JULY 7 2026

PR12-26-003

EXCLUSIVE NEAR-THRESHOLD J/ψ PHOTOPRODUCTION AT LARGE SKEWNESS IN HALL C AT JLAB

Program Advisory Committee 54

FERNANDO ANTONIO FLOR
Argonne National Laboratory

On behalf of the **J/ψ-007-II Collaboration**

Spokespeople:
F.A. Flor (fflor@anl.gov), M.K. Jones, S.J. Joosten

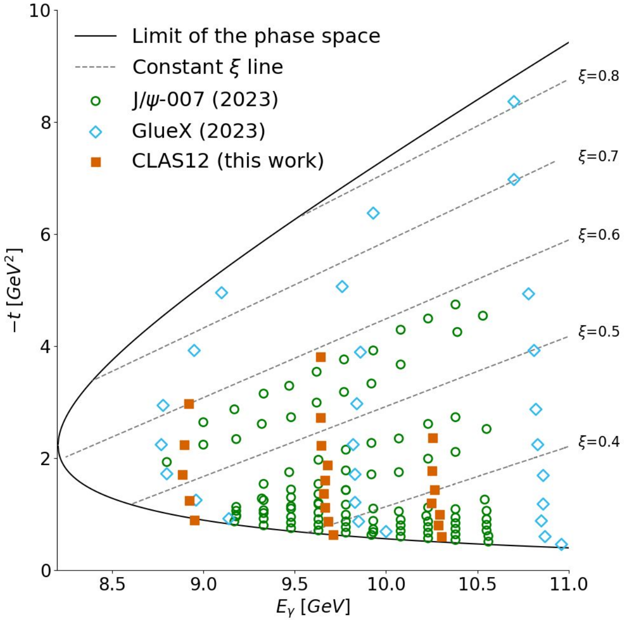
J/ψ PHOTOPRODUCTION AT 12 GeV JLAB

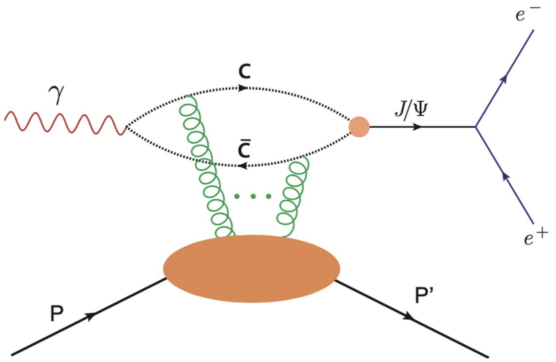
Jefferson Lab is the ideal laboratory for near threshold J/ψ photoproduction

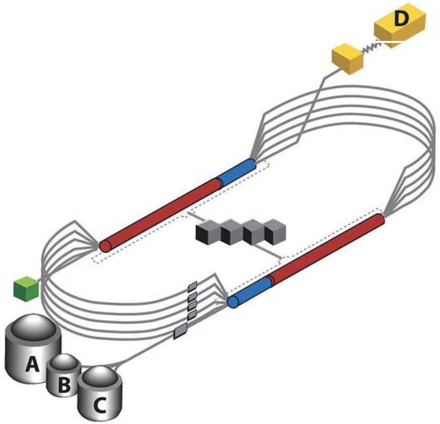
12 GeV era J/ψ Experiments at JLab

- ❖ **Hall D:** First J/ψ at JLab 12 GeV (GlueX) and full phase space
- ❖ **Hall C:** First 2D cross section measurement near threshold (J/ψ-007)
- ❖ **Hall B:** J/ψ Photoproduction Run Groups A and B (CLAS12)
- ❖ ***Hall A:** Dedicated J/ψ electro/photoproduction Experiment (SoLID)*

Chatagnon et al (CLAS12). ***arXiv:2602.22128***







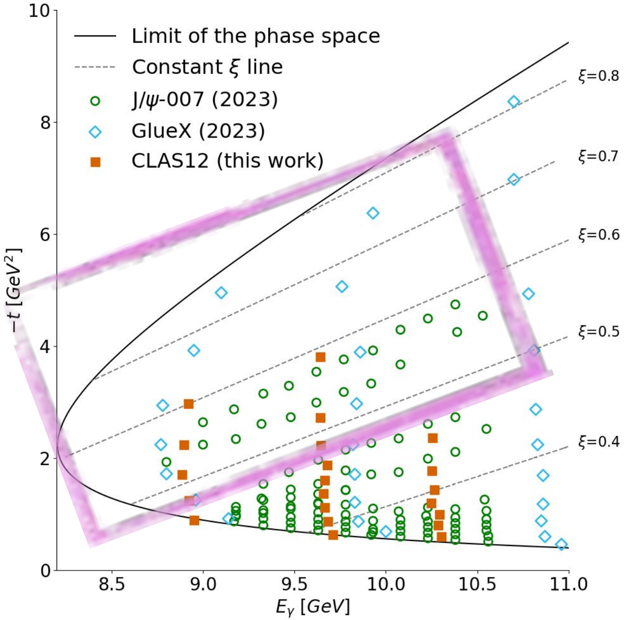
Duran et al (J/ψ-007). *Nature*. **615** [2023]

J/ψ PHOTOPRODUCTION AT 12 GeV JLAB

Jefferson Lab is the ideal laboratory for near threshold J/ψ photoproduction

Phase space coverage sparse for higher values of ξ

Chatagnon et al (CLAS12). *arXiv:2602.22128*



ξ is the asymmetry in the longitudinal momentum between the initial and final state of the proton

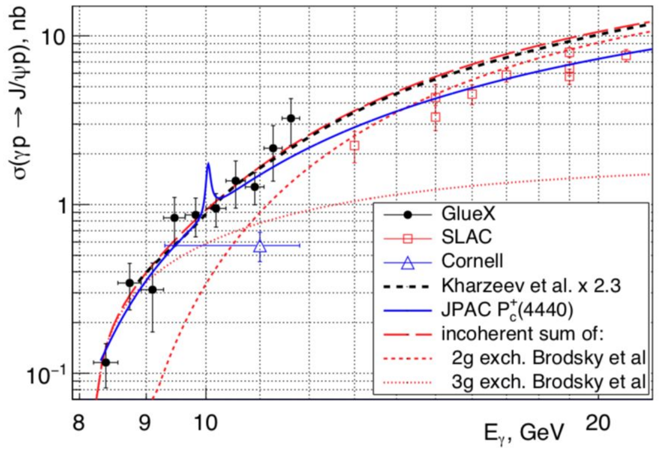
Higher ξ important for pQCD/GPD approach to constrain gravitational form factors, more sensitive to C_g, and reaches into zone where u-channel may play a role

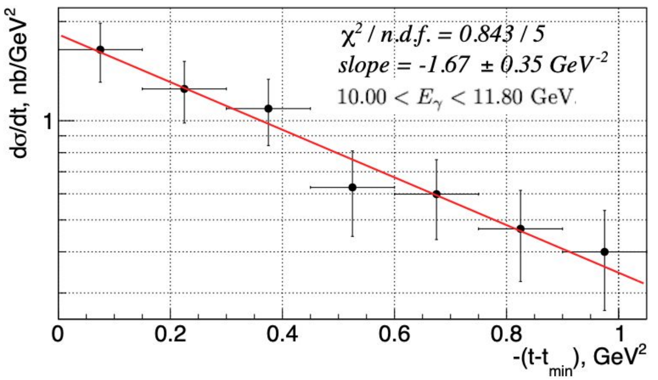
Higher ξ corresponds to larger |t| and/or lower E_γ

J/ψ PHOTOPRODUCTION IN HALL D (GlueX: 2019)

Ali et al. (GlueX). *Phys. Rev. Lett.* ***123*** **(2019)**

- First measured the 1D near-threshold J/ψ photoproduction cross-section at JLab
  - Saw no evidence of hidden-charm pentaquark contribution
  - Explicit t-dependence of differential cross-section seen



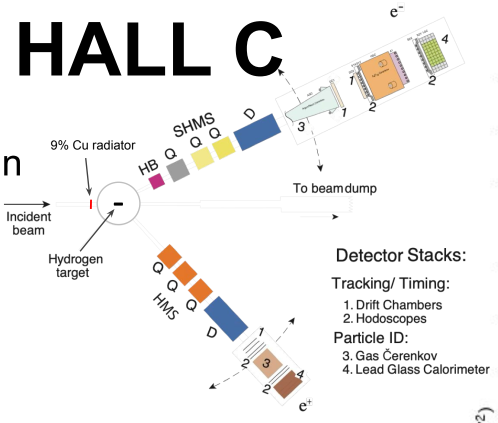


Demonstrated JLab as ideal laboratory for near-threshold J/ψ photoproduction

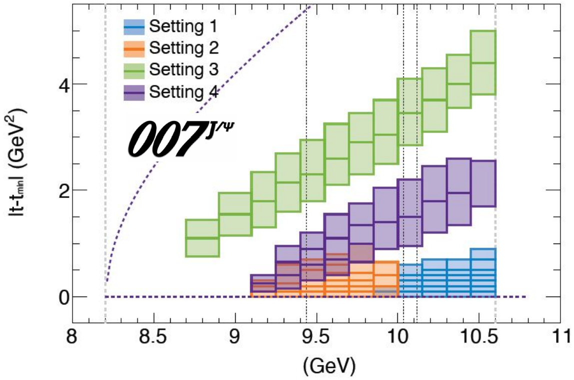
Duran et al (J/ψ-007). *Nature*. **615** [2023]

J/ψ-007 EXPERIMENT IN HALL C

- Measured the J/ψ photoproduction cross-section in the e^+e^- decay channel
- Found no evidence of hidden charm pentaquarks
- Constrained gluon Gravitational Form Factors (published in Nature)



Set precedent for a precisely tuned measurement in phase space with <u>short runtime</u> and <u>high impact</u>



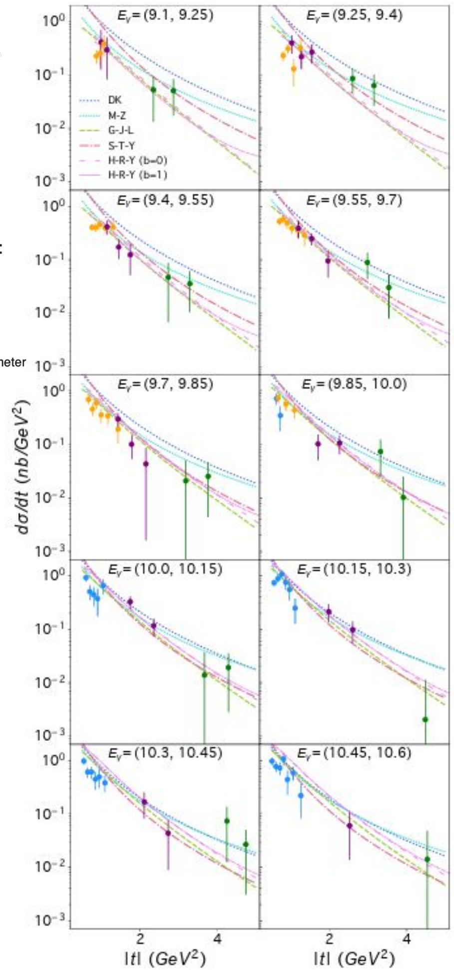


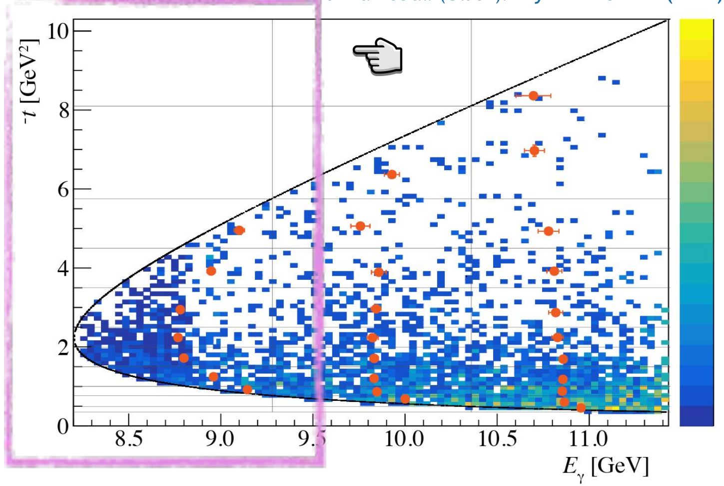
Table 1 | The gluonic GFF fit parameters, proton mass radius and scalar radius

Theoretical approach	χ^2/n.d.f.	m_A (GeV)	m_C (GeV)	$C_g(0)$	$\sqrt{\langle r_m^2 \rangle_g}$ (fm)	$\sqrt{\langle r_s^2 \rangle_g}$ (fm)
GFF functional form						
Holographic QCD	0.925	1.575±0.059	1.12±0.21	−0.45±0.132	0.755±0.035	1.069±0.056
Tripole–tripole						
GPD	0.924	2.71±0.19	1.28±0.5	−0.20±0.11	0.472±0.042	0.695±0.071
Tripole–tripole						
Lattice		1.641±0.043	1.07±0.12	−0.483±0.133	0.7464±0.025	1.073±0.066

J/ψ PHOTOPRODUCTION IN HALL D (GlueX: 2023)

Adhikari et al. (GlueX). *Phys. Rev. C.* ***108*** **(2023)**

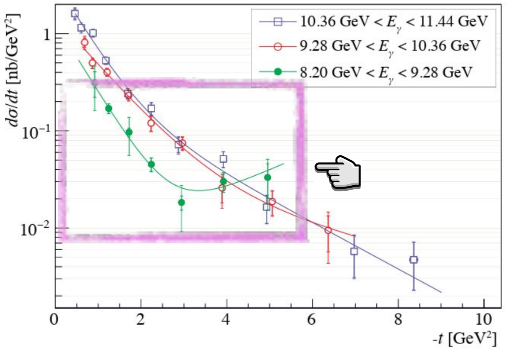
2023 GlueX results in the near-threshold region extracted the 2D differential cross-section in E_γ~ 8.2 - 11.4 GeV

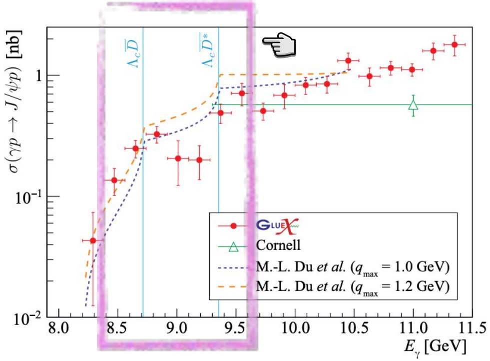


- ❖ Hints of *rise* of the differential cross-section in the lowest E_γ region at large |*t*|
  - ➢ Could indicate u-channel contributions in the lowest E_γ bin (8.2 GeV to 9.28 GeV)

- ❖ Hints of cusps in the total cross-section in vicinity of open-charm production thresholds

Need more data in the low E_γ region

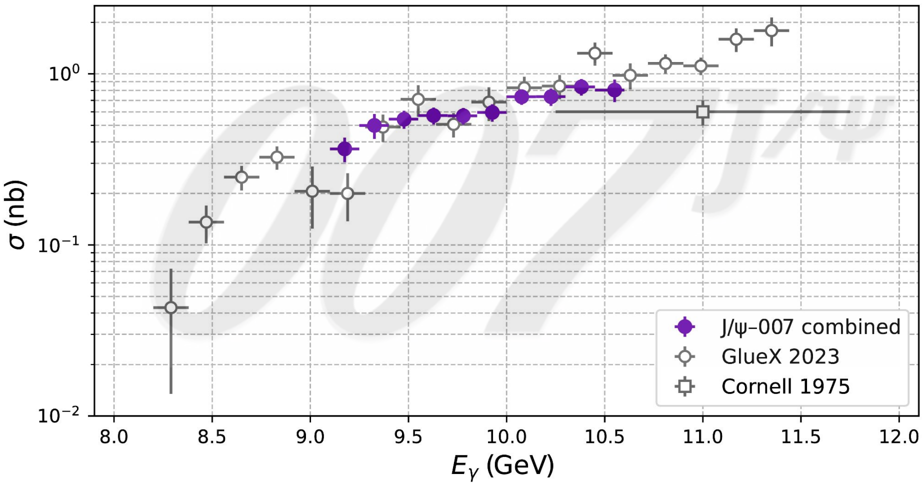


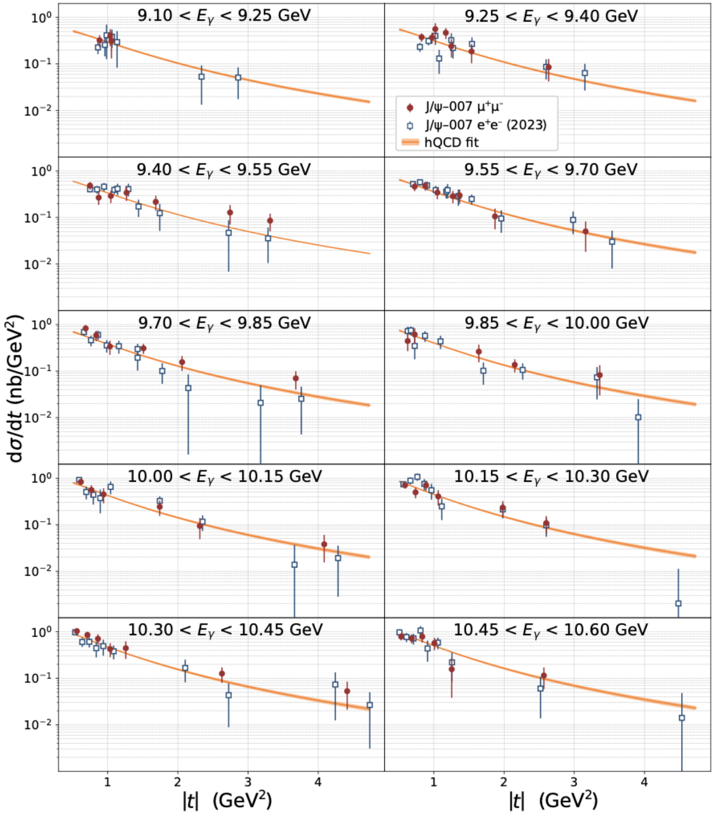


J/ψ-007 EXPERIMENT IN HALL C

Joosten et al (J/ψ-007). **arXiv: 2602.14416**

- ❖ Muon-channel results agree within uncertainties of the e^+e^- channel
- ❖ Results consistent with those from GlueX
- ❖ No evidence for contributions from open-charm production processes
- ❖ Further constraint on gluon GFFs

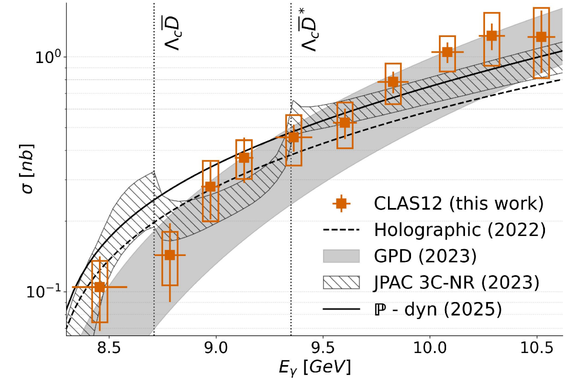


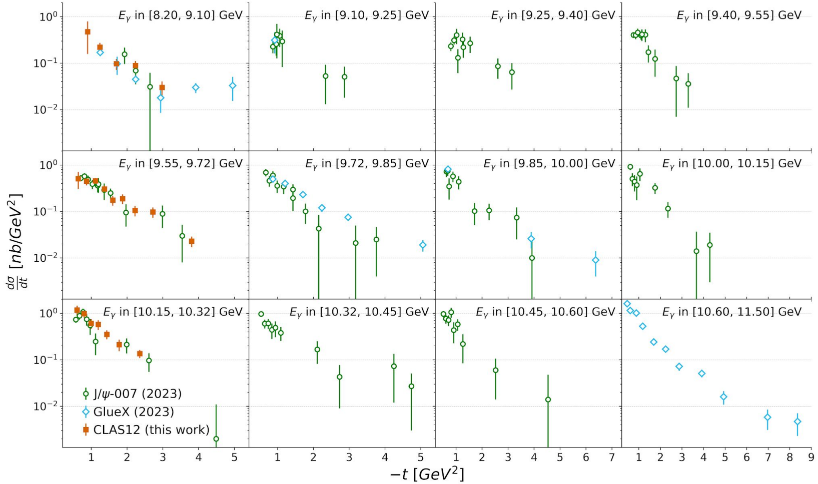


J/ψ PHOTOPRODUCTION IN HALL B (CLAS12)

Provides new data on the total and differential J/ψ photoproduction cross-sections

- ❖ Consistent with existing world data across overlapping kinematics
  - ➢ Smooth energy dependence near open-charm thresholds
  - ➢ Threshold-induced distortions of the unpolarized cross-section may be subtle





Chatagnon et al (CLAS12). *arXiv:2602.22128*

NEED FOR A NEW MEASUREMENT

12 GeV era J/ψ Experiments at JLab are of high impact!

Nevertheless:

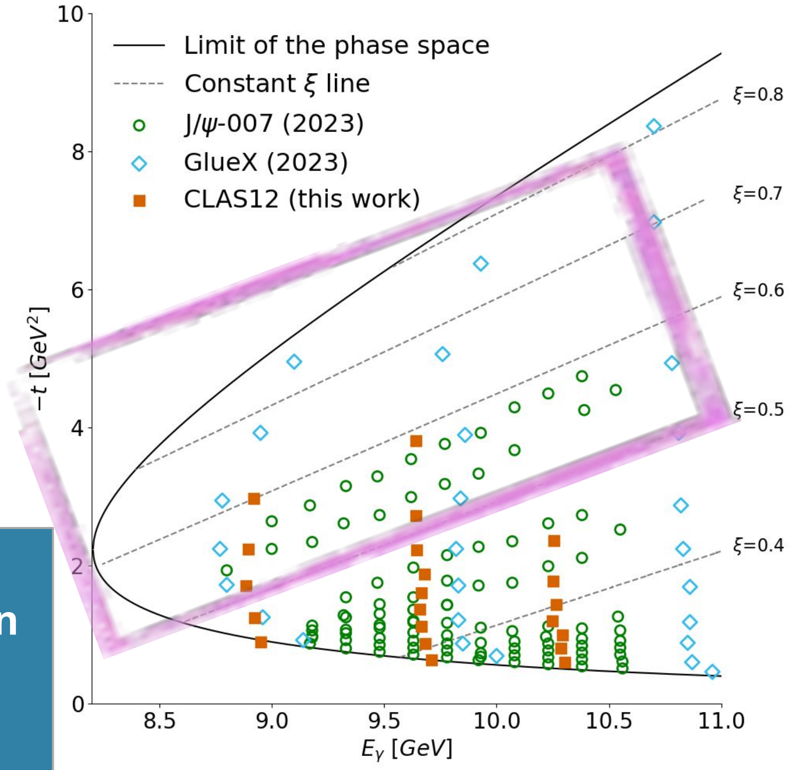
- ❖ Kinematic phase space remains sparsely filled at larger ξ
- ❖ pQCD/GPD description of differential cross-section requires data where ξ > 0.5
- ❖ Open questions on the J/ψ production process

World data would benefit from a targeted measurement

- ❖ J/ψ-007 established Hall C as perfect candidate
  - ➢ Can do this measurement with standard equipment

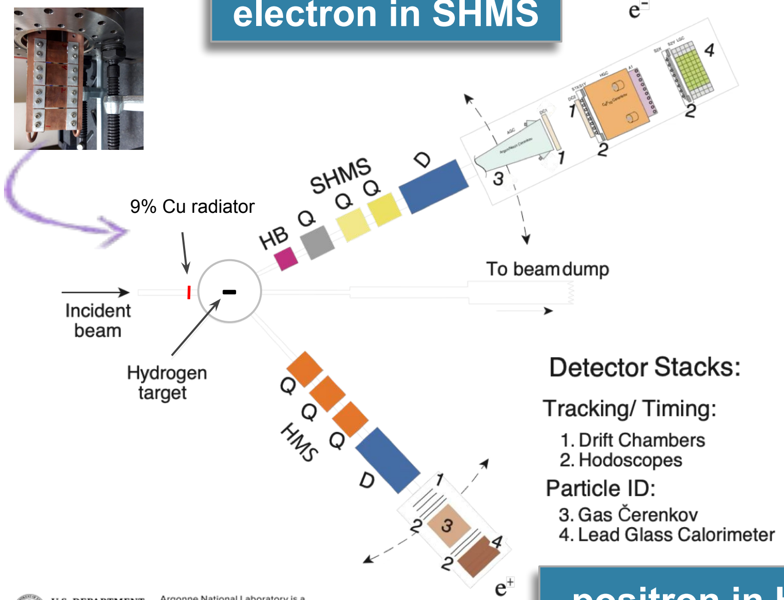
We propose a near-threshold J/ψ photoproduction experiment in Hall C extending the current world data kinematic phase space coverage

Chatagnon et al (CLAS12). ***arXiv:2602.22128***



PROPOSED EXPERIMENT IN HALL C

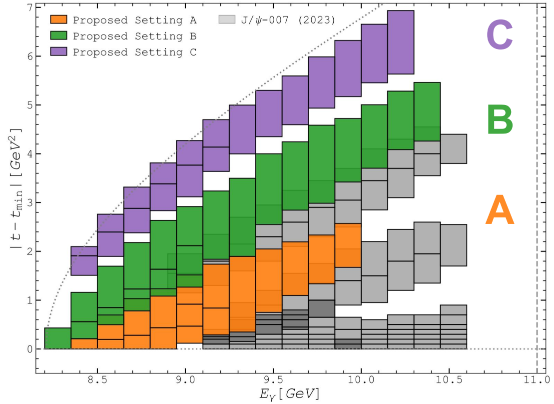
- Same setup as E12-16-007 (J/ψ-007)
  - 50 µA electron beam at 11.0 GeV
  - 9% copper radiator
  - 15cm liquid hydrogen target



positron in HMS

Standard Detector Package and radiator are well understood

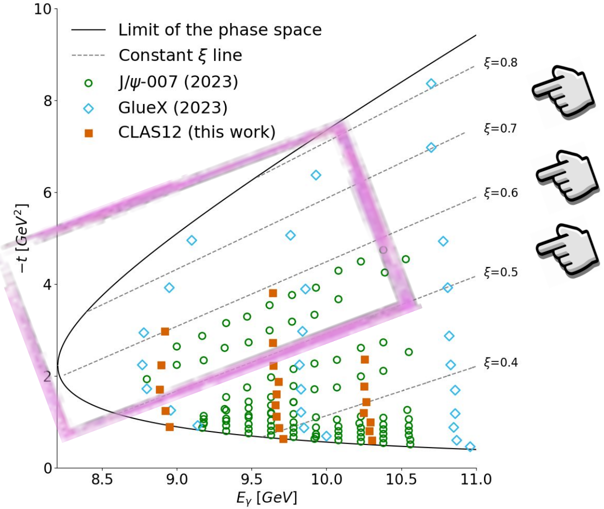
- Run with 3 targeted settings
  - Setting A (5 days)
  - Setting B (10 days)
  - Setting C (10 days)



MEASUREMENT EXPECTATIONS

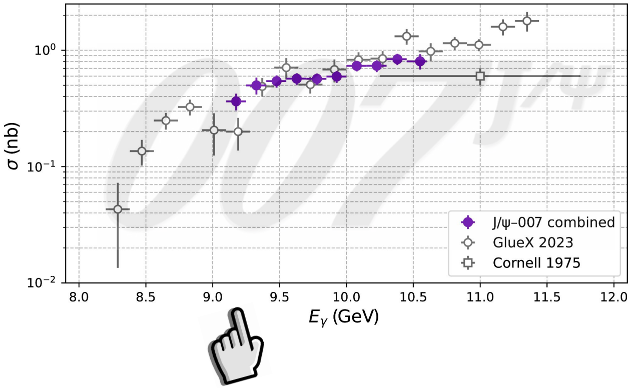
- ❖ Resolve possible upward trend at large |t| in low E_γ region
  - ➢ Sensitive to open-charm/resonance contributions
- ❖ Provide dense coverage at large |t|
  - ➢ Sensitive to u-channel onset
- ❖ **Targeted coverage at large values of ξ**
  - ➢ Constrains gluonic GFF extraction for ξ > 0.5

Chatagnon et al (CLAS12). ***arXiv:2602.22128***

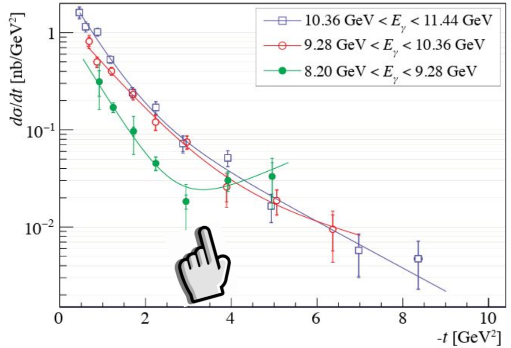


Our proposed experiment precisely targets this phase space region

Joosten et al (J/ψ-007). **arXiv: 2602.14416**

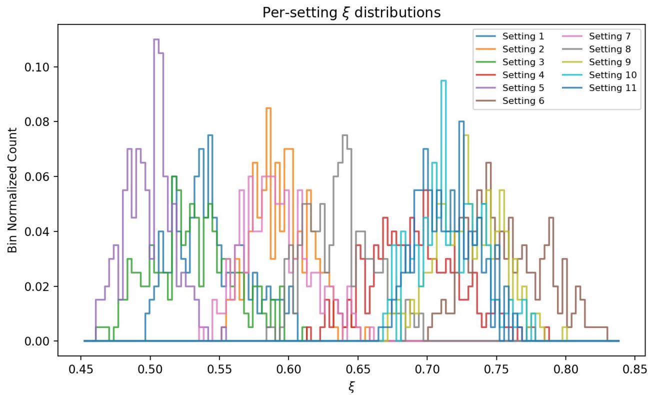


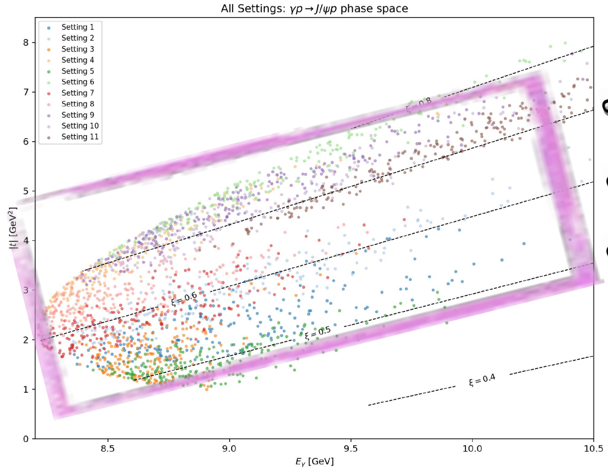
Adhikari et al. (GlueX). *Phys. Rev. C.* ***108*** **(2023)**



OPTIMIZING SPECTROMETER SETTINGS

Hall C Configuration	SHMS (−) $\lvert p \rvert$ (GeV)	SHMS (−) θ (deg.)	HMS (+) $\lvert p \rvert$ (GeV)	HMS (+) θ (deg.)	Kinematic Ranges
J/ψ-007-II Setting 1	1.96	37.5	5.83	17.1	$E_\gamma \in [8.4, 10.5]$ GeV $\lvert t \rvert \in [1.4, 5.0]$ GeV^2 $0.5 \leq \xi \leq 0.6$
J/ψ-007-II Setting 2	3.79	28.6	3.60	21.0	$E_\gamma \in [8.3, 10.5]$ GeV $\lvert t \rvert \in [1.8, 5.7]$ GeV^2 $\xi = 0.6$
J/ψ-007-II Setting 3	4.74	16.2	2.97	33.0	$E_\gamma \in [8.4, 9.3]$ GeV $\lvert t \rvert \in [1.0, 3.4]$ GeV^2 $0.45 \leq \xi \leq 0.6$
J/ψ-007-II Setting 4	4.11	20.2	2.51	37.8	$E_\gamma \in [8.2, 9.1]$ GeV $\lvert t \rvert \in [2.4, 5.0]$ GeV^2 $0.6 \leq \xi \leq 0.8$
J/ψ-007-II Setting 5	4.44	22.4	3.66	23.0	$E_\gamma \in [8.5, 10.2]$ GeV $\lvert t \rvert \in [1.0, 3.1]$ GeV^2 $\xi = 0.5$
J/ψ-007-II Setting 6	3.07	30.1	3.27	28.5	$E_\gamma \in [8.4, 10.0]$ GeV $\lvert t \rvert \in [3.3, 7.3]$ GeV^2 $\xi \geq 0.7$
J/ψ-007-II Setting 7	2.55	32.0	4.80	21.0	$E_\gamma \in [8.2, 9.8]$ GeV $\lvert t \rvert \in [1.6, 4.6]$ GeV^2 $\xi = 0.6$
J/ψ-007-II Setting 8	4.25	22.9	2.76	31.4	$E_\gamma \in [8.2, 9.2]$ GeV $\lvert t \rvert \in [2.1, 4.0]$ GeV^2 $0.6 \leq \xi \leq 0.7$
J/ψ-007-II Setting 9	3.33	31.3	3.27	25.6	$E_\gamma \in [8.3, 10.5]$ GeV $\lvert t \rvert \in [3.0, 7.2]$ GeV^2 $\xi = 0.7$
J/ψ-007-II Setting 10	4.20	28.8	3.00	25.7	$E_\gamma \in [8.7, 10.5]$ GeV $\lvert t \rvert \in [2.0, 7.0]$ GeV^2 $\xi = 0.7$
J/ψ-007-II Setting 11	3.50	28.8	3.00	25.7	$E_\gamma \in [8.3, 10.4]$ GeV $\lvert t \rvert \in [1.7, 7.5]$ GeV^2 $\xi = 0.7$

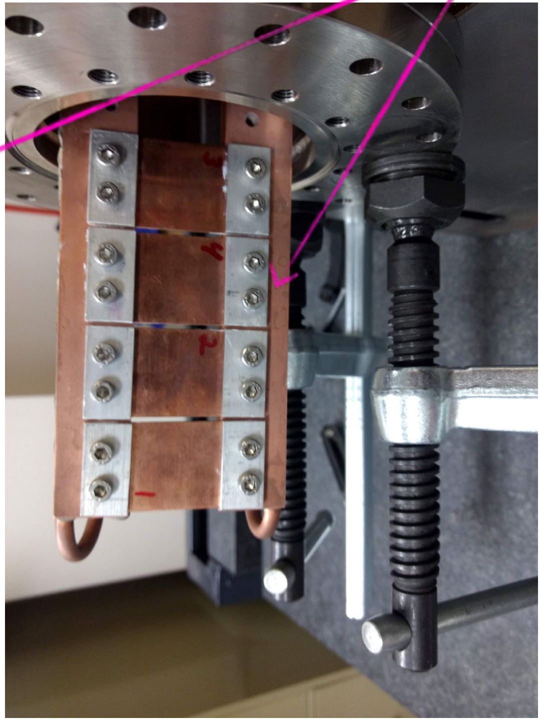




J/ψ-007-II settings were chosen to maximize high-ξ coverage while minimizing runtime

HALL C COPPER RADIATOR SAME AS BEFORE

Sealed/installed Hall C copper foil radiator radiator target(s) subsystem



Unsealed/uninstalled Hall C copper foil radiator radiator targets

BEAMTIME REQUEST

Category	Description	Beam Energy (GeV)	Beam Current (μA)	Target	Days
Production Running					
J/ψ–007-II Setting A	SHMS(−) and HMS(+)	11.0	50	LH_2	5.0
J/ψ–007-II Setting B	SHMS(−) and HMS(+)	11.0	50	LH_2	10.0
J/ψ–007-II Setting C	SHMS(−) and HMS(+)	11.0	50	LH_2	10.0
Subtotal (Production)					**25.0**
Commissioning and Calibration					
Initial commissioning	Detector and DAQ setup				1.0
Optics/momentum calibration	Spectrometer tuning				0.5
Detector calibration	Tracking, PID, timing				0.5
Subtotal (Calibration)					**2.0**
Total Requested Time					**27.0**

Measurement can be achieved in a relatively short time period!

PROJECTED ACCIDENTAL RATES

Hall C Configuration	$R_{\mathrm{SHMS,eff}}$ (kHz)	$R_{\mathrm{HMS,eff}}$ (kHz)	R_{acc} (kHz)
J/ψ–007-II Setting A	8.47	21.2	8.99×10^{-3}
J/ψ–007-II Setting B	0.77	41.9	1.61×10^{-3}
J/ψ–007-II Setting C	0.81	8.34	3.39×10^{-4}

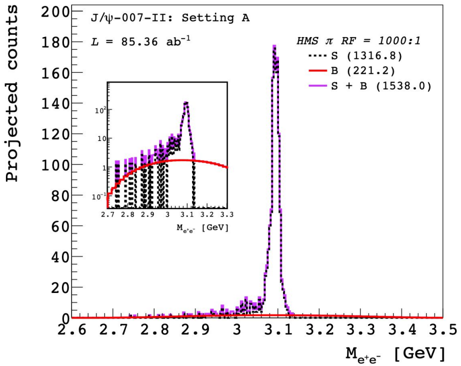
Hall C Configuration	Spectrometer	e^-	π^-	π^+	K^-	K^+	p
J/ψ–007-II Setting A	SHMS	8.47	0.44	0.55	0.02	0.33	1.10
	HMS	21.2	7.15	9.57	0.55	3.74	14.9
J/ψ–007-II Setting B	SHMS	0.77	0.11	0.11	0.00	0.04	0.33
	HMS	41.9	25.2	34.0	1.98	12.1	40.9
J/ψ–007-II Setting C	SHMS	0.81	0.28	0.40	0.01	0.17	1.35
	HMS	8.34	2.97	4.02	0.17	1.59	8.05

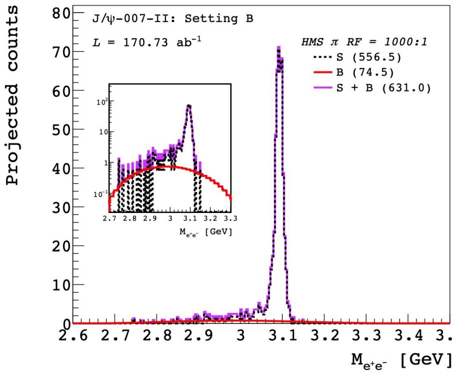
Good experimental control over accidentals

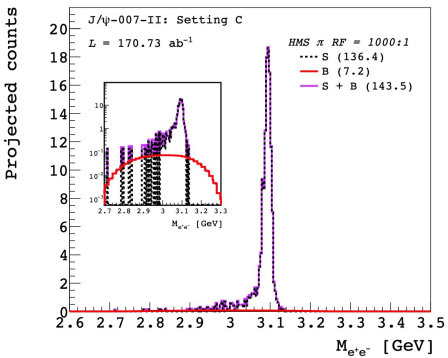
PROJECTED MEASUREMENT

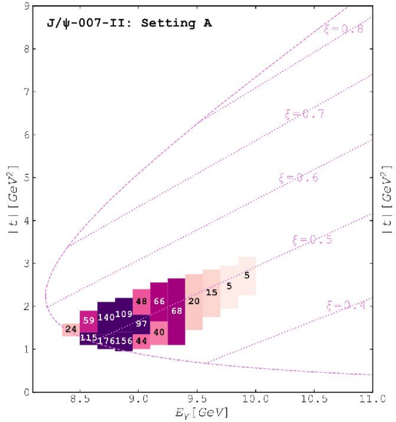
Minimal background in signal region

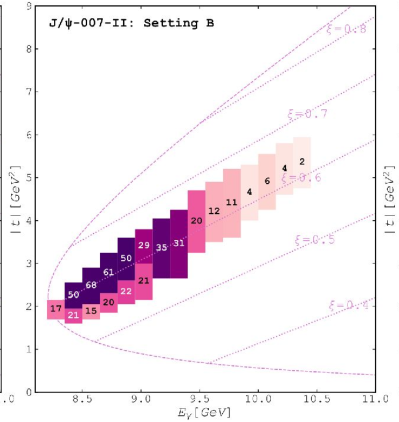
Hall C Configuration	SHMS (−) $\|p\|$ (GeV)	SHMS (−) θ (deg.)	HMS (+) $\|p\|$ (GeV)	HMS (+) θ (deg.)	Kinematic Ranges
J/ψ–007-II Setting A	4.44	22.4	3.66	23.0	$E_\gamma \in [8.4, 10.0]$ GeV $\|t\| \in [1.0, 2.8]$ GeV^2 $\xi \in [0.45, 0.55]$
J/ψ–007-II Setting B	3.79	28.6	3.60	21.0	$E_\gamma \in [8.2, 10.5]$ GeV $\|t\| \in [1.6, 6.0]$ GeV^2 $\xi \in [0.55, 0.65]$
J/ψ–007-II Setting C	3.11	31.3	3.44	25.6	$E_\gamma \in [8.35, 10.5]$ GeV $\|t\| \in [2.9, 7.6]$ GeV^2 $\xi \in [0.65, 0.80]$

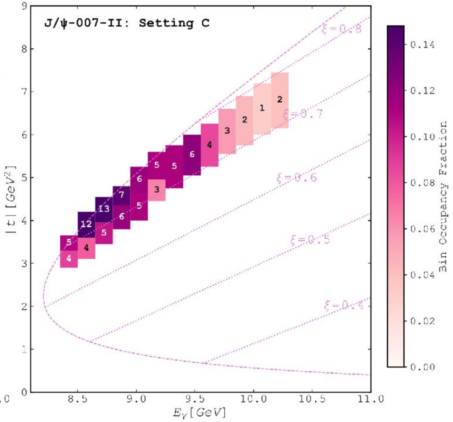




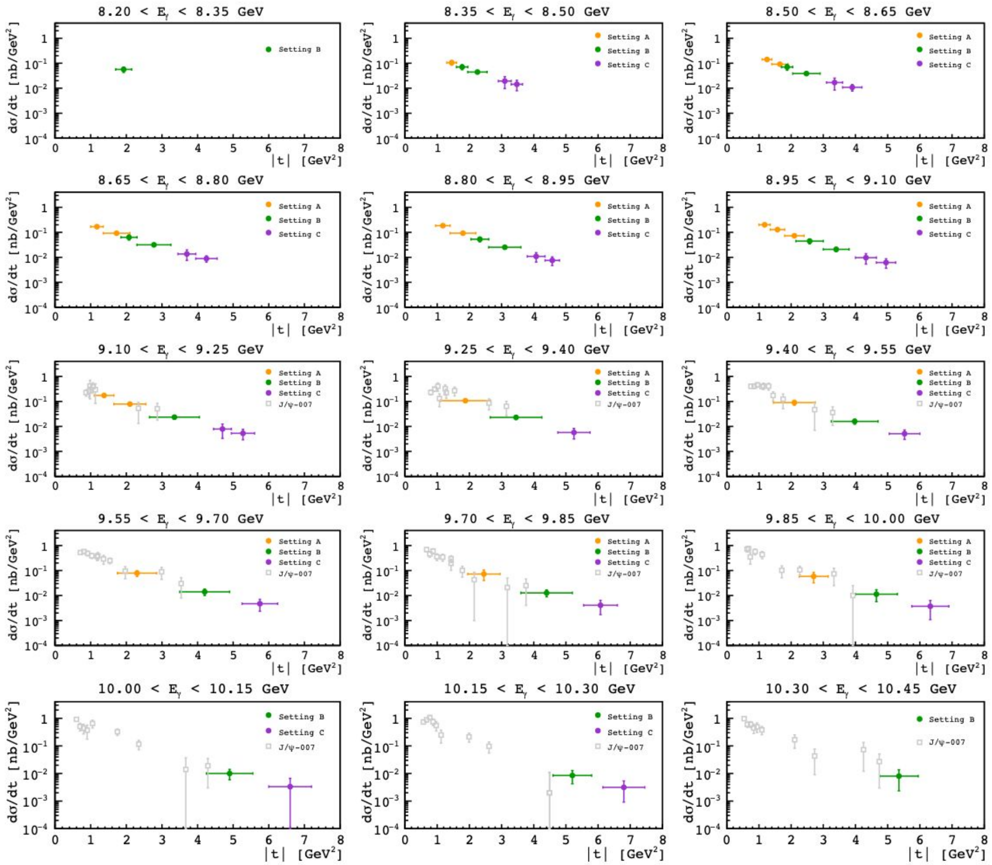


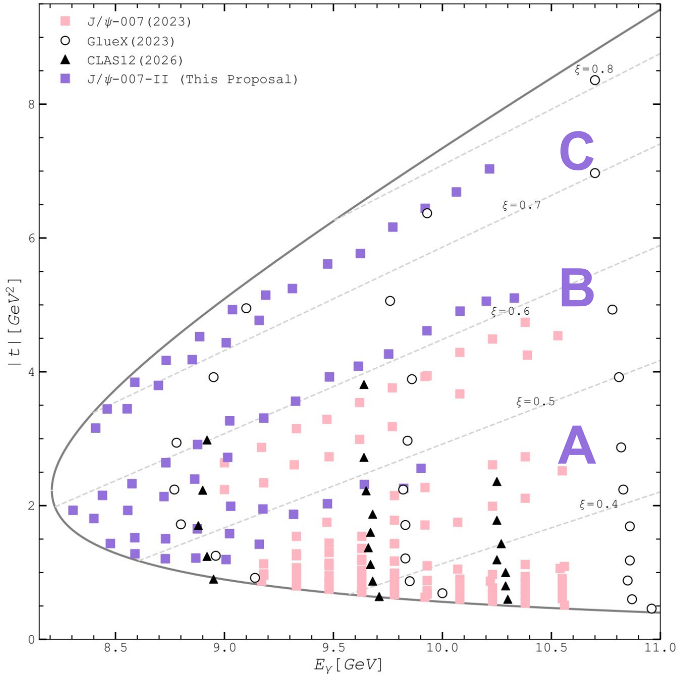






PROJECTED IMPACT ON WORLD J/ψ DATA





Measurements will perfectly complement the world data

STRONG SUPPORT FROM THEORY COMMUNITY

Theory Report very supportive

> *"It should be noted that the application of QCD factorization schemes to heavy quarkonium production near threshold is a matter of ongoing theoretical research. [...] This is an area of active theoretical research, and* ***the data of the proposed experiment will be valuable for testing and refining the QCD-based reaction theory****."*

Uniquely sensitive to u-channel J/ψ production

> *"[...] the u-dependence is a most interesting observable, since it is directly connected to the transverse position of the baryonic charge inside the nucleon ([...]. To establish both the existence of the backward peak and the shape of this u-dependence needs clearly more precise data than the available GlueX samples.* ***The proposed Hall C experiment will thus complement the ongoing effort in backward meson electroproduction, which will be decisive in proving or disproving the QCD approach in the backward region****."*
> *— B. Pire, K. Semenov, and L. Szymanowski*

Large-ξ measurement impactful for GFFs

> *"[...] accessing the large-ξ region offers several important advantages. It provides a* ***cleaner and more direct probe of the gravitational form factors****, with a suppressed imaginary amplitude;* ***enhances sensitivity to the C_g form factor****, whose contribution scales as ξ^2 and therefore becomes more prominent at large ξ; and supplies the* ***broad ξ coverage needed for future analyses*** *that incorporate the small-ξ region and the imaginary amplitude, for example, within a dispersion-relation framework."*
> *— Y. Guo, X. Ji, and F. Yuan*

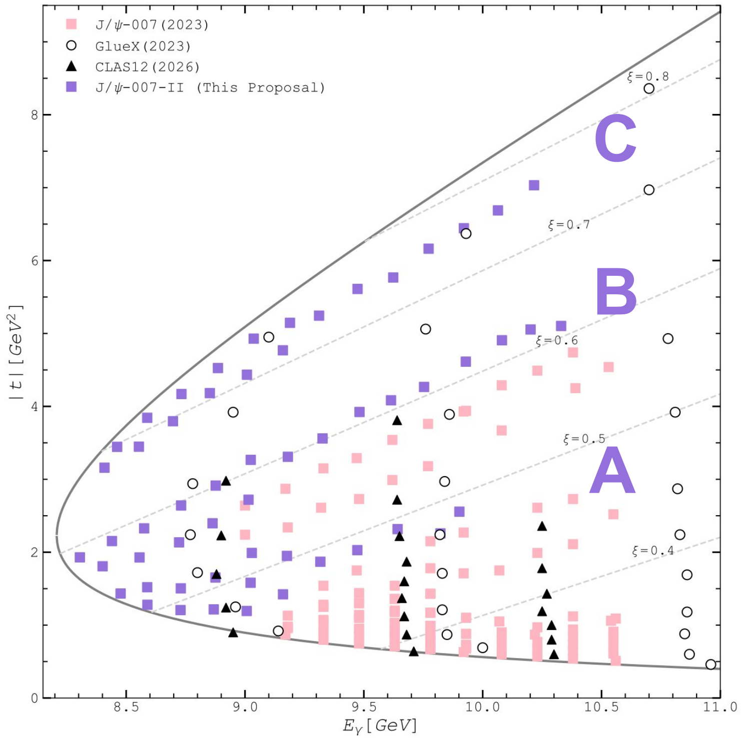
Illustration: sensitivity to GFFs

Expect factor 4-5 reduction in error for C_g

As impactful as orders of magnitude more data from CLAS12 or GlueX

SUMMARY

- ❖ High impact result will provide:
  - ➢ Valuable measurements of the J/ψ photoproduction cross-section
  - ➢ Very useful data for both experimental and theoretical communities
- ❖ Requires only 27 days of runtime
  - ➢ Minimal background in signal region
- ❖ Straightforward experiment with standard Hall C equipment
  - ➢ Systematics well-understood
  - ➢ Direct absolute cross-section measurement supports future high-lumi J/ψ at JLab (μCLAS or SoLID)



J/ψ-007-II COLLABORATION

Exclusive Near-Threshold J/ψ Photoproduction at Large Skewness in Hall C at Jefferson Lab
(A Proposal to the Jefferson Lab PAC 54)

Whitney R. Armstrong, Fernando A. Flor†, Sylvester J. Joosten*, Bobae Kim, Minho Kim, Henry T. Klest, Valerii Klimenko, Zein-Eddine Meziani, Chao Peng, Noémie Pilleux, Paul E. Reimer, Chun Y. Tsang, Zhiwan Xu, and Maria Żurek

Physics Division, Argonne National Laboratory, Lemont, IL, USA

Haiyan Gao, Yining Liu, Bo Yu, Yi Yu, and Zhiwen Zhao

Duke University and Triangle Universities Nuclear Laboratory, Durham, NC, USA

Holly Szumila-Vance

Florida International University, Miami, FL, USA

Yijie Wang

Massachusetts Institute of Technology, Cambridge, MA, USA

Devesh Bhattarai, Vladimir Khachatryan, Wenliang Li, Preet Mann, Zakia Tithi, and Zichen Yin

Mississippi State University, Mississippi State, MS, USA

Sangbaek Lee

Temple University, Philadelphia, PA, USA

Alexandre Camsonne, Jian-Ping Chen, Dave Gaskell, Mark K. Jones*, Michael D. McCaughan, Lubomir Pentchev, Bhawani Singh, Arun S. Tadepalli, and Stephen A. Wood

Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

Marie Boër, Gyang Chung, Mahmoud Gomina, and Kemal Tezgin

Virginia Tech, Blacksburg, VA 24061, USA

BACKUP SLIDES

Theory Report very positive!

The ***backgrounds (accidental and physics) seem to be well under control****. The dominant physics backgrounds are well understood from the previous JLab Hall C J/ψ experiment and can be modeled and subtracted even where significant. The interpretation of the physics results will be performed in the broader context of theoretical studies of J/ψ photoproduction near threshold and will be well supported.*

It should be noted that the application of QCD factorization schemes to heavy quarkonium production near threshold is a matter of ongoing theoretical research. In collinear factorization with GPDs [Guo et al Phys. Rev. D 103, 096010 (2021), Phys. Rev. D. 108, 034003 (2023)], challenges arise from the small velocities of the outgoing hadrons in the CM frame, and from the large values of $\sqrt{-t}$ *implied by the near-threshold kinematics. The factorization scheme determines what gluonic operators are actually sampled in the production process, and how their matrix elements are related to the measured cross section. The interpretation of the data of the proposed experiment may therefore change as the collinear factorization scheme is improved or revised. This is an area of active theoretical research, and* ***the data of the proposed experiment will be valuable for testing and refining the QCD-based reaction theory****.*

TAC Report - Question:

Could the experiment use a more standard 10 cm cell?

In principle yes: We could use a 10 cm target cell and increase beam current and/or number of days to compensate (e.g. 75μA instead of 50μA, or 50% more days). Running at higher current would increase accidental rates, but we could easily tolerate higher rates so that is not an issue.

However, either option has the same main downside: To compensate we would have to run 50% more current on the radiator, which would increase the radiation in the Hall with 50%. This is something we could plan around and mitigate. This is a conversation we expect to happen as part of a Beam Time Request and Experimental Readiness Review.

TAC Report - Comments:

Modest modifications to the existing target system will be needed. Standard dummy, alignment, and optics targets are assumed.

Lead shielding will be needed around the Cu radiator as was done when the Cu radiator was used in the previous J/psi experiment. FLUKA calculations will need to be done to assess the activation of the beam line and target area and for the site boundary dose. The Cu radiator need to be rebuilt since it was damaged during the last deinstallation.

Nothing unusual is required of the accelerator

No showstoppers; radiological safety will be addressed together with the target group in preparation of a Beam Time Request and Experimental Readiness Review.

pQCD and large-ξ (Answers to PAC Reader Questions)

Is the pQCD description of J/ψ production really dependent on the large-ξ kinematic region? *It would seem that the applicability of pQCD and the GPD factorization of the amplitude are supported (to a certain extent at the least, this is also contestable) by the large mass of the c quark, that is, by the small radius of the J/ψ. What large ξ would actually bring is an improvement in the quality of the approximation in which one retains only the lowest moments of the GPDs [Guo et al., Ref. 49], and thus a more direct access to the GFFs. But the GPD description is, in principle, equally usable in the kinematics already covered by the J/ψ-007 and GlueX measurements.*

We reached out to Yuxun Guo, Xiangdong Ji, and Feng Yuan to help answer this question:

> "*Indeed, the large-ξ requirement should be viewed as a phenomenological preference rather than a prerequisite for NRQCD-based GPD factorization, supported by the heavy charm mass. Nevertheless, accessing the large-ξ region offers several important advantages. It provides a cleaner and more direct probe of the gravitational form factors, with a suppressed imaginary amplitude; enhances sensitivity to the C_g form factor, whose contribution scales as ξ^2 and therefore becomes more prominent at large ξ; and supplies the broad ξ coverage needed for future analyses that incorporate the small-ξ region and the imaginary amplitude, for example, within a dispersion-relation framework.*"

From an experimental point of view: there is currently very little data constraining the high-ξ region. The large uncertainties leave the t-dependence of the cross section poorly determined, since many functional forms describe the existing data equally well. More data in this region give us two things at once: much greater statistical precision for observables sensitive to high ξ, and sensitivity to the functional ansatz for the t-dependence itself.

Cusps and u-channel (Answers to PAC Reader Questions

The comments in [Adhikari et al., Ref. 1, Sect. VI] suggest that the increase of dsigma/dt at larger -t could come either from open-charm exchanges or from u-channel production.

I. ***If the data do not show cusps in the integrated cross section, but do confirm an increase at larger -t, how exactly will it be possible to distinguish which of these mechanisms is responsible?***
II. *Also, are there any model-based or other theoretical analyses suggesting that u-channel production could appear in the kinematic region to be measured, or are you relying primarily on the GlueX hint?*

Bernard Pire, Kirill Semenov and Lech Szymanowski graciously helped us answer these questions:

> *"u-channel production models may be viewed from two different point of views: Regge hadronic models and QCD-inspired (called TDA factorized approach) which are both quite flexible in their predictions.*
> *However the u-dependence is a most interesting observable, since it is directly connected to the transverse position of the baryonic charge inside the nucleon (as the t-dependence of DVCS is connected to the transverse position of quarks in the proton). To establish both the existence of the backward peak and the shape of this u-dependence needs clearly more precise data than the available GlueX samples.* ***The proposed Hall C experiment will thus complement the ongoing effort in*** *backward meson electroproduction, which will* ***be decisive in proving or disproving the QCD approach*** *in the backward region."*

To summarize, from our data alone, we will not be able to definitively disentangle the exchange mechanism near u_min. However, for the interpretation of the peak, the open-charm and partonic mechanisms are not mutually exclusive. In fact, both Regge-based hadronic exchange models and QCD calculations of Pire et al. based on transition distribution amplitudes have been used to describe the u-channel peak, and one can expect some degree of duality between these models. Since our experiment will be the first to measure differentially in this region, one can expect that future phenomenology in this direction will be driven almost entirely by our experimental results.

For the interpretation in terms of a baryonic radius of the nucleon, the extraction in Ref. (Klein et al. arXiv: 2603.03730 [hep-ex]) is agnostic to the actual exchange mechanism. In fact, the authors utilize mainly photoproduction of light mesons such as pi0, which does not lend itself to a perturbative description.

u-channel (Answers to PAC Reader Questions)

The comments in [Adhikari et al., Ref. 1, Sect. VI] suggest that the increase of dσ/dt at larger -t could come either from open-charm exchanges or from u-channel production.

I. *If the data do not show cusps in the integrated cross section, but do confirm an increase at larger -t, how exactly will it be possible to distinguish which of these mechanisms is responsible?*

II. ***Also, are there any model-based or other theoretical analyses suggesting that u-channel production could appear in the kinematic region to be measured, or are you relying primarily on the GlueX hint?***

Bernard Pire, Kirill Semenov and Lech Szymanowski graciously helped us answer these questions:

> *"The description of small-u (namely, the backward peak) region in a factorized QCD approach for exclusive scattering amplitudes in a generalized Bjorken regime -- either high Q^2 in electroproduction or the heavy quark mass in photoproduction -- has been detailed in a series of works described by B. Pire, K. Semenov-Tian-Shansky, and L. Szymanowski (Phys.Rept. 940 (2021), 1-121; arXiv: 2103.01079 [hep-ph]).*
>
> *There also exists experimental backward pion data from the CLAS Collaboration (Phys.Lett.B 780 (2018), 340-345; arXiv: 1711.08486 [nucl-ex]) and backward omega-meson electroproduction from the JLab Fπ Collaboration (Phys.Rev.Lett. 123 (2019) 18, 182501; arXiv 1910.00464 [nucl-ex]) which have been successfully predicted/explained by the factorized approach where the Nucleon to meson Transition Distribution Amplitudes (TDAs) play the role of the GPDs in the forward regions.*
>
> *The specific case for charmonium photoproduction, as well as the timelike Compton Scattering case in lepton pair photo-production has been discussed by B. Pire, K. Semenov-Tian-Shansky, A. A. Shaikhutdinova, and L. Szymanowski (AAPPS Bull. 33 (2023) 1, 26; arXiv: 2212.07688 [hep-ph]) and B. Pire, K. Semenov-Tian-Shansky, A. A. Shaikhutdinova, and L. Szymanowski (Eur.Phys.J.C 82 (2022) 7, 656; arXiv: 2201.12853 [hep-ph]). There, the photon to nucleon TDAs are the corresponding GPD-like non-perturbative hadronic matrix elements factorizing from a QCD hard amplitude."*

u-channel, continued (Answers to PAC Reader Questions)

The comments in [Adhikari et al., Ref. 1, Sect. VI] suggest that the increase of dσ/dt at larger -t could come either from open-charm exchanges or from u-channel production.

I. *If the data do not show cusps in the integrated cross section, but do confirm an increase at larger -t, how exactly will it be possible to distinguish which of these mechanisms is responsible?*

II. ***Also, are there any model-based or other theoretical analyses suggesting that u-channel production could appear in the kinematic region to be measured, or are you relying primarily on the GlueX hint?***

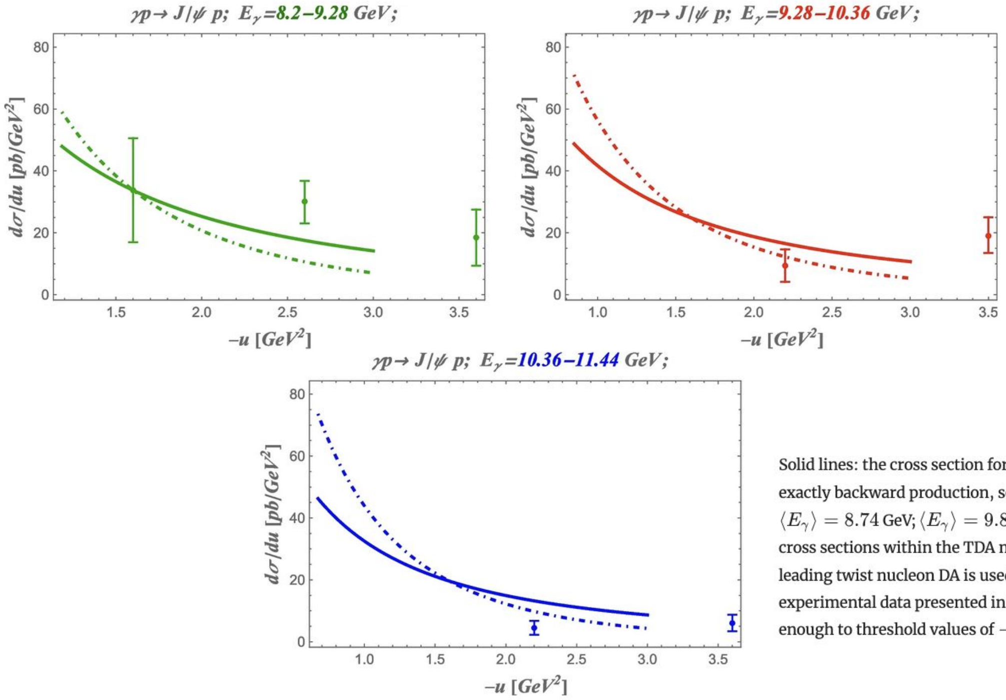


Figure from Pire et al.
AAPPS Bull. 33 (2023) 1, 26;
arXiv: 2212.07688 [hep-ph]

Solid lines: the cross section for backward J/ψ photoproduction $\frac{d\sigma}{du}$ as a function of $-u$ from the threshold value $-u_0$ (corresponding to the exactly backward production, see Table 1) up to $-u = 3$ GeV^2 for the three central values of E_γ from the range of the GlueX experiment $\langle E_\gamma \rangle = 8.74$ GeV; $\langle E_\gamma \rangle = 9.82$; and $\langle E_\gamma \rangle = 10.9$ GeV in the model (61) with the dipole-type u-dependence (63). Dot-dashed lines show the cross sections within the TDA model with a modified normalization and u-dependence (64) with $\alpha = 0.25$ GeV^{-2}. COZ [21] solution for the leading twist nucleon DA is used as the phenomenological input. With error bars we show the points closest to the backward threshold from the experimental data presented in Fig. 13 of Ref. [19]. Note that for the $\langle E_\gamma \rangle = 9.82$ and $\langle E_\gamma \rangle = 10.9$ GeV bins, no data point approaches close enough to threshold values of $-u = -u_0$

Impact on precision of GFF extractions (Answers to PAC Reader Questions)

What quantitatively supports the claim that the measurements will give a dramatic increase in the precision of the extraction, given that the proposal contains no simulations of GFF extraction?

In the absence of such simulations, if we look at the extraction of gluon GFFs from the existing GlueX and J/ψ-007 data in Ref. 49, see Table II and Fig. 3 there, we see that the results for the GFF parameters are largely driven by lattice QCD, while the sensitivity of the GFFs to the J/ψ data looks relatively weak, at least in this analysis. Indeed, good coverage of the large-ξ part of phase space promises some improvement, but ***what promises a "dramatic improvement"?***

The answer to this question is three-fold:

1. To quantify the increase in *statistical* precision due to the proposed measurement, we repeated a GFF extraction in the holographic QCD approach with and without the new high-ξ "data". Statistical precision on the C_g form factor (tripole ansatz) improves by a factor of 4-5 on both fit parameters (mass and intercept)*). To get the same level of improvement in the high-ξ region from large-acceptance experiments would require well over an order of magnitude more data than currently available.
2. The GPD-based approach to relate the GFFs to the measured cross section requires an expansion in ξ assuming $\xi \sim 1$. Guo and collaborators in Ref. 49 demonstrate that for $\xi > 0.5$ the uncertainty on this approximation is below 30%, while it rises quickly for smaller values of ξ. The near-threshold world data (including the recent 2026 CLAS12 results) do not have sufficient statistical precision for $\xi > 0.5$ to yield a stable fit: the χ^2 surface is very flat with many local minima. This is exactly why in Ref. 49 the results are dominated by the Lattice QCD calculations. Adding our proposed data addresses this problem.
3. For all approaches, increasing the statistical reach at high |t| will reduce model uncertainty by providing a tighter constraint on the t-dependence of the cross section.

We wanted to convey that the measurement will notably impact the state of GFF extractions from near-threshold J/ψ data at multiple levels; one could of course argue that the word "dramatic" is a bit vague.

*) The impact on A_g is smaller, as A_g depends more on the low-$|t|$ behavior.

Leptoproduction background; statistics/bin (Answers to PAC Reader Questions)

*Is there any background from **leptoproduction**, that is, from electrons that pass through the radiator and produce J/ψ?*

There is indeed a small background due to leptoproduction. We studied this extensively for the original J/ψ-007 experiment. Due to the way the spectrometer acceptance is tuned to our target kinematics, our acceptance for events with non-zero Q^2 is very small. Together with the electroproduction cross section dropping rapidly with Q^2, the only notable contribution from the leptoproduction background is for very small Q^2 (quasi-real interactions). The incoming quasi-real photon flux that can create J/ψ is comparable to a bremsstrahlung spectrum for a ~1% radiator. This is something we account for through Monte Carlo simulations when we convert the measured event rates to cross sections.

Is each J/ψ-007-II square in Fig. 1 expected to give a final bin in which dσ/dt will be determined? The extreme Setting-C bins, which are very important, are at large -t and have bin counts of 1-2 according to Fig. 4. How robust are these counts? What happens if the large-|t| cross-section is factor 2 or so below the holographic model?

We did not explicitly discuss this in the proposal: We optimized our experiment to cover a large range in t for photon energy E_γ < 9.5 GeV, coinciding with the region where the GlueX results show hints of "interesting" behavior. The high-t bins with bin counts of 1-2 are at higher E_γ. While data in these bins are not necessary for the main goal of our experiment, our acceptance is sensitive to them, and a more sizable cross section at high t, for example due to possible u-channel contributions, will in itself be interesting.

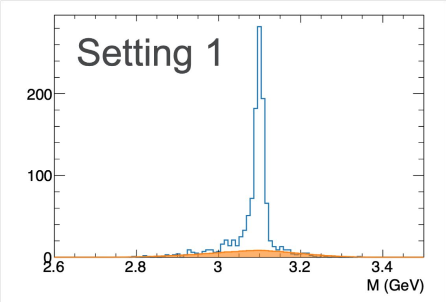
Background due to Bethe-Heitler (Answers to PAC Reader Questions)

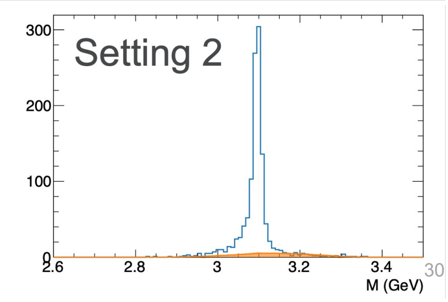
Can you be more quantitative on the background due to Bethe-Heitler production?

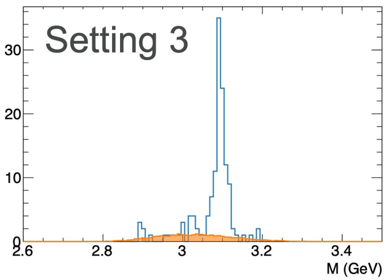
The total Bethe-Heitler background to the e^+e^- yield in the J/ψ invariant mass region is below 10% (estimated through calculations by Pauk and Vanderhaeghen). The Bethe-Heitler rate within our our spectrometer acceptance will be even lower as the majority of Bethe-Heitler events are concentrated close to the photon direction, and our spectrometers are positioned at relatively large angles. Here we can draw on our own experience with J/ψ-007, where the contribution of Bethe-Heitler to the J/ψ invariant mass spectrum was negligible. Any residual background, even at higher levels, will add to the continuum background under the J/ψ invariant mass peak, which is easy to deal with.

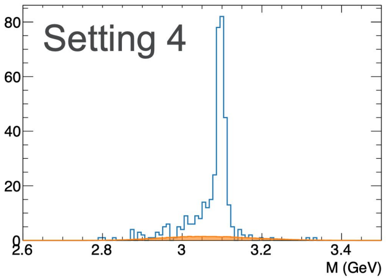
To illustrate, we include invariant mass spectra for all four settings from the original J/ψ-007 experiment. The background is low and very-well described by residual $e^-\pi^+$ events, and any other contributions (e.g. $\pi^-\pi^+$ or e^-e^+) are negligible.

As Bethe-Heitler drops steeply with t, we expect even less Bethe-Heitler background for the new experiment.









Systematic Uncertainties (Answers to PAC Reader Questions)

You refer to the J/ψ-007 experiment for all systematic effects, but what about the kinematic region that was not covered by J/ψ-007? ***A table on expected systematic effects, possibly vs (t, E_γ) would be useful.***

We include an overview of the **scale uncertainties**. These numbers are based on the existing J/ψ-007 experiment. There is no reason to expect worse performance for the follow-up experiment. The new experiment uses well-understood angle and momentum settings for the spectrometers where the performance is ideal. If anything, due to a better knowledge of the spectrometers we expect lower values for the leading uncertainty (spectrometer acceptance).

Scale Uncertainty Source	**Size**	**Basis of Estimate**
Detector Acceptance	<3-4%	Experience with J/psi-007
Luminosity	~1%	Typical BCM calibration numbers
Target Window Subtraction	~1%	Based on dummy target measurement uncertainty
Electroproduction Subtraction	~1%	Experience with J/psi-007
Radiator Thickness	~1%	Experience with J/psi-007
Rate dependent effects	~1.5%	Typical tracking efficiency, target boiling, live time correction, etc. uncertainties
TOTAL	**< 4%**	Identical (or better) than J/psi-007

Point-to-point systematic uncertainties will originate from: detector smearing, multiple scattering, invariant mass background subtraction, radiative effects, and residual Monte-Carlo model dependence in the unfolding procedure. All of these effects will be similar between both experiments as the spectrometers will operate in similar (optimal) conditions. We expect the point-to-point uncertainties to increase the total uncertainty (when added in quadrature with the statistical uncertainty) no more than 20%, i.e. the measurement will be dominated by statistical uncertainties.

MECHANICAL STRUCTURE OF THE PROTON

The mechanical structure of the proton is well-defined by analogy at the continuum through the **QCD Energy-Momentum Tensor (EMT)**

- Gravitational Form Factors (**GFFs**) are defined as the *matrix elements* of the *QCD EMT for both* ***quarks*** *and* ***gluons***:

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

Role of the GFFs:

$A_{q,g}(t)$: Momentum/energy distribution component (2nd Mellin transform of the GPD ***H***)

- For $t = 0$, $A_q(0) = \langle x \rangle_q, \langle x \rangle_g \ni \sum A(0) = 1 \longrightarrow$ *Momentum Sum Rule*

$B_{q,g}(t)$: Spin component (2nd Mellin transform of the GPD ***E***)

- For $t = 0$, $J_{q,g} = \frac{1}{2}[A_{q,g}(0) + B_{q,g}(0)] = \frac{1}{2} \longrightarrow$ *Spin Sum Rule*

$D_{q,g}(t)$: Internal forces component, where $D_{q,g}(t) = 4C_{q,g}(t)$

- For $t = 0$, $D(0) = \sum_q D_q(0) + D_g(0)$

$\bar{C}_{q,g}(t)$: Trace component

- For $t = 0$, $\bar{C}(0) = \sum_q \bar{C}_q(0) + \bar{C}_g(0) = 0$

Energy Density

Momentum Density

$$T^{\mu\nu} = \begin{pmatrix} T^{00} & T^{01} & T^{02} & T^{03} \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & T^{33} \end{pmatrix}$$

Shear Stress

Energy Flux

Normal Stress ("pressure")

Momentum Flux

HALL C SPECTROMETER CONFIGURATION

Standard Hall C spectrometer configuration with HMS (+) and SHMS (-) in coincidence

Parameter	*HMS Performance*	*SHMS Specification*
Range of Central Momentum	0.4 to 7.4 GeV/c	2 to 11 GeV/c
Momentum Acceptance	±10%	-10% to +22%
Momentum Resolution	0.1% – 0.15%	0.03% – 0.08%
Scattering Angle Range	10.5° to 90°	5.5° to 40°
Target Length Accepted at 90° (HMS)/45° (SHMS)	10 cm	25 cm
Horizontal Angle Acceptance	±32 mrad	±18 mrad
Vertical Angle Acceptance	±85 mrad	±45 mrad
Solid Angle Acceptance	8.1 msr	4 msr
Horizontal Angle Resolution	0.8 mrad	0.5 – 1.2 mrad
Vertical Angle Resolution	1.0 mrad	0.3 – 1.1 mrad
Target resolution (y_{tar})	0.3 cm	0.1 - 0.3 cm
Maximum Event Rate	4–5 kHz	4–5 kHz
Max. Flux within Acceptance	∼ 5 MHz	∼ 5 MHz
e/h Discrimination	>1000:1 at 98% efficiency	>1000:1 at 98% efficiency
π/K Discrimination	100:1 at 95% efficiency	100:1 at 95% efficiency

Hall C Configuration	SHMS (−) $\lvert p\rvert$ (GeV)	SHMS (−) θ (deg.)	HMS (+) $\lvert p\rvert$ (GeV)	HMS (+) θ (deg.)	Kinematic Ranges
J/ψ–007-II Setting A	4.44	22.4	3.66	23.0	$E_\gamma \in [8.4, 10.0]$ GeV $\lvert t\rvert \in [1.0, 2.8]$ GeV^2 $\xi \in [0.45, 0.55]$
J/ψ–007-II Setting B	3.79	28.6	3.60	21.0	$E_\gamma \in [8.2, 10.5]$ GeV $\lvert t\rvert \in [1.6, 6.0]$ GeV^2 $\xi \in [0.55, 0.65]$
J/ψ–007-II Setting C	3.11	31.3	3.44	25.6	$E_\gamma \in [8.35, 10.5]$ GeV $\lvert t\rvert \in [2.9, 7.6]$ GeV^2 $\xi \in [0.65, 0.80]$