FONDAZIONE BRUNO KESSLER

Overview of silicon radiation detector technologies at FBK

Nicola Zorzi

GASPARD-HYDE-TRACE Workshop 2012 - 29-31 October 2012

Outline

- FBK organization and expertise
- Examples of radiation detector productions
- R&D on radiation detectors

FBK

"Fondazione Bruno Kessler" (http://www.fbk.eu/) is a research organization of the Autonomous Province of Trento

Areas of studies:

- Information Technology
- Materials and Microsystems
- Theoretical nuclear physics
- Public policy effectiveness
- Italian-German History
- Religious sciences

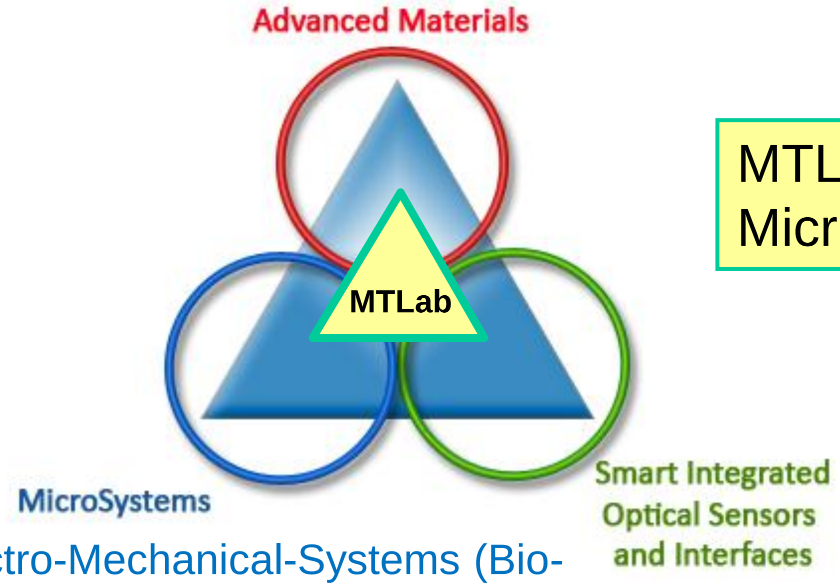
More than 350 researchers

CMM

Centre for Materials and Microsystems (http://cmm.fbk.eu/)

Organization: Research Units focused in three main areas

- New Materials and Analytical Methods for Biosensors and Bioelectronics (M2B2)
- MiNALab - Micro Nano Analytical Laboratory
- Biosint - Biofunctional Surfaces and Interfaces
- Plasma and Advanced Materials (PAM-SE)
- Interdisciplinary Laboratory for Computational Science (LISC)



MTLab
Micro Technology Laboratory

- BIO-Micro-Electro-Mechanical-Systems (Bio-MEMS)
- Micro-Electro-Mechanical-Systems (MEMS)
- Advanced Photonics and Photovoltaic (APP)
- **Silicon Radiation Sensors (SRS)**

- Smart Optical Sensors and Interfaces (SOI)
- 3D Optical Metrology (3DOM)

Micro Technology Laboratory

2 separate clean rooms:

- CR Detectors
  500 m^2 in class 10 and 100
- CR MEMS
  200 m^2 in Class 100 and 1000

Equipments:

- Lithography
- Diffusion
- Implantation
- Dry Etching
- Wet Etching
- Control Area

Test Laboratories

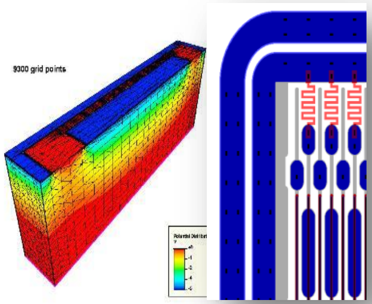
- Manual probers
- Automatic probers
- Parametric Test
- Functional Test (partial)

Now we are working with 4” wafers

An up-grade to 6” will take place starting next month

Expertise

TCAD simulation
CAD design



Process flow development


MTLab WebFabIS v4.2

Job: MLM_alluminium

Run: MLM_alluminium
Technolgy:
Device: testing

Project: internal
Mask set: null
Research unit: MTLab

step no	split no	macro	description	status	note_in	note_out	t_wafer	wafer	step_in	step_out
1	1	Alu etch wet. DETECTORS	alu etch	OK		fette da 9 a 14 da MLM_testing			2012-05-28 14:10:45	2012-05-28 15:02:13
2	1	DEFRECKEL. DETECTORS	defrekel	OK					2012-05-28 15:02:13	2012-05-28 15:02:18
3	1	TEPLA. DETECTORS	resist strip tepla w9-w14	OK					2012-05-28 15:02:18	2012-05-28 16:37:22
4	1	Rinser dryer furnaces. DETECTORS	di rinse	OK					2012-05-28 16:37:22	2012-05-29 08:25:33
5	1	T4 - Sintering. DETECTORS	sintering	OK	2 split			9-13-14	2012-05-29 08:25:34	2012-05-29 11:42:18
5	2	T4 - Sintering. DETECTORS	sintering	OK	2 split			10-11-12	2012-05-29 11:42:18	2012-05-29 11:42:37
6	1	Rinser dryer. DETECTORS	di rinse	OK					2012-05-29 11:42:37	2012-06-04 09:06:34
7	1	SPS-MPS PECVD. DETECTORS	SIOHDR PECVD	OK					2012-06-04 09:06:34	2012-06-04 11:05:53
8	1	Rinser dryer. DETECTORS	di rinse	OK					2012-06-04 11:05:53	2012-06-05 09:20:48
9	1	Track SVG coating. DETECTORS	front coating	OK					2012-06-05 09:20:48	2012-06-06 10:47:48

Fabrication

Device testing

People:

- **SRS**: 8 researchers
  (3 design and simulation, 1 processing, 4 testing)
  http://srs.fbk.eu/en/home

SRS SILICON RADIATION SENSORS

- **MTLab**: 3-4 researchers
  (processing)
  http://mtlab.fbk.eu/

MTLab MicroTechnologies Laboratory

Sensors for what kind of radiation?

High-energy particles

- Ionizing particles
- X/γ rays

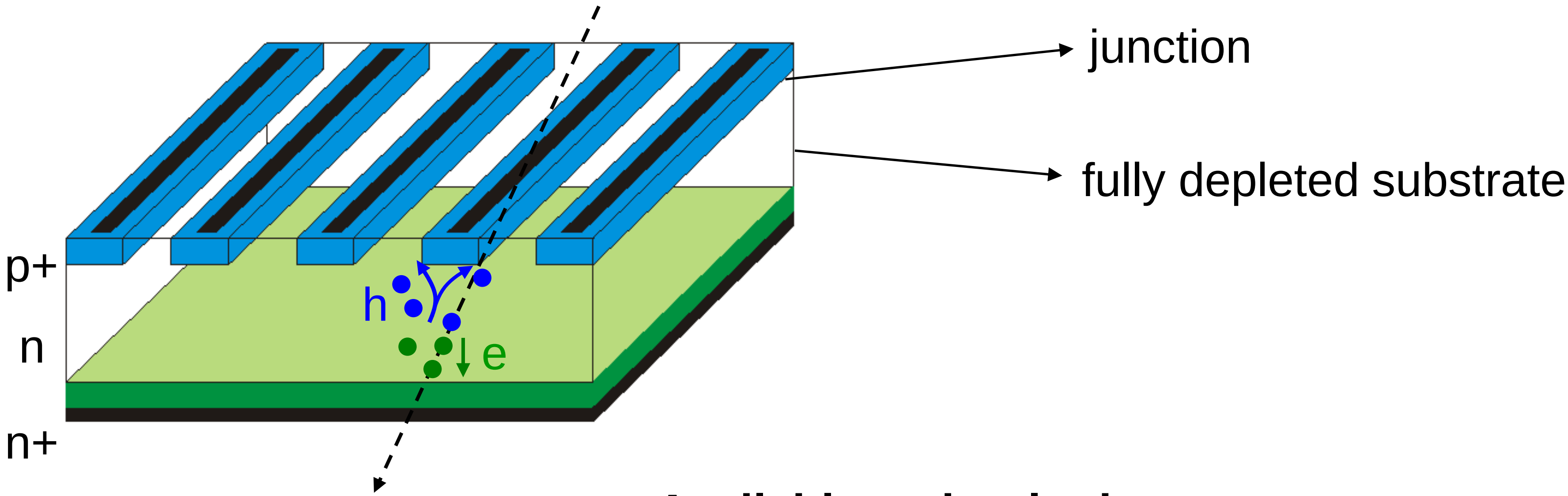
light

Mainly detection of extremely low intensity light

Main Applications

- Physics experiments
- Nuclear medicine
- Astrophysics
- Biology
- Material analysis

Radiation detectors

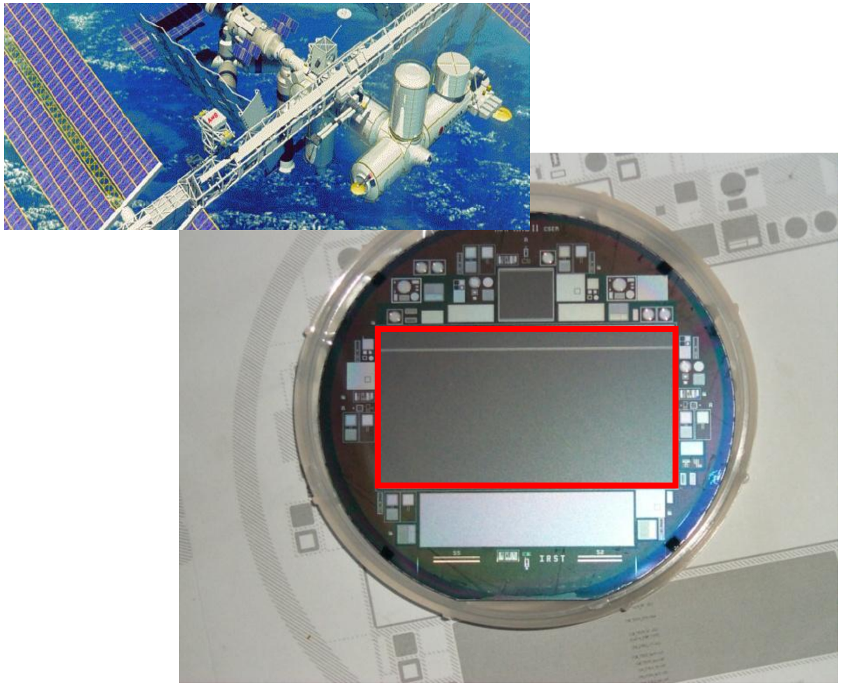


Types of detectors:
- Pixel detectors
- Strip detectors
- Drift detectors
- Pad detectors

Available technologies:
- n-in-p, n-in-n, p-in-n
- single- or double-side
- p-spray and p-stop isolation
- guard-ring termination
- gettering techniques
- punch-through and poly-resistor biasing
- integrated AC coupling capacitors

Strip Detectors: productions

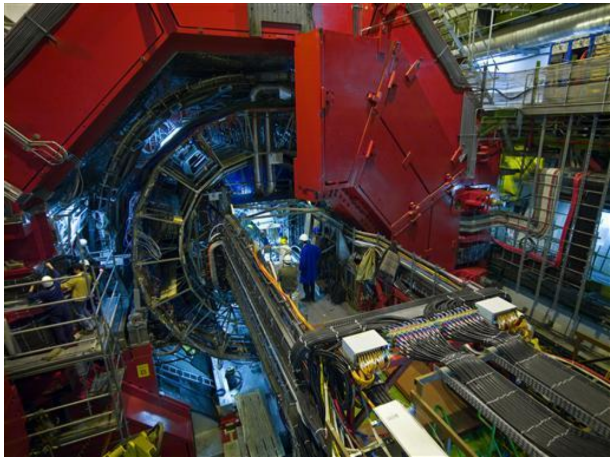
AMS experiment (@ISS)



Silicon microstrip detectors:

700 large-area double-sided in spec detectors fabricated in 2002-2004.

ALICE experiment (@LHC)



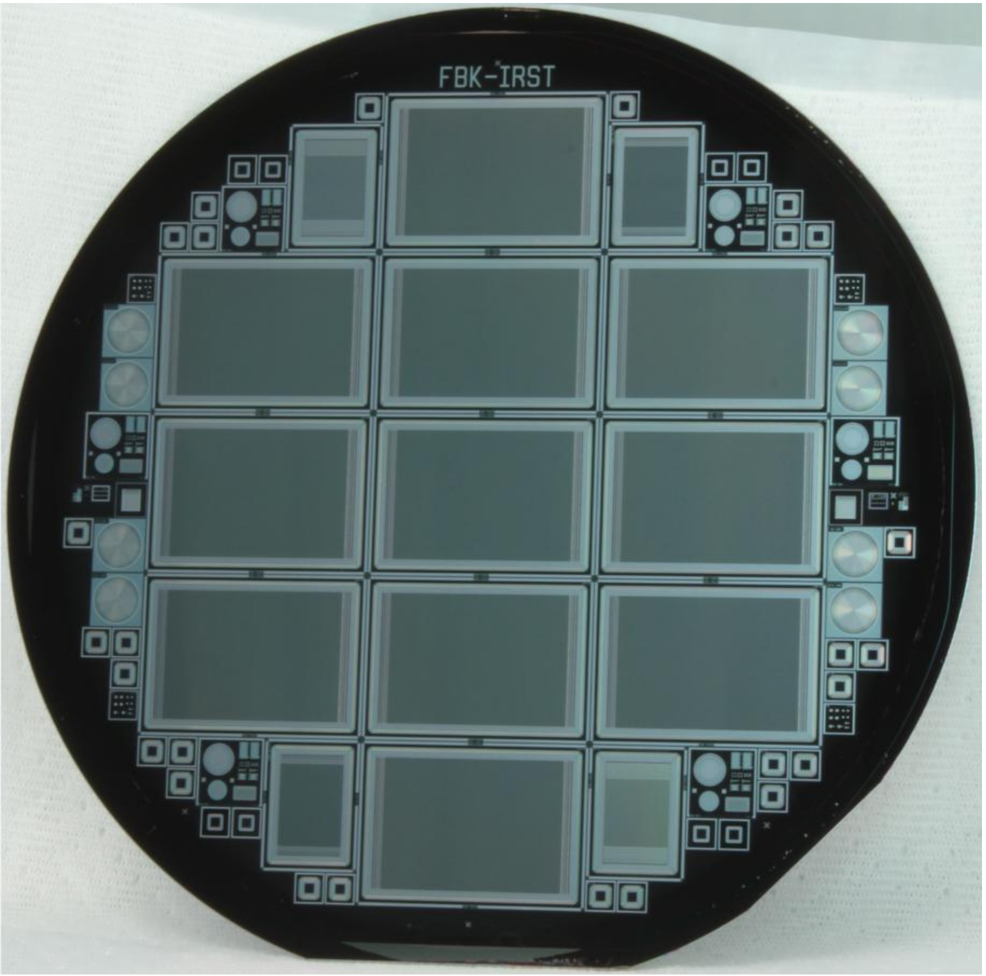
Silicon microstrip detectors:

600 large-area double-sided in spec detectors fabricated in 2003-2005.

Silicon pixel detectors:

p-on-n pixel detectors fabricated in 2006-2007.

Strip Detectors: custom

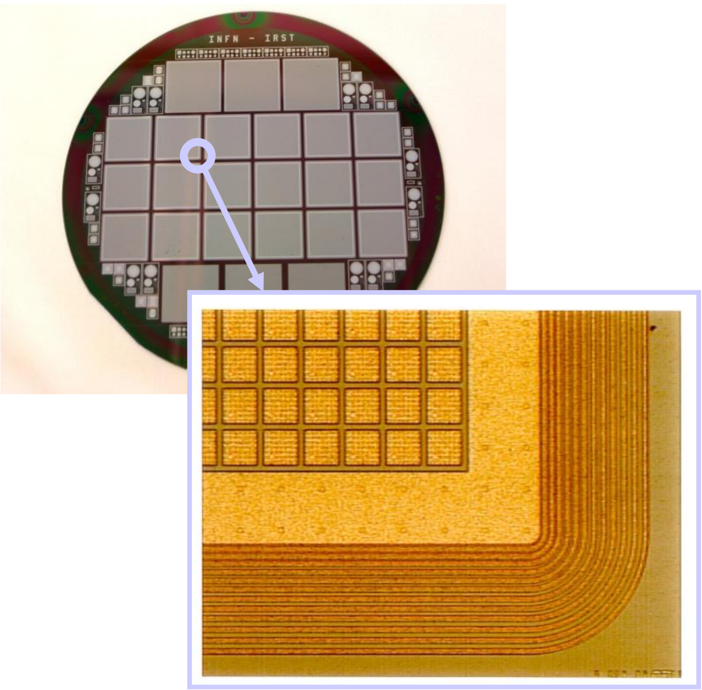


Custom development of strip detectors for private companies:

- single-side,
- DC/AC coupled,
- very low leakage,
- high yield

Pixel detectors: examples

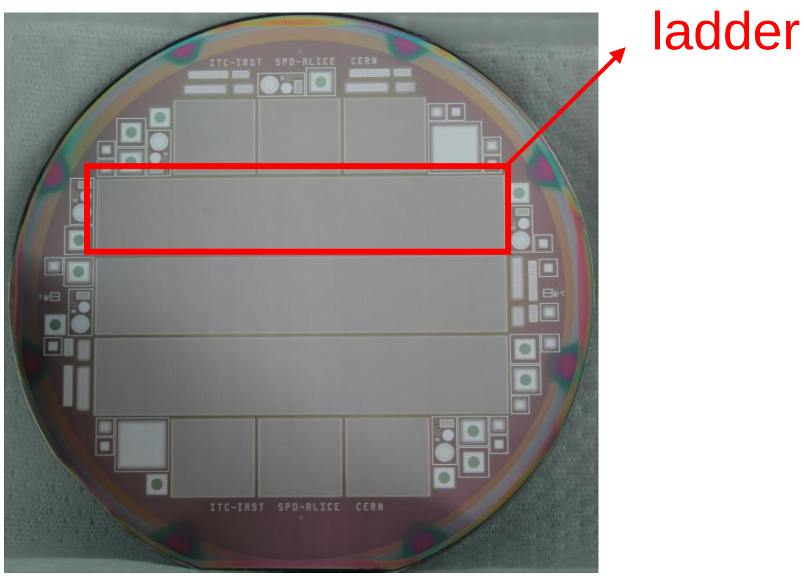
Medipix 1&2



• Medipix1: pixel size 170x170μm^2
• Medipix2: pixel size 55x55μm^2

Substrate thick.: up to 1.5mm → **Substrate thickness: 200μm**

NA48/ALICE experiment



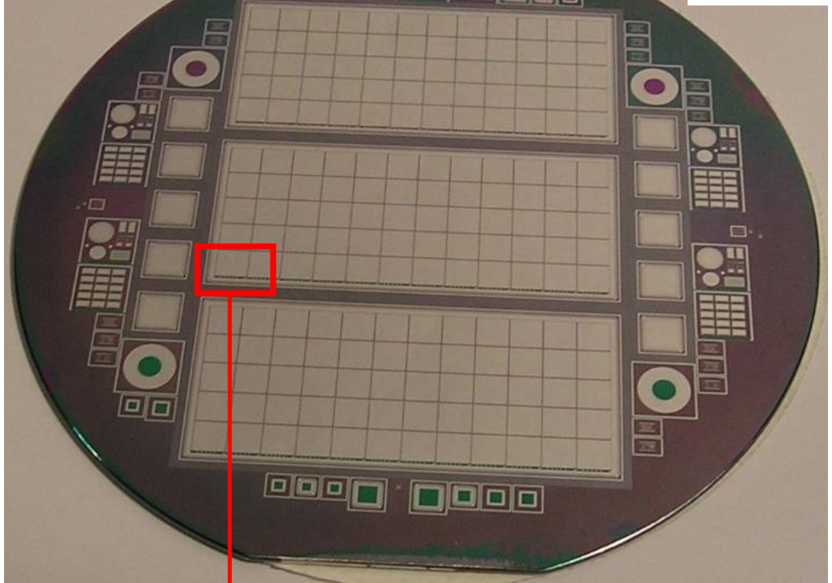
• ALICE SPD layout
• pixel size 50x400μm^2

Leakage current ~100pA/cm^2 for 300μm substrates

Thick detectors: example

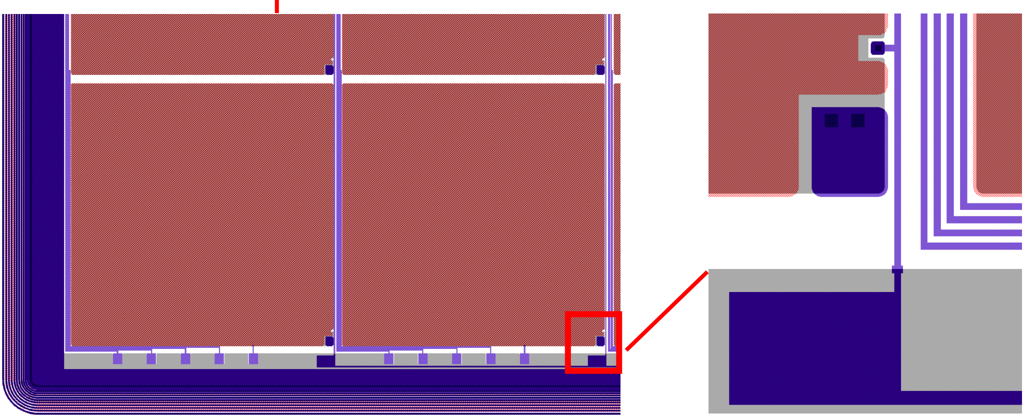
INFN-PD/LNL

1.5mm-thick wafer (also 200µm-thick, same design)



PAD detectors for TRACE:

- 12x5 elements
- 4mm pitch (X and Y)
- AC coupling
- punch-through biasing
- termination structure
  (voltage handling, lateral depletion)



Non standard processing:

- Special quartz supports
- Critical automatic handling
- Starting substrates play a role

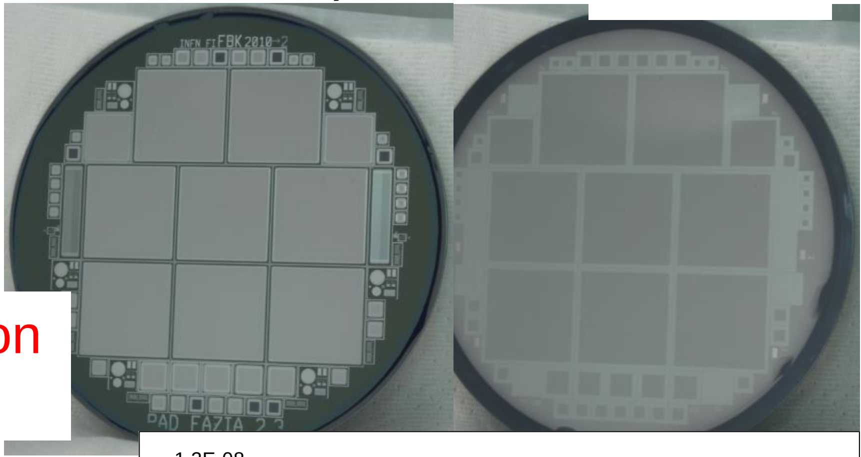
Detectors for FAZIA

INFN-FI

Requirements for ΔE-E and pulse-shape analysis

- Non standard substrate orientation: ~8° off from <100>
- NTD wafers (high uniformity in resistivity → high voltage)
- 2 thicknesses (300µm and 500µm, V_{depl} ~ 120V ÷ 300V)
- very low dead layers and dead borders
- 2x2cm^2 active area
- low sheet resistance
- capable to see visible light

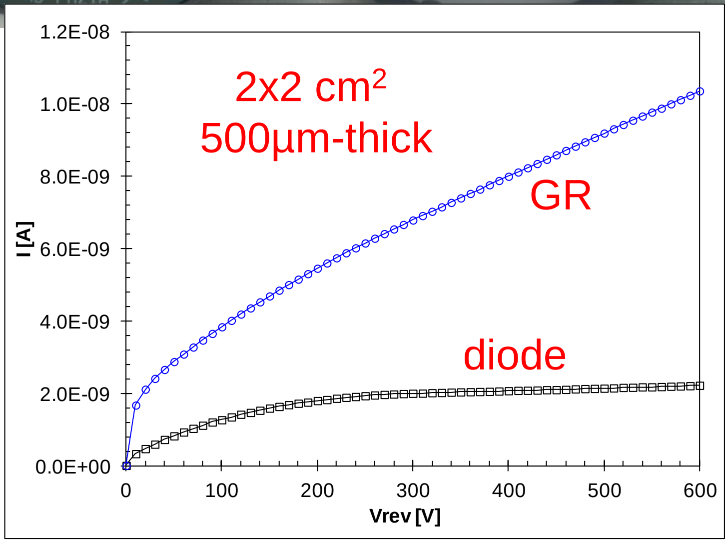
ohmic side



junction side

Dedicated technology

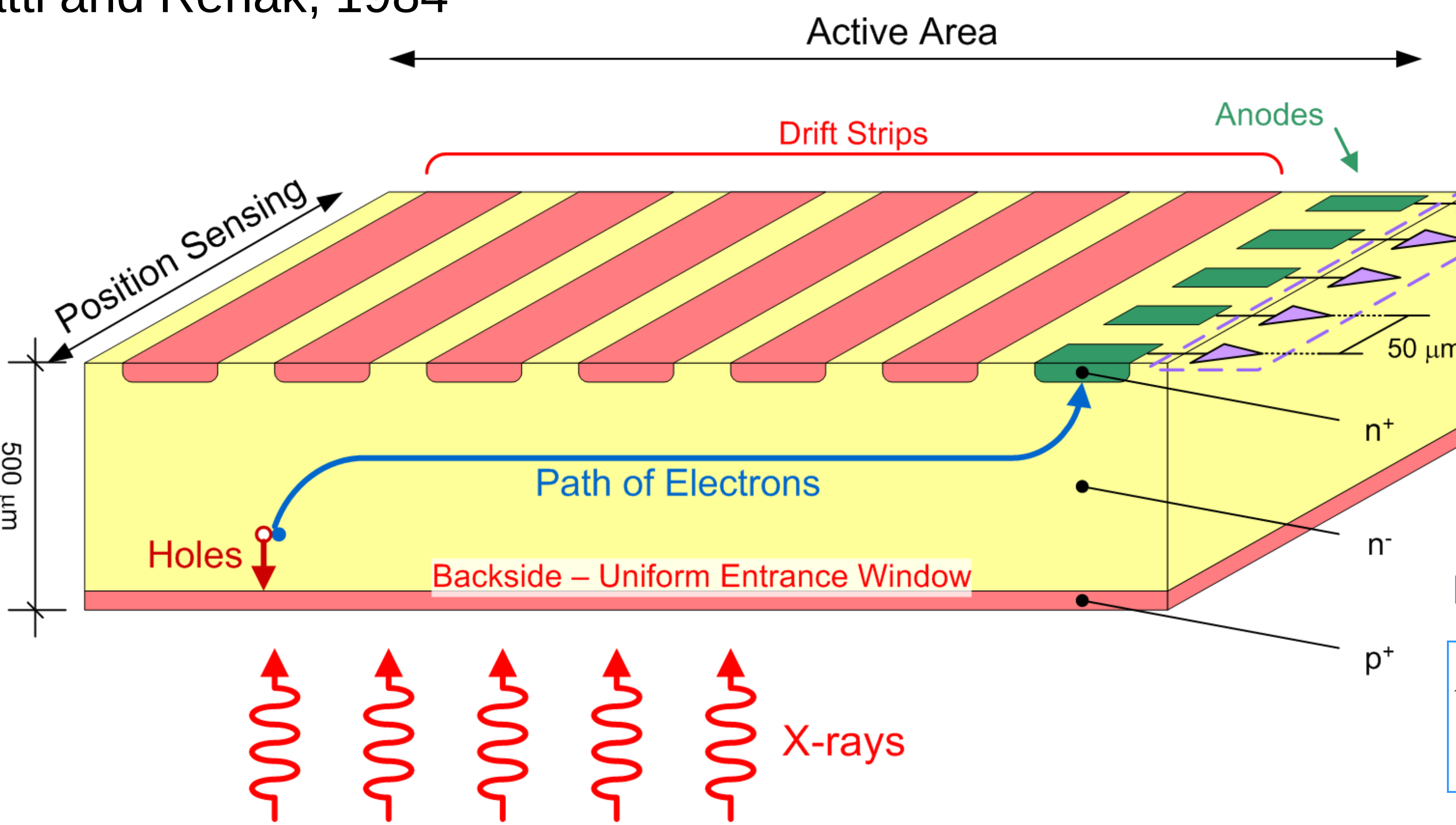
- double side process
- thick + thin (~30nm) metal levels on both sides
- thin junction on front-side; dead layer ~150nm
- dead layer at back-side ~ 700nm*
- dead region at border ~ 800µm*



* different solutions give lower values but kill the yield

Silicon Drift Detectors: R&D

Gatti and Rehak, 1984



$$\tau_d = \frac{x_S - x_A}{\mu_e \frac{\Delta V}{L}}$$

Applications:

- spectroscopy
- gamma-ray spectrometry (with scintillator)
- position sensitive detector

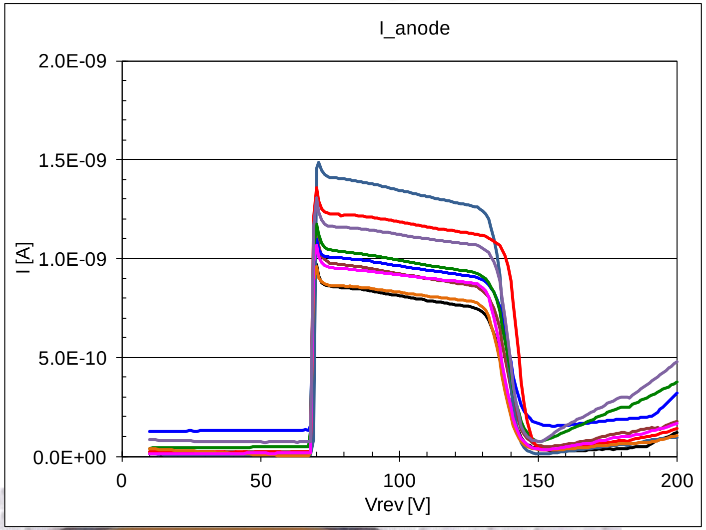
3 running projects:

- private contract
- ESA
- INFN

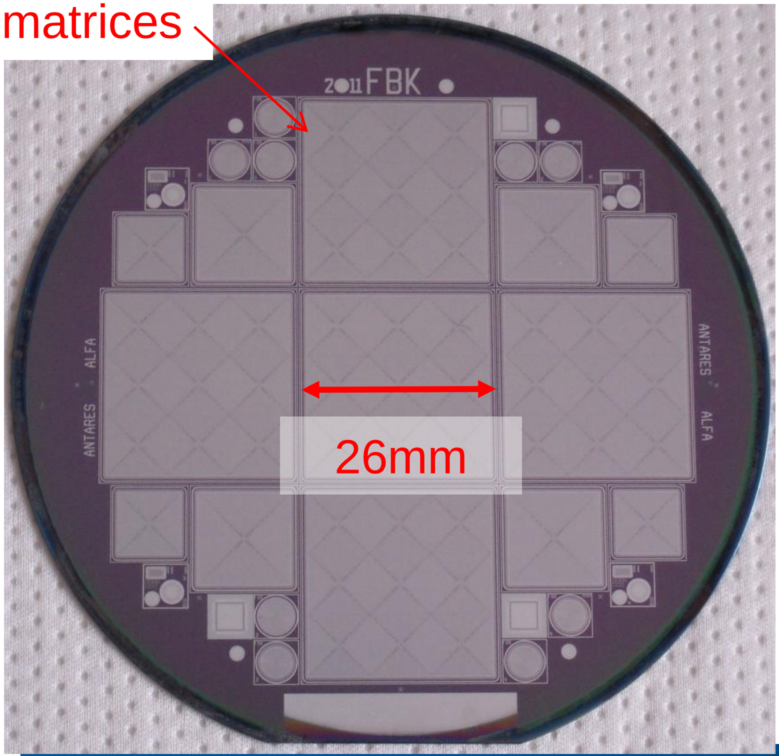
Silicon Drift Detectors: ESA project

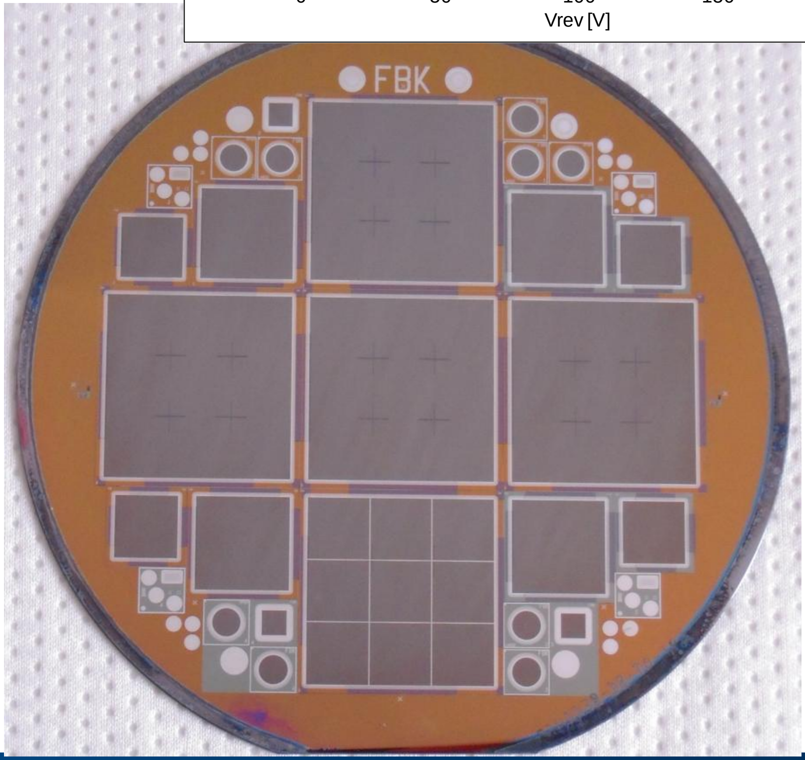
ESA/PoliMI/INFN-MI

- double side technology
- γ-ray detector
- $LaBr_3$:Ce scintillator (2” and 3” Ø)
- optical entrance window for ~370nm light



3X3 SDD matrices





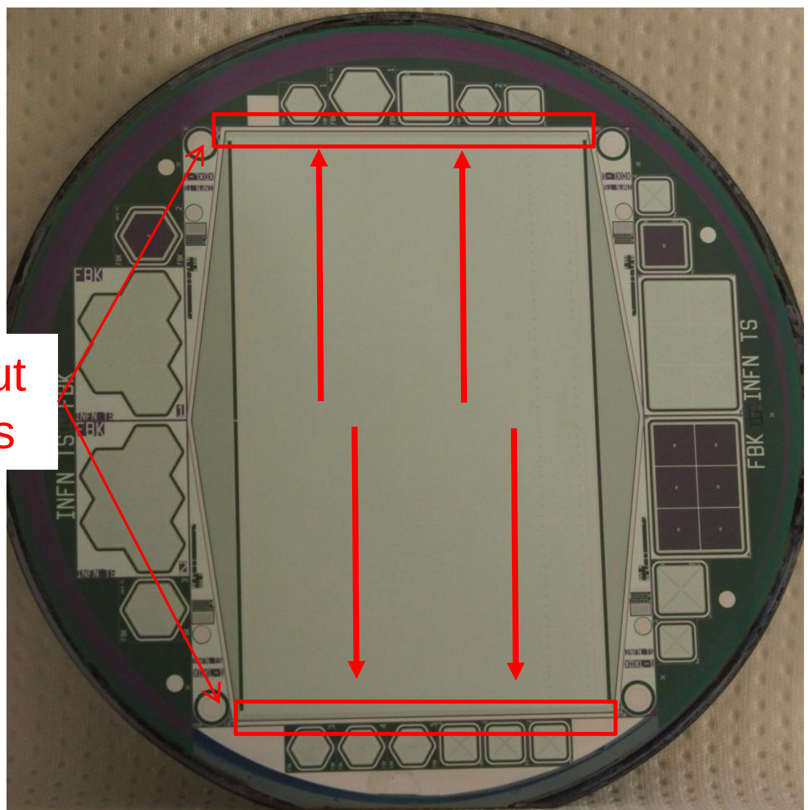
Silicon Drift Detectors: INFN project

INFN-TS

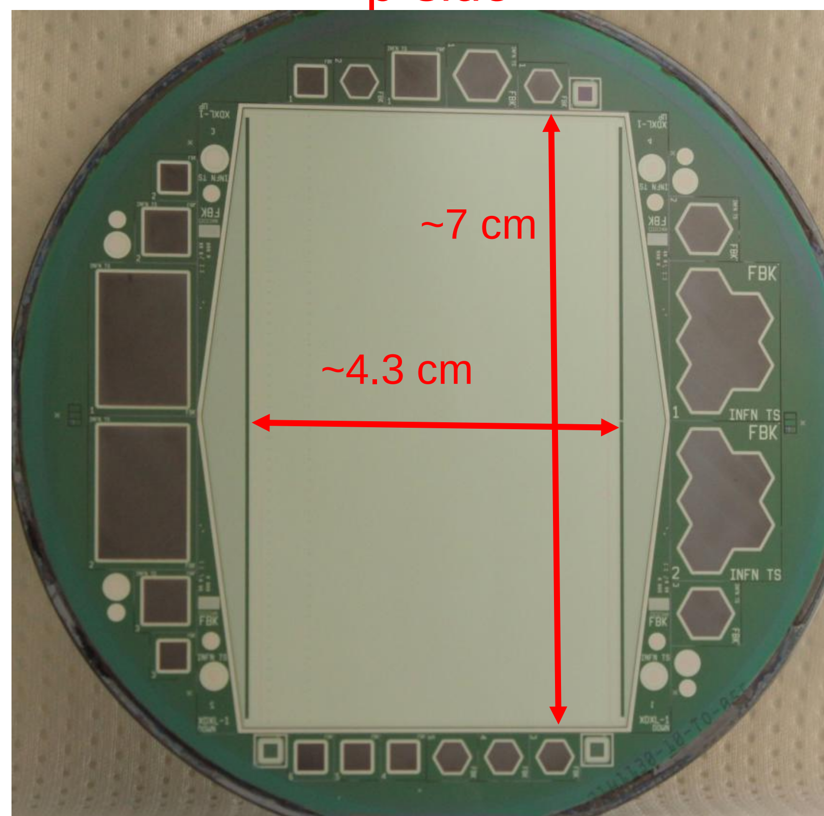
- double side technology
- large area linear SDD device (ALICE-type)
- X-ray detection
- test production capability for LOFT (~12x7.4cm^2)

anode side

read-out anodes



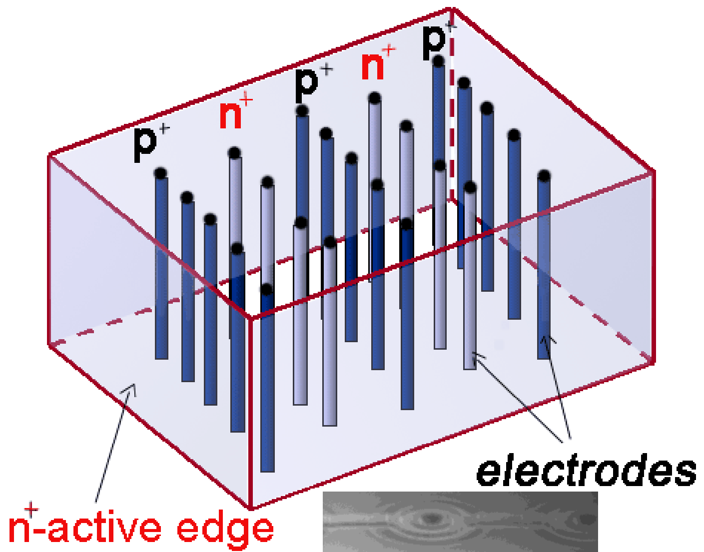
p-side

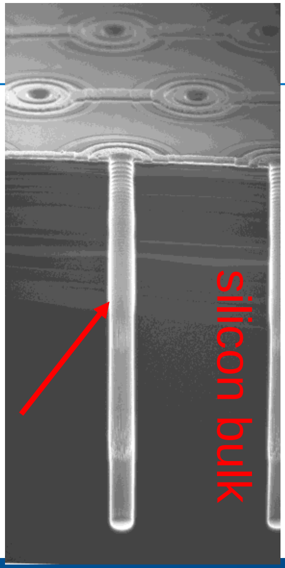


3D sensors: R&D activity

INFN
CERN

First proposed by S. Parker et. al.
in NIMA 395 (1997), 328





ADVANTAGES:

- Electrode distance and substrate thickness decoupled:
- low depletion voltage
- high speed
- good charge collection efficiency

→ **High radiation hardness**

- Active edges:

- Dead area reduced to few μm from the edge

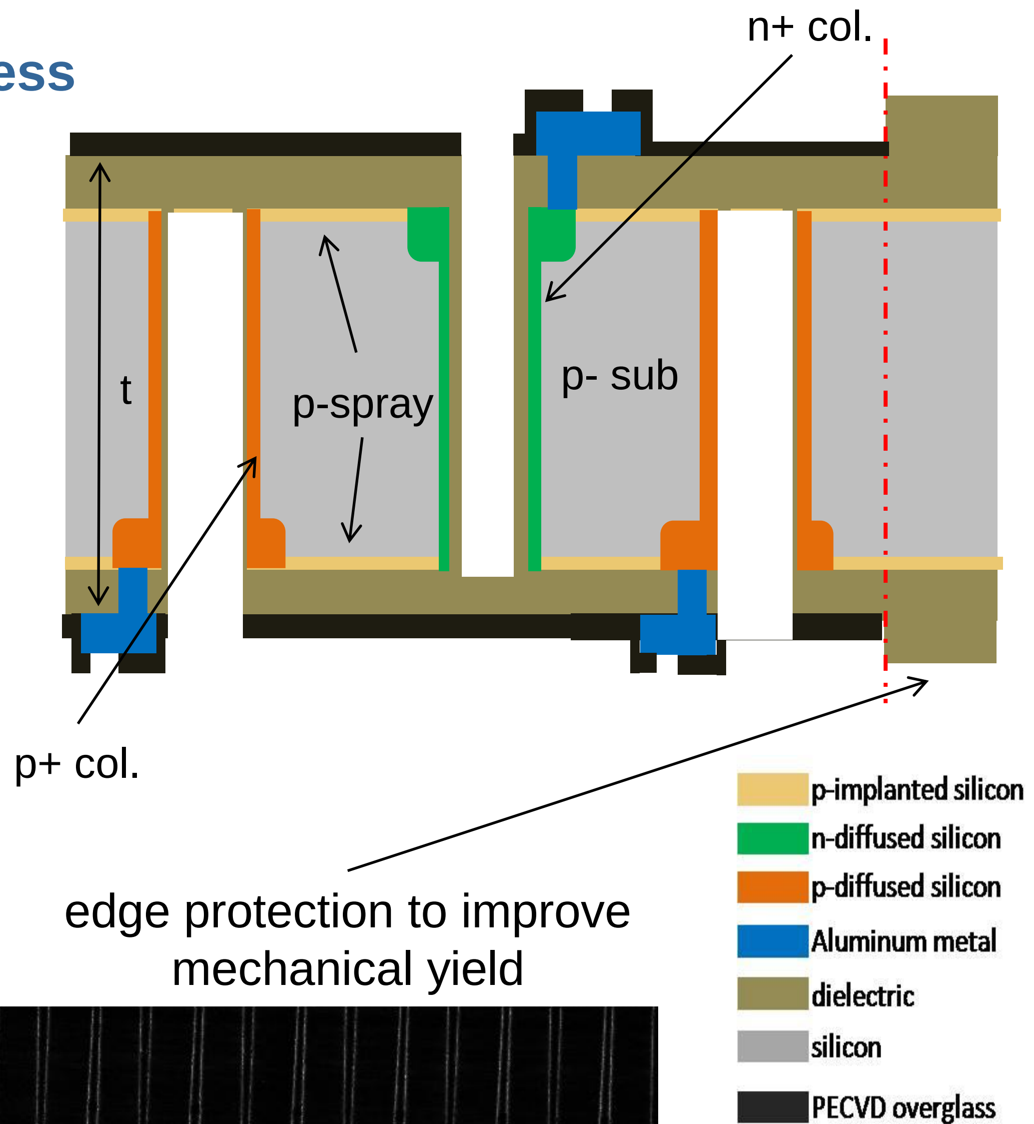
DISADVANTAGES:

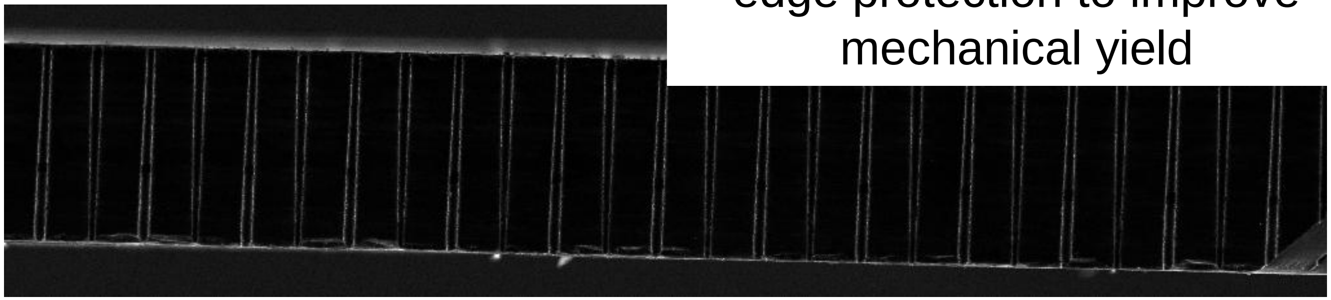
- Non uniform response due to electrodes
- **Complicated technology**
- Higher capacitance with respect to planar

FBK 3D technology

Double side fabrication process

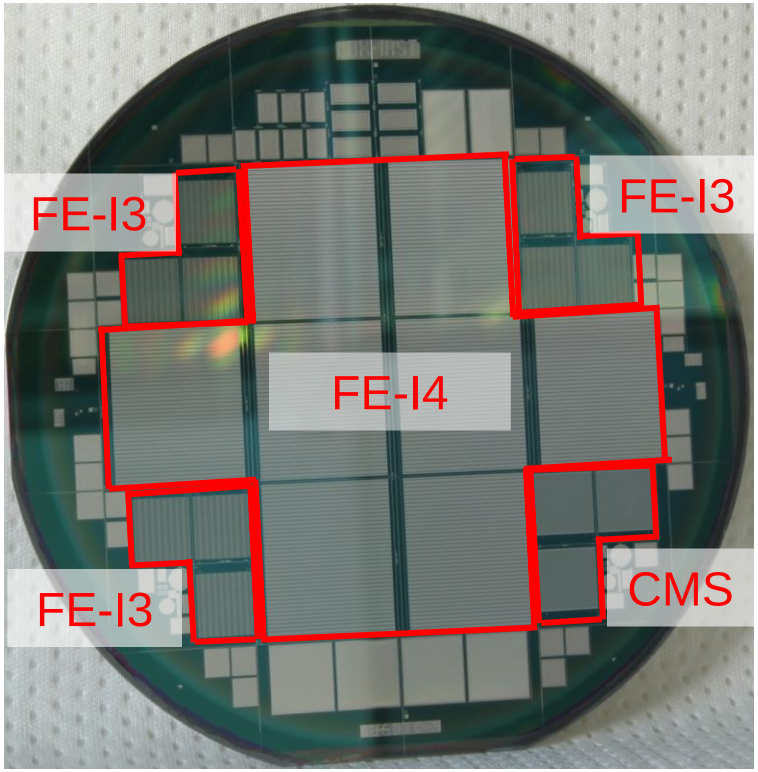
- junction holes etched from front
- ohmic holes etched from back
- empty holes (~11µm diam.) (no poly-Si)
- holes depth equal to the wafer thickness (230µm)
- p-type FZ wafer
- p-spray isolation
- edge protection

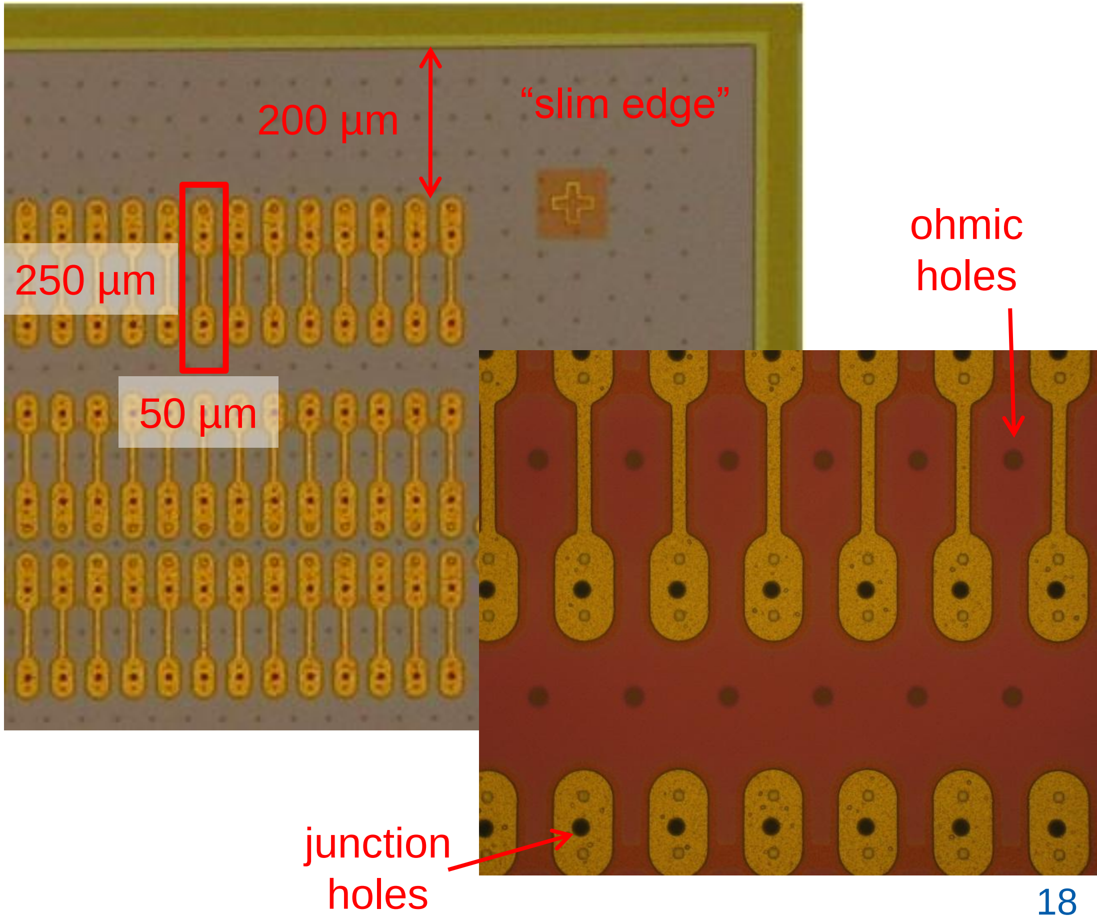




3D detectors for ATLAS IBL up-grade

- Common layout of *ATLAS 3D sensor Collaboration* (CNM-IMB, SINTEF, SNF, FBK)
- ATLAS FE-I4 compatible 3D pixel detectors
- ~20% of pixel sensors for IBL will be 3D



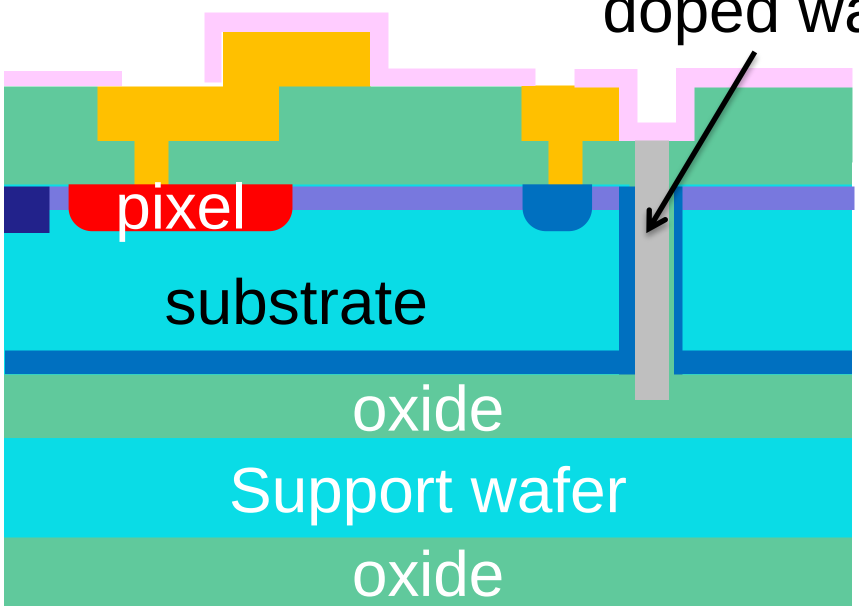


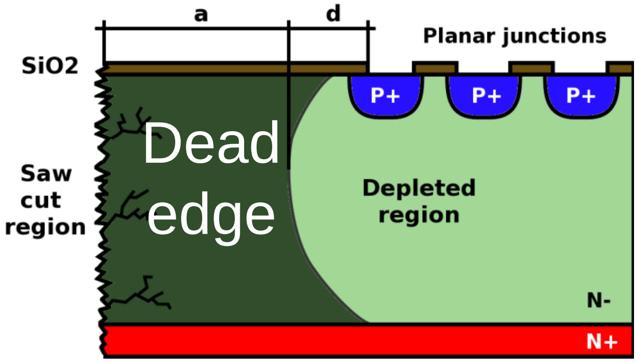
Active edge (edgeless) detectors

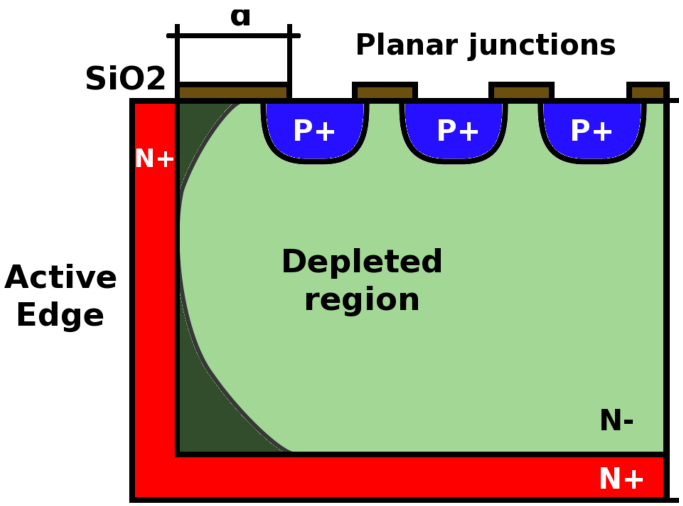
Main motivation:
minimize dead area at the borders

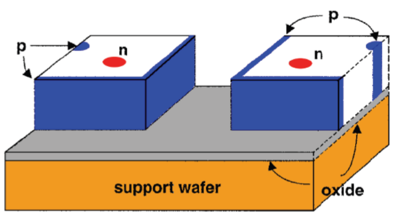
Compatible with both planar and 3D devices

Requires a support wafer
(wafer bonding, epi substrates)



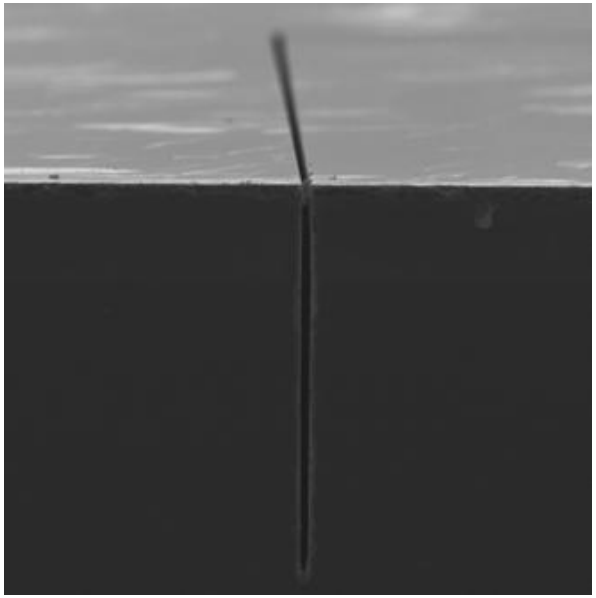


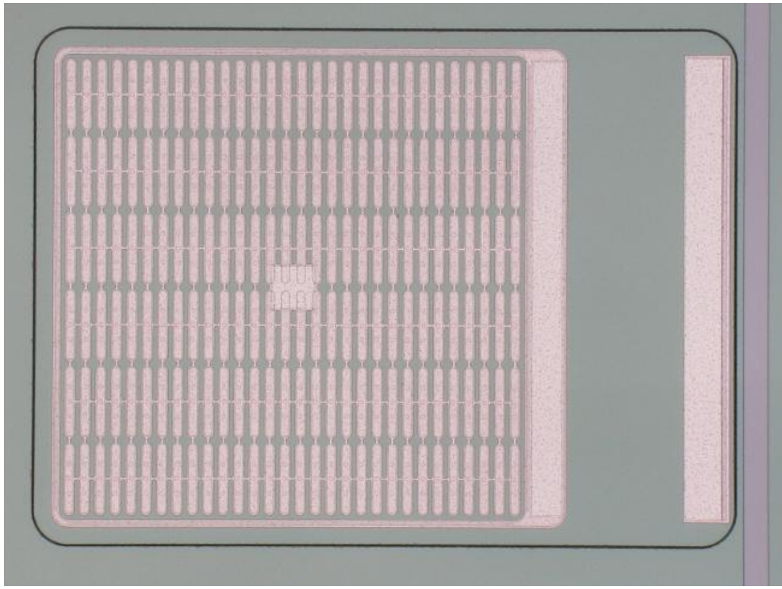




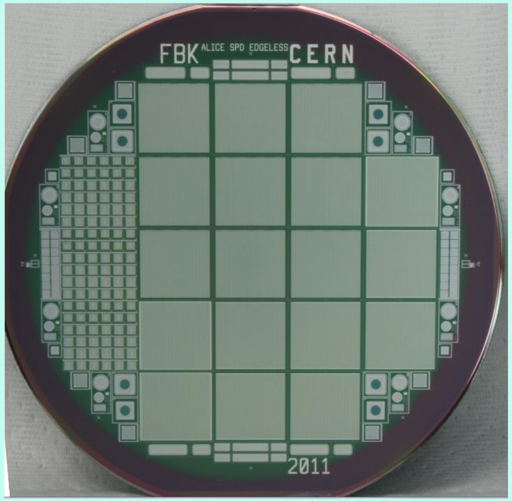
Active edge: example

- 4.5µm wide trench
- 200µm deep
- polysilicon filled
- test structures to study collection efficiency at the border





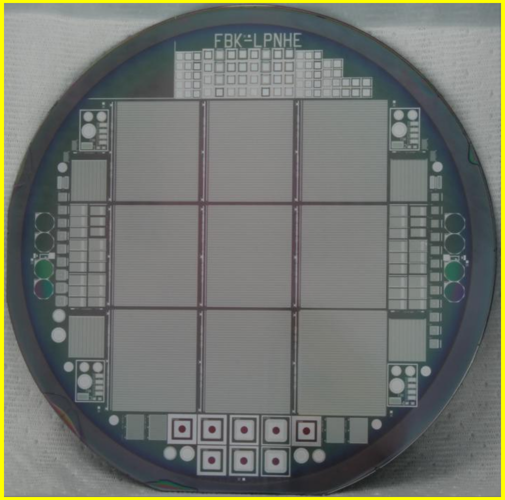
INFN-BA, CERN



2 running projects:

- pixel sensors compatible with ALICE ROC (epi wafers, 100µm thick + sub)
- pixel sensors compatible with ATLAS FE-I4 (200µm-thick FZ + waf-bond sub)

LPNHE Paris



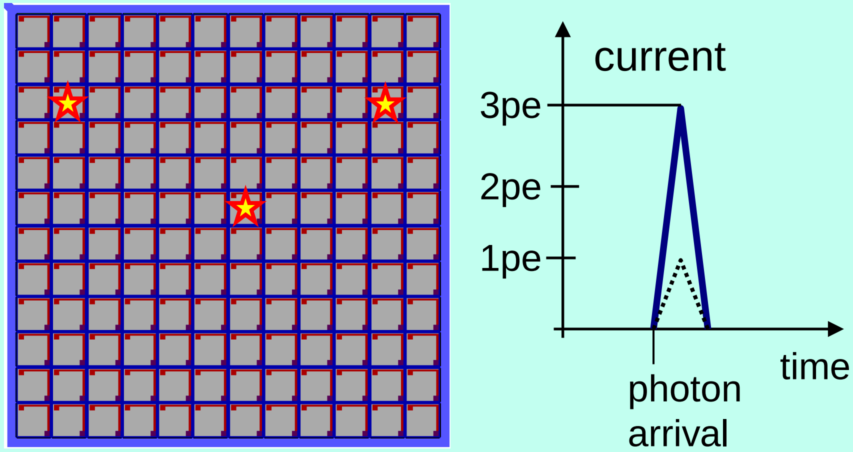
Low-level light sensors

Avalanche Geiger-mode photodiodes

Each photon triggers a discharge which is shortly quenched

- Gain ~10^6
- Timing ~ 100ps /1ph.e.
- Bias voltage <100V
- Sensitivity ~1 ph. e.
- QE ~ medium

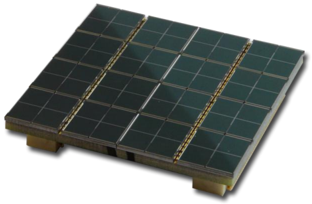
Array of tiny GM APDs: proportionality



SiPM:

Silicon Photo-Mulitplier

From vacuum…



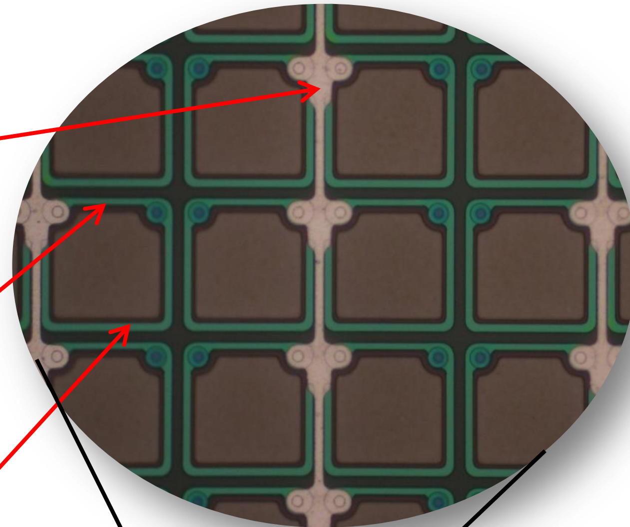
…to solid-state

Device Layout: example

Metal line connecting all cells in parallel (one common anode)

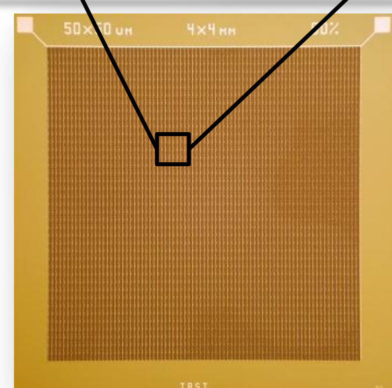
Polysilicon resistor

Field-plate to reduce electric field around the junction



The cathode is contacted on the back side

Resistor is located outside the active Area → no fill factor loss

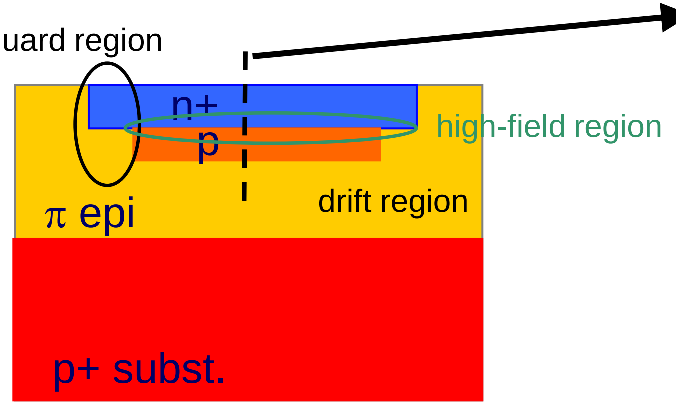


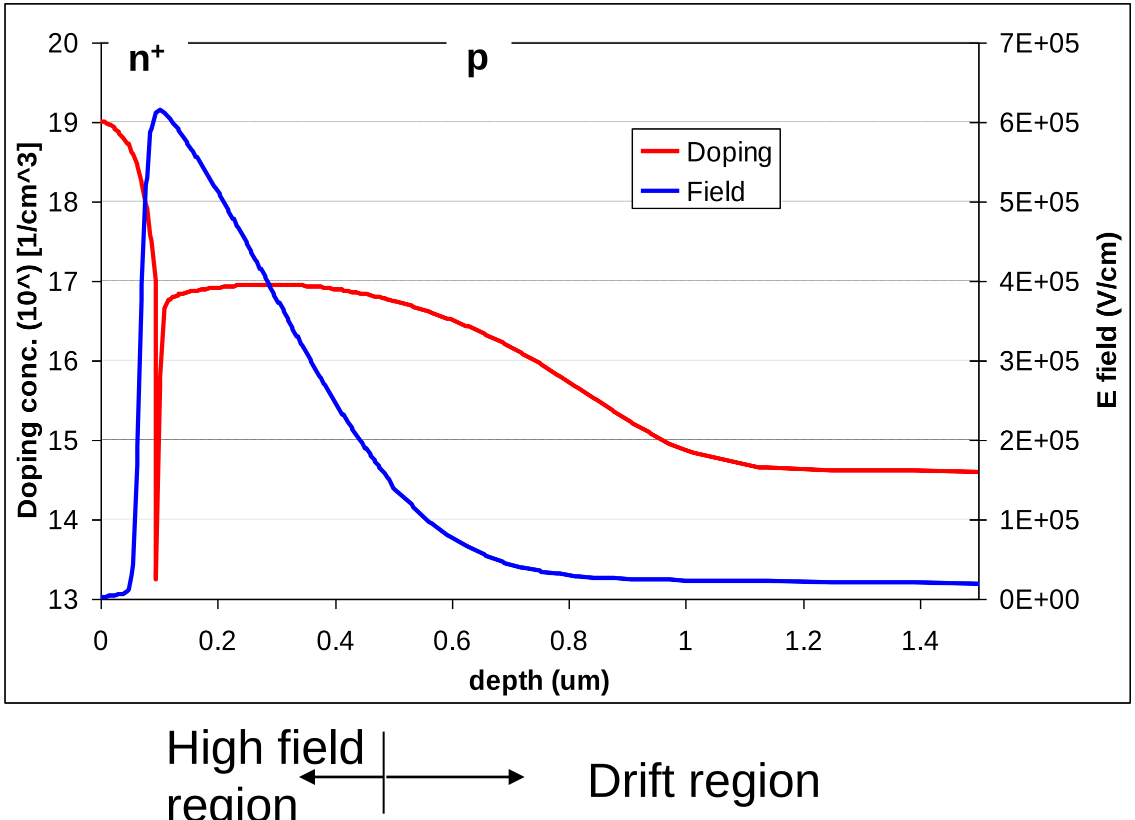
4x4mm^2
50x50μm^2 cell

Fill Factor
~ 45% 40x40 μm^2 cell
~ 55% 50x50 μm^2 cell
~ 72% 100x100 μm^2 cell

FBK original technology

Shallow-junction SiPM N-on-P technology





1) Substrate: p-type epitaxial
2) Very thin n^+ layer
3) Quenching resistance made of doped polysilicon
4) Anti-reflective coating optimized for λ~420nm

FBK SiPM R&D

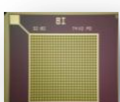
FONDAZIONE BRUNO KESSLER

2005

MEMS agreement PAT/FBK/INFN

One of the main topics was develop. and application of SiPMs

2006

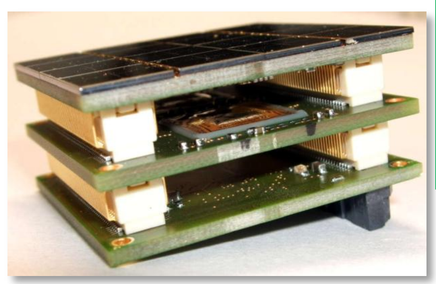


1x1mm^2
40x40μm^2 cell

2008

FP7 project HYPERimage

With Philips. Develop. of a PET/MR system

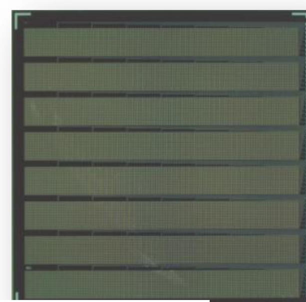


2009

MEMS2 agreement FBK/INFN

2012

SiPM is again one of main topics



2010

FP7 project SUBLIMA

2014

Improvements:
- Junction techn.
- Small cell size
- Interconnections

!!Spin-off company on this subject: AdvanSiD Advanced Silicon Detectors http://www.advansid.com/

…what applications?

Nuclear medicine:

PET

intra-operative probes

Biology:

Confocal Fluorescence Microscopy

Real Time PCR

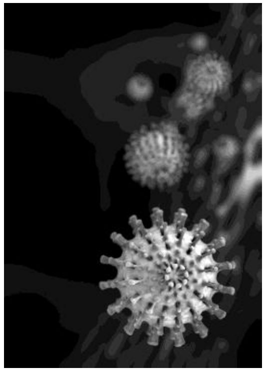
Flow Citometry

Physics experiments:

Cosmic rays detections

Gamma

X-rays detections



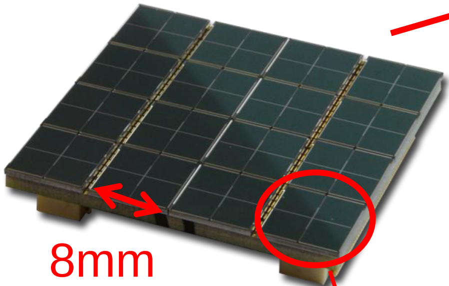
Materials analysis:

SEM

Homeland security

HyperImage preclinical system

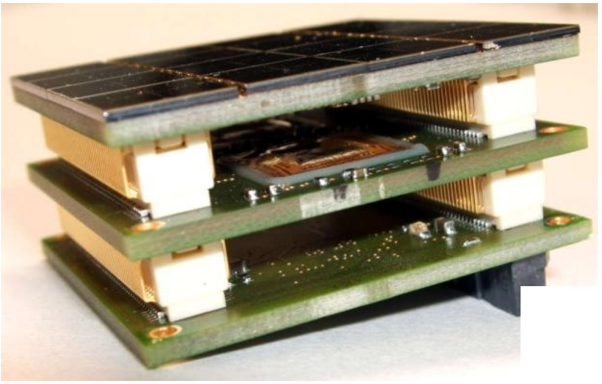
SiPM tile



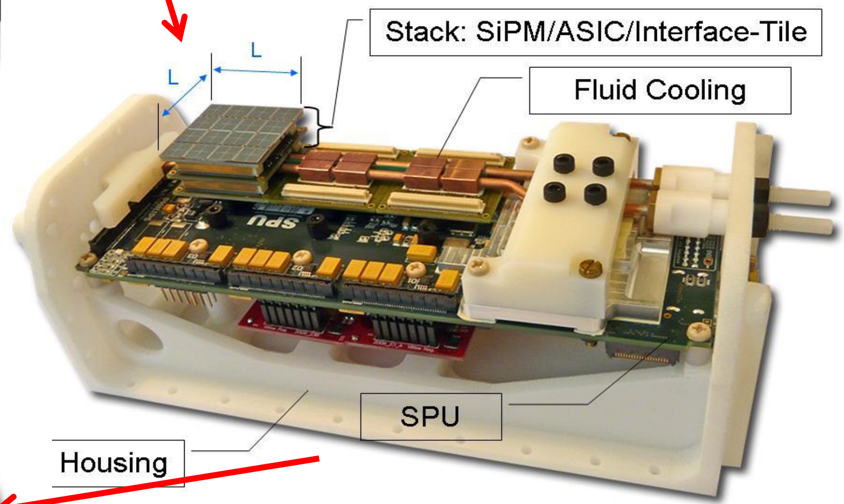
8mm

FBK monolithic QUAD

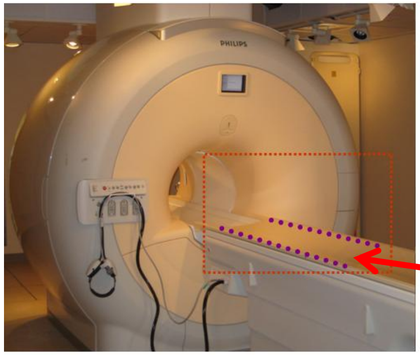
The stack

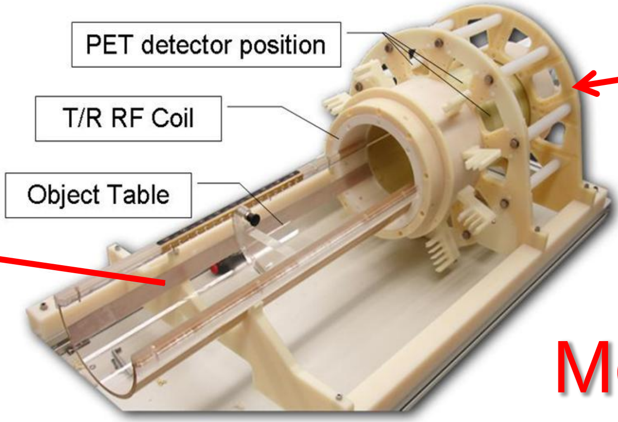


The module



PET-MR

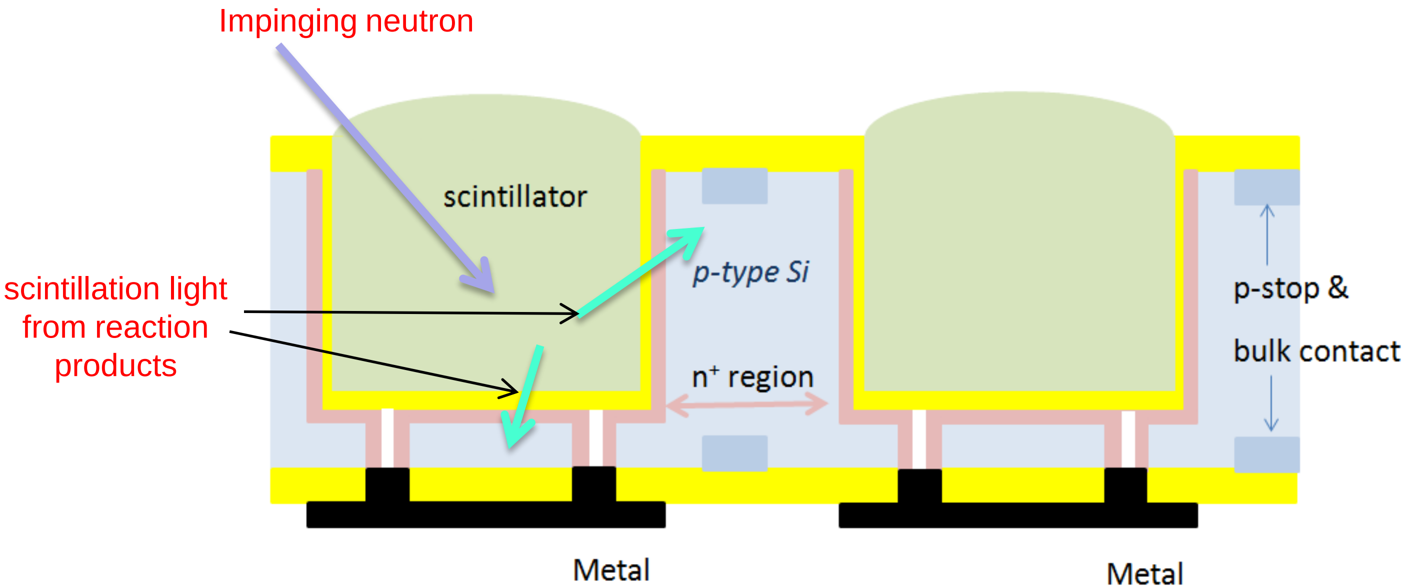




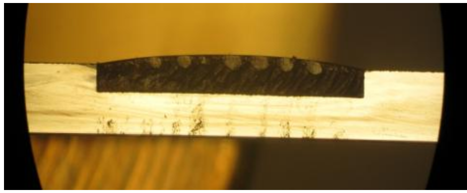
Mechanics

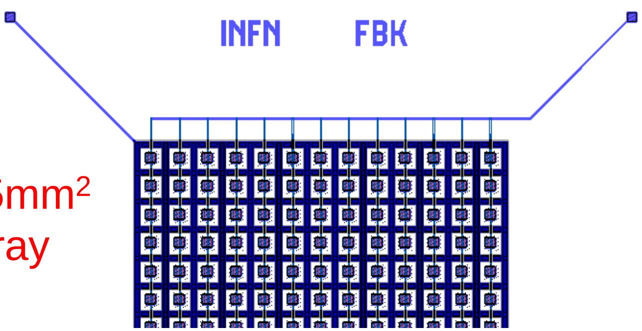
Neutron detector for HYDE

- R&D project with INFN TN-PD
- idea: increase interaction volume and light collection surface
- use of polysiloxane based scintillator

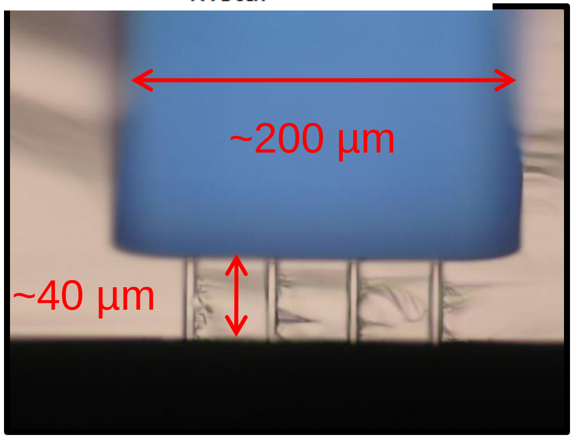


preliminary filling tests





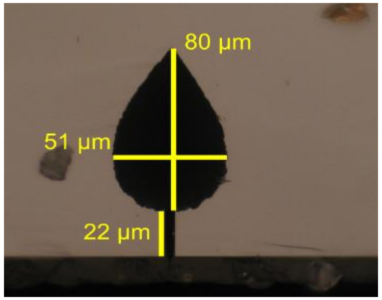
~5x5mm^2 array

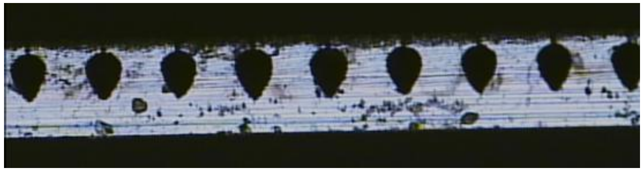


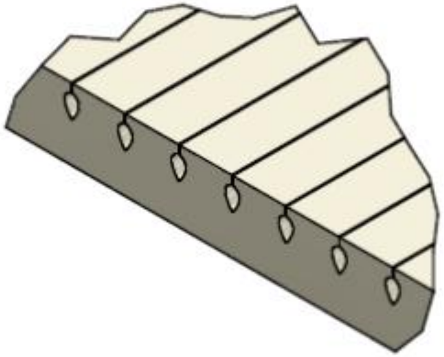
Silicon buried channels

… not only detectors

- R&D project with INFN PI
- integrate in the same silicon substrate the cooling system
- based on microchannels obtained by DRIE
- channel section determined by DRIE process
- channel length defined by the layout







FONDAZIONE BRUNO KESSLER

Other activities

- Rad-hard studies on different Si sub types (FZ, Cz, epi, p-type, …)
- JFET based active elements integrated on the detector substrate
- BJT-based detectors for radon detection
- Diode array for dosimetry applications
- Supports for CNT: surface preparation and electrode definition