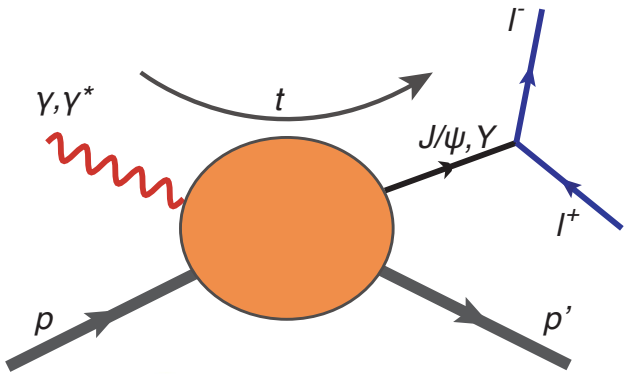
SOLID J/Ψ PHYSICS AND GLUONIC FORM FACTORS



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On behalf of SoLID collaboration

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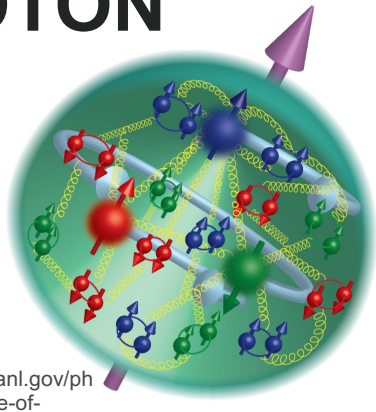
01/27/2023
Winter Hall A collaboration meeting

OUTLINE

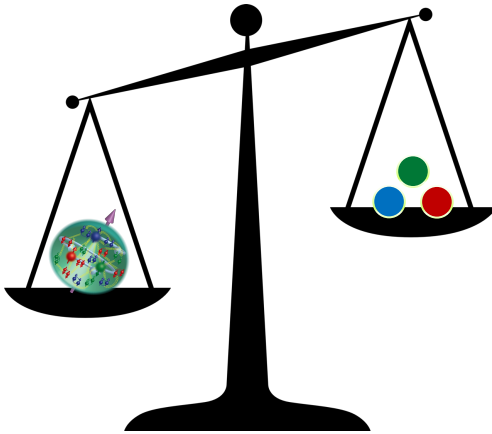
- Introduction – J/Ψ production at threshold
- Current status on J/ψ production measurement at JLab
  - GlueX (Hall D)
  - J/ψ 007 (Hall C)
- SoLID J/ψ and Gluonic Form factors
  - Understanding of threshold region & GFFs
- Summary

UNDERSTANDING THE ORIGIN OF PROTON MASS AND ITS DISTRIBUTION

- Proton's macroscopic properties – charge, spin, mass – arise from a very complex dynamics between the quarks and gluons (QCD)
- Studying it's charge radius and spin from electron scattering experiments have been an active area of research
  - Quarks carry electromagnetic charge
- Little is known about its mass density which is dominated by energy carried by gluons
  - Gluons do not carry electric charge and difficult to access via electron scattering experiments.



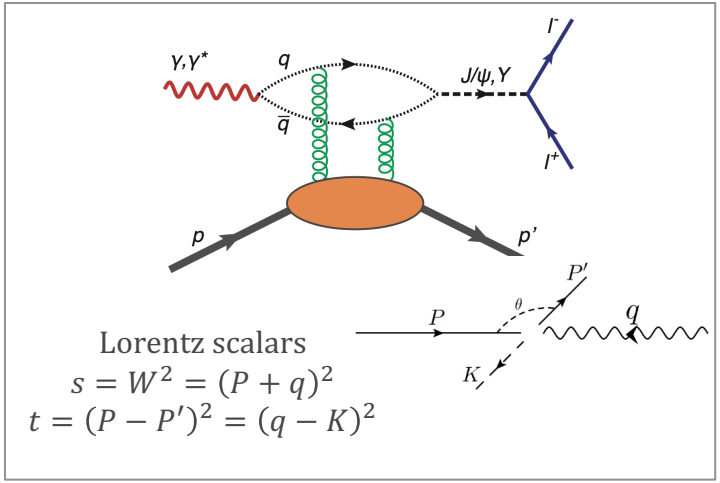
https://www.anl.gov/phy/3d-structure-of-protons-and-neutrons



NEAR THRESHOLD J/Ψ PRODUCTION

Why is it interesting?

- t-channel differential cross section of quarkonium production at threshold → promising channel to access the gluons
  - GFFs are matrix elements of the proton's energy-momentum tensor (EMT)
  - Gluon Form Factors (slope and magnitude)→ encode mechanical properties e.g., radii, pressure, shear



$$\langle N'|T^{\mu,\nu}_{q,g}|N\rangle = \bar{u}(N')\left(A_{g,q}(t)\gamma^{(\mu}p^{\nu)} + B_{q,g}\frac{iP^{(\mu}\sigma^{\nu)}\rho\Delta_\rho}{2M} + C_{g,q}(t)\frac{\Delta^\mu\Delta^\nu - g^{\mu\nu}\Delta^2}{M} + \bar{C}_{g,q}(t)Mg^{\mu\nu}\right)u(N)$$

$A_{g,q}(t)$: Related to quark and gluon momentum fraction; $A_{g,q}(0) = \langle x_{g,q}\rangle$

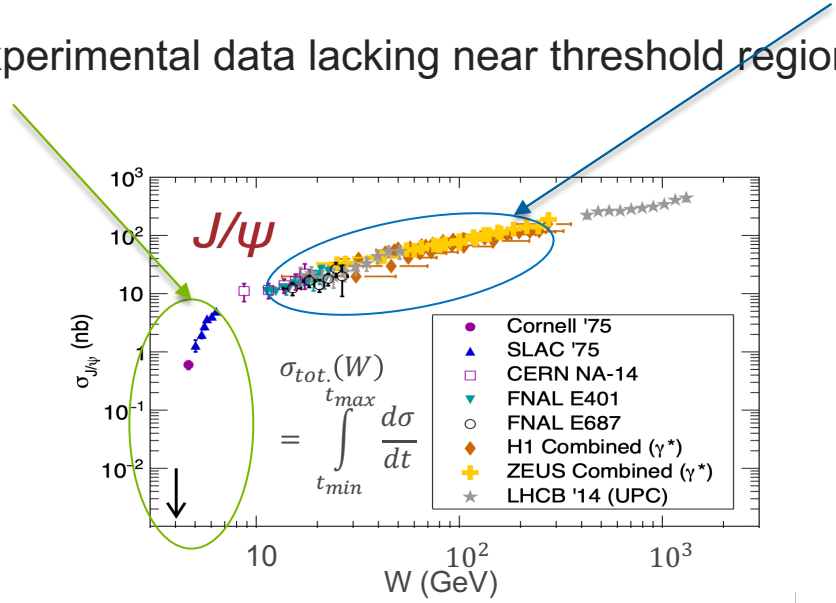
$B_{g,q}(t)$: Total angular momentum $J_{g,q}(t) = \frac{1}{2}(A_{g,q}(t) + B_{g,q}(t))$

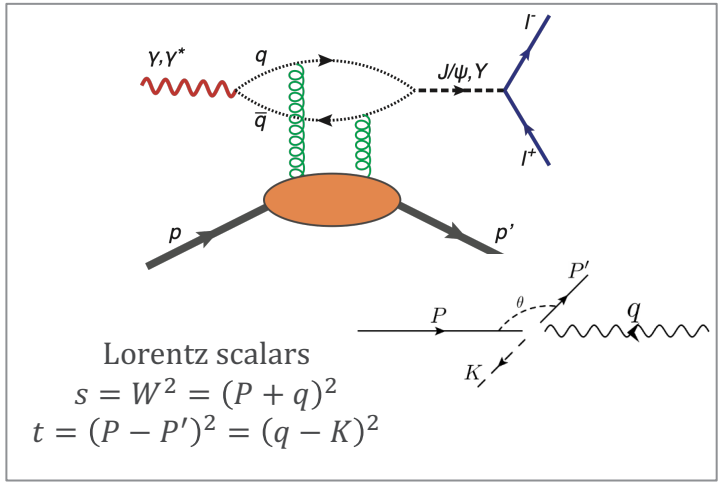
$C_{g,t}(t)$: Pressure and Shear distribution $D_{g,q}(t) = 4C_{g,q}(t)$

NEAR THRESHOLD J/Ψ PRODUCTION

Existing measurements

- Cross section well constrained at higher energies.
- Experimental data lacking near threshold region.

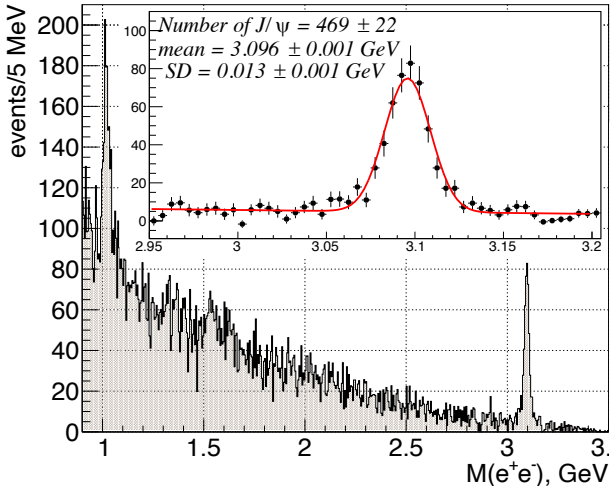


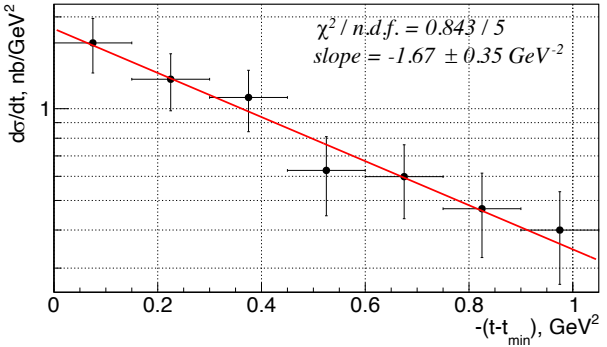


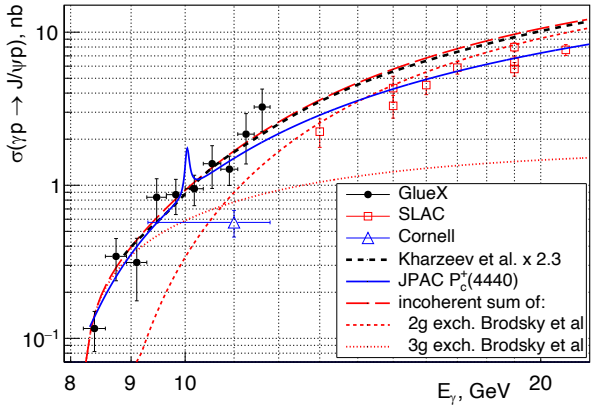
J/Ψ PHOTOPRODUCTION NEAR THRESHOLD AT HALL D

- First to measure J/Ψ at JLab.
- Reported 1D differential cross section $\frac{d\sigma}{dt}$ in E_γ bin (10 GeV - 11.8 GeV) upto $t = 1.4\ GeV^2$

PRL 123, 072001 (2019)

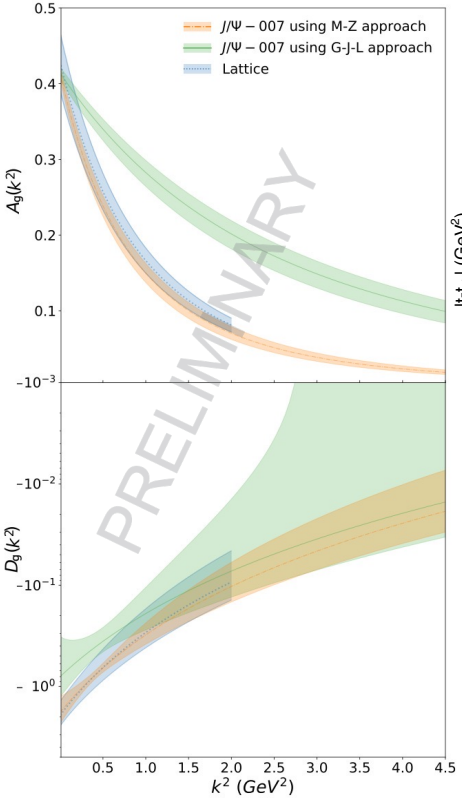


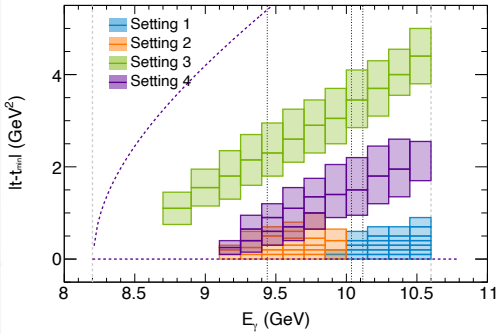


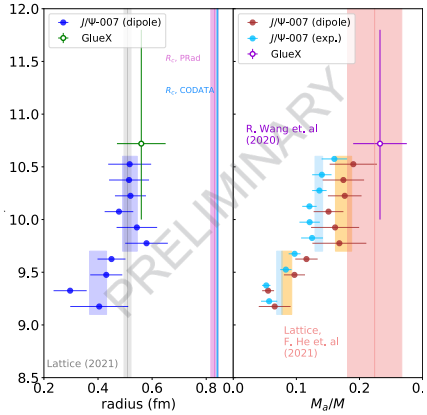


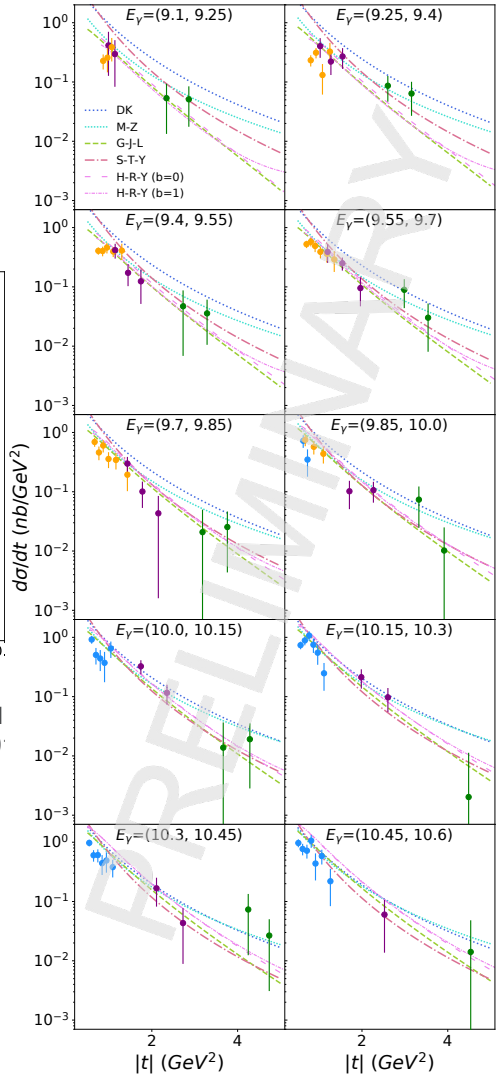
2-D CROSS SECTIONS- J/Ψ 007

Model dependent extractions of GFFs and radii









Mamo, K. A. & Zahed, I. Phys. Rev. D 103, 094010

Guo, Y., Ji, X. & Liu, Y. Phys. Rev. D 103, 096010

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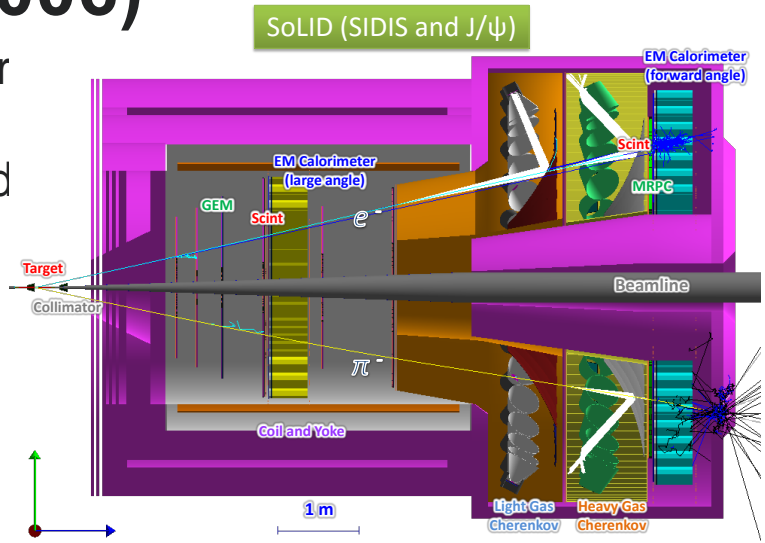
1. DK: Phys. Rev. D 104, 05401
2. M-Z: Phys. Rev. D 103, 0940
3. G-J-L: Phys. Rev. D 103, 096010
4. S-T-Y: Phys. Lett. B 822, 136655
5. H-R-Y: Phys. Rev. D 98, 074003, Phys. Rev. D 100, 014032 JHEP 12, 008

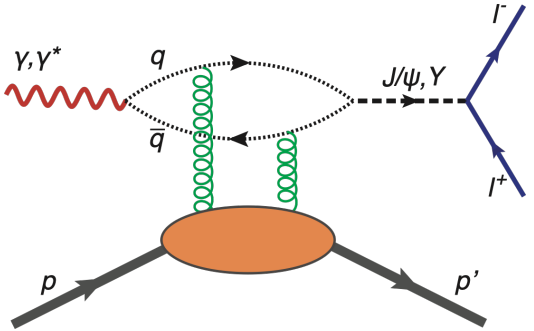
arxiv: 2207.05212

Accepted for publication in Nature

SOLID EXPERIMENT (E12-12-006)

- Large acceptance spectrometer designed for higher luminosity
  - Capable of handling high signal and background rates
- Detector configuration similar to SoLID-SIDIS (except for unpolarized liquid hydrogen)
- 50+10 days of 3μA beam on a 15 cm long target at $10^{39}\ cm^2 s^{-1}$
- Open 2 particle trigger
  - Photoproduction ((e)p → e+e-) : 3-fold coincidence
  - Electroproduction (e(p) → e+e-) : 3-fold coincidence
  - Exclusive (ep → e+e-) : 4-fold coincidence
  - Inclusive (e+e-) : 2-fold coincidence

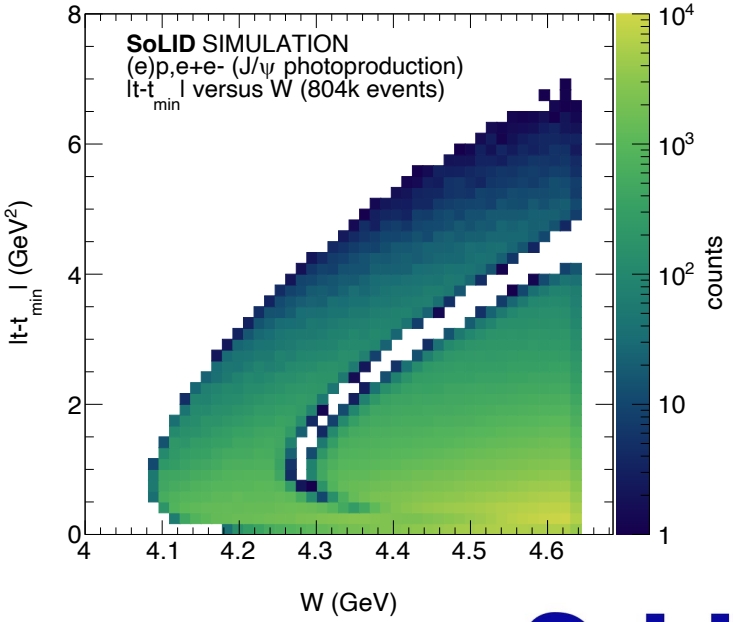




J/Ψ PHOTOPRODUCTION AT SOLID

Very high statistics and high-t reach

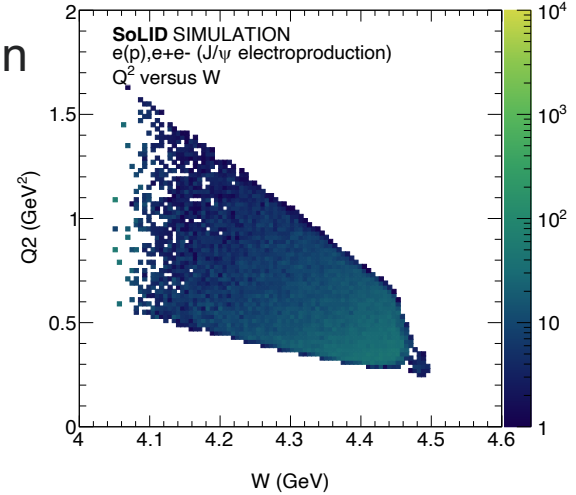
- Contribution from quasi-real and bremsstrahlung
- Measurement requires coincidence of electron- positron pair from decay of J/Ψ and the recoil proton
- High-t reach for higher W.

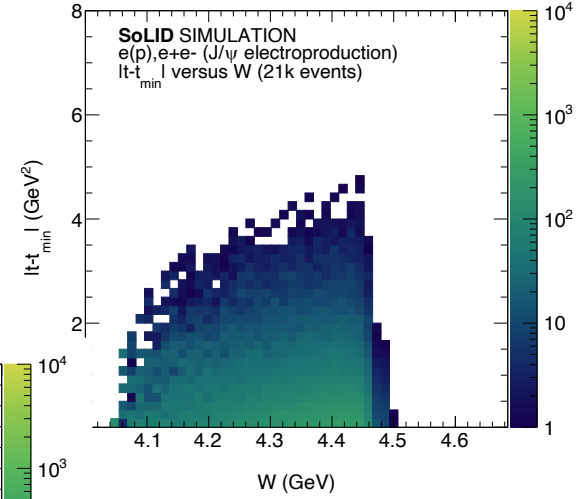


J/Ψ ELECTROPRODUCTION AT SOLID

Much closer reach in threshold region

- Production via virtual photon
- Measurement requires coincidence of electron- positron pair from decay of J/Ψ and the scattered electron
- Complementary to photoproduction
- Superior reach in near-threshold region
- Lever arm in Q^2

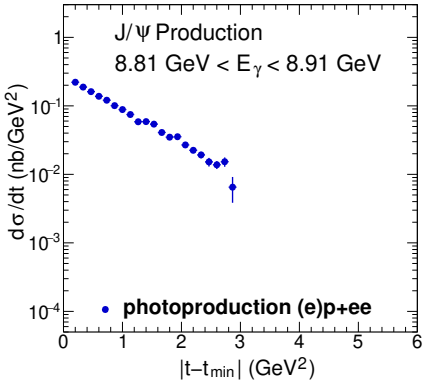


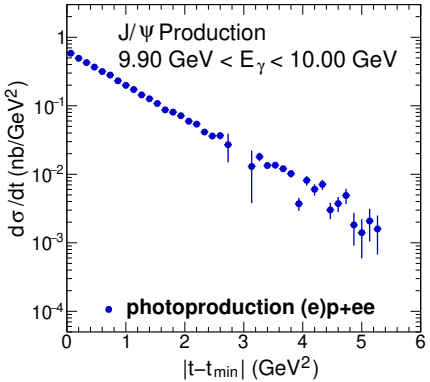


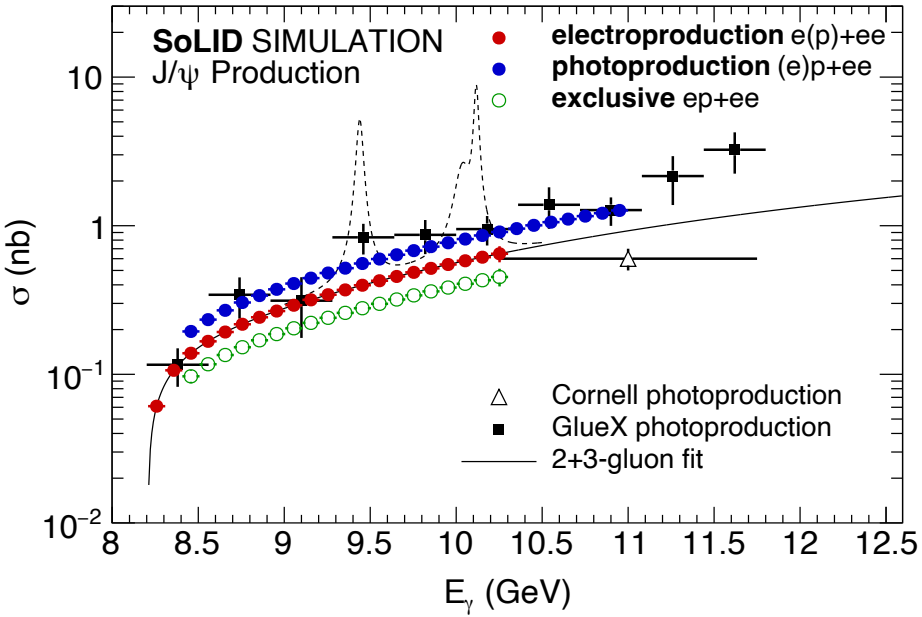
COMPARISON OF EXISTING J/Ψ PRODUCTION NEAR THRESHOLD DATA WITH SOLID

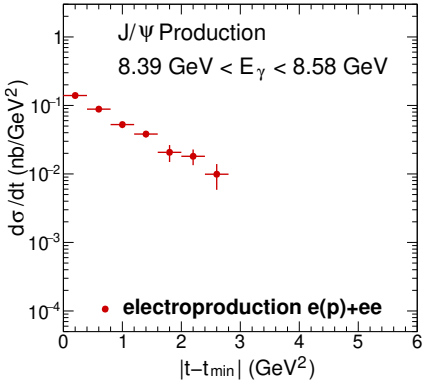
	GlueX Hall D	J/Ψ 007 Hall C	SoLID Hall A
J/Ψ counts (photoproduction)	469 published ~10k phase I+II	2k electron channel 2k muon channel	804k
J/Ψ counts (electroproduction)	N/A	N/A	21k
Features	Good reach near threshold No high-t reach	Reach high-t Low statistics	Reach high-t High statistics
Timeline	Finished/ongoing	Finished	Future

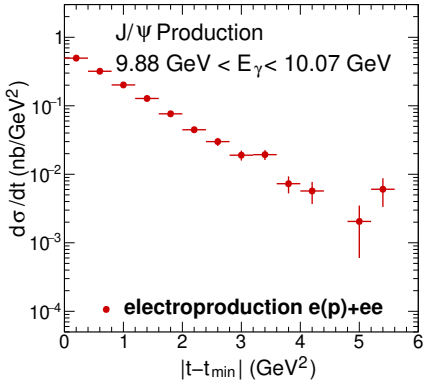
SENSITIVITY FOR SOLID EXPERIMENT







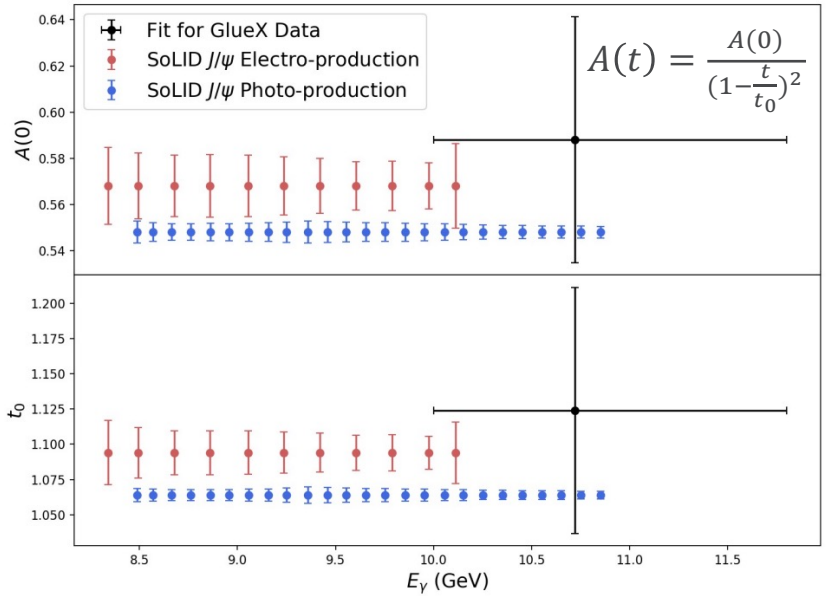


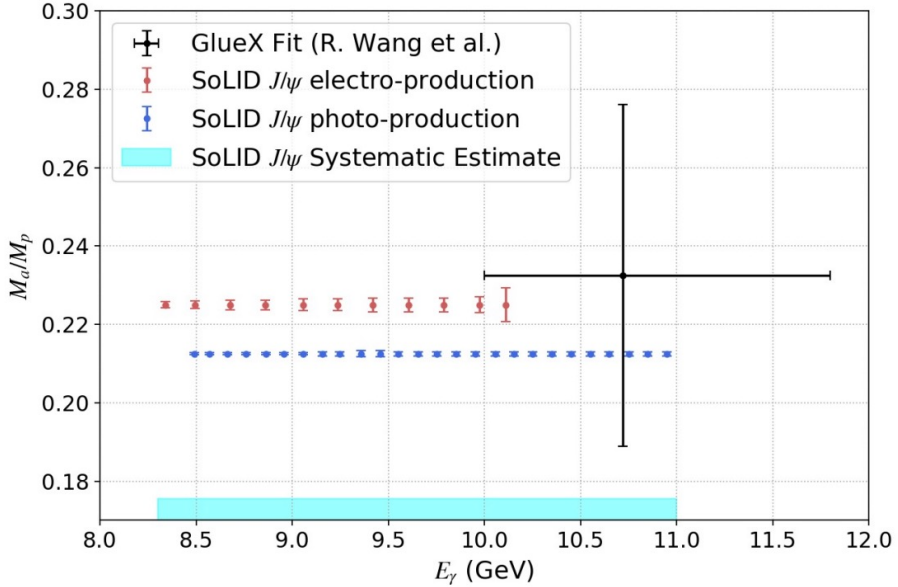


Precise measurement of t-dependence crucial for constraining GFFs

Rapidly falling CS requires high luminosity at high t

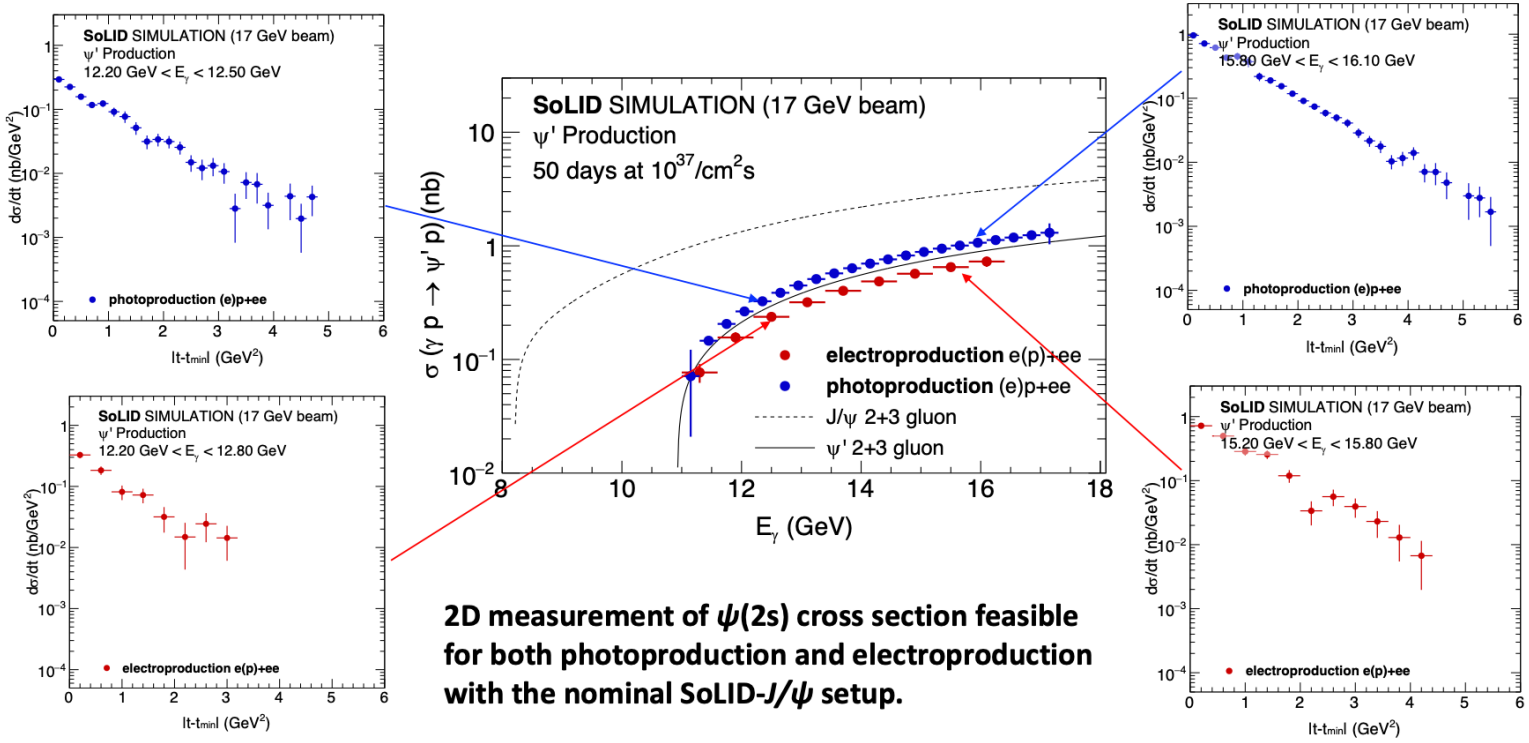
PROJECTED IMPACT OF SOLID J/Ψ MEASUREMENT





M_a/M using Ji's approach

JLAB ENERGY UPGRADE: POSSIBLE Ψ' MEASUREMENT



2D measurement of $\psi(2s)$ cross section feasible for both photoproduction and electroproduction with the nominal SoLID-J/ψ setup.

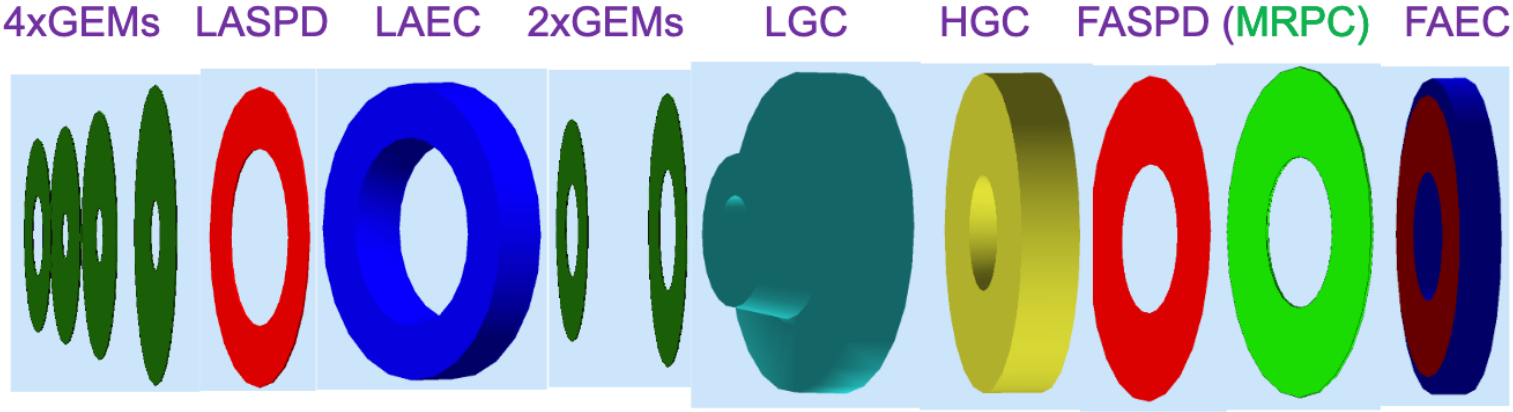
SUMMARY

- J/Ψ production measurement at threshold provides unique opportunity to access gluons
  - Gluonic form factors
  - Mass and scalar radii
  - Trace anomaly
- JLab 12 GeV program has been able to successfully have a first look at results from near-threshold J/Ψ production (GlueX and J/Ψ-007 experiments)
  - While model dependent, preliminary results on radii extracted from the J/Ψ 007 experiment data show that mass radii is smaller than charge radius –dense core??
- Upcoming SoLID J/Ψ program crucial for understanding important physics related to mechanical properties of matter.
  - High luminosity and large acceptance well suited for precision measurement at high t for photoproduction as well as better reach in the threshold region for electroproduction

THANK YOU

QUESTIONS?

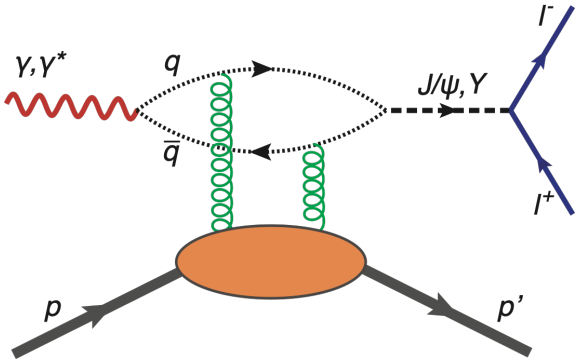
SOLID DETECTOR



Pre-R&D items: LGC, HGC, GEM's, DAQ/Electronics, Magnet

- LASPD: Large-angle Scintillator Pad detector; TOF resolution 150 ps; photon rejection 10:1
- LAEC: Large Angle E Cal; primary electron trigger and detection; also MIP trigger for pions
- LGC: electron identification, CO2, part of electron trigger system
- HGC: identify charged pion, suppress charged kaons, C4F8
- FASPD: Forward-angle Scintillator pad detector; photon rejection 5:1
- MRPC: Multi-gap resistive Plate Chamber; used as TOF system
- FAEC: Forward-angle E Cal; primary electron trigger and detection

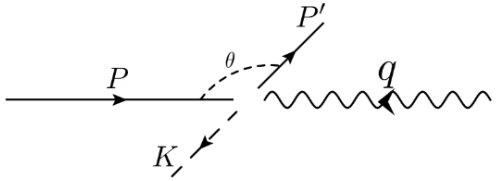
J/Ψ PHOTOPRODUCTION KINEMATICS

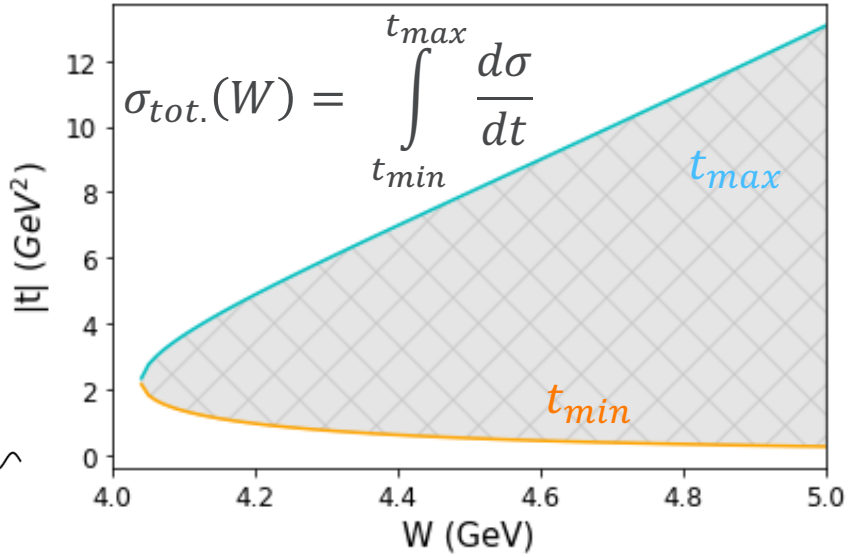


Lorentz scalars

$$s = W^2 = (P+q)^2$$

$$t = (P-P')^2 = (q-K)^2$$





- Phase space for J/Ψ production is limited by t_{min} and t_{max}
  - t_{min} → J/Ψ in the forward/ along the direction of photon
  - t_{max} → J/Ψ in the backward/ along the direction of proton

MODEL DEPENDENT EXTRACTION OF GLUONIC GRAVITATIONAL FORM FACTORS

- Used two different approaches to perform extraction
  - Holographic approach : (Mamo, K. A. & Zahed, I. Phys. Rev. D 103, 094010)
  - GPD approach : (Guo, Y., Ji, X. & Liu, Y. Phys. Rev. D 103, 096010)

- Two form factors (tripole form) considered. Contribution from $B_g(t)$ is assumed to be negligible

$$A_g(t) = \frac{A_g(0)}{\left(1 - \frac{t}{m_A^2}\right)^3} \qquad C_g(t) = \frac{C_g(0)}{\left(1 - \frac{t}{m_C^2}\right)^3}$$

- Fixed $A_g(0)$ to $\langle x_g \rangle$ → from CT18 global fit.
  - m_A, $C_g(0)$ and $m_C$determined from fits

- Results undergoing peer review
  - Preprint → arxiv: 2207.05212