



**12 GeV Upgrade**

*Future Science at Jefferson Lab*



# SoLID $J/\psi$ and TCS

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*for the SoLID Collaboration*

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# SoLID (Solenoidal Large Intensity Device)

General purpose device, large acceptance, high luminosity

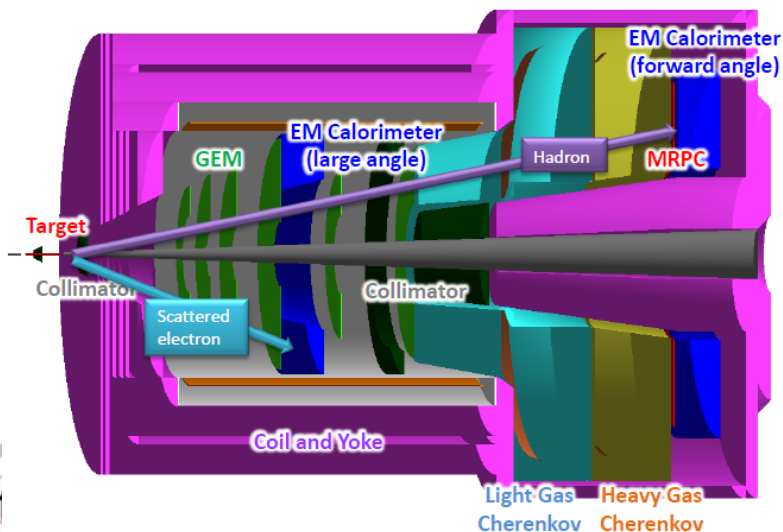
Lumi  $1e^{37}/\text{cm}^2/\text{s}$  (open geometry)

- 3D hadron structure
  - ❑ TMD (SIDIS on both neutron and proton)
  - ❑ GPD (Timelike Compton Scattering)
- Gluon study
  - ❑  $J/\psi$  production at threshold

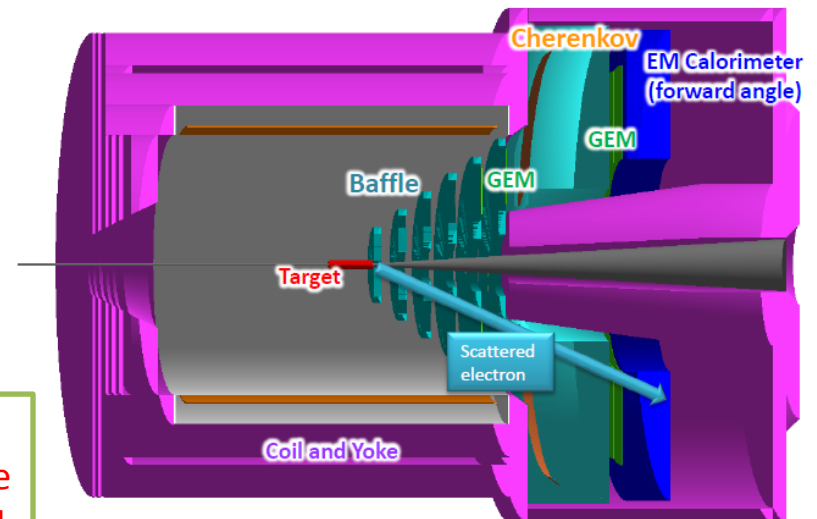
Lumi  $1e^{39}/\text{cm}^2/\text{s}$  (baffled geometry)

- Standard Model test and hadron structure
  - ❑ PVDIS on both deuterium and hydrogen

SoLID CLEO SIDIS



SoLID CLEO PVDIS



High rate  
High dose  
High field

# Gluon Study Using J/ψ

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

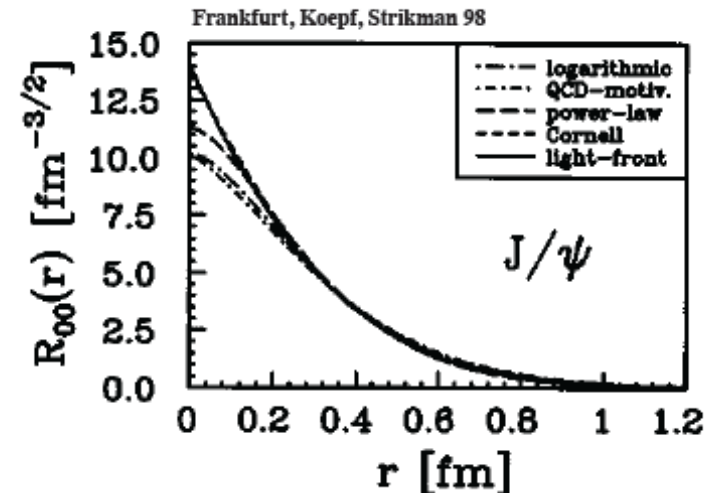
## ➤ J/ψ is a charm-anti-charm system

- ❑ 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 $\gg \Lambda_{\text{QCD}}$

- ❑ Typical size of J/ψ is 0.2-0.3 fm

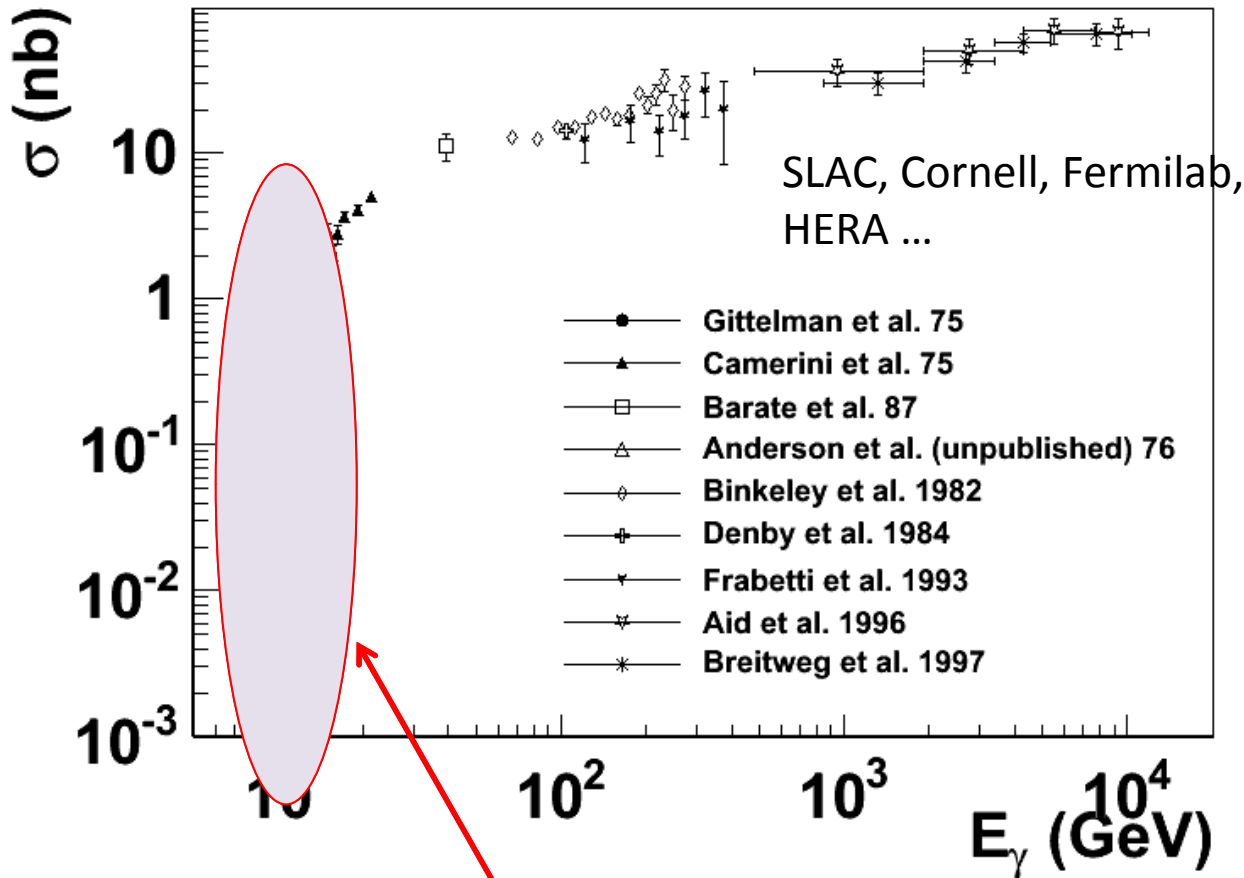
## ➤ J/ψ as probe of the strong color field in the nucleon



# Interaction between $J/\psi$ -N

- New scale provided by the charm quark mass and size of the  $J/\psi$ 
  - ❑ 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  $J/\psi$ -Nuclei bound state
    - Brodsky et al. ....
- Experimentally no free  $J/\psi$  are available
  - ❑ Challenging to produce close to threshold!
  - ❑ **Photo/electro-production of  $J/\psi$  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

The physics focus is this threshold region

# Reaction Mechanism

## Models (I): Hard scattering

(Brodsky, Chudakov, Hoyer, Laget 2001)

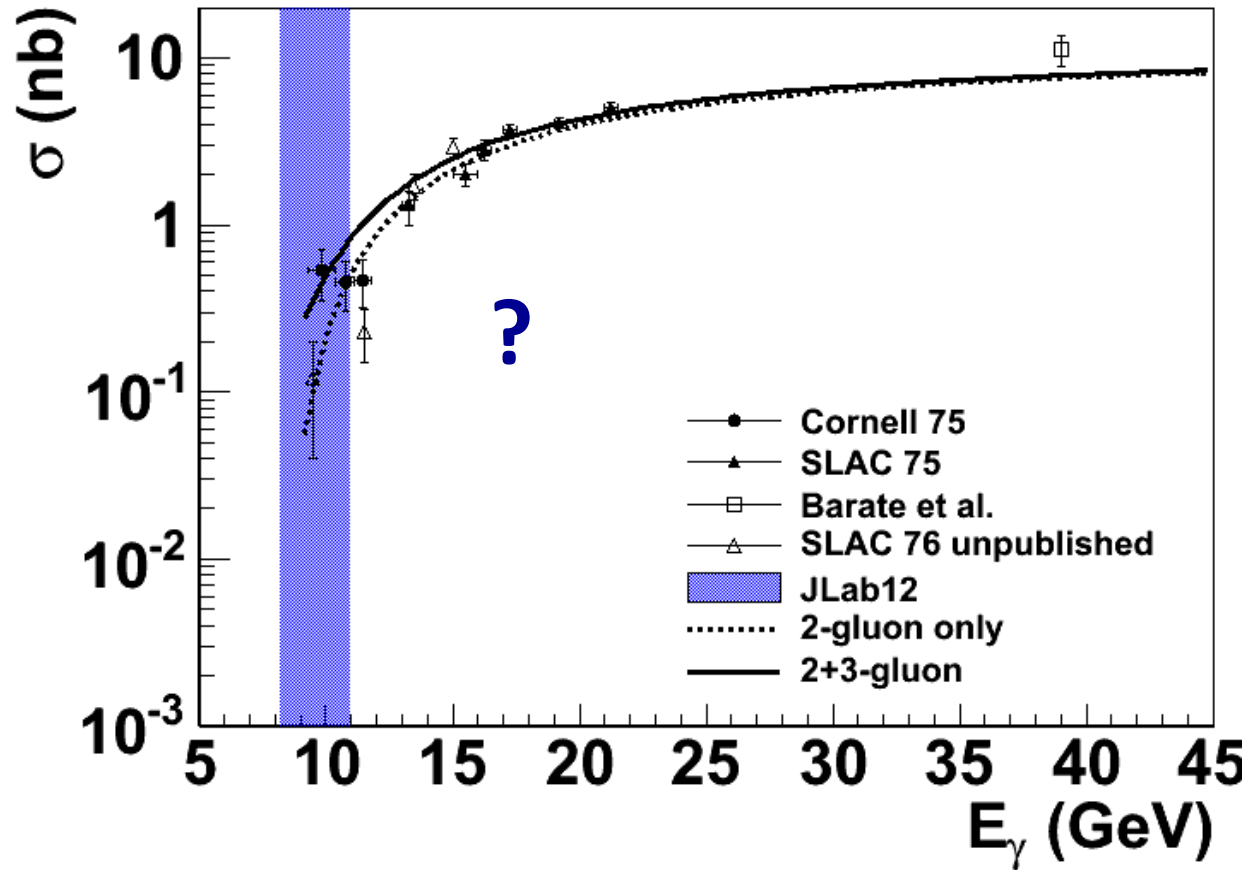
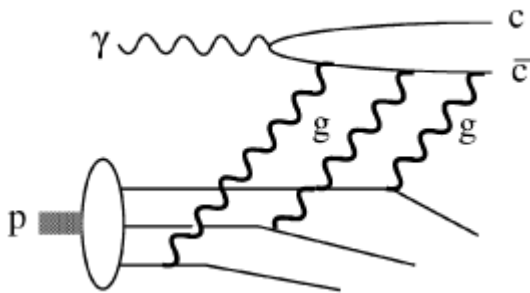
Add in 3-gluon scattering

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

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

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

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



# SoLID J/ψ Goal

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

- ⊙ **Measure the  $t$  dependence and energy dependence of  $J/\psi$  cross sections near threshold.**
  - ⊙ Probe the nucleon strong fields in a non-perturbative region
  - ⊙ Search for a possible enhancement of the cross section close to threshold

**Establish a baseline for  $J/\psi$  production in the JLab energy range!**

## ➤ **Bonuses:**

- ❑ Decay angular distribution of  $J/\psi$
- ❑ Interference with Bethe-Heitler term (real vs. imaginary)

## ➤ **Future Plans:**

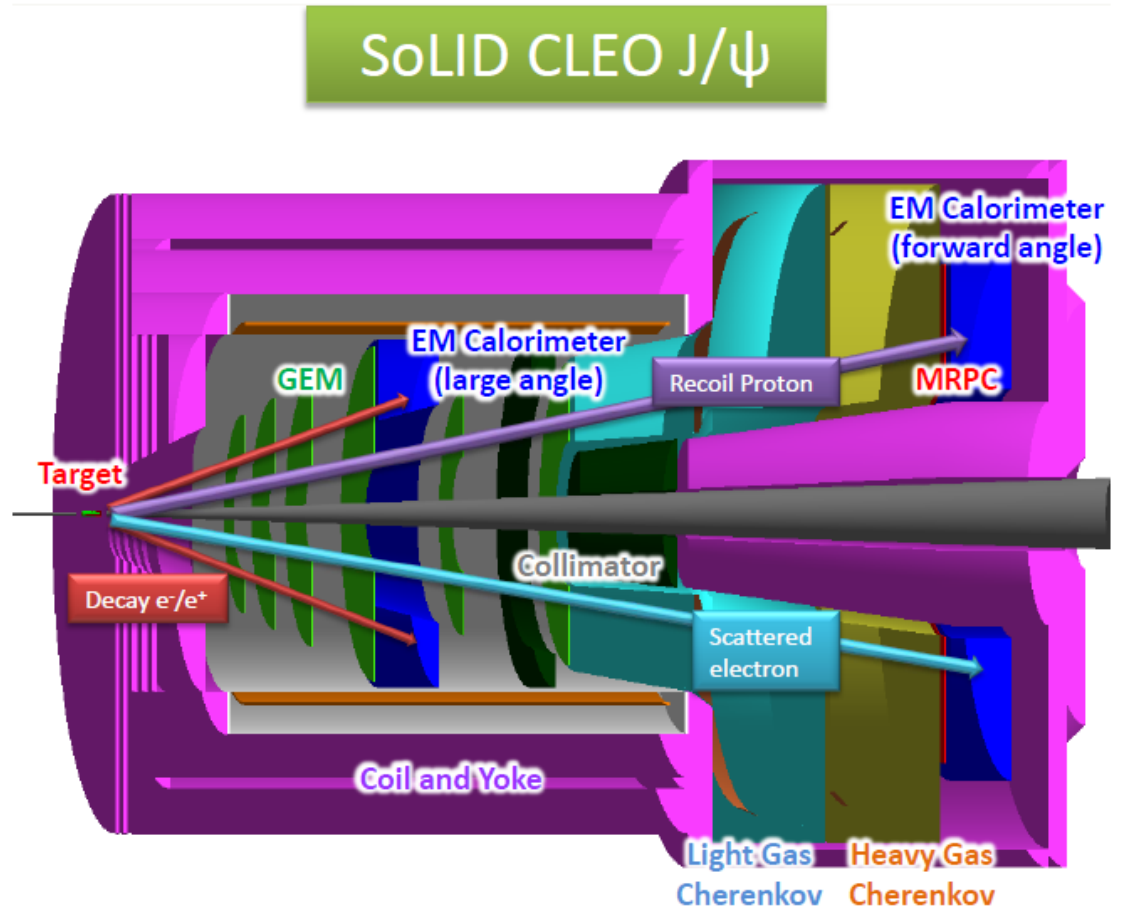
- ❑ Search for  $J/\psi$ -Nuclei bound state
- ❑  $J/\psi$  medium modification

# SoLID J/ $\psi$ Setup

$$e p \rightarrow e' p' J/\psi(e^- e^+)$$

$$\gamma p \rightarrow p' J/\psi(e^- e^+)$$

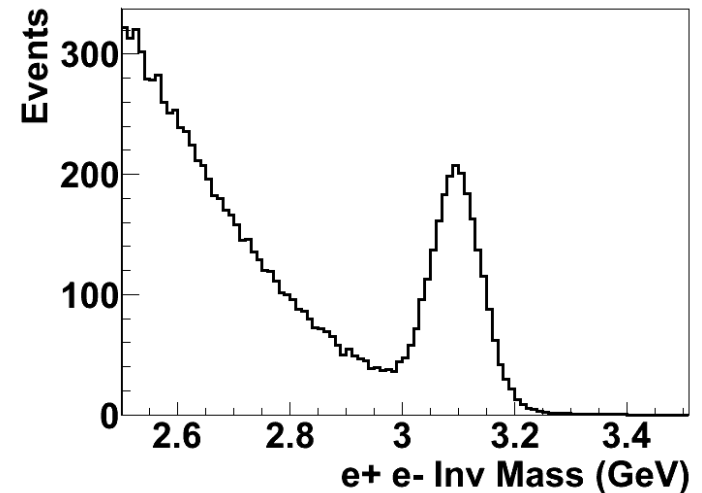
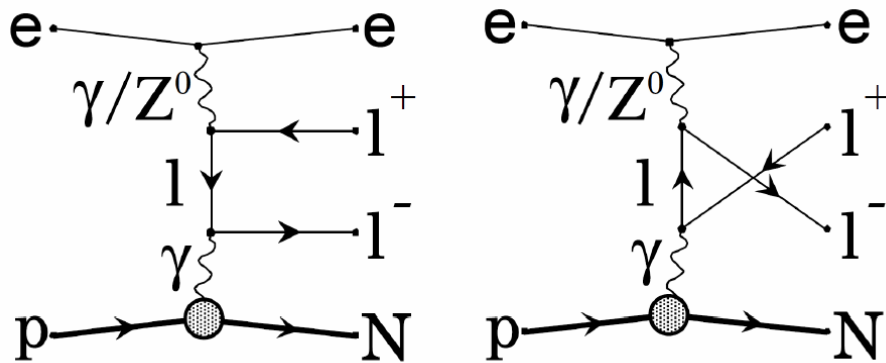
- Detect decay  $e^- e^+$  pair
- Detect (or not) scattering  $e$  for electroproduction (or photoproduction)
- Detect recoil  $p$  to be exclusive





# Signal and Background

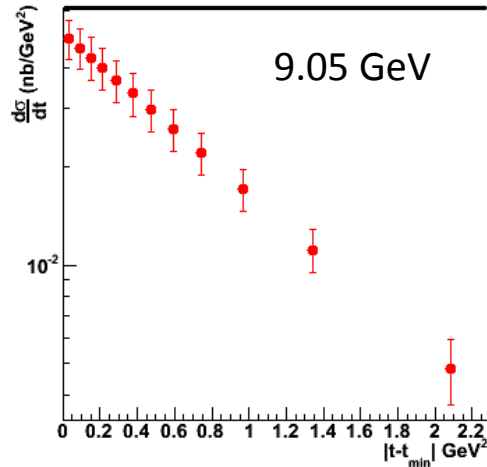
- Signal by invariant mass of the decay lepton pair
- Due to the large mass of  $J/\psi$  and near-threshold kinematics, There are little physics background
- The main background is the two photon Bethe-Heitler process



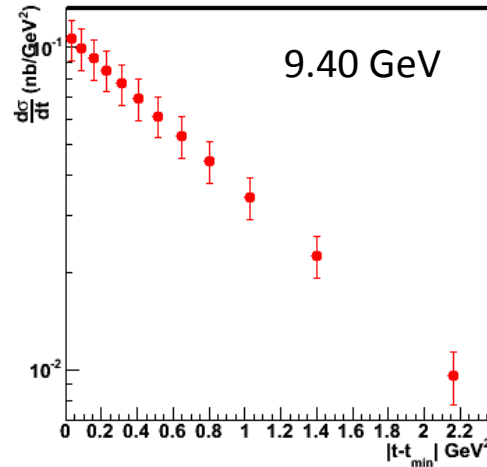
# Projections of $d\sigma/dt$ with 2-g model

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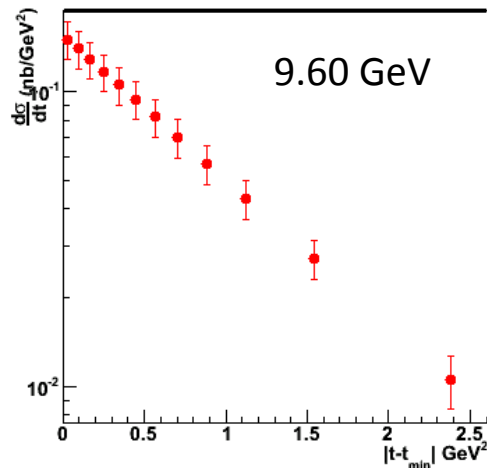
Effective Photon Energy 9.05 GeV



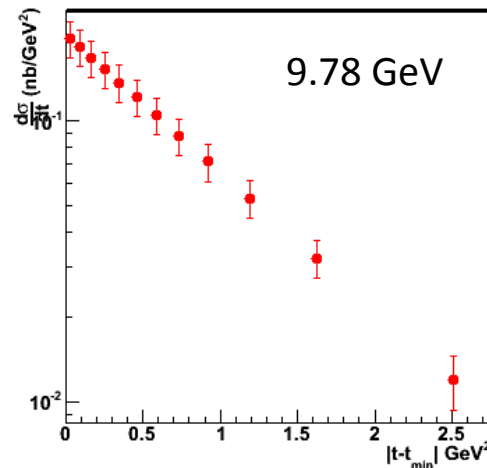
Effective Photon Energy 9.40 GeV



Effective Photon Energy 9.60 GeV



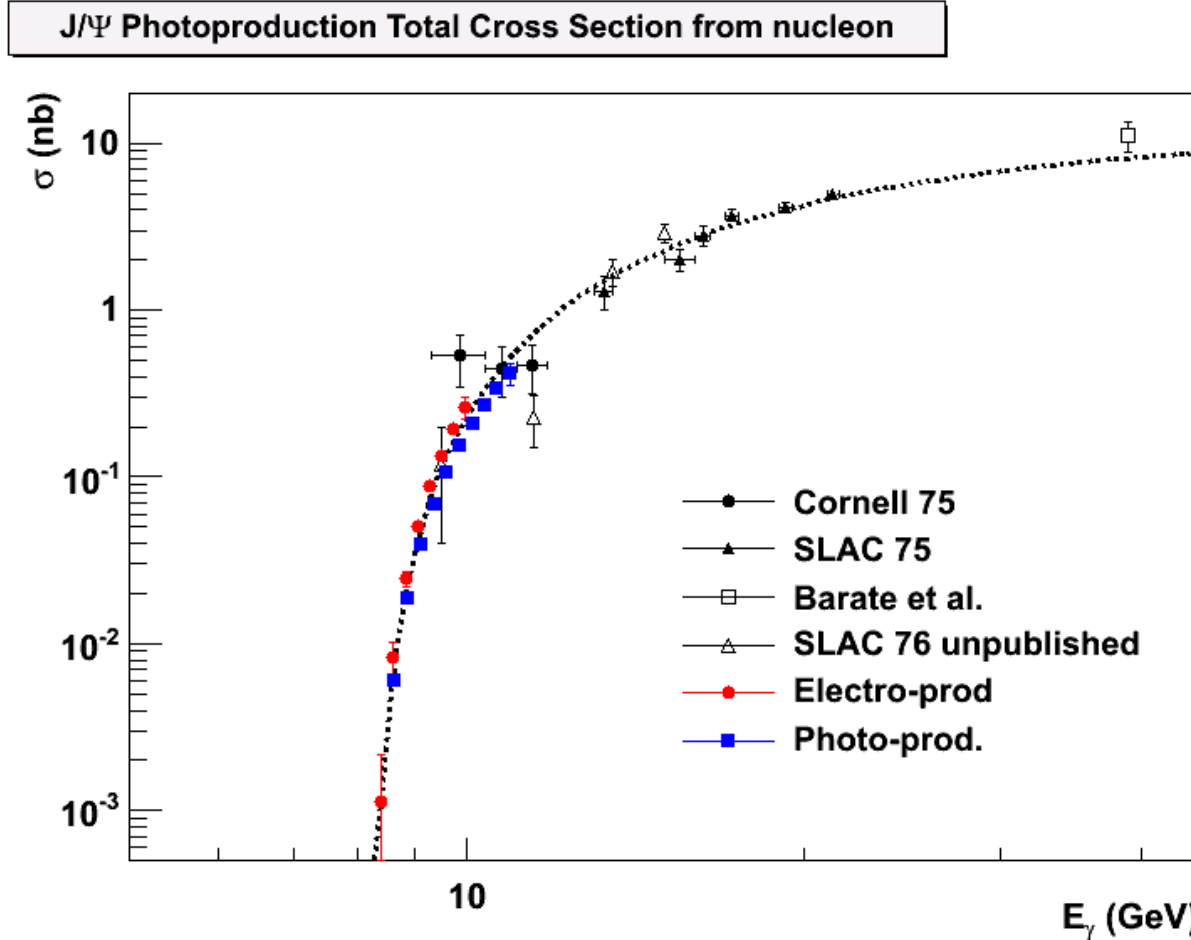
Effective Photon Energy 9.78 GeV



- ⊙ 50 days running, 3uA electron beam on 15cm long LH2 target, luminosity  $1e^{37}/\text{cm}^2/\text{s}$
- ⊙ Data will be first binned in  $t$  at different  $W$  (or effective photon energy) to study the  $t$ -dependence of the differential cross section, then derive total cross section

$$E_{\gamma}^{eff} = \frac{W^2 - M_p^2}{2M_p}$$

# Total $\sigma$ Projection



With  $< 0.01$  GeV energy resolution and small binning to study the threshold behavior of cross section

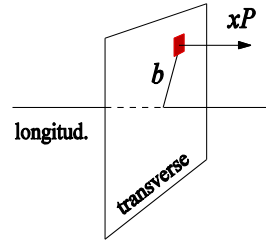
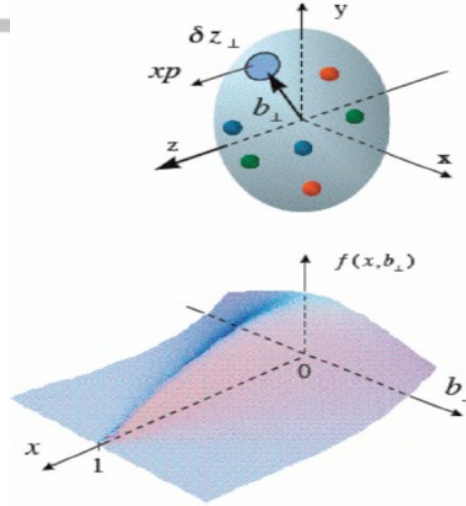
# Summery of SoLID J/ $\psi$ Program

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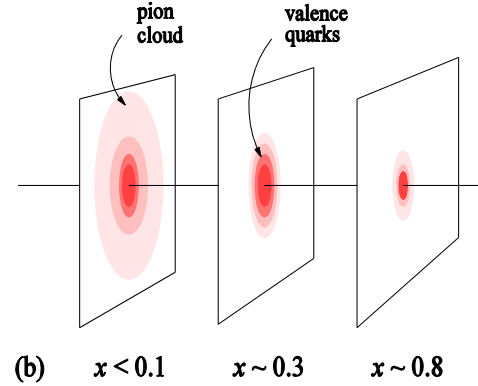
- It was not accessible at CLAS 6GeV, perfect for 12GeV
- Familiar resonance with a new perspective and a unique approach to gluon study
- Probe the nucleon strong fields in a non-perturbative region
- Search for a possible enhancement of the cross section close to threshold
- Goal: 10-15% cross section measurements
- More studies on decay angle distribution and nuclei target may follow

# Generalized Parton Distribution (GPD)

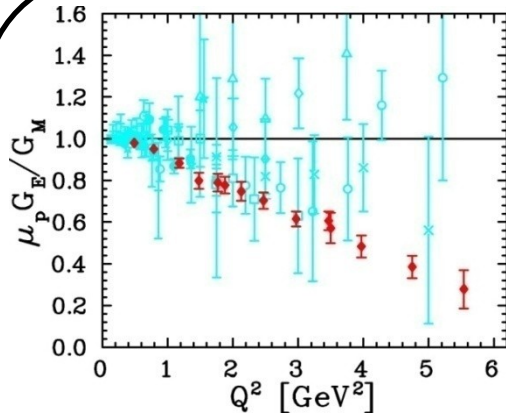
A unified descriptions of partons (quarks and gluons) in the momentum and impact parameter space



(a)

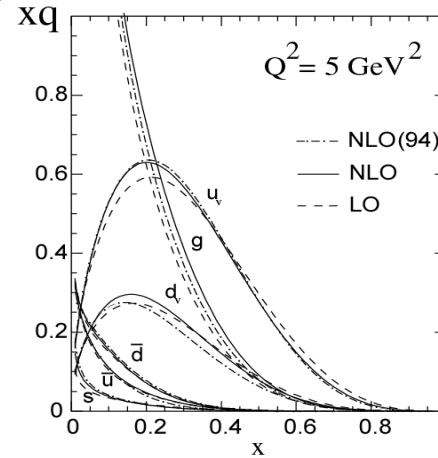
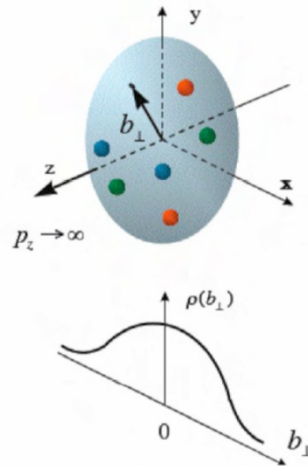


(b)



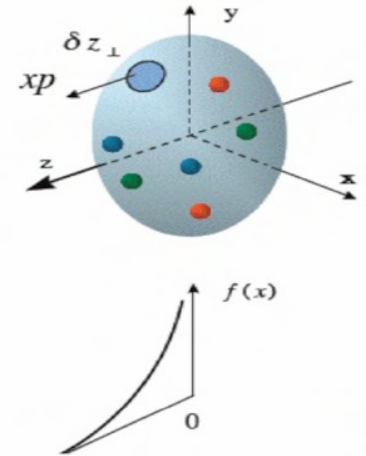
Elastic form factors

Transverse spatial distributions



Parton Distribution Functions

Longitudinal momentum distributions

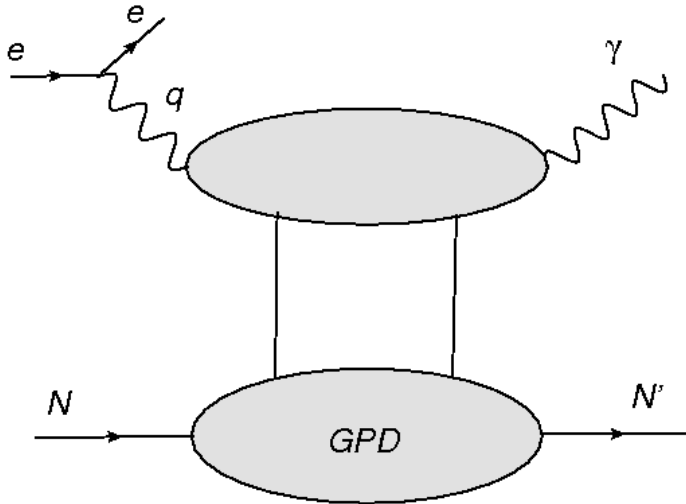


# DVCS and TCS: access the same GPDs

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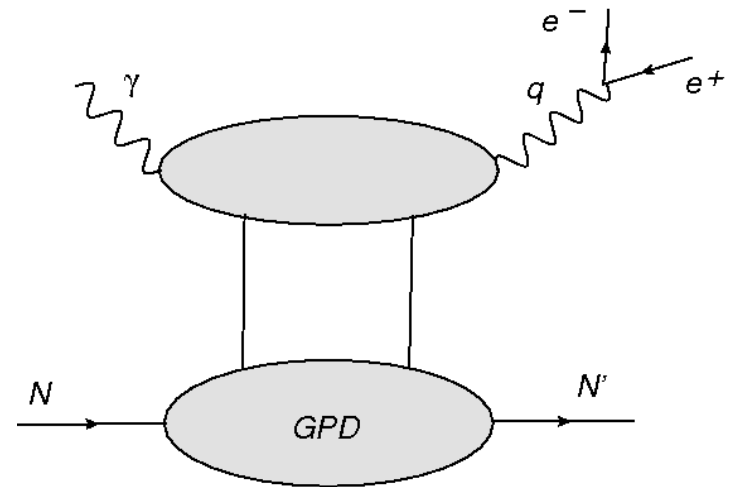
Spacelike Deeply Virtual Compton Scattering

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



Timelike Compton Scattering

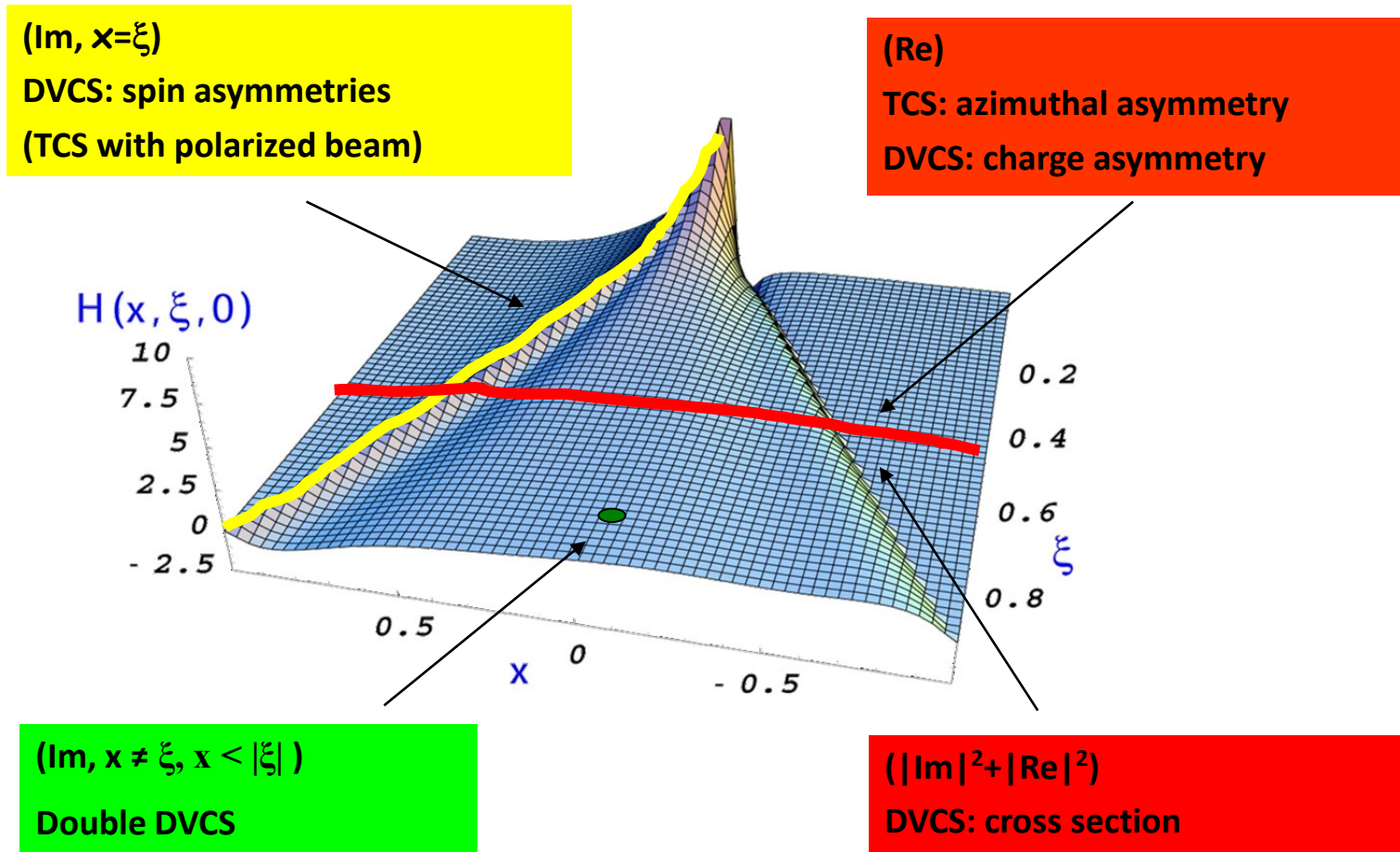
$$\gamma p \rightarrow \gamma^*(e^- e^+) p'$$



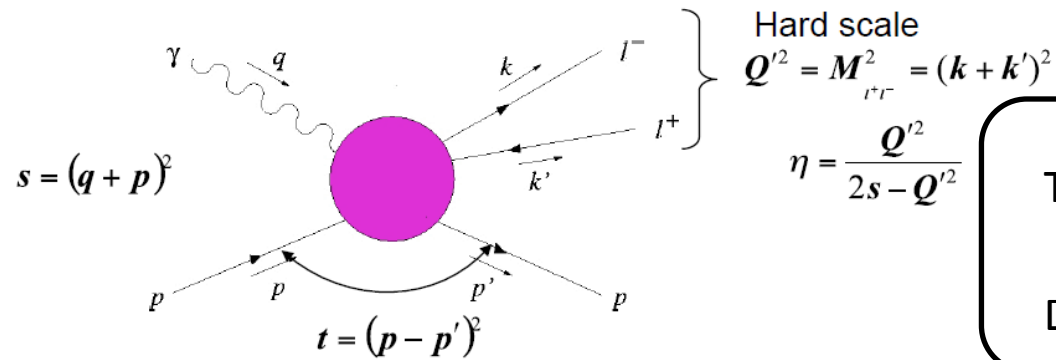
- “The amplitudes of these two reactions are related at Born order by a simple complex conjugation but they significantly differ at next to leading order (NLO)”
- “The Born amplitudes get sizeable  $O(\alpha_s)$  corrections and, even at moderate energies, the gluonic contributions are by no means negligible. 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: access the same GPDs



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

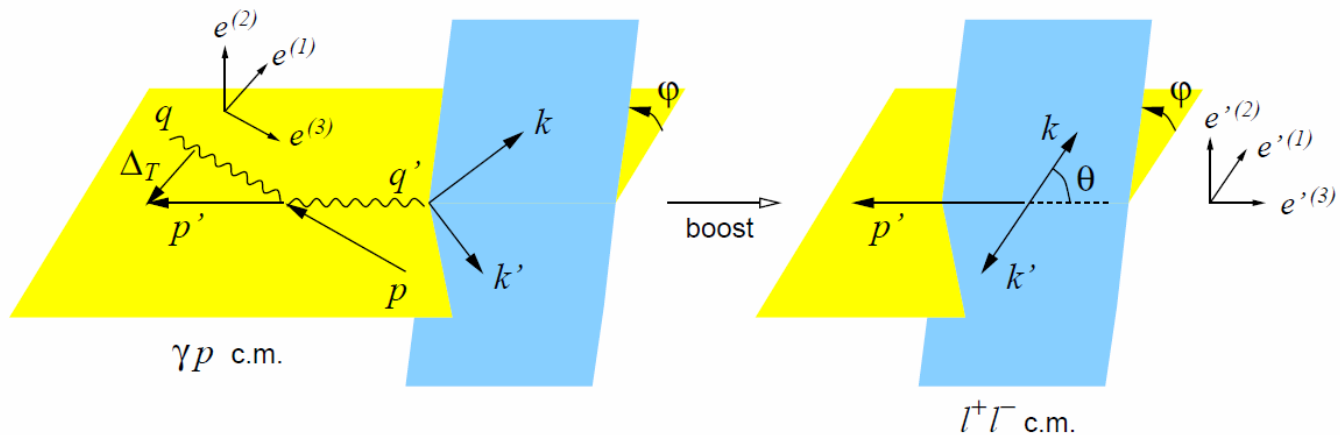


TCS

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

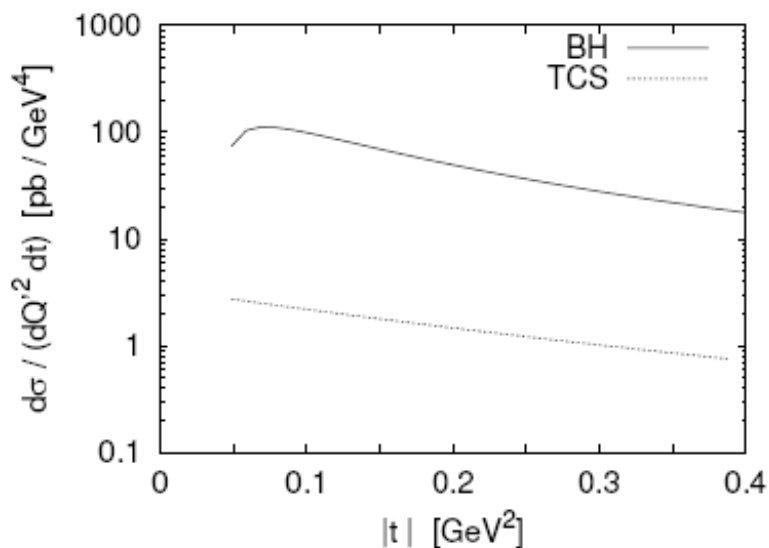
DVCS

$$x_B = Q'^2 / (2p \cdot q) \quad \eta = x_B / (2 - x_B)$$

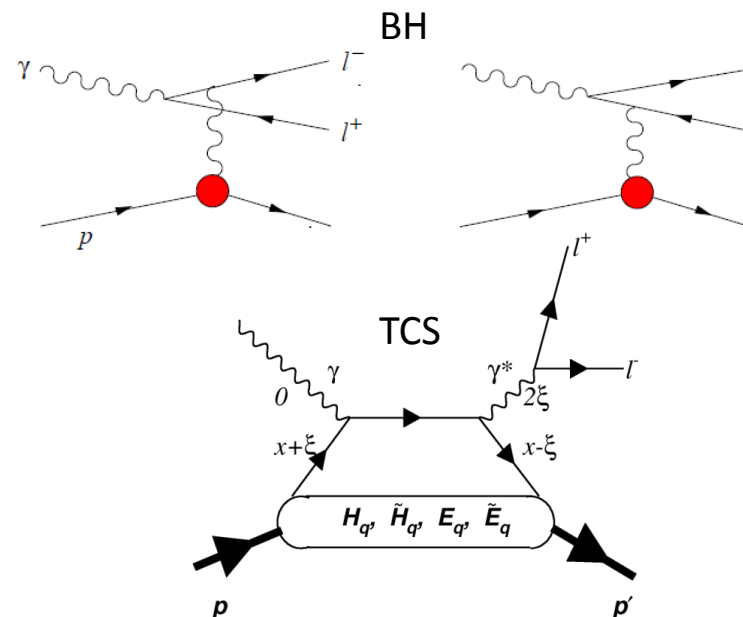




# TCS and Bethe-Heitler (BH) Interference



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



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

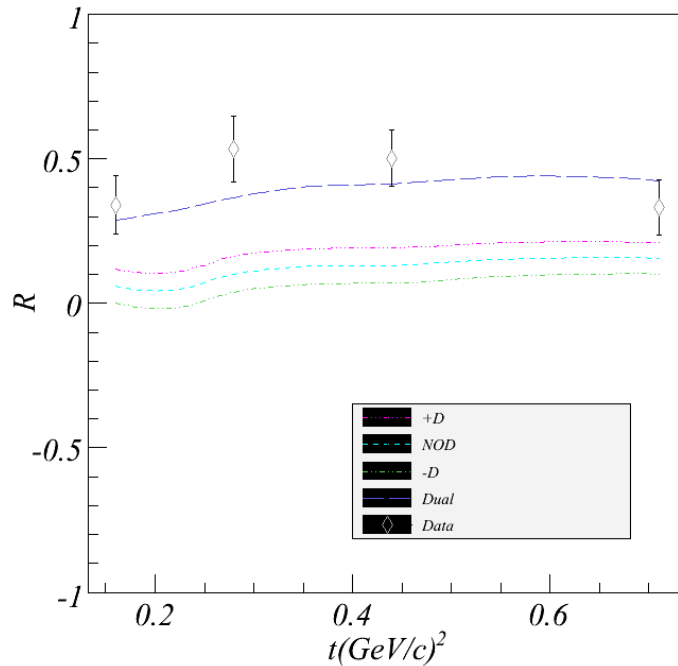
- For lepton charge conjugation, TCS and BH amplitudes are *even*, while the interference term is *odd*
- Therefore, direct access to interference term through angular distribution of the lepton pair (cosine and sine moments)

Cosine moment of weighted cross sections

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

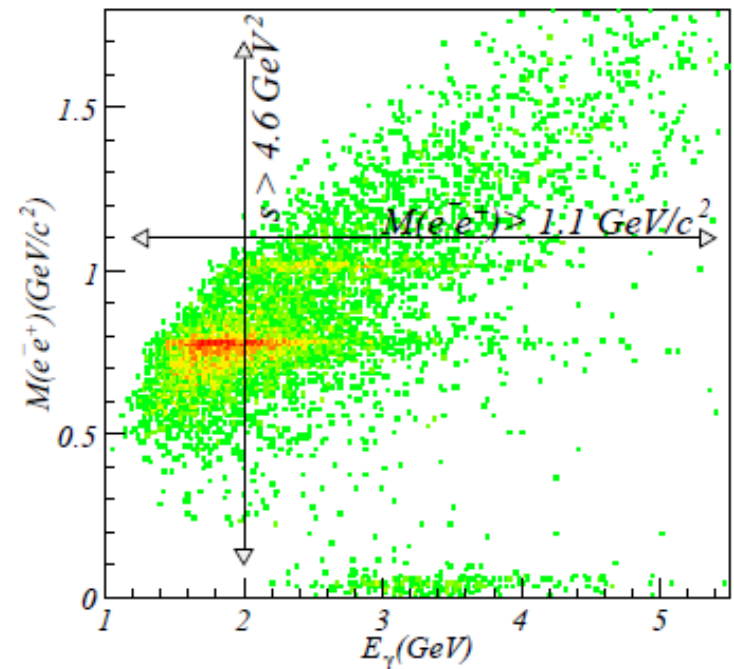
$$R = \frac{2 \int_0^{2\pi} d\varphi \cos \varphi \frac{dS}{dQ^2 dt d\varphi}}{\int_0^{2\pi} d\varphi \frac{dS}{dQ^2 dt d\varphi}}$$

R can be compared directly with GPD models



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

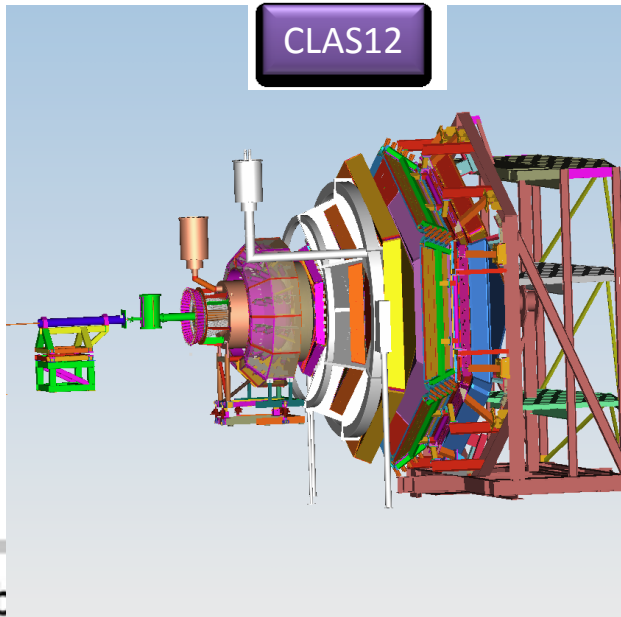
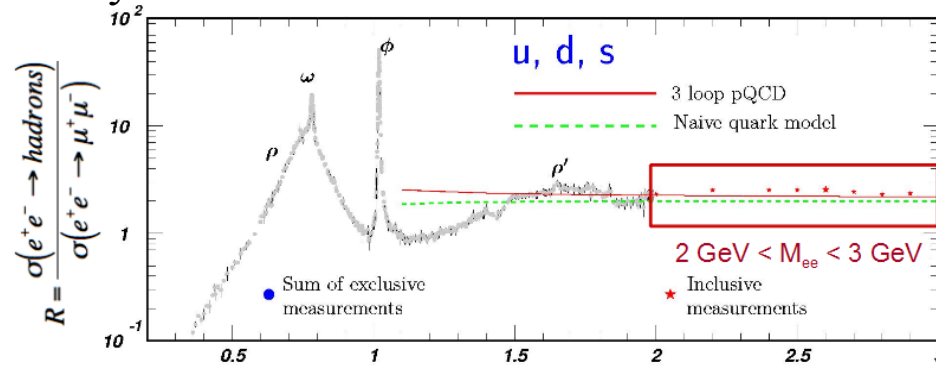
- 6 GeV data were important for developing methods
- But its kinematics are limited to  $M_{e^+e^-} < 2 \text{ GeV}$



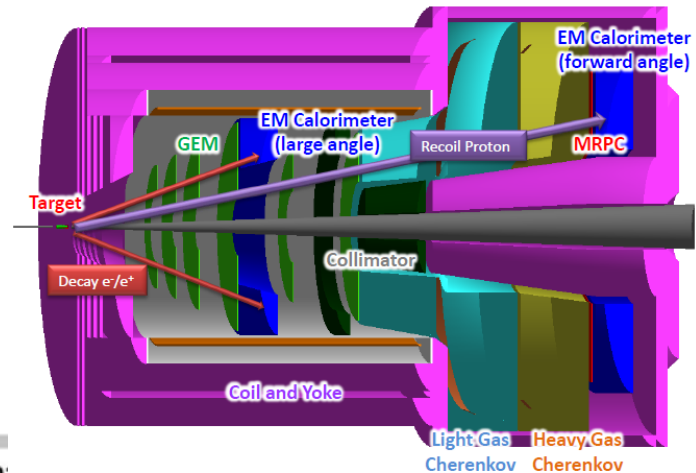
Analysis of CLAS g12 with tagged real photons is ongoing

# TCS at JLab 12GeV

- 11 GeV beam extends s to 20GeV<sup>2</sup>
- $M_{e^+e^-}(Q')$  reaches about 3.5GeV and this allows the access to the resonance free region from 2GeV to 3GeV
- $\tau$  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



SOLID CLEO TCS

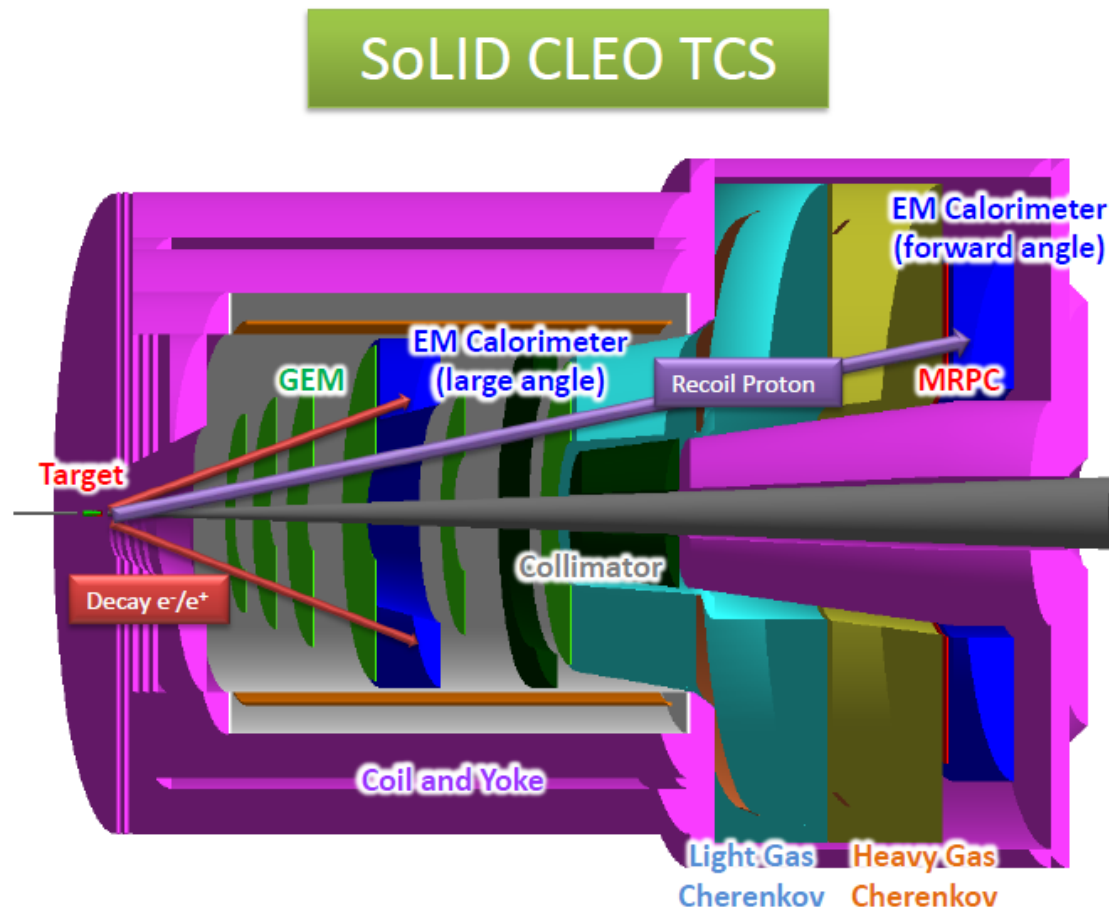


# SoLID TCS Setup

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

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

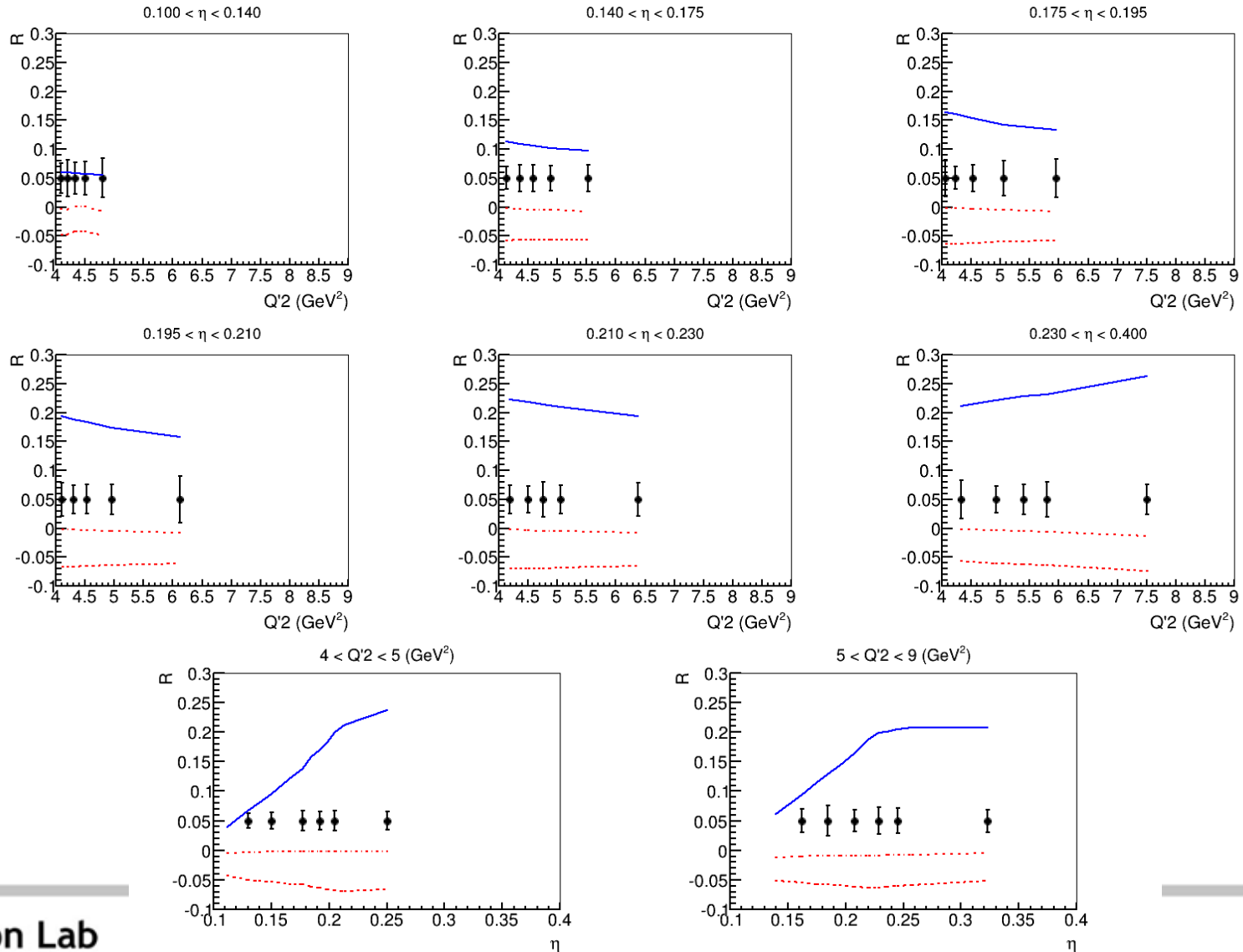
- Detect decay  $e^- e^+$  pair
- Detect recoil  $p$  to be exclusive
- Cut on missing momentum and mass to ensure quasi-real process



# SoLID TCS Projection

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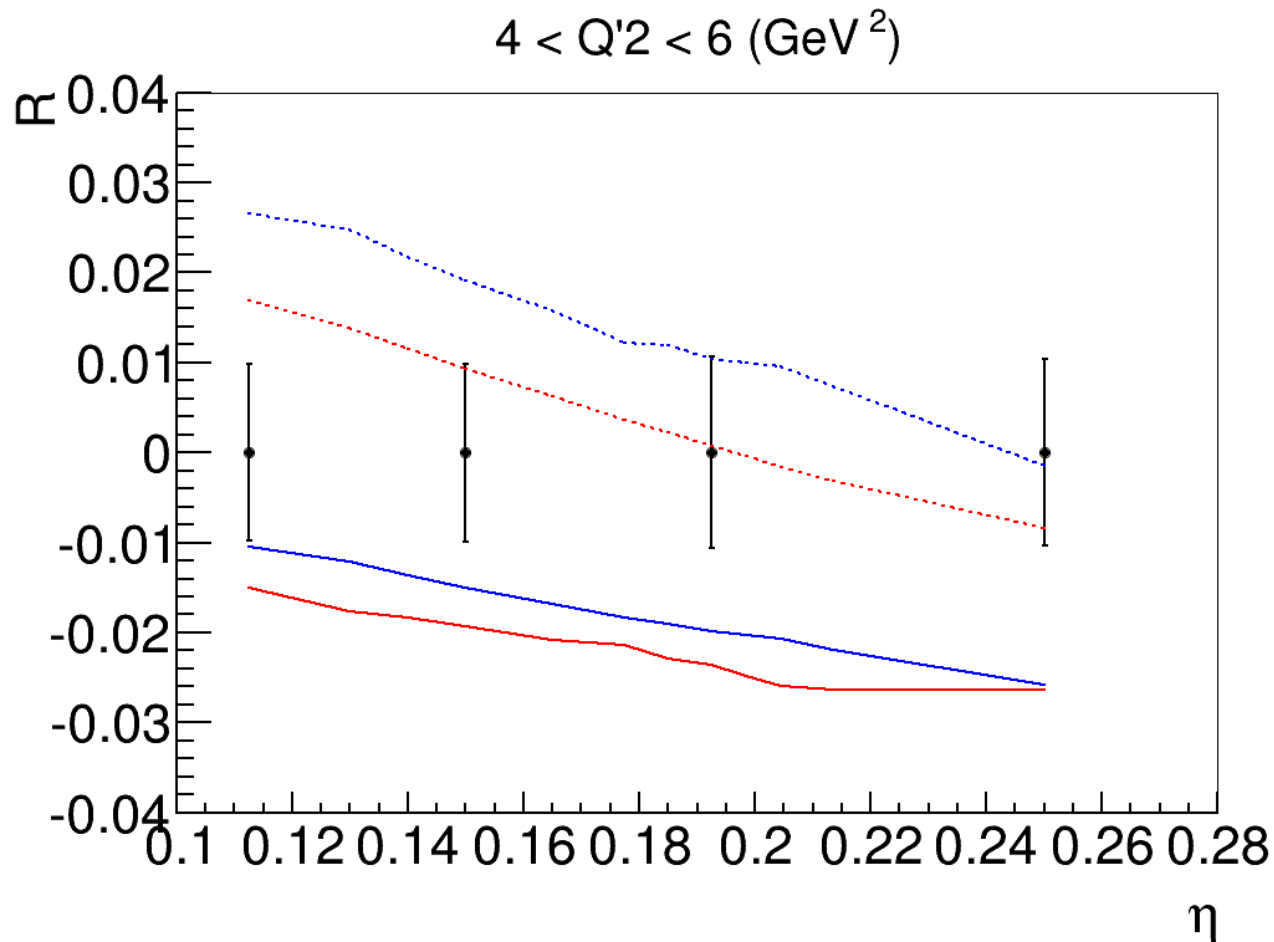
- Blue solid line, dual parameterization model
- Red dash-dot line, double distribution with D-term model
- Red dash line, double distribution without D-term model



# SoLID TCS Projection

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



# Summary of SoLID TCS Program

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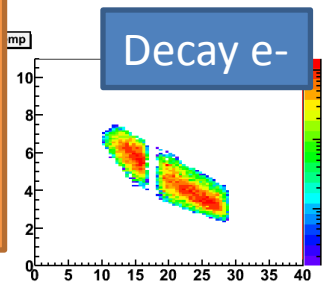
- First measurement on TCS in the resonance free region
- Open a new way to GPD study besides DVCS
- Coherent program with other GPD programs at Jlab 12 GeV
- Other GPD programs may follow

# SoLID J/ $\psi$ and TCS

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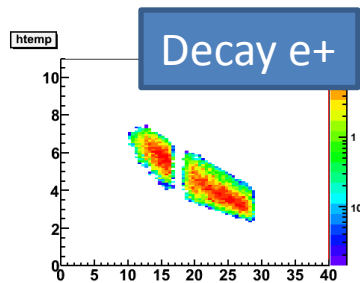
- BH process as background (J/ $\psi$ ) or signal (TCS) to have crosscheck on measurement
- Common Di-lepton production and detection
- Trigger including two leptons to share beam time (work in progress)
- Both are relative young programs. The plan is evolving quickly.
- ***Collaboration WELCOME!***

Mom(GeV)



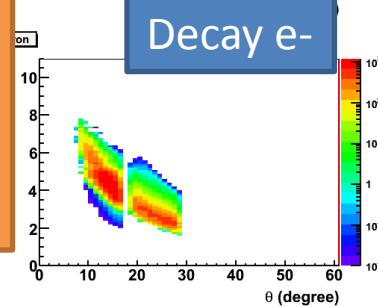
J/ $\psi$

htemp



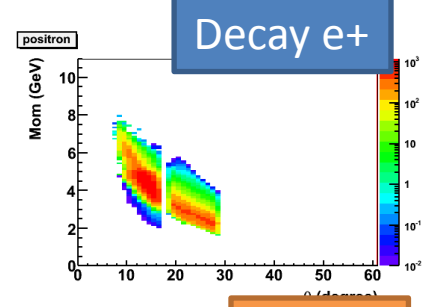
$\theta$  (deg)

Mom(GeV)



TCS

positron



$\theta$  (deg)



# backup

# TOF at large angle

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- 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

