Timelike Compton Scattering with SoLID

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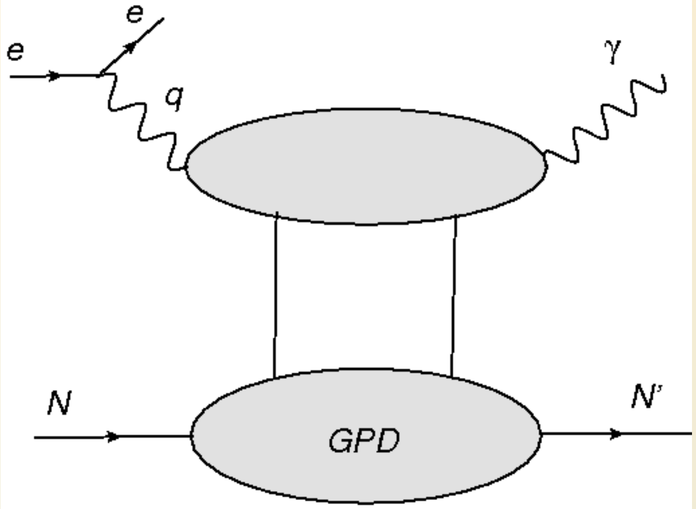
For TCS collaboration

2013/05/23

DVCS and TCS access the same GPDs

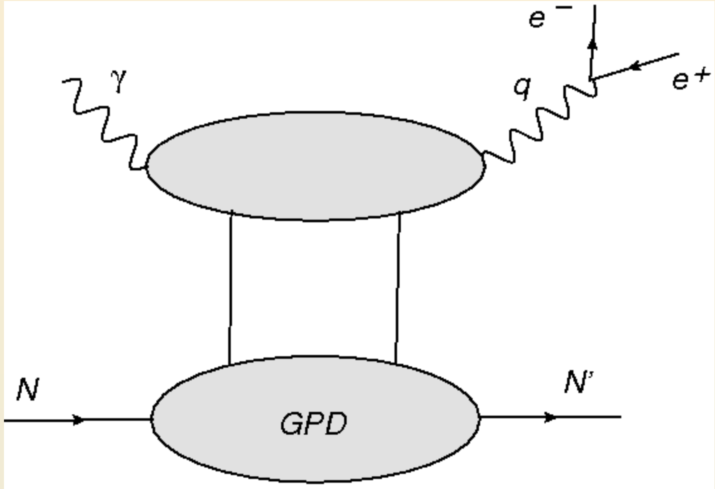
Spacelike Deeply Virtual Compton Scattering

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



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."

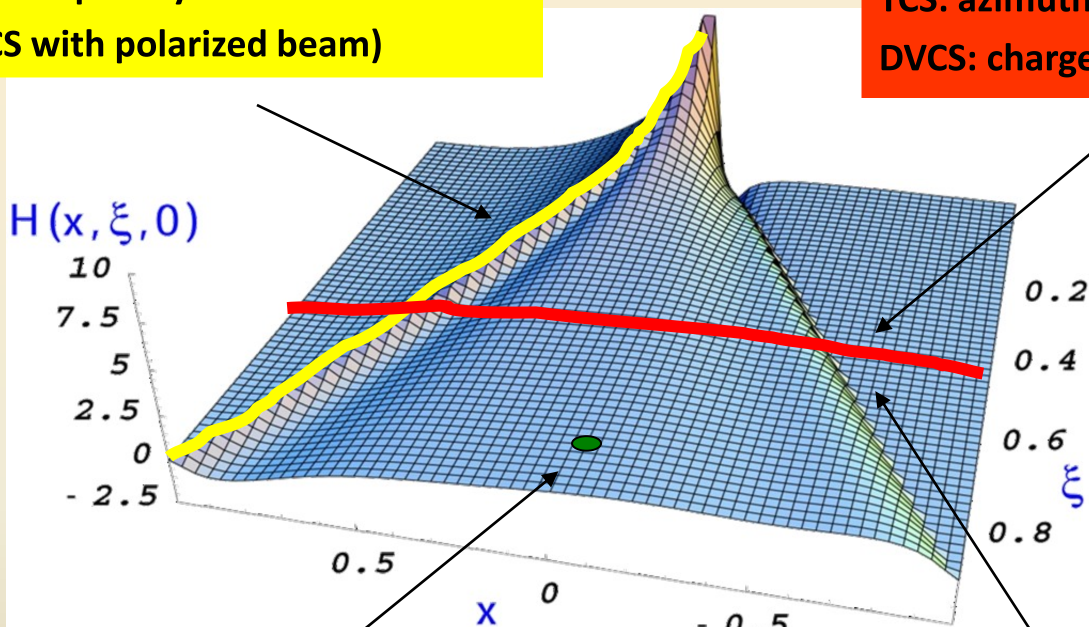
H. Moutarde et al. arXiv:1301.3819, 2013

General Compton Process

accessing GPDs

(Im, $x=\xi$)
DVCS: spin asymmetries
(TCS with polarized beam)

(Re)
TCS: azimuthal asymmetry
DVCS: charge asymmetry

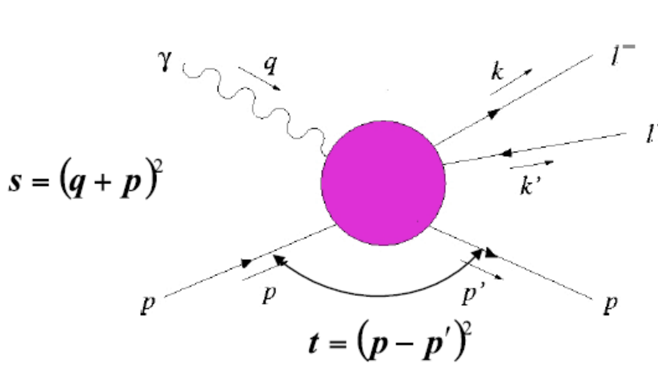


(Im, $x \neq \xi$, $x < |\xi|$)
Double DVCS

($|Im|^2+|Re|^2$)
DVCS: cross section

TCS

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

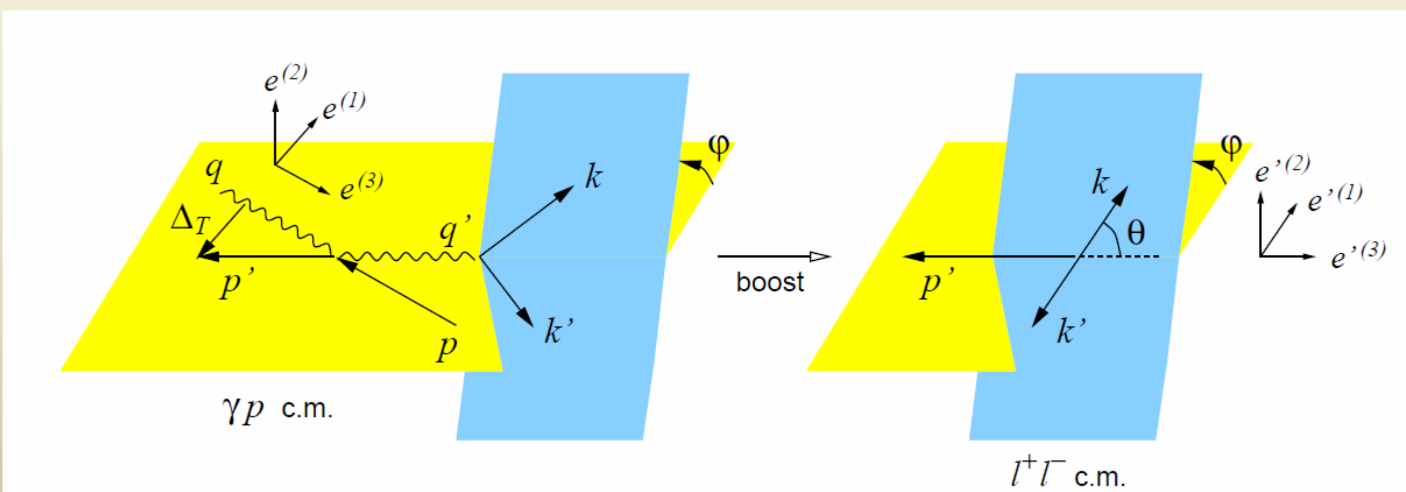


Hard scale

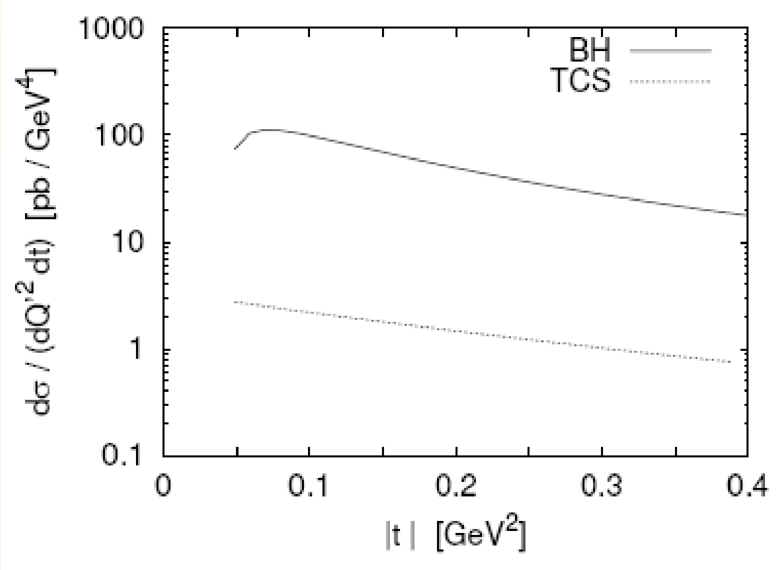
$$Q'^2 = M^2_{l^+l^-} = (k+k')^2$$

$$\eta = \frac{Q'^2}{2s - Q'^2}$$

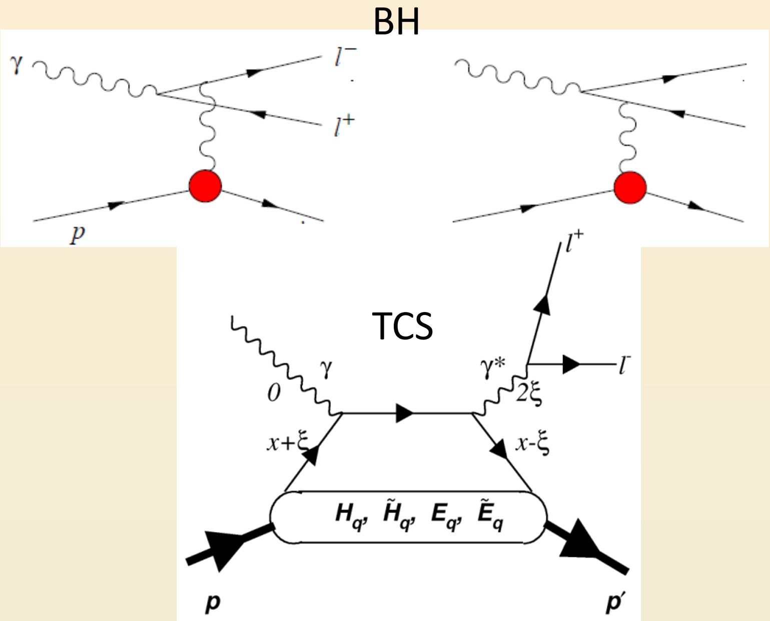
TCS	$\tau = \frac{Q'^2}{2p \cdot q} = \frac{Q'^2}{s - M^2}$	$\eta = \tau/(2-\tau)$
DVCS	$x_B = Q^2/(2p \cdot q)$	$\eta = x_B/(2 - x_B)$



TCS and Bethe-Heitler (BH) Interference



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



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

- 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

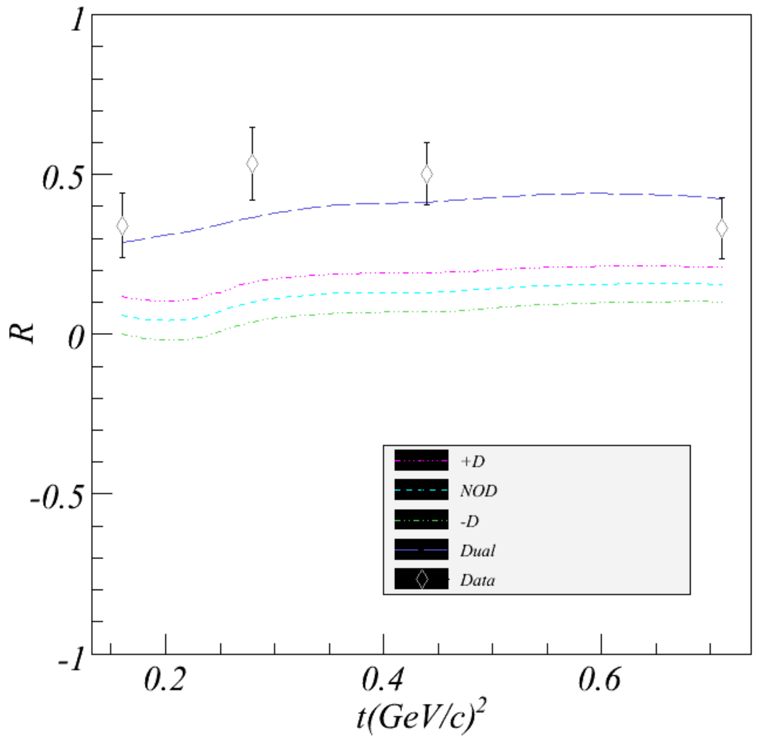
Cosine moment of weighted cross sections

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

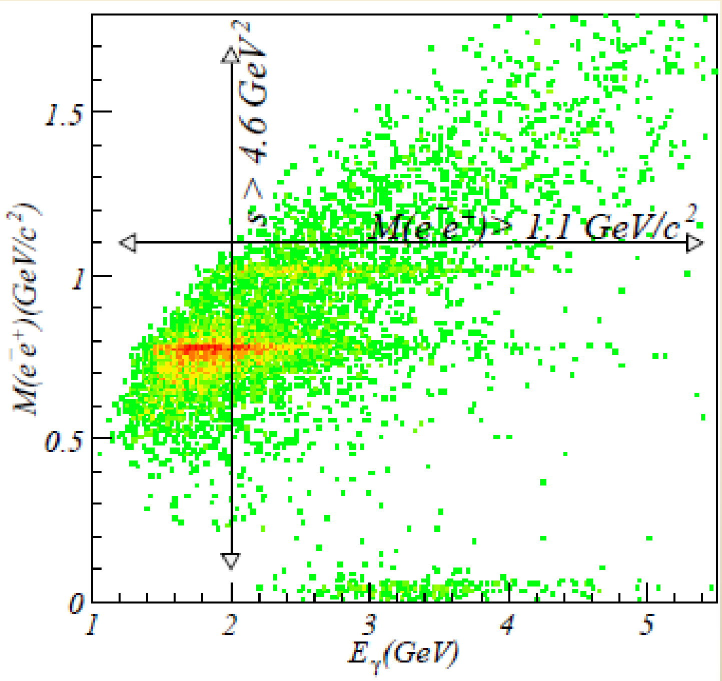
$$R = \frac{2\int_0^{2\pi} d\varphi \cos\varphi \frac{dS}{dQ^2\,dt\,d\varphi}}{\int_0^{2\pi} d\varphi \frac{dS}{dQ^2\,dt\,d\varphi}}$$

R can be compared directly with GPD models

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



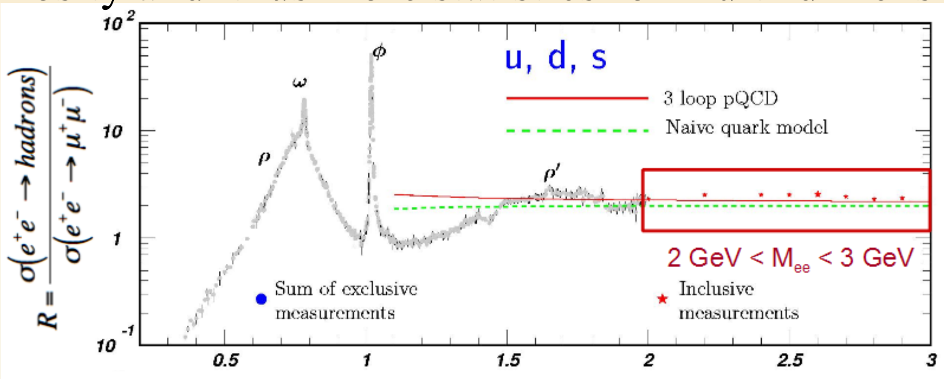
Comparison of results by R. Paremuzyan *et al* from CLAS e1-6/e1f with calculations by V. Guzey.

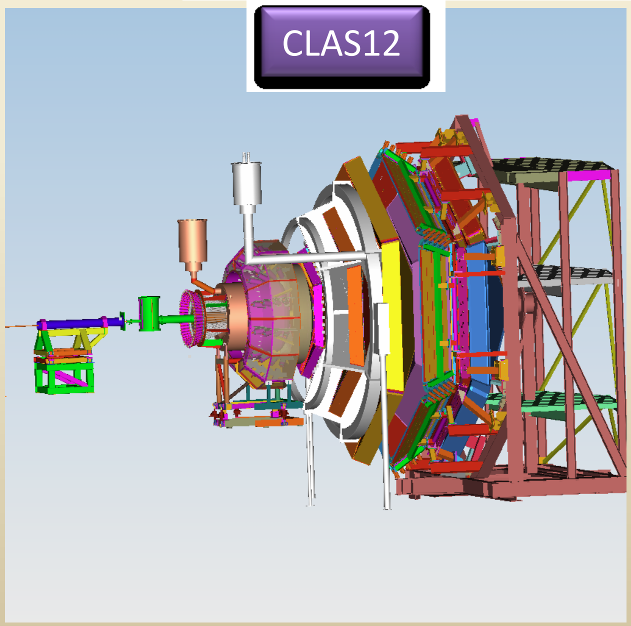


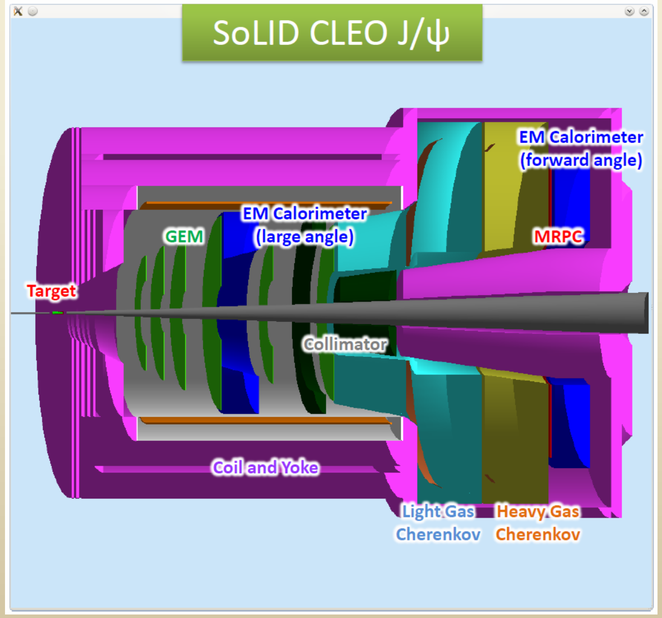
Analysis of CLAS g12 with tagged real photons is ongoing

TCS at JLab 12GeV

- 11 GeV beam extends s to 20GeV^2
- 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

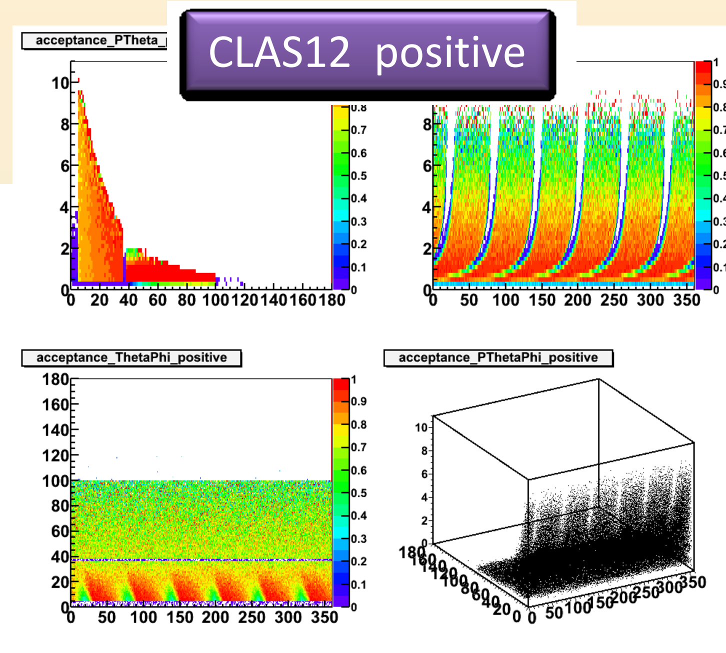


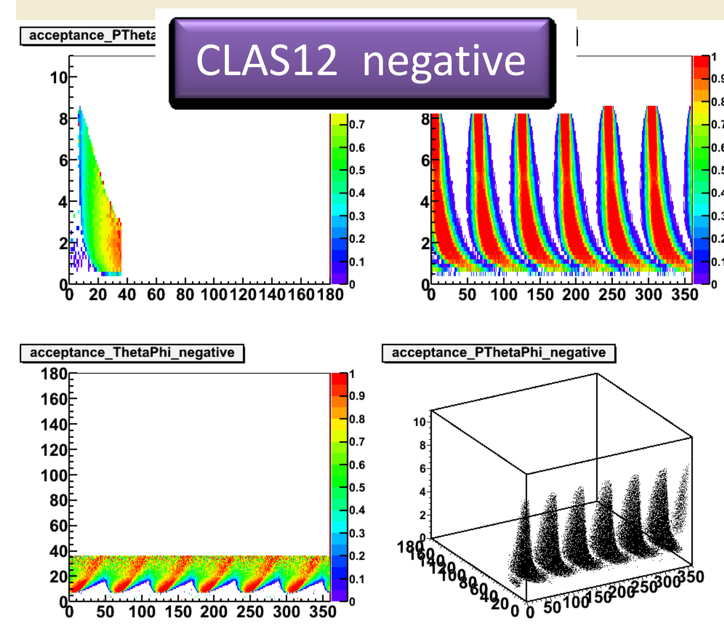




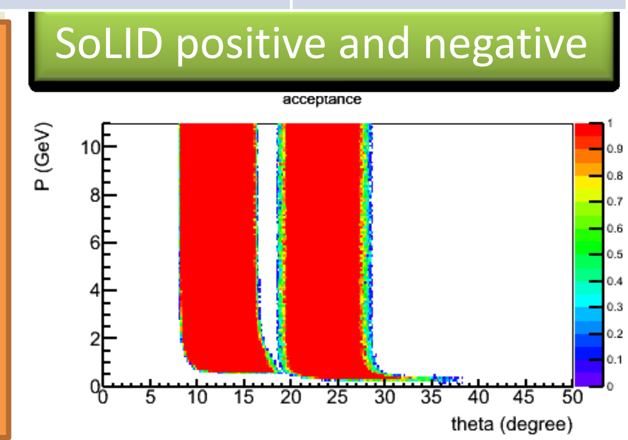
CLAS12 and SoLID: Acceptance

	CLAS12	SoLID
e^- and e^+ coverage	θ(5° – 36°) ϕ (~ 80% full) Asymmetric	θ(8° – 17°) θ(18° – 28°) ϕ(full) Symmetric
proton coverage	θ(5° – 36°) Θ(38° – 125°) ϕ (~ 80% full)	θ(8° – 17°) θ(18° – 28°) ϕ(full)
Luminosity	10^{35}/cm²/s	10^{37}/cm²/s





- CLAS12 larger CC coverage
- CLAS12 large TOF (proton PID) coverage



CLAS12 and SoLID: Resolution

- CLAS12 better resolution

CLAS12

Parameters	Forward Detector	Central Detector
Charged tracks:		
polar angular range (θ)	5° to 35°	35° to 125°
resolution:		
polar angle ($\delta\theta$)	< 1 mr	< 10 mr to 20 mr
azimuthal angle ($\delta\phi$)	< 4 mr	< 5 mr
momentum ($\delta p/p$)	< 1% at 5 GeV/c	< 5% at 1.5 GeV/c

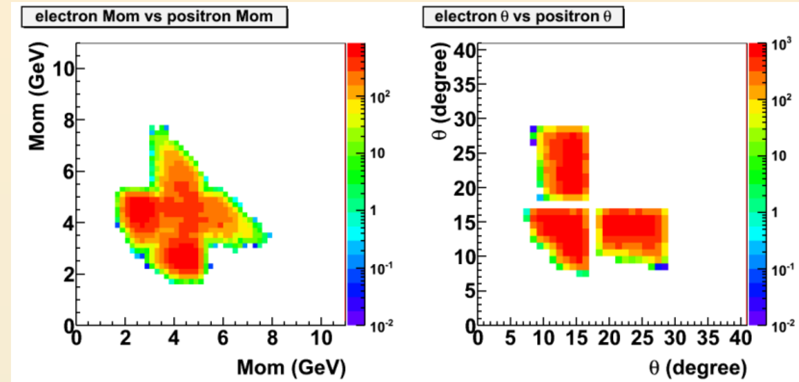
SoLID

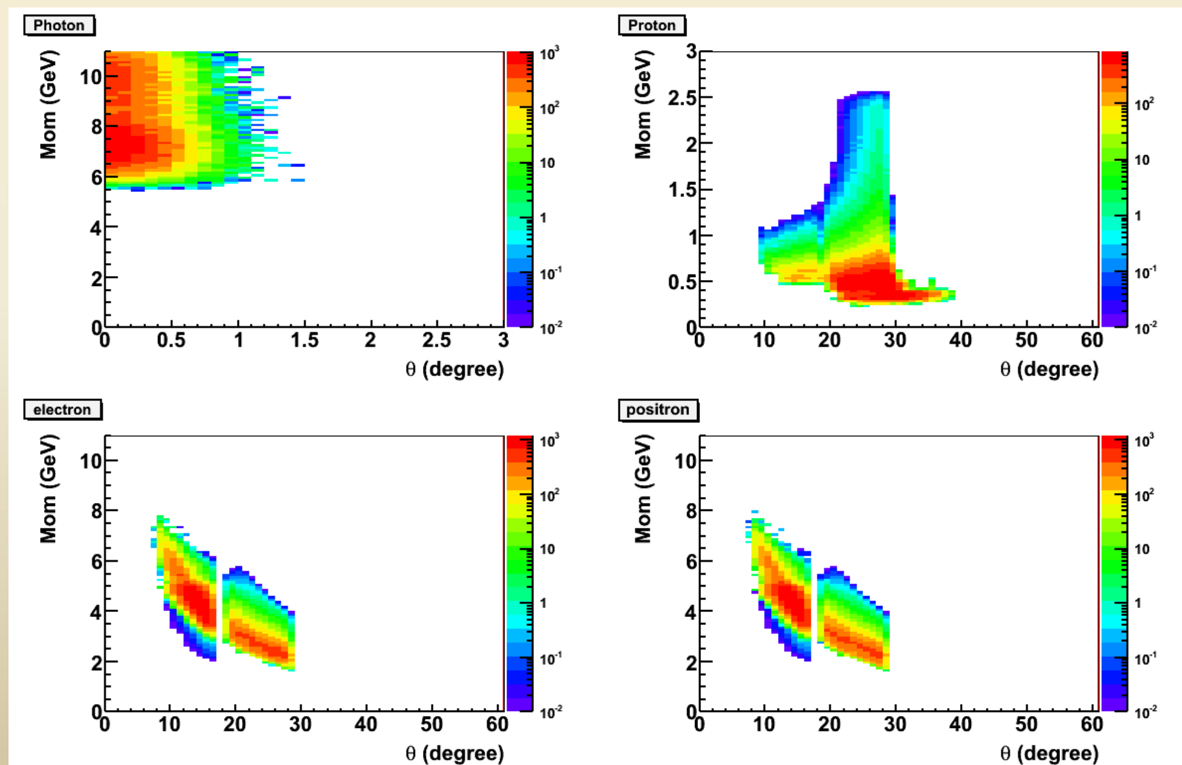
Parameters	S … or
polar angular range (θ)	8° to 17° and 18° to 28°
azimuthal angular range (ϕ)	full
resolution:	
polar angle ($\delta\theta$)	< 0.6 mr
azimuthal angle ($\delta\phi$)	< 5 mr
momentum ($\delta p/p$)	< 2%
PID:	
e/π by EC	full momentum range
e/π by CC	< 5 GeV/c at $8° < \theta < 17°$
p/K by TOF	< 4.5 GeV/c at $8° < \theta < 17°$ and < 2.5 GeV/c at $18° < \theta < 28°$

TABLE II: SoLID design characteristics.

SoLID TCS

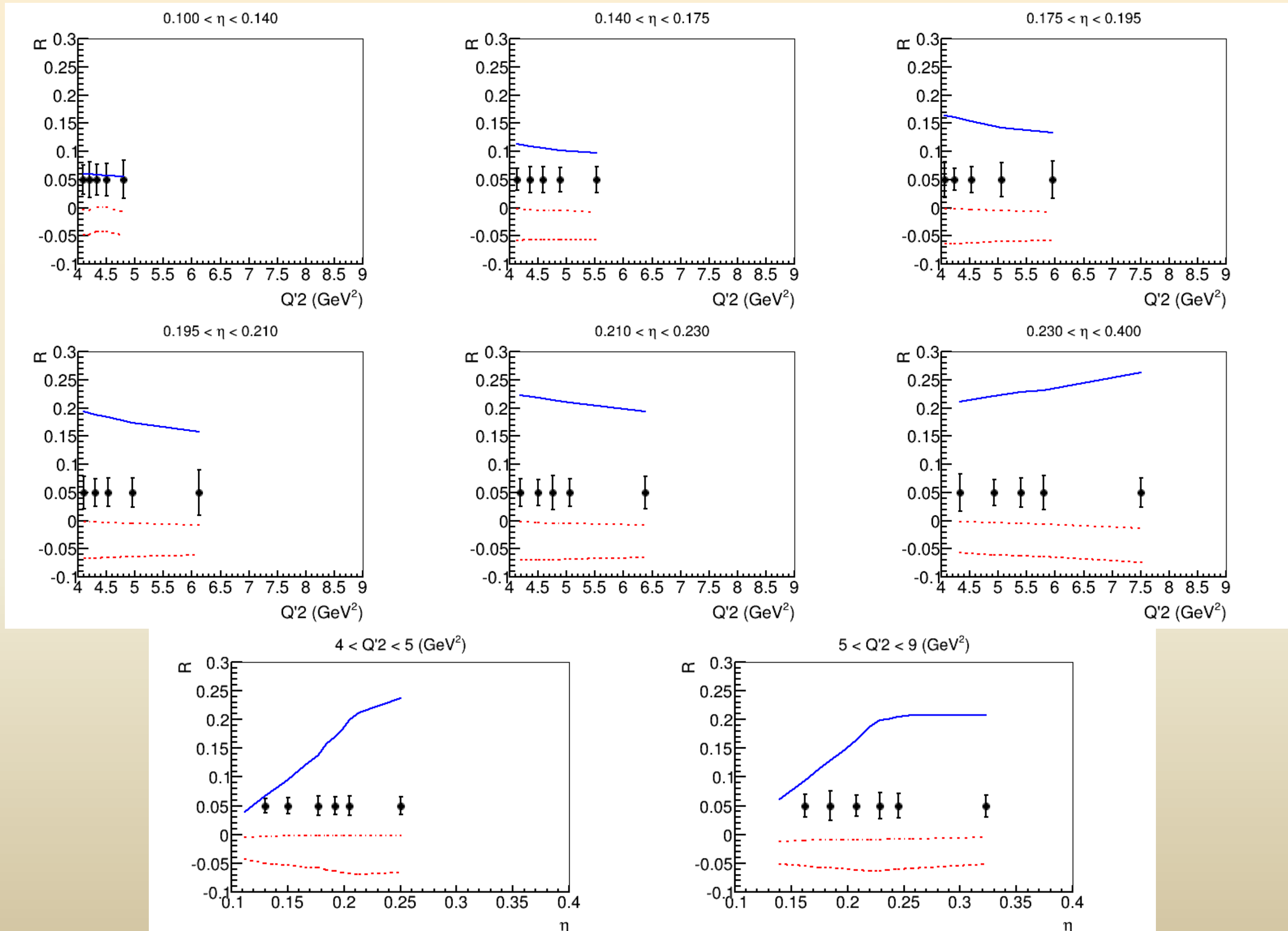
- SoLID/CLAS12 luminosity 100
- CLAS12 has 6 times better selection power for TCS physics than SoLID
- SoLID JPsi approved for 50 days
- CLAS12 TCS approved for 120 days
- SoLID 100k events, CLAS12 14k events
- SoLID/CLAS12 statistics about a factor of 7





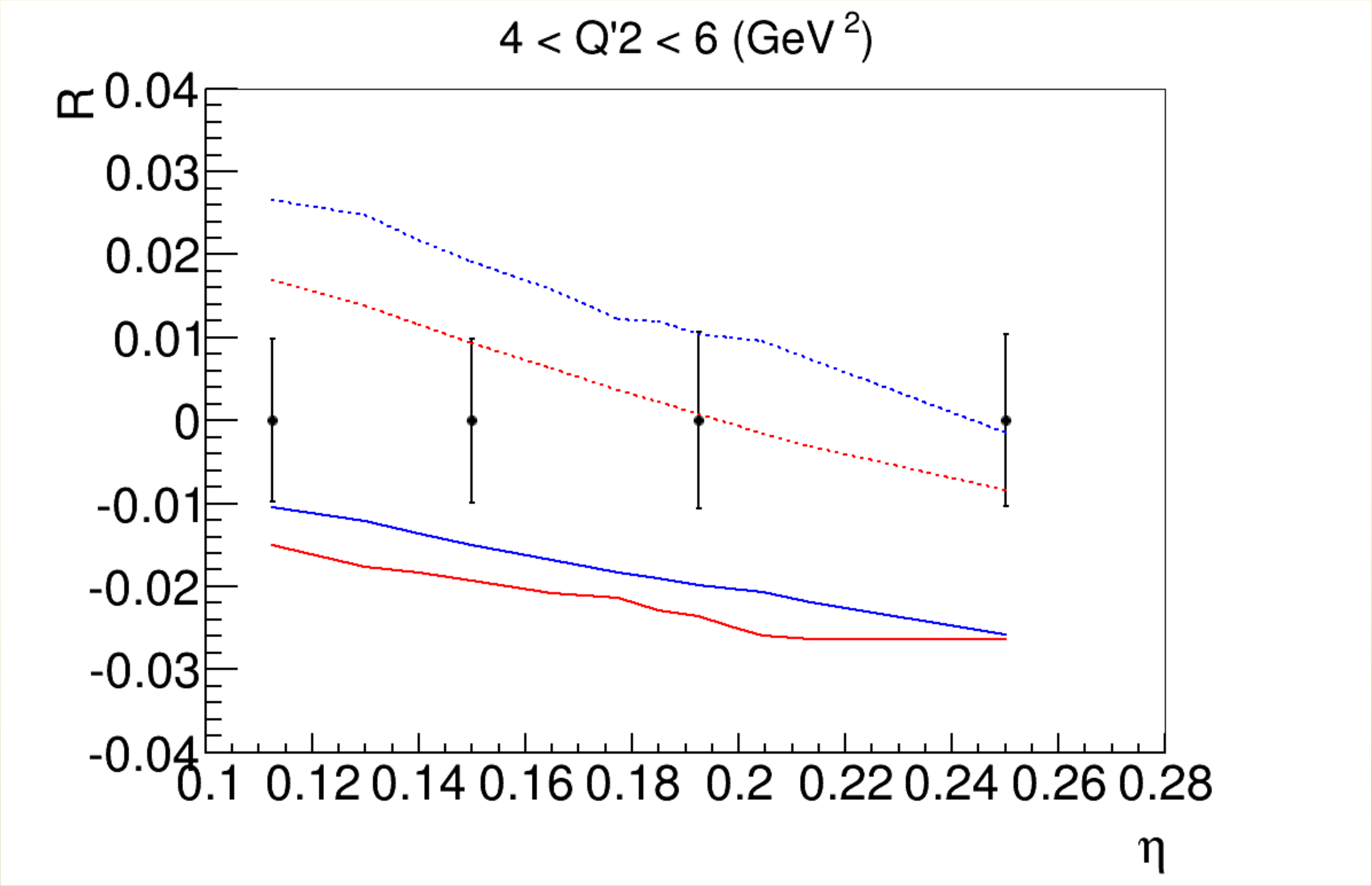
SoLID TCS projection

- Blue solid line, dual parameterization model
- Red dash-dot line, double distribution with D-term model
- Red dash line, double distribution without D-term model



SoLID TCS projection

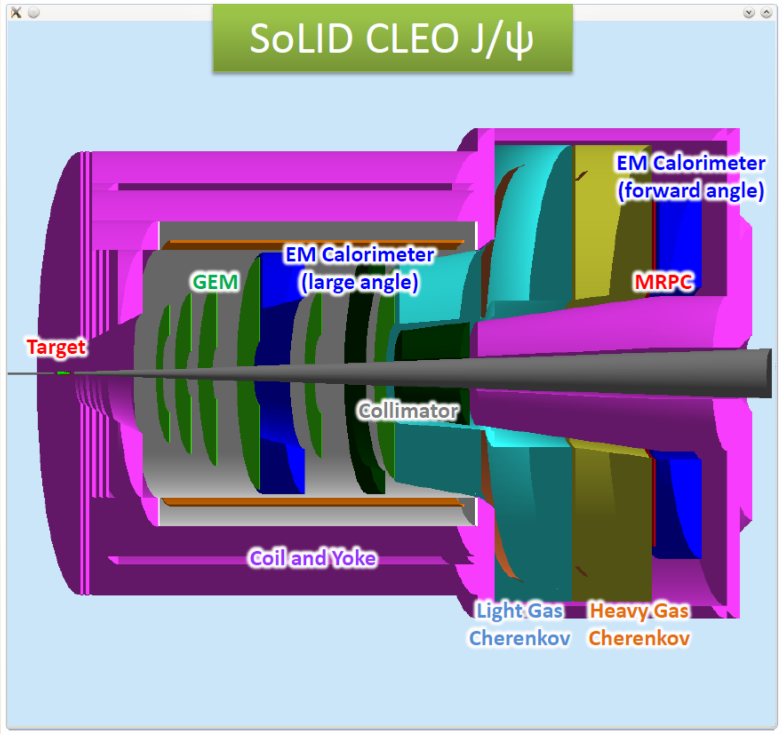
- Solid line: two models, LO
- dotted line: two models, NLO



SoLID JPsi and TCS

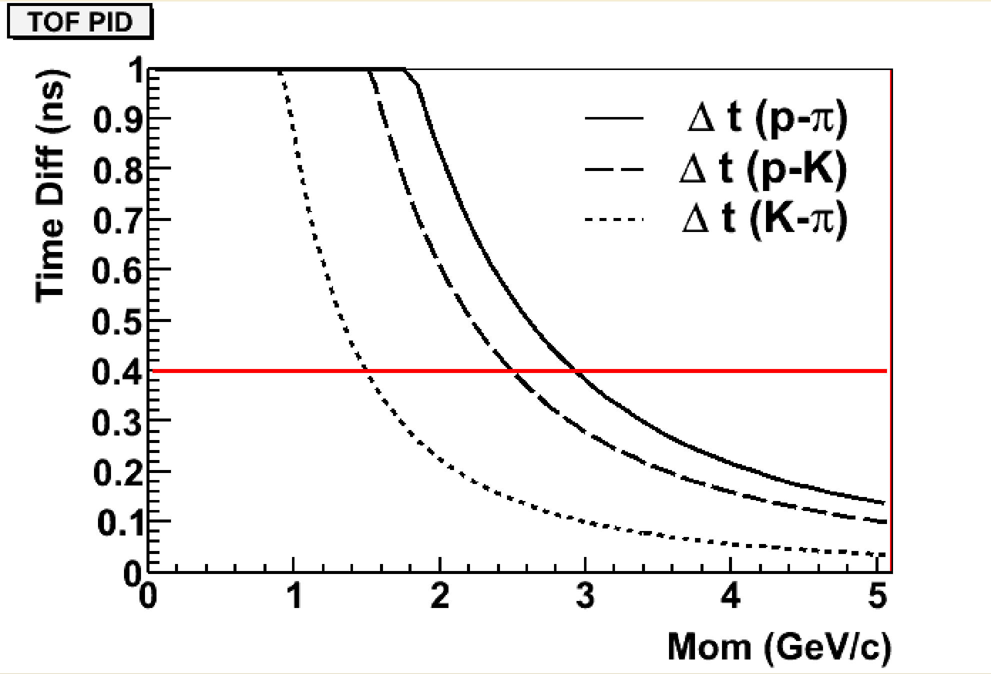
- JPsi setup
  - 15cm LH2 taget 300cm upstream from solenoid coil center.
  - 3uA current, 1e37/cm2/s luminosity for 50 days
  - forward angle coverage about 8-16 degree, large angle coverage about 17-28 degree
  - Trigger on scattered e- at forward angle and decay lepton pair

    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



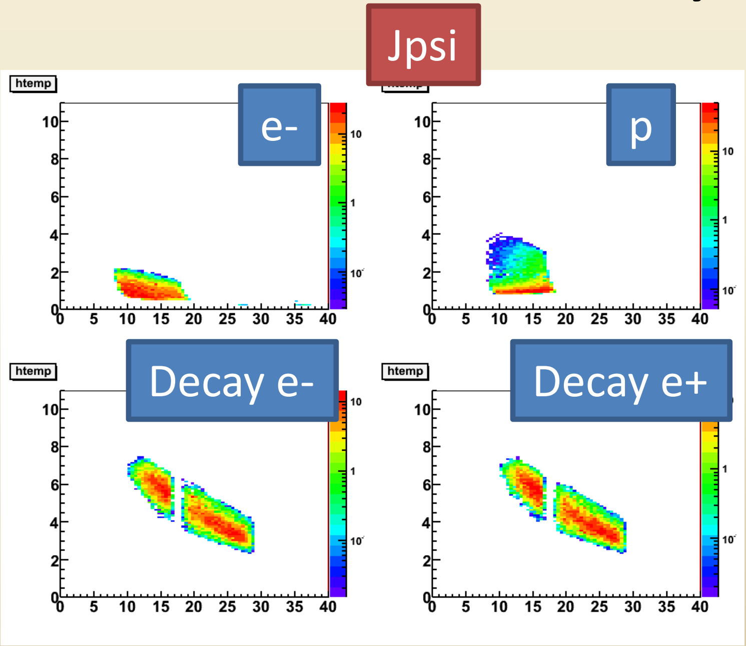
TOF at large angle

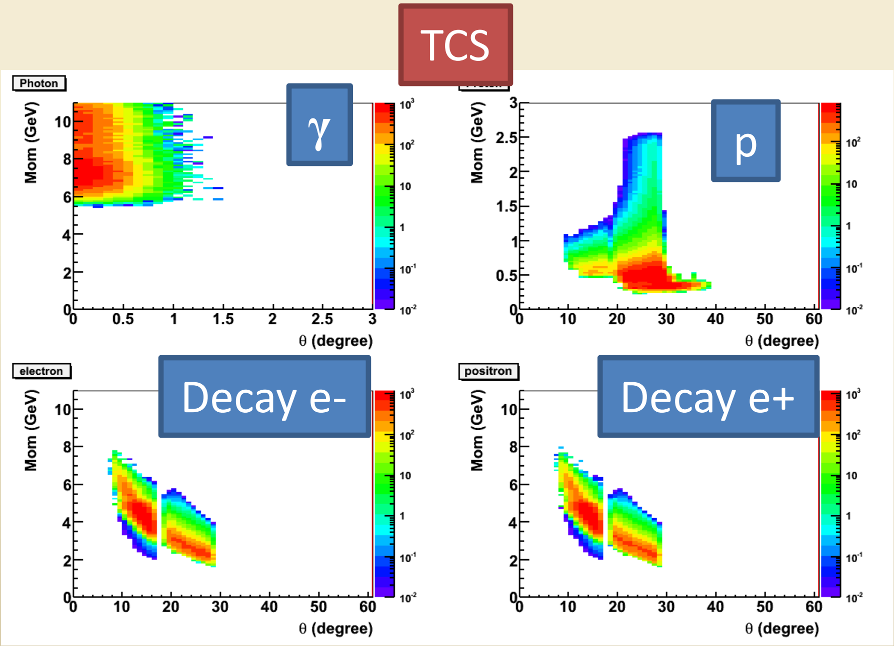
- Add a TOF plane before large angle EC
- The minimum flight distance is about 245cm from target
- Assume 5sigma separation for different particles and 80ps time resolution, then "red" line shows the cut at 400ps
- The proton identification can reach at least 2.5GeV
  - proton pion separation at 3.0GeV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



Trigger

- The decay pair has similar kinematic coverage
- if using the decay pair only, JPsi needs to consider lowE scattered e- and has stronger requirement on trigger than TCS
- Need more study



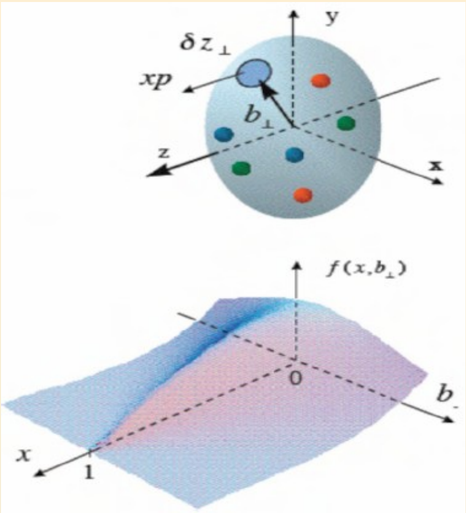


Summary

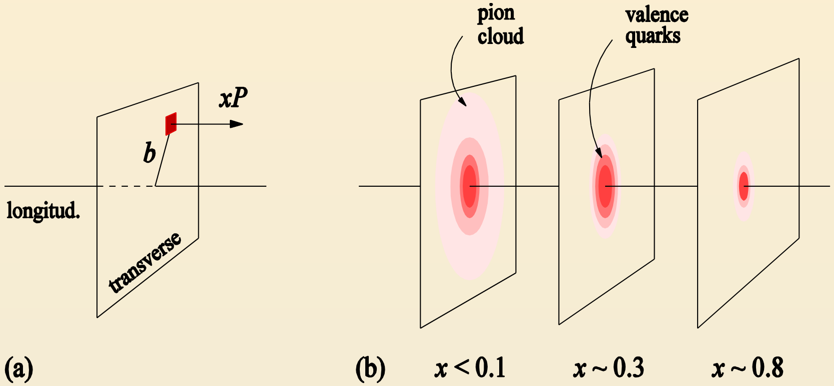
- Dilepton production at JLab 12GeV
  - J/ψ production near threshold for gluonic interaction
  - Timelike Compton Scattering (TCS) for GPD
- CLAS12 and SoLID can form a complementary program and will make important contributions in the field
- TCS program can continue at MEIC/EIC
- Run together with Jpsi or more beamtime is an open question

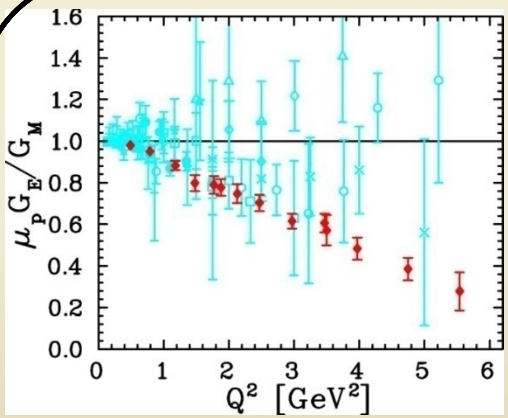
Backup TCS

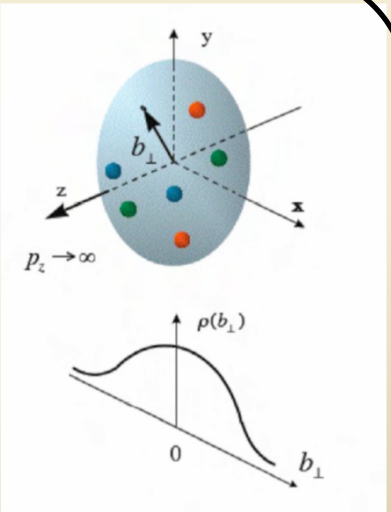
Generalized Parton Distribution (GPD)



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

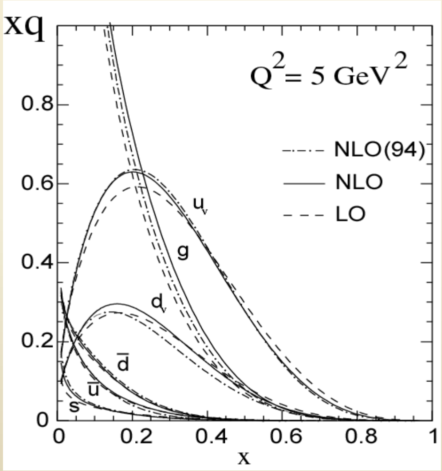


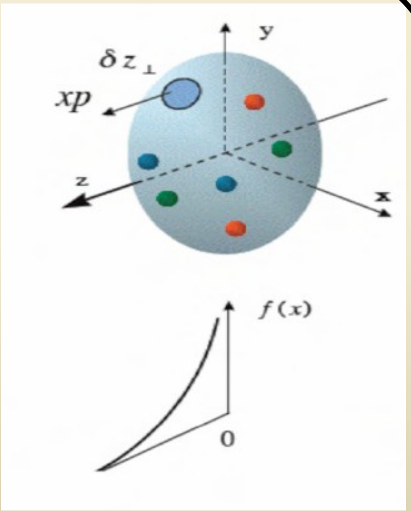




Elastic form factors

Transverse spatial distributions





Parton Distribution Functions

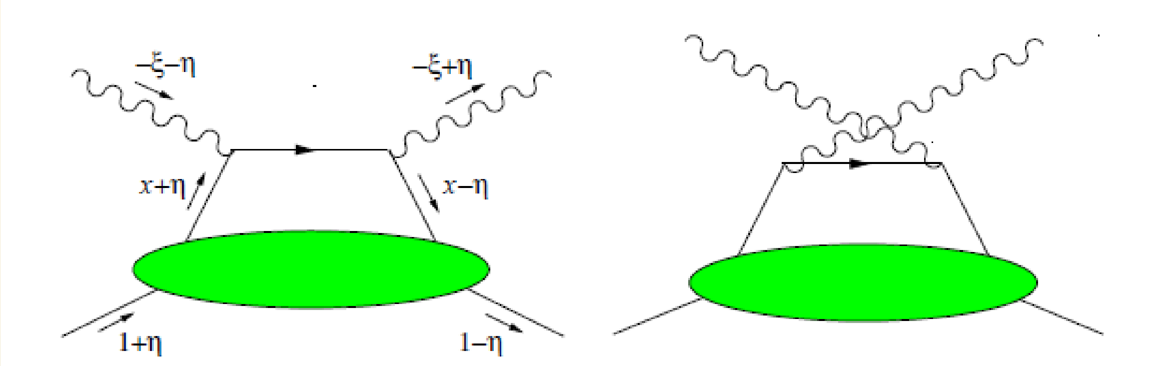
Longitudinal momentum distributions

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)

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

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

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

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

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

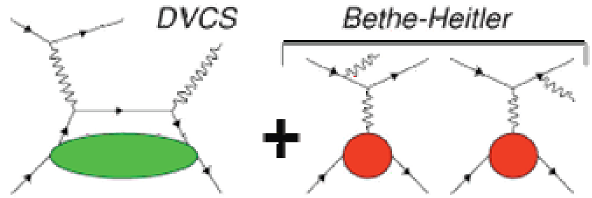
$$\eta = -\frac{(q-q')\cdot(q+q')}{(p+p')\cdot(q+q')} \approx \frac{Q^2 + Q'^2}{2s + Q^2 - Q'^2},$$

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

E.R. Berger et al. Eur. Phys. J. C 23, 675–689 (2002)

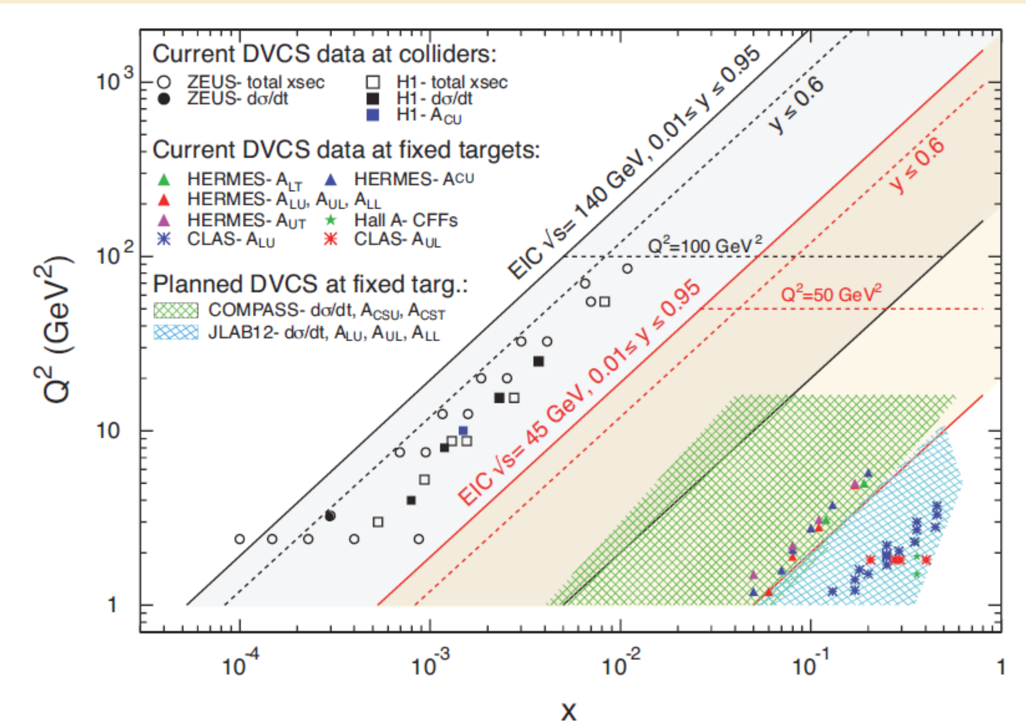
DVCS

ep' epγ =

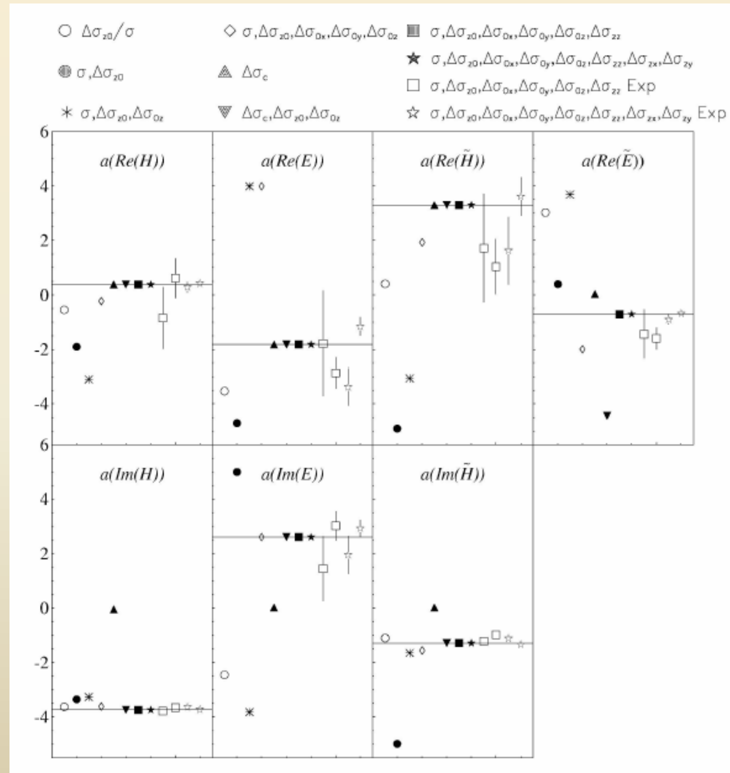


$$\mathcal{T} = |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}$$

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



An overview of existing and planned measurements of DVCS



Global fit to the DVCS data

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

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 crosssection

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

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

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

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

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

Interference term

In terms of helicity amplitudes:

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

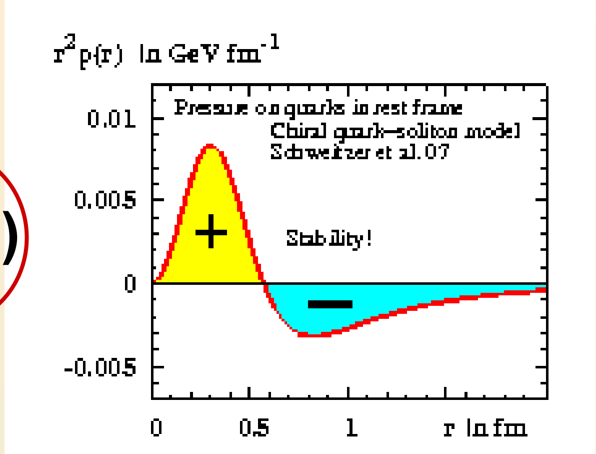
$$\ldots\frac{\alpha_{em}^3}{4\pi s^2}\,\frac{1}{-t}\,\frac{M}{Q'}\,\frac{1}{\tau\sqrt{1-\tau}}\,\frac{L_0}{L}\left[\sin\varphi\,\frac{1+\cos^2\theta}{\sin\theta}\ldots - \sin 2\varphi\,\sqrt{2}\cos\theta\ldots + \sin 3\varphi\,\sin\theta\ldots + O\left(\frac{1}{Q'}\right)\right]$$

circular polarization of incoming photon also gives access to imaginary part

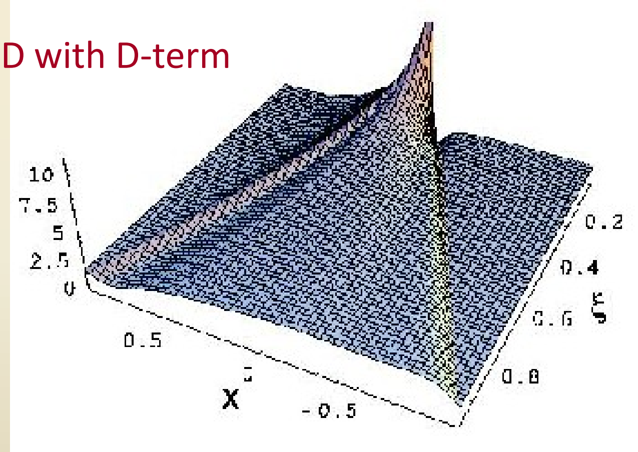
$$\frac{1}{2}\sum_{\lambda,\lambda'}|M^{\lambda'-,\lambda-}|^2 = (1-\eta^2)\left(\ldots^2+\ldots^2\right) - 2\eta^2\,\mathrm{Re}\left(\ldots+\ldots\right) - \left(\eta^2+\frac{t}{4M^2}\right)\ldots - \eta^2\frac{t}{4M^2}\ldots,$$

The D-term and the pressure balance in the nucleon

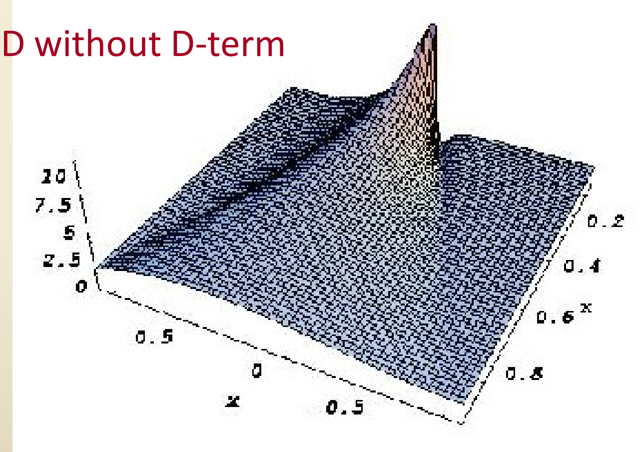
$$H(x,\xi) = H_{DD}(x,\xi) + \theta(\xi - |x|)\frac{1}{N_f} D\left(\frac{x}{\xi}\right)$$



GPD with D-term



GPD without D-term



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

TCS NLO

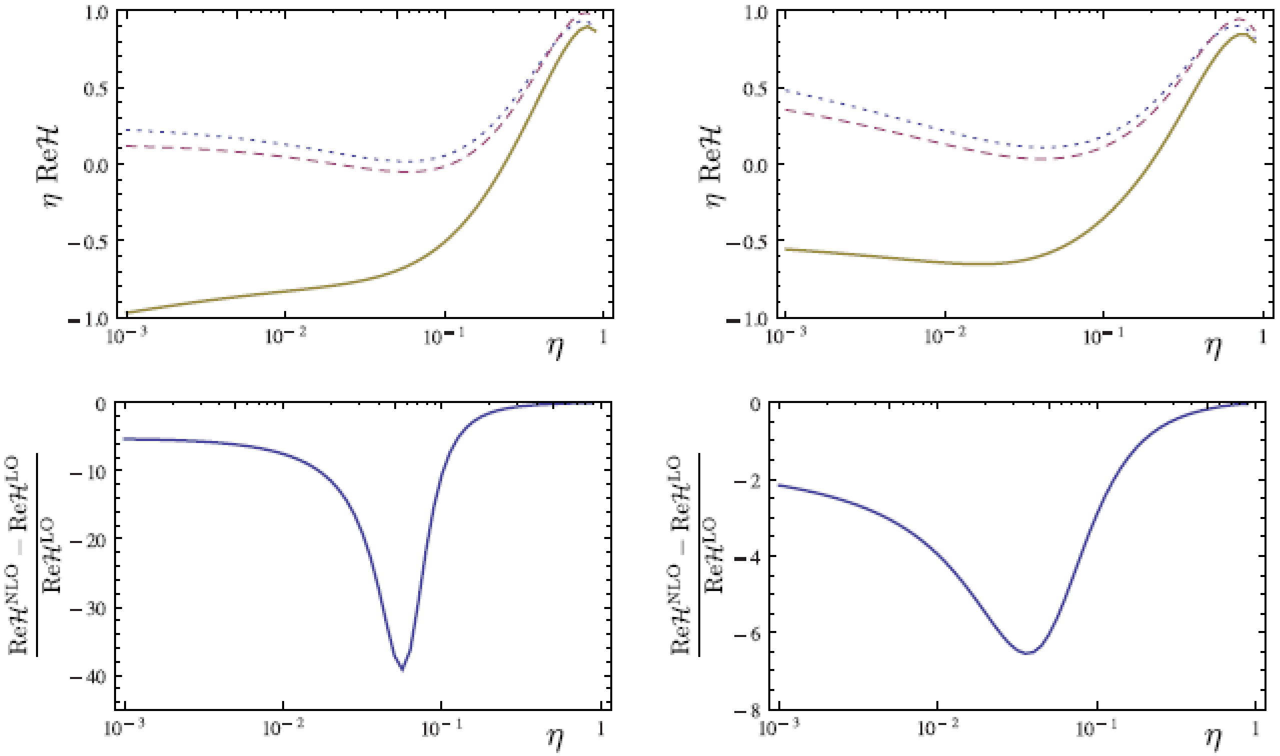


Figure 4: The real part of the *timelike* Compton Form Factor $\mathcal{H}$ multiplied by η, as a function of η in the double distribution model based on Kroll-Goloskokov (upper left) and MSTW08 (upper right) parametrizations, for $\mu_F^2 = Q^2 = 4$ GeV^2 and $t = -0.1$ GeV^2. Below the ratios of the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

DVCS NLO

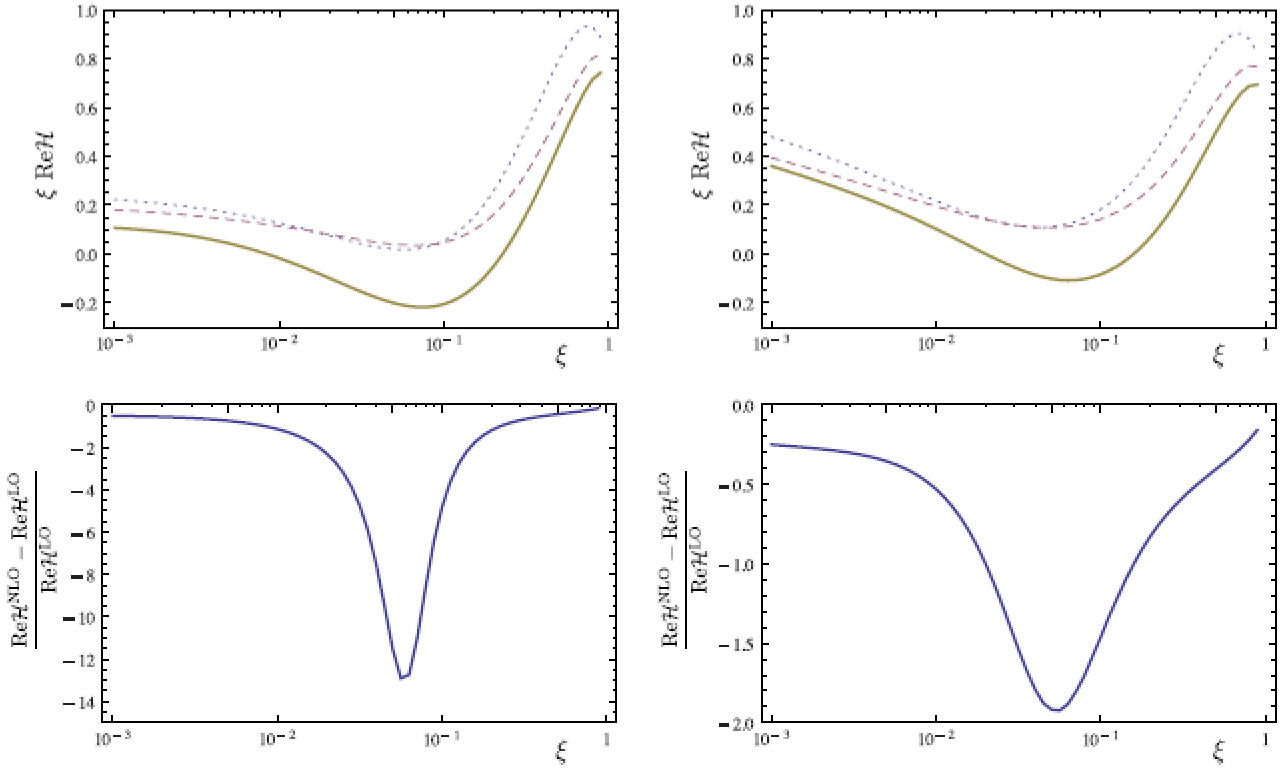
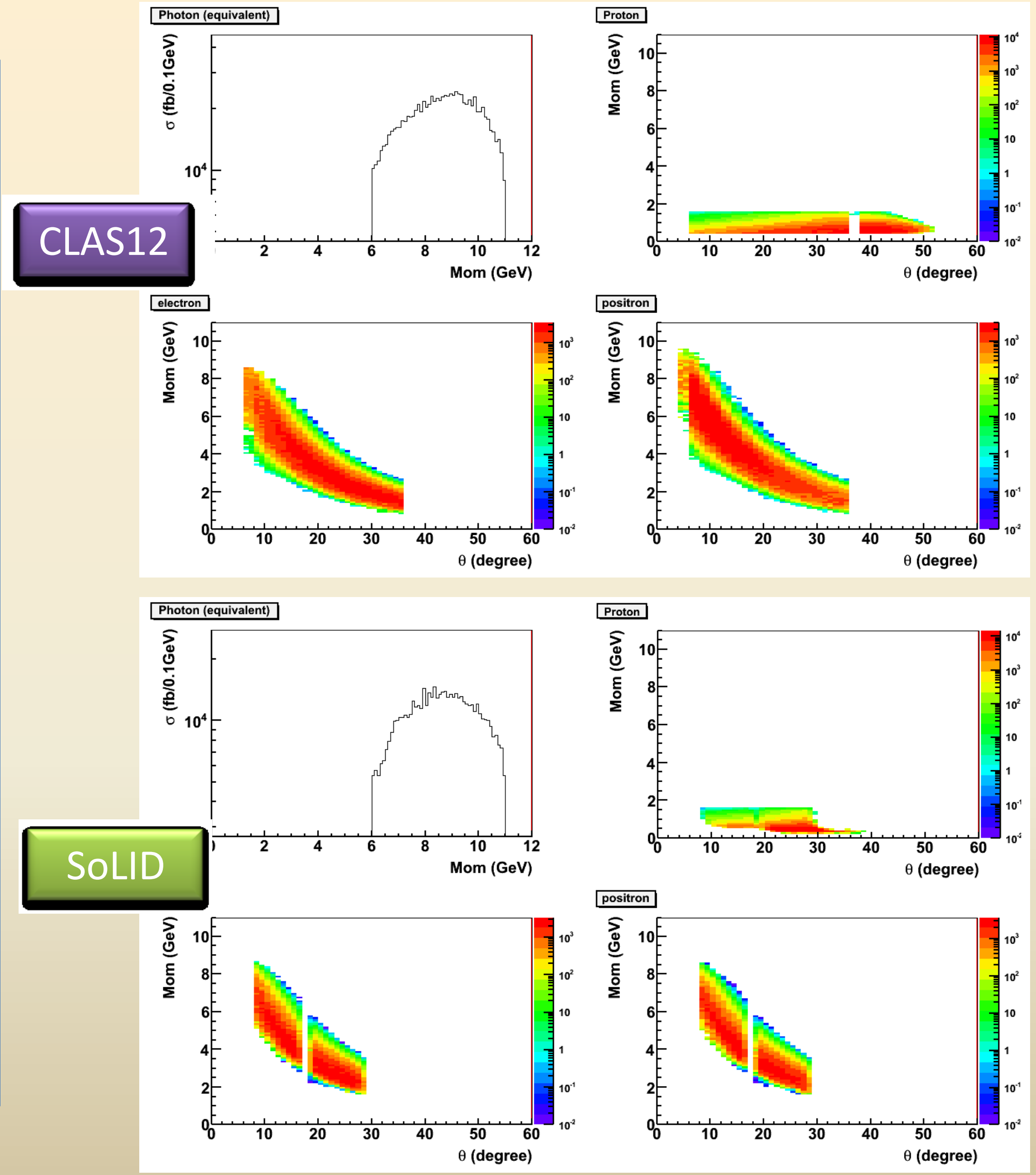


Figure 1: The real part of the *spacelike* Compton Form Factor $\mathcal{H}(\xi)$ multiplied by ξ, as a function of ξ in the double distribution model based on Kroll-Goloskokov (upper left) and MSTW08 (upper right) parametrizations, for $\mu_F^2 = Q^2 = 4\,\mathrm{GeV}^2$ and $t = -0.1\,\mathrm{GeV}^2$, 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.

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



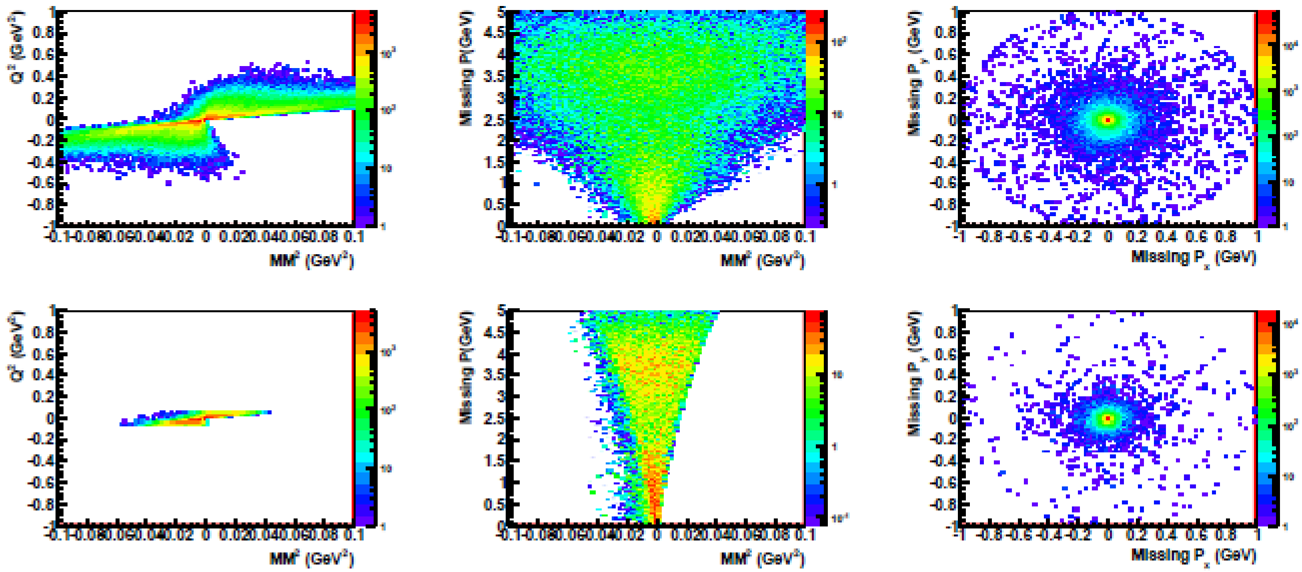
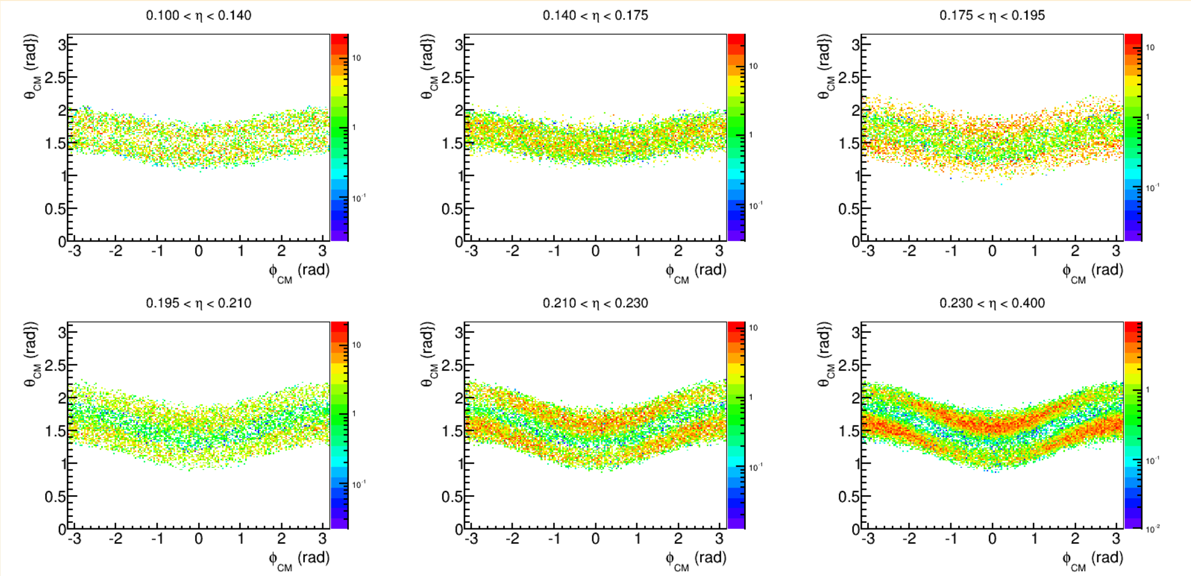
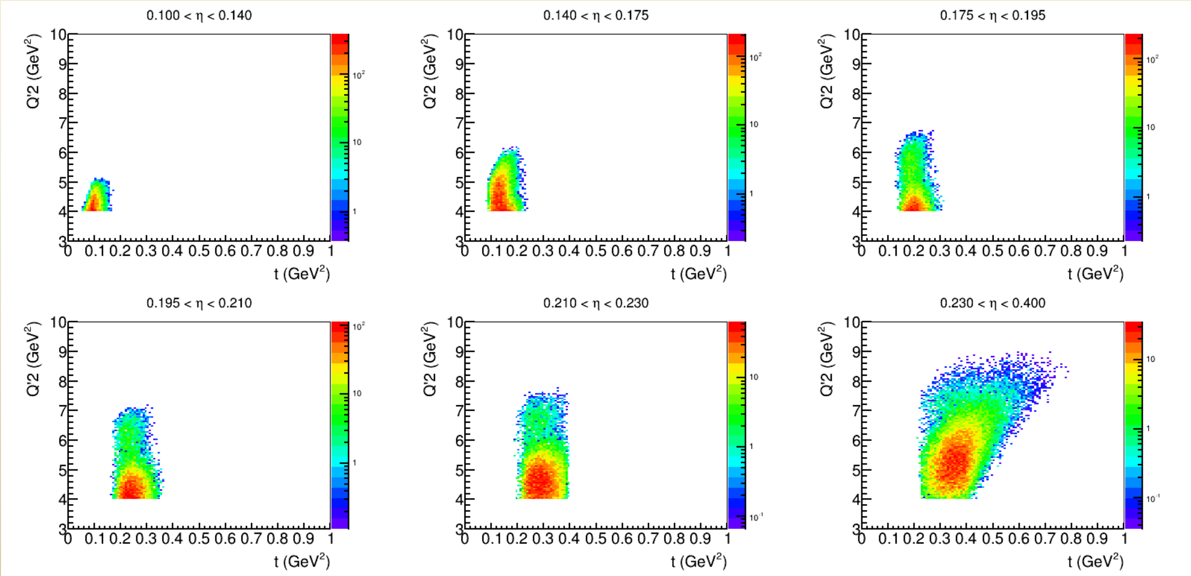
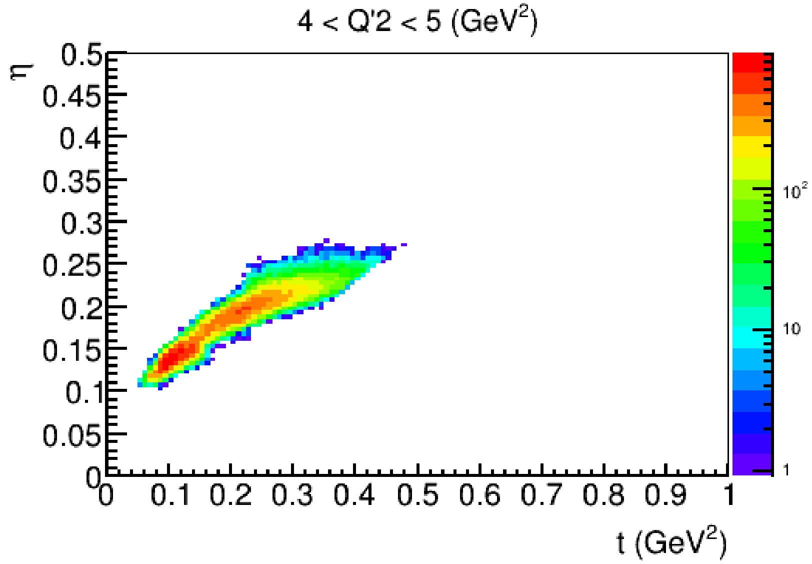
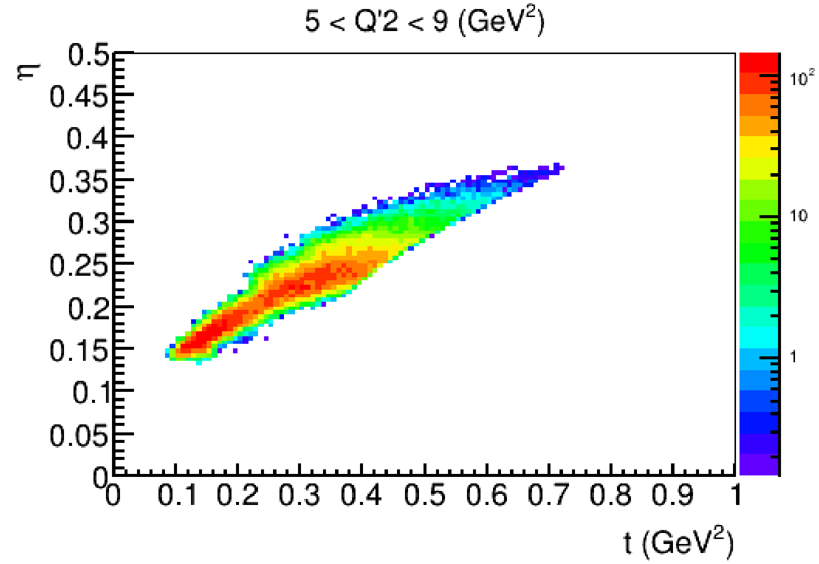


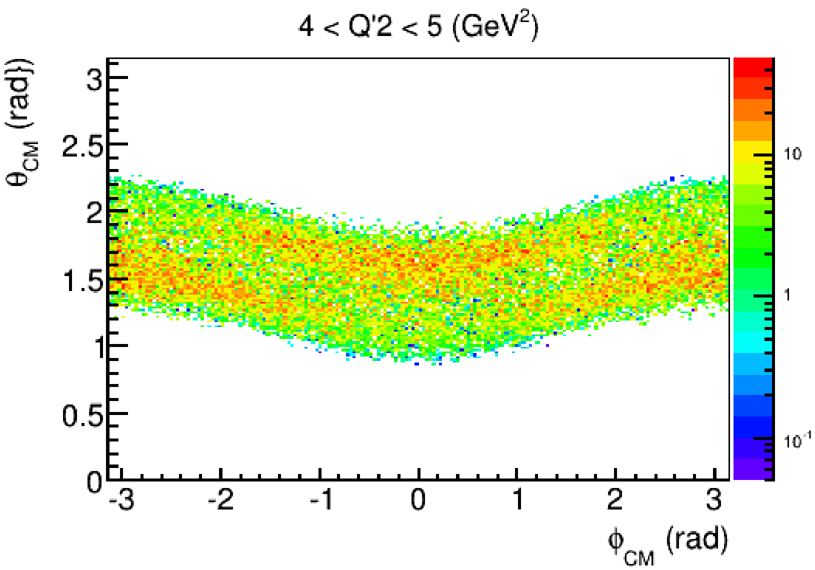
FIG. 23: Missing-particle kinematics before and after the cut $Q^2 < 0.05$ GeV^2 *Left panels:* Q^2 versus missing mass squared MM^2. *Middle panels:* Missing momentum versus missing mass squared MM^2. *Right panels:* Missing momentum P_x versus missing momentum P_y. *Top row:* before the Q^2 cut *Bottom row:* after the Q^2 cut.

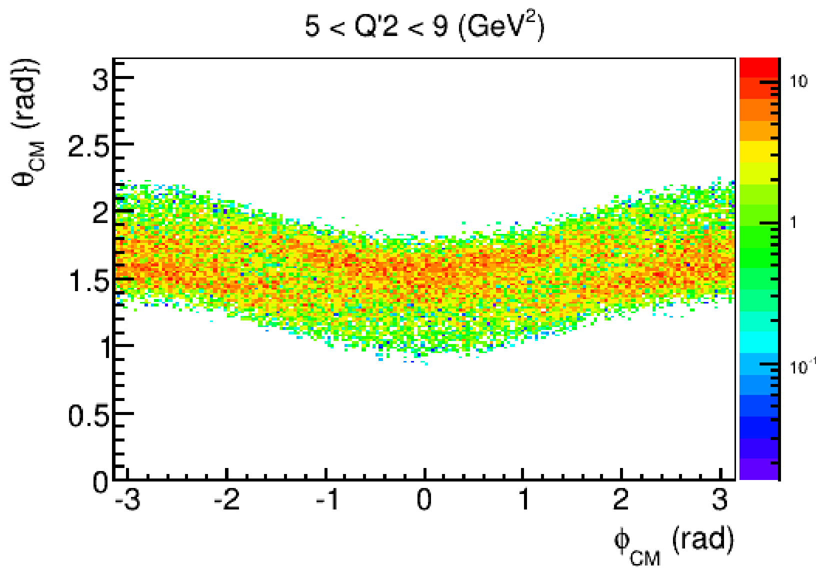

0.100 < η < 0.140
0.140 < η < 0.175
0.175 < η < 0.195
0.195 < η < 0.210
0.210 < η < 0.230
0.230 < η < 0.400
θ_CM (rad)
ϕ_CM (rad)


0.100 < η < 0.140
0.140 < η < 0.175
0.175 < η < 0.195
0.195 < η < 0.210
0.210 < η < 0.230
0.230 < η < 0.400
Q'2 (GeV²)
t (GeV²)


4 < Q'2 < 5 (GeV^2)
η
t (GeV^2)
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
1
10
10^2


5 < Q'2 < 9 (GeV^2)
η
t (GeV^2)
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
1
10
10^2


4 < Q'2 < 5 (GeV^2)
θ_{CM} (rad})
ϕ_{CM} (rad)
0 0.5 1 1.5 2 2.5 3
-3 -2 -1 0 1 2 3
10^{-1}
1
10

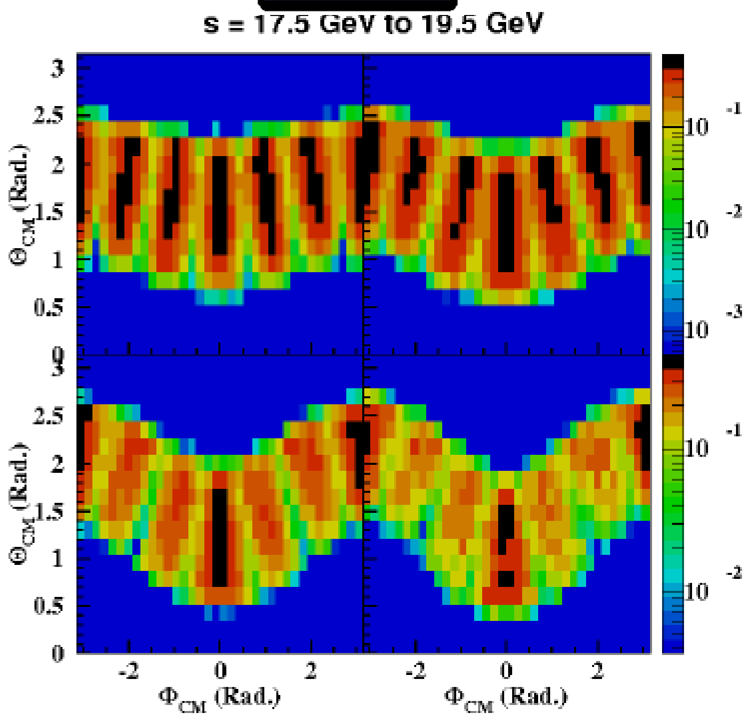

5 < Q'2 < 9 (GeV^2)
θ_{CM} (rad})
ϕ_{CM} (rad)
0 0.5 1 1.5 2 2.5 3
-3 -2 -1 0 1 2 3
10^{-1}
1
10

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

$4GeV^2 < Q'2 < 9GeV^2$
$17.5GeV^2 < s < 19.5GeV^2$
4 t-bins within $0.1GeV^2 < t < 0.9GeV^2$

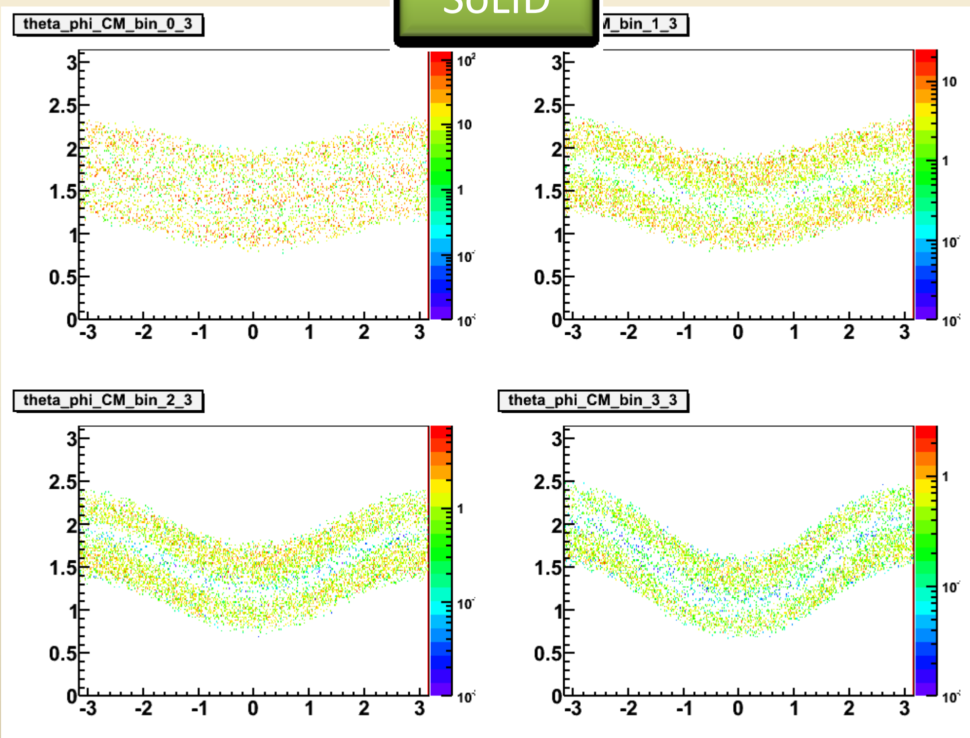
- CLAS12 has ϕ structure which has to be corrected by acceptance
- SoLID is smooth over ϕ, but has θ gap

CLAS12



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

SoLID



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

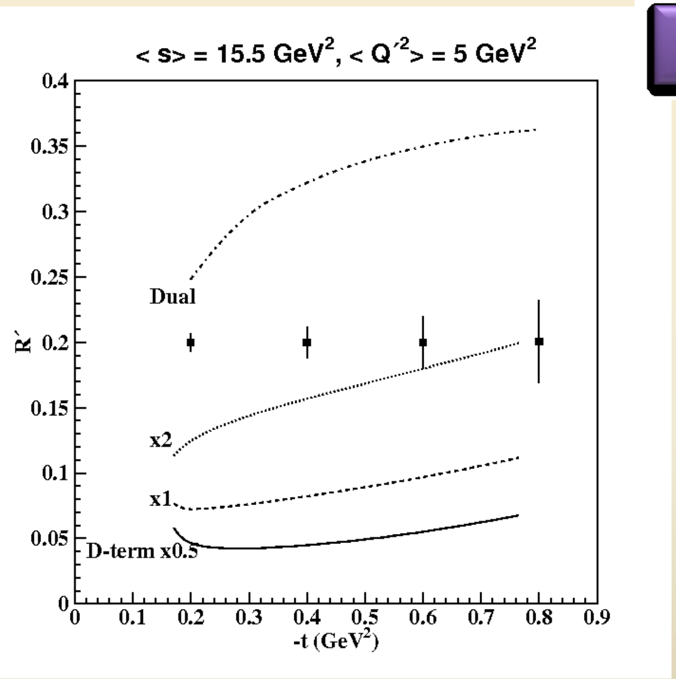
Proposal	Physics	Contact	Rating	Days	Group	Energy	Target
E12-06-108	Hard exclusive electro-production of $\pi 0$, η	Stoler	B	80			
E12-06-112	Proton's quark dynamics in SIDIS pion production	Avakian	A	60			
E12-06-119	Deeply Virtual Compton Scattering	Sabatie	A	80			
E12-09-003	Excitation of nucleon resonances at high Q2	Gothe	B+	40	119 days + 20 days with reversed torus field	11 GeV	Liquid H_2
E12-11-005	**Hadron spectroscopy with forward tagger**	Battaglieri	A-	119			
[redacted]	[redacted]	Nadel-Turonski	A-	100 +20			
E12-12-007	Exclusive φ meson electroproduction with CLAS12	Stoler, Weiss	B+	60			

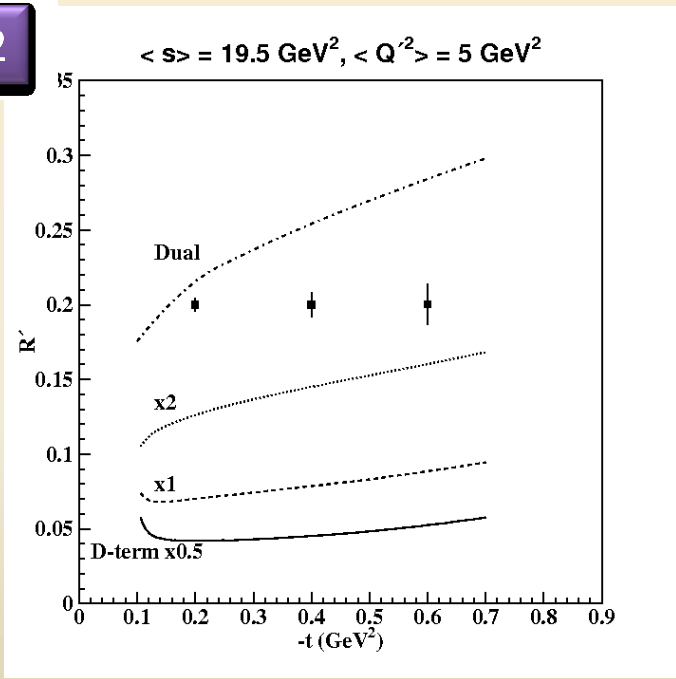
- Unpolarized proton target will be first to run
- Experiment E12-12-001 for e+e- physics was approved at the last PAC meeting
- Spectroscopy (119 PAC days) and e+e- (100+20 days) experiments drive the total beam time for proton running (119+20 days), which can be shared by all.
- Approved beam time 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
- ***<u>CLAS12 and SoLID will run at different time and be well complementary</u>***

CLAS12

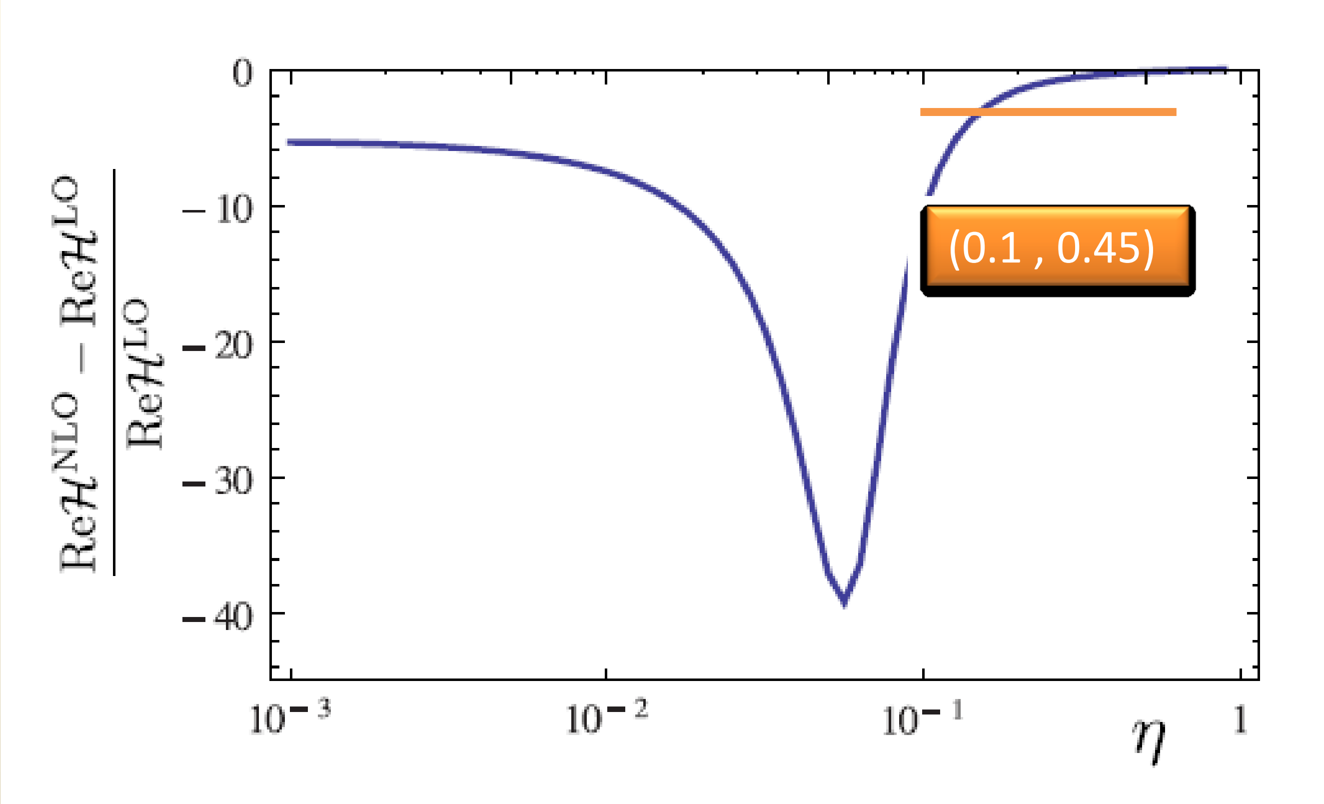




- Statistical uncertainties for 100 days at a luminosity of 10^{35} cm^{-2}s^{-1}
- Uncertainties for cosine moment R', integrated over the CLAS12 acceptance, for two bins in photon energy, for the lowest Q'^2 bin above the ρ' resonance.
- Different values of the D-term are only shown for the double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

SoLID TCS

- (preliminary) estimated **500k** events for 1e37cm^{-2}s^{-1} lumi and 50 days
- Higher statistics enables multi-dimension binning (Q2, s, t , eta…)
  - e.g. study the change over eta and search for NLO (gluonic)



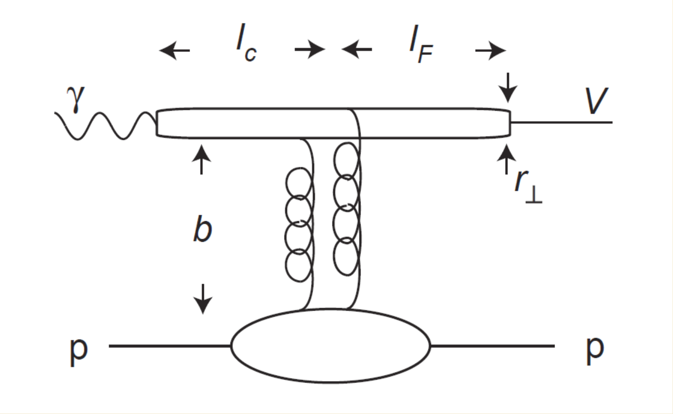
Bacup jpsi

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

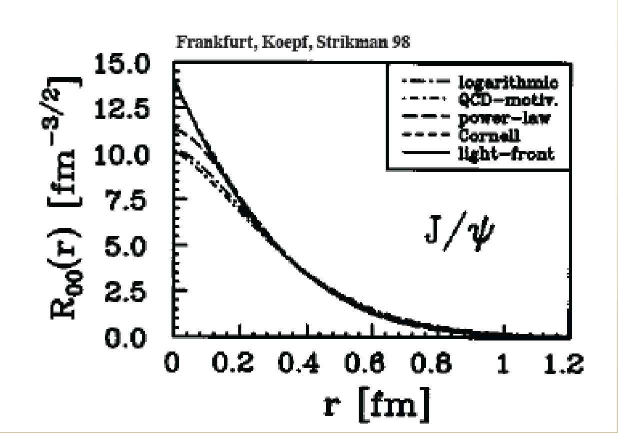
J/ψ Production on Neuclon

$J/\psi(1S): I^G\left(J^{PC}\right) = 0^-\left(1^{--}\right)$ $M_{J/\psi} \approx 3.097 GeV$ 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 ~ $1/m_c$ ~ 0.1fm



Interaction between J/ψ-N

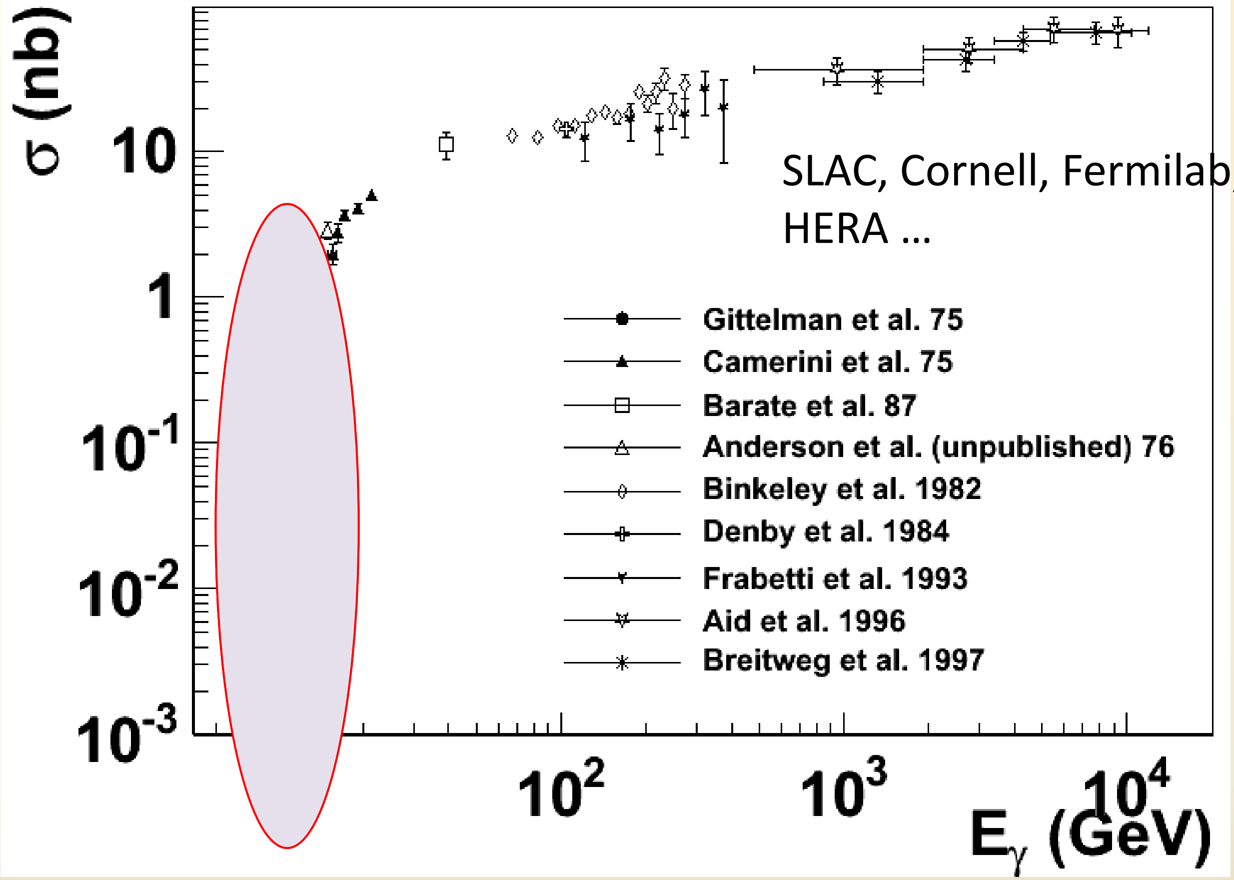
New scale provided by the charm quark mass and size of the J/ψ

- 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

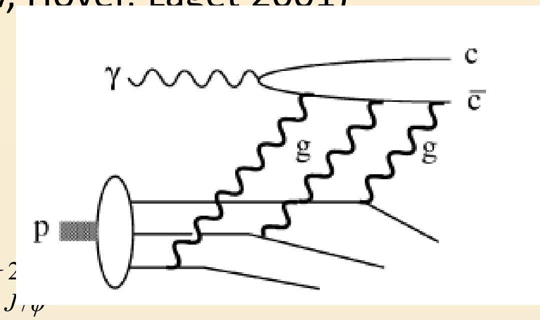
(Brodsky, Chudakov, Hover, Laget 2001)

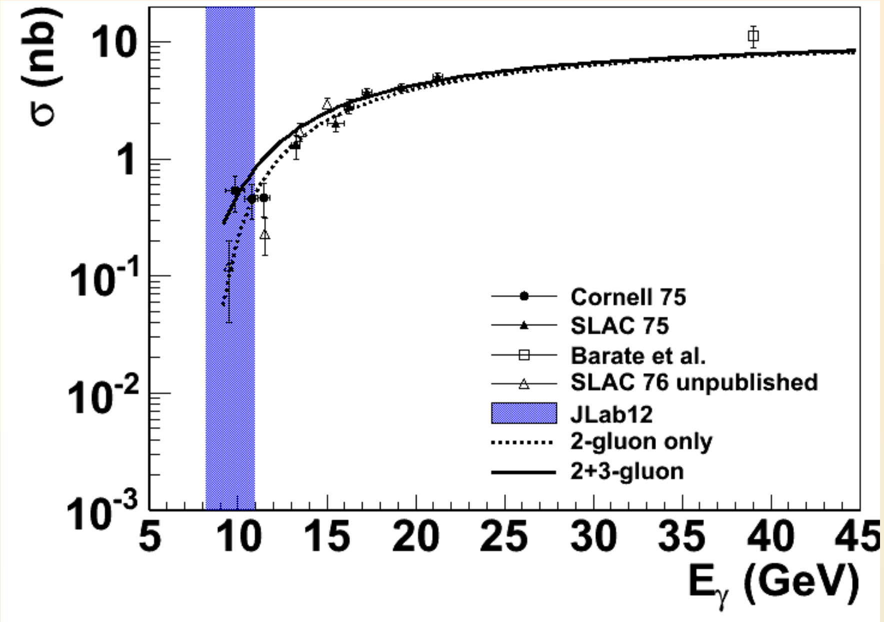
$$2-g:(1-x)^2 F(t)$$

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

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

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



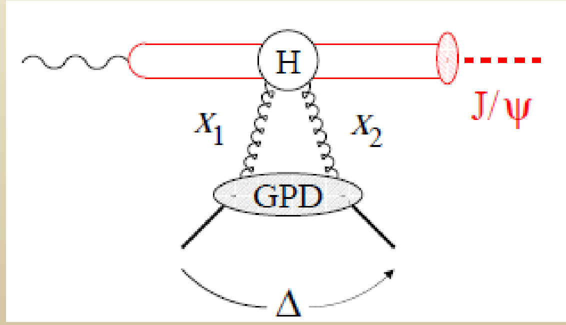


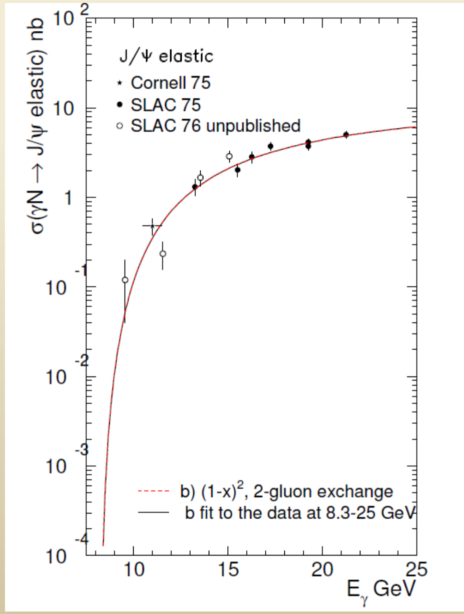
Model -II: Partonic soft mechanism

(Frankfurt and Strikman, PRD 66, 031502 [2002])

2-gluon Form Factor

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





40

Reaction mechanism

Model-III: soft mechanism, final state interaction?

D. Kharzeev. Quarkonium interactions in QCD, 1995,

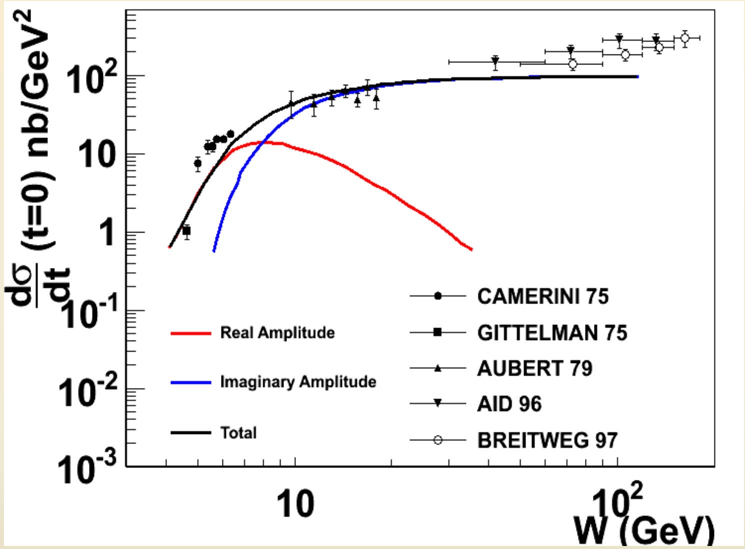
D. Kharzeev, H. Satz, A. Syamtomov, and G. Zinovjev, Eur.Phys.J., C9:459–462, 1999)

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

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

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

- **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

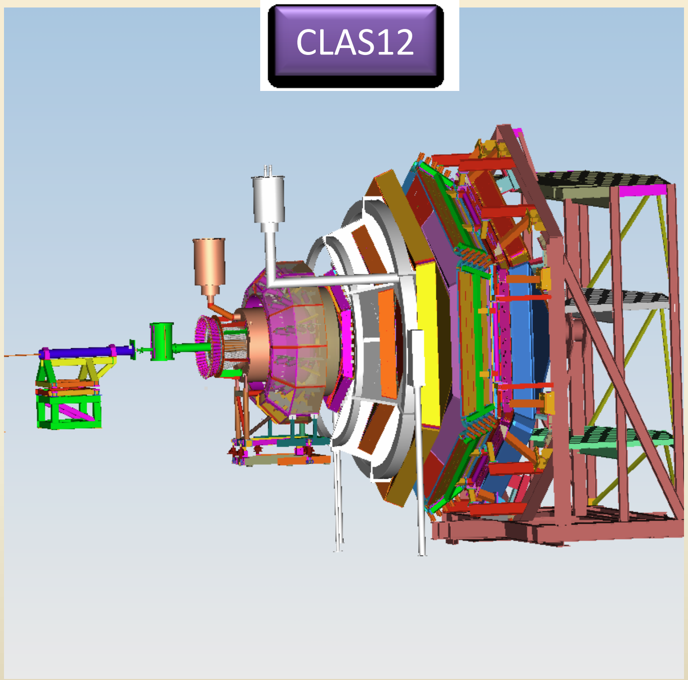


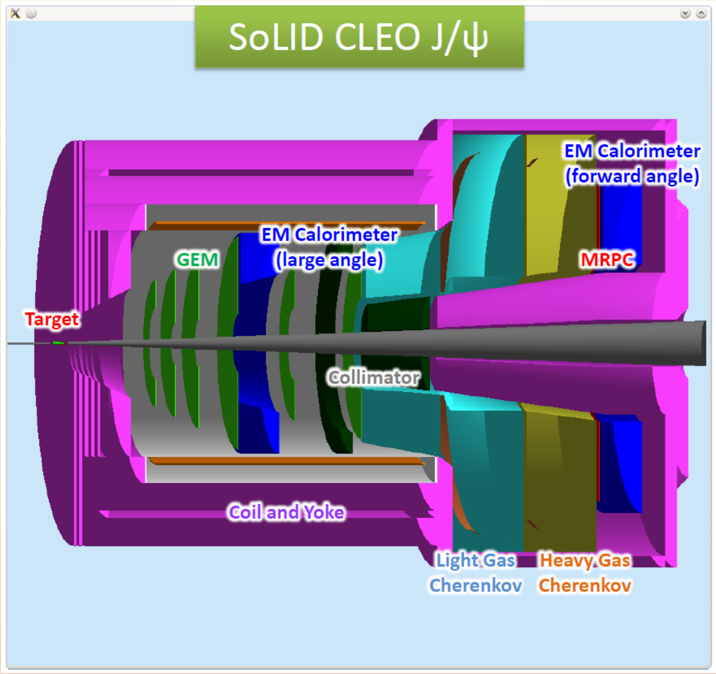
A measurement near threshold could shed light on the conformal anomaly which accounts for a portion of proton mass

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



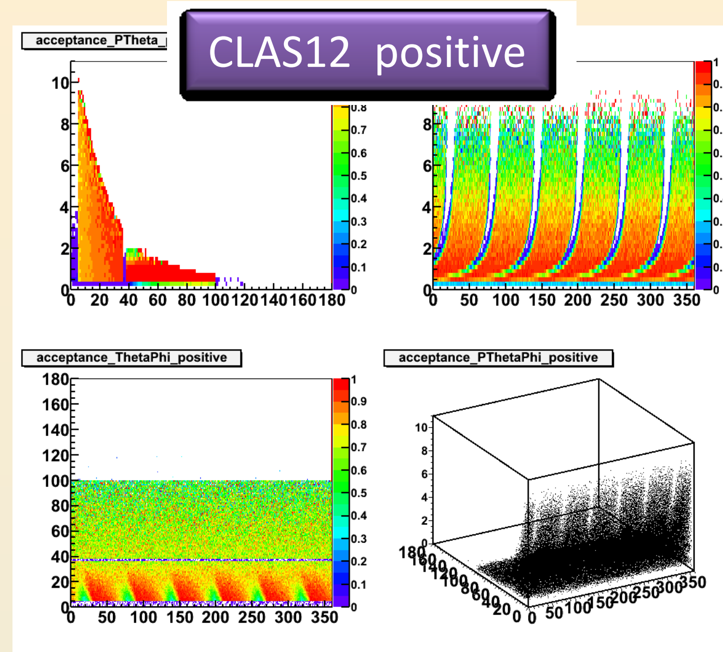


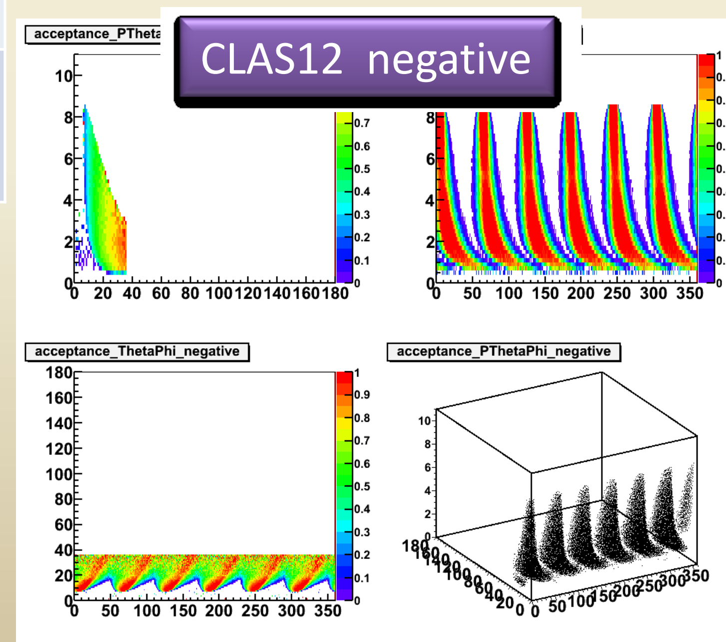
E12-12-001
approved for 120 days

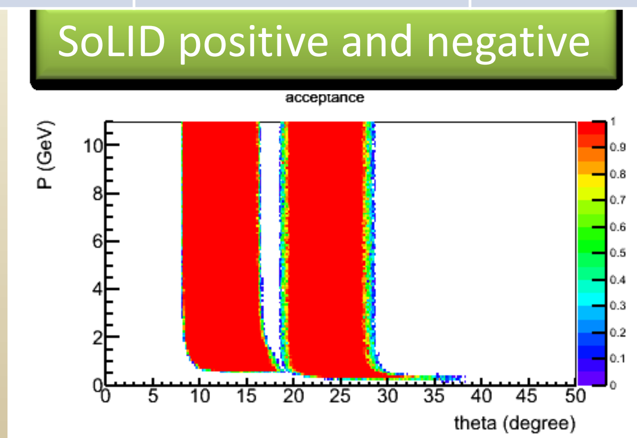
E12-12-006
approved for 60 days

CLAS12 and SoLID: Acceptance

	CLAS12	SoLID
e^- and e^+ coverage	θ(5° – 36°) ϕ (~ 80% full) Asymmetric	θ(8° – 17°) θ(18° – 28°) ϕ(full) Symmetric
proton coverage	θ(5° – 36°) Θ(38° – 125°) ϕ (~ 80% full)	θ(8° – 17°) θ(18° – 28°) ϕ(full)
Luminosity	$10^{35}/cm^2/s$	$10^{37}/cm^2/s$



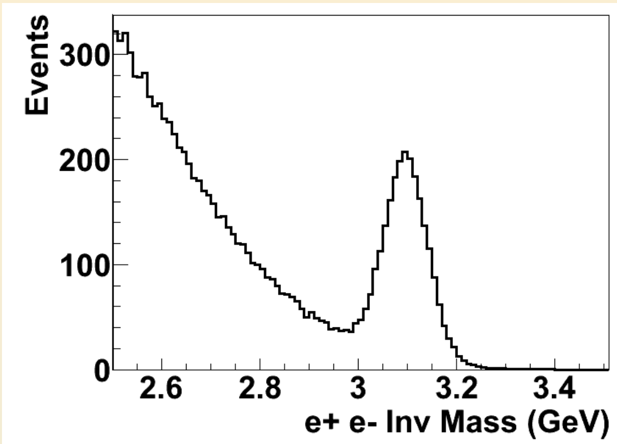


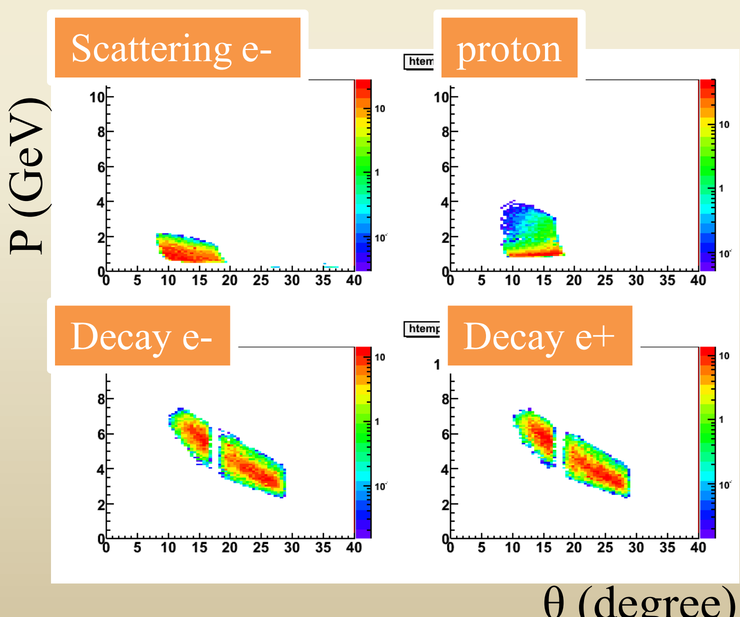


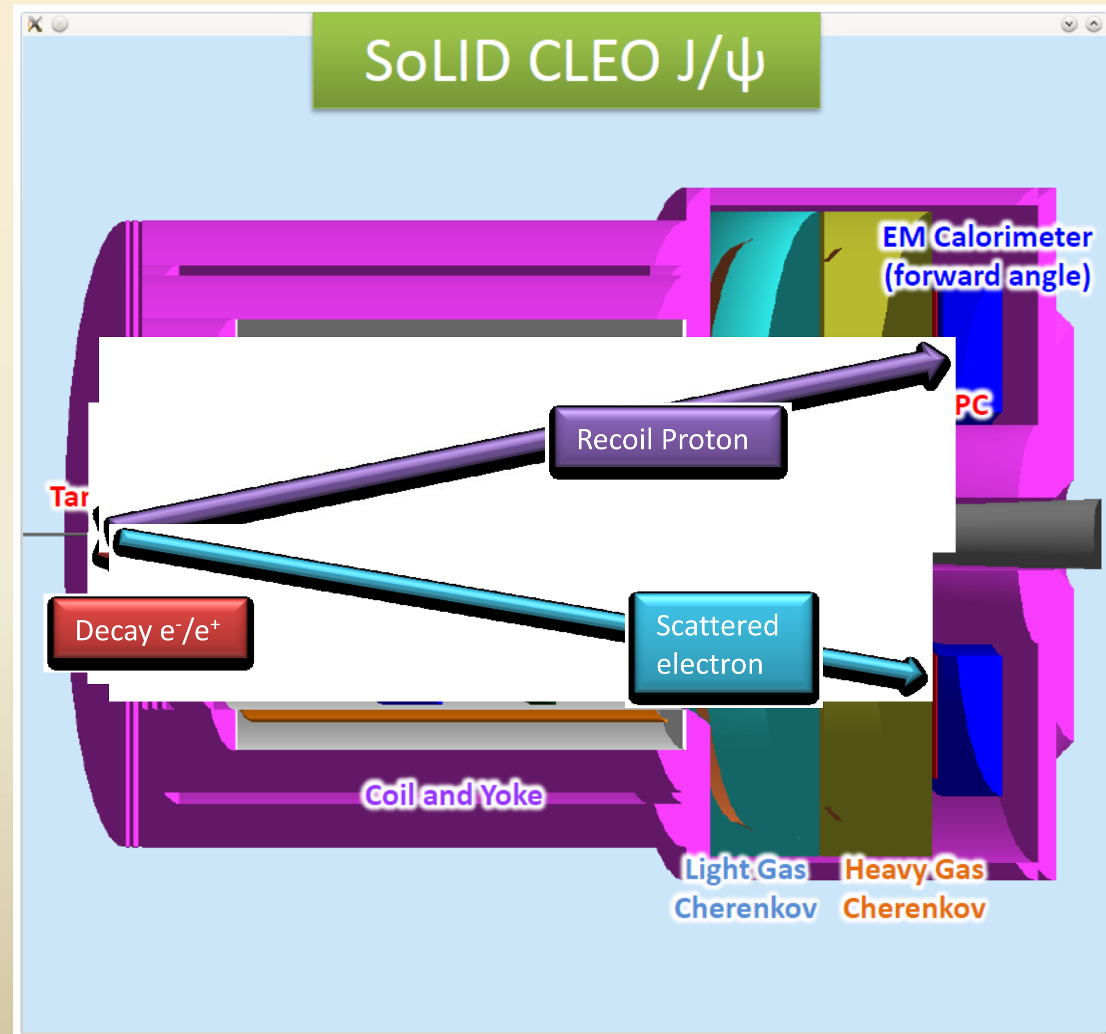
SoLID J/ψ Detection

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

Possible to detect all 4 final particles, fully exclusive production

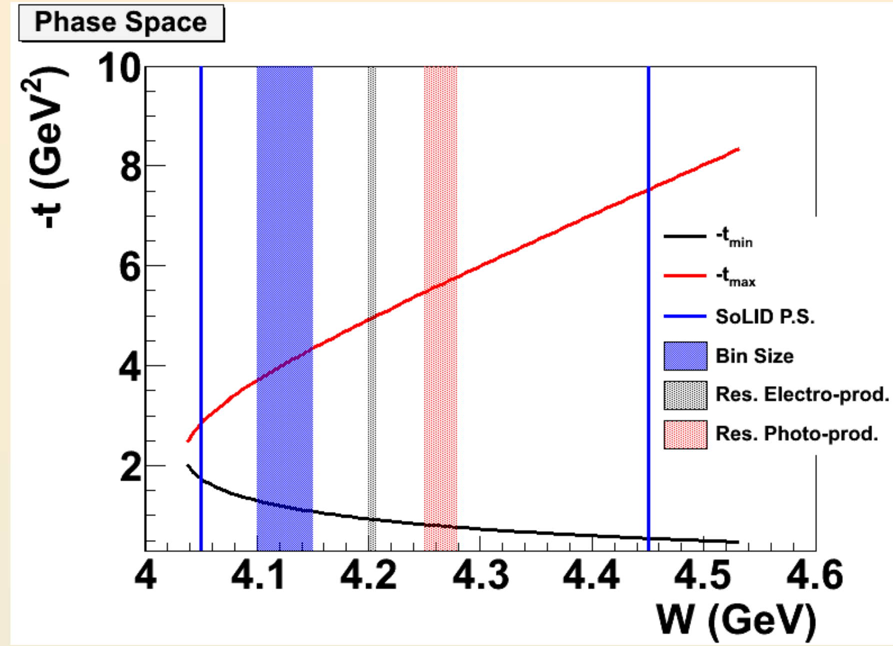




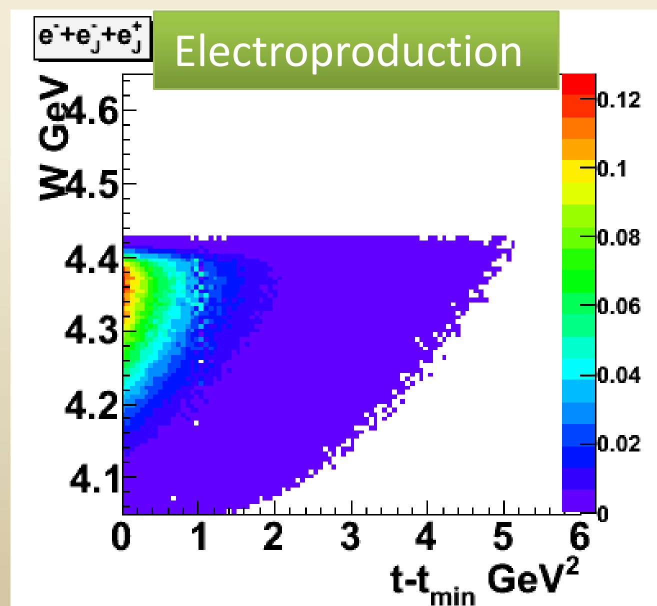


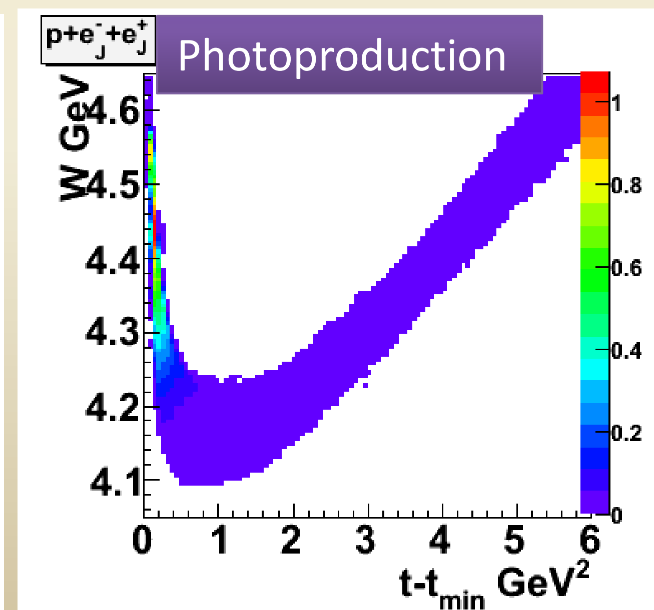
Electroproduction vs Photoproduction

- 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



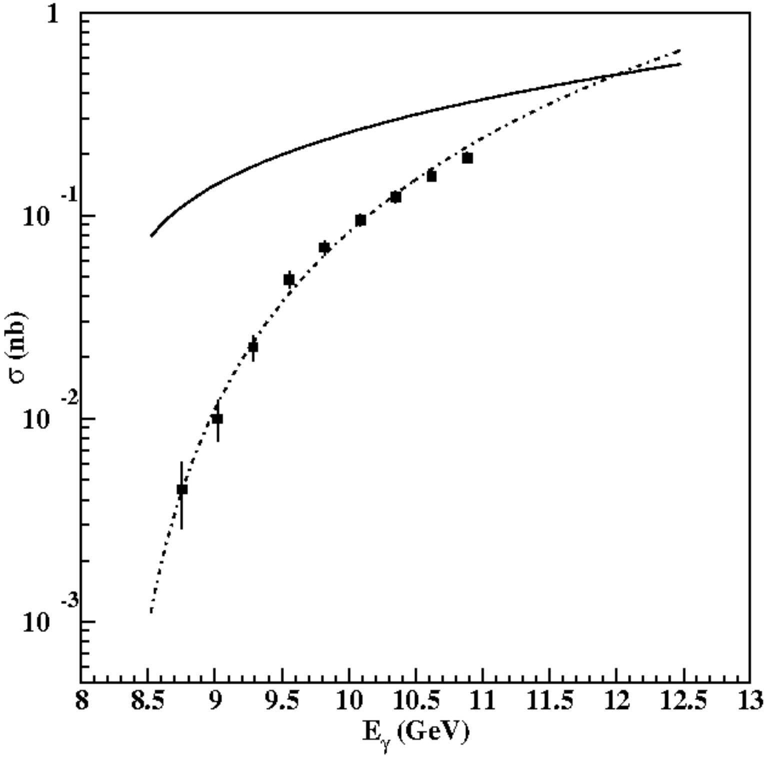


$$
\begin{aligned}
W^2 &= 2\nu \cdot M_p + M_p^2 - Q^2 \\
&= 2E_\gamma^{eff} \cdot M_p + M_p^2
\end{aligned}
$$

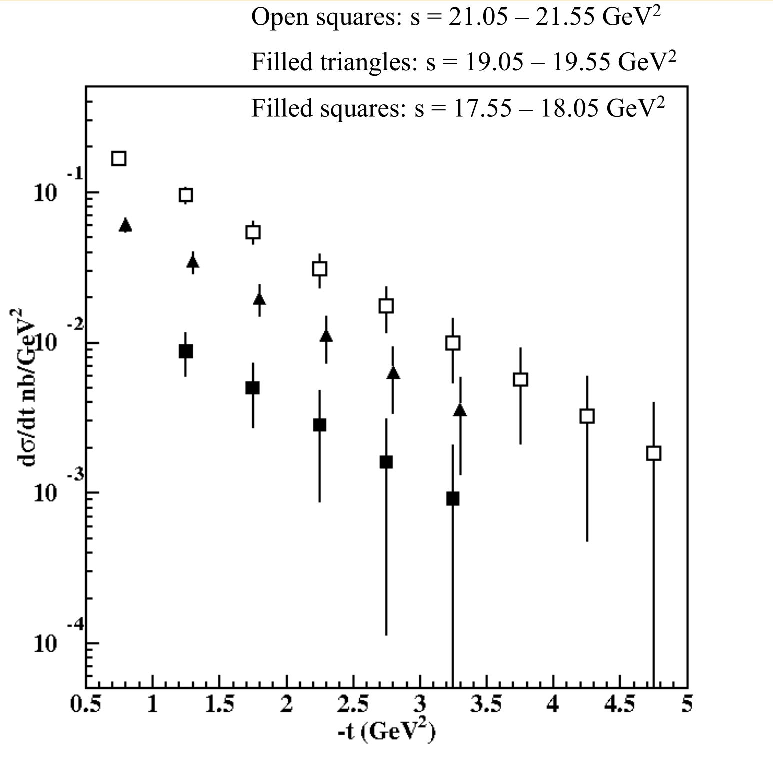
CLAS12 J/ψ Projection

exclusive J/ψ production

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



Uncertainties for the total cross section assuming the most conservative prediction

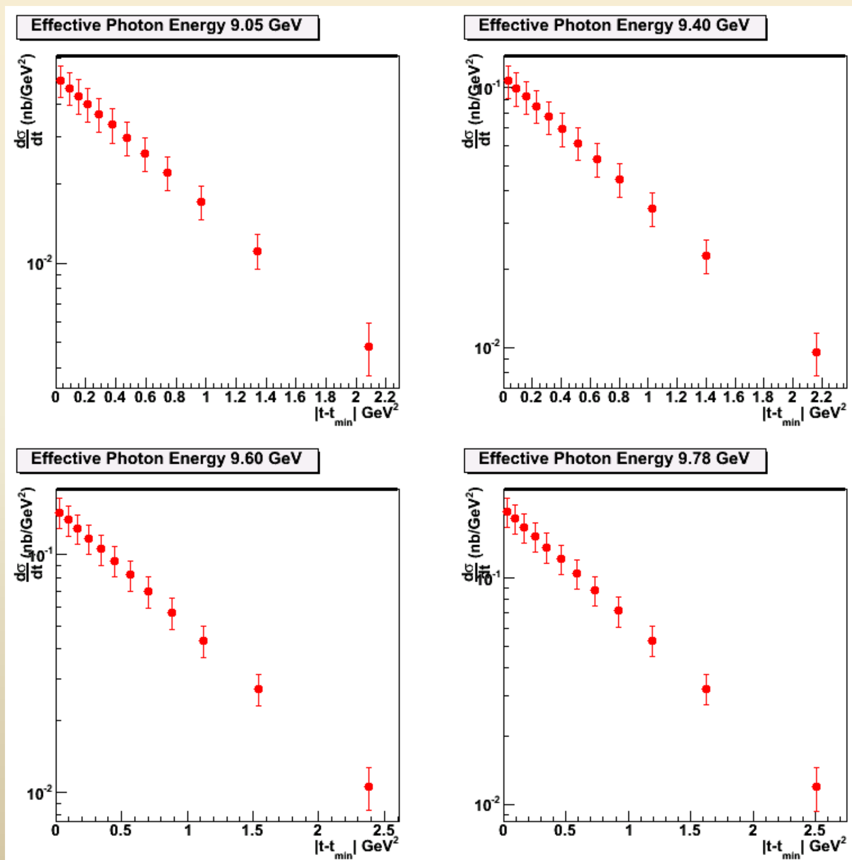


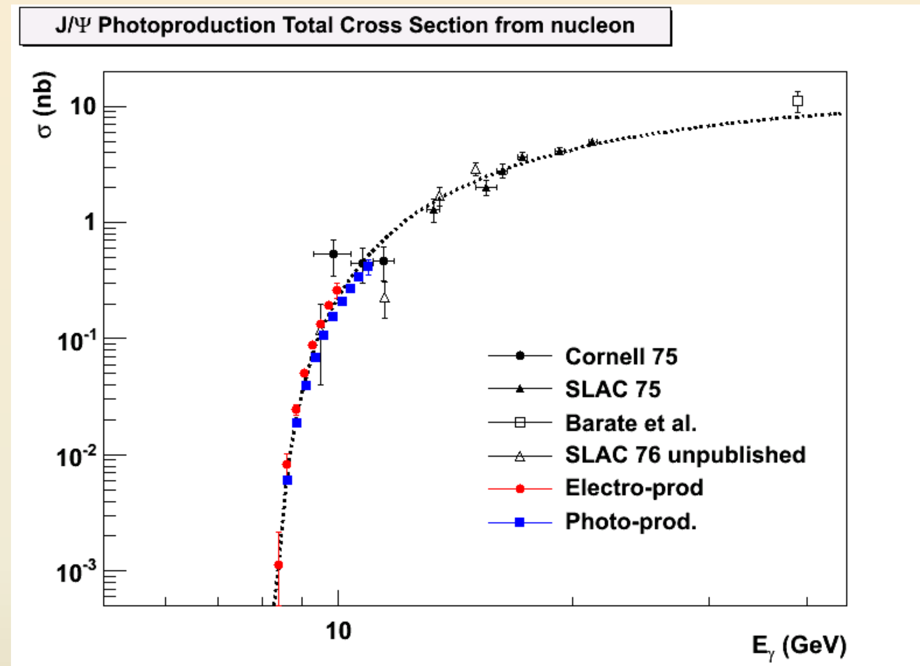
t-dependence in narrow bins of *s* for a total cross section given by the lower curve on the left

SoLID J/ψ Projection

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

t-dependence of the differential cross section





With < 0.01 GeV energy resolution in W and 8 energy bins in W to study the threshold behavior of cross section

J/ψ at JLab 12GeV

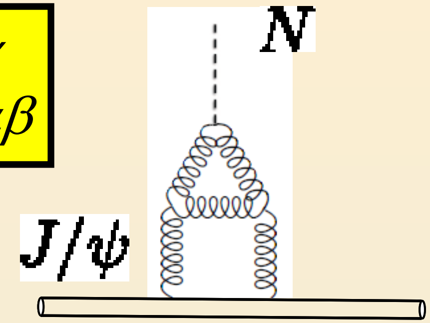
- Its production near threshold will be explored with both photoproduction and electroproduction
- Good energy resolution and large statistics can constrain models and shed lights on the gluonic interaction
- ***CLAS12 and SoLID will run at different time and be well complementary***

Backup JPsi

Conformal (Trace) Anomaly

Trace of energy momentum tensor

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



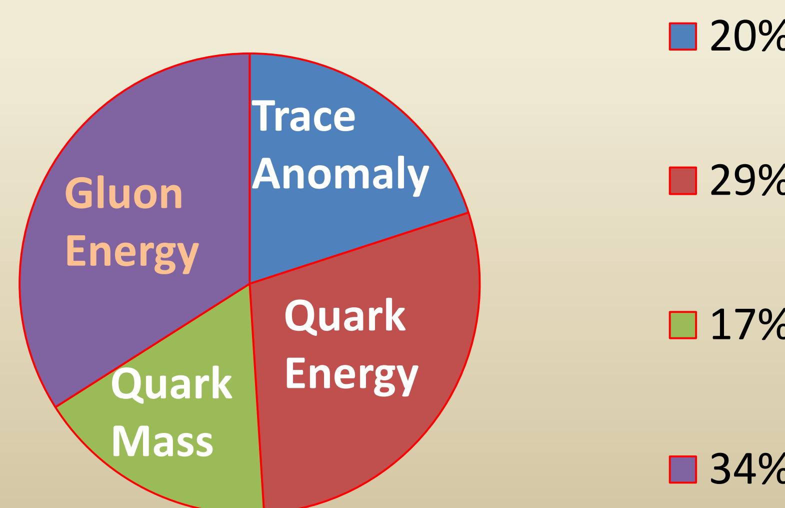
"Beta" function energy evolution of strong interaction coupling constant

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

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

[X. Ji PRL 74 1071 (1995)]

Proton Mass Budget



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^-** **$7.30\ 10^{-5}$**	**e^+e^-** **$4.71\ 10^{-5}$**	**e^+e^-** **$2.97\ 10^{-4}$**	**γγ** **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

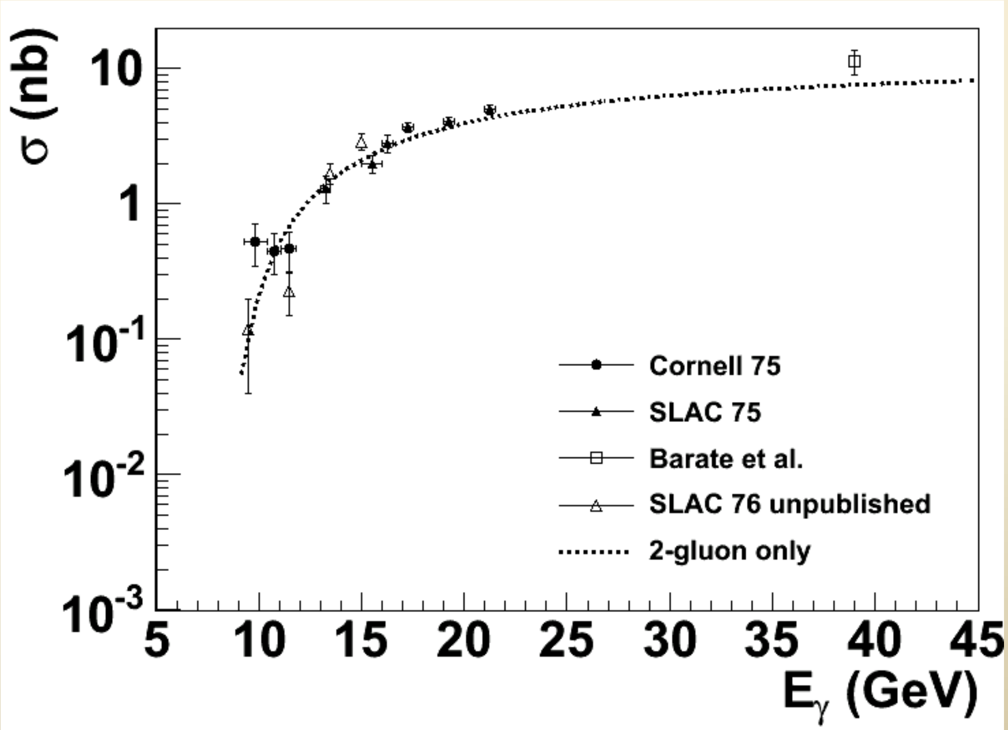
- Acceptance Effect: 10% for triple coincidence
- Detector and Trigger Efficiency <2%
- Target Luminosity: <2%
- Contribution from Al wall <1%
  - Dummy run + target vertex Cut
- Background Contamination ~0.5%
  - B-H background + Random Coincidence (measured directly)

Goal: 10-15% cross section measurements

Rates Estimates

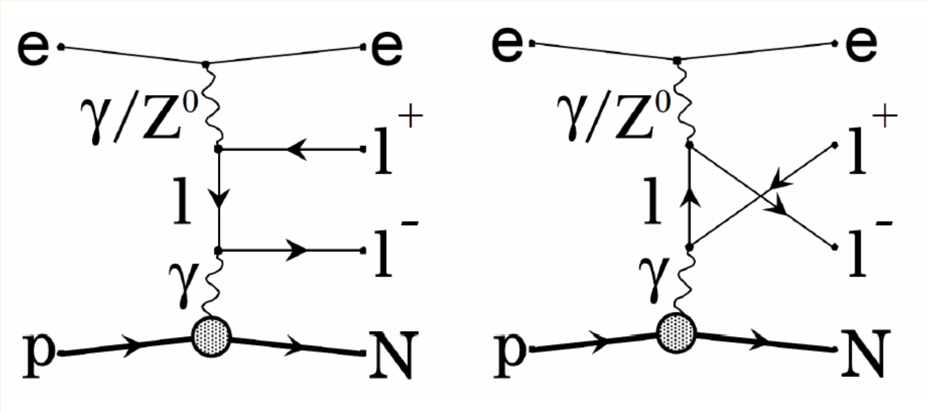
$$\frac{d^5\sigma}{d\Omega_e dP_e d\Omega_P} = \Gamma \frac{J}{2\pi}\frac{d\sigma}{dt}$$

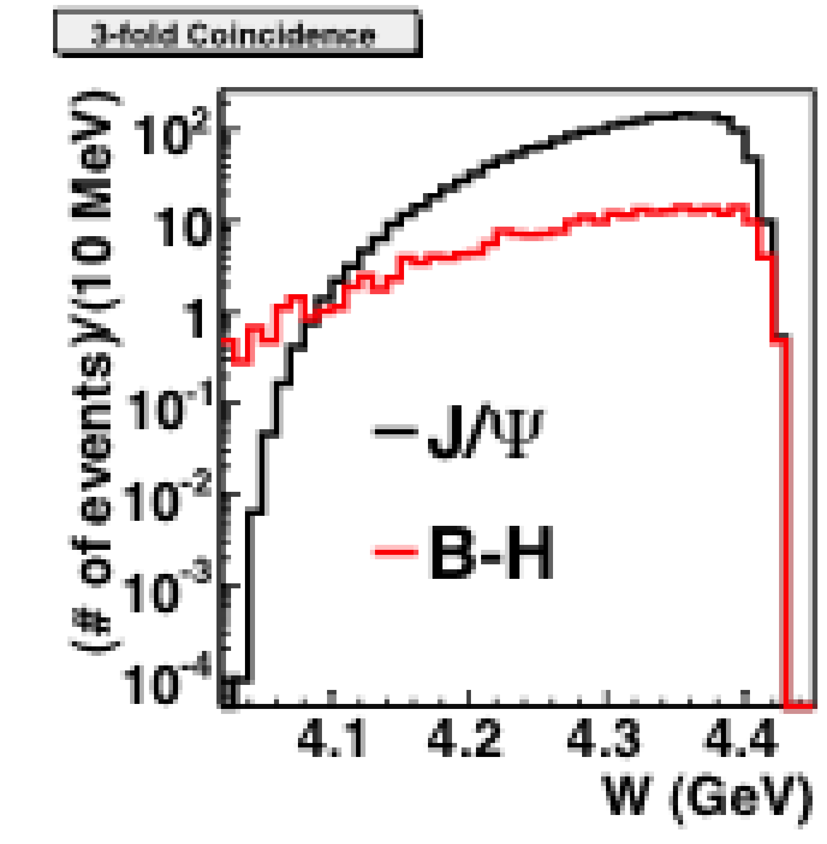
- Used equivalent photon approximation
- Γ is the virtual photon flux and J is the Jacobian
- Cross section is based on fits to data at high *W* within the 2-gluon exchange model



Physics Background

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



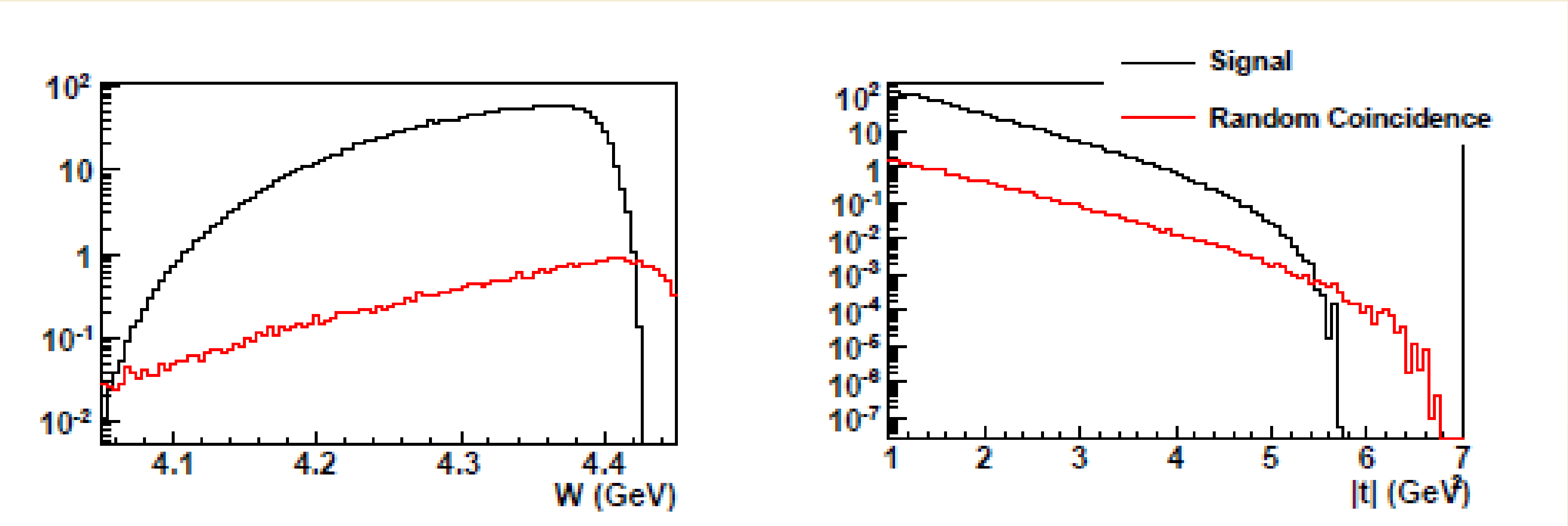


B-H process calculated with GRAPE-Dilepton program. Compared with 2-gluon model assuming no threshold enhancement.

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:

- $8.5 < E_\gamma < 9.0 GeV$
- Cross secction 0.01 nb
- Minimal statistics $\sim$ 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

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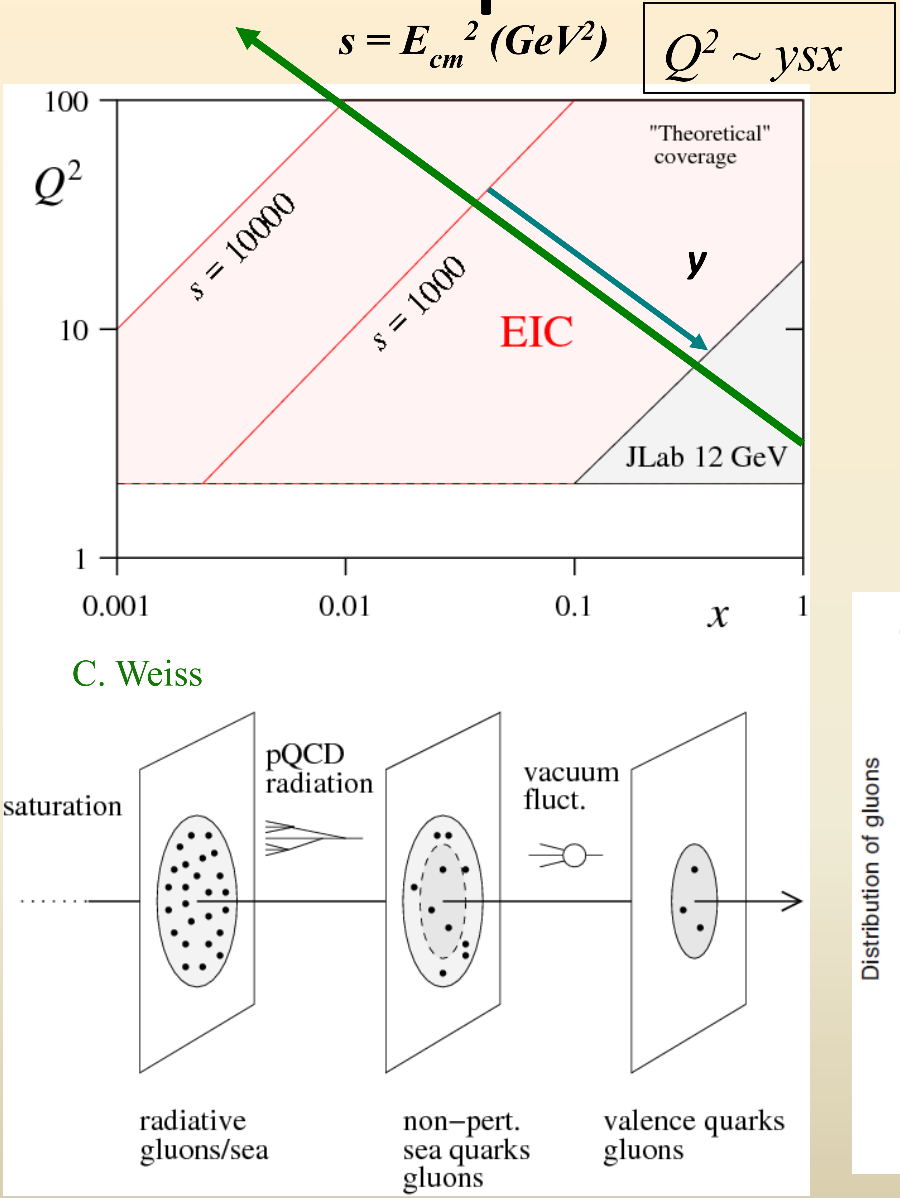
TCS EIC

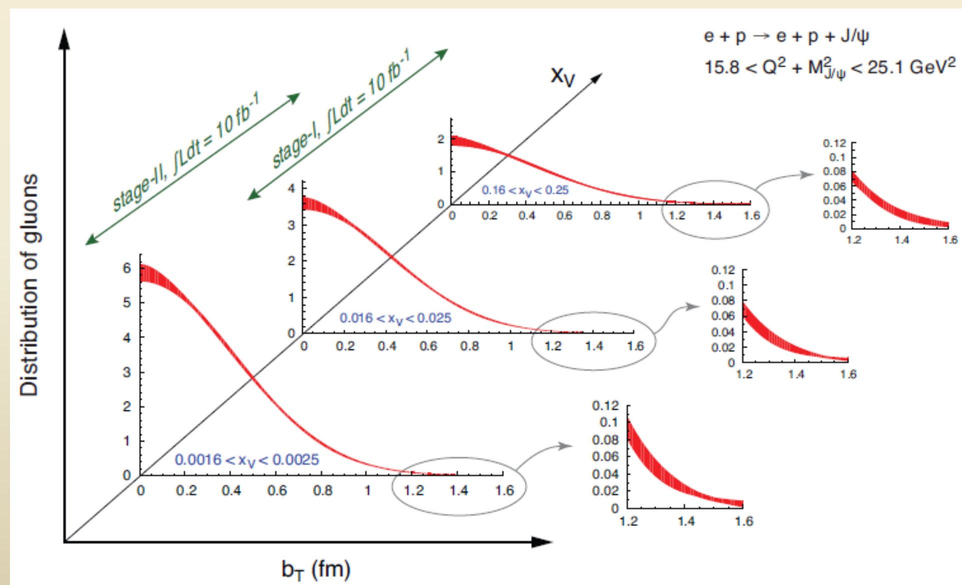
Dilepton Production at EIC



LHeC

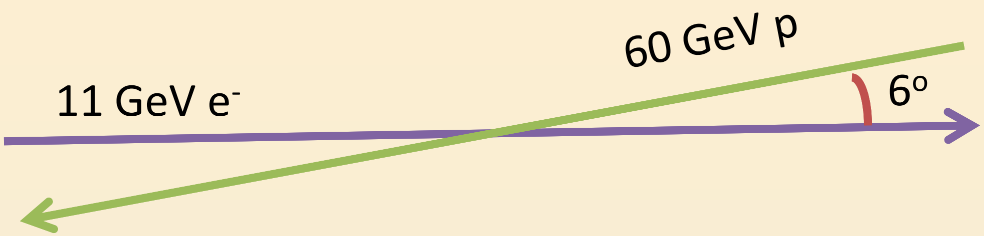
EIC Stage II (ELIC) **EIC Stage I (MEIC)** **JLab 12 GeV**

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

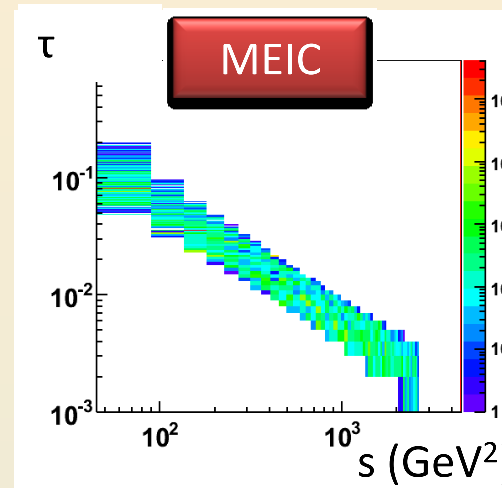


Transverse gluon distribution from deep exclusive J/ψ electroproduction

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
- Recoild proton goes backward
- Decay leptons have large coverage in the middle