Report from WP13
Prospective and Technology-driven Detector R&D

AIDAinnova Annual Meeting, April 25, 2023
ADEIT and CSIC, Valencia (Spain)

Valentina Sola
Torino University and INFN

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Projects

- Thin Silicon Sensors for Extreme Fluences

  Make Si sensors radiation tolerant by using a thin bulk, internal amplification and using a gain implant that would withstand a factor of 50 higher fluences than what is presently available

- The Silicon Electron Multiplier, a new approach to charge multiplication in solid state detectors

  Make Si sensors radiation tolerant by a novel biasing method – electrodes embedded in silicon

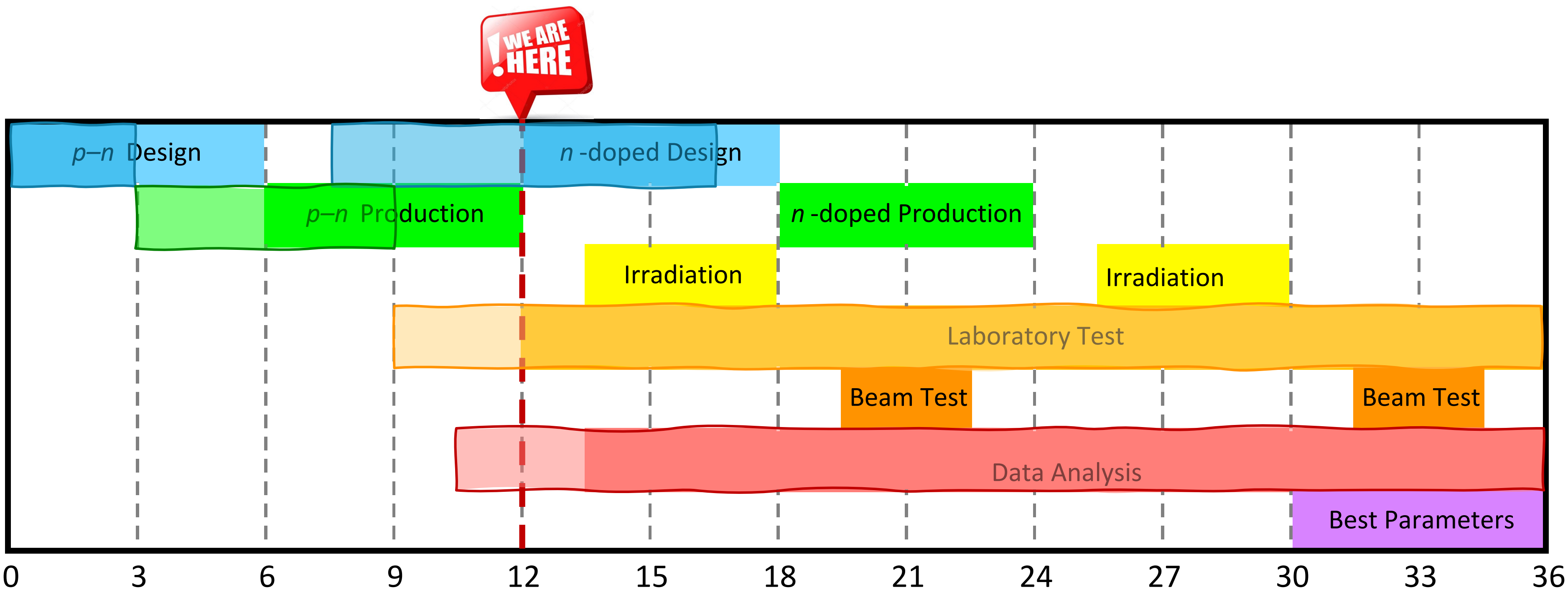
- Development of fine-sampling calorimeters with nanocomposite scintillating materials

  Develop a new generation of fine-sampling calorimeters that use innovative scintillating materials based on perovskite nanocrystals dispersed in a plastic matrix to form fast (~100ps) and radiation resistant (~1 MGy) scintillators

- Wireless Data Transfer for High-Energy Physics Applications

  Develop mm-wave-based wireless communication as an alternative to optical and wired links in a HEP-like environment to reduce the material and optimize the read-out

eXFlu-innova – Project Plan



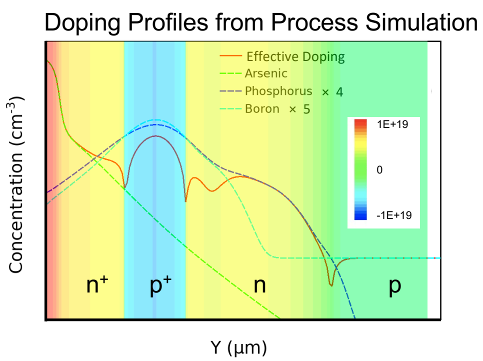
Deliverables:

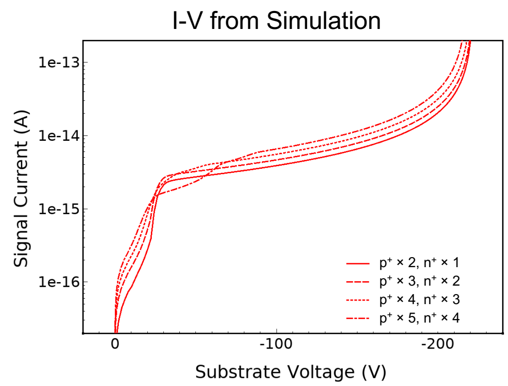
1. **simulation and design** of the *p–n* compensated gain implant (M6) – DONE
2. **production** of *p–n* compensated sensors (M12) – DONE and *n*-doped sensors (M24) –

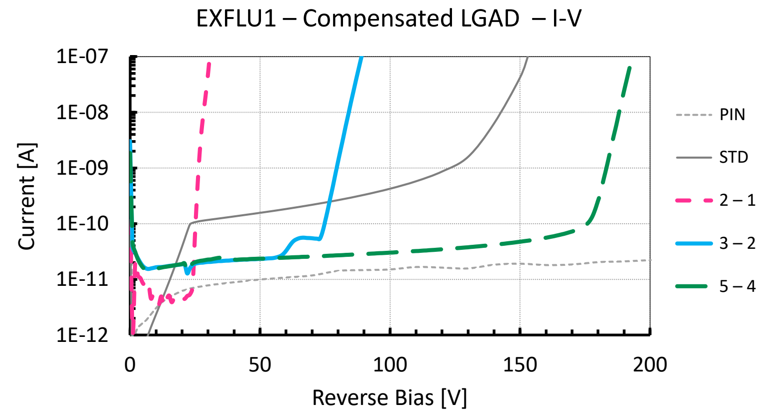
3. **identifications of the best parameters** to manufacture compensated LGADs (M36) – pending

The first *p–n* compensated LGAD

The first ***p–n* compensated LGAD** production batch released in November 2022







Ongoing testing on the *p–n* compensated LGAD batch:

⟶ I-V, C-V & test structure characterisation

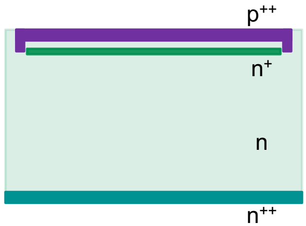
⟶ TCT scan as a function of bias voltage using different laser wavelengths

⟶ TCT scan over the sensor surface to investigate the peripheral region of the gain implant

⟶ SIMS on the gain implants to investigate the boron and phosphorus profiles

⟶ preparation of the irradiation campaign

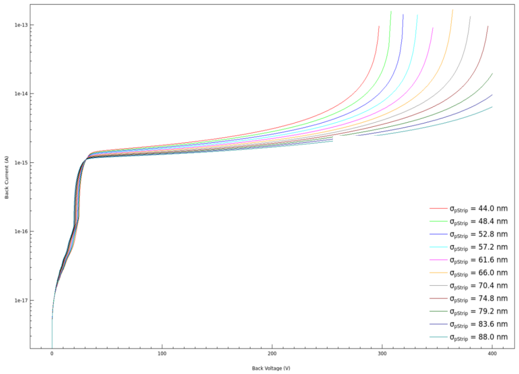
Outside eXFlu-innova: HPK presented a *p–n* compensated LGAD batch @ TREDI2023 [link]



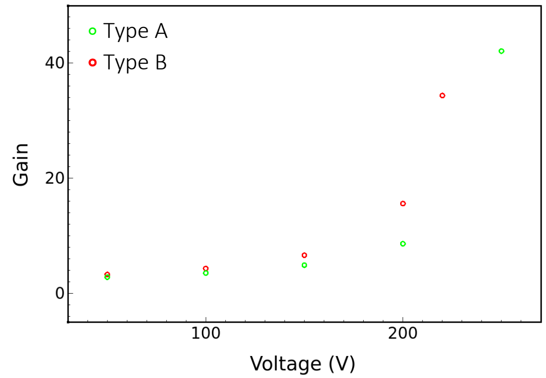
p-in-n LGAD

The **p-in-n LGAD** production batch is necessary to study the donor removal coefficient

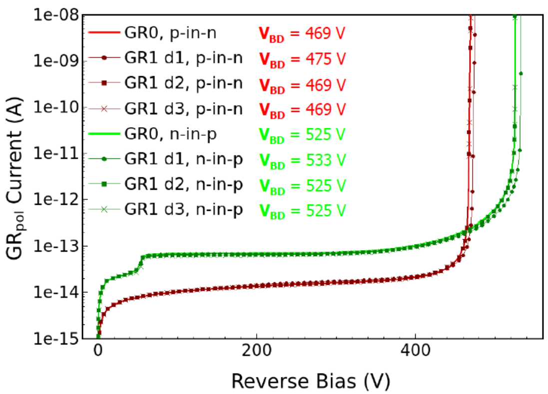
I-V simulation for different p^{++} contacts



Gain simulation for different n^{+} designs



Simulation of different guard-ring structures



Ongoing simulation of the p-in-n LGAD batch:

→ simulation of the electrostatic behaviour for different designs of the p^{++} contact

→ simulation of the transient behaviour for different designs of the n^{+} gain implant

→ simulation of the electrostatic behaviour for different guard-ring designs optimised for thin substrates

→ short-loop run to define the p^{++} contact process parameters

Outside eXFlu-innova: CNM presented a p-in-n NLGAD batch @ 41st RD50 [link]

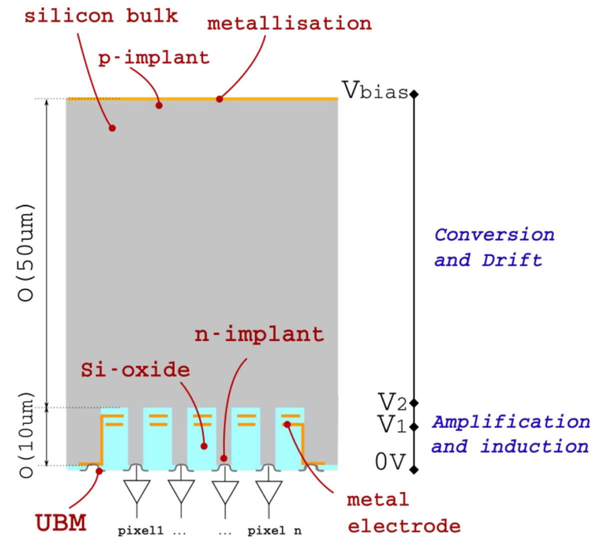
Silicon Electron Multiplier demonstrator

- **Project lead by CERN and CNM**
- **Aim at demonstrating the concept of SiEM described in** NIM A 1041 [2022] 167325

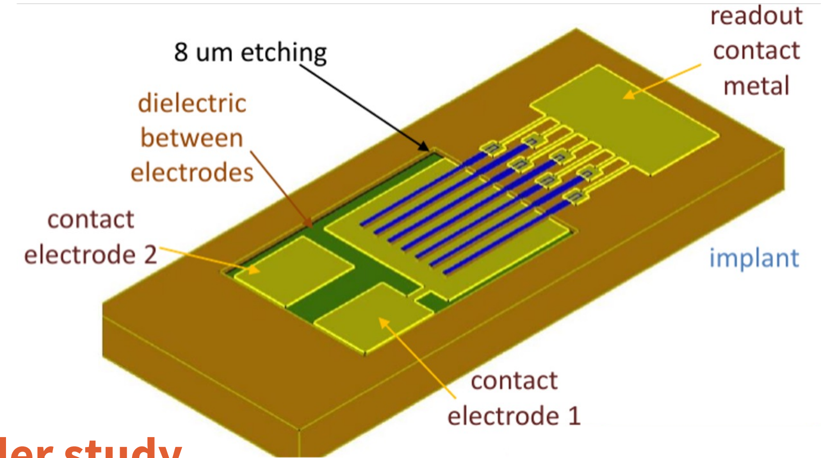
⇒ try to achieve gain in Si sensor with difference of potential applied to embedded electrodes rather than doping

- **Project organised in several phases**
  - [1] Definition of the process (technics, marterial, etc…)
  - [2] TCAD simulation and design of the chosen process
  - [3] Production
  - [4] Characterisation
  - [5] Investigation of alternative approach (different available tech., materials)
- **Proposed process based on DRIE**
  - Process defined in second half of 2022
  - Photolithography for etching pattern
  - Deep reactive ion etching
  - Metallisation and oxide deposition

⇒ Limits and constraints of the process under study

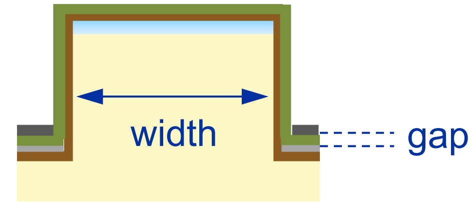


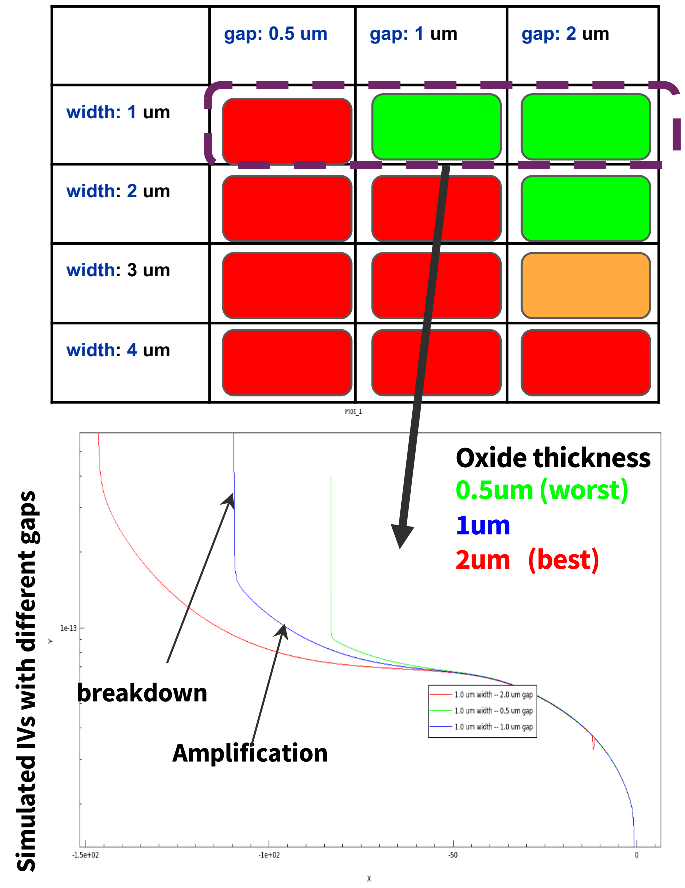
Process proposal

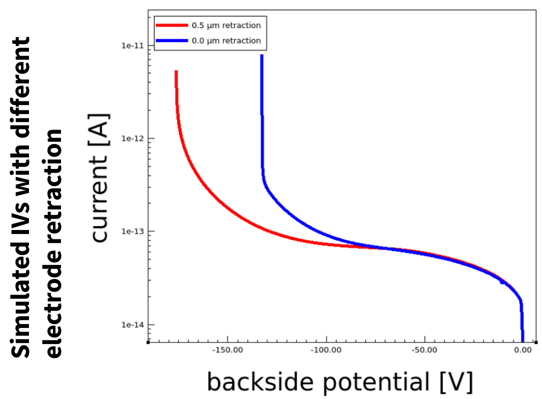


Geometry study

- **Generic interplay between geometrical parameters studied in [NIM A 1041 [2022] 167325]**
- **Geometry adapted to the real production process**
- **Specific geometrical constraints**
  - width of the amplification pillar
  - gap between amplification electrodes
  - distance between pillar and electrodes
- **Study with TCAD simulation of geometry compatible with process**
  - IV used to check if amplification happens before breakdown (checked with transient sim.)
  - best for low width and high gap
  - width limited by lithography and gap limited by oxide deposition
  - retraction of the electrode from the pillar still allow amplification (see next slide)



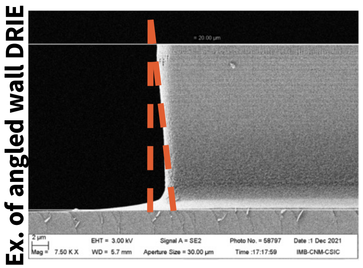




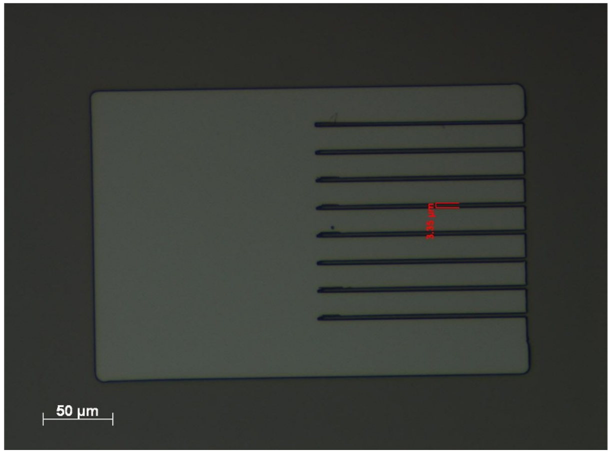
Process definition and test

- **Test of photolithography procedure for etching**
  - 2,3,4µm achieved
- **1µm at the limit of what can be done with photolithography**
  - use e-beam lithography (prefer to avoid for demonstrator)
  - inverted pyramid geometry (ie. 1µm at the bottom with slanted walls)
    ⇒ impact is that electrodes are retracted from the pillar wall by the pyramid shadow (OK in simulation)
- **First test of the DRIE step**
  - over-etching to be corrected in the next batch (25µm instead of 8µm)
  - measurement to qualify the angle of the inverted pyramid wall on-going
- **Preparing next step**
  - metallisation and oxide deposition

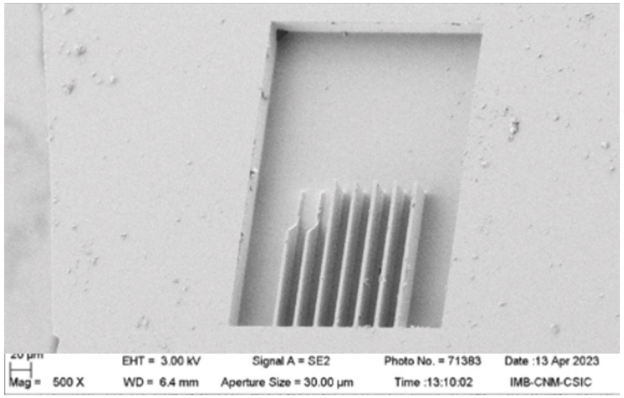
Ex. of angled wall DRIE



Photolithography test (3um)



First etching batch

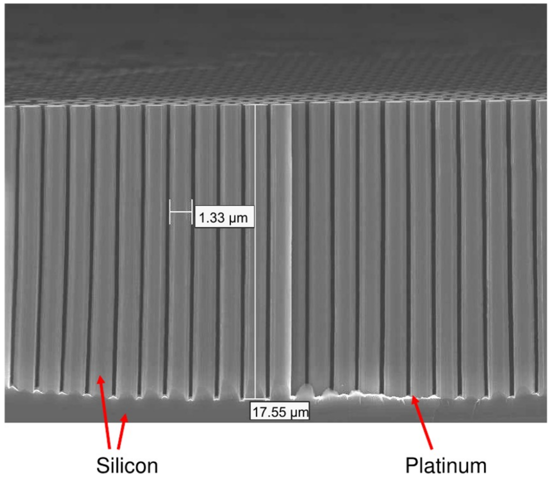


Alternative approach to SiEM

- **Study possible use of Metal assisted etching [5]**
  - parallel project between CERN and PSI, based on AdEM 22 (2020) 2000258
  - very different process constraints (cheap, high aspect ratio, first electrode deposited while etching), but never used in active device

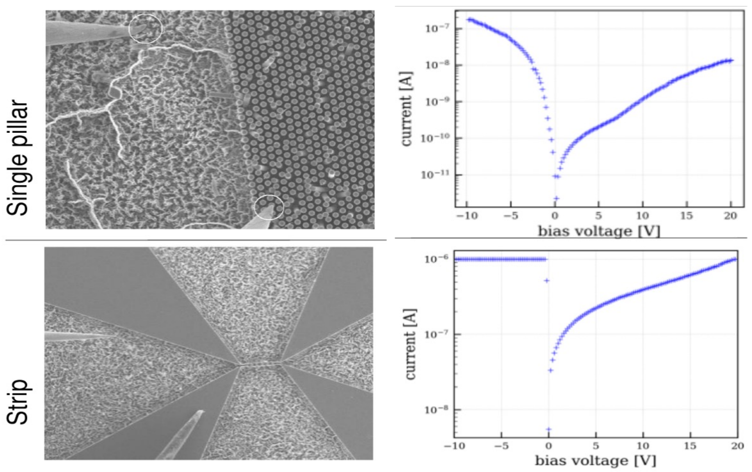
- **Testing the structures**
  - IV just after production with probe-station ⇒ pn junction conserved
  - bonding of test structures for IV in the lab
  - preparing setup for laser/ source test.

Pillar made with MacEtch process

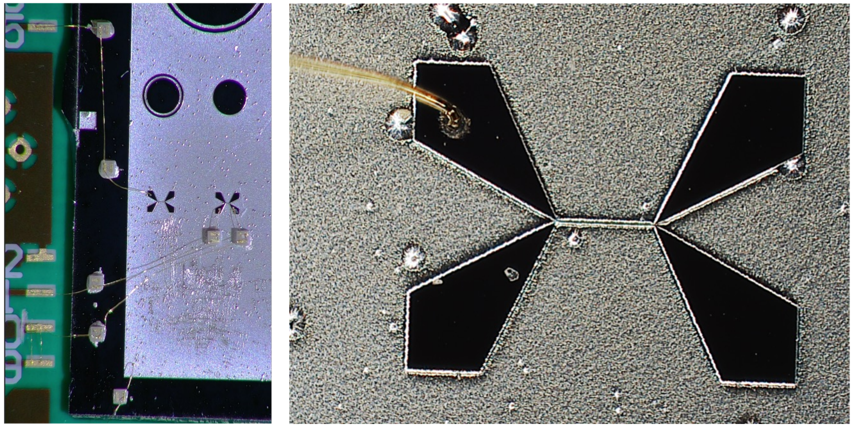


see M. Halvorsen @ RD50 41st workshop

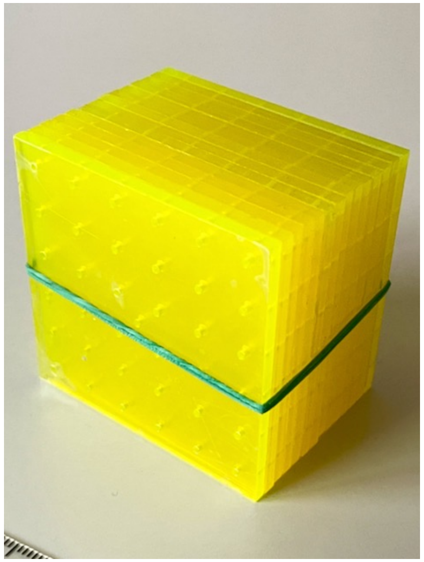
IV measured under SEM after prod.

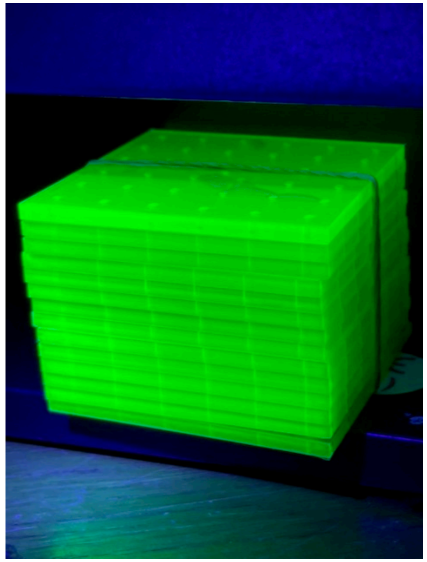


Strip structure bonded for testing



Nanomaterial composites (NCs)





Semiconductor nanostructures can be used as sensitizers/emitters for ultrafast, robust scintillators:

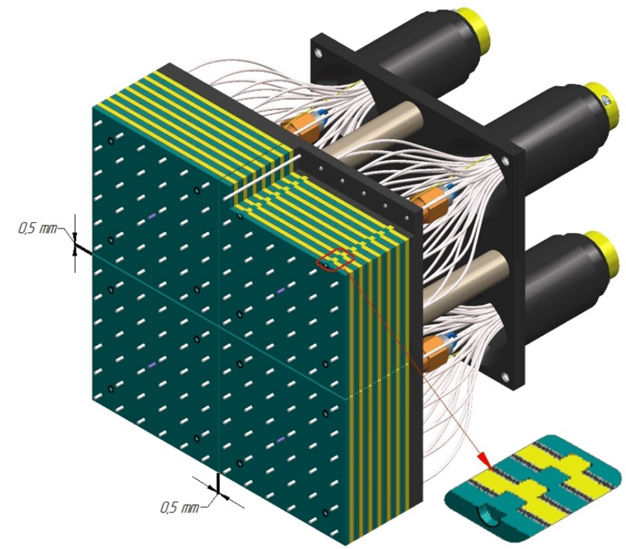
- Perovskite (ABX_3) or chalcogenide (oxide, sulfide) nanocrystals
- Cast with polymer or glass matrix
- Decay times down to O(100 ps)
- Radiation hard to O(1 MGy)

Despite promise, **applications in HEP have received little attention to date**

No attempt yet to build a **real calorimeter with NC scintillator** and **test it with high-energy beams**

Shashlyk design naturally ideal as a test platform:

- Easy to construct a shashlyk calorimeter with very fine sampling
- Primary scintillator and WLS materials required: both can be optimized using NC technology

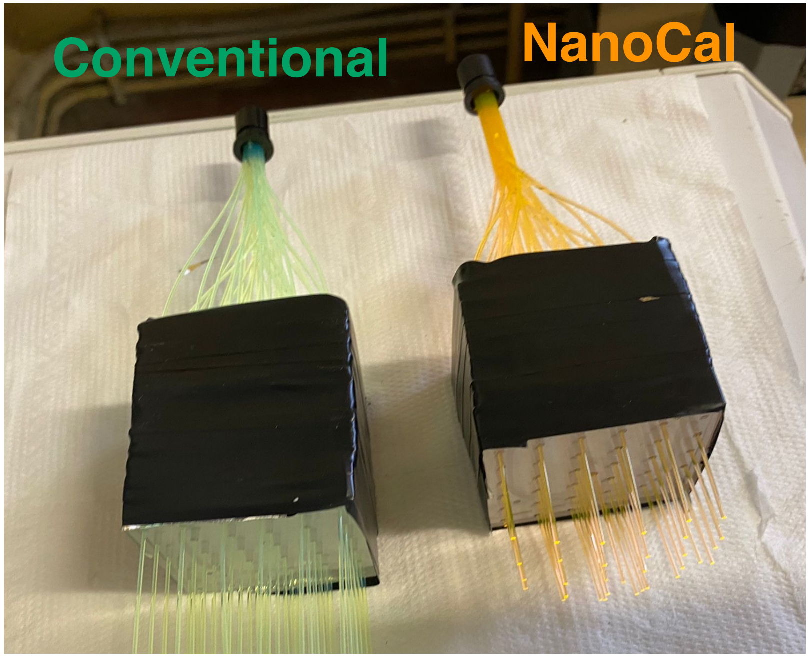


KOPIO/PANDA design
Fine-sampling shashlyk

NanoCal project status

Schedule:

- **Oct 2022: First shashlyk component test at CERN: fibers/tiles/SiPMs**
- **2023**: Further iterations to improve performance of NC scintillator prototype
- **2024:** Construction of full-scale shashlyk modules; performance comparison



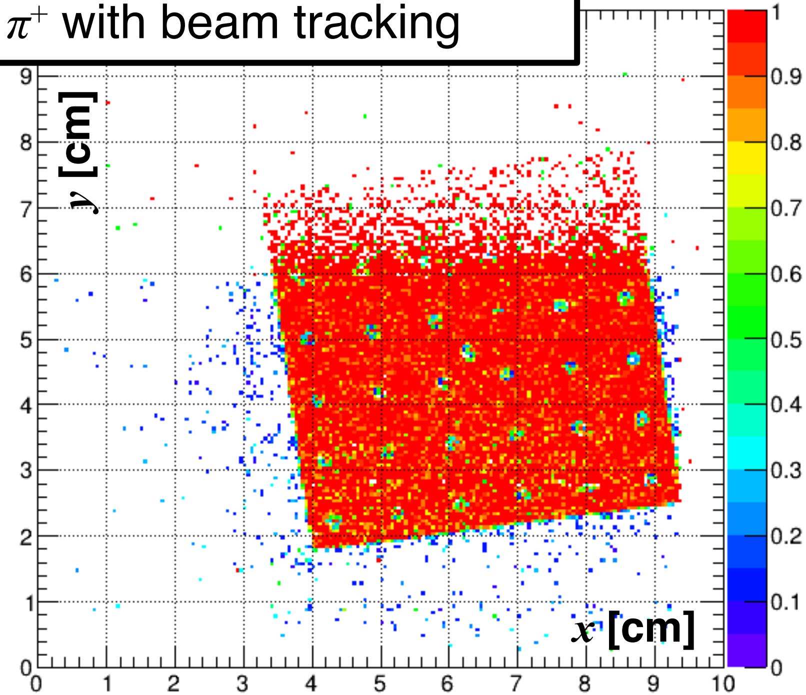
2 prototypes with 12 fine sampling layers

$1.3X_0$ in depth: MIP deposit = 10 MeV

Known formulation for NC scintillator:

- 0.2% $CsPbBr_3$ in UV-cured PMMA
- 50% of light emitted with $\tau < 0.5$ ns

Oct 2022 test: SPS H2 beamline
e^- and π^+ with beam tracking



Conclusion of 2022 test:

NC prototype seems to work but with low light yield and many open questions

NanoCal goals for 2023

Big effort in 2022 to test first prototype only 5 months after project start!

Beam test results ambiguous due to construction errors for NC prototype

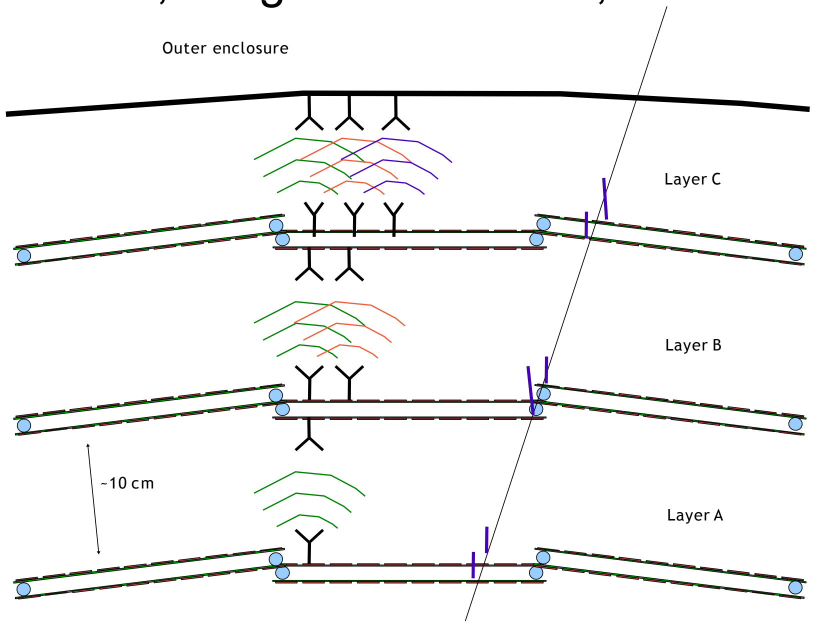
2023 NanoCal beam test
14-21 July, T9 at CERN PS
e^- and MIPs, 1-10 GeV

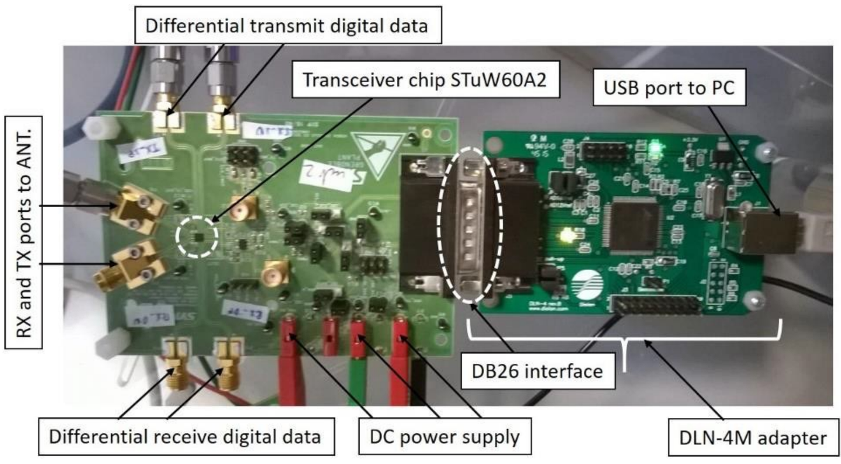
Comprehensive test program for 2023, prototypes under construction:

Conventional scintillator Nanocal scintillator, 0.2% (rebuilt)	Re-establish quantitative baseline with errors corrected
Nanocal scintillator, 0.2% + custom fibers	New fiber developed with Kuraray specifically optimized for CsPbBr3 emitter: fast de-excitation, high Stokes shift
High concentration (0.8%?) + custom fibers	Test improvement in light yield with increased concentration
New formulation with $CsPbCl_3$ + intermediate WLS dye	Test improvement in light yield with increased absorption length

Blues Sky project: Wireless Data Transfer for High-Energy Physics Applications

- Study of components and antennas integration
- Full link demonstrator(s) from 1 tile to 2 and 3 tiles – several mock-ups to be tested
- Use and integrate commercially available components
- Study the performance of the system (data rate, bit error rate, modulation schemes, usage of bandwidth, crosstalk in repeater, etc.)





Debit 1 Gbps per layer and is cumulative, thus it will be reaching 3 Gbps at the outer enclosure.

Courtesy of CEA-Letti and STMicroelectronics

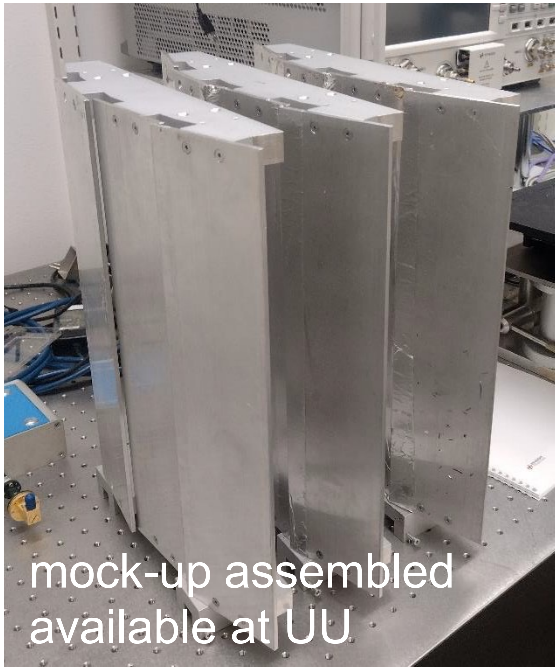
Deliverables

Deliverable 1: First mock-up assembled and tested during the first year, including study of antenna technologies allowing a seamless integration in such a harsh environment (strong irradiation and magnetic fields); specification of the antennas.

Deliverable 2: Second mock-up assembled and tested during the two next years. Three or four layers of silicon detector with their readout, equipped with low power consumption transceiver and antennas.

Deliverable 3: Published study of performance in HEP environment and access to technology for new user communities. Make packages available with user support.

Deliverable 4: (in option depending on the time left) Study of the cumulative noise in multi-hop data transmission and jitter, development of wireless communications strategies for managing crosstalk



available 10 TX/RX at UU

Summary and outlook

- The four projects are up and running
- They report at each annual meeting
- MS51: projects selection Dec 2021
  MS52: midterm review Dec 2022
- A final written report is due 2 months before the end of AIDAinnova
  It is expected to include an evaluation of the potential of the studied technologies, which takes into account the results of the project