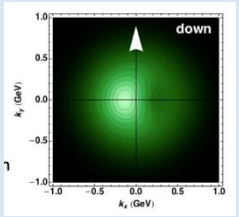
CLAS12 Experiments with a Transversely Polarized Target

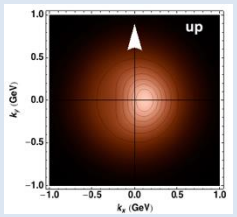
Contalbrigo Marco - INFN Ferrara

DIS 2026, 4th- 8th May 2026

TMD (x, k_T) quark polarisation

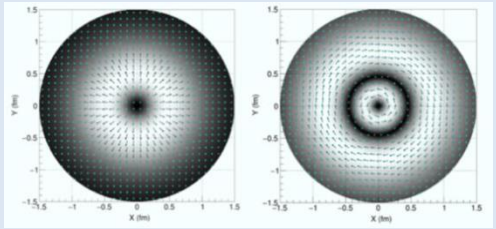
nucleon polarisation: N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	$h_1, h_{1T}^\perp$



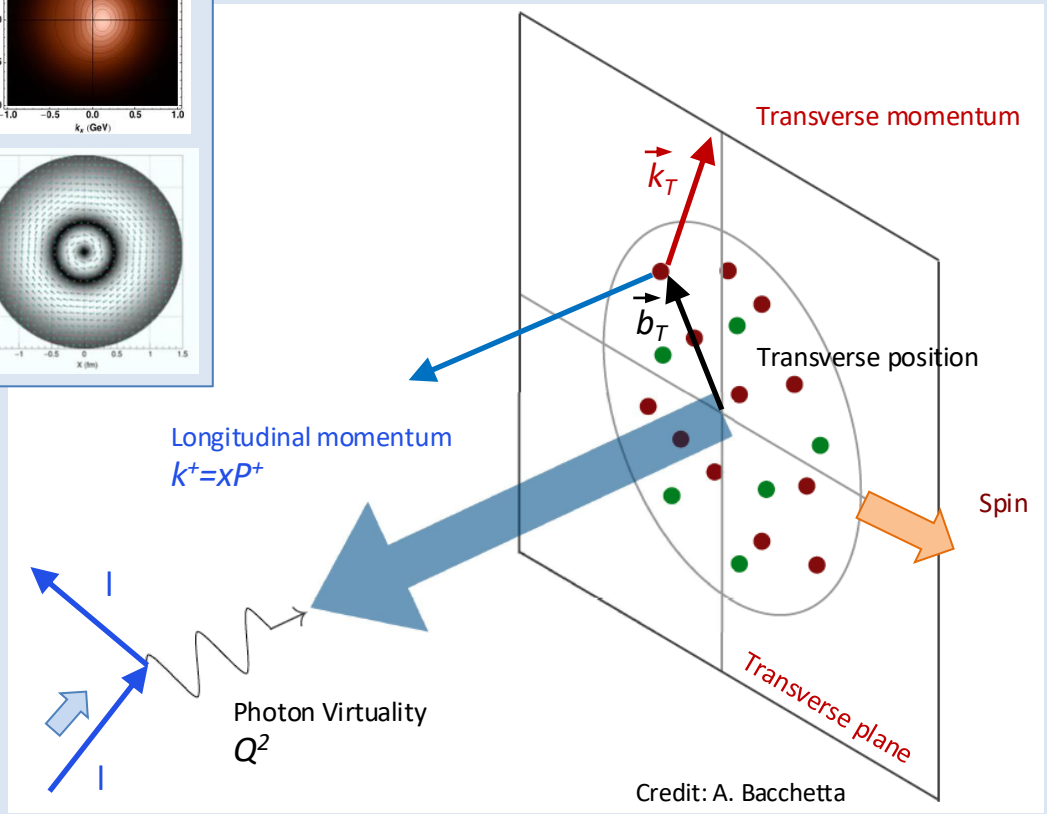


GPD (x, b_T) quark polarisation

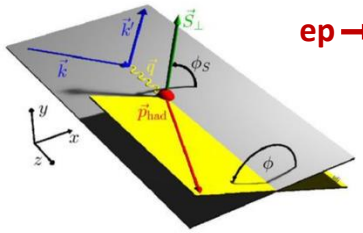
nucleon polarisation: N/q	U	L	T
U	H		$\mathcal{E}_T$
L		$\tilde{H}$	$\tilde{E}_T$
T	E	$\tilde{E}$	$H_T, \tilde{H}_T$



Confinement Scale



High Energy Probe
Hard Scale



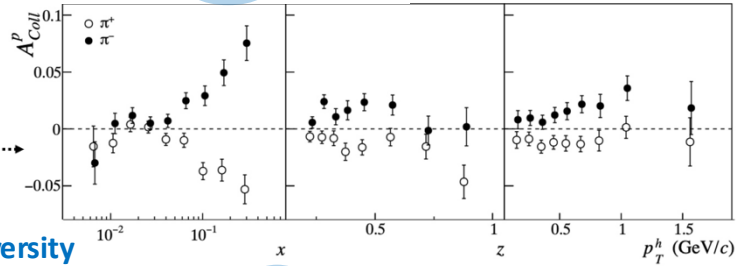
ep → e'hX, e'hhX

$$\frac{d\sigma_{UT}}{dxdQ^2dzdP_{h\perp}d\phi d\phi_S} \propto \left[F_{UU} + \epsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\right] + S_L\left[\sin(2\phi)F_{LU}^{\sin(2\phi)}\right] + \lambda_e S_L\left[\sqrt{1-\epsilon^2}F_{LL}\right]$$

$$+ S_T\left[\sin(\phi-\phi_S)\,F_{UT}^{\sin(\phi-\phi_S)} + \epsilon\sin(\phi+\phi_S)\,F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)\,F_{UT}^{\sin(3\phi-\phi_S)}\right]$$

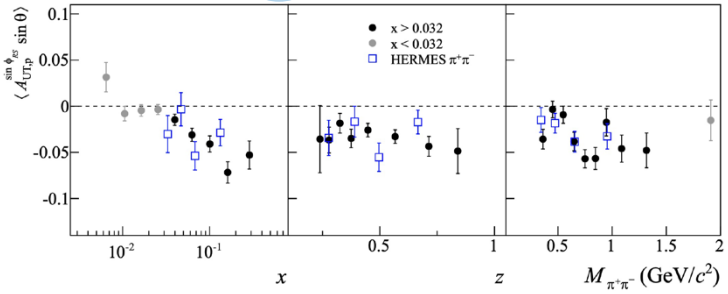
$$+ \lambda_e S_T\left[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)\,F_{LT}^{\cos(\phi-\phi_S)}\right] + O\left(\frac{1}{Q^2}\right)$$

$\sigma_{UT}^{Collins} \propto S_T \sin(\phi+\phi_S)\, C[h_1(x,k_T) \times H_1^\perp(z,p_T)]$ C. Adolph, PLB 744 (2015) 250



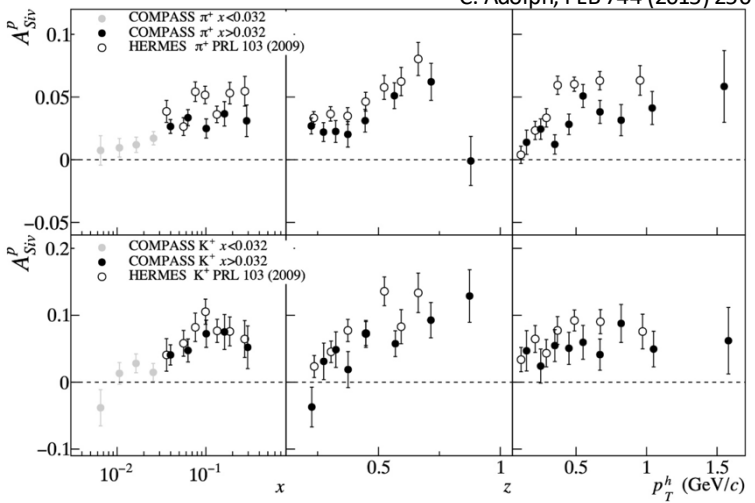
Transversity

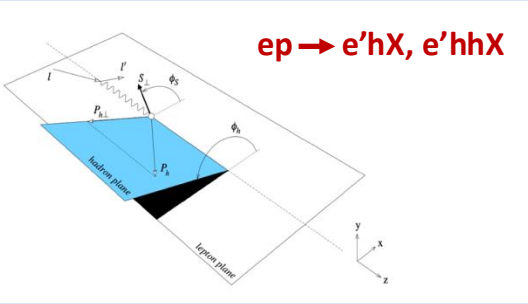
$\sigma_{UT}^{IFF} \propto S_T \sin(\phi_{R\perp}+\phi_S)\sin(\theta)\, h_1(x) H_1^\sphericalangle(z, M_{hh})]$ G.D. Alexeev, PLB 845 (2023) 138155



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

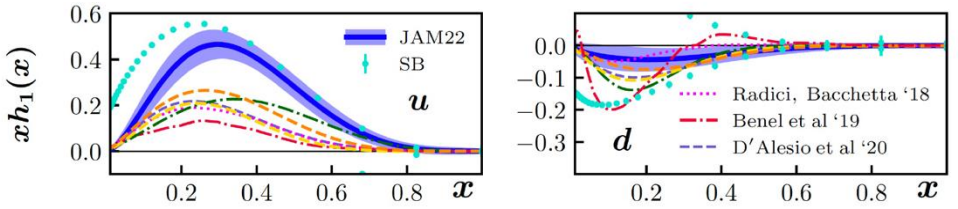




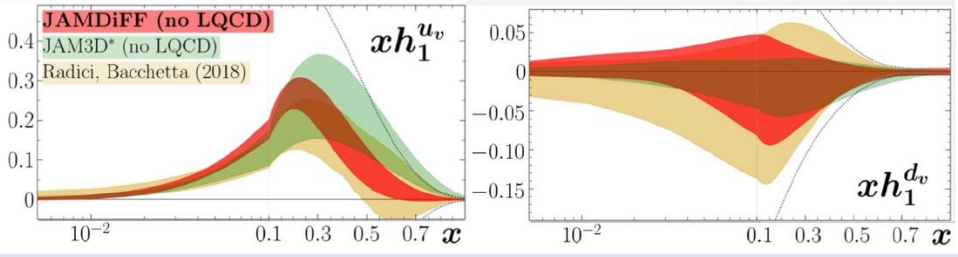
Large sensitivity expected in the valence region
Lack of data above x = 0.3 and no fully differential (4D) analysis available so far

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

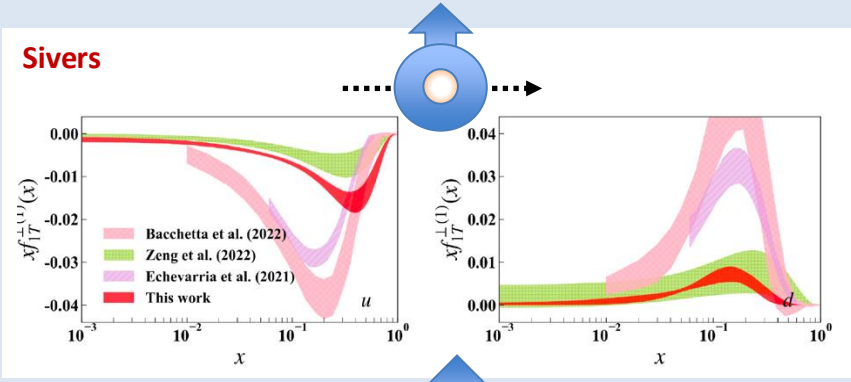
Transversity from single hadron SIDIS



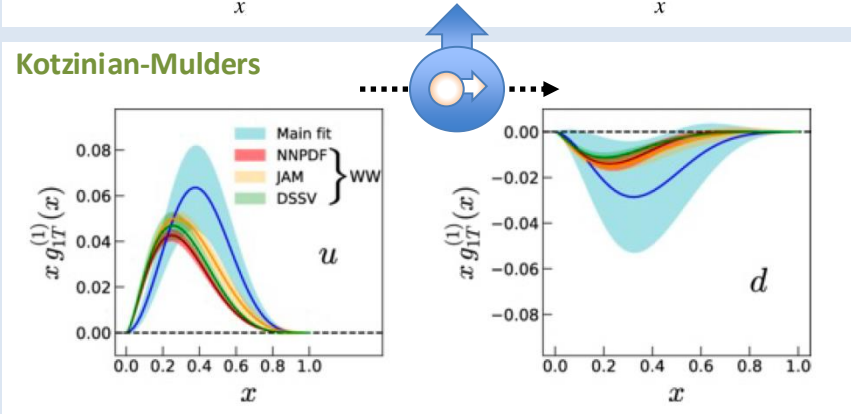
Transversity from di-hadron SIDIS



Sivers

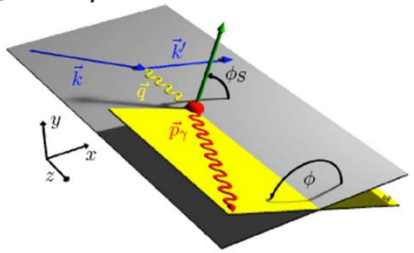


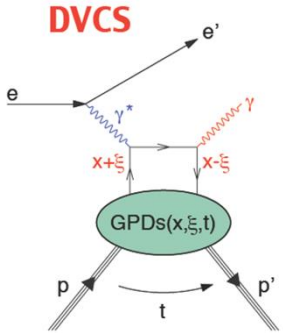
Kotzinian-Mulders

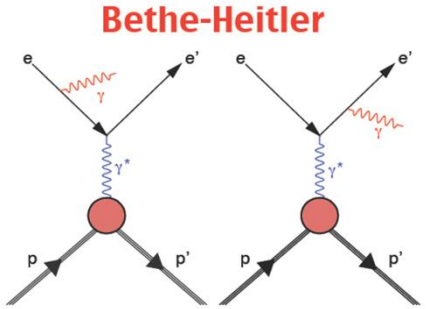


$$\frac{d^4\sigma}{dQ^2\, dx_B\, dt\, d\phi} \propto \left(|\mathcal{T}_{DVCS}|^2 + |\mathcal{T}_{BH}|^2 + \mathcal{I}\right)$$

ep → e' p' γ





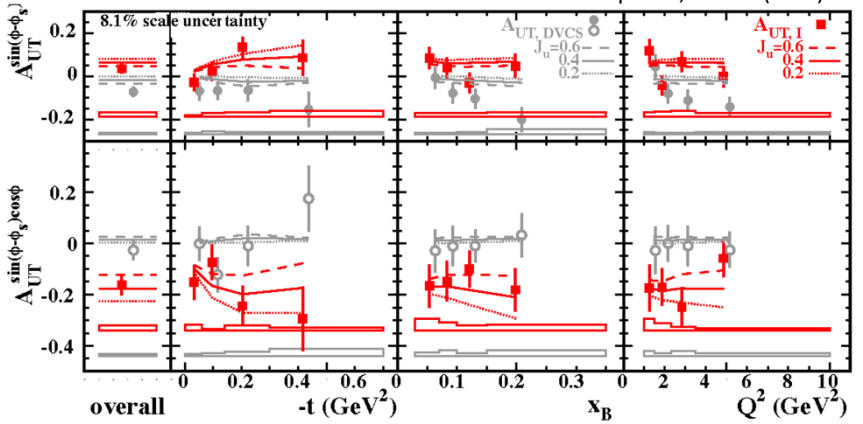


Rare access to Im$\mathcal{E}$ CFF with no kinematic suppression

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

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

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

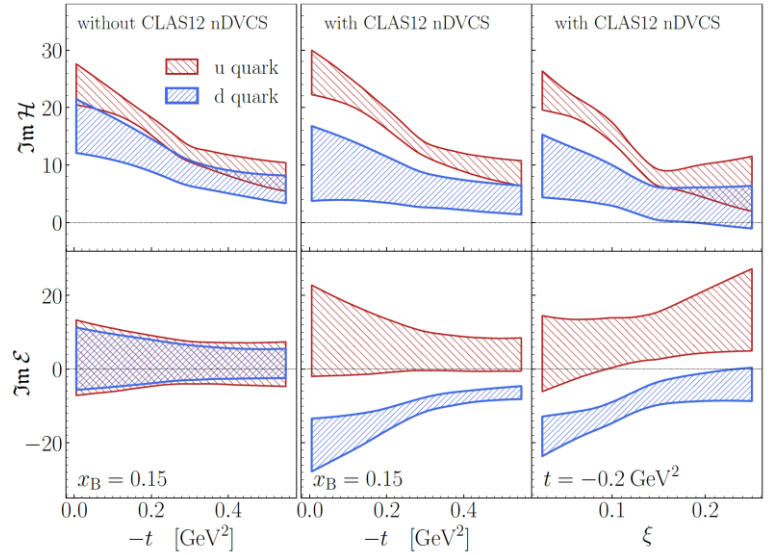
$$\sum_q \int_{-1}^{+1} dx\, x[H^q(x,\xi,t=0) + E^q(x,\xi,t=0)] = 2\,J_q$$

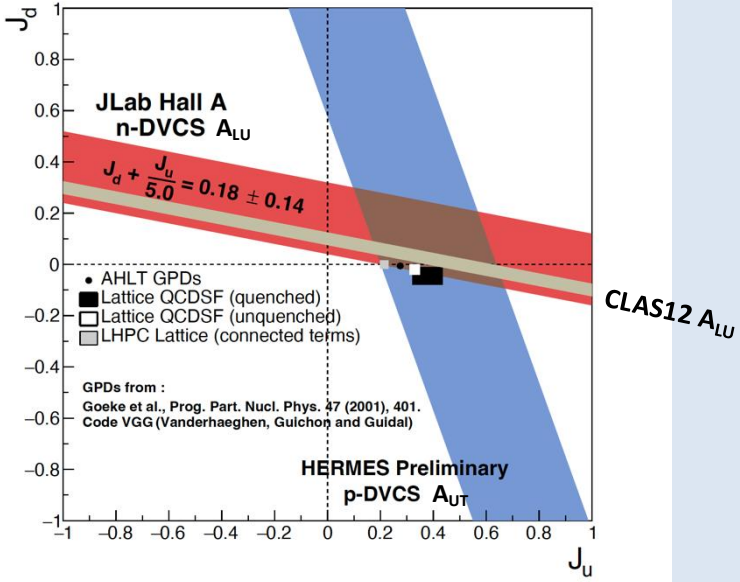
CLAS12 can be the first experiment in exploiting both
A_{LU} measurement on neutron with
A_{UT} measurement on proton

$$\Delta\sigma_{LU} \sim \sin\phi\ \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - kF_2\mathcal{E} + \dots\}$$

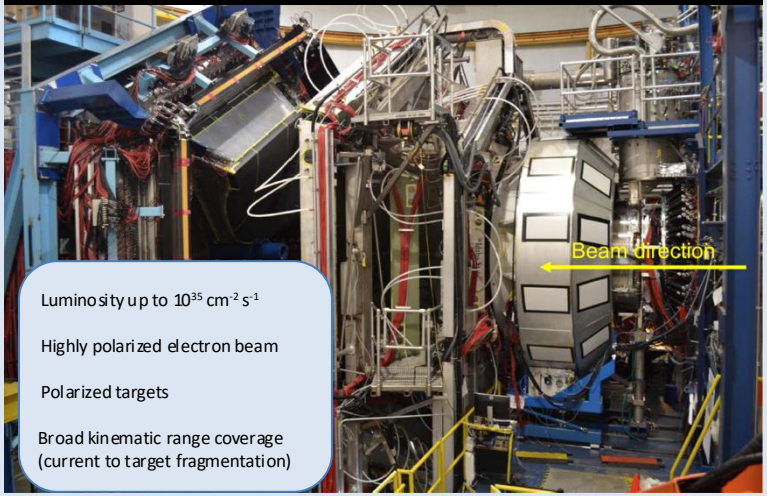
$$\Delta\sigma_{UT} \sim \cos\phi\sin(\phi_s-\phi)\mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \dots\}$$

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



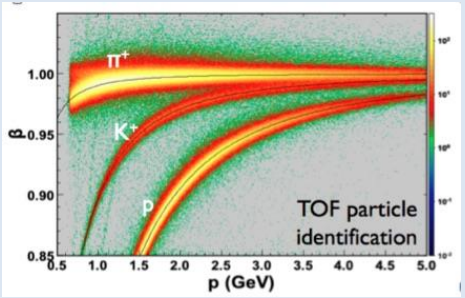


Large acceptance spectrometer. Operational since 02/18

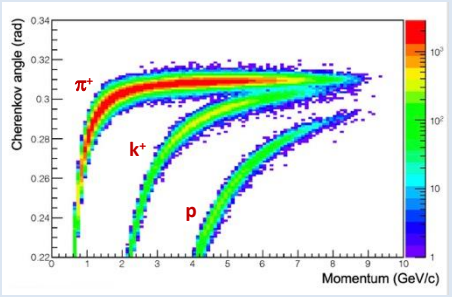


Year	Period	Run	Target	Polarization	Beam
2018	Spring-Fall	RGA	Proton	-	10.6 GeV
	Fall	RGK	Proton	-	6.5-7.5 GeV
2019	Spring	RGA	Proton	-	10.6 GeV
2019	Spring-Fall	RGB	Deuteron	-	10.6 GeV
2020	Spring-Fall	RGF	Deuteron	-	10.6 GeV
2021	Fall	RGM	Nuclear	-	Several GeV
2022	Spring-Fall	RGC	NH_3-ND_3	Longitudinal	10.6 GeV
~ 2029		RGH	NH_3-ND_3	Transverse	10.6 GeV
> 2029			^{3}He	Longitudinal	10.6 GeV
> 2029		RGG	^{7}LiD, ^{6}LiH	Longiudinal	10.6 GeV

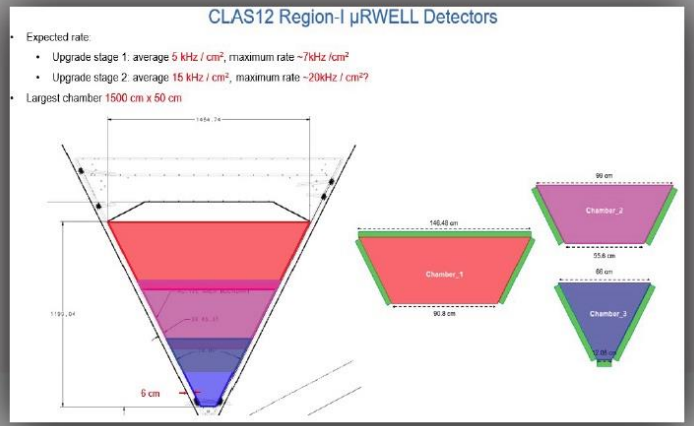
Time of flight



Ring-imaging Cherenkov

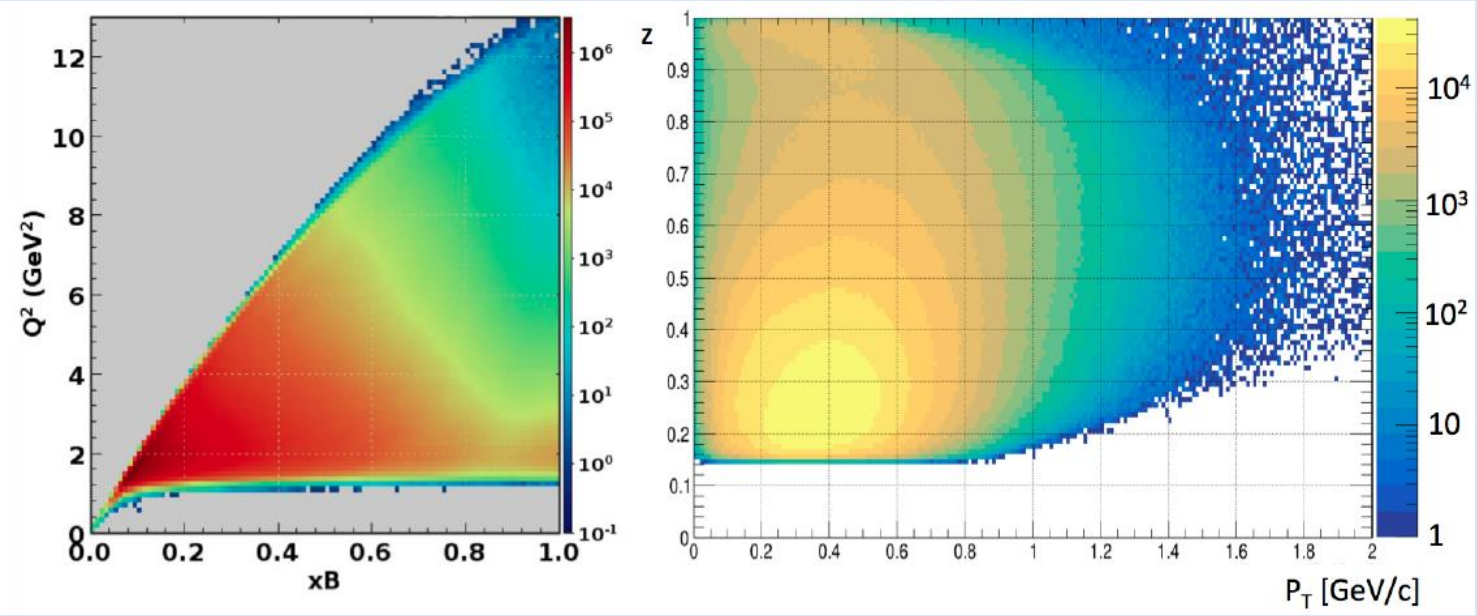


Luminosity upgrade Stage-1: 2×10^{35} cm^{-2}s^{-1} 2 years
Stage-2: $> 10^{37}$ cm^{-2}s^{-1} 5-8 years



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)

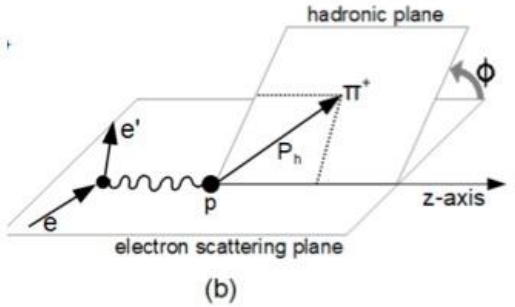


CLAS12 proton data (RGA)

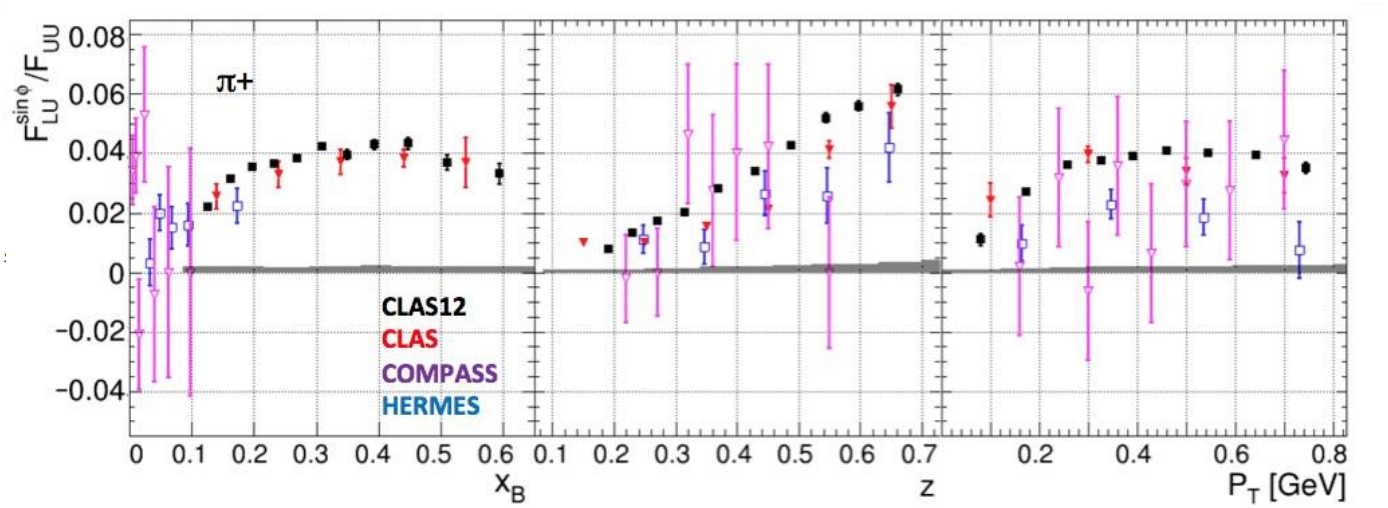
S. Diehl et al., e-Print: 2101.03544

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(x_B e H_1^{\perp} + \frac{M_h}{M} f_1 \frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{h}\cdot P_T}{M}\left(x_B g^{\perp} D_1 + \frac{M_h}{M} h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

86.9 ± 2.6 %



$$A_{LU} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$



RGH approved with NH_3 target by PAC 53 - 2025

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	100 + 25
C12-12-009	H. Avakian	Measurement of transversity with di-hadron production in SIDIS with a transversely polarized target	A	100 + 25
C12-12-010	L. Elauadrhiri	Deeply Virtual Compton scattering at 11 GeV with transversely polarized target using the CLAS12 detector	A	100 + 25
C12-11-111A	H. Avakian	Measurements of Single Spin Asymmetries in exclusive production of hadrons with RGH transversely polarized target		100 + 25

Access to unique observables in

- SIDIS hadron
- SIDIS di-hadron
- DVCS
- DVMP

Gather unprecedented information on

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

HD-ice: ruled out after beam tests at UITF

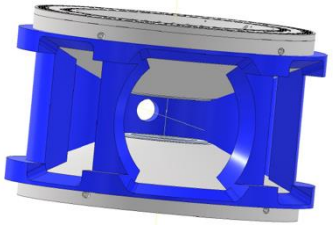
NH_3: Viable solution to prioritize physics (2-3 yr)

Consolidated dynamically polarized 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)

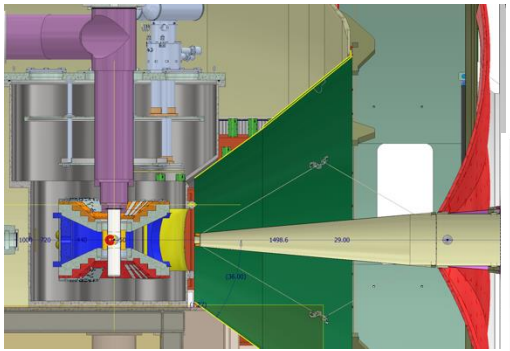
Magnet



5T dipole acceptance:

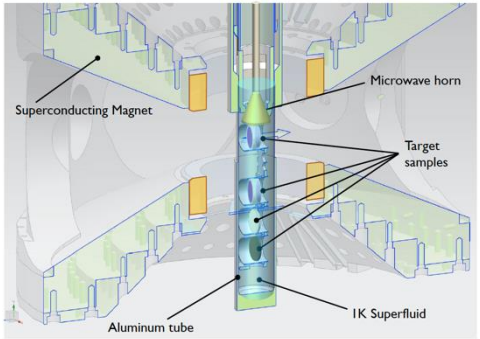
$\pm 25^{o}$ vertical

$\pm 70^{o}$ horizontal

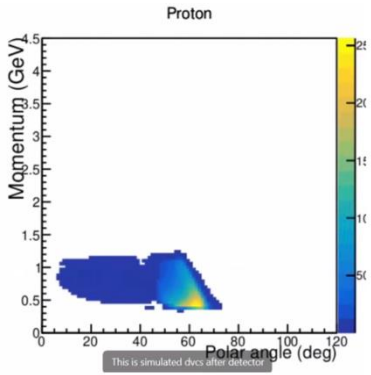


Target cryostat in front of CLAS12

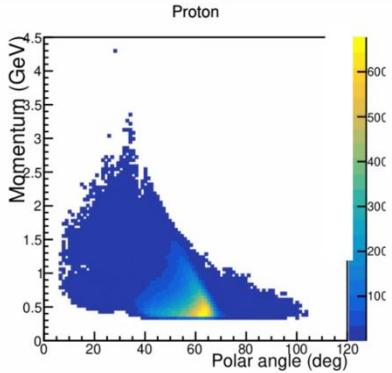
Target ladder details



RGH (MC)



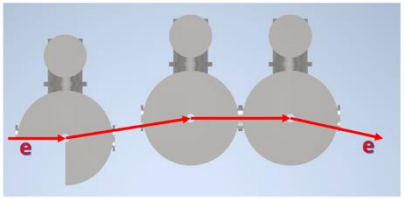
RGA (data)



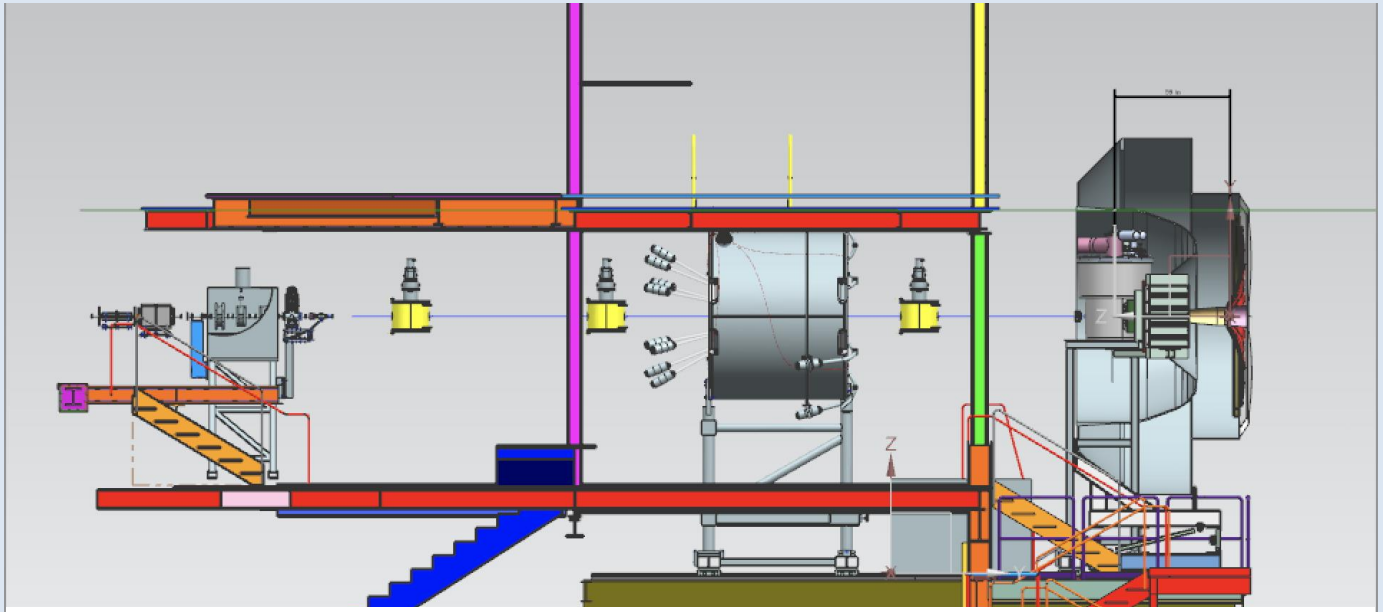
Based on

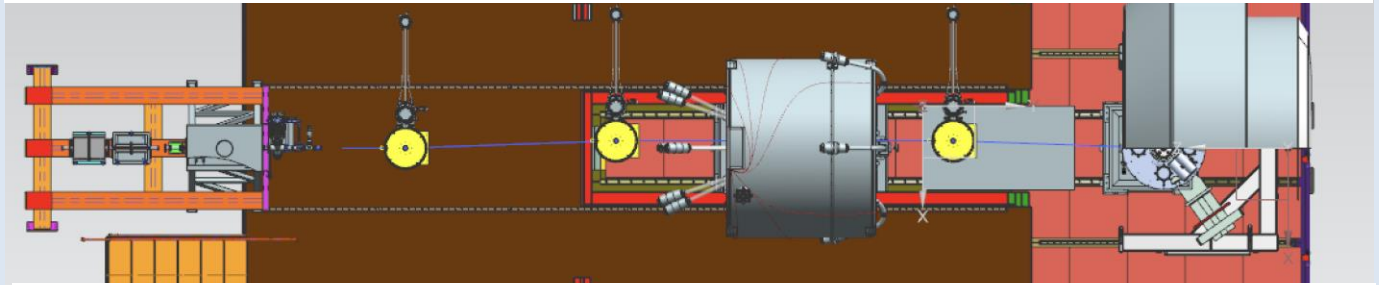
existing 0.7 cm raster

commercial 7.5T magnets



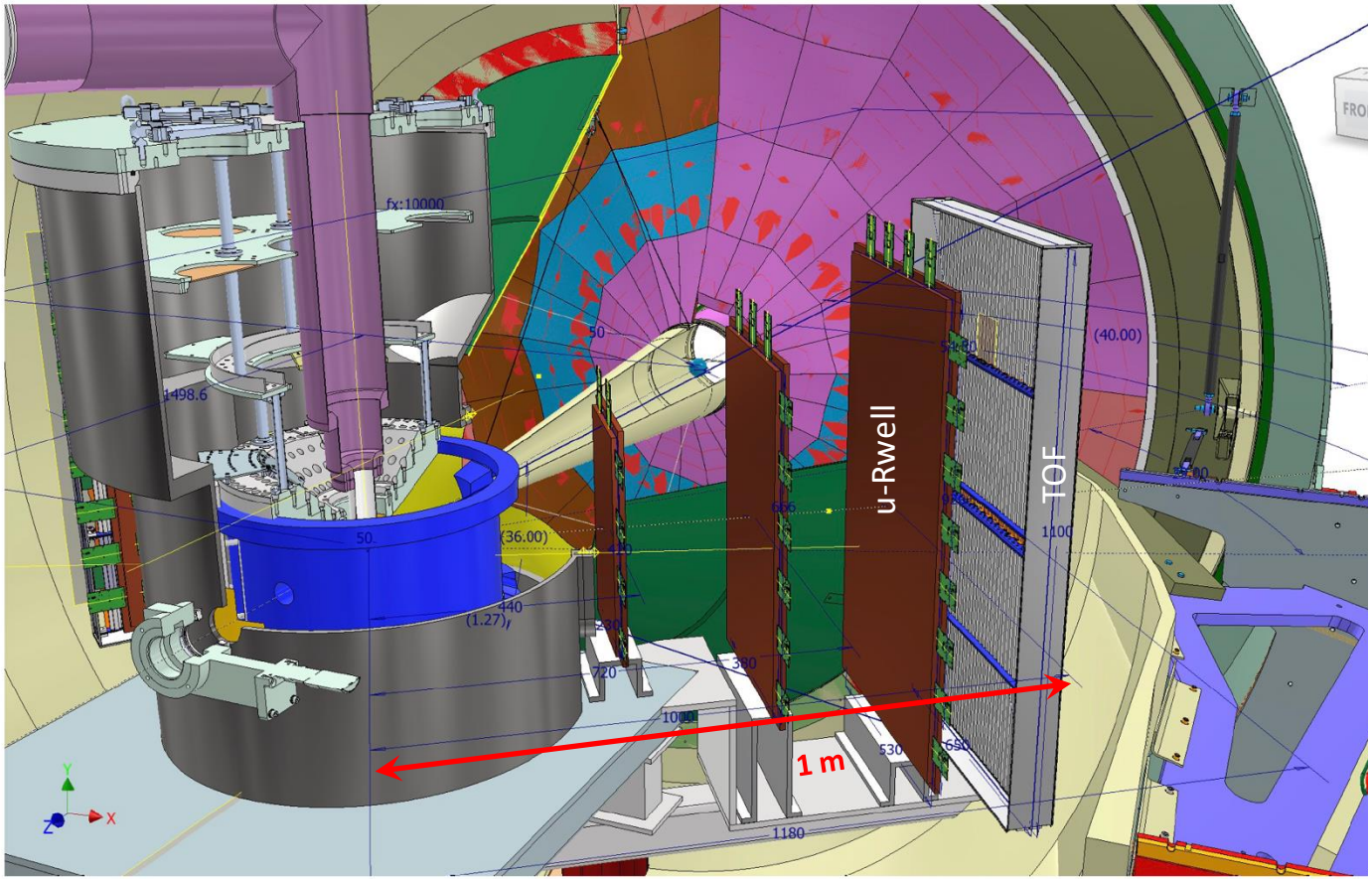
- ✓ space
- ✓ synchrotron radiation
- ✓ beam rastering



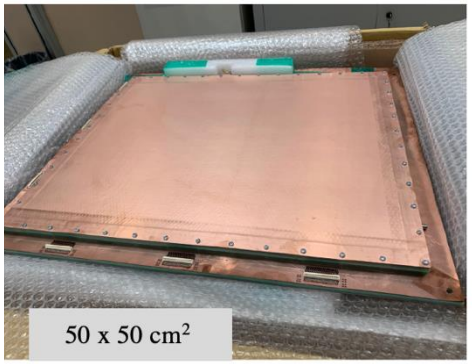


Beam pipe + 1 cm lead in the proper locations suppress synchrotron radiation to a negligible level

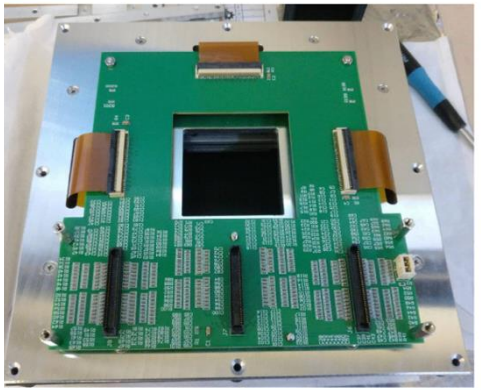
New recoil detector to cover the optimized target magnet acceptance. R&D expected to be completed in 2027.



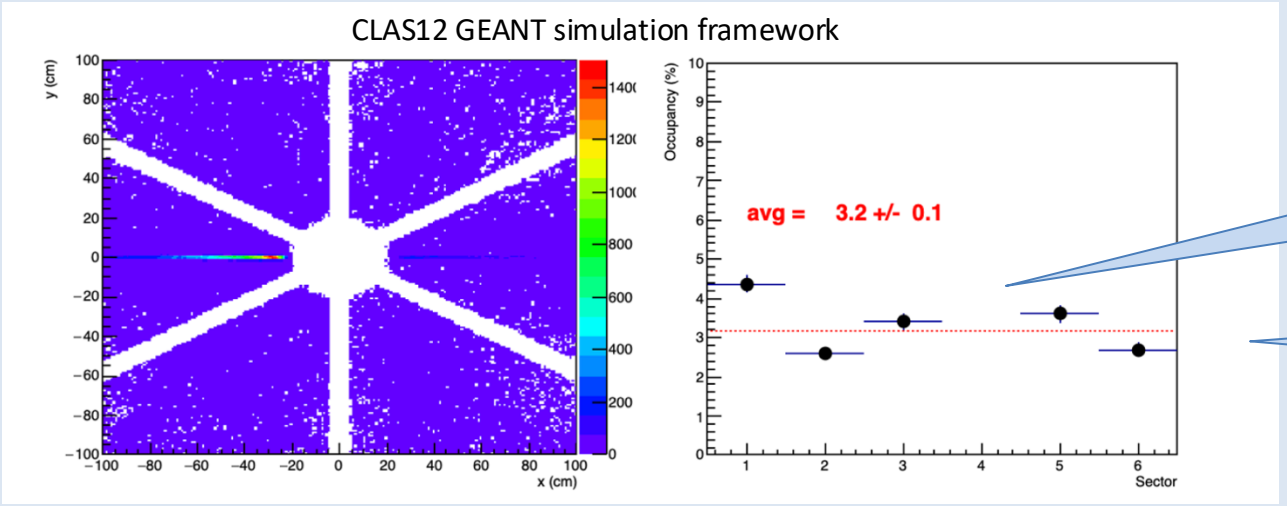
μ-Rwell tracking



Scintillator + SiPM TOF



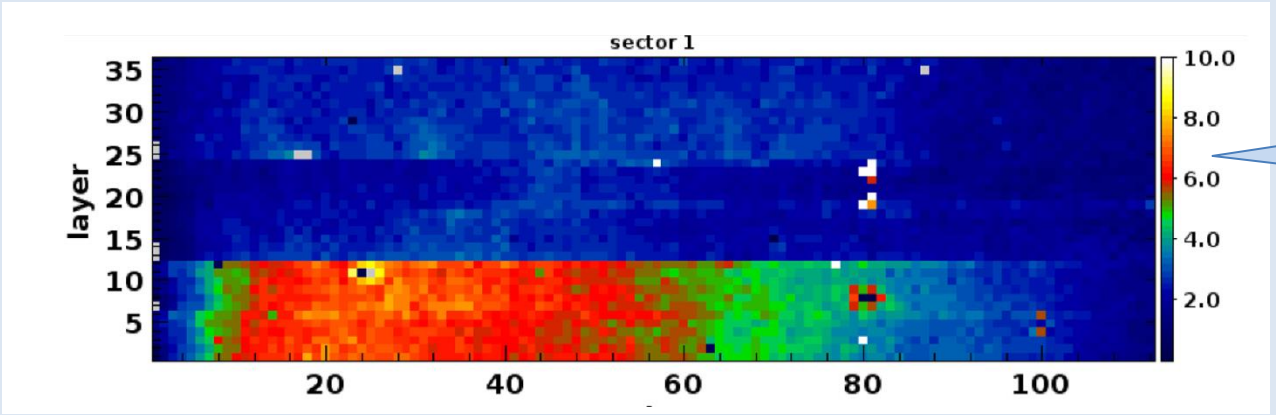
Geant Simulation: DC Occupancy



RGH MC (NH_3)

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

x2 with CLAS12 gate



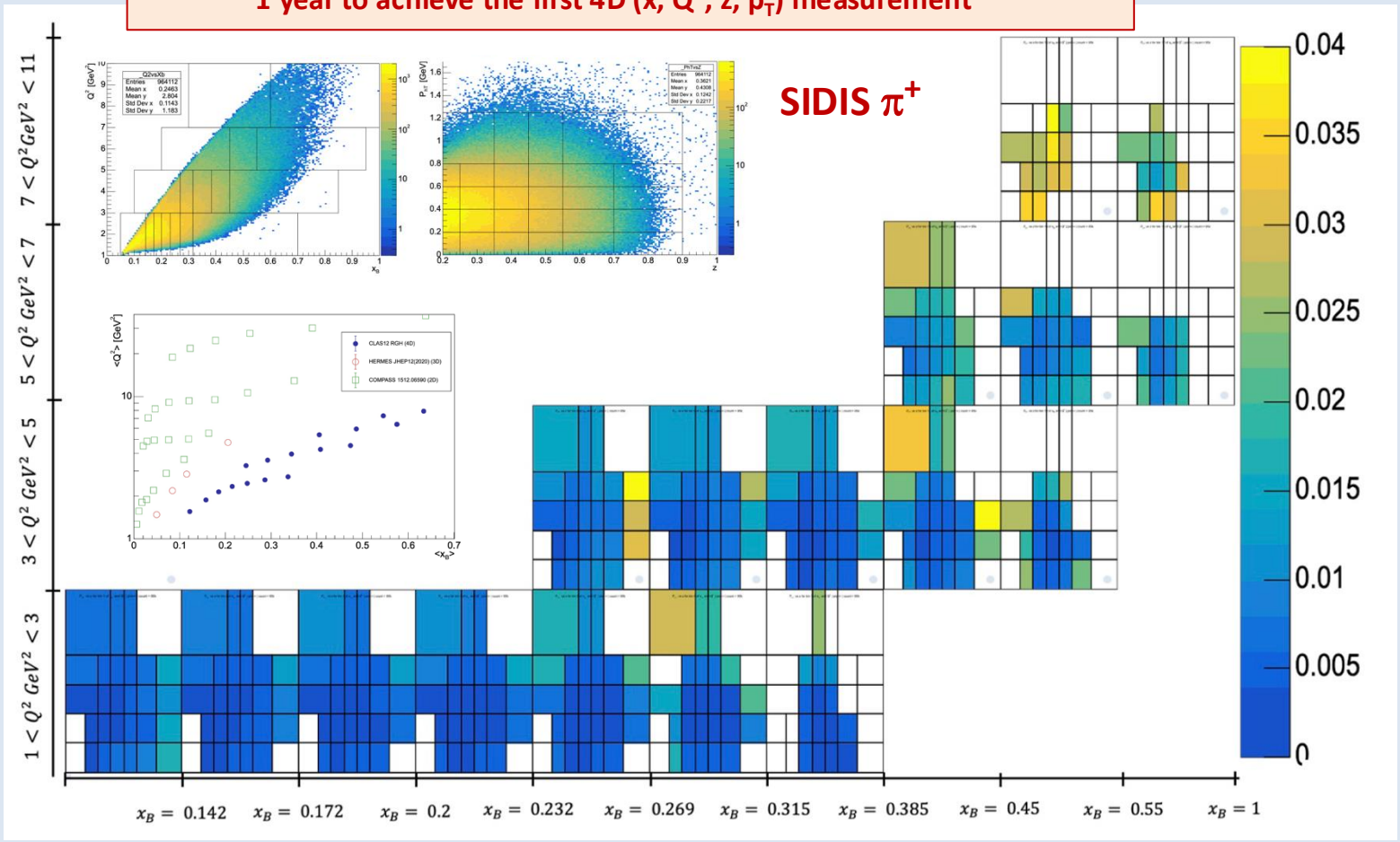
RGC DATA (NH_3)

Present performance*

Typical DC occupancy measured at CLAS12

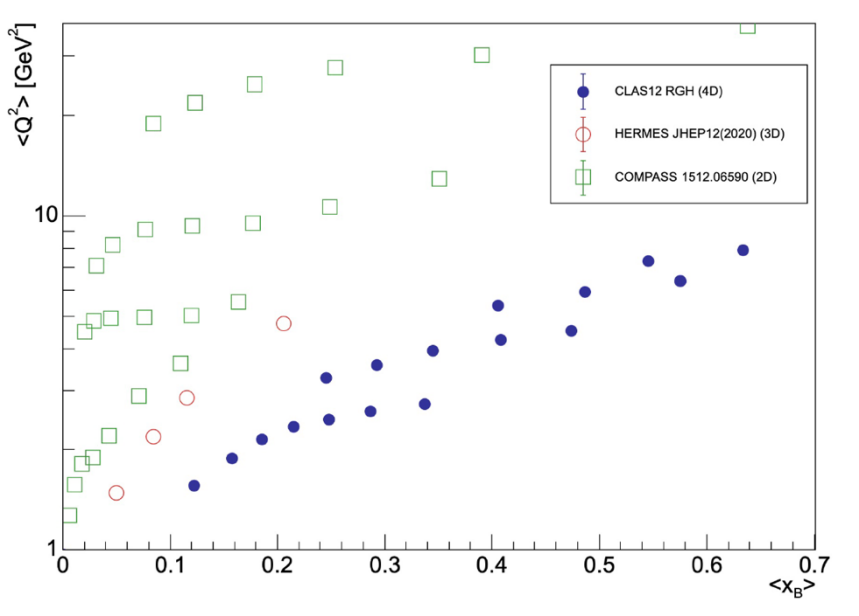
*No high-lumi

~ 1 year to achieve the first 4D (x, Q^2, z, p_T) measurement

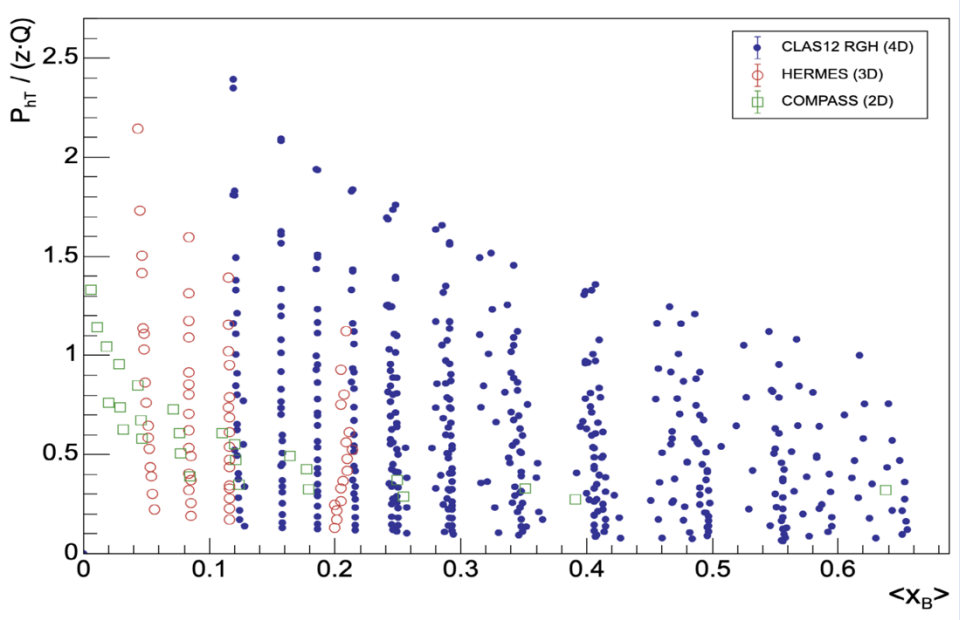


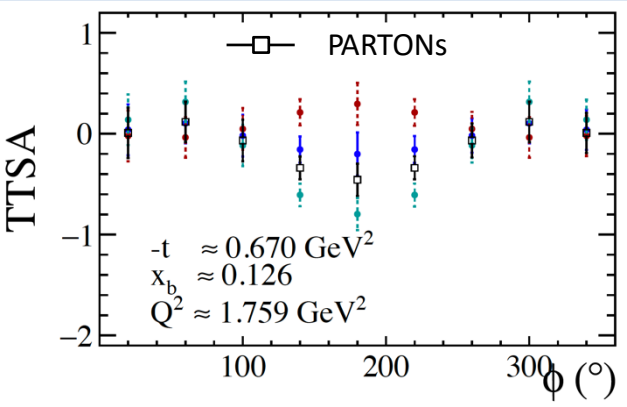
~ 1 year to achieve a broad kinematic coverage in an unexplored valence regime

Fully differential analysis over Q^2
in between HERMES and COMPASS



Wide span over conventional parameters
used to single-out QCD (TMD) regimes



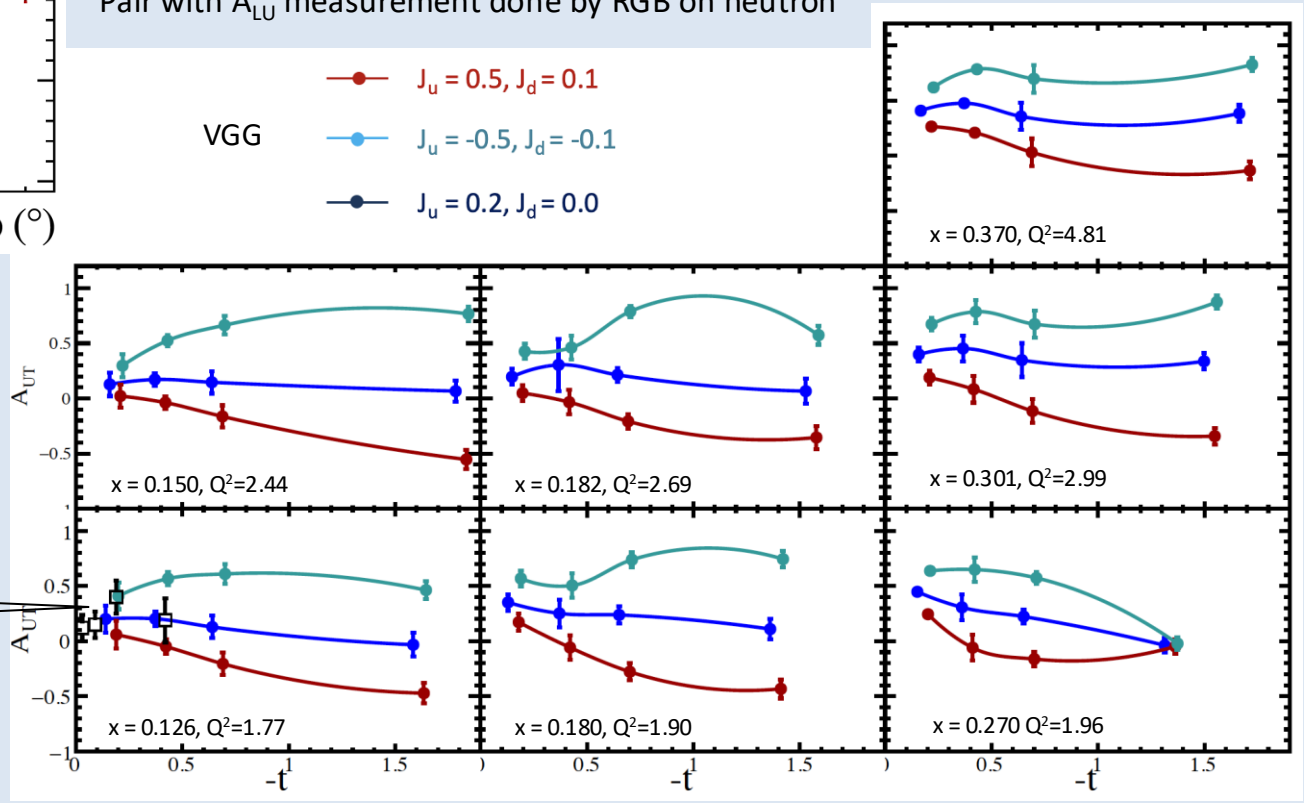


~ 1 year to get unprecedented access to elusive quark angular momenta

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

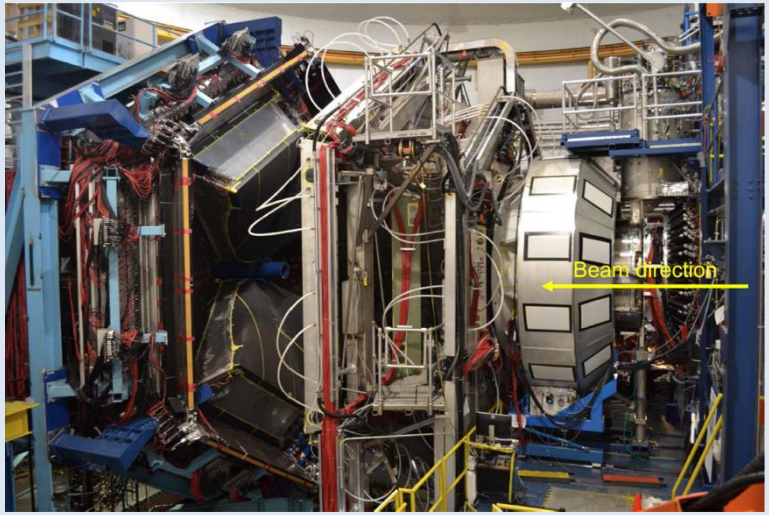
HERMES

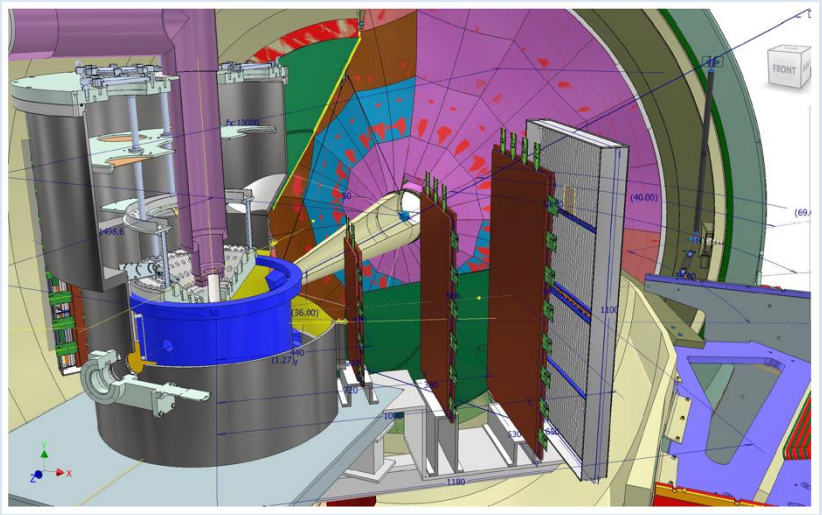


Conclusions

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 approved to achieve unprecedent precision in the valence region





RGH aim: The SIDIS and exclusive measurements will significantly improve our understanding of tensor charge, spin-orbit correlations, and quark angular momentum, complementing past and ongoing CLAS12 studies.