Electroproduction of ϕ mesons off ^{4}He

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CLAS Collaboration Meeting
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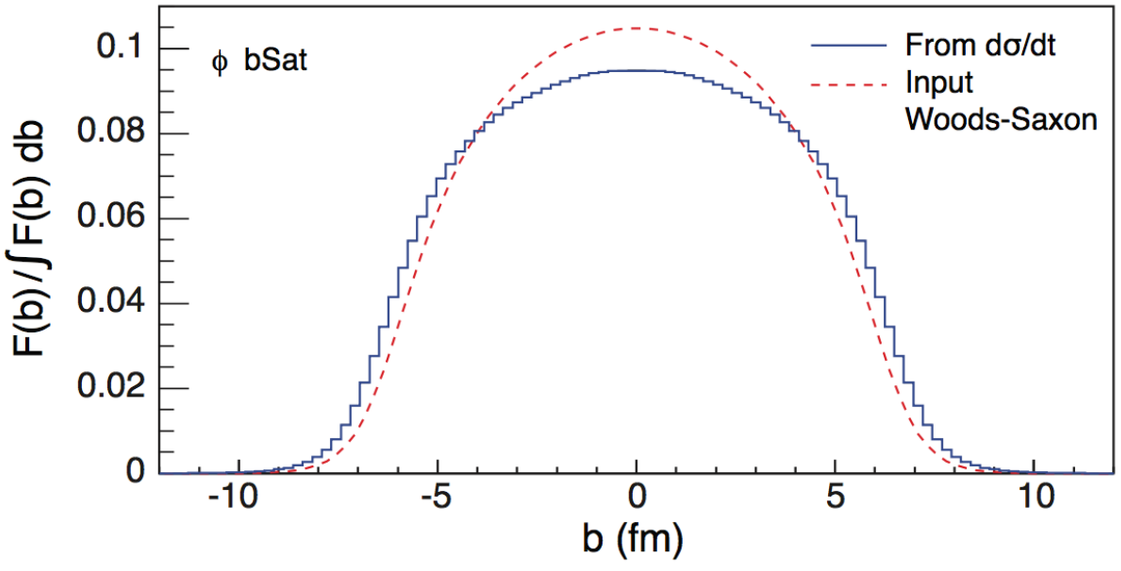
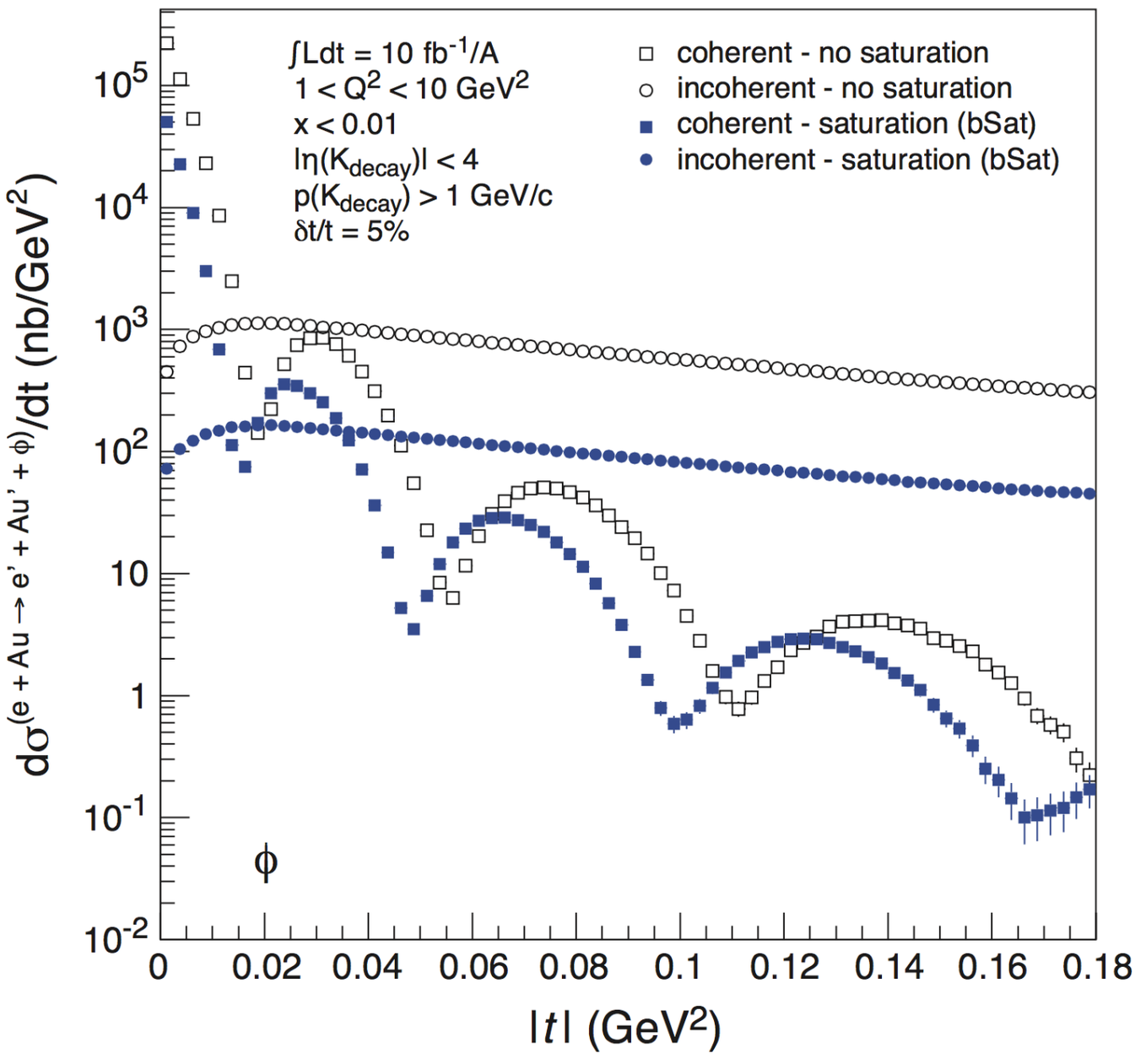
Coherent production of J/Ψ and ϕ at EIC

- **EIC White Paper**: Tull and Ullrich[1,2]: Measurements of Diffractive Events (p.83)

- Uses convention of Munier, Stasto, and Mueller[3]:
  - Fourier transform of cross section can give information on gluon distribution in impact parameter (b) space!

$$F(b) = \int_0^\infty \frac{dq\,q}{2\pi} J_0(q\,b) \sqrt{\frac{d\sigma_{coherent}}{dt}}$$

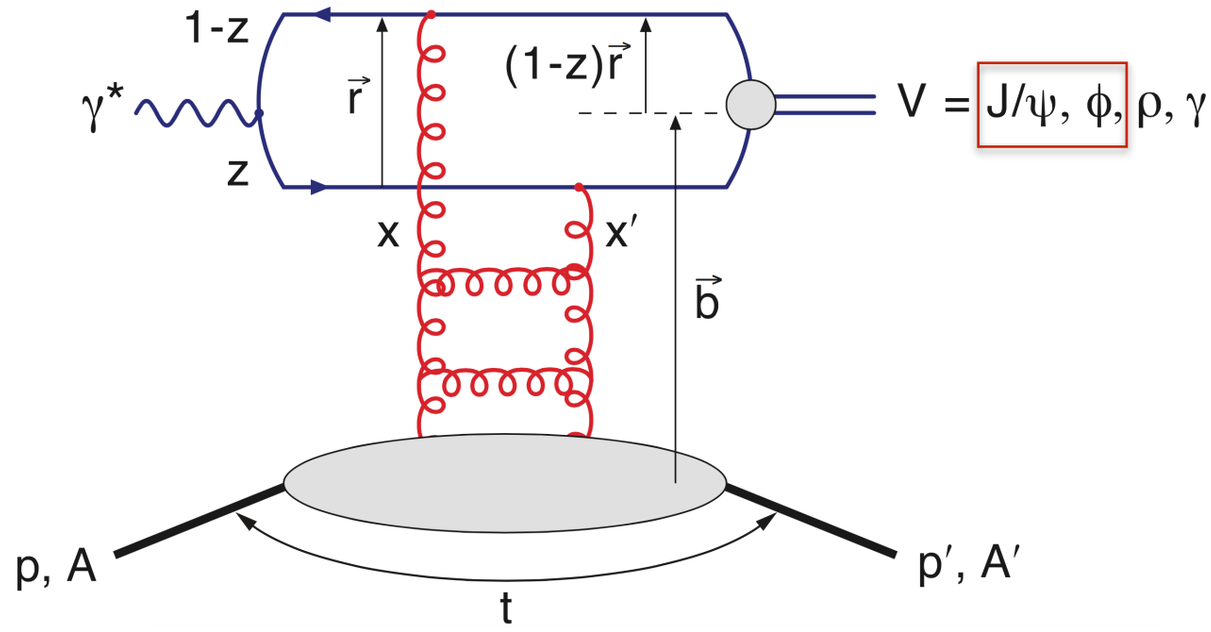




[1]EIC white paper (arXiv:1212.1701)
[2]Phys. Rev. C 87, 024913 (2013) (arXiv:1211.3048)
[3]Nucl.Phys. B603 (2001) 427-445 (arXiv:hep-ph/0102291)

$c\bar{c}$ or $s\bar{s}$ production to probe gluon distributions

- Diffractive scattering occurs when the DIS electron interacts with a color-neutral vacuum excitation:
  - Within a perturbative QCD framework, this vacuum excitation can be represented by a combination of 2+ gluons (Pomeron).
- Hard diffractive cross-section is proportional to the square of the gluon density.
  - Most sensitive tool to access gluon density distributions



For J/Ψ and ϕ production, flavor disparity between target and meson suppresses direct quark exchange!

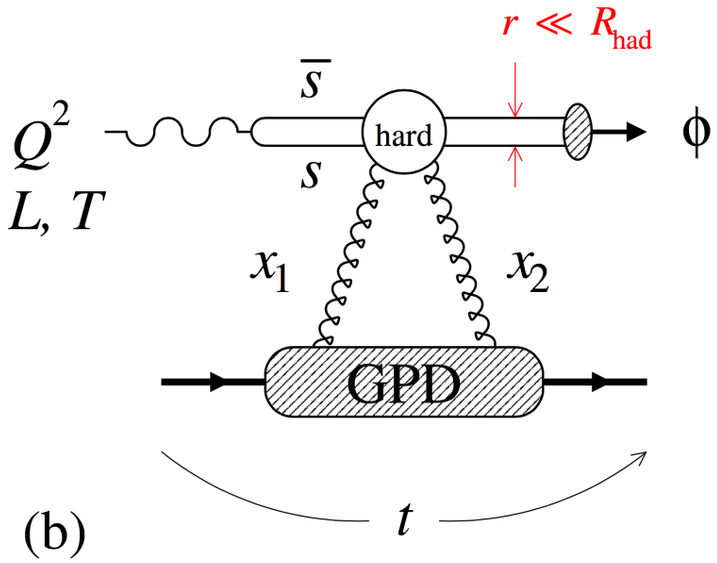
Tull, Ullrich dipole model formalism for diffractive DIS production amplitude on protons:

$$\mathcal{A}_{T,L}^{\gamma^* p \to V p}(x, Q, \Delta) = i \int \mathrm{d}r \int \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b} \left(\Psi_V^* \Psi\right)(r, z)$$

$$\times 2\pi r J_0([1-z]r\Delta) e^{-i\mathbf{b}\cdot\Delta} \frac{\mathrm{d}\sigma_{q\bar{q}}^{(p)}}{\mathrm{d}^2\mathbf{b}}(x, r, \mathbf{b}) \quad (1)$$

$\gamma^* + p \rightarrow p + \phi$ (CLAS12 proposed)

- Recent proposal in CLAS12 approved with a "B+" rating to study the gluonic density distribution on Hydrogen.



Proposal to Jefferson Lab PAC39
Exclusive Phi Meson Electroproduction with CLAS12

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[3] *Fairfield University*
[4] *Joint Institute for Nuclear Research, Dubna, Russia*
[5] *Institut de Physique Nucleaire Orsay, France*
[6] *Rensselaer Polytechnic Institute*
[7] *Department of Physics, University of Connecticut, Storrs, CT 06269, USA*
[8] *Wuppertal University, Wuppertal, Germany*
[9] *LPSC Grenoble, France*

- In the GPD framework, the light-cone momentum fractions are: $x_{1,2} = x \pm \xi$
- The momentum transfer is then: $\xi = x_B/(2 - x_B)$
- and the gluon GPD is written: $H_g(x, \xi; t)$ with $H_g(x, \xi = 0, t = 0) = xg(x)$
- The longitudinal cross-section is then written:

$$\frac{d\sigma_L}{dt} = \frac{\alpha_{\rm em}}{Q^2} \frac{x_B^2}{1 - x_B} \left[(1 - \xi^2) |\langle H_g \rangle|^2 + \text{terms in } \langle E_g \rangle \right]$$

$\gamma^* + p \rightarrow p + \phi$ (CLAS12 proposed)

- A useful parameter to describe the gluon density distribution is the reduced gluon distribution:

$$\rho_g(x,b) \equiv g(x,b)/g(x)$$

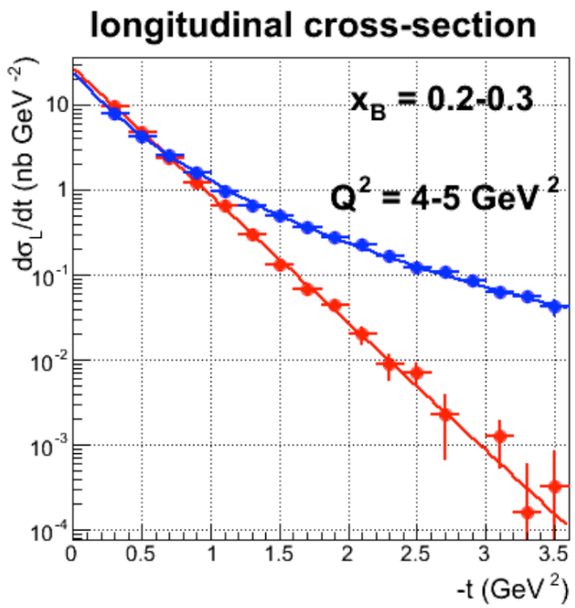
- Then, defining a gluonic form-factor as:

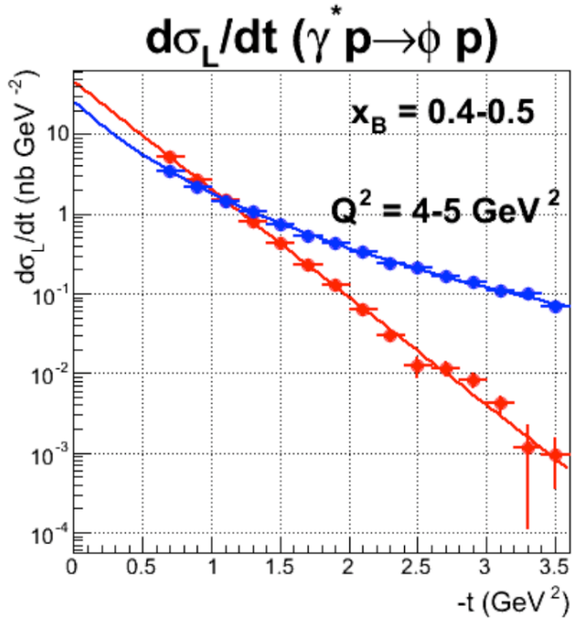
$$F_g(x,t) \equiv H_g(x,\xi=0,t)/H_g(x,\xi=0,t=0)$$

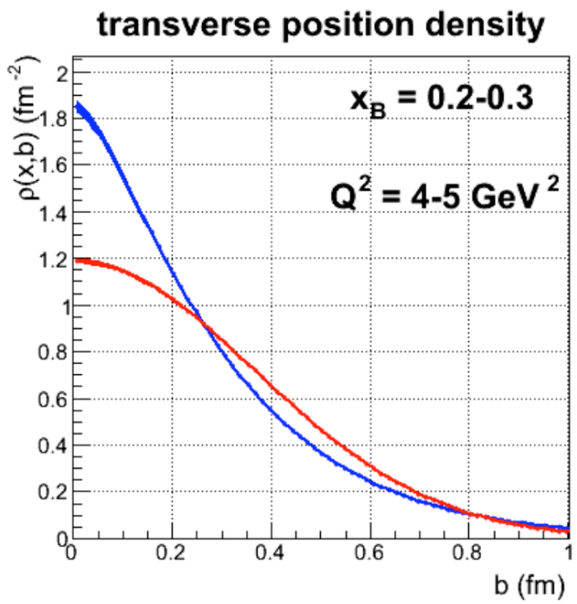
- One can extract the gluon distribution via Fourier transform:

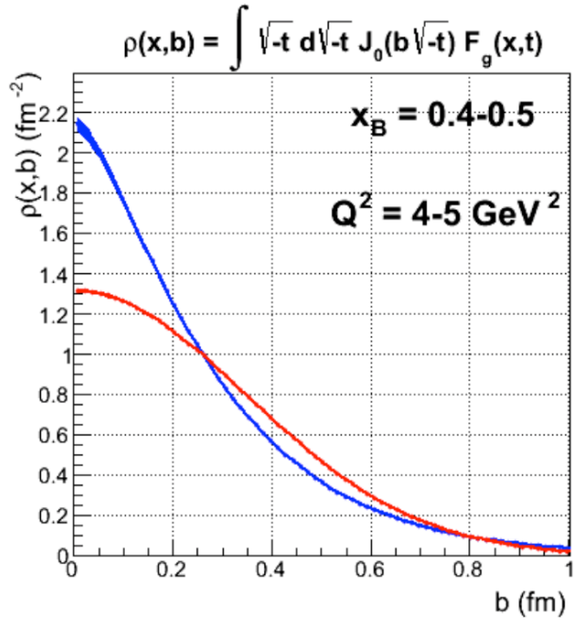
$$\rho_g(x,b) = \int \frac{d^2\Delta_T}{(2\pi)^2} e^{i(\boldsymbol{\Delta}_T \boldsymbol{b})} F_g(x,t=-\boldsymbol{\Delta}_T^2)$$

The red and blue curves correspond respectively to an exponential or dipole parameterization of the cross-section.







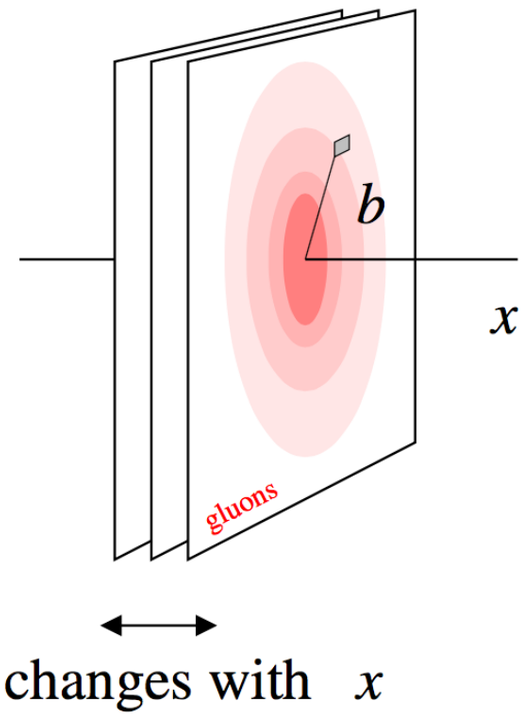


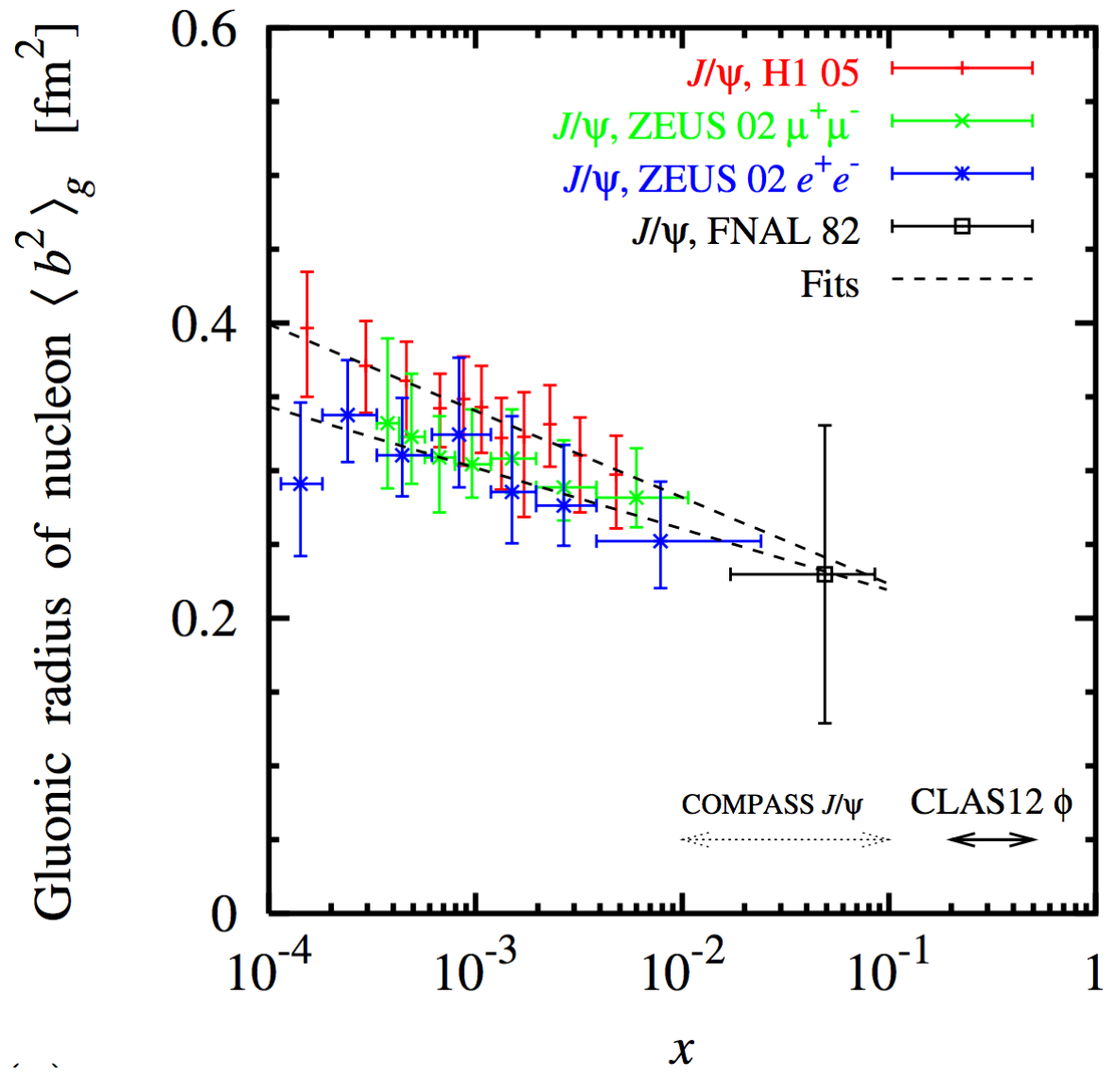
$\gamma^* + p \rightarrow p + \phi$ (CLAS12 proposed)

- One can also access the gluonic radius in x-space by defining the average gluonic transverse radius as:

$$\langle b^2 \rangle_g \equiv \int d^2b\, b^2\, \rho_g(b,x) = 4\frac{\partial F_g}{\partial t}(t=0)$$

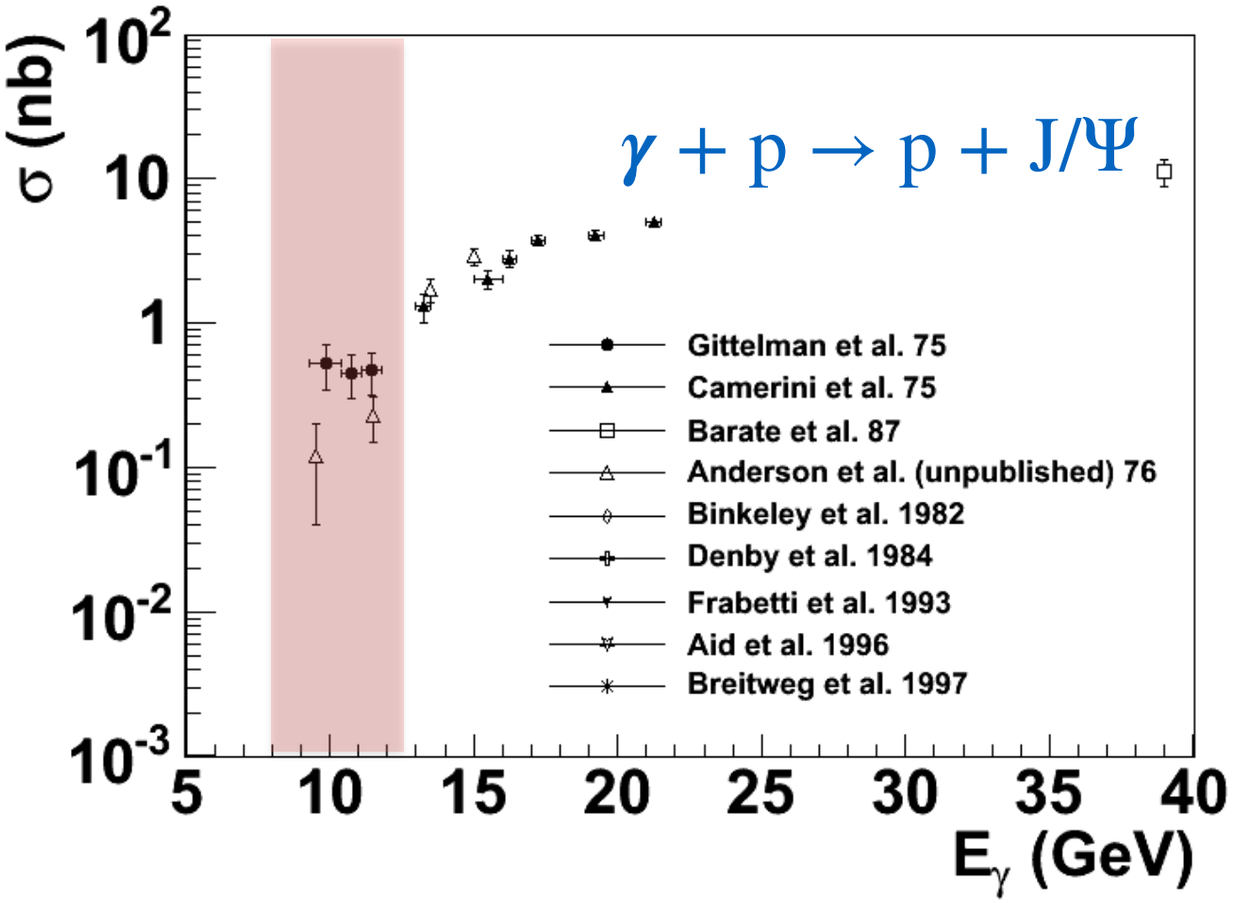
- J/Ψ studies have been performed at HERA and FNAL to extract the gluon radius.

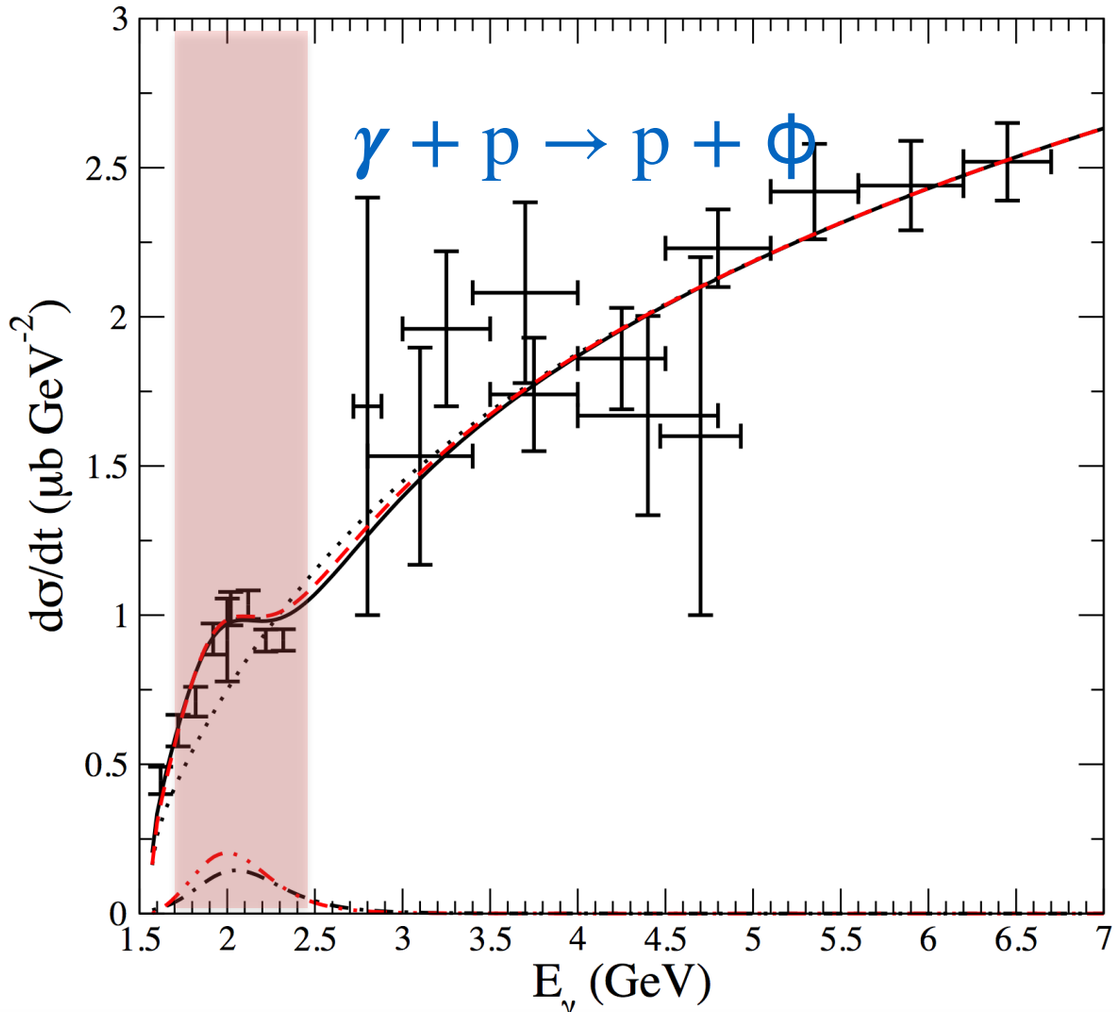




Electroproduction of ϕ near threshold

- There is a predicted resonance (LHCb pentaquark) at threshold in the p + J/Ψ channel.
  - Early measurements have shown a possible signature as a threshold enhancement.
- A similar type of threshold enhancement is seen in the ϕ photoproduction data.





Kiswhandi, Yang. Phys.Rev. C86 (2012)

Estimating the coherent ϕ electroproduction cross-section off ^{4}He

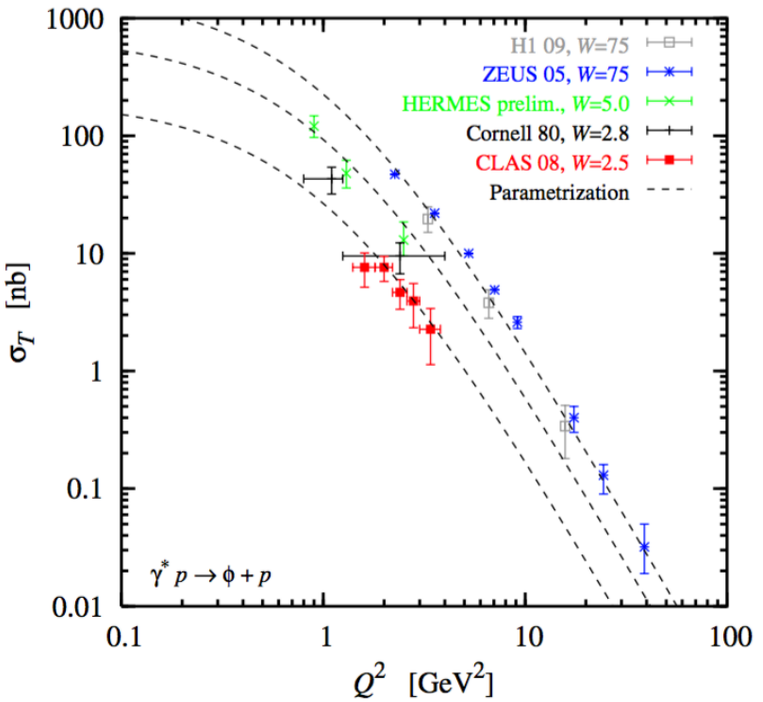
- Phenomenological approach to production off proton:

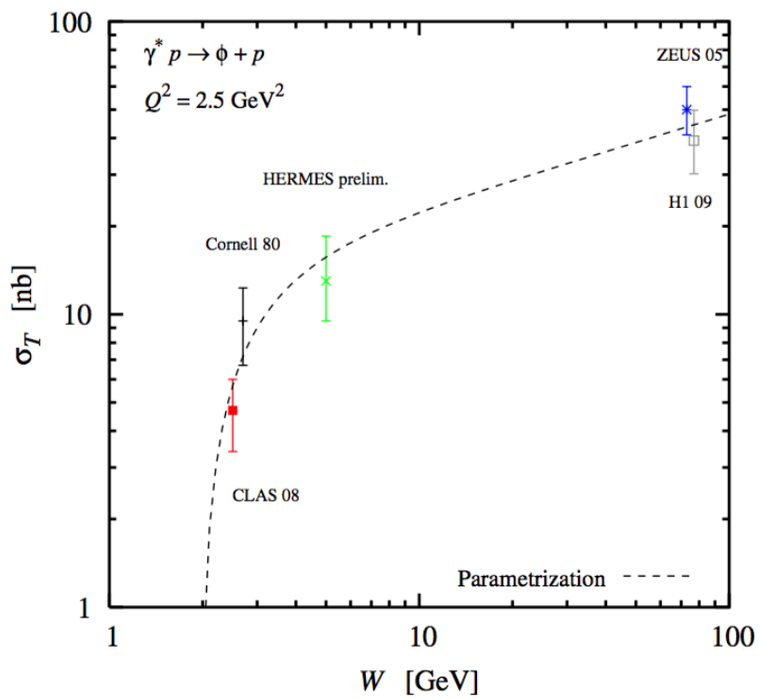
$$\frac{d\sigma}{dx_B dQ^2 dt} = \Gamma(Q^2, x_B, E)\left(\frac{d\sigma_T}{dt}(Q^2, x_B, t) + \epsilon\frac{d\sigma_L}{dt}(Q^2, x_B, t)\right)$$

  - Longitudinal and transverse response functions
  - Exponential t-dependance of ϕ
  - W, Q^2 dependence parameterized to world data.
- Kinematics are restricted to e + ^{4}He → e' + ^{4}He + ϕ.
  - Cross-section is calculated with (naively) modified "t" and "W":
    - "target nucleon" has random isotropically distributed fermi-momentum
    - "recoil nucleon" has (^{4}He momentum)/4 + random fermi-momentum
- Helium charge form factor $F_{c,4He}$ is calculated with both a Fourier-Bessel transform and DQSM for large Q^2.
  - Q^2 → |t - t_{min}| = t', for calculation of all form-factors.
- Cross-section goes like:

$$\frac{d\sigma_{^4He}}{dx_B dQ^2 dt} = \frac{d\sigma_p}{dx_B dQ^2 dt}\left|\frac{A\,F_C(t')_{^4He}}{F_C(t')_p}\right|^2$$

Identical parametrization as CLAS12 proposal for ϕ production off p





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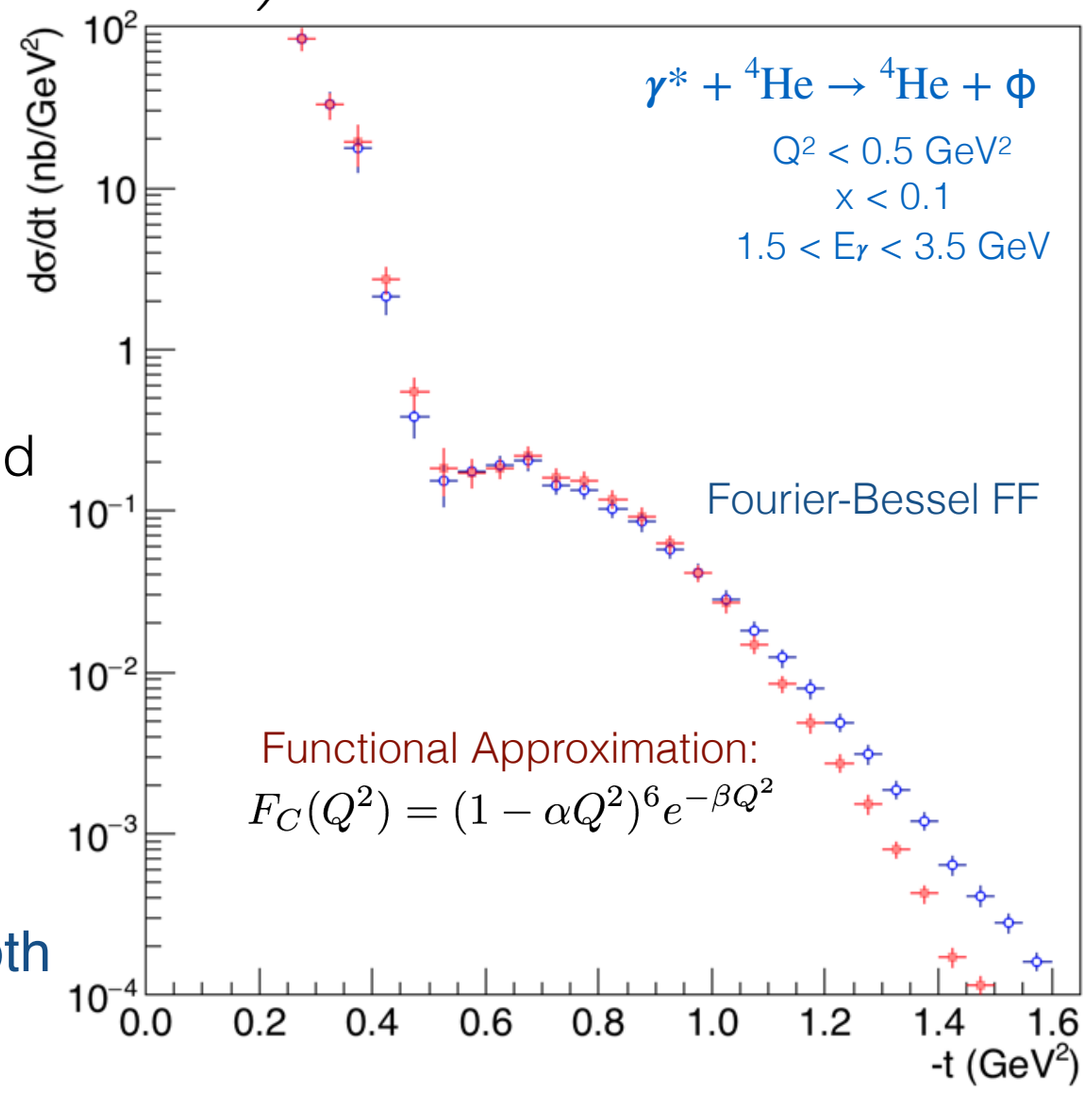
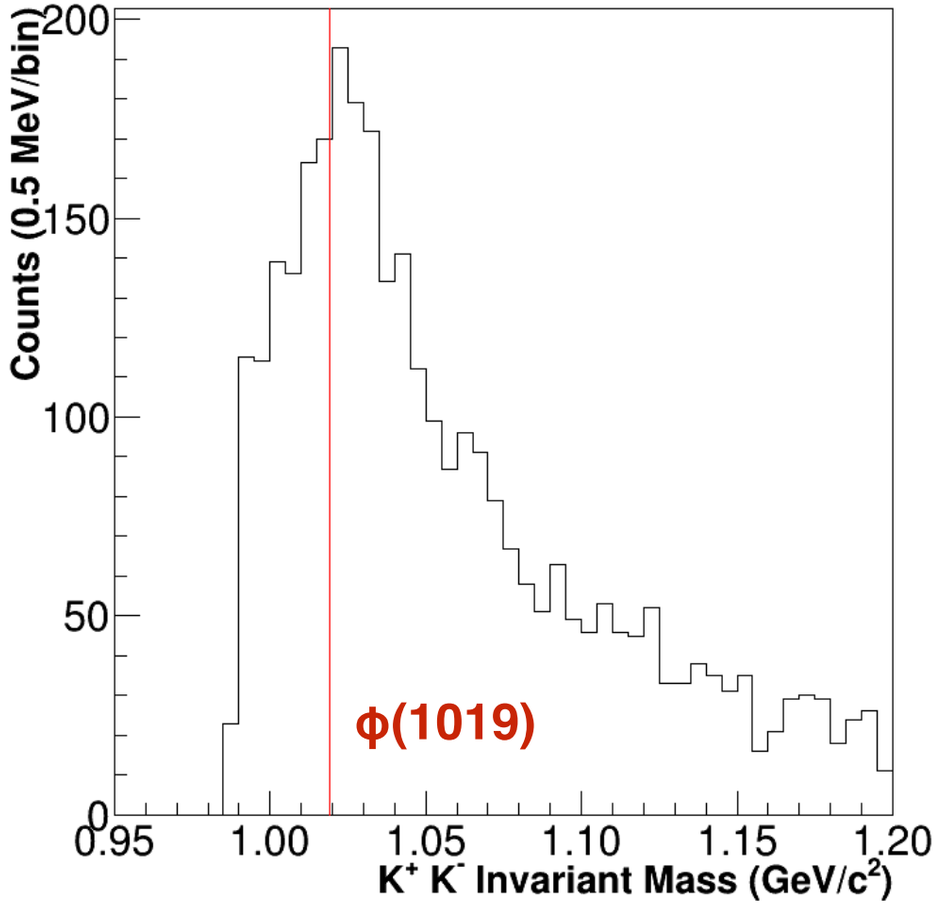


EG6

- The CLAS6 run eg6 is a good place to start looking.
- Initial “easiest channel” was explored:

$$\gamma^* + {}^4He \rightarrow ({}^4He) + K^+ + K^-$$

  - invariant mass of kaons = mass of phi.
  - ^{4}He left missing (no need for RTPC)

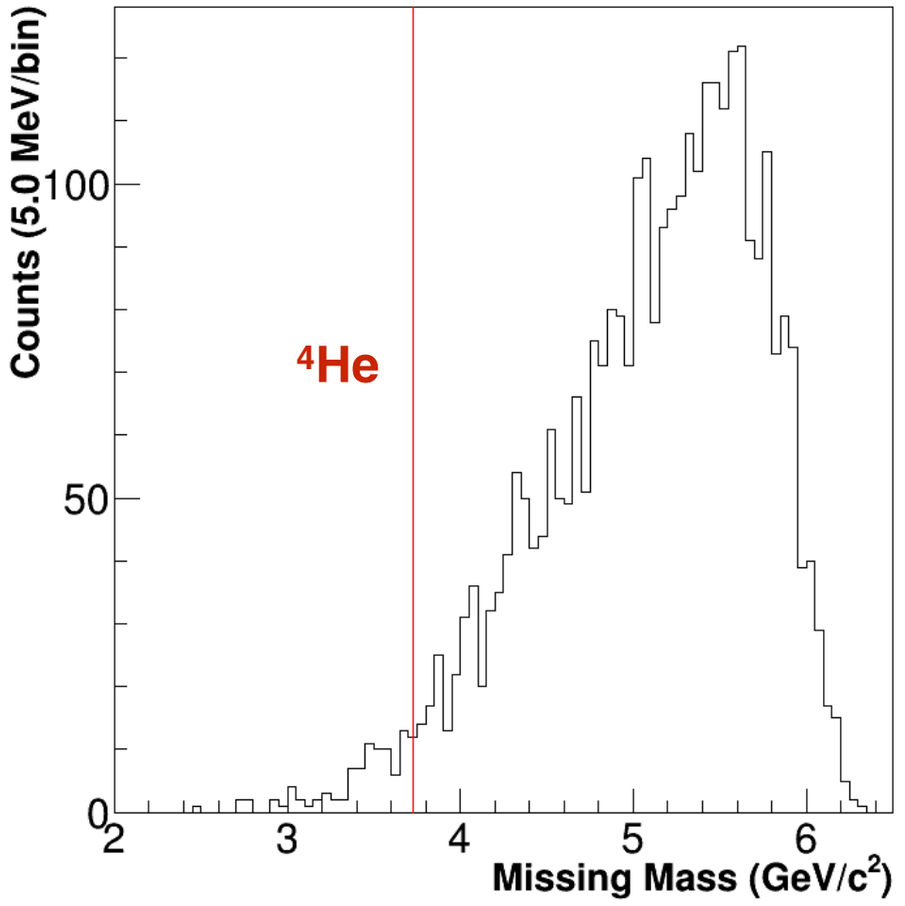


- More channels need to be explored:

$$\gamma^* + {}^4He \rightarrow {}^4He + K^+ + (K^-)$$

$$\gamma^* + {}^4He \rightarrow {}^4He + 3\gamma$$
$$(\phi \rightarrow \eta + \gamma, \quad \eta \rightarrow \gamma + \gamma)$$ ~ 0.5% BR

  - Model XS calculation allows MC simulation!
    - Should know soon what channels will yield what results.

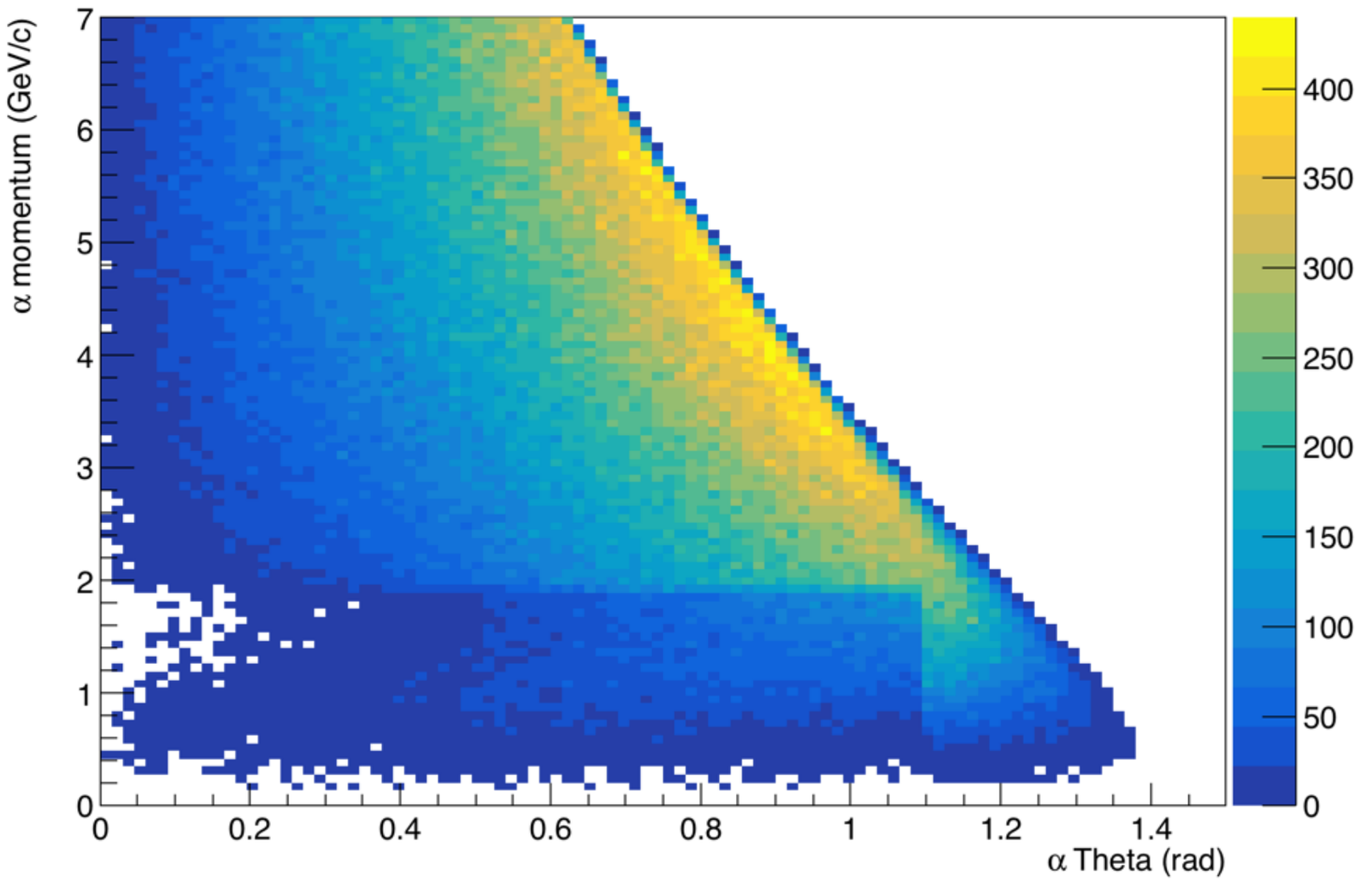


CLAS12 and ALERT

- We plan on producing a proposal for ϕ electroproduction off ^{4}He using the ALERT TPC detector to tag the scattered ^{4}He.
- Procedure:
  - Generate events with a reasonable cross-section **— Done**
  - Pass events through acceptance MC's
    - ALERT acceptance fast-MC for ^{4}He momenta up to 1.5 GeV **— Done** (preliminary, thanks to Gabriel Charles!)
      - (needs to be updated with latest MC as it is developed)
    - CLAS12 fast-MC
      - Geometrical acceptance through coatjava / groovy scripts. **—PROBLEM**
      - Track smearing with C++ fast-MC function **— Done**
      - Appropriate efficiencies for electron and kaon detection. **— To be done**
  - Generate realistic background events **— To be done**

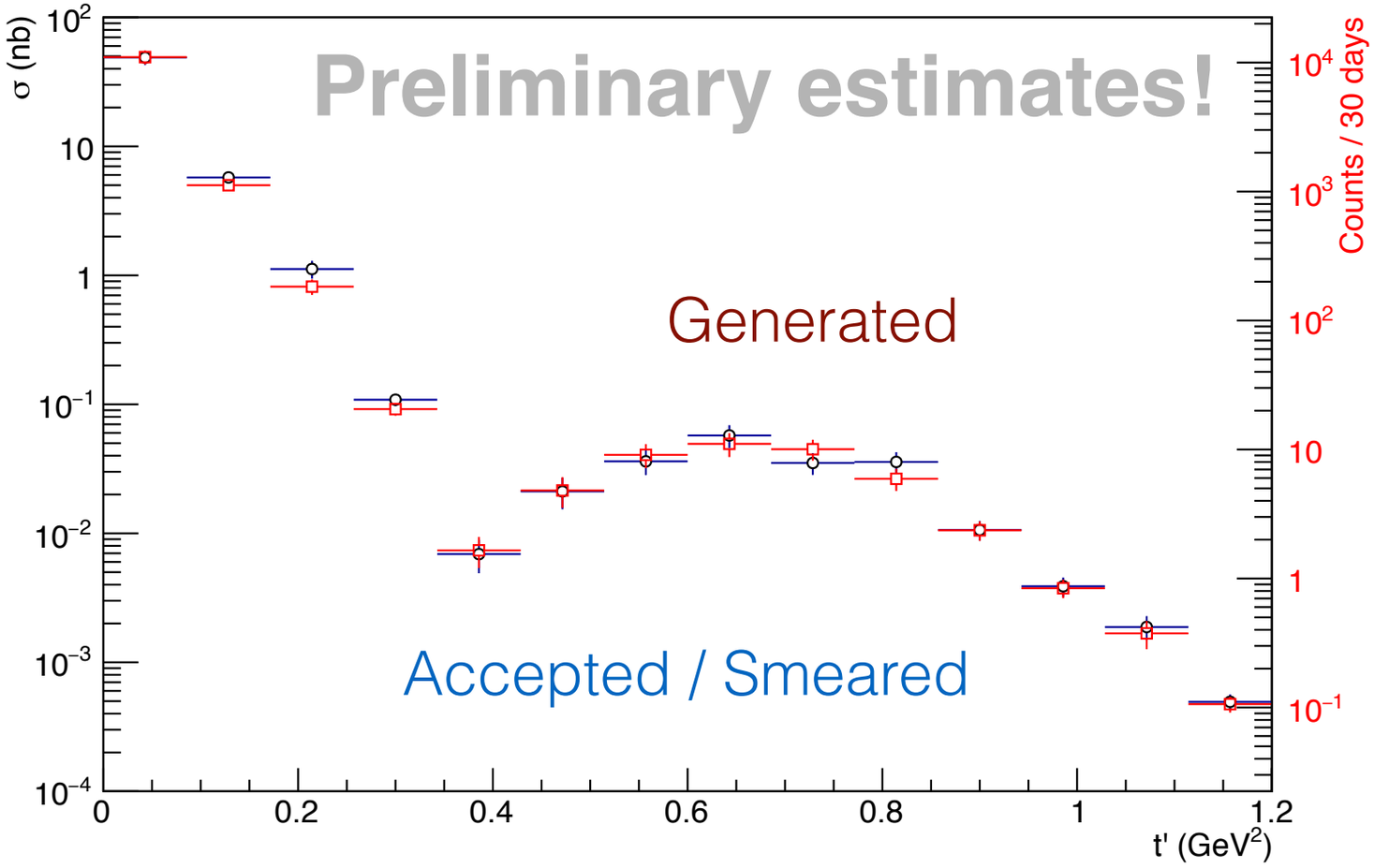
java fast-MC issue?

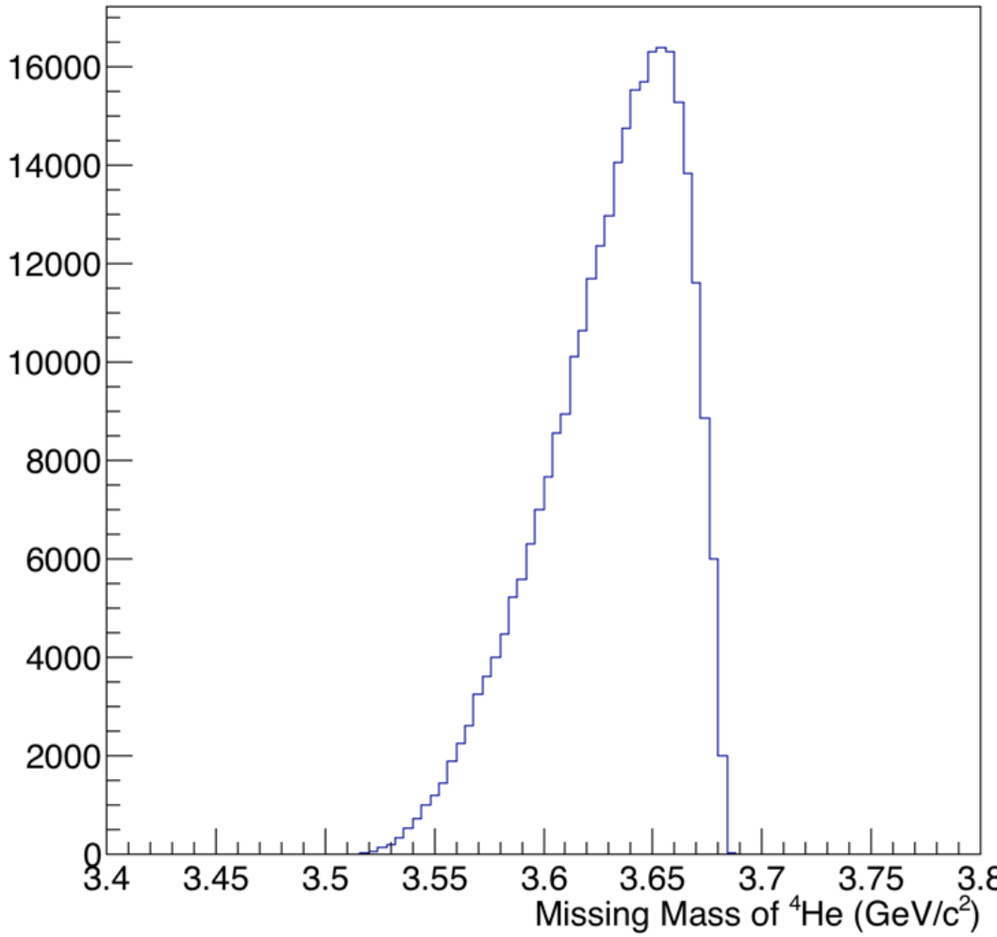
- coatjava fast-MC (LUND)
  - IN:
    - Generated events
  - OUT:
    - Generated events
    - Geometrically accepted events
- Strange structure in the “OUT:Generated events” (not seen in the input).
- Could be a bug I have introduced.



Untagged ^{4}He

- Since there is a problem with the ^{4}He events, lets assume everything else is done correctly in the fast MC, and look at what can be seen with no detected recoil ^{4}He.
- Rate calculation includes:
  - a luminosity of 1e35 cm^{-2} s^{-1}
  - electron and kaons only detected in forward CLAS12 acceptance.
  - an additional 50% detection efficiency for accepted electrons
  - an additional 10% detection efficiency for accepted Kaons





Summary

- Electroproduction of ϕ mesons off ^{4}He is a novel way of probing the gluon distributions of a light nucleus.
  - Threshold region is interesting!
- Experiments on the free proton are approved. Proposals are being prepared to study coherent ϕ off the nucleus at JLab.
- Simulations are underway to extract the exact precision that can be expected using the CLAS12 in concert with the ALERT TPC.

Thank You!