Measurement of the coherent J/ψ electroproduction off ^{4}He with the ALERT at 11 GeV

Sangbaek Lee

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Physics Motivation

- The Gravitational form factors are an elegant and fundamental way to describe the mechanical properties of nucleons and nuclei
  - They allow to access the mass, pressure and shear forces densities
    - Approved ALERT will provide needed information in the quark sector with DVCS and the gluon sector with DVMP (ϕ production). However, J/ψ production is even cleaner to access the gluonic GFFs.
- Is it possible to determine the gluon gravitational form factors of ^{4}He?
  - *That is a goal this draft proposal wants to address.*

Gravitational Form Factors $\langle p', s'|T^a_{\mu\nu}|p, s\rangle = \bar{u}(p')\big[\frac{1}{2}\gamma_{\{\mu}P_{\nu\}}A_a(t) + \frac{iP_{\{\mu}\sigma_{\nu\}\rho}q^\rho}{4M_N}B_a(t) + \frac{q_\mu q_\nu - g_{\mu\nu}q^2}{M_N}C_a(t) + M_N\bar{C}_a(t)g_{\mu\nu}\big]u(p), \qquad \sum_a \bar{C}_a(t) = 0,\ a = g, u, d, ...$

Druck-term $D(t)$=4$C(t)$ is related to the pressure distribution.

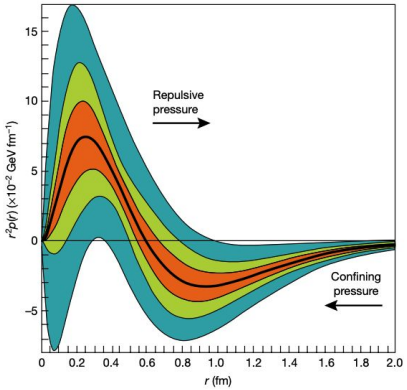
For example, in the Breit Frame, $p(r) = \frac{1}{6M}\int \frac{d\mathbf{\Delta}}{(2\pi)^3} e^{i\mathbf{\Delta}\cdot\mathbf{r}} tD(t)$

The related radii are $\langle r^2\rangle_s = 6\frac{dA(t)}{dt}\Big|_{t=0} - \frac{9D(0)}{2M^2}$ $\langle r^2\rangle_m = 6\frac{dA(t)}{dt}\Big|_{t=0} - \frac{3D(0)}{2M^2}$ $\langle r^2\rangle_t = 6\frac{dA(t)}{dt}\Big|_{t=0}$

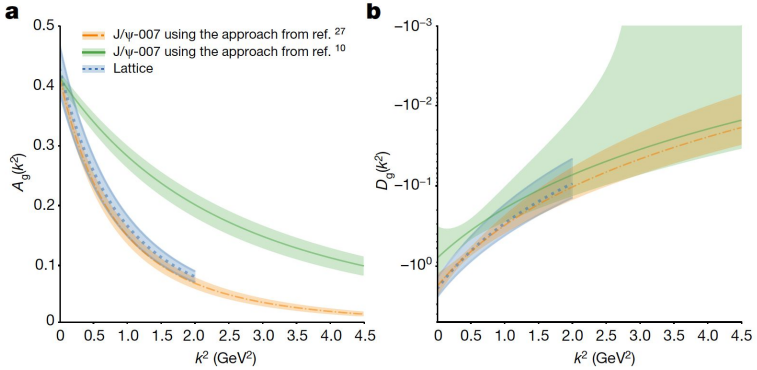
Nucleon Gravitational Form Factor (GFFs)

A recent history

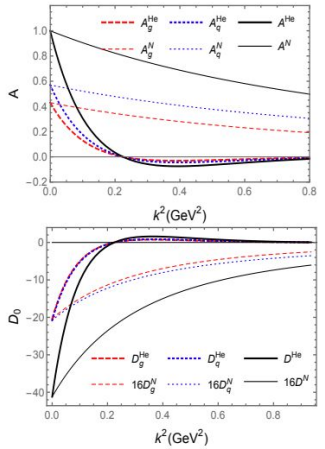
- First extraction of the quarks GFF [$D_q(t)$] using DVCS. Pressure and shear forces in the Breit frame displayed
- First extraction of the gluonic GFFs [$A_g(t)$ and $D_g(t)$] on the proton using near-threshold J/ψ photoproduction off the proton
- The theoretical predictions for **nuclei** GFFs using different models has been recently produced and published



V. Burkert, L. Elouadrhiri & F. X. Girod, Nature 557, 396–399 (2018)



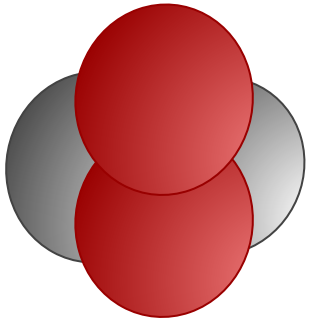
B. Duran et al., Nature 615, 813-816 (2023)



F. He and I. Zahed, arXiv:2310.12315

Gravitational Form Factor (GFFs)

From nucleon to spin zero nuclei



- ^{4}He is
  - a tightly-bound system
  - spin-0 → simpler structure for the electromagnetic and gravitational

$$\langle p', s'|T^a_{\mu\nu}|p, s\rangle = \bar{u}(p')\Big[\frac{1}{2}\gamma_{\{\mu}P_{\nu\}}A_a(t) + \frac{iP_{\{\mu}\sigma_{\nu\}\rho}q^\rho}{4M_N}B_a(t) + \frac{q_\mu q_\nu - g_{\mu\nu}q^2}{M_N}C_a(t) + M_N\bar{C}_a(t)g_{\mu\nu}\Big]u(p)$$

$$= \bar{u}(p')\left[\frac{P_\mu P_\nu}{M_N}A(t) + \frac{iP_{\{\mu}\sigma_{\nu\}\rho}q^\rho}{2M_N}J(t) + \frac{q_\mu q_\nu - g_{\mu\nu}q^2}{4M_N}D(t) + M_N\bar{C}^a(t)\right]u(p)$$

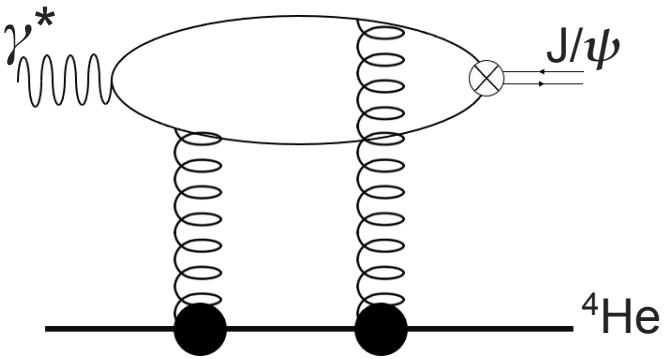
$$\longrightarrow \quad \langle p'|T^a_{\mu\nu}(x)|p\rangle = \left[2P_\mu P_\nu A^a(t) + \frac{1}{2}(q_\mu q_\nu - g_{\mu\nu}q^2)D^a(t) + 2M_N^2\bar{C}^a(t)\right]$$

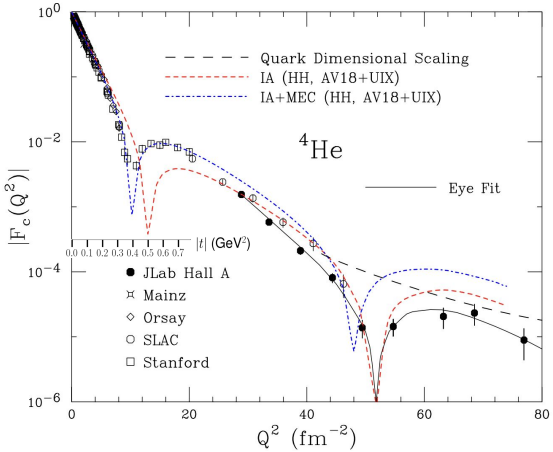
$$\sum_a \bar{C}_a(t) = 0, \;\; a = g, u, d, ...$$

  - has a comparable mass to the J/psi
    - ^{4}He: 3.73 GeV, J/ψ: 3.1 GeV

Proposed Measurement

- **Coherent J/ψ** production on **^{4}He** with **CLAS12** and **ALERT.**
  - ALERT runs at high luminosity $L > 10^{35}$ cm^{-2}s^{-1} with a gas target
  - Kinematics will center in $|t|$ around the first minimum of the charge form factor
  - It would be important to determine the existence and position of a minimum for the gluonic form factor for ^{4}He.
  - **Measure** the **$|t|$ and E_γ** dependence of the J/ψ production cross section at low Q^2



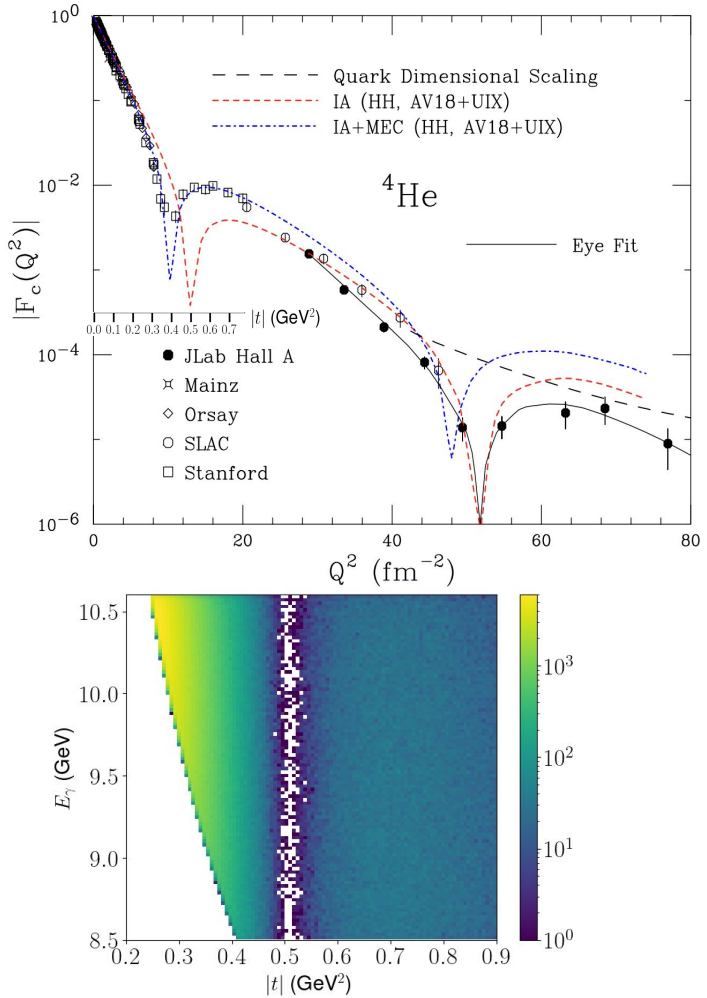


- Hall A charge form factor
  - Phys. Rev. Lett. 112, 132503 (2014)

Objectives of Experiment

1. Determination of the diffraction minimum.
   - Charge form factor has the first diffraction minimum at $|t|\sim 0.4–0.5$ GeV^2.
   - Does the matter distribution of the ^{4}He follow the charge distribution?

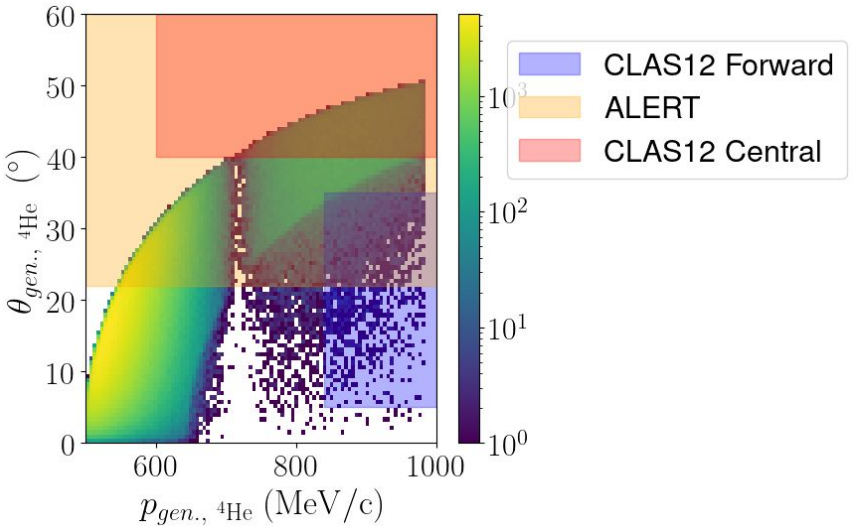
2. Measurement of t-dependent cross sections
   - We extract the GFFs of ^{4}He.
   - We separate the A and D form factor to achieve the pressure distribution using the D form factor.
   - **First extraction of GFFs of the light nuclei**

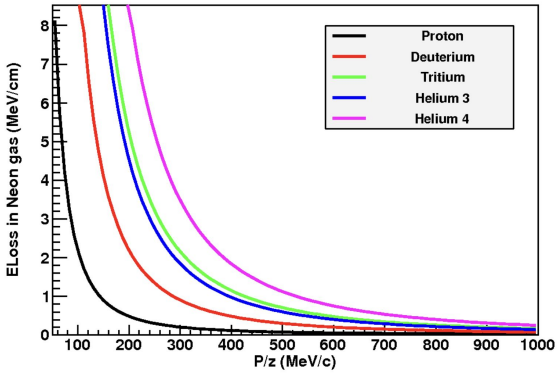


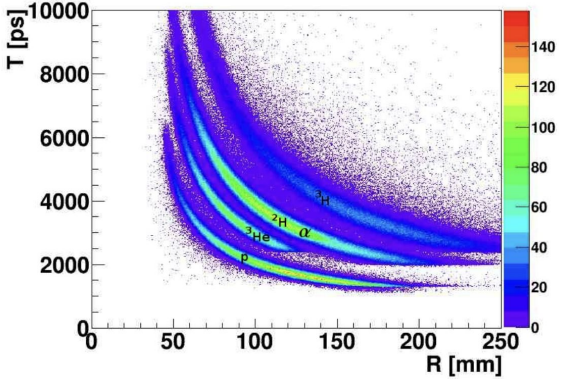
Why ALERT?

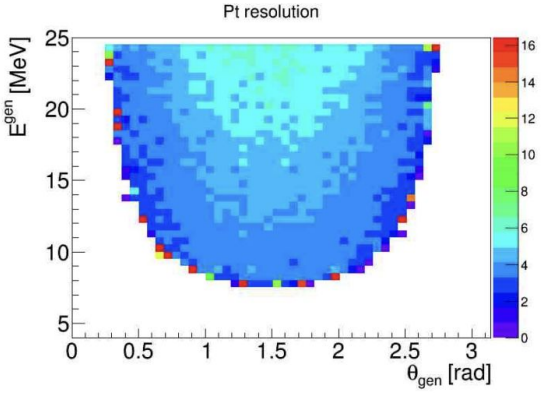
- ALERT offers
  1. Large detector acceptance
  2. PID to reject the incoherent background
  3. Reconstruction for measuring $|t|$

  for the ^{4}He recoil.





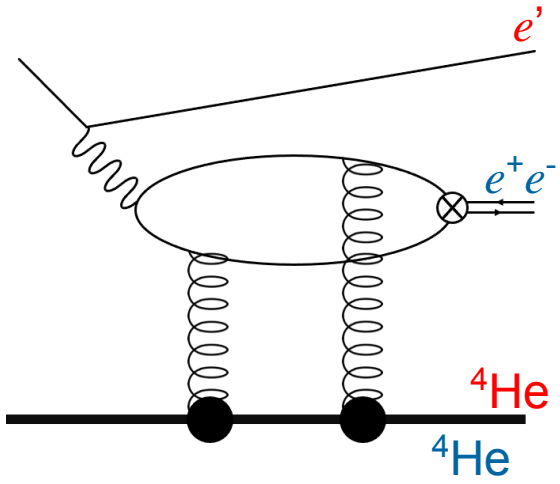


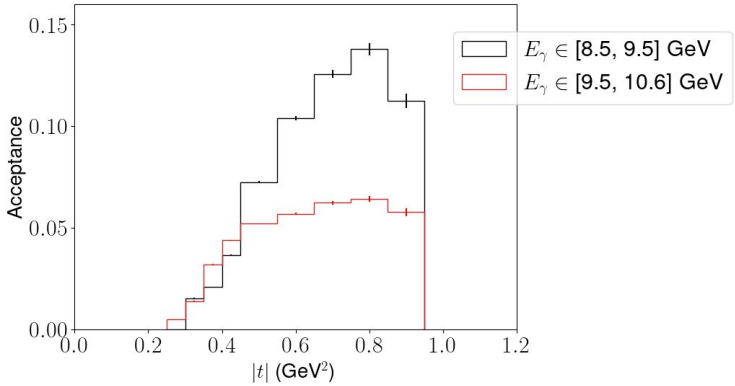


From approved ALERT proposal E12-17-012 (arXiv:1708.00888)

Detector Acceptance

Topology	Particle	Detector	Condition
1	e' (trigger)	Forward Tagger	p > 0.5 GeV/c 2.5°<θ<4.5°
		Forward Detectors	p > 1 GeV/c CLAS12 FastMC
	^{4}He	ALERT	r > 8 cm (ATOF)
2	e^+e^- (trigger)	Forward Detectors	p > 1 GeV/c CLAS12 FastMC
	^{4}He	ALERT	r > 8 cm (ATOF)



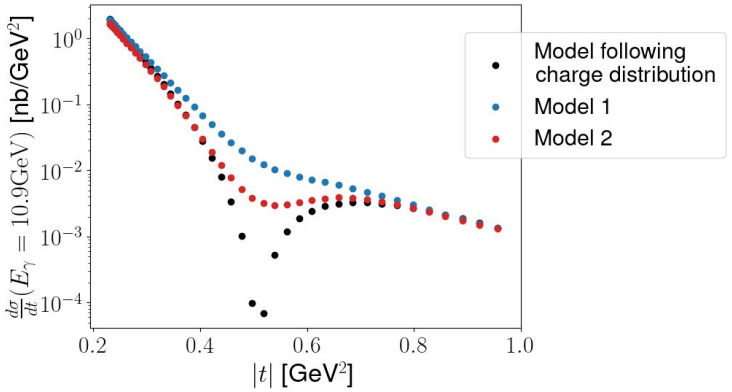


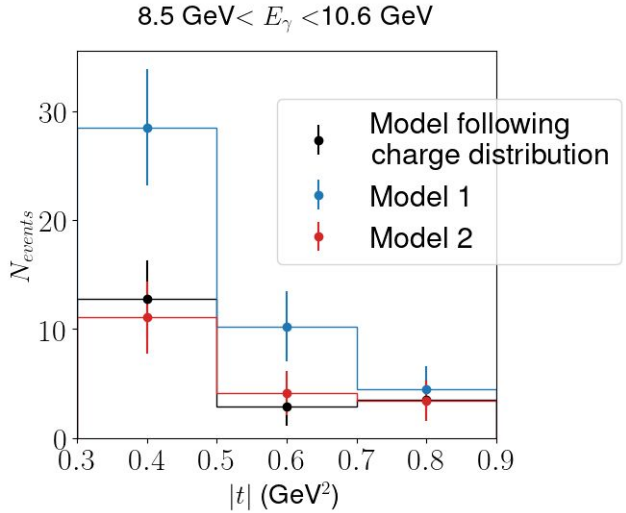
- ^{4}He p was smeared out with 5% resolution.
- Topology 2 has higher geometrical acceptance
  - Caveat) BR(J/$\psi \to e^+e^-$) = 5.971%

Run Group-L Statistics

Looking at the Diffraction Minimum with the RG-L

- ALERT uses the gaseous ^{4}He target
- (7 atm, 40 cm) leads to 7×10^{21} cm^{-2} target thickness.
- ALERT (RG-L) approved beam time:
  - ~60 nb^{-1}/s (nucleon), 10 days
  - ~30 nb^{-1}/s (nucleon), 20 days
  - 26 fb^{-1} integrated luminosity for the nuclei (coherent process)
- Chose a bin such that the existence (or location) of the first diffraction minimum can be checked.
- Question revisited) Does the charge distribution follow the gluon distribution?

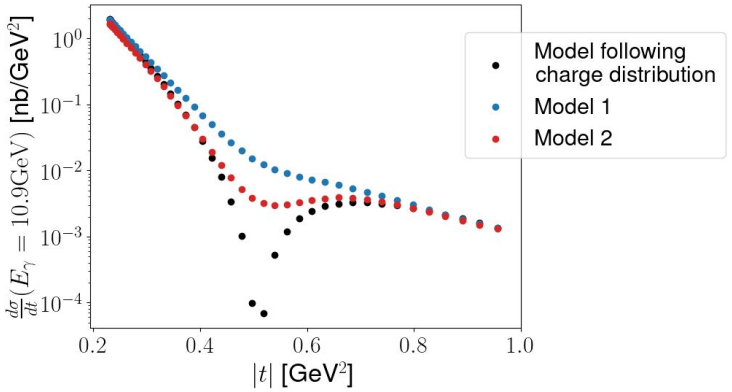




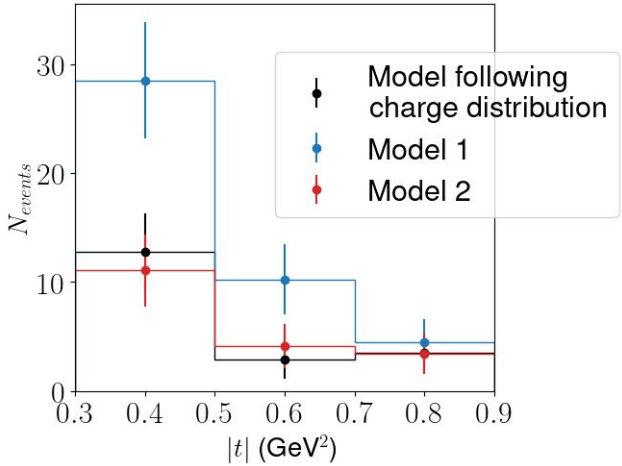
Lessons from the RG-L

- With the successful run in the approved RG-L beam time,
  - the overall size of cross section can be established
  - the feasibility of the measurement
  - determination of the diffraction minimum, contingent on the actual t-dependence of the cross section

- With this result, we can improve the proposed measurement with new beam time
  - Detailed efficiency/ acceptance study
  - Refined phase space
  - Improve projected statistical uncertainties



8.5 GeV< E_γ <10.6 GeV



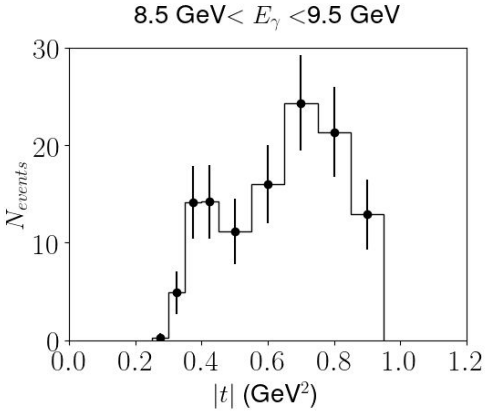
New beam time proposal

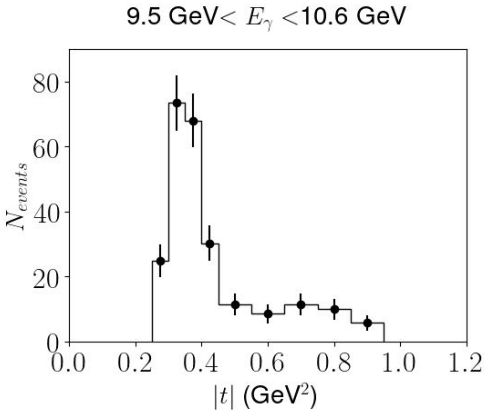
Projected Results and Requested Beamtime

- To ensure that each bin has more than 10 counts, 450 fb^{-1} is the nominal integrated luminosity for coherent processes.
  - RG-L approved: 26 fb^{-1}

- With ALERT and a factor of 2 luminosity upgrade, a luminosity of L = $5x10^{34}$ $cm^{-2}s^{-1}$ is possible for the coherent process at a beam current 1.16 μA
  - the beam blocker limit: 1.3 μA
    (R. Paremuzyan, https://indico.ijclab.in2p3.fr/event/9131/contributions/28948/attachments/20755/28907/Paris_Workshop_2023.pdf)

- We request beam time of 98 days with ALERT and ^{4}He target in CLAS12





Accessing the GFFs and Binning

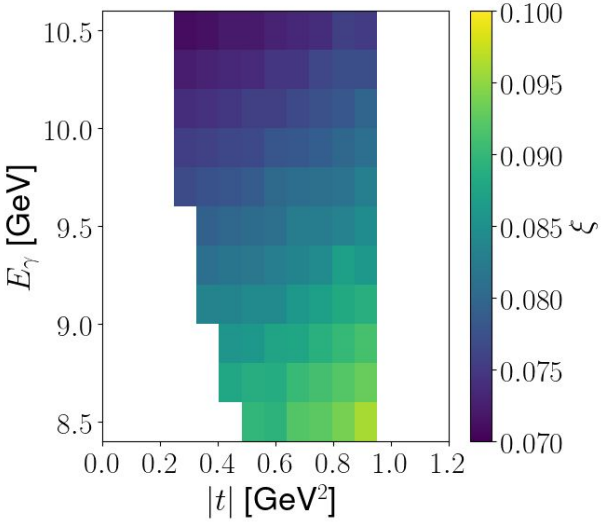
$$\frac{d\sigma}{dt} = \text{Kinematic Factor}(E_\gamma, t) \times |A(t) + \xi^2 D(t)|^2$$

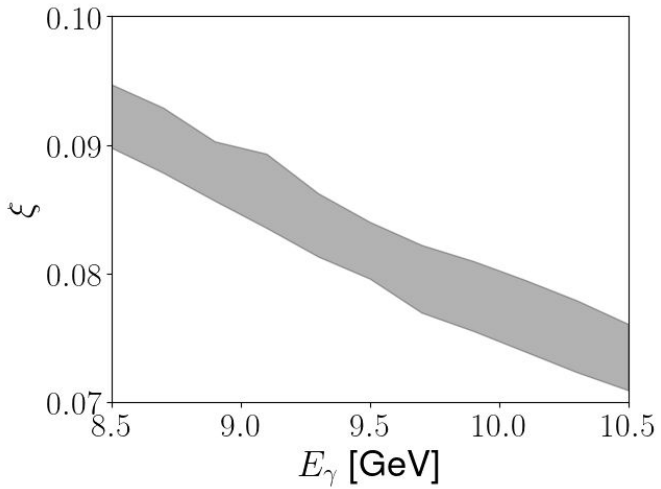
$$\xi = \frac{t - M_{J/\psi}^2}{2M_{^4He}^2 + M_{J/\psi}^2 - 2W^2 - t}$$

$$\begin{cases} A(t) + \xi_1^2 D(t) = F[\sqrt{\frac{d\sigma}{dt}}_1, \xi_1; t] \\ A(t) + \xi_2^2 D(t) = F[\sqrt{\frac{d\sigma}{dt}}_2, \xi_2; t] \end{cases}$$

- 2 bins in $E\gamma$

  Bin 1: [8.5, 9 .5] GeV
  Bin 2: [9.5, 10.6] GeV
- 9 bins in $|t|$





Summary

- We propose to use CLAS12 and ALERT to study QCD in nuclei
  - Coherent J/psi electroproduction on ^{4}He at 11 GeV
  - First extraction of GFFs for ^{4}He

- Next steps towards the proposal
  - Careful investigation of all backgrounds with simulation
  - Update the projection of the latest cross section models
  - Refine measured cross-section binning for the optimal GFF extraction
  - Perform the impact study on the GFFs using detailed simulation data