Double DVCS Measurement with the CLAS12 High-Luminosity Upgrade

Hadron23 Conference

Genova, Italy

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Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

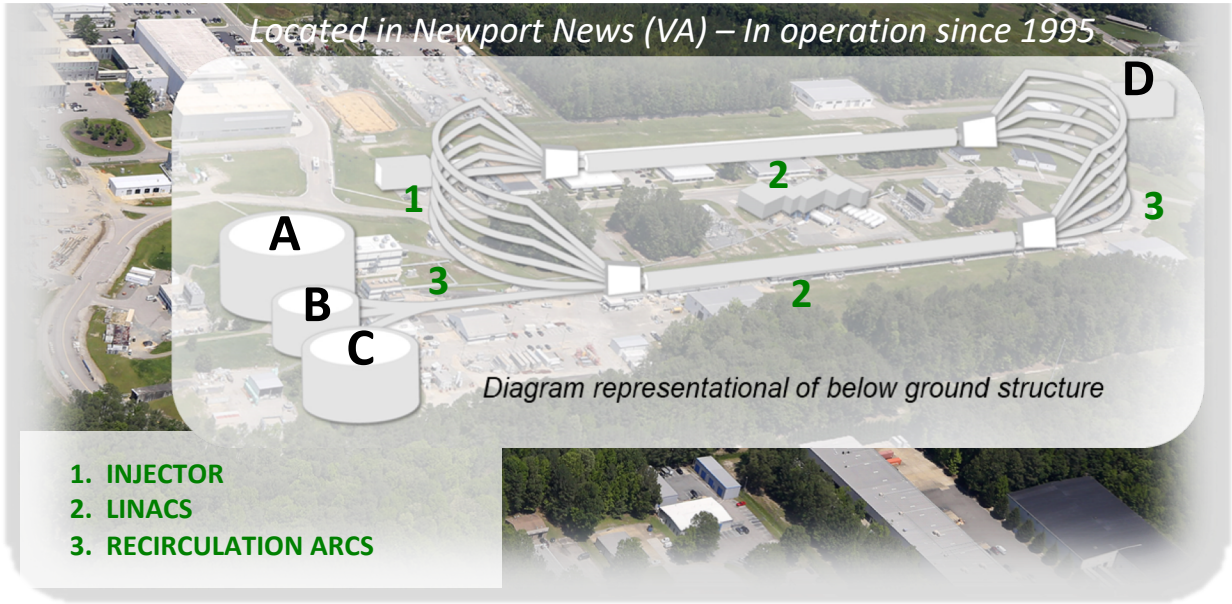
JSA

Outline

- Overview
  - Jefferson Lab
  - CLAS12
    - Physics Program
    - Detector
- Luminosity Upgrades
  - Phase I: *Doubling*
    - Motivation
    - Hardware and Software, Plans and Progress
  - Phase II: *100x*
    - Motivation
    - Proposed μCLAS12 detector
    - **Double Deeply Virtual Compton Scattering**
- Summary

Jefferson Lab – Experimental Overview

- **CEBAF Upgrade completed in September 2017**
  - CW electron beam
  - E_{max} = 12 GeV
  - I_{max} = 90 mA
  - Pol_{max} ~ 90%



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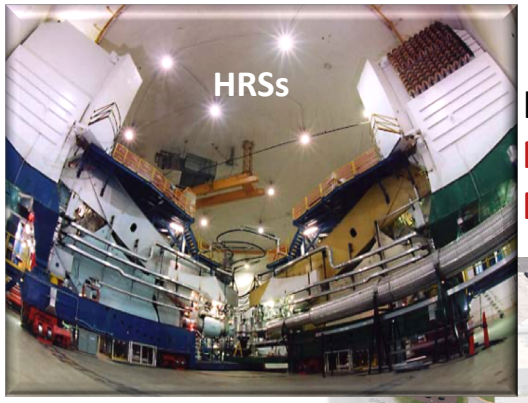
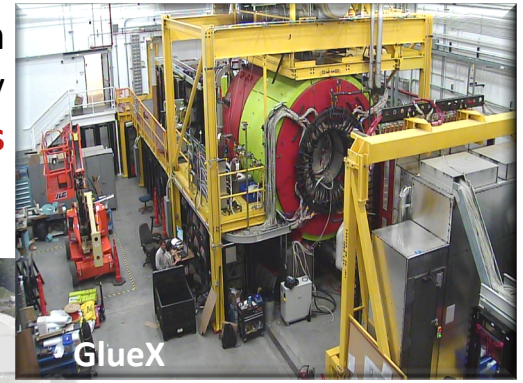
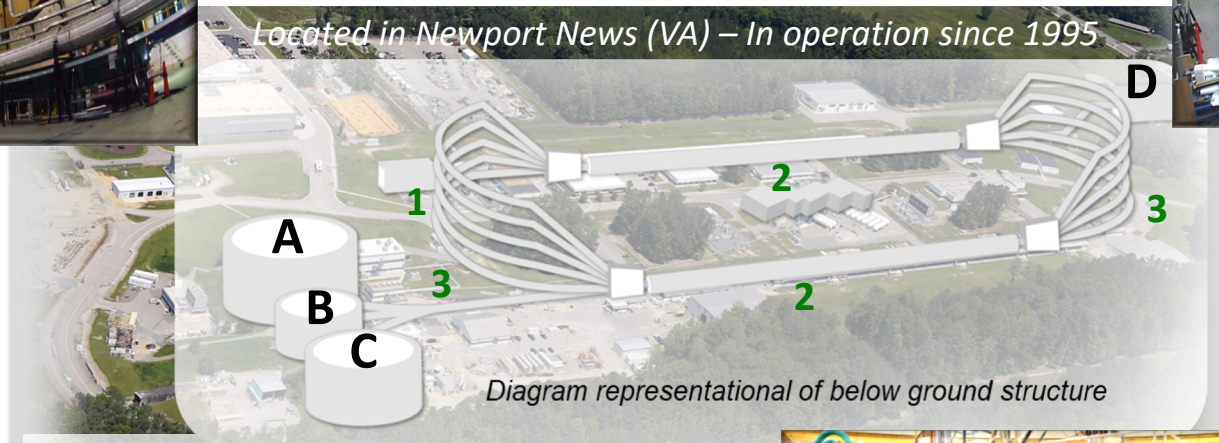
Jefferson Lab – Experimental Overview



Hall A – SRC, **form factors and PDFs**, hyper-nuclear physics, **Physics BSM**

Hall D – exploring origin of **confinement** by studying **exotic mesons**





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  - 4 halls running simultaneously since January 2018

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Hall C – precision determination of **valence quark** properties in nucleons and nuclei

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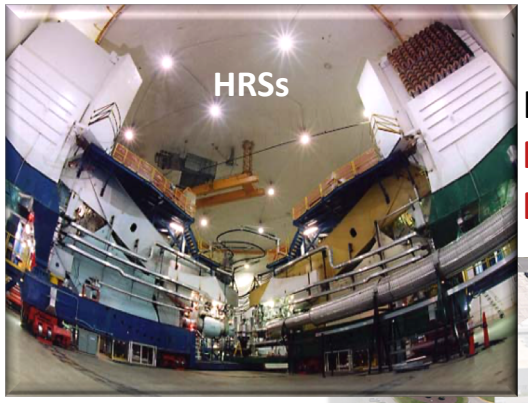
Jefferson Lab – Experimental Overview



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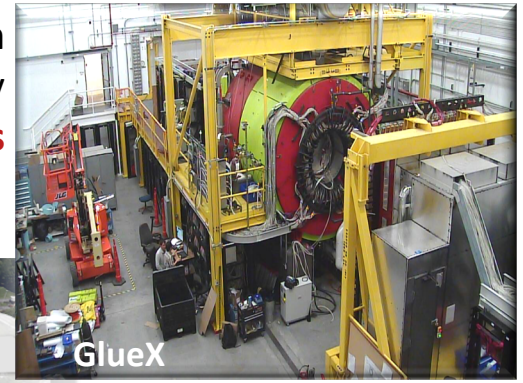

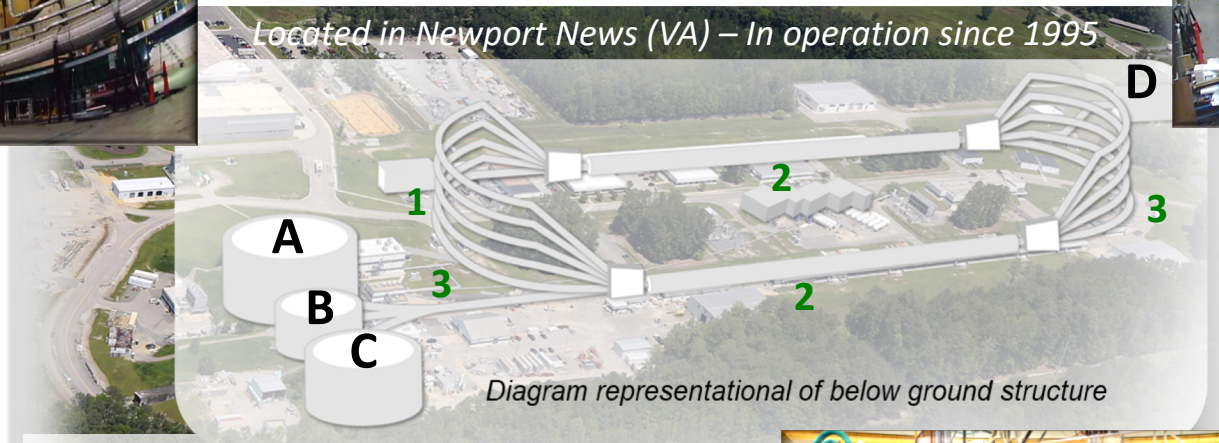

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1. INJECTOR
2. LINACS
3. RECIRCULATION ARCS

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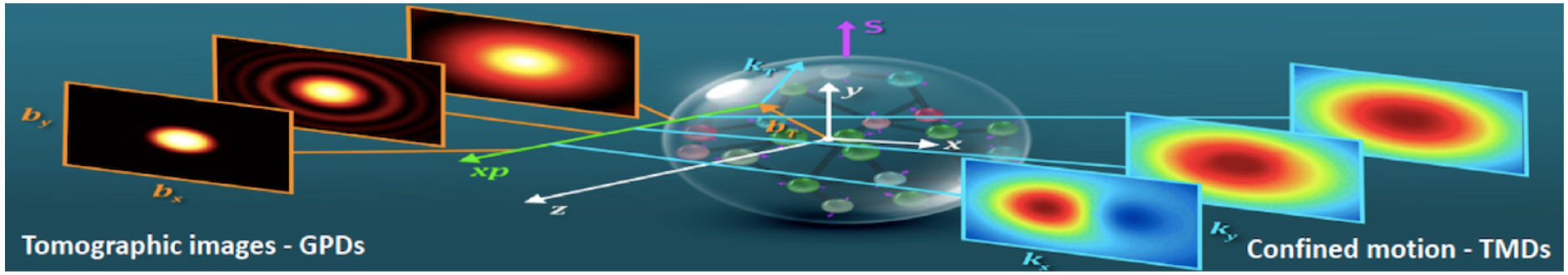
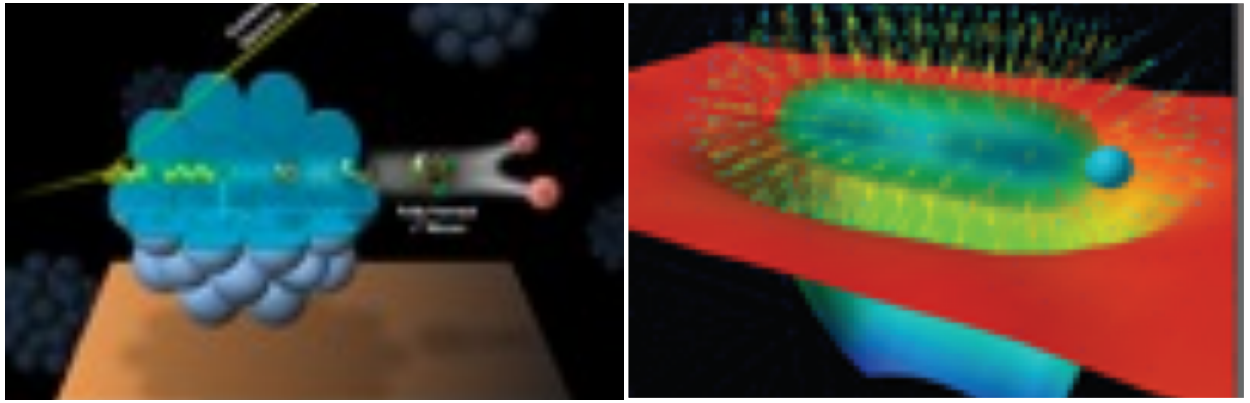
Hall C – precision determination of **valence quark** properties in nucleons and nuclei

CLAS12 – Physics Program



- Nucleon and nuclear structure, spatial and momentum tomography, form factors …
- Cold nuclear matter, NN correlations, hadronization, color transparency …
- Exploring origin of confinement, meson and baryon spectroscopy, exotics …



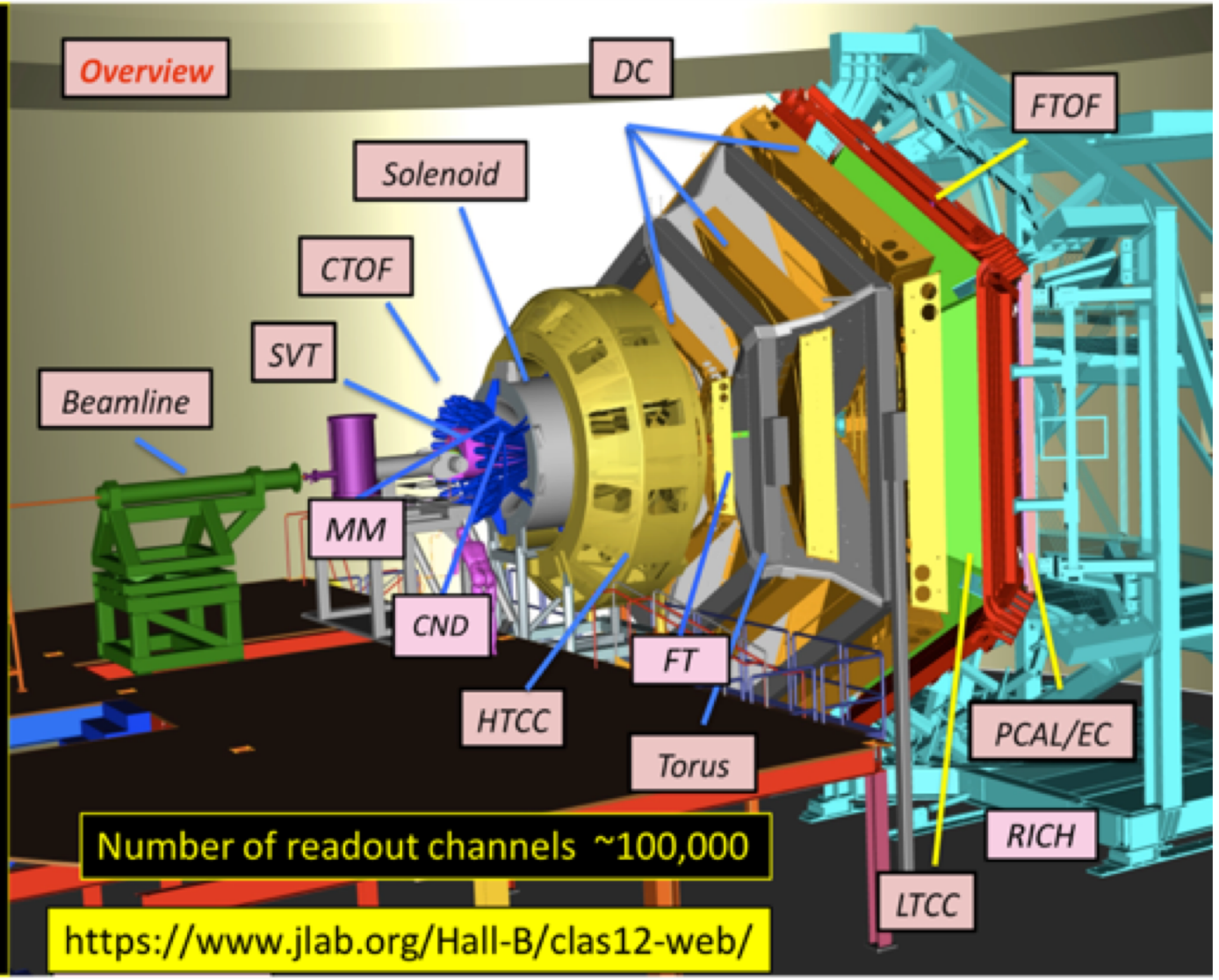
- *Currently a total of 44 approved experiments, with large coverage of the nuclear physics field*
- Organized into 11 run groups to optimize accelerator usage, based on overlapping experimental configurations, e.g., beam energy, target, magnetic fields

CLAS12 – Detector

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



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

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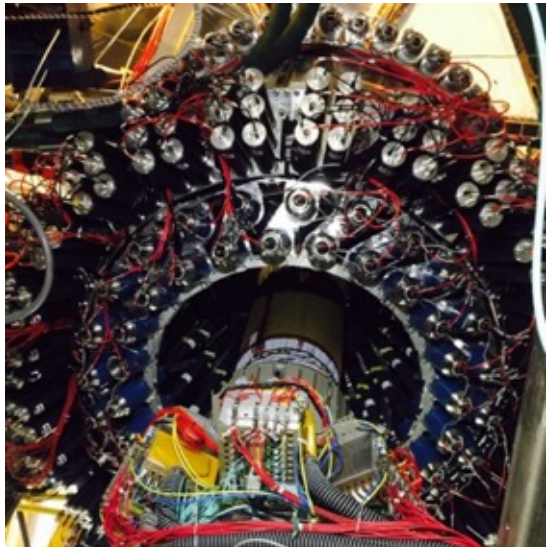
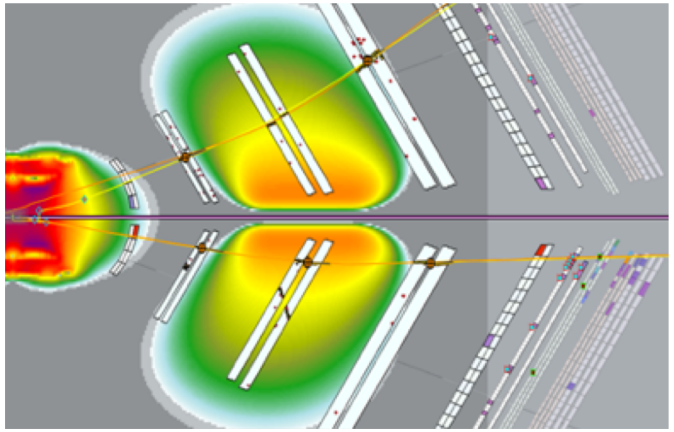
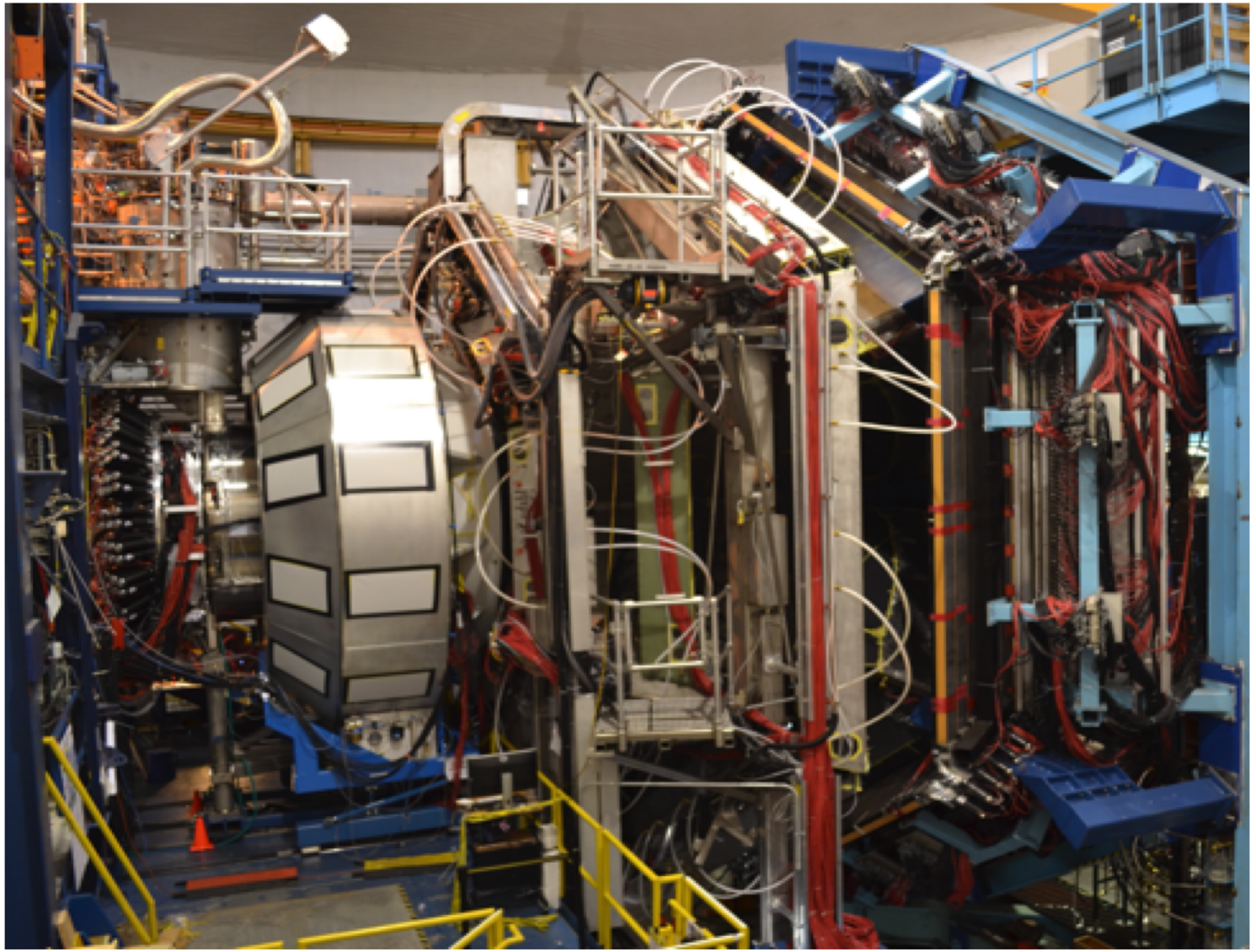
CLAS12 – Detector

Installation complete in 2017,
production running since 2018

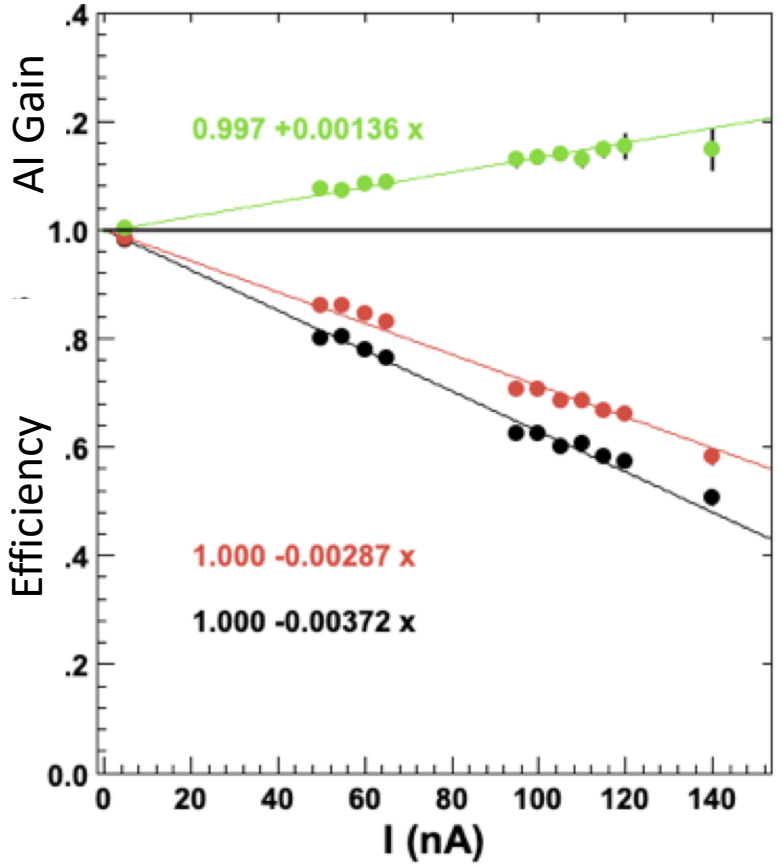


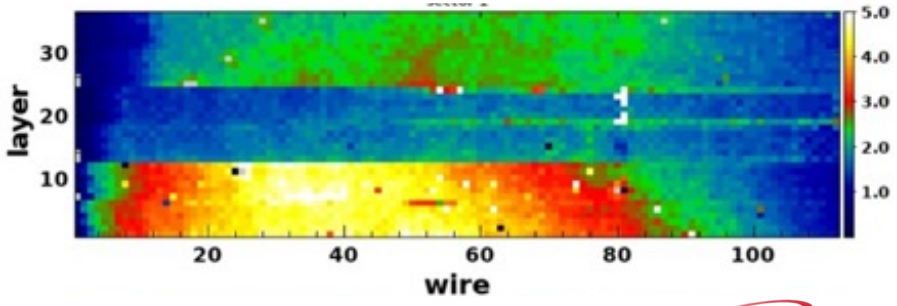




CLAS12 – Luminosity Upgrade – Phase 1 – Motivation

- A lot was learned from the first year(s) of data collection about detector and software performance, by analysis of many key reactions
- High-occupancy, forward tracking inefficiencies, which led to conservative running at less than design luminosity, combined with optimistic assumptions in the original proposals, e.g., perfect efficiency and unrealistic acceptance
  - and we are effectively down by about a factor of ~2 in proposed detection rates for some physics channels of interest
- The goal of phase 1 is to catch up by increasing performance to double the luminosity
  - → **2×10^{35} cm^{-2} s^{-1}**
  - *Significant efficiency recovery has already happened with AI/ML-based software techniques and efforts are continuing*
  - *But tracking hardware improvements will also be required to keep occupancies and efficiencies acceptable and achieve 2x luminosity*





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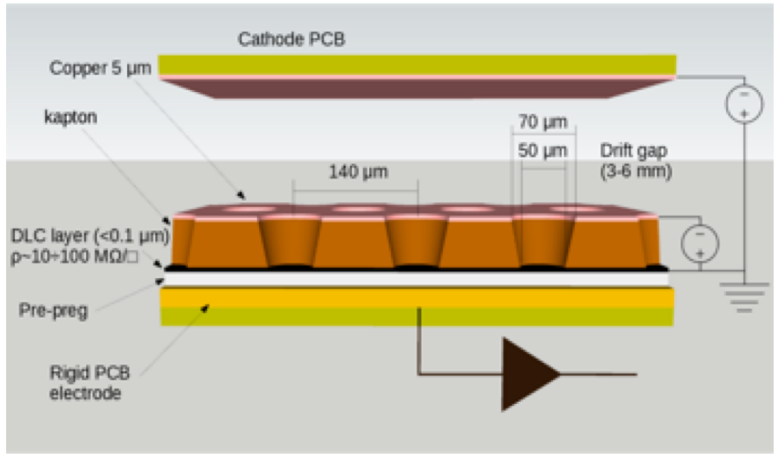
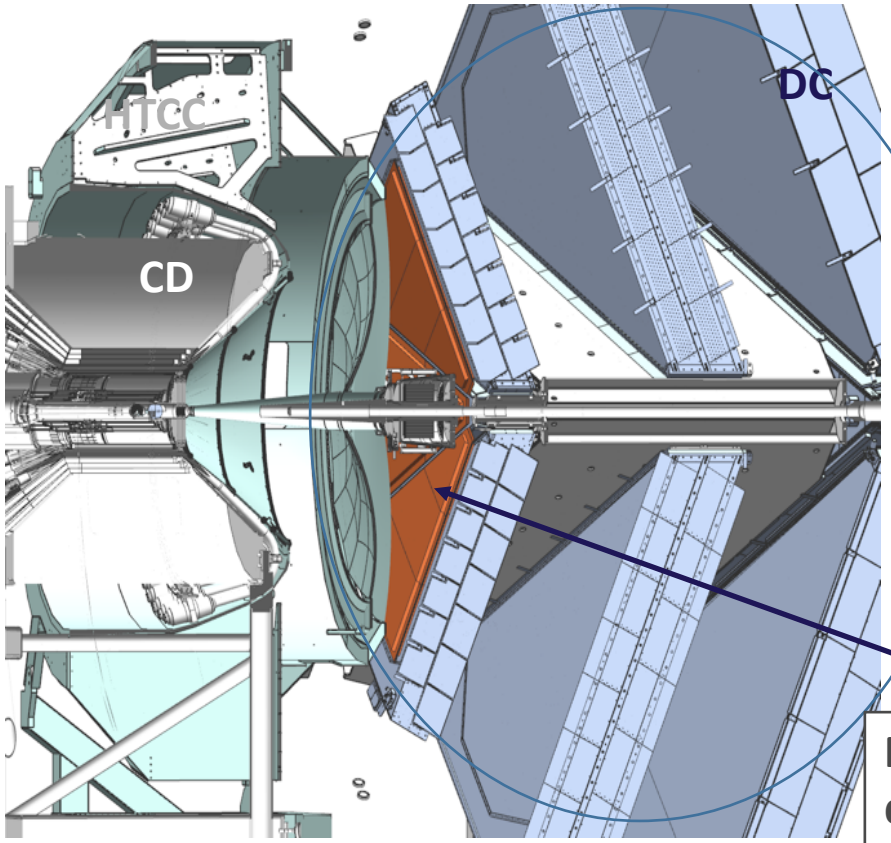
CLAS12 – Luminosity Upgrade – Phase 1 – Plans

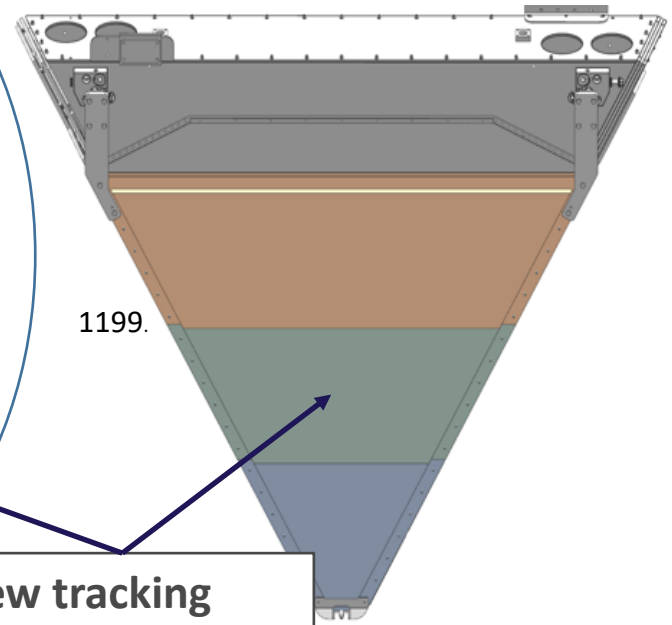
To mitigate occupancy-related inefficiency of forward tracking, an additional tracking layer with fast timing will be added to the 1st, most upstream, tracking region

- µRWell with 2-D, 10º stereo, strip readout with capacitive sharing, is the chosen technology
- Integration wise, only minor repositioning of upstream detectors is required
- Simulations fully developed and show existing tracking software can already achieve the desired efficiency at higher luminosities





µRWELL module mounted on R1 DC



New tracking detectors

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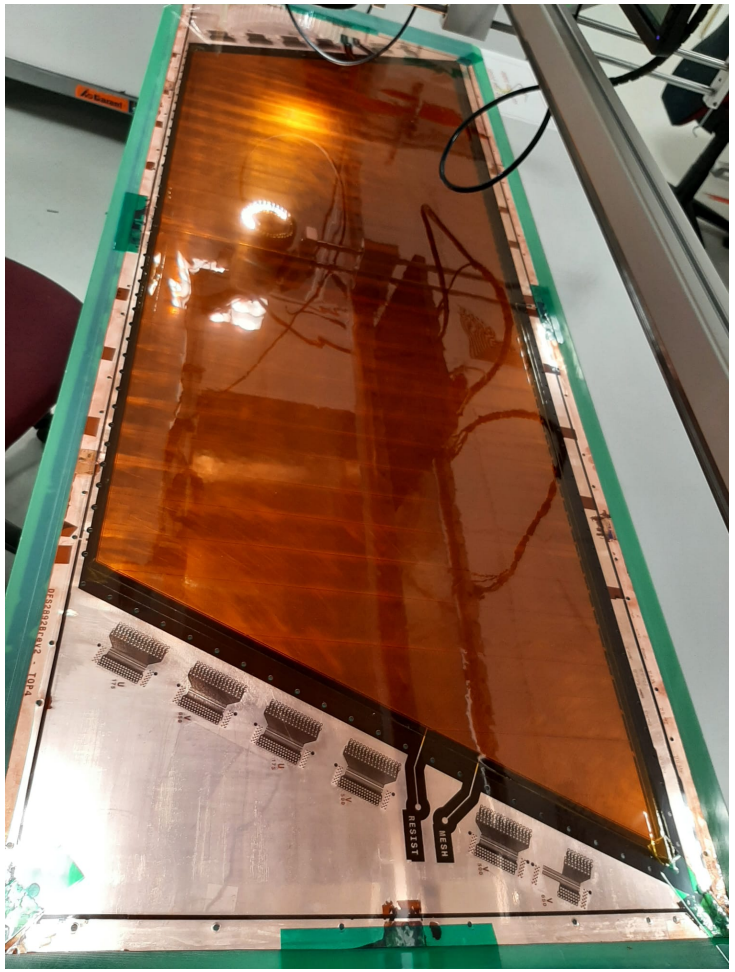
CLAS12 – Luminosity Upgrade – Phase 1 – Status

- Forward tracker upgrade
  - Small uRWell prototype built and tested at JLab in 2022
  - Full-scale, single-sector, prototype assembled at CERN, in collaboration with University of Virginia
    - Partially installed in proposed location in CLAS12 for a few weeks with beam in 2023, data analysis underway and lessons learned
  - Timeline:
    - 2023: design final, including electronics
    - 2024: testing of prototype-1, start procurement
    - 2025: fabrication of full 6 sectors
    - 2026: installation



- All other CLAS12 detectors can already handle doubling the luminosity, except some need for aging mitigation/replacement of PMTs, in progress
- Some DAQ hardware components will require incremental upgrades, e.g. TDCs and one detector's front-end boards, in progress

CLAS12 – Luminosity Upgrade – Phase 2 – Motivation

- CEBAF at the luminosity frontier, with large-acceptance detector systems, is a natural continuation of the JLab12 physics program and complementary to EIC.
- The upgraded CLAS12 will be one of future facilities at JLab capable of taking nuclear *femtography* to a new level.
- Two orders of magnitude higher luminosities, μCLAS12 for muon-pair electroproduction at ≥ 10^{37} cm^{-2} s^{-1}, is proposed for the 2nd phase of the CLAS12 luminosity upgrade.

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

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

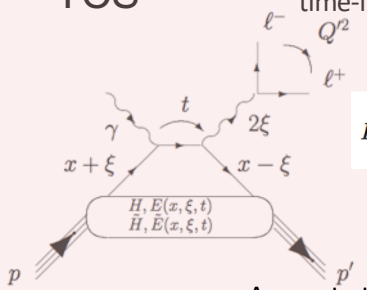
μCLAS12 is one of two proposed facilities, another being SoLID in Hall-A, capable of carrying out such measurements.

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



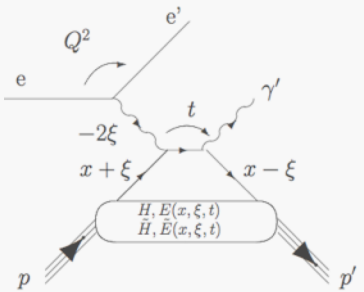
$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^{-}(\xi,x) H(x,\xi,t)$$

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

Access to the Re-part of the Compton amplitude

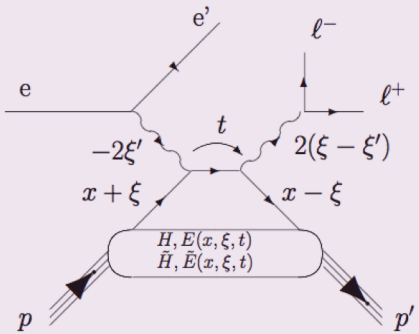
DVCS

Hard scale is defined by space-like photon



DDVCS

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



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

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

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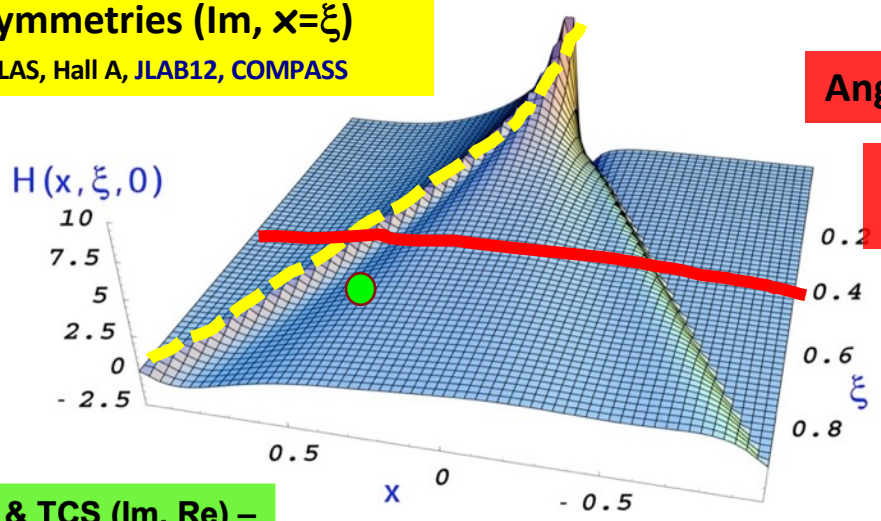
GPDs in Virtual Compton Scattering

See tomorrow's plenary talk by Maxime Defurne on "Experiment Studies of GPDs"

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



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

Angular asymmetry in TCS (|Re|) JLAB12

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

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

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

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

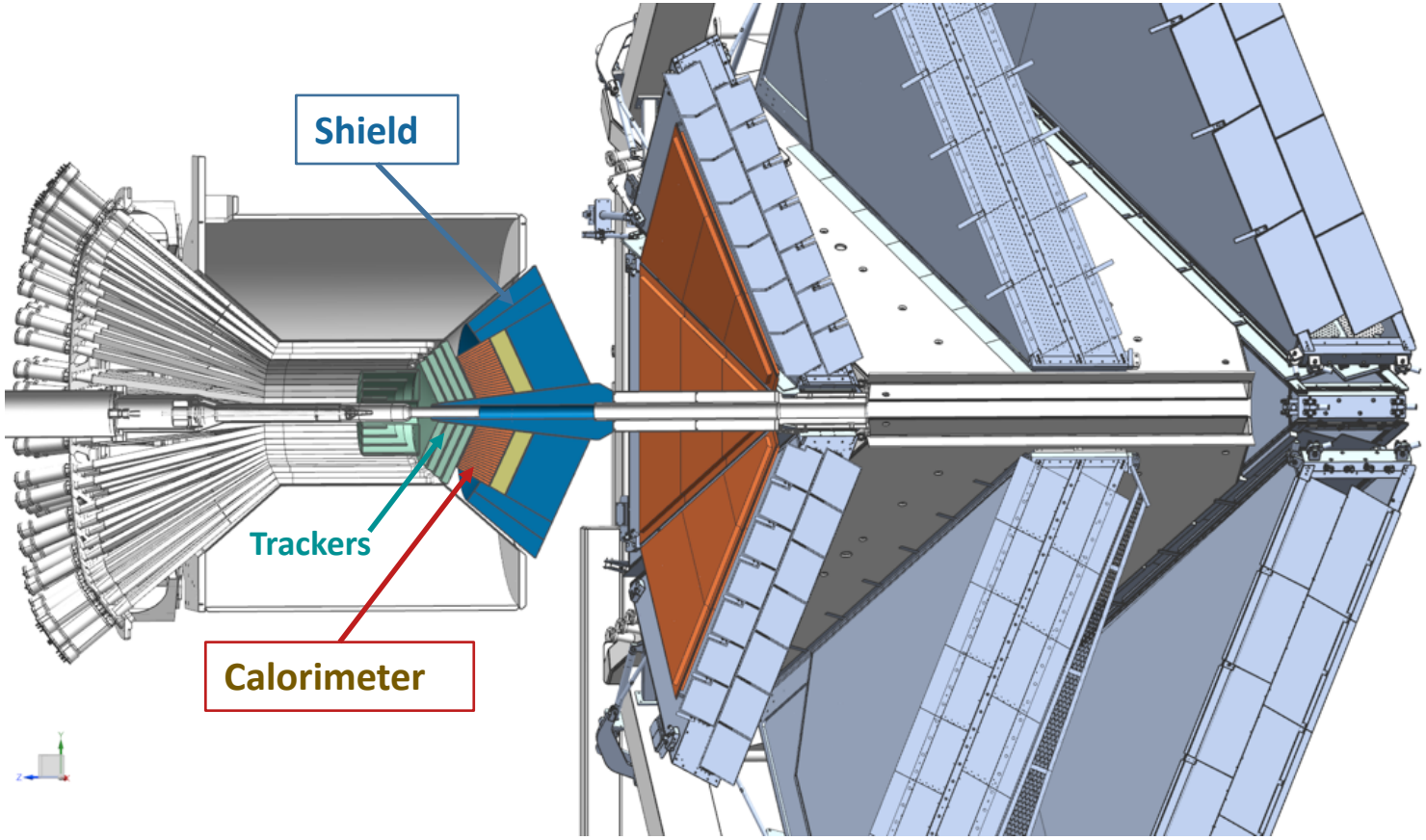
μCLAS12 – Luminosity Upgrade – Phase 2 – Plans

Remove the high-threshold Cherenkov counter and install:

- a new Moller cone that extends to larger polar angles, $\sim 7^o$
- shield the forward detector from electromagnetic and hadronic backgrounds
- a new $PbWO_4$ calorimeter to cover 7^o to 30^o polar angles for electron and photon detection;
- install fast, high rate MPGD trackers in front of the calorimeter for vertexing and inside the solenoid for recoil tagging (with some detector for simple timing-based PID).

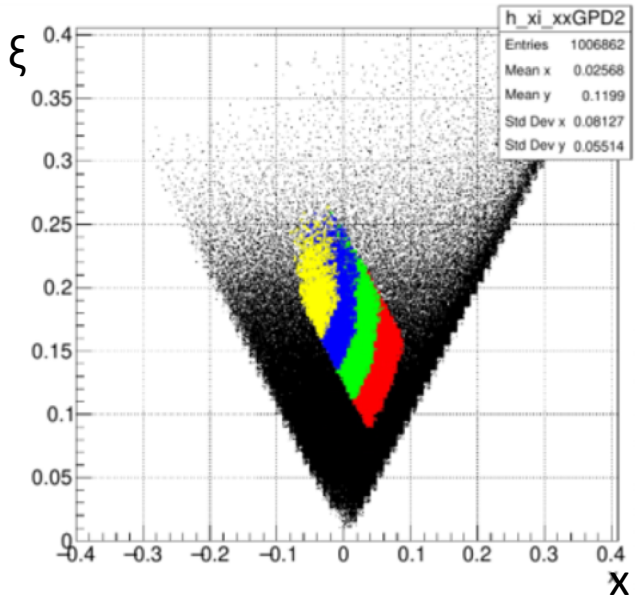
- **The existing downstream trackers and toroidal field become a muon spectrometer for luminosities of 10^{37} cm^{-1} s^{-1}**

- Time frame for Phase 2 is 6-8 years.



μCLAS12 – DDVCS Projections

- MC studies validate the proposed measurement, with acceptable background and trigger rates and muon/pion separation.
- DDVCS letter of intent submitted to JLab's PAC in 2016, with recommendation to wait for DVCS measurements from CLAS12 to be realized before submitting full proposal.
- More studies necessary to finalize detector design for a final proposal.



Kinematic Coverage

Scan over Q'²

2 GeV² < Q² < 3 GeV²

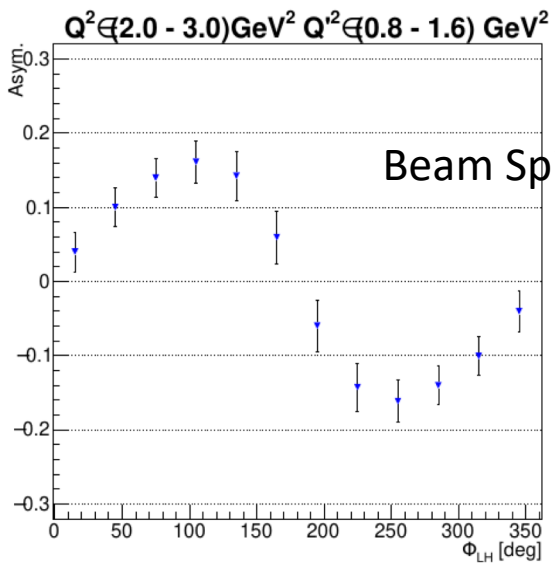
0.8 GeV² < Q'² < 1.6 GeV²

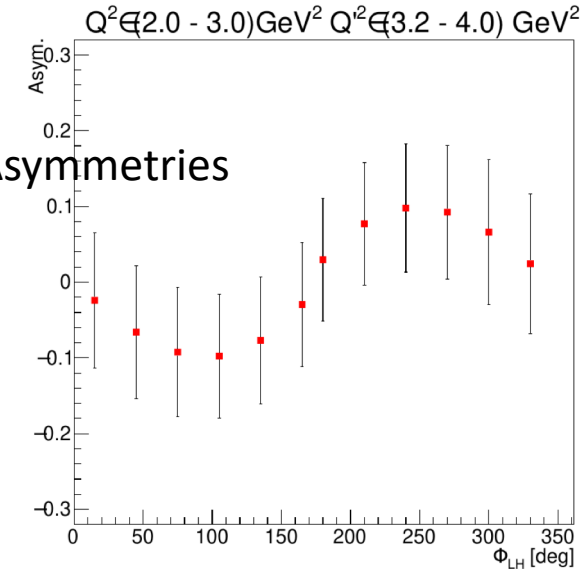
1.6 GeV² < Q'² < 2.4 GeV²

2.4 GeV² < Q'² < 3.2 GeV²

3.2 GeV² < Q'² < 4. GeV²

Beam Spin Asymmetries





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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.
- Two phases of luminosity increases are planned.
  - The first, a doubling to 2×10^{35} cm^{-2} s^{-1}, is in progress with an additional, fast tracking layer and en route in the next 3 years.
  - The second, larger, phase, to 10^{37} cm^{-2} s^{-1}, converts CLAS12's forward acceptance region into a muon detector.
- µCLAS12 in the 2nd phase is one of only two facilities in the world that can measure DDVCS, extending access to GPDs into new kinematic space.
  - Also can provide, for example, access to heavy quarkonium.

See also, an energy extension, P. Rossi's plenary talk tomorrow, "New Opportunities with Jefferson Lab at 22 GeV"