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

Contalbrigo Marco - INFN Ferrara

for RGH and CLAS Collaboration

CLAS Collaboration Meeting, March 6 - 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. Elouadrhiri	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 (with HDice) confirmed at PAC48 in 2020 (during jeopardy process)
RGH (without HDice) status modified to C2 in 2024

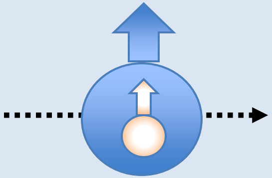
Access to unique observables in

- SIDIS hadron
- SIDIS Di-hadron
- DVCS

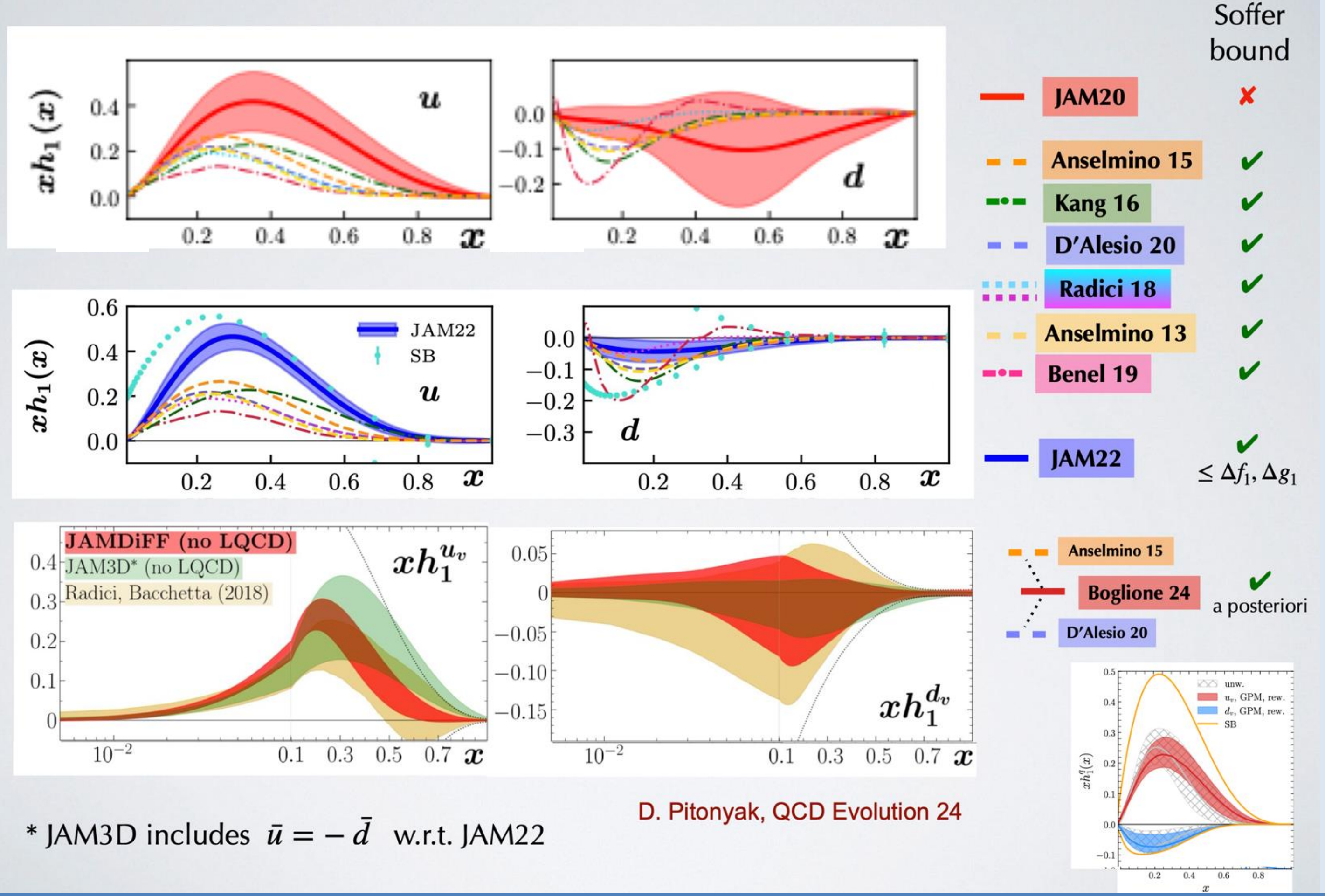
Gather unprecedented information on

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

Collins
(TMDs)



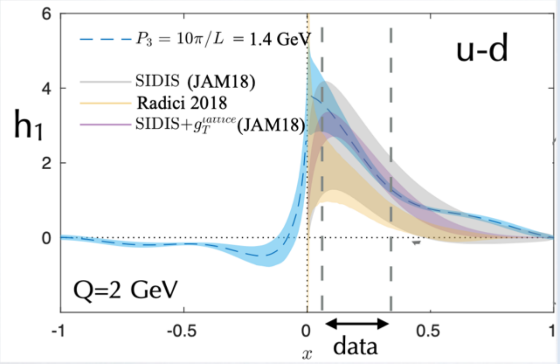
Di-hadron
(Collinear)

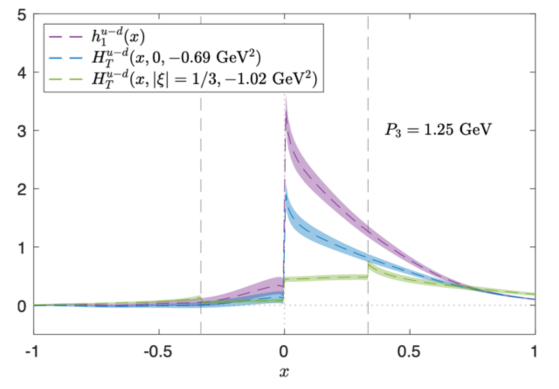


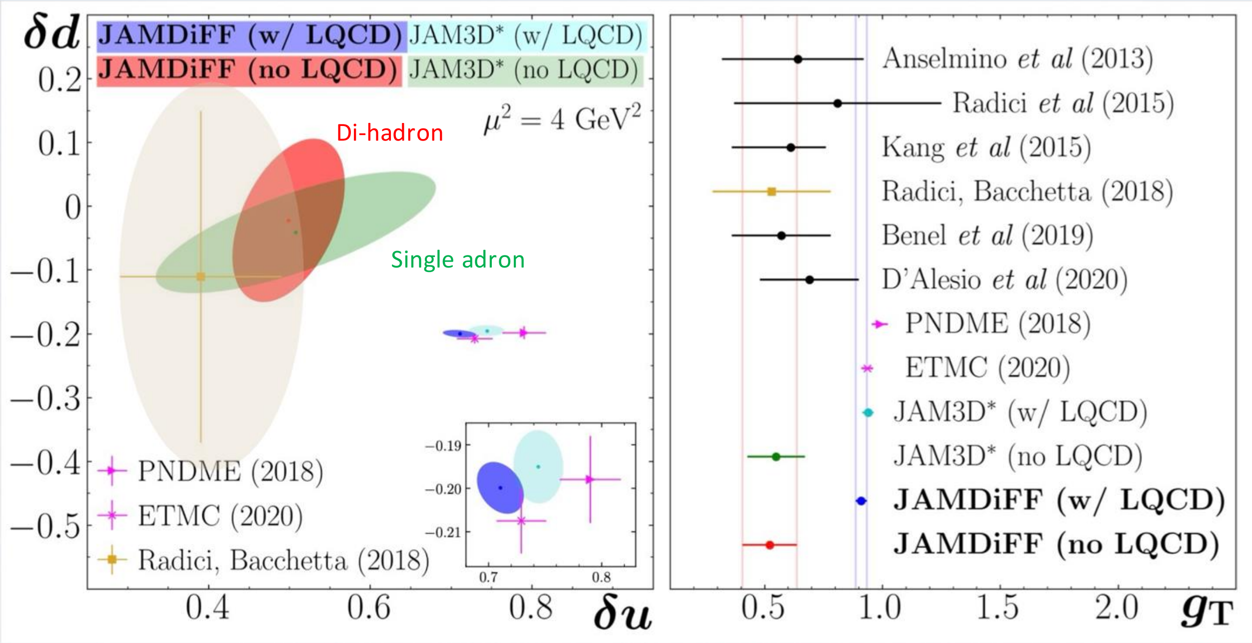
* JAM3D includes $\bar{u} = -\bar{d}$ w.r.t. JAM22

D. Pitonyak, QCD Evolution 24

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



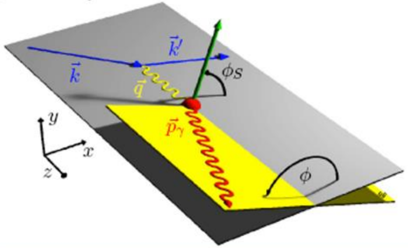


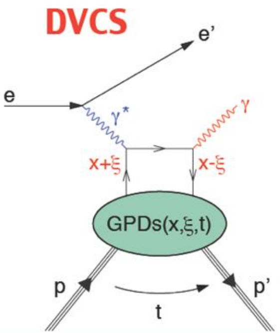


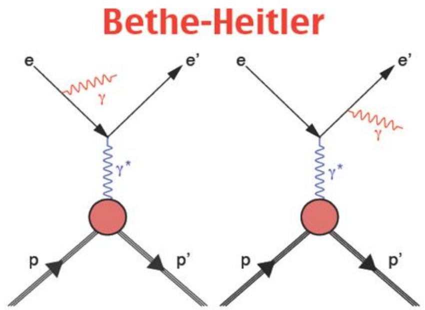
Adapted from D. Pitonyak @ QCD Evolution 24

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

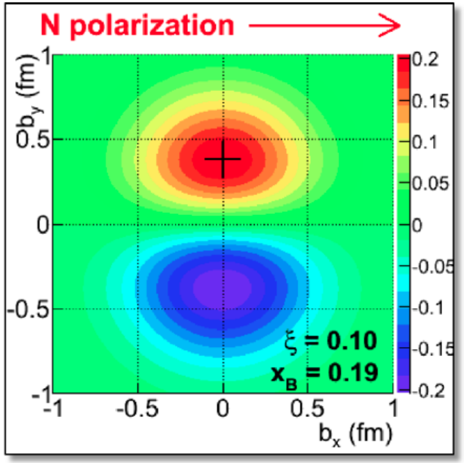
ep → e' γ p'







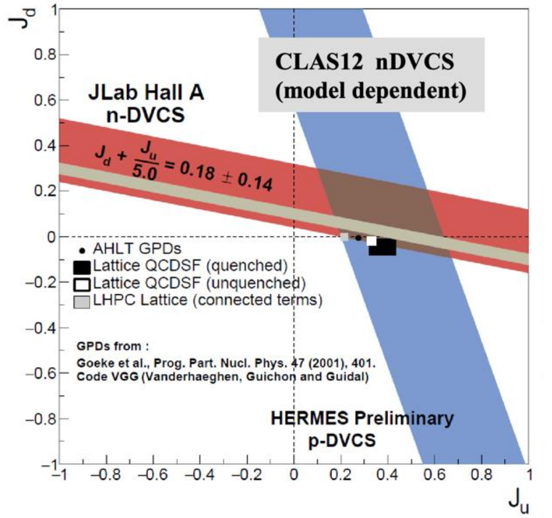
Information on the real and imaginary part of the QCD scattering amplitude



Access to elusive E_p GPD

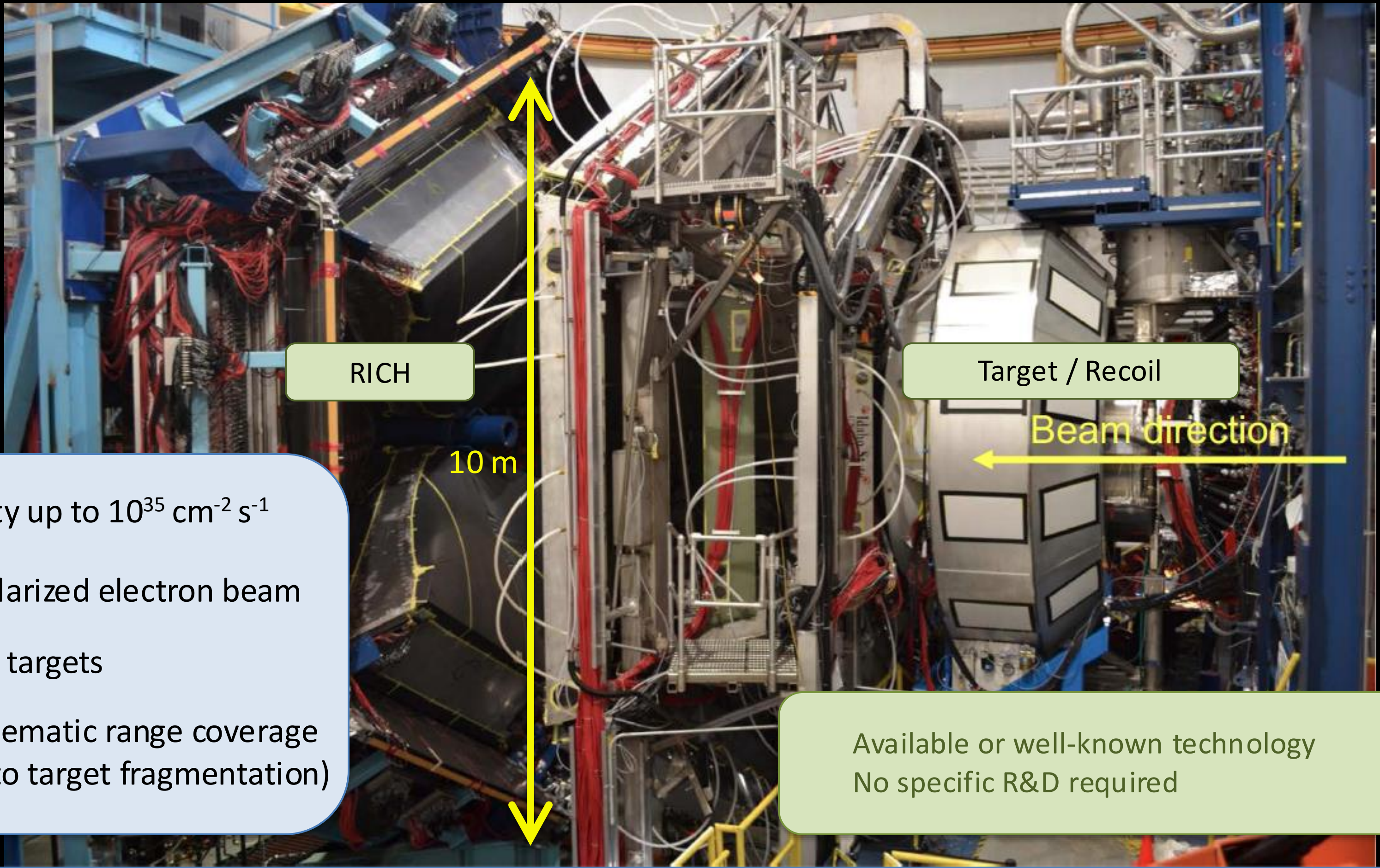
OAM $L_q = J_q - ½\Delta\Sigma$ via Ji sum rule

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



Run Group H

Large acceptance spectrometer. Operative since 02/18



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

Highly polarized electron beam

Polarized targets

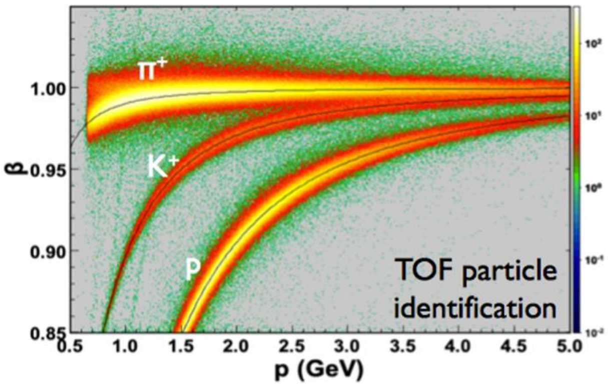
Broad kinematic range coverage
(current to target fragmentation)

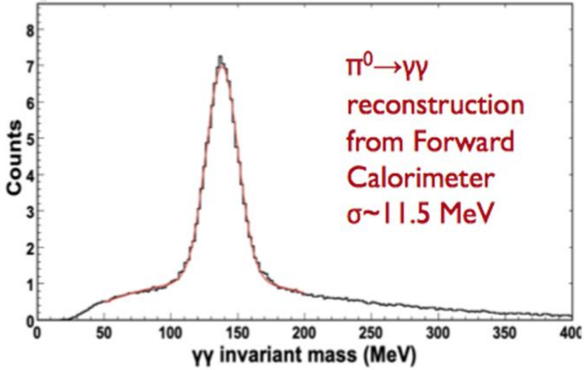
Available or well-known technology
No specific R&D required

RGH Particle ID

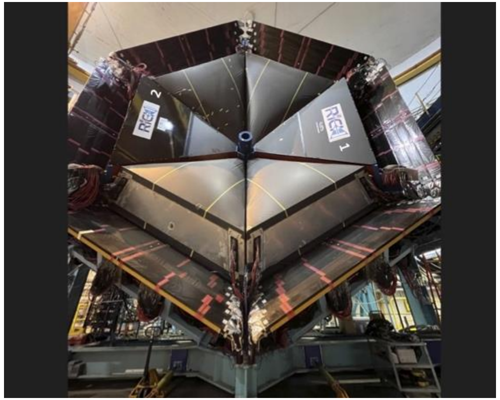
Semi-inclusive physics with unprecedented coverage of valence & flavor sensitivity

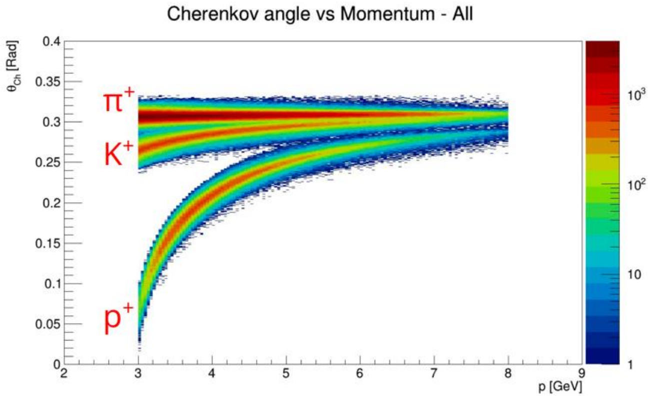
Time-of-flight system

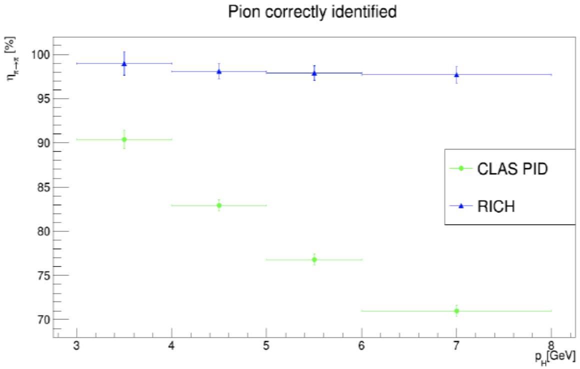


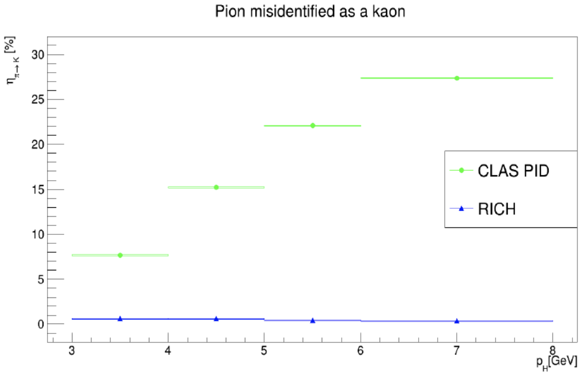


Ring-imaging Cherenkov (completed in 2022)









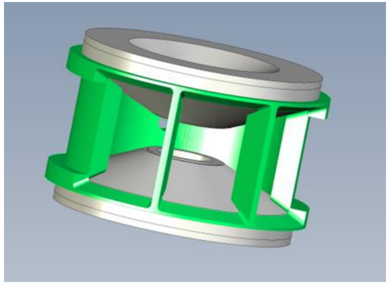
HDice (frozen-spin) did not meet RGH specifications

Most viable solution to prioritize physics vs R&D

Consolidated dynamically polarized NH_3 technology

Designed based on already successful realizations

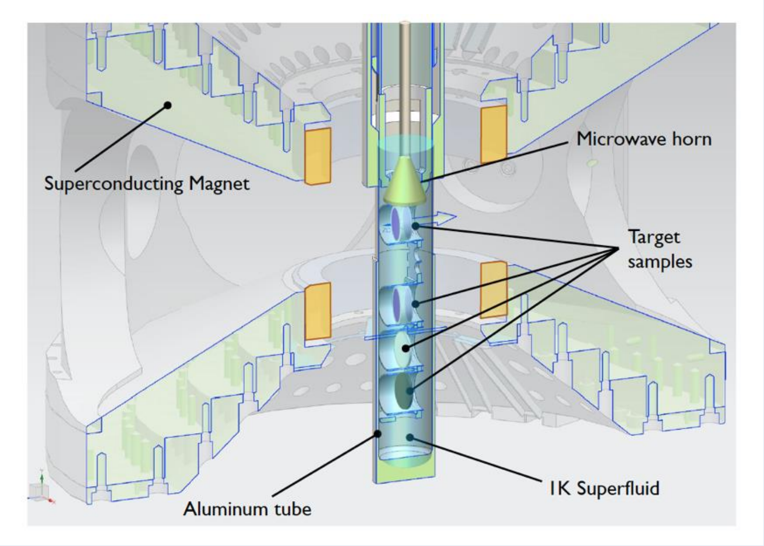
Hall-A G2p-Gep target (copy optimized for HTCC)
Hall-C E12-15-005 magnet (copy optimized for recoil detection)

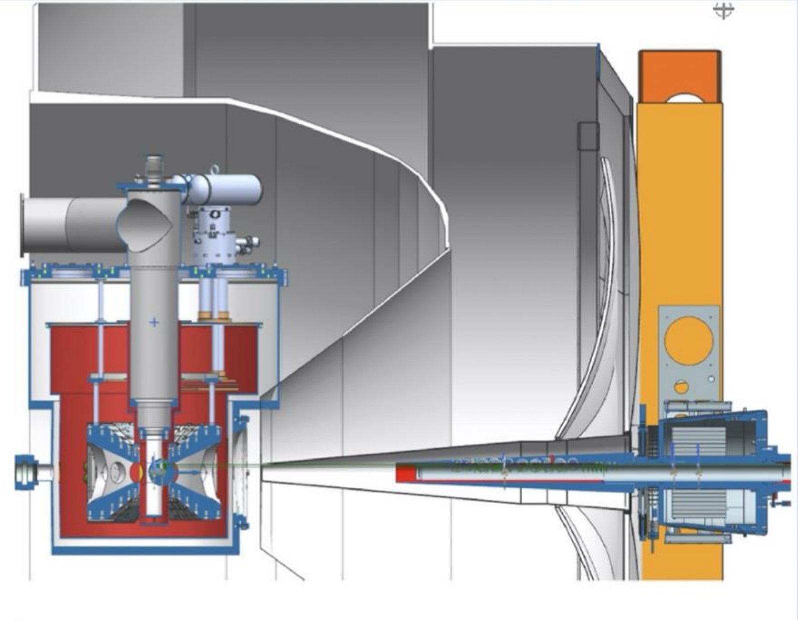


5T dipole acceptance:

$\pm$ 25^{o} horizontal

$\pm$ 65^{o} horizontal





Within RGH program, HDice was upgraded and tested at UITF and found unable to provide the wanted luminosity

RGH current solution is most viable (no R&D) and superior to the conditionally approved HDice by PAC

PAC stipulated conditions for approval

Quantity	HD	NH_3
$(1-\tau)$	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

Limited by polarization lifetime

Conservative estimate:

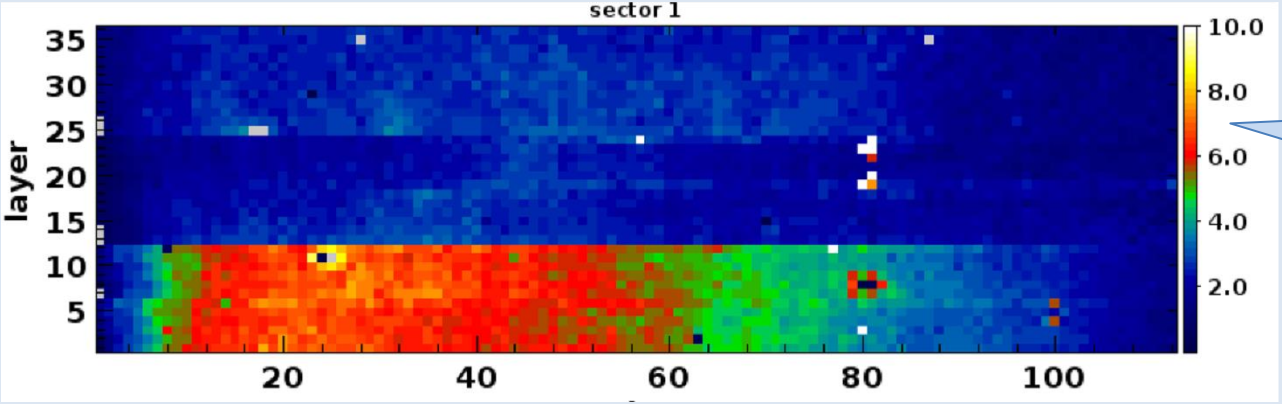
Existing or commercial magnets

Consolidated target technology

Target design already in use at JLab

Current CLAS tracking capability

Limited by background

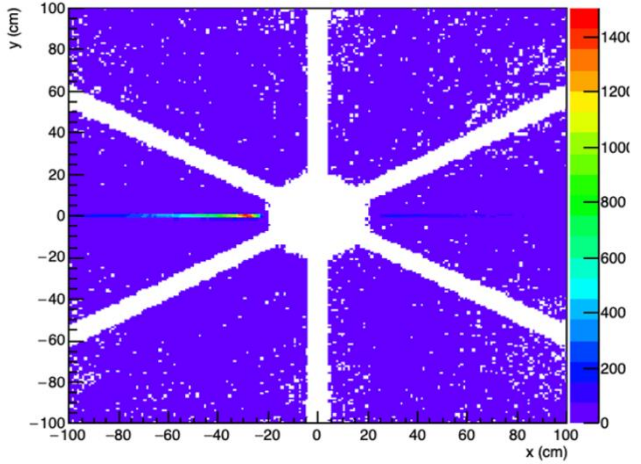


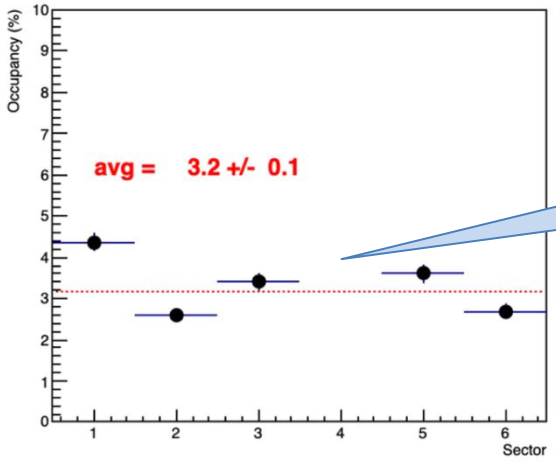
RGC DATA

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

PAC52 Outcome

PAC52 report:

- concludes that scientific case remains strong but details need to be sorted out

- does not differentiate between SIDIS and DVCS experiments

- does not inquiry the feasibility of the new setup

- wants detailed model and full simulation:

  - beamline
  - recoil
  - background vs systematics

- wants the scientific impact to be clarified:

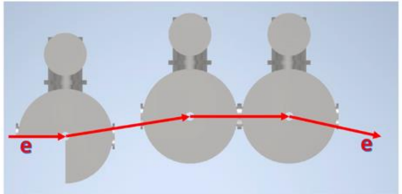
  - update phenomenology vs CLAS12 phase space
  - PAC days vs acceptance

RGH Beam Line

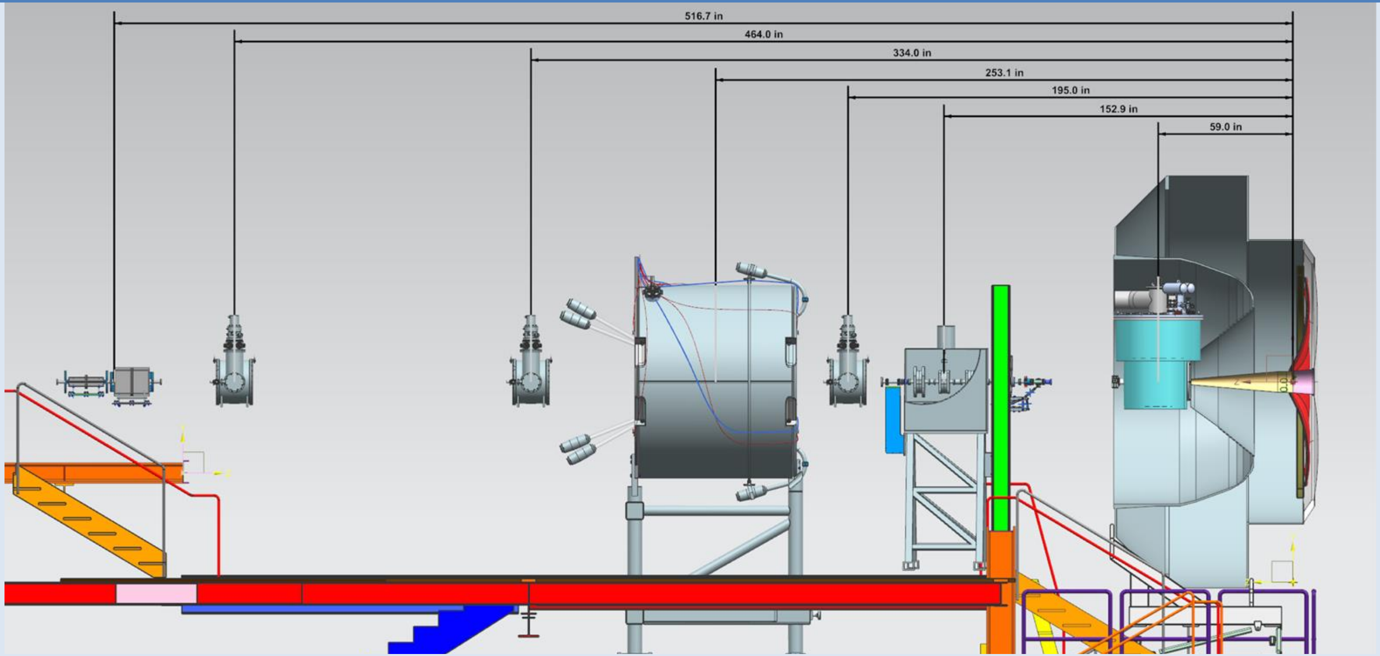
Based on

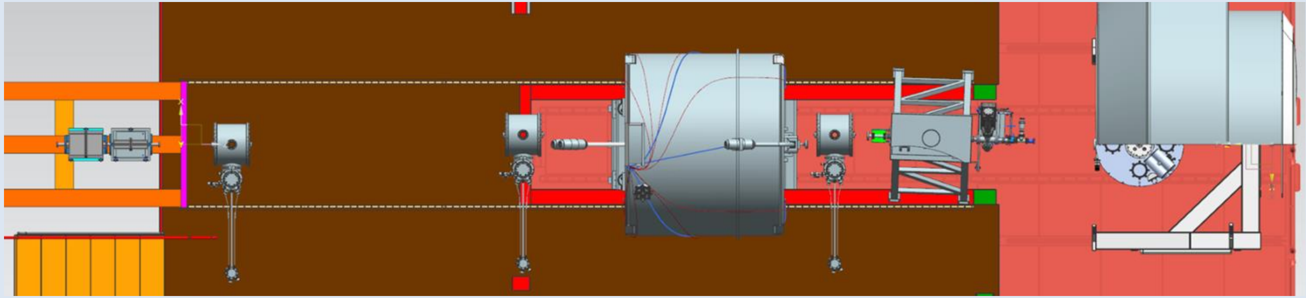
existing 0.7 mm raster

commercial 7.5T magnets

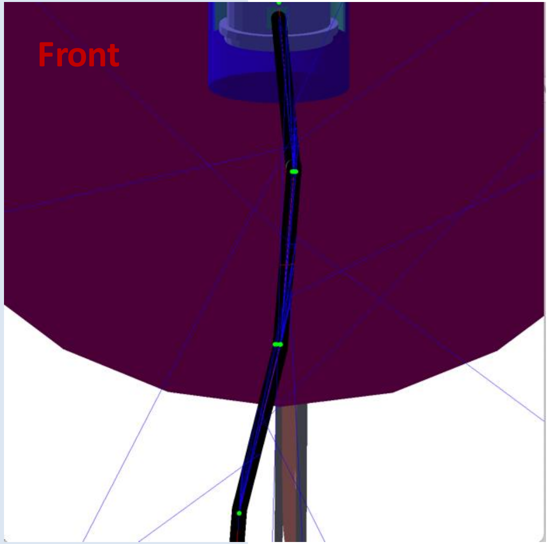


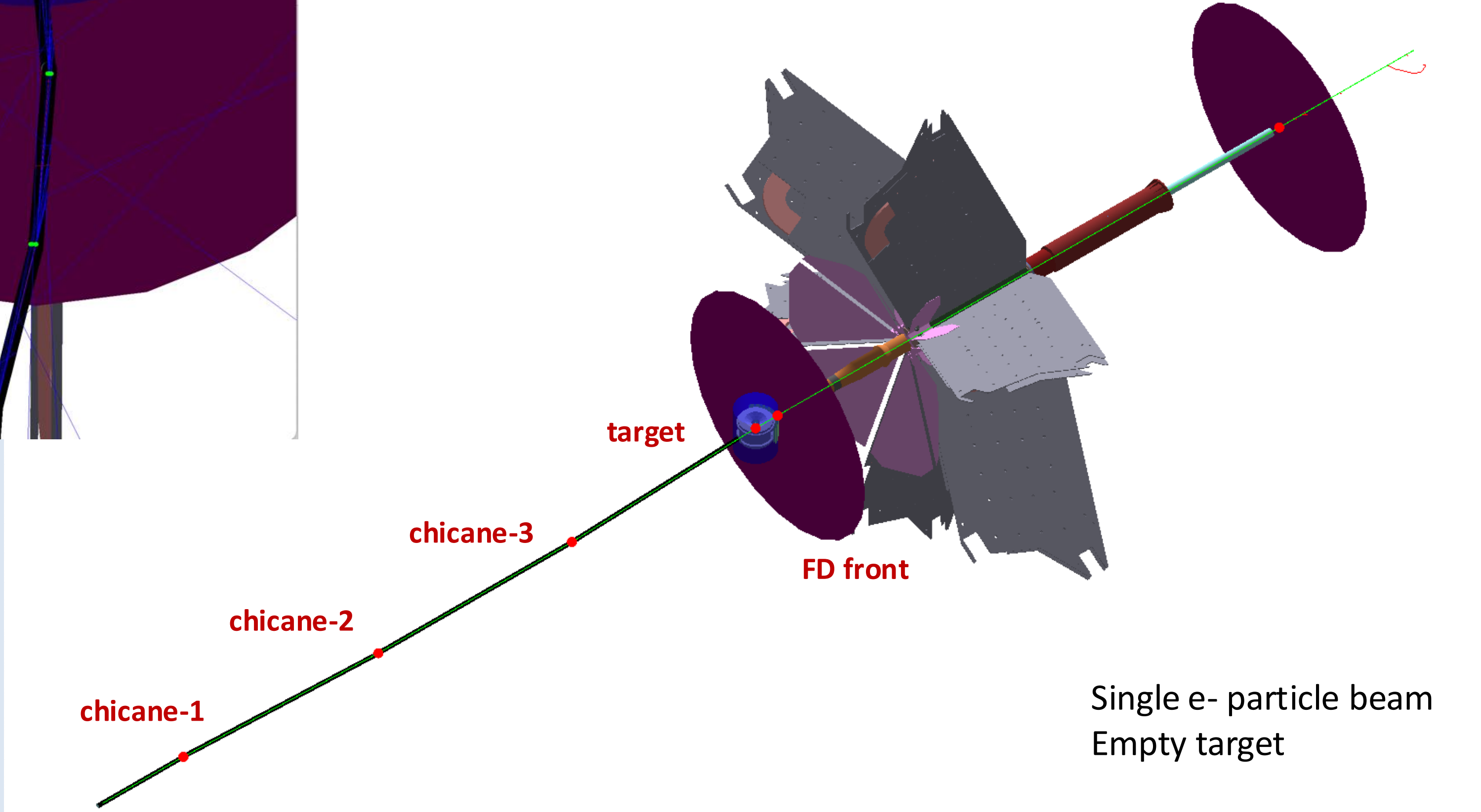
- ✓ space
- ✓ synchrotron radiation
- ✓ beam rastering



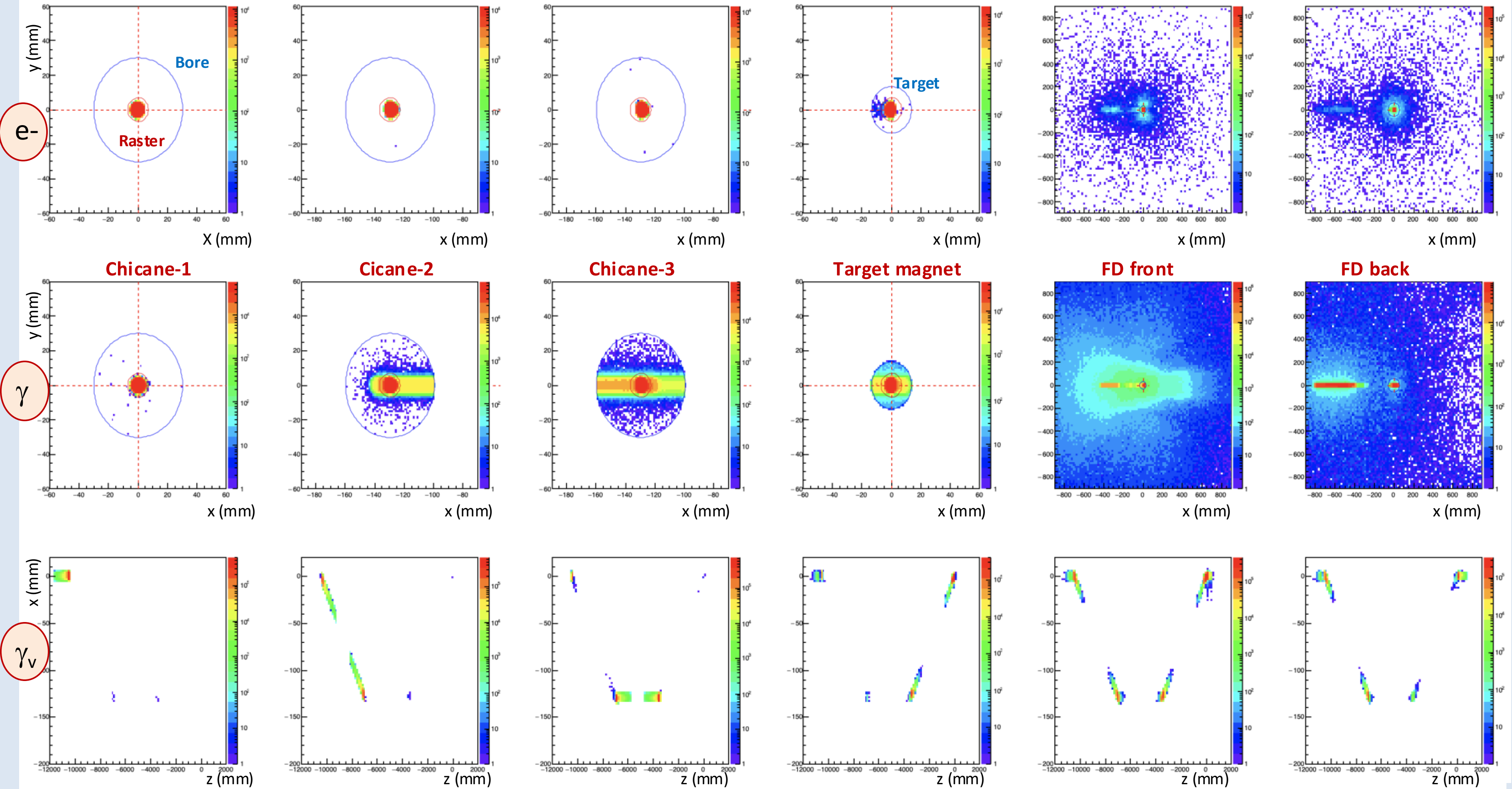


RGH Beam Line



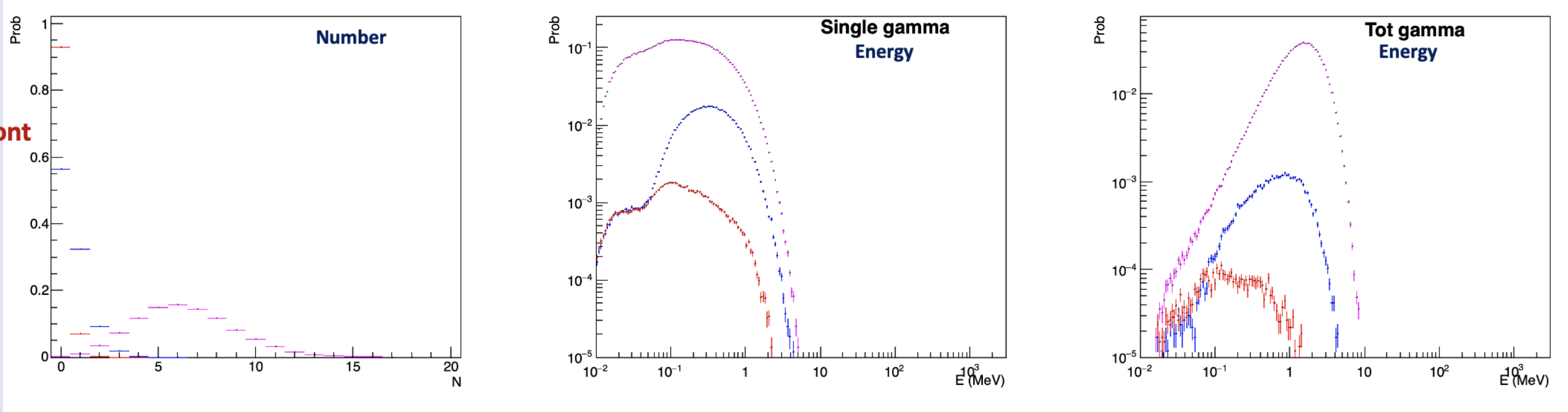


Single e- particle beam
Empty target


e-
γ
γ_v
Bore
Raster
Target
Chicane-1
Cicane-2
Chicane-3
Target magnet
FD front
FD back
y (mm)
X (mm)
x (mm)
z (mm)

Pipe + 15 mm Pb is enough to effectively suppress the synchrotron radiation

FD front

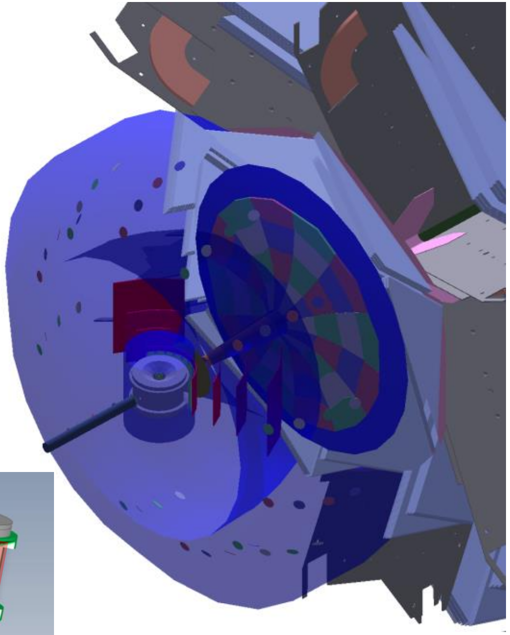


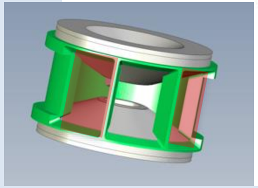
Residual background provides a negligible contribution to DC occupancies at 5 10^{33} cm^{-2} s^{-1} luminosity

RGH Recoil Reconstruction (from PAC52)

Recoil concept (left-right)
3 tracking layers + 1 TOF layer (50 x 50 cm^2)

based on "flux detector"
with reasonable resolution



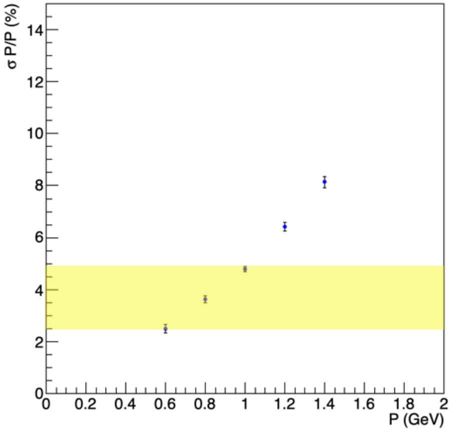


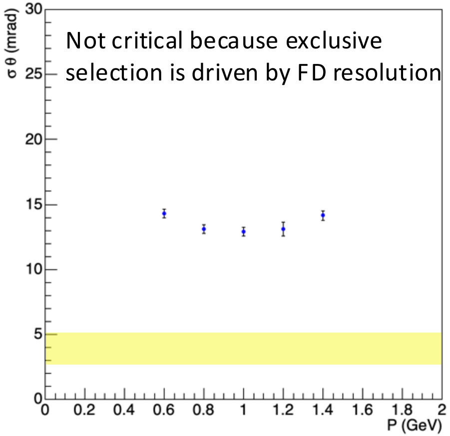
Simulated recoil resolution for

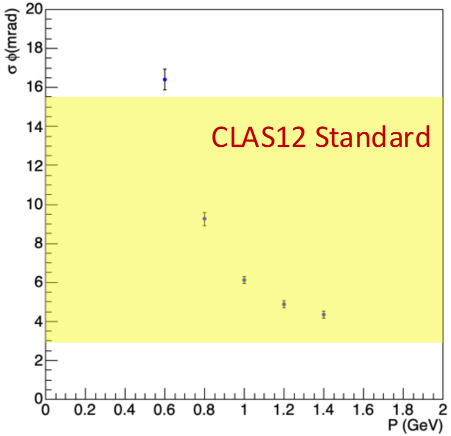
$\sigma_{x,y}$ O(100 μm)

σ_t O(100 ps)

and CLAS12 FD tracking resolution





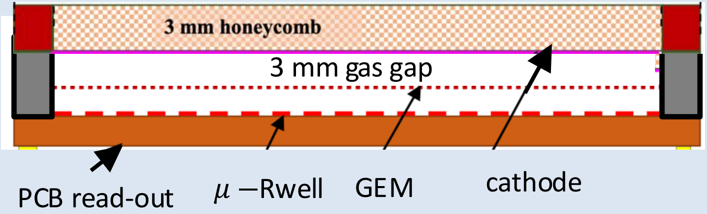


Recoil Tracking

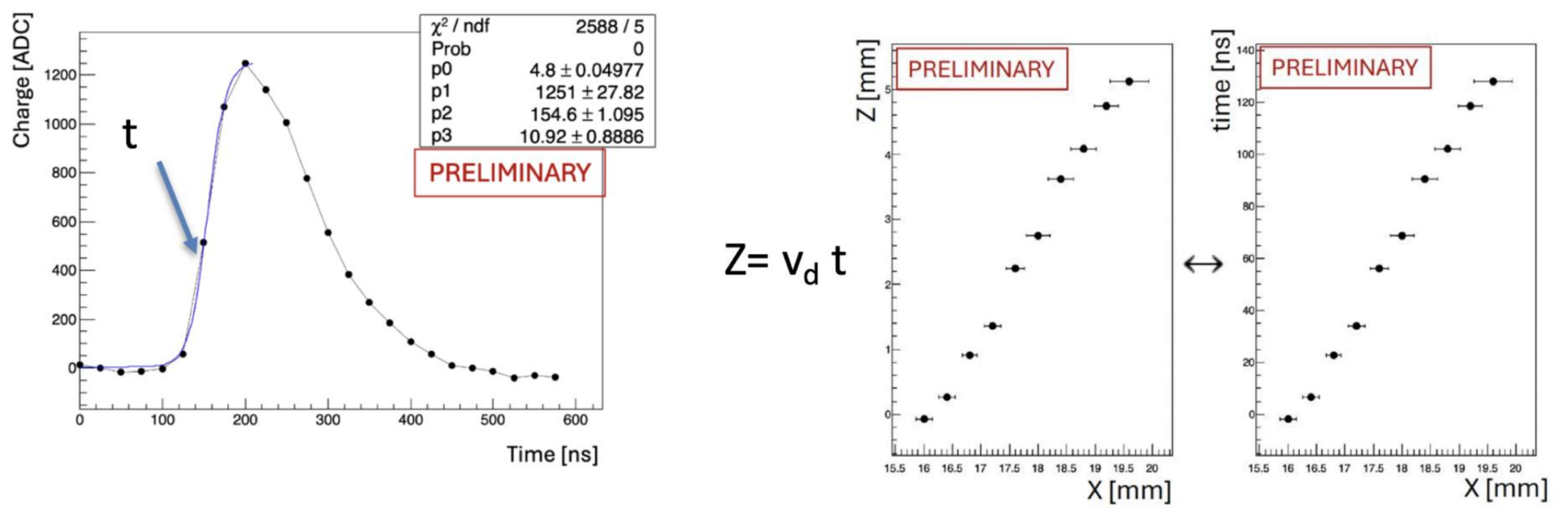
μRwell as spin off of the high-lumi project (various prototypes from 10 x 10 cm^2 up to 40 x 46 cm^2 exist)

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



Test-beam at CERN in Oct ’24

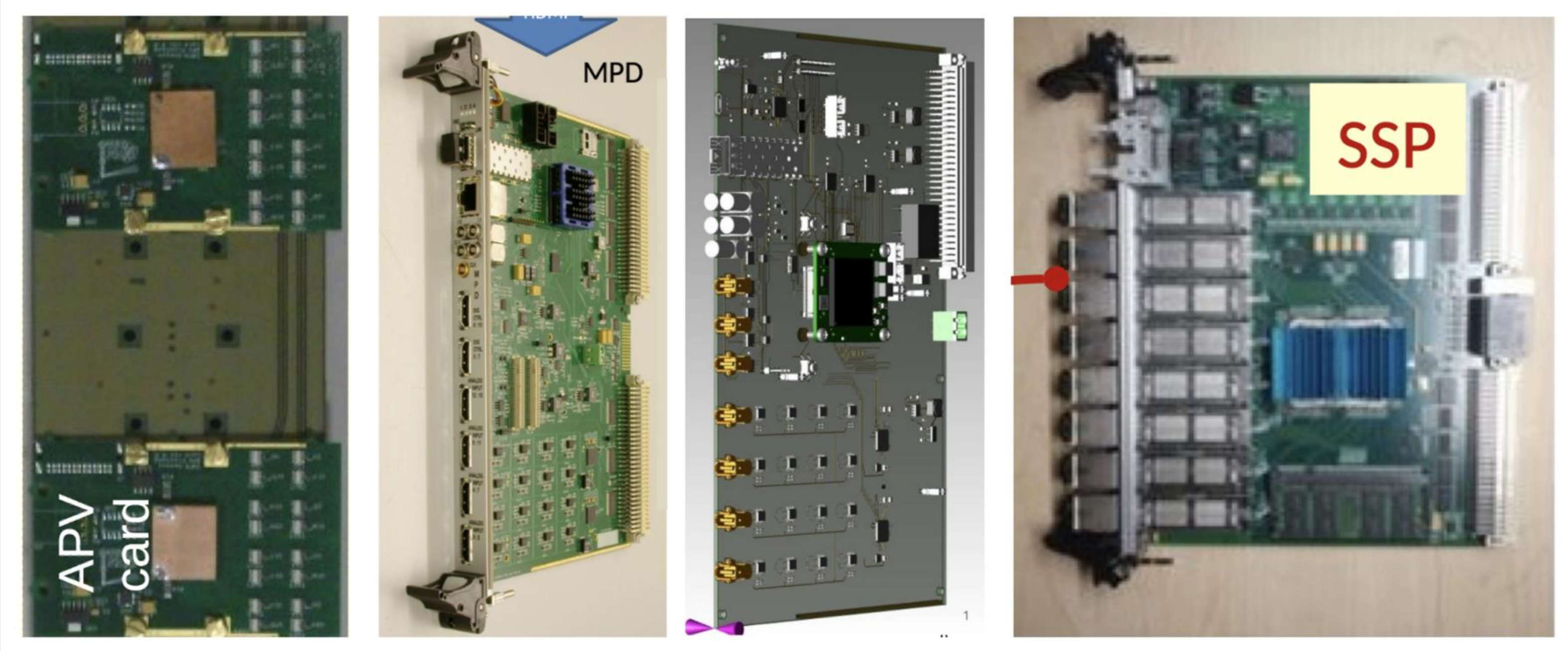


Recoil Tracking Readout

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)

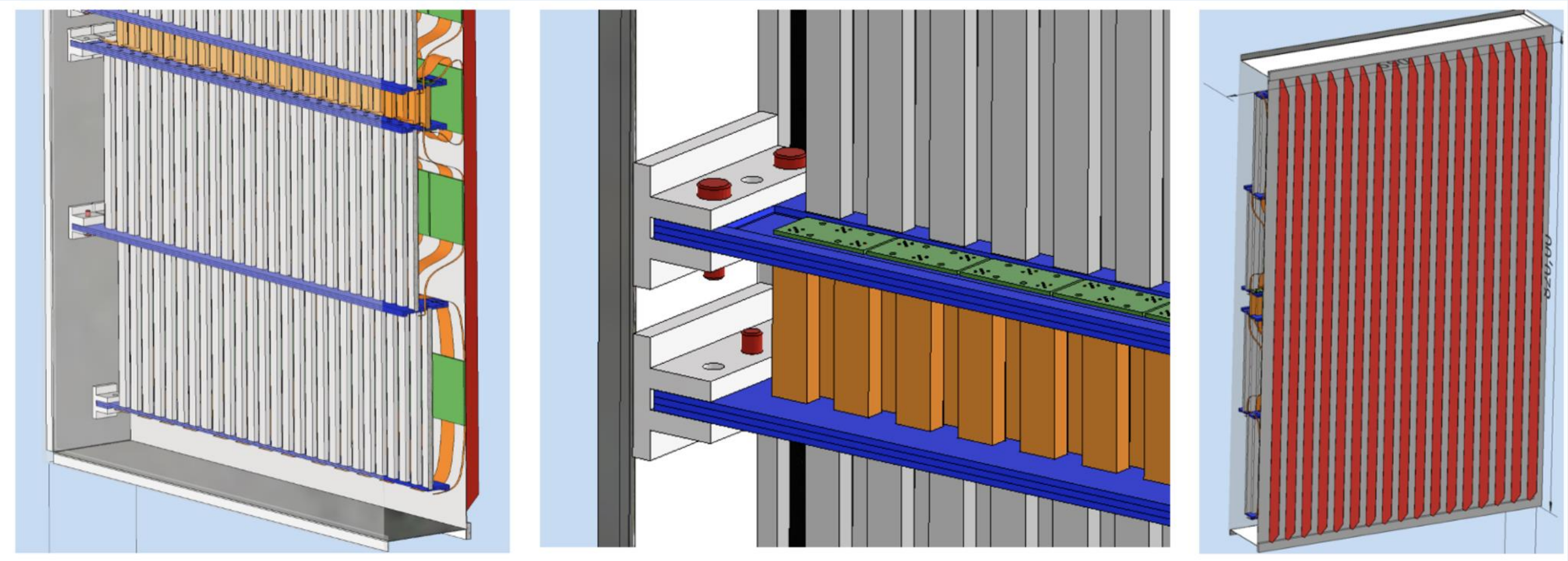
- ✓ Able to cope with 500 kHz/cm^2 and 60% occupancy
- ✓ Same system used with the υRwell prototypes



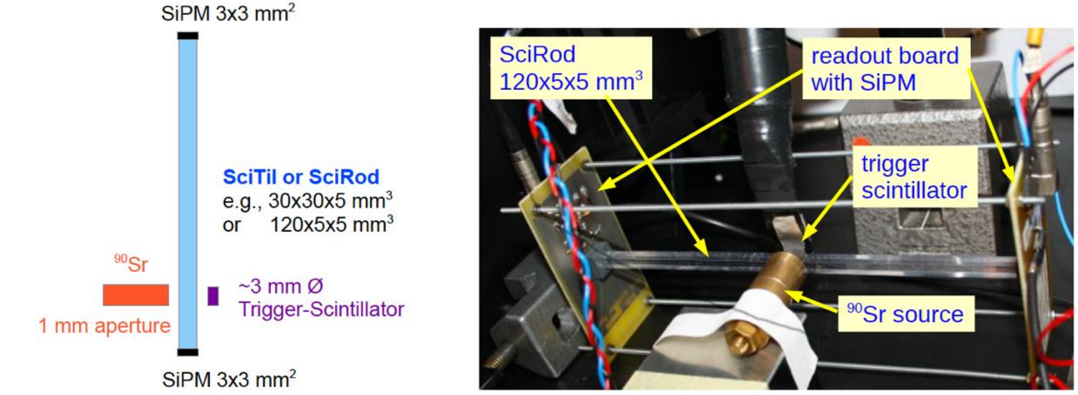
Scintillating bars readout by SiPM

Proven to match 100 ps, e.g. by PANDA and MUSE.

- ✓ Flexible geometry to provide spatial matching and control of accidentals
- ✓ Compact layout



M. Bohm et al., JINST 11 (2016) C05018 – PANDA TOF



(a) schematic **(b)** photograph

scintillator size	MPPC	BC408	BC420
$170 \times 5 \times 5\,\mathrm{mm}^3$	S10362-050P	97 ± 19	
$120 \times 5 \times 5\,\mathrm{mm}^3$	S12652-050C	81 ± 12	68 ± 10
$50 \times 5 \times 5\,\mathrm{mm}^3$		83 ± 6	62 ± 5
$120 \times 10 \times 5\,\mathrm{mm}^3$	S10362-100P	105 ± 18	93 ± 25
$50 \times 10 \times 5\,\mathrm{mm}^3$	S12572-050P	109 ± 16	

T. Rostomyan, Nucl. Instrum. Meth. A 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	σ_T (ps)	ϵ (%)
BC-404	S13360-3075PE	59	≥ 99.9
BC-404	S13360-3050PE	60	≥ 99.7
BC-404	ASD-NUV3S-P-40	65	≥ 99.0

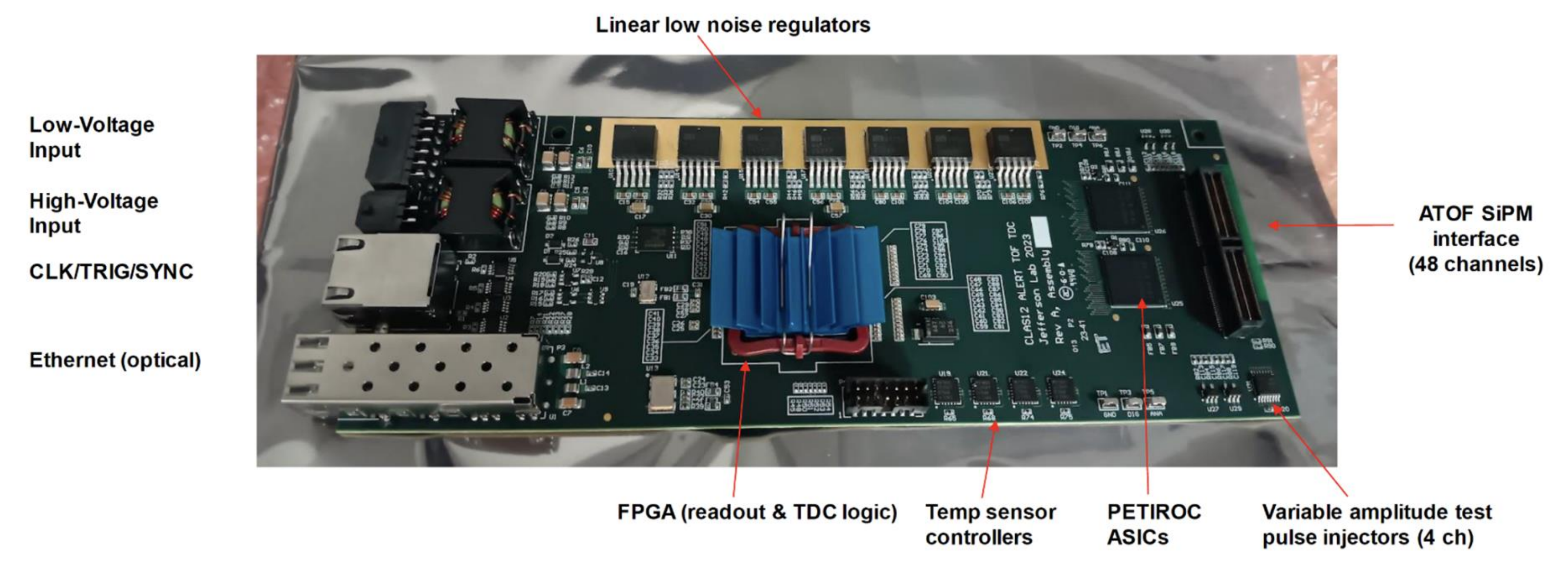
Option to cover the rod rims with SiPMs connected in series (full coverage with 1 readout channel)

Recoil TOF Readout

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

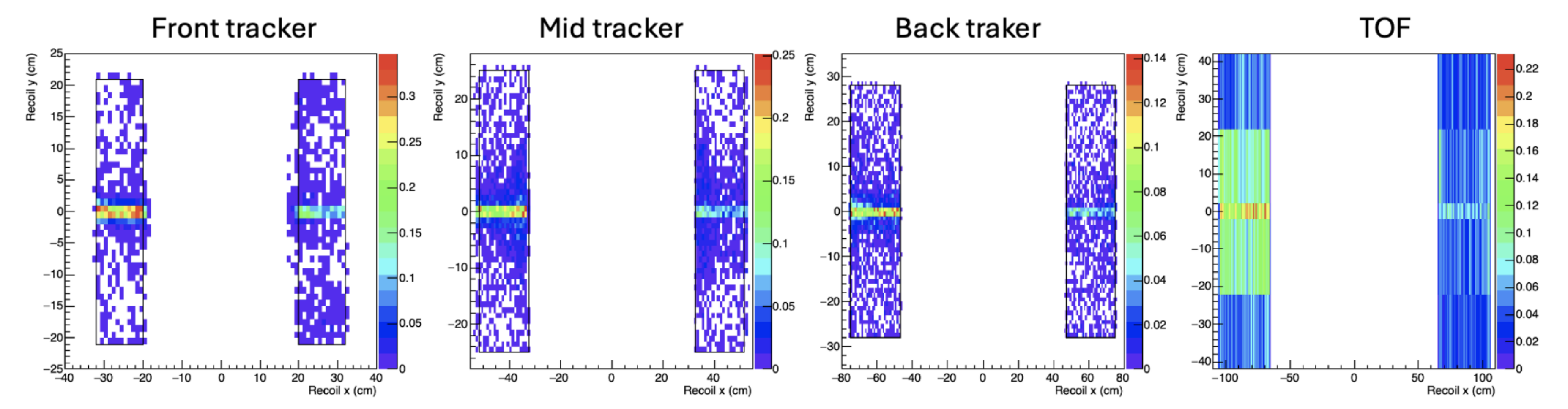
Option to adopt ALERT readout

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



Background rate approaches 300 kHz/cm^2 only in hot spots along the sheet-of-flame

Fine with the proposed detector and readout technology



Recoil Resources

Task	Cost (k$)	Leading Institution	Expertise
μRwell detector	120	INFN-RM2, INFN-CT	CLAS12 upgrade, ePIC tracking
μRwell readout	40^*	INFN-GE, INFN-RM1	SBS GEM tracking readout
TOF detector	70	DUKE, Orsay	EIC KLM, CLAS12 CND
TOF readout	60^*	INFN-GE, INFN-FE	CLAS12 FT and RICH readout
Mechanics	30	INFN-LNF	CLAS12 RICH mechanics
Integration	100	JLab	Hall-B infrastructure and beam

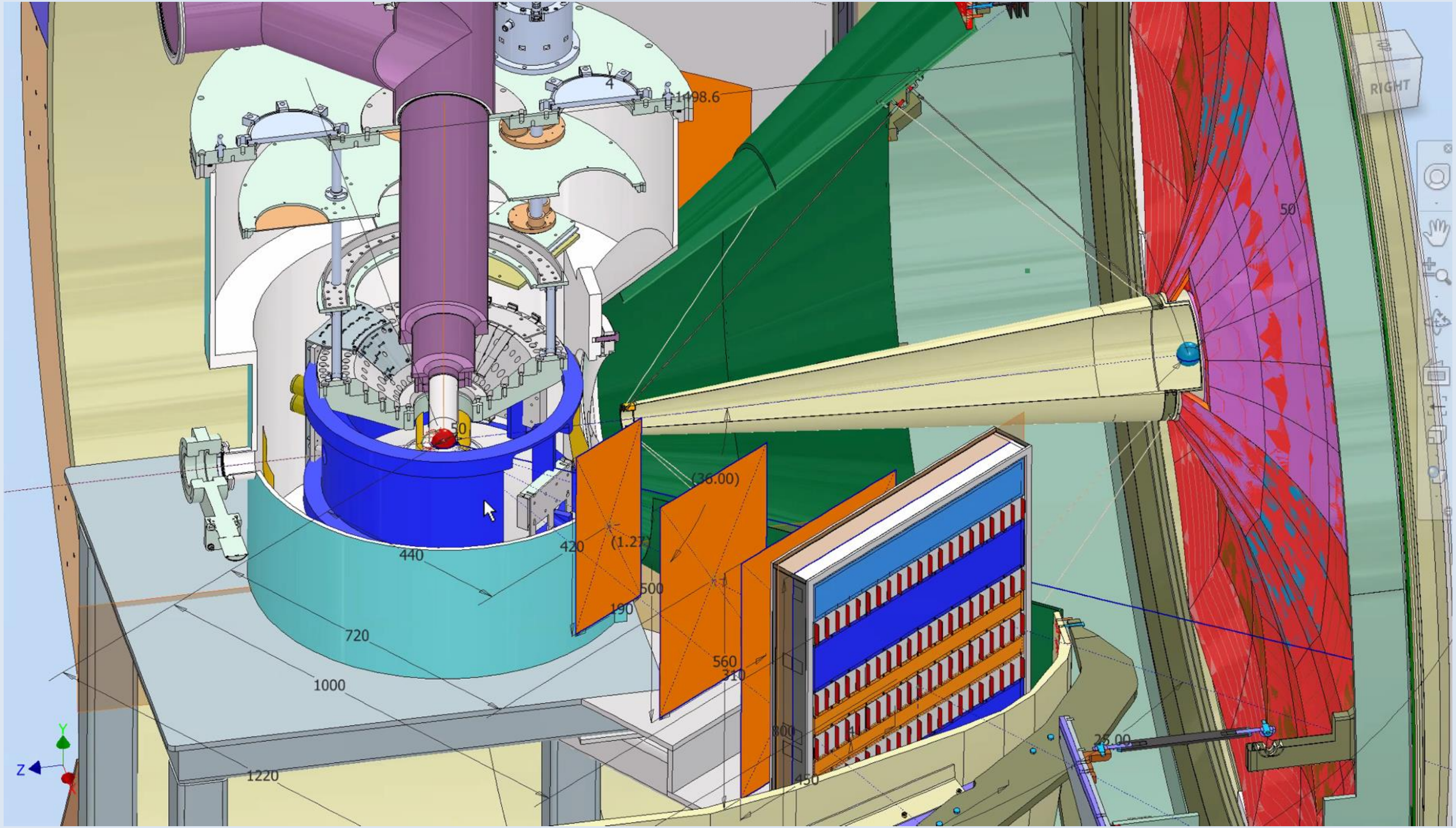
Costs are based on recent quotations or productions

The asterisks indicate optional costs for performance upgrade

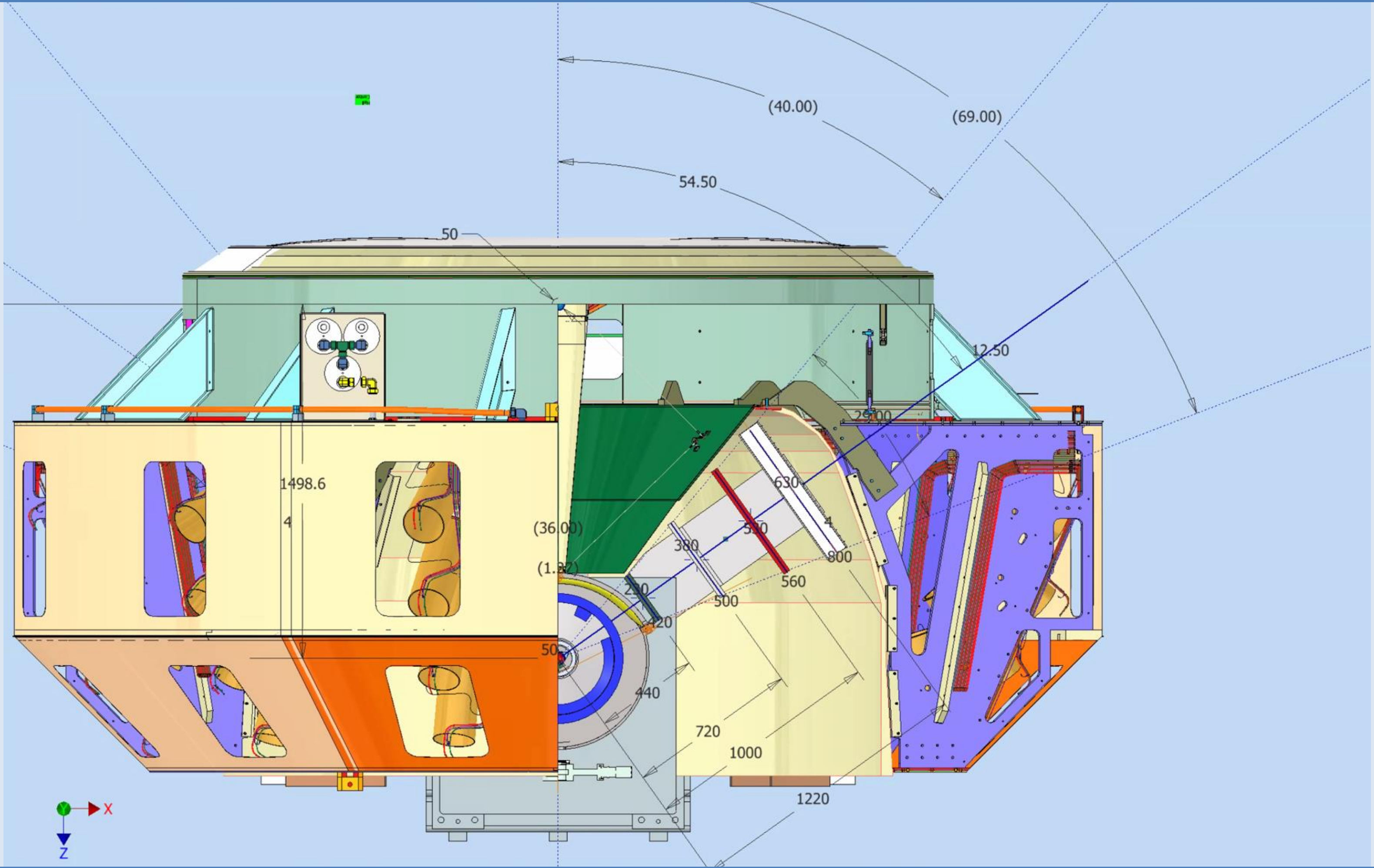
Good case for a MRI application

Target & Recoil Detector Mechanics

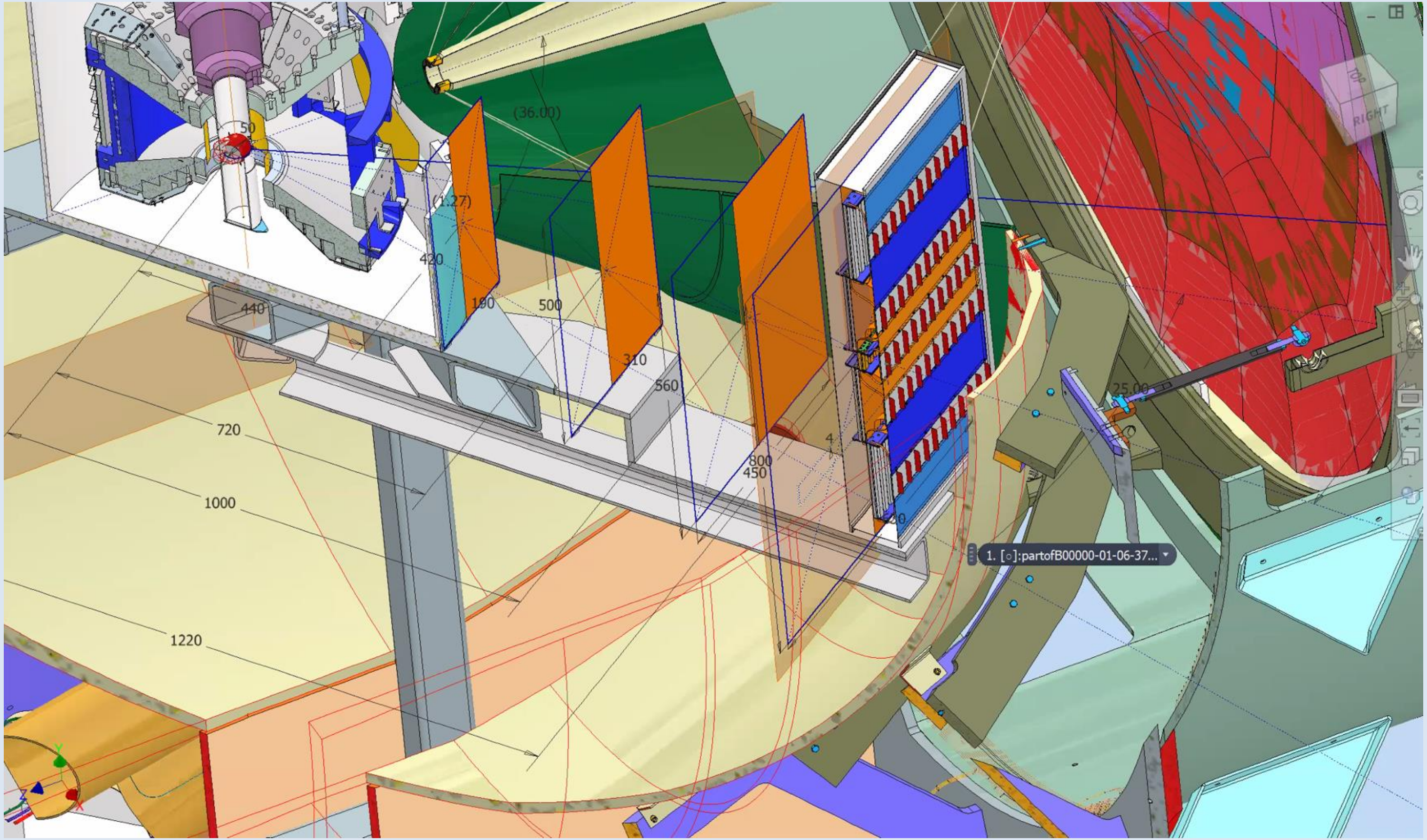
Joint effort between target group, Hall-B technical staff and INFN-LNF engineer (S. Tomassini)



Recoil Detector Envelope

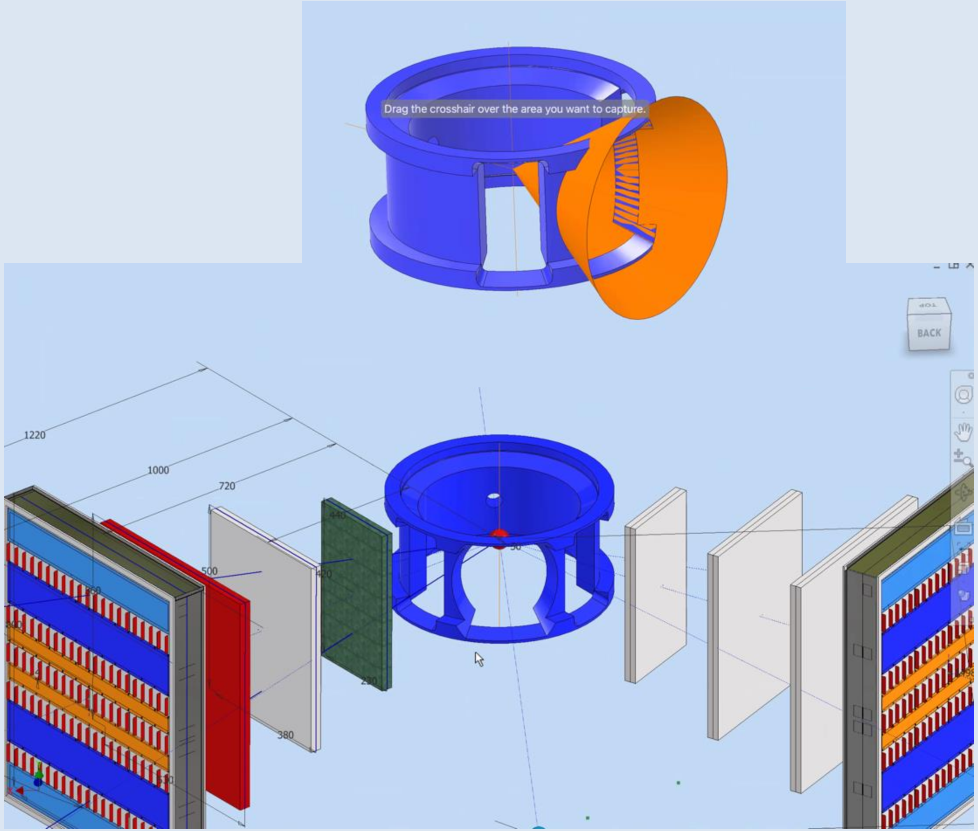


Recoil Detector Support

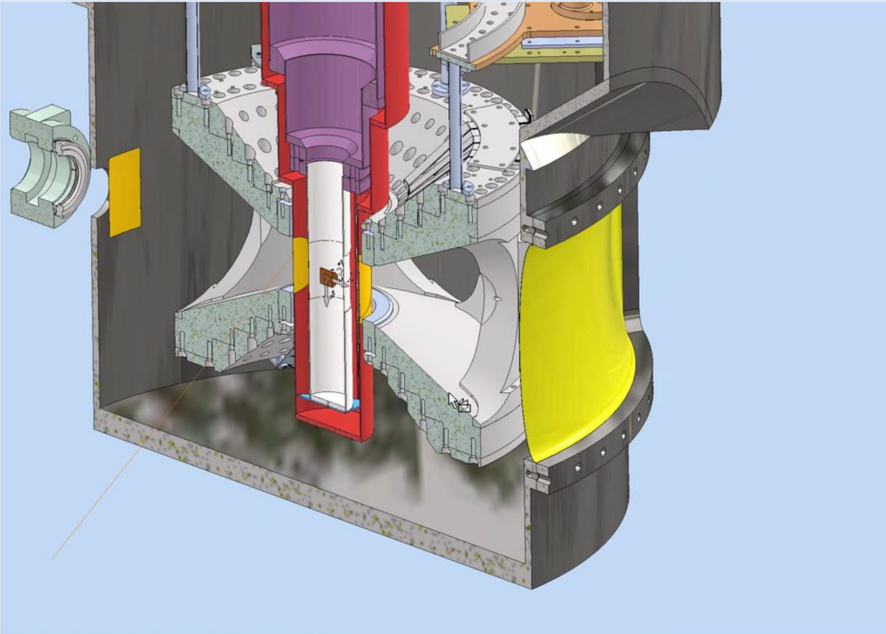


Magnet and Cryostat Structure

Pillars shaped along a 32 degrees cone (to stay within the HTCC shadow).
Openings for the recoil up to 65 degrees.

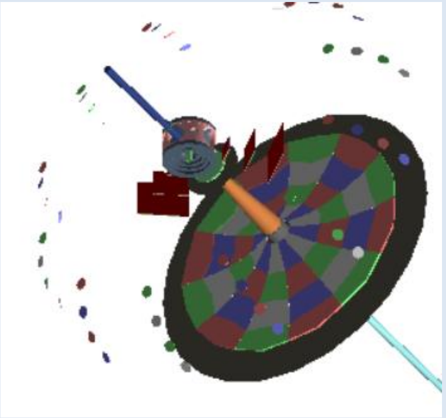


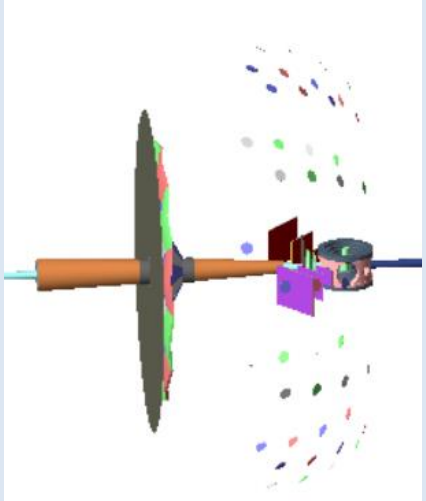
Cylindrical exit window (as done already in Hall-C).

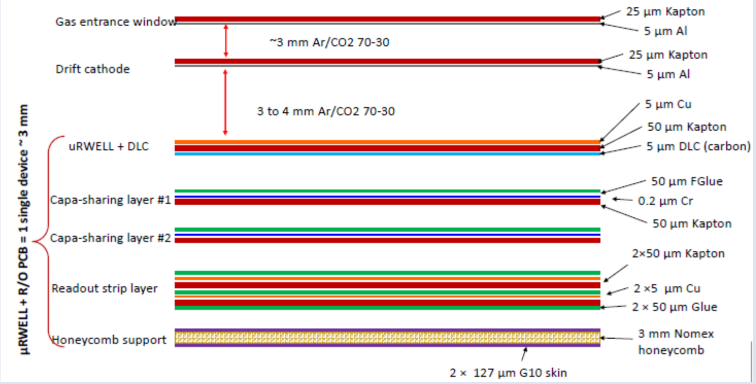


Implementation in GEMC/Coatjava

- Branched Coatjava, GEMC/detectors, and GEMC/source
- Followed the examples of the µRwell for the CLAS12 high lumi, implemented by Mariangela Bondi (lots of thanks to her for the help!)
- Geometry and positioning defined in CJ
- GEMC scripts call CJ to create geometry/material files
  - 2 sectors, 3 regions/sector of µRwell, placed where Marco placed his flux detectors; flexible angular openings or number of layers
  - correctly visualized with interactive GEMC
  - each sector and region has x and y readout
  - gcard available for those who want to play with this: /w/hallb-scshelf2102/clas12/silvia/source/rgh_good_recoil.gcard
  - contact me for the proper environment settings
- Digitization completed, RECOIL::adc bank created and correctly filled; all is now part of the official gemc
- Reconstruction work done to create and fill RECOIL::hits, RECOIL::clusters, and RECOIL::crosses banks.
- Work underway to determine the best tracking algorithm

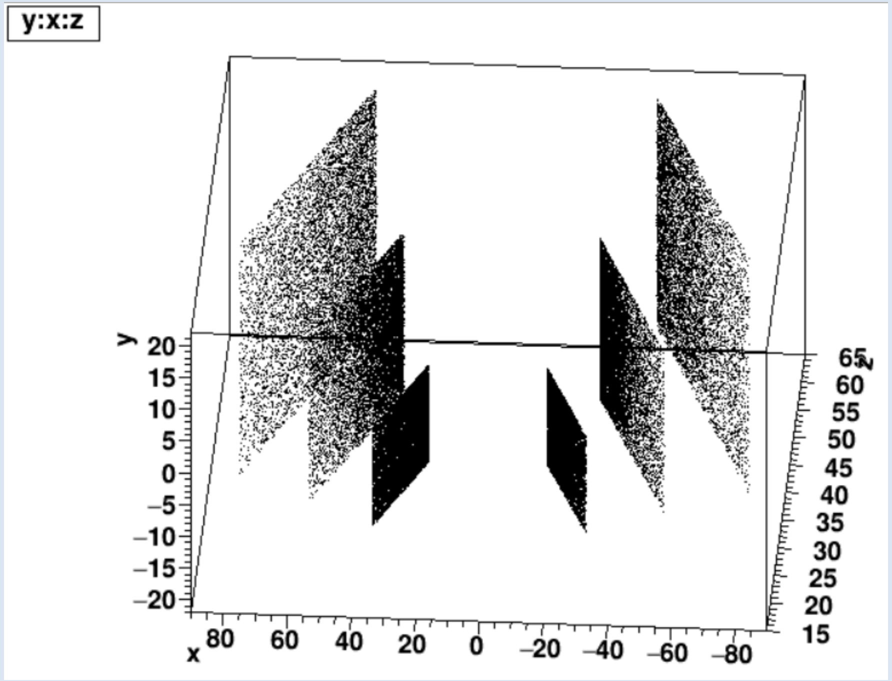


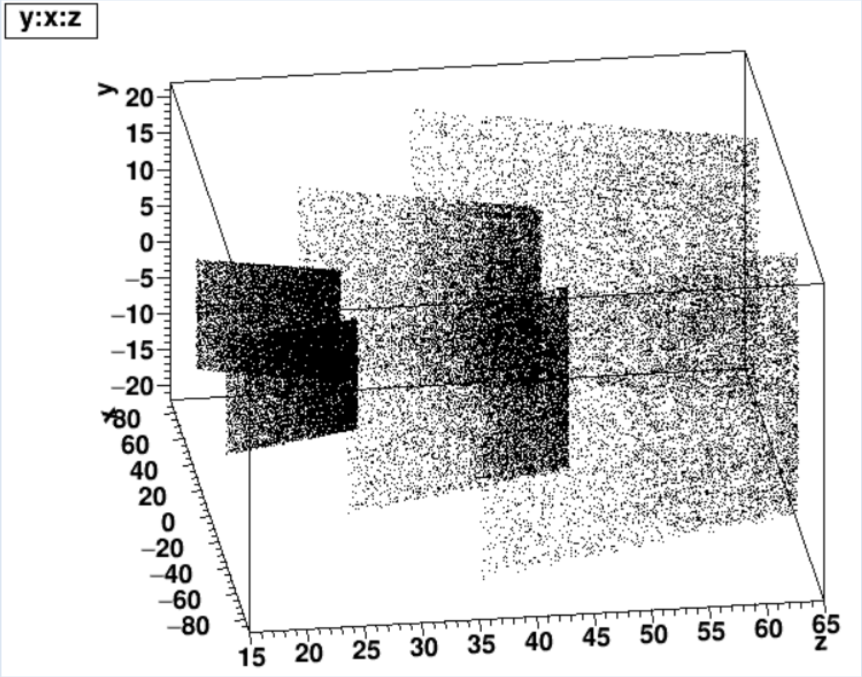




Credit: Silvia N. (Orsay)

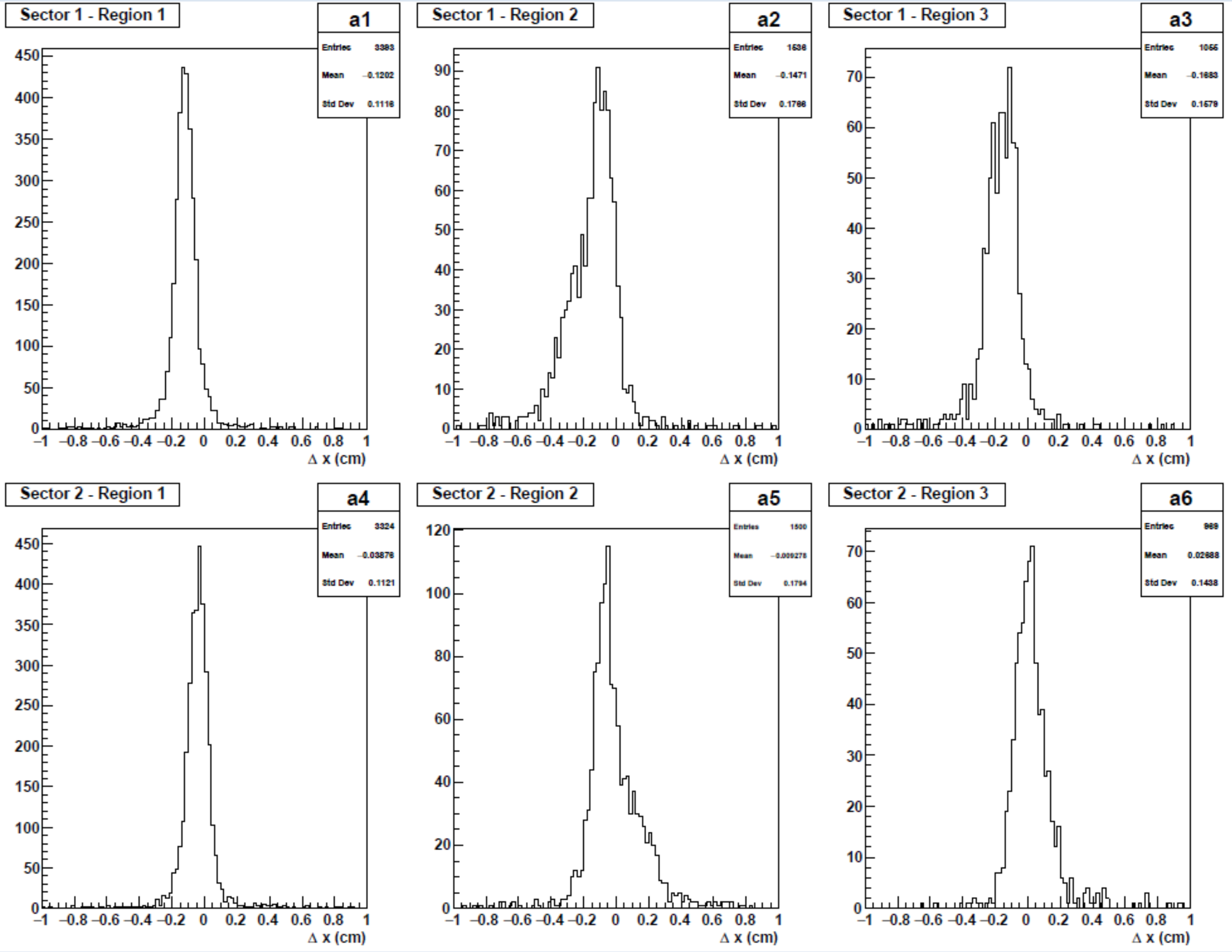
Reconstructed crosses in RECOIL tracker (3D view)





Credit: Silvia N. (Orsay)

μRwell Reconstruction

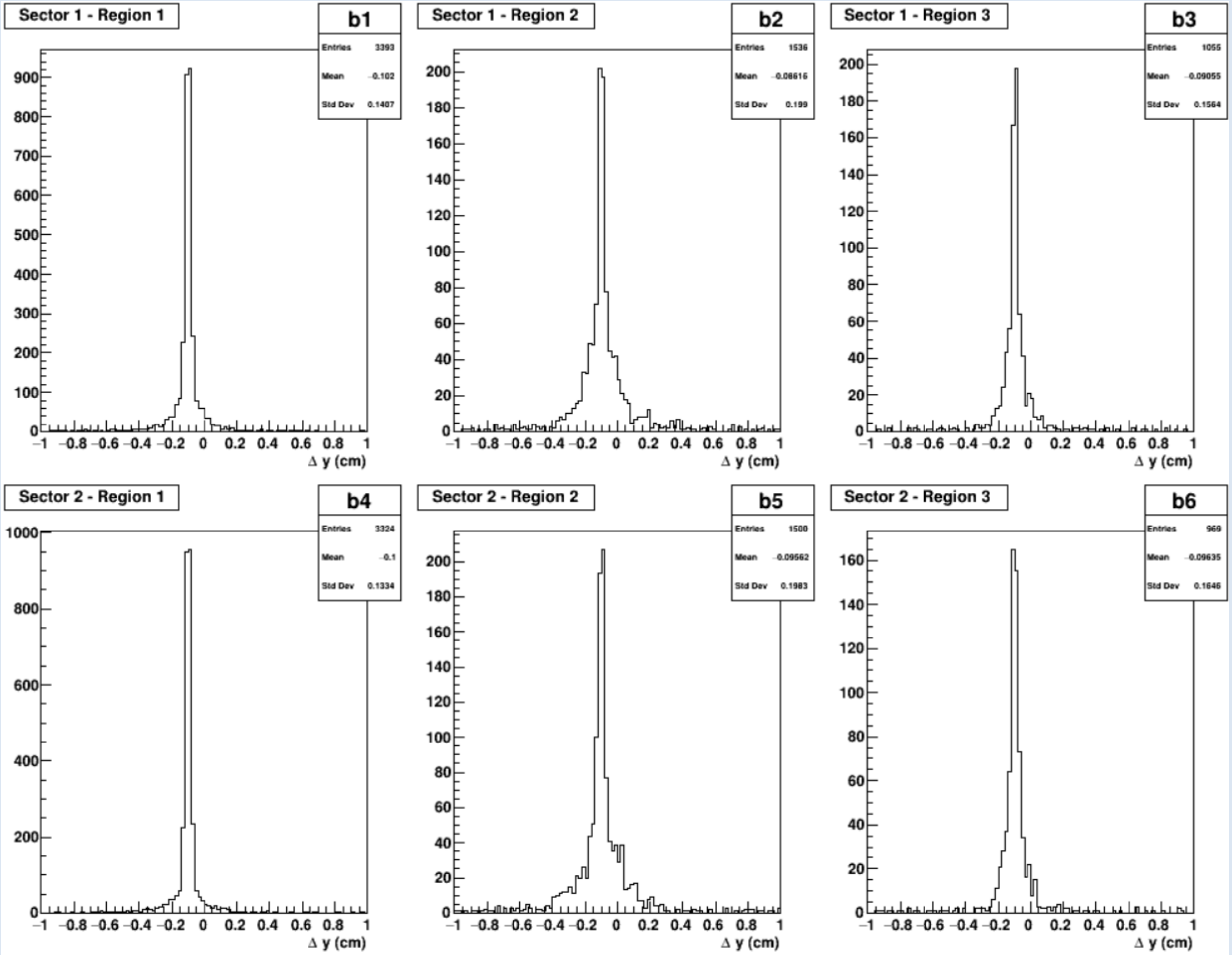


Comparison of positions from RECOIL::crosses and MC::True, after matching of the crosses, clusters, hits, true banks

pDVCS simulated events
GEMC with RGH gcard
CJ including recoil reconstruction

Sector 1 is at negative x
Sector 2 is at positive x

Credit: Silvia N. (Orsay)



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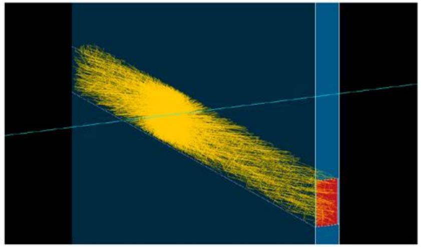
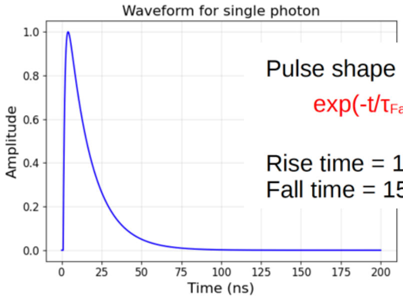
TOF Simulation





Pulse shape model

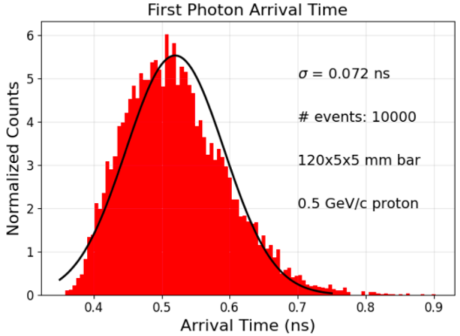
$\exp(-t/\tau_{Fall}) - \exp(-t/\tau_{Rise})$

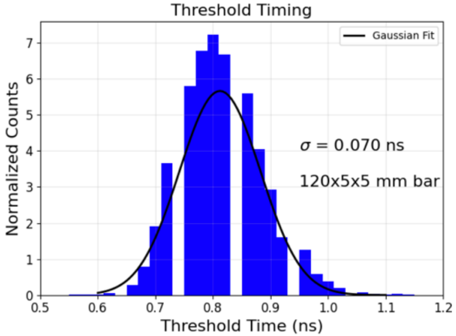
Rise time = 1.1 ns
Fall time = 15 ns

Bar dimensions (mm)	Time Resolution (ps) - without electronics	Time Resolution (ps)	Scale factor	New time resolution (ps)	PANDA resolution BC408 (ps)	PANDA resolution BC420 (ps)
170 x 5 x 5	90	87	0.6	145	97 +- 19	
120 x 5 x 5	72	70	0.6	117	81 +- 12	68 +- 10
50 x 5 x 5	43	43	0.6	72	83 +- 6	62 +- 5
120 x 10 x 5	53	49	0.42	117	105 +- 18	93 +- 25
50 x 10 x 5	33	31	0.42	74	109 +- 16	

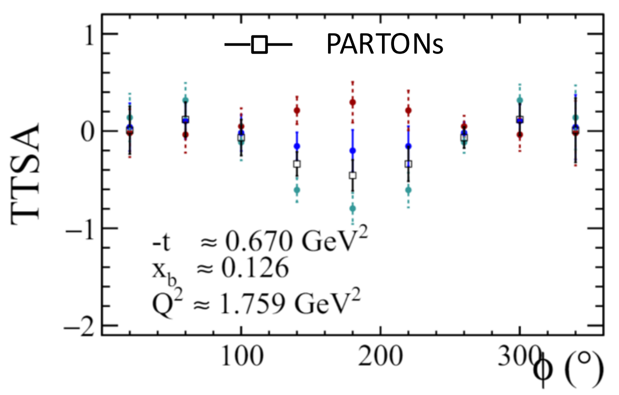
BC408 material

Rise time = 0.9 ns
Decay time = 2.1 ns



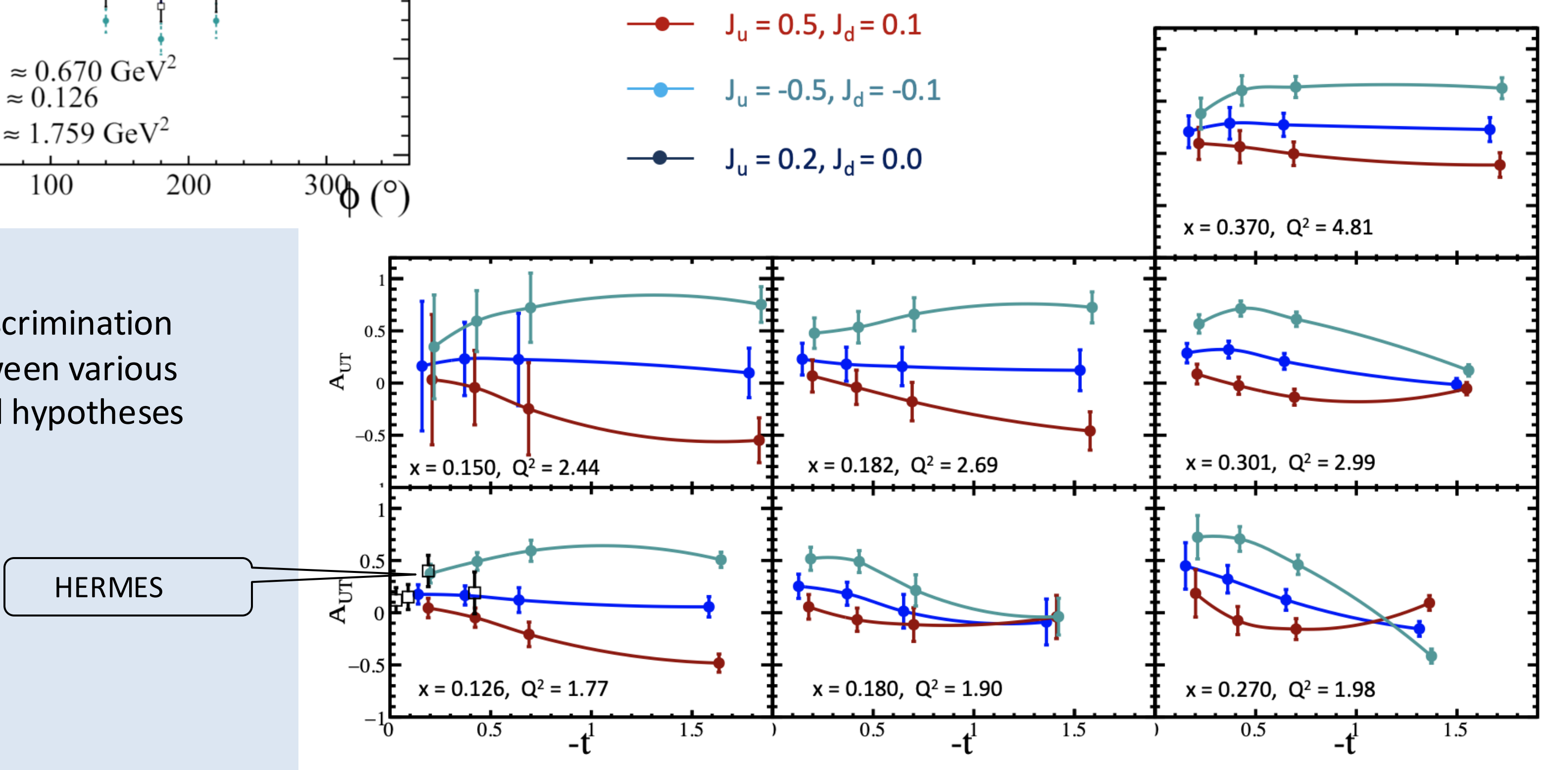


Credit: Nilanga W. (Duke)



$$Y_{RGH}(i) = Y_{RGA}(i) \cdot \frac{Acc_{RGH}(i)}{Acc_{RGA}(i)} \cdot \frac{L_{RGH}}{L_{RGA}} \cdot \frac{3}{17}$$

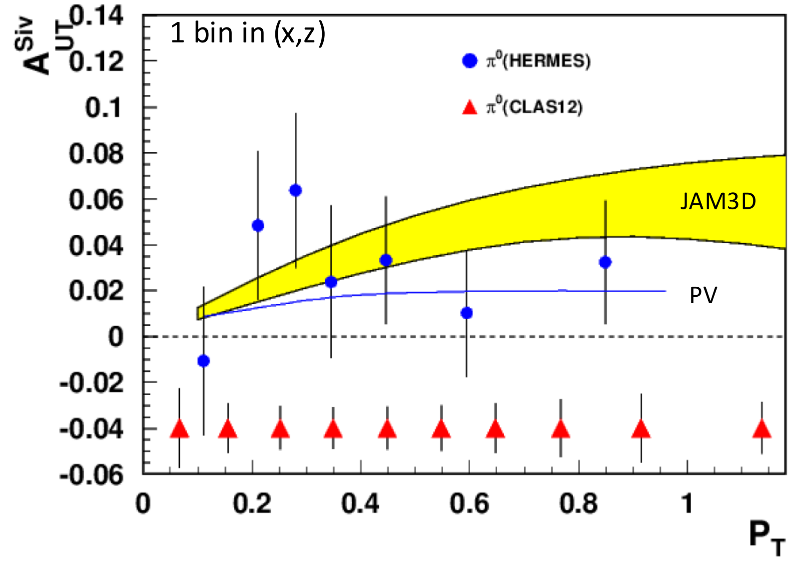
Superior discrimination power between various OAM model hypotheses

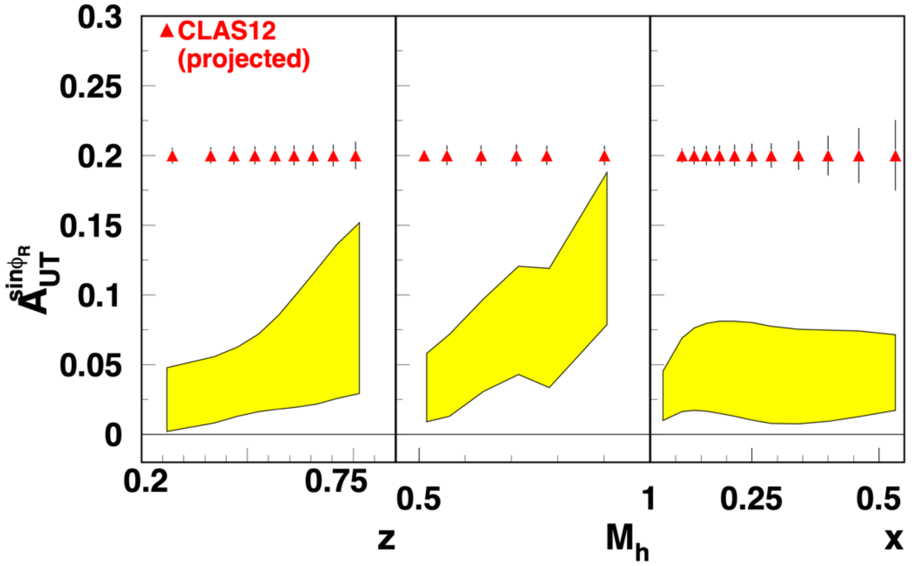


Better than approved FoM (forward phase-space is basically untouched)

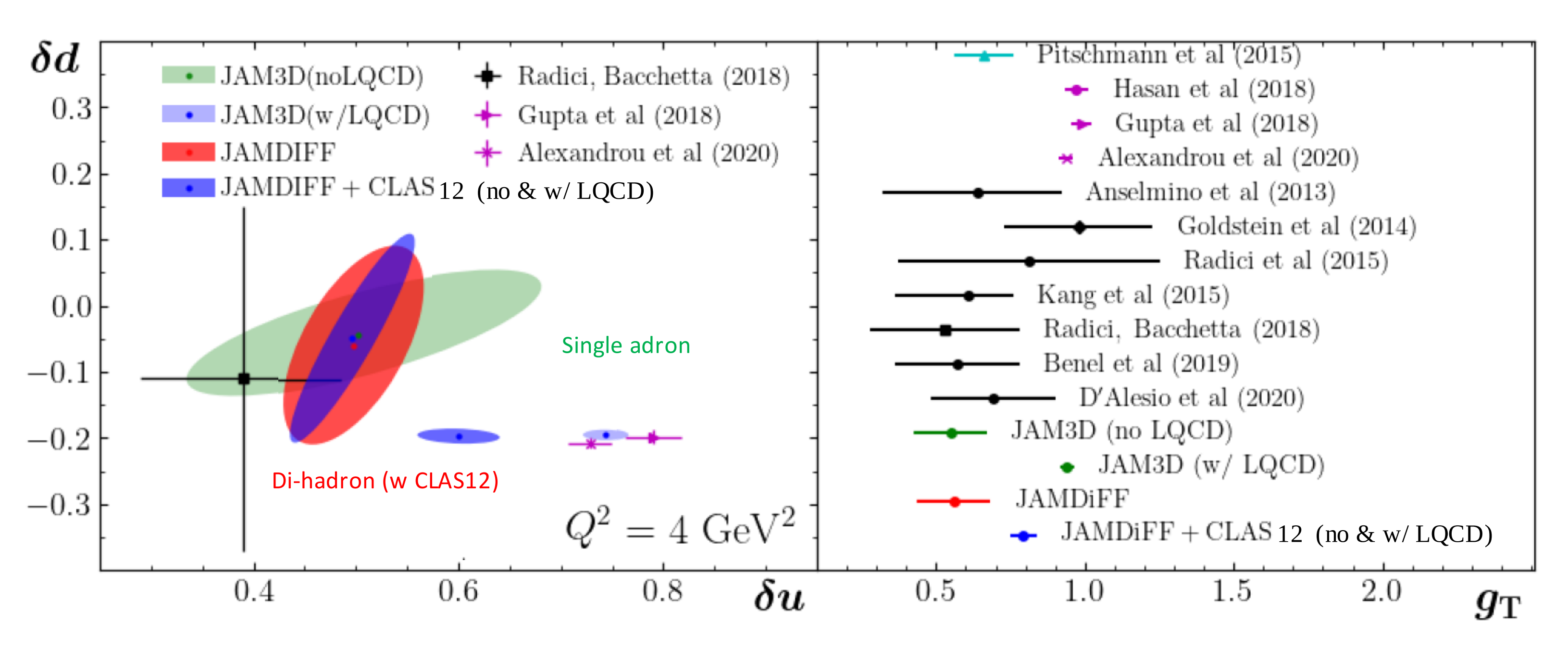
Example 1: π^0 provides clean probe
minor VM and γ_L contribution

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





Projections with and without CLAS pseudo-data (with lattice inputs)
100 PAC days request to be competitive to lattice for δu



Impact studies

SIDIS (DUKE):

Collaboration with JAM

Mini-workshop with phenomenologists being organized at the end of March

DVCS (Orsay):

Collaboration with Melany Higuera Angulo, who is working on global JLab impact studies within a LDRD project

Conclusions

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

Science: paramount case with novel lattice inputs but awaiting data

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

Target: viable solution better than the original PAC condition for approval

Recoil: technology baseline being defined and resources being structured

We are working to clarify the approval condition at the next PAC for the whole physics program

This is an open proposal: anybody interested is more than welcome to join