GPD program with SoLID spectrometer

N and N* Structure with Hard Exclusive Process
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Outline

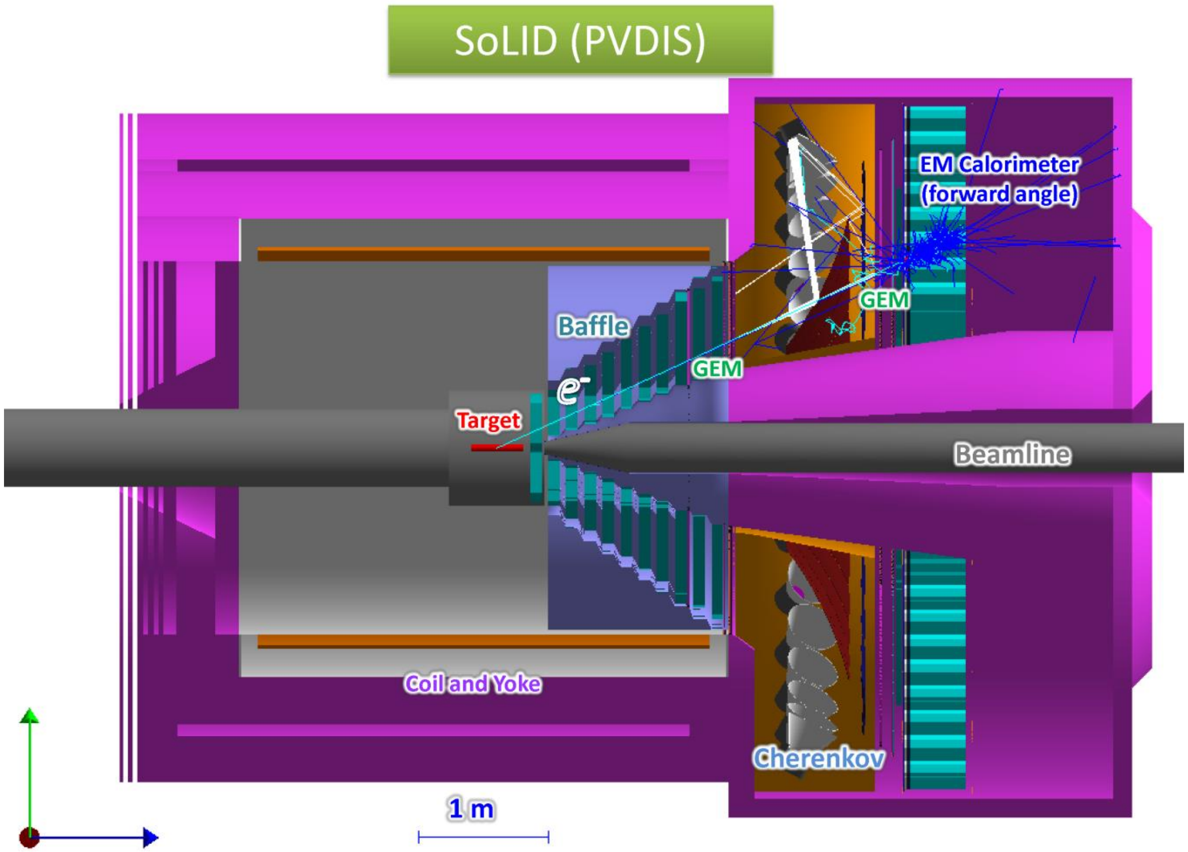
- SoLID overview
- Possible measurements
  - Deep Exclusive π^- Production using Transversely Polarized ^{3}He Target
  - Timelike Compton Scattering
- Double Deeply Virtual Compton Scattering
- Luminosity increase
- Conclusion

SoLID overview

- Solenoidal detector
- Designed for high luminosity
  - Forward GEM trackers $\theta(8^o - 17^o)$ and $\theta(18^o - 28^o)$
  - ϕ(full) Symmetric with solenoidal symmetry
- Hall A targets :
  - polarized Helium 3 10^{36} $cm^{-2}s^{-1}$)
  - LH2 LD2 15 cm (10^{37} $cm^{-2}s^{-1}$ at 3 uA) and 40 cm cryotargets (~ 4.10^{38} $cm^{-2}s^{-1}$ at 60 uA)
  - Polarized NH3 target (50 to 100 nA : 10^{36} $cm^{-2}s^{-1}$)

http://hallaweb.jlab.org/12GeV/SoLID/

PVDIS configuration



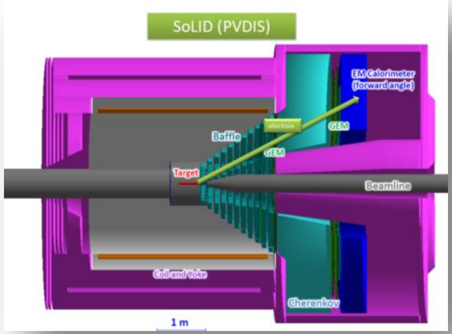
- Parity violation measurement
- Physics beyond standard model
- Parity violation in Deeply Inelastic Scattering
- Up to 450 KHz of trigger rate
- inclusive electron scattering
- 30 separates sectors

gives a rate of 15 KHz per sector

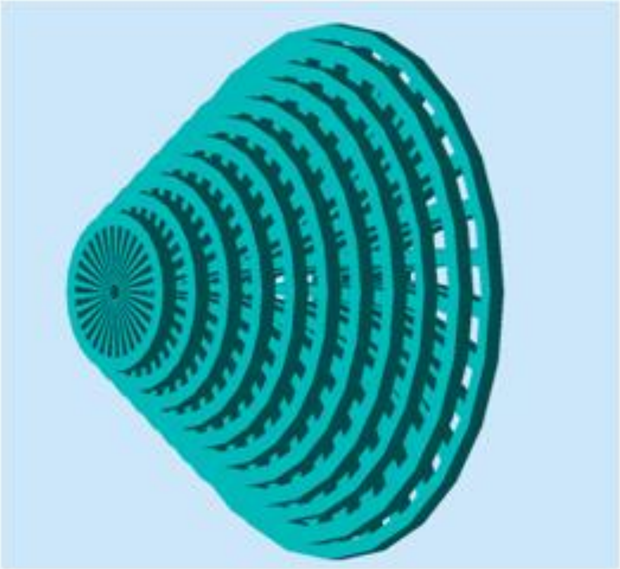
GEM trackers

Baffles

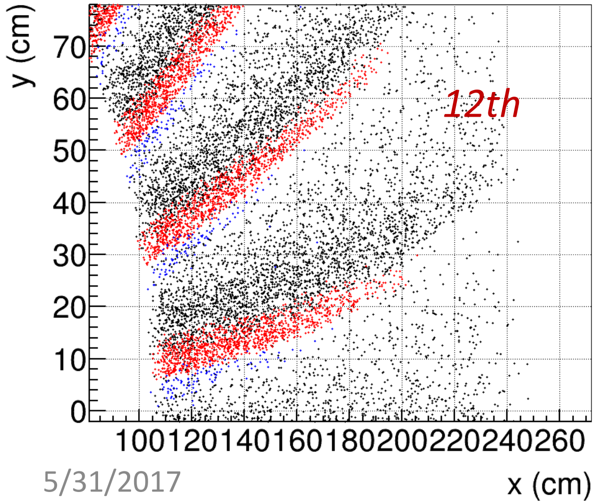
Baffle



◆ PVDIS Baffle:



hits before FAEC (black(-),red(0),blue(+))



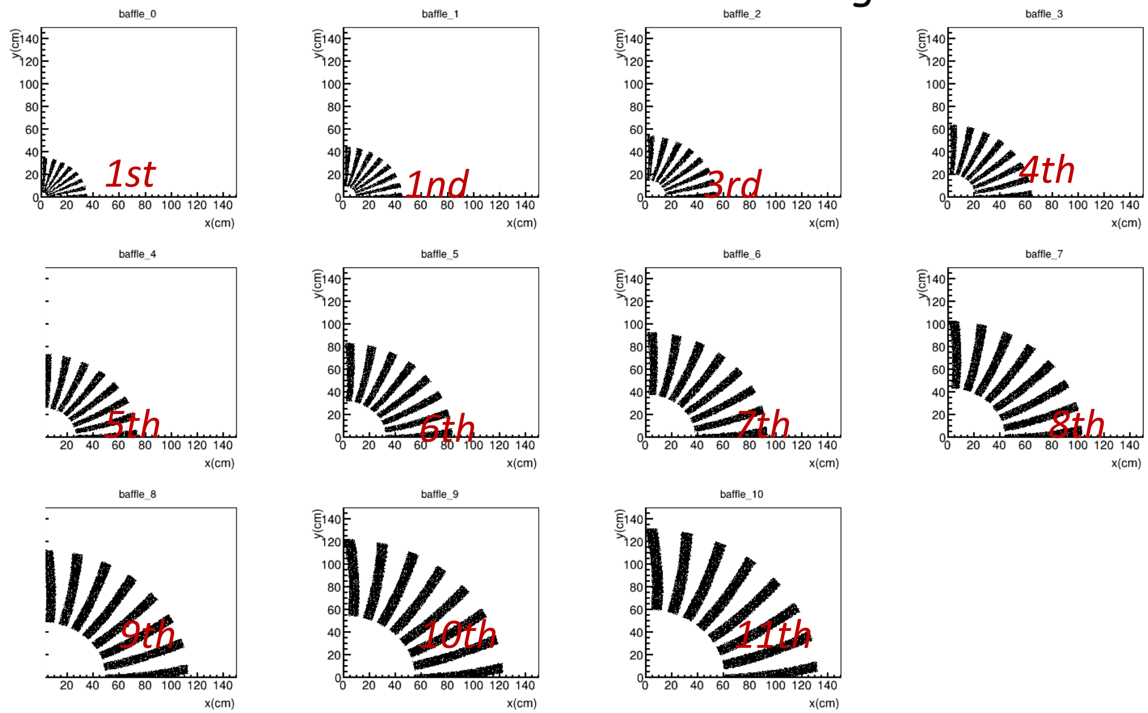
Goals:

→ For PVDIS only

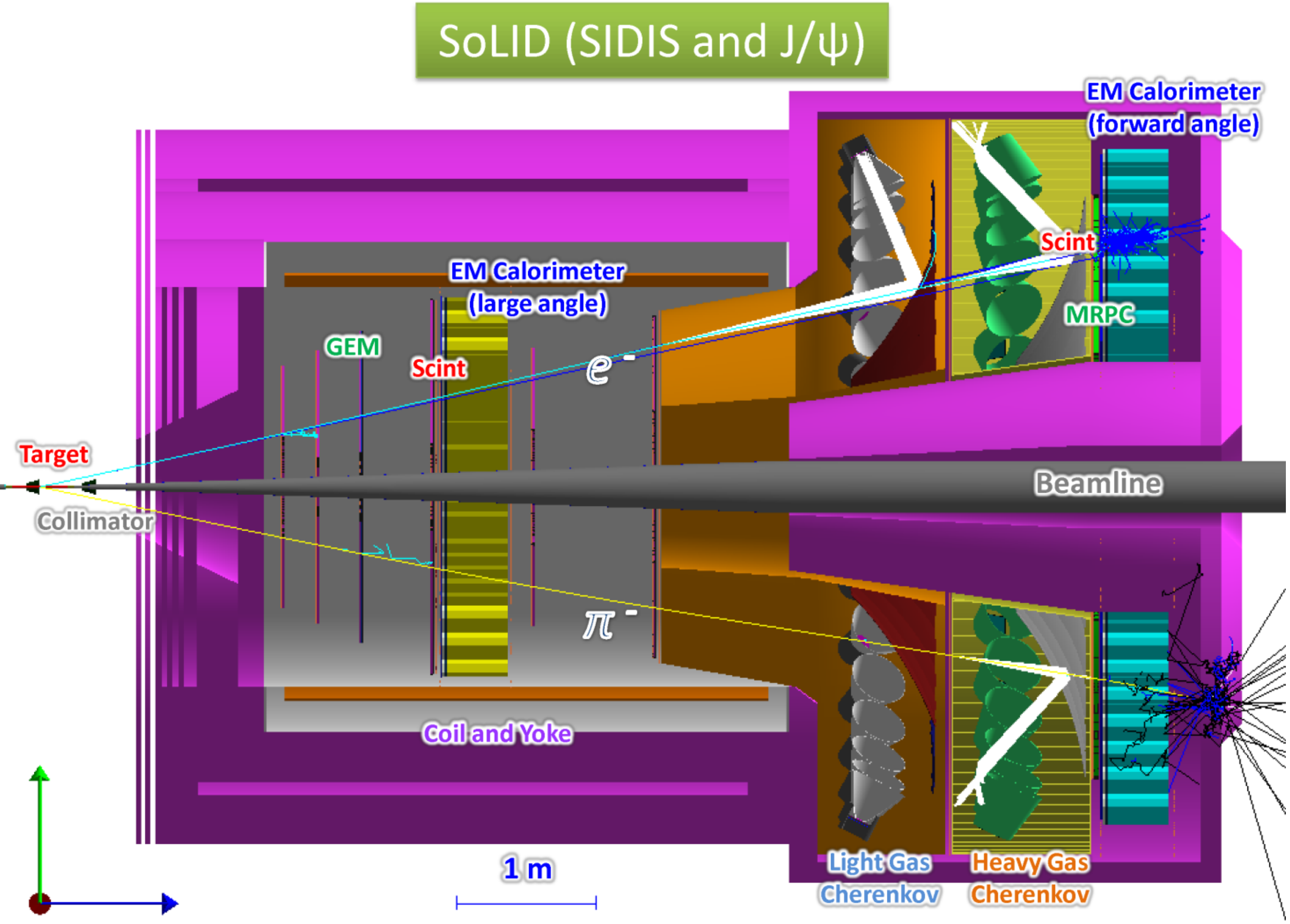
→ 11 layers of 9cm thick lead and one layer of 5cm lead

→ Right after the target to block photons, pions and secondary particles.

→ Follow charge particle bending in the field, preserve the same azimuthal slice and block line of sight.



SIDIS J/Psi configuration



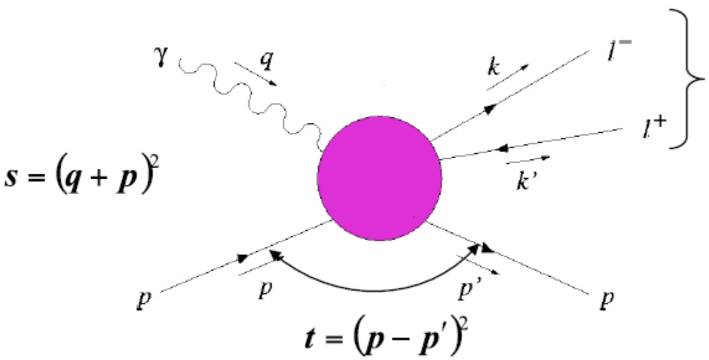
- SIDIS on He3 and NH3
- J/psi thresold on 15 cm LH2
- Angular coverage
- Additionnal PID
  - Heavy gas cerenkov (pi/K)
  - MRPC TOF (80 ps)

Possible measurements

- Deep Exclusive π^- Production using Transversely Polarized ^3He Target (Huber (Regina), Ahmed (Regina) and Ye (ANL)) *PR12-10-006B*
- Timelike Compton Scattering (Zhao, Turonski, Boer) E12-12-006A
- Double Deeply Virtual Compton Scattering in dimuons channel

TCS (E12-12-006 Zhao, Boer, Turonski)

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

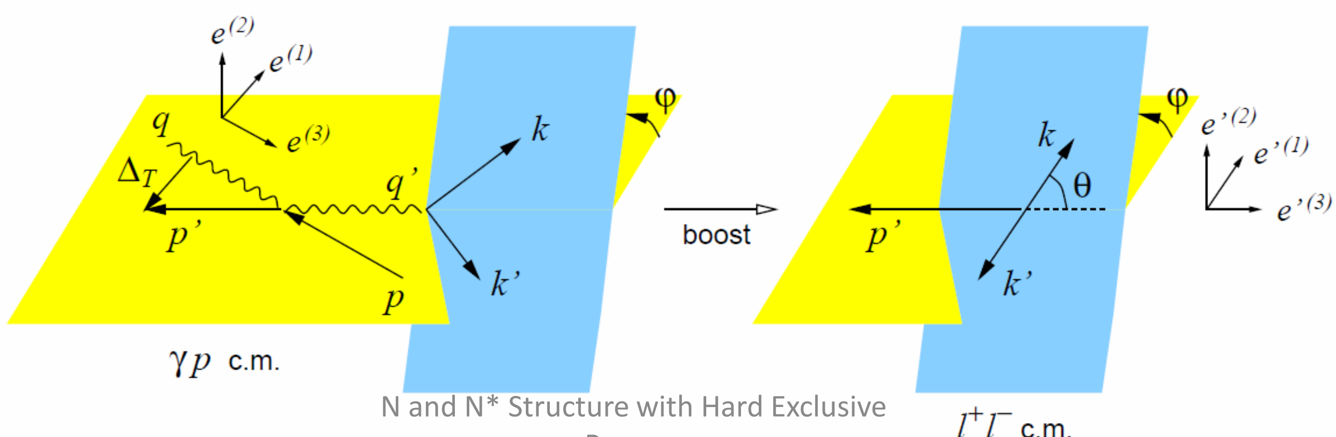


Hard scale

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

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

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



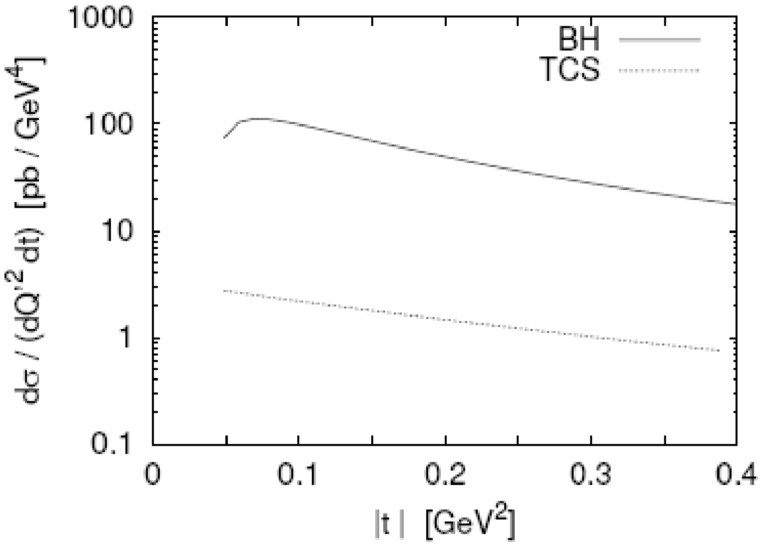
Timelike Compton Scattering (TCS)

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

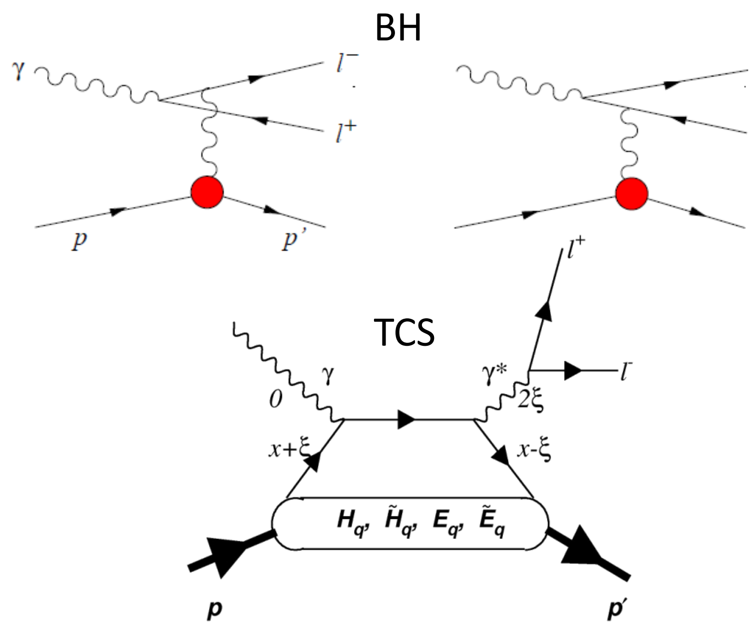
- Test spacelike-timelike correspondence and the universality of GPDs
  - Input for global analysis of Compton Form Factors
  - access through azimuthal asymmetry of lepton pair
- Explore GPDs of quarks and gluons at different kinematics

(Zhiwen Zhao, Duke)

TCS and Bethe-Heitler (BH) Interference



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

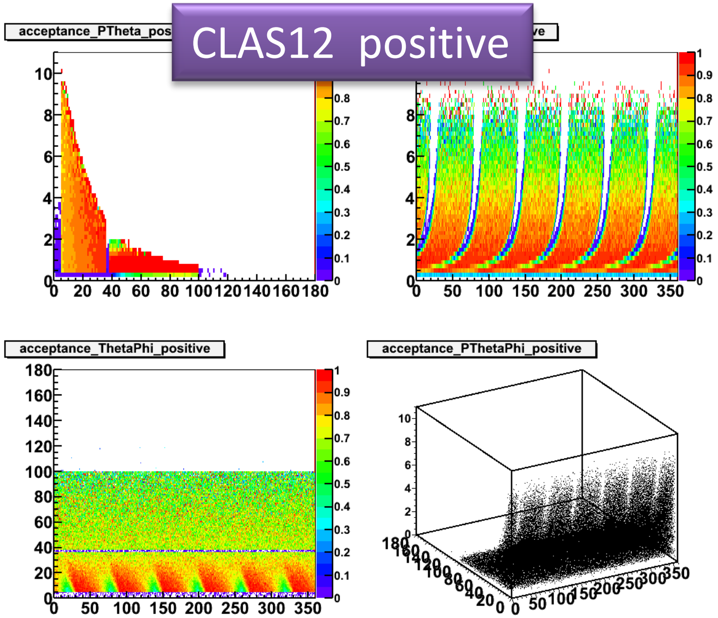


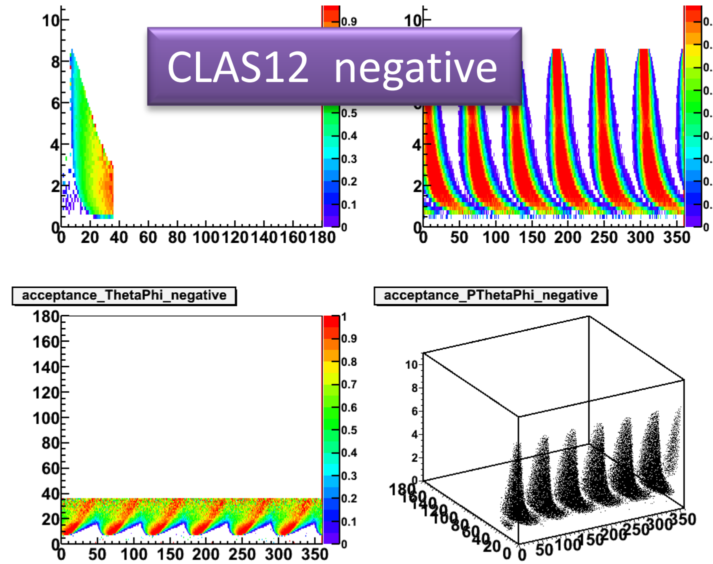
$$\frac{d\,\sigma^4}{dQ'^2\,dt\,d(\cos\theta)\,d\phi} = |BH|^2 + I(BH\cdot TCS) + |TCS|^2$$

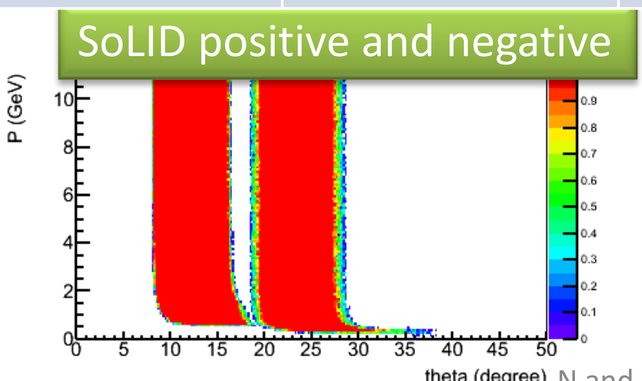
- For lepton charge conjugation, TCS and BH amplitudes are ***even***, while the interference term is ***odd***
- Therefore, direct access to interference term through angular distribution of the lepton pair (cosine and sine moments) (Zhiwen Zhao, Duke)

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	$10^{35}/cm^2/s$	$10^{37}/cm^2/s$





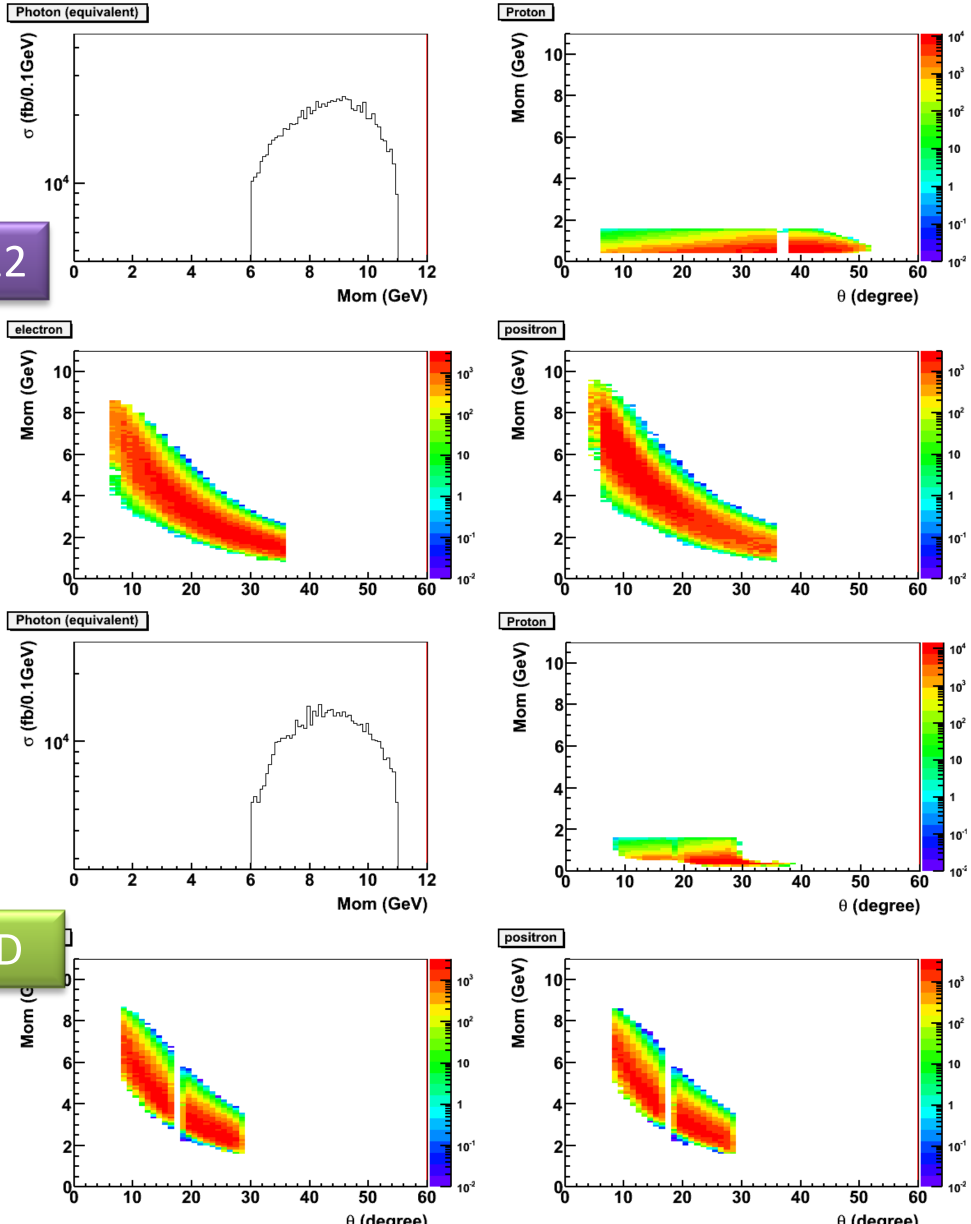


CLAS12 and SoLID: BH Detection (Lab Frame)

- 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

CLAS12

SoLID



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

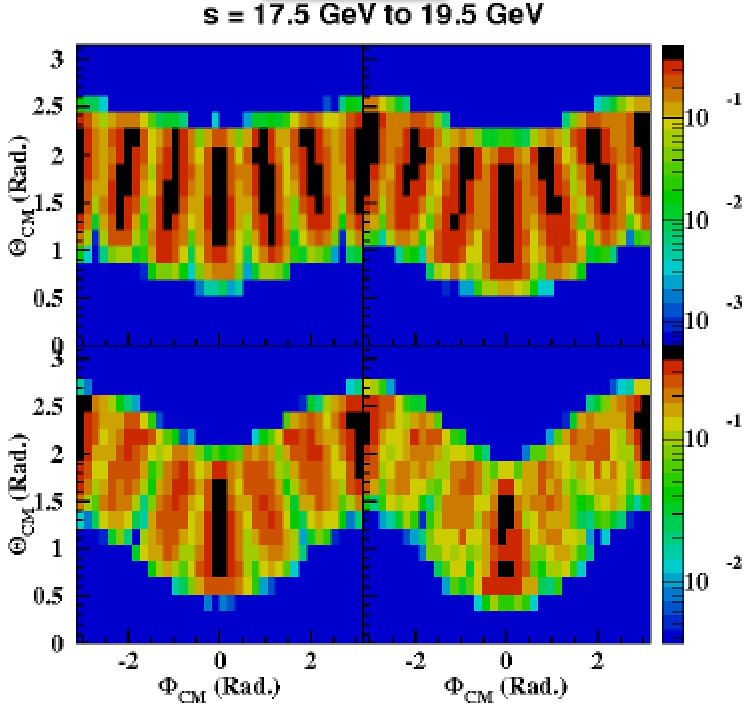
$4 GeV^2 < Q'2 < 9 GeV^2$

$17.5 GeV^2 < s < 19.5 GeV^2$

4 t-bins within $0.1 GeV^2 < t < 0.9 GeV^2$

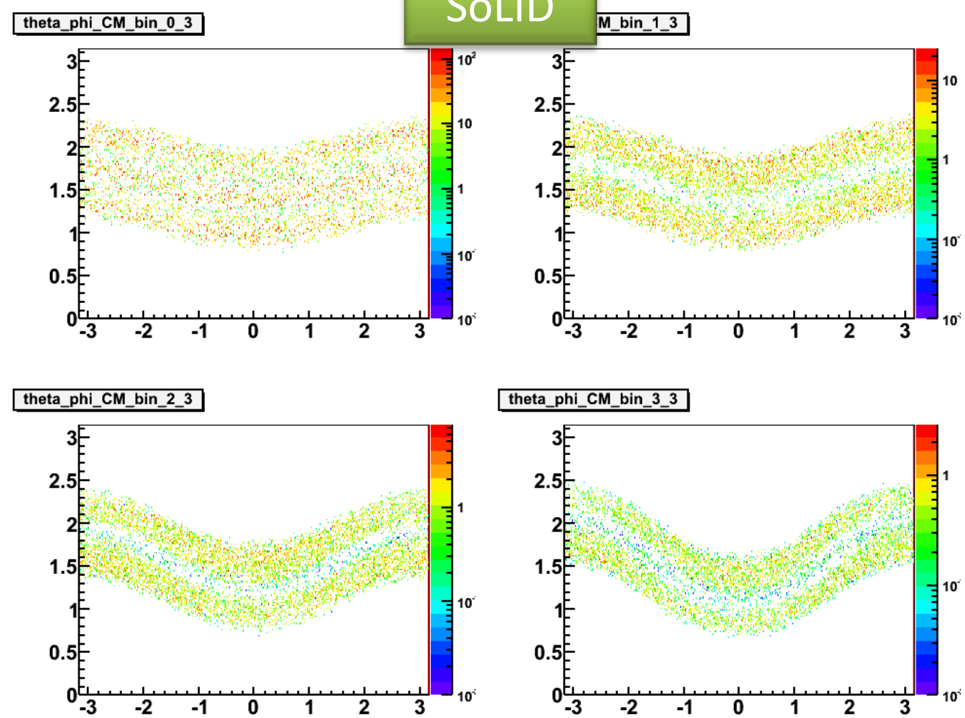
- CLAS12 has ϕ structure which has to be corrected by acceptance
- SoLID is smooth over ϕ, but has θ gap

CLAS12



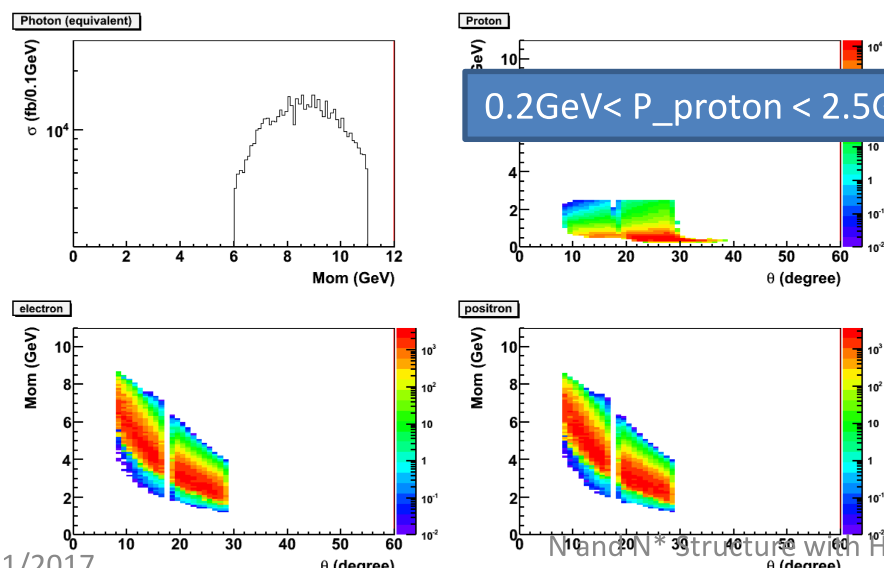
Accepted events for four t-bins.
The observable R' is integrated over the CLAS acceptance

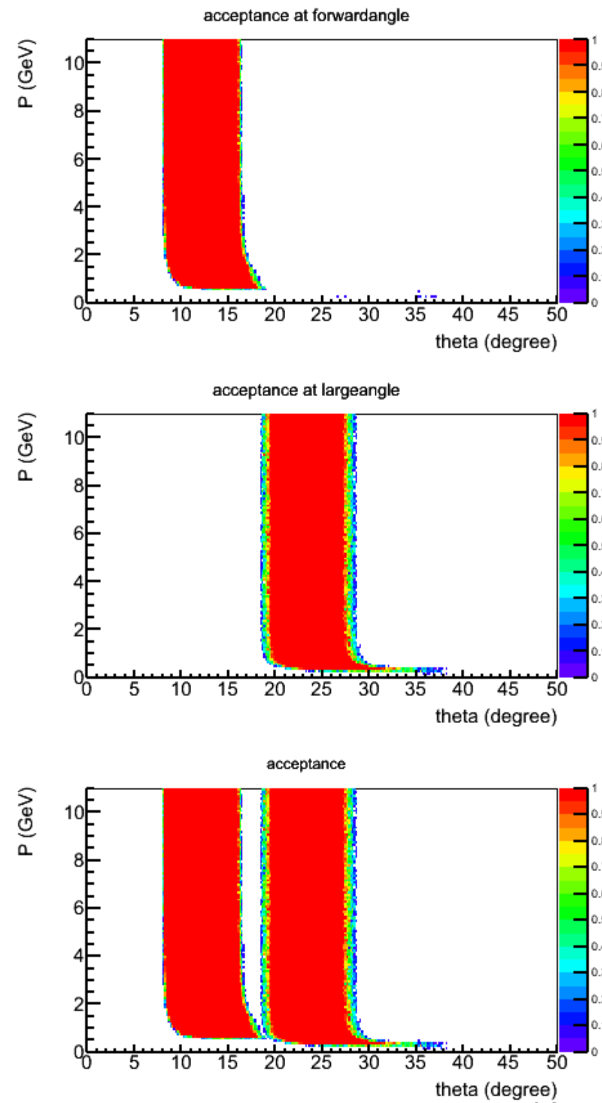
SoLID



SoLID JPsi and TCS

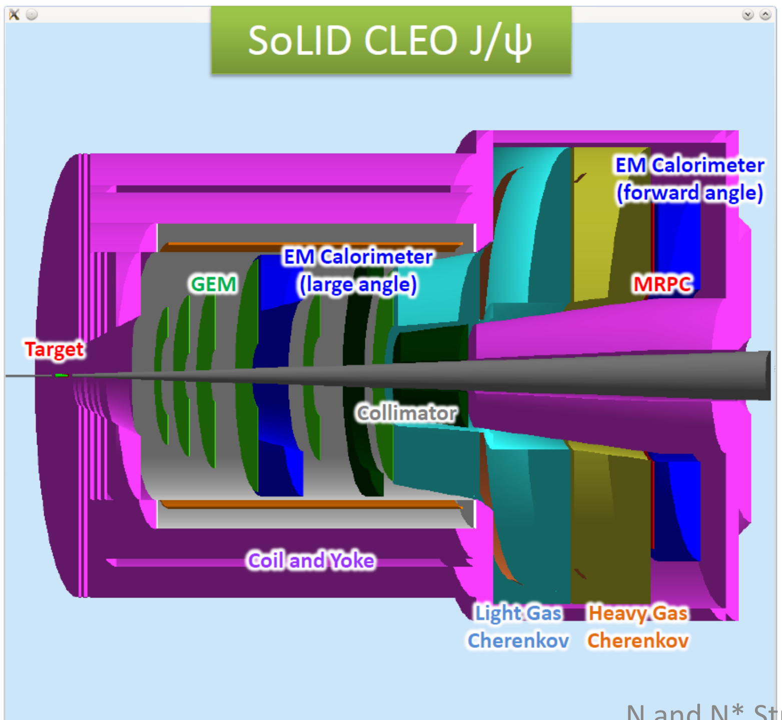
- JPsi setup
  - 15cm LH2 taget 300cm upstream from solenoid coil center.
  - 3uA current, 1e37/cm2/s luminosity for 50 days
  - forward angle coverage about 8-16 degree,
    large angle coverage about 17-28 degree
  - Trigger on scattered e- at forward angle and decay lepton pair at forward and large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

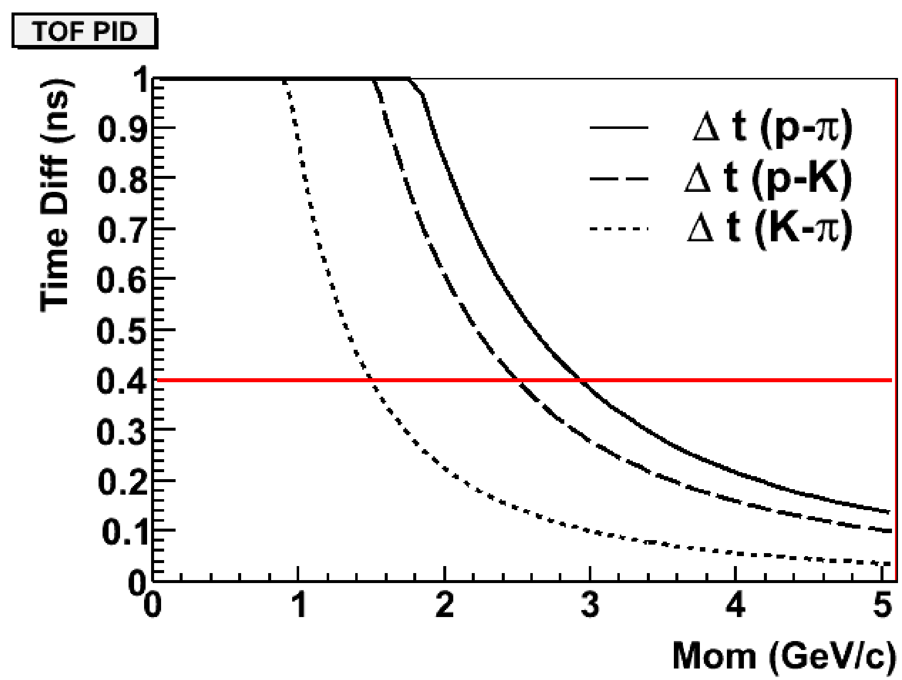




TOF at large angle

- 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

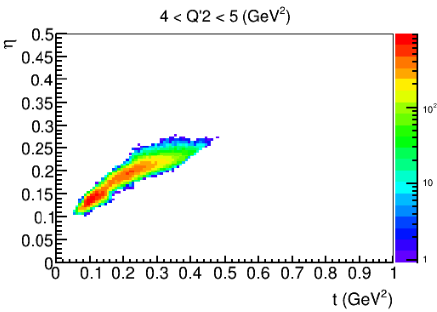


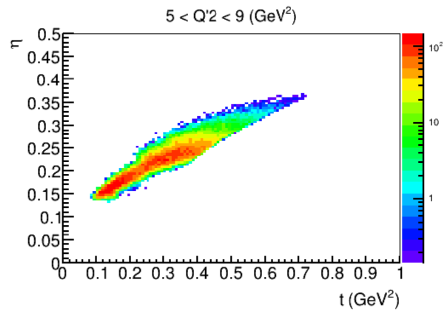


Zhiwen Zhao, Duke

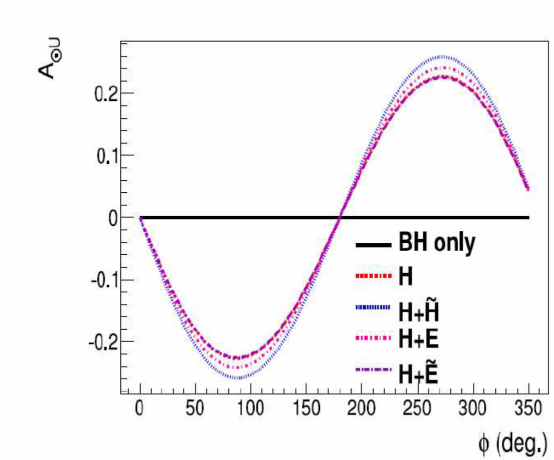
SoLID TCS Projection

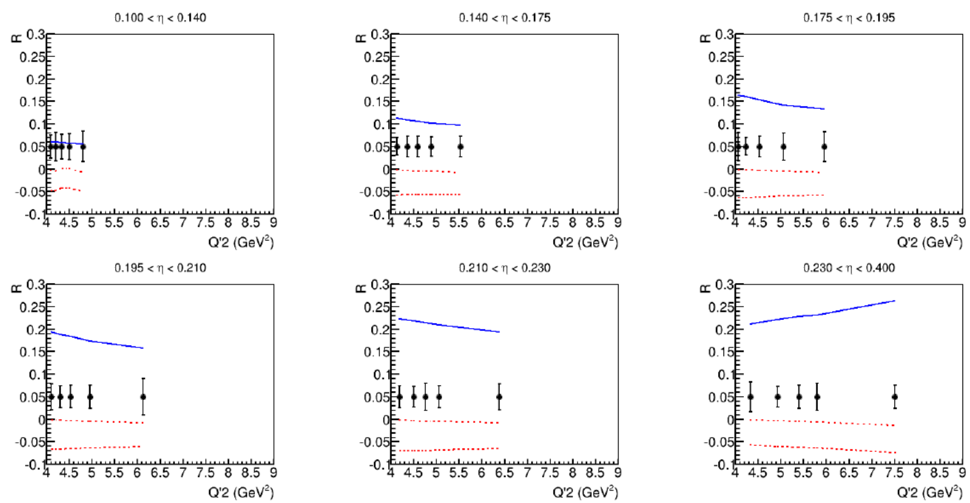
15cm LH_2 target, 3μA current, 1.2e37/cm^2/s luminosity for 50+10 days





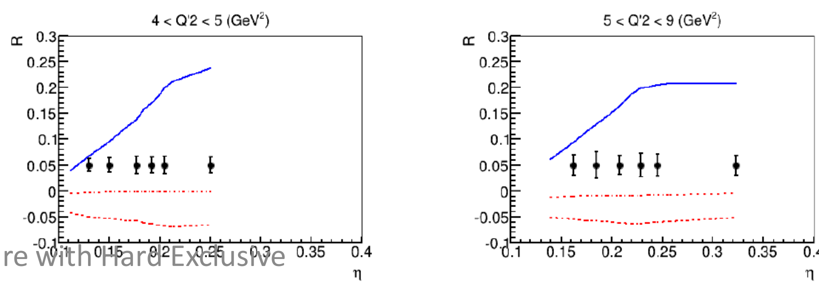
All will be input for global GPD fit





cosine moment of weighted cross sections

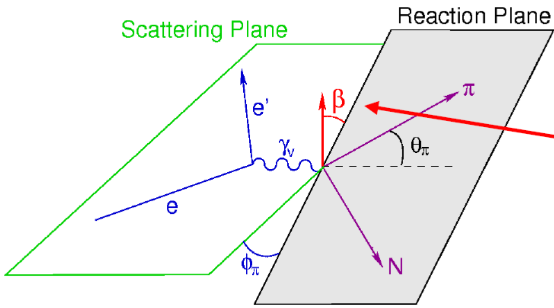
$$R = \frac{2\int_0^{2\pi} d\varphi\ \cos\varphi\ \frac{dS}{dQ'^2\,dt\,d\varphi}}{\int_0^{2\pi} d\varphi\ \frac{dS}{dQ'^2\,dt\,d\varphi}}$$



Deep Exclusive π^- Production using Transversely Polarized ^{3}He Target

- Probe GPD $\tilde{E}$ with DEMP $\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$
  - *GPD $\tilde{E}$ is not related to any already known parton distribution.*
  - *$G_P(t)$ is highly uncertain because it is negligible at the momentum transfer of β-decay.*
  - *Experimental measurements can provide new nucleon structure information unlikely to be available from any other source.*

The most sensitive observable to probe $\tilde{E}$ is the transverse single-spin asymmetry in exclusive π production:



Fit $\sin\beta = \sin(\varphi - \varphi_S)$ dependence to extract asymmetry.

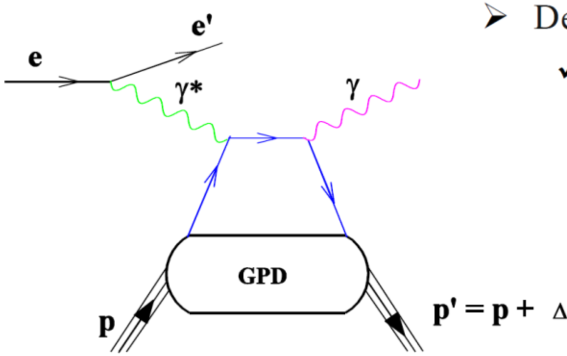
$$A_\perp = \frac{\int_0^\pi d\beta \frac{d\sigma_L^{\pi^-}}{d\beta} - \int_\pi^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}{\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}$$

Theoretical calculations suggest higher twist corrections, which may be significant at low Q^2 for σ_L, likely cancel in $A_\perp$.

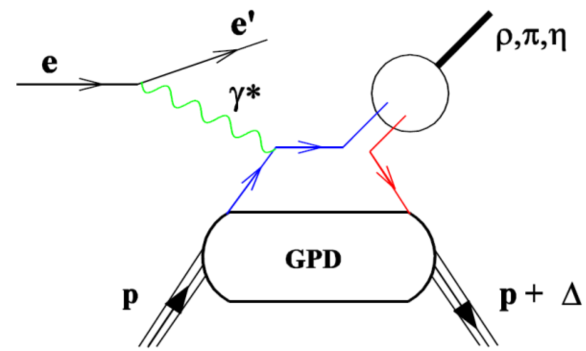
- **May allow access to GPDs at Q^2~4 GeV^2 while Q^2>10 GeV^2 needed for σ_L.**

Deep Exclusive π^- Production using Transversely Polarized ^3He Target

- Exclusive Hard Processes to probe GPDs:



- Deeply Virtual Compton Scattering (DVCS):
  - ✓ Sensitive to all four twist-2 GPDs (H, E, $\tilde{H}$ and $\tilde{E}$).



Virtual *(DVMP)*

- Deep Exclusive Meson Production (DEMP): *at leading twist*
  - ✓ Vector mesons sensitive to spin-average H, E.
  - ✓ Pseudoscalar mesons sensitive to spin-difference , $\tilde{H}$ and $\tilde{E}$.
  - ✓ neutron+pseudoscalar DEMP is uniquely sensitive to $\tilde{E}$
  - ✓ DEMP is also sensitive to chiral-odd GPDs (H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$)

- Time-Like Compton Scattering (TCS), Double Deeply Virtual Compton Scattering (D-DVCS), etc.

Need a variety of Hard Exclusive Measurements to disentangle different GPDs

Deep Exclusive π^- Production using Transversely Polarized ^{3}He Target

- Probe GPD-$\tilde{E}$ with DEMP:

$$\sum_q e_q \int_{-1}^{+1} dx \tilde{E}^q(x,\xi,t) = G_p(t)$$

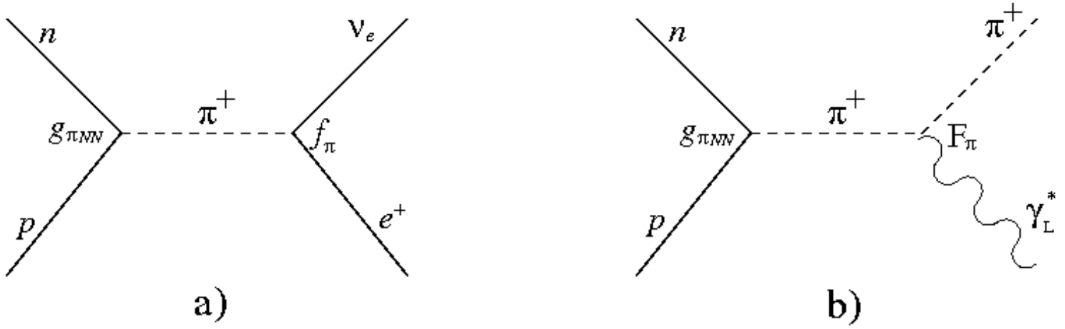
✓ GPD-$\tilde{E}$ is not related to an already known parton distribution.

✓ Experimental information can provide new nucleon structure info unlikely to be available from any other source.

✓ $G_P(t)$, which is highly uncertain, contains an important pion pole contribution.

Pion pole contribution to $G_P(t)$

Pion pole contribution to meson electroproduction at low –t.



For this reason, a pion pole-dominated ansatz is typically assumed:

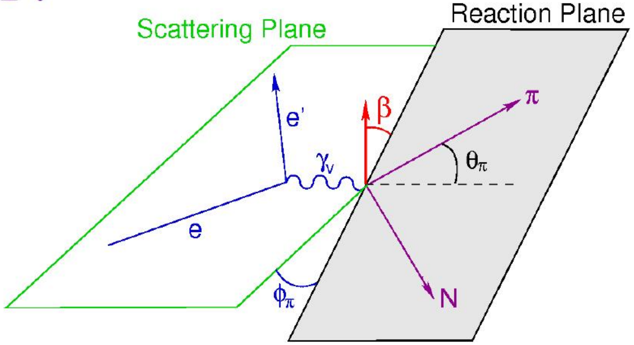
$$\tilde{E}^{ud}(x,\xi,t) = F_\pi(t)\frac{\theta(\xi > |x|)}{2\xi}\phi_\pi(\frac{x+\xi}{2\xi}),$$

where F_π is the pion FF and ϕ_π the pion PDF.

Target Single Spin Asymmetry in DEMP:

- Asymmetry with transversely polarized target and longitudinally polarized virtual photon

$$A_L^{\perp} = \frac{\sqrt{-t'}}{m_p} \frac{\xi\sqrt{1-\xi^2}\ \mathrm{Im}(\tilde{E}^*\tilde{H})}{(1-\xi^2)\tilde{H}^2 - \frac{t\xi^2}{4m_p}\tilde{E}^2 - 2\xi^2\mathrm{Re}(\tilde{E}^*\tilde{H})}.$$



- Unpolarized Cross section

L/T Separation

$$2\pi\frac{d^2\sigma}{dtd\phi} = \epsilon\frac{d\sigma_\mathrm{L}}{dt} + \frac{d\sigma_\mathrm{T}}{dt} + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_\mathrm{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_\mathrm{TT}}{dt}\cos 2\phi$$

$\beta = \phi - \phi_S$

$$A_L^{\perp} = A_{LT}^{\sin\beta} = -\frac{1}{P_\perp}\frac{2}{\pi}\frac{2\sigma_L^y}{\sigma_L}$$

- Transversely polarized cross section:

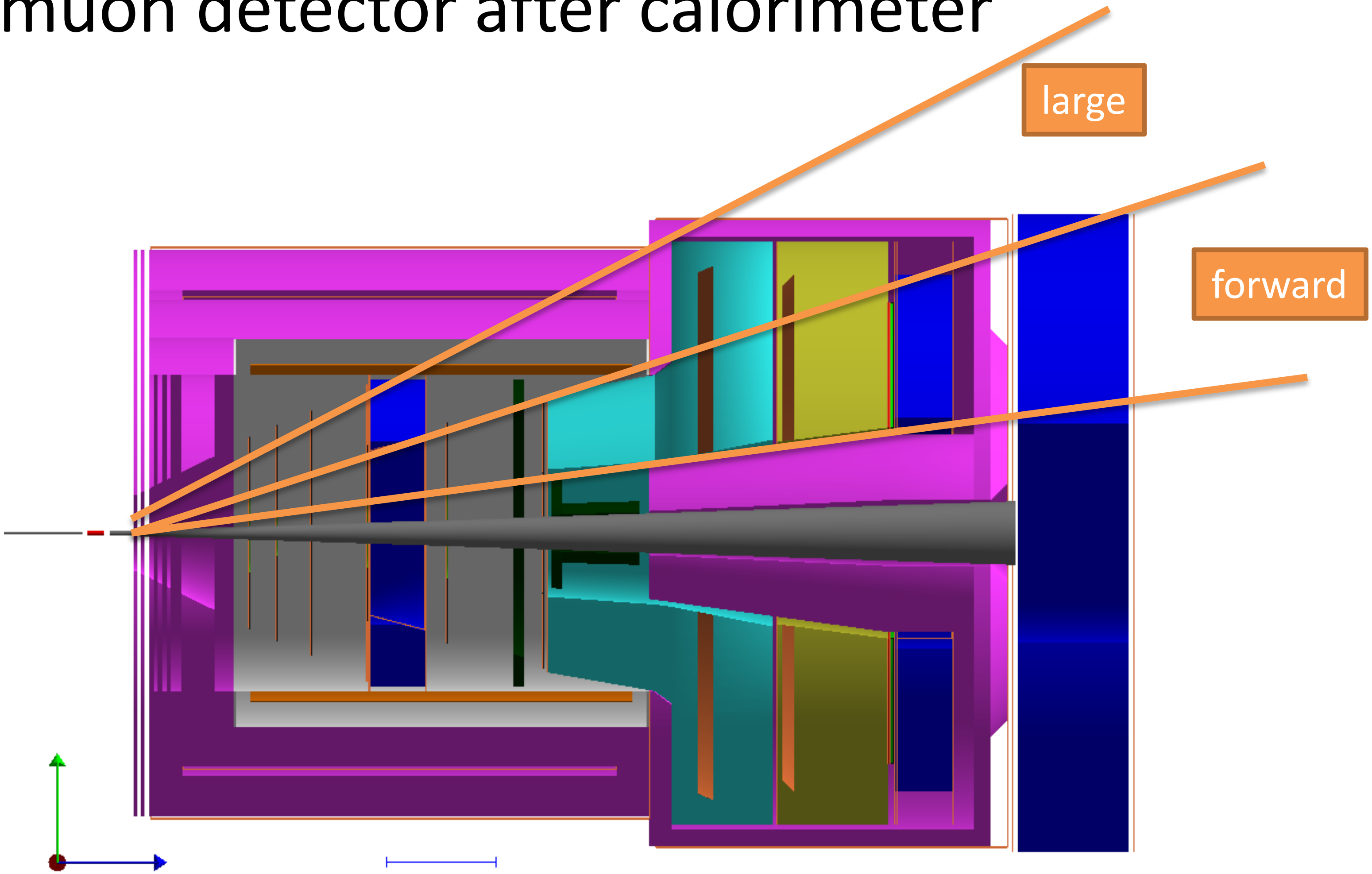
$$\sigma_t = -P_\perp \sin\beta\,[\sigma_{TT}^y + 2\epsilon\,\sigma_L^y]$$
$$- P_\perp \sin\beta\,[\epsilon(\cos 2\phi_s \cos 2\beta + \sin 2\phi_s \sin 2\beta)\ \sigma_{TT'}^y]$$
$$- P_\perp \sin\beta\left[\sqrt{2\epsilon(1+\epsilon)}(\cos\phi_s\cos\beta + \sin\phi_s\sin\beta)\ \sigma_{LT}^y\right]$$
$$- P_\perp \cos\beta\left[\sqrt{2\epsilon(1+\epsilon)}(\sin\phi_s\sin\beta - \cos\phi_s\cos\beta)\ \sigma_{LT}^x\right]$$
$$- P_\perp \cos\beta\,[\epsilon(\sin 2\phi_s \sin 2\beta - \cos 2\phi_s \cos 2\beta)\ \sigma_{TT}^x]$$

sin β module

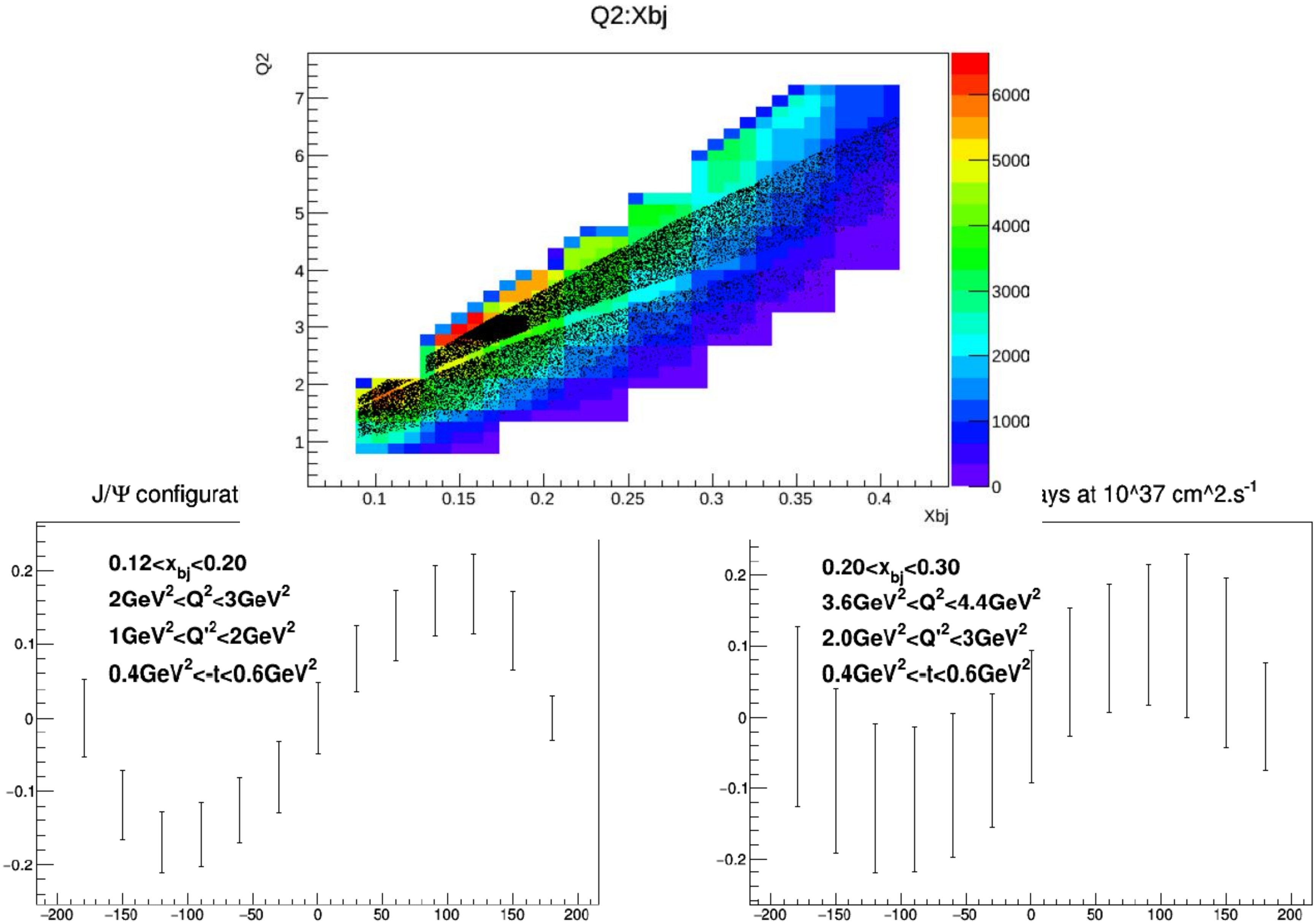
$d\sigma_\pi^L$ = exclusive π cross section for longitudinal γ*

SoLID DDVCS JPsi Setup

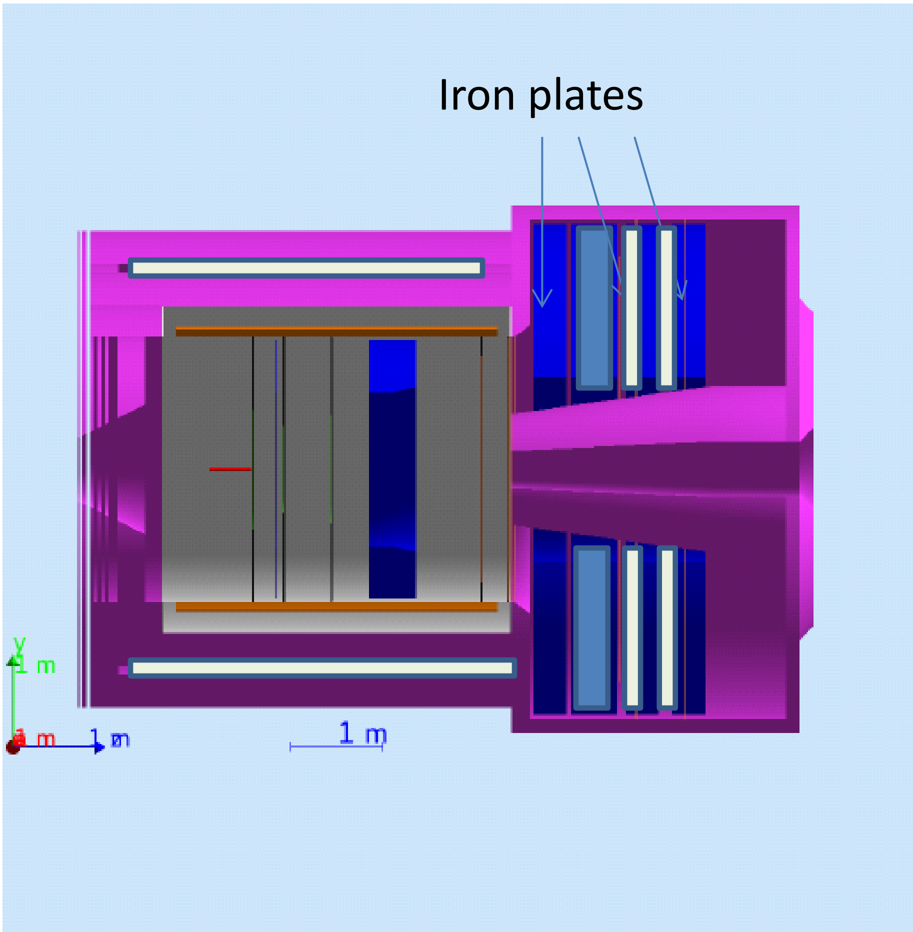
- Add muon detector after calorimeter



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

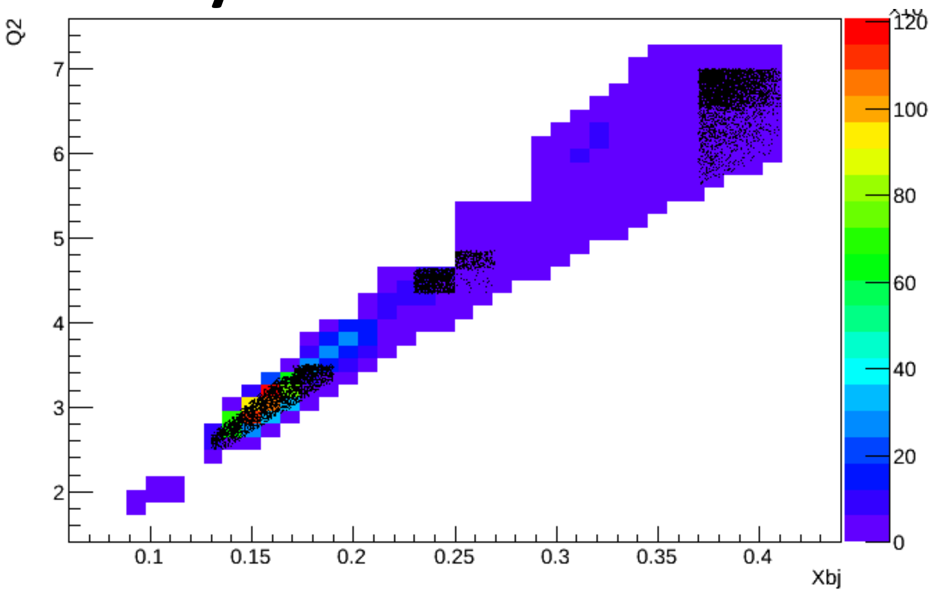


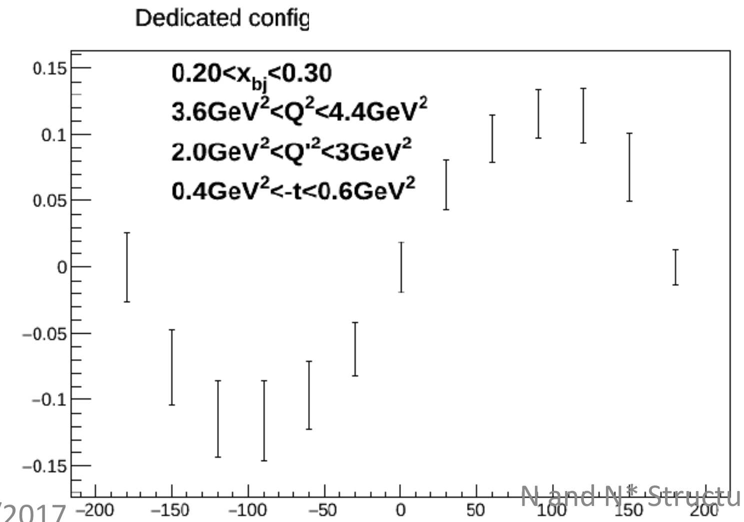
DDVCS Dedicated setup

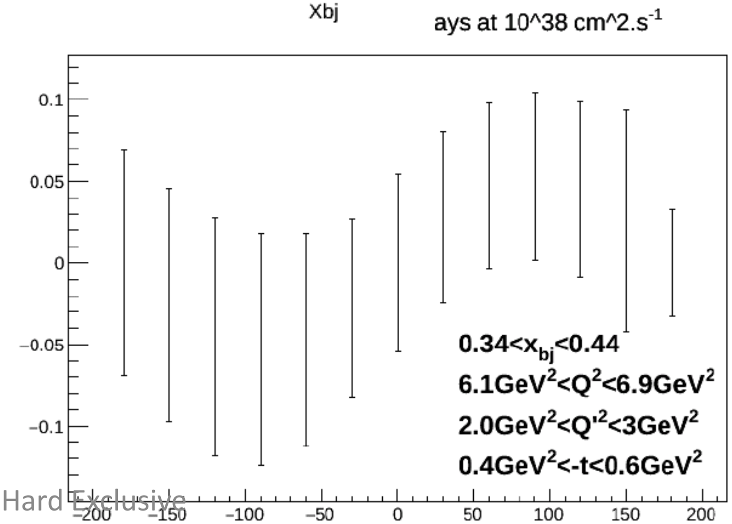


- Target moved 2m from Jpsi position inside and switch to 45 cm target
- Iron plate from 3rd layer yoke in front and behind calorimeter
- Remove Gas Cerenkov
- Try to reach 10^{38} $cm^{-2}s^{-1}$
- 10 uA on 45 cm target

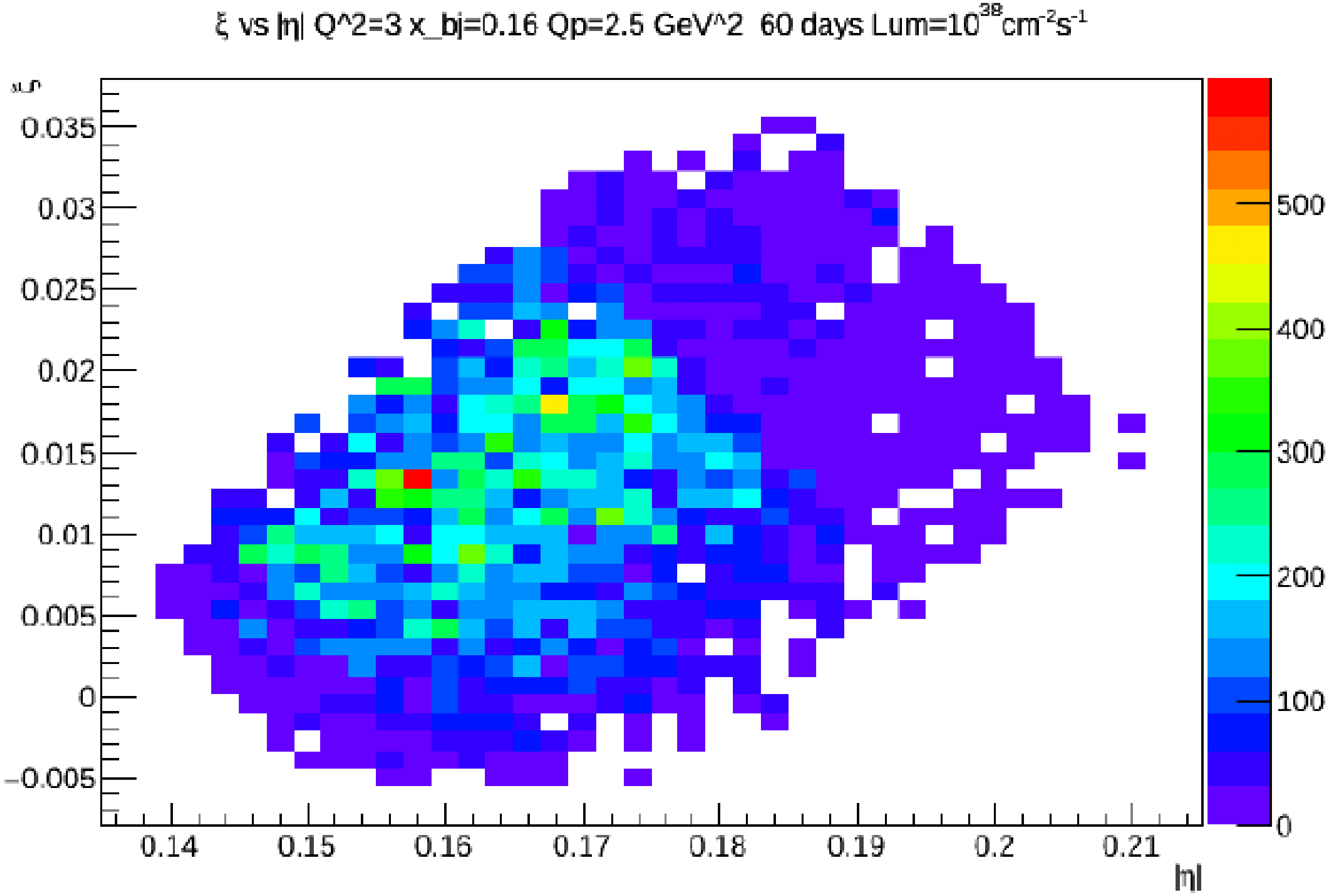
Expected accuracy dedicated setup 90 days at 10^{38} $cm^{-2}s^{-1}$



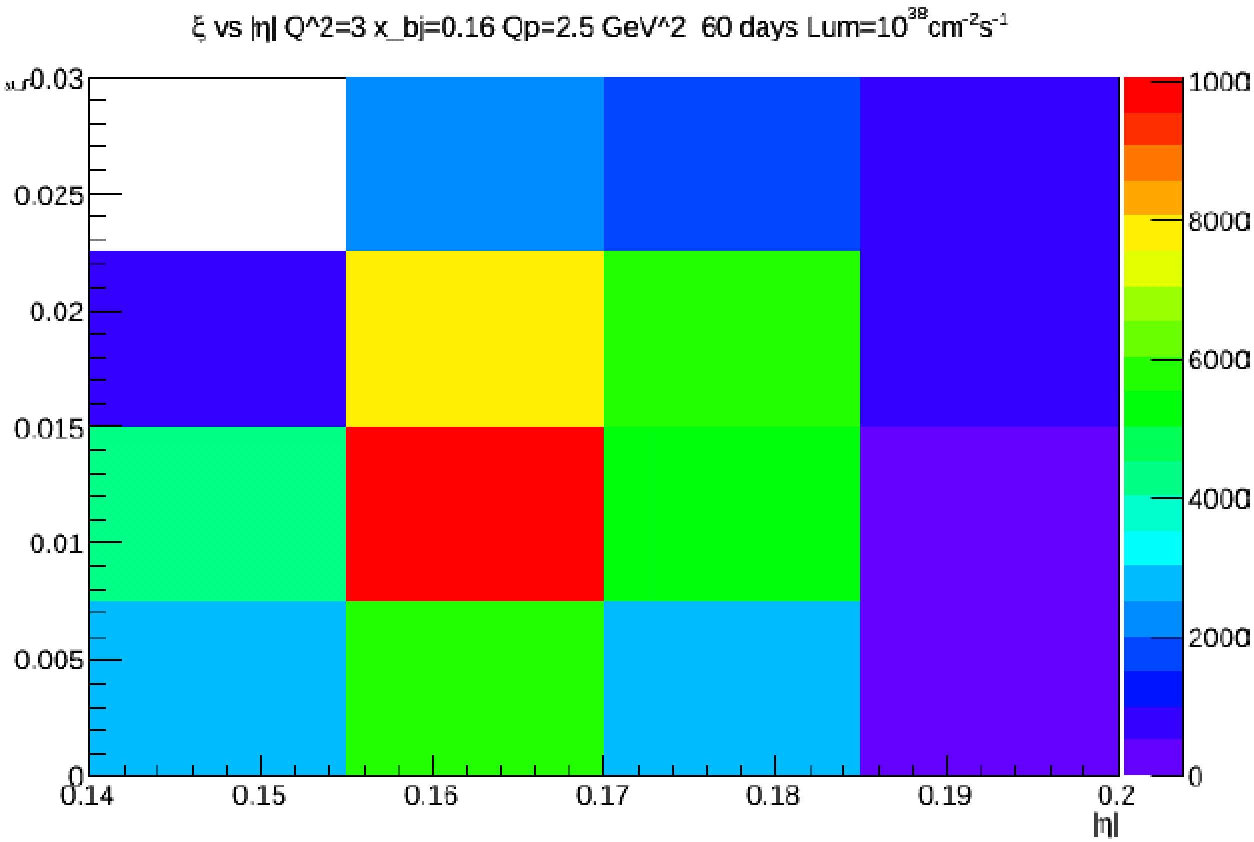




Eta and xi coverage



Eta Xi coverage large bin



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
  - $PbWO_4$
  - Superconducting detector to replace PMT (1 ns width pulse to increase rate capability), MCP-PMT, solid state photodetectors
- Cerenkov
  - Superconducting detector to replace PMT (1 ns width pulse to increase rate capability),MCP-PMT, solid state photodetectors
  - HBD type Cerenkov for Large Angle calorimeter

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

Technically doable mostly matter of cost

Conclusion

- 2 baseline SoLID detector configurations for PVDIS and SIDIS
- several possible parasitic experiments : TCS and DVMP on He3
- could have dedicated GPD exclusive experiments if calorimetry is upgraded
- Opportunity for DDVCS at high luminosity and high x with addition of muon detector and possible dedicated configuration
- SoLID can benefit of detector and electronics improvement
- Other measurements possible which needs more luminosity than resolution and acceptance compared to CLAS12

($\gamma\rho$)