Solid State Detectors: rapidfire talks

A. Morozzi	Innovations in the design of thin silicon sensors for extreme fluences
M. Da Rolo	ARCADIA - piattaforma INFN per FD-MAPS in tecnologia CMOS
A. Ciavatti	Novel ionizing radiation detectors based on perovskite films
B. H. Lim	Thin monolithic pixel sensors with fast operational amplifier output in a 65 nm imaging technology
D. Colella	ALICE ITS3: the first truly cylindrical inner tracker
A. Loi	Timespot timing performance from 3D trenches sensors
L. Piccolo	Timespot results on CMOS 28nm electronics
M. Duranti	Requirements for Si-microstrip (LGAD) for next generation space detectors
B. Fraboni	Organic thin films as flexible, large area X-ray and proton detectors
A. Lai	Silicon Photonics high speed links for HEP and space

IFD 2022 : INFN Workshop on Future Detectors

17-19 October 2022 Bari- Italy

INFN

AIDA innova

Innovations in the design of thin silicon sensors for extreme fluences

V. Sola, R. Arcidiacono, P. Asenov, G. Borghi, M. Boscardin, N. Cartiglia, M. Centis Vignali, T. Croci, M. Ferrero, S. Giordanengo, L. Menzio, V. Monaco, <u>A. Morozzi</u>, F. Moscatelli, D. Passeri, G. Paternoster, F. Siviero, M. Tornago

Fisica Torino Dipartimento di Eccellenza

FONDAZIONE BRUNO KESSLER

ISTITUTO OFFICINA DEI MATERIALI

The Challenge

At present, difficult to operate silicon sensors above 10^{16} n_{eq}/cm^2

The goals

➢ Measure the **properties of silicon sensors** at fluences above 10^{16} n_{eq}/cm^2

➢ Design **planar silicon sensors** able to work in the fluence range $10^{16} – 10^{17}$ n_{eq}/cm^2

➢ Estimate if such sensors generate **enough charge** to be used in a detector exposed to extreme fluences

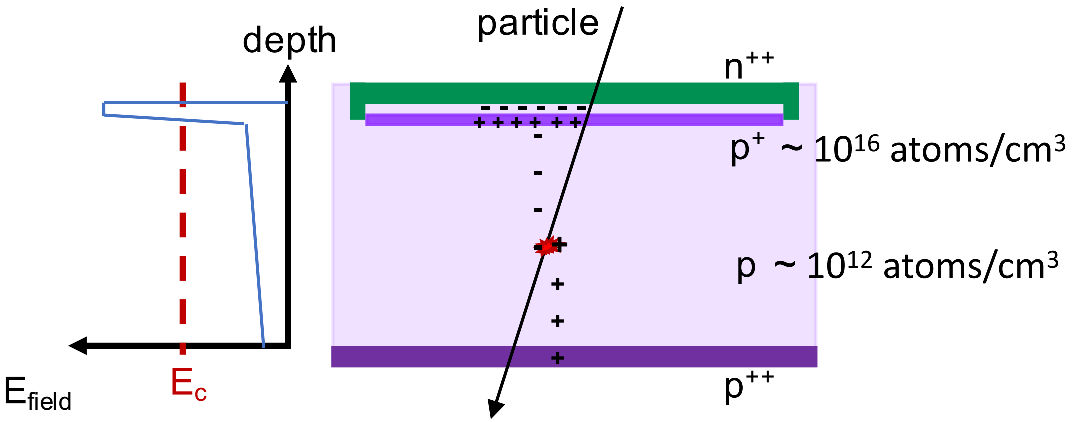
The strategy

To overcome the present limits above 10^{16} n_{eq}/cm^2 we exploit:

1. **Saturation** of the radiation damage effects above $5{\cdot}10^{15}$ n_{eq}/cm^2
2. The use of **thin** active substrates (20 – 40 μm)
3. **Extension** of the charge carrier multiplication up to 10^{17} n_{eq}/cm^2

→ **The whole research program is performed in collaboration with FBK**

Low-Gain Avalanche Diodes

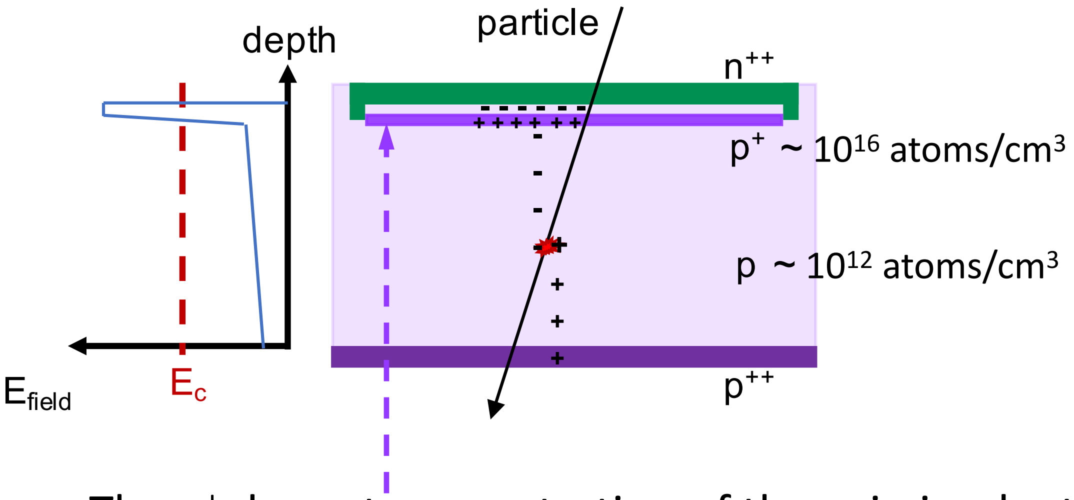


Low-Gain Avalanche Diodes (**LGADs**) are n-in-p silicon sensors

Operated in low-gain regime (~ 20) **controlled** by the external bias

Critical electric field $E_C \sim 20 - 30$ V/µm ⟶ **gain layer region**

Low-Gain Avalanche Diodes – **Innovation**



The p^+ dopant concentration of the gain implant gets **reduced** by irradiation and LGADs loose their multiplication power above ~ $3{\cdot}10^{15}$ n_{eq}/cm^2

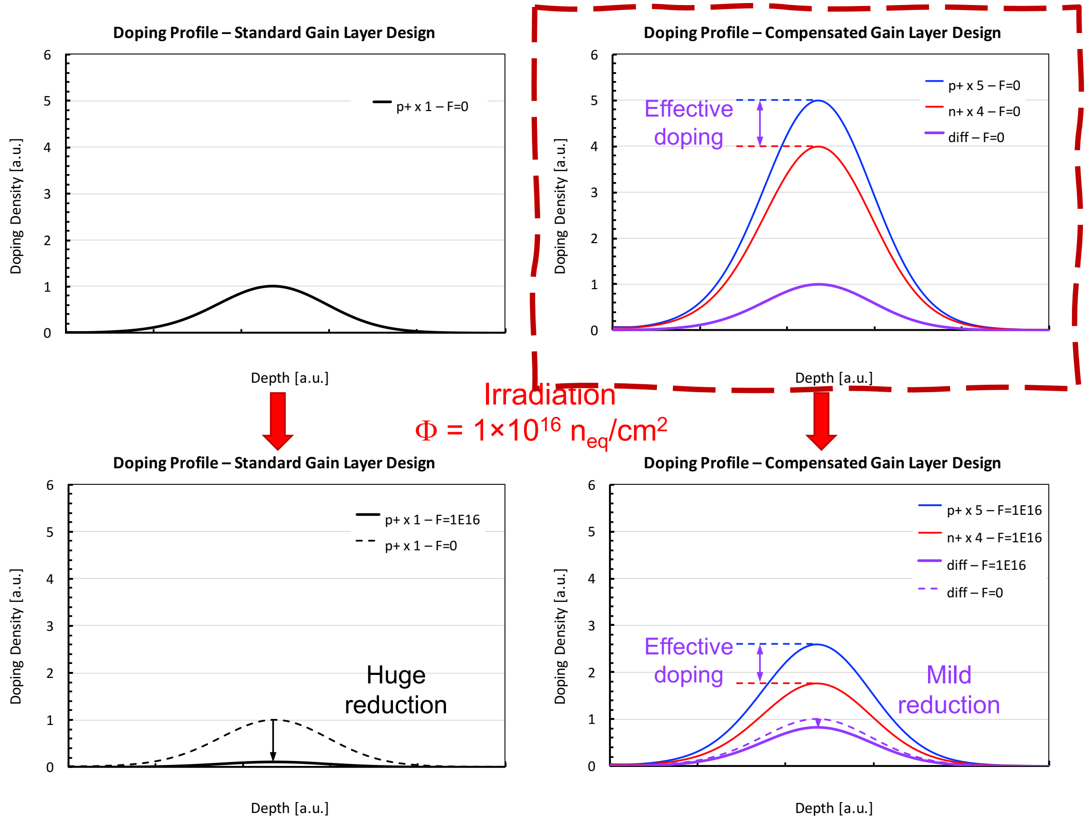
An **innovative design** of the gain implant has been designed to extend signal multiplication up to ~ 10^{17} n_{eq}/cm^2

→ **Complensated LGAD**

Low-Gain Avalanche Diodes (**LGADs**) are n-in-p silicon sensors

Operated in low-gain regime (~ 20) **controlled** by the external bias

Critical electric field E_C ~ 20 – 30 V/µm → **gain layer region**

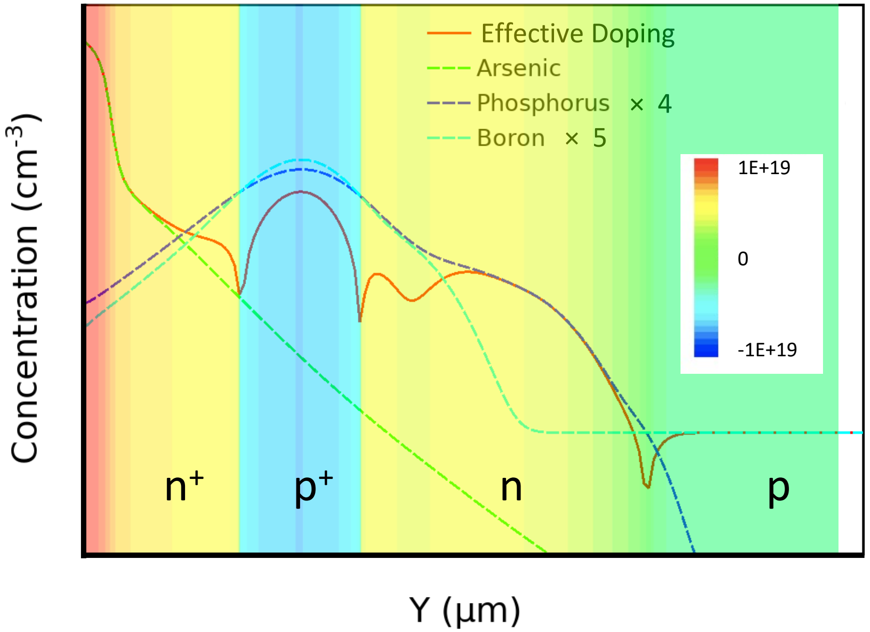


From Simulation to Production

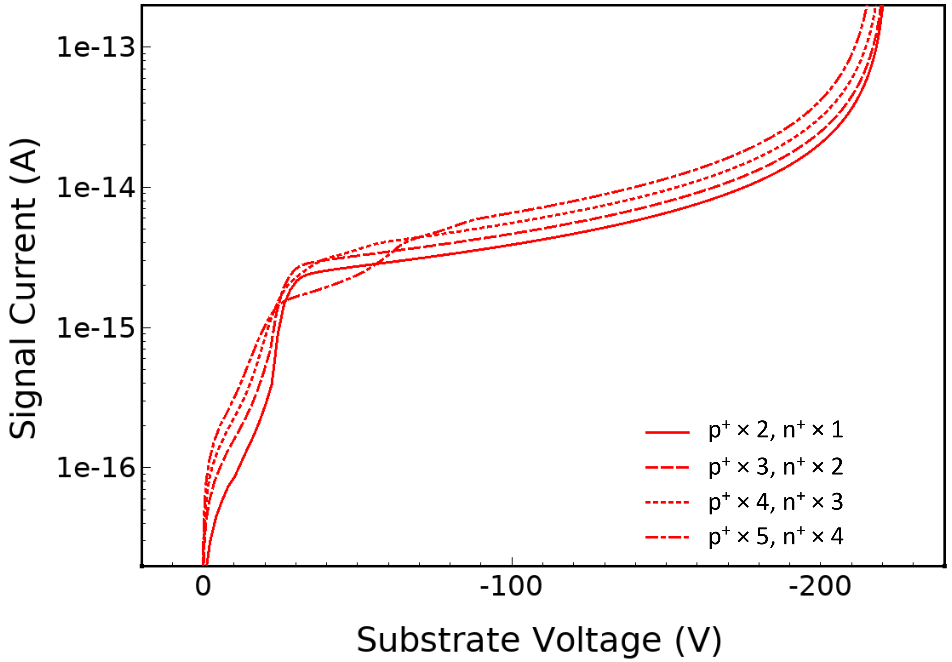
Process simulations of Boron (p^+) and Phosphorus (n^+) implantation have been performed

The electrostatic simulation shows that it is possible to optimise the production process to replicate the operation conditions of standard LGADs

Doping Profiles from Process Simulation



I-V from Simulation

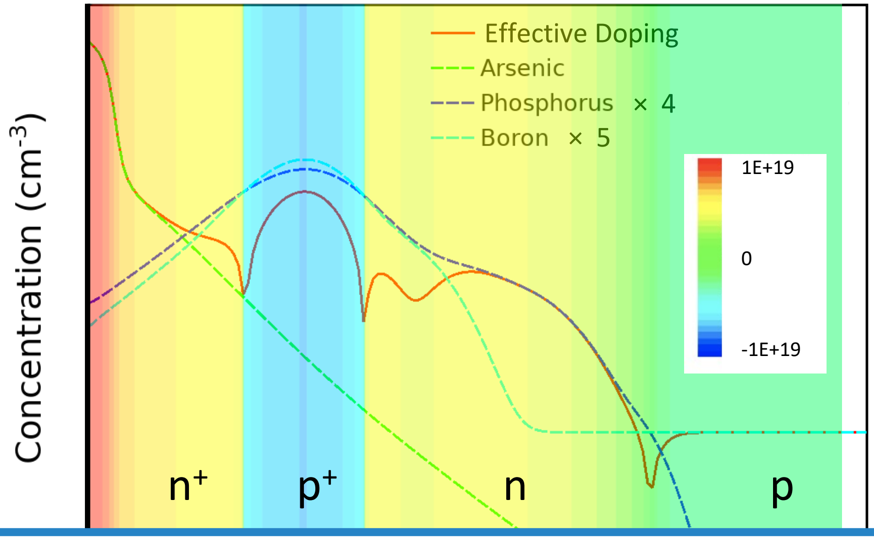


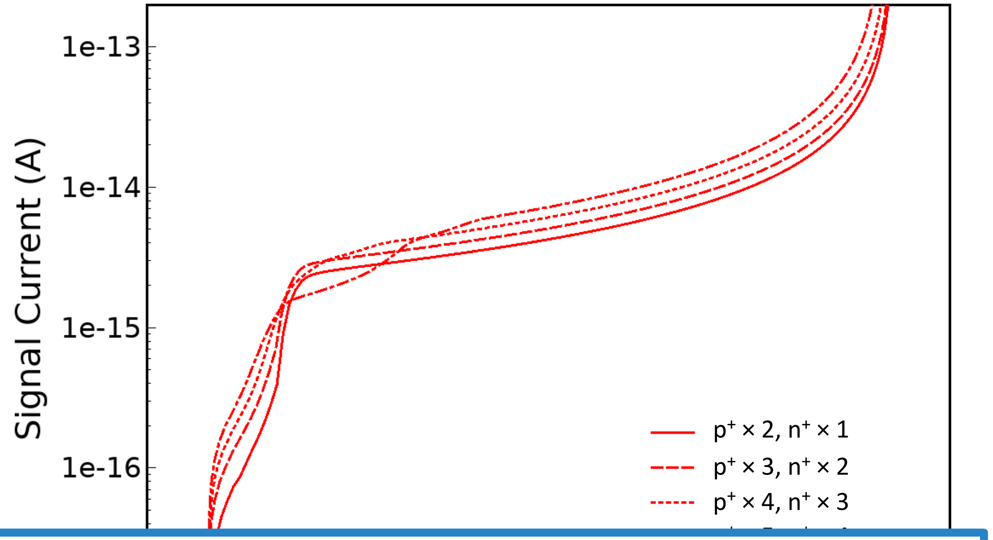
→ The first batch of compensated LGAD is about to be delivered by FBK

From Simulation to Production

Process simulations of Boron (p⁺) and Phosphorus (n⁺) implantation have been performed

The electrostatic simulation shows that it is possible to optimise the production process to replicate the operation conditions of standard LGADs


Doping Profiles from Process Simulation


I-V from Simulation

→ A 3 years project has been accepted for funding by AIDAinnova as Blue Sky R&D to investigate and develop the compensated LGAD design

Acknowledgements

We kindly acknowledge the following funding agencies and collaborations:

- INFN CSN5
- Ministero della Ricerca, Italia, FARE, R165xr8frt_fare
- Ministero della Ricerca, Italia, PRIN 2017, progetto 2017L2XKTJ – 4DinSiDe
- MIUR, Dipartimenti di Eccellenza (ex L. 232/2016, art. 1, cc. 314, 337)
- Università deli Studi di Torino, Grant for Internationalization – SOLV_GFI_22_01_F
- European Union’s Horizon 2020 Research and Innovation programme, Grant Agreement No. 101004761
- AIDAinnova, WP13
- RD50, CERN

ARCADIA

an INFN Design and Production Platform for Fully Depleted MAPS with a 110-nm CMOS Process

ARCADIA

Istituto Nazionale di Fisica Nucleare

AIDA innova

Manuel Rolo (INFN)
on behalf of the ARCADIA Collaboration

IFD2022

INFN Workshop on Future Detectors
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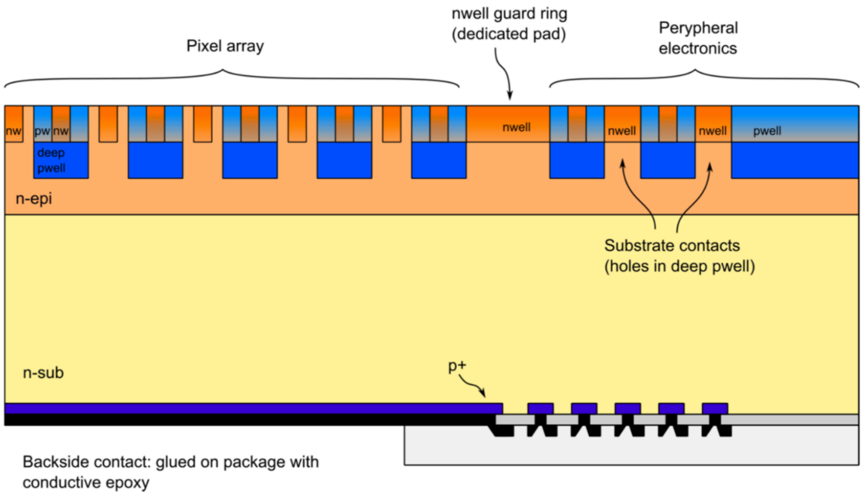
ARCADIA (INFN CSNV Call Project)

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

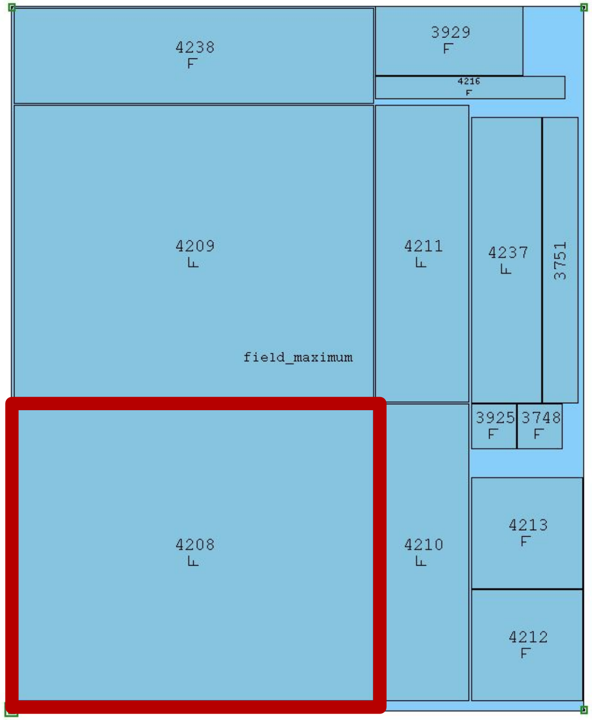
Fully Depleted Monolithic Active Pixel CMOS sensor technology platform allowing for:

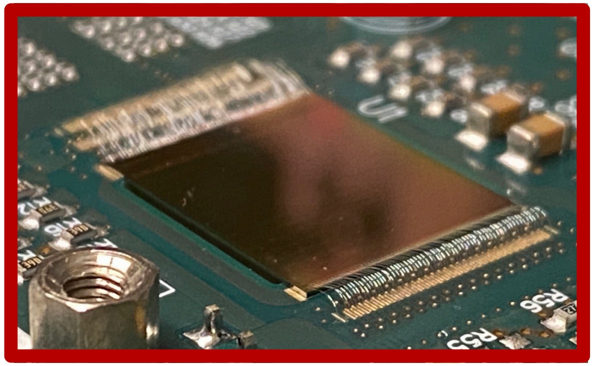
- Active sensor thickness in the range 50 µm to 500 µm or more;
- Operation in full depletion with fast charge collection by drift, small collecting electrode for optimal signal-to-noise ratio;
- Scalable readout architecture with ultra-low power capability (O(10 mW/cm2));
- Compatibility with standard CMOS fabrication processes: concept study with small-scale test structure (SEED), technology demonstration with large area sensors (ARCADIA)
- Technology: 110nm CMOS node (quad-well, both PMOS and NMOS), high-resistivity bulk
- Custom patterned backside, patented process developed in collaboration with LFoundry



"Fully Depleted MAPS in 110-nm CMOS Process With 100–300-µm Active Substrate," in IEEE Transactions on Electron Devices, June 2020, doi: 10.1109/TED.2020.2985639.

ARCADIA Technology demonstrators

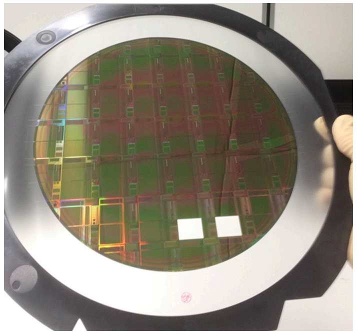


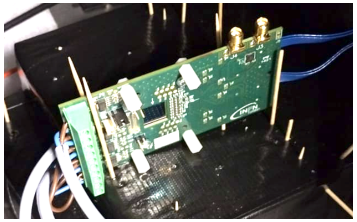


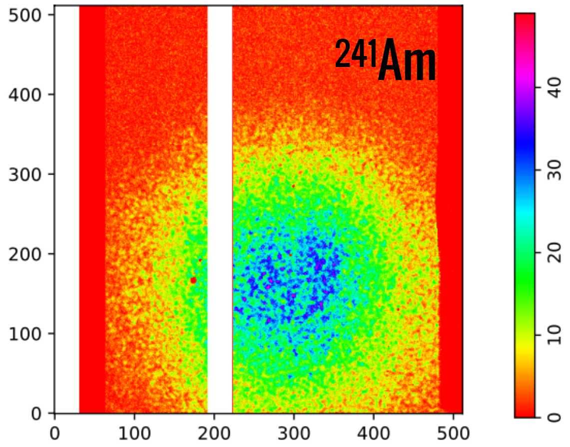
- **ARCADIA-MD1a**/b Main Demonstrator
- ARCADIA-miniD (debug)
- ARCADIA-miniD with on-chip LDOs for large-scale yield management
- MAPS and test structures for PSI (CH)
- MATISSE Low Power (ULP front-end for space instruments)
- pixel and strip test structures down to 10um pitch
- ASTRA 64-channel mixed signal ASIC for Si-Strip readout
- 32-channel monolithic strip and embedded readout electronics
- (LC2) MATISSE_TIMING: VFE for fast timing (R&D for ALICE3 timing layers)
- (LC3) Small-scale demonstrator of a X-ray multi-photon counter
- (LC3) Wafer splits with timing layer, new R&D towards <<100 ps timing performance: test structures and multi-pixel active demonstrator chip

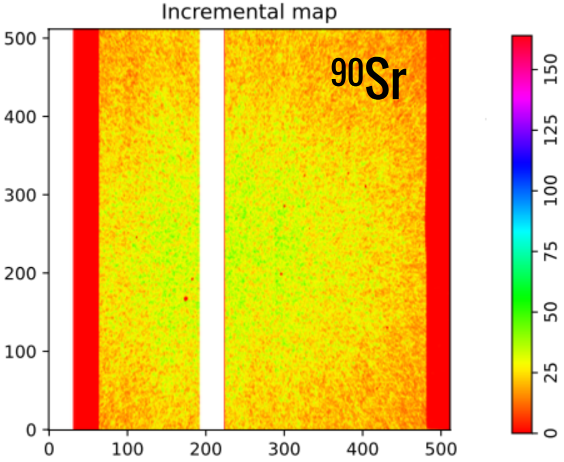
ARCADIA Design and Test Platform

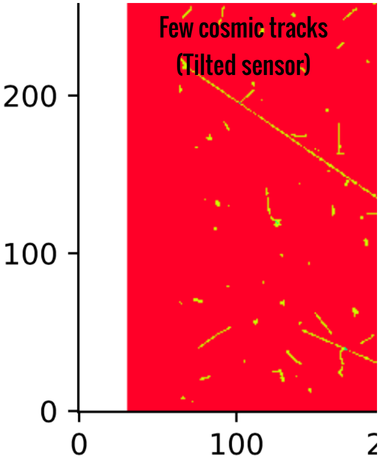
- **ARCADIA:** CMOS sensor design and fabrication platform with several groups working on:
  - Sensor R&D and Technology
  - CMOS IP Design and Chip Integration
  - Data Acquisition for electrical characterisation and beam tests with multi-chip telescopes
  - Radiation Hardness qualification
  - System-level characterisation for Medical (pCT), Future Leptonic Colliders and Space
- Allocated budget ≈ 1.4MEur (INFN and external funds) for 3 full SPW runs (2020-2022), 52 Members from 7 INFN Divisions. Moving from a CSN5 Call into RD_FCC, AIDAinnova, ALICE3.











Outlook: ARCADIA… or CMOS DMAPS in general

- **Monolithic active pixel sensors** are now ubiquitous in **HEP** trackers and are making their inception into (low-power) **space**, (high-rate) **medical** applications. Cost effective reticle scale sensors, compatible with standard CMOS fabrication, could pave the way to very large area tracking and timing detectors

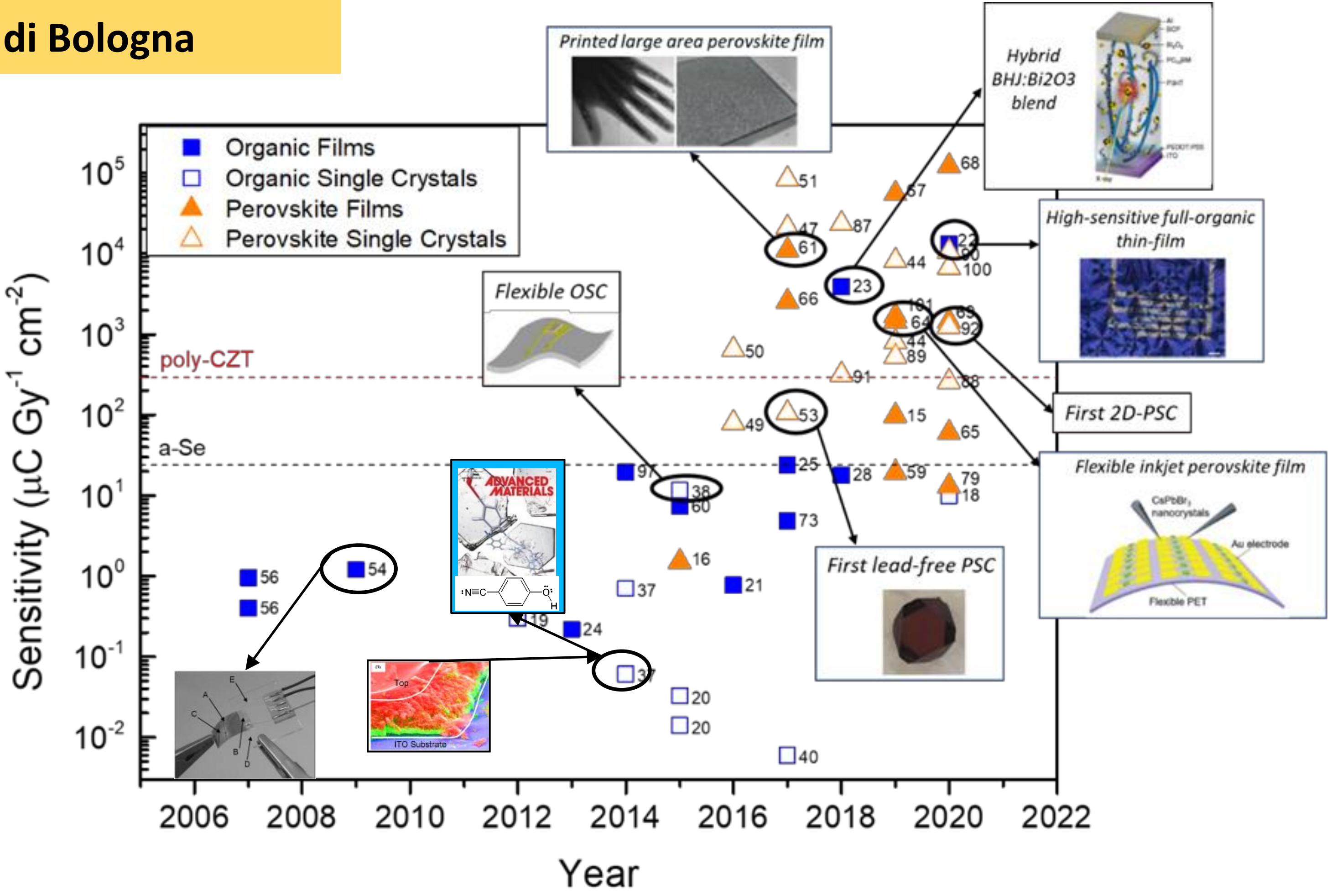
- CMOS Depleted monolithic pixel (and strip) sensors are now a strong candidate both for future low material budget silicon trackers and for timing layers, with investment and R&D mostly focusing on:
  - very low-power architectures O (20 mW/cm^2)
  - process engineering for better time resolution O (100 ps) or better
  - larger and thinner chips towards all/only-silicon inner trackers

- We need to foster access to advanced technologies and foundries, and make a good use of the most advanced integration and industry standard wafer stacking/bonding techniques

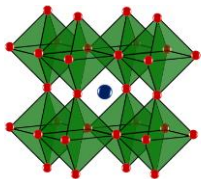
- The federation of the activity on sensors and microelectronics, working alongside experts on detector, system integration and analysis will dramatically increase our scientific impact factor.

**Andrea Ciavatti
CSN V – Sezione di Bologna**

Novel ionizing radiation detectors based on perovskite film



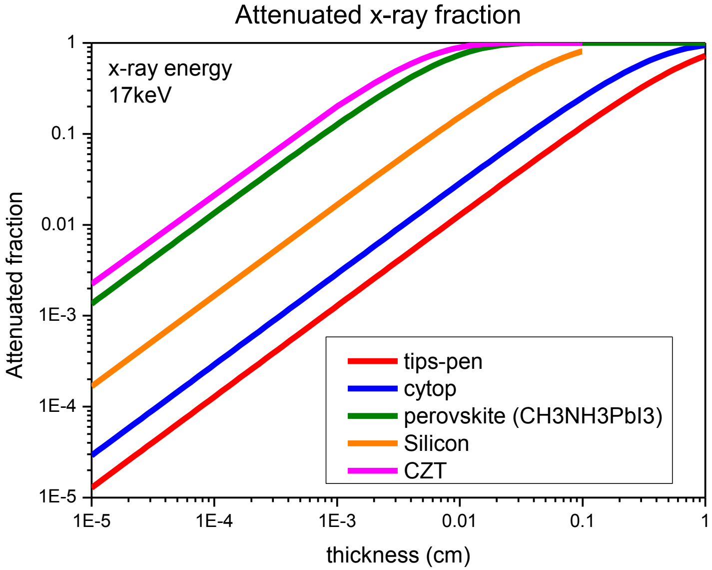
Hybrid Organic/Inorganic Lead Halide Perovskites (HOIP) Why?



→ High perfoming, solution processed optoelectronic devices

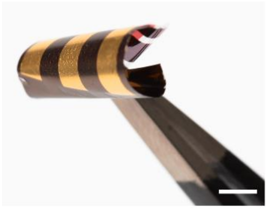
→ High charge carriers mobility tens of cm^2/Vs

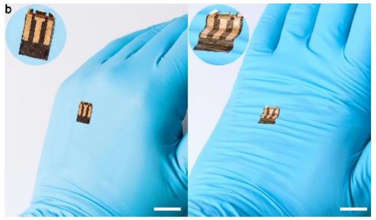
→ High XR attenuated fraction: Heavy atoms (eg. Pb) inside

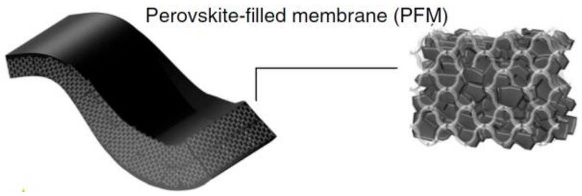


L. Basiricò et al., Adv. Mater. Technol. 2020, 2000475

Flexible Perovskite X-ray detectors



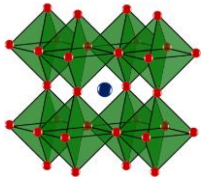




S. Demchyshyn, L. Basiricò et al.. Adv. Science, 2020, 7, 24, 2002586

2D layered HOIP micro-crystalline films photoconductor

3D HOIP

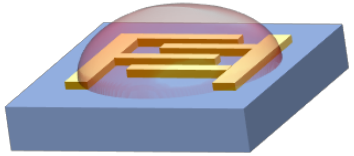


- X Low bulk resistivity
- X High trap states density
- X Significant ion migration effects
- X Fast degradation in air and in radiative fields

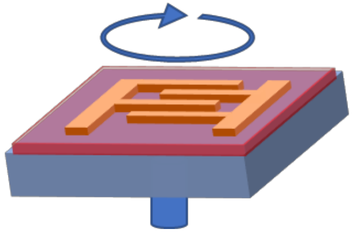
→ large dark current drift and poor stability!

PEA_2PbBr_4 (PEA = $C_6H_5C_2H_4NH_3^+$)

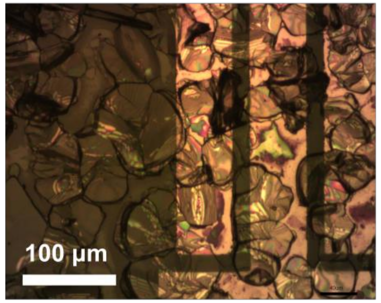
- charge carriers strongly confined in the inorganic layers
- highly anisotropic charge transport
- high resistivity due to low intrinsic charge carrier density, suppressed ion migration.
- Environmental stable due to low oxidation

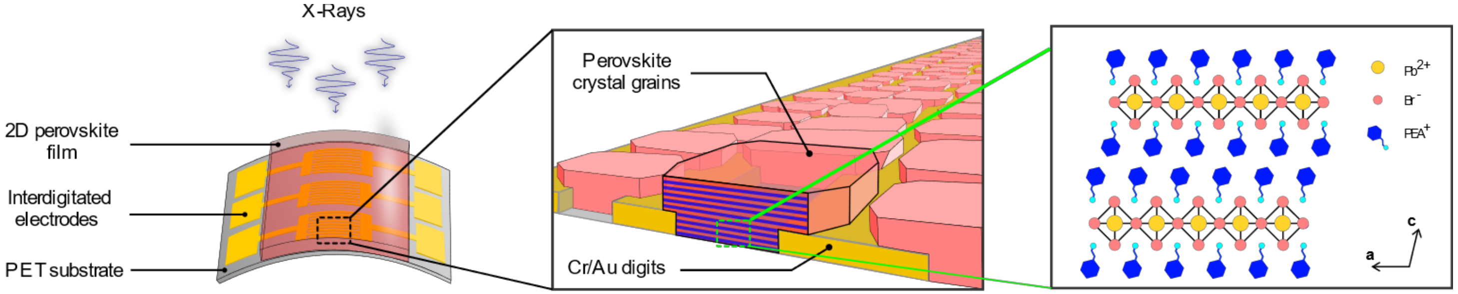


1. Solution droped on Au/Cr patterned substrate

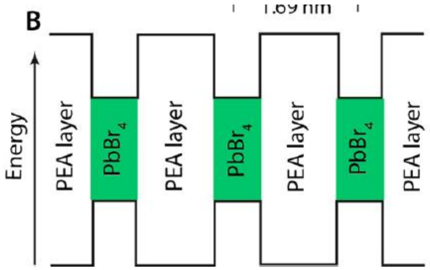


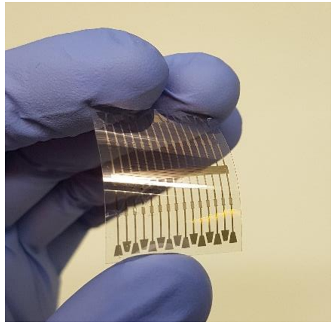
2. Spin-coating + annealing





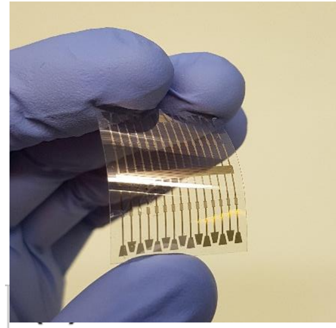
electronic structure is akin to a <u>multiple quantum well</u>

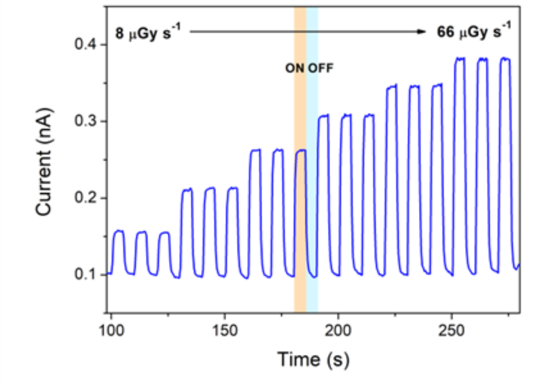


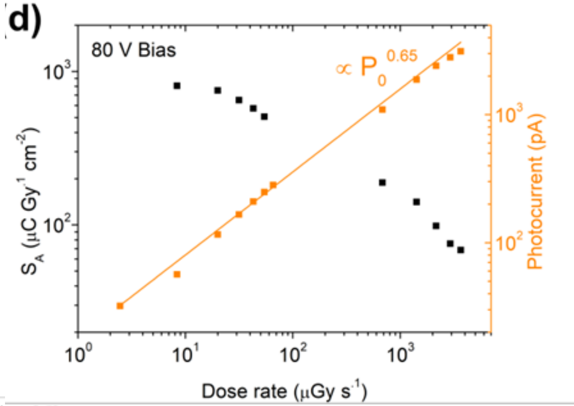


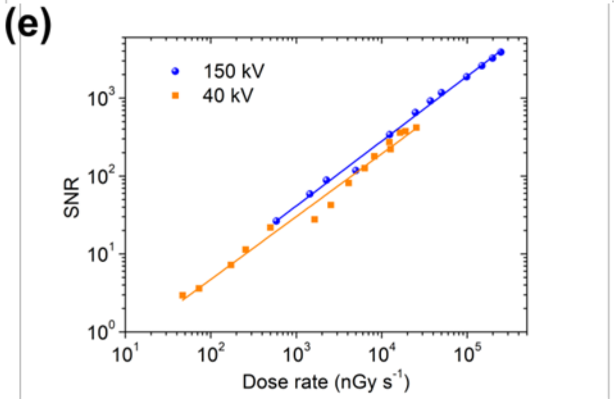
A.Ciavatti et al., Adv.Optical Mater., 2021
10.1002/adom.202101145

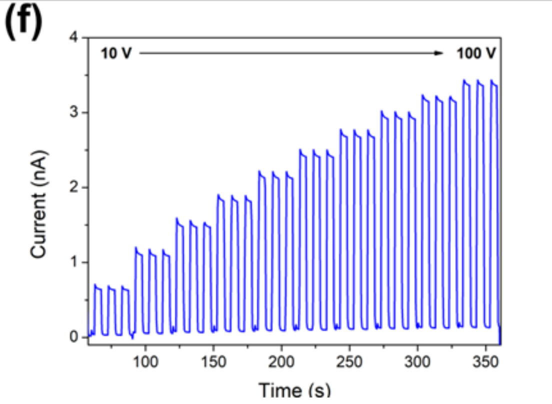
2D (PEA2PbBr4) X-ray direct direct detection









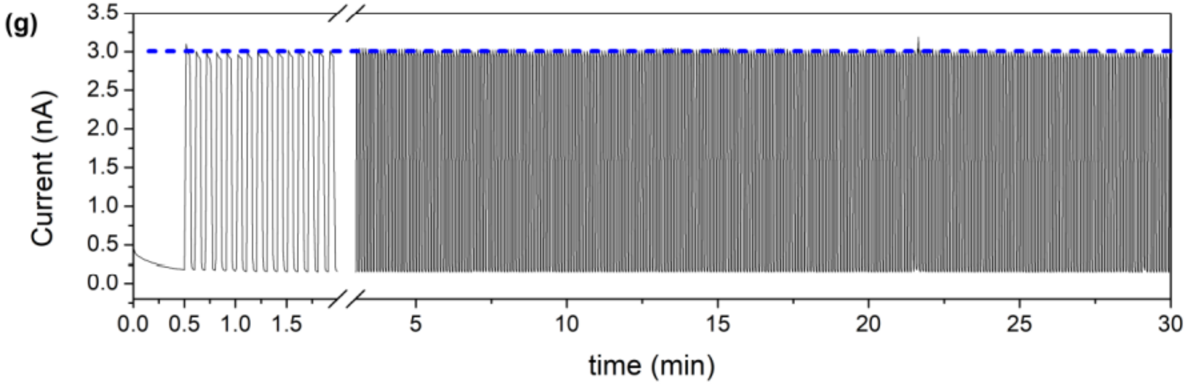


- ✓ Tested energy range from 40kVp to 150 kVp
- ✓ Operative bias from 3 V to 100 V
- ✓ Sensitivity > 800 uC/Gy cm^2 → comparable to best (but less stable) film detectors
- ✓ SNR of 10^2 at 2 µGy/s (typical mammography)
- ✓ Limit of Detection down to 42 nGy/s (best for thin film detector)

Stability:

- No drifting or bias stress under
- Stable to repeated pulses (300 pulses for 30 minutes@80V).

80 days of shelf storage.



ANEMONE (esperimento CSN V)

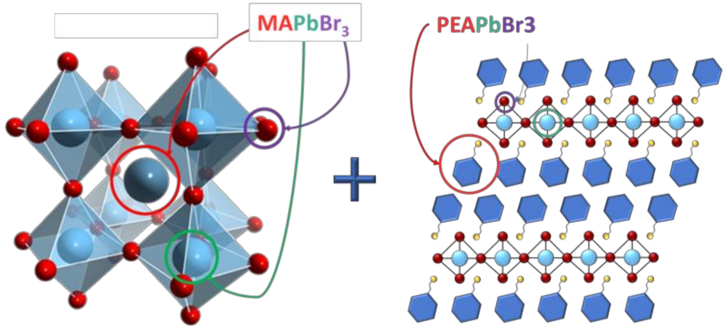
hAdroN bEam MONitoring by pErovskite based detectors

2022-2023 Area di ricerca: Rivelatori
RN: Laura Basiricò (INFN- sezione Bologna)
Unità partecipanti:

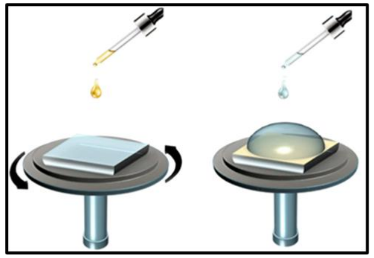
- **INFN Bologna section (INFN-BO)**
- **Laboratori Nazionali del Sud (LNS)**
- **INFN Firenze section (INFN-FI)**

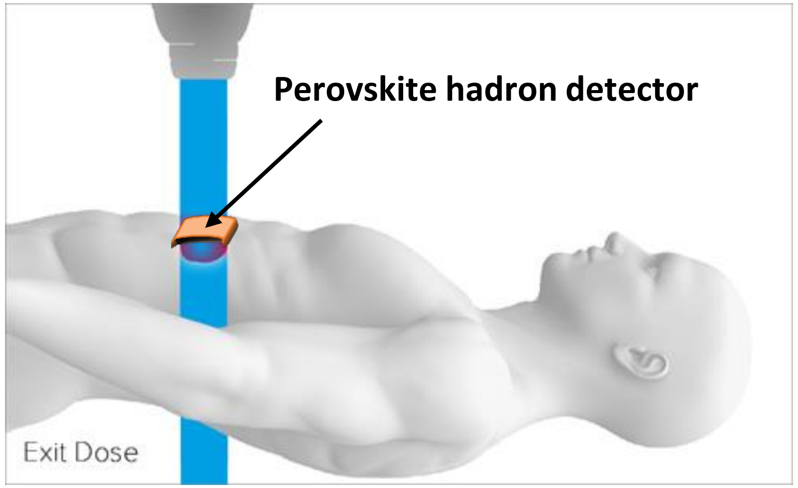
MAIN AIM:

Development of **the first PEROVSKITE (Hybrid and Inorganic) film-based real-time direct detector for PROTONS and IONS**, as **beam monitor** for **hadron therapy** and as beam test tool for high-energy experiments, realized on flexible substrate.

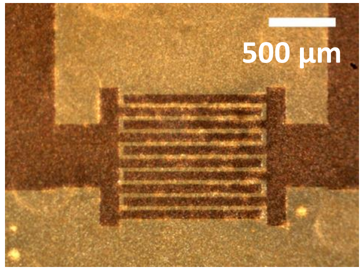


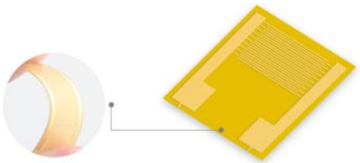
Mixed 3D/2D Hybrid organic-inorganic halide perovskite:
MAPbBr$_3$/ PEA$_2$PbBr$_4$





Solution grown on PET **flexible substrate**





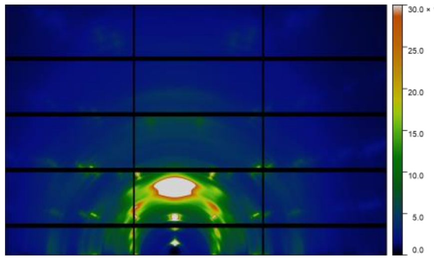
OBJECTIVES:

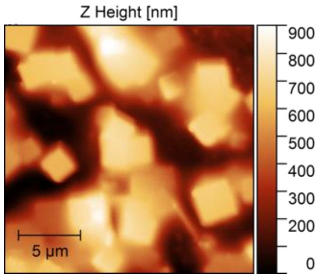
i) **Unravel the interaction of charged particles** with nanostructured **hybrid and inorganic perovskite** films to design novel detectors.

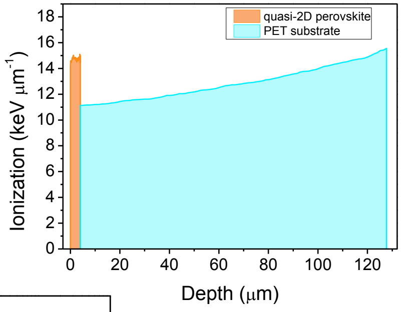
ii) **Design and optimization** of the most performing PVK-based active layer (hybrid and inorganic) and detector layout for hadron detection.

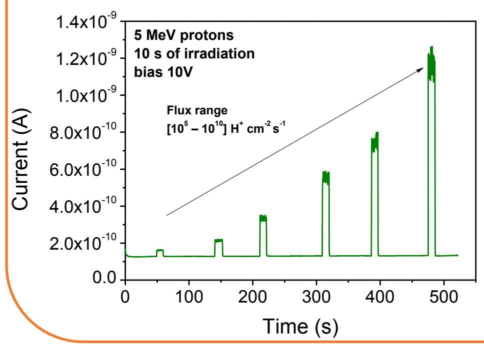
iii) **Test under relevant proton/ion irradiation and dosimetric characterization** (at TIFPA, CNAO, LNS facilities) for beam monitoring application during hadrontherapy treatments.

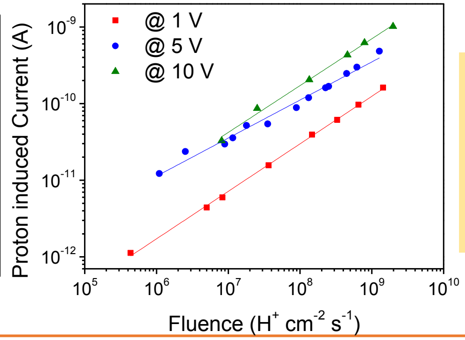
Activity M1-6: DEVICE FABRICATION - STRUCTURAL, MORPHOLOGICAL CHARACTERIZATION – PRELIMINARY TESTS @LABEC







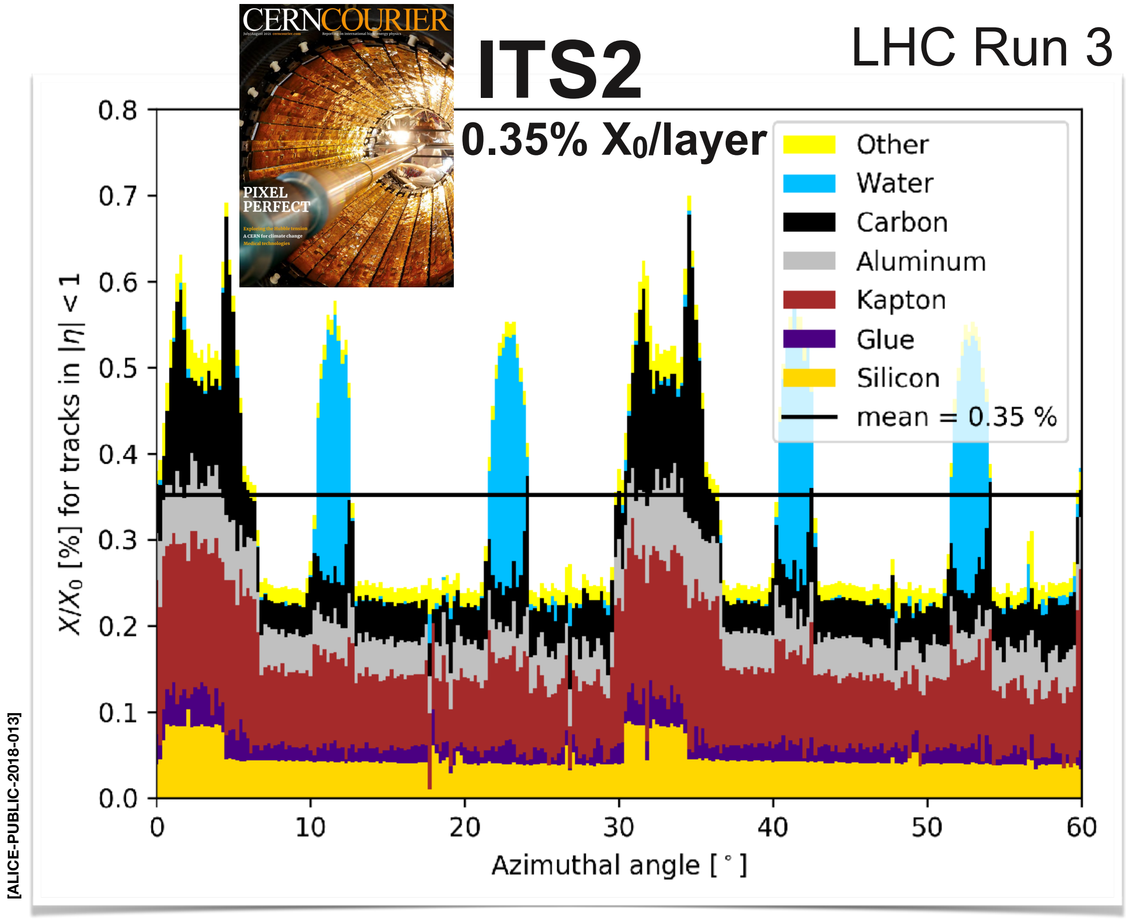




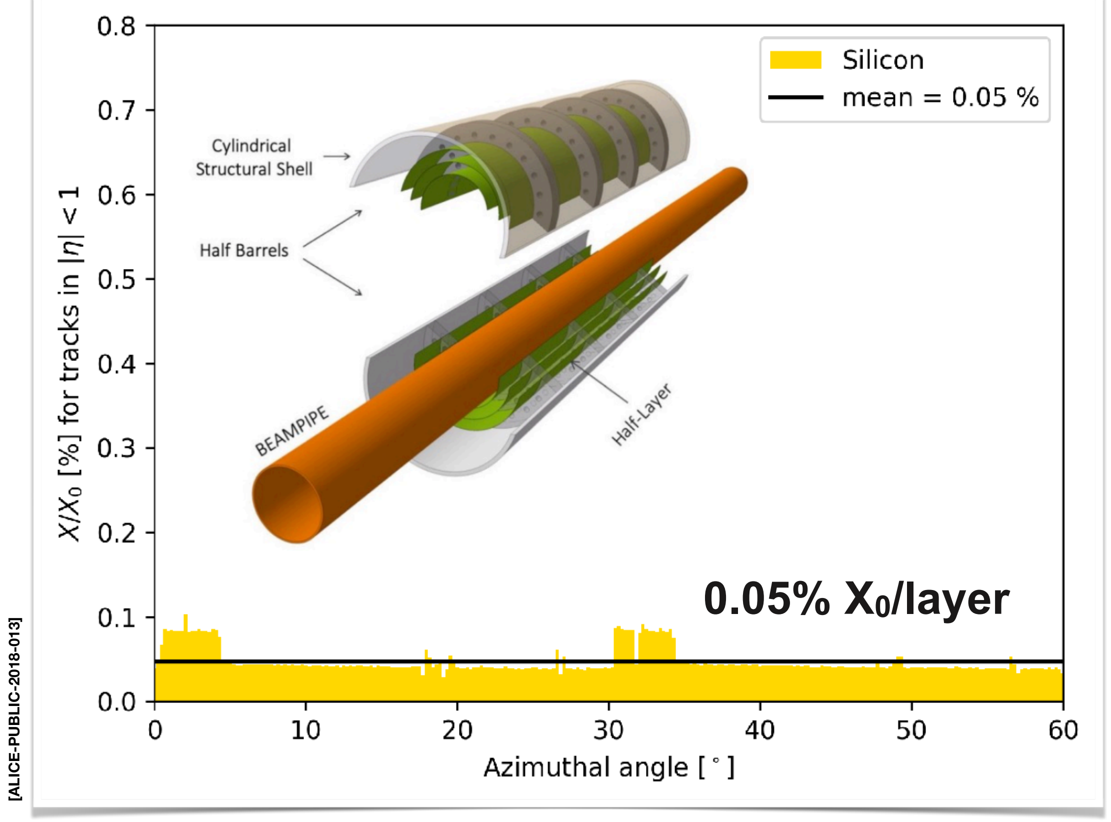
BEAM-TIME @TIFPA Allocated in Fall 2022

ALICE ITS3: motivation and detector concept

ITS2 LHC Run 3



ITS3 LHC Run 4



Requirements

» *Removal of water cooling*
  → **possible** if power consumption stays below 20 mW/cm^2
  → move to (low flow) air cooling system

» *Removal circuit board* (power+data)
  → **possible** if integrated on chip

» *Removal of mechanical support*
  → **benefit** from increased stiffness by rolling Si wafers

Key ingredients

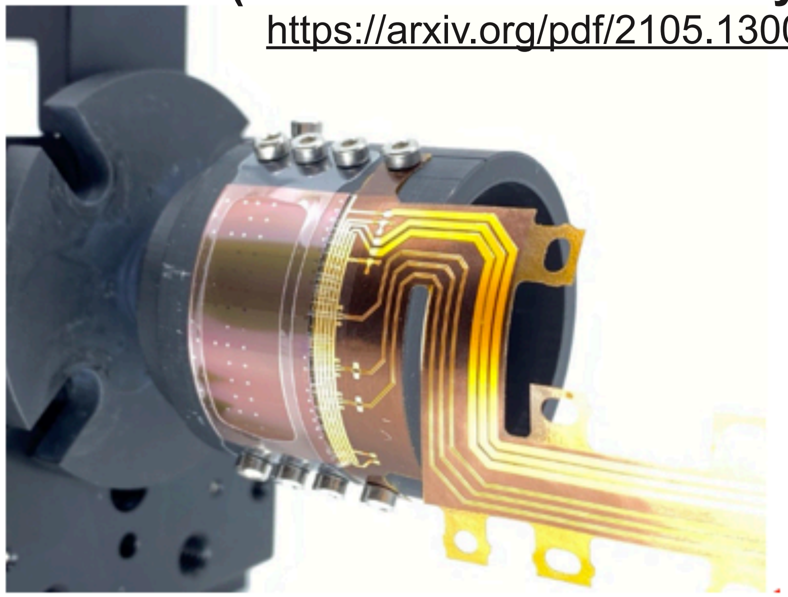
» Wafer-scale sensor fabricated using *stitching*
» Sensor thickness 20-40 μm
» Chips bent in cylindrical shape at target radii
» Si MAPS sensor based on 65 nm technology
» Carbon foam structures
» Smaller beam pipe diameter and wall thickness (0.14% X_0)

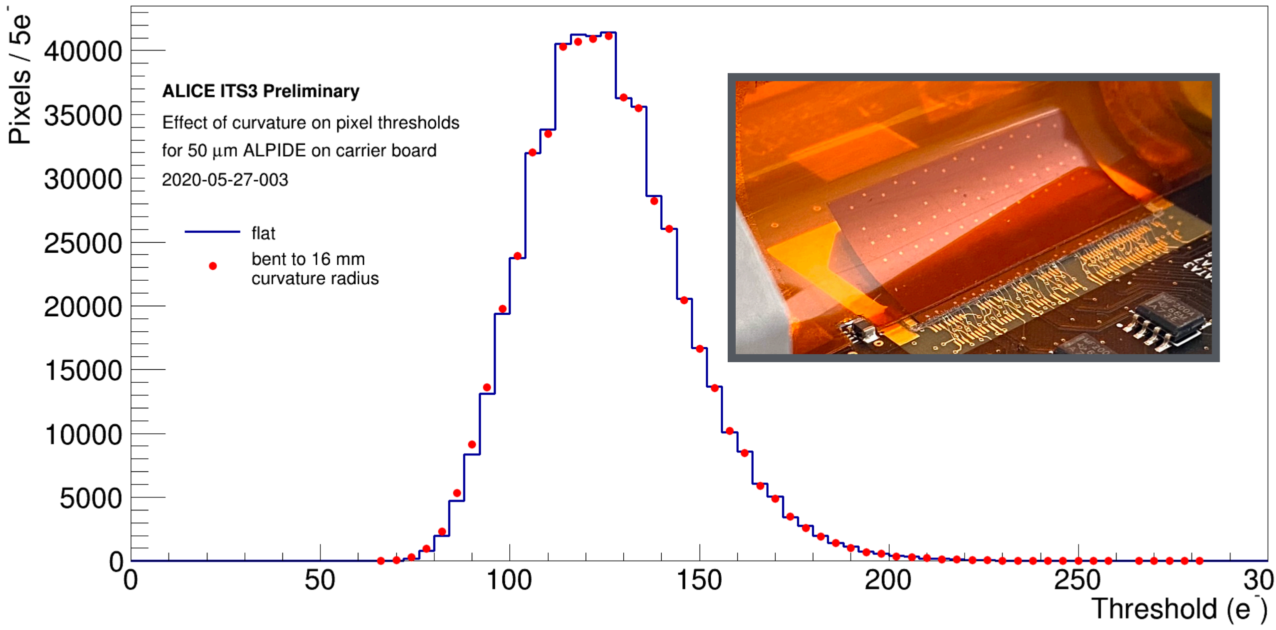
ALICE ITS3: R&D lines - Bent sensor performance

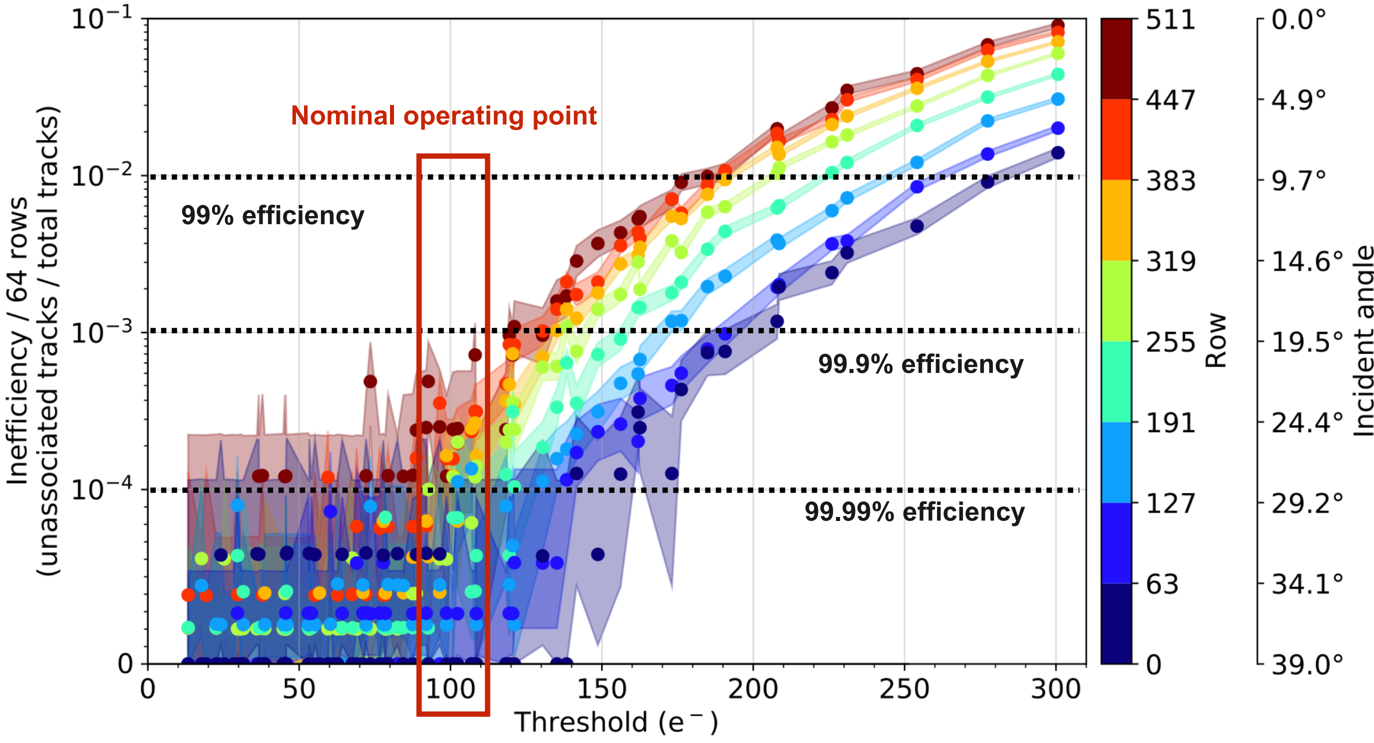
Bent ALPIDE

(MAPS used to assembly ITS2)

https://arxiv.org/pdf/2105.13000.pdf





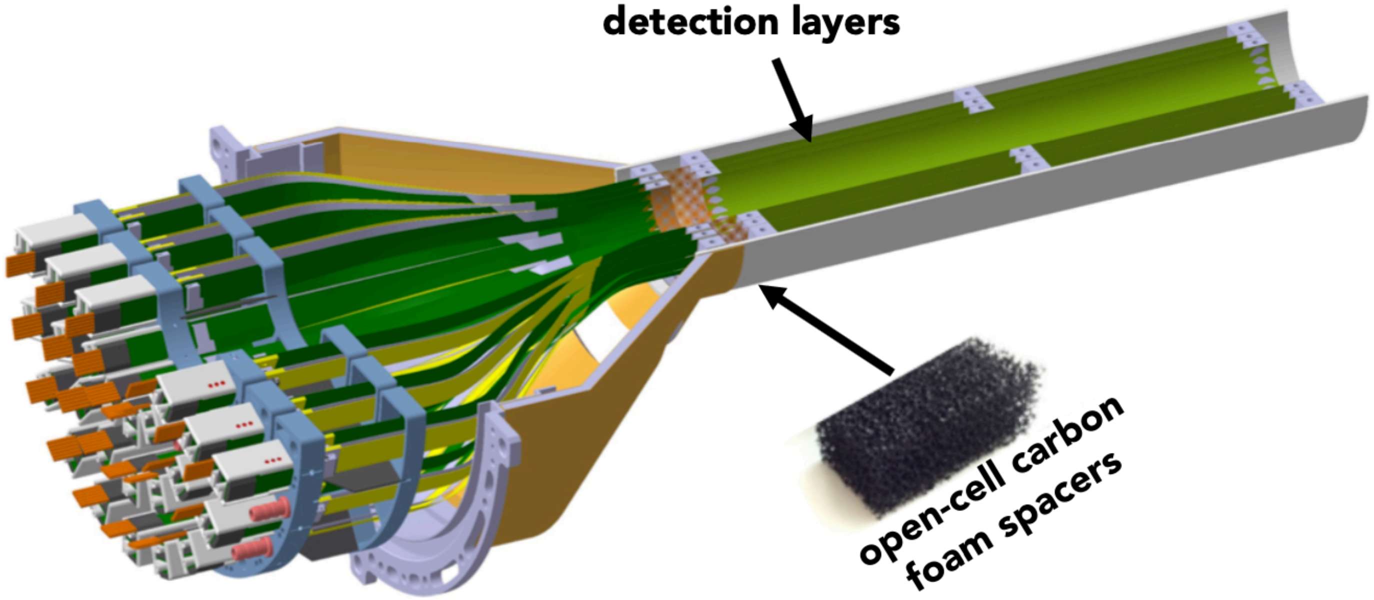


» **Sensor performance doesn't change after bending**
  - Pixel matrix threshold distribution does not change
  - Efficiency above 99.9% at a threshold of 100 e^{-} (nominal operating point)

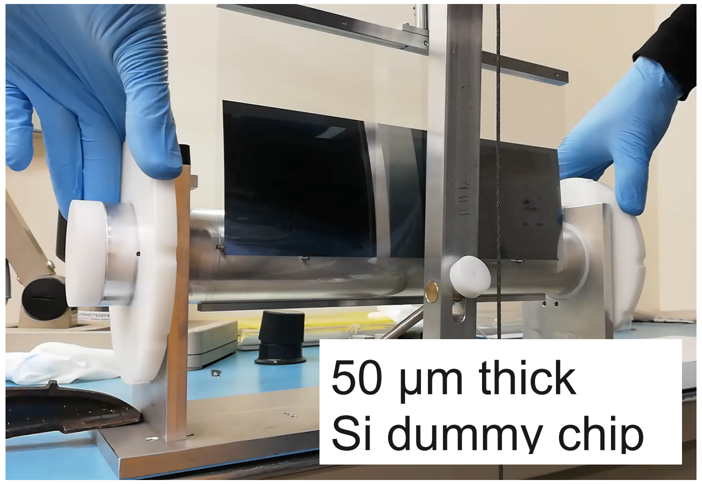
ALICE ITS3: R&D lines - Detector Integration

Beam pipe inner/outer radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length of sensitive area (mm)	300.0		
Number of sensors per layer	2		
Pixel size (μm^2)	O (10 x 10)		

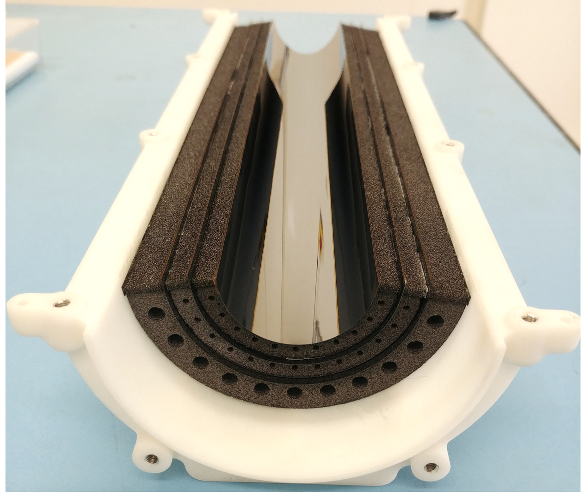
The whole detector will comprise six chips and barely anything else!



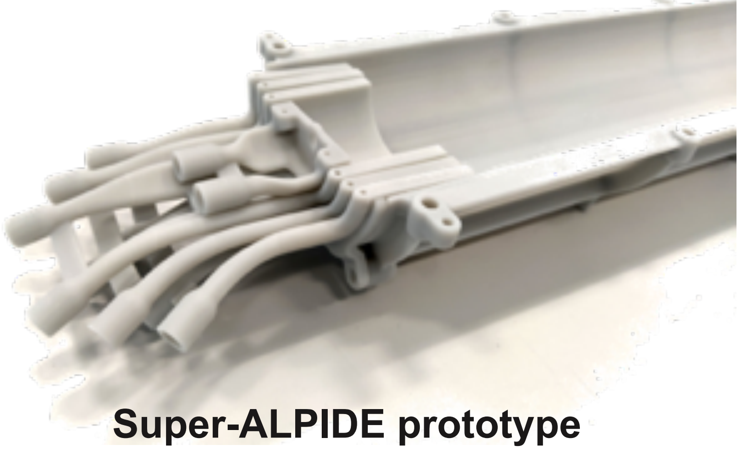
Silicon bending tools



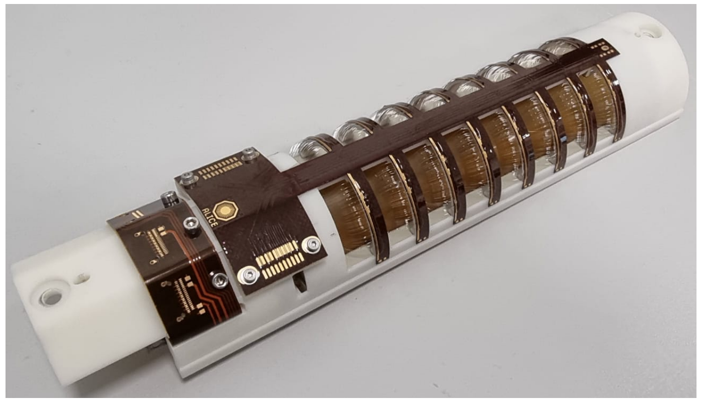
Carbon foam support structure



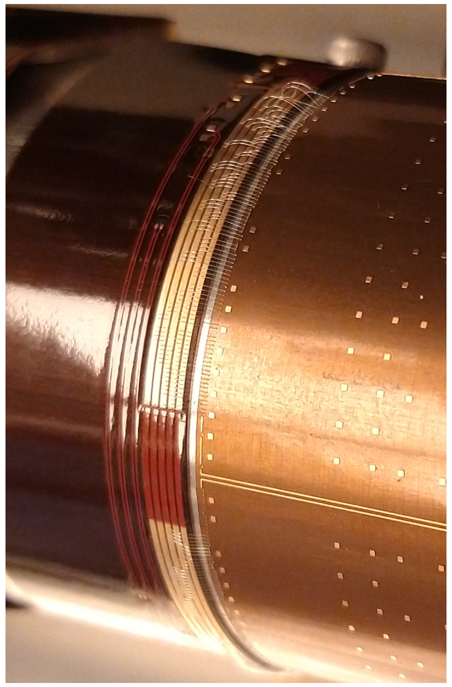
Airflow cooling



Super-ALPIDE prototype



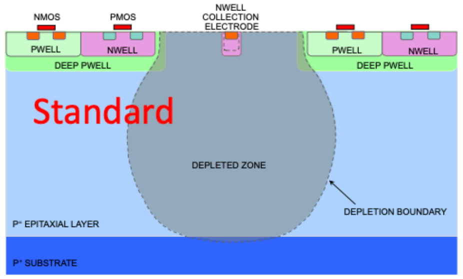
Wire-bonding on curve surface

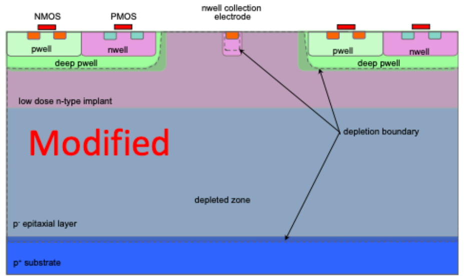


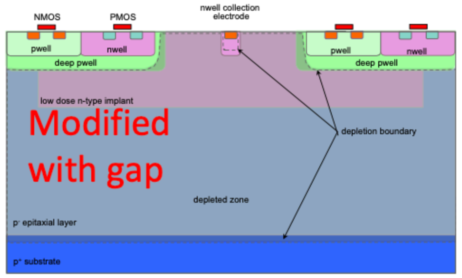
ALICE ITS3: R&D lines - Sensor design

» Tower Semiconductor (TPSCo) 65 nm SMOS IS technology

- TPSCo 65 nm continuation of the TowerJazz 180 nm (ITS2)
- scoped within CERN EP R&D WP1.2, significant drive from ITS3
- 300 nm wafers → 27 × 9 cm^2
- 7 metal layers
- Process modifications for full depletion:
  - Standard (no modifications)
  - Modified (low dose n-tope implant)
  - Modified with gap (low dose n-type implant with gaps)



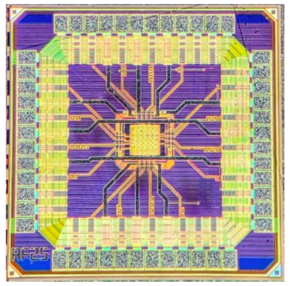




» **MLR1**: first test submission

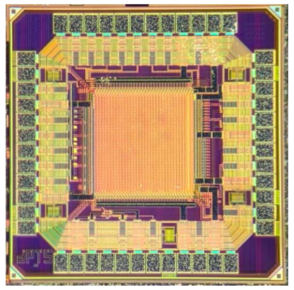
- Main goals: learn technology features, characterise carte collection, validate radiation tolerance
- Submitted Dec. 2020 - Received Jul. 2021

APTS



Two output drivers:
- Traditional source follower (SF)
- Very fast OpAmp (OP)

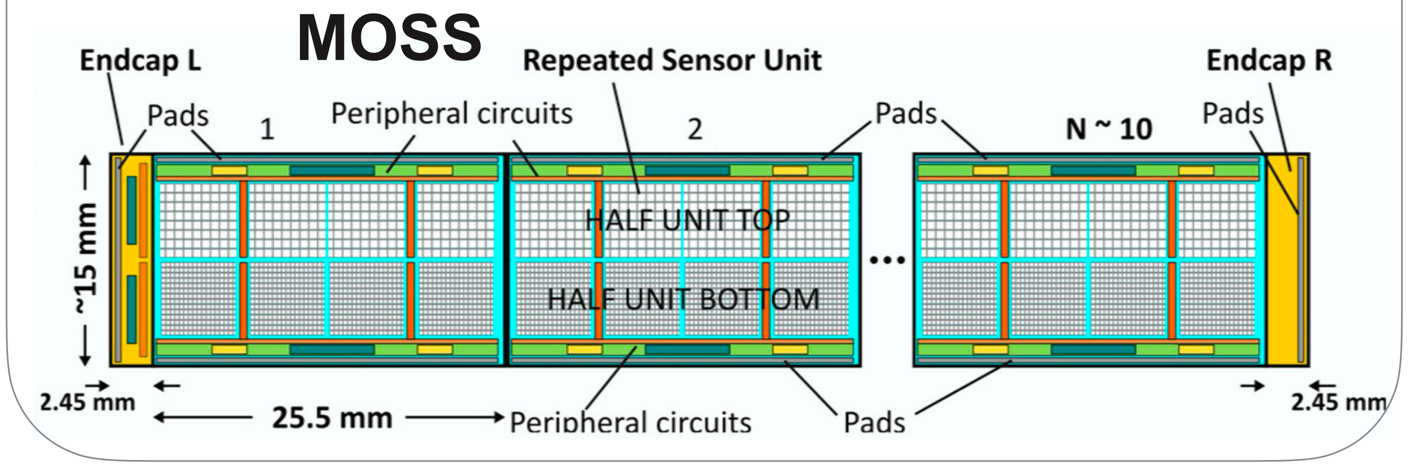
DPTS



- 32 × 32 pixel matrix
- Asynchronous digital readout
- Tunable power vs time resolution

» **ER1**: first stitching implementation

- MOSS : focus on technology options, power distribution, signal routing, yield
- MOST : focus on yield with high density layout parts and fine power segmentation



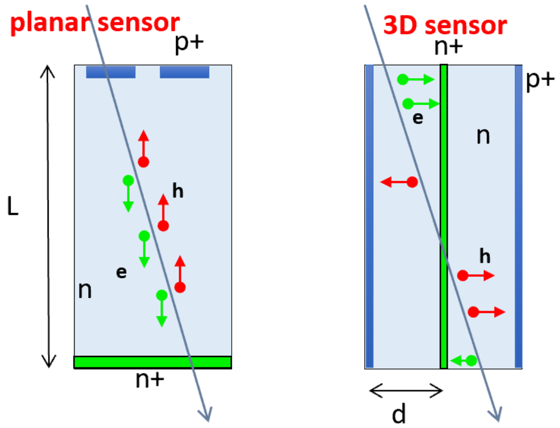
Time resolution of 3D silicon sensors with trench electrodes

Development, test and characterisation

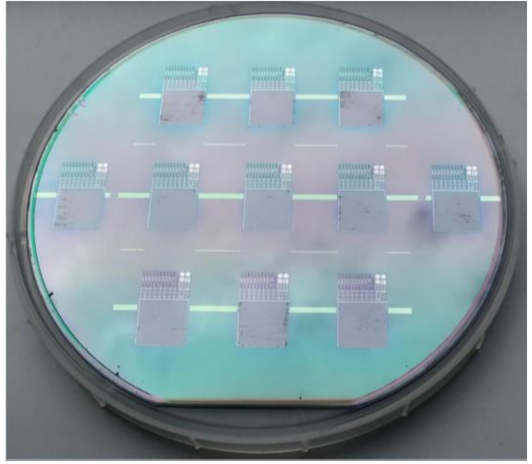
Angelo Loi

Technology and design

- **The approach within TimeSPOT was to use 3D silicon (and Diamond) sensors to achieve fast timing**
  - **Reducing inter-electrode distance**
    - **Reducing charge collection time**
      - As well improving intrinsic time resolution
    - **Increasing radiation hardness**

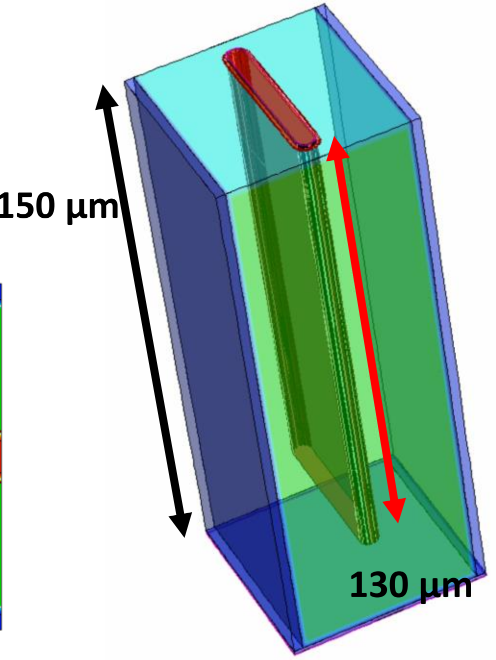


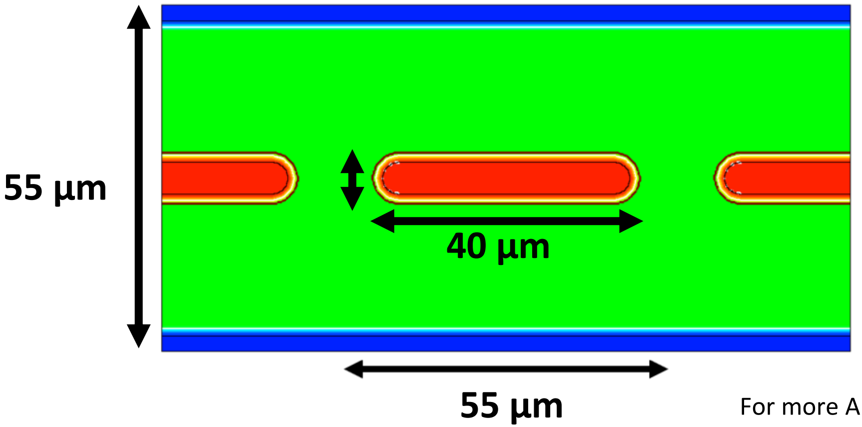
First TimeSPOT batch, produced by FBK



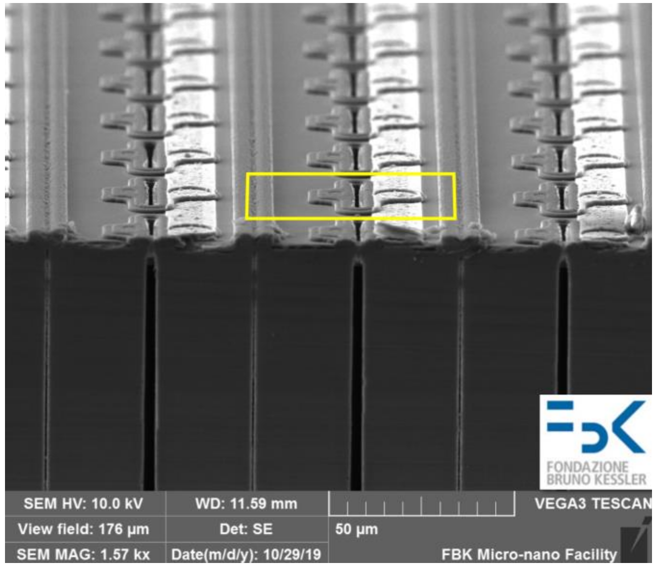
- **The final geometry selected for the fast timing 3D sensor is the "parallel-trench"**
  - **Already produced in two batches (2019 and 2021) by FBK**

TCAD model of the selected geometry



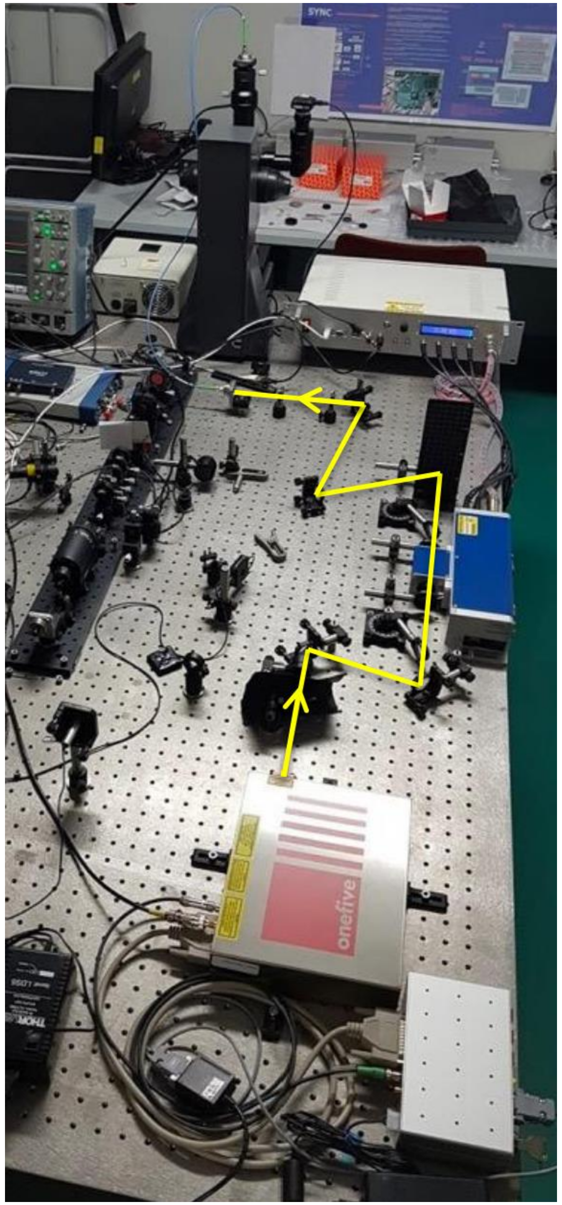


Cut along a parallel trench device based strip sensor



For more A. Loi https://iris.unica.it/handle/11584/284136

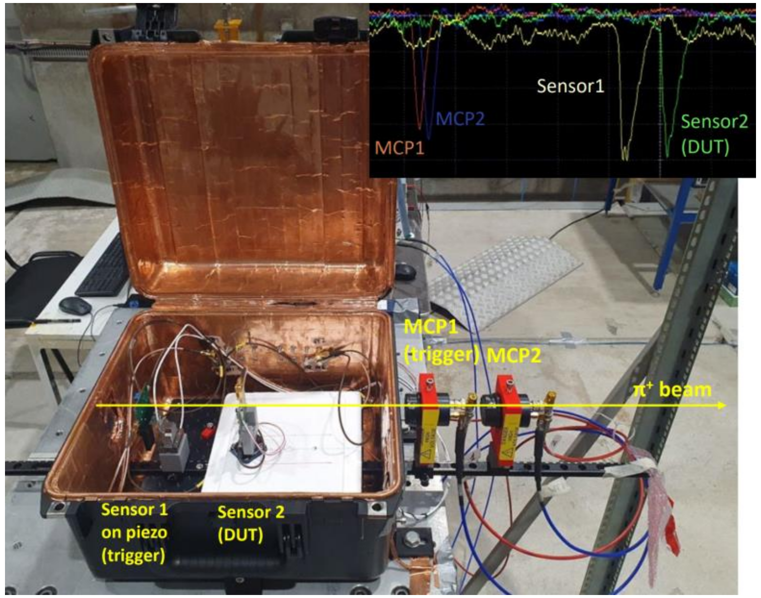
TimeSPOT TCT setup



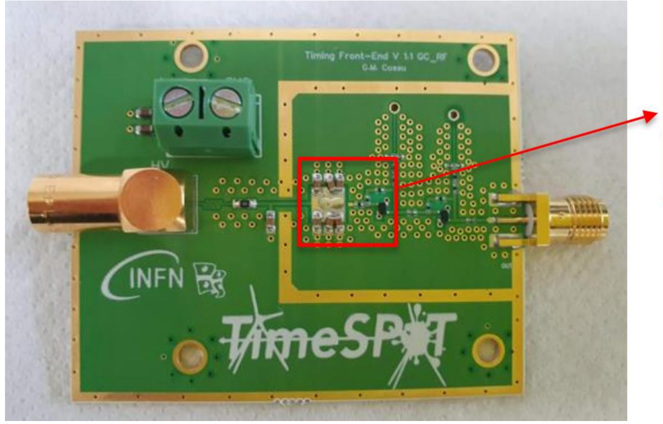
Measurements

- **Sensor has been characterised**
  - Test beams (10/2019, 10/2021 and 5/2022) →
    - Intrinsic time resolution
    - Performance by tilting the device
    - Sensor Efficiency
    - Performance after radiation
  - ← Own constructed TCT setup in Cagliari
- **Customised fast readout has been developed in order to fully explore sensor performance ↓**

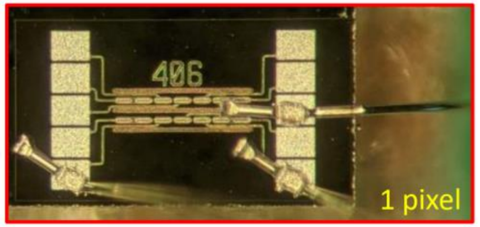
Test beam setup for intrinsic time resolution characterisation



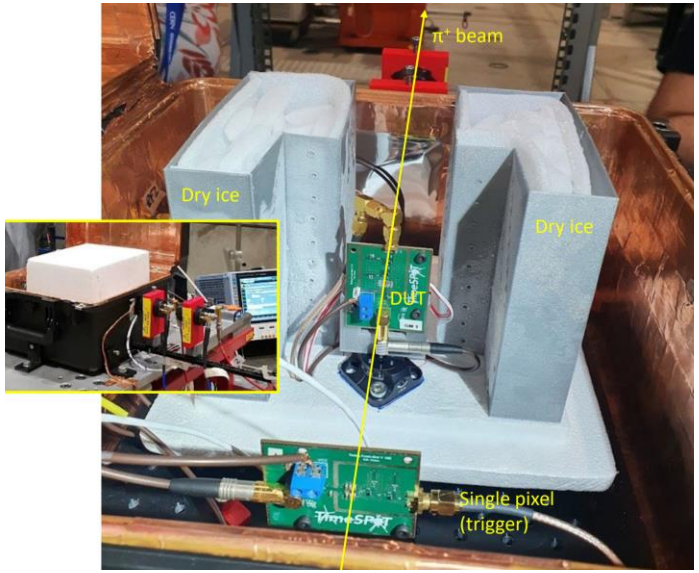
TimeSPOT fast-electronics



Single pixel test device



Dry ice enclosure for rad hard measurements

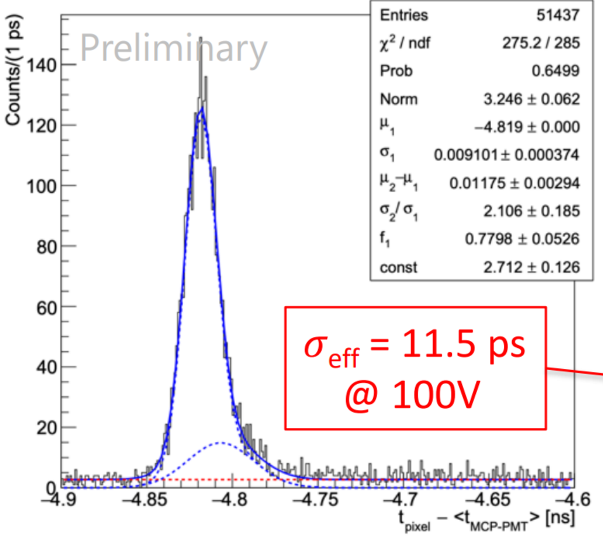


For more G.M. Cossu https://arxiv.org/pdf/2209.11147.pdf

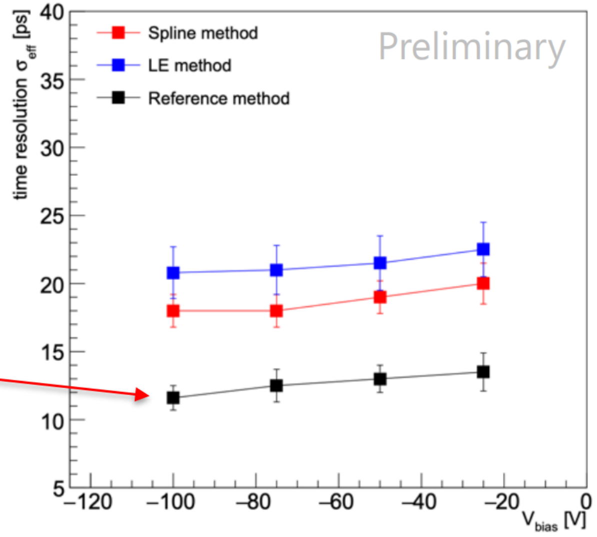
Results (1)

- **Intrinsic time Resolution before and after radiation damage above 10^{16} n_eq**

No rad damage

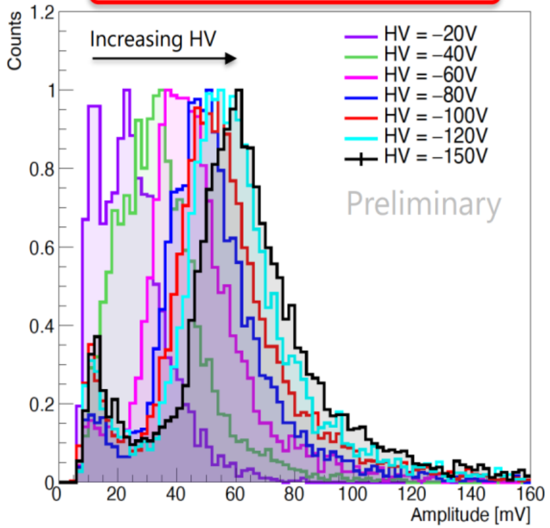


σ_{eff} = 11.5 ps @ 100V

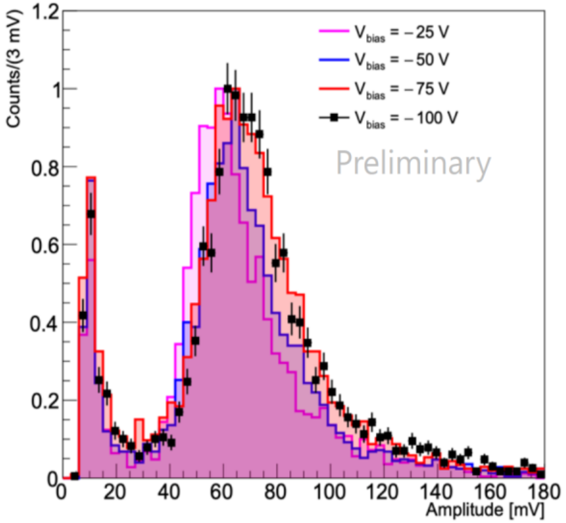


After rad damage ↓

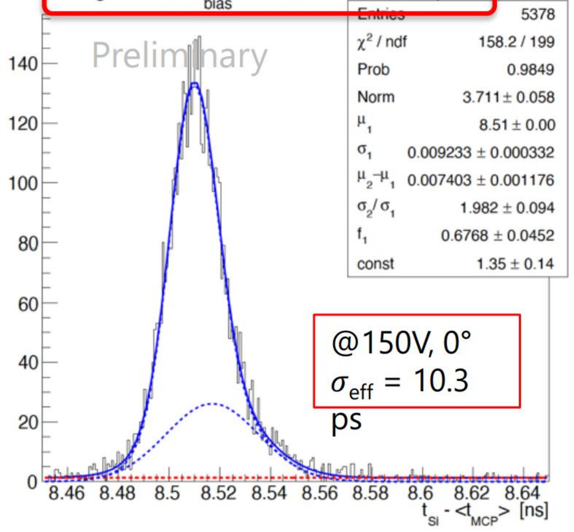
Single Pixel $2.5e^{16}$neq/cm^2 - 0°



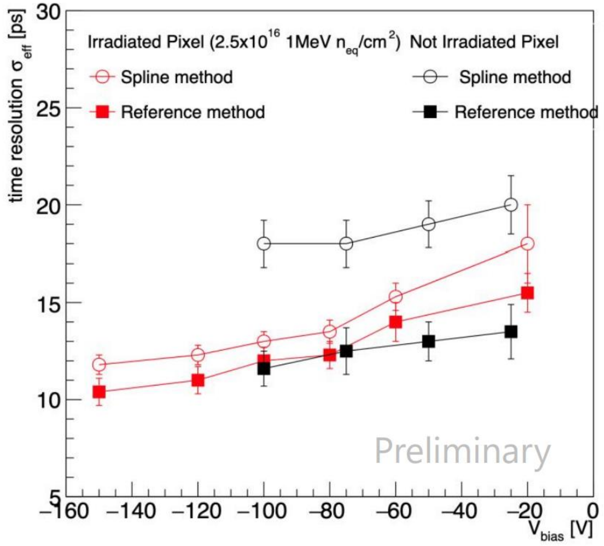
Single pixel non irradiated – 0°



Single Pixel V_{bias} = −150V - $2.5e^{16}$neq/cm^2



@150V, 0°
σ_{eff} = 10.3 ps

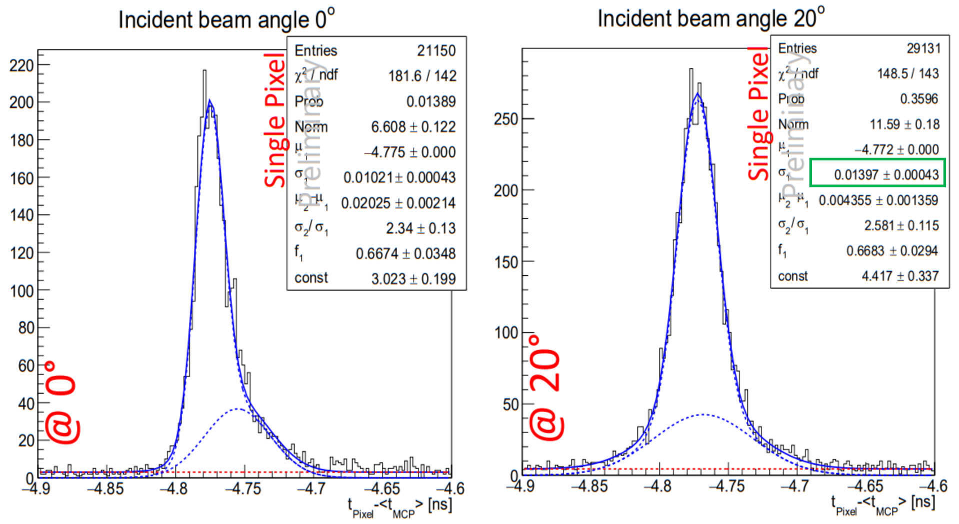


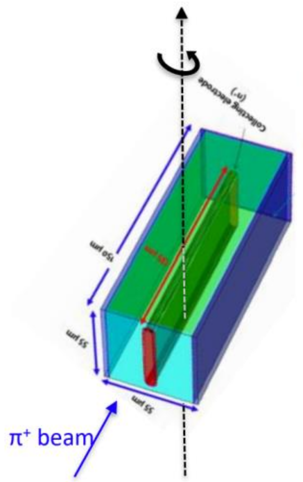
With a slightly larger bias voltage (w.r.t. non-irradiated pixel working point) the signal amplitude of irradiated sensors is recovered!

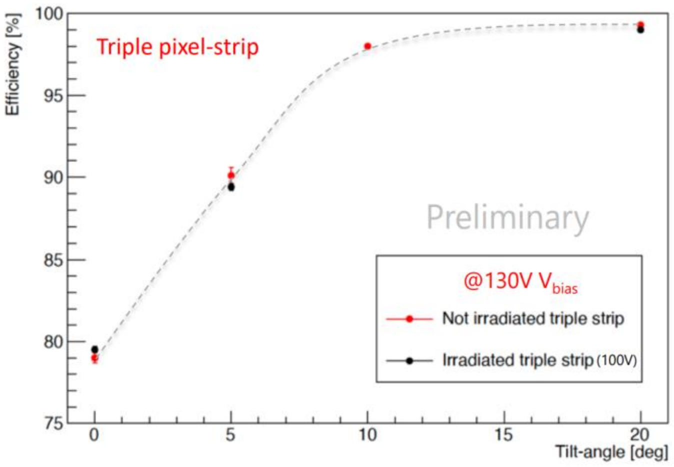
For more info: A. Lampis
https://indico.cern.ch/event/1120714/contributions/4867208/attachments/2472539/4242526/Andrea_Lampis_iworid2022.pdf
https://indico.cern.ch/event/1127562/contributions/4954529/attachments/2511647/4317271/TimeSPOT_TWEPP2022_Final.pdf

Results (2) and outlook

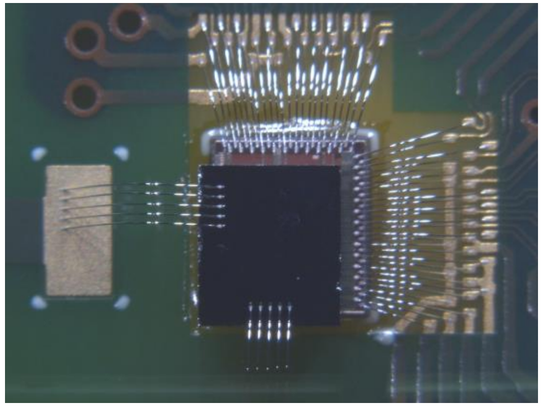
- **Sensor behaviour has been studied also by tilting it**
  - **ToA distribution at 20° becomes more gaussian**
  - **The inefficiency (at normal incidence) due to the dead-area of the trenches is fully recovered by tilting the sensors around the trench axis**
    - **It also works for irradiated sensors**





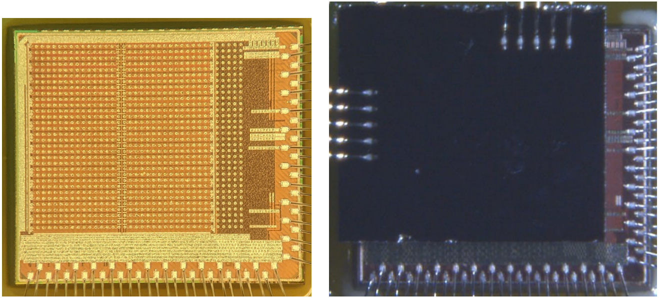


- **Outlook:**
  - **32x32 pixel matrix has been bump-bonded on the TimeSPOT-1 ASIC and currently tested. Future 4D tracking detector and its components are under test and caracterisation (more about it on Lorenzo's slides)**



The TimeSPOT1 ASIC

a 28 nm CMOS timing front-end ASIC

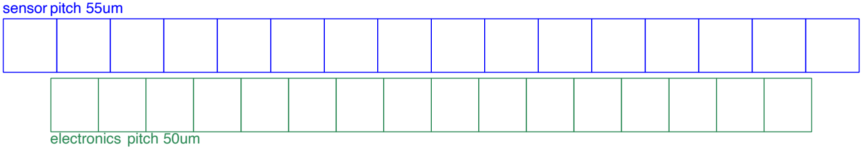


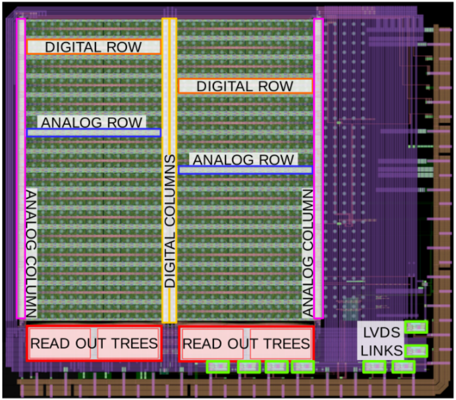
TimeSPOT1 ASIC **TimeSPOT1 Hybrid**

Lorenzo Piccolo - INFN Torino

INFN workshop on Future Detector, IFD2022
17 October 2022

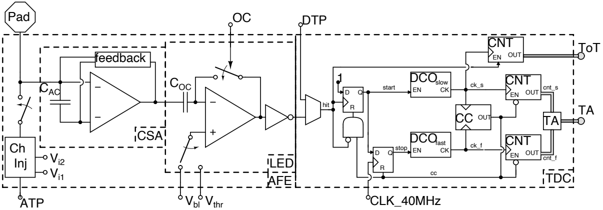
The ASIC



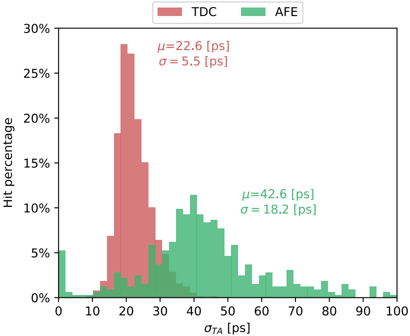


- 1024 channels organized in a 32 × 32 matrix of 55 µm × 55 µm pixels (2.6 mm × 2.3 mm)
- electronics pitch reduced in the horizontal direction (50 µm) → insensitive area reduction
- Local timing measurement → 3 MHz peak hit rate per channel, 200 kHz average.
- Power consumption under 1.5 W/cm^2

Timing Performance



pixel architecture



Timing performance (electrical tests):

- CSA → < 20 ps
- Analog FE → ~ 50 ps (Discriminator Issue)
- TDC → ~ 23 ps

Future Prospects

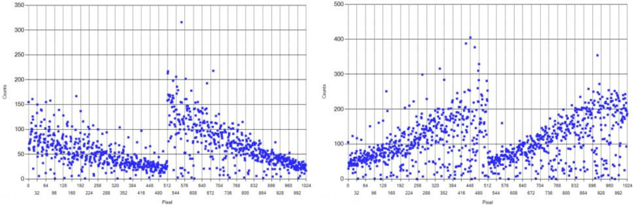
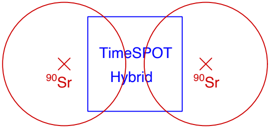
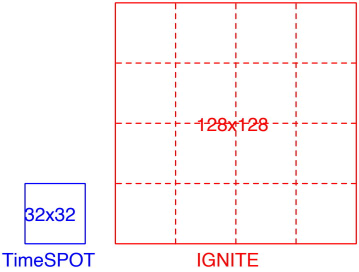


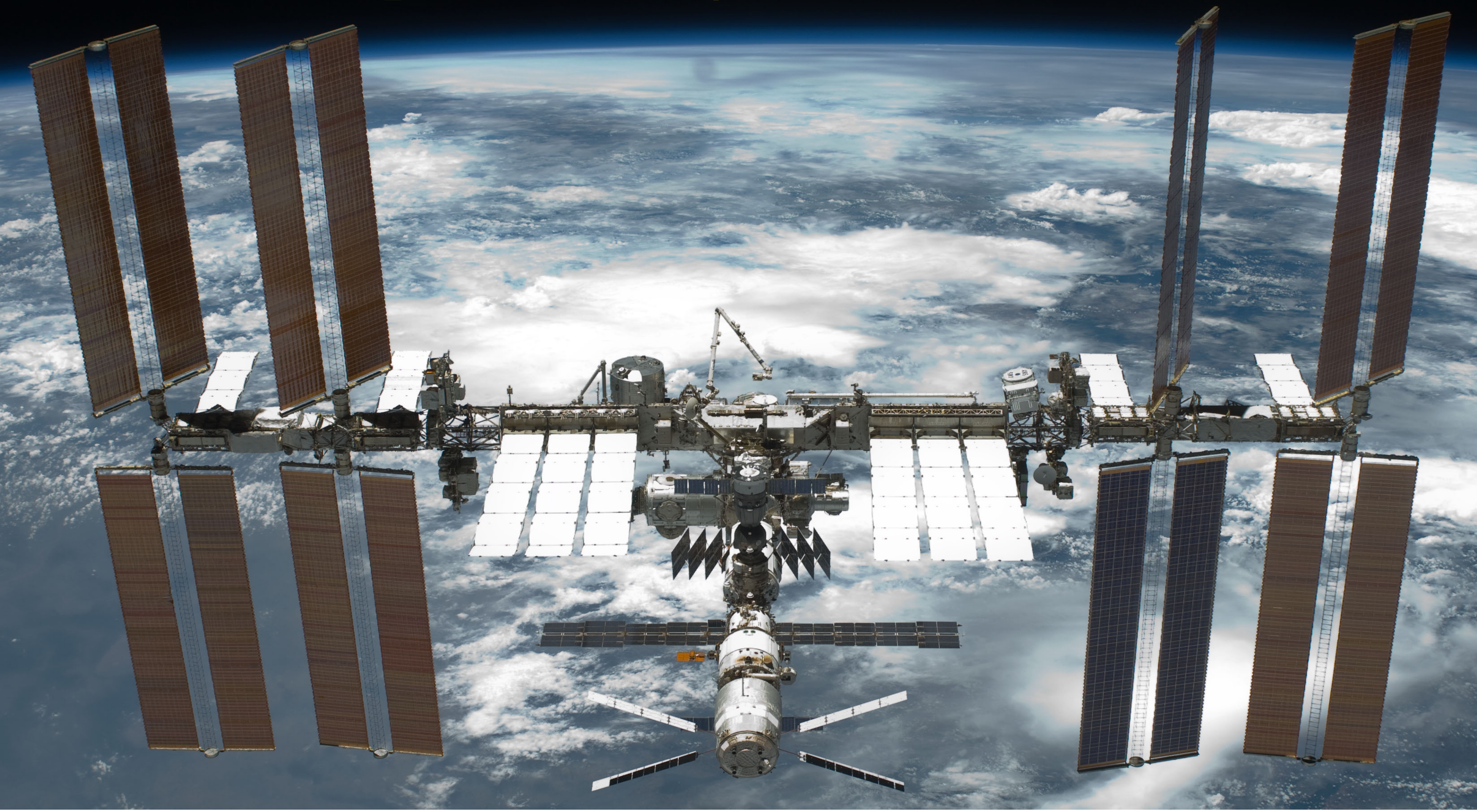
Figure: Hybrid test: off center ^{90}Sr source





- Hybrid tests: laser, radiation sources, test beam.
- New Version → IGNITE:
  - Scheme improvement and fixes → 20 ps resolution
  - x16 scale-up ($\sim 7\,\mathrm{mm} \times 7\,\mathrm{mm}$)
  - 3D integration (TSV)

Requirements for Si-microstrip (LGAD) for next-generation space detectors



Matteo Duranti

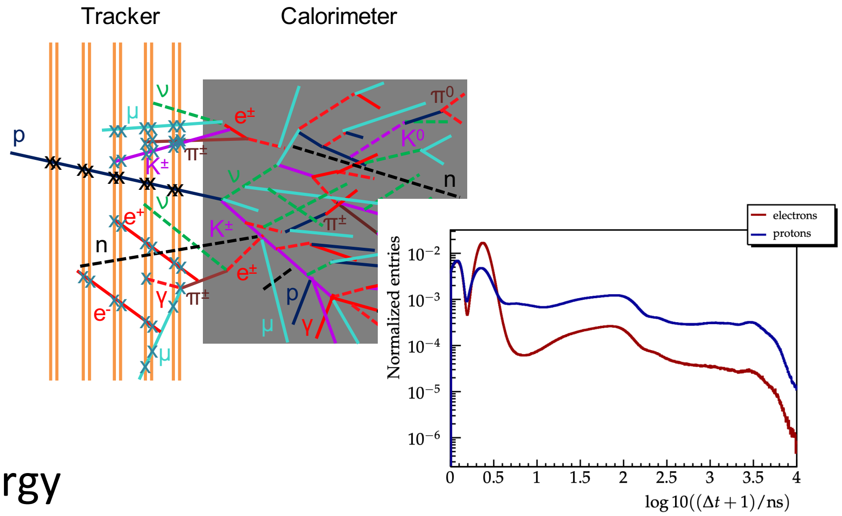
Istituto Nazionale Fisica Nucleare – Sez. di Perugia

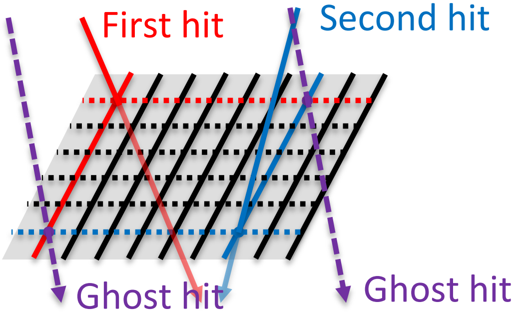
Timing in an astro-particle tracker

(see M. Duranti, V. Vagelli *et al.*, *Advantages and requirements in time resolving tracking for Astroparticle experiments in space*, Instruments 2021, 5(2), 20; https://doi.org/10.3390/instruments5020020)

Including the timing into the Tracker of an astro-particle detector permits to:

- substitute (or provide full redundancy to) any other **ToF detector** (i.e. planes of scintillators) in measuring β → arrival direction (downward vs upward), isotopic composition for nuclear species (combined with *E* or *p* measurement), …;
- help to mitigate/solve different limitations in current operating experiments such as:
  - identification of the hits coming from **back-scattering** from the calorimeter. Example: identify photons without vetoing when large back-scattering (DAMPE: photons lost due to back-scattering 30%@100GeV, 50%@1TeV);
  - **e/p identification**. The presence of a low energy (i.e. *β<1*) back-scattered particles (i.e. hadrons) from a shower identifies the CR as hadron;
  - solve the **"ghost"** problem, typical of a microstrip silicon sensor, from back-scattering, pile-up particles, etc…;

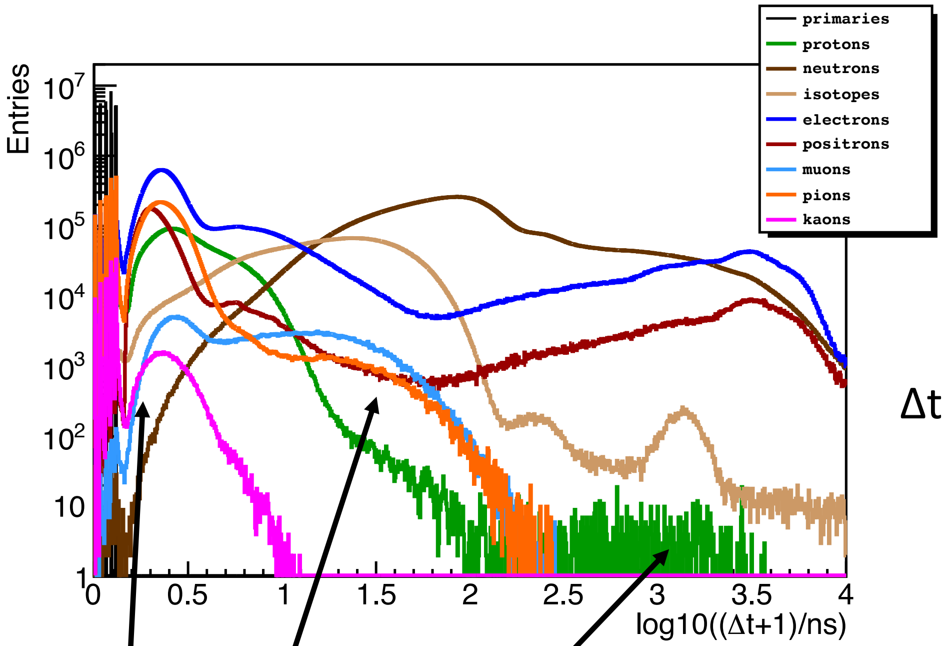




Back-scattering

1 TeV protons

Hits in the tracker (E_{dep} >10 keV vs Δt between the i^{th} hit and the 1^{st} hit (i.e. the CR passing in the first layer of the tracker)



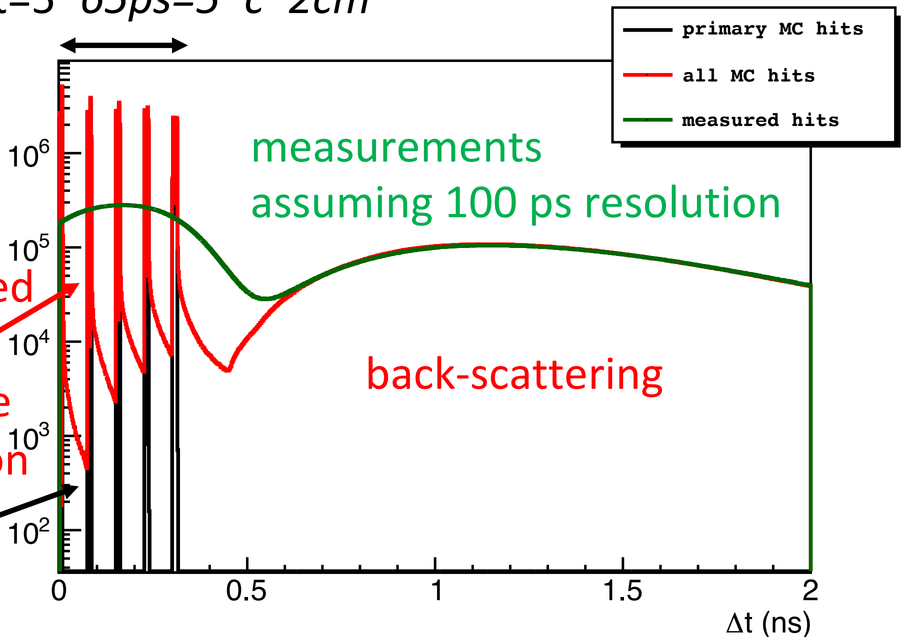
Δt=O(100ps)

Δt=O(10ns)

Δt=O(10μs)

Hits from back-scattering

Δt=5*65ps=5*c*2cm



measurements assuming 100 ps resolution

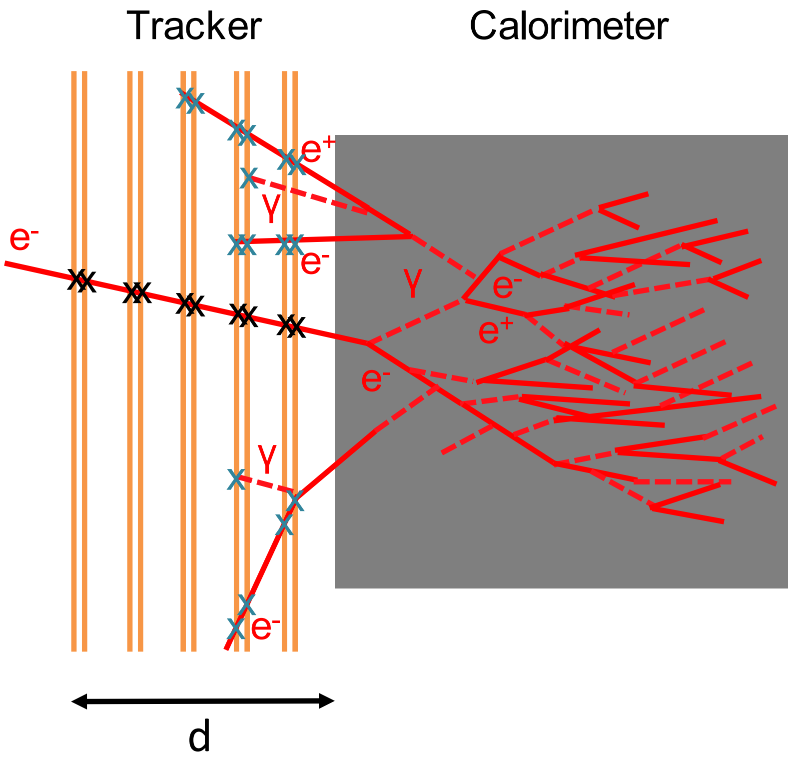
particles produced from the interaction of the CR with the silicon detectors

back-scattering

tracker layers

O(100ps) timing resolution enables to separate back-scattering from primary hits in the tracker → improved efficiency in track reconstruction

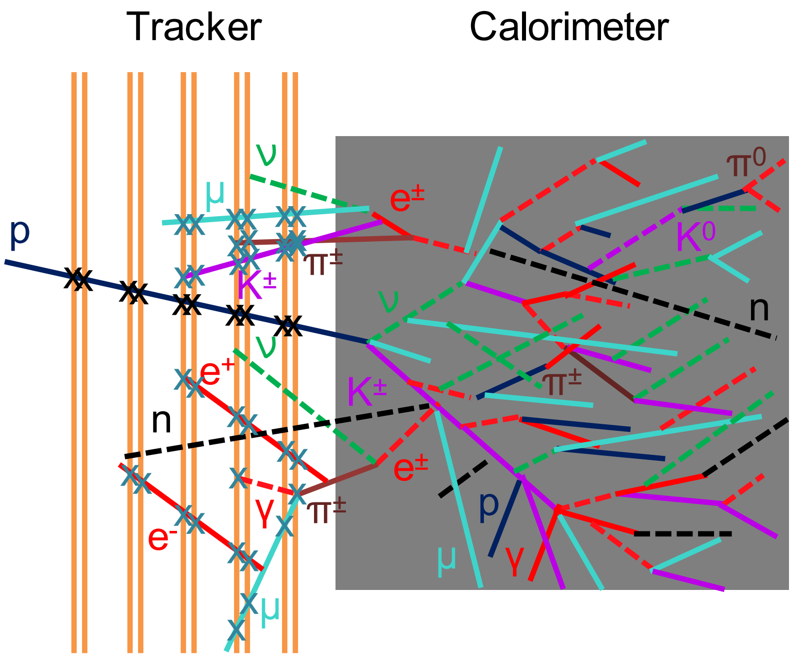
e/p identification



the electromagnetic shower is composed only by "ultra-relativistic" particles
→ the time arrival in the tracker is (at most):

$\sim 2d / c$

the hadronic shower could be composed by "slow" particles
→ the time arrival in the tracker could be delayed

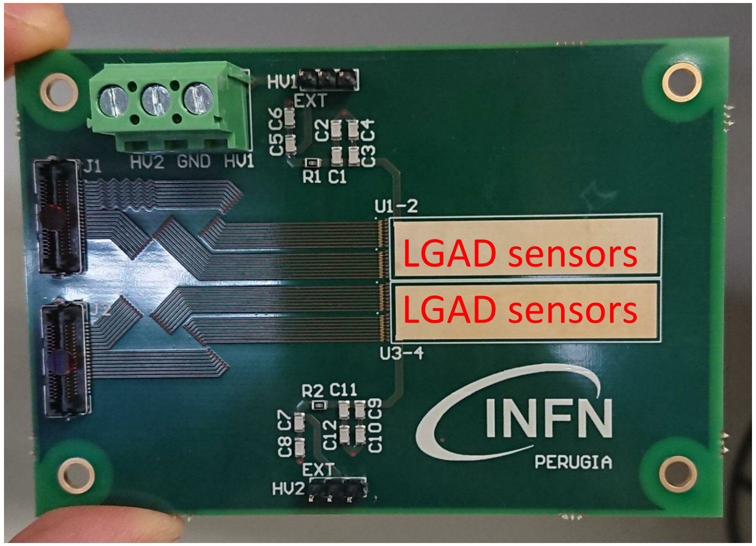


LGAD detectors

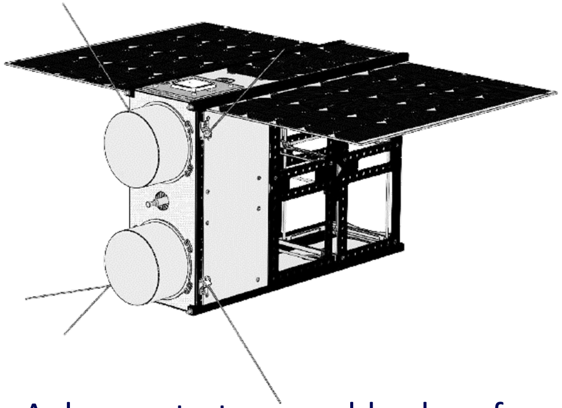
Requirements:

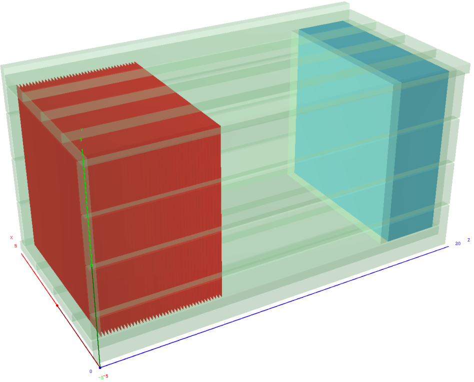
- measure the coordinate with < 10 µm accuracy
- measure the time with < 100 ps accuracy
- keep the linearity with the *Z* (i.e. energy deposit), up to *Z*~=30 and more
- possibly measure the *Z* with < 0.3 c.u. accuracy
- consume < 20 W/m^2 for the coordinate measurement
- consume < 20 W/m^2 for the time measurement
- very moderate radiation hardness (~ krads) required

to PETIROC



Space LGAD for Astroparticle - SLA





How to read-out these sensors with a very low power budget available?

- produce a custom ASIC (optimal solution)
- use a COTS ASIC (i.e. PETIROC-2A) developed per other sensors (SiPM) and "see what happens"

A demonstrator, capable also of some physics measurements, can be done in a 3U or 6U CubeSat:

- the idea has been proposed in an Italian Space Agency (ASI) "topical board"
- the idea was included in a Italian Research Ministry call for fundings (PRIN, "SLA")
- the detector (launch included!) is doable with a ~ 1M€ budget envelope

Future HEP links

INFN
Istituto Nazionale di Fisica Nucleare

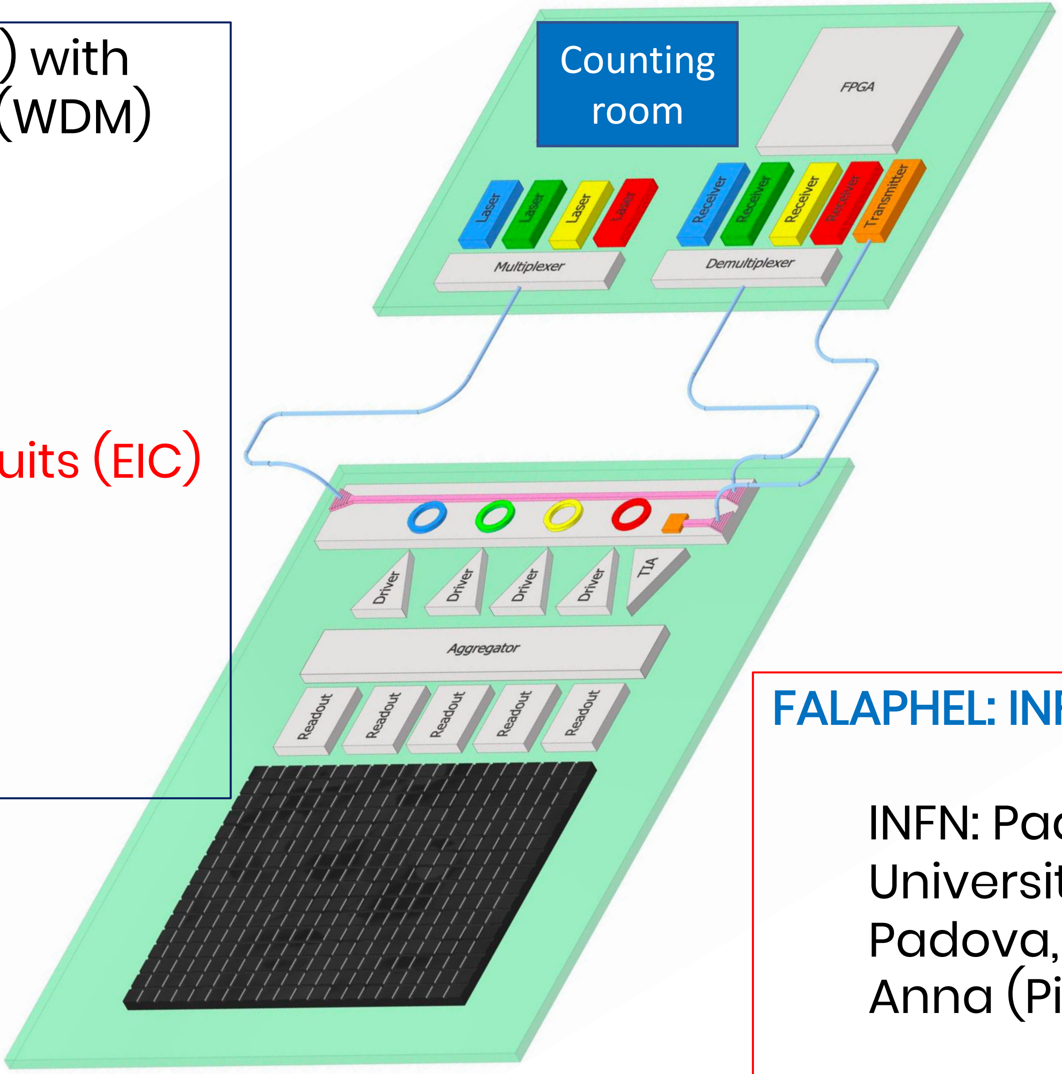
Photonics Integrated Circuits (PIC) with wavelenght division multiplexing (WDM)

Total 100 G = 4x 25G lanes

Radiation hard

Needs Electronics Integrated Circuits (EIC)

- Front-End
- Serialisers
- Drivers
- PLL



Fabrizio.Palla@pi.infn.it

FALAPHEL: INFN Call (2021-2023)

INFN: Padova, Pavia, Pisa
Universities: Bergamo, Milan, Padova, Pisa, Scuola Superiore S. Anna (Pisa)

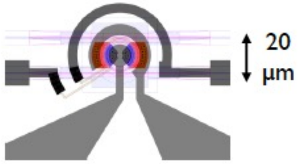
P.I. Fabrizio Palla

PIC Technology: iSipp50G by IMEC

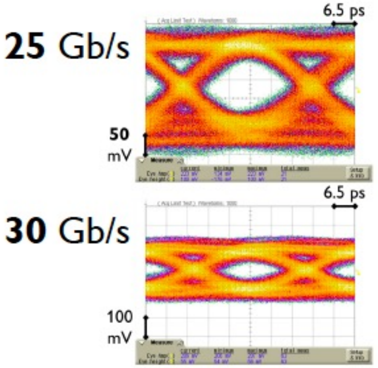
Istituto Nazionale di Fisica Nucleare

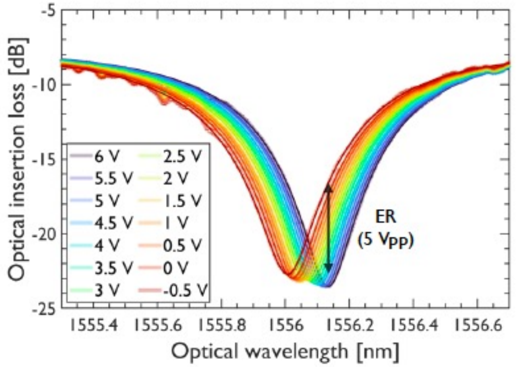
Ring Modulator – RM7

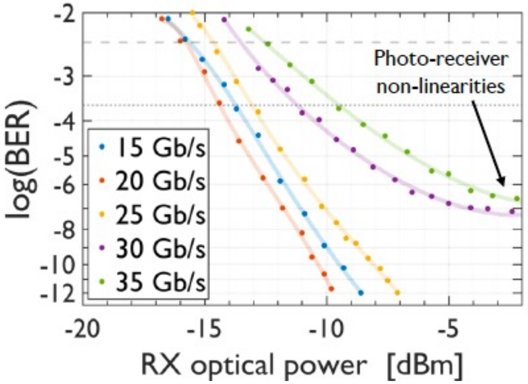
- Ring modulators (**RMs**): light intensity modulation is achieved via resonance shifts produced with a PN phase shifter.
- Testing conditions: λ = 1556.16 nm, Vbias = 1.7 V, Vpp ~ 5 V, T = 21.3 °C, P_{tls} = 13 dBm, $OSNR_{1nm}$ = 28.5 dB



FWHM	~ 790 pm
Quality factor	~ 2000
Modulation depth	~ 15 dB
Modulation efficiency	~ 25 pm/V







5 mm x 5 mm chip

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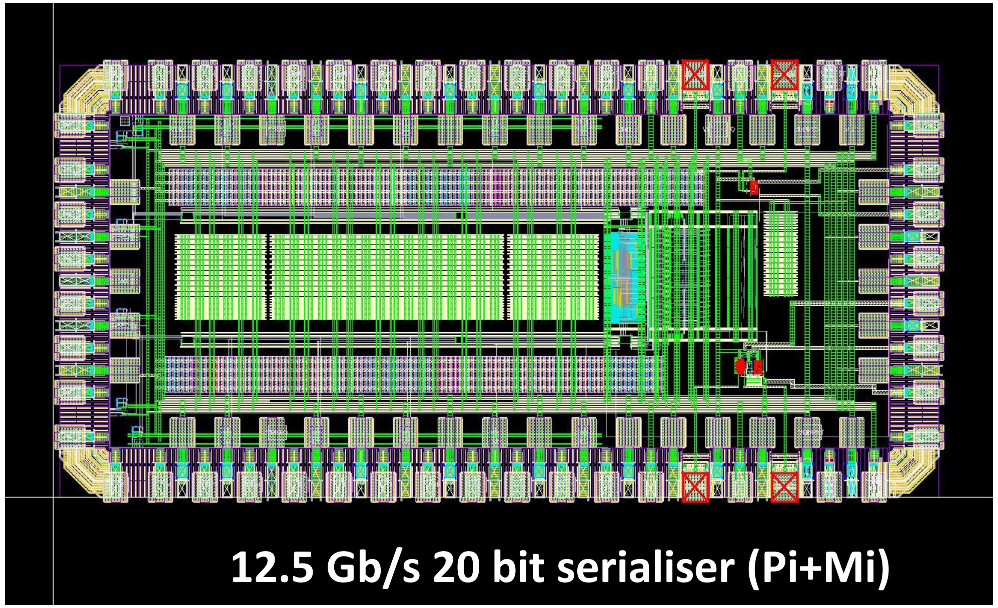
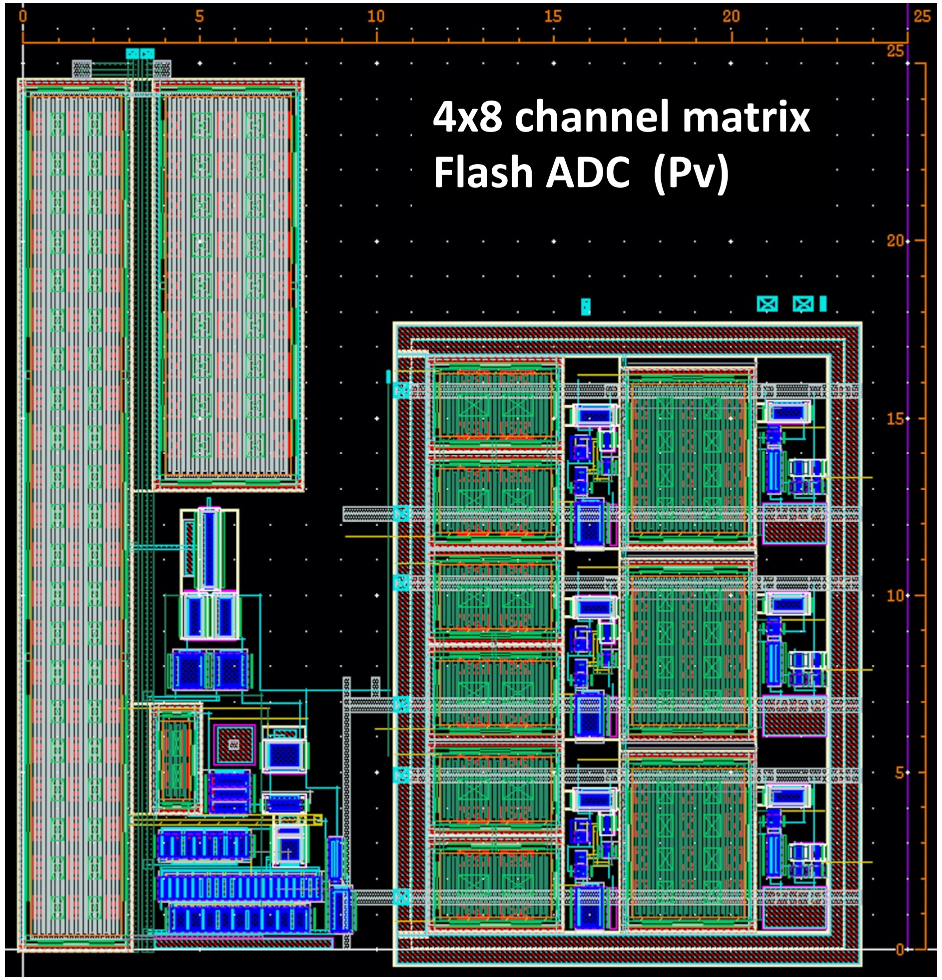
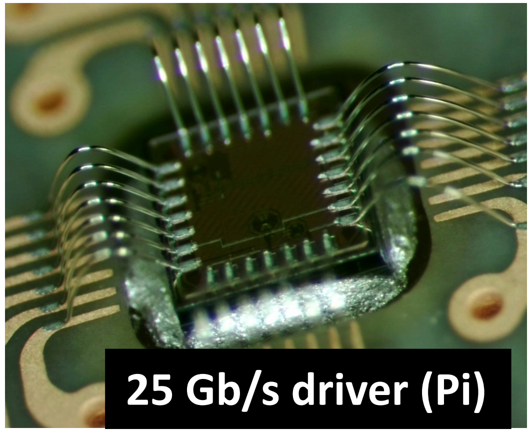
Electronics Integrated Circuits (28 nm TSMC)

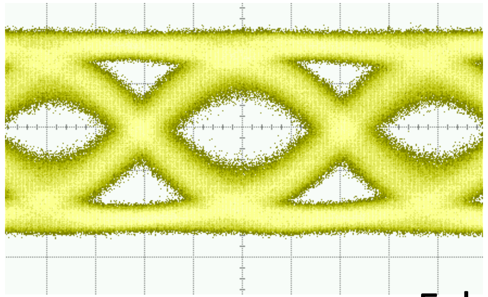
Istituto Nazionale di Fisica Nucleare


12.5 Gb/s 20 bit serialiser (Pi+Mi)


4x8 channel matrix
Flash ADC (Pv)


25 Gb/s driver (Pi)

25 Gb/s



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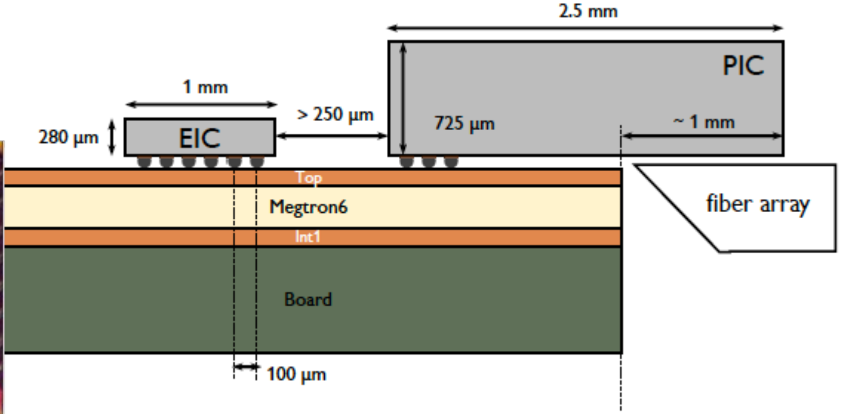
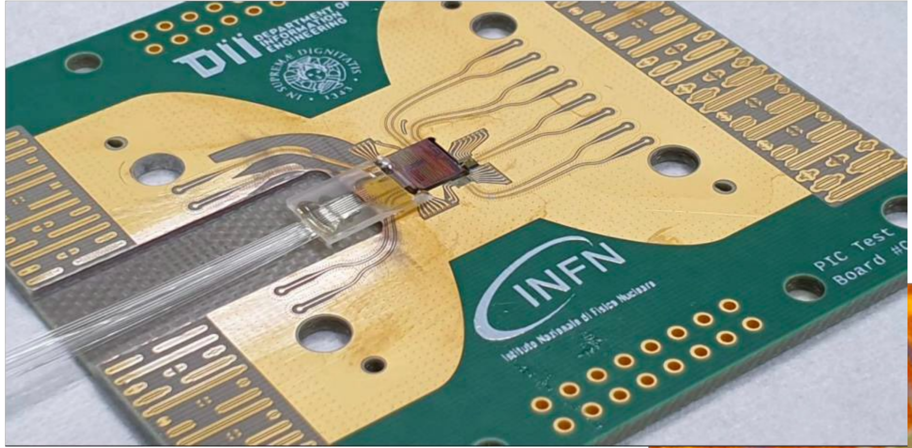
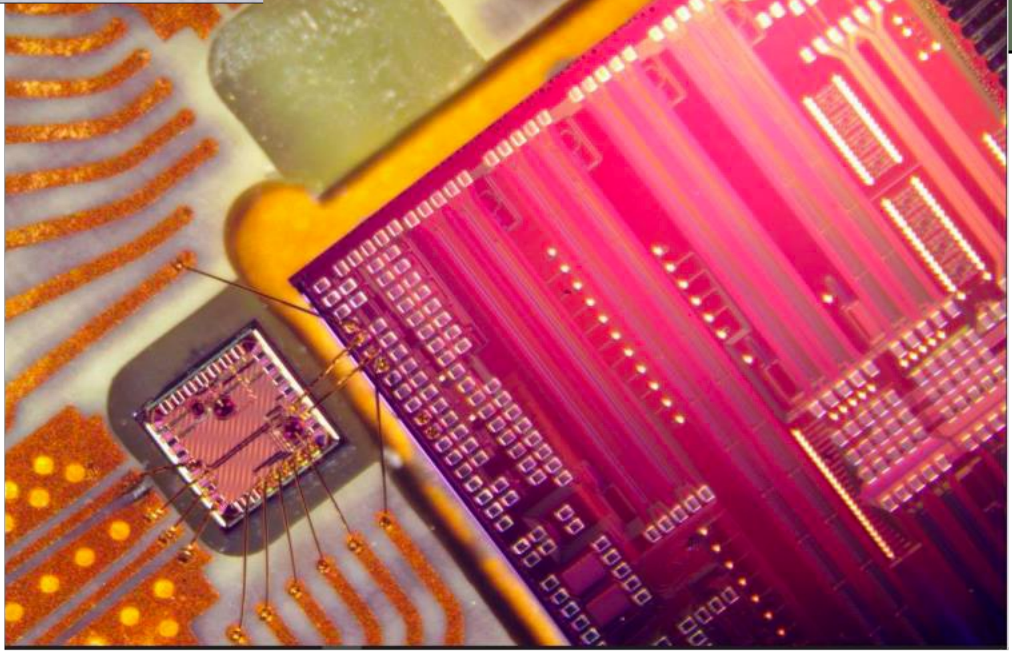
Integration PIC + EIC

- Future: study PCB flip chip





- Wire bond integration at Camgraphic (Pisa)



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Organic thin films as flexible, large area X-ray and proton detectors: why?

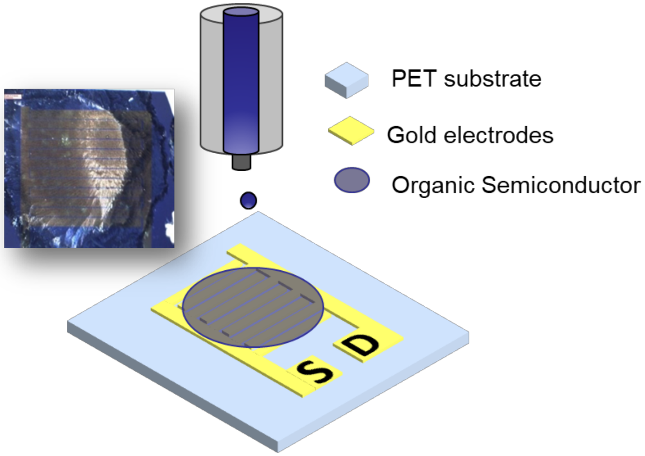
- ✓ flexible and light-weight materials
- ✓ solubility and tunability→ INKS
- ✓ low cost printing techniques
- ✓ large area applications -scalability
- ✓ Biocompatibility

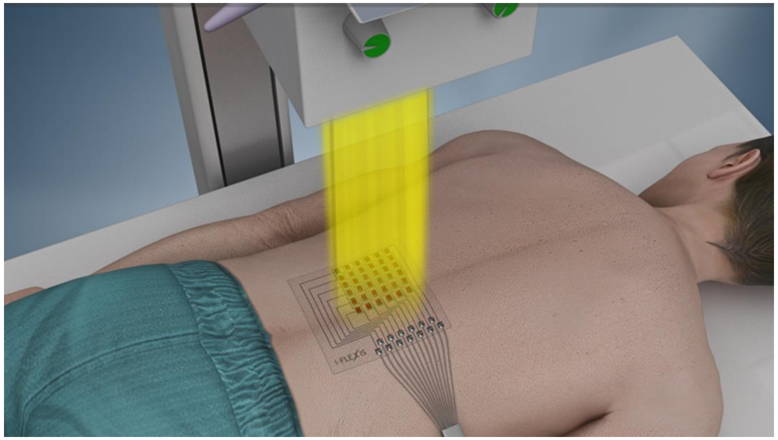
- ✓ **Limited absorption - Radiation hardness**
- ✓ **Human tissue-equivalent materials**

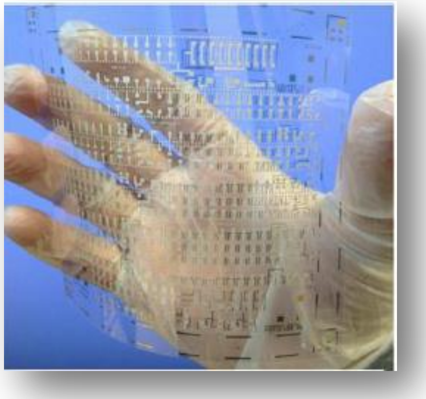
→ **Photoconductive GAIN!**

CALL INFN-CSN5 «FIRE -Flexible ionizing radiation detectors» 2019-2022

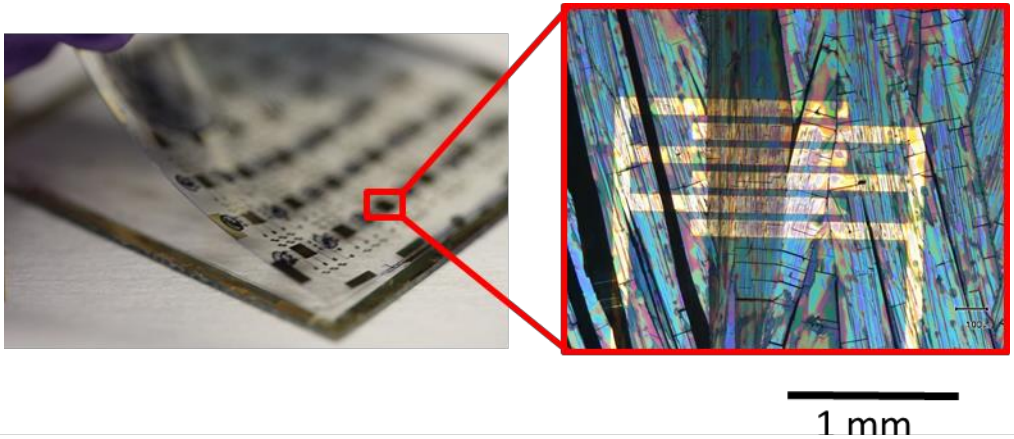
Partners: INFN-BO, INFN-RM3, INFN-NA, LNL, TIFPA

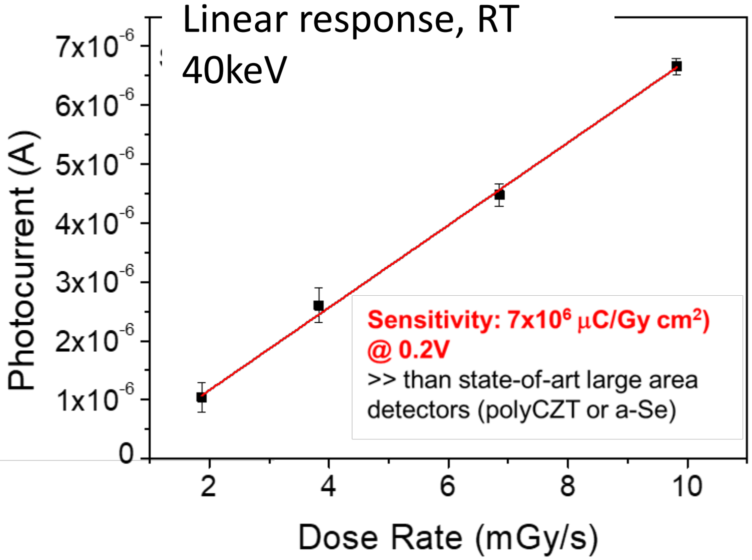






Direct X-ray detection with fully organic devices



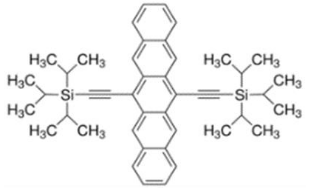


Linear response, RT
40keV

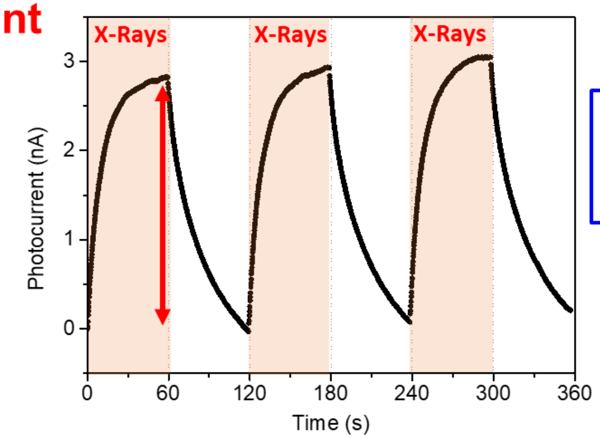
Sensitivity: 7x10^6 μC/Gy cm^2)
@ 0.2V
>> than state-of-art large area detectors (polyCZT or a-Se)

X-ray photocurrent

Synchrotron X-ray beam
Energy 17 keV
Dose rate 19 mGy/s



TIPS Pentacene

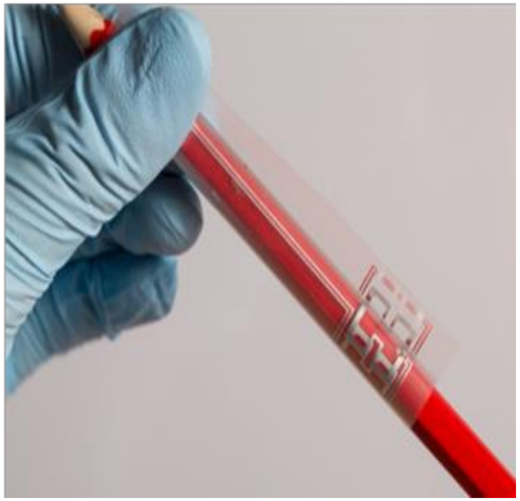


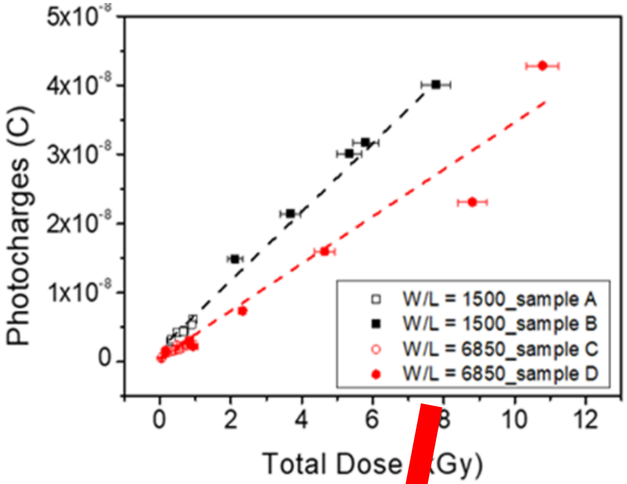
ΔI = 3 nA (max 30nA)
bias voltage 0.2 V

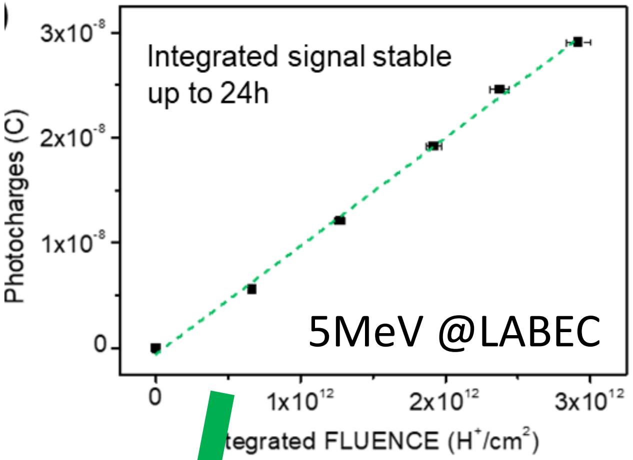
L. Basiricò et al., *Nature Commun.* 7, (**2016**)

I.Temino et al. *Nature Commun. 11*, (***2020***)

Direct Proton detection with fully organic devices

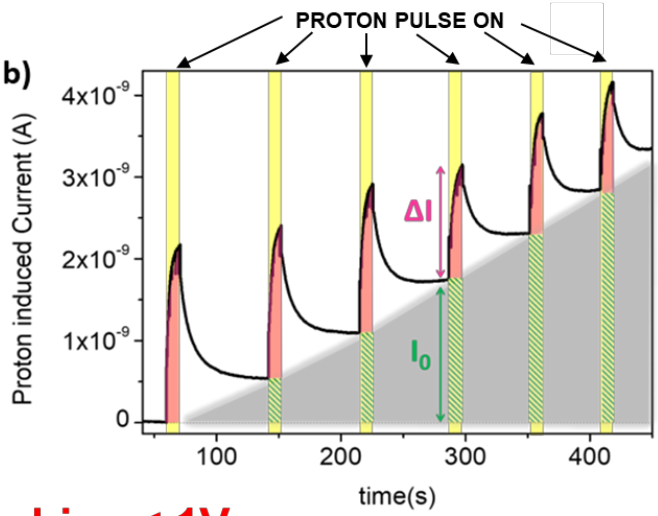






Integrated signal stable up to 24h

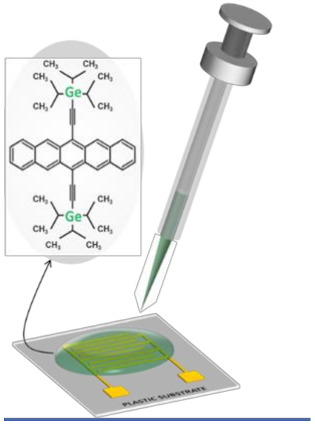
5MeV @LABEC



bias < 1V

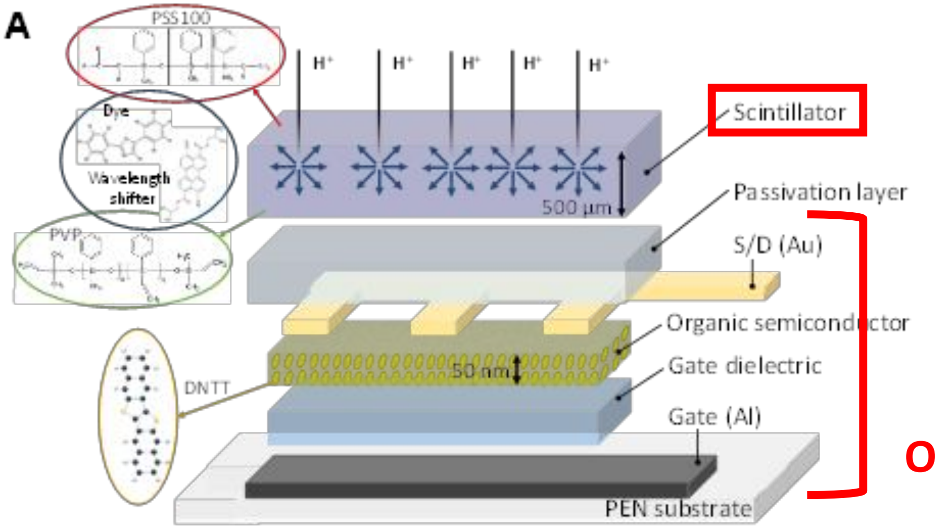
Two different contributions :

1) **the real-time response**, proportional to the dose ΔI (pink shadow)
2) **Integration-mode response** :I_0 (green shadow): baseline shift due to the fixed charges trapped in the plastic substrate.

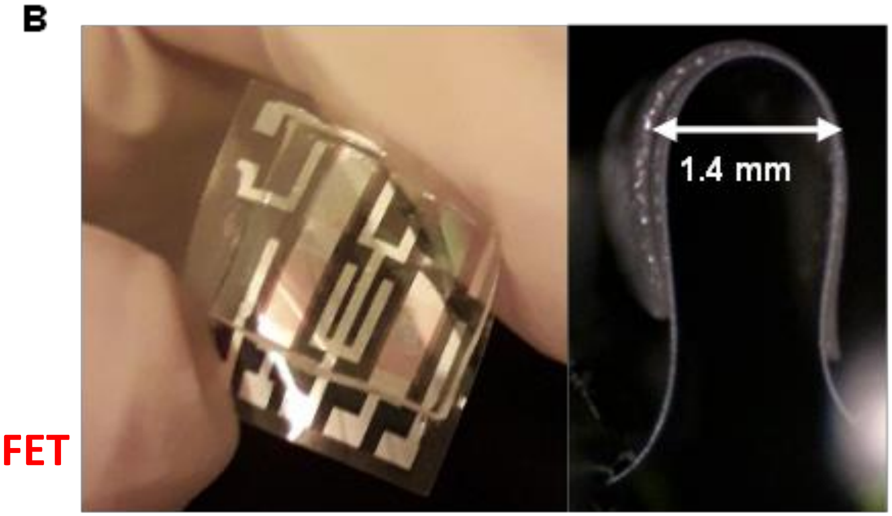


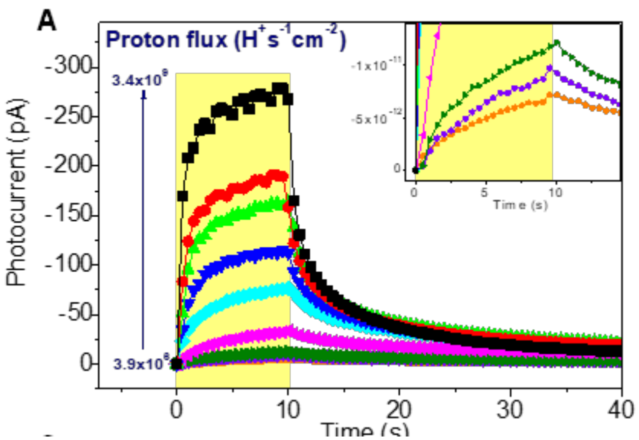
I. Fratelli et al., *Science Advances 3*, (**2021**).

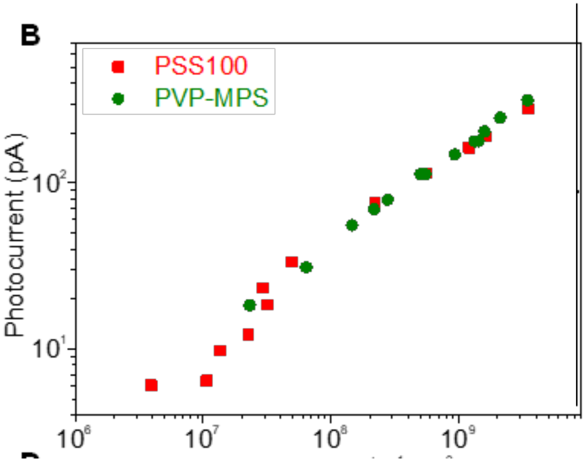
Indirect Proton detection with fully organic devices

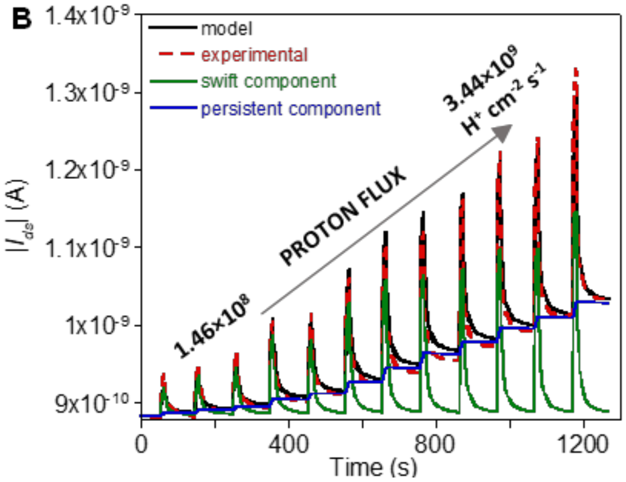


OFET









5MeV @ LABEC

S.Calvi et al., *Nature Flexible Electronics* in press (**2022**).

1. Space Resolution $\sigma_s \approx 10$ µm (→ pixel pitch ≈ 40–60 µm)
2. Time Resolution $\sigma_t \leq 50$ ps on the full chain ($\sigma_t = \sigma_{sensor} \oplus \sigma_{FE} \oplus \sigma_{TDC}$)
3. Radiation hardness to high fluences (for sensors) and high doses (for electronics). Fluences $\Phi = 10^{16} \div 10^{17}$ 1 MeV n_{eq}/cm^2 and Doses > 1 ÷ 2 Grad
4. A detection efficiency of ε > 99% per layer is tipically required (high fill factor)
5. The material budget must be kept below 1 ÷ 0.5 % radiation length per layer

Very challenging front-end electronics must be developed:
high resolution @ 10s µW/pixel, huge data bandwidth ≈ 100 Gbps/cm².
Today a complete solution for that is FAR from being available.
Developments ongoing

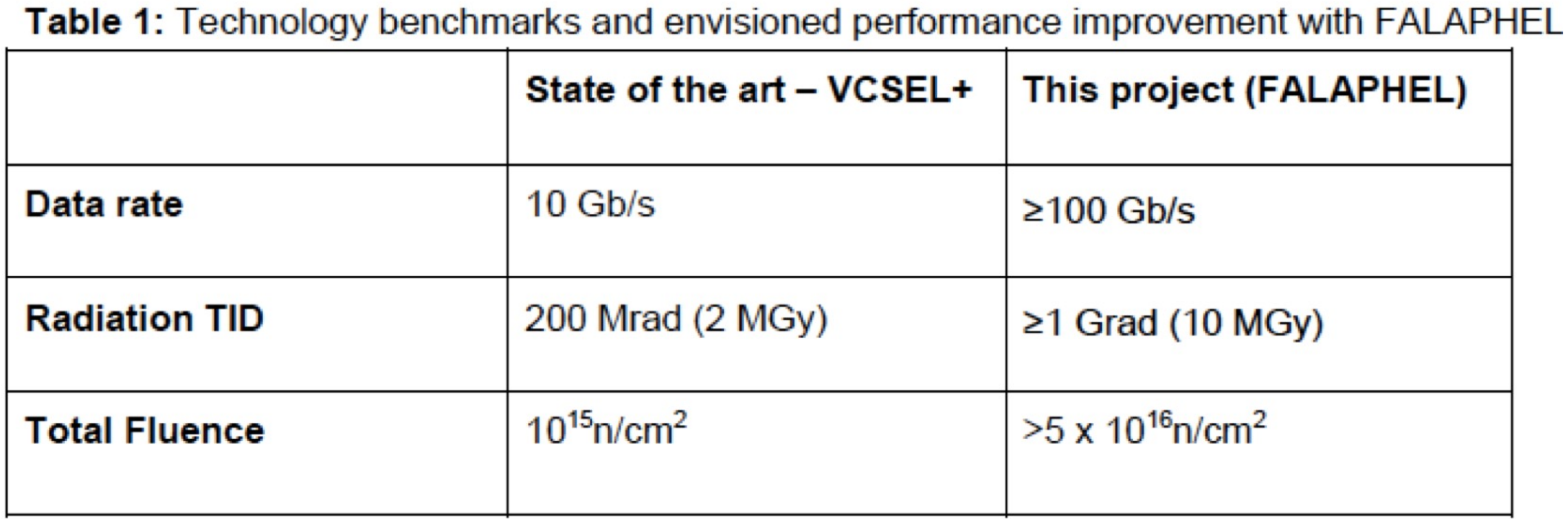


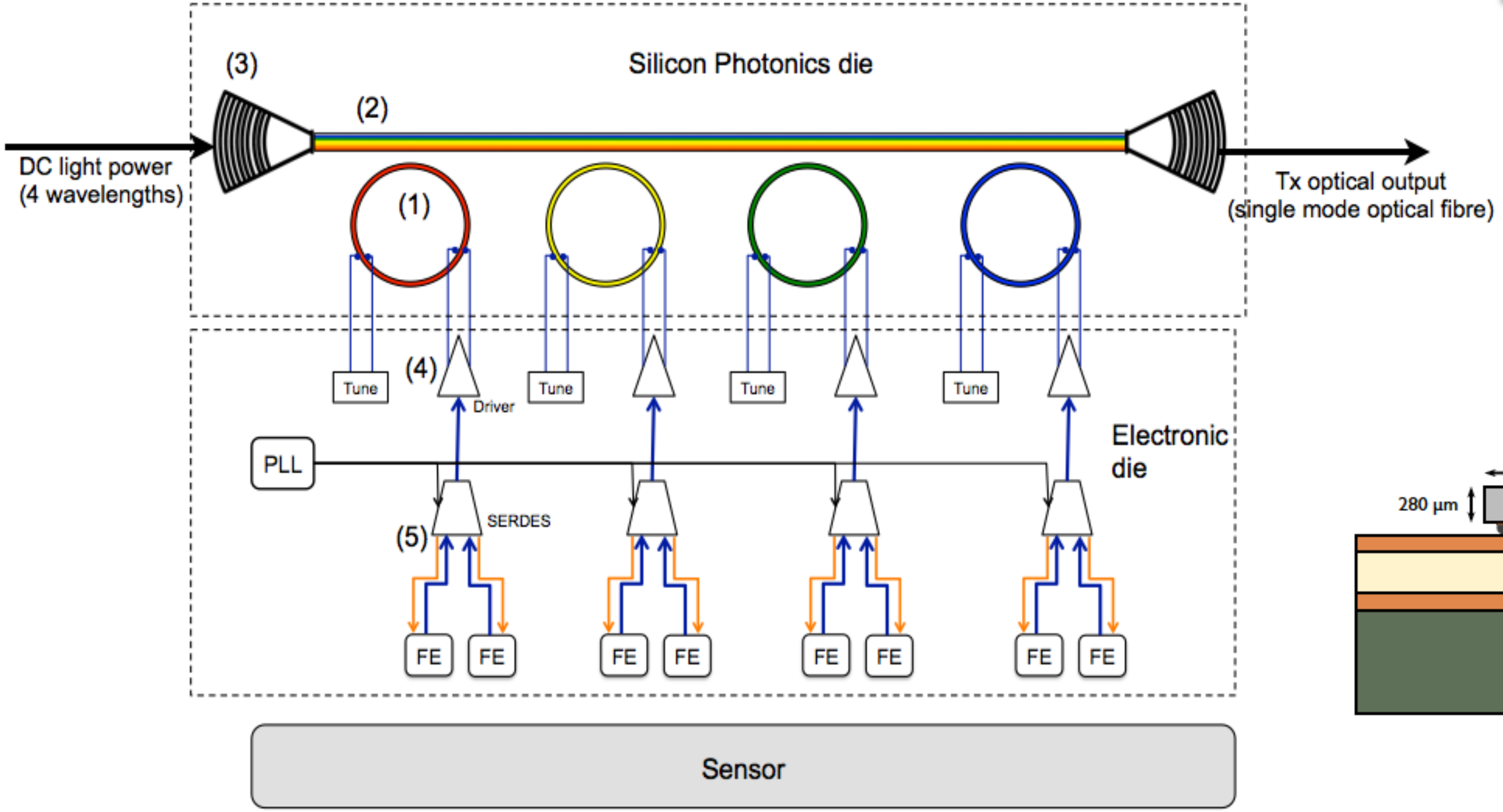
Table 1: Technology benchmarks and envisioned performance improvement with FALAPHEL

	State of the art – VCSEL+	**This project (FALAPHEL)**
Data rate	10 Gb/s	≥100 Gb/s
Radiation TID	200 Mrad (2 MGy)	≥1 Grad (10 MGy)
Total Fluence	10^{15}n/cm^2	>5 x 10^{16}n/cm^2

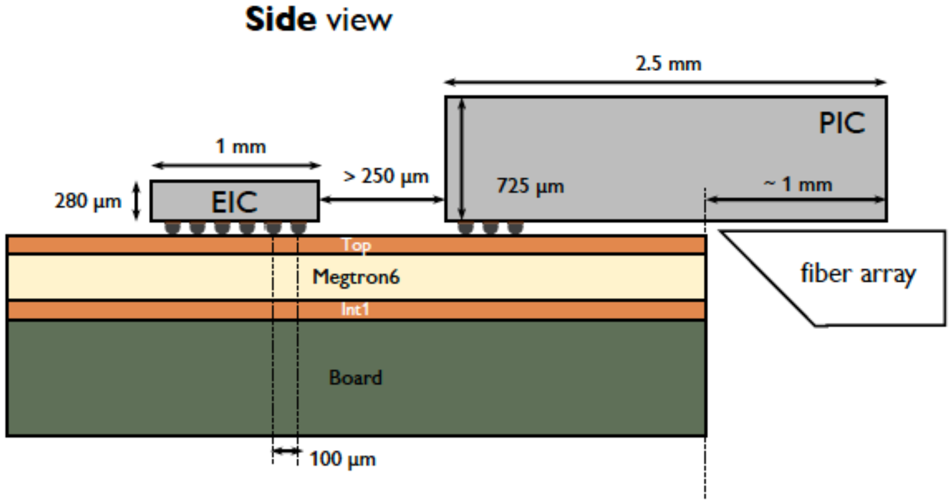
A challenging Back-end….

→ Aggregated 100 Gb/s links using wavelength division multiplexing (4 wavelength on a single optical fibre) and Integrated Front-End electronics

Key: Silicon Photonics



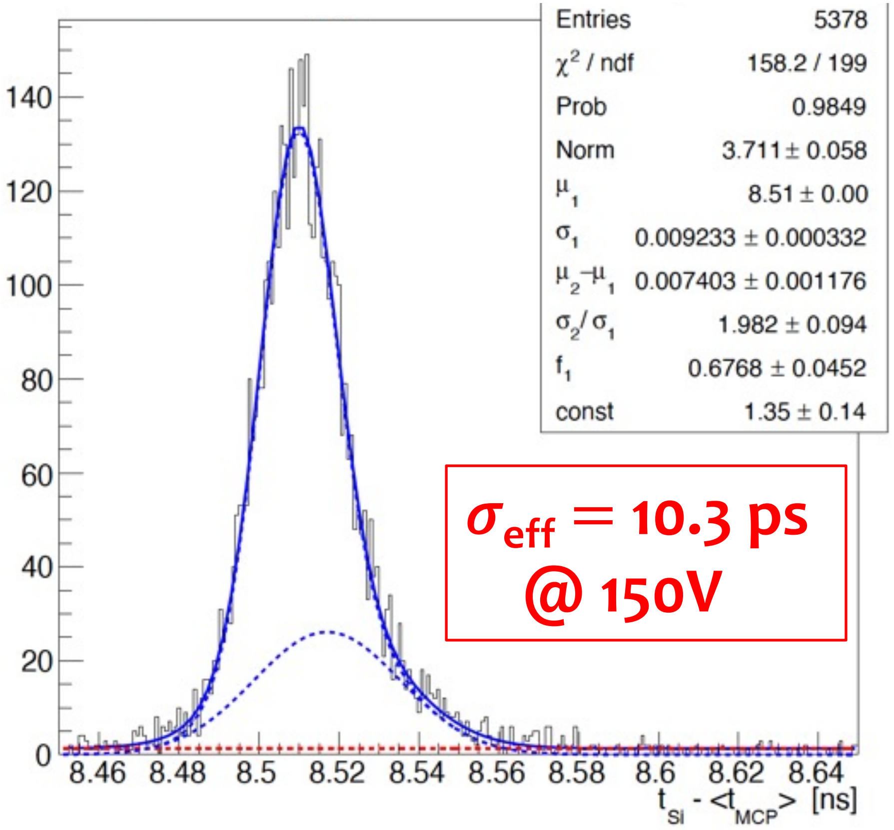
Schematics of the PIC and EIC assembly (FALAPHEL demonstrator). Ring resonators (1) with different and tunable resonator wavelengths are located along horizontally drawn bus waveguides (2) which are connected to optical glass fibers by efficient and robust focusing grating.



Interposer-free flip-chip integration using a high-speed PCB

Results & future

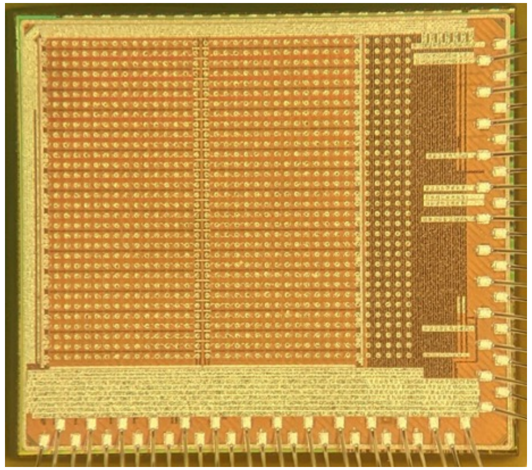
Irradiated @ 2.5 10^{16} n_{eq}/cm^2 , α_{tilt} = 0°

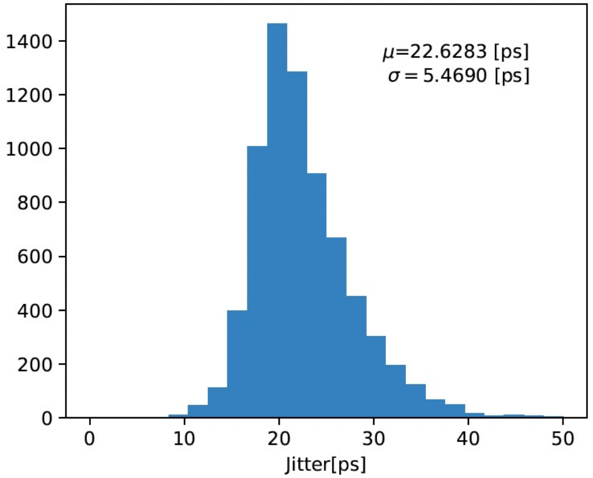


σ_{eff} = 10.3 ps @ 150V

TimeSPOT
TIME and SPace real-time Operating Tracker
INFN

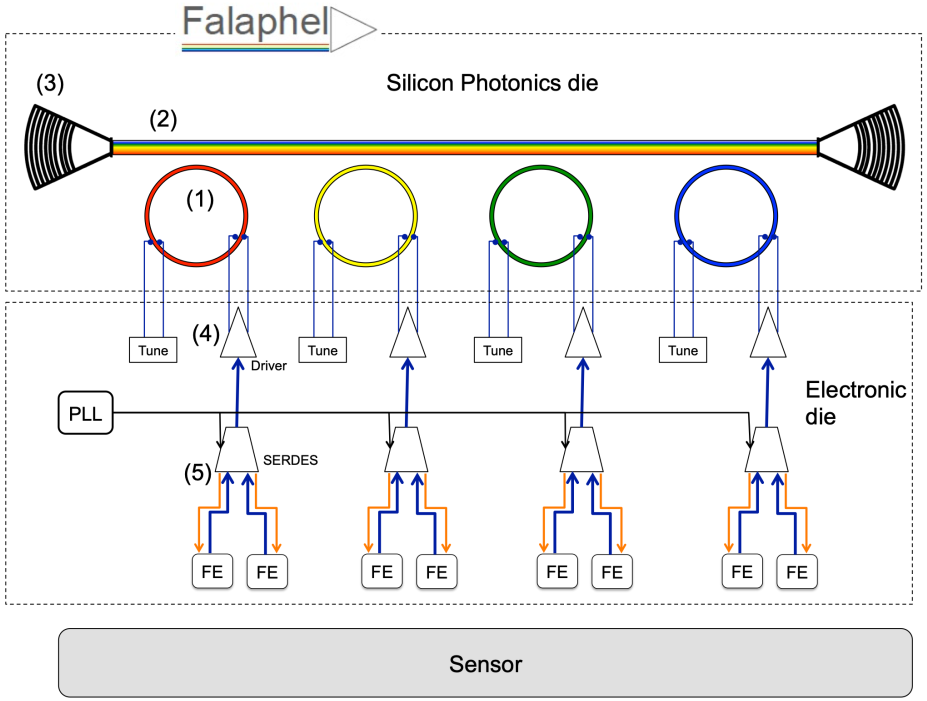
CMOS 28-nm Timespot1 ASIC

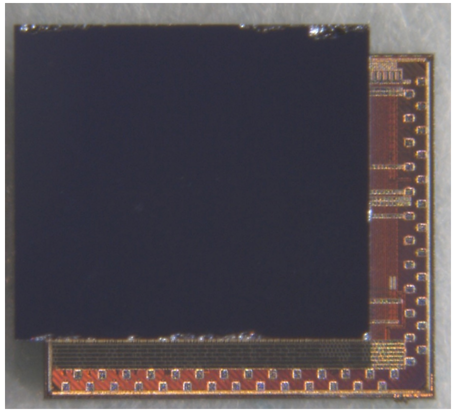




Distribution of the TA standard deviation across 1024 channels and 7 phases. Each point is computed from 100 repeated measurements.

Falaphel





AM 28-nm
Associative Memories

Scaltech28
28nm rad hardness

Electronics and Technologies for fast (high density) timing

(in the «hybrid approach»)

IGNITE µEd

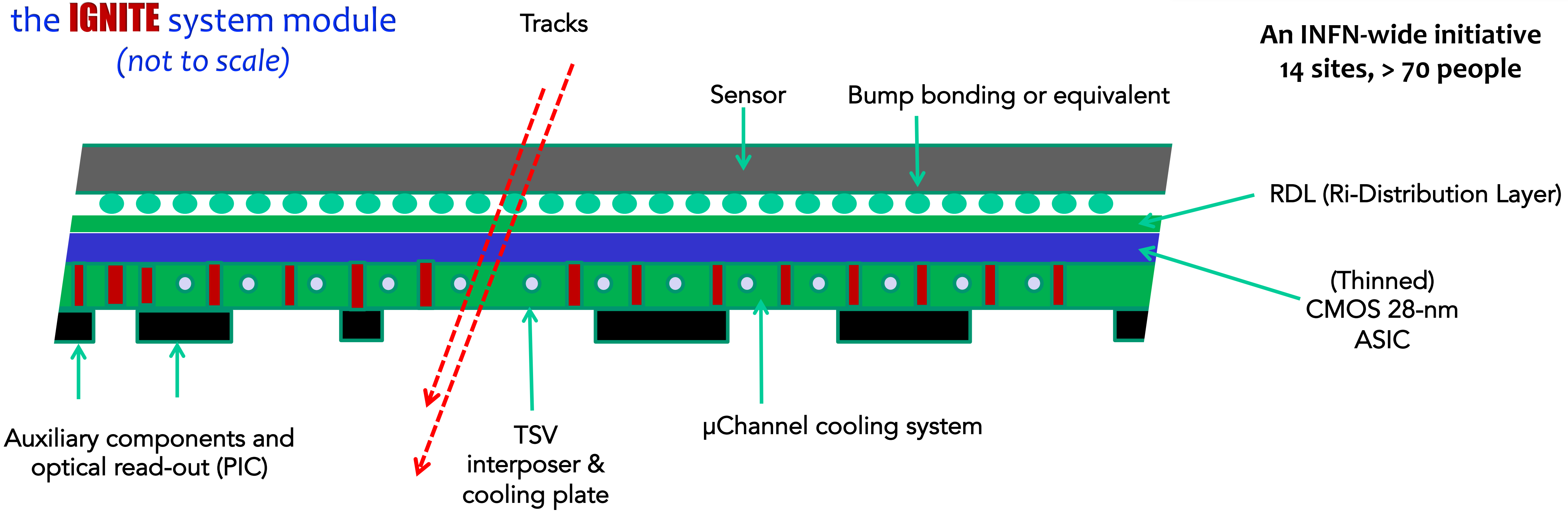
INFN

Istituto Nazionale di Fisica Nucleare

INFN Ground-up iNITiative for µElectronics developments

An INFN-wide initiative
14 sites, > 70 people

Vision/concept of a cut of the **IGNITE** system module
(not to scale)



Target deliverable of the IGNITE project:

- **A complete module (sensor, read-out ASIC, vertical IC, photonic circuit for data links, cooling system)**
- **The module development as a route to optimize material budget issues and High Density Interconnectivity between the device stages**
- **The whole thing below 0.8 (LHCb) ÷ 0.5 (NA62) % X_0**