TCS with NPS/CPS and Transversely Polarized Target

M.Boër, D.Keller, V.Tadevosyan

Joint Halls A/C Summer Meeting 2020

Outline

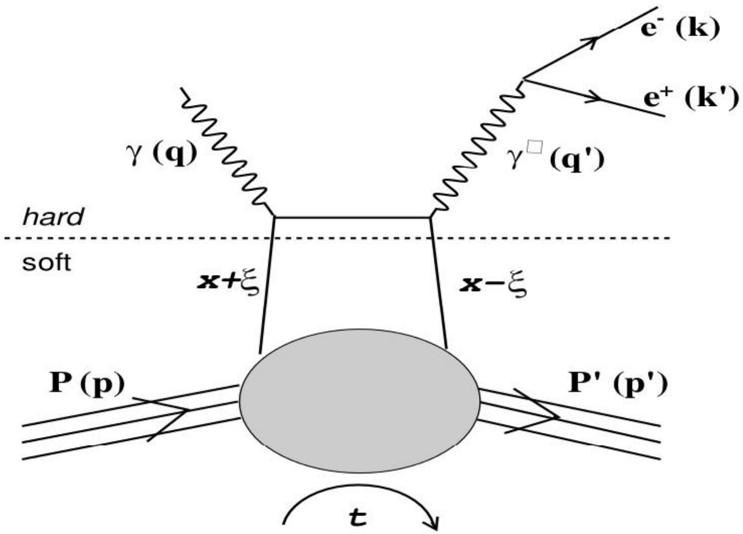
Physics case and motivation

Experimental setup

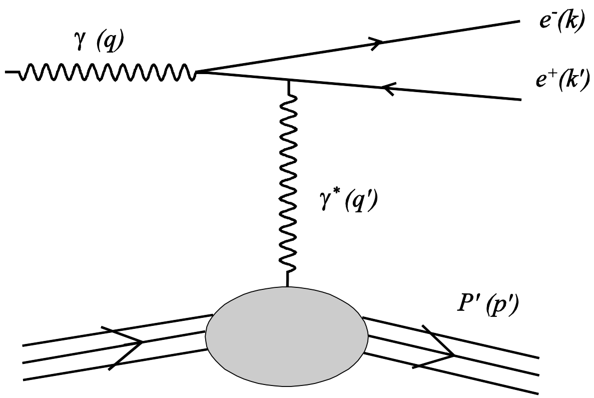
Anticipated results

Summary and Outlooks

Physics case, motivation



TCS



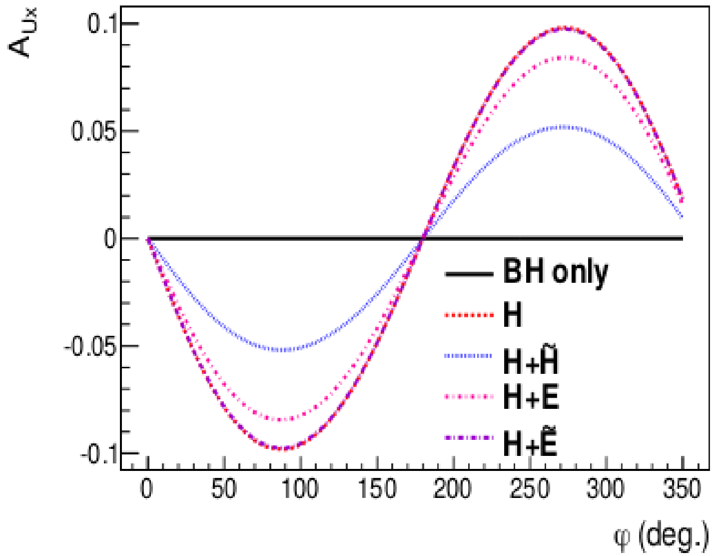
BH

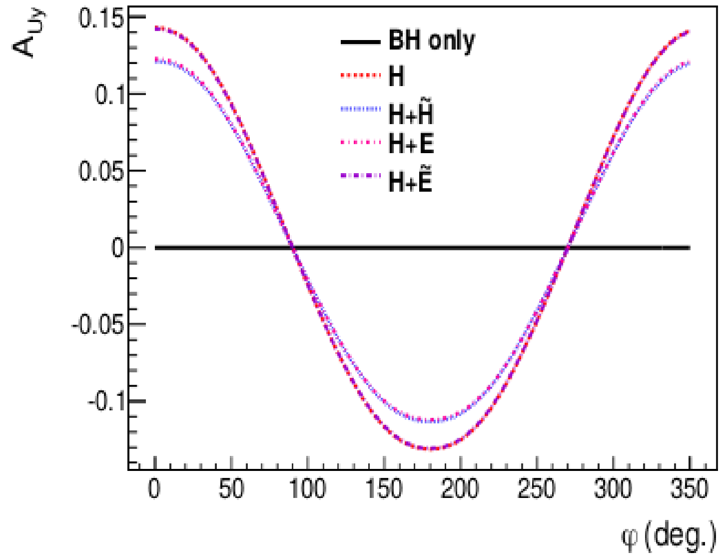
Time-like Compton Scattering (TCS):

- Scattering of real photon from quark in nucleus
- Emission of high virtulaity (>> 1 GeV^2) photon
- Attained in interference with Bethe-Heitler (BH) process
- Cross section parameterized in Compton Form Factors (CFF), which include GPDs
- Sensitive to GPDs , in particular to **GPD E if transversely polarized target**
- **GPD E**, poorly constrained, **access to the spin structure of nucleon**

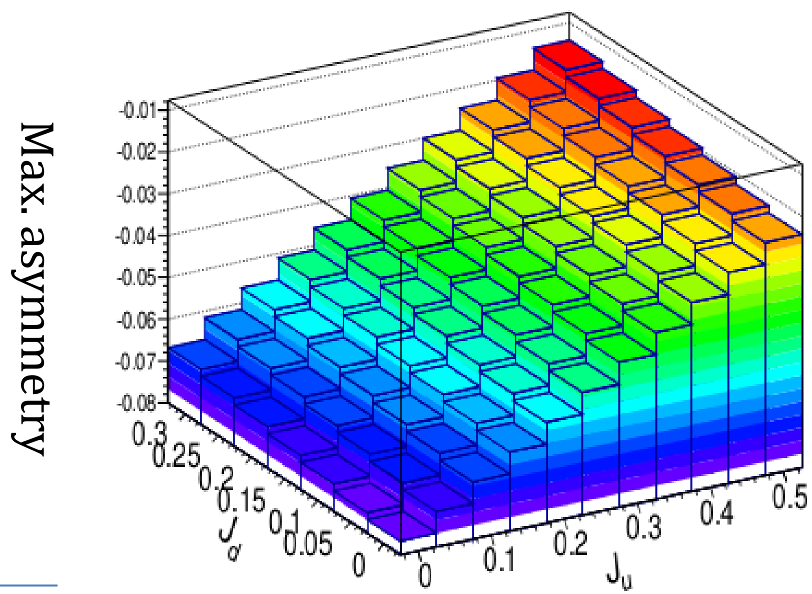
Physics case: Transverse target spin asymmetries

Orthogonal transverse spin asymmetries with different GPD parametrizations





“Size" of asymmetry when running Ju and Jd

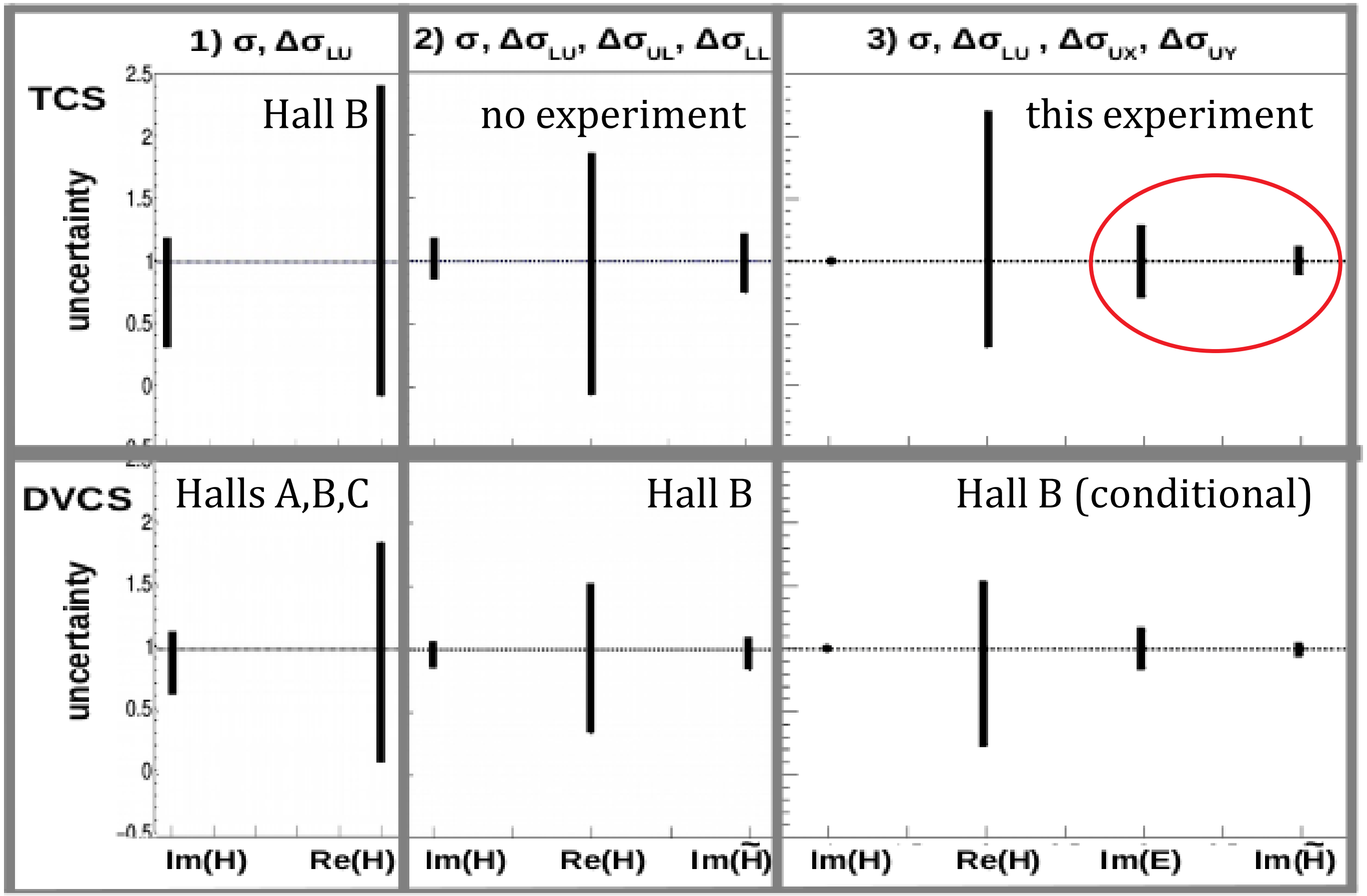


- Asymmetry sensitive to GPDs
- Reflect TCS contribution through interference

→purely imaginary, BH cancels

- Sensitive to angular momenta J_u, J_d and GPD E

Physics case: Extraction of CFFs from TCS versus DVCS



Example estimates of accuracies on the model extraction of CFFs.
TCS with trans. Pol. taget allows extraction of Im(E).

Physics case, main goals

Analysis:

- Extraction of CFF Im(E), parameterization of GPD E (access to partitioning of nucleon angular momentum among quarks);
- Testing of GPD universality, by comparison of CFFs from TCS (timelike virtuality) to DVCS (spacelike virtuality);
- Constrain CFFs (twist 2) by simultaneous fit of all CFF data from TCS and DVCS, provided the universality is established.

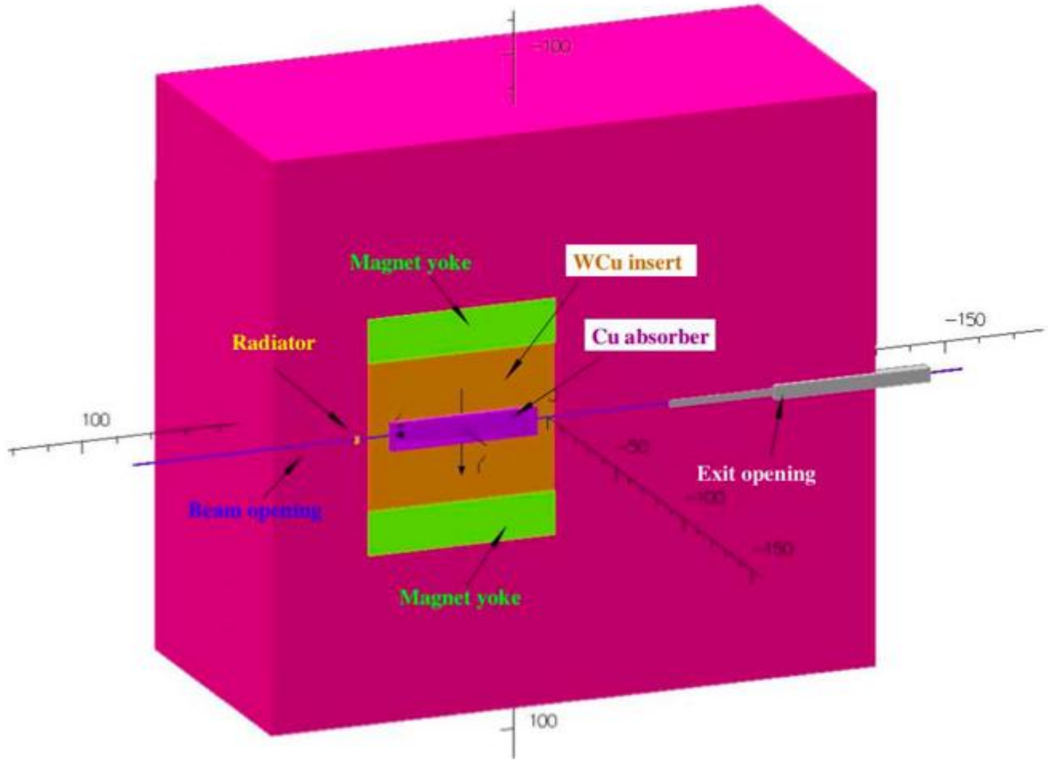
Measurements:

- Target spin asymmetries of TCS+BH;
- Unpolarized cross sections (opportunistic);
- Beam polarized cross sections (circularly polarized beam, opportunistic);

Experimental apparatus:

- High intensity untagged brem. photon beam from CPS;
- UVA/Jlab transversely polarized (85%) ammonia target;
- Detector setup for tracking and detection in coincidence of outgoing e+ ,e-, p.

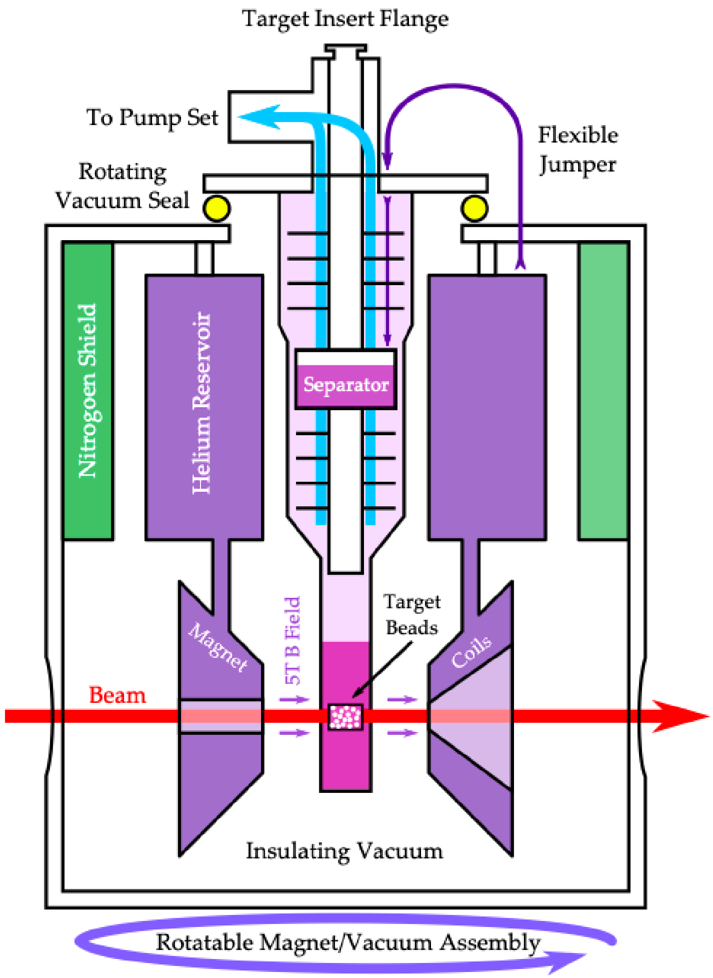
Experimental apparatus, CPS



Compact Photon Source under development in Hall C at JLab:

- Combines polarized photon source, collimator and beam dump;
- High intensity collimated brem. photon beam (1.5×10^{12} γ/s in [5.5 GeV, 11 GeV] range from 2.5 μA primary e- beam on 10% X_0 Cu radiator , ~1 mm spot size at 2 m from radiator)
- 3.2 T warm magnet to bend incoming electrons to local beam dump;
- Highly shielded design (W/Cu alloy) to minimize prompt and residual radiation.

Experimental apparatus: UVA/JLab polarized target



UVA target, nominal configuration

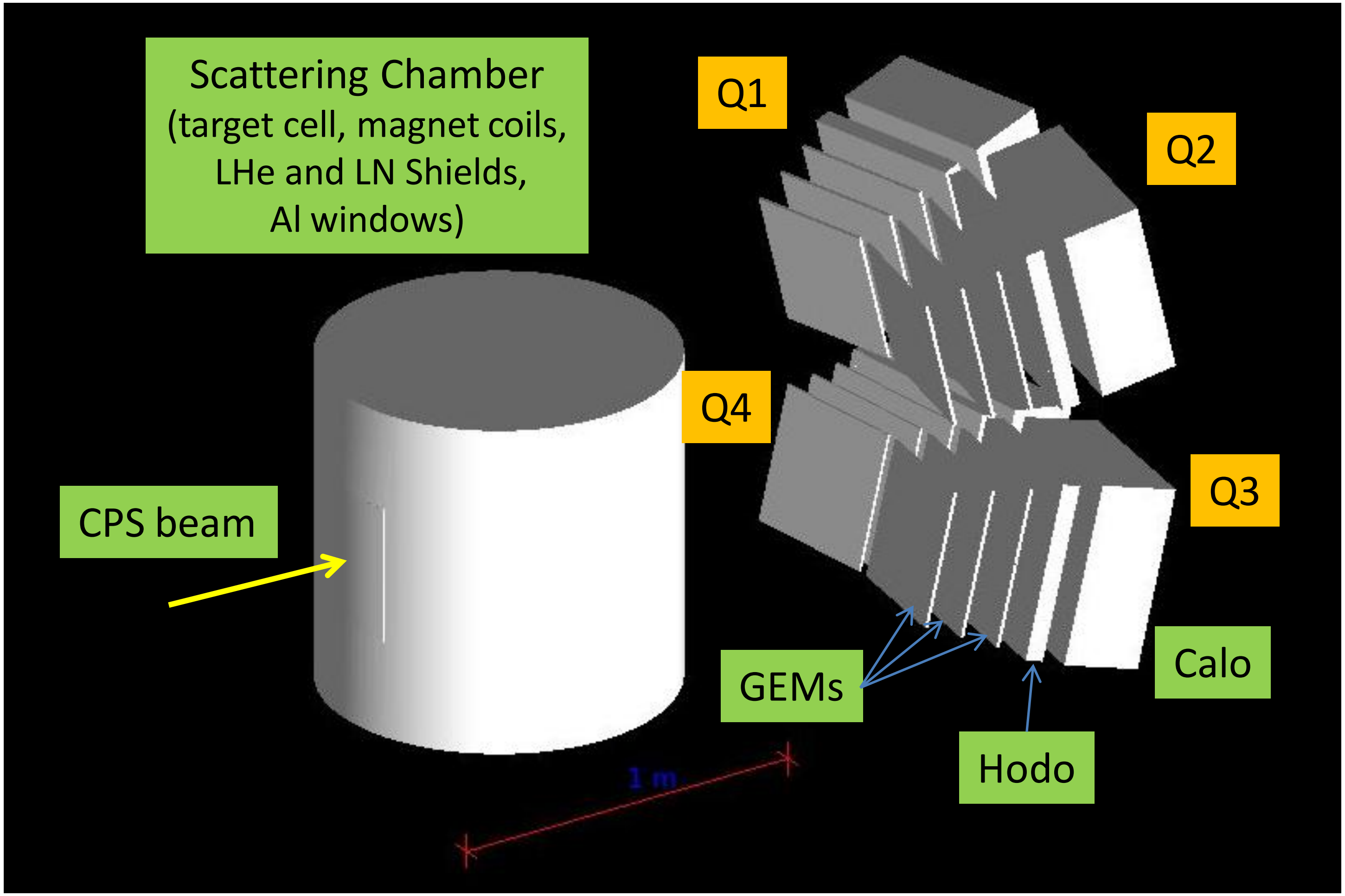
- Target material: $^{15}NH_3$, in LHe at 1°K.
- Packing fraction 0.6.
- 5T (uniform to 10^{-4}) mag field generated by superconducting Helmhotz coils.
- DNP polarization by 140 GHz, 20 W RF field.
- Polarization monitored via NMR.

<u>TCS configuration</u>:

- Setup rotated by 90° around vertical axis.
- Sideways magnetic field and polarization.
- Angular acceptance ±17° horizontally, ±21.7° vertically (*±25° horizontally may be available in the future*).

<u>Depolarization mitigated</u> by combined rotation (~1 Hz) around horizontal axis and vertical up/down movement (~10 mm).

Experimental apparatus: detectors



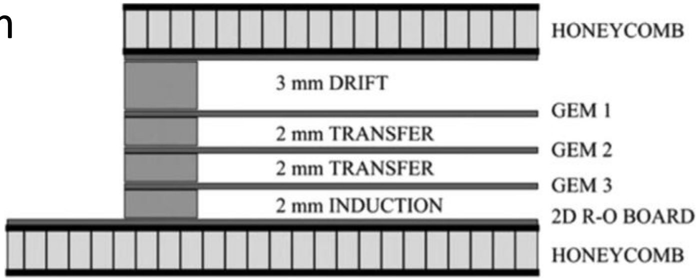
- Detectors arrainged in 4 quarters, oriented to target
- Central gap of $\pm 1.6°$ to exclude high rate background
- Triple-GEMs for e^+ , e^- , p tracking
- Hodoscopes for recoil proton detection/PID
- $PbWO_4$ calorimeters for e^+ , e^- detection/PID

Experimental apparatus: trackers, hodoscopes

GEM trackers:

- Coordinate reconstruction accuracy better than 100 μm
- Background rate tolerance up to 10^6 Hz/mm^2
- Magnetic field tolerance up to 1.4 T
- Good radiation resistance
- Minimum material thickness along particle pass
- Big size manufacturing

Use at Jlab: SBS, SoLID DDVCS, Prad



Layout of COMPASS GEM-s
(*F.Sauli, NIMA 805 (2016) 12-24*)

Hodoscopes:

- To provide dE/dX signal from low momentum recoil protons
- 2x2x5 cm^3 scintillators arranged in “Fly’s eye” hodoscopic construction
- Light detectors attached to the rear side of scintillators

Experimental apparatus: calorimeters

Detect and identify leptons, measure energy and coordinates. Define Q'^2, x, ξ.

Modular construction, similar to the NPS calorimeter:

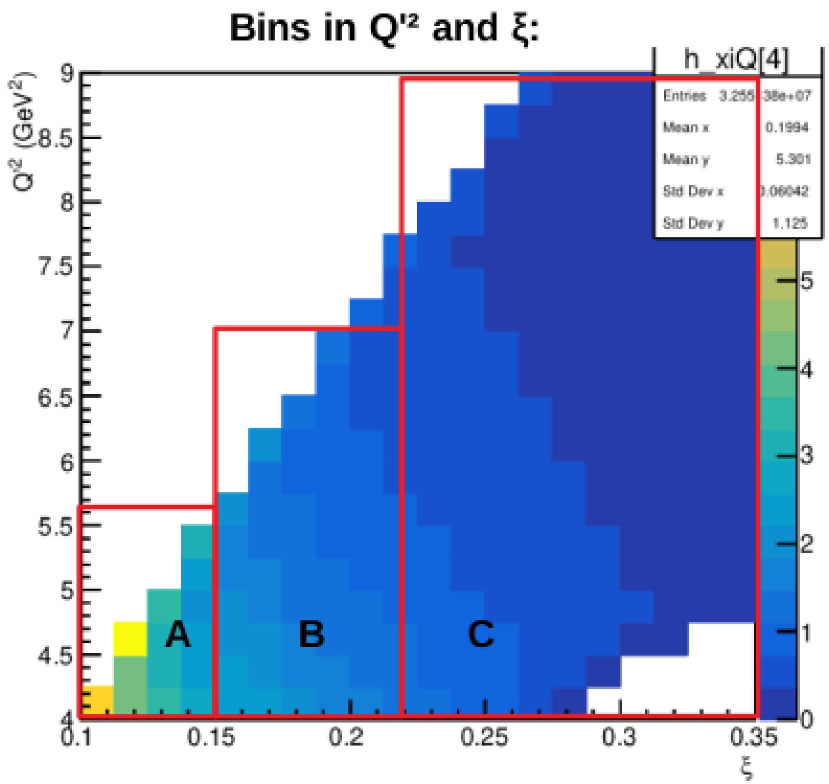
- 2x2x20 cm^2 **$PBWO_4$ scin. crystals**, optically isolated
- Hamamatsu **R4125 PMTs** (¾", bialcali photocathode) for light collection
- **Active devider** linear up to 1 MHz rate.
- Modules arranged in a mesh of μ-metal
- Expected **energy resolution** 2.5%/√E + 1%
- Expected **coordinate resolution** ~3 mm at 1 GeV.

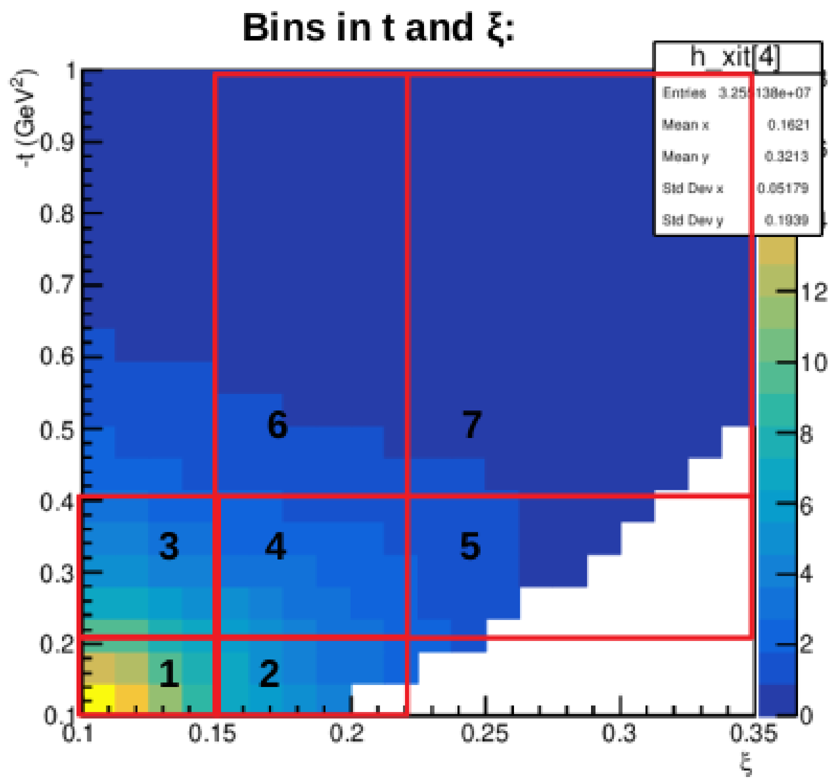
For TCS case, modules arranged in 4 "fly's eye" assemblies of 23x23 matrix.
Total number of modules needed **2116**.

<u>Progress in NPS construction</u>

- Crystals from vendors (SICCAS, Crytur) are being ordered and obtained, evaluated at Jlab, CUA
- R4125 Hamamatsu PMTs obtained
- Prototypes constructed and tested under beam conditions in Hall D
- Design & construction of support structures are underway
- Design of enclosure is underway

Unticipated results: kinematic coverage

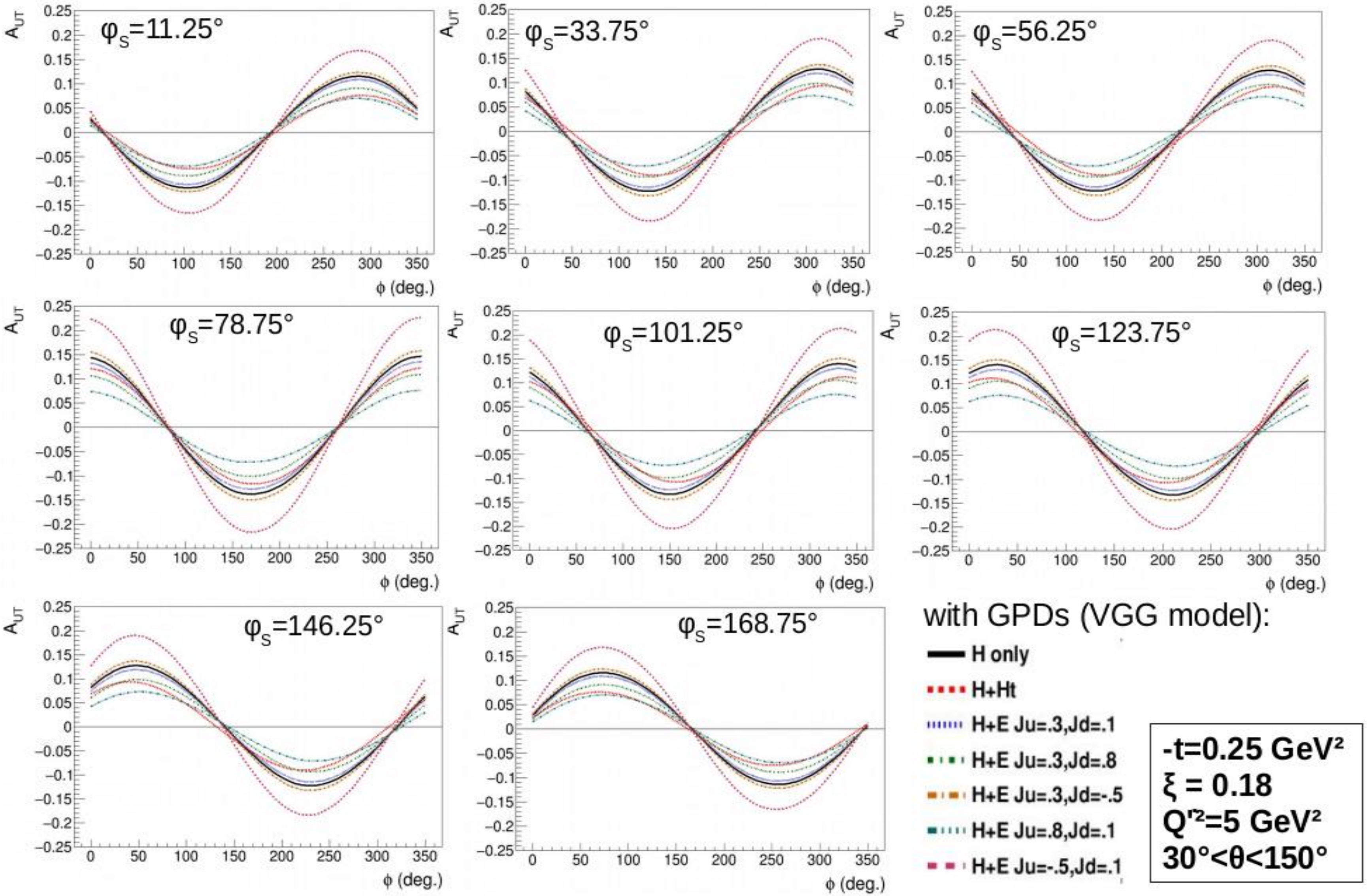




A: $.10 < \xi < .15$; $4 < Q'^2 < 5.5$ GeV²
B: $.15 < \xi < .22$; $4 < Q'^2 < 7$ GeV²
C: $.22 < \xi < .35$; $4 < Q'^2 < 9$ GeV²

1, 2: $.1 < -t < .2$ GeV²
3, 4, 5: $.2 < -t < .35$ GeV²
6, 7: $.35 < -t < .7$ GeV²

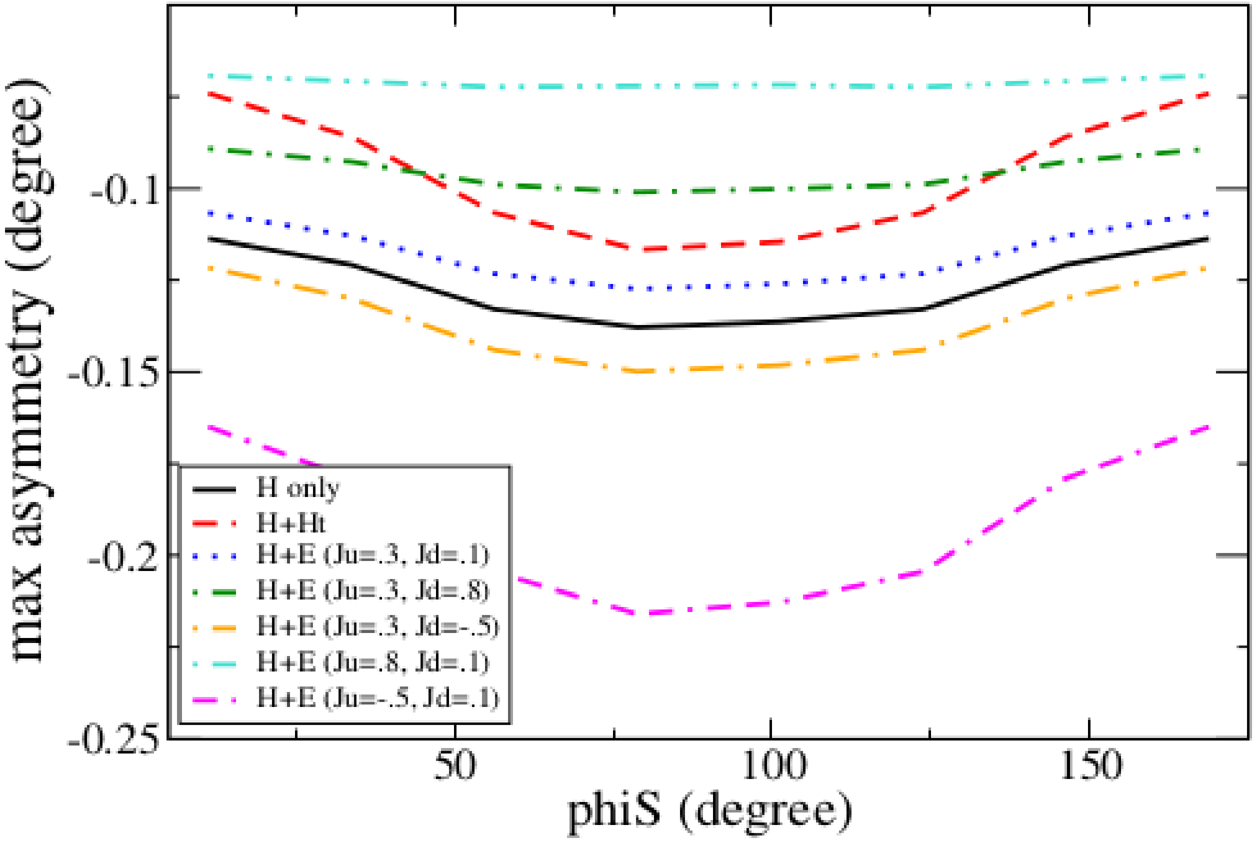
Anticipated results: target asymmetries



- Shows strong dependence on angular momenta
- 8 bins: fit of 2x2 orthogonal bins (4 independent ones) for CFFs global fits

Anticipated results: target asymmetries

Projection of maximum asymmetry for various models (from previous slide)



Strong sensitivity to GPD E and quark angular momenta.

Summary and Outlooks

TSA measurement with transversely oriented target spin is sensitive to Im(E) CFF, hence to GPD E and OAM of partons.

Adding data from TCS with transversely oriented target spin to the data bank from other TCS and DVCS experiments renders an opportunity to **probe the universality of GPDs**, contribute to data set for **GPD global fits**.

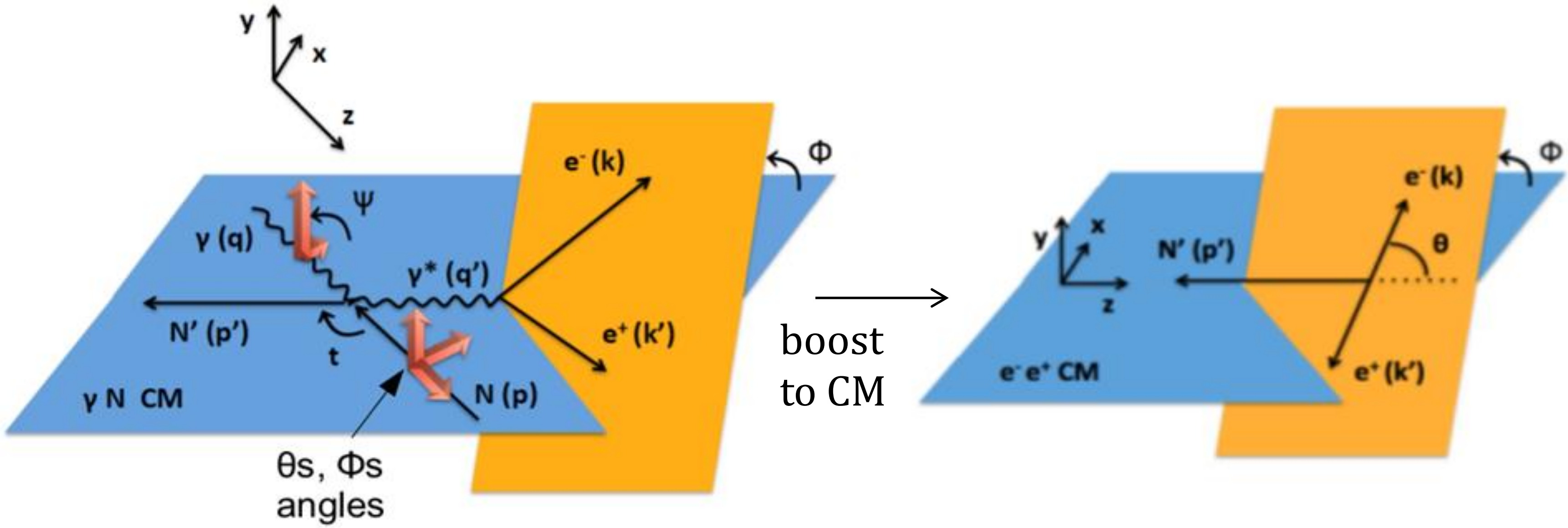
With Compact Photon Source, and modified UVA/JLab target, Hall C TCS becomes a competitive project, complementary to other TCS and DVCS measurements.

PR-12-18-005 proposal for the experiment in Hall C was conditionally approved by PAC 46, updated and presented to PAC48.

Thank you for your attention!

Backup slides

Measuring Timelike Compton Scattering



dσ: 5 or 6 independent variables
choice:
E_γ (or ξ), t, Q^2, φ, θ; for transverse target spin φ_s

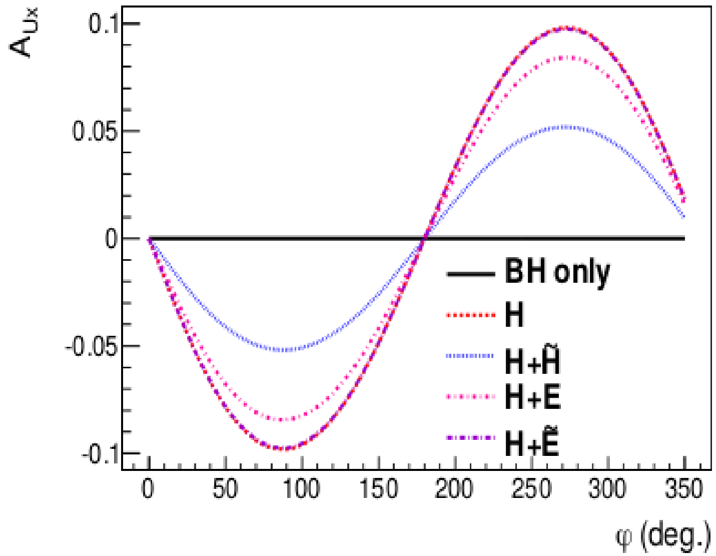
Angles: φ: (hadronic plane, pair) φ_S, θ_S: (hadronic plane, target spin)
θ: (γ*, e⁻) Ψ: (hadronic plane, γ spin)

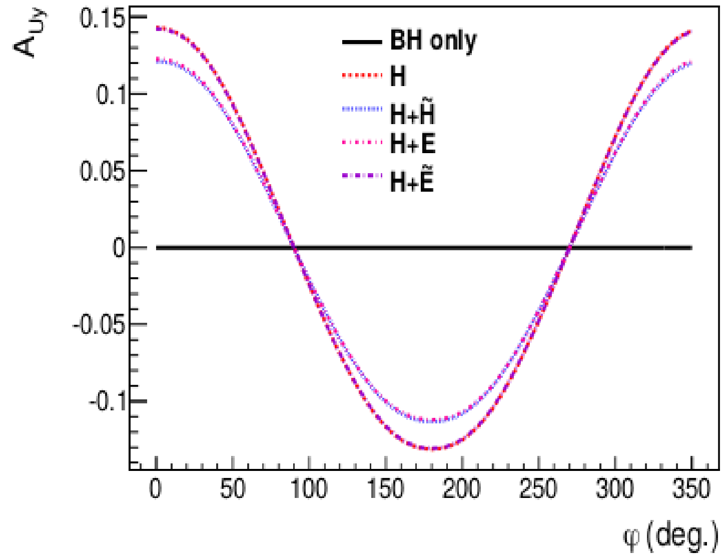
Various unpolarized, polarized cross sections, target and/or spin asymmetries or angular momenta are sensitive to different Compton Form Factors and GPDs

notations: σ (x-section) or A (asymmetry)≡$[\sigma^{\downarrow}-\sigma^{\uparrow}]/[2\sigma]$, index 1=beam polar., index 2=target polar.

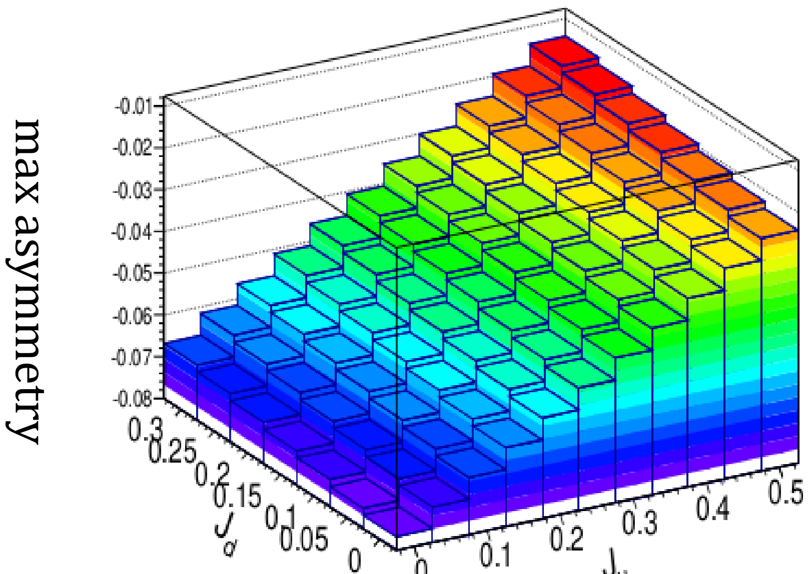
Transverse target spin asymmetries

example: 2 orthogonal transverse spin asymmetries with different GPD parametrization





"size" of asymmetry when running Ju and Jd

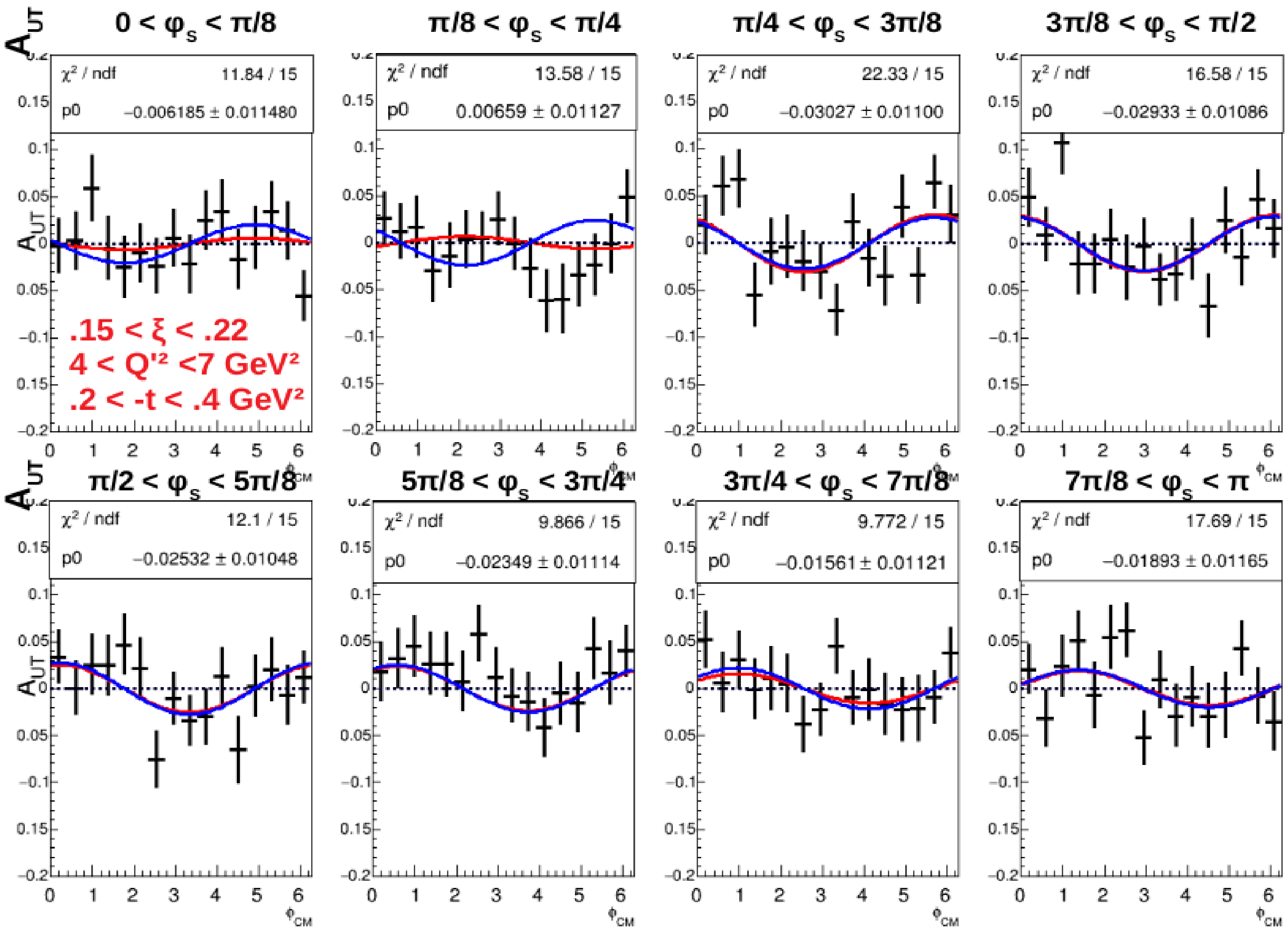


- Asymmetry sensitive to GPDs
- Reflect TCS contribution through interference

→purely imaginary, BH cancels

- Sensitive to angular momenta J_u, J_d and GPD E

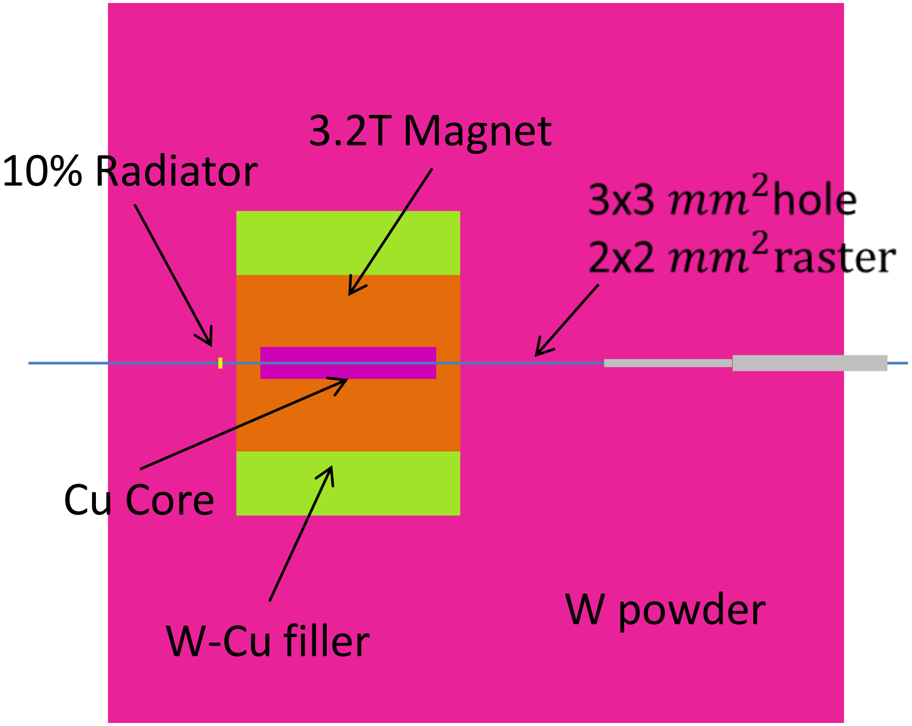
Illustration of sin(φ-φS) fitting of bin 4



black: smeared simu
blue: ideal
red: 1 fit attempt

with dilution factors, exp. stat. uncertainty

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

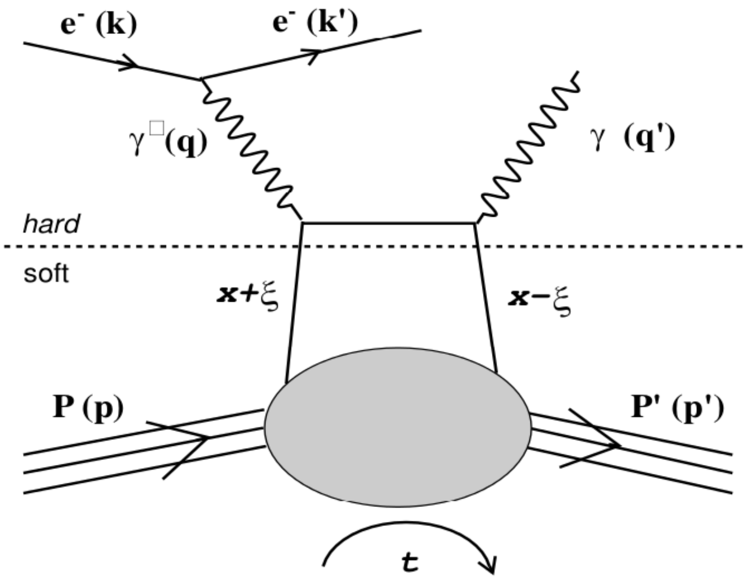
- Up to 2.7 µA, 11 GeV e- beam incident
- 10% radiator to produce (untagged) γ beam
- 3.2 T, 40 cm magnet to bend residual e^-
- Magnet serves as a beam dump
- High Z shielding to minimize prompt radiation and residual activation

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

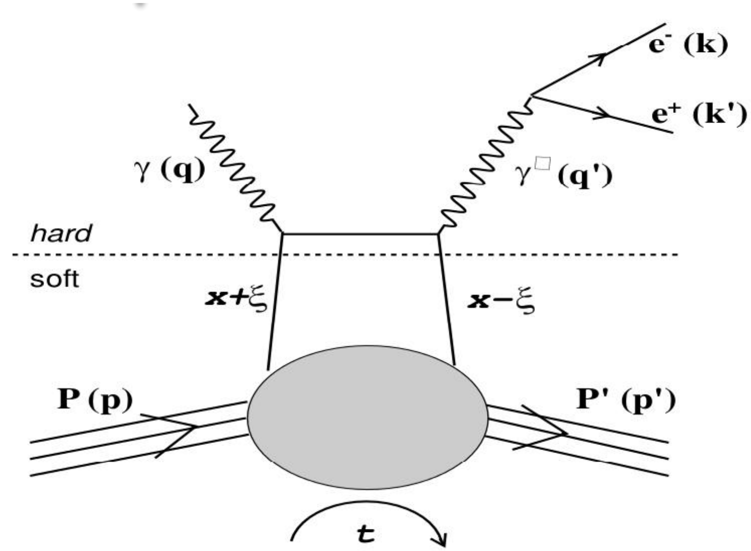
- increase of useful photon flux by 18 times ($\sim 10^{12}\ ^{\gamma}/_{s}$);
- less heat load, increase of max. polarization from 90% to 95%;
- less rad. damage to target material, less depolarization -> increase of average polarization from 70% to 90%.

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.