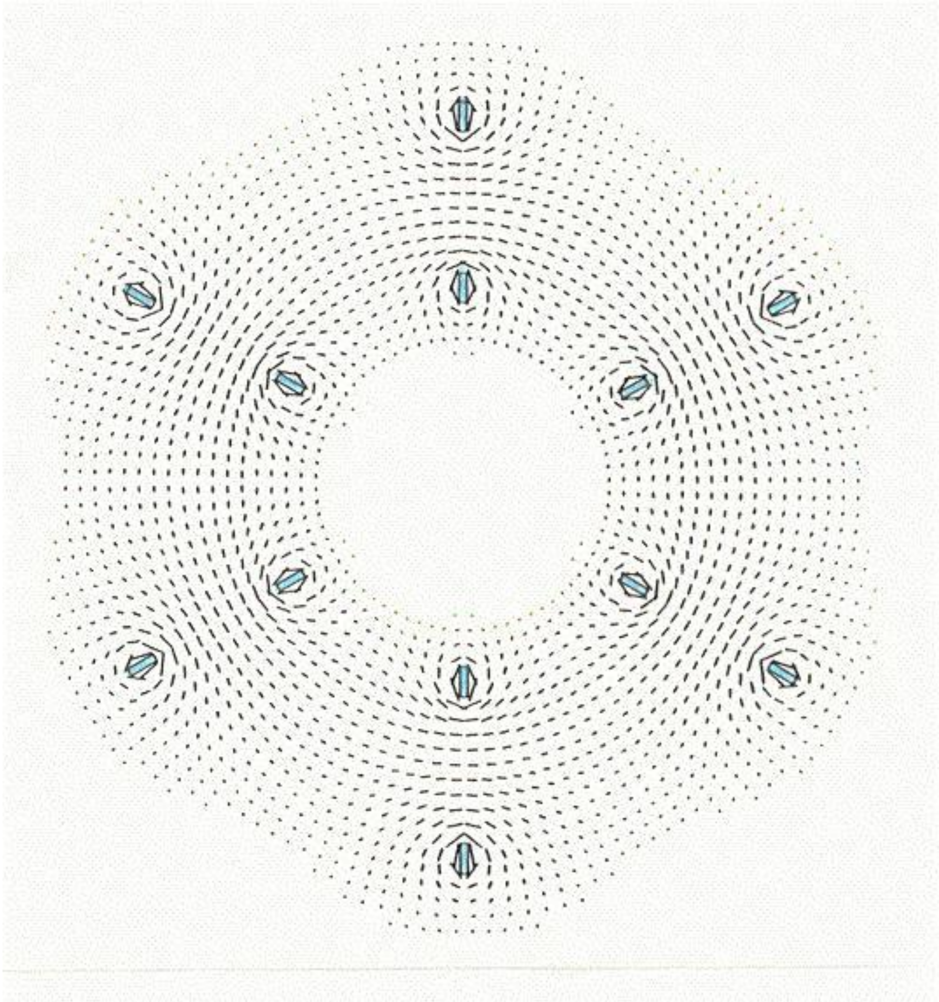
Hall B Side View

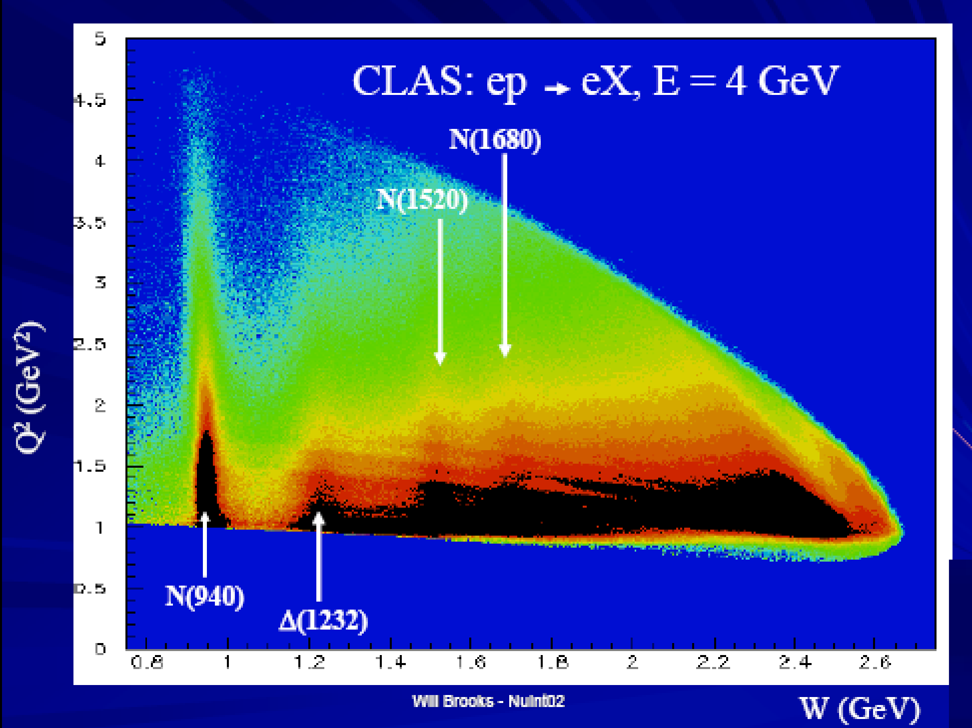


Super-conducting toroidal magnet with six kidney-shaped coils

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

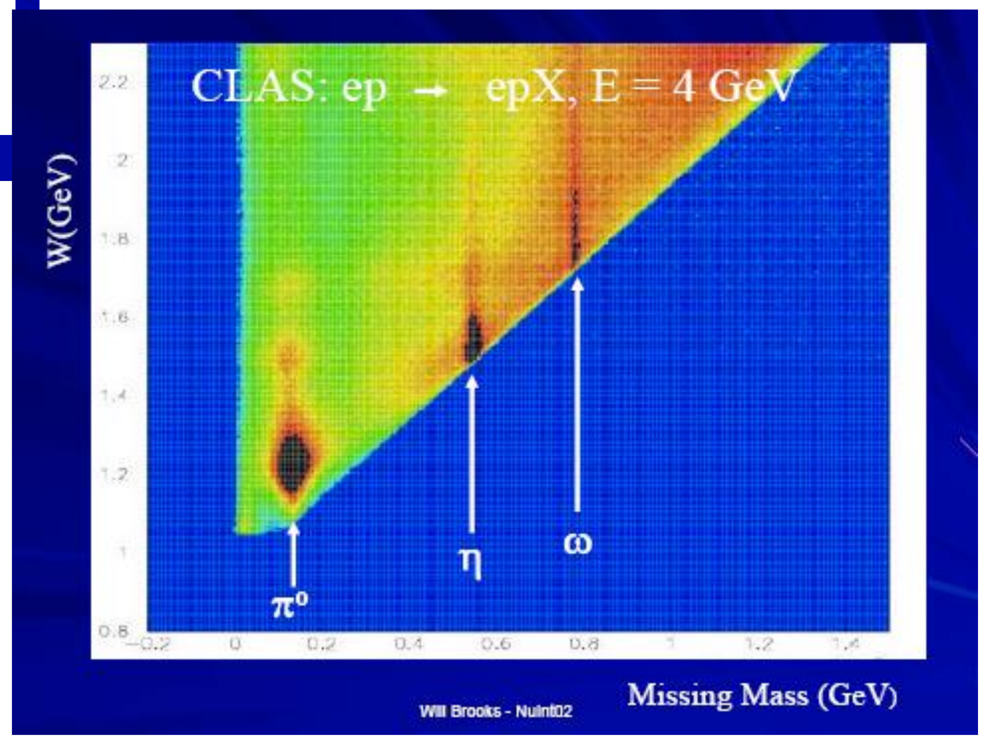






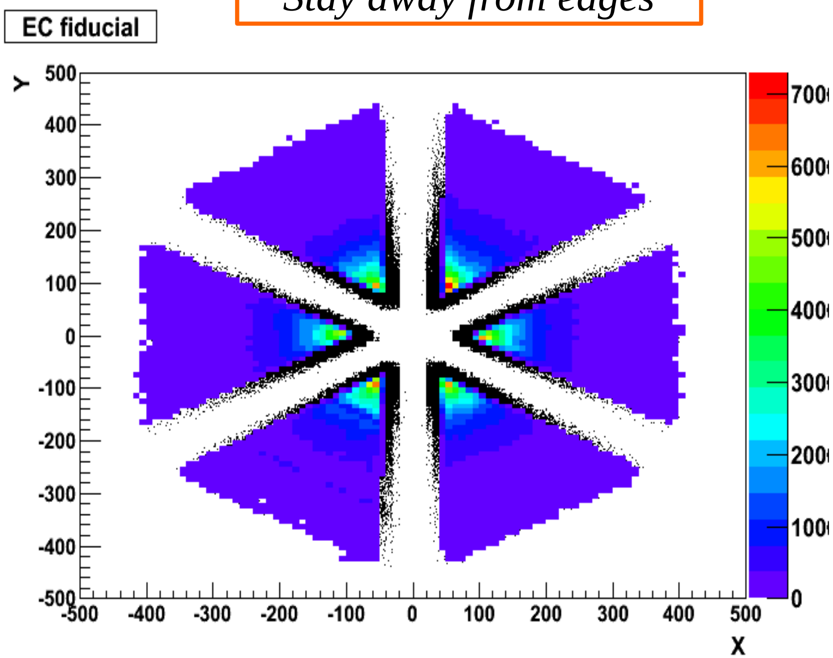
From Will Brooks at NUINT02

H target with E_{beam} = 4 GeV illustrates the power of CLAS

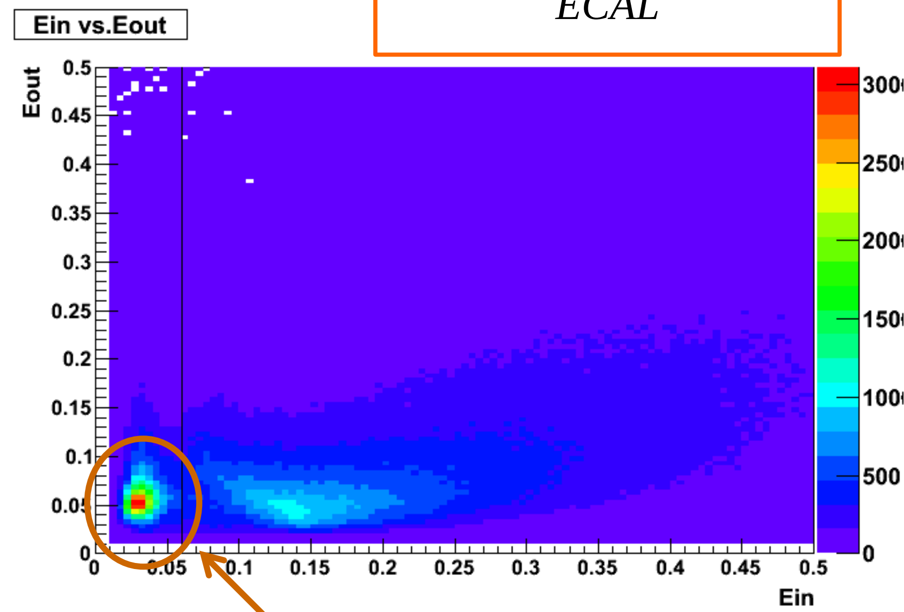


Analysis cuts

Stay away from edges



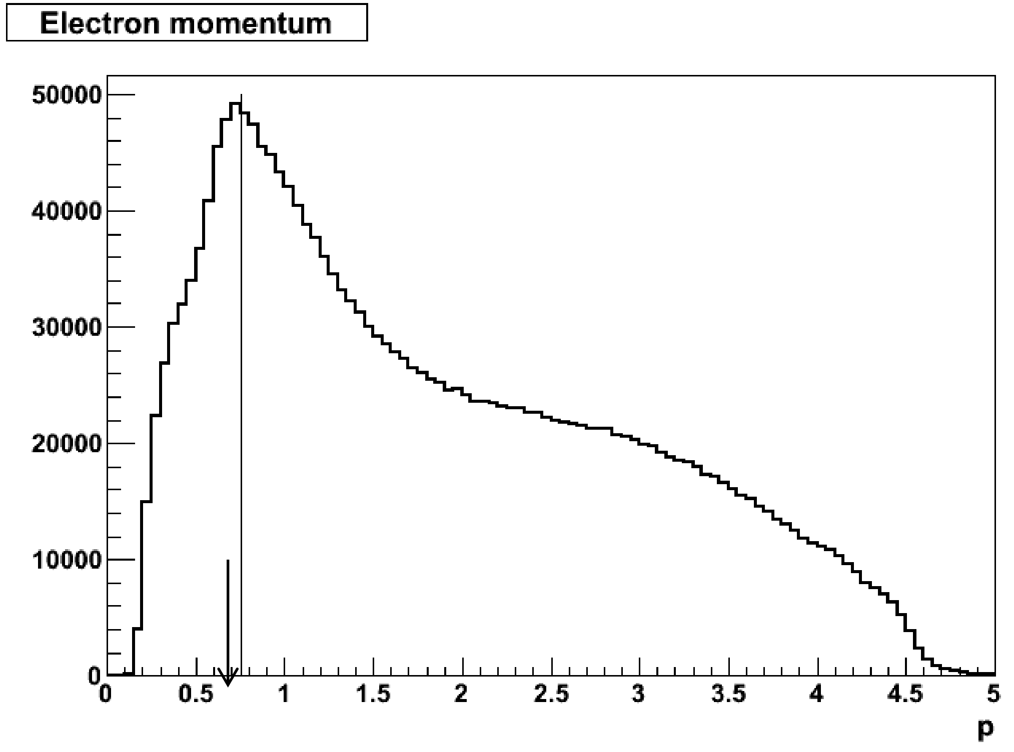
Remove events with even energy depostion in the two layers of the ECAL



Mostly pions and muons

Calorimetric fiducial and ID cuts on outgoing e^-

Analysis cuts



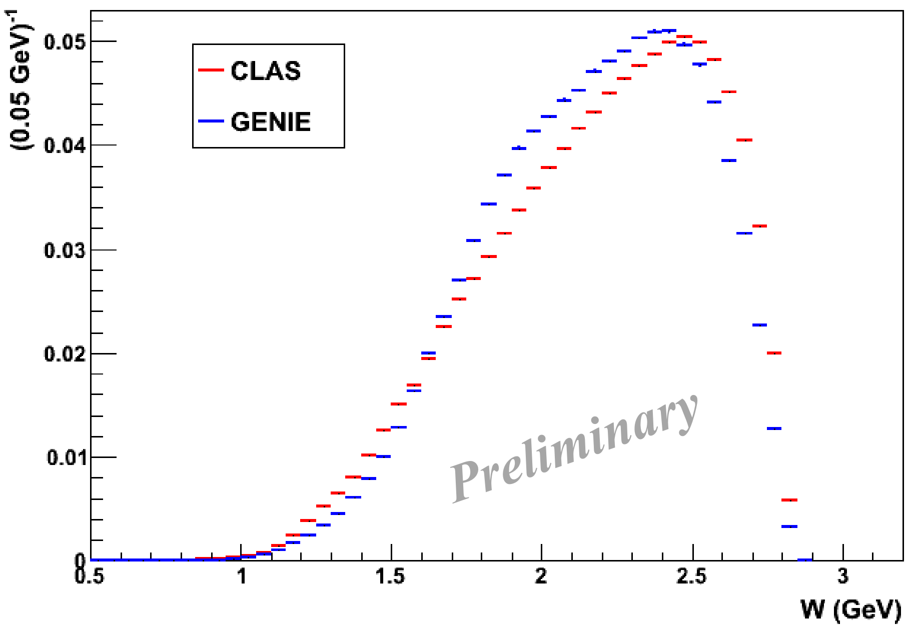
- Momentum of outgoing e-: p>0.64 GeV (or y<0.872)
- Removes bias due to electromagnetic energy threshold in trigger.
- Also reduces sensitivity to radiative effects.

Data-MC comparison

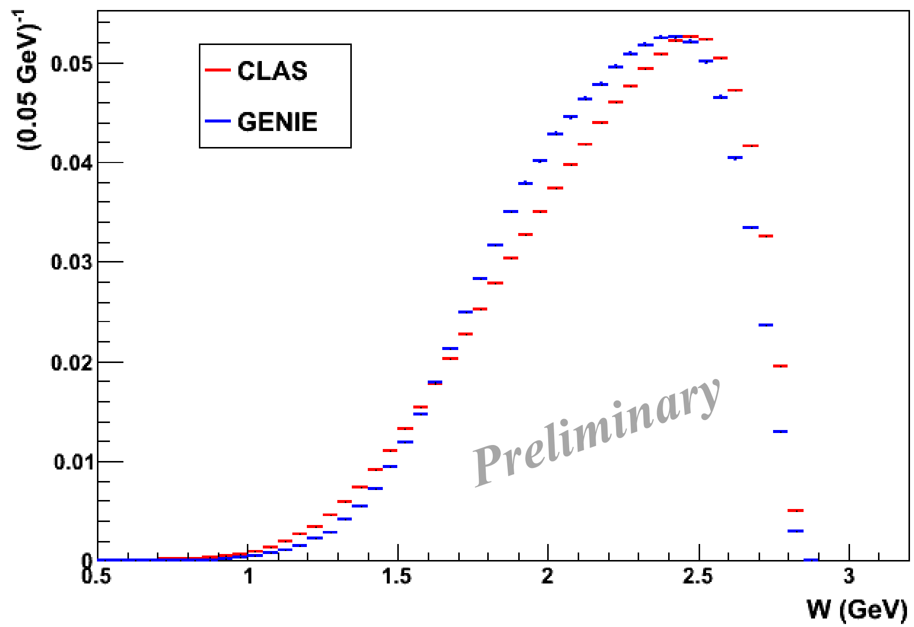
(no acceptance corrections, detector optimized fiducial definition)

- 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

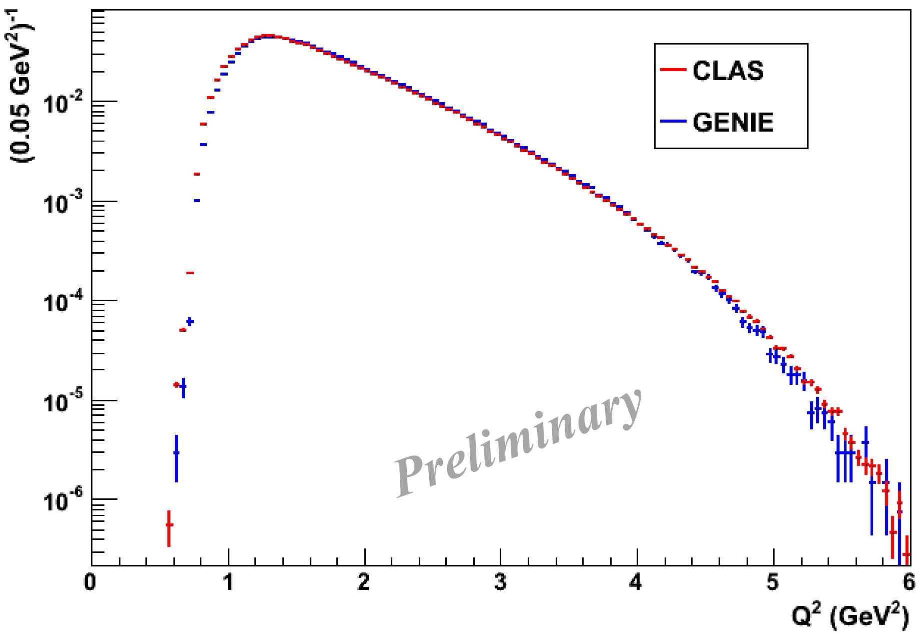


W distribution (other variables integrated over)

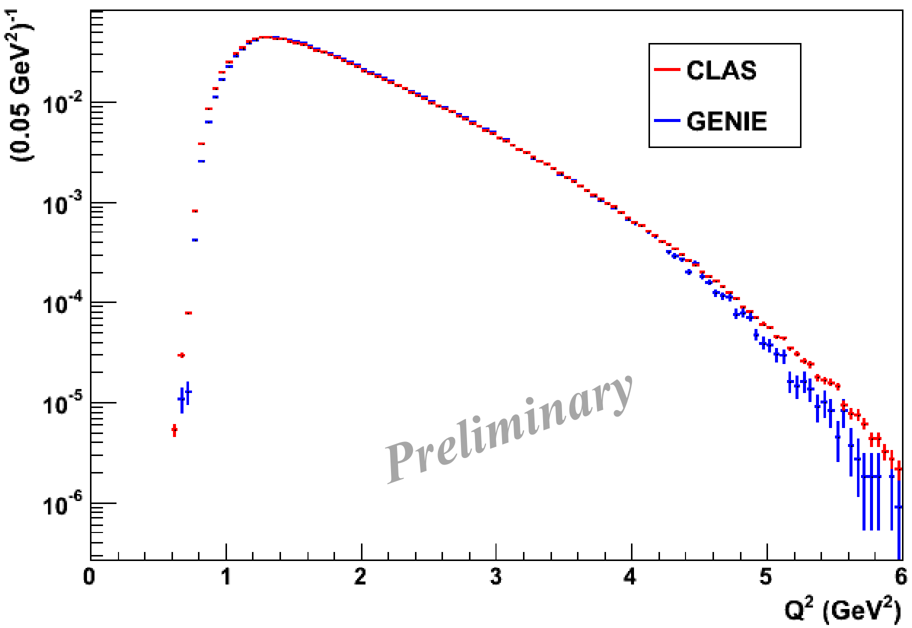
Data-MC comparison

(no acceptance corrections, detector optimized fiducial definition)

Deuterium



Carbon

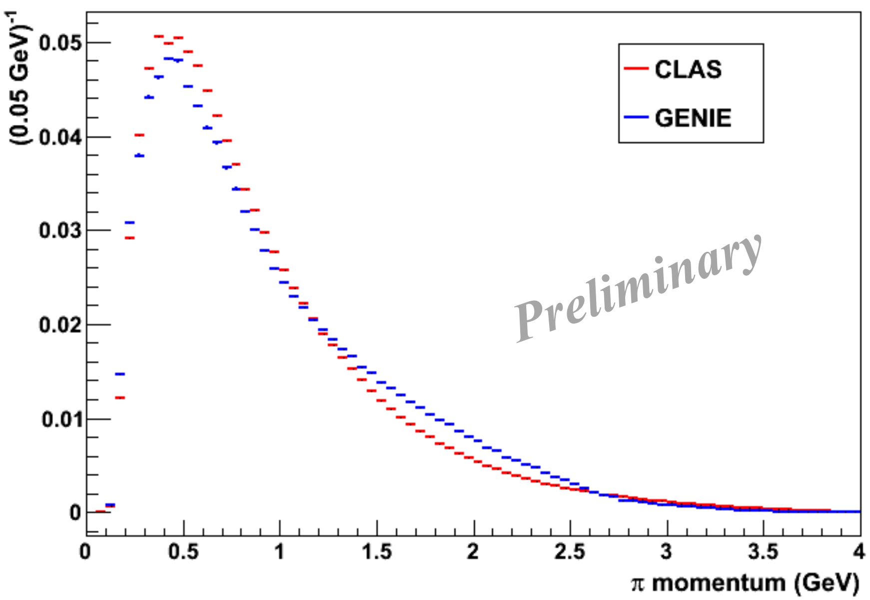


Q^2 distribution (other variables integrated over)

Data-MC comparison

(no acceptance corrections, detector optimized fiducial definition)

Deuterium



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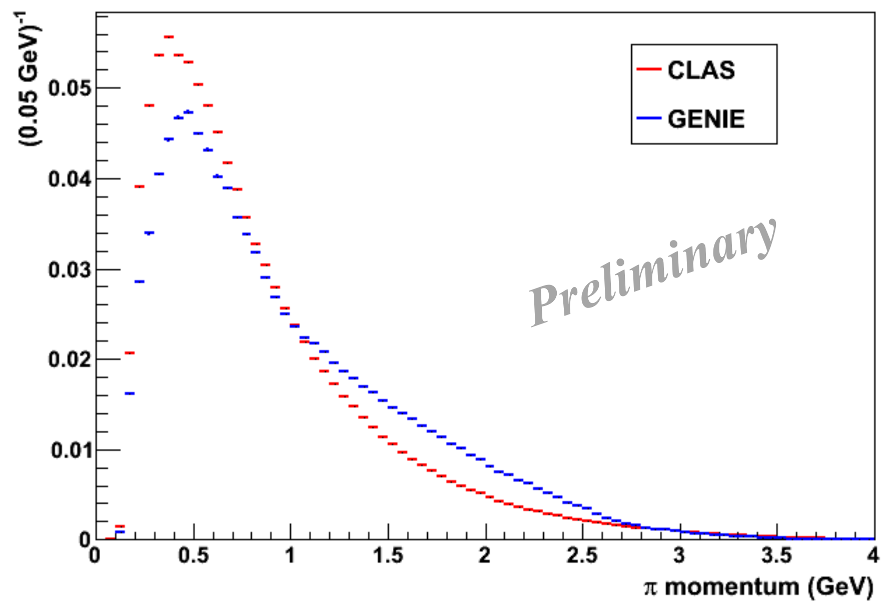
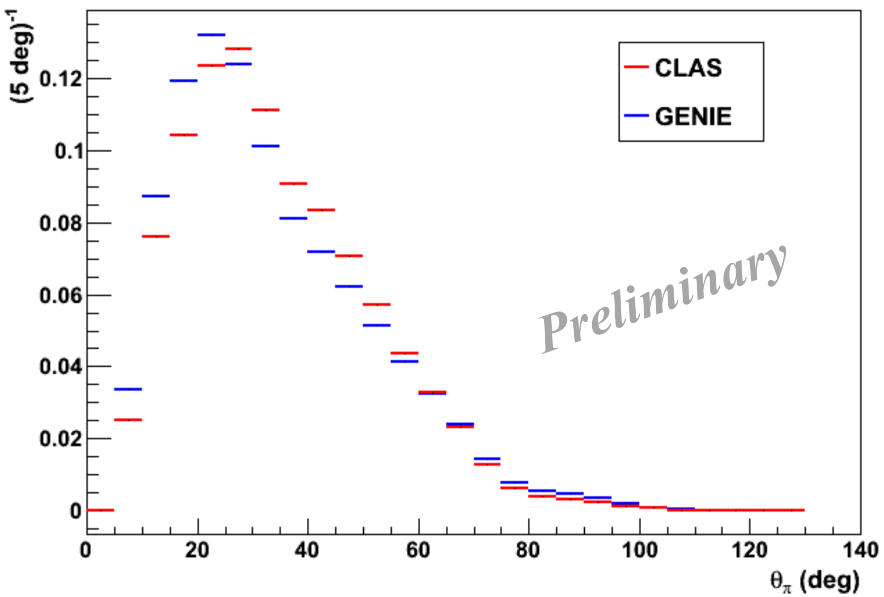


Momentum of π in the lab frame
(other variables integrated over)

Data-MC comparison

(no acceptance corrections, detector optimized fiducial definition)

Deuterium



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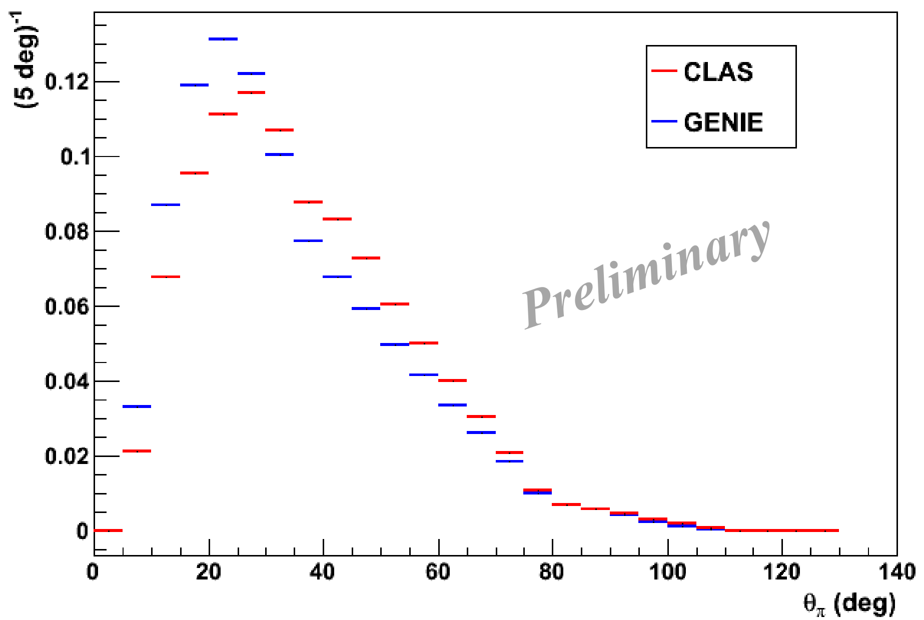

Angle of π with respect to the beam direction

(other variables integrated over)