Timelike Compton Scattering off transversely polarized target
A Hall C project

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(*AANSL*)
for the TCS and NPS collaborations

Hall A & C Summer Collaboration Meeting
6/21-22/2018

Outline

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Summary and Outlooks

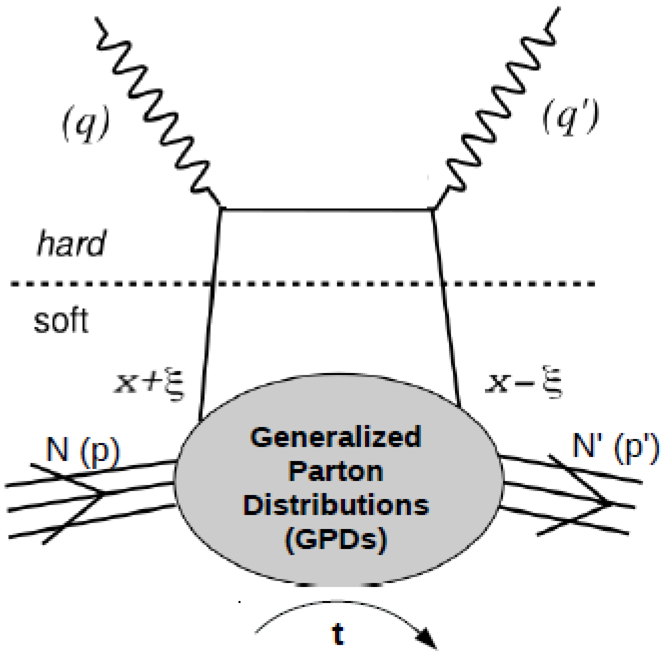


Photo- and electro-production of a lepton pair

γ (q) N (p) $\rightarrow \gamma$ (q') N' (p') $\rightarrow$ e+ e- N'

Deeply Virtual Compton Scattering:
$q^2 < 0, q'^2 = 0$

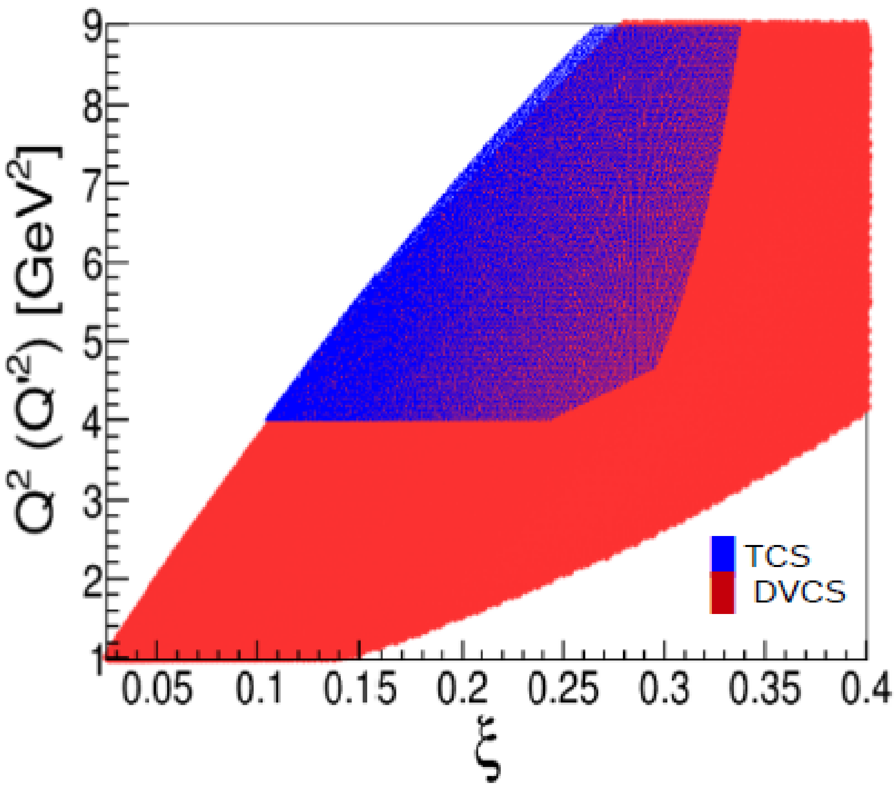
Timelike Compton Scattering:
$q^2 = 0, q'^2 > 0$

Double Deeply Virtual Compton Scattering:
$q^2 < 0, q'^2 > 0, -q^2 \neq q'^2$

Cross section factorizes to hard (perturbative QED) and soft (non-perturbative QCD) parts at photon virtualities $> 1\ GeV^2$.
Soft part parametrized in GPDs which contain information on intrinsic structure of nucleons in terms of partons.
GPDs enter into cross section through amplitude decomposition into CFFs:

$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \underbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}_{\mathrm{Re}(\mathcal{H})} - \underbrace{i\pi H(\pm\xi,\xi,t)}_{\mathrm{Im}(\mathcal{H})} + \ldots$$

Comparing DVCS and TCS in CFF extraction



ξ vs Q^2 (Q'^2) for DVCS and TCS
"JLab-like" phase-space
$0 < -t < 1$ GeV^2
$s > 4$ GeV^2, E= 11 GeV for DVCS
$5 < E_\gamma < 11$ GeV for TCS
mass cut: out of resonences region

Fits of CFFs from DVCS and TCS observables at same (ξ, t) points

CFF extraction from twist 2 and LO DVCS and TCS independently and combined

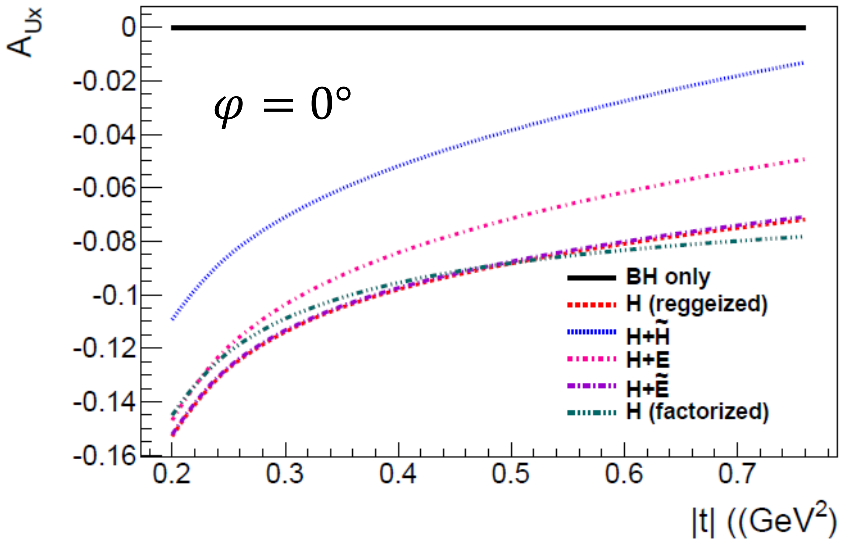
Interpretations, depending on size of NLO and higher twist

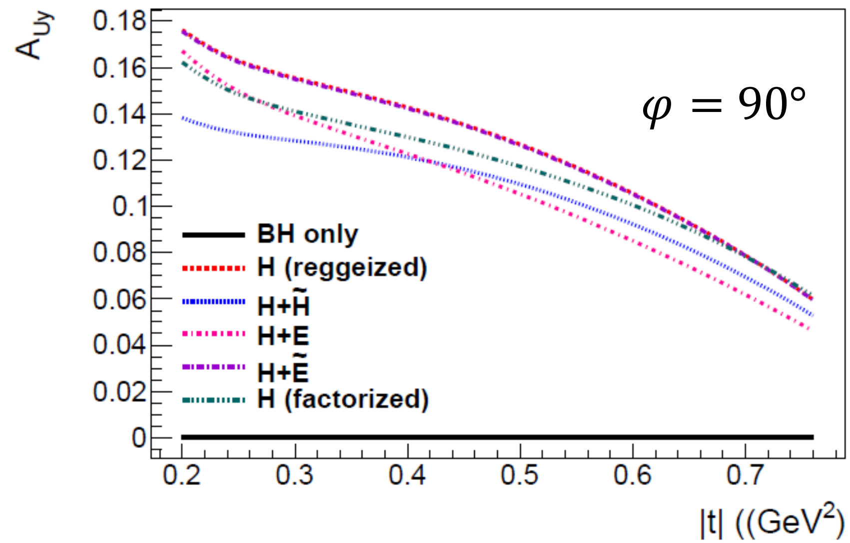
- small effects: combine DVCS+TCS observables → global fits
- small/moderate effects: independent analysis → constraint on GPD universality
- large effects: observation of higher twist in spacelike (DVCS) vs timelike (TCS)

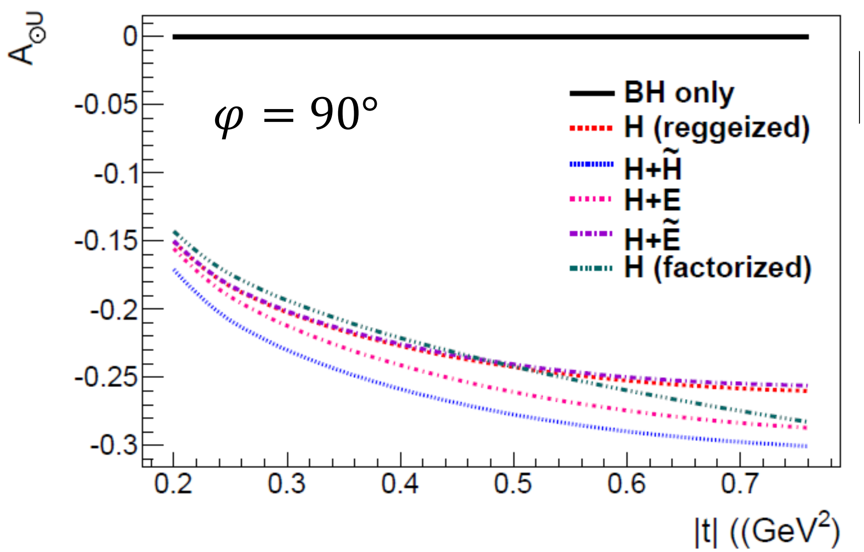
Cortesy of M.Boër

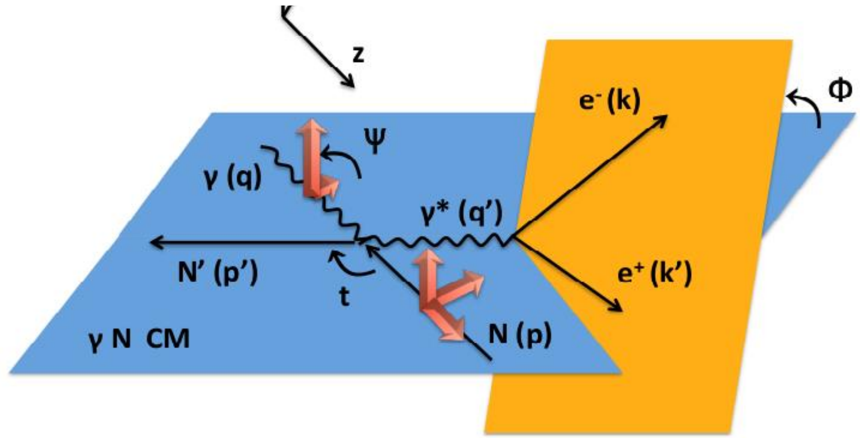
Physics case

$\xi = 0.2, Q'^2 = 7\ GeV^2, \theta \in [45°, 135]$









M. Boër, M. Guidal, M. Vanderhaeghen, Eur. Phys. J. A51 (2015) 8, 103 (arXiv:1501.00270)

TSA and BSA significant, sensitive to GPDs.

TCS measurements at JLab

Hall B CLAS 6 GeV, exploratory measurements in 2012

- Quasi-real photons from e- beam on unpolarized target
- Cross section, $\cos\varphi$ moments

Hall B CLAS12 E12-12-001

- Quasi-real photons from l**ongitudinally polarized** e- beam on unpolarized target
- Unpolarized cross section and BSA
- Sensitive to $Amplitude$, $Re(H)$, $Im(H)$, $Im(\widetilde{H})$
- Approved, part of Run Group A, data taking in 2018

Hall A SoLID E12-12-006A

- Complementary to CLAS12: same observables, **higher luminosity**, different acceptance
- Approved to run with E12-12-006 (SoLID J/ψ)

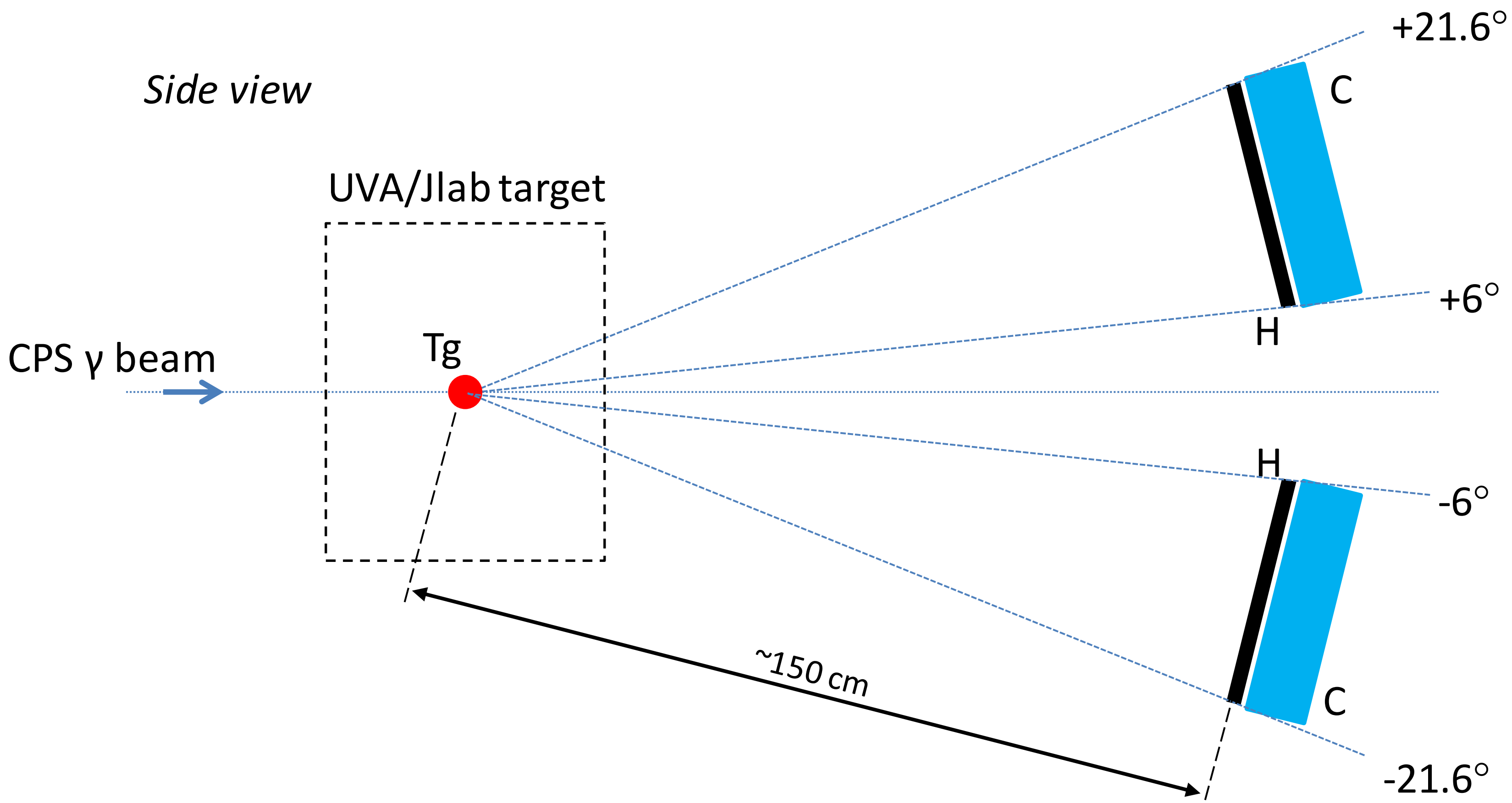
Hall D GlueX

- **Linearly and circularly polarized** (low intensity) **real photon beam** on unpolarized target.
- Unpolarized cross section, linearly polarized BSAs. Sensitive to $Re(H)$, D-term. Good alternative to charge asymmetries.
- Data taking in 2016, 2017, 2018. **Ongoing studies.**

Hall C proposal to PAC46

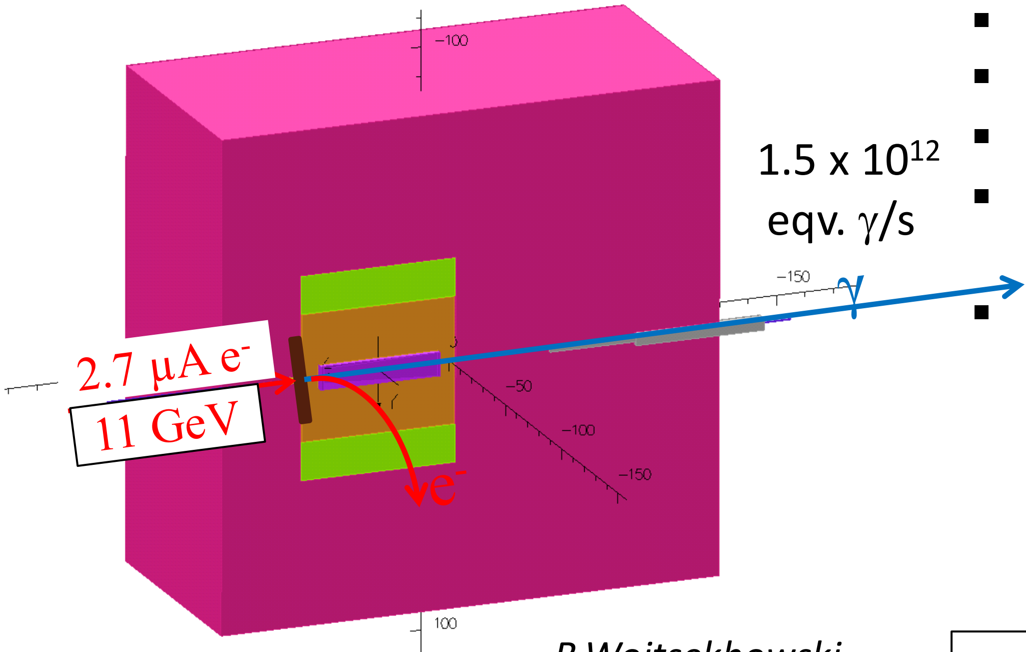
- Untagged (circularly polarized) **photon beam** on **transversely polarized target**.
- Cross section, TSA, BSA.
- Sensitive to $Im(H)$, $Re(H)$, $Im(\widetilde{H})$, $Im(E)$.
- **Universality checks of DVCS and TCS** possible with $Im(H)$ and $Im(\widetilde{H})$.
- **Sensitivity to $\boldsymbol{Im(E)}$**, similar to trans. pol. target DVCS.

Experimental Setup



- Untagged 1.5· 10^{12}/s $\left(E_\gamma > 0.5E_e\right)$ photon beam from **CPS**
- **Transversely polarized UVA/JLab target** ($\pm 18°$ horizontal, $[\pm 6°, \pm 21.6°]$ vertical acceptance)
- **Detectors** suited to $\gamma + \vec{p} \rightarrow (e^+, e^-) + recoil\ p$:
  - **EM Calorimeters** for e^+, e^- detectection and identification
  - **Scintillation hodoscopes** for recoil proton detection

CPS concept



B.Wojtsekhowski

- 2x2 mm^2 rasterized photon beam
- Water cooled Cu heat absorber (30 kW)
- W powder external shield (16 $^{g}/_{cm^3}$)
- Segmented, flared beam line to reduce radiation leak
- Radiation from source few times less than from γ beam interaction with target

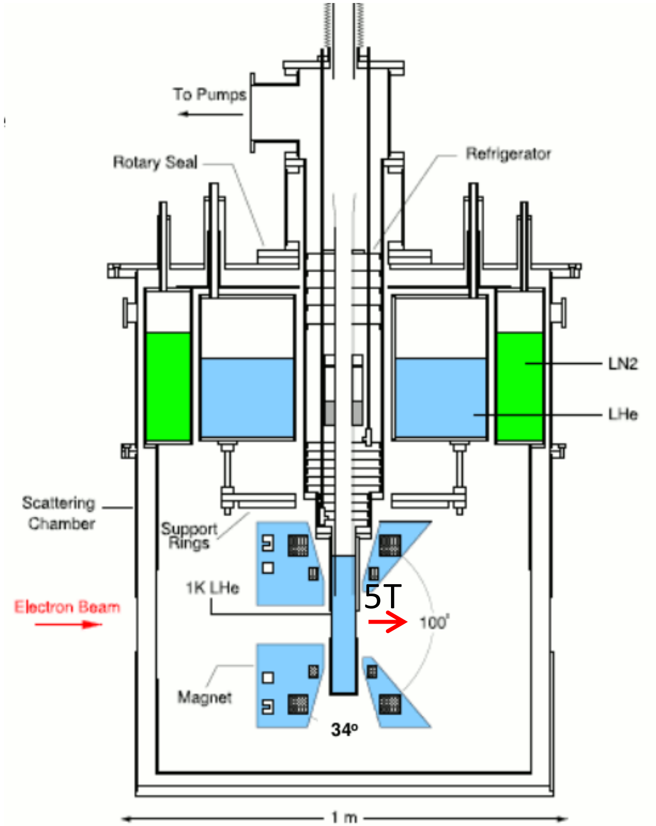
- Up to 2.7 μA, 11 GeV e- beam incident
- 10% radiator to produce (untagged) γ beam
- 3.2 T, 40 cm magnet to bend residual e^-
- Magnet serves as a beam dump
- High Z shielding to minimize prompt radiation and residual activation

Pure photon beam on solid polarized target versus mixed e^- / γ beam:

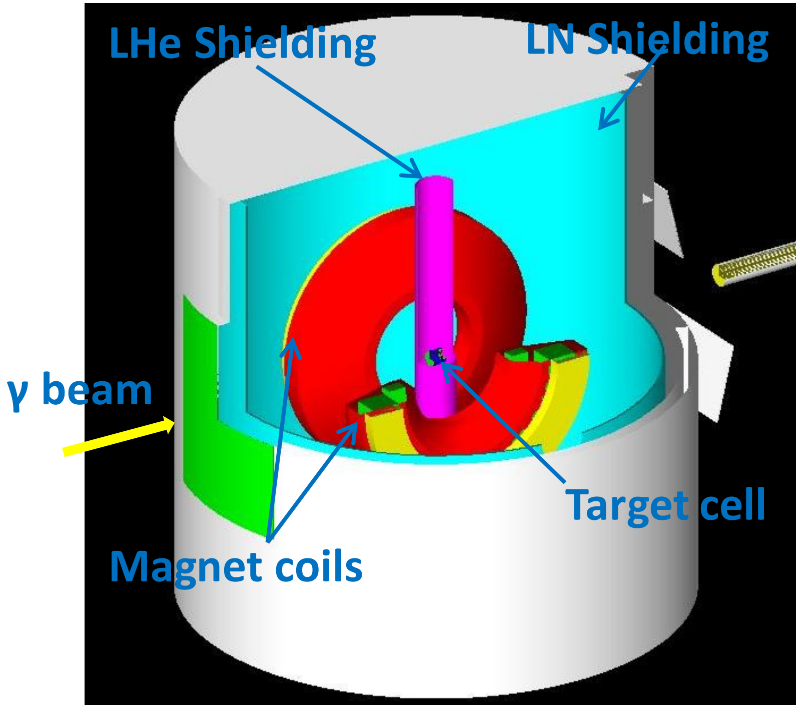
- increase of useful photon flux by 18 times ($\sim 10^{12}\ ^{\gamma}/_{s}$);
- less heat load, increase of max. polarization from 90% to 95%;
- less rad. damage to target material, less depolarization -> increase of average polarization from 70% to 90%.

Overall increase of FOM 30 times!

UVA/JLab polarized target



UVA target, nominal configuration



UVA target, TCS configuration

Target material: ammonia ($^{15}NH_3$) in LHe, 0.6 packing fraction.
5T (uniform to 10^{-4}) mag. field generated by superconducting Helmhotz coils.
DNP Polarization by 140 GHz, 20 W RF field.
Polarization monitored via NMR Q-meter.

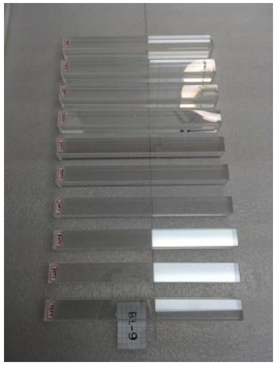
Magnet and scattering chamber rotated by 90° around vertical axis.
Sideways magnetic field and **polarization**.
Angular acceptance ±17° horizontally, from ±6° to ±21.7° vertically.

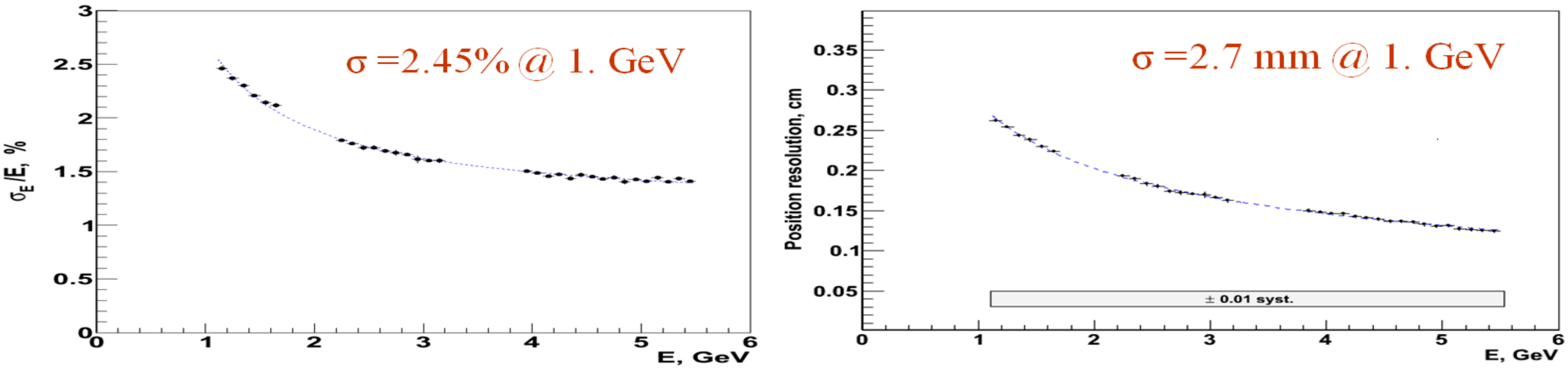
Calorimeters

- **Detect and identify leptons**, measure **energy and X and Y** coordinates. Define Q'^2, ξ and τ.
- **Similar to the NPS** PbWO calorimeters (**22.5 rad. length deep**).
- **Active area of 0.74 m^2** at 1.5 m from target, **angular acceptance ~0.33 sr**.
- **2,116 blocks** total (~2xNPS size).

Progress in NPS construction

- 340 PbWO crystals from SICCAS obtained, evaluated at Jlab, CUA
- 320 R4125 Hamamatsu PMTs obtained
- PMT base prototyped and tested, design construction chosen
- Design of support structures, enclosure underway



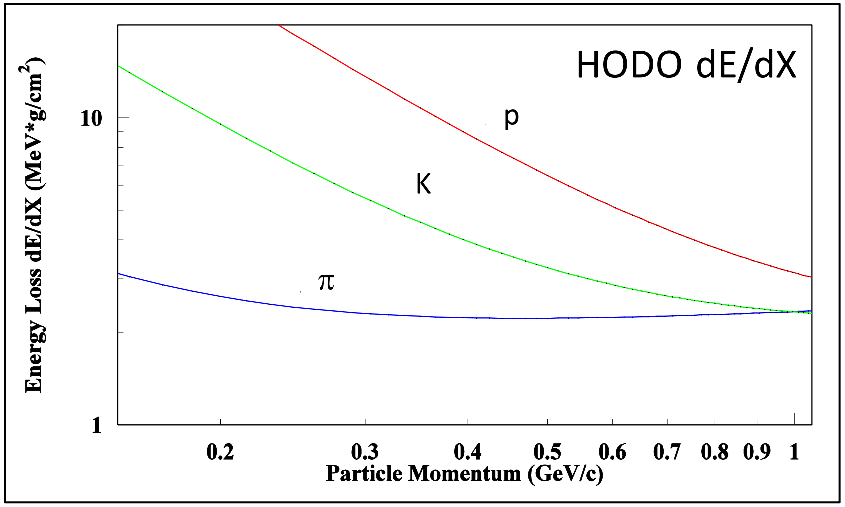


Energy and coordinate resolutions of PrimEx PbWO calorimeter (*from A.Gasparyan*)*

2.2% energy resolution for 4 GeV e- incident from the NPS 3x3 prototype in Hall D.

Recoil proton detector

- **Hodoscopes** for reconstruction of **recoil proton (P_p, ϑ_p, ϕ_p)**. Crucial for determining $-t$.
- **Proton identification** capability with dE/dx.
- X and Y planes from **1 cm thick scintillator**.
- **Total area ~1 m^2** at 1.5 m from target, **angular acceptance $\sim$0.44 sr**.



GEM trackers as alternative
- Sub-mm position accuracy
- Single electron sensitivity
- Long-term stability and reliability
- High rate capability
- Magnetic field tolerance up to 1.4 T
- Good radiation resistance

F.Sauli, NIMA 805 (2016) 12-24

Use at JLab: SBS, SoLID DDVCS, Prad, SHMS GEM Tracker

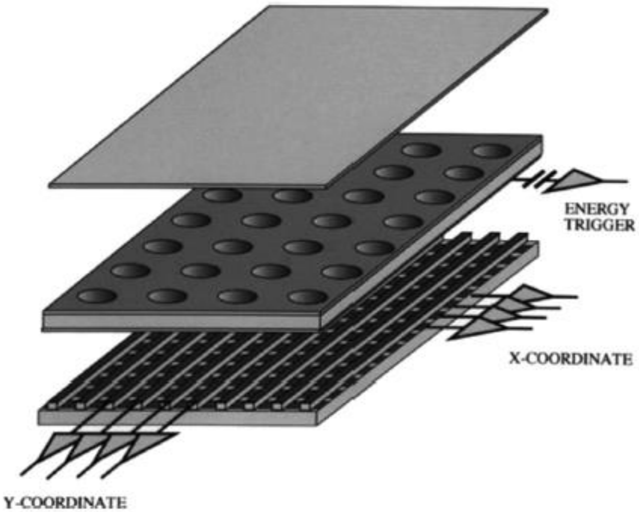
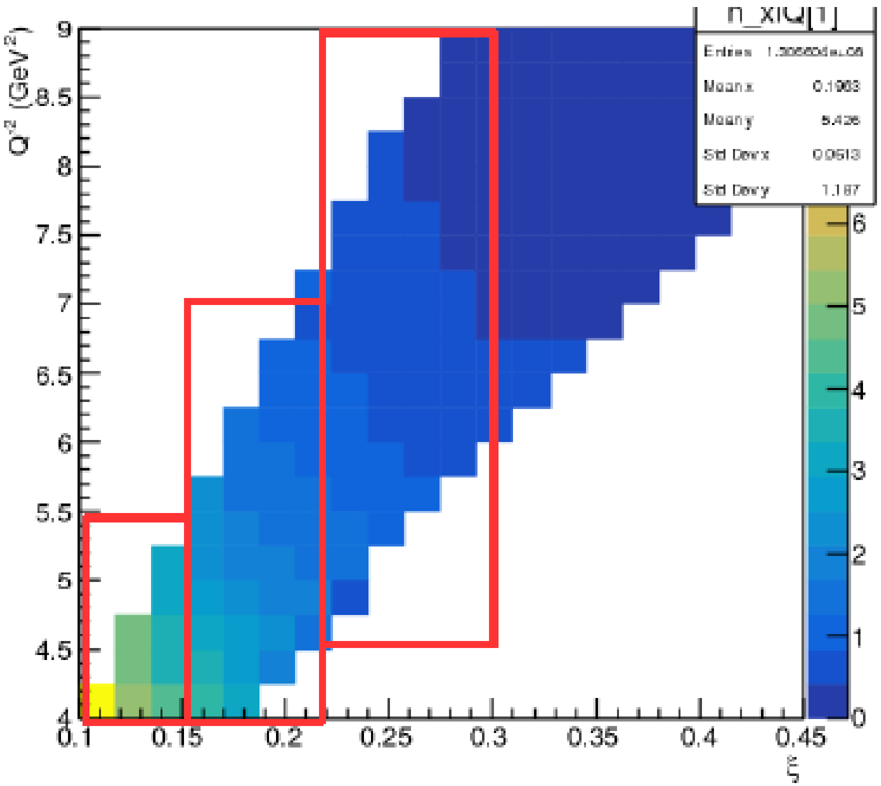
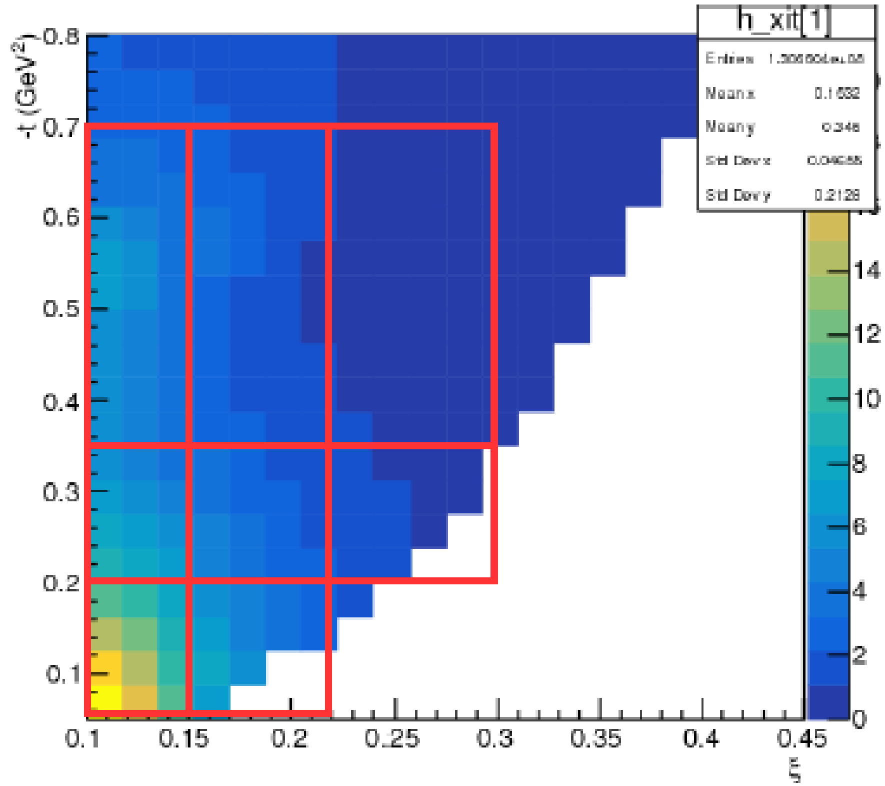


Fig. 3. Schematics of single GEM detector with Cartesian two-dimensional strip readout.

Phase space coverage





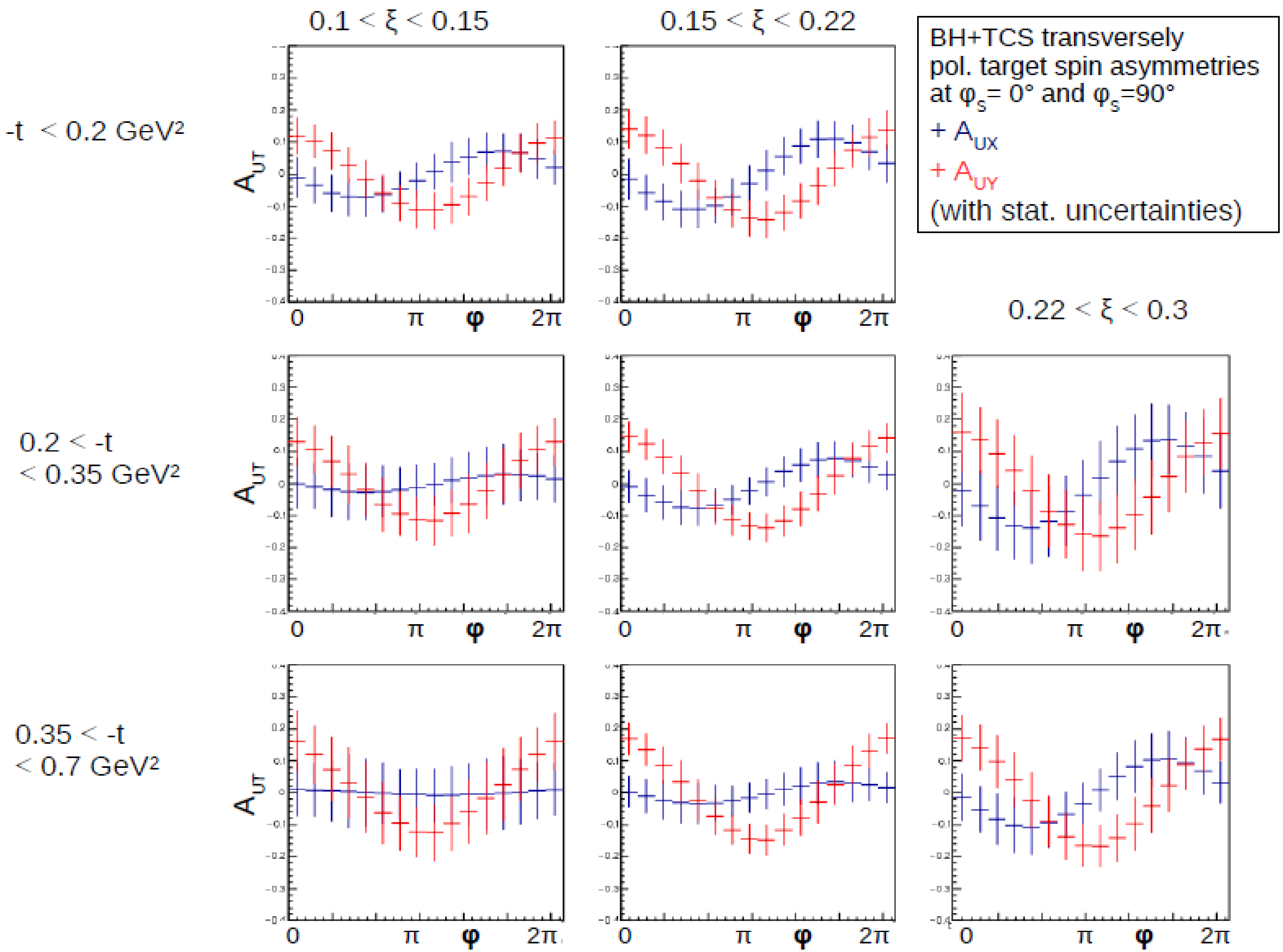
Triple coincident events within acceptance of detectors, with main cuts applied:

$$7.5 < E_\gamma < 11\ GeV$$
$$4 < Q'^2 < 9\ GeV^2$$
$$0.04 < -t < 0.7\,GeV^2$$
$40^\circ < \theta < 140^\circ$ or narrower (kinematic dependent)

Cuts on θ_{CM} and φ_{CM} to avoid BH sharp peaks

$$E_{e+} + E_{e-} > 5\ GeV$$

TSA projections from simulations



16 bins in φ, 16 bins in φ_S. Acceptance, phase space and energy cuts applied. Target pol. dilution factor not included. $5.85 \cdot 10^5 pb^{-1}$ integrated luminosity.

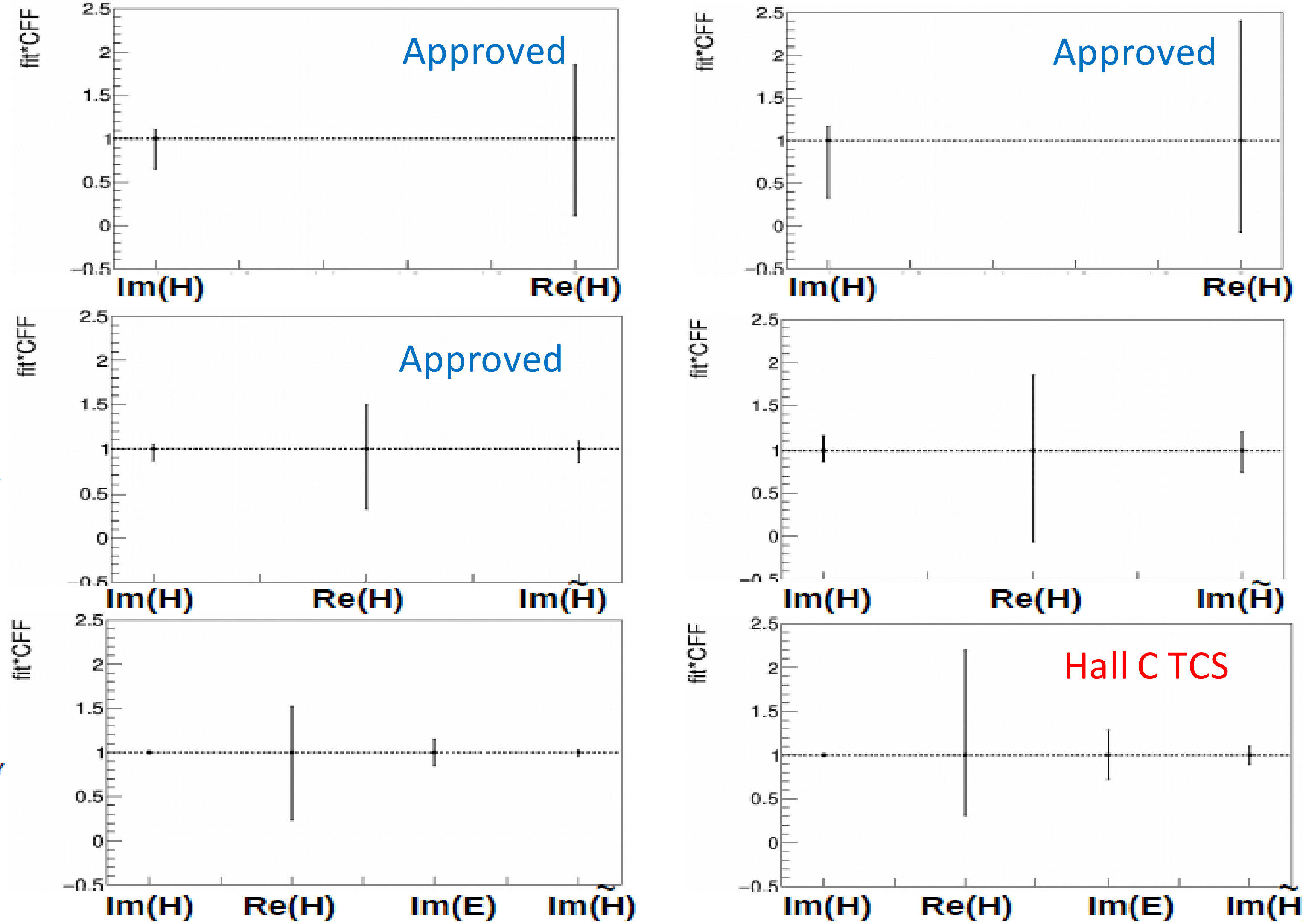
CFF extraction from assumed asymmetries

DVCS | TCS

1) σ, $\Delta\sigma_{LU}$

2) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$

3) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UX}$, $\Delta\sigma_{UY}$



Assumptions: 5% error/bin on unpol. X-sect., 7% error/bin on pol. X-sect., 16 φ bins.

DVCS: $Q^2 = 2.5\ GeV^2, E = 11\ GeV, -t = 0.2GeV^2, \xi = 0.15.$ TCS: $Q'^2 = 5\ GeV^2, \theta = 90°, -t = 0.2GeV^2, \xi = 0.15$

Summary and outlook

Main goals of the Hall C TCS project:

- Transverse target spin asymmetry measurement from the TCS+BH process, in addition to the unpolarized cross section and circularly polarized beam spin asymmetry measurements.
- Extraction of CFF $\mathrm{Im}(E)$, access to nucleon angular momentum partition among the quarks.
- Probing of GPDs universality by comparison of CFFs extracted from TCS and DVCS.
- If large higher twist effects: studies in a time-like (TCS) versus a space-like (DVCS) process.
- Simultaneous fit of CFFs with DVCS and TCS to constrain all CFFs (twist 2) at the same time.

First measurement to access $\mathrm{Im}(E)$ from TCS transverse target spin asymmetries.

High intensity real photon beam on transversely polarized target: big advantage of TCS over DVCS to access $\mathrm{Im}(E)$.

Unpolarized and beam polarized cross section measurements with 10 or 100 times higher luminosities than before.

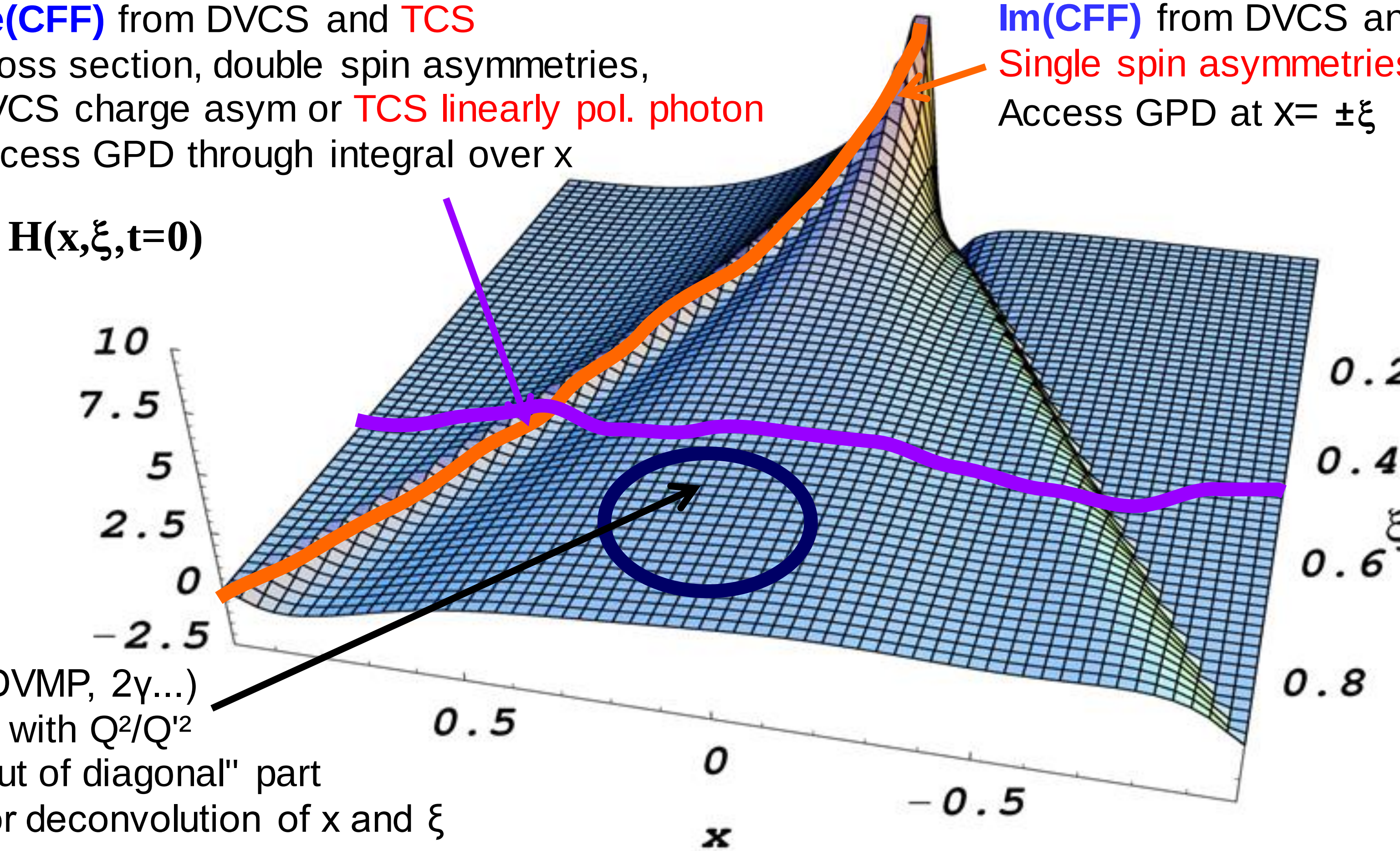
A proposal is submitted to JLab PAC 46 (M.Boër, V.Tadevosyan, D.Keller spokespersons).

Backup slides

Probing GPD x vs ξ dependence with experimental observables:

Re(CFF) from DVCS and TCS
Cross section, double spin asymmetries,
DVCS charge asym or TCS linearly pol. photon
Access GPD through integral over x

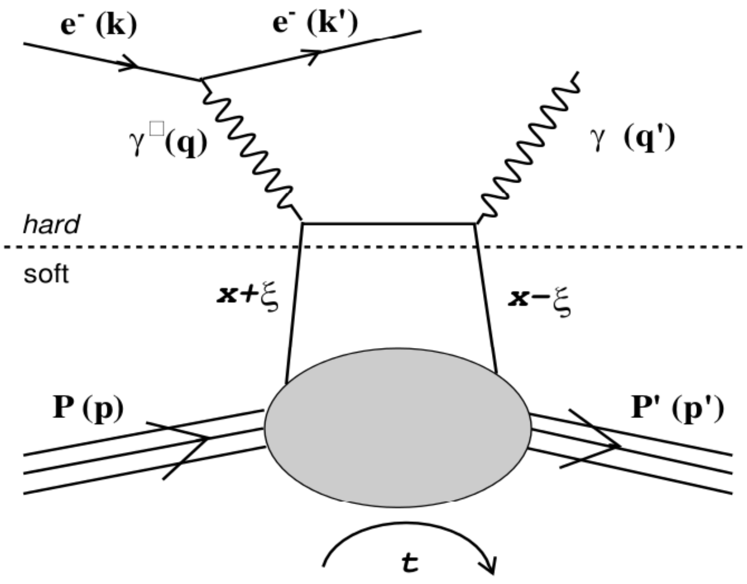
Im(CFF) from DVCS and TCS
Single spin asymmetries
Access GPD at x= ±ξ



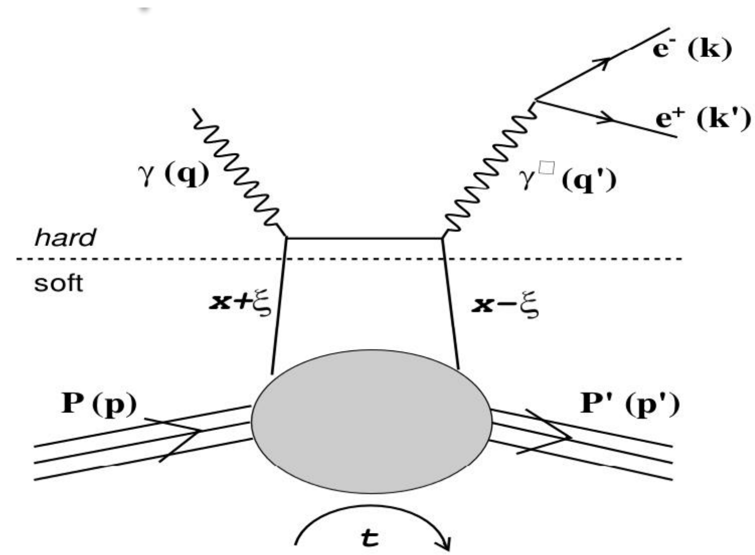
DDVCS (DVMP, 2γ...)
Lever arm with Q^2/Q'^2
Access "out of diagonal" part
Needed for deconvolution of x and ξ

Cortesy of M.Boër

Physics case



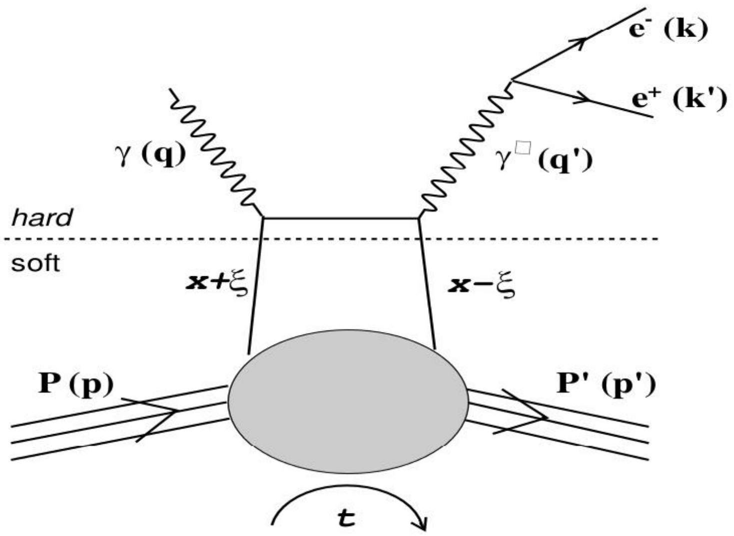
DVCS

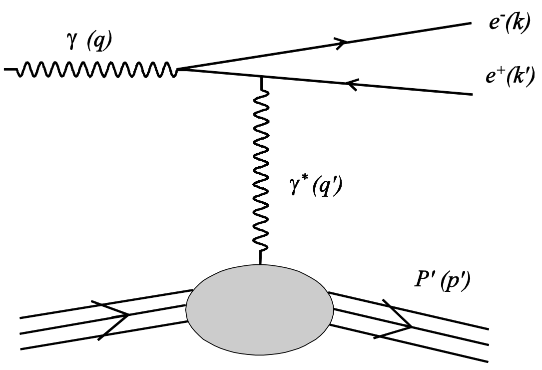


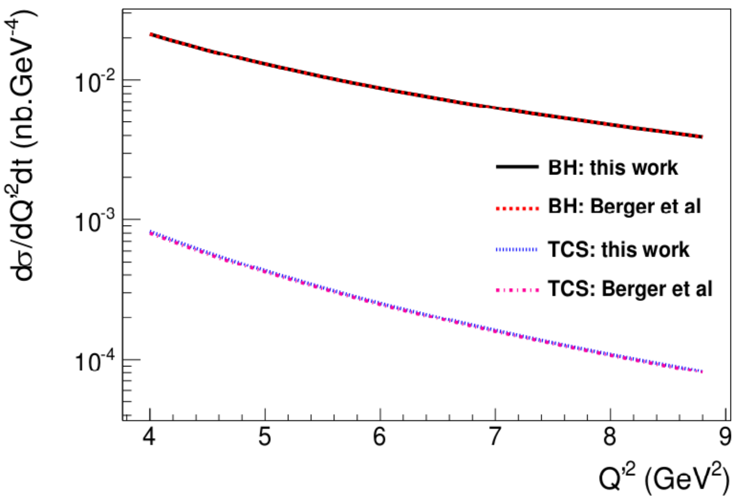
TCS

- **DVCS and TCS, limiting cases of Compton Scattering**
$$\gamma^*(q) + P(p) = \gamma^*(q') + P(p').$$
- At leading order of α_S and leading twist **amplitudes and CFFs are complex conjugate**.
- **TCS hard scale** provided by virtuality of the final state photon.
- **Comparison of DVCS and TCS data** provides a **test for universality of GPDs**.
- **Combining DVCS and TCS data**
  - Will reduce CFF fit uncertainties (provided universality established).
  - Alternatively, higher twist effects can be studied.

Physics case







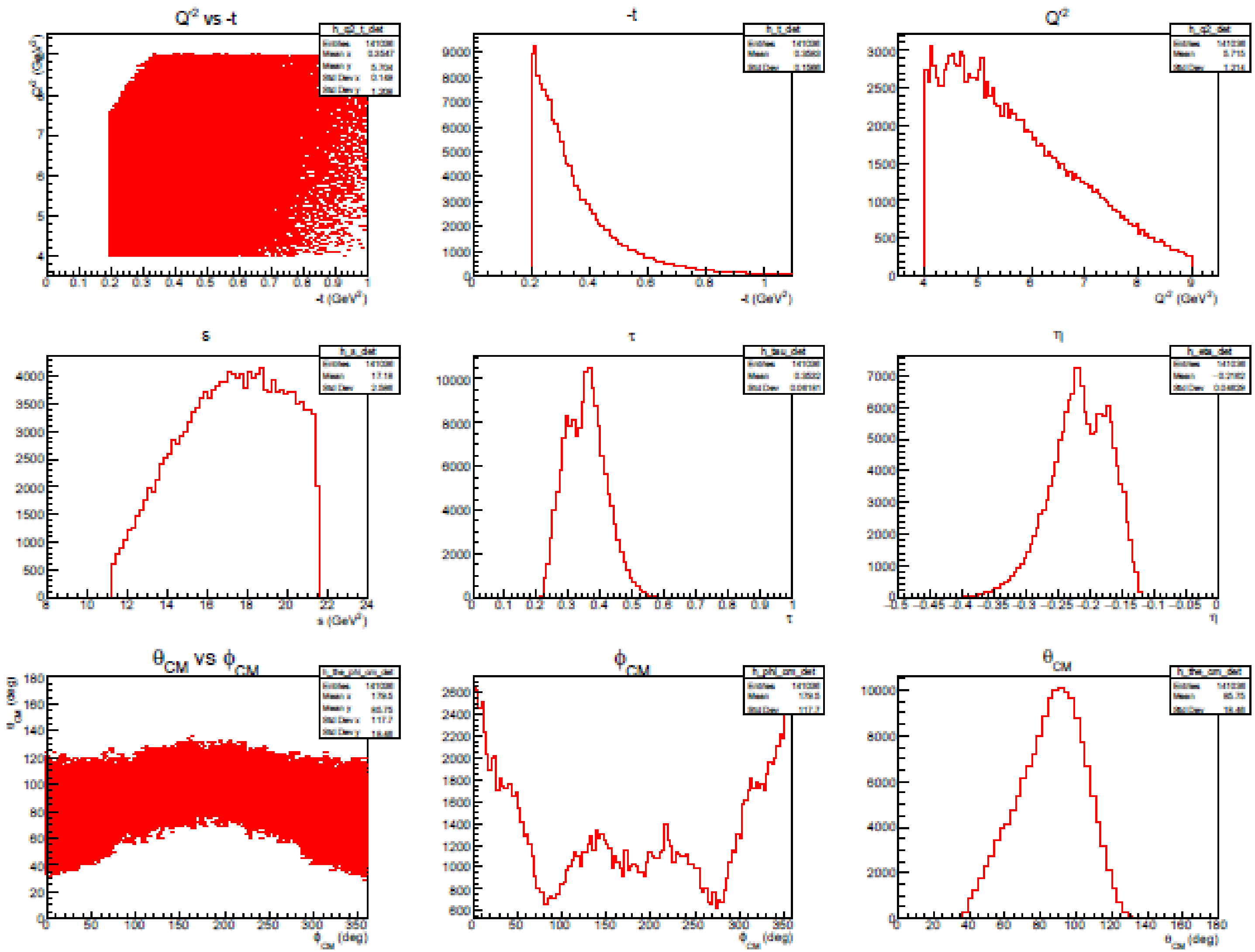
M. Boër, M. Guidal, M. Vanderhaeghen, Eur. Phys. J. A51 (2015) 8, 103 (arXiv:1501.00270)

- **BH produces same final state** as TCS.
- At Jlab energies $\boldsymbol{\sigma_{BH} >> \sigma_{TCS}}$ (10--100 times).
- *But,* **TCS interferes with BH:**

$$d^4\sigma = |T^{BH}|^2 + |T^{TCS}|^2 + (T^{BH} \cdot T^{TCS})$$

- **TCS signal magnify in interference with BH**.
- **TCS signal can be detected in BSA (circularly polarized photon) and TSA (sensitive to the interference and Im(CFFs))**.

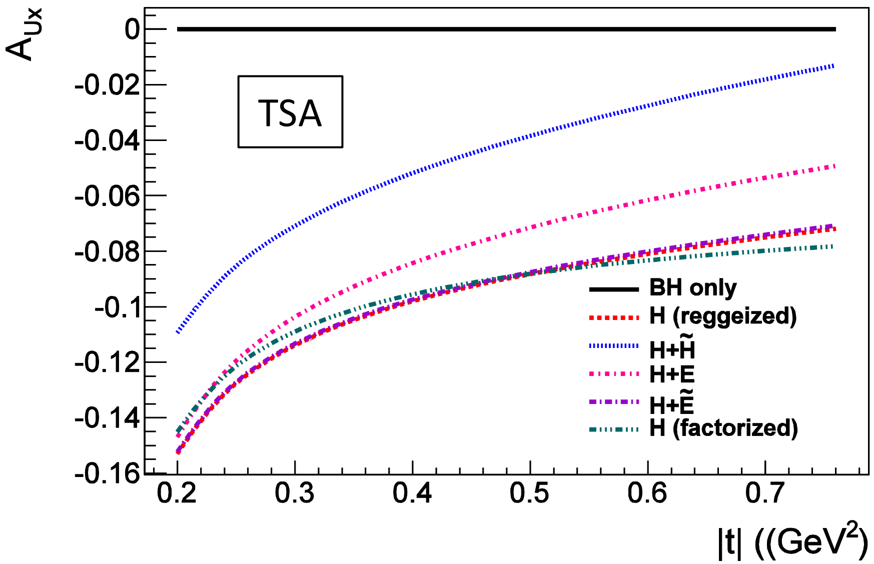
Kinematic coverage

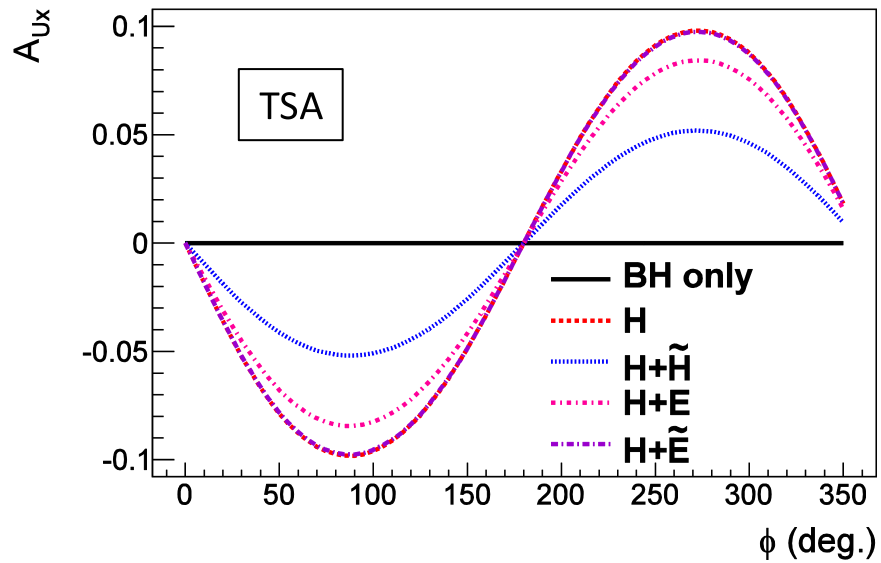


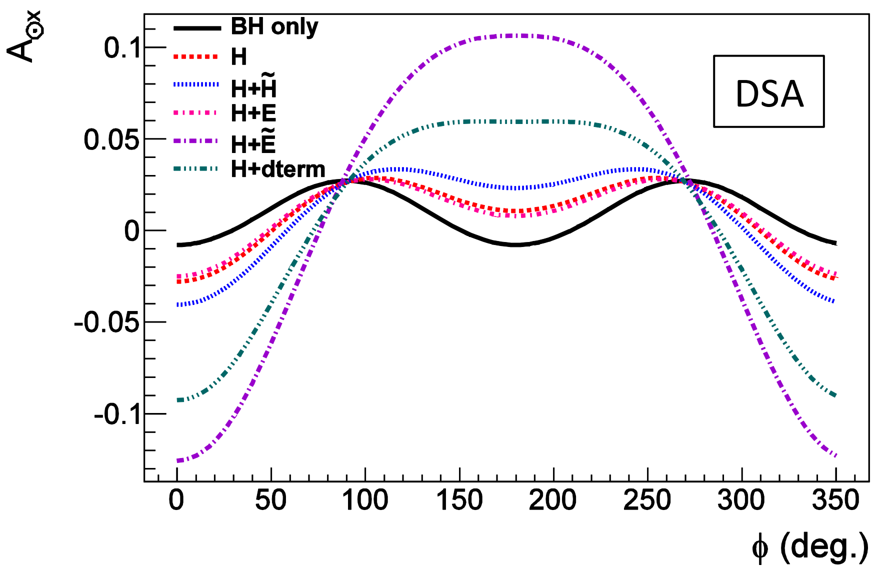
Before analysis cuts applied. $\theta_{CM} \sim 90° \rightarrow \; max\, TH/BH$.

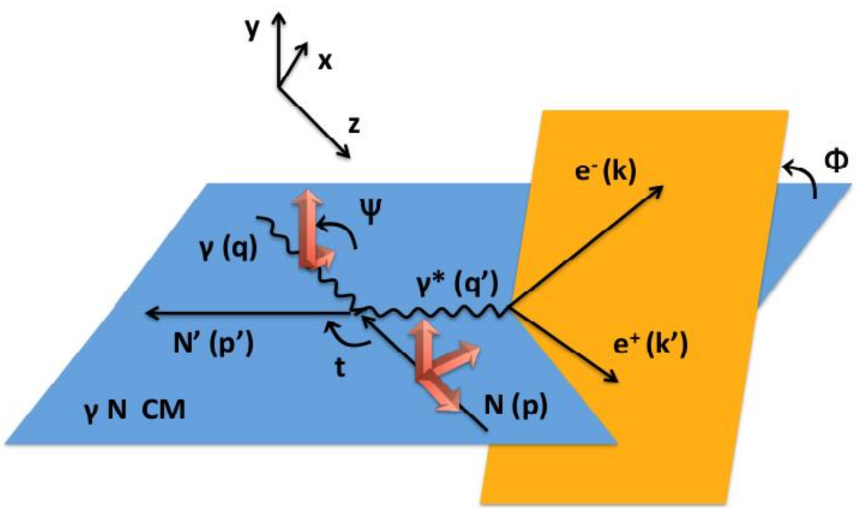
Physics Case: TSA

$\xi = 0.2,\ Q'^2 = 7\ GeV^2,\ \theta \in [45°, 135]$



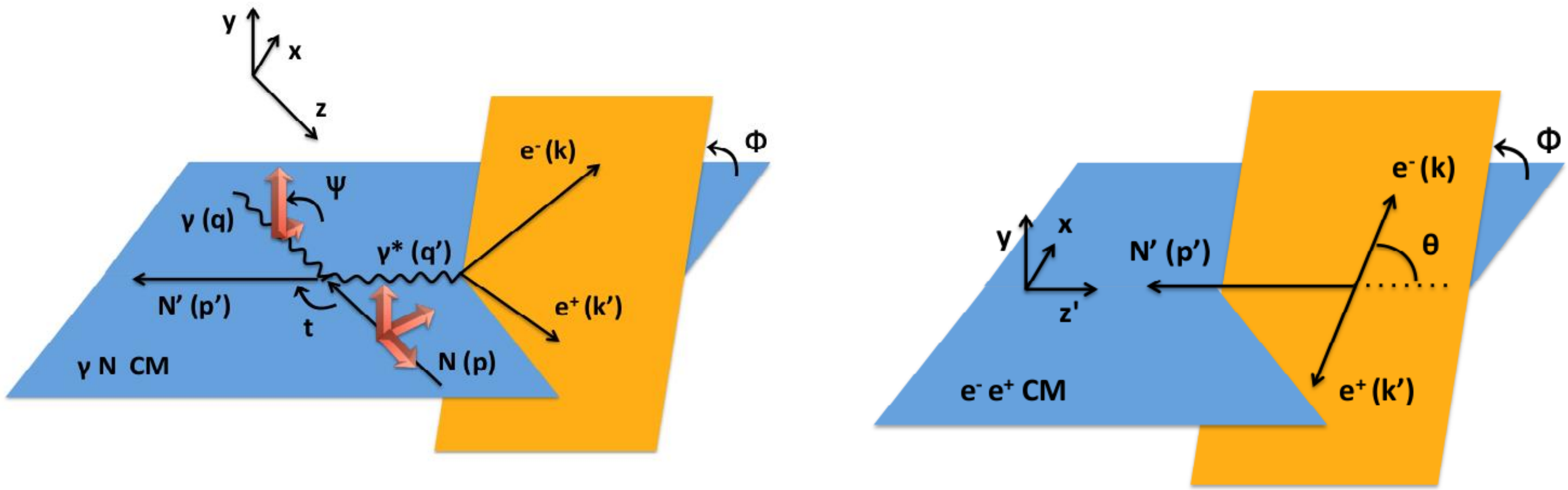






Transverse TSA significant, sensitive to GPDs.

TCS kinematics and cuts



$$\sigma_{TCS} = F(Q'^2, t, \theta_{CM}, \phi_{CM})$$

Analysis cuts:

To have GPD interpretation of TCS:

$$Q'^2 \gg {m_N}^2$$

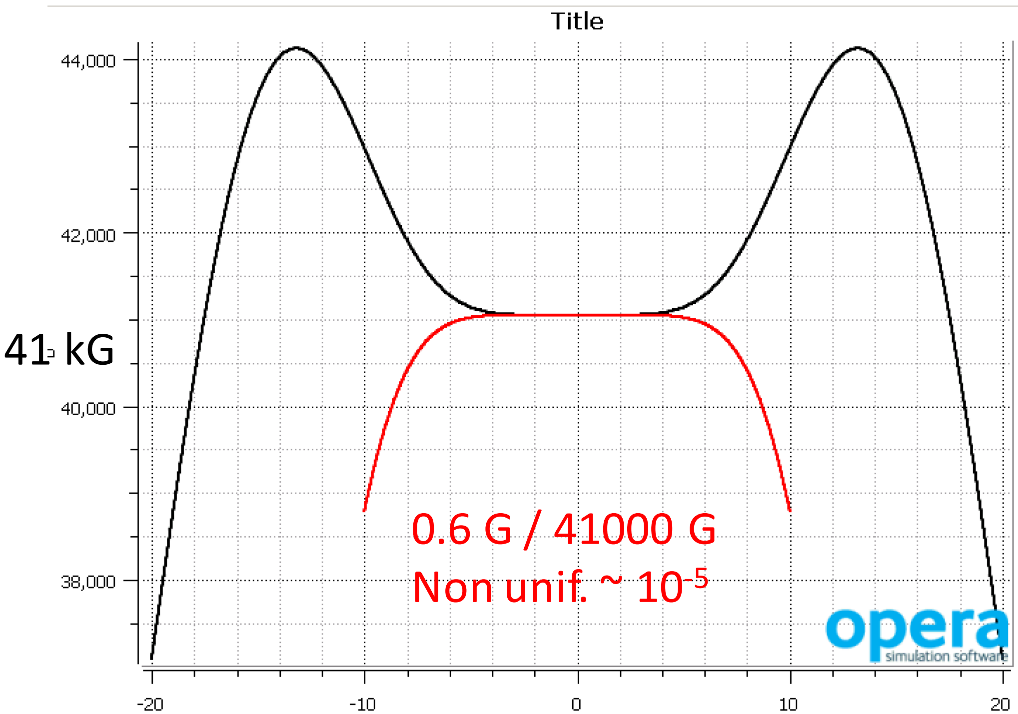
$$\frac{|t|}{Q'^2} \ll 1$$

From DVCS and DIS:

$Q'^2 > 4\,GeV^2$ (*keeps di-lepton system out of resonances*)

$-t < 1GeV^2$ (or $\frac{-t}{Q'^2} < 30\%$)

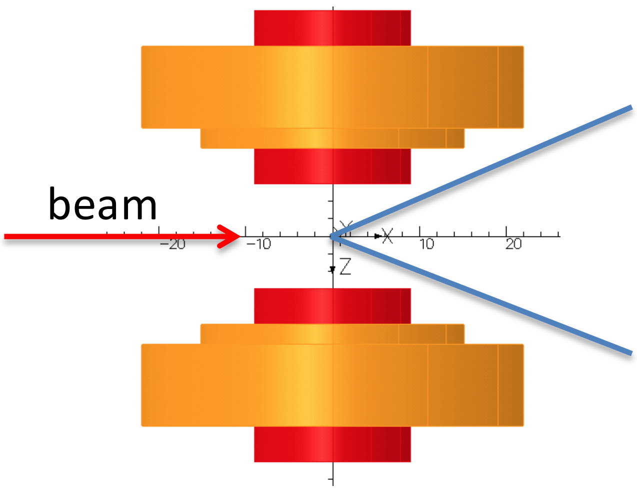
Wide open magnet for NH3 target



Red is Bz along the beam direction
Black is Bz along the axis of a solenoid

Double the gap (+ 10 cm)

Opening is > 50 deg!!



Correction solenoids are outside of the aperture
They drive the field in opposite direction to the main coils field.

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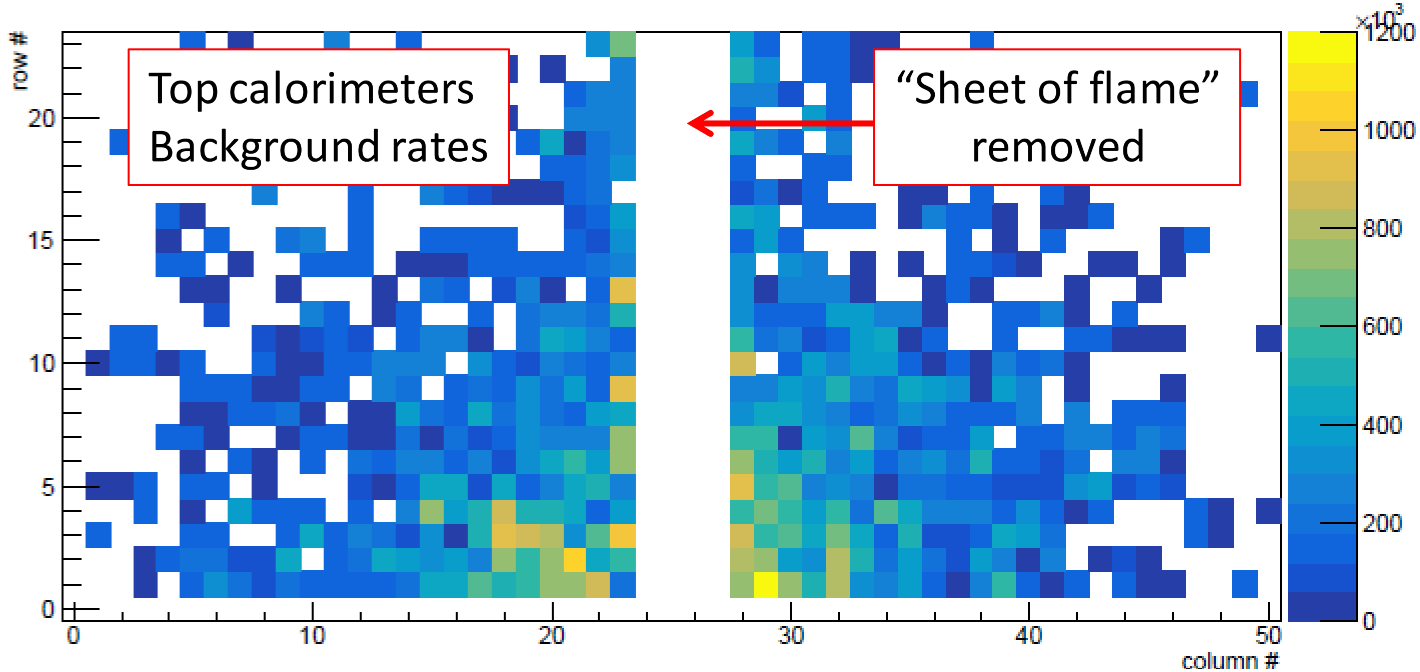
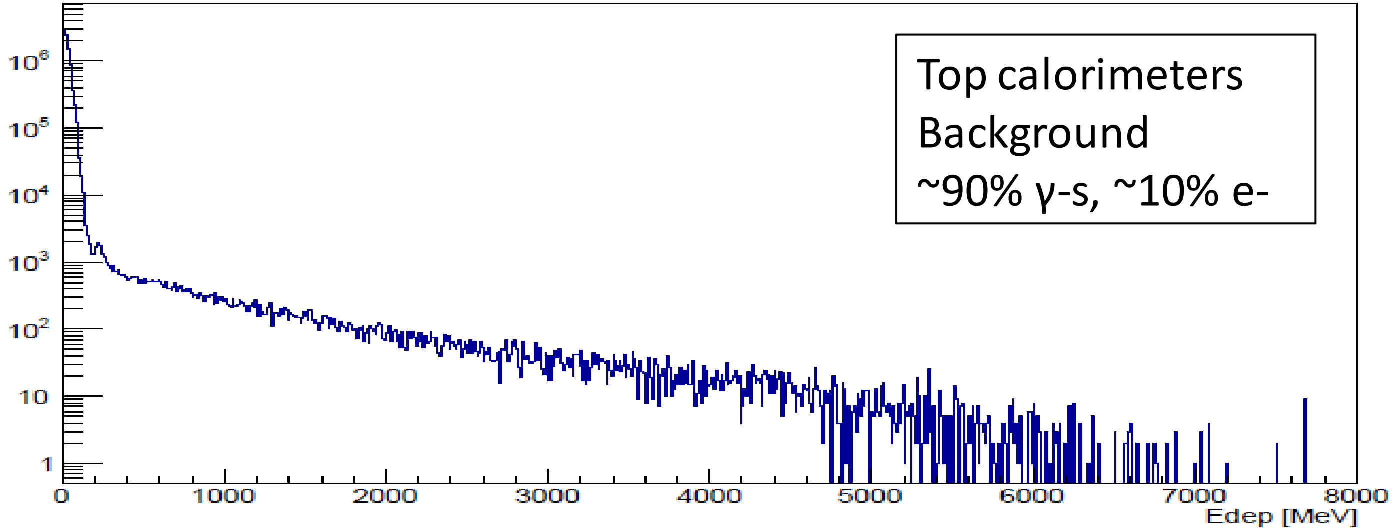
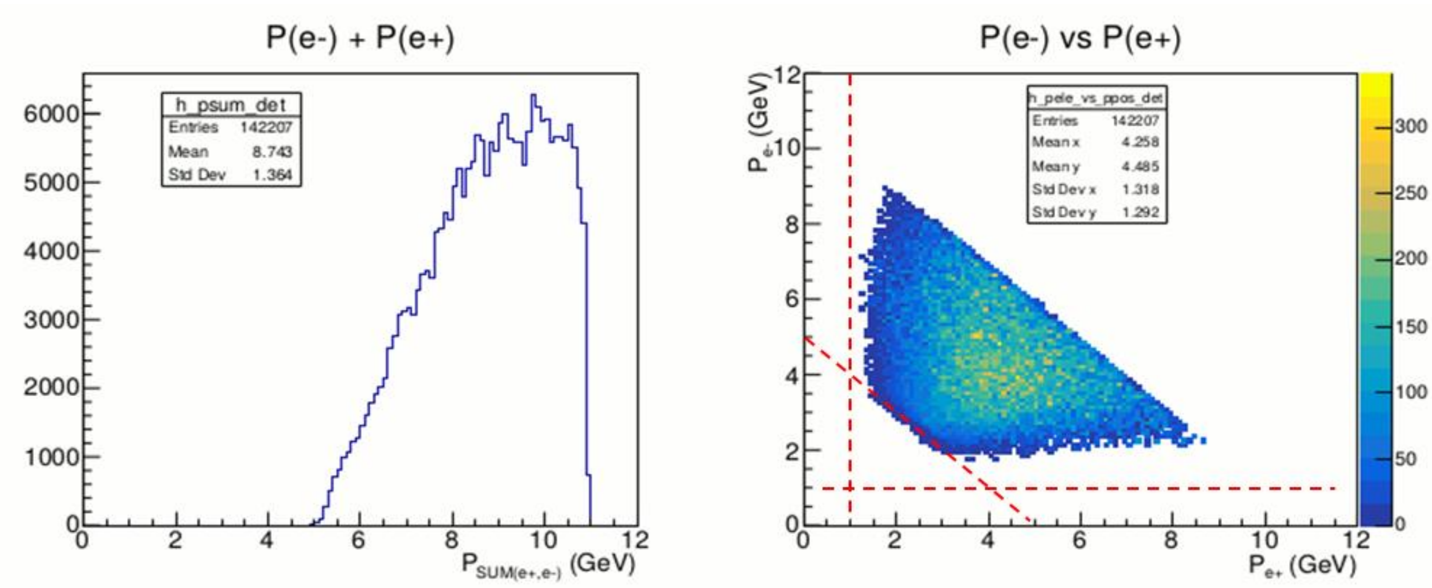
Backgrounds



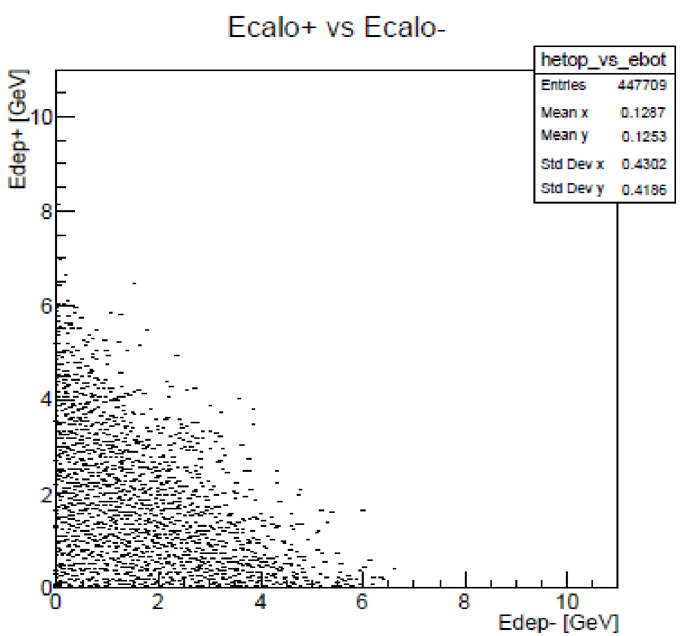


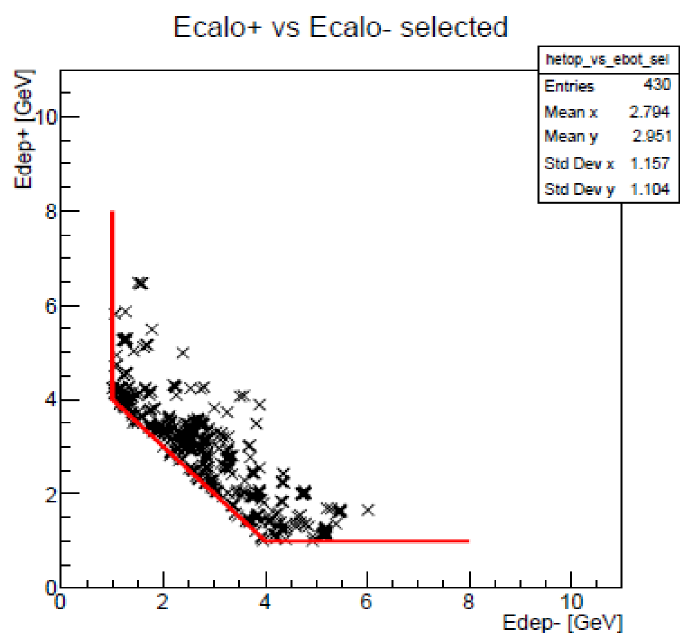
$$E_{beam} \in [5.5, 11]\ GeV, E_{calo\_hit} > 200\ MeV$$

Trigger considerations



Triple coincidence BH events ($4 < Q'^2 < 9\ GeV^2$, $-t < 1 GeV^2$)





Double coincidence background events In the calorimeters, 3 orders reduction due to cuts.