Workshop Dipartimento di Ingegneria – INFN Perugia
11 gennaio 2021

Sensori ed Elettronica per la Fisica delle alte energie

D. Passeri, G.M. Bilei

Physics & Electronics

- ✓ From an informal meeting about 25 years ago...
- ✓ (Micro)Electronics Tools & Methods for Physics (HEP) applications?

ELSEVIER

Nuclear Physics B (Proc. Suppl.) 54B (1997) 293–298

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

Numerical Simulation of Silicon Microstrip Detectors

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In this work, the application of the general-purpose device simulator HFIELDS to the analysis of silicon microstrip detectors is presented. In the framework of CMS collaboration, a comprehensive device characterization has been performed by means of steady-state (DC) and small-signals (AC) numerical analyses. The study of charge collection dynamics has been carried out as well, by means of transient analysis. Simulation results exhibit a good agreement with literature data, and allow for detailed insights of device behavior. This makes it possible to investigate device-performance sensitivity to fabrication and environmental parameters and highlights potential applications of numerical analysis as a device design and optimization aid.

1. INTRODUCTION

Microelectronics techniques, originally aimed at producing small and dense integrated circuits, have been exploited by the particle physicist community to obtain large-area, high-resolution, position-sensitive radiation detectors. Such devices, although relying on very simple operating principles, still pose some challenging design problems, mostly related to their performance in terms of S/N ratio and radiation hardness. The integration of on-board, signal-processing circuitry on high-resistivity silicon chips represents a further, non-trivial issue being faced in this field.

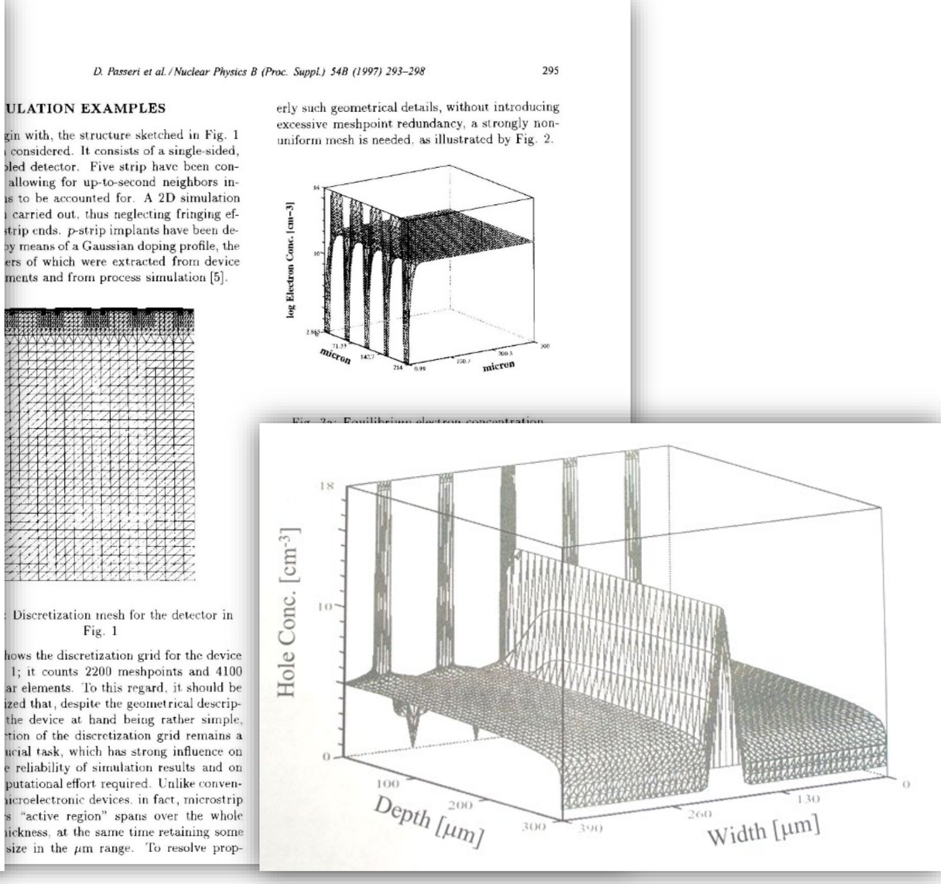
Technology CAD tools (process and device simulation) are being routinely used to design "conventional" integrated circuits: they have instead seldom been applied to the design and optimization of microstrip detectors (see, e.g., [1]). A number of advantages can be obtained by exploiting TCAD techniques to design such devices:

- prototipization time and costs can be significantly reduced
- numerical simulation allows for inspecting "internal" device behavior, making informations available which can hardly be extracted from actual device measurements (e.g., field and mobile charge distribution). "Virtual" experiments can be carried out under unpractical conditions, allowing for cause-effect relationships to be more easily assessed. This fosters the comprehension and interpretation of many operating details and allows for a close link to be established between fabrication process parameters and device electrical response.

In this paper, we preliminarily report on the application of a general-purpose device simulator (HFIELDS [2]) to the analysis of silicon microstrip detectors being developed in the framework of CMS collaboration. Reliable predictions can be obtained from device simulation, provided detailed knowledge of physical and geometrical device structure is available. Such a knowledge can be usually extracted from fabricated device measurements, as well as from numerical process simulation. Suitable physical models are also needed, embedded into the device simulator code. With particular reference to microstrip detector, a key role is played by the charge distribution within oxide and at the $Si - SiO_2$ interface, as well as by recombination dynamics.

In Sect. 2 below, the basic features of the simulation code we used are reviewed, and some of the specific questions posed by the simulation of radiation detectors are addressed. A few, preliminary simulation results are illustrated in Sect. 3, whereas conclusions and future work plans are discussed in Sect. 4.

PII: S0920-5632(97)00125-4



D. Passeri et al. / Nuclear Physics B (Proc. Suppl.) 54B (1997) 293–298 295

ULATION EXAMPLES

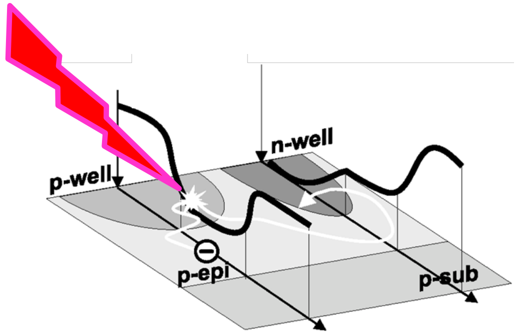
gin with, the structure sketched in Fig. 1 considered. It consists of a single-sided, led detector. Five strip have been con- allowing for up-to-second neighbors in- s to be accounted for. A 2D simulation carried out, thus neglecting fringing ef- trip ends. p-strip implants have been de- y means of a Gaussian doping profile, the ers of which were extracted from device ments and from process simulation [5].

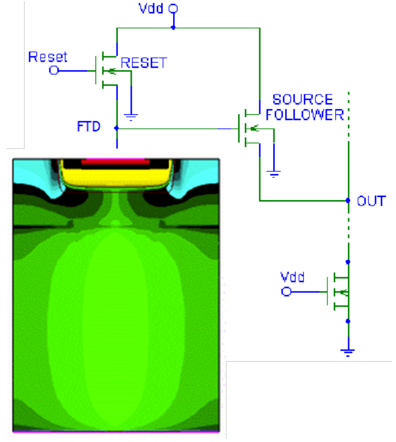
Discretization mesh for the detector in Fig. 1

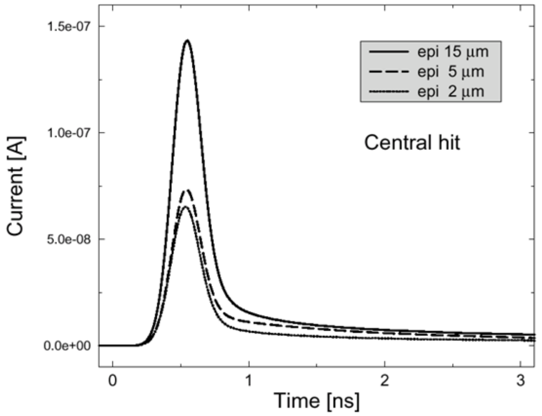
hows the discretization grid for the device 1; it counts 2200 meshpoints and 4100 ar elements. To this regard, it should be ized that, despite the geometrical descrip- the device at hand being rather simple, tion of the discretization grid remains a ucial task, which has strong influence on e reliability of simulation results and on putational effort required. Unlike conven- icroelectronic devices, in fact, microstrip s "active region" spans over the whole ickness, at the same time retaining some size in the μm range. To resolve properly such geometrical details, without introducing excessive meshpoint redundancy, a strongly non-uniform mesh is needed, as illustrated by Fig. 2.

Physics & Electronics (2)

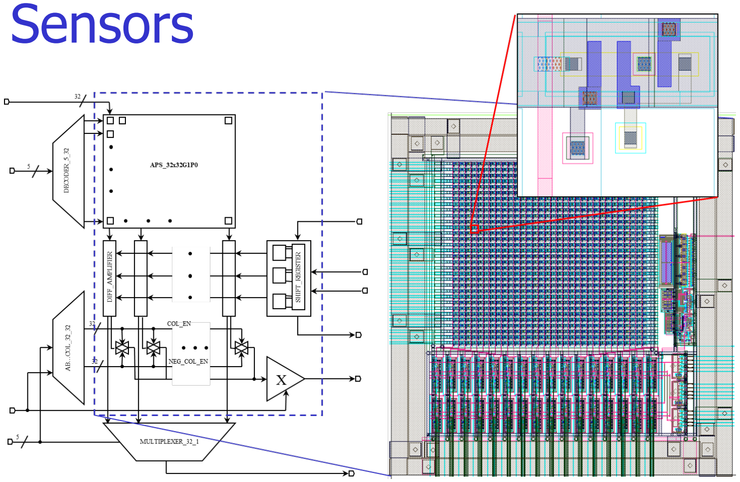
- ✓ TCAD Modelling of the interaction between radiation (particle) & semiconductor devices.

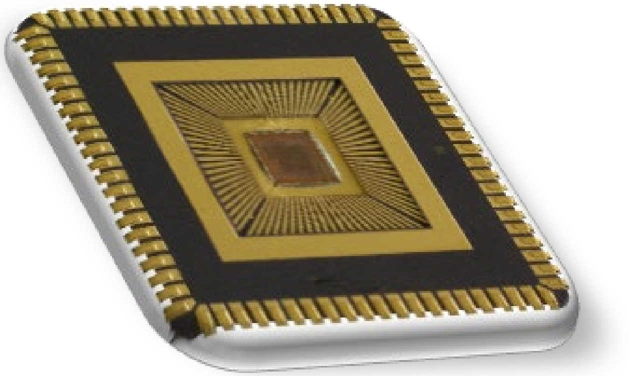






- ✓ Read-out electronics integrated within sensor -> CMOS Active Pixel Sensors

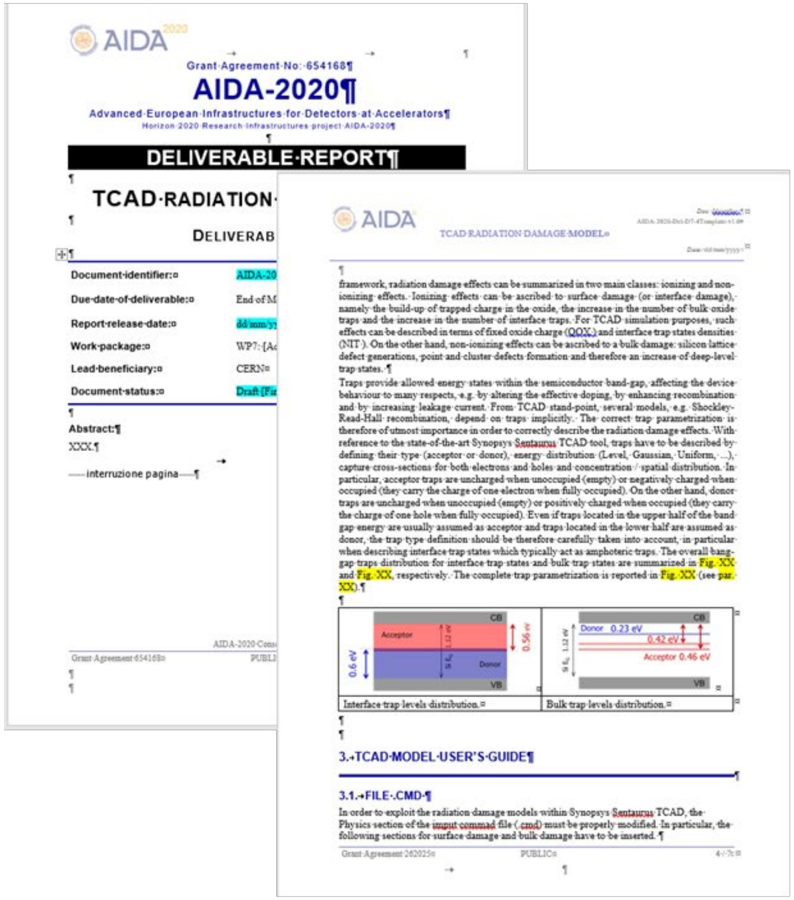




The RAPS01 chip: first Italian CMOS Active Pixel Sensor for HEP (UMC 0.18um)

Physics & Electronics (3)

- ✓ Radiation damage effects in semiconductor devices: TCAD “University of Perugia” model.



AIDA 2020

Grant Agreement No: 654168

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDA-2020

DELIVERABLE REPORT

TCAD RADIATION

DELIVERAB

Document identifier:	AIDA-20
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Report release date:	dd/mm/y
Work package:	WP7: [Ac
Lead beneficiary:	CERN
Document status:	Draft [Fi

Abstract:

XXX.

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AIDA-2020-Cons

Grant Agreement 654168 PUBLI

AIDA TCAD RADIATION DAMAGE MODEL

framework, radiation damage effects can be summarized in two main classes: ionizing and non-ionizing effects. Ionizing effects can be ascribed to surface damage (or interface damage), namely the build-up of trapped charge in the oxide, the increase in the number of bulk oxide traps and the increase in the number of interface traps. For TCAD simulation purposes, such effects can be described in terms of fixed oxide charge (QOX) and interface trap states densities (NIT). On the other hand, non-ionizing effects can be ascribed to a bulk damage: silicon lattice defect generations, point and cluster defects formation and therefore an increase of deep-level trap states.

Traps provide allowed energy states within the semiconductor band-gap, affecting the device behaviour to many respects, e.g. by altering the effective doping, by enhancing recombination and by increasing leakage current. From TCAD stand-point, several models, e.g. Shockley-Read-Hall recombination, depend on traps implicitly. The correct trap parametrization is therefore of utmost importance in order to correctly describe the radiation damage effects. With reference to the state-of-the-art Synopsys Sentaurus TCAD tool, traps have to be described by defining their type (acceptor or donor), energy distribution (Level, Gaussian, Uniform, …), capture cross-sections for both electrons and holes and concentration / spatial distribution. In particular, acceptor traps are uncharged when unoccupied (empty) or negatively charged when occupied (they carry the charge of one electron when fully occupied). On the other hand, donor traps are uncharged when unoccupied (empty) or positively charged when occupied (they carry the charge of one hole when fully occupied). Even if traps located in the upper half of the band gap energy are usually assumed as acceptor and traps located in the lower half are assumed as donor, the trap type definition should be therefore carefully taken into account, in particular when describing interface trap states which typically act as amphoteric traps. The overall band-gap traps distribution for interface trap states and bulk trap states are summarized in Fig. XX and Fig. XX, respectively. The complete trap parametrization is reported in Fig. XX (see par. XX).

Interface trap levels distribution.	Bulk trap levels distribution.

3. TCAD MODEL USER'S GUIDE

3.1. FILE .CMD

In order to exploit the radiation damage models within Synopsys Sentaurus TCAD, the Physics section of the imput commad file (.cmd) must be properly modified. In particular, the following sections for surface damage and bulk damage have to be inserted.

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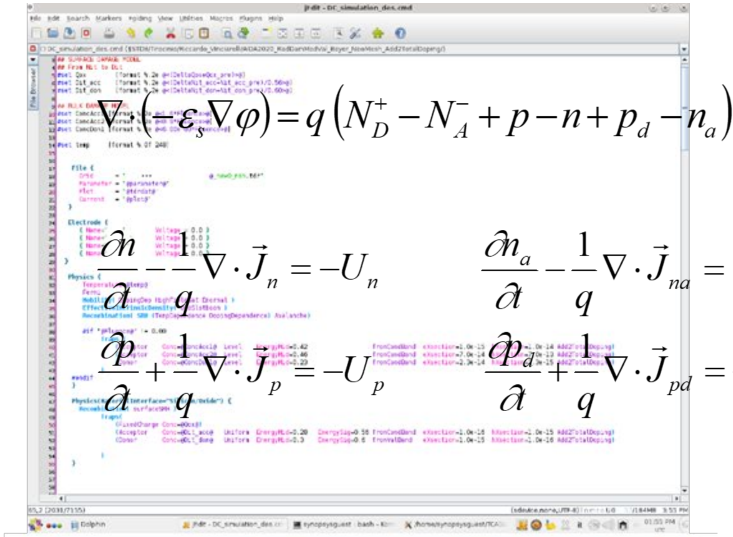
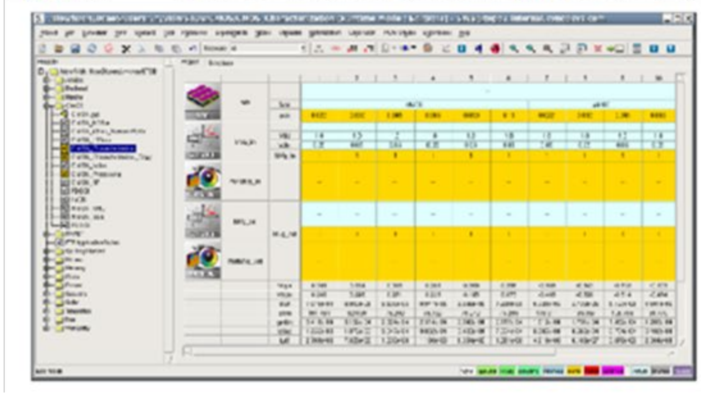


$$\nabla\cdot\left(-\varepsilon_s\nabla\varphi\right)=q\left(N_D^+-N_A^-+p-n+p_d-n_a\right)$$

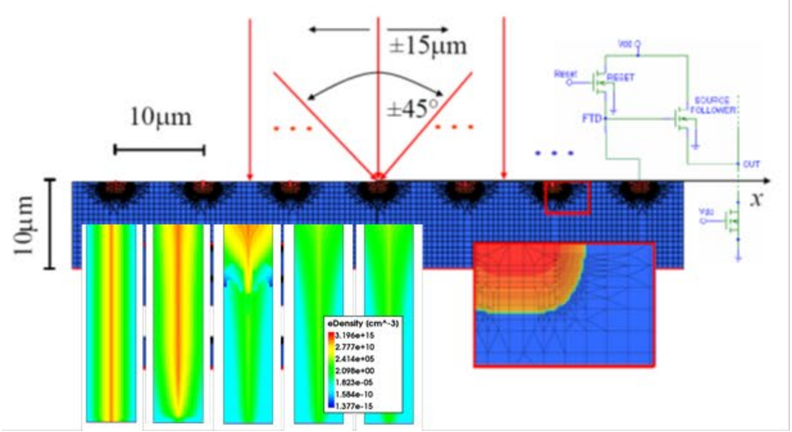
$$\frac{\partial n}{\partial t}-\frac{1}{q}\nabla\cdot\vec{J}_n=-U_n \qquad \frac{\partial n_a}{\partial t}-\frac{1}{q}\nabla\cdot\vec{J}_{na}=-U_{na}$$

$$\frac{\partial p}{\partial t}+\frac{1}{q}\nabla\cdot\vec{J}_p=-U_p \qquad \frac{\partial p_d}{\partial t}+\frac{1}{q}\nabla\cdot\vec{J}_{pd}=-U_{pd}$$

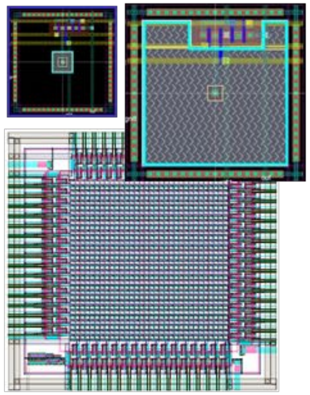


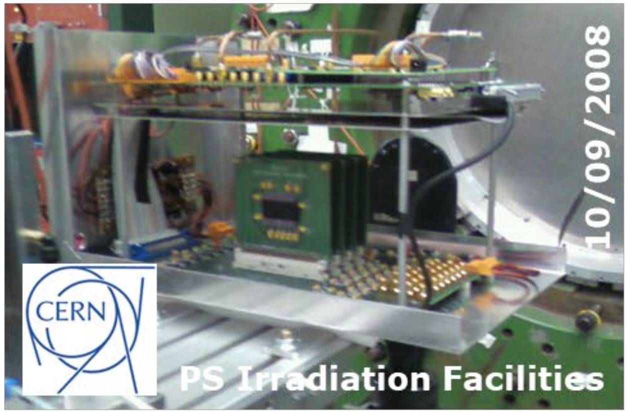
Micro/Nanoelectronics - R&D activities

Numerical Analysis and Physical Modeling of solid-state devices.

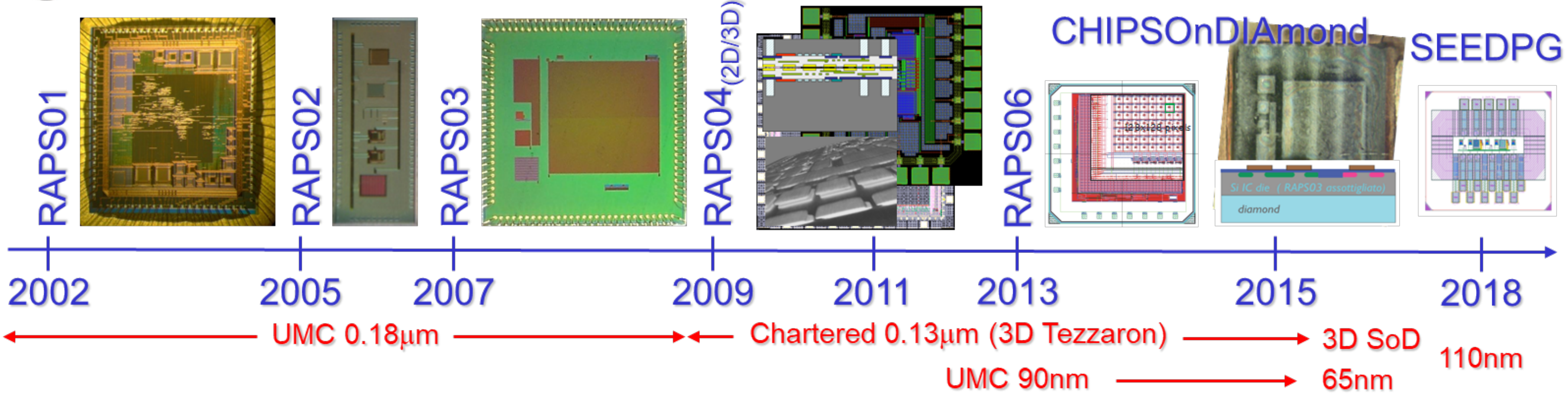


VLSI Design and Characterization of integrated circuits: CMOS Active Pixel Sensors.





UNIPG – Electronics VLSI Timeline

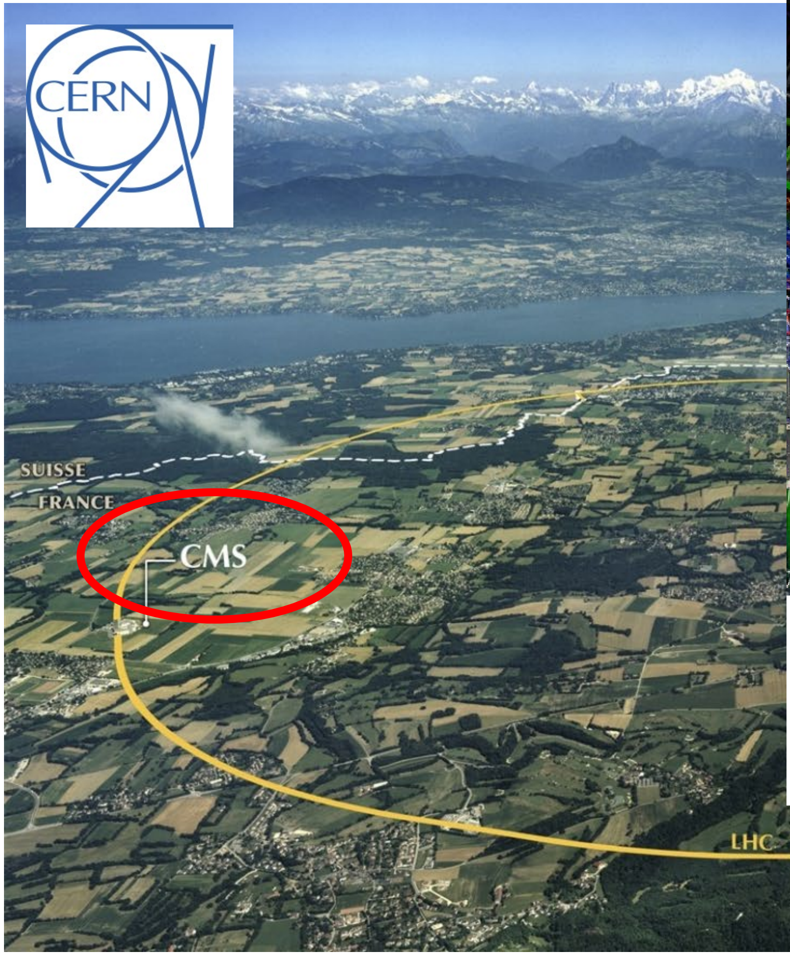


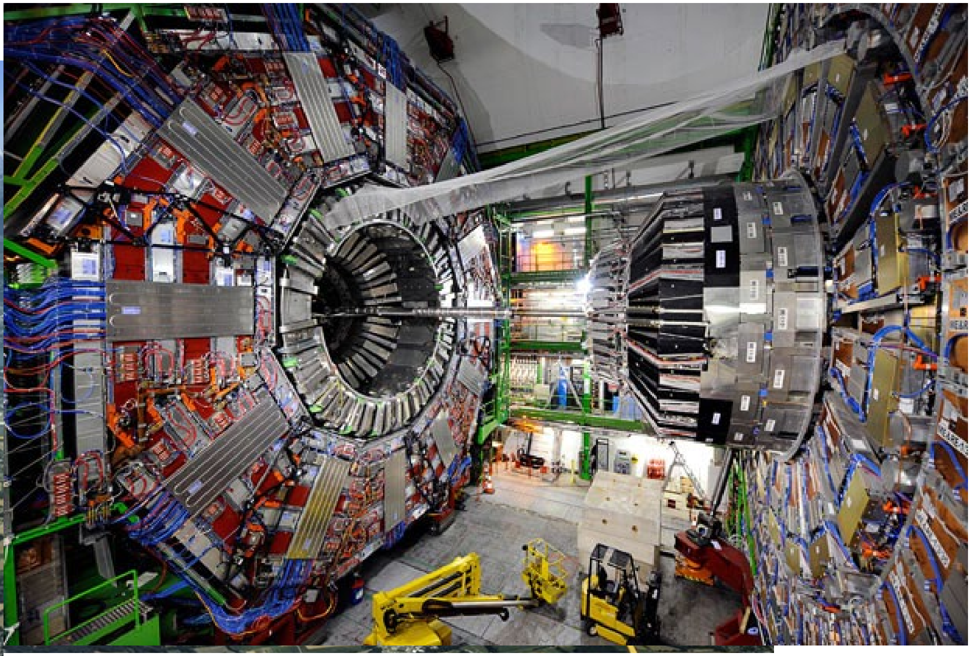
RAPS01 — 2002
RAPS02 — 2005
RAPS03 — 2007
RAPS04(2D/3D) — 2009
2011
RAPS06 — 2013
CHIPSOnDIAmond — 2015
SEEDPG — 2018

UMC 0.18µm
Chartered 0.13µm (3D Tezzaron) → 3D SoD
UMC 90nm → 65nm
110nm

The CERN (Geneva, Switzerland) & Perugia…

The world's largest and most complex scientific instruments to study the basic constituents of matter.



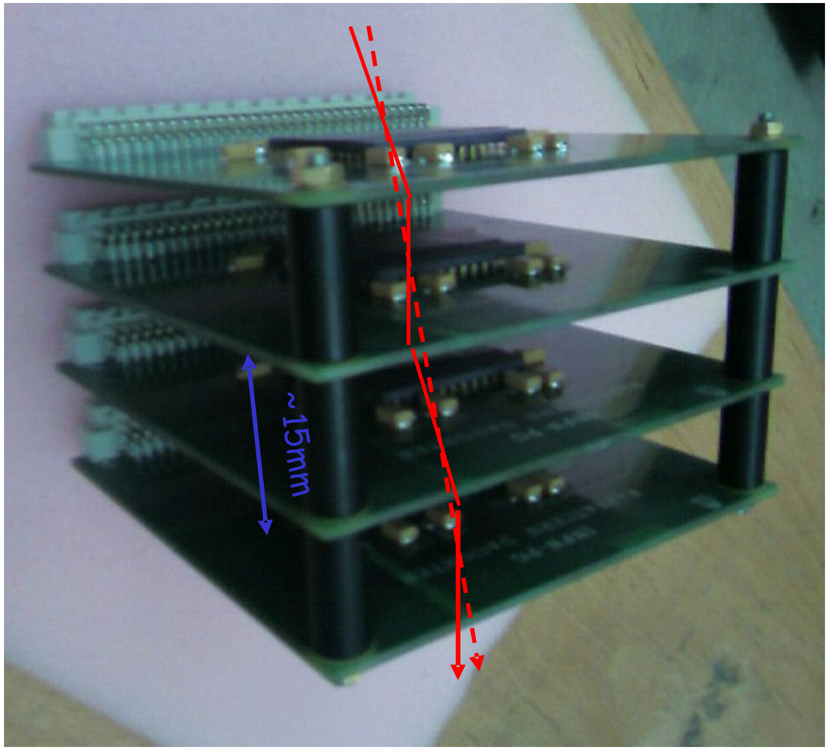


CMS 220 mq^2 Si detectors (Hamamatsu)
- Rad-Hard design solution @Perugia Model

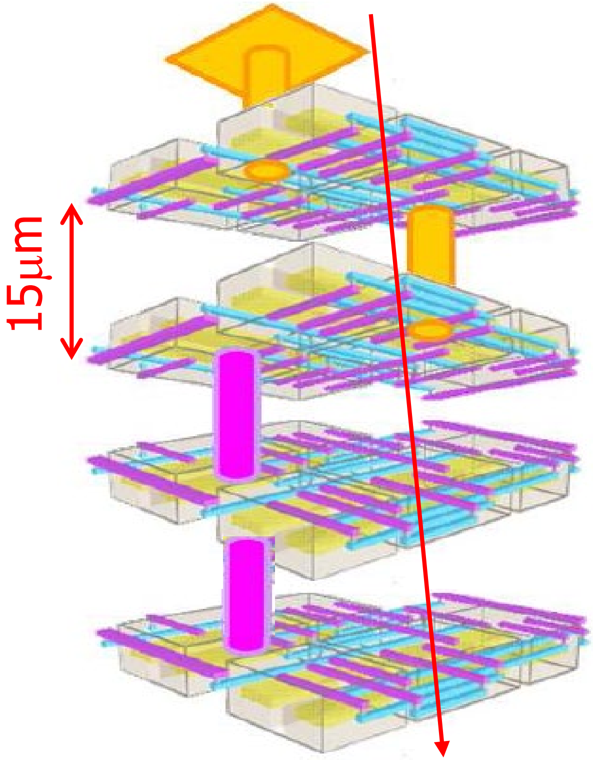
RD53 Read-Out Electronics 65nm CMOS

3D Vertical Scale CMOS Active Pixel Sensors

- ✓ 3D monolithically-stacked CMOS Active Pixel Sensor detector for single ionizing particle trajectory and momentum identification.



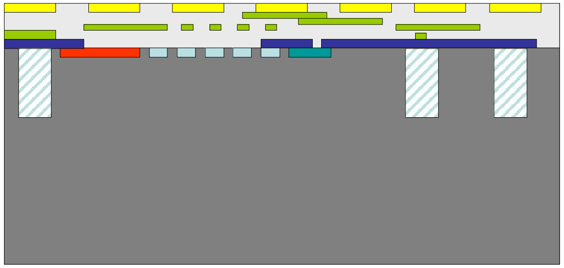
Stack of separate multi-layer CMOS APS detectors. Worries: multiple scattering and material budget…

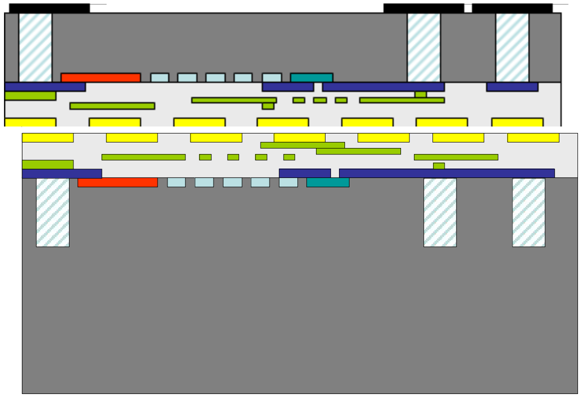


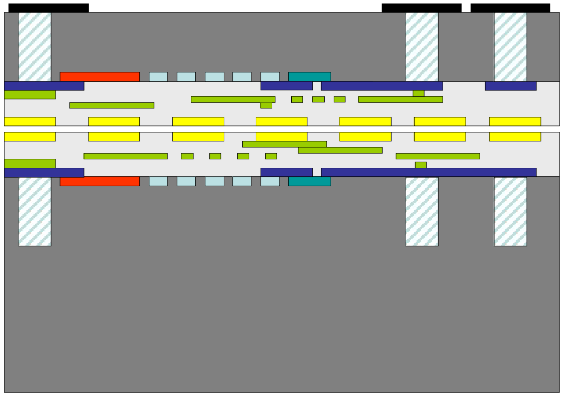
Stack of monolithically integrated (vertical scale or 3D) CMOS APS detectors.

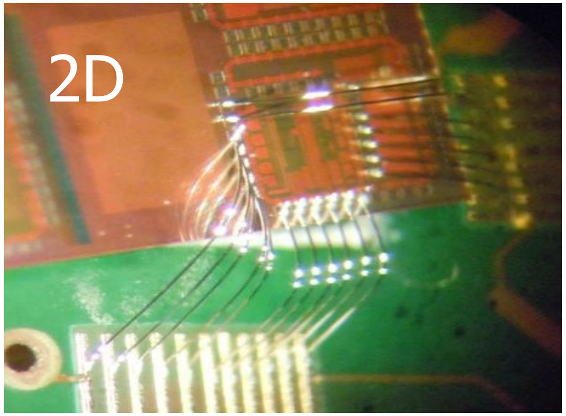
The 3D chip structures

- ✓ Tezzaron/GlobalFoundries
  3D-IC Integrated 2-tier stack
  130nm CMOS

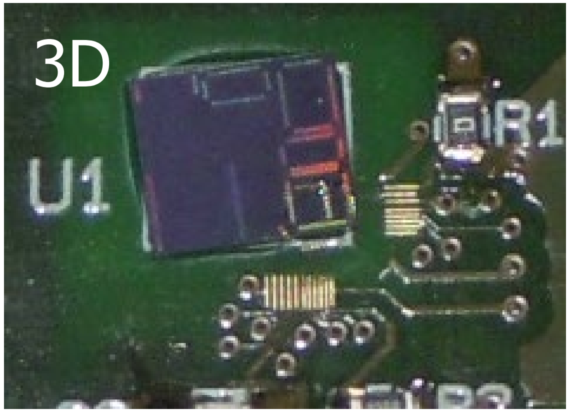




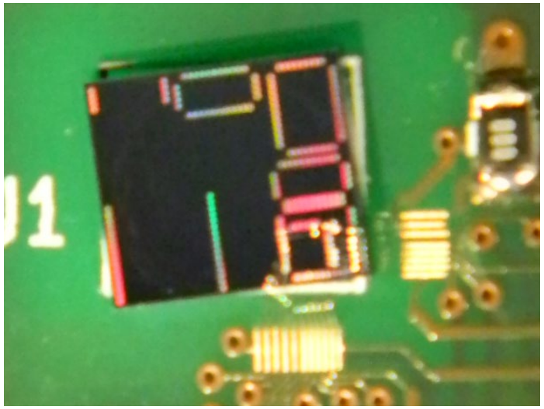




2D



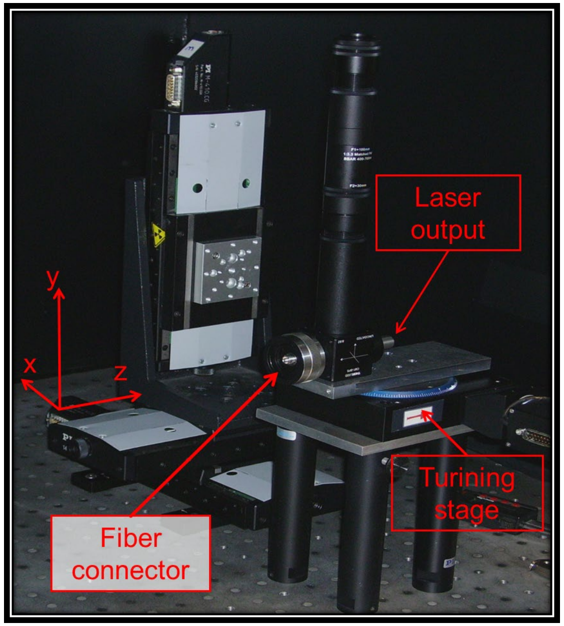
3D Not Aligned

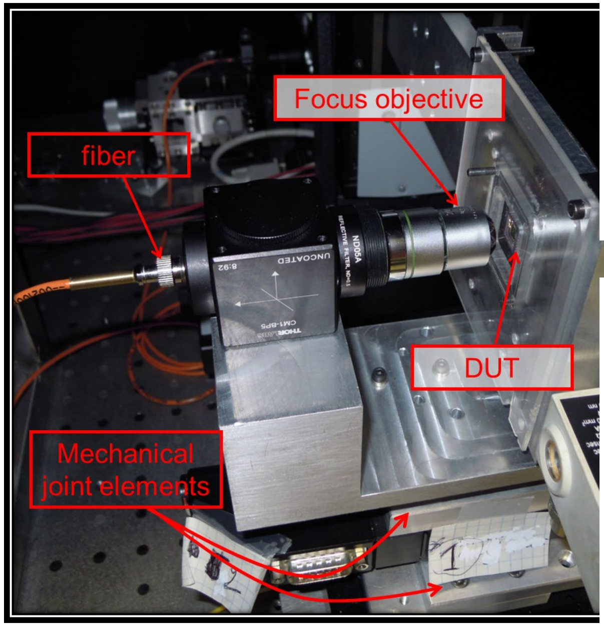


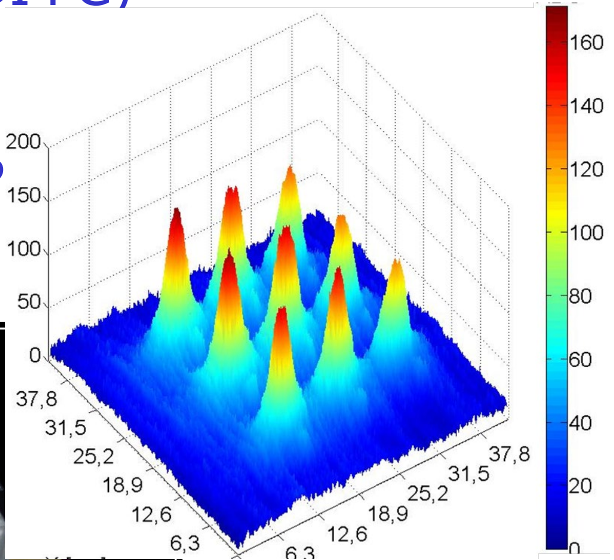
3D Aligned
(Ziptronix/Tezzaron).

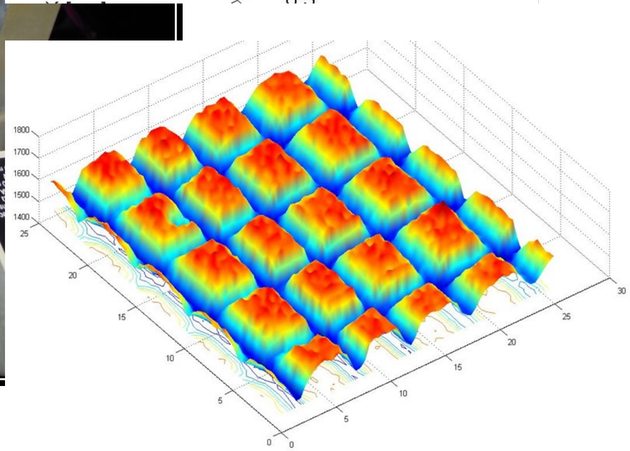
Lab Facilities (@DI, @INFN PG)

- ✓ Advanced **TCAD & VLSI Design** Laboratory (@DI PG)
  - 2 PowerEdge R640 Server Dell + 8 PCs
- ✓ **Optical Workbench** IR, UV, VIS laser (@INFN P with μ-focusing and μ-positioning capabilities.



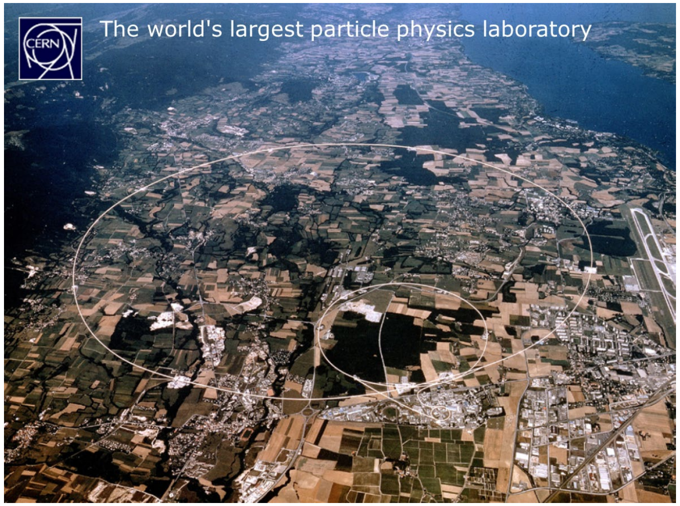




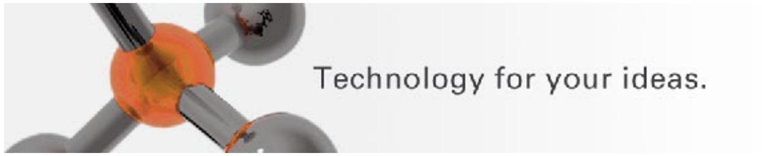


Collaborations

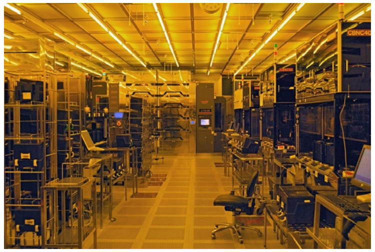
- ✓ CERN (Geneve, Switzerland)



- ✓ Micron (USA), LFoundry, Micron®



LFoundry



FONDAZIONE BRUNO KESSLER

- ✓ Fondazione Bruno Kessler (FBK)

- ✓ Rutherford Appleton Laboratory (UK)

UKRI Science and Technology Facilities Council

INFN & DI(EI): some numbers…

- ✓ More than 150 scientific papers on International Journals.
- ✓ More than 50 contributions to International Conferences.
- ✓ More than 80 among B.Sc., M.Sc., Ph.D. Thesis.
- ✓ More than 10 Ph.D. Students (CERN doctoral, CERN staff).
- ✓ Joint Organization: Conferences, Workshops, …
- ✓ AR grants


1688 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 48, NO. 5, OCTOBER 2001

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 53, NO. 5, OCTOBER 2006

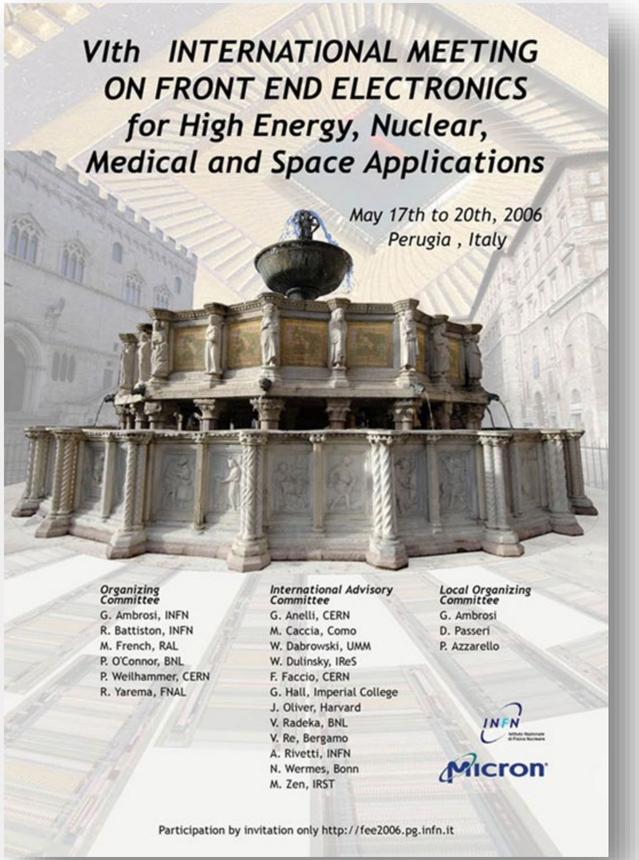
Numerical Simulation of Radiation Damage in p-Type and n-Type FZ Silicon Detectors

Interdefect Charge Exc… Detectors at Cryo…

Barry MacEvoy, Attilio Santocchia, Geoff Hall, Fra…

DANIEL RICCI
Section leader of Fibre Optics and Cabling - Engineering

STEFANO MEROLI
Ingegnere Elettronico con Dottorato in Fisica che lavora al CERN. Divulgatore scientifico.
SPEAKER
FISICA


VIth INTERNATIONAL MEETING ON FRONT END ELECTRONICS for High Energy, Nuclear, Medical and Space Applications

May 17th to 20th, 2006
Perugia , Italy

Organizing Committee	International Advisory Committee	Local Organizing Committee
G. Ambrosi, INFN	G. Anelli, CERN	G. Ambrosi
R. Battiston, INFN	M. Caccia, Como	D. Passeri
M. French, RAL	W. Dabrowski, UMM	P. Azzarello
P. O'Connor, BNL	W. Dulinsky, IReS	
P. Weilhammer, CERN	F. Faccio, CERN	
R. Yarema, FNAL	G. Hall, Imperial College	
	J. Oliver, Harvard	
	V. Radeka, BNL	
	V. Re, Bergamo	
	A. Rivetti, INFN	
	N. Wermes, Bonn	
	M. Zen, IRST	

Participation by invitation only http://fee2006.pg.infn.it

Main Projects

- ✓ INFN (RAPS, SHARPS, VIPIX, SEED, TIMESPOT, …)
  - TimeSPOT

- ✓ MIUR MIUR MINISTERO DELL' ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA
  - 4DInSiDe

- ✓ EU European Commission
  - Horizon 2020 (Advanced European Infrastructures for Detectors at Accelerators - AIDA 2020), Horizon Europe (AIDA INNOVA)

AIDA 2020

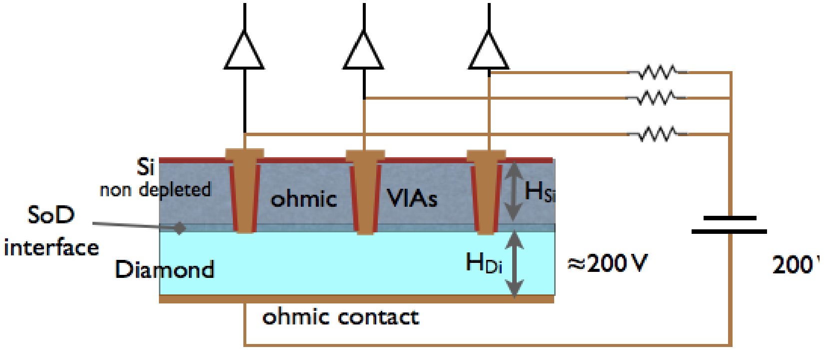
Workshop Dipartimento di Ingegneria – INFN Perugia
11 gennaio 2021

On going activities

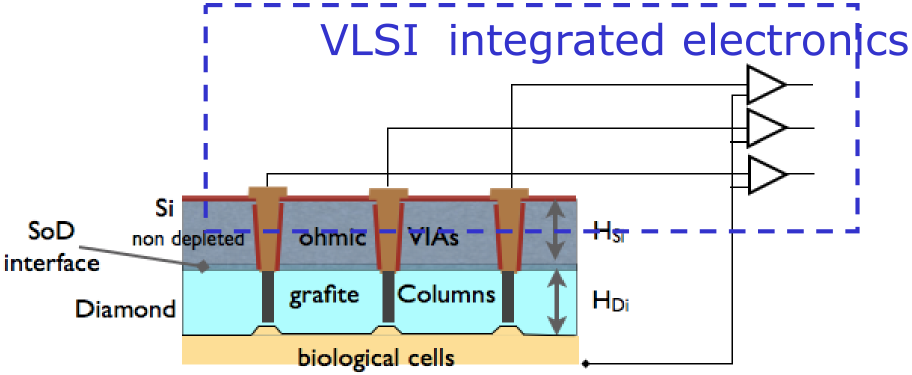
D. Passeri, G.M. Bilei

CHIPS On DIAmond

- ✓ Novel silicon-on-diamond (SoD) material obtained by laser processing.



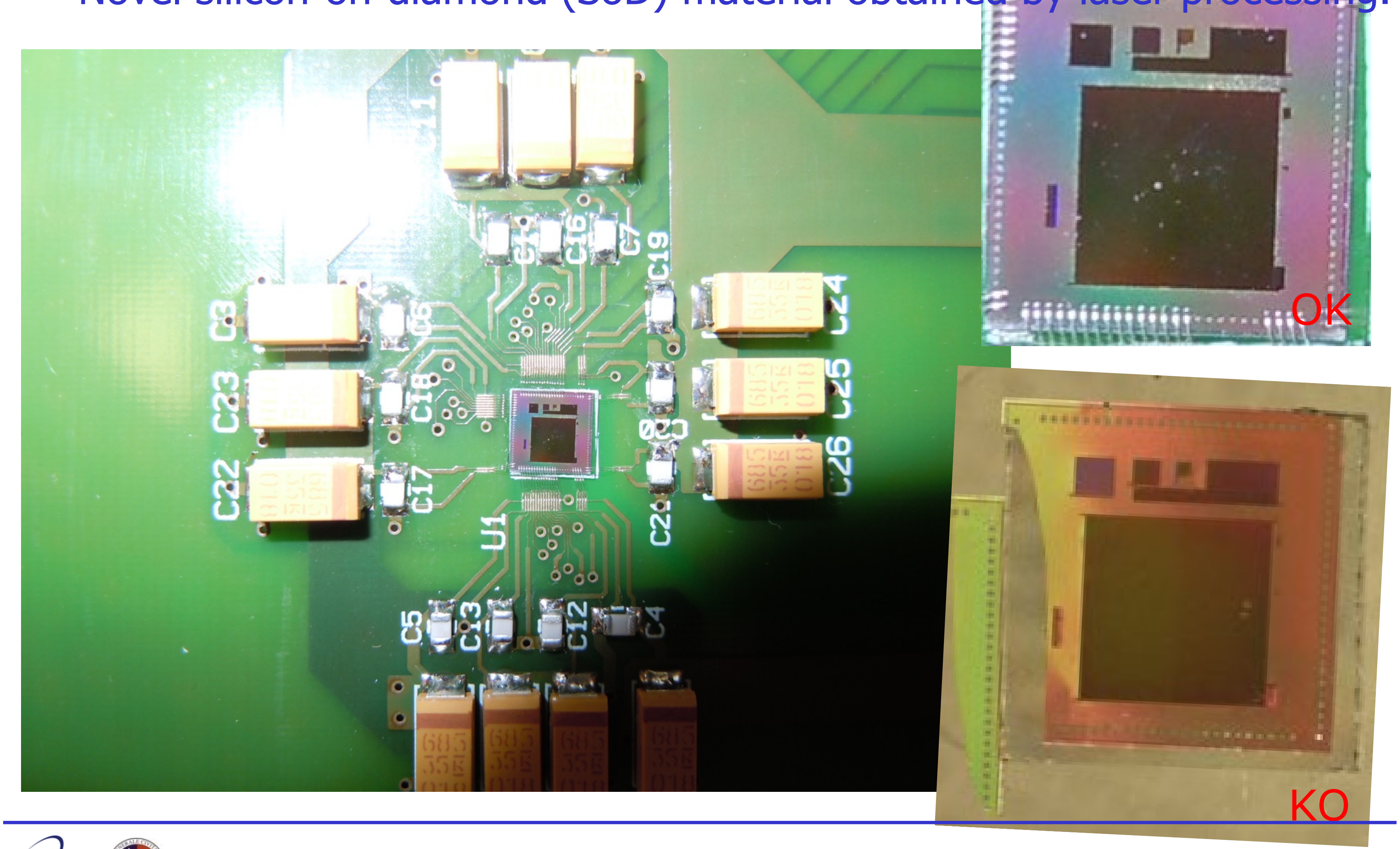
SoD as particle detector.



SoD as bio-sensor.

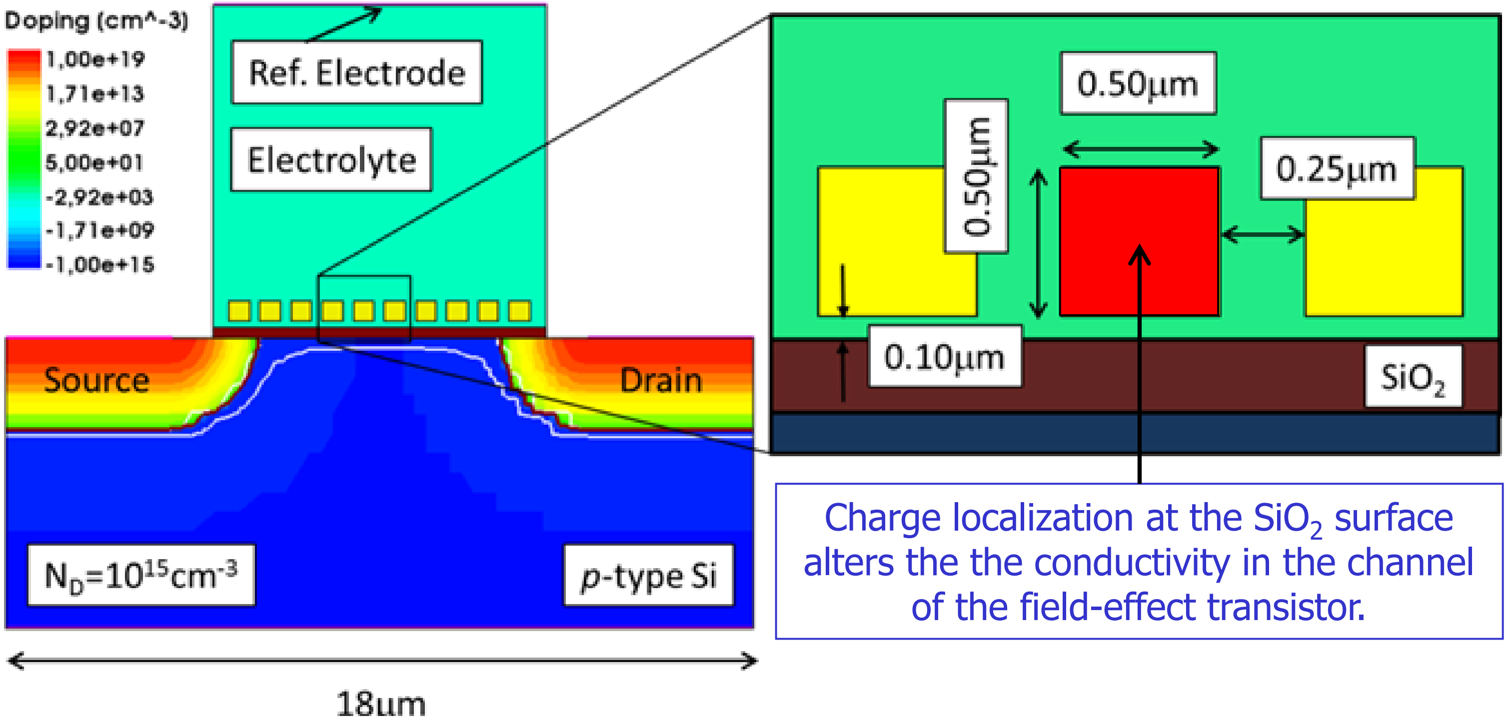
CHIPS On DIAmond (2)

- ✓ Novel silicon-on-diamond (SoD) material obtained by laser processing.



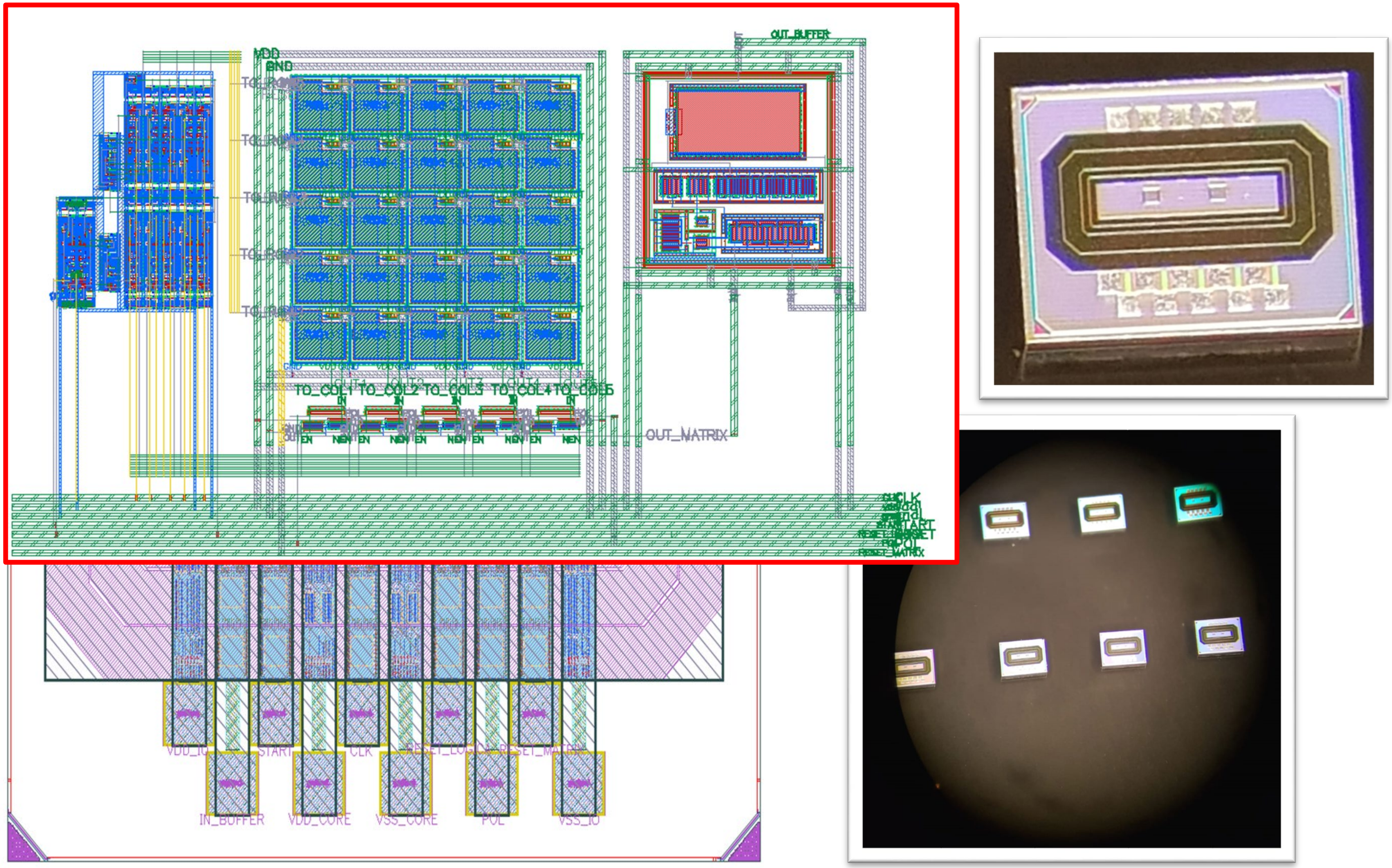
Biosensori - BioFET

- ✓ BioFET operating principle: if target molecules bind to the receptors, a change in the surface charge density occurs.
- ✓ This change alters the (electrical) potential in the semiconductor and thus the conductivity in the channel of the field-effect transistor.



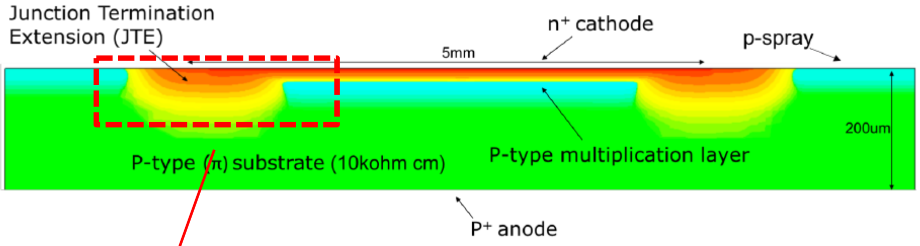
Charge localization at the SiO_2 surface alters the the conductivity in the channel of the field-effect transistor.

CMOS Active Pixel Sensor – SEED PG



Sensori di radiazione LGAD

- ✓ Low Gain Avalanche Diode (LGAD).
- ✓ Sensori di radiazione allo stato dell’arte basati su controllo del guadagno (moltiplicazione di carica).
- ✓ Effetti del danneggimento da radiazione.



DC analysis: **Electric field**

- DC polarization
  - ○ *n+ cathode*: 0 V
  - ○ *p+ anode*: **-400 V**

C1 => cut X = -5 µm
C2 => cut X = -35 µm

Abs(ElectricField-V) (V*cm^-1)
9.48e+04
7.90e+04
6.32e+04
4.74e+04
3.16e+04
1.58e+04
6.36