Time-like Compton Scattering with Compact Photon Source

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With help from R.Ent, M.Boër

NPS/CPS Collaboration Meeting
JLab, 1/23/2018

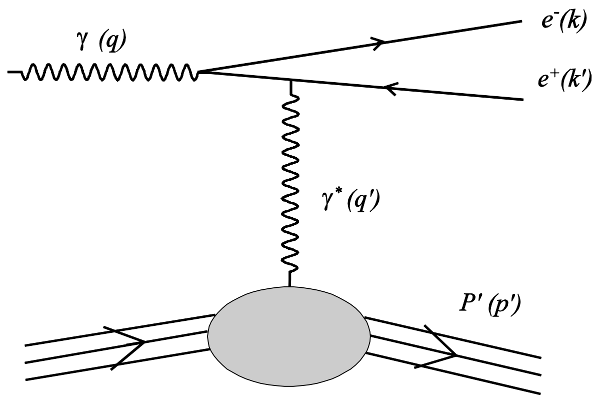
Outline

Physics case and motivation

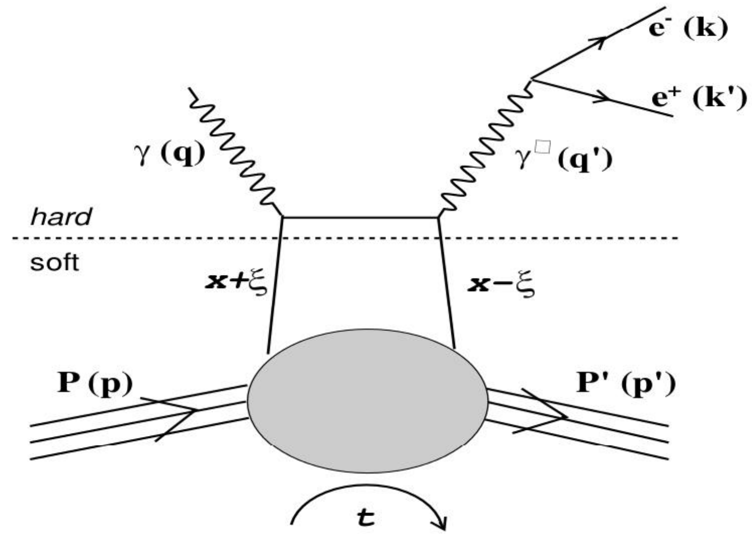
Experimental setup

Summary and Outlooks

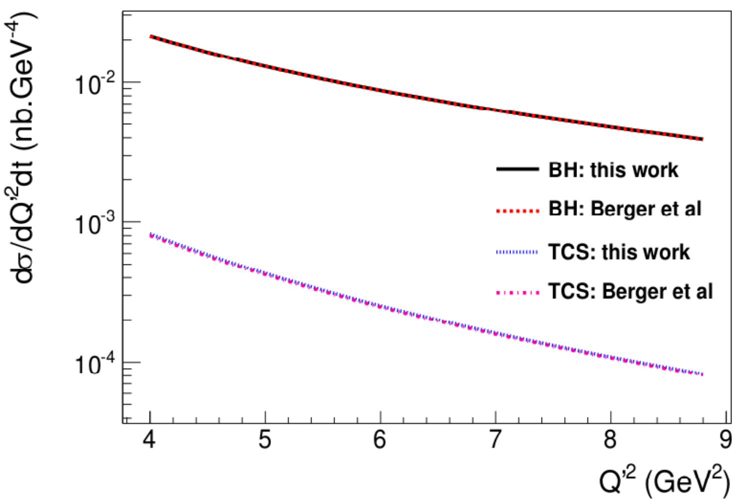
Physics case: general considerations



BH



TCS



M.Boer et al, arXiv:1501.00270

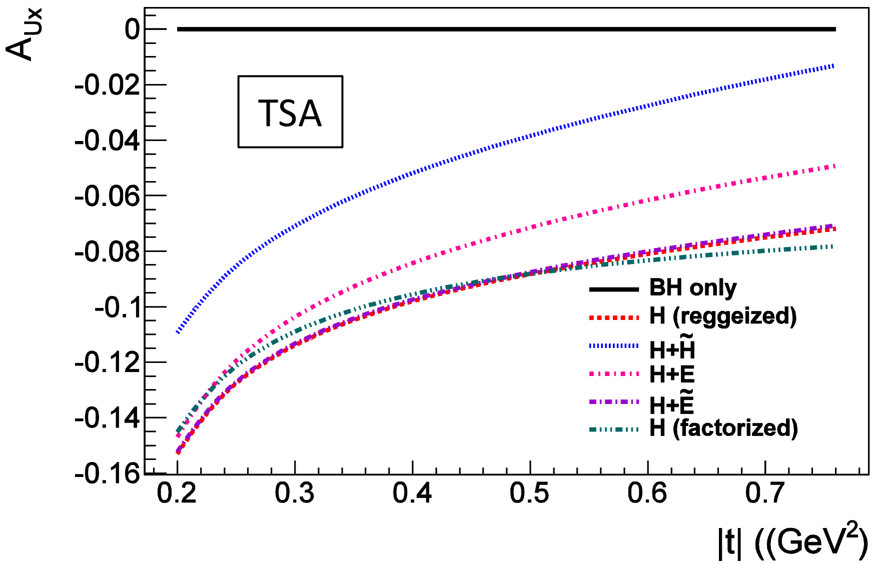
- **BH produces same final state** as TCS.
- At Jlab energies $\boldsymbol{\sigma_{BH} \gg \sigma_{TCS}}$ (10--100 times).
- *But,* **TCS interferes with BH:**

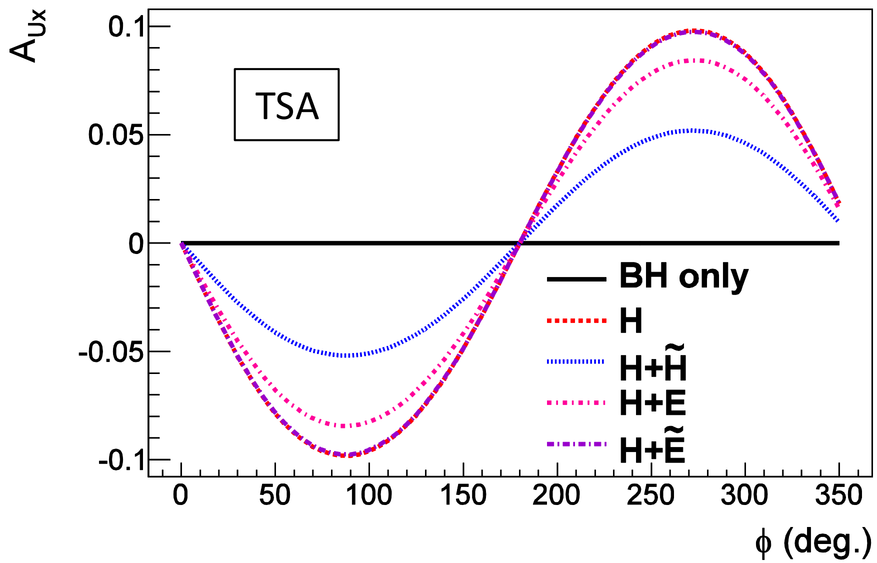
$$d^4\sigma = |T^{BH}|^2 + |T^{TCS}|^2 + (T^{BH} \cdot T^{TCS})$$

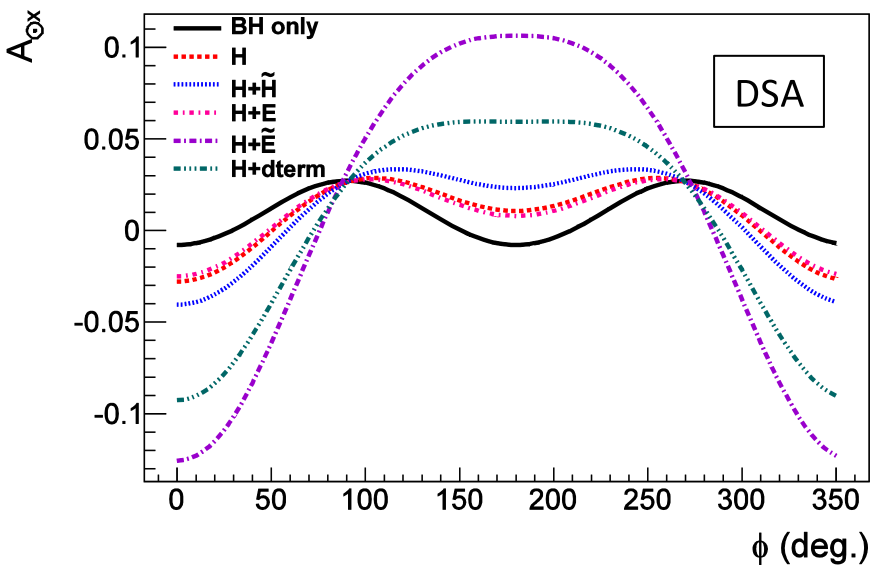
- **TCS signal magnify in interference with BH**.
- **TCS signal can be detected in BSA and/or TSA**.

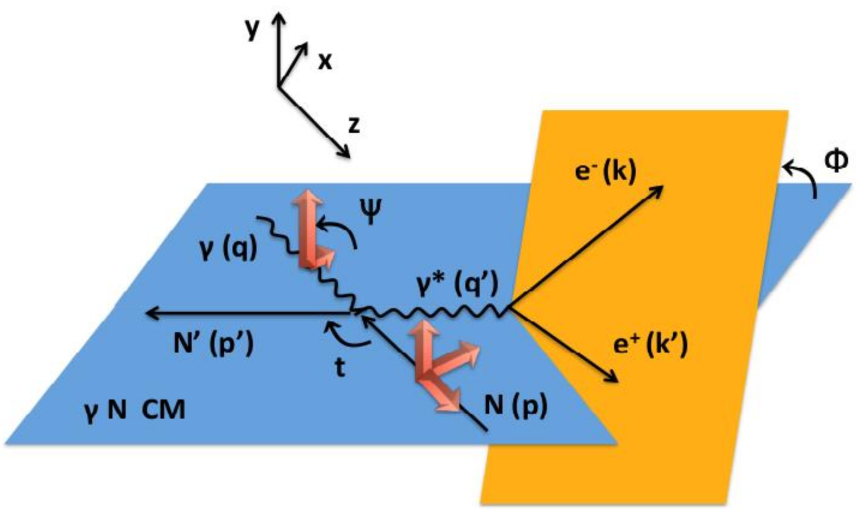
Physics Case: TSA

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









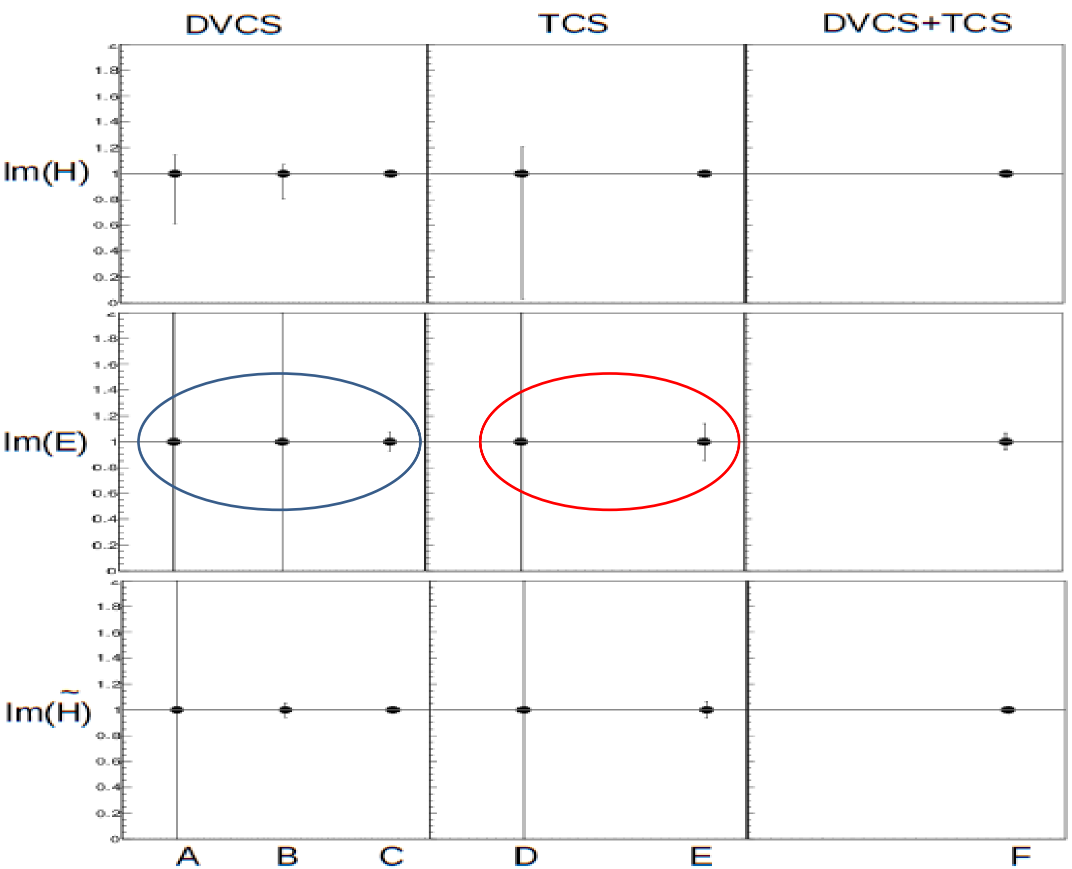
Transverse TSA significant, sensitive to GPDs.

Physics Case: CFF model extractions

Configuration of observables
A. DVCS $\sigma + \Delta\sigma_{LU}$ (Hall A, B, C)[1]
B. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ (Hall B)[1]
C. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{U\perp}$ (+Hall B)[2]
D. TCS $\sigma + \Delta\sigma_{OU}$ (Hall A, B)[1]
E. TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$ (+Hall C)[3]
F. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ + TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$

Legend
___ generated CFF value = 1
--- limits of CFF variation during fit
[1] approved experiments
[2] conditionally approved
[3] proposal in progress
# of independent parameters: 7
Assumed uncertainties: 5% with 20 points for each observable

→ 5% uncertainty in σ^+ and σ^-



→ Universality of CFFs from DVCS and TCS

→ TCS with TSA and $\delta\sigma^{\pm}\sim 5\%$ competitive with DVCS!

→ Universality of CFFs from DVCS and TCS

Transverse spin asymmetries in DVCS and TCS are sensitive to $Im(E)$.

From M.Boer's explorative studies

TCS measurements at JLab

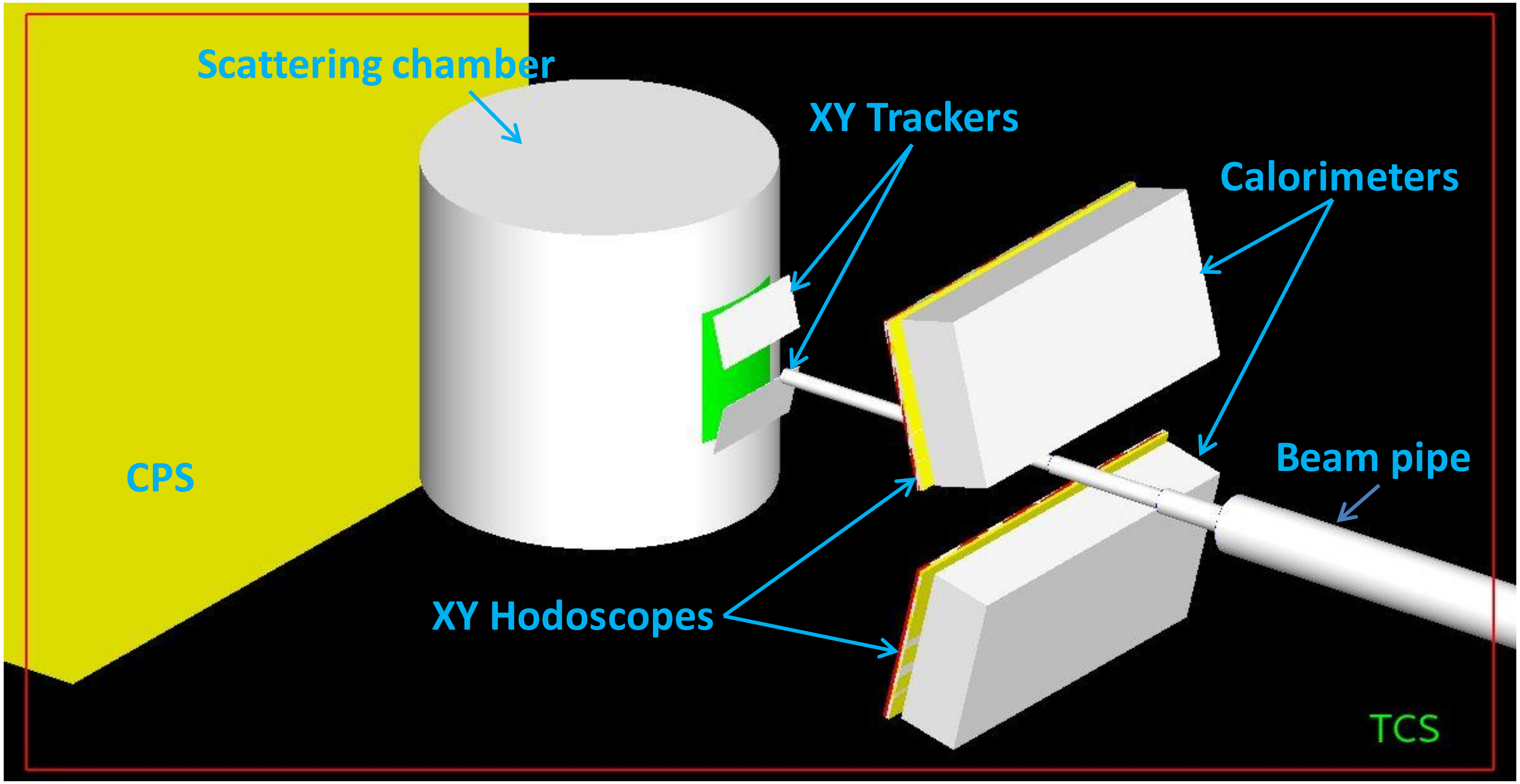
Hall B CLAS 6 GeV, exploratory measurements in 2012
- Quasi-real photons from e- beam on unpolarized target
- Quasi-real photo-production of e-e+ pairs
- Cross section, $\cos\varphi$ moments
- Data taken in 2012, analyzed.

Hall B CLAS12 E12-12-001
- Quasi-real photons from **longitudinally 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 $^{J}/_{\psi}$)

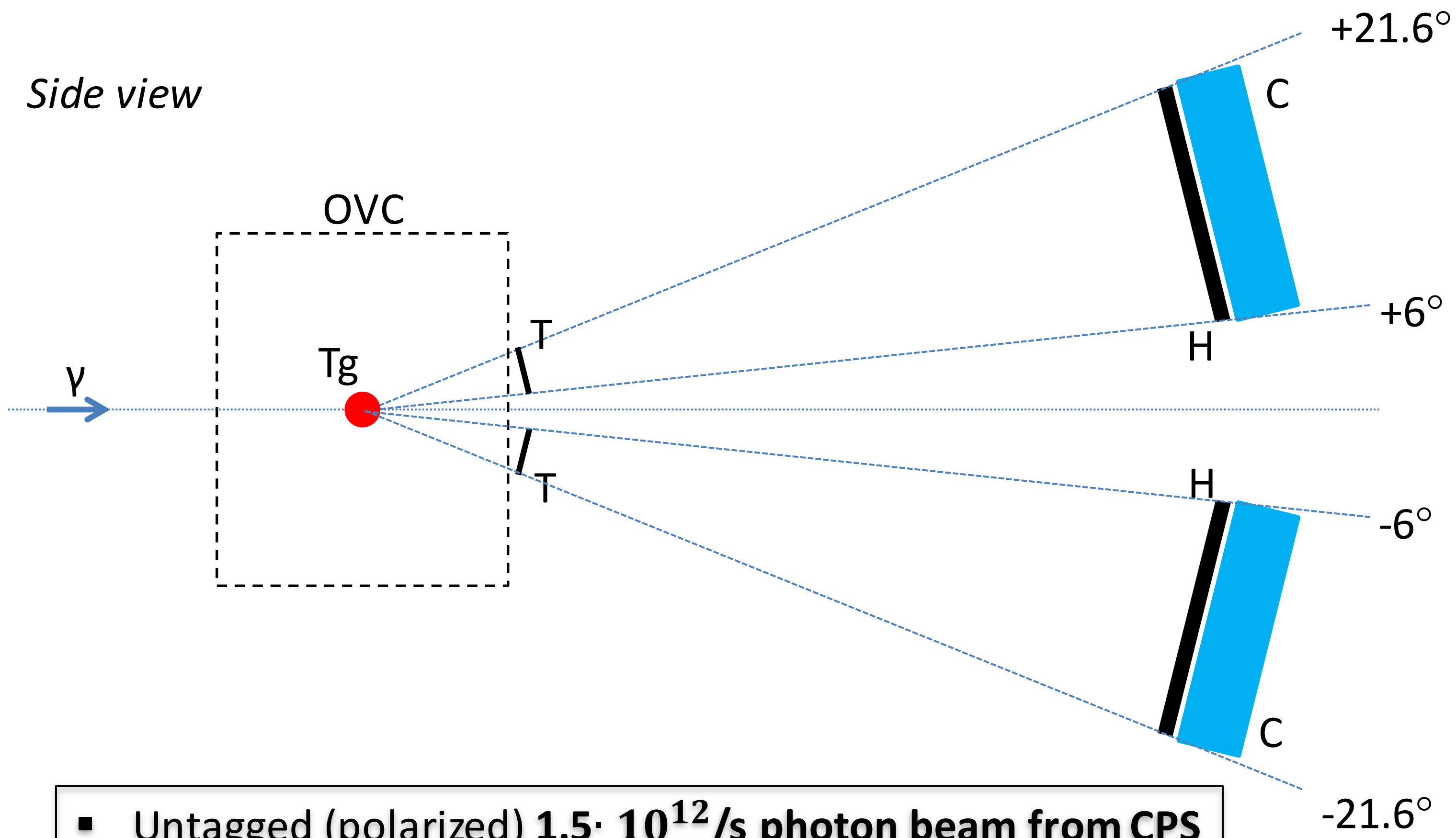
Hall C LOI 12-15-007
- Transversely polarized target, (circularly polarized) untagged photon beam
- Cross section, TSA, (DSA)
- **With CPS, high statistics with photon beam on polarized target!**
- Sensitive to $Im(H)$, $Im(\widetilde{H})$, $Im(E)$ (and $Re(H)$)
- **Universality checks of DVCS and TCS** possible with $Im(H)$ and $Im(\widetilde{H})$.
- **Similar (or even improved!) sensitivity to $\boldsymbol{Im(E)}$** as trans. pol. target DVCS.

Experimental Setup



- Compact Photon Source to deliver beam of untagged photons
- UVA NH_3 transversely polarized target
- Beam pipe of large critical angle
- Detector package of trackers, hodoscopes and calorimeters

Experimental Setup



- Untagged (polarized) **1.5· 10^{12}/s photon beam from CPS**
- **Transversely polarized UVA target** ($\pm 18°$ horizontal, [$\pm 6°$, $\pm 21.6°$] vertical acceptance)
- **Detectors** suited to $\gamma + \vec{p} \rightarrow (e^+, e^-) + recoil\ p$:
  - scin. *T*rackers, scin. *H*odoscopes, EM *C*alorimeters
  - e^+, e^- (charged) detected in *T*, *H*, identified in *C*
  - Recoil p detected in *T* and *H*, identified via TOF

FOM

<u>Figure of Merit</u> for asymmetry measurements with polarized target:

$$FOM = R_A \cdot D_f^2 \cdot P_t^2$$

R_A -- event rate in acceptance,
D_f -- dilution factor of target,
P_t -- target polarization.

Hall B DVCS (PR12-12-10):

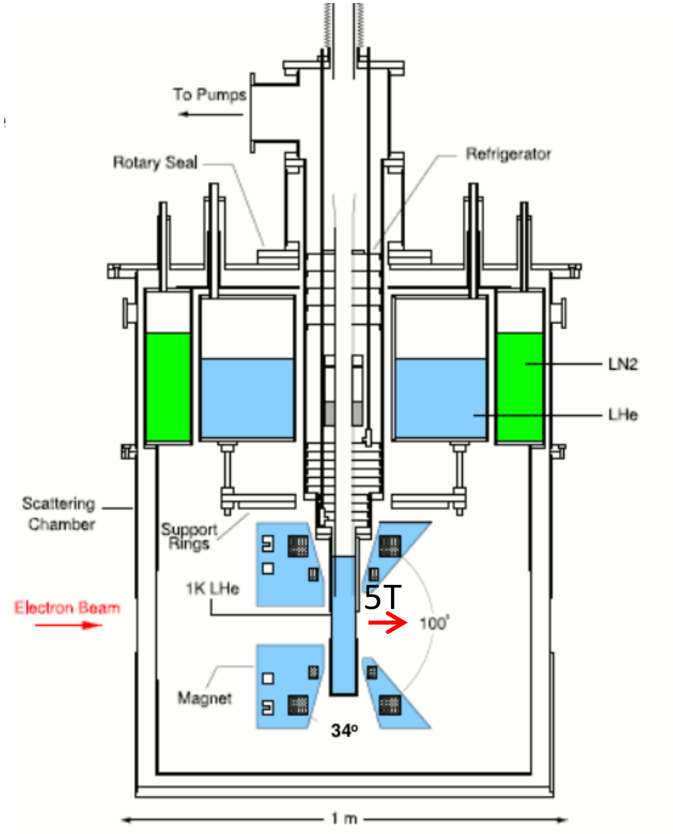
- **Event rate**: **0.36 Hz** total (1M in 100 days → 0.12 Hz useful event rate; ~1/3 dilution factor).
- **Dilution factor: ~1/3.**
- **Target polarization: 60%.**
- $\boldsymbol{FOM = 0.014\ Hz}$.

Hall C TCS:

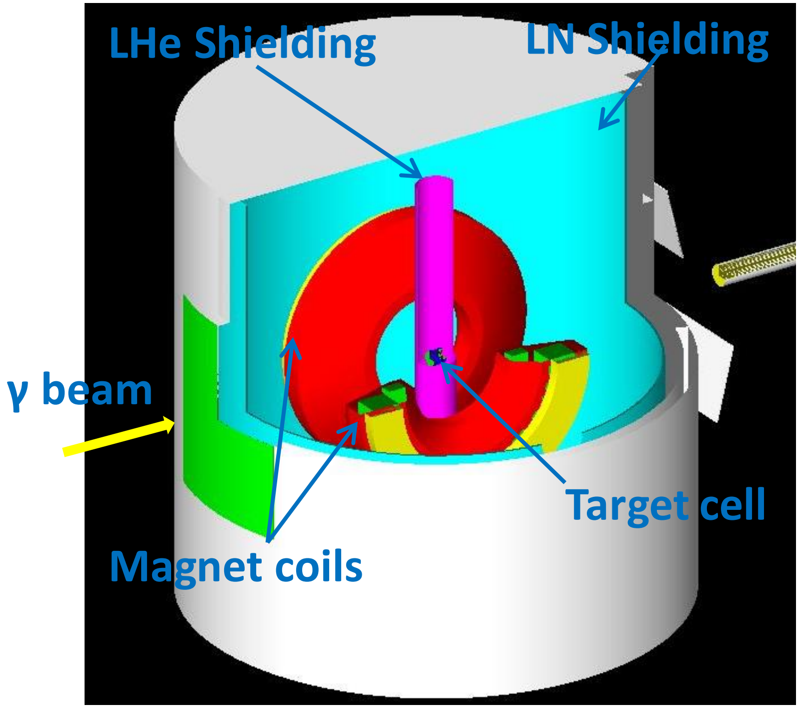
- **Event rate: 0.72 Hz (**simulation with $1.5 \cdot 10^{12}$/s photon flux (WACS proposal), 3 cm UVA target with 0.6 packing fraction);
- **Dilution factor**: **0.154** (naïve estimate; depends on kinematics, ranges from 0.05 to 0.2).
- **Target polarization: 90%** (CUA HIPS workshop).
- $\boldsymbol{FOM = 0.014\ Hz}$.

Hall C TCS project is **compatible**!

Setup: UVA polarized target



UVA target, nominal configuration



UVA target, TCS configuration

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

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

Setup: Trackers

- **Trackers** will be used **for reconstruction of trajectories** and as a **start-time for TOF**.
- Construction analogous to Scintillating Fibre Tracker (SFT) in HERMES Recoil Detector.
- Can be constructed from **1mm Kuraray SCSF-78** fibers with **rad. resistance ~100 Gy/yr**.
- **X and Y planes** of ~ **15×33 cm^2** area. **~150 and 330 fibers per plane**. Accuracy ~ **0.9 mm**.
- **Multi-anode phototubes (64 channel Hamamatsu**) for read-out of fibers.
- **High magnetic field at Trackers**, ~1.5 kG. Light from both sides transported to PMTs by **~2.5 m long Wave-Length-Shifters**, to where field is below ~100 G (like in SANE).

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

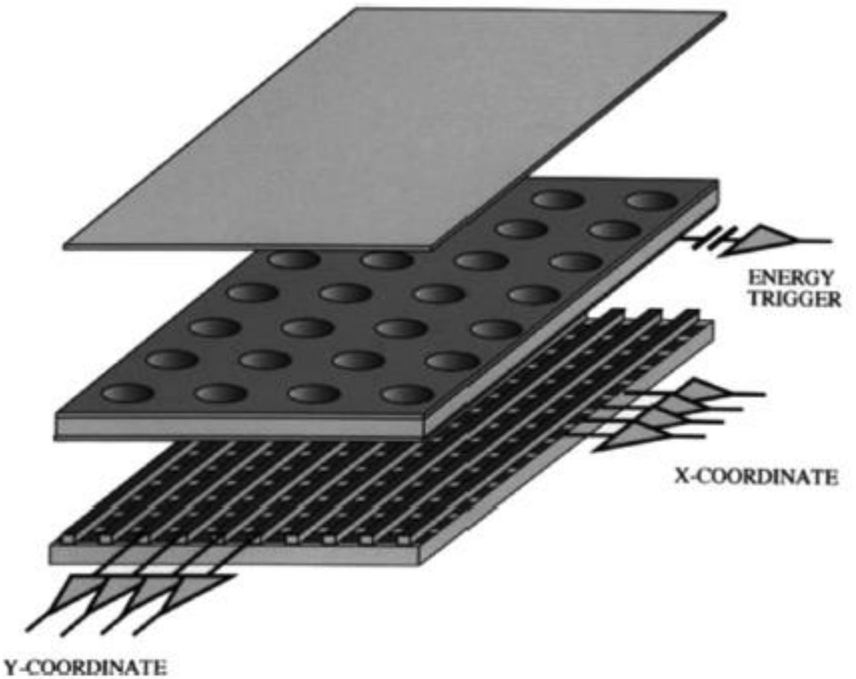
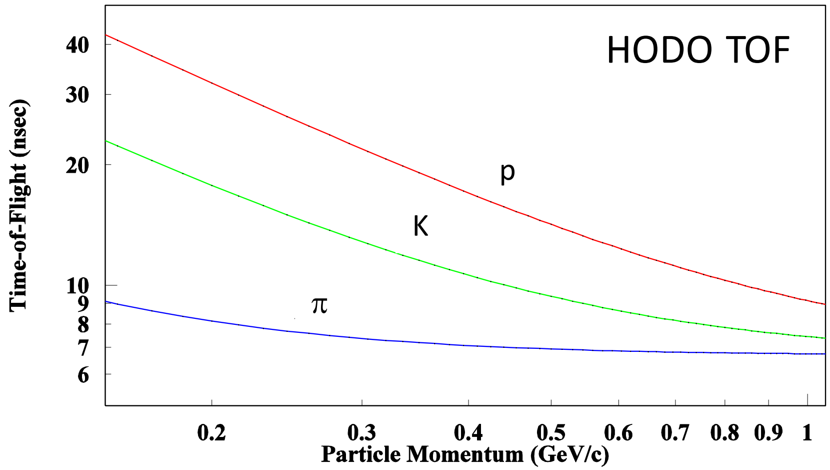
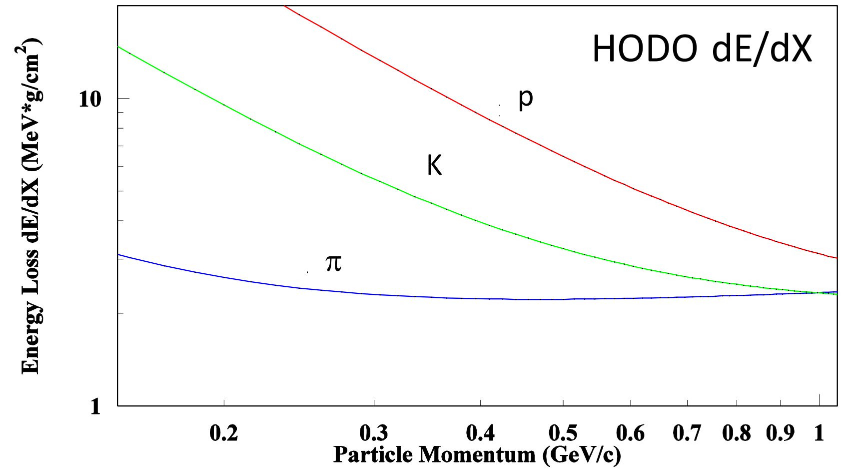


Fig. 3. Schematics of single GEM detector with Cartesian two-dimensional strip readout.

Setup: Hodoscopes

- **Hodoscopes** for reconstruction of recoil **proton (P_p, ϑ_p, ϕ_p)**. Crucial for determining $-t$.
- **Proton identification** with TOF and dE/dx. Expected time **resolution ~200 ps**.
- X and Y planes from **1 cm thick scintillator**.
- **Eff. area** ~ 108 × 48 cm^2 (150 cm from target) to cover ±20° horizontally, 6°--22° vertically.

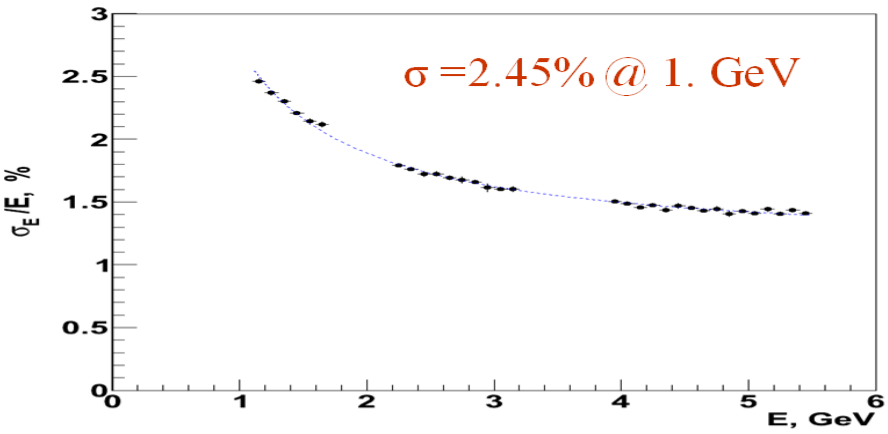


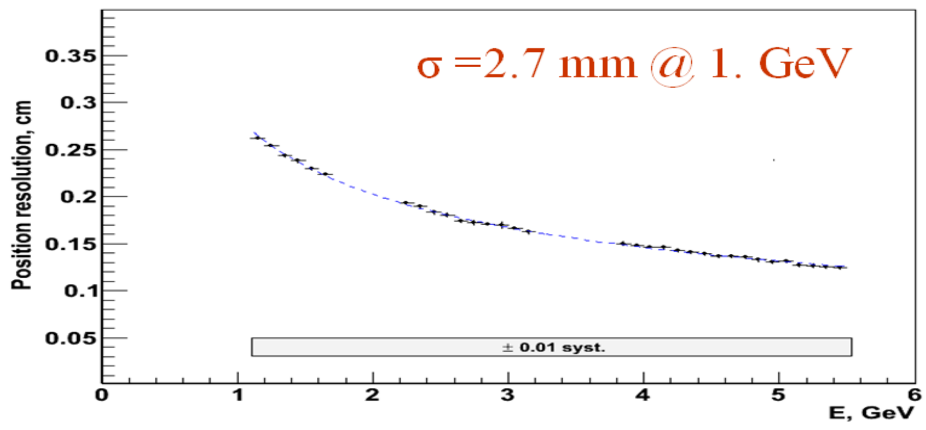


Alternative: Micro-Pattern Gaseous Detectors MPGDs (GEM, THGEM).

Setup: Calorimeters

- **Detect and identify leptons**, measure **energy and X and Y coordinates**. Define Q'^2, ξ and τ.
- A pair of **similar to the NPS** PbWO calorimeters*.
- **Angular acceptance** ±18° horizontally, 6°-21.7° vertically
    - 98×47 cm^2 active area at 150 cm from target;
    - 50 ×23 = **1,150 blocks** total for each calorimeter **(~NPS size)**.

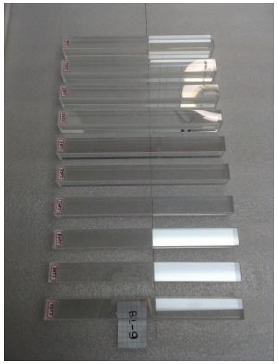




Energy and coordinate resolutions of PrimEx PbWO calorimeter (*from A.Gasparyan)*

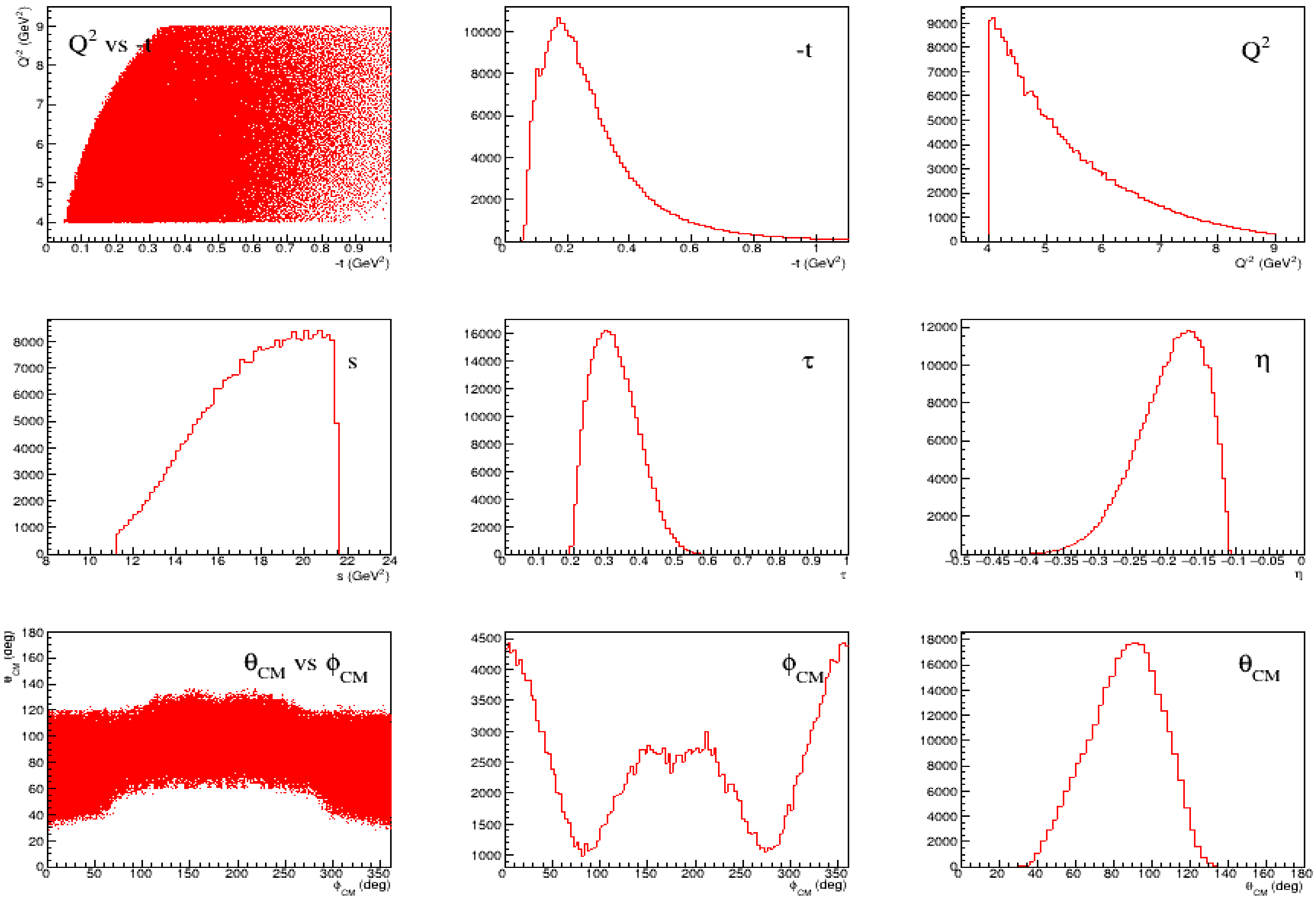
Progress in NPS construction

- 360 PbWO crystals from SICCAS obtained, under evaluation at Jlab, CUA
- 100 R4125 Hamamatsu PMTs obtained
- PMT base prototyped and tested, design construction chosen
- Design of support structures, enclosure underway



**Alternative: combine PbWO calorimeter with* PbF_2 *calorimeter.*

Kinematic coverage



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

Summary and Outlook

TSA measurement with transversely oriented target spin is a *must* for access of imaginary part of GPD E.

Adding data from TCS with transversely oriented target spin to the data bank from other TCS and DVCS experiments **constrains** $\boldsymbol{Im(E)}$, $\boldsymbol{Im(H)}$, $\boldsymbol{Im(\widetilde{H})}$. This renders an opportunity to probe the universality of GPDs, and access OAM of partons.

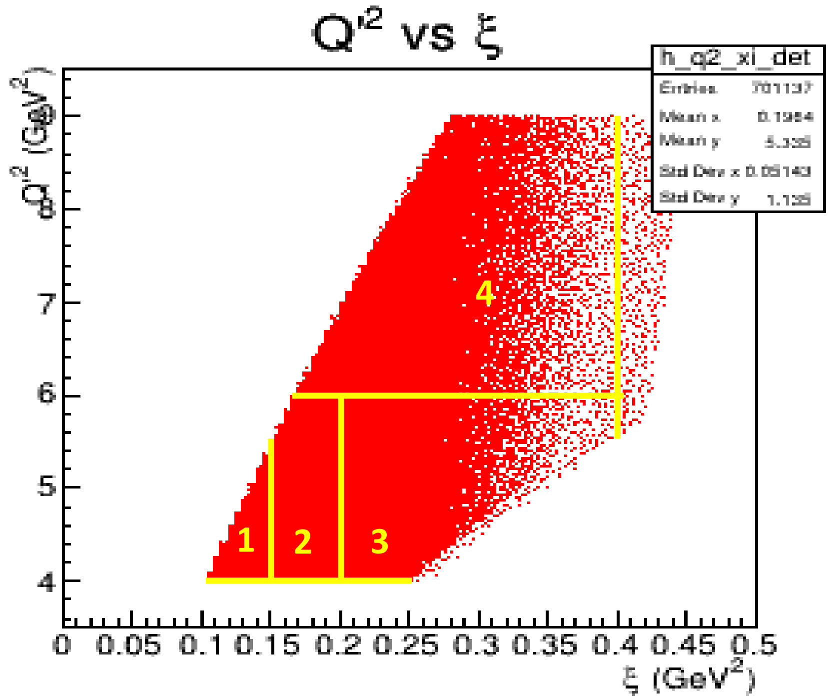
With Compact Photon Source, and modified UVA target, Hall C TCS becomes a competitive project, complementary to other TCS and DVCS measurements.

The proposed modifications of the detector setup may enhance further merits of the project.

Work is underway to compose a **Run Group proposal** of the Hall C TCS and measurements such as SSA in quasi-real photon production off transversely polarized target and exclusive pion production.

Backup slides

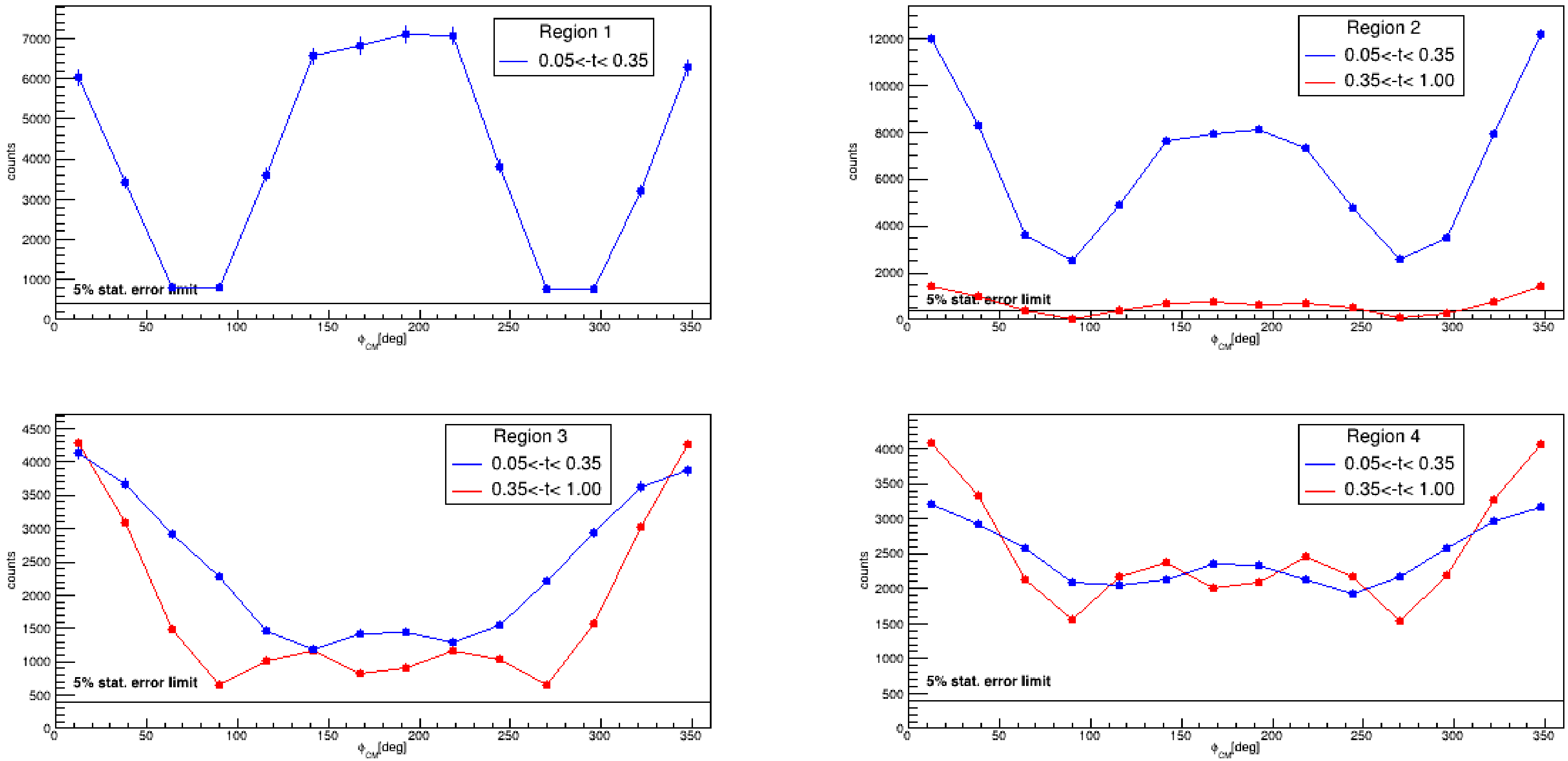
Phase space division



Region	ξ	Q^2	$-t$
1.0	0.10 – 0.15	4 - 6	0.05 – 0.35
2.0	0.15 – 0.20	4 – 6	0.05 – 0.35
2.1	0.15 – 0.20	4 – 6	0.35 – 1.00
3.0	0.20 – 0.40	4 - 6	0.05 – 0.35
3.1	0.20 – 0.40	4 - 6	0.35 – 1.00
4.0	0.15 – 0.40	6 – 9	0.05 – 0.35
4.1	0.15 – 0.40	6 – 9	0.35 – 1.00

Example phase space division for the TCS analysis.
May be optimized based on analysis cuts.

Expected statistics



Expected statistics for 1 month of beam on target, **above required 5% stat. error limit**.
12 – 20 φ_{CM} bins sufficient for data analysis.
The binning may be optimized based on phase space division, analysis cuts.

Physics Case: CFF model extractions

Configuration of observables

A. DVCS $\sigma + \Delta\sigma_{LU}$ (Hall A, B, C)[1]

B. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ (Hall B)[1]

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D. TCS $\sigma + \Delta\sigma_{OU}$ (Hall A, B)[1]

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F. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ + TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$

Legend

___ generated CFF value = 1

--- limits of CFF variation during fit

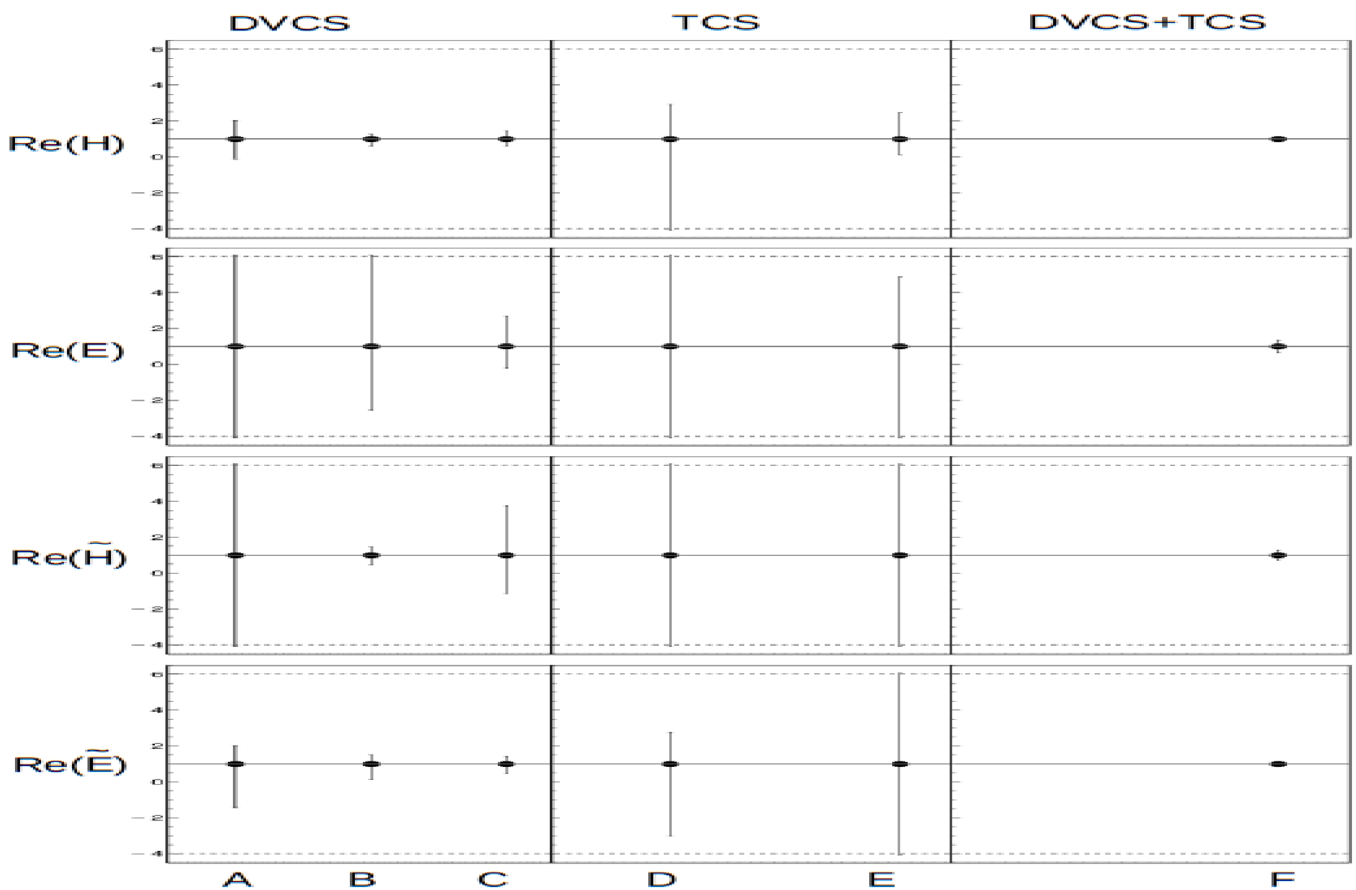
[1] approved experiments

[2] conditionally approved

[3] proposal in progress

# of independent parameters: 7

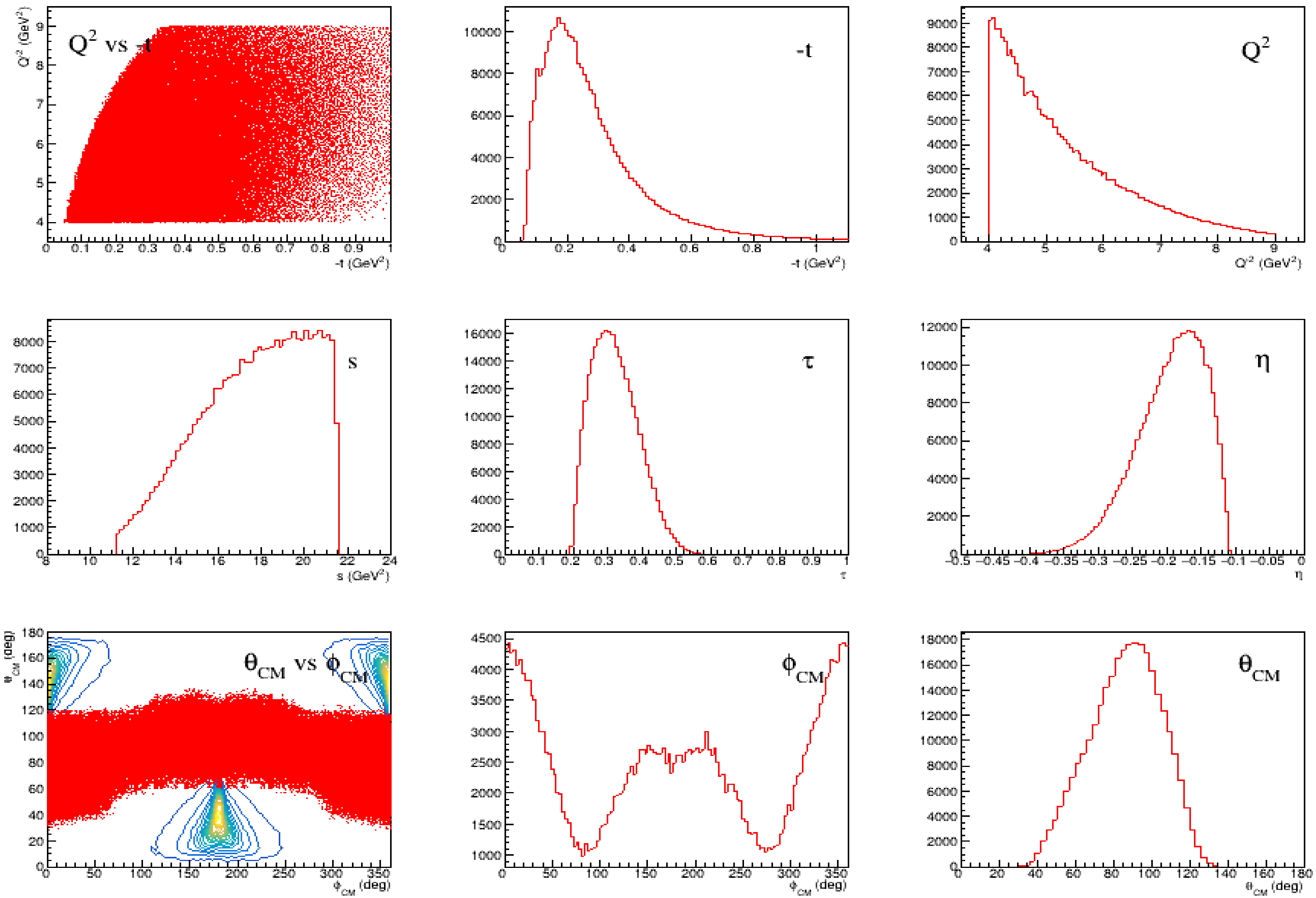
Assumed uncertainties: 5% with 20 points for each observable



Re(E) is not sensitive to TSA in TCS.

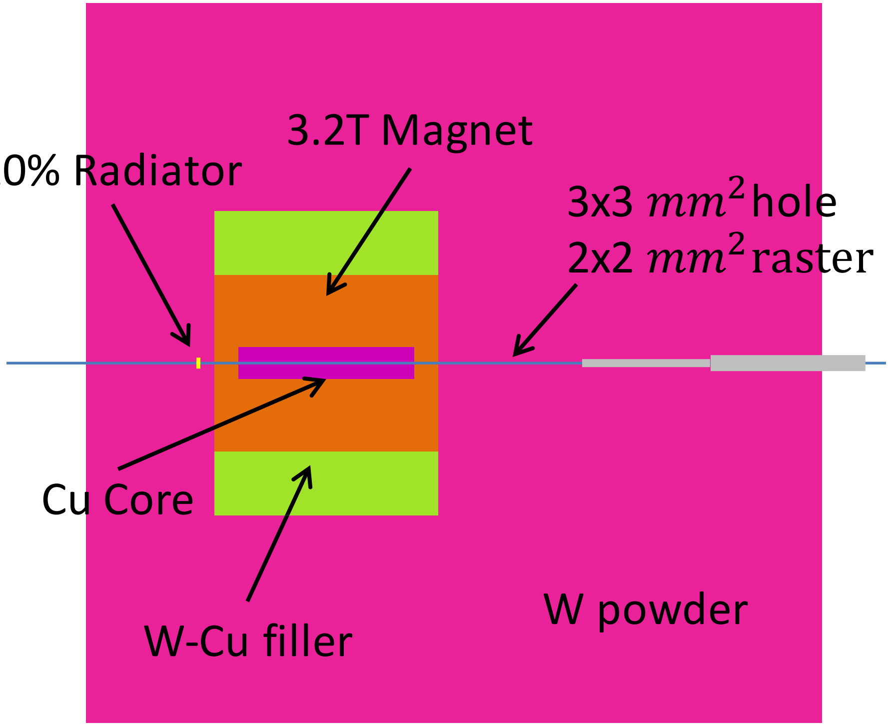
From M.Boer's explorative studies

Kinematic coverage



BH singularities at $(\theta_{CM}, \varphi_{CM}) = (180°, 0°)$ and $(0°, 180°)$ avoided. $\theta_{CM} \sim 90° \rightarrow max\, TH/BH$.

CPS concept



Stage-2 modeling, October 2017, 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

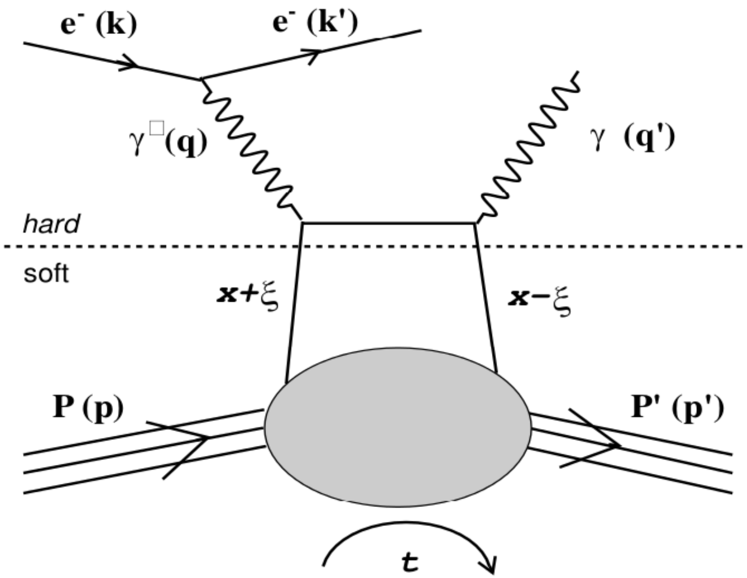
- Up to 2.7 µA, 11 GeV e- beam incident
- 10% radiator to produce (untagged) γ beam
- 3.2 T, 40 cm magnet to bend residual e^-
- Magnet serves as a beam dump
- High Z shielding to minimize prompt radiation and residual activation

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

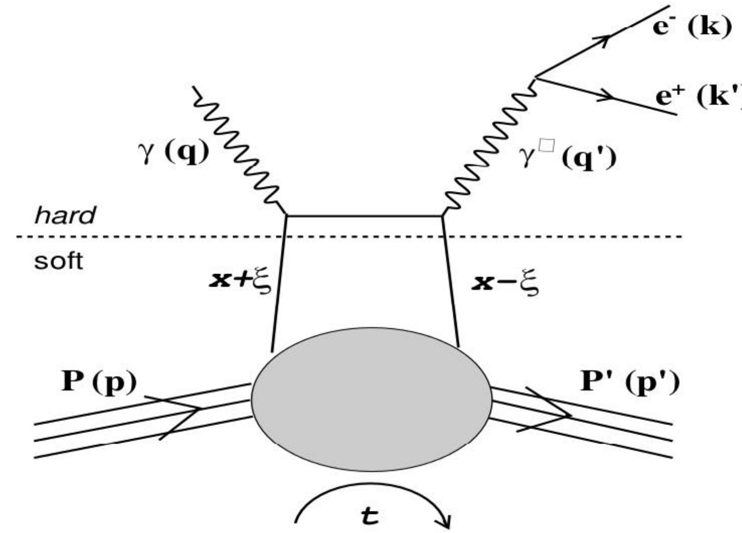
- increase of useful photon flux by 18 times ($\sim 10^{12}\ ^{\gamma}/_{s}$);
- less heat load, increase of max. polarization from 90% to 95%;
- less rad. damage to target material, less depolarization -> increase of average polarization from 70% to 90%.

Overall increase of FOM 30 times!

Physics case: TCS -- DVCS relations



DVCS



TCS

- **DVCS and TCS, limiting cases** of double DVCS (DDVCS)

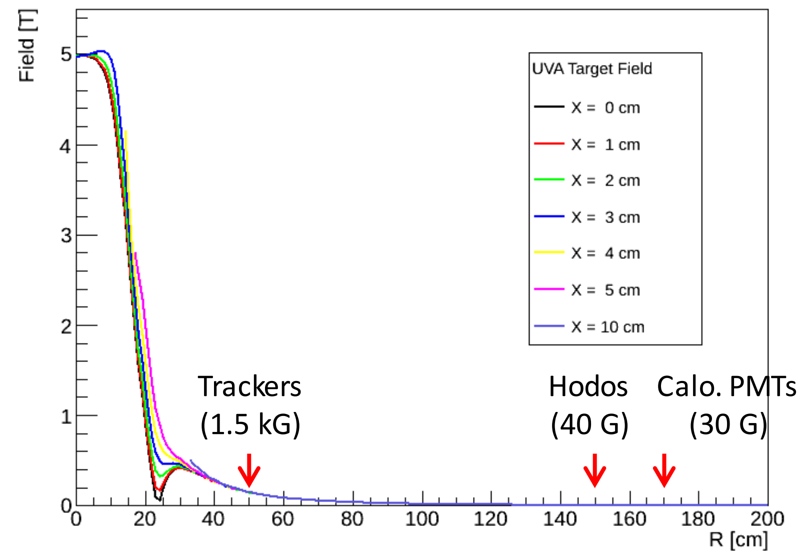
$$\gamma^*(q) + P(p) = \gamma^*(q') + P(p').$$

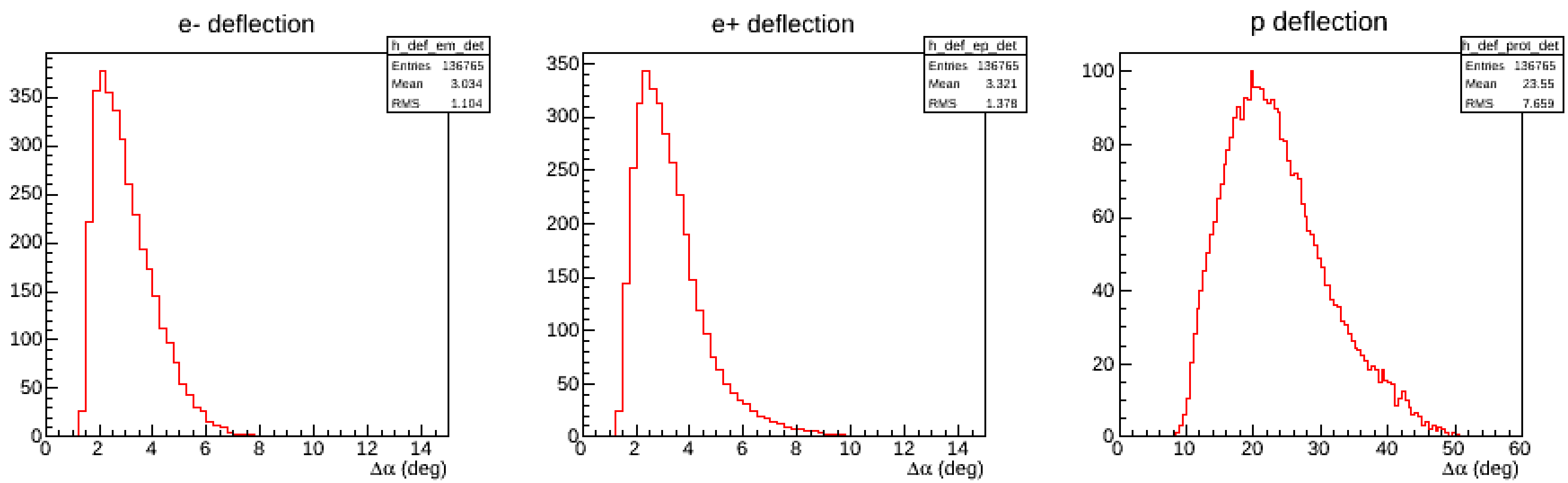
- At leading order of α_S and leading twist **CFFs are complex conjugate**.
- **NLO and HT effects different** in space-like and time-like, can be evaluated from TCS/DVCS.
- Comparison of DVCS and TCS**, test for universality** of GPDs.
- **Complementarity of observables** sensitive to different CFFs.
- Combine DVCS and TCS data → **reduce uncertainties of the CFF fits over DVCS only.**

See M.Boer, GPD studies with exclusive dileptons photo- and electro-production, INT Workshop, University of Washington, 08/28-09/01, 2017.

TCS Analysis Options

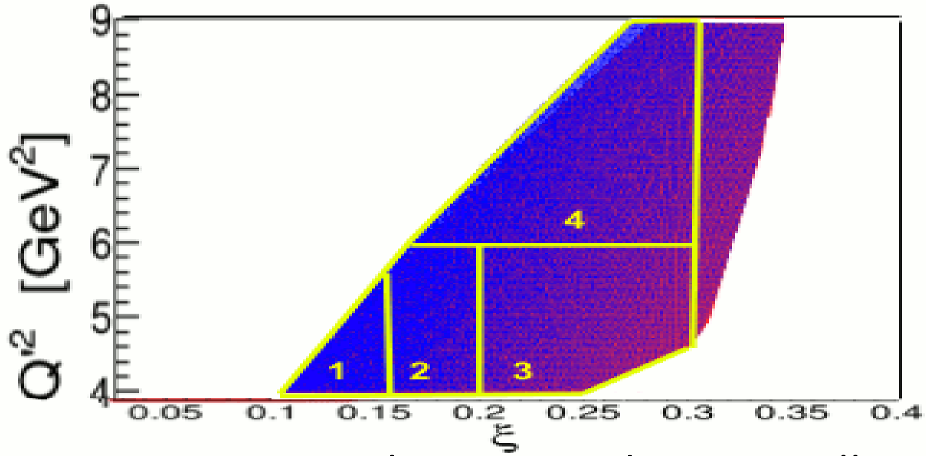
- **Significant magnetic field** from target, mostly transverse and confined in R < 20 cm.
- **Bends vertically** e^+, e^- by ~2.5°, and p by 20 °!
- **Will reconstruct tracks at vertex** (provided field is mapped to good accuracy).
- **Reconstructed momenta** can be used in conjunction with β_{TOF} for PID.





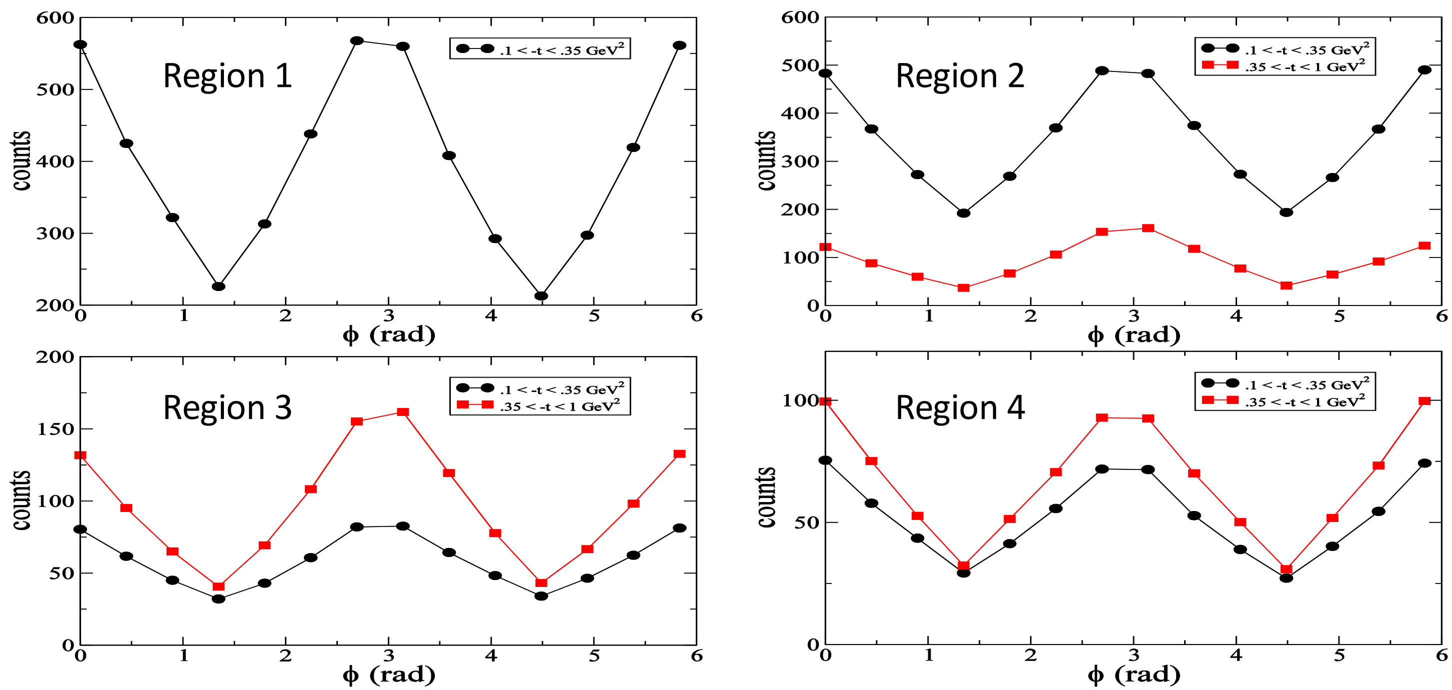
Deflections of accepted tracks in the target magnetic field (BdL~0.7 Tm) relative to directions at target (from simulations).

Phase Space Binning (LOI)



N	ξ limits	Q'² limits (GeV²)	-t limits (GeV²)
1.0	0.10, 0.15	4, 6	0.1, 0.35
2.0	0.15, 0.20	4, 6	0.1, 0.35
2.1	0.15, 0.20	4, 6	0.35, 1
3.0	0.20, 0.30	4, 6	0.1, 0.35
3.1	0.20, 0.30	4, 6	0.35, 1
4.0	0.15, 0.30	6, 9	0.1, 0.35
4.1	0.15, 0.30	6, 9	0.35, 1

Phase space division. Will study Q^2, ξ and t dependences.

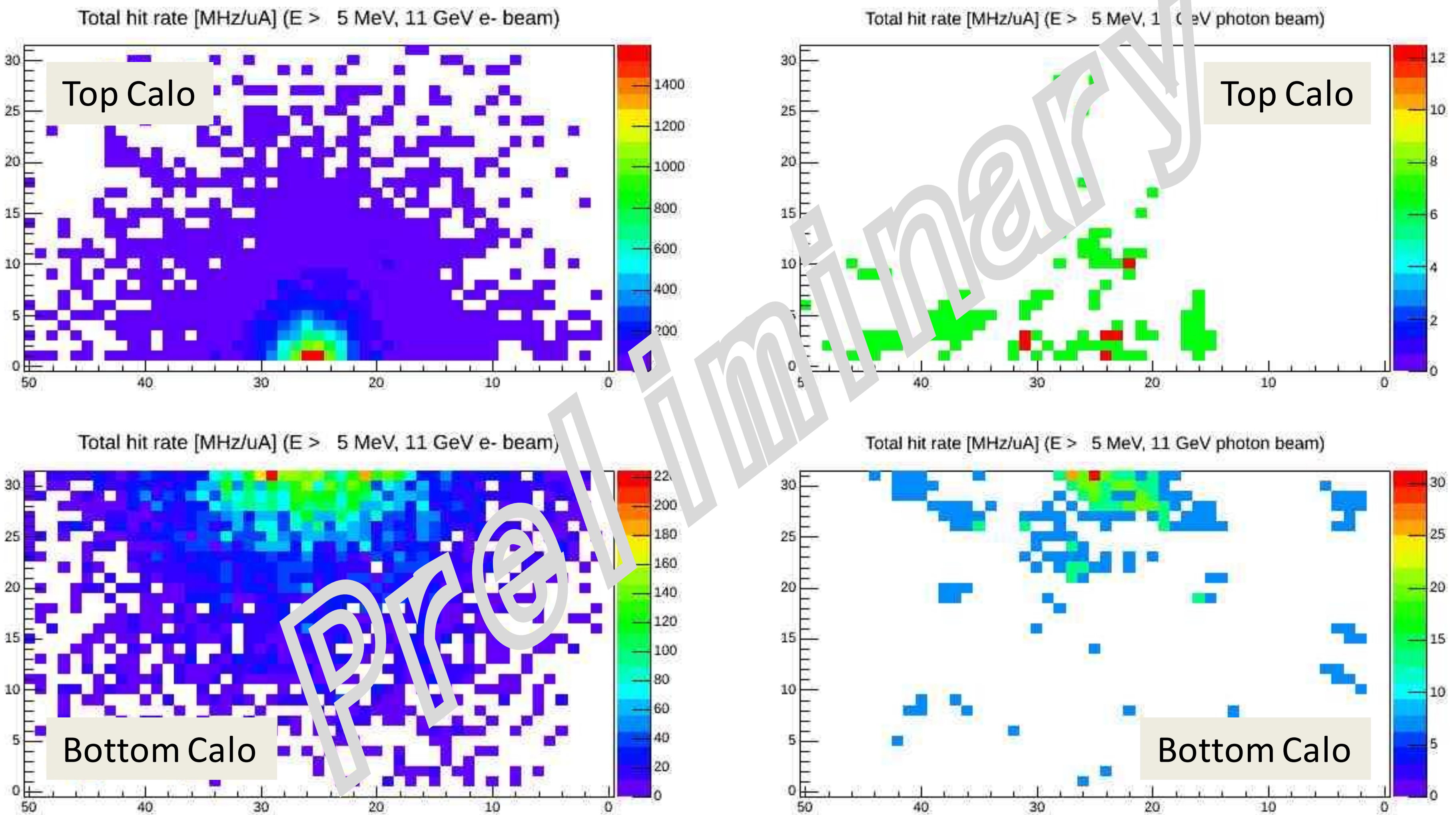


Count rates in 14ϕ_{CM} bins.

Preliminary result from G4 simulation

<u>Beam mode</u>

11 GeV **e-** beam | 11 GeV **photon** beam

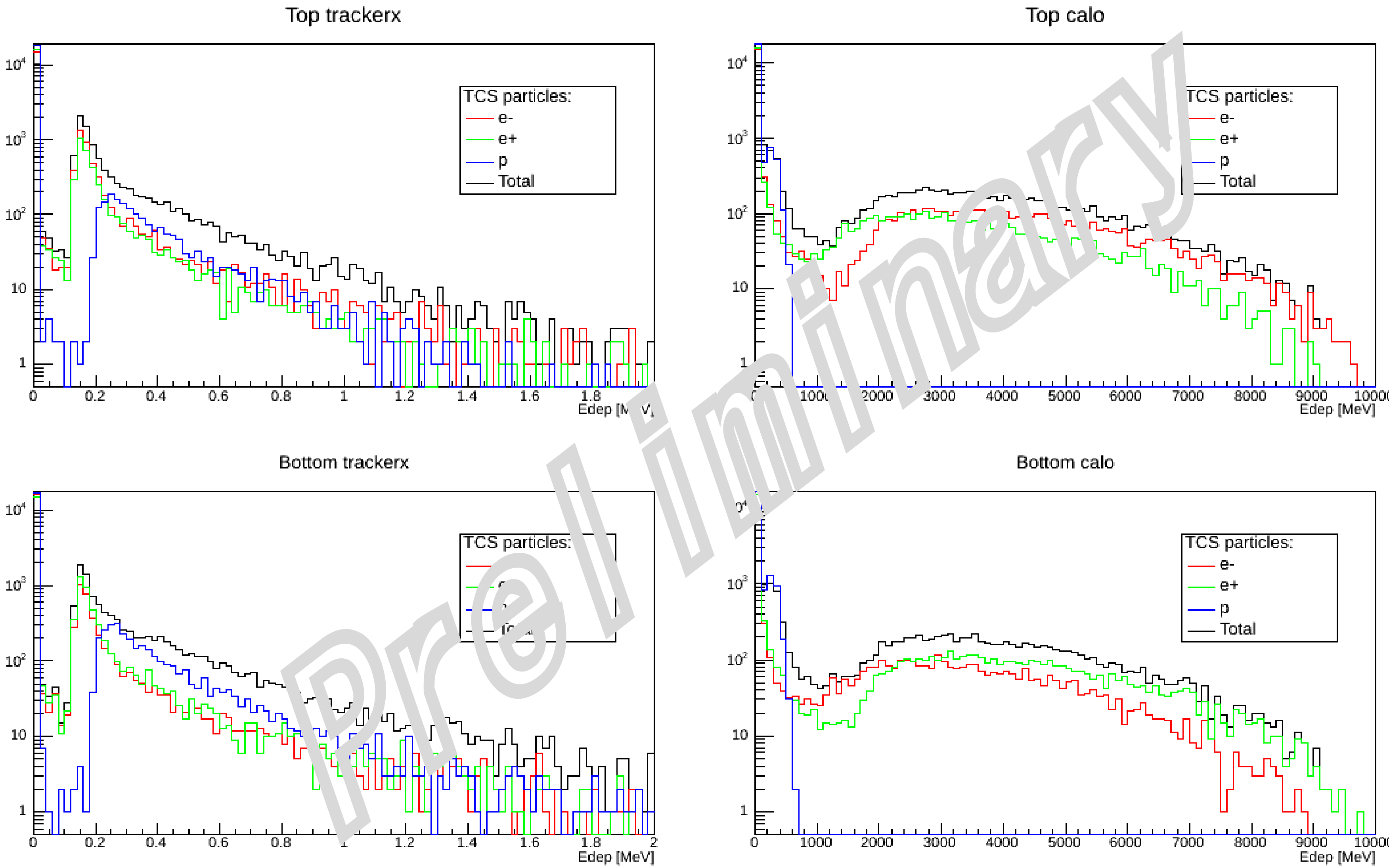


Significantly lower background hit load from photon beam than from electron beam.

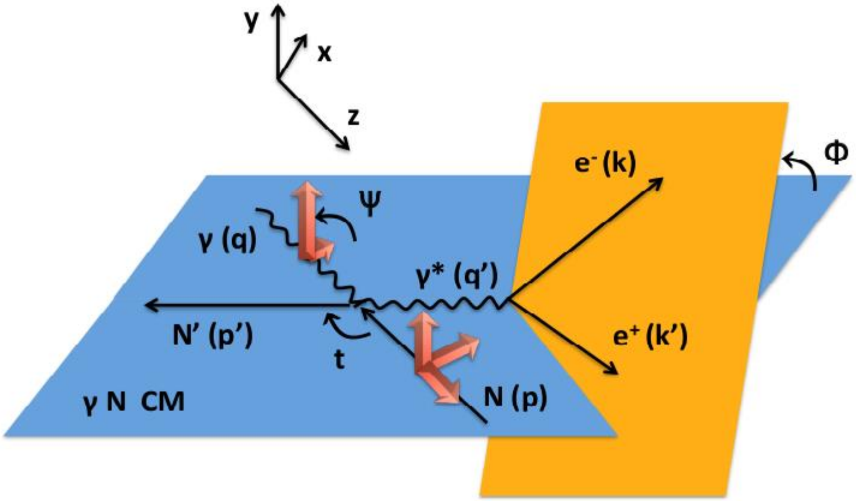
Preliminary result from G4 simulation

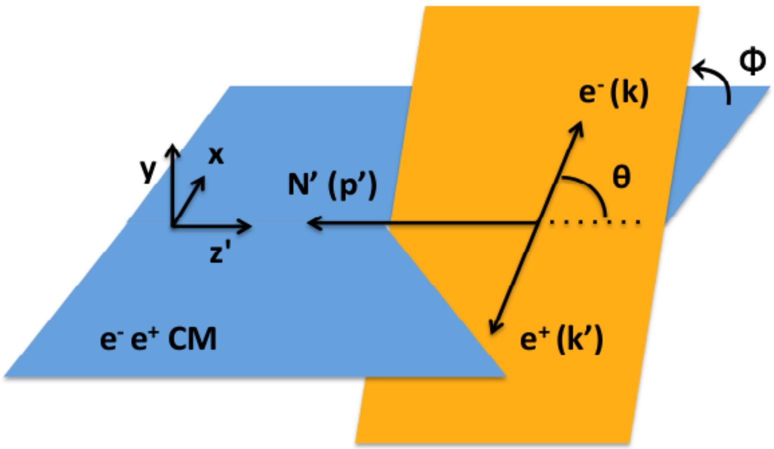
<u>TCS_mode</u>

Energy depositions



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:

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

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