

IJCLab activities at JLab/EIC

- Goals
- Physics highlights
- Ongoing projects
- Plans for JLab and EIC
- Institutional infos

Equipe JLab/EIC
IJCLab, 14 mai 2024

Physics goals of IN2P3 team at JLab

Study of **nucleon structure**, mainly via **Generalized Parton Distributions (GPDs)**:

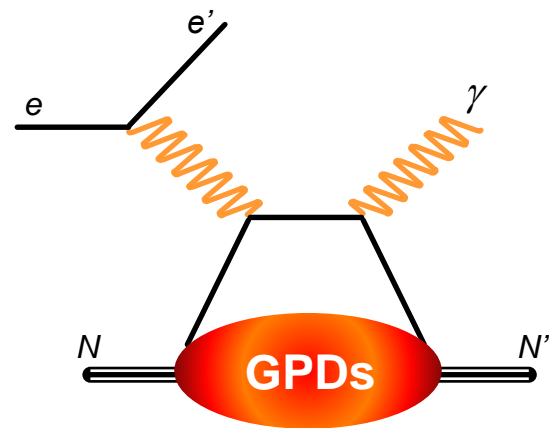
Correlations between position, momentum, and spin of partons in the nucleon

→ **nucleon tomography, quarks' angular momentum,...**

GPDs are accessed in **exclusive electroproduction** at high momentum transferred

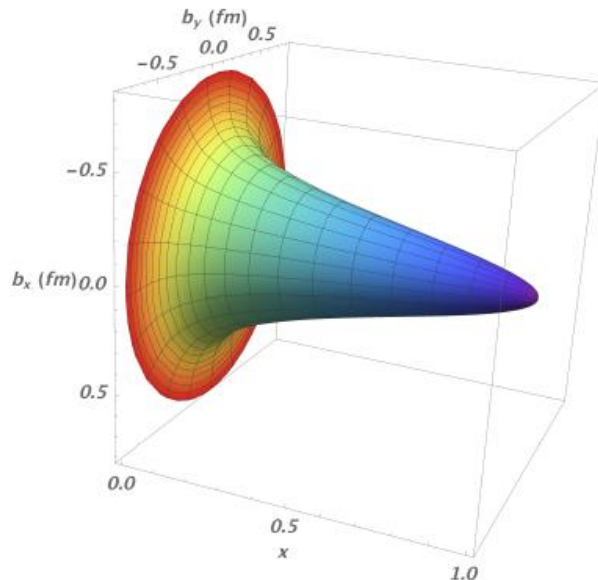
→ **virtual photons scattering on quarks**

DVCS (Deeply Virtual Compton Scattering) $eN \rightarrow e'N'\gamma$



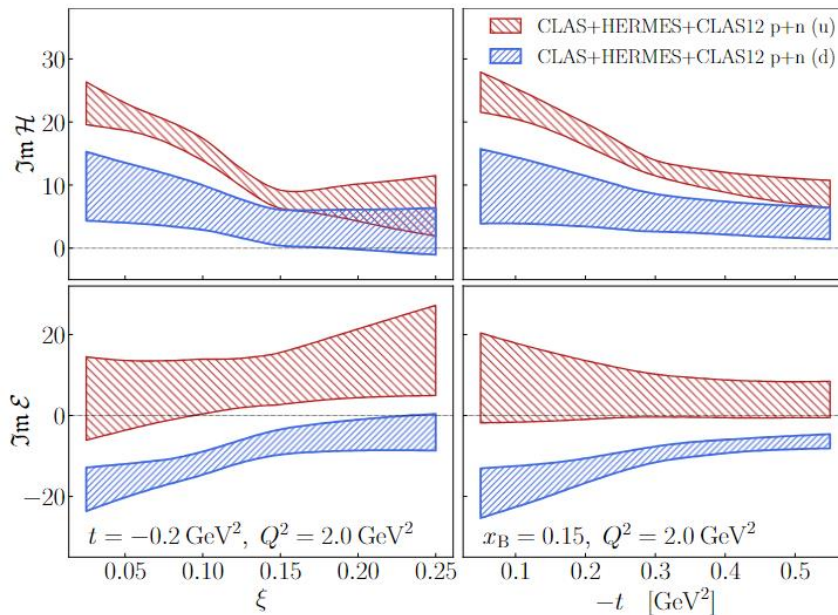
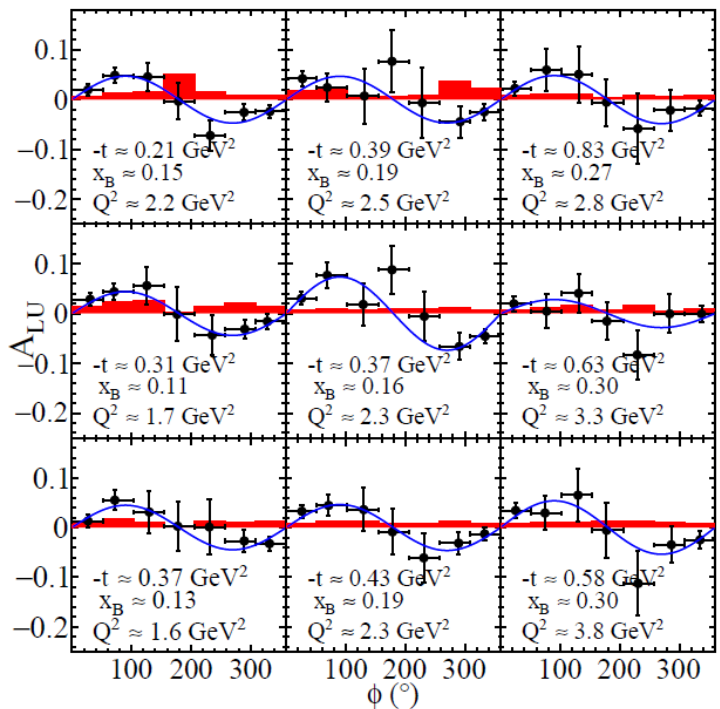
- The IN2P3 team has been leading the JLab experimental program on GPDs for the last ~25 years
- Most approved proposals on GPD physics at JLab have at least one IJCLab spokesperson
- IJCLab lead author on > 30 articles on DVCS, meson electroproduction, GPD extraction and modeling

**Direct involvement in all aspects of the experiments:
proposition, detector conception and development,
data taking, analysis, phenomenological
interpretation of the results**



Proton tomography, derived from fits to DVCS data we obtained with JLab@6 GeV: High-momentum quarks (valence) are at the core of the nucleon, low-momentum quarks (sea) are at its periphery

Physics highlights from ongoing analyses of JLab data



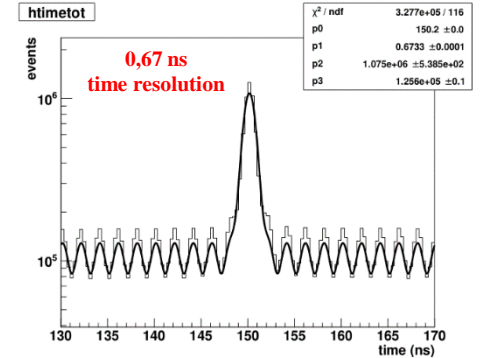
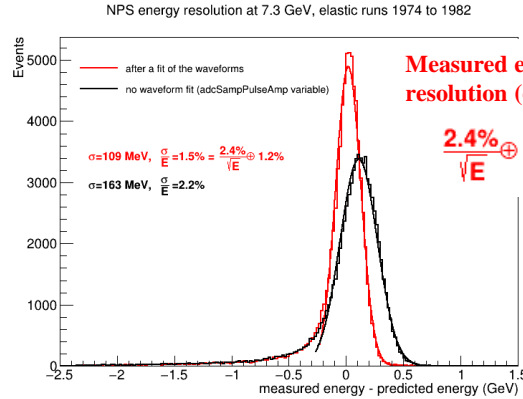
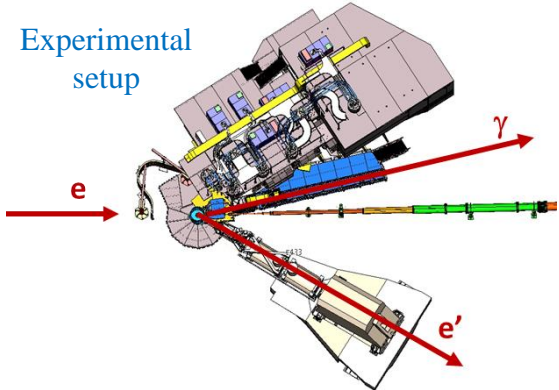
“First measurement of deeply virtual Compton scattering on the neutron with detection of the active neutron” (M. Hoballah, S. Niccolai), **will be submitted to PRL in June: our data allow quark-flavor separation of the $\text{Im}\mathcal{H}$, $\text{Im}\mathcal{E}$ Compton Form Factors** (integrals of GPDs); data taken with **CLAS12+CND** in 2019-2020

Other ongoing projects:

- Cross sections for neutron DVCS (L. Xu)
- Target-spin asymmetries for neutron DVCS (N. Pilleux)
- Neutron DVCS beam spin asymmetries with detection of the spectator proton (M. Ouillon)
- Nuclear TMDs (D. Matamoros) – data taking underway
- DVCS with Machine Learning; phenomenology of double DVCS (J.S. Alvarado)

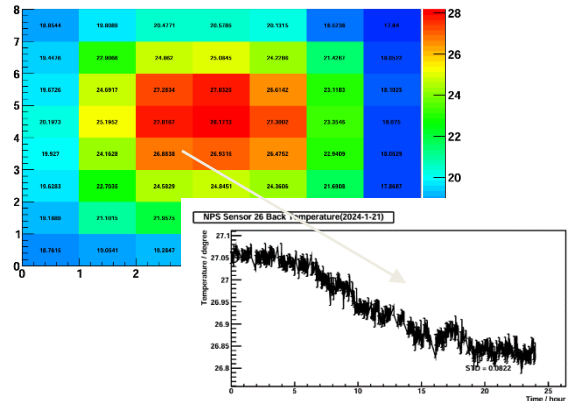
NPS experiment in JLab Hall C

- Experiment currently running: **Sep 15 (2023) – May 20 (2024)**
- LH2 and LD2 targets

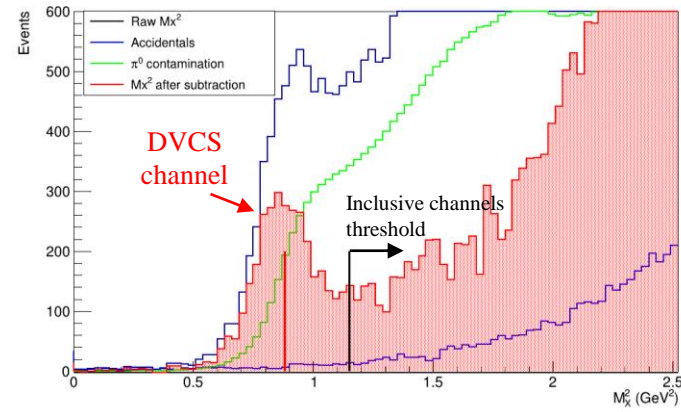


IPN/IJLab in charge of mechanical design and construction of the calorimeter frame

Good temperature stability: $\pm 0.1^\circ\text{C}$

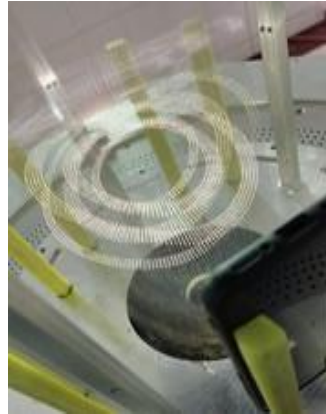


DVCS missing mass squared



The ALERT Detector

- **A Low Energy Recoil Tracker**
 - Joint effort of CLAS Collaboration and HallB
 - Hyperbolic **drift chamber** (by IJCLab)
 - **Time-of-Flight** array (by ANL)
- Motivation:
 - Quark and gluon structure of **light nuclei**
 - Measure of **PDFs and GPDs of nuclei** and bound nucleons
- **Stringing of ALERT wire chamber**
 - Started in September 2023, finished early March 2024
 - A single wire appears below nominal tension and needs repair
- **Delivered to JLab in April**, tested in May
- **Commissioning** of the detector during the summer
 - Already took some cosmics
 - Last parts will be installed in the summer
- **ALERT is the next experiment running in HallB**



Ce⁺BAF: a polarized positron beam for JLab

PEPPO @ Ce⁺BAF

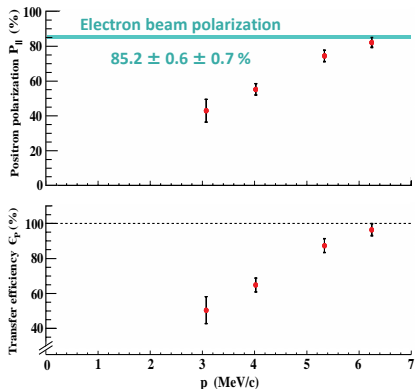
(Ce⁺BAF Working Group) J. Grames *et al.* JACoW IPAC2023 (2023) MOPL152; arXiv2309.15581

- The **PEPPO** (Polarized Electrons for Polarized Positrons) experiment demonstrated a new technique for the production of **polarized positron beams**.
- This technique is the founding concept of the novel **Ce⁺BAF** positron injector which will benefit a **unique** and **high impact experimental program**.

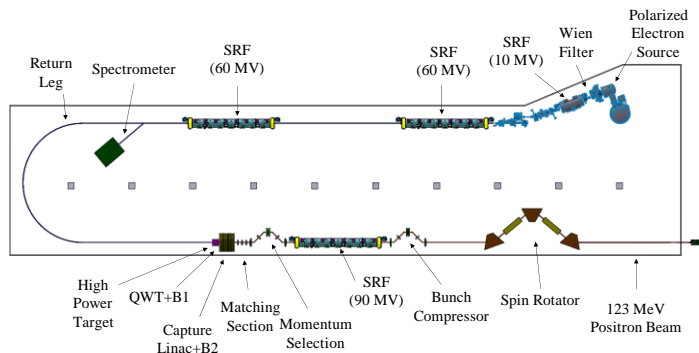
(JLab Positron Working Group) A. Accardi *et al.* EPJ A 57 (2021) 261

(CLAS Collaboration and JLab Positron Working Group) PR12+23-002 E. Voutier *et al.* (Approved C1) – Beam charge asymmetries in DVCS @ CLAS12

(NPS Collaboration and JLab Positron Working Group) PR12+23-006 C. Muñoz Camacho *et al.* (Approved C1) – Positron cross section in DVCS @ NPS



From a **proof-of-principle** experiment (**PEPPO**) to a novel **polarized positron injector (Ce⁺BAF)** at Jefferson Lab.

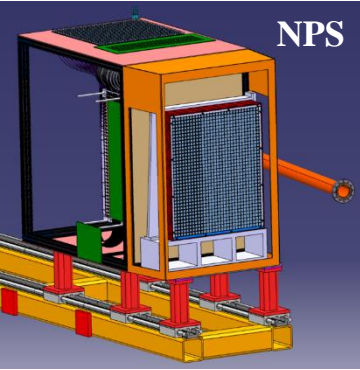


(PEPPO Collaboration) D. Abbott *et al.* PRL 116 (2016) 214801

S. Habet, Doctorate Thesis, Université Paris-Saclay (2023)

Plan for data taking at JLab@12 GeV...and beyond

All these experiments have **IJCLab** spokespersons and/or a **technical contribution** of IJCLab

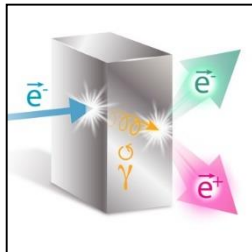
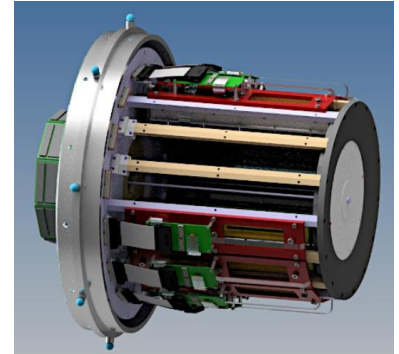


NPS

pDVCS and π^0 @ Hall C + NPS (2024)

DVCS on nuclei – ALERT @ CLAS12 (2024-2025)

DVCS on transversely polarized target @ CLAS (~2028)



GPDs with polarized positrons beam (> 2030)

Long term: Electron-Ion Collider (EIC) (>2034)

IJCLab involvement in EIC

2014: Participation to the EIC White Paper



2019: EICUG Meeting in Paris



2020: Expressions of Interest

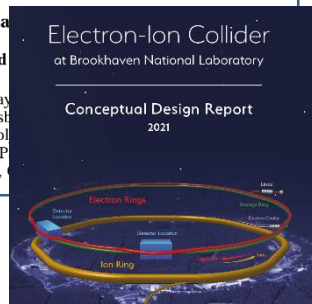
Expression of Interest (EOI)

Laboratories of CNRS-IN2P3 (France)

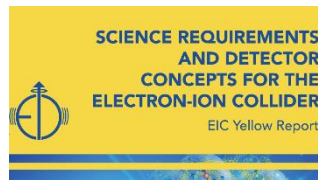
Questionnaire

Please indicate all institutions collectively involved

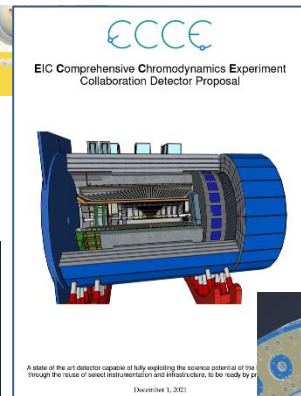
IJCLab, Université Paris-Saclay, CNRS-IN2P3, Orsay
IPHC, Université de Strasbourg, CNRS-IN2P3, Strass
LLR, CNRS-IN2P3, Ecole Polytechnique, Institut Pol
OMEGA - Centre de Microélectronique, CNRS-IN2P
SUBATECH, IMT Atlantique, Université de Nantes,



2020: Co-conveners and leadership roles in Yellow Report



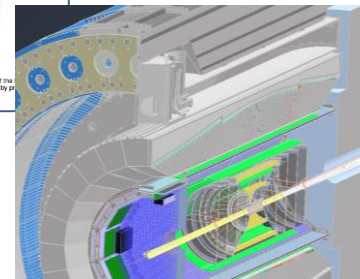
2020: Physics co-convenor in the ECCE detector proposal



IJCLab physicists are **experts in nucleon 3D imaging**, central to the EIC science, with a fruitful experimental program being carried out at Jefferson Lab

ePIC Collaboration:

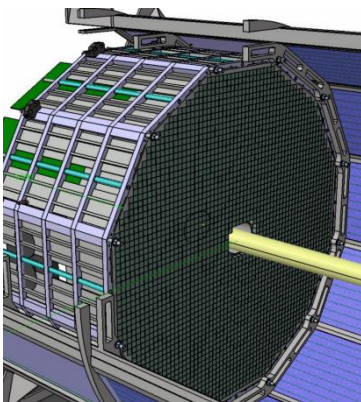
- Calorimetry co-convenor
- Exclusive processes WG co-convenor
- Backward ECAL Technical Coordinator
- Membership Committee



Also, IJCLab members have served in several EICUG committees and serve in the new EIC-related generic detector R&D advisory panel

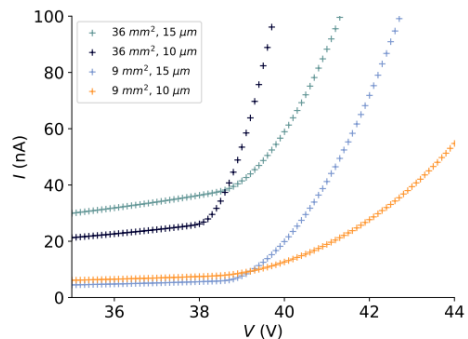
2021: Contribution to the EIC CDR

ePIC backward ECAL

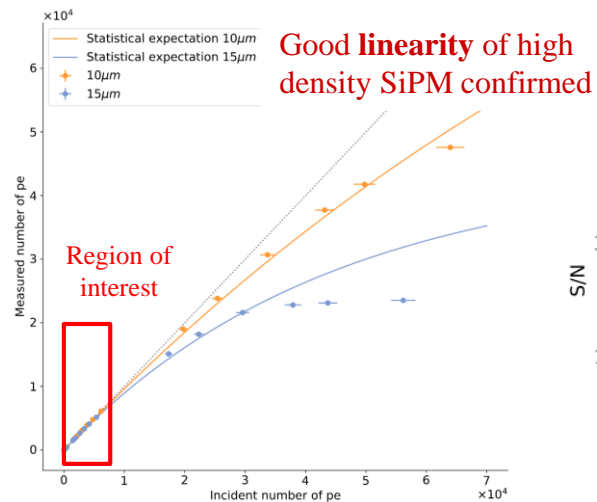
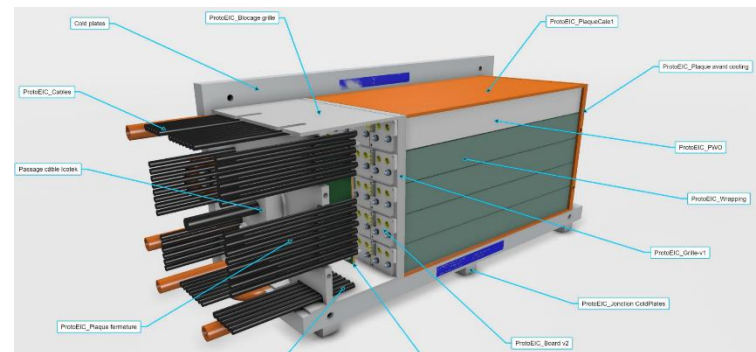


IN2P3 R&T on SiPM readout:

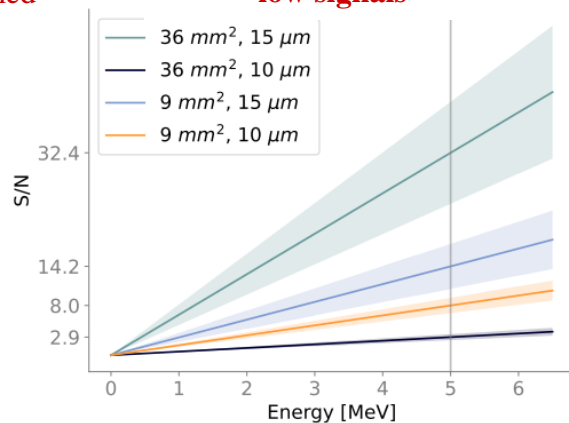
Several models of Hamamatsu SiPM tested



5x5 SiPM readout PWO prototype



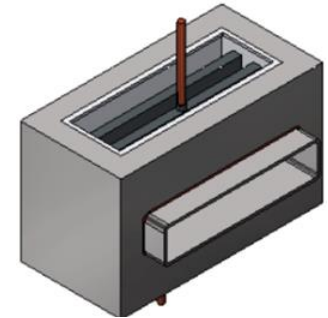
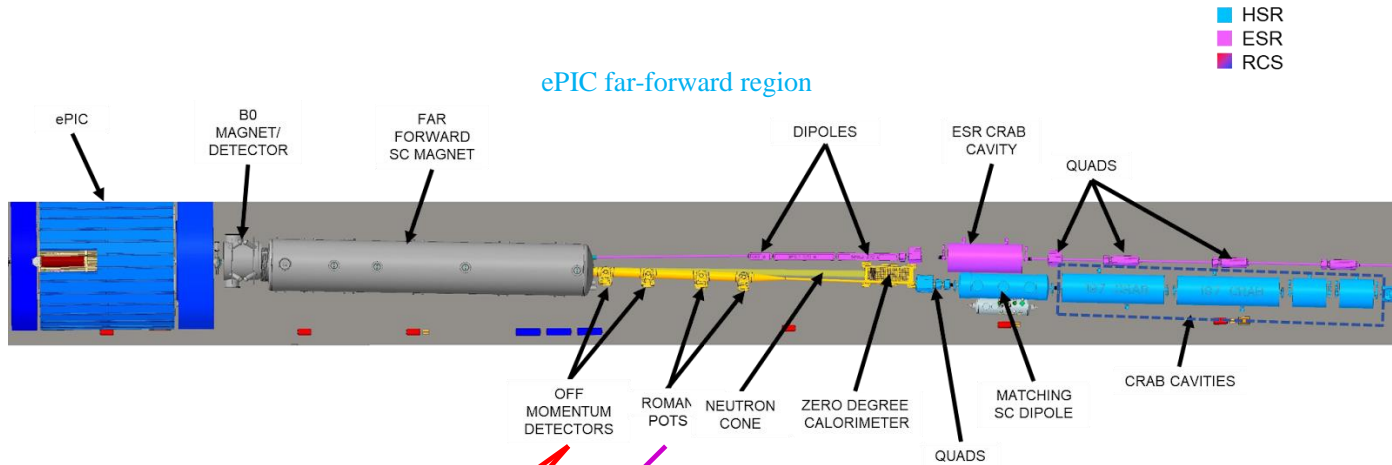
Reasonable S/N ratio for low signals



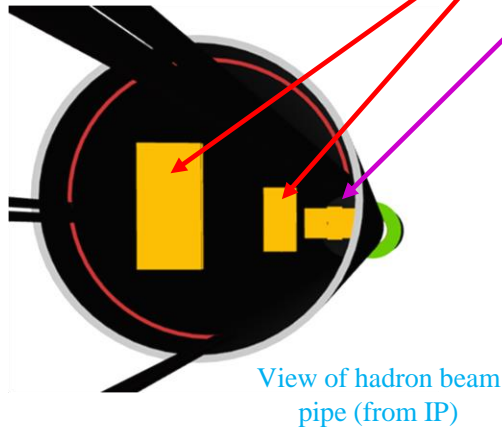
- **Primary goal:**
thermal stability studies
- **Will be fully instrumented** for beam tests:
 - August @ CERN
 - Fall'24 @ DESY (and/or JLab)

Ongoing: readout with HGCROC in collaboration with LLR and OMEGA

ePIC Roman Pots (RP) and Off-Momentum Detectors (OMD)



Conceptual design of a RP station



View of hadron beam pipe (from IP)

- Strong involvement from IJCLab on detector characterization (AC-LGAD sensor + EICROC ASIC)
- Contributions to mechanics under discussion:
 - Cooling
 - Support/insertion system
 - Possible extension to OMD (exact same sensor and ASIC)

Design and characterization of a large size ASIC (32x32 pads), EICROC, optimized to read out pixelated AC-LGADs sensors

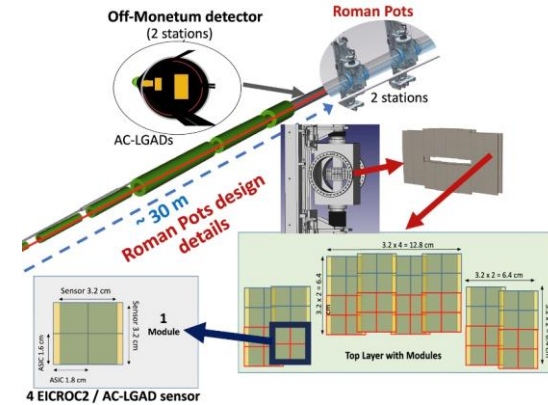
(Low Gain Avalanche Diode coupled AC) – R&T IN2P3, 2023-2025

First intention: for the Roman Pots (far-forward detectors), essential for exclusive processes (e.g. DVCS)

Goal: to achieve ~20 ps time resolution & ~20 mm spatial resolution

Requirements for the ASIC:

- pixel size **0.5 x 0.5 mm²** (HGTD 1.3x1.3 mm²), 7x smaller
- low power consumption < **1 mW/channel** (in vacuum)
- low jitter ~ **20 ps**
- low noise ~ **1 mV/channel**
- sensitivity to low charge (**2 fC**) (charge sharing)



Collaboration/synergy:



- JLab-EIC,
- ATLAS/HGTD (L. Serin)



TDC

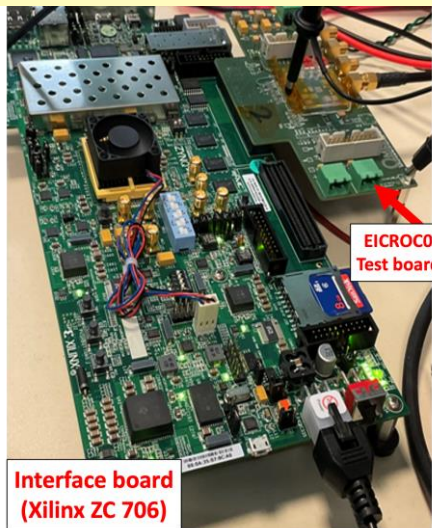


Strategy: Stepping up through successive ASIC iterations to control performances and fulfill detector requirements

➤ **EICROC0 prototype** (16 channels; 4 x 4): under test since March '23

EICROC0 1st prototype (4x4 pads) characterization

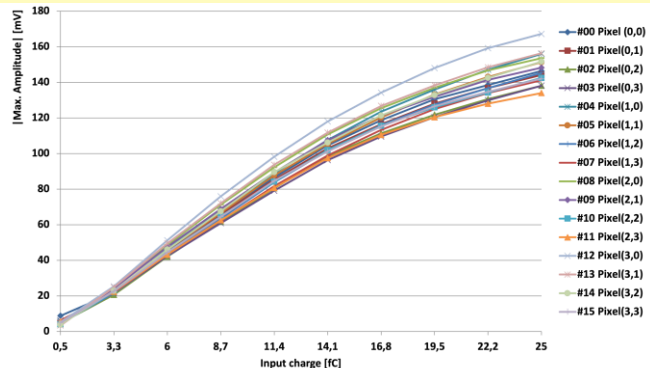
EICROC0 testbench



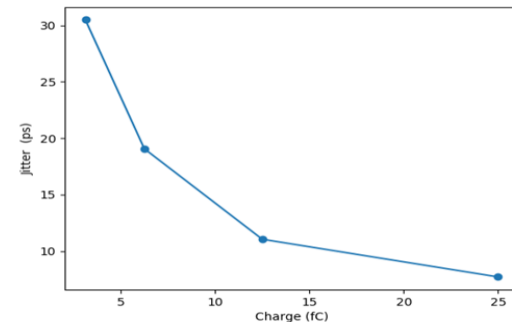
EICROC0
Test board

Interface board
(Xilinx ZC 706)

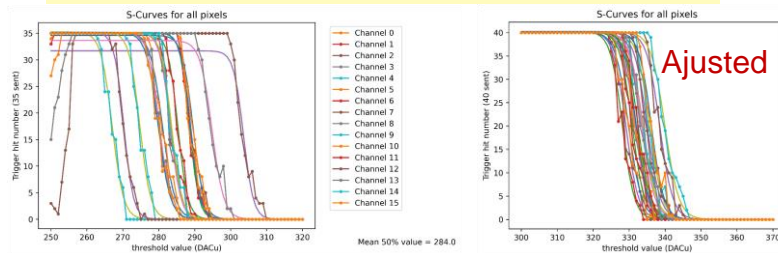
Probe PA Max. Ampl. | vs injected charge (16 channels)



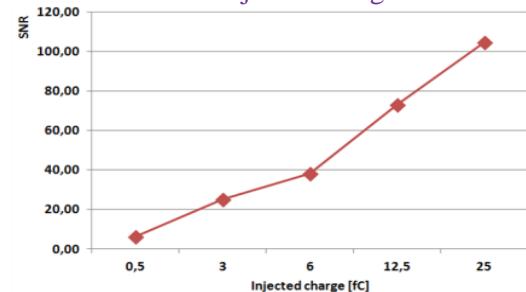
Probe PA jitter vs injected charge



Discriminator efficiency (S-Curves) vs threshold



Probe PA Signal-to-Noise Ratio vs injected charge



Status:

- Individually each component shows performance in agreement with design
- Investigation of noise/clock coupling issues ongoing mandatory to drive next ASIC iteration

Perspectives:

- Characterization with an updated PCB (starting)
- EICROC0A (8x32) & EICROC1 (4x4 + low-power ADC) Submission in Fall 24

Ressources humaines JLab/EIC

6 permanents: R. Dupré, M. Hoballah, D. Marchand, C. Munoz-Camacho, S. Niccolai, E. Voutier

1 post-doctorant:

- L. Xu, section efficace du nDVCS, financement IN2P3 (S. Niccolai), fin contrat octobre 2025

4 doctorants:

- N. Pilleux, 3^{ème} année, analyse nDVCS@CLAS12 avec cible polarisée (S. Niccolai) + Calo EIC (C. Munoz-Camacho), Bourse ED
- H. Huang, 1^{ère} année, expérience NPS@Hall C (C. Munoz), financement Taiwan (NCKU)
- J.S. Alvarado Galeano, 2^{ème} année, analyse données CLAS12 pDVCS + phénoménologie du double DVCS (E. Voutier, M. Hoballah), Bourse ED
- D. Matamoros, 2^{ème} année, analyse données CLAS12 sur cibles nucléaires (R. Dupré), ERC Partonic Nucleus

Stages en cours/imminents:

- F. Touchte-Codjo (M2), préparation expérience ALERT (R. Dupré)
- C. Marechal (M1), caractérisation EICROC0 (D. Marchand)
- Tobias Staub (M1), projet TBD

Soutenances:

- S. Habet, 12/2024 (E. Voutier)
- M. Ouillon, 4/2024 (R. Dupré)
- N. Pilleux, 10/2024 (S. Niccolai & C. Munoz)

Publications majeures and conférences (1/1/2023-aujourd'hui)

Publications avec une forte implication de l'équipe JLab/EIC:

Design, construction, and performance of the GEM based radial time projection chamber for the BONuS12 experiment with CLAS12, I. Albayrak et al. Nucl. Instrum. Meth. A 1062 (2024) 169190

First Measurement of A Electroproduction off Nuclei in the Current and Target Fragmentation Regions, T. Chetry et al. Phys. Rev. Lett. 130 (2023) 14, 142301

Detector requirements and simulation results for the EIC exclusive, diffractive and tagging physics program using the ECCE detector concept, A. Bylinkin et al., Nucl. Instrum. Meth. A 1052 (2023), 168238

+ ~25 articles de collaboration (CLAS, Hall-A, EIC, HPS,...)

Présentations données en conférences/workshops internationaux et nationaux par membres du groupe JLab/EIC:

- 4th International Workshop on Quantitative Challenges in Short-Range Correlations and the EMC Effect Research, Saclay, France
- International workshop on CLAS12 physics and future perspectives at JLab, Paris, France
- Electron-Nuclei Interaction at EIC, Stony Brook University, USA
- Short-Distance nuclear structure and PDFs, Trento, Italy
- REVESTRUCTURE Workshop, Zagreb, Croatia
- 15th European Research Conference on Electromagnetic Interactions with Nucleons and Nuclei, Paphos, Cyprus
- 25th International Spin Symposium (SPIN2023), Durham (NC), USA
- 31st International Workshop on Deep Inelastic Scattering (DIS2024), Grenoble, France
- International Workshop on Hadron Structure and Spectroscopy 2023, Prague, Czechia

Organisation de conférences/workshops:

- Joint meeting of the "Proton Radius European Network" (PREN 2023) and the "Muonic Atom Spectroscopy Theory Initiative" (μ ASTI), Johannes Gutenberg University Mainz
- GDR QCD « From hadronic structure to heavy Ion collisions » international summer school, IJCLab
- International workshop on CLAS12 physics and future perspectives at JLab, Paris
- "IPN Historic Site of EPS", IJCLab
- 31st International Workshop on Deep Inelastic Scattering (DIS2024), Grenoble, France

Ressources financières

- Bourses ED pour doctorants (N. Pilleux, J.S. Alvarado Galeano)
- ERC Partonic Nucleus, Starting Grant (R. Dupré) : 1.4 M€ (2018-2024)
- STRONG 2020, porte-paroles de 3 WP:
 - WP23 (GPD-ACT, S. Niccolai): 50 k€, utilisés pour ~1 an de post-doc de M. Hoballah; 5 k€ de missions
 - WP15 (PREN, D. Marchand) 22 k€ de missions + 39 k€ personnel utilisés pour Mariam Atoui (post-doc), 01/12/22-31/08/2023.
 - WP31 (P3E, E. Voutier): tout utilisé pour le post-doc de A. Ushkarov
- Gluodynamics - P2IO (C. Munoz), 55 k€, post-doc de Y. Zhu
- R&D EIC – DOE (C. Munoz): 151 k\$ (2015-présent)
- P2IO R&D EIC AC-LGAD 75k€ (IJCLab 65 k€, C. Munoz)
- R&T IN2P3 (C. Munoz): SiPM readout of PbWO crystals, 2024 (40 k€)
- R&T IN2P3 (D. Marchand): EICROC (Read out of AC-LGADs), 2023-2025 (20 k€/year)
- Univ. Paris-Saclay/P2I (D. Marchand): Projet ELLE (Effort pour la Lecture d'AC-LGADs pour EIC) ⇔ 1 year post-doc (60 k€), 2023, Arzo Sharma, 01/07/24 - 30/06/25.
- PROBES (S. Niccolai), financement Marie-Curie EU pour missions de longue durée à JLab: 16 k€/an, 2022-2026
- Thèses en cotutelle et/ou co-financement: Taiwan (P.K. Wang)

Rayonnement et autres responsabilités

Responsabilités autres que dans les projets : laboratoire, université, site :

- Chair de la CLAS Collaboration (fini à septembre 2023)
- Chair du Jefferson Lab Users Group Board of Directors
- Directeur GDR QCD
- Co-convenir GDR QCD WP1 « Simple & Multiple Parton Scatterings »
- EPJA, associate editor

Participation à l'évaluation de projets (Europe, ANR, autres), aux comités internationaux :

- Membre du Board du Nuclear Physics Division du EPS, responsable de la communication (e-EPS) (fini à décembre 2023)
- Membre du LHCC au CERN, « head referee » pour CMS
- Membre du "Machine Advisory Committee de MESA" (Mainz Energy-recovering Superconducting Accelerator)
- Convenir et membres de WG pour la rédaction du Long Range Plan de Nupecc

Coopérations spécifiques (locales, internationales) :

- JLab: Halls A, B, C
- R&D calorimétrie pour EIC: collaboration BNL, CUA, INFN, CalTech
- R&D AC-LGAD: OMEGA, Irfu, BNL
- Allocation de ressources de IJCLab sur la grille de computing pour la CLAS Collaboration
- CIS (Center for Injectors and Sources) de JLab
- Université de Hamburg et l'Université de Mayence au sein du WP P3E de STRONG-2020
- Nombreuses autres universités au sein du PWG (Positron Working Group) de Jefferson Lab (~250 personnes, 75 Institutions)
- NREC (Nuclear Radii Extraction Collaboration)

Activité d'enseignement/pédagogie :

- Cours sur « Deep exclusive reactions » à l'école d'été de JLab « HUGS »
- Membre du comité scientifique / organisation des "Rencontres de l'infiniment grand à l'infiniment petit", financement P2IO avec soutien de l'IN2P3, IJCLab, APC, IAS, LLR, des universités d'Ile-de-France (Paris-Saclay, Paris Cité), CEA/Irfu et Ecole Polytechnique.
- Contribution à la réalisation d'un film dédié aux activités de recherche sur le proton (financement P2I, IJCLab, CEA/Irfu)

Summary

The JLab/EIC team focuses on **nucleon structure studies**, mainly aiming to GPDs:

- **JLab@12 GeV**: ideal facility in the **valence-quarks** regime
- **EIC**: ideal facility in the **gluon** regime
- ✓ Several **results** are coming out of the analysis of JLab@12 GeV experiments
- ✓ Detector projects for JLab: **NPS** (experiment finishing), **ALERT** (experiment upcoming)
- ✓ Ongoing studies for a **polarized positrons beam** for JLab
- ✓ Data takings and analyses of JLab data planned for the next ~ 10 years
- ✓ In parallel, **detector R&D for EIC (calorimeter and Roman Pots)**
- ✓ **EIC operation** foreseen to start in 2034

Expectations/remarks

- Personnel : 1 poste permanent EIC et une thèse
- « Moyens »: continuing support to travels for JLab/EIC