The JLab Coulomb Sum Rule Experiment

Precision Measurement of R_L and R_T of Quasi-Elastic Electron Scattering

Jian-ping Chen, Jefferson Lab
On behalf of JLab E05-110 and Hall A Collaborations

Elba2010 Workshop
June 21, 2010
Elba, Italy

People: JLab E05-110 Collaboration

- Kalyan Allada, Korand Aniol, John Arrington, Todd Averett, Herat Bandara, Werner Boeglin, **Alexandre Camsonne,** Mustafa Canan, **Jian-Ping Chen**, Wei Chen, Khem Chirapatpimol, **Seonho Choi**, Eugene Chudakov, Evaristo Cisbani, Francesco Cusanno, Raffaele De Leo, Chiranjib Dutta, Cesar Fernandez-Ramirez, Salvatore Frullani, Haiyan Gao, Franco Garibaldi, Ronald Gilman, Oleksandr Glamazdin, Brian Hahn, Ole Hansen, Douglas Higinbotham, Tim Holmstrom, Bitao Hu, Jin Huang, Florian Itard, Liyang Jiang, Xiaodong Jiang, Hoyoung Kang, Joe KatichMina Katramatou, Aidan Kelleher, Elena Khrosinkova, Gerfried Kumbartzki, John LeRose, Xiaomei Li, Richard Lindgren, Nilanga Liyanage, Joaquin Lopez Herraiz, Lagamba Luigi, Alexandre Lukhanin, Maria Martinez Perez, Dustin McNulty, **Zein-Eddine Meziani,** Robert Michaels, Miha Mihovilovic, Joseph Morgenstern, Blaine Norum, **Yoomin Oh**, Michael Olson, Makis Petratos, Milan Potokar, Xin Qian, Yi Qiang, Arun Saha, Brad Sawatzky, Elaine Schulte, Mitra Shabestari, Simon Sirca, Patricia Solvignon, Jeongseog Song, Nikolaos Sparveris, Ramesh Subedi, Vincent Sulkosky, Jose Udias, Javier Vignote, Eric Voutier, Youcai Wang, John Watson, Yunxiu Ye, **Xinhu Yan, Huan Yao**, Zhihong Ye, Xiaohui Zhan, Yi Zhang, Xiaochao Zheng, Lingyan Zhu
- **PhD Students: Yoomin Oh, Xinhu Yan and Huan Yao; postdocs: Alexandre Camsonne**
- **Spokespersons: Jian-ping Chen, Seonho Choi and Zein-Eddine Meziani**
- Hall-A Collaboration

Outline

- Motivation
- Previous Results
- New Experiment at JLab
- Analysis progress and preliminary results
- Summary

Electron Scattering on Nucleons

- Excellent tool to study properties of nucleons, nuclei etc.
  - Charge distribution of various nucleus
  - Elastic form factors of nucleons
- Goal: Study of the nucleon properties inside the nucleus
- How? - Comparison of
  - Elastic scattering on a free nucleon and
  - Quasi-elastic scattering from a bound nucleon
  - Especially interested in the electric form factor of the proton

Elastic Scattering of Electrons

- Elastic cross section of *eN* scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{\rm Mott}\left[\frac{Q^4}{q^4}(1+\tau)G_E^2 + \left(\frac{Q^2}{2q^2} + \tan^2\frac{\theta}{2}\right)(2\tau G_M^2)\right]$$

- Form Factors
  - G_E: Charge distribution
  - G_M: Magnetization distribution

Quasi-Elastic Scattering

- Almost elastic scattering on moving nucleons inside the nucleus

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{\text{Mott}} \left[\frac{Q^4}{q^4} R_L(q,\omega) + \frac{Q^2}{2q^2} \frac{1}{\varepsilon} R_T(q,\omega) \right]$$

$$\varepsilon = \left[1 + \frac{2q^2}{Q^2} \tan^2 \frac{\vartheta}{2} \right]^{-1}$$

- R_L corresponds to G_E,
  R_T corresponds to a combination of G_E and G_M

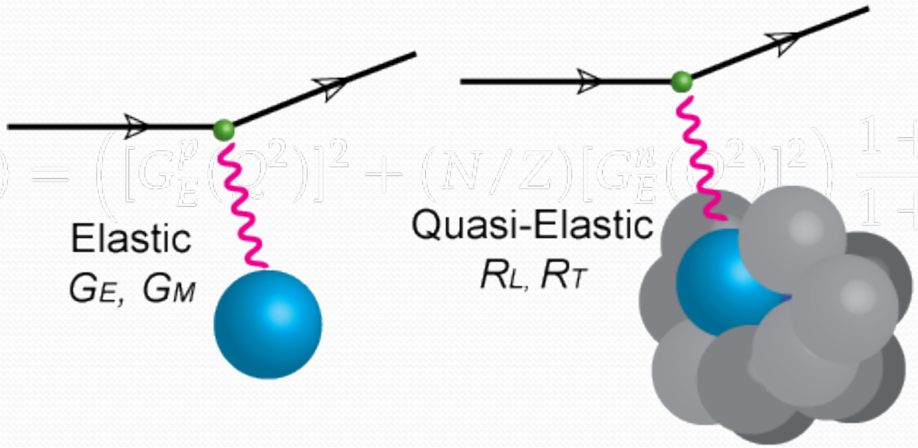
Coulomb Sum

- Integral of R_L at constant q

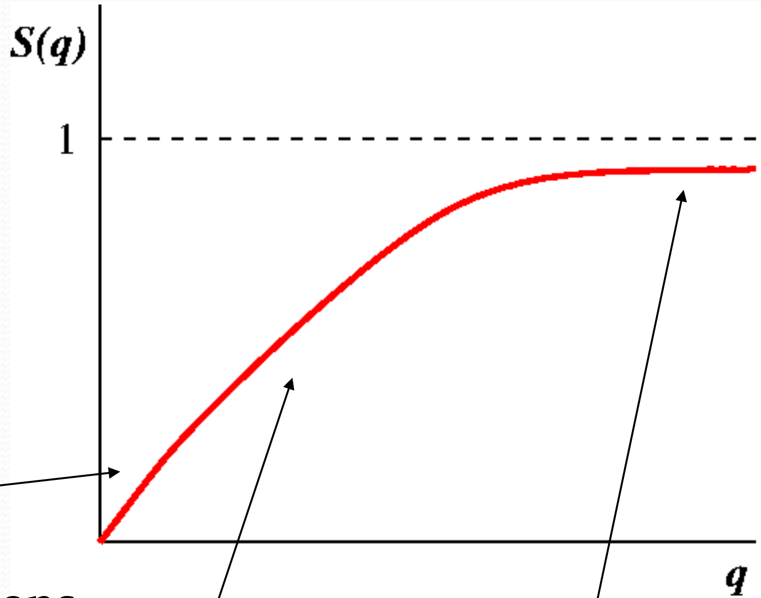
$$S_L(q) = \int_{\omega_{\mathrm{el}}^+}^{\infty} d\omega \frac{R_L(q,\omega)}{Z\tilde{G}_E^{\,2}(Q^2)}$$

$$\tilde{G}_E^{\,2}(Q^2) = \left([G_E^p(Q^2)]^2 + (N/Z)[G_E^n(Q^2)]^2\right)\frac{1+Q^2/4M^2}{1+Q^2/2M^2}$$

- Probing a nucleon inside a nucleus



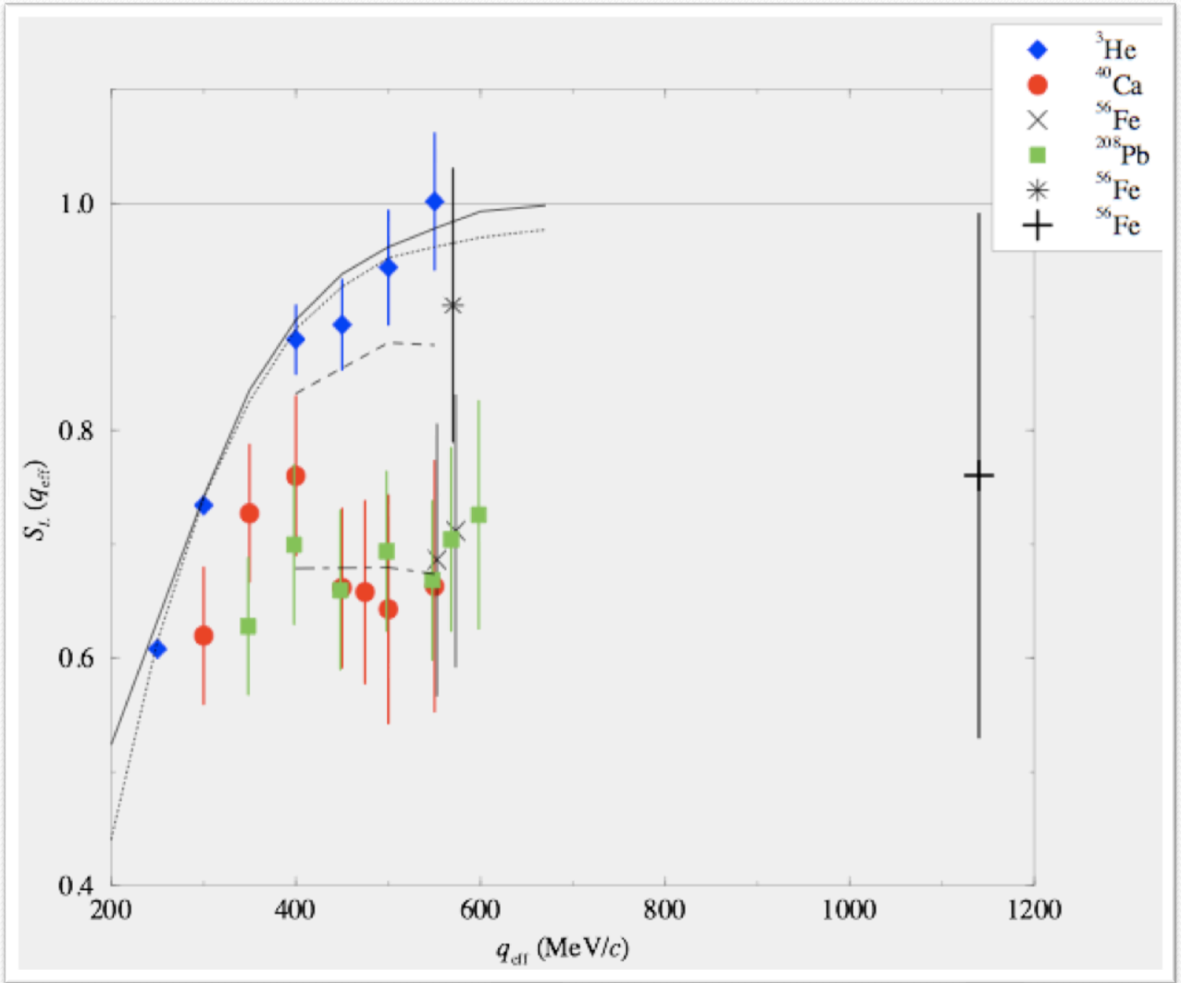
Saturation/Quenching of the Coulomb Sum



- Saturation of the Coulomb Sum
  - $S_L(q) \rightarrow 1$ at sufficiently large q
- Deviation of the Coulomb Sum
  - at small q
    - Pauli blocking
    - Nucleon-nucleon long-range correlations
  - at large q
    - Short range correlations
    - Modification of the free nucleon electromagnetic properties inside the nuclear medium
- One of the long lasting questions in physics

Previous Measurements

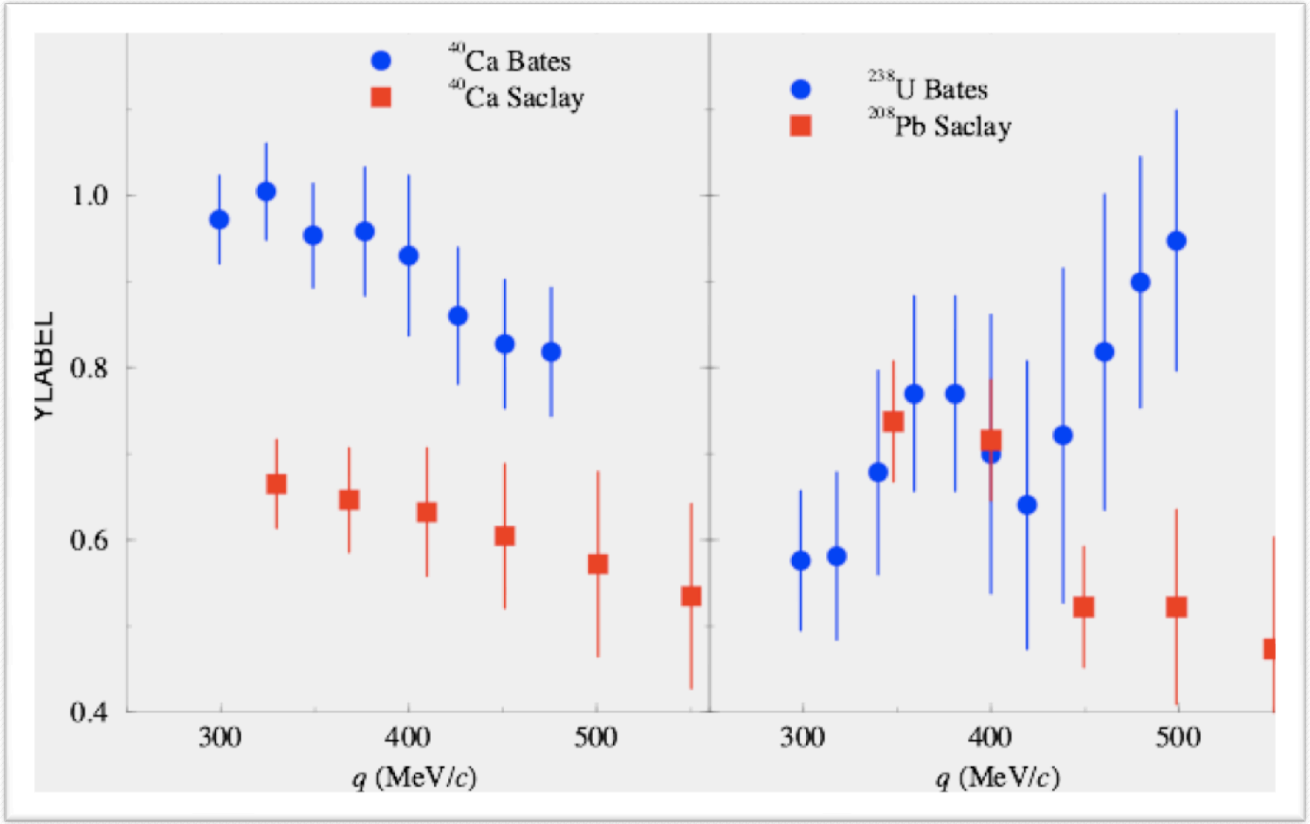
- For the past 20 years, a large experimental program at Bates, Saclay and SLAC
- Limited kinematic coverage in q and ω



The figure does NOT include all the existing data.

Controversy on CSR

- Early Bates/Saclay data show significant quenching.
- With the addition of forward angle data, Bates claims NO significant quenching.
- Saclay new analysis shows that quenching persists.



Overview

- Comprehensive measurements of the Coulomb sum at various labs for over 20 years
  - Limited range in q and ω
  - Saturation/Quenching of the Coulomb sum still controversial

- E05-110 (CSR) at JLab
  - Covers a region q =550 MeV/c - 1 GeV/c
    - Free of long range correlations/Pauli blocking
    - Effect of short range correlations, < 10%?
  - Largest lever arm for Rosenbluth separation in a single experiment
  - Better control of systematic uncertainties
  - Better control of experimental backgrounds

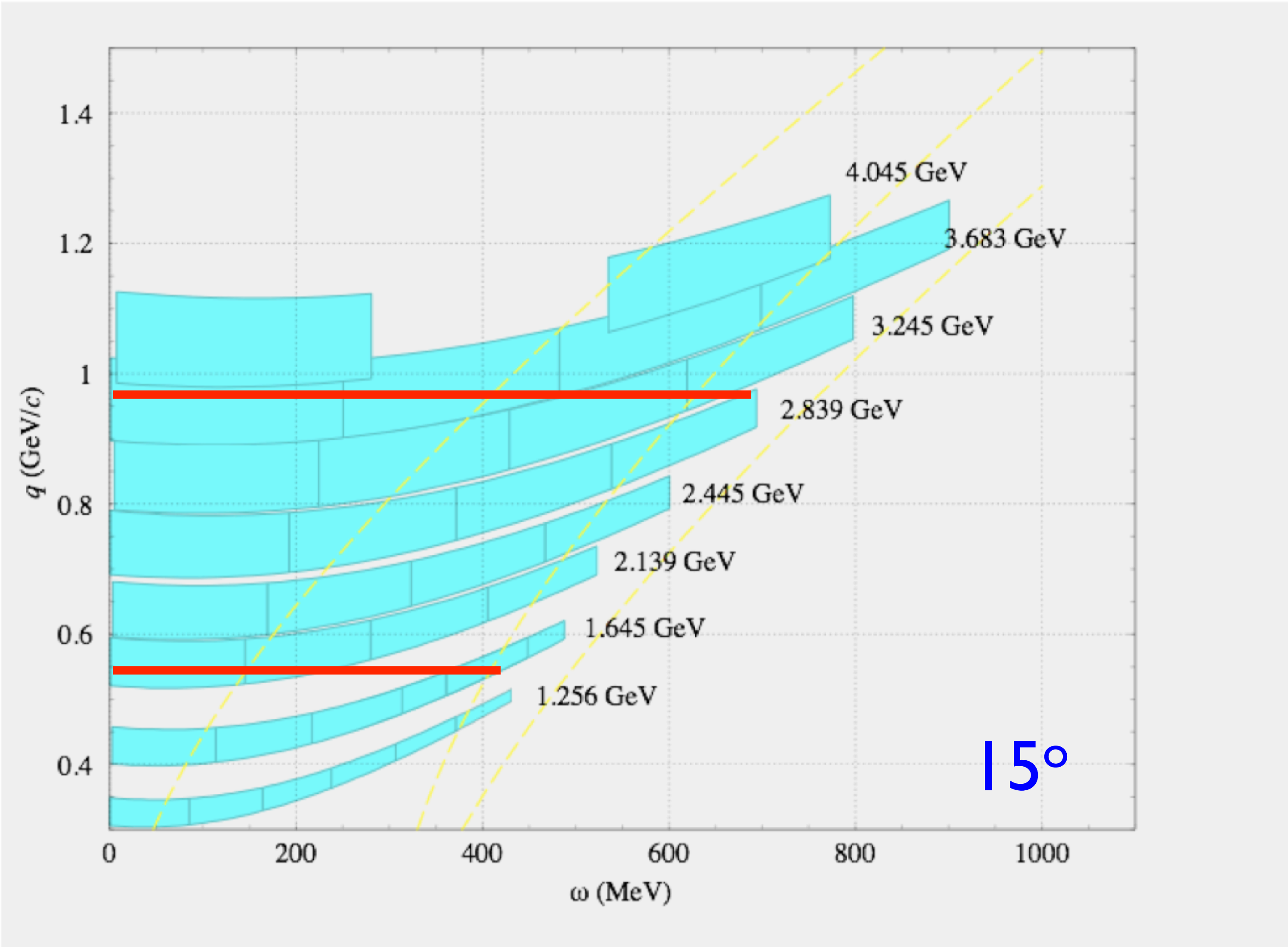
New Experiment at JLab: E05-110

- Beam: 16 energies from 0.4 to 4.0 GeV
- Scattering angles: 15^o, 60^o, 90^o, 120^o
- Targets: ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb

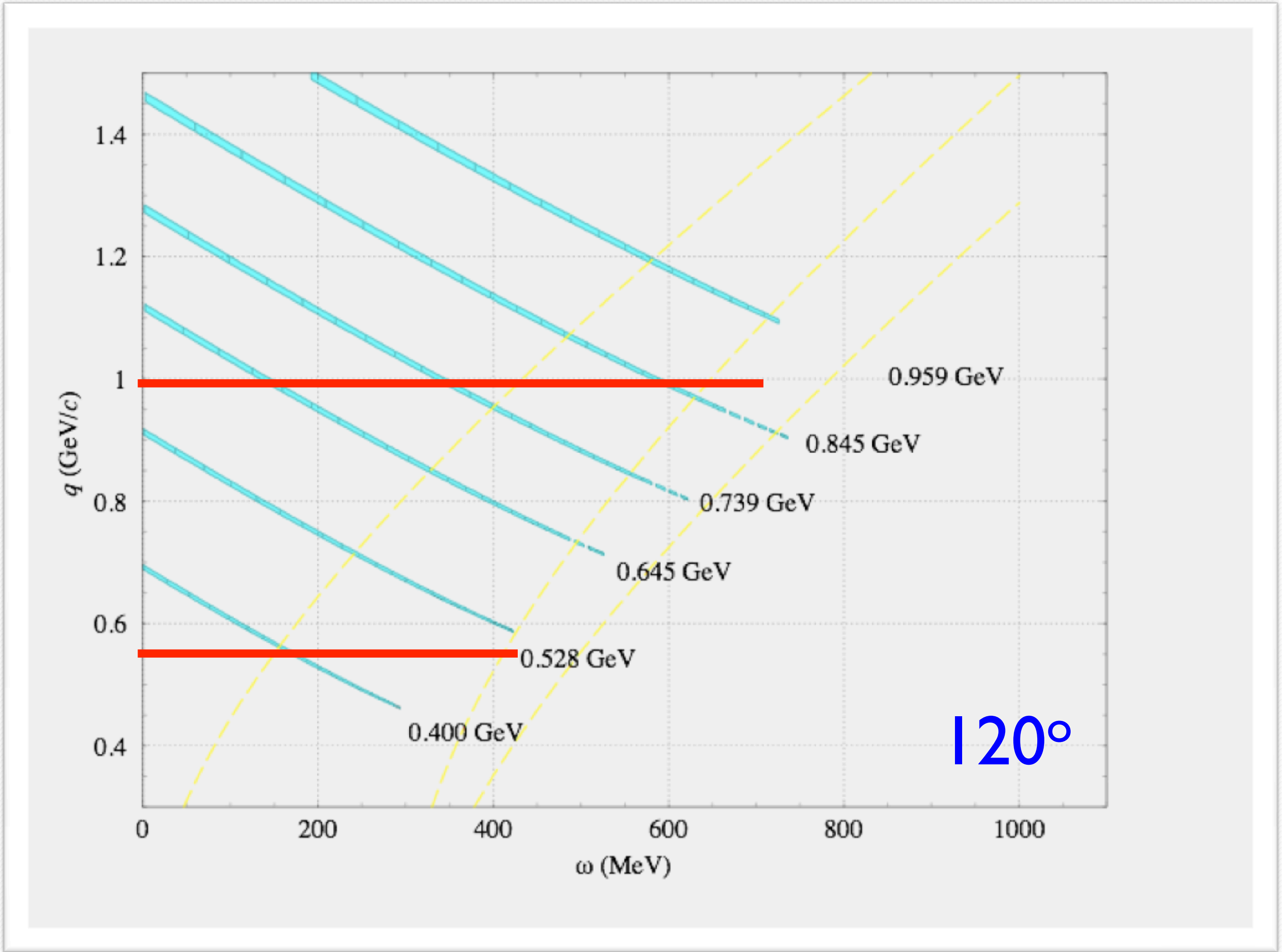
  study A or density dependent effect
- Spectrometer momentum range from 4 GeV down to 100 MeV

  covers complete range of QE peak and beyond
- Covers q from 550 to 1000 MeV/c

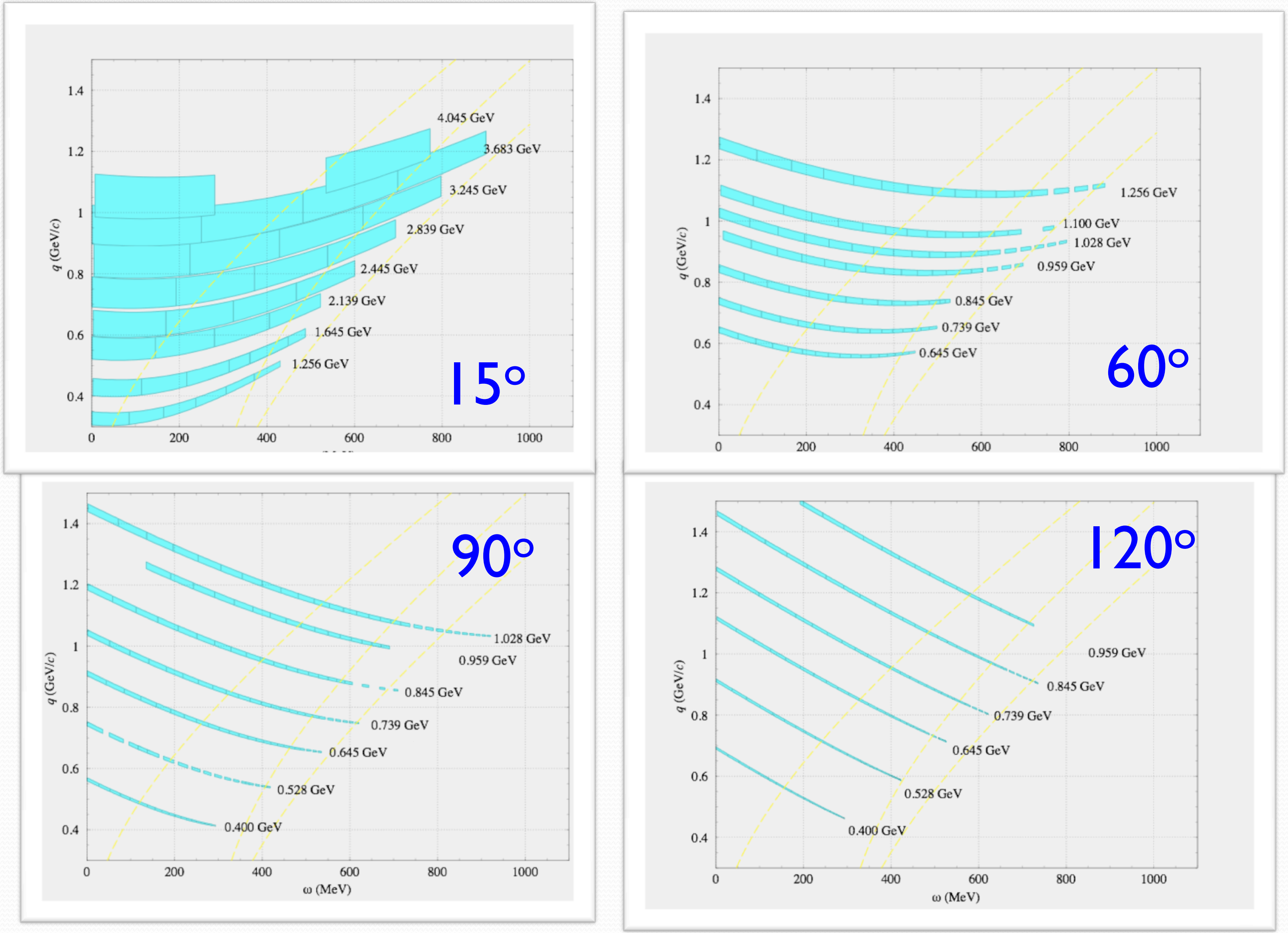
Coverage at 15°



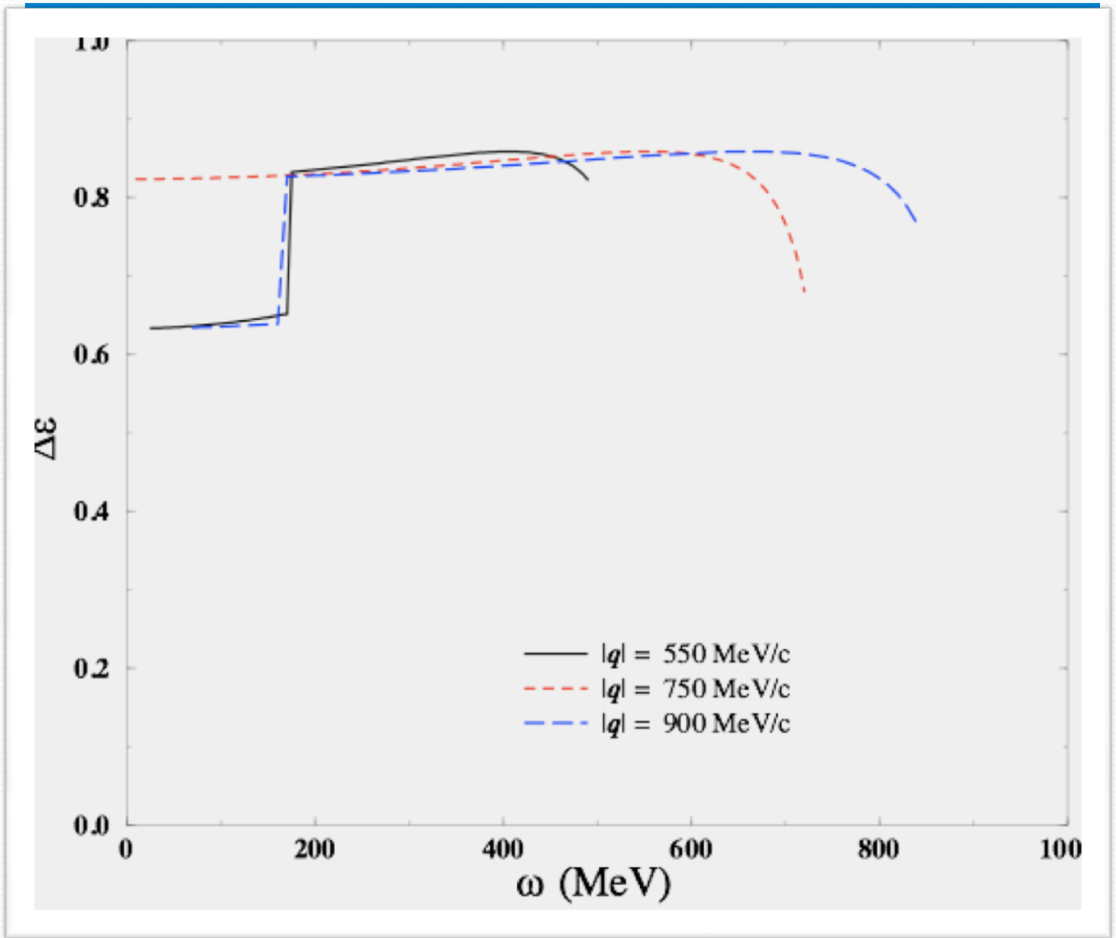
Coverage at 120º



Kinematic Coverage



Lever Arm for Rosenbluth Separation



What's New?

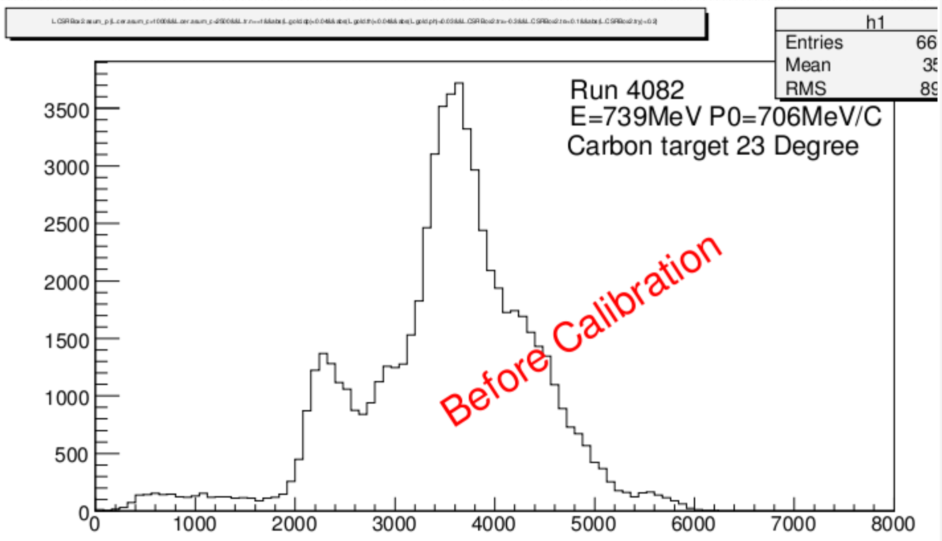
- Comfortable high values of q
  - From 550 MeV/c to 1000 MeV/c
  - High enough for clean observation of CSR
  - Previously unexplored region
- Comprehensive single experiment
  - Largest lever arm
  - Measurement at 4 angles
- Better control of background with NaI detector
- Light (^{4}He) to medium-weight (^{12}C, ^{56}Fe) to heavy (^{208}Pb) targets

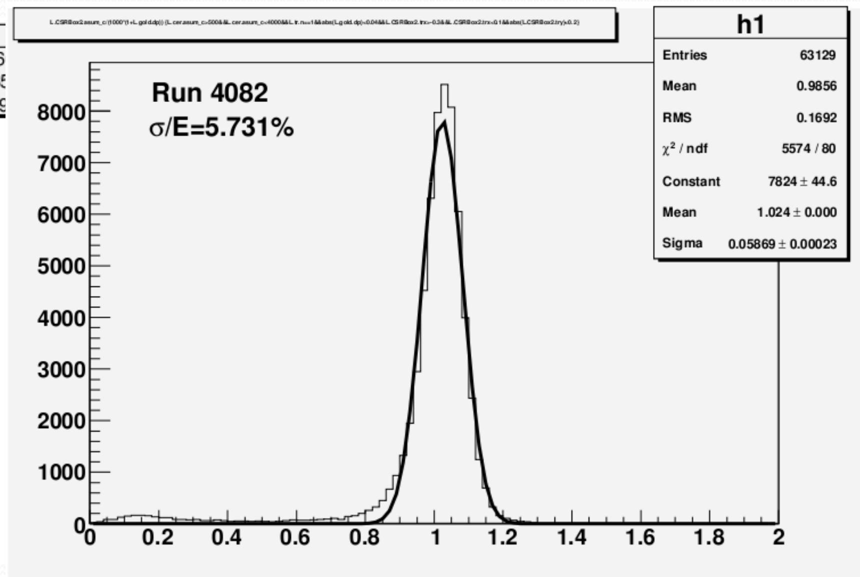
Analysis Progress

- 3 PhD students
- Completed detector calibrations
- Completed spectrometer optics optimization
- Completed spectrometer acceptance study
- Completed E/p calibration with elastic data
- Completed study of target density fluctuation vs beam current
- Completed analysis of beam current/position
- Preliminary elastic cross sections
- Data quality/stability checks
- Preliminary cross sections

NaI Detector Calibration

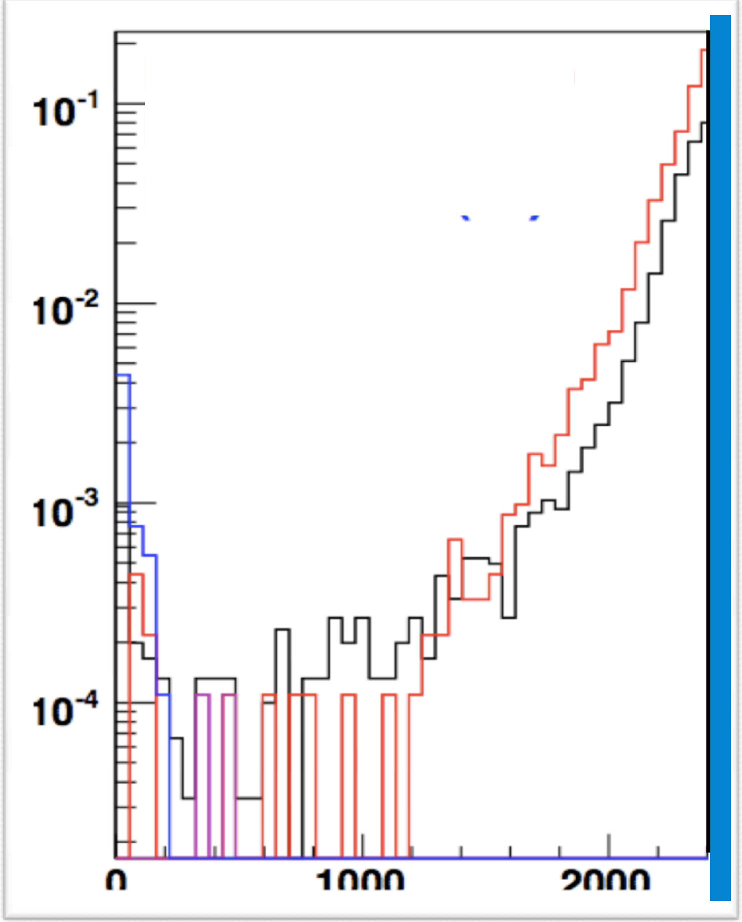
- Refurbished a ***20 years-old*** NaI detector from BNL to reduce low-energy electron background from pole-tip scattering
- Calibration completed
- Resolution a factor of 4 better than lead-glass in HRS_L



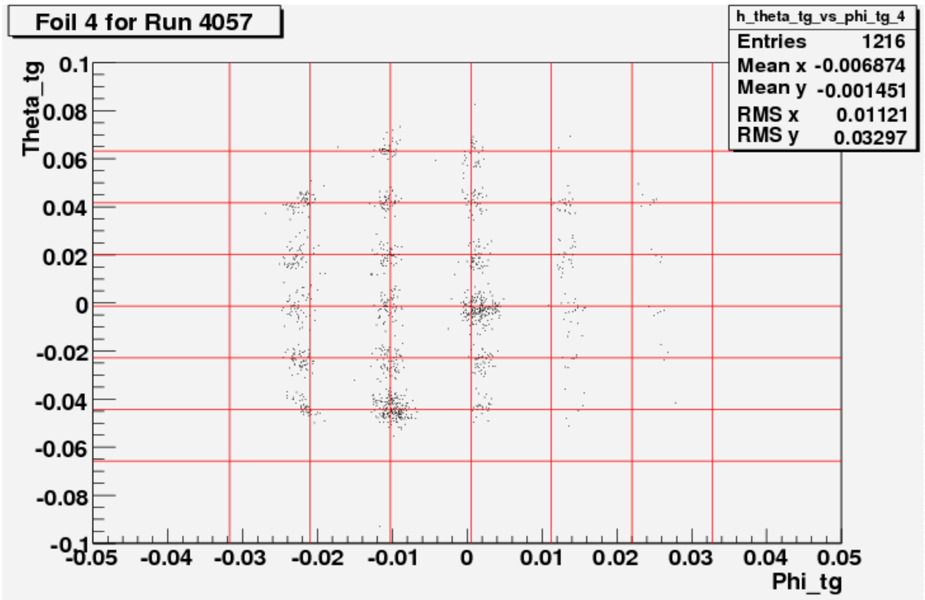


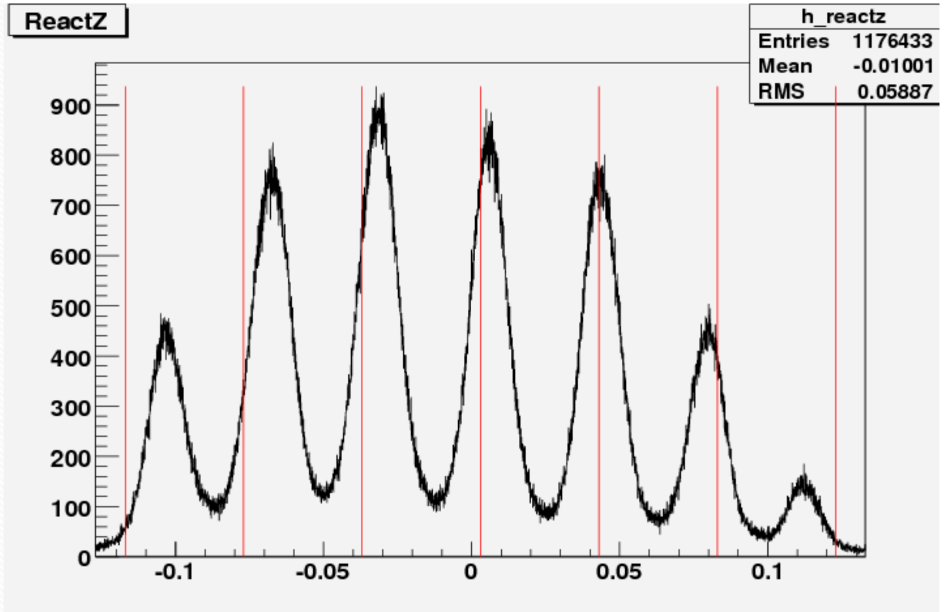
Detector Performance

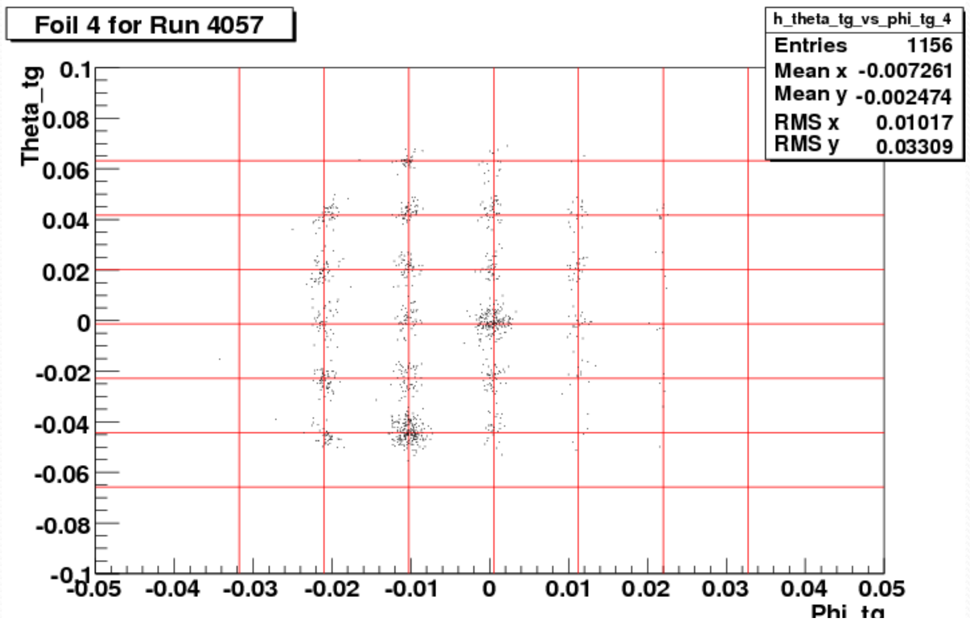
- NaI Detector
  - Independent measurement of the electron energy
  - Control of low energy scattered electrons
- Simulation
  - Electrons reflected inside the spectrometer
  - Comparison of low energy tail

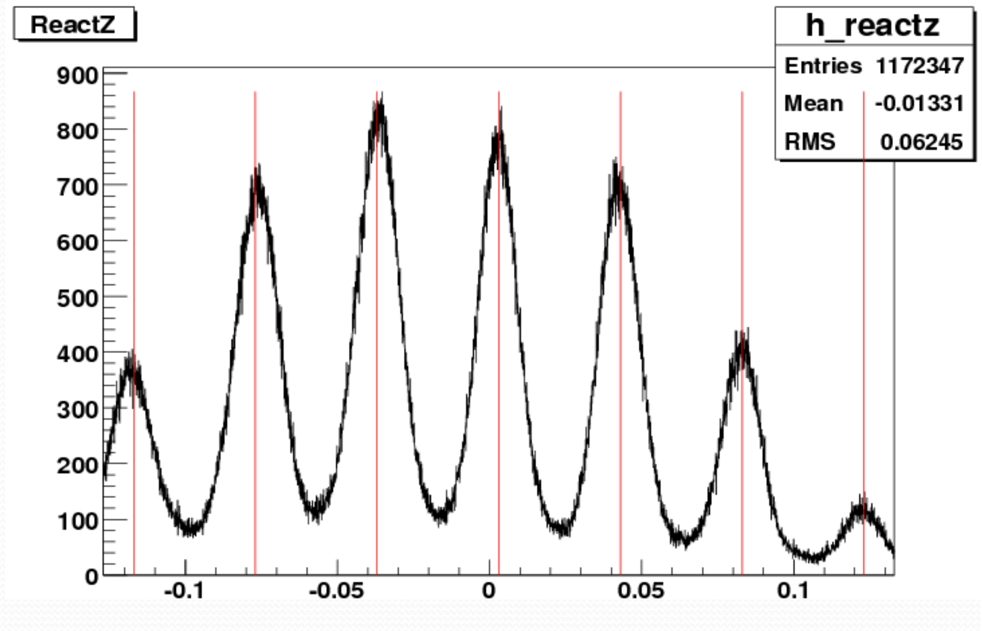


Analysis Progress

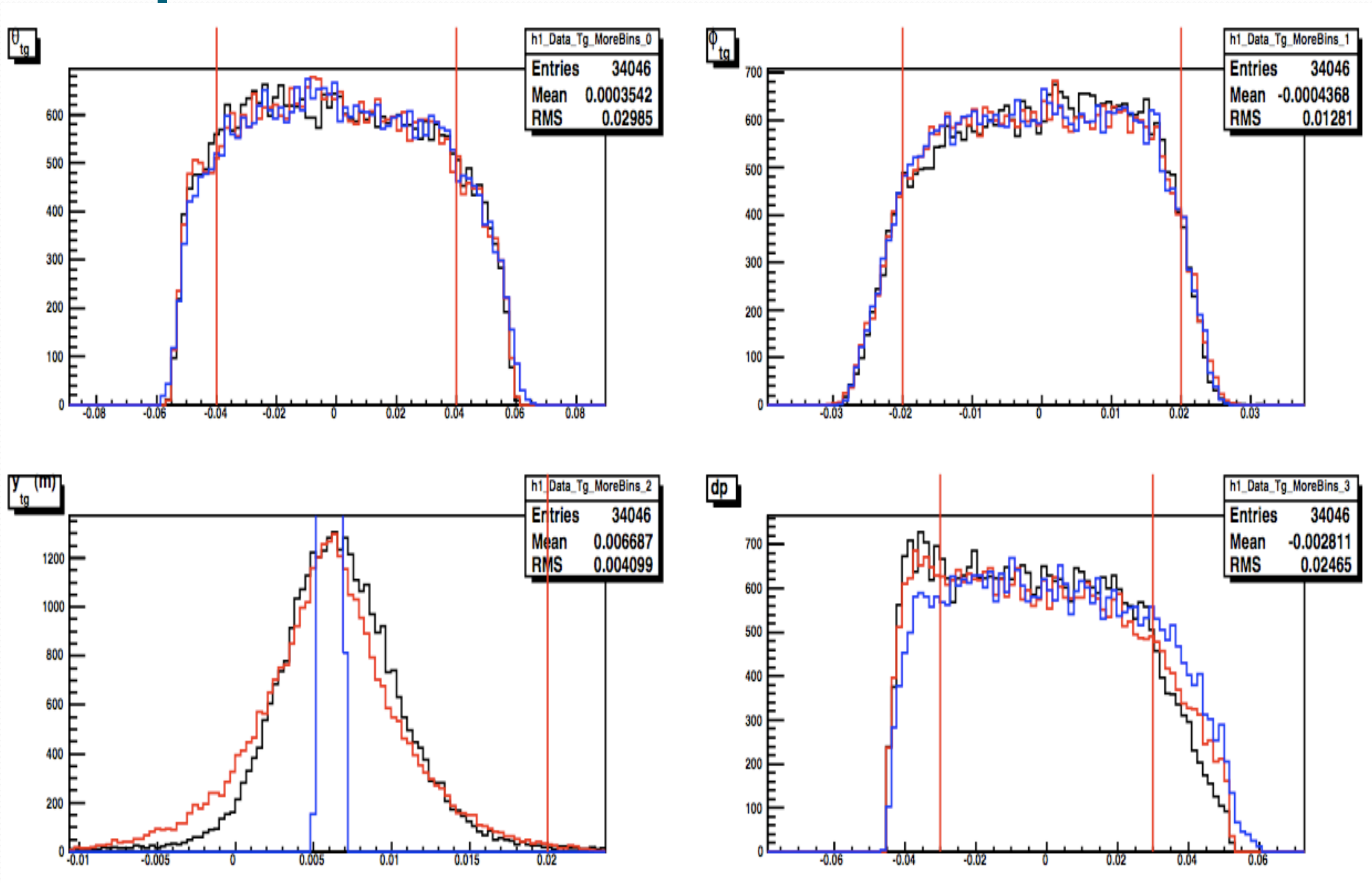






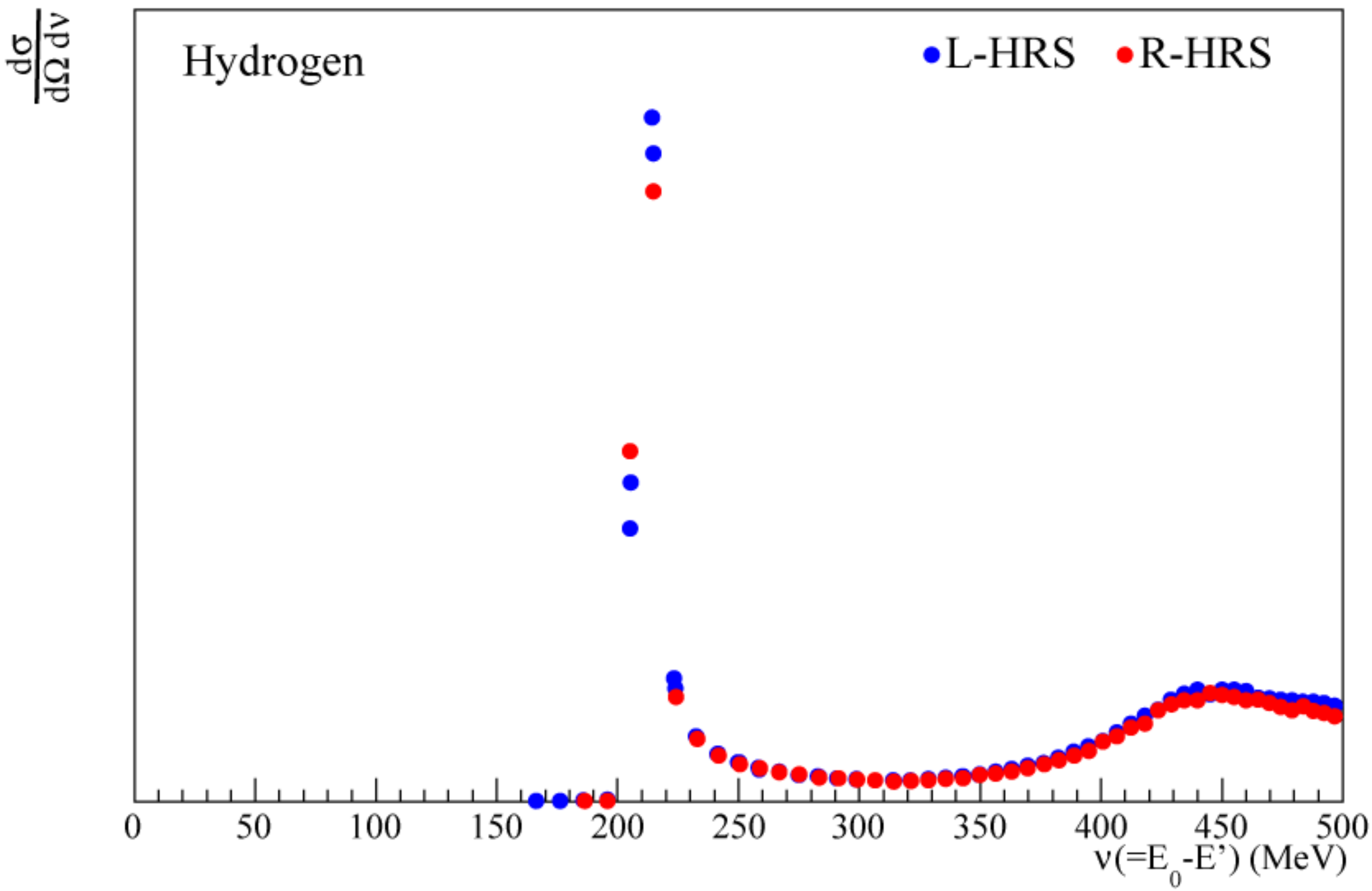


Acceptance

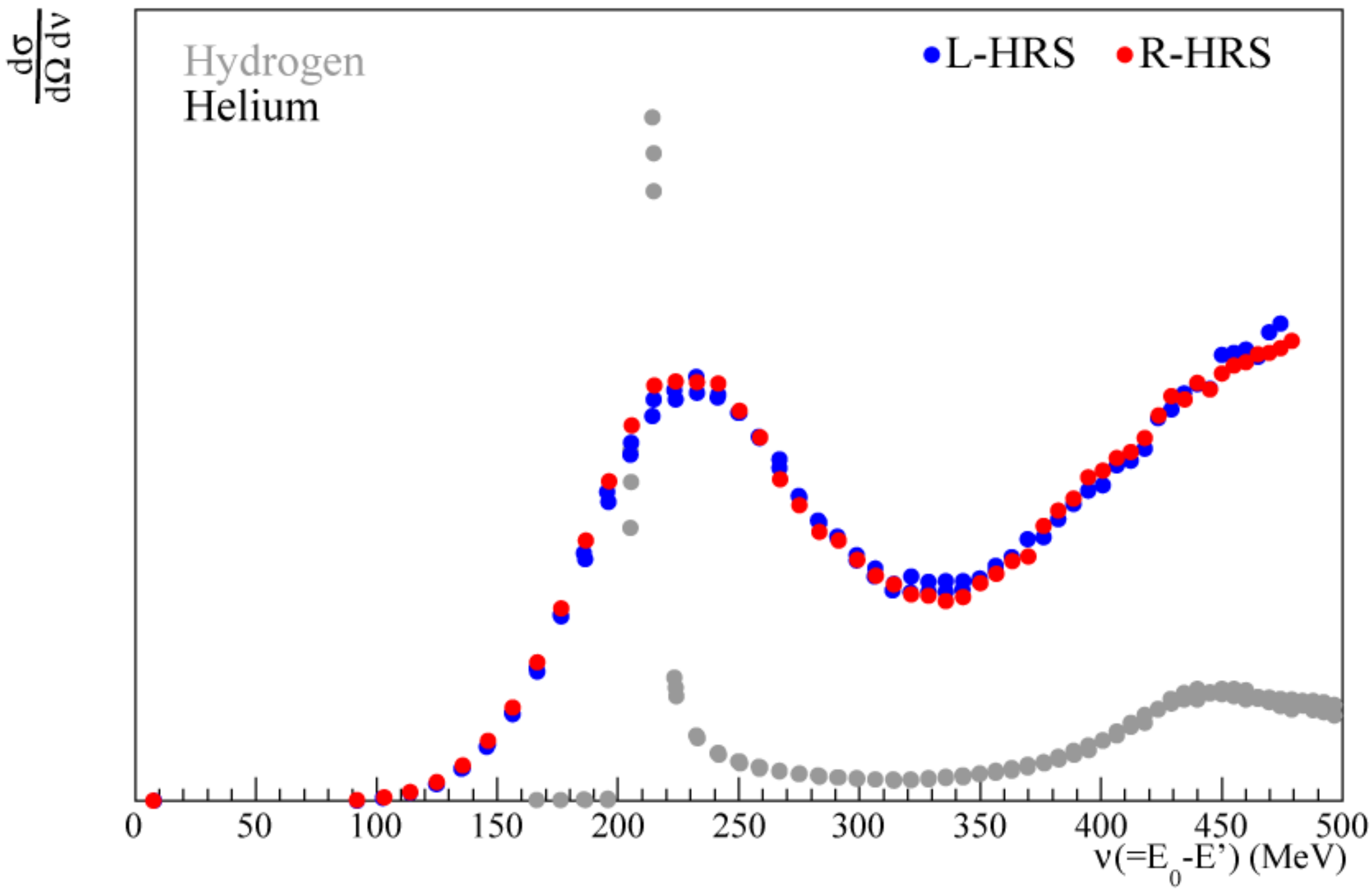


θ_tg
h1_Data_Tg_MoreBins_0
Entries 34046
Mean 0.0003542
RMS 0.02985
φ_tg
h1_Data_Tg_MoreBins_1
Entries 34046
Mean -0.0004368
RMS 0.01281
y_tg (m)
h1_Data_Tg_MoreBins_2
Entries 34046
Mean 0.006687
RMS 0.004099
dp
h1_Data_Tg_MoreBins_3
Entries 34046
Mean -0.002811
RMS 0.02465

Left/Right Spectrometer Cross Check H_2

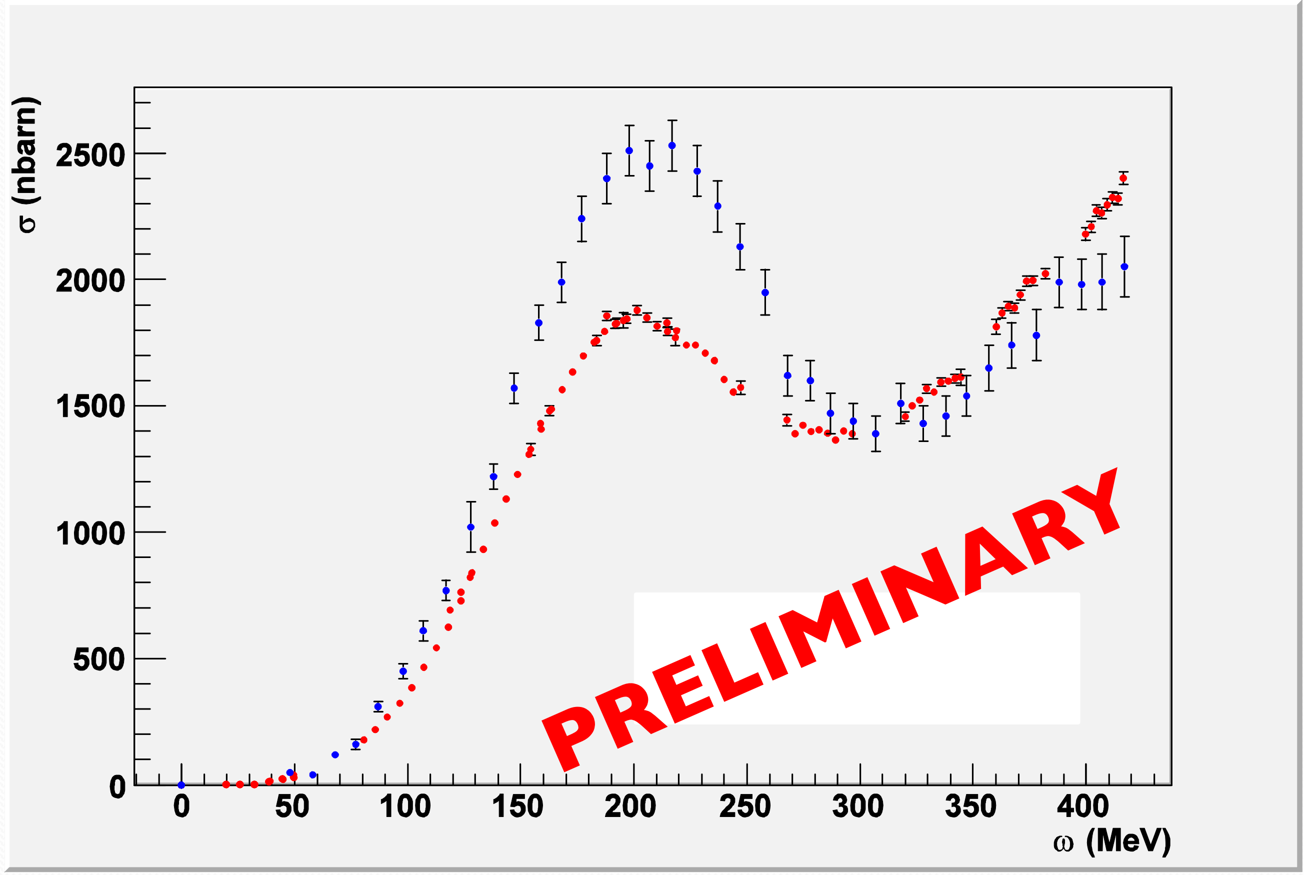


L/R Cross Check on ^{4}He



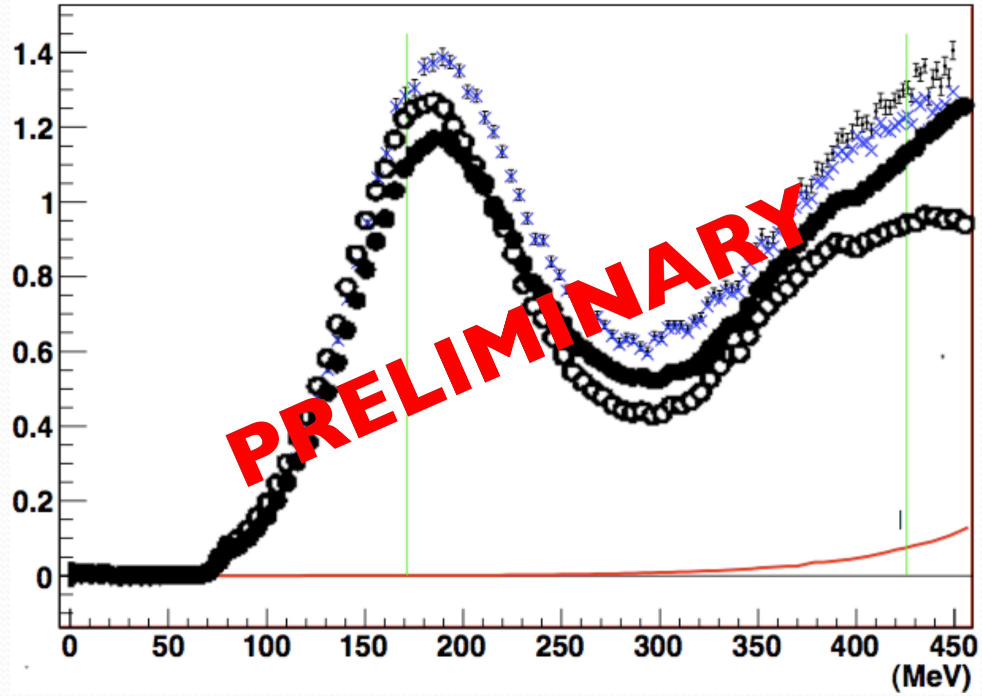
Preliminary Cross Section Comparison: ^{12}C

- JLab: 646 MeV, 60º
  - Blue: No radiative corrections yet
- Saclay: 680 MeV, 60º
  - Red: after the radiative corrections

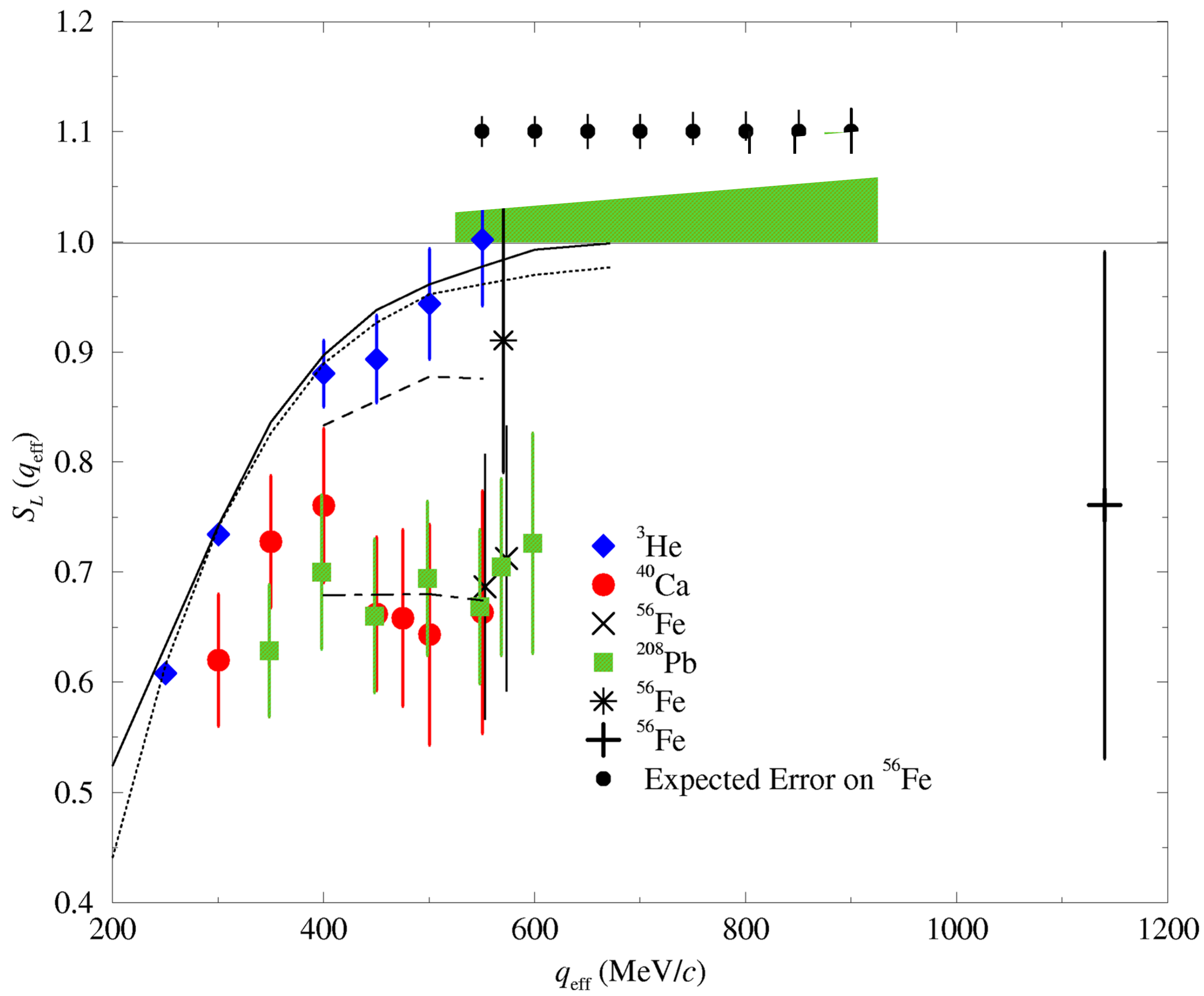


Preliminary Cross Section Comparison: ^{4}He

- JLab: 646 MeV, 60°
  - Blue cross: No radiative corrections yet
- Saclay: 640 MeV, 60°
  - Filled circle: without radiative corrections
  - Open circle: after the radiative corrections



Expected Uncertainties



Summary

- **Precision measurement of R_L and R_T over QE scattering range**
  - **Momentum transfer: 550 MeV/c to 1000 MeV/c**
  - **On four nuclei: ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb**
- **Experiment completed successfully**
  - **New features compared to previous measurements**
- **Analysis in the final stage**
  - **Preliminary cross sections obtained**
  - **Radiative corrections in progress**
- **Resolve the controversy on the Coulomb Sum Rule**
- **Shed lights on nucleon properties in nuclear medium**

Back-Up Slides

Coulomb Corrections - Introduction

- Need to take into account the effect of the nucleus Coulomb field to the incoming/outgoing electrons
- Full treatment of Coulomb corrections via Distorted Wave Born Approximation (DWBA)
- Approximate corrections via Effective Momentum Approximation (EMA)

Is EMA good enough?

In a Nutshell

- EMA is a reasonable approximation, especially
  - For medium-light nuclei
  - For incident electron energies higher than 500 MeV
- How good is EMA for R_L in the case of ^{208}Pb?
  - Less than 7% according to 3 groups
  - Less than 10% according to 1 group (work still in progress)
- For different nucleus, the effect goes as $\left(1 - \frac{V(0)}{E}\right)^2$
- $V_{Fe} \simeq \frac{1}{2} V_{Pb}$, and Coulomb corrections on ^{56}Fe is about 4 times smaller compared to those on ^{208}Pb.

➜ Coulomb corrections are **less than 2%** for ^{56}Fe

Workshops on Coulomb Corrections

- Two workshops
  - Mini-workshop on Coulomb Corrections (Mar. 2005)
  - A session during JLab/INT workshop (Aug. 2005)
- Presentations and round-table discussions with 4 independent theory groups
  - A. Aste (Basel), K. Kim (Sungkyunkwan, Korea), J. Tjon (Maryland), J. Udias (Madrid), S. Wallace (Maryland), L. Wright (Ohio)
- More information available at http://www.jlab.org/~choi/CSR/workshop

Conclusions from the Workshops

1. A Rosenbluth-like procedure based on detailed comparisons with DWBA calculations is being developed to ensure that the longitudinal (R_L) and transverse (R_T) response functions can be extracted from data on nuclei.

2. The size of corrections in medium-light to light nuclei is small enough that an EMA procedure will give a good result in the extraction of R_L and R_T.

3. As the incident and scattered energies as well as the momentum transfer get larger the Coulomb effects become smaller.

4. Everyone is committed to continue work in a coordinated effort to quantify the corrections for the specific kinematics of this experiment.

A. Aste (U. of Basel, Switzerland)
K. Kim (Sungkyunkwan U., Korea)
J. Tjon (U. of Maryland)
J. Udias (U. of Madrid, Spain)
S. Wallace (U. of Maryland)
L. Wright (U. of Ohio)

Two theorists, A. Aste and J. Udias have joined the proposal.