CLAS12 luminosity upgrade and future physics opportunities

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Jefferson Lab

Outline

- Jefferson Lab CEBAF machine

- CLAS12 detector in Hall-B

- Detector performance

- CLAS12 physics program

- Planned luminosity upgrade
  - Phase I: upgrade to $L = 2{\times}10^{35} cm^{-2}sec^{-1}$
  - Phase II: μCLAS12 for $L > 10^{37} cm^{-2}sec^{-1}$

- Conclusion

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Experimental Halls

Hall D

A

B

C

LERF

Continuous Electron Beam Accelerator Facility

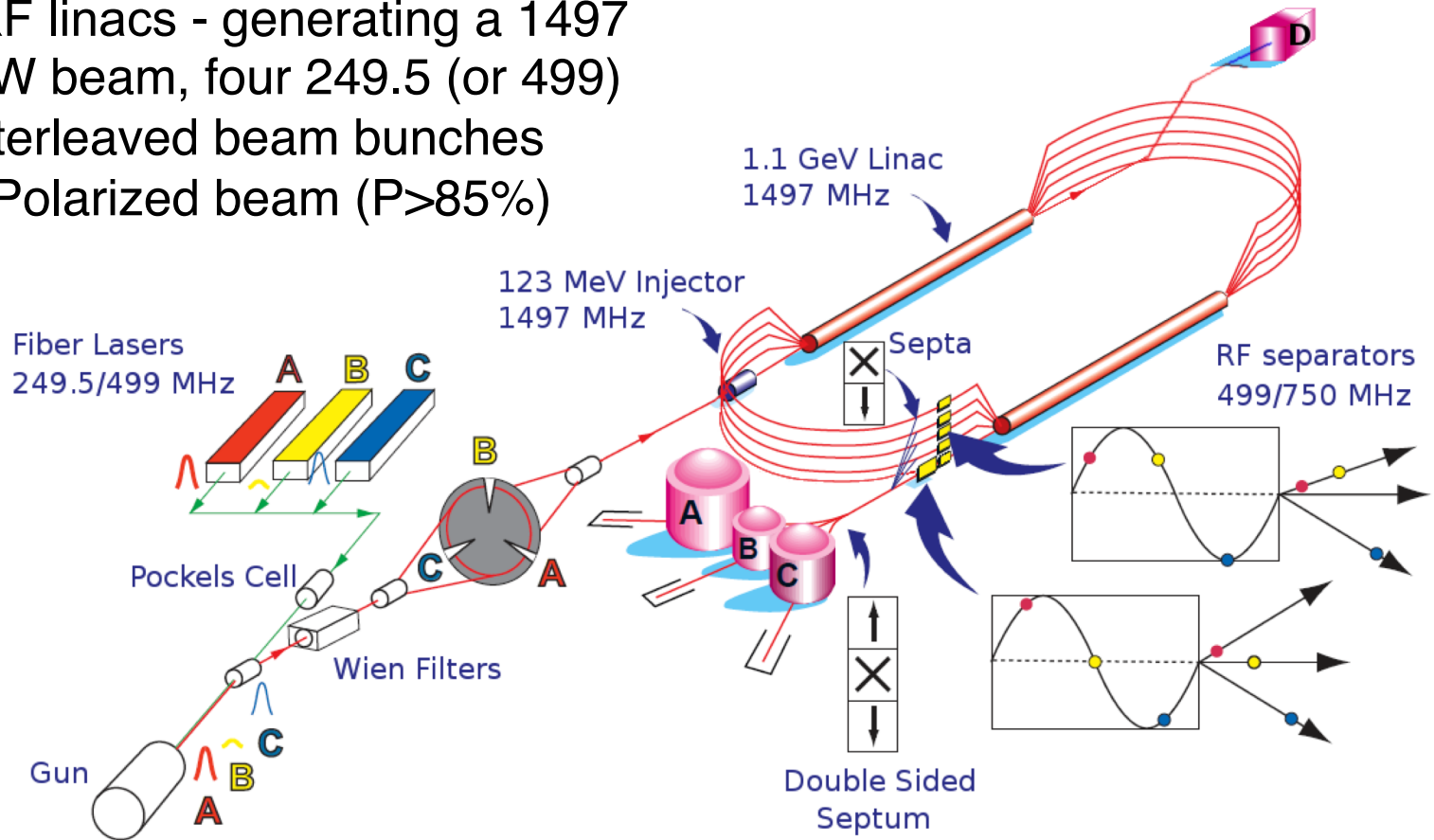# CEBAF12

- CW SRF linacs - generating a 1497 MHz CW beam, four 249.5 (or 499) MHz interleaved beam bunches
- Highly Polarized beam (P>85%)

- Design energy (max) 2.2 GeV/pass:
  - 5 passes, 11 GeV (Halls A,B & C)
  - 5.5 passes, 12 GeV (Hall-D)
- Flexible extraction options for ABC, 1st…5th pass
- Hall A & C 1 MW high power dumps

CLAS12 in Hall-B at JLAB

Commissioned in 2018
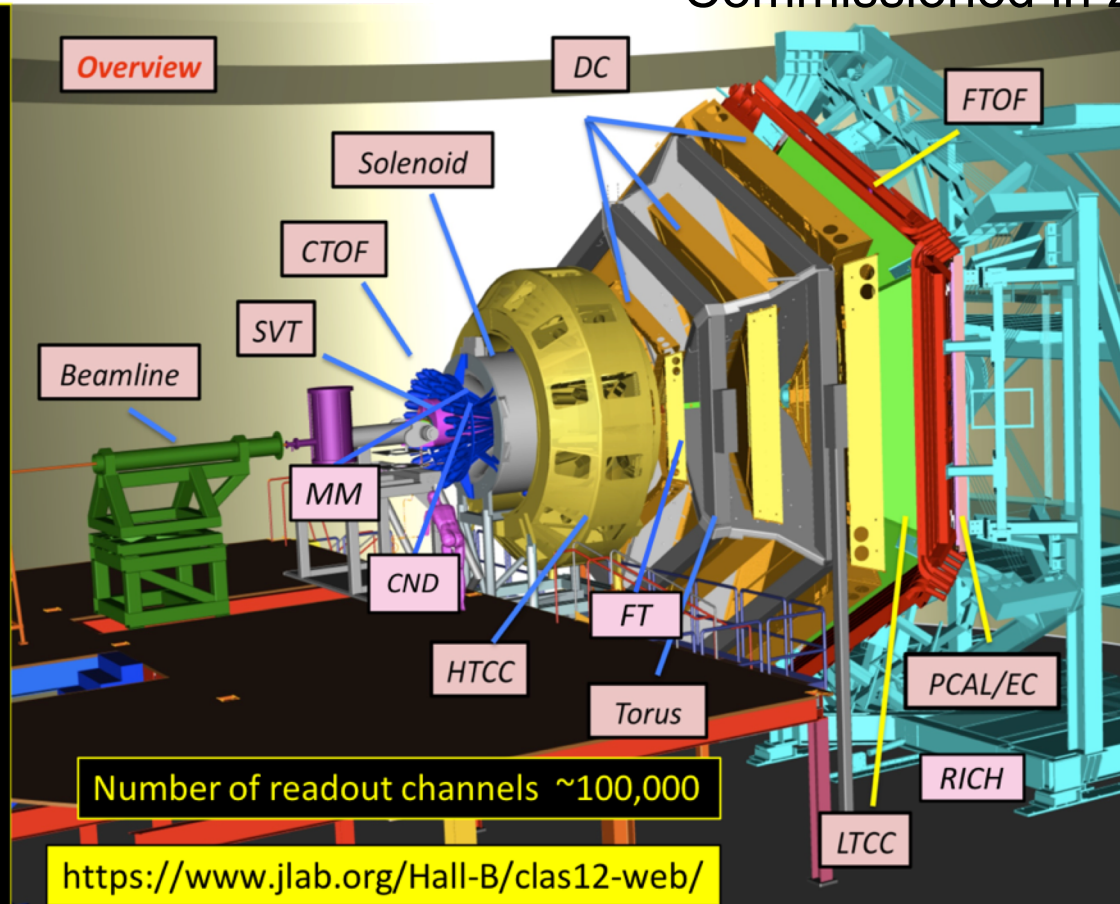
Forward Detector (FD)
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter
- Forward Tagger
- RICH detector

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

Overview

DC

FTOF

Solenoid

CTOF

SVT

Beamline

MM

CND

HTCC

FT

Torus

PCAL/EC

RICH

LTCC

Number of readout channels ~100,000

https://www.jlab.org/Hall-B/clas12-web/

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

Designed luminosity $10^{35} cm^{-2} sec^{-1}$

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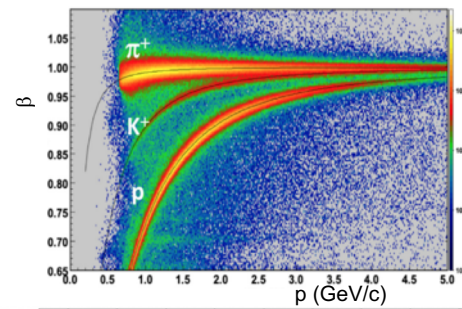
clas
CEBAF Large Acceptance Spectrometer

CLAS12 performance: FD
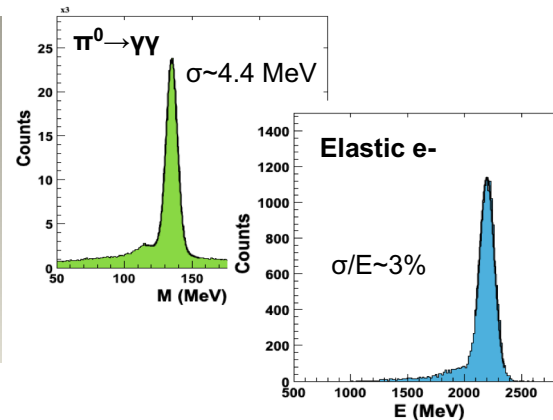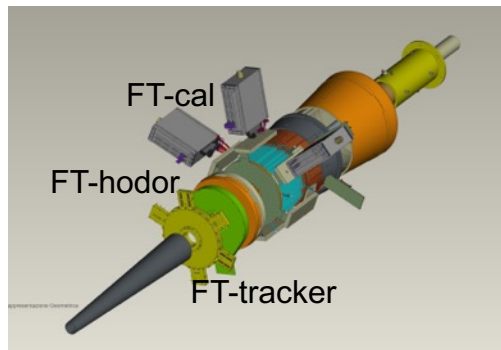
$e^-\pi^+$ event in FD
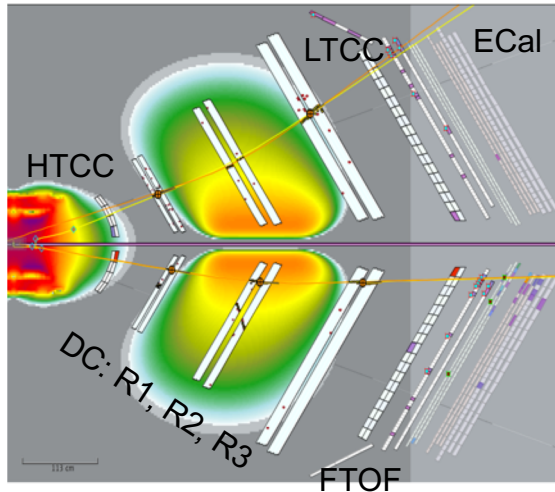
Hadron ID (time-of-flight)

e^- kinematics at 10.6 GeV

Vertex reconstruction

Multiple
Carbon foils

Forward tagger system

FT-cal
FT-hodor
FT-tracker

$\pi^0 \to \gamma\gamma$
$\sigma \sim 4.4$ MeV
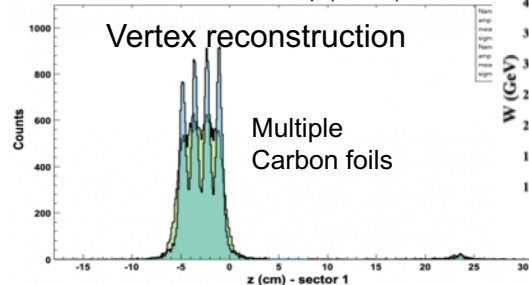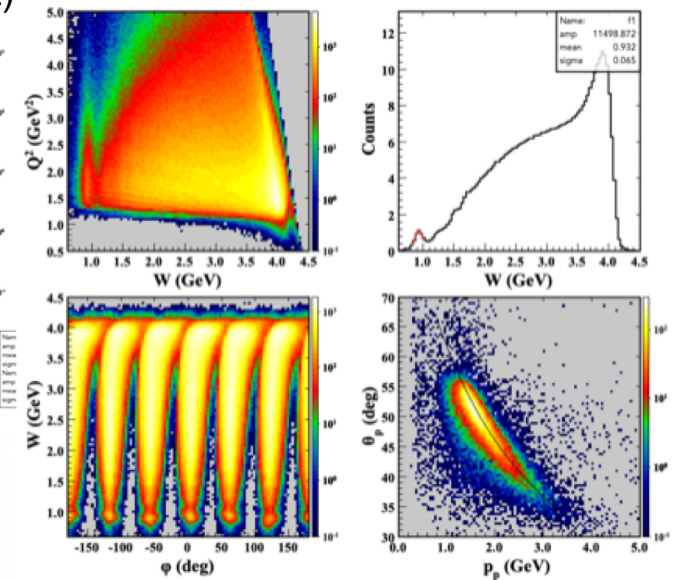
Elastic e-
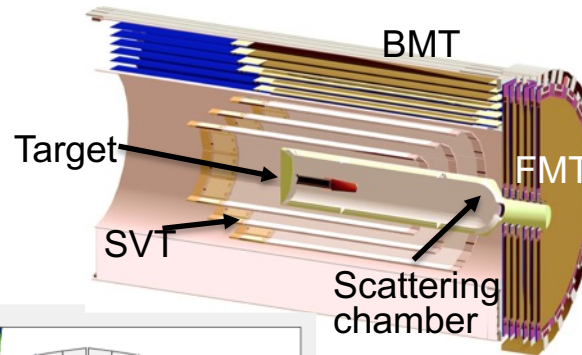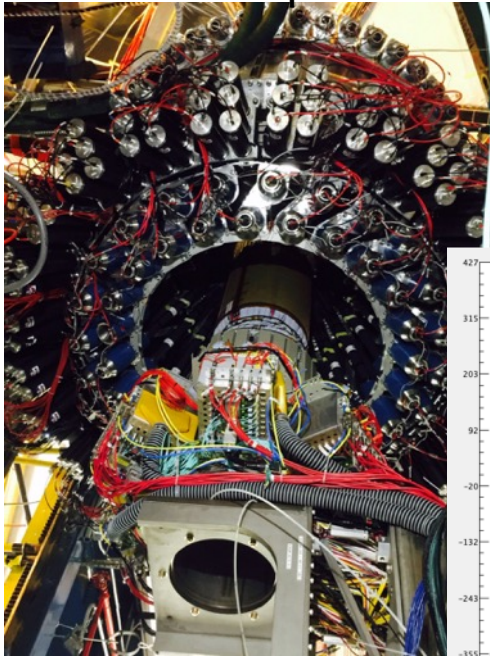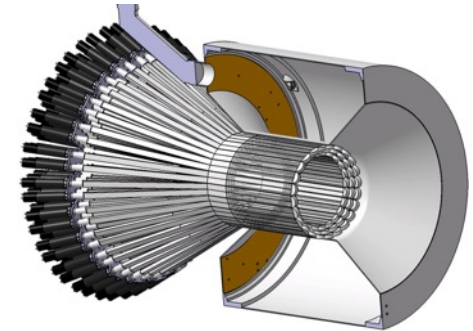$\sigma/E \sim 3\%$

RICH
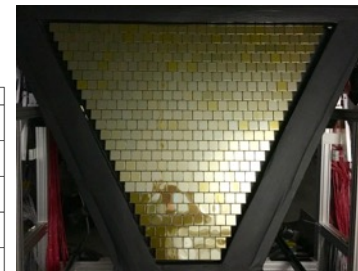
25000 channels
Aerogel tiles
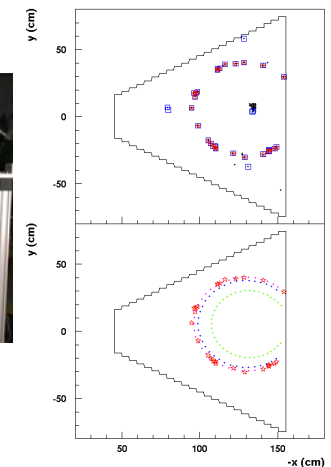
CLAS12 performance: CD

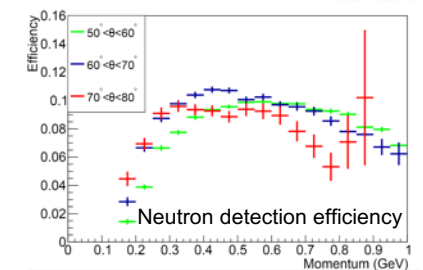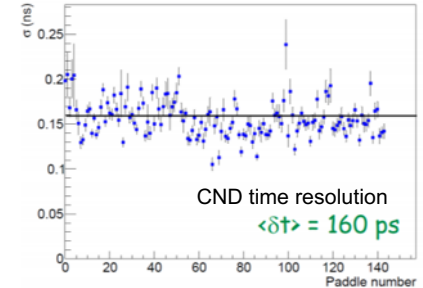View from upstream
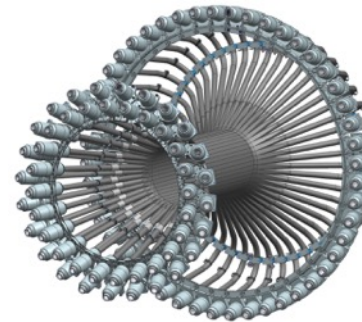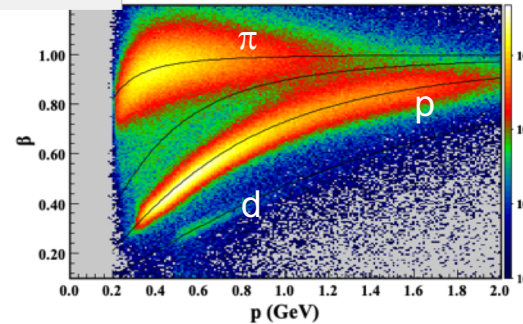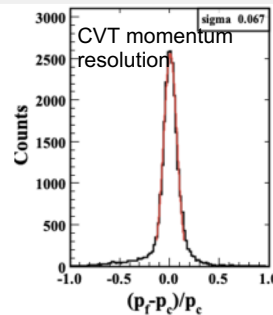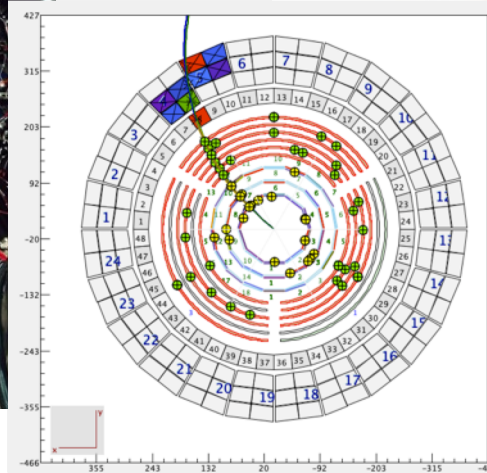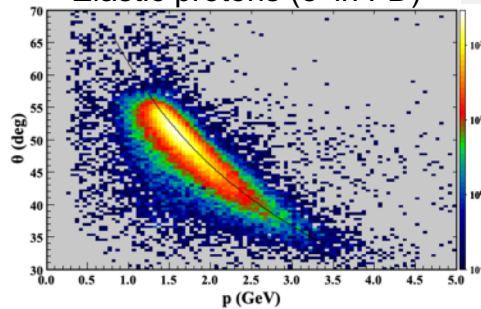
BMT

Target

FMT

SVT

Scattering
chamber

CND

CTOF

CND time resolution
⟨δt⟩ = 160 ps

Elastic protons (e⁻ in FD)

CVT momentum
resolution

π

p

d

Neutron detection efficiency

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CLAS12 Physics program

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

- Nucleon and nuclear structure studies, spatial and momentum tomography, form-factors …
  - Phys. Rev. Lett. 126, 152501 (2021), double pion BSA;
  - Phys. Rev. Lett. 127, 262501 (2021), Timeline Compton;
  - Phys. Rev. Lett. 128, 062005 (2022), π^+ SIDIS;
  more to come

- Cold nuclear matter, NN correlations, hadronization, color transparency…
  - Data for NN SRC on targets D to Pb at beam energies 2 to 6 GeV are on hand;
  - runs with 11 GeV beams with nuclear targets are planed next couple years, covering experiments on hadronization, color transparency ...

- Exploring origin of confinement – meson and baryon spectroscopy, exotics …
  - About 40% of data on hands;
  - K+Y (Λ, Σ) electroproduction, arXiv:2202.03398, submitted to Phys. Rev. C (2022) more in the pipeline ...
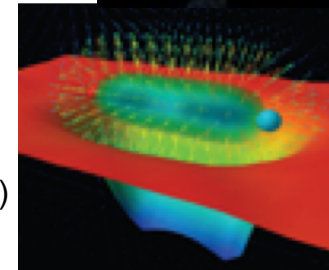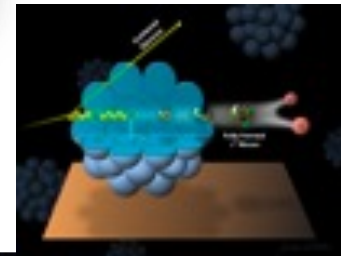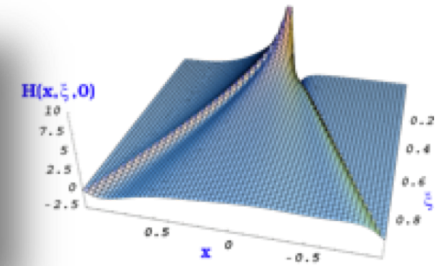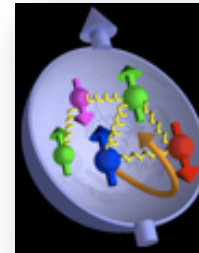
About 1/3rd of run groups collected an average of about 30% of the expected statistics. It will take about nine years to complete the approved program.

Expediting the data collection and providing an opportunity for high statistics measurements of small cross section processes are the drivers of the CLAS12 luminosity upgrade.

CLAS12 luminosity upgrade, staged approach

I. Achieve luminosity of ~2×10^{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;
    – Support a growing demands of physics program with a low rate, exclusive reactions (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;
    – Time frame for the upgrade: 2 to 3 years.

II. Configuration for a two orders of magnitude higher luminosities – for muon-pair electroproduction, μCLAS12 at ≥ 10^{37} cm^{-2} sec^{-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;
    – Time frame for the upgrade: 5 to 8 years.

DC occupancies and tracking efficiency

- 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 $\sim 5\%$).

- Problem has been somewhat mitigated with the inclusion of an AI-based pattern recognition algorithm. More efforts are underway but will not be enough to reach the goal.

FD tracking efficiency needs an upgrades to get close to $\eta = 1 - 0.001 \cdot I$ or $\eta \geq 85\%$ at $2L$

(I is the beam current, η is the track reconstruction efficiency)
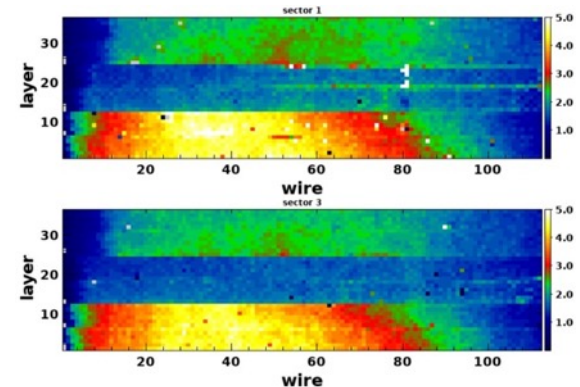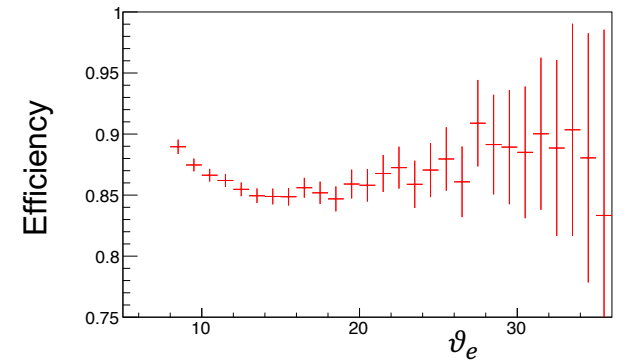
Conventional tracking
AI-assisted tracking
The ratio – AI/Conv.
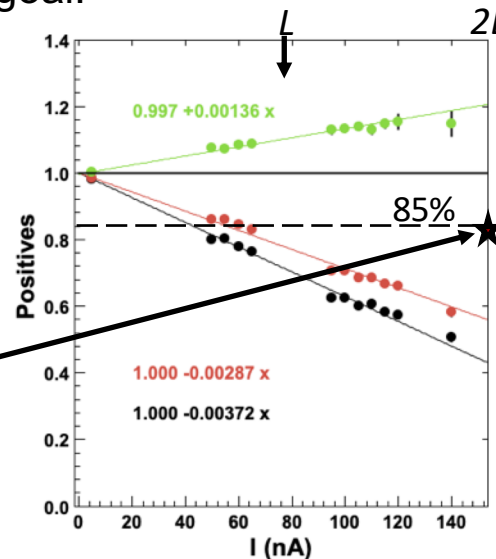
More improvements are needed to reach the goal of running at $2L$.

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

- Proposal is to add new, high-rate capable tracking modules in front of the R1 drift chambers to reduce occupancy related inefficiency (at $2L$, the occupancy in R1 DC will reach $> 10\%$).

- From available detector technologies, μRWELL with capacitive sharing readout is chosen as the best option for the CLAS12 FD tracking upgrade.

- A new technology, only small prototypes have been built and tested. But, it is a low material budget detector ($<0.5\%X_0$), easy to build, without support structures in the active volume.

- Simulations show no sizable degradation of momentum resolution with pair of such detectors in front of R1 DC (arrangement requires moving HTCC and CD upstream by ~10 cm).
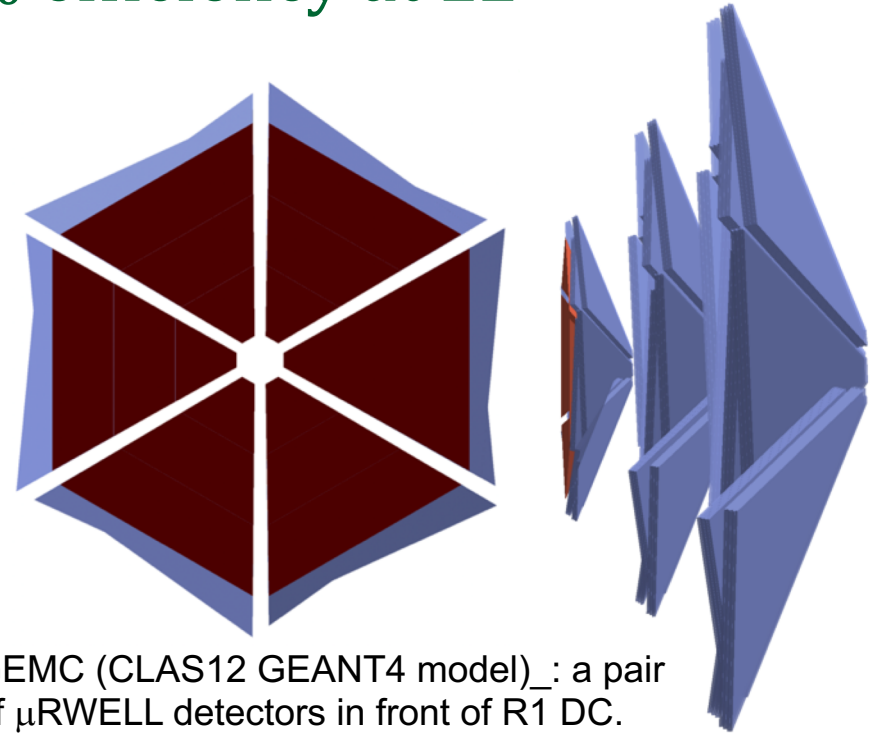
GEMC (CLAS12 GEANT4 model)_: a pair of μRWELL detectors in front of R1 DC.

Mariangela Bondi

Resistive micro-WELL Detector
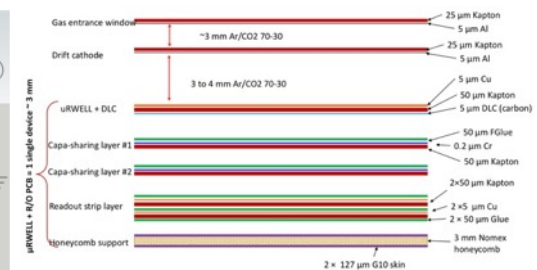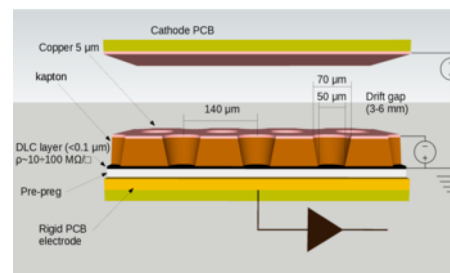
µRWELL detector for CLAS12 FD

- A small prototype of a µRWELL detector with X-Y capacitive sharing strip readout was built and tested at JLAB (Kondo Gnanvo). Measured position and time resolutions from beam test data are well within requirements.
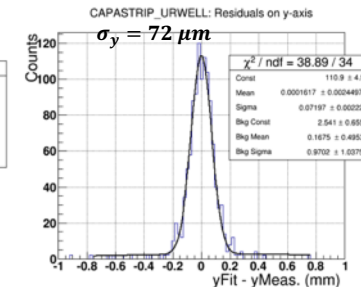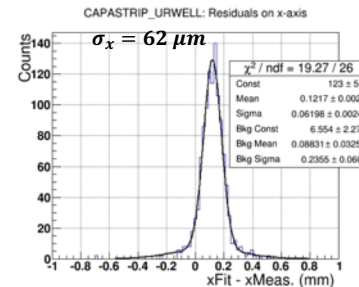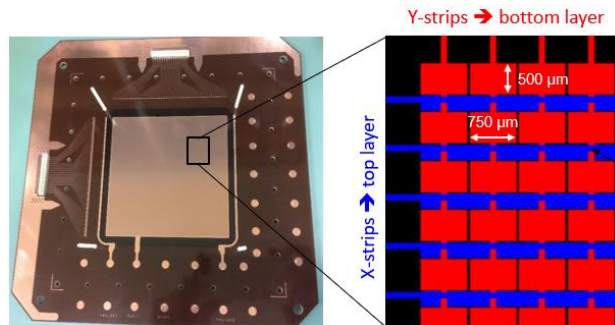
- Fabrication of the prototype of the largest of the three sections is underway.

- The readout concept is U-V strips with $\pm 10^\circ$ stereo angles relative to the base of the trapezoid with a pitch size of 1 mm.

- Standard APV25-SRS readout with standard DATE and amoreSRS DAQ.

- Beam tests the prototype in Hall-B during January – March 2023
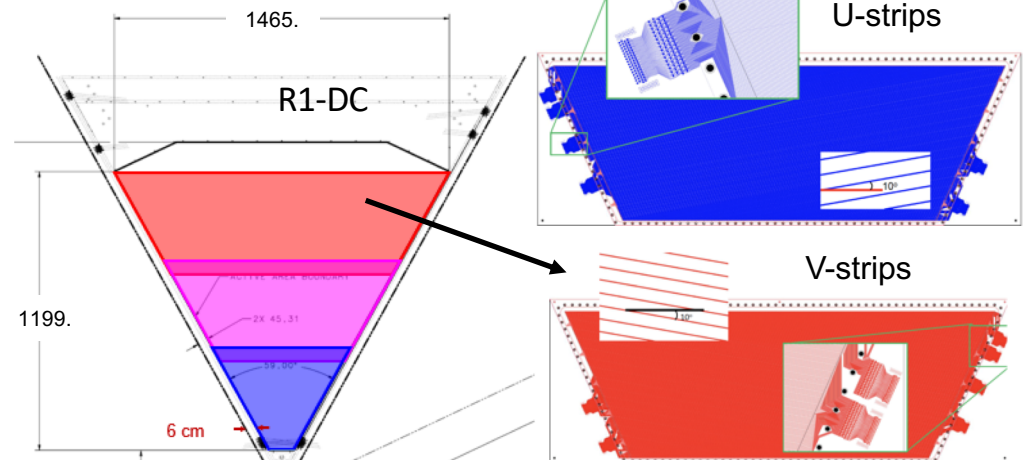
Plan is to start fabrication of the full modules in fall 2023

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

CLAS12 GPD studies

μCLAS12, one of two proposed facilities capable of measuring
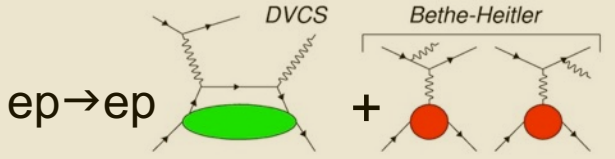
First experimental measurement with CALS12
PRL 127, 262501 (2021)

Started in 2001, PRL 87, 182002
Is the large part of the CLAS12 physics program

TCS
Hard scale is defined by time-like photons
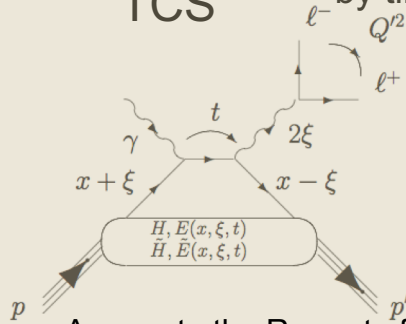
$$Re\ \mathcal{H}(\xi, t) = PV \int_{-1}^{1} dx\, C^{-}(\xi, x) H(x, \xi, t)$$

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

Access to the Re-part of the Compton amplitude

Hard scale is defined by space-like photon
DVCS
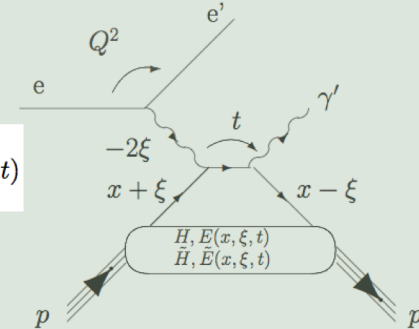
DDVCS

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

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

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

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

GPDs in Virtual Compton Scattering

Space-like Photon

$ep \rightarrow ep$ + (Bethe-Heitler diagrams)

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

$\gamma \bar{\mathcal{T}}_{DVCS} \sim CFF$

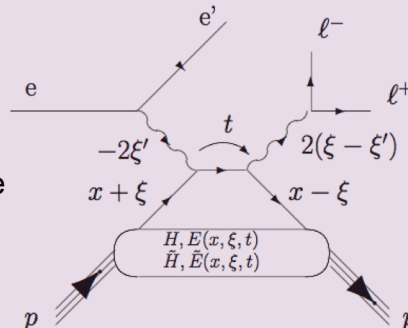$$\mathcal{H}(\xi,t) = \underbrace{i\pi\left[H(\xi,\xi,t) - H(-\xi,\xi,t)\right]}_{Im} + \underbrace{P\int_{-1}^{+1}dx\left(\frac{1}{\xi-x} \pm \frac{1}{\xi+x}\right)\left[H(x,\xi,t) \mp H(-x,\xi,t)\right]}_{Re}$$

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

Angular asymmetry in TCS (|Re|)
JLAB12

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

DVCS Cross sections (|Re|²)
H1, Hall A, JLAB12, COMPASS
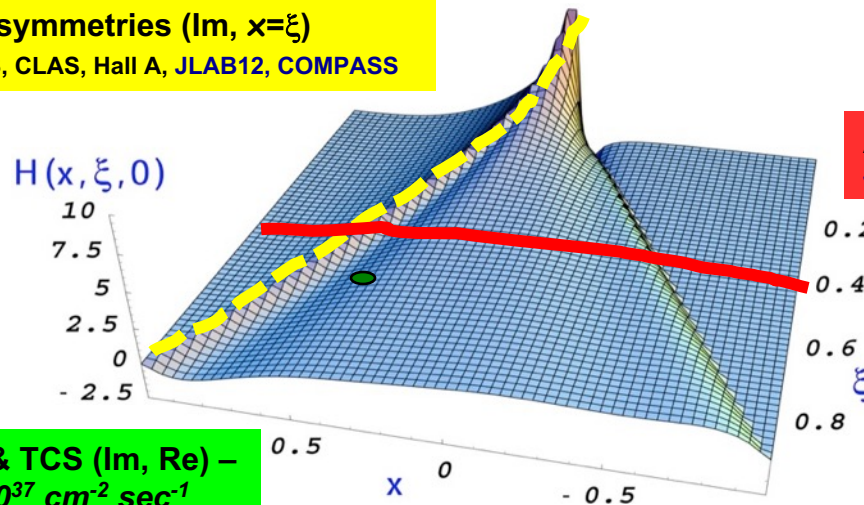
DDVCS ($x \neq \xi$) & TCS (Im, Re) – JLAB12 at *L* ≥ 10³⁷ cm⁻² sec⁻¹

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

μCLAS12 for *DDVCS* and e^-J/ψ

Two main challenges in DDVCS measurements:

- Cross section is two to 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 electroproduction.

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

Shield the CLAS12 FD from electromagnetic and hadronic backgrounds. Allow only muons to pass through. Detect the scattered electron in the EM calorimeter (part of the shield).

Electron kinematics:

$$Q^2 = 2.5 \pm 0.5 \, GeV^2$$
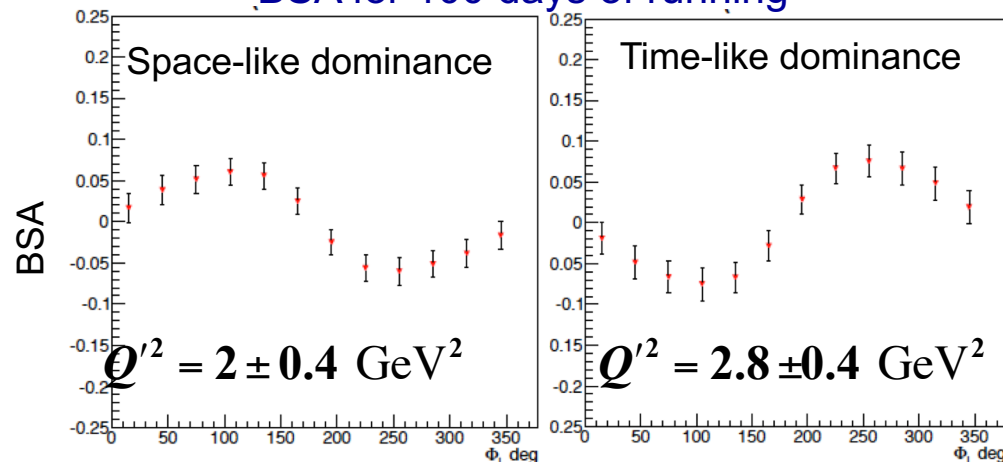
$$x_B = 0.15 \pm 0.05$$

Transferred momentum squared:

$$t = 0.25 \pm 0.15 \, GeV^2$$
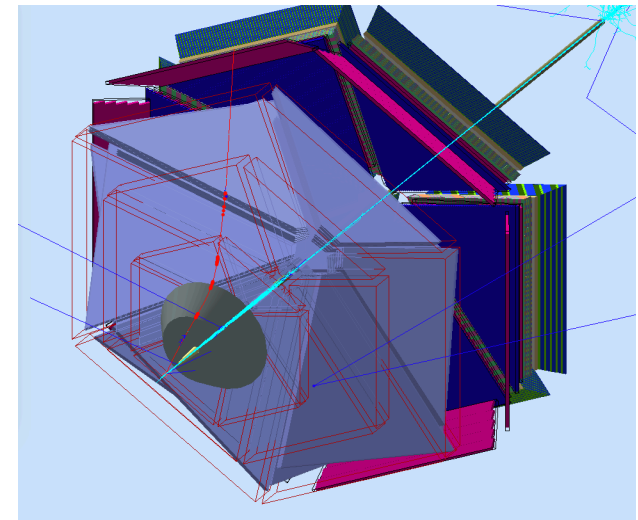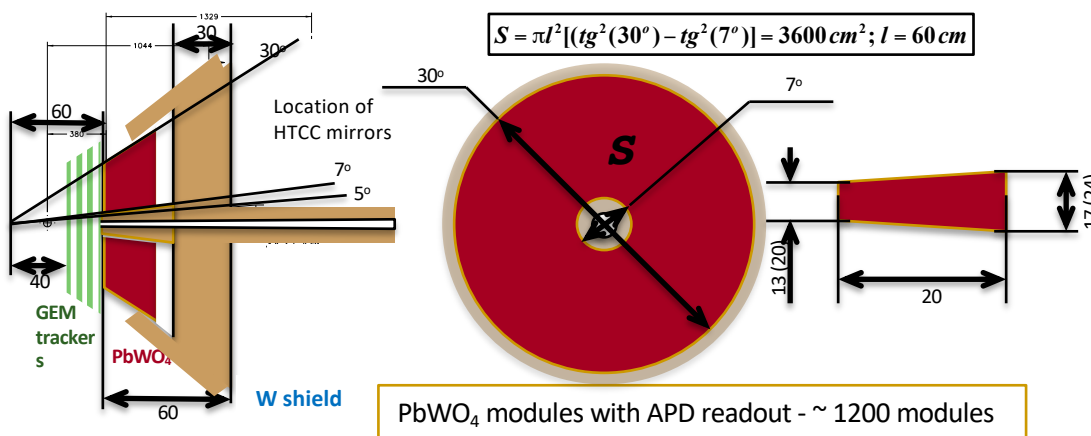
From Boer, Paremuzyan

BSA for 100 days of running

Space-like dominance

$$Q'^2 = 2 \pm 0.4 \ GeV^2$$

Time-like dominance

$$Q'^2 = 2.8 \pm 0.4 \ GeV^2$$

Concept of μCLAS12

- Remove HTCC and install in the region of active volume of HTCC:
  - a new Moller cone that extends to larger polar angles, $\sim 7^o$;
  - 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 FD.

- MPGD tracker in front of the calorimeter for vertexing and inside the solenoid for a recoil tagging.

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

Location of HTCC mirrors

GEM trackers

$PbWO_4$

W shield

PbWO$_4$ modules with APD readout - ~ 1200 modules

The project is in its early stage. MC simulations showed the concept's validity in terms of background and the trigger. Dedicated MC studies and detector R&D are planned to explore the best option for detector technologies.

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clas
CEBAF Large Acceptance Spectrometer

To conclude

- CLAS12 detector at Jefferson lab was commissioned in the early spring of 2018 and has taken physics data since then.

- The performance of the detector is close to the design. Implementation of AI-based event reconstruction algorithms 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 upgrade.

- Phase-I, in progress, will allow running x2 higher than the designed luminosity with the same or even better event reconstruction efficiency, time frame for the upgrade is 2-3 years.

- Phase-II upgrade, 5 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.