Run Group H
Transversely Polarized Target Exp.

CLAS Collaboration Meeting
Jefferson Lab, 21st March 2023

Run Group H

CLAS12 with a transversely polarized target and polarized beam

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". PAC39 [2012]

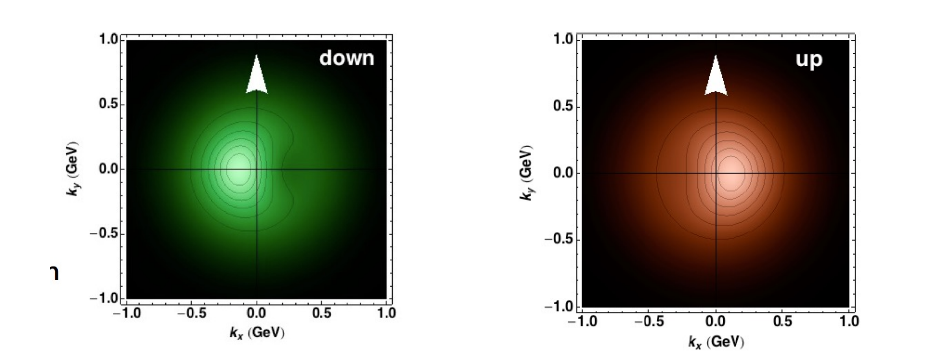
All RGH experiments selected among the high impact JLab measurements PAC42 [2014]

Since then: RGH status confirmed during jeopardy in 2020
RGH program becomes a pillar of EIC science case
Only new data: COMPASS 2022 deuteron run

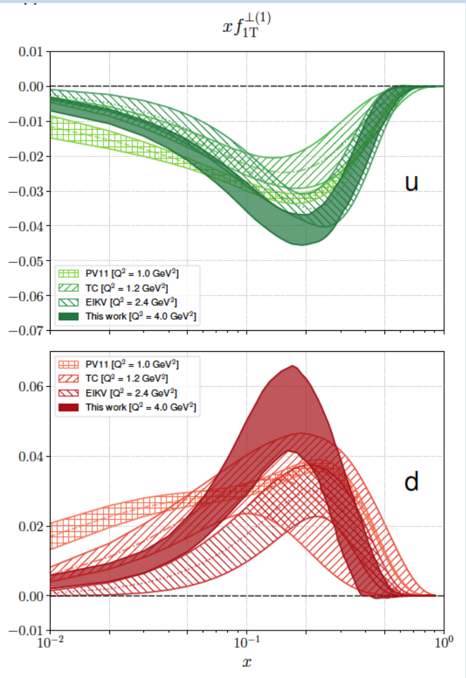
EIC Center at Jefferson Lab

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

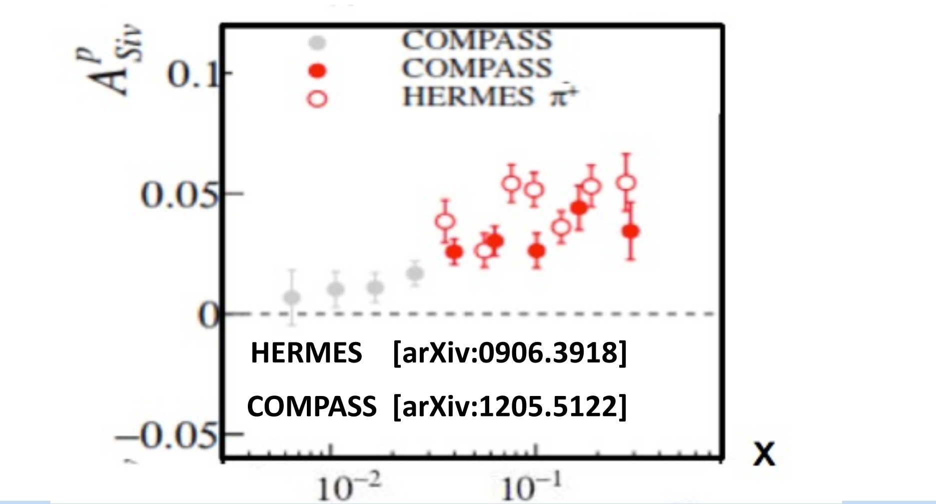
Quark distribution imbalance connected to orbital angular momentum and FSI



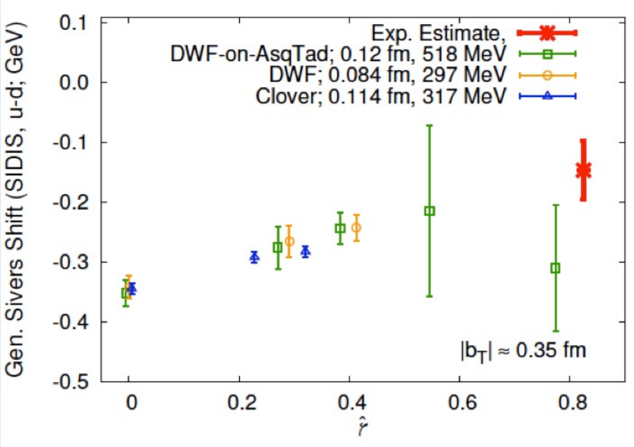
Phenomenology A. Bacchetta++ [arXiv: 2004.14278]



SIDIS data

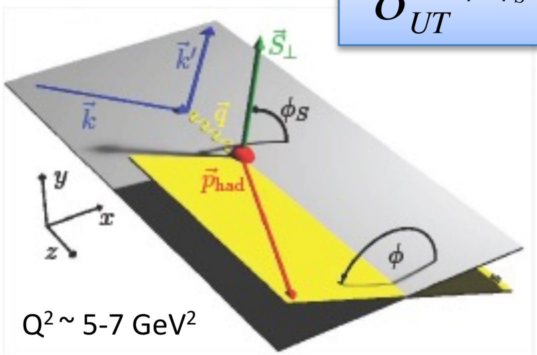


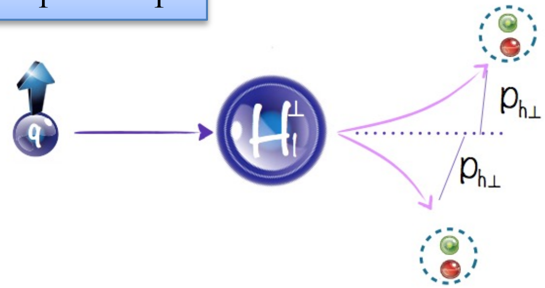
Lattice calculations Yoon++ [arXiv: 1706.03406]



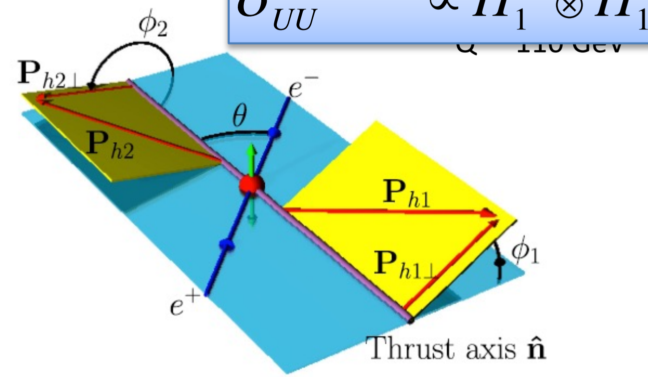
SIDIS: Collins Spin-Orbit Effect

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



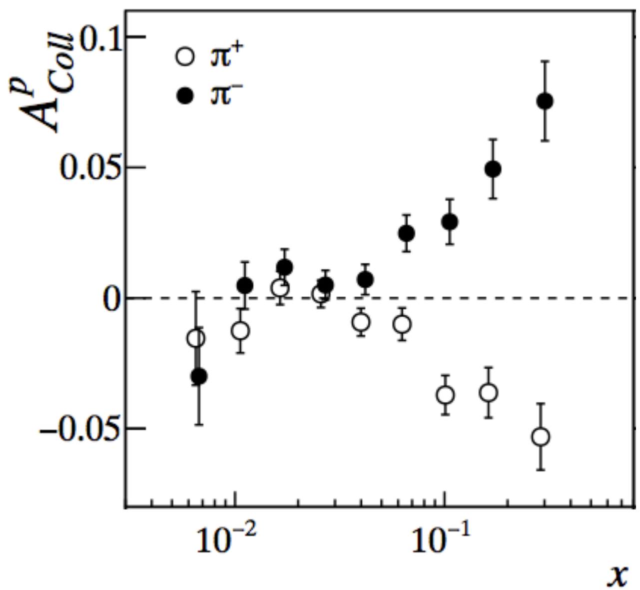


$\sigma_{UU}^{\sin(\phi_1+\phi_2)} \propto H_1^{\perp} \otimes H_1^{\perp}$



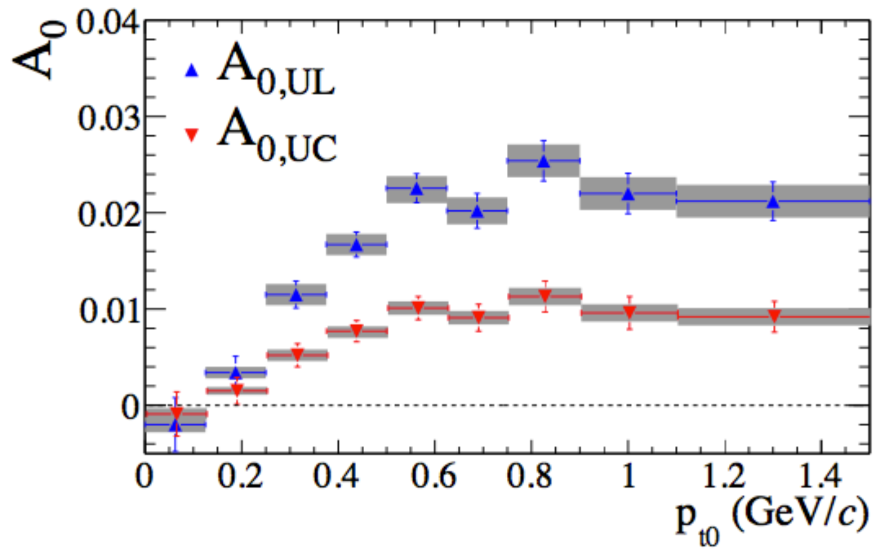
SIDIS

HERMES [arXiv 0408013]
HERMES [arXiv 0906.3918]
COMPASS [arXiv 1005.5609]
COMPASS [arXiv 1408.4405]



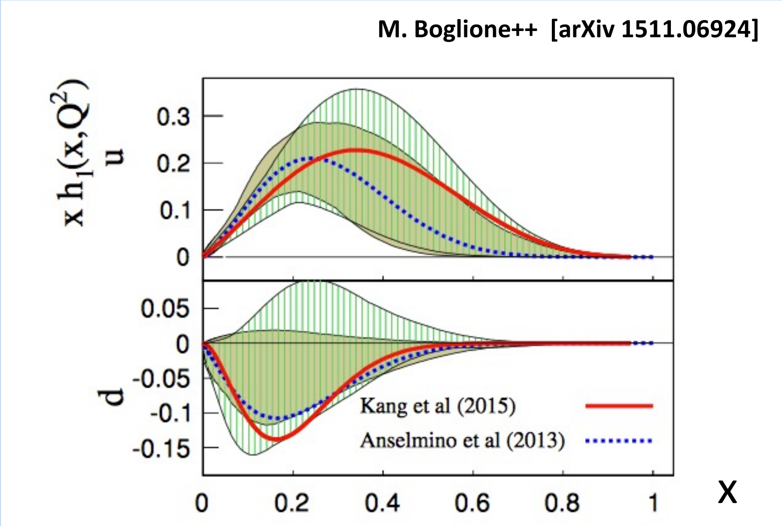
e+e- colliders

Belle [talk at DIS2014]
BESIII [arXiv 1507.06824]
Babar [arXiv 1309.5278]

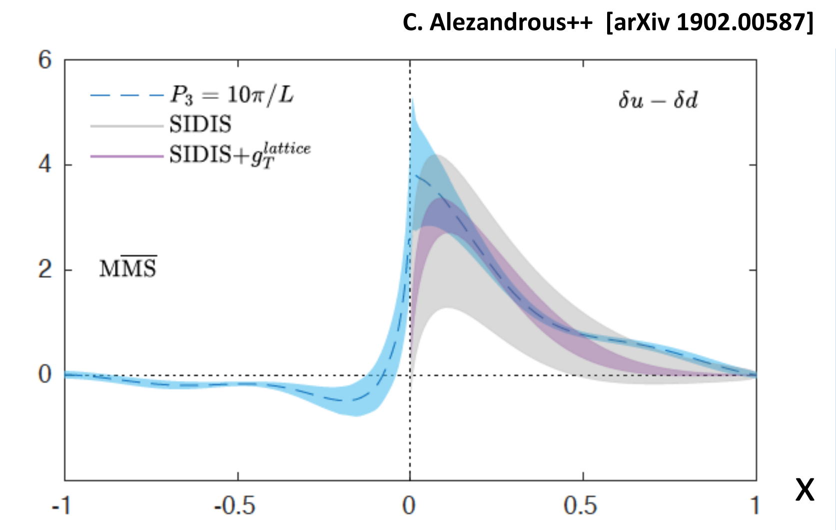


SIDIS: Transversity & Tensor Charge

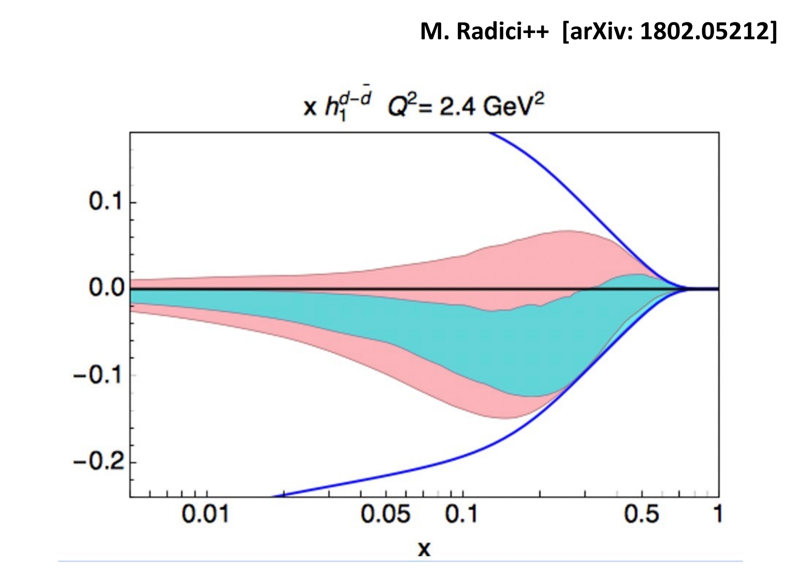
TMD formalism validated for SIDIS, DY, e+e-



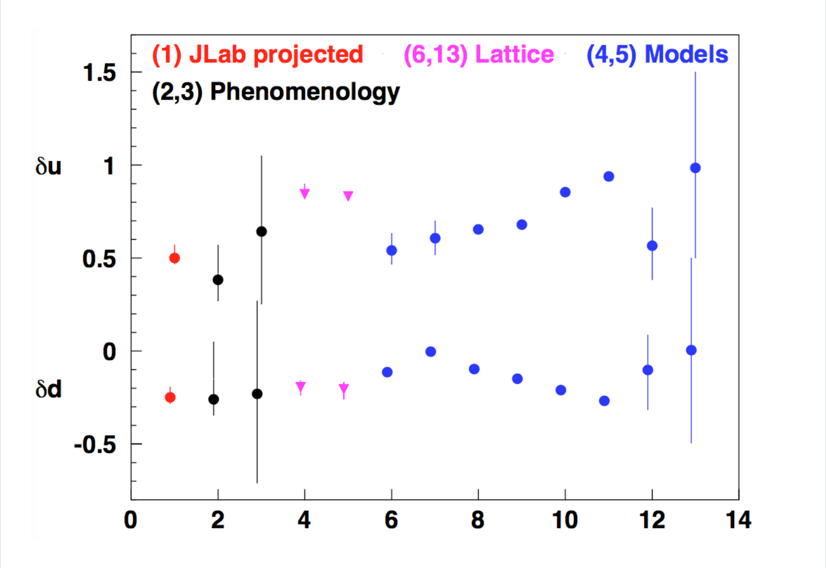
New lattice tools being developed



Di-hadron: Collinear formalism, access to pp data



BSM links: tensor coupling and electric dipole moment



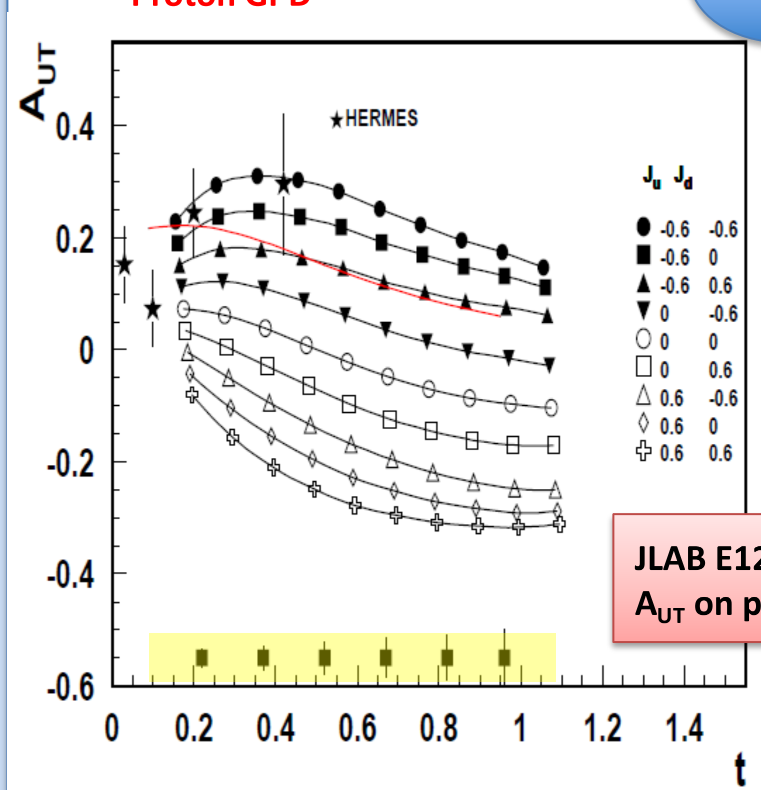
DVCS: Orbital Angular Momentum

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

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

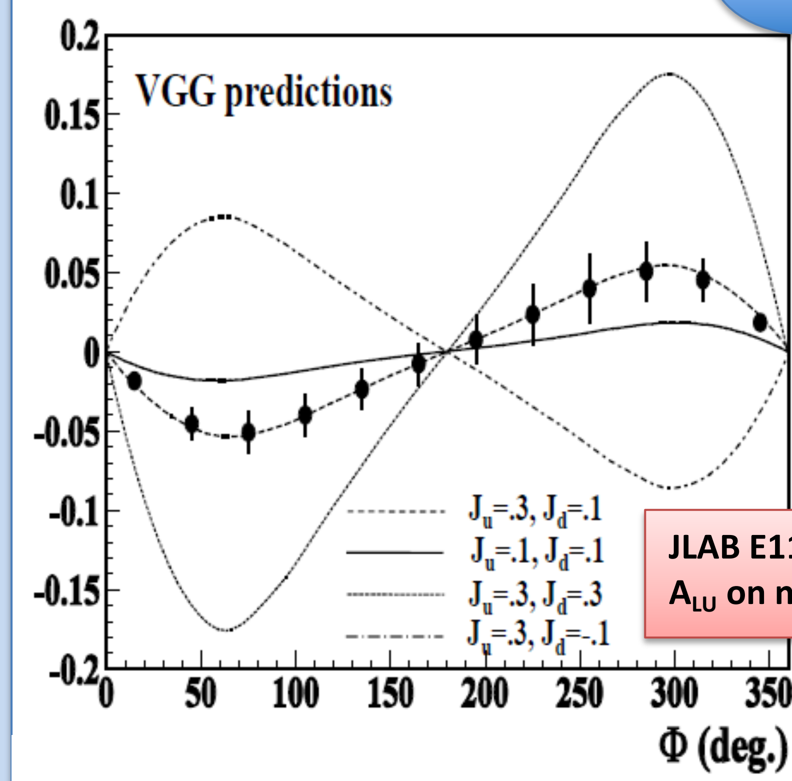
New: comprehensive approach
same apparatus
To access E_u & E_d both E_p & E_n are needed

RGH



JLAB E12-010
A_{UT} on proton

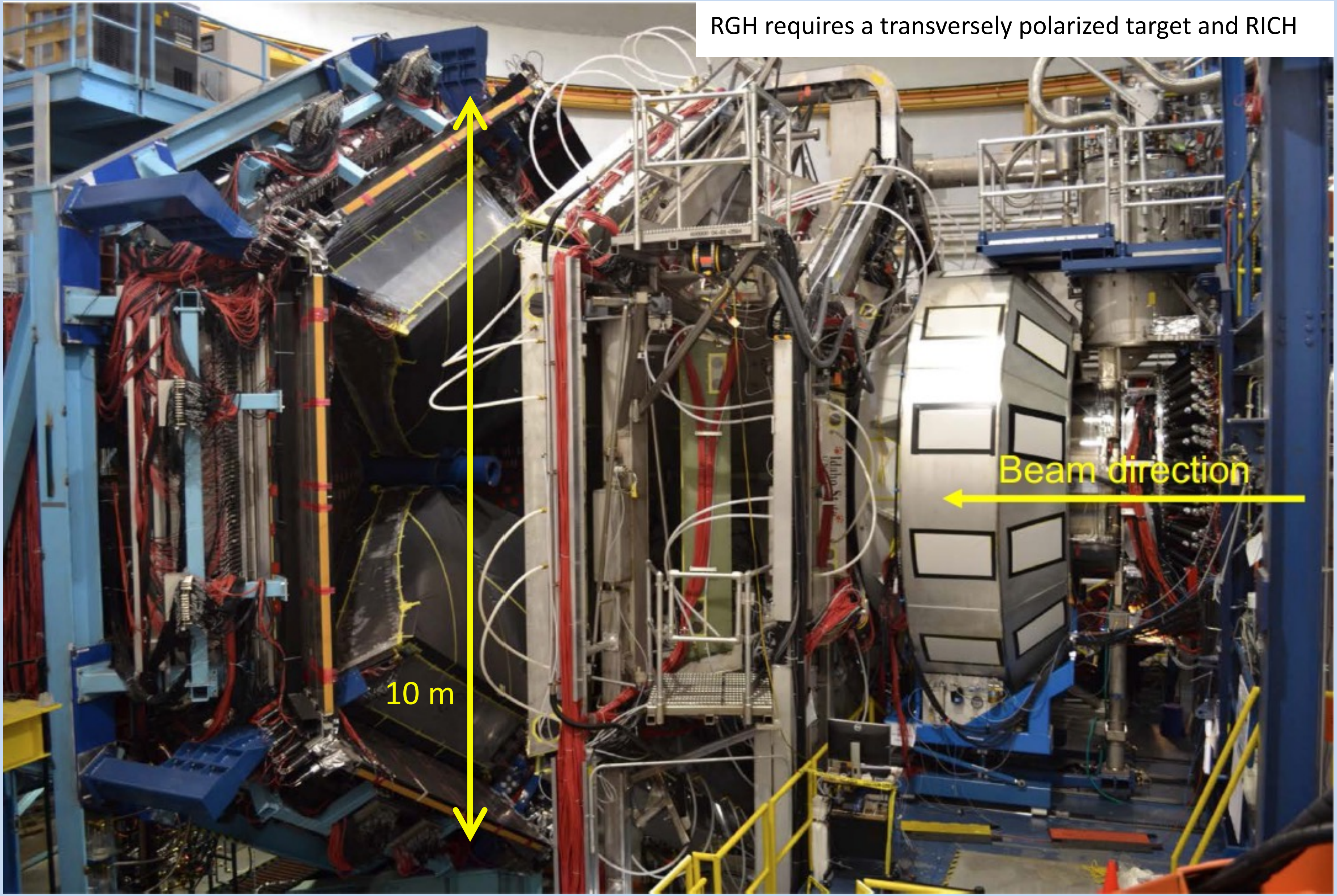
RGB



JLAB E11-003
A_{LU} on neutron

RGH Experimental Setup

RGH requires a transversely polarized target and RICH



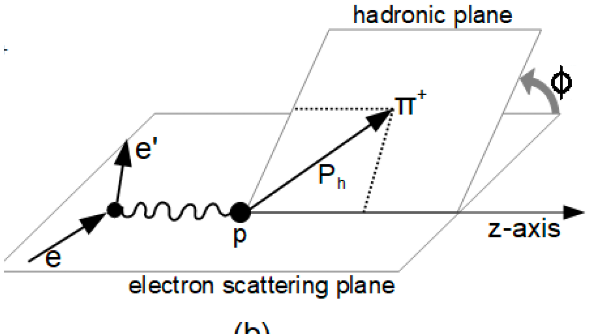
Beam Spin Asymmetry (π+)

CLAS12 proton data (RGA)

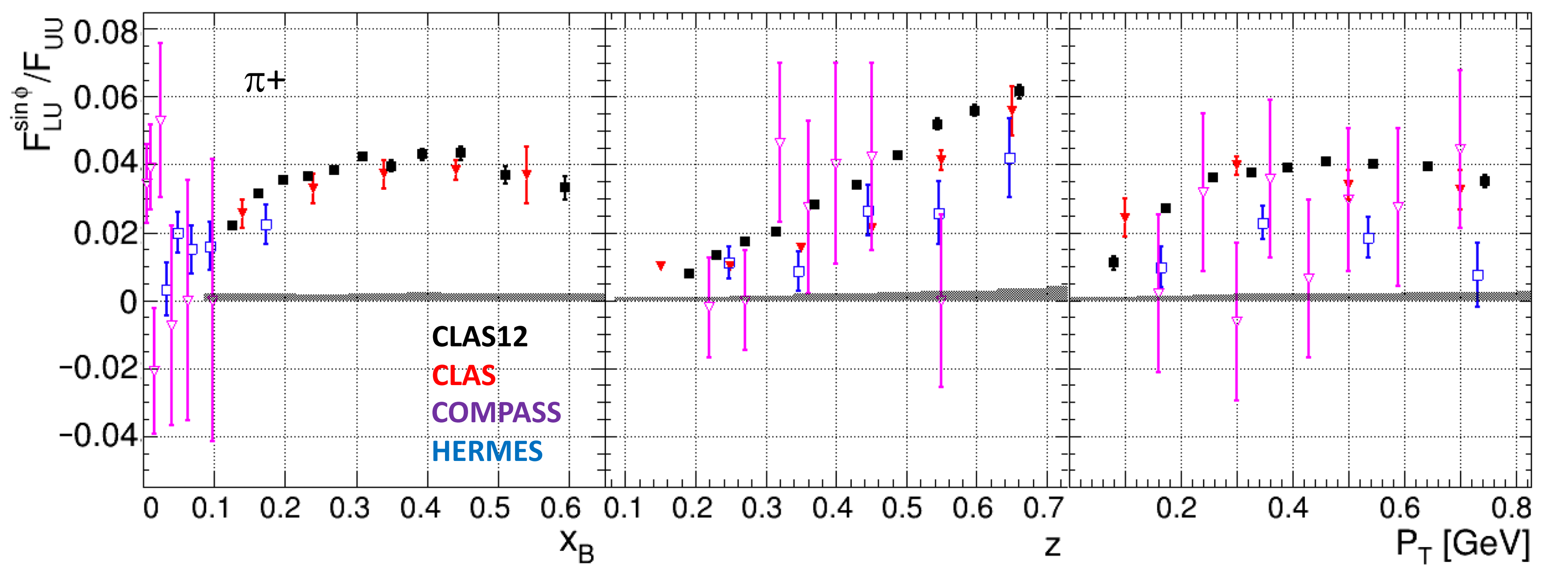
S. Diehl et al., e-Print: 2101.03544

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

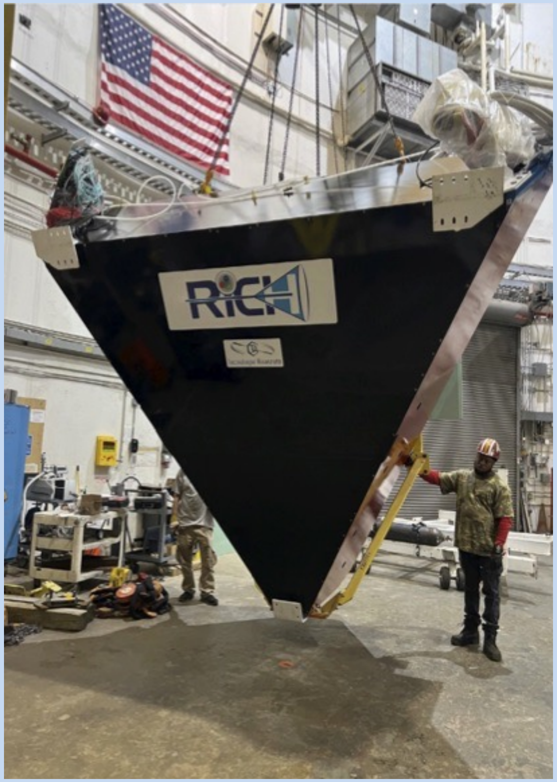
86.9±2.6 %

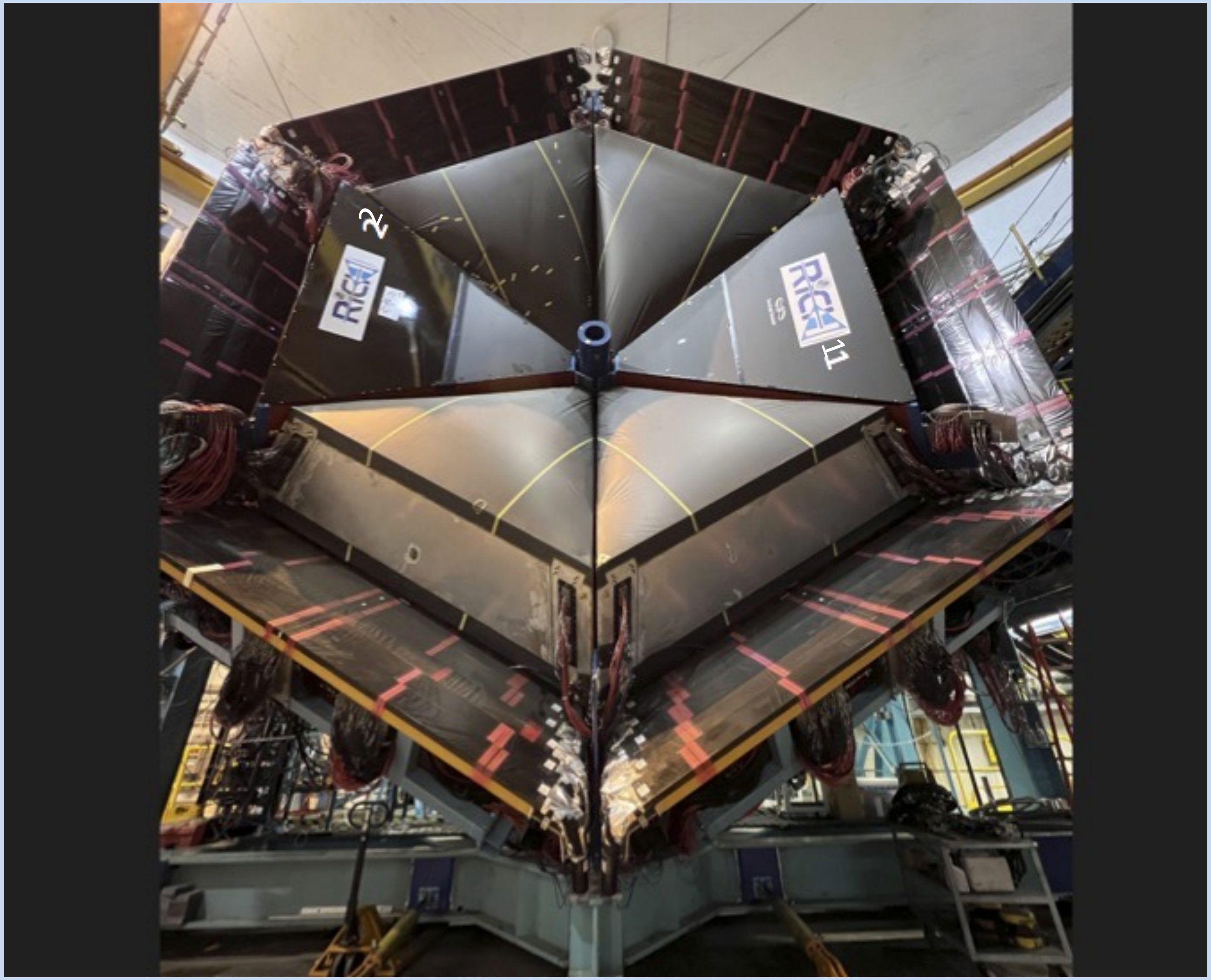


(b)



Completed in June 2022 with the symmetric configuration dedicated to the runs with polarized targets (now ongoing)





Particle Identification

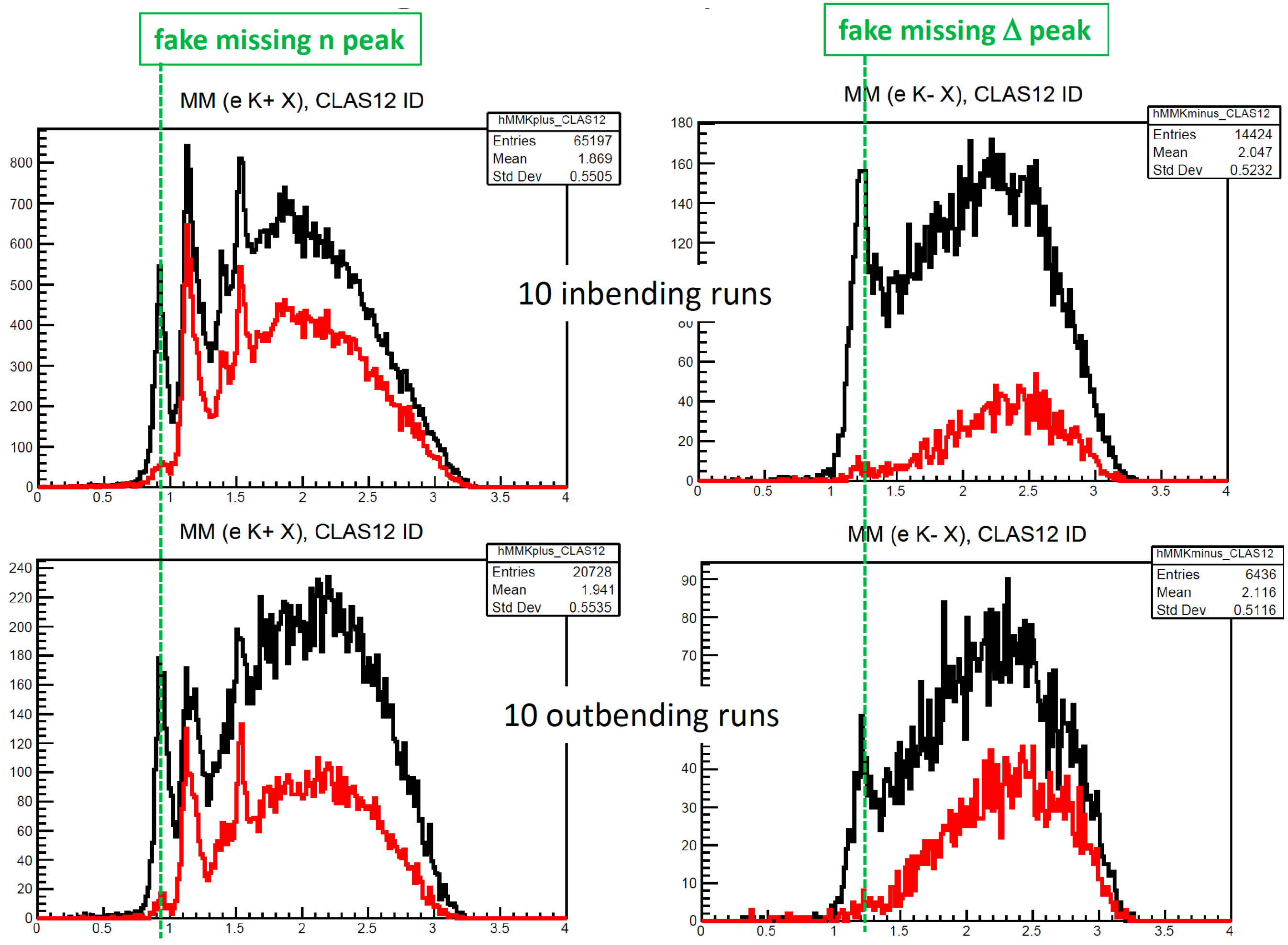
Entering PID game with pass2 data

Check with semi-inclusive physics channel ep→eKX

RGA fall 2018 data

black: Event builder
- p>1.5 GeV/c

red: RICH
- p>1.5 GeV/c
- ntot>2.5
- no cuts on chi2, RL



Courtesy: M. Mirazita

Target Alternatives

HDice: pros: minimize the dilution and nuclear background (due to not-polarizable material)

pros: maximize acceptance (thanks to the light magnetic system)

cons: beam heating and radiation damage

cons: long preparation time

NH_3/ND_3 : pros: consolidated technology and infrastructure at JLab

cons: increased systematic effect (nuclear effects, non uniform target density)

cons: impact on the experimental setup
(massive magnet of strong field and reduce acceptance)

Target	HDice	NH3/ND3
Average polarization	41%	86%
Overhead	10%	3-5%
Dilution	1/3	3/17
FOM	13%	15%

Target Options

Use standard material NH_3/ND_3 with optional alternatives

External DNP: A target of NH_3/ND_3 that is continuously polarized at 1.0 K and 5 T in place of the CLAS12 solenoid

Target CLAS12

Most viable target solution but largest impact on CLAS12

Aka-HDice: A frozen-spin target of NH_3 and ND_3 inside the CLAS12 solenoid and operating at approximately 0.1 K and 1 T

Target CLAS12

Resembling HDice approach, similar performance and risks
New R&D against beam heating
Similar specifications for MgB_2

MgB_2

Internal DNP: A target of NH_3/ND_3 that is continuously polarized at 0.3 K and 2.5 T inside the CLAS12 solenoid

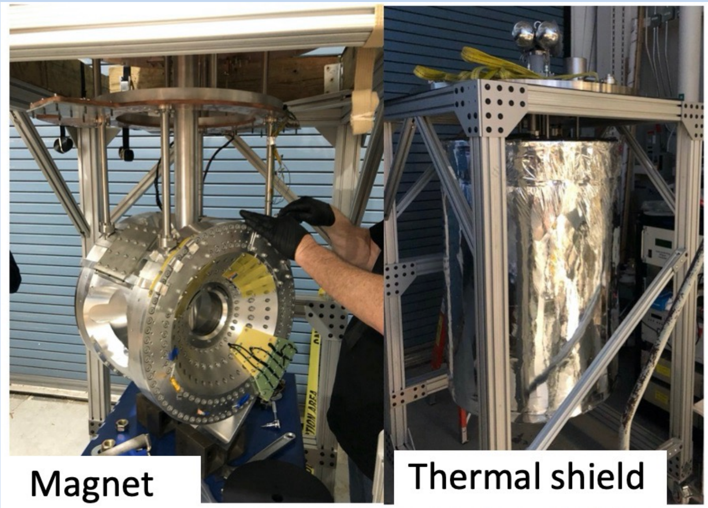
Target CLAS12

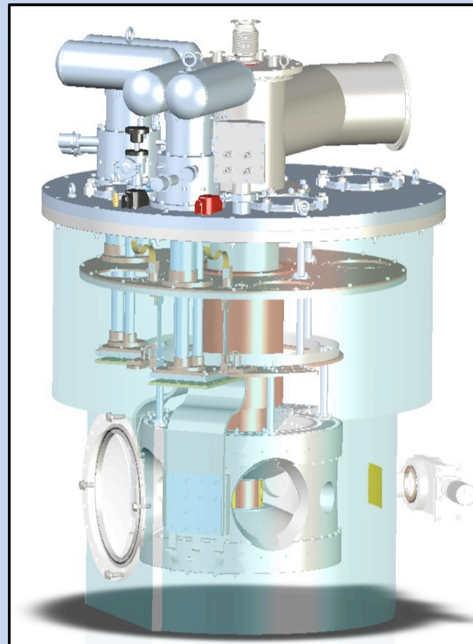
Compelling but challenged by the required field uniformity
New specifications for MgB_2

MgB_2

Current Most Viable Solution

Low risk:
5T magnet being prepared for Hall-C





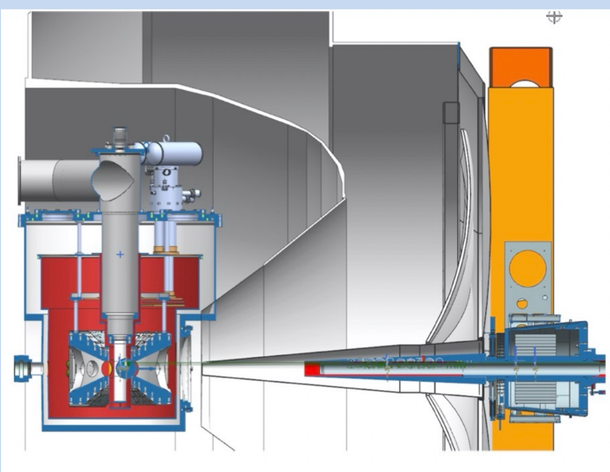
Still needed:

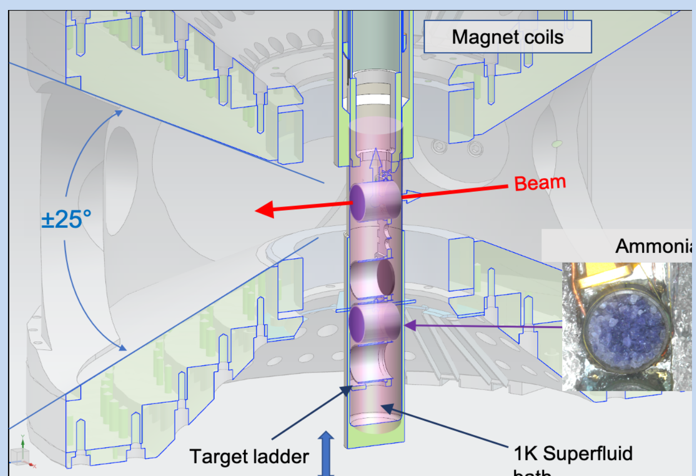
suitable cryostat design

1K target refrigerator

compensating beam chiacane

Major impact on CLAS12:
Incompatible with central detector





Limited acceptance

$\pm 25^{o}$ Forward

Around 90^{o} Recoil

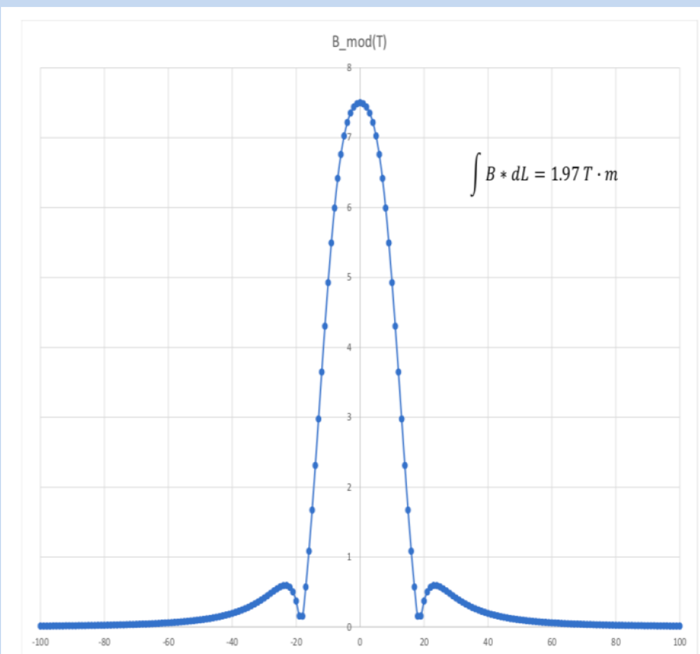
Hall-C magnet field integral

$$\int Bdl = 1.36\ \mathrm{Tm}$$

A symmetric 3-magnet beam chicane at 11 GeV requires

1.4 Tm and 2.8 Tm magnets

Possible commercial solution may exist



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Home » 7.5 Tesla Split Pair Cryogen-FREE Magnet System Dual RTB

7.5 Tesla Split Pair Cryogen-FREE Magnet System Dual RTB

By Steve Short | January 21, 2020 | 0 Comments

7.5 Tesla, Split Pair Cryogen-FREE Superconducting Magnet System with dual room temperature bores. Compact design allows for use with optical cryostat.

Customer Location: Florida, USA

- 7.5 Tesla Split Pair Magnet.
- 2.375 inch (60.3mm) ID Vertical (Radial to Field) Room Temperature Bore.
- 9.5 inch (241mm) Distance to Field Center.
- 2.00 inch (50.8mm) ID Horizontal (Axial to Field) Room Temperature Bore.
- 8.0 inch (203mm) Distance to Field Center.
- + 0.1 % Central Field Homogeneity Over 10 mm DSV.
- Single, Sumitomo Pulse Tube Cryocooler, Remotely Mounted.

Courtesy: X. Wei

Existing design by Cryomagnetics, Inc

Could be already suitable for a new target magnet design

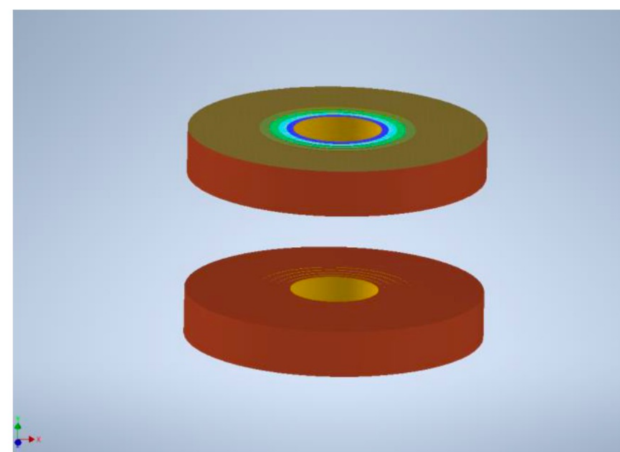
Could be anyway adapted (uniformity is not an issue here) :

- ✓ Field orientation
- ✓ Maximum field increase
- ✓ Bore size enlargement

Production time ≥ 2 years

	ID(")	OD(")	Width(")	zCen(")	NTurns
1.	4.250	4.912	2.250	2.875	377.800
2.	4.912	5.708	2.250	2.875	523.900
3.	5.708	6.563	2.250	2.875	711.800
4.	6.563	7.535	2.250	2.875	1095.500
5.	7.535	14.407	2.250	2.875	10966.800
6.	4.250	4.912	2.250	-2.875	377.800
7.	4.912	5.708	2.250	-2.875	523.900
8.	5.708	6.563	2.250	-2.875	711.800
9.	6.563	7.535	2.250	-2.875	1095.500
10.	7.535	14.407	2.250	-2.875	10966.800

* operating current 87.32 amps

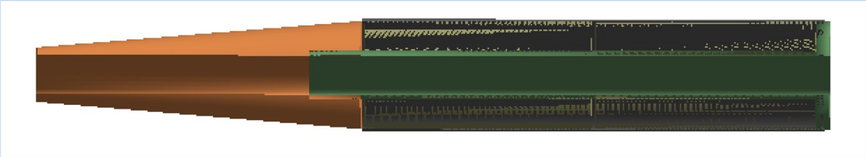


Moeller Shield

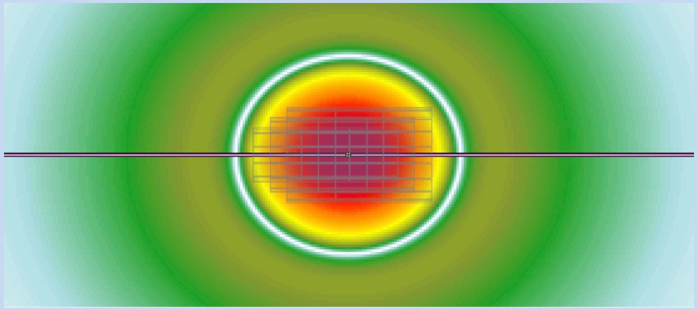
New shielding optimization

Transverse magnet field

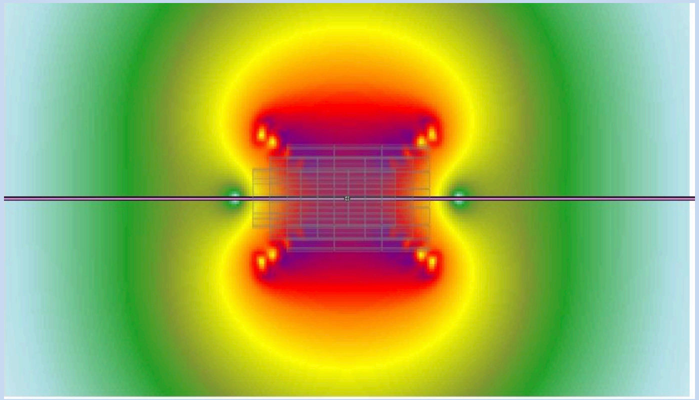
ELMO GEMC Cross-section (without Tungsten Tip)



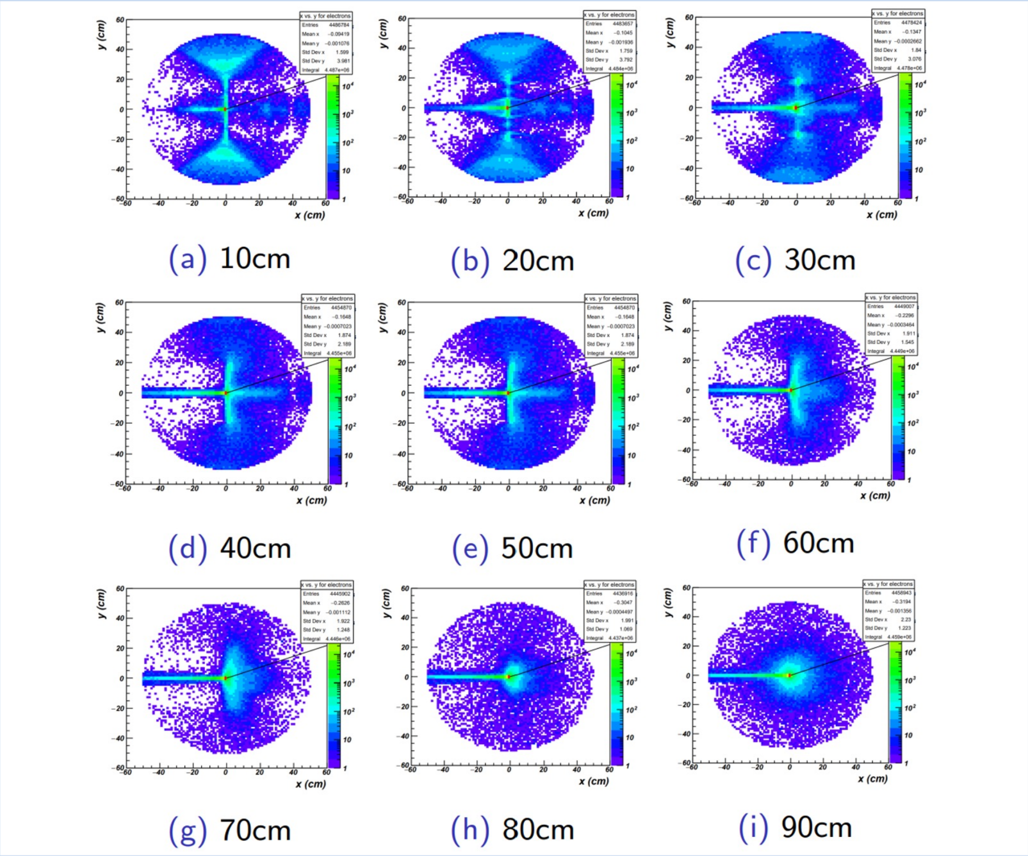
Top view



Side view



Moller distribution along dummy tracking planes



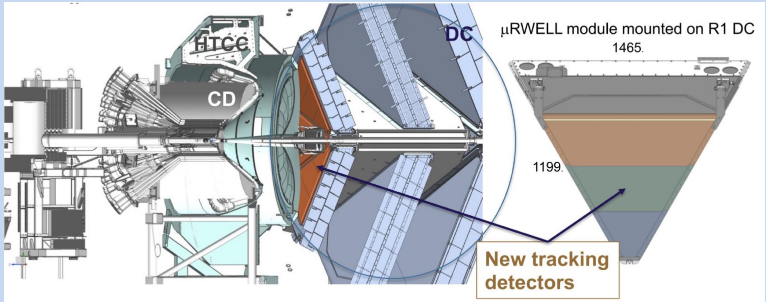
DC Occupancy

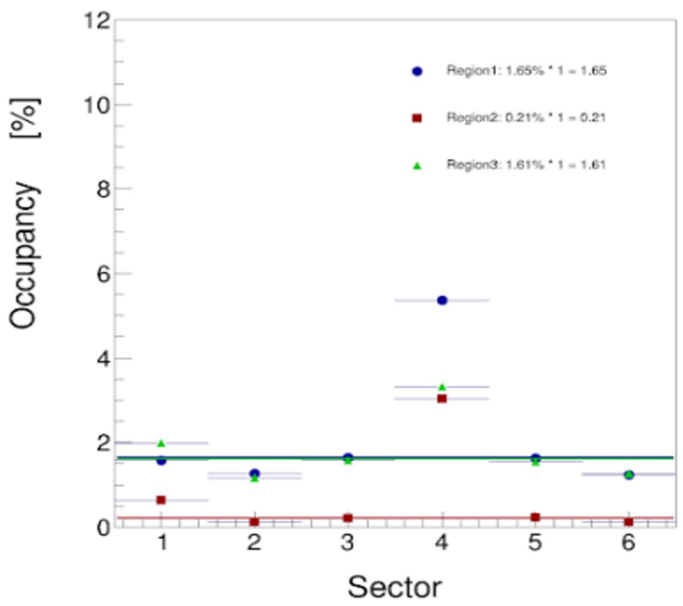
Mostly reasonable except for one sector

On sector 4 concentrates on a small portion of wires

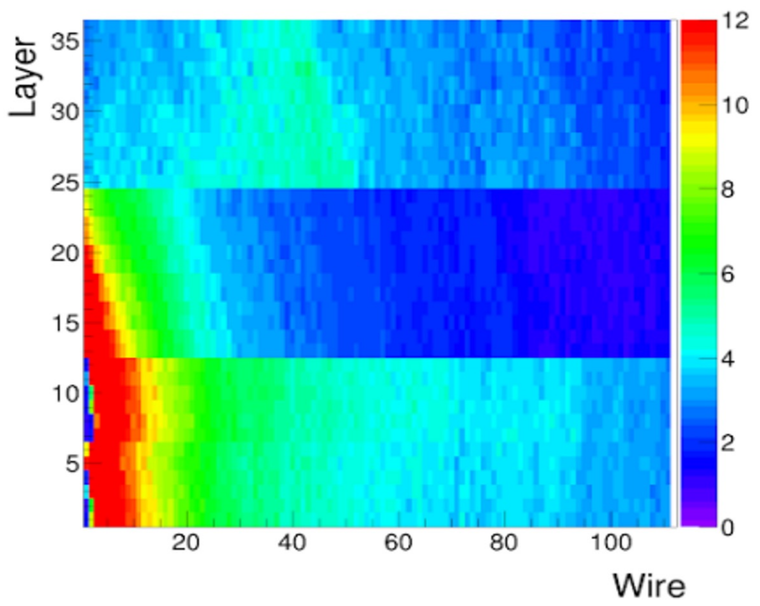
Should benefit from the AI based tracking (pass2)

May benefit from the high-luminosity upgrade (μ-Rwell)





(a) Average occupancy Rate.



(b) Occupancy Map.

From the report to the S&T DOE Review:

- ✓ C12-11-111
- ✓ C12-12-009
- ✓ C12-12-010

Even with the most conservative approach

- reduction in luminosity from $4x10^{33}$ $cm^{-2}s^{-1}$ to $1x10^{33}$ $cm^{-2}s^{-1}$;
- increase in average target polarization from 41% to 86%;
- change in the dilution factor from 1/3 to 3/17;
- operation of 5 sectors (instead of 6) of CLAS12 Forward Detector due to electromagnetic background;
- CLAS12 Central Detector removal (this only affects the DVCS program).

RG-H experiments will provide significant data in the valence quark region, extending significantly the kinematics covered by HERMES and COMPASS measurements and providing a unique and crucial input for studies on the 3D structure of the proton.

Further studies indicate it should be possible to operate CLAS12 with a transversely dynamically polarized ammonia target at a luminosity of at least $2x10^{33}$ $cm^{-2}s^{-1}$ (minimum PAC requirement) with remaining limitations:

- polar angle acceptance limited to forward angles less than 25 degrees by the transverse magnet aperture;
- CLAS12 Central Detector incompatibility with the proposed setup.

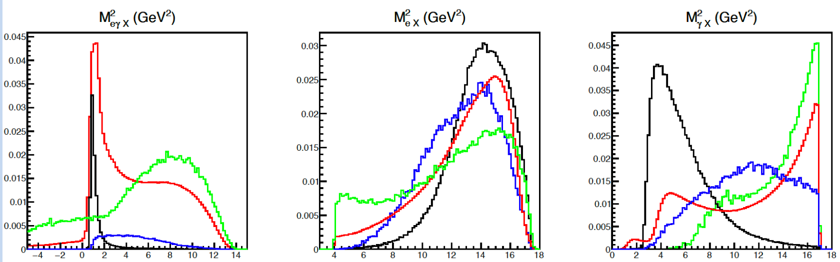
High luminosity CLAS12 program is essential for RGH goals

DVCS without Proton

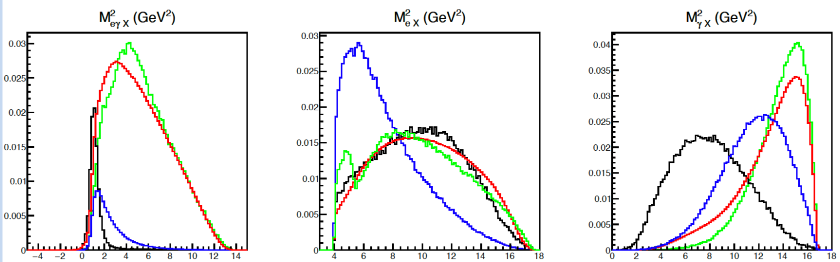
Test of ML approach on RGA data (LH_2 target: the simplest case)

Challenging background rejection, but potentially extended statistics and phase space

Model training



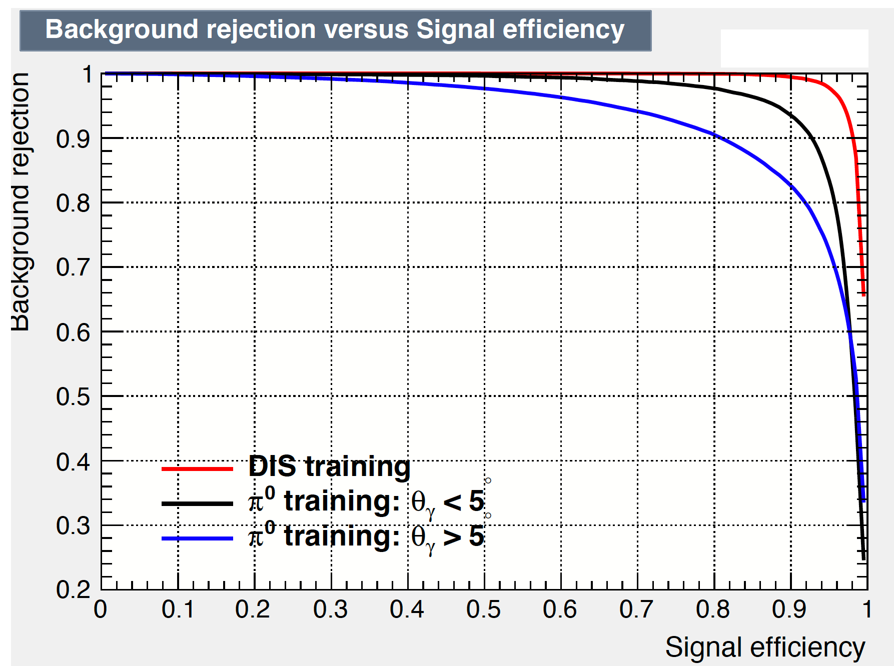
(a) Photons detected at $\theta_\gamma < 5°$.



(b) Photons detected at $\theta_\gamma > 5°$.

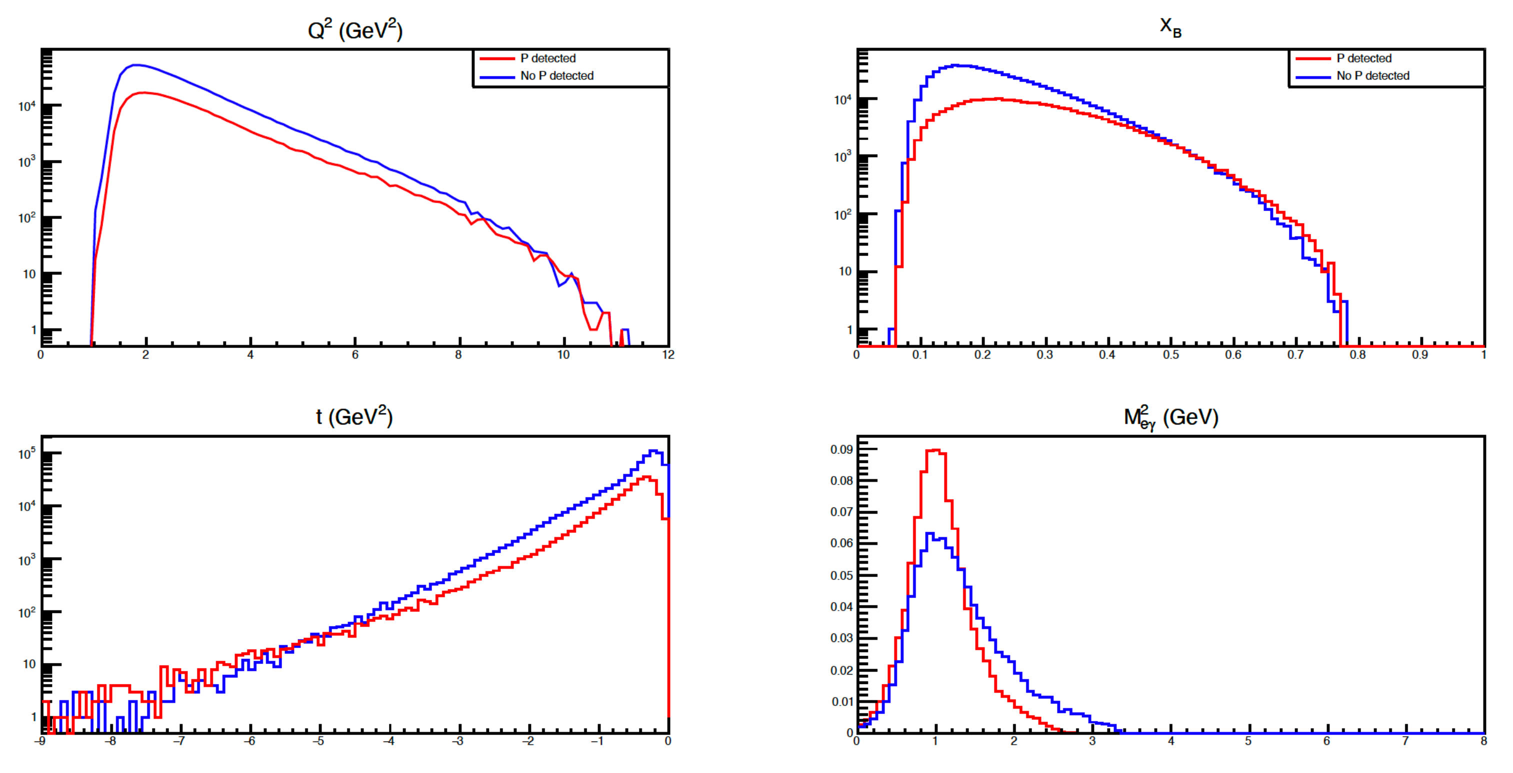
-- Data -- DVCS -- pi0 -- DIS

BDT performance



Courtesy: S. Alvarado

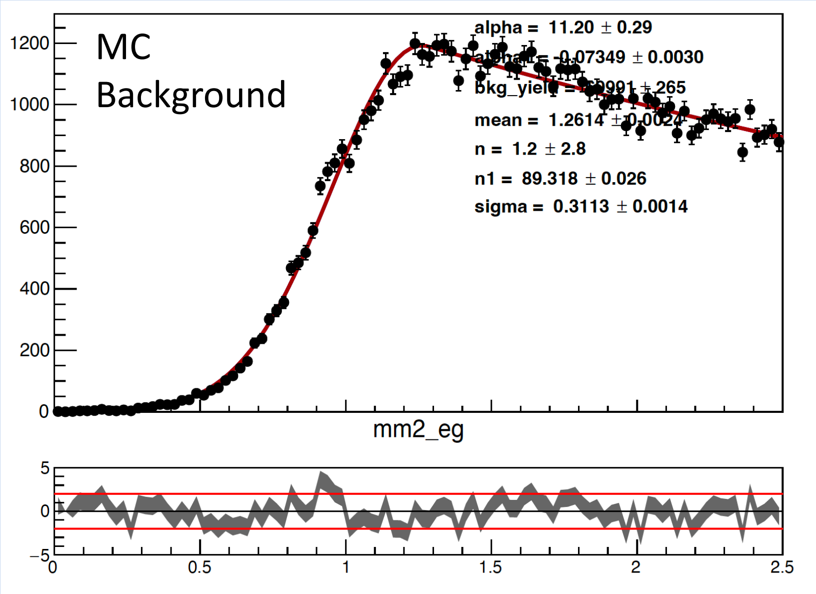
After BDT selection:

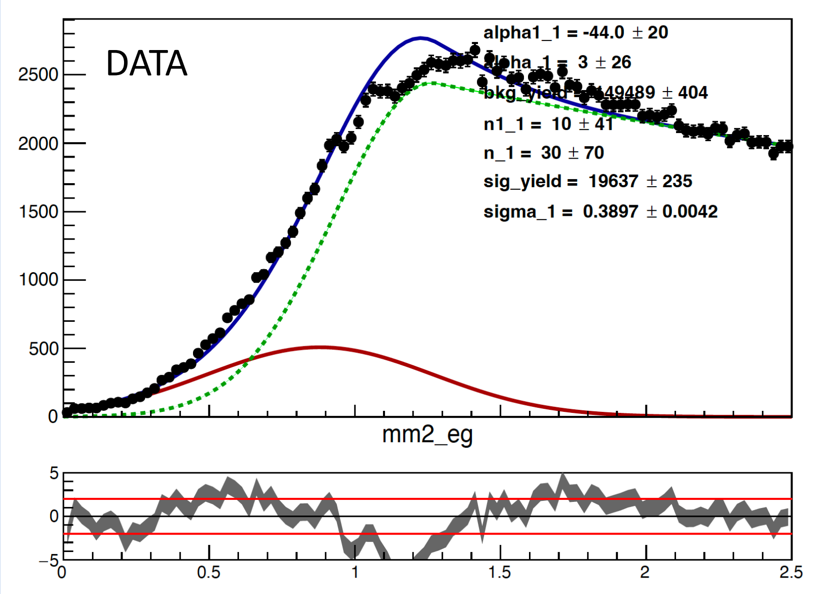


	$\theta_\gamma < 5°$	Remaining on data	$\theta_\gamma > 5°$	Remaining on data
DVCS	83.5%		86.93%	
π^0	3.64%	<10.3%	16.3%	<100%
DIS	0.044%	<1.2%	0.77%	<9.16%

DVCS without Proton

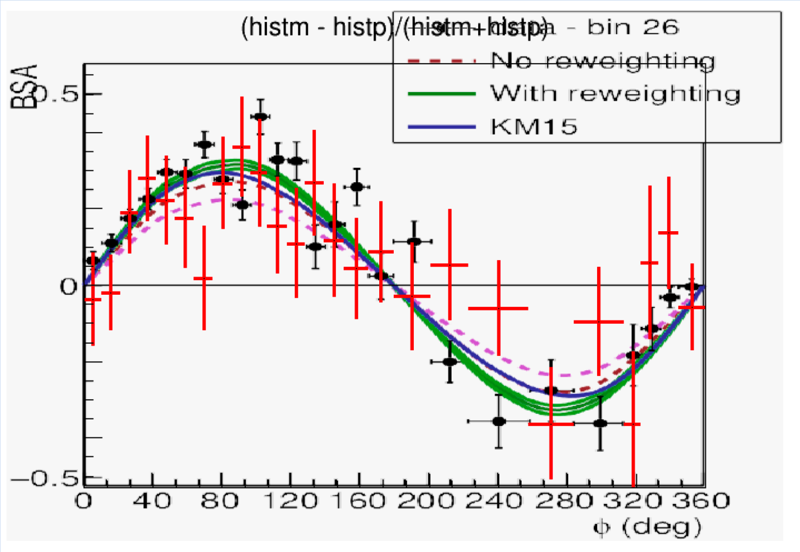
Sweight method: weight each event as defined by a discriminating distribution analysis





RGA Analysis note

Sweight analysis



$1.4 < Q^2 < 2.8$ GeV^2

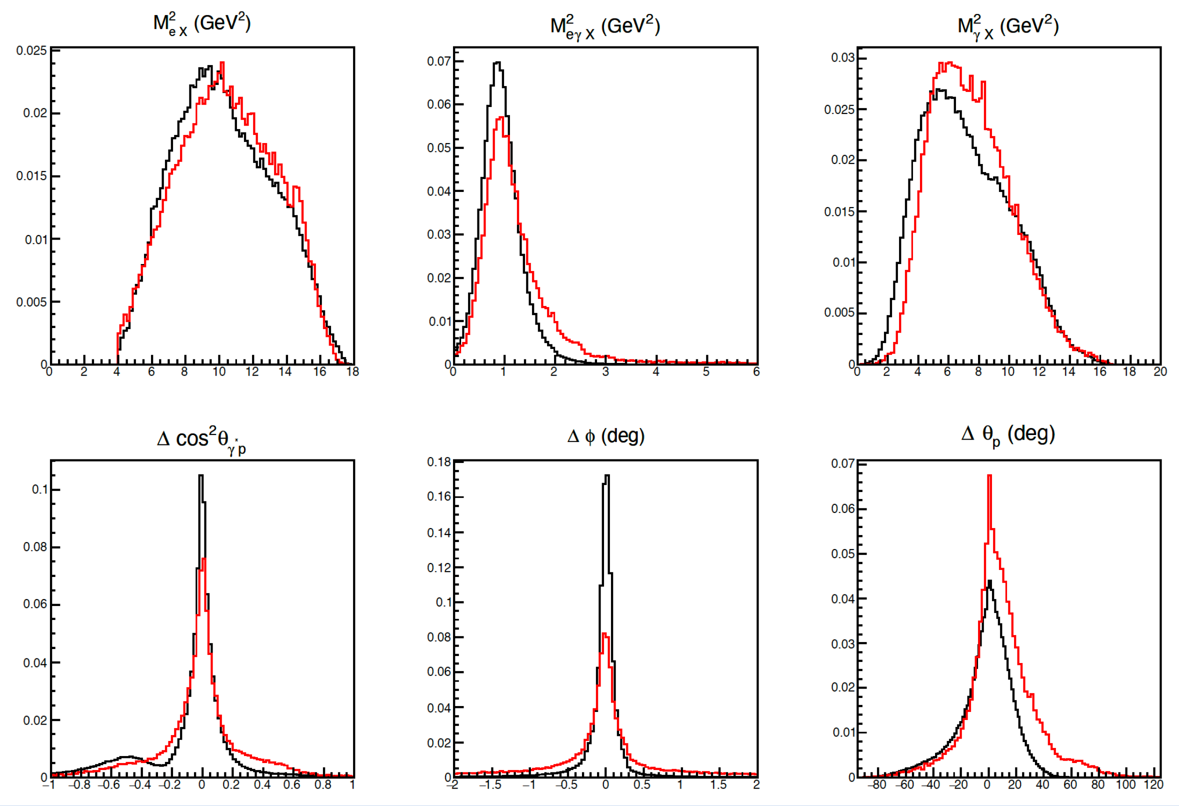
t > - 0.2 GeV

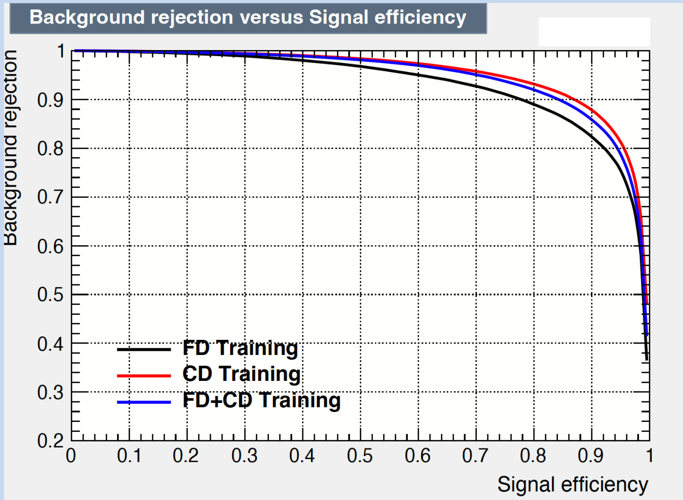
$0.16 < x < 0.26$

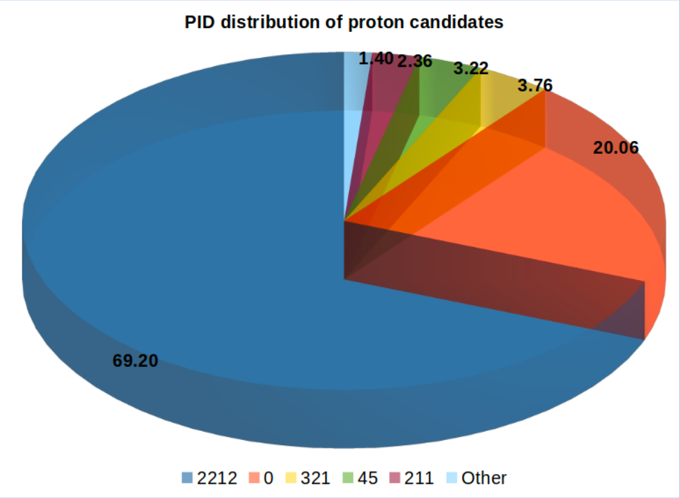
DVCS with Proton Tagging

Assume just a basic tracking (only angles)

After BDT selection:







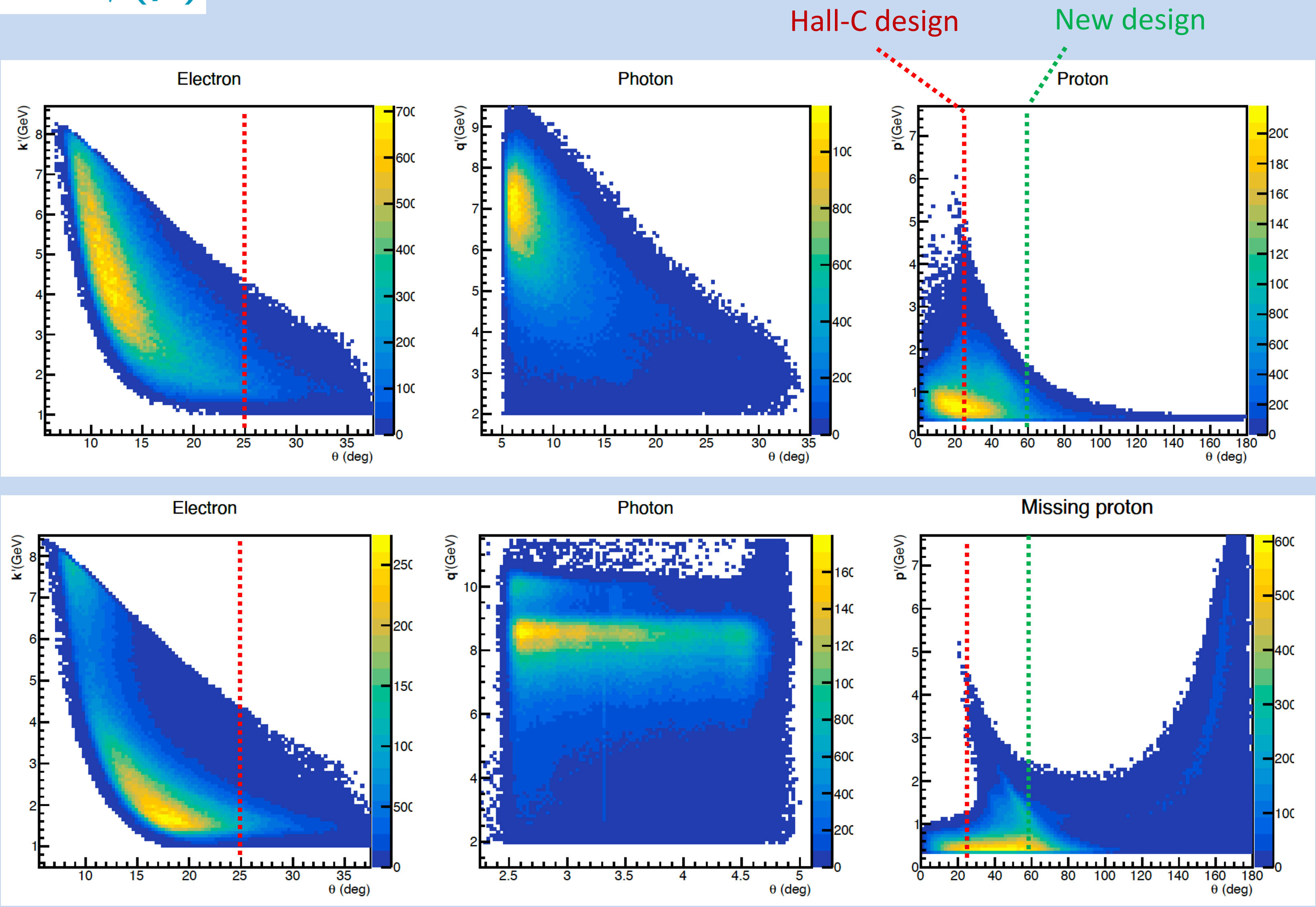
Part of mis-ID could be recover with pass2 tracking

Better control, but need validation on RGC data

$$ep \rightarrow e\gamma(p)$$

FD:

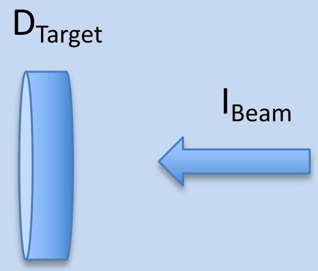
FT:

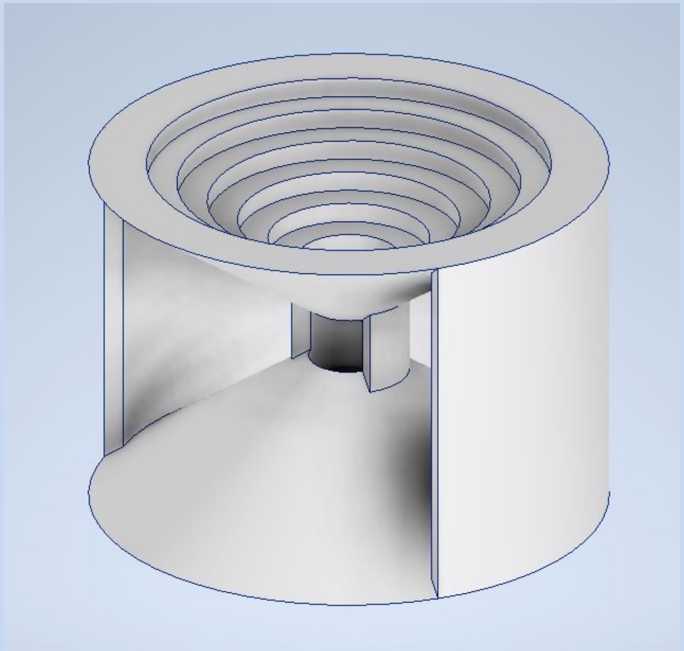


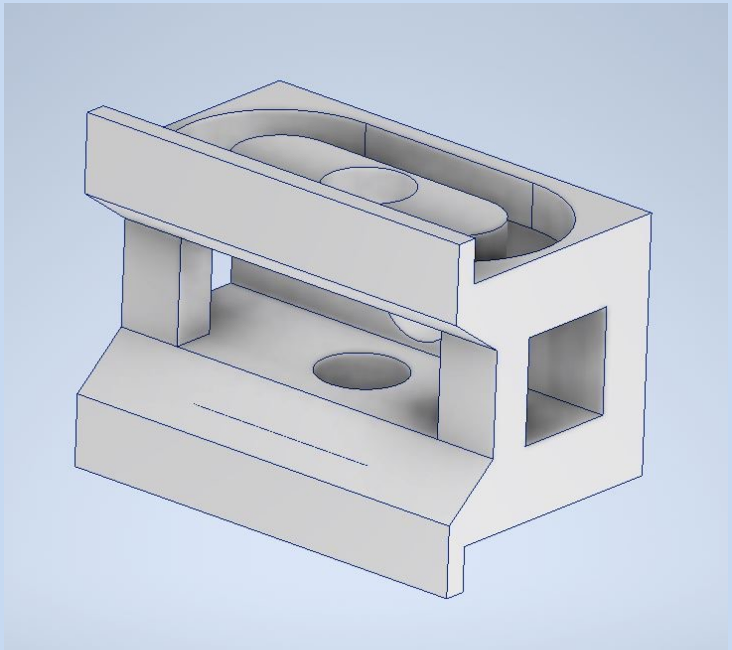
Alternate Target Holding Magnet

New concept being investigated with JLab magnet group
Goal: maximize the physics outcome

* design for a short target (Lumi $\propto$ D_{Target} x I_{beam})
* optimize acceptance
* reduce integrated field → simplify beam chicane
→ limit Moeller dispersion ?





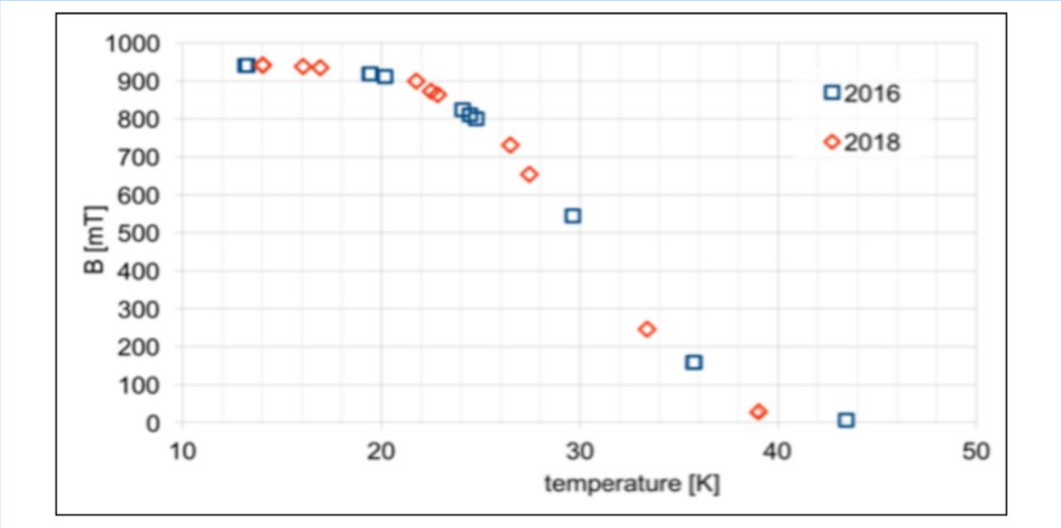


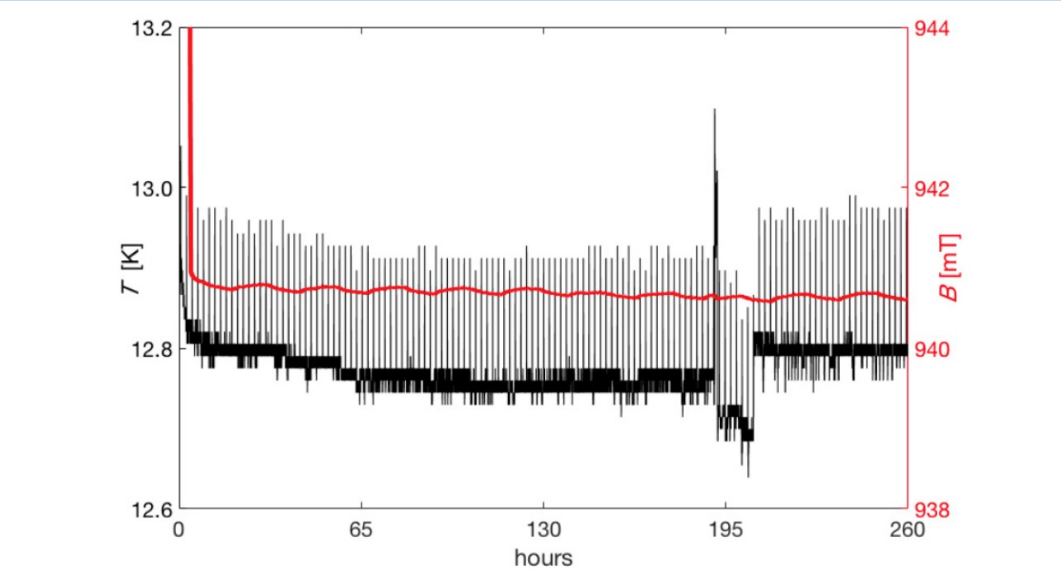
Courtesy: X. Wei

Challenges: preserve 100 ppm uniformity, cope with strong forces

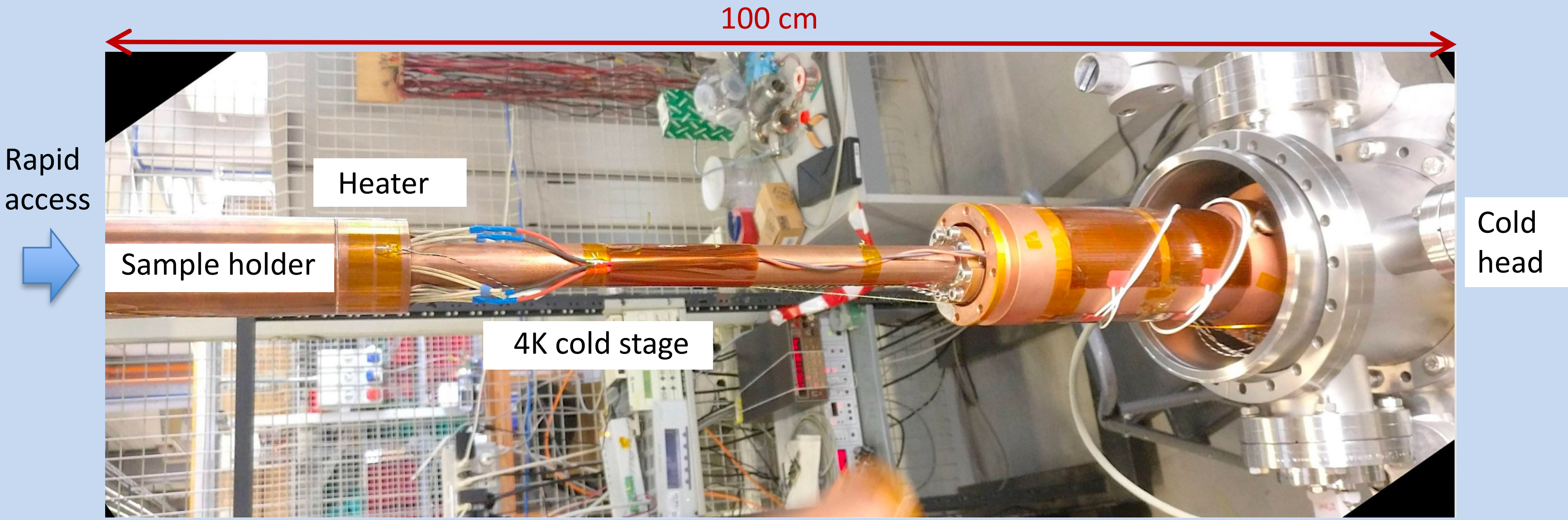
Bulk superconducting MgB_2 magnet
magnetization frozen at the transition to superconductor

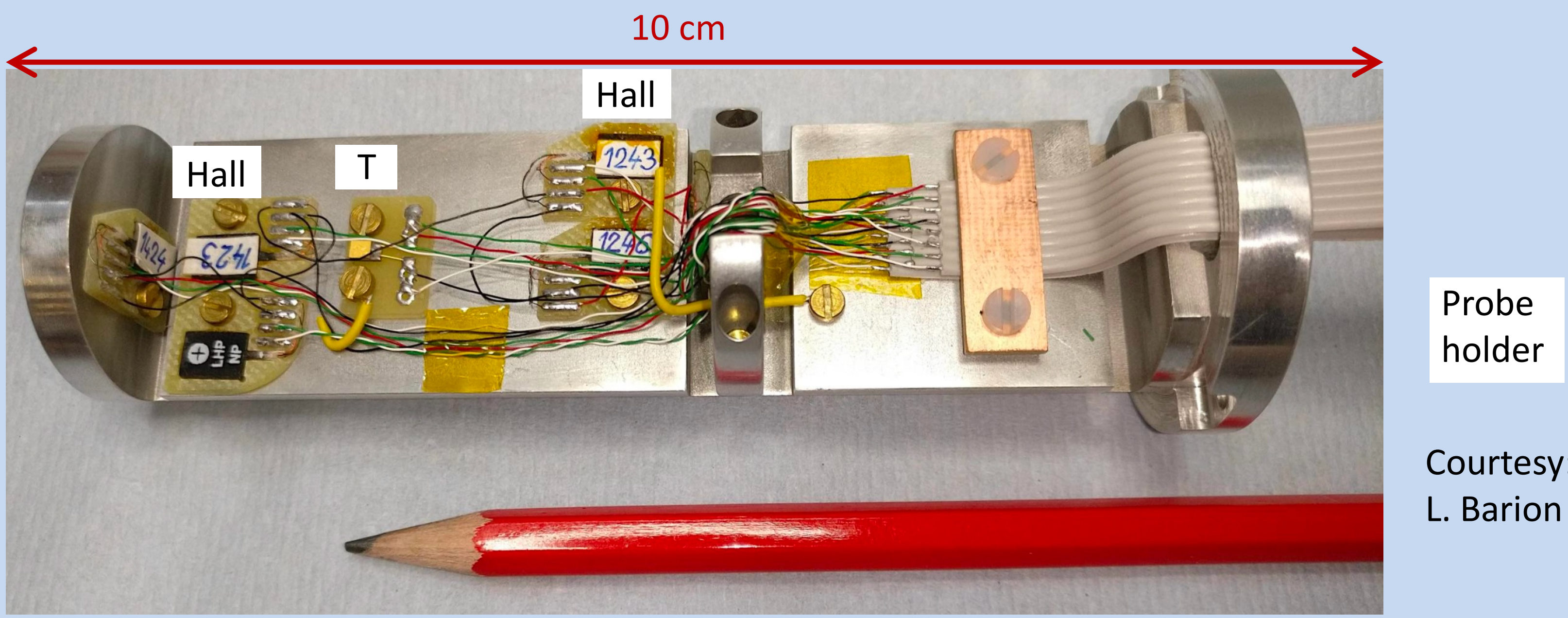
- ✓ Decouple mechanics
- ✓ Reduce material budget
- ✓ Increase acceptance
- ✓ Simplify cryostat
- ✓ Suppress quenches





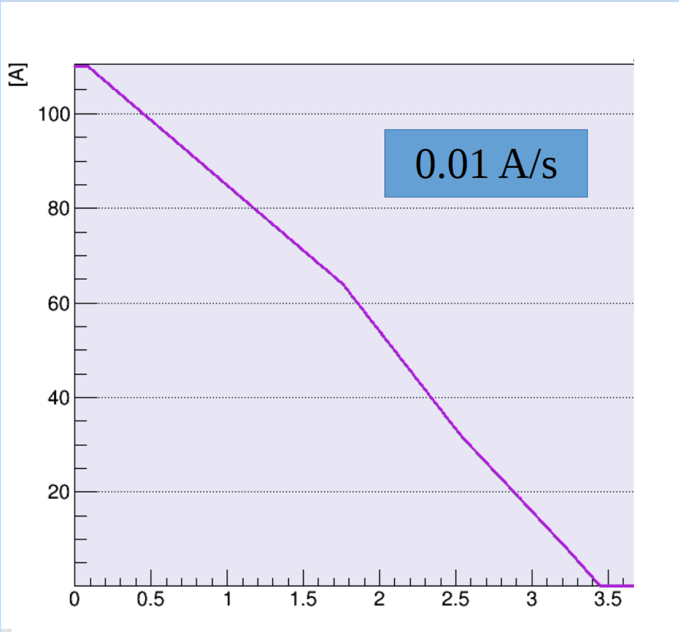
New Cryostat

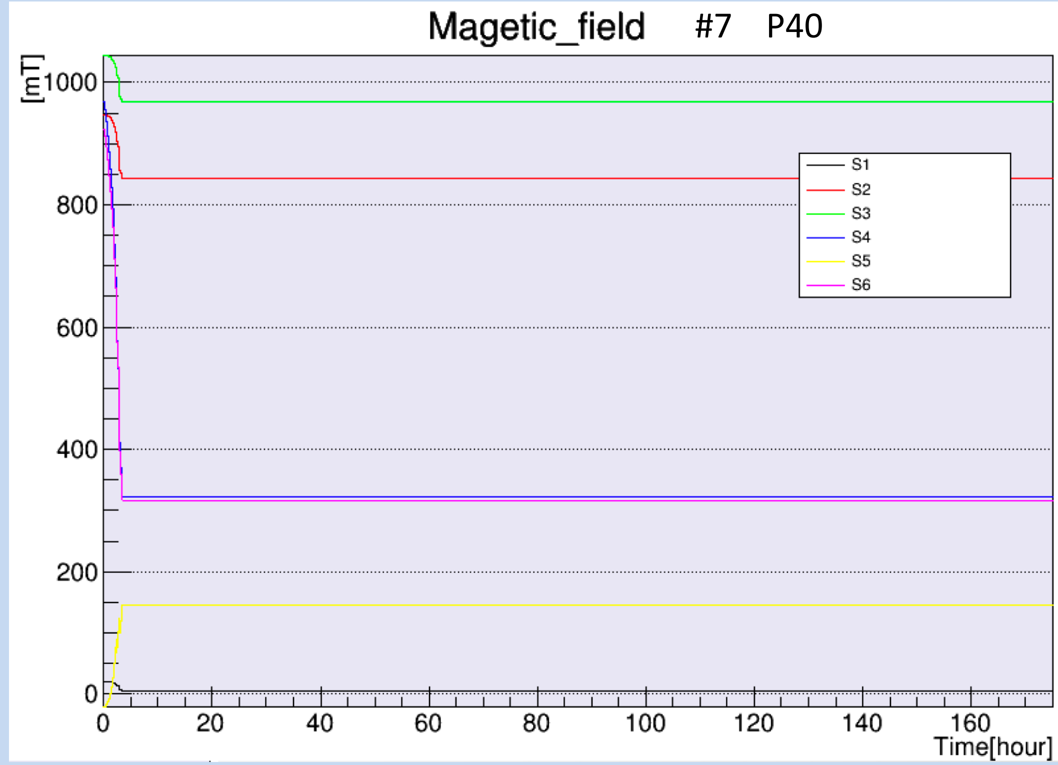


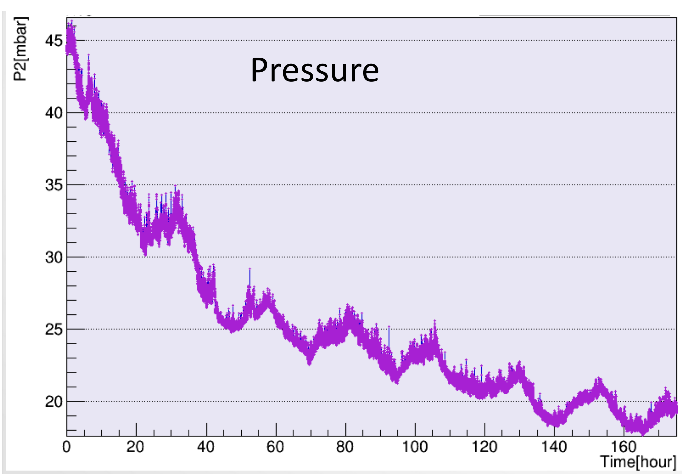


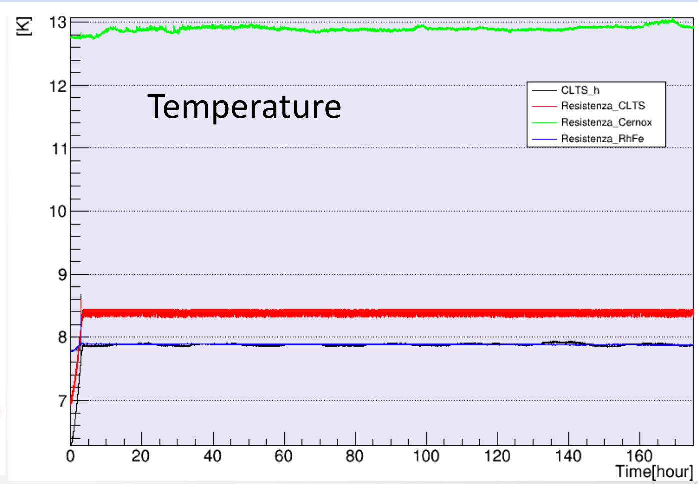
Courtesy: L. Barion

External dipole current
Ramp down from 110 to 0 A



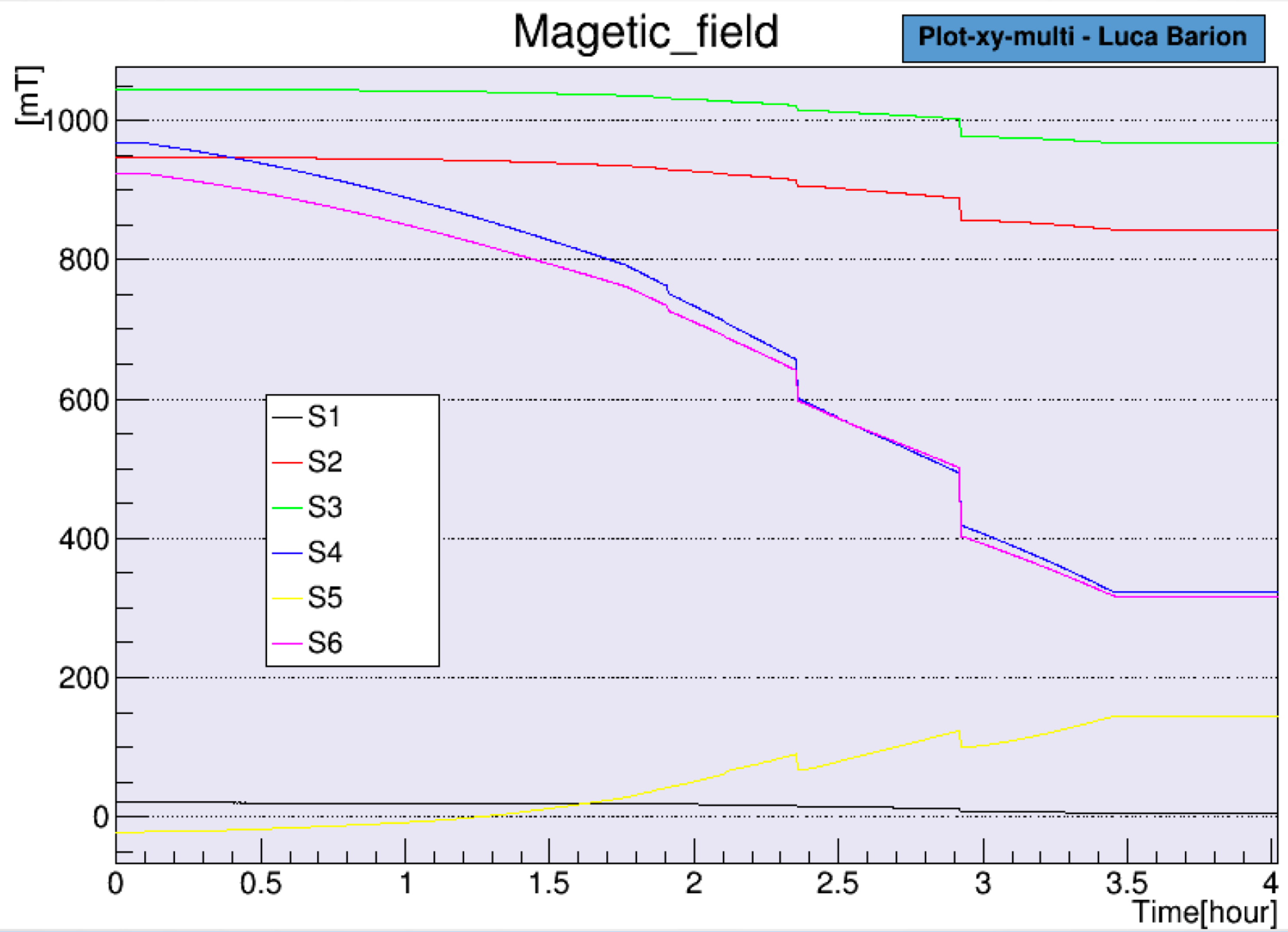






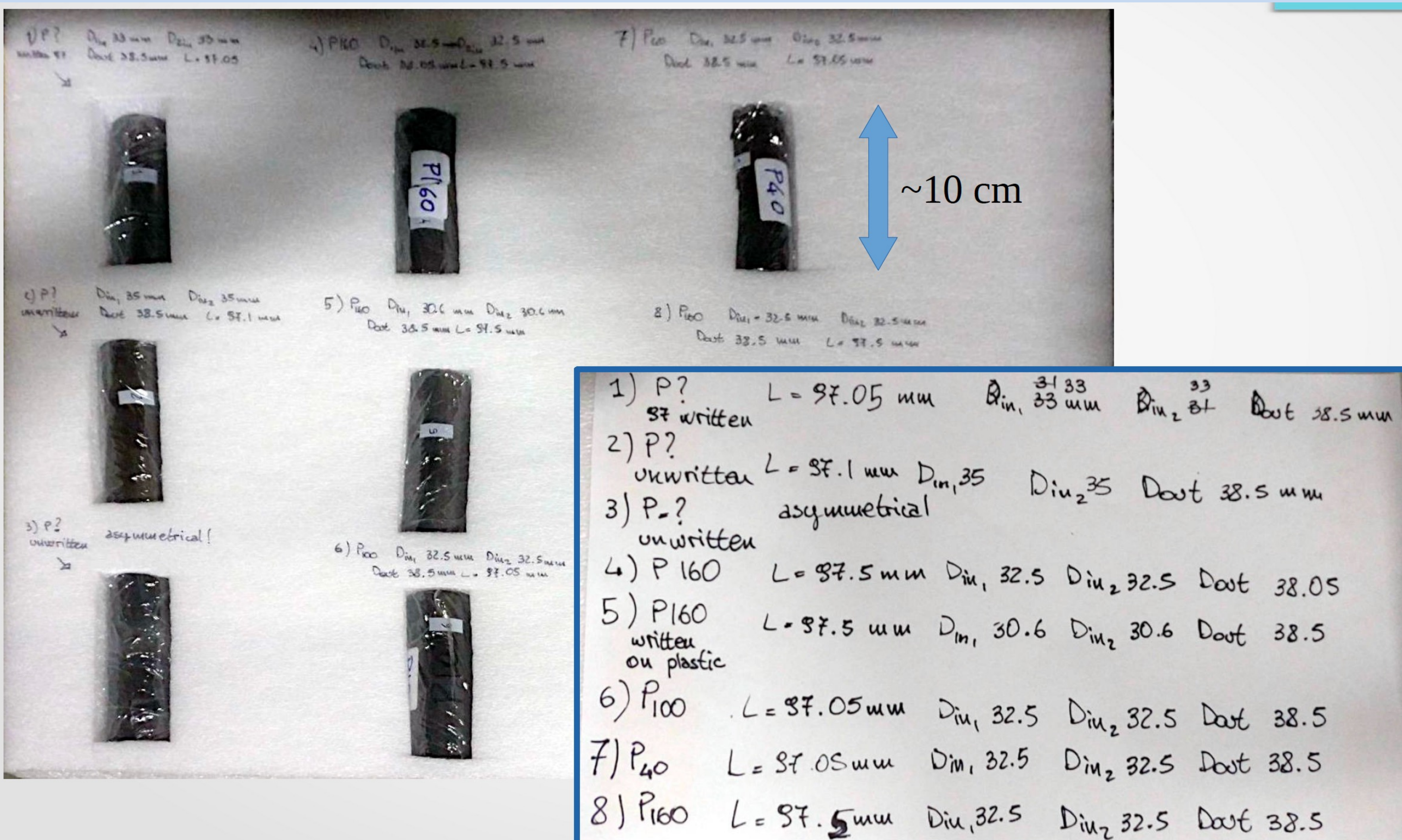
MgB_2 Flux Jumps

Exploring relationship with working temperature, field strength, field ramping time, MgB_2 alloy



Goal: ✓ Reproducibility (same or equivalent sample)

✓ Different grain size and thickness (sample optimization)



MgB_2 Performance

Cylinder #6 P100

Misura	Data		T(ITC)	Heater (ITC)	T(Rh Fe)	T(Cer nox)	inizo	fine	Ramp a	S2_inizio	S2_fin e	Delta	#F J	Fj_1	FJ@
			[K]	[%]	[K]	[K]	[A]	[A]	[A/s]	[mT]	[mT]	[mT]		[mT]	[A]
M	2023-01-28	a	off	0	8.8	15.0	110	0	0.05	976	92	884	0	0	-
S	2023-01-30	b	9	1.8	9.0	14.9	0	110	0.05	7	26	19	1	9	70
M	2023-01-30	d	11	24.1	11.7	16.4	110	0	0.05	975	149	826	1	815	5
S	2023-01-30	f	13	35.1	13.8	18.0	0	110	0.05	7	972	965	1	682	73
M	2023-01-31	a	13	35.1	13.8	18.0	110	0	0.05	975	274	701	1	692	21
S	2023-01-31	b	17	44.6	16.0	19.4	0	110	0.05	7	967	960	1	696	75
M	2023-01-31	c	17	44.6	16.0	19.4	110	0	0.05	975	222	753	1	744	15
S	2023-02-01	a	11	24.1	11.8	16.8	0	110	0.05	7	25	18	1	9	70
M	2023-02-01	b	11	24.1	11.8	16.8	90	0	0.05	852	829	23	1	15	13
M	2023-02-01	c	11	24.1	11.8	16.8	110	0	0.05	977	326	651	1	642	27
M	2023-02-01	d	11	24.1	11.8	16.8	110	0	0.01	977	311	666	1	657	24
S	2023-02-02	a	off	0	9.0	15.6	0	110	0.05	7	975	968	2	5	65
M	2023-02-02	b	9	1.9	8.9	15.6	110	0	0.05	975	957	18	1	10	32

The MgB_2 sample could sustain (or screen) the wanted field, but not (yet) in a reproducible way
Observed for all samples except the first that came as leftover from a past development*

* going to contact the manufacturer

Conclusions

RGH: a challenging but high-impact group of experiments

Moving towards a realistic experimental configuration that fulfills the PAC condition for approval

- forward CLAS12 detector with RICH
- upgrades in tracking systems
- existing or optimized target magnet
    - study background containment
    - assess physics reach

Working to present a viable configuration to the Lab management

You are all welcome to join:

Mailing list: clas12_rgh@jlab.org
Wiki page: https://clasweb.jlab.org/wiki/index.php/Run_Group_H

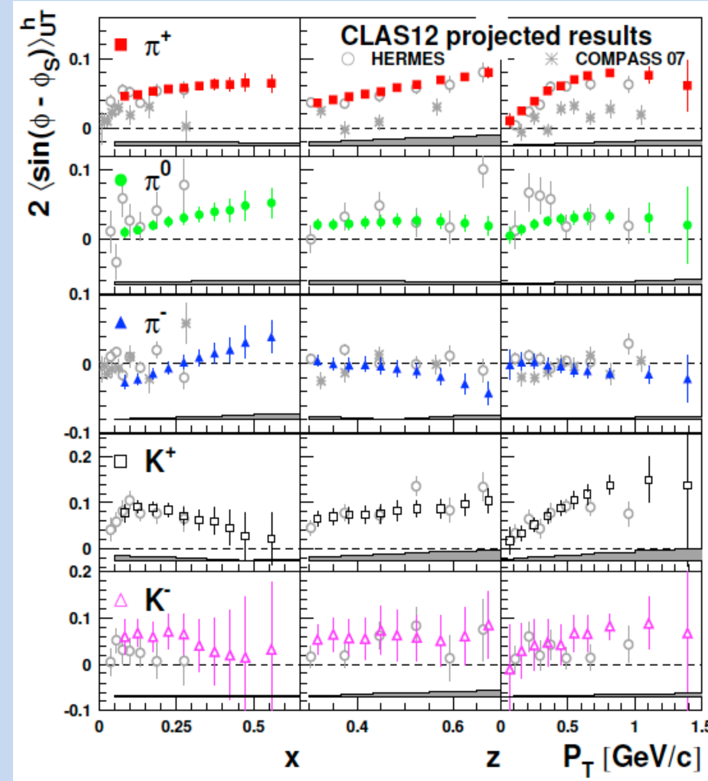
RGH Physics Goals

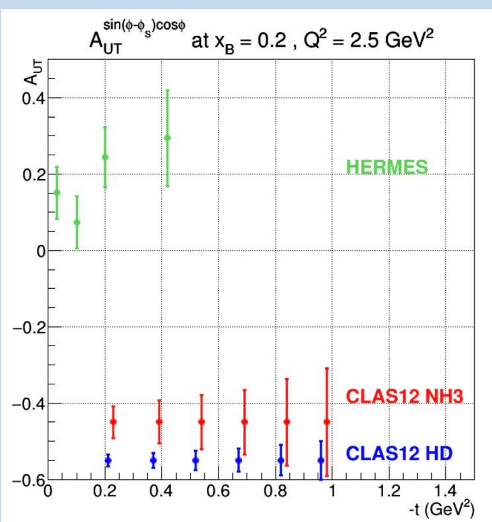
Experiment	Contact	Title	Rating	PAC days
C12-11-111	M. Contalbrigo	Transverse spin effect in SIDIS at 11 GeV with a transversely polarized target using CLAS12	A	110
C12-12-009	H. Avakian	Measurement of transversity with di-hadron production in SIDIS with a transversely polarized target	A	110
C12-12-010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

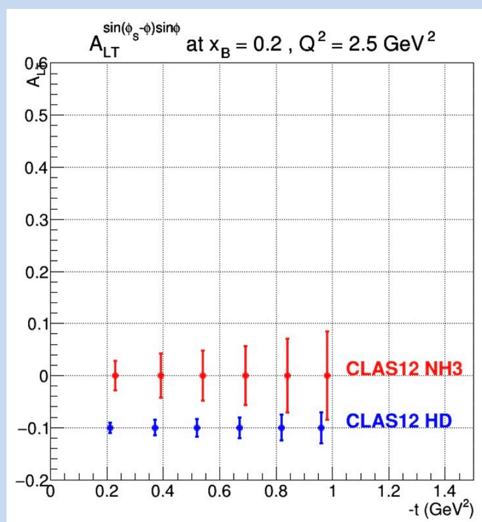
Moving from ideal HD-ice to realistic NH_3 target: conservative assumptions on luminosity and acceptance (recoil, wide angles)

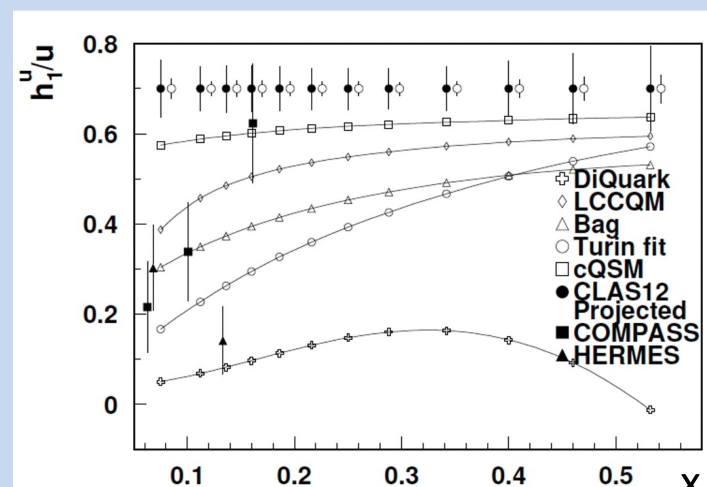
Even @ 10^{33} cm^{-2} s^{-1} projections show that RGH remains unique for wide-range A_{UT} towards e.g. GPD E, transversity and Sivers TMDs

Working is ongoing to optimize the new configuration



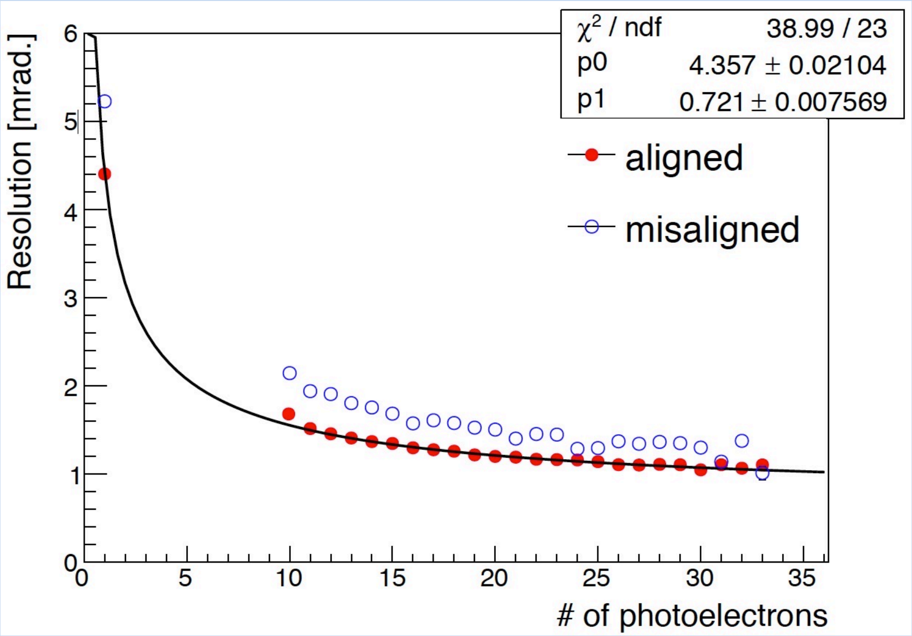


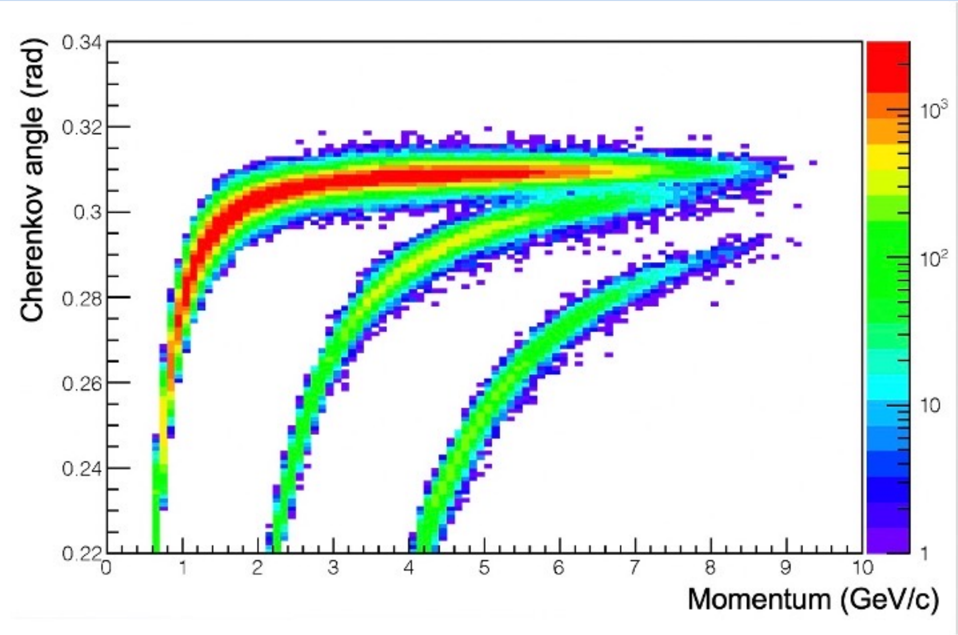




Angular Resolution

The goal of a pion-kaon 4σ separation at 8 GeV/c requires a resolution of 1.5 mrad*
(*forward region, less stringent requirements at large angles)





In line or better with respect the TDR targets:

- single-photon resolution of 4.5 ns

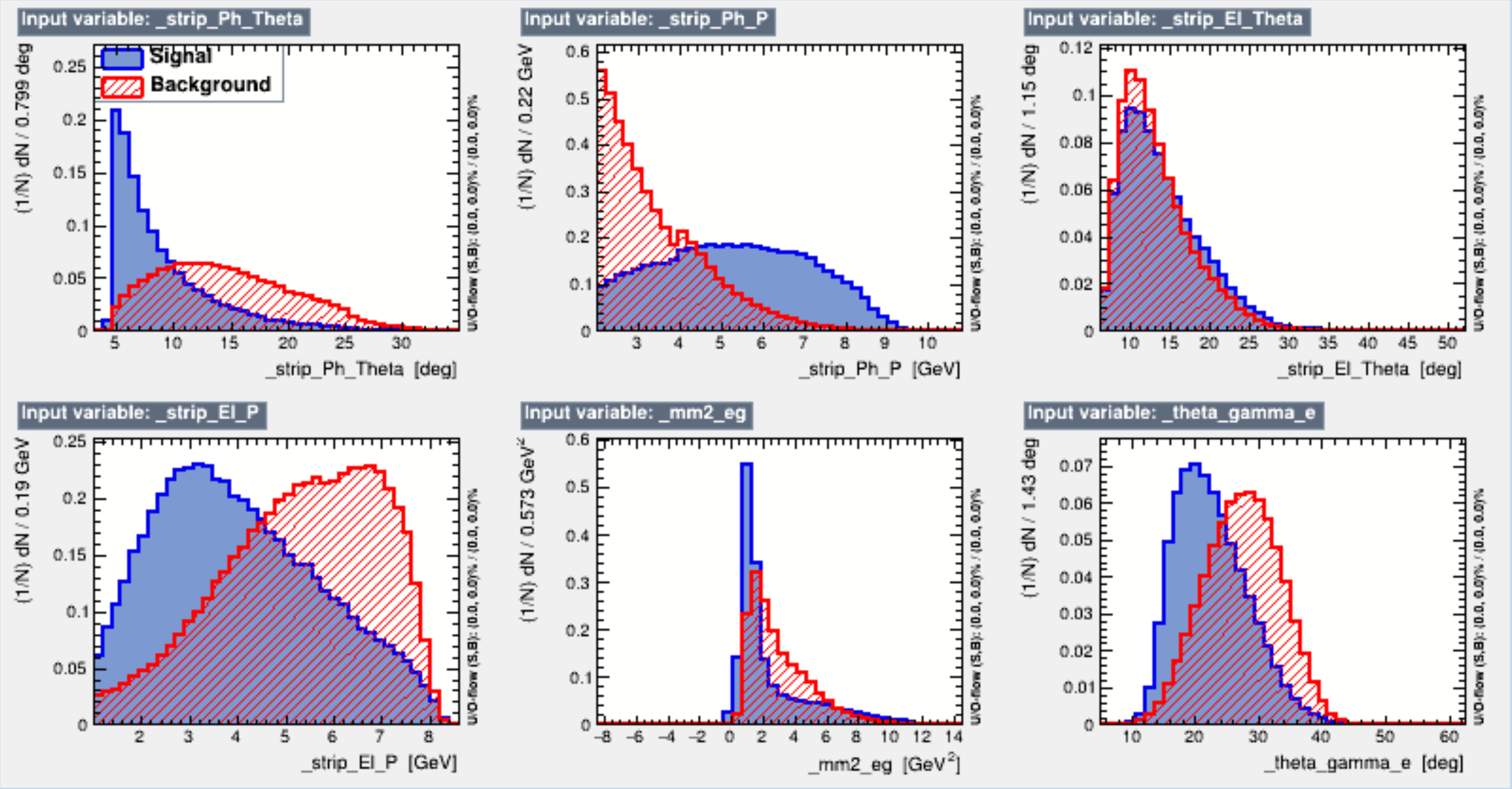
- number of photons around 18 for direct imaging

DVCS without Proton

Training of a MVA analysis based on ML techniques

Signal: DVCS simulation in RGH config.

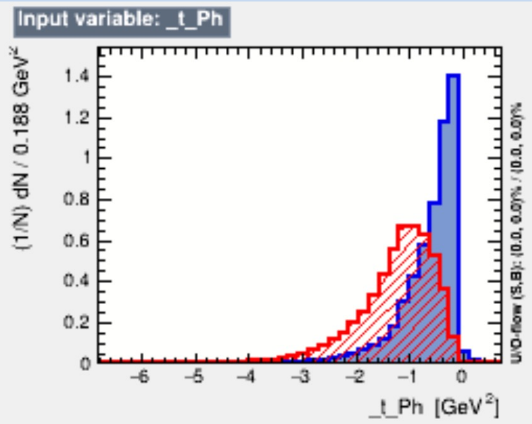
Background: pi0 simulation as DVCS in RGH config.

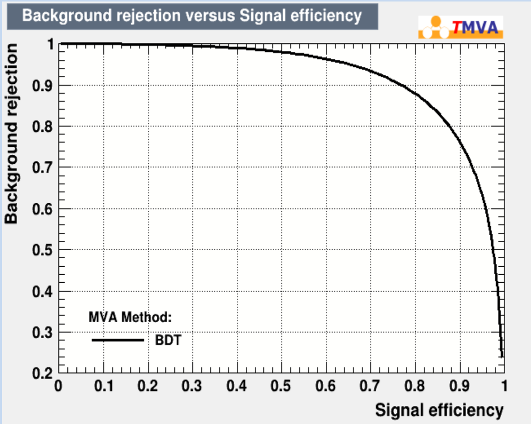


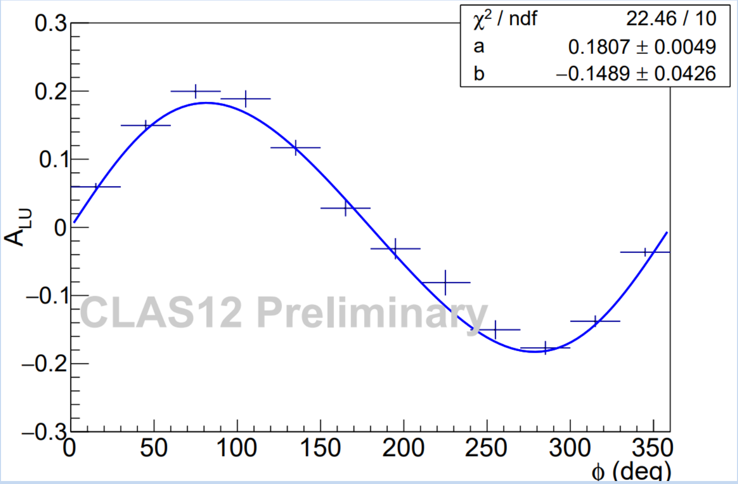
Classifier response assessment with

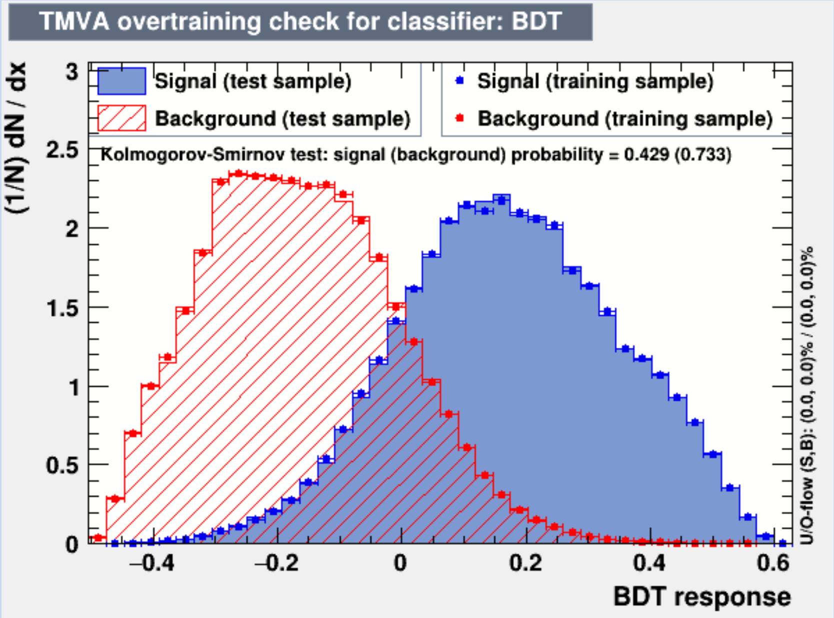
- data from RGA, to be extended to RGB and RGC
- alternative background subtraction methods

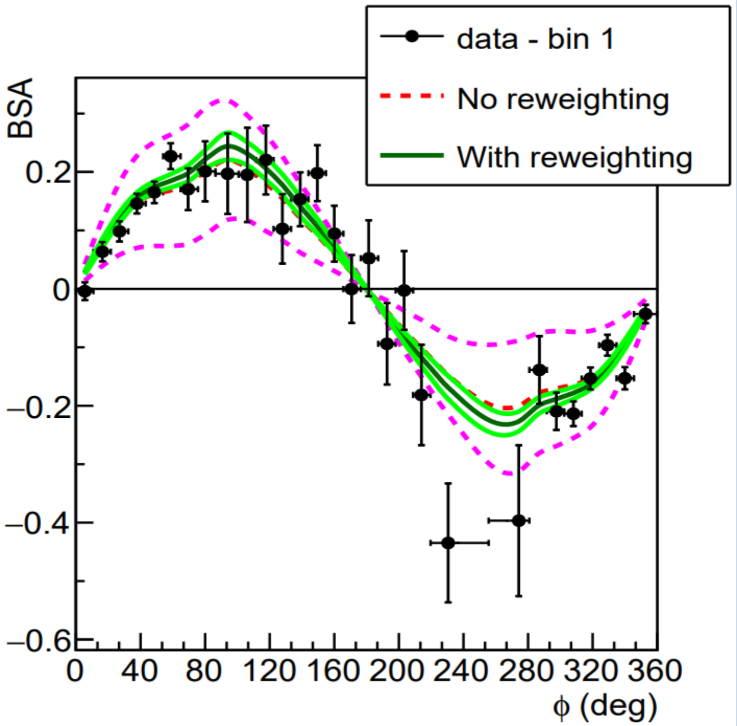
Results similar to RGA analysis note





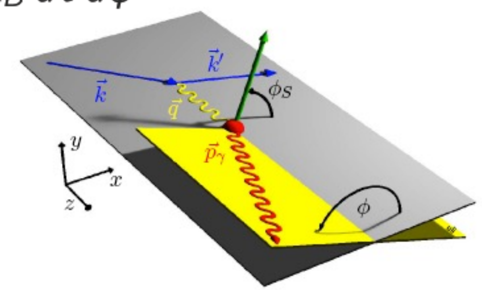


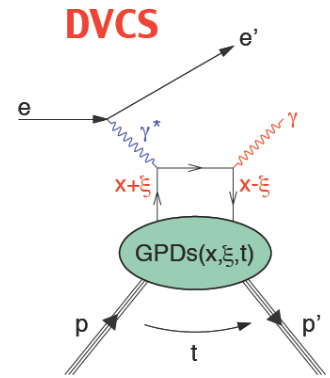


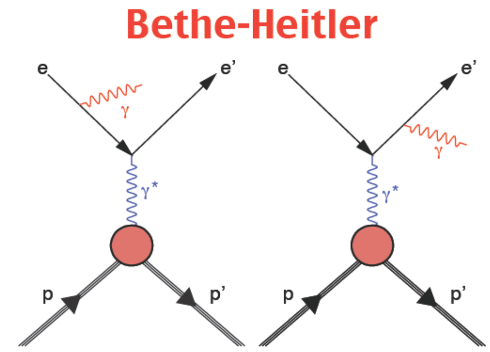


Nucleon 3D: DVCS

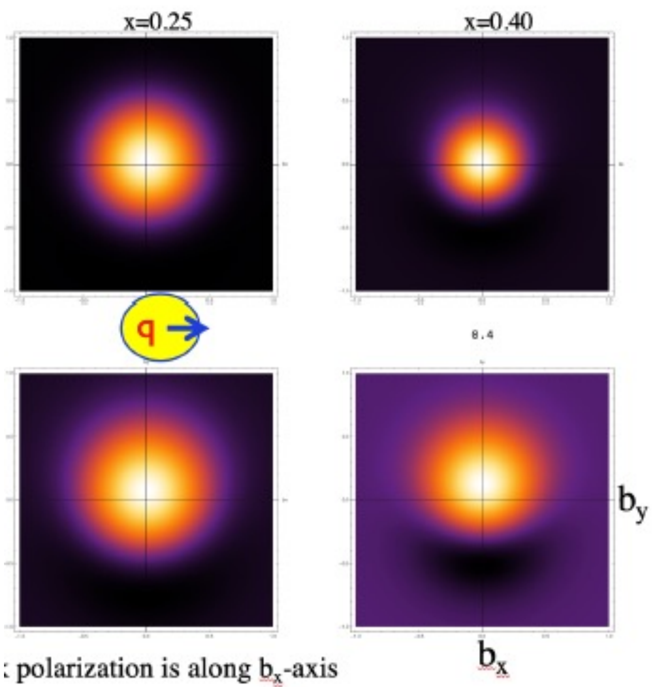
$$\frac{d^4\sigma}{dQ^2\,dx_B\,dt\,d\phi} \propto \left(|\mathcal{T}_{DVCS}|^2 + |\mathcal{T}_{BH}|^2 + \mathcal{I}\right)$$

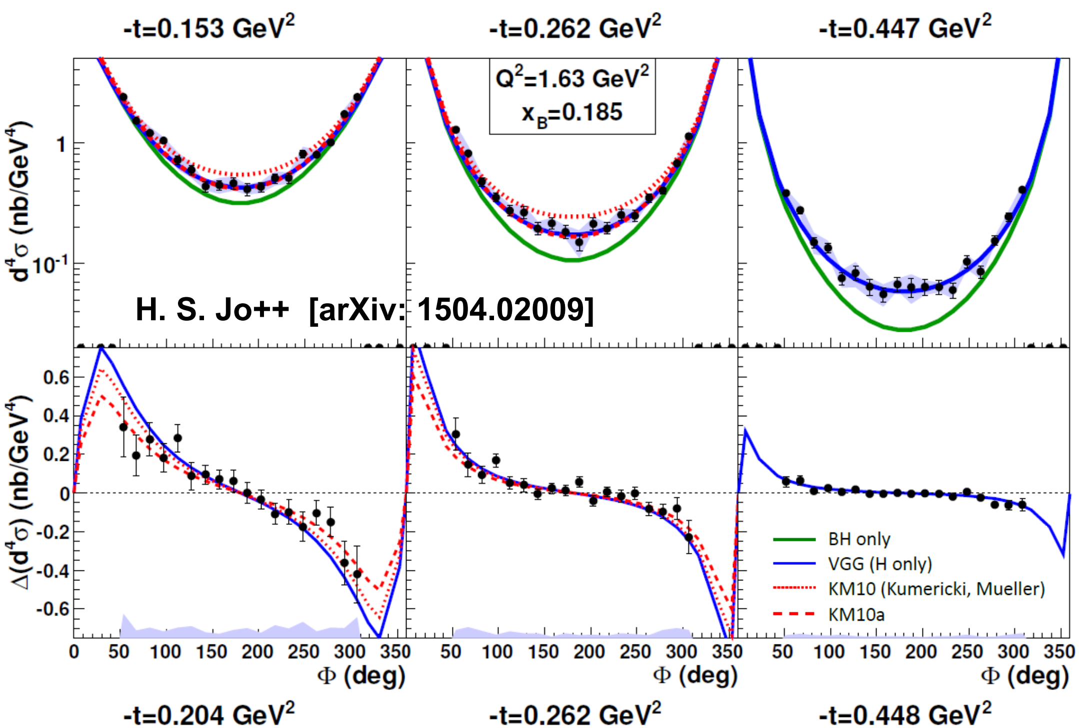






Information on the real and imaginary part of the QCD scattering amplitude





Run Group C

Example of 3 particle event into two RICHes (no calibration)