C12-18-005

Timelike Compton Scattering off a transversely polarized proton in JLab Hall C

PAC50, July 12th, 2022, Jefferson Lab

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And the NPS and CPS collaborations

Context

C12-18-005 was conditionally approved (C2) by PAC 48

Technical concerns in 2020

- using GEM in the trigger and high rates
- timing resolution for trigger components
- Proton PID
- full GEANT4
- systematics, radiations
- tracking
- background analysis

Motivations

Why measuring TCS off a transversely polarized proton?

- **Unique access to GPD E of the proton**

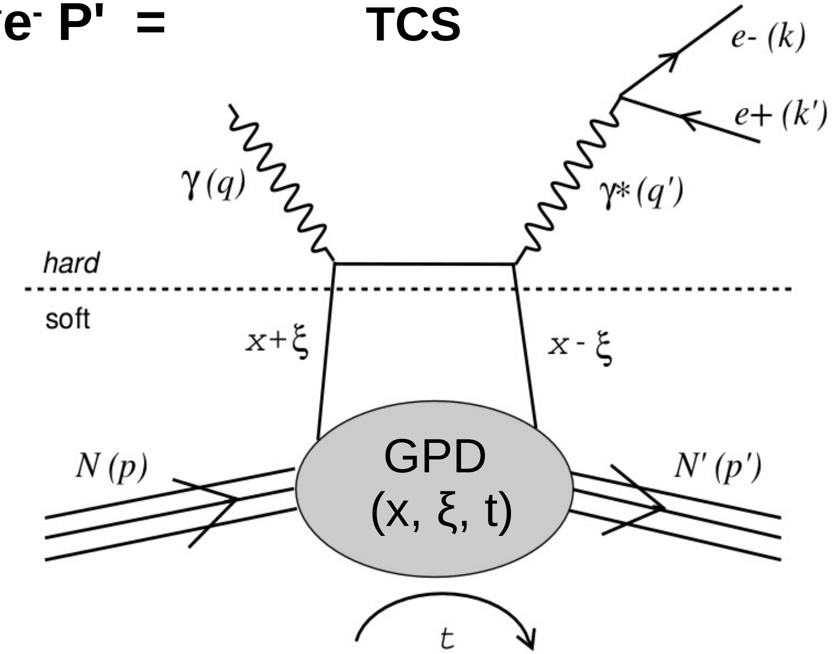
Besides CFFs Im(H), Re(H)

=> Im(E) (TSA) with TSA

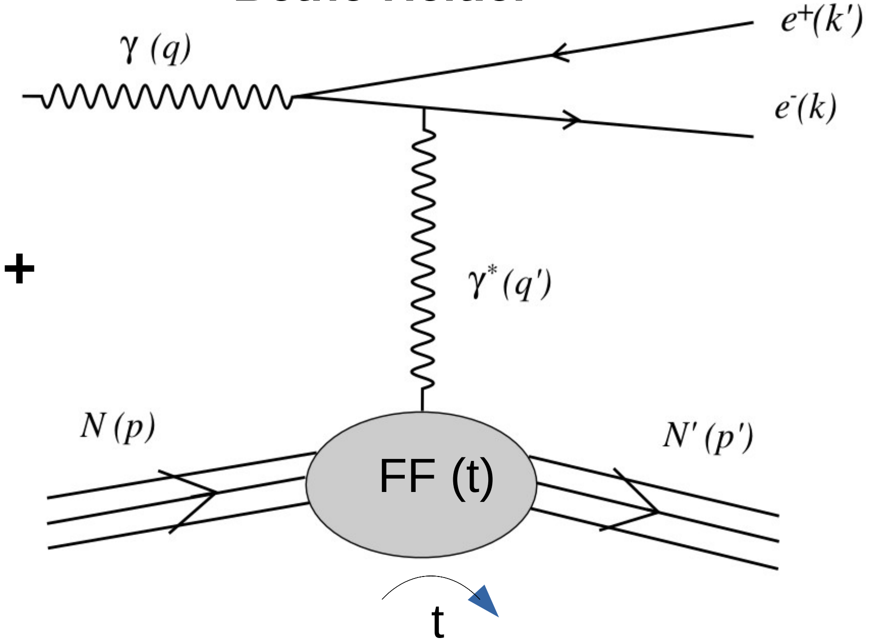
=> Re(E), Re(H~) with BTSA

- **GPD universality studies (TCS vs DVCS)** [with complementary data, reduce correlation errors]
- **Complementary, simultaneous fits with DVCS, multichannel database and standalone**

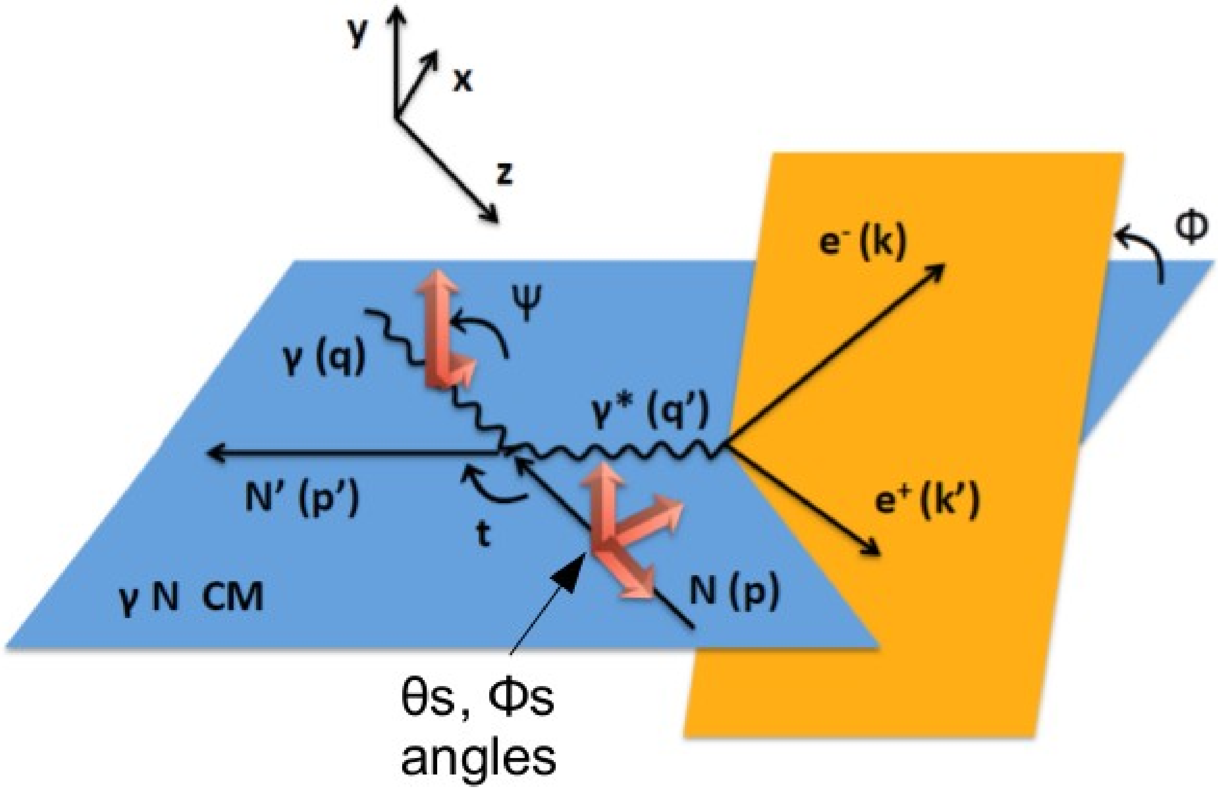
γ P $\rightarrow$ e^+e^- P' = **TCS**



+ **Bethe-Heitler**



Observables

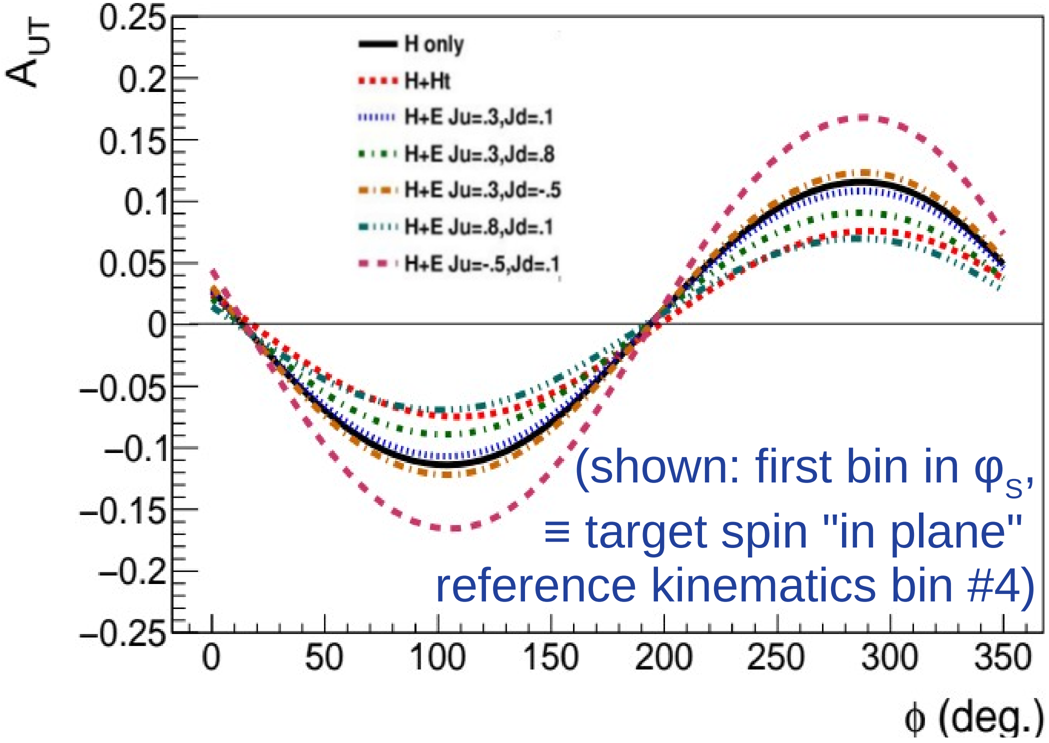


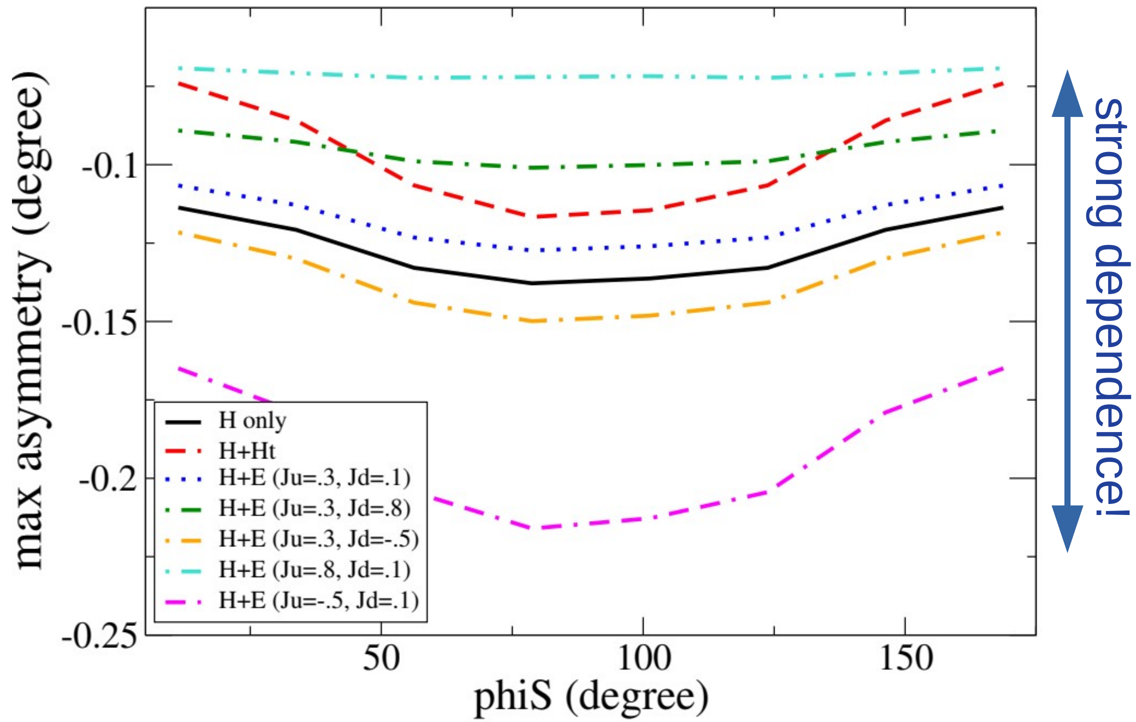
φ: e⁻ vs reaction plane
φ_S: P spin vs reaction plane
θ: polar angle (integrated)
E_γ ($\rightarrow$ ξ), t, Q'²

6 independent variables for transversely polarized TCS

Observables

Dependence in GPD parametrization and J_u, J_d (VGG model) vs φ and φ_S





TSA with various quark angular momenta scenarios
(choice of same parameters as Jlab DVCS experiments)

- strong model dependence
- large sensitivity to angular momenta

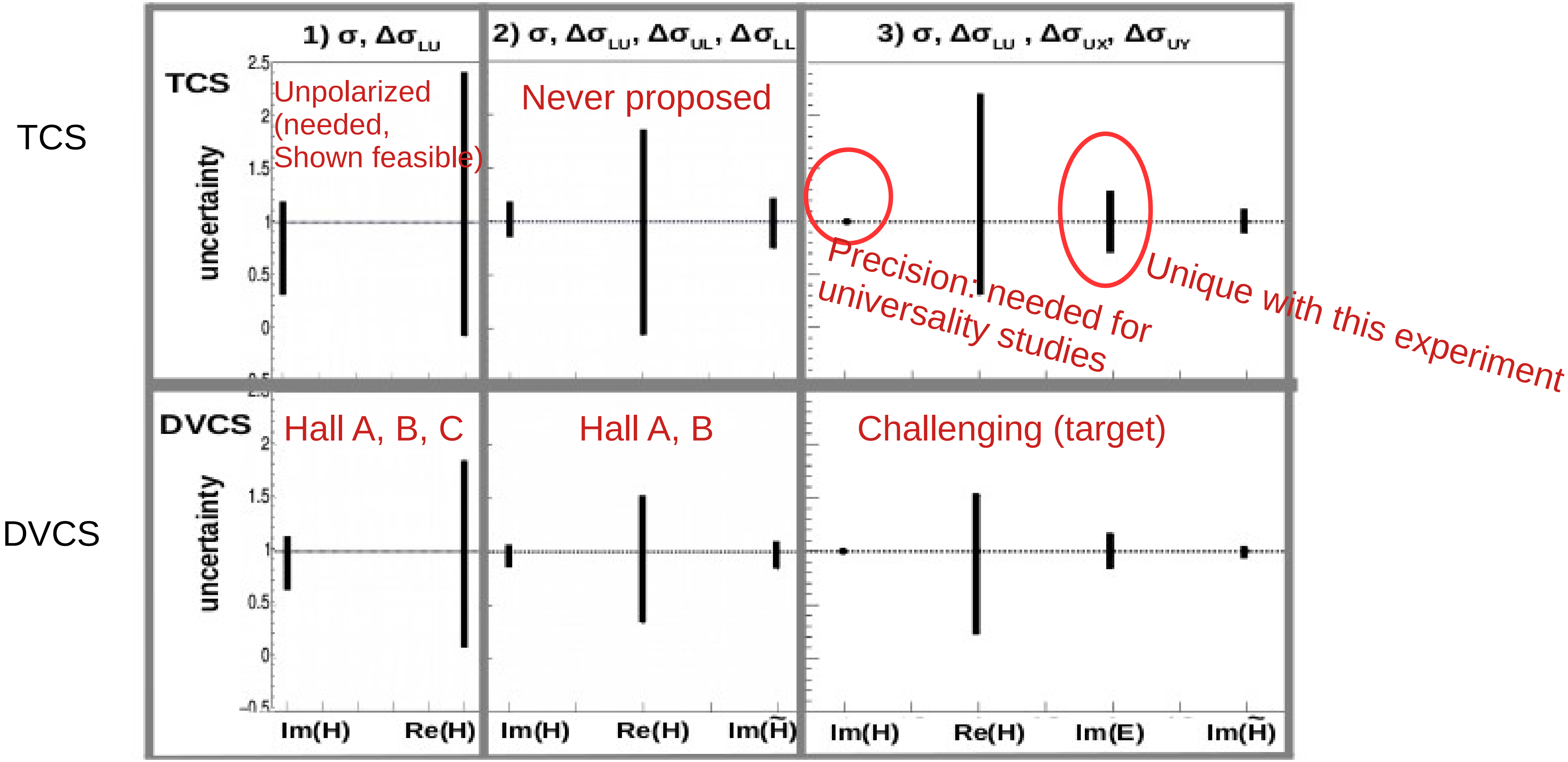
Sinus momenta versus spin angle
=> discriminates model
=> huge dependence in J(quarks)

BH cancels: asym from Compton contribution

Note: model dependent projection
But: poor knowledge of E, any data will greatly improve all models!

Extracting CFFs with TCS versus DVCS

Which CFF can be extracted, approximate precision



- "sketch" assuming same uncertainties. TCS is more difficult experimentaly, lower cross section
- up to ~40% uncertainties can still extract something. 10% on asymmetry is ideal

Same CFFs for leading order, leading twist
(multichannel database + universality studies)

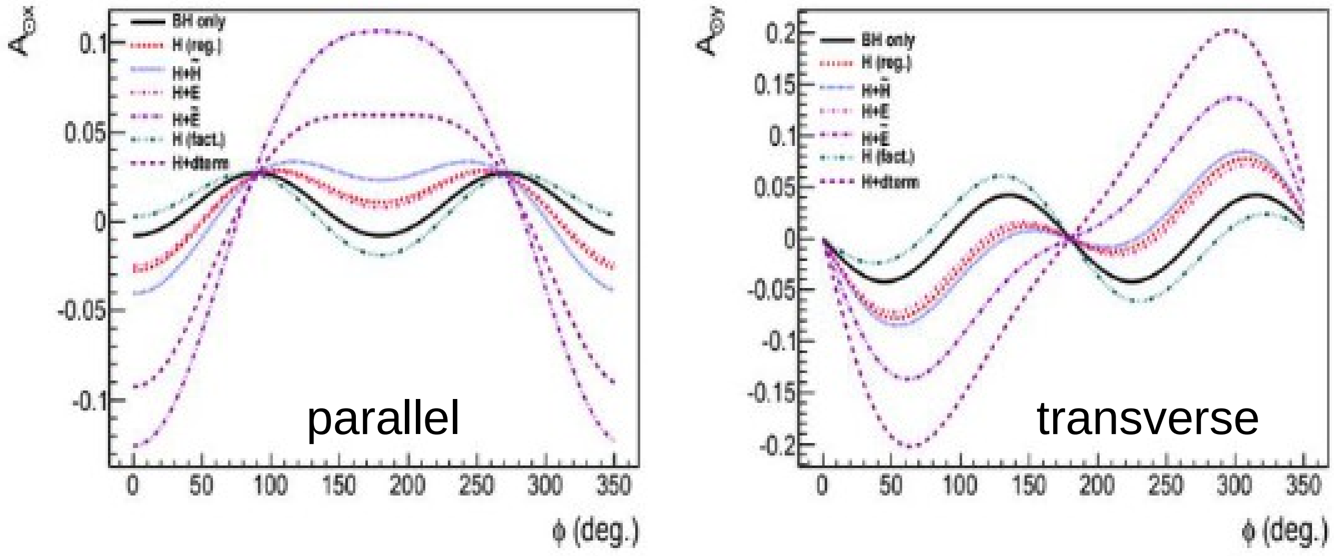
Extra-observables (not proposed)

Observable (proton target)	**Experimental challenge**	**Main interest for GPDs**	**JLab experiments**
Unpolarized cross section	1 or 2 order of magnitude lower than DVCS, require high luminosity	Im + Re part of amplitude. Re(H), Im(H)	CLAS 12, SoLID approved NPS conditionnal
Circularly polarized beam	Easiest observable to measure at JLab	Im(H), Im(H) Sensitivity to quark angular momenta, in particular for neutron	CLAS 12, SoLID approved NPS conditionnal
Linearly polarized beam	Need high luminosity, at least 10x more than for circular beam, and electron tagging	Re(H), D-term. Good to discriminate models and very important to bring constrains to real part of CFF	GlueX (?)
Longitudinaly polarized target	Polarized target	Im(H)	no / "for free"?
Transversely polarized target	Polarized target, and high luminosity: binning in θs, φs	Im(H), Im(E)	NPS conditionnal
Double spin asymmetry with circularly polarized beam	Polarized target, very high luminosity, precision measurement	Real part of all CFF	no / "for free"?
Double spin asymmetry with longitudinally polarized beam	Polarized target, electron tagging, very high luminosity and precision	Not the most interesting, Im(CFFs) but difficult to measure	no

Secondary: extra measurement needed or unnecessary dilution

Primary: BSA, BTSA come “for free”

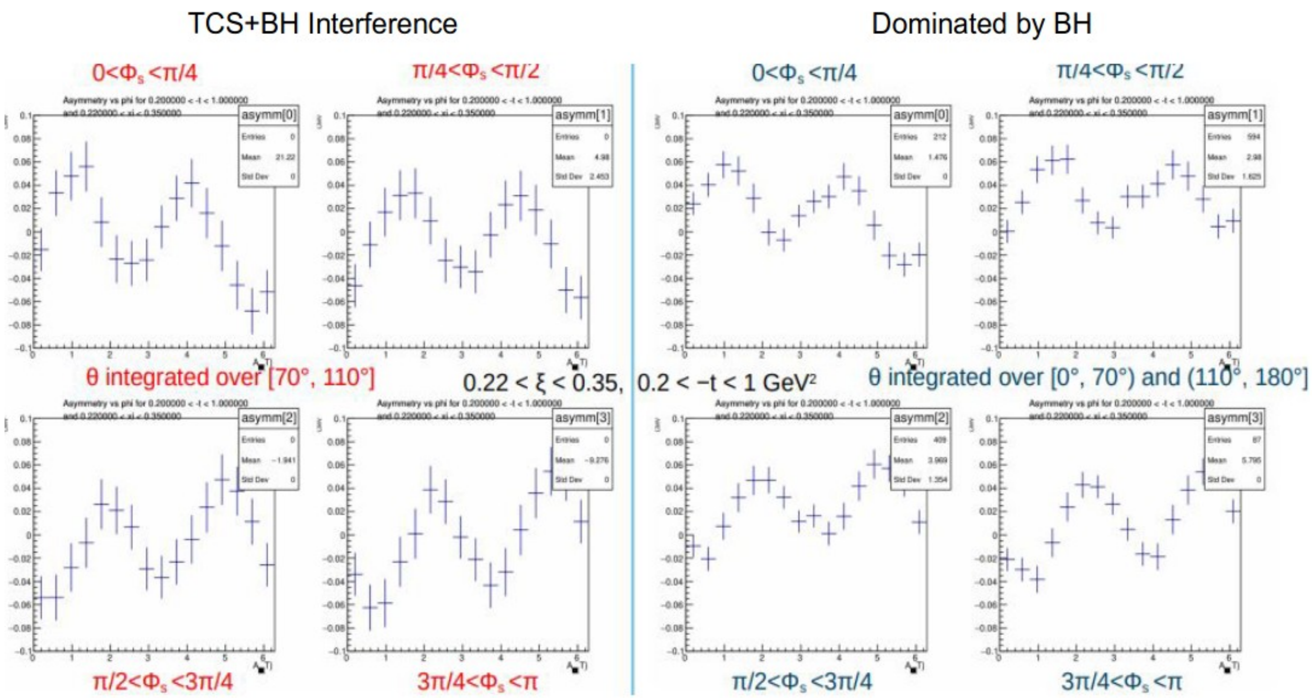
Extra-observables (not proposed but "free")



Similarly, BTSA from various model Parametrization (VGG only)

BH doesnt cancel = difficulty
Not sure which scenario, D-term...

Huge model dependence
(will be even more with other's)
=> absolutely need constraints



<u>Projections for our experiment</u>

Left: th bin dominated by interference

Right: bin dominated by BH

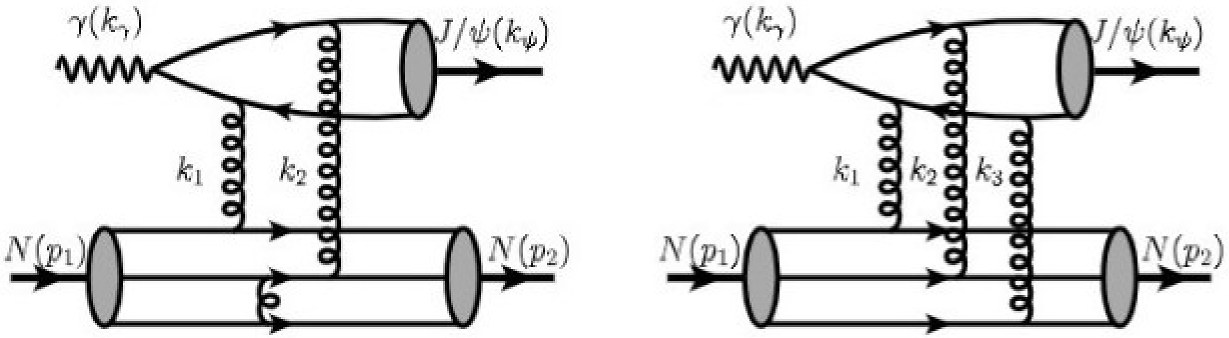
(same xi bin as other projections here)

Same shape, but larger with Compton

Any data is huge progress for Re(CFFs)

Extra-observables (not proposed but “free”)

- New magnet allow extension to parallel measurements of J/psi near threshold transverse target (never proposed, MC studies done – our setup can do it at larger angles)



Left-right asymmetries:
Diluted, or large?
Depends on production mechanism

GPD interpretation near threshold?
How to parametrize N structure?

Figure: 2-gluon and 3-gluon production diagrams for J/Ψ [6].

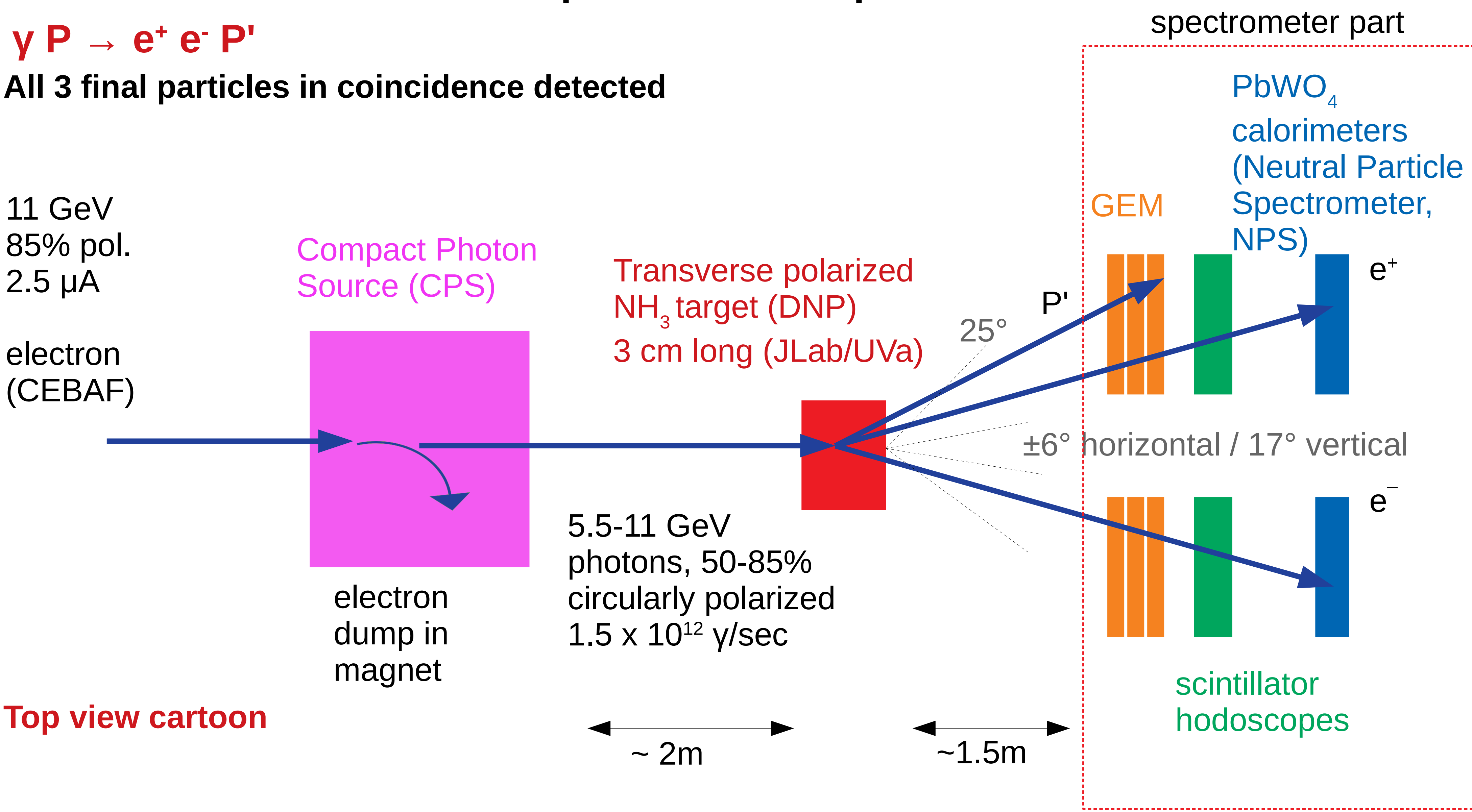
- Measurement of mesons with high resolution and high intensity (spectroscopy…)

(not exhaustive)

Experimental setup

$\gamma P \rightarrow e^+ e^- P'$

All 3 final particles in coincidence detected



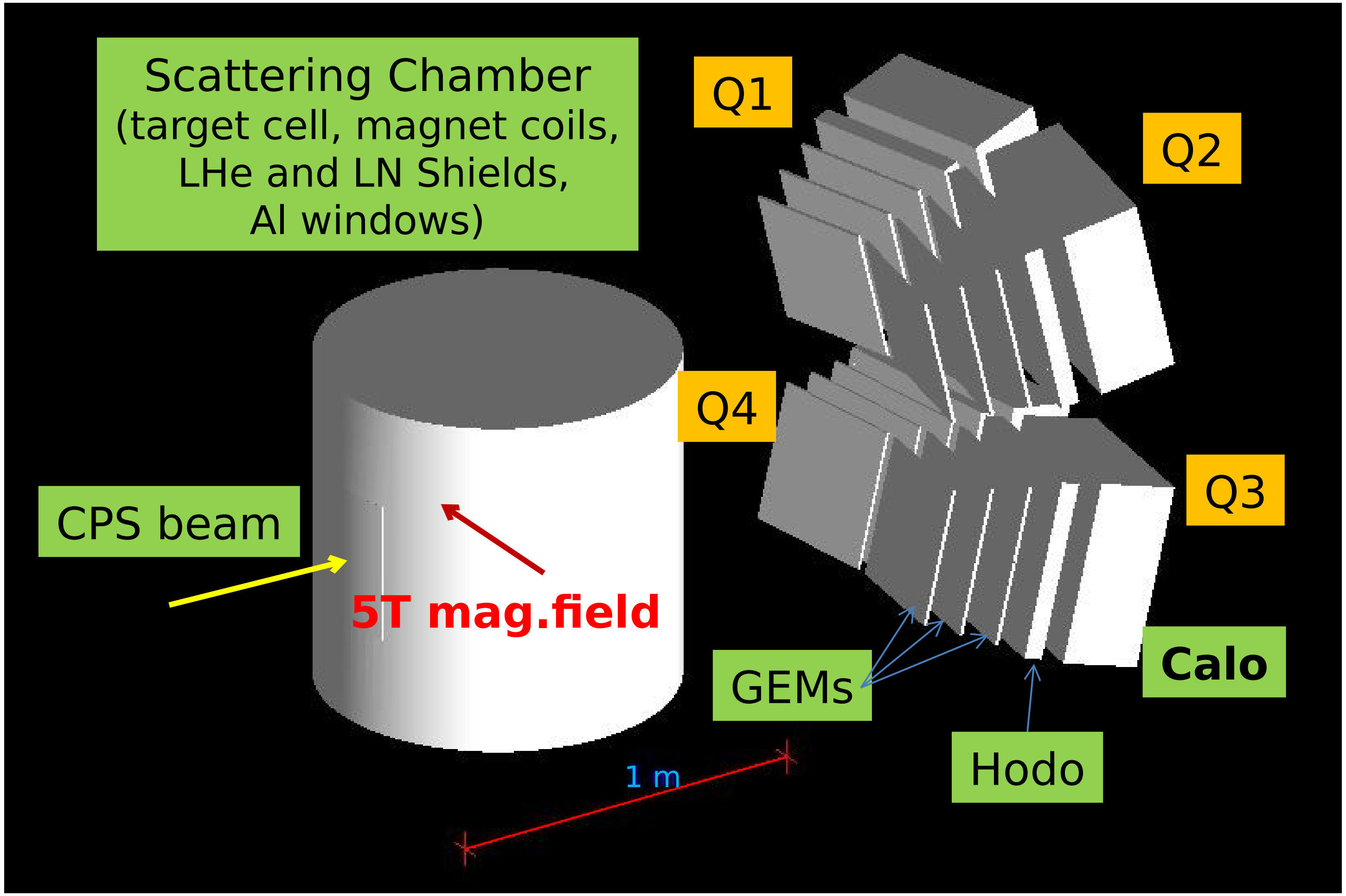
Top view cartoon

Trigger: GEMs, hodoscopes, calorimeters (all 3 particles)

Integrated luminosity: 5.85 x 10^5 pb^{-1} for 30 PAC days of "physics"
Condition PAC: trigger system, will be re-submitted this year (2021)

Experimental setup

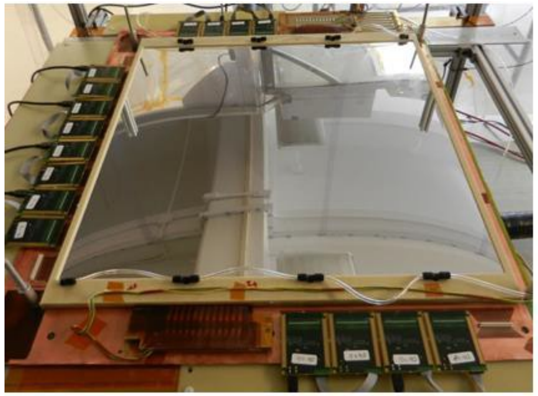
$$\gamma + p \rightarrow \gamma^* (e^+ + e^-) + p'$$



- Detect e^+, e^-, recoil p' in coincidence
- CPS bremsstrahlung photon beam
- UVA/Jlab NH_3 target,

  transversely polarized
- Detectors arranged in 4 quarters, oriented to target
- Triple-GEMs for e^+, e^-, p tracking
- Hodoscopes for recoil proton detection/PID
- $PbWO_4$ calorimeters for e^+, e^-, p detection/PID

Tracking, GEMs, hodoscopes



SBS BT GEM prototype
(*K.Gnanvo et al., NIMA 782 (2015) 77-86*)

GEM trackers:

- Coordinate reconstruction accuracy **~80 μm**
- Background rate tolerance up to **10^6 Hz/mm²**
- Minimum material thickness along particle pass
- Big size manufacturing

Use at Jlab: SBS, SoLID DDVCS, Prad

Hodoscopes:

- To provide dE/dX signal from low momentum recoil protons
- 2x2x5 cm^3 scintillators in “Fly’s eye” hodoscopic construction

Improvement of PID and background reduction (since 2020)

- TOF for PID: up to 450 MeV protons

- lowering threshold: suppress pions in Hodoscope and high low energy particles in GEMs

- GEMs now in use in Hall A: some difficulties, will be addressed by SBS

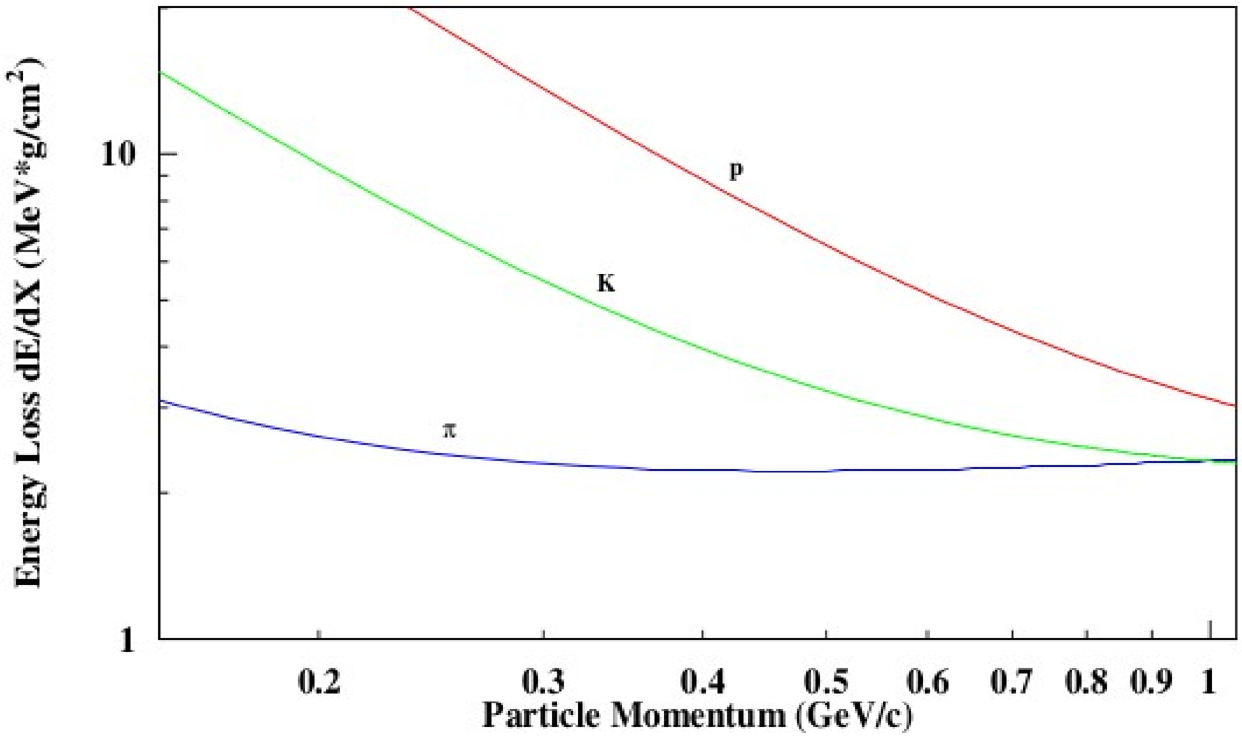
- GEMs not included in our trigger

- backtracking GEANT4 simulations improved

- Hodoscope: readout not decided, but simple technology (R&D starting soon)

Proton PID

Low energy protons, E_{KIN} from ~30 MeV to 450 MeV



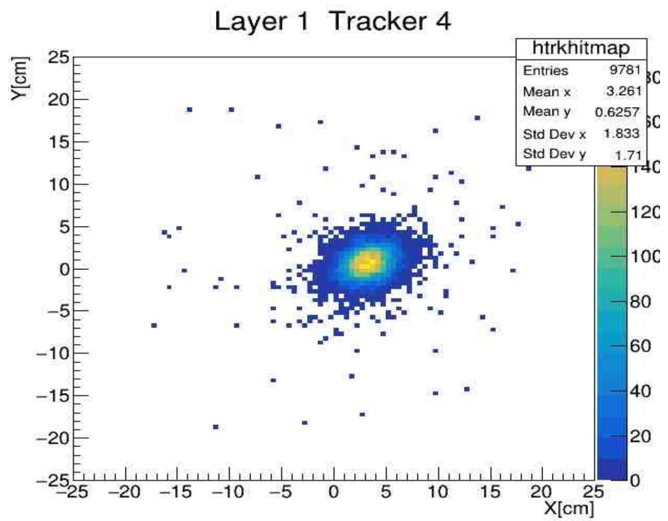
Updated with complete MC, PID in recoil detector

=> better backtracking also allows to track proton at lower momenta

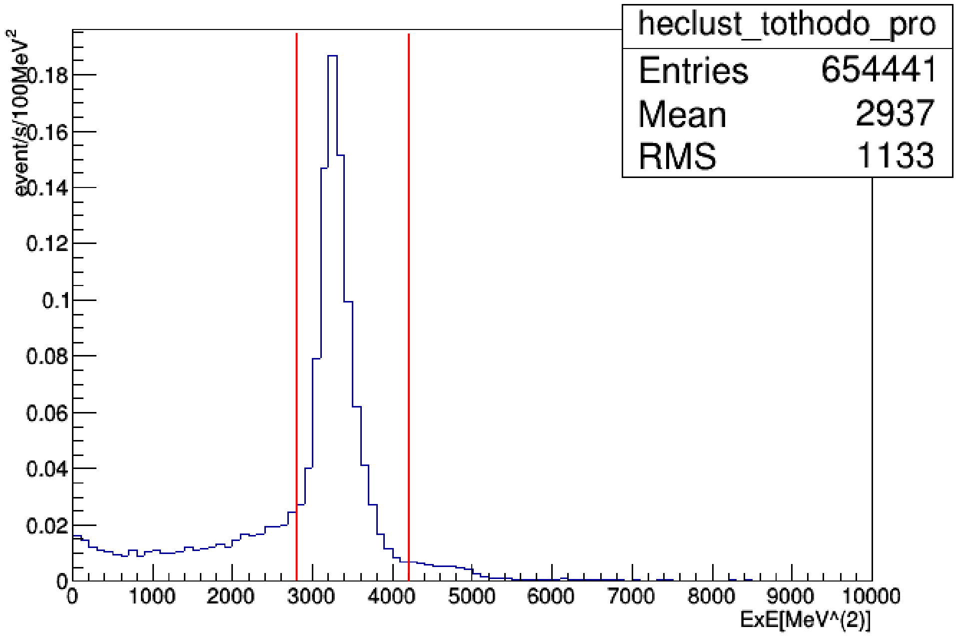
Proton PID

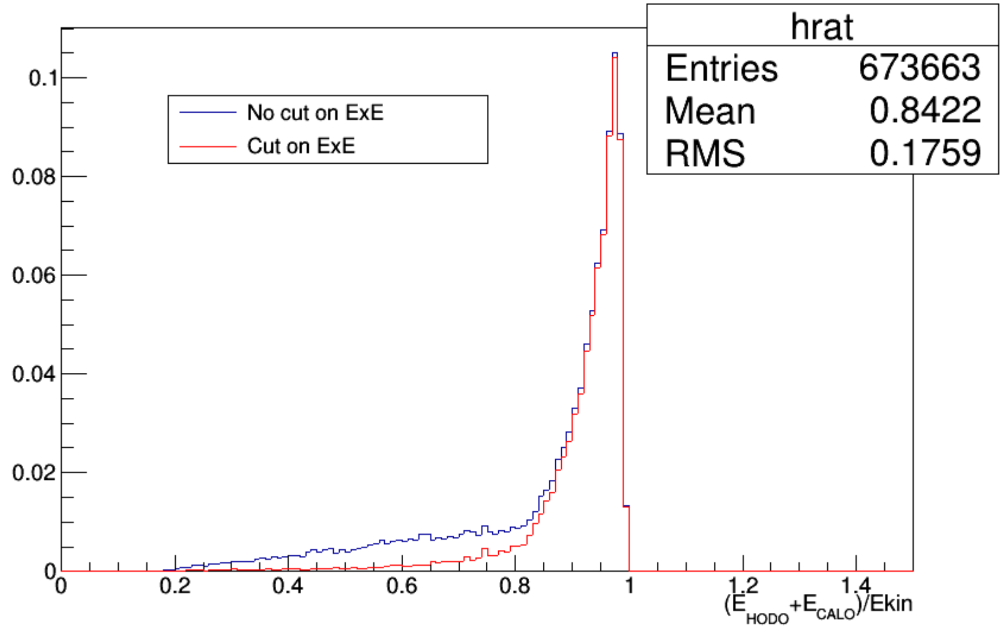
dE/dx cut from hodoscope signal + TOF +
low threshold to suppress background <50 MeV

Gamma conversion, 10% electrons, <1% positrons
- most not in acceptance
- but up to GeV energy, and deflected to large angle



GEM hit pattern from protons.





Calorimeters

<u>Calorimeters, **clones of the NPS calorimeter**:</u>

- 2x2x20 cm^2 **$PBWO_4$ scin. crystals**, optically isolated
- Modules arranged in a mesh of carbon fiber/μ-metal
- Expected **energy resolution** 2.5%/√E + 1%
- Expected **coordinate resolution** ~3 mm at 1 GeV
- Modules arranged in 4 “fly’s eye” assemblies of 23x23 matrix

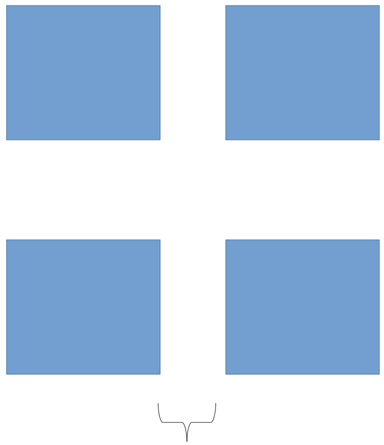
Total number of modules needed **2116**.

Assembling of NPS calorimeter
(June 2022)

Radiation dose: no deterioration expected over experiment

Used for trigger (without GEMs now)
High E coincidence pair, min E=2.5 GeV, 8° min angle
=> 72% signal efficiency or higher, low background

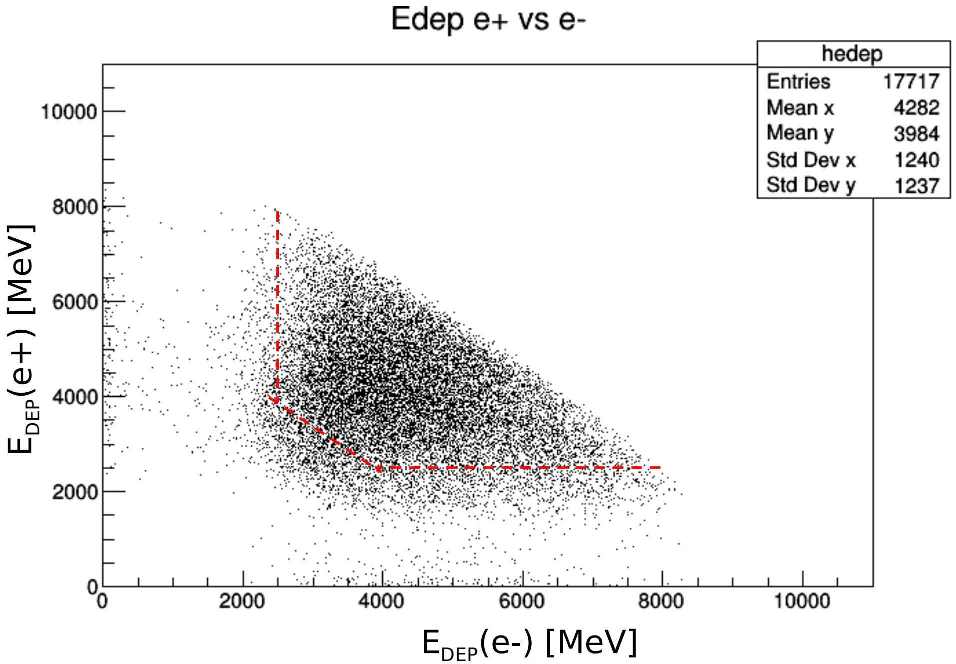
4 symmetrical parts:

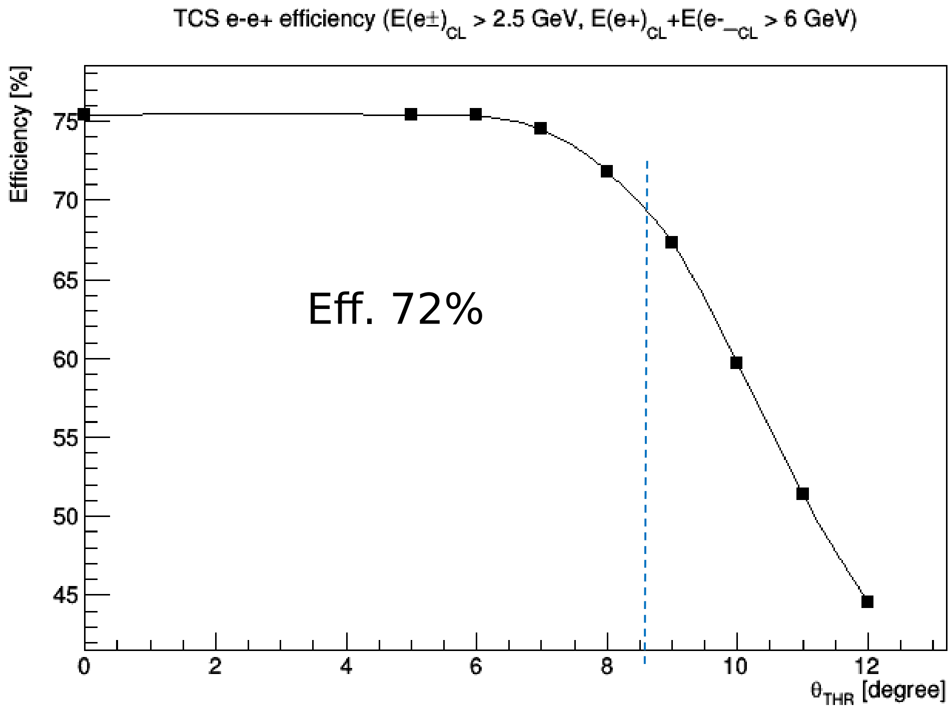


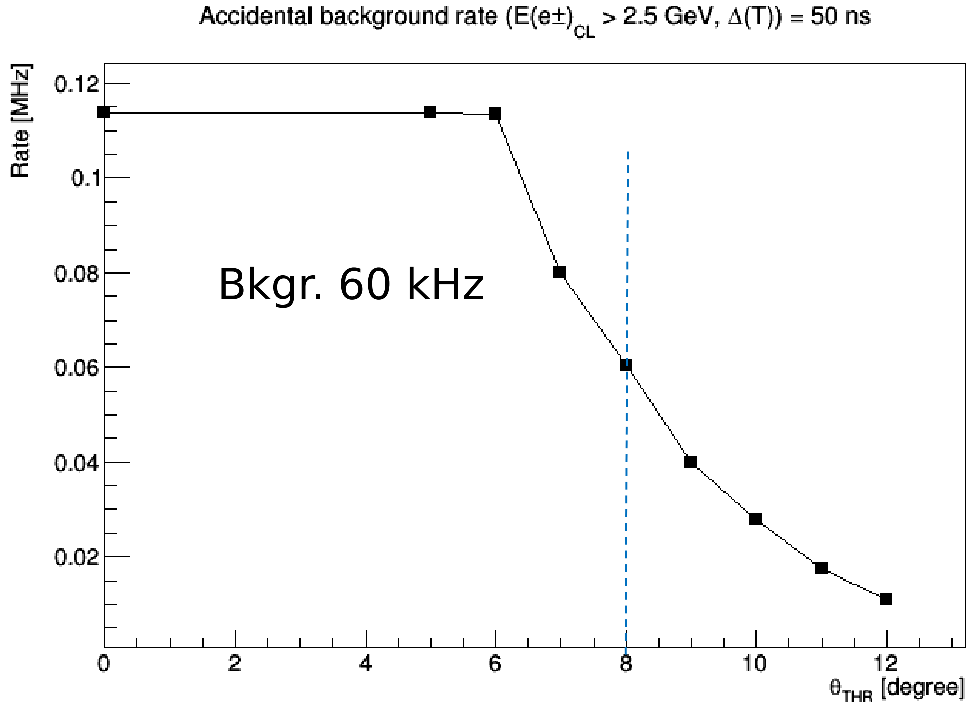
vertical gap

Trigger

- Trigger based on e+ and e- coincident signals from calorimeters in opposite quarters
- Establish high thresholds on $E_{DEP}(e+)$, $E_{DEP}(e-)$, $E_{DEP}(e+)+E_{DEP}(e-)$ to control background
- Exclude high background region close to beam pipe







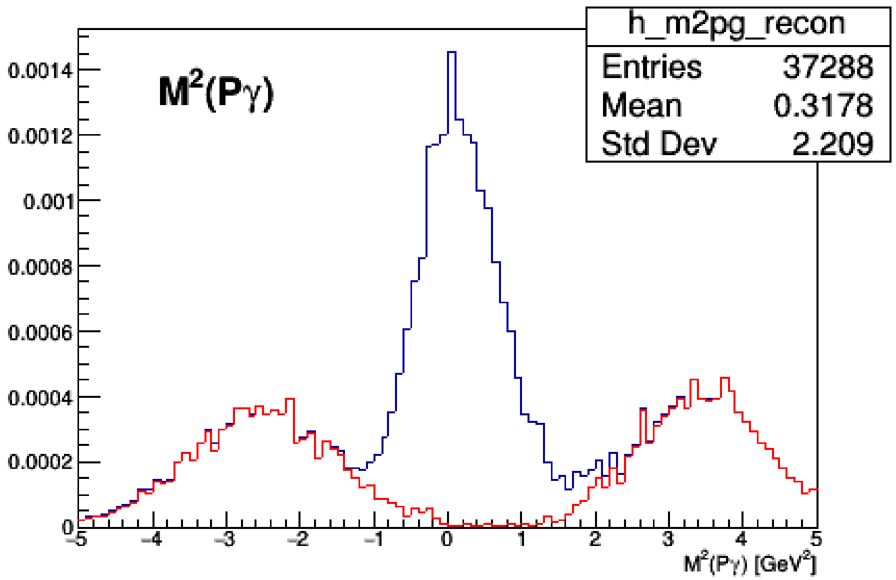
Lepton charge assignment

5T target field localized at target cell

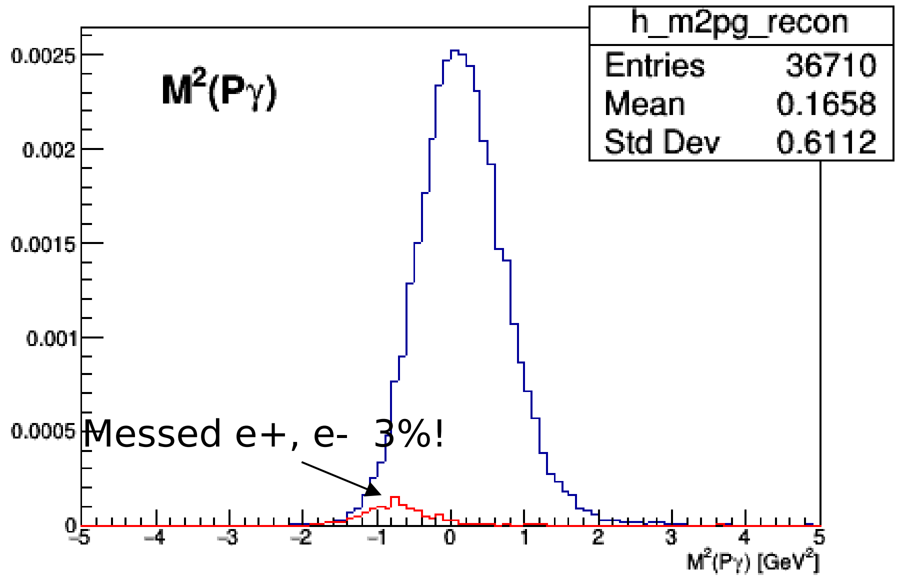
Field behind scattering chamber too weak to distinguish pos. and neg. tracks.

Alternative: use reconstructed incident photon mass:
- Reconstruct p;
- Reconstruct leptons twice, by assigning (+,-) and (-,+) charges;
- Combine with reconstructed proton to get 2 masses, choose smaller one.

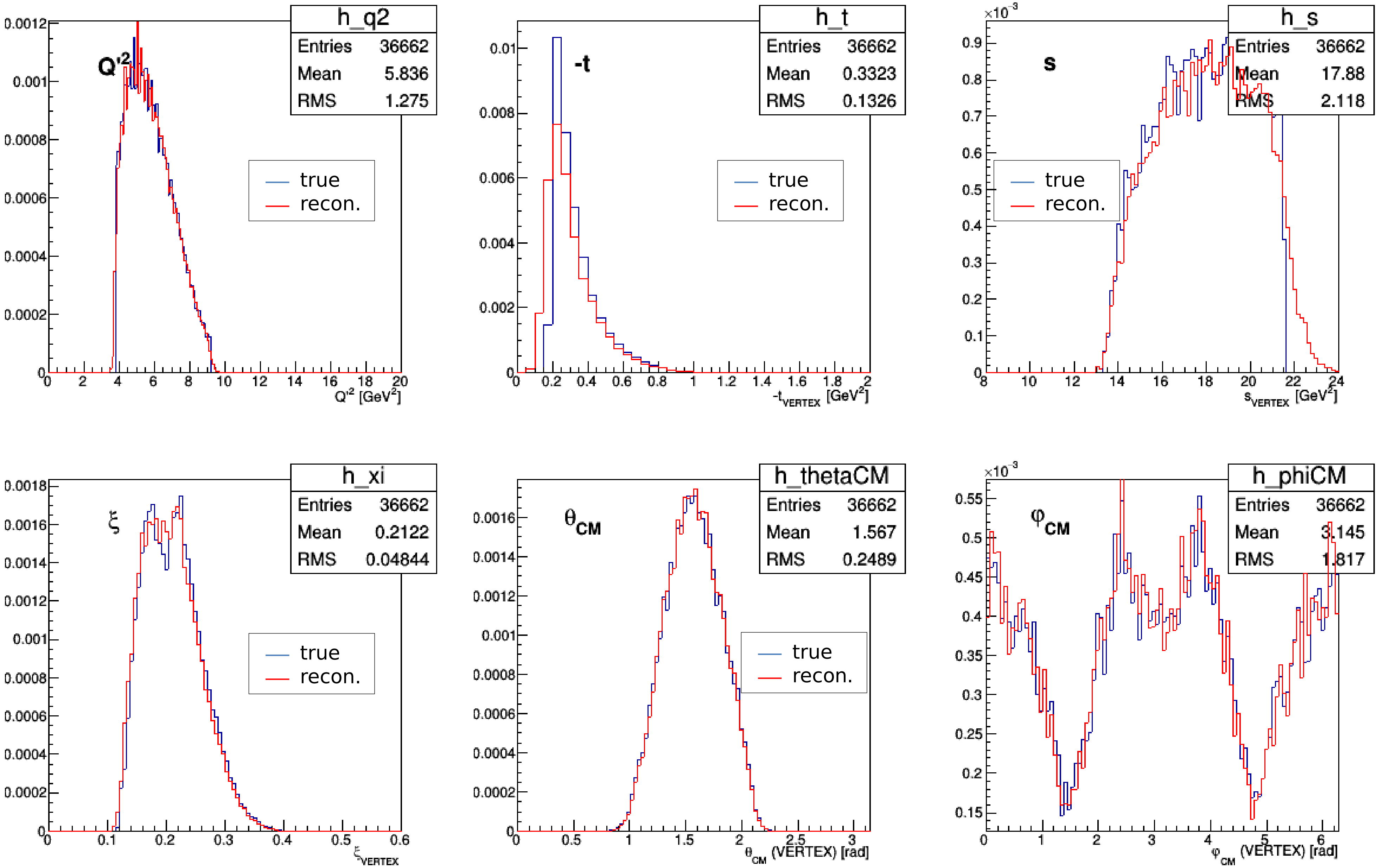
Random lepton charge assignment



Lepton charges according selection criteria

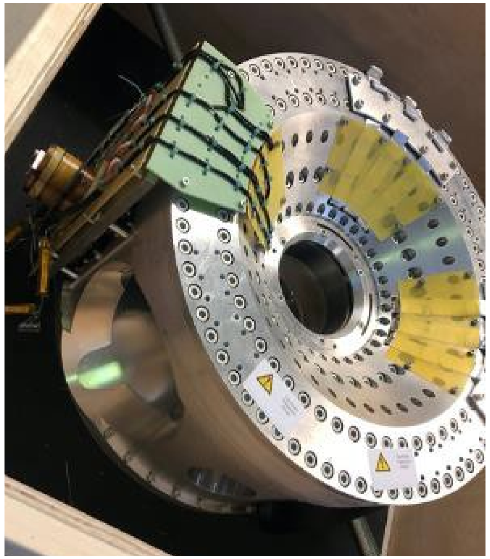


Resolution for kinematics: reconstructed vs generated



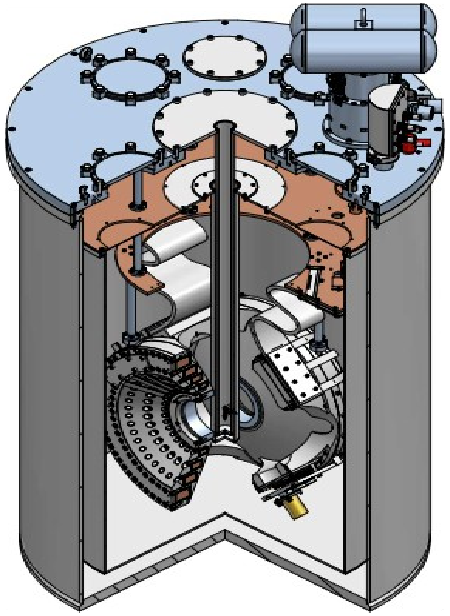
Polarized Target

- 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).



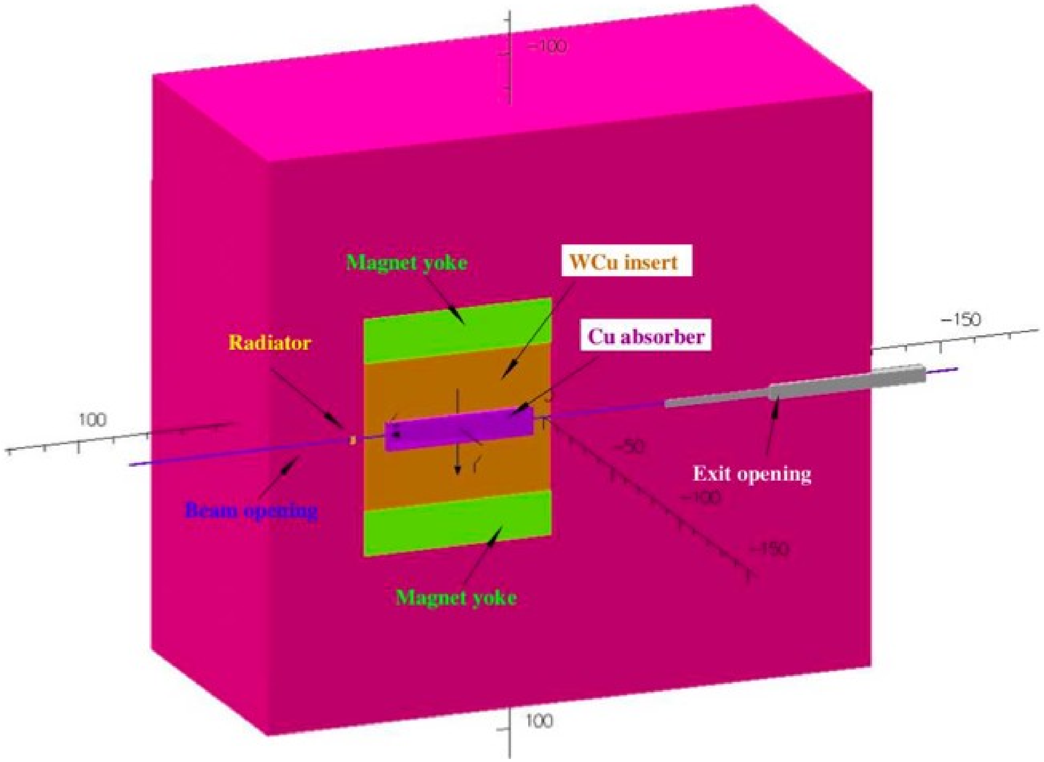
<u>New polarizing magnet arrived in September 2021!</u>

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



Horizontal field orientation

Compact Photon Source



Compact Photon Source under development in Hall C at JLab:

•Combines polarized photon source, collimator and beam dump;

• High intensity directed brem. photon beam (**1.5x10[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.

Beam time request

setup and installation	2.5 (PAC days)
signal and electronic checkout	2.5
gain matching of the detector's channels	0.5
Decomissioning	1.5
Overhead	7.5
commissioning with beam	**5**
physics	**30**

Total: 49.5 PAC days, 35 days with beam

Overhead	Number	Time Per (hr)	total (hr)
Polarization/depolarization	60	2.0	120
Target Anneals	15	4.0	60
Target T.E. Calibrations	10	4	28
Packing fraction/Dilution runs	6	2	12
Target Material Change	8	4	32
NPS Crystal Recovery	1	24	24
BCM/BPM Calibration	8	2	16
Moller Measurements	1	1	42
Total Overhead			346 (14.4 days)

Projections:
30 physics PAC day, L=5.85x10^{5} pb^{-1} with 11 GeV e^{-} beam and CPS (1.5x10^{12} γ/s or 10^{35} γ/cm²/s)

SUMMARY

Technical updates since 2020

- full GEANT4 simulations have been developed
- improved backtracking, and PID
- no GEM in trigger
- better understanding of background and rates, under control with adjustments made
- systematics, radiation damages under control, calibration from DVCS (similar)

New experimental context

- Benefit from other experiments currently or soon running
- Hall B measurement (lower Q'^2, not same kinematics, low statistics): shows feasibility
- Not much theory progress since 2020, but more and more people interested

Some other perspectives

- more complete TCS program soon in Hall C? Hall A complementarity?
- enhanced phase space at higher energy?

Experimental data are really needed to open new perspectives in GPD physics!