



Timelike Compton Scattering with SoLID

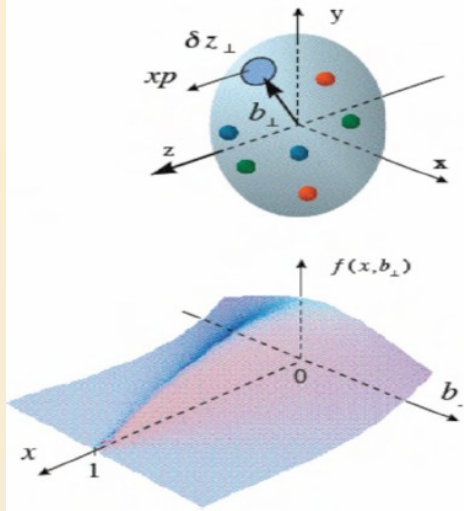
Zhiwen Zhao

For TCS collaboration

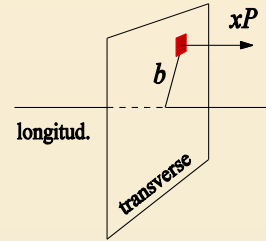
2013/03/23



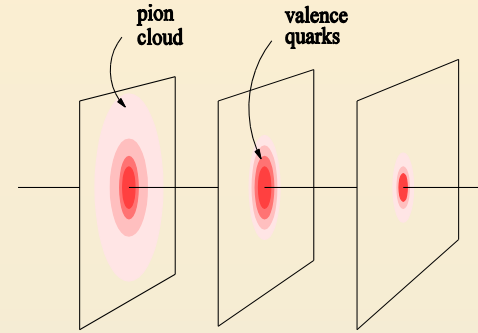
Generalized Parton Distribution (GPD)



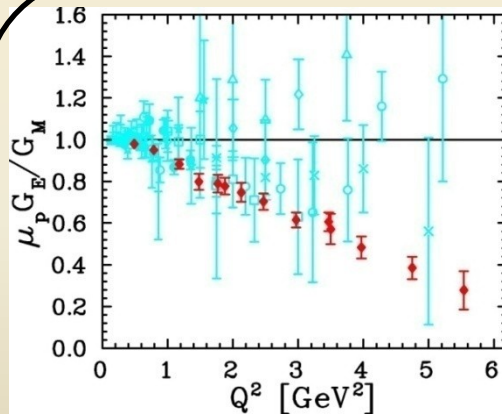
A unified descriptions of partons (quarks and gluons) in the momentum and impact parameter space



(a)

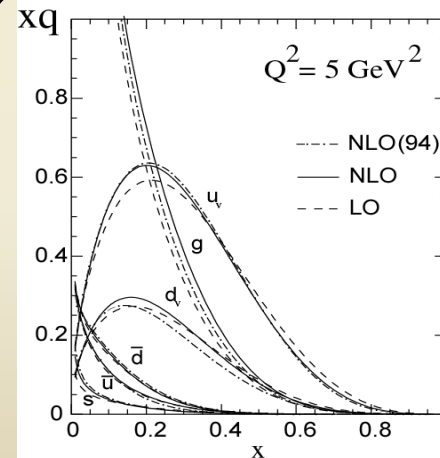
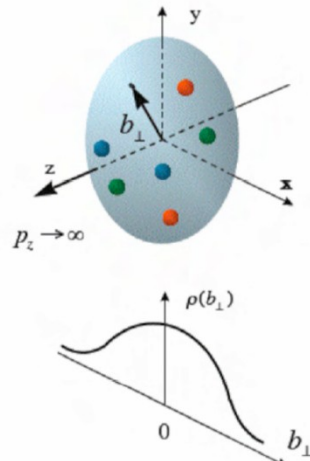


(b) $x < 0.1$ $x \sim 0.3$ $x \sim 0.8$



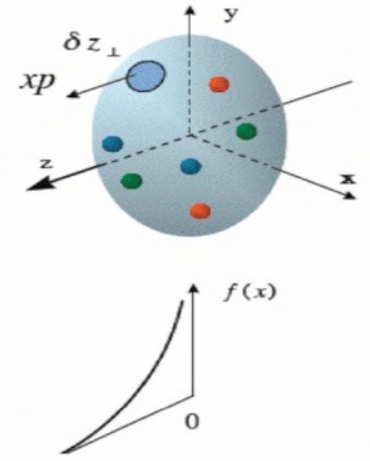
Elastic form factors

Transverse spatial distributions



Parton Distribution Functions

Longitudinal momentum distributions

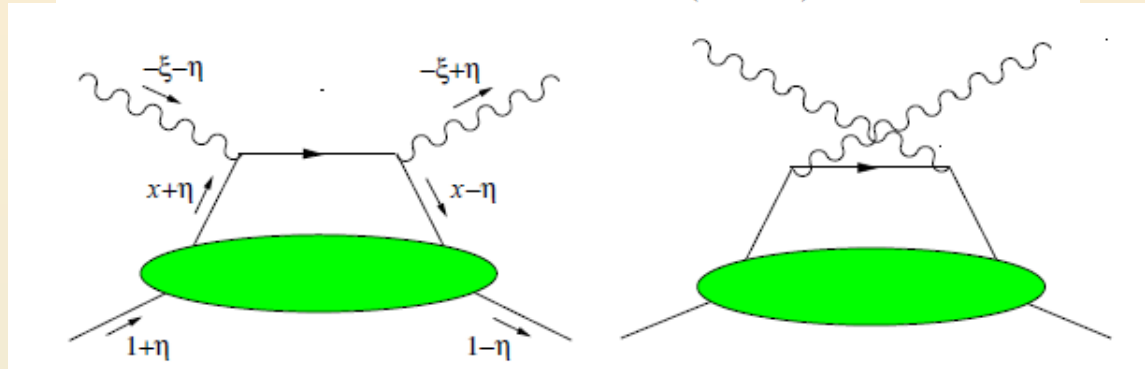


General Compton Process

accessing GPDs

$$\gamma(q) + p(p) \rightarrow \gamma(q') + p(p')$$

$$Q^2 = -q^2, \quad Q'^2 = q'^2, \quad s = (p + q)^2, \quad t = \Delta^2,$$



Compton Form Factor (CFF)

$$\mathcal{H}_1(\xi, \eta, t) = \sum_q e_q^2 \int_{-1}^1 dx \left(\frac{H^q(x, \eta, t)}{\xi - x - i\epsilon} - \frac{H^q(x, \eta, t)}{\xi + x - i\epsilon} \right),$$

$$\mathcal{E}_1(\xi, \eta, t) = \sum_q e_q^2 \int_{-1}^1 dx \left(\frac{E^q(x, \eta, t)}{\xi - x - i\epsilon} - \frac{E^q(x, \eta, t)}{\xi + x - i\epsilon} \right),$$

$$\tilde{\mathcal{H}}_1(\xi, \eta, t) = \sum_q e_q^2 \int_{-1}^1 dx \left(\frac{\tilde{H}^q(x, \eta, t)}{\xi - x - i\epsilon} + \frac{\tilde{H}^q(x, \eta, t)}{\xi + x - i\epsilon} \right),$$

$$\tilde{\mathcal{E}}_1(\xi, \eta, t) = \sum_q e_q^2 \int_{-1}^1 dx \left(\frac{\tilde{E}^q(x, \eta, t)}{\xi - x - i\epsilon} + \frac{\tilde{E}^q(x, \eta, t)}{\xi + x - i\epsilon} \right)$$

$$\xi = -\frac{(q + q')^2}{2(p + p') \cdot (q + q')} \approx \frac{Q^2 - Q'^2}{2s + Q^2 - Q'^2},$$

$$\eta = -\frac{(q - q') \cdot (q + q')}{(p + p') \cdot (q + q')} \approx \frac{Q^2 + Q'^2}{2s + Q^2 - Q'^2},$$

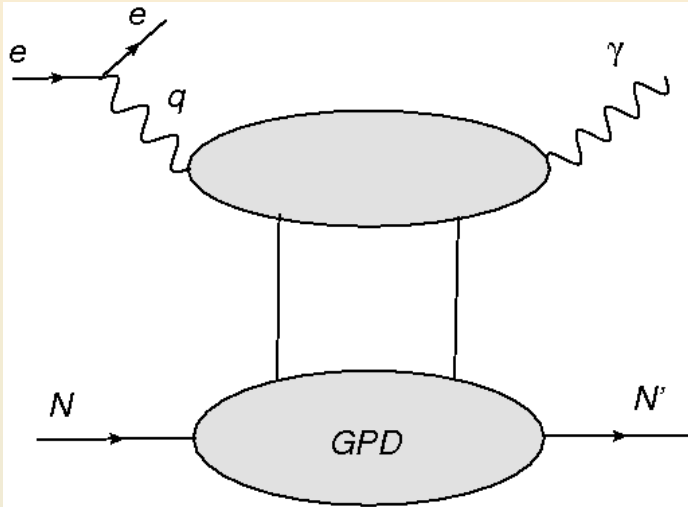
$$x = \frac{(k + k')^+}{(p + p')^+}, \quad \xi \approx -\frac{(q + q')^+}{(p + p')^+}, \quad \eta \approx \frac{(p - p')^+}{(p + p')^+}.$$

DVCS and TCS

access the same GPDs

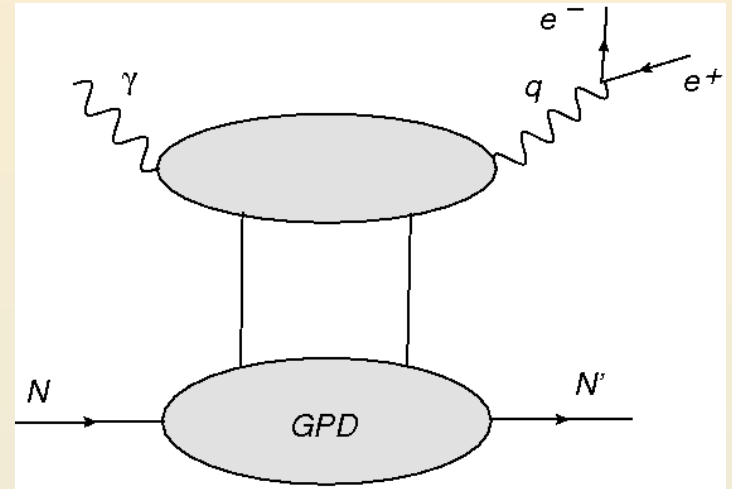
Spacelike Deeply Virtual Compton Scattering

$$\gamma^* p \rightarrow \gamma p'$$



Timelike Compton Scattering

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



- “The amplitudes of these two reactions are related at Born order by a simple complex conjugation but they significantly differ at next to leading order (NLO)”
- “The Born amplitudes get sizeable $O(\alpha_s)$ corrections and, even at moderate energies, the gluonic contributions are by no means negligible. We stress that the timelike and spacelike cases are complementary and that their difference deserves much special attention.”

General Compton Process

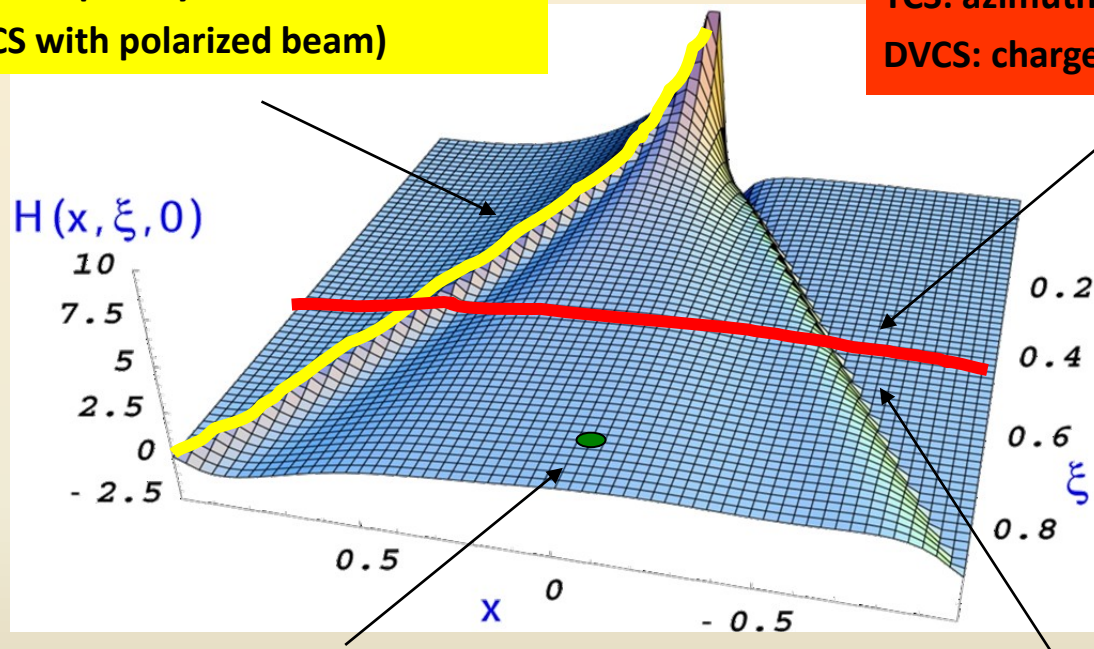
accessing GPDs

(Im, $x=\xi$)

DVCS: spin asymmetries
(TCS with polarized beam)

(Re)

TCS: azimuthal asymmetry
DVCS: charge asymmetry



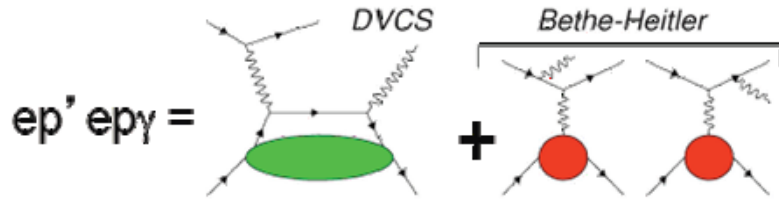
(Im, $x \neq \xi, x < |\xi|$)

Double DVCS

$(|\text{Im}|^2 + |\text{Re}|^2)$

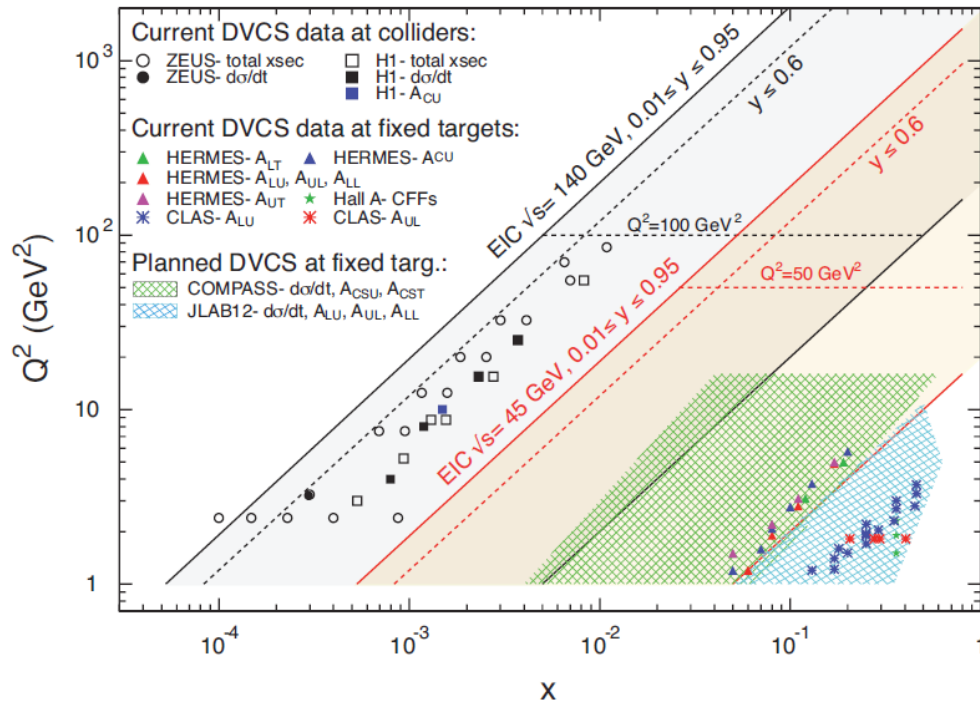
DVCS: cross section

DVCS

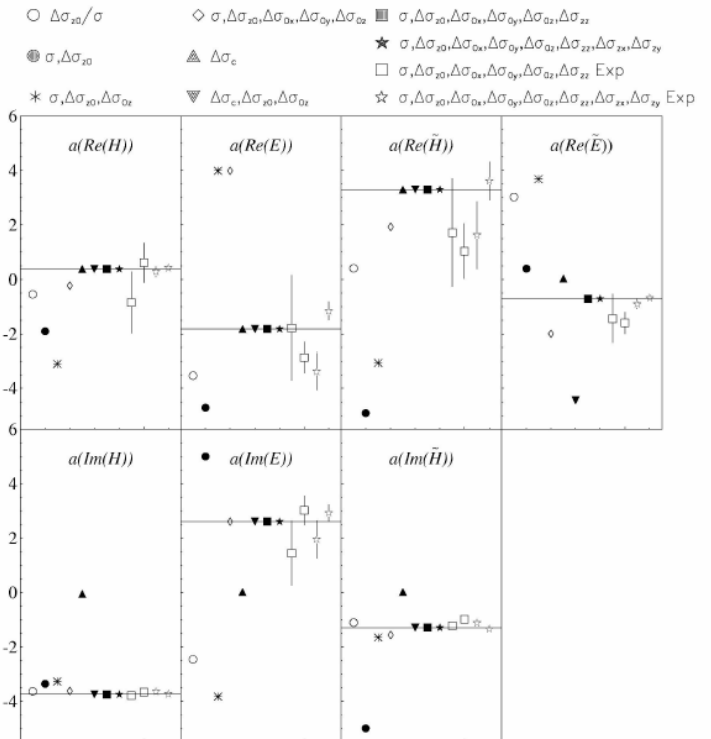


$$T = |T_{BH}|^2 + |T_{DVCS}|^2 + T_{DVCS}^* T_{BH} + T_{BH}^* T_{DVCS}$$

$$\mathcal{H}(\xi, t) = \underbrace{i\pi [H(\xi, \xi, t) - H(-\xi, \xi, t)]}_{\text{Im}} + \underbrace{P \int_{-1}^{+1} dx \left(\frac{1}{\xi - x} \pm \frac{1}{\xi + x} \right) [H(x, \xi, t) \mp H(-x, \xi, t)]}_{\text{Re}}$$



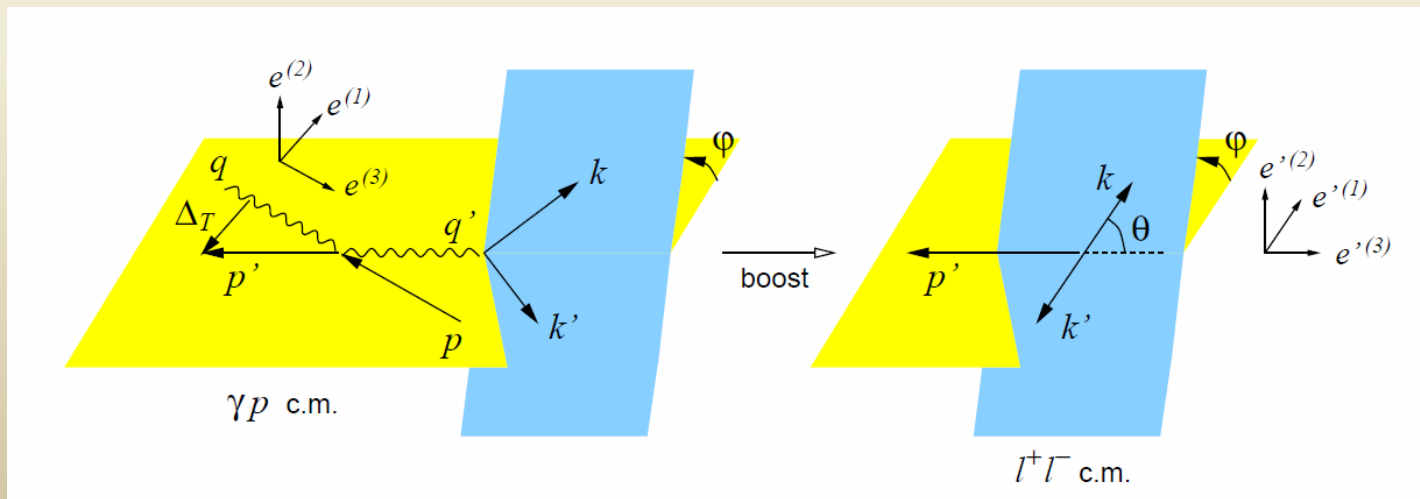
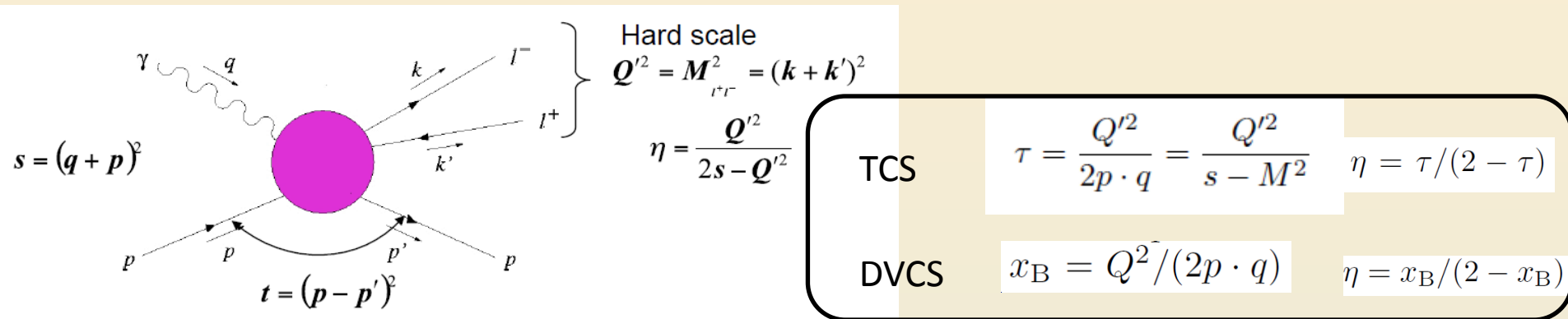
An overview of existing and planned measurements of DVCS



M. Guidal, Eur.Phys.J. A37, p319 (2008)

TCS

Information on the real (imaginary) part of the Compton amplitude can be obtained from photoproduction of lepton pairs using unpolarized (circularly polarized) photons

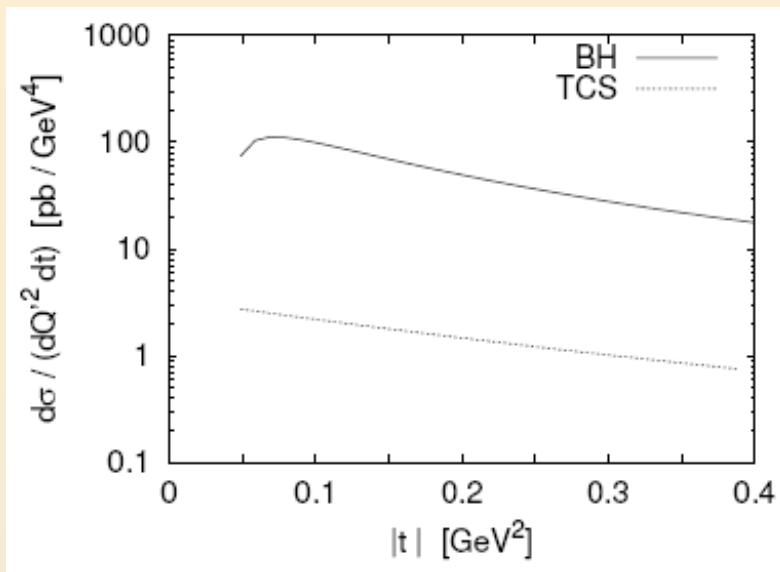


Timelike Compton Scattering (TCS)

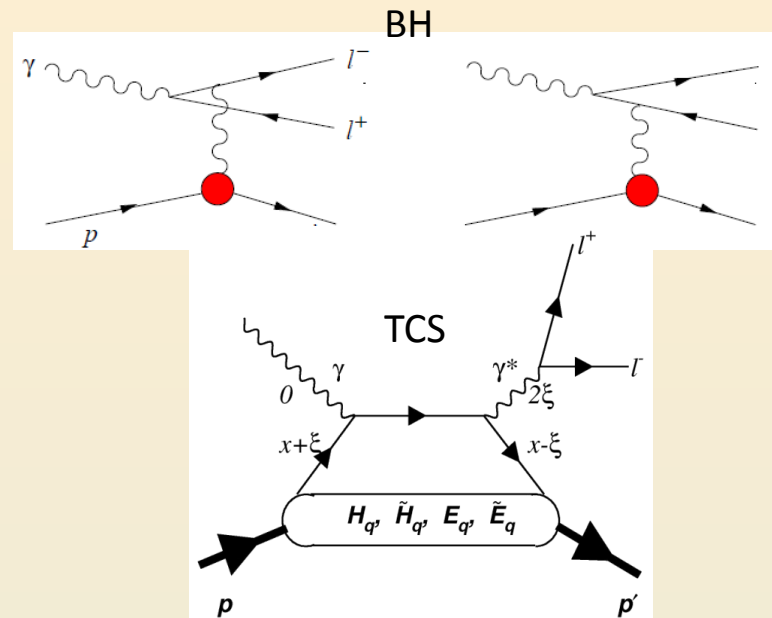
$$\gamma \, p \rightarrow p' \, \gamma^*(e^- e^+)$$

- Test spacelike-timelike correspondence and the universality of GPDs
 - Input for global analysis of Compton Form Factors
 - access through azimuthal asymmetry of lepton pair
- Explore GPDs of quarks and gluons at different kinematics

TCS and Bethe-Heitler (BH) Interference



E. Berger *et al.*, Eur. Phys. J. C23, 675 (2002)



$$\frac{d\sigma^4}{dQ'^2 dt d(\cos\theta) d\phi} = |BH|^2 + \underbrace{I(BH \cdot TCS)} + |TCS|^2$$

- For lepton charge conjugation, TCS and BH amplitudes are **even**, while the interference term is **odd**
- Therefore, direct access to interference term through angular distribution of the lepton pair (cosine and sine moments)

TCS at JLab 6GeV

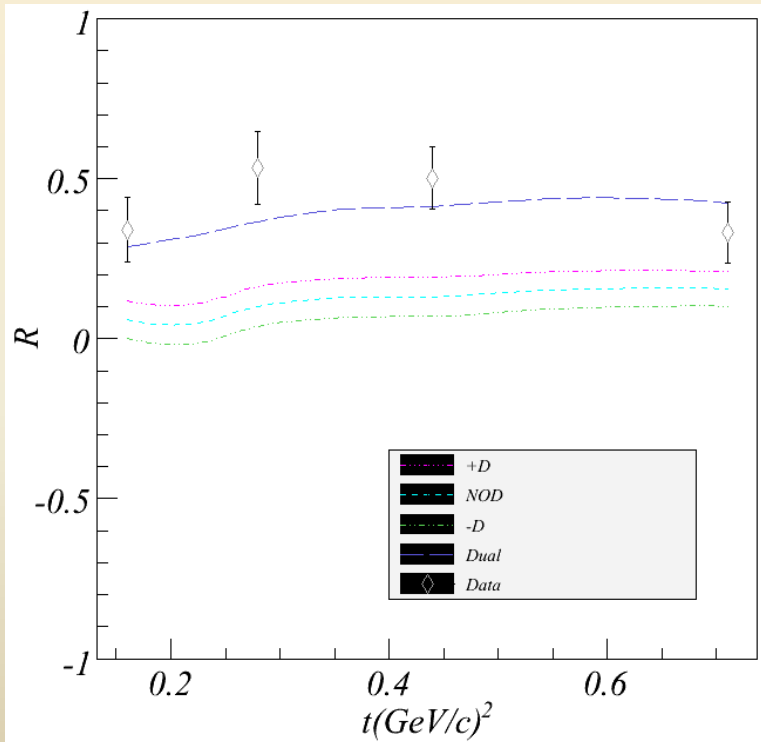
Cosine moment of
weighted cross sections

$$\frac{dS}{dQ^2 dt d\varphi} = \int \frac{L(\theta, \varphi)}{L_0(\theta)} \frac{d\sigma}{dQ^2 dt d\varphi d\theta} d\theta$$

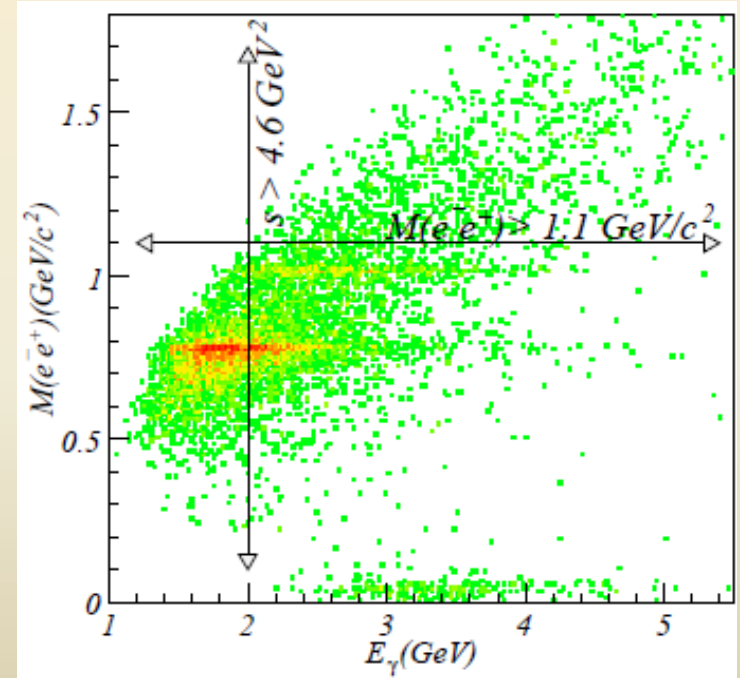
$$R = \frac{2 \int_0^{2\pi} d\varphi \cos \varphi \frac{dS}{dQ^2 dt d\varphi}}{\int_0^{2\pi} d\varphi \frac{dS}{dQ^2 dt d\varphi}}$$

R can be compared directly with GPD models

- 6 GeV data were important for developing methods
- But its kinematics are limited to $M_{e+e-} < 2 \text{ GeV}$



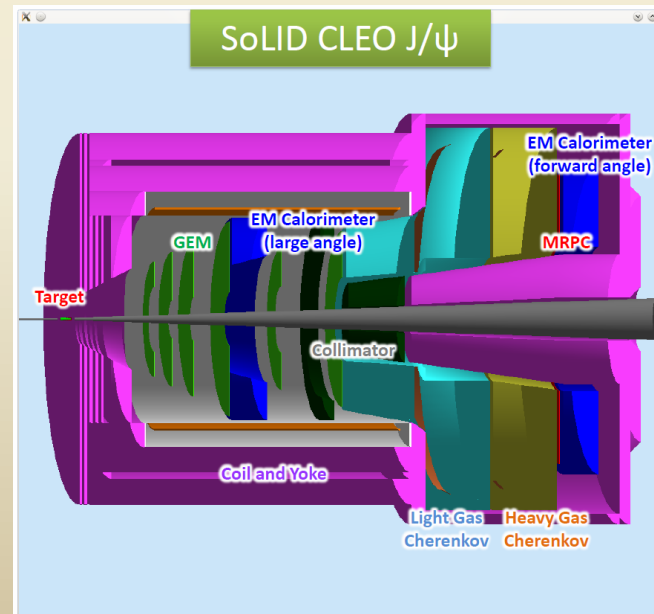
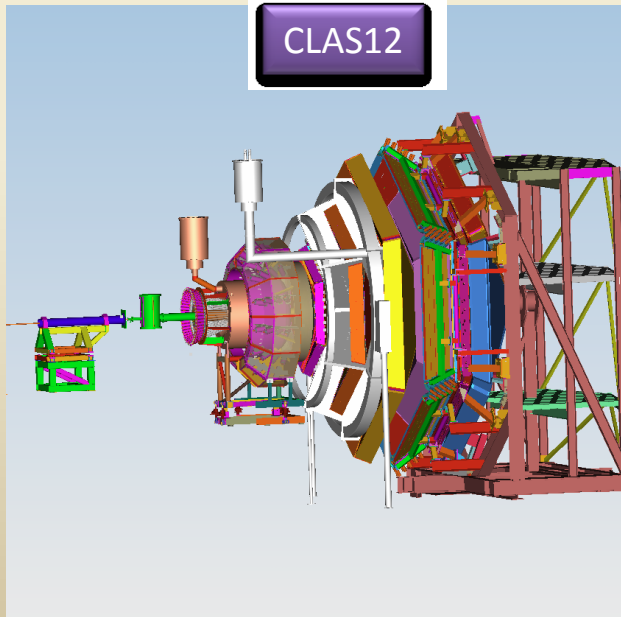
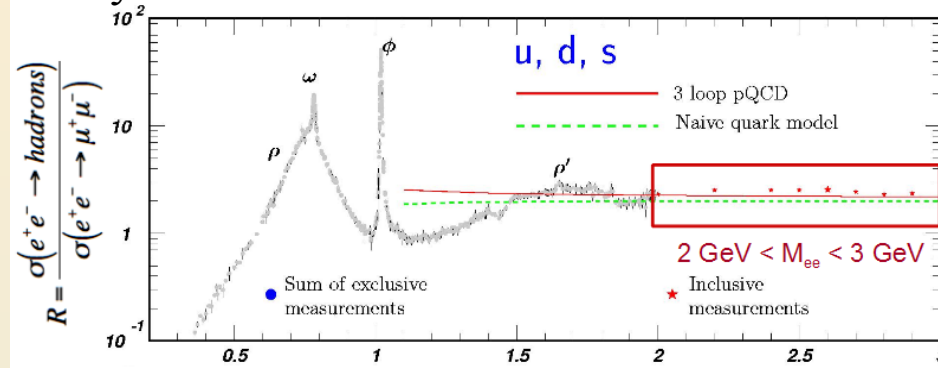
Comparison of results by R.
Paremuzyan *et al* from CLAS
e1-6/e1f with calculations by V.
Guzey



Analysis of CLAS g12 with tagged real photons is ongoing 10

TCS at JLab 12GeV

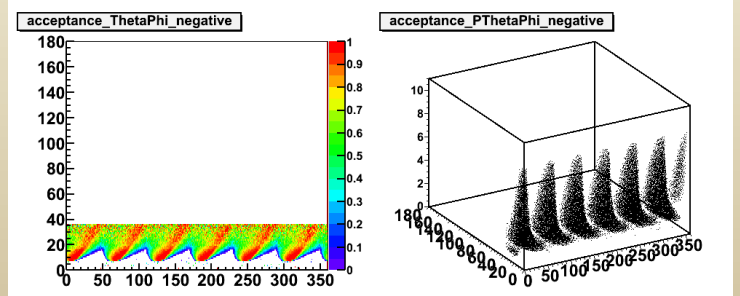
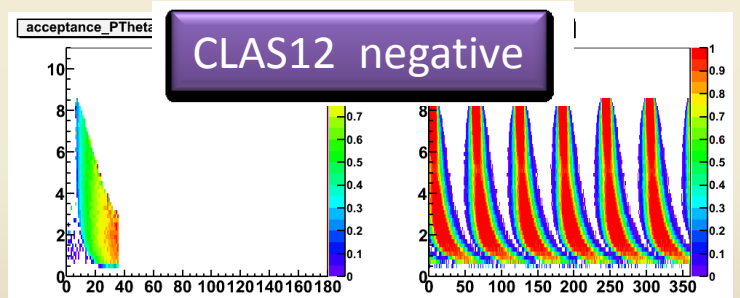
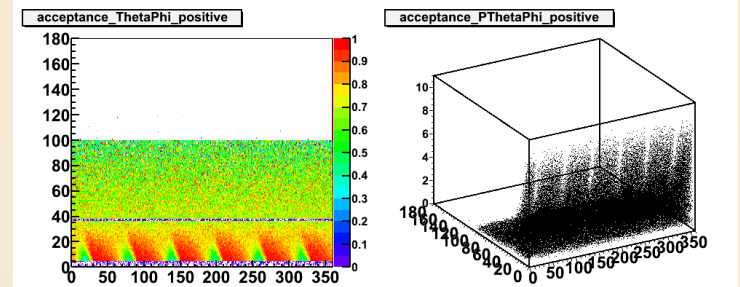
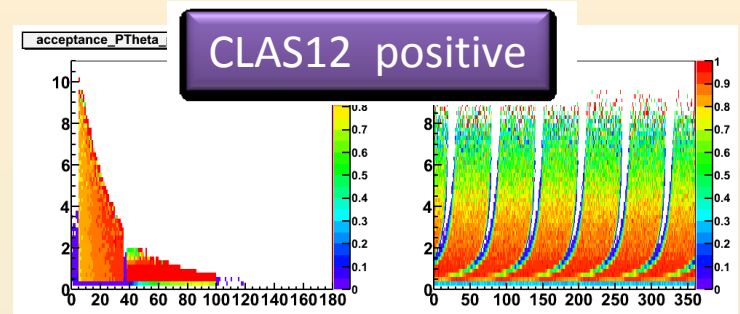
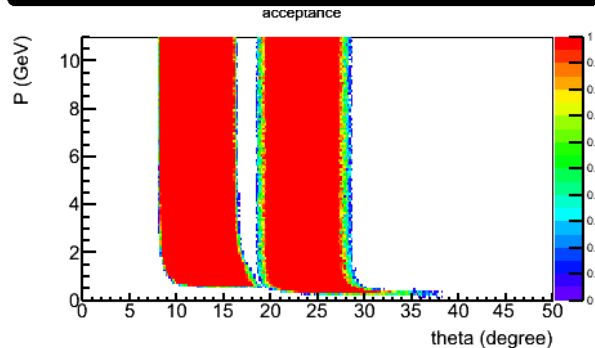
- 11 GeV beam extends s to 20GeV²
- $M_{e^+e^-}(Q')$ reaches about 3.5GeV and this allows the access to the resonance free region from 2GeV to 3GeV
- τ can reach from 0.2 to 0.6, eta reaches from 0.1 to 0.45
- Higher luminosity and thus more statistics for multi-dimensional binning



CLAS12 and SoLID: Acceptance

	CLAS12	SoLID
e^- and e^+ coverage	$\theta(5^\circ - 36^\circ)$ ϕ ($\sim 80\%$ full) Asymmetric	$\theta(8^\circ - 17^\circ)$ $\theta(18^\circ - 28^\circ)$ ϕ (full) Symmetric
proton coverage	$\theta(5^\circ - 36^\circ)$ $\Theta(38^\circ - 125^\circ)$ ϕ ($\sim 80\%$ full)	$\theta(8^\circ - 17^\circ)$ $\theta(18^\circ - 28^\circ)$ ϕ (full)
Luminosity	$10^{35}/\text{cm}^2/\text{s}$	$10^{37}/\text{cm}^2/\text{s}$

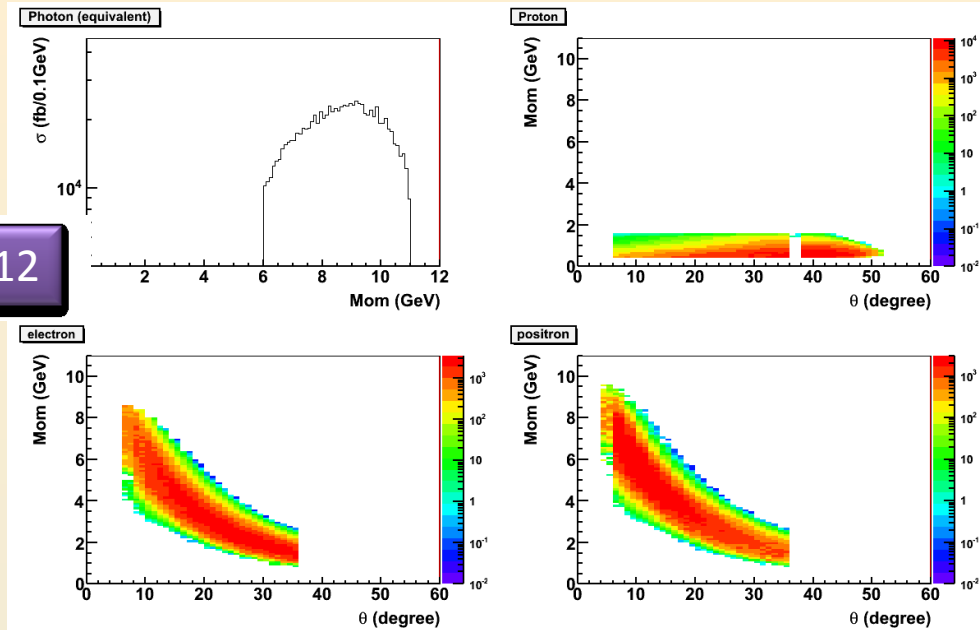
SoLID positive and negative



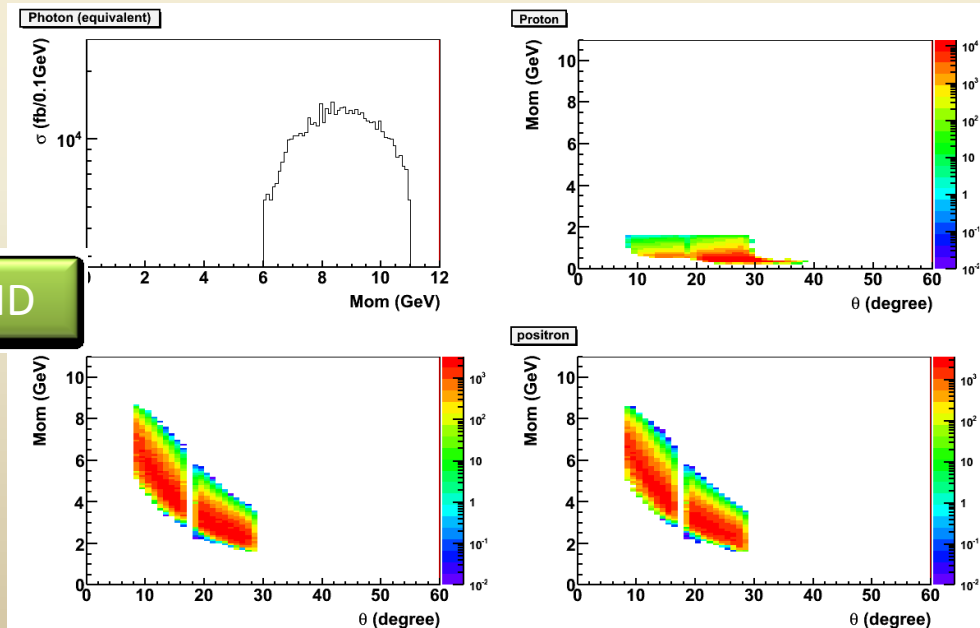
CLAS12 and SoLID: BH Detection (Lab Frame)

- BH events in the resonance free region are used for simulation
- CLAS12 and SoLID have similar overall coverage
- CLAS12 acceptance is slightly larger SoLID, but within a factor of 2

CLAS12



SoLID



CLAS12 and SoLID: BH Detection (γ^* CM Frame)

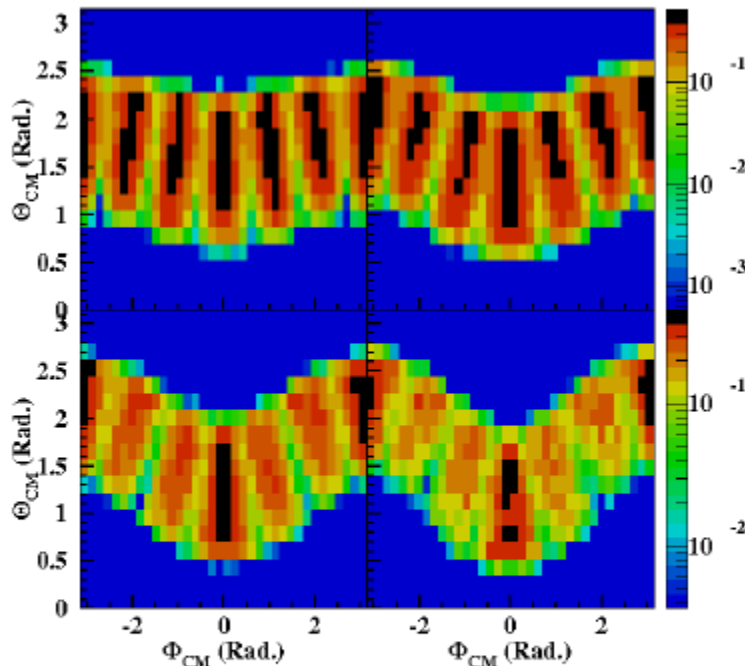
$$4\text{GeV}^2 < Q'^2 < 9\text{GeV}^2$$

$$17.5\text{GeV}^2 < s < 19.5\text{GeV}^2$$

$$4 \text{ t-bins within } 0.1\text{GeV}^2 < t < 0.9\text{GeV}^2$$

CLAS12

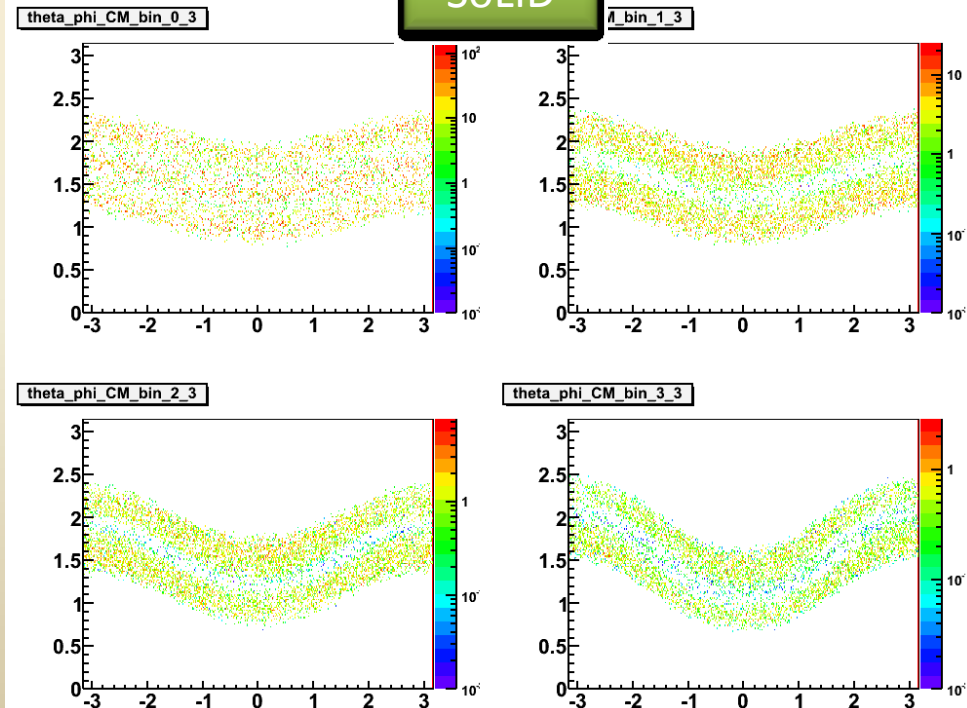
$s = 17.5 \text{ GeV to } 19.5 \text{ GeV}$



Accepted events for four t-bins.
The observable R' is integrated
over the CLAS acceptance

- CLAS12 has ϕ structure which has to be corrected by acceptance
- SoLID is smooth over ϕ , but has θ gap

SoLID



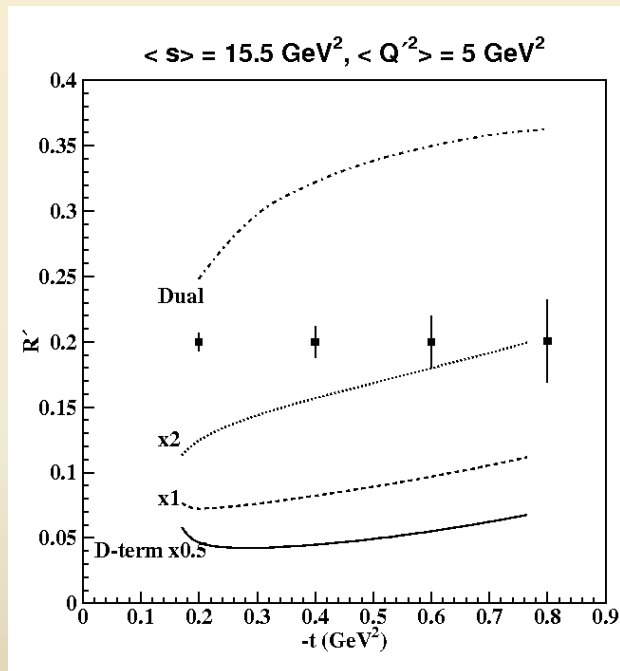
Approved $ep \rightarrow e'pe^+e^-$ program for CLAS12

Proposal	Physics	Contact	Rating	Days	Group	Energy	Target
E12-06-108	Hard exclusive electro-production of π^0, η	Stoler	B	80	119 days + 20 days with reversed torus field	11 GeV	Liquid H ₂
E12-06-112	Proton's quark dynamics in SIDIS pion production	Avakian	A	60			
E12-06-119	Deeply Virtual Compton Scattering	Sabatie	A	80			
E12-09-003	Excitation of nucleon resonances at high Q ²	Gothe	B+	40			
E12-11-005	Hadron spectroscopy with forward tagger	Battaglieri	A-	119			
		Nadel-Turonski	A-	100 +20			
E12-12-007	Exclusive ϕ meson electroproduction with CLAS12	Stoler, Weiss	B+	60			

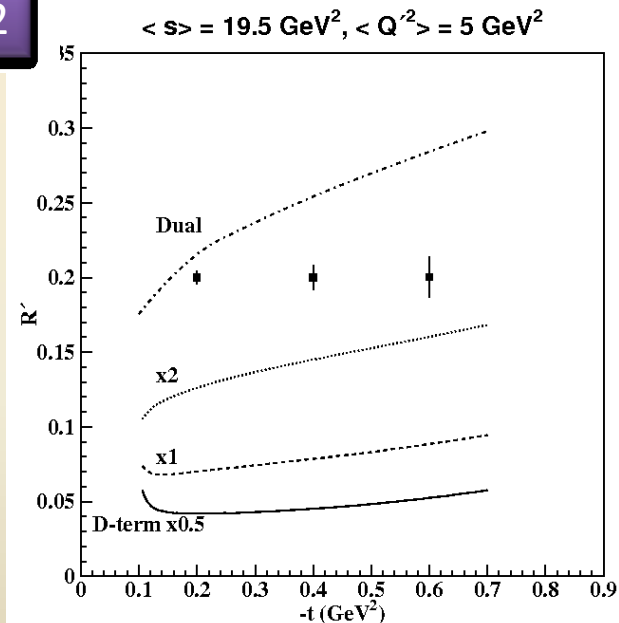
- Unpolarized proton target will be first to run
- Experiment E12-12-001 for e^+e^- physics was approved at the last PAC meeting
- Spectroscopy (119 PAC days) and e^+e^- (100+20 days) experiments drive the total beam time for proton running (119+20 days), which can be shared by all.
- Approved beam time corresponds to more than a year of actual running

TCS at JLab 12GeV Projected Result

- **SoLID**, with 100 time more luminosity, should have about factor of 50 more events than CLAS12 under same running time
- **CLAS12 and SoLID will run at different time and be well complementary**



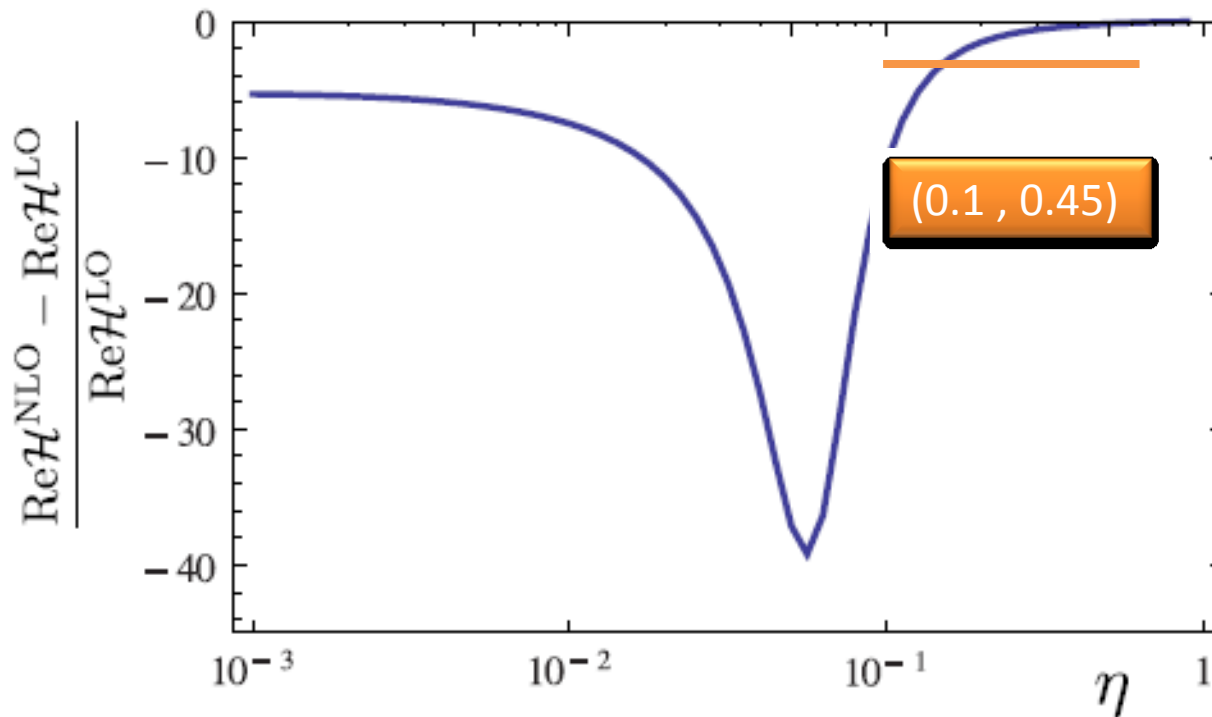
CLAS12



- Statistical uncertainties for 100 days at a luminosity of $10^{35} \text{ cm}^{-2}\text{s}^{-1}$
- Uncertainties for cosine moment R' , integrated over the CLAS12 acceptance, for two bins in photon energy, for the lowest Q^2 bin above the ρ' resonance.
- Different values of the D-term are only shown for the double distribution

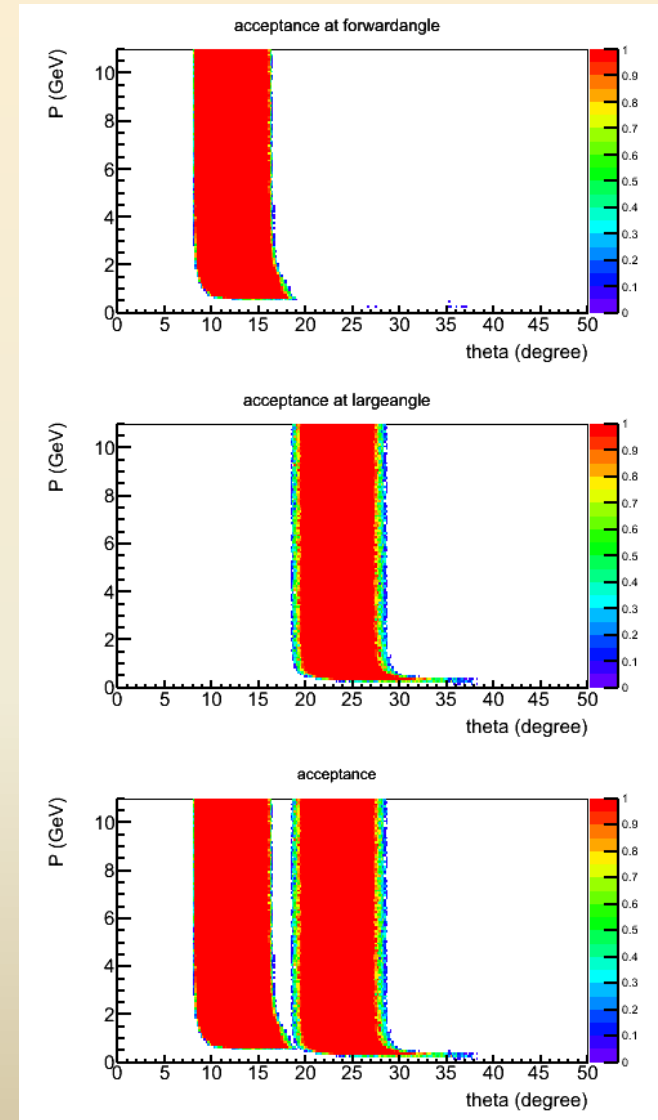
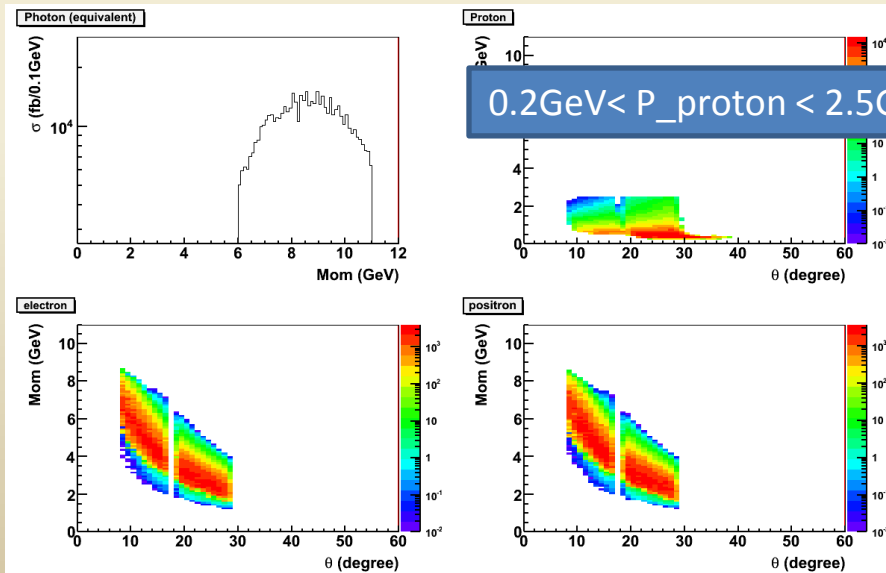
SoLID TCS

- (preliminary) estimated **500k** events for $1\text{e}37\text{cm}^{-2}\text{s}^{-1}$ lumi and 50 days
- Higher statistics enables multi-dimension binning (Q^2 , s , t , η ...)
 - e.g. study the change over η and search for NLO (gluonic)



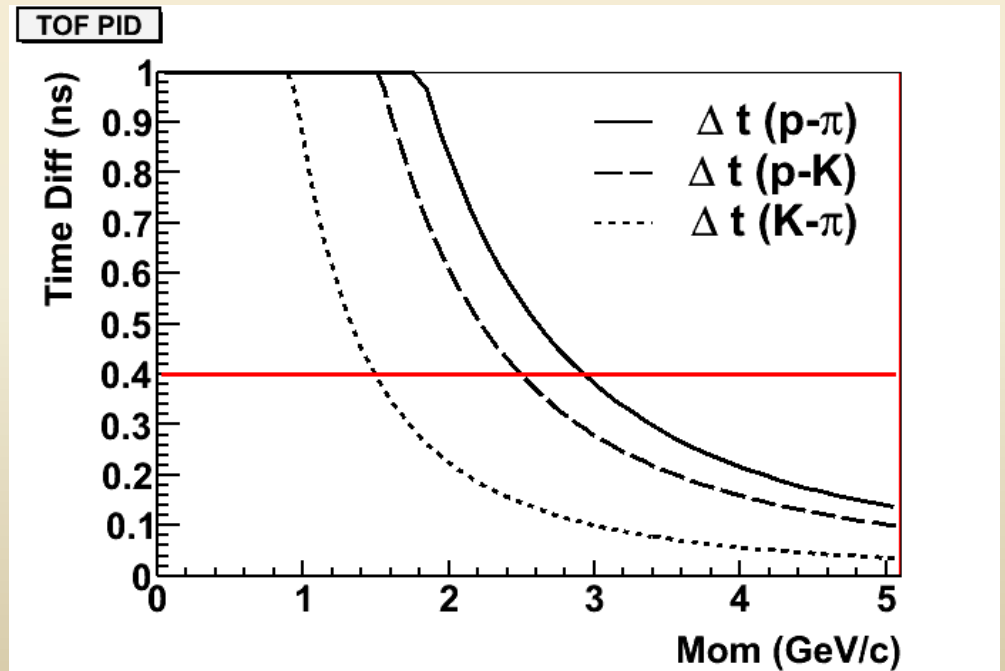
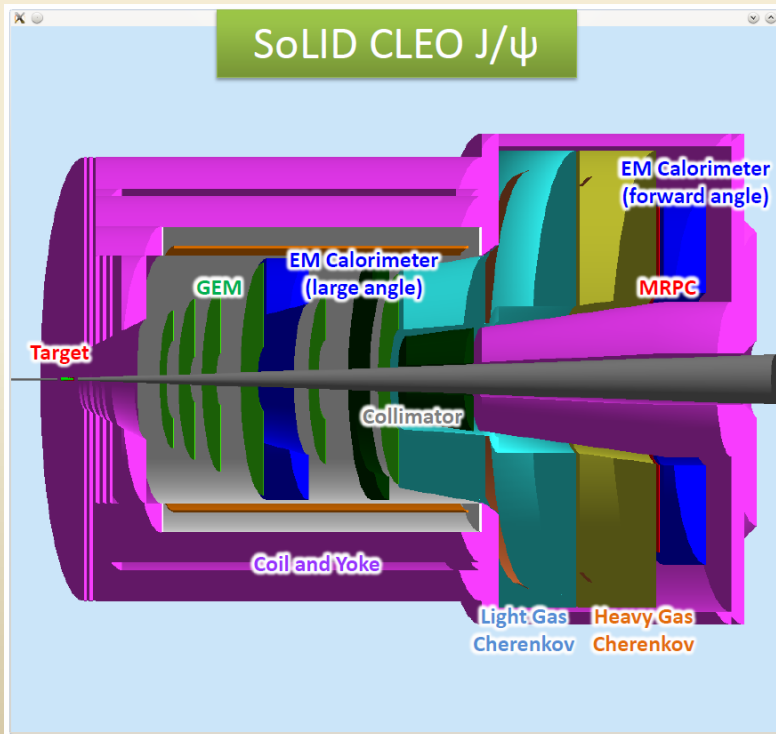
SoLID JPsi and TCS

- JPsi setup
 - 15cm LH2 target 300cm upstream from solenoid coil center.
 - 3uA current, $1e37/cm^2/s$ luminosity for 50 days
 - forward angle coverage about 8-16 degree, large angle coverage about 17-28 degree
 - Trigger on scattered e- at forward angle and decay lepton pair at forward and large angle
- TCS setup
 - Same final particles with JPsi, possible to run in parallel
 - Detect proton instead of scattered e-
 - Add a TOF plane at large angle for proton pid
 - Trigger on decay lepton pair only



TOF at large angle

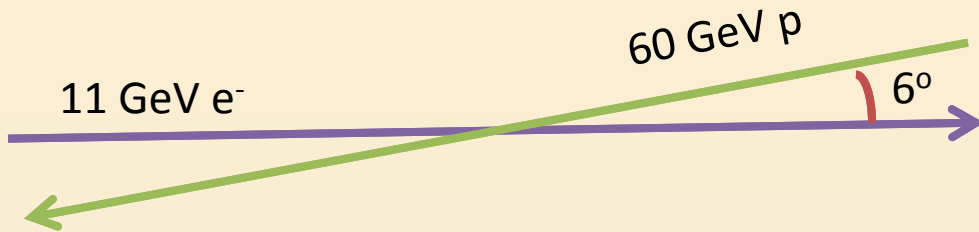
- Add a TOF plane before large angle EC
- The minimum flight distance is about 245cm from target
- Assume 5sigma separation for different particles and 80ps time resolution, then “red” line shows the cut at 400ps
- The proton identification can reach at least 2.5GeV
 - proton pion separation at 3.0GeV
 - Proton kaon separation at 2.5GeV
 - Kaon pion separation at 1.5GeV



Things to do

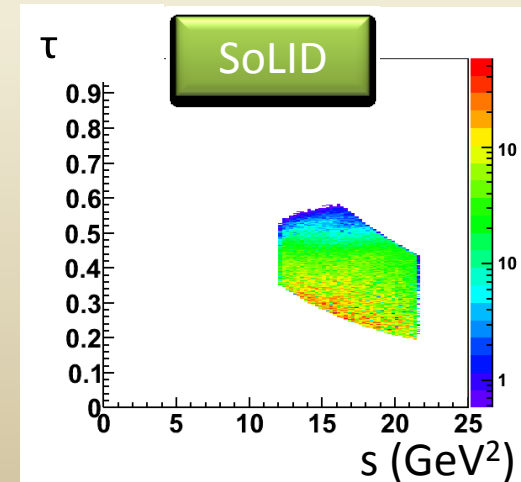
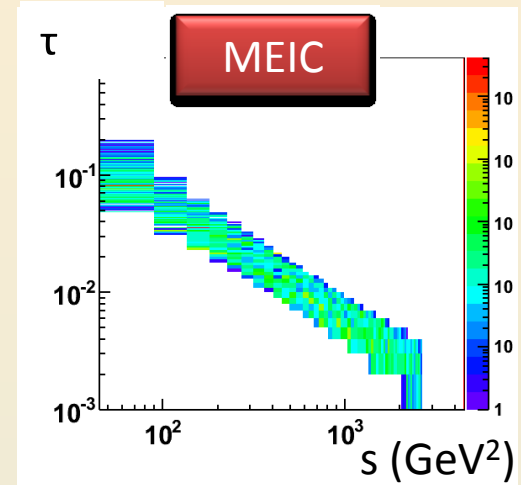
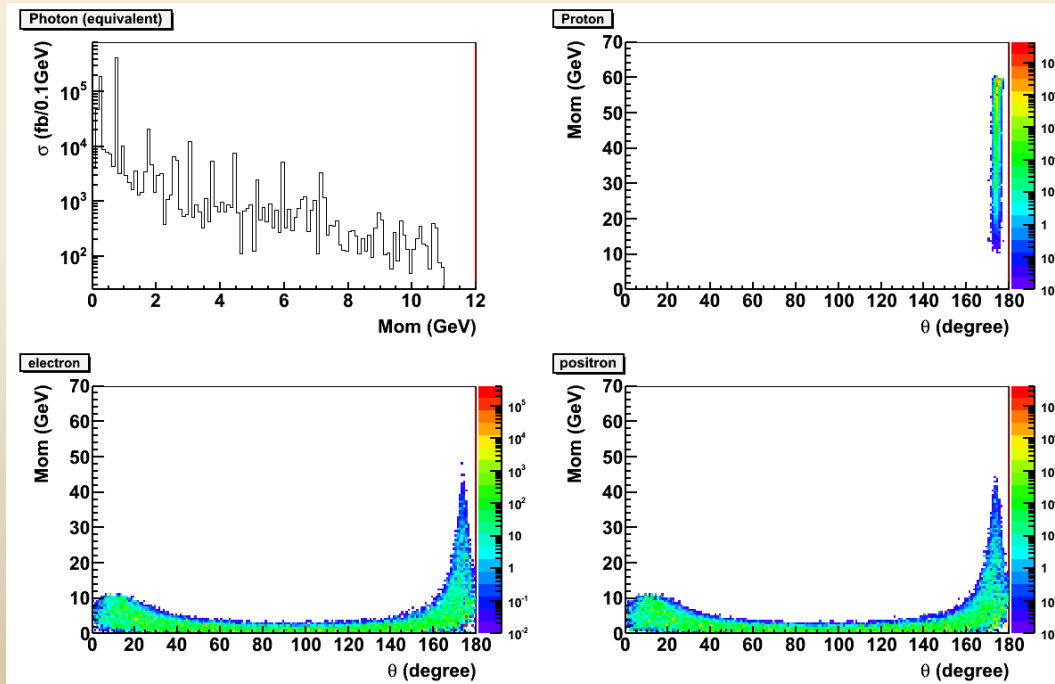
- Resolution study
- Background and rate (large angle TOF)
- Trigger study
-

TCS at MEIC



- JLab 12GeV reaches 0.2 for τ explores valence quarks.
- MEIC reaches 10^{-3} for τ and will explore the sea quarks and gluons.

- BH at resonance free region used for simulation
- Quasi- real scattering electron goes forward
- Recoil proton goes backward
- Decay leptons have large coverage in the middle



Summary

- Dilepton production at JLab 12GeV
 - J/ψ production near threshold for gluonic interaction
 - Timelike Compton Scattering (TCS) for GPD
- CLAS12 and SoLID can form a complementary program and will make important contributions in the field
- The program can continue at MEIC/EIC

Backup TCS

TCS crosssection

$$\frac{d\sigma_{BH}}{dQ'^2 dt d\cos\theta} \approx 2\alpha^3 \frac{1}{-tQ'^4} \frac{1+\cos^2\theta}{1-\cos^2\theta} \left(F_1(t)^2 - \frac{t}{4M_p^2} F_2(t)^2 \right)$$

$$\frac{d\sigma_{TCS}}{dQ'^2 d\Omega dt} \approx \frac{\alpha^3}{8\pi} \frac{1}{s^2} \frac{1}{Q'^2} \left(\frac{1+\cos^2\theta}{4} \right) 2(1-\xi^2) |\mathcal{H}(\xi, t)|^2$$

$$\frac{d\sigma_{INT}}{dQ'^2 dt d\cos\theta d\varphi} = - \frac{\alpha_{em}^3}{4\pi s^2} \frac{1}{-t} \frac{M}{Q'} \frac{1}{\tau\sqrt{1-\tau}} \frac{1+\cos^2\theta}{\sin\theta}$$

$$\tilde{M}^{--} \approx \frac{2\sqrt{t_0-t}}{M} \frac{1-\xi}{1+\xi} [F_1(t)\mathcal{H}(\xi, t)]$$

$$\mathcal{H}(\xi, t) = \sum_q e_q^2 \int_{-1}^1 dx \left(\frac{1}{\xi - x + i\epsilon} - \frac{1}{\xi + x + i\epsilon} \right) H^q(x, \xi, t)$$

Interference term

In terms of helicity amplitudes:

$$\frac{d\sigma_{INT}}{dQ'^2 dt d(\cos\theta) d\varphi} = -\frac{\alpha_{em}^3}{4\pi s^2} \frac{1}{-t} \frac{M}{Q'} \frac{1}{\tau\sqrt{1-\tau}} \frac{L_0}{L} \left[\cos\varphi \frac{1+\cos^2\theta}{\sin\theta} \text{ (green oval)} \right. \\ \left. - \cos 2\varphi \sqrt{2} \cos\theta \text{ (green oval)} + \cos 3\varphi \sin\theta \text{ (green oval)} + O\left(\frac{1}{Q'}\right) \right],$$

$$\text{ (yellow circle) } \frac{\alpha_{em}^3}{4\pi s^2} \frac{1}{-t} \frac{M}{Q'} \frac{1}{\tau\sqrt{1-\tau}} \frac{L_0}{L} \left[\sin\varphi \frac{1+\cos^2\theta}{\sin\theta} \text{ (blue oval)} \right. \\ \left. - \sin 2\varphi \sqrt{2} \cos\theta \text{ (blue oval)} - \sin 3\varphi \sin\theta \text{ (blue oval)} + O\left(\frac{1}{Q'}\right) \right]$$

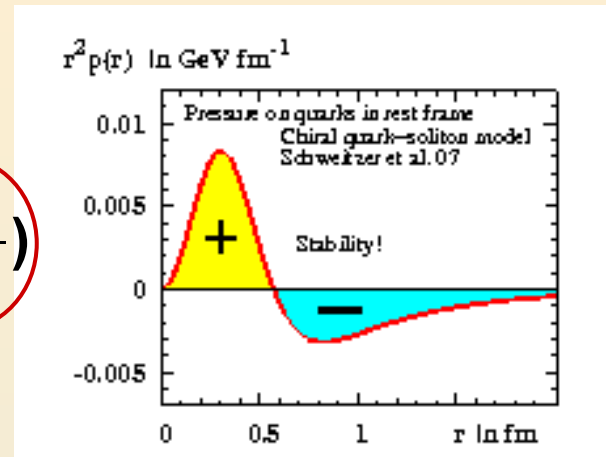


circular polarization of incoming photon also gives access to imaginary part

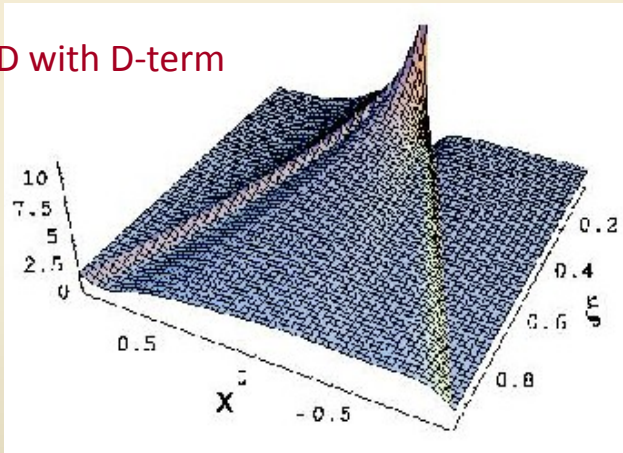
$$\frac{1}{2} \sum_{\lambda, \lambda'} |M^{\lambda', \lambda-}|^2 = (1 - \eta^2) \left(\text{ (red circle) }^2 + \text{ (red circle) }^2 \right) - 2\eta^2 \text{Re} \left(\text{ (red oval)} + \text{ (red oval)} \right) \\ - \left(\eta^2 + \frac{t}{4M^2} \right) \text{ (red circle)} - \eta^2 \frac{t}{4M^2} \text{ (red circle)},$$

The D-term and the pressure balance in the nucleon

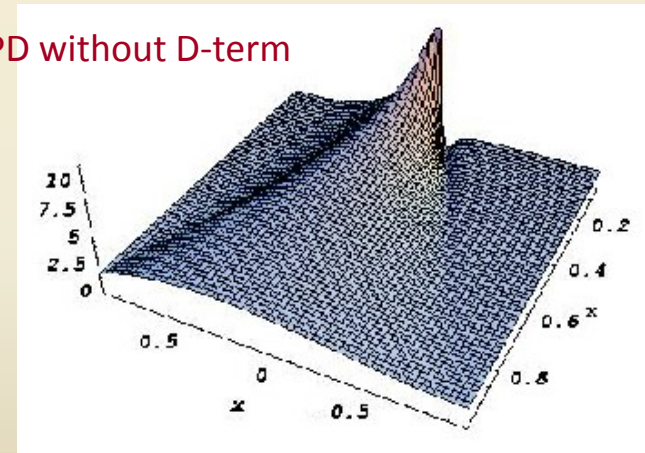
$$H(x, \xi) = H_{DD}(x, \xi) + \theta(\xi - |x|) \frac{1}{N_f} D\left(\frac{x}{\xi}\right)$$



GPD with D-term



GPD without D-term



- The D-term contributes only to the real part of the Compton amplitude

TCS NLO

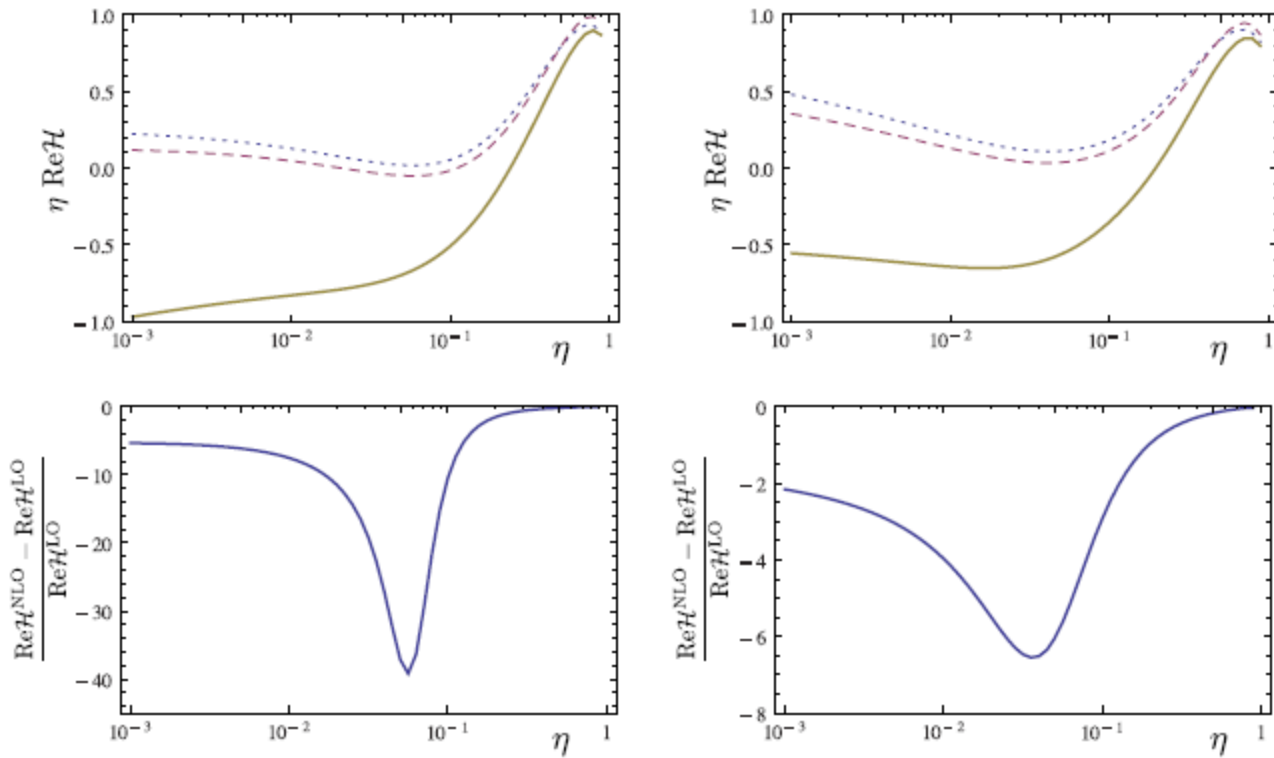


Figure 4: The real part of the *timelike* Compton Form Factor \mathcal{H} multiplied by η , as a function of η in the double distribution model based on Kroll-Goloskokov (upper left) and MSTW08 (upper right) parametrizations, for $\mu_F^2 = Q^2 = 4 \text{ GeV}^2$ and $t = -0.1 \text{ GeV}^2$. Below the ratios of the NLO correction to LO result of the corresponding models.

DVCS NLO

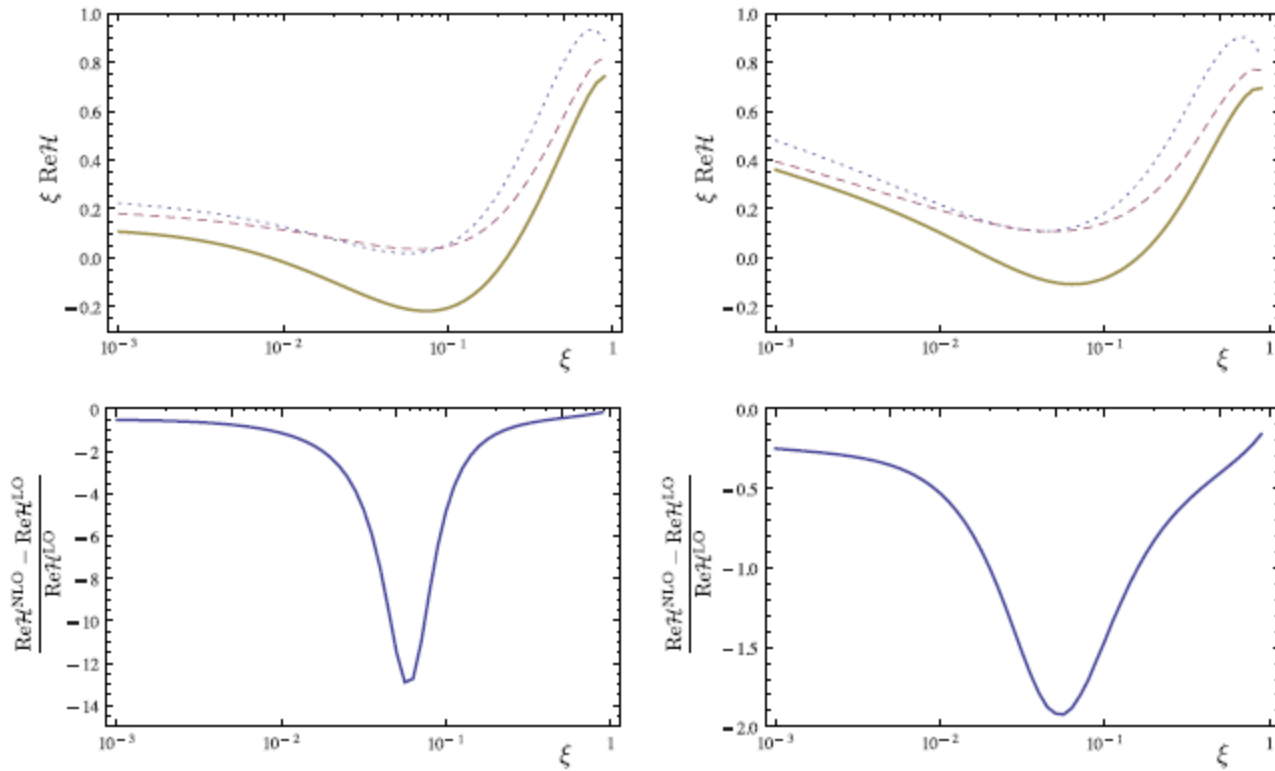


Figure 1: The real part of the *spacelike* Compton Form Factor $\mathcal{H}(\xi)$ multiplied by ξ , as a function of ξ in the double distribution model based on Kroll-Goloskokov (upper left) and MSTW08 (upper right) parametrizations, for $\mu_F^2 = Q^2 = 4 \text{ GeV}^2$ and $t = -0.1 \text{ GeV}^2$, at the Born order (dotted line), including the NLO quark corrections (dashed line) and including both quark and gluon NLO corrections (solid line). Below the ratios of the NLO correction to LO result in the corresponding models.

Bacup jpsi

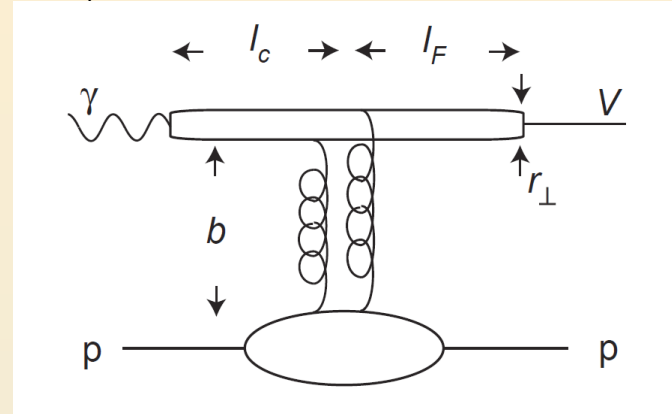
Introduction

- Dilepton production can be used to probe
 - strongly interacting quark-gluon plasma (RHIC)
 - gluon distribution in nucleon (HERA)
 - Drell-Yan, resonances ...
- Dilepton production at JLab 12GeV
 - J/ψ production near threshold for gluonic interaction
 - Timelike Compton Scattering (TCS) for GPD

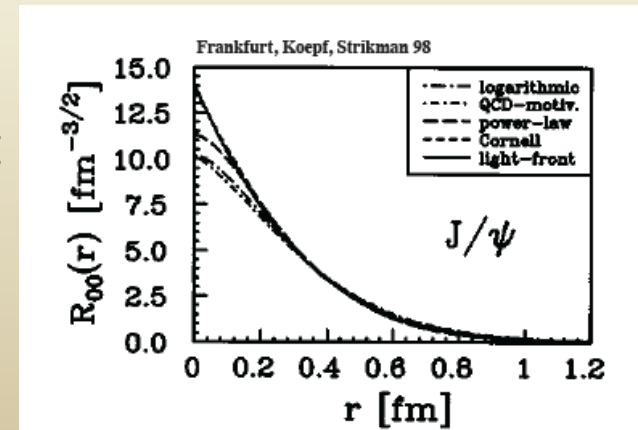
J/ψ Production on Neutron

$$J/\psi(1S): I^G(J^{PC}) = 0^-(1^{--}) \quad M_{J/\psi} \approx 3.097 \text{ GeV} \quad \text{Width: 93 KeV}$$

Probe strong color field
in nucleon



- J/ψ is a **charm-anti-charm** system
 - Little (if not zero) common valence quark between J/ψ and nucleon
 - Quark exchange interactions are strongly suppressed
 - Pure gluonic interactions are dominant
- Charm quark is heavy $\gg \Lambda_{QCD}$
 - Typical size of J/ψ is 0.2-0.3 fm
 - Impact distance $b \sim 1/m_c \sim 0.1 \text{ fm}$

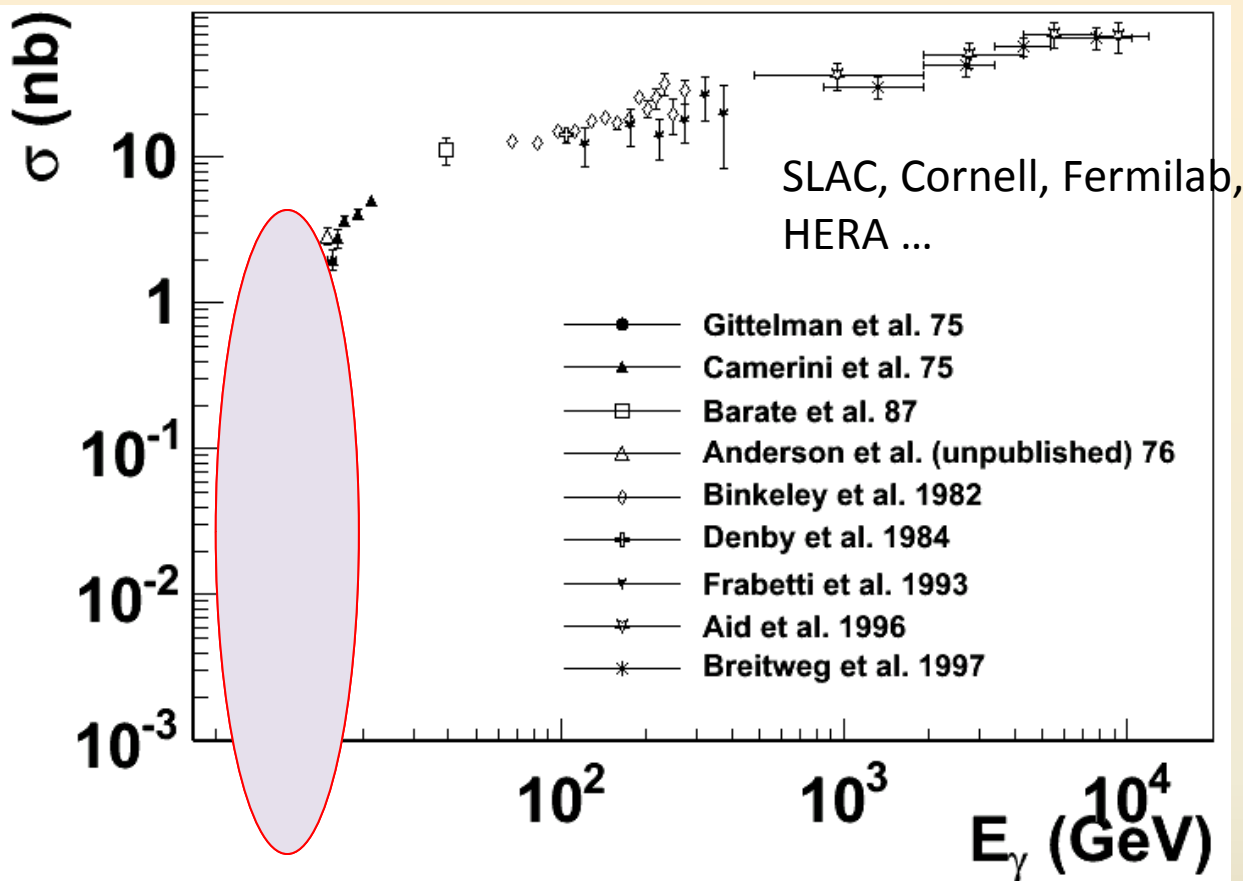


Interaction between J/ψ -N

New scale provided by the charm quark mass and size of the J/ψ

- OPE, Phenomenology, Lattice QCD ...
- High Energy region: Pomeron picture ...
- Medium/Low Energy: 2-gluon exchange
- Very low energy: QCD **color** Van der Waals force
 - Prediction of J/ψ -Nuclei bound state
 - Brodsky et al.
- Experimentally no free J/ψ are available
 - Challenging to produce close to threshold!
 - **Photo/electro-production of J/ψ at JLab is an opportunity**

Experimental Status



More data exist with inelastic scattering on nuclei, such as A-dependence.

Not included are the most recent results from HERA
H1/ZEUS at large momentum transfers and diffractive production with electro-production

- Intense experimental effort (SLAC, Cornell ...) shortly after the discovery of J/ψ
- But near threshold not much since. JLab 12GeV has the access now.

Reaction Mechanism

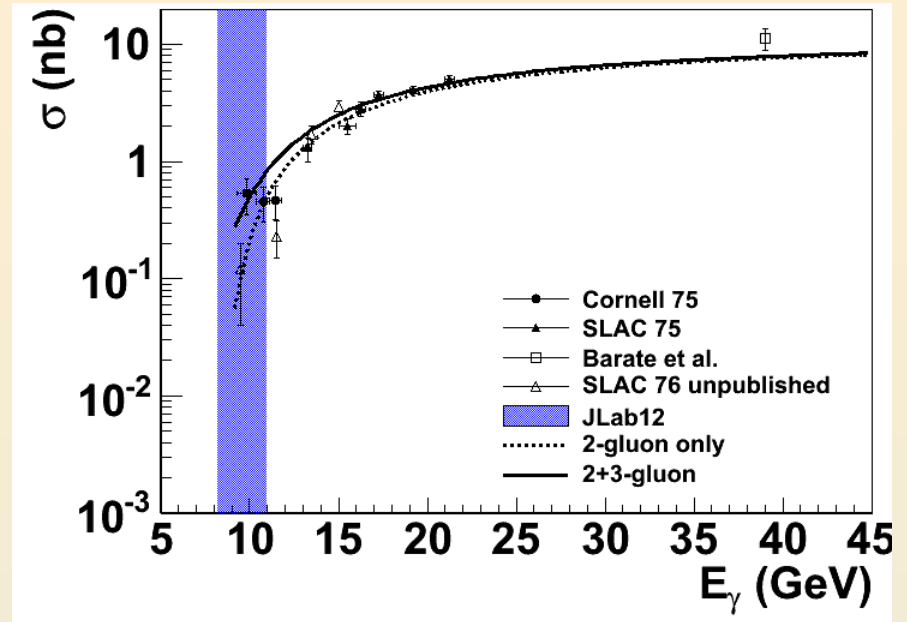
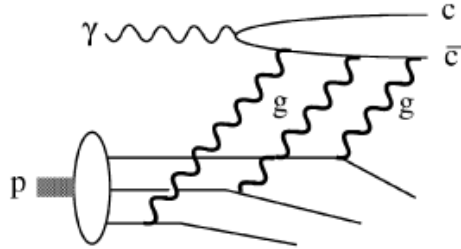
Model-I: Hard scattering mechanism
(Brodsky, Chudakov, Hover. Laget 2001)

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

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

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

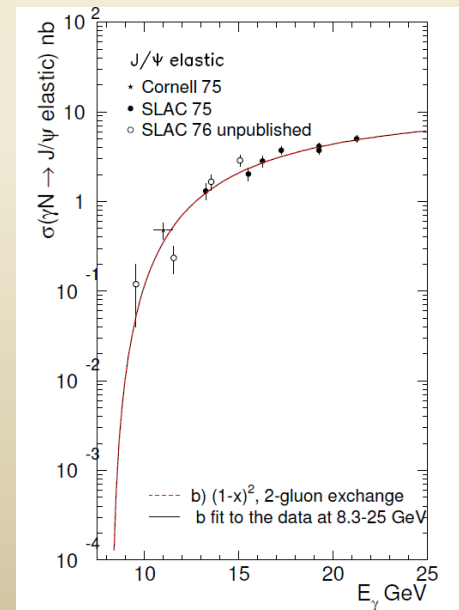
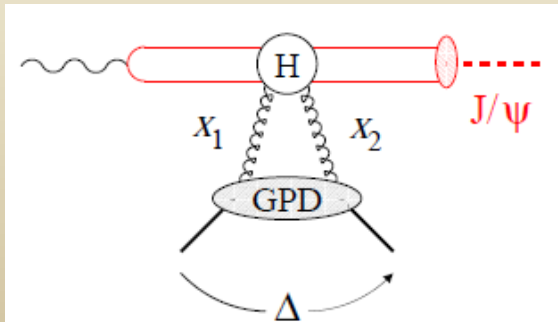
$$x = \frac{2M_p M_{J/\psi} + M_{J/\psi}^2}{2E_\gamma M_p}$$



Model -II: Partonic soft mechanism
(Frankfurt and Strikman, PRD 66, 031502 [2002])

2-gluon Form Factor

$$F.F. \propto (1 - t/1.0 \text{ GeV}^2)^{-4}$$



Reaction mechanism

Model-III: soft mechanism, final state interaction?

D. Kharzeev. Quarkonium interactions in QCD, 1995,

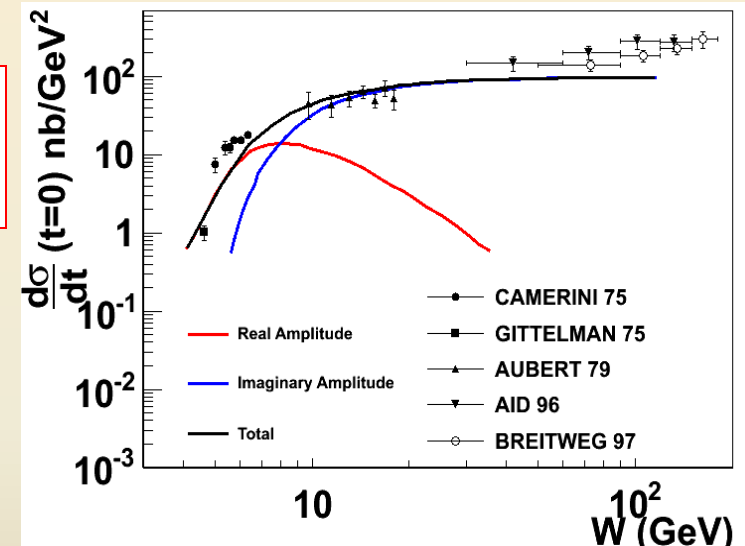
D. Kharzeev, H. Satz, A. Syamtomov, and G. Zinovjev, Eur.Phys.J., C9:459–462, 1999)

$$\frac{d\sigma_{\gamma N \rightarrow \psi N}}{dt}(s, t=0) = \frac{3\Gamma(\psi \rightarrow e^+e^-)}{4m_{\psi}} \left(\frac{k_{\psi N}}{k_{\gamma N}} \right)^2 \frac{d\sigma_{\psi N \rightarrow \psi N}}{dt}(s, t=0)$$

$$\frac{d\sigma_{\psi N \rightarrow \psi N}}{dt}(s, t=0) = \frac{1}{64\pi} \frac{1}{m_{\psi}^2(\lambda^2 - m_N^2)} |\mathcal{M}_{\psi N}(s, t=0)|^2$$

$$\langle N | \frac{1}{2} \vec{E}^a \cdot \vec{E}^a | N \rangle = \frac{4\pi^2}{b} \langle N | \theta_{\mu}^{\mu} | N \rangle + 2\pi\alpha_s \langle N | \theta_G^{00} | N \rangle,$$

- **Imaginary part** is related to the total cross section through optical theorem
- **Real part** contains the *conformal (trace) anomaly* which Dominate the near threshold region

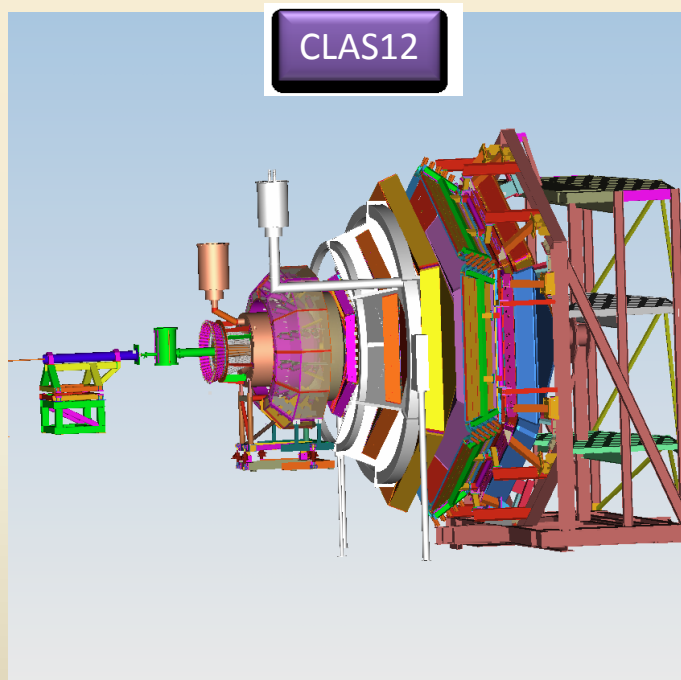


A measurement near threshold could shed light on the conformal anomaly which accounts for a portion of proton mass

X. Ji PRL 74 1071 (1995)

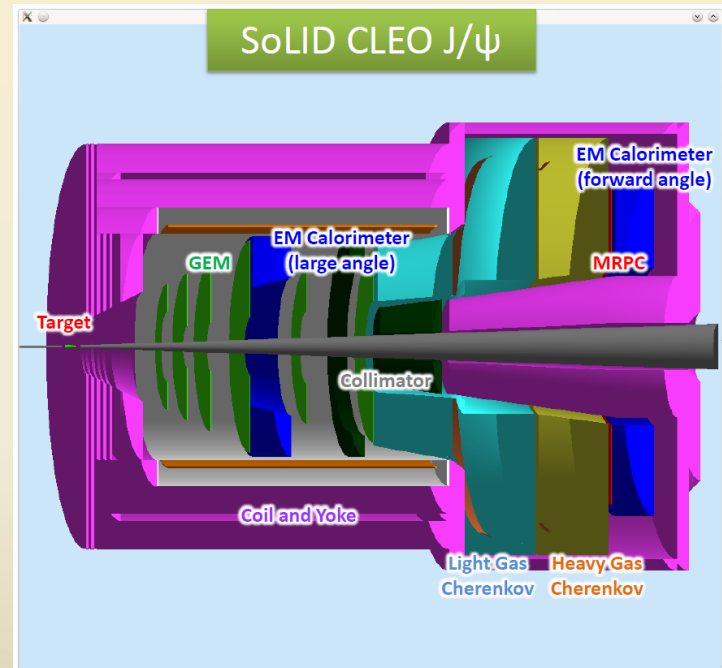
Hungry for Data from JLab 12GeV

11GeV beam and luminosity upgrade enable the measurement of the energy and t dependence of J/ψ cross sections near threshold



E12-12-001

approved for 120 days



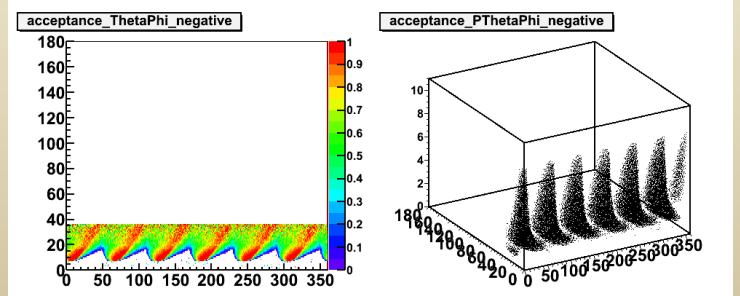
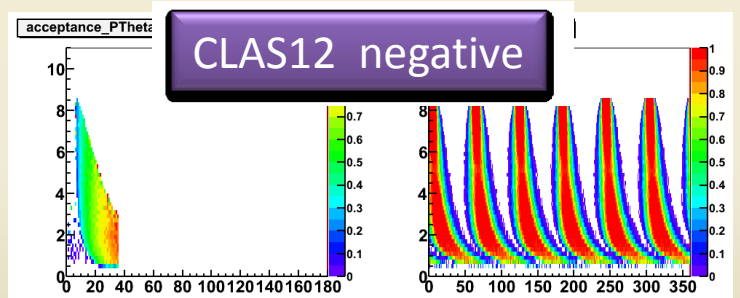
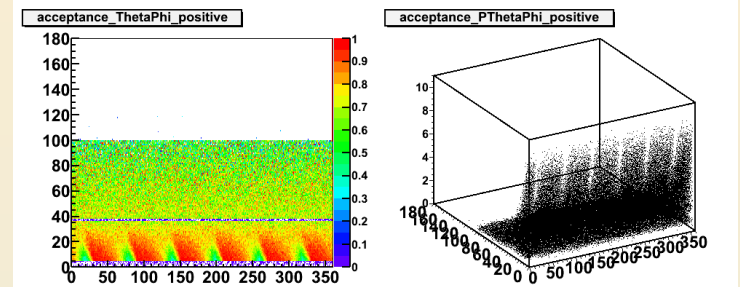
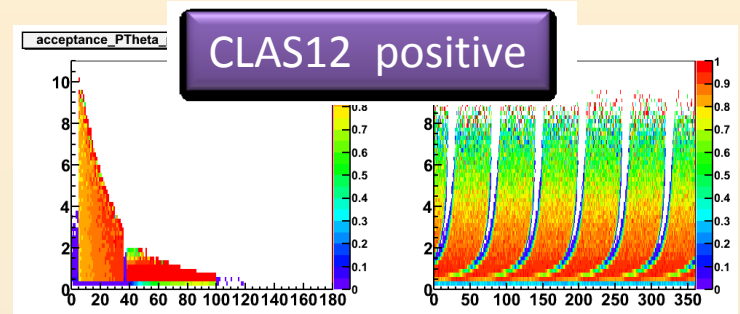
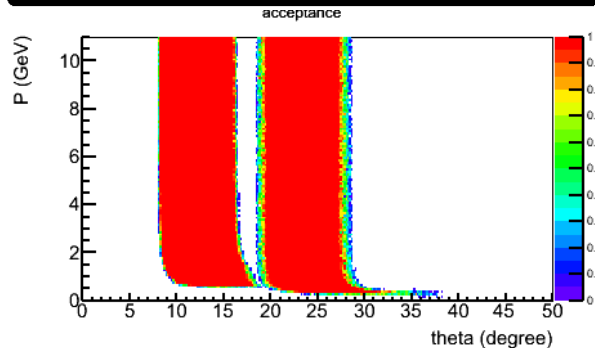
E12-12-006

approved for 60 days

CLAS12 and SoLID: Acceptance

	CLAS12	SoLID
e^- and e^+ coverage	$\theta(5^\circ - 36^\circ)$ ϕ ($\sim 80\%$ full) Asymmetric	$\theta(8^\circ - 17^\circ)$ $\theta(18^\circ - 28^\circ)$ ϕ (full) Symmetric
proton coverage	$\theta(5^\circ - 36^\circ)$ $\Theta(38^\circ - 125^\circ)$ ϕ ($\sim 80\%$ full)	$\theta(8^\circ - 17^\circ)$ $\theta(18^\circ - 28^\circ)$ ϕ (full)
Luminosity	$10^{35}/\text{cm}^2/\text{s}$	$10^{37}/\text{cm}^2/\text{s}$

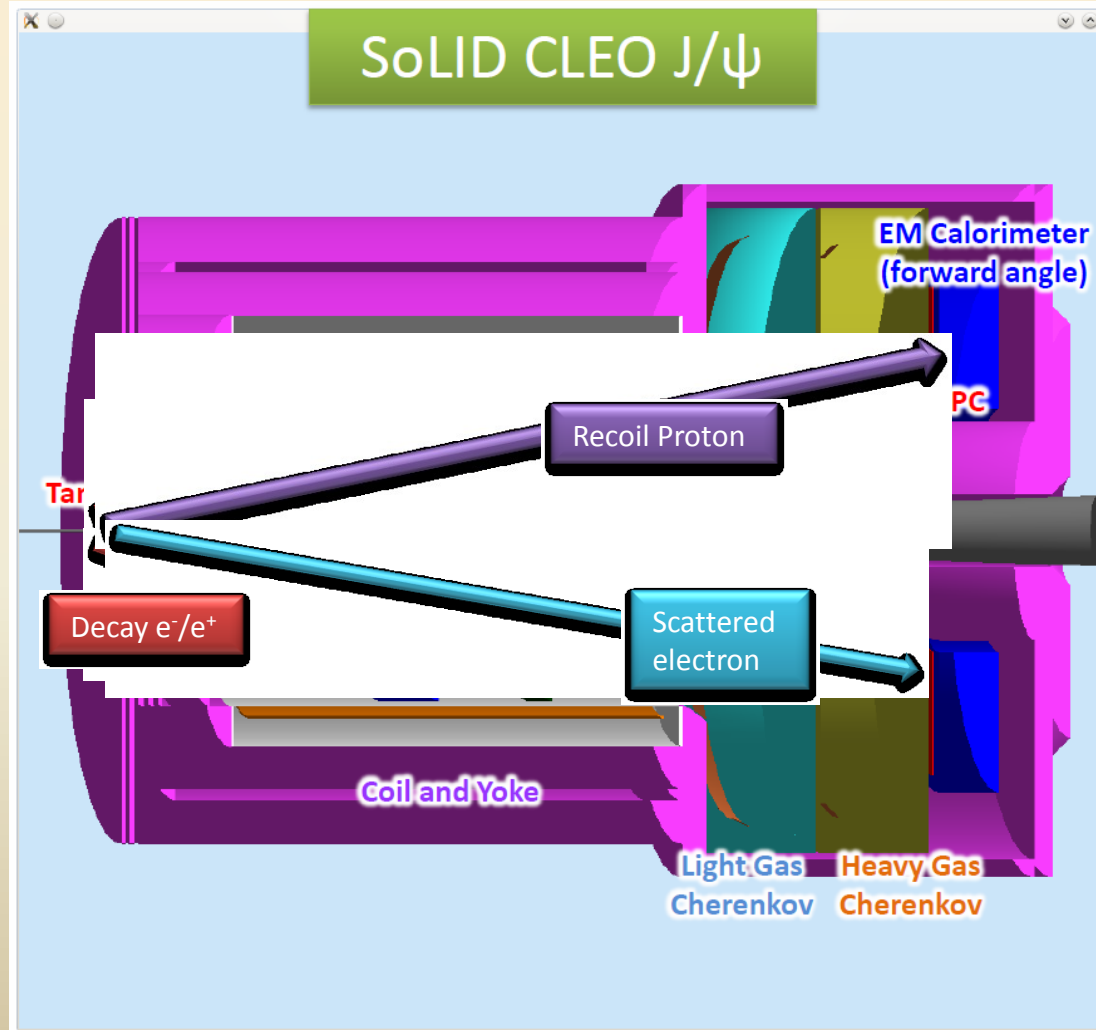
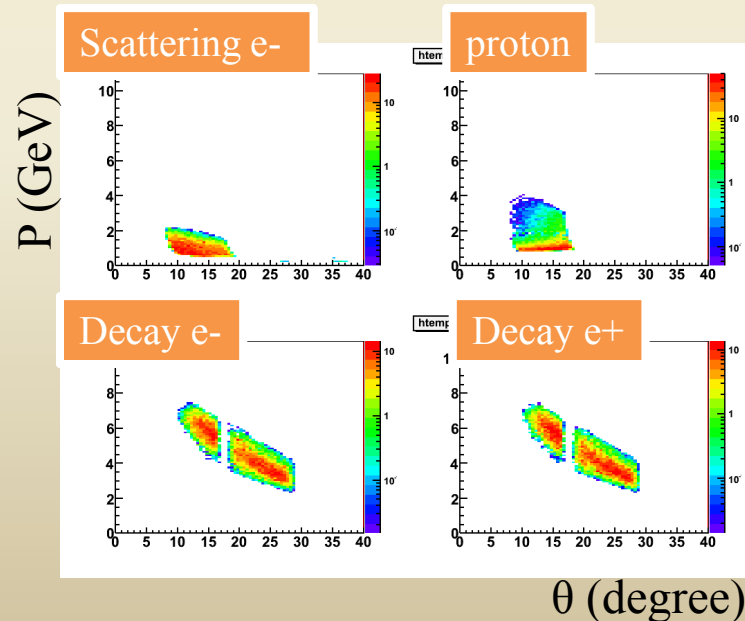
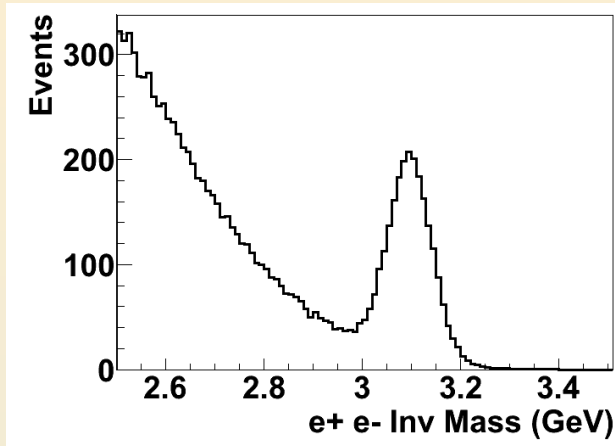
SoLID positive and negative



SoLID J/ψ Detection

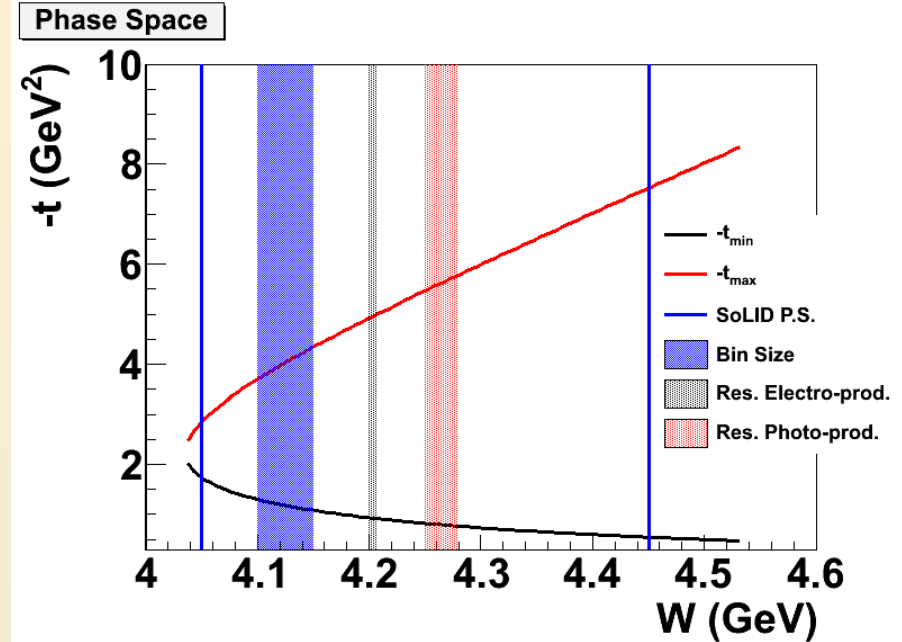
$$e^- + p \longrightarrow e^- + p + J/\Psi(e^- + e^+)$$

Possible to detect all 4 final particles, fully exclusive production



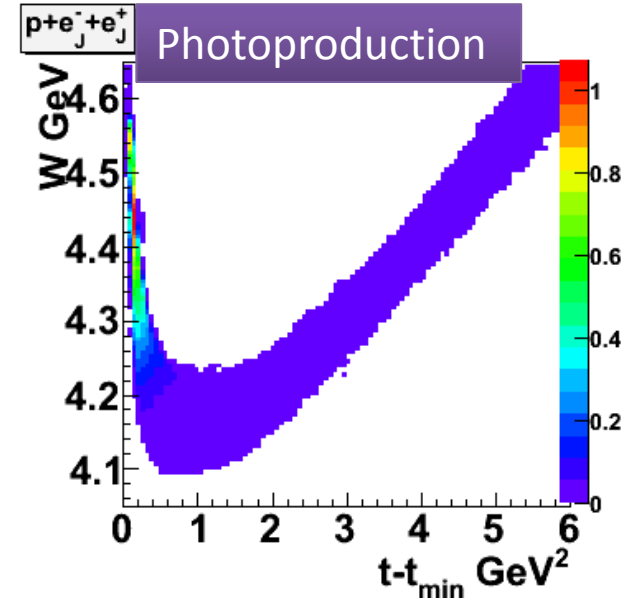
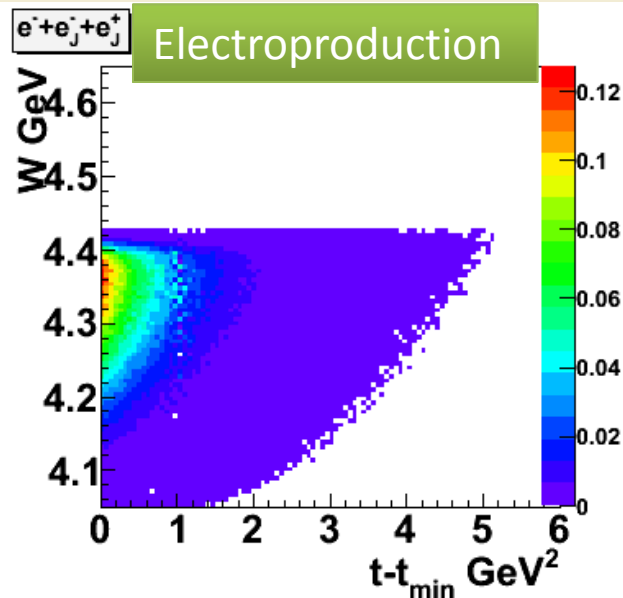
Electroproduction vs Photoproduction

- Better resolution near threshold
 - use of a tagged photon beam
- Larger coverage in t
- Lower radiation budget
- Less background (full exclusivity)
- Near threshold



Electroproduction
is very important

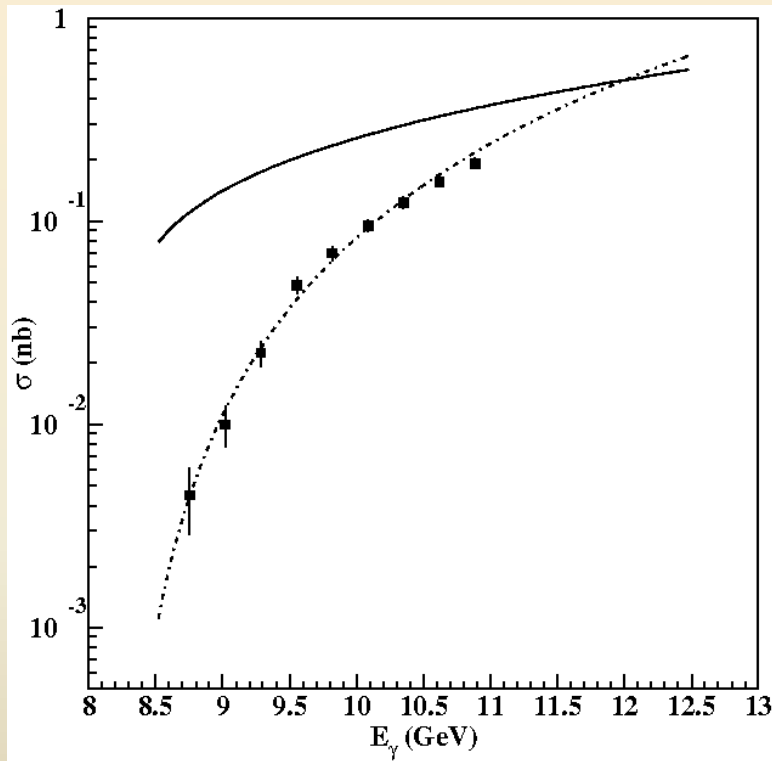
$$\begin{aligned}
 W^2 &= 2\nu \cdot M_p + M_p^2 - Q^2 \\
 &= 2E_{\gamma}^{\text{eff}} \cdot M_p + M_p^2
 \end{aligned}$$



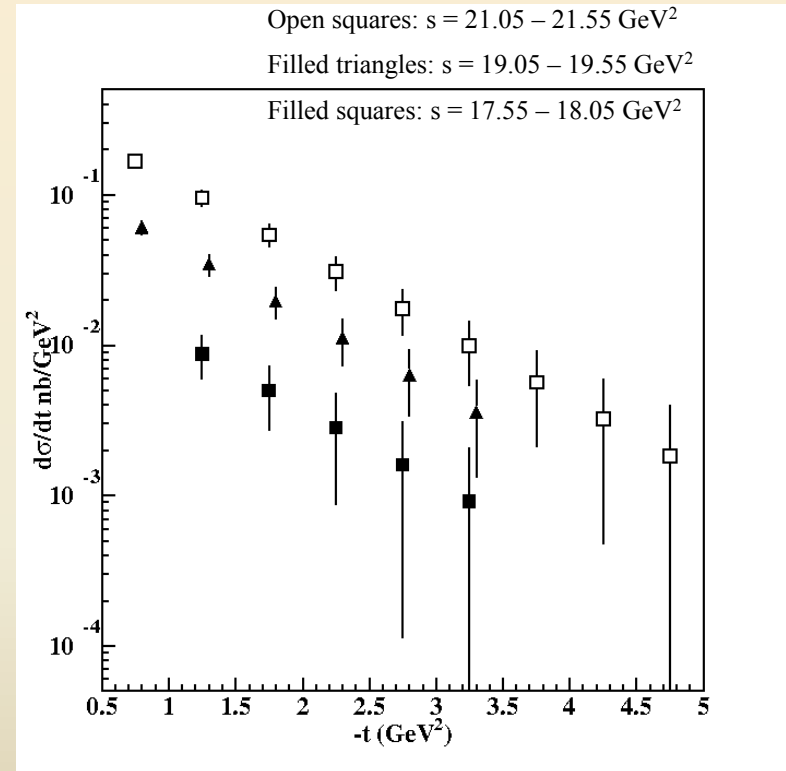
CLAS12 J/ψ Projection

exclusive J/ψ production

Statistical uncertainties for 100 days at a luminosity of $10^{35} \text{ cm}^{-2}\text{s}^{-1}$



Uncertainties for the total cross section assuming the most conservative prediction

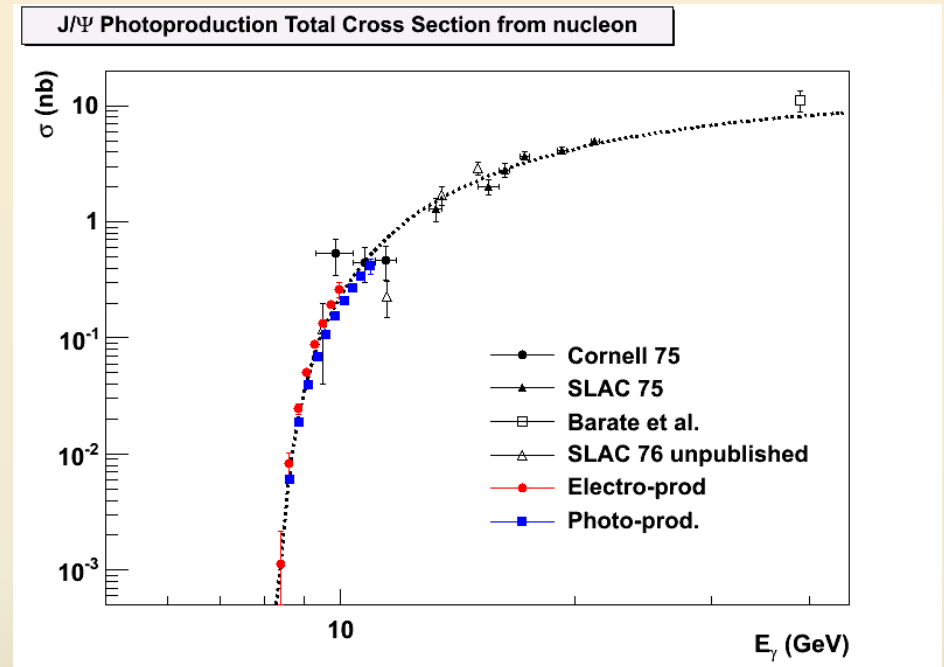
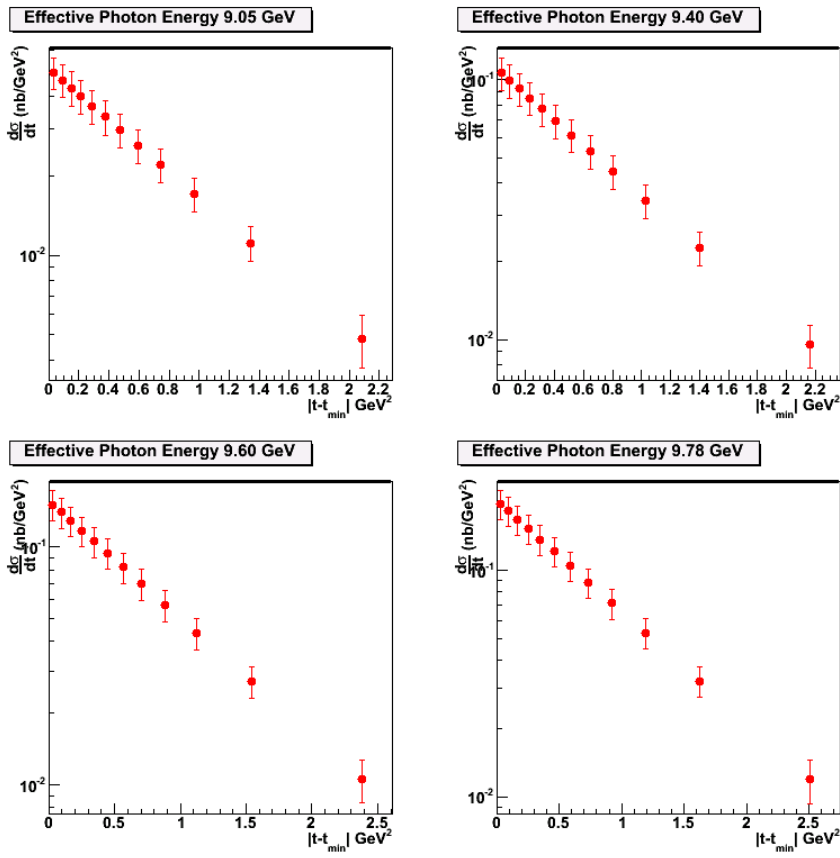


t -dependence in narrow bins of s for a total cross section given by the lower curve on the left

SoLID J/ ψ Projection

50 days of $3\mu\text{A}$ beam on a 15 cm long LH_2 target
at luminosity $10^{37}/\text{cm}^2/\text{s}$

t-dependence of the differential
cross section



With $< 0.01\text{ GeV}$ energy resolution in W
and 8 energy bins in W to
study the threshold behavior of cross
section

J/ψ at JLab 12GeV

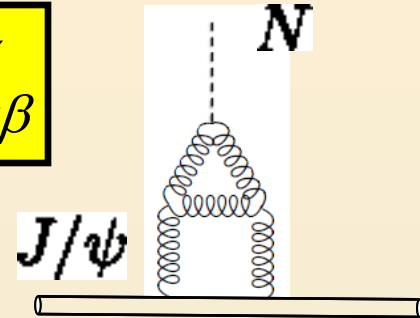
- Its production near threshold will be explored with both photoproduction and electroproduction
- Good energy resolution and large statistics can constrain models and shed lights on the gluonic interaction
- *CLAS12 and SoLID will run at different time and be well complementary*

Backup JPsi

Conformal (Trace) Anomaly

Trace of energy momentum tensor

$$G^{\alpha\beta\gamma} G^{\gamma}_{\alpha\beta}$$



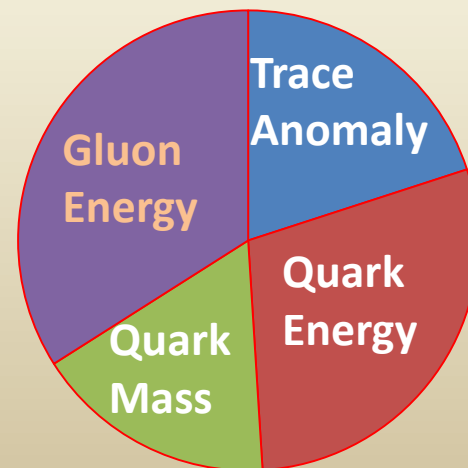
“Beta” function energy evolution of strong interaction coupling constant

$$\langle N | \frac{\beta(g)}{2g} G^{\alpha\beta\gamma} G^{\gamma}_{\alpha\beta} + \sum_{u,d,s} m_q \bar{q}q | N \rangle = M_N$$

Proton Mass Budget

CM frame $\overline{MS} @ 1\text{GeV}^2$

[X. Ji PRL 74 1071 (1995)]



20%

29%

17%

34% 44

Cross Section Validation

$$e + p \rightarrow e' + V(e^- + e^+) + p$$

	Bethe-Heitler	ω	ρ	ϕ	η
Cross Section	0.1 ub	1ub	1ub	50 nb	10 ub
Decay Channel and BR	e^+e^- 1.0	e^+e^- $7.30 \cdot 10^{-5}$	e^+e^- $4.71 \cdot 10^{-5}$	e^+e^- $2.97 \cdot 10^{-4}$	$\gamma\gamma$ 0.39
Compared to J/ψ	>10	x2	x1	x0.5	Large
SoLID capability	good	good	good	good	good

- ⦿ e+p elastic channel: (2.2 and 4.4 GeV beam)
SoLID Optics Calibration Channel for electrons
- ⦿ SIDIS charged pion (also DIS)
SIDIS program, comparing with Hall C measurements

Systematic Budget

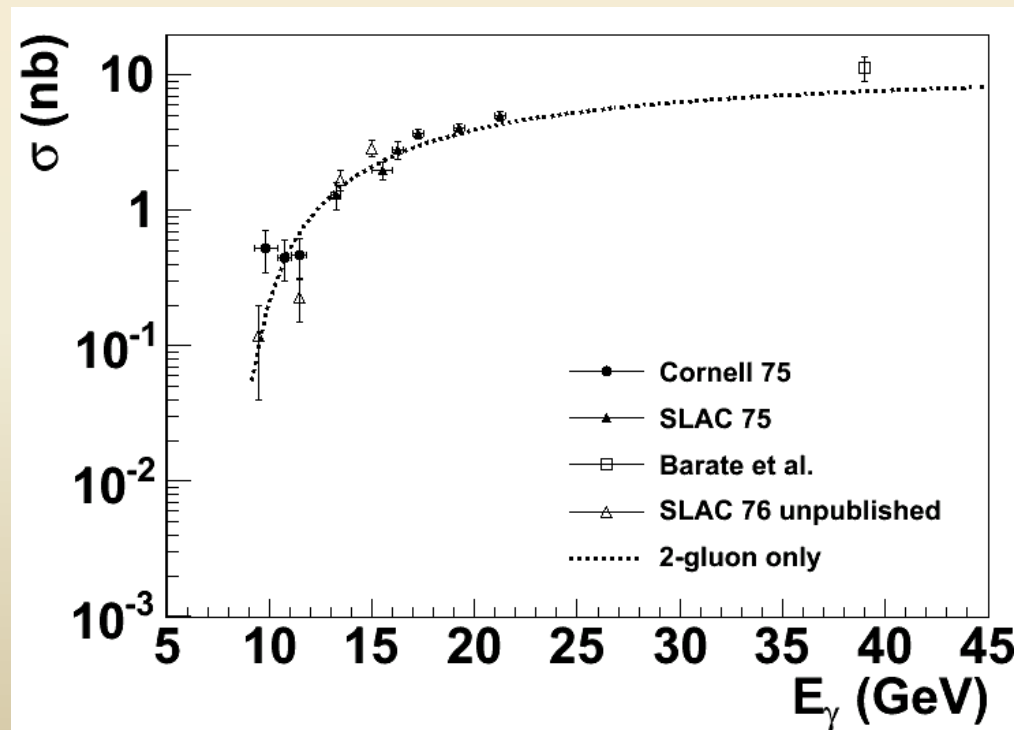
- Acceptance Effect: 10% for triple coincidence
- Detector and Trigger Efficiency $< 2\%$
- Target Luminosity: $< 2\%$
- Contribution from Al wall $< 1\%$
 - Dummy run + target vertex Cut
- Background Contamination $\sim 0.5\%$
 - B-H background + Random Coincidence (measured directly)

Goal: 10-15% cross section measurements

Rates Estimates

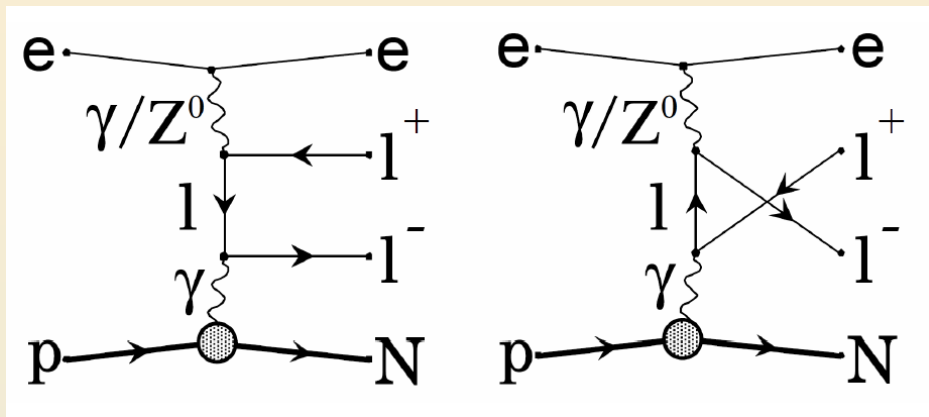
$$\frac{d^5\sigma}{d\Omega_e dP_e d\Omega_P} = \Gamma \frac{J}{2\pi} \frac{d\sigma}{dt}$$

- Used equivalent photon approximation
- Γ is the virtual photon flux and J is the Jacobian
- Cross section is based on fits to data at high W within the 2-gluon exchange model



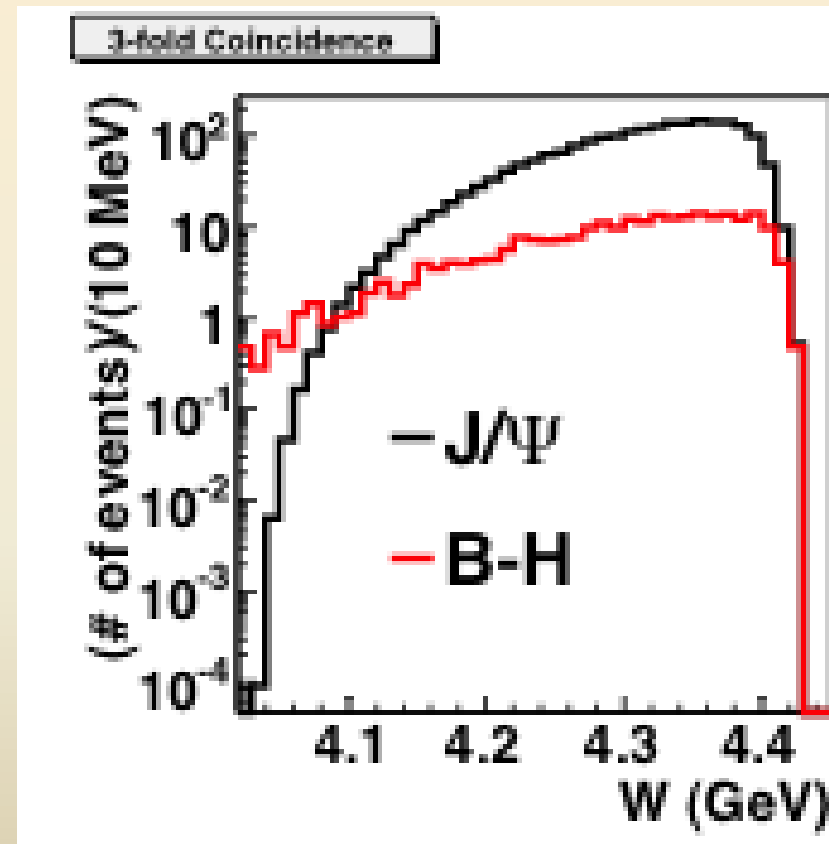
Physics Background

- Due to large mass of J/ψ and near-threshold kinematics, little physics background
 - The main background is Bethe-Heitler term



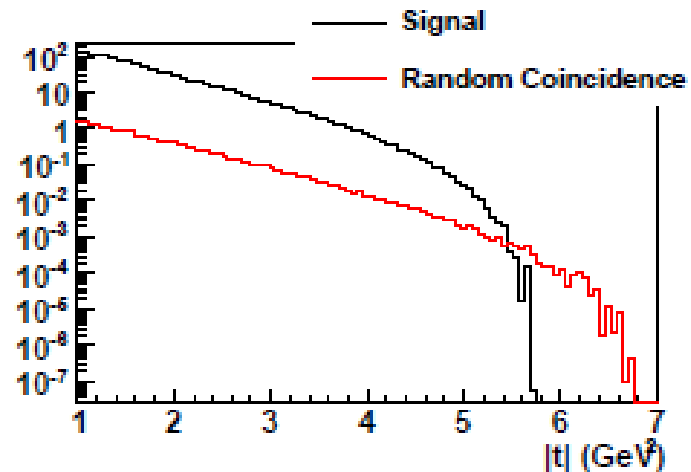
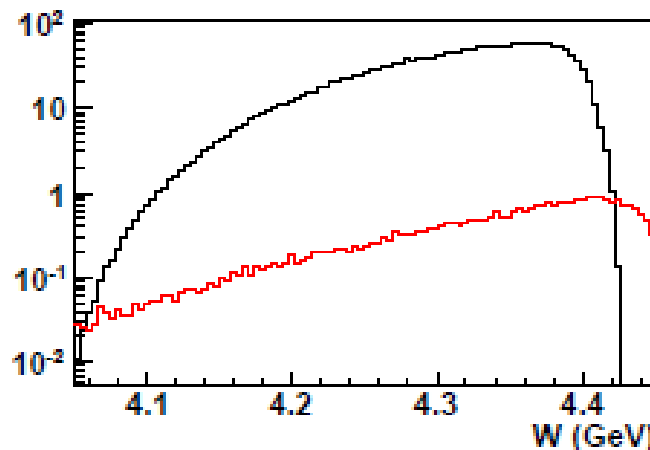
⊙ B-H process calculated with GRAPE-Dilepton program. Compared with 2-gluon model assuming no threshold enhancement.

The t-dependence background level is acceptable.



Random Coincidence Background

- Studied with Pythia and can be subtracted.
 - Largest contribution coming from J/ψ photoproduction in random coincidence with a scattered electron.
 - With the same 2-gluon model, we calculated the random coincidence rate after all cuts and a 6 ns window.



Do not expect a problem either from physics (B-H) or random coincidence background!

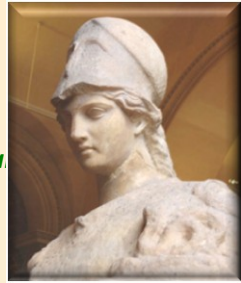
Expected rates with different detectors

The lowest energy bin:

- $8.5 < E_\gamma < 9.0 \text{ GeV}$
- Cross section 0.01 nb
- Minimal statistics ~ 400 events

Setup	E_{e^-} GeV	I_{e^-} μA	RL eff	N_γ Hz	E_{e^-} meas	target cm	BR	Accept	J/ψ /day
Hall C	11	50	0.09	$1.4 \cdot 10^{12}$		20	0.12	0.03%	40
Hall B	11	0.03	0.02	$2.2 \cdot 10^8$	MM	10	0.06	10%	0.4
Hall D	12			$1 \cdot 10^7$	tag	30	0.06	50%	0.3
SoLID	11	1.0	0.04	$1.4 \cdot 10^{10}$	MM	40	0.06	20%	240

ATHENNA Collaboration



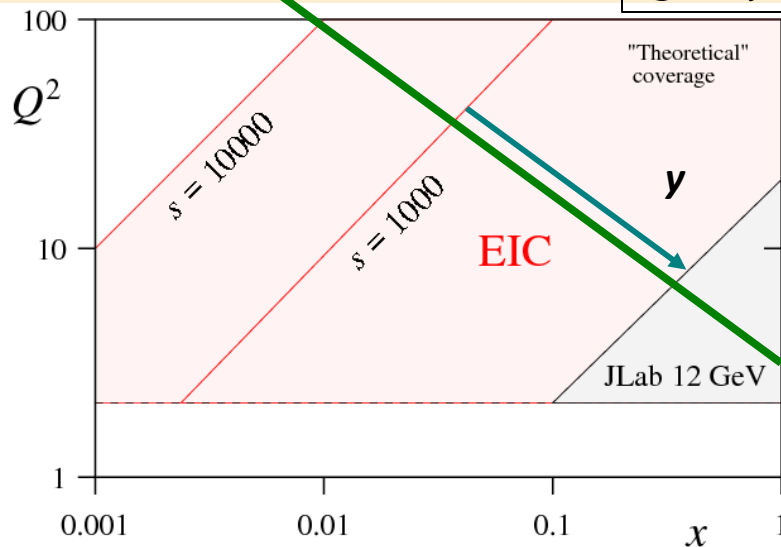
J. Arrington, N. Baltzell, A. El Alaoui, D. F. Geesaman, K. Hafidi (*Co-spokesperson*), R. J. Holt, D. H. Potterveld, P. E. Reimer (*Argonne National Argonne, IL*)
X. Qian (*Co-spokesperson*) (*California Institute of Technology, Pasadena, CA*)
K. Aniol (*California State University, Los Angeles, CA*)
J. C. Cornejo, W. Deconinck, V. Gray (*College of William & Mary, Williamsburg, VA*)
X. Z. Bai, H. X. He, S. Y. Hu, S. Y. Jian, X. M. Li, C. Shan, H. H. Xia, J. Yuan, J. Zhou, S. Zhou (*China Institute of Atomic Energy, Beijing, P. R. China*)
P. H. Chu, H. Gao, M. Huang, S. Jawalkar, G. Laskaris, M. Meziane, C. Peng, Q. J. Ye, Y. Zhang, X. F. Yan (*Duke University, Durham, NC*)
P. Markowitz (*Florida International University, Miami, FL*)
A. Afanasev (*The George Washington University, Washington, DC*)
F. J. Jiang, H. J. Lu, X. H. Yan (*Huangshan University, Huangshan, P. R. China*)
J. B. Liu, W. B. Yan, Y. Zhou, Y. X. Zhao (*University of Science and Technology of China, Hefei, P. R. China*)
K. Allada, A. Camsonne, J.-P. Chen, E. Chudakov, J. Gomez, M. Jones, J. J. Lerose, B. Michaels, S. Nanda, P. Solvignon, Y. Qiang (*Jefferson Lab, Newport News, VA*)
M. Mihovilovič, S. Širca (*Jožef Stefan Institute of University of Ljubljana, Slovenia*)
G. G. Petratos, A. T. Katramatou (*Kent State University, Kent, OH*)
Y. Cao, B.T. Hu, W. Luo, M. Z. Sun, Y.W. Zhang, Y. Zhang (*Lanzhou University, Lanzhou, P. R. China*)
T. Holmstrom (*Longwood University, Farmville, VA*)
J. Huang, X. Jiang (*Los Alamos National Laboratory, Los Alamos, NM*)
J. Dunne, D. Dutta, A. Narayan, L. Ndukum, M. Shabestari, A. Subedi, L. Ye (*Mississippi State University, Mississippi State, MS*)
E. Cisbani, A. d. Dotto, S. Frullani, F. Garibaldi (*INFN-Roma and gruppo collegato Sanità and Italian National Institute of Health, Rome, Italy*)
M. Capogni (*INFN-Roma and gruppo collegato Sanità and ENEA Casaccia, Rome, Italy*)
V. Bellini, A. Giusa, F. Mammoliti, G. Russo, M. L. Sperduto, C. M. Sutura (*INFN-Sezione di Catania, Catania, Italy*)
D. Y. Chen, X. R. Chen, J. He, R. Wang, H. R. Yang, P. M. Zhang (*Institute of Modern Physics, Lanzhou, P. R. China*)
C. E. Hyde (*Old Dominion University, Hampton, VA*)
L. El Fassi, R. Gilman (*Rutgers University, Piscataway, NJ*)
S. Choi, H. Kang, H. Kang, Y. Oh (*Seoul National University, Seoul, Korea*)
P. Souder and R. Holmes (*Syracuse University, Syracuse, NY*)
W. Armstrong, A. Blomberg, D. Flay, E. Fuchey, M. Paolone, N. Sparveris (*Co-spokesperson*), Z.-E. Meziani (*Co-spokesperson/Contact*), M. Posik, E. Schulte (*Temple University, Philadelphia, PA*)
K. Kumar, J. Mammei, S. Riordan (*University of Massachusetts, Amherst, MA*)
T. Badman, S. K. Phillips, K. Slifer, R. Zielinski (*University of New Hampshire, Durham, NH*)
H. Badhdasaryan, G. D. Cates, M. Dalton, D. Day, D. Keller, V. V. Nelyubin, K. Paschke, A. Tobias, Z. W. Zhao (*Co-spokesperson*), X. Zheng (*University of Virginia, Charlottesville, VA*)
F. R. Wesselmann (*Xavier University of Louisiana, New Orleans, LA*)

TCS EIC

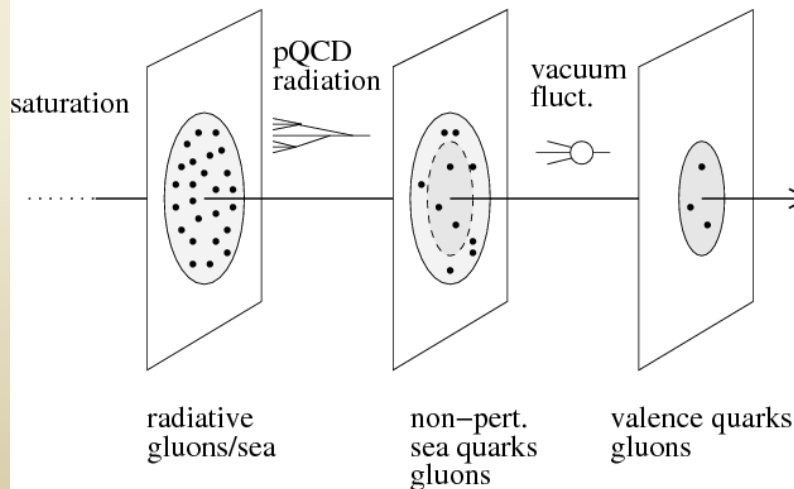
Dilepton Production at EIC

$$s = E_{cm}^2 (GeV^2)$$

$$Q^2 \sim y s x$$



C. Weiss



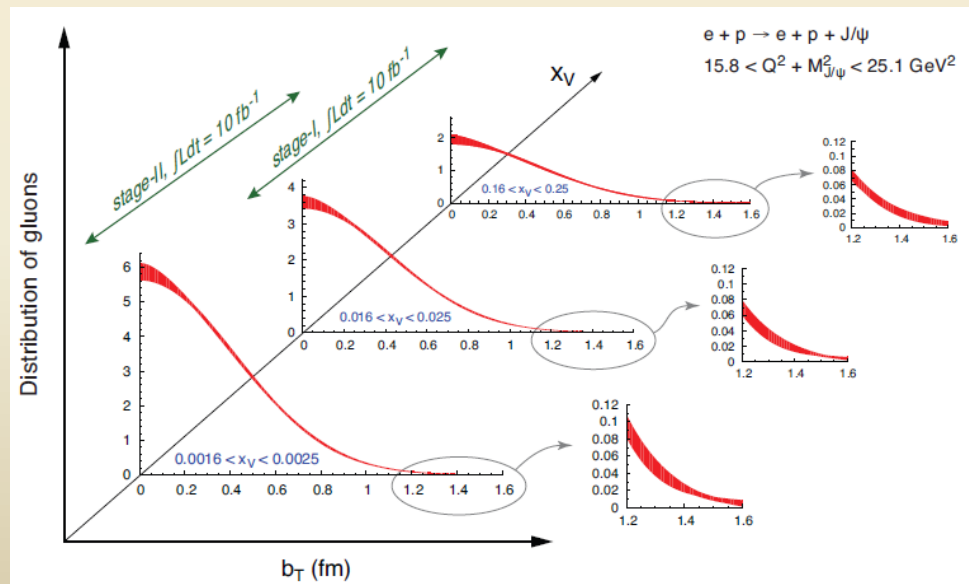
LHeC

EIC Stage II
(ELIC)

EIC Stage I
(MEIC)

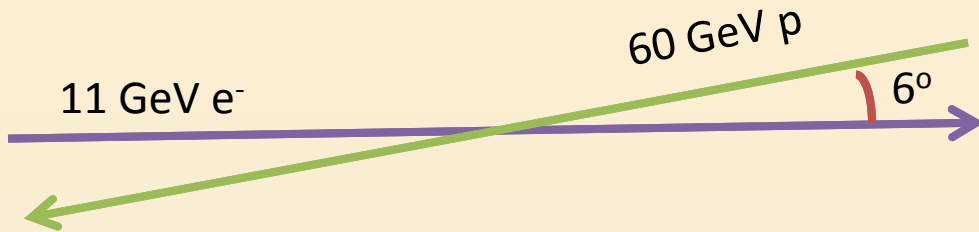
JLab 12 GeV

- GPDs with J/ψ
- GPDs with TCS, no need for positron beam like DVCS



Transverse gluon distribution from deep exclusive J/ψ electroproduction

TCS at MEIC



- JLab 12GeV reaches 0.2 for τ explores valence quarks.
- MEIC reaches 10^{-3} for τ and will explore the sea quarks and gluons.

- BH at resonance free region used for simulation
- Quasi- real scattering electron goes forward
- Recoil proton goes backward
- Decay leptons have large coverage in the middle

