Polarized and unpolarized Timelike Compton Scattering

Alexandre Camsonne

Hall C collaboration meeting

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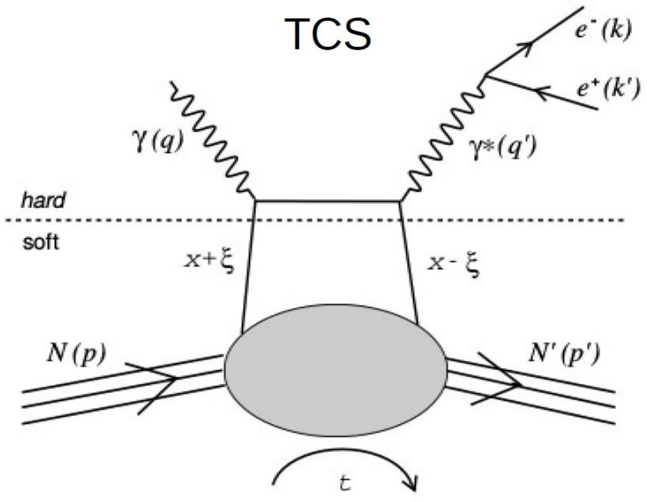
Outline

- Timelike Compton Scattering
- Polarized TCS
- Unpolarized TCS
- To do
- Conclusion

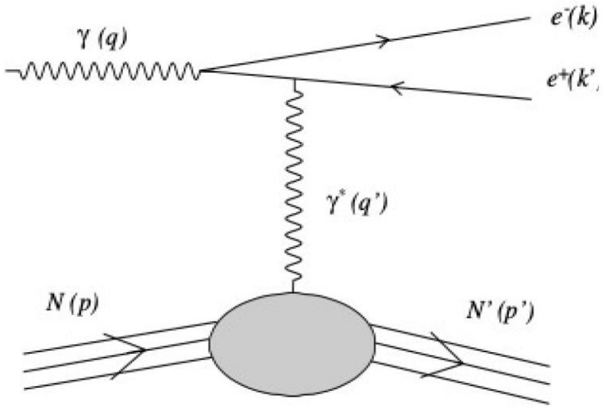
Timelike Compton Scattering

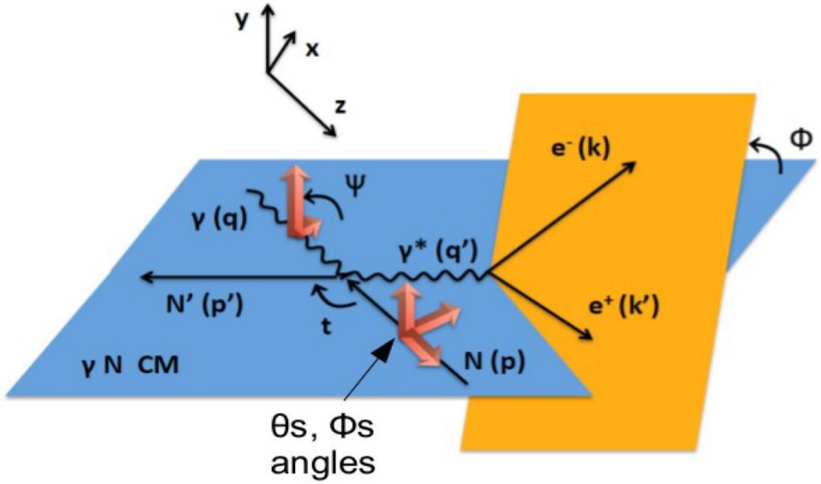
$\gamma N \rightarrow e^+e^- N' = TCS + BH$

TCS



Bethe-Heitler

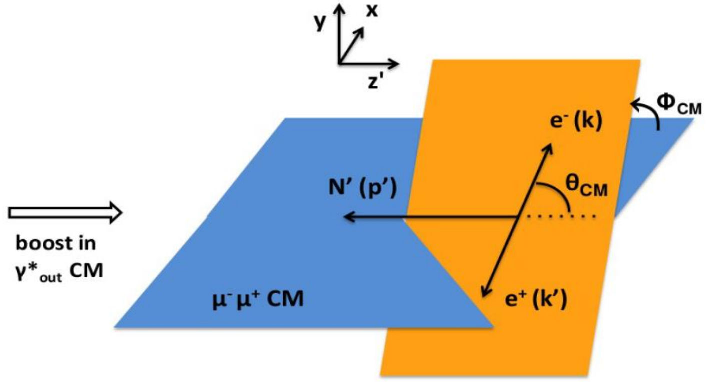




5-differential unpolarized
6-differential perp target

Choice in presented work:
Q'^2, t, Eγ, φ, θ or Q'^2, t, ξ, φ, θ

Ψ: (reaction plane, γ spin)
φ: (hadronic plane, e^+e^- pair)
θ: (γ^*, e^-)
θs, Φs: (target spin vector orientation)



Notations: σ = unpolarized cross section, Axx = asymmetry
A⊙u = circularly polarized beam, unpolarized target / ALu = linearly polarized beam
Aui (i=x, y, z) = unpolarized beam, polarized target along i axis.

Polarized proton TCS

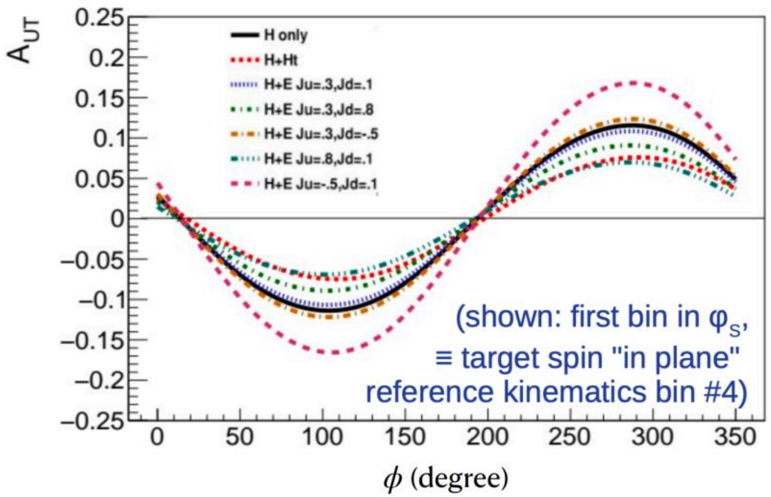
Single Spin Asymmetry (A_{UT}) : unpolarized beam and transversely polarized target

$$A_{UT} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \qquad \ldots(1)$$

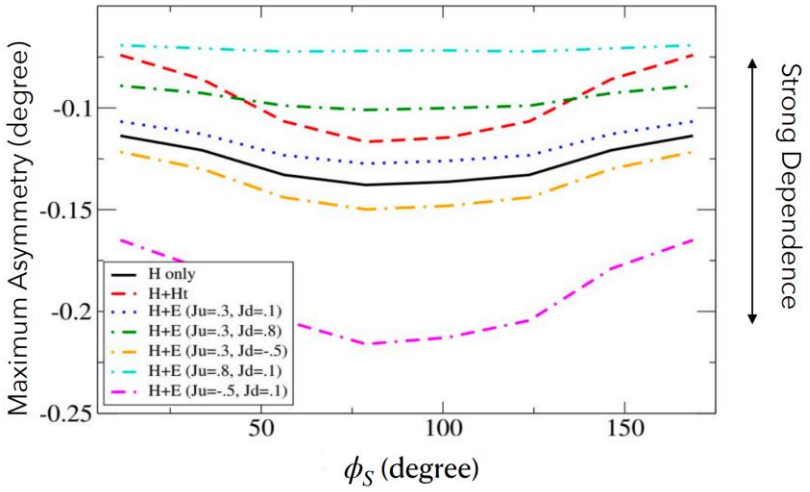
1. $\sigma^{\pm} \equiv \frac{d^6\sigma}{dQ'^2\ dt\ d\Omega\ d\phi_s\ dE_\gamma}$: 6 differential scattering cross-section TCS+BH
2. $\pm$: x direction (+) or y direction (-) of spin ϕ_s of the transversely polarized target
3. 6 differential cross section sensitive to Imaginary part of CFF
4. Asymmetry arises due to the interference between the TCS and BH processes
5. $A_{UT} \propto sin(\phi, \phi_s)$ moment of the $\frac{d^6\sigma^{INT}}{dQ'^2\ dt\ d(cos\theta)\ d\phi\ d\phi_s\ dE_\gamma}$
6. A_{UT} is sensible to the Imaginary part of the amplitude
7. As BH amplitude is purely Real, A_{UT} asymmetry is due to TCS process only

Polarized TCS

Dependence in GPD parametrization and J_u, J_d (VGG model) vs ϕ and $\phi_S = 0$



$sin(\phi)$ moment of transverse spin asymmetry vs ϕ_S, Dependence in GPD E and $J^{u,d}$ (VGG model)



High sensitivity with spin of different quarks ($J^{u,d}$)

TCS with CPS

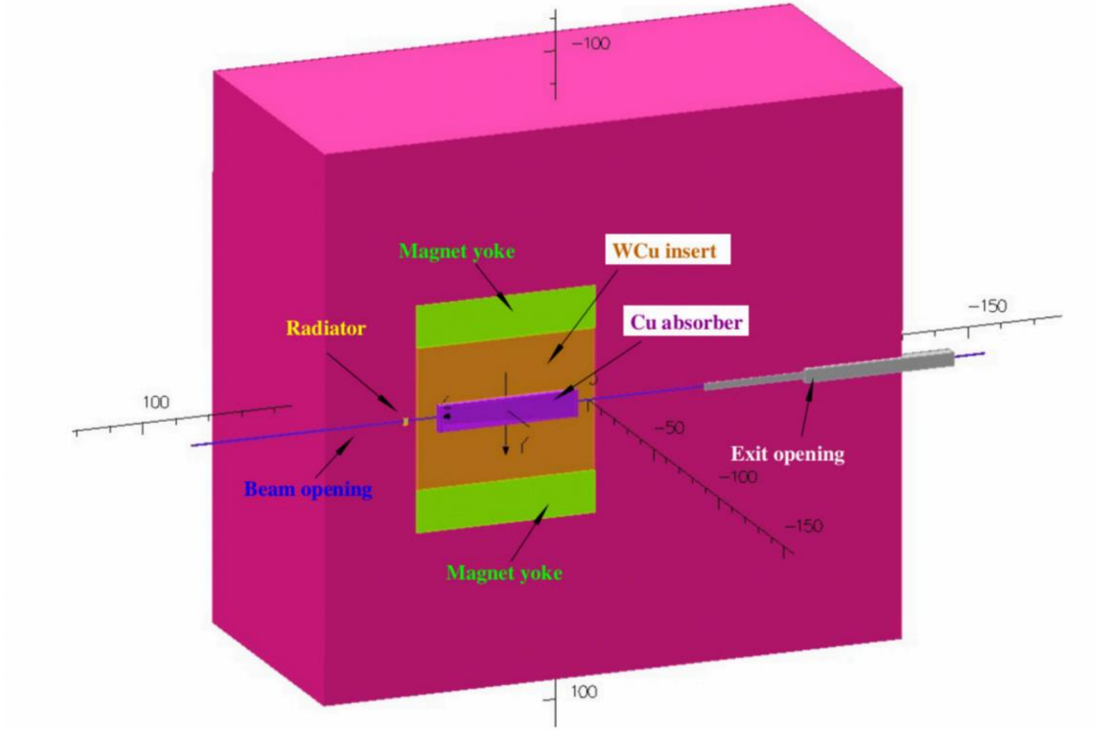


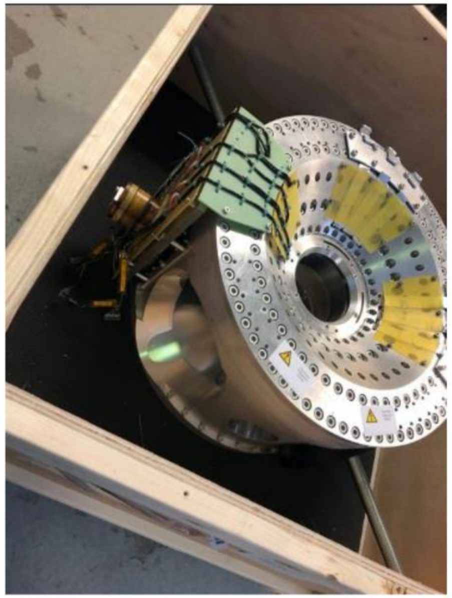
Fig : The CPS Cut off view

Source :A Conceptual Design Study of a Compact Photon Source (CPS) for Jefferson Lab

1. Spot size $\sim 0.9\ mm$ at a distance of 2m away from the radiator
2. Photon Flux $\sim 1.5 \times 10^{12}\ s^{-1}$ from electron beam current $2.5\ \mu A$ on 10% X_0 Cu radiator
3. Photon energy $> 0.5\ E_{beam}$
4. T warm magnet to bend incoming electrons to local beam dump
5. Source : D.Day et al., NIMA 957 (2020) 163429

Polarized proton target

- Target material: $^{15}NH_3$, in LHe at 1°K.
- Packing fraction 0.6.
- Magnetic field generated by superconducting Helmhotz coils.
- DNP polarization by 140 GHz, 20 W RF field.
- Polarization monitored via NMR.
- Depolarization mitigated by combined rotation (~1 Hz) around horizontal axis and vertical up/down movement (~10 mm).



New polarizing magnet arrived in September 2021!

- Drop-in replacement for old Jlab-UVA target
- 5 T magnetic field, 100 ppm uniformity
- ±25° horizontal opening angle in transverse field configuration (increase from ±18° --> increase of TCS acceptance, help with background rates.)
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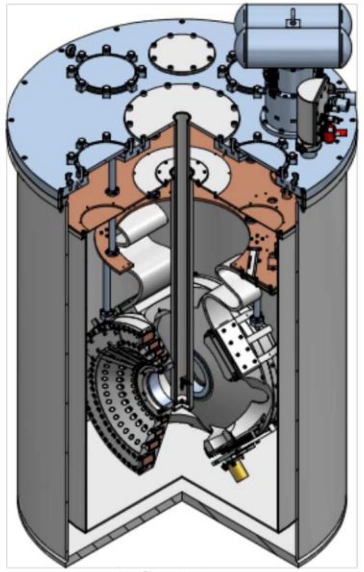


Horizontal field orientation

Polarized TCS

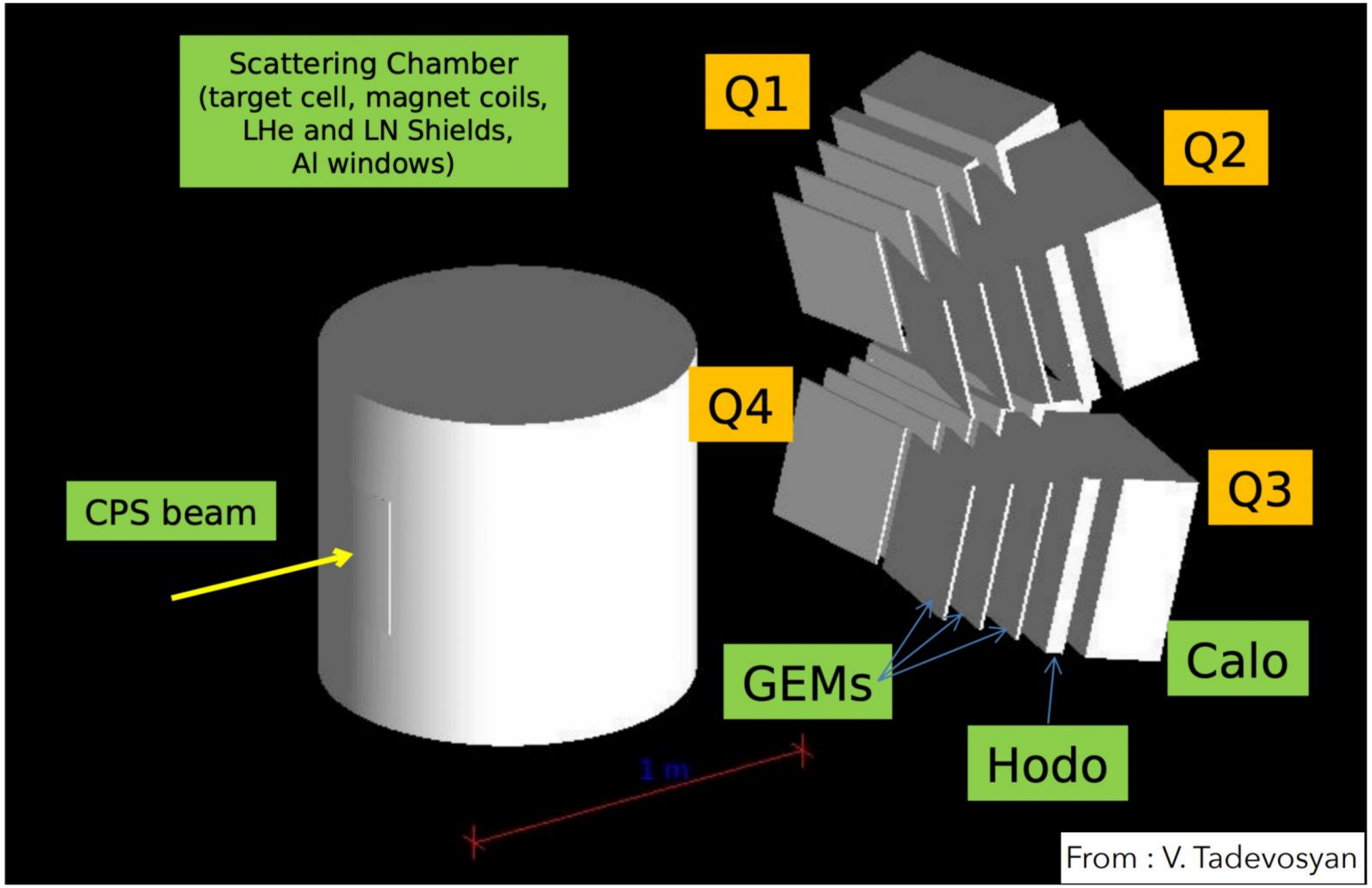


Fig : Geant4 simulation of detector setup at Hall C
for proposed polarized TCS experiment

1. High intensity photon source
1.5 x 1012 γ/sec (CPS)

2. Target chamber: NH3, 3cm
Polarized via DNP

3. Tracking: GEM+hodoscopes,
4 symmetric quadrants

4. Calorimeters: 4 symmetric
quadrants, equivalent of 2 NPS
~ 6° to 27° aperture

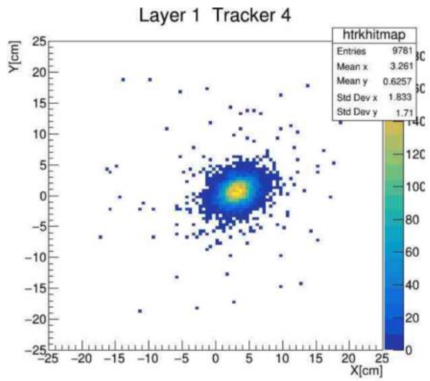
5.Lumi request: 5.85 x 105
pb-1

Polarized TCS

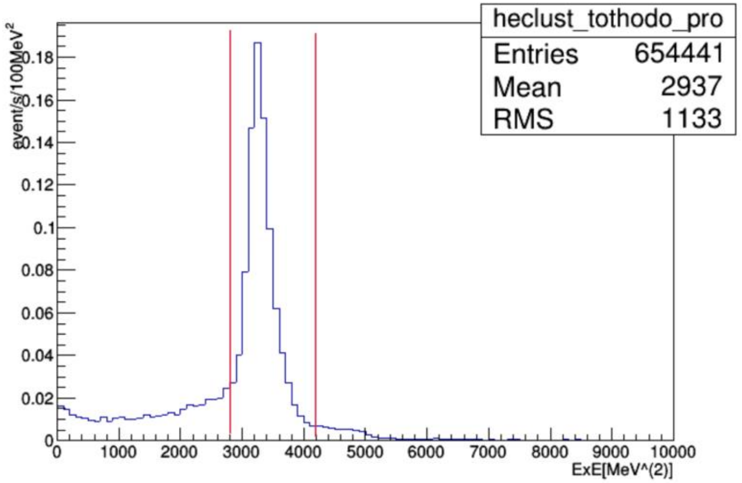
Low energy protons : E_{kin} ~ 30 MeV - 450 MeV
Cuts to select good protons :

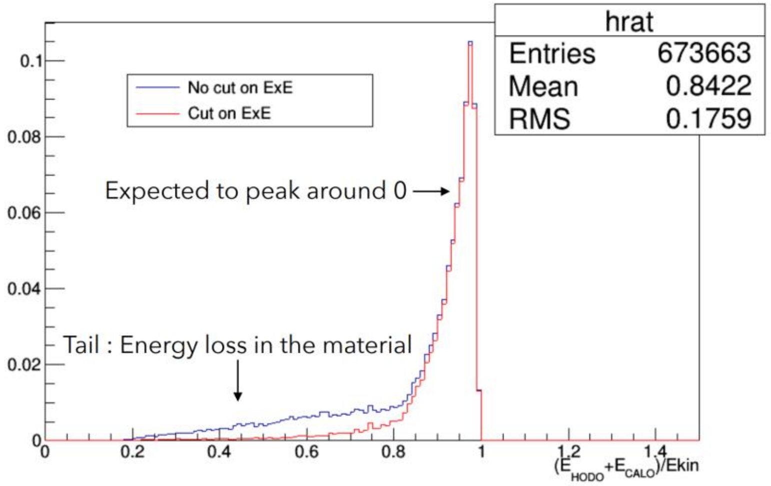
1. E_{HODO} > 15 MeV
2. 90 MeV < $E_{HODO} + E_{CALO}$ < 450 MeV
3. 2800 MeV^2 < E.E < 4200 MeV^2

Where E.E = $(E_{HODO} + E_{CALO} - 12).(E_{HODO} - 7)$



GEM hit patter from 400 MeV/C protons





Unpolarized TCS

Single Spin Asymmetry ($A_{\odot U}$) : circularly polarized beam and unpolarized target

$$A_{\odot U} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \qquad \ldots(2)$$

1. $\sigma^{\pm} \equiv \frac{d^5\sigma}{dQ'^2\ dt\ d\Omega\ dE_\gamma}$: 5 differential scattering cross-section TCS+BH
2. $\pm$: right (+) or left (-) handed circular polarization of the real photon
3. 5 differential cross section sensitive to both Real and Imaginary part of CFF
4. Asymmetry arises due to the interference between the TCS and BH processes
5. $A_{\odot U} \propto sin(\phi)$ moment of the $\frac{d^5\sigma^{INT}}{dQ'^2\ dt\ d(cos\theta)\ d\phi\ dE_\gamma}$
6. $A_{\odot U}$ is sensible to the Imaginary part of the amplitude
7. As BH amplitude is purely Real, $A_{\odot U}$ asymmetry is due to TCS process only

Unpolarized TCS

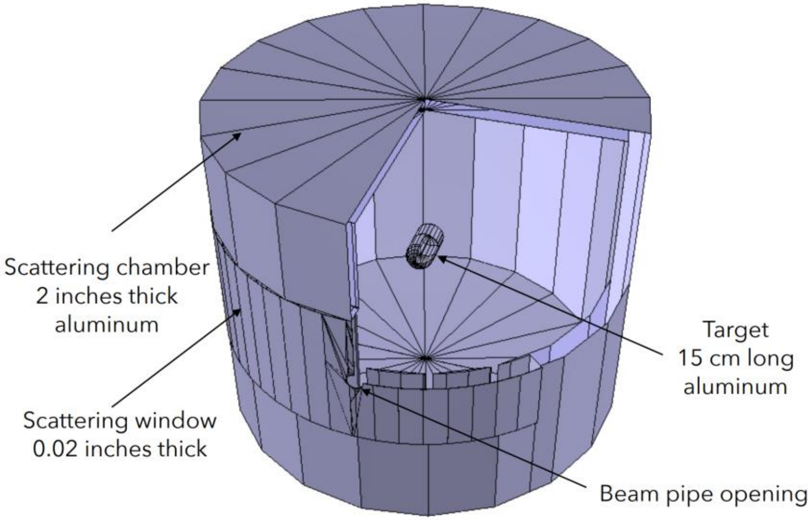


Fig : Geant4 simulation of scattering chamber and target

1. Scattering chamber inner diameter = 41 inches
2. Scattering chamber outer diameter = 45 inches
3. Angular range : horizontal HMS : 3.2 to 77.0 degrees
4. Angular range : SHMS : 3.2 to 47.0 degrees
5. Vertical angular range : ±17.3 degrees
6. Target thickness of Entrance and exit cap = 0.1778 cm
7. Target cell wall thickness = 0.0254 cm

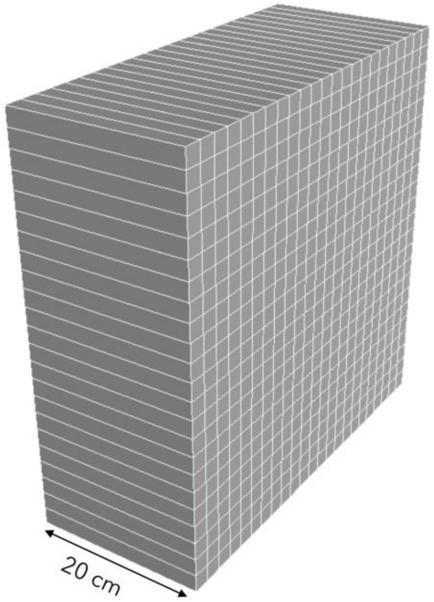


Fig : Geant4 simulation calorimeter

1. e^-, e^+, P detection and PID
2. Clones of the NPS calorimeter at Hall C
3. 2x2x20 cm^2 PBWO4 scintillator crystal
4. Expected energy resolution $\frac{2.5\,\%}{\sqrt{E}} + 1\,\%$
5. Coordinate resolution ~3 mm at 1 GeV
6. Fly's eye assembly of 23x23 matrix of total 2116 modules

Unpolarized TCS

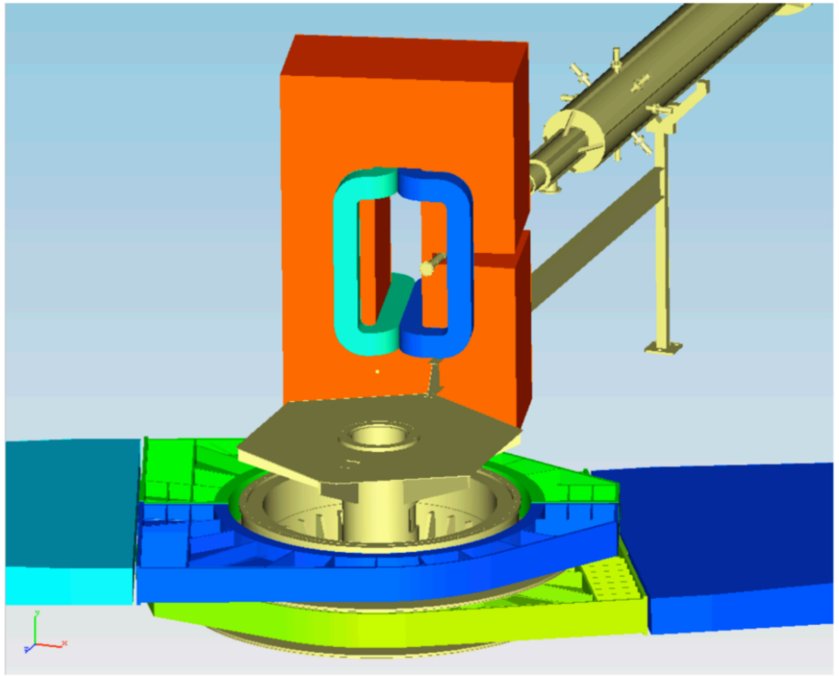


Fig : CAD Drawing for Super Bigbite Magnet
Source : https://userweb.jlab.org/~bogdanw/SBS-general.pdf

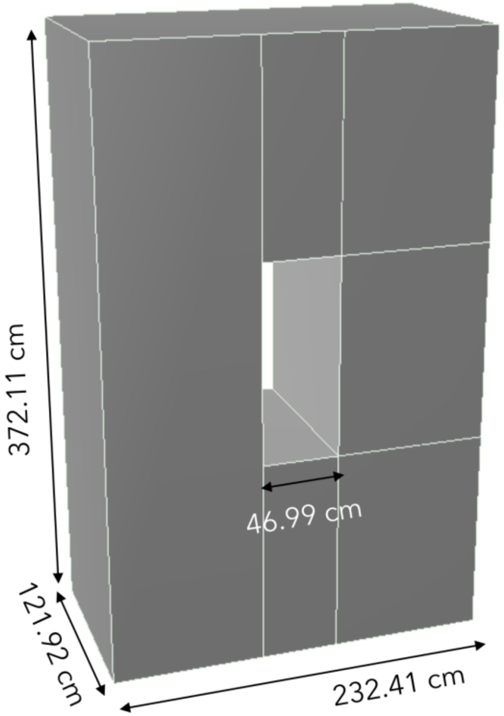
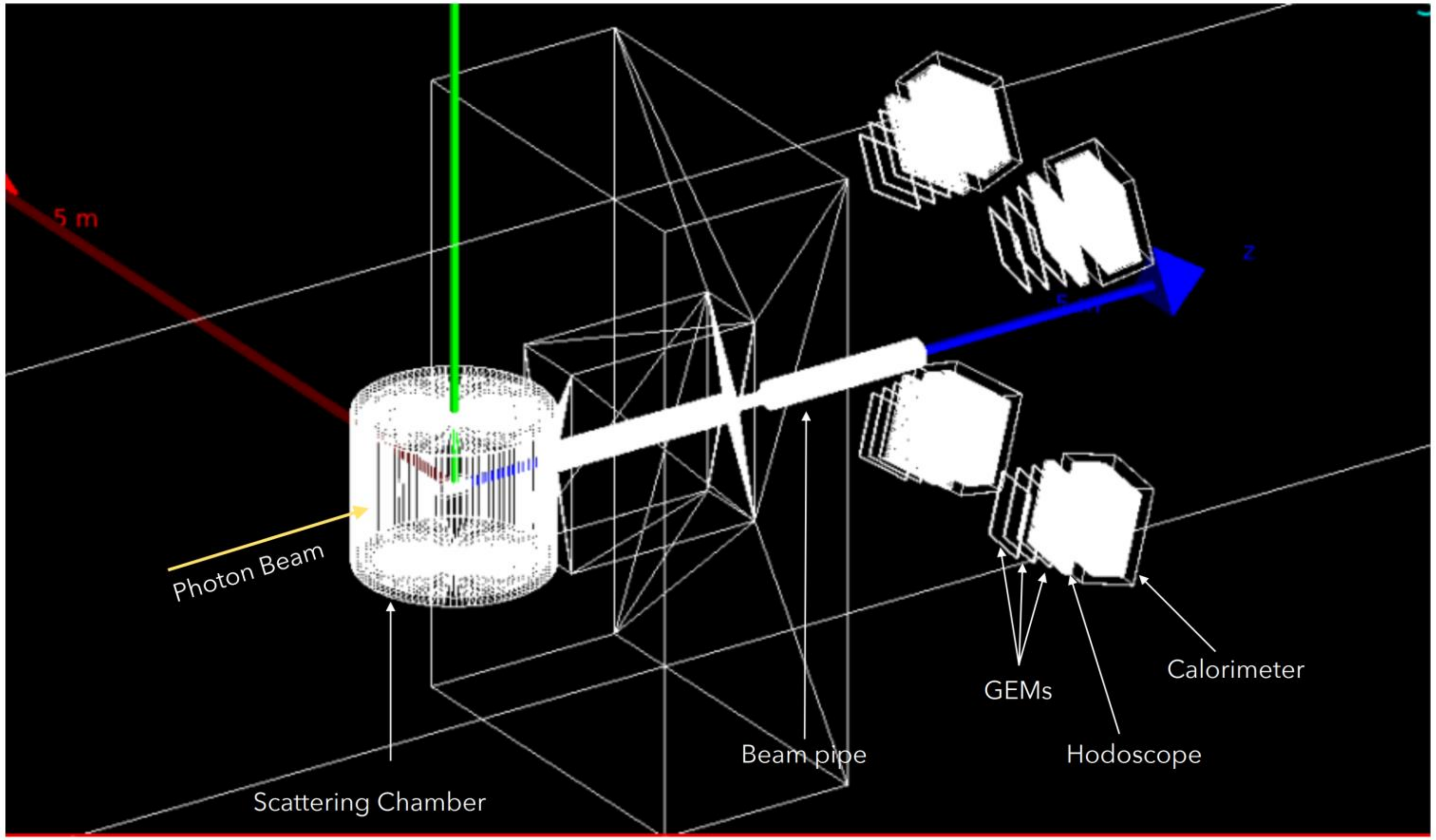


Fig : Geant4 simulation of simple magnet geometry

1. The field integral is 2.4 Tesla-meter with 1.2 m long pole

Unpolarized TCS



To do list

- Simulation work with full background
  - Develop analysis software for reconstruction (PID and tracking)
  - Demonstrate operation of GEM tracker possible
  - Demonstrate proton detection is possible

  - Looking into adapting SBS software

Conclusion

- Timelike Compton Scattering can test universality of GPDs and is an additional way to access GPDs in particularly E

- Experimental challenge with proton detection

- Polarized TCS with CPS and NPS
  - Study ongoing for next PAC

- Unpolarized TCS with CPS,NPS and SBS and cryogenic LH2 target being investigated