2^{nd} APCTP workshop on the Physics of the EIC
EPIC Physics and Detectors

Accessing GPDs using the dilepton final state

Results and perspectives with CLAS12

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for the CLAS collaboration

November 30^{th} - December 2^{nd} 2023
Daegu, South Korea & online

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Outline

I The Generalized Parton Distributions and motivations for their measurements

II The CLAS12 experiment at Jefferson Lab

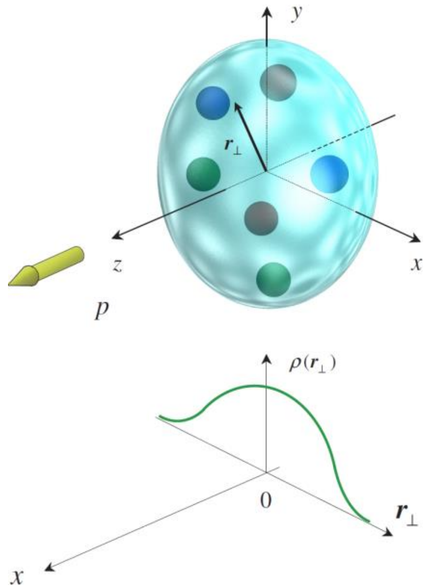
III Timelike Compton Scattering measurement with CLAS12

IV Near threshold J/ψ photoproduction cross-section measurement with CLAS12

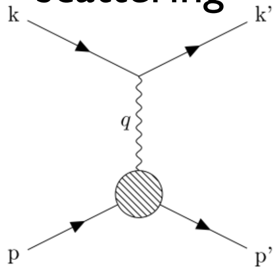
V Long term perspectives with CLAS12: Luminosity upgrade and muon detection

The Generalized Parton Distributions

Form Factors



Accessed via elastic scattering

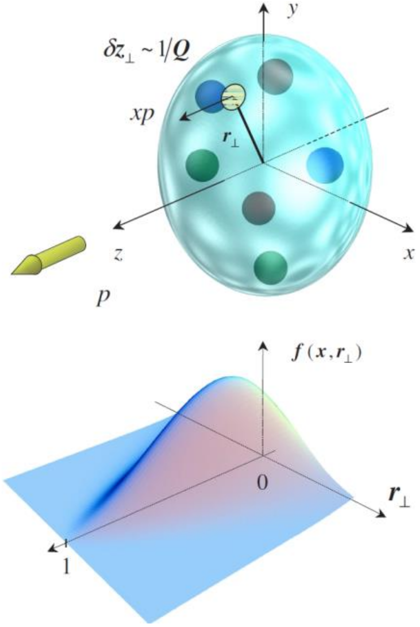


Position in the transverse plane

$$\int_{-1}^{1} dx H^q(x,\xi,t) = F_1^q(t)$$

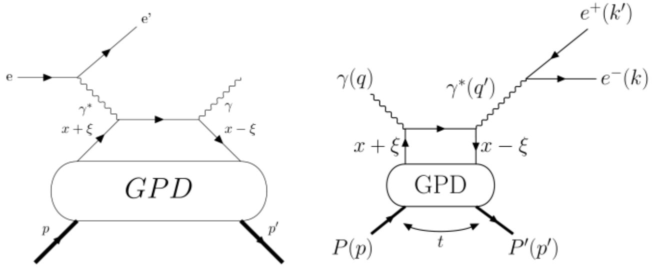
$$\int_{-1}^{1} dx E^q(x,\xi,t) = F_2^q(t)$$

GPDs



… and their correlations

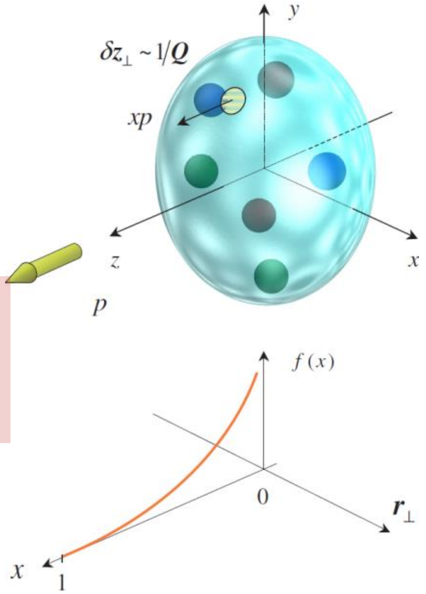
Accessed via exclusive reactions



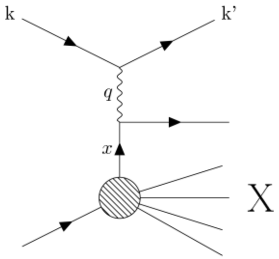
Momentum in the longitudinal direction

$$H^q(x,0,0) = \begin{cases} q(x), & x > 0 \\ -\bar{q}(-x), & x < 0 \end{cases}$$

PDFs



Accessed via Deep Inelastic Scattering



Figures in A.V. Belitsky, A.V. Radyushkin, Unraveling hadron structure with generalized parton distributions, Physics Reports, Volume 418, Issues 1–6 2005

What can we learn from GPDs ?

- Tomography of the nucleon. The Fourier transform of the GPDs can be interpreted as a probability density:

$$H^q(x, b_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{-ib_\perp \Delta_\perp} H^q(x, 0, -\Delta_\perp^2)$$

- Understanding the spin composition of the nucleon (aka the "spin puzzle") using the Ji's sum rule:

$$\frac{1}{2} = J_Q + J_G \longrightarrow J_Q = \sum_q \frac{1}{2} \int_{-1}^{1} dx\ x(H^q(x,\xi,0) + E^q(x,\xi,0)) = \sum_q \frac{1}{2}(A^q(t) + B^q(t))$$

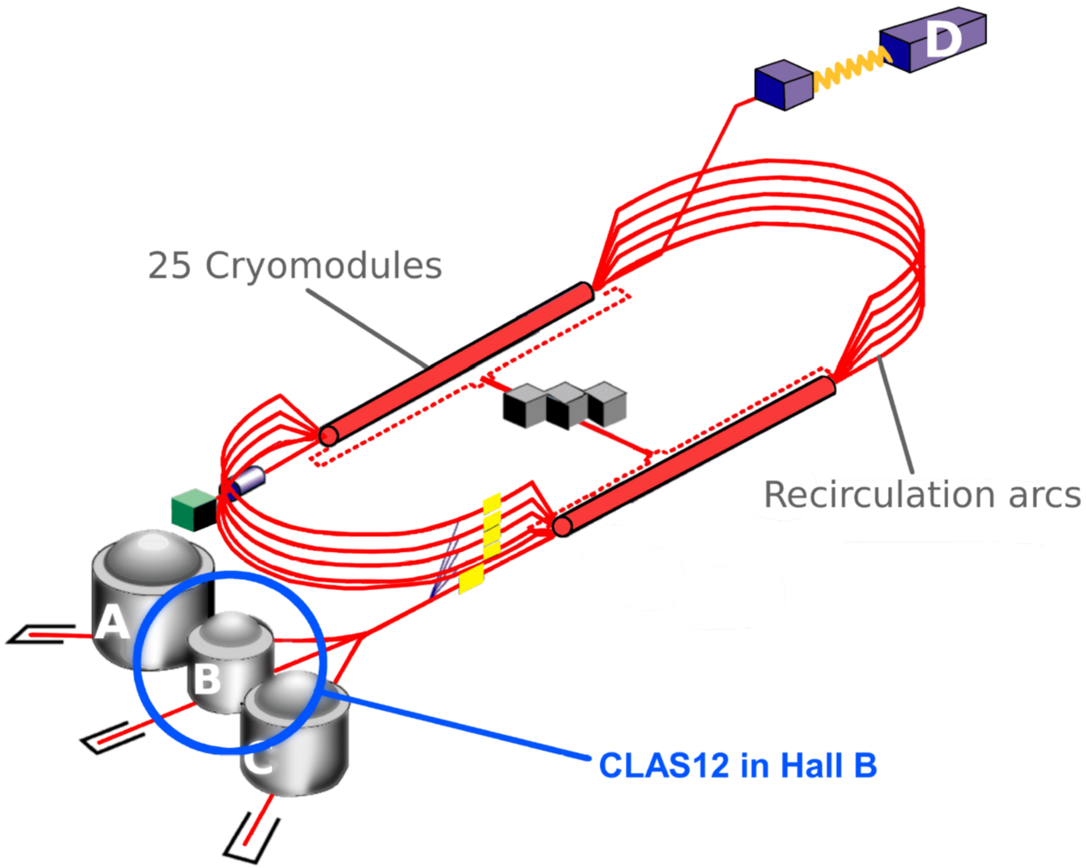
- Accessing Gravitational Form Factors, which appear in the nucleon EMT matrix elements:

$$\int_{-1}^{1} dx\ xH^q(x,\xi,t) = A^q(t) + \xi^2 D^q(t) \qquad \int_{-1}^{1} dx\ xE^q(x,\xi,t) = B^q(t) - \xi^2 D^q(t)$$

Compton Form Factors (CFFs)

$$\mathcal{H} = \int_{-1}^{1} dx H(x,\xi,t) \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon} \right)$$

The CLAS12 experiment at Jefferson Lab

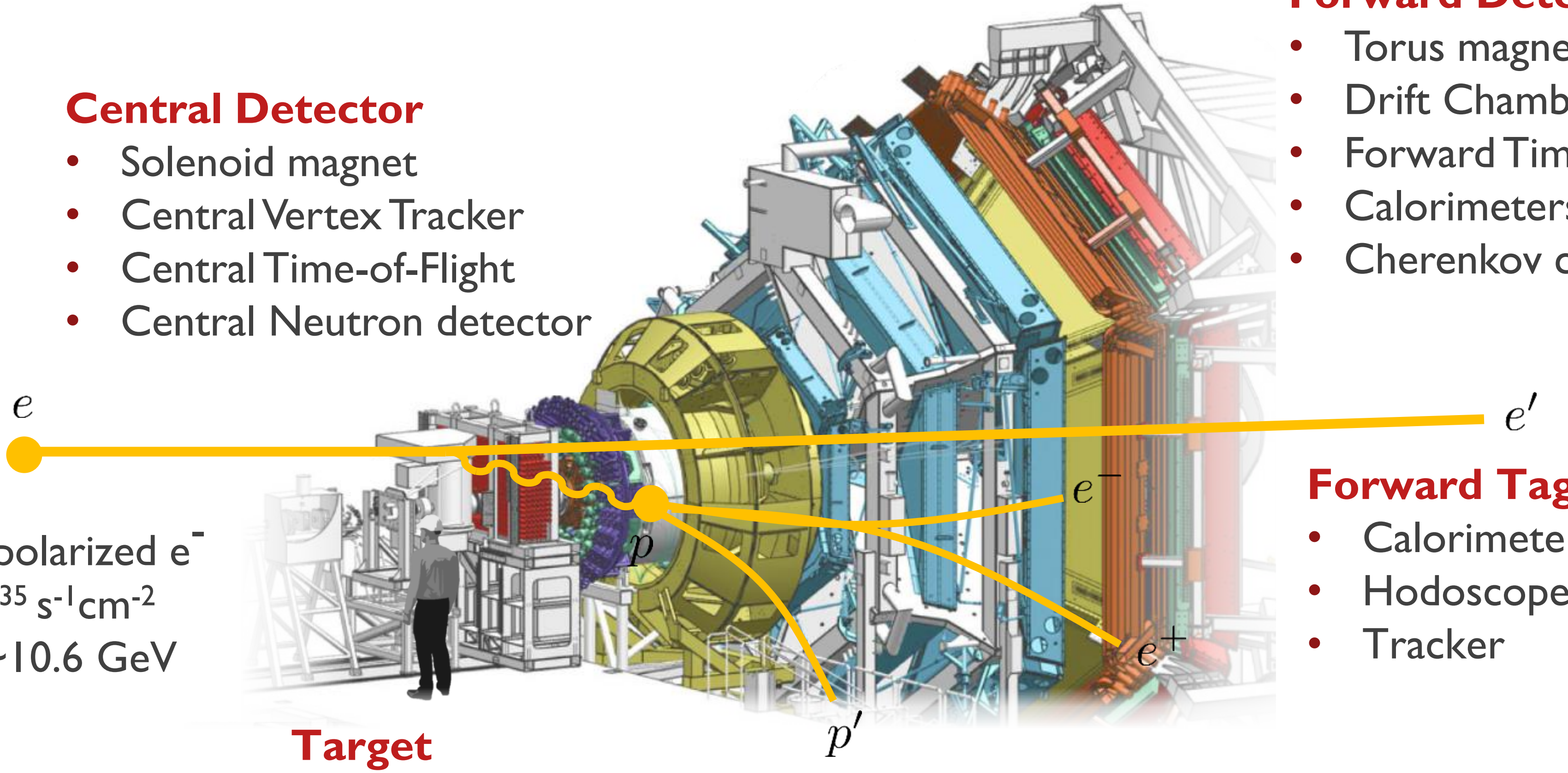


- Jefferson Lab is located in Newport News, Virginia, USA
- The Continuous Electron Beam Accelerator Facility provides a quasi-continuous beam of polarized electron, up to 12 GeV.
- Build around two anti-parallel linear accelerators, with recirculation arcs on both ends. The maximum energy is reached after 6 pass through linear accelerators.
- 4 experimental halls: A,B,C and D
  A & **C**: Small acceptance but large luminosity
  B: CLAS12, a large acceptance experiment
  D: GlueX, a tagged photon beam experiment

The CLAS12 detector

Central Detector
- Solenoid magnet
- Central Vertex Tracker
- Central Time-of-Flight
- Central Neutron detector

Forward Detector
- Torus magnet
- Drift Chambers
- Forward Time-of-Flight
- Calorimeters
- Cherenkov counters



Beam
- 85% longitudinally polarized e^-
- Max. luminosity: $10^{35}\ s^{-1}cm^{-2}$
- Energy: 6.5 / 7.5 / ~10.6 GeV

Forward Tagger
- Calorimeter
- Hodoscope
- Tracker

Target
- Proton
- Deuterium
- Longitudinally pol. H/D

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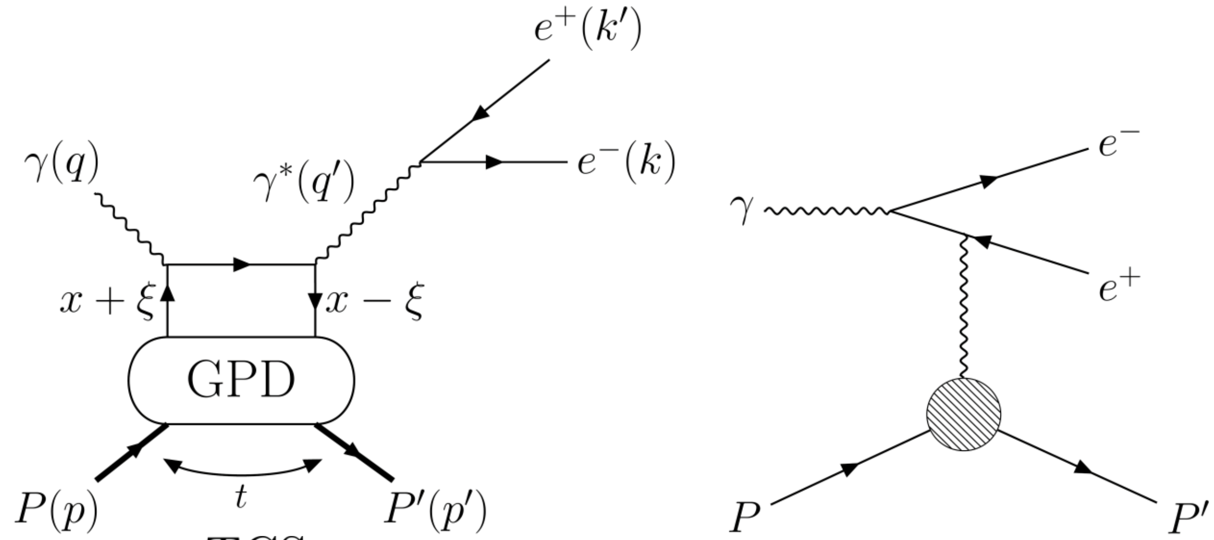
Timelike Compton Scattering

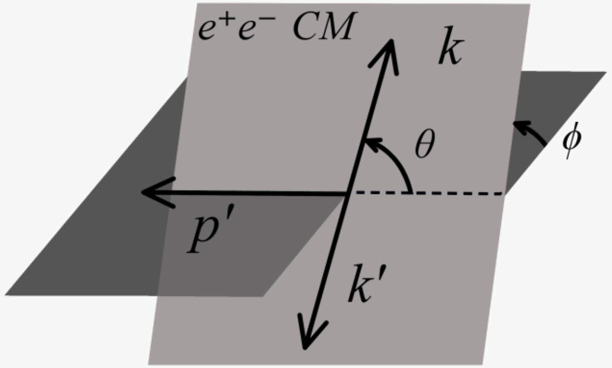
$$\text{DVCS: } ep \rightarrow e'p'\gamma \qquad \text{TCS: } \gamma p \rightarrow e^+e^-p'$$



TCS
(factorization regime, $-t/Q'^2 \ll 1$)

Bethe-Heitler

Kinematic variable



$$-t = (p - p')^2$$
$$Q'^2 = (k + k')^2$$
$$L = [(q-k)^2 - m_l^2][(q-k')^2 - m_l^2]$$
$$L_0 = (Q'^2 \sin^2\theta)/4$$

- BH cross section only depends on Electromagnetic Form Factors.
- At JLab energies, the BH cross section is expected to be larger than the TCS one
  → We aimed at measuring the **interference cross-section** between BH and TCS.

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Motivations to measure TCS

Test of the universality of the GPDs

- Both DVCS and TCS amplitudes are parametrized by GPDs.
- The imaginary part of the CFF $\mathcal{H}$ is well known from DVCS results…

  …and also accessible from TCS polarization asymmetry.
- TCS does not involve Distribution Amplitudes unlike Deeply Virtual Meson Production (DVMP)

  → Direct comparison between TCS and DVCS (at leading twist).

Unique access to the real part of the CFF $\mathcal{H}$

- Angular dependence of the unpolarized interference cross-section gives access to the real part of $\mathcal{H}$
- This quantity is not well constrained by existing data.
- However it is of great interest as related to the GFFs D, itself related to the mechanical properties of the nucleon:

$$\mathrm{Re}\mathcal{H}(\xi,t) = \mathcal{P}\int_{-1}^{1} dx \left(\frac{1}{\xi - x} - \frac{1}{\xi + x}\right) \mathrm{Im}\mathcal{H}(\xi,t) + \Delta(t)$$

$$\Delta(t) \propto D^Q(t) \propto \int d^3\mathbf{r}\, p(r) \frac{j_0(r\sqrt{-t})}{t}$$

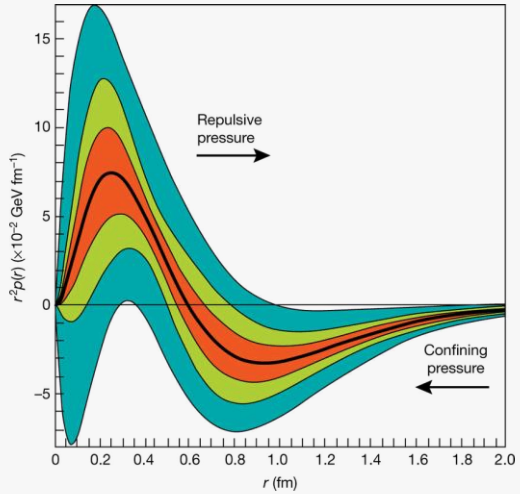


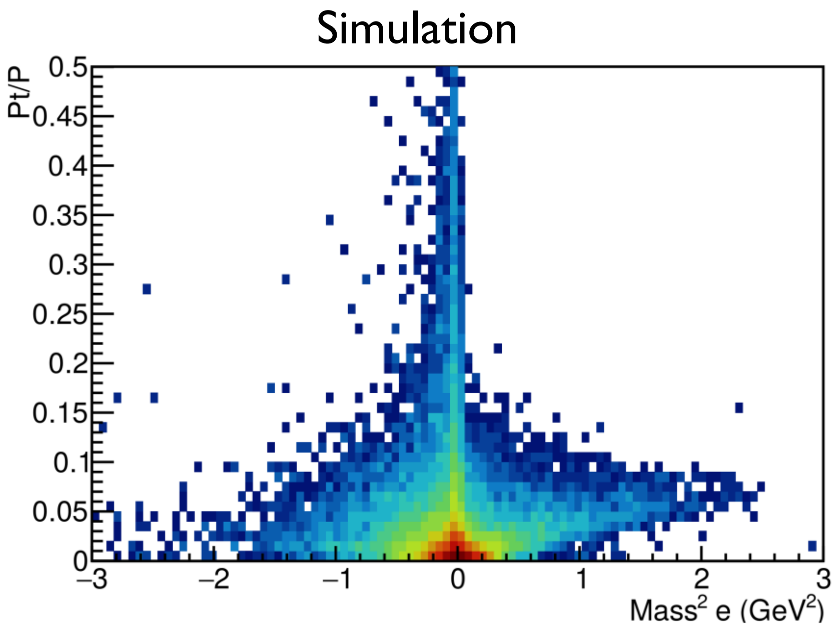
Figure in Burkert, V.D., Elouadrhiri, L. & Girod, F.X. The pressure distribution inside the proton. Nature 557, 396–399 (2018)

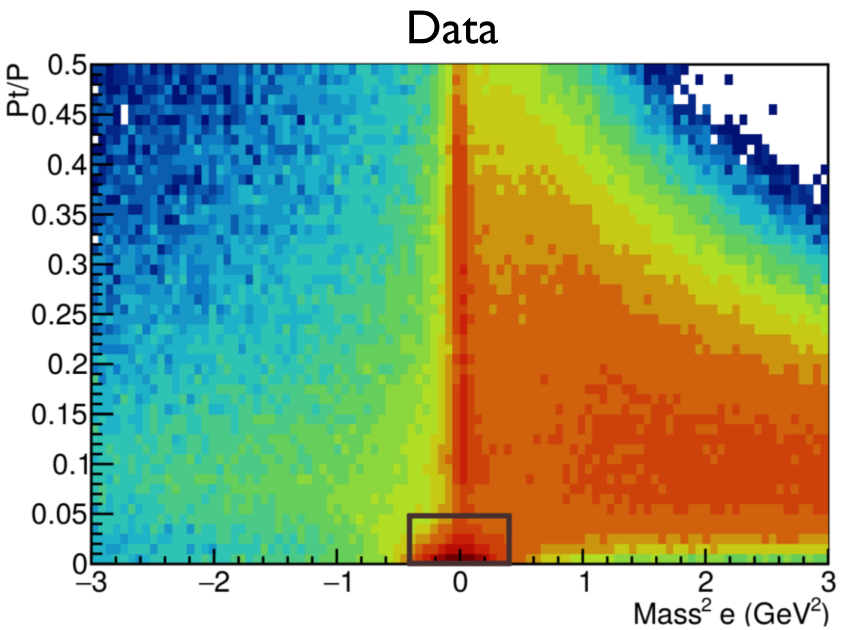
(Quasi-)Photoproduction events selection

1) CLAS12 PID + Positron NN PID

$$ep \to (e')\gamma p \to (X)e^+e^-p'$$

$$p_X = p_{beam} + p_p - p_{e^+} - p_{e^+} - p_{p'} \rightarrow 2)\ |M_X^2| < 0.4GeV^2 \rightarrow 3)\ \frac{Pt_X}{P_X} < 0.05 \rightarrow Q^2 < 0.1\ \text{GeV}^2$$





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Dilepton invariant mass spectrum

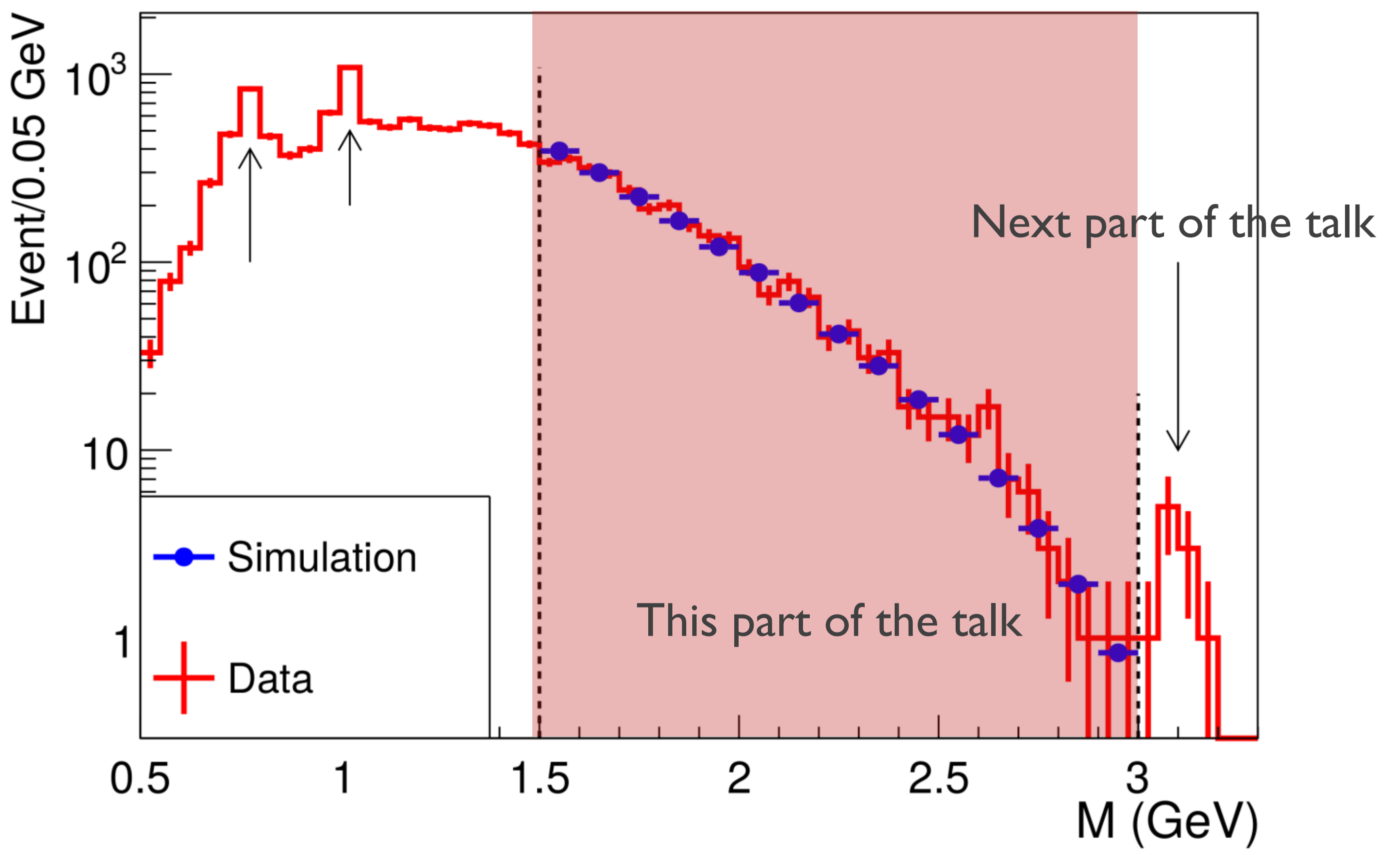
Dataset

- Data taken in Fall 2018
- 10.6 GeV beam on Liquid H_2 target
- Accumulated charge: 37mC or 48 fb^{-1}

- Vector mesons peaks are visible in data: $\omega(770)$, $\rho(782)$, $\phi(1020)$ and $J/\psi(3096)$.
- Data/simulation are matching at the 15% level, up to an overall normalization factor.
- No clear contribution of higher mass vector meson production $(\rho(1450), \rho(1700))$.

Phase space for the TCS analysis

$$0.15\ \text{GeV}^2 < -t < 0.8\ \text{GeV}^2$$
$$1.5\ \text{GeV} < M_{e^+e^-} < 3\ \text{GeV}$$
$$4\ \text{GeV} < E_\gamma < 10.6\ \text{GeV}$$



Photon polarization asymmetry results

Observable definition

$$A_{\odot U} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto \frac{\frac{L_0}{L}\sin\phi \frac{(1+\cos^2\theta)}{\sin(\theta)} \mathrm{Im}\mathcal{H}}{d\sigma_{BH}}$$

Experimentally:

$$A_{\odot U}(-t, E\gamma, M; \phi) = \frac{1}{P_b}\frac{N^+ - N^-}{N^+ + N^-}$$

- A sizeable asymmetry is measured, above the expected vanishing asymmetry predicted for BH.
- Results have been compared to 2 model predictions:
  1. VGG model
  2. GK model
- The size of the asymmetry is well reproduced by both models, giving a hint for the universality of GPDs.

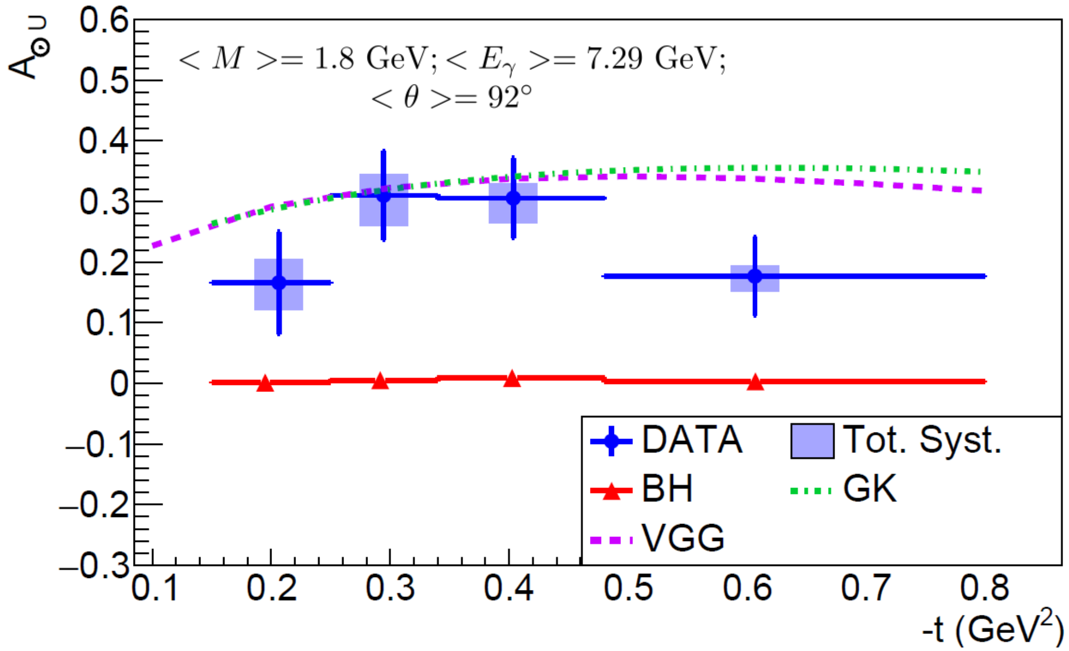


Figure in First Measurement of Timelike Compton Scattering, P. Chatagnon *et al.* (CLAS Collaboration), Phys. Rev. Lett. 127, 262501 (2021)

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Forward-Backward asymmetry results

Observable definition

$$A_{FB}(\theta_0, \phi_0) = \frac{d\sigma(\theta_0, \phi_0) - d\sigma(180^\circ - \theta_0, 180^\circ + \phi_0)}{d\sigma(\theta_0, \phi_0) + d\sigma(180^\circ - \theta_0, 180^\circ + \phi_0)}$$

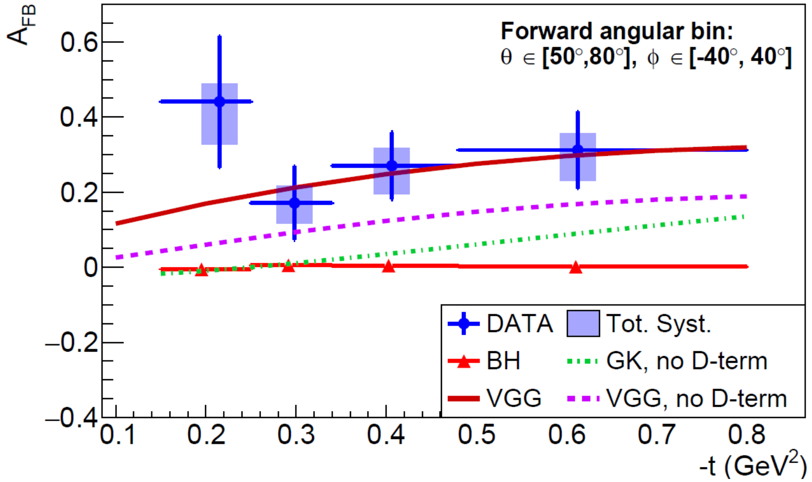
$$\propto \frac{\frac{L_0}{L}\cos\phi_0 \frac{(1+\cos^2\theta_0)}{\sin(\theta_0)} \mathrm{Re}\tilde{M}^{--}}{d\sigma_{BH}(\theta_0, \phi_0) + d\sigma_{BH}(180^\circ - \theta_0, 180^\circ + \phi_0)}$$

- Integration over the forward angular bin :

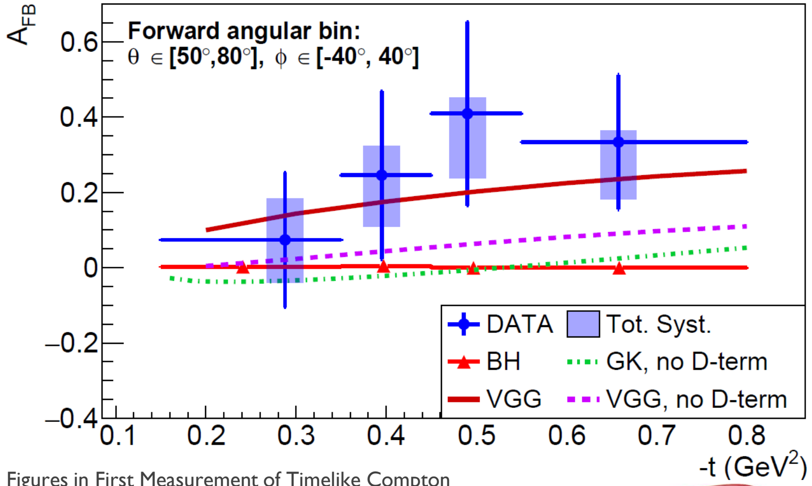
$$\theta \in [50^\circ, 80^\circ] \text{ and } \phi \in [-40^\circ, 40^\circ]$$

- The measured asymmetry is non-zero: **evidence of signal** beyond pure BH contribution
- Measured asymmetry is better reproduced by the VGG model including the D-term
  1. Confirmation of the importance of the D-term in the parametrization of the GPD
  2. One can use TCS data to constrain it

$< M >= 1.8$ GeV; $< E_\gamma >= 7.24$ GeV



$< M >= 2.25$ GeV; $< E_\gamma >= 8.13$ GeV



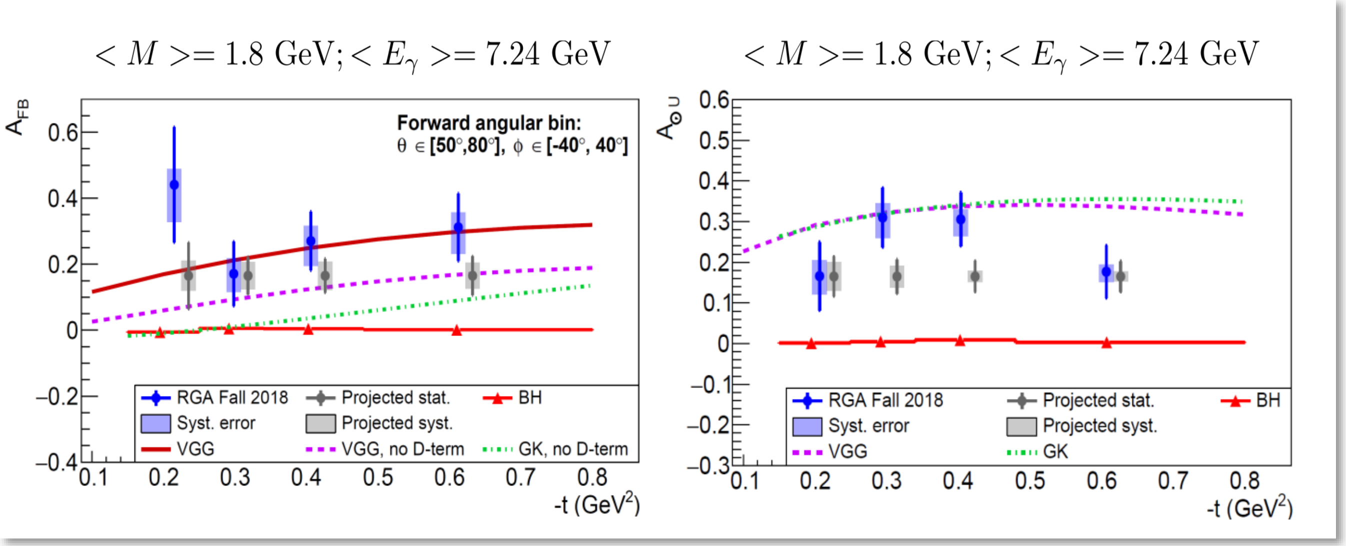
Figures in First Measurement of Timelike Compton Scattering, P. Chatagnon *et al.* (CLAS Collaboration), Phys. Rev. Lett. 127, 262501 (2021)

Short term perspectives with CLAS12

Projections for the full proton target dataset

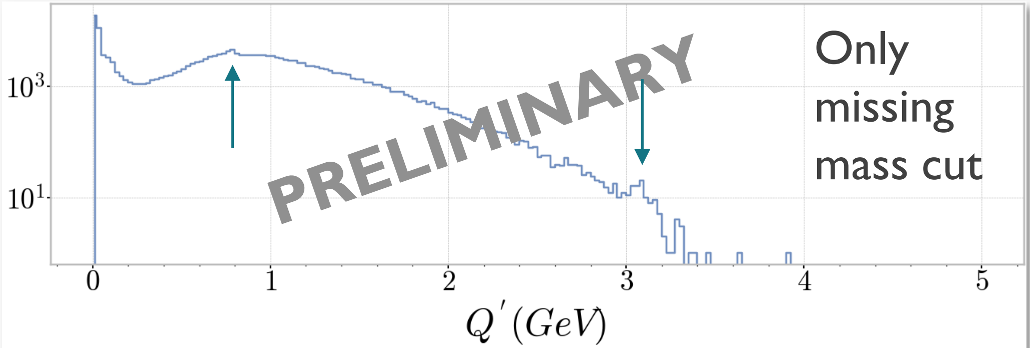
- Only a ~1/3 of the proton dataset was used for the 1st publication
- New significant improvement on the tracking software have been done since 2020

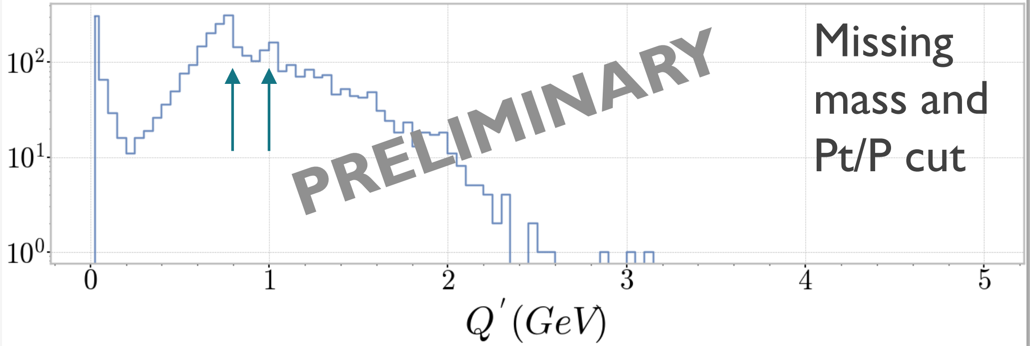
  → 50% more efficiency for the 3-particle final state



Analysis on longitudinally polarized proton target dataset (GPDs H and H̃)

Analysis by K. Gates, U. of Glasgow





+ Deuterium dataset available for TCS on neutron and TCS on bound proton

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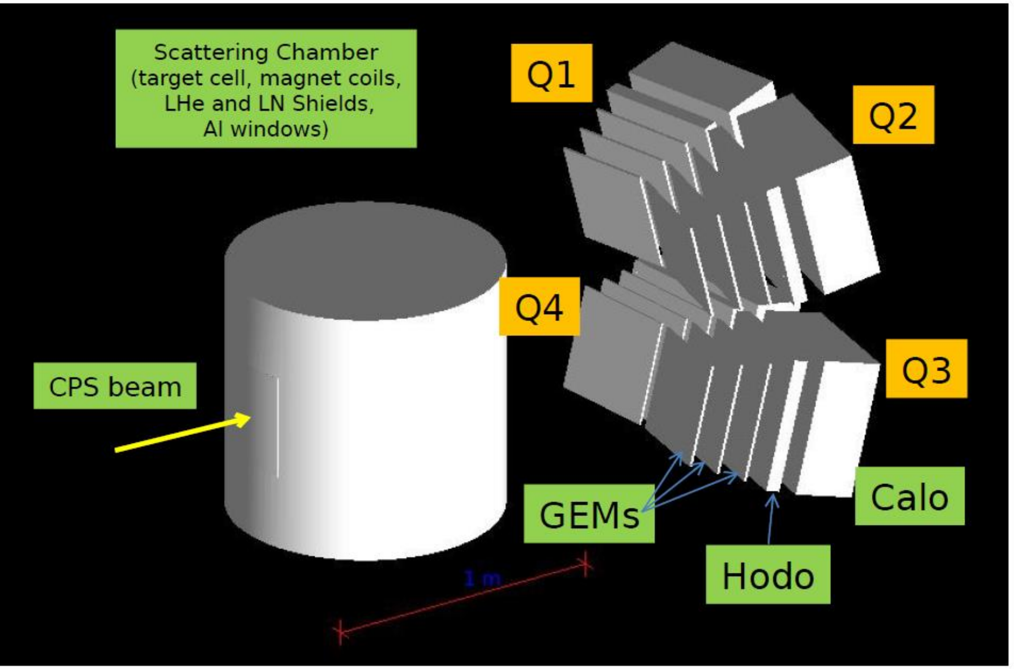
Other TCS measurements at Jefferson Lab

Transversely polarized TCS in Hall C

$\gamma P \rightarrow e^+ e^- P'$



Material provided by M. Boer (V. Tech)

1. High intensity photon source 1.5×10^{12} γ/sec (CPS)

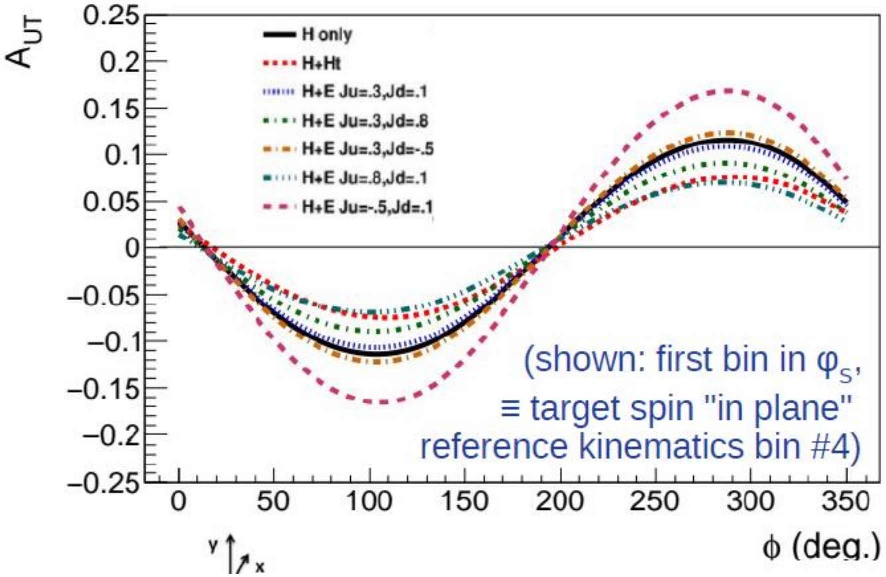
2. Target chamber: NH_3, 3cm Polarized via DNP

3. Tracking: GEM+hodoscopes, 4 symmetric quadrants

4. Calorimeters: 4 symmetric quadrants, equivalent of 2 NPS

~ 6° to 27° aperture
Lumi request: 5.85×10^5 pb^{-1}

Dependence in GPD parametrization and J_u, J_d (VGG model) vs φ and φ_S

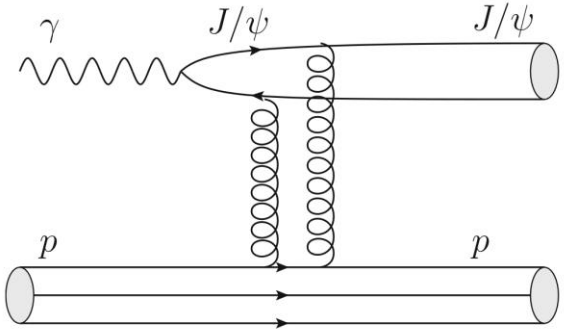


- Access to the GPD E
- Complementary way to neutron and transversely polarized DVCS

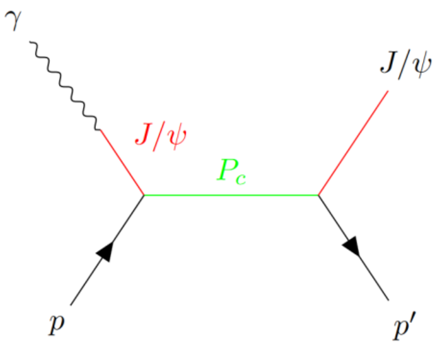
+ Ongoing measurement by GlueX on unpolarized proton

Near threshold J/ψ photoproduction

- Probe the gluon content of the proton
  (under 2-gluon exchange assumption and no open-charm contributions)



- The t-dependence of the cross-section allow to access gluon Gravitational Form Factors (GFFs), mass radius of the nucleon
- Model-dependent limit on the branching ratio of the Pc pentaquark.



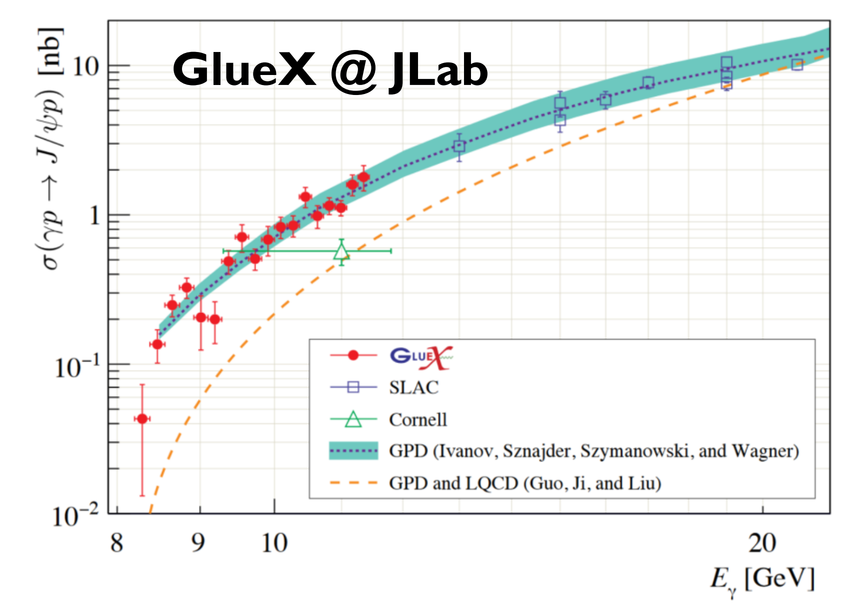


Figure in, Measurement of the J/ψ photoproduction cross section over the full near-threshold kinematic region, S. Adhikari *et al.* (GlueX Collaboration) Phys. Rev. C 108, 025201 (2023)

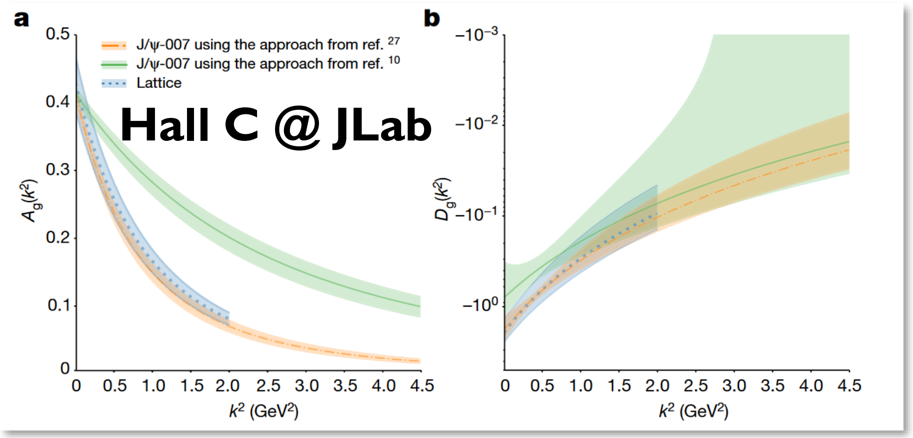
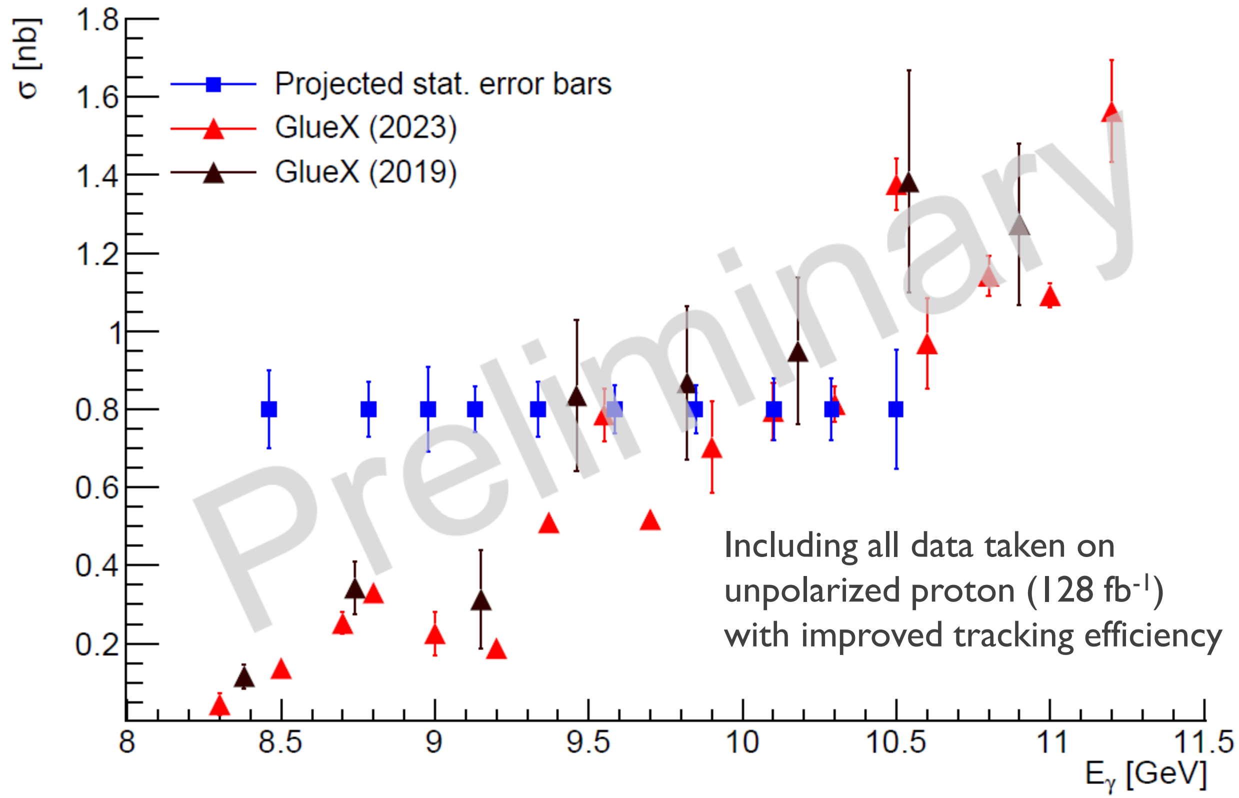


Figure in Duran, B., Meziani, ZE., Joosten, S. *et al.* Determining the gluonic gravitational form factors of the proton. *Nature* 615, 813–816 (2023)

Projections for CLAS12 proton target dataset

$$ep \to (e')\gamma p \to (e')J/\psi\ p' \to (X)e^+e^-p'$$

- Preliminary statistical error bars based on full dataset available on proton target (128 fb^{-1}).
- Smaller range of photon energy than GlueX.
- Statistics are slightly less than GlueX…
  … but very different systematics.
- The t-dependent cross-section is also extracted.



Other measurements

- Deuterium data were taken by CLAS12 in 2019/2020.
- Measurements of J/ψ production on (bound) neutron and (bound) proton.
- Muon decay channel also measured.

Analysis lead by R.Tyson (JLab)

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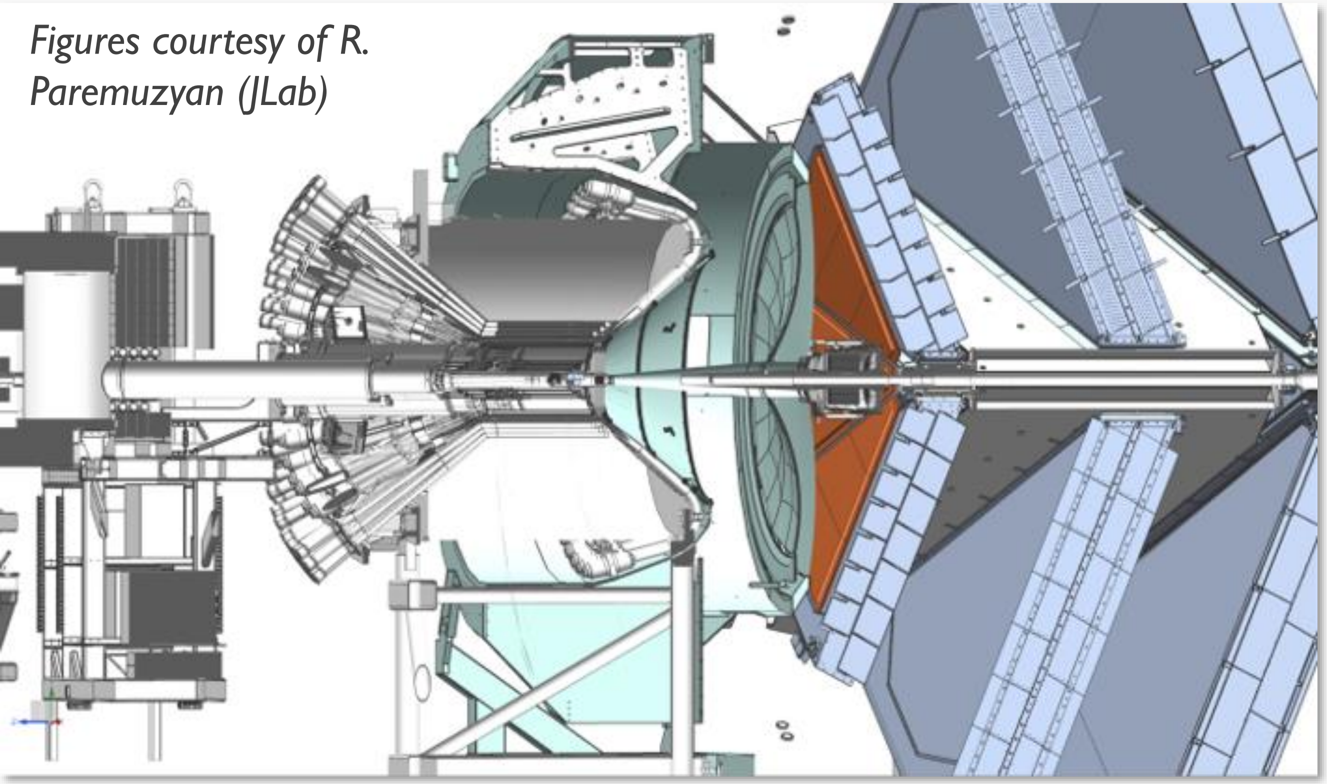
First perspective with CLAS12: Luminosity upgrade

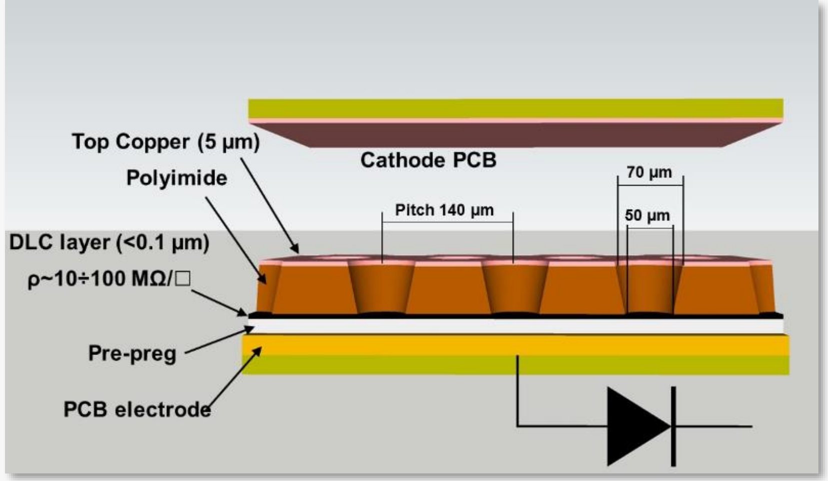
- Exclusive reaction have typically a low cross-section.
- Each additional detected track/particle comes with a detection efficiency "penalty".
- These measurement require large luminosity, which is mostly limited by DC occupancies in CLAS12.

A potential solution: the CLAS12 luminosity upgrade

Figures courtesy of R. Paremuzyan (JLab)



- µRwell-based detector in front of DC region 1…

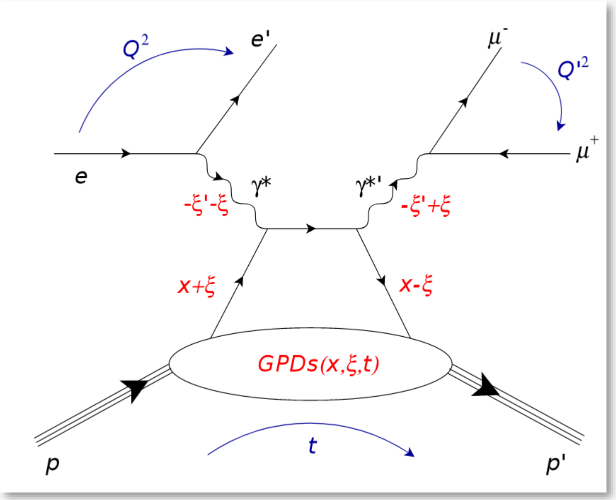


- … combined with increased efficiency of AI tracking, already in place for the current data-processing
- Goal: doubling the current luminosity !

Long term perspective: Double DVCS measurement

$$ep \to e'\gamma^* p' \to e'\mu^+\mu^- p'$$

Capturing the complete kinematic dependence of GPDs

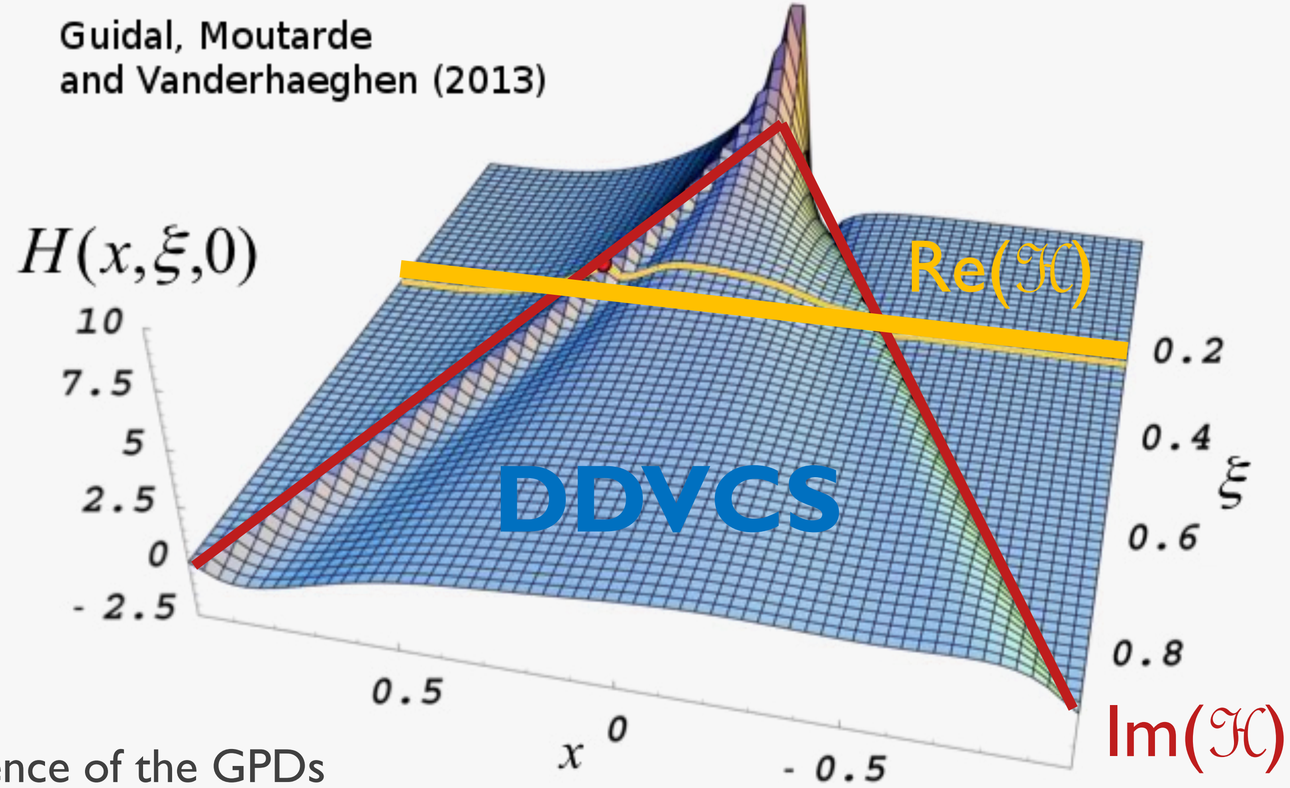


$$\mathcal{H}(\xi',\xi,t) = \int_{-1}^{1} dx H(x,\xi,t)\left(\frac{1}{\xi'-x-i\epsilon} - \frac{1}{\xi'+x-i\epsilon}\right)$$

$$Im\mathcal{H}(\xi',\xi,t) \propto H(\xi',\xi,t) - H(-\xi',\xi,t)$$

→ Allow to completely map the kinematic dependence of the GPDs

Guidal, Moutarde and Vanderhaeghen (2013)



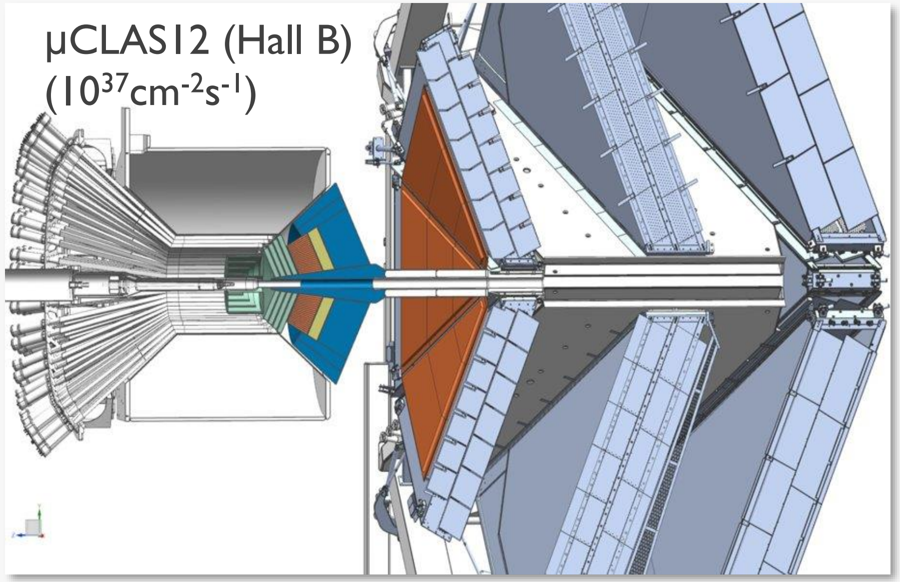
μ-CLAS12 at Jefferson Lab

Two main challenges for DDVCS measurement:

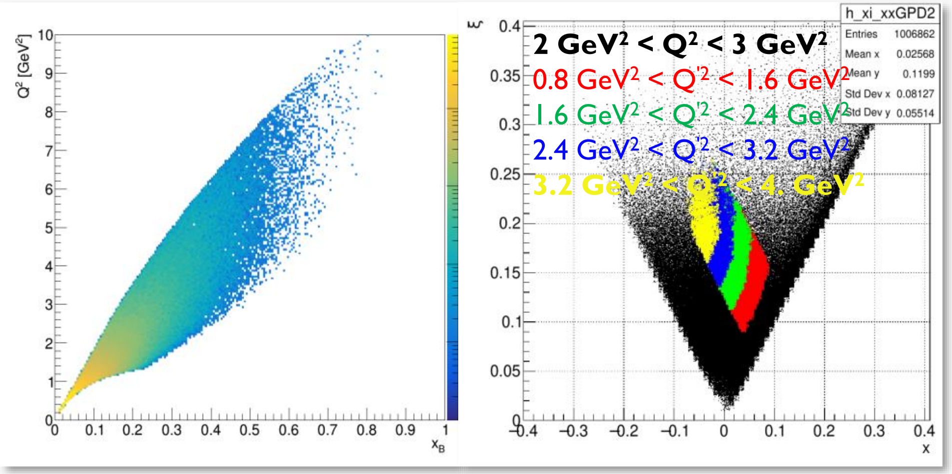
1. Low x-section: requires high-luminosity
2. Muon detection needed

A potential solution: μ-CLAS12

- Luminosity increase by a factor 100.
- Shielding to reduce DC occupancy and pion background.
- Additional calorimeter for electron ID.
- New tracking system around the target.



Kinematic reach for DDVCS with μ-CLAS12



Material from JLab LOI-12-16-004 (Stepanyan, Paremuzyan, Baltzell, De Vita,Ungaro et al.)

Figures courtesy of Rafayel Paremuzyan (JLab)

+ Measurement with the SoLID detector in Hall A

Take-aways

I — The dilepton final state allows to access fundamental properties of the nucleon (GPDs, GFFs).

II — **Rich experimental program** at Jefferson Lab, already producing some **important results**.

III — The **first extraction of TCS observables** on unpolarized proton target was done using the CLAS12 detector. More TCS results from CLAS12, GlueX, Hall A/C to come.

IV — **Large effort to extract J/ψ photoproduction cross-section** on various targets both for electron and muon final state (GlueX, Hall C, and CLAS12).

V — **New experiments** are proposed to extend this program to DDVCS, J/ψ electro-production, μ-TCS

BACK-UP

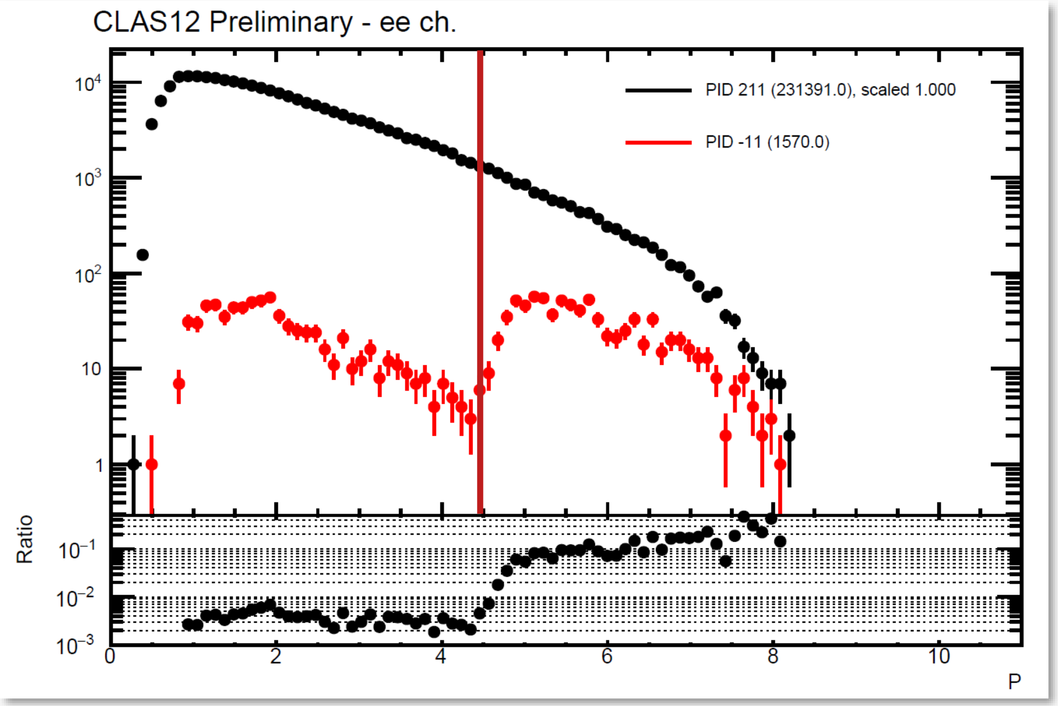
Positron PID

One important challenge: a clean positron identification

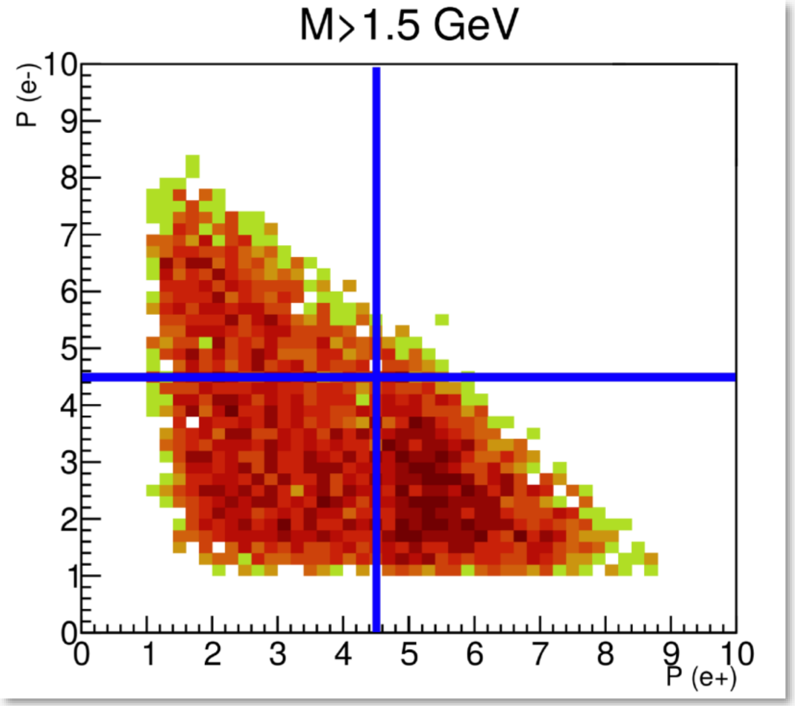
Pion background at large momenta

At high momenta (typically above the HTCC threshold at 4.5 GeV), both pions and leptons will emit Cherenkov light.

$$ep \to ep\pi^+\pi^- \text{ VS } ep \to epe^+\pi^-$$



$$\gamma p \to e^+e^-p$$



AI identification of the positrons

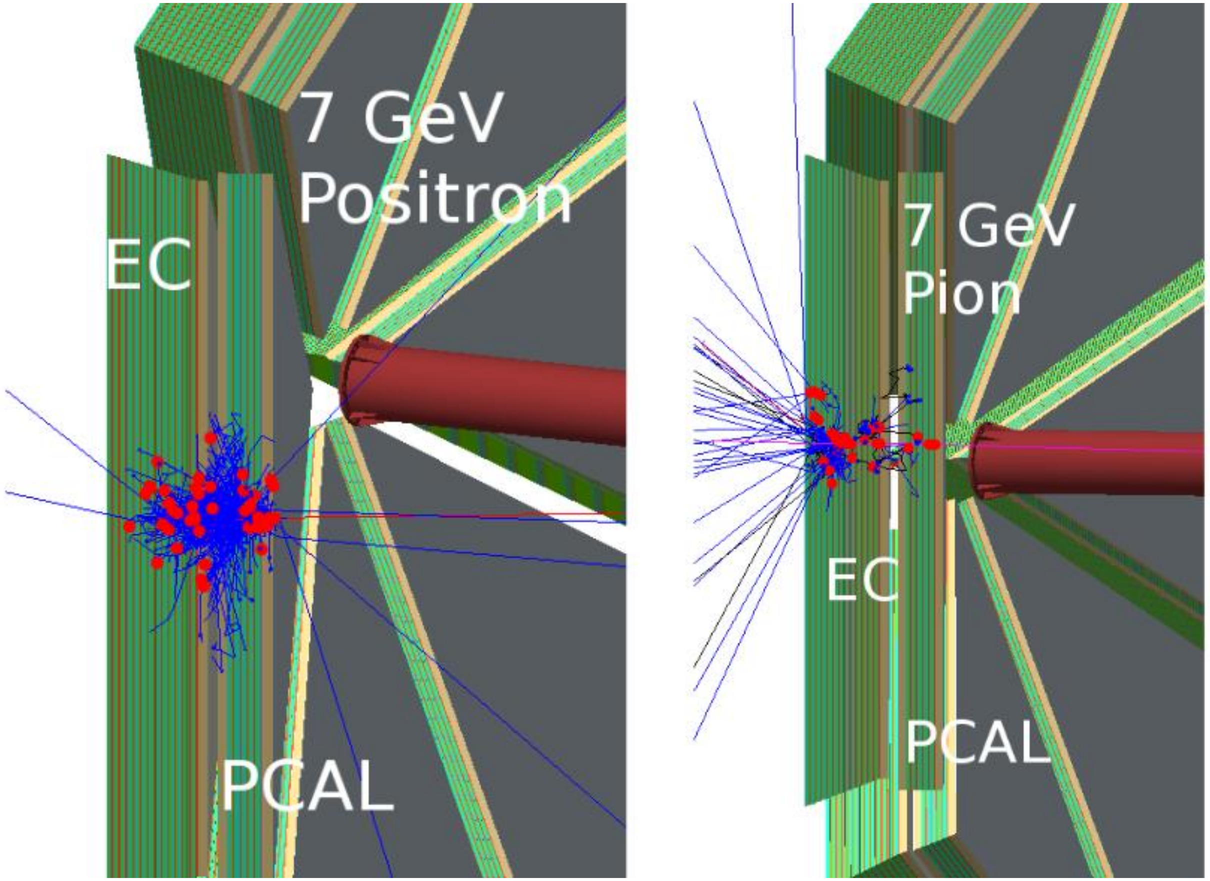
Strategy and discriminating variables

- Leptons produce electromagnetic showers and tend to deposit energy in the first layers of the calorimeters.
- Pions are **M**inimum **I**onizing **P**articles in the GeV region, they deposit small amounts of energy all along their path.

- Two main characteristics to use:

1. $$SF_{\text{EC Layer}} = \frac{E_{dep}(\text{EC Layer})}{P}$$

2. $$M_2 = \frac{1}{3}\sum_{U,V,W} \frac{\sum_{\text{strip}} (x-D)^2 \cdot \ln(E)}{\sum_{\text{strip}} \ln(E)}$$

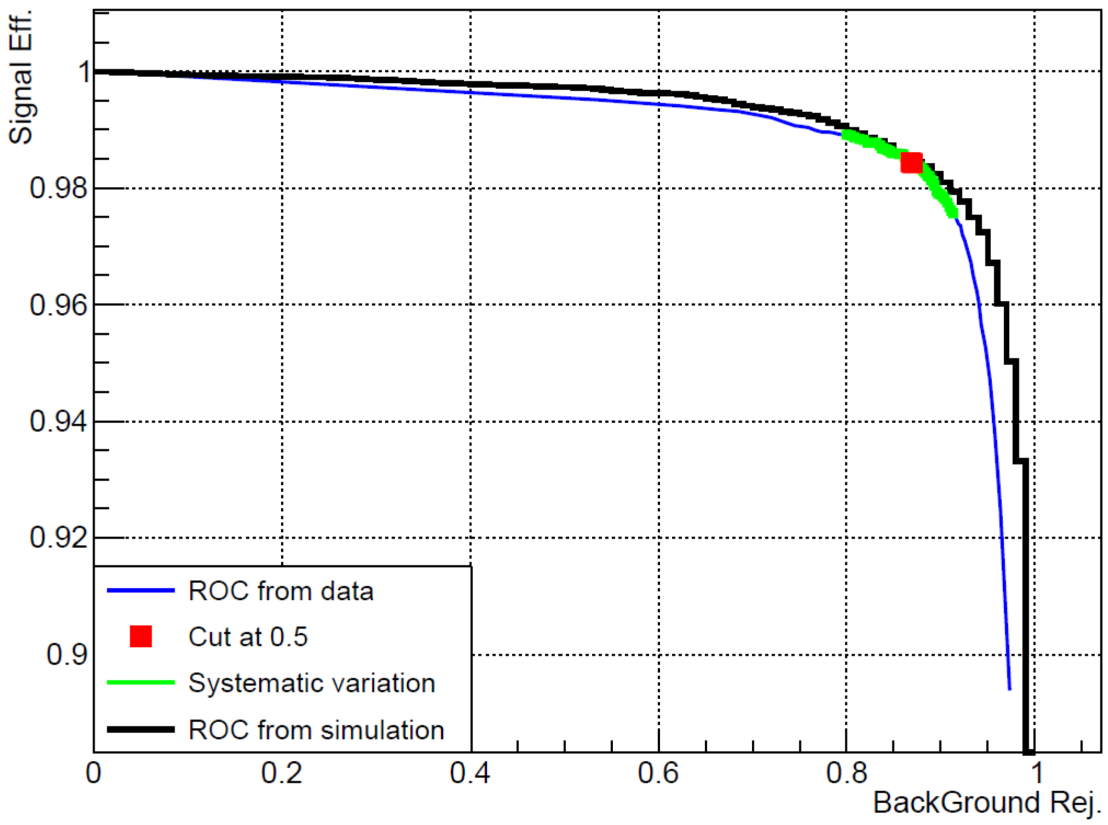


Performances of AI identification of the positrons

Strategy and discriminating variables

- Leptons produce electromagnetic showers and tend to deposit energy in the first layers of the calorimeters.
- Pions are **M**inimum **I**onizing **P**articles in the GeV region, they deposit small amounts of energy all along their path.

- Two main characteristics to use:
  1. $$SF_{\text{EC Layer}} = \frac{E_{dep}(\text{EC Layer})}{P}$$
  2. $$M_2 = \frac{1}{3}\sum_{U,V,W} \frac{\sum_{\text{strip}}(x-D)^2 \cdot \ln(E)}{\sum_{\text{strip}} \ln(E)}$$



TCS analysis

TCS interference cross-section formulae and CFFs

Unpolarized cross-section

Formulae and notations of Berger, Diehl, Pire, Eur.Phys.J.C23:675-689,2002

$$\frac{d^4\sigma_{INT}}{dQ'^2 dt d\Omega} \propto \frac{L_0}{L}\left[\cos(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)}\mathrm{Re}\tilde{M}^{--} + \ldots\right]$$

$$\rightarrow \tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{M}\frac{1-\xi}{1+\xi}\left[F_1\mathcal{H} - \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right]$$

Compton Form Factors (CFFs)

$$\mathcal{H} = \int_{-1}^{1} dx H(x,\xi,t)\left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right)$$

Polarized cross-section

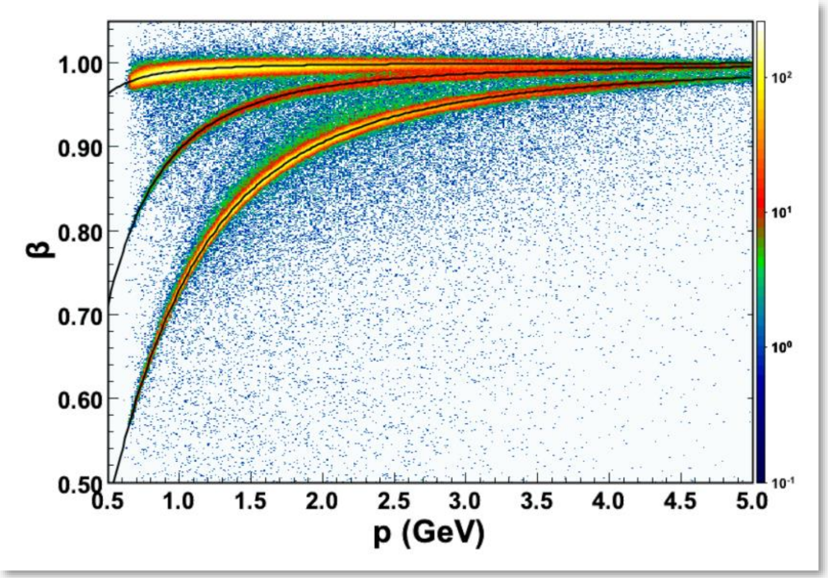
$$\frac{d^4\sigma_{INT}}{dQ'^2 dt d\Omega} = \frac{d^4\sigma_{INT}\,|_{\mathrm{unpol.}}}{dQ'^2 dt d\Omega} - \nu \cdot A\frac{L_0}{L}\left[\sin(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)}\mathrm{Im}\tilde{M}^{--} + \ldots\right]$$

(Quasi-)Photoproduction events selection

1) CLAS12 PID + Positron NN PID

$$ep \rightarrow (e')\gamma p \rightarrow (X)e^+e^-p'$$

Proton identification

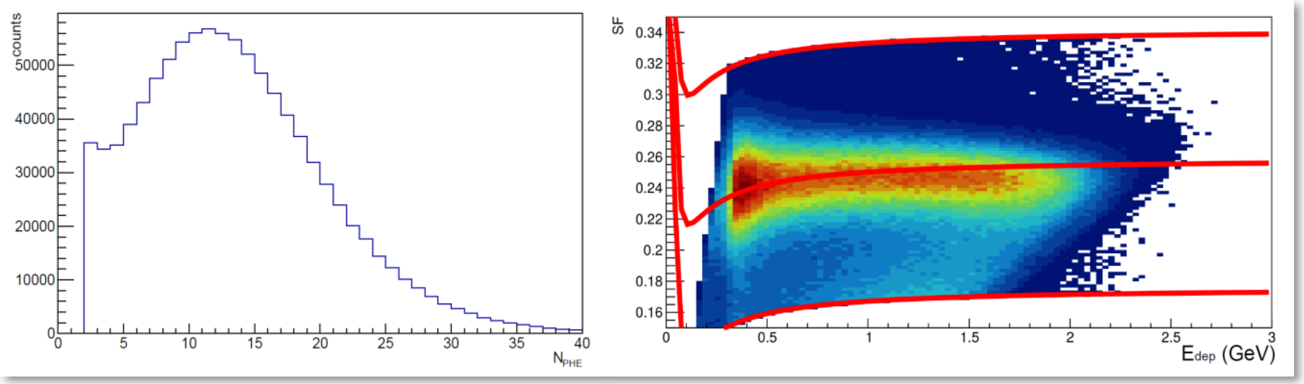


Velocity from the time-of-flight

Momentum from the track curvature

Lepton identification

Cherenkov counters + Calorimeter energy deposition



$$Sampling\ Fraction = \frac{E_{dep}}{P}$$

J/ψ analysis

J/ψ (quasi-)photoproduction events selection

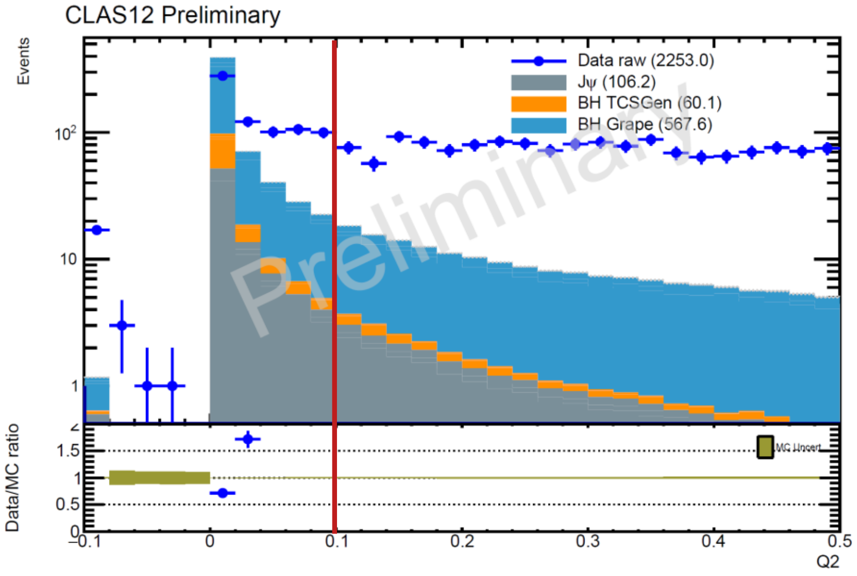
Can we do the same as for TCS ? In principle yes…

1) CLAS12 PID + Positron NN PID

$$ep \to (e')\gamma p \to (e')J/\psi\ p' \to (X)e^+e^-p'$$

$p_X = p_{beam} + p_p - p_{e^+} - p_{e^+} - p_{p'}$ → 2) $|M_X^2| < 0.4GeV^2$ → 3) $|\frac{Pt_X}{P_X}| < 0.05$

In practice, it is not so simple



Background removal procedure

Sample contents

Opposite charge leptons

Background final states ($\pi^+ \rightarrow e^+$)

$$e'p'e^+(e^- + X) + e'p'\pi^+(\pi^- + X)$$

Physics final state

$$e^-e^+p'(e')$$

$$N(e^+e^-p') = n_S(e^+e^-) + n_{BG}(e'e^+/\pi^+)$$

Same charge leptons

$$ep \rightarrow p'e^-e^-(X \simeq e)$$

$$e'p'\pi^-(\pi^+ + X) + e'p'e^-(e^+ + X)$$

$$R^{in} = \frac{N^{in}(e'e^-p')}{N^{in}(e^+e^-p')} = \frac{a^2 \cdot \sigma_{BG}}{a \cdot b \cdot \sigma_{BG+S}} = \frac{a \cdot \sigma_{BG}}{b \cdot \sigma_{BG+S}}$$

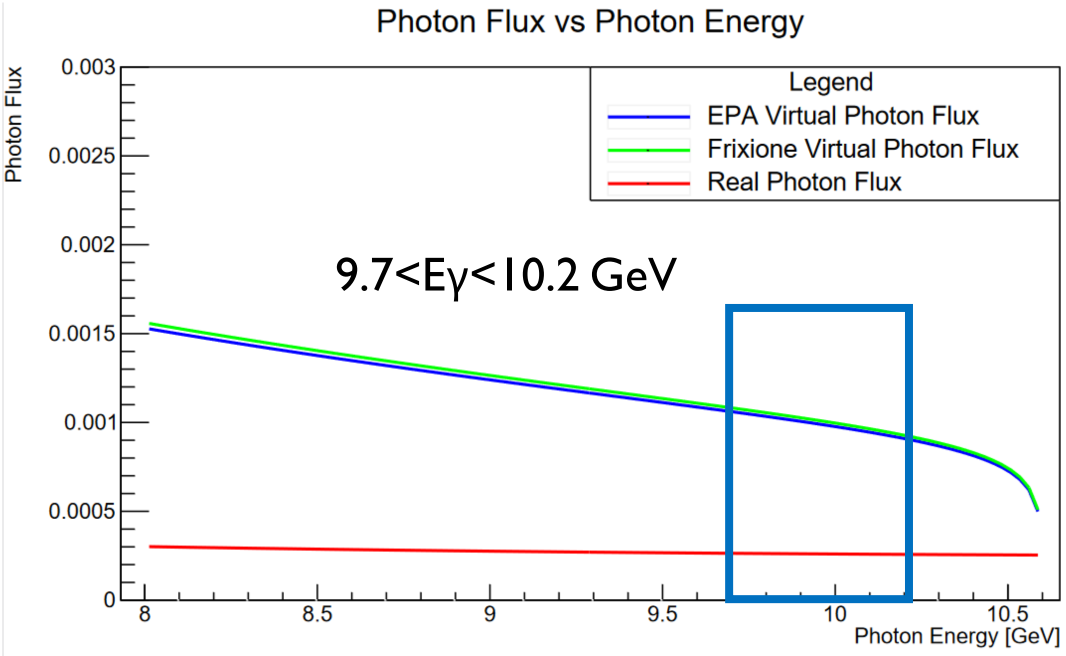
$$R^{out} = \frac{N^{out}(e'e^-p')}{N^{out}(e^+e^-p')} = \frac{b^2 \cdot \sigma_{BG}}{a \cdot b \cdot \sigma_{BG+S}} = \frac{b \cdot \sigma_{BG}}{a \cdot \sigma_{BG+S}}$$

$$w = \frac{S}{(S+B)_{In}} = 1 - \frac{N_{e^-e^-p}}{N_{e^-e^+p}}_{In} \frac{b}{a} = 1 - \sqrt{\frac{N_{e^-e^-p}}{N_{e^-e^+p}}_{In} \frac{N_{e^-e^-p}}{N_{e^-e^+p}}_{Out}}$$

Photon flux and accumulated charge

$$\sigma_0(E_\gamma) = \frac{N_{J/\psi}}{\boxed{N_\gamma \cdot n_T} \cdot \omega_c \cdot Br \cdot \epsilon(E_\gamma)}$$

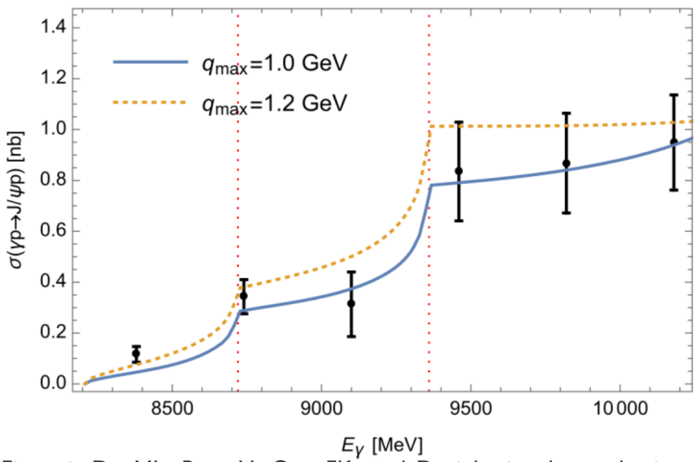
- Number of photons (from accumulated charge and photon flux from QED)
- Number of targets (from the density of dihydrogen and length of the target)



Motivations to measure J/ψ photoproduction near threshold: the open-charm "issue"

Open-charm "issue"

- The previous considerations rely on the application of Vector Meson Dominance.
- Thus the contribution from open-charm meson channels must be ruled-out/understood.



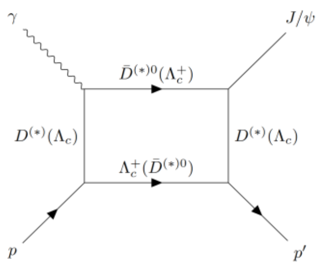


Figure in Du, ML., Baru, V., Guo, FK. *et al.* Deciphering the mechanism of near-threshold *J*/*ψ* photoproduction. *Eur. Phys. J. C* 80, 1053 (2020)

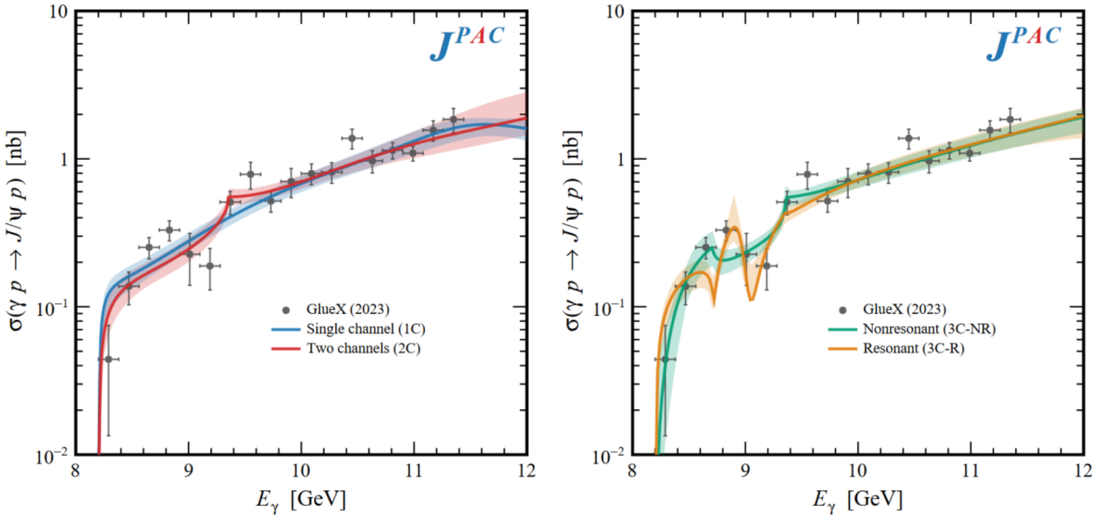


Figure in D. Winney, C. Fernandez-Ramirez, A. Pilloni, A. N. Hiller Blin et al. (JPAC), Dynamics in near-threshold J/ψ photoproduction arXiv:2305.01449

Background subtracted data using same-charge lepton events

- Opposite charge leptons

Background final states $(\pi^+ \to e^+)$

$$e'p'e^+(e^- + X) + e'p'\pi^+(\pi^- + X)$$

Physics final state

$$e^-e^+p'(e')$$

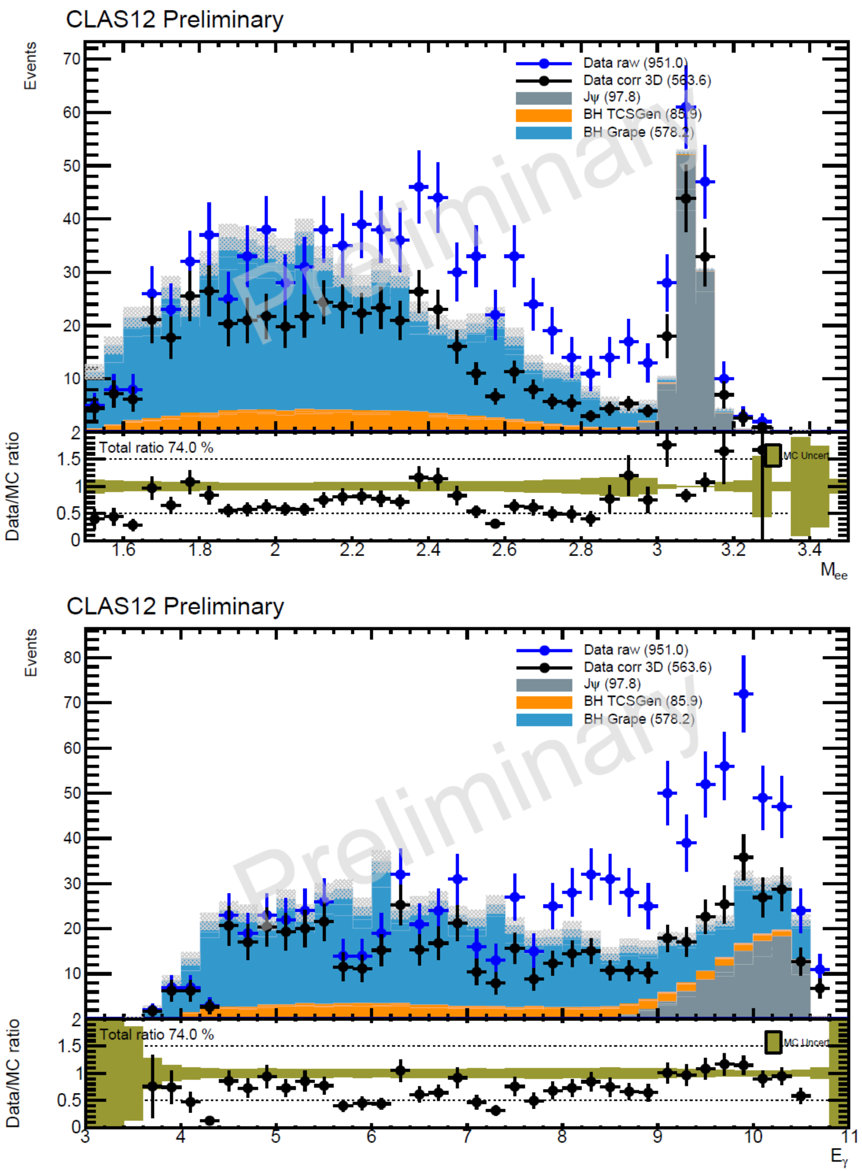
$$N(e^+e^-p') = n_S(e^+e^-) + n_{BG}(e'e^+/\pi^+)$$

- Same charge leptons

$$ep \to p'e^-e^-(X \simeq e)$$
$$e'p'\pi^-(\pi^+ + X) + e'p'e^-(e^+ + X)$$

- Background correction weight, combining inbending and outbending data:

$$w = \frac{n_S}{(n_S + n_{BG})} = 1 - \sqrt{\left.\frac{N_{e^-e^-p}}{N_{e^+e^-p}}\right|_{In} \left.\frac{N_{e^-e^-p}}{N_{e^+e^-p}}\right|_{Out}}$$

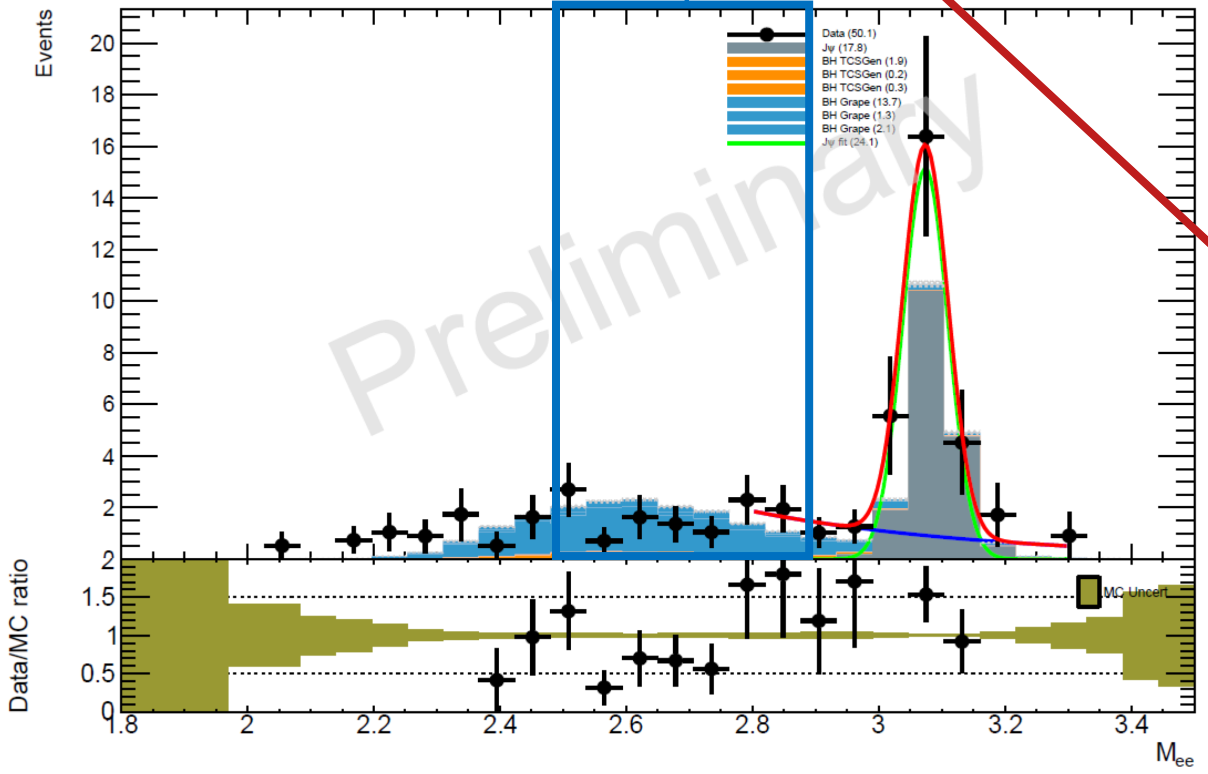


Cross-section extraction

$$\sigma_0(E_\gamma) = \frac{N_{J/\psi}}{N_\gamma \cdot n_T \cdot \omega_c \cdot Br \cdot \epsilon(E_\gamma)}$$

Number of J/ψ

- Number of photons (from accumulated charge and photon flux from QED).
- Number of targets (from the density of dihydrogen and length of the target).



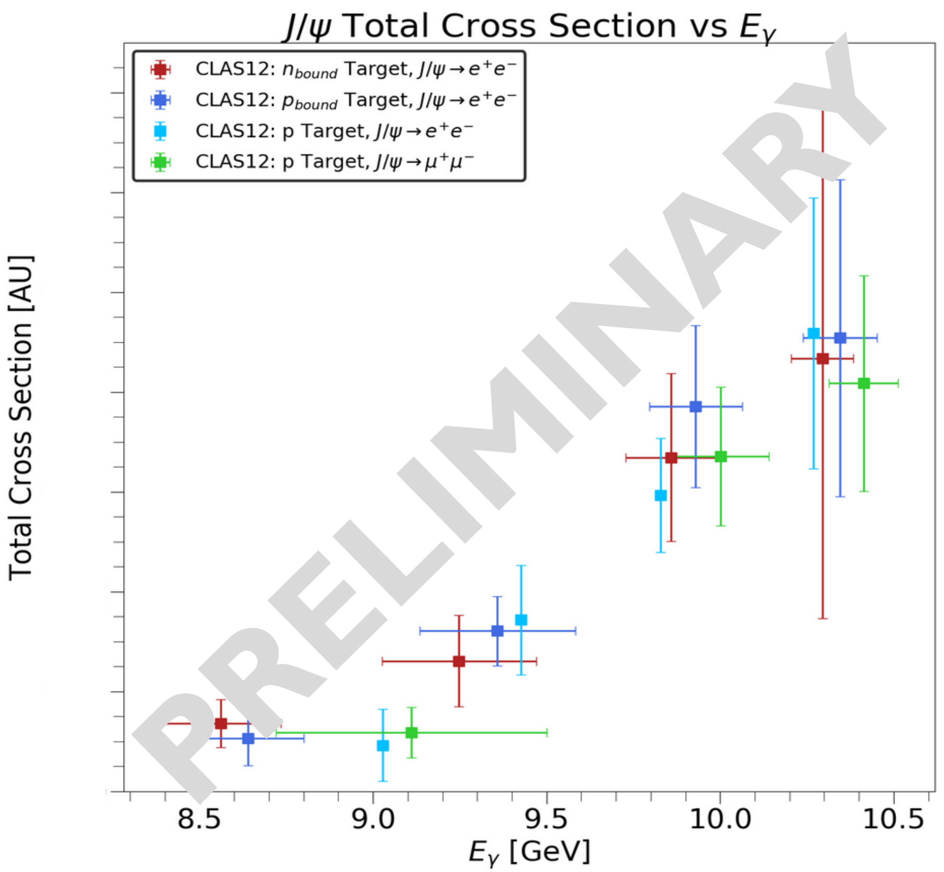
Reconstruction efficiency of the J/ψ → from MC

Branching ratio of J/ψ → e^+e^- → 6%

Preliminary results for CLAS12 proton/neutron data

- Deuterium data were taken by CLAS12 in 2019/2020.
- Opportunity to measure J/ψ production on (bound) neutron and (bound) proton.
- Alongside this analysis, a framework to explore the muon decay channel was developed.
- This effort is lead by R. Tyson from JLab.

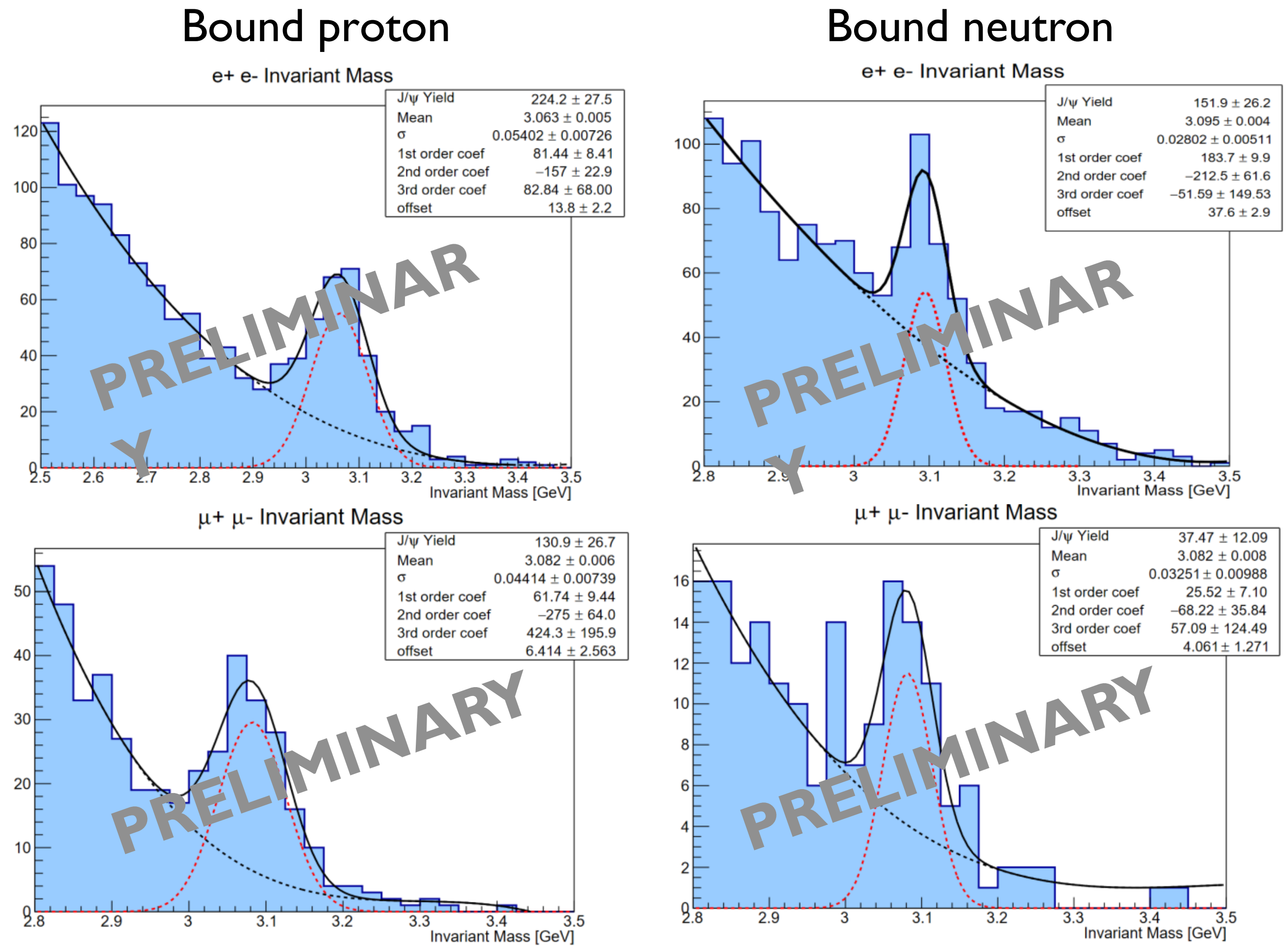
- Preliminary results for the comparison of decay channels and target nucleon.
- This measurement could have implication on understanding open-charm channels contribution.



Taken from R. Tyson PhD analysis, Univ. of Glasgow

Deuterium target and muon final state

- Deuterium data were taken by CLAS12 in 2019/2020.
- Opportunity to measure J/ψ production on (bound) neutron and (bound) proton.
- Alongside this analysis, a framework to explore the muon decay channel was developed.
- This effort is lead by R. Tyson from University of Glasgow.

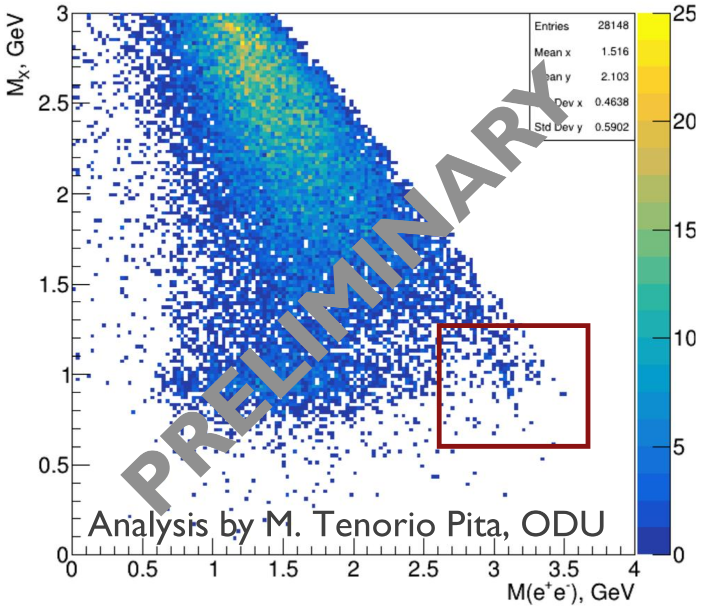


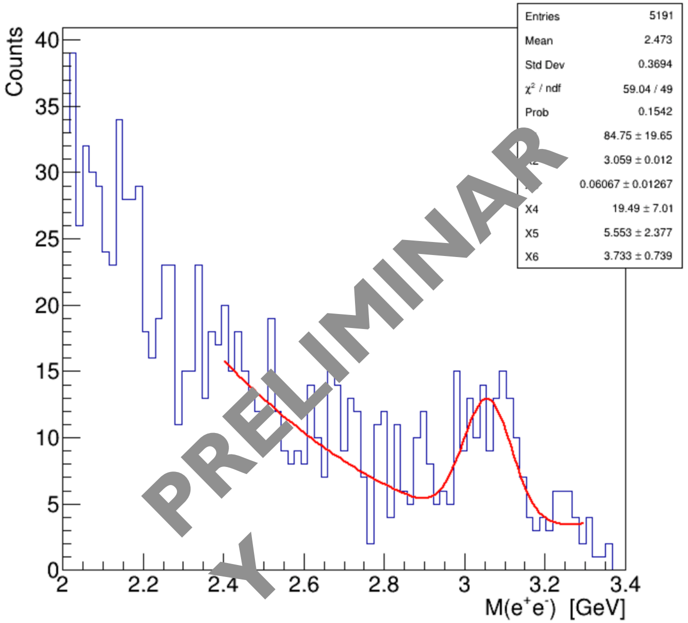
Taken from R. Tyson PhD analysis, Univ. of Glasgow

Tagged J/ψ quasi-photoproduction with CLAS12

$$ep \to e' J/\psi\ p' \to e' l^+ l^- (X)$$

- Analysis conducted by M. Tenorio Pita, ODU.
- In this case, one electron in the Forward Tagger (Low lab angle <5°) and a lepton pair in CLAS12.
- Excellent cross-check of the quasi-photoproduction approach.
- Early results show low statistics, the new data "cooking" including better tracking efficiency will be beneficial for this analysis.
- Other event topologies will be explored.





Other potential J/ψ analysis using CLAS12 data

- Available data for longitudinally polarized proton target