IBIS

Innovative Backside Illuminated Single photon imaging sensor

INFN CSN5 project (2021-2022)

Units: Bologna, TIFPA-FBK , Torino

P.I.: Alessandro Montanari

Target

- Development of a sensor that coupled to an appropriate optics perfoms **fast** and **high- resolution** imaging on a **wide range of wavelengths**

- Ideal sensor:
  - High PDE in VUV (or NIR)
  - Small cell size (High dynamic range)
  - Single photon counting (Low light)
  - High speed
  - Integrated readout

- Application of our interest:
  - Imaging with scintillation light
    - **Liquid Argon detectors**
    - **Scintillators**

The goal and the team

- IBIS is focused on the development of an innovative SiPM architecture, as key technology for a new imaging device:

INFN & UNIBO Bologna: Simulation Requirements Characterization

INFN Bologna

Name	Surname	Title	
Sergio	Bertolucci	*Full Professor*	
Alessandro	Montanari	*Senior Researcher*	0.4
Nicolo'	Tosi	*Junior Researcher*	0.4
Tiziano	Rovelli	*Associate Professor*	0.3
Fabrizio	Fabbri	*Senior Researcher*	0.1
Carla	Sbarra	*Junior Researcher*	0.2
Michele	Pozzato	*Junior Researcher*	0.3
Gabriele	Sirri	*Senior Researcher*	0.1
Laura	Patrizii	*Senior Researcher*	0.1
Nicoletta	Mauri	*Researcher*	0.1
Valerio	Pia	*PhD student*	0.2

FBK / TIFPA: Sensor design and production

FBK / INFN TIFPA

Name	Surname	Title	FTE
Alberto Giacomo	Gola	*Senior Researcher*	0.2
Andrea	Ficorella	*Researcher*	0.4
Alberto	Mazzi	*Researcher*	0.2
Fabio	Acerbi	*Researcher*	0.2
Stefano	Merzi	*Researcher*	0.1

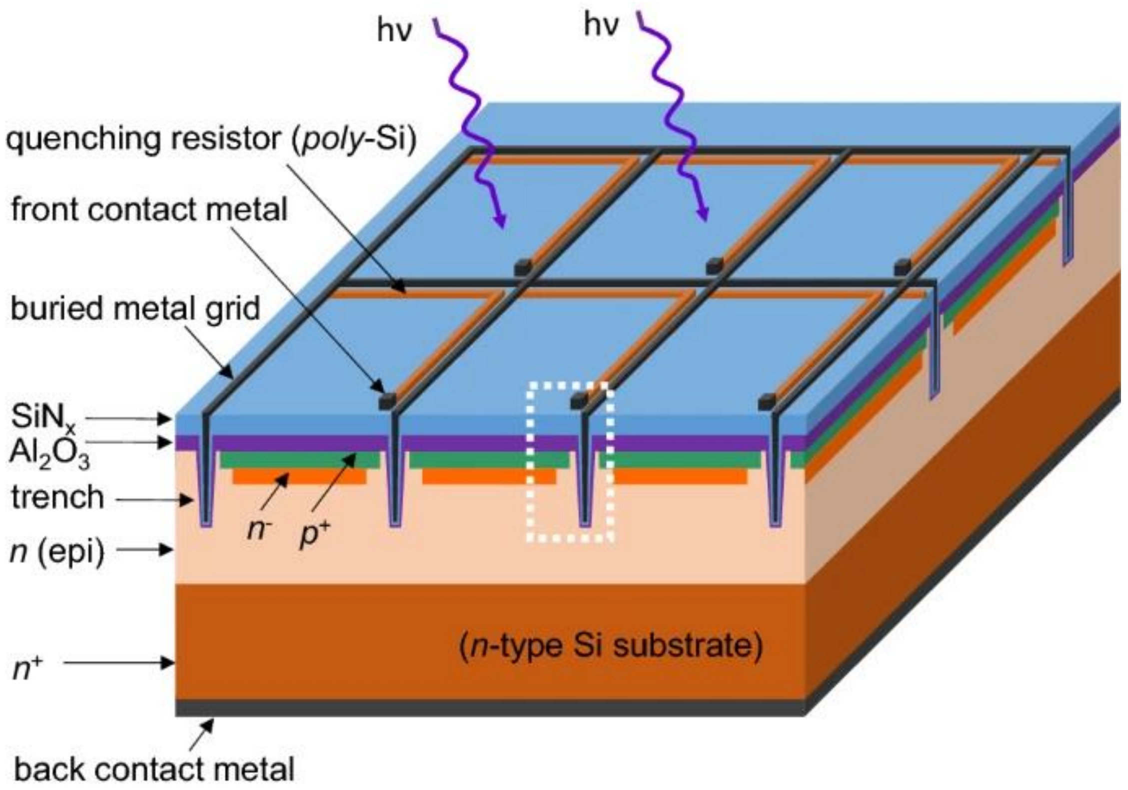
INFN Torino

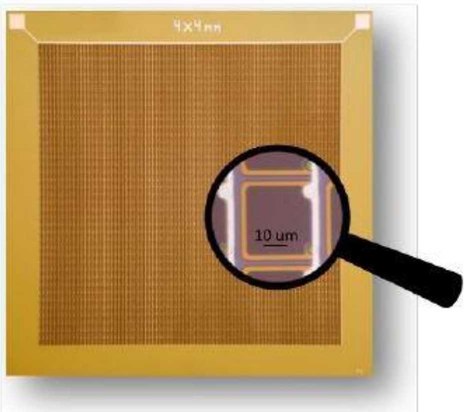
Name	Surname	Title	FTE
Lorenzo	Piccolo	*PhD Candidate*	0.20
Giovanni	Mazza	*Senior Researcher*	0.20
Angelo	Rivetti	*Director of Research*	0.15

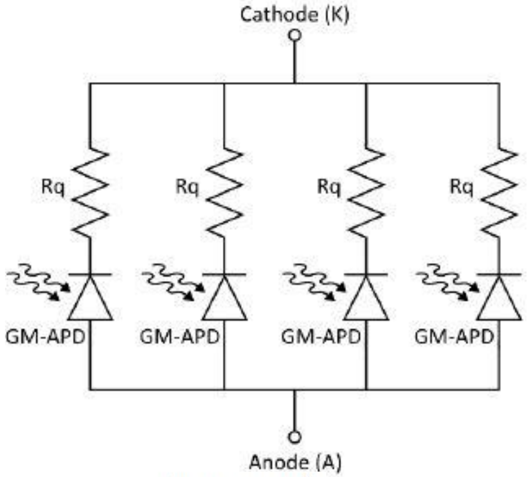
INFN Torino: FE and readout electronics

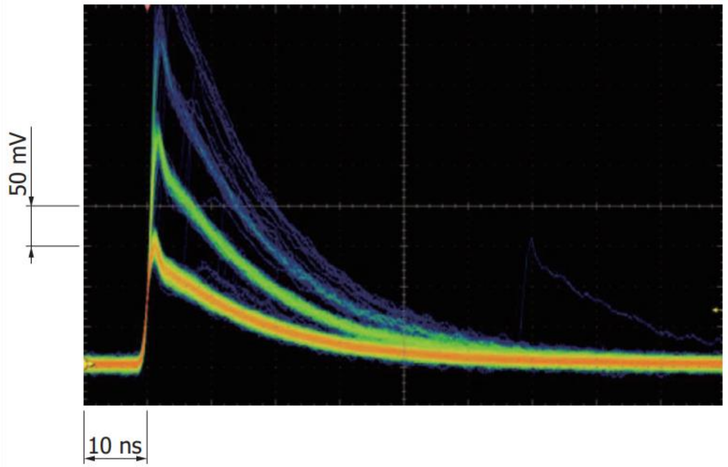
The standard SiPM

- A set of Geiger avalache photodiodes (SPAD) connected in parallel
  - the analog output is «linearly» proportional to number of impinging photons

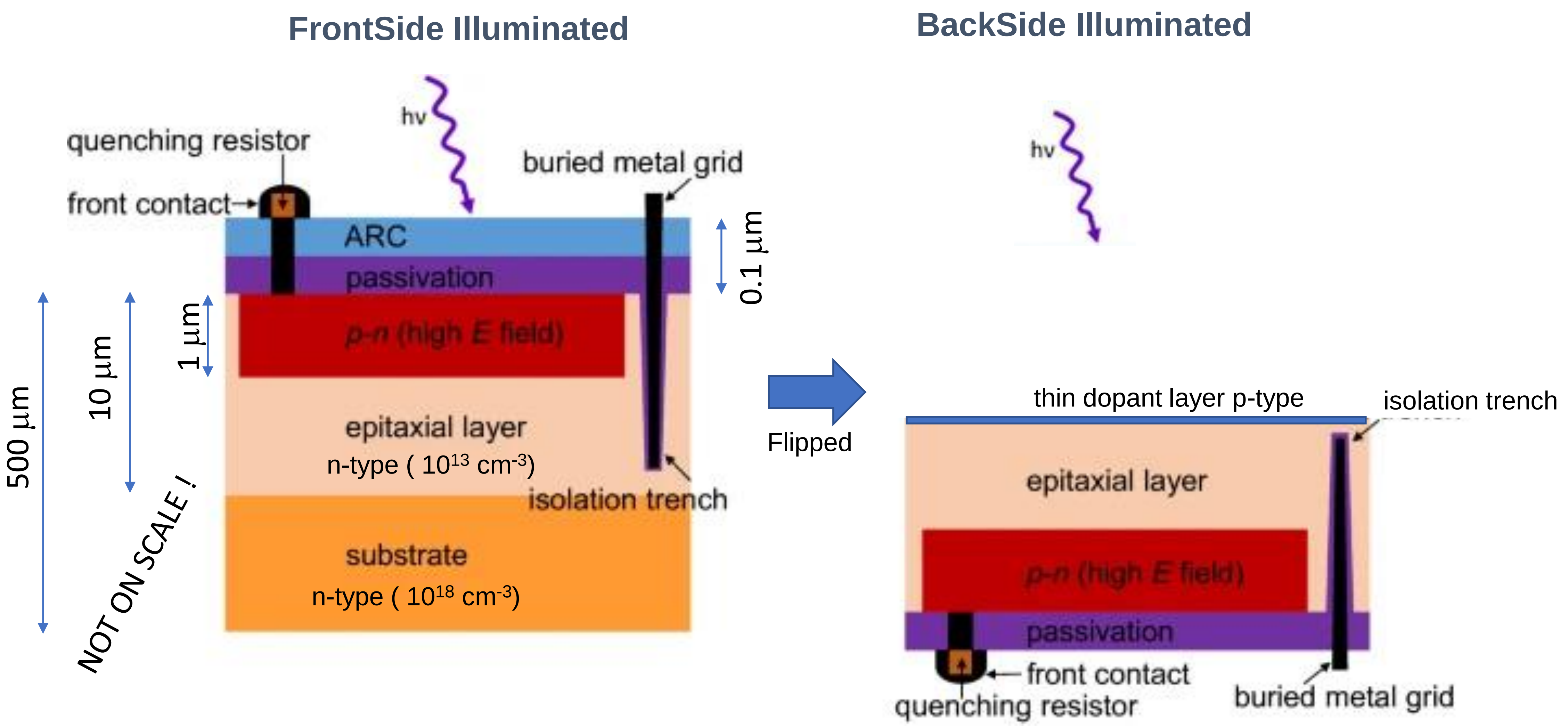








What is a Backside Illuminated SiPM?



State of the art

- A lot of interest about Backside Illuminated:
  - Max Plank Institute: no news since prototype built in 2007
  - TCAD simulations, but no prototype
  - Innovative Anti Reflective Coating (ARC) for Backside, but no prototype
  - A matrix of BSI-SiPM for LiDAR
  - ...??

31 January 2020

64x48 pixel backside illuminated SPAD detector array for LiDAR applications

Jennifer Ruskowski, Charles Thattil, Jan H. Drewes, Werner Brockherde

...lectronics and Photonics XVII; 1128805 (2020)

...l States

www.nature.com/scientificreports

scientific reports

Check for updates

OPEN **Advanced antireflection for back-illuminated silicon photomultipliers to detect faint light**

Yuguo Tao, Arith Rajapakse & Anna Erickson

Nuclear and Radiological Engineering, Georgia Institute of Technology, Atlanta, GA, USA. email: yuguo.tao@gatech.edu

PROCEEDINGS OF SCIENCE

Development of Back Illuminated SiPM at the MPI Semiconductor Laboratory

H.-G. Moser*, S. Hass, C. Merck, J. Ninkovic, R. Richter, G. Valceanu

Max-Planck-Institut für Physik, Föhringer-Ring 6, D-80805 Munich, Germany

MPI Halbleiterlabor, Otto-Hahn-Ring 6, D-81739 Munich, Germany

Advanced Back-Illuminated Silicon Photomultipliers With Surrounding P+ Trench

Publisher: IEEE Cite This PDF

Haifan Hu ; Ying Wang ; Penghao Liu ; Xiubo Qin ; Junpeng Fang ; Hongming Zhao ; Zhe Ma ; Jiatong Wei **All Authors**

1 Paper Citation | 165 Full Text Views

PRO and CONS

☺

- ❑ Entrance window is free of metal grid, quenching resistance, Through Silicon Vias:
  - ✓ Better Fill Factor

☺

- ❑ No need of Vias allows small SPAD size:
  - ✓ High Dynamic range
  - ✓ Better Radiation Tollerance

☺

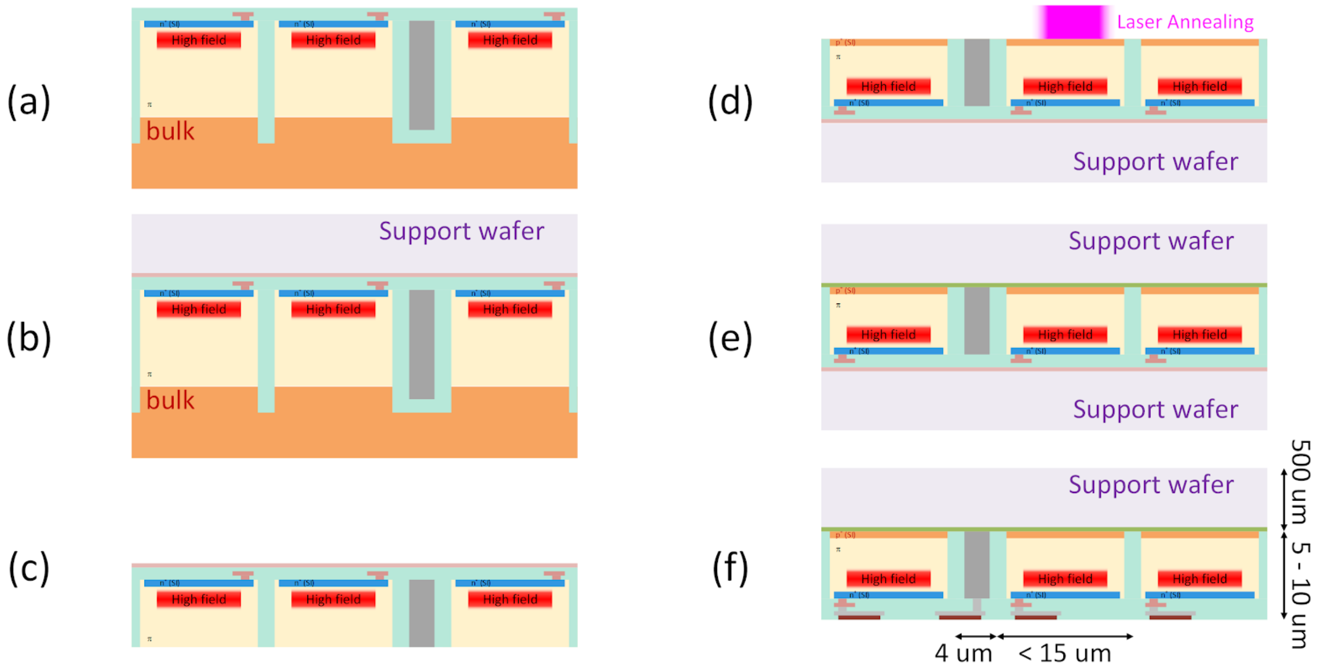
- ❑ All the contacts are on one side:
  - ✓ Easy to couple Read Out Chip with bump bonding
  - ✓ Natural to build monolithic Sensor + Electronics

☹

- ❑ No metallization in Entrance Window:
  - ✓ More difficult to control CrossTalk and AfterPulse

Sensor Development

- ❑ Microfabrication process deeply revised for the BSI
  - Start from the front side
  - Remove the bulk and laser annealing
  - Interconnection pads on the front side
- ❑ Test prototypes in FBK and Bologna also in liquid Nitrogen



a) Build new cell
b) Attach Support Wafer on Front side
c) Remove completely Silicon bulk
d) Laser annealing on backside thin dopant
e) Attach Support Wafer on Backside
f) Remove Support wafer from Back side

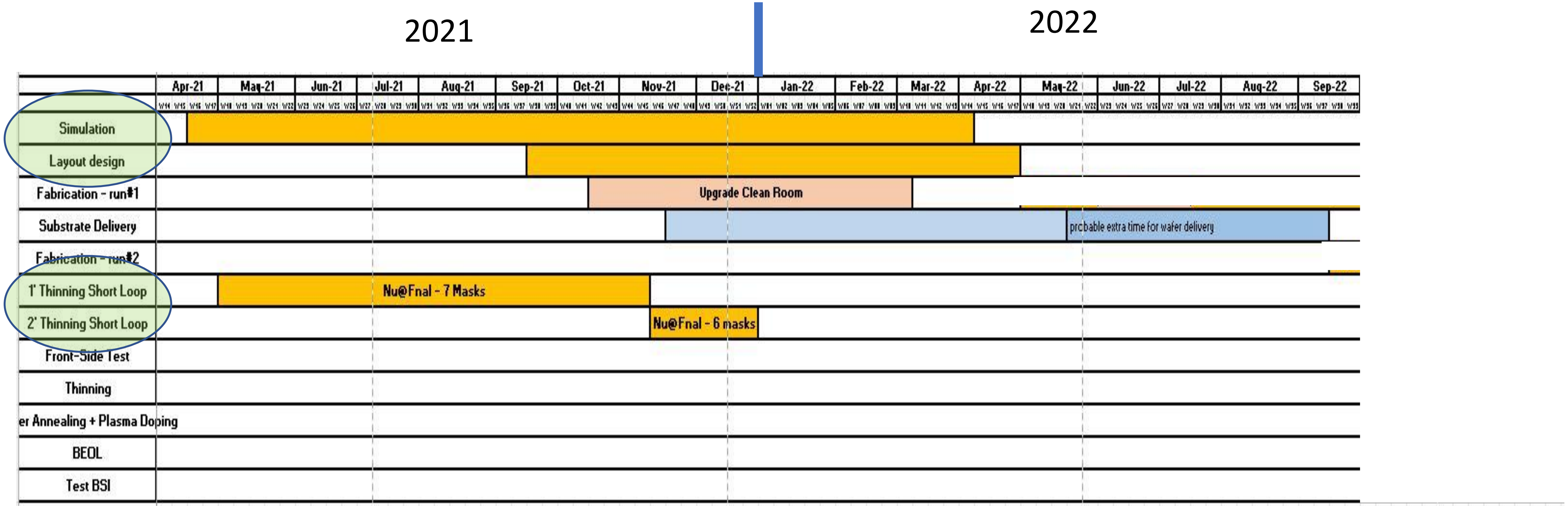
Sensor Development

- ❑ Most critical processes:
  1. Design new cell (must limit Crosstalk, AfterPulse, Dark Count rate)
  2. Bulk removal (keeping flat surface: ‹ 1 μm)
  3. Laser annealing (in outsourcing)

- ❑ Delay of over 1 year wrt original plan due to:
  - COVID
  - upgrade of FBK clean room
  - Queue of projects at FBK

DONE in 2021(Apr)-2022 (Sept)

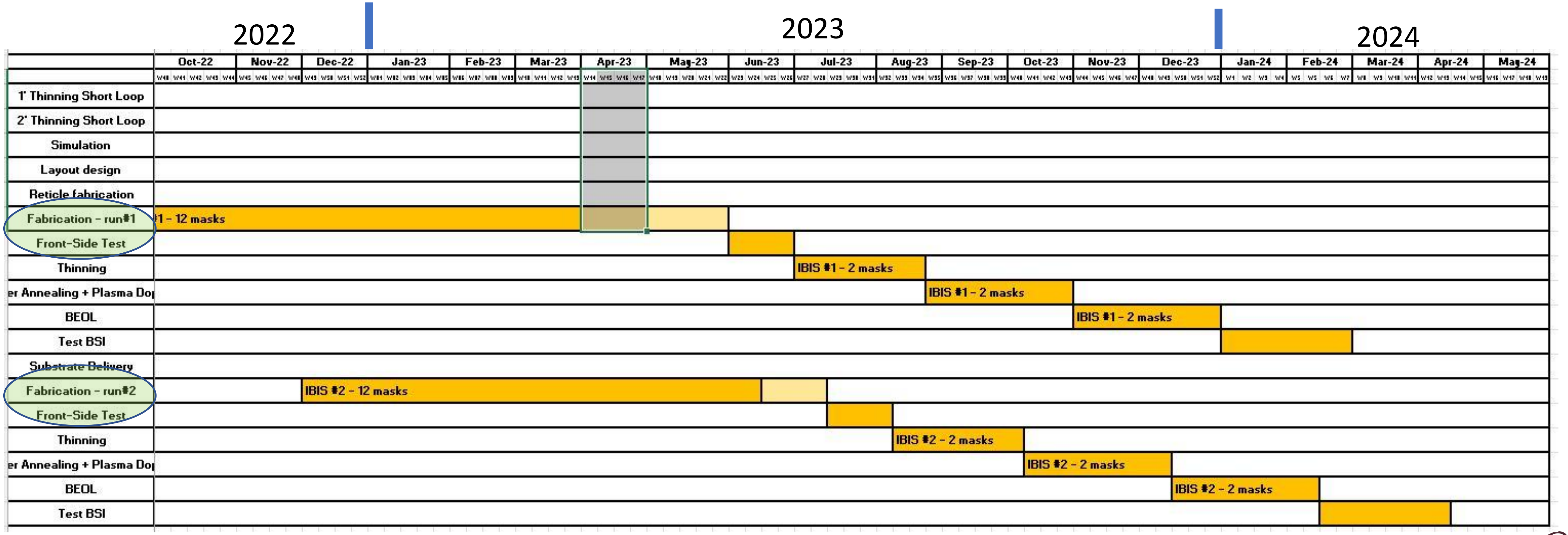
- Thanks to availabilty of a standard run from CSN 2 (Nu_at_FNAL):
  - Process 1. (new cell) and 2. (thinning) were completed (13 masks = 30 kE)



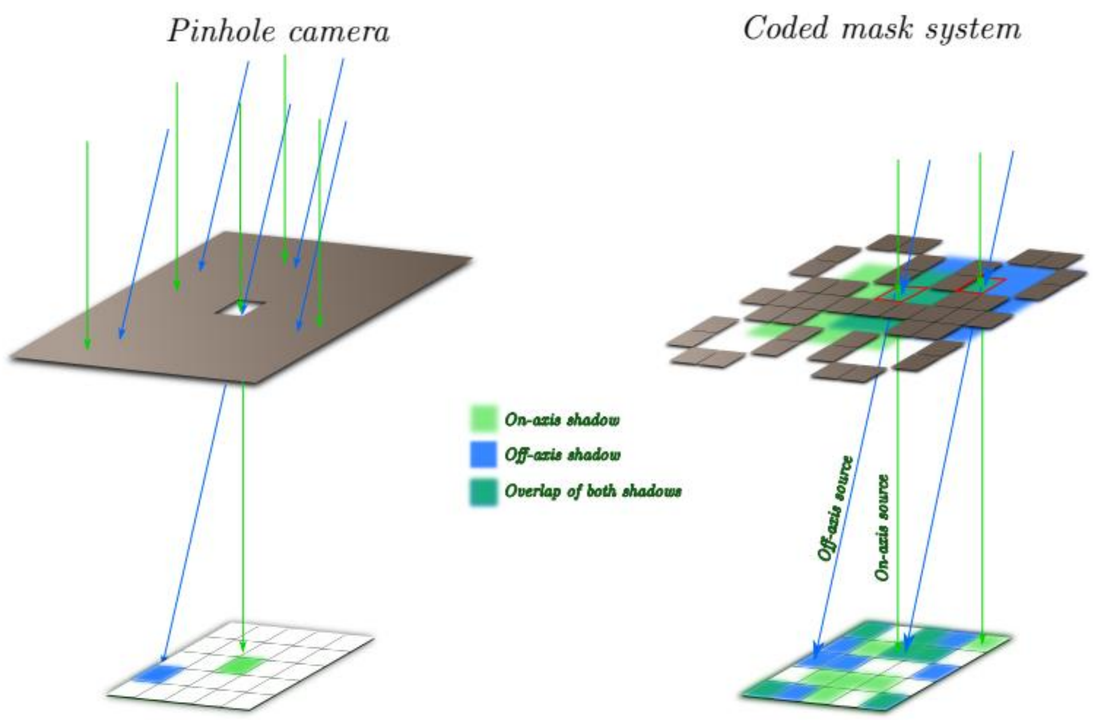
Where we are

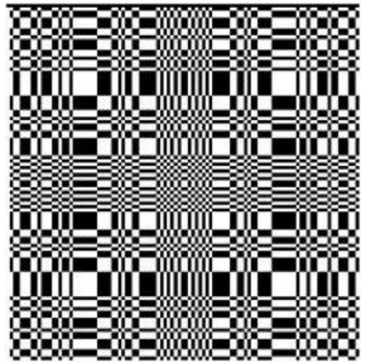
- 2 IBIS R&D run (2x45 kEuro) started in autumn 2022

  - First Front Side (with BSI cell) in June 2023
  - **First Back Side Jan 2024**

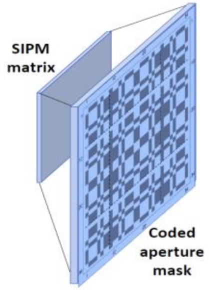


Optics development

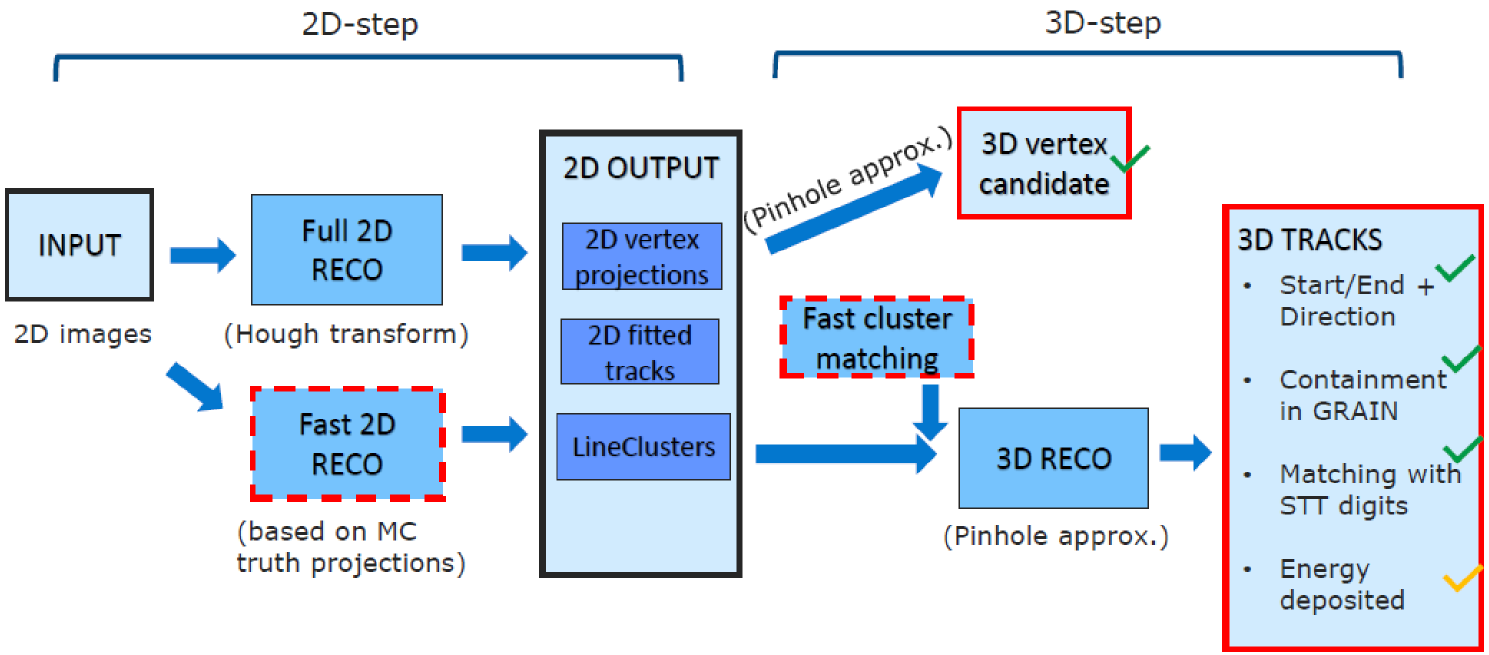




- Coded Aperture mask techniques were developed as the evolution of a single pinhole camera
  - matrix of multiple pinholes to improve light collection and reduce exposure time
- Image formed on sensor is the superimposition of multiple pinhole images.
- Advantages
  - Good light transmission (50%)
  - Good depth of field
  - Small required volume



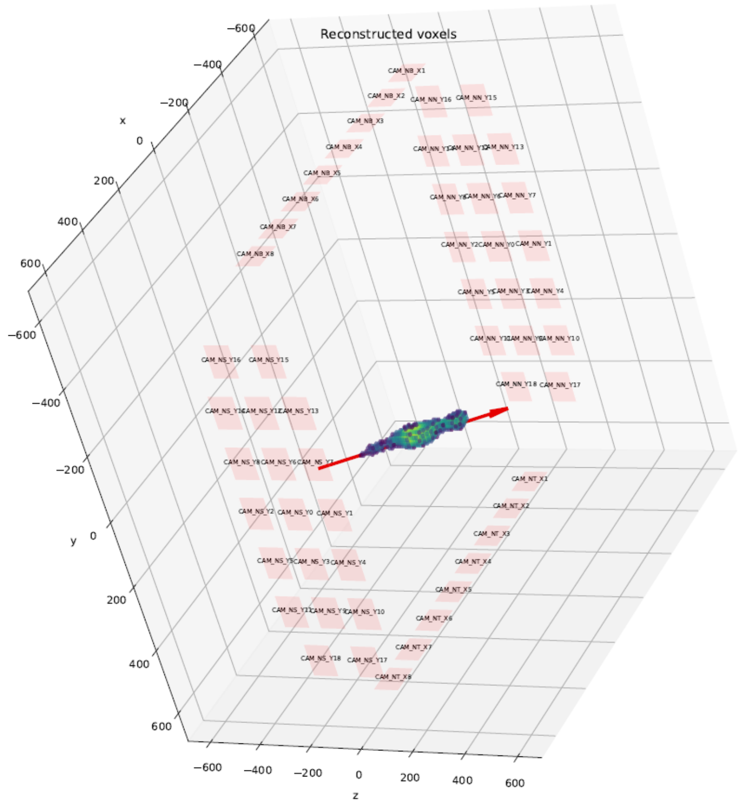
Simulation



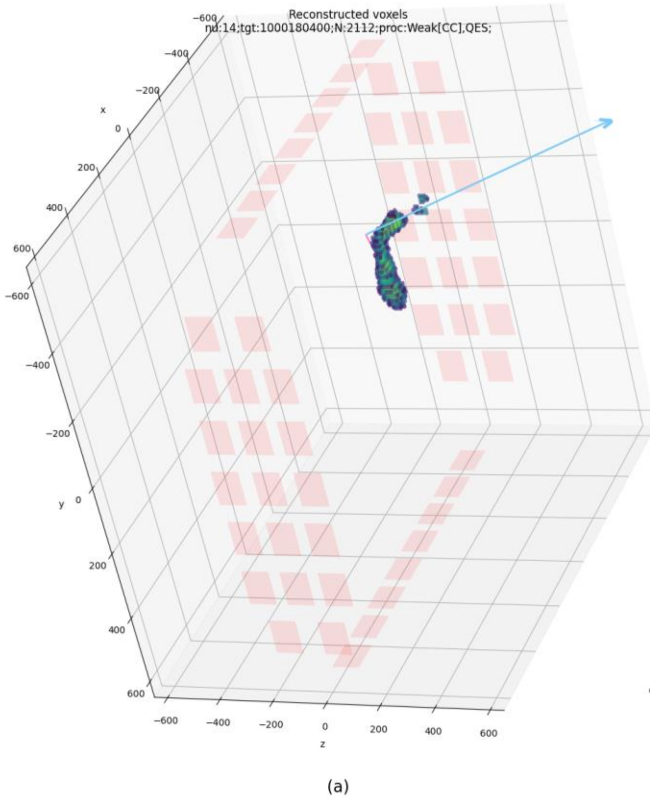
- ❑ Simulate interaction of radiation in Liquid Argon (and scintillator)
  - Photon generation and propagation (Geant4)
- ❑ Interaction with Masks or Lens or Mirror
- ❑ Determine number of photons on sensor
  - -> requirements for photo-sensor

Examples

- Simulations of Coded Aperture masks with 3D reconstruction algorithm in LAr:



Cosmic Muon

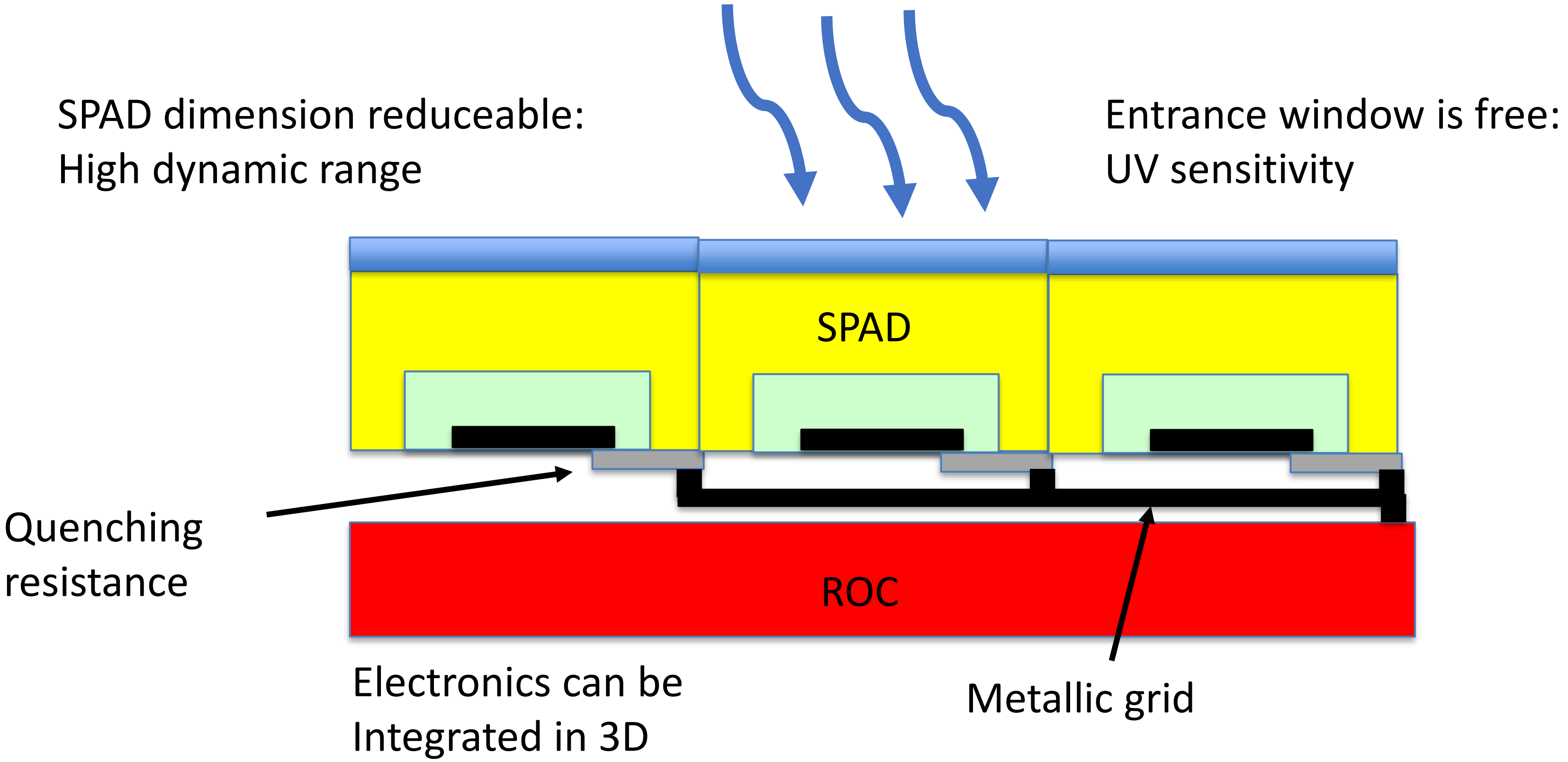


Neutrino Interaction (proton + muon)

Electronics

❑ As a first step of 3D integration, the design of INFN-Torino foresee a ReadOut Chip (ROC) based on the “Alcor” ASIC:

- one channel in 440x440 um2
- mini-SiPM by grouping SPADS so that the size correspond to one channel
- chip bonding



Conclusion

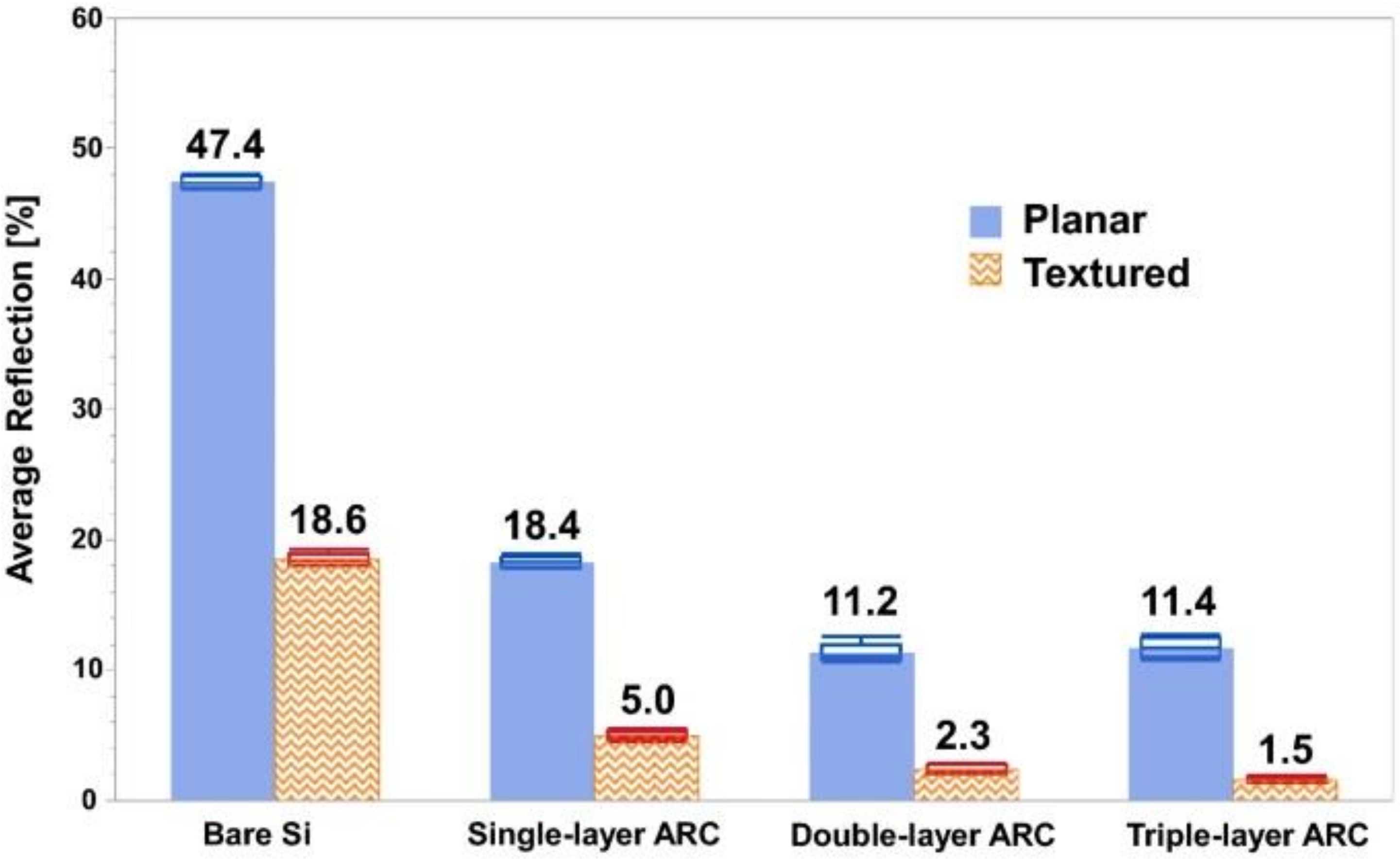
- ❑ Hopefully next June we will have the new cell (in FSI) to be tested
- ❑ Beginning of 2024 we will have the first BSI SiPM produced by FBK
- ❑ Simulation and reconstruction software are very advanced
- ❑ Electronics will benefit of the experience gained with Alcor chip

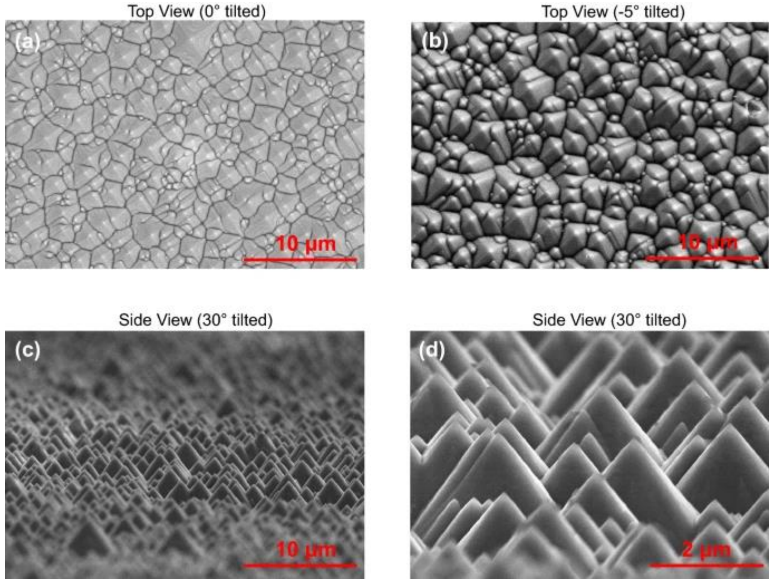
- ❑ IBIS ended in 2022, but the original budget for runs (90 kEuro) was granted in 2023 [requests for local services: Electronic Lab 3 mu (test boards etc..)]

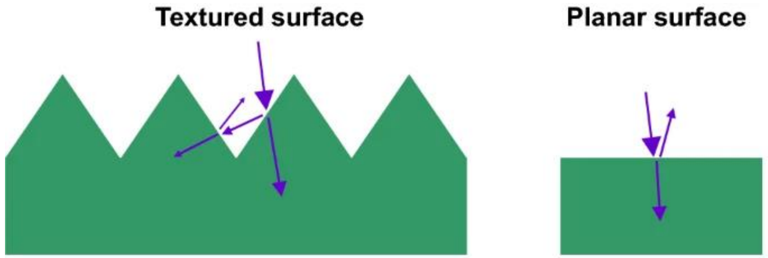
- ❑ In total we invested about 120 kEuro to push the R&D in FBK on BSI and IBIS SiPM will be the first device ever produced
- ❑ We would like to continue to push this development to complete maturity: many groups in Italy are now interested on this technology. If we reach a critical mass we could propose a bigger project (CSN5 Call??).......

Thanks for attention !

ARC with textured surface







Scale prototype

- Use commercial products to build a prototype and corresponding simulation
- Allows tuning of free parameters
- Verify optics and technical issues