Dispersive effects in unpolarized inclusive elastic electron/positron-nucleus scattering

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Outline

LOI12-23-015 (PAC51)

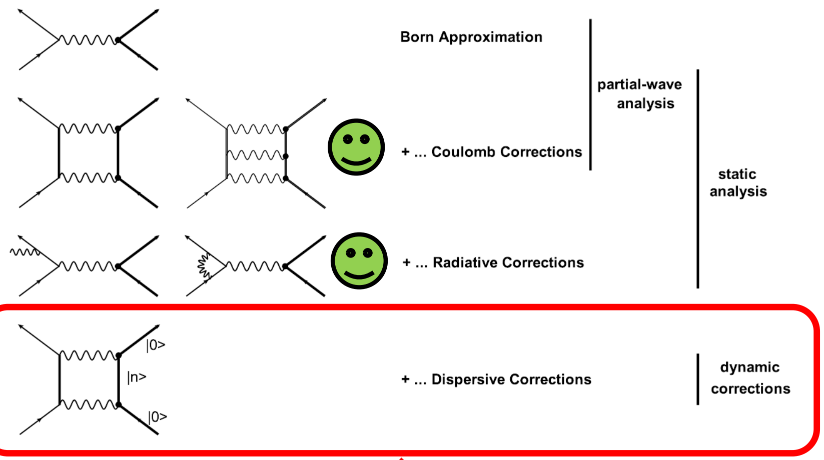
- Energy Dependence of Dispersive effects in Unpolarized Inclusive Elastic Electron/Positron-Nucleus Scattering

Physics

- Charge radii and IAEA recommendation
- EDM search in electron scattering
- Other
  - Neutron skin puzzle
  - Data mining
  - Extension to Rare Isotope Beams

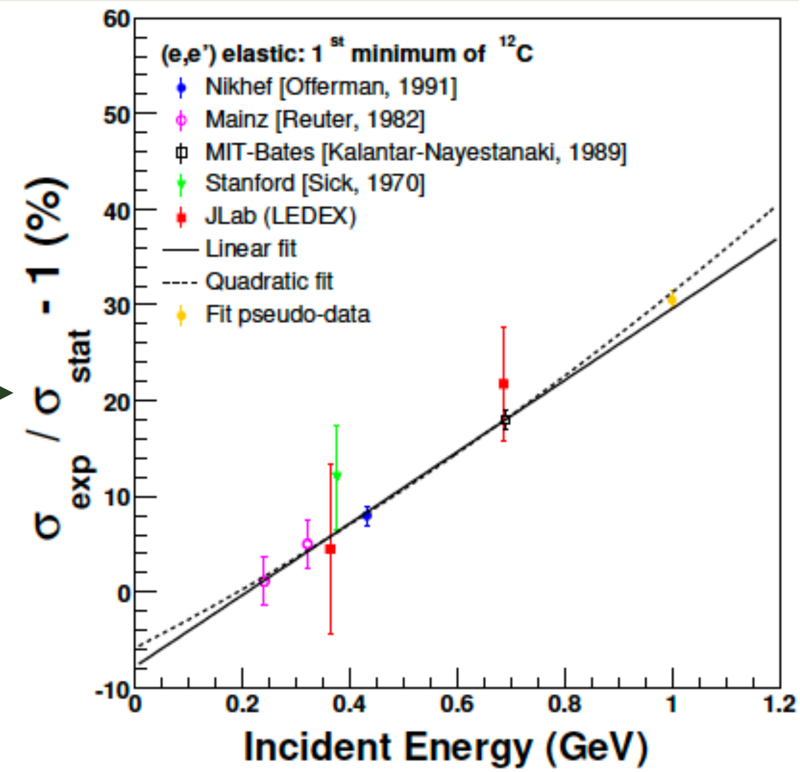
PAC53 proposal

LOI12-23-015 – Background



$$
\begin{aligned}
|\mathcal{M}_{elast+disp}|^2 &= (\alpha Z)^2 [F(q^2)]^2 \\
&+ 2(\alpha Z)^3 [F(q^2)\mathcal{R}e\{G(q^2)\}] \\
&+ (\alpha Z)^4 [|\mathcal{R}e\{G(q^2)\}|^2 + |\mathcal{I}m\{G(q^2)\}|^2]
\end{aligned}
$$

$$\sigma_{disp} = \sigma_{stat}[1 + \delta_{disp}(E_e)]$$



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10.1140/epja/s10050-020-00135-7

LOI12-23-015 – Original Goals

Elastic scattering A(e,e')

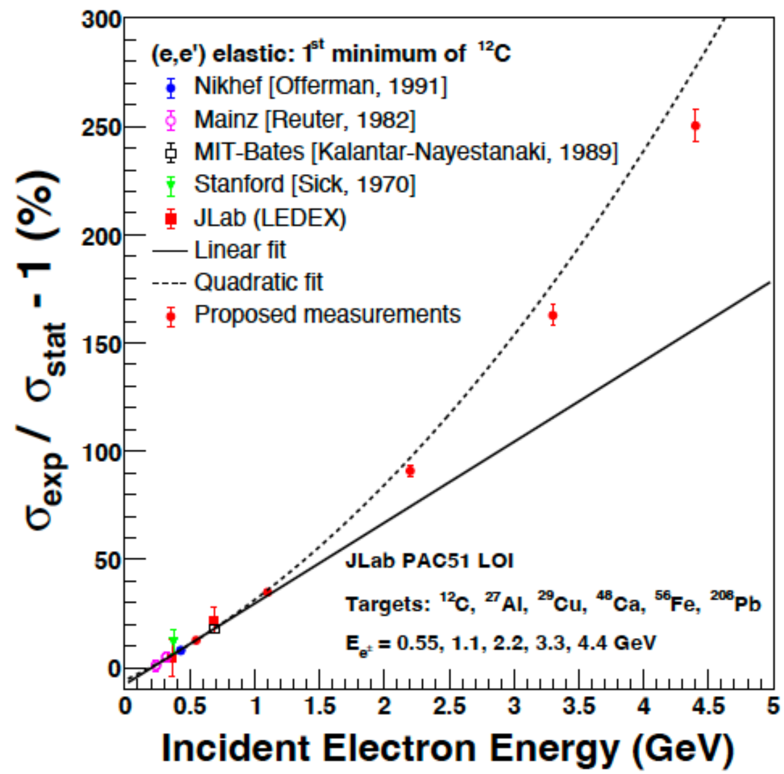
- Measure energy dependence of dispersive effects
- Around first diffraction minimum

Setup

- Hall A or C
- Beam: electrons* & positrons
- Targets: ^{12}C, ^{27}Al, ^{63}Cu, ^{48}Ca, ^{56}Fe, and ^{208}Pb
- Beam energies: 0.55, 1.1, 2.2, 3.3 and 4.4 GeV

Combined run with SuperRosenbluth (J. Arrington)

- PR12+23-012 in Hall C



LOI12-23-015 – PAC Report

Polarization?

- Now: no
- Future: yes (no such measurements exist!)

Use of e±?

- Required to extract interference term
- Observable?
  - σ(Θ)
  - Difference between e^+ and e^-
  - Correct for Coulomb effect
- Impact on parity-violating experiments?
  - Occurred near diffraction minima

$$|\mathcal{M}_{elast+disp}|^2 = (\alpha Z)^2\left[F(q^2)\right]^2 + 2(\alpha Z)^3\left[F(q^2)\mathcal{R}e\{G(q^2)\}\right] + (\alpha Z)^4\left[|\mathcal{R}e\{G(q^2)\}|^2 + |\mathcal{I}m\{G(q^2)\}|^2\right]$$

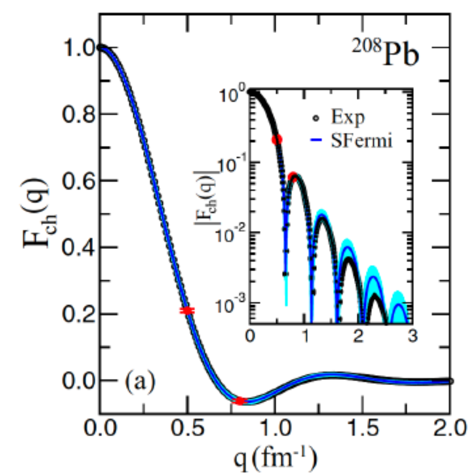
$$\left(\frac{\sigma_{exp}}{\sigma_{stat}}\right)_{e^-} - \left(\frac{\sigma_{exp}}{\sigma_{stat}}\right)_{e^+}$$

$$q \rightarrow q_{eff} = q\left(1 \pm \frac{V_C}{E_{inc}}\right)$$

Theoretical calculation?

- Only existing at high energies: Friar & Rosen, from 1974
- Closure approximation and only spin-0 nuclei

Monte Carlo simulation?



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Charge Radii and IAEA Recommendation [1]

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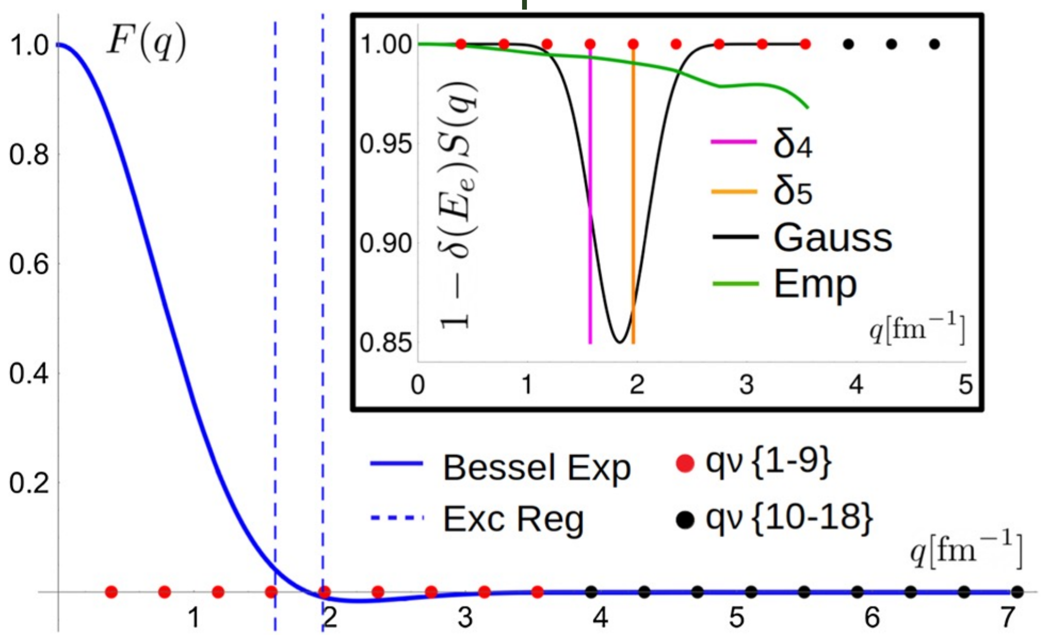
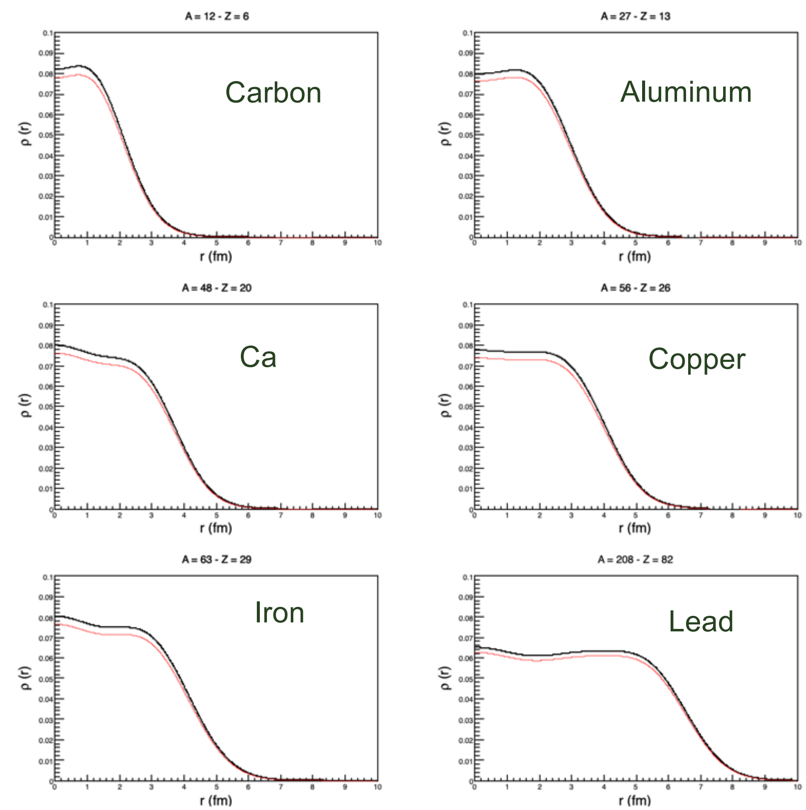
F(q) = 1 - 0.00833q





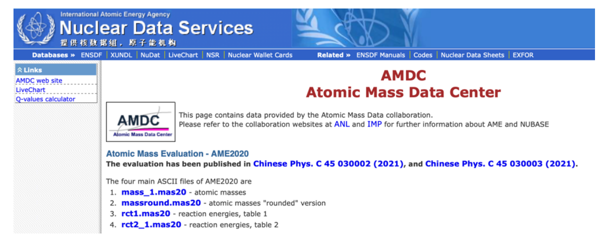
Charge Radii and IAEA Recommendation [2]

Technical Meeting on the Compilation and Evaluation of Nuclear Charge Radii

- January 27-30, 2025
- https://www.iaea.org/events/evt2404492

Goals

- More accurate compilation of rms charge nuclear radii
  - » Last compilation: in 2013 (previous: 2004 by Angeli; 1995-2004 by Fricke, Heilig et al.)
    - Angeli, I. and Marinova , K. P, Atom. Data Nucl. Data Table, **99**, 69 (2013)
    - doi: 10.1016/j.adt.2011.12.006
  - » Large uncertainties: mainly theory; needs guidance for experiments
- Best practices to extract precise RMS nuclear charge radii?
  - » Stable: electron scattering, muon spectroscopy and laser spectroscopy
  - » Unstable: laser spectroscopy (ref. nuclei), electron (SCRIT @ RIKEN)
  - » Standardize: e.g., Barrett moments from μ-spectroscopy (accuracy: ≤0.1%)
- What are the needs to get there on both experimental and theoretical sides?
- Create a team to generate regular charge nuclear radii compilation
  - » “à la” AMDC



Charge Radii and IAEA Recommendation [3]

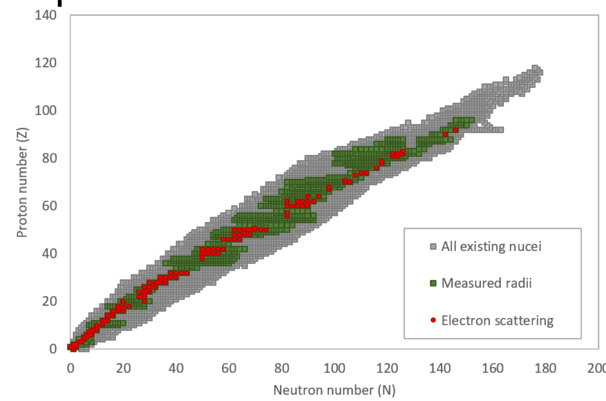
Ambar Alicea Rodriguez
MSU, M.Sc. Thesis (2024)

One of the main outcomes

- Dispersive effects not accounted for in past compilations!
- Lack of theoretical calculations
- Lack of experimental quantification

Stable (deVries, 1987) & Atomic Data (2013)

- deVries: electron scattering
- Atomic data: experiment + theory

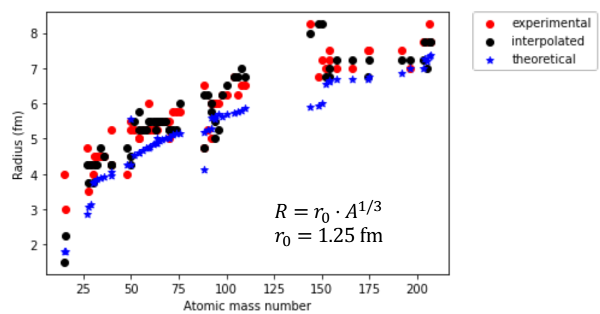


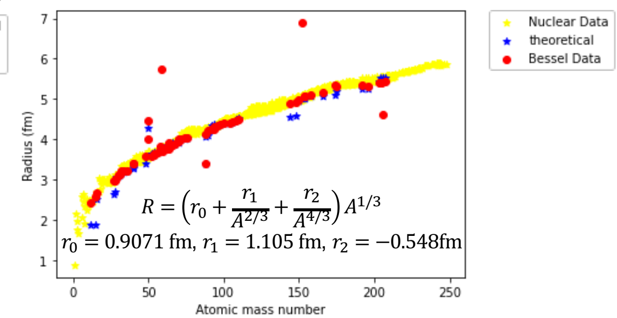
$$\rho(r) = \frac{1}{2\pi^2}\int F(q)\,\frac{\sin(qr)}{qr}q^2 dq$$

$$= \sum a_\nu j_0(qr)$$

$$F(q) = 4\pi\int \frac{\sin(qr'/\hbar)}{qr'/\hbar} r'^2 \rho(r') dr'$$

$$j_0(qr) = \sum_{n=0}^{\infty}\frac{(-1)^n (qr)^{2n}}{2^{2n}(n!)^2} = \frac{\sin(qr)}{qr}$$





EDM Search [1]

Collaboration with Jaideep Singh @ MSU

Need: nuclei with spin >0

- Good reading
  - » All electromagnetic form factors [1]
- Four electromagnetic form factors
  - » F_1 (charge) and F_2 (anomalous magnetic moment)
    - Experimentally measured
    - F_2 lead to 2-photon exchange puzzle [2]
  - » F_3 (electron dipole moment)
    - No non-zero measured but possible [3,4]
  - » F_4 (Zeldovich anapole moment)
    - No experimental evidence
    - Through coupling to off-shell photons (virtual exchanged between 2 fermions) [1]
    - PV through F4 competes with PV through Z0: very hard to disentangle!

$$F_1(0) = Q = e$$

$$\frac{1}{2m}[F_1(0) + F_2(0)] = \mu \to a = \frac{g}{2} - 1 = \frac{F_2}{e}$$

$$-\frac{1}{2m}F_3(0) = d$$

$$H^{\mathrm{NR}}_{\mathrm{int}}[F_4] \propto F_4(0)\sigma \cdot \left[\nabla \times \mathbf{B} - \frac{\partial \mathbf{E}}{\partial t}\right]$$

[1] M. Nowakowski, E. A. Paschos and J. M. Rodríguez, Eur. J. Phys. **26** 545–560 (2005)
[2] Bosted P. E., Phys. Rev. **C51** 409–11 (1995)
[3] Commins E. D., Advances in At., Mol. and Opt. Phys., **40** 1–55 (1999)
[4] Regan B. C. et al., Phys. Rev. Lett. **88** 071805 (2002)

EDM Search [2]

Goal

- Constrain EDMs from electron scattering data in a model independent way
- Note on small Z: theory prediction that they are immeasurably small
  - No one have even tried to measure them
- Experimental verification
  - Experimental limits even if crude
- Would need polarized experiments

LOI targets

- ^{12}C (spin 0), ^{27}Al (spin 5/2) 🙂, ^{63}Cu (spin 3/2) 🙂, ^{48}Ca (spin 0), ^{56}Fe (spin 0), and ^{208}Pb (spin 0)

Other Physics [1]

Neutron skin puzzle

- ^{208}Pb a special case?
- Nuclear breakup during scattering process (Andrei A. talk)

Data mining

- Copious existing elastic data from Hall A/C: 4 GeV, 6 GeV, and 12 GeV
- Various targets: H, He, C, Al, Pb …
- Need to identify those with data around 1st minimum of diffraction
- Collaboration with Doug H.

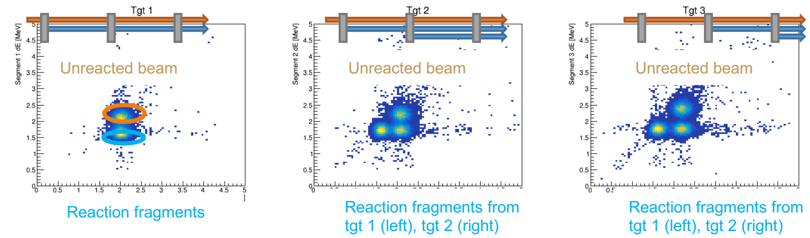
Other Physics [2]

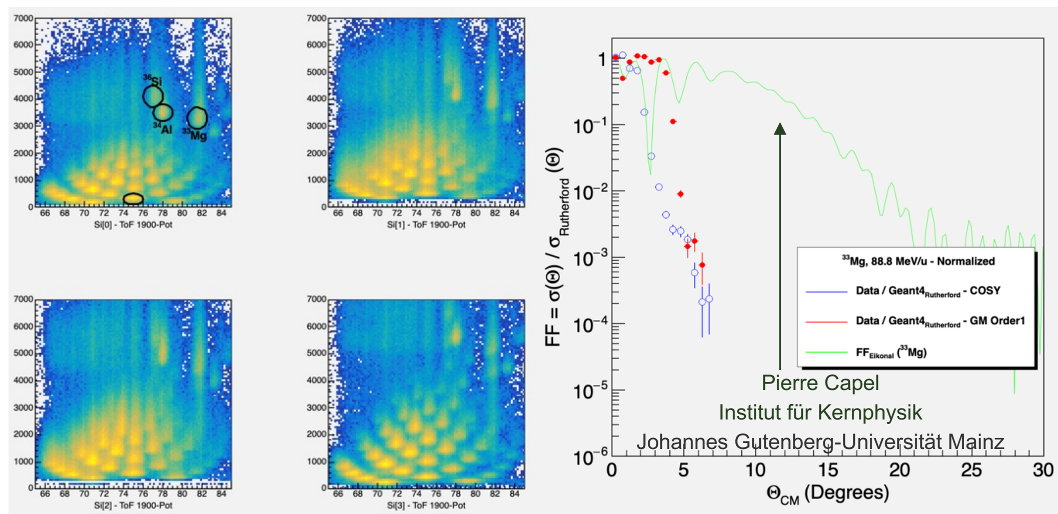
Extension to rare isotopes

- MoNA Collaboration
  - Si-Be segmented target
  - 4 TLPSDs + 3 Be
- Rutherford scattering-like data
- Preliminary results for matter radii
  - Impact from charge radii
  - Sensitivity to neutron distribution?

Graduate student

- Paula Plazas Isanoa (Fall 2024)
- Joint thesis project
  - Laser spectroscopy (BECOLA)
  - Matter radii (MoNA Collaboration)

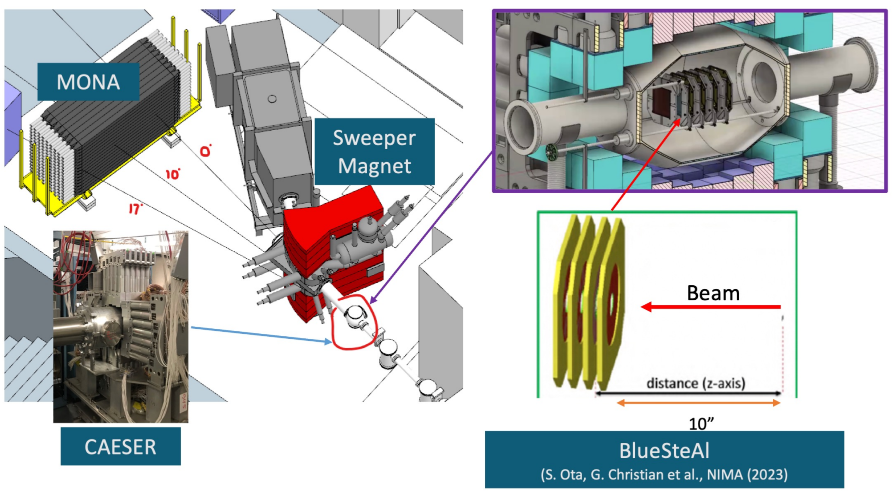


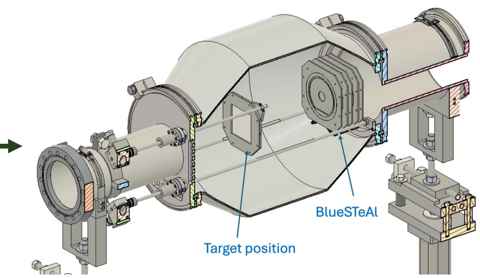


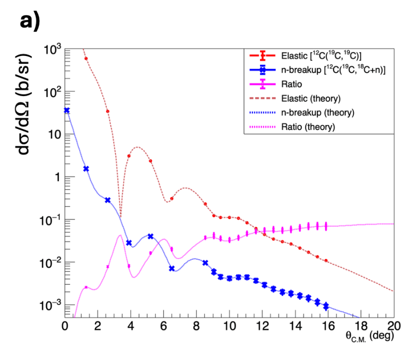
Other Physics [3]

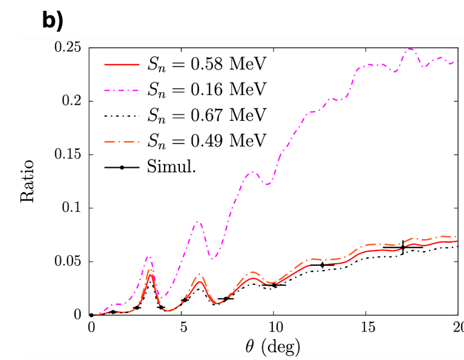
FRIB PAC3 proposal

- PR25076: spokespersons are S. Ota (BNL), P. Capel (JHUM) & P. Guèye (FRIB)
- Establish a complete picture of the halo nucleus ^{19}C using a novel technique: the ratio method









PAC53 Proposal [1]

Compilation of data from Hall A/C

Targets

Element	C	Al	Cu	Ca	Fe	W	Pb	U
A	12	27	63	48	56	184	208	238
Z	6	13	29	20	26	74	82	92

Kinematics

- Beam energies: 0.545, 1.090, 2.180, 4.36, 6.540, 8.720 GeV

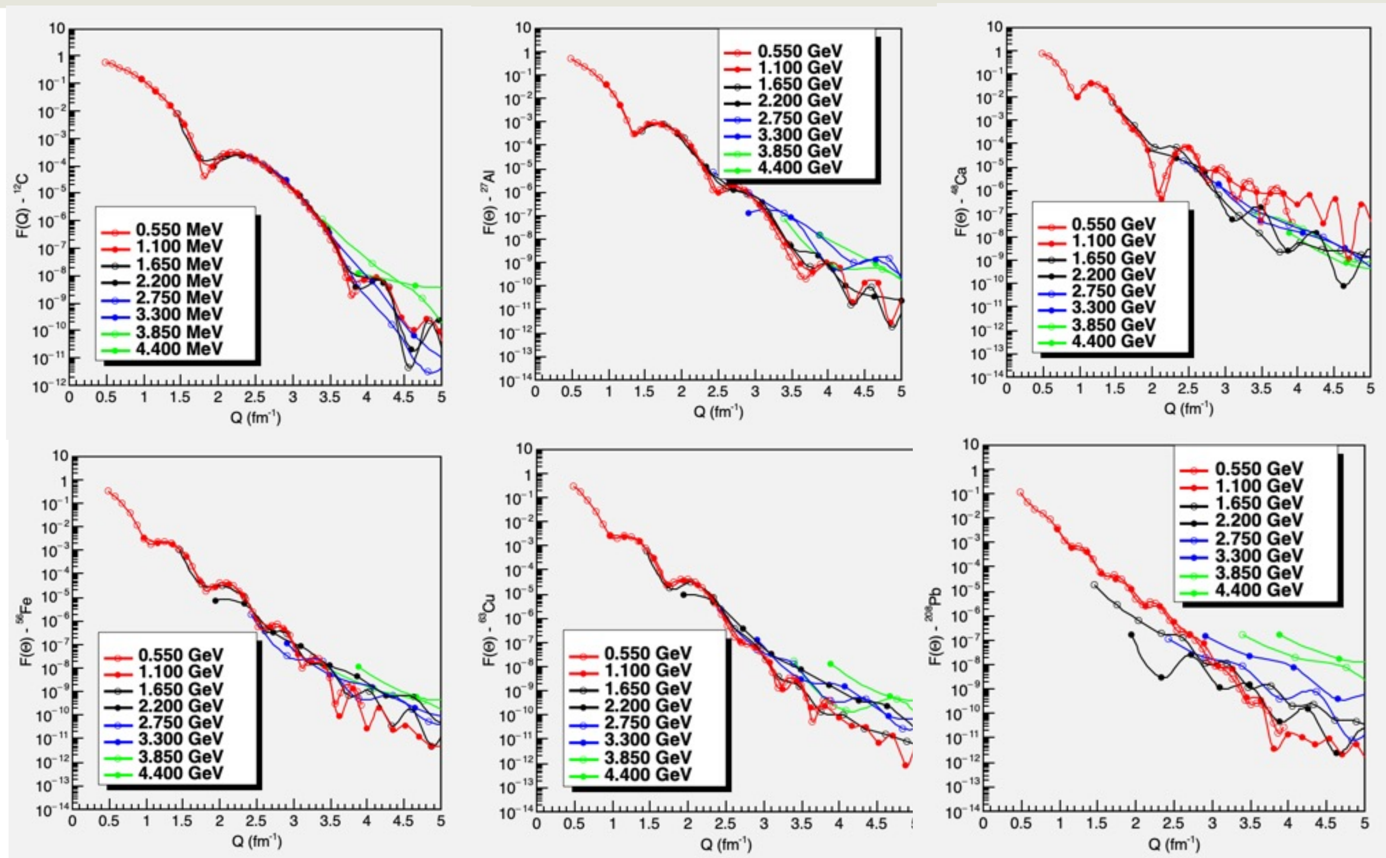
Experiment

- As standalone (will find overlaps if possible)
  - No combination with the SuperRosenbluth proposal (J. Arrington)
- Can have dedicated and more efficient measurements

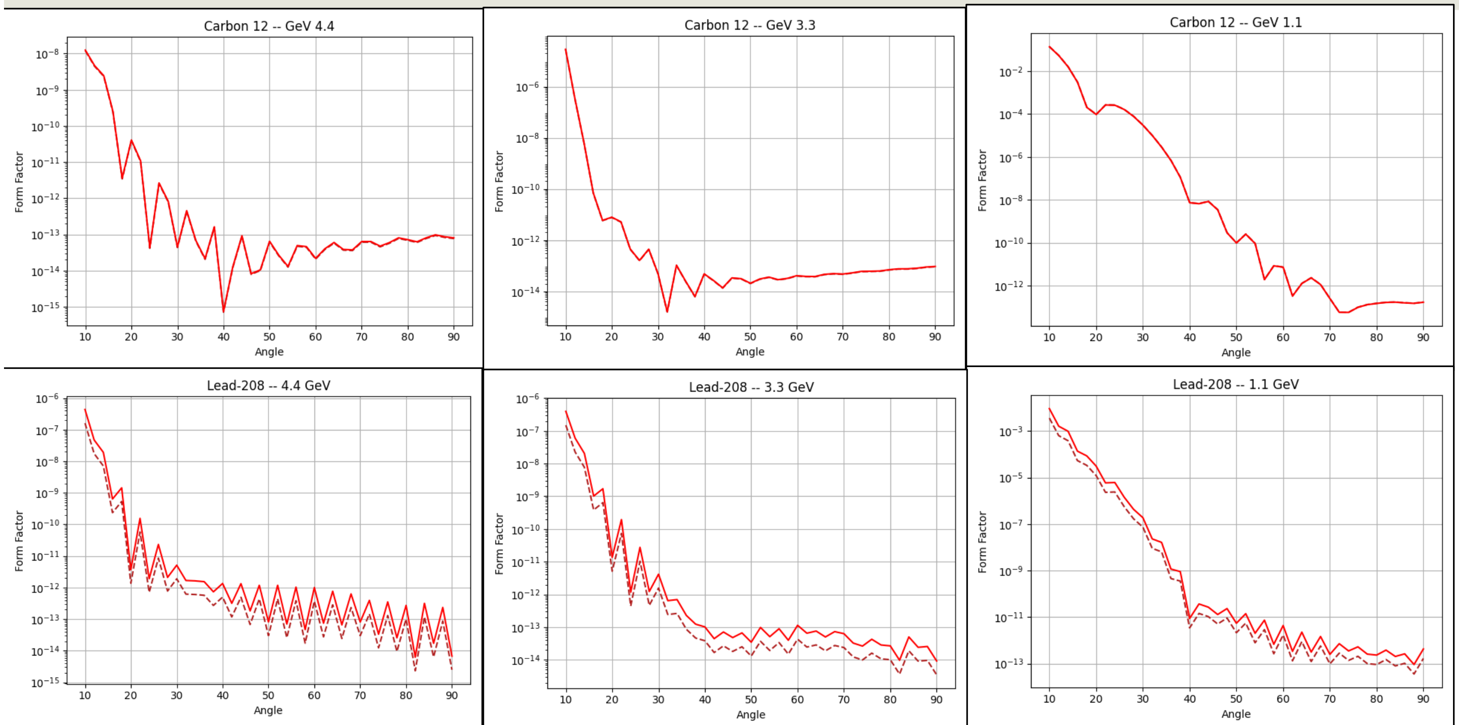
PAC53 Proposal (from LOI) [2]

Charge distribution

- Bessel parameterization
- deVries et al. (1987)



PAC53 Proposal (from LOI) [3]



Zoê Cogan
High school student

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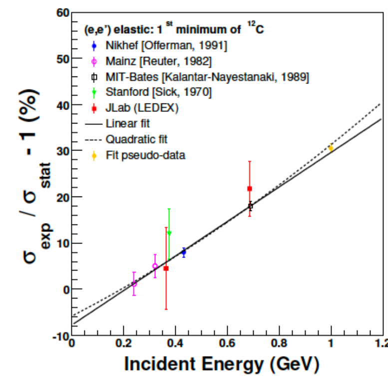

Table 4 Polynomial fit parameters on the world data set for dispersive effects in the first minimum of ^{12}C

	Linear fit	Quadratic fit
p_0	-6.64 ± 1.13	-4.40 ± 4.04
$p_1(10^{-2}\ \text{MeV}^{-1})$	$+3.55 \pm 0.26$	$+2.36 \pm 2.08$
$p_2(10^{-5}\ \text{MeV}^{-2})$		$+1.30 \pm 2.25$
χ^2/ndf	2.092/6	1.758/5

$$S_1 = R_0 A^{1/3}$$
$$S_2 = \frac{\sigma_{exp}}{\sigma_{stat}} - 1$$
$$S = S_1 S_2 = (a + bE)\left(\frac{M_{\text{target}}}{M_{\text{C}}}\right)^{1/3}$$

PAC53 Proposal [4]

Simulation

- JLab account issue …

Thanks