LoI:

Characterization & Development of novel Low Gain Avalanche Diode sensors for Nuclear and High Energy Physics

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

HORIZON

European Commission

Dominique Marchand (IJCLab)

On behalf of **Ana-Sofia Torrentó**

(IJCLab, ana.torrento@ijclab.in2p3.fr)

& all involved collaborators

Nantes

01 - 03/07/25

IJCLab Irène Joliot-Curie Laboratoire de Physique

LPNHE PARIS

Universität Zürich[UZH]

Context & motivation

CD_nLGAD_NuHEP

Collider experiments

Time

~2029

~2035

High Luminosity Large Hadron Collider (HL-LHC)

14 TeV protons

10 x $\mathcal{L}_{LHC}$

Electron Ion Collider (EIC)

10:18 GeV electrons

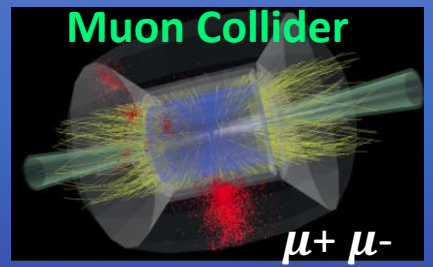
275 GeV protons // ions

Approved & under construction

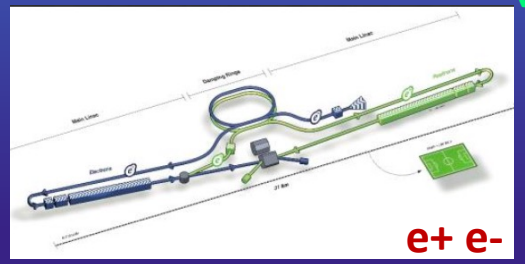
Future Circular Collider

100 TeV protons

Muon Collider



International Linear Collider (ILC)



Planned facilities

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All these experiments (high luminosity & high intensity) require

- 4D- Tracking detectors
  10-30 ps timing resolution
  10-20 μm spatial resolution
- radiation hard detectors
  up to 10^{16} n_{eq}/cm^2

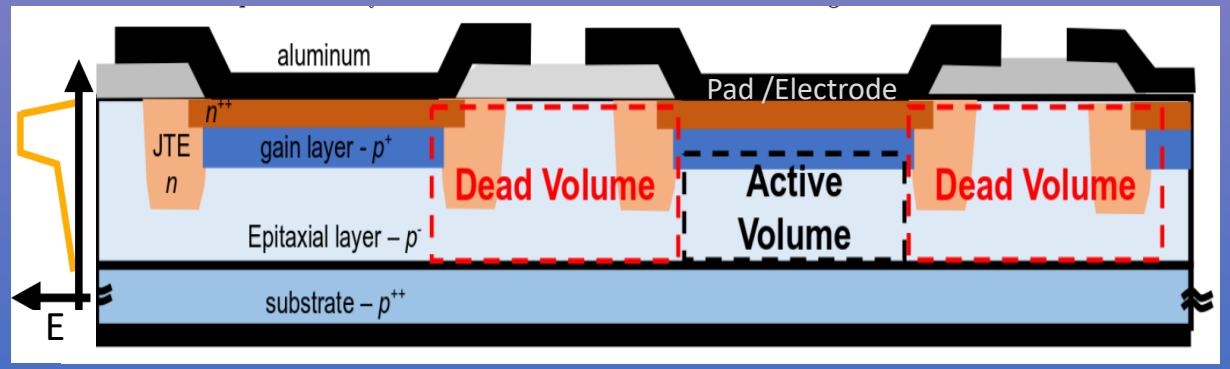
To solve pileups, for particle ID, …

Development of novel generation of 4D-Tracking solid-state sensors: Low Gain Avalanche Diode (LGAD)-based + associated read-out ASICs

Low Gain Avalanche Diode (LGAD) Sensors

- **Silicon** sensors fabricated in a thin (≈50 µm) **high resistive p-type substrate**
- **Charge gain** (**up to 100**) to achieve **very high timing resolution** (10 -30 ps)

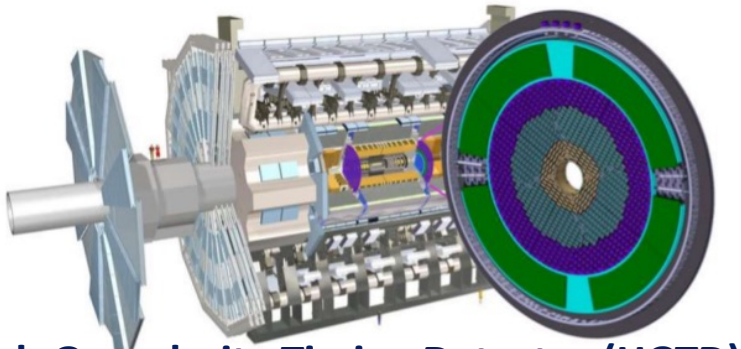
(DC)-LGAD [« Direct Current coupled »]



1D (timing)

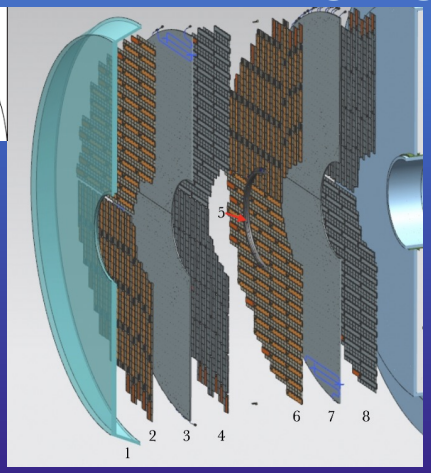
- Localized amplification (pad)
- No charge sharing
- Low fill factor
- Spatial resolution limited by « dead » volumes betw. pads

LHC Upgrade phase II (HL-LHC): pixel size: 1.3 x 1.3 mm²



High Granularity Timing Detector (HGTD)

[Read-out: ALTIROC (OMEGA)
15 x 15 ; CMOS 120 nm]



Endcap Timing Layer (ETL)

[Read-out: ETROC (Fermilab)
16 x 16 ; CMOS 65 nm]

Achieved 30 ps time resolution

Low Gain Avalanche Diode (LGAD) Sensors

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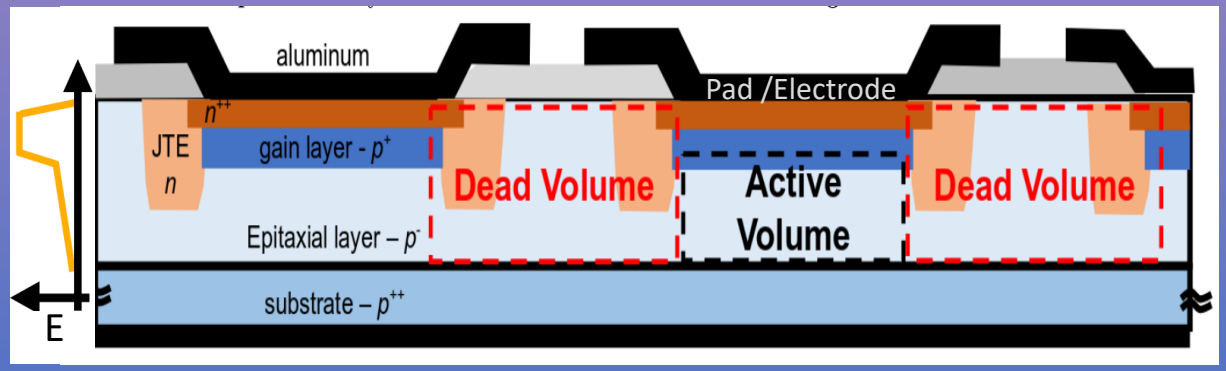


1D (timing)

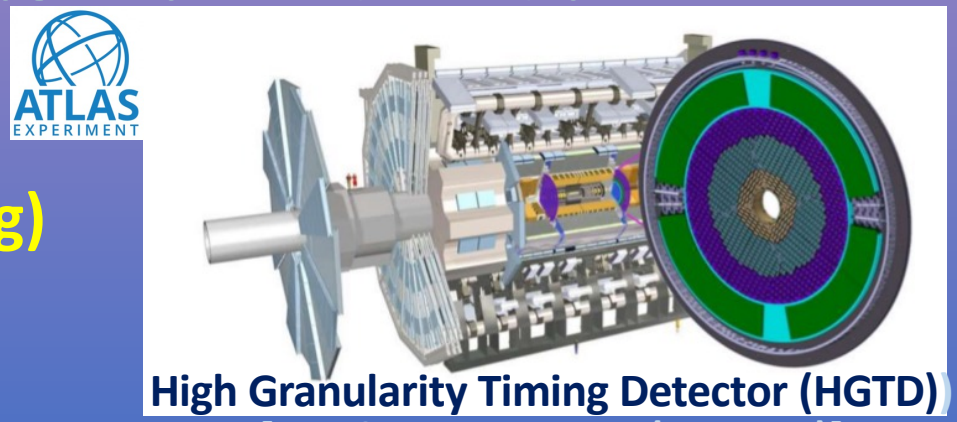
- Localized amplification (pad)
- No charge sharing
- Low fill factor
- Spatial resolution limited by « dead » volumes betw. pads

1D (timing) → **4D (timing & position)**

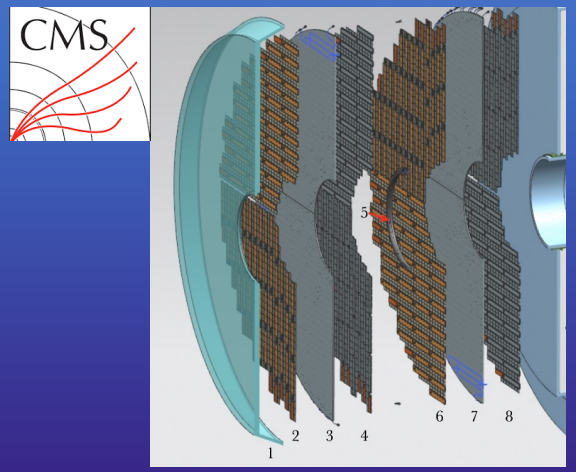
2 approaches to achieve a very good spatial resolution:

- **Segmentation: « isolated » fine pitch electrodes (~ 100 μm pitch)**
- **Interpolation from charge sharing ratio among neighboring pixels**

LHC Upgrade phase II (HL-LHC): pixel size: 1.3 x 1.3 mm²



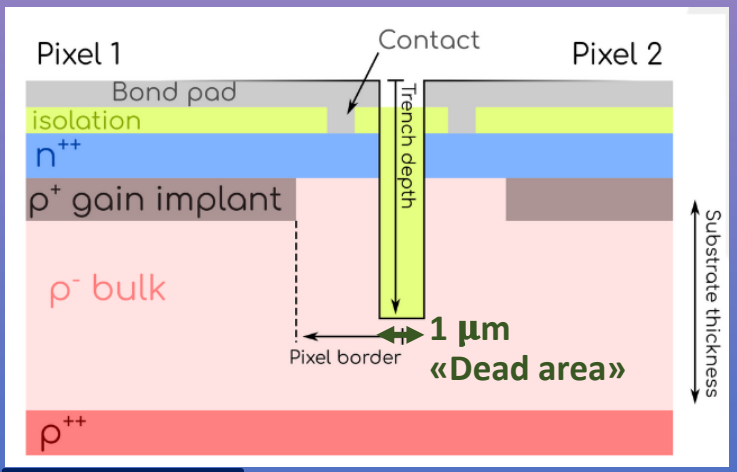
High Granularity Timing Detector (HGTD)
[Read-out: ALTIROC (OMEGA)]



Endcap Timing Layer (ETL)
[Read-out: ETROC (Fermilab)]

Achieved 30 ps time resolution

4D-Tracking: DC-coupled Trench-Isolated (TI-) LGADs



- Electrical isolation between pixels obtained with **narrow** (< 1 µm) **deep trenches** etched in the silicon and filled with silicon dioxide.
- Ultimate goal is to **minimize the no-gain region** and minimize the dimensions of pixels to about ***O*(100) µm** while keeping the fill factor higher than 90% for 4D tracking applications.

- TI-LGAD designed by **FBK** (Trento, Italy)
  « Characterization of novel trench-isolated LGADs for 4D tracking », A. Bisht *et al.*, NIM A 1048 (2023) 167929. [2 x 1 pixels]
- Next production which will be made available for testing in 2027.

- Performances of TI-LGAD will be evaluated with read-out chips developed for LHCb Vertex Locator (VELO) upgrade II: **IGNITE (INFN)** and/or **PicoPix (CERN)**, both designed in CMOS **28 nm** technology (link with ECFA DRD7)

ECFA DRD3/WG2 “Development of TI-LGADs for 4D Tracking” lead by Anna Macchiolo (Univ. Zürich)

➢ Very promising technology concept for tracking & vertexing in future collider experiments

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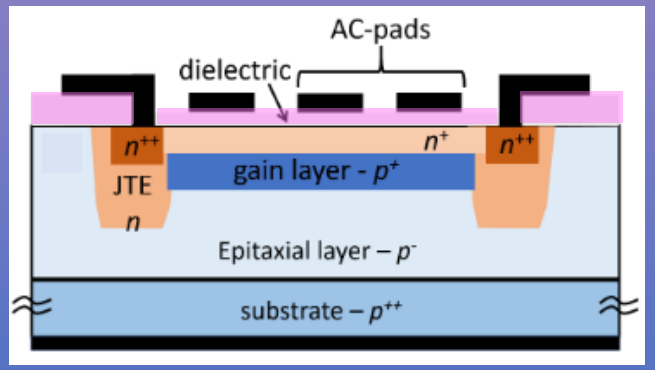
4D-Tracking LGAD sensors: AC-LGADs

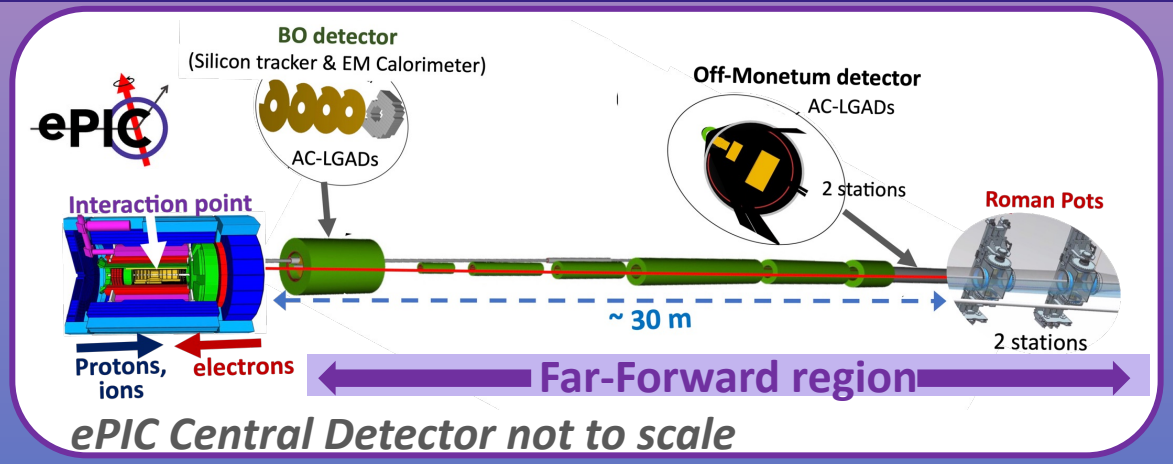
CD_nLGAD_NuHEP

AC-LGAD [« Alternating Current coupled »]



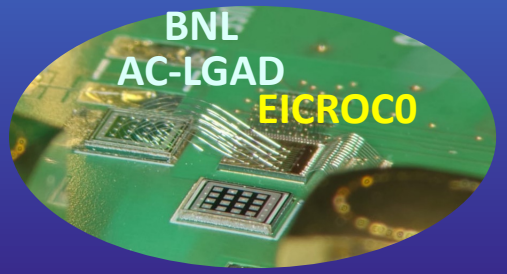
Signal capacitively coupled

- Metal electrodes placed at a fine pitch over a thin insulator layer (dielectric)
- Uniform amplification
- **100 % fill factor** (No dead volume)
- **Charge sharing among neighboring pads**
- Insensitive area (edges) can be minimized
- **Timing resolution as good as DC-LGAD**
- Lower input capacitance



Pixelated AC-LGADs (500 x 500 µm² pixel size):

- in all ePIC Far-Forward detectors + Forward TOF
- Read-out by **EICROC**, specific optimized ASIC, being designed at OMEGA Microelectronics in collaboration with cea irfu (TDC)
  (1st prototype EICROC0 [4x4] ; final EICROC2 [32x32]
- AC-LGAD + EICROC characterization coordinated by IJCLab



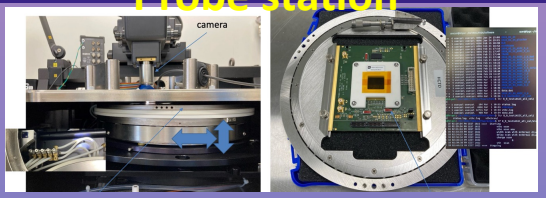
Benefits from US – Japan collaboration & FJPPN (2023 – 2024)

Main AC-LGAD designers / providers: HAMAMATSU, Brookhaven National Laboratory, FONDAZIONE BRUNO KESSLER

Brookhaven National Laboratory, SCIPP SANTA CRUZ INSTITUTE FOR PARTICLE PHYSICS UC SANTA CRUZ, KEK, 筑波大学 University of Tsukuba

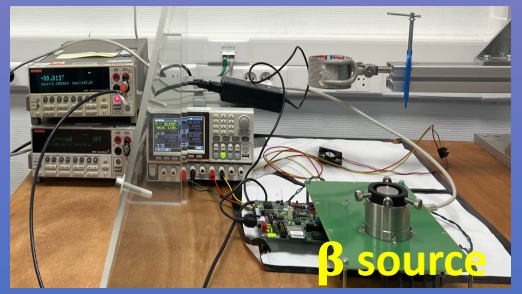
CD_nLGAD_NuHEP: objectives

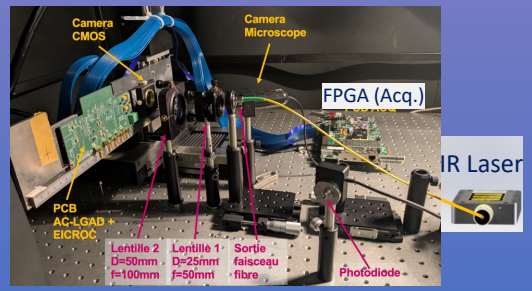
Probe station



❖ Joint efforts on AC-LGAD characterization associated to read-out chip (EICROC)

- ➢ IV-CV measurements exploiting IJCLab probe station (at semi-conductor technological platform – PSI)
- ➢ Determination of achievable timing & spatial resolutions of BNL, HPK & FBK AC-LGADs (wire/bump-bonded) associated to each EICROC iterations [➔ 32 x 32] exploiting @ IJCLab Beta source & infrared laser (Transient Current technique -TCT) test benches + beam tests @ TNAs (CERN, MaMi, JLab, BNL)





❖ Joint efforts on TI-LGAD characterization associated to read-out chip (IGNITE & PicoPix)

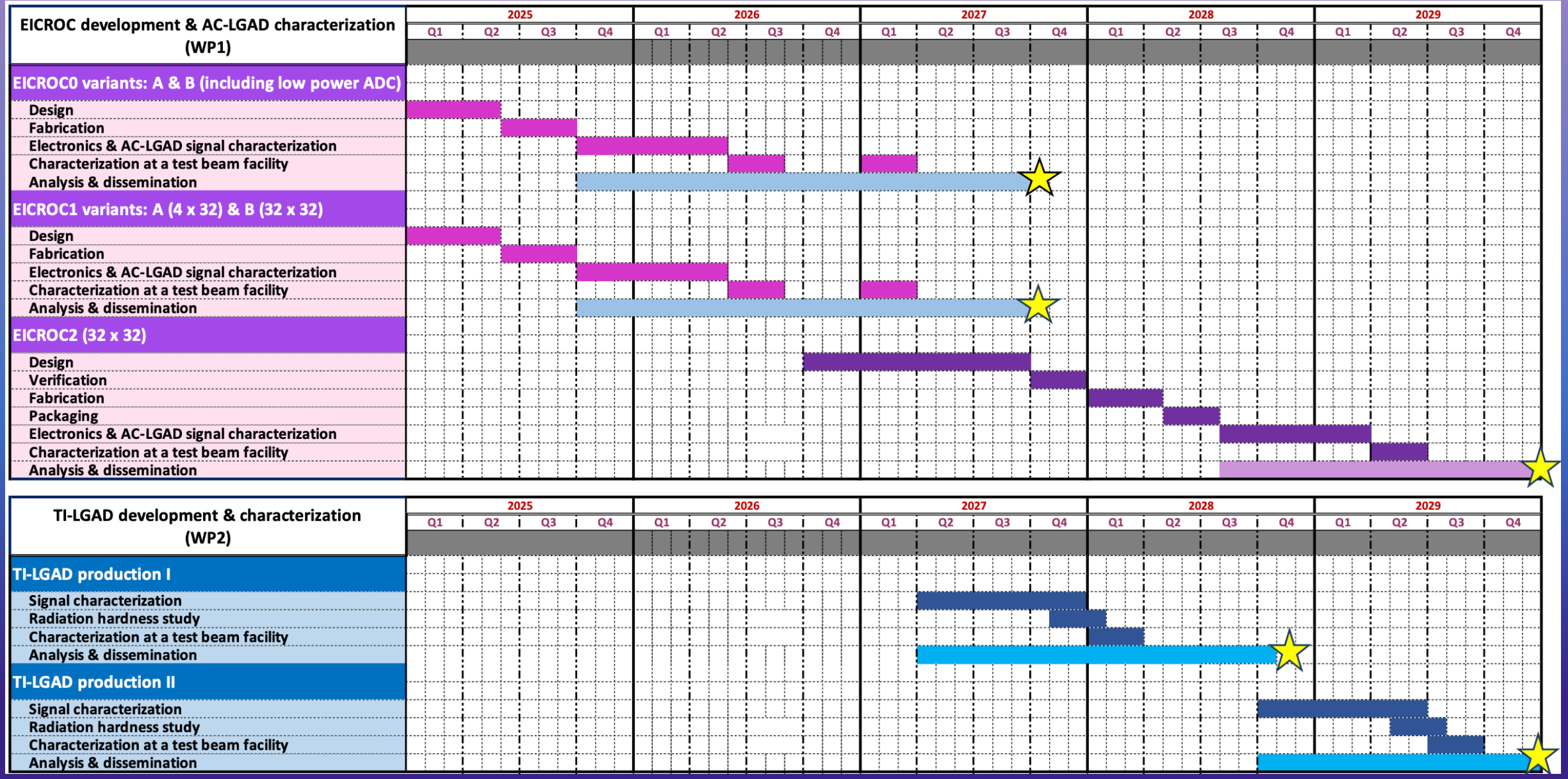
- ➢ IV-CV measurements exploiting IJCLab probe station (at semi-conductor technological platform – PSI)
- ➢ Determination of achievable timing & spatial resolutions of FBK TI-LGADs (availability 2027 →) exploiting Beta source & Infrared laser test benches @ LPNHE + beam tests @ TNAs (CERN, MaMi, JLab, BNL)

❖ Effort on LGAD sensor development to sustain radiation up to 10^{16} n_{eq}/cm^2

- ➢ Performing LGAD simulation with different doping (Silvaco TCAD software)
- ➢ Taking part to irradiation campaigns
- ➢ Radiation hardness study from LGAD characterization before & after irradiation

CD_nLGAD_NuHEP: timeline

★ : publication



CD_nLGAD_NuHEP: the team

Ana-Sofia Torrentó (IJCLab)

- Coordinator of the French IN2P3 – IRFU Semi-conductor Instrumental Network
- IJCLab contact person for ECFA DRD3 (R&D on Solid State Detectors)
- Scientific coordinator of the Plateforme Semi-conducteurs (PSI, IJCLab) [clean room]
- Technical responsible of the Probe Station @ PSI ; radioprotection correspondent
- Responsible of AC-LGAD characterization for the EIC Roman Pots
- Collaboration membership:
  - **ATLAS** (Inner Tracker (ITk) – pixel)
  - **EIC**

Management

- Project follow-up
- Reporting
- Recruitements
- Periodic meetings
- Project documentation
- Dissemination
- Outreach

Dominique Marchand

(IJCLab)

- Scientific responsible of AC-LGAD read-out chip (EICROC) characterization & associated cooling system for the **EIC** Roman Pots (2021-)
- Co-coordinator of STRONG-2020 / Proton Radius European Network (WP15, NA4, 2019-2024)
- Focuses: Hadron Physics & instr.

Giovanni Calderini

(LPNHE)

- French IN2P3 **ATLAS** Inner Tracker (ITk) Upgrade Coordinator (2019 -)
- Module Hybridization Coordinator for ATLAS Pixel Tracker Upgrade
- Deputy Scientific Coordinator of AIDAInnova project (2020 - 2024)
- Member of the Project Proposal Team of ECFA DRD3 (2023-)
- Focuses: Higgs Physics, pixel sensor characterization, radiation hardness, set-up a clean room @ LPNHE

Anna Macchiolo

(University of Zürich)

- Deputy Tracker Upgrade Coordinator for the **CMS** exp. (2021-)
- Coordination of the AIDAinnova work package on Hybrid Pixel Sensors for 4D Tracking and Interconnection Technologies (2021-2024)
- Focuses:
  - Development of passive CMOS detectors and 4D-Tracking LGAD (CMS Tracker Extended Pixel detector)
  - DMAPs (CMOS 65 nm) characterization (FCC-ee tracker)

(Bios not exhaustive)

CD_nLGAD_NuHEP: budget request

- **Human resources: reinforcement required for LGAD characterization & development**
  - Post-doctoral fellow at IJCLab (2-yr contract, 2027-2028)
  - Post-doctoral fellow at LPNHE (2-yr contract, 2027-2028)

  Closely collaborating with the team in University of Zürich.

- **Logistics funds: travels & meeting organization**
  - In-person meetings (Paris, Zürich, CERN, BNL)
  - Beam/irradiation tests campaigns at TNAs (CERN, MaMi, JLab, BNL)

Item \ Partner	IJCLab	LPNHE	Univ. Zürich
Human resources	230 k€	230 k€	
Logistics	12 k€	12 k€	12 k€
Sub-total :	**242 k€**	**242 k€**	**12 k€**
Grand total :		**496 k€**	

(15 % indirect costs included)

Summary

- Performance study of novel generation of LGAD sensors (AC-LGADs & TI-LGAD) which are very promising technology concepts for 4D-tracking satisfying upcoming nuclear and high energy physics experiment needs in terms of timing (10-30 ps) and spatial (10-20 μm) resolutions.
- Exploiting complementary techniques available in our labs (probe station, β source, TCT) and performing beam tests and irradiation campaigns benefiting of facilitated accesses at TNAs
- Build a real synergy and foster collaborations between IJCLab, LPNHE & Univ. of Zürich to increase TI-LGAD fill factor minimizing pixel size and to improve radiation hardness for future collider experiments.
- Project in line with the key technological developments identified by European Committee for Future Accelerators (ECFA) Detector R&D Roadmap to be primordial to the progress of research in particle physics
- Budget request: 496 k€ (2 x 2 year post-doctoral fellowships + logistics funds, indirect costs included)

Thank you for your attention

CD_nLGAD_NuHEP