CLAS12 High-Luminosity Upgrade

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CLAS collaboration meeting, June 1 – 4 2021

Why do the Upgrade?

- Improving the current performance of CLAS12 in terms of $L \times \eta$ is crucial for the approved physics program
  - All our proposals assumed $L = 10^{35} cm^{-2} sec^{-1}$ and $\eta = 1$ (reconstruction efficiency) for their projections
  - We run RG-A with an average luminosity of $0.7 \times L^{a,b}$ on a 5cm LH_2 and have $\eta = 0.8$ for a single track
  - As it stands analysis with 2-particles in the final state will get only ~40% of the expected statistics
  - There are significant efforts underway to improve reconstruction efficiency (AI-assisted tracking) as well as the tracking detector hardware

Note: (a) including beam windows and the air downstream of the scattering chamber, the RG-A luminosity was L, (b) while we run RG-B with 1.3×L on the 5 cm LD_2, projections in the proposals assumed 2×L.

- Should start thinking and planning for the future, it is never too early
  - Large scale upgrades typically start ≥ 5 years earlier
  - We expect to see new cutting edge physics to surface after few years of CLAS12 running (e.g. most of the current physics program of CLAS12 have been seeded after few years of CLAS running)
  - Hard to imagine that the new physics will be satisfied with $L = 2 \times 10^{35} cm^{-2} sec^{-1}$, studying reactions with small cross sections or conducting high statistical precision measurements will require much higher luminosity (see e.g. some of the "golden" physics motivations for SoLID or high lumi EIC)
  - CLAS12 can be very relevant in several key areas of future physics at JLAB; DDVCS, e-J/ψ, tagged-nuclear DIS (DVCS. DVMP) …. *and we want to be relevant*

Little bit of the history

- Ideas and discussions about increasing the CLAS12 luminosity goes back to days of the CLAS12 construction
- The real first step was done with the LOI12-16-004 for DDVCS and J/ψ electroproduction showing that running at L ≥ 10^{37} cm^{-2} sec^{-1} is possible for μCLAS12
- In FY20, Hall-B had a Lab agenda item to develop a strategy towards the most promising option for CLAS12 to achieve operations at higher luminosities
- A task-force was organized to address this question (V. Burkert, L. Elouadrhiri, M. Mestayer, M. Ungaro, V. Ziegler). The TF with help of many contributors came up with two-stage upgrade proposal
  - first, work towards increasing luminosity by x2 with high efficiency of reconstruction and
  - then proceed with >x10 increase
- Full report of the TF is available as CLAS12 Note 2020-006
- Details of TF work can be found on the wiki - https://wiki.jlab.org/physdivwiki/index.php/Task_Forces_2020#tab=High_Luminosity

CLAS12 Upgrade for High Luminosity Operations
Task Force Report

Task Force group: S. Stepanyan (PI), V. Burkert, L. Elouadrhiri, M. Mestayer, M. Ungaro, V. Ziegler

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(Dated: October 7, 2020)

Improving the performance of CLAS12 in terms of $L \times \eta$ (luminosity times the reconstruction efficiency) will significantly enhance the physics reach of experiments in Hall B. In the proposal stage, experiments assumed operations at a luminosity of $L = 10^{35}$ $cm^{-2}s^{-1}$ (the design luminosity of CLAS12) with a particle reconstruction efficiency of $\eta \simeq 1$. As it turns out, the reconstruction efficiency of charged particles (both in the Forward Detector and in the Central Detector) have a strong dependence on the luminosity and at the design luminosity is presently ~75% − 80%. This amounts to > 35% loss of the reconstructed events for two-prong final states. This higher than expected inefficiency has limited the operating luminosity on the LH_2 target, for example, to ~ 0.6×10^{35} $cm^{-2}s^{-1}$. It was also realized that with improved tracking detectors and track reconstruction algorithms, this inefficiency can be reduced significantly. Below is a report of the task force dedicated to study various options for improving the response of the CLAS12 detector for efficient operation at much higher luminosity than was originally proposed.

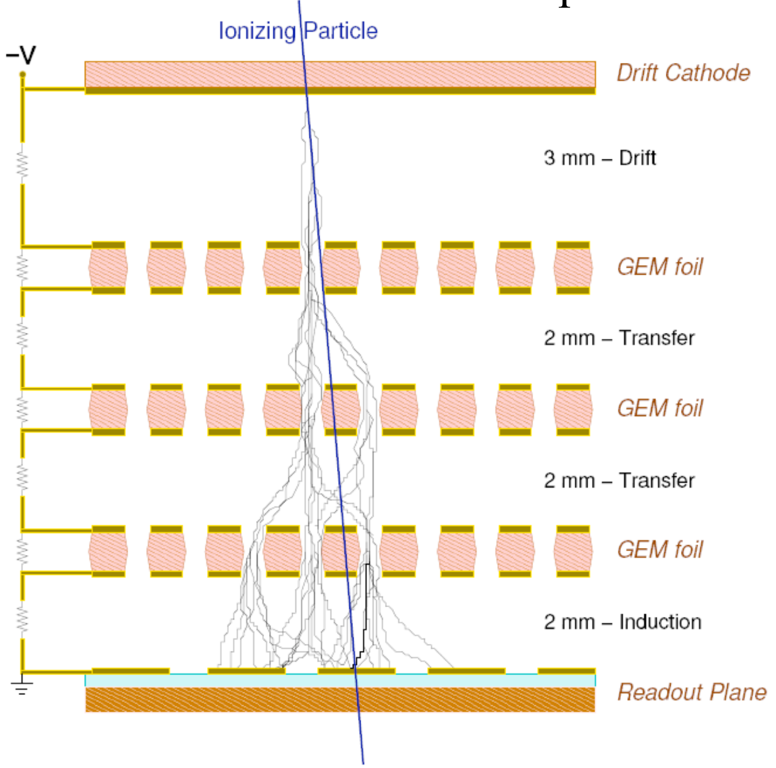
Stage–1 of CLAS12 luminosity upgrade

I. Achieve luminosity of ~$2x10^{35}$ cm^{-2} sec^{-1} for CLAS12 normal running conditions (e.g. RG-A/B/K) with charged particle reconstruction efficiency of >85%
   - Will support efficient and fast execution of the current program
   - Time frame – 2 to 3 years
   - Required upgrades for the CLAS12 subsystems:
     - Beamline/FT – no need for changes or upgrades
     - HTCC/RICH - generally low rates should not be a problem
     - SVT/MVT – will perform if the software/alignment issues are resolved
     - DAQ/trigger – replace some of the L1 hardware, TDCs, the readout of MVT, and need L3 trigger
     - FTOF/CTOF/ECal – will work but the life time of PMTs is a concern.
     - **DC – will need upgrades**:
       - more segmentation of HV system, x2 more channels (replacement of old HV system started)
       - possible improvements to the DC readout – time-over-threshold (tests are in progress)
       - replace or add new tracking planes to DC R1 (e.g. with MPGD tracker) – major project, R&D started

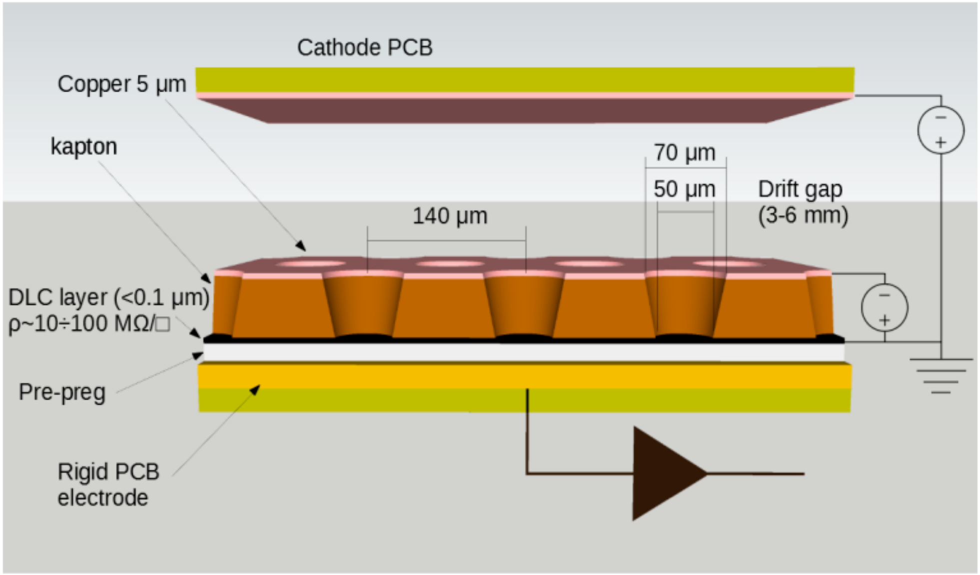
Upgrading DC tracking for Stage-1

- Two MPGD detector technologies have been discussed, triple-GEM and μRWELL
- Large area triple-GEM detectors have been used in experiments (PRad, SBS, …). The μRWELL technology is new, so far only small prototypes have been tested.
- The μRWELL detector is best suited for CLAS12 – low material budget, easy to build, less support structures in the active volume of the detector. But will require extensive R&D.

GEM: Gas Electron Multipliers



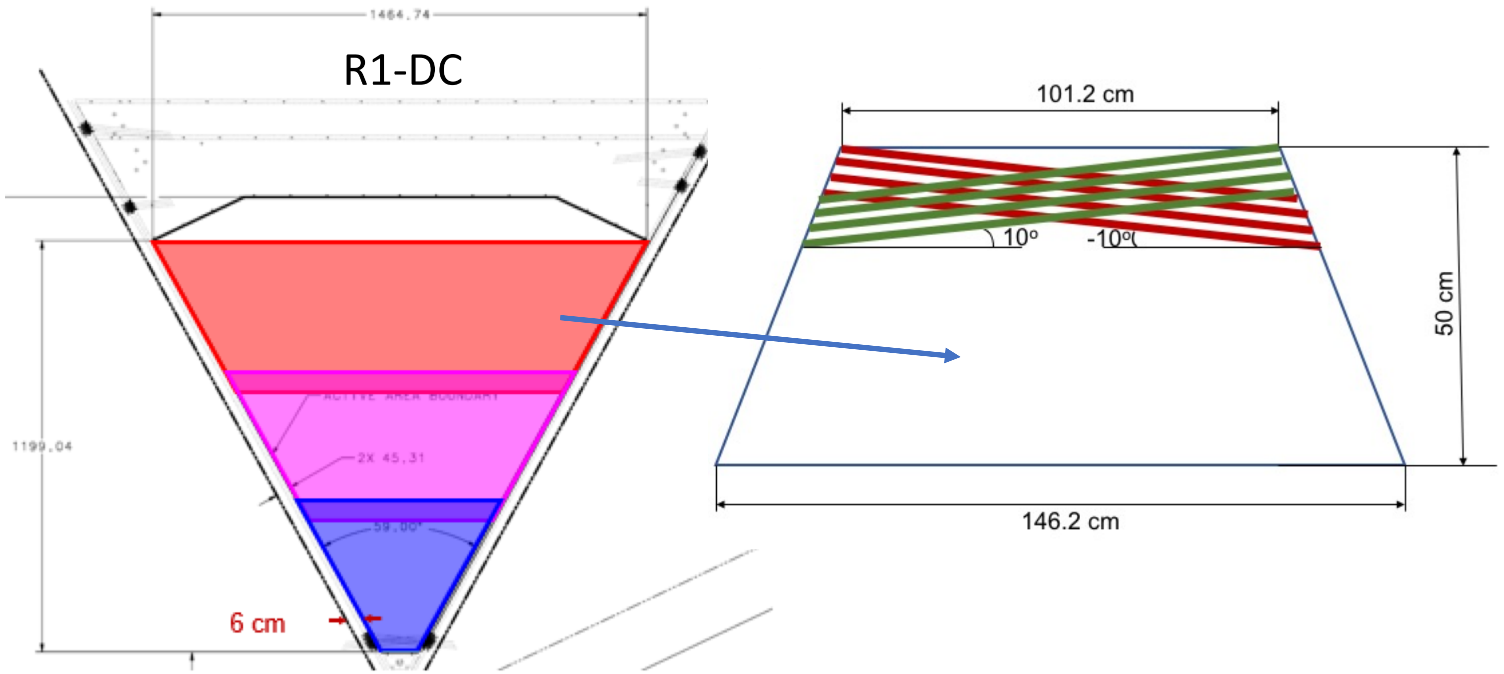
Resistive micro-WELL Detector



Giovanni Bencivenni

µRWELL prototyping

- The DC-R1 active area is a trapezoid with a height of 151 cm, a large base of 146.2 cm, and a small base of 10.4 cm
- With available foil sizes for MPGD detectors, such an area cannot be covered with a single foil. The whole module can be constructed from three sections
- The largest of the three sections will be prototyped as part of the initial R&D. The readout will be based on APV25 chip, currently used in many GEM detectors. Exploring newer chips (SAMPA and VMM3) for the main detector.



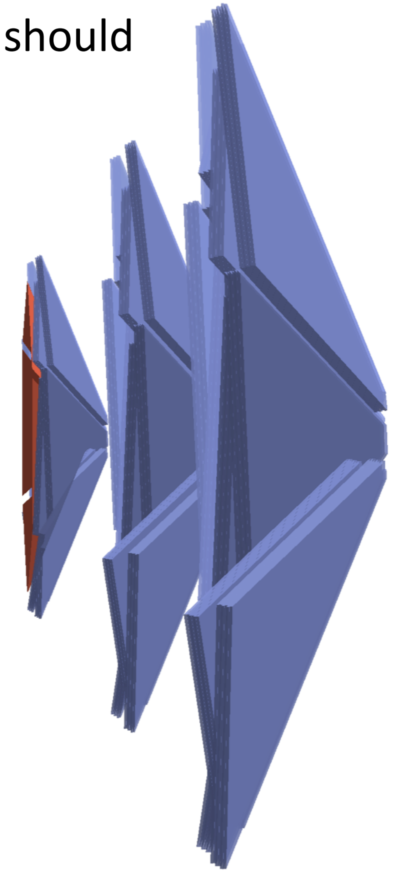
- The largest segment is a trapezoid with a large base of 146.2 cm, the height of the chamber will be 50 cm, the small base of 101.2 cm
- The readout concept is U-V strips with ±10° stereo angles relative to the base of the trapezoid, strips traced on two sides of the readout plane will be used.
- The charge share will be through capacitive coupling. The pitch size of the readout 0.8 mm, the strip width 0.4 mm.
- The total number of U&V readout strips is about 685.

Initial performance studies with GEMC

- Momentum reconstruction accuracy with MPGD tracking layers upstream of the R1 DC were studies by increasing material thickness of DC volume by 2% (assuming 4 modules of MPGD detectors)
- No degradation in the momentum or angular resolutions have been observed, only slight worsening of the vertex resolution
- More studies are underway with fully implemented μRWELL detectors in GEMC and in the tracking - should understand how many detectors will be needed for efficient running at high luminosities

	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Al	1	3	2.7	89	1	0.0034	0.0008
μRWELL							
Copper	1	3.2	8.96	14.3	0.8	0.0179	0.0023
Kapton	1	50	1.42	286	0.8	0.0140	0.0057
G10 total							
G10	3	100	1.7	194	1.008	0.1559	0.0514
Readout							
Copper	2	5.8	8.96	14.3	1	0.0811	0.0104
Kapton	5	50	1.42	286	1	0.0874	0.0355
NoFlu glue	6	50	1.5	200	1	0.1500	0.0450
Gas							
70Ar30CO2)	1	4000	1.84E-03	141270	1	0.0028	0.0007
					Total	**0.530**	**0.159**

GEMC: pair of μRWELL detectors in front of R1 DC. This arrangement will require moving HTCC and CD upstream by about 10 cm



Stage–2 of CLAS12 luminosity upgrade

II. A new configurations for two orders of magnitude higher luminosities (≥ 10^{36} cm^{-2} sec^{-1}). Will open up new physics opportunities for CLAS12

A. **μCLAS12, L ≥ 10^{37} cm^{-2} sec^{-1} for DDVCS and e^-–*J*/ψ (LOI12-16-004)**
- large acceptance calorimeter, “FTCal-large”, for electron detection combined with an absorber as a shield/π-absorber in front of the CLAS12 FD – converting the CLAS12 FD into a muon detector
- No CD, instead a high rate recoil detector inside the solenoid
- time frame 7-10 year

B. **Open acceptance mode, L~10^{36} cm^{-2} sec^{-1}, need more thoughts and well defined physics case**
- New forward tracker, most likely MPGD based tracking system
- replace aging PMTs (FTOF/ECal)
- No CD, instead a high rate recoil detector of some kind
- No HTCC and FT, instead a larger Moller cone that will limit FD acceptance to $\geq 8^o$
- new Cherenkov counter for e^- ID (sort of LTCC with CO_2)
- need streaming DAQ and AI for event construction
- time frame > 10 years

Double Deeply Virtual Compton Scattering (DDVCS)

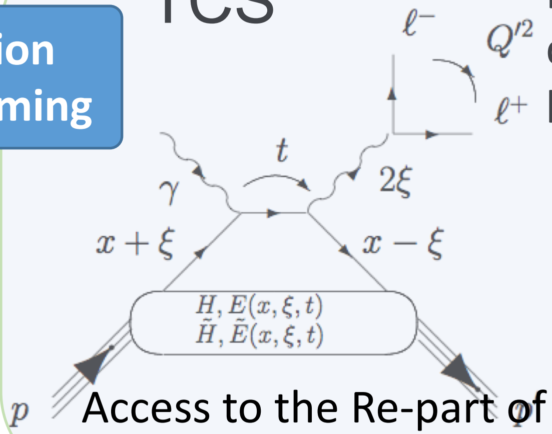
- During April-October of 2020, a small task force lead by Bob McKeown put together a white paper examining options for future research activities using CEBAF. Three major areas were identified: higher luminosity facilities, positron beams, and higher energy CEBAF ($\sim 24\ GeV$)
- CLAS12 upgrade to higher luminosities was among highest priority items for the first major area of interest beyond the current physics program. The emphases for physics with higher luminosity facilities were on DDVCS using the upgraded CLAS12 in Hall-B and SoLID in Hall-A.
- The study of DDVCS is a natural extension of the ongoing GPD program. It enables more complete coverage of the x-ξ plane giving wider access to the GPDs. This program is robust even in the era of EIC operations, since EIC at expected luminosities would not be capable of studying DDVCS.
- While DDVCS allows for mapping the GPDs along each of the three axes (x, ξ, and t), experimentally it is a challenging reaction to study:
    - The cross section of DDVCS is significantly smaller (more than two orders of magnitude) than that of DVCS
    - To eliminate ambiguity and anti-symmetrization issues, the outgoing time-like photons must be reconstructed through their di-muon decays.
- These two conditions require a large acceptance detector capable of running at very high luminosities, $L \geq 10^{37}$ cm^{-2} sec^{-1}, with a good muon detection.

Compton Scattering with Space-like, Time-like photons

CLAS12 GPD studies

1st publication in PRL is coming

TCS



Hard scale is defined by time-like photons

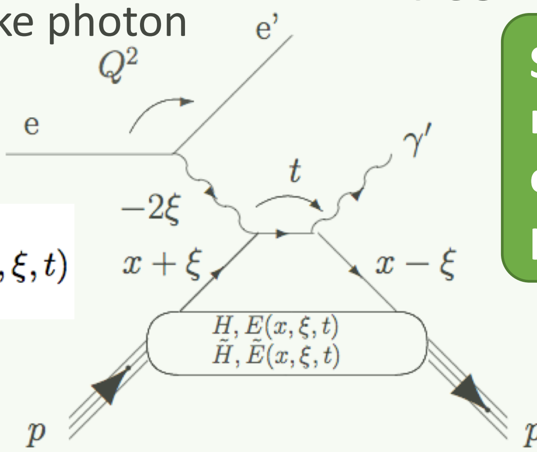
Access to the Re-part of the Compton amplitude

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

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

DVCS

Hard scale is defined by space-like photon

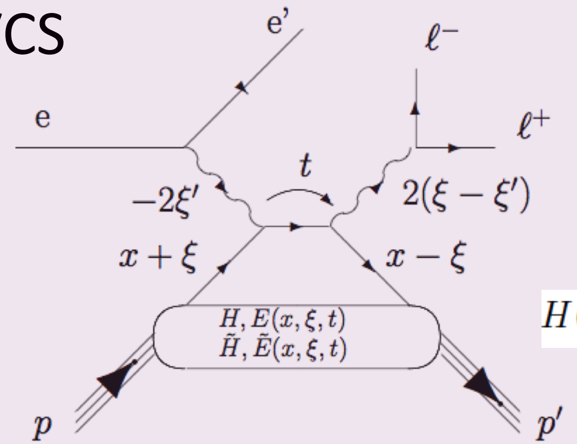


Started in 2001, now is a large part of the existing physics program

μCLAS12, one of two proposed facilities capable of measuring

DDVCS

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



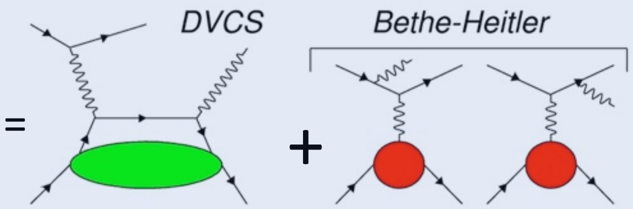
$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

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

Accessing GPDs in Virtual Compton Scattering

Space-like Photon

ep→epγ =



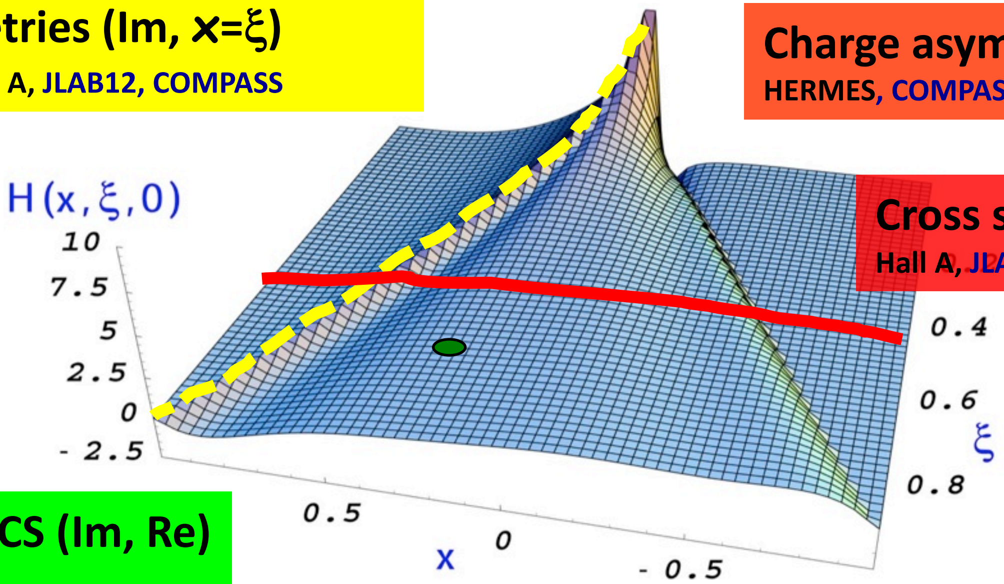
$$\mathcal{T}^2 = |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}$$

$$\mathcal{T}_{DVCS} \sim CFF \quad \mathcal{H}(\xi,t) = \underbrace{i\pi\left[H(\xi,\xi,t) - H(-\xi,\xi,t)\right]}_{Im} + \underbrace{P\int_{-1}^{+1} dx \left(\frac{1}{\xi - x} \pm \frac{1}{\xi + x}\right)\left[H(x,\xi,t) \mp H(-x,\xi,t)\right]}_{Re}$$

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

Charge asymmetry (|Re|)
HERMES, COMPASSJ, LAB12

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

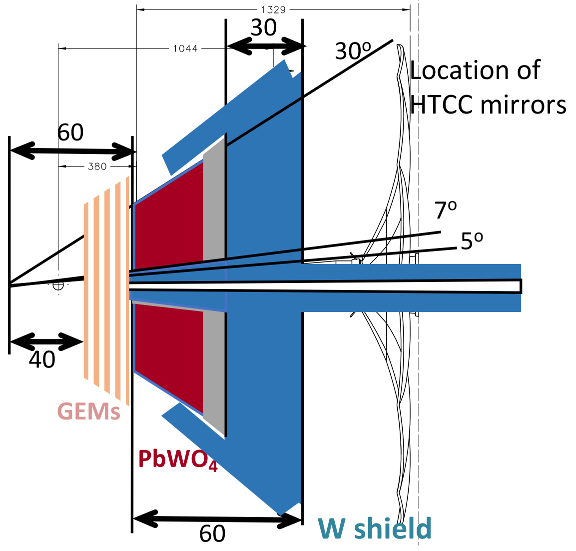


DDVCS ($x \neq \xi$) & TCS (Im, Re) – JLAB12

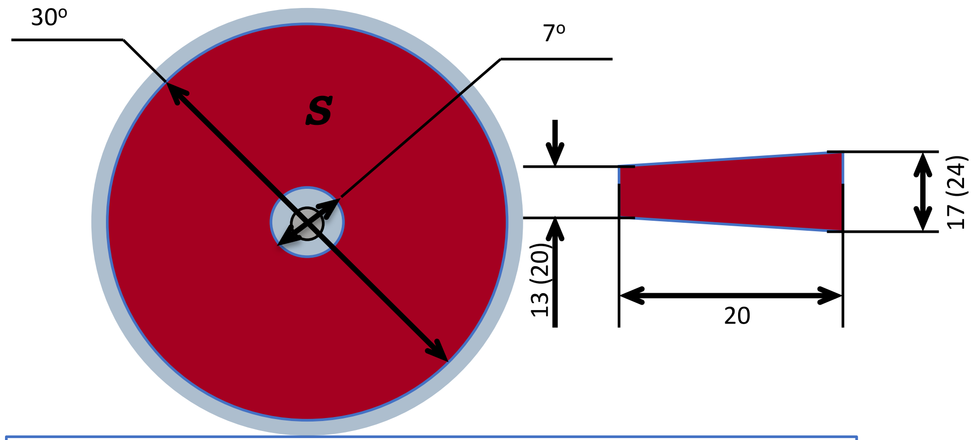
μCLAS12 for *DDVCS* and $e^- J/\psi$ (LOI12-16-004)

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

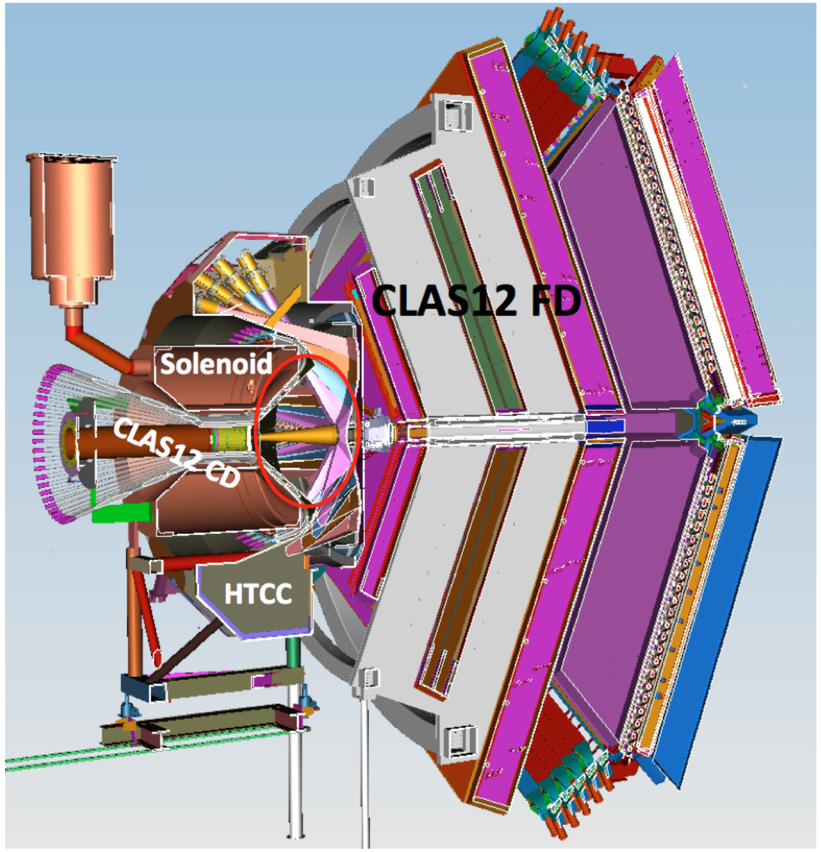
- Remove HTCC and install in the region of active volume of HTCC
  - a new Moller cone that extends up to 7°
  - a new $PbWO_4$ calorimeter that covers 7° to 30° polar angular range with 2π azimuthal coverage.
- Behind the calorimeter, a 30 cm thick tungsten shield covers the whole acceptance of the CLAS12 FD
- MPGD tracker in front of the calorimeter for vertexing and inside the solenoid for recoil proton tagging



$$S = \pi l^2[(tg^2(30^o) - tg^2(7^o)] = 3600\,cm^2;\; l = 60\,cm$$

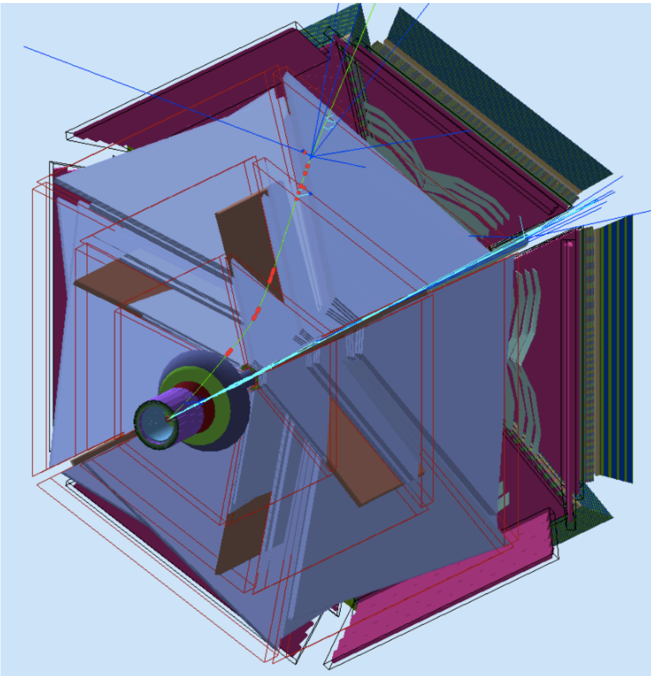


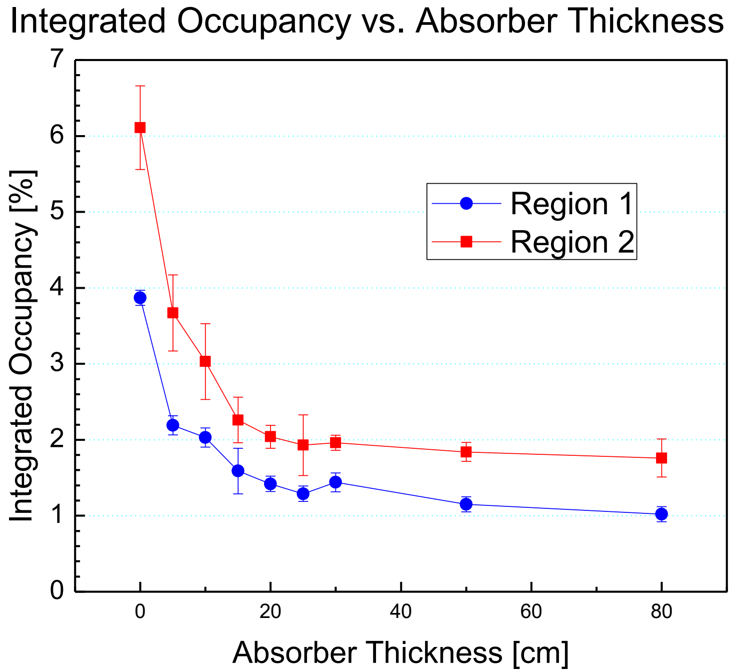
$PbWO_4$ modules with APD readout - ~ 1200 modules

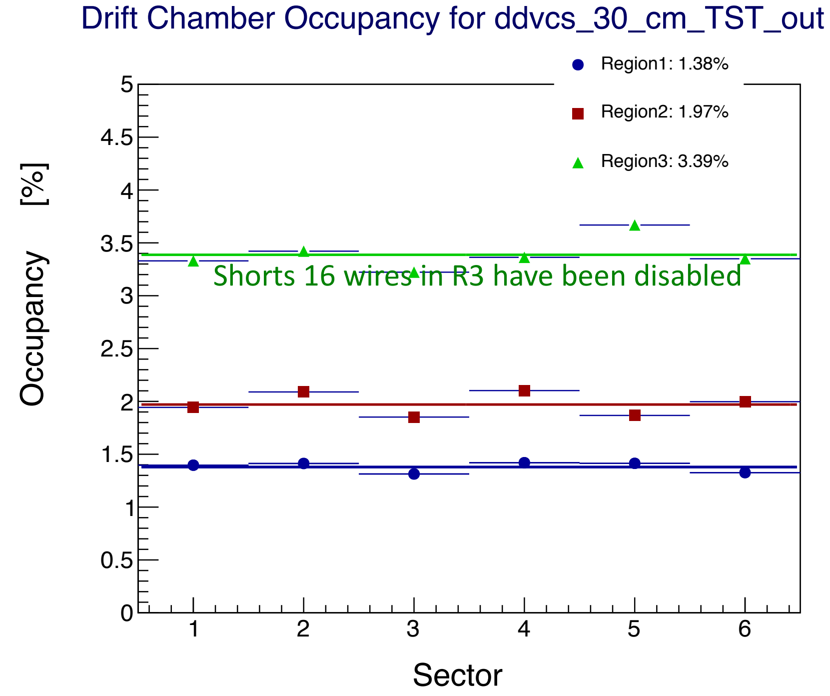


μCLAS12 - Background and trigger rates

- GEMC model with the calorimeter and absorber to study DC occupancies and trigger rates
- At luminosity of 10^{37} $cm^{-2}sec^{-1}$ luminosity and 30 cm thick tungsten absorber DC occupancies were fond to be <4%.





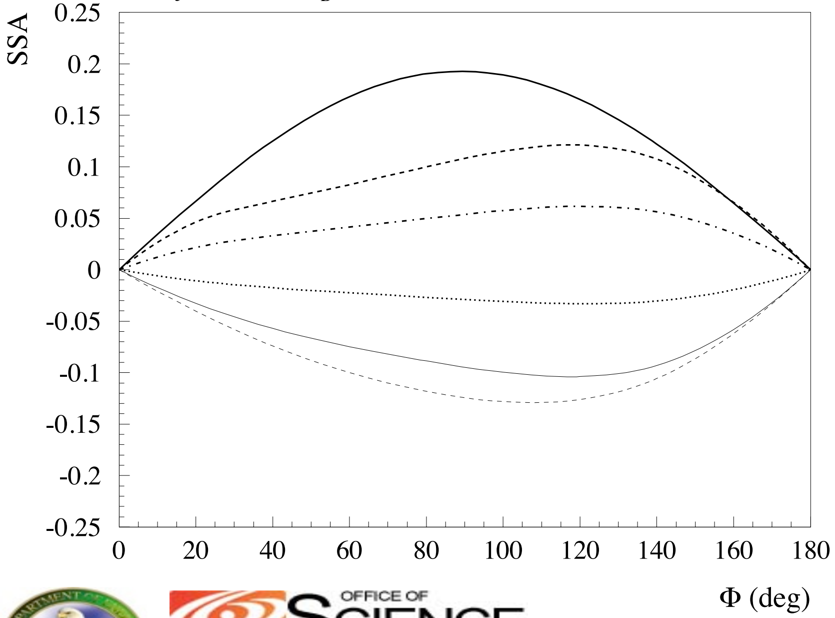


- The trigger rate for two charged tracks in forward detector with MIP energy deposition signature in ECal was found to be dominated by accidental and was estimated to <500 Hz.

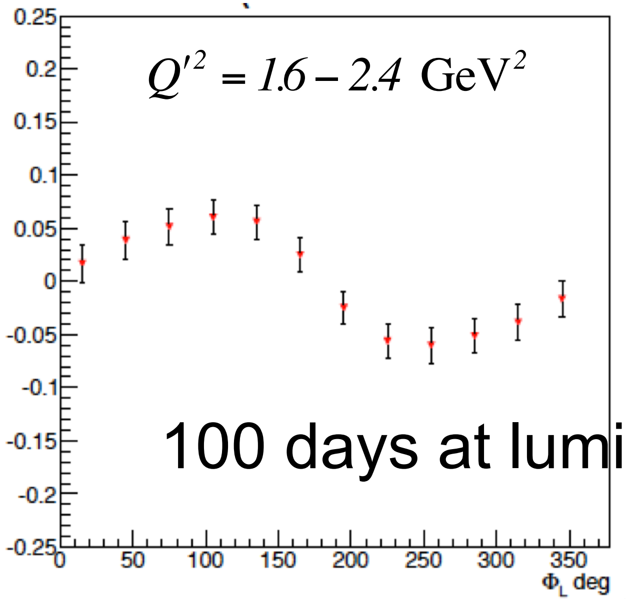
DDVCS projections

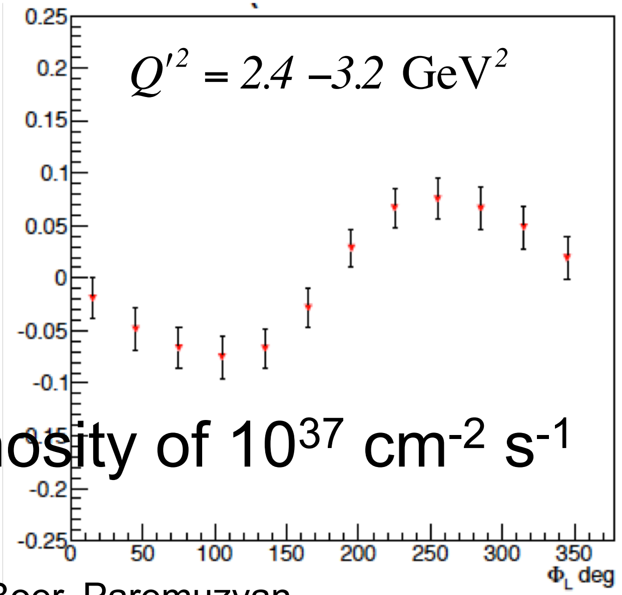
$$ep \rightarrow e'p'\mu^+\mu^-$$

- μCLAS12 will be able to study DDVCS in both spacelike, $Q^2 > Q'^2$, and time-like, $Q^2 < Q'^2$, regions
- Transitioning from the DVCS-dominated to TCS-dominated region will be manifested by a change of the sign in the beam spin asymmetry
- This is a prediction of the “handbag" formalism and a very strong test that one is in the right regime to access GPDs



Q^2=2 – 3 GeV^2 , -t = 0.1 – 0.4 GeV^2, x_B= 0.11 – 0.2





100 days at luminosity of 10^{37} cm^{-2} s^{-1}

Boer, Paremuzyan

Summary

- CLAS12 luminosity upgrade has been in the discussions for while. A task force organized last year to find the most promising option for the upgrade proposed a multi-stage approach.
- **Stage-1** aims to achieve a luminosity of $2\times10^{35}cm^{-2}sec^{-1}$ for nominal running conditions with charged particle reconstruction efficiency of >85%
  - Such upgrade will benefit the approved physics program and will open new opportunities for studying low rate processes and perform high precisions measurements
  - Efforts are underway to improve the reconstruction efficiency for the existing system but to achieve desired luminosity improvements to the detectors will be needed
  - R&D for new MPGD detector technologies for FD R1 tracking and the development of software for the new tracking system has started
  - The choice of the new detector and the detector design will be ready within two years. The whole upgrade is possible in 3 years with a budget of ~2M$
- **Stage-2** upgrade is for operating CLAS12 at two orders of magnitude higher luminosity, $> 10^{37}cm^{-2}sec^{-1}$
  - The main physics objective for such upgrade is DDVCS and electroproduction of J/ψ mesons
  - More MC studies, detector R&D, and engineering are needed to finalize details of the upgrade
  - Upgrade TF conclusion - can be done in 7-10 years time frame with a budget of about 10M$