Double Deeply Virtual Compton with SoLID

Alexandre Camsonne
Jefferson Laboratory Hall A
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ECT
Opportunities with Jefferson Laboratory luminosity and energy upgrades

U.S. DEPARTMENT OF ENERGY | Office of Science

Jefferson Lab
Thomas Jefferson National Accelerator Facility

JSA

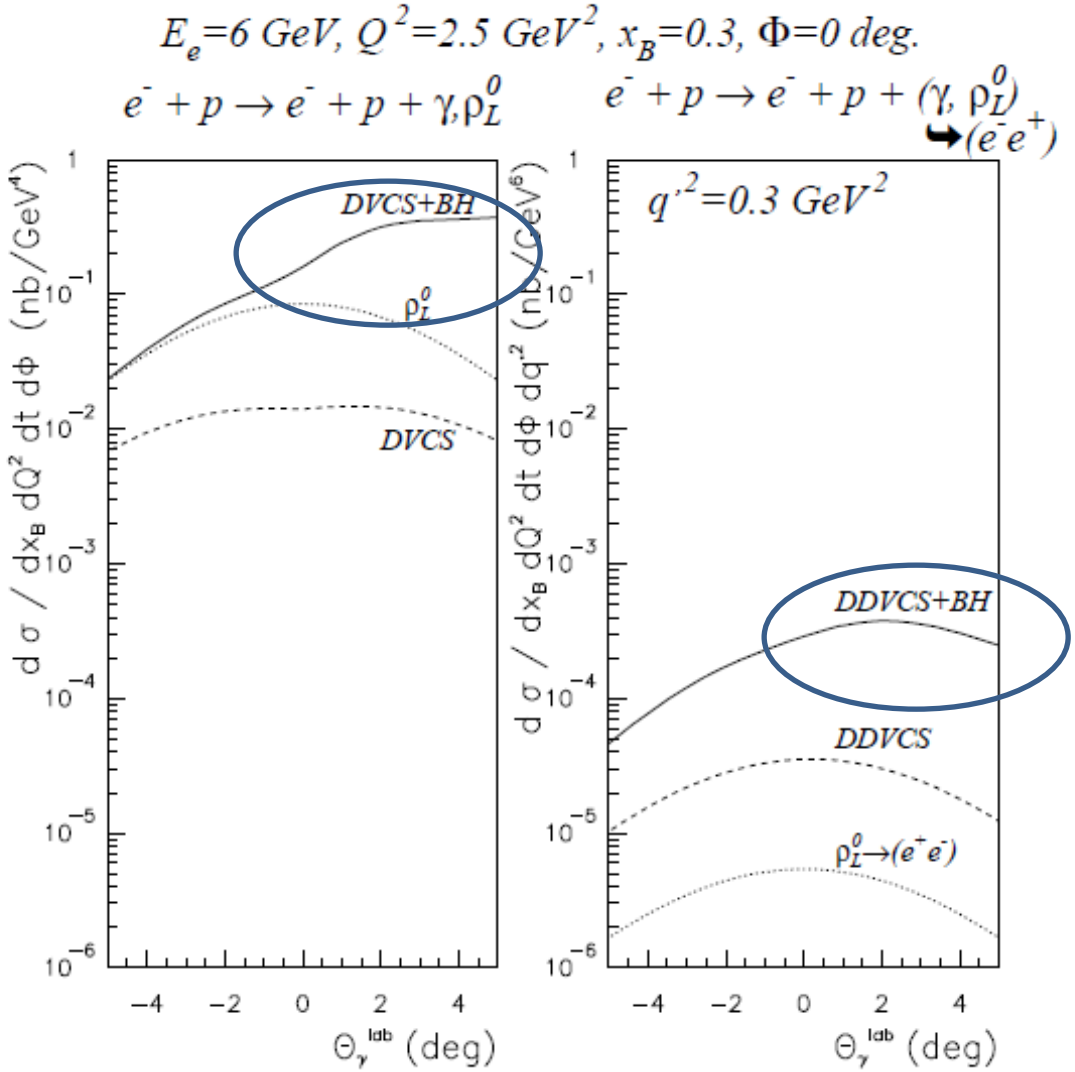
DVCS / Double DVCS

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

$$\gamma'(*) \longrightarrow l^+ + l^-$$

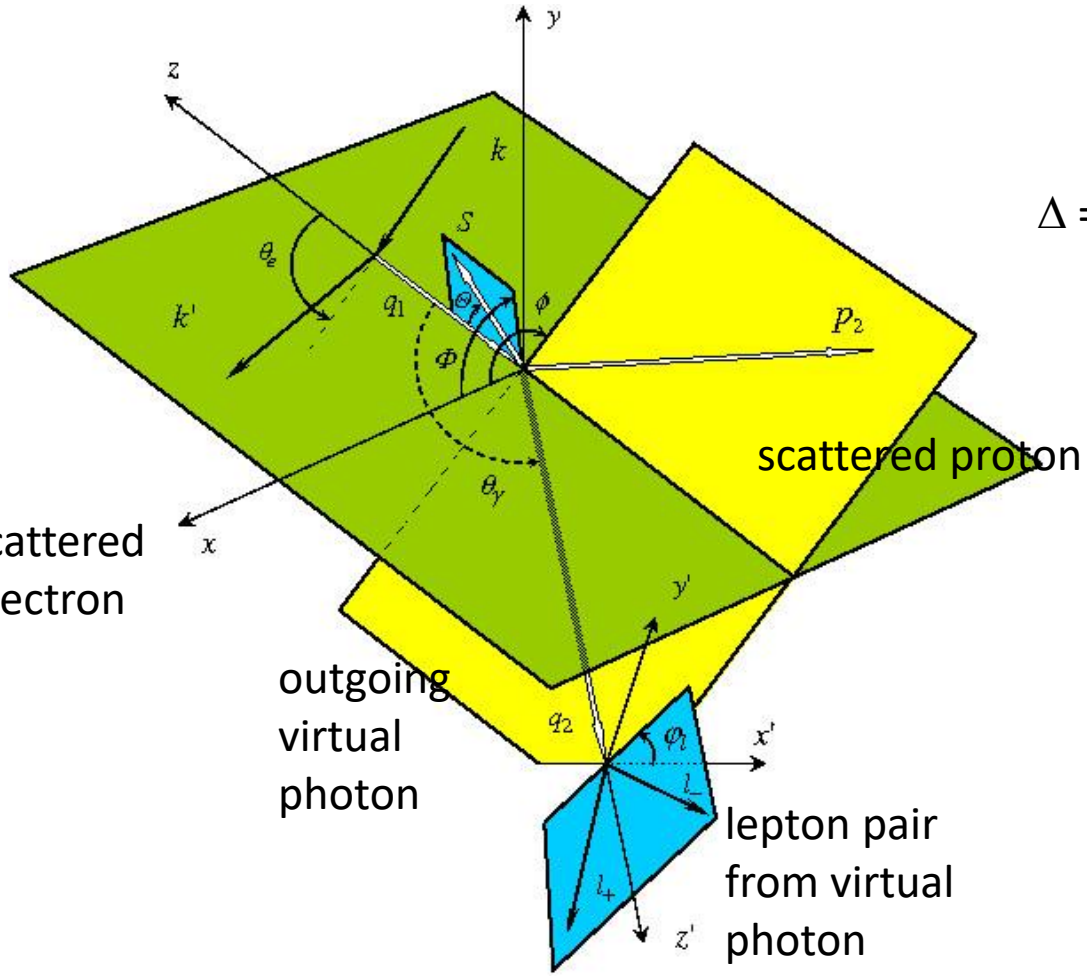
Guidal and Vanderhaegen : Double deeply virtual Compton scattering off the nucleon (arXiv:hep-ph/0208275v1 30 Aug 2002)
Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

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



scattered proton

scattered electron

outgoing virtual photon

lepton pair from virtual photon

Δ = p1-p2 = q2-q1

$Q^2 = -q^2$

p = p1+p2

q = ½ (q1+q2)

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

$Q^2 = -(k-k')^2$

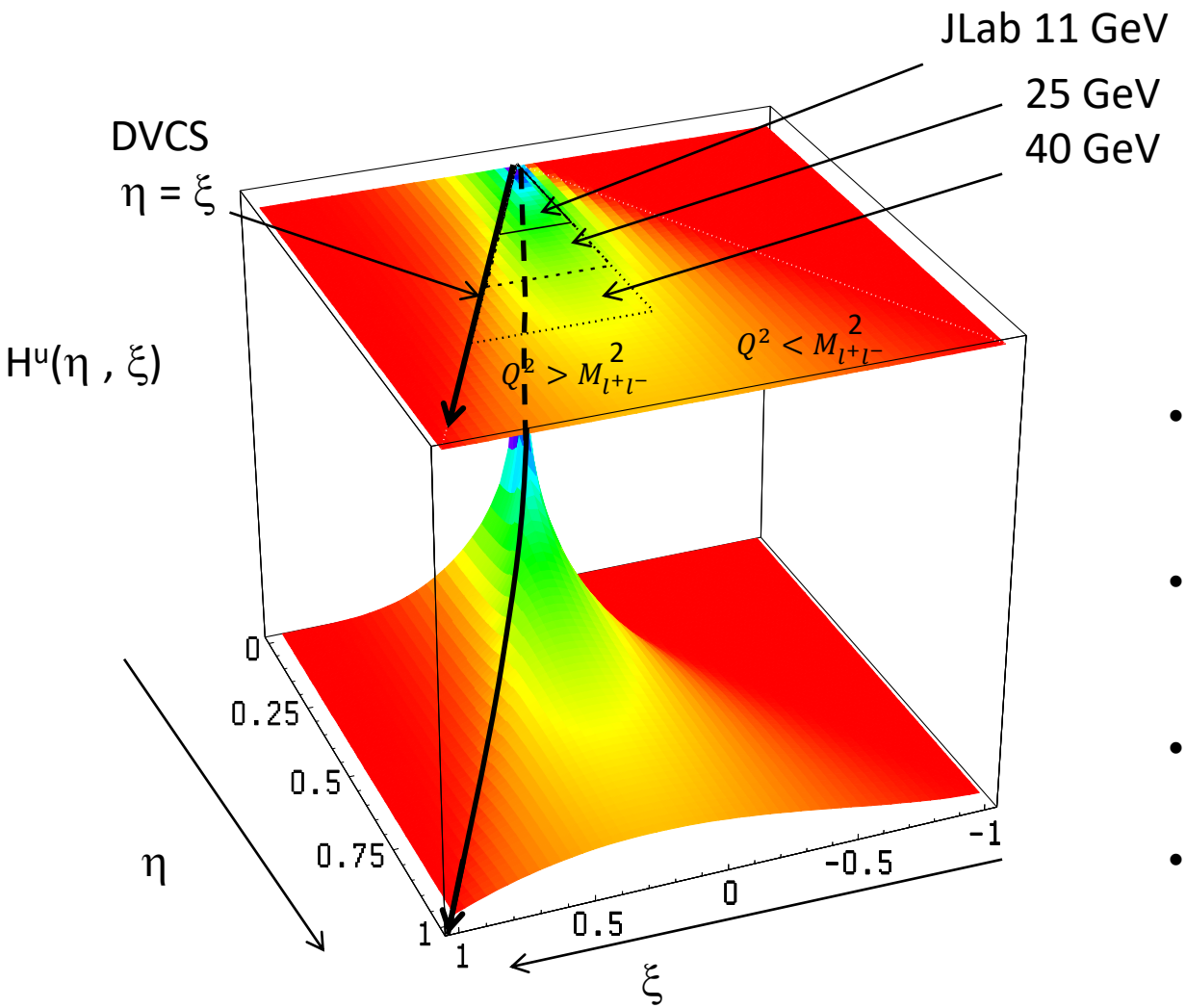
$$x_{bj} = \frac{Q^2}{2p_1q_1}$$

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

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

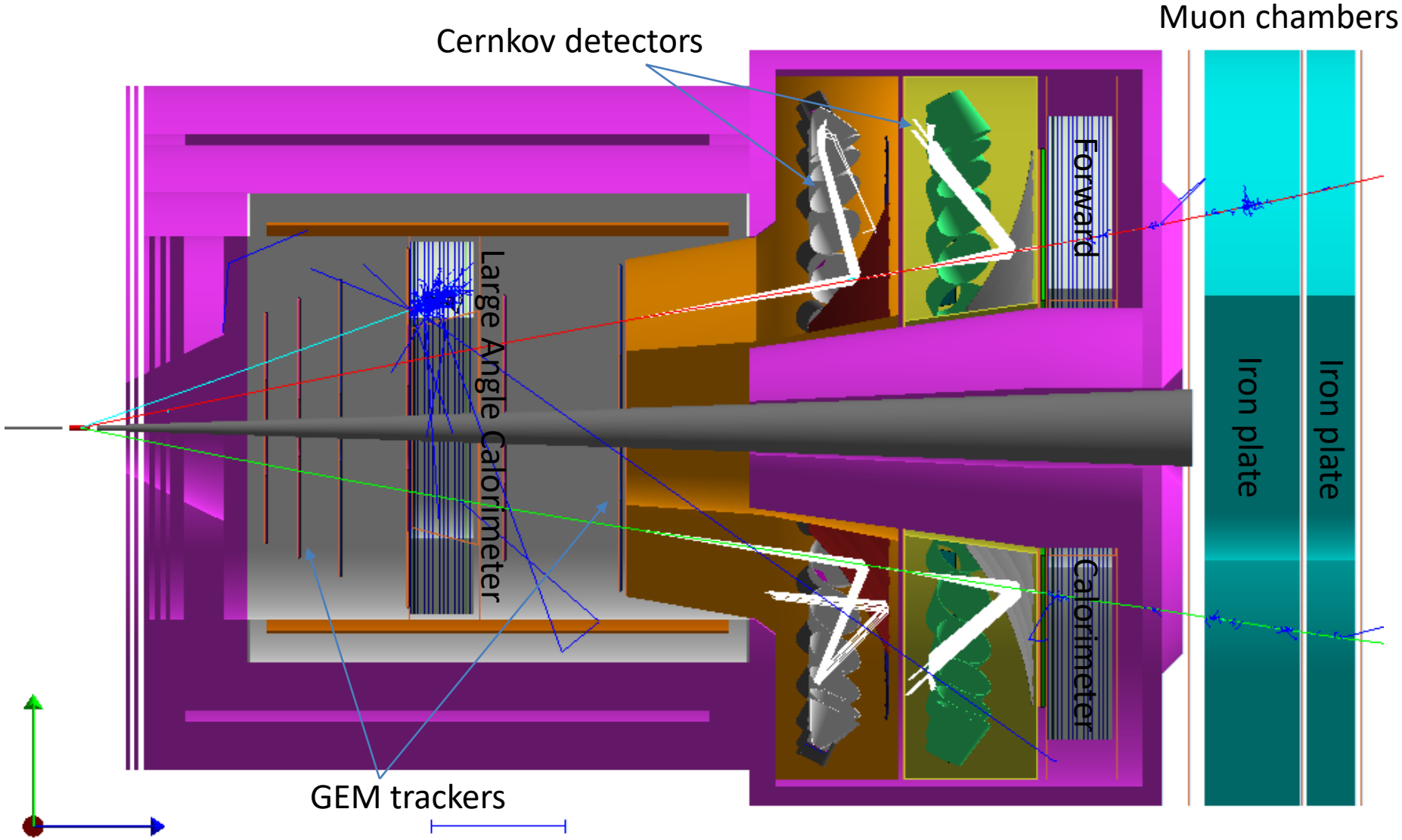
$$\propto \Im\mathrm{m} \left\{ F_1\mathcal{H} - \frac{t}{4M_N^2} F_2\mathcal{E} + \xi(F_1+F_2)\widetilde{\mathcal{H}} \right\},$$

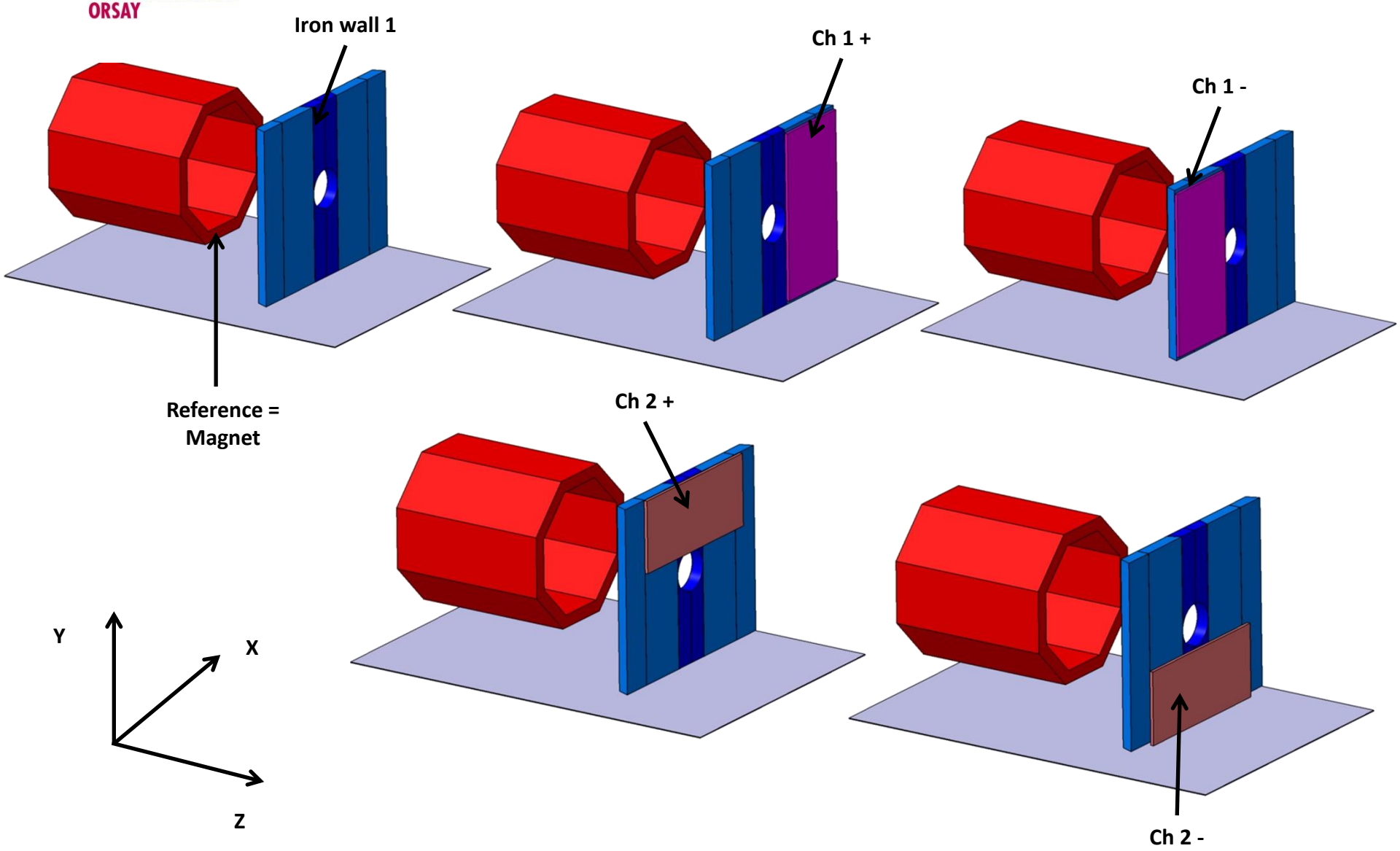
Kinematical coverage

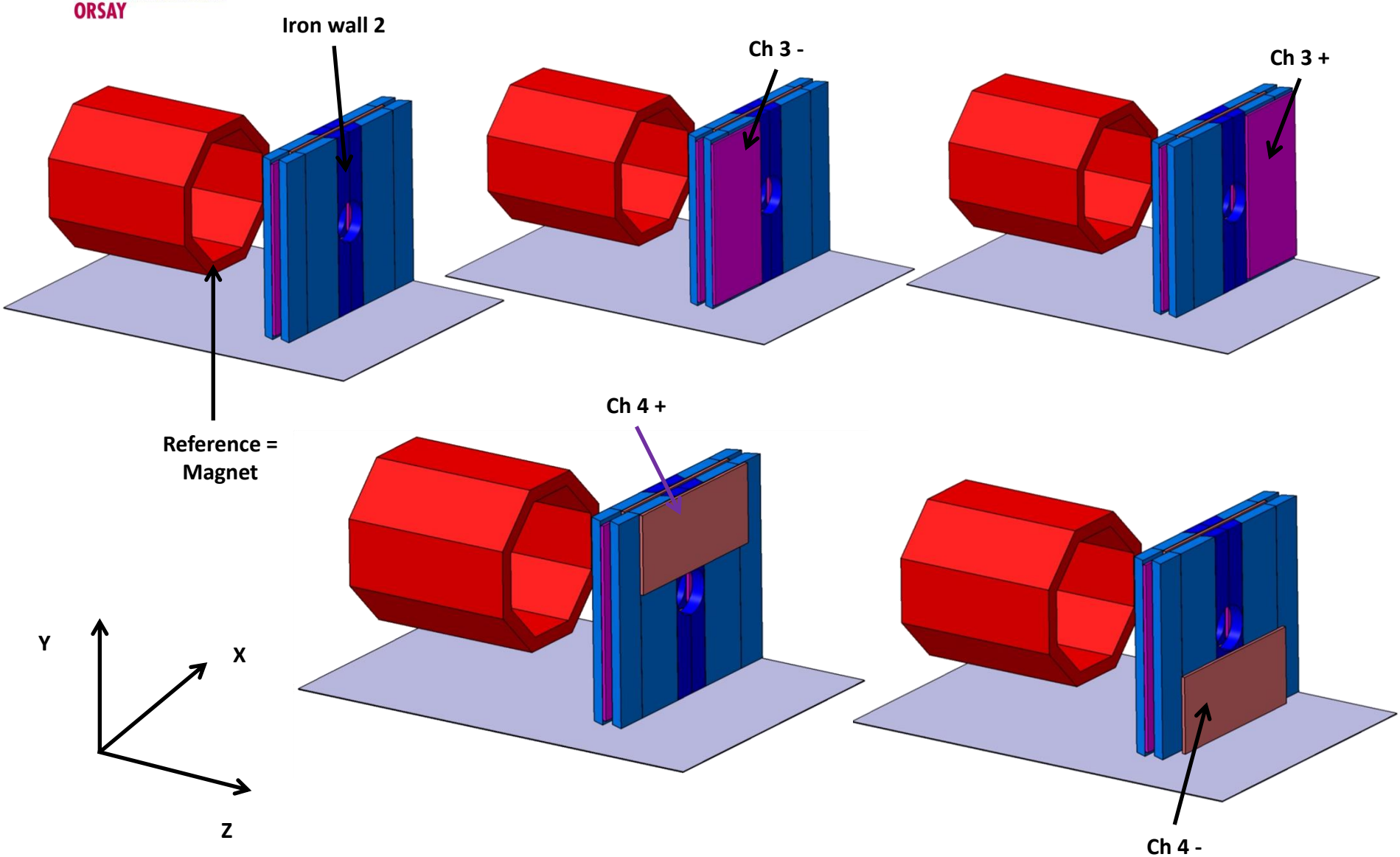


- DVCS only probes η = ξ line
- Example with model of GPD H for up quark
- Jlab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)

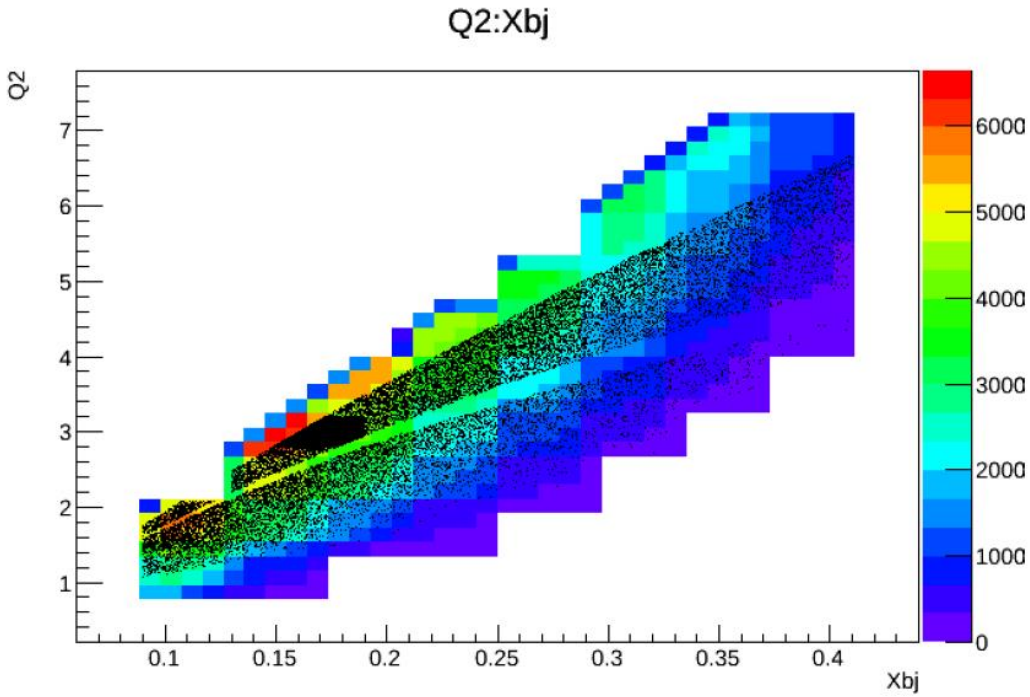
SoLID JPsi Setup

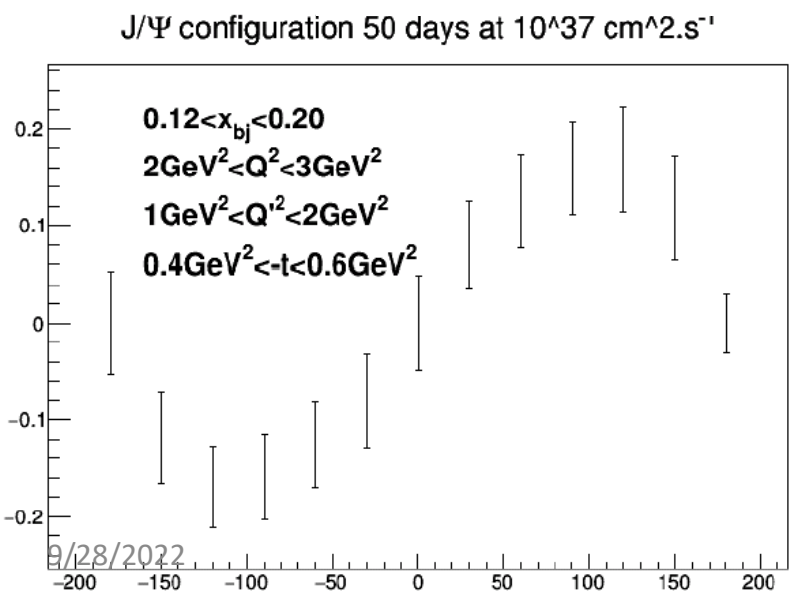


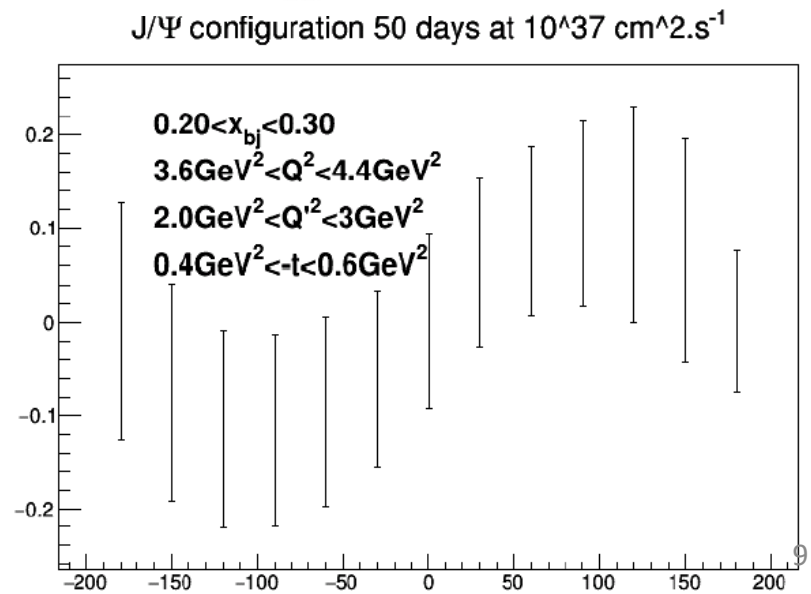

Iron wall 1
Ch 1 +
Ch 1 -
Reference =
Magnet
Ch 2 +
Y
X
Z
Ch 2 -


Iron wall 2
Ch 3 -
Ch 3 +
Reference =
Magnet
Ch 4 +
Y
X
Z
Ch 4 -

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

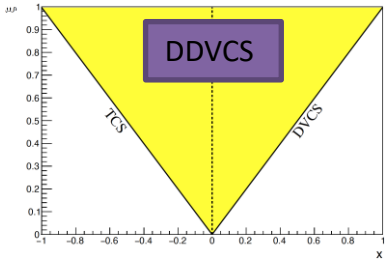




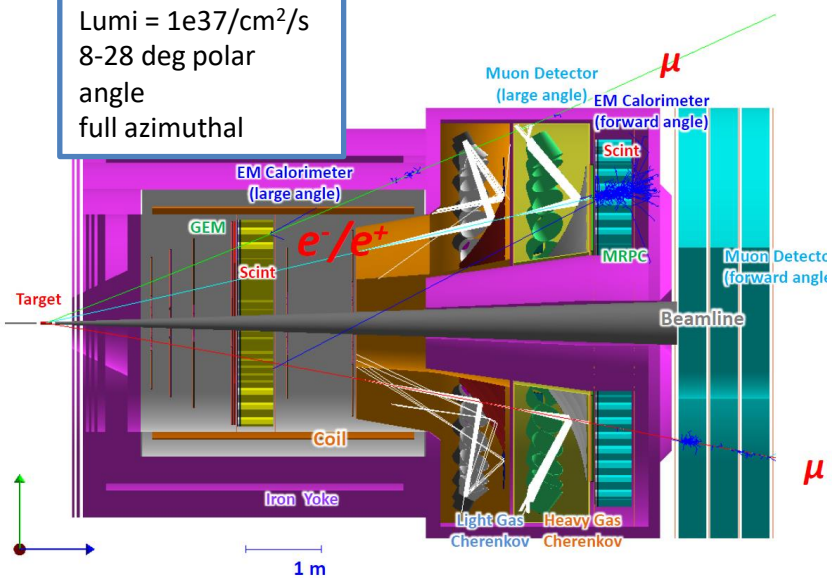


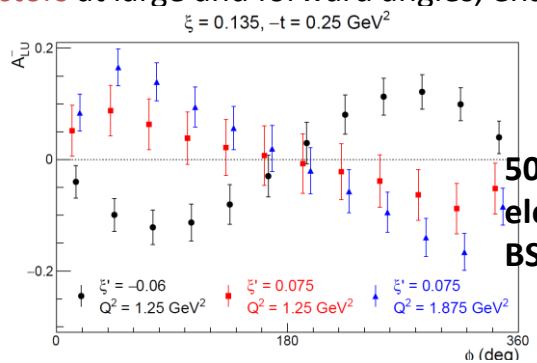
Double Deeply Virtual Compton Scattering with SoLID at JLab 12GeV

- DDVCS explores wide off-axis kinematic region of GPDs, beyond DVCS and TCS. The exclusive reaction has about 100 times smaller crosssection than DVCS and thus needs high luminosity and large acceptance.
- The SoLID apparatus completed with muon detectors at large and forward angles, enables DDVCS measurements with both polarized electr

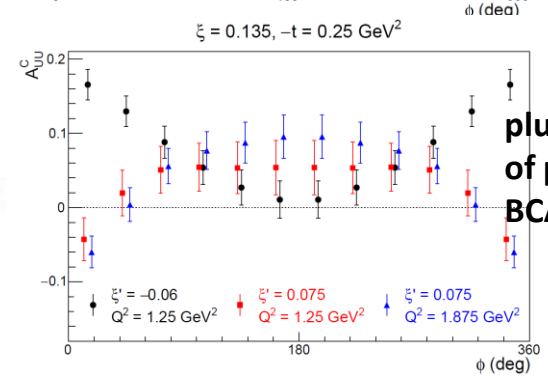


Lumi = 1e37/cm^2/s
8-28 deg polar angle
full azimuthal

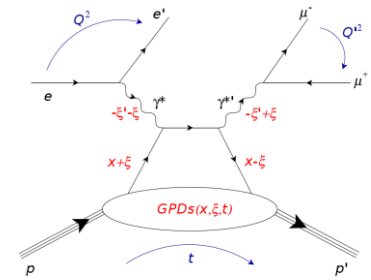


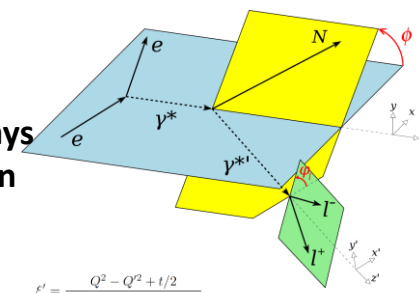


50 days of electron BSA



plus 50 days of positron BCA



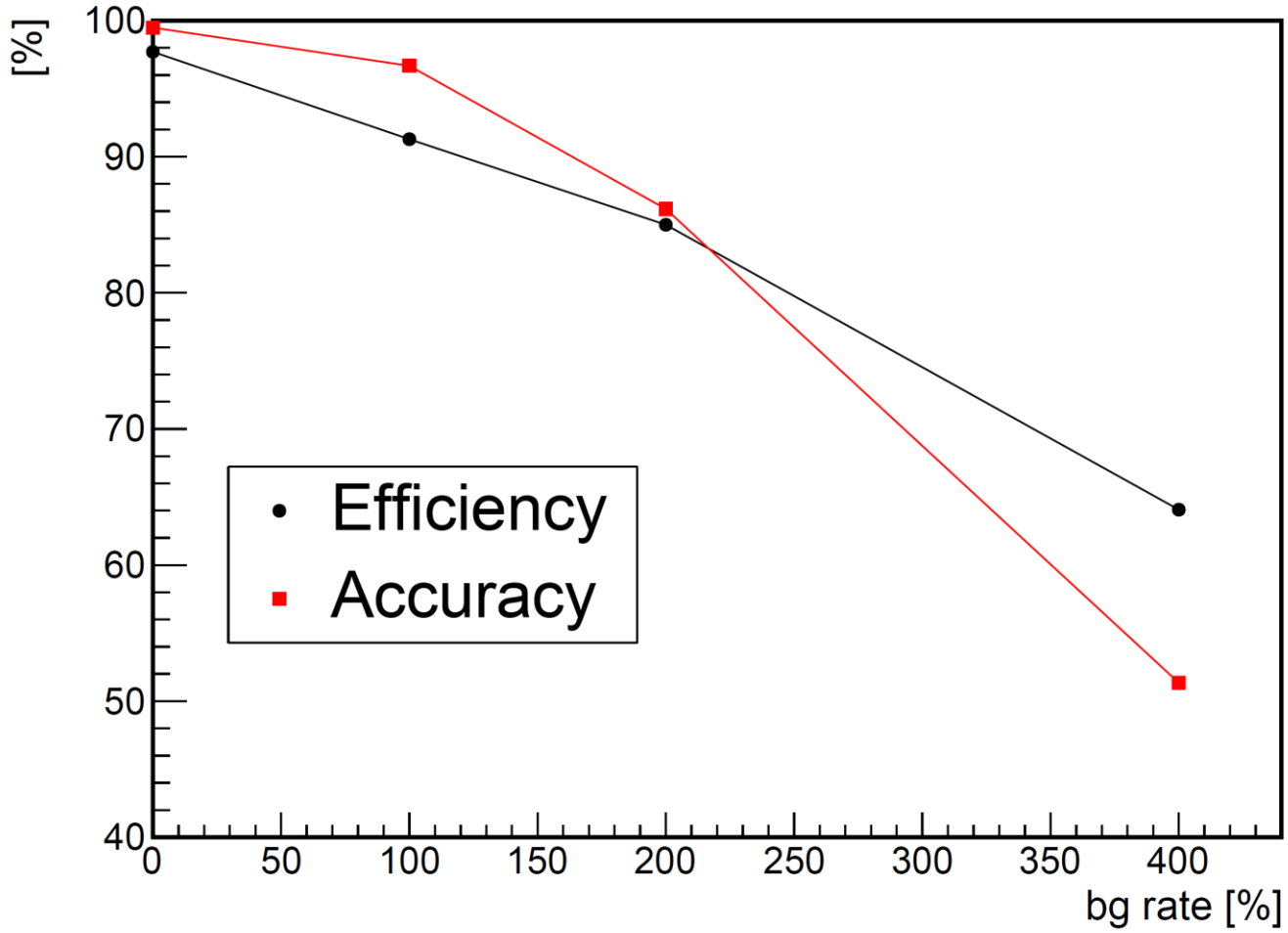


$$\xi' = \frac{Q^2 - Q'^2 + t/2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

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

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.**)

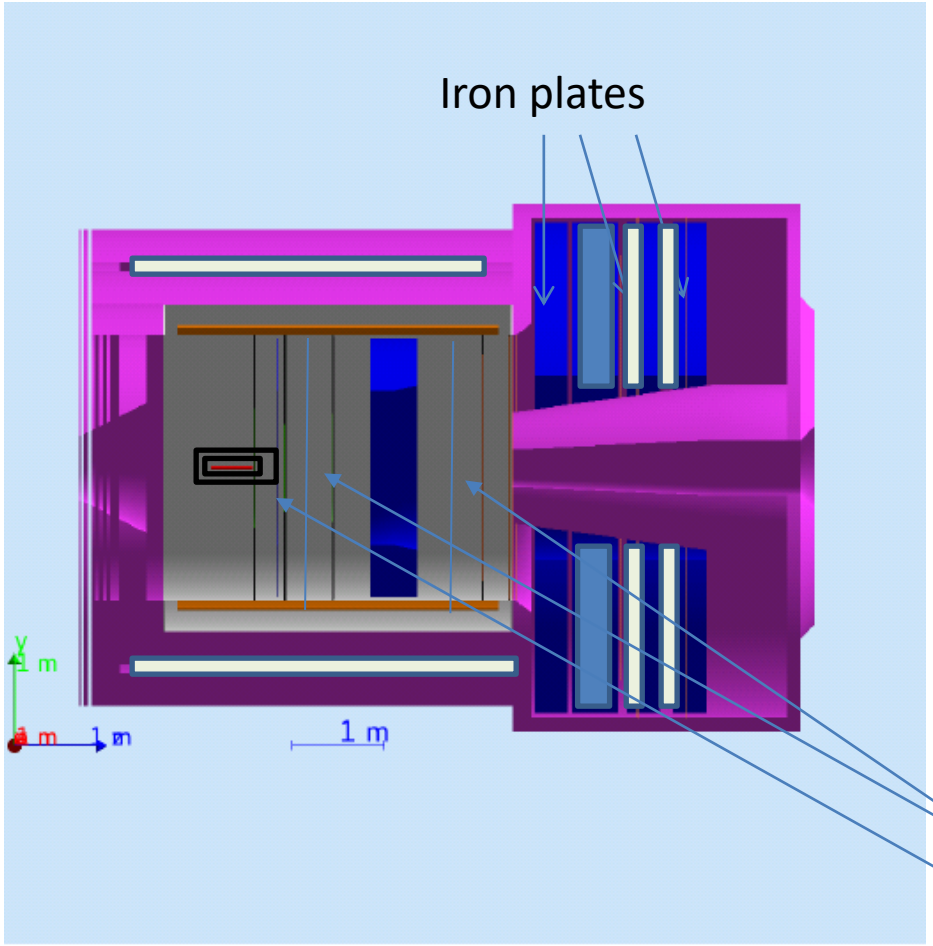
Higher luminosity J/Psi setup tracking study



Weizhi Xiong

Simple Kalman filter tracking

Dedicated setup



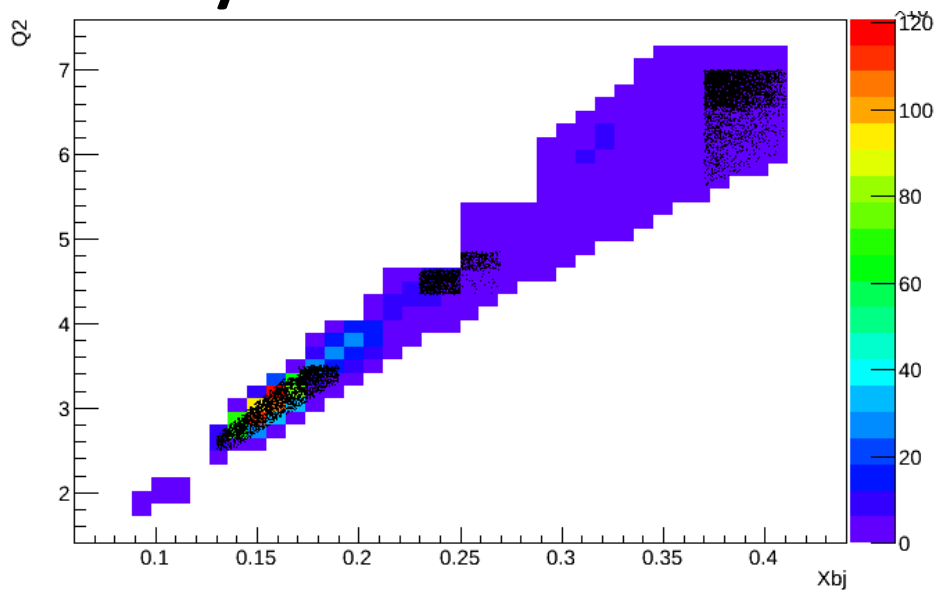
- Target moved 2m from Jpsi position inside and switch to 45 cm target
- Iron plate from 3rd layer yoke in front and behind calorimeter

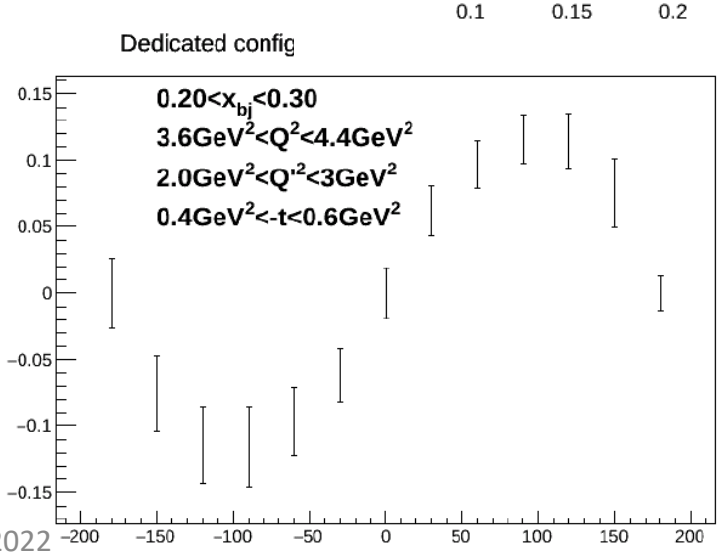
- Remove Gas Cerenkov

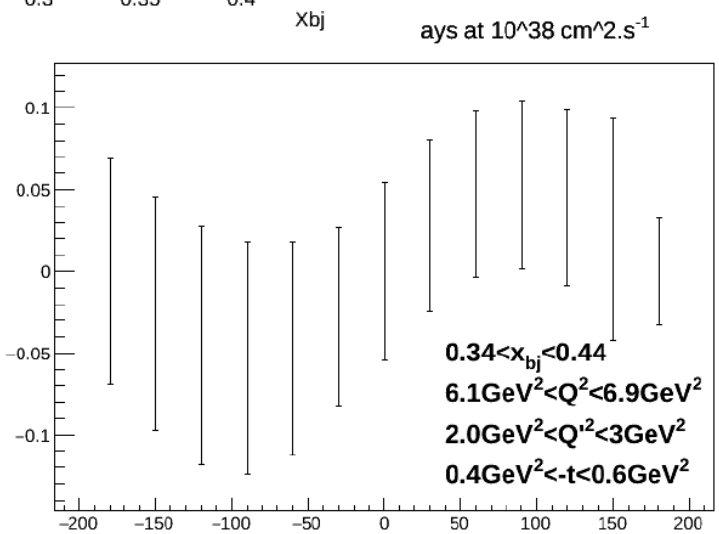
- Try to reach 10^{38} $cm^{-2}s^{-1}$
- 30 uA on 15 cm target (typical run in Hall A no beam dump upgrade required)

- 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} $cm^{-2}s^{-1}$





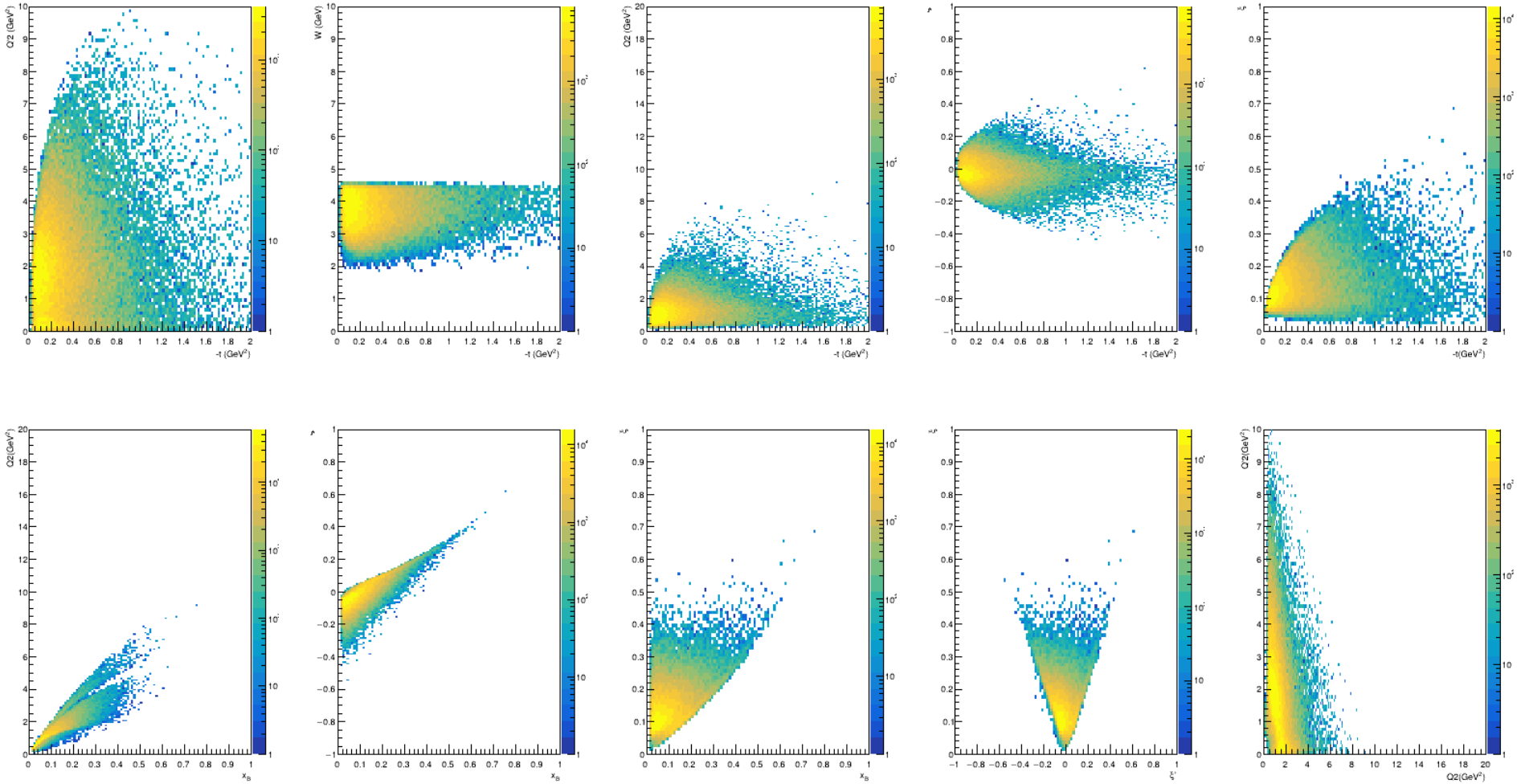


Higher luminosity ?

- Current could go up to 80 uA
- Target length up to 1 meter (~1.8 10^39 $cm^{-2}s^{-1}$)
- 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

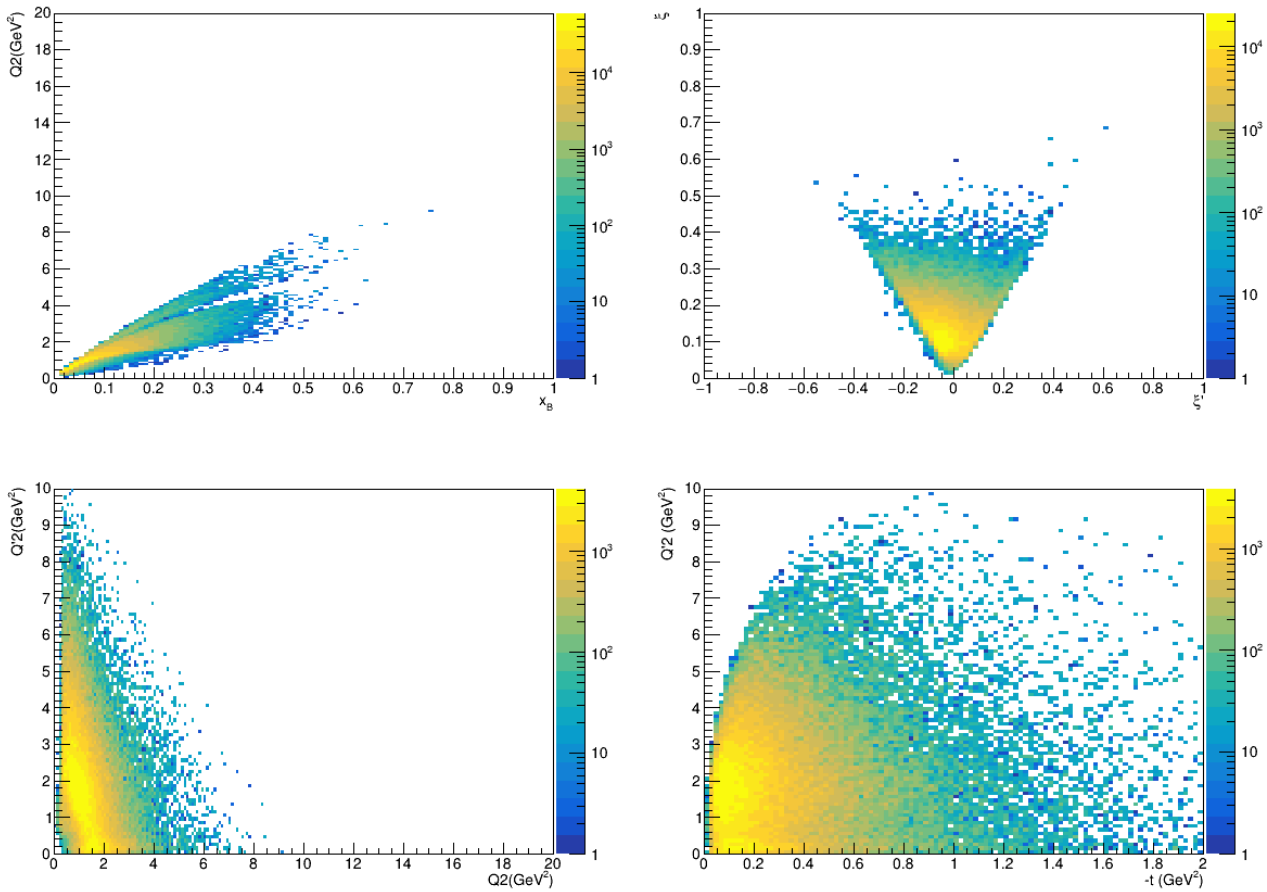
6. 10^38 $cm^{-2}s^{-1}$
Technically doable mostly matter of cost

Kinematical coverage 11 GeV



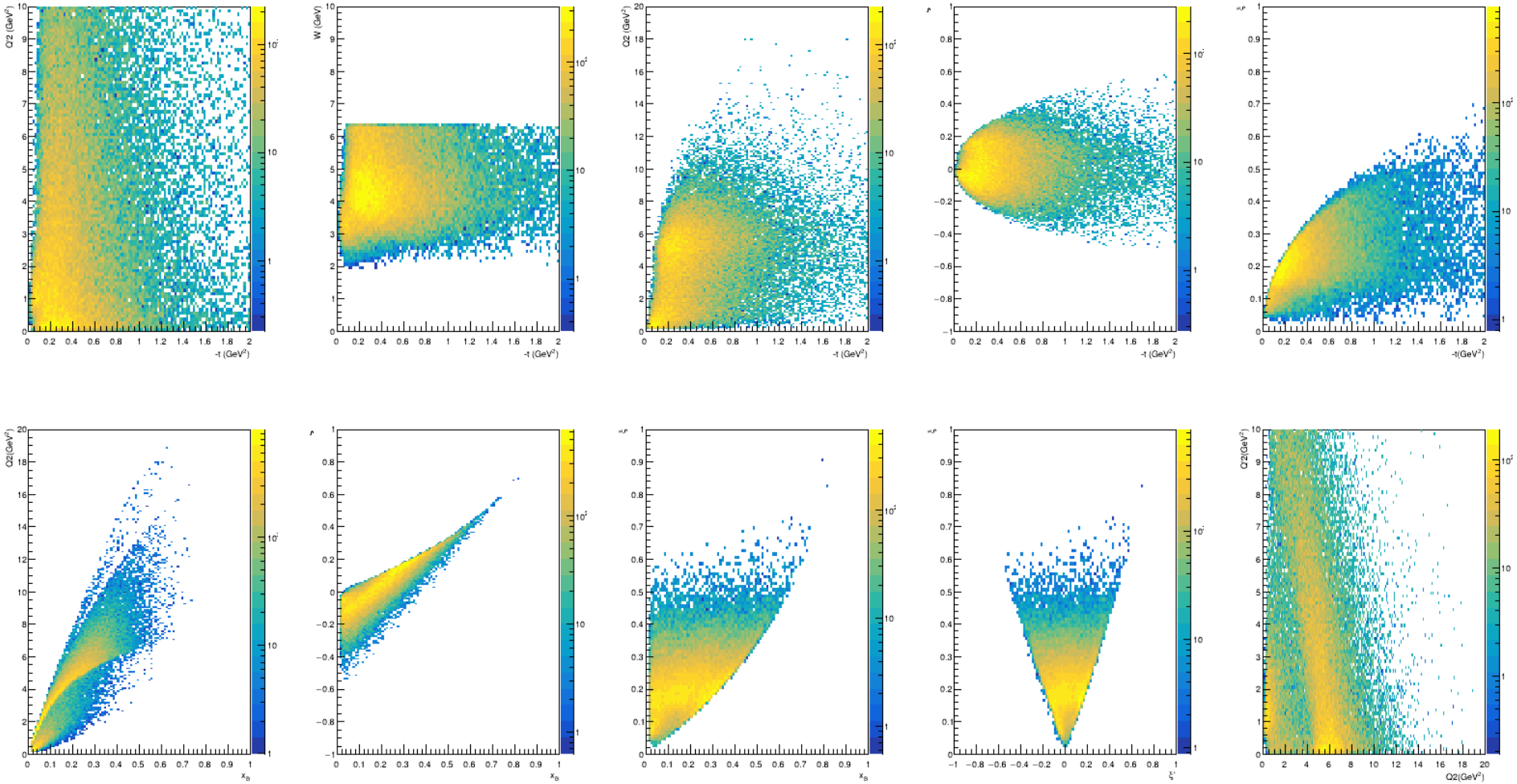
Zhiwen Zhao (GRAPE)

Kinematical coverage 11 GeV



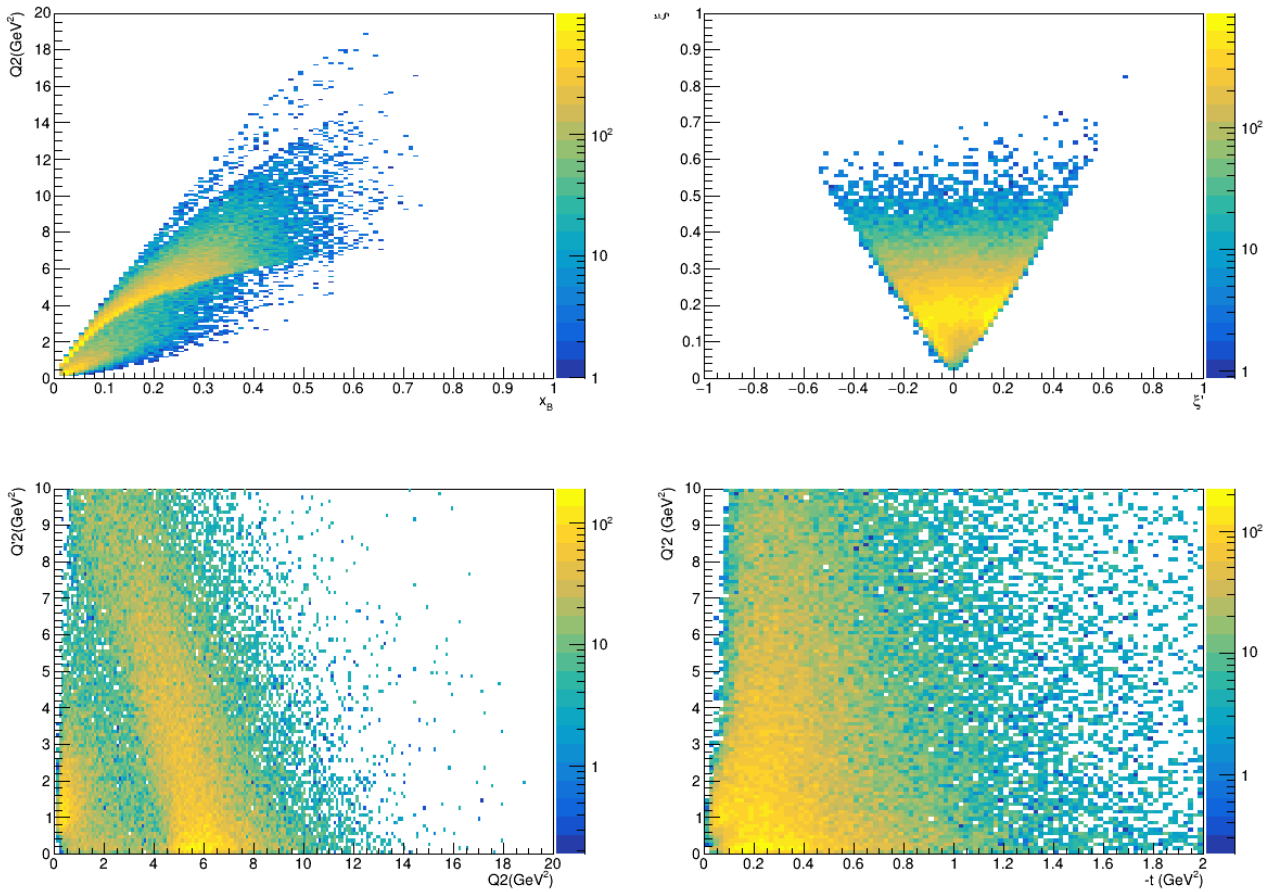
Zhiwen Zhao (GRAPE)

Kinematical coverage 22 GeV



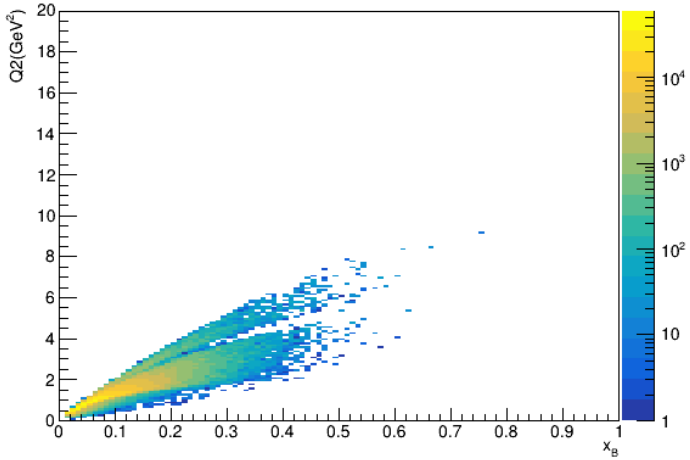
Zhiwen Zhao (GRAPE)

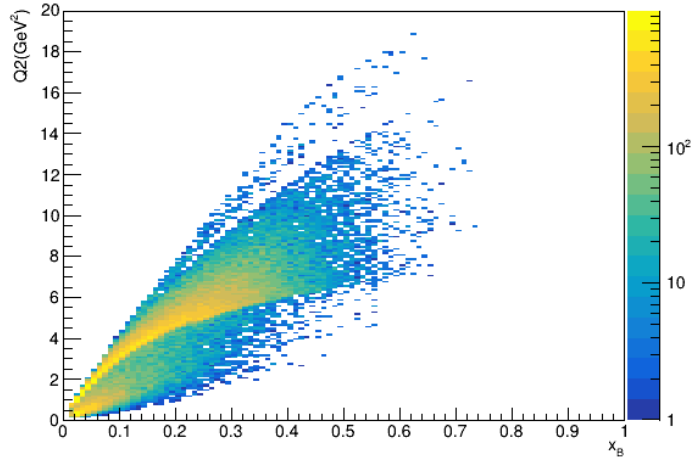
Kinematical coverage 22 GeV

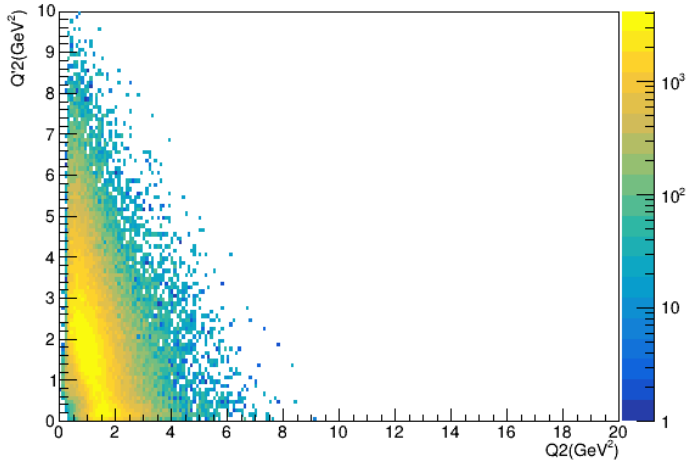


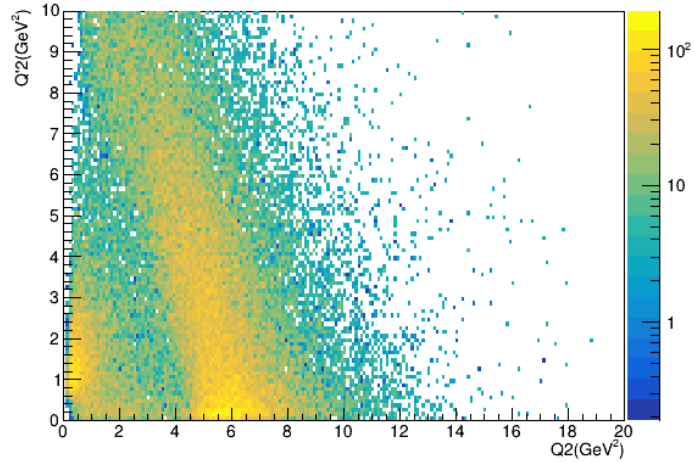
Zhiwen Zhao (GRAPE)

11 GeV vs 22 GeV

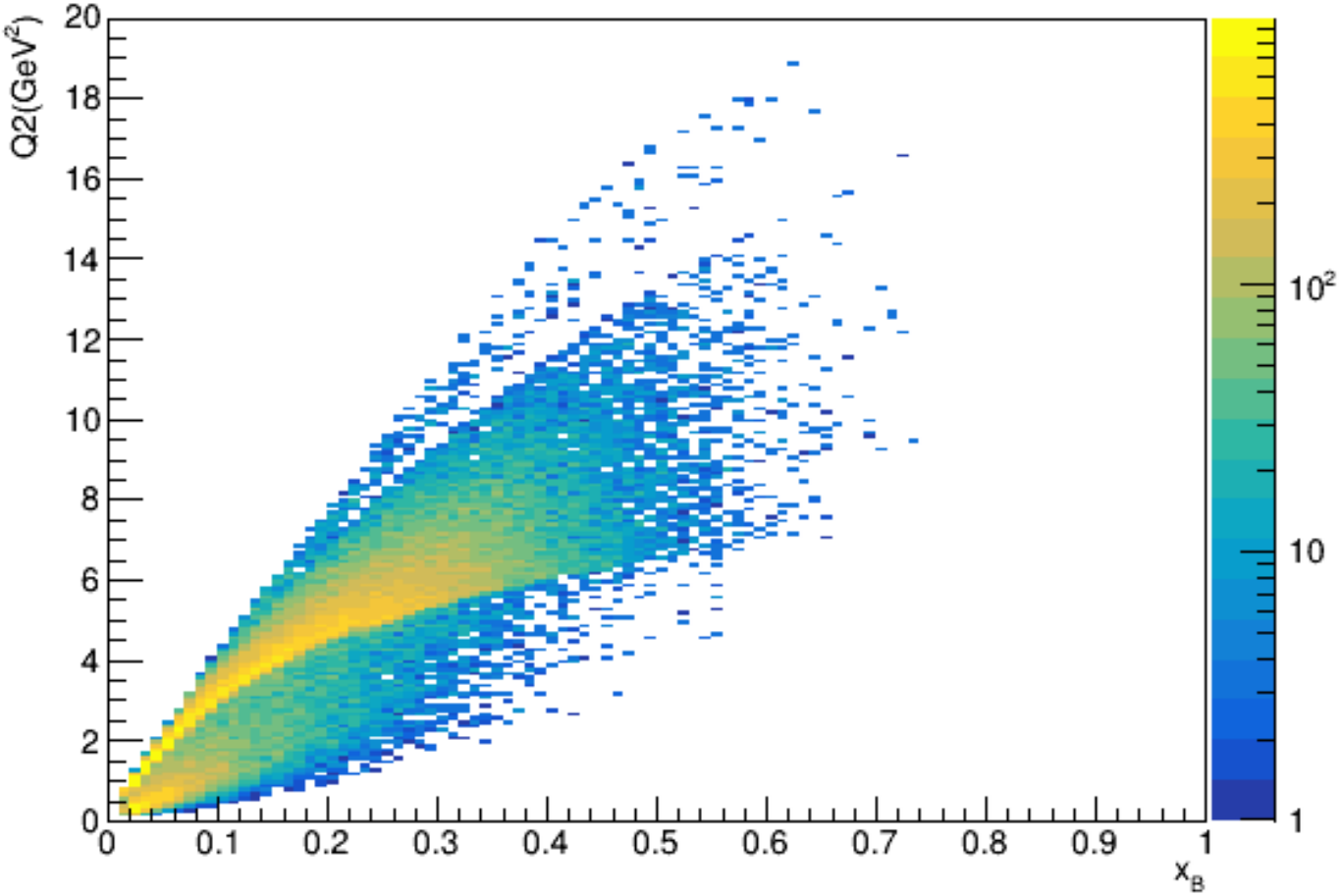


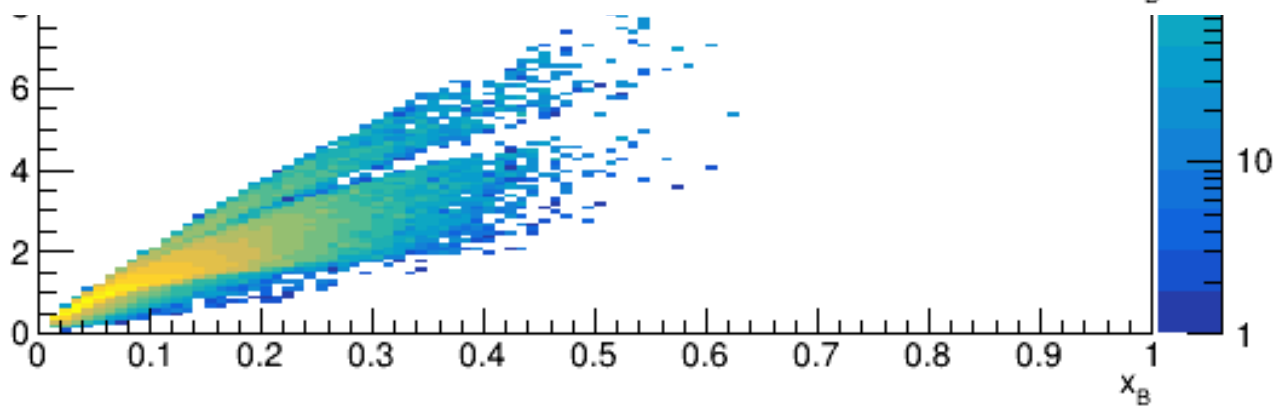






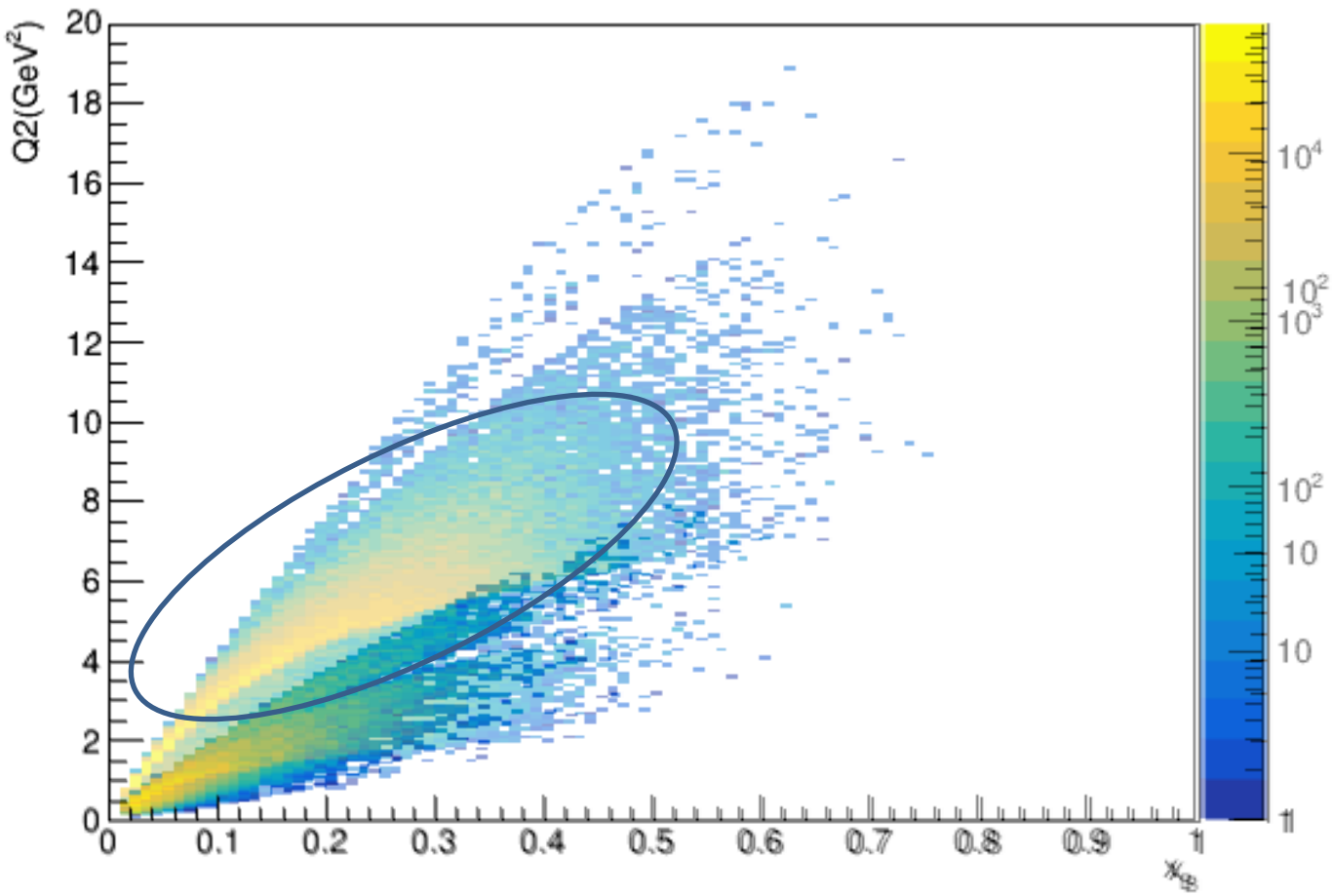
Zhiwen Zhao (GRAPE)





Zhiwen Zhao (GRAPE)

11 GeV vs 22 GeV



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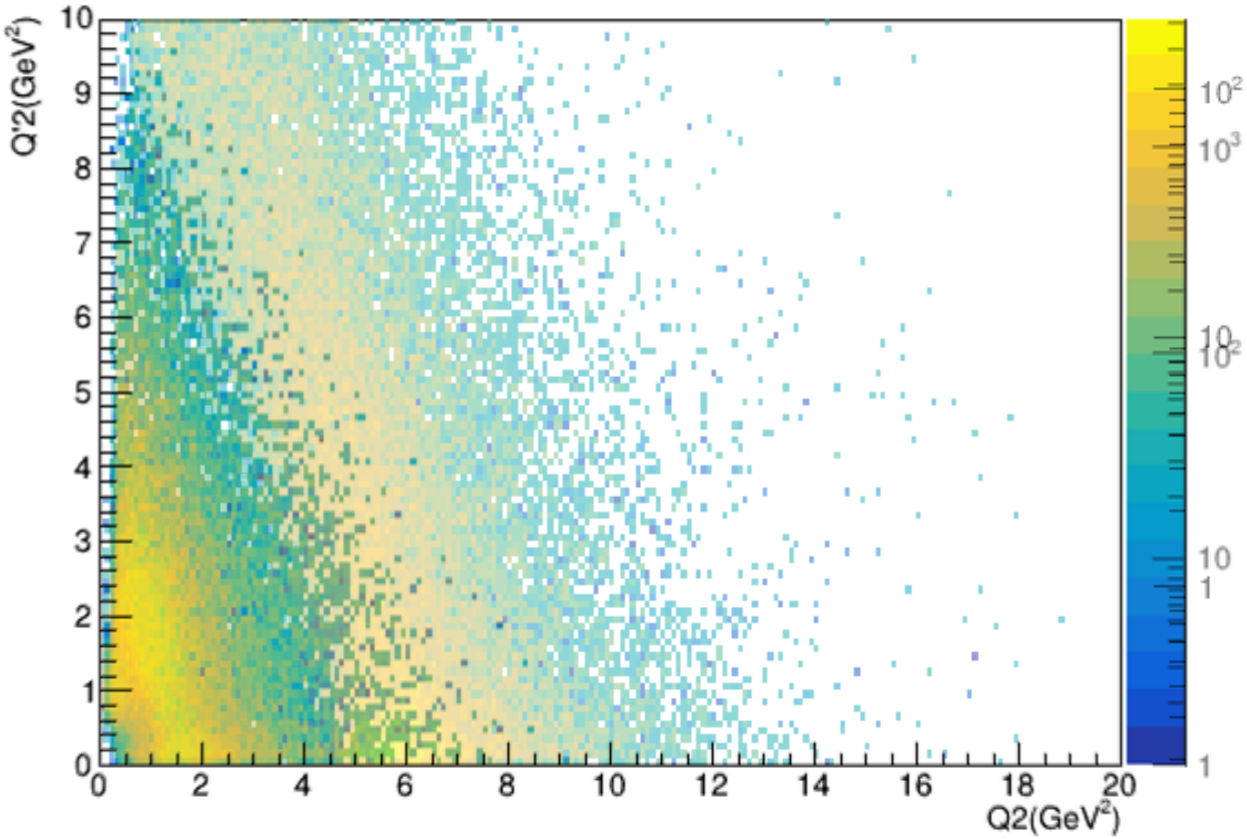
11 GeV vs 22 GeV



Much better Q2 Q'2 coverage

Want Q2 and Q'2 large enough for factorization

Zhiwen Zhao (GRAPE)

Quick numbers for J/Psi settings

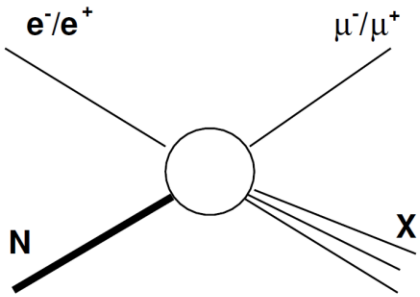
50 days at 10^37

Beam energy	e-mu-mu+	pmu-mu+
11	180156	1.37175e+06
22	51600	2.75867e+06

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

Charged Lepton Flavor Violation ($e^+ \to \mu^+$)



$$e^+ + N \to \mu^+ + X$$

Fig. 3. The SoLID J/Ψ configuration with muon detectors [28]. Other sub-detectors are labeled.

- Low center of mass energy but high luminosity:

$$\sqrt{s} \sim 4.5 \text{ GeV}$$
$$\mathcal{L} \sim 10^{36} \text{ - } 10^{39} \text{ cm}^{-2} \text{ s}^{-1}$$

- Detectors should be equipped with muon detectors and a good tracker. Proposed SoLID spectrometer meets these requirements

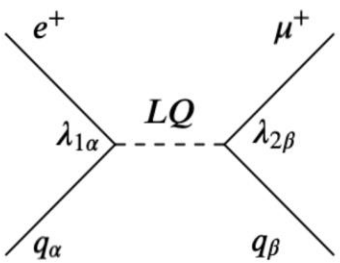
- High luminosity will allow for substantial improvement over HERA limits on CLFV.

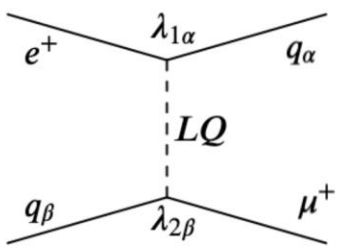
- For $\mathcal{L} \sim 10^{38}\ cm^{-2}s^{-1}$ one can expect two to three orders of magnitude improvement over HERA.

Yulia Furletova
and Sonny Mantry

Charged Lepton Flavor Violation via Leptoquarks

- Convenient to study CLFV in Leptoquark framework which mediates CLFV at tree-level:





$$\sigma^{e^+p}_{F=0} = \sum_{\alpha,\beta} \frac{s}{32\pi}\left[\frac{\lambda_{1\alpha}\lambda_{2\beta}}{M^2_{LQ}}\right]^2 \int dx \int dy \left\{ x q_\alpha(x, xs) f(y) + x\bar{q}_\beta(x, -u) g(y) \right\}$$

$$\sigma^{e^+p}_{|F|=2} = \sum_{\alpha,\beta} \frac{s}{32\pi}\left[\frac{\lambda_{1\alpha}\lambda_{2\beta}}{M^2_{LQ}}\right]^2 \int dx \int dy \left\{ x\bar{q}_\alpha(x, xs) f(y) + q_\beta(x, -u) g(y) \right\}$$

- 14 LQ states. Positron beam can help disentangle F=0 and |F|=2 LQ states. Polarized beams can help distinguish between left-handed and right-handed LQs.

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
S_0^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	λ_L	1/2
				$e_L^- u_L \to \nu_\ell d$	$-\lambda_L$	1/2
S_0^R	0	2	$-1/3$	$e_R^- u_R \to \ell^- u$	λ_R	1
$\tilde{S}_0^R$	0	2	$-4/3$	$e_R^- d_R \to \ell^- d$	λ_R	1
S_1^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	$-\lambda_L$	1/2
				$e_L^- u_L \to \nu_\ell d$	$-\lambda_L$	1/2
			$-4/3$	$e_L^- d_L \to \ell^- d$	$-\sqrt{2}\lambda_L$	1
$V_{1/2}^L$	1	2	$-4/3$	$e_L^- d_R \to \ell^- d$	λ_L	1
$V_{1/2}^R$	1	2	$-1/3$	$e_R^- u_L \to \ell^- u$	λ_R	1
			$-4/3$	$e_R^- d_L \to \ell^- d$	λ_R	1
$\tilde{V}_{1/2}^L$	1	2	$-1/3$	$e_L^- u_R \to \ell^- u$	λ_L	1

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
V_0^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	λ_L	1/2
				$e_R^+ d_L \to \bar{\nu}_\ell u$	λ_L	1/2
V_0^R	1	0	$+2/3$	$e_L^+ d_R \to \ell^+ d$	λ_R	1
$\tilde{V}_0^R$	1	0	$+5/3$	$e_L^+ u_R \to \ell^+ u$	λ_R	1
V_1^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	$-\lambda_L$	1/2
				$e_R^+ d_L \to \bar{\nu}_\ell u$	λ_L	1/2
			$+5/3$	$e_R^+ u_L \to \ell^+ u$	$\sqrt{2}\lambda_L$	1
$S_{1/2}^L$	0	0	$+5/3$	$e_R^+ u_R \to \ell^+ u$	λ_L	1
$S_{1/2}^R$	0	0	$+2/3$	$e_L^+ d_L \to \ell^+ d$	$-\lambda_R$	1
			$+5/3$	$e_L^+ u_L \to \ell^+ u$	λ_R	1
$\tilde{S}_{1/2}^L$	0	0	$+2/3$	$e_R^+ d_R \to \ell^+ d$	λ_L	1

Crossection proportional to center of mass energy ~ factor 2 at 22 GeV

Yulia Furletova
and Sonny Mantry

Timeline / To do list

- Full analysis with tracking
- Dust off generator and complete physics simulation
- Muon detector simulation and design
- 12 GeV Proposal DDVCS J/Psi setup with muon detector
- Study impact of DDVCS on GPDs and D-term extraction
- Study of maximum luminosity achievable with dedicated setup
- Proposal for dedicated setup at 12 GeV ?
- Proposal for 22 GeV running with J/Psi setup

Conclusion

- DDVCS measurement can be do concurrently with J/psi experiment at 10^37 $cm^{-2}.s^{-1}$ with additional muon detectors outside of SoLID (doubles J/Psi statistics)
- Studying improved setup for 10^38 $cm^{-2}.s^{-1}$
- 22 GeV greatly enhance the kinematical reach, rates down by about factor of 3
- CLFV experiment can also run concurrently with DDVCS setup
- First step propose muons detector for J/Psi setup and study higher luminosity dedicated setup