Pixelated AC-LGAD sensors for the Electron-Ion Collider (EIC) Roman Pots: read-out performances with EICROC0_v0 ASIC

Dominique Marchand (presented by Ch. de La Taille)
On behalf of all teams involved

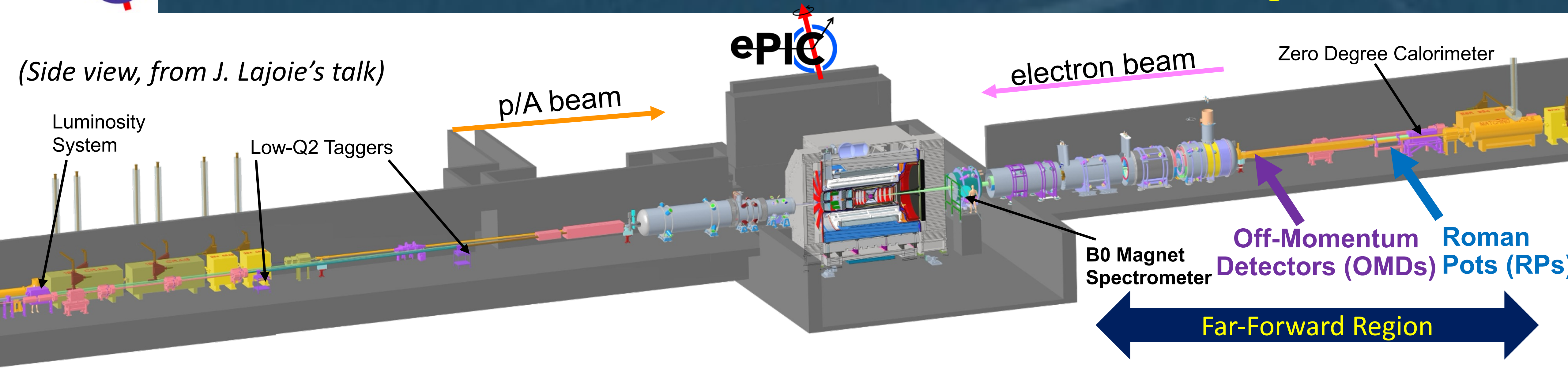
TIPP2026

Outline

- The ePIC Roman Pots: context & requirements
- AC-LGAD read-out characterization:
  - with Beta source
  - with infrared laser
- Schedule and project team
- Conclusion & outlook

ePIC Detectors & Far-Forward Region

(Side view, from J. Lajoie's talk)



Far-Forward detectors are essential to measure exclusive processes, as Deep Virtual Compton Scattering (DVCS) → Generalized Parton Distributions (GPDs)

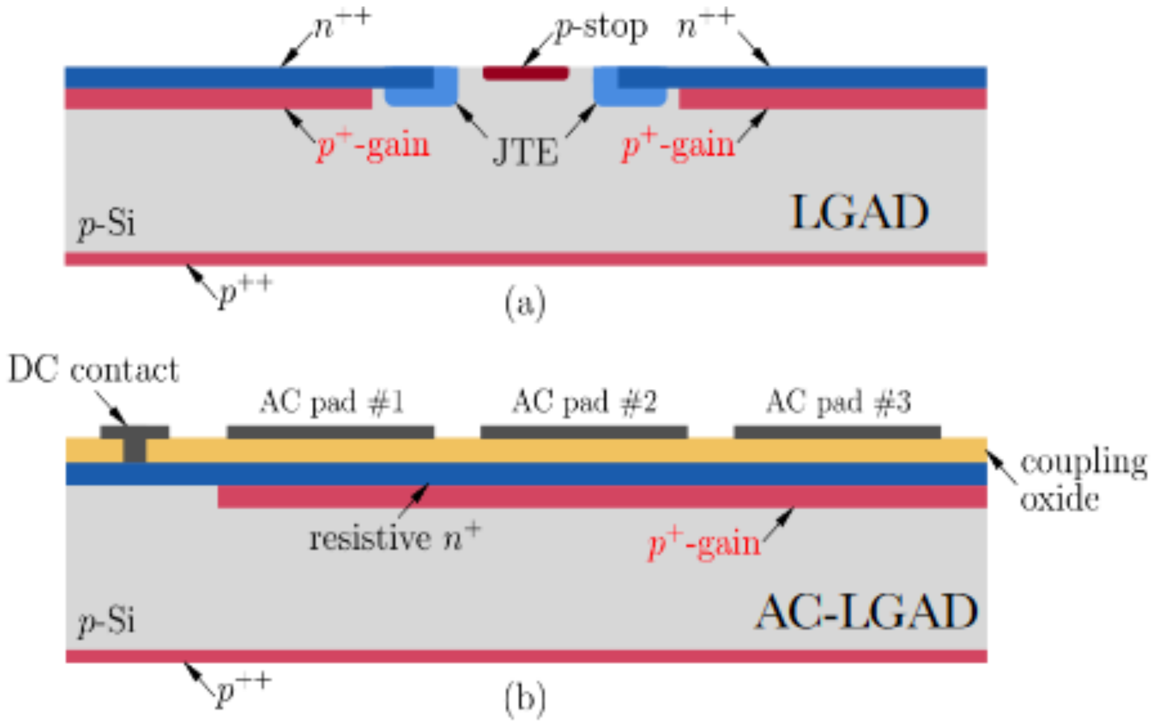
❖ Roman pots (RP)

- Detect particles scattered at very small angle (< 5 mrad)
- Required to measure exlusive processes on proton targets
  - **DVCS, DVMP…**
  - **All the channels relevant to GPDs of quarks and gluons**

❖ Off-Momentum Detectors (OMD)

- Detect small angle particles with a different rigidity than the beam
  - **Access angles down to 0 for rigidity < 0.65**
- Necessary for all tagged measurements
  - **Study of nuclear effects**
  - **Effective neutron target**

Far-Forward Detectors



RPs & OMDs requirements:

- 30 ps Time resolution
- < 50 μm Spatial resolution

Novel generation of Low-Gain Avalanche Diode (LGAD) sensors: « Alternating Current coupled LGAD, referred as AC-LGADs

4D-Tracking

- **Excellent time resolution**, *as LGADs*
- **Very good spatial resolution from charge sharing among neighboring pixels, relying on barycenter computation.**

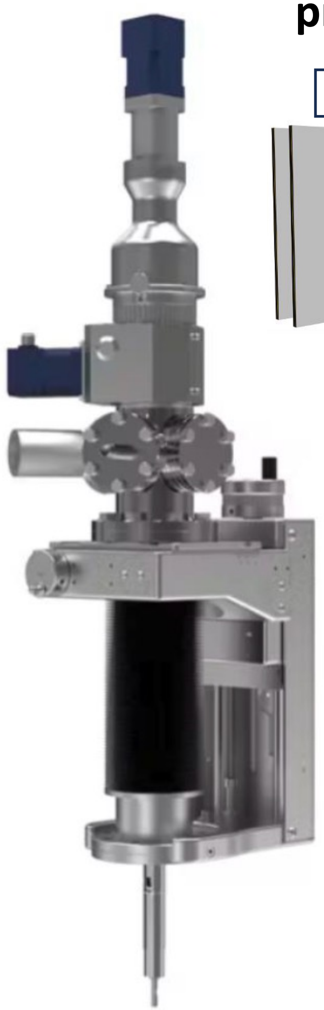
B0 spectrometer, OMDs & Roman Pots will consist of modules of pixelated AC-LGADs, also Forward Time of Flight system

BUT no optimized chip exists yet to read-out pixelated AC-LGADs exploiting their 4D-tracking capabilities

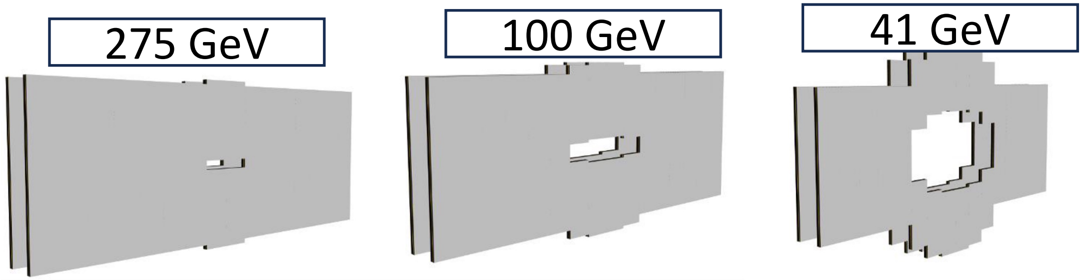
Rationalization of design efforts: all pixelated AC-LGAD to be read-out by the same large scale (32 x 32 channels) ASIC: EICROC (EIC Read-Out Chip)

★ RP AC-LGAD + EICROC mounted on **movable plates and** in **vacuum** ⟷ **Very low power read-out chip + challenging cooling system**

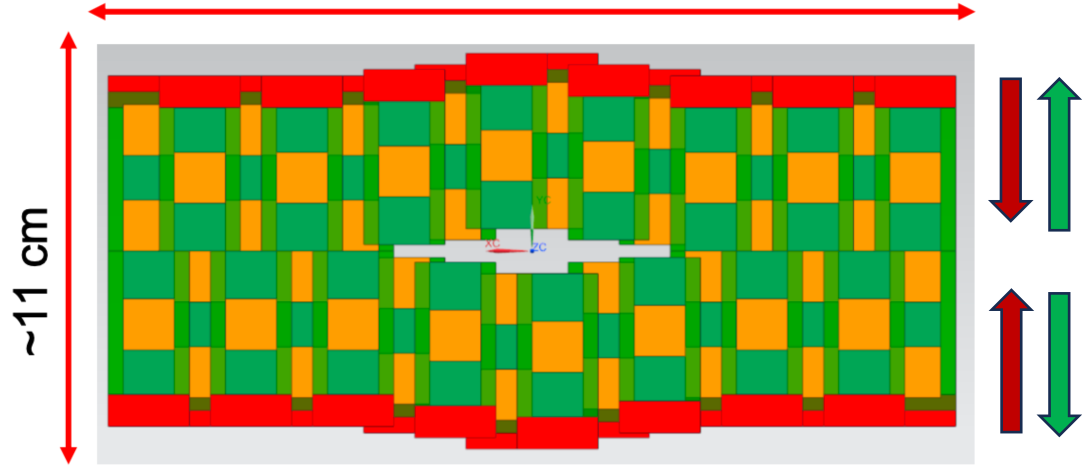
Roman Pots design *(still under development)*



« Aperture » of the RP inversely ∝ dispersion of the scattered proton « beam » versus incoming proton energy



Movable AC-LGAD supports



2 layers staggered composed of 16 modules each to provide full active-area coverage

1 module = AC-LGAD + EICROC bump-bonded

EICROC (32 x 32)

AC-LGAD (32 x 32)

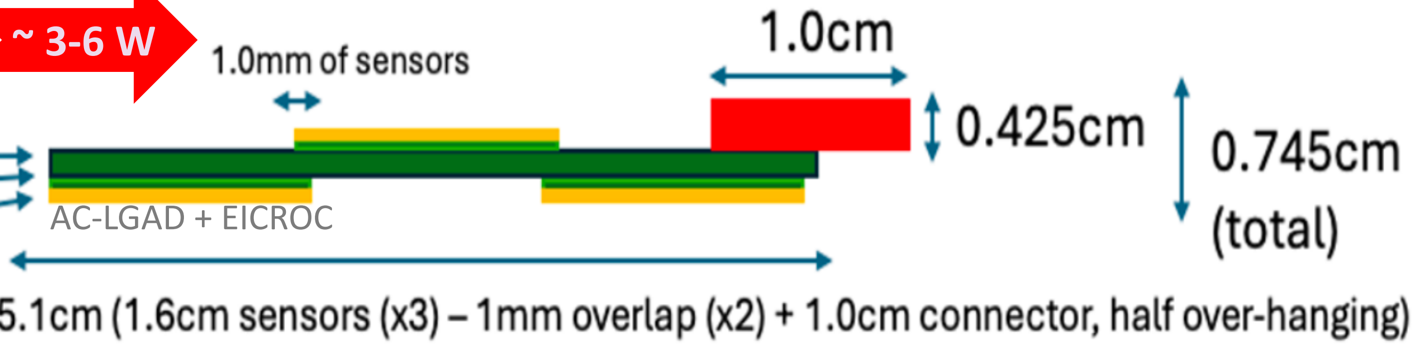
~ 1-2 W

1 stave = 3 modules staggered ~ 3-6 W

PCB: 2.0mm thickness

ASIC: 300um thickness

Sensor: 300um thickness



Pixelated AC-LGAD read-out chip: EICROC

Objective: **Development** and **characterization** of an **ASIC EICROC (32 x 32)** able to read-out the **new generation** of pixelated (**500 x 500 μm²**) silicon sensors: **AC-LGAD** (**A**lternating **C**urrent coupled **L**ow-**G**ain **A**valanche **D**iode) for the **Electron Ion Collider** (EIC)

Target: optimized for the ePIC **Roman Pots (RP)**, as first intention (most demanding)

Pixelated AC-LGADs ↔ low input capacitance: 1-5 pF

RP AC-LGAD read-out chip requirements:

- **30 ps time resolution**
- **< 50 μm spatial resolution exploiting charge sharing among neighboring pixels**
  → low charge sensitivity (~3 fC)
- **low power consumption (< 1 mW/channel) as placed inside vacuum**
- **low noise (< 1 mV)**

Pads of 500 x 500 μm²

Stepping up process through successive ASIC iterations to control performances fulfilling ePIC detector requirements

EICROC iterations being designed by OMEGA Microelectronics, cea irfu, LPC (Laboratoire de Physique de Clermont)

(contribution from AGH Krakow for **EICROC0** and **EICROC1** ADCs)

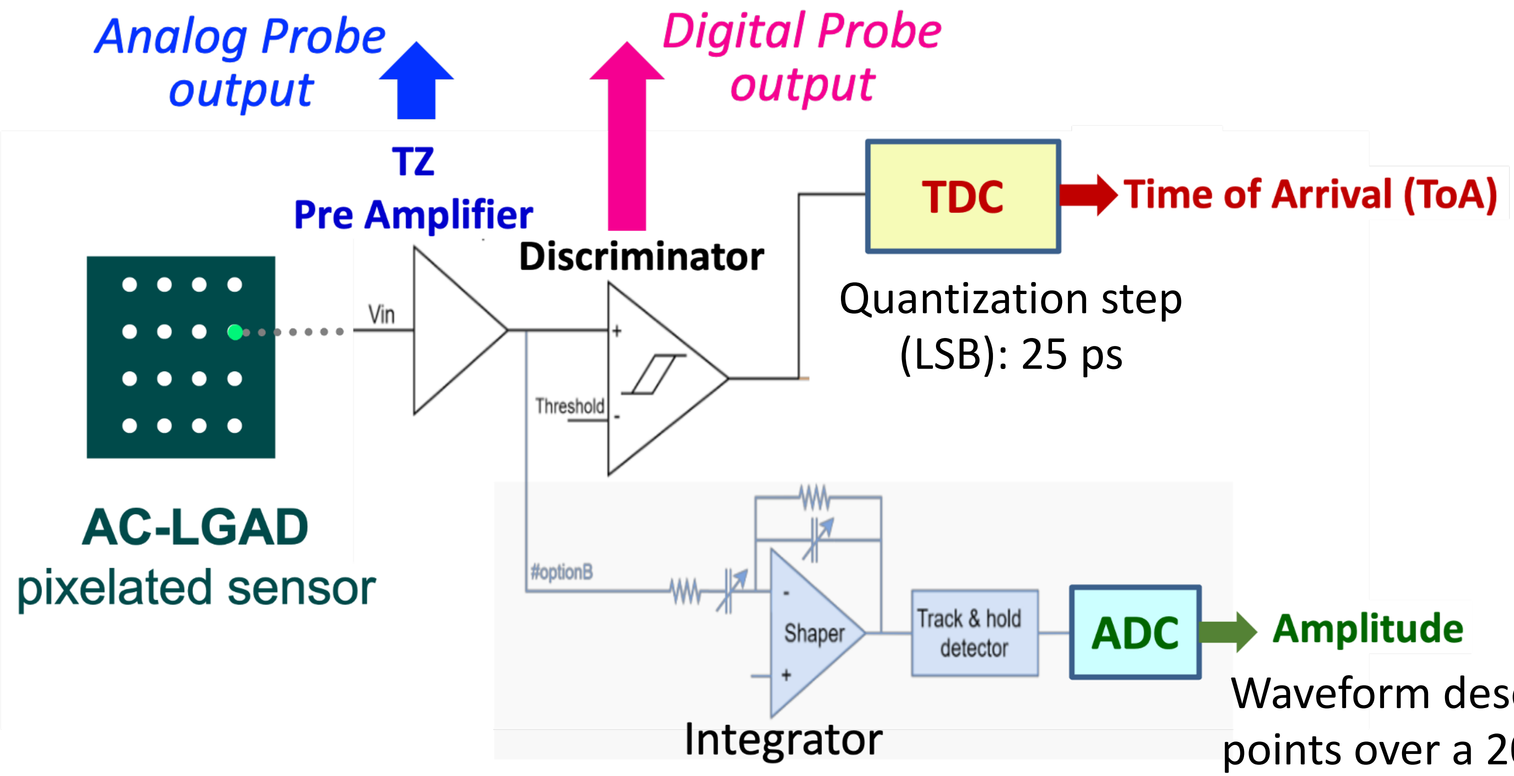
1st EICROC prototype under test: **EICROC0** (4 x 4 channels)

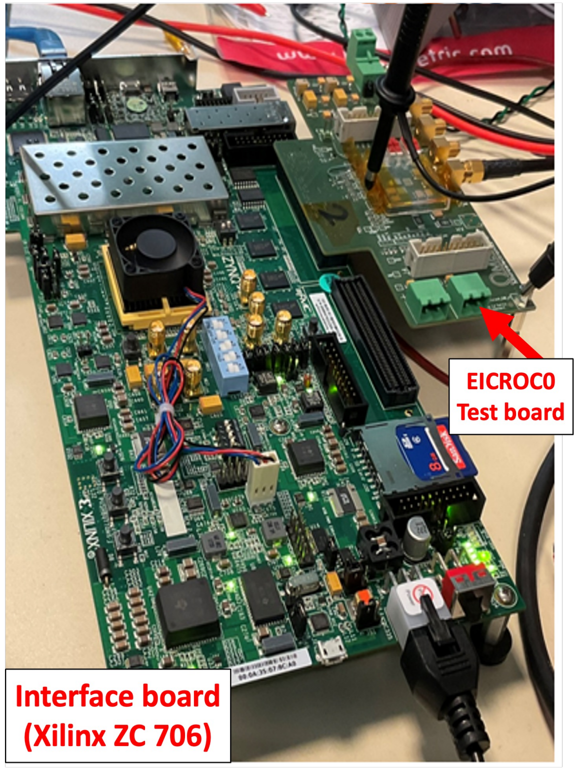
EICROC2 (32x32)

This work is benefitting from support from the French Agence Nationale de la Recherche (ANR), under grant ANR-24-CE31-5571 (project ROAD_4_EIC, 02/2025 – 01/2029)

EICROC0 (4x4): 1st EICROC prototype under test since 2024

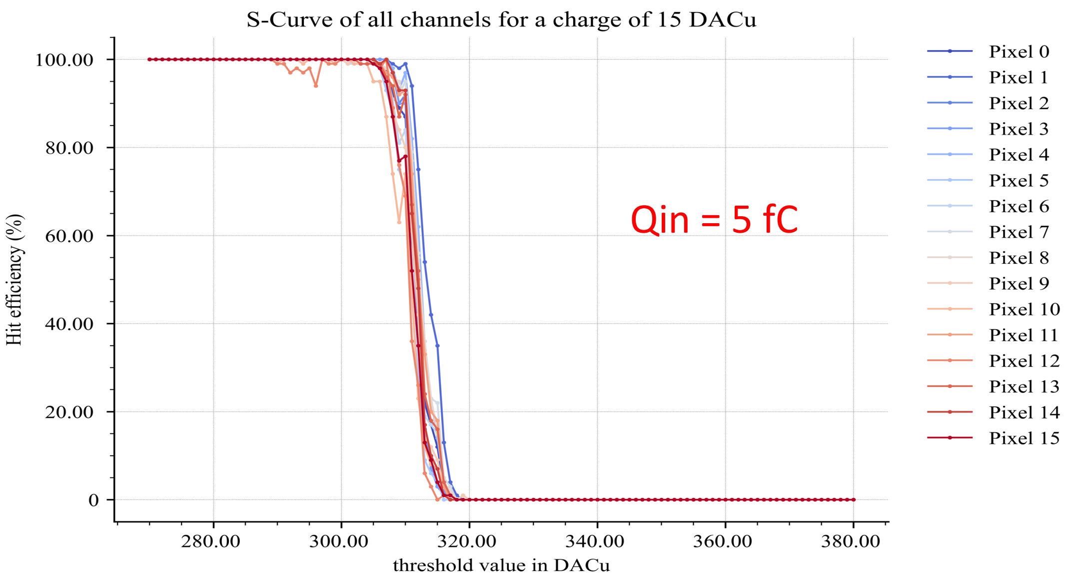
1 channel (1 pixel) schematics

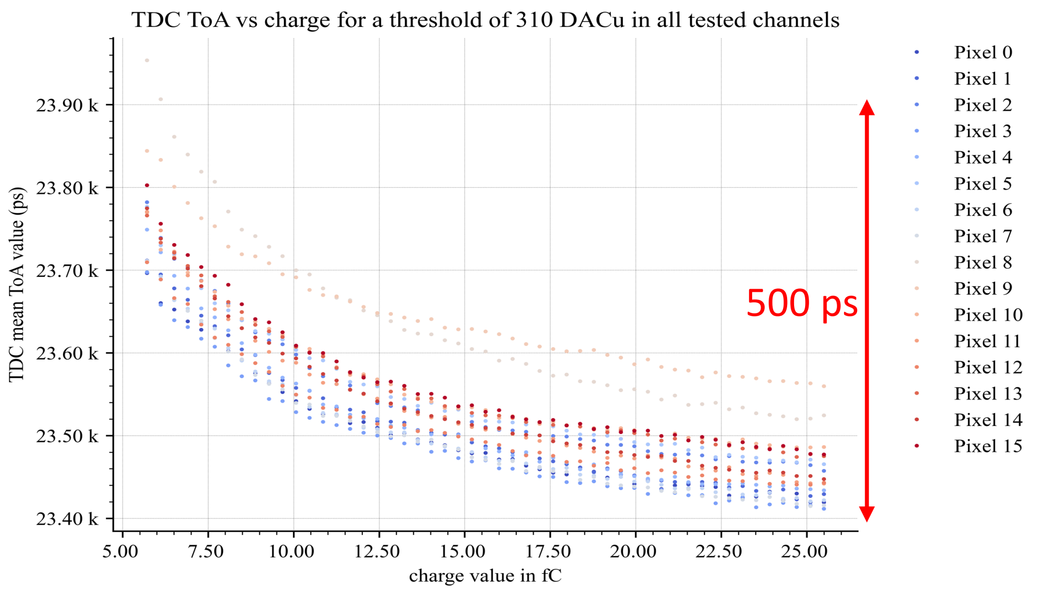


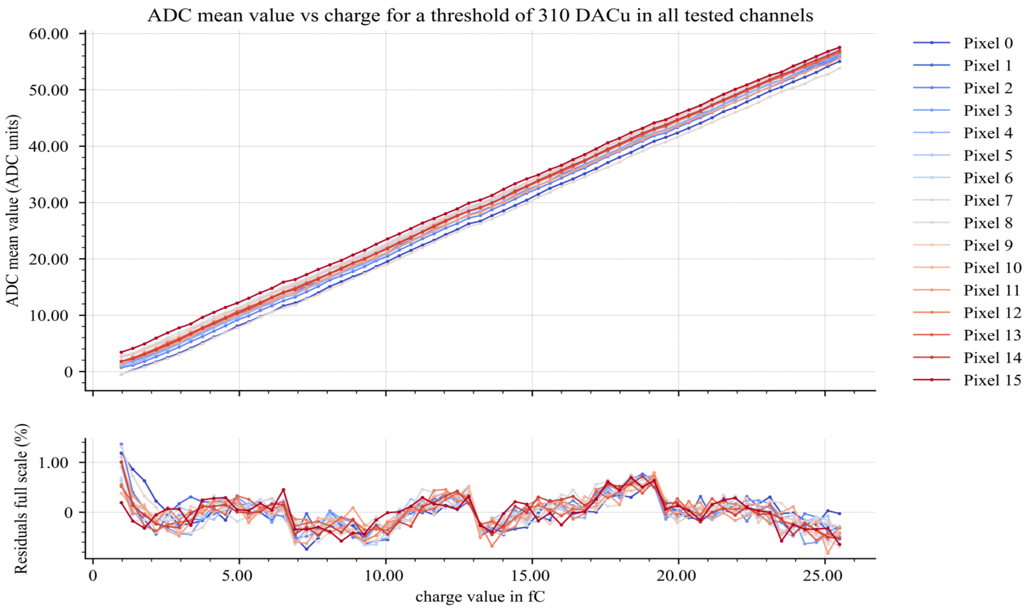


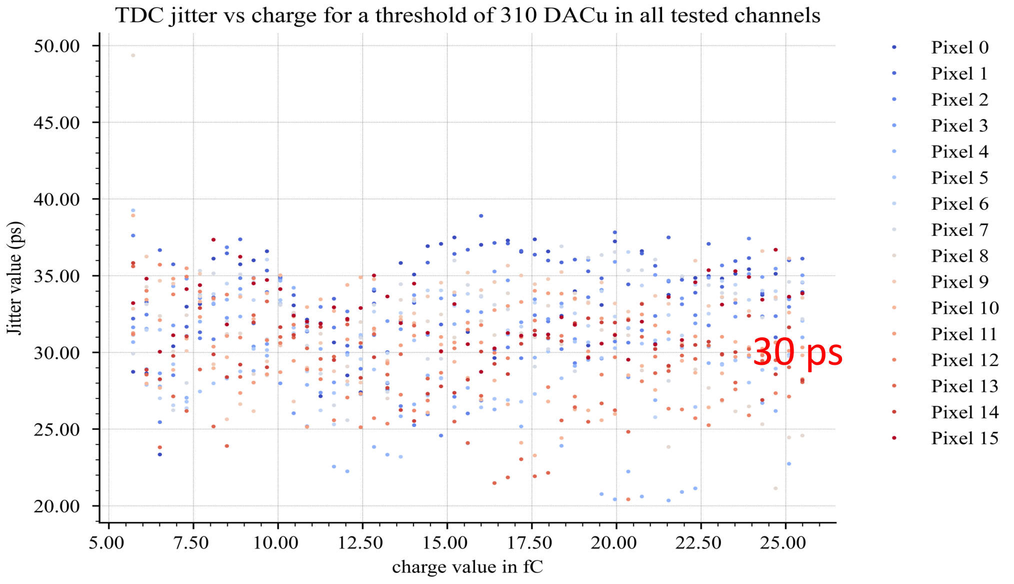
- **2024:**
  - ➢ ASIC alone evaluation (PreAmplifier output signals, ADC & TDC responses)
  - ➢ EICROC0 + AC-LGAD (wire/bump-bonded): Beta source measurements exploiting analog Probe PreAmp signal output (oscilloscope)
- **2025:** EICROC0 + AC-LGAD **(ADC & TDC data)** ⇒ Measurements with **Beta source** & **infrared laser**

EICROC0 (4x4): ASIC alone characterisation





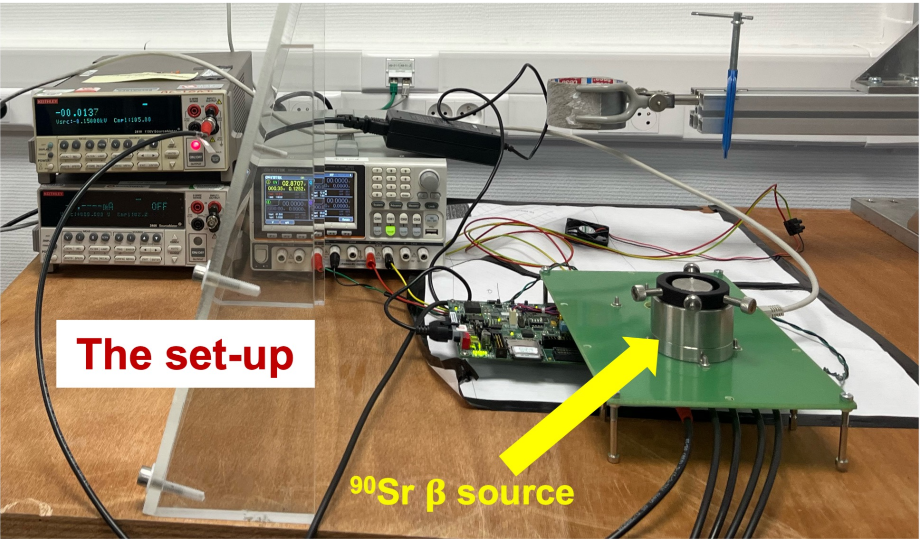




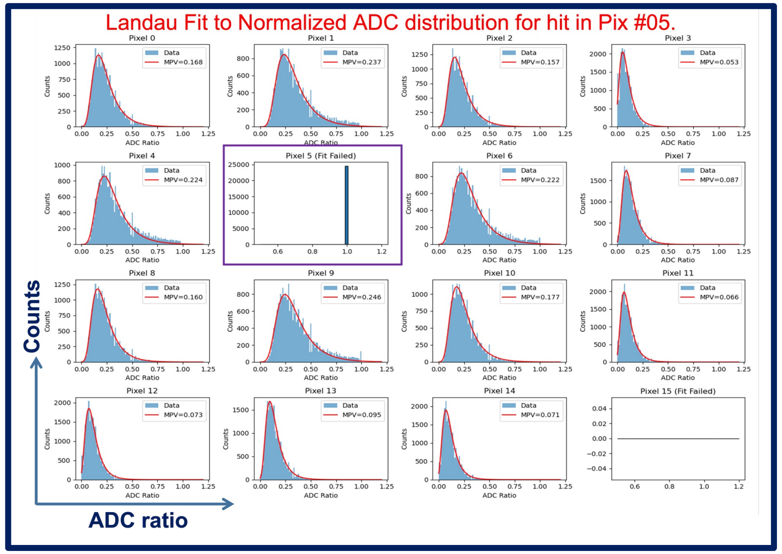
Pixelated AC-LGAD read-out characterization

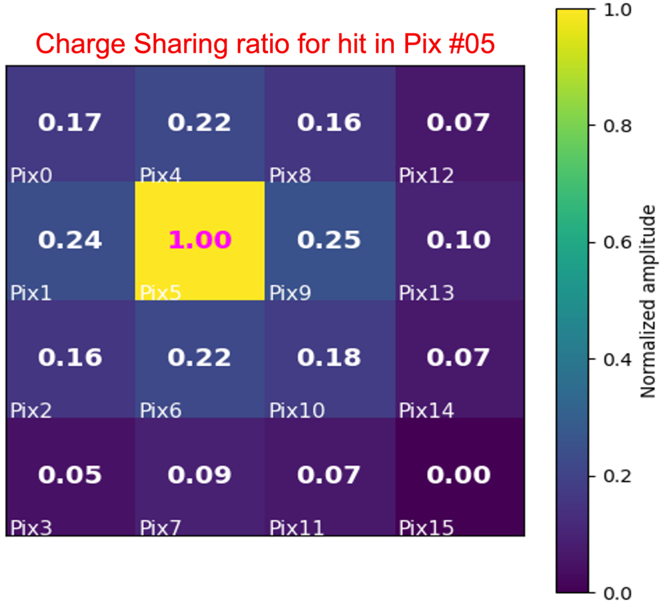
Measurements with ^{90}Sr β source at IJCLab PSI platform (July '25)

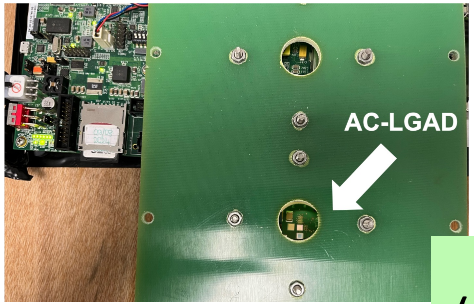
1) digital data stored when the PreAmp signal amplitude of at least 1 channel among the 16 is passing the discriminator threshold
2) long run (~ 10 hours) splitting data into multiple files with r fixed number of events/file

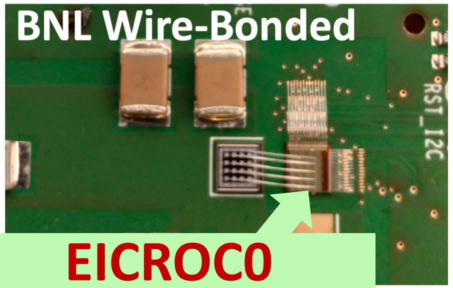


From ADC data

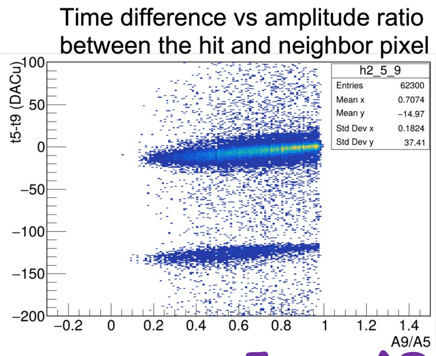


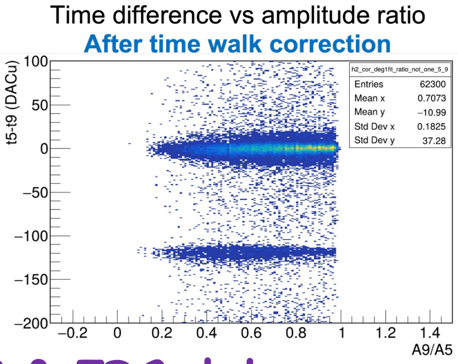






EICROC0
(4 x 4 channels)
CMOS 130 nm



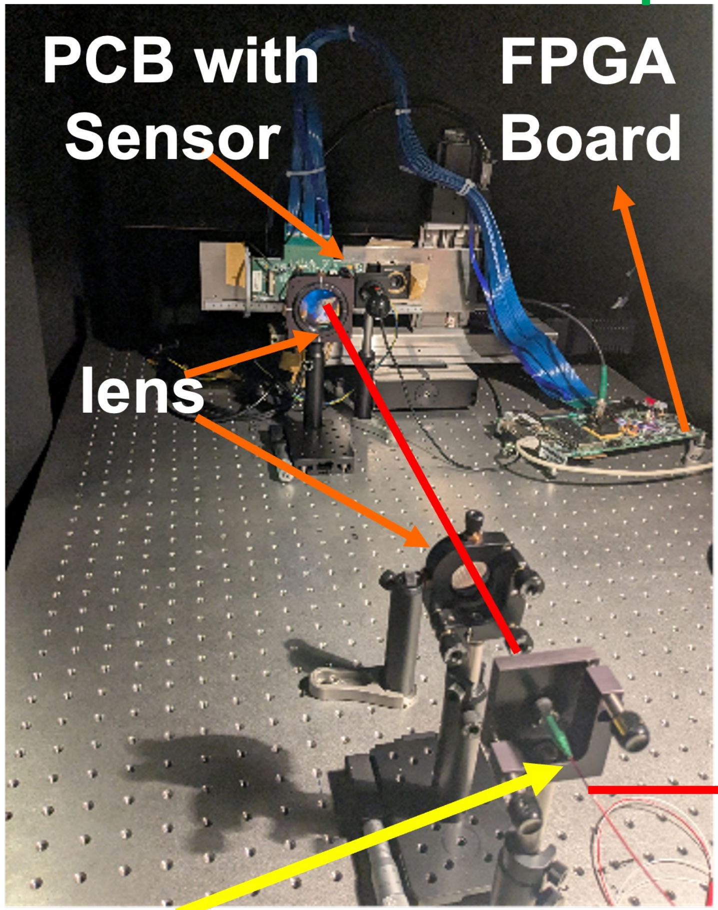


From ADC & TDC data

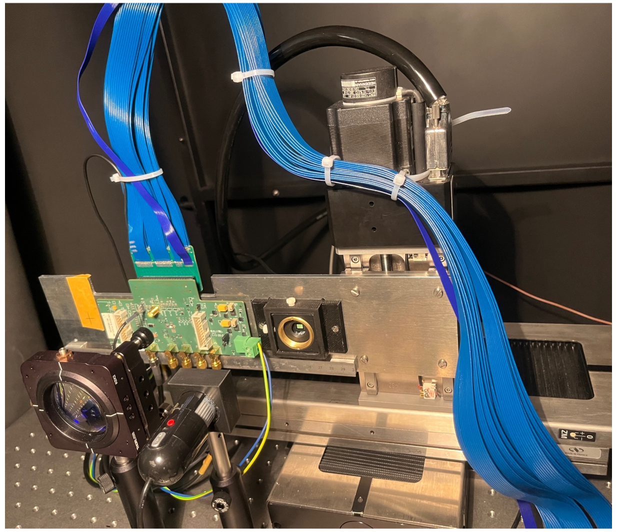
- ADC pedestal subtraction computed from "far" pixel
- More charge sharing (~23%) for adjacent neighbors
- Time walk correction applied successfully to TDC data

Pixelated AC-LGAD read-out characterization With Infrared Laser: The setup

Operational since end of Summer 2025



Pulsed Infrared laser λ 1056 nm



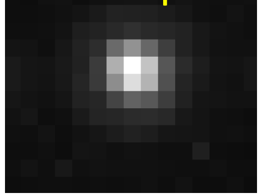
Viewed by a numerical microscope

Focal point

NKT Photonics Diode Laser

- 1056.4 ± 7.4 nm
- 7 nW av. Power
- 150 mW peak intensity
- 0 – 40 MHz
- 35 ps pulse width (FWHM)
- Jitter RMS = 10.8 ps
- Fiber MFD: 5.3 – 6.4 µm @ 980 nm

Laser spot



With CMOS camera

- Clean spot
- $\phi \lesssim 20$ µm (CMOS pixel = 3.75 µm)

A.-S. Torrento, O. Brand-Foissac, V. Chaumat, T. Cornet, D. Hohov, B.-Y. Ky, A. Sharma, D. Marchand, L. Serin

Pixelated AC-LGAD read-out characterization
Preliminary results with Infrared Laser

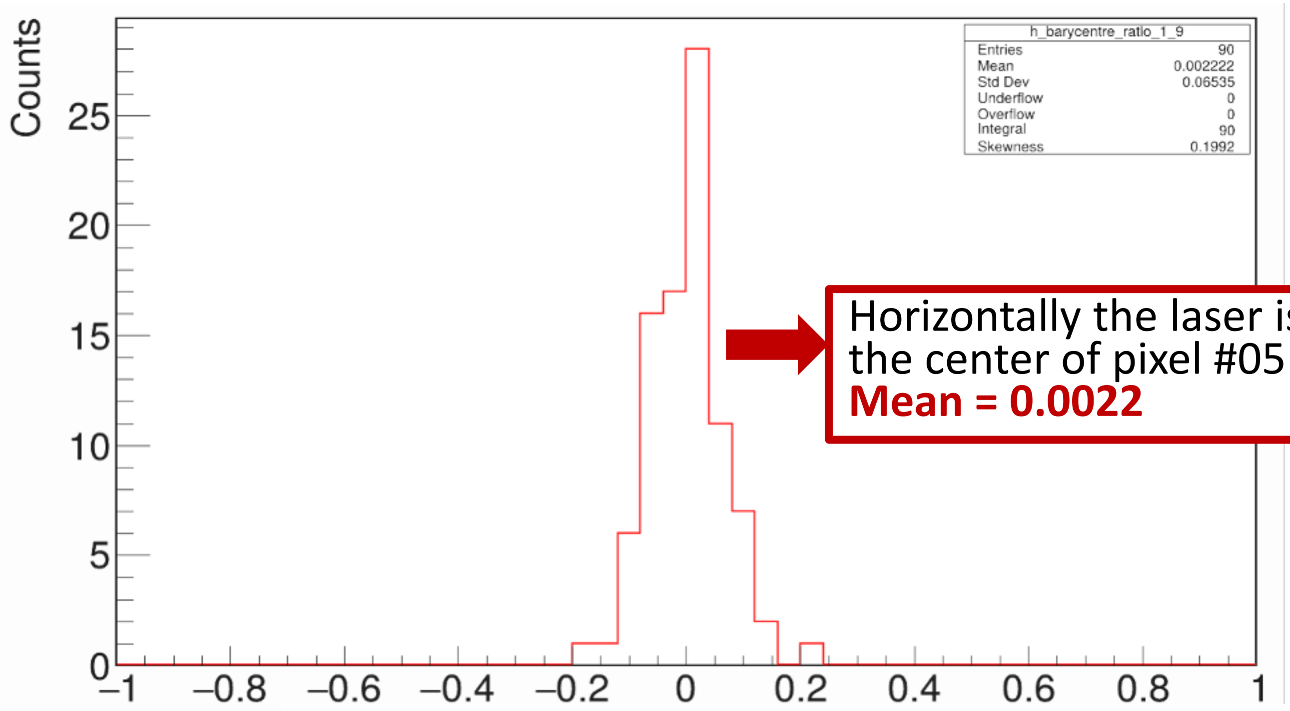
Barycenter calculation from ADC data (Sept. 18, 2025)

Considering pixels **#01, #05 & #09**

Pixel / Channel Mapping	Column 0	Column 1	Column 2	Column 3
Line 0	Pixel (**0**,0) **#00**	Pixel (**1**,0) **#04**	Pixel (**2**,0) **#08**	Pixel (**3**,0) **#12**
Line 1	Pixel (**0**,1) **#01**	Pixel (**1**,1) **#05**	Pixel (**2**,1) **#09**	Pixel (**3**,1) **#13**
Line 2	Pixel (**0**,2) **#02**	Pixel (**1**,2) **#06**	Pixel (**2**,2) **#10**	Pixel (**3**,2) **#14**
Line 3	Pixel (**0**,3) **#03**	Pixel (**1**,3) **#07**	Pixel (**2**,3) **#11**	Pixel (**3**,3) **#15**

Very encouraging!

Position Accuracy ~ +/- 17 μm
(**RMS 0.065** x 500 μm = 33 μm)



Amplitude Ratio = (A9-A1)/(A1+A5+A9)

Horizontally the laser is shooting the center of pixel #05
Mean = 0.0022

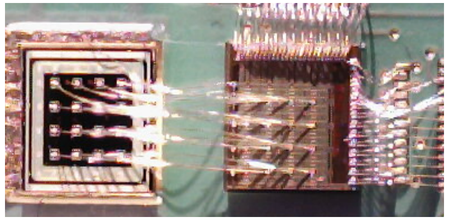
This method to be extended to the whole matrix

Pixelated AC-LGAD read-out characterization
With Infrared Laser (Dec. 19th, 2025)

TDC differences between 2 hit neighboring pixels

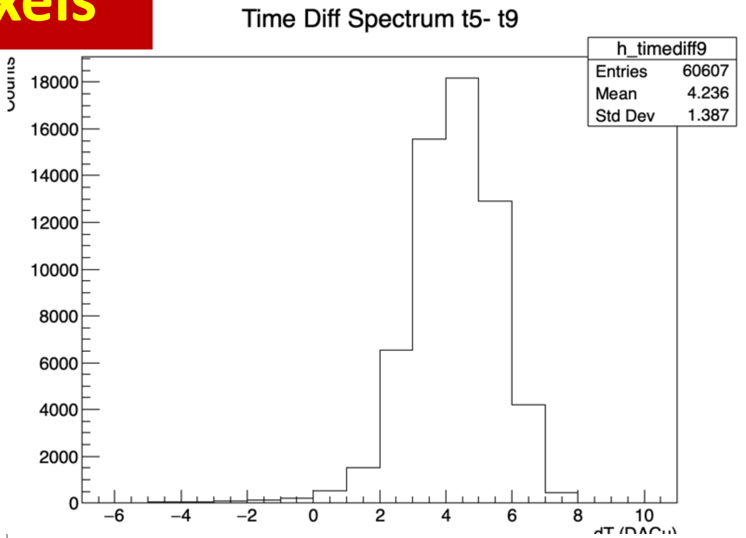
[Assumption: 1 TDC DACu = 25 ps]

Very recent

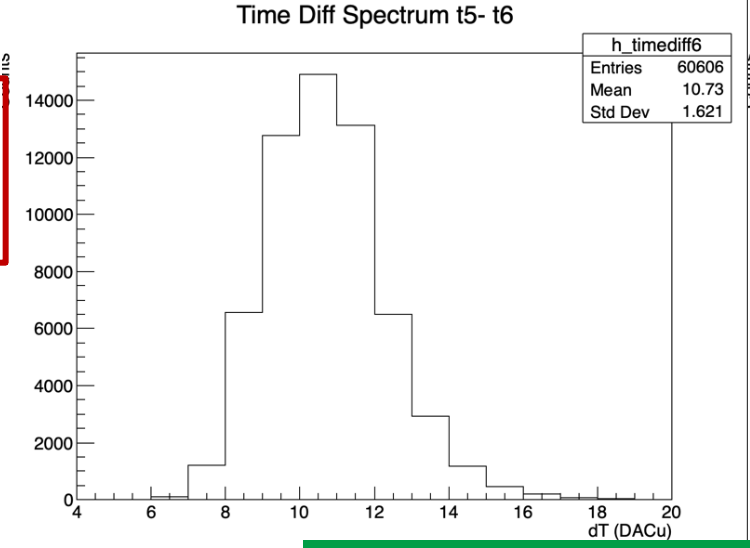


Laser 1 KHz, 77.6% attenuation, ~60 000 evts

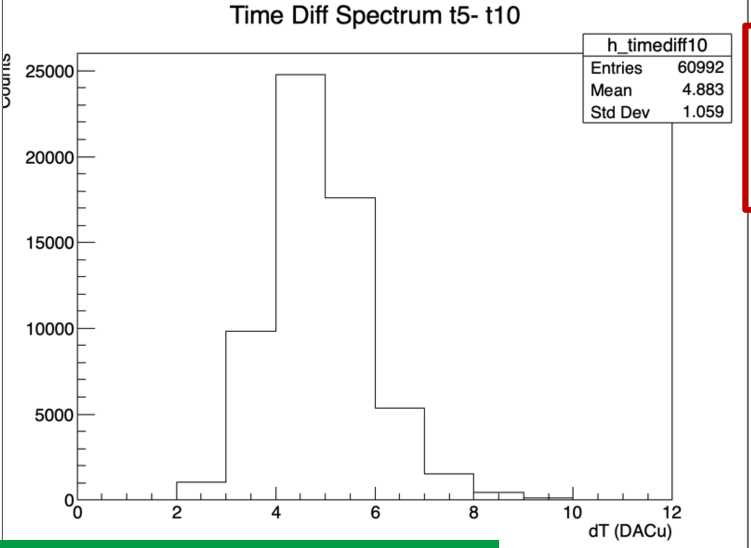
BNL sensor biased at HV = -190V



σ [pix05 – pix09]$_{DACu}$ = 1.387
➜ TDC jitter for individual pixel [= σ / √2]: **24.5 ps**



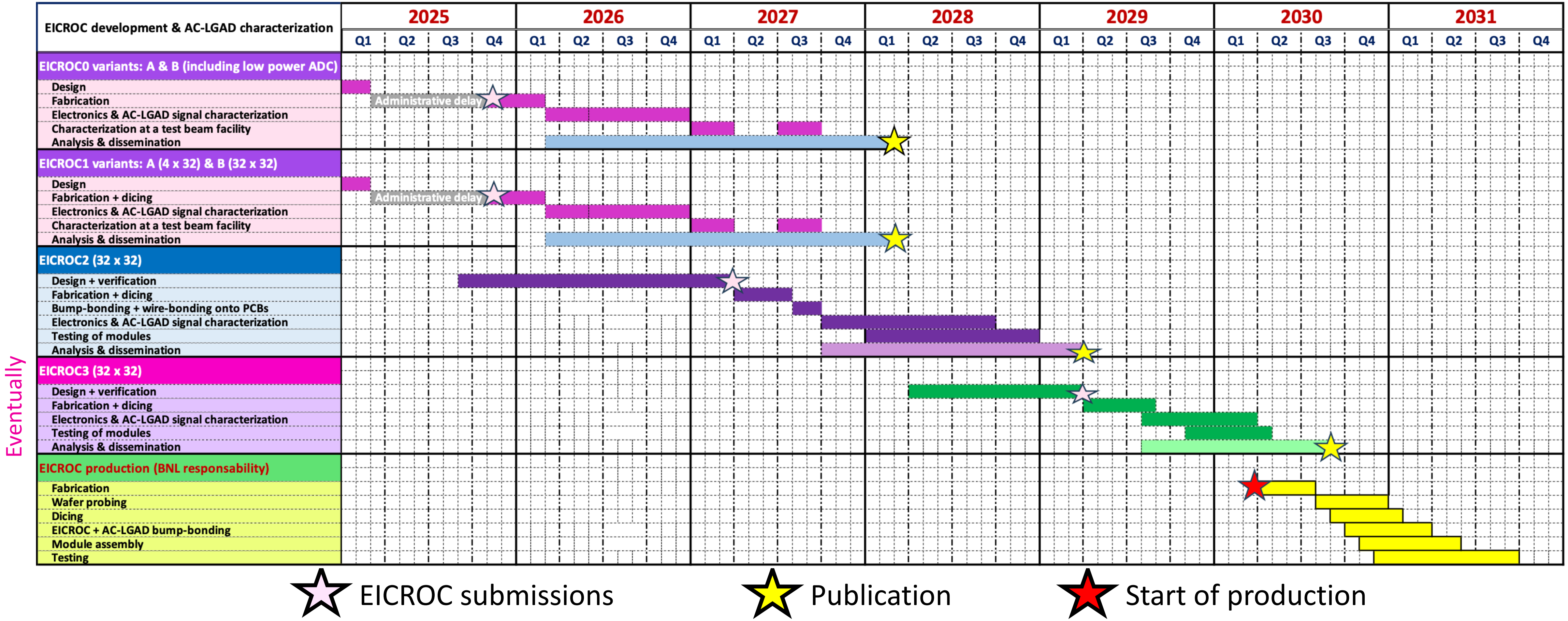
σ [pix05 – pix06]$_{DACu}$ = 1.623
➜ TDC jitter for individual pixel [= σ / √2]: **28.7 ps**



σ [pix05 – pix10]$_{DACu}$ = 1.059
➜ TDC jitter for individual pixel [= σ / √2]: **18.7 ps**

Individual Pixel jitter from 19 ps up to 29 ps

EICROC & AC-LGAD read-out characterization
Timeline



Start of Early Science Program: ~ 2035 ; Roman Pots & OMD installation: not before 2036 → **« On schedule »**

The Team

Roman Pots (& OMD) CNRS/IN2P3 Project
D. Marchand (RS) + O. Brand-Foissac (RT)

WP1 – EICROC Micro-electronics
C. de La Taille

Front-End	C. De La Taille, A. Verplancke
Low power ADC	A. Verplancke
TDC	F. Bouyjou, E. Delagnes
Overall Design & Documentation	C. De La Taille, F. Dulucq, K. Guillossou-Jnaid, N. Seguin-Moreau, L. Serin
PCB	P. Dinaucourt, J. Favre
Firmware / Software	B.-Y. Ky
Data acquisition	F. Dulucq
EICROC2 (32x32) Digital architecture, implementation and verification	N. Arveuf, G. Blanchard, F. Dulucq, H. Chanal, N. Kachkachi, L. Royer, A. Soulier (Resp.)

WP2 – EICROC Characterization
D. Marchand / A.-S. Torrento

ASIC Functionnal Response	O. Brand-Foissac, F. Bouyjou, D. Marchand, K. Guillossou-Jnaid, N. Seguin-Moreau, L. Serin, Post-Doc (2026-2028), A. Verplancke
ASIC + AC-LGAD Functionnal Response	O. Brand-Foissac, K. Guillossou-Jnaid, D. Marchand, N. Seguin-Moreau, L. Serin, Post-Doc (2026-2028), A. Verplancke
Source Beta, IR Laser, Test beam	O. Brand-Foissac, V. Chaumat, T. Cornet, D. Hohov, D. Marchand, L. Serin, Post-Doc (2026-2028), A-S. Torrento
Dissemination	All people involved in WP1 & WP3

WP3 – Roman Pots Mechanics
R. Dupré / C. Le Galliard

Cooling design: heat flow simulation	C. Le Galliard, R. Dupré
Mechanics design	C. Le Galliard
Prototyping	C. Le Galliard, Mechanics workshop
Beam tests	C. Le Galliard, Instrumentation support, Data acquisition support, R. Dupré, D. Marchand
Detector simulation	R. Dupré, Post-Doc (2026-2028), PhD student (2026-2029)
Data analysis	R. Dupré, Post-Doc (2026-2028), PhD student (2026-2029)
Dissemination	All people involved in WP3

WP4 – Management
R.S + R. T. (IJCLab)

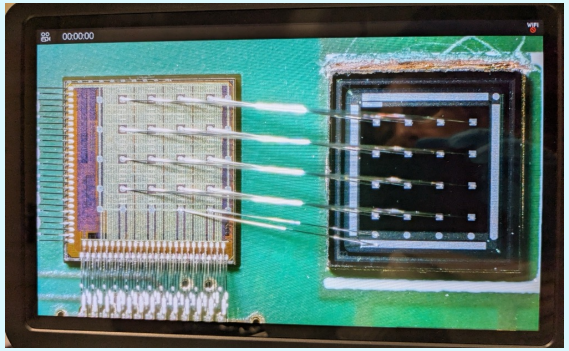
- Project follow-up
- Reporting / Proposals
- Recruitements
- Periodic meetings
- Project documentation: ATRIUM (C. Le Gallaird) https://atrium.in2p3.fr/6928d9e1-303b-430f-aeb0-1d75aa60970d
- Dissemination

Close collaboration with Brookhaven National Laboratory

Scientific leaders: C. De La Taille (OMEGA) , F. Bouyjou (CEA/Irfu/DEDIP), A. Soulier (LPCA), D. Marchand (IJCLab)

Conclusion & Outlook

- ❖ Roman Pots and Off-Momentum Detectors are master pieces for ePIC Physics Program (Exclusive & Tagged processes, ./..)
- ❖ AC-LGAD read-out characterization with **EICROC0**, 1st prototype (4x4) // AC-LGAD
  - ✷ With Beta source (^{90}Sr) at IJCLab PSI:
    - ➢ Preliminary results on charge sharing ratio
    - ➢ TDC values corrected for time-walk
  - ✷ With infrared laser at IJCLab: preliminary results, work on-goig
    - ➢ Measured TDC jitter: from 19 to 29 ps ⇒ within specifications
    - ➢ Position resolution from ADC data: very encouraging results



- ➢ Exploit Beta source & IR laser testbenches with different AC-LGAD sensor configurations (wire-bounded, flipchip) to extract charge sharing ratio, time resolution & position resolution
- ➢ Take part to beam tests
- ➢ Perform AC-LGAD readout characterization with upcoming EICROC iterations
  Characterize **EICROC0A** (4x4) coupled to AC-LGAD - improved testability & TDC tuning
  Characterize **EICROC0B** (4x4) coupled to AC-LGAD – includes a low power ADC
  Testing of **EICROC1** (4x32) and **EICROC1A** (32x32)

Thank you for your attention

आपके ध्यान देने के लिए धन्यवाद!

TIPP2026