MICHAEL PAOLONE

TEMPLE UNIVERSITY

3D PARTON DISTRIBUTIONS: PATH TO THE LHC

WEDNESDAY, NOVEMBER 30TH, 2016

VECTOR MESON PRODUCTION NEAR THRESHOLD WITH JLAB12

TEMPLE UNIVERSITY® Jefferson Lab

THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

- Located in Newport News, Virginia USA
- Four main experimental halls
- Recently completed upgrade allows electron beam energies up to 12 GeV

VECTOR MESON PRODUCTION AT THRESHOLD, WHAT CAN WE LEARN?

- Vector meson production on nucleons:
  - Similar quark production (ρ, ω)
    - DVMP, SIDIS, VMD.
  - Disparate quark production (ϕ, J/ψ, Υ):
    - Gluon GPDs for the nucleon.
    - Threshold enhancements: mesic-nucleon binding, exotic quark configurations, multi-gluon exchanges, new physics?
- Production on the nucleus:
    - Gluon GPDs for the nucleus.
    - Medium effects.
    - Threshold enhancements.

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    - DVMP, SIDIS, VMD.
  - Disparate quark production (**ϕ**, **J/ψ**, Υ):
    - **Gluon GPDs for the nucleon.**
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- Production on the nucleus:
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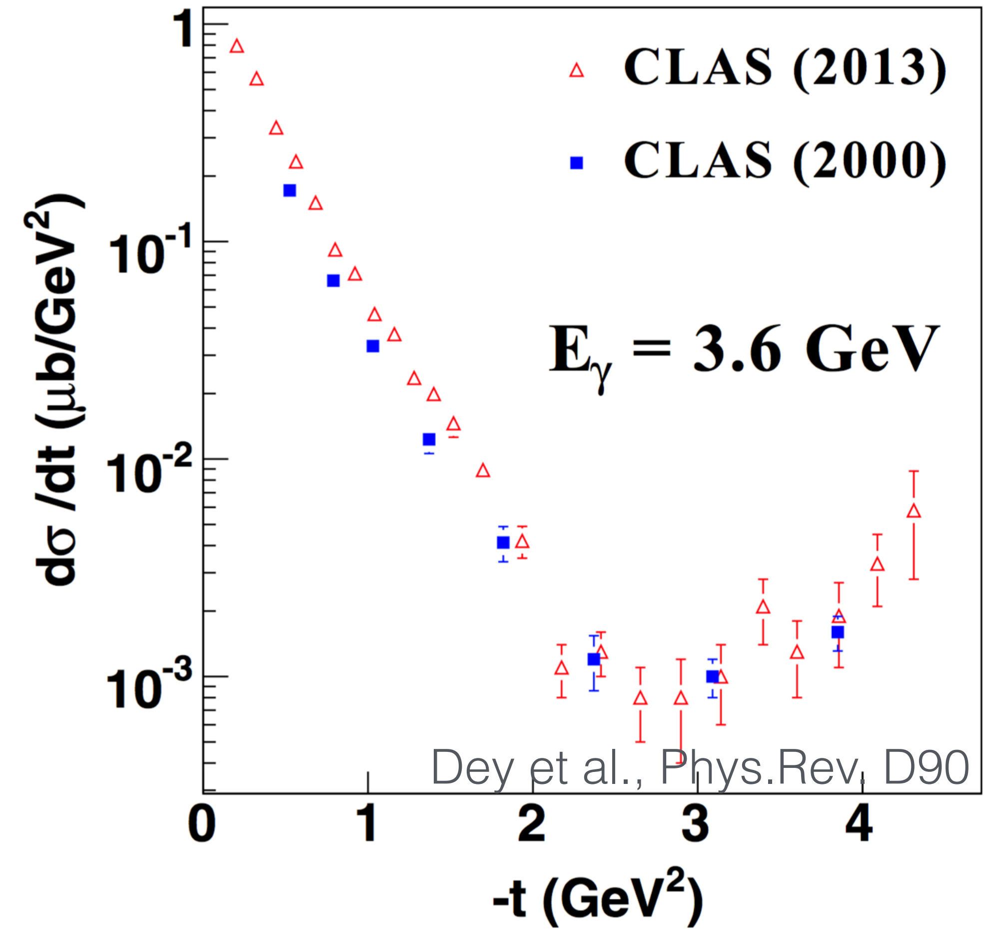
    - Medium effects.
    - Threshold enhancements.

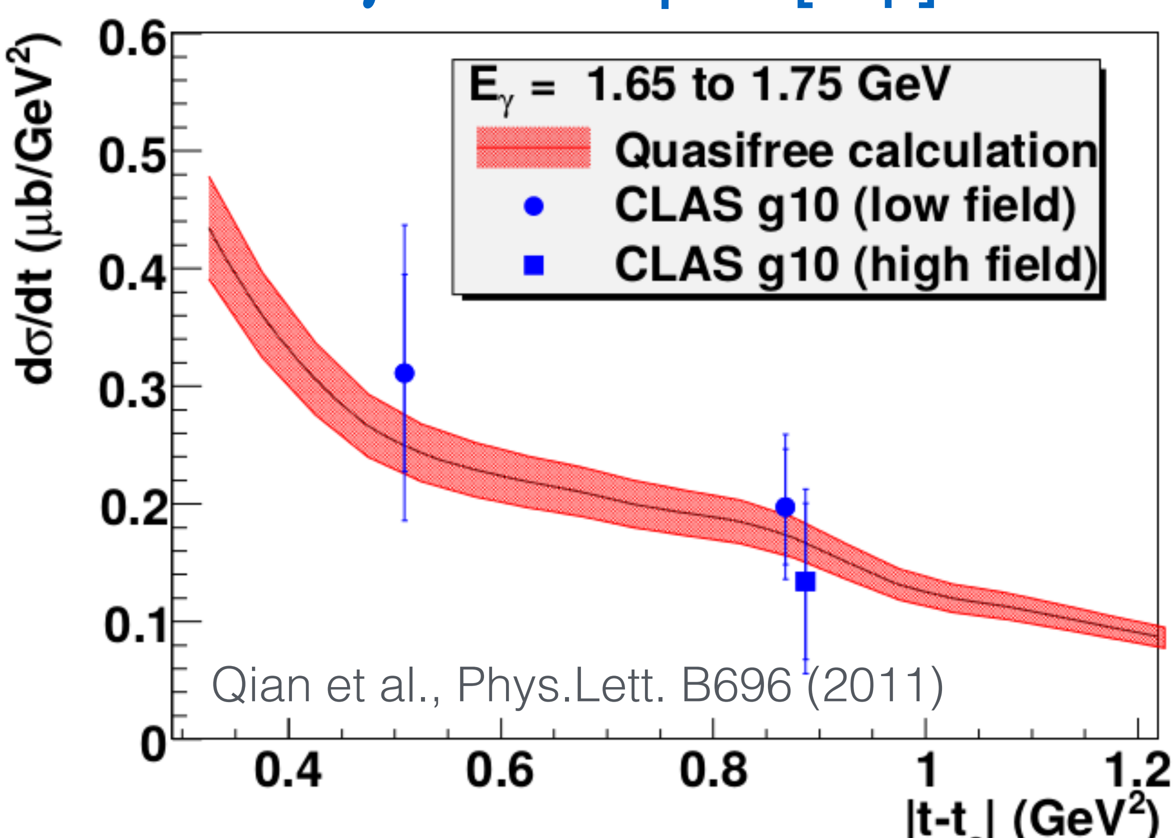
PHI PRODUCTION IN THE 6 GEV ERA

- JLab-6 provided many interesting studies of the ϕ meson (largest mass vector meson the facility could reach).
    - Some interesting photoproduction analyses in Hall-B (NOT a comprehensive list)

$\gamma + p \rightarrow p + \phi$



$\gamma + d \rightarrow p + [n\phi]$



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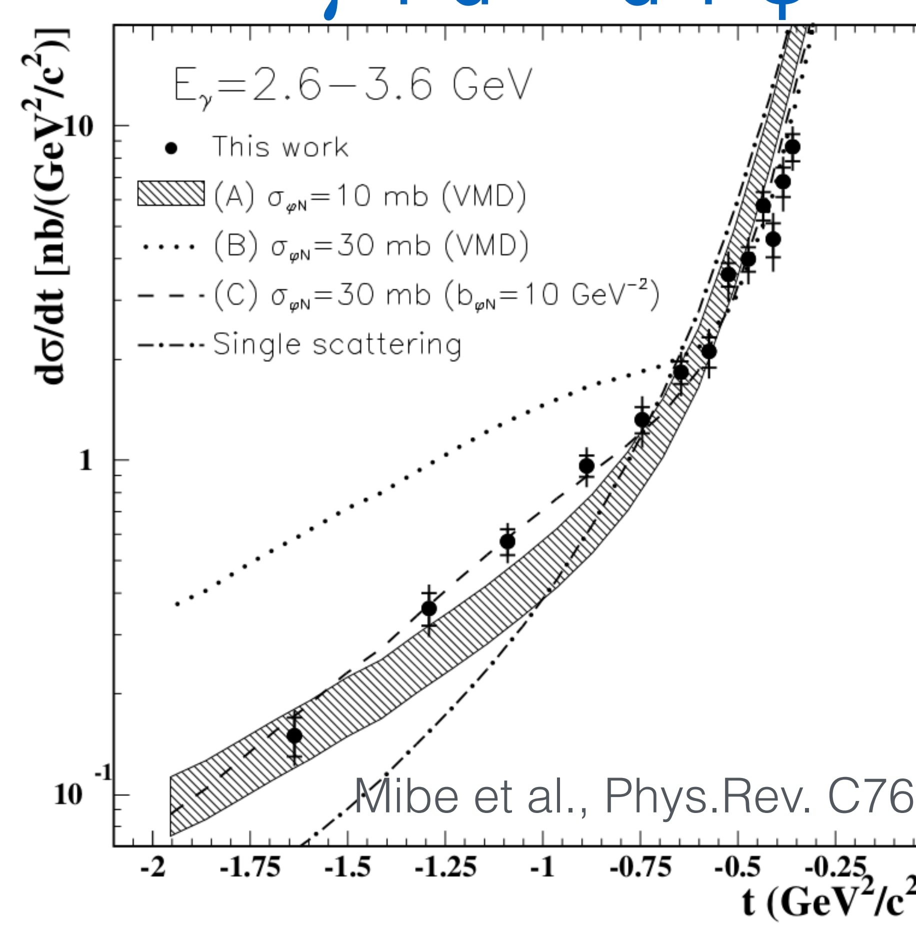

Top Right: Anciant et al., Phys.Rev.Lett. 85 (CLAS 2000 data)

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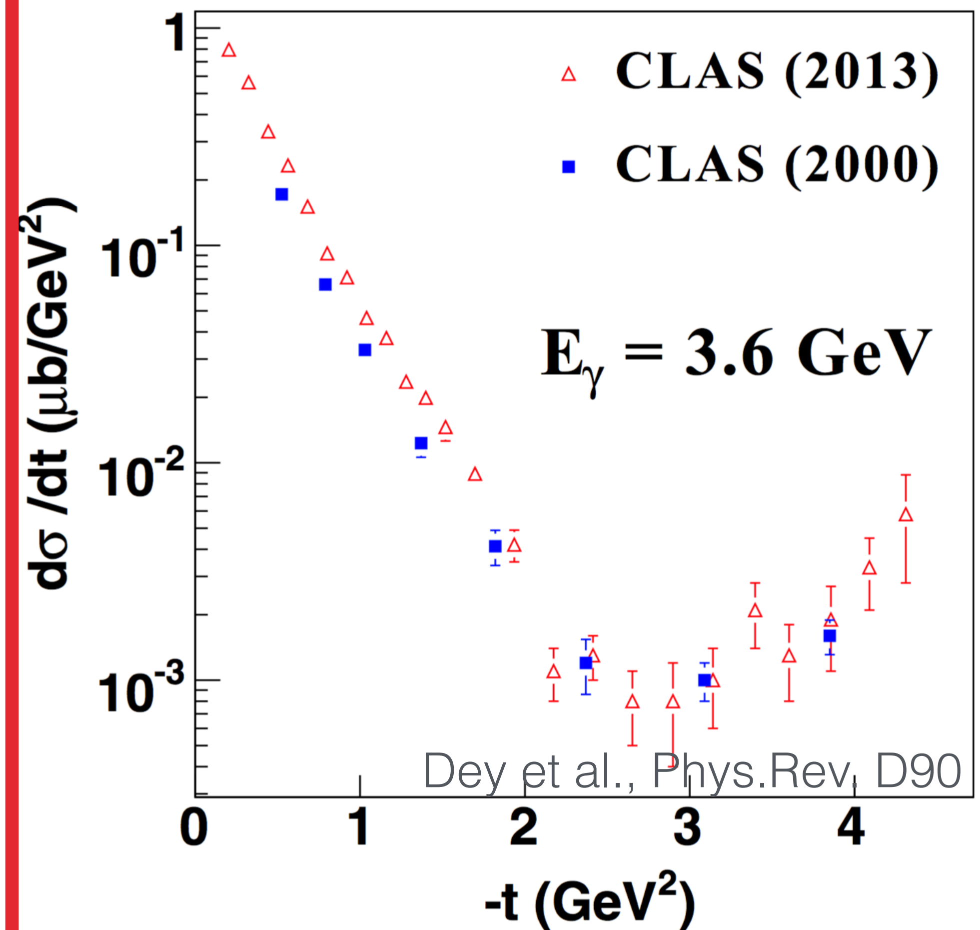

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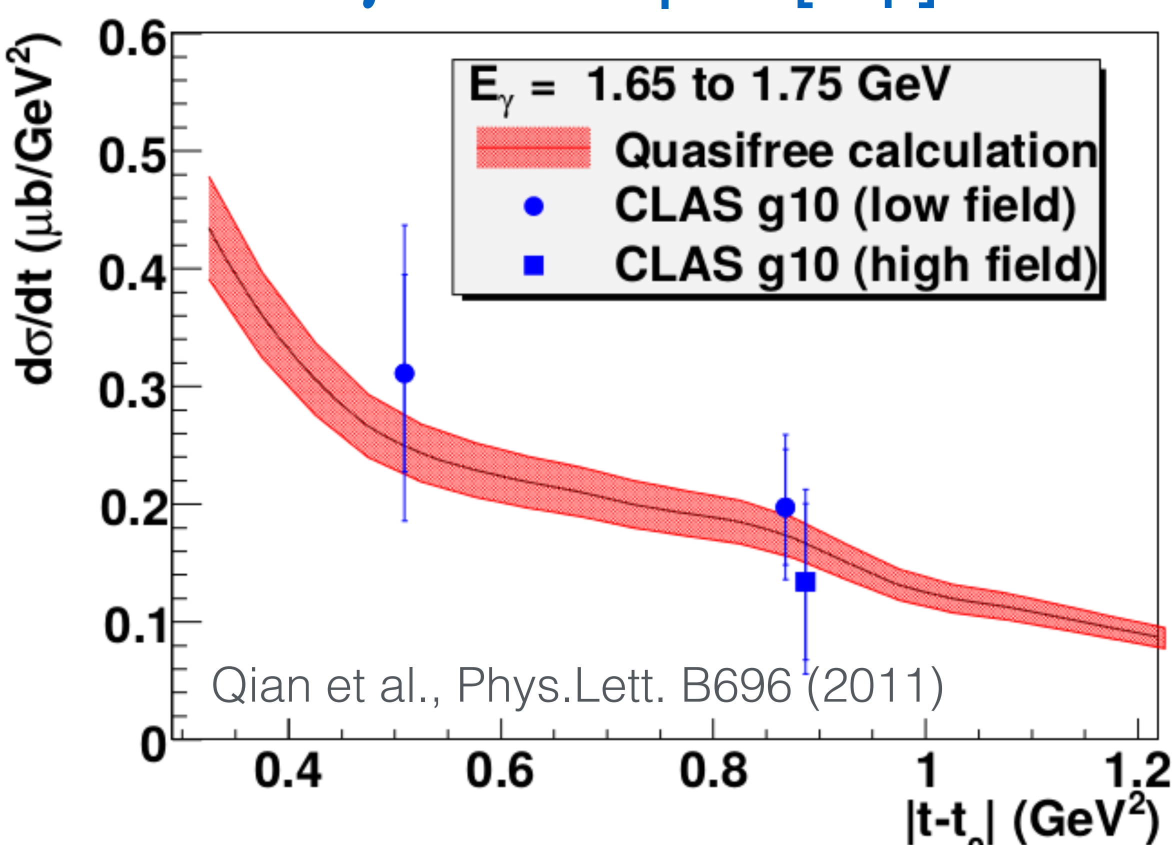
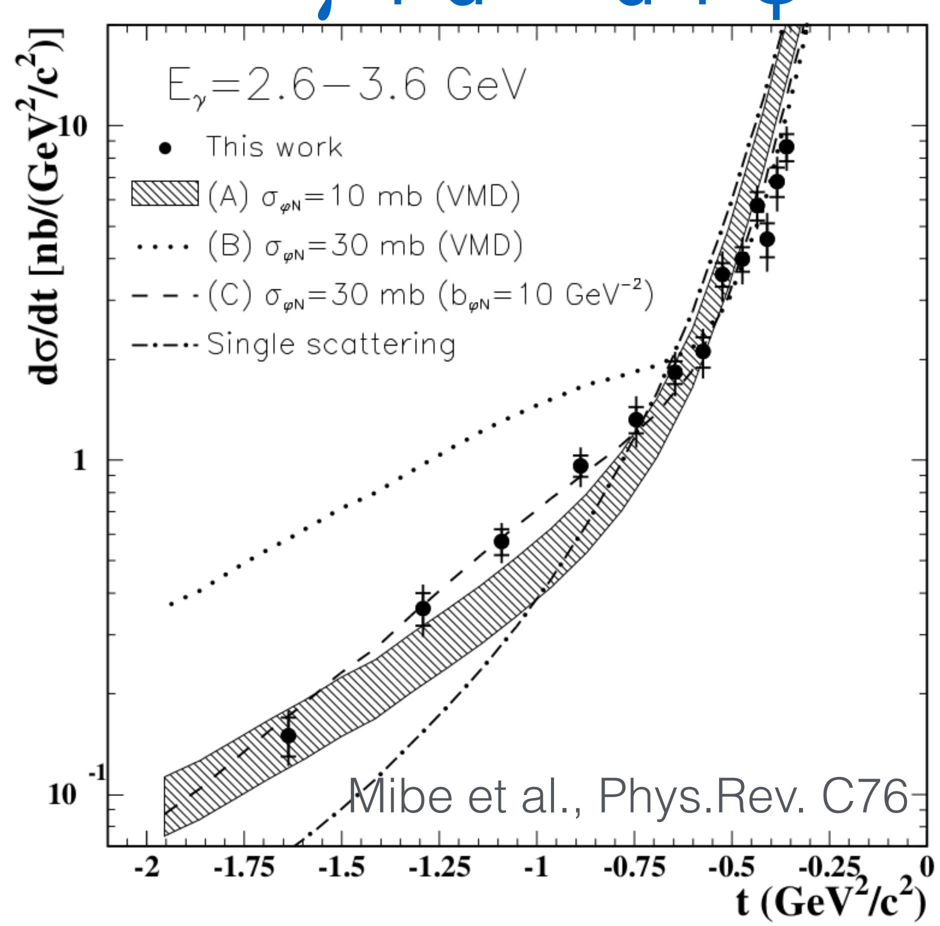


$\gamma + d \rightarrow d + \phi$



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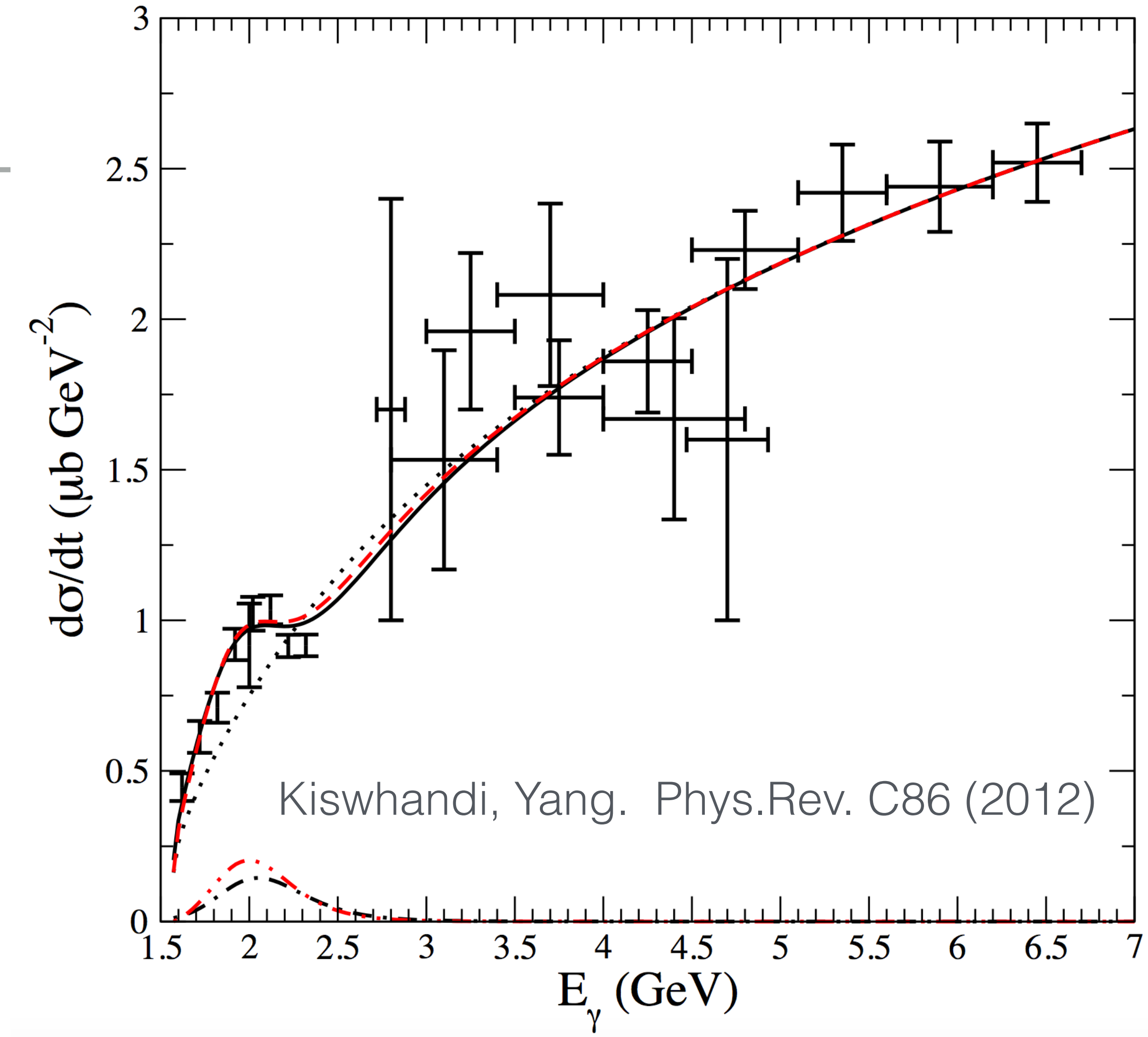
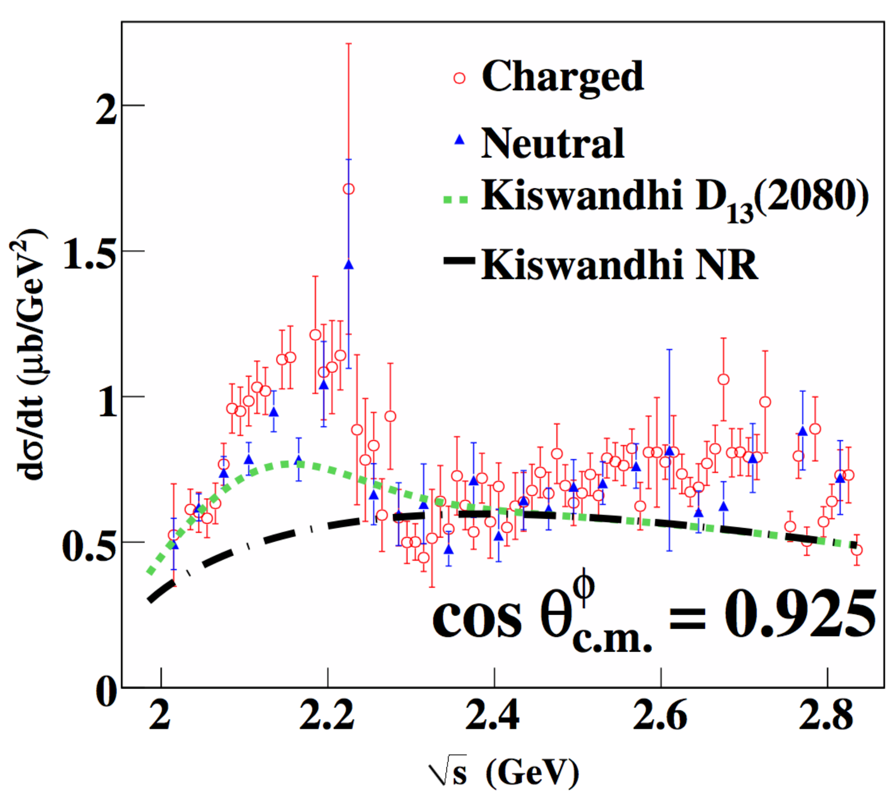
$\gamma + p \rightarrow p + \Phi$

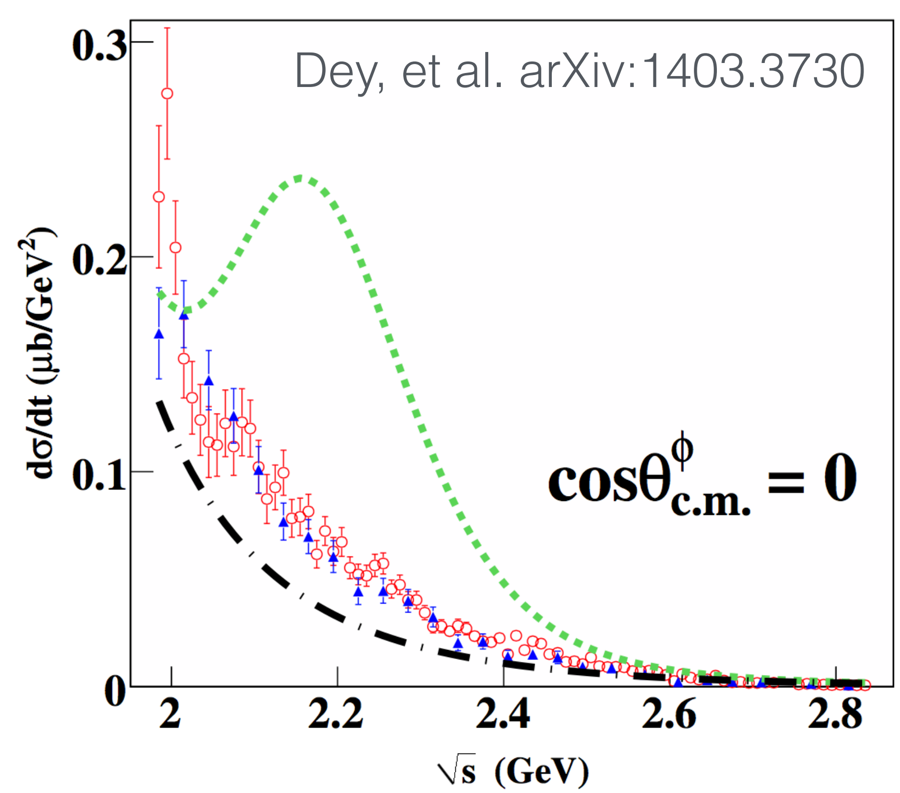
($J^P = 3/2^{\pm}$ resonance?)

- One of the more interesting puzzles to come out of angular studies of φ production is the mysterious peaking nature near 2 GeV photon energies.
  - **Possible solution**: $J^P = 3/2^{\pm}$ resonance [D_{13}(2080)] contributions?
    - Resonance structure disappears at low angle?



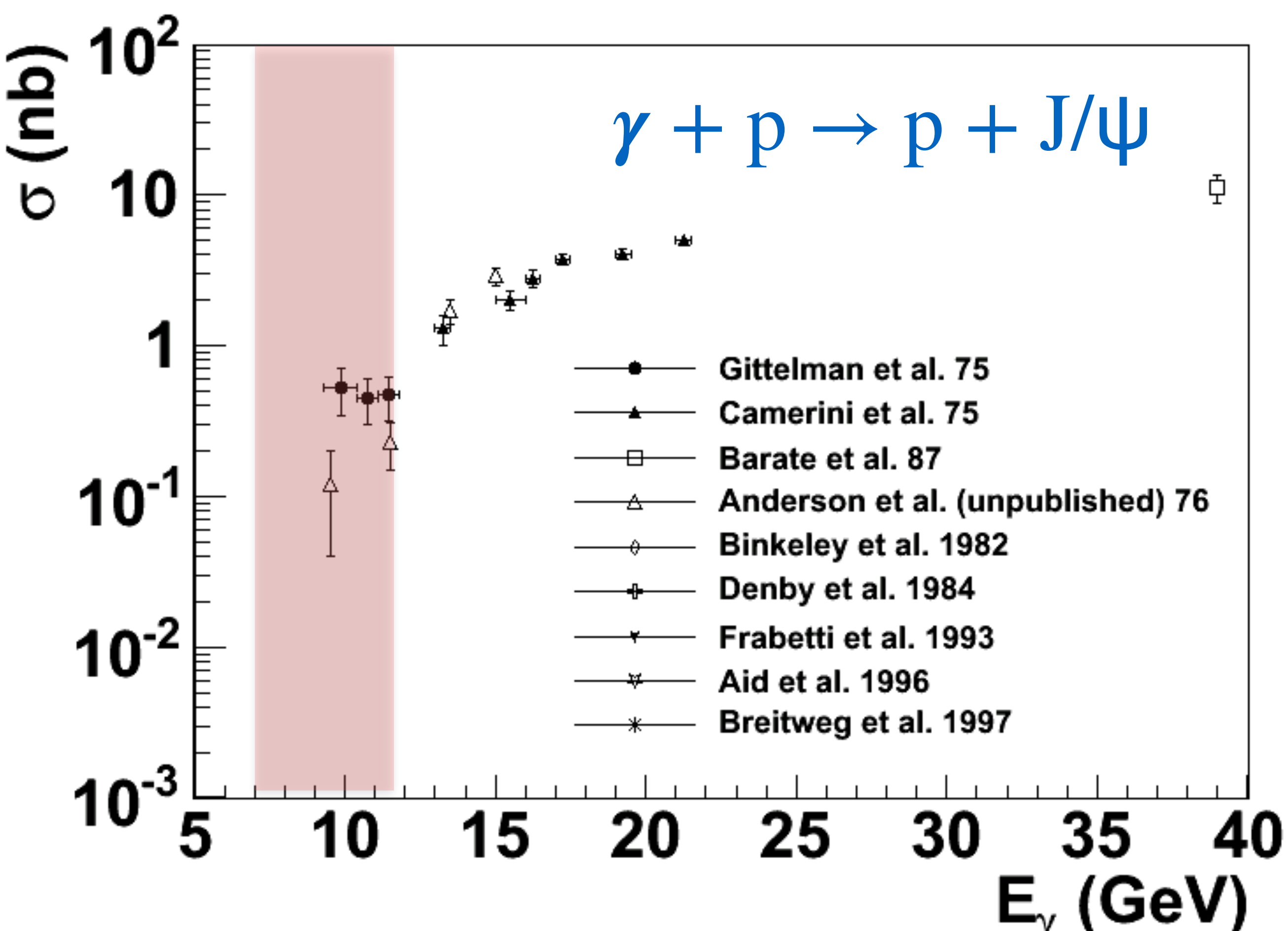
- **Possible Solution**: Re-scattering from Lambda-K production?
  - Neutral (K^0K^0) channel shows exact same structure?

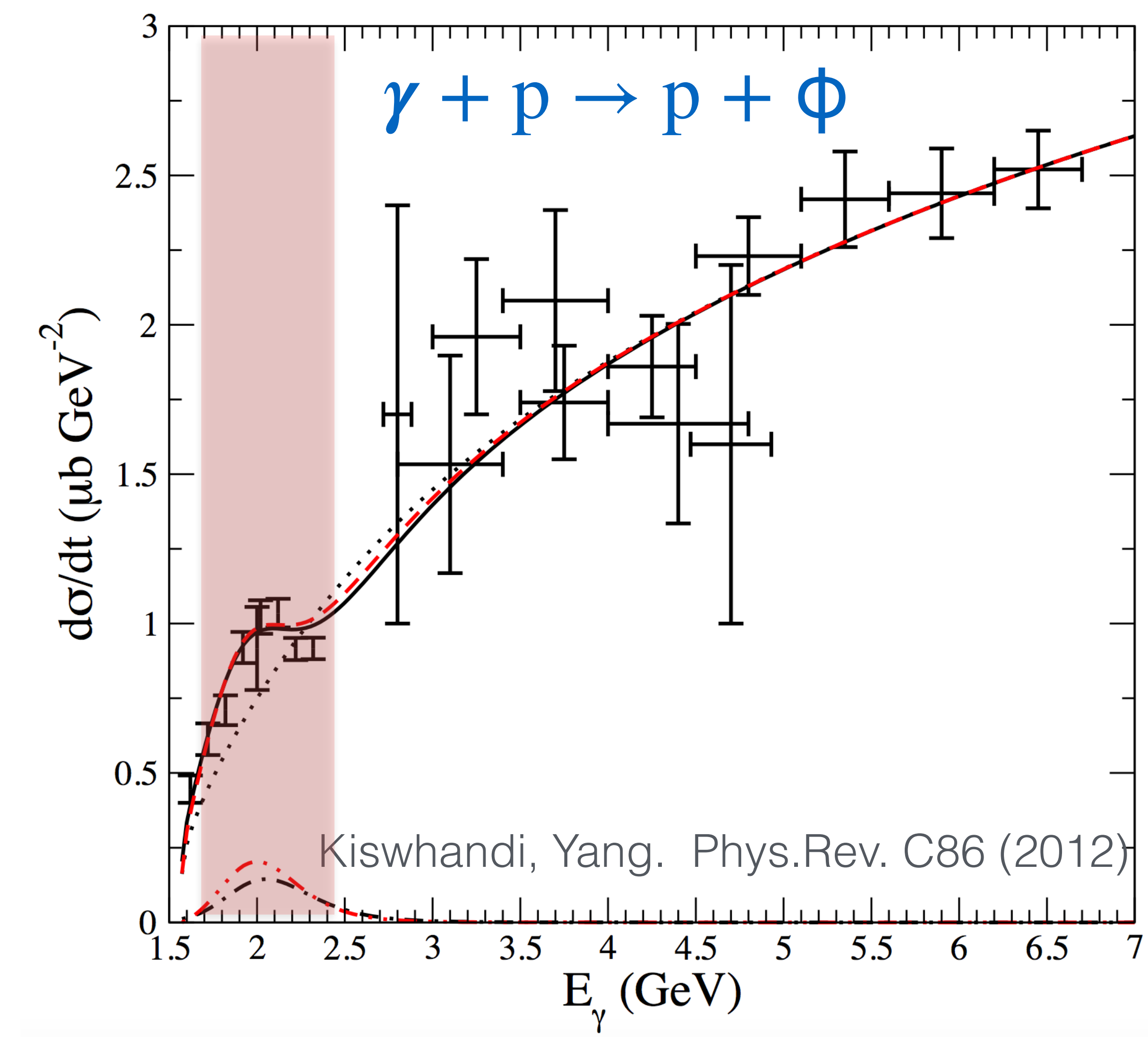




ELECTROPRODUCTION OF J/ψ OFF A PROTON TARGET NEAR THRESHOLD

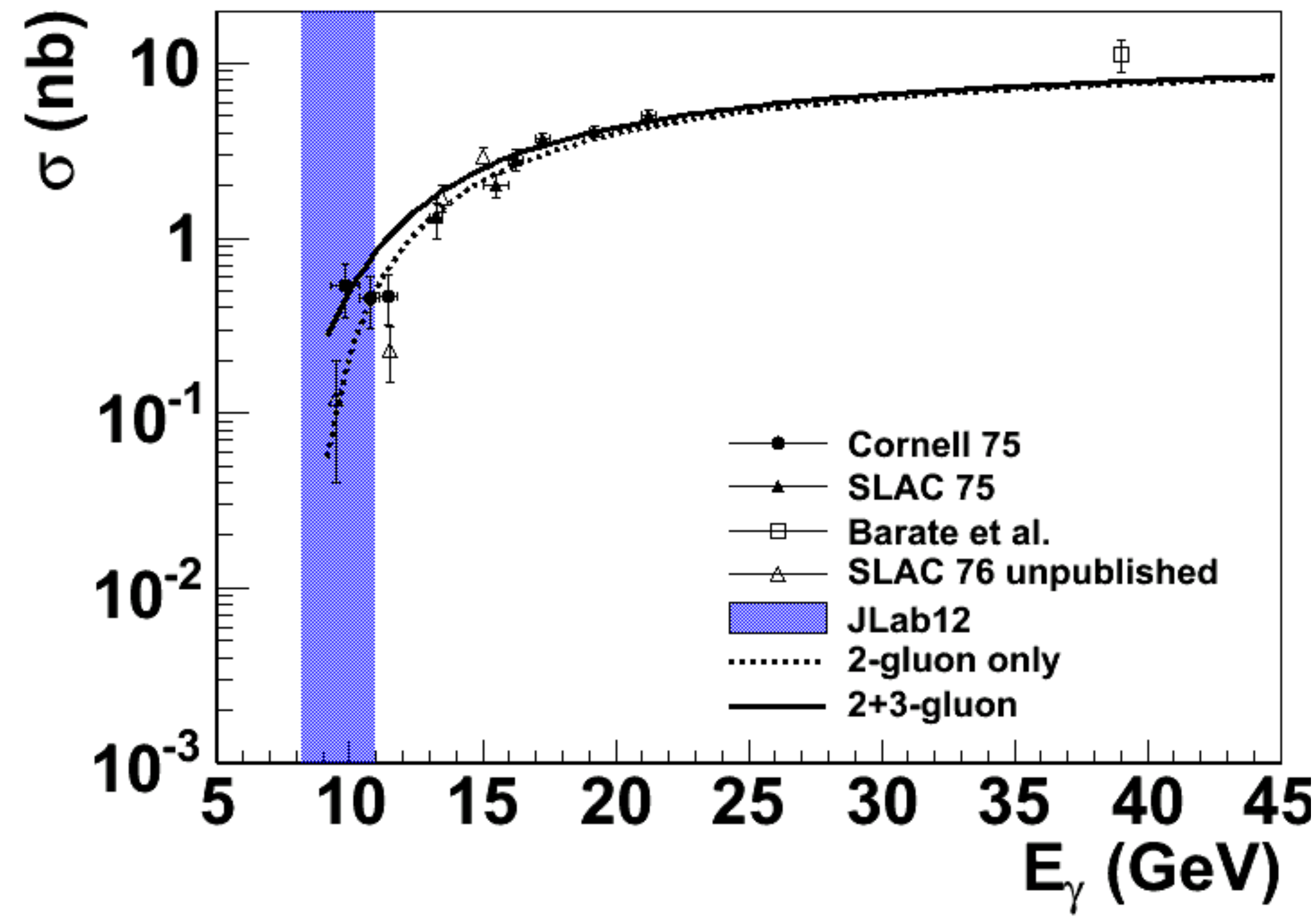
- An 11 GeV electron beam allows one to reach just beyond threshold for J/Ψ production.
  - The threshold region is very rich in physics.
    - Enhancements in J/ψ and φ??





ENHANCEMENT OF J/ψ NEAR THRESHOLD DUE TO GLUON EXCHANGE

- An 11 GeV electron beam allows one to reach just beyond threshold for J/Ψ production.
  - The threshold region is very rich in physics.
  - According to a hard scattering model, the J/ψ is produced via 2-gluon exchange, with a possible 3-gluon near threshold from Brodsky, Chudakov, Hoyer, Laget (PLB 498, 23 [2001])

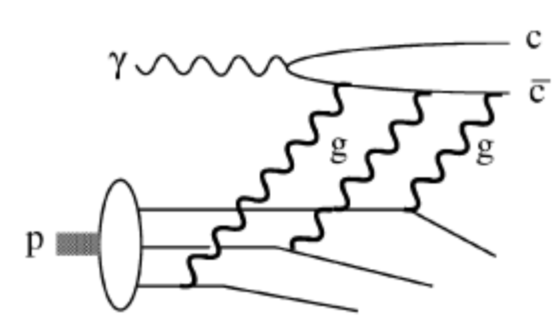


$$2-g:(1-x)^2 F(t)$$

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

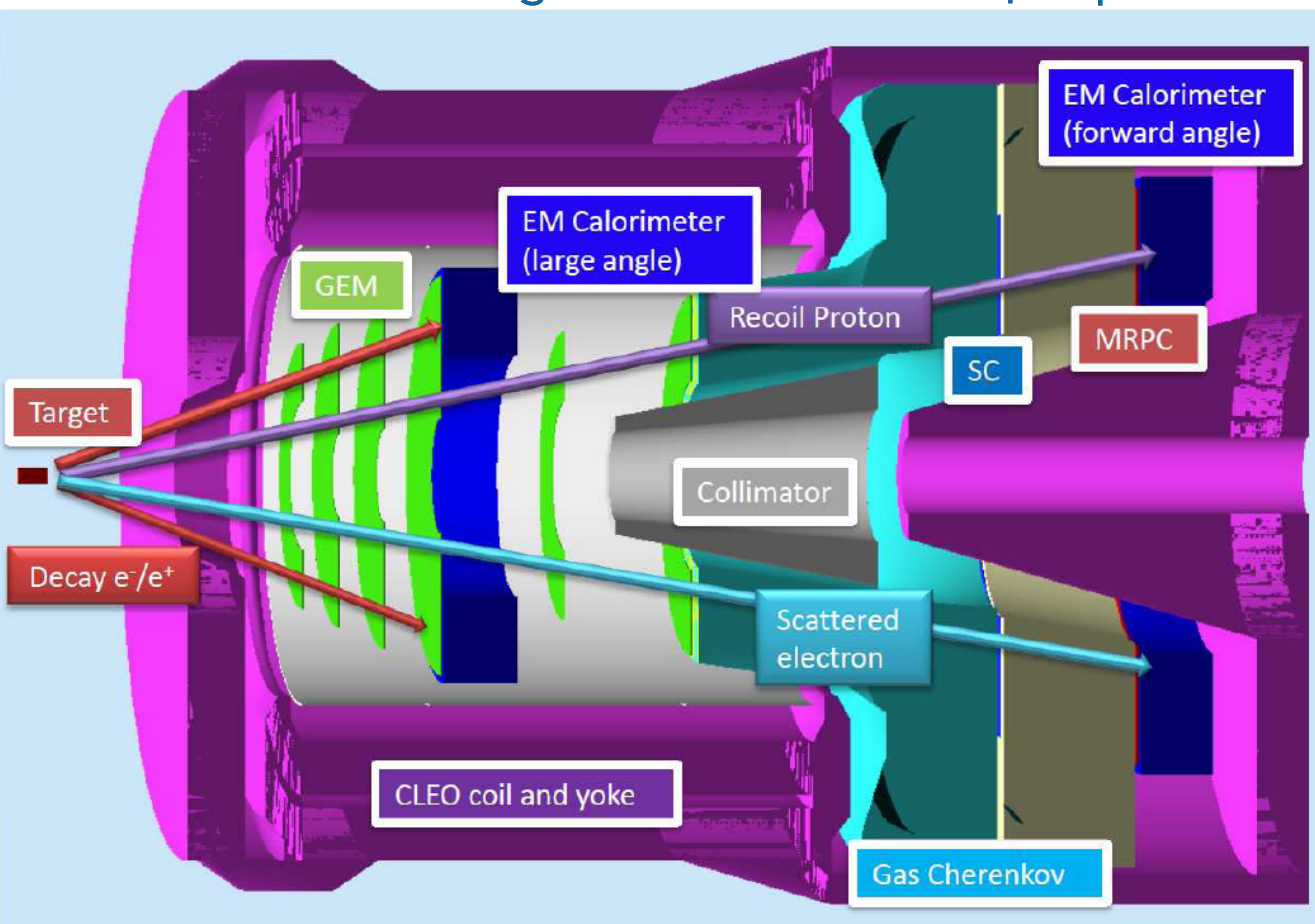
$$F(t) \propto \exp(1.13t)$$

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



ENHANCEMENT OF J/ψ NEAR THRESHOLD DUE TO GLUON EXCHANGE

SoLID detector configuration for SoLID-J/ψ experiment



Near Threshold Electroproduction of J/Ψ at 11 GeV

May 4, 2012

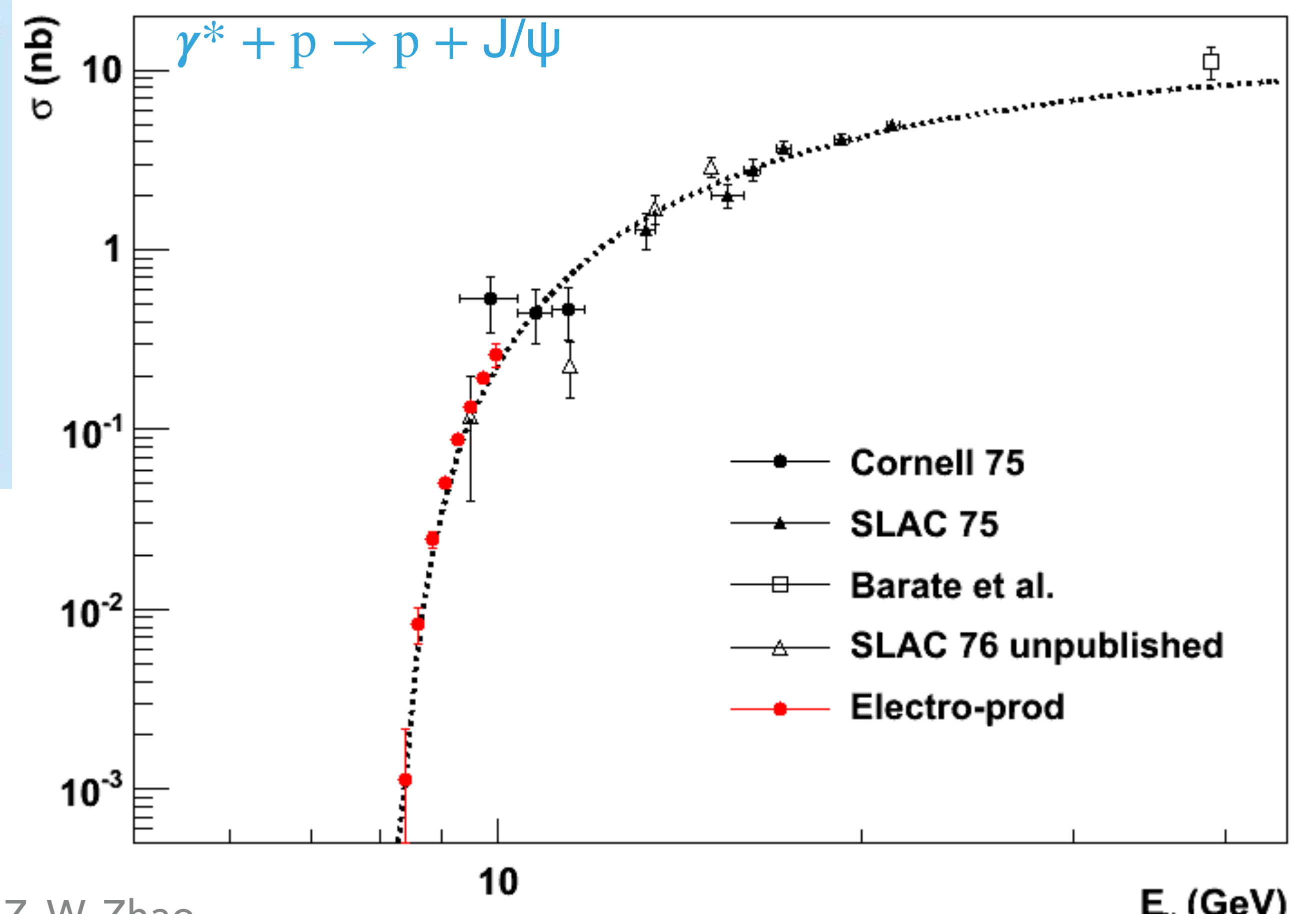
the ATHENNA Collaboration [1]

(A new experiment proposal to JLab-PAC39)

https://www.jlab.org/exp_prog/proposals/12/PR12-12-006.pdf

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:



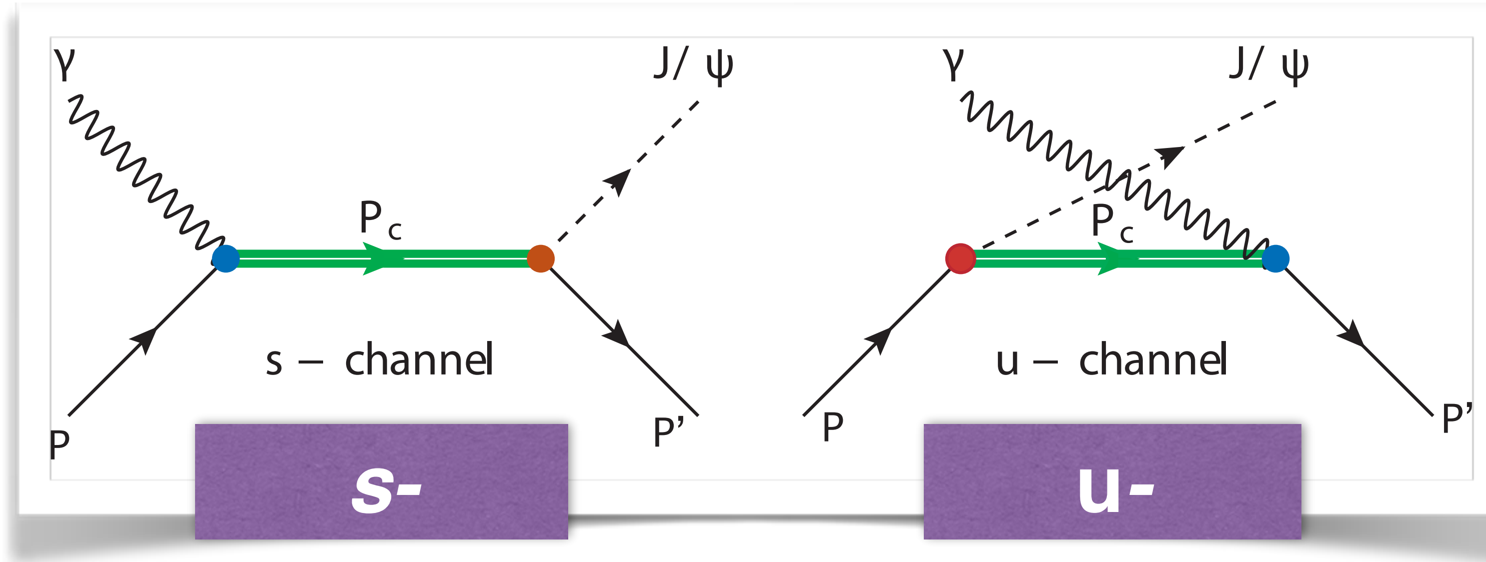
[1]Spokespeople for ATHENNA: K. Hafadi, Z.-E. Meziani, N. Sparveris, X.Qian, Z. W. Zhao

ENHANCEMENT OF J/ψ NEAR THRESHOLD DUE TO PENTAQUARK RESONANCE

- The LHCb discovery of the $P_C^+(4450)$ and $P_C^+(4390)$ from Λ_b decay:

$$\Lambda_b \to \Lambda^* J/\Psi \to (K^- p) J/\Psi$$

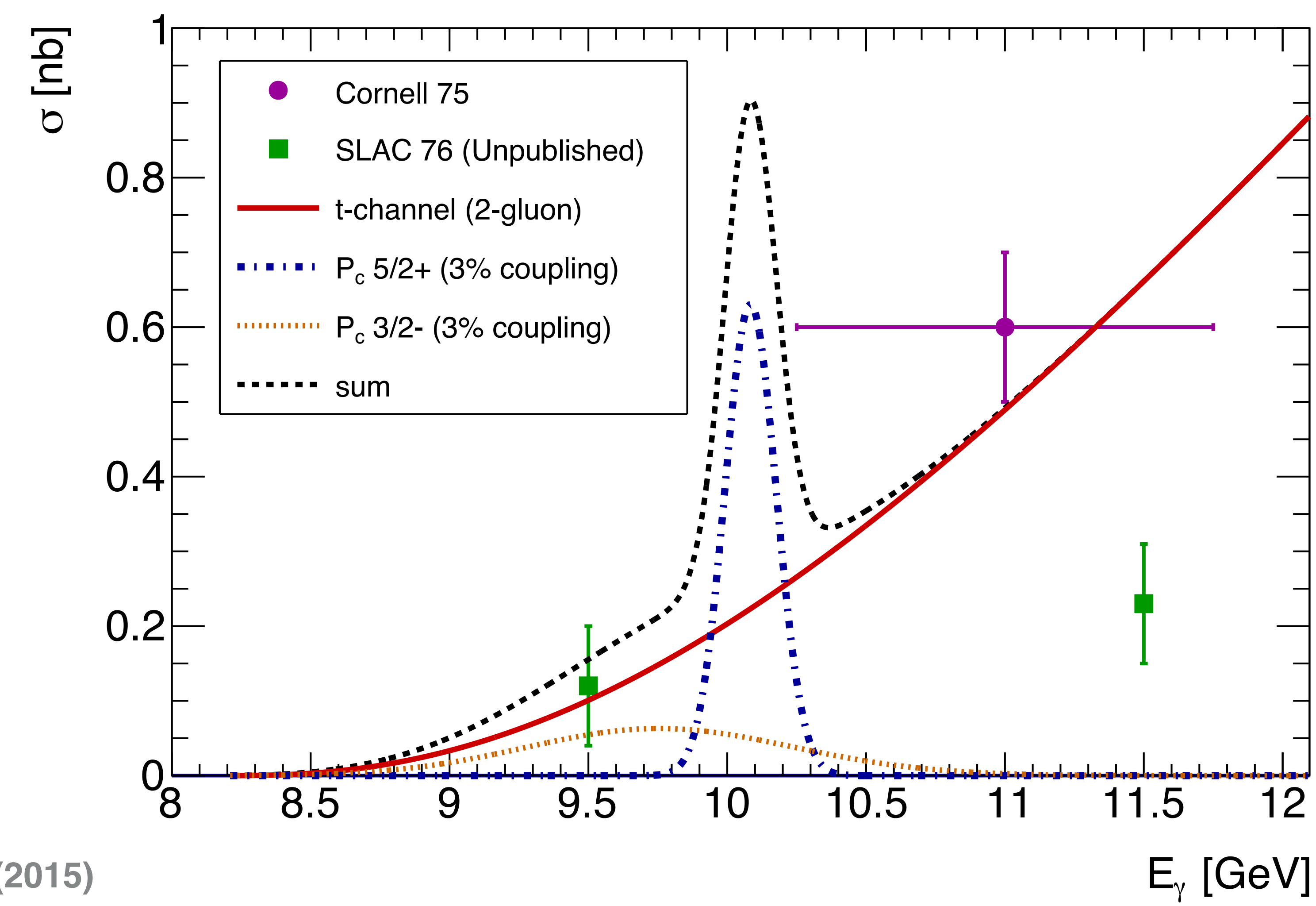
$$\Lambda_b \to K^- P_c \to K^- (p J/\Psi)$$



- The proton-J/Ψ decay suggests a simple s-channel production is possible:

$$\gamma + p \to P_c^+ \to p + J/\Psi$$

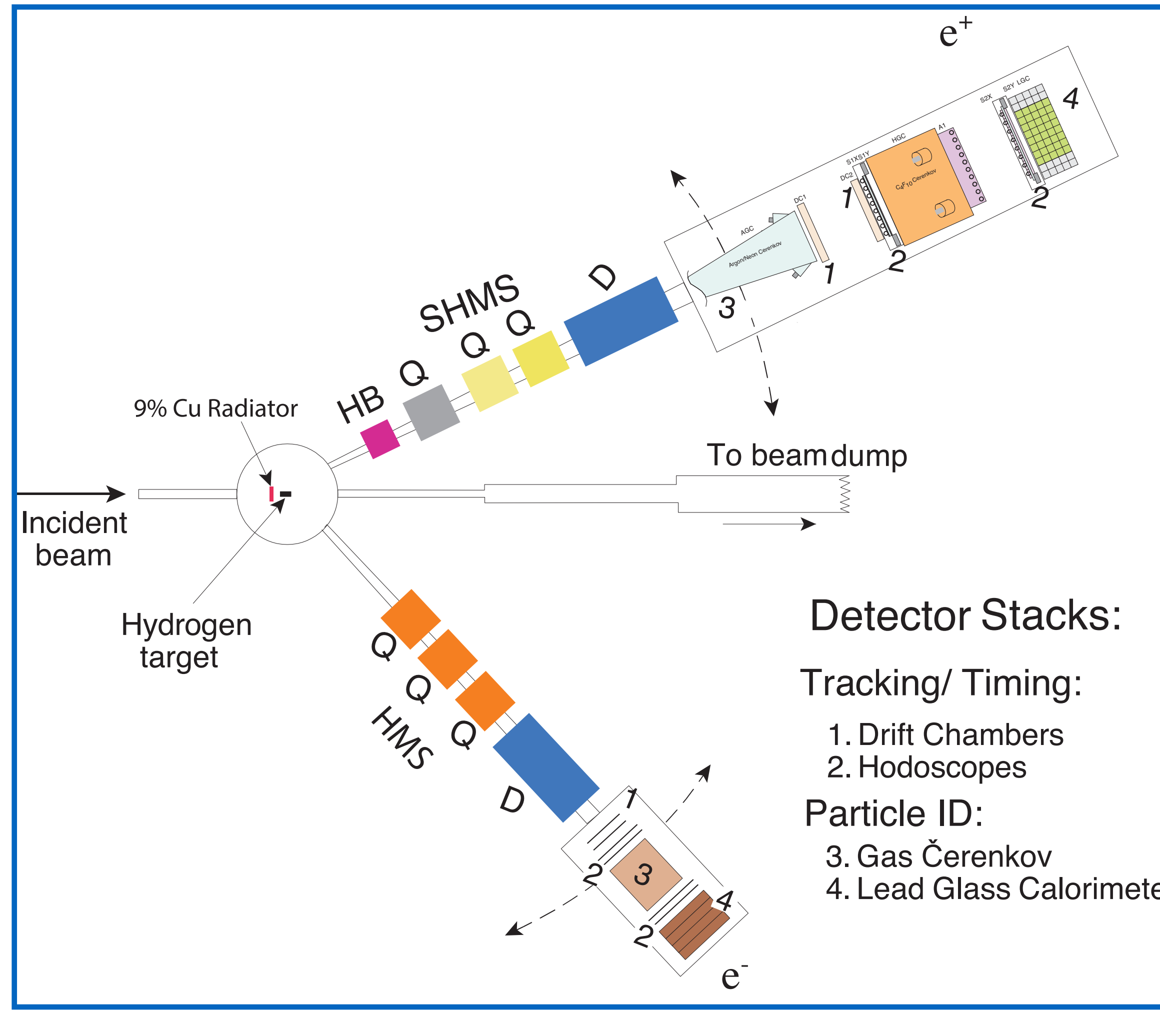
- An s-channel resonance would exist where there is very little experimental data near J/Ψ threshold.

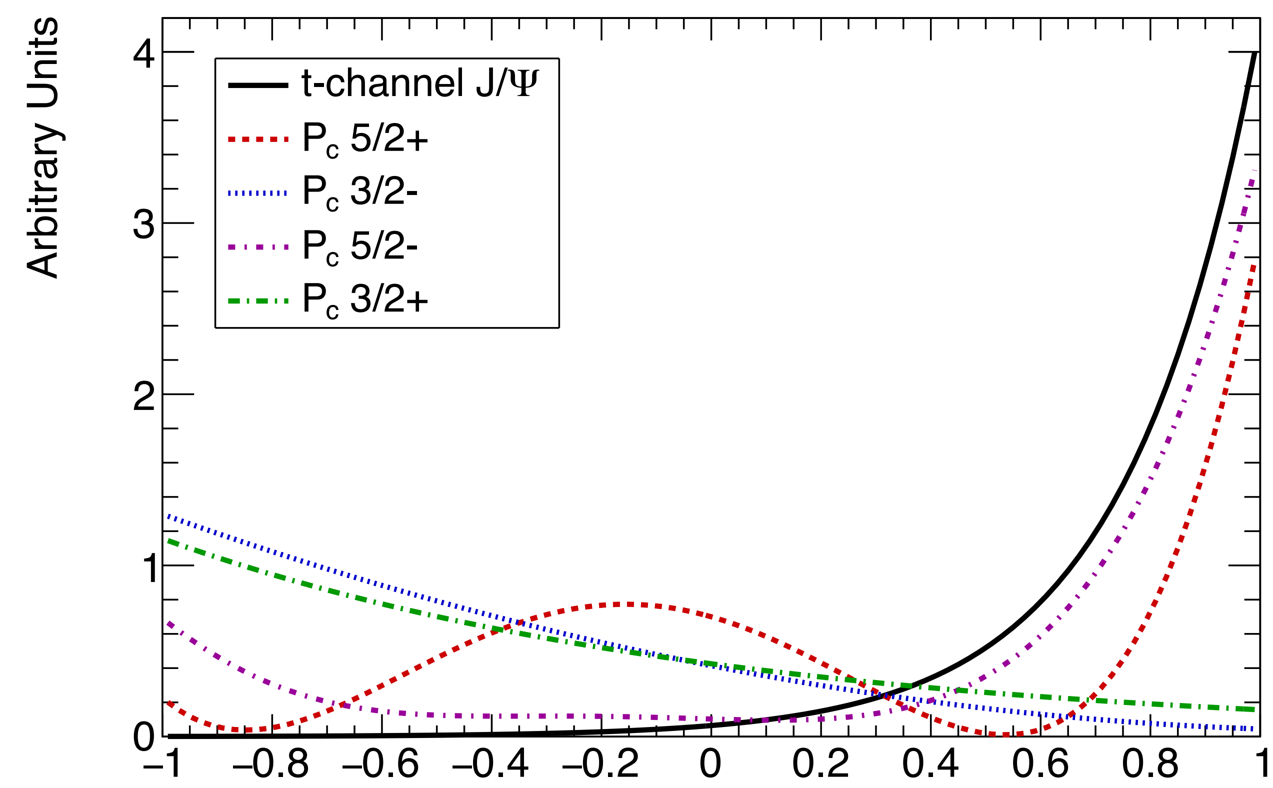


LHCb Pentaquark Discovery: Aaij, R, et. al (LHCb) PRL 115-7 (2015)

SEARCH FOR $P_c^+(4450)$ IN JLAB'S HALL-C

- Two-arm experiment
    - Detect J/ψ decay of electron and positron in coincidence.
- 50μA electron beam at 10.7 GeV
- 9% copper radiator
- 15cm liquid hydrogen target
- 9-days of "signal" production
    - Leverage angular decay to maximize signal / background
- 2-days of t-channel "background" production





Calculations from: Wang Q., *et al.*, PRD 92-3 (2015)

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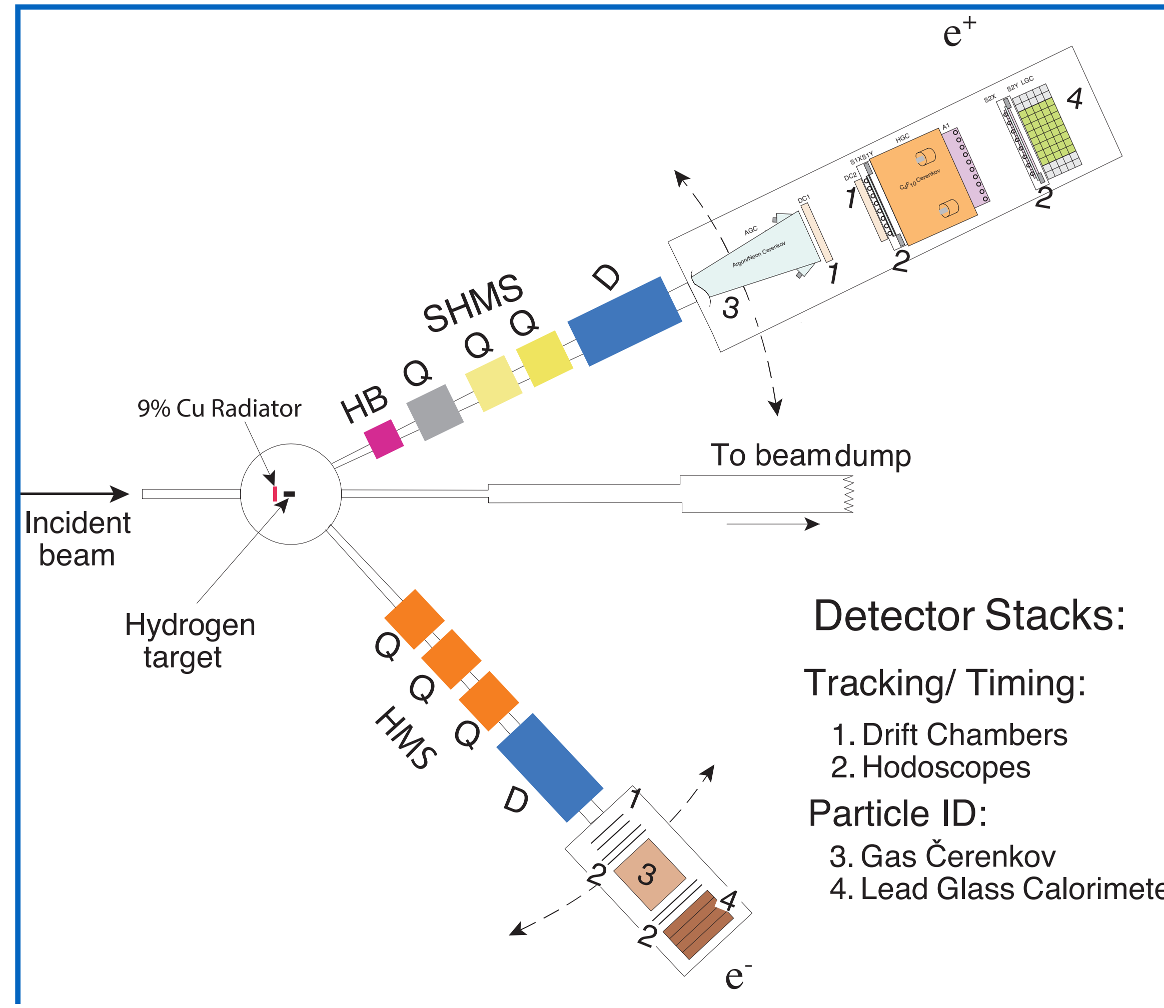
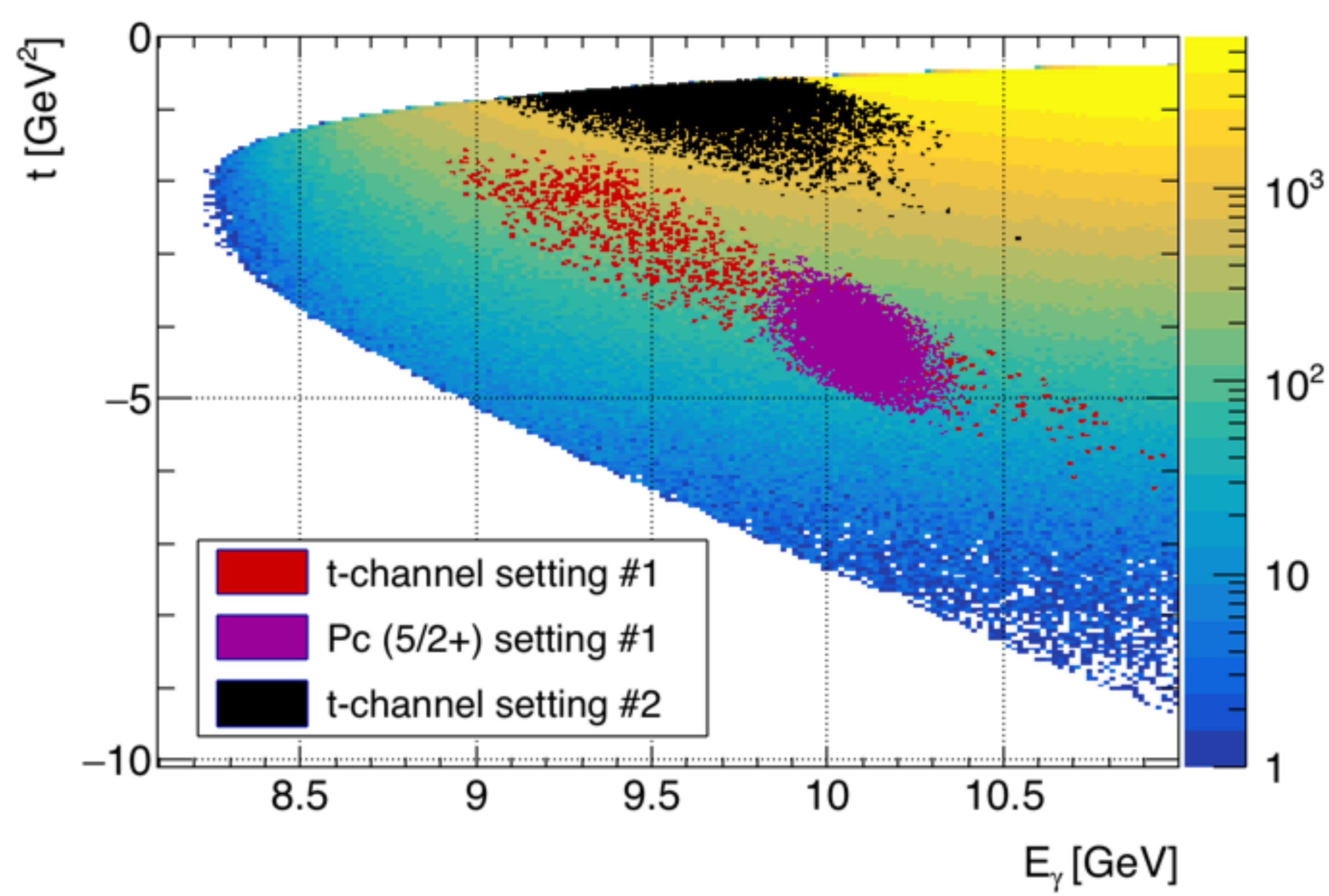




SEARCH FOR $P_C^+(4450)$ IN JLAB'S HALL-C

PR12-16-007

Scientific Rating: A – High Impact

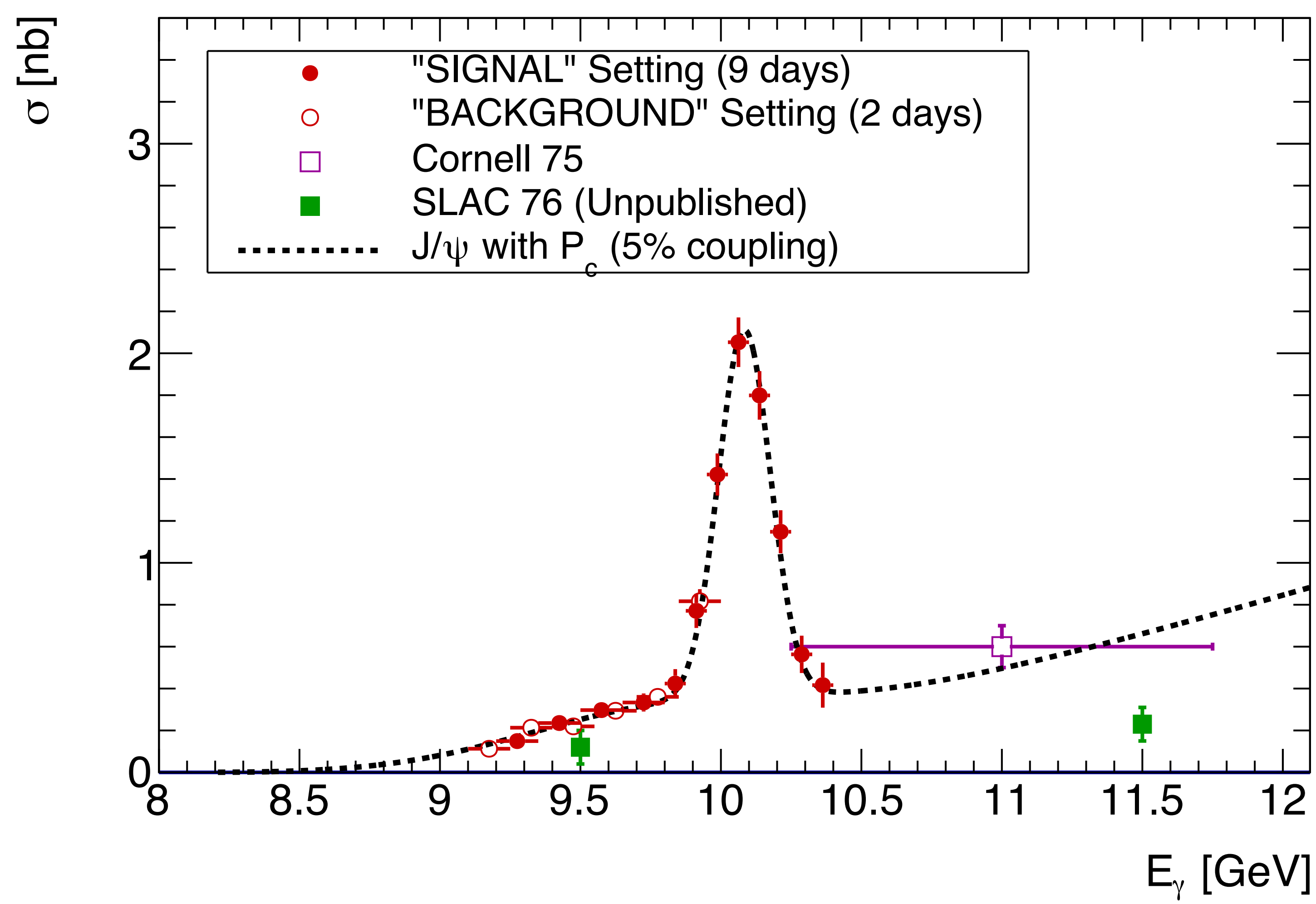
Recommendation: Approved

Title: "A search for the LHCb Charmed 'Pentaquark' using Photoproduction of J/ψ at threshold in Hall C at Jefferson Lab"

Spokespersons: Z.-E. Meziani (contact), S. Joosten, M. Paolone, E. Chudakov, M. Jones

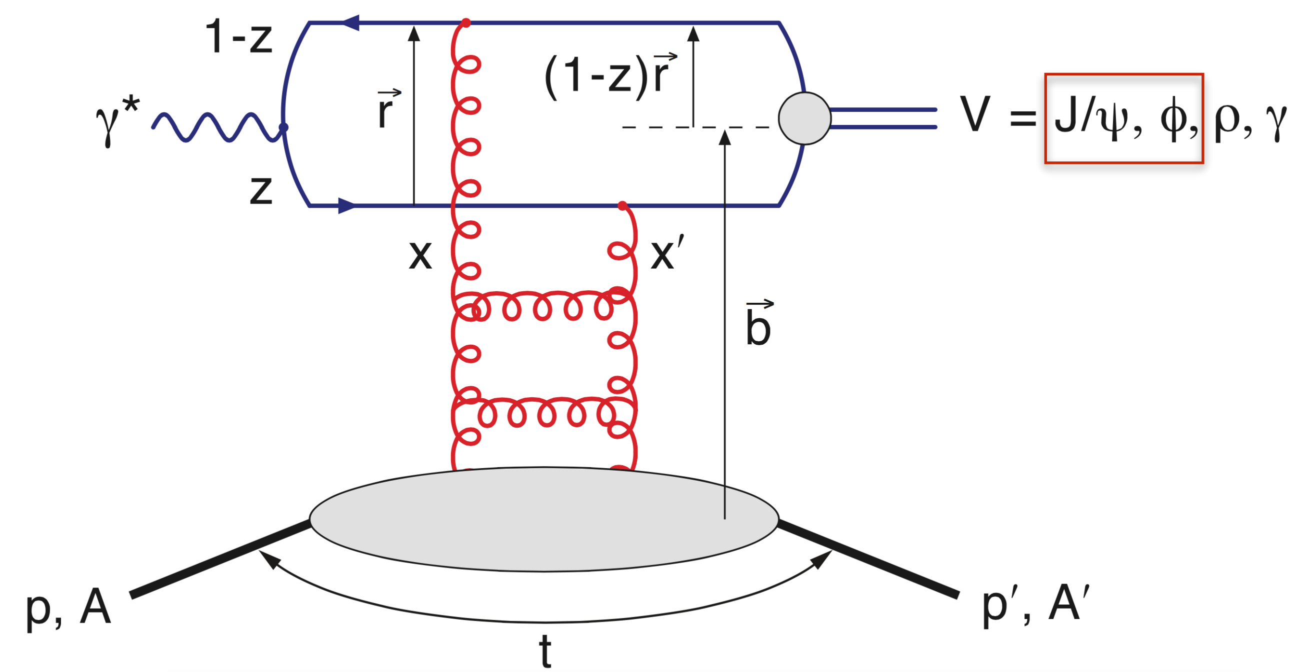
Full proposal: https://arxiv.org/abs/1609.00676

- Approved to run with the highest rating - "A + High Impact"
- Exact coupling/branching ratio is unknown.
  - Experiment is sensitive down to 1.3% coupling with 5σ confidence



$C\bar{C}$ OR $S\bar{S}$ ELECTROPRODUCTION 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:

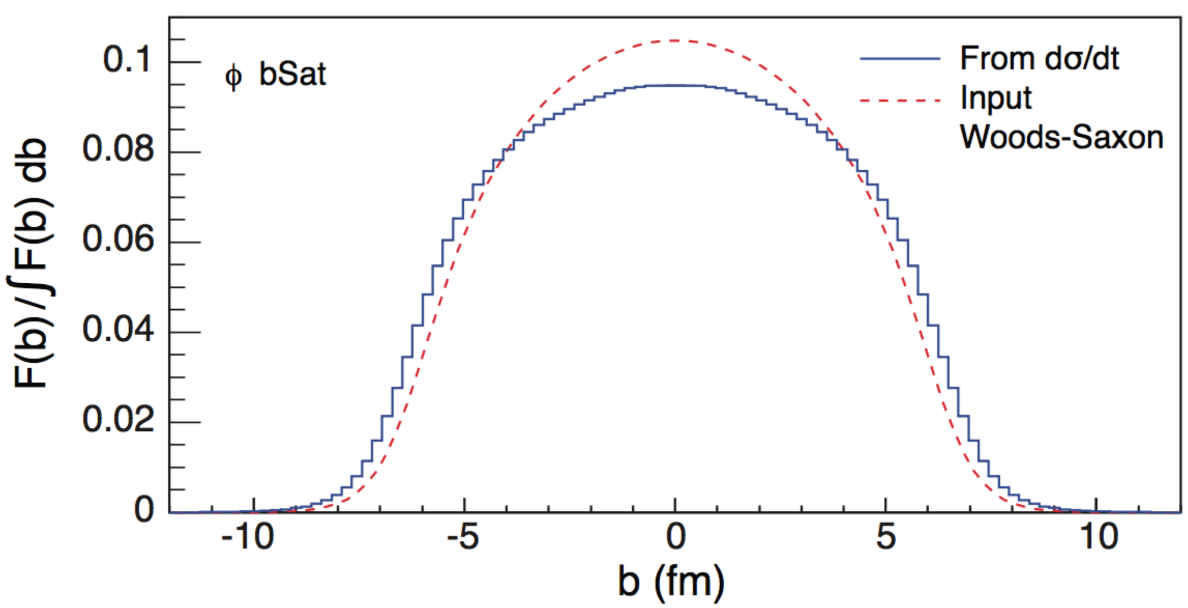
$$\mathcal{A}_{T,L}^{\gamma^* p\to Vp}(x,Q,\Delta) = i\int \mathrm{d}r \int \frac{\mathrm{d}z}{4\pi}\int \mathrm{d}^2\mathbf{b}\,(\Psi_V^*\Psi)(r,z)$$
$$\times 2\pi r J_0([1-z]r\Delta)e^{-i\mathbf{b}\cdot\Delta}\frac{\mathrm{d}\sigma_{q\bar{q}}^{(p)}}{\mathrm{d}^2\mathbf{b}}(x,r,\mathbf{b}) \;\; (1)$$

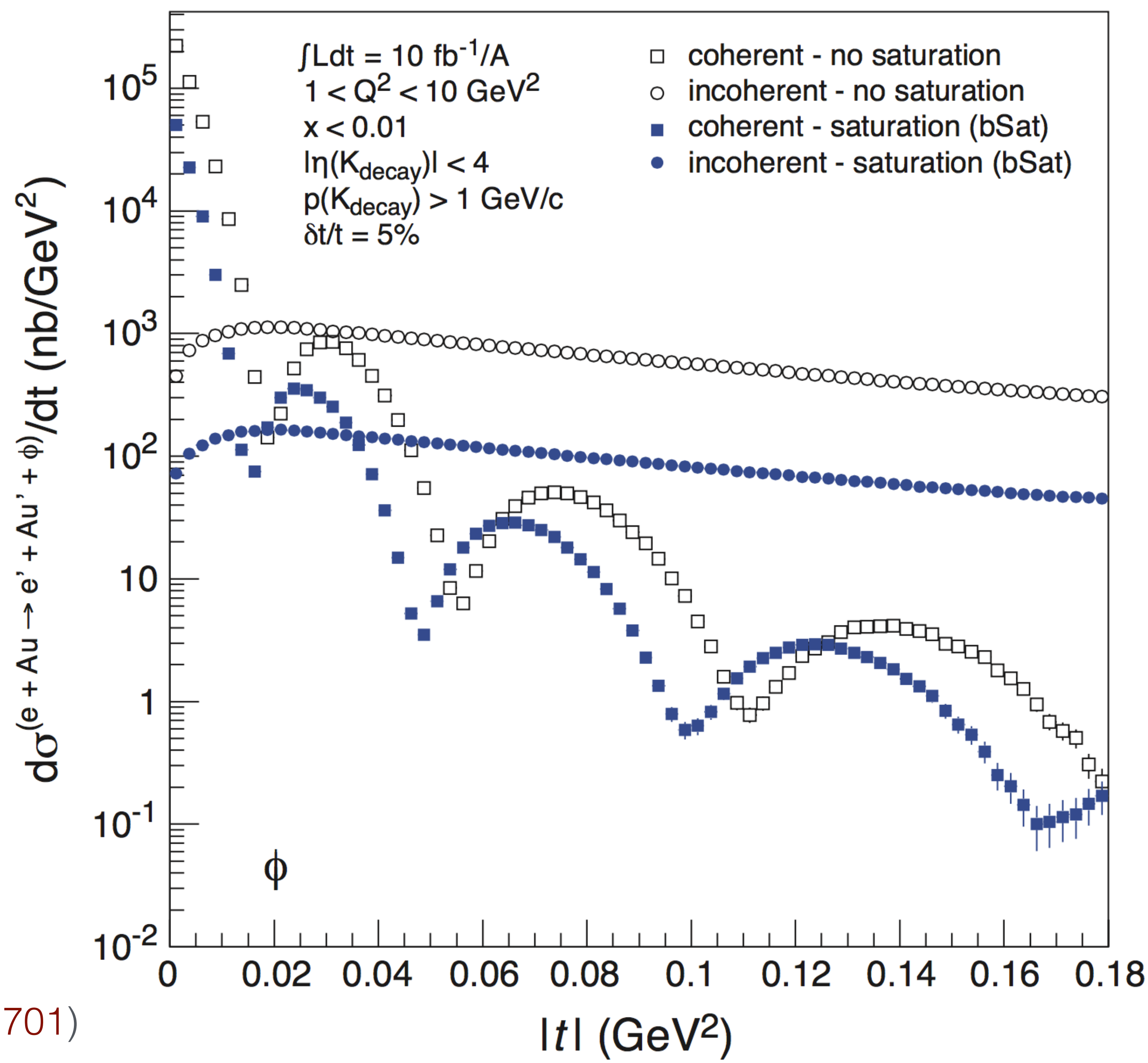
COHERENT ELECTROPRODUCTION OF Φ OFF HEAVY NUCLEI AT EIC

- **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: Eur.Phys.J. A52 (2016) (arXiv:1212.1701)
[2]Phys. Rev. C 87, 024913 (2013) (arXiv:1211.3048)
[3]Nucl.Phys. B603 (2001) 427-445 (arXiv:hep-ph/0102291)

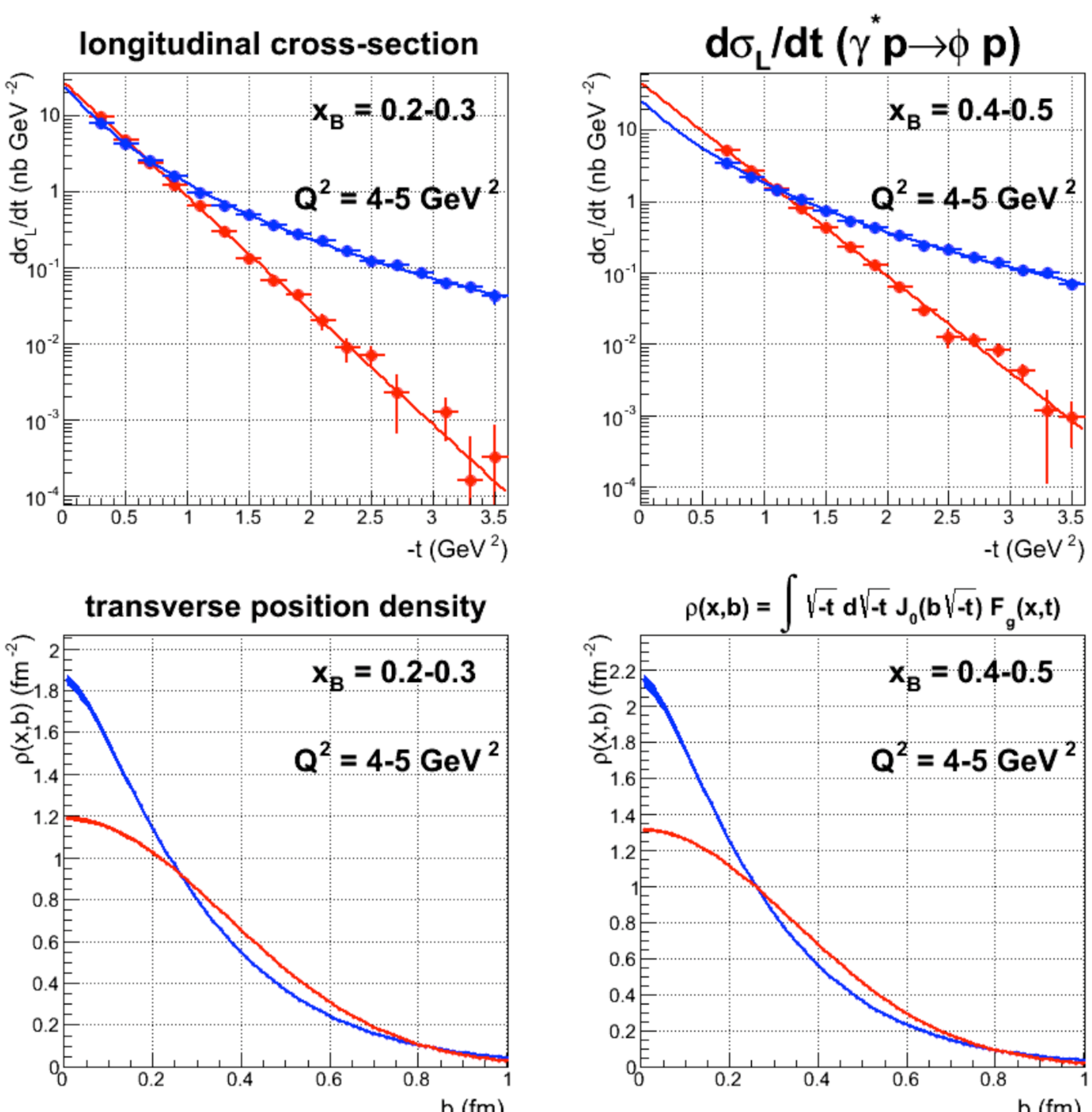
$\gamma^* + p \rightarrow p + \phi$ (CLAS12)

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

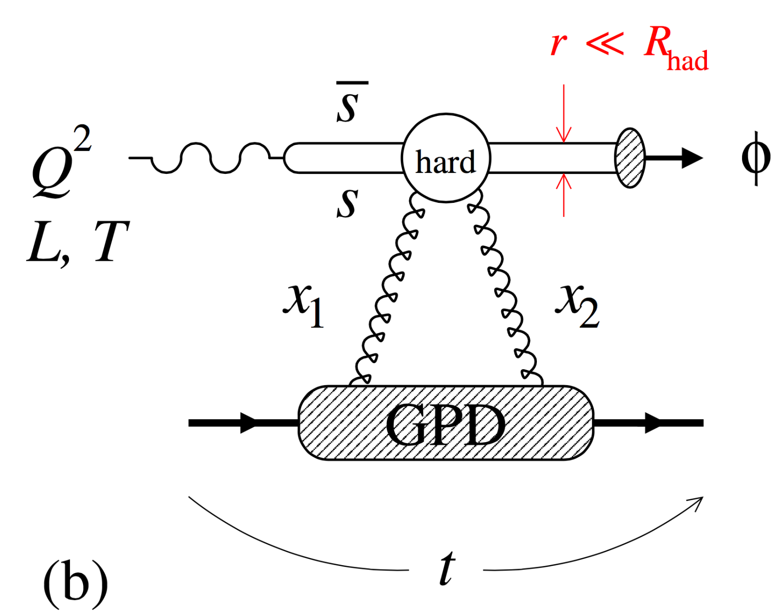
Proposal to Jefferson Lab PAC39
Exclusive Phi Meson Electroproduction with CLAS12

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*



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

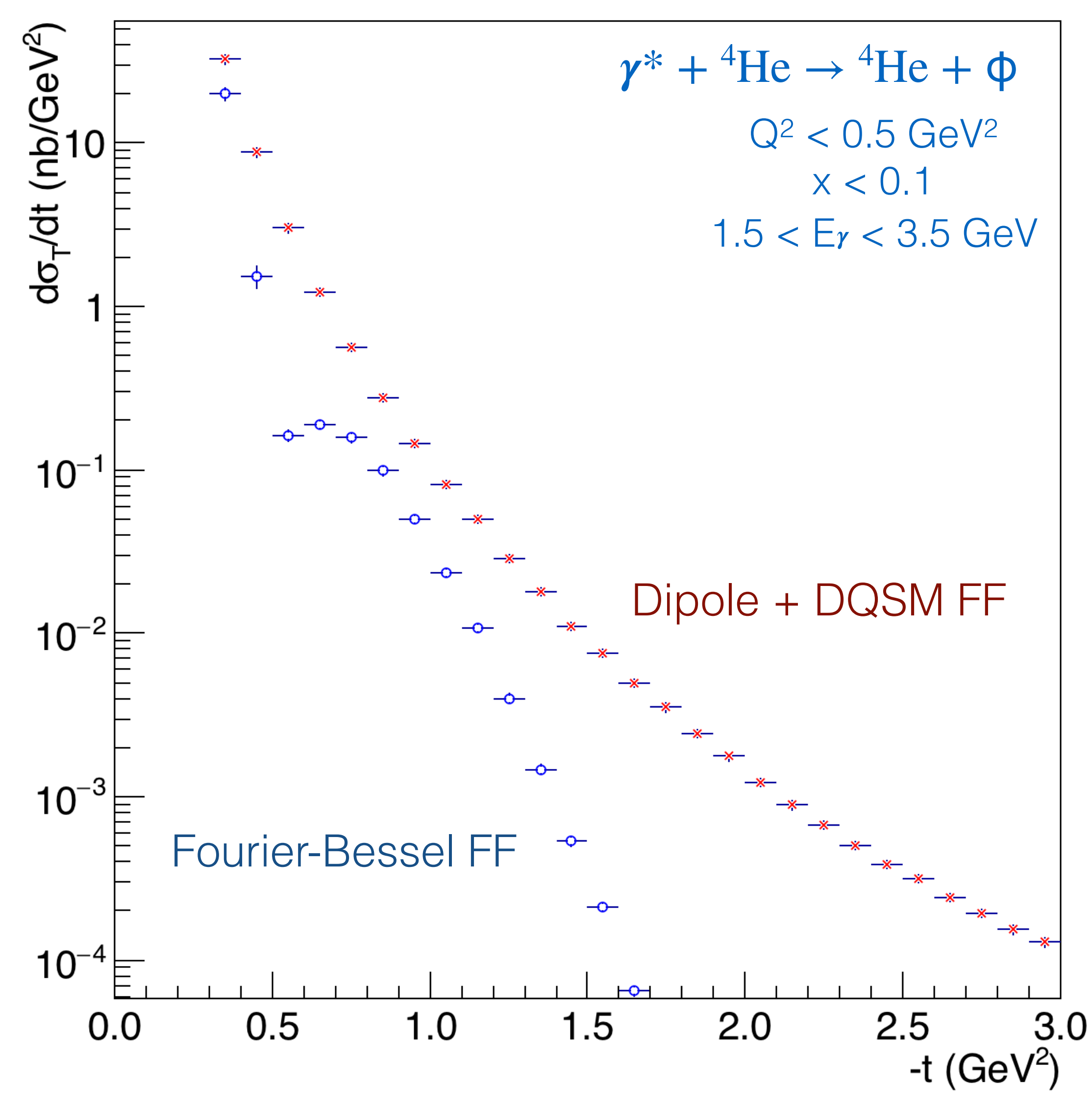


$\gamma^* + {}^4\mathrm{He} \to {}^4\mathrm{He} + \phi$

- ^{4}He is nice place to search for medium effects: relatively light, dense, and the 4-nucleon system is not overly complicated. Spin-0 means one chiral-even GPD at twist-2:

$$\frac{d\sigma_L}{dt}[{}^4He] \propto |\langle H_g \rangle|^2$$

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



- How are partons / gluons distributed in a nucleus? First steps toward a global analysis.

We can compare x_V in DVMP (gluon GPD) to x_B in DVCS (parton GPD)

$$x_V = \frac{Q^2 + M_\phi^2}{W^2 + Q^2 + M_{He}^2} = x_B\left(\frac{Q^2 + M_\phi^2}{Q^2}\right)$$

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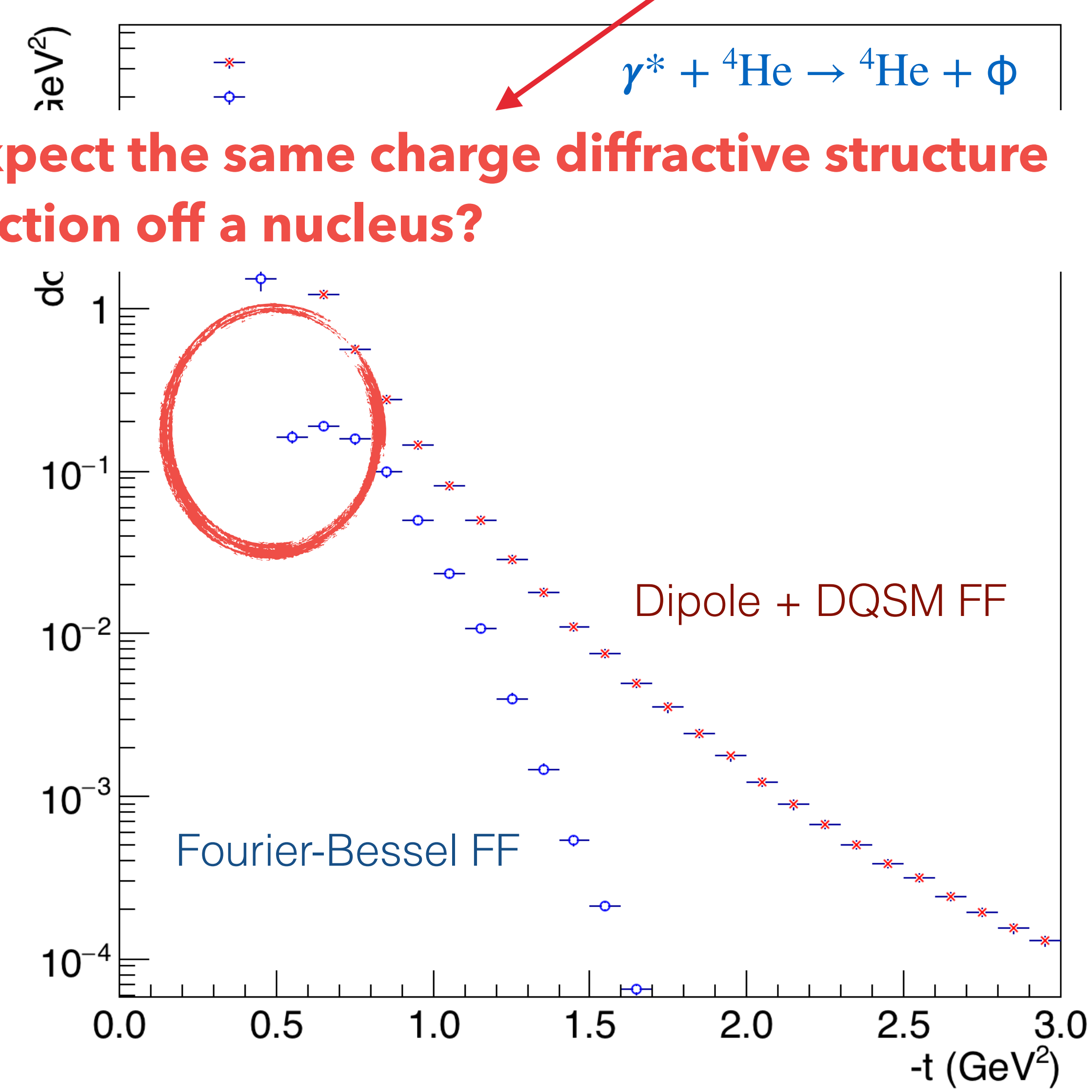
Should we expect the same charge diffractive structure for phi production off a nucleus?



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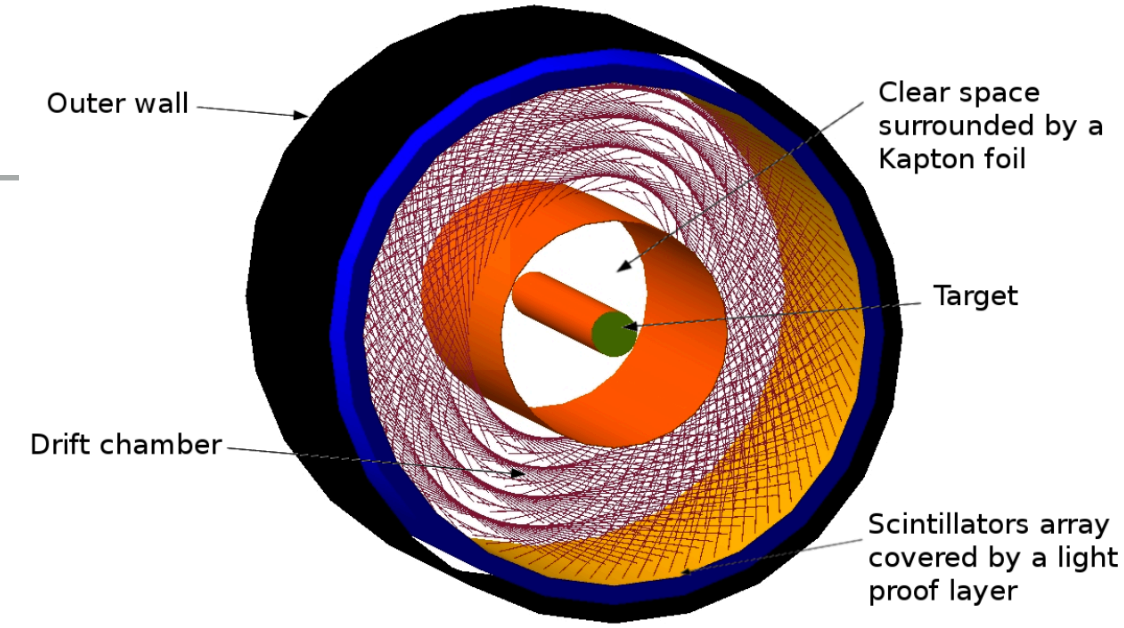
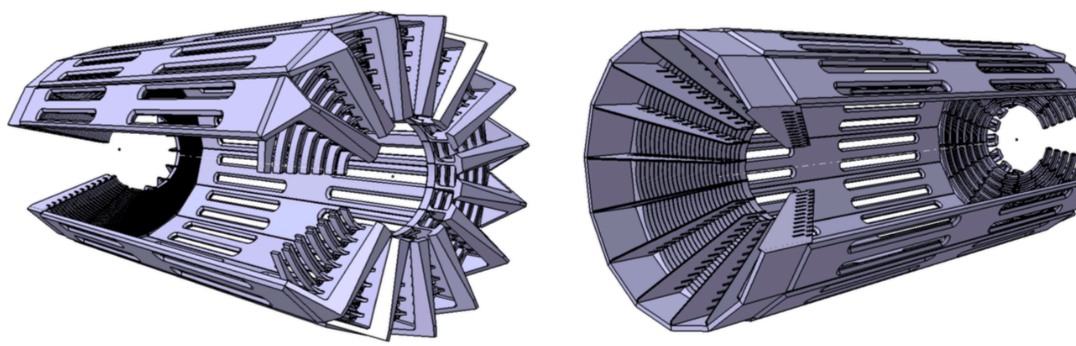
$\gamma^* + {}^4\mathrm{He} \rightarrow {}^4\mathrm{He} + \phi$ (ALERT)

- The ALERT detector program was presented to JLAB's PAC44.
  - ALERT is **a** **l**ow **e**nergy **r**ecoil **t**racker for use with CLAS12 at JLab.
  - Robust physics motivation on light nuclei targets:
    - tagged DVCS, DVMP, EMC studies.
  - Deferred
    - Committee enthusiastic about the physics proposed! (but proposal needs refinement)





Prototype structure

PR12-16-011

Scientific Rating: N/A

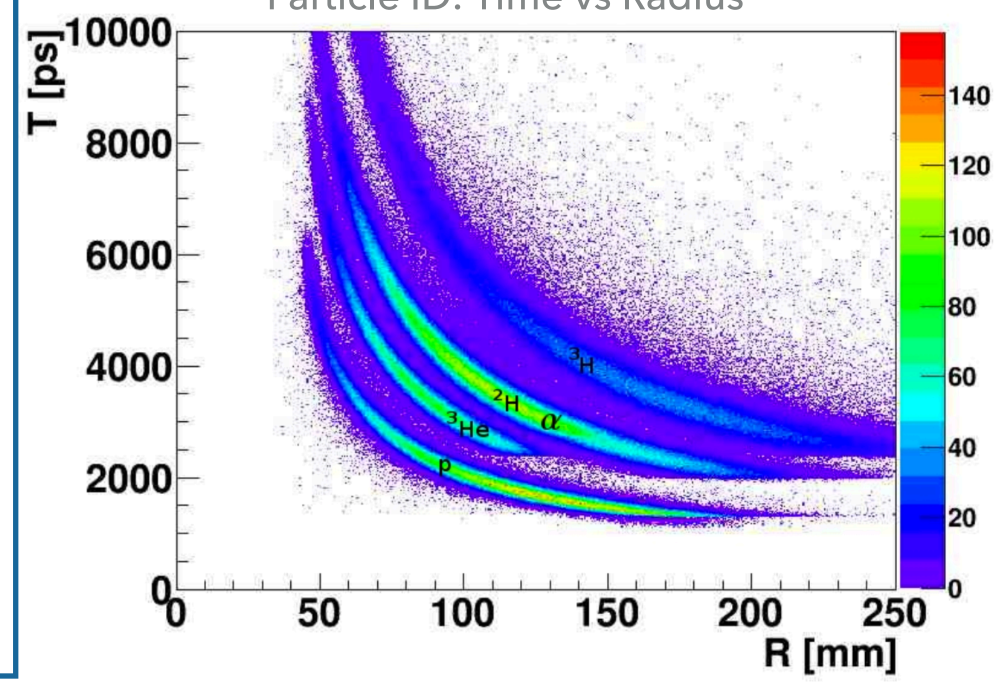
Recommendation: Deferred

Title: ALERT Run group: 12-16-011:
"Nuclear Exclusive and Semi-inclusive Measurements with a New CLAS12 Low Energy Recoil Tracker"
"12-16-011A, Partonic Structure of Light Nuclei"
"12-16-011B: Tagged Deeply Virtual Compton Scattering On Light Nuclei"
"12-16-011C, Other Physics Opportunities with the ALERT Run Group »

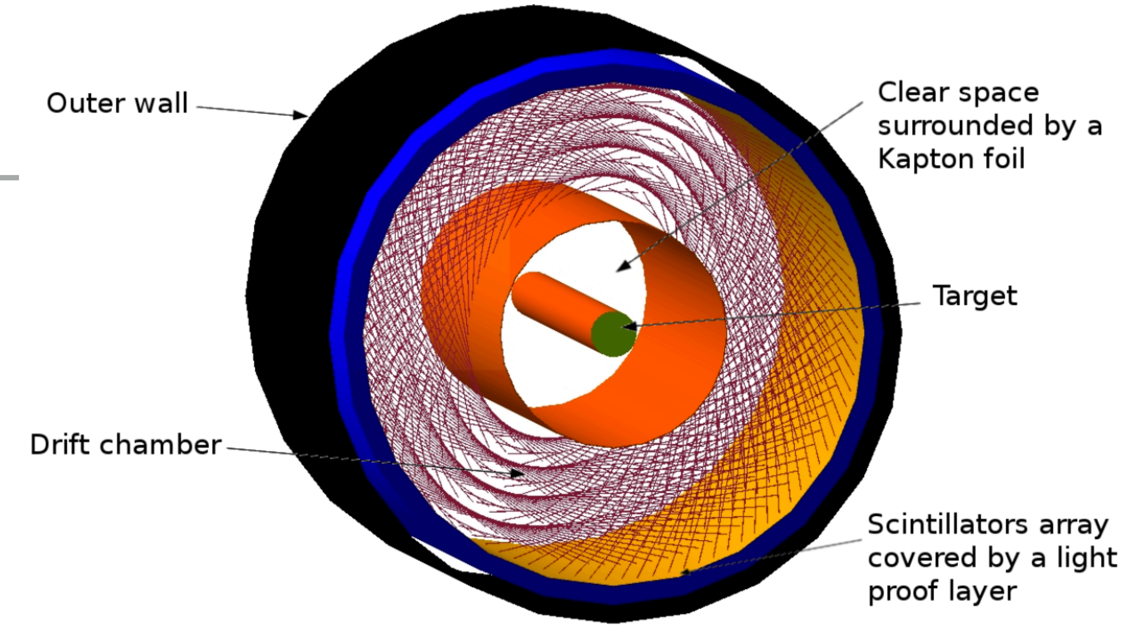
Spokespersons: Raphael Dupre, Nathan Baltzell, Kawtar Hafidi, Gabriel Charles, Gail Dodge, Mohammad Hattawy, Michael Paolone, Zein-Eddine Meziani, Whitney Armstrong

https://www.jlab.org/exp_prog/proposals/16/PR12-16-011.pdf

Particle ID: Time vs Radius



$\gamma^* + {}^4\text{He} \rightarrow {}^4\text{He} + \phi$ (ALERT)



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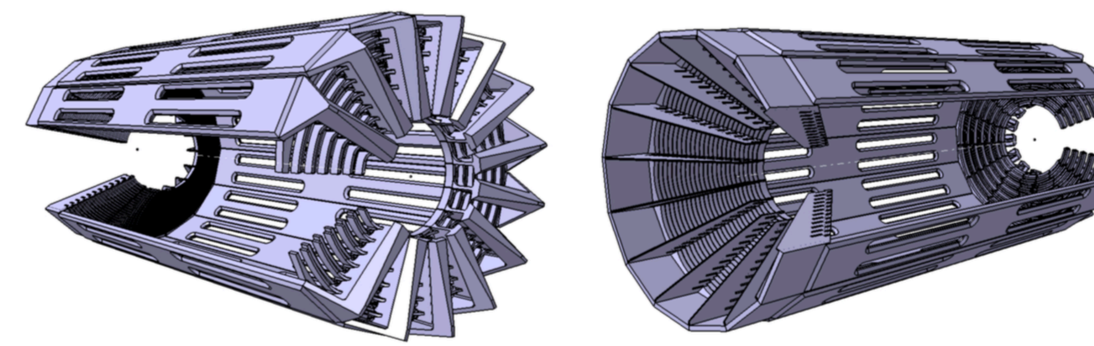
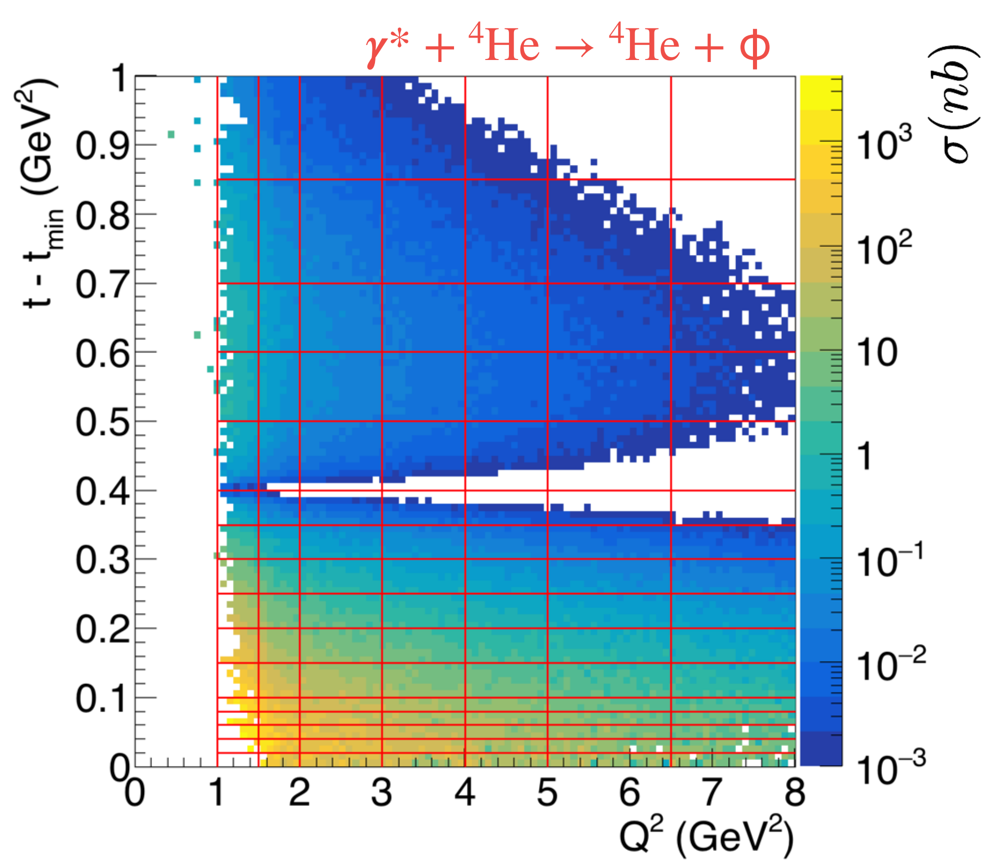
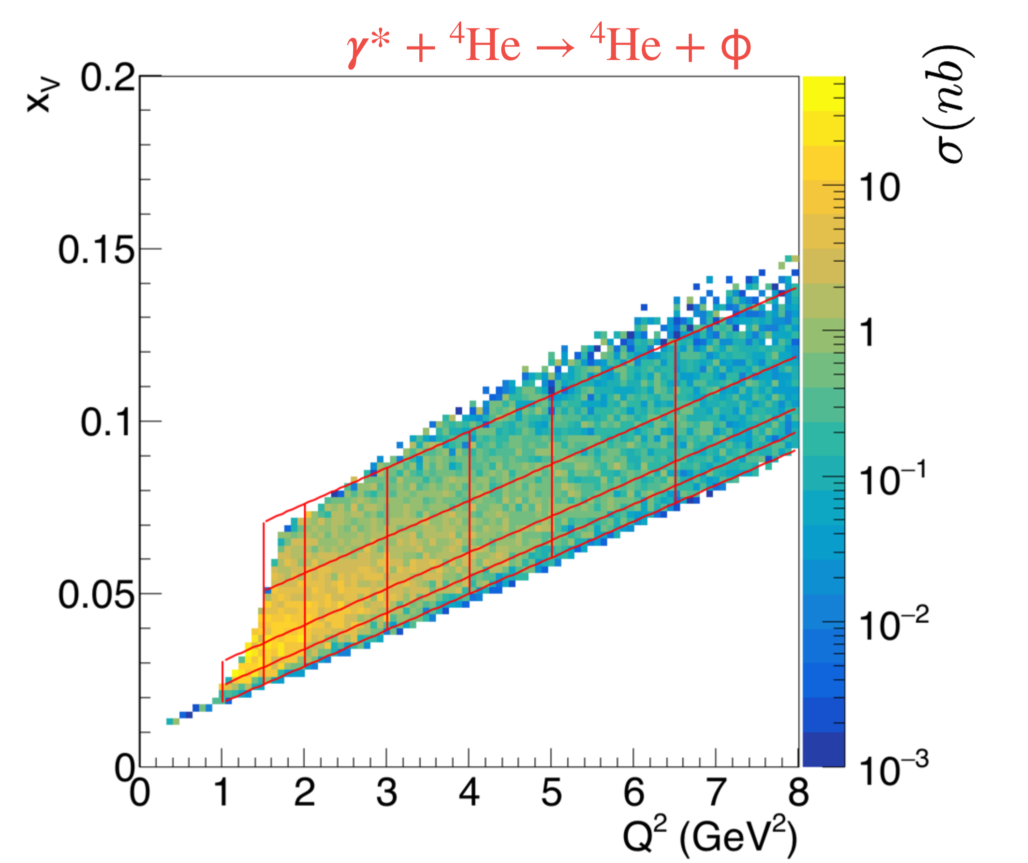


Prototype structure

- For coherent production off ^{4}He, allows measurements at very low t!





$\gamma^* + {}^4\mathrm{He} \to {}^4\mathrm{He} + \phi$ (ALERT)

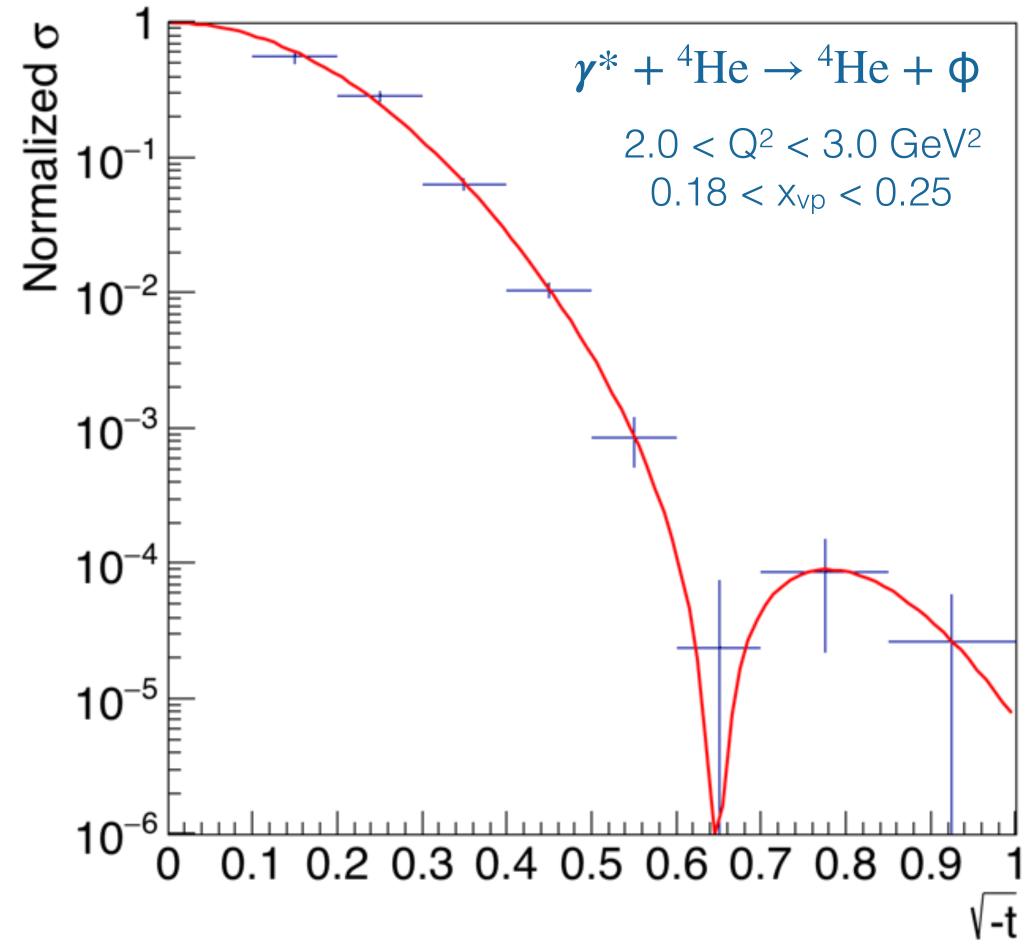
- Extraction of gluons GPD on ^{4}He
  - Longitudinal cross-section is normalized to t=0 point.

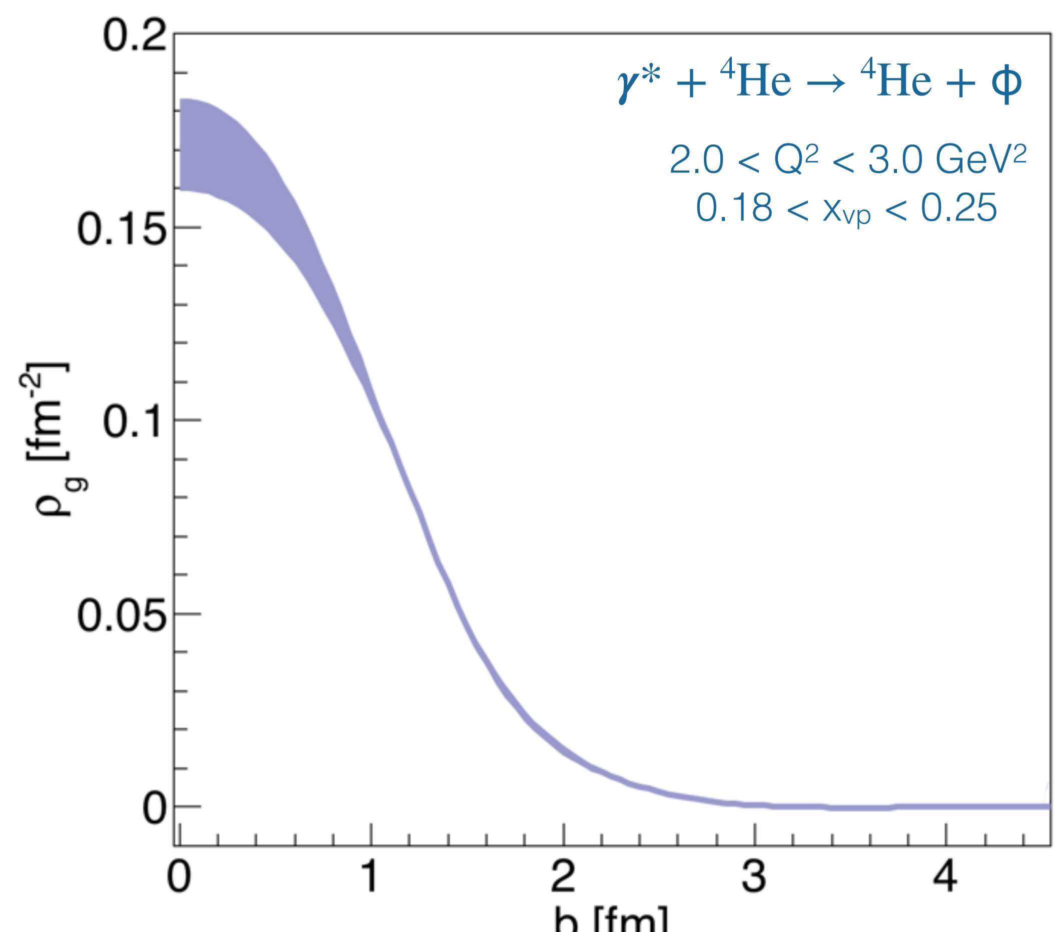
$$|\langle H_g \rangle|(t) \propto \sqrt{\frac{d\sigma_L}{dt}(t - t_{min}) \Big/ \frac{d\sigma_L}{dt}(0)}$$

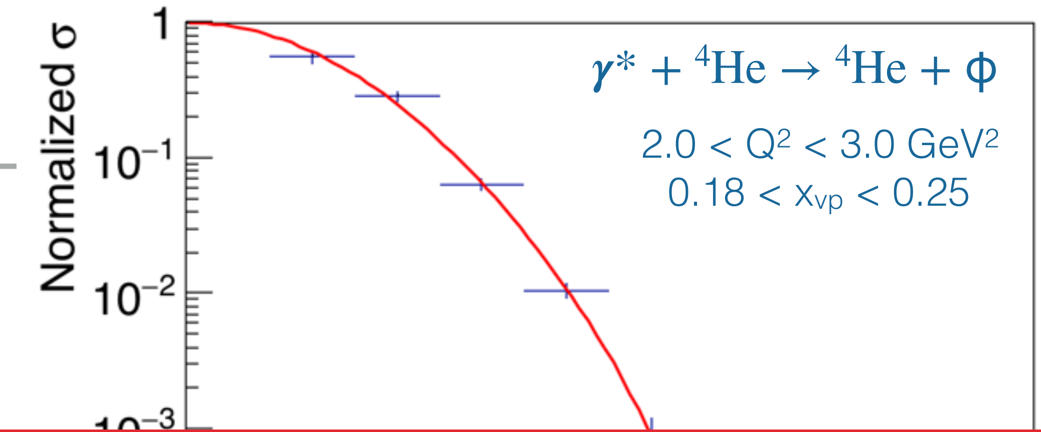
  - Fourier (Hankel) transform retrieves the transverse (impact parameter) density function.

$$\rho(x, 0, b_\perp) = \int_0^\infty J_0(b\sqrt{t}) H_g(x, 0, t) \sqrt{t} \frac{dt}{2\pi}$$

  - Piece of the global analysis of 3D tomography of ^{4}He (DVCS + DVMP(s) + DVMP(u/d))







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

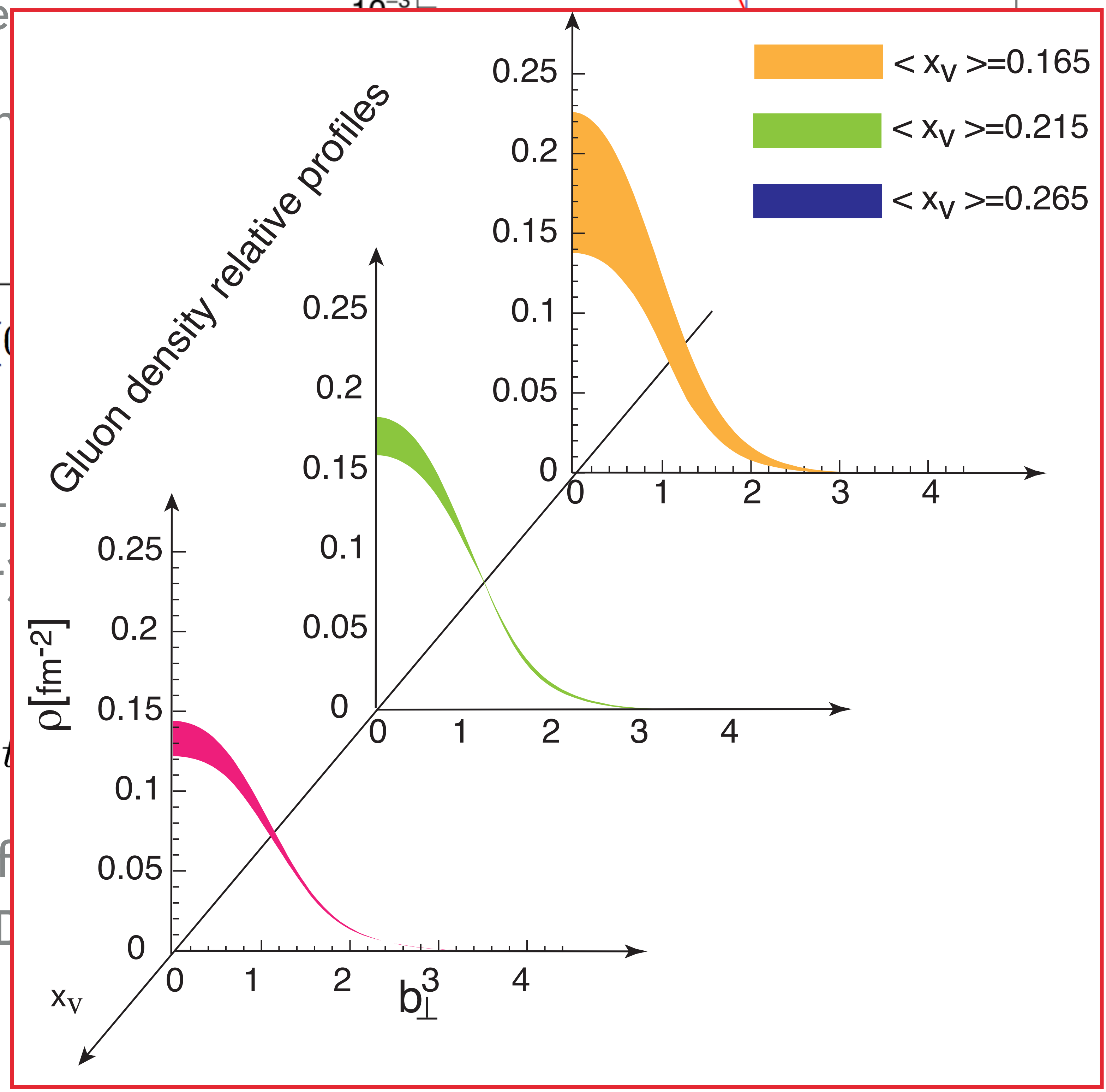
- Extraction of gluons GPD on ^{4}He
  - Longitudinal cross-section is n
    to t=0 point.

$$|\langle H_g \rangle|(t) \propto \sqrt{\frac{d\sigma_L}{dt}(t - t_{min}) \Big/ \frac{d\sigma_L}{dt}(($$

  - Fourier (Hankel) transform ret
    transverse (impact parameter)
    function.

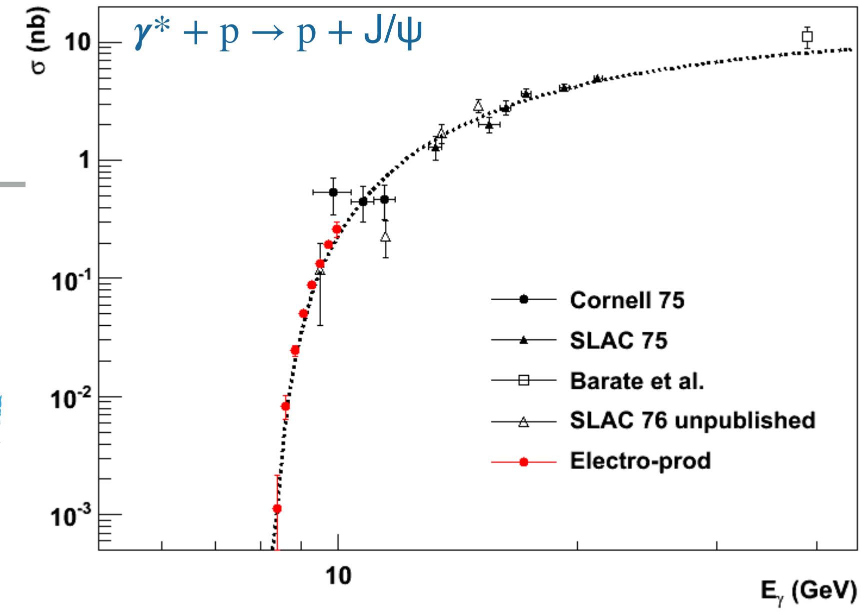
$$\rho(x, 0, b_\perp) = \int_0^\infty J_0(b\sqrt{t}) H_g(x, 0, t$$

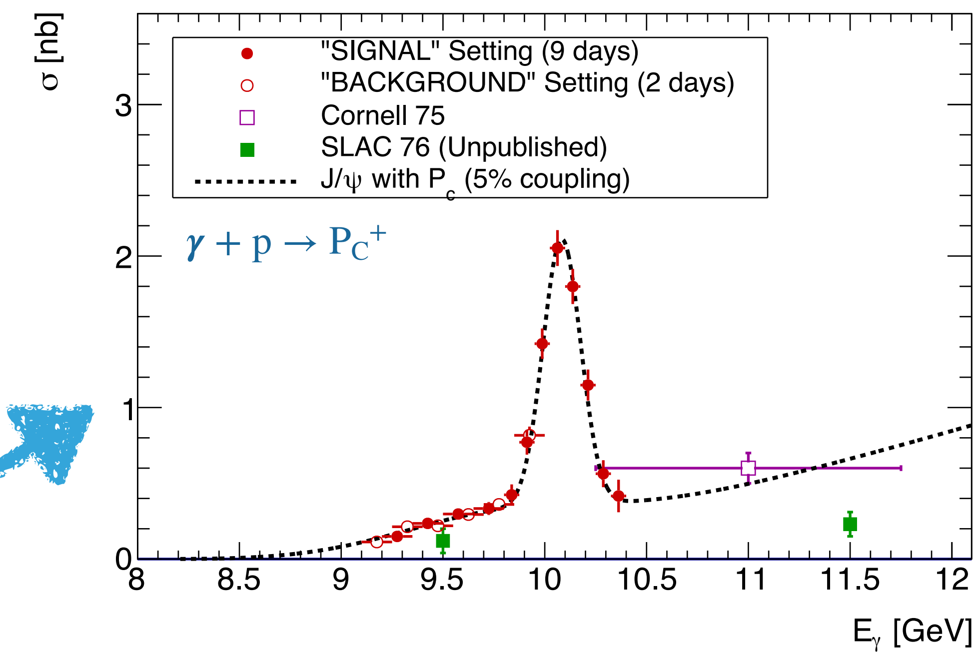
  - Piece of the global analysis of
    tomography of ^{4}He (DVCS + D
    DVMP(u/d))

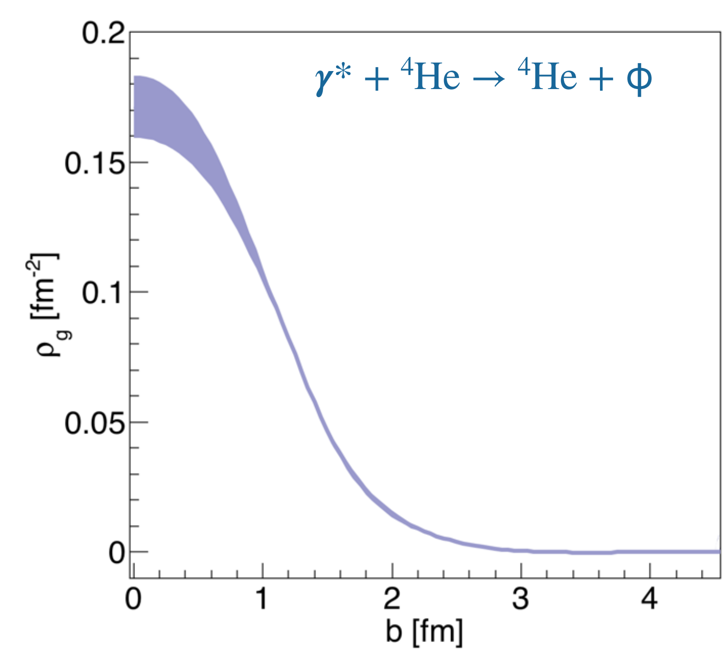


CONCLUSIONS

- Many exciting studies of vector meson production at threshold are coming from JLAB12, including (but not exclusively):
  - Production of J/ψ to probe multi-gluon contributions to cross-section in Hall-A using the SoLID detector:
  - A search for the LHCb pentaquark in Hall-C
  - Gluon GPDs for the proton and (hopefully) light nuclei with CLAS12







ACKNOWLEDGEMENTS

Temple University

Jefferson Lab

Hall-A/C collaboration

CLAS / CLAS12 collaboration

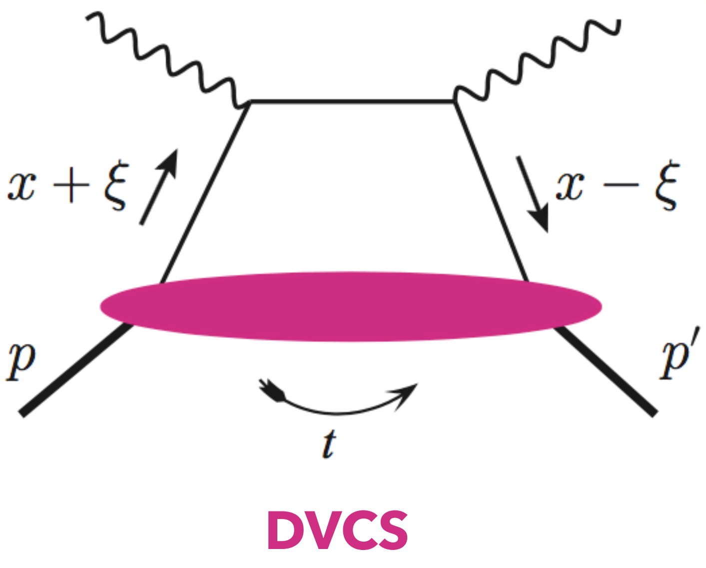
SoLID collaboration

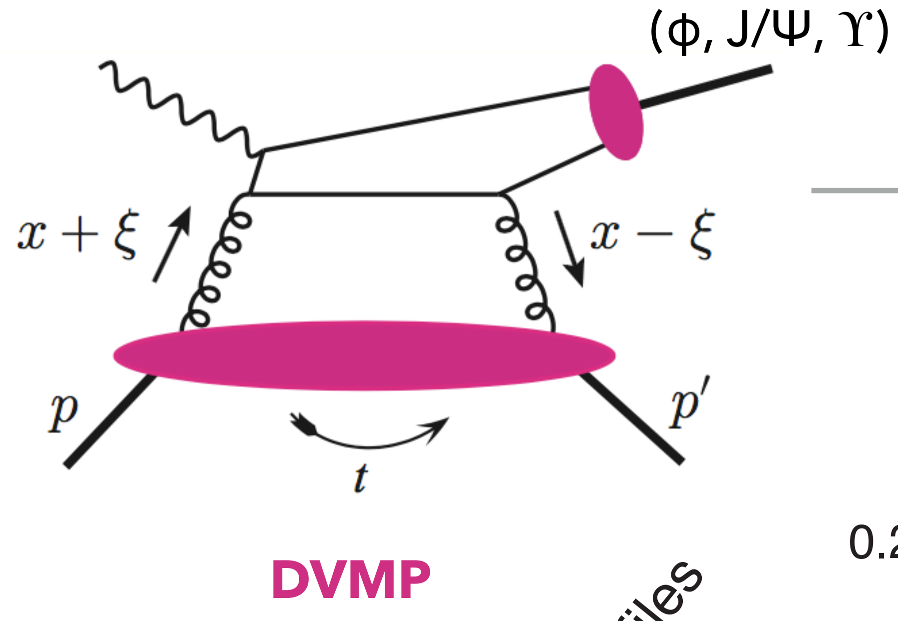
ALERT collaboration

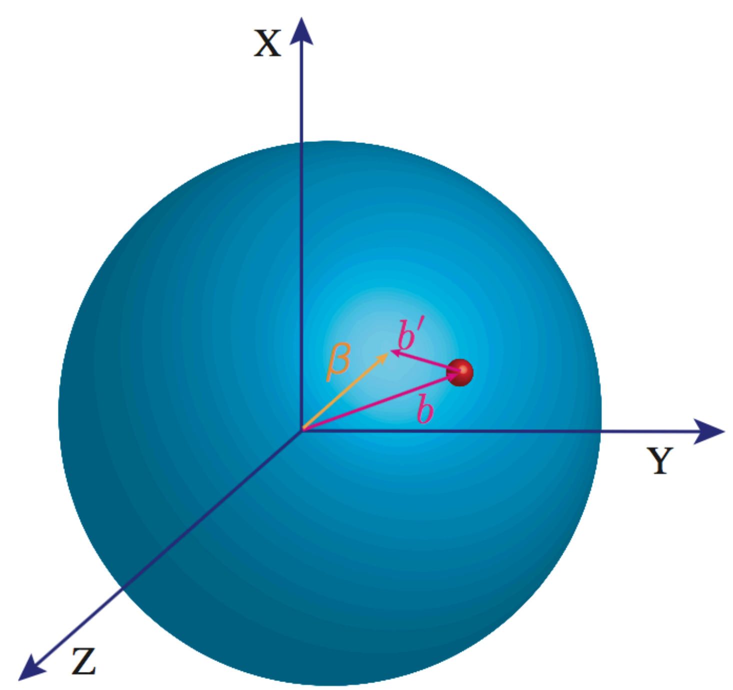
EIC collaboration

This work is supported in part by the U.S. Department of Energy Grant Award DE-FG02-94ER4084.

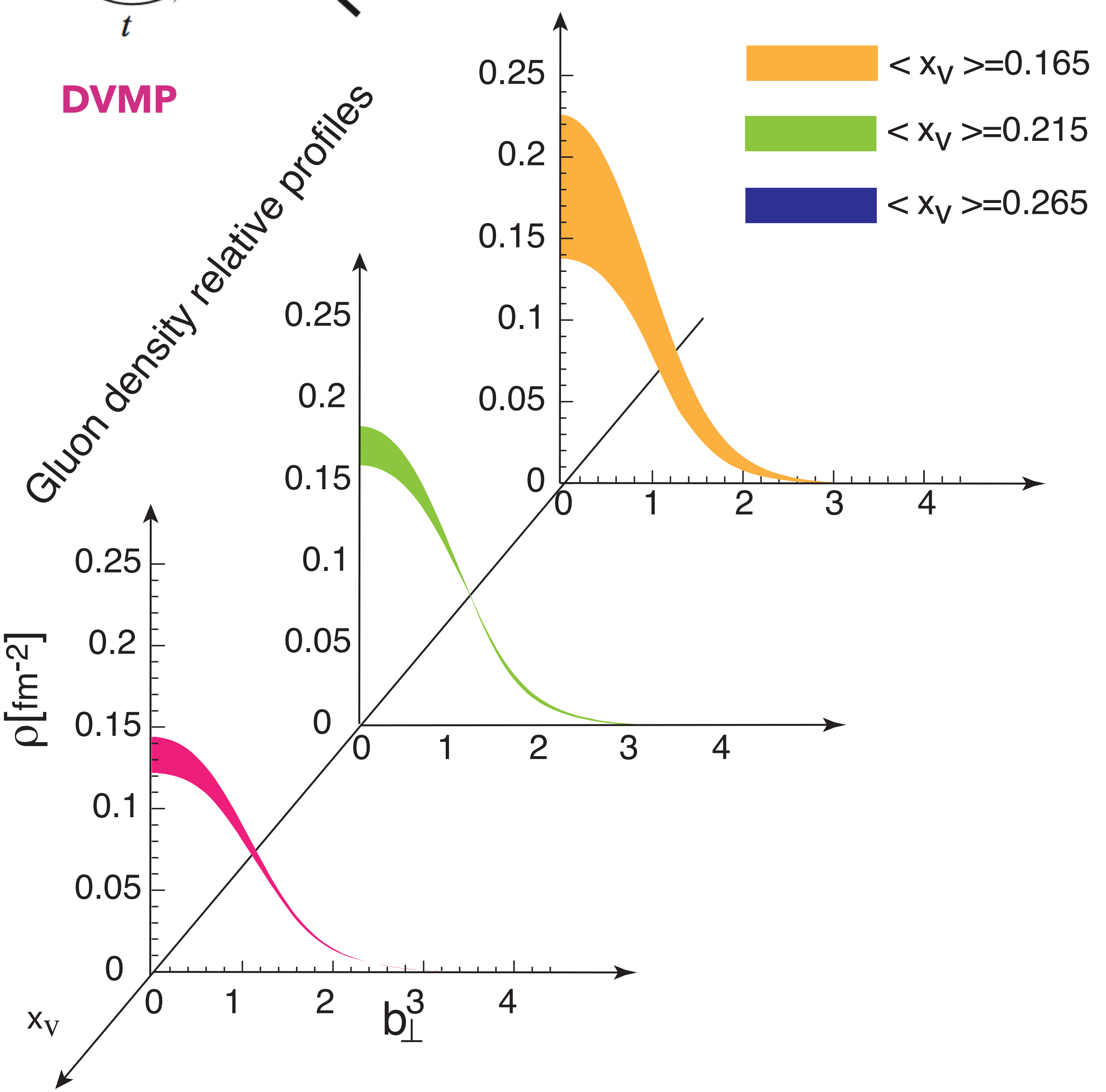
BACKUPS



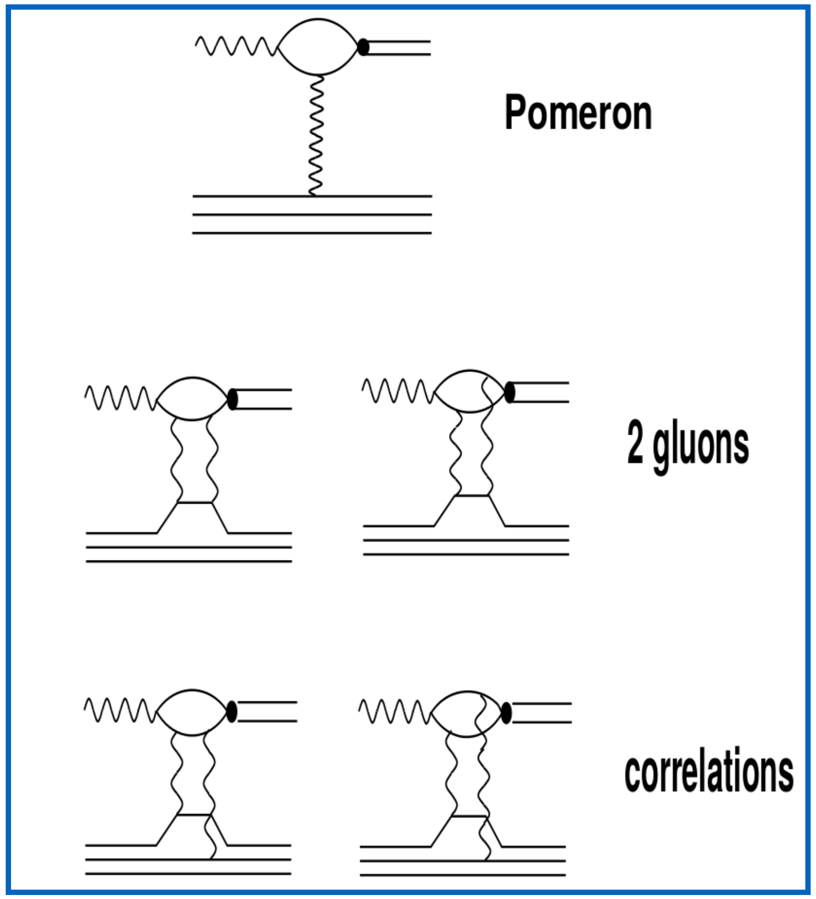




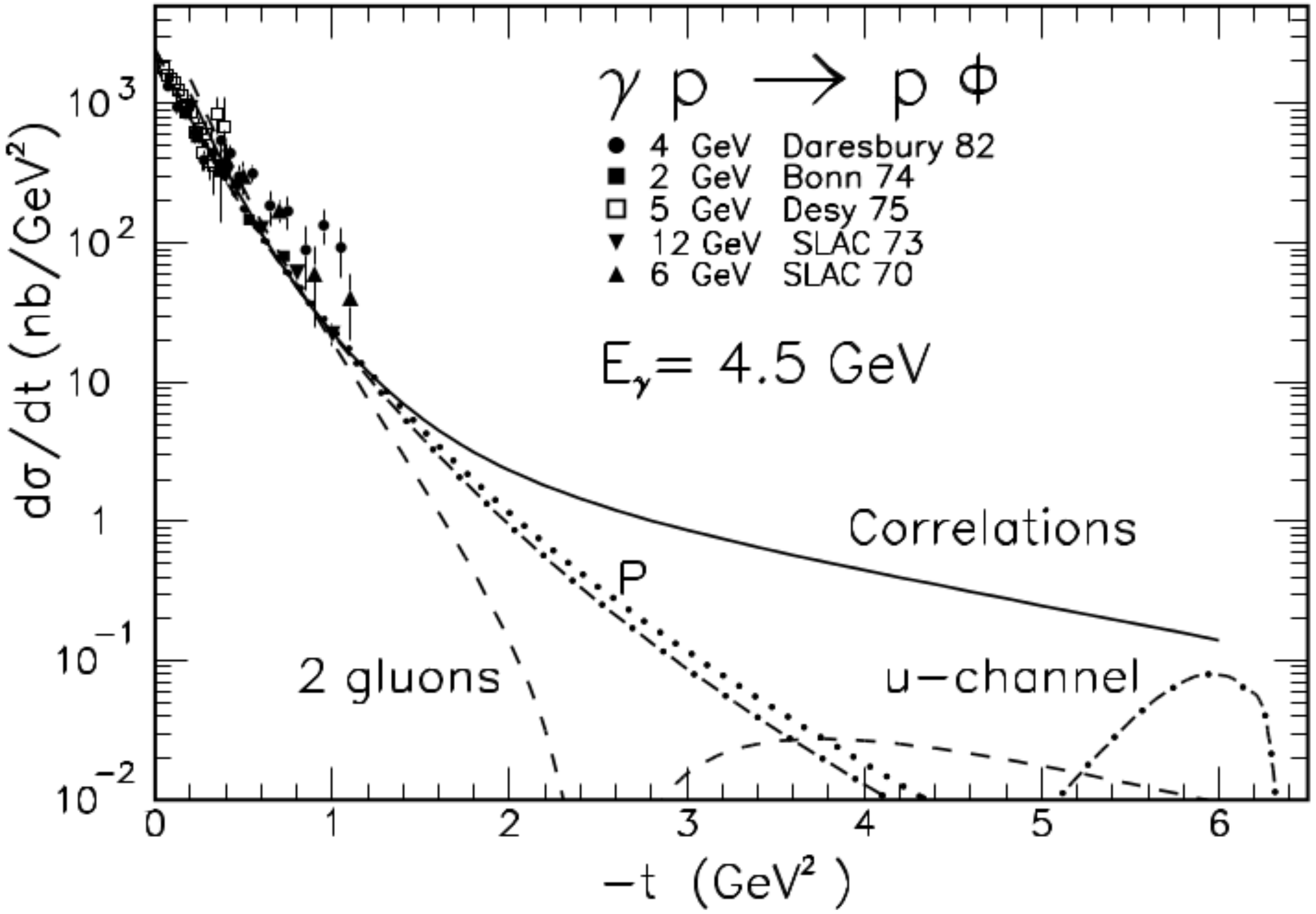
b′ = transverse separation of quarks in **nucleon**
b= transverse separation of quarks in **nucleus**



$\gamma + p \to p + \phi$ (theory)



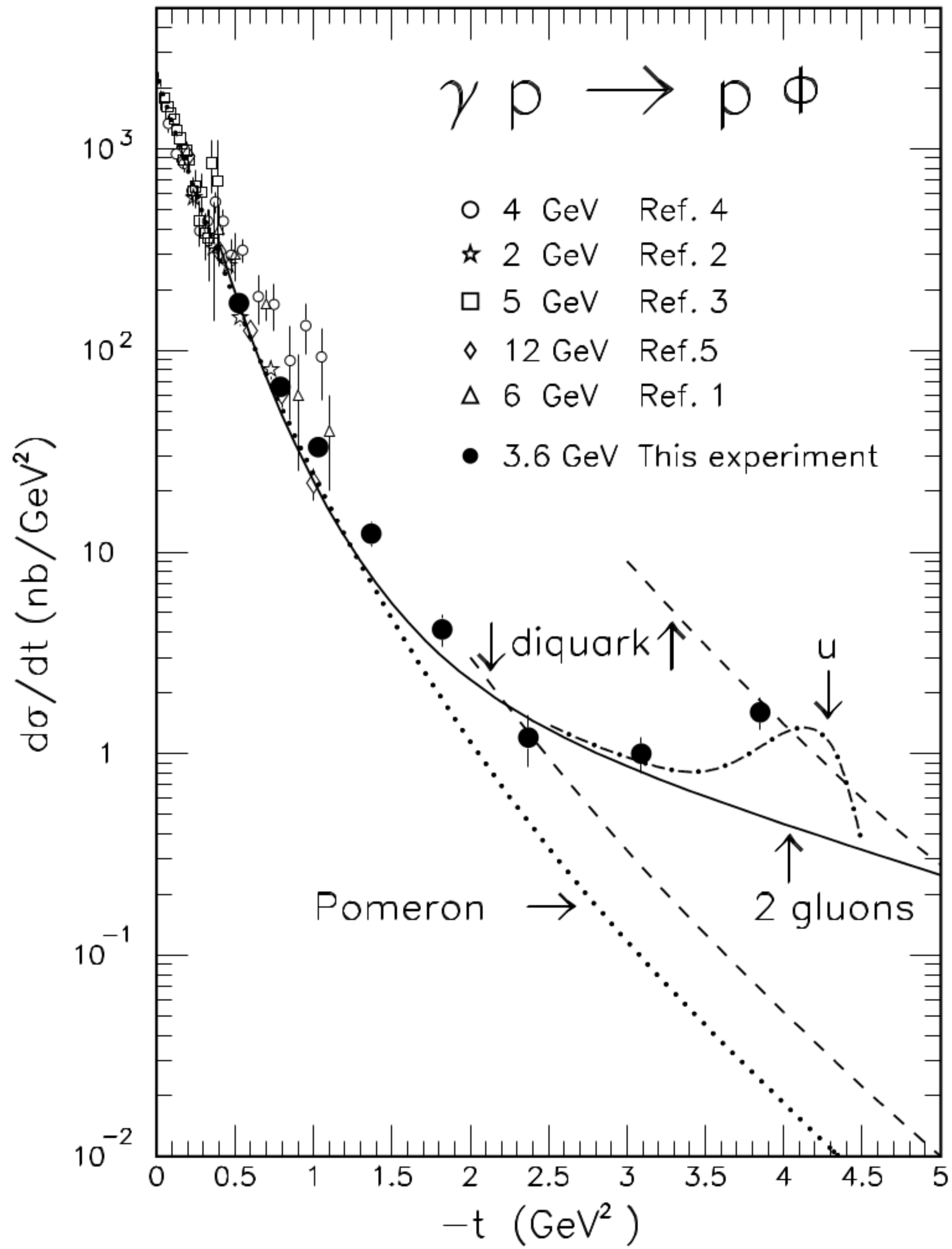
- Laget Description:
  - Since ϕ is mostly strange, meson exchange is highly suppressed (OZI rule)
  - Considering this suppression, Pomeron exchange explains the observed production very well at small |t|.
  - At intermediate |t| when the scattering parameter b becomes comparable to the gluon correlation length, the two-gluon exchange channel opens up.
    - At higher |t|, the gluons can couple to different quarks in the nucleon (correlations)
  - At large angles (and small u), u-channel nucleon exchange is also possible.



Laget, Phys.Lett. B489 (2000) 313-318

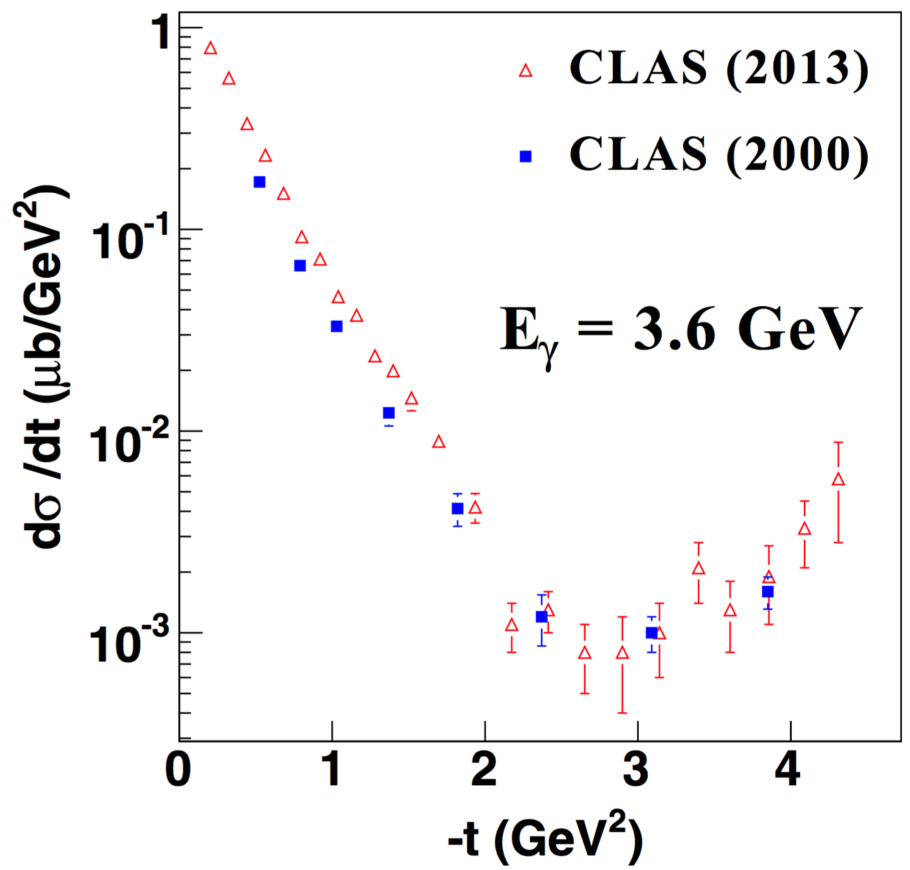
$\gamma + p \rightarrow p + \phi$ (CLAS6)

- Anciant, et al. found strong evidence for a two-gluon contribution.
  - A u-channel contribution is also evident. The dash-dot curve uses a $g_{\phi NN} = 3$ (higher than predicted from SU(3) mass splitting, but in line with observations of nucleon-nucleon and nucleon-hyperon scattering).
  - A larger $g_{\phi NN}$ implies a larger strange contribution to the nucleon sea.



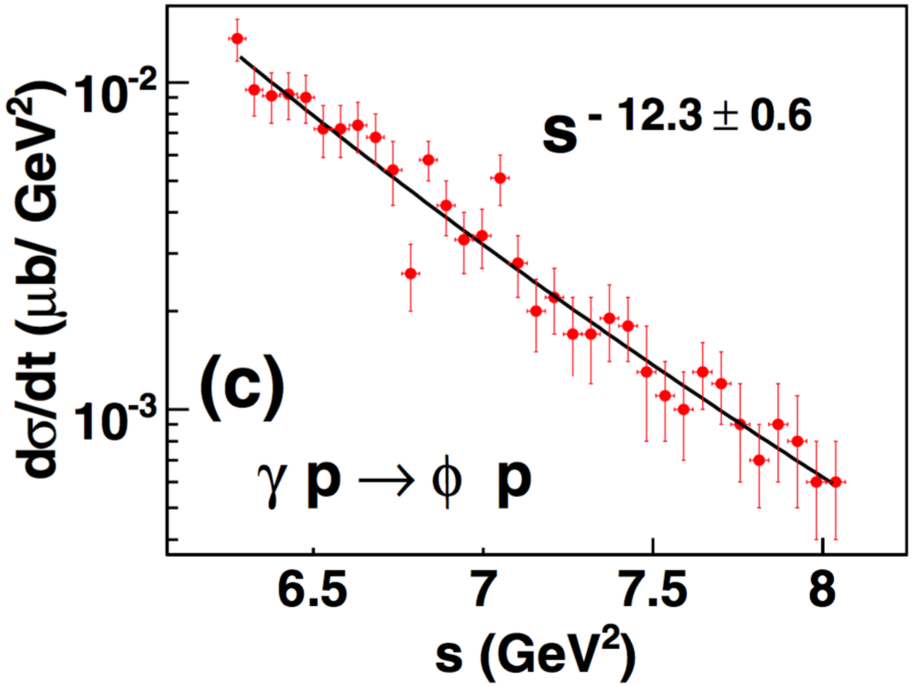
Anciant et al., Phys.Rev.Lett. 85 (2000) 4682-4686

$\gamma + p \rightarrow p + \phi$ (CLAS6 cont.)

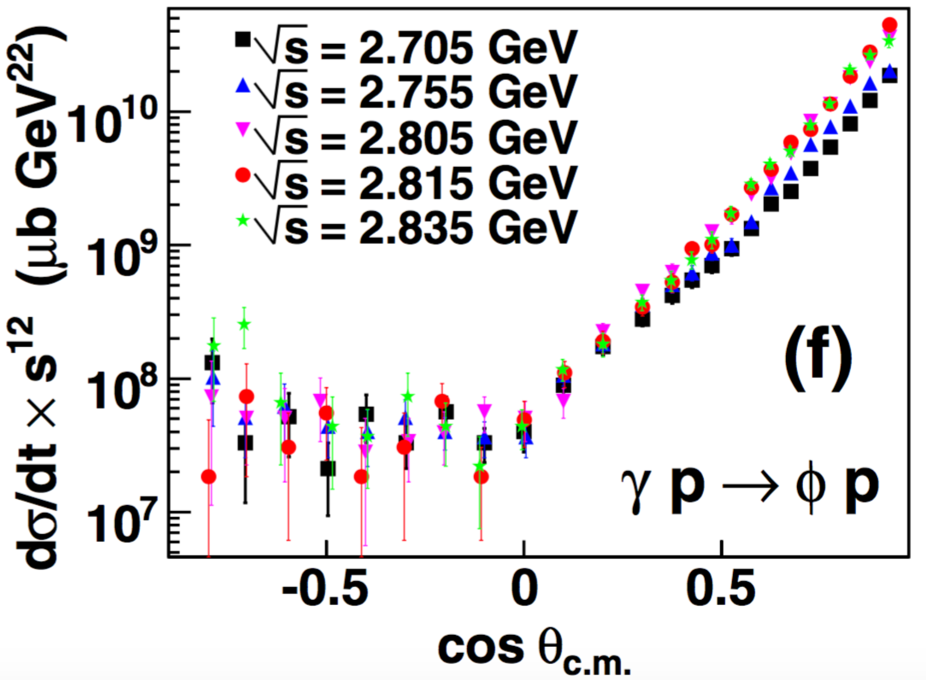


Dey et al., Phys.Rev. D90 (2014)

- Dey, et al. gives most recent CLAS6 results. Agrees with previous studies at CLAS.



Dey et al., Phys.Rev. C89 (2014)



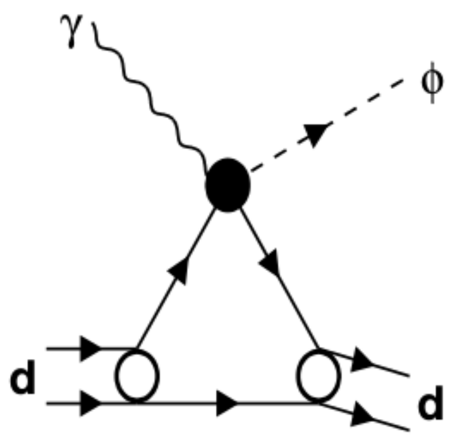
We expect s-scaling like:

$$\frac{d\sigma}{dt} \approx s^{-n+2} f(\cos\theta_{c.m.})$$

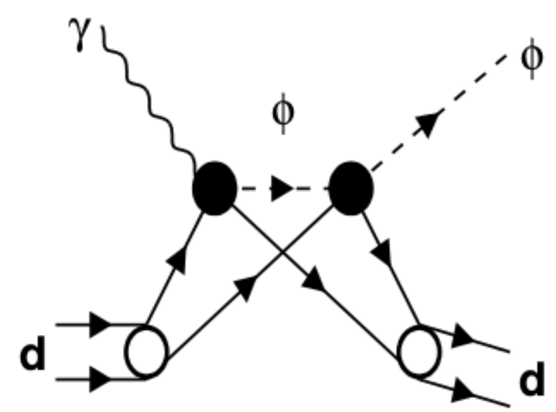
One way to get s^{-12}:

$$n = 2 \times |s\bar{s}g\rangle + 2 \times |uudg\rangle = 14$$

$\gamma + d \rightarrow d + \phi$ (CLAS6)

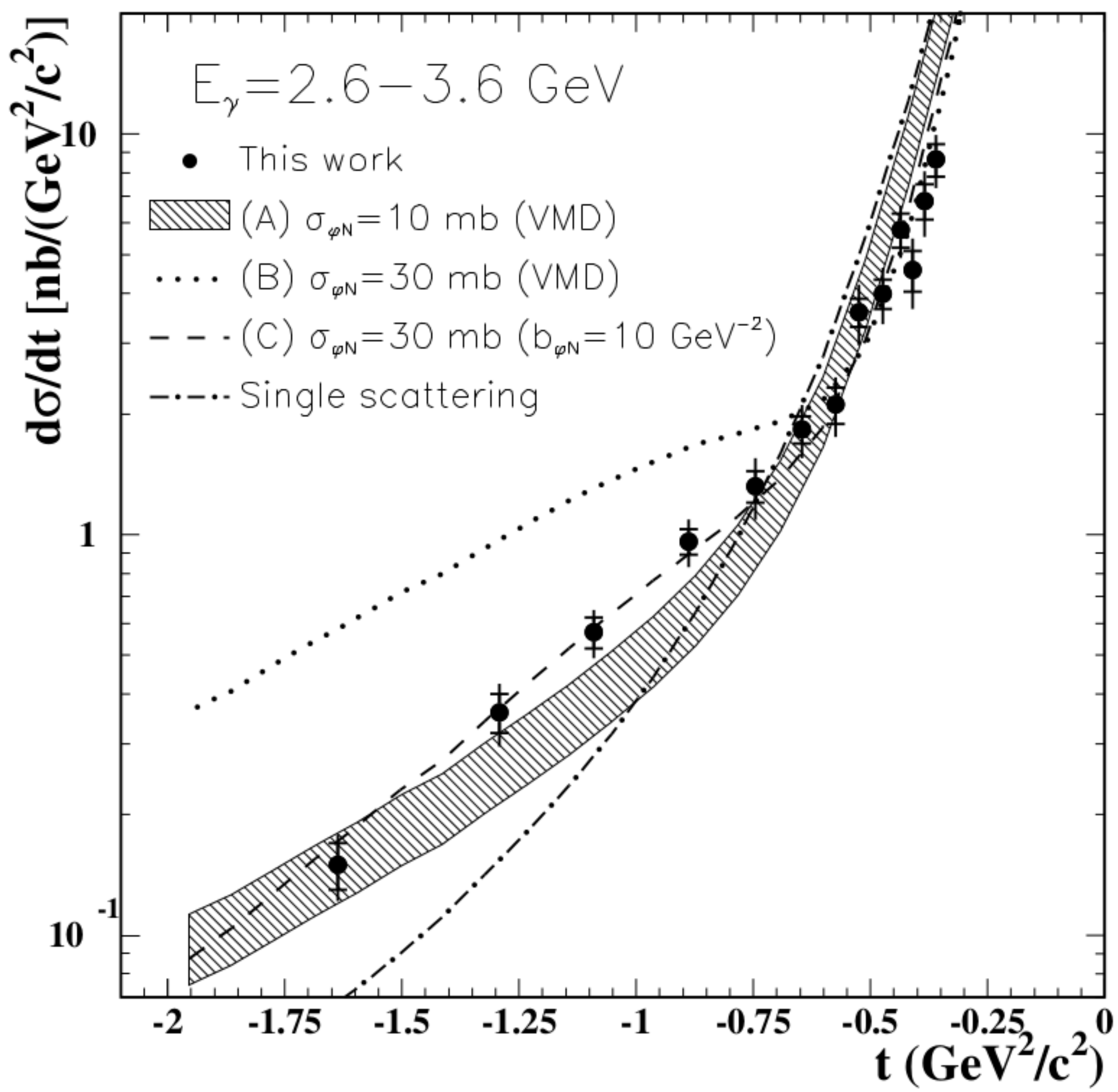


Single Scattering



Double Scattering

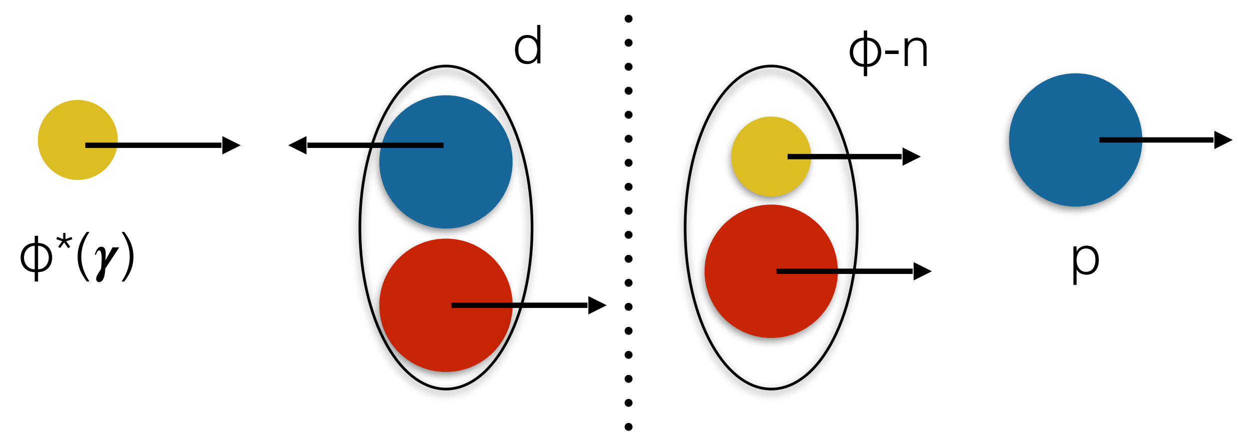
- Single scattering underestimates the cross-section at larger |t|
- Using the pure VMD prediction and the expected ϕ-N cross-section does not agree well (Shaded band)
- Increasing the ϕ-N cross-section (due to A > 1) to 30mb agrees well at low |t| but overestimates at high |t| (dotted curve)
- Assuming that the phi can also fluctuate into K pairs before the re-scatter (with a new slope parameter, b = 10 GeV^{-2}) gives good-agreement.



Mibe et al., Phys.Rev. C76 (2007) 052202

$\gamma + d \rightarrow p + [n\phi]$

- At sub-threshold phi production on deuterium, you gain a handle on the momentum of the recoil neutron and phi.
- At the right kinematics, the phi and the neutron will travel together at the same speed, increasing the likelihood of a bound state.

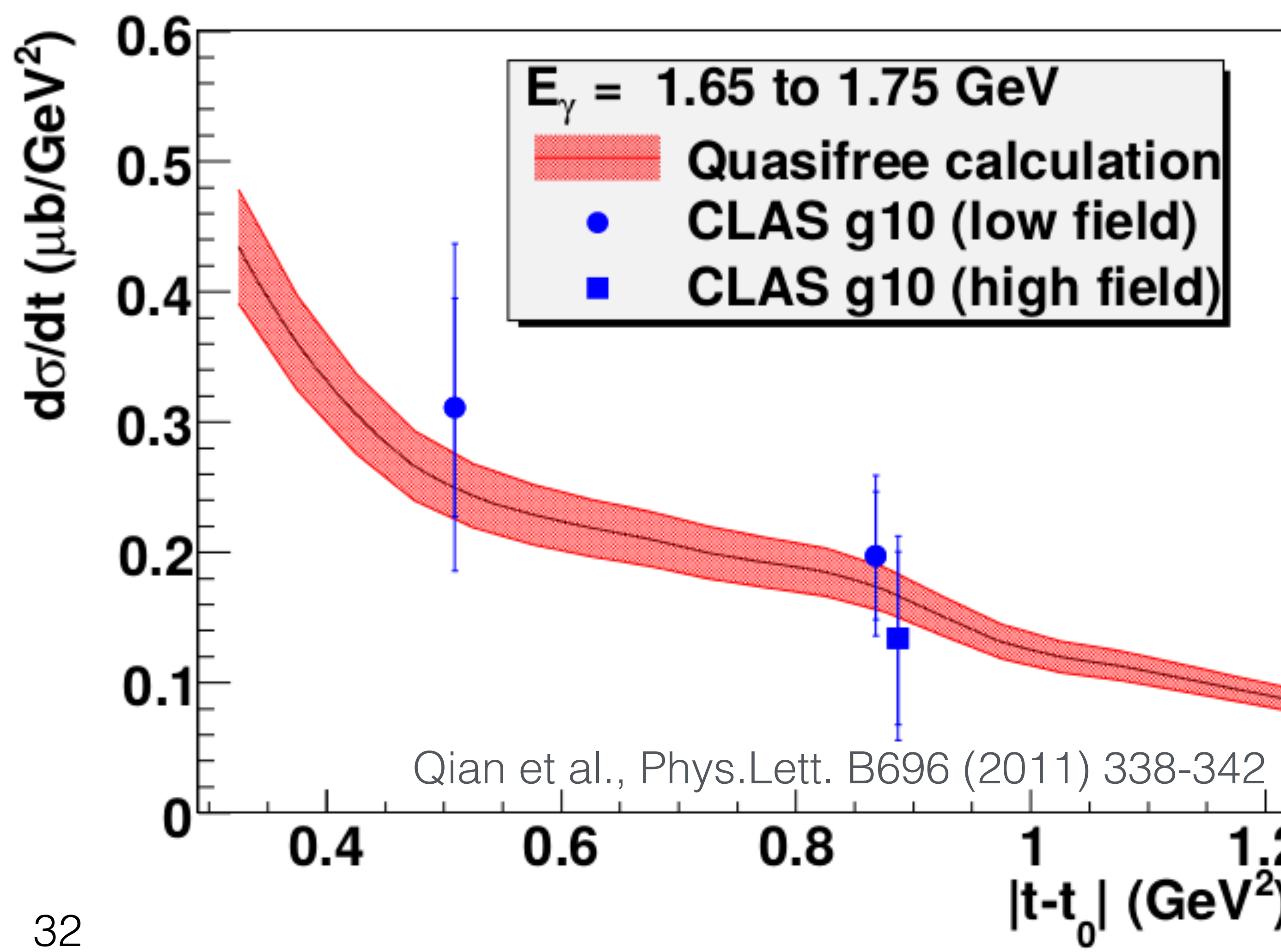


- Gao, Lee, and Marinov predict a ϕ-N bound state with a QCD van der Waals attraction with:

$$V_{(s\bar{s}),N} = -\alpha e^{\mu r}/r$$

α = 1.25 and μ = 0.6 GeV
The binding energy will be 1.8 MeV

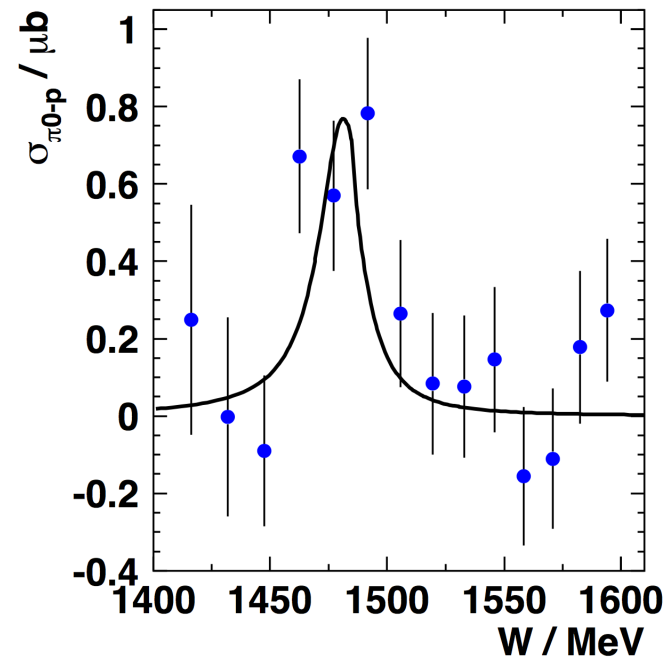
Phys.Rev. C63 (2001) 022201

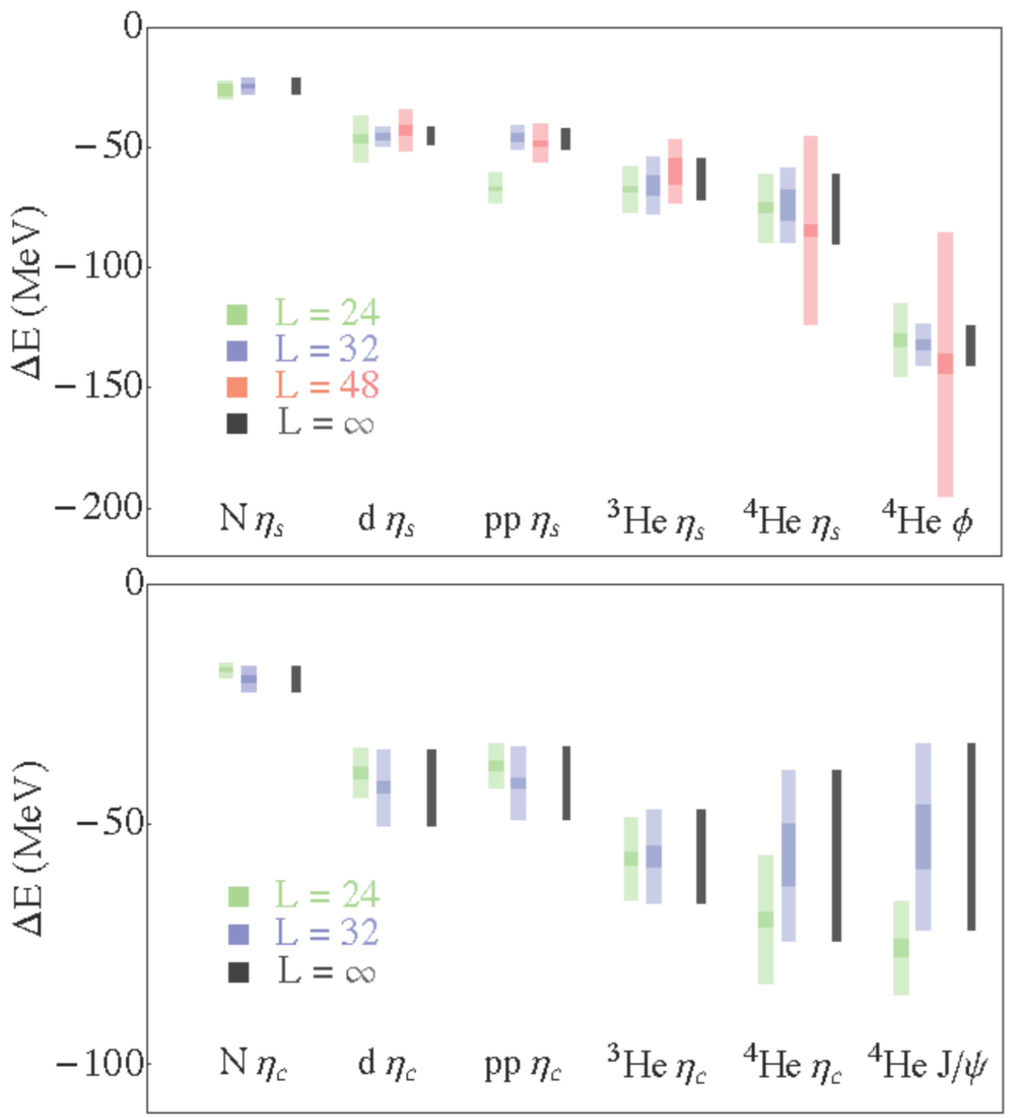


Qian et al., Phys.Lett. B696 (2011) 338-342

Mesic bound states

- **Published results for a η-^{3}He with TAPS at MAIMI** →
  - Binding energy of (-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)





Recent lattice calculations from NPLQCD group predict a strong binding with ϕ-^{4}He!

ϕ electroproduction 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.

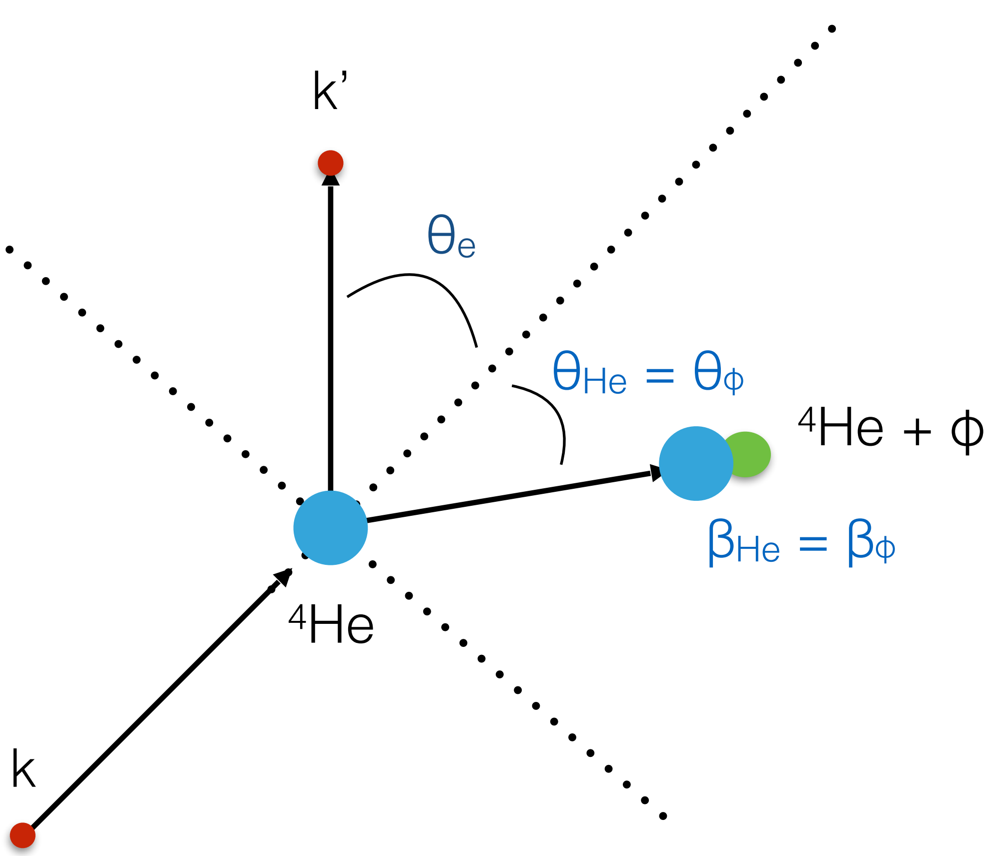
Investigating neutral meson-nuclei bound states with coherent electroproduction of η and ϕ mesons off of ^{4}He in Hall-C

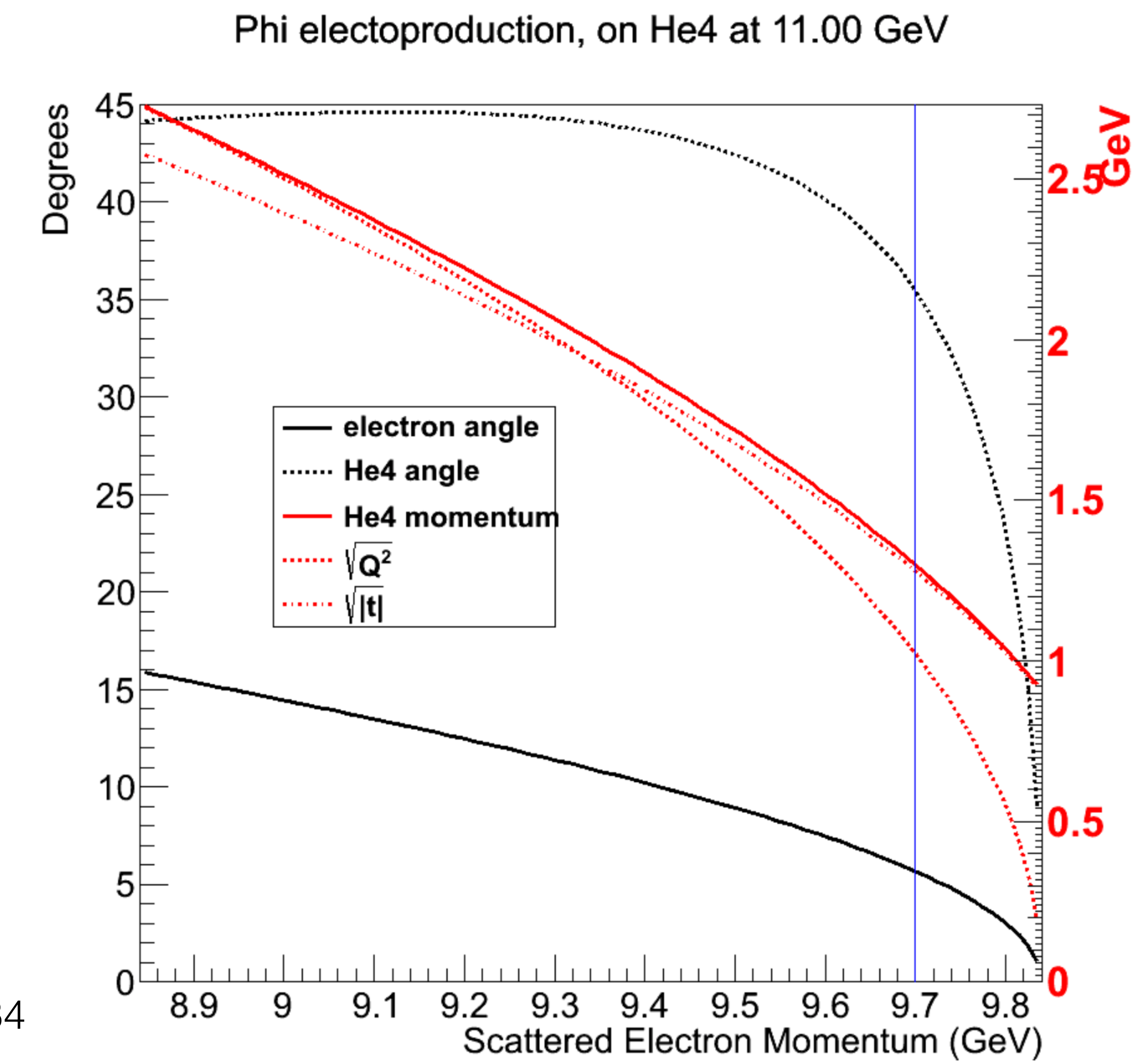
A Letter of Intent to PAC 42

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





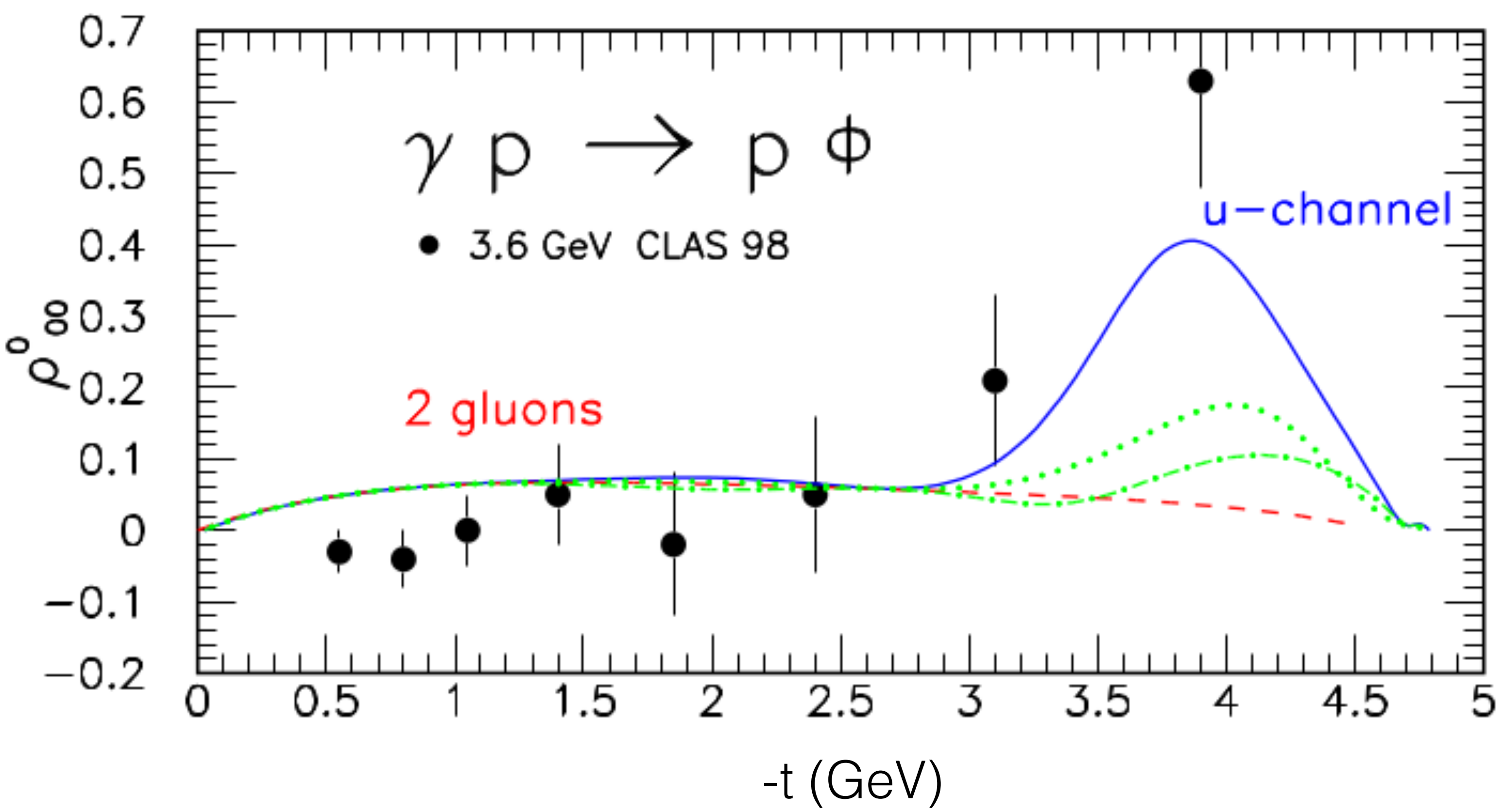
$\gamma + p \rightarrow p + \varphi$ (Spin Density Matrix)

- If s-Channel helicity conservation (SCHC) holds for vector mesons with Pomeron/two-gluon exchange (early rho studies showed this), and the u-channel process breaks SCHC, then angular information about the ϕ decay can help separate processes.

- With an unpolarized beam only the first term of the spin density matrix survives. The angular distribution can be written as:

$$\frac{dN}{d\theta} = \frac{3}{4}\sin\theta\left[\left(1-\rho^0_{00}\right)\sin^2\theta + 2\rho^0_{00}\cos^2\theta\right]$$

- ρ^0_{00} describes the probability that a longitudinally polarized ϕ meson is produced by a transverse real photon.
  - If this term is much larger than zero then SCHC is broken.



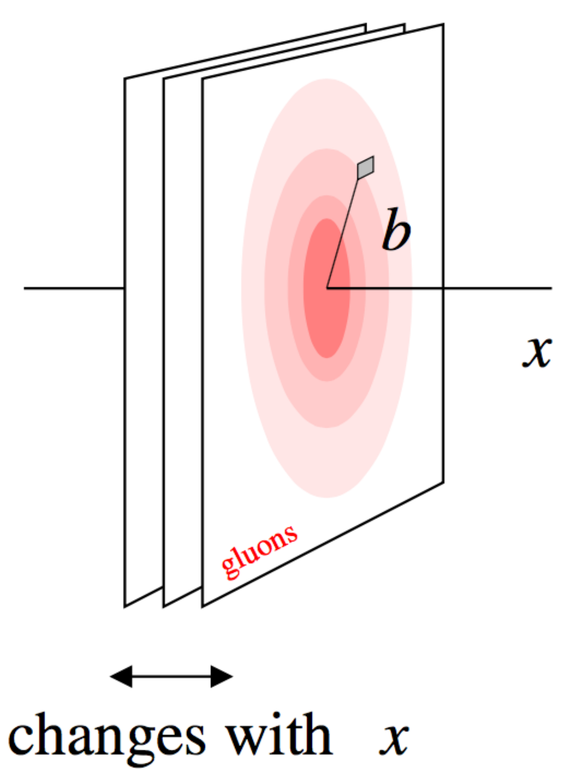
McCormick et al., Phys.Rev. C69 (2004) 032203

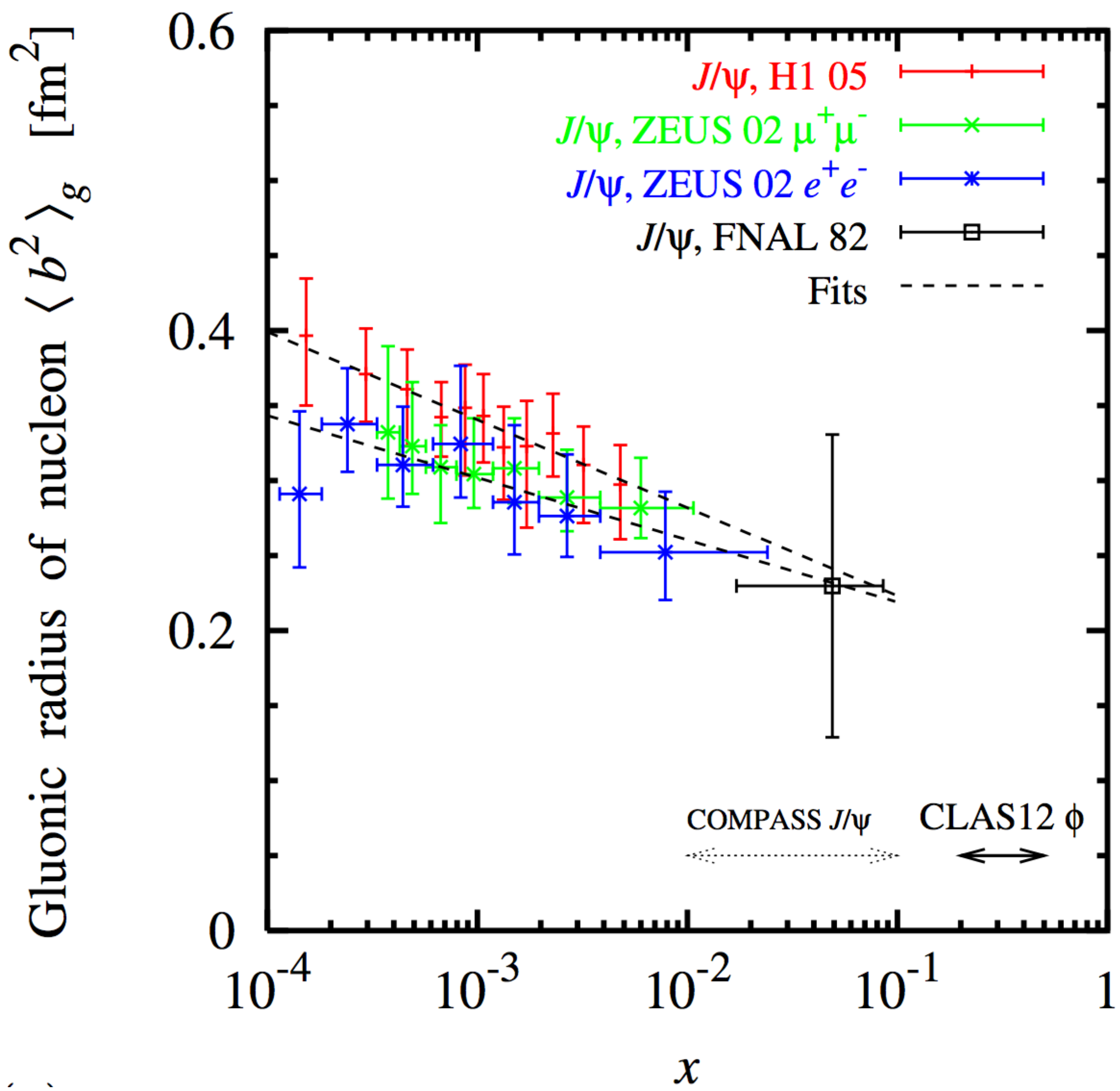
$\gamma^* + p \rightarrow p + \phi$ (CLAS12 proposed)

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

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

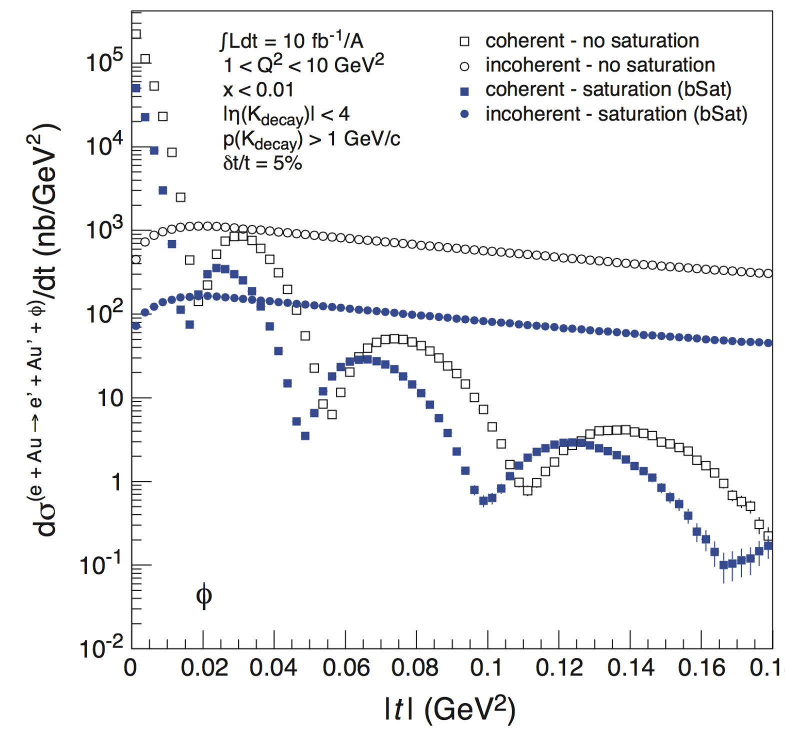
- J/Ψ studies have been performed at HERA and FNAL to extract the gluon radius.

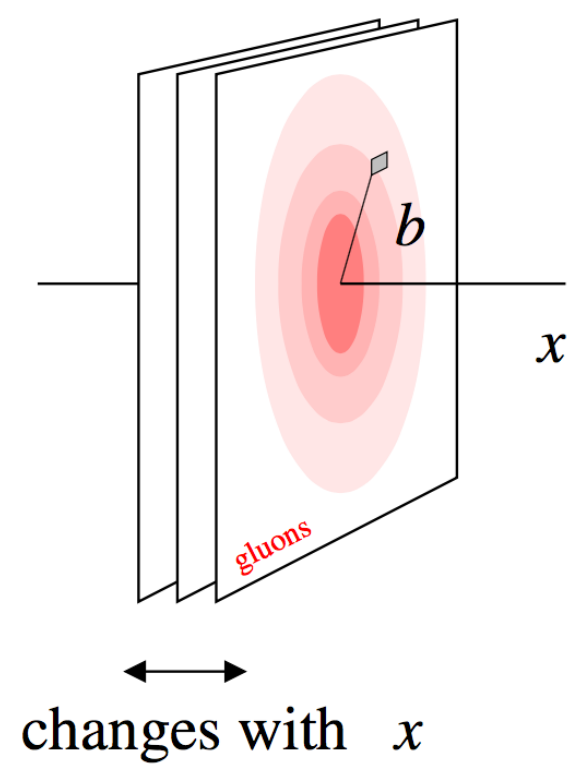




Value in $\gamma^* + {}^4He \rightarrow {}^4He + \phi$?

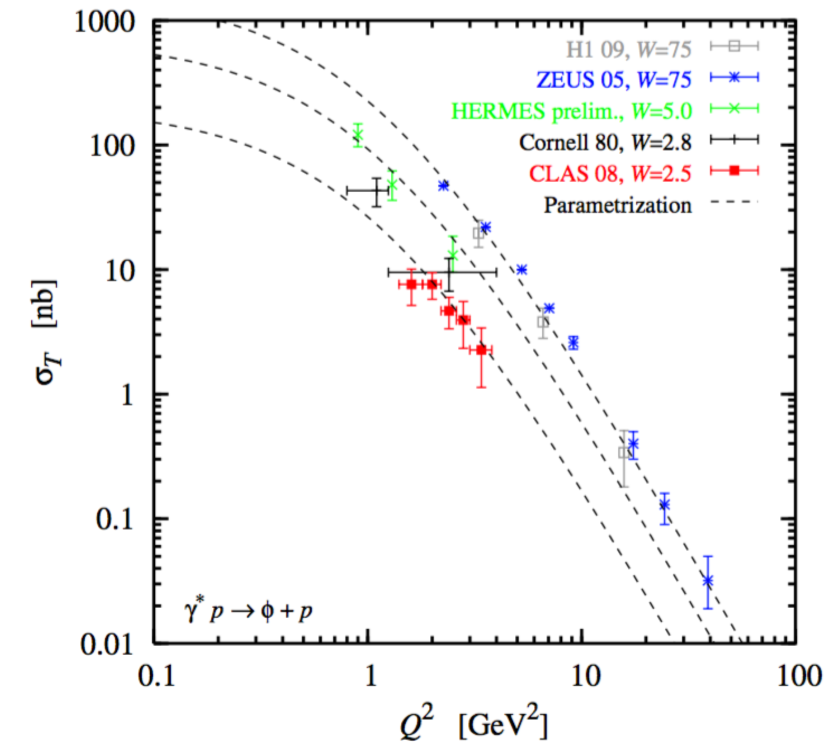
- What does the gluon distribution look like for nuclei?
- Does the phi-production process sample individual nucleons, or the nucleus as a whole?
    - A diffractive pattern would indicate an interaction with the gluon field of a nucleon. No diffractive pattern would indicate an interaction with the gluon field of the entire nucleus.
    - Would high-x reveal an average gluon radius near that of a nucleon, and low-x give the radius of the nucleus?
- Re-scattering? Other medium effects?

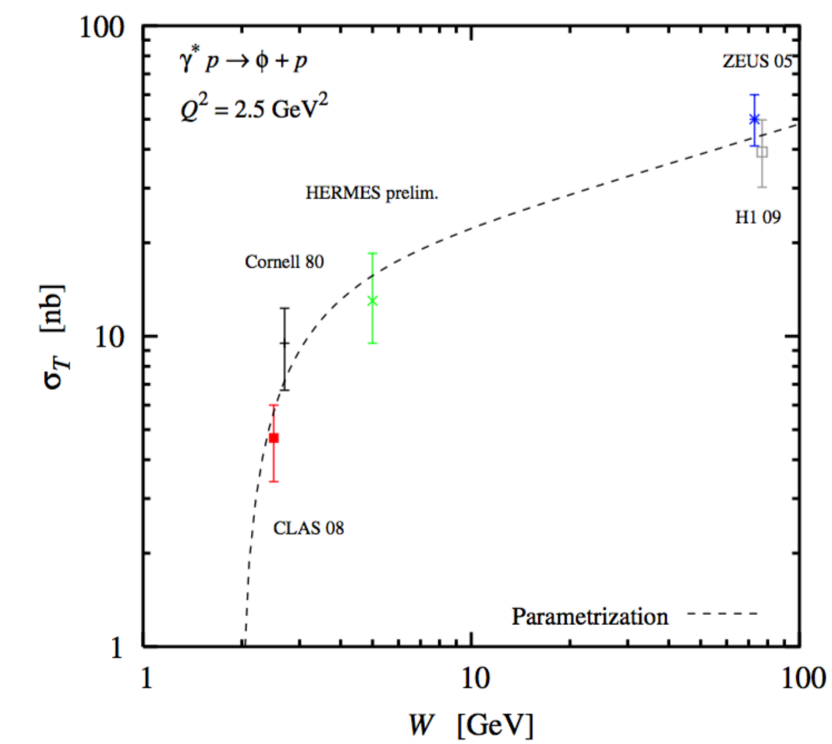




Estimating the coherent ϕ electroproduction cross-section off ^{4}He

Identical parametrization as CLAS12 proposal for ϕ production off p





- 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.
  - $Q^2 \to |t - t_{min}| = t'$, for calculation of all form-factors.
- Cross-section goes like:

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

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

- Phenomenological approach to production off proton:

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

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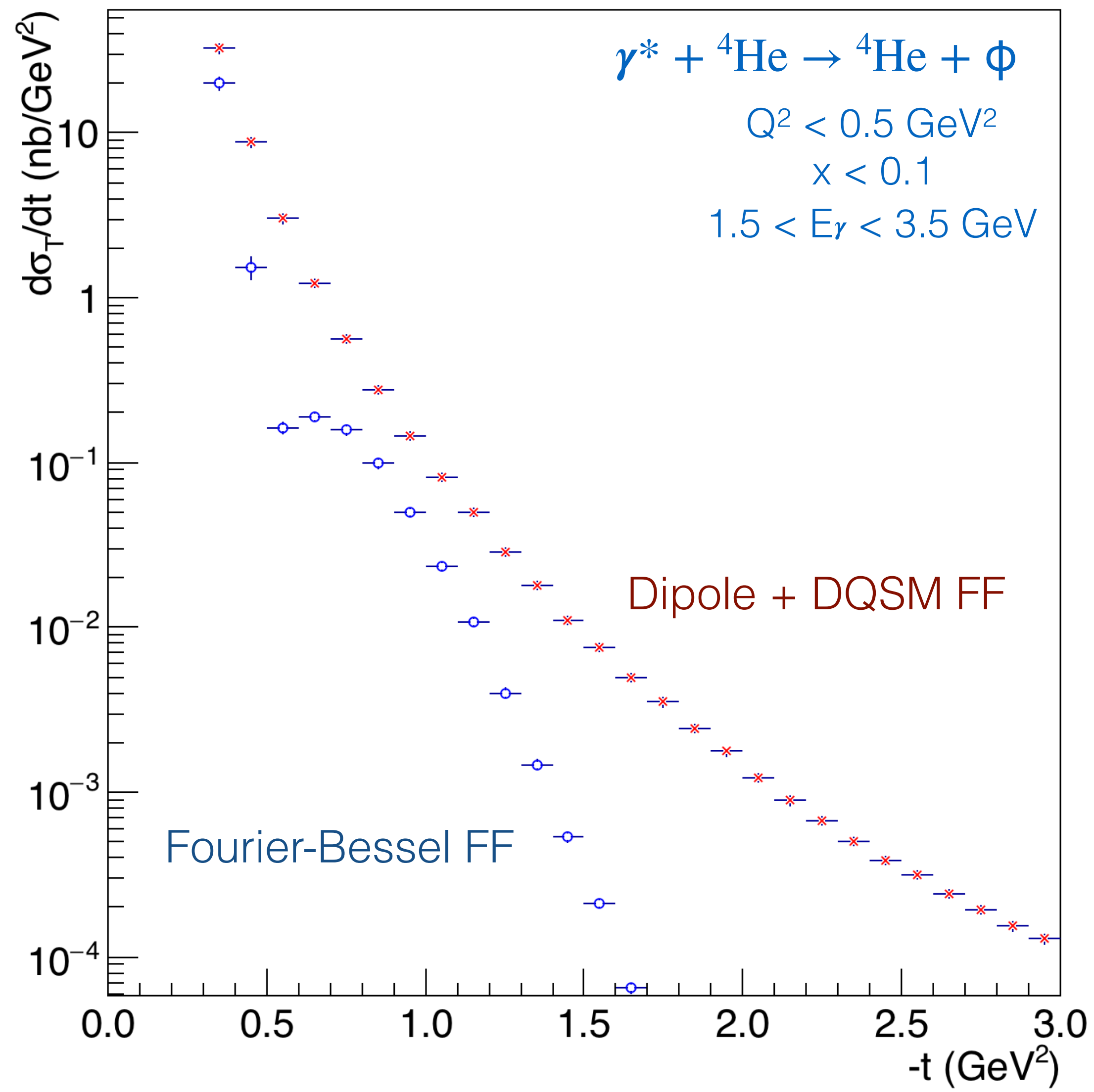
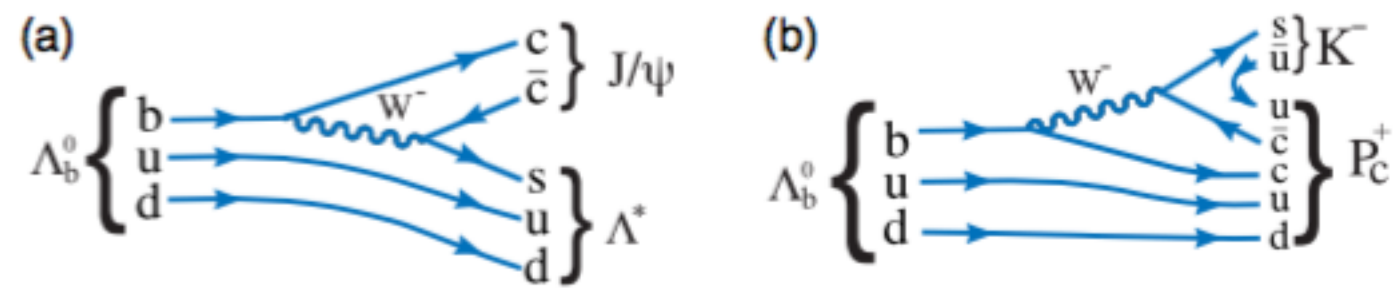


Discovery of the LHCb charmed "pentaquark" P_c

$$\Lambda_b \to \; K^- p J/\Psi$$

Aaij, R, et. al (LHCb) PRL 115-7 (2015)

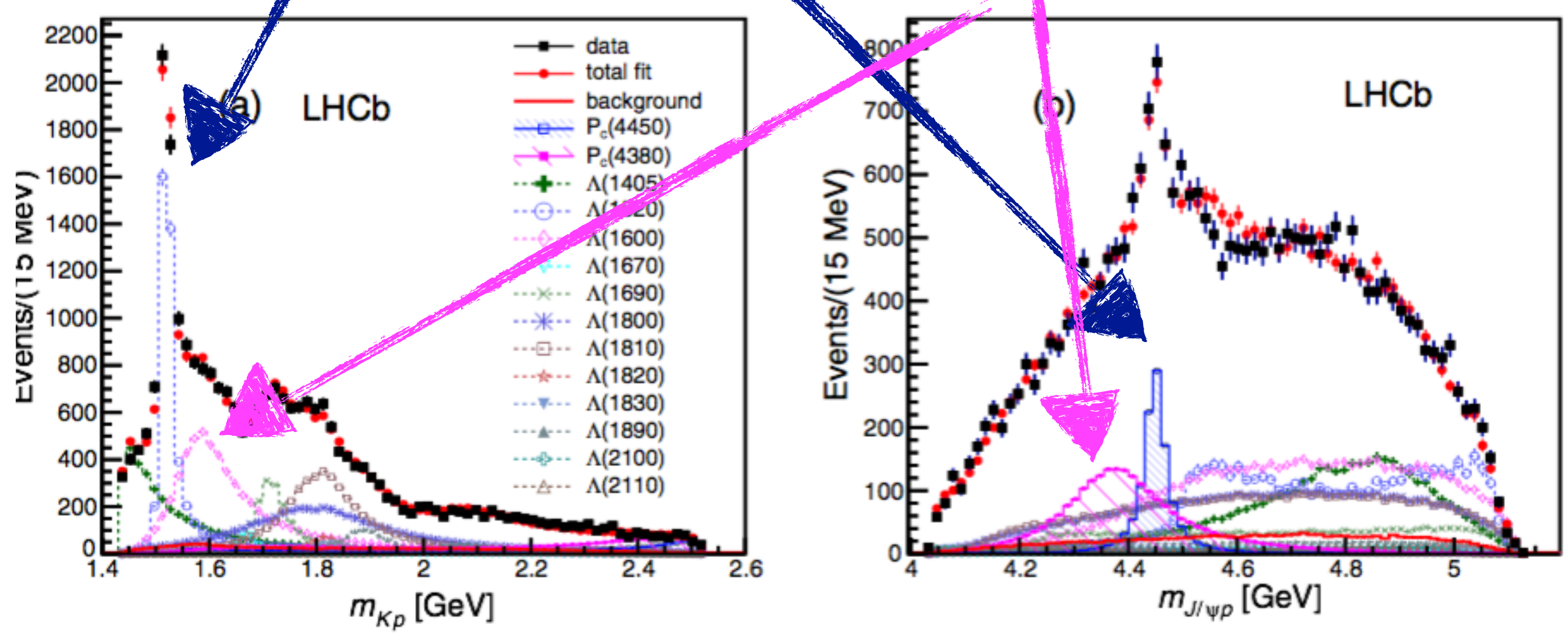


$$\Lambda_b \to \Lambda^* J/\Psi \to (K^- p) J/\Psi$$
$$\Lambda_b \to K^- P_c \to K^-(pJ/\Psi)$$

- **2 P_c states** needed to describe results
  - **narrow**: $P_c(4450)$
  - **wide**: $P_c(4380)$
- spin/parity either:
  - **5/2+, 3/2- (most likely!)**
  - 5/2-, 3/2+
  - 3/2-, 5/2+

narrow: P_c(4450) (12 σ)

wide: P_c(4390) (9σ)



charmed "pentaquark" in **photo-production**

- Common explanations:
  - **LHCb**: 2 new **charmed "pentaquark"** (P_c) states
  - **alternative: kinematic enhancements** through anomalous triangle singularity **(ATS)**

Lui X-H, *et al.,* PLB 757 (2016), p231
(and references therein)

- **Photo-production** ideal tool to **distinguish** between both explanations
  - if P_c real states, **also created in photo-production**
  - kinematic enhancement through **ATS not possible in photo-production**

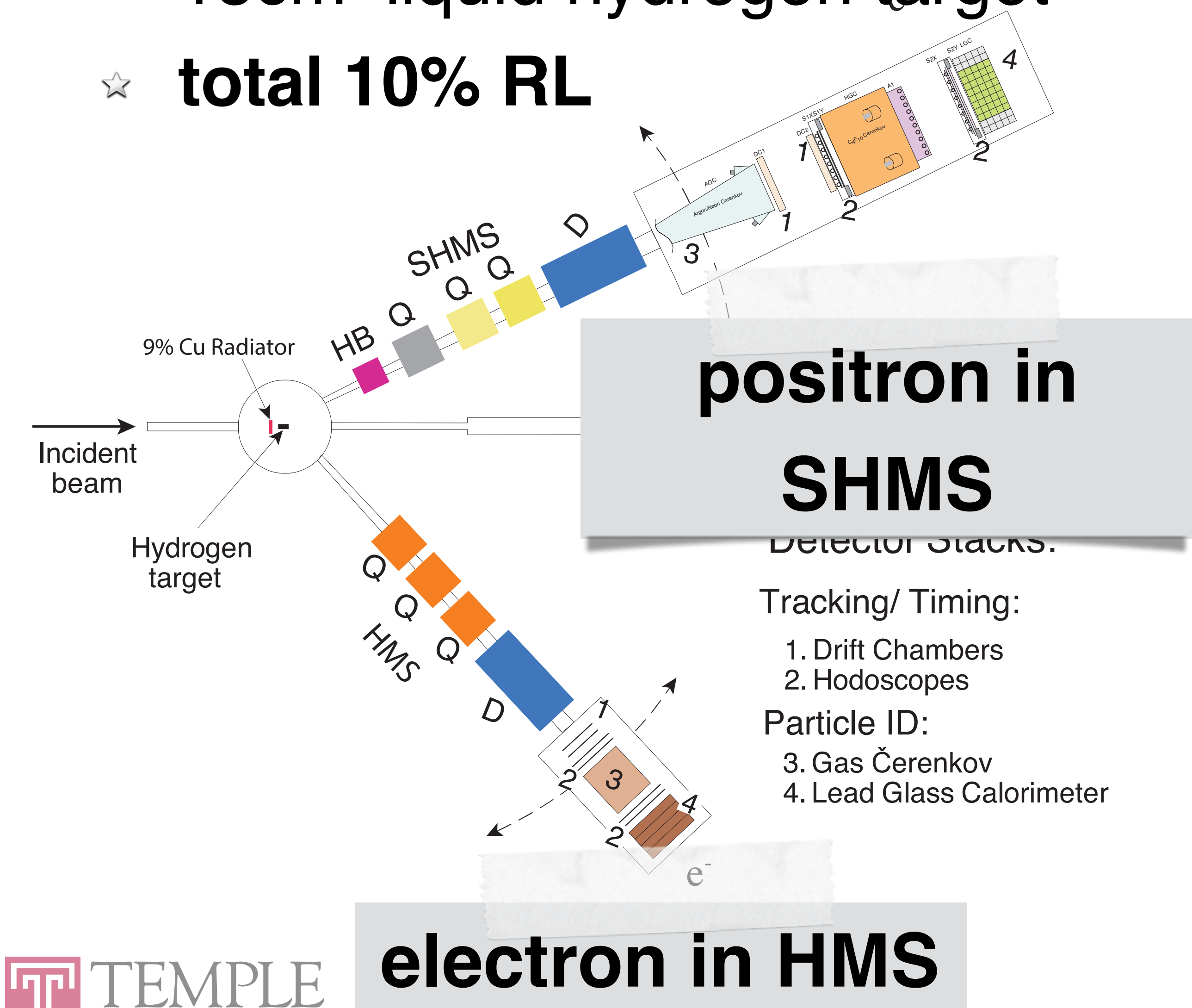
Wang Q., *et al.,* PRD 92-3 (2015) 034022-7
(and references therein)

- P_c(4450) translates to **narrow peak around $E_\gamma = 10$ GeV**

JLab is the ideal laboratory for the measurement, due to luminosity, resolution and energy reach at threshold!

Proposed Experiment in **Hall C**

- Setup similar to E-05-101(WACS)
  - 50µA electron beam at 10.7 GeV (or 11 GeV)
  - 9% copper radiator
  - 15cm liquid hydrogen target
  - **total 10% RL**



- **Run with 2 settings:**
  - **"SIGNAL" Setting** (9 days): minimizes accidentals and **maximizes signal/background**:
    - HMS: 34°, 3.25 GeV electrons
    - SHMS: 13°, 4.5 GeV positrons
  - **"BACKGROUND" Setting:** (2 days): precise determination of the ***t*-channel background**
    - HMS: 20°, 4.75 GeV electrons
    - SHMS: 20°, 4.25 GeV positrons

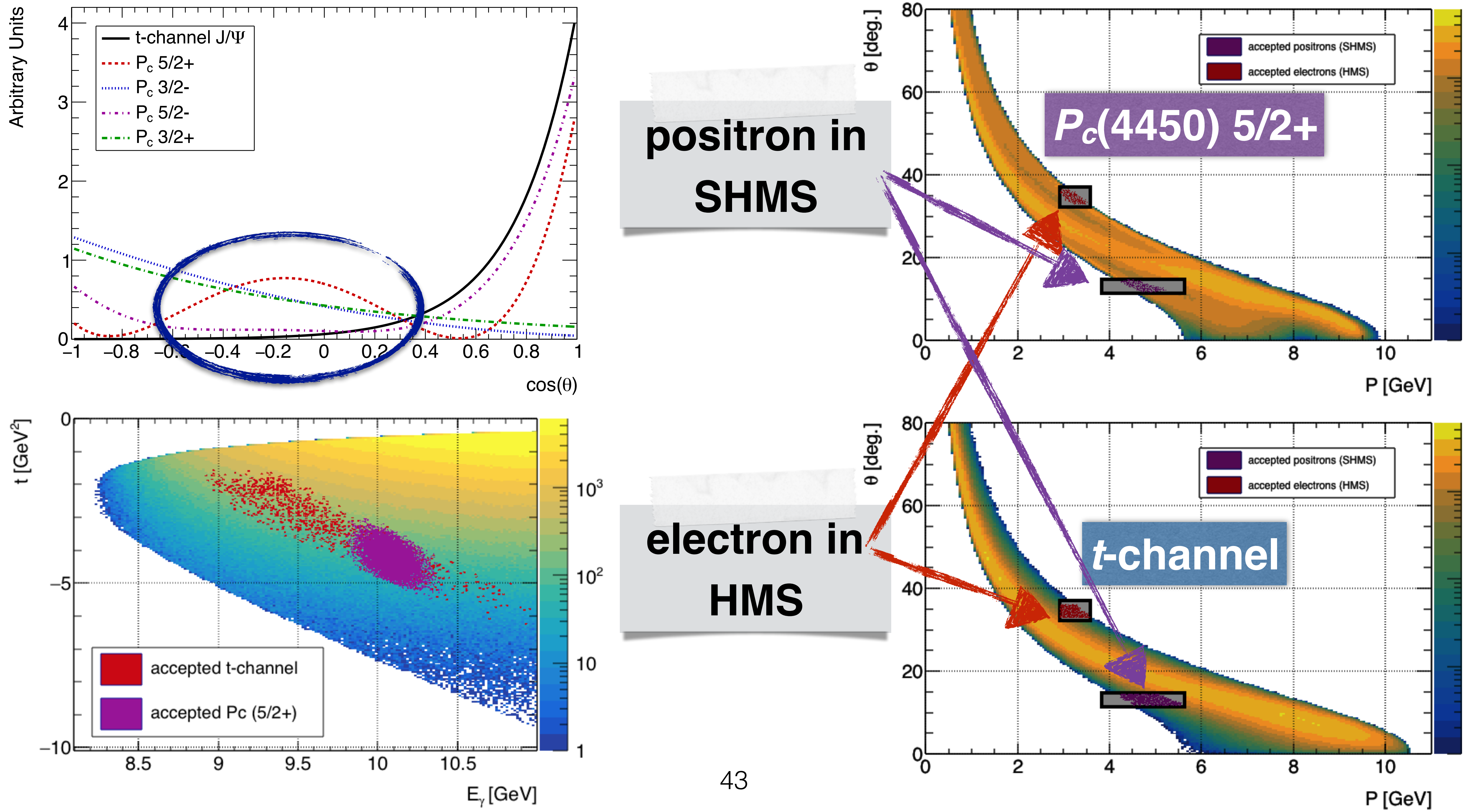
Standard Detector Package, Radiator Well Understood

Bottom line: can run SOON and FAST

Maximizing the sensitivity

- Use **HMS** and **SHMS** to maximize P_c signal over *t*-channel background

“SIGNAL” Setting



Photon Energy Reconstruction

- Can **unambiguously** reconstruct the initial photon energy from the reconstructed J/ψ momentum and energy
- Assumptions:
  - photon beam along the *z*-axis
  - proton target at rest
  - 2 final state particles: a proton and a *J/ψ*

$$E_\gamma = \frac{M_J^2 - 2E_J M_P}{2(E_J - M_p - P_J \cos\theta)}$$

TEMPLE UNIVERSITY®

ALERT drift chamber details

- a clear space filled with helium to reduce secondary scattering from the high rate Moller electrons. Its outer radius is 30 mm;
- the drift chamber, its inner radius is 32 mm and its outer radius is 85 mm. It will detect the trajectory of the low energy nuclear recoils;
- two rings of plastic scintillators placed inside the gaseous chamber, with total thickness of roughly 20 mm.