Double Deeply Virtual Compton Scattering at 22 GeV

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Jefferson Laboratory Hall A
January 23rd 2023
Jefferson Laboratory
Science at the Luminosity Frontier: Jefferson Lab at 22 GeV Workshop

U.S. DEPARTMENT OF ENERGY | Office of Science

Jefferson Lab
Thomas Jefferson National Accelerator Facility

JSA

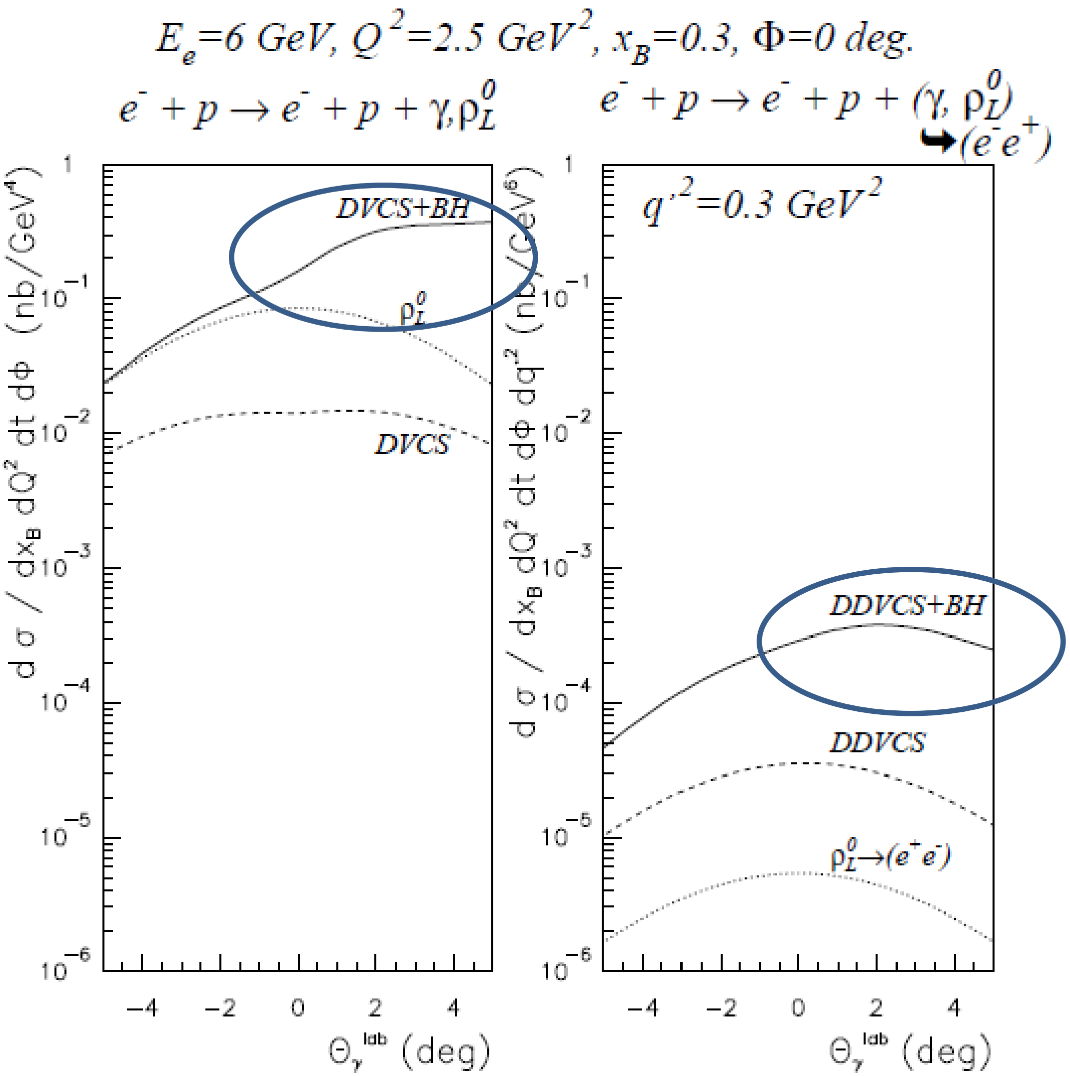
DVCS / Double DVCS

$$\gamma^* + p \longrightarrow \gamma'(*) + p'$$

$$\hookrightarrow l^+ + l^-$$

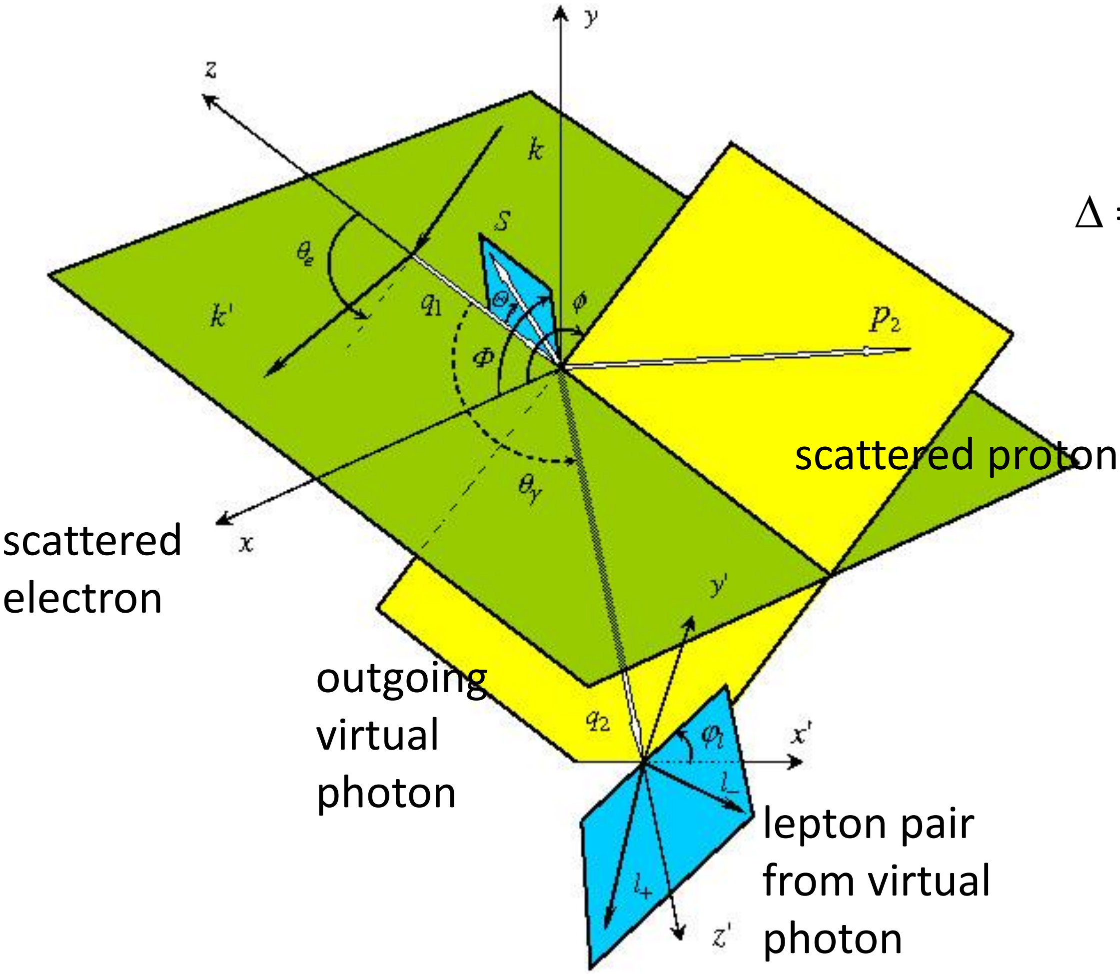
Guidal and Vanderhaegen : Double deeply virtual Compton scattering off the nucleon (arXiv:hep-ph/0208275v1 30 Aug 2002)
Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

DDVCS cross section



- VGG model
- Order of ~0.1 pb = 10^{-36}cm^2
- About 100 to 1000 smaller than DVCS
- Virtual Beth and Heitler
- Interference term enhanced by BH
- Contributions from mesons small when far from meson mass

Double Deeply Virtual Compton Scattering



Δ = p1-p2 = q2-q1

p = p1+p2

q = ½ (q1+q2)

$Q^2 = -q^2$

$$\xi = \frac{Q^2}{2p.q} \qquad \eta = \frac{\Delta.q}{p.q}$$

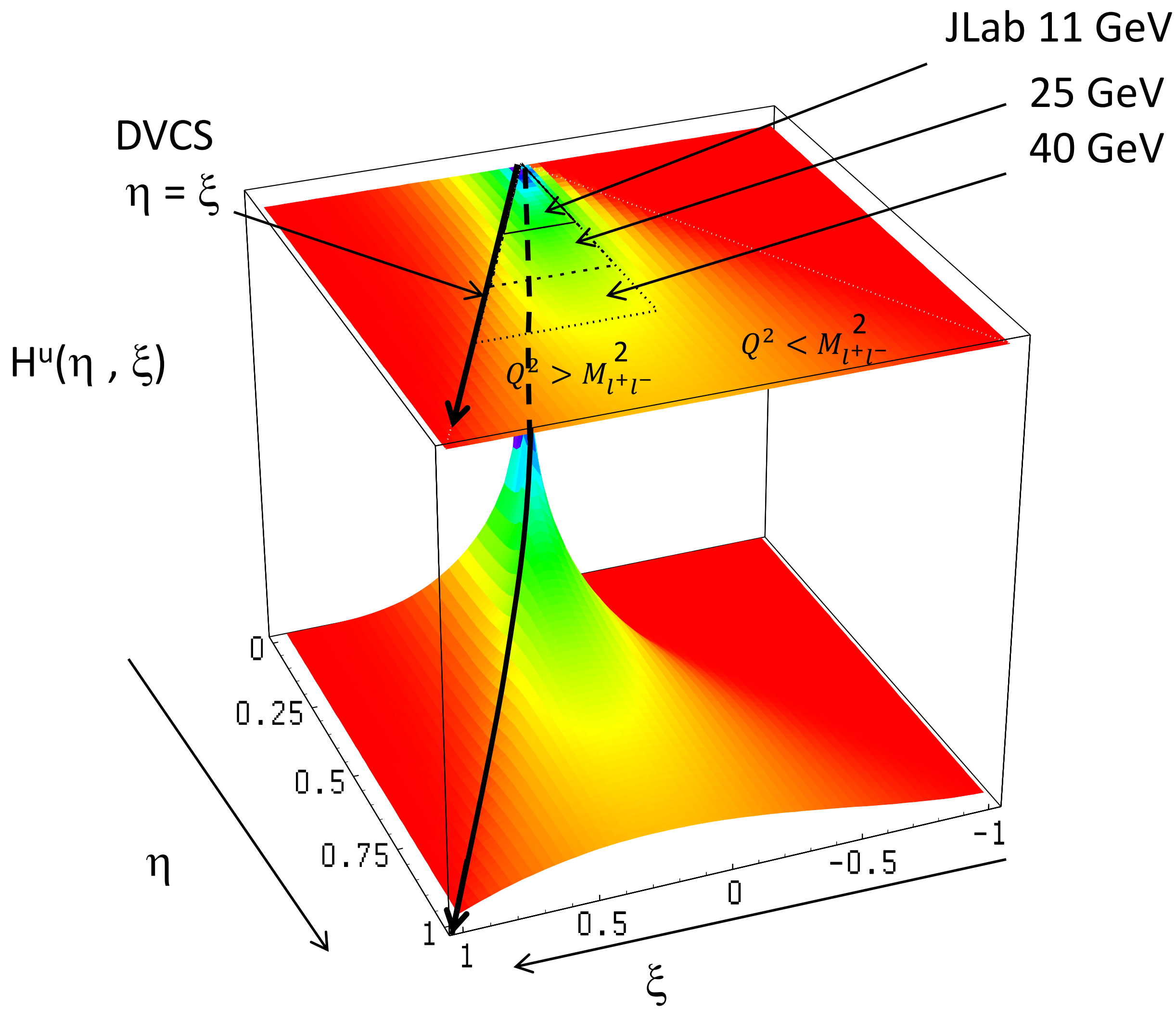
$$Q^2 = -(k-k')^2 \qquad x_{bj} = \frac{Q^2}{2p_1q_1}$$

Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

$$\left\{ \begin{array}{c} A_{\rm LU}^{\sin\phi} \\ A_{\rm LU}^{\sin\varphi_\mu} \end{array} \right\} = \frac{1}{\mathcal{N}} \int_{\pi/4}^{3\pi/4} d\theta_\mu \int_0^{2\pi} d\varphi_\mu \int_0^{2\pi} d\phi \left\{ \begin{array}{c} 2\sin\phi \\ 2\sin\varphi_\mu \end{array} \right\} \frac{d^7\overrightarrow{\sigma} - d^7\overleftarrow{\sigma}}{dx_B\, dy\, dt\, d\phi\, dQ'^2\, d\Omega_\mu}$$

$$\propto \Im\mathrm{m} \left\{ F_1 \mathcal{H} - \frac{t}{4M_N^2} F_2 \mathcal{E} + \xi (F_1 + F_2) \widetilde{\mathcal{H}} \right\} ,$$

Kinematical coverage

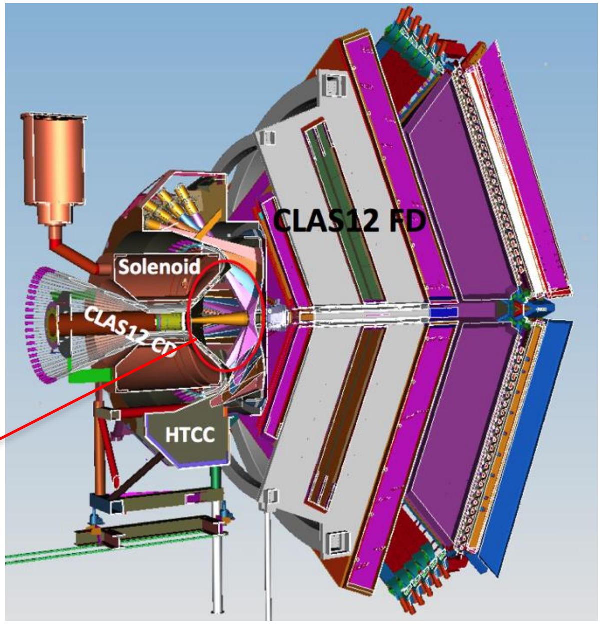


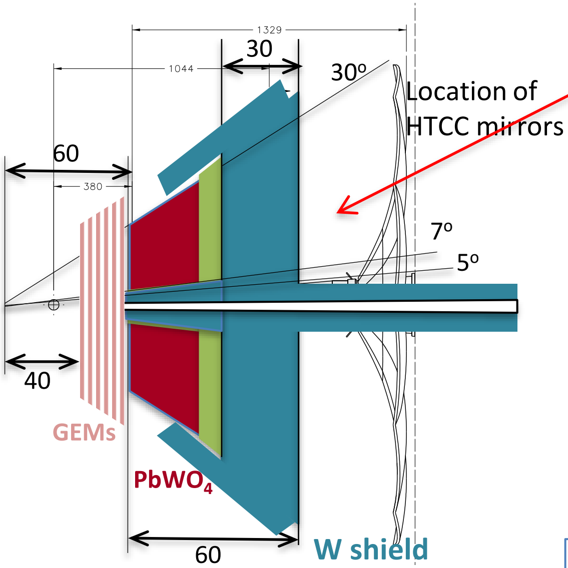
- DVCS only probes $\eta = \xi$ line
- Example with model of GPD H for up quark
- Jlab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)
- Dependence in η of GPDs
- Could give access to D term (non η dependent part of GPD)

CLAS12 modifications for

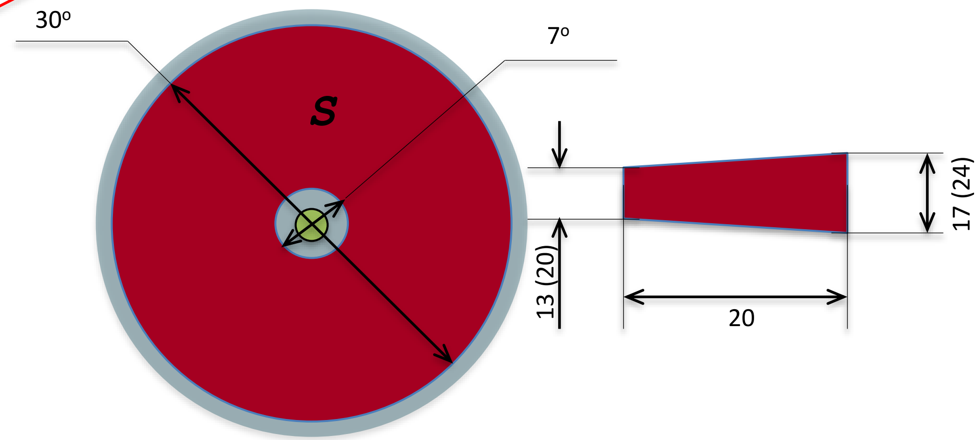
$$ep \to e'p'\mu^+\mu^- \ @ \ 10^{37}\, cm^{-2}\, s^{-1}$$

- 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





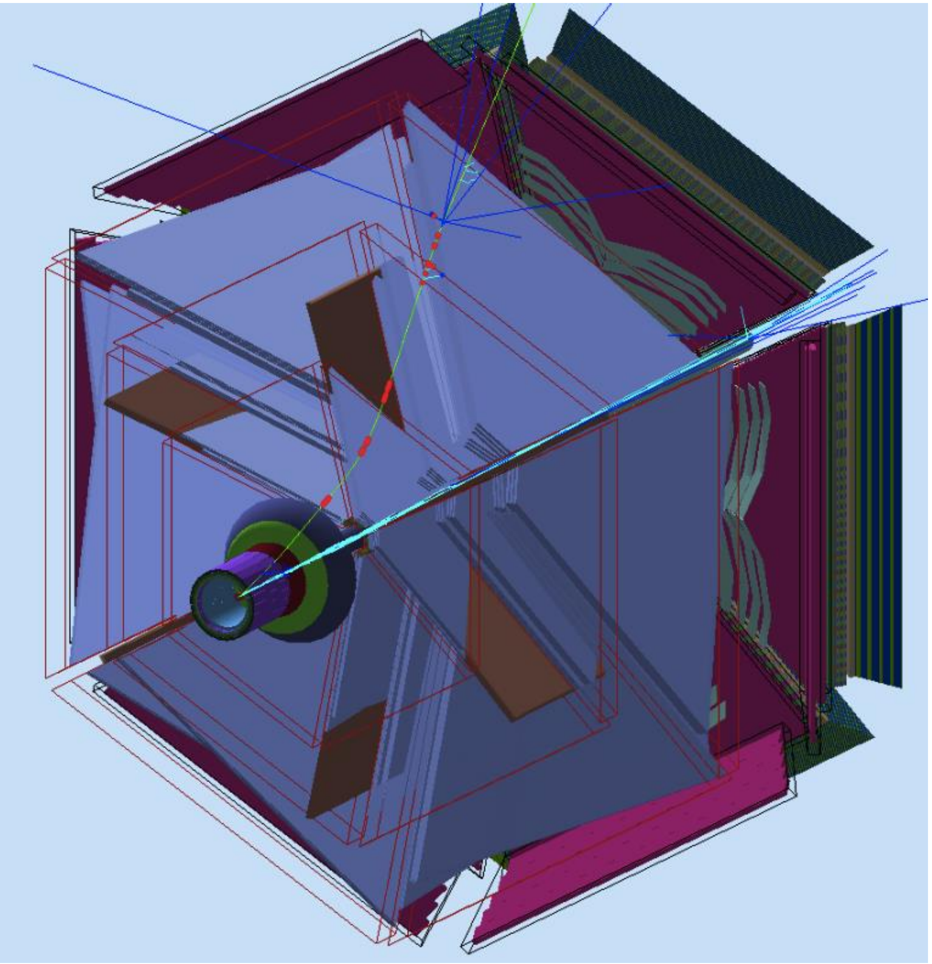
$$S = \pi l^2[(tg^2(30^o) - tg^2(7^o)] = 3600\, cm^2;\, l = 60\, cm$$



$PbWO_4$ modules with APD readout - ~ 1200 modules

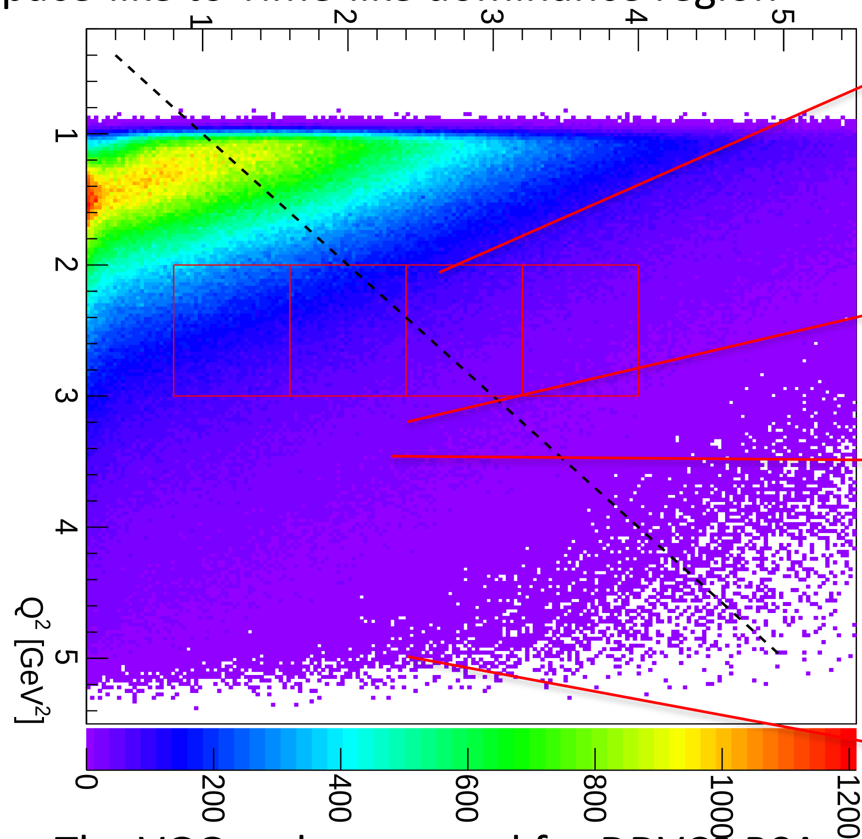
CLAS12 FD new configuration

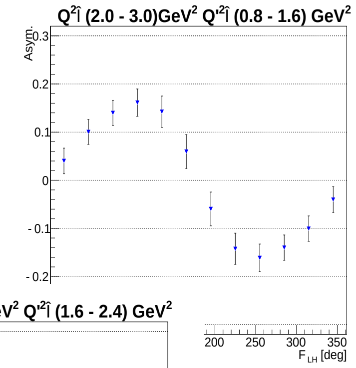
- In this configuration the forward drift chambers are fully protected from electromagnetic and hadronic background
- Calorimeter/shield configuration will play a role of the absorber for the muon detector, i.e. the CLAS12 FD
- The scattered electrons will be detected in the calorimeter
- GEM based tracking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

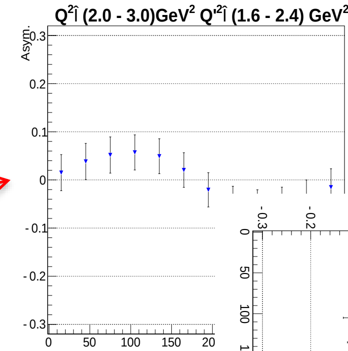


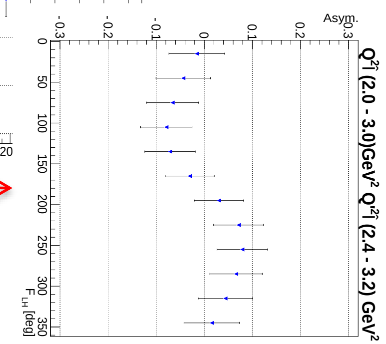
DDVCS beam spin asymmetry

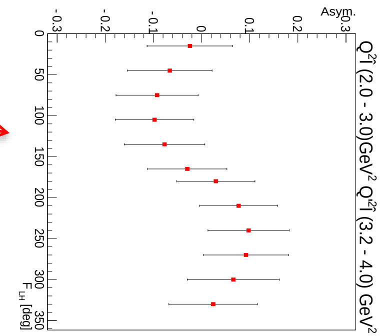
Sign change with change of kinematics – from Space-like to Time-like dominance region





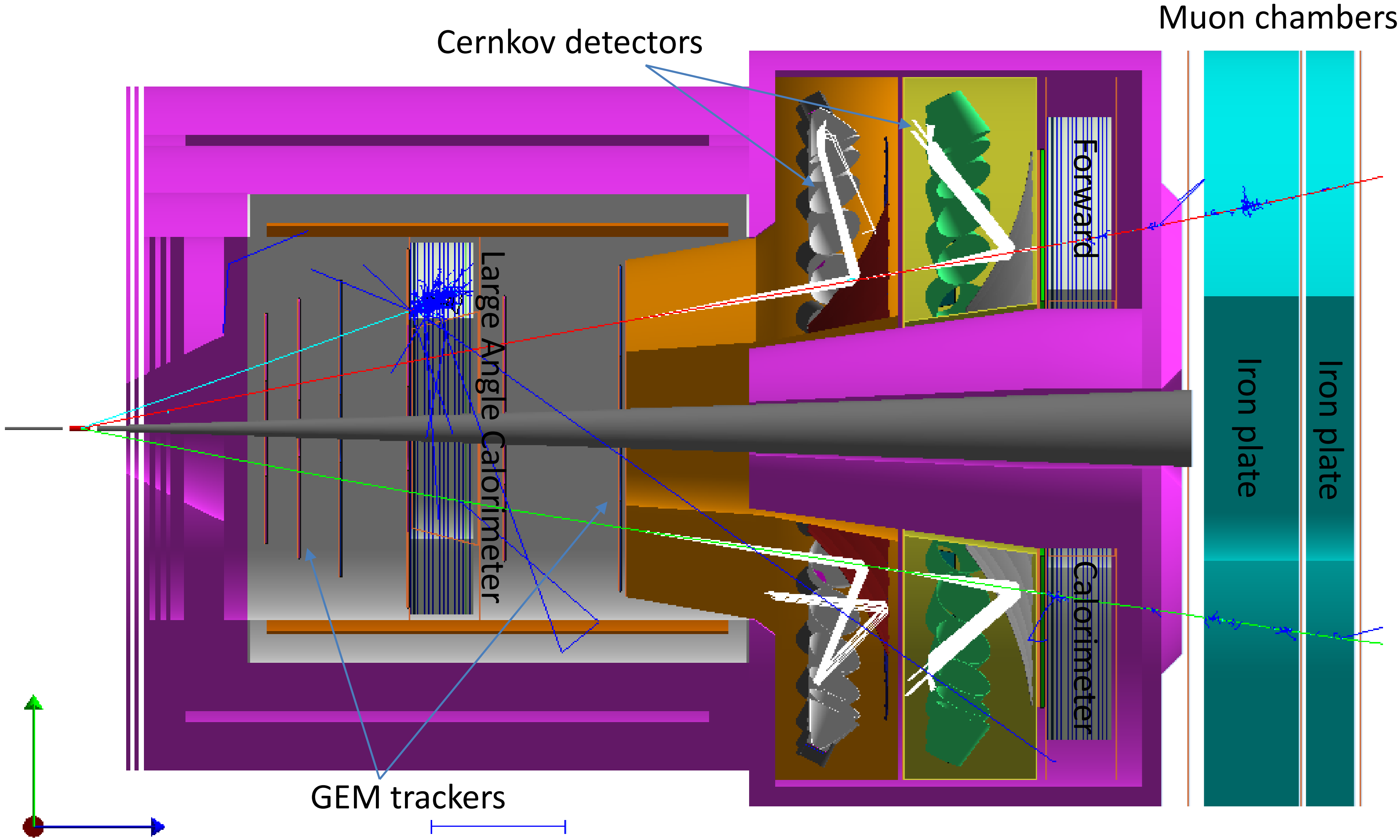




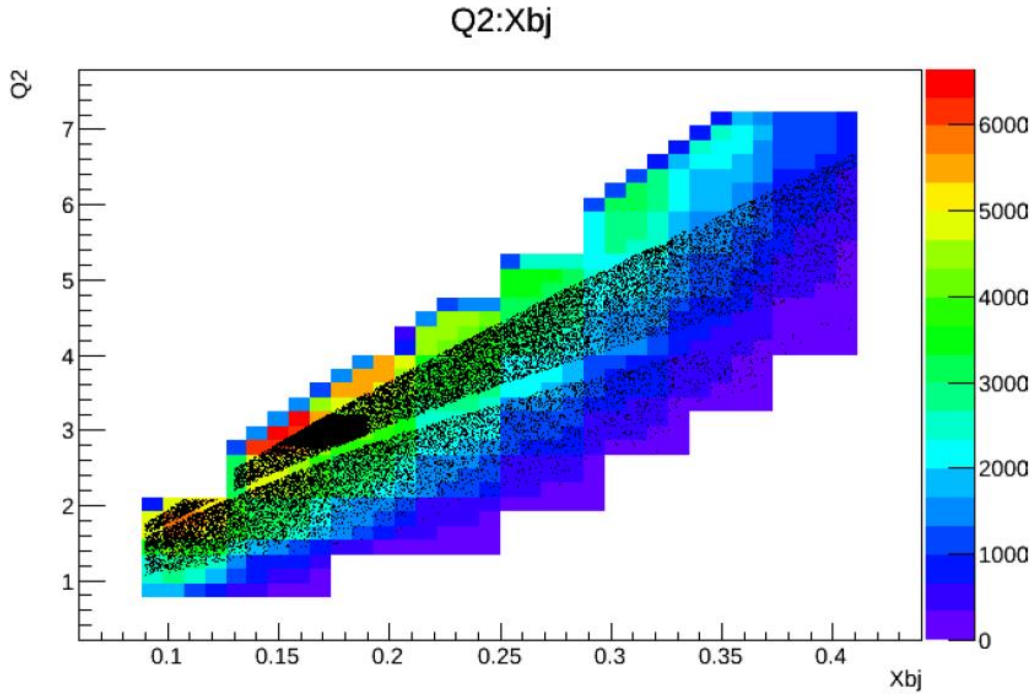


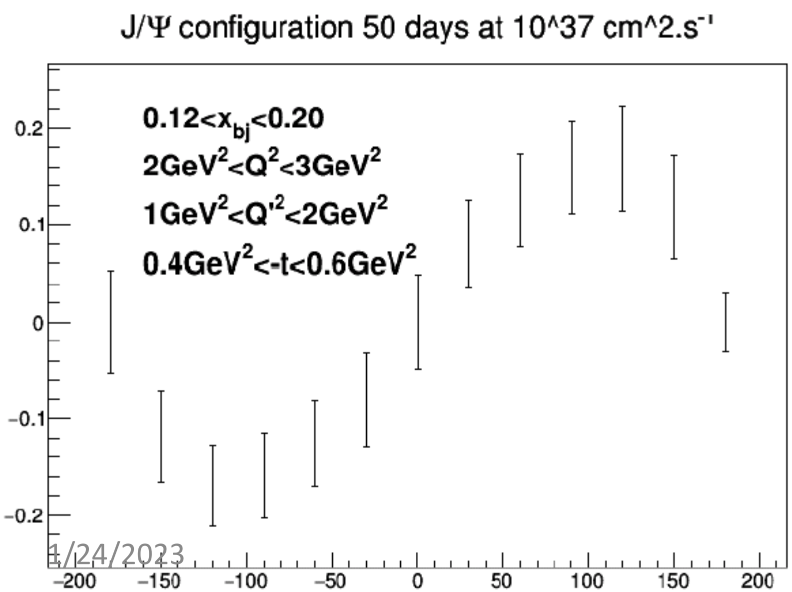
- The VGG code was used for DDVCS BSA
- GRAPE-dilepton event generator was used to estimate rates

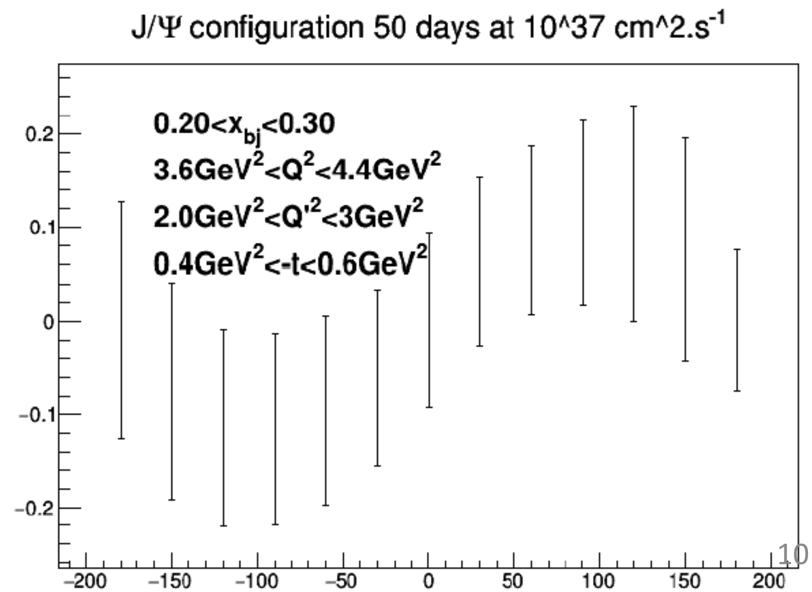
SoLID JPsi Setup



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

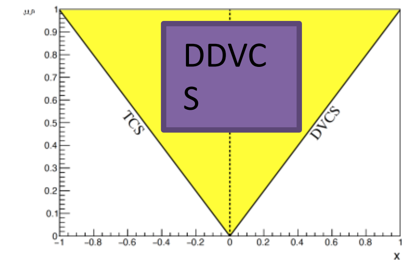


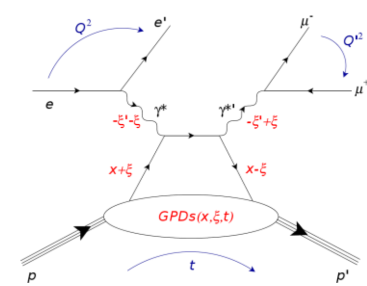




Double Deeply Virtual Compton Scattering with SoLID at JLab 12GeV

- DDVCS explores wide off-axis kinematic region of GPDs, beyond DVCS and TCS. The exclusive reaction has small crosssection and thus needs high luminosity and large acceptance.
- The SoLID apparatus completed with muon detectors at forward and large angles and barrel, enables DDVCS measurements with both polarized electron and positron beams at

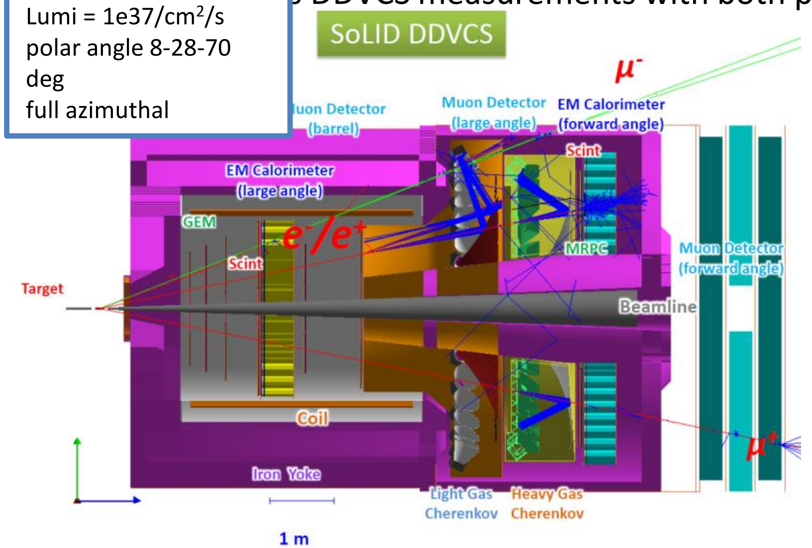




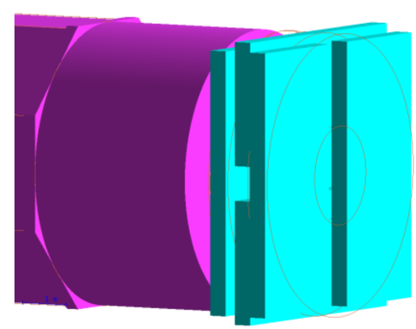
$$\xi' = \frac{Q^2 - Q'^2 + t/2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

$$\xi = \frac{Q^2 + Q'^2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

Lumi = 1e37/cm^2/s
polar angle 8-28-70 deg
full azimuthal



Iron plate for
forward angle muon detector

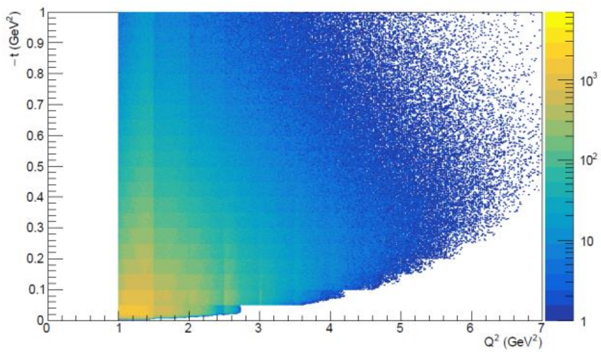


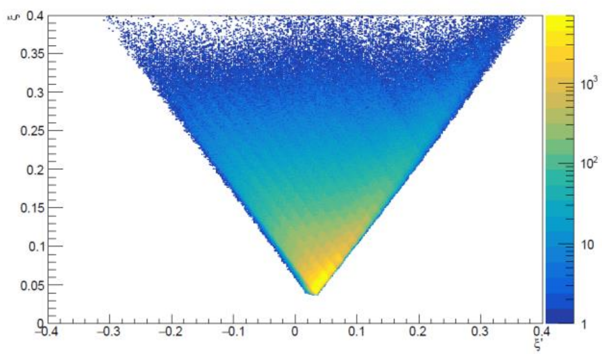
S. Zhao et al. EPJ A 57 (2021) 240
JLab LOI12-15-005 (**M. Boer, A. Camsonne, K. Gnanvo, E. Voutier, Z.W. Zhao et al.**)

DDVCS with 11GeV circular polarized beam and LH2 target

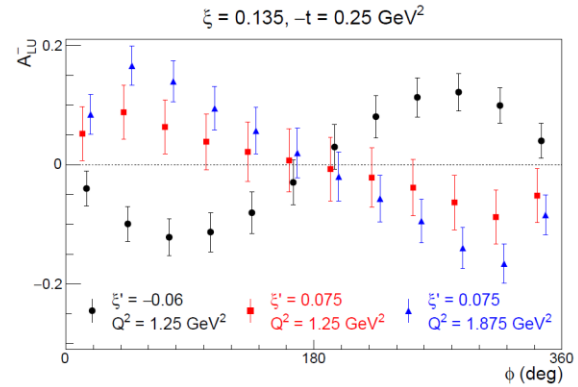
$$\xi' = \frac{Q^2 - Q'^2 + t/2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$
$$\xi = \frac{Q^2 + Q'^2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

coverage

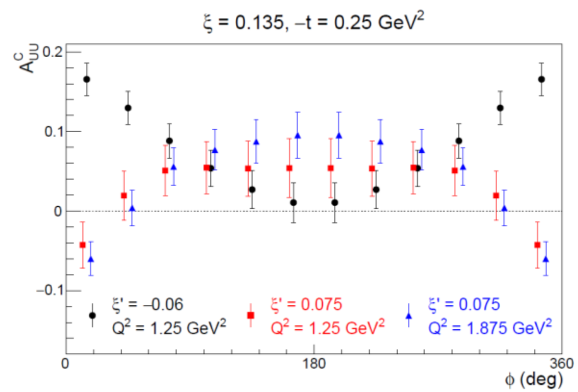




projection



50 days of electron BSA



plus 50 days of positron BCA

$$A^{\pm}_{LU}(\phi) = \frac{1}{\lambda^{\pm}} \frac{d^5\sigma^{\pm}_{+} - d^5\sigma^{\pm}_{-}}{d^5\sigma^{\pm}_{+} + d^5\sigma^{\pm}_{-}} = \frac{d^5\tilde{\sigma}_{DDVCS} \mp d^5\tilde{\sigma}^{\mathrm{INT1}}}{d^5\sigma_{BH_1} + d^5\sigma_{BH_2} + d^5\sigma_{DDVCS} \mp d^5\sigma_{INT_1}} \quad (15)$$

$$A^{C}_{UU}(\phi) = \frac{(d^5\sigma^{+}_{+} + d^5\sigma^{+}_{-}) - (d^5\sigma^{-}_{+} + d^5\sigma^{-}_{-})}{d^5\sigma^{+}_{+} + d^5\sigma^{+}_{-} + d^5\sigma^{-}_{+} + d^5\sigma^{-}_{-}} = \frac{d^5\sigma_{INT_1}}{d^5\sigma_{BH_1} + d^5\sigma_{BH_2} + d^5\sigma_{DDVCS}}$$

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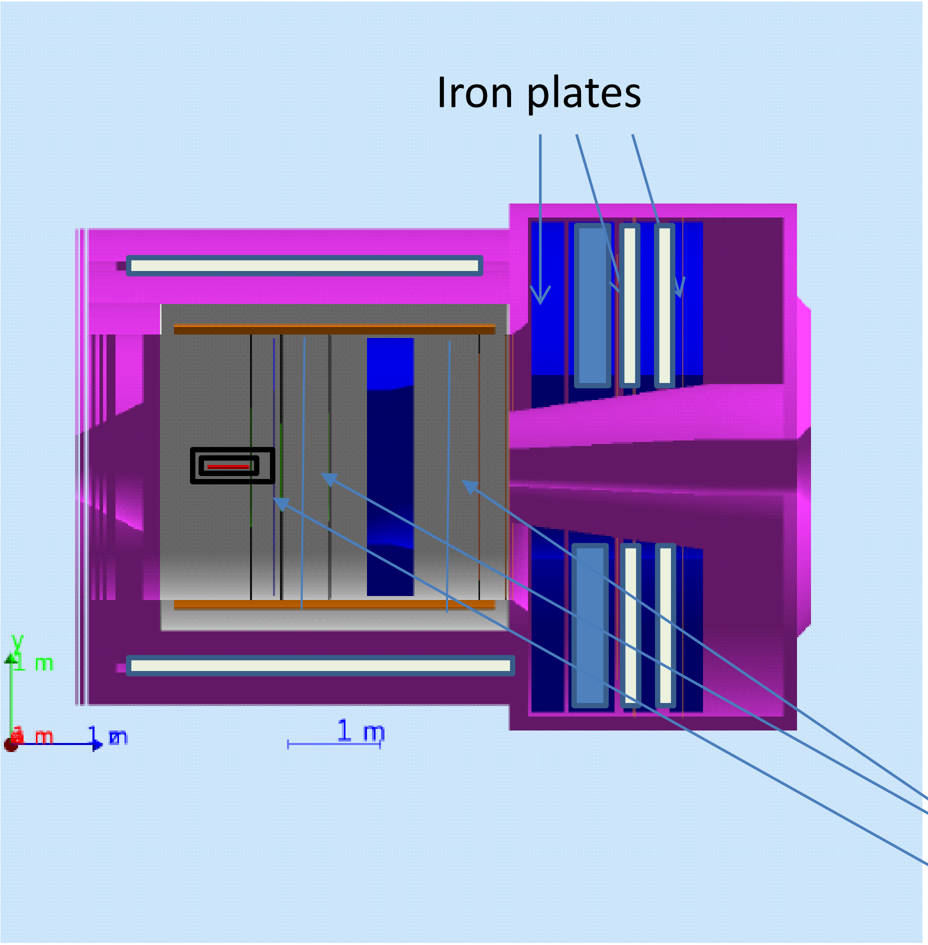
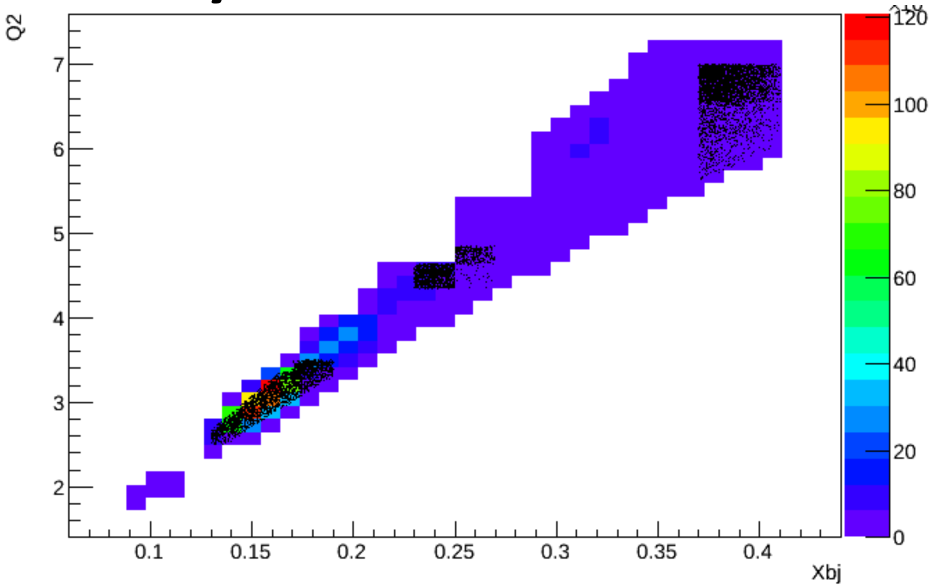
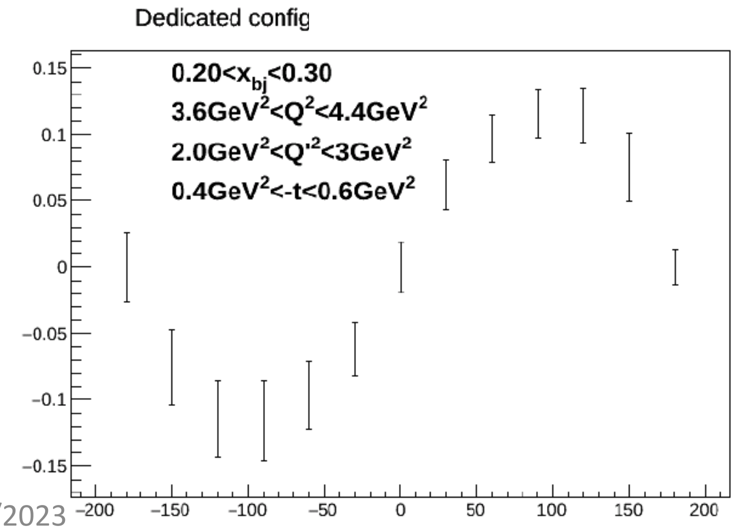
Dedicated setup

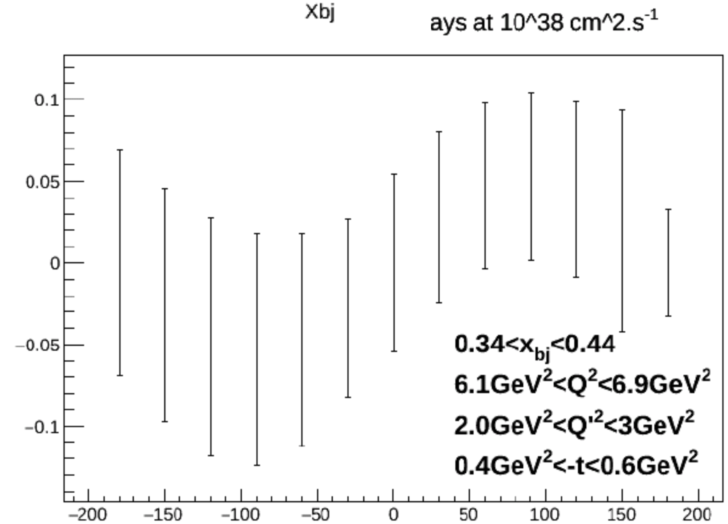


- Target moved 2m from Jpsi position inside and switch to 45 cm target
- Iron plate from 3rd layer yoke in front and behind calorimeter
- Remove Gas Cerenkov
- Try to reach 10^{38} $cm^{-2}s^{-1}$
- 30 uA on 15 cm target (typical run in Hall A no beam dump upgrade required)
- Additionnal trackers planes
- Pixellized (MAPS or GEMs or superconducting nanowire) planes to reduce combinatorial
- Possible superconducting vertex tracker for vertex cut

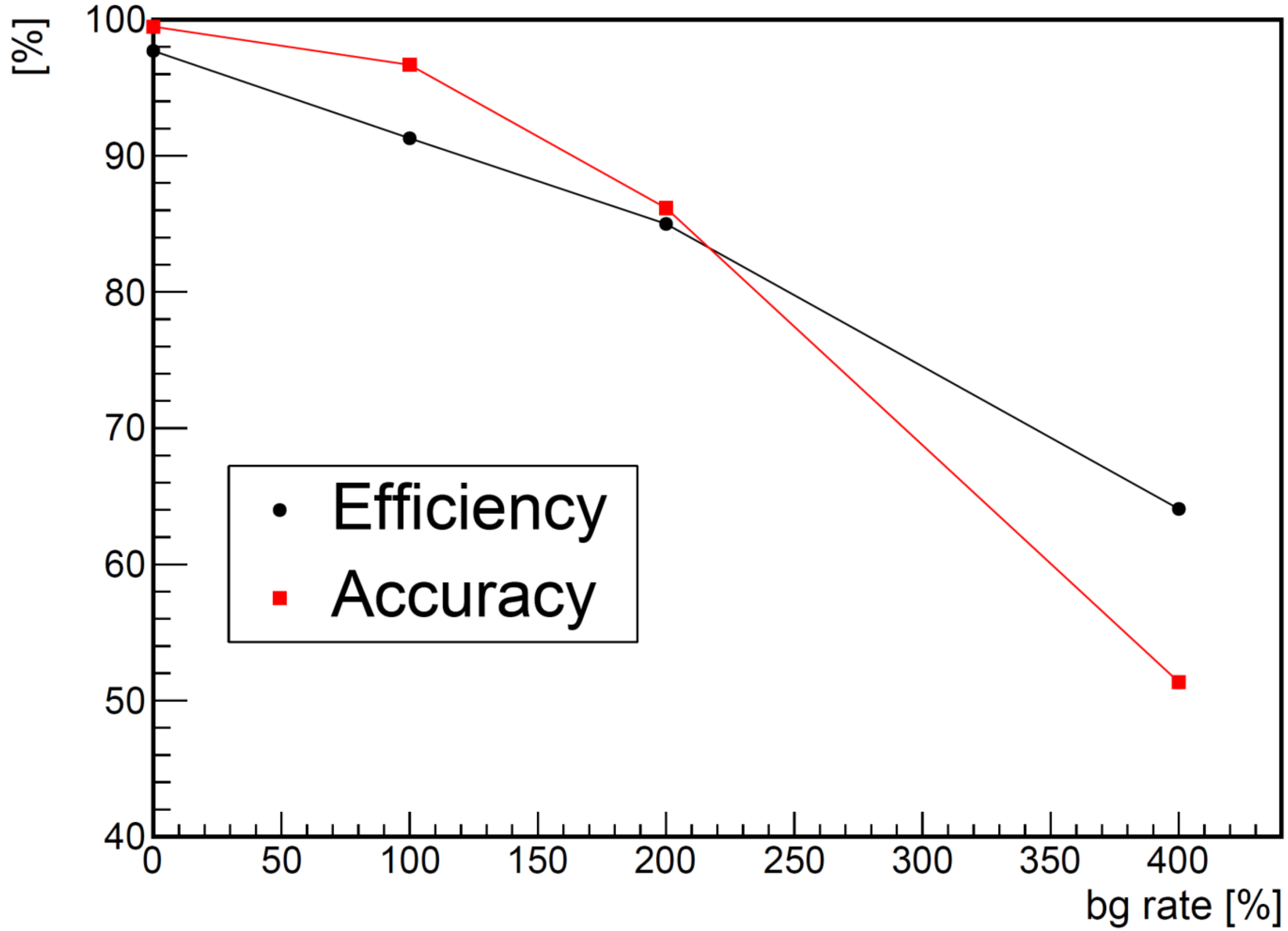
Expected accuracy dedicated setup 90 days at 10^{38} cm^{-2}s^{-1}







Higher luminosity J/Psi setup tracking study



Weizhi Xiong

Simple Kalman filter tracking

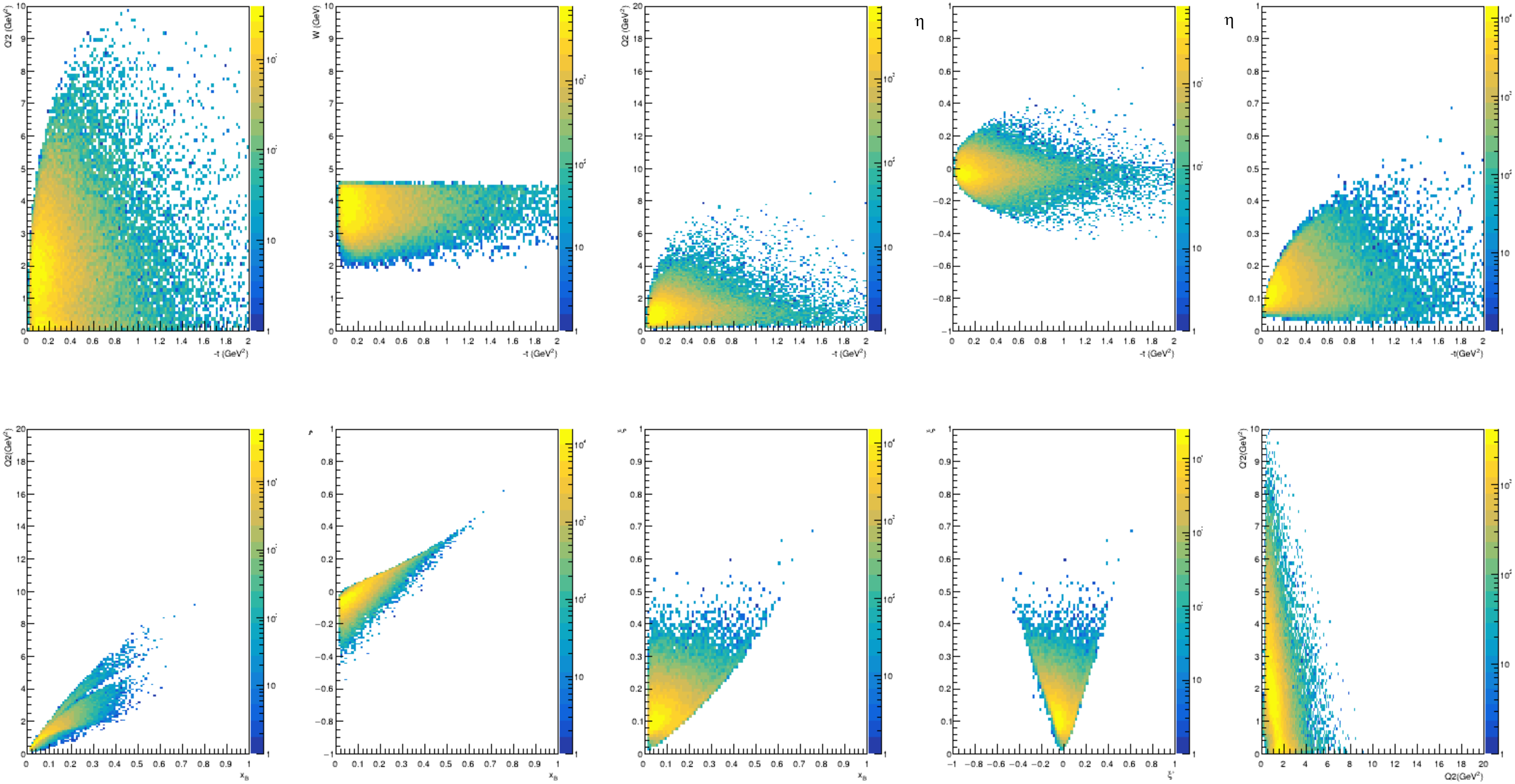
Higher luminosity ?

- Current could go up to 80 uA
- Target length up to 1 meter (~1.8 10^39 $cm^{-2}s^{-1}$), typical 40 cm
- 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
  - Radiation hardened silicon and MAPS
- 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 $cm^{-2}s^{-1}$ at 11 GeV and 3. 10^38 $cm^{-2}s^{-1}$ at 22 GeV

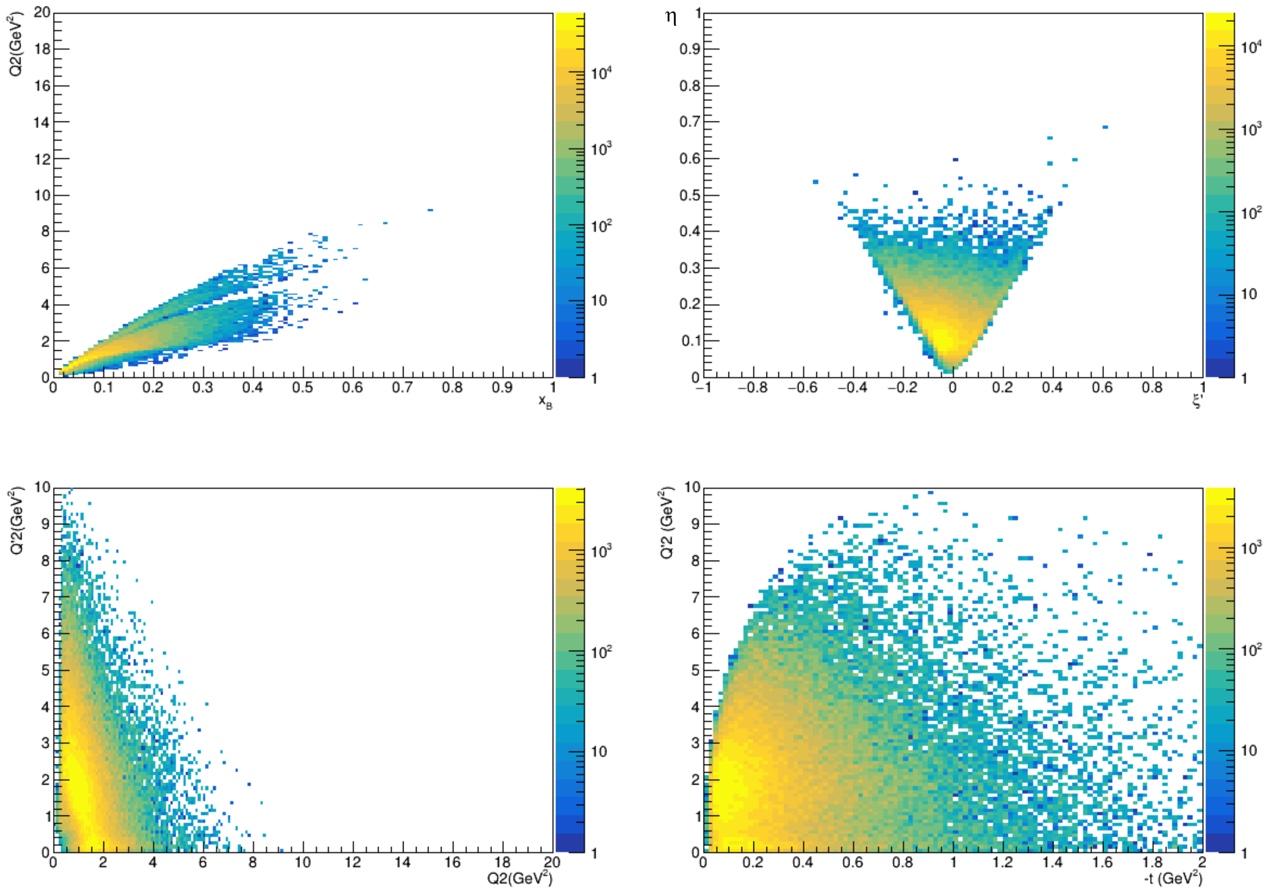
Technically doable mostly matter of cost

Kinematical coverage 11 GeV

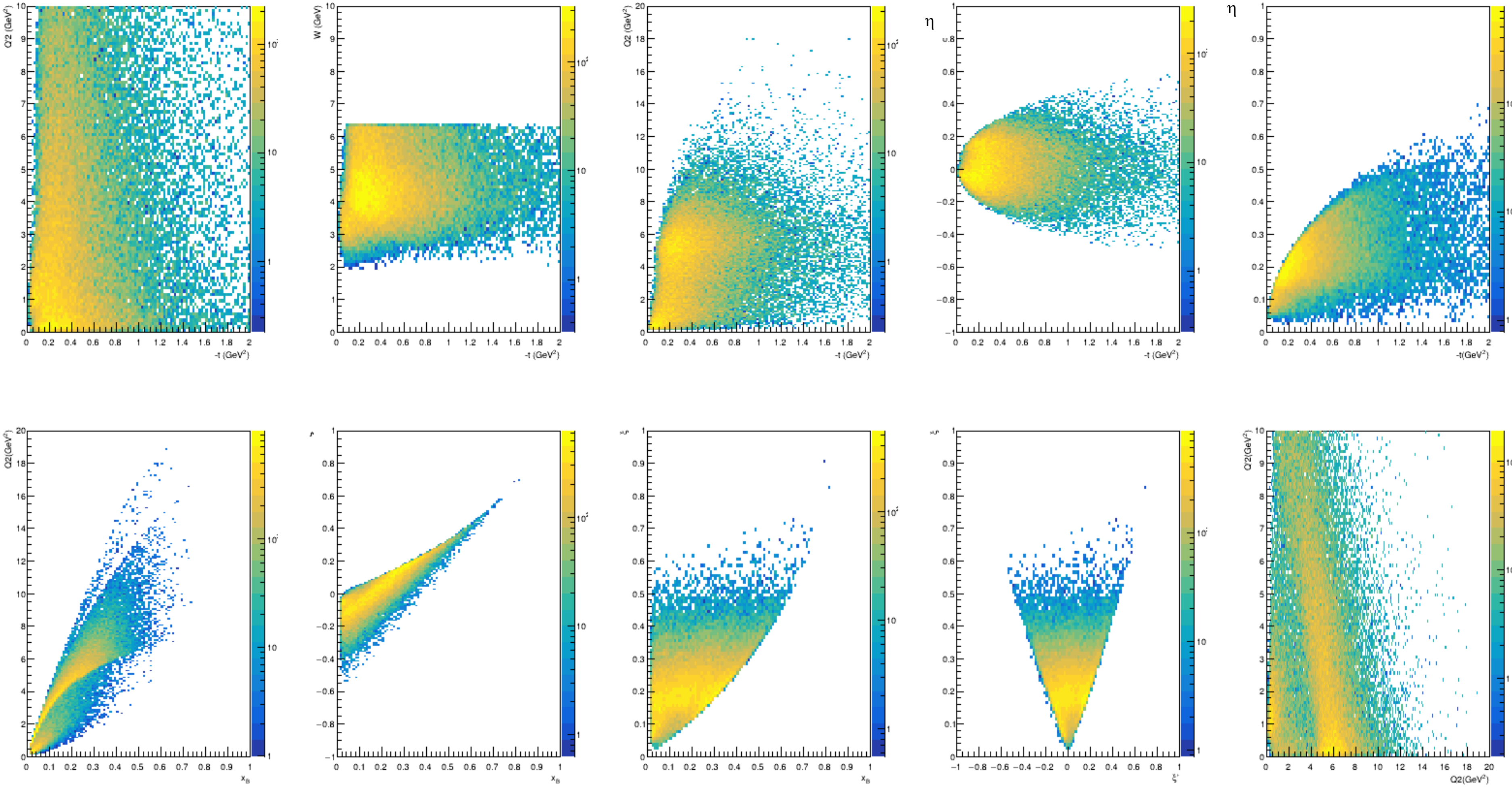


Zhiwen Zhao (GRAPE)

Kinematical coverage 11 GeV

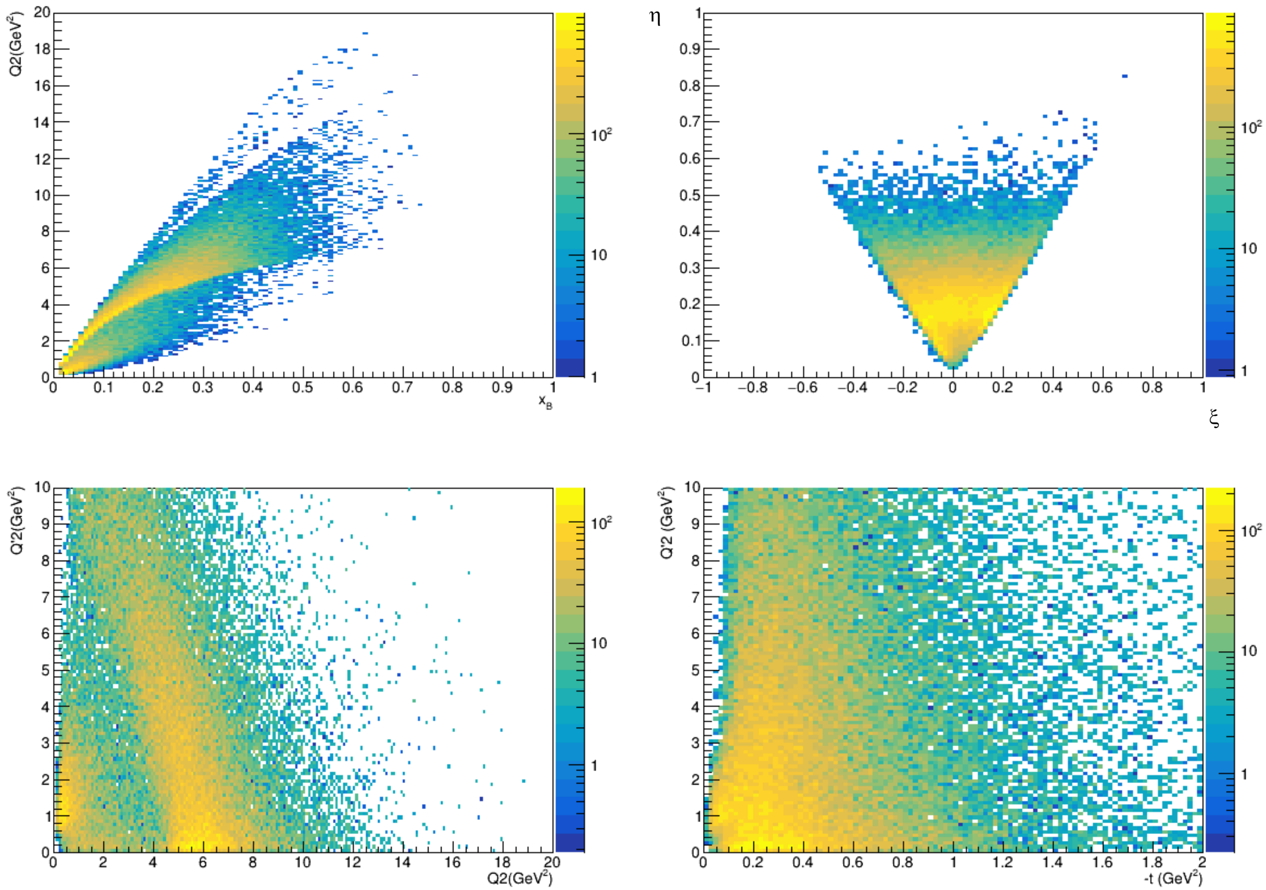


Kinematical coverage 22 GeV

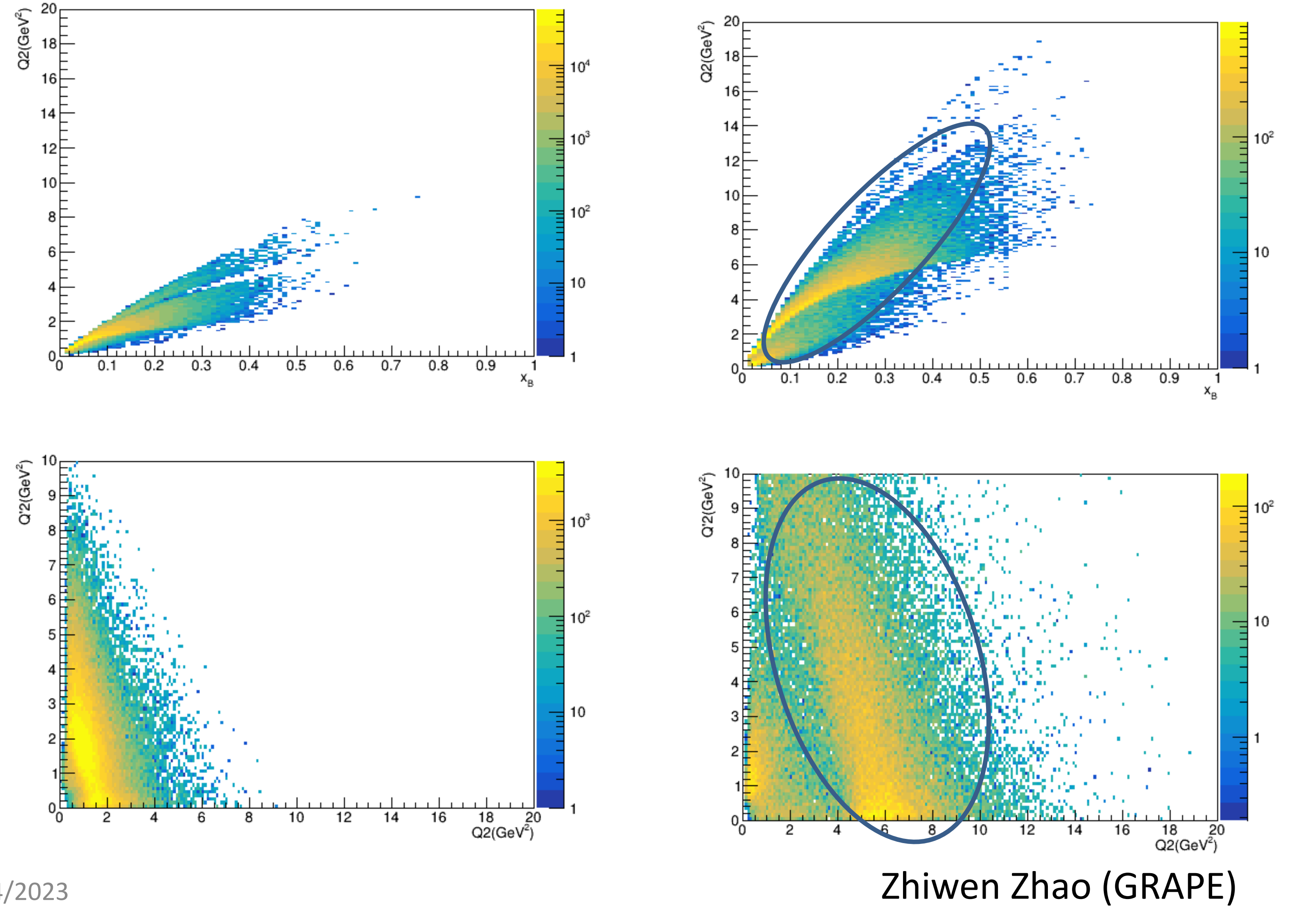


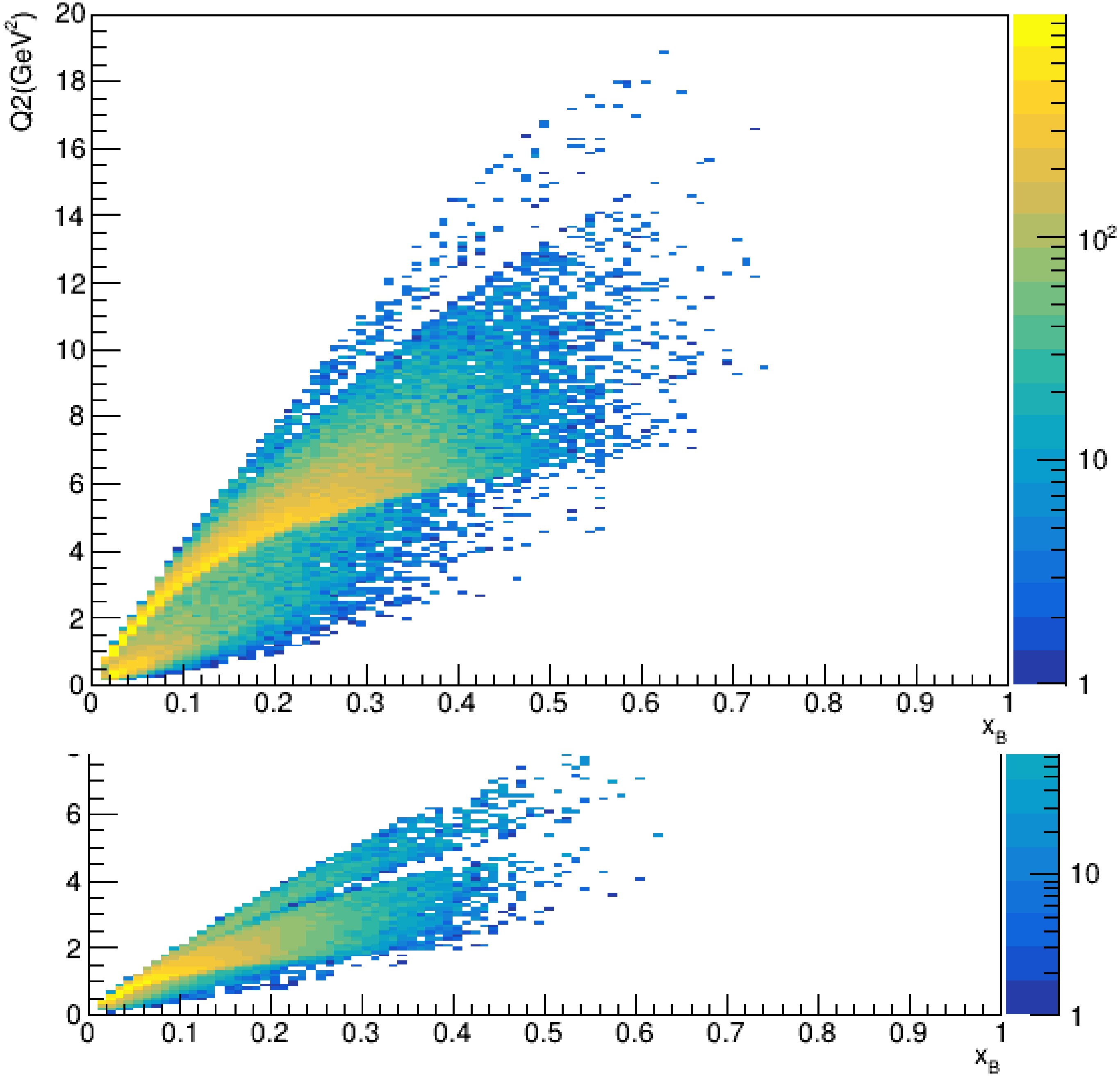
Zhiwen Zhao (GRAPE)

Kinematical coverage 22 GeV



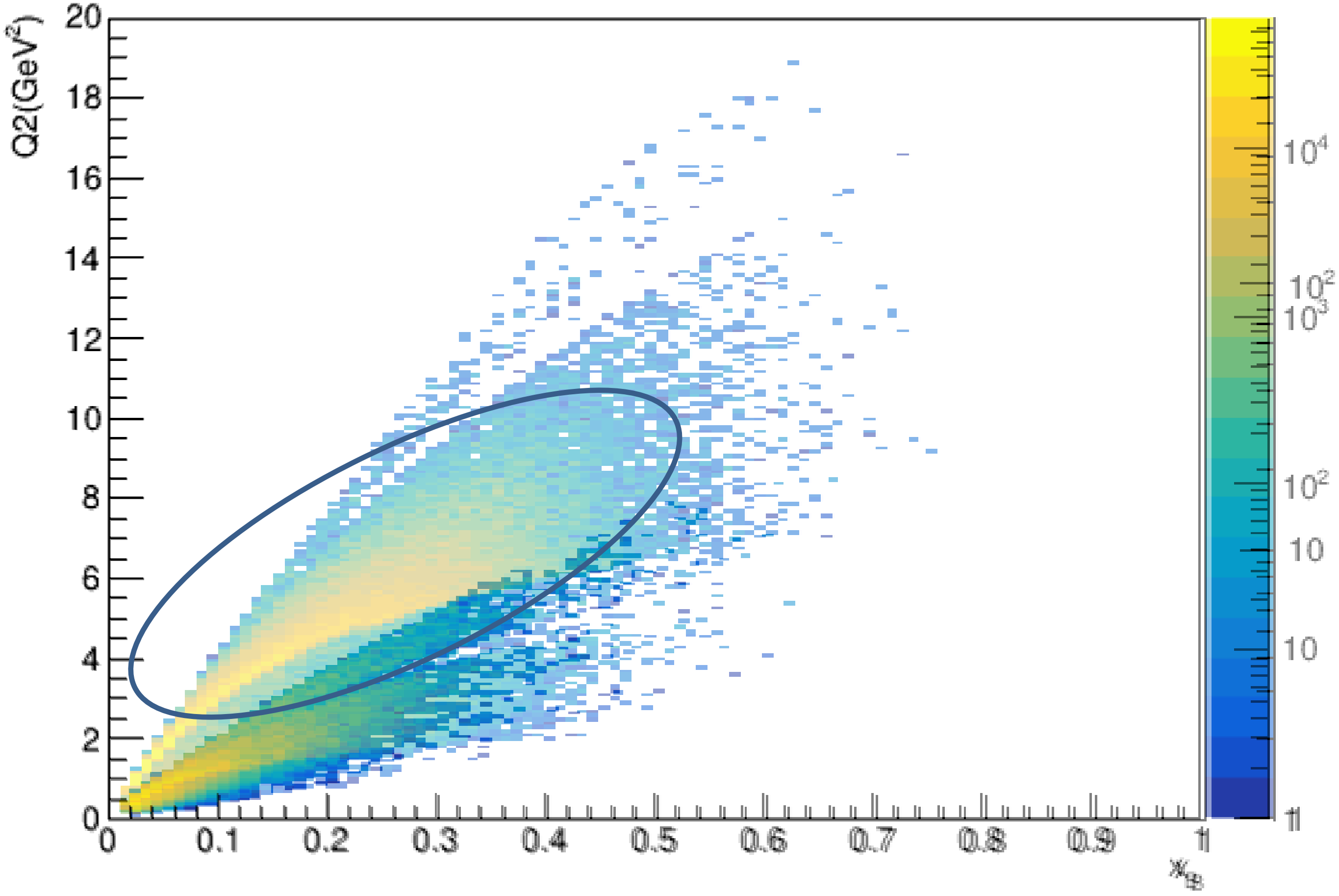
11 GeV vs 22 GeV





Zhiwen Zhao (GRAPE)

11 GeV vs 22 GeV



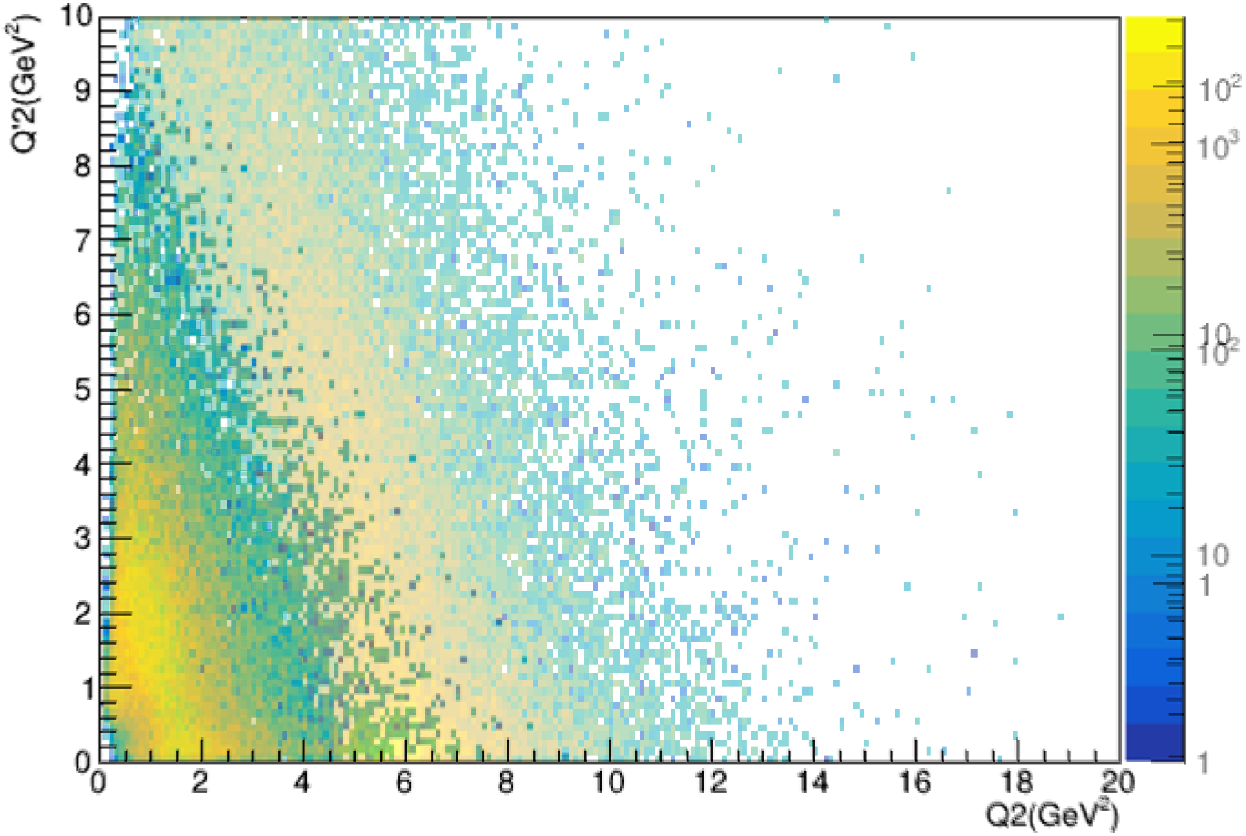
Large Q2 range

Check factorization

evolution

Zhiwen Zhao (GRAPE)

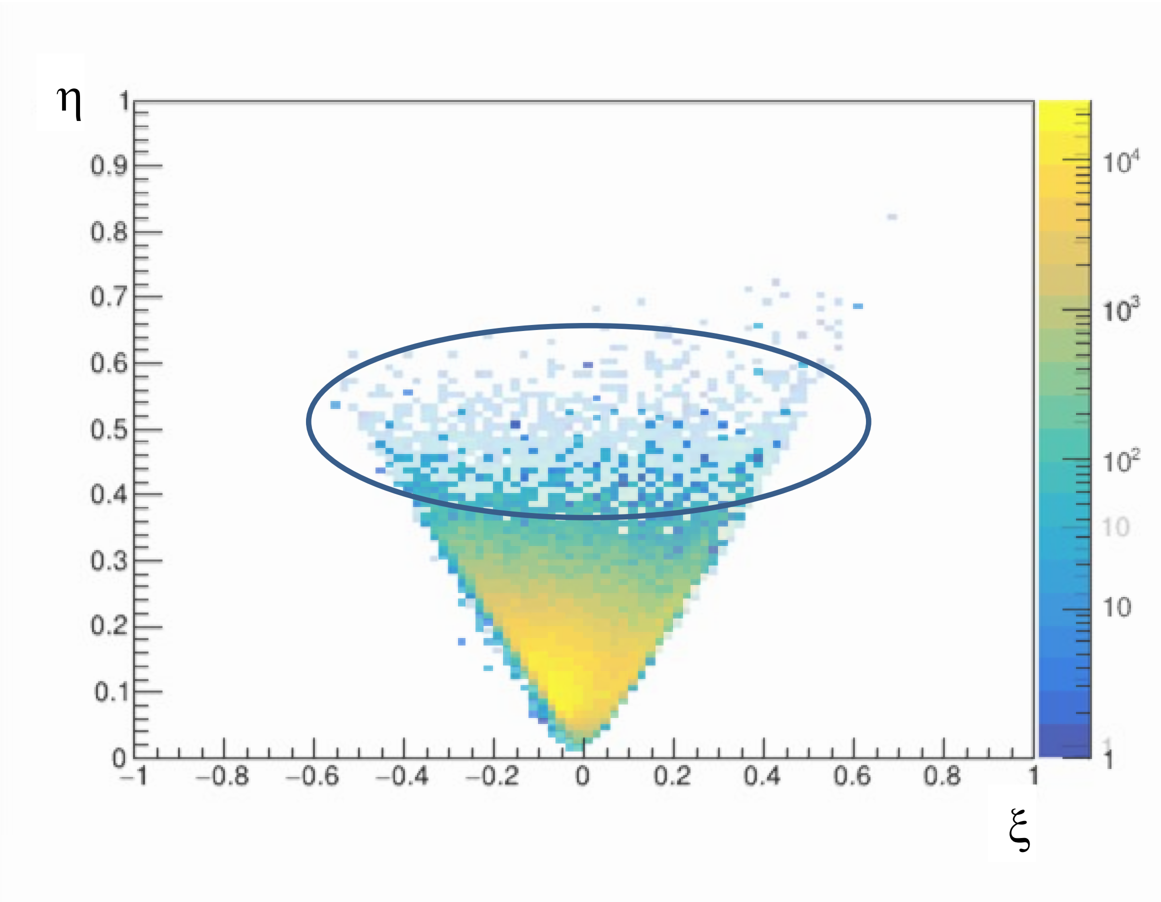
11 GeV vs 22 GeV



Much better Q2 Q'2 coverage

Want Q2 and Q'2 large enough for factorization

11 GeV vs 22 GeV



Increased acceptance in ξ and η

Quick numbers for J/Psi settings

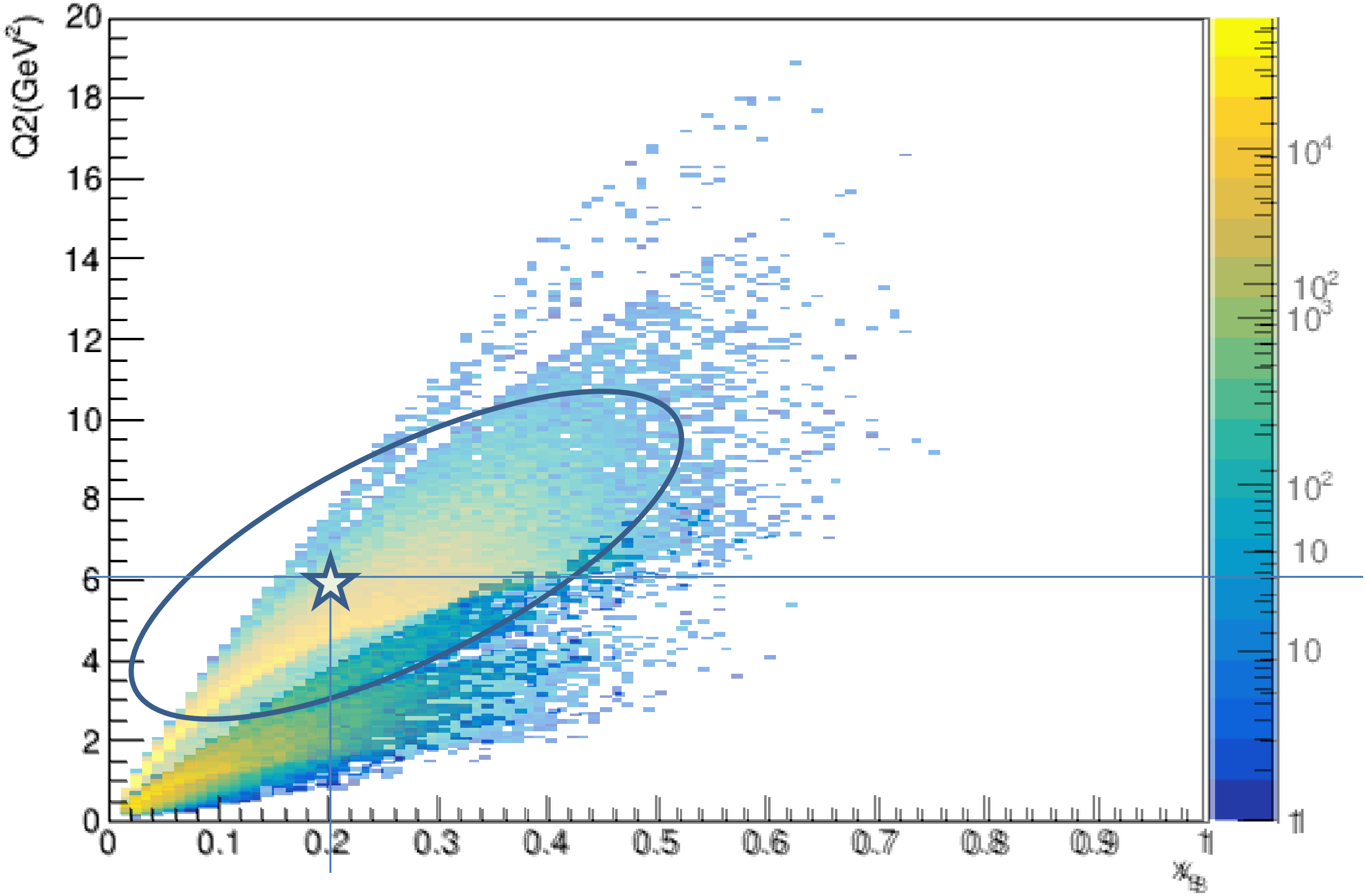
50 days at 10^37

Beam energy	e-mu-mu+
11	180156
22	51600

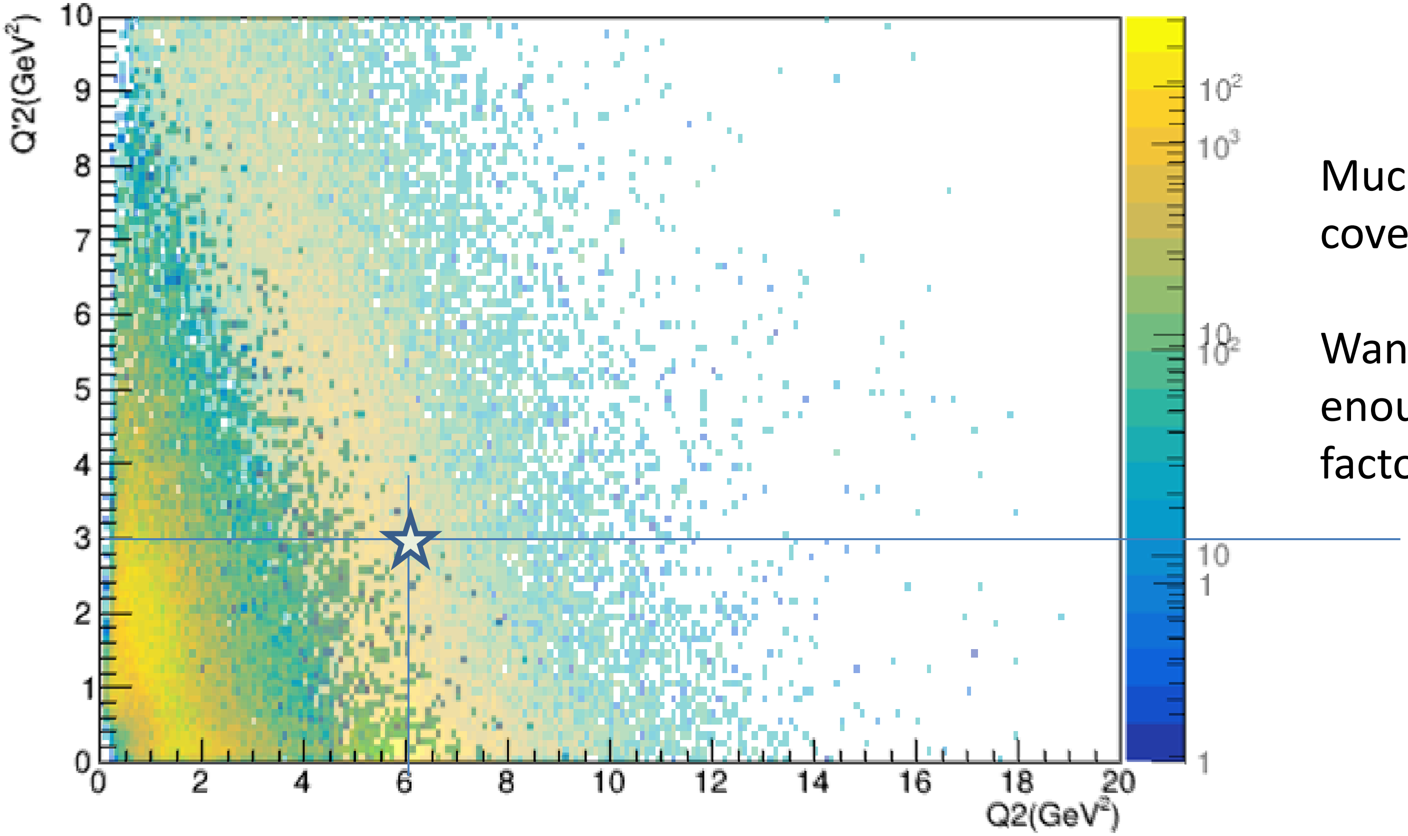
Cross section about 3 times lower : could run at 10 uA or with 45 cm target

Acceptance better when detecting proton but dominated by low Q2/Q'2

11 GeV vs 22 GeV



11 GeV vs 22 GeV

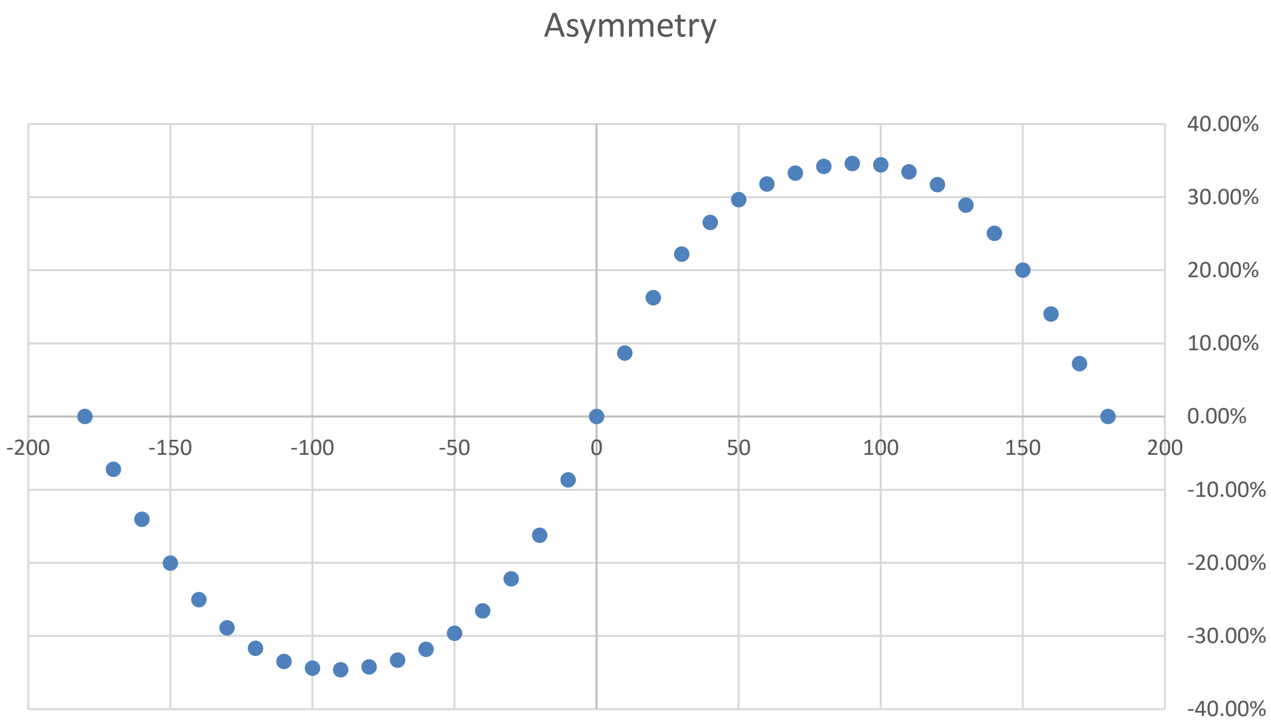


Much better Q2 Q'2 coverage

Want Q2 and Q'2 large enough for factorization

Asymmetry for one point

- xbj=0.20, Q2=6 GeV2,Q’2=3GeV^2, -t=0.25 GeV^2 from VGG



Spectrometre SuperBigBite

Large Dipole 48 in x 48 in

Gem trackers

Hadronic Calorimeter
20 cm x 20 cm x 100 cm

Big Cal

Large Angle Calorimeter

Parameters of SBS

Solid angle

$\theta_{central}$, degree	Ω, msr	D, meter	Hor. range, degree	Vert. range, degree
3.5	5	9.5	$\pm$ 1.3	$\pm$3.3
5.0	12	5.8	$\pm$ 1.9	$\pm$4.9
7.5	30	3.2	$\pm$ 3	$\pm$8
15	72	1.6	$\pm$ 4.8	$\pm$12.2
30	76	1.5	$\pm$ 4.9	$\pm$12.5

Resolution:

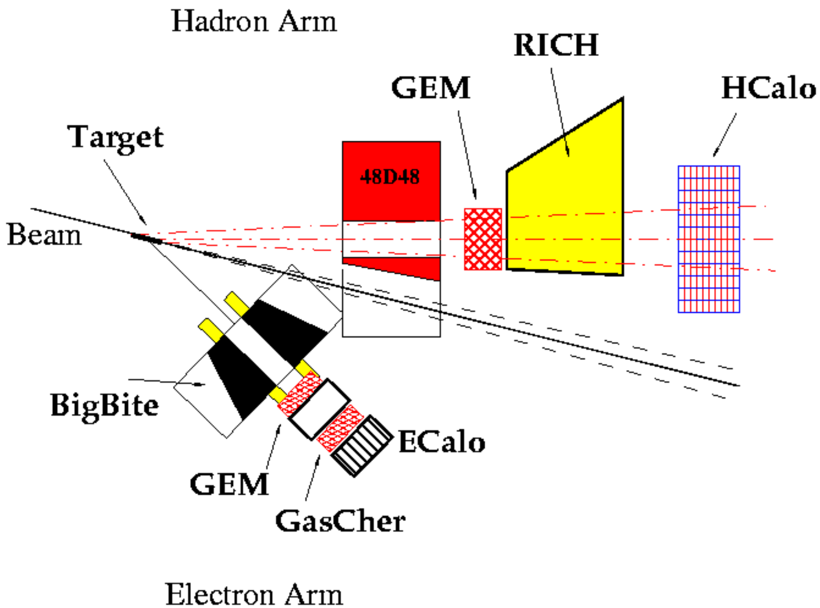
Momentum =>
$$\frac{\sigma_p}{P} = 0.0029 + 0.0003 \times p[\mathrm{GeV}]$$

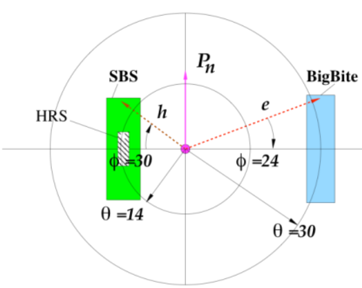
Angular =>
$$\sigma_\theta = 0.14 + 1.3/p \ [\mathrm{GeV}], \mathrm{mrad}$$

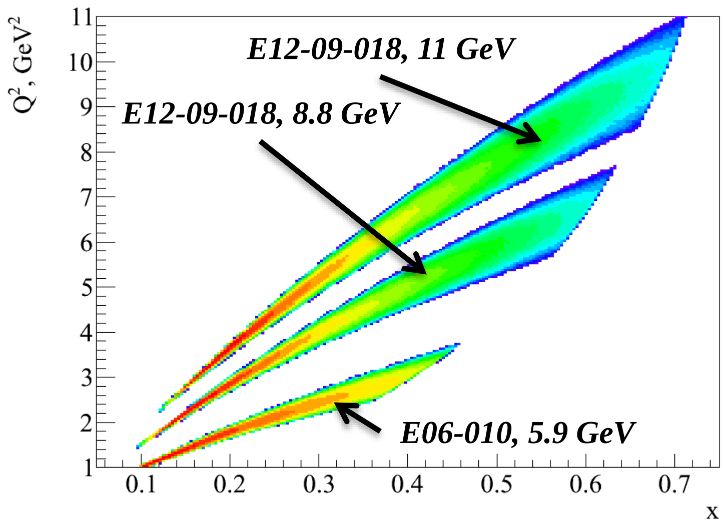
Momentum acceptance =>
$$P \text{ range from } 2 - 10 \quad , \mathrm{GeV/c}$$

0.5 % momentum resolution at 5 GeV

E12-09-018: SIDIS on polarized ^{3}He @ 12 GeV



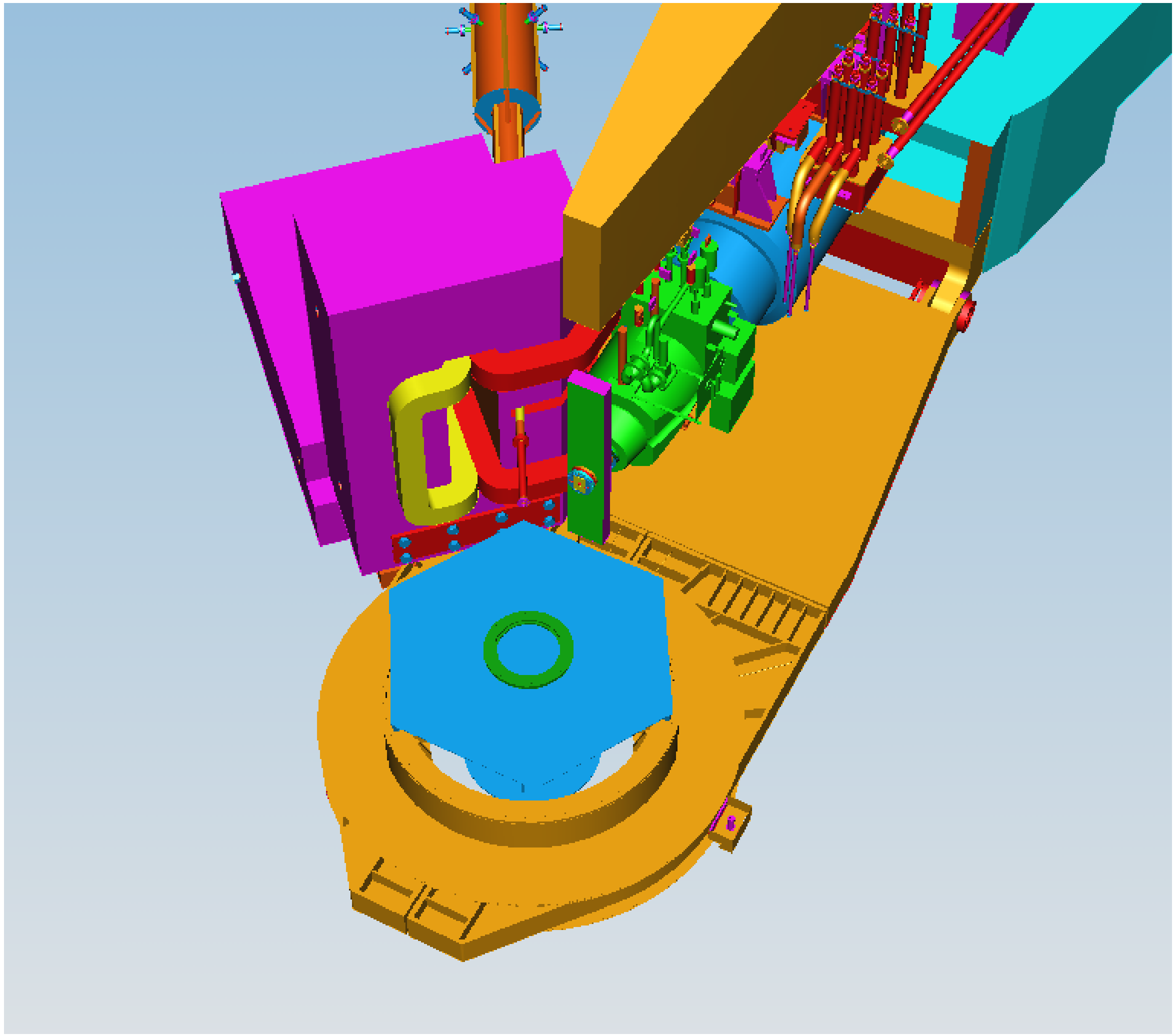




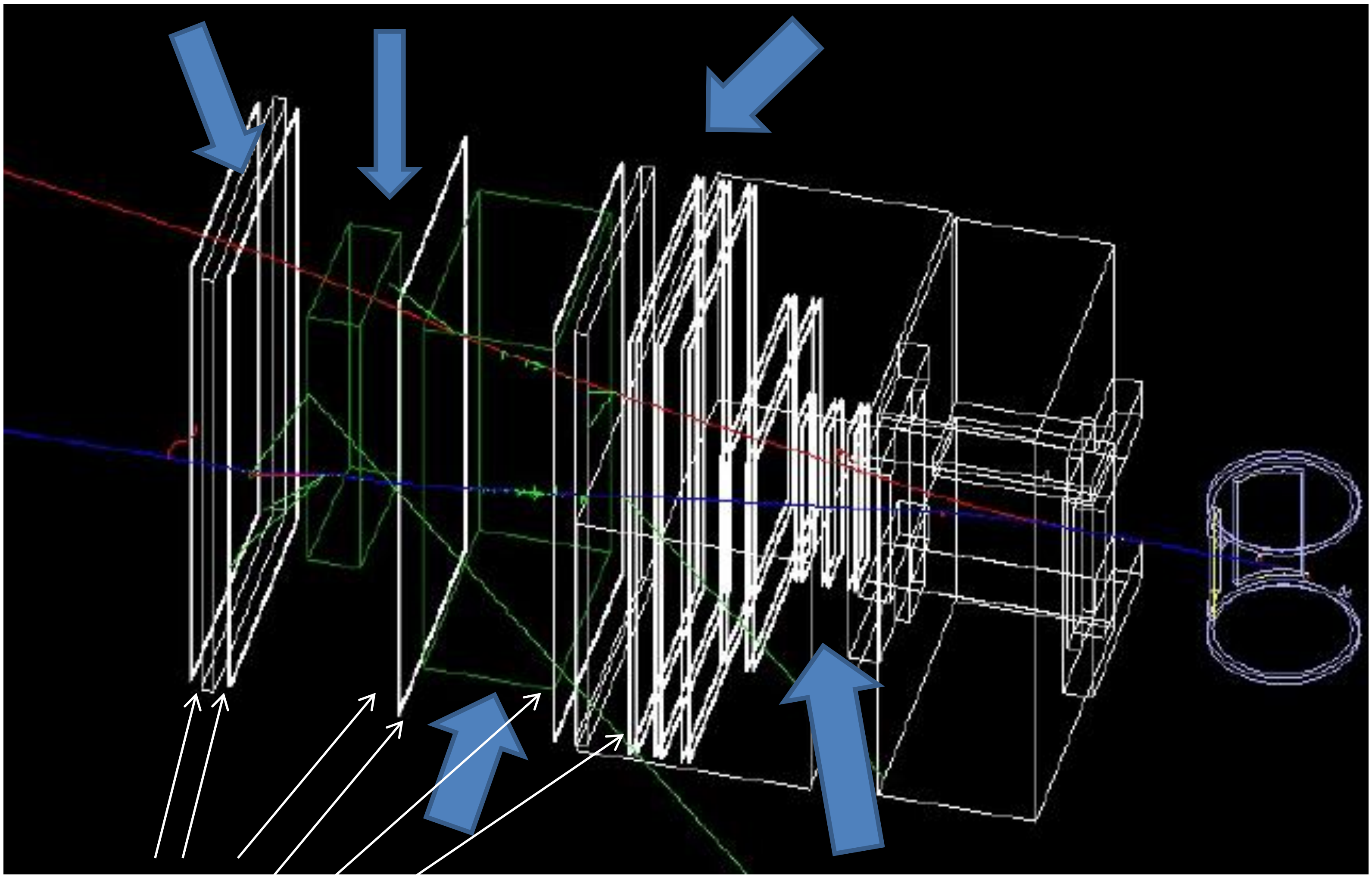
Experiment E12-09-018

- ***Approved by JLab PAC38 (August 2011), 64 days, A- rating***
- ***Spokespersons:***
  - ***G. Cates (UVA)***
  - ***E. Cisbani (INFN)***
  - ***G. Franklin (CMU)***
  - ***A. Puckett (LANL—currently JLab, near future UConn)***
  - ***B. Wojtsekhowski (JLab)***
- In two-months production run, E12-09-018 will reach ~1000X statistical FOM of E06-010 n, ~100X HERMES p
- ***Electron arm: BigBite at 30 deg as in E06-010 + A_1^n detector upgrades***
- ***Hadron arm: Super BigBite (SBS) at 14 deg.***
- Target: high-luminosity polarized Helium-3

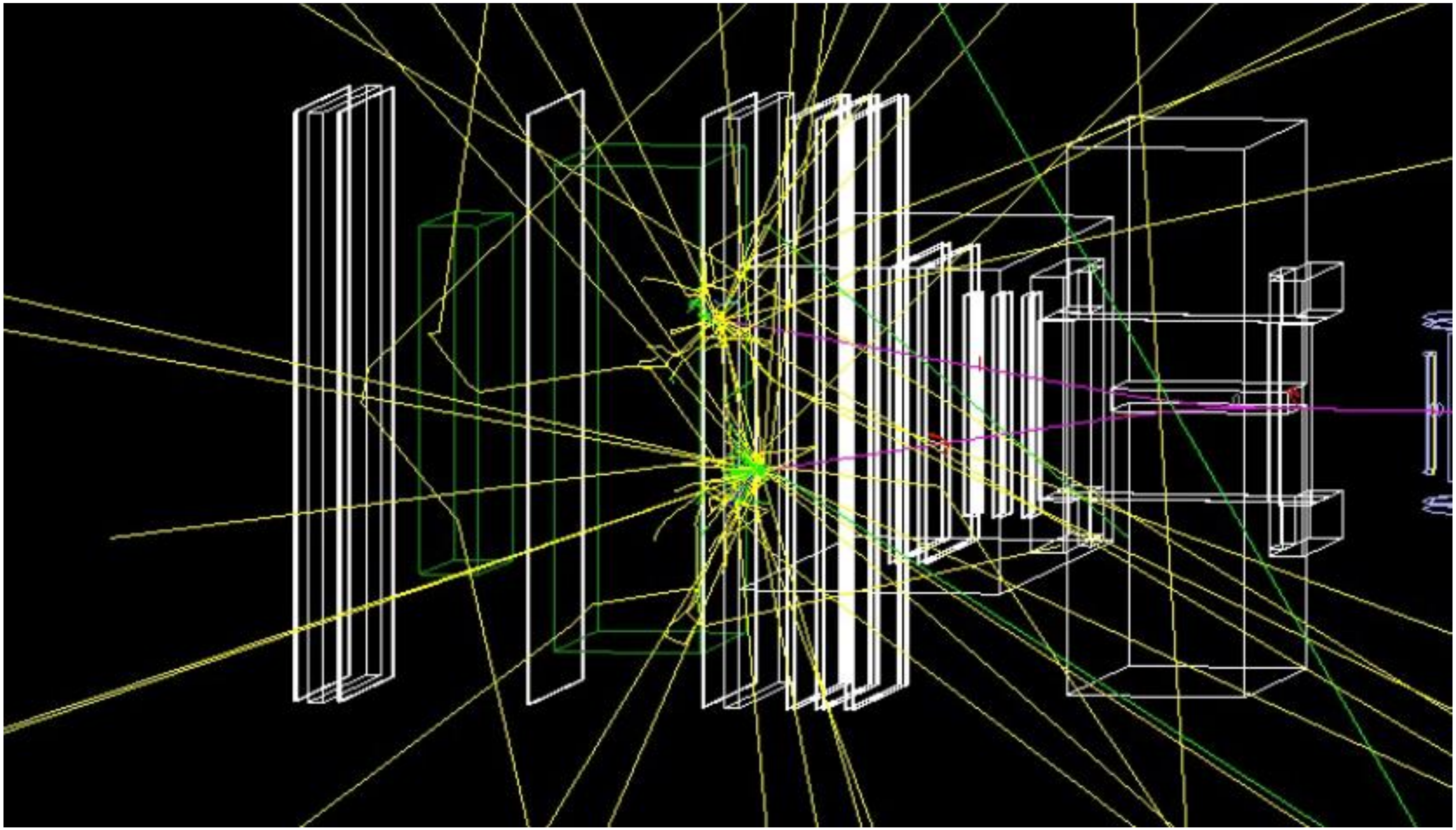
Possible HRS/SBS layout



Experimental setup



Pion event



Conclusion

- DDVCS phase space much better at 22 GeV especially in Q’2
- Can give skewness dependence of GPDs and access to D term
- SoLID Counting rates roughly a factor of 4 lower compared to 11 GeV (J/Psi 3 uA 15 cm LH2) – reasonable coverage with 11 GeV setups
- Asymmetry size seems reasonable from preliminary study
- SBS DDVCS experiment might be possible at 22 GeV
- Need more studies with optimized detector setup and event generator
- 22 GeV upgrade good timing for a dedicated detector