

Time-like Compton Scattering with Compact Photon Source

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(AANSL)

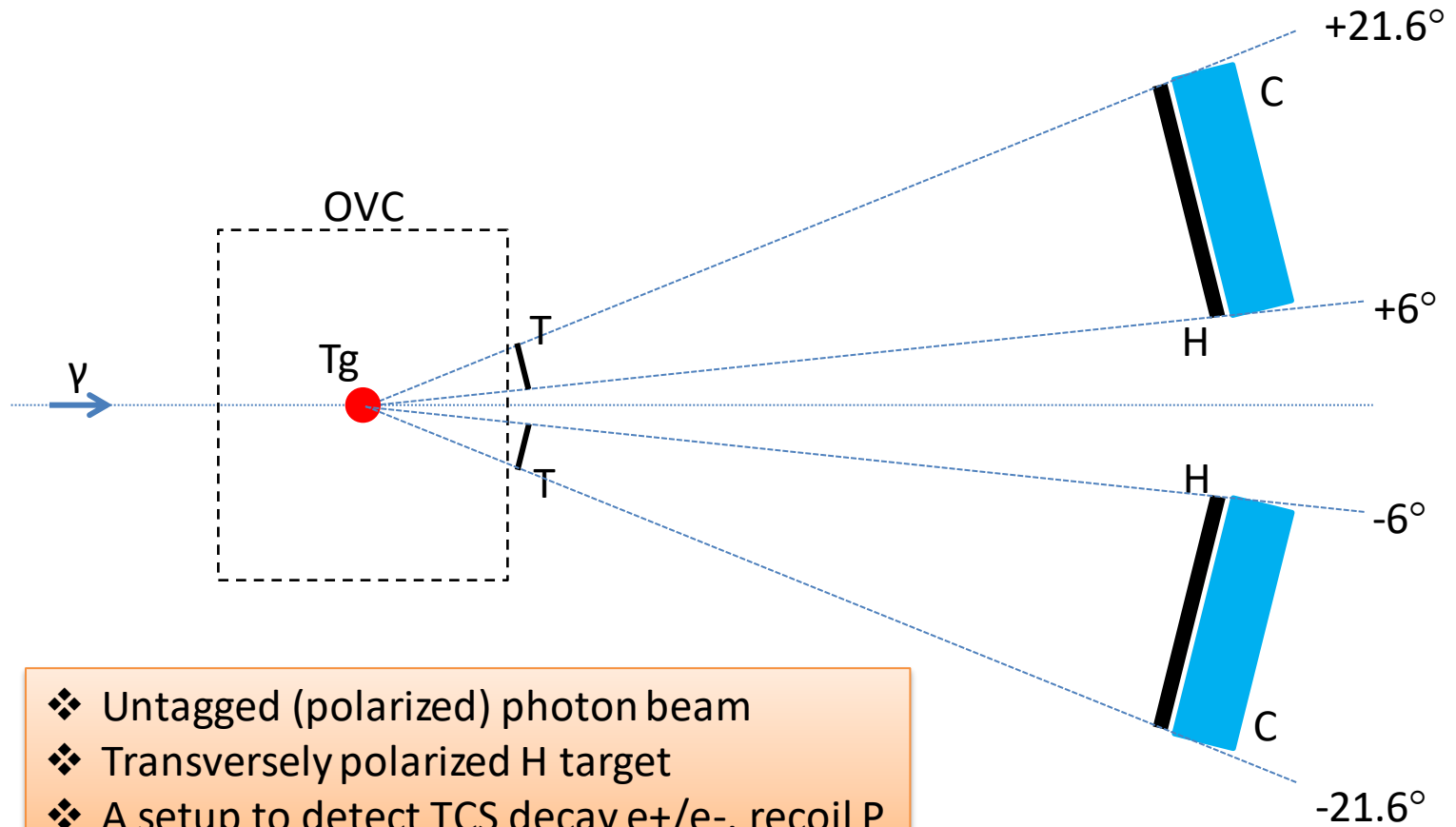
NPS/CPS Collaboration Meeting
JLab, 1/23/2018

Physics case and motivation

Experimental setup

Summary and Outlooks

Hall C TCS basic concept

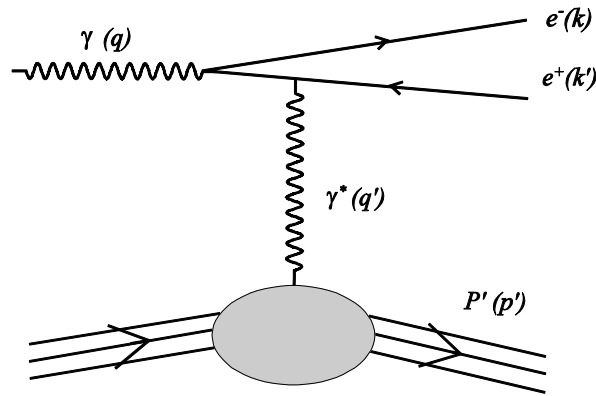


- ❖ Untagged (polarized) photon beam
- ❖ Transversely polarized H target
- ❖ A setup to detect TCS decay e^+/e^- , recoil P

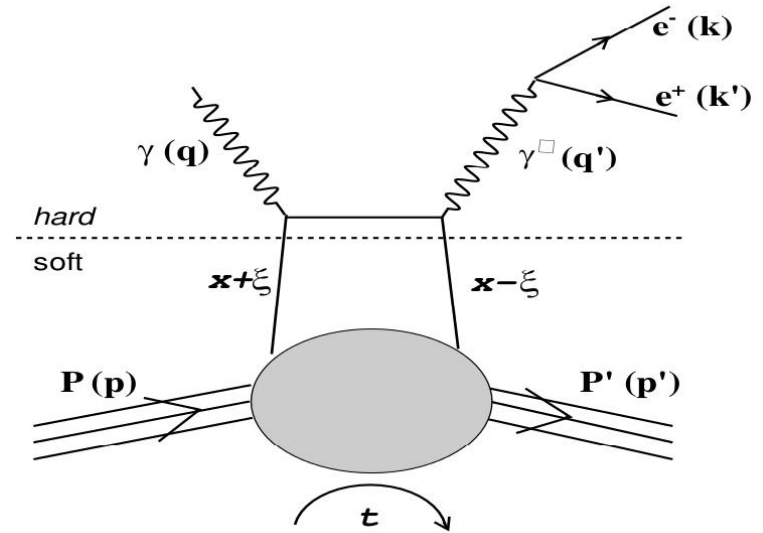
Measure target (beam) spin asymmetry

Access GPDs

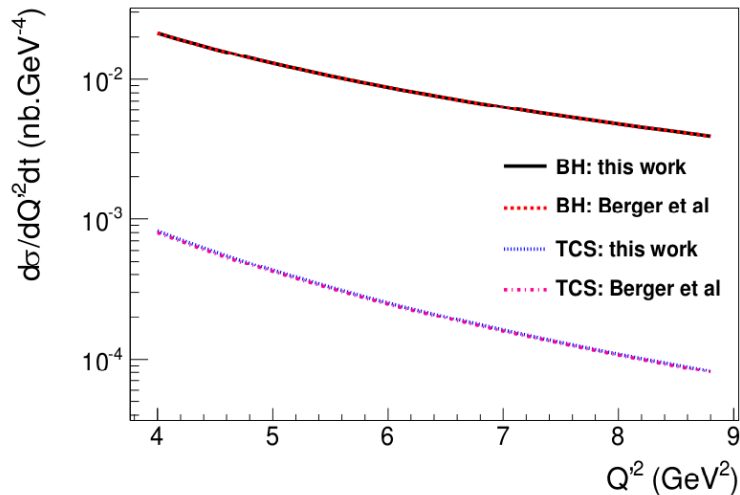
Physics case



BH



TCS



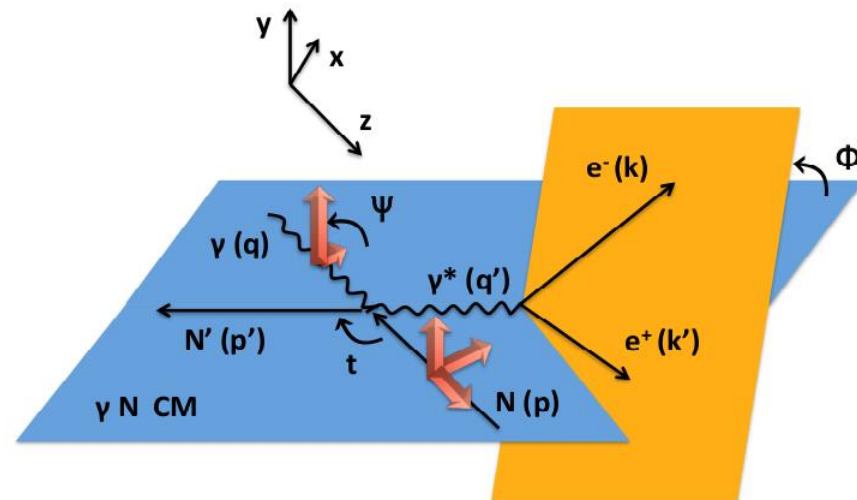
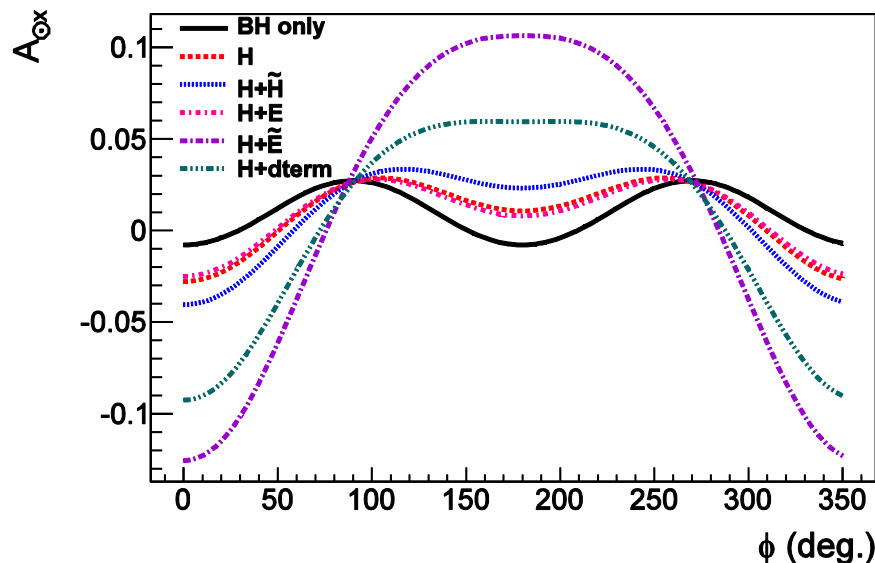
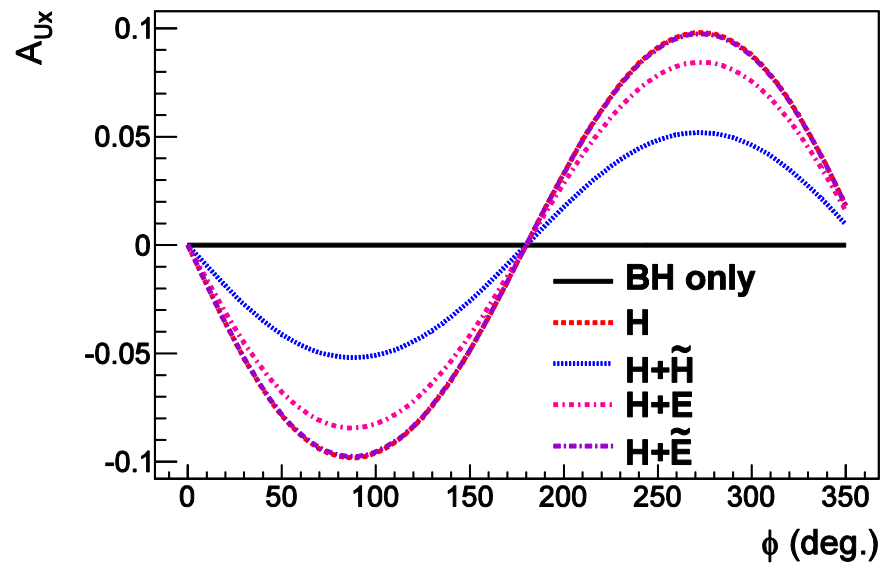
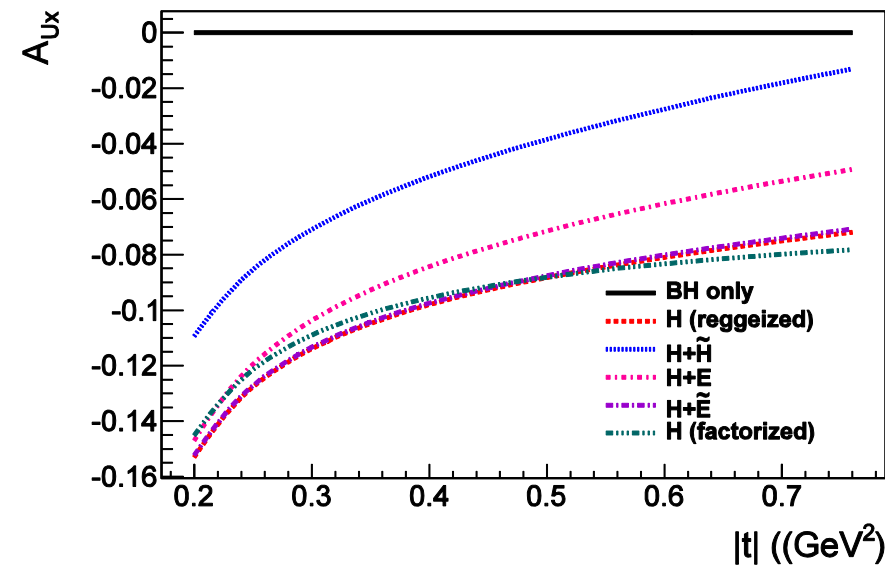
M.Boer et al, arXiv:1501.00270

- **BH produces same final state as TCS.**
- At Jlab energies $\sigma_{BH} \gg \sigma_{TCS}$ (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.**

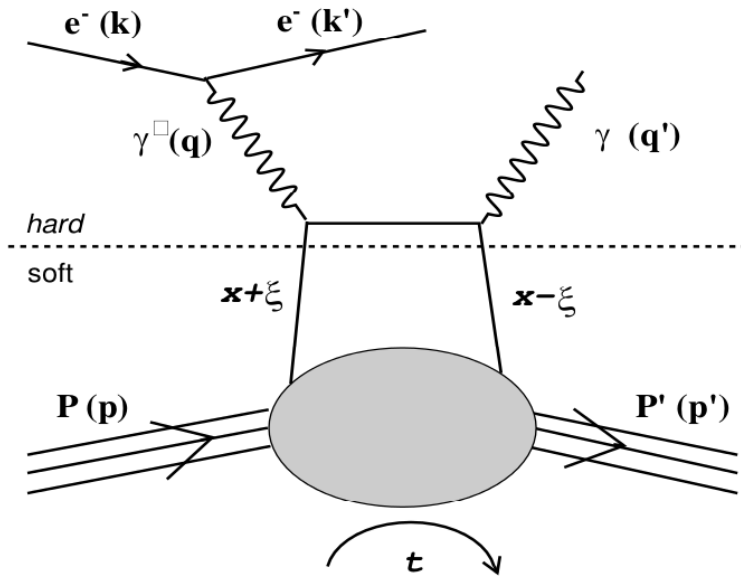
Physics Case

$$\xi = 0.2, Q'^2 = 7 \text{ GeV}^2, \theta \in [45^\circ, 135^\circ]$$

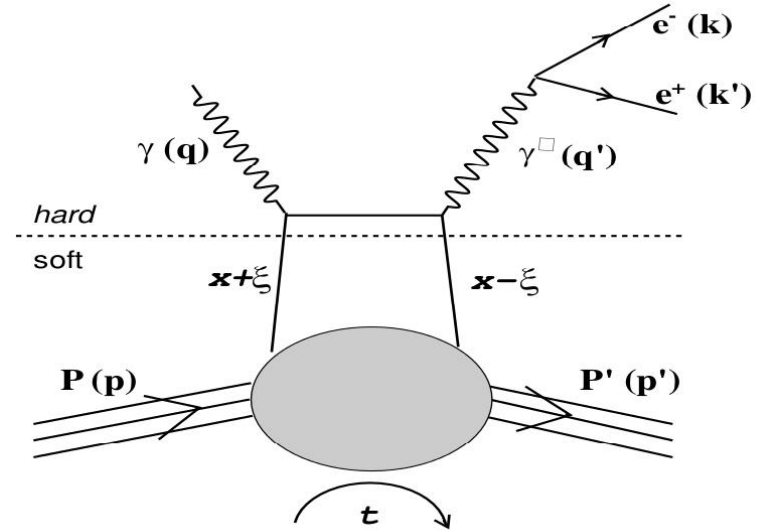


TCS attainable in interference with BH, *sensitive to GPDs*.

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.

Hall B CLAS 6 GeV, exploratory measurements in 2012

- Quasi-real photons from e- beam on unpolarized target
- Cross section, $\cos \varphi$ moments
- Data taken in 2012, analyzed.

Hall B CLAS12 E12-12-001

- Unpolarized cross section and BSA with circularly polarized photon beam
- Sensitive to $Re(Amplitude)$, $Re(H)$, $Im(H)$, $Im(\tilde{H})$
- Approved, part of Run Group A, data taking in 2018

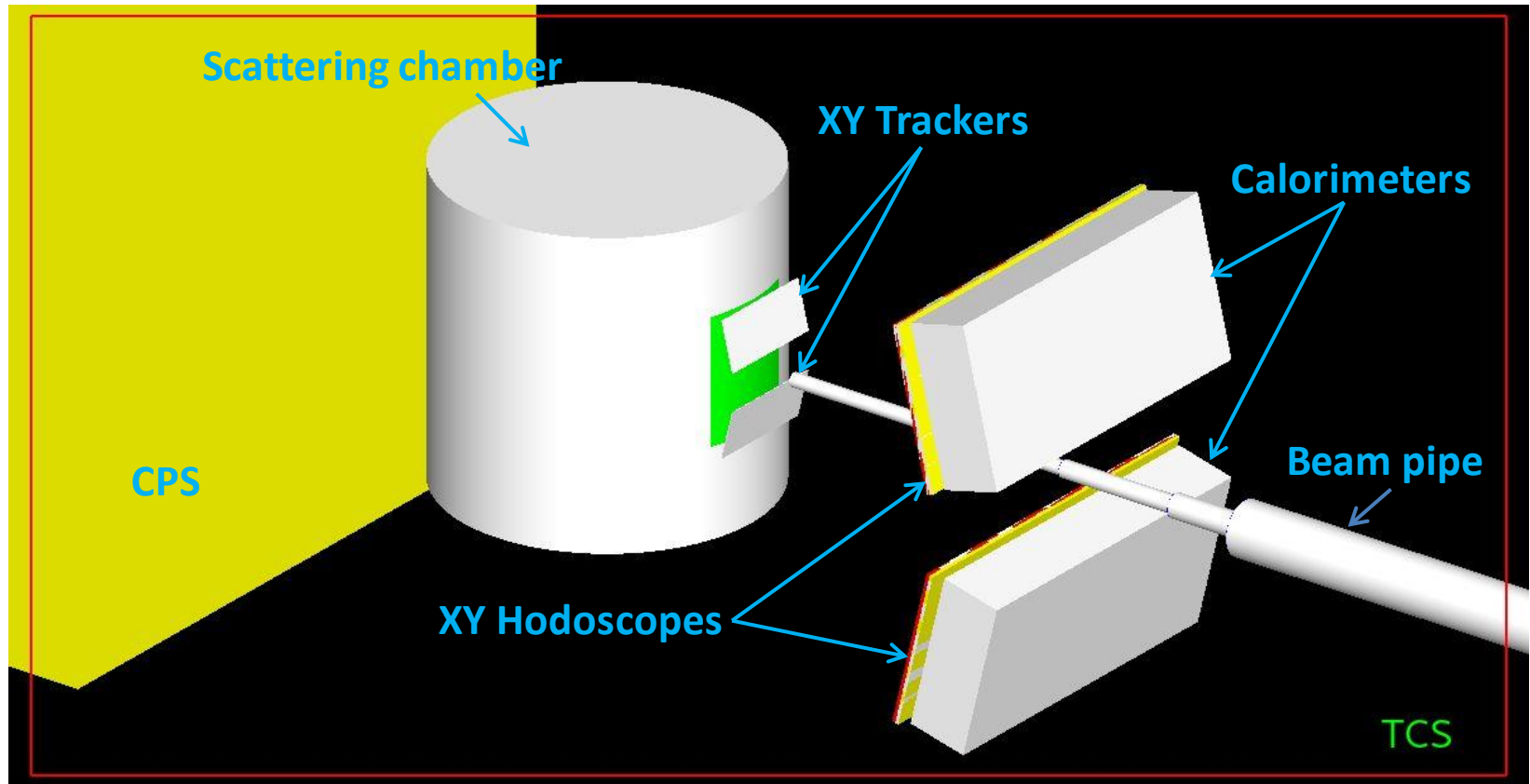
Hall A SoLID E12-12-006A

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

Hall C LOI 12-15-007

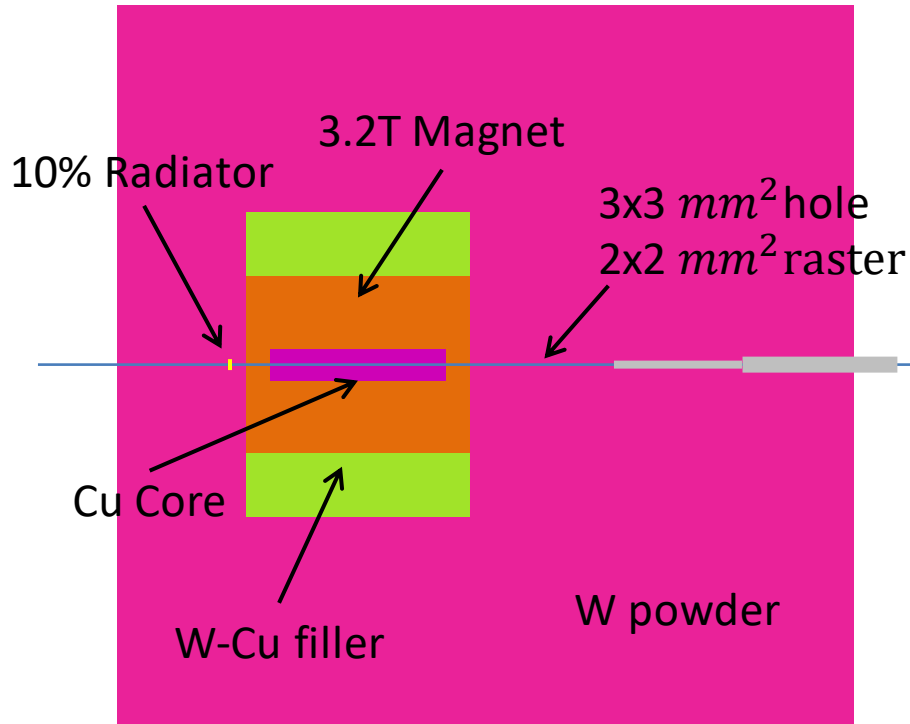
- Transversely polarized target, (circularly polarized) untagged photon beam
- Cross section, TSA, (DSA)
- Sensitive to $Re(Amplitude)$, H , $Im(\tilde{H})$, $Im(E)$
- Similar sensitivity to $Im(E)$ as DVCS with trans. pol. target
- High statistics with photon beam on polarized target!

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

CPS concept



Stage-2 modeling, October 2017, B.Wojtsekhowski

- 2x2 mm² rasterized photon beam
- Water cooled Cu heat absorber (30 kW)
- W powder external shield (16 g/cm³)
- Segmented, flared beam line to reduce radiation leak
- Radiation from source few times less than from γ beam interaction with target

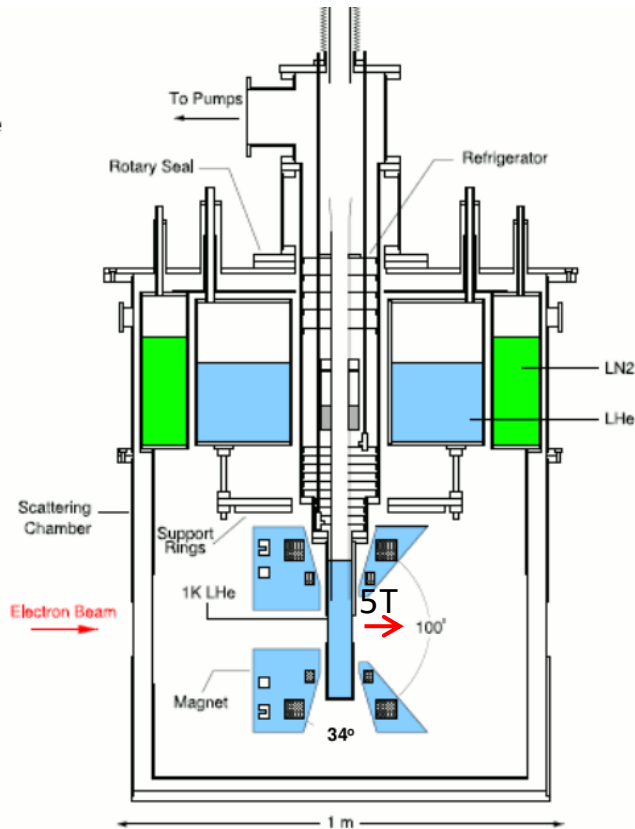
Pure photon beam on solid polarized target versus mixed e^- / γ beam:

- 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%.

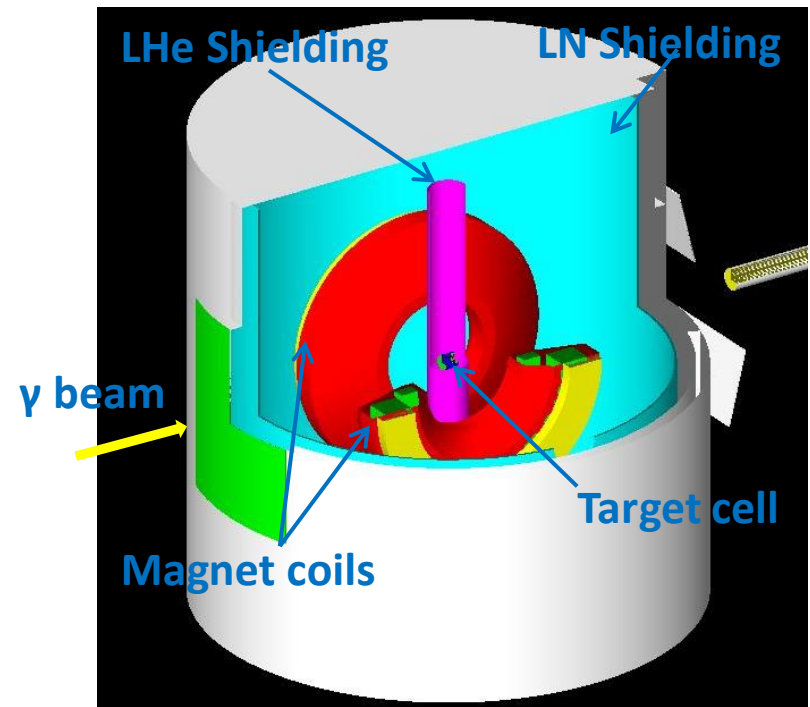
Overall increase of FOM 30 times!

- 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

UVA polarized target



UVA target, nominal configuration



UVA target, TCS configuration

Target material: ammonia ($^{15}\text{NH}_3$), in LHe.
5T (uniform to 10^{-4}) mag. field generated by superconducting Helmholtz 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 $\pm 17^\circ$ horizontally, $\pm 21.7^\circ$ vertically.

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 $\sim 15 \times 33$ cm² 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

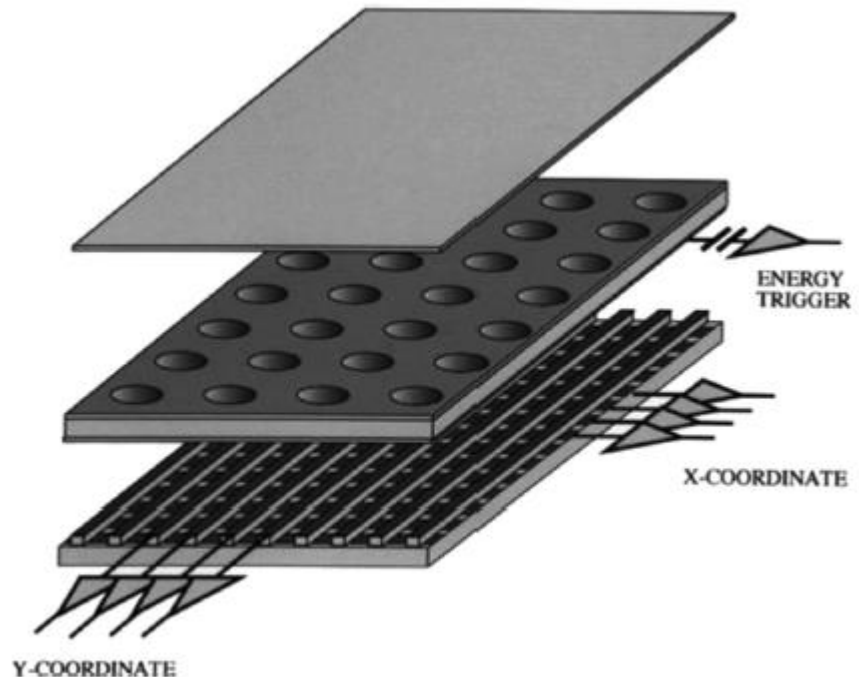
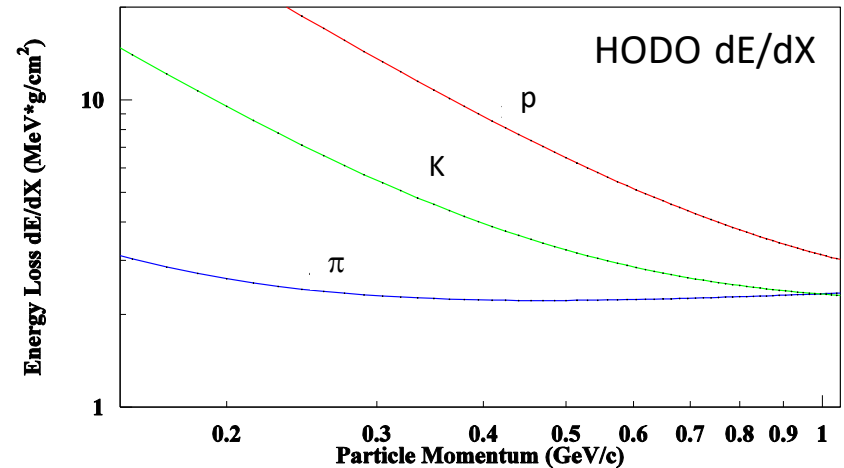
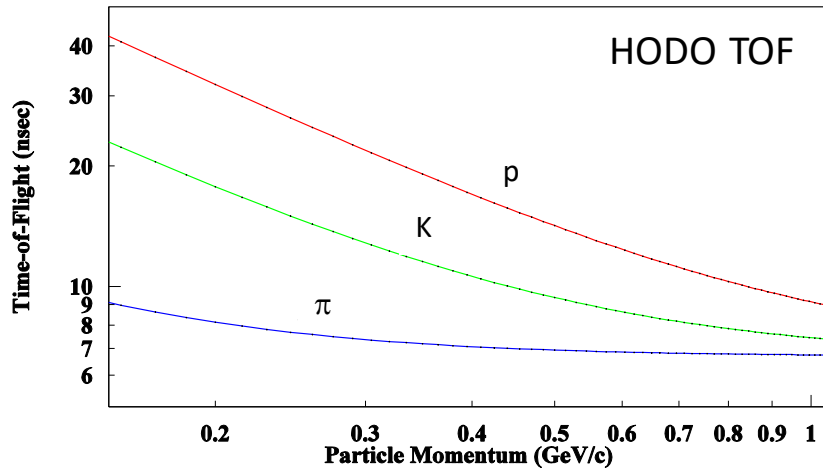


Fig. 3. Schematics of single GEM detector with Cartesian two-dimensional strip readout.

Hodoscopes

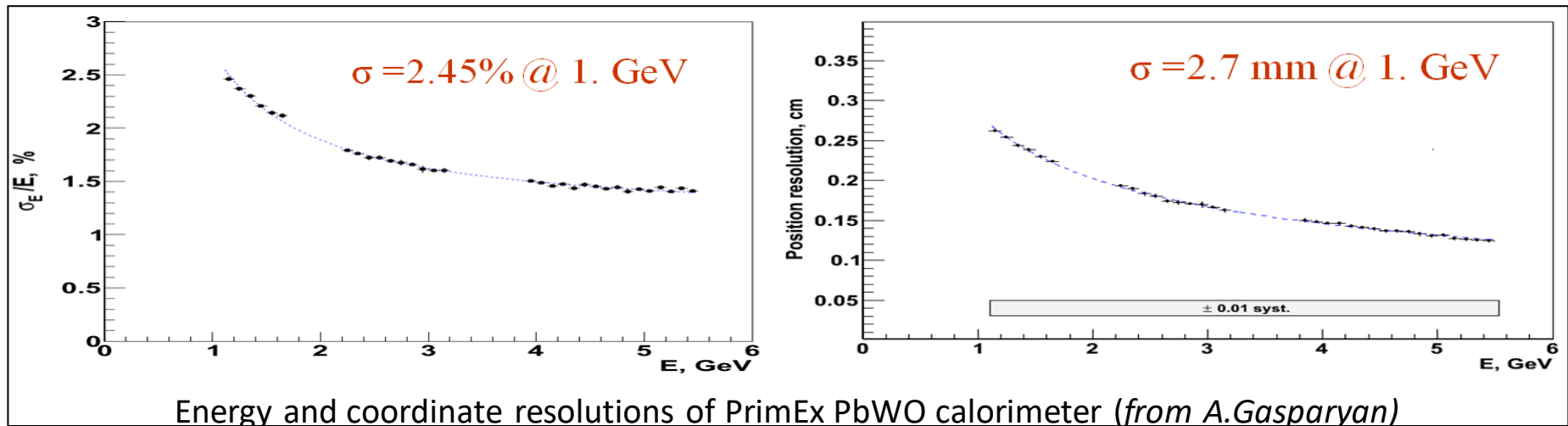
- **Hodoscopes** for reconstruction of recoil **proton** (P_p, ϑ_p, ϕ_p). Crucial for determining $-t$.
- **Proton identification** with TOF and dE/dx . Expected time **resolution** ~ 200 ps.
- X and Y planes from **1 cm thick scintillator**.
- **Eff. area** $\sim 108 \times 48$ cm² (150 cm from target) to cover $\pm 20^\circ$ horizontally, 6° -- 22° vertically.



Micro-pattern gaseous detectors **MPGDs (GEM, THGEM)** as alternative

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** $\pm 18^\circ$ horizontally, 6° - 21.7° vertically
 - $98 \times 47 \text{ cm}^2$ active area at 150 cm from target;
 - $50 \times 23 = \mathbf{1,150 \text{ blocks}}$ total for each calorimeter (**~NPS size**).

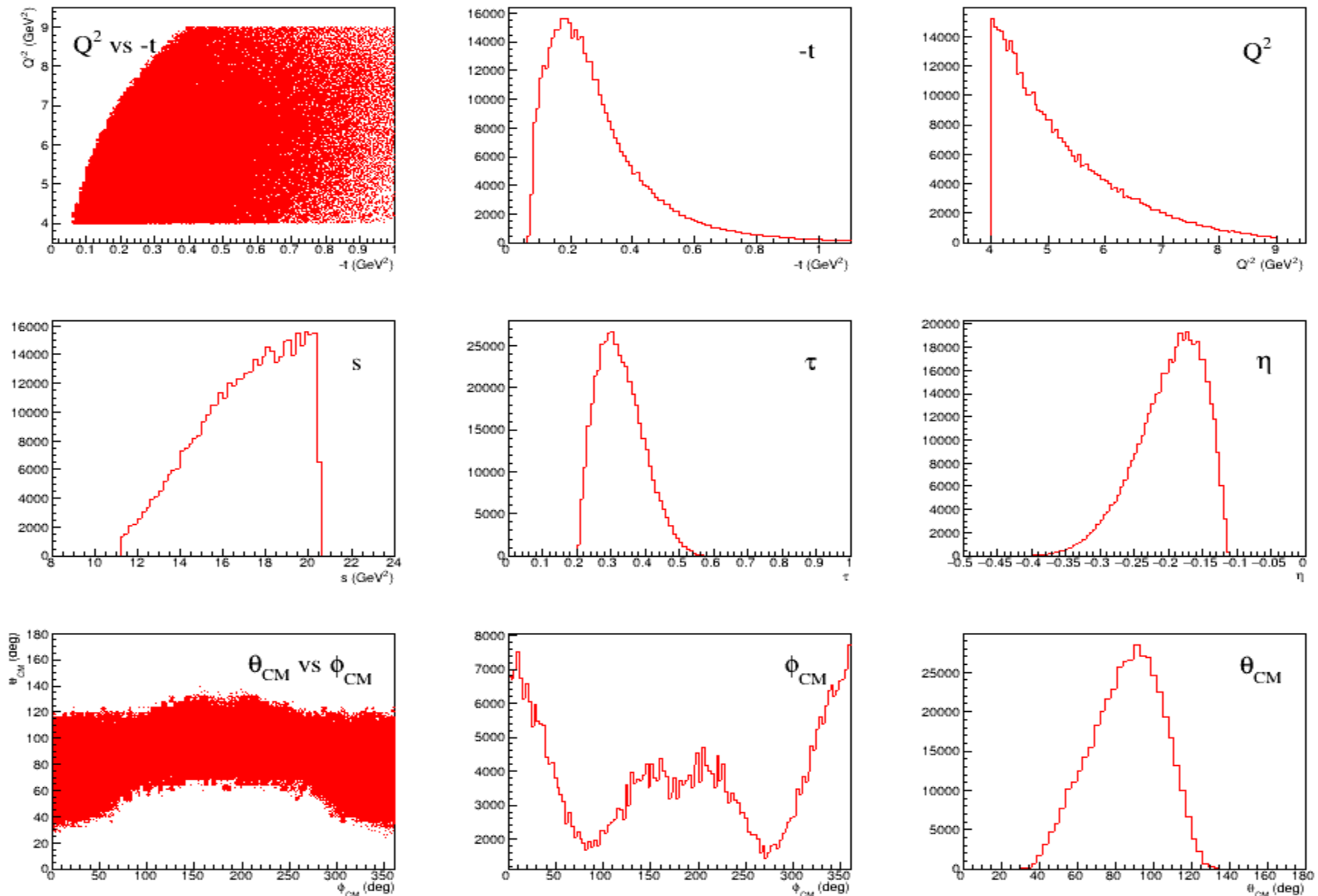


Progress in NPS construction

- 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

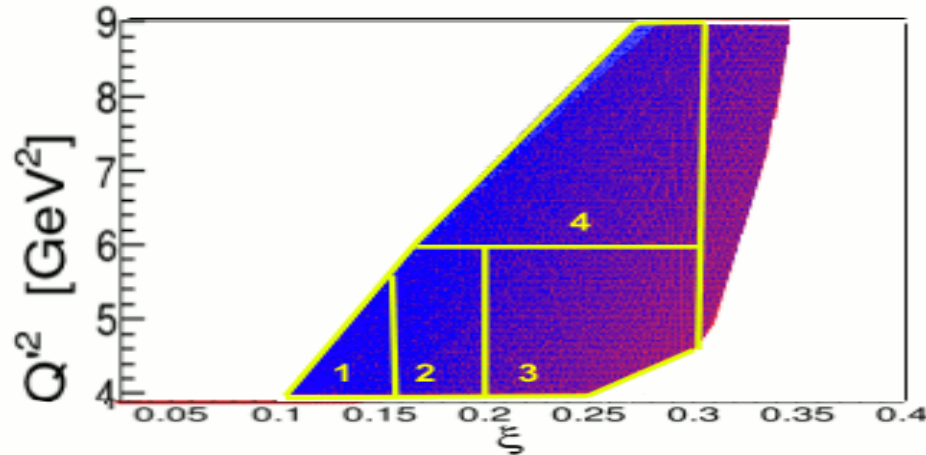


Kinematic coverage



BH singularities at $(\theta_{CM}, \phi_{CM}) = (180^\circ, 0^\circ)$ and $(0^\circ, 180^\circ)$ avoided. $\theta_{CM} \sim 90^\circ \rightarrow \max A_{Ux}$.

Phase space coverage



N	ξ limits	Q'^2 limits (GeV ²)	$-t$ limits (GeV ²)
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

Example phase space division for study of Q^2 , ξ and t dependences.

Summary and Outlook

Studies on the NPS calorimeter's constituents (crystals, PMTs) proceed in good pace.

LOI on TCS in Hall C at JLab presented before PAC 43, welcomed.

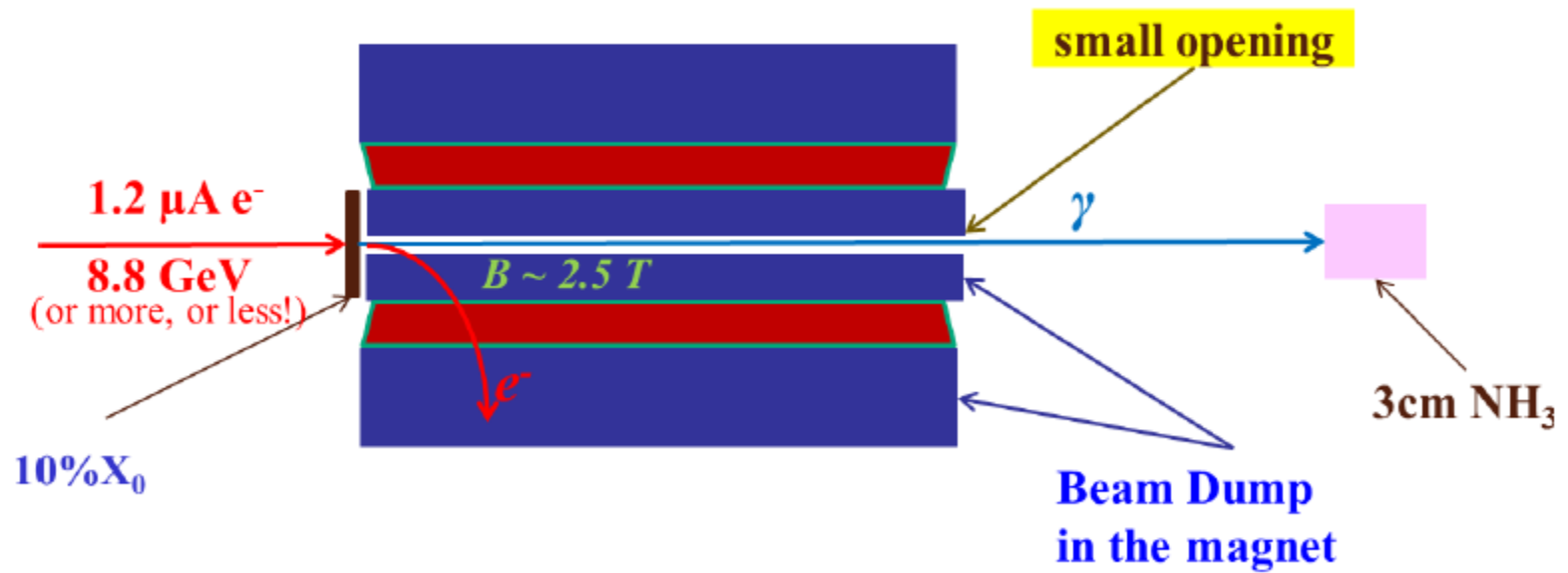
- ✓ Physics case established
- ✓ Design construction of setup outlined
- ✓ Results from preliminary simulations shown.

On the way of developing a full proposal...

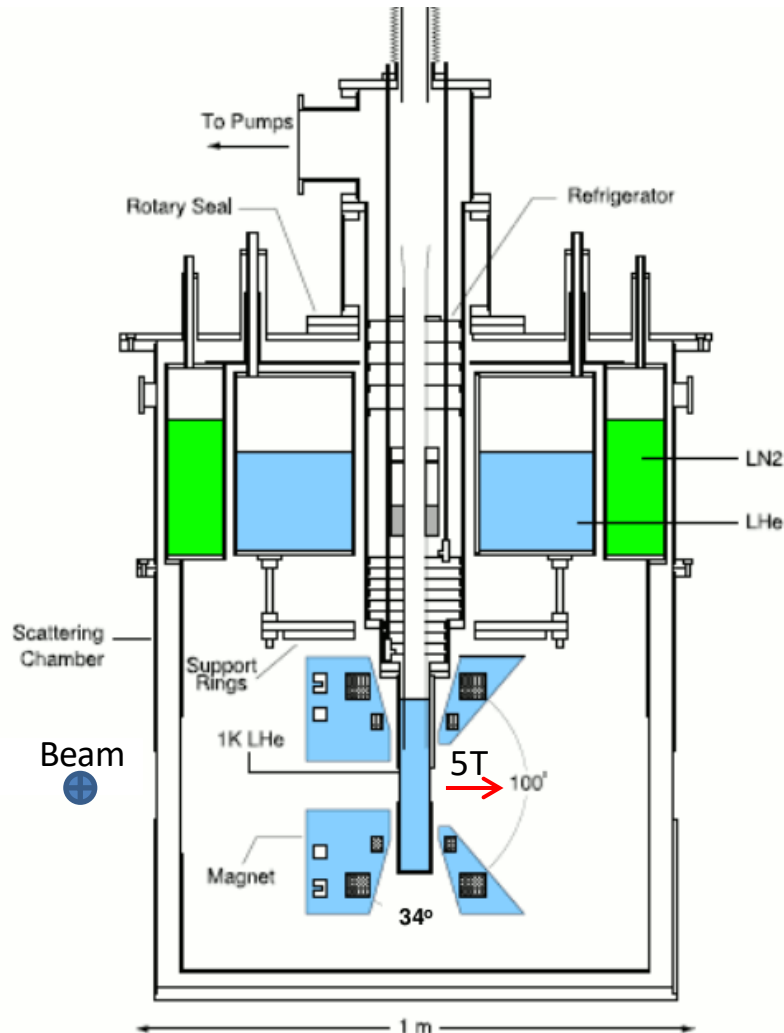
- Update of the Physics Case is under way (M.Boer).
 - Tuning of *Generator_TCS* code (TCS event generator from M.Boer) to be done.
 - Development of Geant4 based simulation code of the TCS setup is in progress.
 - Simulations of the measured asymmetries with *Generator_TCS* and G4 TCS setup simulation codes are needed.
 - A thorough examination of expected results from experiment, from point of view of GPD analyses is needed.
 - Fine tuning of the design setup is needed.
-
- ❖ Interested in development of **High Intensity Photon Source!**
 - ❖ Interested in the **UVA target field modifications!**

Backup slides

CPS concept



TCS UVA Polarized Target



UVA polarized target, cross section view.
(Adopted from J. Zhang)

Used in E93-026, E01-006, SANE.

Target material: ammonia ($^{15}\text{NH}_3$), doped with paramagnetic centers, immersed in LHe (high polarizability, large nucleon content, resistance to rad. damage).

5T (uniform to 10^{-4}) magnetic field generated by pair of superconducting Helmholtz coils (axis known to 0.1°).

Dynamic Nuclear Polarization (DNP) by 140 GHz, 20 W (max) RF field.

Polarization decays due to radiation damage (from above 80% to 60% in 8 hours for 100 nA beam current, typically).

Target polarization monitored via NMR Q-meter.

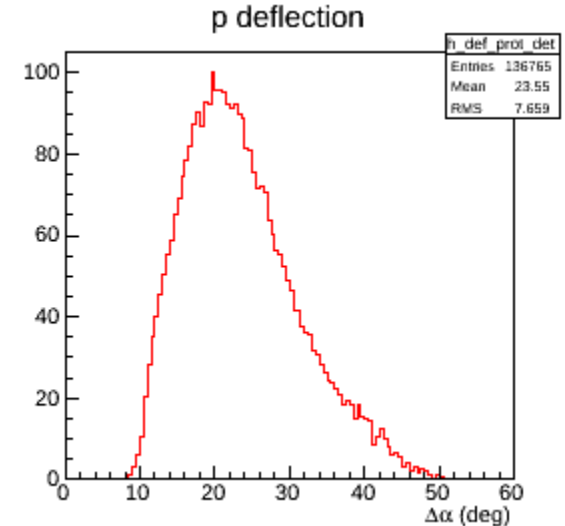
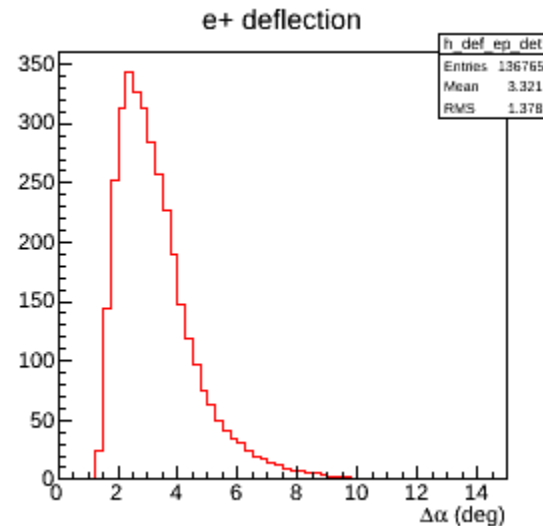
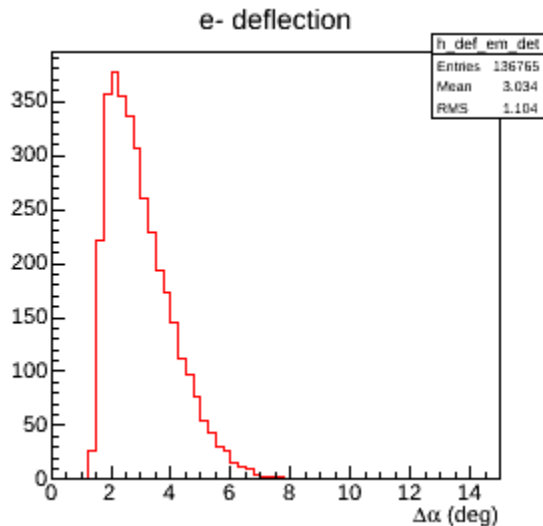
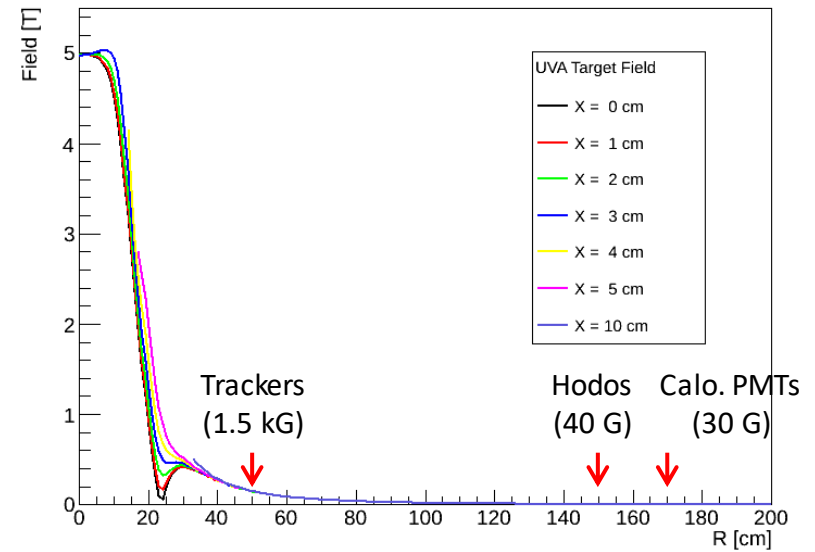
Needs annealing (heating to 70-100 K for 10-60 min).

Will be rotated by 90° around vertical axis.

Angular acceptance $\pm 17^\circ$ horizontally, $\pm 26.5^\circ$ vertically.

TCS Analysis Options

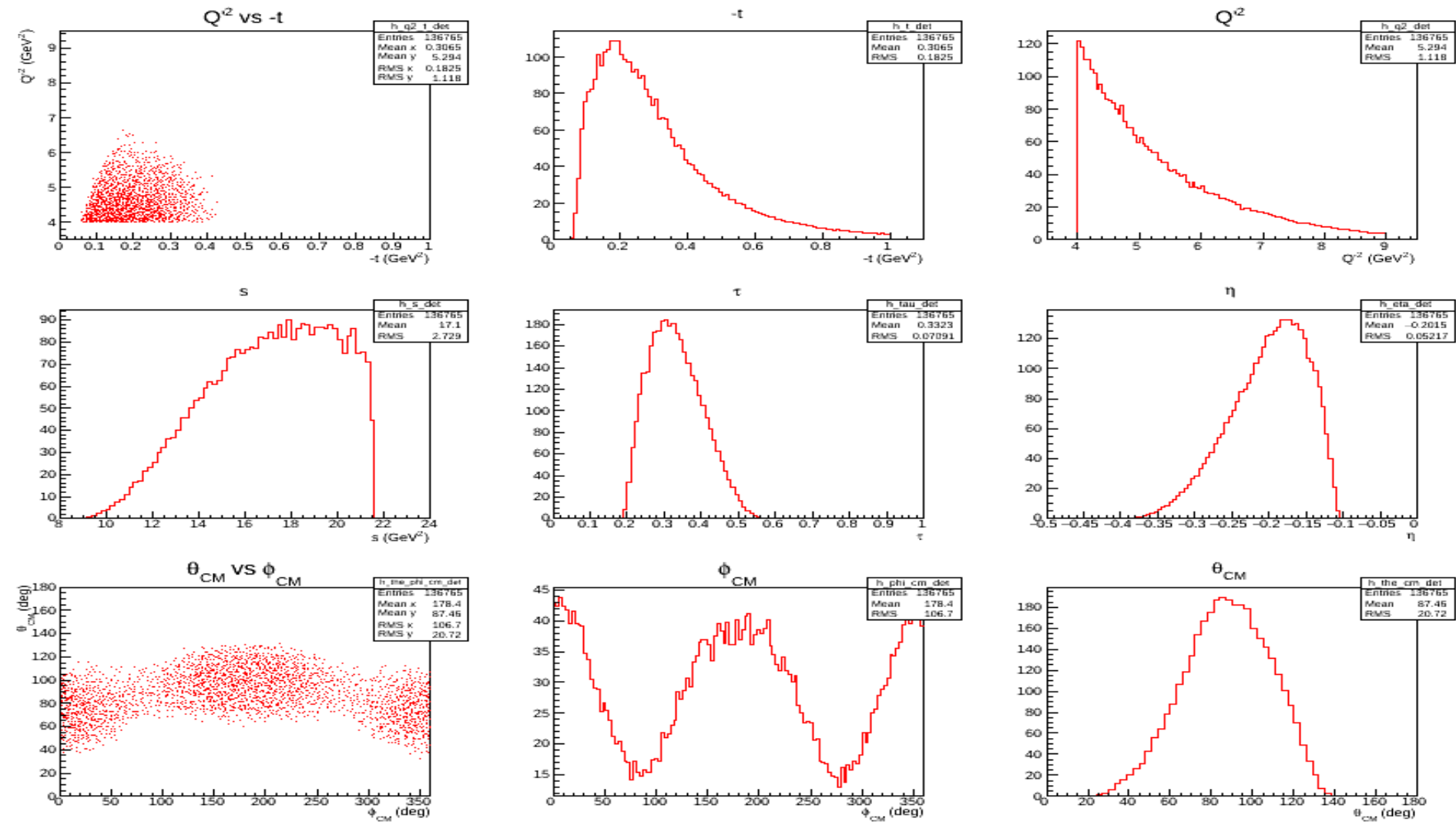
- **Significant magnetic field** from target, mostly transverse and confined in $R < 20$ cm.
- **Bends vertically** e^+ , e^- by $\sim 2.5^\circ$, and p by 20° !
- **Will reconstruct tracks at vertex** (provided field is mapped to good accuracy).
- **Reconstructed momenta** can be used in conjunction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



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

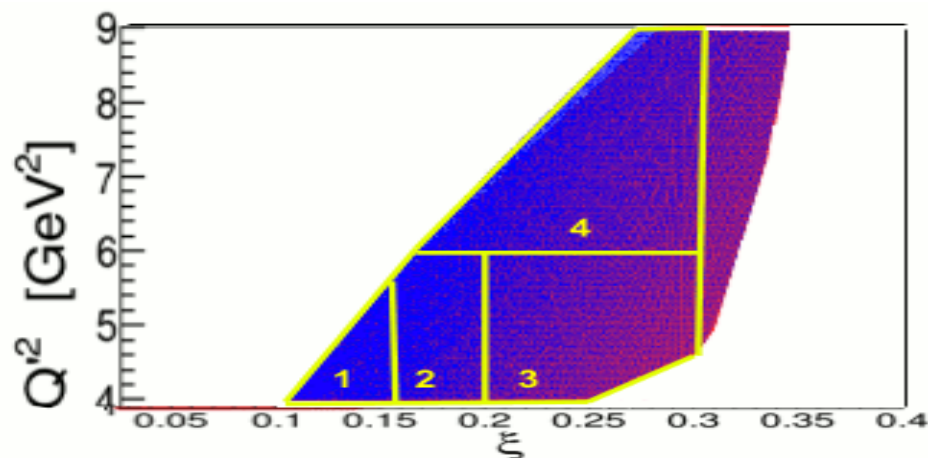
Kinematic Coverage

Setup with **full acceptance** calorimeters.



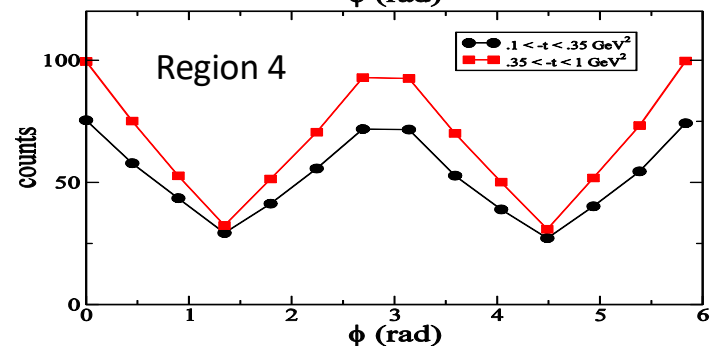
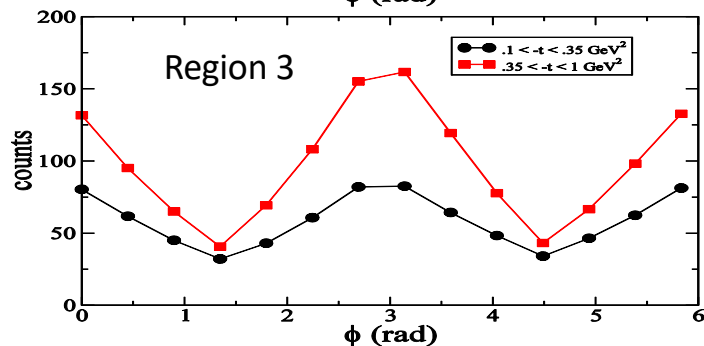
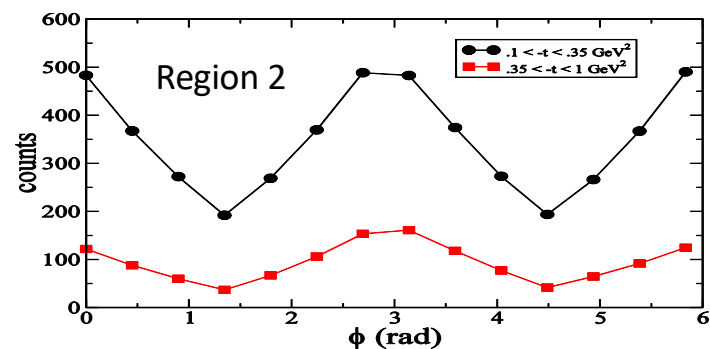
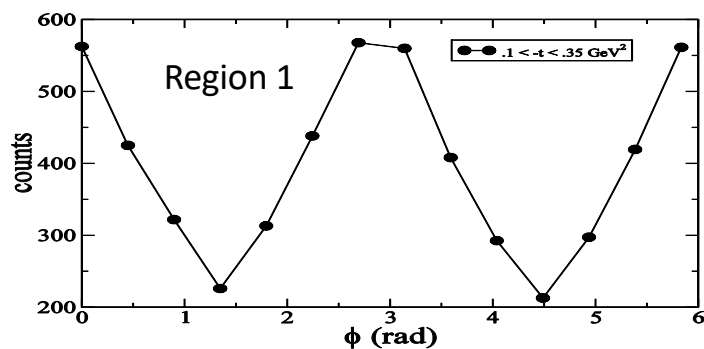
Accepted triple coincidence events.

Phase Space Binning



N	ξ limits	Q'^2 limits (GeV ²)	$-t$ limits (GeV ²)
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.

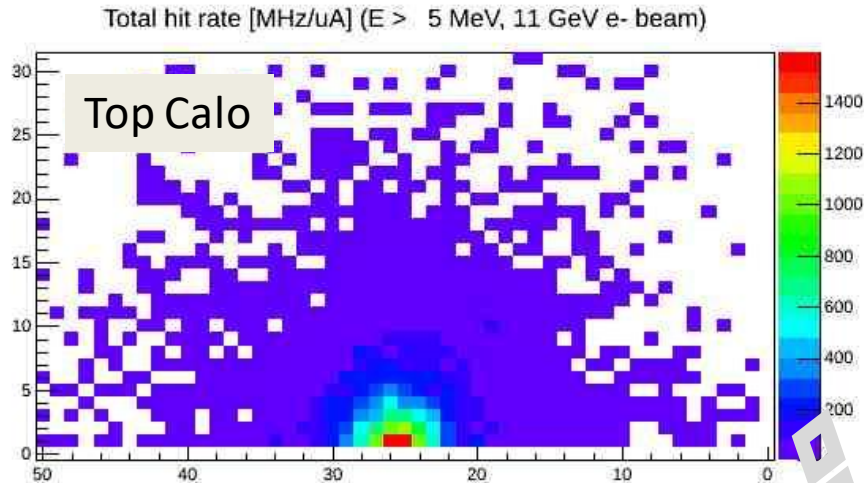


Count rates in $14\phi_{CM}$ bins.

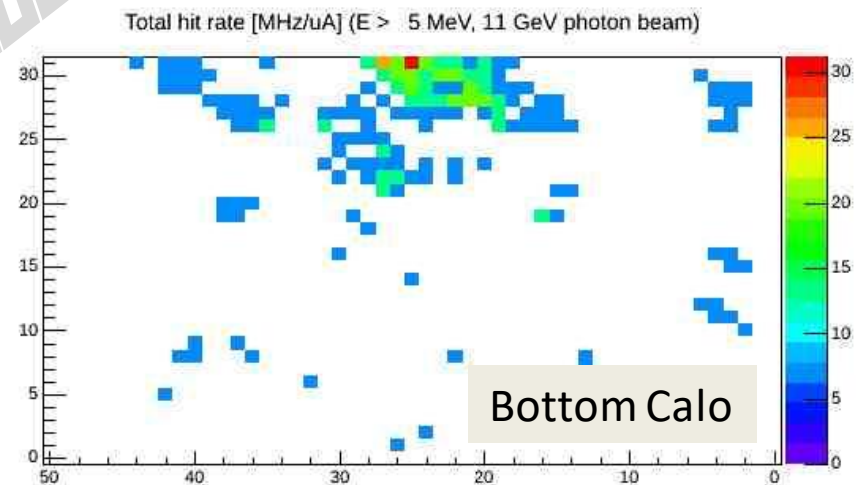
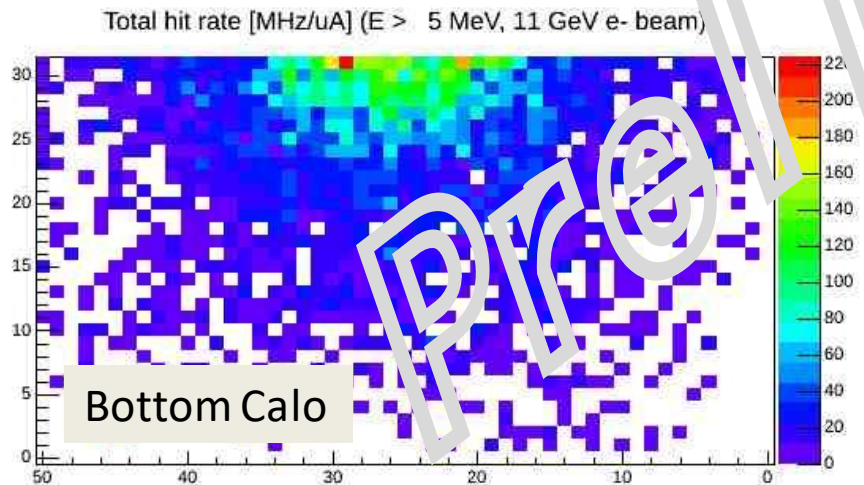
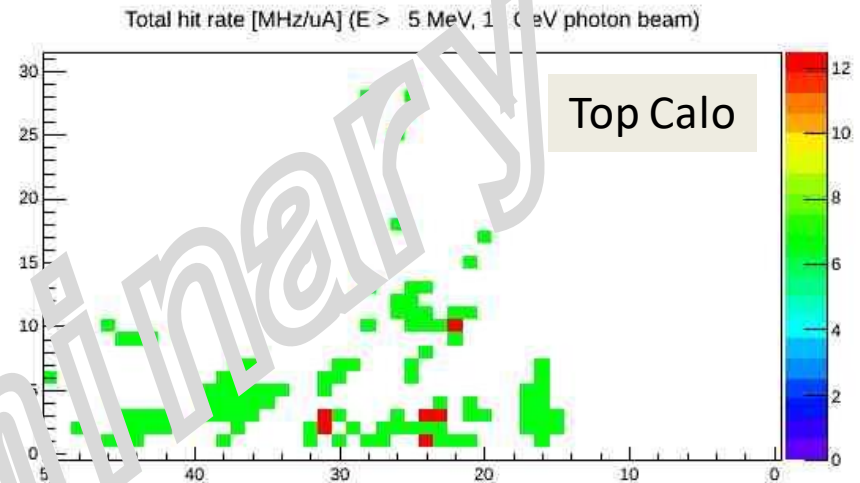
Preliminary result from G4 simulation

Beam mode

11 GeV e- beam



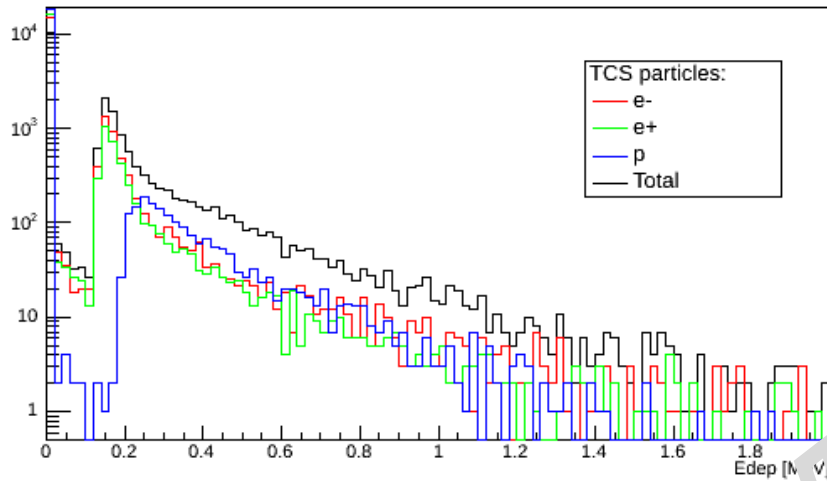
11 GeV **photon** beam



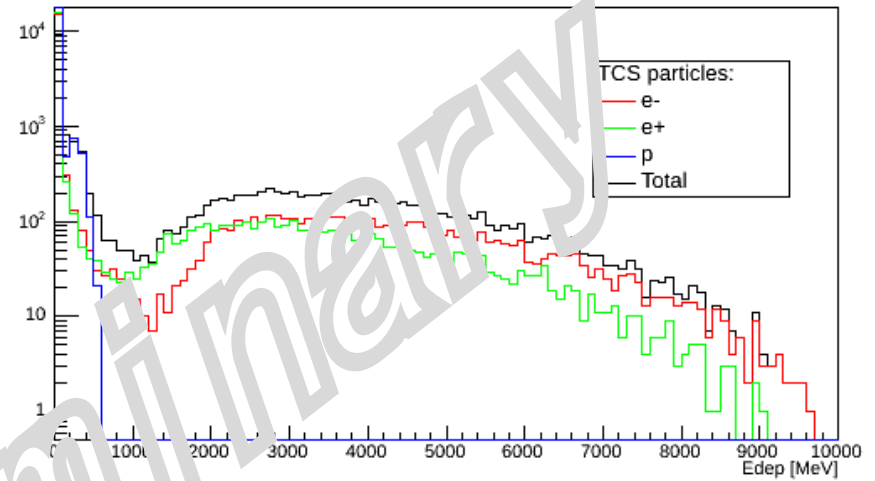
Significantly lower background hit load from photon beam than from electron beam.

Energy depositions

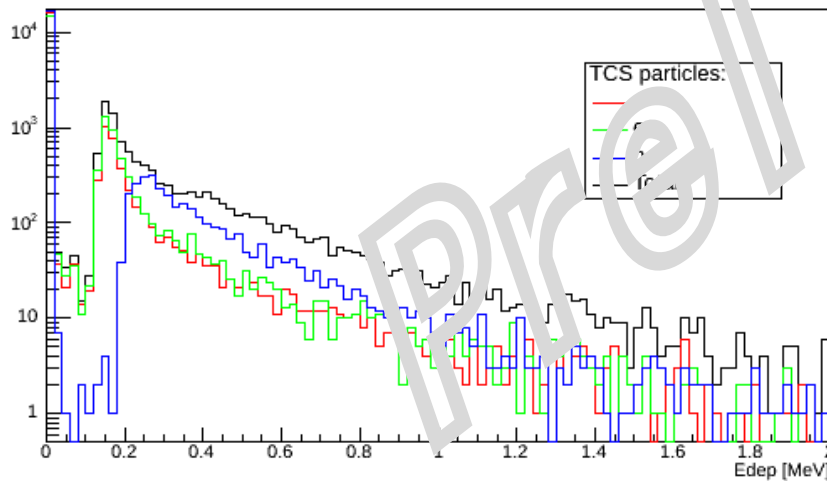
Top trackerx



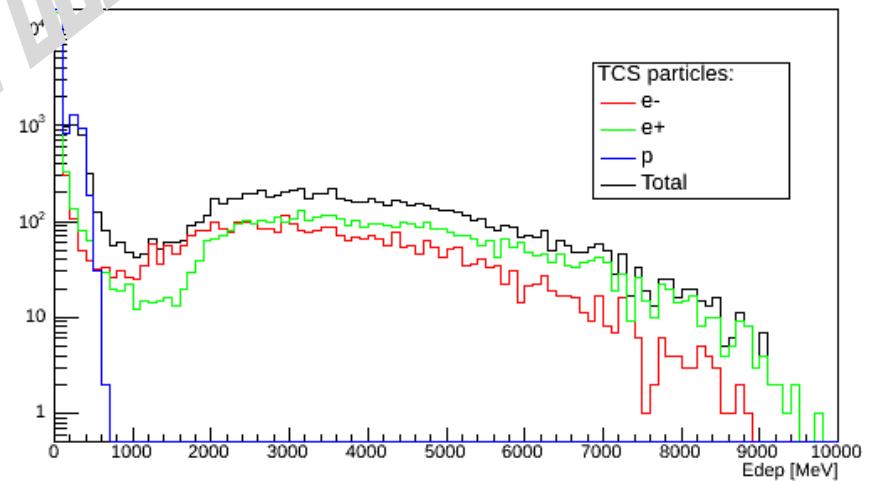
Top calo

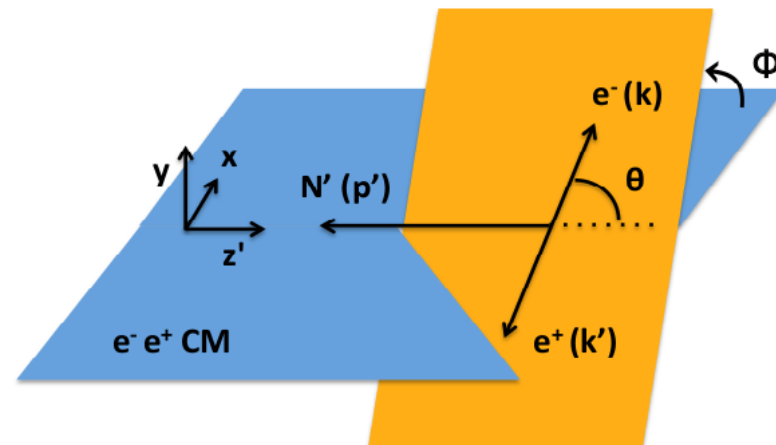
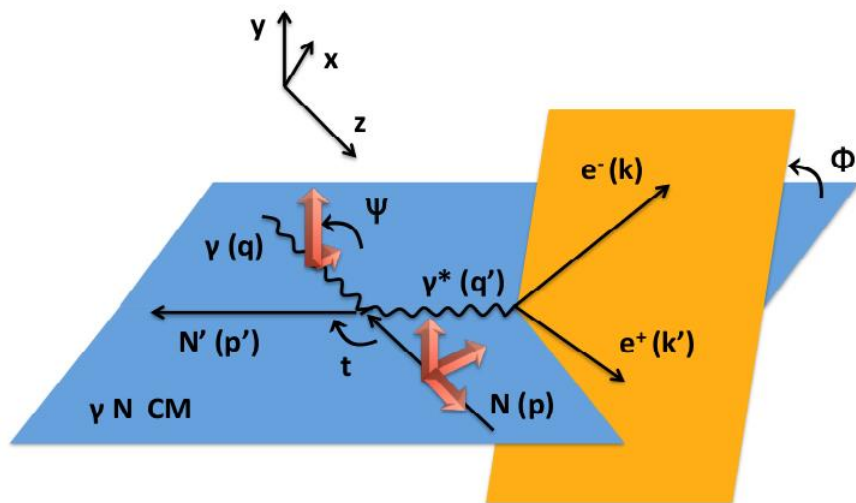


Bottom trackerx



Bottom calo





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

Analysis cuts:

To have GPD interpretation of TCS:

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

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

From DVCS and DIS:

$$Q'^2 > 2 \text{ GeV}^2 \quad (\text{keeps di-lepton system out of resonances})$$

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