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

Contalbrigo Marco - INFN Ferrara

for RGH and CLAS Collaboration

Jefferson Lab PAC52, July 10 - 2024

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. Elauadrhiri	Deeply Virtual Compton scattering at 11 GeV with transversely polarized target using the CLAS12 detector	A	110

C1 condition: "One has to achieve at least within a factor 2 the figure-of-merit determined by the target design value (I=1 nA, and 60% polarization) and a spin relaxation time of 50 days at 1 nA before the experiments with the transversally polarized target are approved".

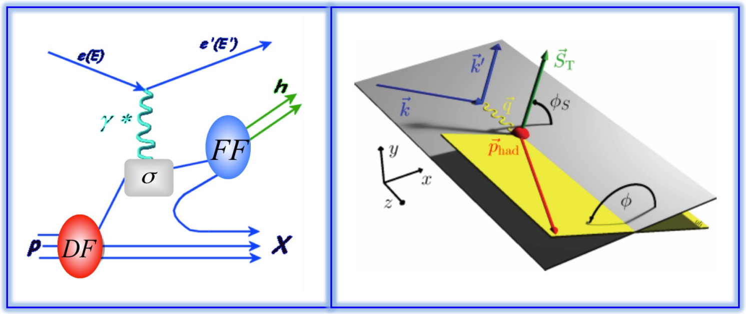
All RGH experiments selected among the high impact JLab measurements PAC42 [2014]

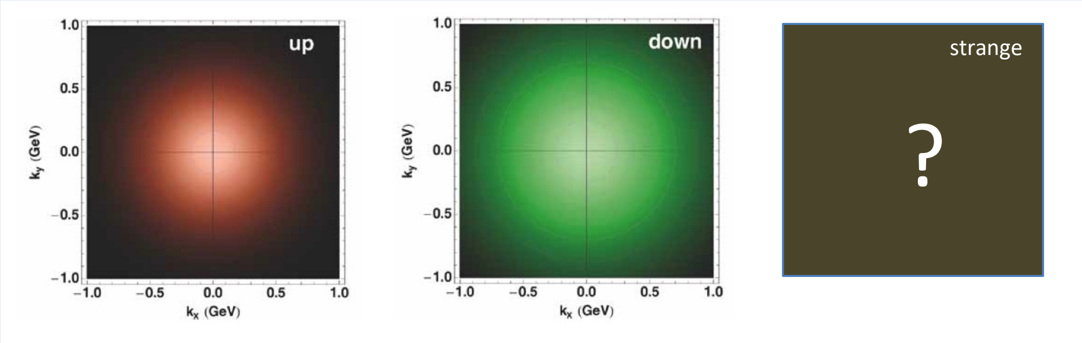
RGH experiment status confirmed at PAC48 in 2020 (during jeopardy process)

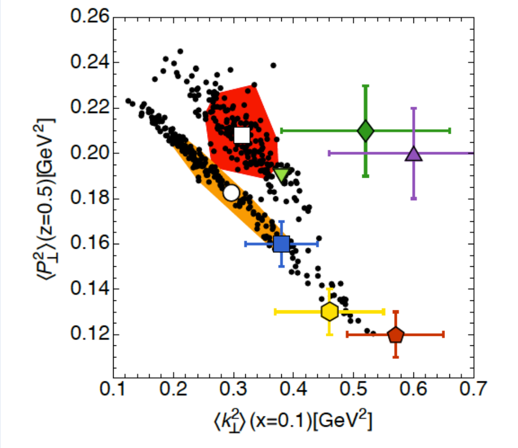
Nucleon 3D Structure: SIDIS

ep → e' h X

$$\langle P_{h\perp}^2 \rangle = z^2 \langle k_T^2 \rangle + \langle p_T^2 \rangle$$



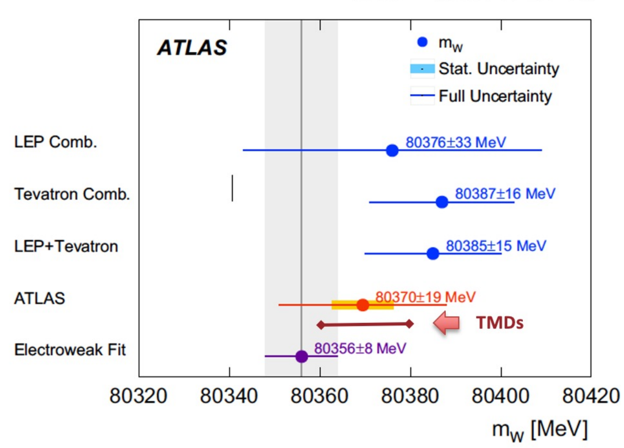




$$m_W = 80370 \pm 7\ (\text{stat.}) \pm 11\ (\text{exp. syst.}) \pm 14\ (\text{mod. syst.})$$

+9 / -6 (TMDs) MeV

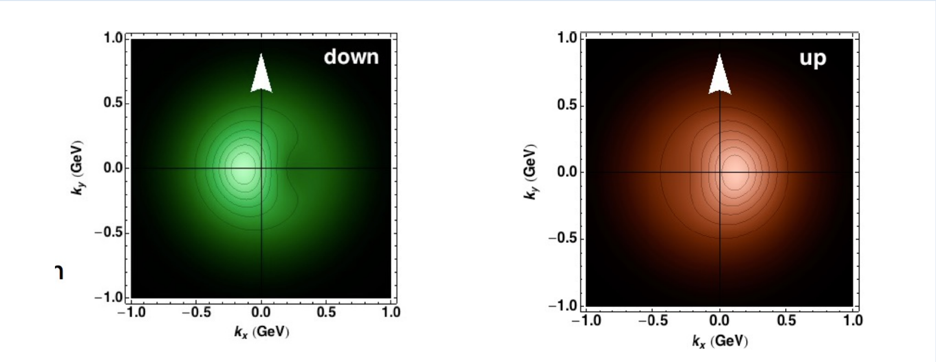
A. Bacchetta++ [arXiv:1807.02101]

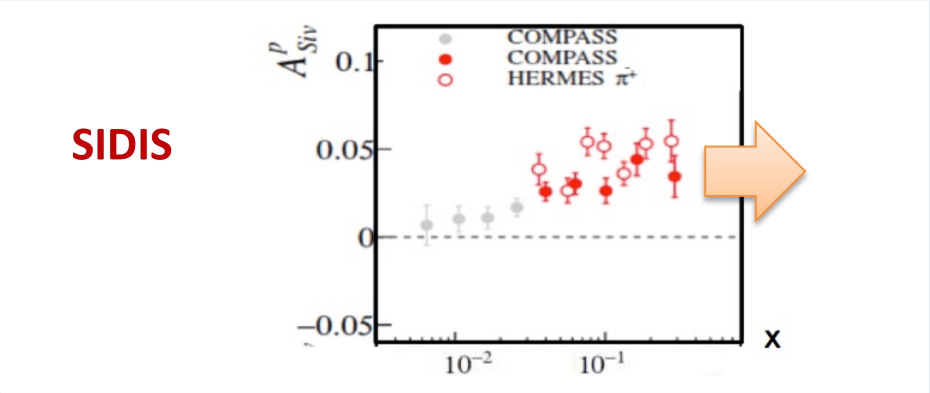


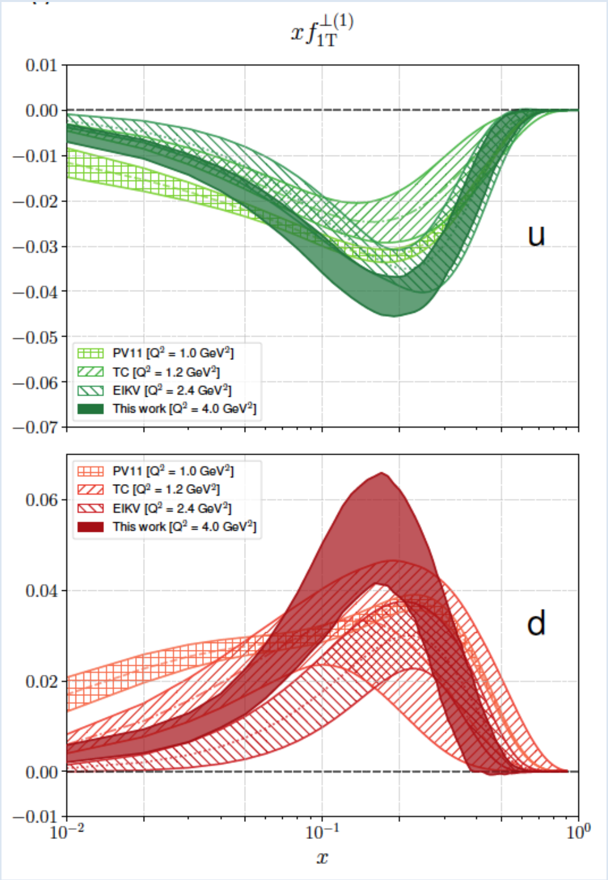
Quark distribution imbalance connected to orbital angular momentum and FSI

$$f_1(x,k_T^2;Q^2) - \frac{k_x}{M} f_{1T}^{\perp}(x,k_T^2;Q^2)$$

A. Bacchetta++ [arXiv: 2004.14278]



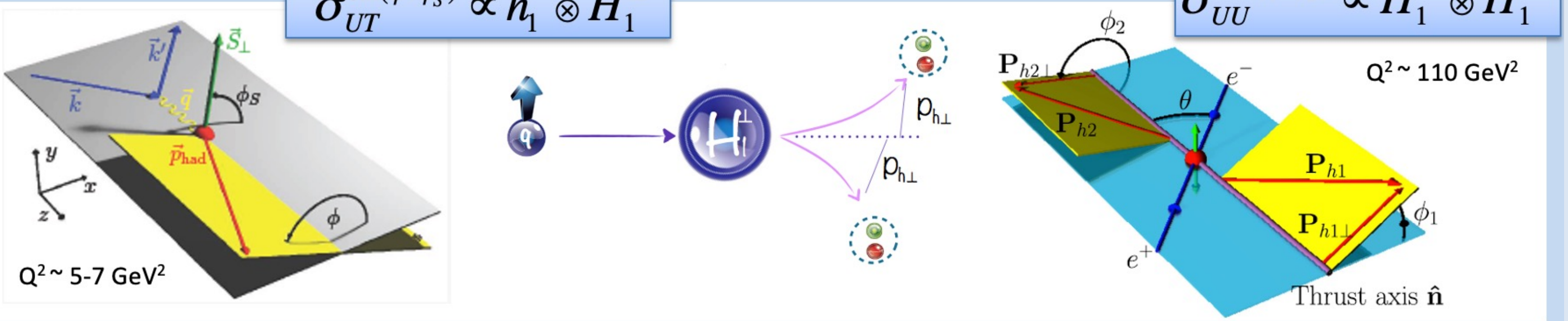




The Collins Spin-Orbit Effect

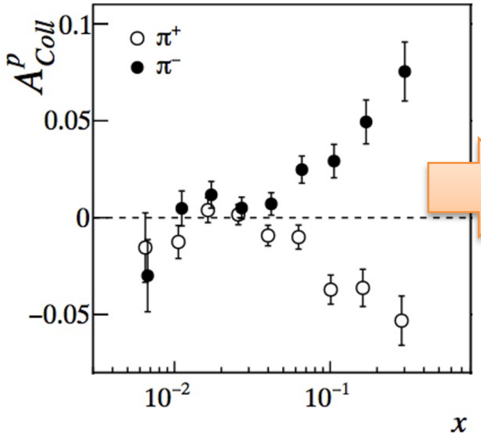
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 \otimes H_1^\perp$$

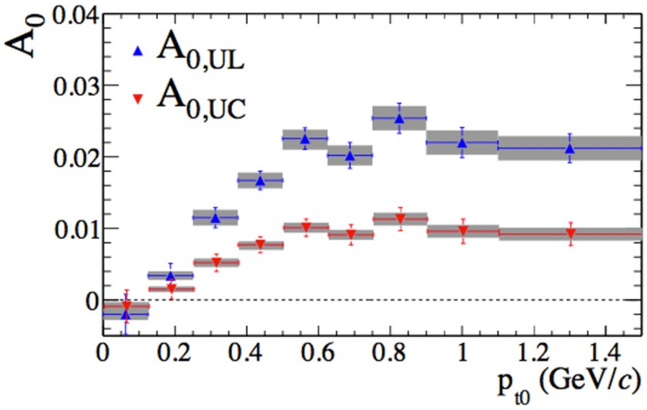
$$\sigma_{UU}^{\sin(\phi_1+\phi_2)} \propto H_1^\perp \otimes H_1^\perp$$



HERMES [arXiv 0408013]
HERMES [arXiv 0906.3918]
COMPASS [arXiv 1005.5609]
COMPASS [arXiv 1408.4405]
Belle [talk at DIS2014]
BESIII [arXiv 1507.06824]
Babar [arXiv 1309.5278]

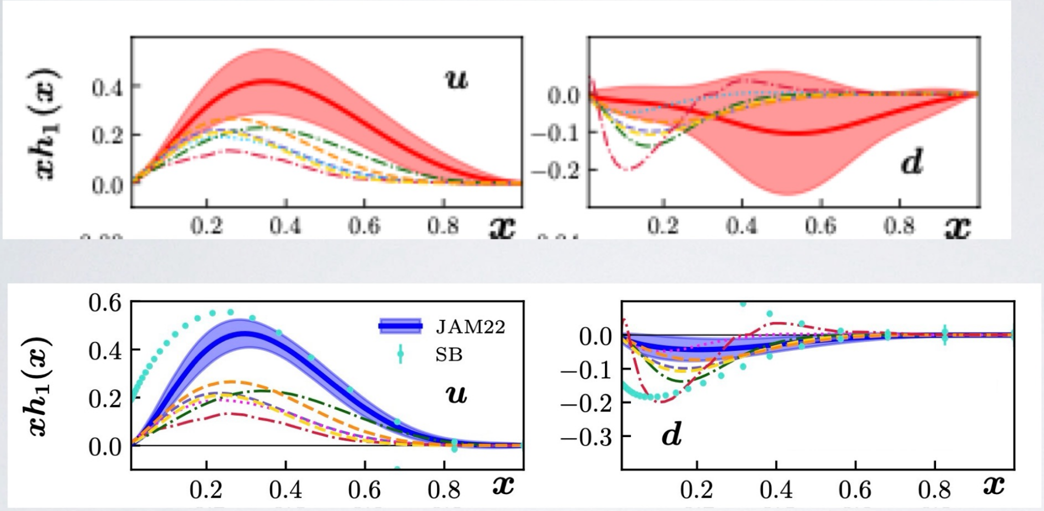
SIDIS





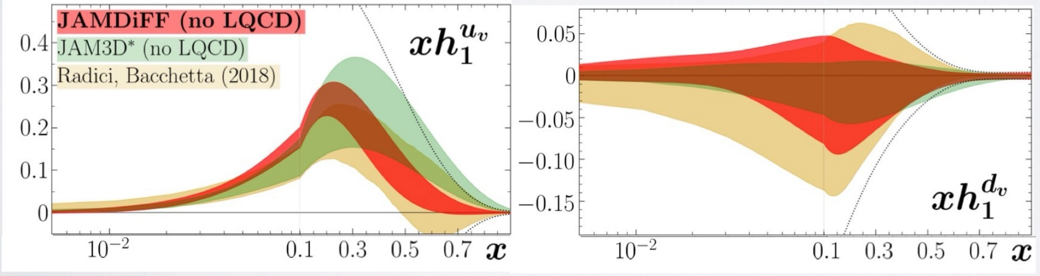
e^+e^- Collision

Collins
(TMDs)

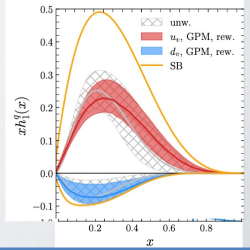


	Soffer bound
JAM20	✘
Anselmino 15	✔
Kang 16	✔
D'Alesio 20	✔
Radici 18	✔
Anselmino 13	✔
Benel 19	✔
JAM22	✔ $\leq \Delta f_1, \Delta g_1$

Di-hadron
(Collinear)



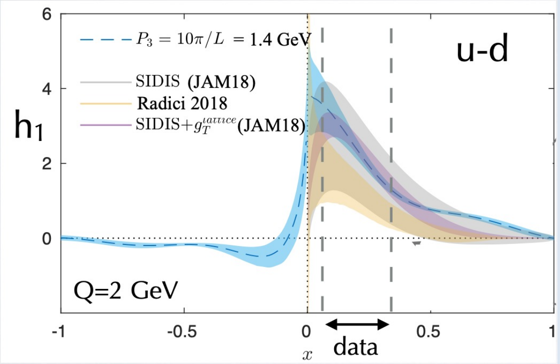
Anselmino 15
Boglione 24 ✔ a posteriori
D'Alesio 20

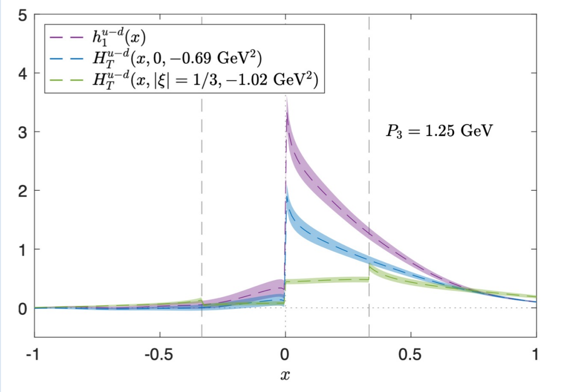


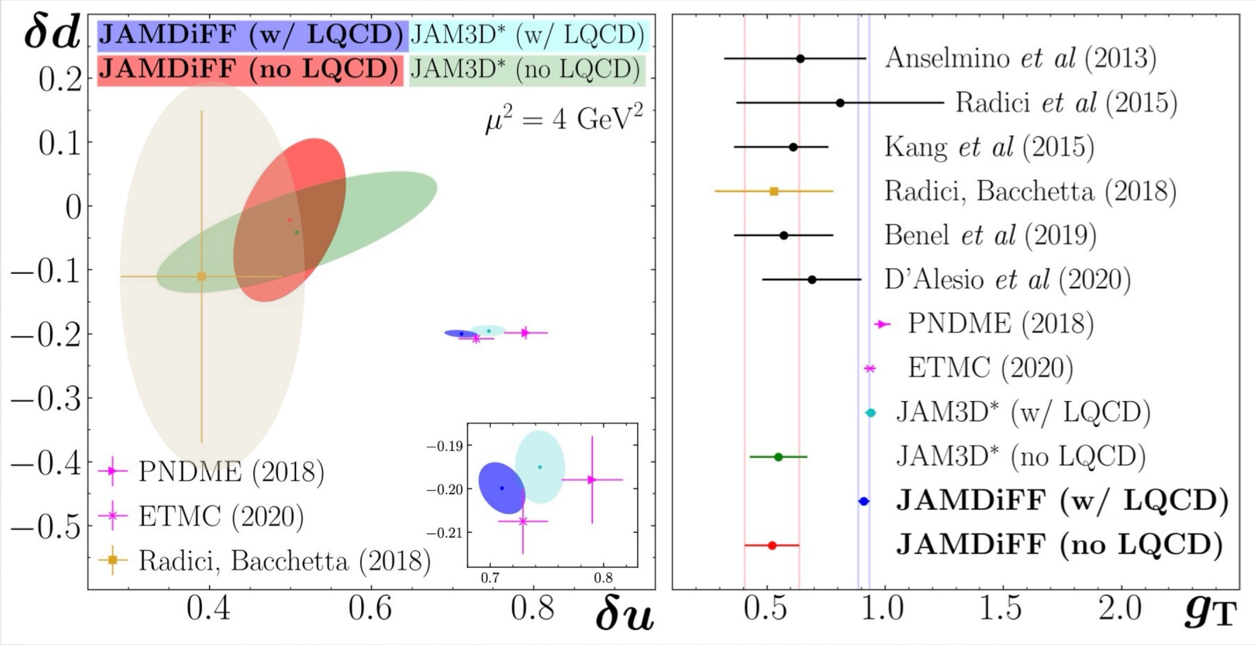
D. Pitonyak, QCD Evolution 24

* JAM3D includes $\bar{u} = -\bar{d}$ w.r.t. JAM22

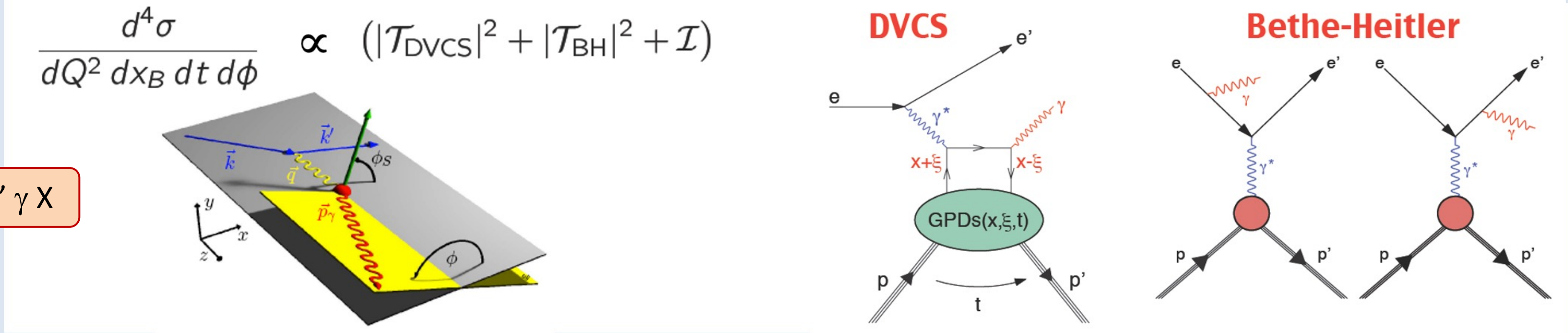
Fundamental quantity connected with BSM phsyics: tensor coupling beyond V-A & EDM violating T and CP
Growing interplay with lattice calculations



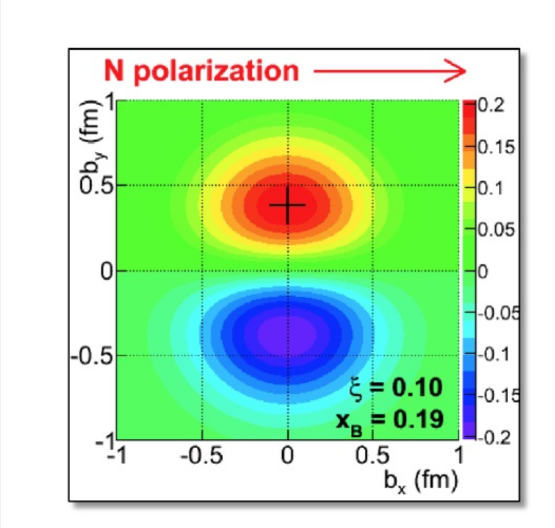




Adapted from D. Pitonyak @ QCD Evolution 24 ep → e' γ X



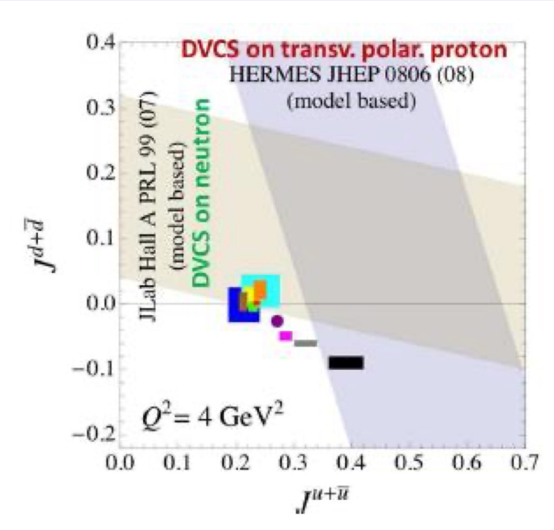
Information on the real and imaginary part of the QCD scattering amplitude



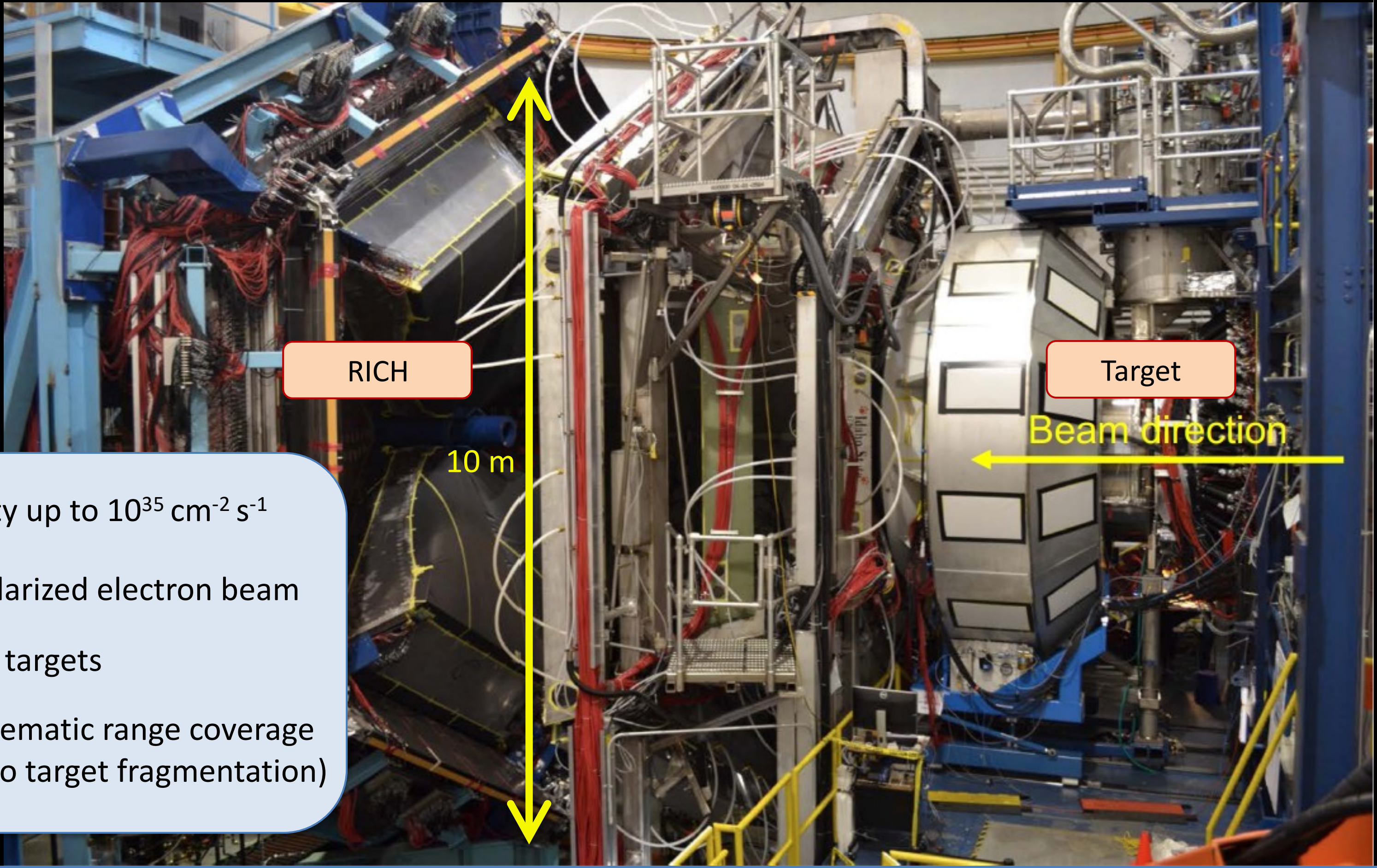
Access to elusive E_p GPD

OAM $L_q = J_q - \frac{1}{2}\Delta\Sigma$ via Ji sum rule

$$J_q = \lim_{t\to 0} \int_{-1}^{1} dx\, x\left[H_q(x,\xi,t) + E_q(x,\xi,t)\right]$$



Large acceptance spectrometer. Operative since 02/18



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

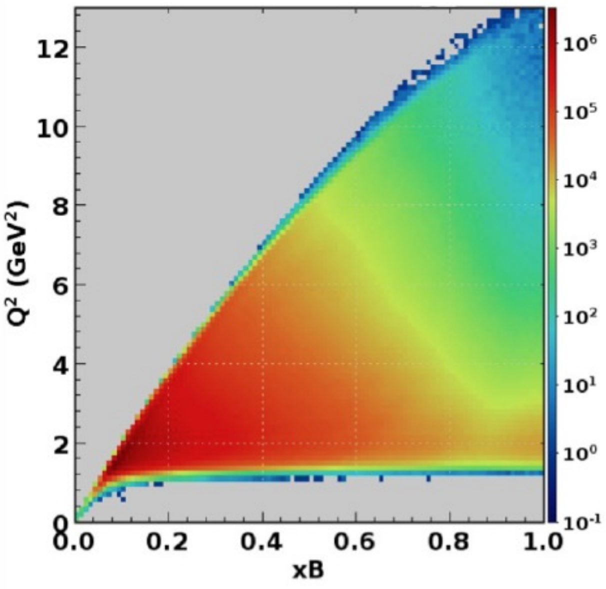
Highly polarized electron beam

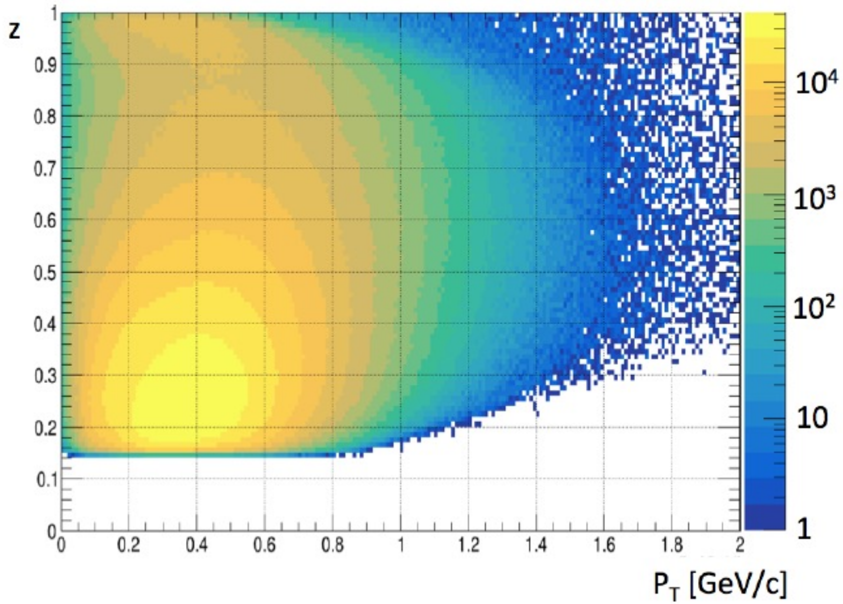
Polarized targets

Broad kinematic range coverage (current to target fragmentation)

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

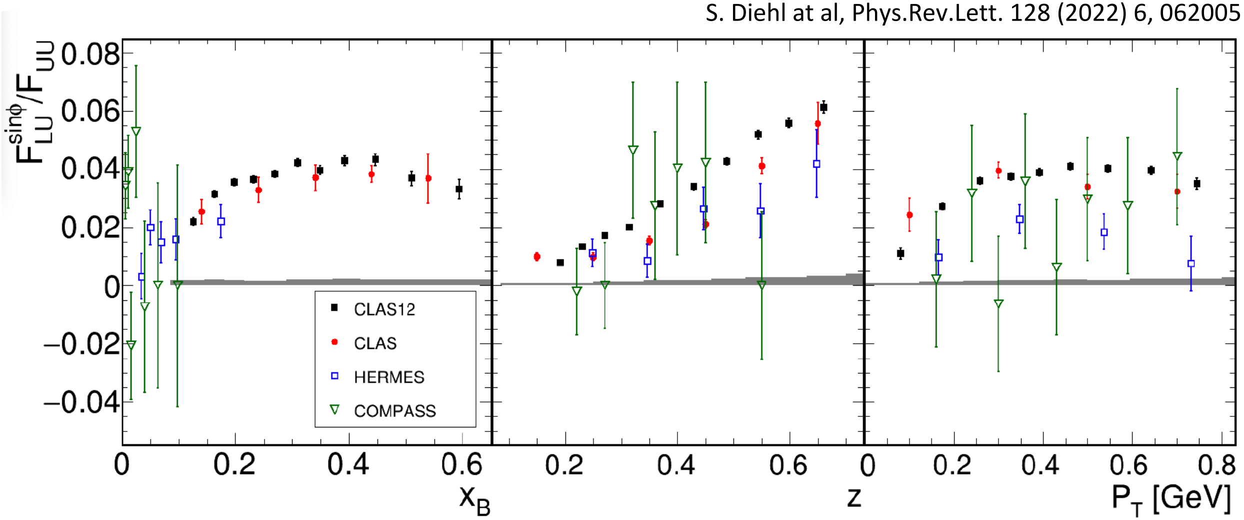
- disentangle kinematical correlations
- verify expected dependences (e.g. in Q^2) and isolate peculiar regimes (e.g. in z)
- study transition regions (e.g. in P_T)





Multidimensional, high precision measurements of beam single spin asymmetries in semi-inclusive π^+ electroproduction off protons in the valence region

S. Diehl at al, Phys.Rev.Lett. 128 (2022) 6, 062005

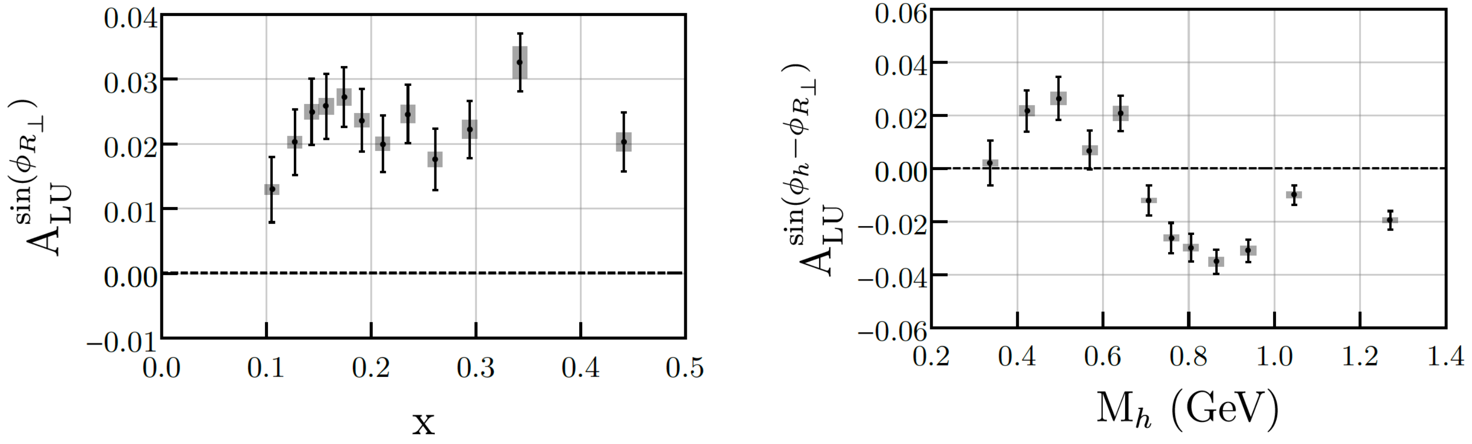


Sensitive to TMDs and the strong-force correlations within the nucleon

With respect the past:
- extended range in the valence region well inside the DIS regime
- superior statistics instrumental for multidimensional study
- comparable wide coverage in z and P_T

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

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

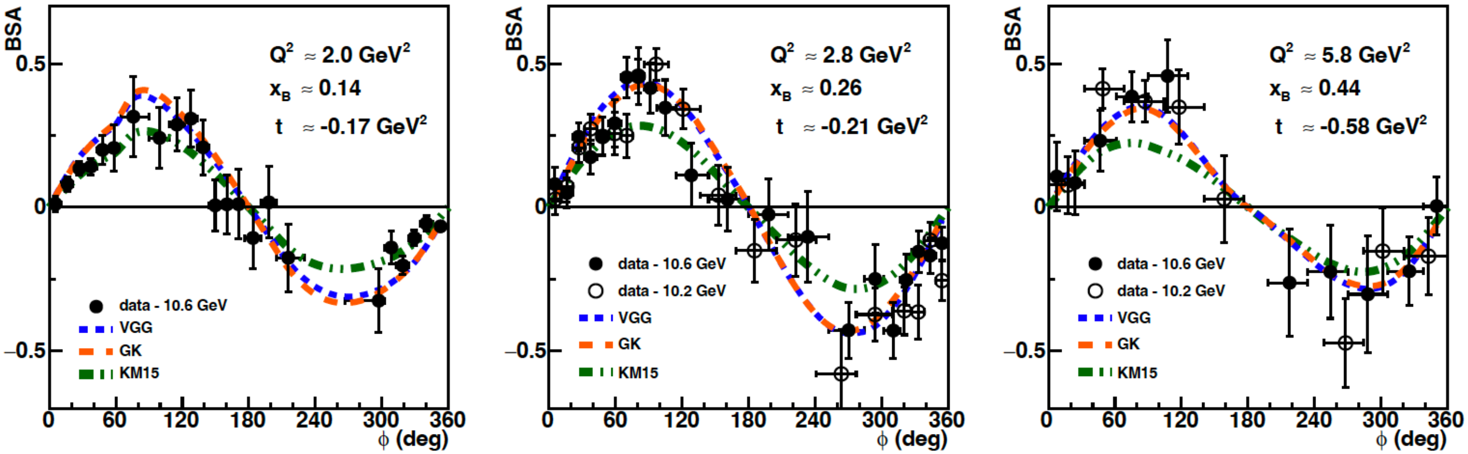


Sensitive to TMDs and the strong-force correlations in hadron formation

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

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

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

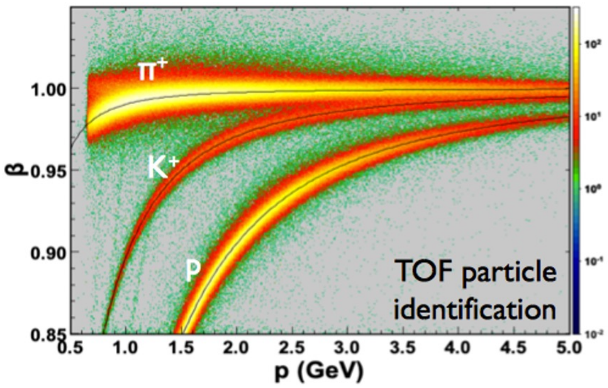


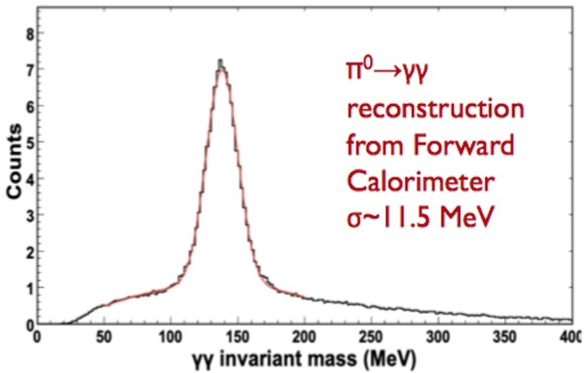
Sensitive to GPDs and the 3D structure of the nucleon

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

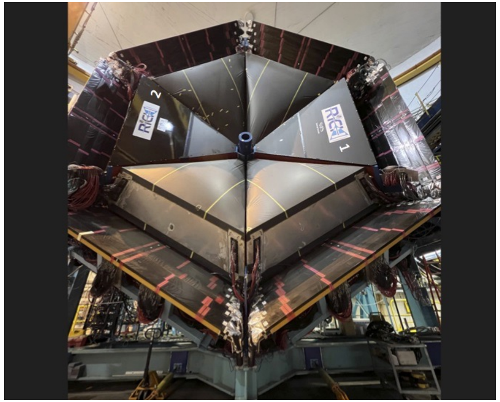
Semi-inclusive physics with unprecedented coverage of valence & flavor sensitivity

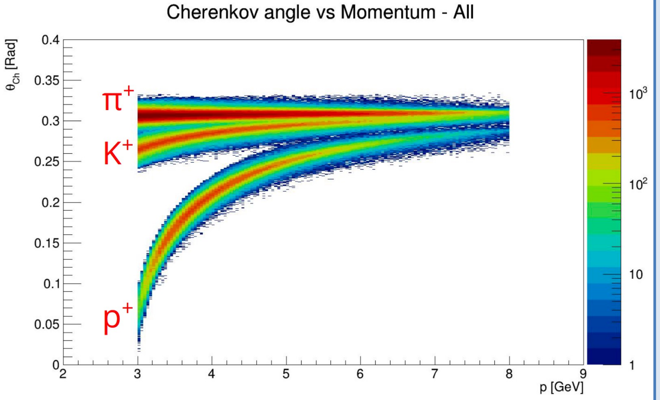
Time-of-flight system

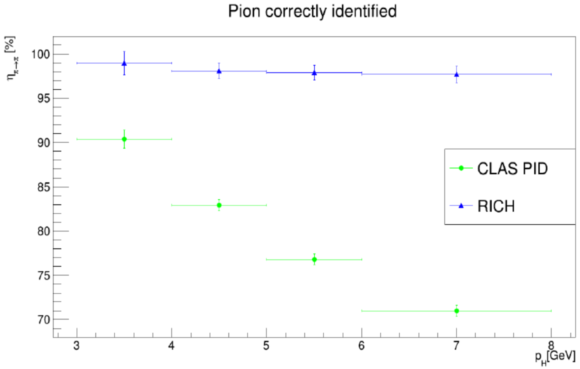


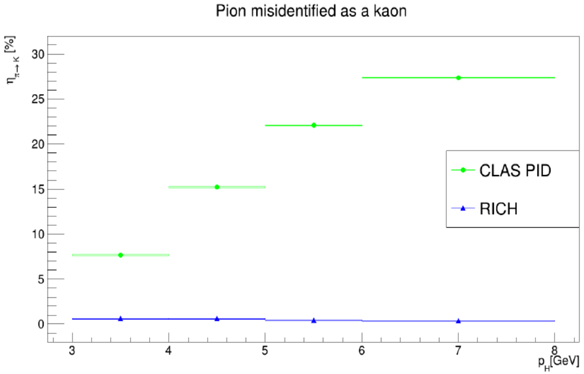


Ring-imaging Cherenkov (completed in 2022)









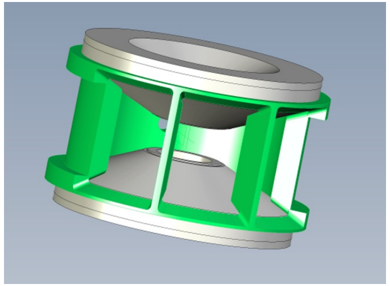
HDice R&D did not achieve RGH specifications

Most viable solution to prioritize physics vs R&D

Consolidated NH_3 technology

Designed based on already successful realizations

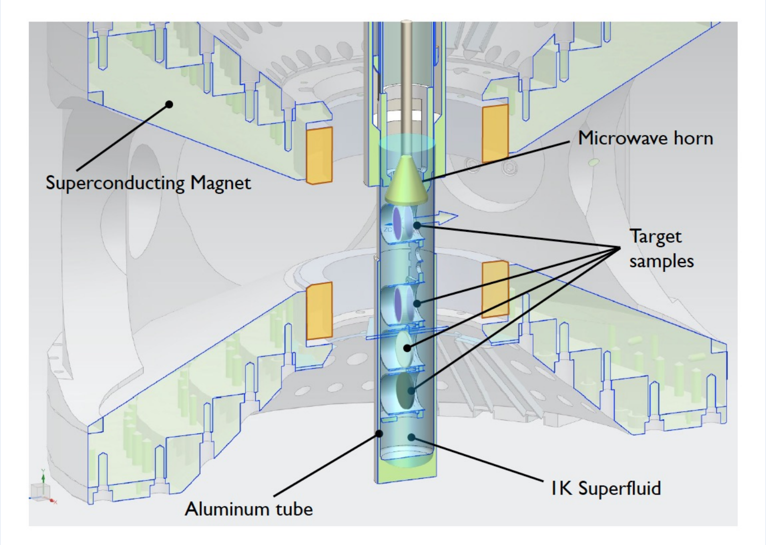
Hall-A G2p-Gep target (copy optimized for HTCC)
Hall-C E12-15-005 magnet (copy optimized for recoil detection)

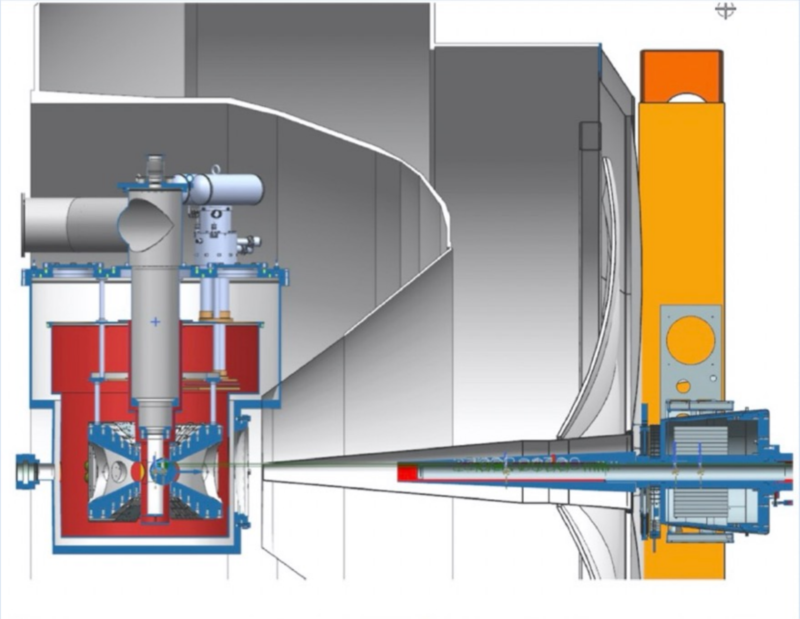


Acceptance:

$\pm 25^{o}$ horizontal

$\pm 60^{o}$ horizontal



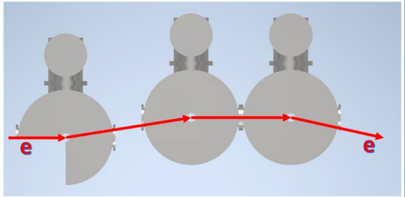


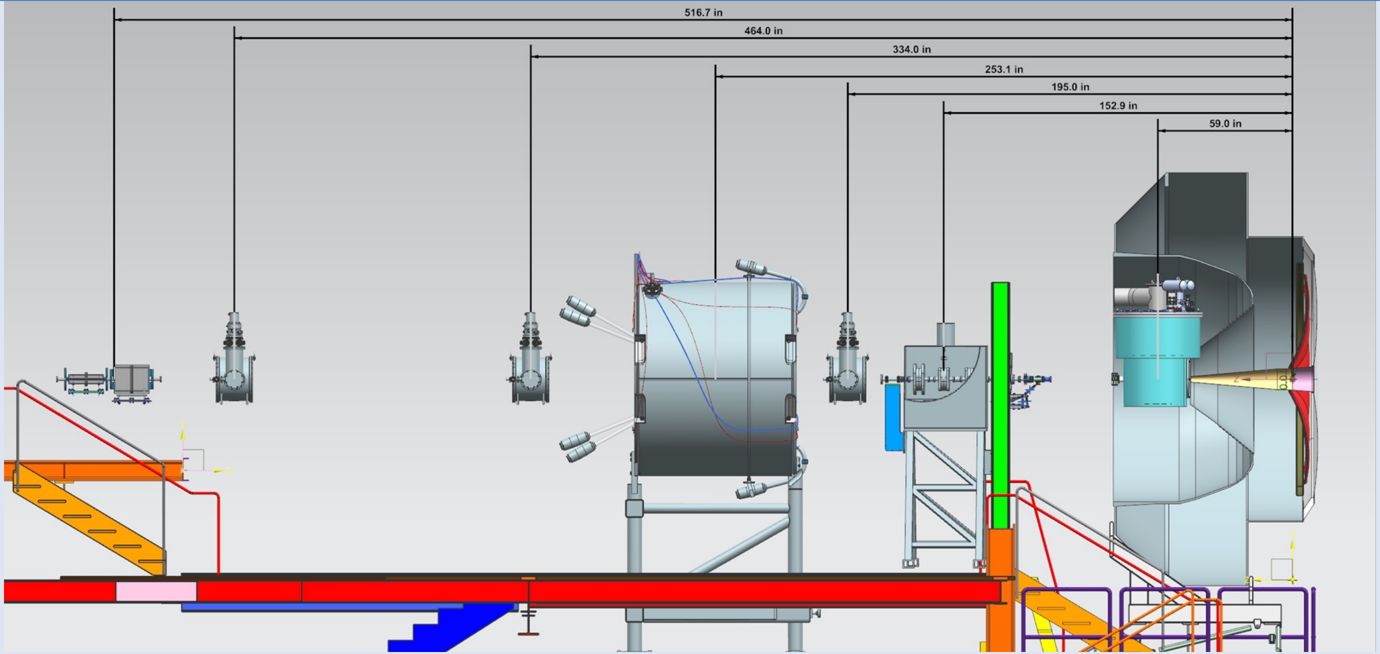
RGH Beam Line

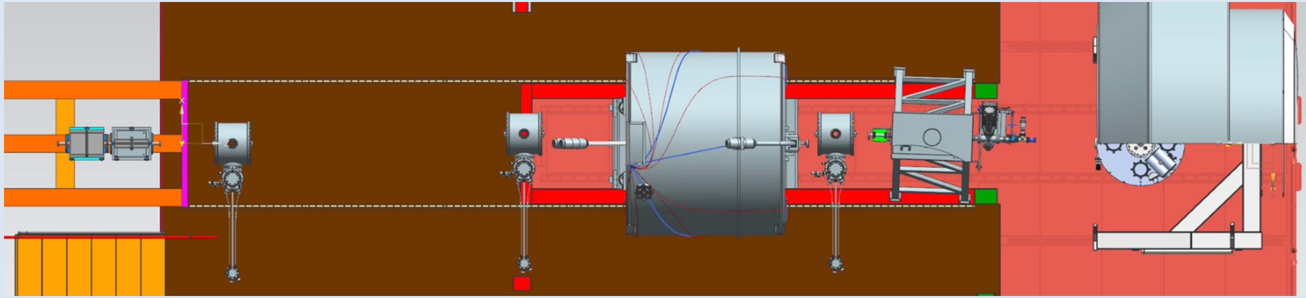
Based on

existing raster

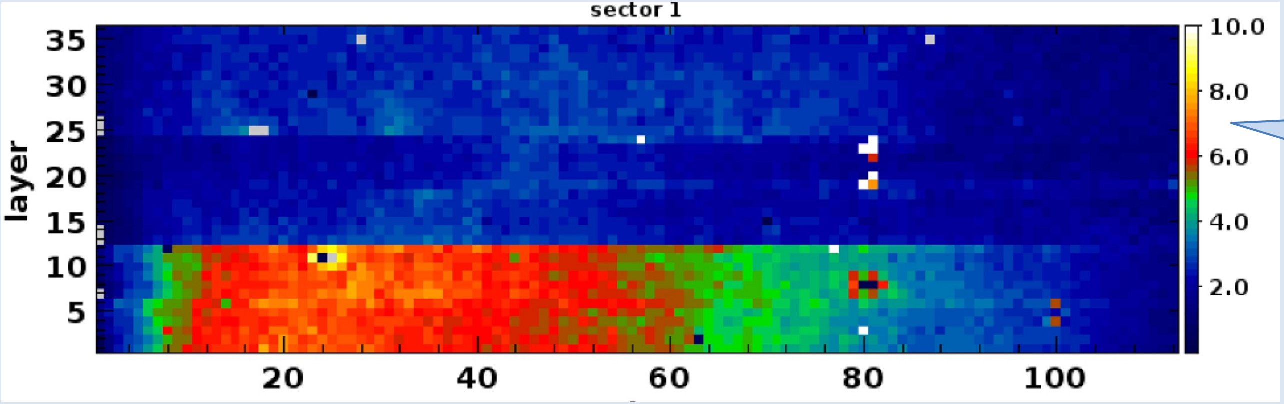
commercial magnets







RGH Background

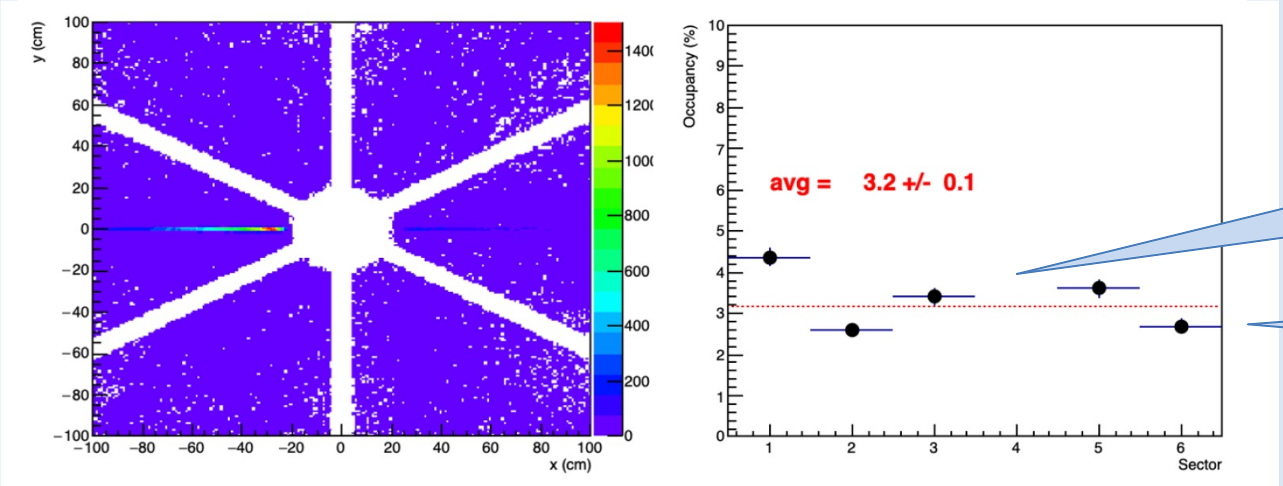


RGC DATA

Present performance*

Typical DC occupancy measured at CLAS12

*No high-lumi



RGH MC

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

x2 with CLAS12 gate

RGH solution is most viable and superior to the conditionally approved one by PAC

PAC stipulated conditions for approval

Quantity	HD	NH_3
$(1\text{-}\tau)$	0.96	0.97
f	1/3	3/17
P	0.41	0.85
I (nA)	1.0	2.0
ρ (g/cc)	0.10	0.87
x (cm)	5.0	1.0
$\mathcal{L} \times 10^{33}$	2.5	5.0
FoM$\times 10^{32}$	0.4	1.1

Conservative estimate

Existing or commercial magnets

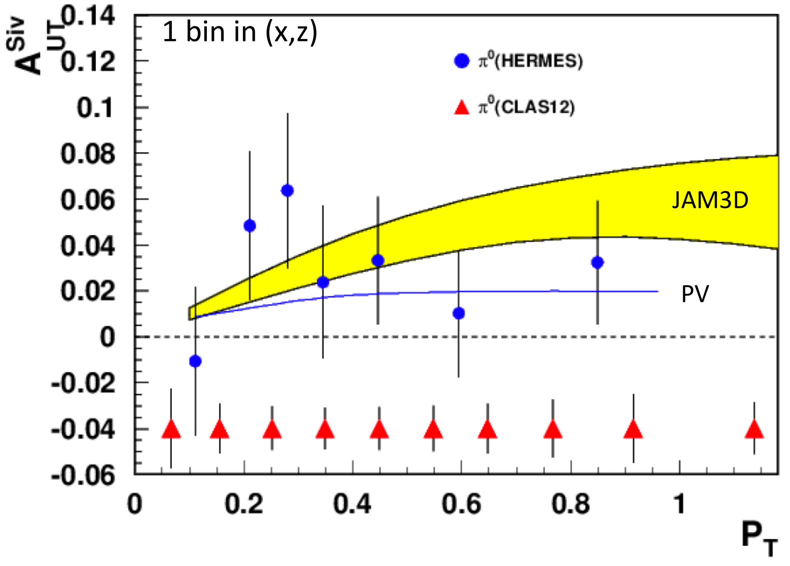
Consolidated target technology

Target design already in use at JLab

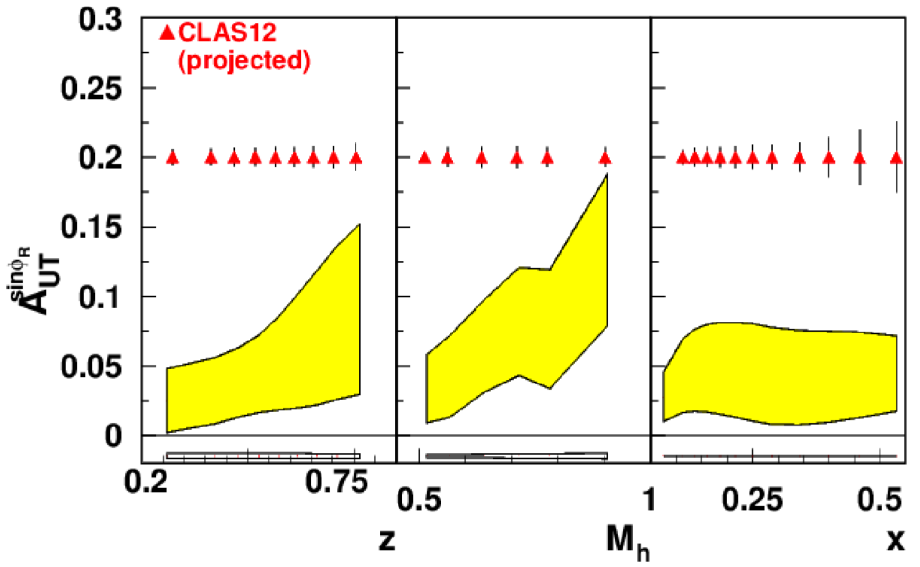
Current CLAS tracking capability

Better than approved FoM (forward phase-space is basically untouched)

Example 1: π^0 provides clean probe
minor VM and γ_L contribution

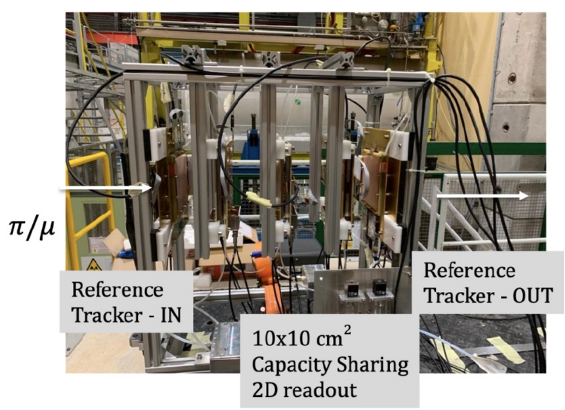


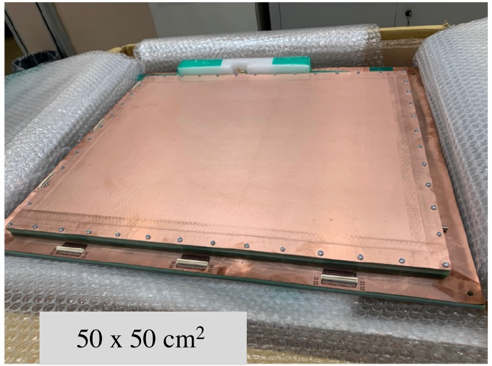
Example 2: di-hadron provides collinear benchmark
validation of TMD formalism

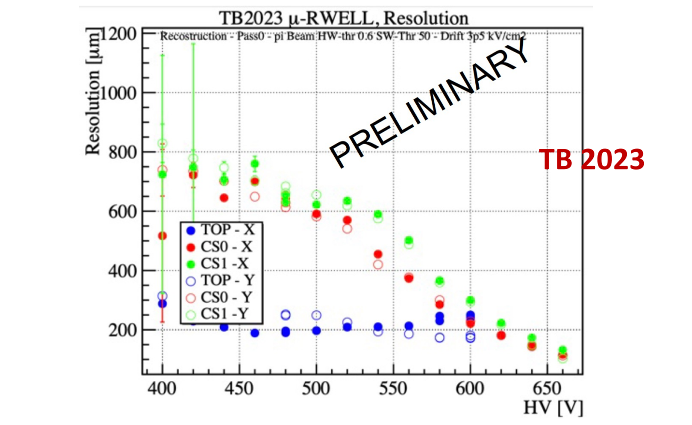


RGH Recoil Detector

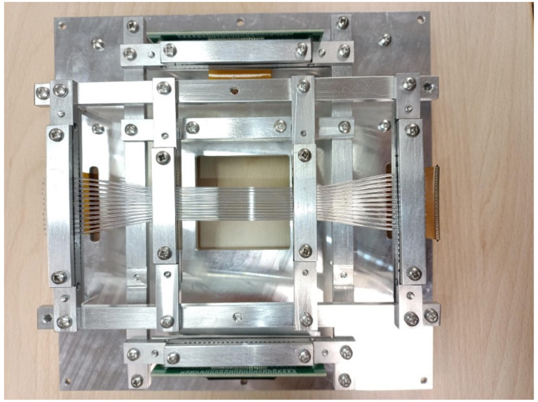
Spatial resolution O(100 μm) with μ-Rwell tecnologyunder development for the CLAS12 high-lumi project

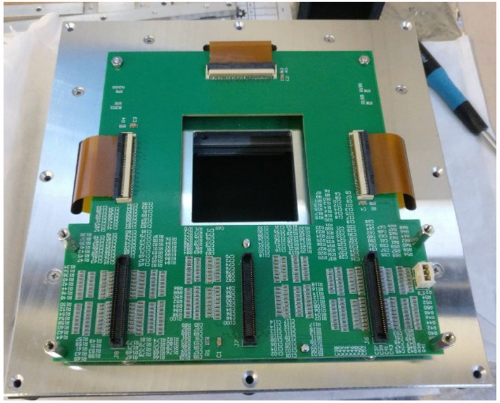


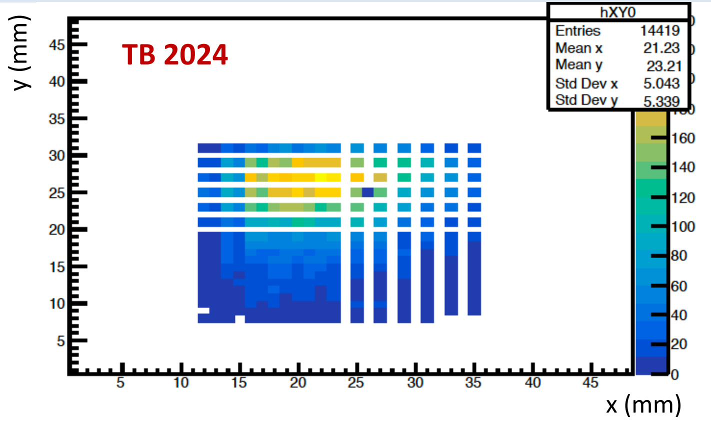




Time resolution O(100 ps) with scintillating fiber tagger in synergy with other (EIC) projects





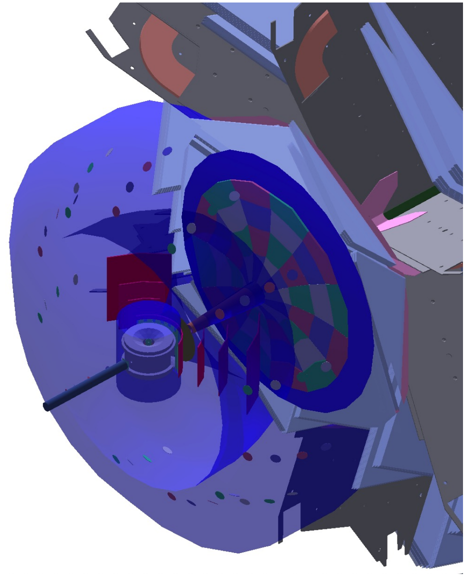


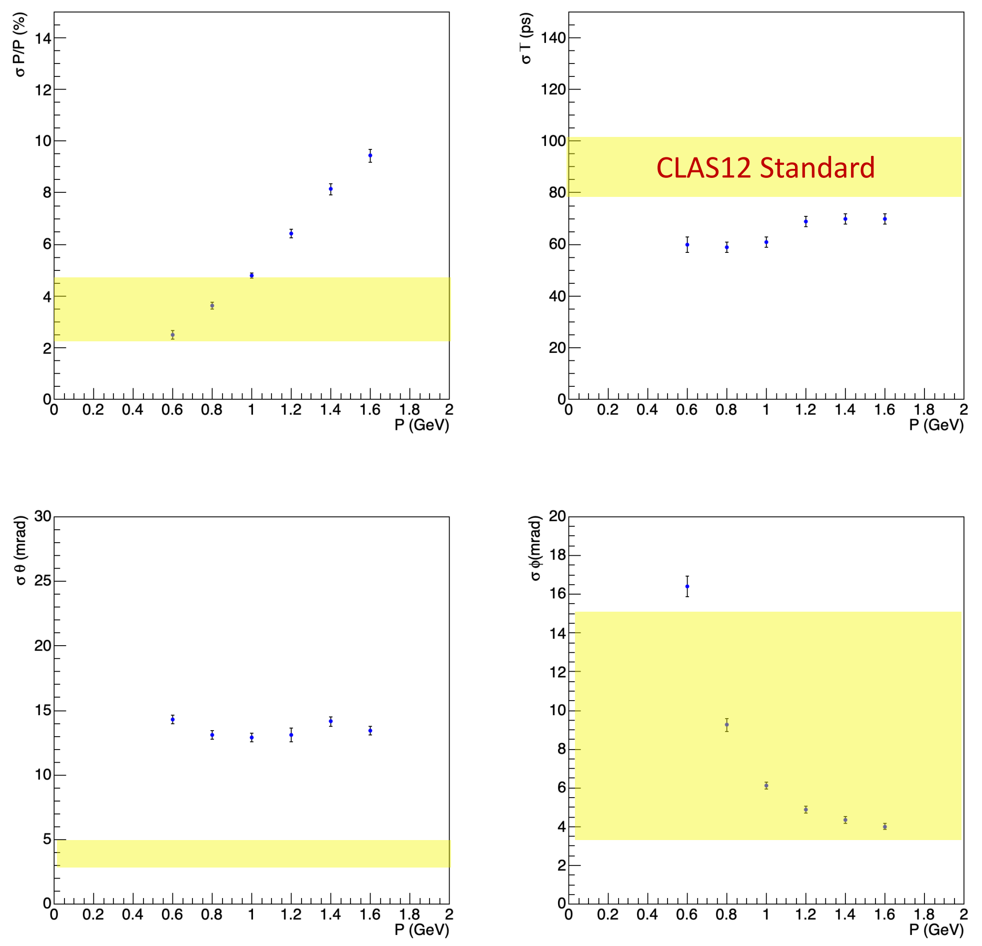
Simulated RGH recoil resolution

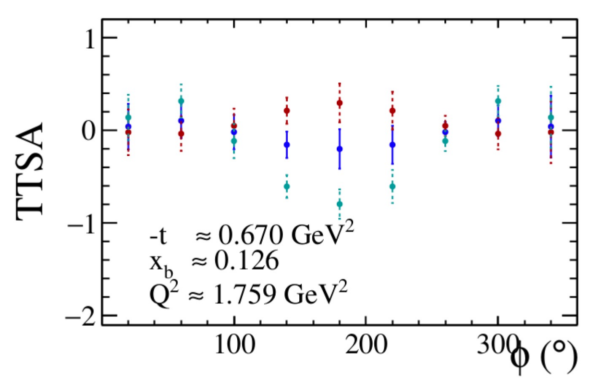
based on ongoing tech. development

and CLAS12 FD tracking resolution

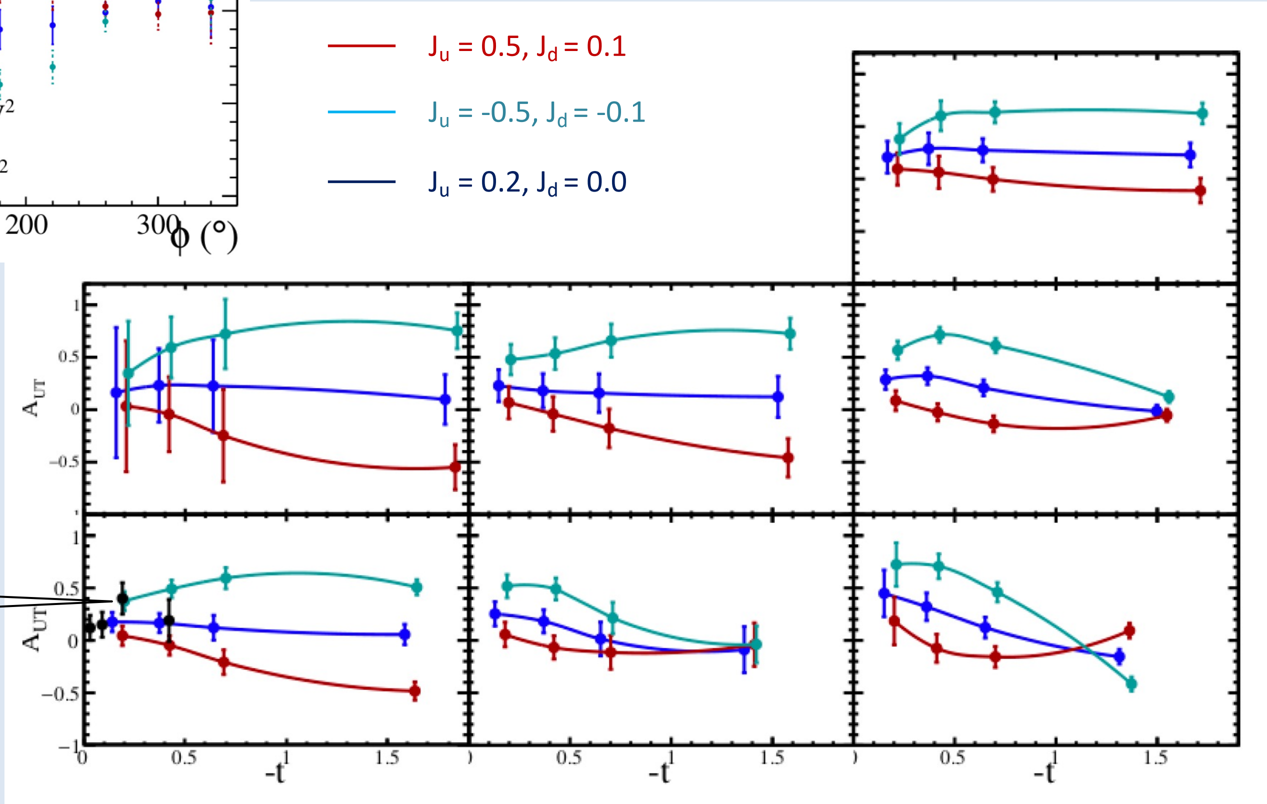
Recoil concept







Superior discrimination power between various OAM model hypotheses



HERMES

Conclusions

RGH team is working hard to make high impact RGH experiments a reality

Experiment	**Contact**	**Title**	**Rating**	**PAC days**
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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. Elauadrhiri	Deeply Virtual Compton scattering at 11 GeV with transversely polarized target using the CLAS12 detector	A	110

Important progresses since the original approval:

Science: [aramount case with novel lattice inputs but awaiting data

CLAS12: up and running with RICH, ideal for SIDIS and exclusive channels

Target: viable solution better than the PAC condition for approval

We request the PAC to confirm the conditionally approved beam time (110 days)

Systematic Uncertainty

C12-11-111 single hadron

Error source	Systematic error (%)
D background	4
Target polarization P_T	4
Acceptance corrections	4
Al background contribution	3
Radiative corrections	2
Total	~ 7

C12-12-010 single hadron

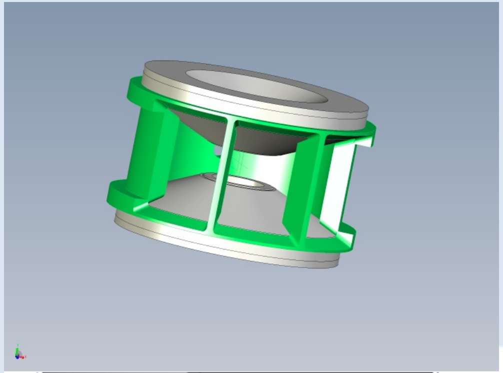
Error source	Systematic error (%)
D background	4
Target polarization P_T	4
acceptance corrections	5
Al background contribution	3
Radiative corrections	2
Total	~ 8

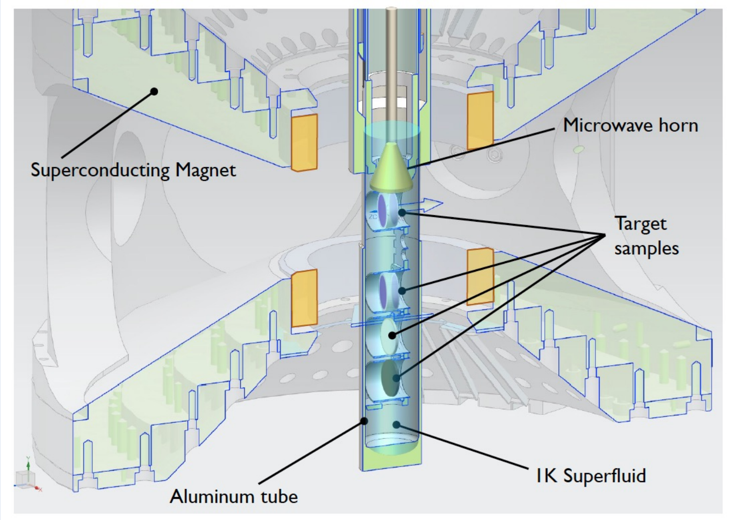
C12-12-009 di-hadron

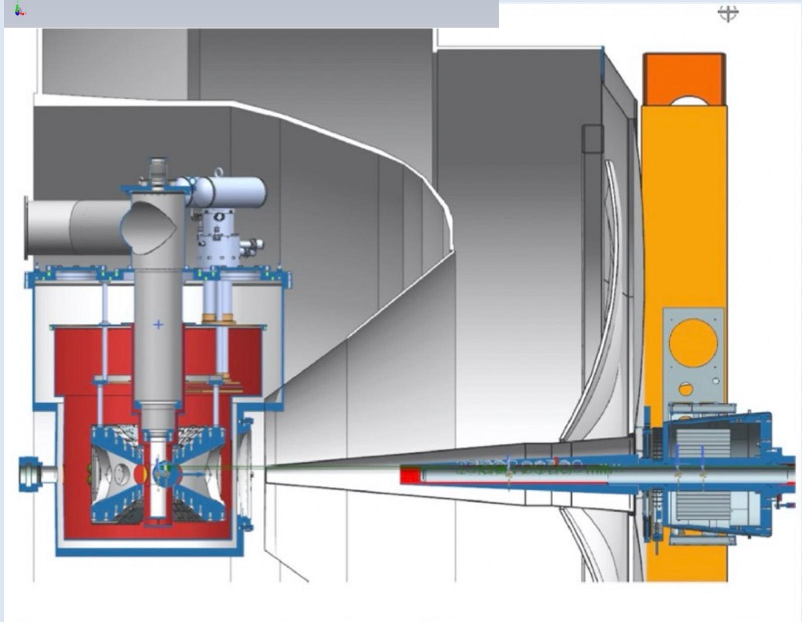
Error source	Systematic error (%)
D background	3
Target polarization, P_t	4
Acceptance corrections	5
Al background contribution	2
π^0 contamination	2
Radiative corrections	3
Total	~ 8

Viable solution to prioritize physics vs R&D

Consolidated NH_3 technology
Based on already successful target and magnet realizations







Recoil Reconstruction

Extended source 2 x 1.5cm^2.

With extended recoil detector

With time information

Baseline CLAS12

Capability	Quantity	Status
Coverage & Efficiency	Tracks (FD)	$5° < \theta < 35°$
	Tracks (CD)	$35° < \theta < 125°$
	Momentum (FD & CD)	$p > 0.2$ GeV
	Photon angle (FD)	$5° < \theta < 35°$
	Photon angle (FT)	$2.5° < \theta < 4.5°$
	Electron detection (HTCC)	$5° < \theta < 35°$, $0° < \phi < 360°$
	Efficiency	$\eta > 99\%$
	Neutron detection (FD)	$5° < \theta < 35°$
	Efficiency	$\leq 75\%$
	Neutron detection (CD)	$35° < \theta < 125°$
	Efficiency	10%
	Neutron Detection (BAND)	$155° < \theta < 175°$
	Efficiency	35%
Resolution	Momentum (FD)	σ_p/p =0.5–1.5%
	Momentum (CD)	$\sigma_p/p < 5\%$
	Pol. angles (FD)	σ_θ = 1–2 mrad
	Pol. angles (CD)	σ_θ = 2–5 mrad
	Azim. angles (FD)	$\sigma_\phi < 2$ mrad/$\sin\theta$
	Azim. angles (CD)	σ_ϕ = 3–15 mrad
	Timing (FD)	σ_T = 60–110 ps
	Timing (CD)	σ_T = 80–100 ps
	Energy (σ_E/E) (FD)	$0.1/\sqrt{E\ (\text{GeV})}$
	Energy (σ_E/E) (FT)	$0.03/\sqrt{E\ (\text{GeV})}$