Probing Nuclear Color States with J/Ψ and ϕ

Michael Paolone
Temple University

Next Generation Nuclear Physics with JLab12 and the EIC

FIU - Miami, Florida
February 12th 2016

J/Ψ and φ experiments at a glance

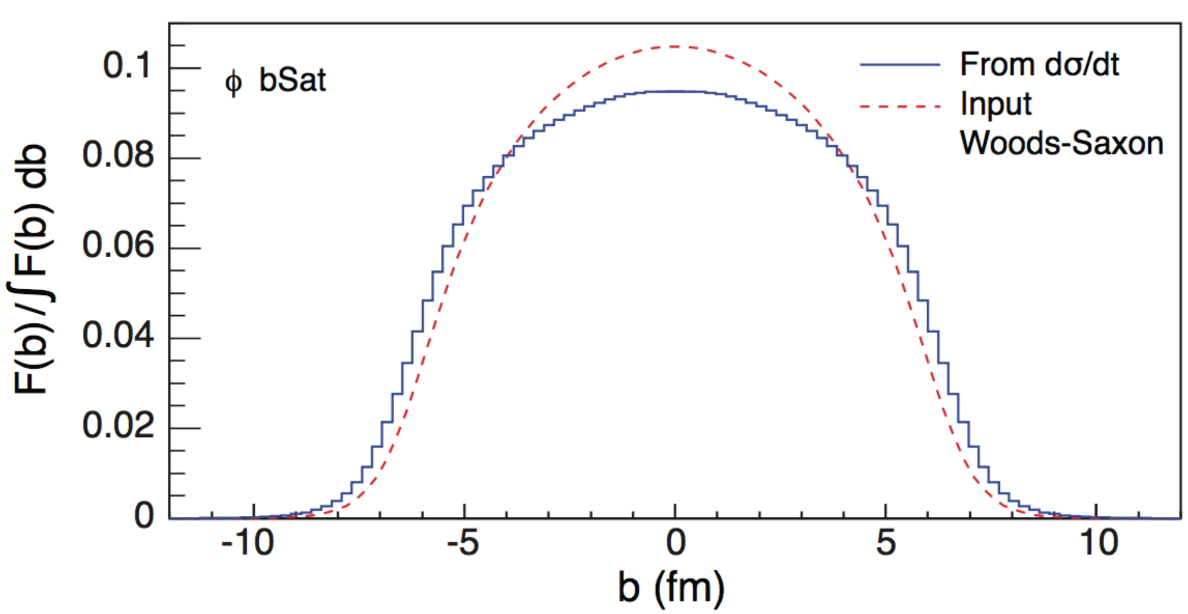
	JLab6	JLab12	EIC
φ off p	Many published results	Approved proposals	
φ off nuclei	Some published results, some data to be analyzed	Approved proposals (incoherent)	Proposed in white paper (coherent / incoherent)
J/Ψ off p		Approved proposals	
J/Ψ off nuclei		Proposals in progress	Proposed in white paper (coherent / incoherent)

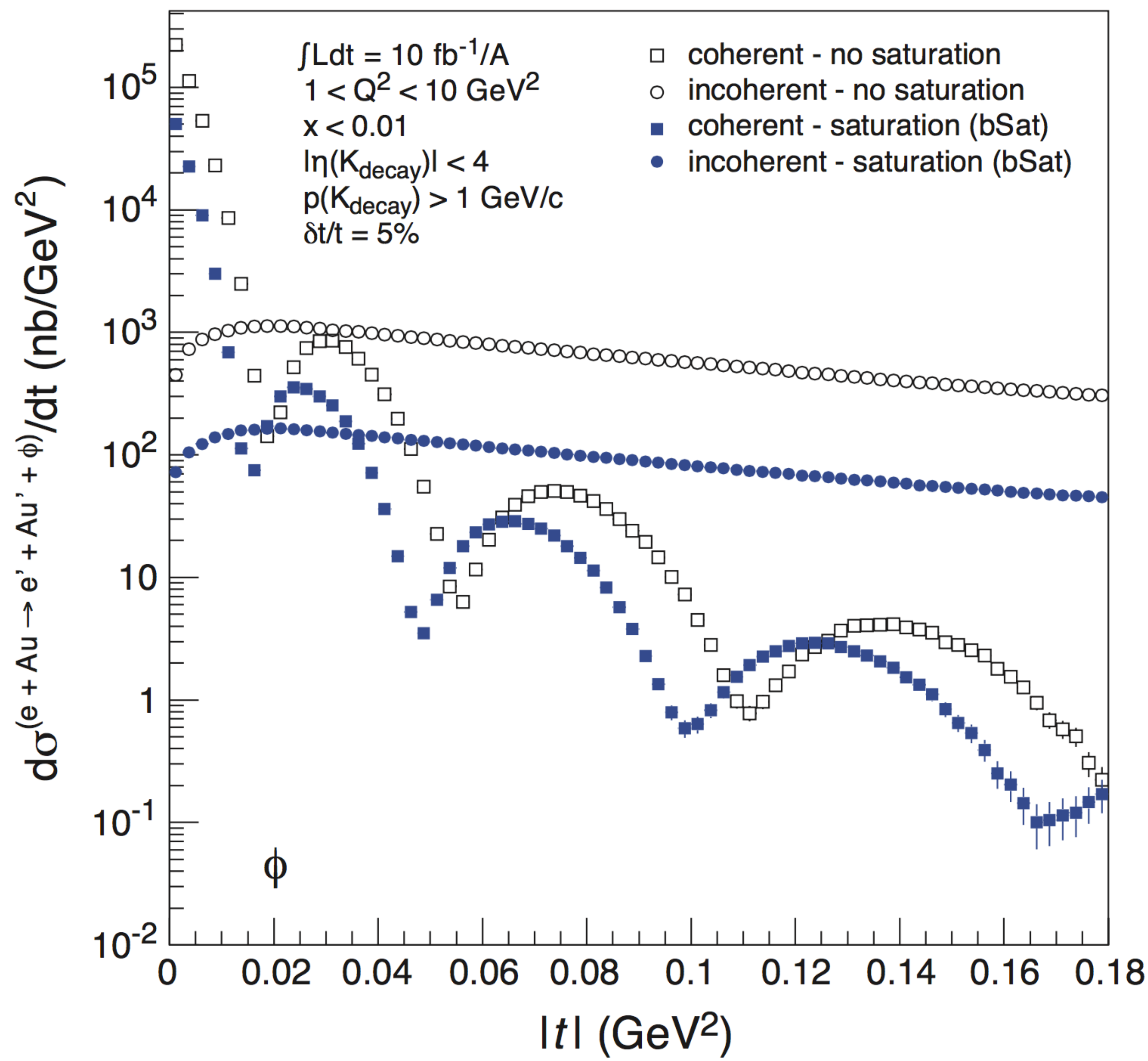
Coherent production of J/Ψ and ϕ at EIC

- **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!

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

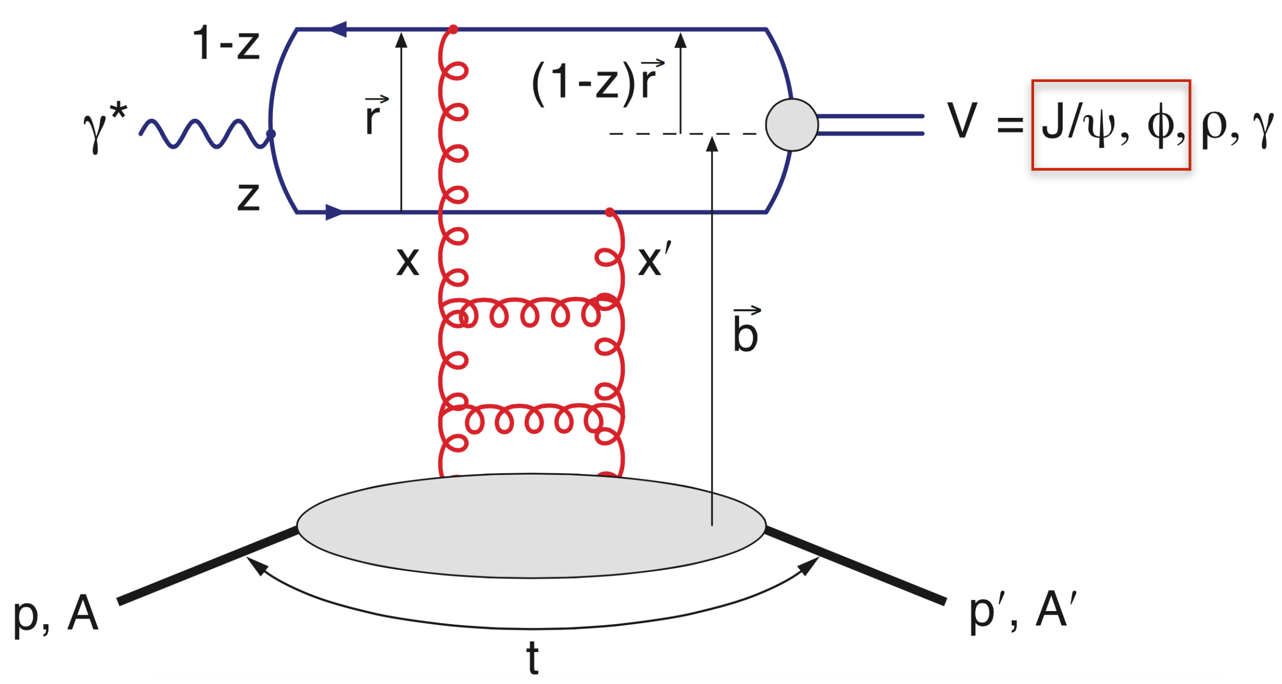




[1]EIC white paper (arXiv:1212.1701)
[2]Phys. Rev. C 87, 024913 (2013) (arXiv:1211.3048)
[3]Nucl.Phys. B603 (2001) 427-445 (arXiv:hep-ph/0102291)

$c\bar{c}$ 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!

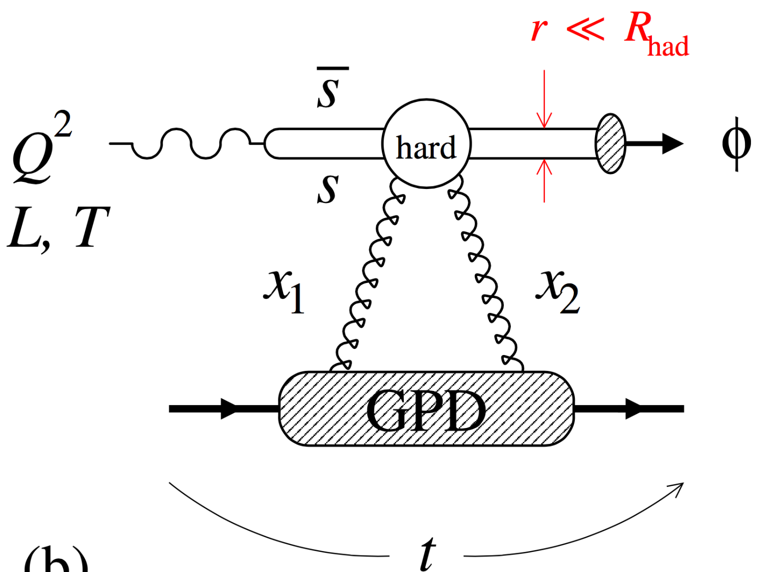
Tull, Ullrich dipole model formalism for diffractive DIS production amplitude on protons:

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

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

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

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



(b)

Proposal to Jefferson Lab PAC39
Exclusive Phi Meson Electroproduction with CLAS12

H. Avakian,[1] J. Ball,[2] A. Biselli,[3] V. Burkert,[1] R. Dupr,[2] L. Elouadrhiri,[1] R. Ent,[1] F.–X. Girod,[1,*] S. Goloskokov,[4] B. Guegan,[5,6] M. Guidal,[5,*] H.–S. Jo,[5] K. Joo,[7] P. Kroll,[8] A Marti,[5] H. Moutarde,[2] A. Kubarovsky,[6,*] V. Kubarovsky,[1,*] C. Munoz Camacho,[5] S. Niccolai,[5] K. Park,[1] R. Paremuzyan,[5] S. Procureur,[2] F. Sabatié,[2] N. Saylor,[6,5] D. Sokhan,[5] S. Stepanyan,[1] P. Stoler,[6,†] M. Ungaro,[7] E. Voutier,[9] C. Weiss,[1,†] D. Weygand,[1] and the CLAS Collaboration

[1] *Jefferson Lab, Newport News, VA 23606, USA*
[2] *IRFU/SPhN, Saclay, France*
[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:

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

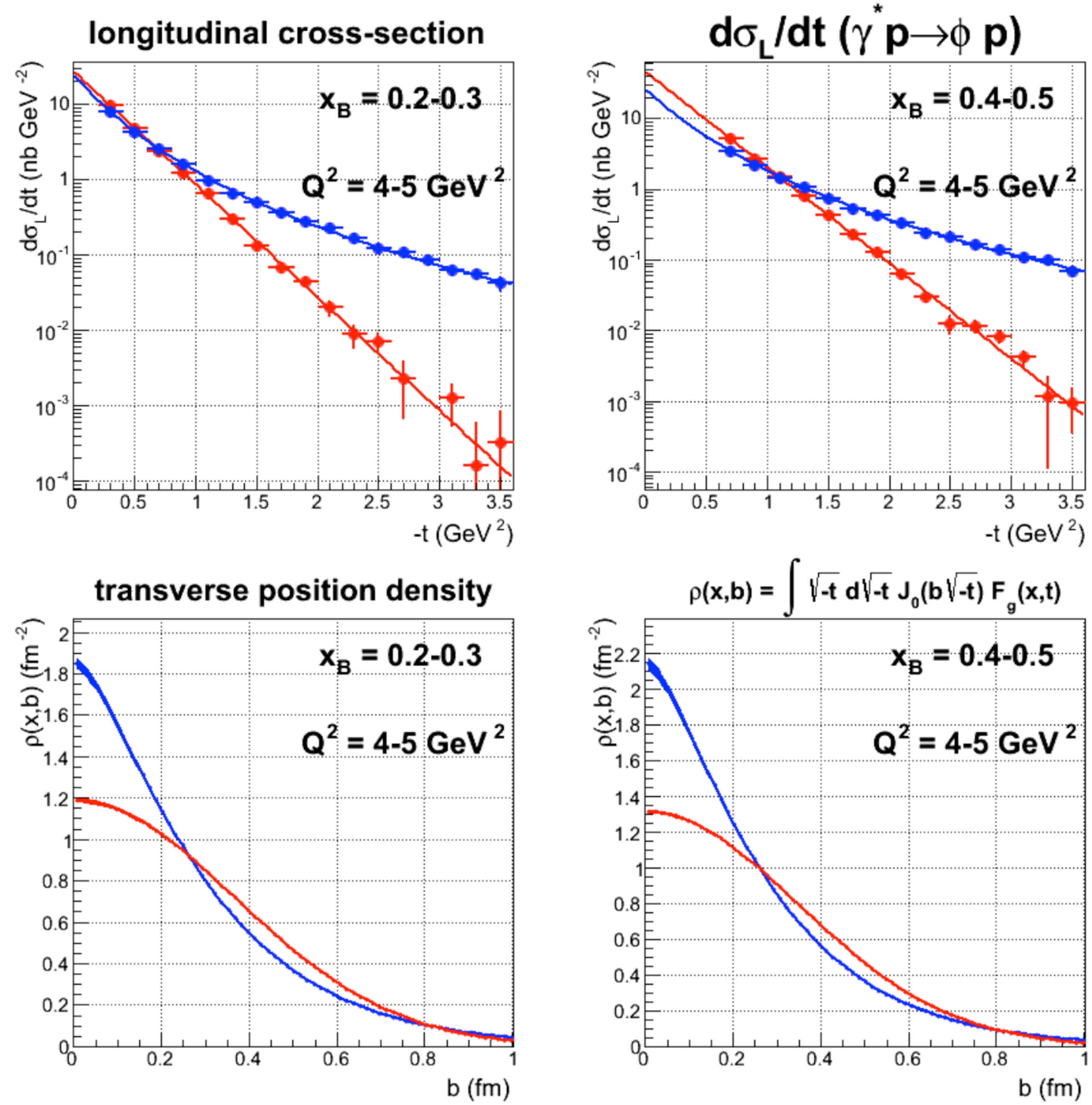
- Then, defining a gluonic form-factor as:

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

- 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.

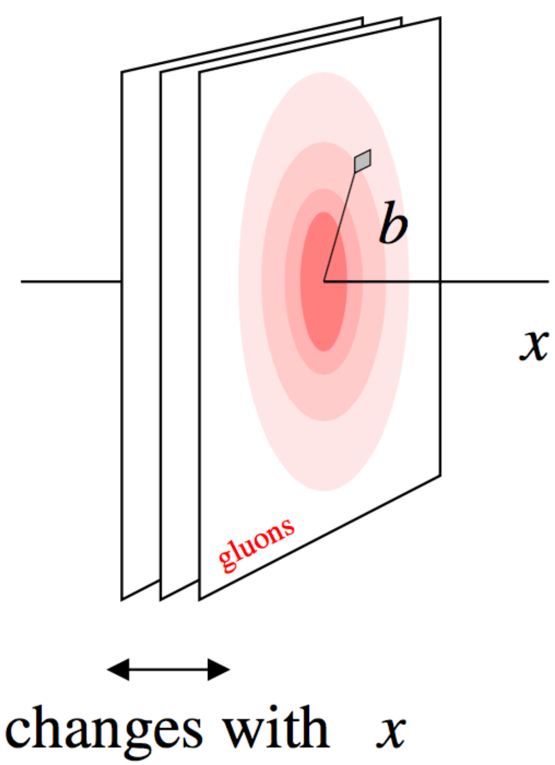


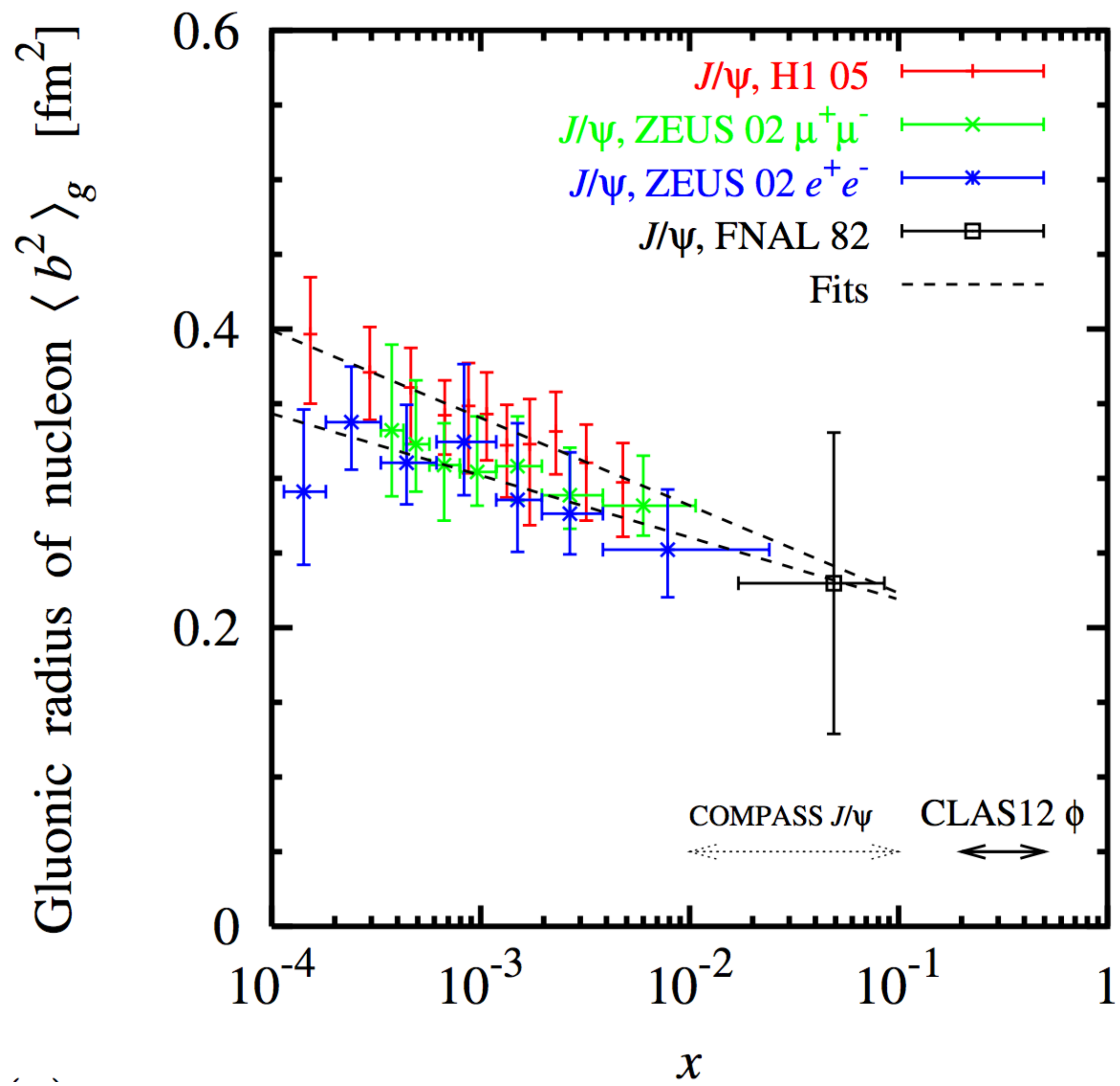
$\gamma^* + p \to p + \phi$ (CLAS12 proposed)

- 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.





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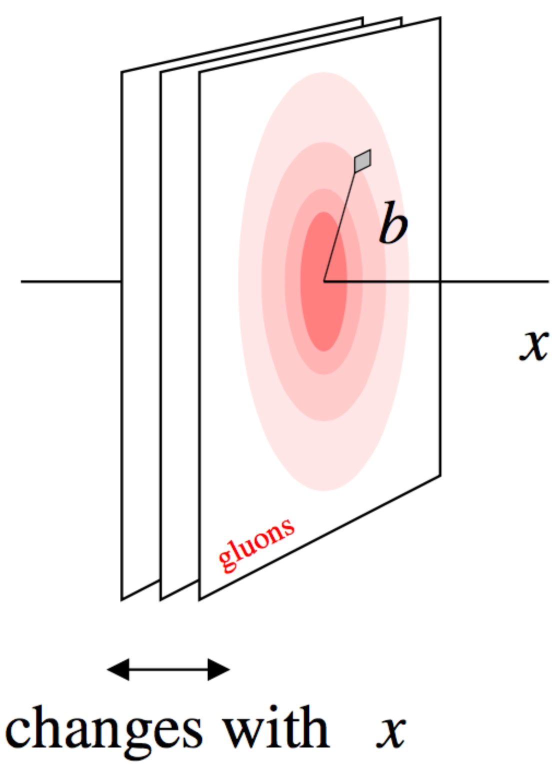

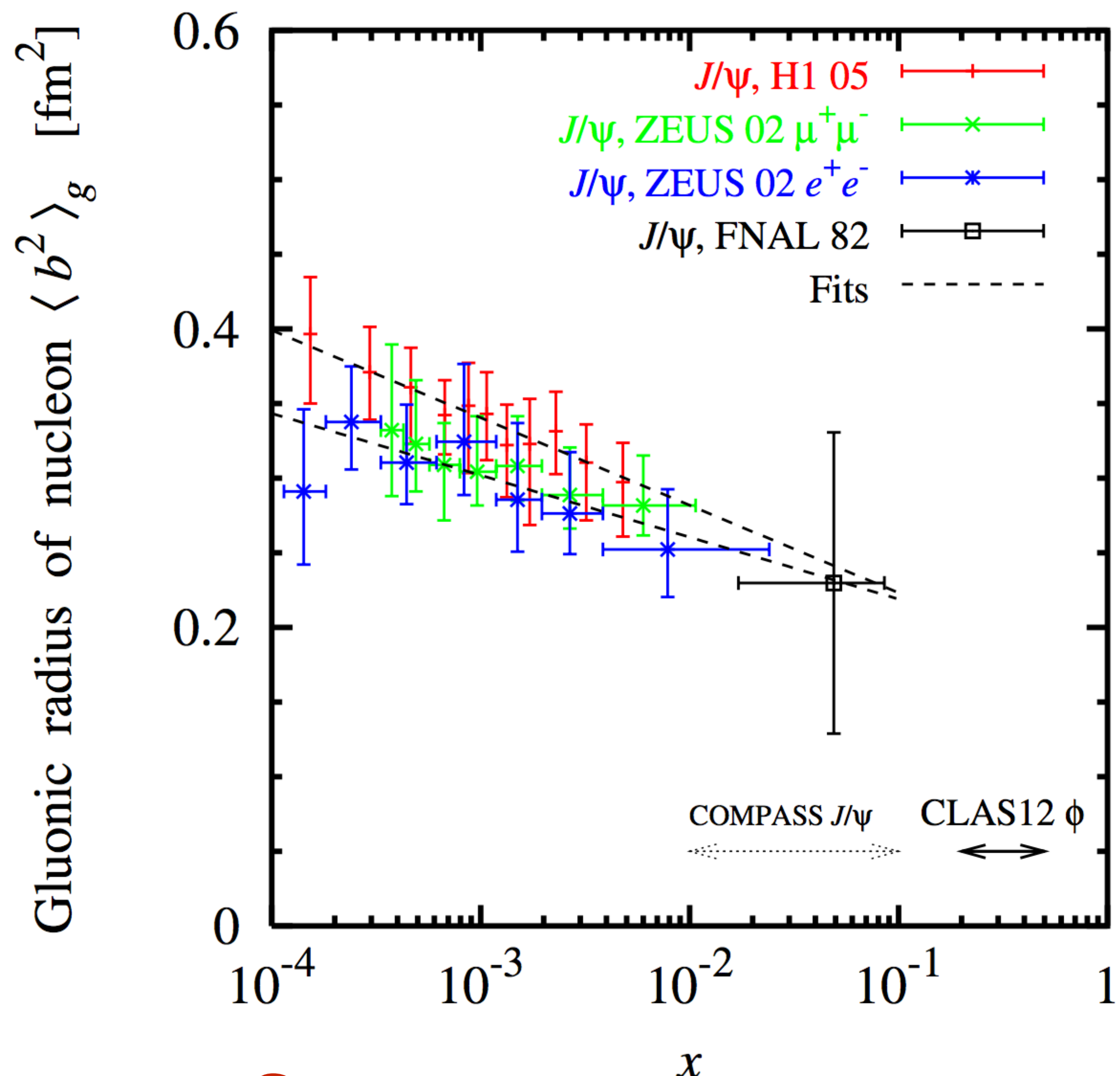

What can we learn with nuclear targets?

$\gamma^* + {}^4He \rightarrow {}^4He + \phi$

- **^{4}He is an ideal nucleus to study gluonic phenomena**
  - Dense, few body system
  - Fairly simple to use experimentally, not so difficult to tag.
- **JLab 6-GeV**
  - **EG6:**
    - A unique TPC chamber was built to detect recoiling nuclei.
    - Gives access to the coherent channel at low-|t|.
    - Analysis ongoing, but overall statistics are low. Will likely need a combined multi-channel analysis to measure signal over incoherent backgrounds.
  - **E2**:
    - No recoil detector but possibly higher statistics.
- **JLab 12-GeV**
  - Higher energy already allows for a more open phase-space.
  - **CLAS12:**
    - a new recoil nucleon/nuclei detector (ALERT detector) is being developed for use with a ^{4}He target.
    - Will allow a low-|t| coherent study. A proposal is in progress, but needs more simulation work before I have exact rates.
  - **Hall-C:**,
    - Allows one to run with higher luminosity at fixed angle, fixed |t|, all the way to threshold. At threshold, one can study mesic bound systems.

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

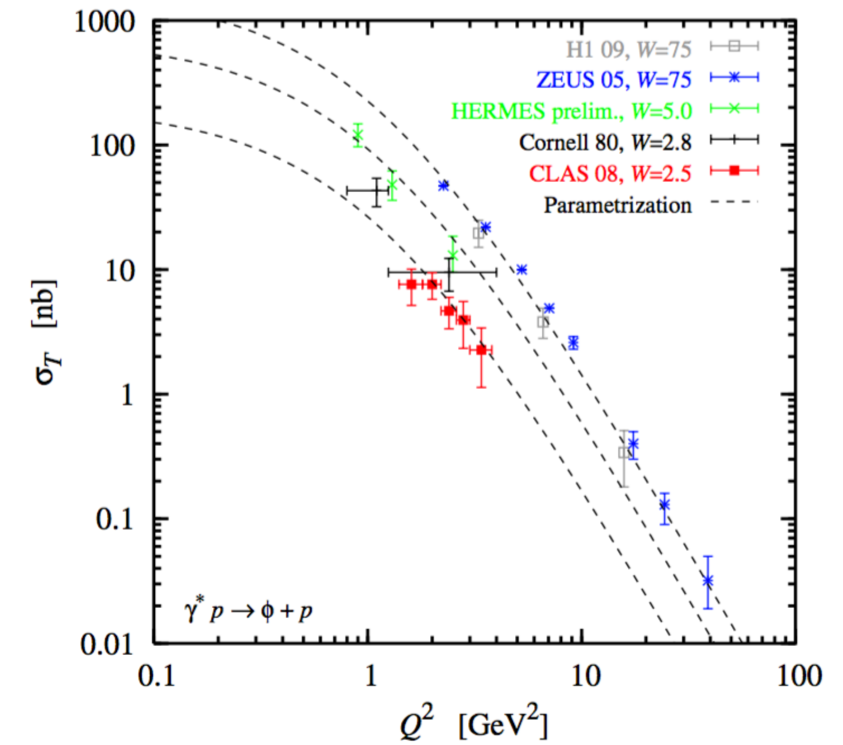
- Phenomenological approach to production off proton:

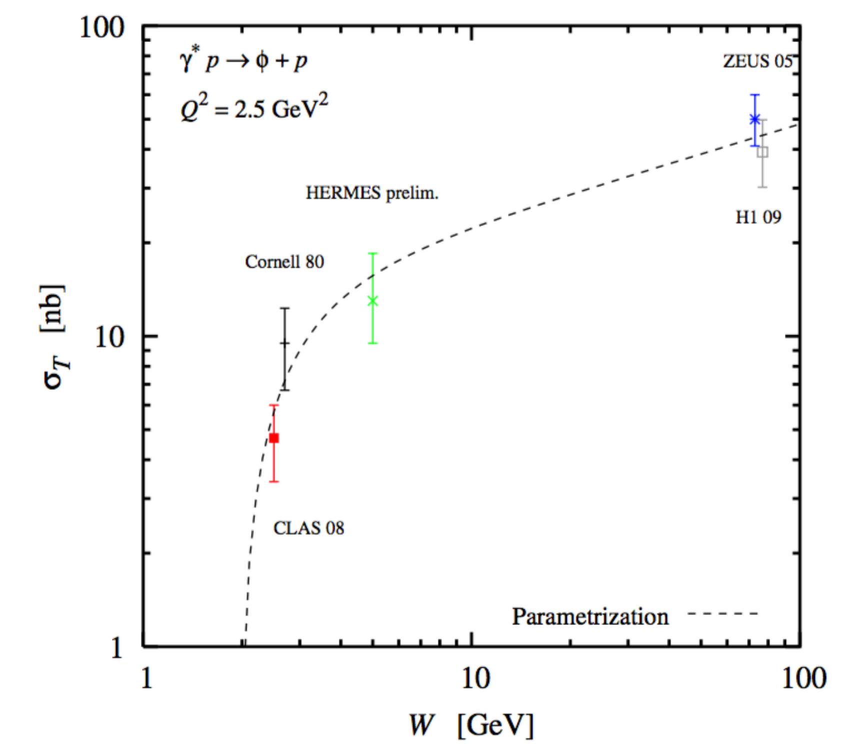
$$\frac{d\sigma}{dx_B dQ^2 dt} = \Gamma(Q^2, x_B, E)\left(\frac{d\sigma_T}{dt}(Q^2, x_B, t) + \epsilon \frac{d\sigma_L}{dt}(Q^2, x_B, t)\right)$$

  - 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.
  - $Q^2 \rightarrow |t - t_{min}| = t'$, 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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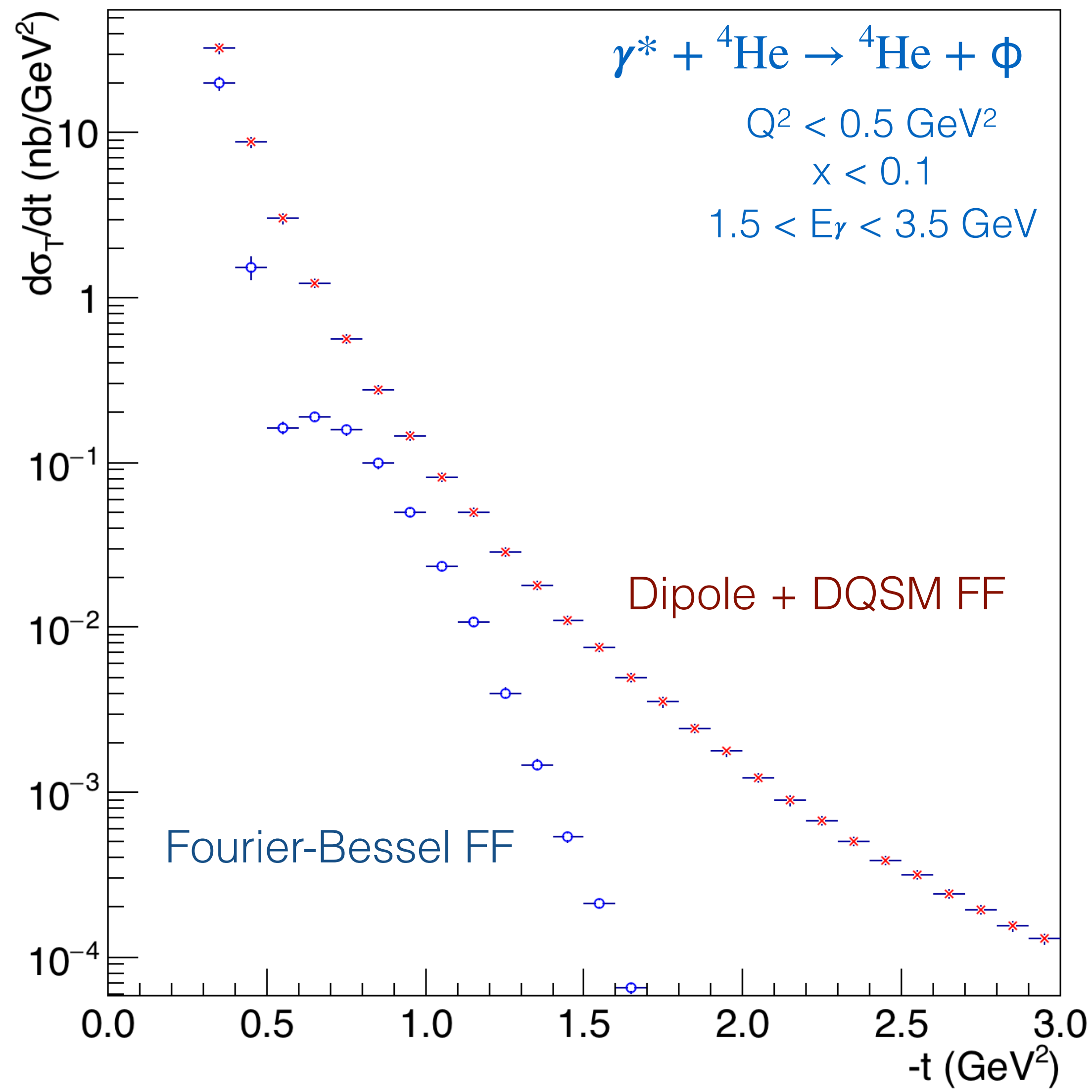
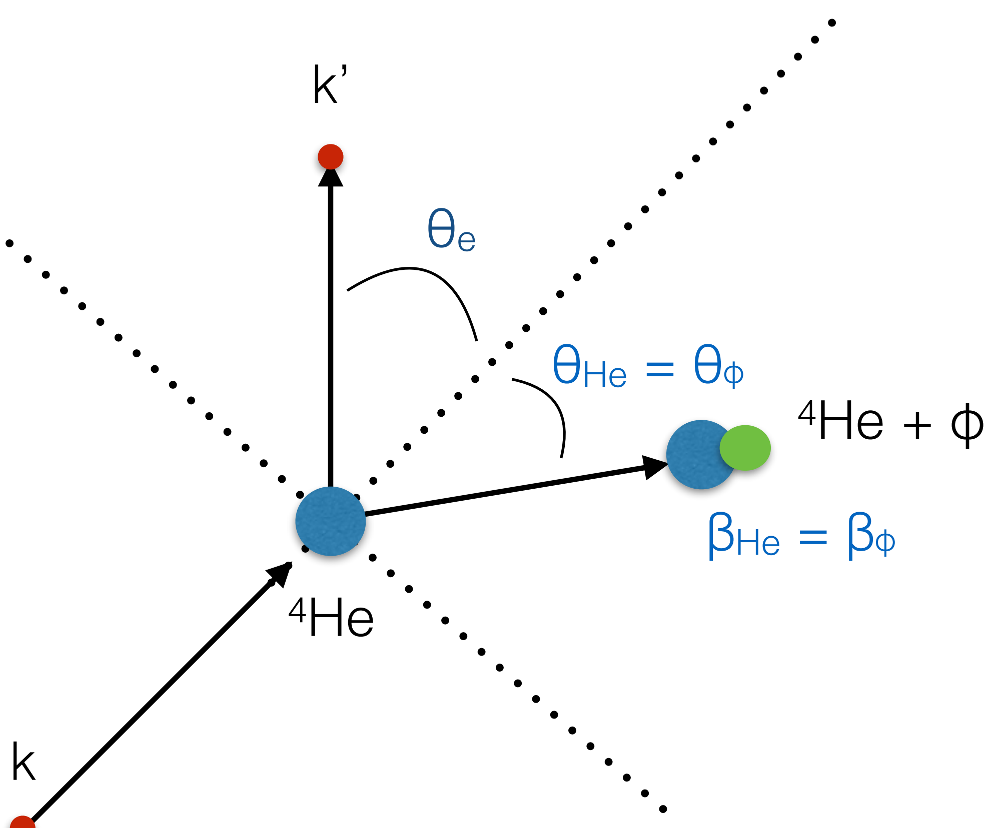


ϕ on ^{4}He at threshold

- Two-arm coincidence between scattered electron and ^{4}He. ϕ and η are selected with missing mass.
- With careful selection of kinematics, the relative velocity between the phi and ^{4}He can be centered at zero.
- Maximizes the possibility of a bound state.



Investigating neutral meson-nuclei bound states with coherent electroproduction of η and ϕ mesons off of ^{4}He in Hall-C

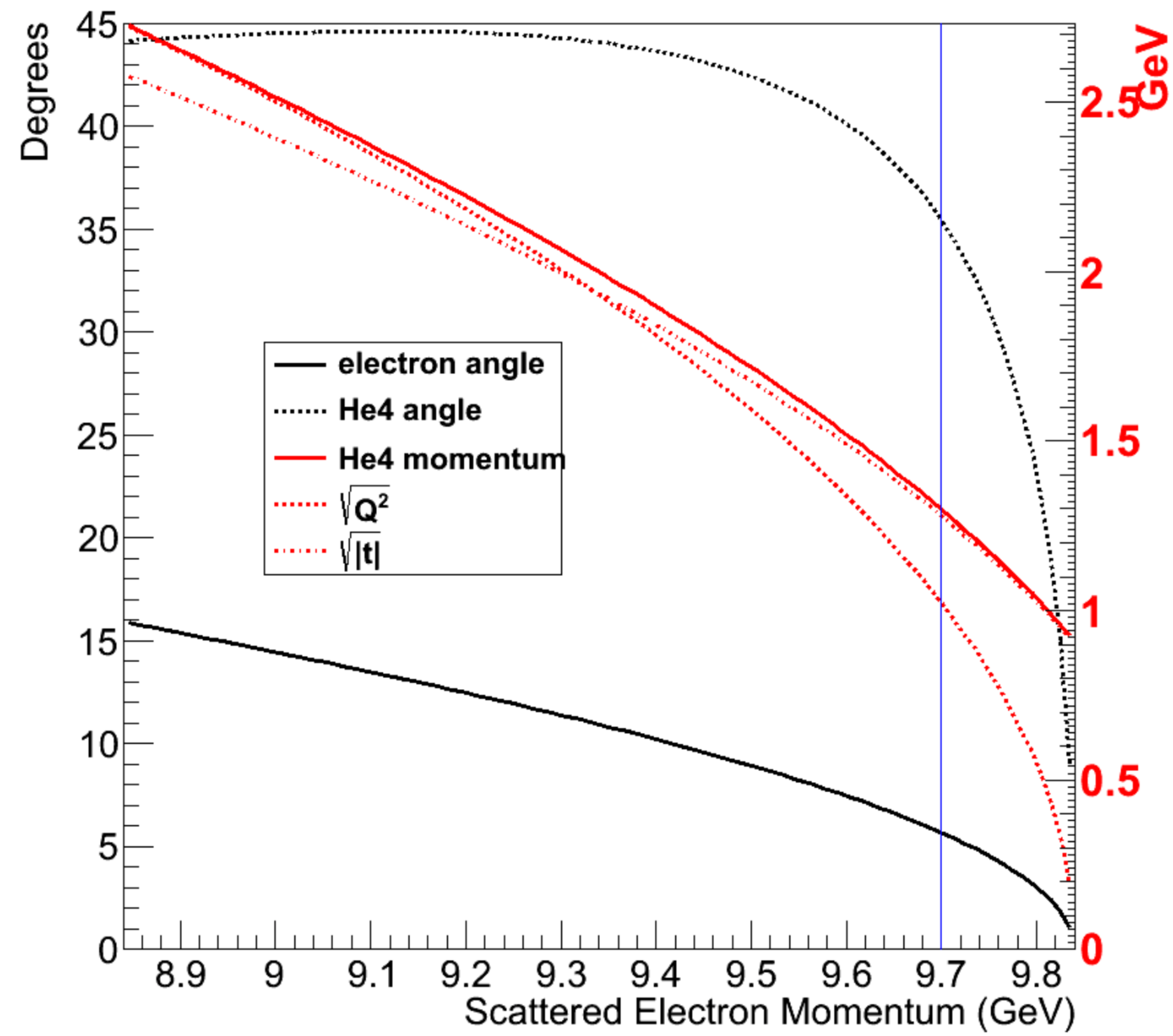
A Letter of Intent to PAC 42

M. Paolone, S. Joosten, Z.-E. Meziani, N. Sparveris
Temple University
Philadelphia, Pennsylvania USA

M. Jones
Thomas Jefferson National Accelerator Facility
Newport News, Virginia USA

May 29, 2014

Phi electoproduction, on He4 at 11.00 GeV



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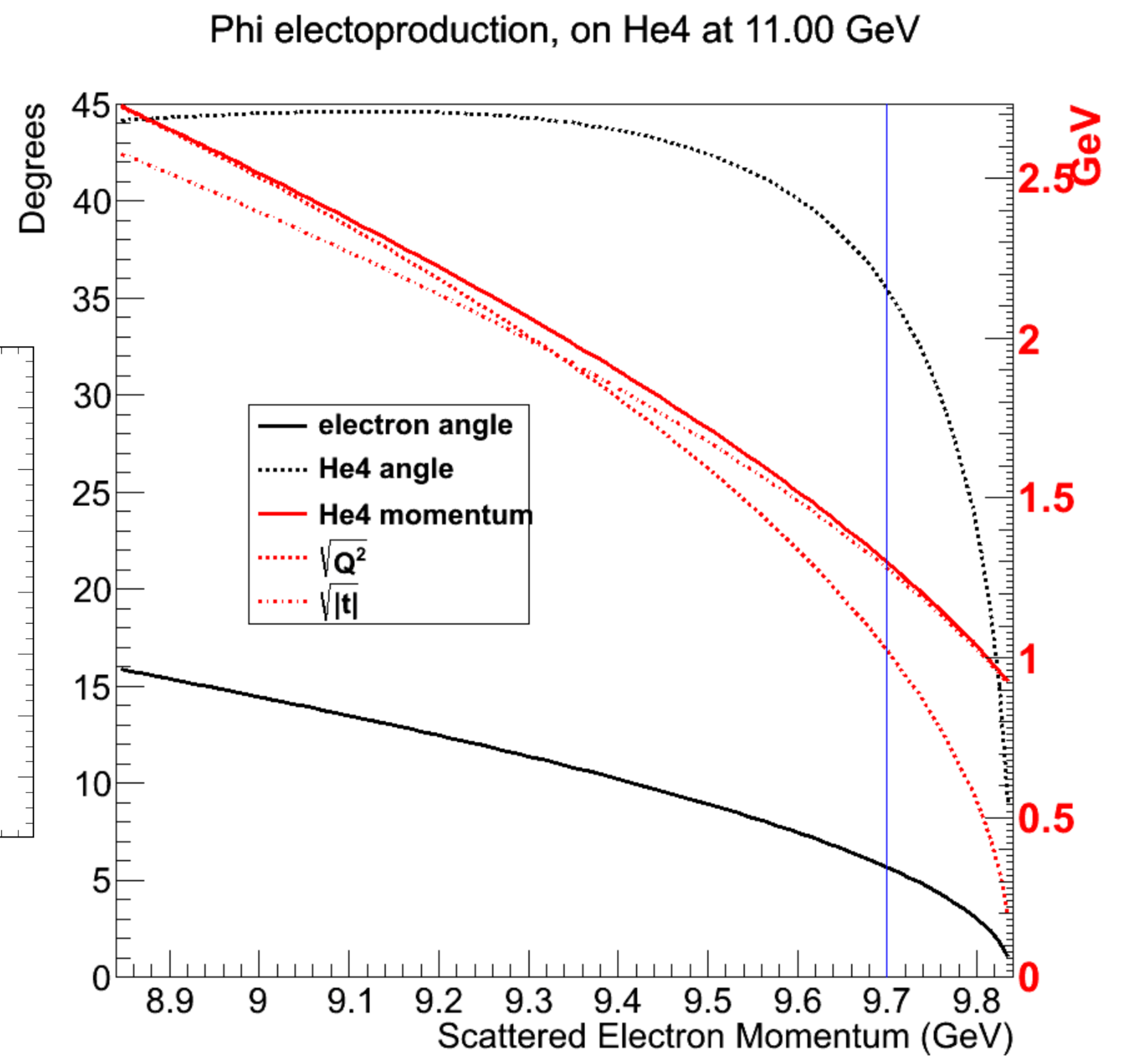

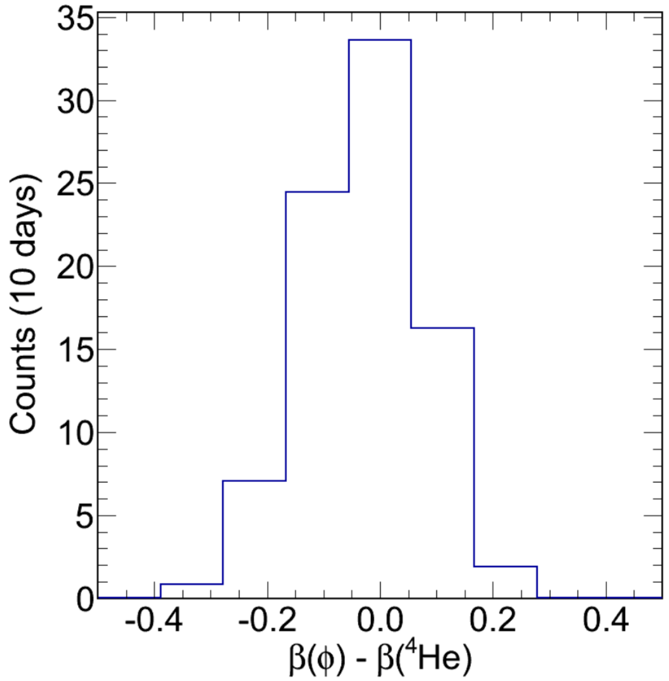

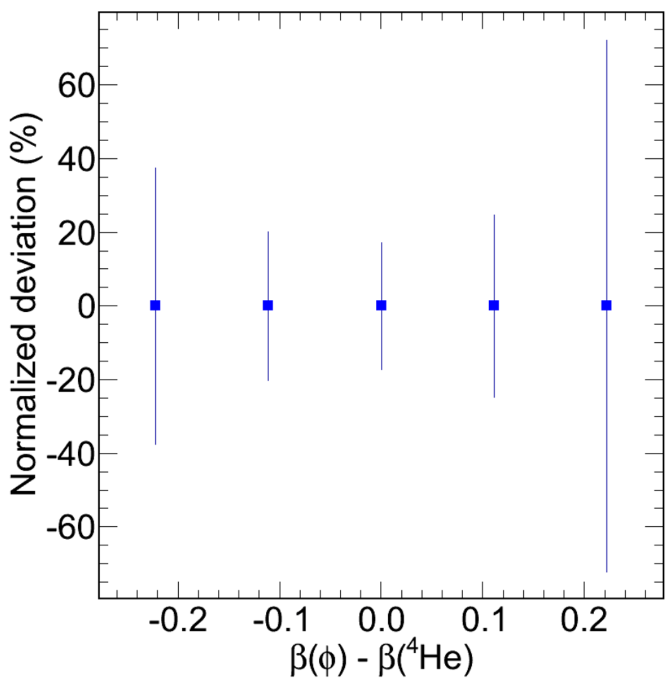

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★ **Need theoretical calculations for bound states!**

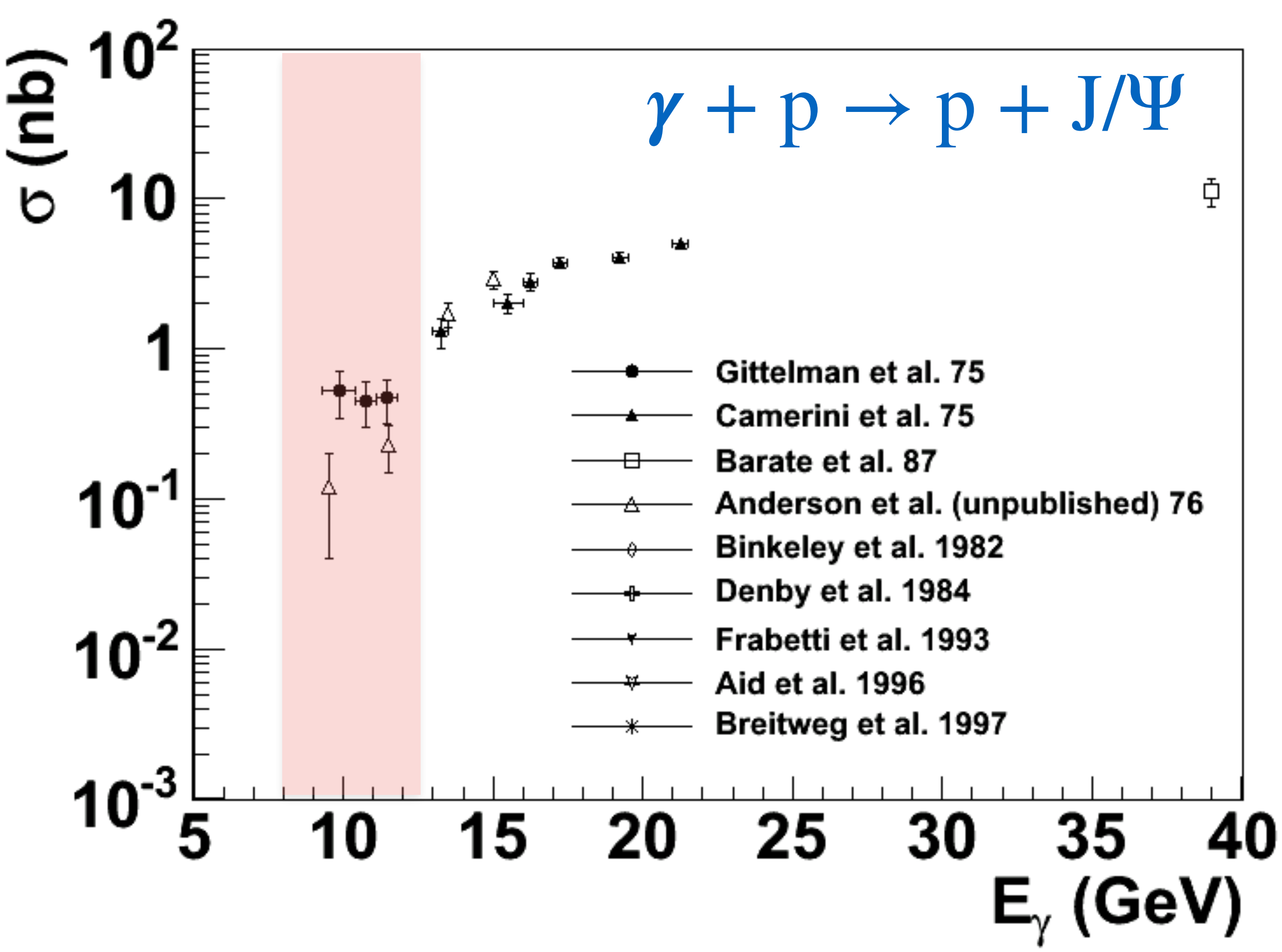
- J/Ψ - ^{3}He binding energies were predicted by J.J. Wu and H. Lee (arXiv:1210.6009v1)
- 3 and 4 body binding calculations exist.
- No direct ϕ-^{4}He calculations available!

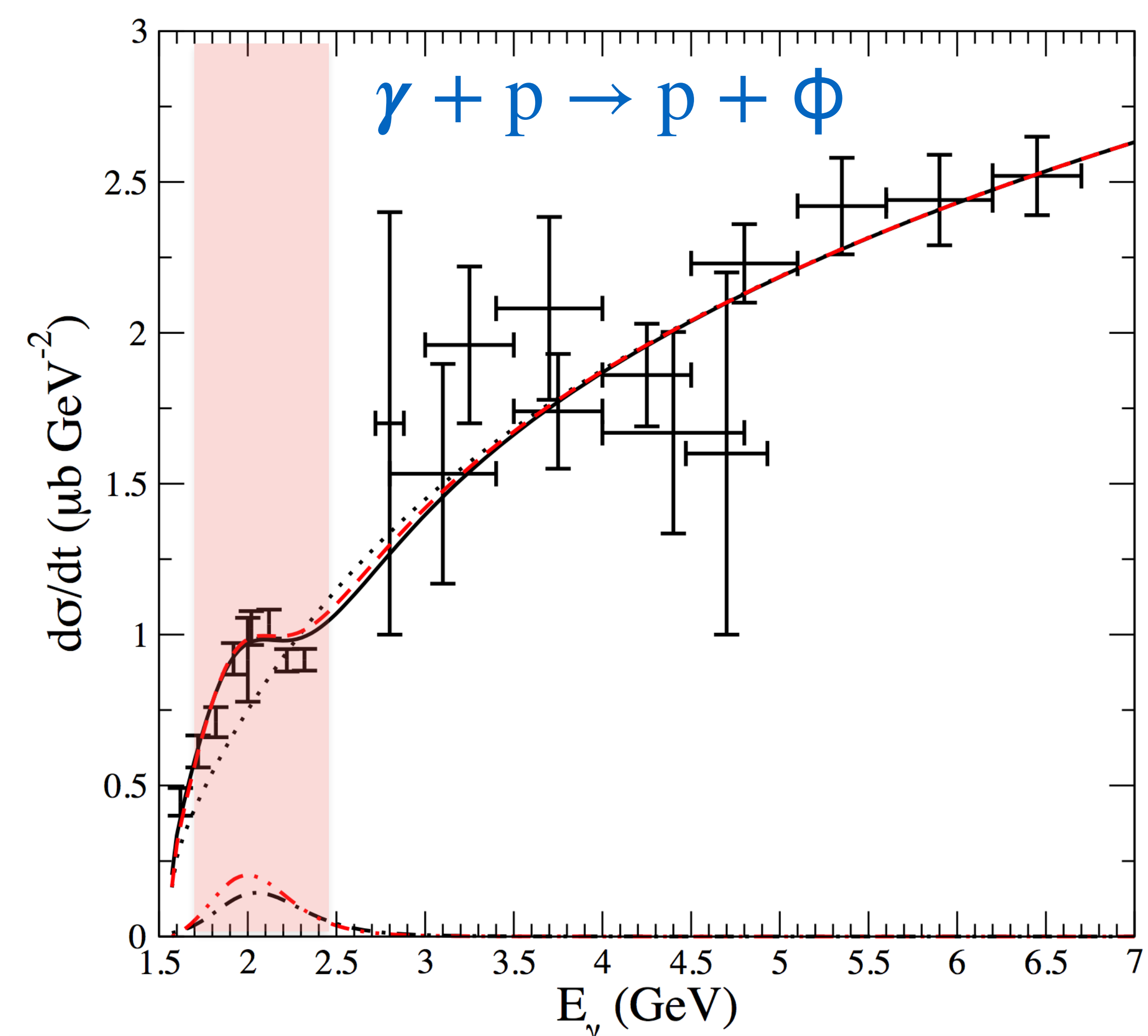
- **Published results for a η-^{3}He with TAPS at MAIMI**
  - (-4.4 ± 4.2) MeV and full width (25.6 ± 6.1) MeV
    M. Pfeiffer, et al. Phys.Rev.Lett. 92 (arxiv.org/abs/nucl-ex/0312011)

[1]

Electroproduction of J/Ψ off a proton target near threshold

- An 11 GeV electron beam allows one to reach just beyond threshold for J/Ψ production.
  - The threshold region is very rich in physics.
    - Enhancements in J/Ψ and ϕ??





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

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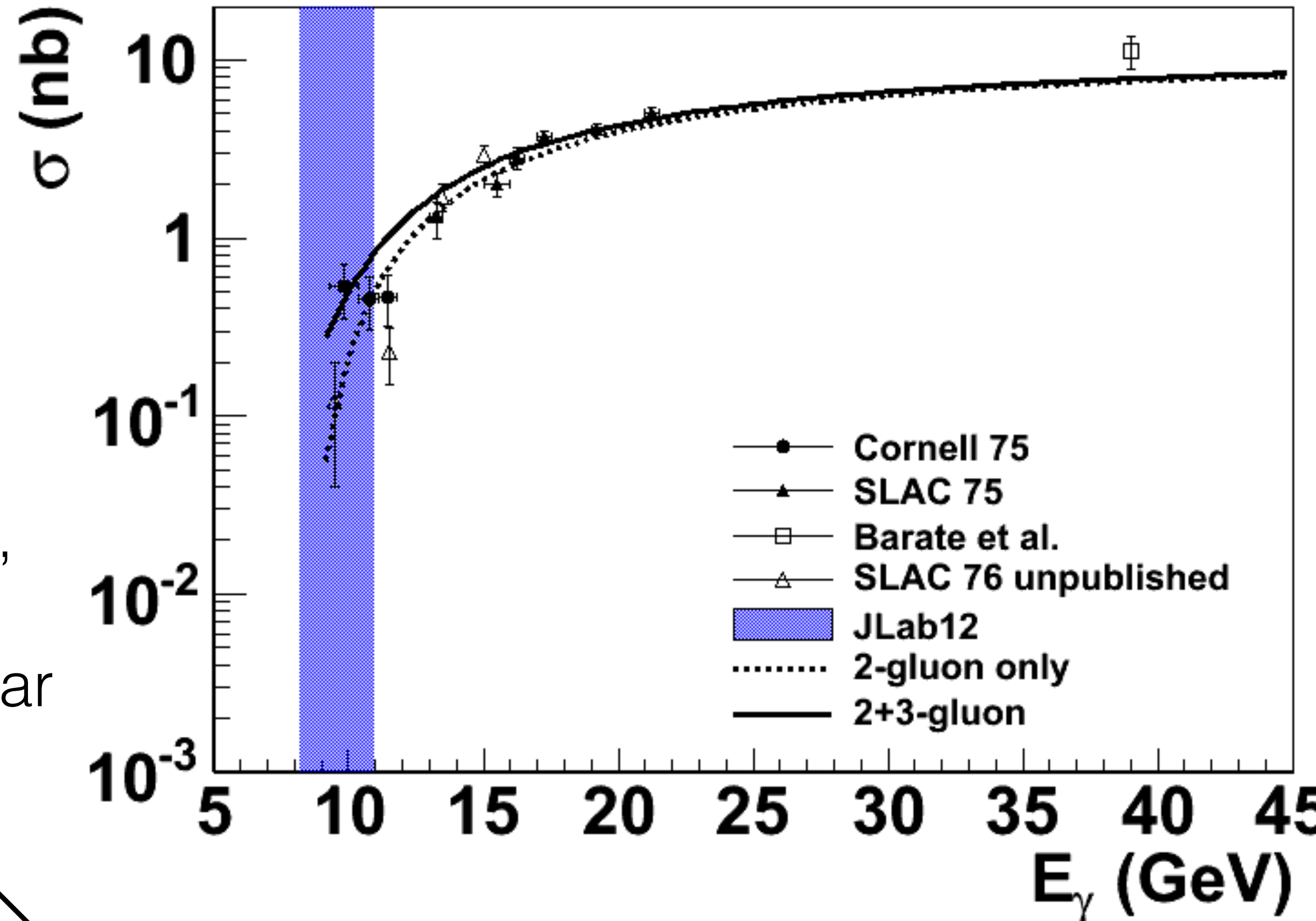
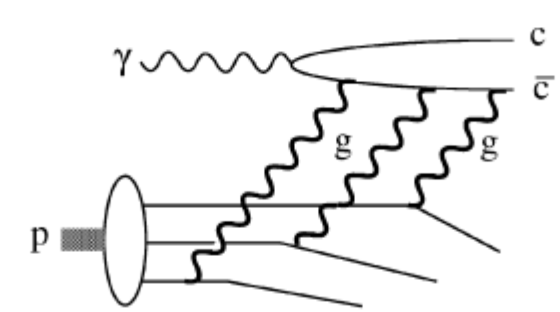


$$2-g:(1-x)^2F(t)$$

$$3-g:(1-x)^0F(t)$$

$$F(t)\propto \exp(1.13t)$$

$$x=\frac{2M_pM_{J/\psi}+M_{J/\psi}^2}{2E_\gamma M_p}$$



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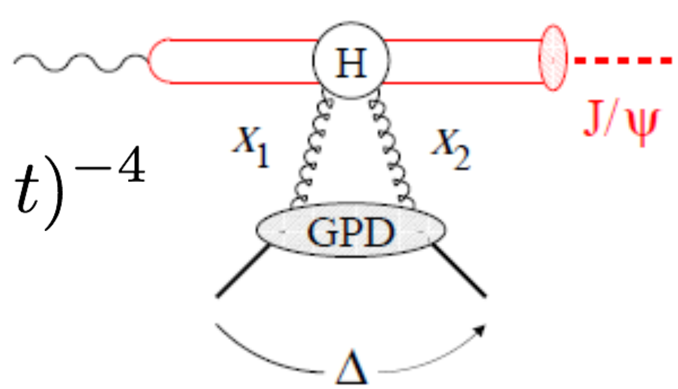
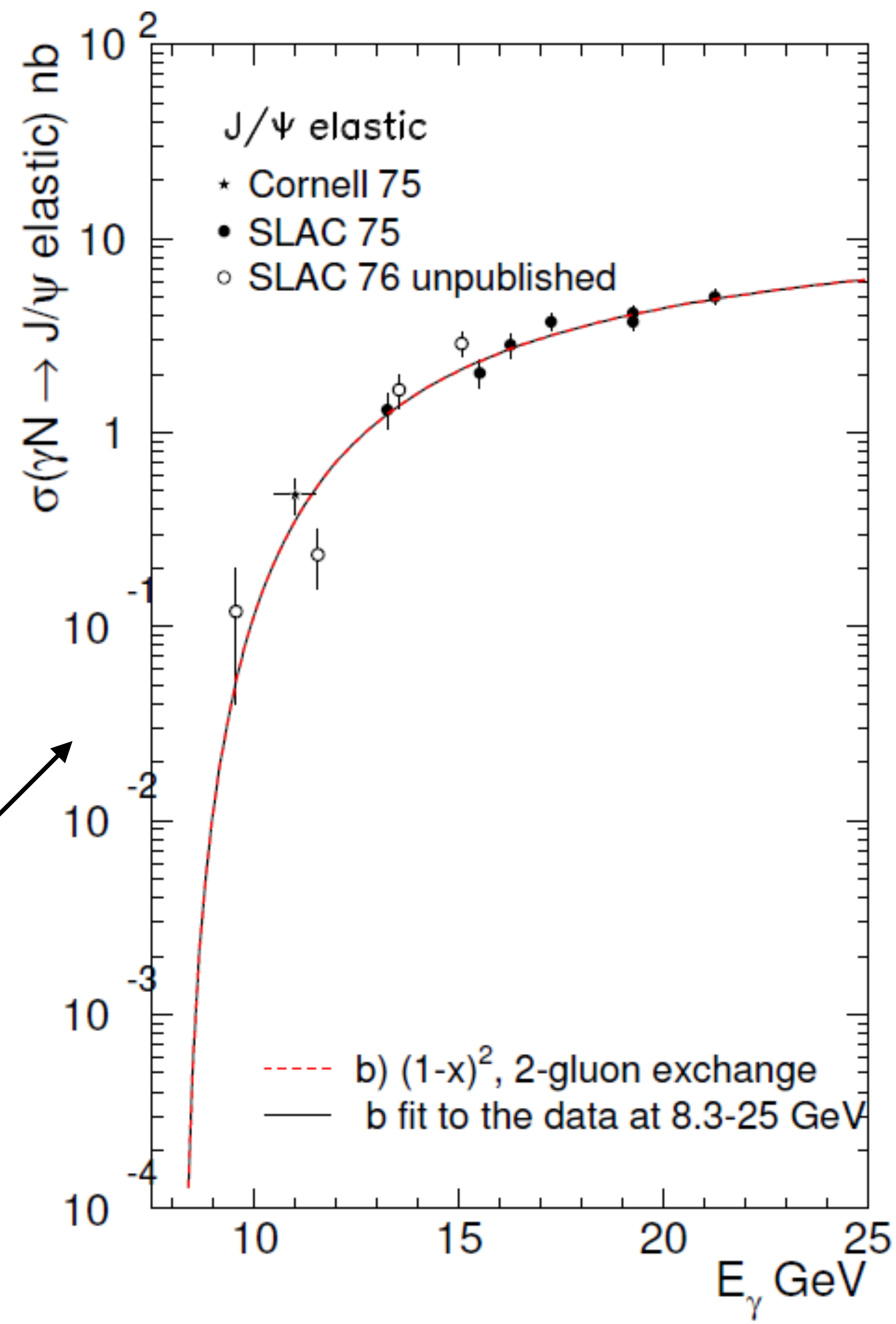
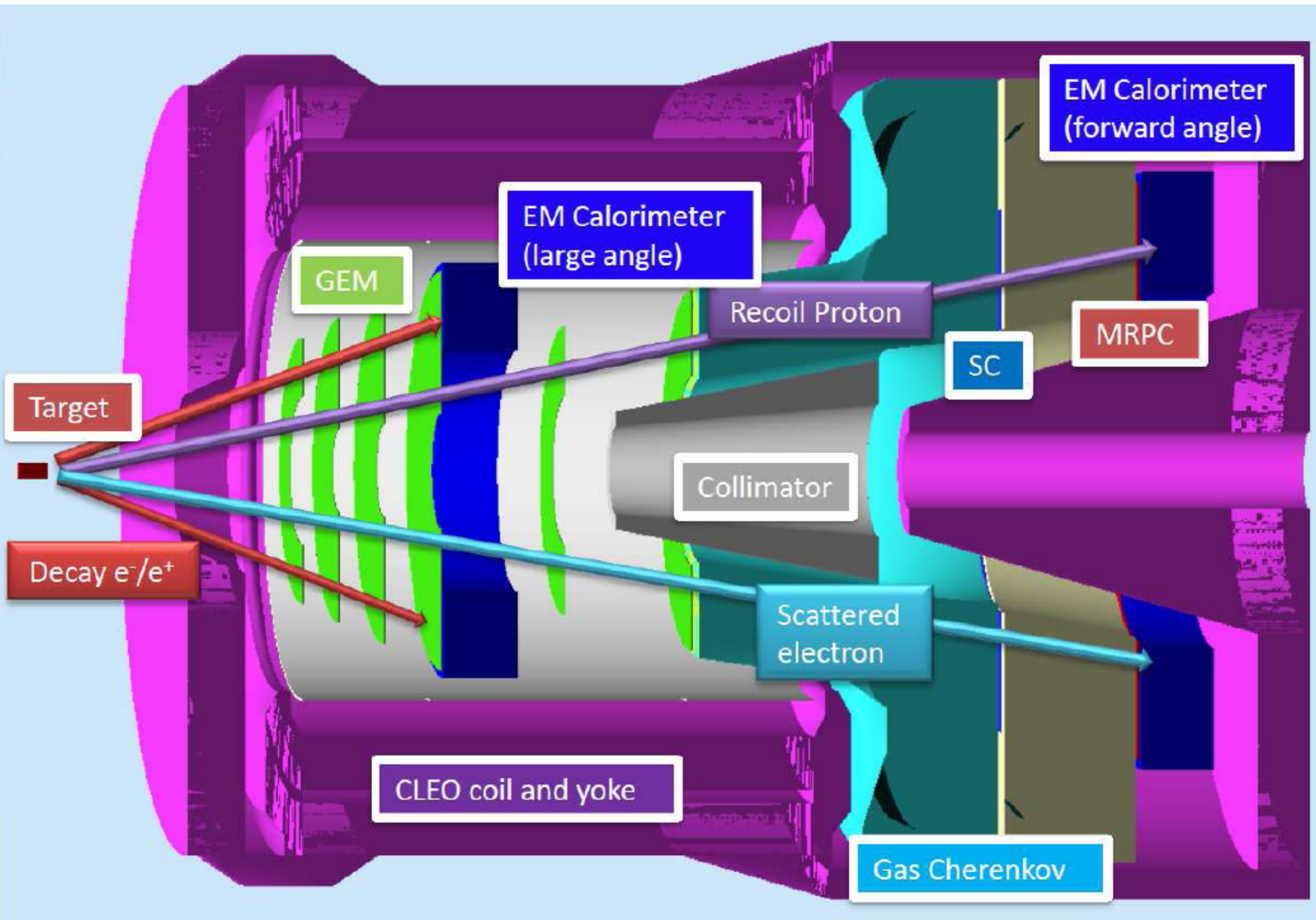
  - A prediction of a partonic soft mechanism using a 2-gluon form factor also is available from Frankfurt and Strikman, (PRD 66, 031502 [2002])

$$FF \propto (1-t)^{-4}$$





Electroproduction of J/Ψ off a proton target near threshold



Near Threshold Electroproduction of J/Ψ at 11 GeV

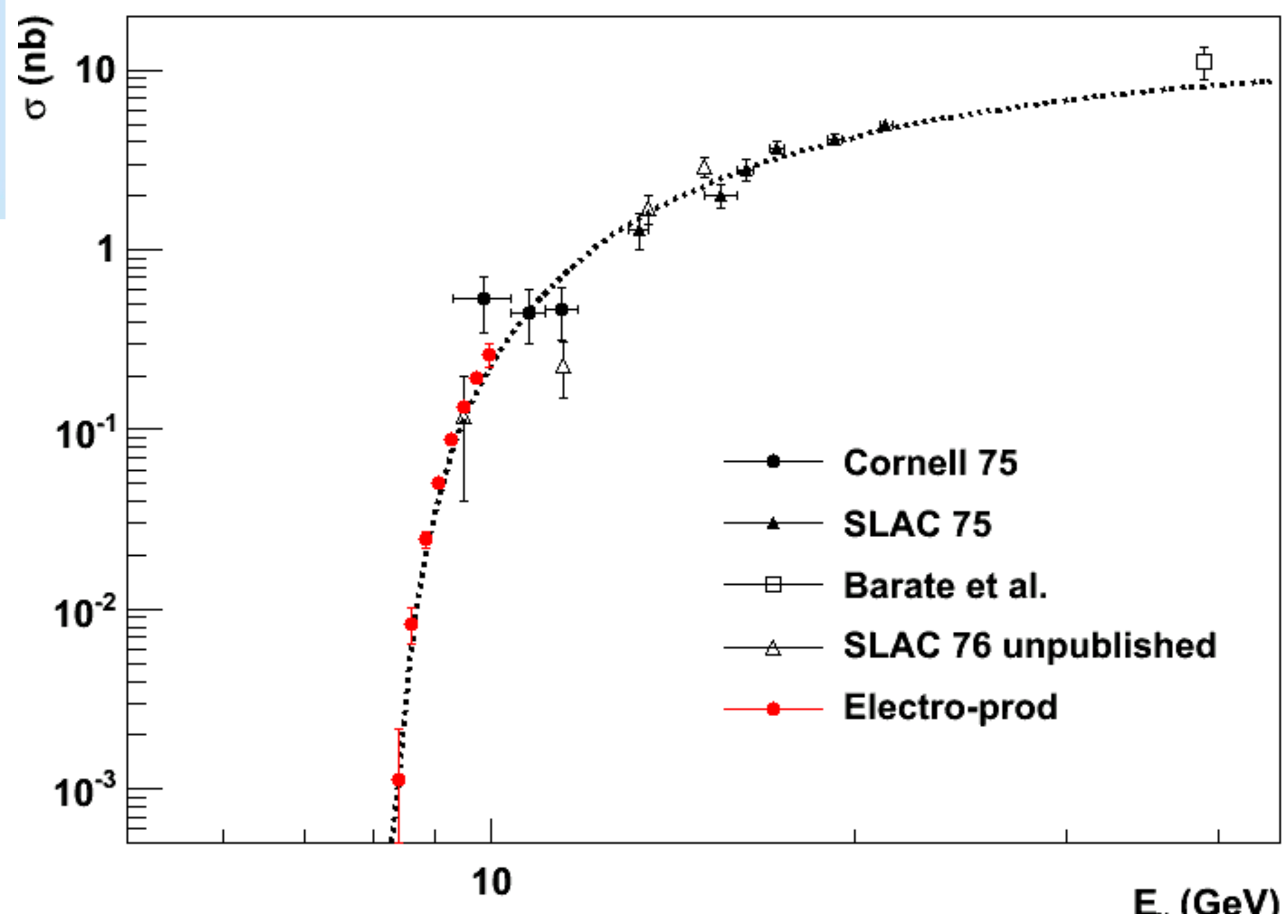
May 4, 2012

the ATHENNA Collaboration [1]

(A new experiment proposal to JLab-PAC39)

Approved with an A rating.
To be run with the SoLID detector in JLab's Hall-A.

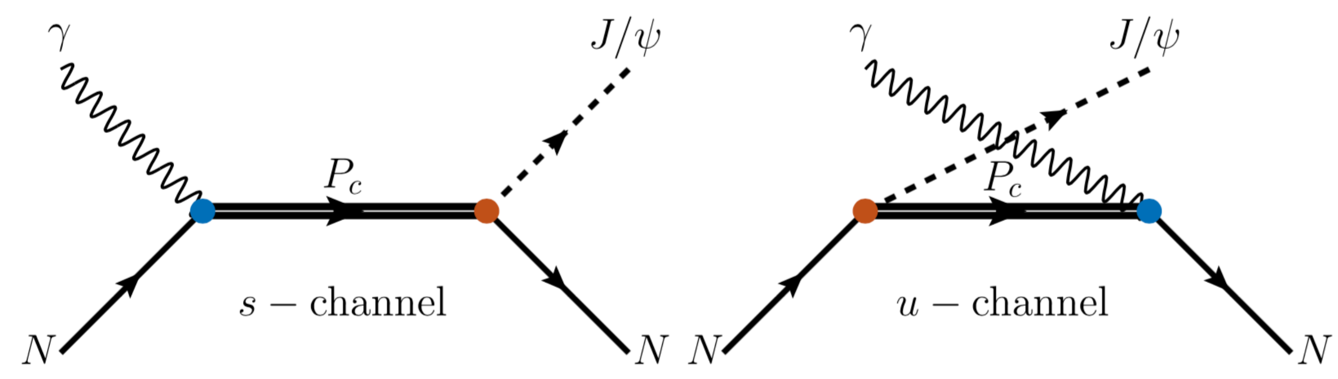
Expected measurement for 1200 hours, triple coincidence (e+, e-, e-) is 2.1k events with 2-g exchange (shown), or 8.08k events with 2-g and 3-g exchange:

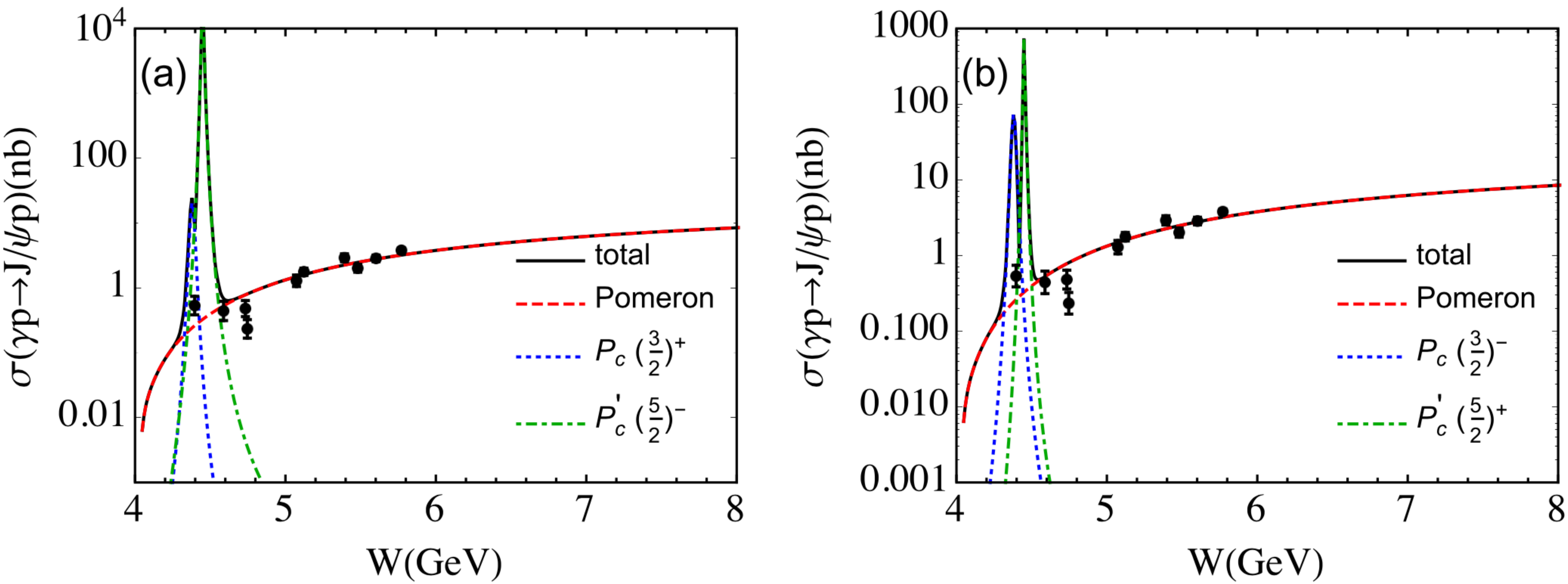


LHCb Pentaquark → J/Ψ + p

- The $P_c^+(4450)$ [Mass = 4449.8 ± 1.7 ± 2.5 MeV, Width = 39 ± 5 ± 19 MeV]
- The $P_c^+(4380)$ [Mass = 4380 ± 8 ± 29 MeV, Width = 205 ± 18 ± 86 MeV]

- Q. Wang, X.-H. Liu, Q. Zhao, *Phys.Rev.D 92*
    - Only s + u production, VMD coupling, hadron typical off-shell form factor, lower order partial waves.





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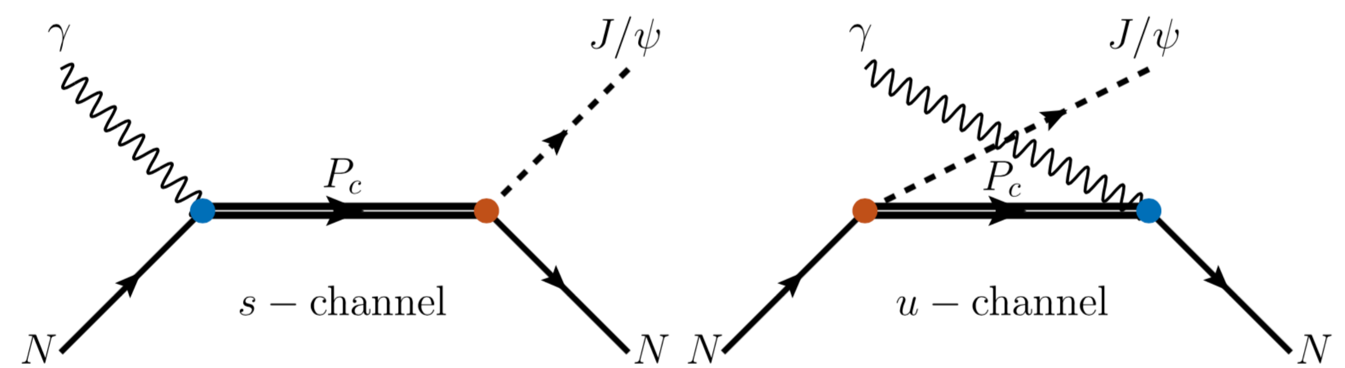
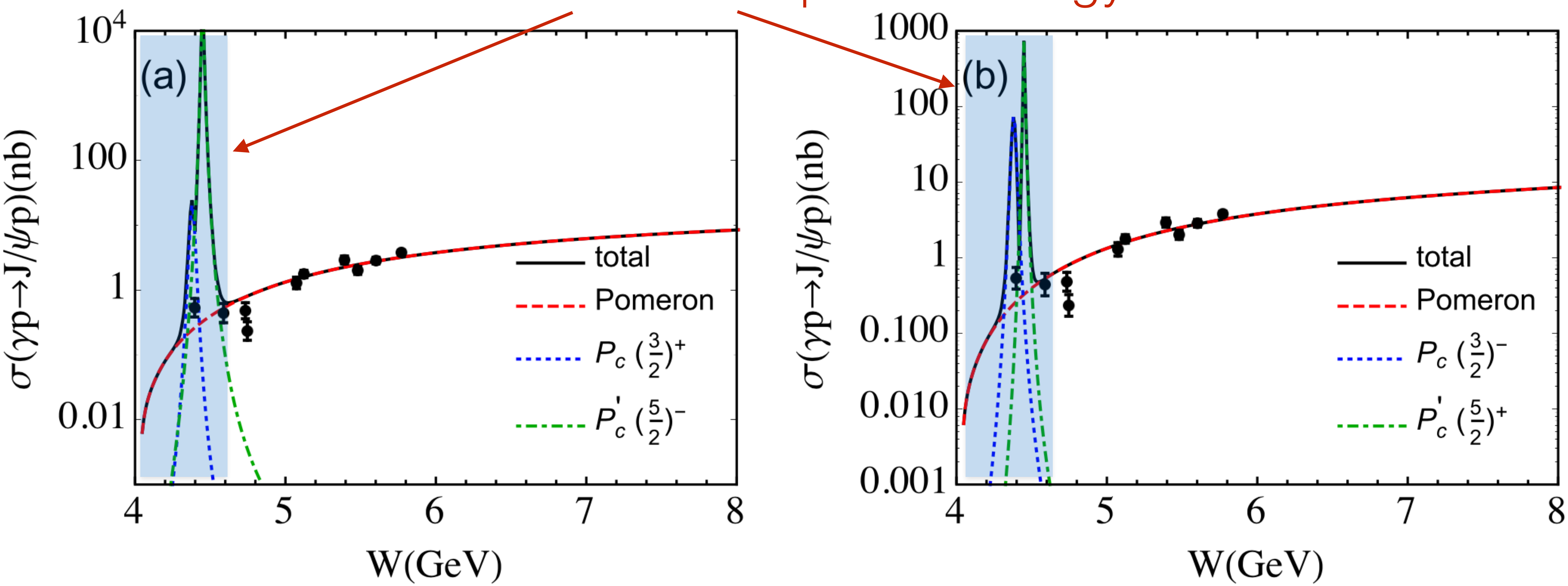
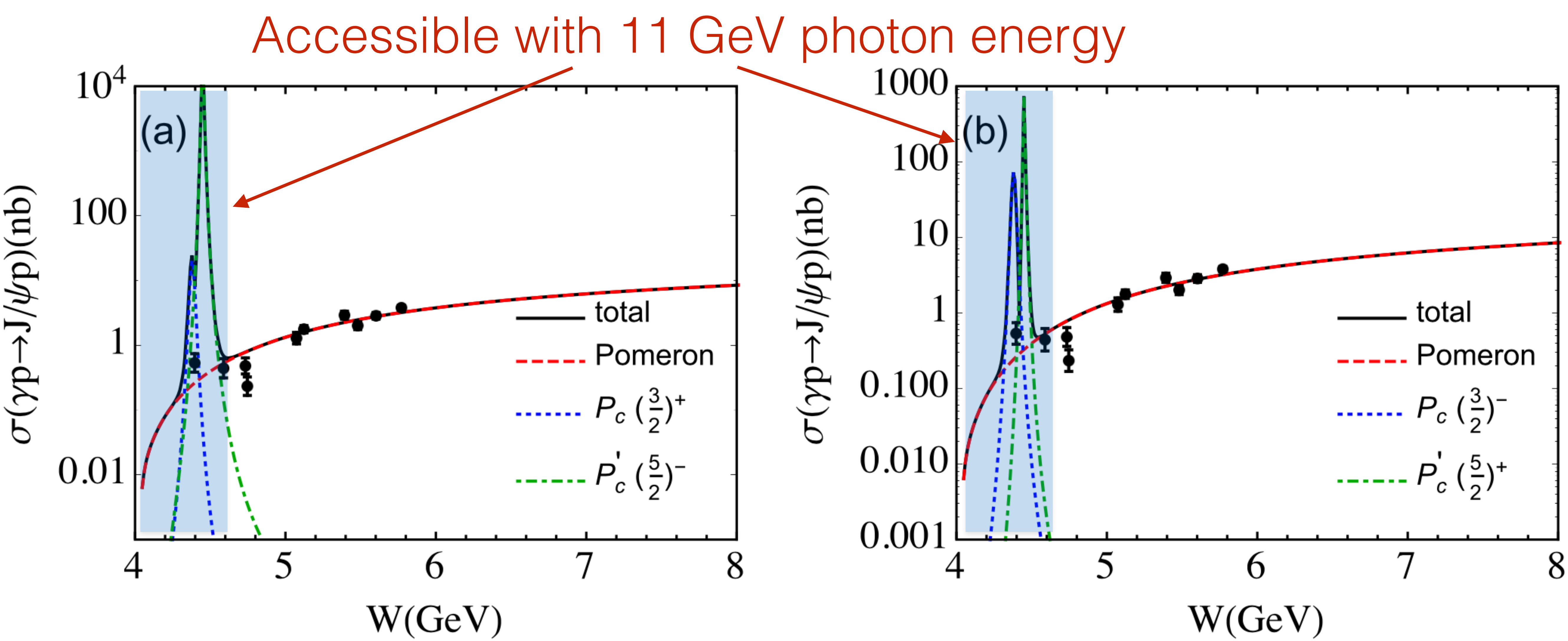


Accessible with 11 GeV photon energy



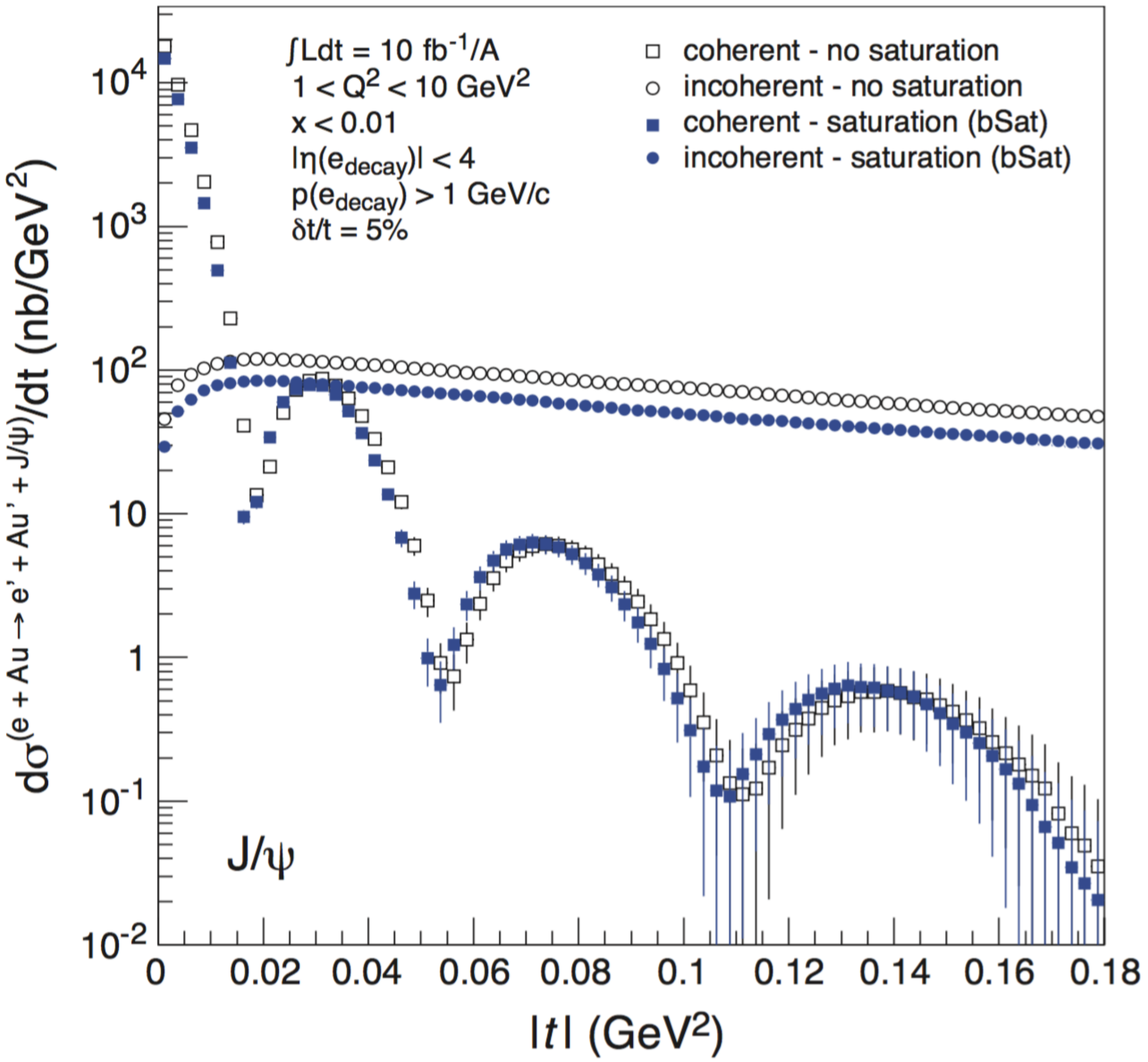
LHCb Pentaquark → J/Ψ + p

- **At Temple University we are working on a proposal for Hall-C:**
  - e+ e- decay of J/Ψ detected in coincidence (p undetected)
  - radiated real-photon beam (untagged)
  - W control with electron beam energy tuning.



Coherent J/Ψ off nuclei

- Excellent probe of gluon distributions
- Already proposed for EIC
- Production threshold smaller than proton, but low-t (tagged recoil) and high luminosity is essential!
  - Possible at JLab12!
    - Threshold effects? Mesic bound states?



Summary

- Many opportunities to probe protons and nuclei with J/Ψ and ϕ production.
  - Transverse gluon distributions can be measured.
  - Experiments on the free proton are approved. Proposals are being prepared to study coherent ϕ off the nucleus at JLab.
  - Threshold production of J/Ψ off proton should come (relatively) soon at JLab.
    - A LHCb pentaquark search is fairly straight-forward at JLab. A proposal is being put together using Hall-C.
  - A ϕ - ^{4}He bound states search would be interesting and is possible at JLab.
  - Feasibility of coherent J/Ψ production on nuclei at JLab will also be investigated.

Thank You!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