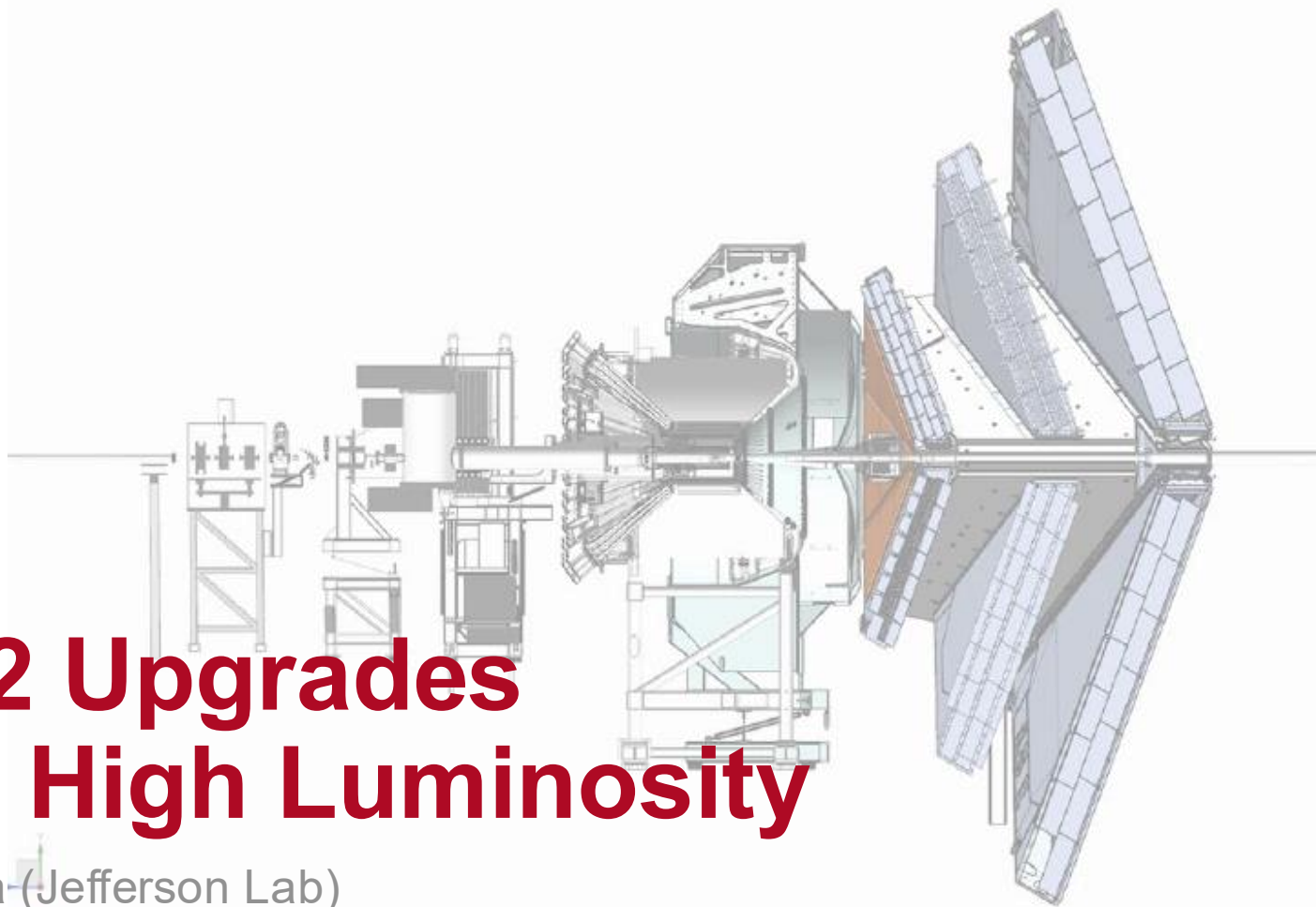


WORKSHOP ON THE PHYSICS PROGRAM WITH HIGH LUMINOSITY
FACILITIES (JEFFERSON LAB, 5-9 OCTOBER 2026)

CLAS12 Upgrades Toward High Luminosity

Raffaella De Vita (Jefferson Lab)
for the CLAS Collaboration



CLAS12

C Beamline
E Target
N Central Vertex Tracker
T Central Time of Flight
R Central Neutron Detector
A Back-Angle Neutron Detector
L

Design luminosity: $10^{35} \text{ cm}^{-2}\text{s}^{-1}$

Torus

Solenoid

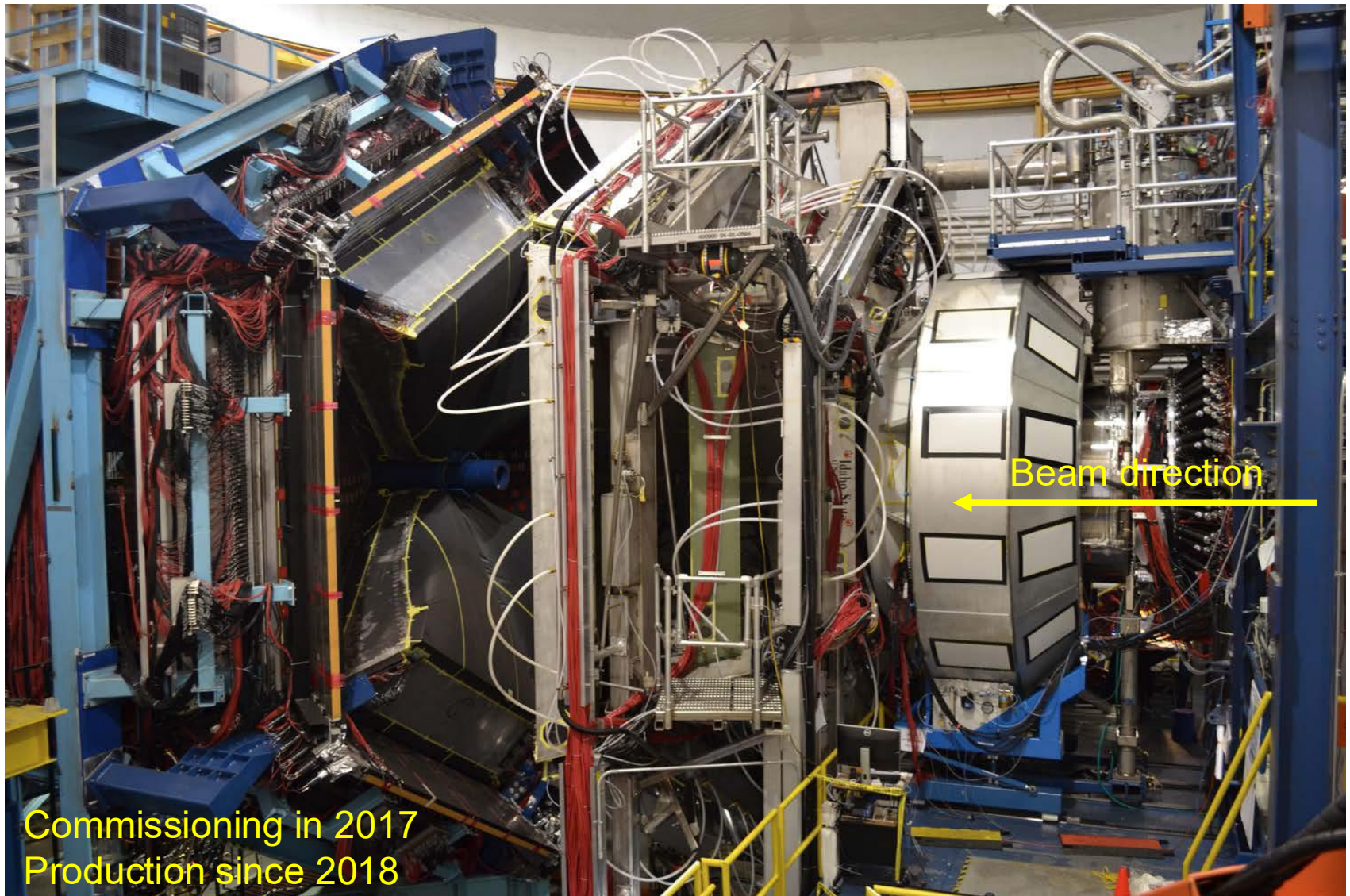
beam

F High Threshold Cherenkov
O Forward Tagger
R Drift Chambers
W Low Threshold Cherenkov
A Ring Imaging Cherenkov
R Forward Time of Flight
D EM Calorimeter

~130000 readout channels

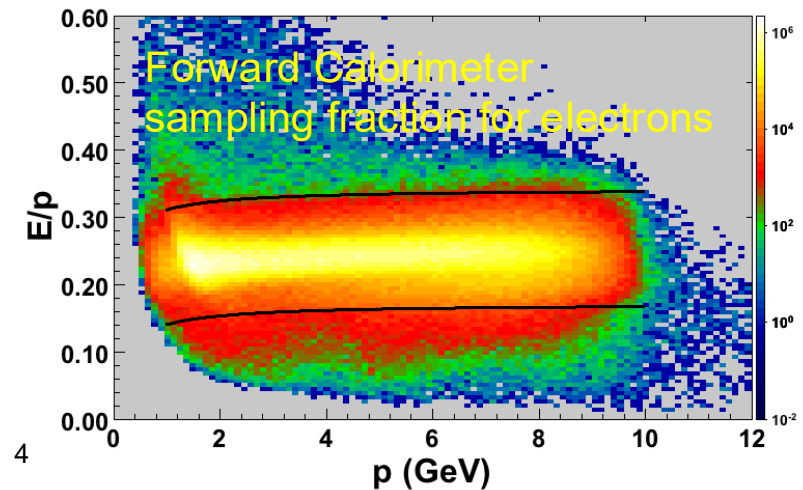
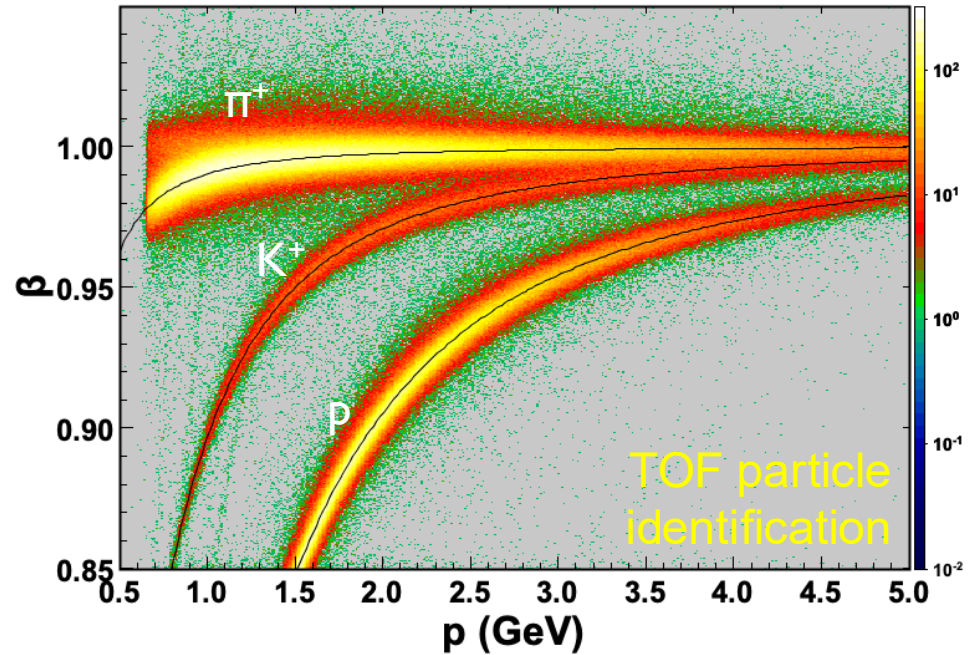
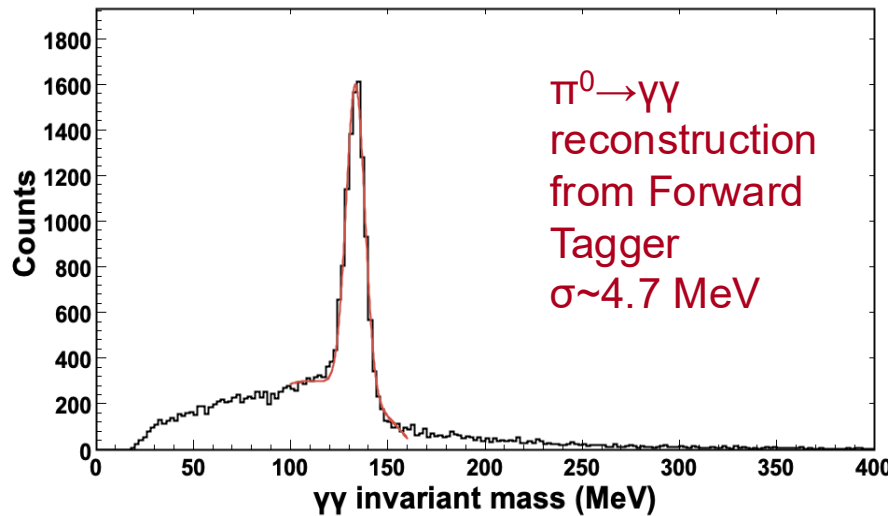
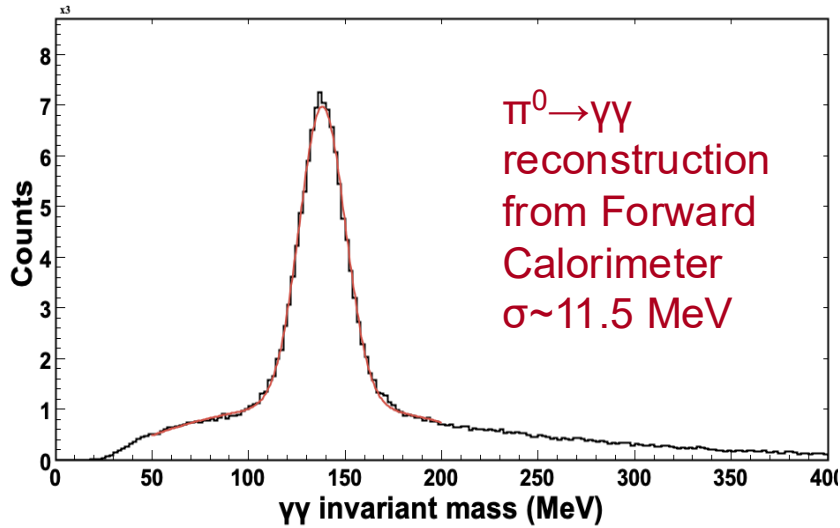
	Forward	Central
Angular coverage	$5^\circ - 35^\circ$	$35^\circ - 135^\circ$
Momentum resolution	$dp/p < 1\%$	$dp/p < 5\%$
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sin θ	5 mrad/sin θ

CLAS12 in Hall B



Commissioning in 2017
Production since 2018

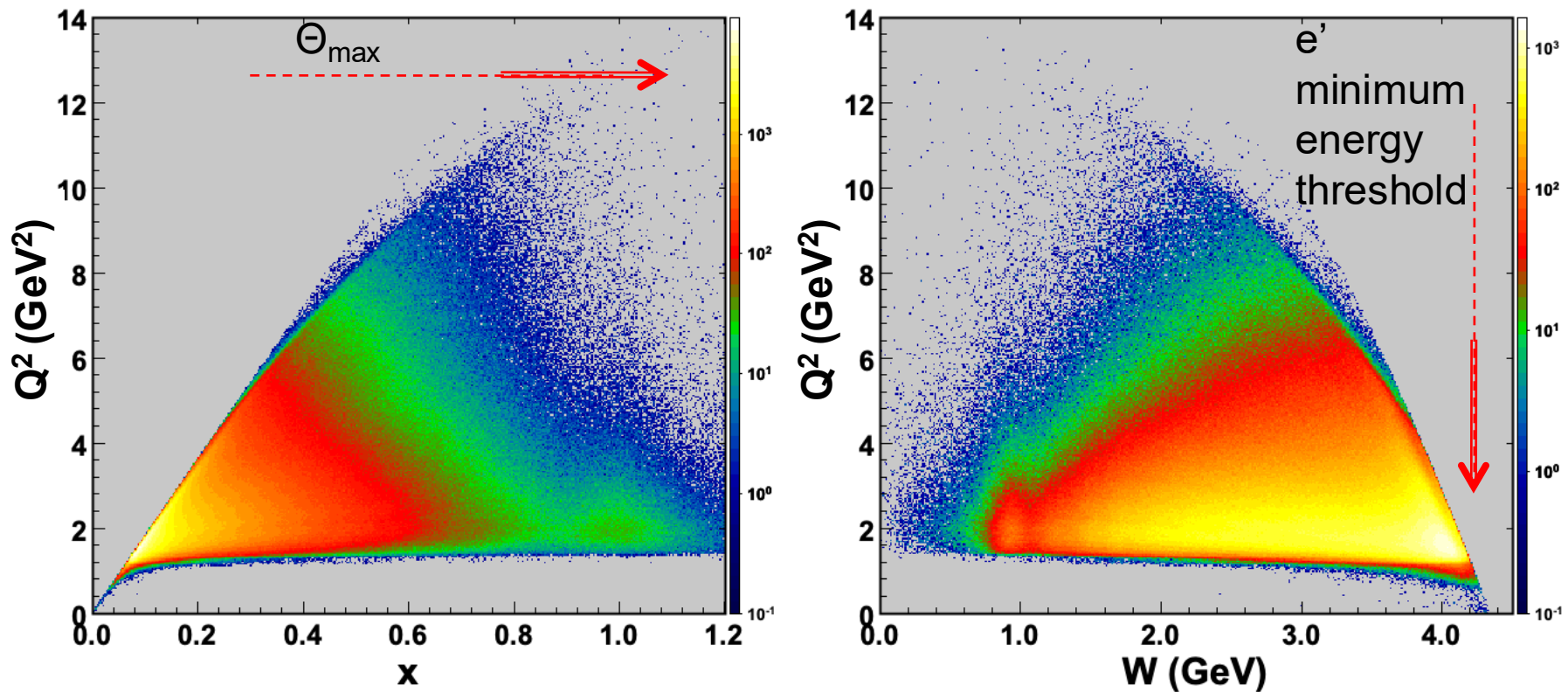
Event reconstruction



CLAS12 kinematic reach

Beam energy at 10.6 GeV Torus current 3770 A, electrons in-bending,
Solenoid magnet at 2416 A.

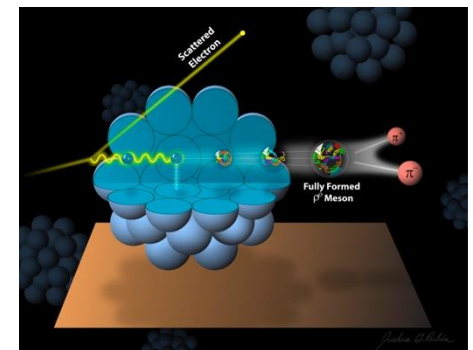
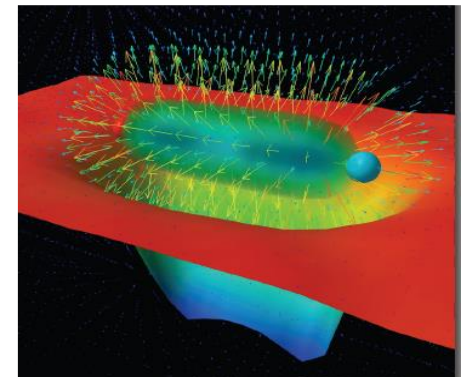
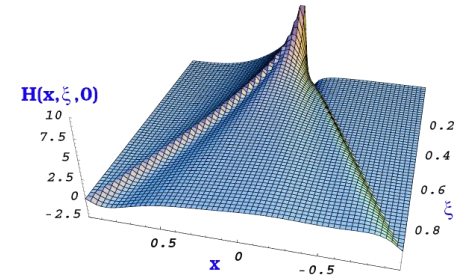
$p(e,e')X$



Plots based on 200 min. of data taking

The 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 in numbers

Collaboration:

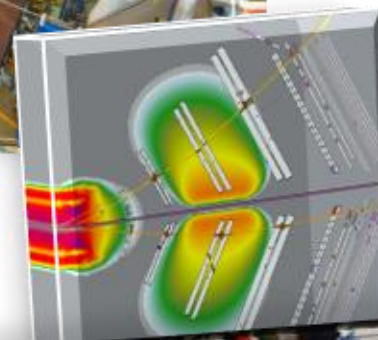
- more than 200 members
- 43 institutions
- 9 countries

Experimental program:

- 53 approved proposals, organized in 14 Run Groups
- 1256 Run Group days, 303 conditionally approved, 457 completed

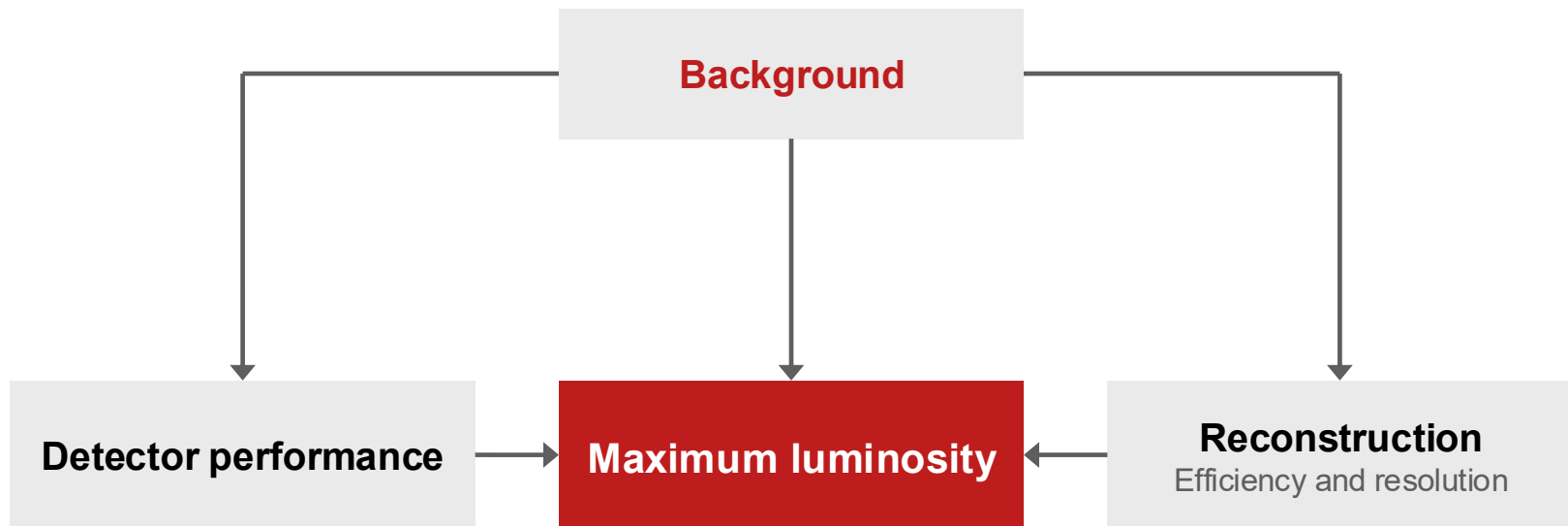
Run configuration:

- targets:
 - proton, deuteron and nuclei
 - unpolarized, longitudinally and transversally polarized
 - solid, liquid and gas
- beam:
 - highly polarized electron beam
 - circularly polarized photons (e' at 0 deg)
 - linearly polarized quasi-real tagged photons
- final states: inclusive, semi-inclusive and exclusive
- **luminosity up to $1.5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$**



High luminosity operation

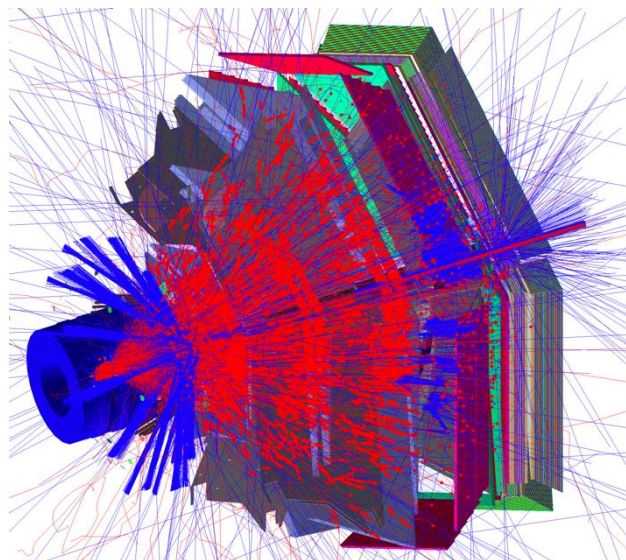
- Maximum luminosity of $1.5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ achieved on liquid deuterium target with 11 GeV electron beam
- Not a hard limit but chosen as the optimal setting, considering background levels, detector performance, reconstruction efficiency and resolution



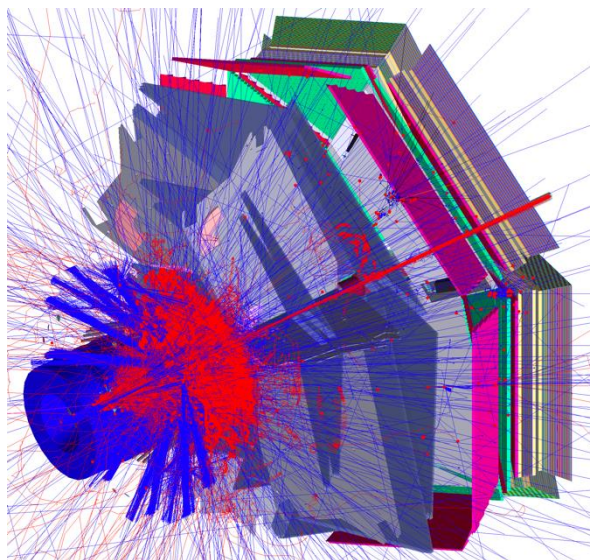
Backgrounds

- Main source is electromagnetic interaction of the electron beam in the target (Moller electrons)
- Suppressed via
 - Active shielding provided by the torus and solenoid magnetic fields
 - Passive shielding: high-Z material surrounding the beamline, outside the detector acceptance
- Highest impact on tracking detectors (DC Region 1)

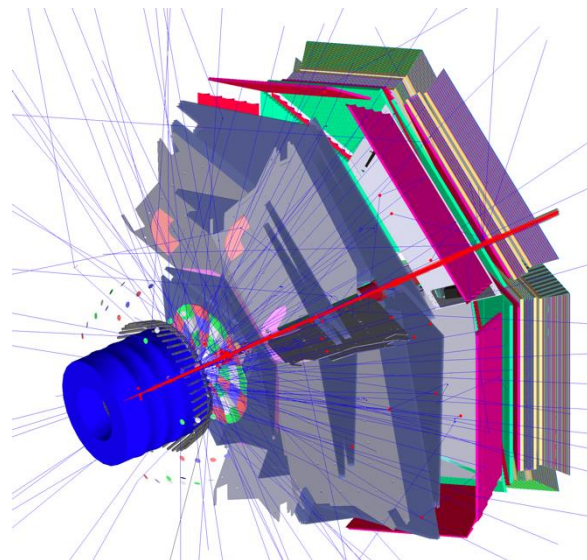
No field



Torus on

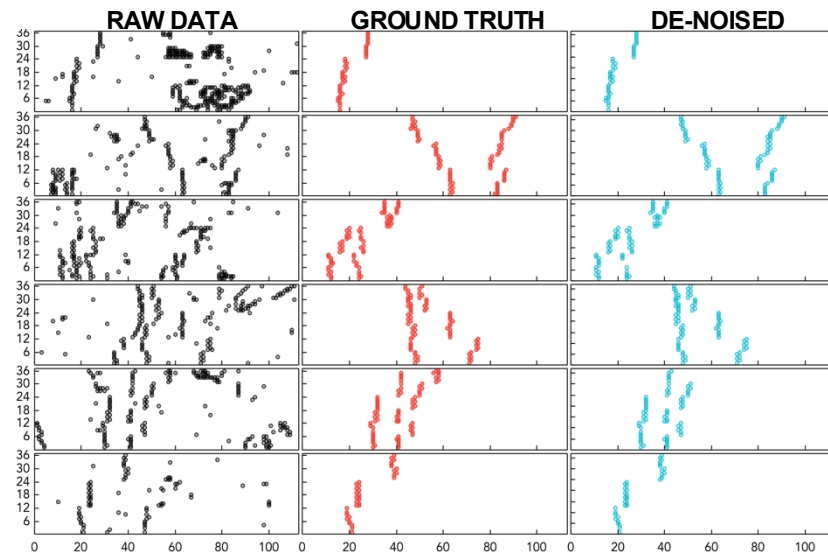
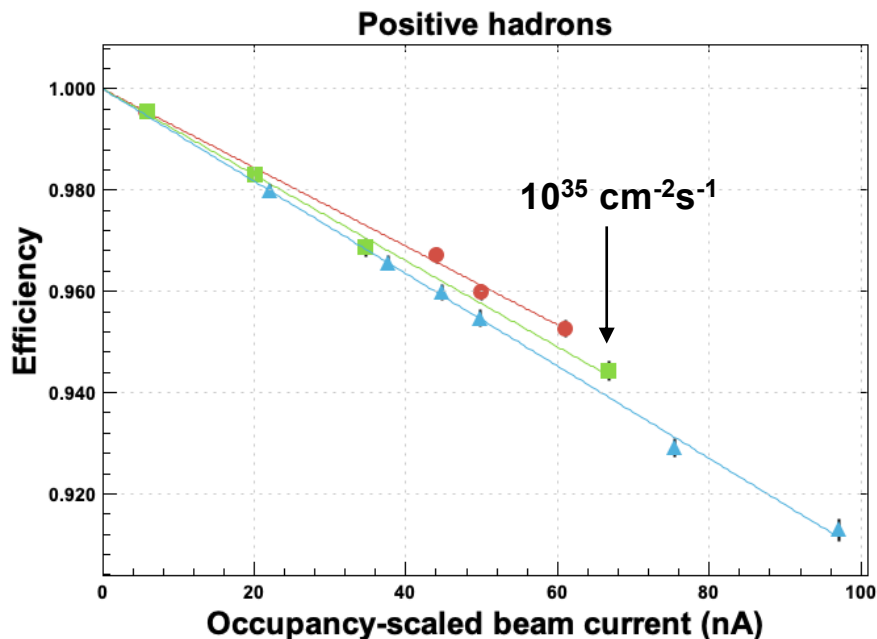


Solenoid on

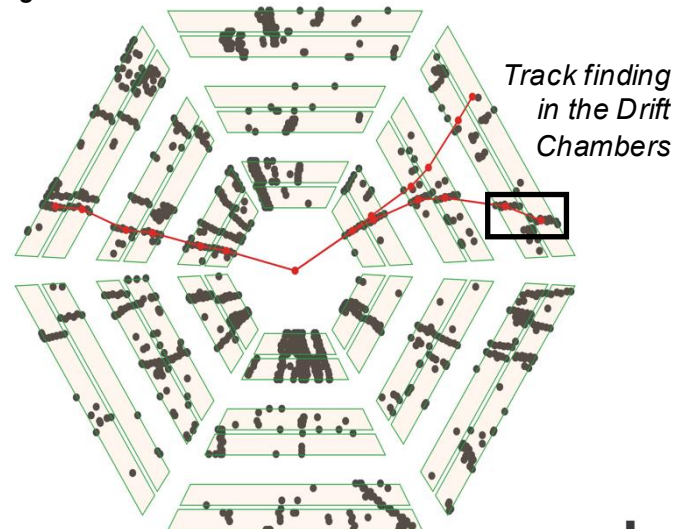


Reconstruction efficiency

- Strong reduction of background impact on reconstruction efficiency achieved using AI
 - Detector denoising
 - Track finding
 - ...



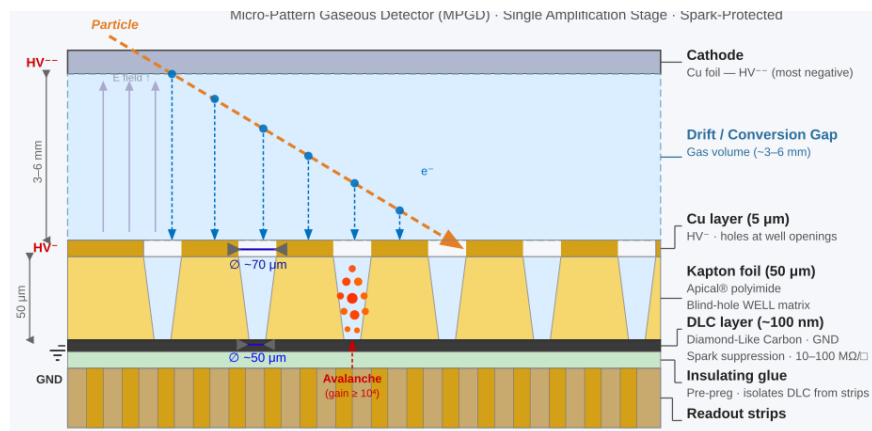
Denoising in the Drift Chambers



μ RWELL tracker for DC Region 1

Goal: μ RWELL layers in front of DC Region 1 recover hits lost at high luminosity and, with better timing, reject noise ($2 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, $>85\%$ track efficiency)

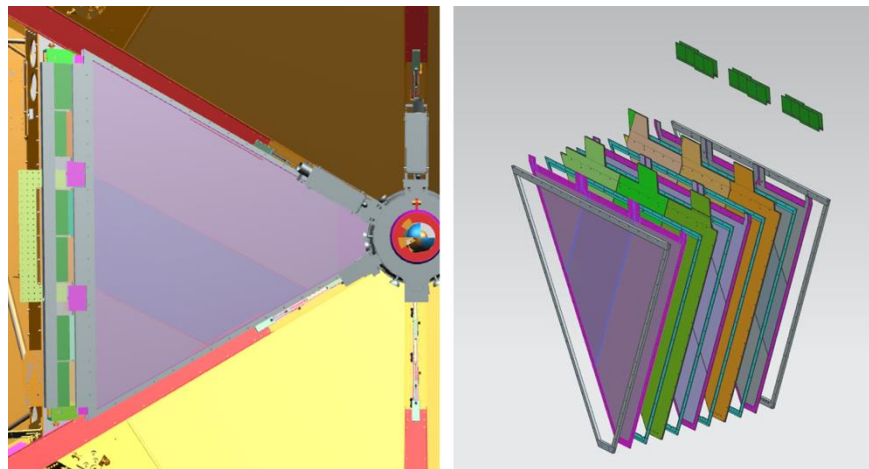
Working principle



μ RWELL cross-section

- Single amplification stage in a 50 μm Kapton well matrix, gain $\sim 10^4$
- Resistive DLC layer suppresses sparks
- Simpler, cheaper and lighter than a triple-GEM, no frames needed in the active area

Full-size design



Module in front of R1 (left) and exploded U-V-U-V layers (right)

- Four 1D layers U-V-U-V, three 44.8-cm sections each
- 1 mm pitch, strips parallel to the sides
- VMM3 readout, 7 ASICs per board
- Candidate production design

μ RWELL R&D status

1st prototype

arrived 2022, CERN
repair 2023

New cathode

Cu/Kapton, UVA 2024

>90% efficiency

cosmics, Ar/iso 90/10

2nd prototype

2×1D, tested at JLab
2026

3rd prototype

full size, production
design

1st prototype: lessons

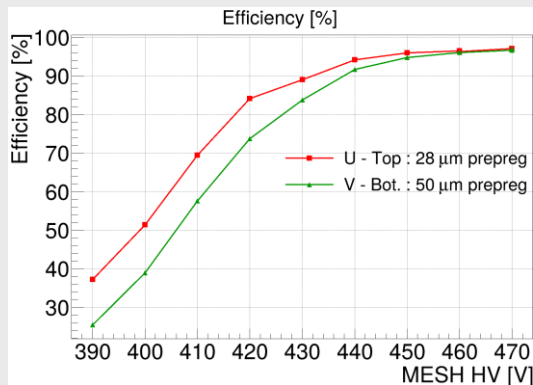
- Al cathode failed → 5 μ m Cu
- >90% efficiency, <10 ns timing
- Too little charge to share U/V → 2×1D design

Test setup at JLab



2nd prototype with gas manifolds (left); cosmic stand with hodoscope and picoammeters (right)

2nd prototype: first results (cosmics, Ar/iso 90/10)



Efficiency vs MESH HV

>92%

U and V efficiency at 440 V

1st prototype: 65% (U), 34% (V)

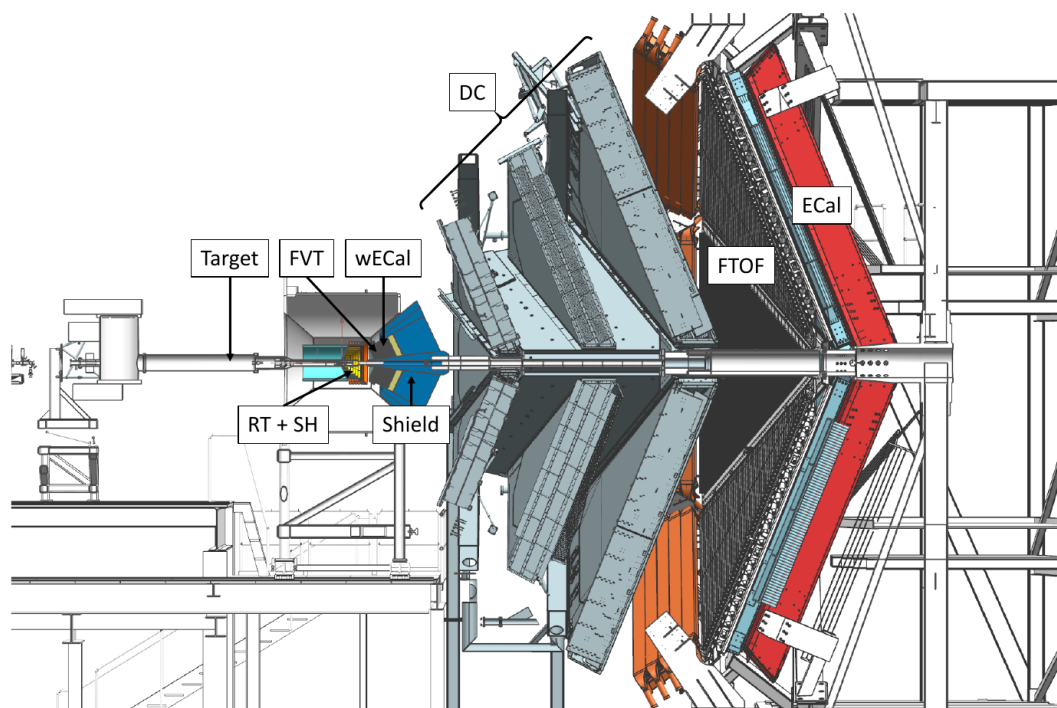
~97%

at 470 V

- Gas tight; uniform efficiency over the area; higher gain than 1st prototype, 28 μ m prepreg $\sim 1.5\times$ larger pulses than 50 μ m
- Open issue: leakage currents from 450–460 V (1st prototype stable to 490 V); max stable HV varies by section, under study with CERN

$\mu\text{CLAS12} - 10^{37} \text{ cm}^{-2}\text{s}^{-1}$

Turning CLAS12 into a muon detector for the measurement of $ep \rightarrow e'\mu^+\mu^-p$: a 60-cm lead shield around a PbWO_4 calorimeter replaces the HTCC, absorbing EM and hadronic background so that only muons ($p > 1.5 \text{ GeV}/c$) reach the Forward Detector



Approved (C1) by PAC53 with A rating

Electron calorimeter (wECal)

$\sim 1320 \text{ PbWO}_4$ crystals at 60 cm, $7^\circ\text{--}30^\circ$: scattered electron

Forward Vertex Tracker (FVT)

Six triple-GEM stations, $< 100 \mu\text{m}$: muon angles at the vertex

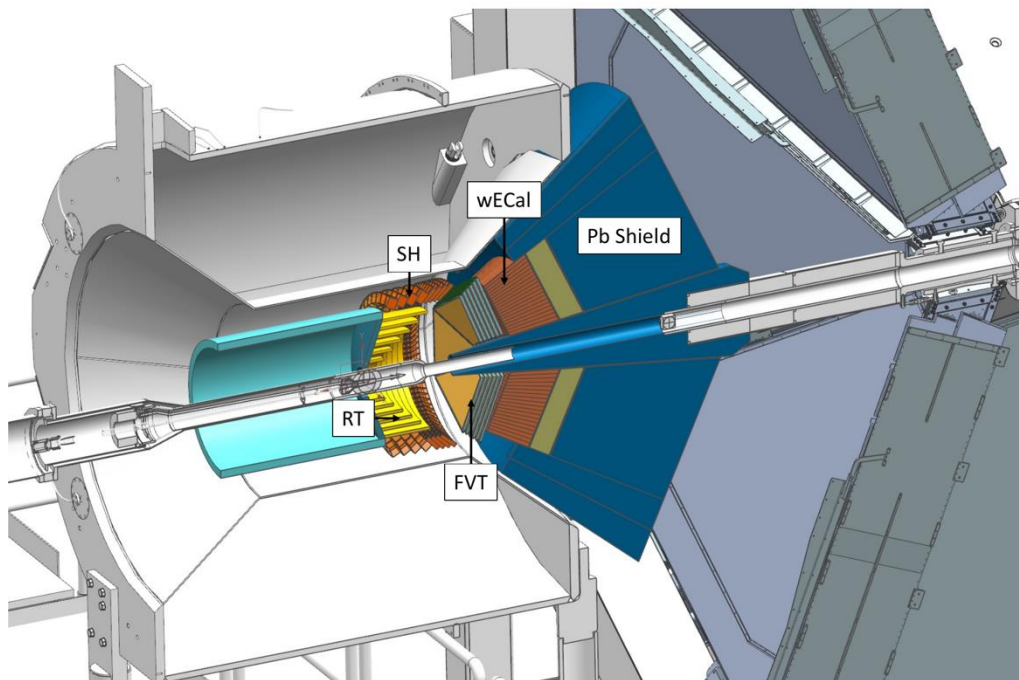
Recoil Tracker + Hodoscope

μRWELL tracker, 540 scintillators: protons at $40^\circ\text{--}70^\circ$

$\pi^+\pi^-$ suppression	$\geq 2 \times 10^4$
MIPs Trigger rate	$\sim 21 \text{ kHz}$ (DAQ: 30 kHz)
Luminosity	$10^{37} \text{ cm}^{-2}\text{s}^{-1}$
Beam time	200 days

$\mu\text{CLAS12} - 10^{37} \text{ cm}^{-2}\text{s}^{-1}$

Turning CLAS12 into a muon detector for the measurement of $ep \rightarrow e'\mu^+\mu^-p'$: a 60-cm lead shield around a PbWO_4 calorimeter replaces the HTCC, absorbing EM and hadronic background so that only muons ($p > 1.5 \text{ GeV}/c$) reach the Forward Detector



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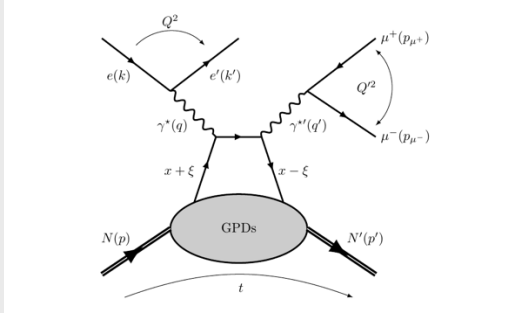
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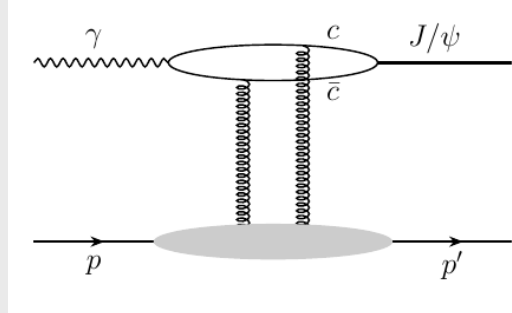
Physics program



Double DVCS

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

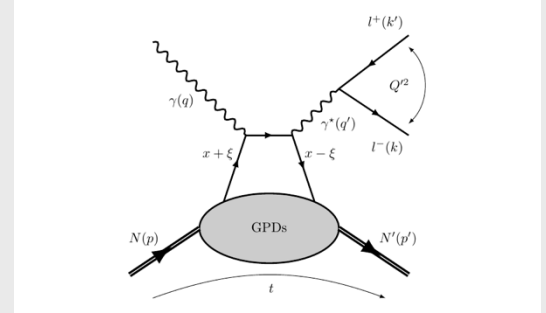
- Q^2 and Q'^2 varied independently
- Im of CFFs gives GPDs at $x = \xi'$, off the $x = \pm\xi$ line
- Maps GPDs in (x, ξ, t) ; constrains shadow GPDs
- Observable: beam-spin asymmetry $A_{LU}(\varphi)$



Near-threshold J/ψ

$$ep \rightarrow e'J/\psi p' \rightarrow e' \mu^+\mu^-p'$$

- Two-gluon exchange probes the gluons in the proton
- $d\sigma/dt \rightarrow$ gluon GFFs: mass radius, pressure
- Tests open-charm and P_c contributions
- Observables: $\sigma(E_\gamma)$, $d\sigma/dt$, $R = \sigma_L/\sigma_T$



Timelike Compton

$$\gamma p \rightarrow \gamma^* p' \rightarrow \mu^+\mu^-p'$$

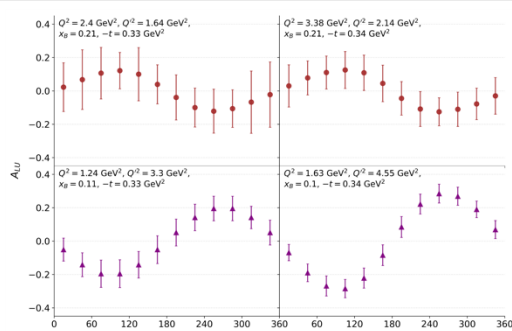
- Timelike partner of DVCS: tests GPD universality
- $A_{\odot U} \rightarrow$ imaginary part of CFFs
- $A_{FB} \rightarrow$ real part of CFF H, D-term
- Sensitive to NLO and gluon GPDs

Expected results (200 days)

DDVCS: A_{LU} vs ϕ

$>0.5 \times 10^6$

events

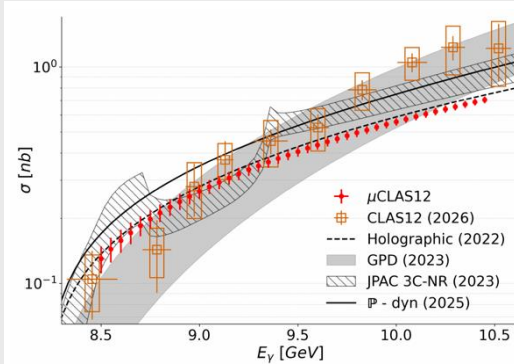


- Sign change of A_{LU} from spacelike (top) to timelike (bottom) clearly resolved
- t -dependence separates GPD models; shadow-GPD effect visible

J/ψ : $\sigma(E_\gamma)$

$\sim 3 \times 10^4$

events, $\sim 40 \times$ CLAS12

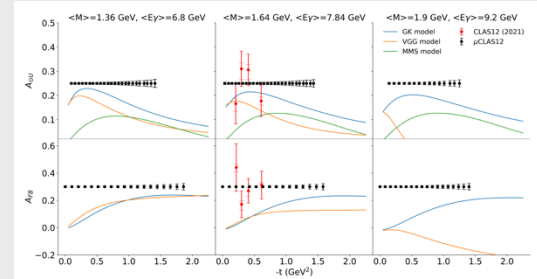


- Discriminates production models, incl. open-charm region 8.7–9.4 GeV
- $d\sigma/dt$ to $-t \approx 4 \text{ GeV}^2$; ~ 4500 $P_c(4457)$ in a 2% BR model

TCS: A_{OU} and A_{FB} vs t

7.7×10^6

events, $\sim 1000 \times$ CLAS12



- Fine t and M bins, up to $M = 2.3 \text{ GeV}$
- Errors far below published CLAS12 data (red)

See talks by P. Chatagnon and R. Paremuzyan

Upgrade path: Stage I

Stage I

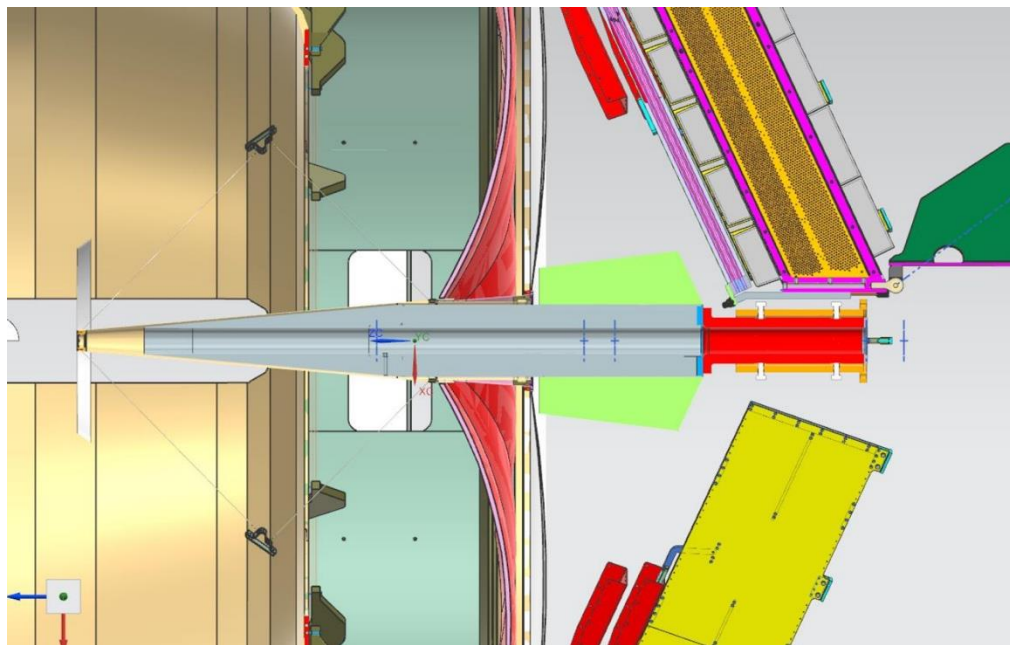
7° Møller cone, no Forward Tagger
up to $5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$

Stage II

wECal + Pb shield, 7°–15°, no HTCC
up to $10^{36} \text{ cm}^{-2}\text{s}^{-1}$

Stage III = μCLAS12

full FD shield and wCal
 $10^{37} \text{ cm}^{-2}\text{s}^{-1}$



Stage I layout: large Møller cone up to 7°

Configuration

- Large Møller cone, as used for RG-C, with extension to 7°
- Forward Tagger removed
- Luminosity up to $5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ ($\times 5$ design)

Required upgrades

- Replace the MicroMegs of the CVT
- New forward vertex tracker (FVT)
- Better shielding downstream of the torus for DC Region 3

Physics

- Most exclusive and semi-inclusive reactions at high Q^2

Upgrade path: Stage II

Stage I

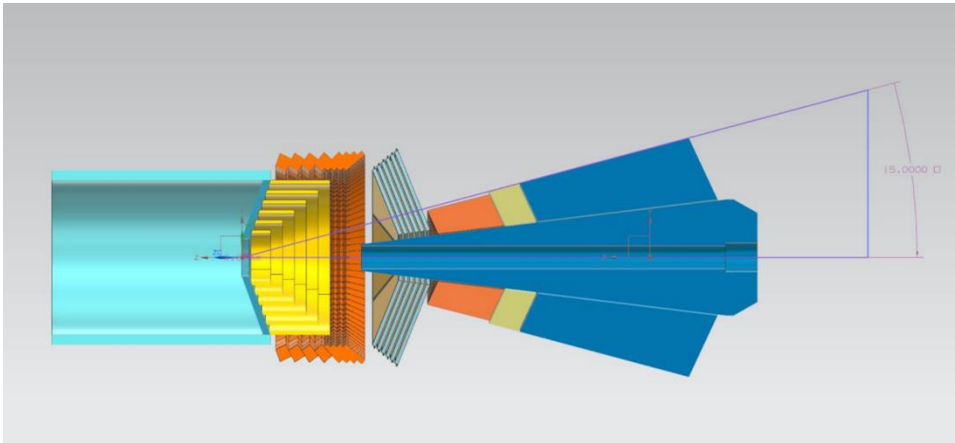
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Stage III = μCLAS12

full FD shield and wCal
 $10^{37} \text{ cm}^{-2}\text{s}^{-1}$



Stage II layout: wECal and Pb shield from 7° to 15°

Simulation studies

- Luminosity up to $10^{36} \text{ cm}^{-2}\text{s}^{-1}$, based on estimated background levels
- First estimates for J/ψ production on neutron

Configuration

- wECal + Pb shield from the 7° Møller cone to 15°
- HTCC removed

Physics

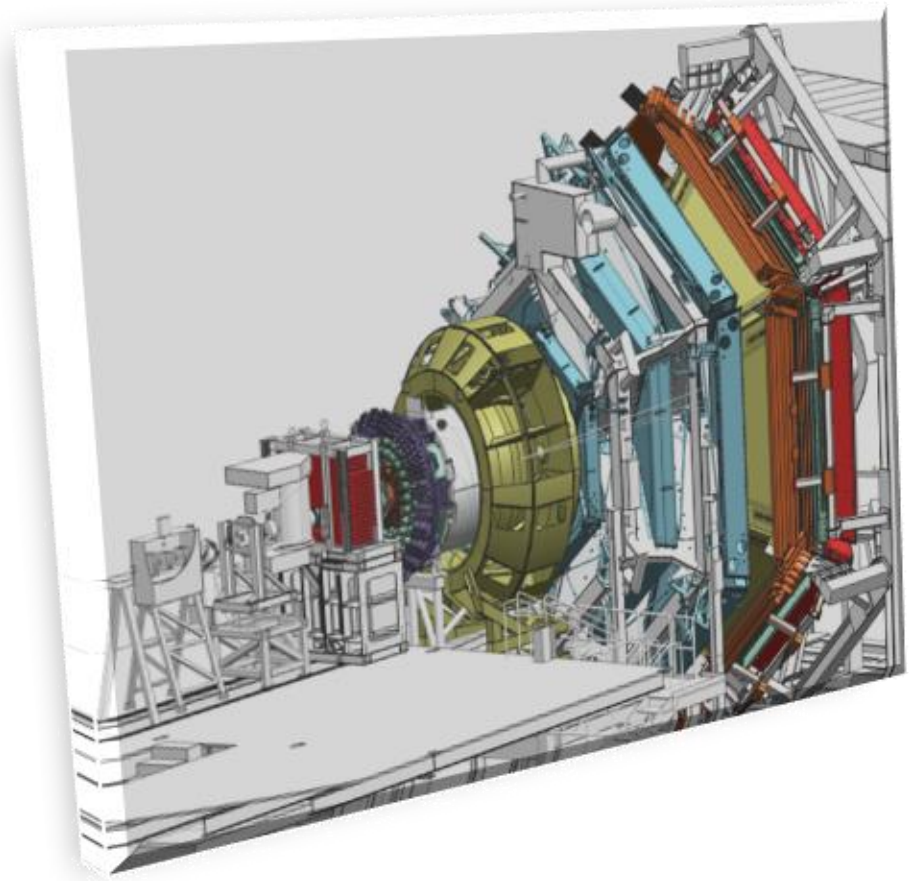
- CLAS12 program, limited to high-rate kinematics
- J/ψ quasi-real photoproduction tagging the recoil nucleon
- Deuteron target: separate bound neutron and proton
- Possible first DDVCS measurements

Operations

- Experience running with μA beam currents

Summary

- CLAS12 spectrometer successfully in operation since 2018, at luminosity up to $1.5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
- Data taking for realization of extensive physics program in progress
- First high-luminosity upgrade (x2) already approved and being implemented
- μCLAS12 proposal approved for 200 days at $10^{37} \text{ cm}^{-2}\text{s}^{-1}$ (x100)
- Intermediate stages (x5, x10) under study to consolidate the path toward high luminosity



CLAS12 Event Display

