Measurement of Quasi-elastic Transverse and Longitudinal Response Functions in the range

$$0.55 GeV/c \leq | \overrightarrow{q} | \leq 1.0 GeV/c$$

HUGS 2016

Hamza Atac

Temple University

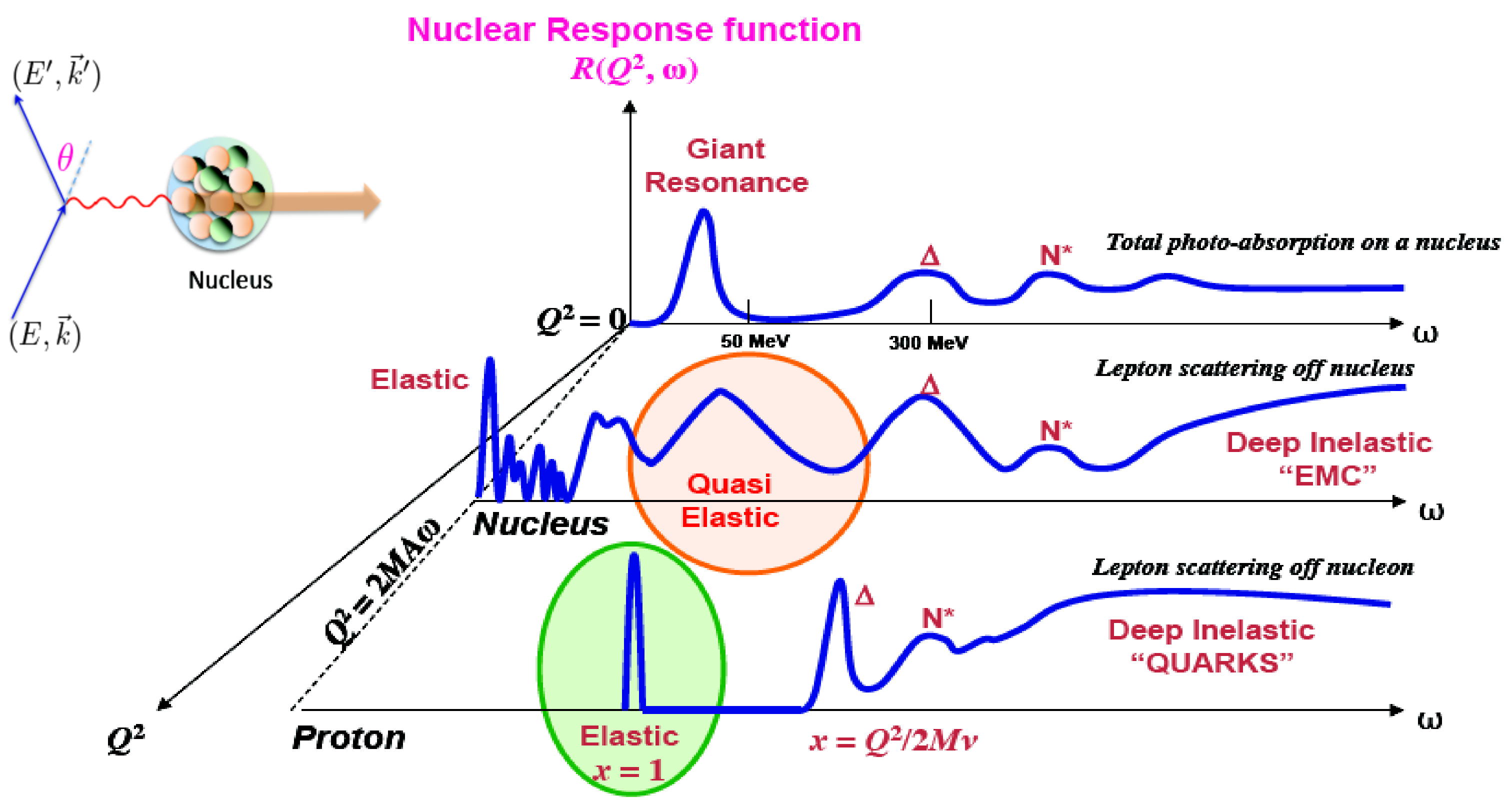
TEMPLE UNIVERSITY®

Jefferson Lab

U.S. DEPARTMENT OF ENERGY

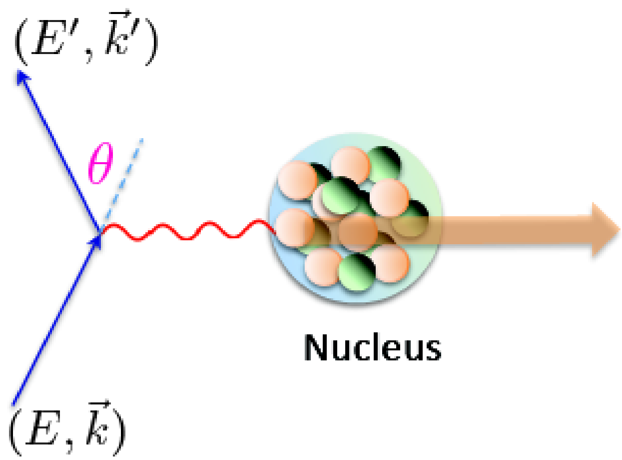
Quasi Elastic Electron Scattering

➔The structure of the nuclear response seen in inclusive electron scattering can be classified as : elastic peak , nuclear excitation levels, giant resonance, quasi-elastic peak,meson exchange currents, Δ peak,higher resonances and deep in-elastic scattering. Jiang-Ping Chen (1990)



Quasi Elastic Electron Scattering

In the Born approximation:



$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{Mott}\left[\frac{Q^4}{\vec{q}^4} R_L(|\vec{q}|, w) + \frac{Q^2}{2\vec{q}^2\epsilon} R_T(|\vec{q}|, w)\right]$$

Virtual photon polarization :
$$\epsilon(|\vec{q}|, \omega, \theta) = \left[1 + \frac{2\vec{q}^2}{Q^2} tan^2\frac{\theta}{2}\right]^{-1}$$

Mott Cross Section :
$$\sigma_M = \frac{\alpha^2 cos^2(\frac{\theta}{2})}{4E^2 sin^4(\frac{\theta}{2})}$$

Four-momentum squared → $Q^2 = \vec{q}^2 - \omega^2 = 4EE' sin^2(\theta/2)$

Invariant mass → $W^2 = M_N^2 + 2M_N\omega - Q^2$

Charge information : $R_L(|\vec{q}|, w)$

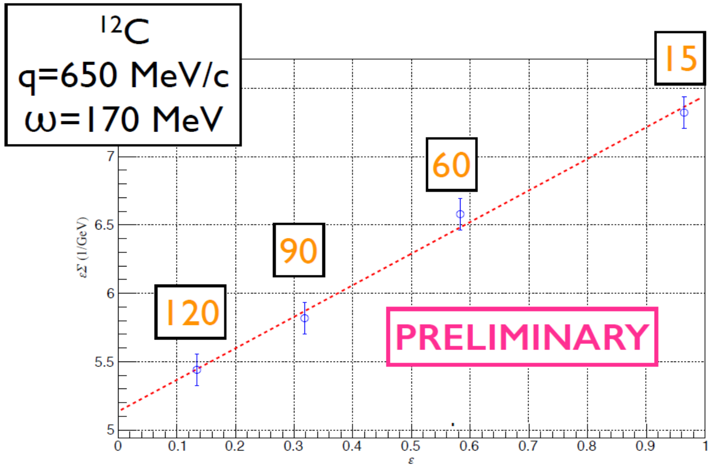
Magnetization information : $R_T(|\vec{q}|, w)$

Rosenbluth Separation

➔ **In order to extract the transverse and longitudinal response functions Rosenbluth Separation can be used.**

At a constant $\vec{q}$ measuring d²σ/dΩdω at two or more angles

$$R = \frac{\sigma}{\sigma_M} = \frac{Q^4}{\vec{q}^4} R_L + \frac{Q^2}{2\vec{q}^2}\frac{R_T}{\epsilon} \quad \longrightarrow \quad \epsilon R = \epsilon \frac{Q^4}{\vec{q}^4} R_L + \frac{Q^2}{2\vec{q}^2} R_T$$



Slope = $\frac{Q^4}{\vec{q}^4} R_L$

Intercept = $\frac{Q^2}{2\vec{q}^2} R_T$

Coulomb Sum Rule(CSR)

Coulomb Sum Rule

Integration of R_L to be used to get CSR :

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

R_L ⟶ Longitudinal Response Function

Denominator includes protons and neutrons electric form factors and a relativistic correction:

$$Z\tilde{G}_E^2(Q^2)$$

De Forest(1984)

At sufficiently large $|\vec{q}|$

$$S_L \rightarrow 1$$

This picture becomes complicated due to various effects inside nucleus :

At low $|\vec{q}|$

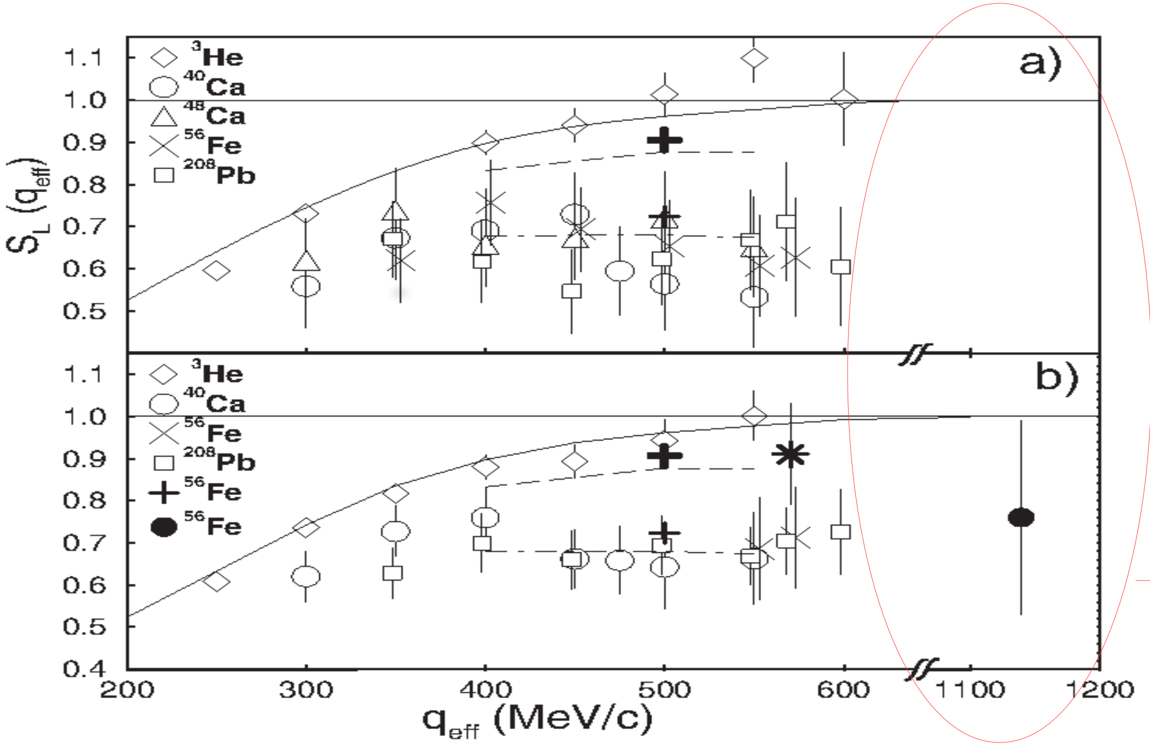
- Pauli Blocking
- NN long range correlations

At $|\vec{q}| \gg 2k_f$

- Short range correlations
- Nucleon Properties in the nuclear medium

Existing Data of CSR Puzzle

Morgenstern&Meziani(2001)



(a)Saclay data only

(b) Saclay+SLAC NE3+Bates

Not enough Data in high $|\vec{q}|$ region

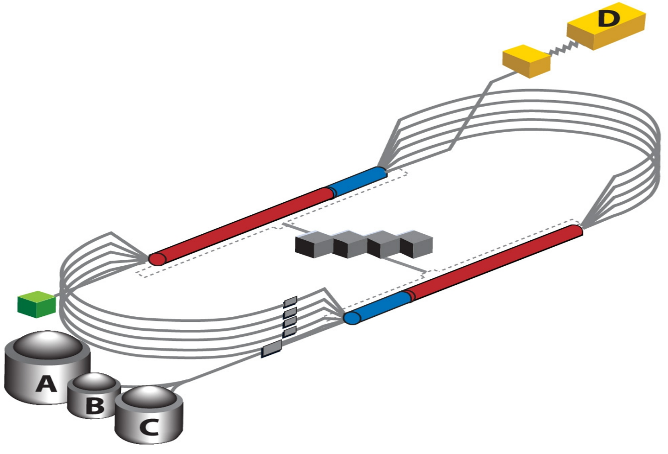
- Existing experimental results in low $|\vec{q}|$ range show a quenching of CSR from 1 for heavy nuclei.

?

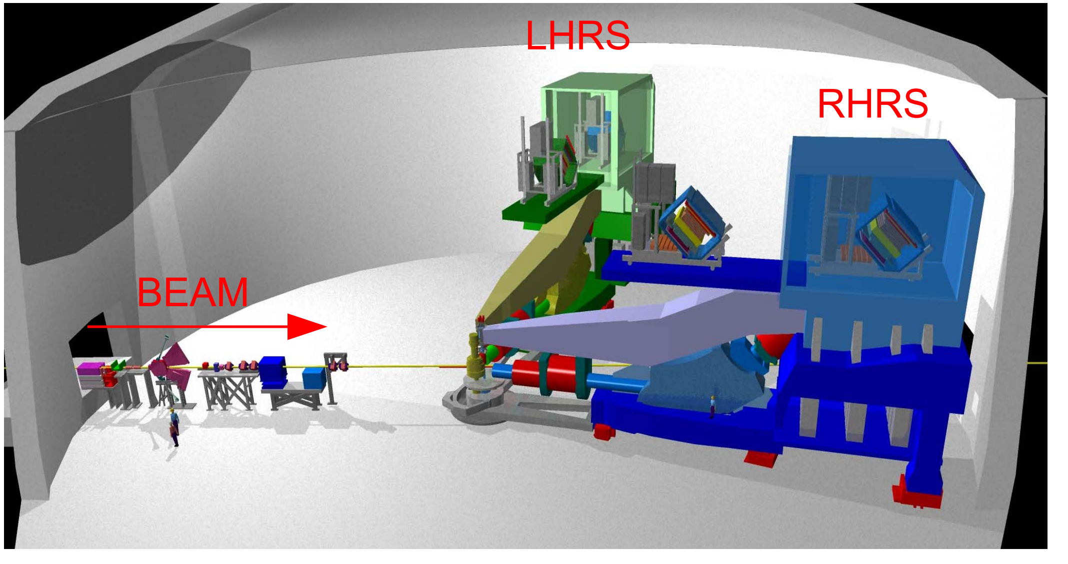
- Deviation from the CSR above $2k_f$ might indicate a possible modification of the nucleon electric properties in the nuclear medium.

Thomas Jefferson Lab (JLAB)

JLAB Top View



JLAB Schematic view



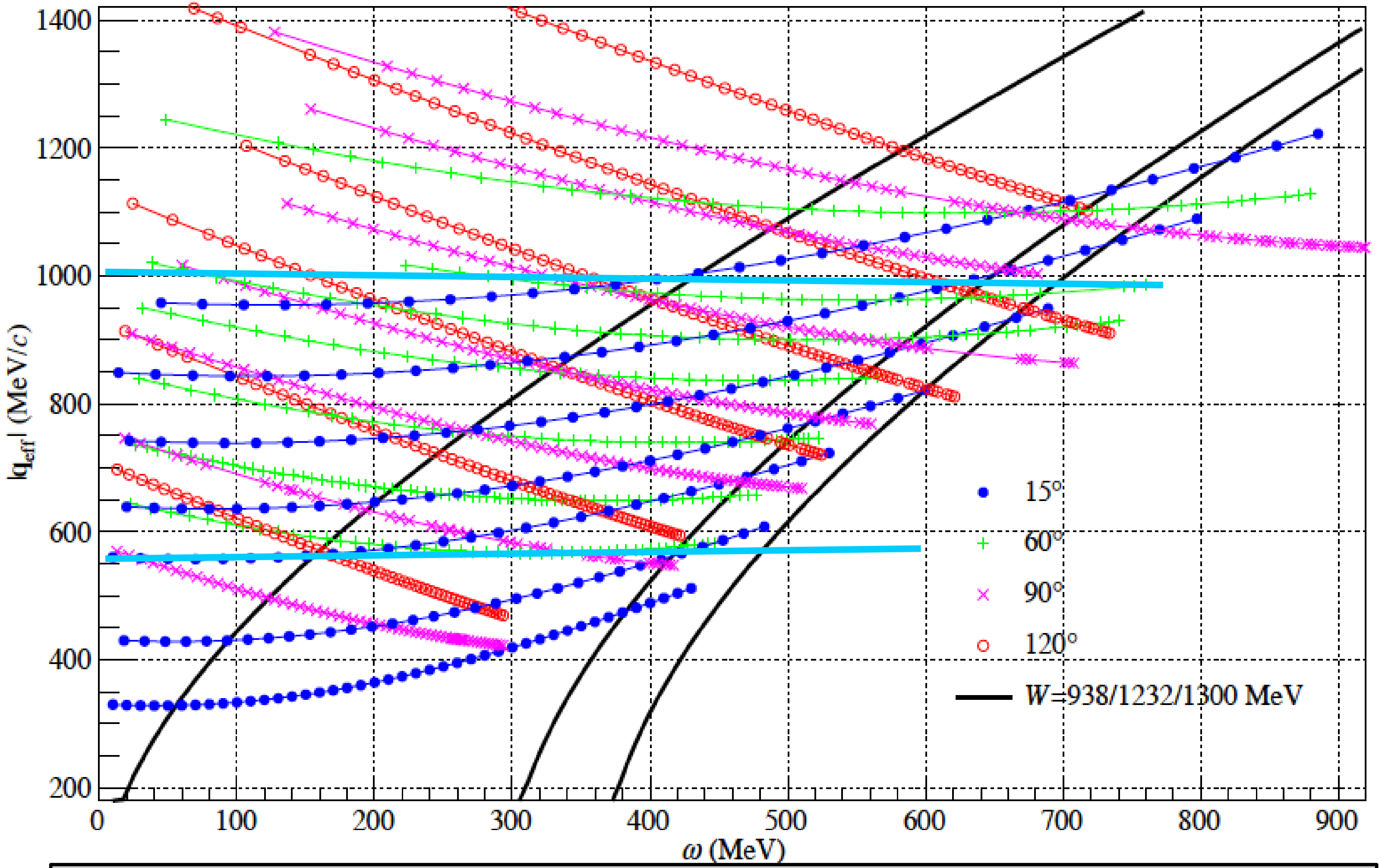
Hall A

E05-110 Experiment at JLab

Experiment Details :

- Both LHRS and RHRS used independently
- 550 MeV/c $< |\vec{q}| <$ 1000 MeV/c
- Incident electron energy : 0.4 - 4 GeV
- Scattered electron energy : 0.1- 4 GeV
- Scattering angle : 15°, 60°, 90° and 120°
- Targets : $^{4}He, ^{12}C, ^{56}Fe, ^{256}Pb$

E05-110 Experiment -Kinematics



- Each dotted line with different color corresponds to a different angle and beam energy .Black solid curves are positions of peaks. Light blue lines are lower and upper limit of Rosenbluth separation .

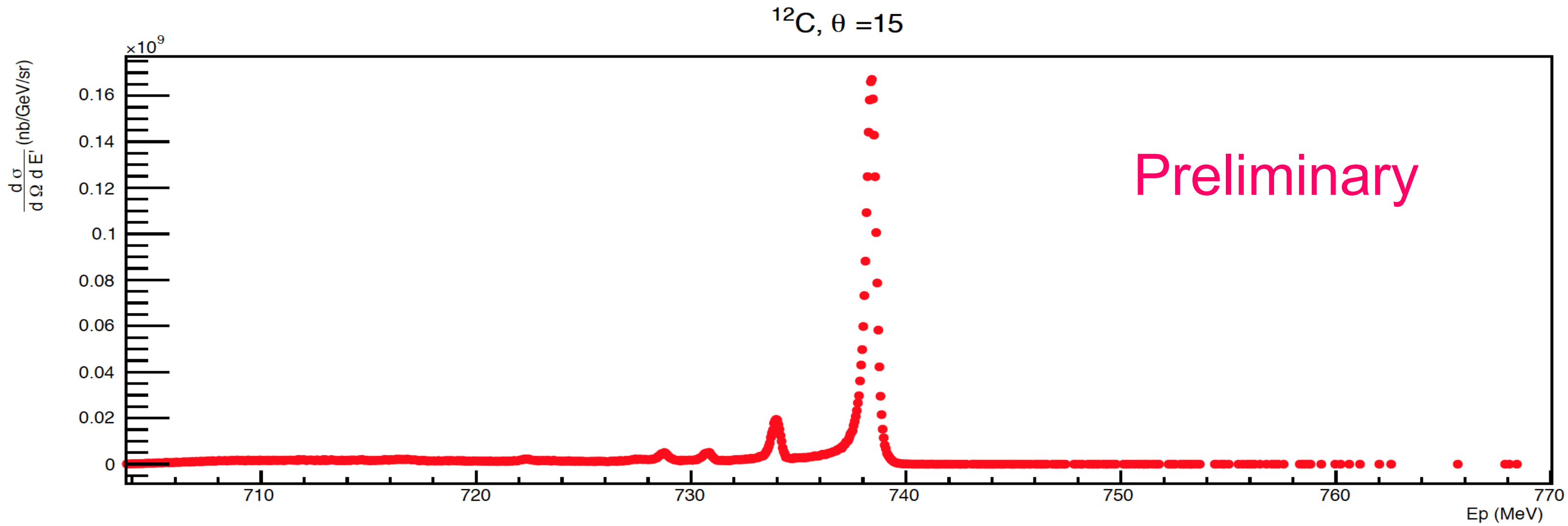
Advantages Of This Experiment

- **Comfortable reach of high values of $|\vec{q}|$**
  - Momentum transfer values from 550 MeV/c to 1000 MeV/c
  - High enough $|\vec{q}|$ for clean observation of CSR
  - Previously unexplored region

- **Comprehensive single experiment**
  - **Largest lever arm (Δε) in a single experiment**
  - Measurement at 4 angles

Elastic Form Factors

- Elastic form factors has been well studied by World.
- Elastic form factors are extracted to compare with World Data.

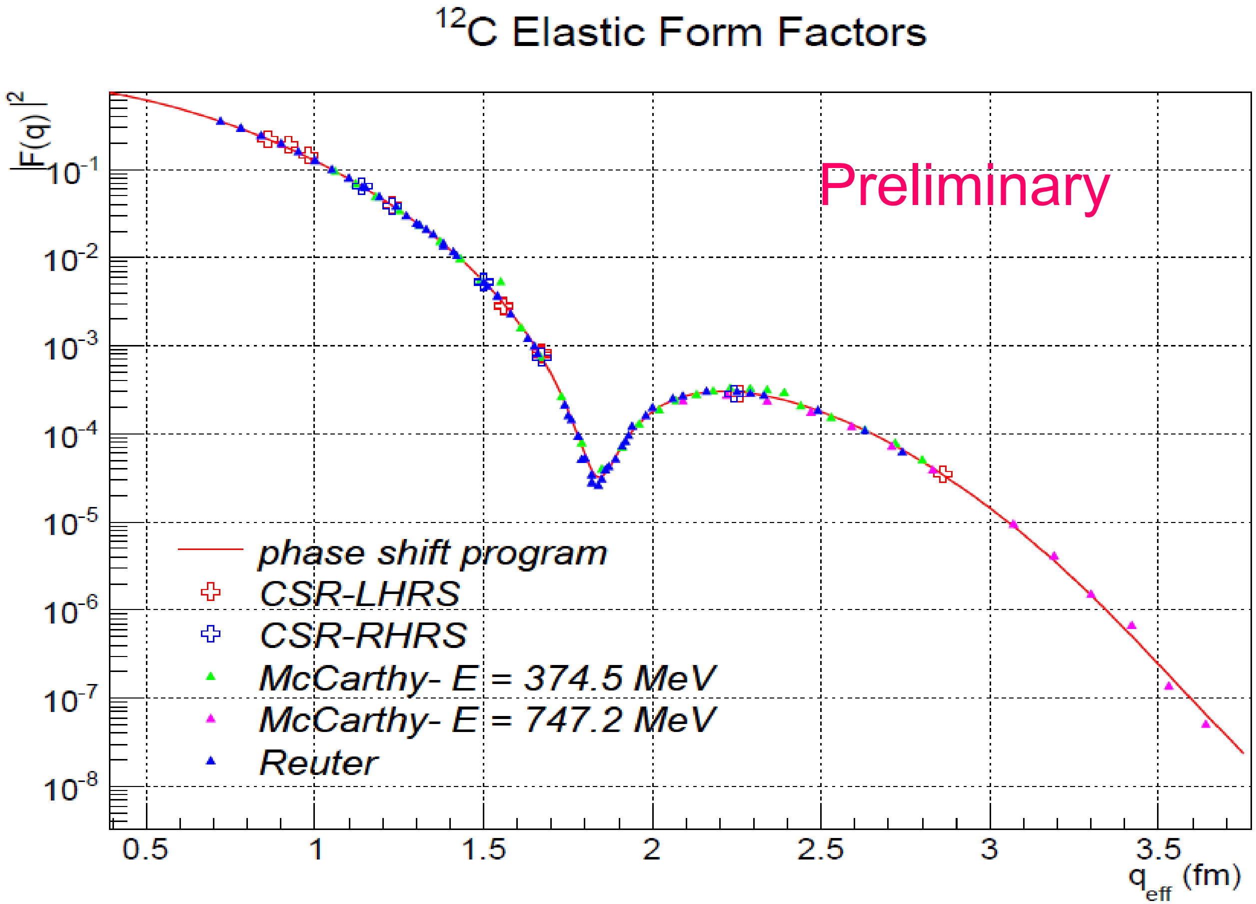


$$\sigma(\theta) = \sigma_{Mott}|F(q)|^2$$

Experimental cross section — Mott cross section — Form Factor

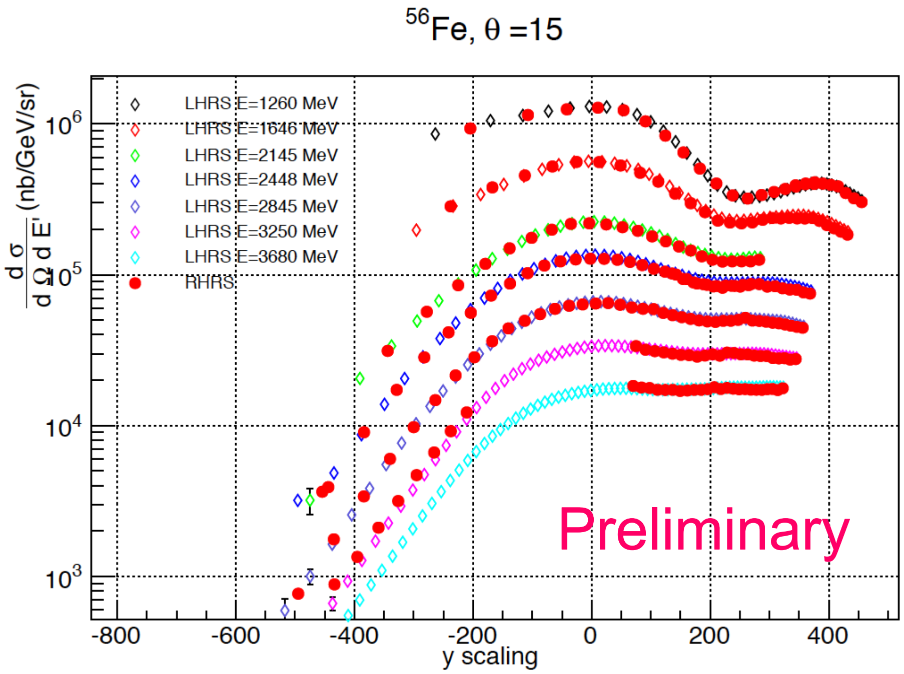
Elastic Form Factors

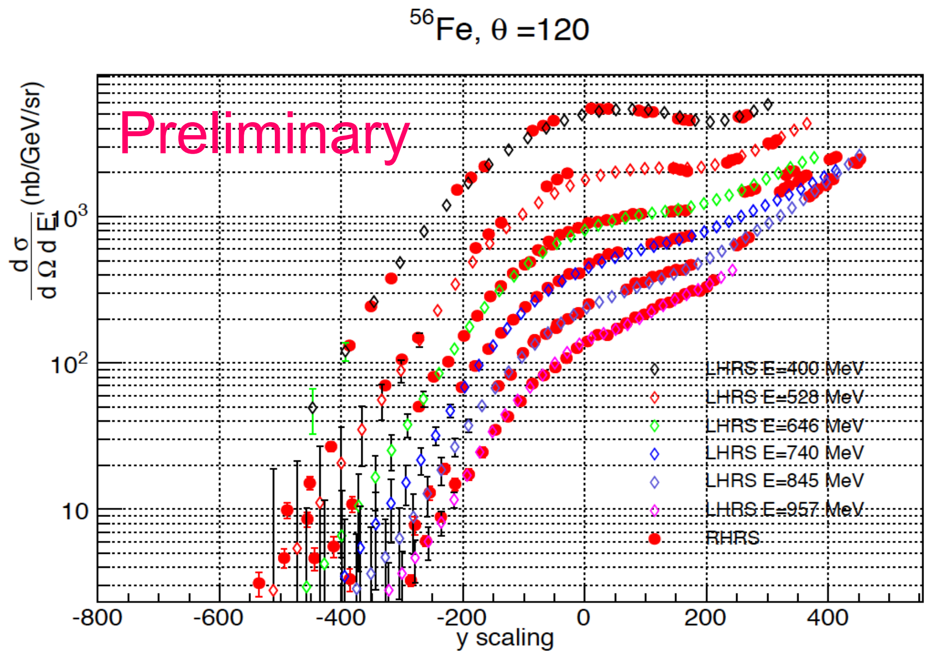
Elastic form factors agree with world data.



Corrected Cross Sections

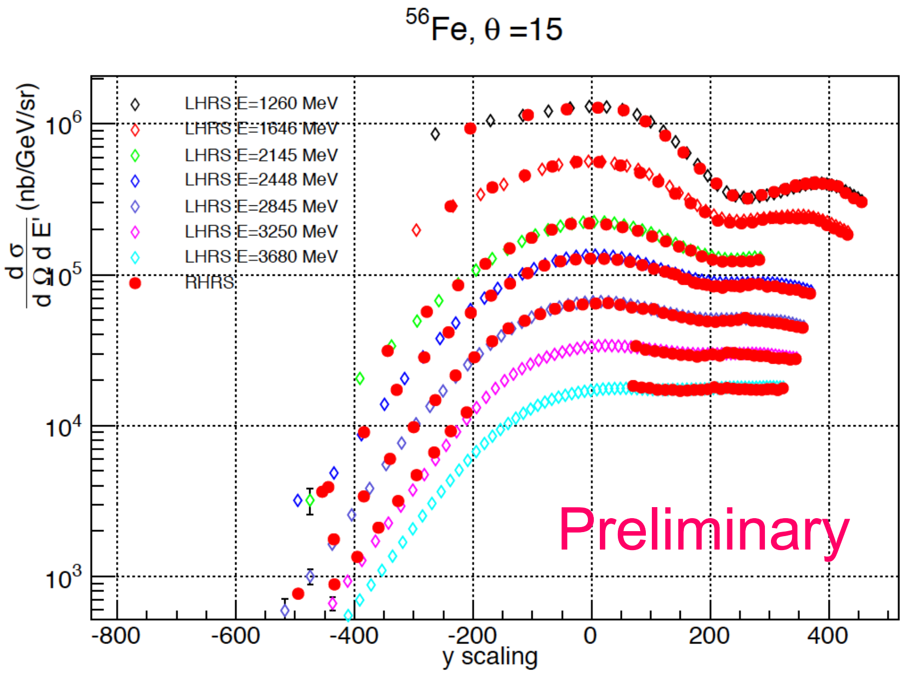
- Extracted Cross sections for two independent spectrometers give same results.

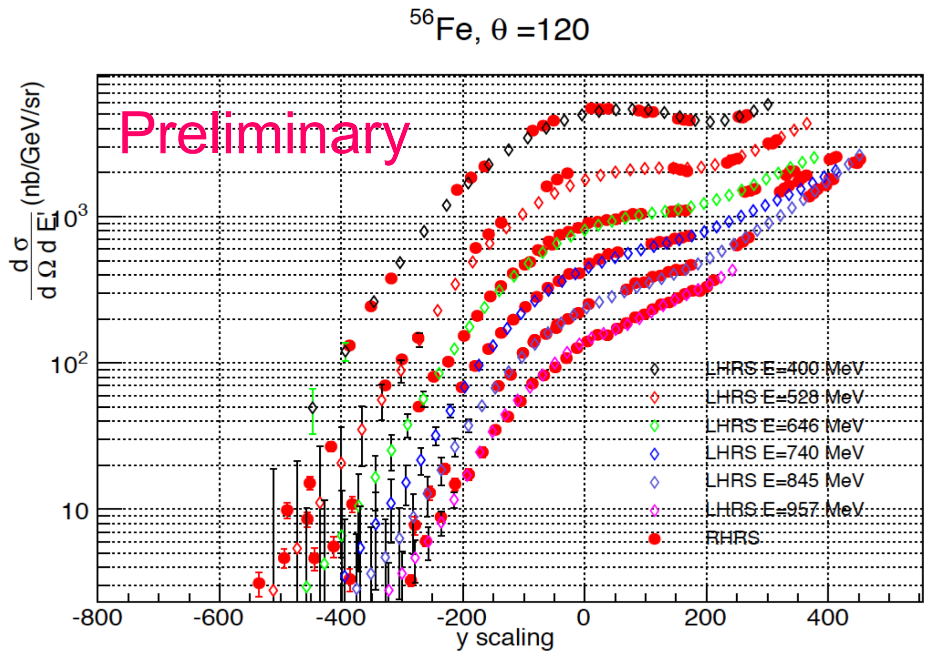




Corrected Cross Sections

- Extracted Cross sections for two independent spectrometers give same results.

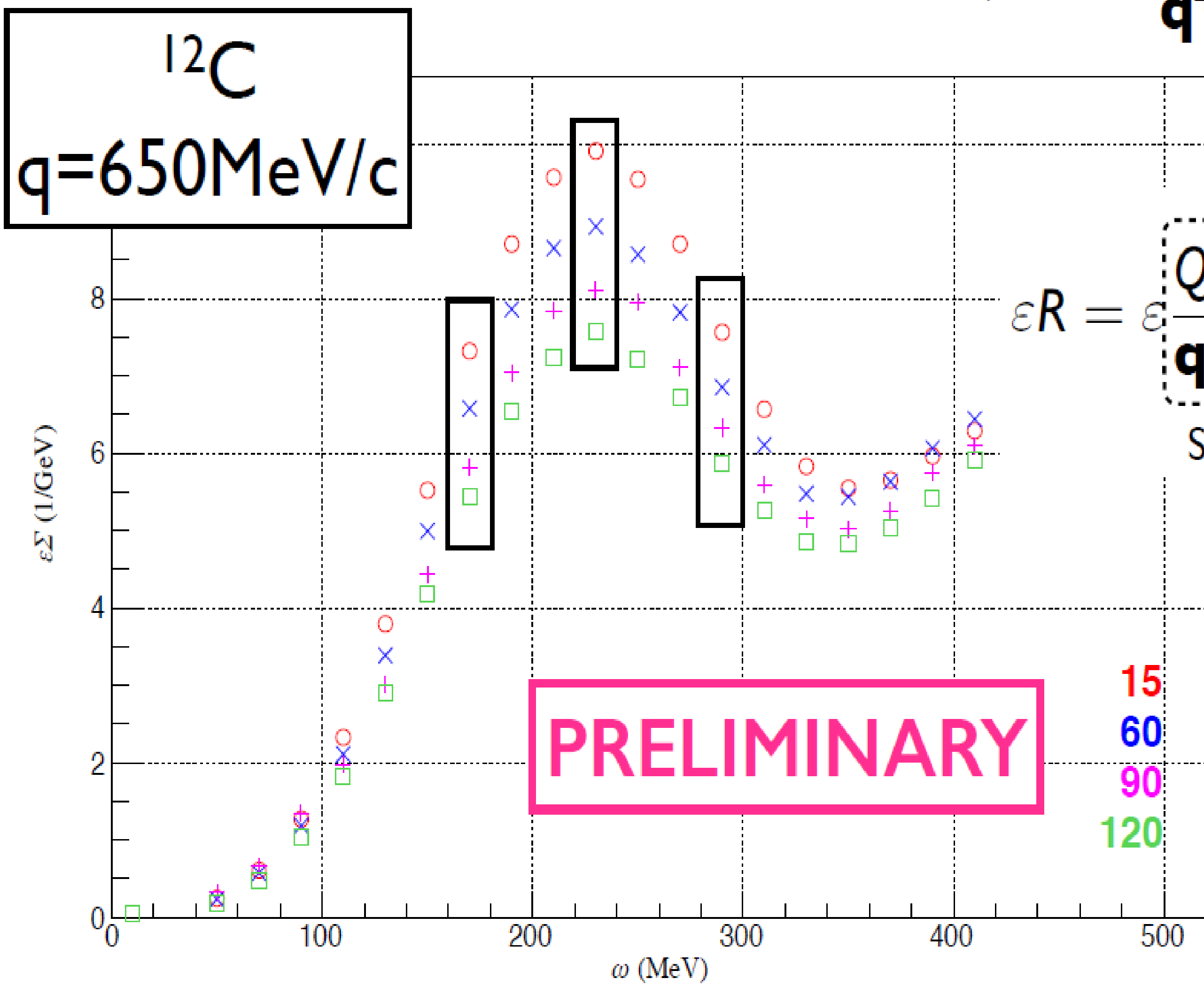




Preliminary Results

$$R \equiv \sigma / \sigma_M = \frac{Q^4}{\mathbf{q}^4} R_L + \frac{Q^2}{2\mathbf{q}^2} \frac{R_T}{\varepsilon}$$

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

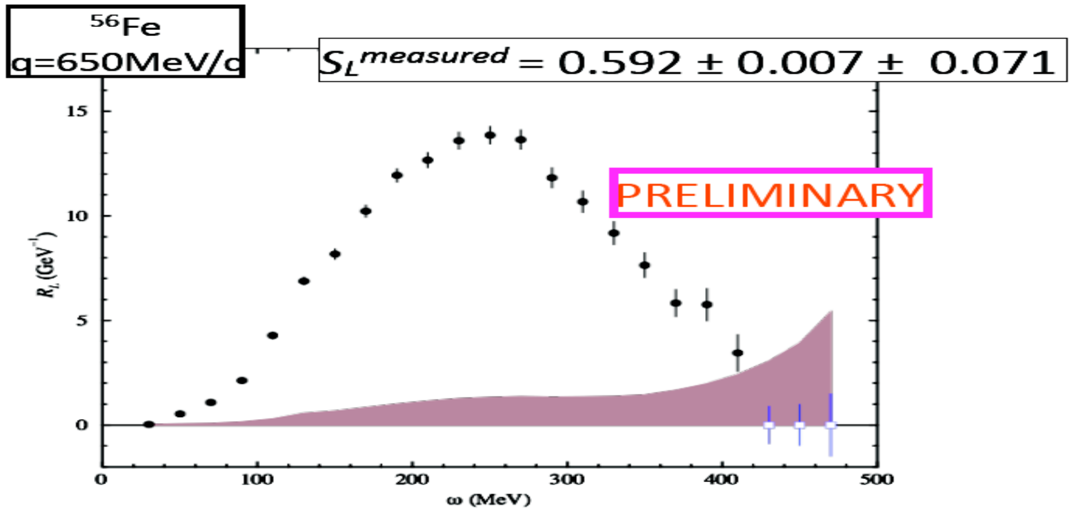


$$\varepsilon R = \varepsilon \frac{Q^4}{\mathbf{q}^4} R_L + \frac{Q^2}{2\mathbf{q}^2} R_T$$

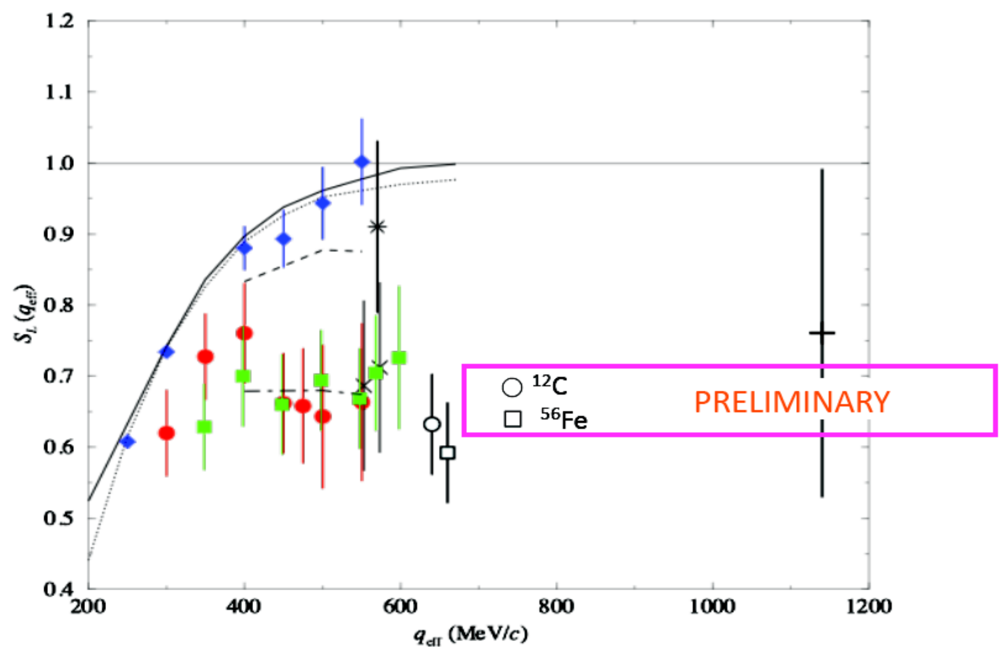
Slope Intercept

Preliminary Results

- **RL**



- **Coulomb Sum**



Status

- Cross sections extracted.
- Elastic Form Factors extracted.
- Positron Cross Sections extracted.
- Elastic Tail extracted.
- Acceptance and Radiative correction studies are done.
- Rosenbluth Separation needs to be studied more carefully.

Acknowledgement

- I would like to thank A.Camsonne, J-P.Chen, S.Choi,D.Flay, Z-E.Meziani, Y.Oh and M.Paolone for their help and support.
- This work is supported by the Department Of Energy through grant DE-FG02-94ER4084

People

Kalyan Allada, Korand Aniol, John Arrington, **Hamza Atac**, 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, **David Flay**, 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 Katich, Mina 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

---

and

Hall-A Collaboration

Students **Post-docs** Run Coordinators Collaborators Spokespersons

THANK YOU!

Expected Errors on ^{56}Fe