DDVCS at JLab

Workshop 3D tomography of nucleon

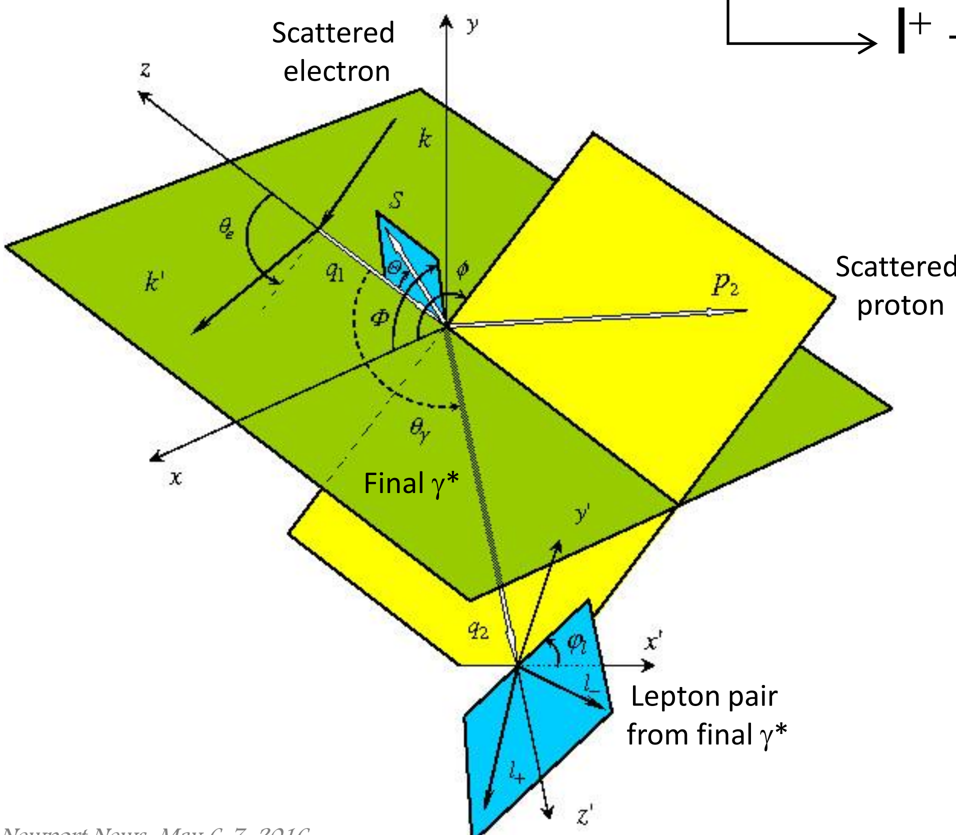
Alexandre Camsonne

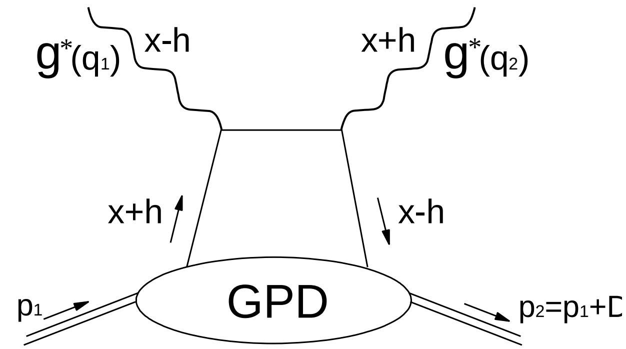
March 17th 2017

Reaction Process

M. Guidal, M. Vanderhaeghen, PRL 90 (2003) 012001   A.V. Belitsky, D. Müller, PRL 90 (2003) 022001

$$e + p \longrightarrow e + p + \gamma^*$$
$$\gamma^* \longrightarrow l^+ + l^-$$





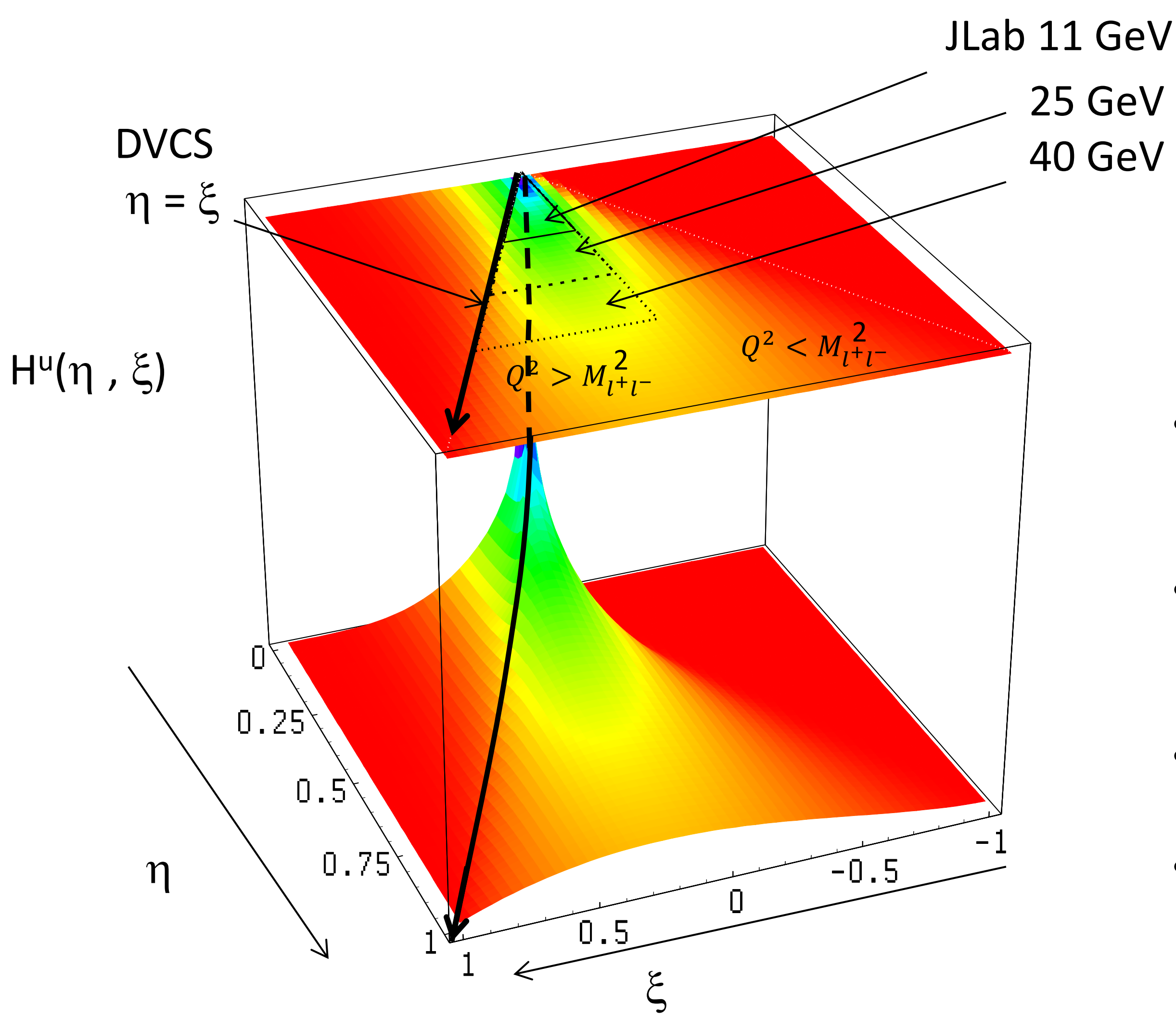
$$Q^2 = -q_1^2 \quad Q'^2 = q_2^2 \quad x_B = \frac{Q^2}{2p_1 \cdot q_1}$$

$$p = \frac{p_1 + p_2}{2} \quad q = \frac{q_1 + q_2}{2}$$

$$\Delta = p_1 - p_2 = q_2 - q_1 \quad \xi = \frac{Q^2}{2p \cdot q} \quad \eta = \frac{\Delta \cdot q}{p \cdot q}$$

$$\xi \propto Q^2 - Q'^2 + \frac{\Delta^2}{2} \qquad \eta \propto Q^2 + Q'^2$$

Kinematic Coverage

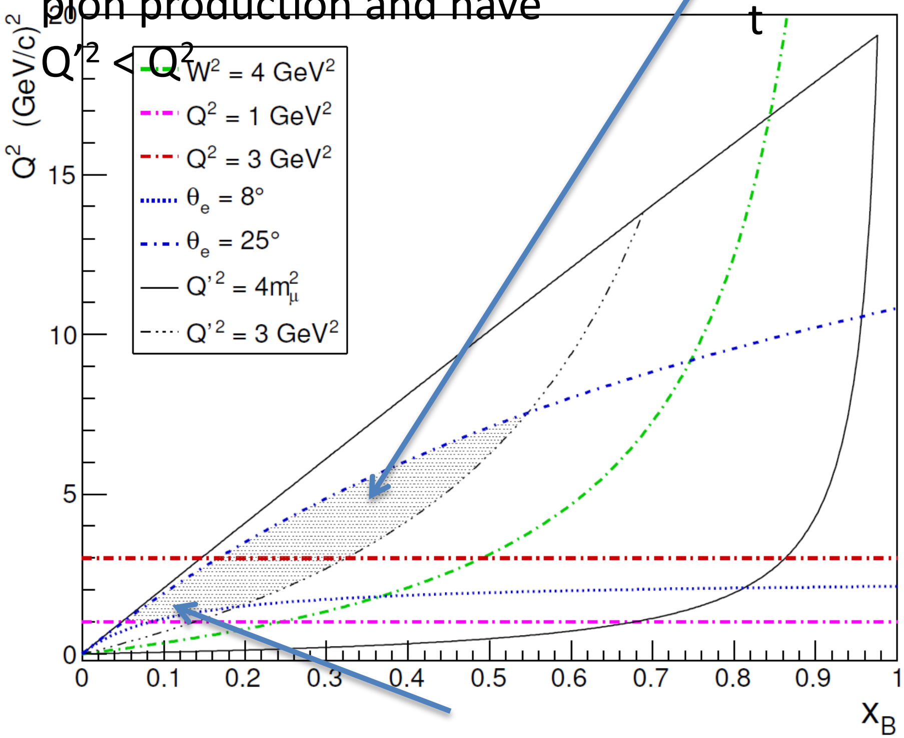


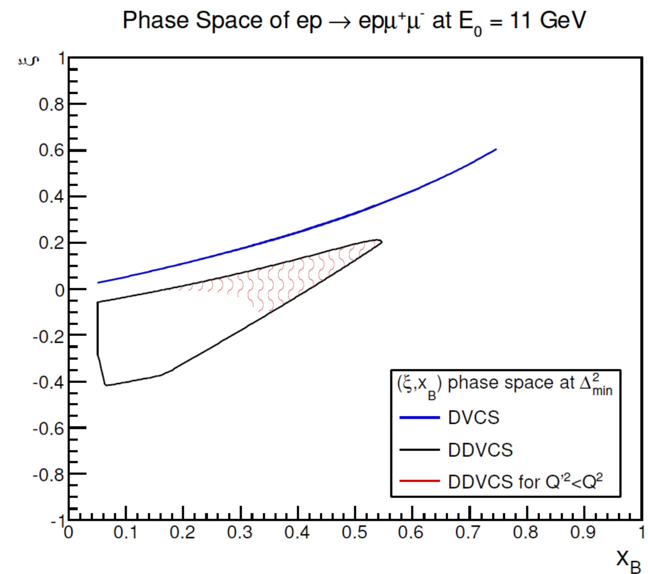
- DVCS only probes η = ξ line
- Example with model of GPD H for up quark
- Jlab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)

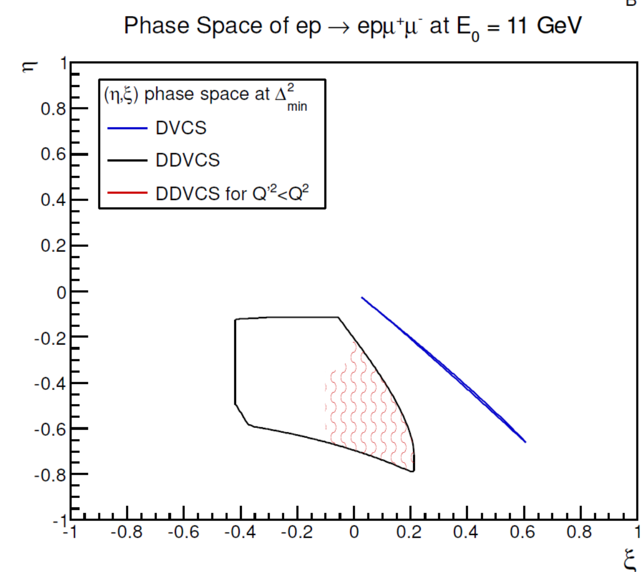
Kinematic Coverage

Ideally want Q'^2 to be high enough to be away from pion production and have $Q'^2 < Q^2$

Dedicated experiment







Parasitic experiment first exploratory measurement

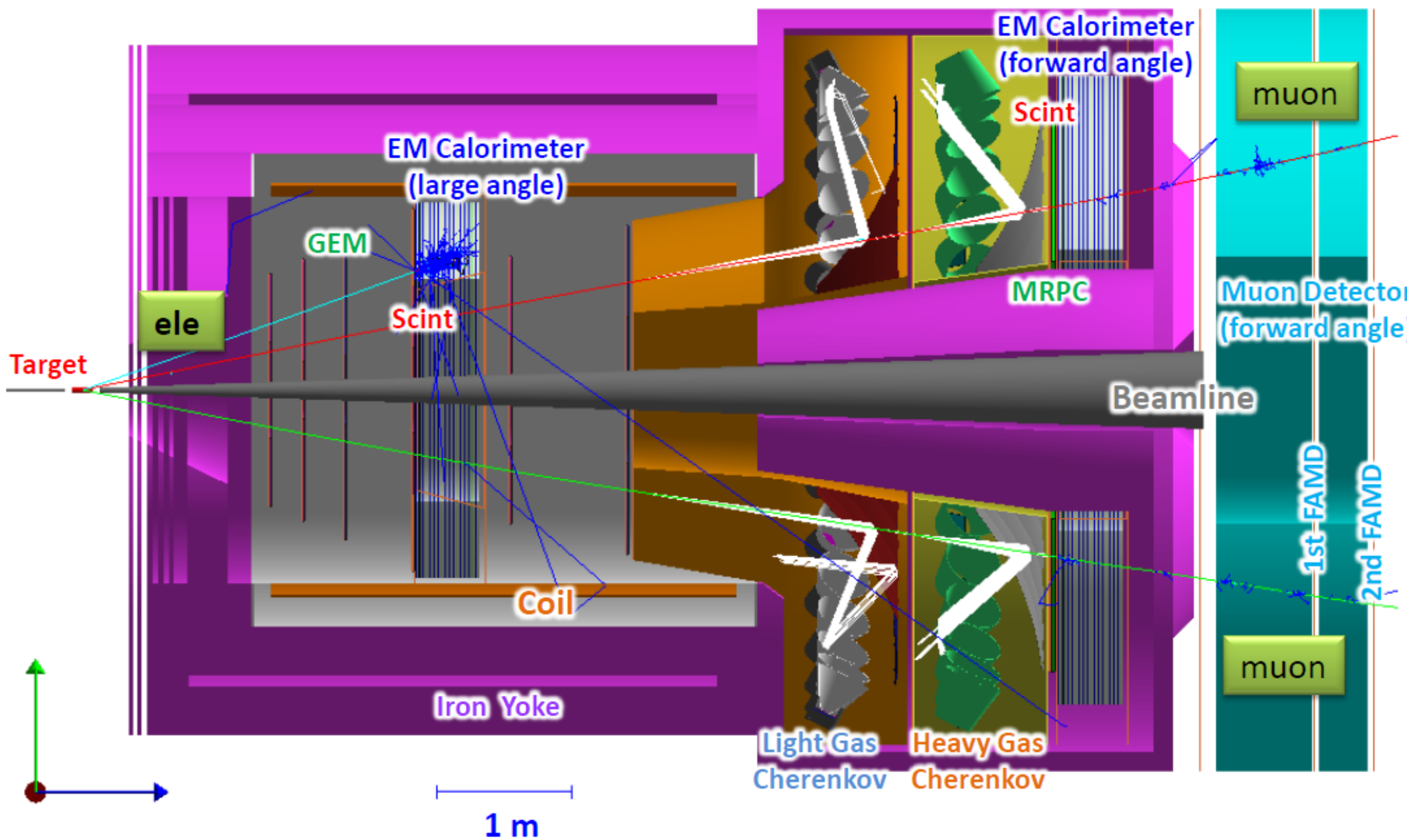
Need luminosity and improved Q'^2 and Q^2 coverage hence SoLID

Two letters of intent at JLab

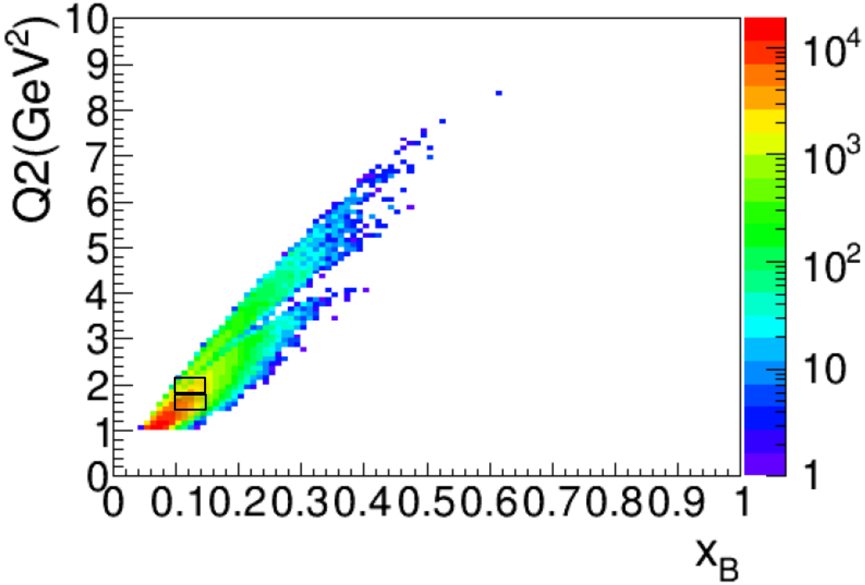
- PAC 43 : Measurement of Double Deeply Virtual Compton Scattering (DDVCS) in the di-muon channel with the SoLID spectrometer (Boer,Camsonne,Gnanvo,Sparveri,**Voutier**,Zhao)
- PAC 44 : Electroproduction of muon pairs with CLAS12: Double DVCS and J/ψ electroproduction (Boer,Guidal,**Stepanyan**,Guidal,Paremuzyan)

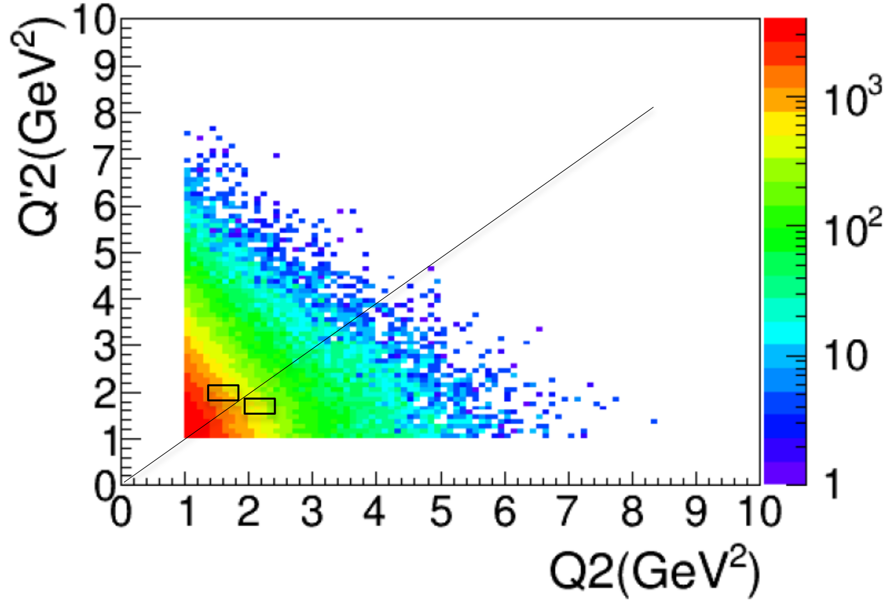
Detector Configuration

SoLID (DDVCS, JPsi/TCS)

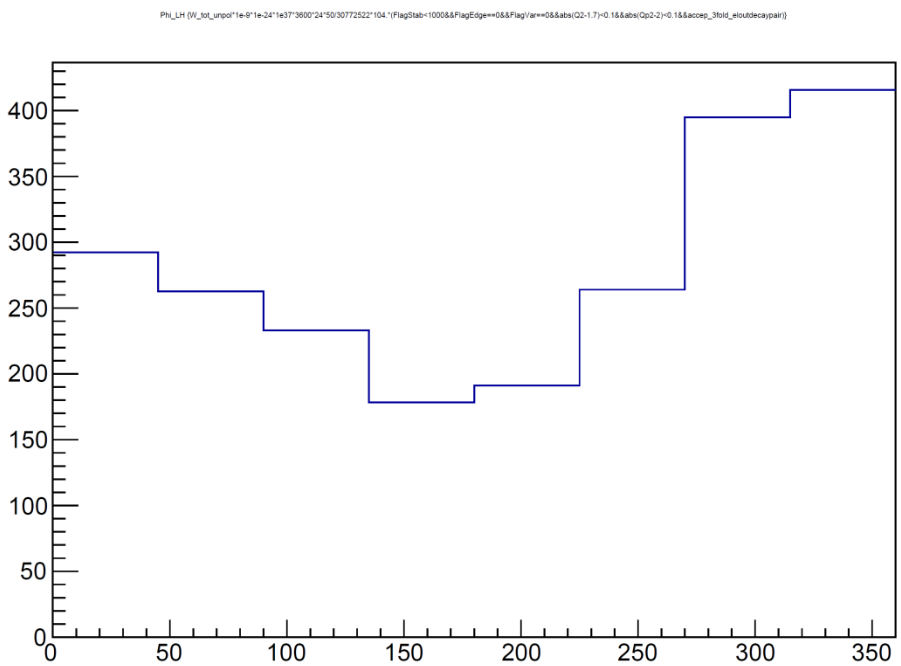


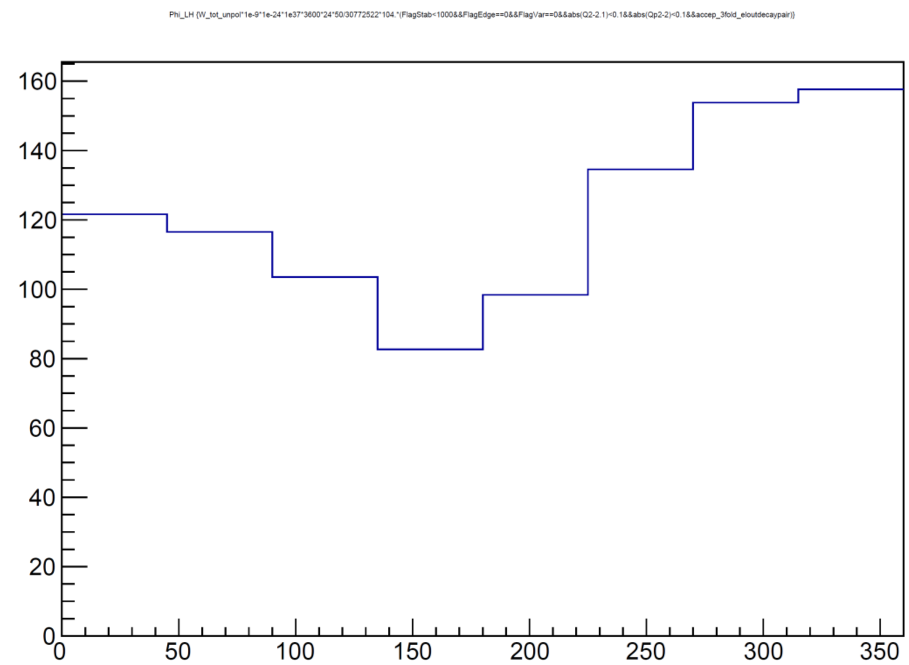
Expected Results





Expected Results





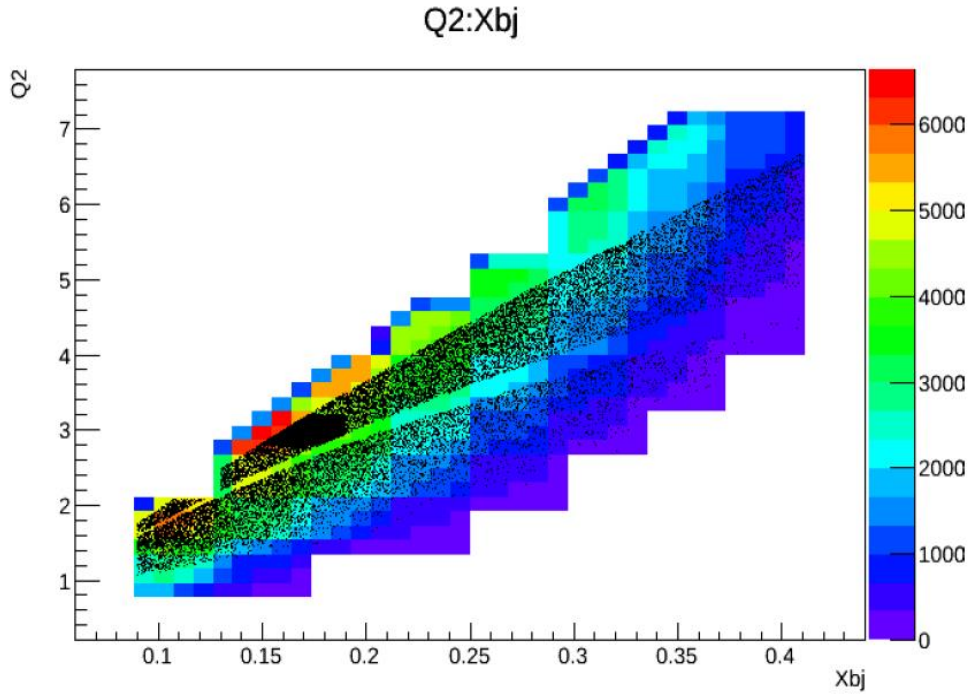
Two bins : 8 bins in Phi

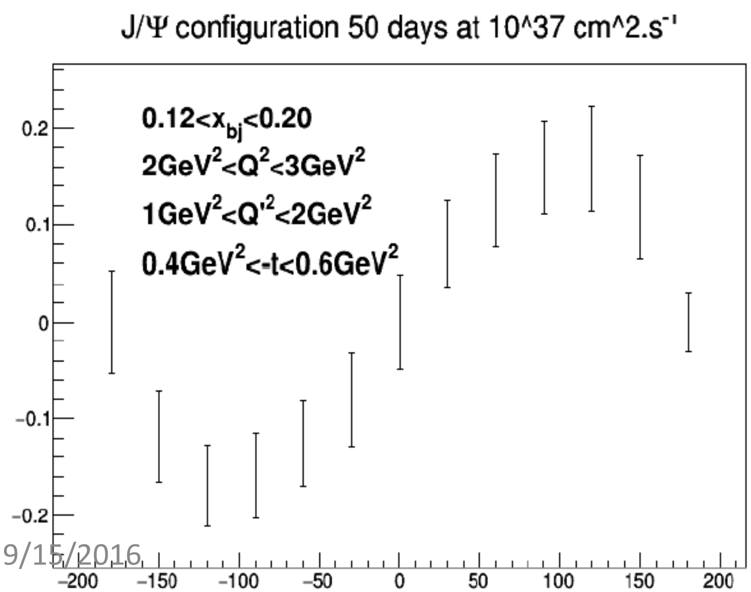
$Q^2 > Q'^2$: 2.0 GeV^2< Q^2<2.2 GeV^2 1.9 GeV^2< Q^2<2.1 GeV^2

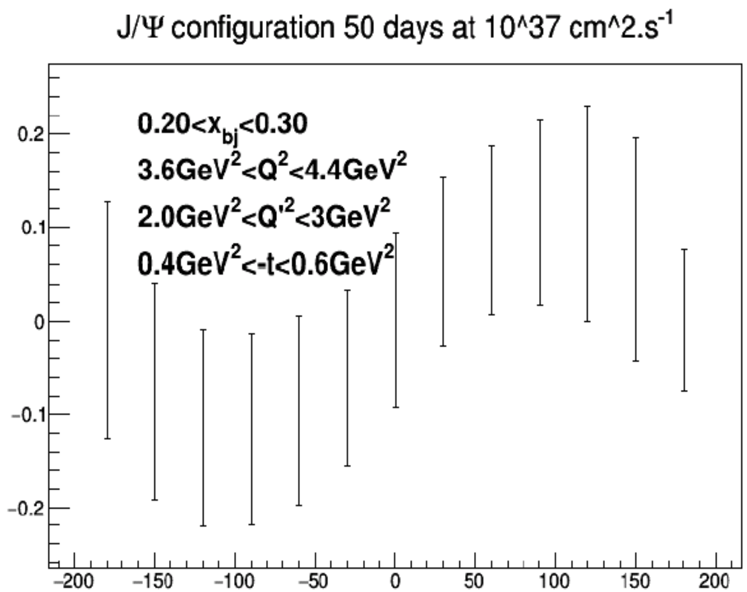
$Q^2 < Q'^2$: 1.6 GeV^2< Q^2<1.8 GeV^2 1.9 GeV^2< Q^2<2.1 GeV^2

Asymmetries from 5 to 10 %

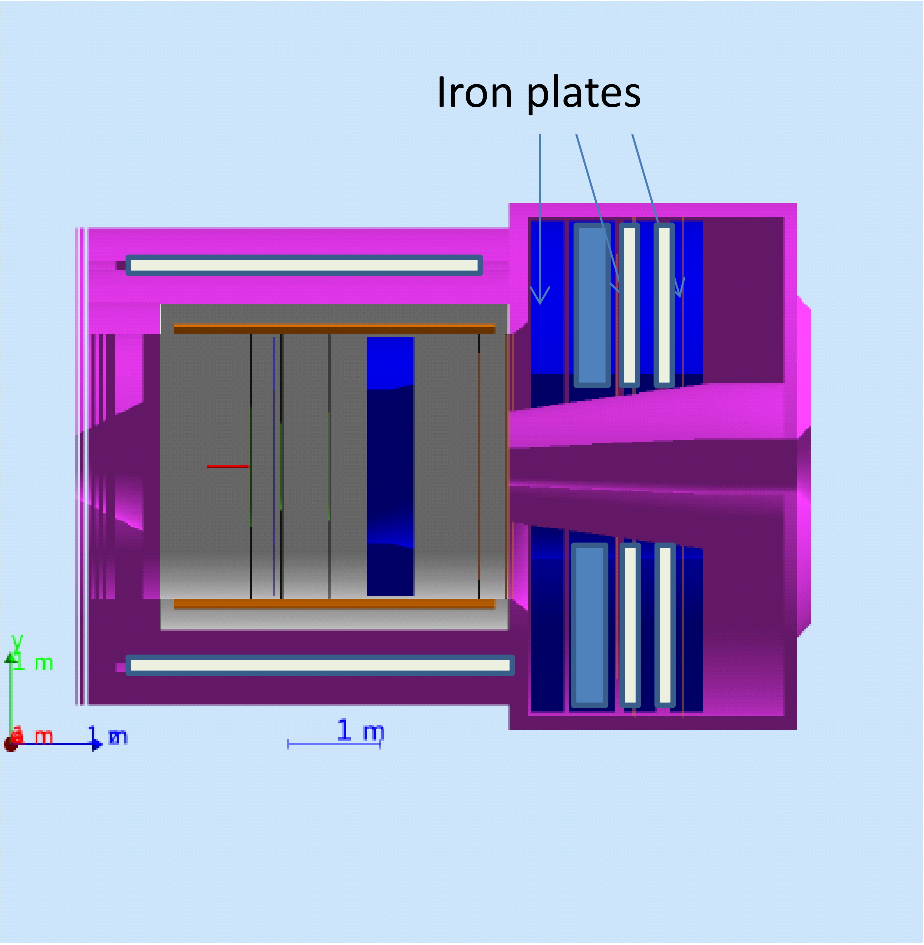
Counts J/psi setup 60 days at 10^37 $cm^{-2}s^{-1}$





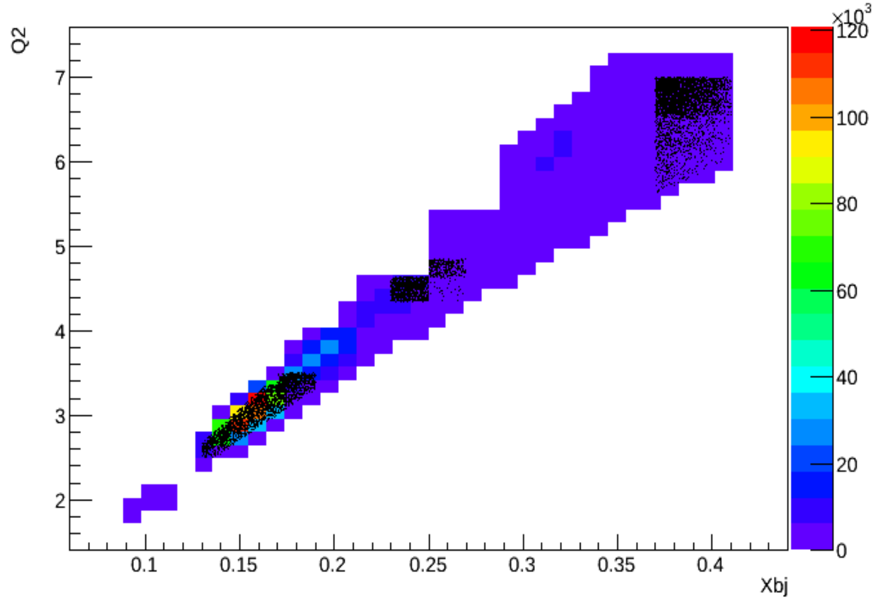


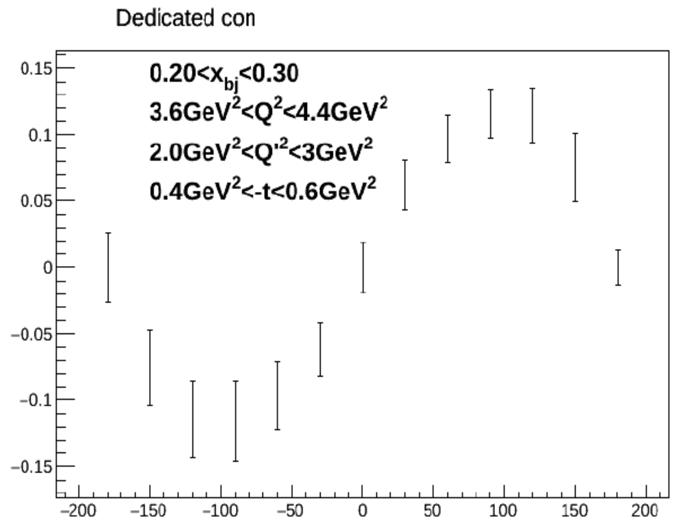
Dedicated setup

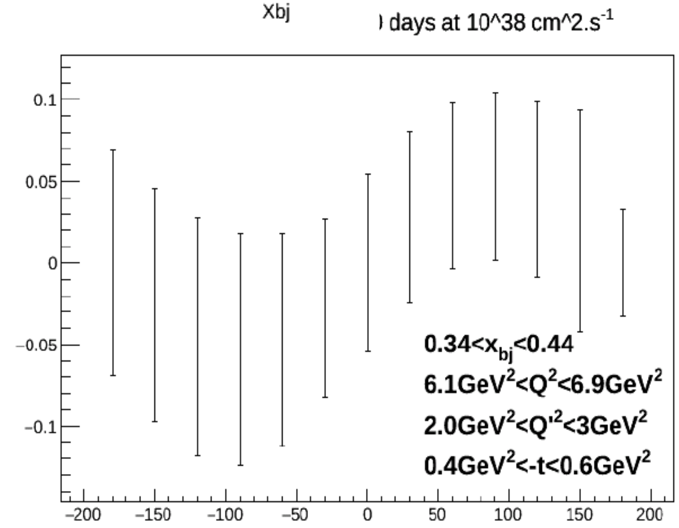


- Target moved 2m from Jpsi position inside and switch to 45 cm target
- Iron plate from 3rd layer yoke in front and behind calorimeter
- Remove Gas Cerenkov
- Try to reach 10^{38} $cm^{-2}s^{-1}$
- 10 uA on 45 cm target

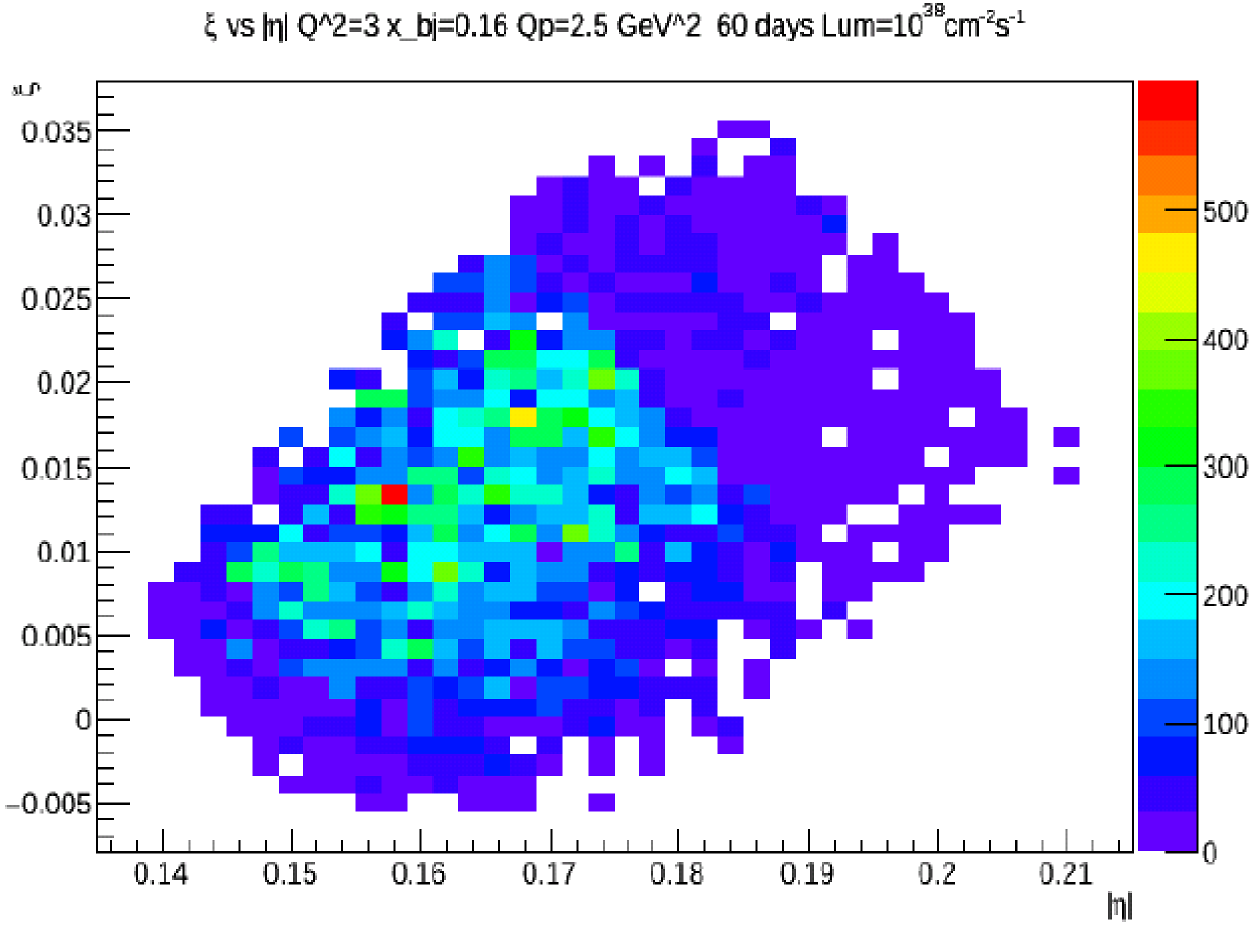
Expected accuracy dedicated setup 90 days at 10^{38} $cm^{-2}s^{-1}$



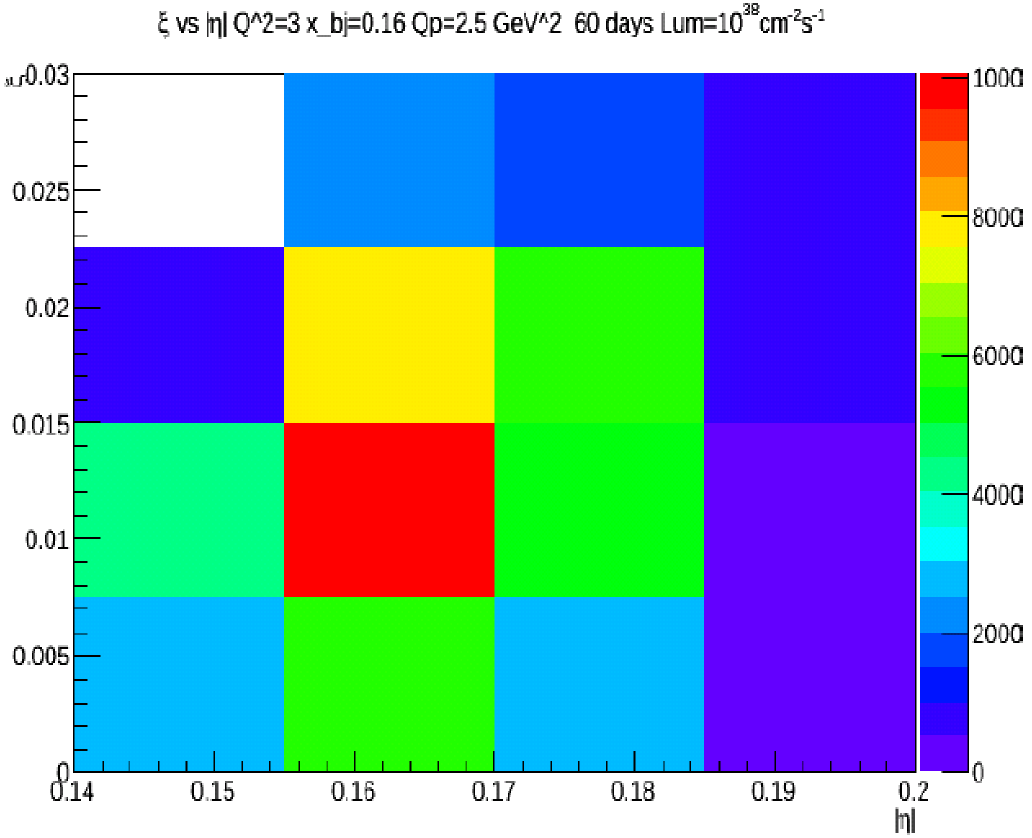




Eta and xi coverage



Eta Xi coverage large bin



LOI12-15-005: *"Measurement of Double Deeply Virtual Compton Scattering in the di-muon channel with the SoLID spectrometer"*

Anatoly Radyushkin

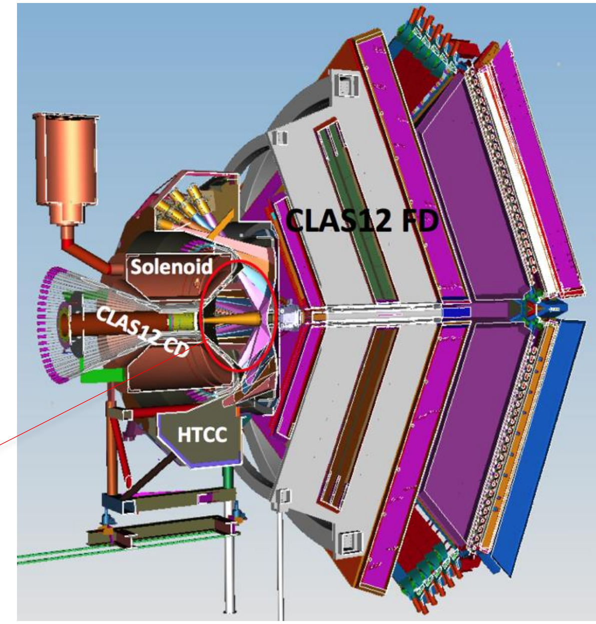
This Letter of intent proposes to study deeply virtual exclusive electroproduction of a muon pair with the aim of obtaining information about generalized parton distributions $H(x, \xi, t)$ away from the line $x = \xi$.

The basic ideais that having, in the initial state, a spacelike photon with virtuality $q_1^2 = -Q_1^2 \equiv -(\xi+\eta)Q^2$ and producing, in the final state, a timelike photon with virtuality $q_2^2 = Q_2^2 \equiv (\xi - \eta)Q^2$, one would have access, through a single-spin asymmetry, to generalized parton distributions $H(\eta, \xi, t)$ (our notations ξ and η here differ from those used in the LOI). Since q_2^2 is the invariant mass of the muon pair, it should be positive, i.e. $\eta < \xi$, and $H(\eta, \xi, t)$ corresponding to values of a GPD in the central (or ERBL) region. This region is sensitive to the so-called D-term $D(\alpha, t)$ at the value $\alpha = \eta/\xi$, the knowledge of which is extremely desirable. In this connection, it is worth mentioning that in a dispersion relation approach, it is sufficient to know the "border function" $H(\xi, \xi, t)$ and the D-term $D(\xi, t)$ to get Compton form factors $\mathcal{C}(\xi, t)$. Also, knowing $H(\xi, \xi, t)$ and $D(\xi, t)$, one can formally reconstruct GPD $H(x, \xi, t)$ in the whole $-1 < x < 1$ region.

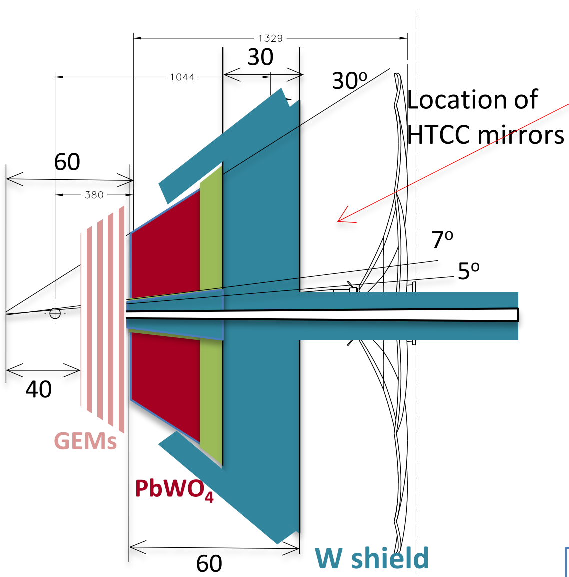
However, for the proposed extraction of $H(\eta, \xi, t)$ to succeed, one should be absolutely sure that the observed muon pair was not produced from a meson decay in the reaction $\gamma^* p \to Mp \to \mu^+\mu^- p$. This means that q_2^2 should be well above the resonance region, and that the statistics of the proposed setup is sufficient for a reliable extraction of a non-resonant signal.

CLAS12 modifications for

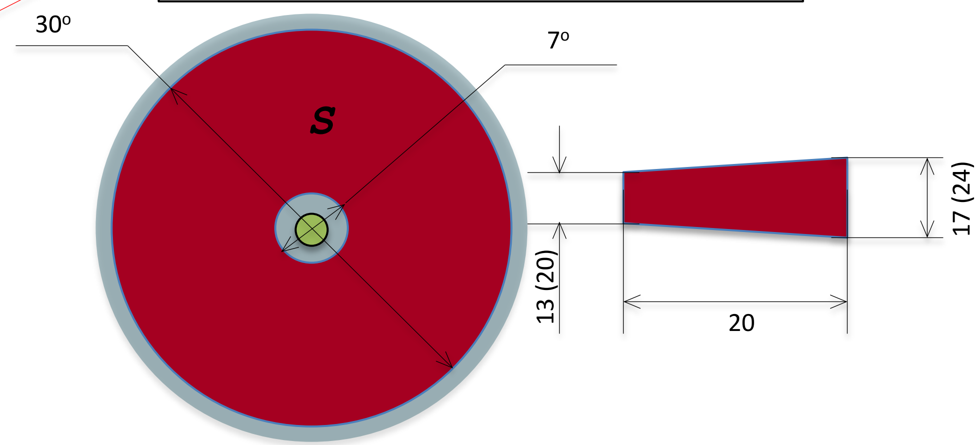
$$ep \rightarrow e'p'\mu^+\mu^- \;\; @ \;\; 10^{37}\, cm^{-2}\, s^{-1}$$



- Remove HTCC and install in the region of active volume of HTCC
  - a new Moller cone that extends up to 7°
  - a new $PbWO_4$ calorimeter that covers 7° to 30° polar angular range with 2π azimuthal coverage.
- Behind the calorimeter, a 30 cm thick tungsten shield covers the whole acceptance of the CLAS12 FD
- GEM tracker in front of the calorimeter for vertexing



$$S = \pi l^2[(tg^2(30^o) - tg^2(7^o)] = 3600\, cm^2;\; l = 60\, cm$$

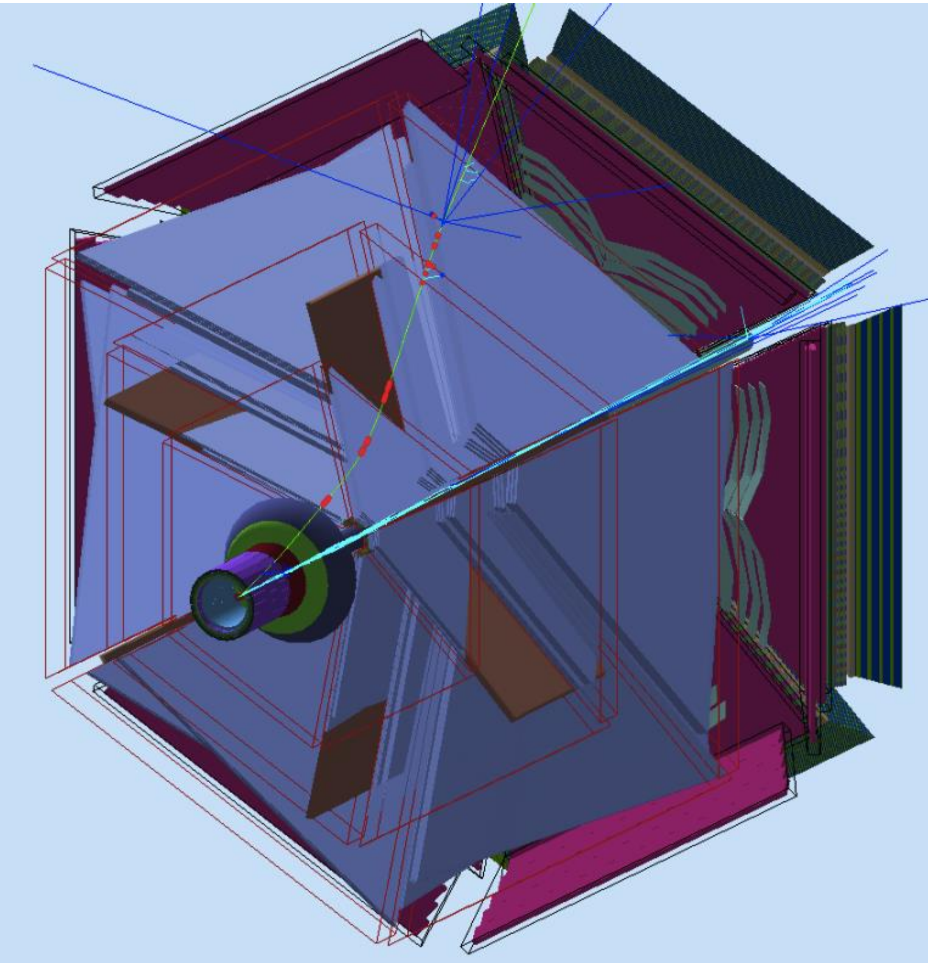


$PbWO_4$ modules with APD readout - ~ 1200 modules

S. Stepanyan, CLAS collaboration meeting

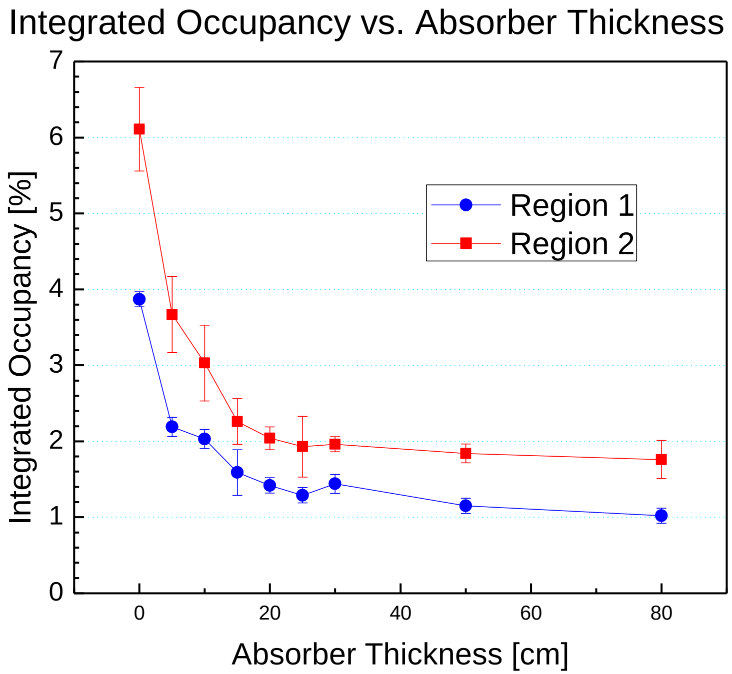
CLAS12 FD new configuration

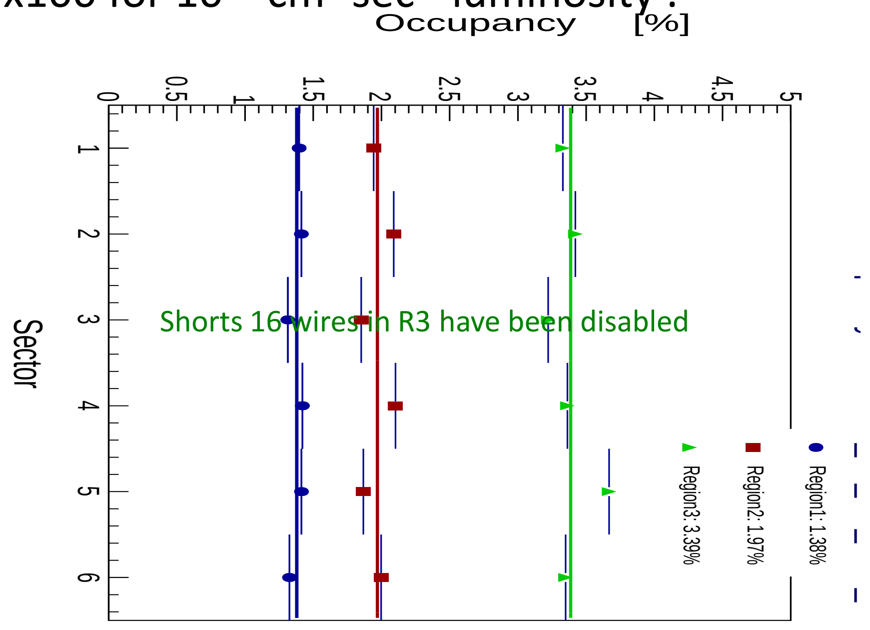
- In this configuration the forward drift chambers are fully protected from electromagnetic and hadronic background
- Calorimeter/shield configuration will play a role of the absorber for the muon detector, i.e. the CLAS12 FD
- The scattered electrons will be detected in the calorimeter
- GEM based tracking detectors will aid reconstruction of vertex parameters (angles and positions) of charged particles.



Simulation of background rates

- CLAS12 simulation software, GEMC
- Studies were done at 10^{35} $cm^{-2}sec^{-1}$ luminosity using a 5 cm long LH_2 target
- Generated events in the time window of 252 ns, grouped in bunches of 4 ns
- The rates provided below are scaled by x100 for 10^{37} $cm^{-2}sec^{-1}$ luminosity .

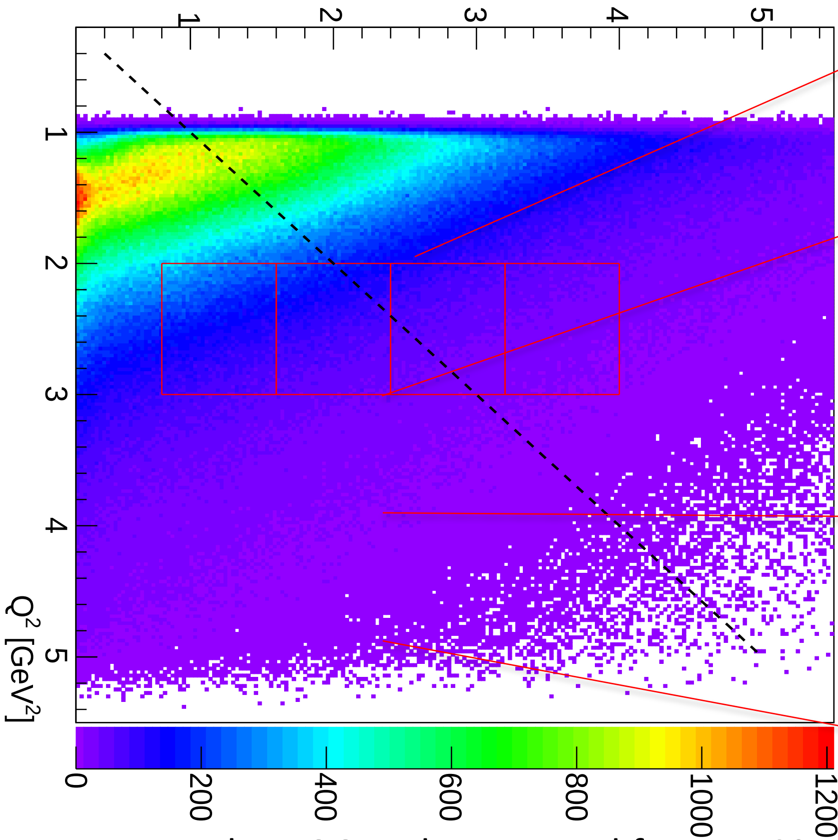


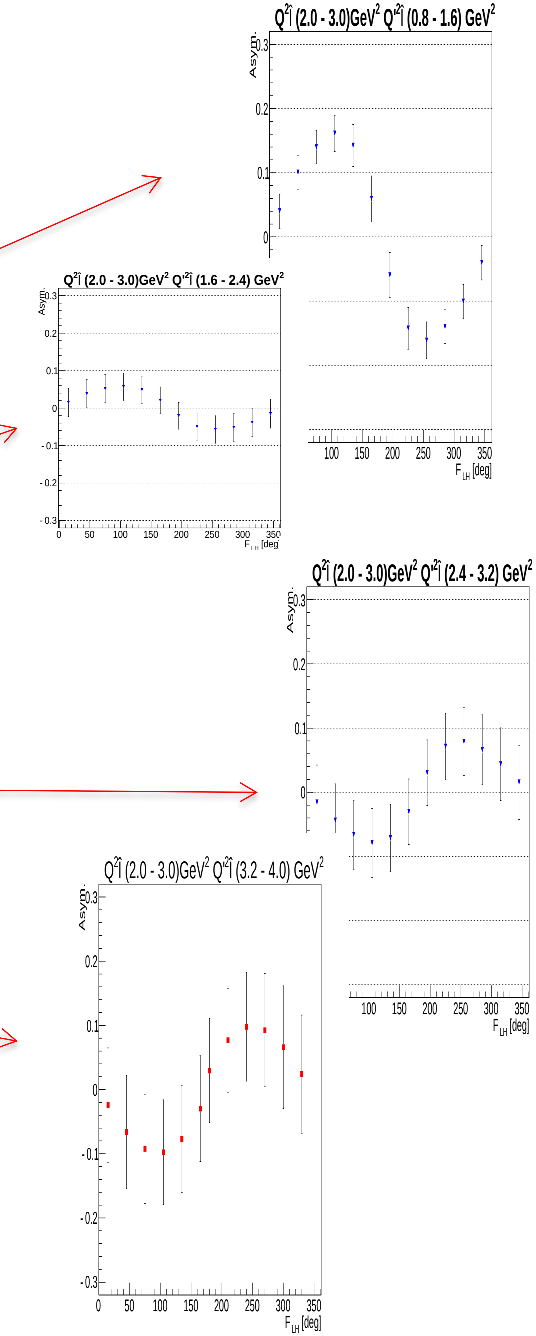


The final thickness of the absorber, 30 cm, was chosen based on considerations of π/μ separation, muon energy loss, and the muon momentum resolution

DDVCS beam spin asymmetry

Sign change with change of kinematics – from Space-like to Time-like dominance region





- The VGG code was used for DDVCS BSA
- GRAPE-dilepton event generator was used to estimate rates

LOI12-16-004: *Electroproduction of muon pairs with CLAS12: Double DVCS and J/ψ electroproduction*

C. Weiss

The proposed experiment would measure exclusive electroproduction of muon pairs on a proton target, $e + p \to e' + p' + (\mu^+\mu^-)$, at $\gamma^* p$ CM energies $2 < W < 4.5$ GeV, momentum transfers $Q^2 \sim 1 - 5$ GeV^2, and muon pair masses $M_{\mu+\mu-} < 3.5$ GeV. The setup uses a modification of the CLAS12 detector with a shield for forward EM and hadronic backgrounds, and detection of the scattered electron with a new compact $PbWO_4$ calorimeter, which effectively converts CLAS12 into a forward muon detector and allows to operate at luminosities of the order 10^{37} cm^2 s^{-1} ($\sim 10^2$ larger than the nominal CLAS12 luminosity). The physics objectives are (a) to constrain the nucleon GPDs through measurements of double deeply-virtual Compton scattering (DDVCS); (b) to probe the nucleon's gluonic form factor through J/ψ electroproduction in the near-threshold region; (c) to study electroproduction of the LHCb pentaquark in the $J/\psi + p$ channel. The experimental method and physics objectives are related to those of the CLAS e^+e^- photoproduction experiment E12-12-001.

The DDVCS process is unique in that the imaginary part of the leading-twist amplitude involves the GPDs at values of x and ξ (the quark light-cone fraction and the momentum transfer fraction) that are not kinematically correlated but can be changed independently by varying the invariants W^2, Q^2 and M^2_{l+l-}. This makes it possible, in principle, to probe the GPDs point-by-point in x and ξ through the beam spin asymmetry measuring the Bethe-Heitler-DDVCS interference cross section. In contrast, in DVCS (final photon real) the GPDs are accessible through the imaginary part of the amplitude only at $x = \xi$, while the real part probes a certain dispersive integral over x, and similar restrictions apply in TCS (initial photon real). DDVCS has therefore attracted considerable attention as a theoretically ideal tool for GPD extraction. The practical challenges are very considerable, however. The DDVCS cross sections are suppressed relative to DVCS by a power $\alpha_{\rm em} \sim 10^{-2}$, and using the additional kinematic dependence requires control of QED radiative corrections (which generally exhibit strong variations across phase space) and acceptance effects. On the theoretical side, the size of higher-twist corrections in DDVCS remains an open question, specifically effects associated with the finite mass of the produced timelike system (this applies to TCS as well).

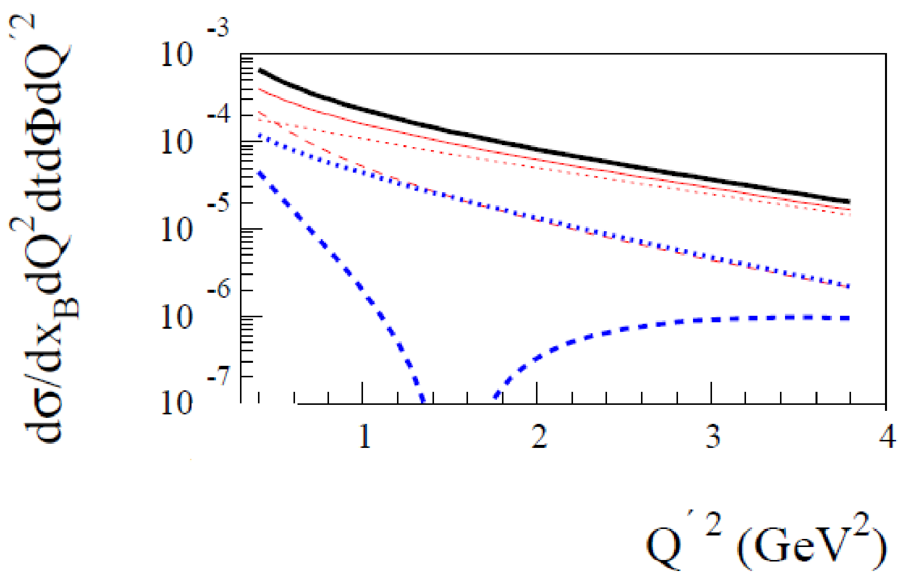
PAC recommendations

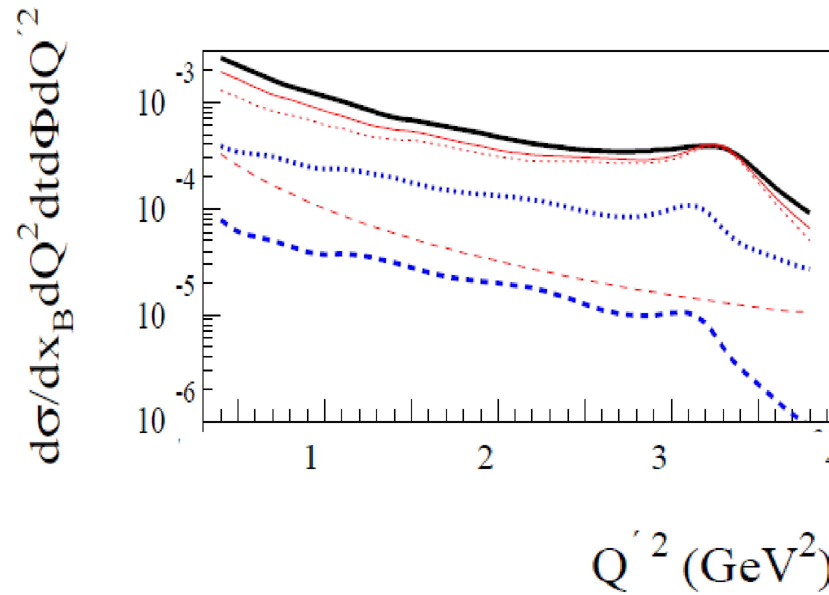
- " The PAC endorses the phase of this experiment that would be in the run group led by the E12-12-006, which is at lower luminosity than the second phase. This run would be enough to **demonstrate operation of the muon system** and **observe the reaction**, albeit at relatively low Q^2. Consideration of this phase will still require a **run group proposal**, **vetted by the SoLID collaboration** using whatever are the appropriate internal means. The second, high luminosity, phase must be considered as a separate proposal, along with whatever other physics goals might be achieved in the new run group defined by this high luminosity configuration. "

Recommendation:
The PAC recognizes the importance of the measurements of DDVCS for the determination of GPDs, but finds it premature to develop a full proposal. Results have yet to be realized at 12 GeV from the DVCS program. Furthermore, the SoLID collaboration has a similar Letter of Intent (submitted to PAC43) to study this physics, and complementarity between the two approaches will need to be demonstrated.

Dimuons vs e+e- pair

$E_e = 11\ GeV$ $x_B=0.12, Q^2=1.71, t=-0.23$





w/o anti-symmetrization

w anti-symmetrization

DDVCS+BH

Re(DDVCS)

Im(DDVCS)

BH (BH_t + BH_s)

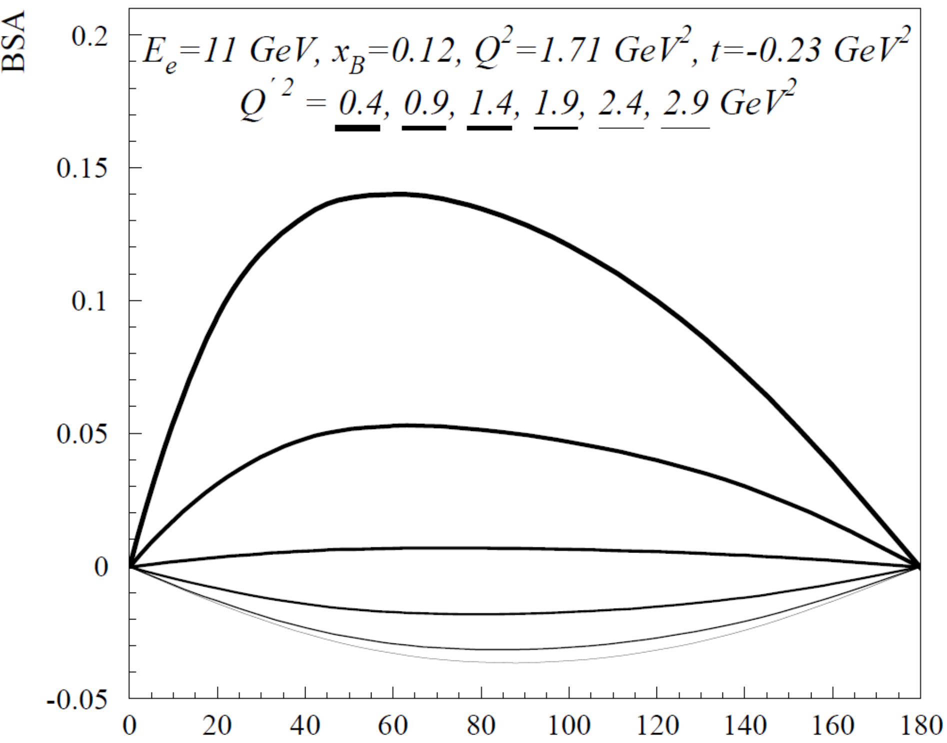
BH_s

BH_t

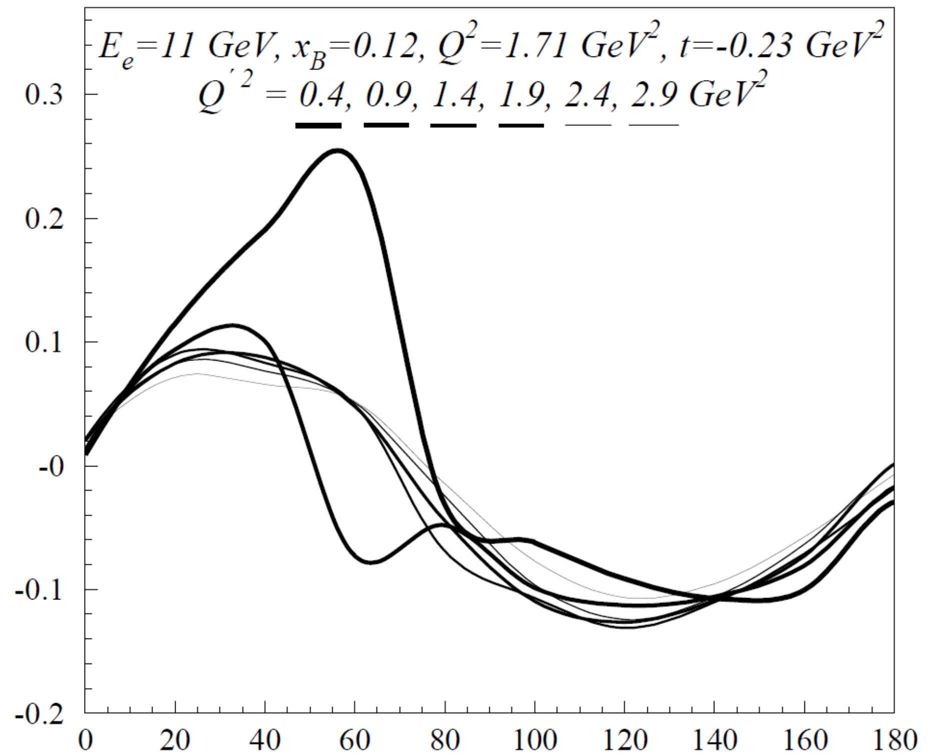
Michel Guidal, Dileptons Trento Workshop October 2016

Dimuons vs e+e- pair

w/o anti-symmetrization



w anti-symmetrization



Michel Guidal, Dileptons Trento Workshop October 2016

Higher luminosity ?

- Current could go up to 80 uA
- Target length up to 1 meter
- Tracker occupancy and photon background
  - Reduce amount of Copper in GEM
  - Micromegas option
  - Build smaller chambers and add more channels
  - Study complement with 2D pad readout
  - Superconducting tracker option
- Calorimetry
  - Study liquid scintillator and cryogenics calorimeter option
  - Superconducting detector to replace PMT (1 ns width pulse to increase rate capability)
- Cerenkov
  - Superconducting detector to replace PMT (1 ns width pulse to increase rate capability)
  - HBD type Cerenkov for Large Angle calorimeter

$6.\ 10^{38}\ cm^{-2}s^{-1}$

Technically doable mostly matter of cost

Options for DDVCS

- Standard CLAS12 for e+e- DDVCS (Muons detector ?)
- Dedicated for CLAS12 dimuons DDVCS measurement
- Parasitic SoLID experiment during J/psi for e+e-
- Parasitic SoLID experiment during J/psi for dimuons
- SoLID dimuons DDVCS high luminosity

Questions

- Is DDVCS mandatory for 3D imaging program ?
  - Only access out of diagonal
  - D-term
- Are muons absolutely needed ?
  (dedicated vs parasitic)
- JLab 12 might be only chance to measure DDVCS ever (EIC luminosity too low) Improve physics case for dedicated experiment
  - Is it worth a dedicated detector ?
  - Is it worth an energy upgrade ?
- Muons DDVCS vs positron