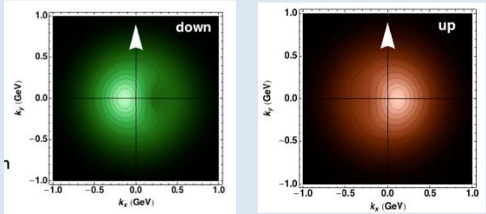
# Hall-B Run Group H
# CLAS12 Experiments with a Transversely Polarized Target

**Contalbrigo Marco  - INFN Ferrara**

JLab PAC53 Meeting, 23th July 2025

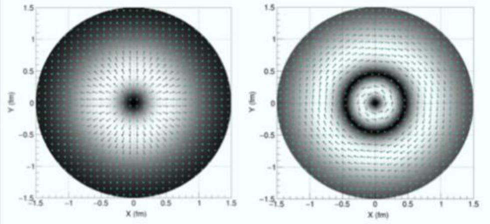
**TMD (x, $k_T$)** quark polarisation

| nucleon polarisation N/q | U | L | T |
|---|---|---|---|
| U | $f_1$ | | $h_1^{\perp}$ |
| L | | $g_1$ | $h_{1L}^{\perp}$ |
| T | $f_{1T}^{\perp}$ | $g_{1T}^{\perp}$ | $h_1, h_{1T}^{\perp}$ |

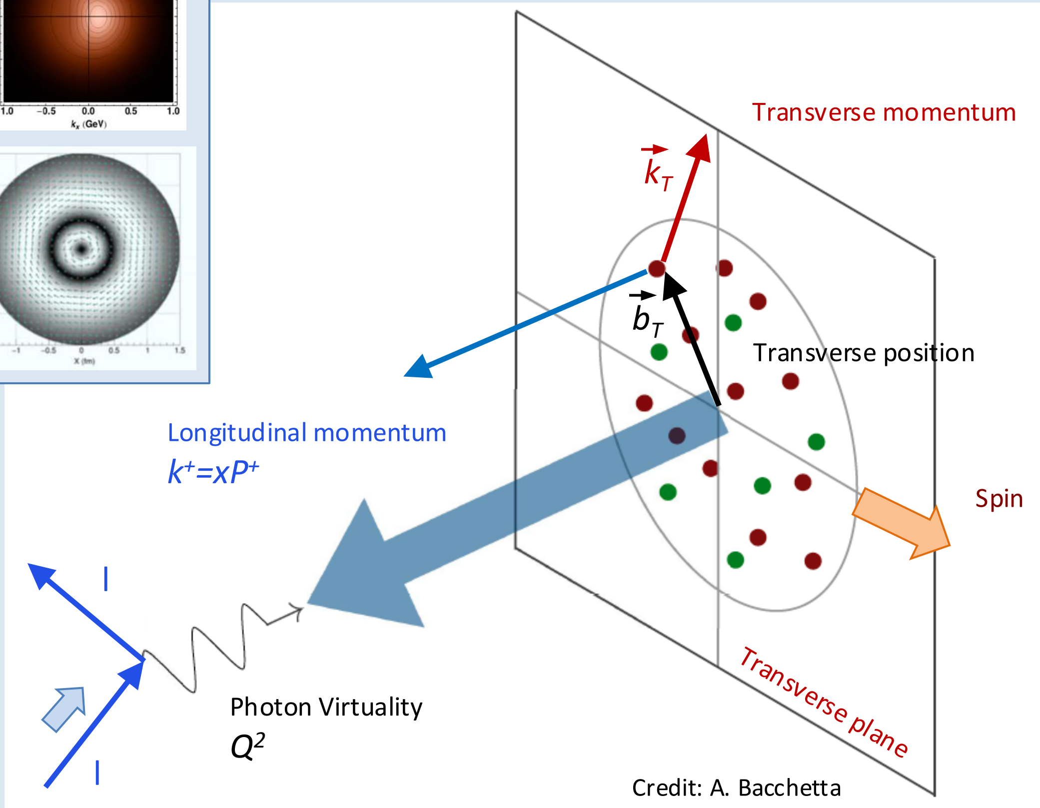



**GPD (x, $b_T$)** quark polarisation

| nucleon polarisation N/q | U | L | T |
|---|---|---|---|
| U | $H$ | | $\mathcal{E}_T$ |
| L | | $\tilde{H}$ | $\tilde{E}_T$ |
| T | $E$ | $\tilde{E}$ | $H_T, \tilde{H}_T$ |




Confinement Scale




High Energy Probe
Hard Scale

# Run Group H

## PAC39 2012

| Experiment | Contact | Title | Rating | PAC days |
|---|---|---|---|---|
| C12-11-111 | M. Contalbrigo | Transverse spin effect in SIDIS at 11 GeV with a transversely polarized target using CLAS12 | A | 110 |
| C12-12-009 | H. Avakian | Measurement of transversity with di-hadron production in SIDIS with a transversely polarized target | A | 110 |
| C12-12-010 | L. Elouadrhiri | Deeply Virtual Compton scattering at 11 GeV with transversely polarized target using the CLAS12 detector | A | 110 |

Access to unique observables in

- SIDIS hadron
- SIDIS Di-hadron
- DVCS

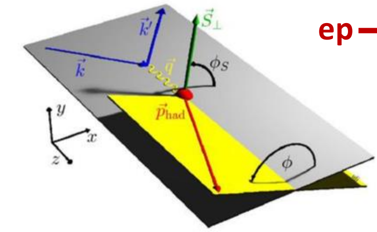
**All RGH experiments selected among the high impact JLab measurements PAC42 [2014]**

RGH experiment status (with HDice) confirmed at PAC48 in 2020 (during jeopardy process) with C1 condition on target performance

RGH status modified to C2 in 2024 (during jeopardy process) to properly evaluate the target change
✓ GEANT simulations ✓ Impact study ✓ Systematics

Gather unprecedented information on

- Transversity
- Tensor charge
- Sivers, $h_{1T}^{\perp}$, $g_{1T}^{\perp}$, $H_1^{\perp}$
- GPD E
- quark OAM

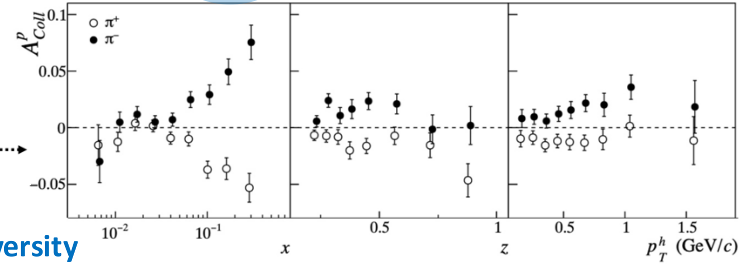



**ep ⟶ e'hX, e'hhX**

$$\frac{d\sigma}{dx\,dQ^2\,dz\,dP_{h\perp}\,d\phi\,d\phi_S} \propto \left[F_{UU} + \epsilon\cos(\phi) F_{LU}^{\cos(2\phi)}\right] + S_L\left[\sin(2\phi) F_{LU}^{\sin(2\phi)}\right] + \lambda_e S_L\left[\sqrt{1-\epsilon^2}F_{LL}\right]$$
$$+ S_T\left[\sin(\phi-\phi_S)\,F_{UT}^{\sin(\phi-\phi_S)} + \epsilon\sin(\phi+\phi_S)\,F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)\,F_{UT}^{\sin(3\phi-\phi_S)}\right]$$
$$+ \lambda_e S_T\left[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)\,F_{LT}^{\cos(\phi-\phi_S)}\right] + O\left(\frac{1}{Q^2}\right)$$

$$\sigma_{UT}^{Collins} \propto S_T \sin(\phi+\phi_S)\, C[h_1(x,k_T) \times H_1^\perp(z,p_T)]$$

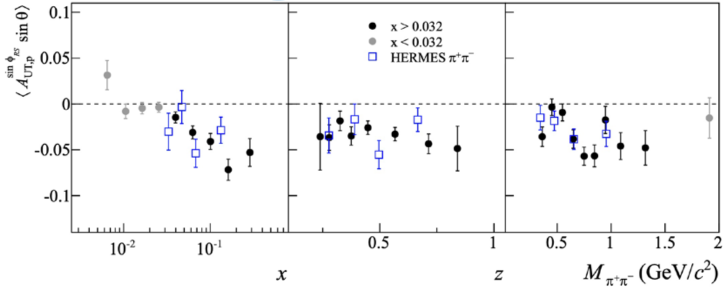
C. Adolph, PLB 744 (2015) 250




**Transversity**

$$\sigma_{UT}^{IFF} \propto S_T \sin(\phi_{R\perp}+\phi_S)\sin(\theta)\, h_1(x) H_1^{\sphericalangle}(z, M_{hh})]$$

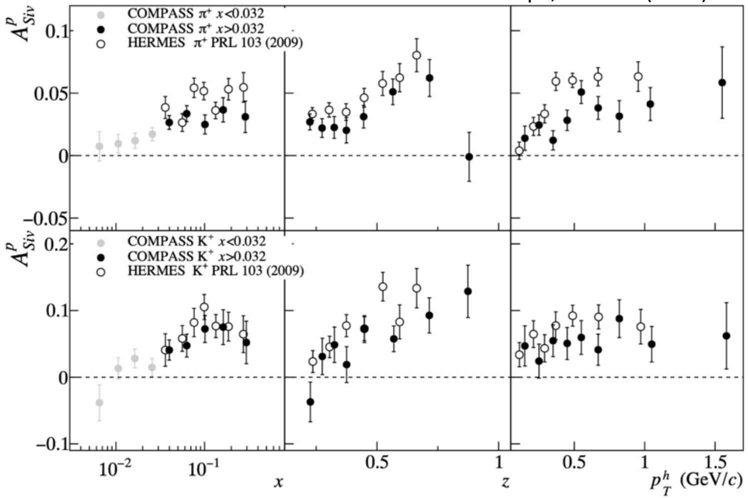
G.D. Alexeev, PLB 845 (2023) 138155

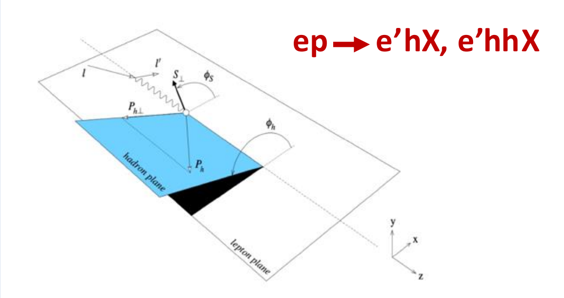



**Sivers**

$$\sigma_{UT}^{Sivers} \propto S_T \sin(\phi-\phi_S)\, C[f_{1T}^\perp(x,k_T) \times D_1(z,p_T)]$$

C. Adolph, PLB 744 (2015) 250

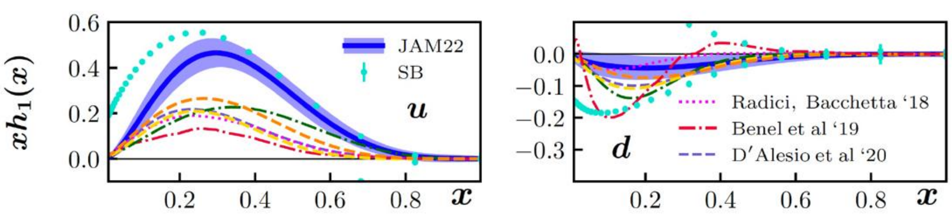




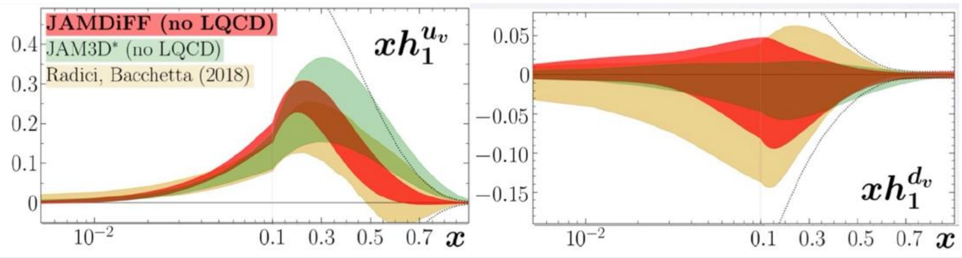

Large sensitivity expected in the valence region
Lack of data above x = 0.3 and no fully differential (4D) analysis available so far

**CLAS12 can be the first experiment to achieve a 4D analysis in the valence region**

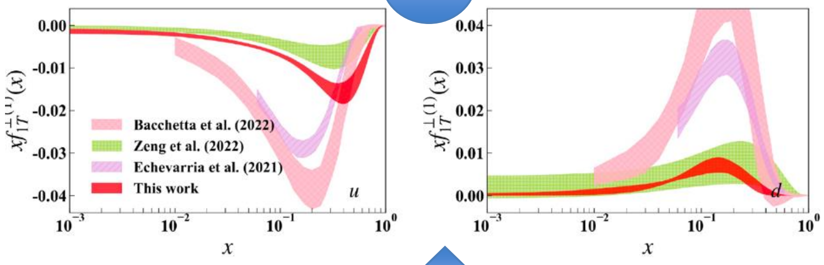
## Transversity from single hadron SIDIS



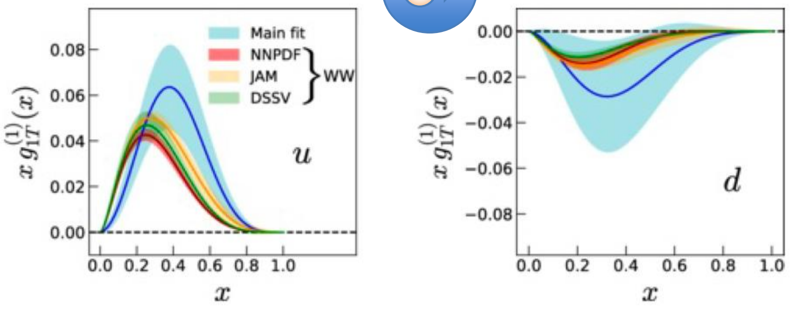

## Transversity from di-hadron SIDIS




## Sivers

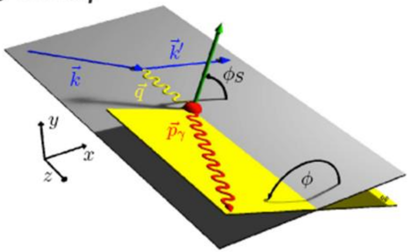


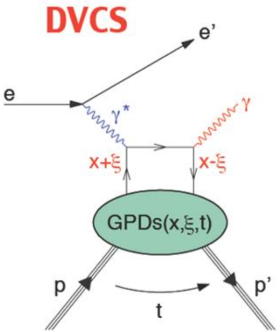

## Kotzinian-Mulders

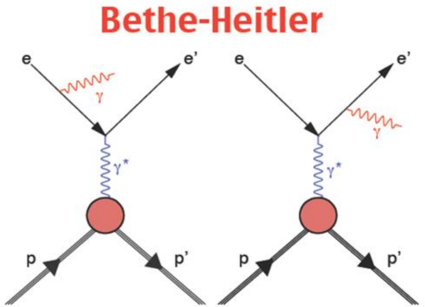


$$\frac{d^4\sigma}{dQ^2\,dx_B\,dt\,d\phi} \propto \left(|\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}\right)$$

ep → e’ p’ γ



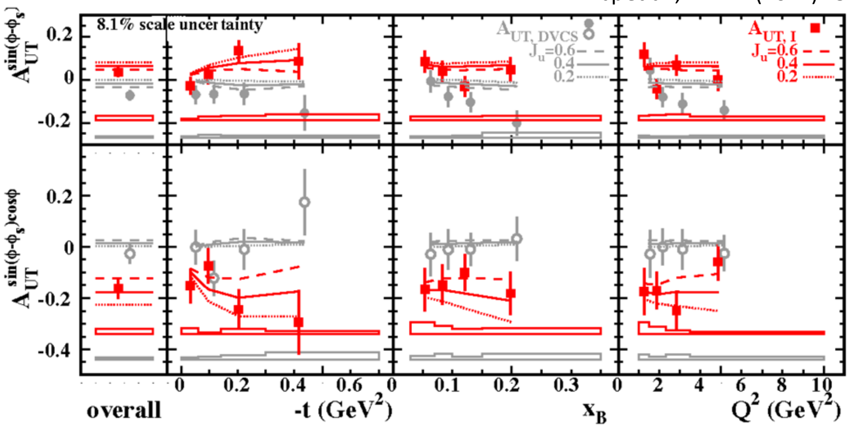




Rare access to Imℰ CFF with no kinematic suppression

$$d\sigma_{UT}^{\mathrm{I}} = \frac{-K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left\{\sum_{n=0}^{3} c^{\mathrm{I}}_{n,\mathrm{TP}-}\sin(\phi-\phi_S)\cos(n\phi) + \sum_{n=1}^{3} s^{\mathrm{I}}_{n,\mathrm{TP}+}\cos(\phi-\phi_S)\sin(n\phi)\right\}$$

$$c^{\mathrm{I}}_{1,\mathrm{TP}-} \propto -\frac{M}{Q}\Im\mathrm{m}\left\{\frac{t}{4M^2}\left[(2-x_B)F_1\mathcal{E} - 4\frac{1-x_B}{2-x_B}F_2\mathcal{H}\right] + x_B\xi\left[F_1(\mathcal{H}+\mathcal{E}) - (F_1+F_2)(\tilde{\mathcal{H}} + \frac{t}{4M^2}\tilde{\mathcal{E}})\right]\right\}$$

A. Airapetian, PLB 74 (2011) 15

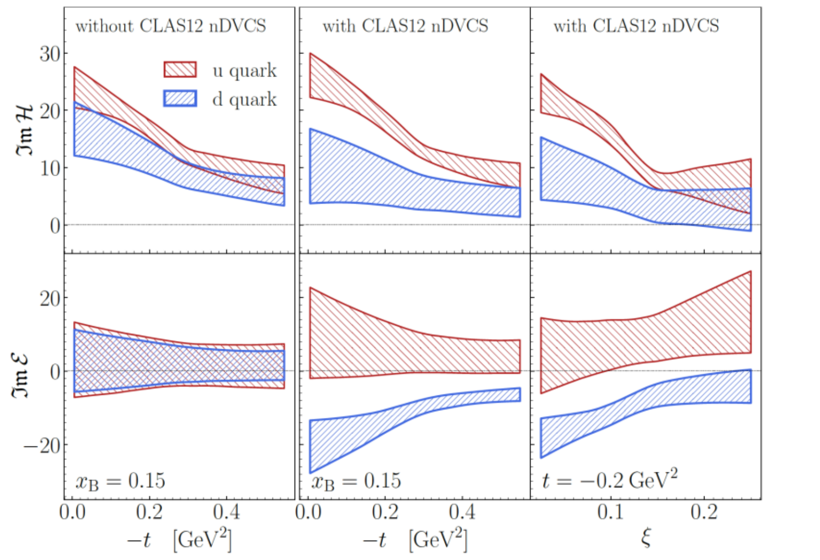


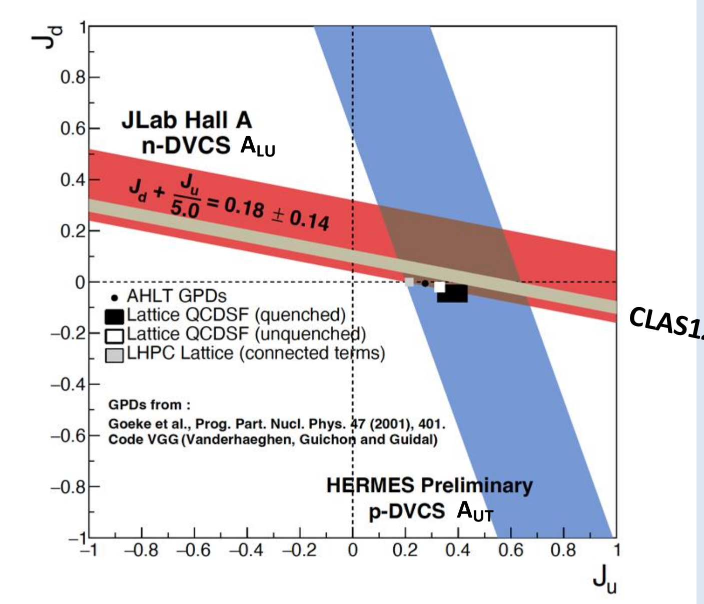
GPD E is essential to pin down the quark dynamics (OAM)
It is poorly known expecially for the u-quark flavor

$$\sum_q \int_{-1}^{+1} dx\, x[H^q(x,\xi,t=0) + E^q(x,\xi,t=0)] = 2\,J_q$$

**CLAS12 can be the first experiment in exploiting both**
**$A_{LU}$ measurement on neutron with**
**$A_{UT}$ measurement on proton**

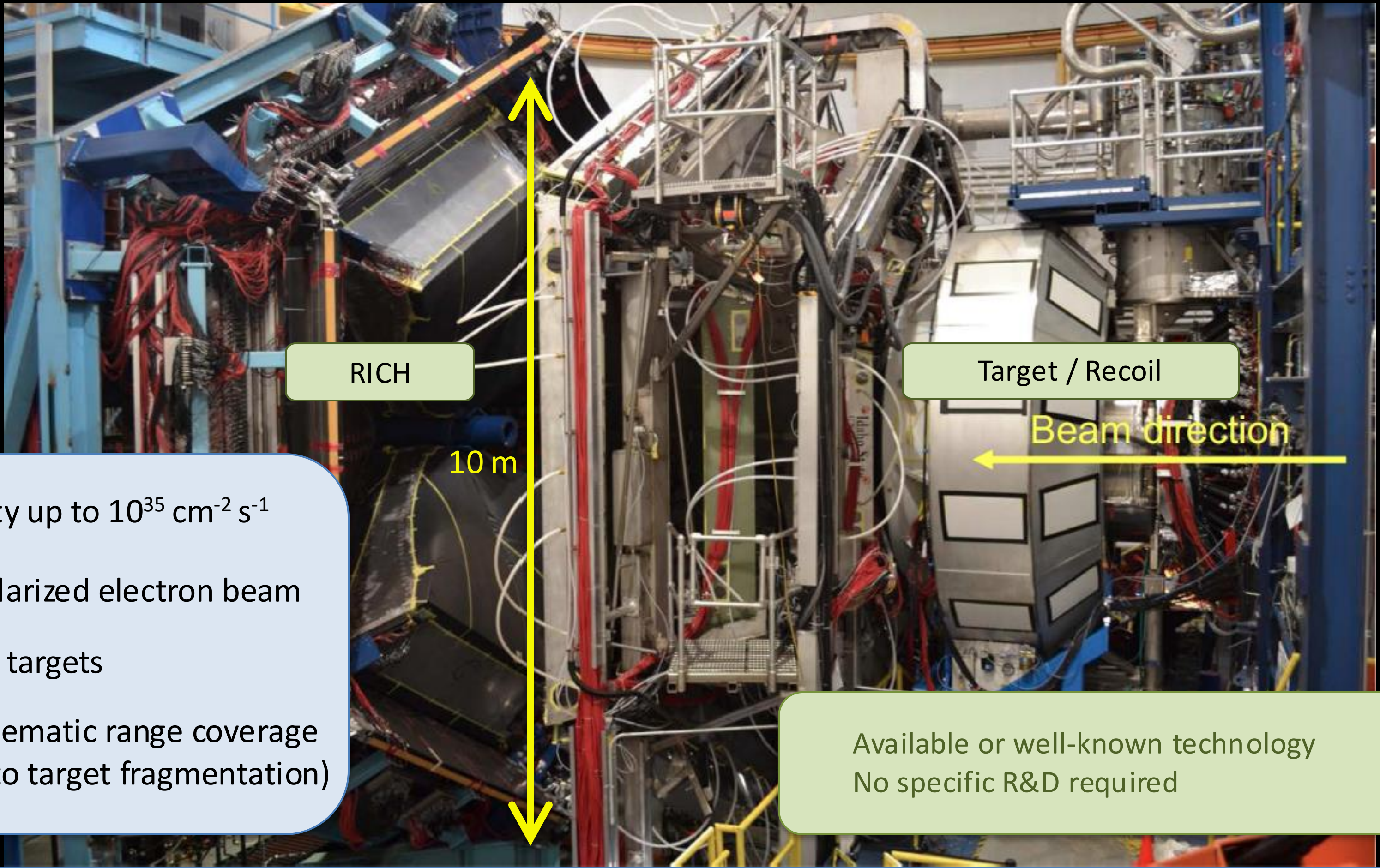
CLAS12 RGB measurement of $A_{LU}$ on neutron, Phys.Rev.Lett. 133 (2024) 21, 211903




CLAS12 $A_{LU}$

Large acceptance spectrometer. Operational since 02/18




Luminosity up to $10^{35}$ cm$^{-2}$ s$^{-1}$

Highly polarized electron beam

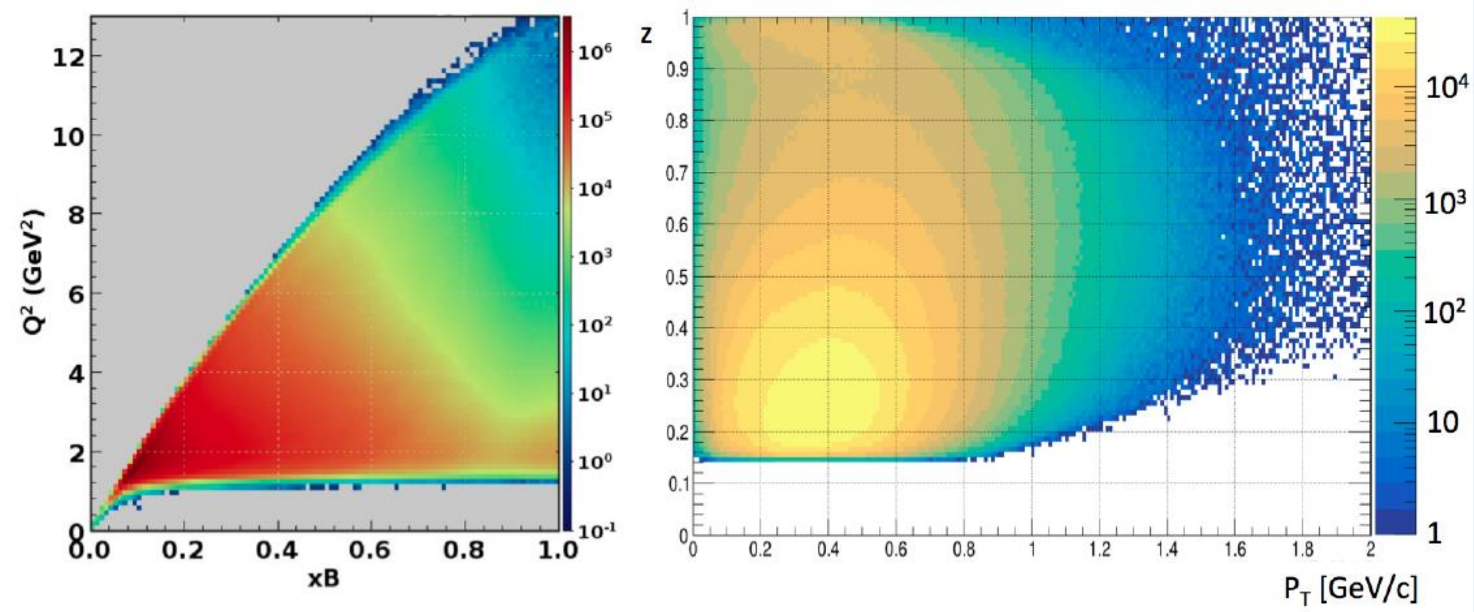
Polarized targets

Broad kinematic range coverage (current to target fragmentation)

Available or well-known technology
No specific R&D required

**Features: wide phase space cover, excellent PID and statistics optimized for a multi-D analysis**

- disentangle kinematical correlations
- verify expected dependences (e.g. in $Q^2$) and isolate peculiar regimes (e.g. in z)
- study transition regions (e.g. in $P_T$)

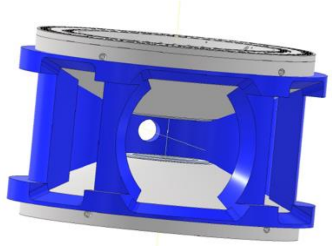


## Most viable solution to prioritize physics

Consolidated dynamically polarized $NH_3$ technology

Designed based on already successful realizations

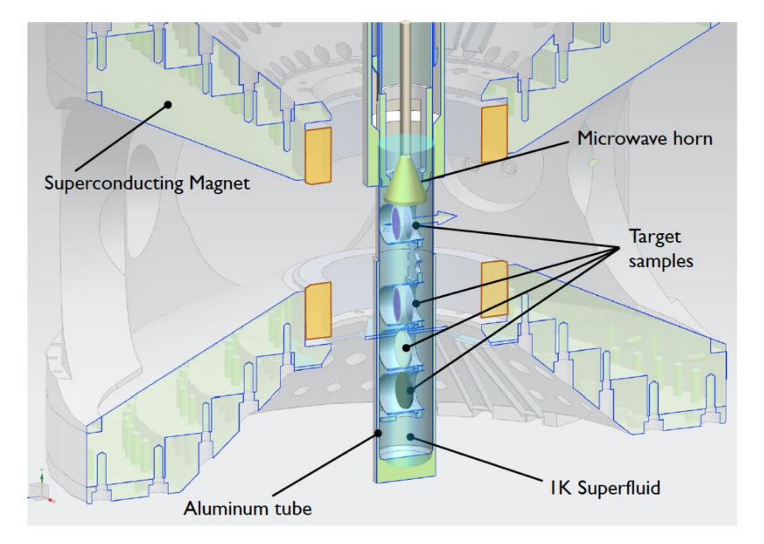
- Hall-A G2p-Gep target (replica optimized for HTCC )
- Hall-C E12-15-005 magnet (replica optimized for recoil detection)

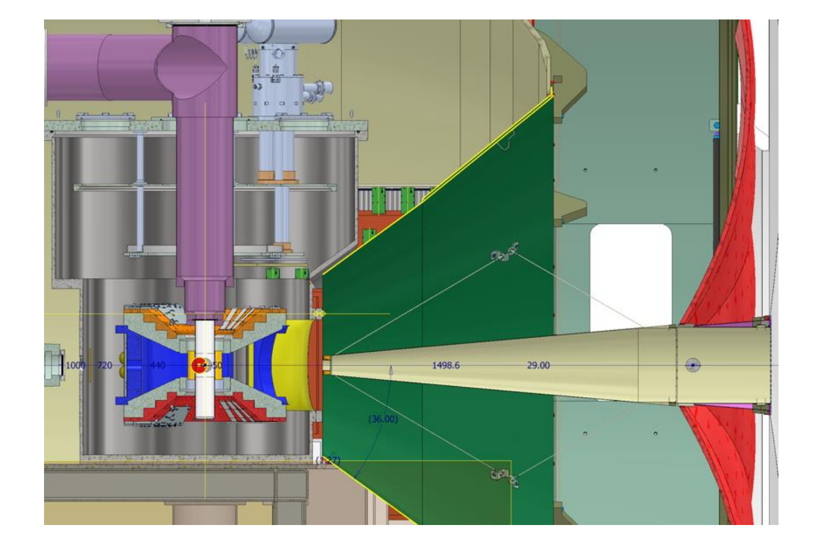



5T dipole acceptance:

$\pm 25^{o}$ vertical

$\pm 65^{o}$ horizontal

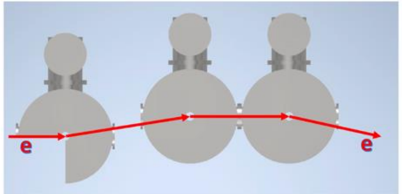


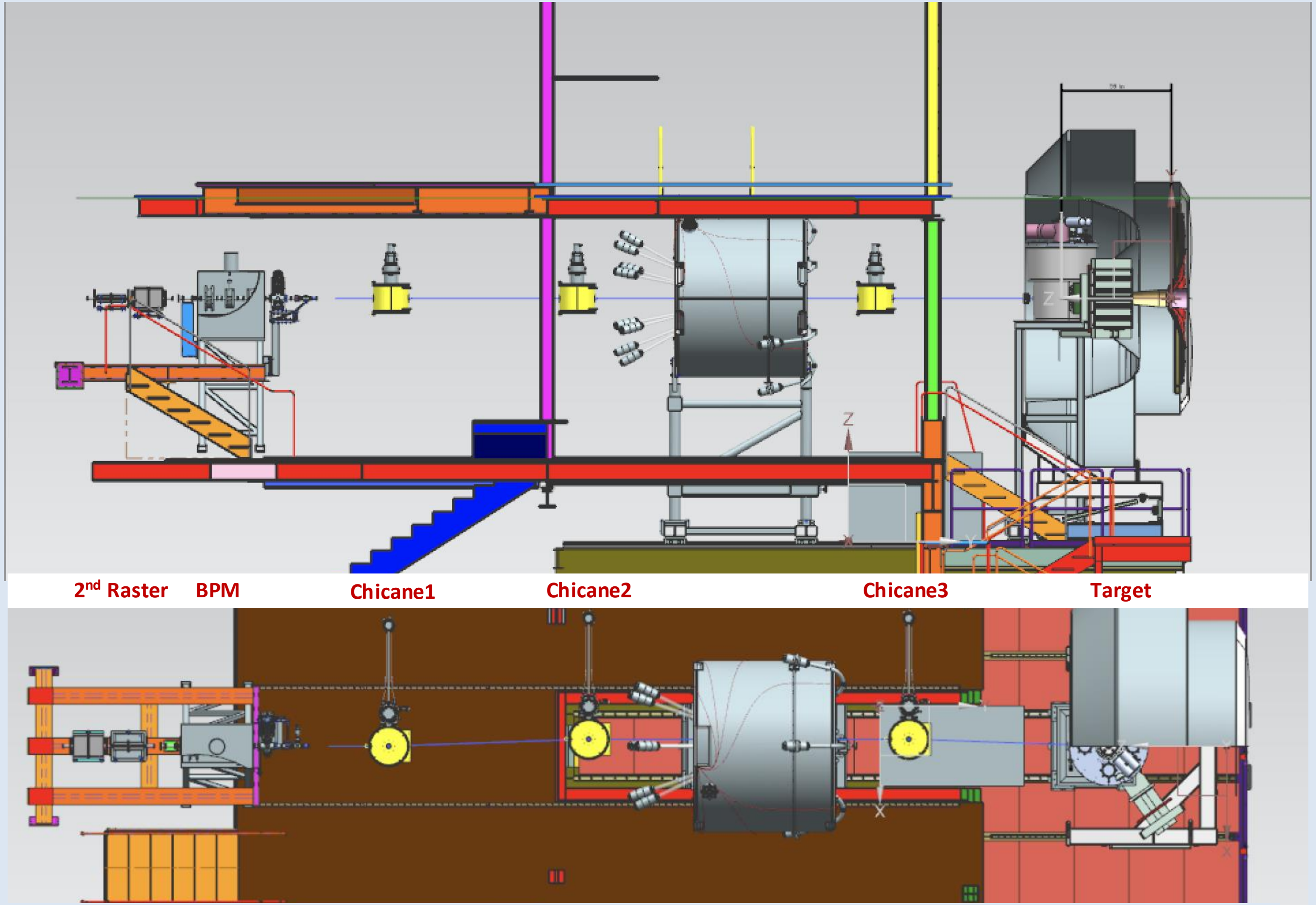
Based on

existing 0.7 cm raster

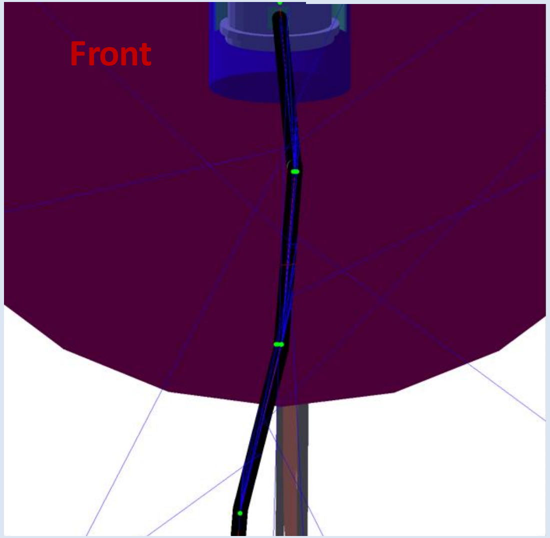
commercial 7.5T magnets



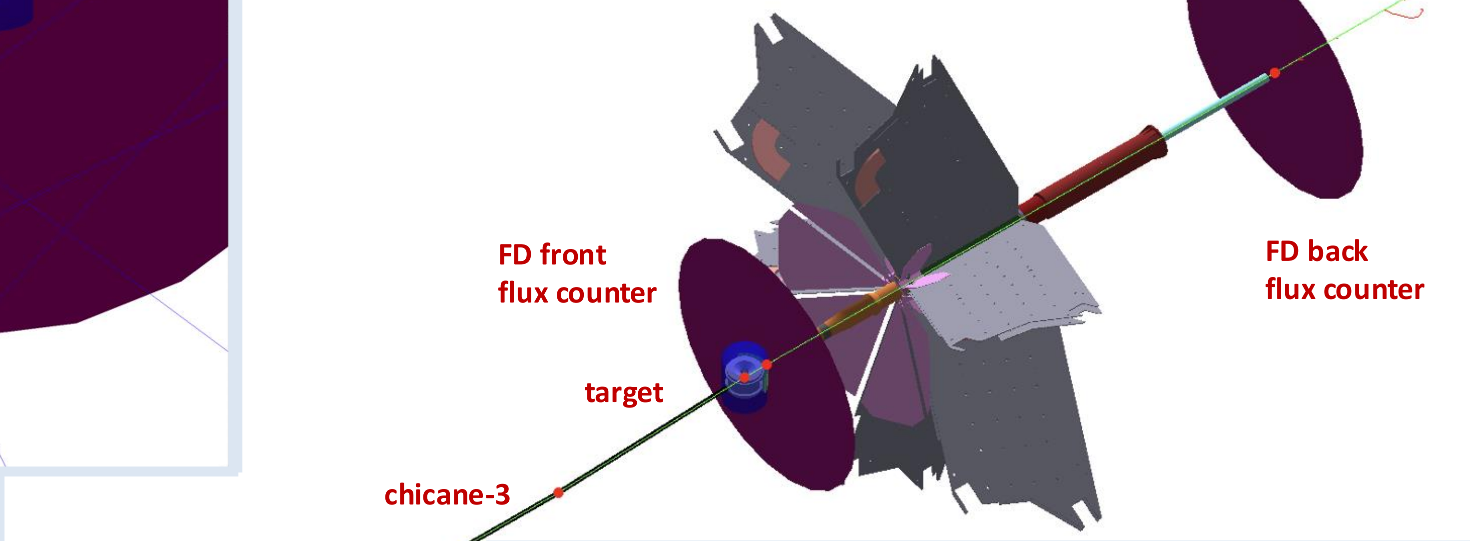

- ✓ space
- ✓ synchrotron radiation
- ✓ beam rastering



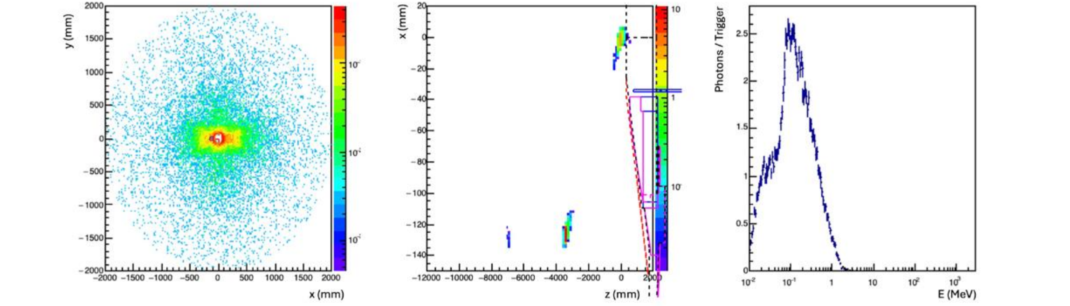
# Geant Simulation: RGH Beam Line



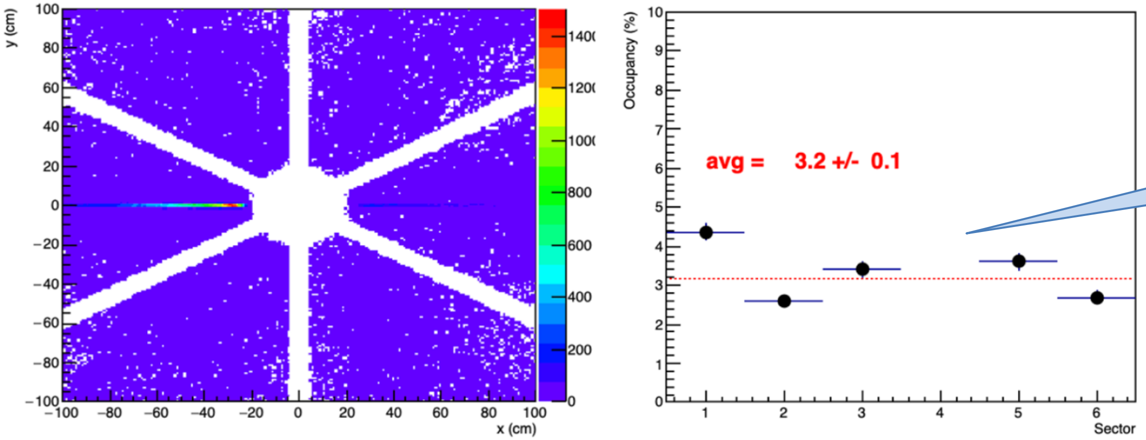

CLAS12 GEANT simulation framework




Beam pipe + 1 cm lead in the proper locations suppress synchrotron radiation to a negligible level



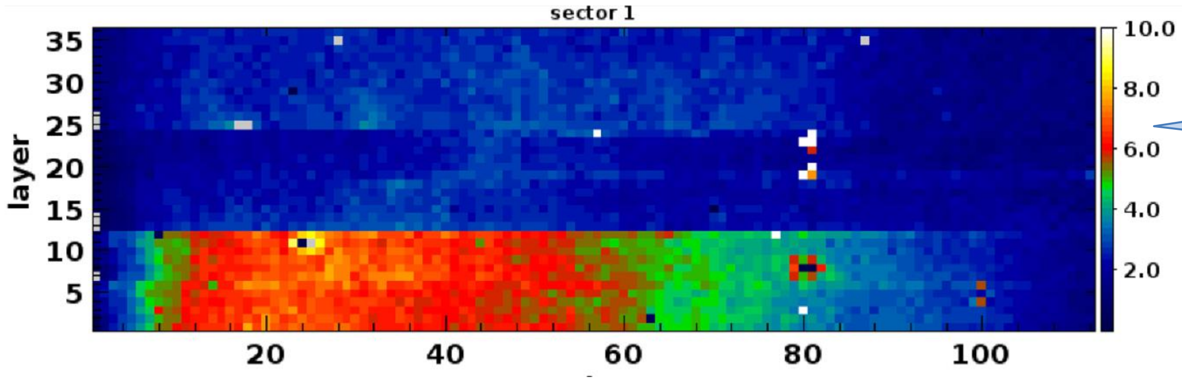
CLAS12 GEANT simulation framework




**RGH MC ($NH_3$)**

Assume to switch OFF DC in sector 4 and move RICH in sector 3

x2 with CLAS12 gate




**RGC DATA ($NH_3$)**

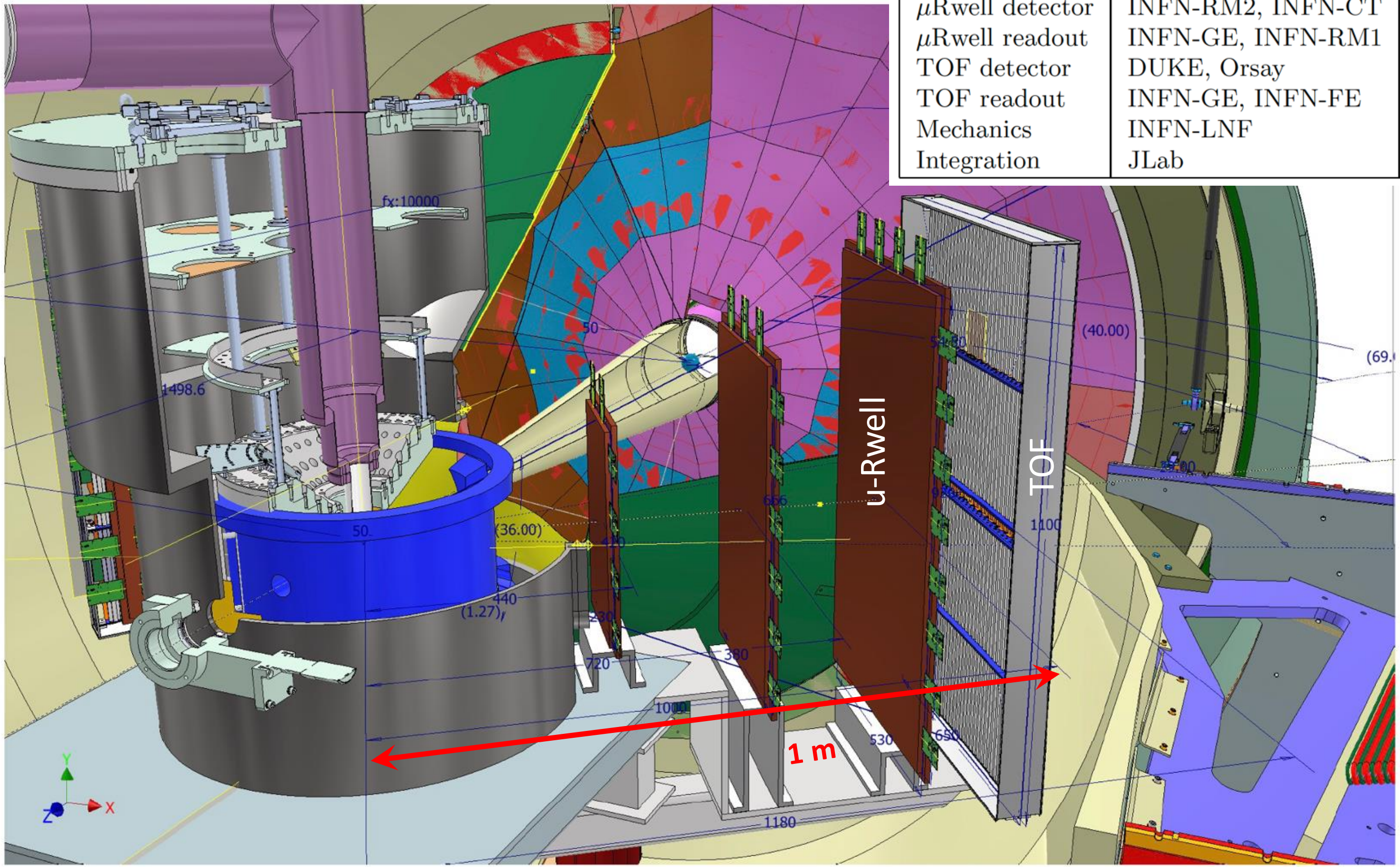
Present performance*

Typical DC occupancy measured at CLAS12

*No high-lumi

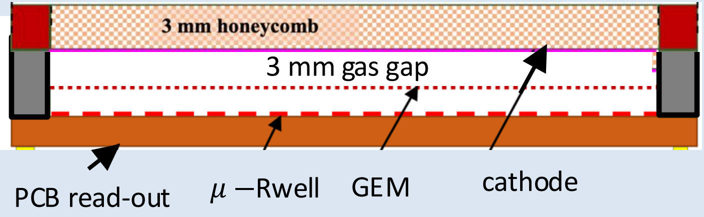
# Target & Recoil Detector

| Task | Leading Institution | Expertise |
|---|---|---|
| $\mu$Rwell detector | INFN-RM2, INFN-CT | CLAS12 upgrade, ePIC tracking |
| $\mu$Rwell readout | INFN-GE, INFN-RM1 | SBS GEM tracking readout |
| TOF detector | DUKE, Orsay | EIC KLM, CLAS12 CND |
| TOF readout | INFN-GE, INFN-FE | CLAS12 FT and RICH readout |
| Mechanics | INFN-LNF | CLAS12 RICH mechanics |
| Integration | JLab | Hall-B infrastructure and beam |



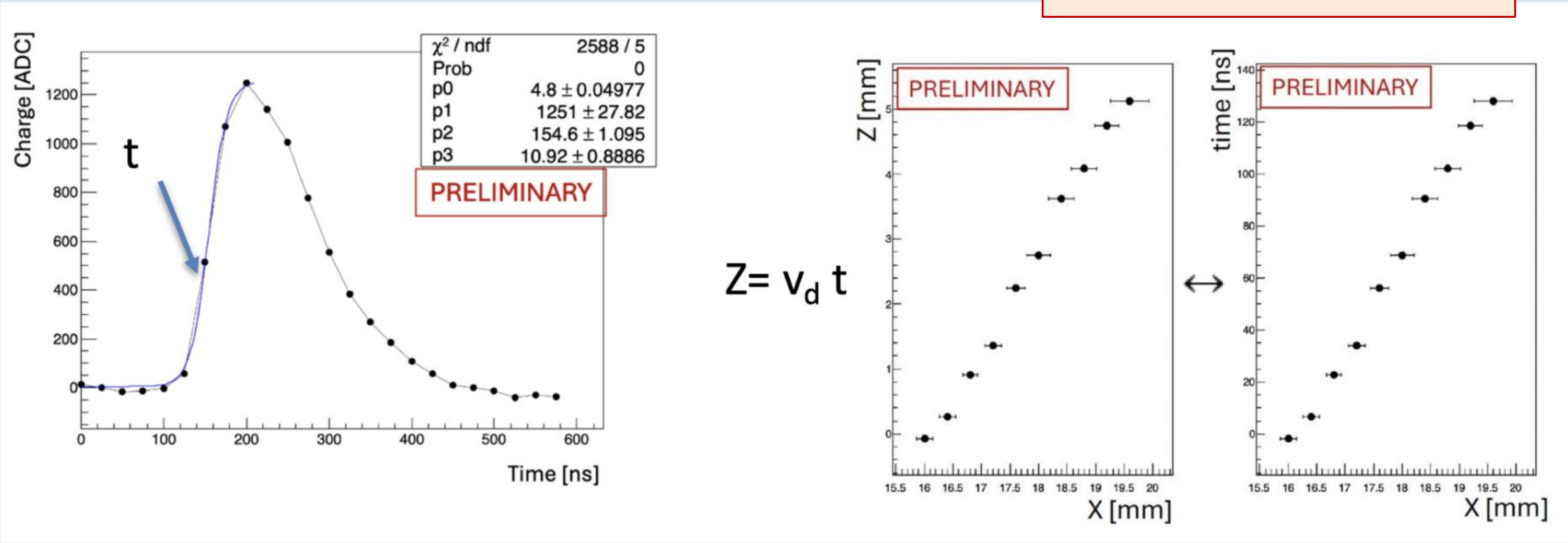
**GEM-μRwell to provide 2D information with 100 μm resolution**

- ✓ Wanted gain/efficiency is preserved below 600 V safe bias
- ✓ 5 ns time resolution can be achieved from signal shape fit
- ✓ TPC-like readout to correct the impinging angle has been proven
- ✓ Suitable APV25 readout available




**μRwell as spin off of the high-lumi project (various prototypes up to 40 x 46 cm² exist)**

**Test-beam at CERN in Oct '24**



**Scintillating bars + SiPM to tag particles with 100 ps resolution**

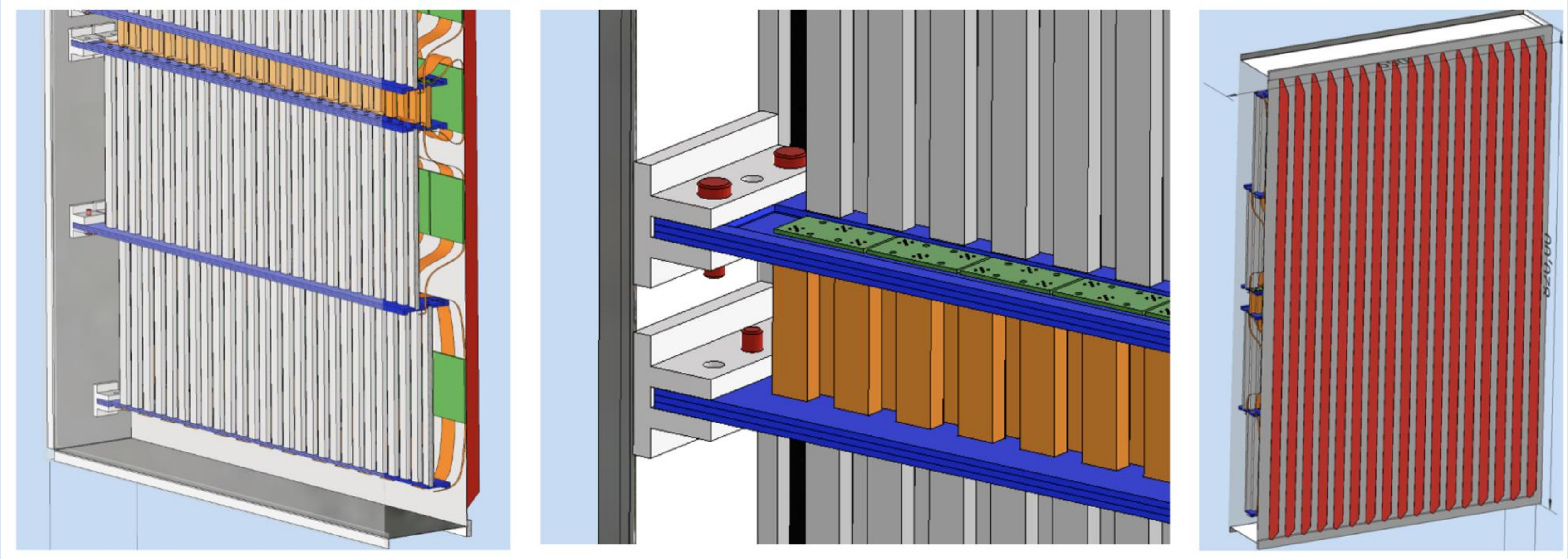
- ✓ Flexible geometry to provide spatial matching and control of accidentals
- ✓ Compact layout
- ✓ Suitable readout exist (MAROC or PETIROC chip)

**Proven to match 100 ps by PANDA and MUSE R&D**

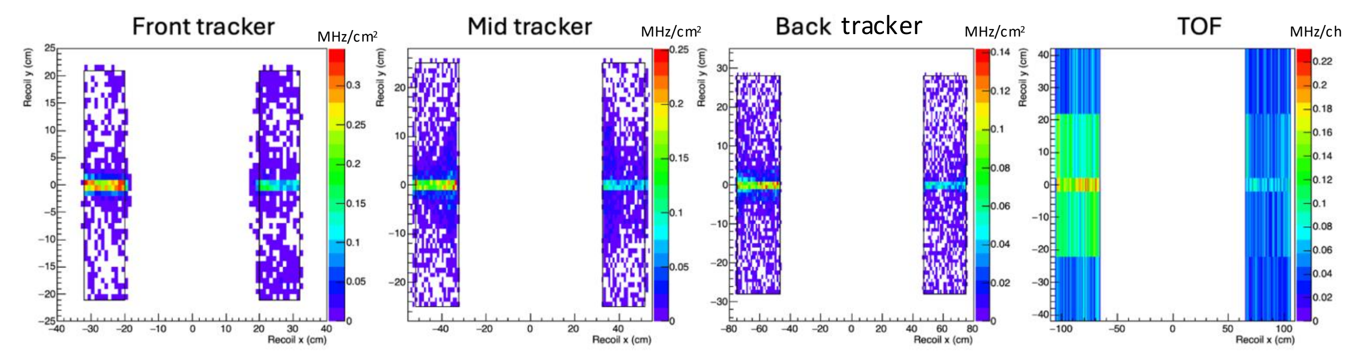
T. Rostomyan, NIMA 986 (2021) 164801 – MUSE experiment

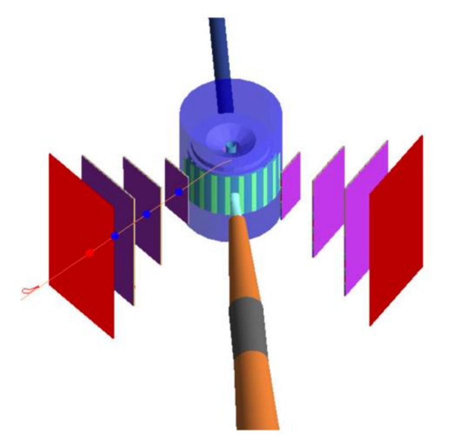
Table A.2: Time resolutions and efficiencies for 3 mm thick, 300 mm long and 12 mm wide BC-404 BM paddles. All results are better than the experimental requirements.

| Scintillator | SiPM | $\sigma_T$ (ps) | $\epsilon$ (%) |
|---|---|---|---|
| BC-404 | S13360-3075PE | 59 | $\geq 99.9$ |
| BC-404 | S13360-3050PE | 60 | $\geq 99.7$ |
| BC-404 | ASD-NUV3S-P-40 | 65 | $\geq 99.0$ |

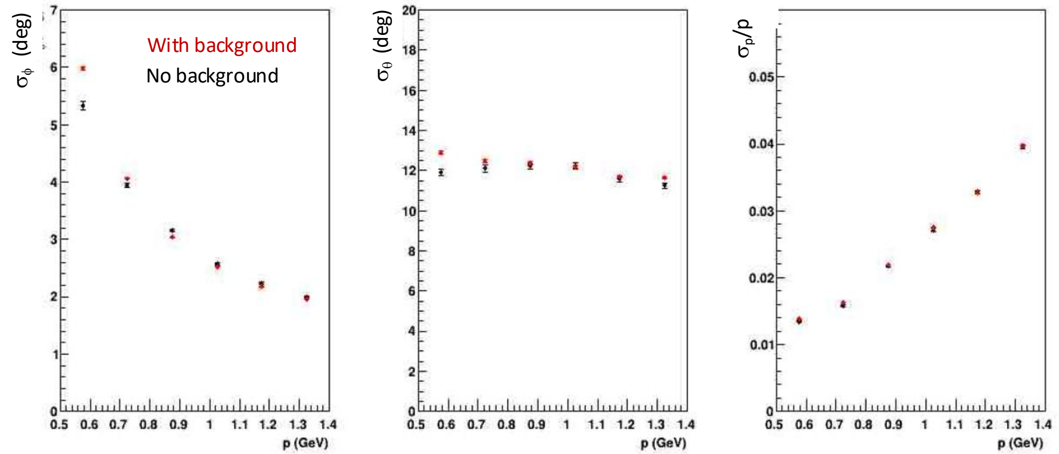


Recoil technology can cope with the background rates



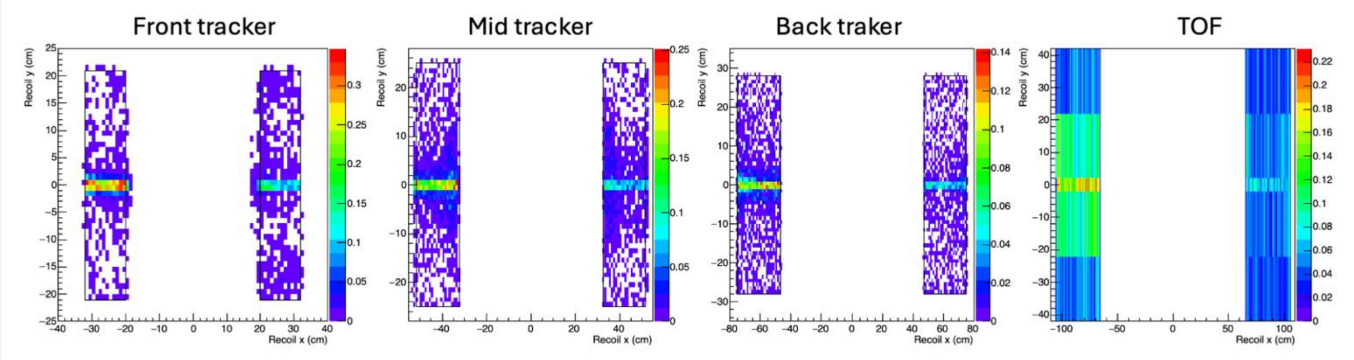
Background has a minimal impact: similar recoil resolution, few percent effiicency loss

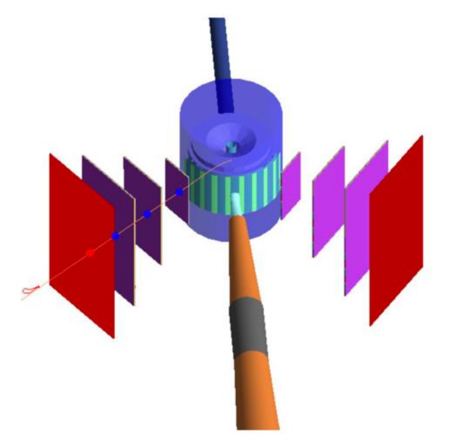



Still basic reconstruction algorithm provides a conservative estimate

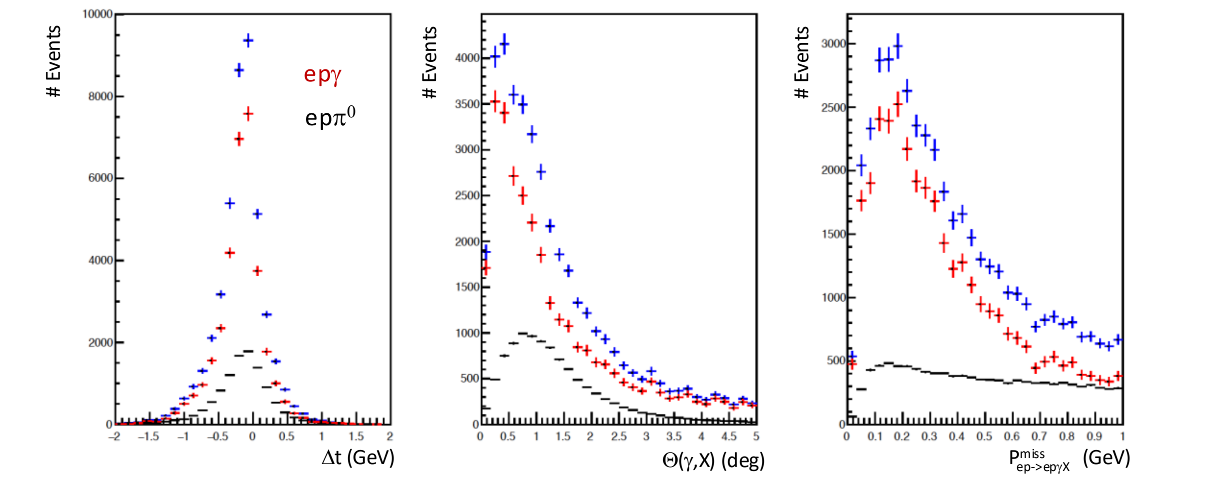
Recoil reconstruction is adequate even in the presence of background

Recoil technology can cope with the background rates



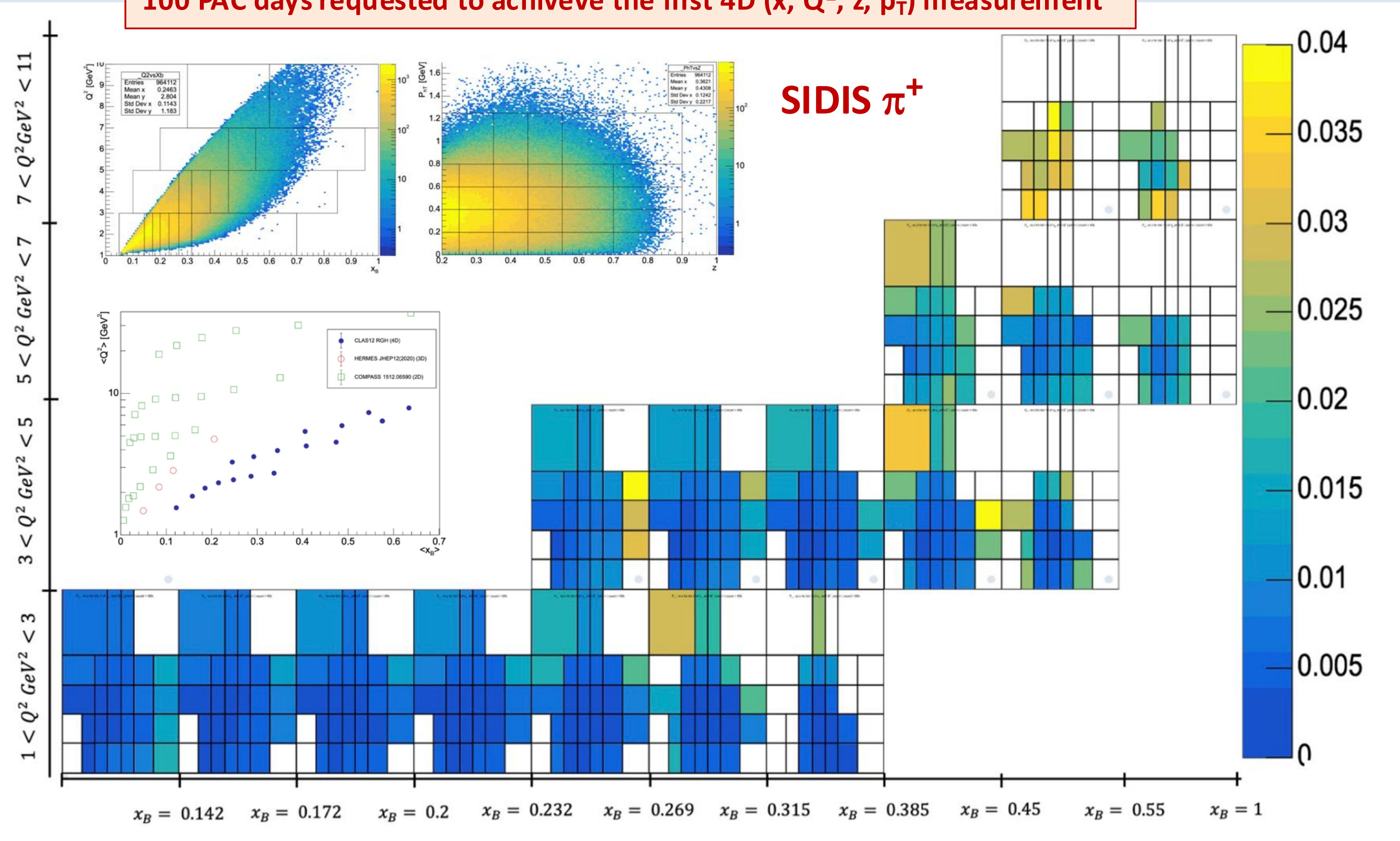
$\pi^0$ contamination is at the level of RGC (~ 30%)




Still basic reconstruction algorithm provides a conservative estimate

Recoil reconstruction is adequate even in the presence of background

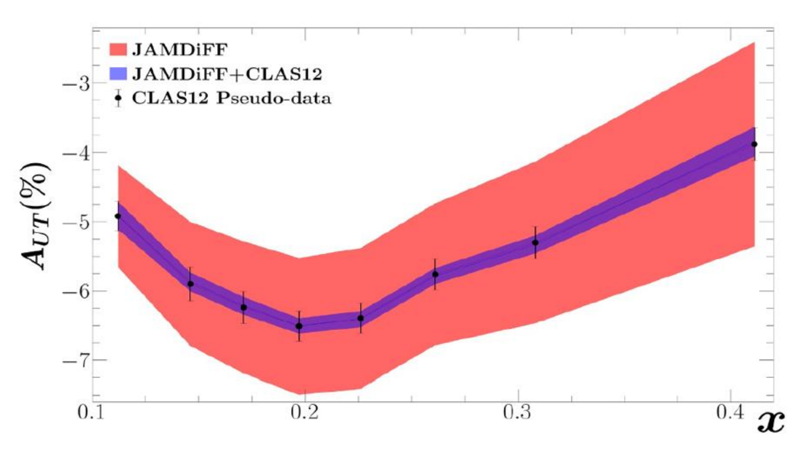
**100 PAC days requested to achiveve the first 4D ($x$, $Q^2$, $z$, $p_T$) measurement**

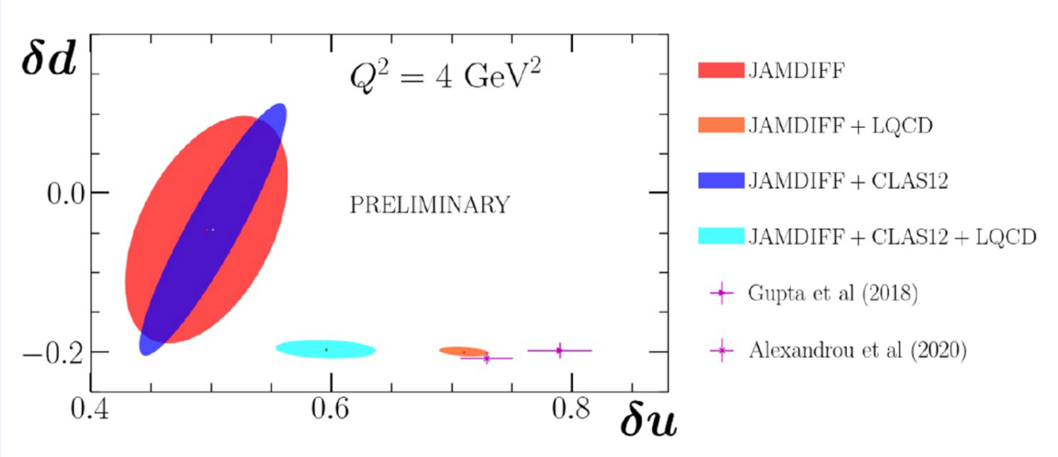


Fundamental quantity related to BSM physics: EDM and tensor coupling

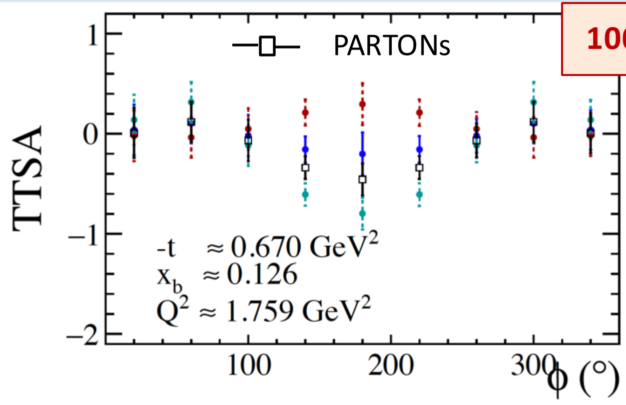
Projections with and without CLAS12 di-hadron pseudo-data (with lattice inputs)

**100 PAC days requested to be competitive in precision to lattice for δu**



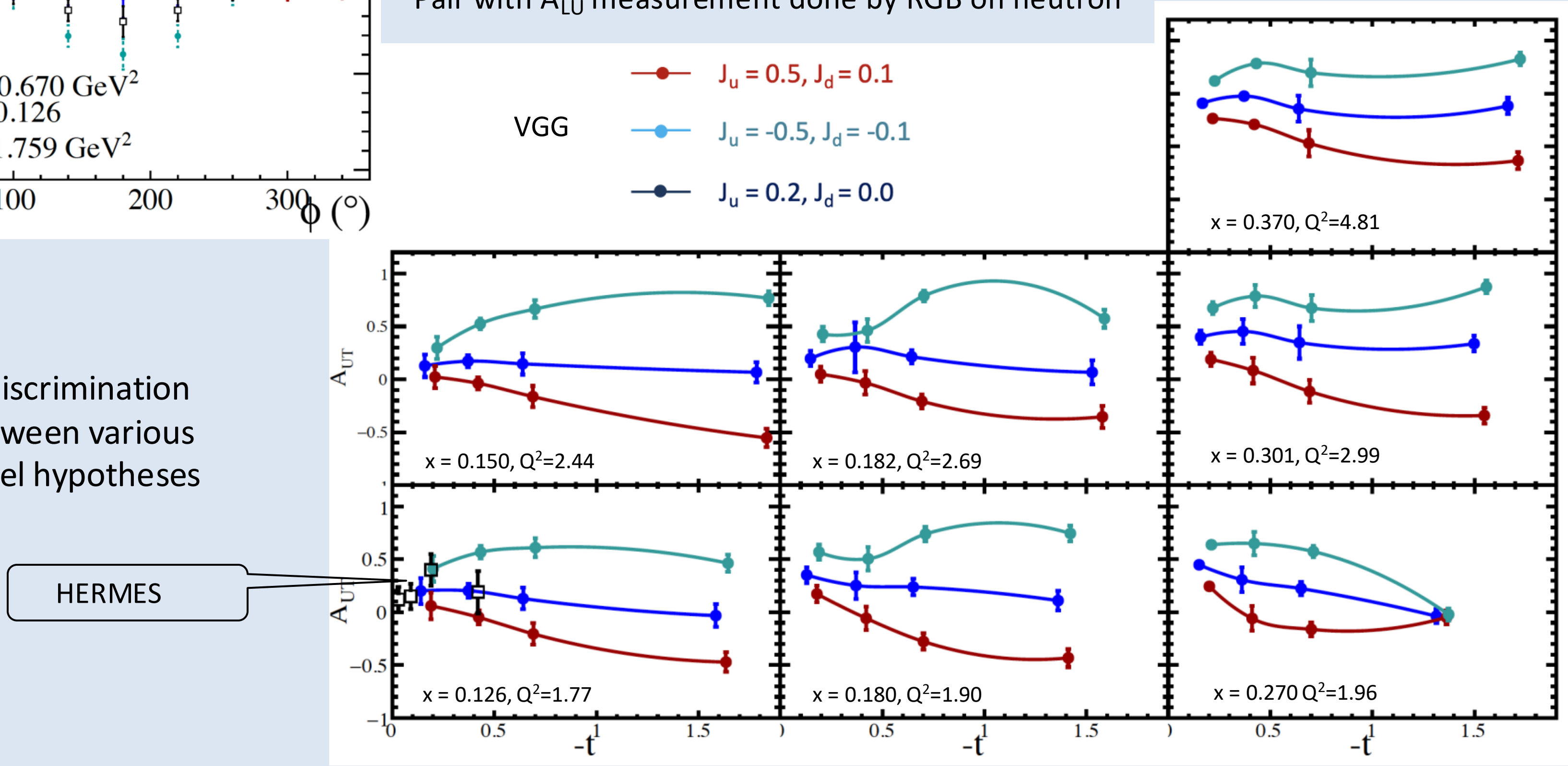




$$\delta u = \int_0^1 dx\,(h_1^u(x) - h_1^{\bar{u}}(x))\,, \quad \delta d = \int_0^1 dx\,(h_1^d(x) - h_1^{\bar{d}}(x))$$




**100 PAC days requested to get unprecedented access to elusive quark angular momenta**

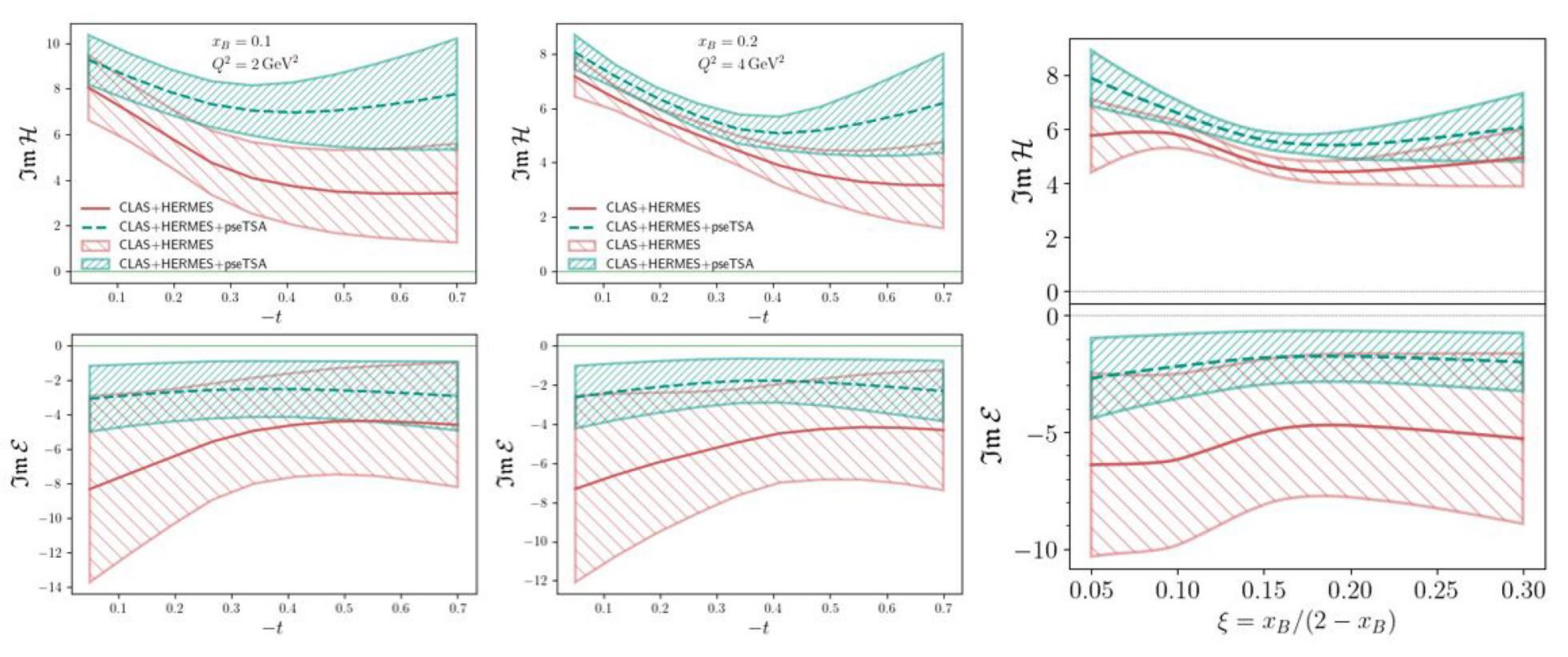
Supersede the only other $A_{UT}$ measurement
Pair with $A_{LU}$ measurement done by RGB on neutron




Superior discrimination power between various OAM model hypotheses

Analysis of Melany Higuera Angulo using GEPARD framework (LDRD project) and relevant data + RGH pseudo-data

**100 PAC days requested to reduce by 2/3 the uncertainty on Im $\mathcal{E}$**



**RGH measurements are expected to be dominated by the statistical uncertainty**

Target spin state can be regularly rotated by microwave-induced swap preserving acceptance
RGH luminosity 5 x $10^{33}$ $cm^2$ $s^{-1}$ is 1/20 of the nominal CLAS12 luminosity
Consolidated methods based on previous experience
Inputs from previous CLAS12 experiments will reduce assumptions in systematics

To be noted: previous high-luminosity CLAS12 experiments provide a solid benchmark e.g., unpolarized cross section terms will be constrained by RGA/RGB and target dilutions by RGC

Conservative systematics are derived from previous relevant realizations and analyses, with a cross-check for RGH acceptance peculiarities.

**SIDIS single hadron**

| Source | Systematic Uncertainty |
| --- | --- |
| Target polarization | 5 % |
| Target dilution | 2 % |
| Radiative effects | 3 % |
| Acceptance and bin-migration | 3 % |

**DVCS**

| Source | Systematic Uncertainty |
| --- | --- |
| Target polarization | 5 % |
| Target dilution | 1 % |
| Recoil performances | 5 % |
| $\pi^0$ background | 3 % |
| Exclusivity cuts | 10 % |

**SIDIS di- hadron**

| Source | Systematic Uncertainty |
| --- | --- |
| Target polarization | 5 % |
| Target dilution | 2 % |
| Baryonic contribution from target fragmentation | 1-6% |
| Bin migration close to $\rho$ mass | 1-10% |

# Beam Request

RGH implements the target configuration which is most sensitive to the 3D nucleon structure study and capitalizes on CLAS12 with a complete set of target polarizations

**100 (physics) + 25 (ancillary) PAC days requested to achieve unprecedent precision in the valence region**

| Beam Energy (GeV) | Beam Current (nA) | Beam Requirements | Target | Material Thickness (mg/cm$^2$) | Beamtime (PAC days) |
|---|---|---|---|---|---|
| 10.6 | 1 | Polarized | $NH_3$ | 1040 | 100 |
| 10.6 | 1 | Polarized | $^{12}C$, $CH_2$ | 1040, 1040 | 5+8 |
| 10.6 | 1 | Polarized | Empty | na | 2 |
| | | | Operations | | 10 |
| Total | | | | | 125 |

100 days of physics run to achieve the RGH goals

5 days for commissioning and alignment

8+2 days for background studies (target dilutions)

10 days for target annealing and target replacements

# PAC Review

**Theory Report**

RGH measurements are critical for the studies of transverse spin phenomena in QCD with high impact physics such as the elusive nucleon tensor charge that is relevant for a broad community including LQCD and BSM physics.

**TAC Report**

No major technical hurdle.

*In the replies, proponents clarified details on: chicane, beam monitor, and beam polarization uncertainty.*

**PAC Readers**

Scientific goals are well aligned with the 2023 NSAC Long Range Plan, preceding and complementing the EIC program.

Awareness of current literature, competing efforts, and theoretical frameworks.

Rare opportunity to get unprecedented access to the parton dynamics in the valence region with a multi-D framework

Acknowledgment of CLAS12 demonstrated capability, established target technology, full GEANT simulation.

*In the replies, proponents clarified details on:*

*Instrumentation (vibrations, field mapping, precision in target re-position, chicane geometry, target spin swap,..)*

*Systematics (background subtraction, unpolarized terms, longitudinal photon component, acceptance effects, radiative effects,…)*

Thank you very much to you and your colleagues for the detailed answers and additional plots.

In addition, we would be happy to understand how the acceptance stability will be ensured and whether the MC will be used to simulate the impact of possible acceptance variations. We can discuss about that point during the PAC next week.

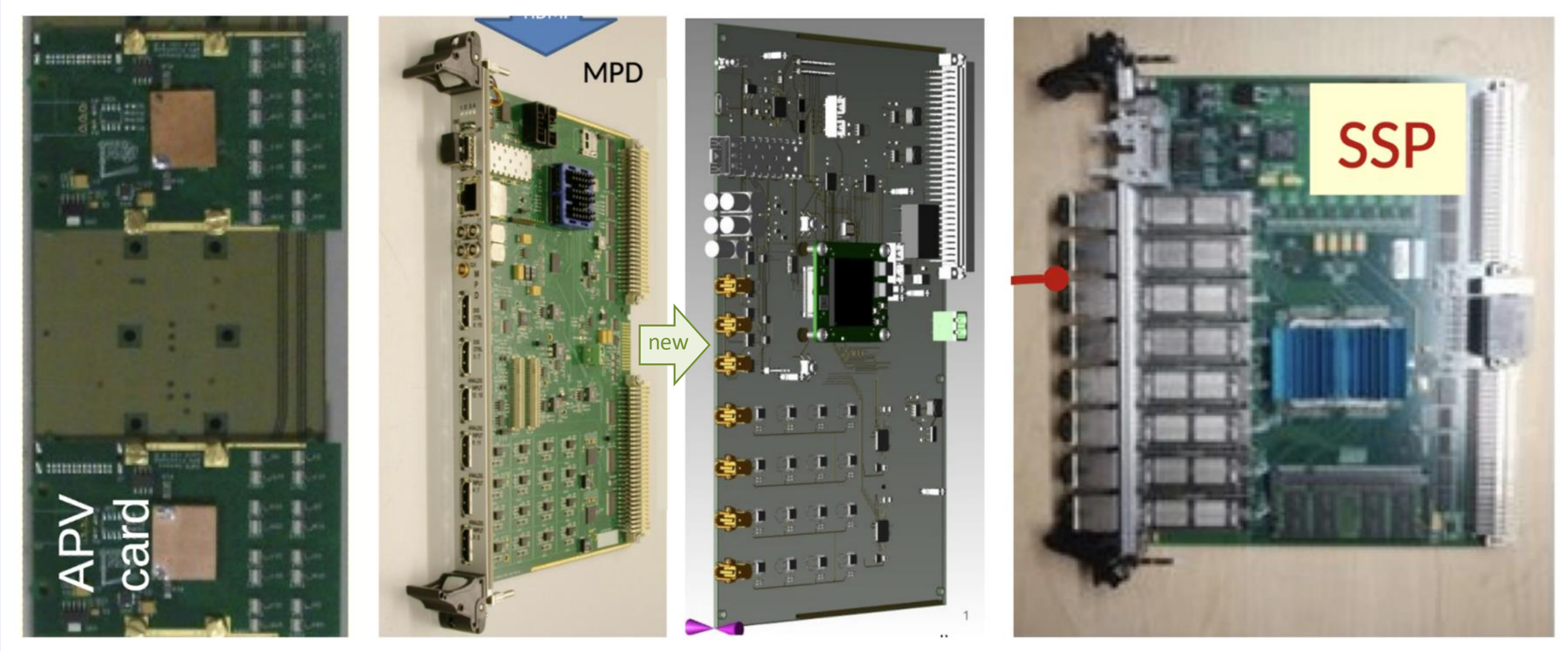
Fiducial cuts will be implemented at the analysis level to select the detector regions of suitable stability. During the calibration procedure of the various CLAS12 subsystems, dead or inefficient channels are flagged, on a run-by-run basis, in the calibration database, and this is done also for the Monte Carlo. These dead/inefficient channels are then eliminated in the reconstruction, for both data and MC. Run-dependent simulations are then produced, which include the run-dependent dead or inefficient detector channels. We don't foresee major differences in the way the acceptance will vary during RGH with respect to previously run CLAS12 experiments. CLAS12 is a quite stable setup overall.

# Recoil Tracking Readout

**Enough (> 10 k) spare channels exist from INFN GEM project for SBS in Hall-A**

Based on the well-known APV25 chip + SSP DAQ (upgraded version of MPD under study)

- ✓ Able to cope with 500 kHz/cm$^2$ and 60% occupancy
- ✓ Same system used with the μRwell prototypes

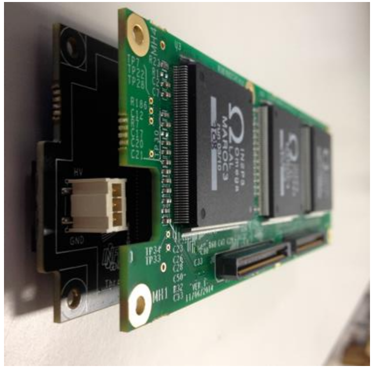


# Recoil TOF Readout

**Enough (> 1 k) spare channels from RICH readout to be updated to ALERT firmware to get < 100 ps readout jitter**

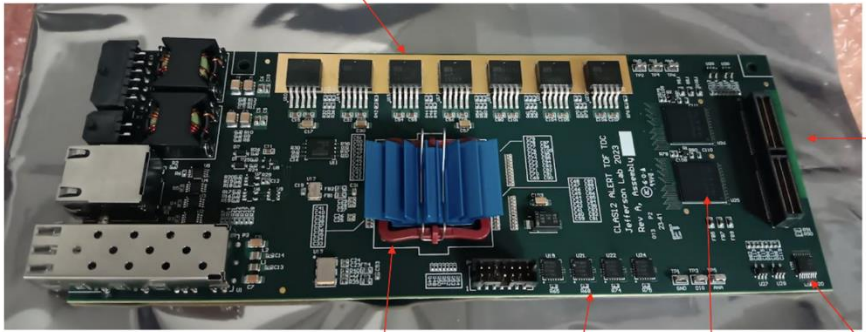
RICH readout

- ✓ MAROC dynamic range can cope with multi-photon signals
- ✓ Clock distribution supports 100 ps readout precision

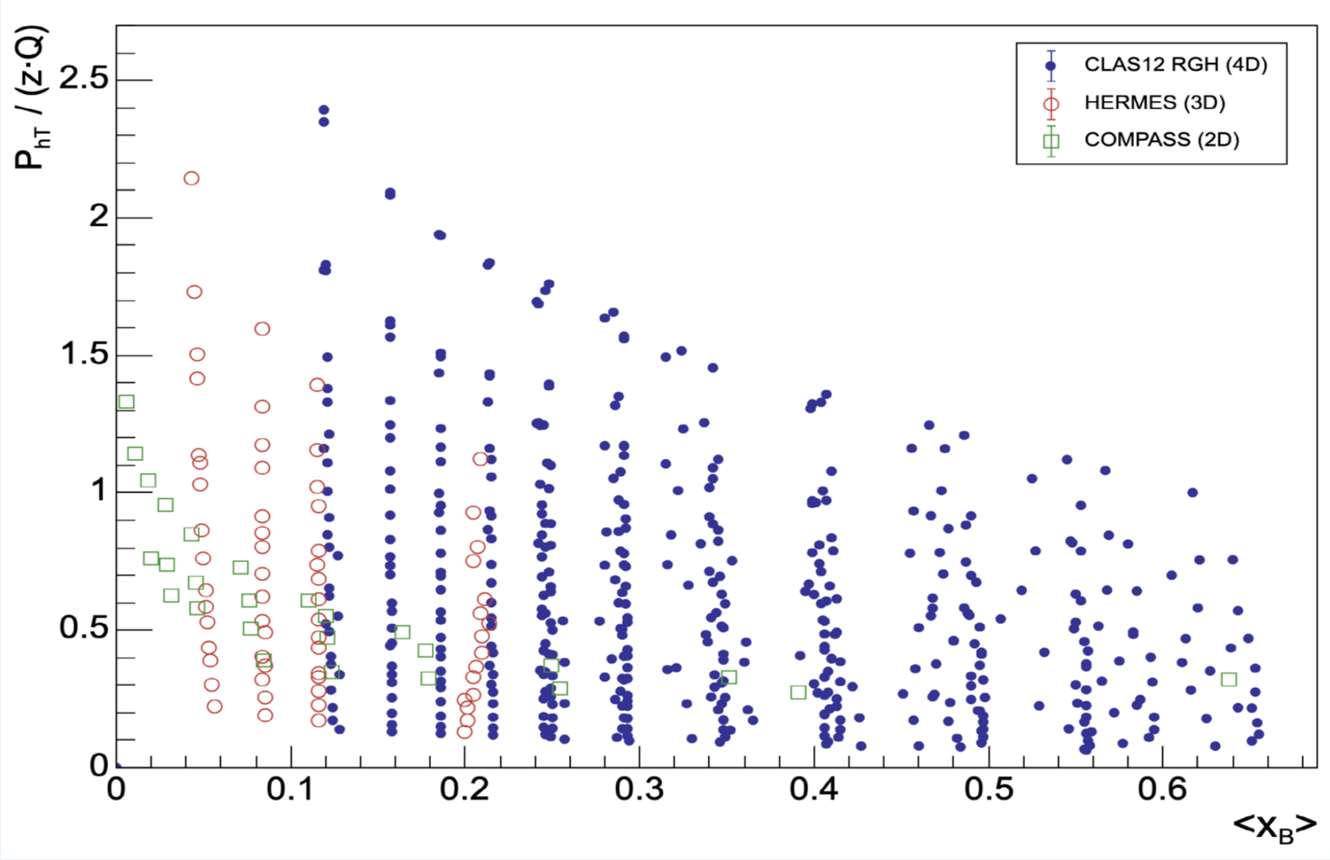



Option to adopt CLAS12-ALERT readout

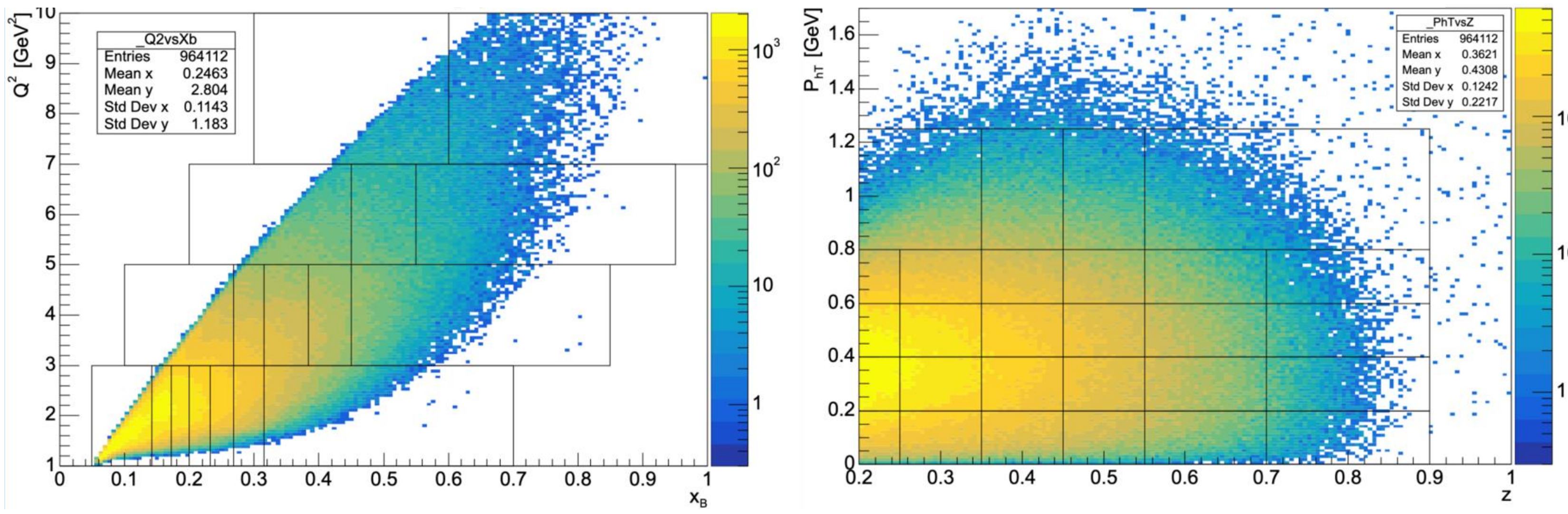
- ✓ PETIROC has a better dynamic range (multi-photons)
- ✓ Clock distribution supports 50 ps readout precision



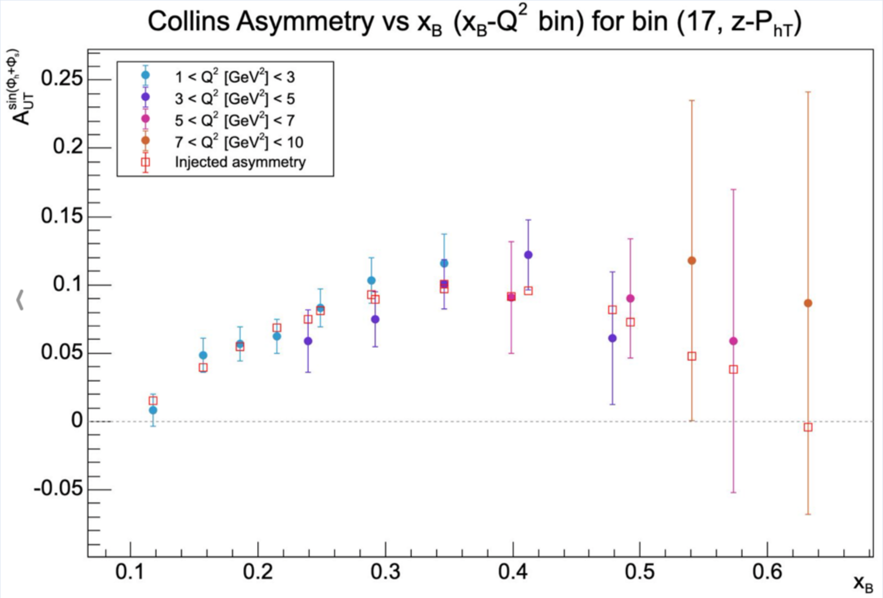
# TMD Regime

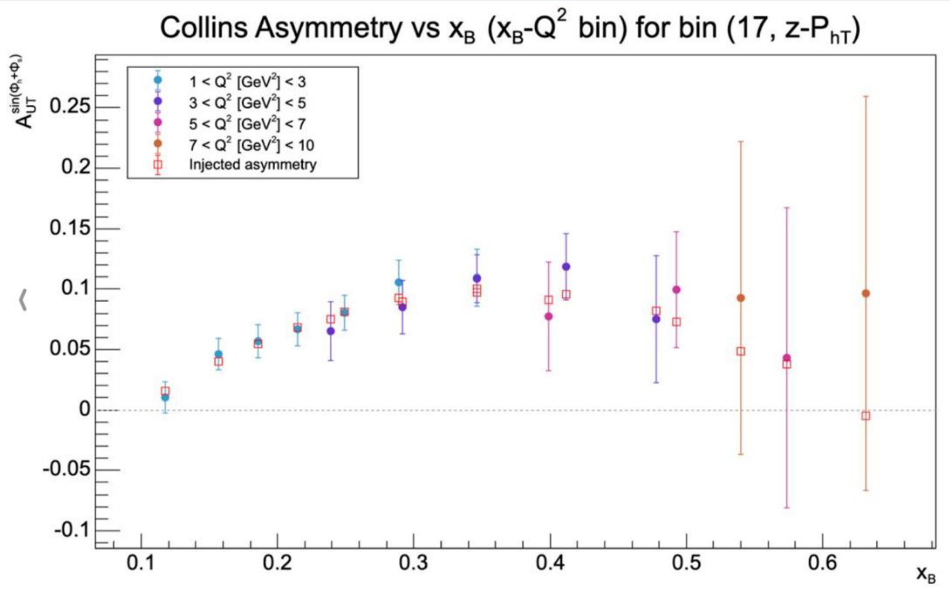


$P_{hT}$ / (z·Q)
2.5
2
1.5
1
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
$\langle x_B \rangle$
CLAS12 RGH (4D)
HERMES (3D)
COMPASS (2D)

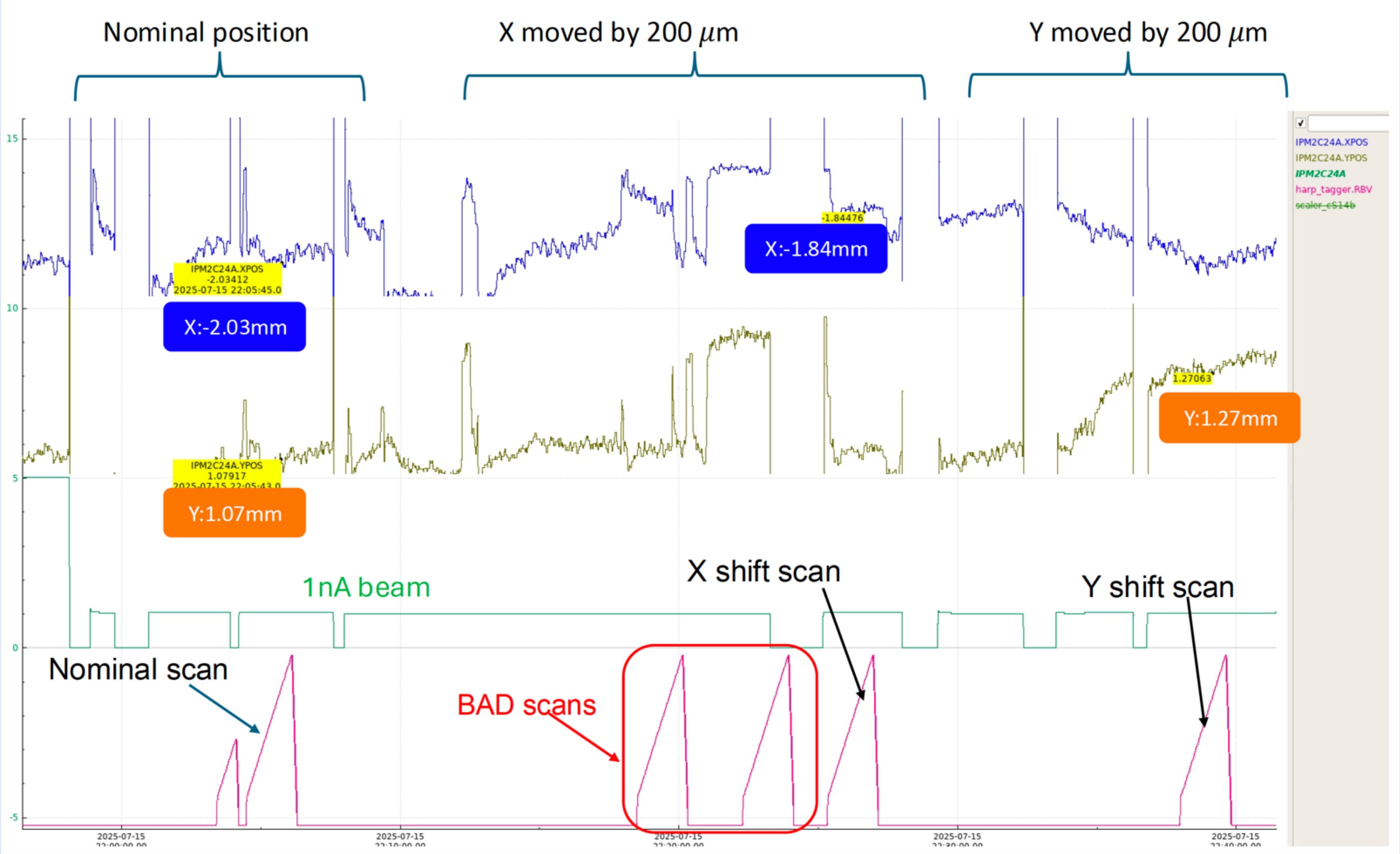

_Q2vsXb
Entries 964112
Mean x 0.2463
Mean y 2.804
Std Dev x 0.1143
Std Dev y 1.183
Q^2 [GeV^2]
x_B
_PhTvsZ
Entries 964112
Mean x 0.3621
Mean y 0.4308
Std Dev x 0.1242
Std Dev y 0.2217
P_hT [GeV]
z

# Simulation Check



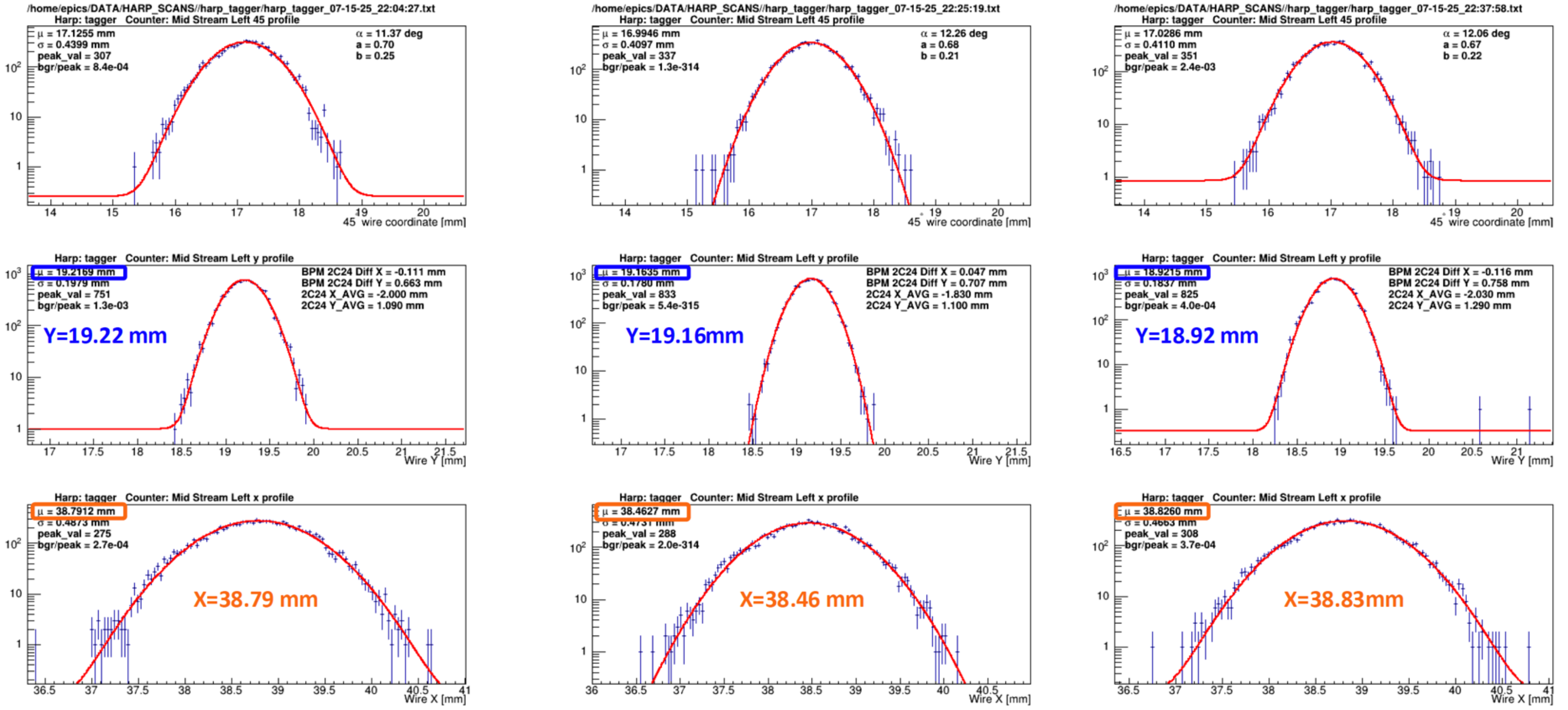



# Beam Line Test at 1 nA



# Beam Line Test at 1 nA

| Nominal positions | X Is moved by 200 $\mu m$ | Y Is moved by 200 $\mu m$ |
| --- | --- | --- |
| 2C24 BPM locked at X -2, Y +1.1 | 2C24 BPM locks at X -1.8, Y +1.1 | 2C24 BPM locks at X -2, Y +1.3 |



# Magnet Configuration

Minimal forces generated by mutual interaction of magnets

## Target vs chicane

Table 3: Coil forces at 5T central field:

| Coil number | Fx (N) | Fy (N) | Fz(N) |
|---|---|---|---|
| 1 | 0 | 644876 | 0 |
| 2 | 0 | 22573 | 0 |
| 3 | 0 | -109371 | 0 |
| 4 | 0 | -64090 | 0 |
| 5 | 0 | -644876 | 0 |
| 6 | 0 | -22573 | 0 |
| 7 | 0 | 109371 | 0 |
| 8 | 0 | 64090 | 0 |
| Total | 0 | 0 | 0 |

Table 4: Coil forces in presence of 3 chicane magnet

| Coil number | Fx (N) | Fy (N) | Fz(N) |
|---|---|---|---|
| 31 | 0 | 644942 | 358 |
| 32 | 0 | 22600 | 178 |
| 33 | 0 | -109362 | 76 |
| 34 | 0 | -64087 | 25 |
| 35 | 0 | -644942 | 358 |
| 36 | 0 | -22600 | 178 |
| 37 | 0 | 109362 | 76 |
| 38 | 0 | 64087 | 25 |
| Total | 0 | 0 | 1275 |

## Target vs torus

Table 5: Target coil force with and without Torus

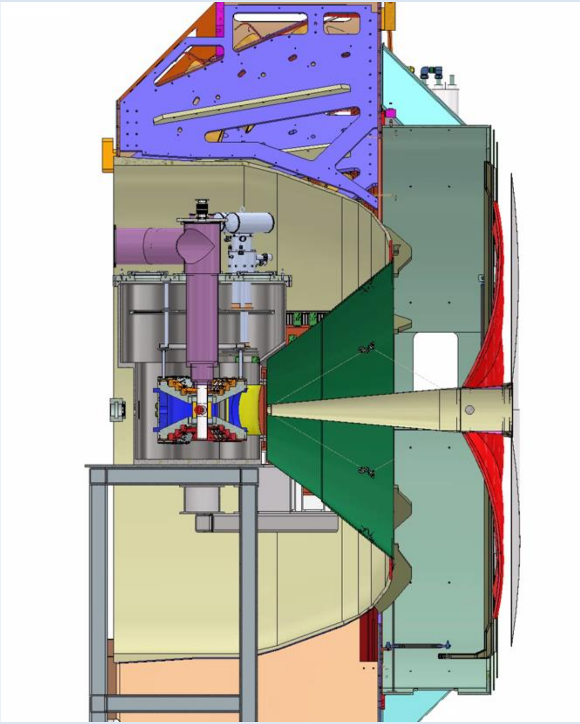
| Target Magnet Coil # | Without Torus | | | With Torus | | |
|---|---|---|---|---|---|---|
| | Fx (N) | Fy (N) | Fz (N) | Fx (N) | Fy (N) | Fz (N) |
| 1 | 0 | -644876 | 0 | 0 | -644876 | 0 |
| 2 | 0 | -22573 | 0 | 0 | -22573 | 0 |
| 3 | 0 | 109371 | 0 | 0 | 109371 | 0 |
| 4 | 0 | 64090 | 0 | 0 | 64090 | 0 |
| 5 | 0 | 644876 | 0 | 0 | 644876 | 0 |
| 6 | 0 | 22573 | 0 | 0 | 22573 | 0 |
| 7 | 0 | -109371 | 0 | 0 | -109371 | 0 |
| 8 | 0 | -64090 | 0 | 0 | -64090 | 0 |
| Total Force | 0 | 0 | 0 | 0 | 0 | 0 |

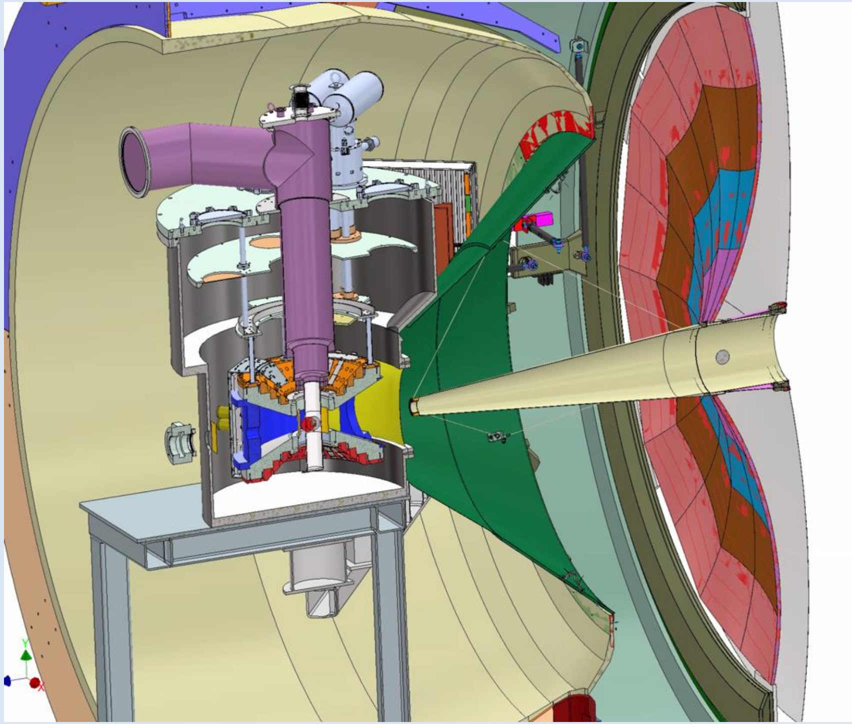
## Torus vs target

Table 7: Comparison of Torus coil force with and without Target magnet

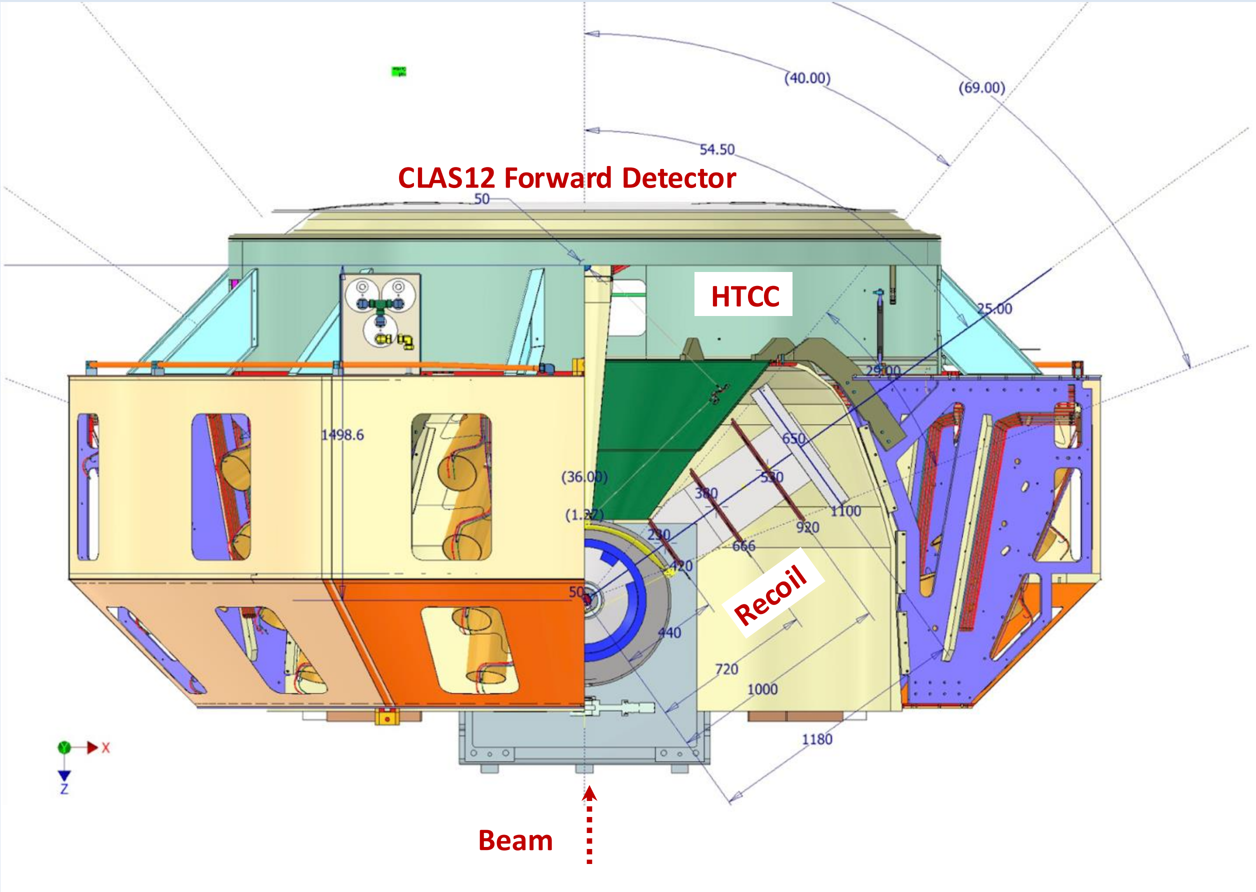
| Torus Magnet Coil # | | Without Target Magnet | | | With Target Magnet | | | Effect of Target Magnet | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Coil | SubCoil | Fx (N) | Fy (N) | Fz (N) | Fx (N) | Fy (N) | Fz (N) | Fx (N) | Fy (N) | Fz (N) |
| 1 | 1 | 0 | 1220649 | 0 | 300 | 1220649 | 0 | 300 | 0 | 0 |
| | 2 | 0 | 361535 | 411162 | 95 | 361535 | 411162 | 95 | 0 | 0 |
| | 3 | 0 | -294544 | 729023 | 338 | -294544 | 729023 | 338 | 0 | 0 |
| | 4 | 0 | -177228 | 75215 | 71 | -177228 | 75215 | 71 | 0 | 0 |
| | 5 | 0 | -246391 | -99549 | -19 | -246391 | -99549 | -19 | 0 | 0 |
| | 6 | 0 | -76474 | -181546 | -258 | -76474 | -181546 | -258 | 0 | 0 |
| | 7 | 0 | 291655 | -721872 | -1139 | 291655 | -721872 | -1139 | 0 | 0 |
| | 8 | 0 | 350962 | -212458 | 125 | 350962 | -212458 | 125 | 0 | 0 |
| 2 | 9 | -1057113 | 610325 | 0 | -1056808 | 610322 | 0 | 305 | -3 | 0 |
| | 10 | -313099 | 180768 | 411162 | -313025 | 180780 | 411086 | 74 | 12 | -77 |
| | 11 | 255083 | -147272 | 729023 | 255048 | -147057 | 728682 | -35 | 215 | -341 |
| | 12 | 153484 | -88614 | 75215 | 153441 | -88548 | 75187 | -43 | 66 | -28 |
| | 13 | 213381 | -123196 | -99549 | 213218 | -123112 | -99475 | -163 | 83 | 74 |
| | 14 | 66228 | -38237 | -181546 | 66109 | -38317 | -181366 | -119 | -80 | 179 |
| | 15 | -252581 | 145828 | -721872 | -252522 | 145137 | -720893 | 58 | -690 | 979 |
| | 16 | -303942 | 175481 | -212458 | -303776 | 175457 | -212346 | 166 | -24 | 112 |
| 3 | 17 | -1057113 | -610325 | 0 | -1056808 | -610322 | 0 | 305 | 3 | 0 |
| | 18 | -313099 | -180768 | 411162 | -313025 | -180780 | 411086 | 74 | -12 | -77 |
| | 19 | 255083 | 147272 | 729023 | 255048 | 147057 | 728682 | -35 | -215 | -341 |
| | 20 | 153484 | 88614 | 75215 | 153441 | 88548 | 75187 | -43 | -66 | -28 |
| | 21 | 213381 | 123196 | -99549 | 213218 | 123112 | -99475 | -163 | -83 | 74 |
| | 22 | 66228 | 38237 | -181546 | 66109 | 38317 | -181366 | -119 | 80 | 179 |
| | 23 | -252581 | -145828 | -721872 | -252522 | -145137 | -720893 | 58 | 690 | 979 |
| | 24 | -303942 | -175481 | -212458 | -303776 | -175457 | -212346 | 166 | 24 | 112 |
| 4 | 25 | 0 | -1220649 | 0 | 300 | -1220649 | 0 | 300 | 0 | 0 |
| | 26 | 0 | -361535 | 411162 | 95 | -361535 | 411162 | 95 | 0 | 0 |
| | 27 | 0 | 294544 | 729023 | 338 | 294544 | 729023 | 338 | 0 | 0 |
| | 28 | 0 | 177228 | 75215 | 71 | 177228 | 75215 | 71 | 0 | 0 |
| | 29 | 0 | 246391 | -99549 | -19 | 246391 | -99549 | -19 | 0 | 0 |
| | 30 | 0 | 76474 | -181546 | -258 | 76474 | -181546 | -258 | 0 | 0 |
| | 31 | 0 | -291655 | -721872 | -1139 | -291655 | -721872 | -1139 | 0 | 0 |
| | 32 | 0 | -350962 | -212458 | 125 | -350962 | -212458 | 125 | 0 | 0 |
| 5 | 33 | 1057113 | -610325 | 0 | 1057418 | -610327 | 0 | 305 | -3 | 0 |
| | 34 | 313099 | -180768 | 411162 | 313172 | -180755 | 411239 | 74 | 12 | 77 |
| | 35 | -255083 | 147272 | 729023 | -255118 | 147487 | 729364 | -35 | 215 | 341 |
| | 36 | -153484 | 88614 | 75215 | -153527 | 88680 | 75243 | -43 | 66 | 28 |
| | 37 | -213381 | 123196 | -99549 | -213544 | 123279 | -99622 | -163 | 83 | -74 |
| | 38 | -66228 | 38237 | -181546 | -66347 | 38157 | -181725 | -119 | -80 | -179 |
| | 39 | 252581 | -145828 | -721872 | 252639 | -146518 | -722851 | 58 | -690 | -979 |
| | 40 | 303942 | -175481 | -212458 | 304108 | -175504 | -212570 | 166 | -24 | -112 |
| 6 | 41 | 1057113 | 610325 | 0 | 1057418 | 610327 | 0 | 305 | 3 | 0 |
| | 42 | 313099 | 180768 | 411162 | 313172 | 180755 | 411239 | 74 | -12 | 77 |
| | 43 | -255083 | -147272 | 729023 | -255118 | -147487 | 729364 | -35 | -215 | 341 |
| | 44 | -153484 | -88614 | 75215 | -153527 | -88680 | 75243 | -43 | -66 | 28 |
| | 45 | -213381 | -123196 | -99549 | -213544 | -123279 | -99622 | -163 | -83 | -74 |
| | 46 | -66228 | -38237 | -181546 | -66347 | -38157 | -181725 | -119 | 80 | -179 |
| | 47 | 252581 | 145828 | -721872 | 252639 | 146518 | -722851 | 58 | 690 | -979 |
| | 48 | 303942 | 175481 | -212458 | 304108 | 175504 | -212570 | 166 | 24 | -112 |
| | All coils | 0 | 0 | -141 | 0 | 0 | -141 | 0 | 0 | 0 |

## 3D Model



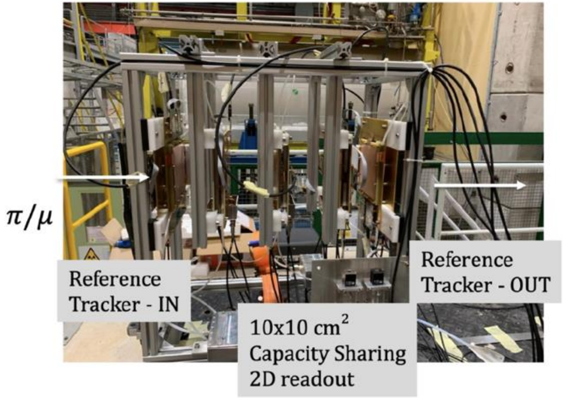


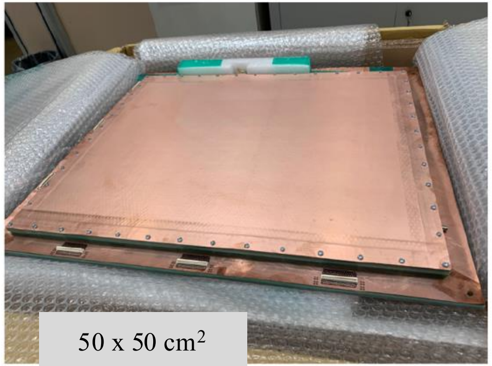
# Recoil Dimensions

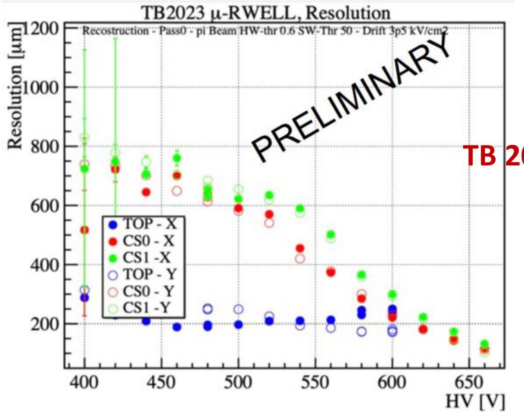


# RGH Recoil Detector

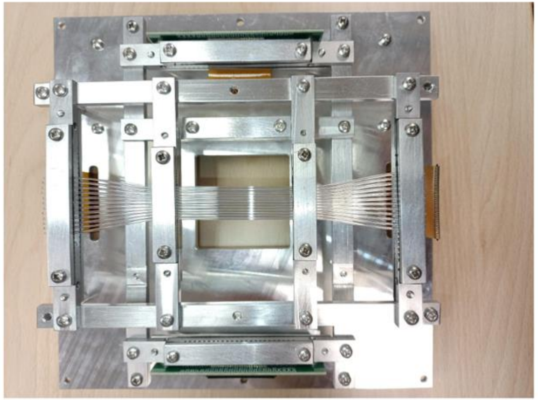
Spatial resolution O(100 μm) with μ-Rwell tecnology under development for the CLAS12 high-lumi project

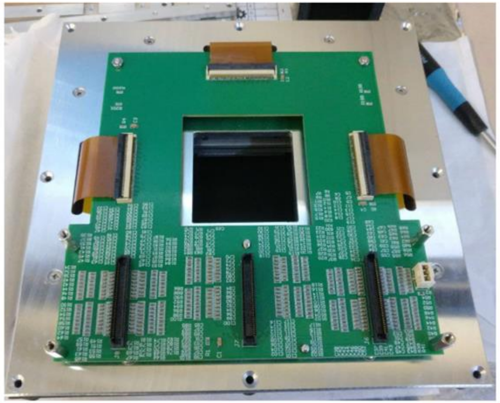


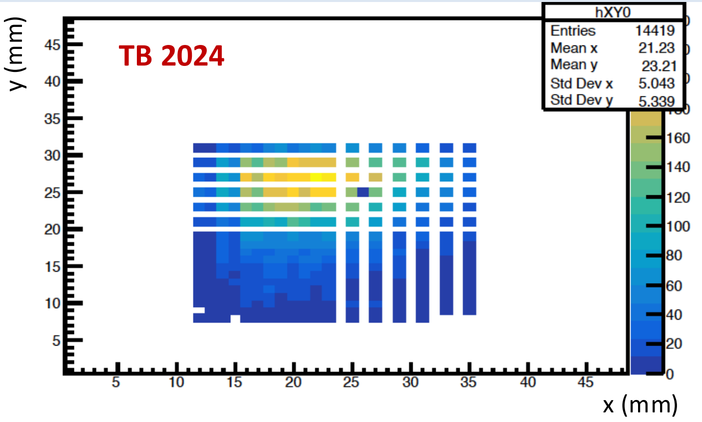




Time resolution O(100 ps) with scintillating technology (CLAS12 TOF) or in synergy with other projects (e.g. INFN fast tracker)

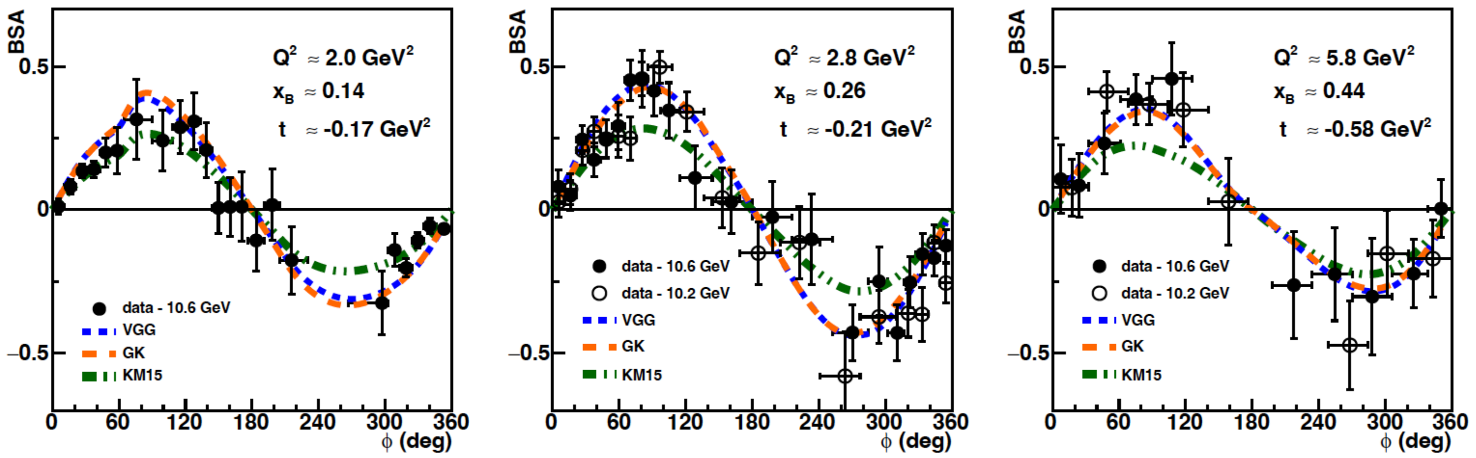






# First CLAS12 measurement of DVCS beam-spin asymmetries in the extended valence region

G. Christiaens at al., Phys.Rev.Lett. 130 (2023) 21, 211902

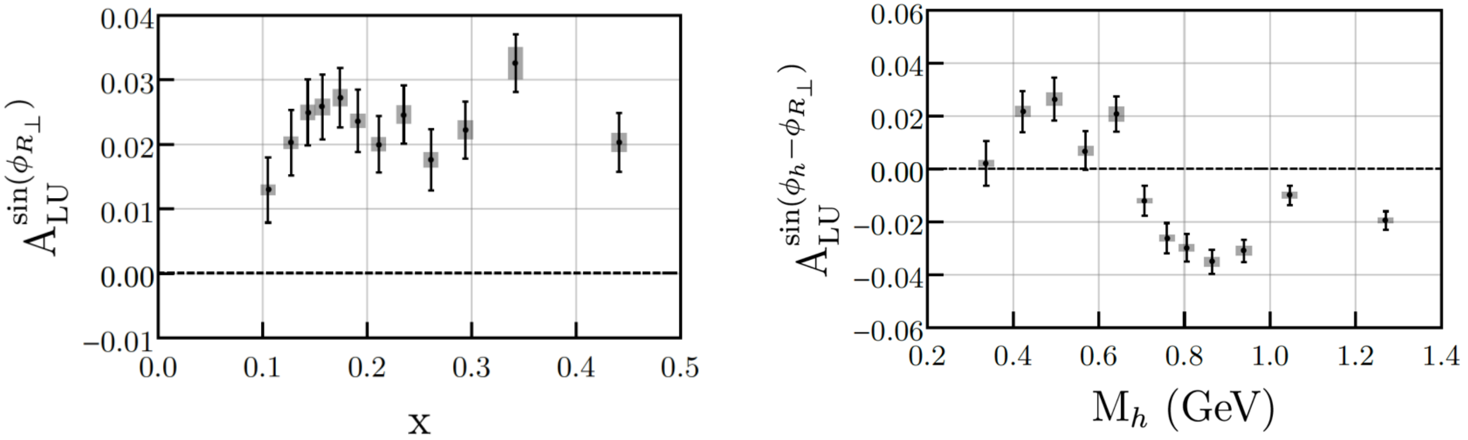



**Sensitive to GPDs and the 3D structure of the nucleon**

With respect the past:
- extended range in the valence region well inside the DIS regime
- superior statistics instrumental for multidimensional study & model assessment

**Observation of Beam Spin Asymmetries in the Process $ep \to e'\pi^+\pi^- X$ with CLAS12**

T.B. Hayward at al., Phys.Rev.Lett. 126 (2021) 152501




**Sensitive to TMDs and the strong-force correlations in hadron formation**

With respect the past:
- extended range in the valence region well inside the DIS regime
- superior statistics instrumental for multidimensional study
- large acceptance for elusive correlations

NH$_3$ target

L = $10^{35}$ cm$^{-2}$ s$^{-1}$

Sheet-of-flame bakground

Forward Angle Detector
covers 8$^o$-15$^o$ in polar angle

Large Angle Detector
Covers 15$^o$-24$^o$ in polar angle