Overview on sensors design and prototyping @FBK

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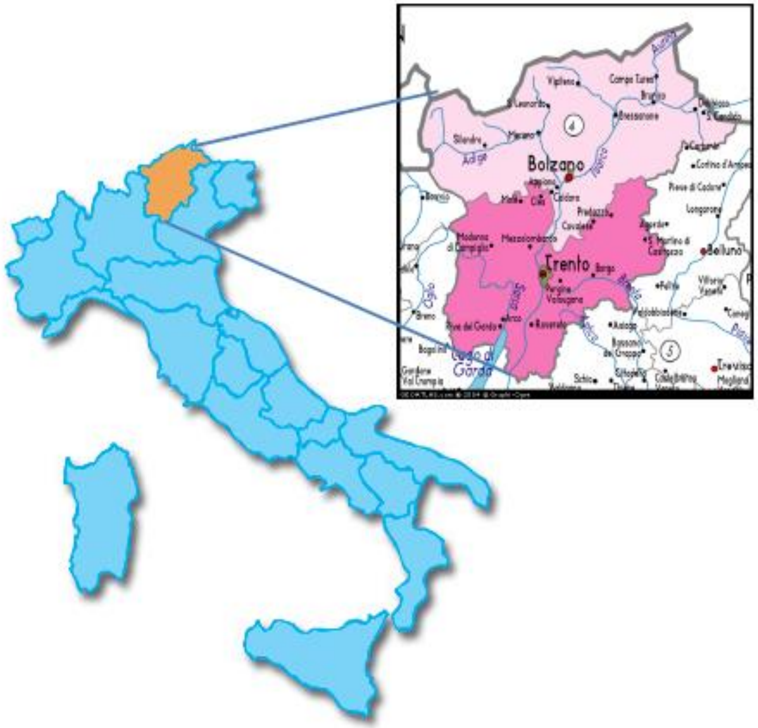
Consistent R&D investment by Local Government (2% of Province’s GDP, Gross Domestic Product)

EUROPAREGION EUREGIO
Tirol Südtirol Trentino
Tirolo Alto Adige Trentino



Scientific and Technological Area

- **CMM** Centre for Materials and Microsystem
- **ICT** Centre for Information Technology
- **ECT*** European Centre for Theoretical Physics
- **CIRM** International Center for Mathematical Research

Humanities Area

- **ISIG** Centre for Italian-German Historical Studies
- **ISR** Centre for Religious Sciences
- **IRVAPP** Research Institute for the Evaluation of Public Policies
- **CERPEG** Research Center on War, Peace and International Change

CMM-FBK People

Research	86
Tech & Staff	23
Postdoctoral Fellows	3
PhD Students	22
All Personnel	**134**
Visiting Scientists	24

Annual Budget: 10.5 M€, 50% self-financing

Partnering

- **R&D and technology transfer with private companies**
  At present we have 3 long-term contracts with multinational companies following this scheme.

- **Collaborative projects**
  with public funding (H2020, ESA…)
  In the past 5 years we participated to ~10 FP7/H2020 projects.

- **Small productions for public and private entities**
  Mainly dealing with custom technologies both for industrial and research applications.

Research Units

The activity is carried out in two Research Units:

IRIS
INTEGRATED RADIATION AND IMAGE SENSORS

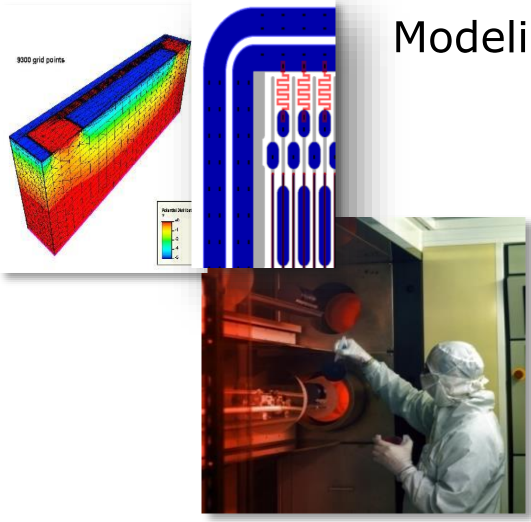
~20 people
(electronic eng, physicists)

MNF
MICRO NANO FACILITY

~40 people
(physicists, chemists, technicians)

Technologies & Competencies

Full Custom Silicon Technology



Modeling-design

In-house production

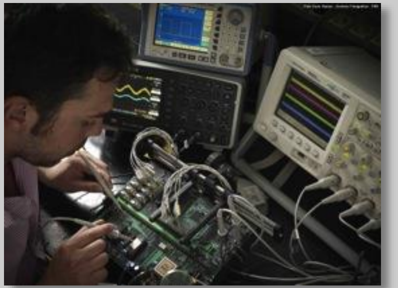
State-of-the art CMOS Technologies

Analog and Digital IC Design

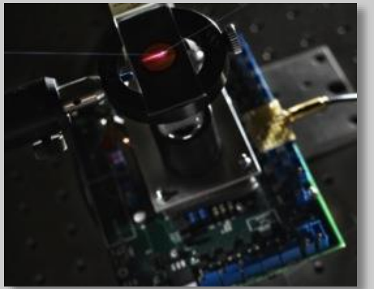
130nm-350nm external Fab

Parametric Testing

Functional Testing



Prototyping



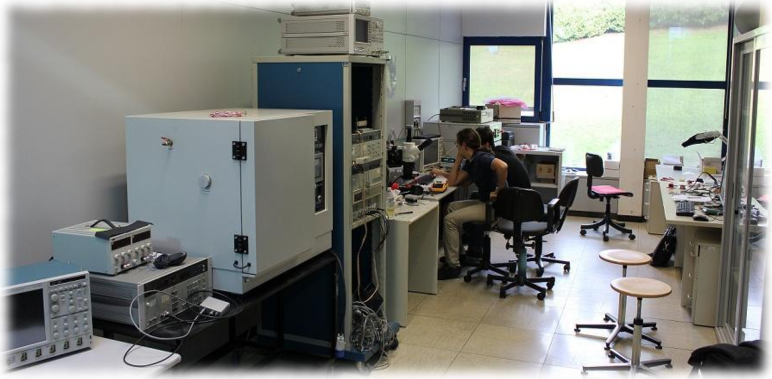
Infrastructures

Microfabrication Area:
CMOS-like pilot line (6” wafers) with 2 Clean Rooms for device fabrication

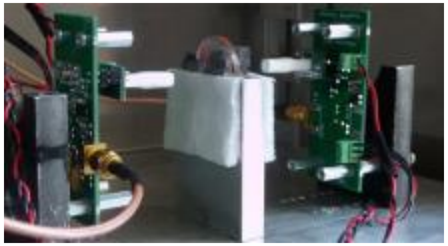
- **Testing Area:** device parametric testing
- **Integration Area:** device packaging and microsystems assembly
- **Micro-Nano Analysis:** surface science analytical methodologies (SIMS, AUGER, AFM, ..)

Infrastructures

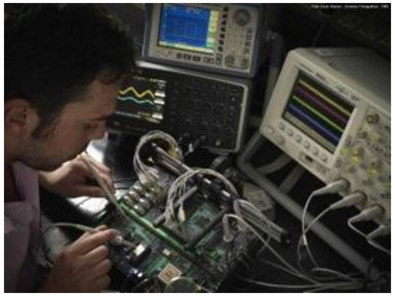
SRSlab:
- electro-optical characterization
- tests with high-energy radiation



FunLab:
- microchip electrical characterization
- PCB and prototype assembly
- THz Test Bench



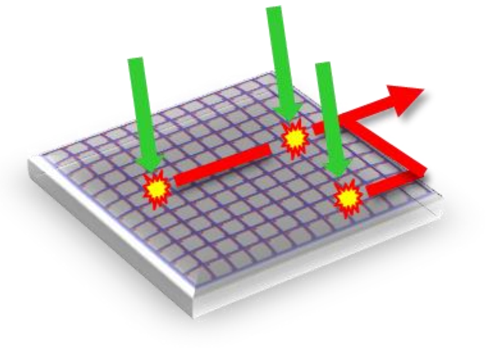
LaserLab:
- electro-optical testing,
- single-photon detectors characterisation
- image sensors testing
- TOF tests



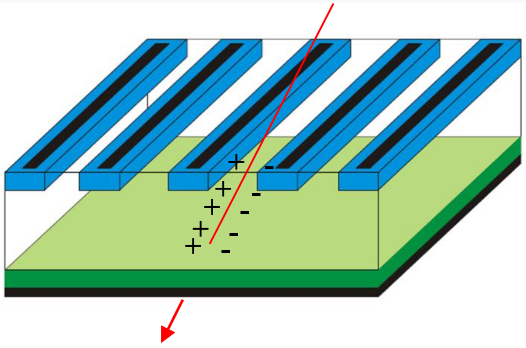
Research topics

Two main platforms:

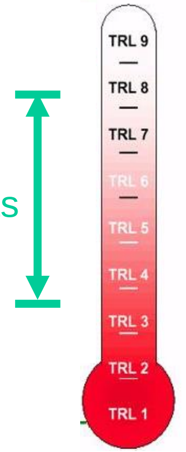
Single-photon light sensors



High-energy radiation detectors



various developments

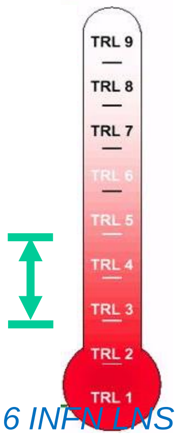


R&D initiatives on:

TeraHertz detectors

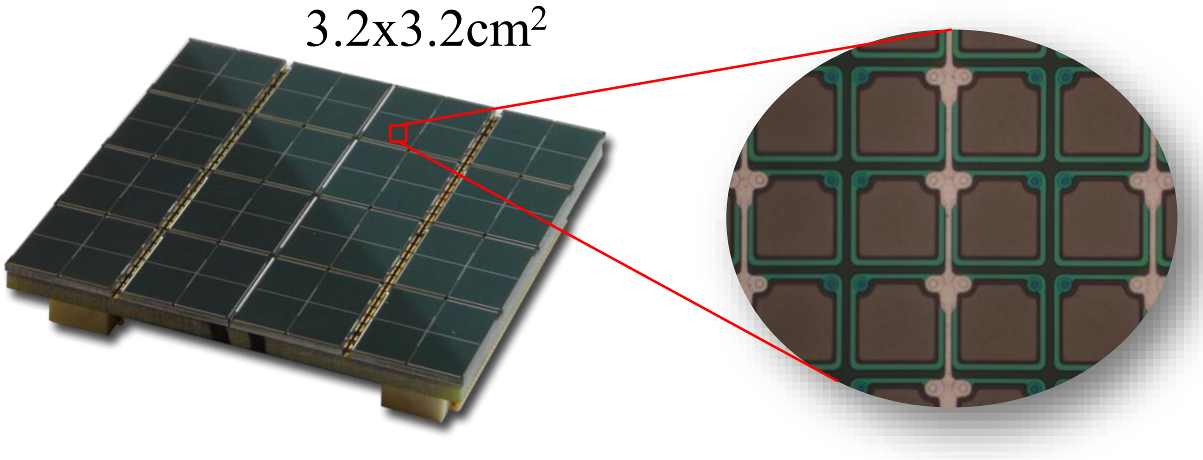
Low-power imaging

Graphene-based detector



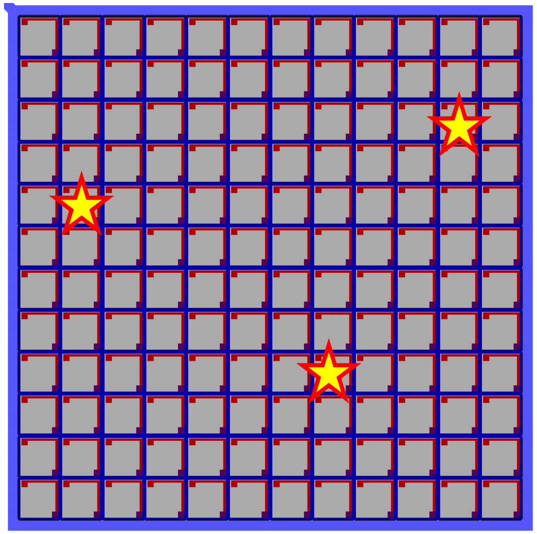
Single-photon light sensors

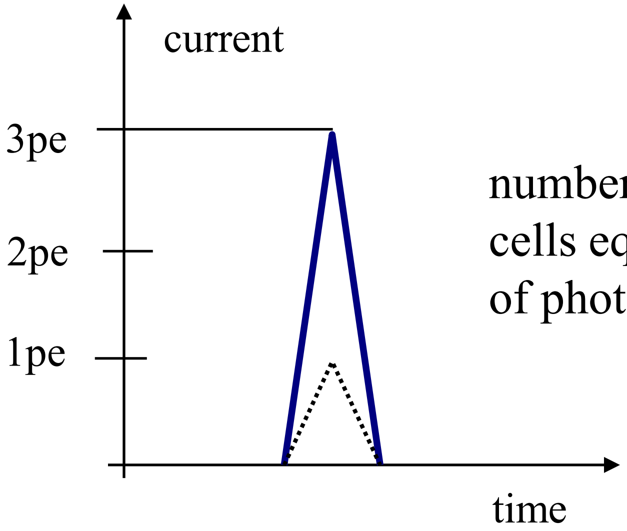
Silicon photomultiplier



SiPM

array of tiny SPADs connected in parallel to give proportional information

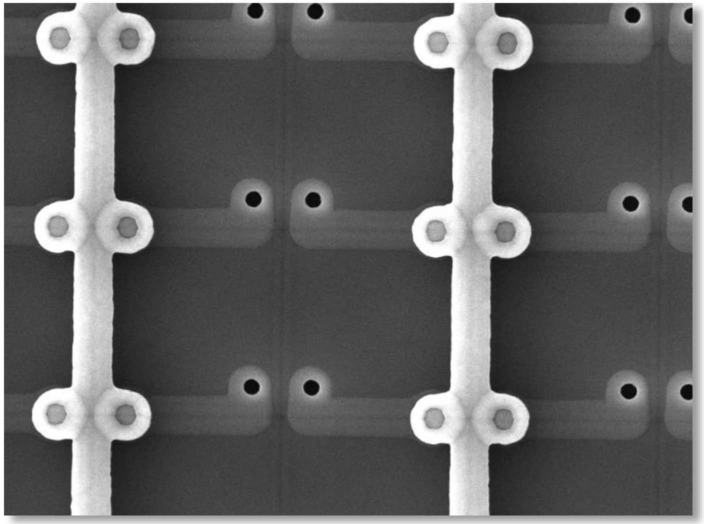


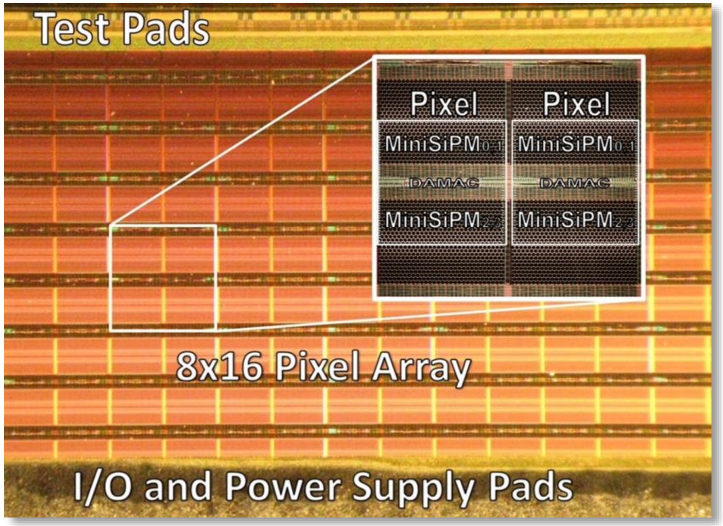


number of activated cells equal to number of photons (PDE=1)

Single photon @ FBK

Single-Photon Avalanche Diodes



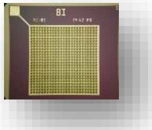


Custom technology:
- high efficiency
- low noise
- high flexibility

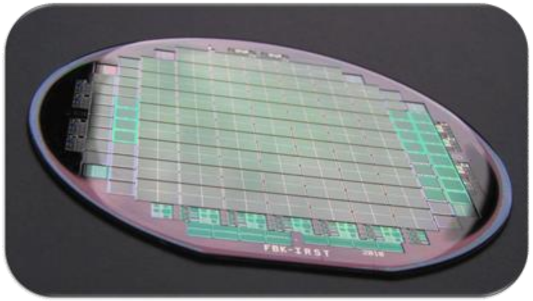
Standard CMOS technology:
- smart architecture
- high-level integration

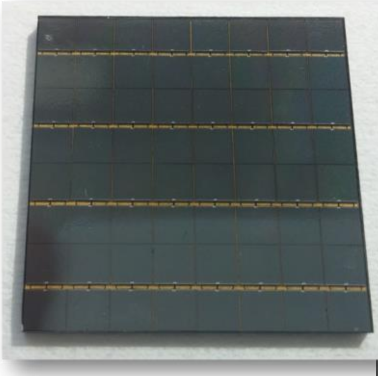
Custom Technology evolution

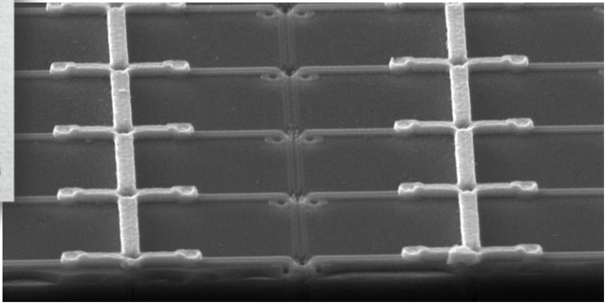
2006

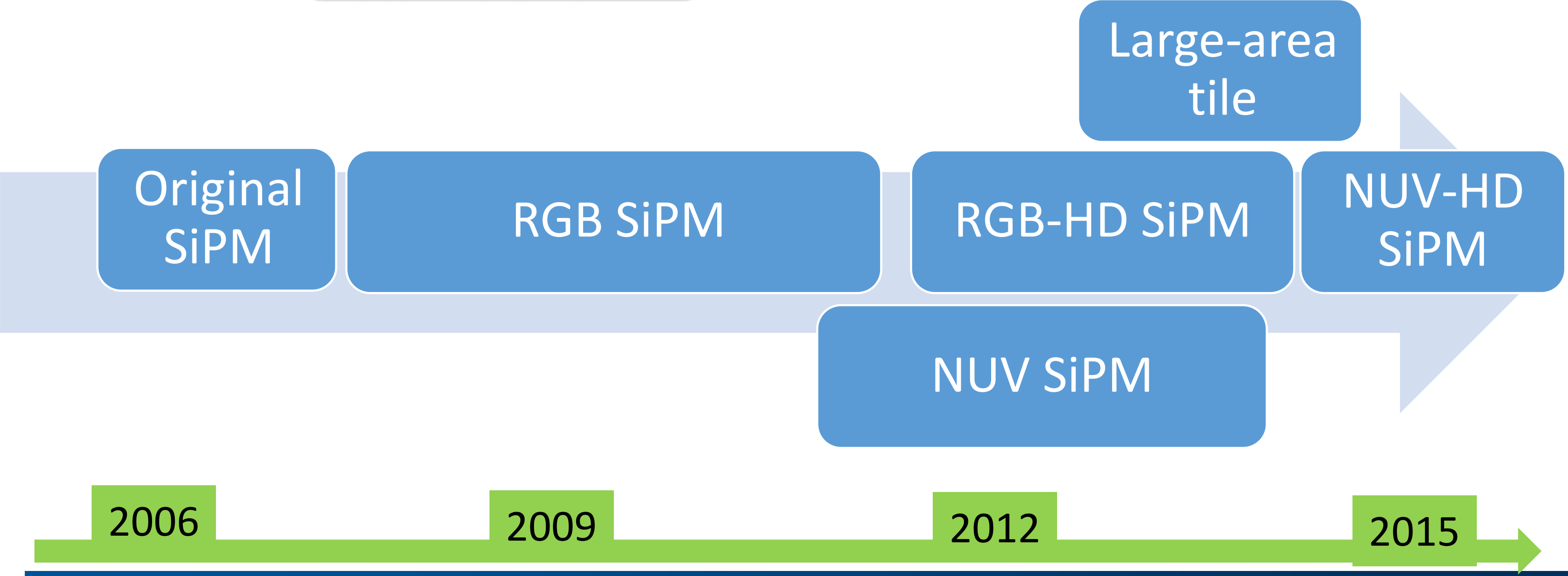


1x1mm^2









Large-area tile

Original SiPM

RGB SiPM

RGB-HD SiPM

NUV-HD SiPM

NUV SiPM

2006

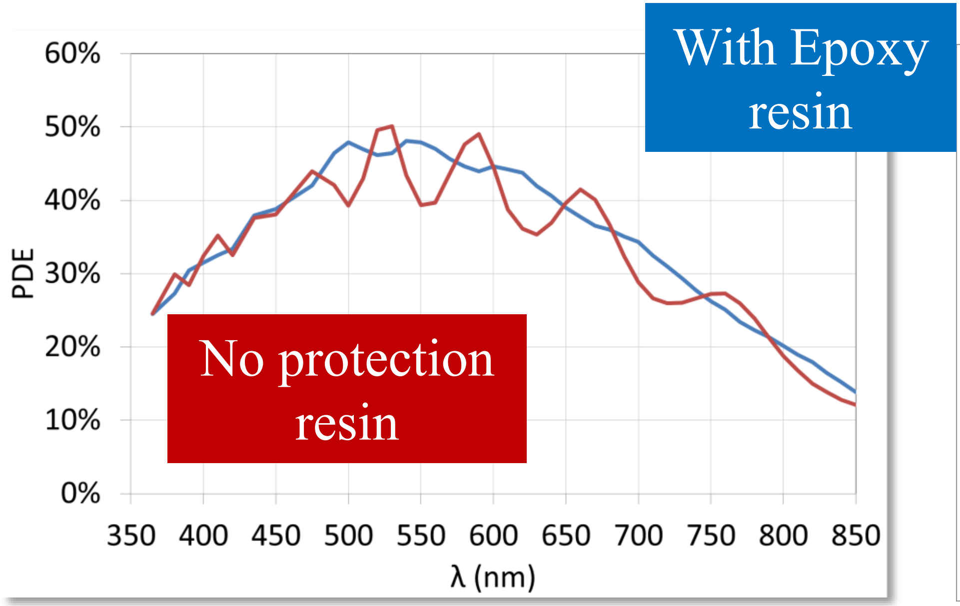
2009

2012

2015

PDE vs λ

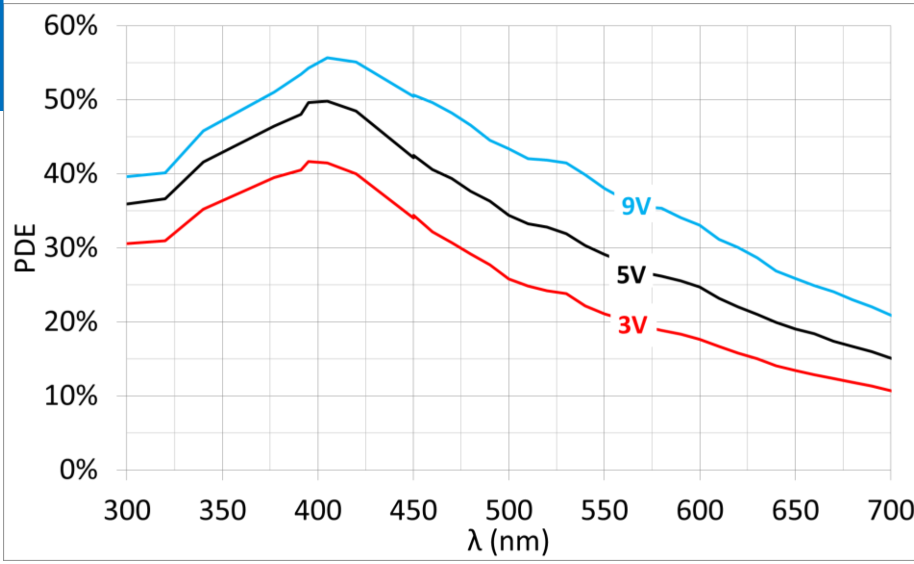
RGB



With Epoxy resin

No protection resin

NUV



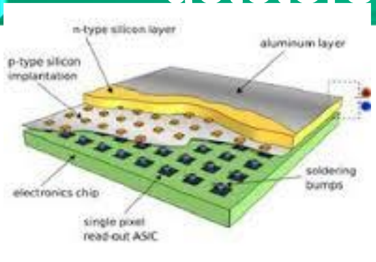
- RGB-HD 25mm
- Over-voltage = 9 V

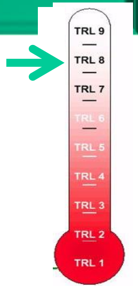
30mm cell pitch
77% fill factor

Technologies

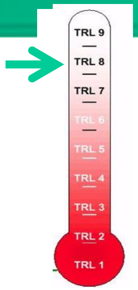
Silicon-based detector in full-custom technology

SPD
silicon pixel detctors

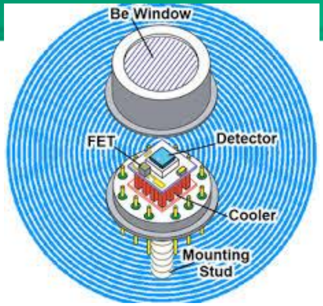


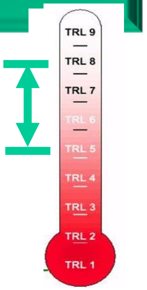


SSD
silicon strip detectors

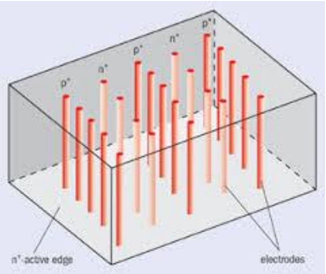


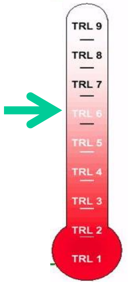
SDD
silicon drift detectors



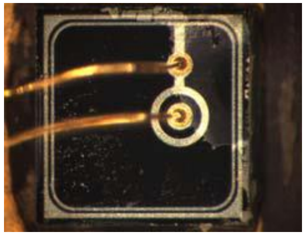


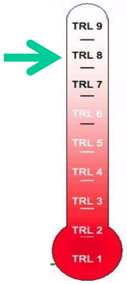
3D detectors



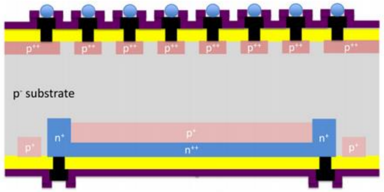


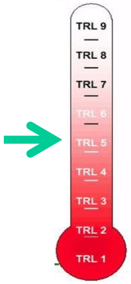
PIN Photodiodes and phototransistors



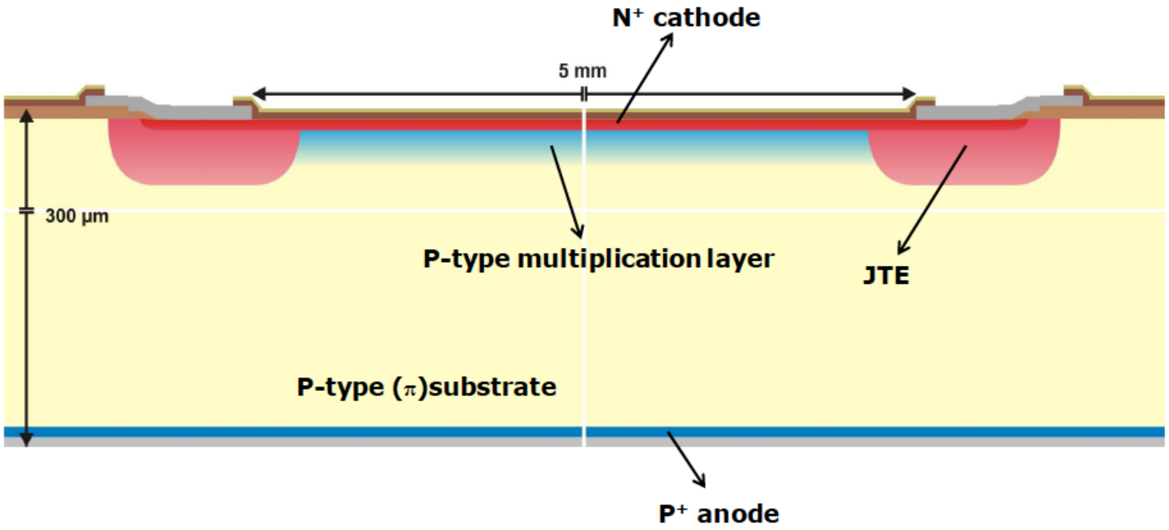


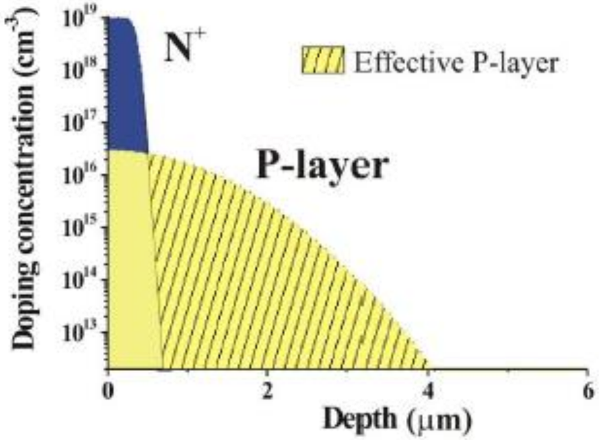
Avalanche photodetectors





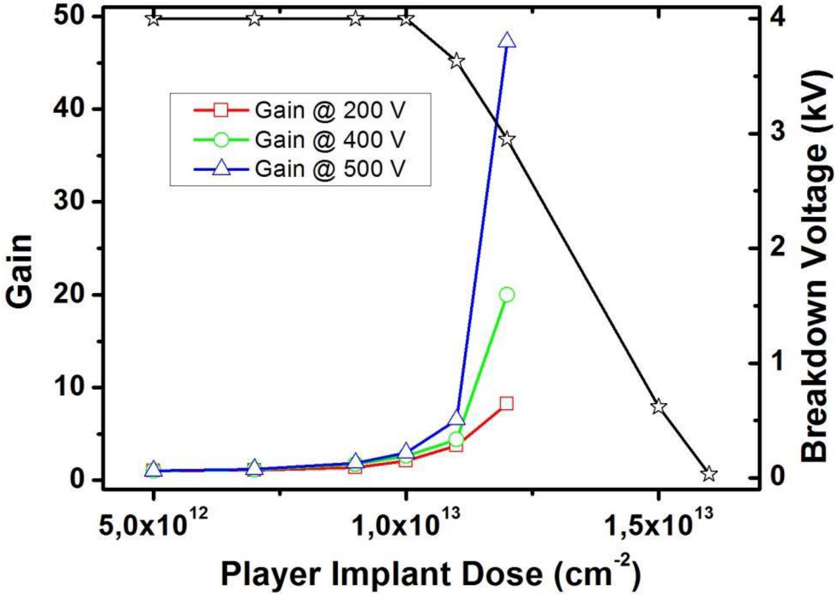
Low Gain Avalanche Detector (LGAD)





G. Pellegrini, et al., HSTD9 (2013)

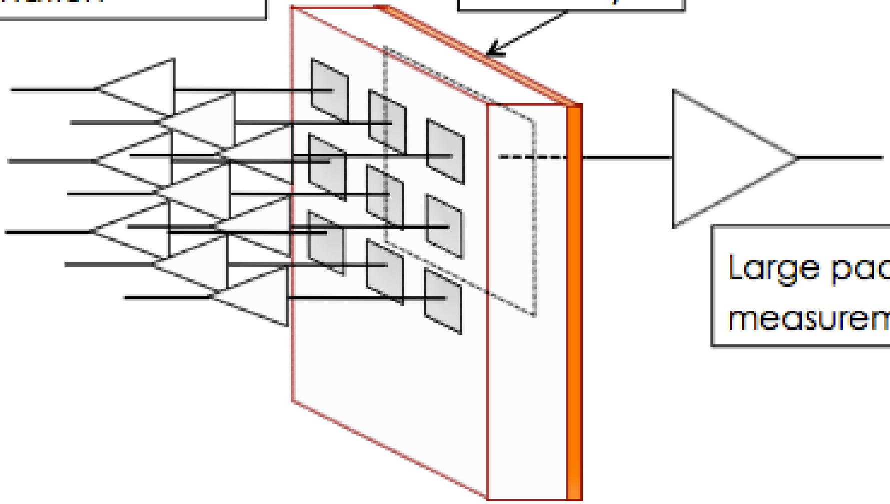
- APDs revisited for ionizing particles
- Aiming at low gain both before and after irradiation
- Gain vs breakdown voltage trade-off
- High sensitivity to the implant dose of the multiplication layer
- JTE to prevent from edge breakdown



Double-Sided Pixelated LGAD

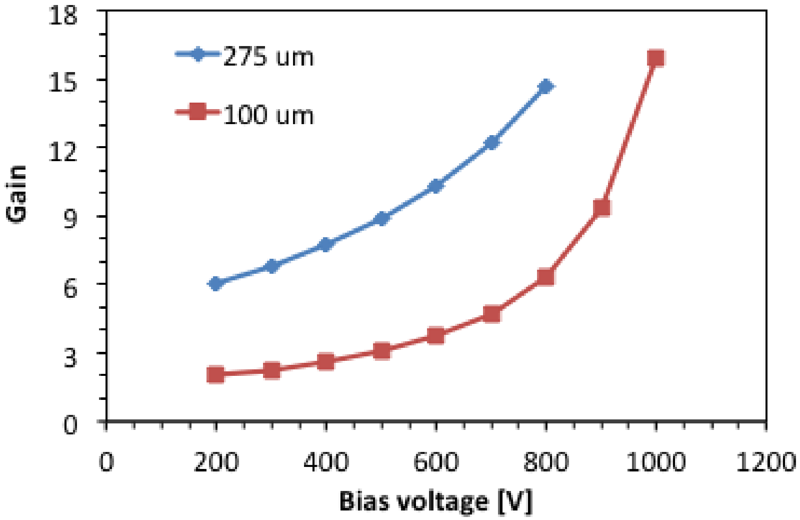
Small pixels for position determination

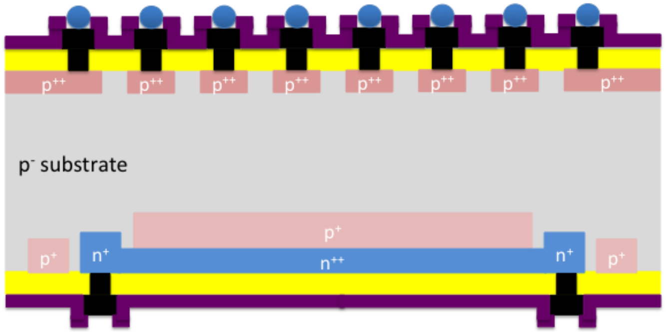
Gain layer



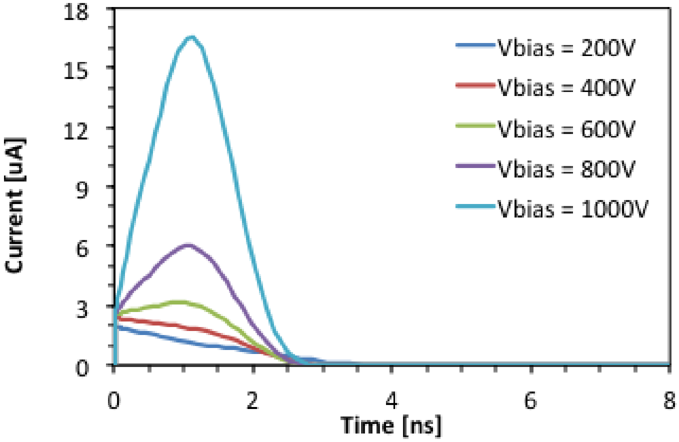
Large pads for time measurements

Simulated Gain comparison



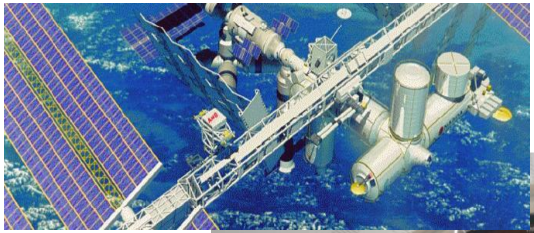


Simulated Transient response
For 100 micron thickness

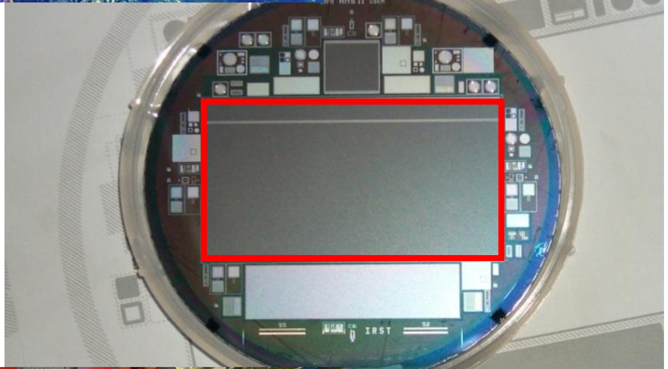


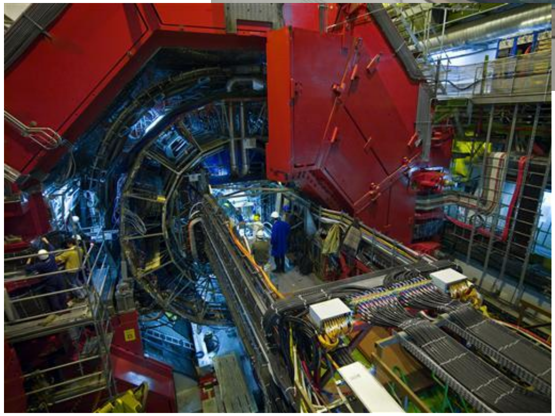
Silicon Strip Detectors

AMS experiment (@ISS)



700 detectors

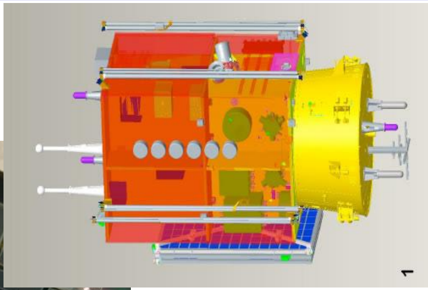




600 detectors

ALICE experiment (@LHC)

Limadou experiment (@CSES)

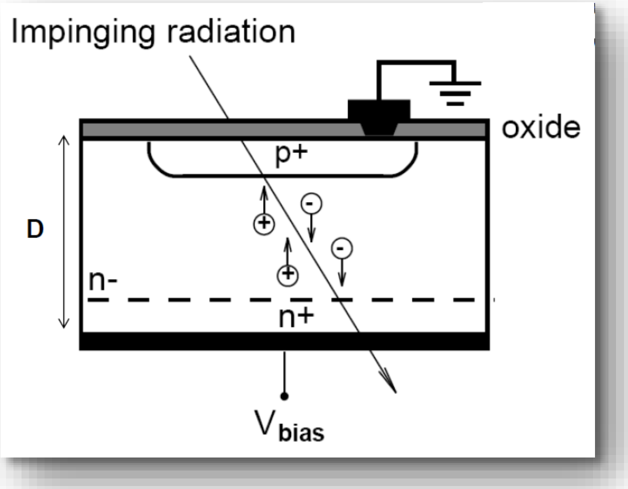


10.5x7cm^2

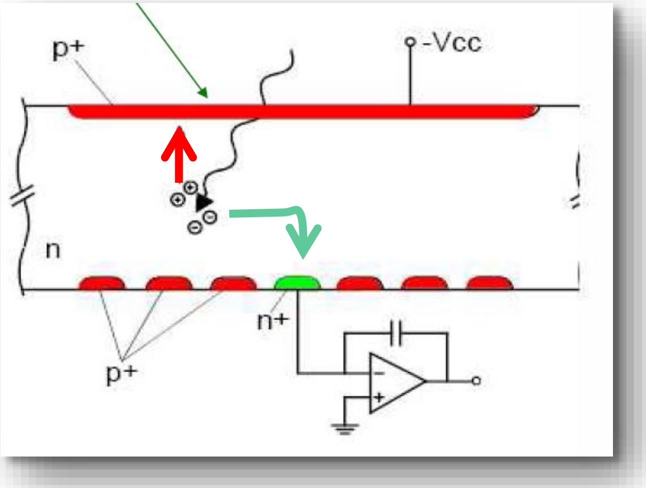
Custom productions for industry

Silicon Drift Detectors

PIN diode



SDD



SDD: Tiny collecting electrode for “large” sensing areas
➔ **minimial series noise**!!!

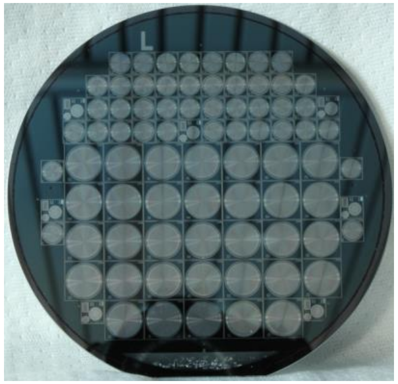
Double-side wafer processing. Fully depleted substrate.

SDD - Projects

2008 **2010** **2012** **2013** **2015**

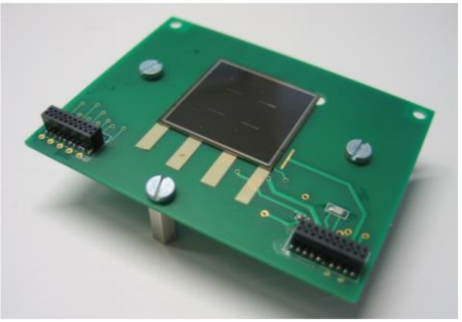
R&D, technology transfer and production with multinatinal company

First SDD development



ESA project PoliMI

Gamma ray detector



RedSox

LOFT

Large area linear SDD

Siddartha project

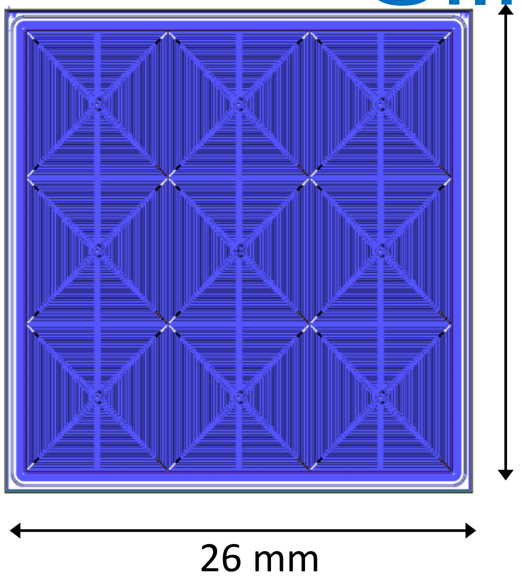
DSSC (XFEL)

sinchro trons

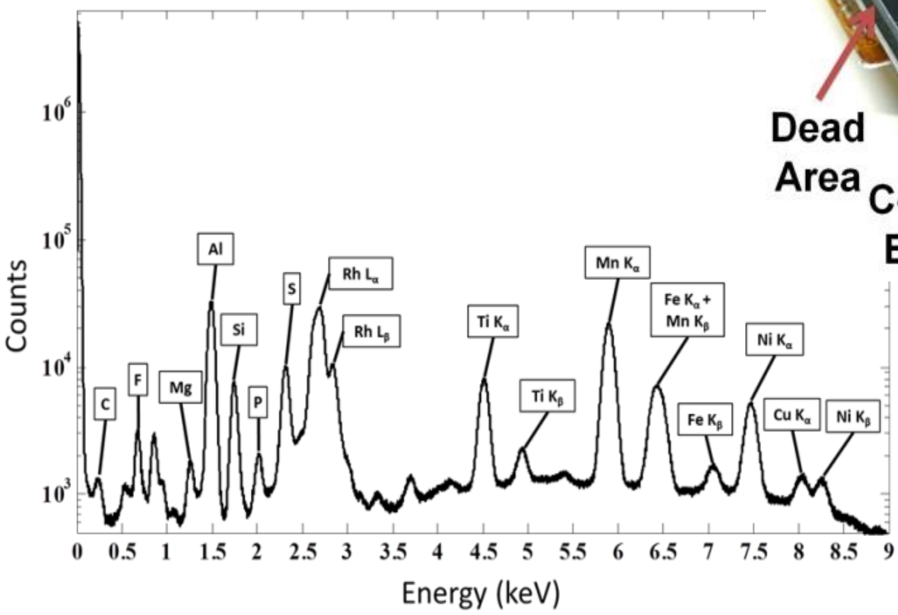
1-2 nA/cm^2

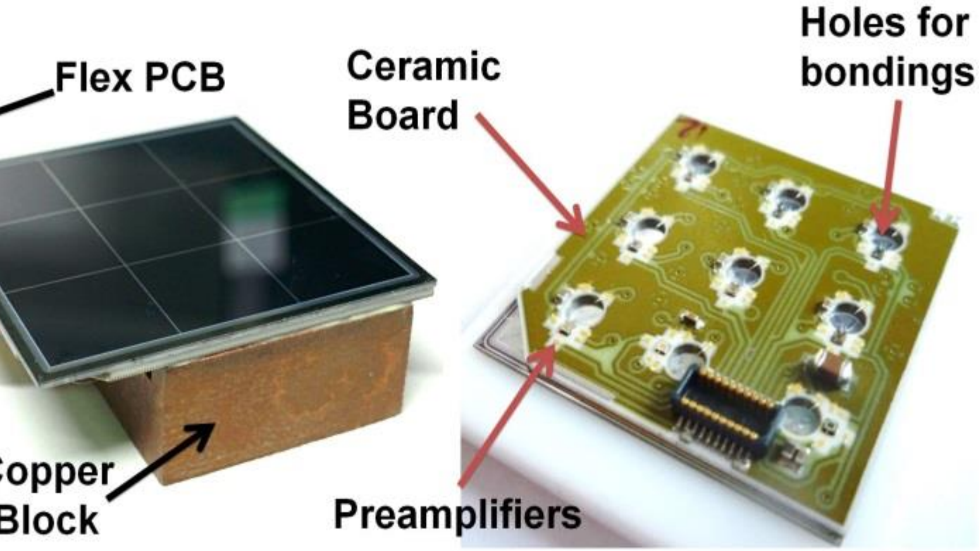
< 200 pA/cm^2

Silicon Drift Detectors



Spettroscopia X

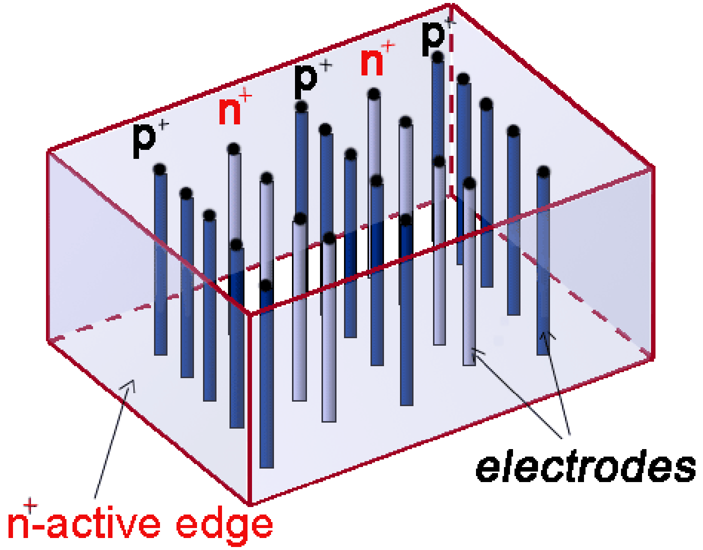




Electronics and tests
@ PoliMI

3D detectors

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



ADVANTAGES:

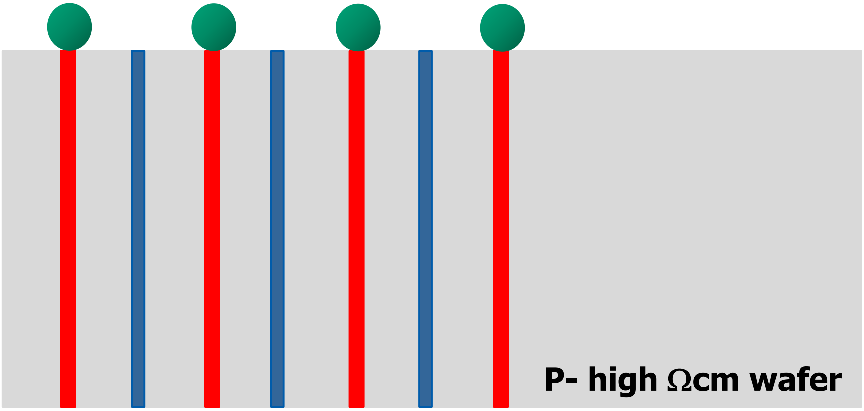
- Electrode distance and substrate thickness decoupled:
    - low depletion voltage
    - high speed
    - good charge collection efficiency
        → **High radiation hardness**

-Active edges:
    - Dead area reduced up to few microns from the edge

DISADVANTAGES:

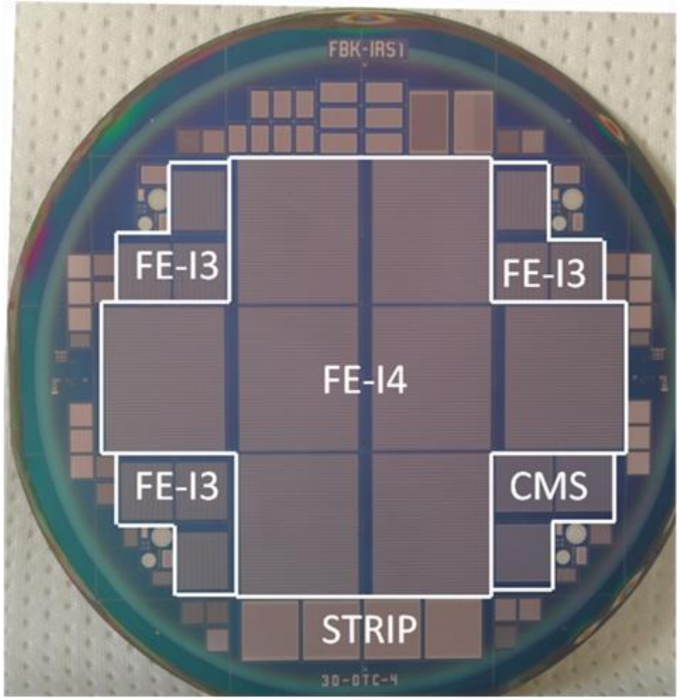
- Non uniform response due to electrodes
- **Complicated technology**
- Higher capacitance with respect to planar

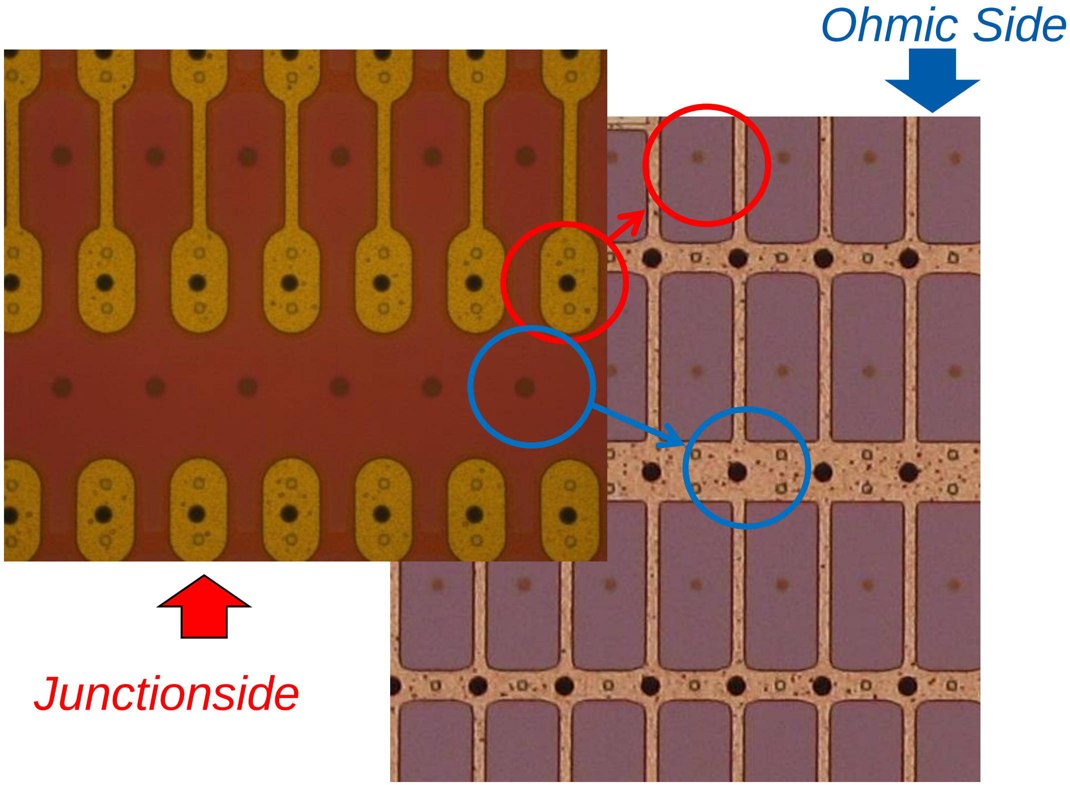
3D pixels @ FBK

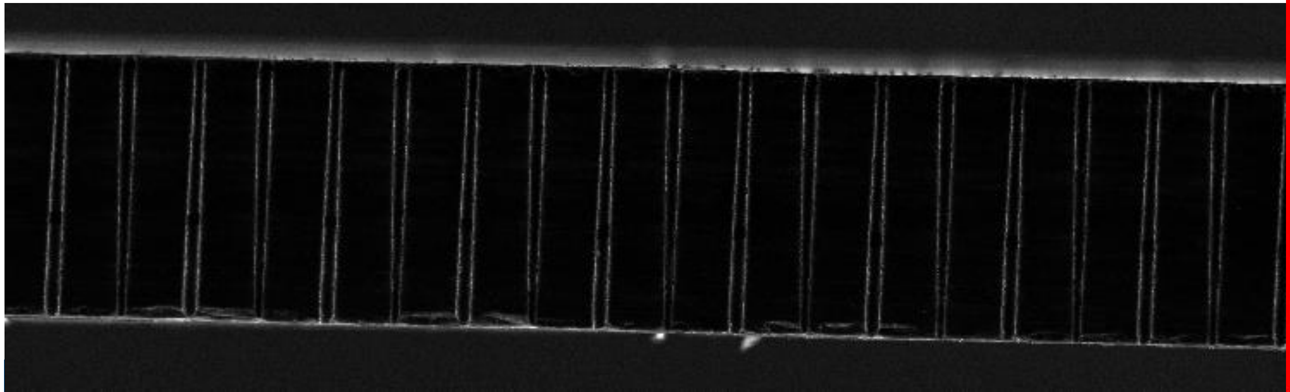


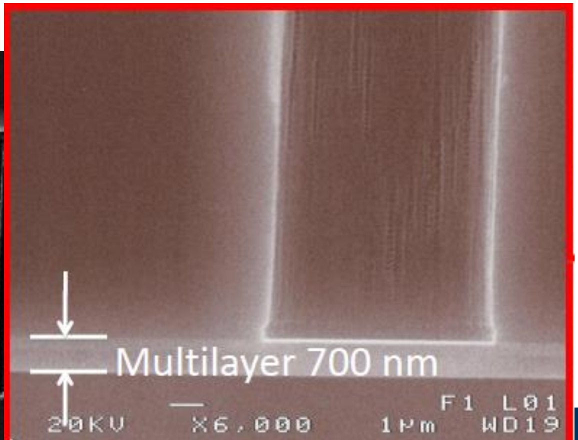
- FZ material
- Double side technology
- Columns are passing and empty
- No support wafers
- Surface isolation with p_spray on both side
- 200micron slim edge

FBK Si-3D for IBL ATLAS

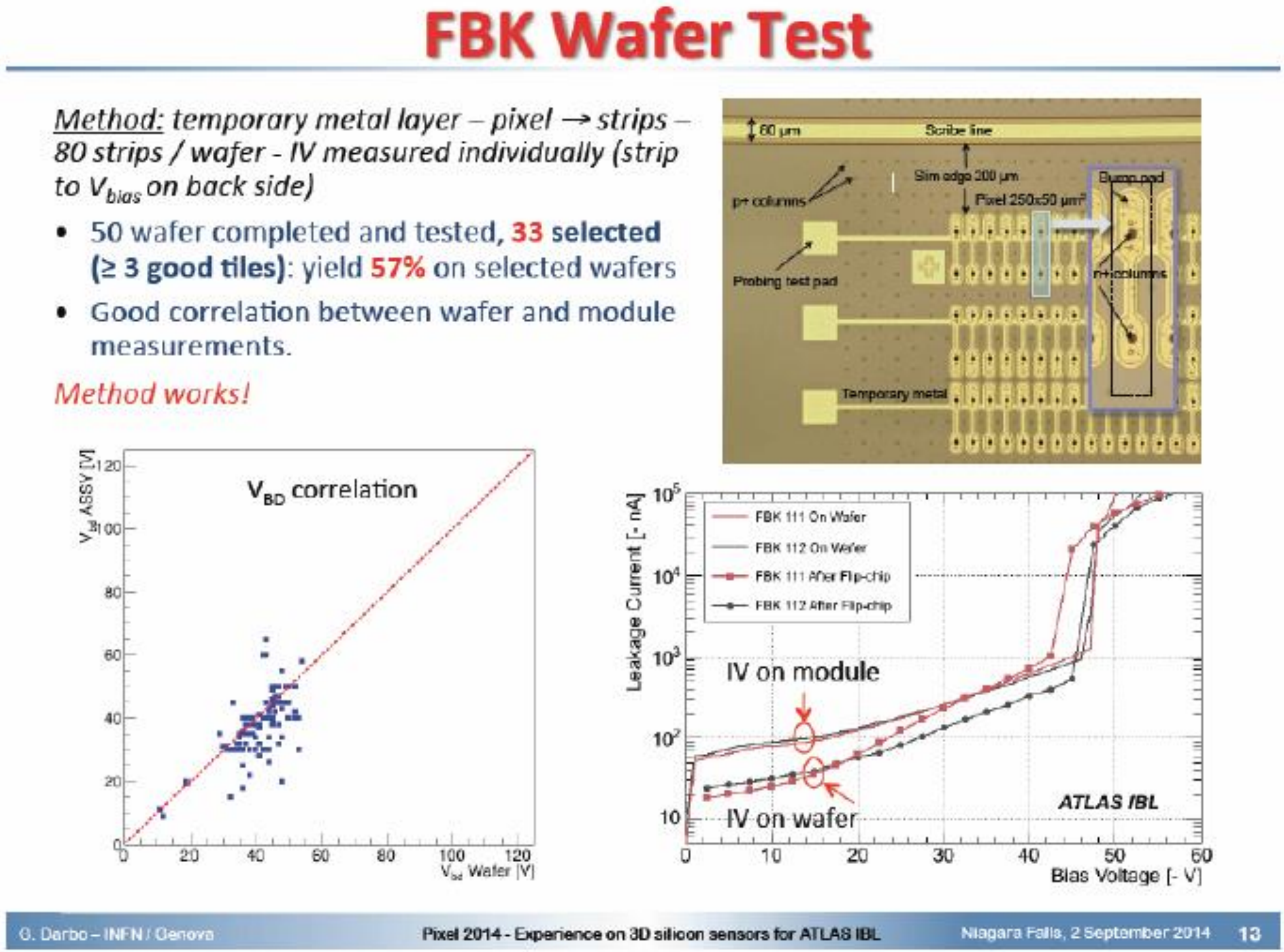








G. Darbo, PIXEL 2014



FBK Wafer Test

Method: temporary metal layer – pixel → strips – 80 strips / wafer - IV measured individually (strip to V_{bias} on back side)

- 50 wafer completed and tested, **33 selected (≥ 3 good tiles)**: yield **57%** on selected wafers
- Good correlation between wafer and module measurements.

Method works!

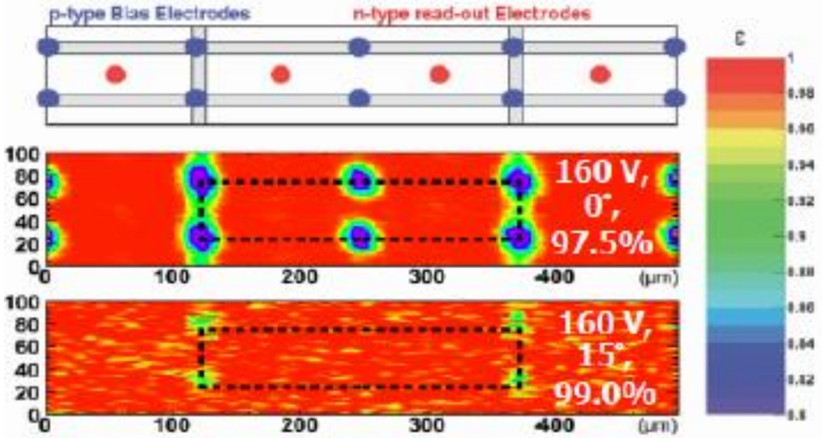
G. Darbo – INFN / Genova Pixel 2014 - Experience on 3D silicon sensors for ATLAS IBL Niagara Falls, 2 September 2014 13

J. Lange, PIXEL 2015

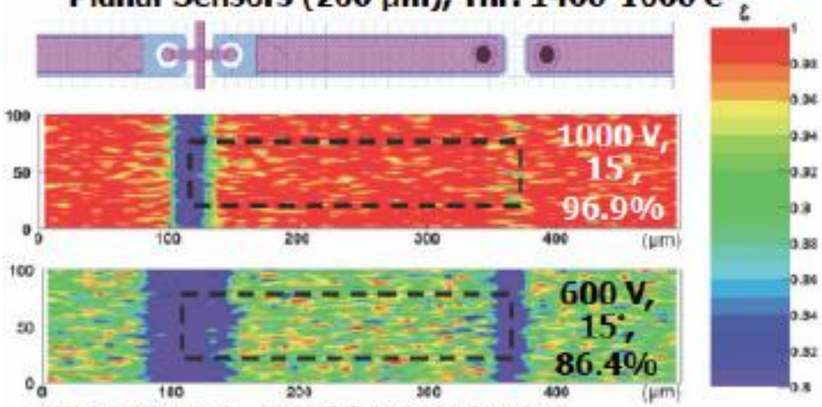
IBL 3D Performance – Radiation Hardness

Sub-Pixel Efficiency at 5×10^{15} n_{eq}/cm^2

CNM 3D Sensors (230 µm), Thr. 1500 e



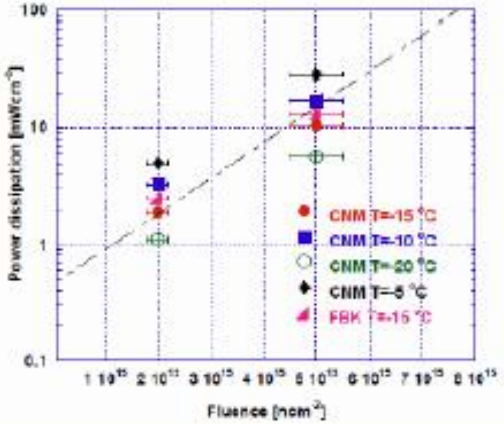
Planar Sensors (200 µm), Thr. 1400-1600 e



ATLAS IBL Coll., JINST 7 (2012) P11010

- Radiation hardness tested up to 5×10^{15} n_{eq}/cm^2
- 3D sensors
  - **Fully efficient at 160 V** and 15° angle
  - Mean efficiency **1-2%** lower at normal incidence due to columns
  - Power dissipation **<15** mW/cm² at T=-15° C
- Planar sensors
  - Need 1000 V for similar efficiency
  - Power dissipation ~90 mW/cm² at T=-15° C

→ **operational advantage for 3D sensors**



Are thin 3D feasible ?

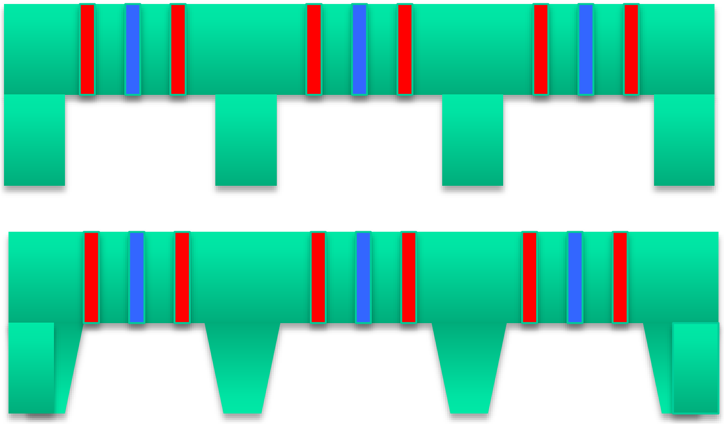
Thin wafers

- at 6-inch not thinned that 200um
- double sided process
- bow ?

Local thinning

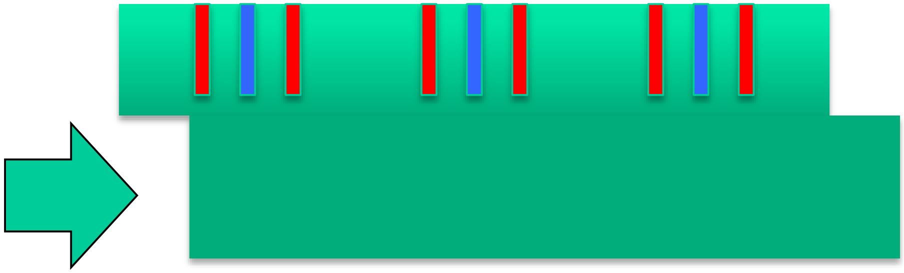
- Single side
- Processing thicker wafers with local thinning of sensor active areas by DRIE (1) or TMAH (2) could be done

G. Pellegrini et al., NIMA 604 (2009) 115

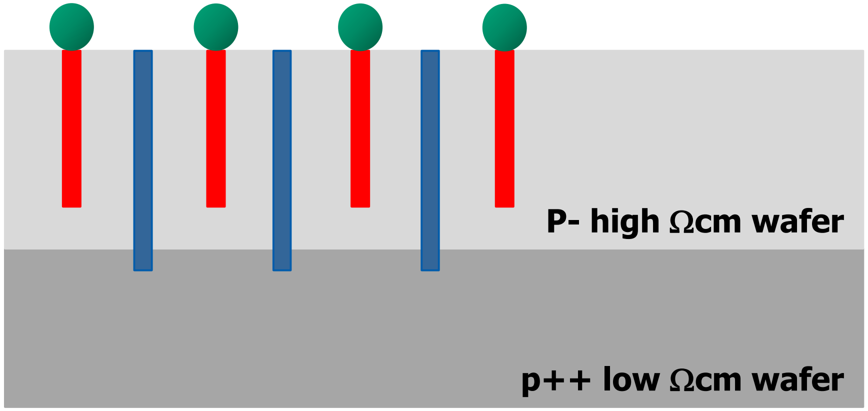


Back end process: thinning the processed wafers

- Single side
- “special” wafers: Epi, SOI, …
- After bump



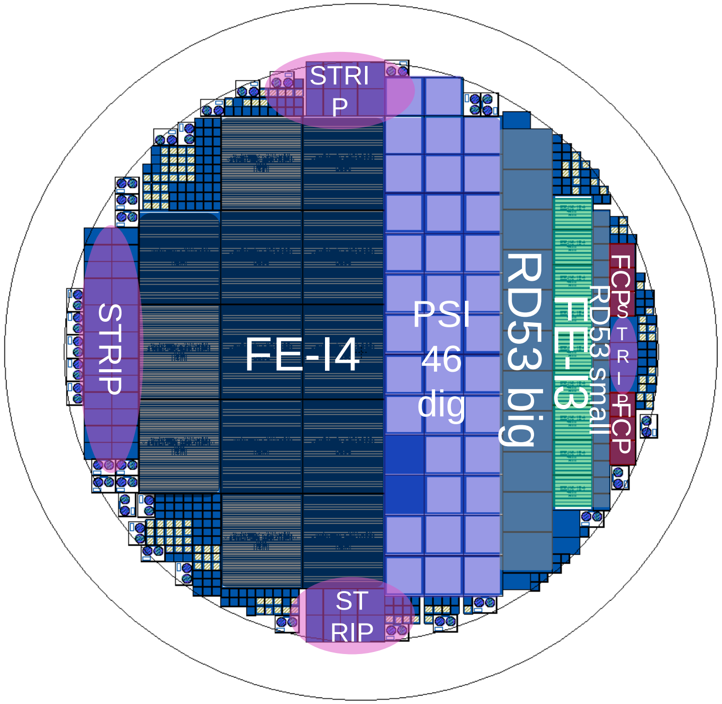
Thin 3D pixels @ FBK



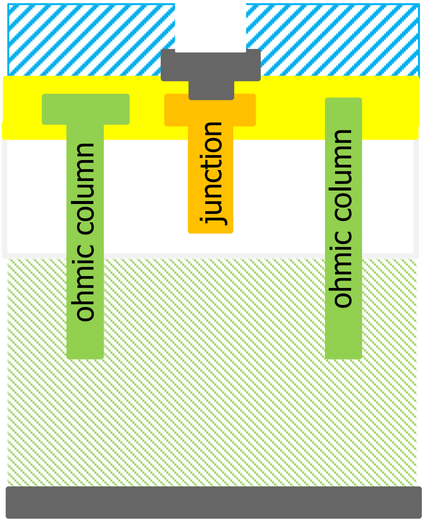
Realizzato un lotto planare su SI-SI

- SI-SI or SOI
- Single Side Technology
- Ohmic columns depth > active layer
- Junction columns depth < active layer
- Holes partially filled with poly-Si
- Slim edge

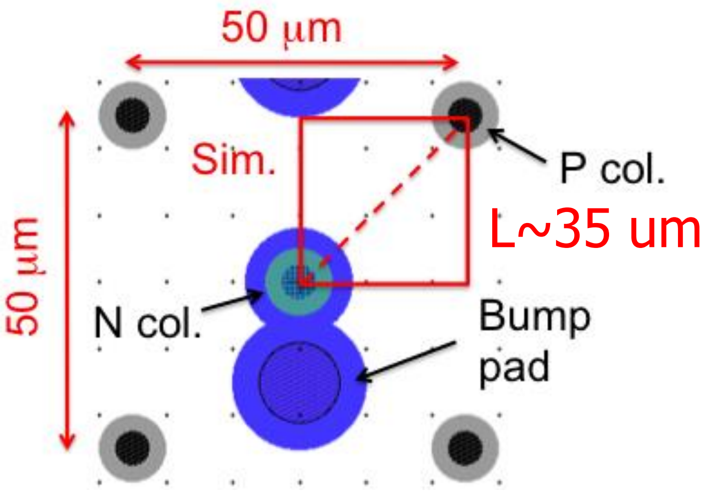
Thin Si-3D … work in progress



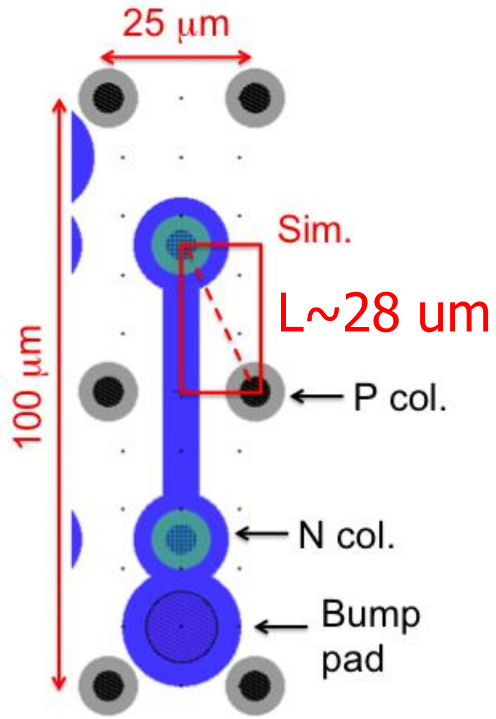
All designs assuming a column diameter of 5 mm



50 x 50



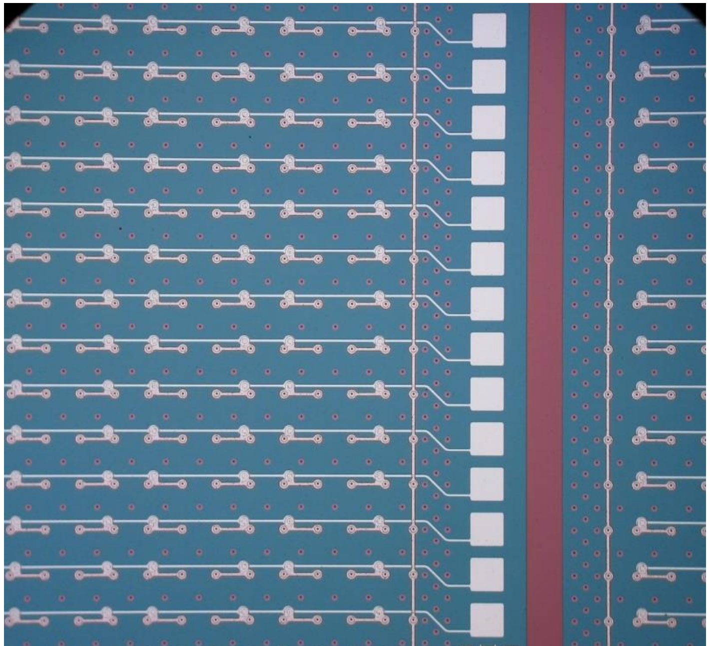
25 x 100

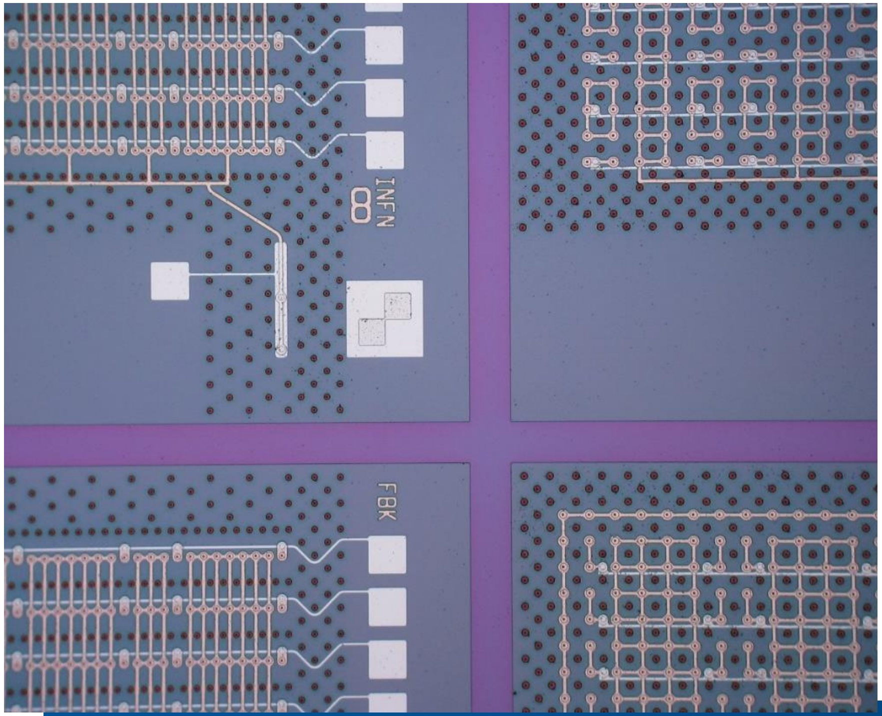


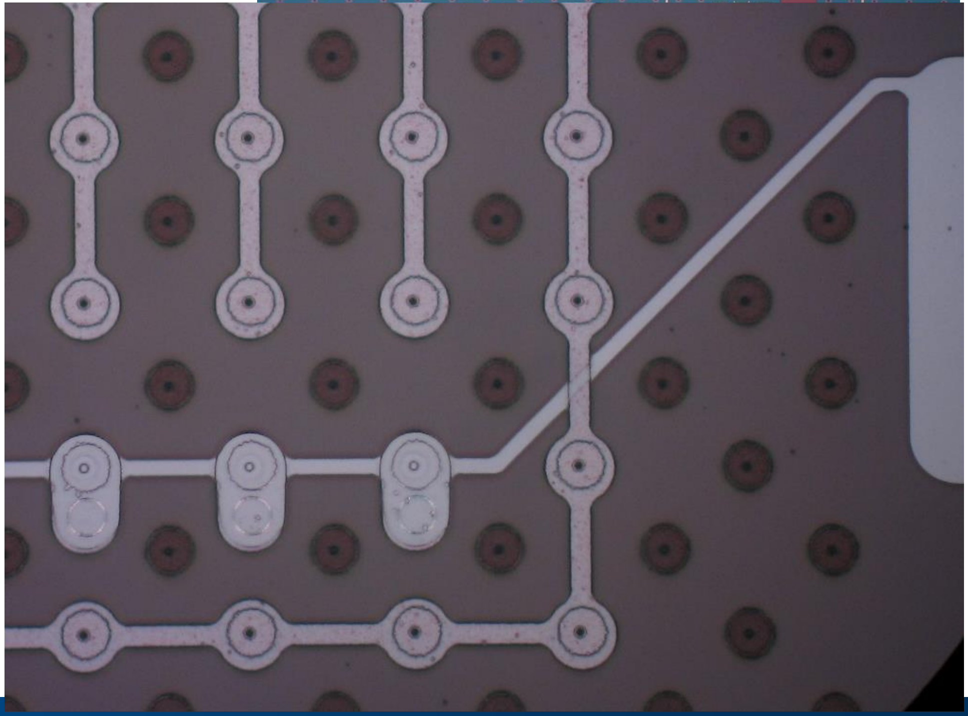
Thanks to G-F Dalla Betta Univ TN

A few pictures

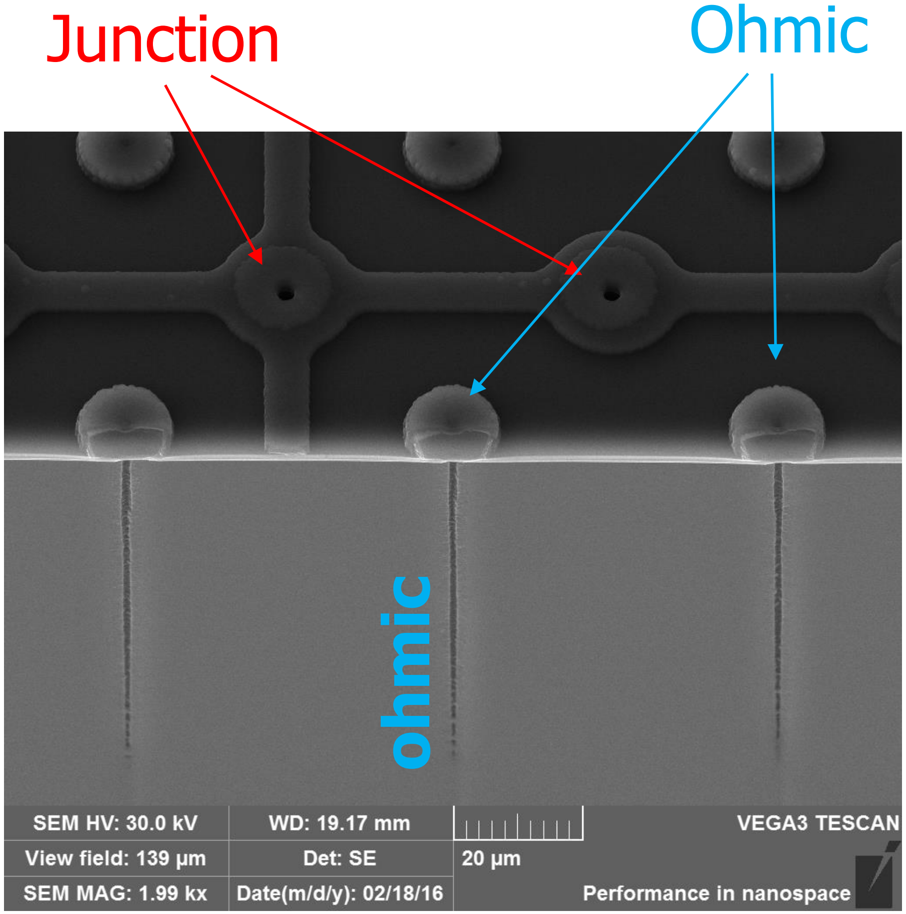
- Wafers with temporary metal
- Good lithographical quality

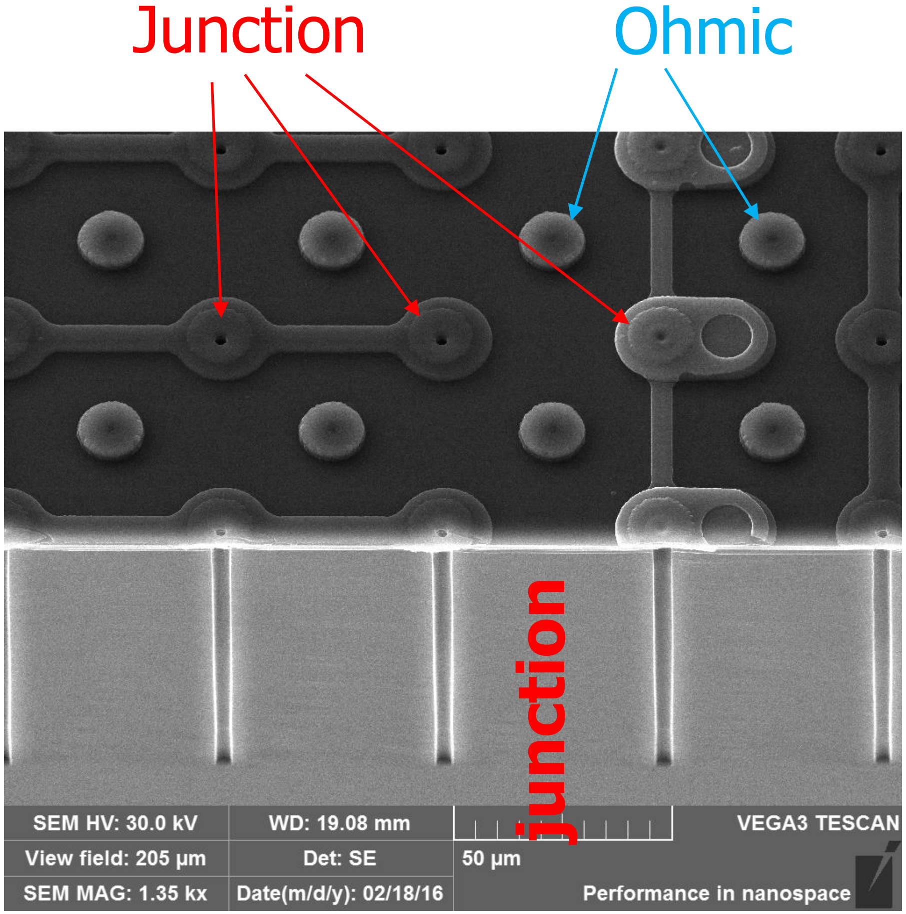






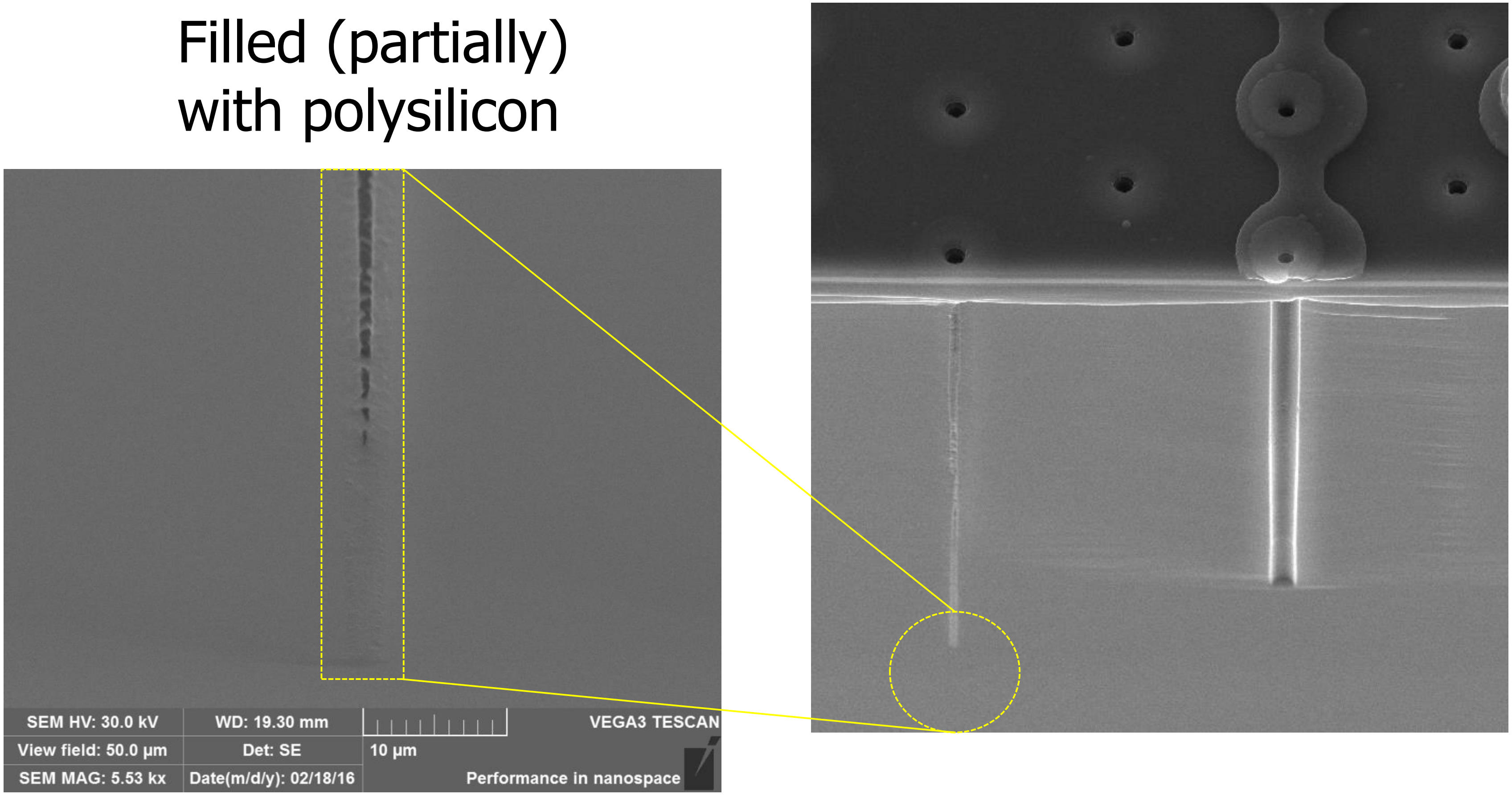
SEM Pictures





Ohmic & Junction Column

Filled (partially)
with polysilicon



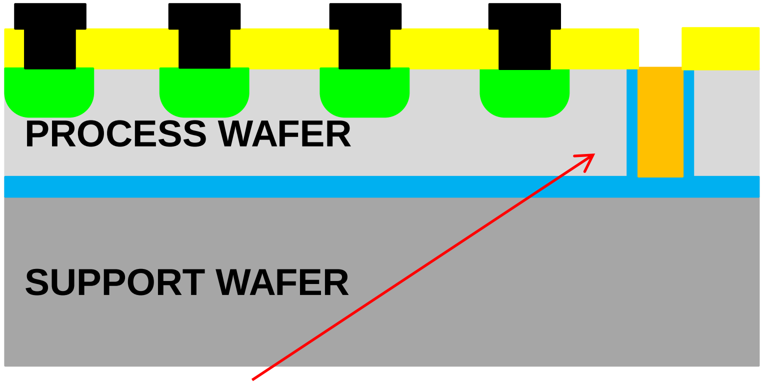
FBK edgless technology

Support wafers

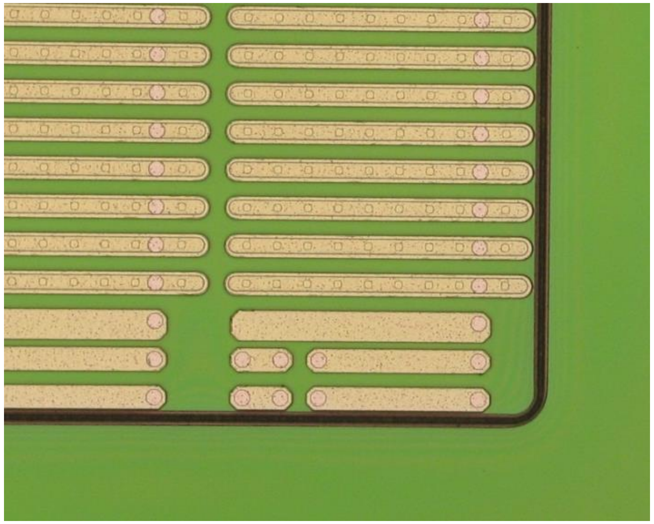
SOI wafers, epi, … Si-Si

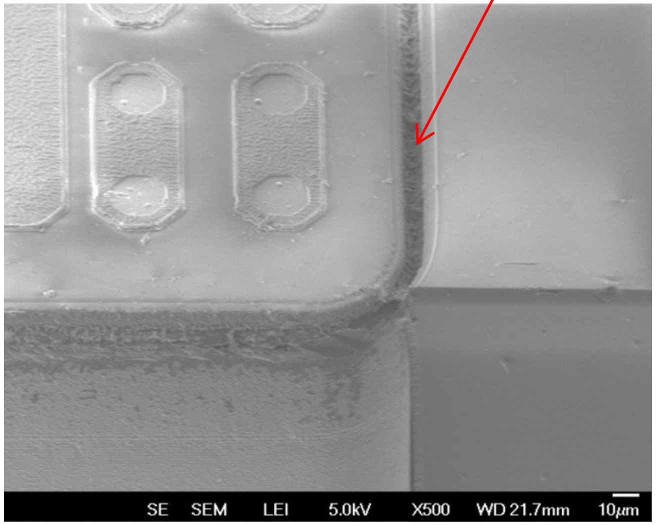
DRIE etched trench and doping

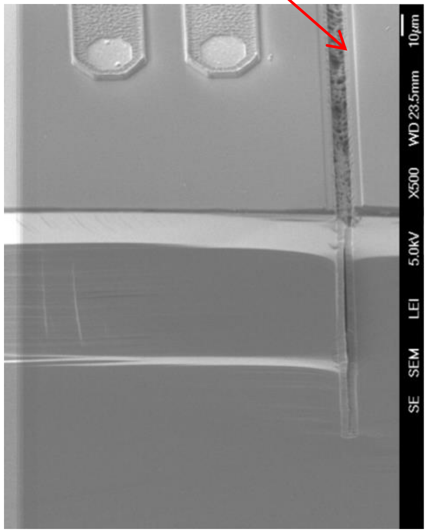
- Trench definition and etching (DRIE)
- Doping using gas source technology
- Trench filling with polysilicon



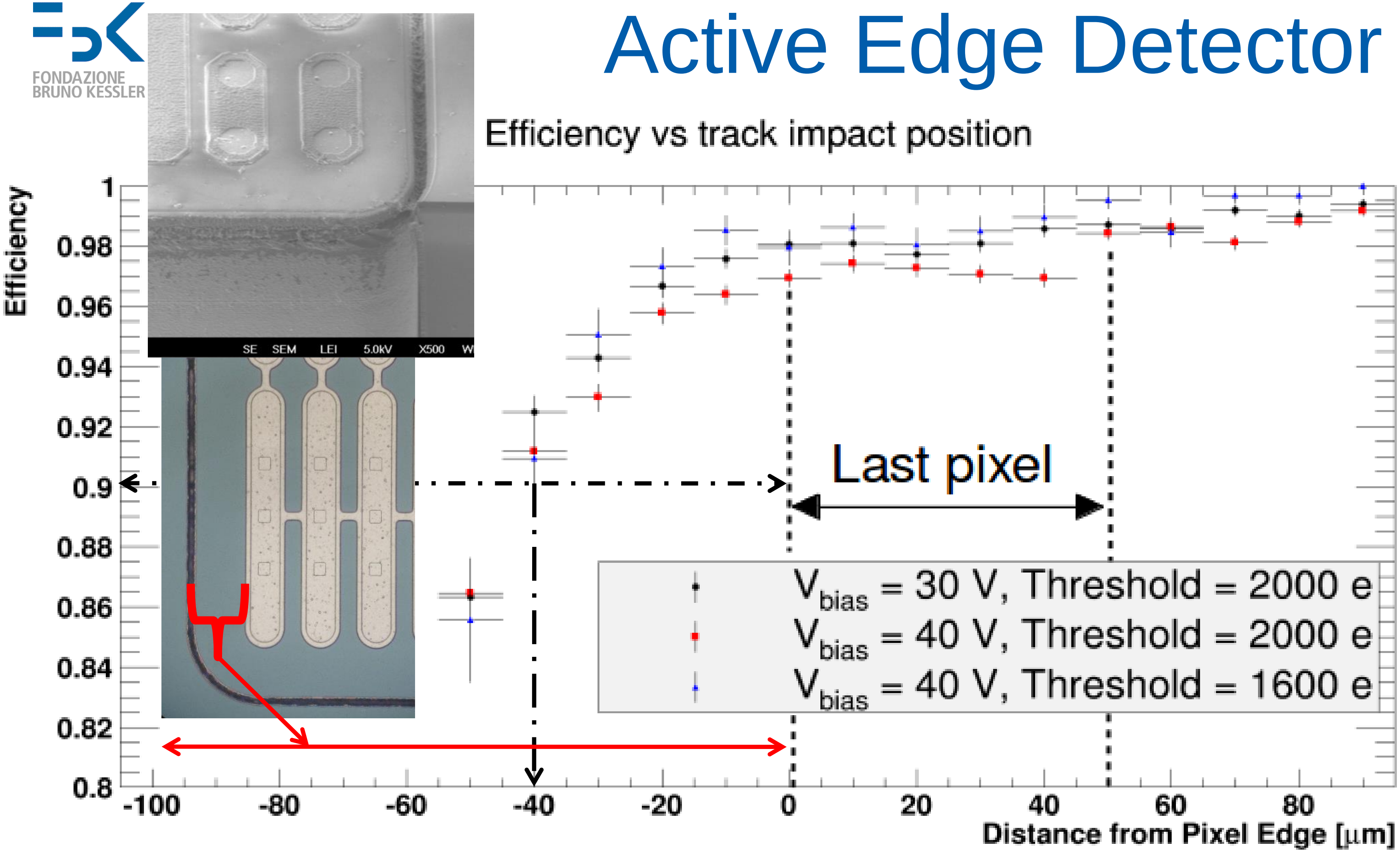
Trench filled with polisilicon







Active Edge Detector



- Hit-efficiency above 90% up to 40 μm away from the last pixel
- No good tracks beyond -50 μm due to quality cuts

M. Bomben *et* al. Nucl. Instrum. Meth. A 712 (2013) 41

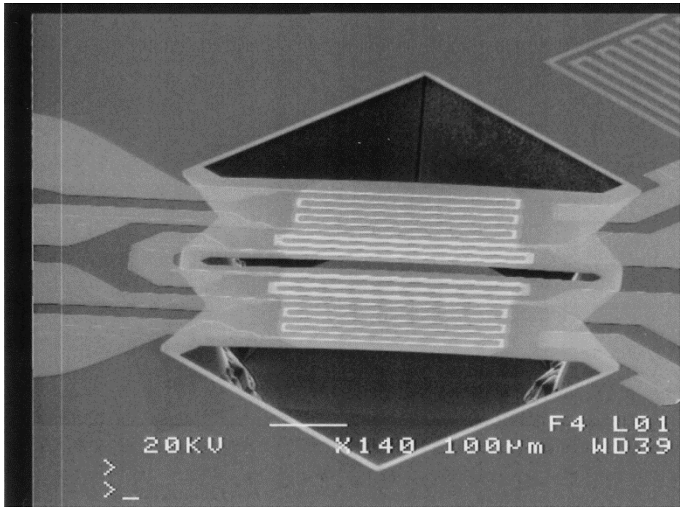
Thanks to Marco Bomben

Anisotropic TMAH Etching

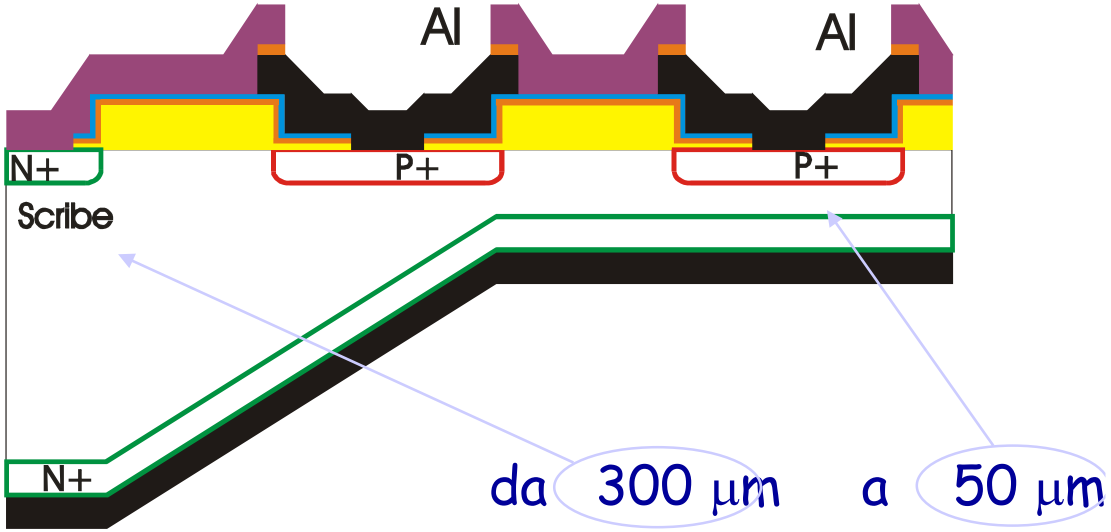
tetramethylammonium hydroxide

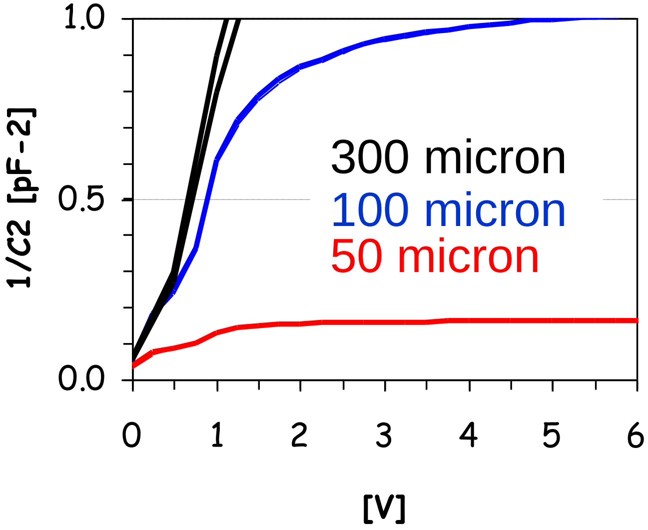
Application

Air Flow Sensor



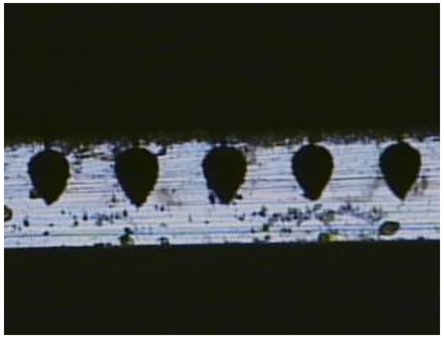
Thin detectors

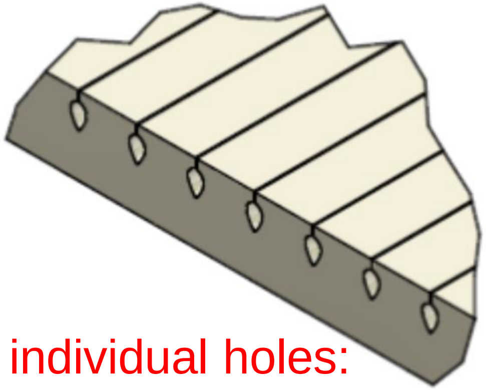




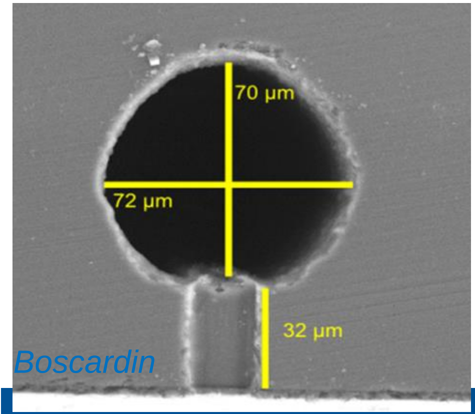
Silicon buried channels for detector cooling

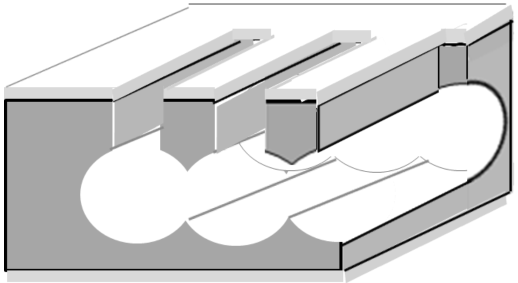
Channels made with individual holes:
The section is determined by the DRIE process, the length by the layout



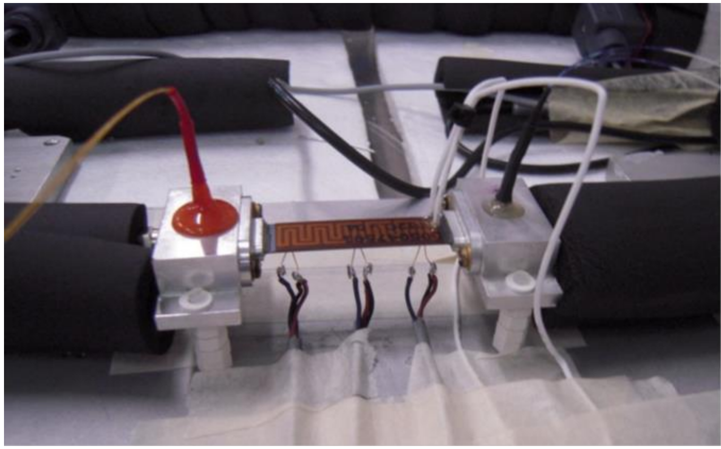


Channels realized as a sum of individual holes:
The section is determined by the process and by layout, the length by the geometry





Experimental results made in the lab TFD INFN of Pisa show a general compliance of the temperature of the sample to the specific fixed at least up to a power of about 2.5 W/cm^2.



grazie