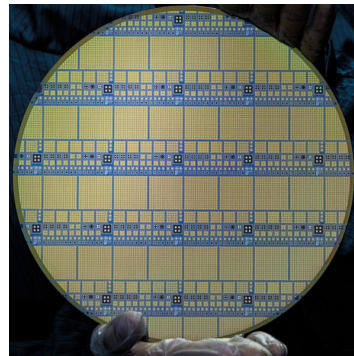
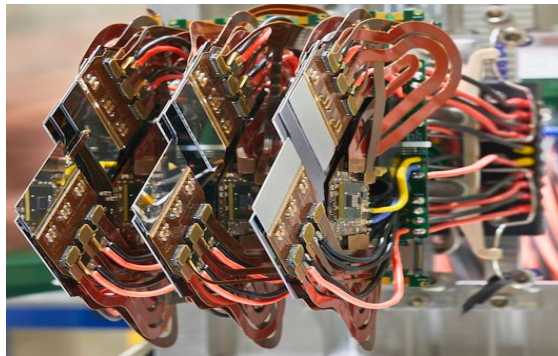
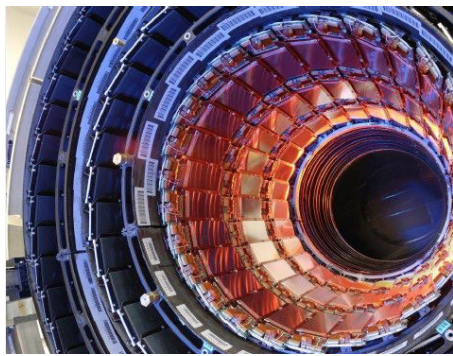


# GT2: Detectores Semicondutores

## Activity report

Antonio Vilela Pereira (CMS-CBPF), Clemencia Mora Herrera (CMS-CBPF),  
Erica Polcarpo (LHCb-UFRJ), Gustavo Gil da Silveira (CMS-UFRGS), Marco Bregant (USP)  
Irina Nasteva (LHCb-UFRJ), Marco Leite (ATLAS-USP), Vinicius Franco Lima (LHCb-UFRJ)

**IV Workshop do INCT CERN-Brasil, Natal, 29 de julho de 2026**



# Scope of GT2: Semiconductor Detectors

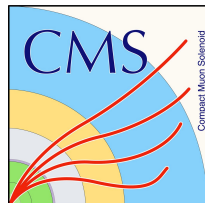
## Institutions

- CBPF
- UERJ
- UFRGS
- UFRJ
- USP

## Technologies

- LGAD
- Diamond
- Hybrid
- 3D...

## LHC experiments



## Technological challenges

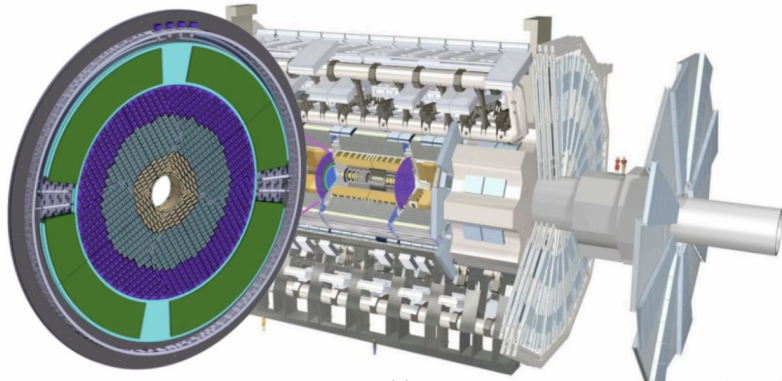
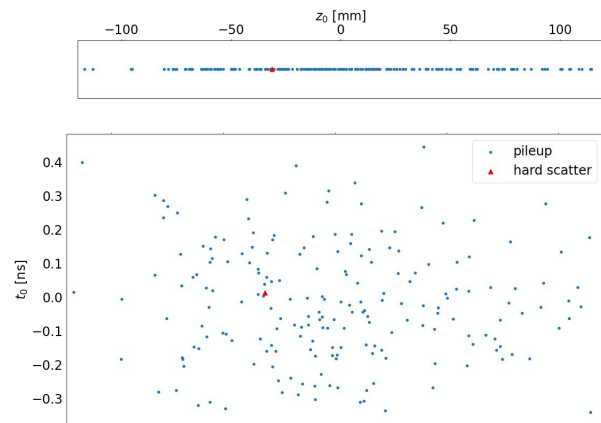
- New sensor technologies
- Ultra-fast timing (picoseconds)
- Fast readout electronics
- Very high radiation resistance
- Thin detectors
- Geometry and spatial resolution
- Power and cooling
- Efficiency

## Applications beyond LHC

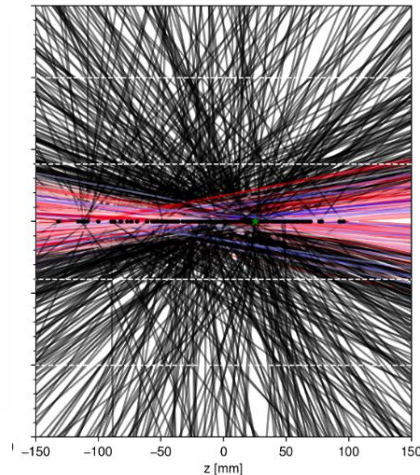
- Photon sciences
- Medical imaging
- Nuclear Physics
- Industry
- ...

# ATLAS: 4D Tracking challenges at the HL-LHC

- For jets (and many other objects), it is essential to reconstruct the primary vertex position  $z_0$ 
  - But the high number of interactions increase the  $z_0$  uncertainty
  - Solution: add time information  $t_0$ !
- ATLAS will add a frontal timing layer (**High Granularity Timing Detector, HGTD**) to provide time information
  - Will cover the region  $2.5 < |\eta| < 4.0$
  - $z_0$  resolution is especially low for tracks that go to the frontal region
  - **Still need to devise reconstruction methods that better incorporate the time measurements**



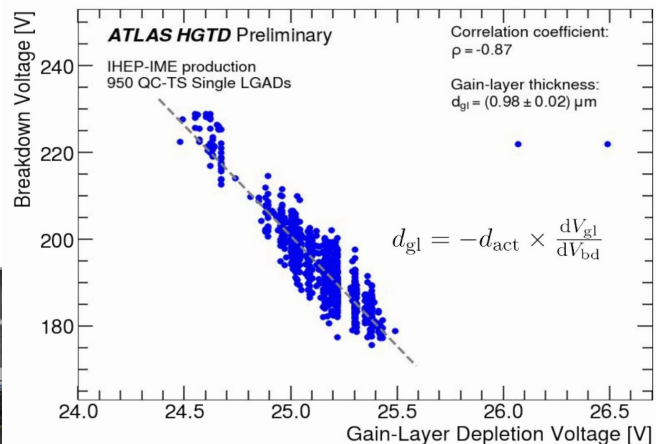
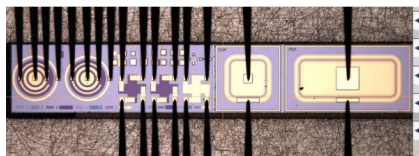
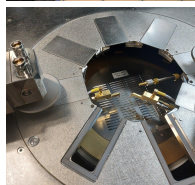
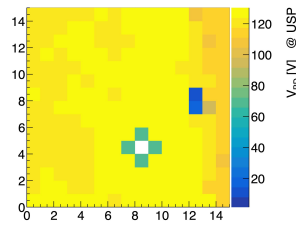
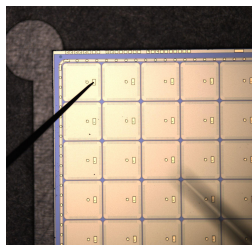
## 3D + forward timing





# HGTD Sensor testing @ USP

- USP and CERN are two main sites or QA/QC of the sensors produce by IHEP/USTC (IME Fab.).
- Around 7 thousand test structures needs testing for production validation.
- Diced structures are reassembled in a stencil holder (80 structures) for 11 tests per structure.
  - Process developed in partnership with a local company (flatness and cut precision requirements)
  - A more complex structure developed for SQC tests at IHEP (9 diced sensors at a time)
  - 3 thousand structures already teste at USP
- USP leaded the effort (workflow, DAQ software development and validation)

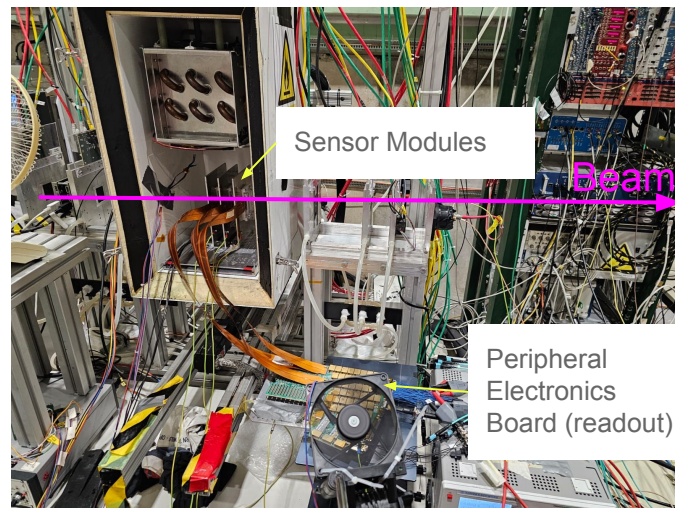
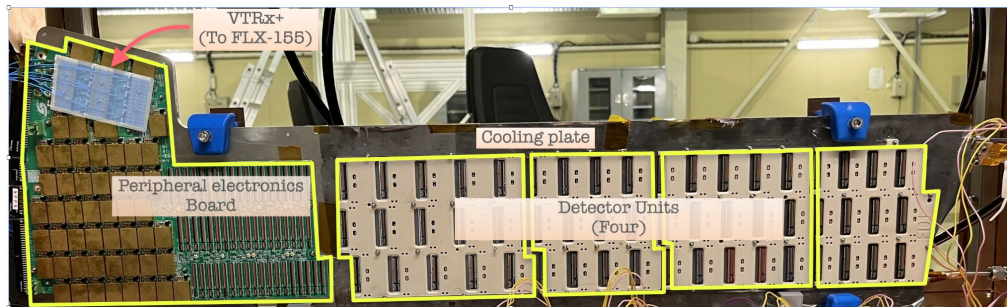




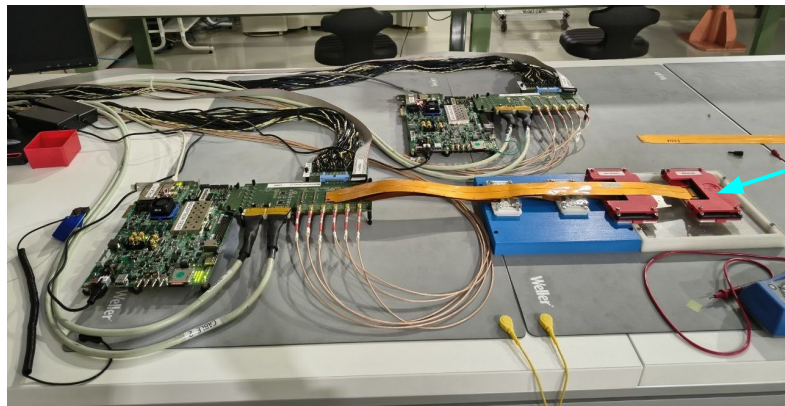
## 2. HGTD Integration (demonstrator)

- CERN will be the construction site for HGTD
- Need to build infrastructure and tooling
- The demonstrator is the 1st step towards the Module 0 ( $\frac{1}{4}$  disk)
- Manpower contribution from construction to commissioning (MoU)

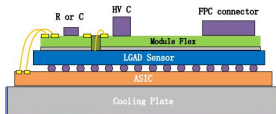
- Full readout system is already being used in test beams



Peripheral Elec. Board test beam readout

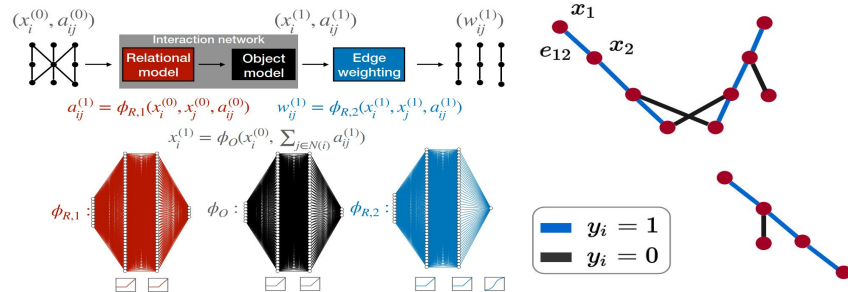
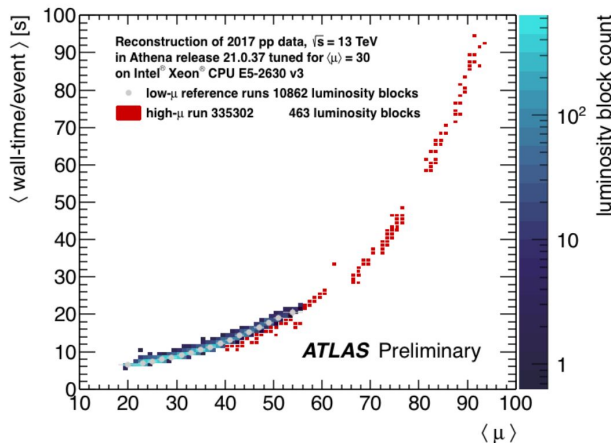
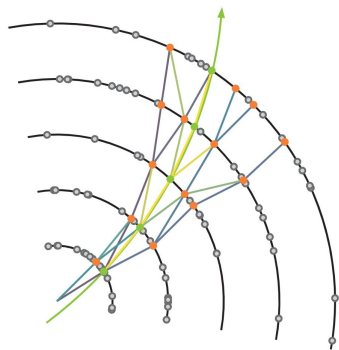


Module test setup @ CERN



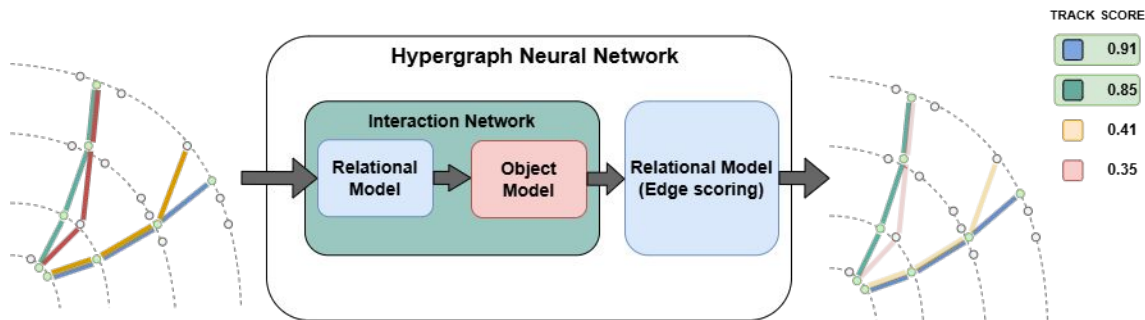
# 4. Tracking challenges at the HL-LHC: throughput

- The current tracking method does not have enough throughput to operate in the HL-LHC scenario.
  - Processing times are  $O(N^2)$ , being  $N$  the number of hits (depositions)
- Combine tracking from ITk with timing from HGTD.
- Need new high-throughput tracking methods  $\Rightarrow$  **Geometric Deep Learning (GDL)**
  - Most promising alternatives use **Graph Neural Networks (GNNs)**



## 4. HGNN implementation: making sense of sensor information

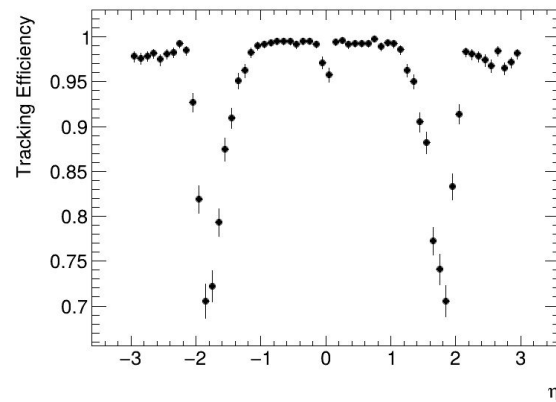
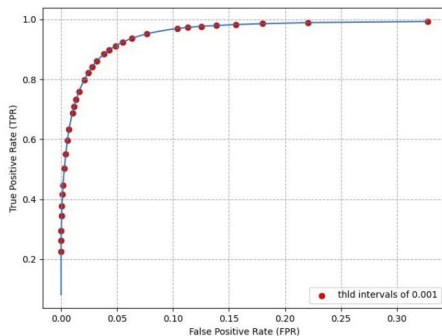
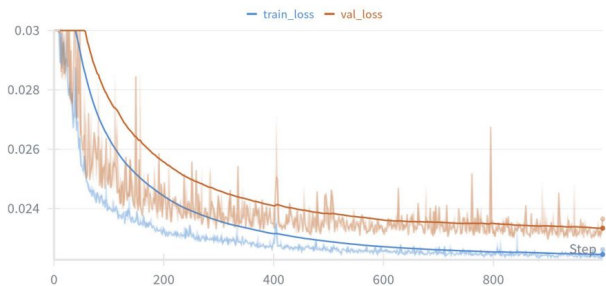
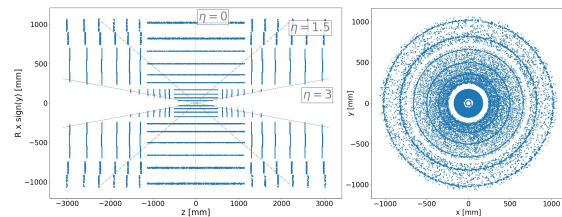
- ACTS (A Common Tracking Software) used as a proxy for event simulation and reconstruction.
  - Running on SAMPA and CERN LXPLUS
- Graph construction is done with ACTS standard reconstruction pipeline, but adapting the track finding step to a faster and less rigorous algorithm.
  - Combinatorial Kalman Filter (CKF) without the Kalman Update
  - Decreases runtime when optimized for parallel execution
  - Generate way more duplicates and fakes than the original method
- HGNN implemented using PyTorch and Cuda libraries.
- Training on a RTX 3090 Ti GPU
  - Would greatly benefit from a better GPU for increase in statistics and massive parallelization approach





# 4. HGNN pipeline evaluation

- We use 50 of the training events for validation and threshold optimization
- Chose a threshold that keeps the FPR bellow 10%
- Different models sizes were tested, varying number of nodes on the hidden layer
- Best performing models occupy ~4 GB of RAM during training
- Still need to improve the training procedure and tune the hyperparameters
- Find best learning rate and weight decay



# 3. HGTD implementation in ATLAS framework

Implementation of full ACTS based reconstruction in ATLAS offline analysis software.

|                                                                                                                                     | Legacy                                                                      | ACTS CKF                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------|
| <b>Branching:</b> when reaching each layer, extrapolation can branch out by “picking” different hits around the extrapolation point | just follows one path, picking the closest hit from the extrapolation point | customizable, can be set to follow N nearest hits.                    |
| <b>Time propagation:</b> is time also extrapolated to next layers and included in the Kalman filtering?                             | All propagation is only geometric                                           | propagates time and check for time consistency at extrapolation level |
| <b><math>\chi^2</math> evaluation:</b> what is used to calculate the score of the extension (ones with high $\chi^2$ are cut)       | only geometric information                                                  | can use the time coordinate together with geometric                   |

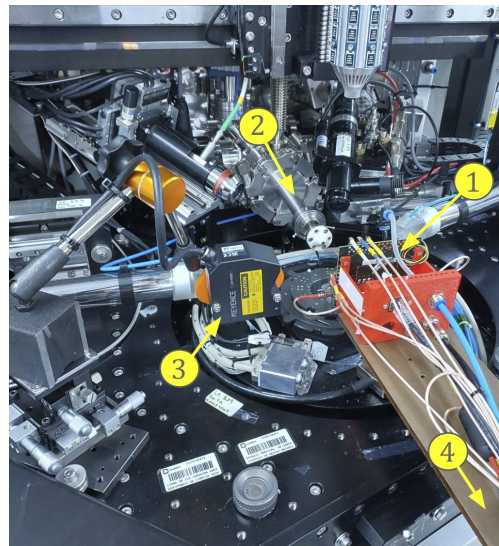
## Progress up to this point

### Inclusions done on the ACTS CKF association algorithm:

- **Kalman update:** now estimates for next layers can be based on the filtered state, not predicted
- **Measurement selector:** without this tool the extrapolation branches out of control, returning hundreds of extension per track
  - The `numMeasurementsCutOff` defines how many closest hits will be picked
- **Track Selector:** I made a simple one to select the extension with lowest  $\chi^2$  for each track particle.
  - Also with a threshold to filter misassignments
- **Time propagation:** Time wasn't being propagated in the correct unit

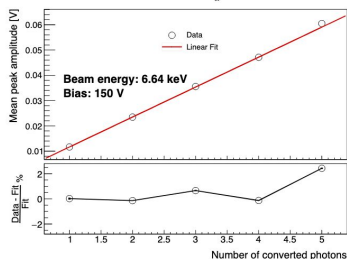
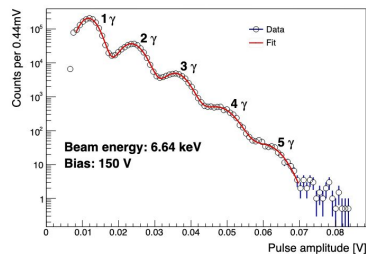
# 5. UFSD sensor applications (R&D)

- **Total of 3 TestBeam campaigns** at Carnaúba beamline at CNPEM (next one in October aiming at AC-LGAD structures - part of DRD3 WP)
- New low energy (2.1 keV data)
- Measurements for gain and interpad distance with focused beam
- New (up to) 16 channel board tested with success
- Also tested IHEP and FBK TI-LGADs
- Paper submitted for publication

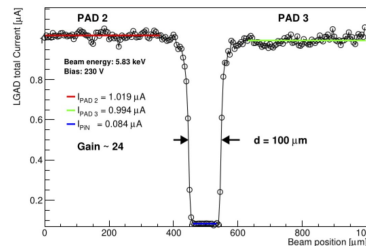
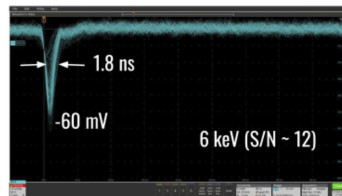
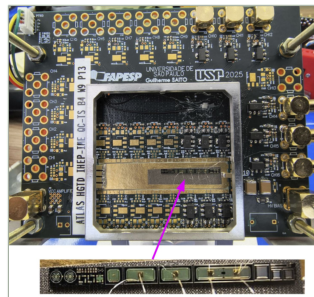


Carnaúba beamline LGAD test setup

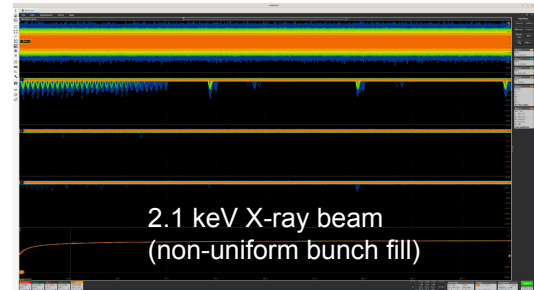
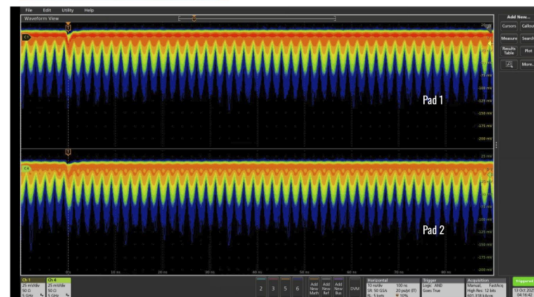
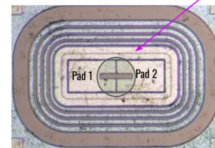
M. Leite



Multiple photons detection



- 6 keV X-rays (350  $\mu m$  spot size)



# PPS2 Trench-Isolated LGAD sensors



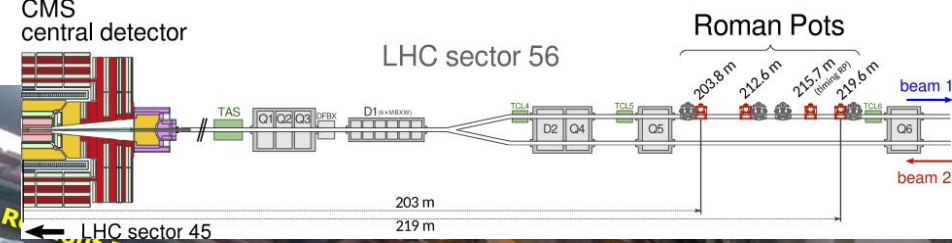
- **The Precision Proton Spectrometer (PPS)** measures tracking and timing of the protons at 200 m from IP.
  - The LHC can be used as a photon collider: search for new physics in the electroweak sector.
- **Diamond** or **LGAD** sensors for timing.



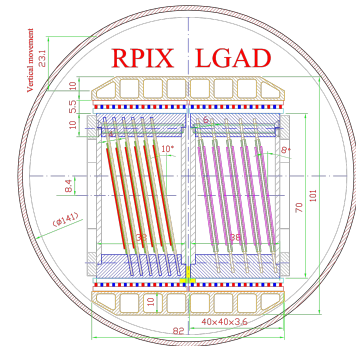
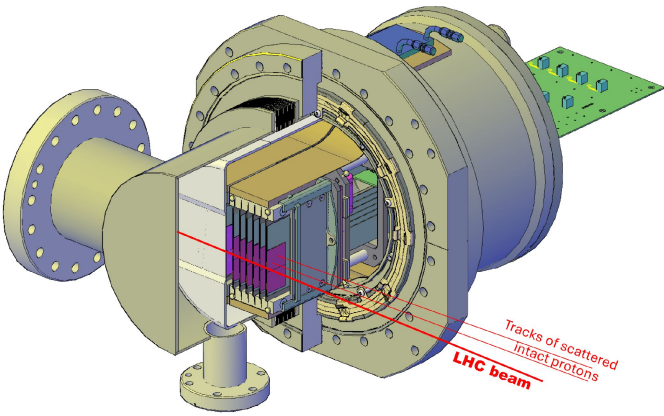
**CBPF**  
Centro Brasileiro  
de Pesquisas Físicas



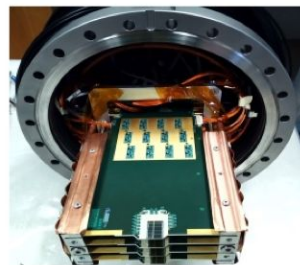
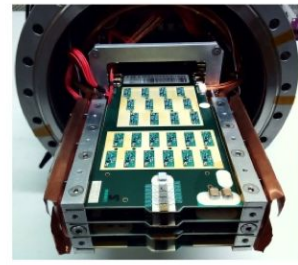
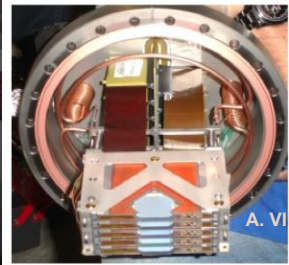
# CMS Precision Proton Spectrometer



For PPS2 (Run 4):

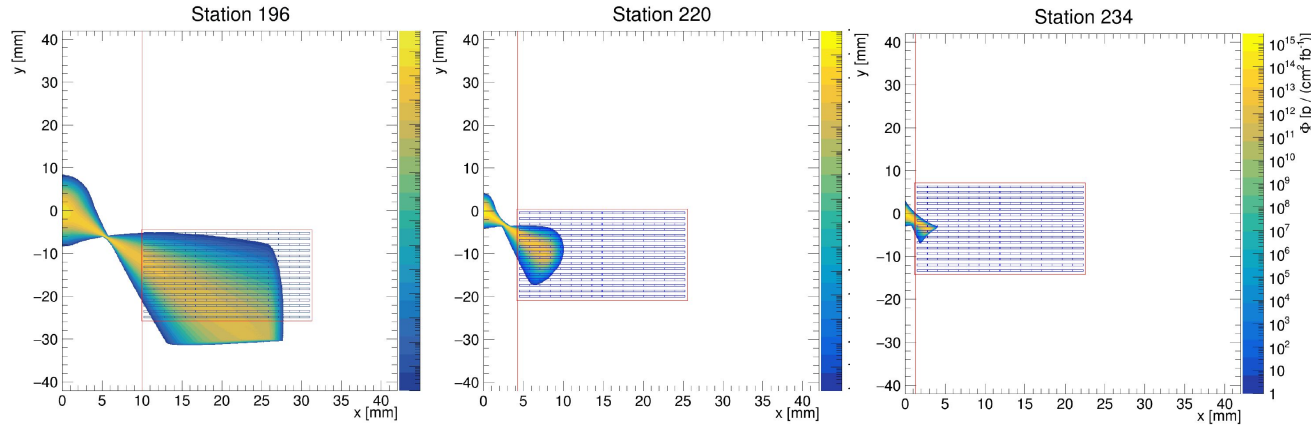


Detectors  
Sector 56 March 2018



A. VILELA - INCT OF RN BR JULHO 2026

# PPS2 Timing Sensors



- PPS2 pre-production wafer batch with pad geometry driven by occupancy and compatibility with the ETROC chip (CMS ETL/MTD).
- About 1/3 of ETL sensor height. Sensor layers to be staggered vertically for full acceptance.
- Trench-Isolated LGADs for smaller interpad dead region (few  $\mu\text{m}$ ) – in PPS horizontal direction.
- Pre-production batch of 10 wafers with Fondazione Bruno Kessler (FBK).

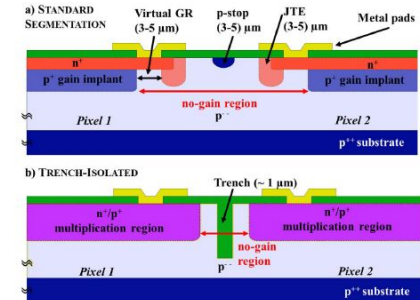
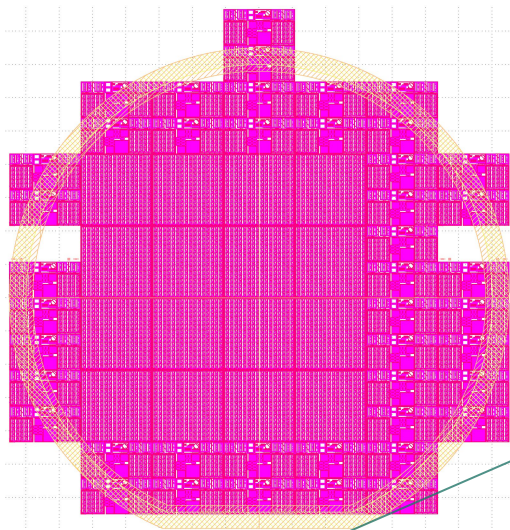


Fig. 1. Schematic drawings of a standard LGAD (a) and of the proposed trench-isolated LGAD (b).

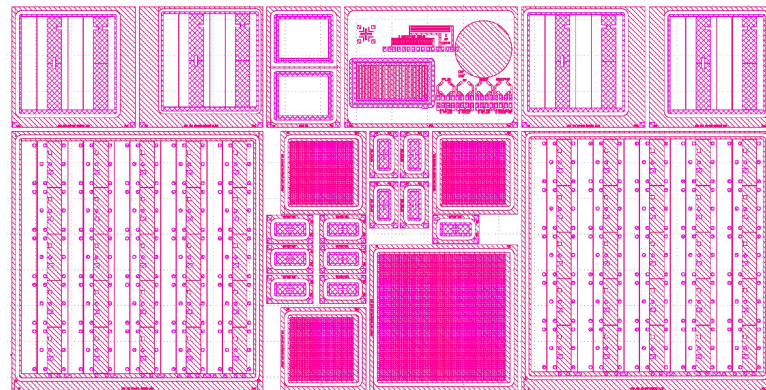
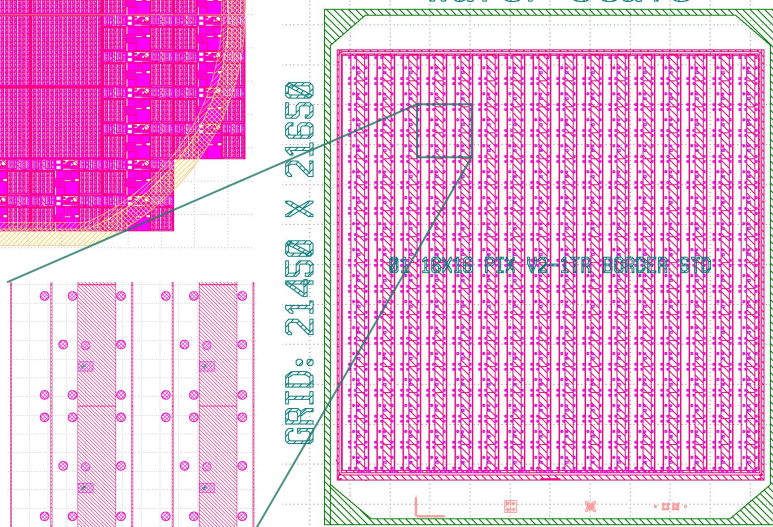


# PPS2 pre-production batch



ETROC  
read-out  
chip

Full sized sensor  
(16x16) *wafer scale*

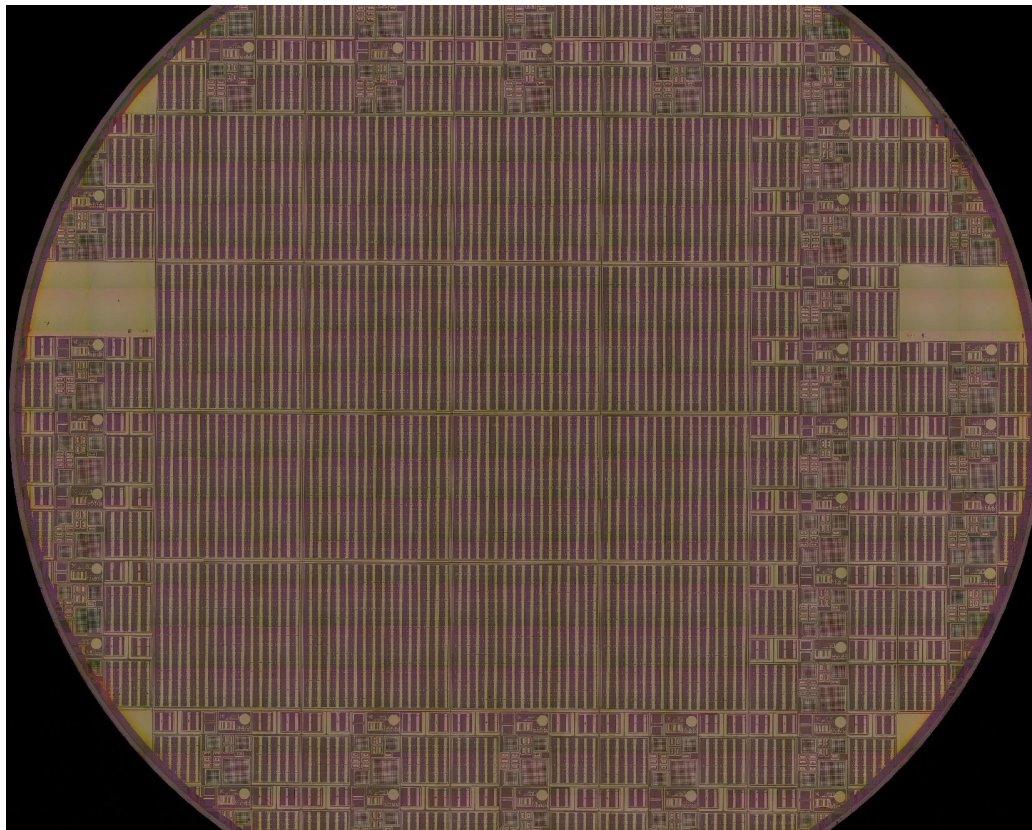


2x2 and 5x5 small sensors with variations (distance between gain layers, variations with smaller metal border and with smaller distance to GR in one edge).

Additional TI-LGAD structures (DRD3).

Brazil contributed to ~95% of submission funding.

# PPS2 pre-production batch



Wafers delivered  
in April 2026



# PPS2 pre-production batch

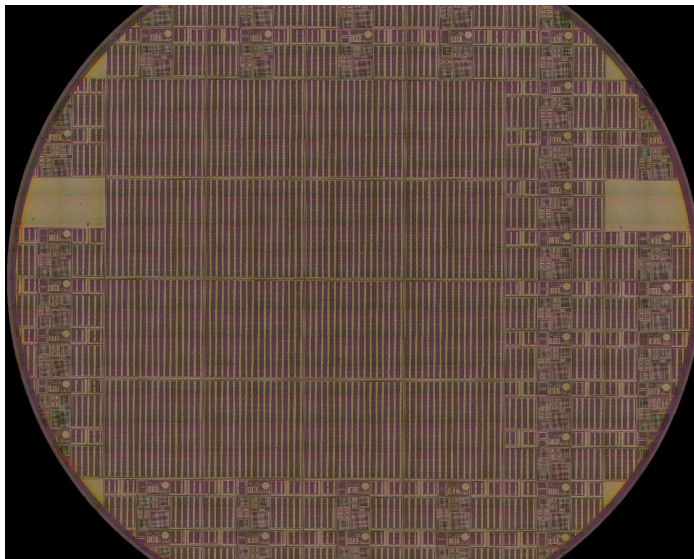
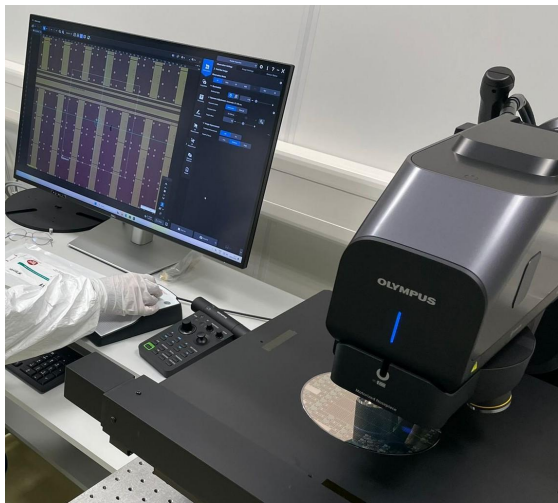


| Wafer | Rel. Gain Dose | Carbon Impl. | Thinning          | Back Metal Grid |
|-------|----------------|--------------|-------------------|-----------------|
| 1     | 1.00           | Yes          | 300 $\mu\text{m}$ | Yes             |
| 2     | 1.00           | Yes          | 300 $\mu\text{m}$ | -               |
| 3     | 1.02           | Yes          | 300 $\mu\text{m}$ | Yes             |
| 4     | 1.02           | Yes          | 300 $\mu\text{m}$ | -               |
| 5     | 1.00           | Yes          | -                 | Yes             |
| 6     | 1.00           | Yes          | -                 | -               |
| 7     | 1.02           | Yes          | -                 | Yes             |
| 8     | 1.02           | Yes          | -                 | -               |
| 9     | 1.00           | -            | -                 | -               |
| 10    | 1.02           | -            | -                 | -               |

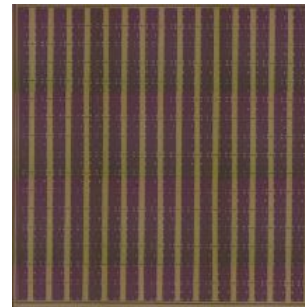
- Wafer 1 broken during thinning.
- A few working experimental wafers (different substrate) also delivered.
- Two non-working experimental wafers delivered as dummy wafers.

+Experimental wafers by FBK

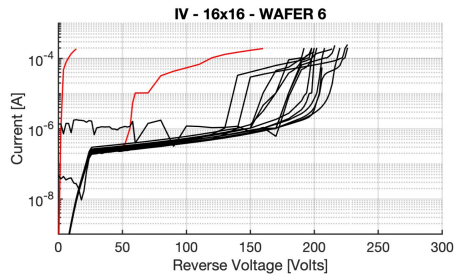
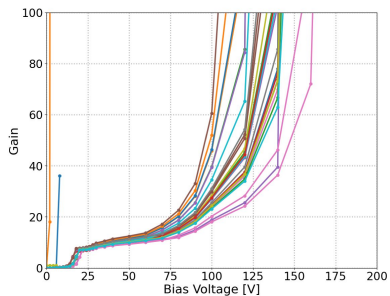
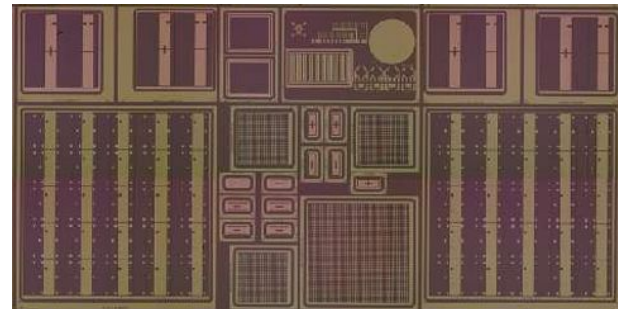
# PPS2 pre-production batch



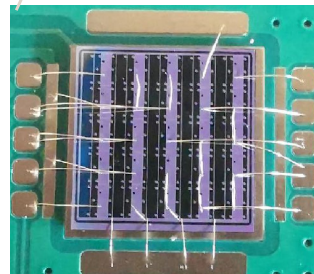
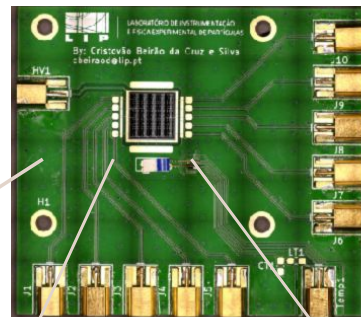
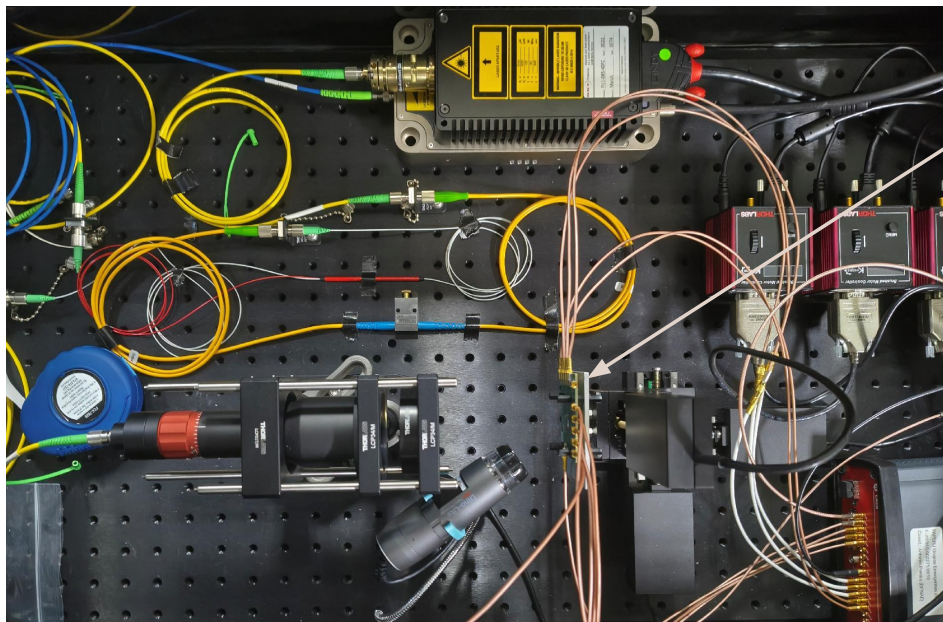
Full sized sensor (16x16)



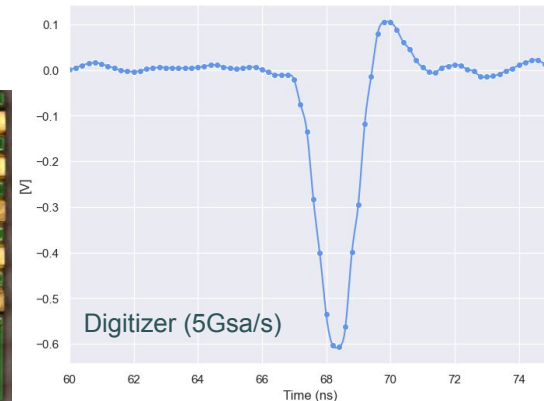
Small sensors + DRD3



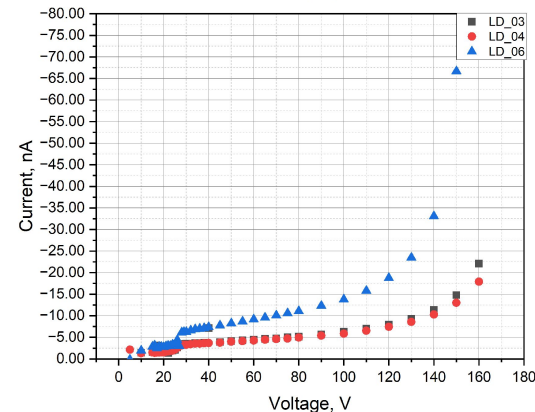
# Preliminary tests



5x5 sensor glued & wire-bonded to PCB



H8 - PPE158, July 2026

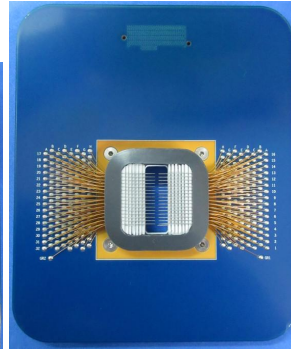


Test beams at CERN & DESY (July/August)



## Next steps

- Full-sized sensor characterization (Probe Station).
- Bump-bonding to ETROC.
- Irradiation campaigns, including non-uniform irradiation.
- Extensive Lab (laser &  $\beta$ -source) and test beam measurements.
- Synchrotron light at SIRIUS.



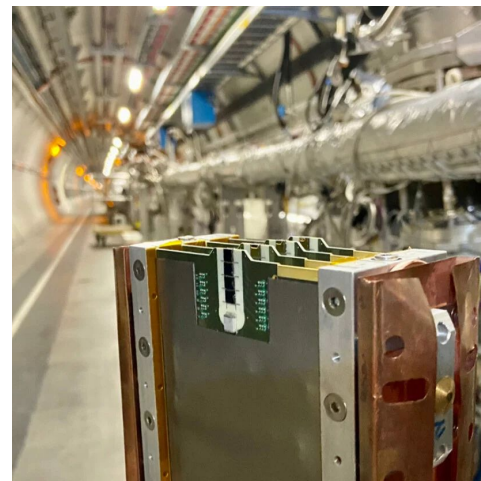
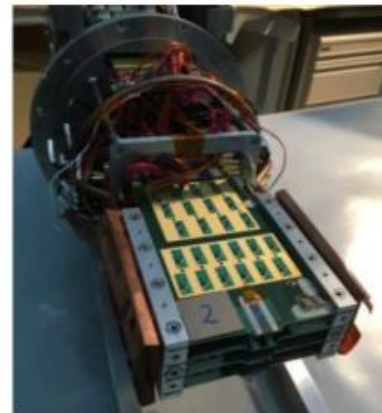
# CMS PPS Diamond sensors



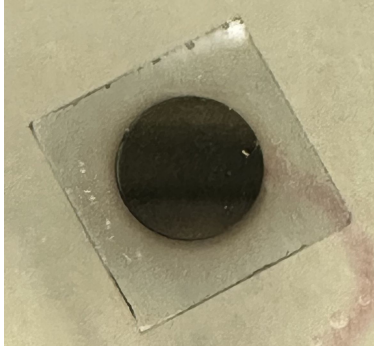
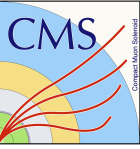
PPS time-of-flight sensors using 5 planes per station, with each plane containing eight 5x5x0.5 mm (double-sided) diamond detectors.

The first phase of this project aims to supply new sensors to the PPS, utilizing diamond material produced with a partner in Brazil and metallization performed at IF-UFRGS.

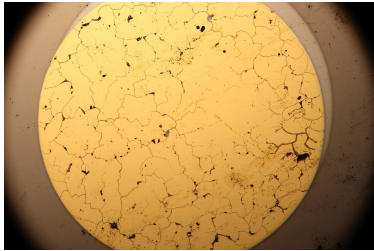
The next step will be to assemble sensor boards suitable for experiments involving detectors placed close to the beam—possibly for the PPS during Run 4 (the specific choice is currently being determined).



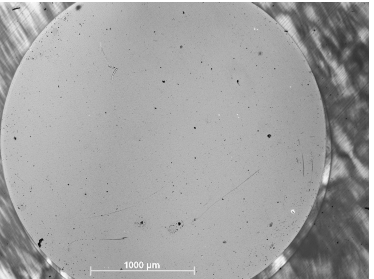
# CMS Diamond : Metal film deposition



First film deposited on an unpolished crystal via sputtering (Cr) and chemical deposition (Au) with a vacuum break; reasonable visual adhesion, but leakage current in the  $O(1E2)$  pA range at 100 V—the target is  $O(1)$  pA.



Specialists prepared new polished samples to improve adhesion; sputtering was chosen for Cr+Au deposition without a vacuum break. Current in the  $<10$  pA range for  $\pm 100$  V. Au cracking suggests post-deposition stresses.



Annealing at 500°C for 6 hours: no cracking, but contamination occurred. Additional tests with a partner in Finland.



# CMS Diamond: Tested samples



- Initial samples tested at IF-UFRGS and with a partner in Finland showed:
  - Good quality of the single-crystal diamond produced in Brazil.
  - A challenge regarding the deposition of a metal film with the quality required to reduce leakage current— $O(1 \text{ pA})$ .
- The Finnish team suggested annealing the diamond (without the film) based on a commercial recipe; however, we observed no reduction in the defect pattern when this was performed at IF-UFRGS.
- A 442 nm bandpass filter acquired by the INCT project confirms that the defects found are inherent to the growth method;
- More advanced techniques will be required to remove nitrogen: high-pressure anvil and temperatures  $>2500^{\circ}\text{C}$ .

# CMS Diamonds: Next steps



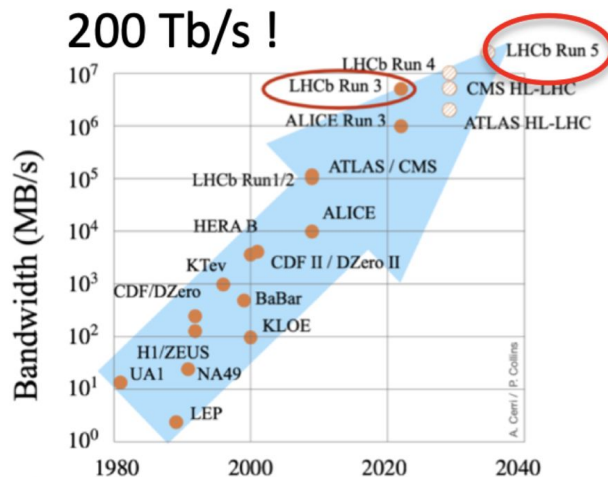
Second half of 2026:

1. Investigate crystal growth processes to achieve high purity, in collaboration with a partner in Brazil.
  - 1.1. The growth recipe depends on deposition conditions at the partner startup.
  - 1.2. Explore the possibility of removing impurities using high pressure and temperature.
  - 1.3. Ideally above 2.5 kPa and above 1000°C – equipment not available in Brazil.
  - 1.4. Ongoing study of diamond deposition structure to refine the growth recipe with the partner startup.
2. Improvement activities for metallic films will be resumed at a later date.

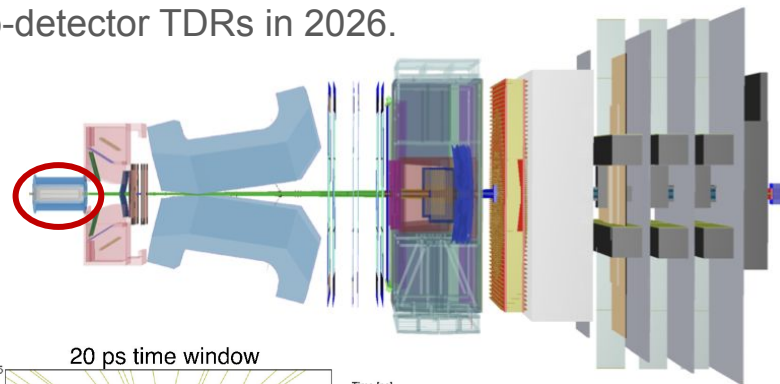
# LHCb VELO Upgrade 2

Big experimental challenges for the LHCb vertex detector VELO at the HL-LHC:

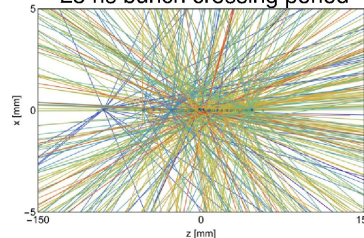
- High track density (50 pileup), high data rate ( $4.5 \times 10^9$  hits/s).
- High radiation damage (up to  $5 \times 10^{16} \text{ n}_{\text{eq}}$ ).
- Maintain performance and spatial resolution.  
=> Include precise time measurements ( $\sim 30$  ps resolution per track).
- Framework TDR in 2021, scoping document in 2024, sub-detector TDRs in 2026.
- Detector installation during LS4 in 2032-34.



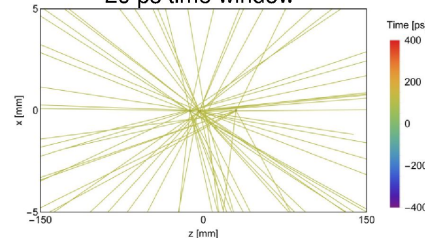
Vertex  
Locator  
(VELO)



25 ns bunch crossing period



20 ps time window

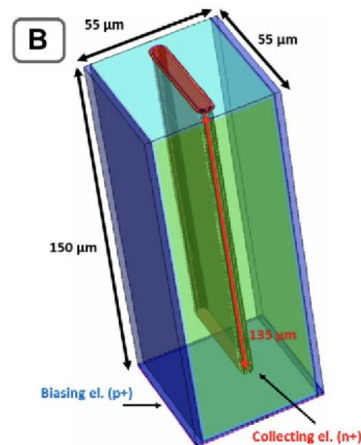
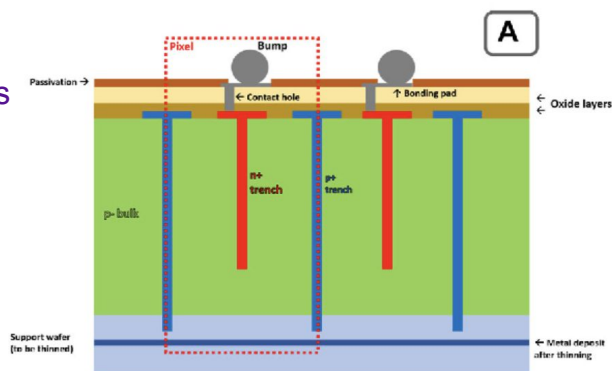


# VELO Upgrade 2 time resolution measurement

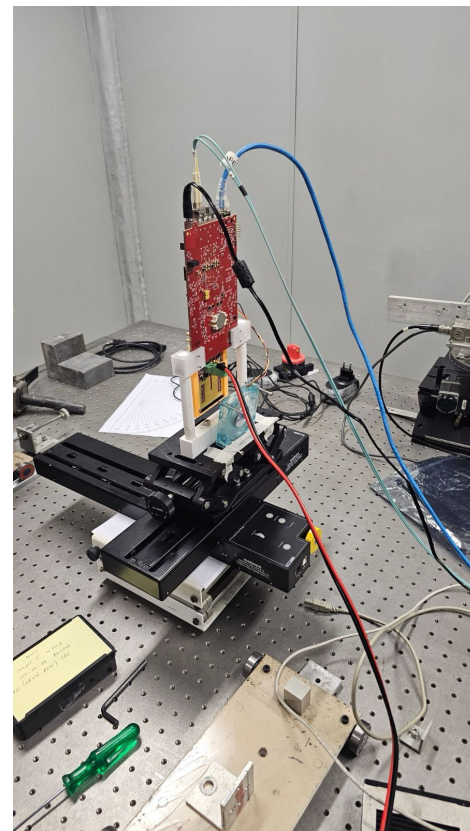
## Time resolution measurement setups:

- Collaboration to measure time resolution of new TI-LGAD, Silicon Carbide and 3D sensors in Sirius/CNPEM (EMA line). New run in Aug.
- Developing lab setup to extract similar information with lasers at LAPE-UFRJ.
- Acquisition in progress of Timepix4 with SPIDR4 readout at LAPE, temporary setup in place.

### 3D prototypes



Timepix4 @ LAPE-UFRJ





# VELO Upgrade 2 Simulation and Test Beam

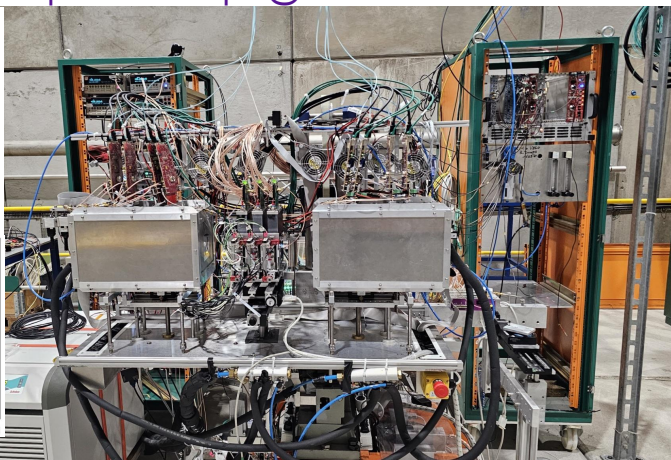
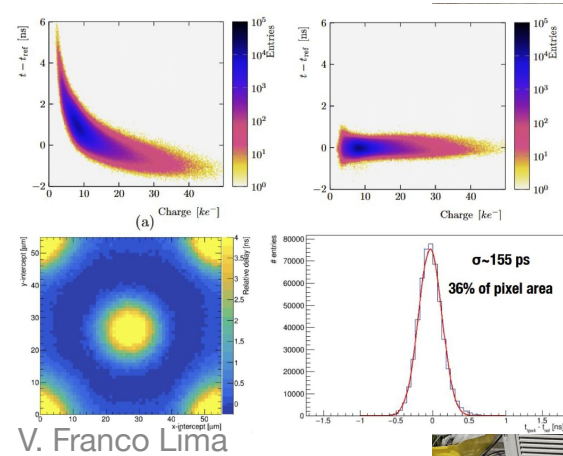
Simulation of silicon detectors:

- Developing software stack to interplay TCAD -> Garfield with radiation damage.
- Applications for VELO U1 and U2.
- Planned integration into the LHCb software framework.

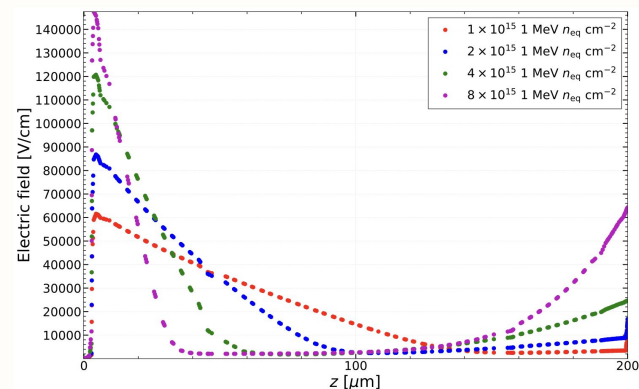
Test beam efforts for sensor characterisation:

- Studies with CERN EP R&D Optima (agnostic platform for sensor prototyping).
- Time resolution analysis of sensors using the Timepix4 Telescope.

Timepix4 Telescope @SPS



TCAD Simulation

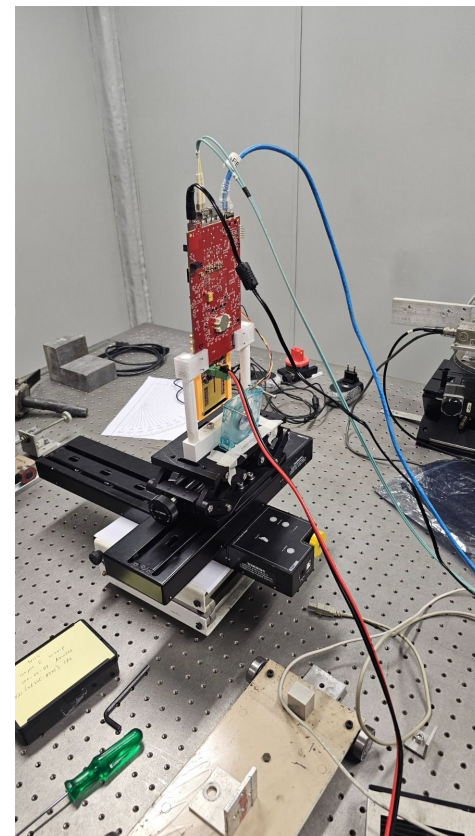




Efforts towards the detector TDR (late 2026):

- Longer term:

- Collaborate on R&D electronics for the control and readout for the several module prototypes going forward from Timepix4 towards Picopix/IGNITE and ultimately Velopix2.



# Summary

## Status and plans:

- ATLAS HGTD testing of LGAD sensors ongoing at USP and CERN, very advanced HGTD integration in hardware and software.
- CMS PPS TI-LGAD sensor production by FBK underway, test beams planned.
- CMS PPS diamond sensor development and testing well underway.
- LHCb VELO developing time measurement test bench and simulations.

## Convergence strategies and synergies:

- Participation in Electronics project (ATLAS FELIX, CMS PPS-2 Timing hybrids, LHCb readout).
- Ongoing collaboration and spin-offs with other institutes (CNPEM/Sirius, Eldorado).
- Collaborative use of infrastructure and labs within GT2:
  - Testing of CMS TI-LGAD, diamond, LHCb Timepix at Semiconductor characterisation lab @USP.
  - Shared detector test benches between CMS and LHCb @CPBF/UFRJ/UERJ.
- Instrumentation school to be held possibly in the second half of 202x ?
  - Needs to be discussed with the other GTs in order to define the scope, content, logistics, cost.

# Expenditure status

- Total foreseen = R\$ 1.052.100,00.
- Spent = R\$ 905k.
- Ongoing acquisition of Spidr4 for LHCb (R\$ 90k).
- Remaining funds for permanent equipment (R\$ 34k), consummables (R\$ 20k).
- Spending status: 86% until now, 9% ongoing in 2026, 5% in the following year.



# Expenditure status - 2025

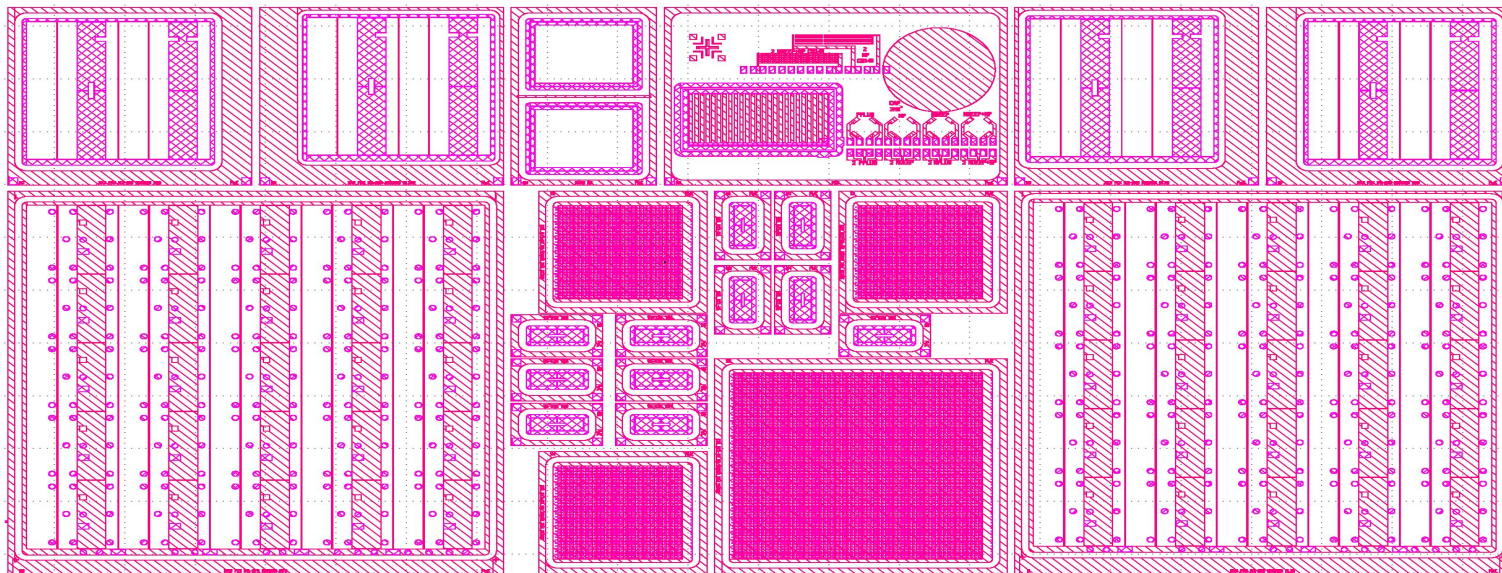
- Total foreseen = R\$1.052.100,00.
- Spent = R\$937.5k. Necessities ~immediate = R\$ 90k, and short-term = R\$ 24.5k (R\$60k?).
- Spending status: 89% until now, 9% in 2026, 2% in the following year.

| Item                                      | Valor          | Rubr | Tipo     | Colaborações | Instituições | Adquirido                   |
|-------------------------------------------|----------------|------|----------|--------------|--------------|-----------------------------|
| Alvo de Iridio                            | R\$ 30.000,00  | Cons | Import   | CMS          | UFRGS        | -> TI-LGAD wafer production |
| Base de Carbetto de Silício               | R\$ 20.000,00  | Cons | Nacional | CMS          | UFRGS        |                             |
| Sistema de aquisição Timepix-4            | R\$ 90.100,00  | Cons | Import   | LHCb         | UFRJ         | Immediate                   |
| Gasto genérico                            | R\$ 80.000,00  | Cons | Import   | CMS          | UERJ         | -> TI-LGAD wafer production |
| Gasto genérico                            | R\$ 10.000,00  | Cons | Nacional | CMS          | UFRGS        |                             |
| Material para preparação dos wafers       | R\$ 185.500,00 | Cons | Import   | CMS          | UERJ         | -> TI-LGAD wafer production |
| Material para montagem de det. de silício | R\$ 106.000,00 | Cons | Import   | CMS          | UERJ         | -> TI-LGAD wafer production |
| High performance Oscilloscope             | R\$ 450.500,00 | Cap  | Import   | ALICE/ATLAS  | USP          | In 2024                     |
| Gasto genérico (HV Power supply)          | R\$ 50.000,00  | Cap  | Nacional | CMS          | UERJ         | In 2024                     |
| Laser profiler                            | R\$ 35.989,47  | Cap  | Nacional | ATLAS        | USP          | In 2025                     |
| Gasto genérico                            | R\$ 30.000,00  | Cap  | Nacional | CMS          | UFRGS        |                             |

- Adaptation (from other sources in the table, with additional from GT3 R\$50.000,00 SiPM + R\$30.000,00 electronic components): Payment for a manufacturing run of TI-LGAD sensors (new technology), to be manufactured by FBK/Italy, to instrument the CMS/PPS. Assembly and testing of sensors in Brazil.
- FELIX Phase-I card + fibers (with remaining \$ from oscilloscope)

Back up slides

# Small sensors / Test structures



- 2x2 and 5x5 with variations (slimmer edges, distance between gain layers).
- Variations with smaller metal border and also with smaller distance to GR in one edge. Down to 50+75  $\mu\text{m}$  (2x2).
- Additional TI-LGAD structures (similar to DRD3).
- Openings in metalization/passivation for LASER (2x2 & 5x5).

# Objetivos específicos do GT2

Para referência:  
INCT I workshop

Sem alteração

**10** - Participação na construção, qualificação, integração e comissionamento de novos sistemas que utilizam sensores semicondutores nos experimentos do LHC e eletrônica associada. Os desafios apresentados pelos experimentos do LHC motivaram intenso progresso nesses sensores para detecção de radiação ionizante e este projeto buscará a participação no desenvolvimento de diferentes tecnologias visando uma contribuição importante para os experimentos com os grupos brasileiros trabalhando em sinergia.

**11** - Simulação, desenvolvimento e teste de novas estruturas e geometrias de sensores semicondutores, principalmente os ultra-rápidos (Ultra Fast Semiconductor Detectors - UFSD) com respostas de picosegundos, visando futuros experimentos de Física de Altas Energias e aplicações multidisciplinares envolvendo medidas de raios-X, com o objetivo de transferir a experiência adquirida sobre esta tecnologia para instituições nacionais.

**16** - Qualificação de tolerância à radiação de ASICs e sensores semicondutores usados nos experimentos do LHC por meio de instalações nacionais de irradiação. Esses estudos são de grande relevância não apenas para os experimentos do LHC, mas para diversas áreas estratégicas no Brasil, uma vez que circuitos integrados (CI) são fortemente influenciados pela radiação e a necessidade de circuitos tolerantes à radiação é crescente para atender, por exemplo, a indústria eletrônica aeroespacial.



# Metas do GT2

Para referência:  
INCT I workshop

Sem alteração

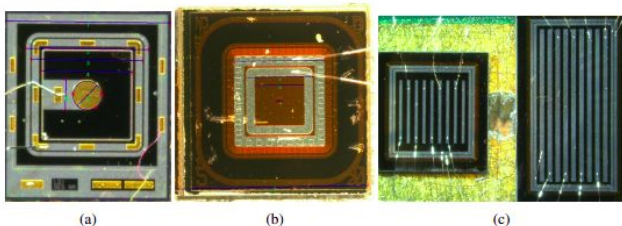
- Validação dos sistemas de testes de sensores semicondutores nas instituições brasileiras participantes (meta 5).
- Apresentações dos resultados em encontros de Project Design and Production and Readiness Reviews (PDR, PRR, PPR) realizados pelas colaborações ATLAS e CMS (metas 5 e 6).
- Finalização da construção, integração e testes das estruturas modulares, em etapas, nas salas-limpas do ATLAS e CMS no CERN (meta 6).
- Integração dos detectores nos experimentos ATLAS e CMS (meta 6).
- Implantação de códigos de simulação de transporte e transiente de resposta decorrente da ionização por partículas carregadas (metas 7 e 8).
- Fabricação e validação de estruturas novas de teste de acordo com os resultados das simulações (metas 7 e 8).
- Campanhas de irradiação de sensores com nêutrons em reatores (meta 20).
- Campanhas Irradiação de sensores com partículas carregadas em aceleradores (meta 20).
- Campanhas Irradiação de sensores com fótons (gama e raios-X) em irradiadores e geradores (meta 20).

# Convergence strategies and synergies - I

## Ongoing projects in collaboration with other institutes

- CNPEM-Sirius: Studies of the applications of ATLAS Low Gain Avalanche Diodes (LGADs) for *Time Resolved x-Ray Applications* .
- Eldorado: Packing and bonding of sensors for testing with X-rays.
- Integration of Timepix-4 with FELIX (LHCb experience with the Timepix architecture).
- Short-term: Sensor integration (PPS wire bonding) – Eldorado.

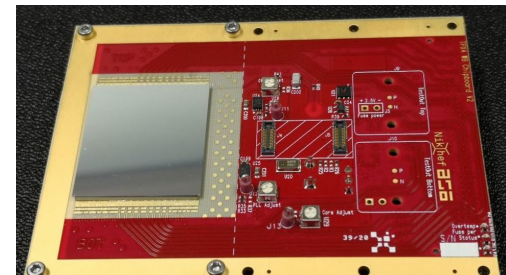
DC (a,b) and AC-coupled (c) LGADs for synchrotron light applications



The FELIX Phase-II DAQ prototype board

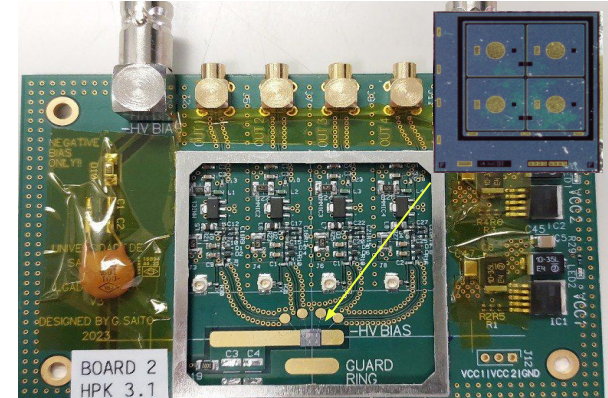
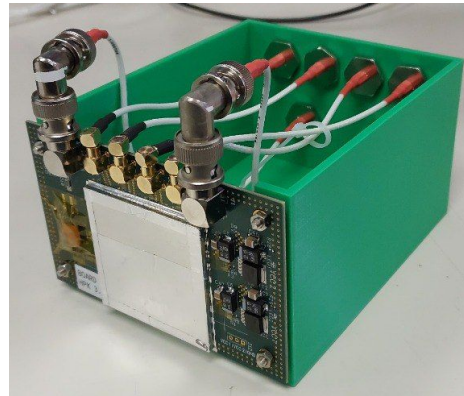
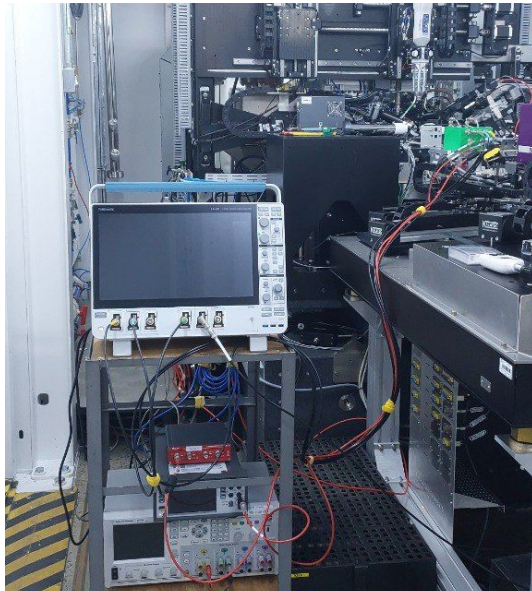
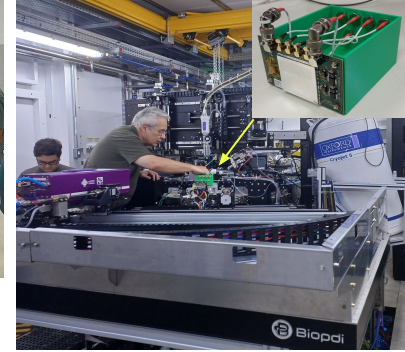


Timepix-4



# LGADS for picosecond time resolved X-ray applications

- 3 campaigns at Carnaúba beamline at LNLS
- Excellent collaboration with Sirius beam line, instrumentation and management
  - **very efficient (and very intense)** campaign
- ATLAS+ALICE collaboration in these tests
- Using HPK 3.1 ATLAS prototype sensor

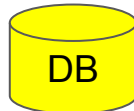
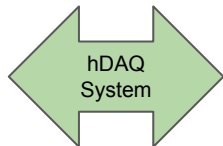




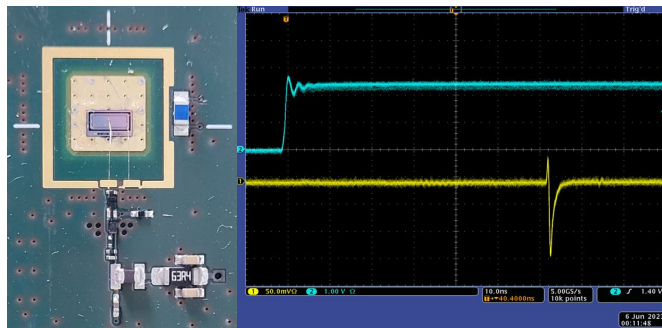
# Convergence strategies and synergies - II

## Collaborative use of infrastructure and labs

- CBPF/UERJ/UFRJ: detector test benches are shared between CMS and LHCb.
- USP: Semiconductor sensor characterisation lab
- Serving ATLAS - ALICE - CMS - LHCb.



## ***Fast Sensor Testing***

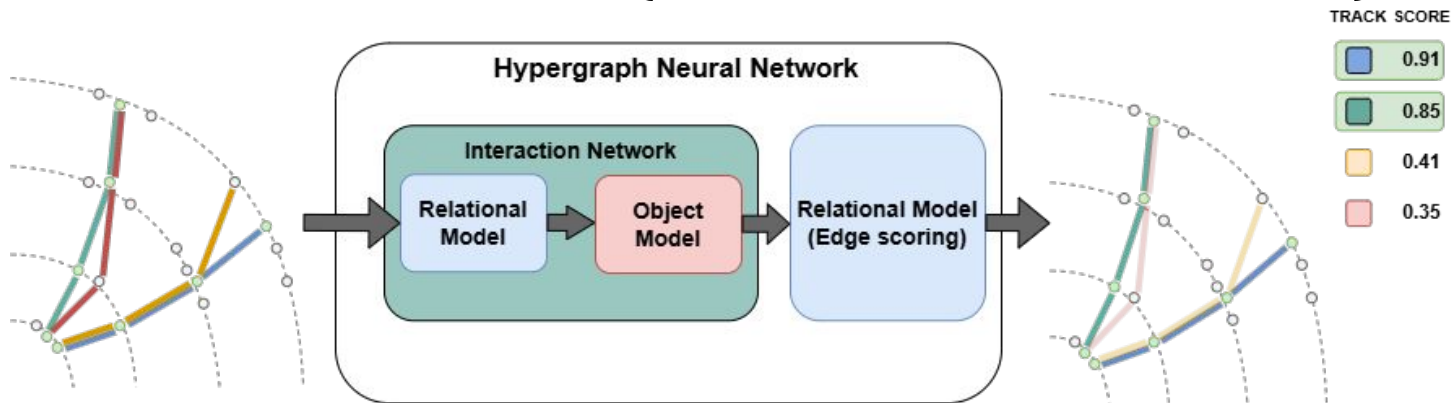




# 4. Hypergraph Neural Network (HGNN) pipeline

- **Hypergraphs** are graphs with (hyper)edges that can connect more than two nodes
- We devised a **Hypergraph Neural Network (HGNN)** pipeline
- Inspired by the Interaction Network (IN) architecture
  - Relational model  $\Rightarrow$  edge-wise (track candidates) convolution
  - Object model  $\Rightarrow$  node-wise (hits) convolution
- Two stages pipeline:
  - Graph construction: devise track candidates and organise them in a hypergraph
  - Network classification: HGNN scores candidates for their likelihood to be a true particle track
- Network input is a hypergraph composed of track candidates with the following feature spaces:

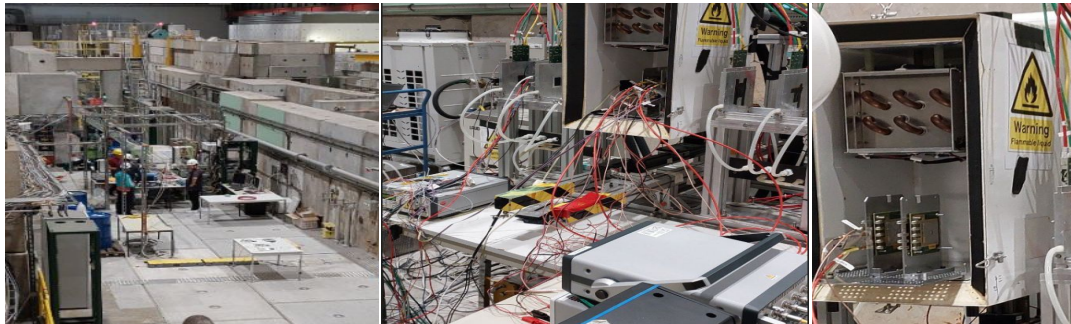
$$n = \{x, y, z, t, r, \phi, \theta\} \quad e = \{\text{nMeasurements}, \text{nOutliers}, \text{nHoles}\}$$



- State-of-the-art, 3.6 million ultra-fast semiconductor sensors (UFSD).
- **USP Activities:** Contribution to HGTD construction, Semiconductor sensor lab at USP
- Strong participation on the on-going HGTD activities at CERN (infrastructure, HGTD demonstrator assembly, sensor test facility)
- First expert integration week in April 2024
  - Sensor+ASIC+PEB+FELIX readout
- Participation in test beam activities at SPS - CERN

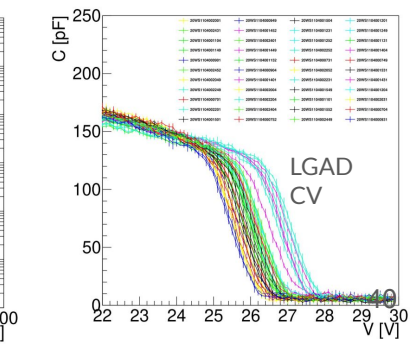
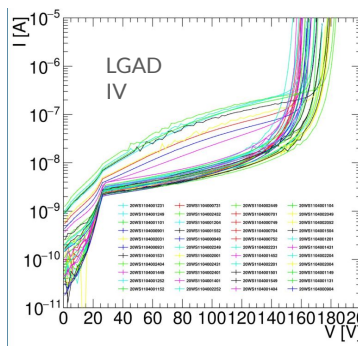
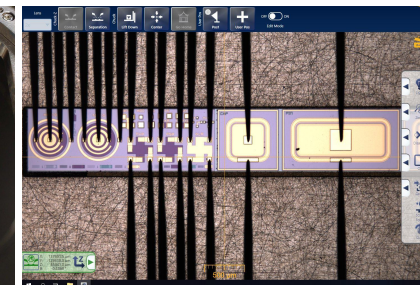
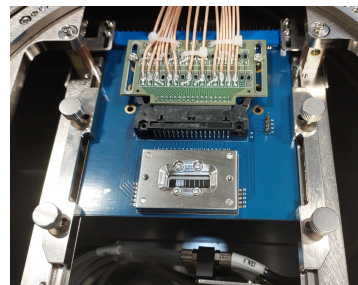
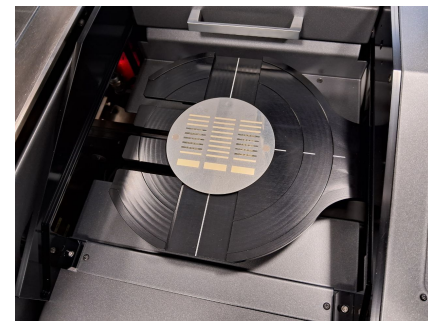
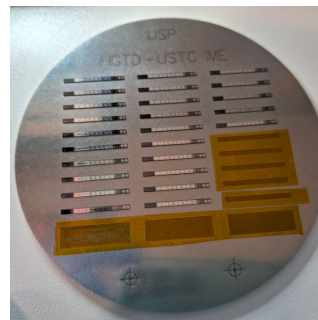
HGTD LGAD sensor test at CERN - SPS

HGTD demonstrator assembly and tests at CERN B180





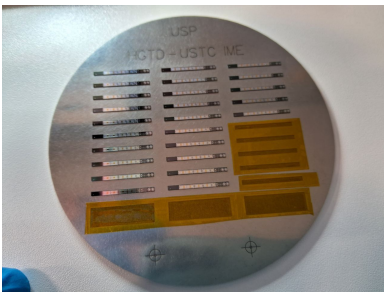
- New semiconductor sensor test facility at USP fully operational and measuring HGTD pre-production samples.
- Clean room with semi-automatic High Voltage probe station and instrumentation.
- Sensor and test structures characterization fully automatic.



- We are in full production mode !
- HGTD sensor PRR in July 17th 2024



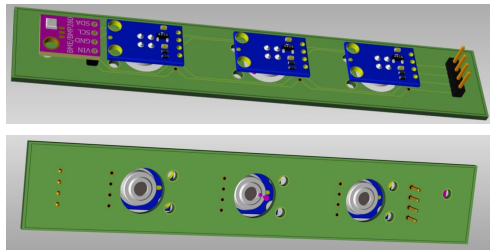
Sensors and structures are arriving from IHEP



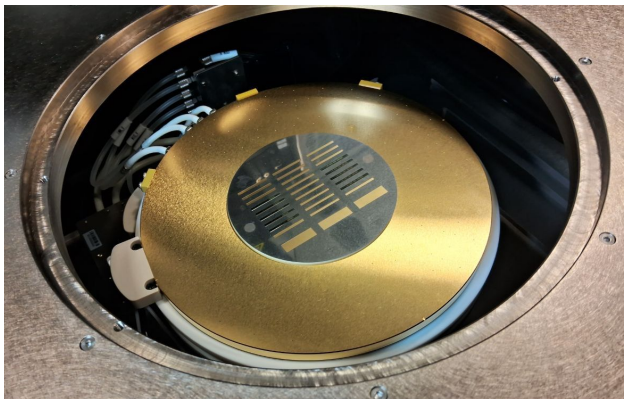
USTC-IME structure holder



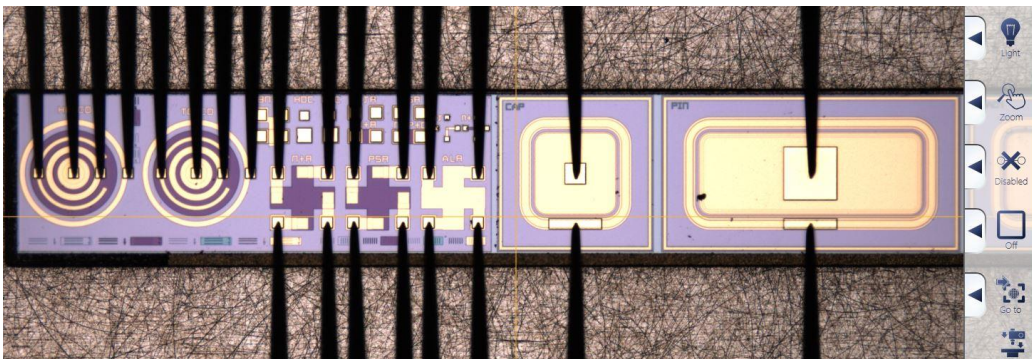
Probe station setup



Non-contact chuck temperature monitor



Holder loading in chuck

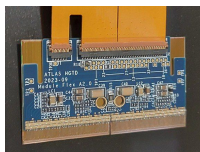


Test structure probing

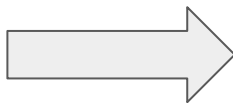
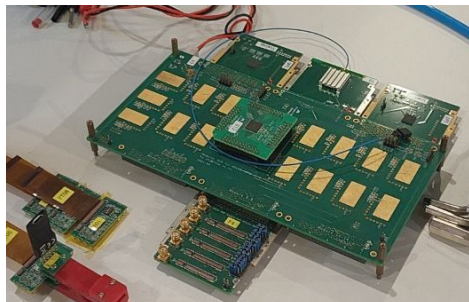


- Replicate a small readout bench at USP
- Monitoring through FELIX
  - Exercise HGTD DAQ
  - Timing distribution studies

PEB @ CERN



Modular PEB @ USP

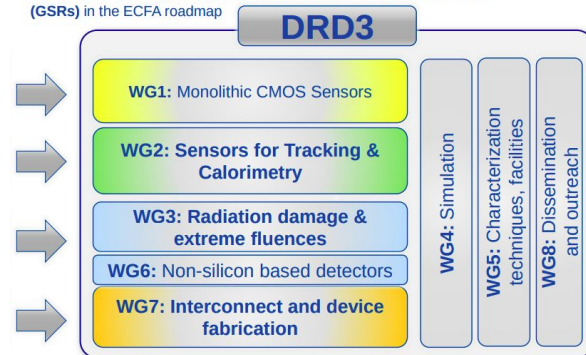


ATLAS Phase-I PCI-E FELIX Card (@ USP)



- HGTD construction @ CERN
- Upgrade the local facility at USP for TCT
- Complete the readout chain in São Paulo
  - New FELIX High Data Acquisition ( 1.2 Tb/s per board) for sensor readout backend
  - Already identified companies in SP able to cope with a very demanding hardware fabrication and firmware development (Eldorado/Lauquen/Hwit)
  - CNPEM also participating, seeking to adopt FELIX for future X-ray detectors data acquisition
- Development of new machine learning techniques for 4-dimension tracking using HGTD + new ATLAS semiconductor tracker
- DRD3- Semiconductors sensors WG 2 (Hybrid sensors) and WG-5 (Characterization methods and techniques)
  - R&D for new, radiation harder UFSD sensors
- Tests of the response of TI-LGAD and AC-LGADs under synchrotrons light

- We are covering all ECFA DRDTs
- Additional WGs were added to cover simulations, facilities and dissemination corresponding to **General Strategic Recommendations (GSRs)** in the ECFA roadmap



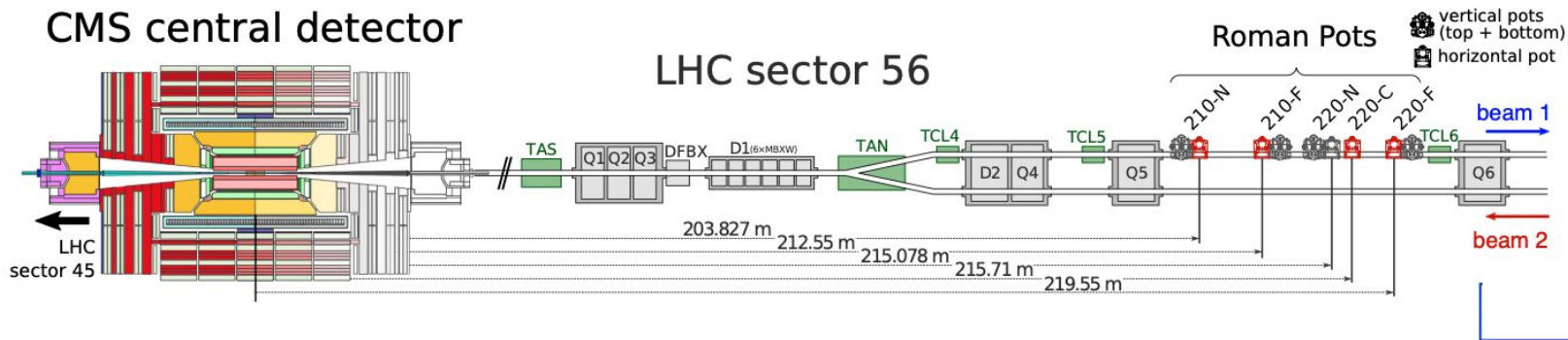
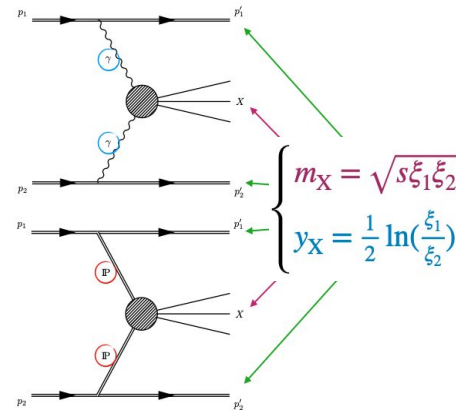
The FELIX Phase-II DAQ prototype board



# CMS PPS Run-3: Diamond sensors



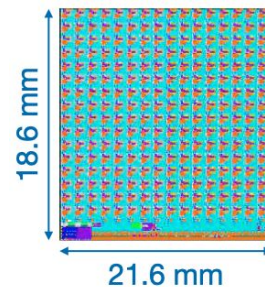
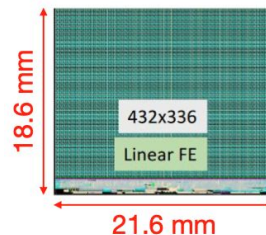
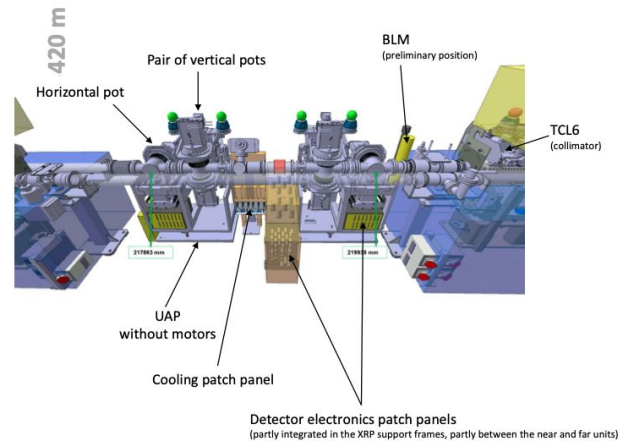
- A fraction of collisions in LHC results in forward "intact" protons
  - QED: photon interactions;
  - QCD: gluon pair interactions (Pomerons).
- **The Precision Proton Spectrometer (PPS)** measures tracking and timing of the protons at 200m from IP.
- The proton energy loss is associated to the central system X.
- The LHC can be used as a photon collider: search for new physics in the electroweak sector.
- Diamond or LGAD sensors for timing.



# PPS2 @ HL-LHC



- PPS2 may deploy 3 or 4 stations.
- Tracking: 6 3D pixels planes; Front-end: CROC 50×50  $\mu\text{m}$ -sq pixels; 2-3 chips per module
- Timing:
  - 5 double-layer planes of LGADs; Front end: ETROC 1.3 × 1.3 mm-sq pads
  - Option of scCVD Diamonds with similar technology for diamonds as Run-3
  - 4 double-sided x 4.5x4.5mm diamond pads in hybrid boards
  - Signal > NINO chip > 8 ch amplifier LVDS > HPTDC





# PPS 2 @ HL-LHC : Ultra-fast silicon sensors

- PPS2 timing sensors will reuse MTD ETL (Endcap Timing Layer) ROCs (ETROC).
- 1/3 of MTD-ETL sensor height in order to reduce occupancy. Sensor layers staggered vertically for full acceptance.
- MTD-ETL uses “standard” LGADs which have however a relatively large interpad distance ( $\sim 100\mu\text{m}$ ).
- PPS2 proposes to use TI-LGADs. Smaller interpad regions ( $\sim 10\mu\text{m}$ ), avoiding dead regions (in horizontal direction with previous layout).
- Pre-production batch to start soon with FBK. Funding from INCT CERN-Brasil.

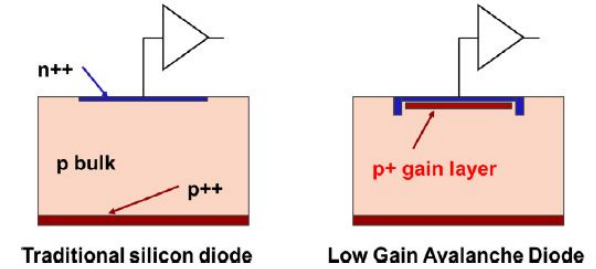


Fig. 1. Schematic of a traditional silicon diode (left) and of a Low-Gain Avalanche Diode (right). The additional  $p^{+}$  layer underneath the  $n^{++}$  electrode creates, when depleted, a large electric field that generates charge multiplications.

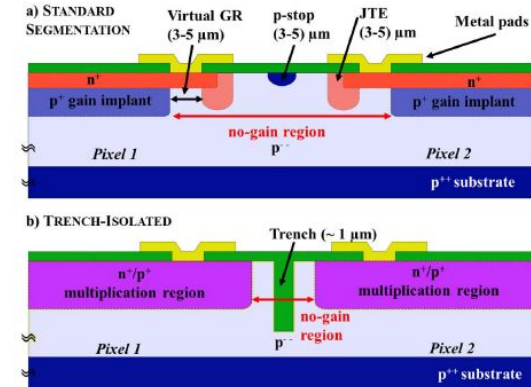
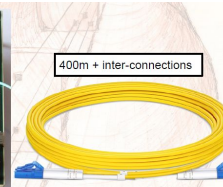
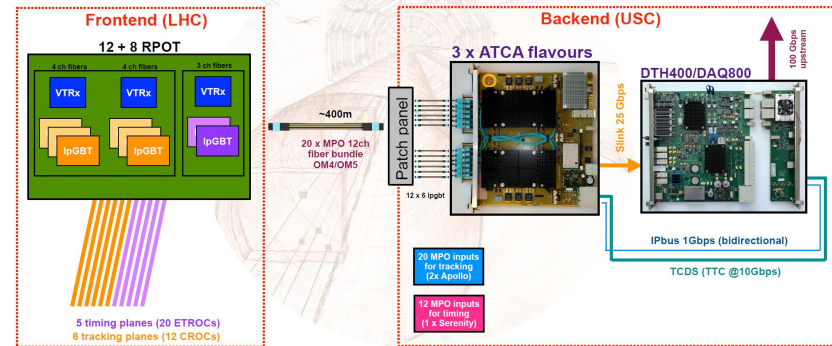
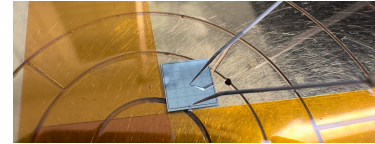


Fig. 1. Schematic drawings of a standard LGAD (a) and of the proposed trench-isolated LGAD (b).

# Planned activities

- Tests of pre-production sensors at HEPIC-USP (semi-automatic probe station)
- PCB project and fabrication for tests, wire-bonding (Eldorado, UERJ).
- Characterization bench (beta source and laser).
- Characterization at low temperature (LAPE/UFRJ).
- Sample tests under X-rays (Sirius - CNPEM).
- Post-irradiation characterization (CERN).
- ETROC bump bonding and PCB attachment for DAQ readout (backend).
- Data transmission tests (PPS/LHC tunnel → CMS).

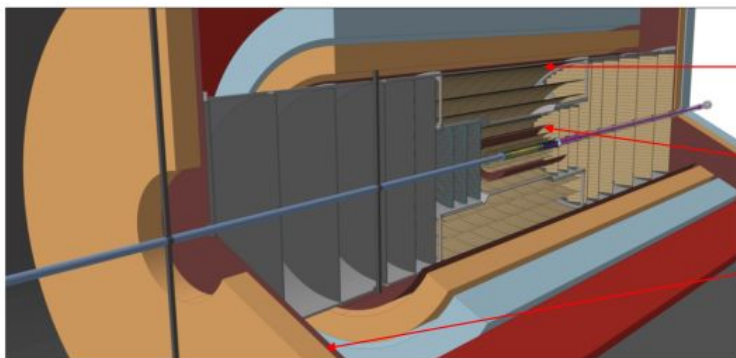


<https://vidbplus.web.cern.ch/manual/index.html>  
<https://vidbplus.web.cern.ch/>

<https://etl-rb.docs.cern.ch/Hardware/#kou195>

# ALICE3 Timing Detector

- ALICE3 Time of Flight (ToF): time resolution  $\sim 20\text{ps}$ .
- R&D for faster and thinner sensors.
- Radiation dose smaller than ATLAS, more flexibility in the project.



## Barrel TOF ( $|\eta| < 1.75$ )

- Outer TOF radius = 85cm  
surface:  $30\text{m}^2$ , pitch: 5 mm
- Inner TOF, radius = 19 cm  
surface:  $1.5\text{m}^2$ , pitch: 1 mm

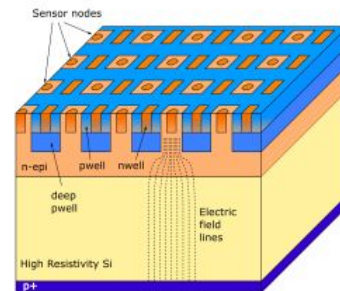
$$\sigma_{\text{TOF}} \lesssim 20\text{ps}$$

## Forward TOF ( $1.75 < |\eta| < 4$ )

- Inner radius = 15 cm, Outer radius = 150 cm  
surface =  $14\text{m}^2$ , pitch = 1mm to 5mm

Two R&D lines

- CMOS sensors with gain (**baseline**): main R&D line in ALICE
- LGADs (**fallback**): R&D line in ALICE with very thin sensors



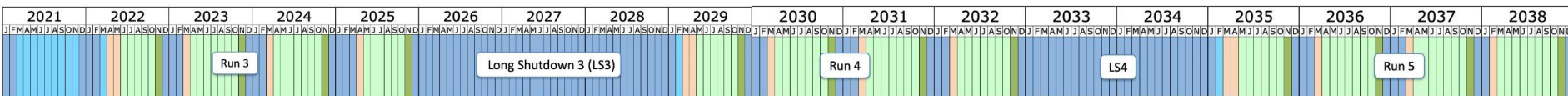
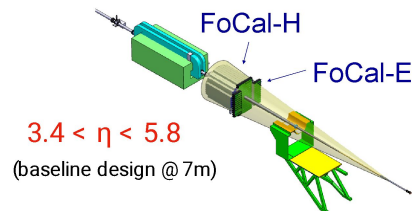


ALICE

# ALICE Upgrades

Run4: FoCal-E: SiW sampling calorimeter.

- Silicon detectors (Pad&Pixels) already defined.
- Brazil is involved in the readout (and trigger?) =>WG4



ALICE3

ALICE3: a completely new detector for Run5: extensive use of silicon!

USP is getting involved in Time-of-Flight detector

- Technology:
  - baseline (or "fallback"): LGAD + hybrid (consolidated technology)
  - target: LGAD monolithic LGAD
- an active cooperation with Torino and Bologna started the second half of 2023

Project timeline:

*"Heavy" R&D 26-27 // construction and pre commissioning 28-31 // detector installed in the 2033-34*

Planned local activities:

- extensive testing and validation of sensors

Needs:

- to extend probe station capacity (in particular the "injection" part of stimuli [rapid pulses, laser?])
- at least one more person with exclusive and full-time dedication (PostDoc? )



# Timeline

- Março/25: Amostras polidas metalizadas no IF-UFRGS com boa adesão.
- Julho/25: Caracterização das amostras de crescimento lento no IF-UFRGS (FTIR, fotoluminescência, MEV).
- Ago25-Set/Fev26: Testes adicionais com parceiro na Finlândia
  - Boa adesão do filme confirmada pelos testes; processo de metalização pode ainda ser melhorado.
  - Contaminação acima do esperado, com sinal e largura menores que o esperado com base em amostras de referência.
  - Sinal não estabiliza ao longo do tempo devido à presença de impurezas.
    - Novas amostras precisam ser estudadas.

# 1. HGTD Sensor testing @ USP

- Structure assembly and metrology to verify the height uniformity (contact height within  $< 5 \mu\text{m}$ ).

