61st International winter meeting on Nuclear Physics
27 -31 January 2025, Bormio, Italy

# Future physics opportunities with CLAS12 upgrade

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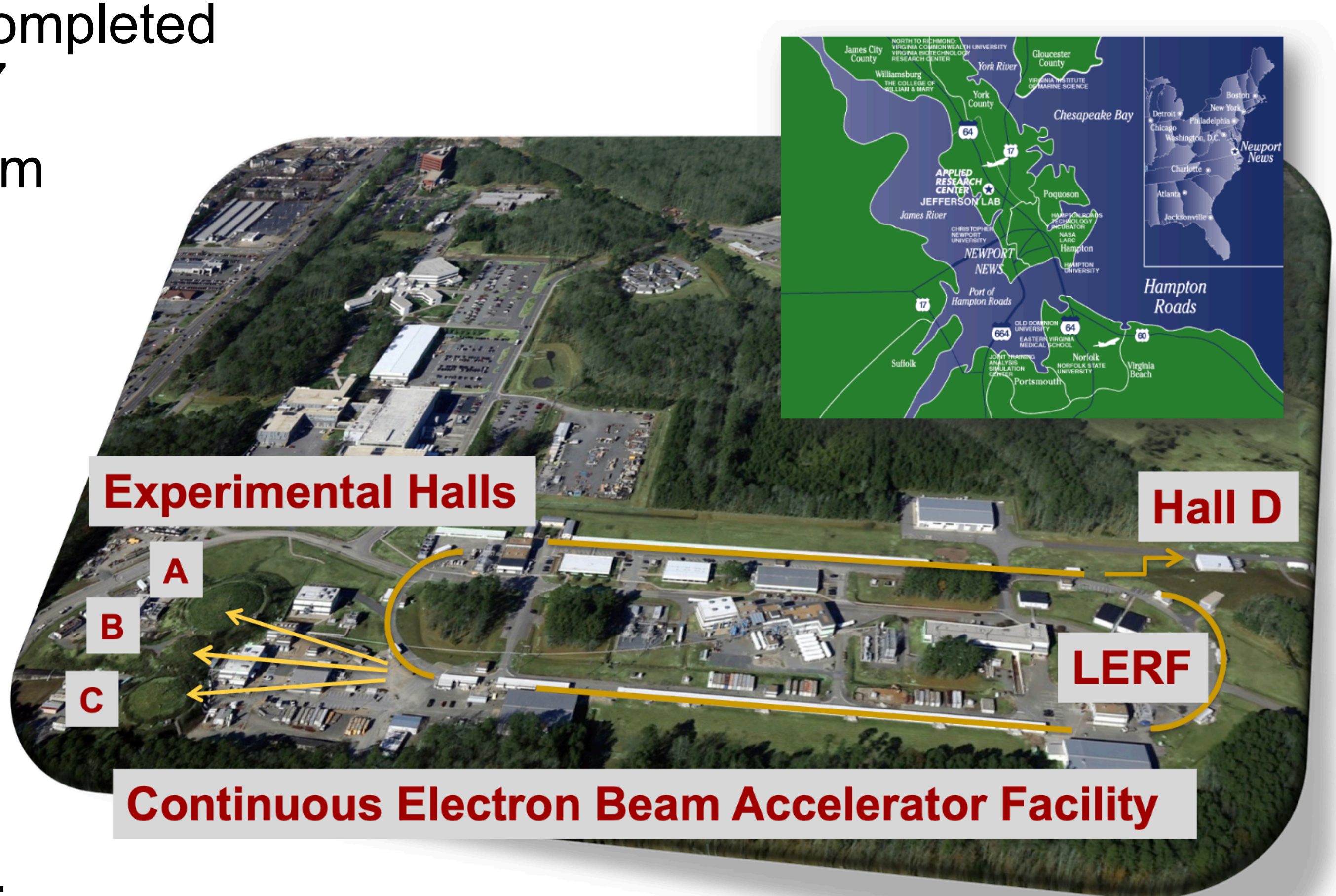
For CLAS collaboration

# Jefferson Lab - Experimental overview (1)

CEBAF upgrade completed in September 2017

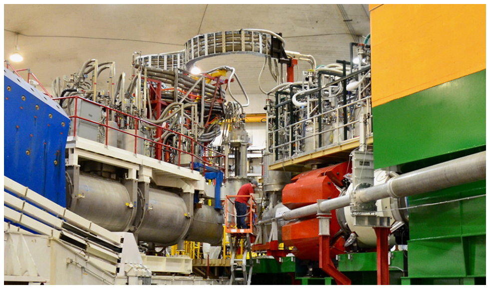
- CW electron beam
- $E_{max}$ = 12 GeV
- $I_{max}$ = 90 μA
- $Pol_{max}$ ~90%



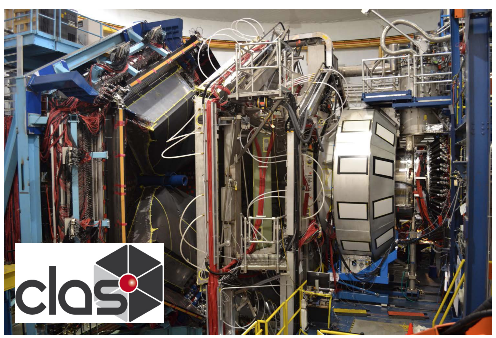

Physics operation

- 4 Halls running simultaneously since January 2018

# Jefferson Lab - Experimental overview (2)



**HALL C** - precision determination of valence quark properties in nucleons and nuclei



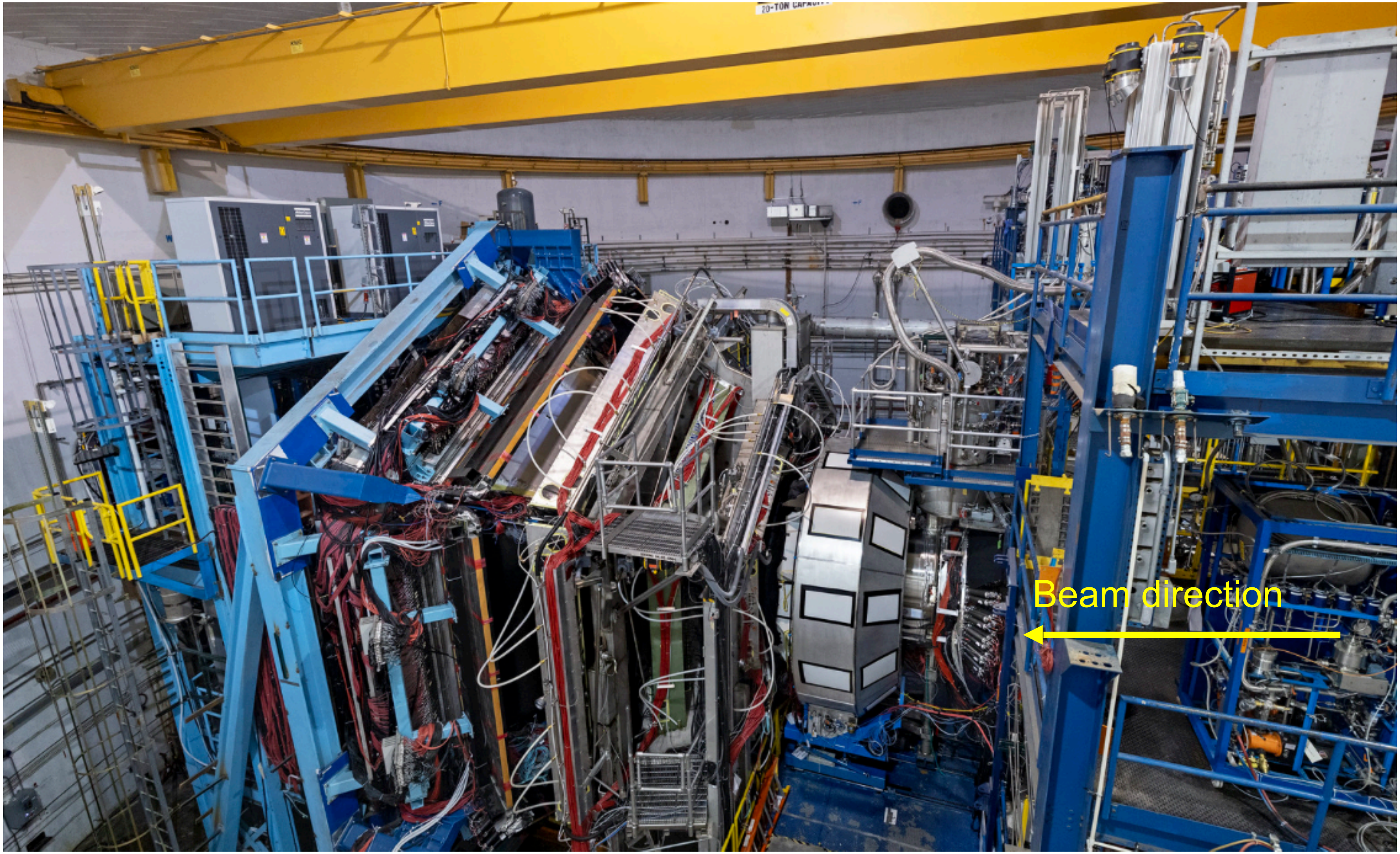

**HALL B** - understanding the 3D nucleon structure, hadron spectroscopy and nuclear effects



**HALL D** - exploring origin of confinement by studying exotic mesons

**HALL A** - form factors and PDFs, hyper nuclear physics, Physics BSM

# CLAS12 in JLAB-HALL B

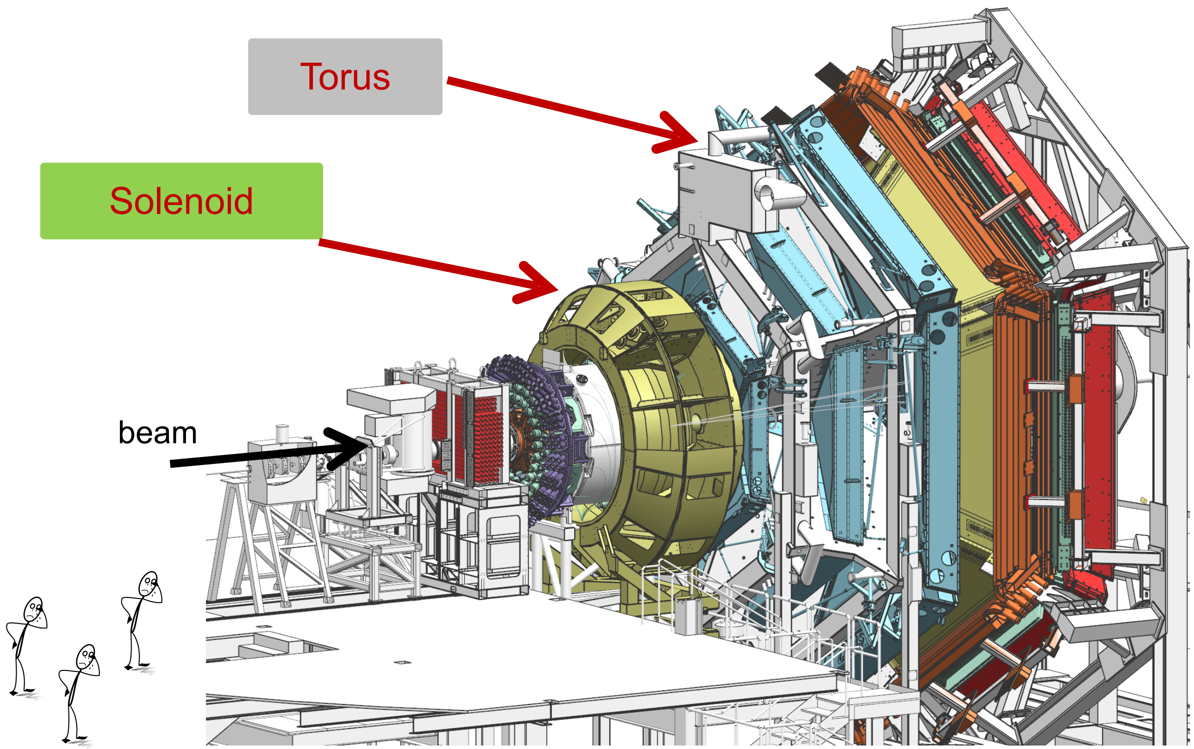


# CLAS12 - Detector

**CENTRAL**
- Beamline
- Target
- Central Vertex Tracker
- Central Time of Flight
- Central Neutron Detector
- Back-Angle Neutron Detector

| | Forward | Central |
|---|---|---|
| Angular coverage | $5^{\circ} – 40^{\circ}$ | $35^{\circ} – 135^{\circ}$ |
| Momentum resolution | $dp/p < 1\%$ | $dp/p < 5\%$ |
| $\theta$ resolution | 1 mrad | 5 – 10 mrad |
| $\phi$ resolution | 1 mrad/sin$\theta$ | 5 mrad/sin$\theta$ |

**FORWARD**
- High Threshold Cherenkov
- Forward Tagger
- Drift Chambers
- Low Threshold Cherenkov
- Ring Imaging Cherenkov
- Forward Time of Flight
- EM Calorimeter

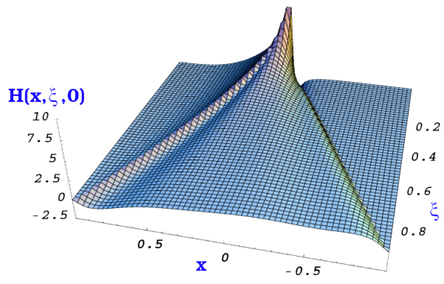



**Design Luminosity:**
- **$10^{35}$ $cm^{-2}s^{-1}$**

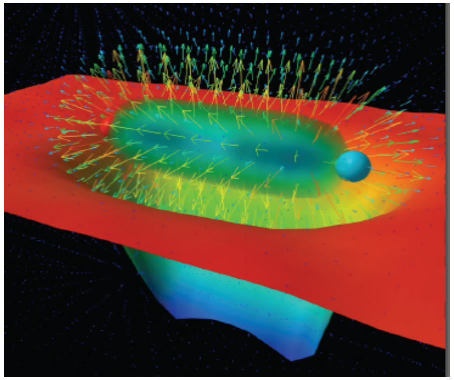
Physics targets:
- $LH_2$, $LD_2$, LHe, LAr
- D, $^{4}He$
- $^{12}C$ to $^{208}Pb$
- Polarized $NH_3$, $ND_3$, $^{6}LiH$, $^{7}LiD$, $^{3}He$-gas

# CLAS12 physics program

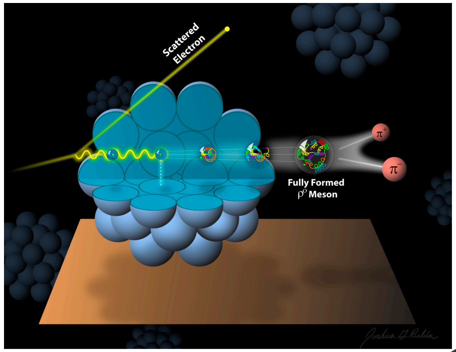
- The multidimensional structure of the nucleon – from form factors and PDFs to GPDs and TMDs




- Quark confinement and the role of the glue in meson and baryon spectroscopy



- The strong interaction in nuclei – evolution of quark hadronization, nuclear transparency of hadrons, short range correlation



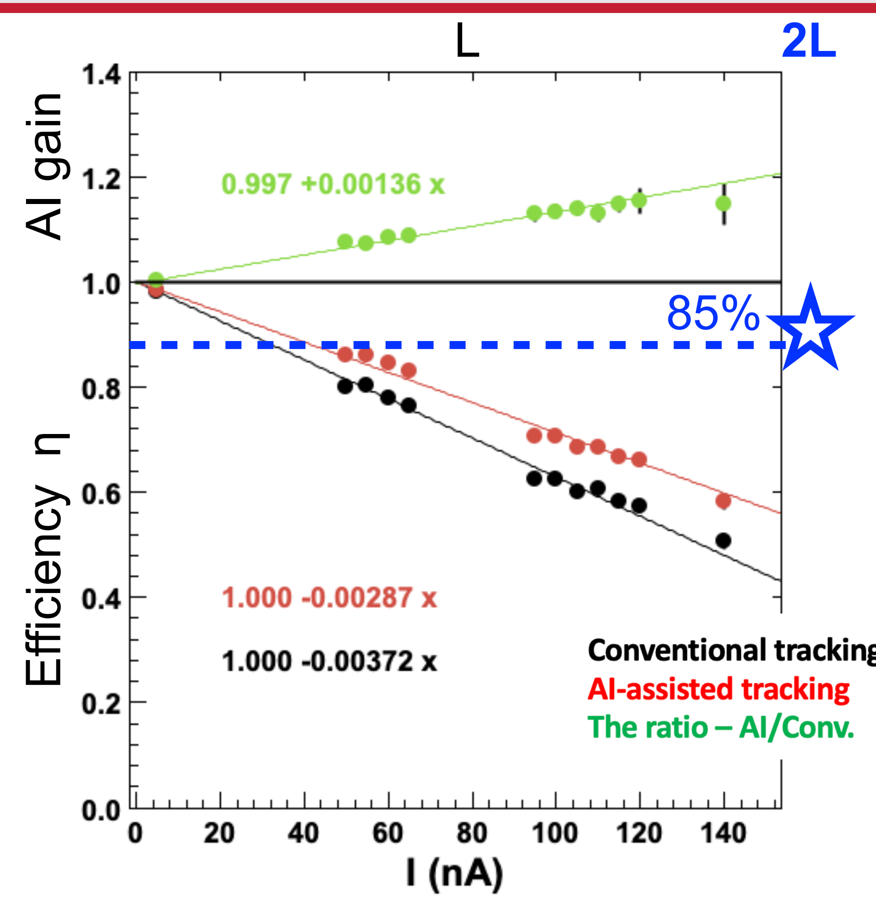
# CLAS12 Luminosity upgrade, staged approach

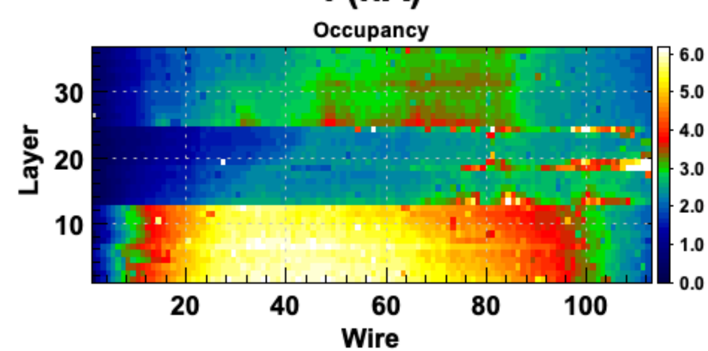
- **Phase1**: achieve luminosity of $2\times10^{35}$ $cm^{-2}s^{-1}$ for CLAS12 normal running conditions with charged particle reconstruction efficiency of >85%.
  - To support efficient and fast execution of the current program;
  - Support a growing demands of physics program with a low rate, exclusive reactions (TCS, J/Psi production,…);
  - Will need to upgrade forward tracking. The beam-line and the rest of the detector systems will perform at x2 higher luminosity;
- **Phase2**: achieve two orders of magnitude higher luminosities: µCLAS12 at > $10^{37}$ $cm^{-2}s^{-1}$
  - New physics opportunities for CLAS12 – DDVCS and e-J/ψ;
  - Requires a large acceptance forward calorimeter (FTCal-Large), a recoil detector and a forward vertex tracker

# CLAS12 Luminosity upgrade - Phase 1 - Motivation

- The limitation for running above the designed luminosity is the FD track reconstruction efficiency defined by the occupancy in R1 of DC
- Significant efficiency recovery has already happened with AI/ML-based software techniques
- Tracking hardware improvements will also be required to keep occupancies and efficiencies acceptable and achieve 2x luminosity

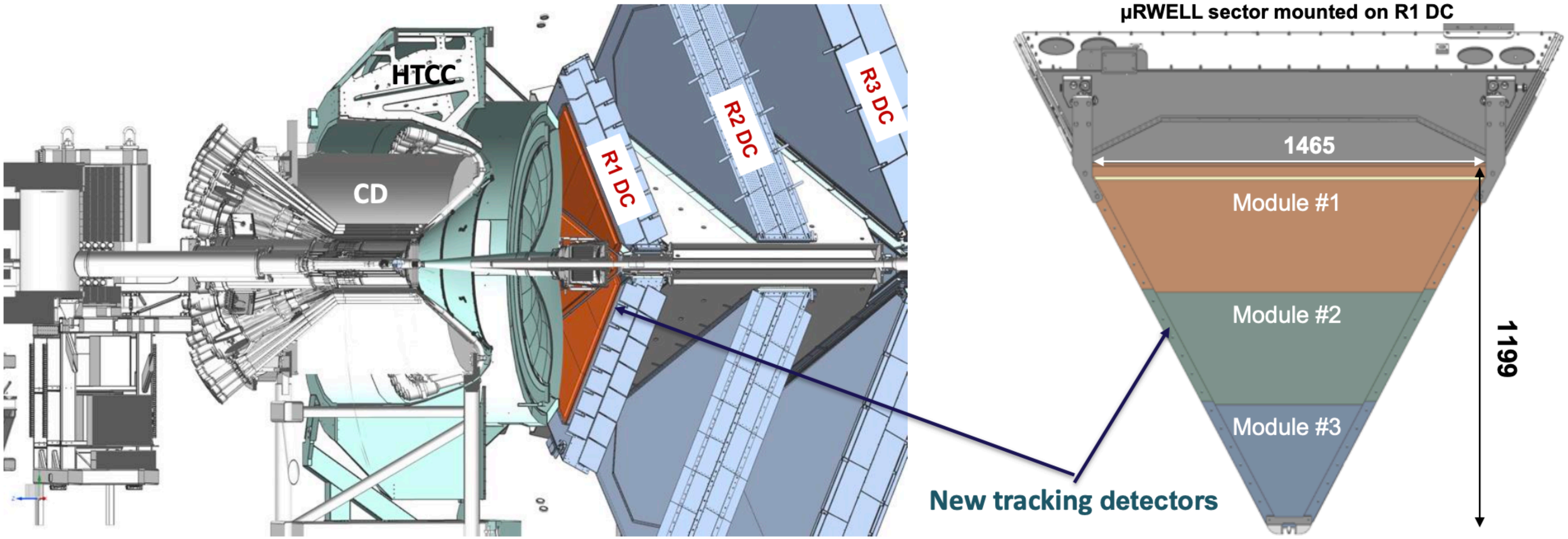
**FD tracking efficiency needs an upgrades to get close to $\eta \geq 85\%$ at 2L**



# CLAS12 Luminosity upgrade - Phase 1 - Plans

To mitigate occupancy-related inefficiency of FD tracking, we plan to add faster tracking MPGD layers to the forward drift chambers.




- Each layer will consist of 6 triangular large detectors
- Each detector will consist of three modules (there are no foils large enough to cover the whole R1).
- µRWell with 2-D readout

# CLAS12 Luminosity upgrade - Phase 1 - µRWELL FD

## The device is composed of:

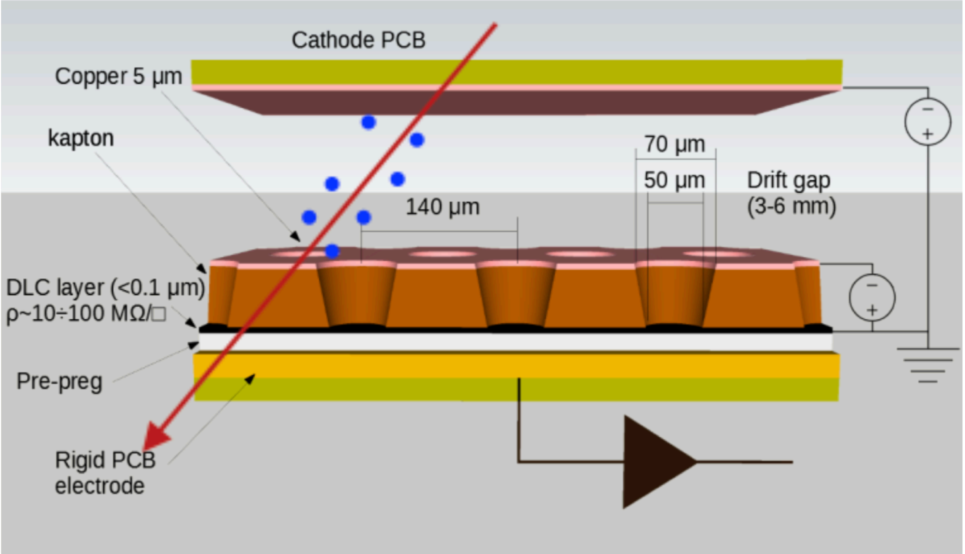
- Drift/Cathode PCB defining the gap
- Amplification stage + DLC film + Readout PCB
  - The "well" acts as a multiplication channel for the ionization produced in the gas of the drift gap

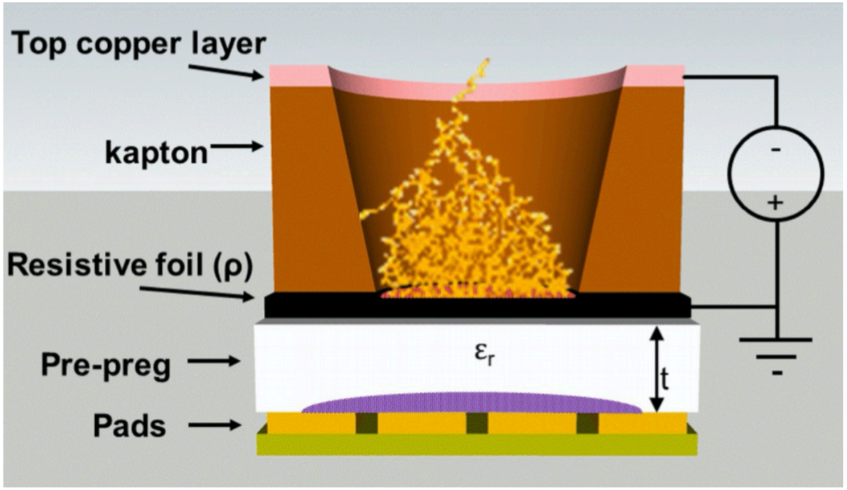
## µRWELL features:

- Low mass & Compactness
- Easy assembly
- Intrinsic spark quenching

## µRWELL performances:

- Gain: $10^4$
- Rate capability up to 10 MHz
- Spatial resolution: ~ 100 µm



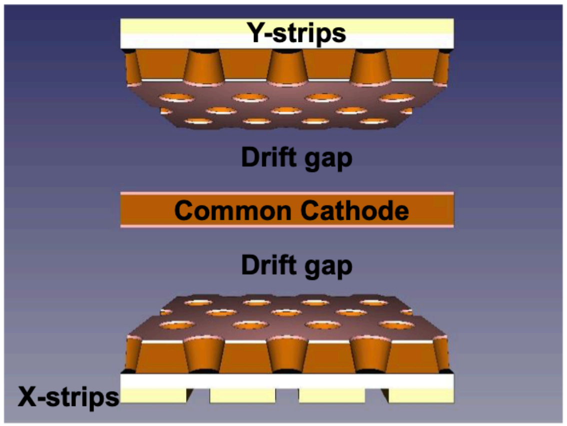




G. Bencivenni et al.; 2015_JINST_10_P02008

# μRWELL 2D tracking readout

*K.Gnanvo et al., NIM 1047 (2023) 167782*

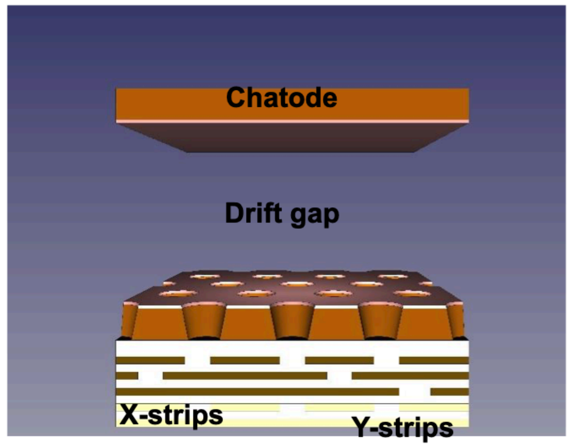
**N.2 u-RWELLs 1D (2⊗1D)**




The layout with two separate detectors equipped with its own r/out is operated at lower gas gain, with respect to the single detector with 2D r/out (COMPASS like).

Tested @ TB2022.

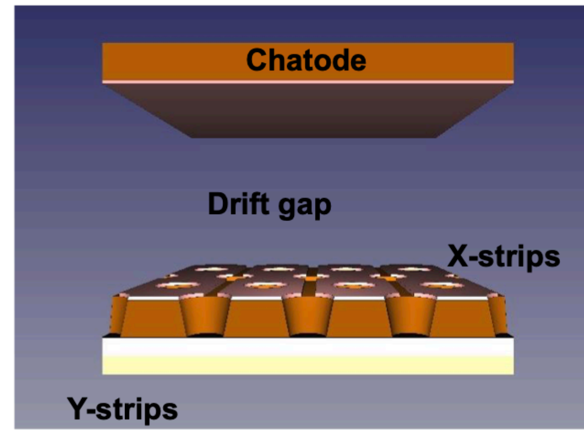
**u-RWELL - Capacitive Sharing r/out**




The charge sharing performed through the capacitive coupling between a stack of layers of pads and the r/out board. Reduce the FEE channels, and the total charge is divided between the X & Y r/out.

Tested @ TB2023.

**u-RWELL TOP r/out**

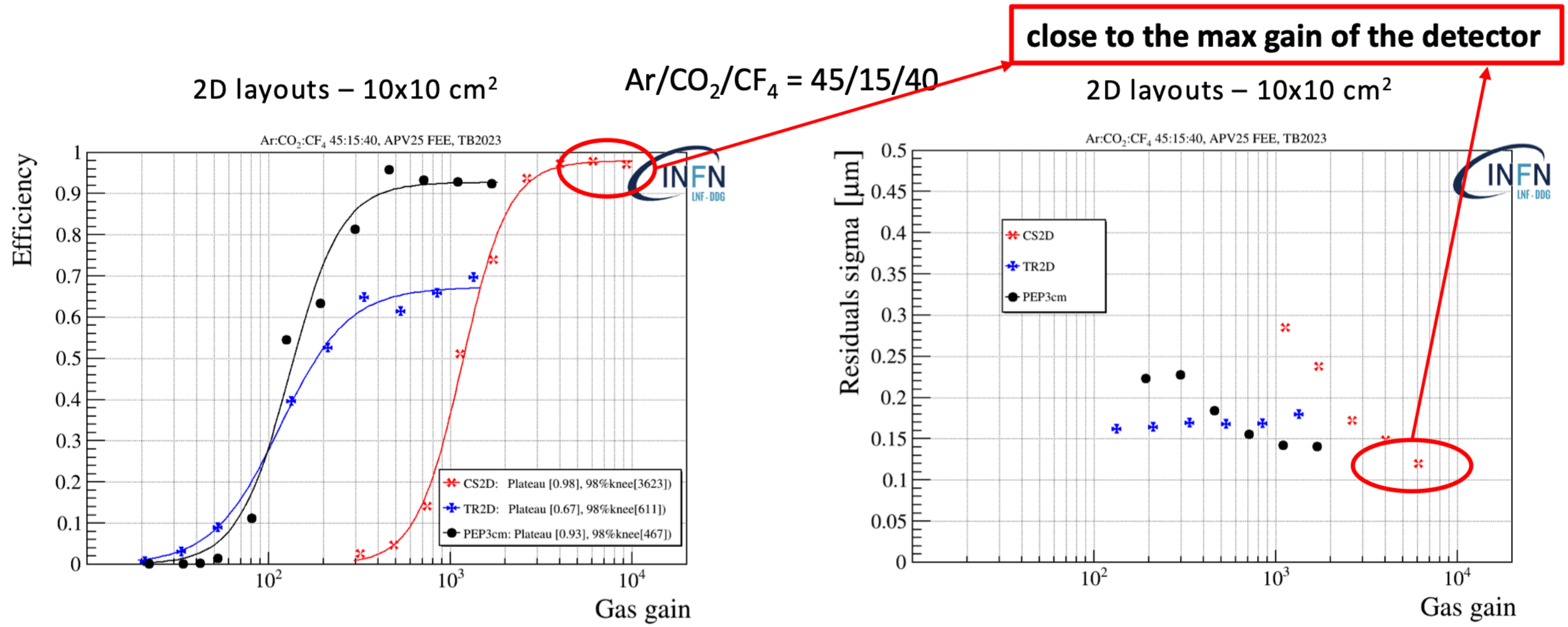



The TOP-readout layout allows to work at lower gas gain wrt the «COMPASS» r/out (X-Y r/out decoupled). X-coordinate on the TOP of the amplification stage introduces dead zone in the active area.

Tested @ TB2023.

**Credit to: G. Bencivenni, A. D'Angelo and et al**

# μRWELL 2D tracking readout



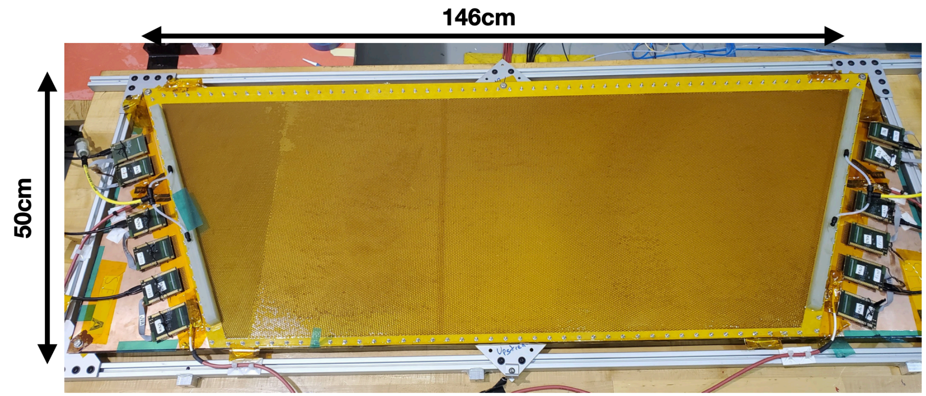

- 2x1D: spatial resolution <200um (pitch 0.8 mm), low voltage operating point ~520V, tracking efficiency ~95%
- CS: spatial resolution <200um (pitch 1.2 mm), high voltage operating point, ≥ 600V, tracking efficiency ~98%
- Top r/out: spatial resolution < 200um (pitch 0.8 mm), low voltage operating point ~520V, tracking efficiency ~70%



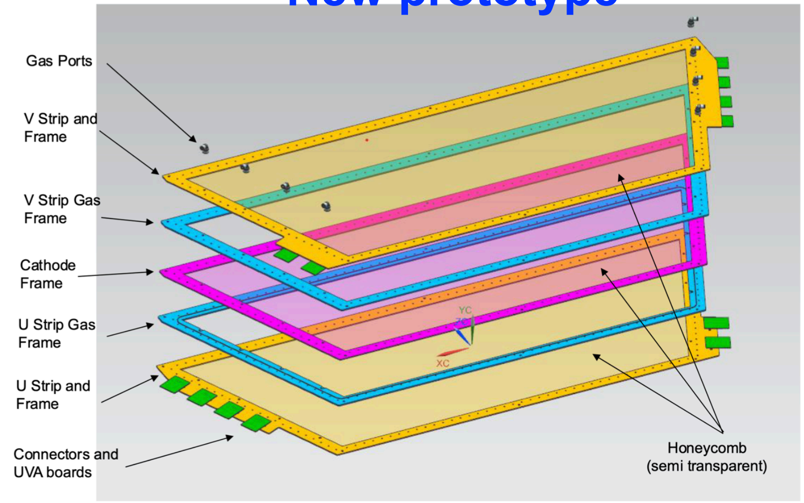
**Credit to: G. Bencivenni, A. D'Angelo and et al**

# CLAS12 Luminosity upgrade - Phase 1 - Status

- Simulations fully developed and show:
  - no sizable degradation of momentum resolution with pair of such detectors in front of R1 DC
- Full-scale, single-sector, prototype
  - Trapezoid with an active area of [1460 mm – 1012 mm] × 50 mm
  - U & V strips at 10-degree stereo pitch = 1 mm
  - Capacitive-sharing R/O scheme
  - Test with cosmic ray using different gas (Ar:Isobutane(90:10) and Ar:Co2(80:20))
    - Similar efficiency for U and V at highest HV
  - Signal in V smaller than U due to low amplification
- Next full-scale prototype:
  - 2 uRwell in one combined frame
  - Separated 1D readout strips (U and V) with same strip width
  - Separate Cathode foils on shared honeycomb support




**New prototype**



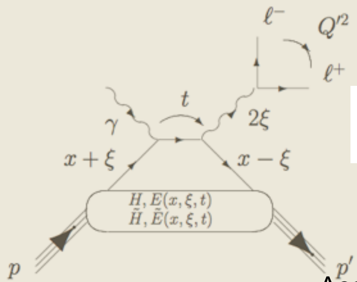
# CLAS12 Luminosity upgrade - Phase 2 - Motivation

**JLAB Flagship program – accessing GPDs through measurements of beam/target asymmetries and the cross sections of Compton processes (TCS and DVCS)**

First experimental measurement with CLAS12 PRL 127, 262501 (2021)

## TCS

Hard scale is defined by time-like photons




$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^{-}(\xi,x) H(x,\xi,t)$$

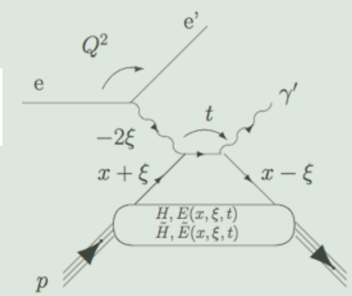
$$Im\ \mathcal{H}(\xi,t) = i\pi H(\xi,\xi,t)$$

Access to the Re-part of the Compton amplitude

Started in 2001, PRL 87, 182002. Now is the flagship physics program

## DVCS

Hard scale is defined by space-like photon

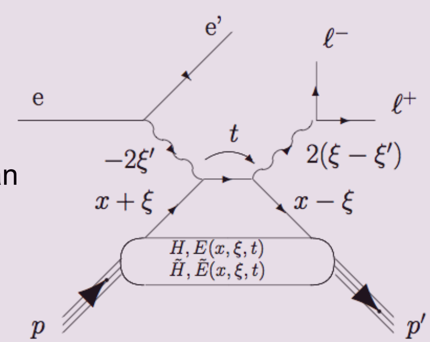



**Jefferson Lab at the luminosity frontier is the only place in the world DDVCS can be measured!**

**μCLAS12 in Hall B and SoLID in Hall A are the two proposed facilities capable of carrying out such measurements.**

## DDVCS

Both space-like and time-like photons can set the hard scale




$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

$$H(2\xi'-\xi,\xi,t) + H(-(2\xi'-\xi),\xi,t)$$

**But DDVCS cross section is three orders of magnitude smaller than DVCS -> inaccessible to CLAS12 without large luminosity increase**

# CLAS12 Luminosity upgrade - Phase 2 - Plans

- **Two main challenges in DDVCS measurements**
  - Cross section is three orders of magnitude smaller than the DVCS cross section;
  - Ambiguities and anti-symmetrization issues with the decay leptons of the outgoing virtual photon and the incoming-scattered lepton.

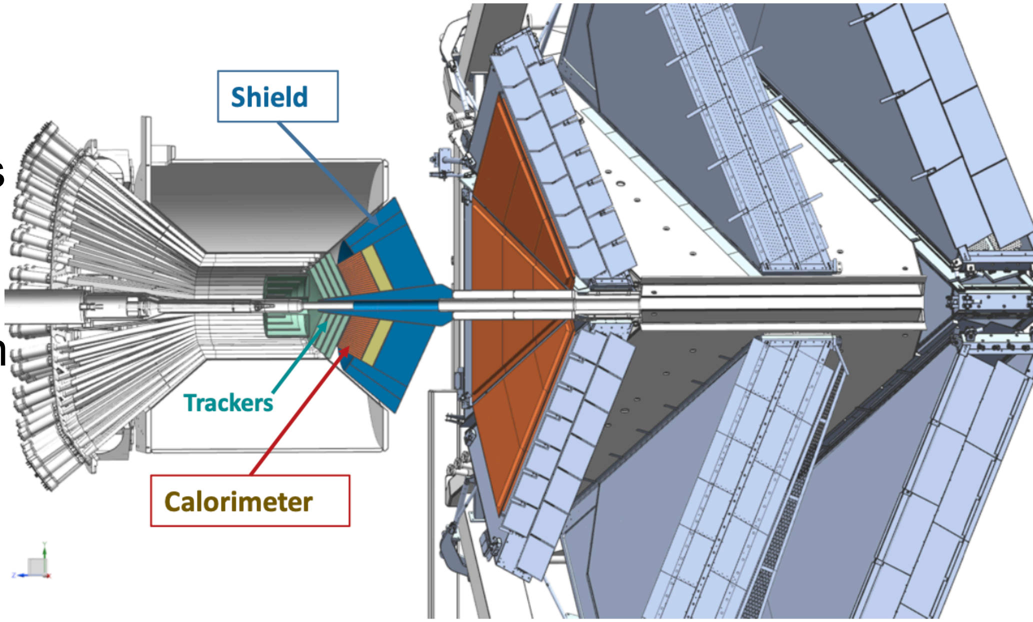
- **Both challenges can be solved by studying di-muon electro-production using upgrade CLAS12:**

$$ep \to e'p'\mu^+\mu^- \;\; @ \, few \times 10^{37} cm^{-2} sec^{-1}$$

# CLAS12 Luminosity upgrade - Phase 2 - Plans

- Remove HTCC and block the CLAS12 forward with a W-shield and $PbWO_4$ calorimeter to prevent flooding of DC by EM background;
- Scattered electrons will be detected in the calorimeter, while shield will work as pion filter, as most of charged pions will shower and will not reach to the forward tracking system;
- Install fast, high rate MPGD trackers in front of the calorimeter for vertexing and inside the solenoid for recoil tagging.
- The existing downstream trackers and toroidal field become a muon spectrometer for luminosity of $10^{37} cm^{-1} s^{-1}$
- Time frame for Phase 2 is 10 years.

## μCLAS12

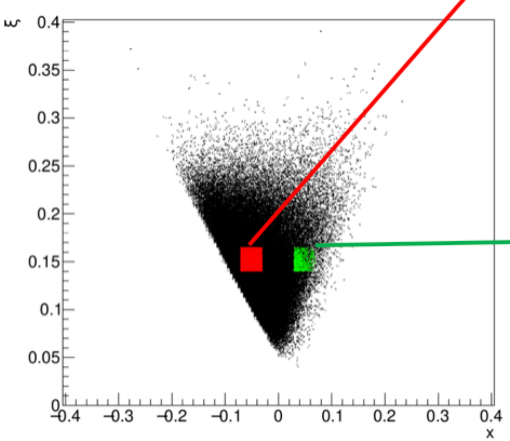


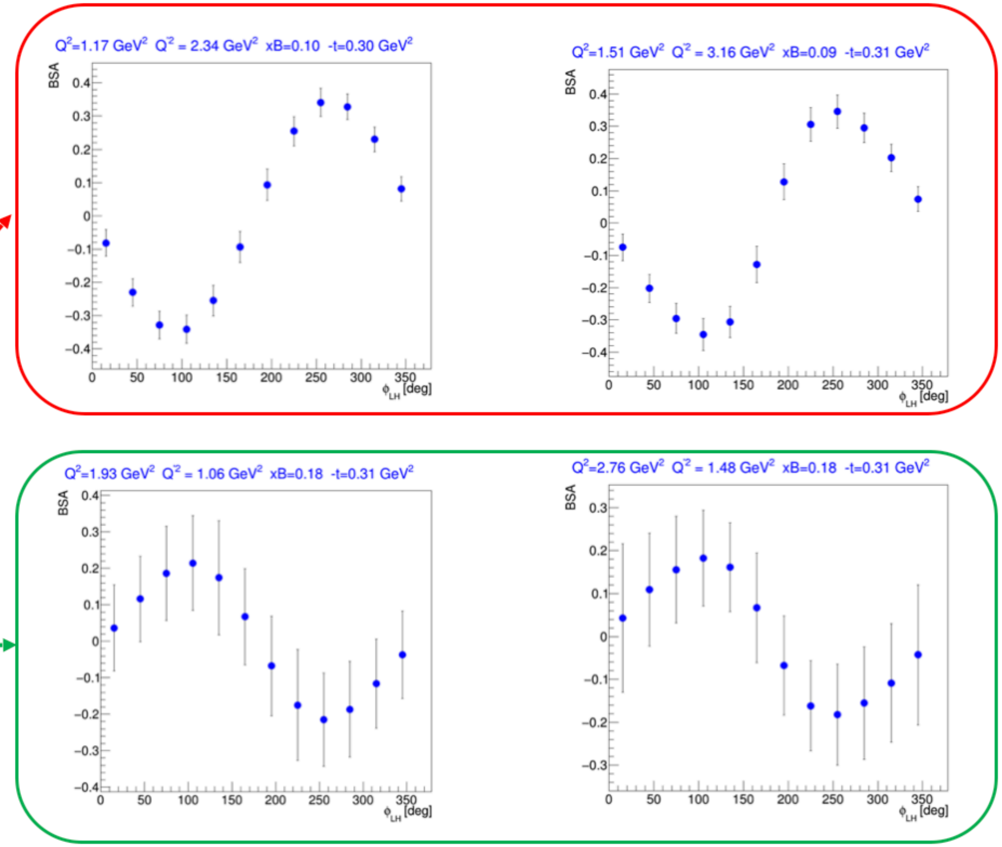

Detector capable of measuring

$$ep \rightarrow e'p'\mu^+\mu^- \ \ @\, L > 10^{37} cm^{-2} sec^{-1}$$

# µCLAS12-DDVCS Projections

- Eb = 10.6 GeV
- 200 days @$10^{37}$cm$^{-2}$s$^{-1}$
- Beam polarization P = 80%
- Asymmetries are obtained using M. Guidal's code






*Credit to R. Paremuzyan*

# Summary

- CLAS12 has a diverse physics program, with its detector commissioned in 2018 and since then acquiring physics data.
- The detector performance is close to design after improvements from AI-assisted tracking, but luminosity upgrades will greatly help efficiently execute the existing physics program and facilitate new physics opportunities.
- The two-stage upgrade is planned for the CLAS12 luminosity upgrade.
  - Phase-I, in progress, will allow running x2 higher than the designed luminosity with an additional, fast tracking layer and en route in the next 3 years.
  - Phase-II upgrade, 5 to 8 years, will allow running CLAS12 at two orders higher luminosity
- µCLAS12 in the phase-II is one of only two facilities in the world that can measure DDVCS, extending access to GPDs into new kinematic space.