CLAS12 luminosity upgrade

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Outline

- CLAS12 detector in Hall-B
- Physics program
- First physics results and a need for a luminosity upgrade
- Planned luminosity upgrades
  - Phase I: upgrade to $L = 2{\times}10^{35} cm^{-2} sec^{-1}$
  - Phase II: μCLAS12 for $L > 10^{37} cm^{-2} sec^{-1}$
- Summary

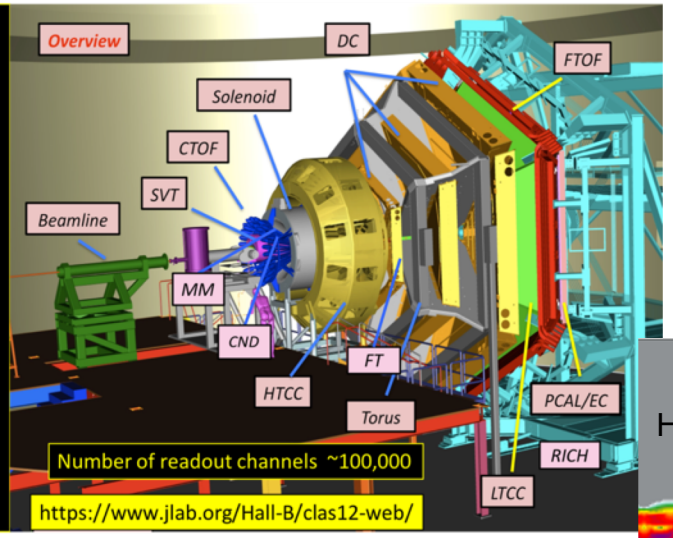
CLAS12 in Hall-B at JLAB

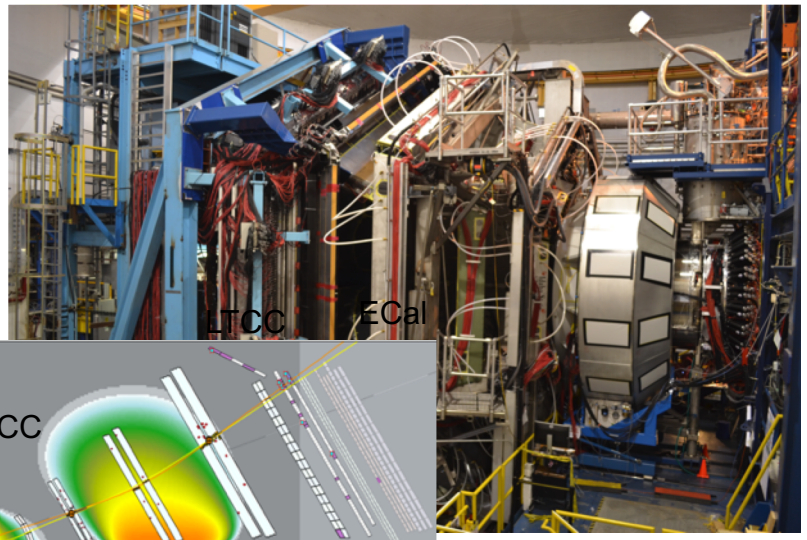
Running luminosity $\approx 10^{35}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1}$

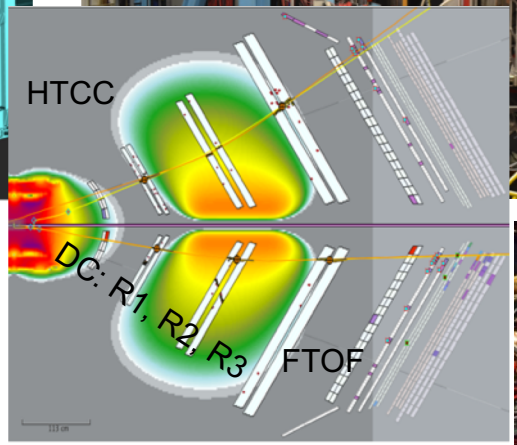
Forward Detector (FD)
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter
- Forward Tagger
- RICH detector

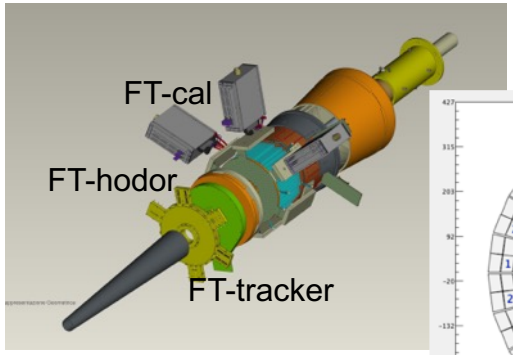
Central Detector (CD)
- Solenoid magnet
- Silicon Vertex Tracker
- Central Time-of-Flight
- Central Neutron Detector
- MicroMegas

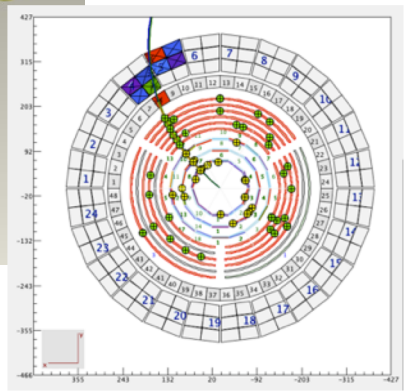
Beamline
- Photon Tagger Dump
- Shielding
- Targets
- Moller Polarimeter
- Faraday Cup

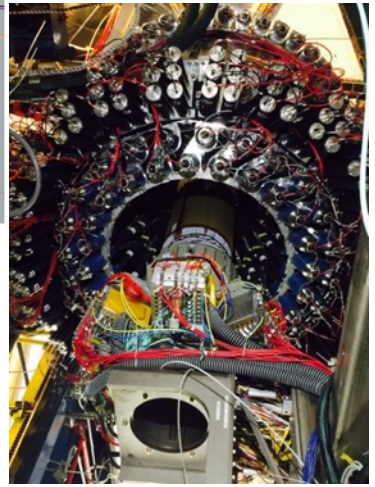








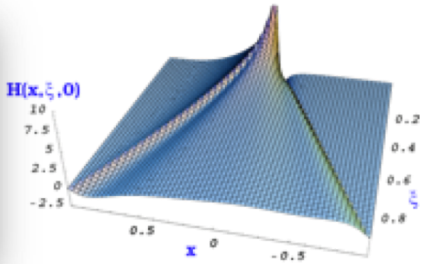


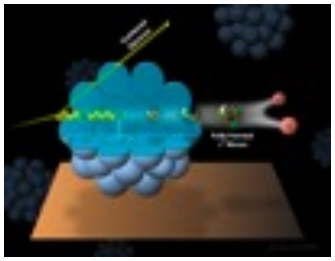


Physics targets:
- LH_2, LD_2, LHe, LAr, D, ^{4}He
- ^{12}C to ^{208}Pb
- Polarized NH_3, ND_3, ^{6}LiH, ^{7}LiD, ^{3}He-gas

CLAS12 Physics program

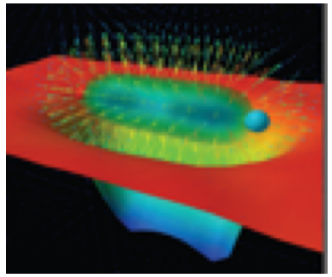
- Nucleon and nuclear structure studies, spatial and momentum tomography, form-factors …





- Cold nuclear matter, NN correlations, hadronization, color transparency…

- Exploring origin of confinement – meson and baryon spectroscopy, exotics …



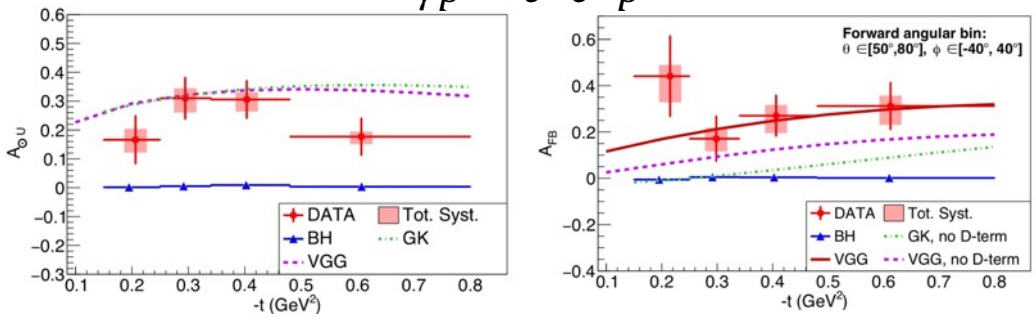
Total of 44 approved CLAS12 experiments, grouped in 11 run groups (based on the beam energy, target, and the mag.fields).

CLAS12 first results: *Compton scattering and GPDs*

P. Chatagnon, et al. (CLAS Collaboration), "First-time Measurement of Timelike Compton Scattering", Phys. Rev. Lett. 127, 262501 (2021).

- BHA, $A_{\odot U} \sim \sin\varphi Im M^{--}$, universality of GPDs
- FB asymmetry, $A_{FB} \sim \cos\varphi Re M^{--}$, access to the EM FF $D^Q(t)$ (D-term).

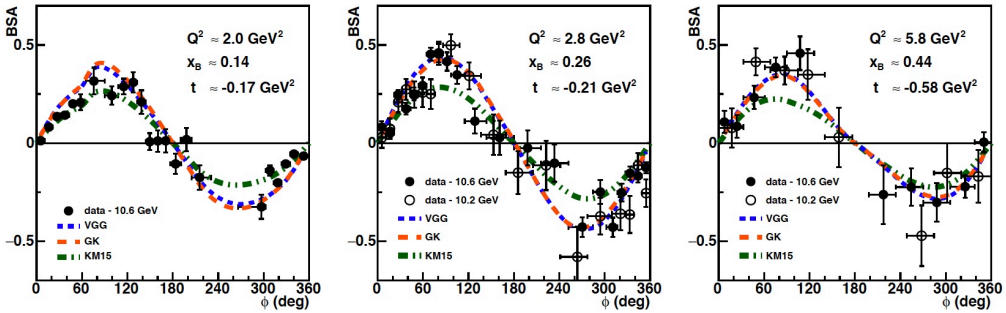
$\gamma p \to e^+ e^- p'$



G. Christiaens, et al. (CLAS collaboration), "First CLAS12 measurement of DVCS beam-spin asymmetries in the extended valence region", getting ready to be submitted to PRL.

Good agreement with GPD models. Extended coverage in Q^2 up to 6 GeV^2, but with large stat. uncertainty.

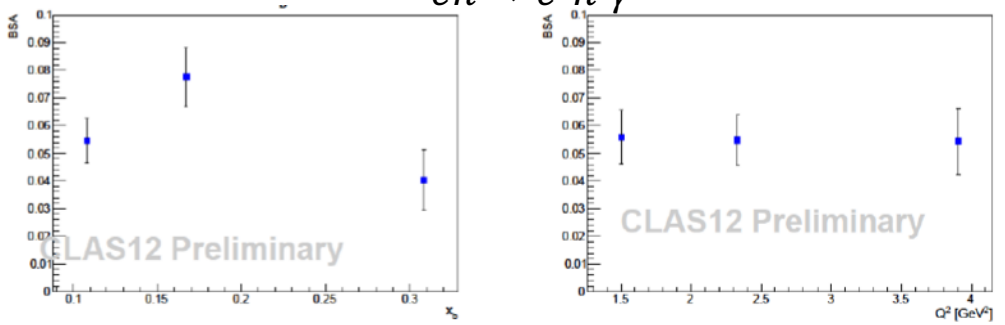
$ep \to e'p'\gamma$



A. Hobart and S. Niccolai, CLAS12 measurement of neutron-DVCS beam-spin asymmetries - in the review process.

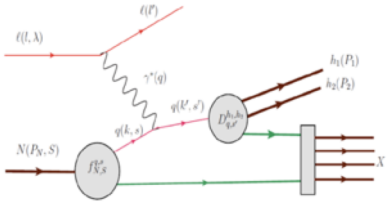
Significantly more data are needed for multidimensional representation.

$en \to e'n'\gamma$

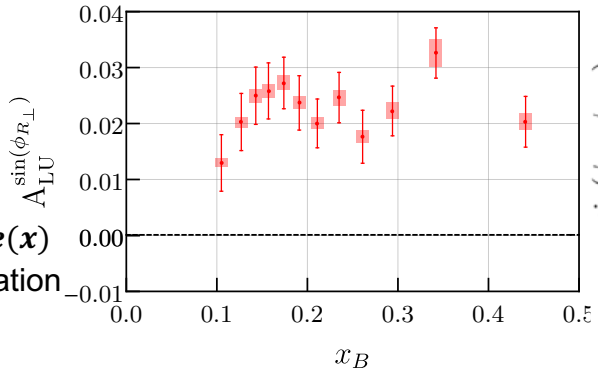


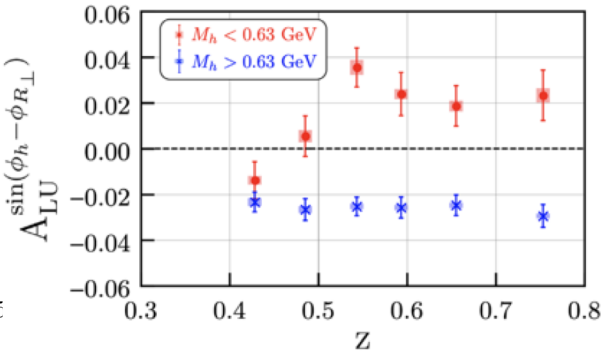
CLAS12 first results: *Di-hadrons in SIDS and TMDs*

T.B. Hayward et al. (CLAS Collaboration), "Observation of Beam Spin Asymmetries in the Process ep→eπ⁺π⁻X with CLAS12", Phys. Rev. Lett. 126, 152501 (2021)

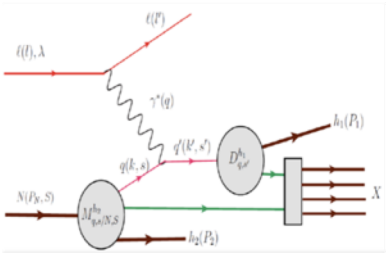


Extraction of twist-3 collinear PDF $A_{LU}^{\sin(\phi_{R_\perp})} \sim \boldsymbol{e(x)}$ and the helicity-dependent two-pion fragmentation function $A_{LU}^{\sin(\phi_h - \phi_{R_\perp})} \sim \boldsymbol{G_1^\perp}$

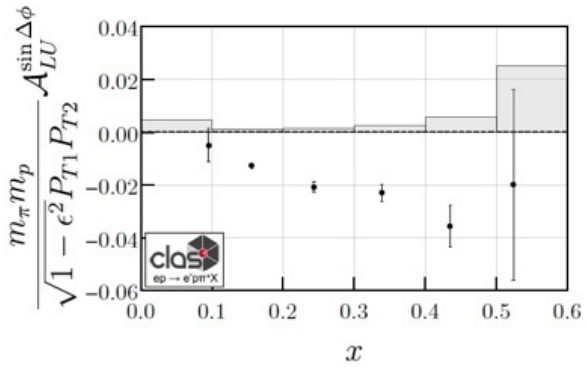


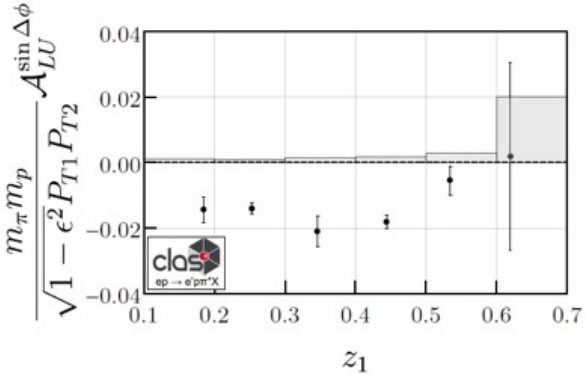


H. Avakian et al. (CLAS Collaboration), "First Observation of Correlations Between Spin and Transverse Momenta in Back-to-Back Dihadron Production at CLAS12", arXiv:2208.05086, submitted to Phys. Rev. Lett. (2022).



Access to the *leading twist* fracture functions, $\hat{l}_1^{\perp h}$ and $\hat{u}_1$.





Significantly more statistics will be needed for multidimensional, high precision measurements for GPD and TMD programs.

CLAS12 luminosity upgrades

A realistic assessment of the detector efficiencies with the first data and measured rates of key reactions prompted discussions of luminosity upgrade.

Two-stage upgrade has been adopted:

I. Achieve luminosity of ~2x10^{35} cm^{-2} sec^{-1} for CLAS12 normal running conditions with charged particle reconstruction efficiency of >85%
   - to support efficient and fast execution of the current program;
   - to support the growing demands of physics program with a low rate, exclusive reactions ([p,n]DVCS, TCS, J/ψ production, $p\bar{p}$ …);

Will need to upgrade forward tracking. The beamline and the rest of the detector systems will perform at x2 higher luminosity. The time frame for the upgrade: 2 to 3 years.

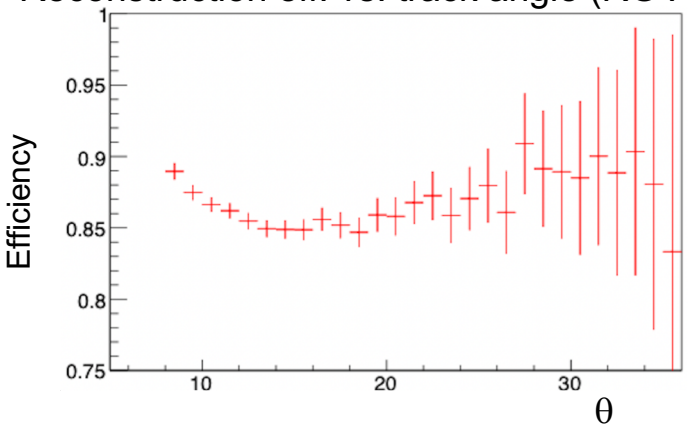
II. Configuration for two orders of magnitude higher luminosities – for muon-pair electroproduction, μCLAS12 at ≥ 10^{37} cm^{-2} sec^{-1}:
   - new physics opportunities for CLAS12 – DDVCS, high-rate TCS, and e-J/ψ;

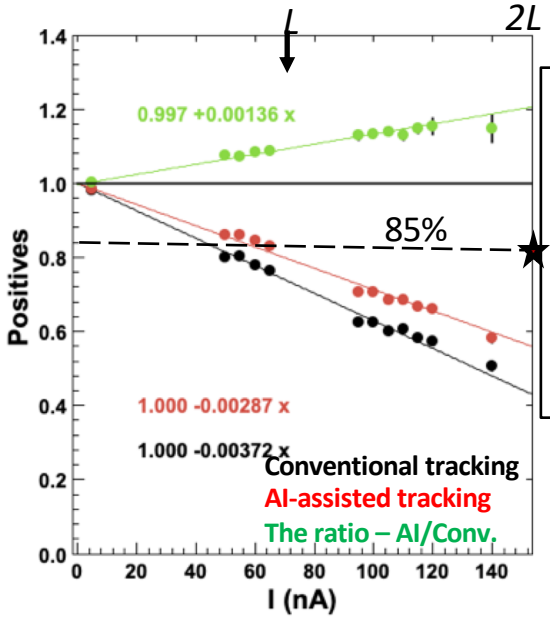
This upgrade requires a large acceptance forward calorimeter (FTCal-large), a recoil detector and a forward vertex tracker. The time frame for the upgrade: 6 to 8 years.

Why only forward tracking?

- The limitation for running above the designed luminosity is the FD track reconstruction efficiency defined by the occupancy in R1 of DC (at L, the occupancy in R1 DC will reach $\sim 5\%$).
- The loss of efficiency has been mitigated with the inclusion of an AI-based pattern recognition algorithm.
- More improvements are needed to reach the goal of running $\mathrm{at}\ 2L$.

Reconstruction eff. vs. track angle (RG-A)

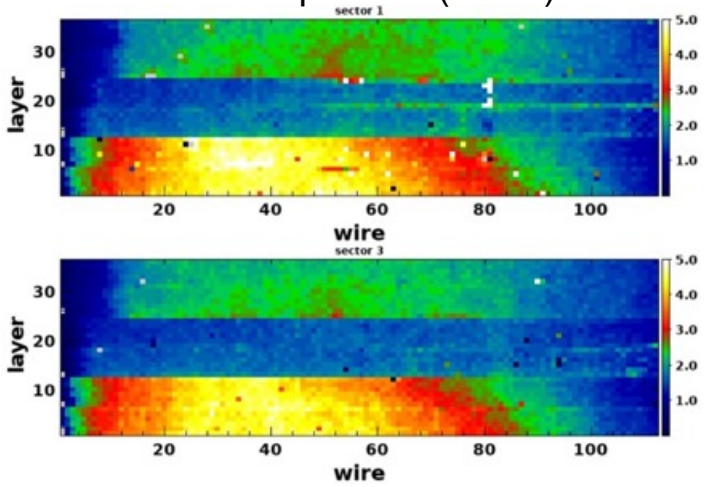




FD tracking efficiency needs an upgrades to get close to $\eta = 1 - 0.001 \cdot I$ or $\eta \geq 85\%$ at $2{\times}10^{35} cm^{-2} sec^{-1}$

(I is the beam current, η is the track reconstruction efficiency)

DC occupancies (RG-A)

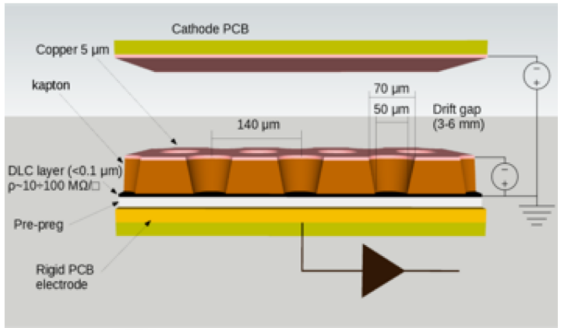


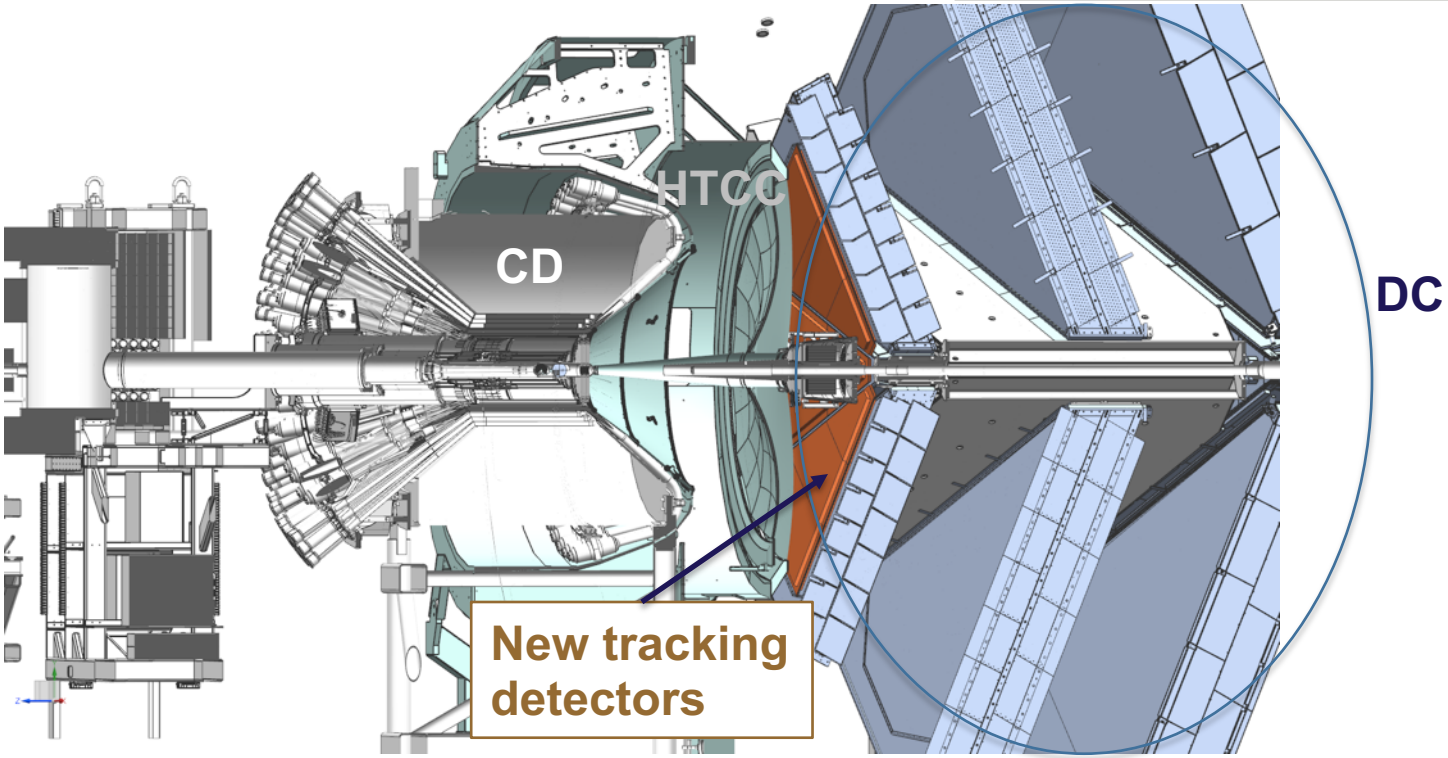
DC R1 cell size 1.5 cm, time window ~250 ns

Phase I: How to get > 85% efficiency at $2L$

- To mitigate occupancy-related inefficiency of FD, add faster tracking detectors to the forward tracking system.
- From available detector technologies, μRWELL with capacitive sharing readout is chosen as the best option for the CLAS12 FD tracking upgrade.

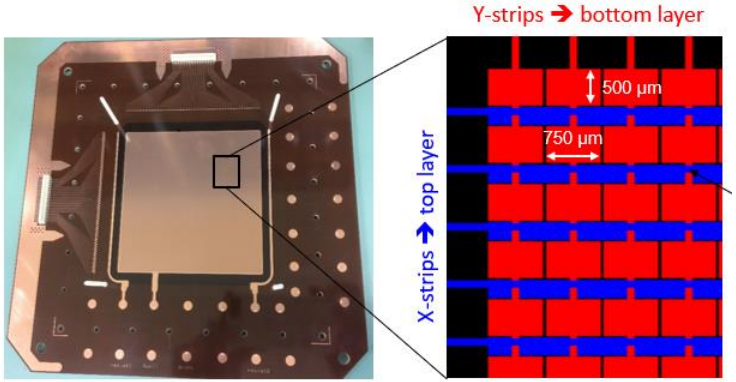
Resistive micro-WELL Detector





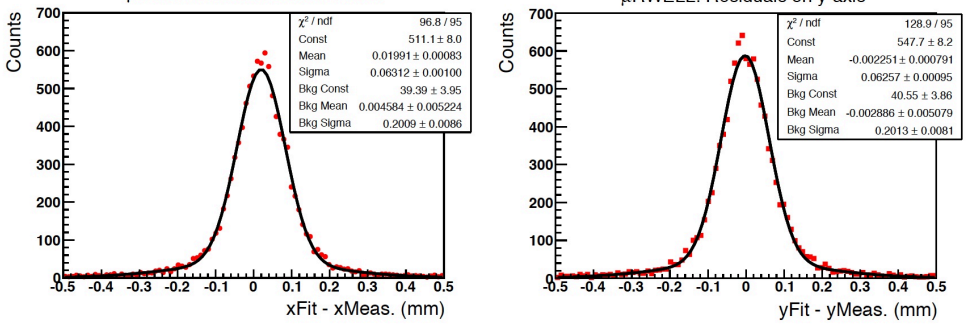
μRWELL detector for CLAS12 FD

A small prototype of a μRWELL detector with X-Y capacitive sharing strip readout was built and tested at JLAB. Measured position and time resolutions from beam test data are well within requirements.

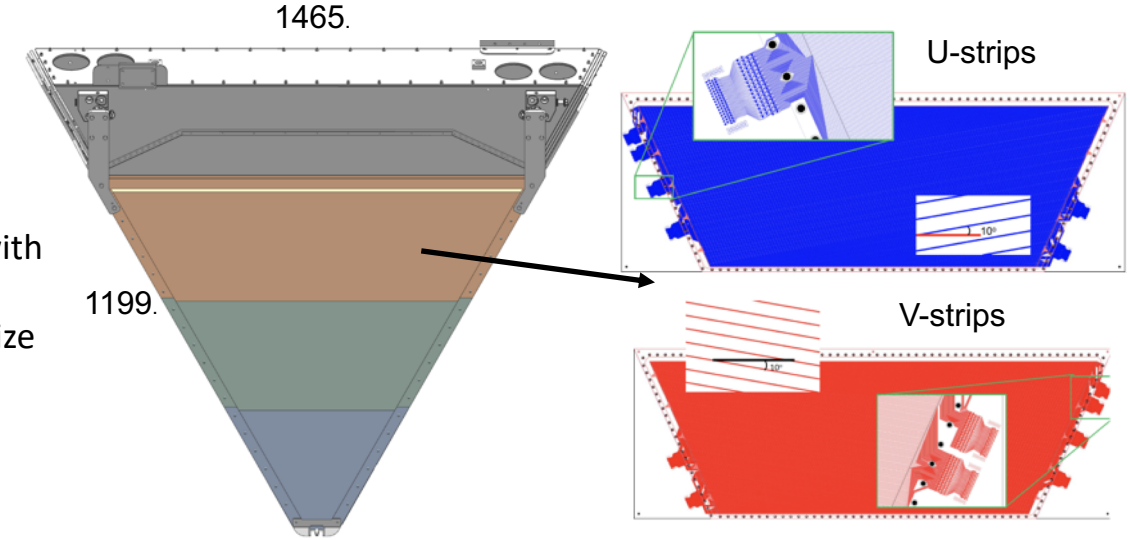


$\sigma = 63\ \mu m$

K. Gnanvo



- Fabrication of the prototype of the largest of the three sections is underway.
- The readout concept is U-V strips with ±10° stereo angles relative to the base of the trapezoid with a pitch size of 1 mm.
- Beam tests the prototype in Hall-B during January – March 2023



A need for $L \geq 10^{37}\ cm^{-2}\ sec^{-1}$

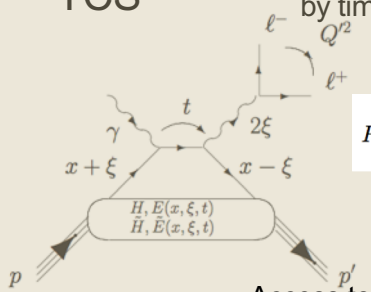
CLAS12 Flagship program – accessing GPDs through measurements of beam/target asymmetries and the cross sections of Compton processes (TCS and DVCS)

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

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

TCS

Hard scale is defined by time-like photons



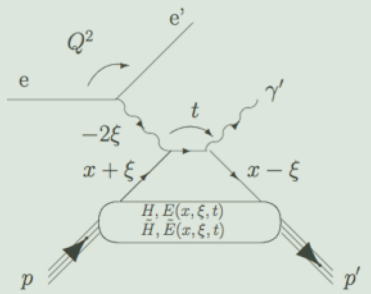
$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^{-}(\xi,x) H(x,\xi,t)$$

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

Access to the Re-part of the Compton amplitude

DVCS

Hard scale is defined by space-like photon

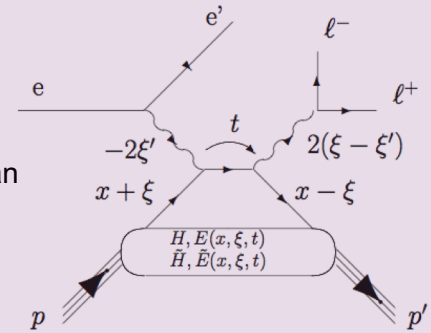


Jefferson Lab at the luminosity frontier is the only place in the world DDVCS can be measured!

μCLAS12 is one of two proposed facilities, another being SoLID in Hall-A, capable of carrying out such measurements.

DDVCS

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

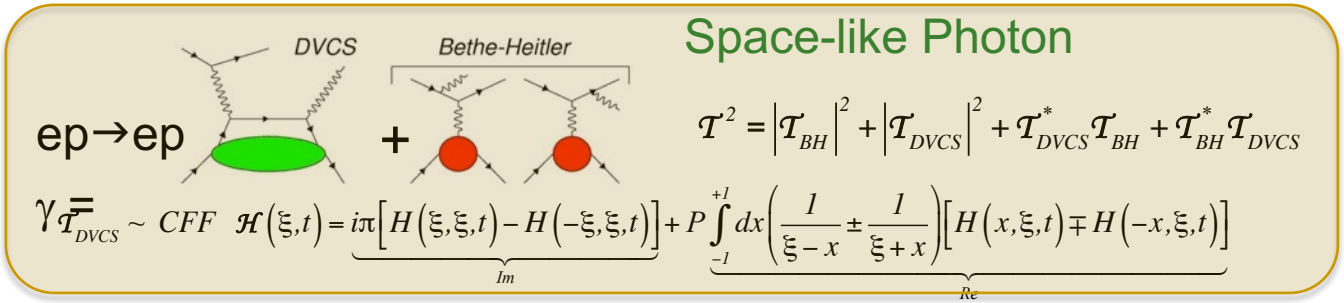


$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

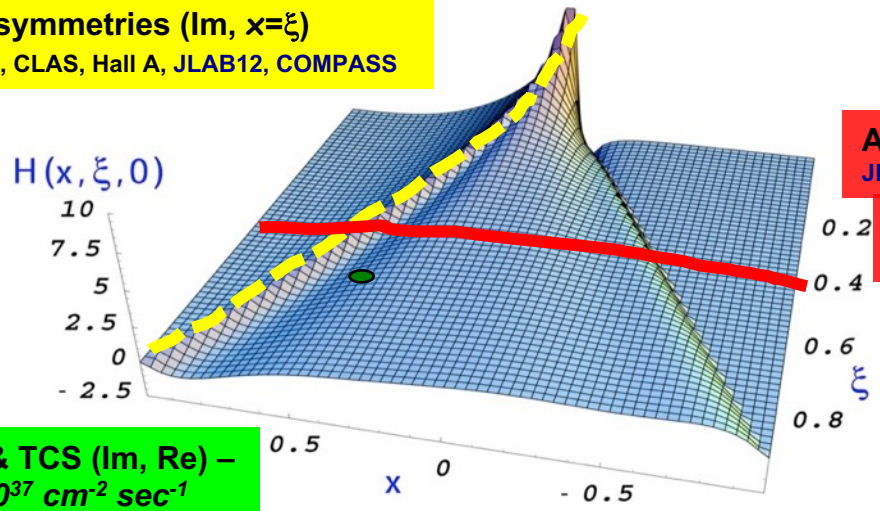
$$H(2\xi'-\xi,\xi,t) + H(-(2\xi'-\xi),\xi,t)$$

σ-DDVCS is three orders of magnitude smaller than σ-DVCS

GPDs in Virtual Compton Scattering



Spin asymmetries (Im, x=ξ)
HERMES, CLAS, Hall A, JLAB12, COMPASS



Angular asymmetry in TCS (|Re|)
JLAB12

Charge asymmetry in DVCS (|Re|)
HERMES, COMPASS, JLAB12

DVCS Cross sections ($|Re|^2$)
H1, Hall A, JLAB12, COMPASS

DDVCS ($x \neq \xi$) & TCS (Im, Re) – JLAB12 at $L \geq 10^{37}$ cm^{-2} sec^{-1}

Re parts of CFFs provides a direct measurement of the D-term and access to the mechanical properties of the proton

Proposal of μCLAS12

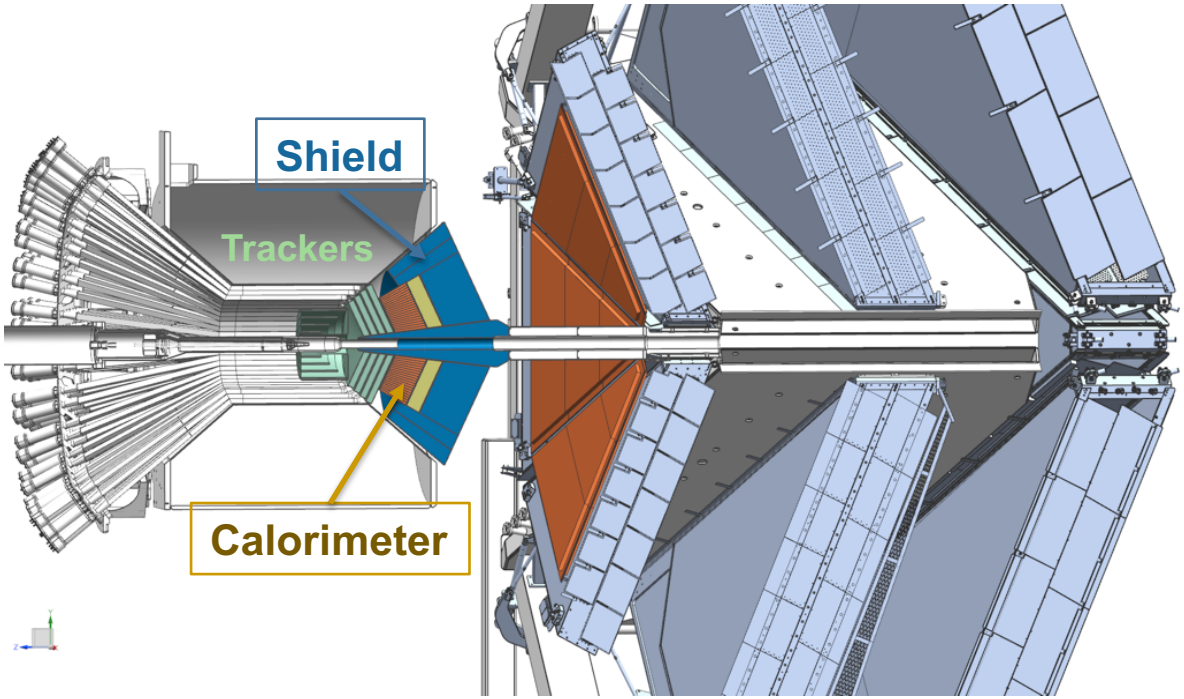
- Cross section of DDVCS is smaller than the DVCS by two to three orders of magnitude;
- There are issues of ambiguity and anti-symmetrization with the same flavor leptons in the decay of the outgoing virtual photon and the incoming-scattered beam particle.

Both challenges can be solved by measuring di-muon electroproduction:

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

The same final state will include J/ψ electroproduction and TCS.

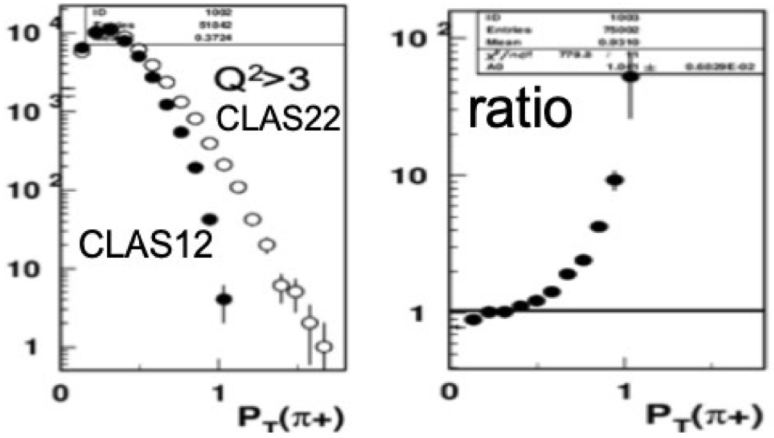
- *Shield CLAS12 FD and convert it into a μ-detector, use calorimeter for e- (γ) detection. Install fast, high rate MPGD trackers for vertexing and recoil tagging.*
- *MC studies validated the proposal. The backgrounds and the trigger rates are within acceptable limits.*
- *More studies are underway.*



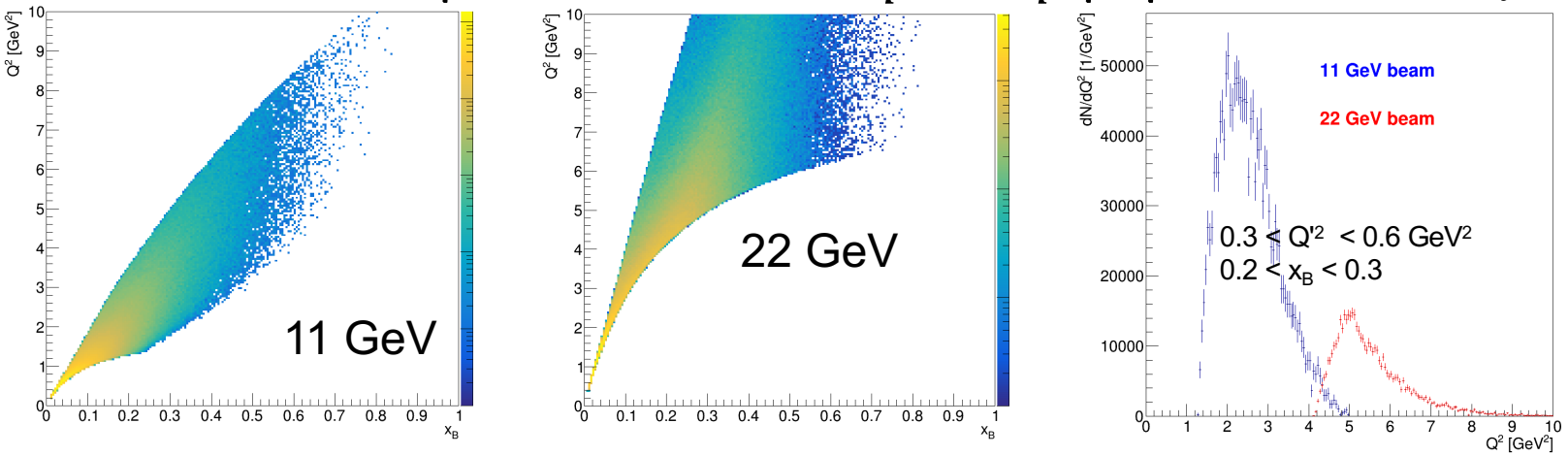
What about CLAS12 with 20+ GeV electrons?

- [μ]CLAS12 will perform with higher energy beams, providing a significant coverage at large Q^2.
- Incremental improvements of the tracking detectors can help to retain momentum resolution for high momentum tracks.
- Available PID will be sufficient for exclusive and for the most semi-inclusive reactions

$ep \rightarrow e'\pi^+X$, relative rates (H. Avagyan)



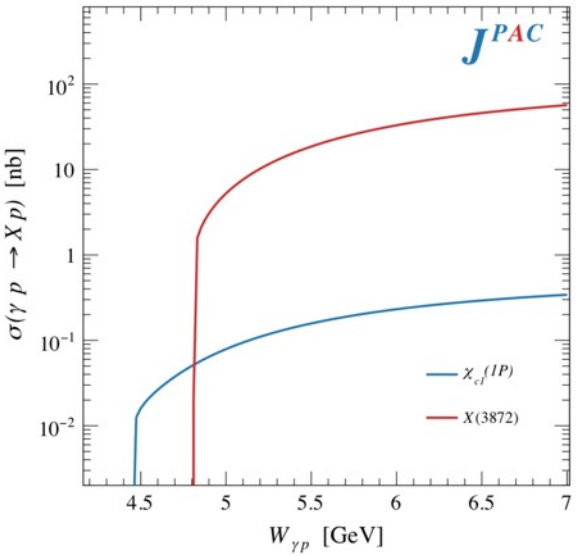
$\mu CLAS12\ BH\ MC, ep \rightarrow e'p'\mu^+\mu^-$ R. Paremuzyan



More with higher energies: XYZ spectroscopy

- Several states in charmonium region have been discovered that do not fit into a simple $q\bar{q}$ model.
- JLAB energy upgrade (20+ GeV) will open a phase space for photoproduction of some of these states.
- **μCLAS12 at 10^{37} cm^{-2} sec^{-1} will contribute in the studies of the lowest mass states.**
- An example, well know exotic $\chi_{c1}(3872)$, aka X(3872), first discovered by Belle in 2003.

$$\gamma p \rightarrow \chi_{c1}(3872) p'$$



The luminosity in the energy range: 13 GeV to 22 GeV is 100 nb^{-1}, even with modest efficiency of 2% one expects **>50 detected $\chi_{c1}(3872)$ per hour** in each decay mode

$\chi_{c1}(3872)$ decay modes:

- $\chi_{c1} \rightarrow \omega J/\psi$ BR= 4.3%
  $\omega \rightarrow \gamma\pi^0$ BR=8.28%
  $J/\psi \rightarrow \mu^+\mu^-$ BR=6%
  $\chi_{c1} \rightarrow \gamma\gamma\gamma\mu^+\mu^-$ BR≥ 2x10^{-4}

- $\chi_{c1} \rightarrow \gamma\, \psi(2S)$ BR= 4%
  $\psi(2S) \rightarrow \mu^+\mu^-$ BR=0.8%
  $\chi_{c1} \rightarrow \gamma\mu^+\mu^-$ BR≥ 2.3x10^{-4}

Summary

- CLAS12 detector at Jefferson lab was commissioned in early 2018 and has taken physics data since then.
- The performance of the detector is close to the design. Implementation of AI-based event reconstruction helped to improve event reconstruction efficiency.
- However, the growing demands for efficient and expedited execution of the current physics program, and the need to support new physics opportunities, require a further upgrade of the running luminosity and reconstruction efficiency.
- The two-stage upgrade is planned for the CLAS12 luminosity increase.
  - Phase-I, in progress, will allow running x2 higher than the designed luminosity with the same or even better event reconstruction efficiency, the time frame for the upgrade is 2-3 years.
  - Phase-II upgrade, in 6 to 8 years, will allow running CLAS12 at two orders higher luminosity and is to study small cross-section processes in the di-muon final state.