FONDAZIONE
BRUNO KESSLER
FUTURE BUILT
ON KNOWLEDGE

Development of tracking and timing sensors and imagers at FBK

Gianluigi Casse
Fondazione Bruno Kessler
FBK-CMM Director

LBL, 12th February 2020

casse@fbk.eu
https://cmm.fbk.eu/it/people/detail/gianluigi-casse

ABSTRACT

The Fondazione Bruno Kessler (FBK) in Trento (Italy) has a 25 year long activity in developing sensors and imagers for experimental physics and applications. It started with a clean room designed to produce CCD cameras for robotics on 4” wafers, and it evolved to today’s infrastructure that makes high end, niche devices for ground and space based experiments (SDD, SSD, PD, 3D column sensors). The requirements on sensors have evolved in a spectacular way with time (on granularity, speed, radiation tolerance, ecc) and FBK has been one of the actors in the fast race to improved performance.

Novel approaches have also emerged, like the progressive substitution of Photo Multipliers Tubes in a number of applications, and the use of tracking with accurate timing information (4D tracking) in particle physics. In this presentation, I will show FBK’s state-of-the-art and future perspectives in the design and development of sensors and imagers for scientific experiments and applications.

FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE

7
research centers

400+
researchers

100+
PhD students from 25 different Countries

200+
scientific publications (2018)

500+
contribution in conferences (2018)

39
patents

43
new EU projects (2018)

20
joint labs and co-located companies

27
innovative startups

Based on **scientific excellence** we provide **unique innovation capabilities** to institutional and industrial partners.

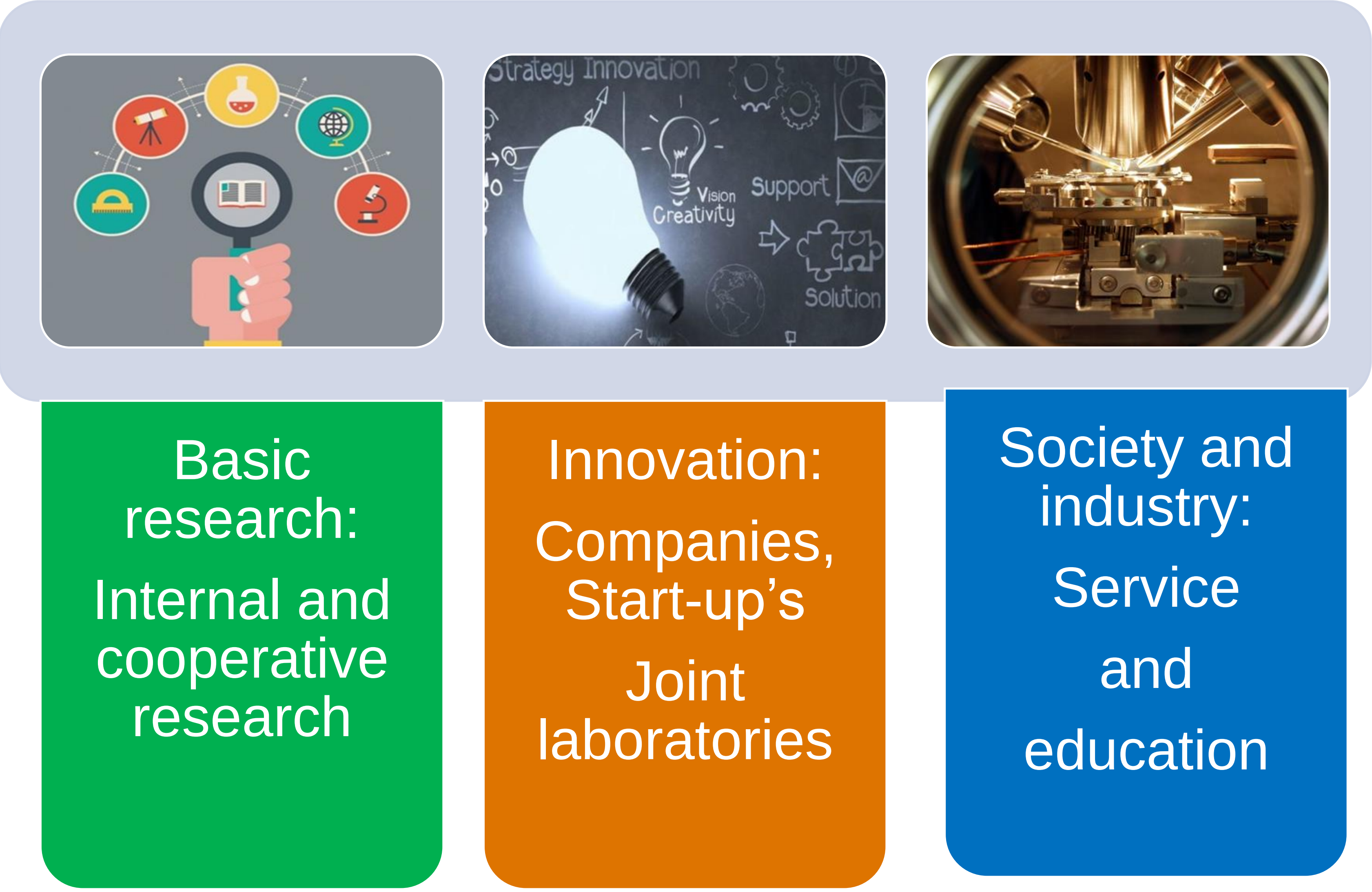
FBK-CMM
CENTRE FOR MATERIALS AND MICROSYSTEMS

More than 130 people between researchers, engineers and PhD students.

CAPABILITIES

- Wide base of complementary competences
- know-how and state of art research infrastructure
- outstanding results in both research and innovation fields.

Photonics
CMOS sensors, imagers
MEMS, Bio-Mems
Nanotechnologies
Innovative Materials and Interfaces
Micro and Nano devices
Energy and sustainable future
Quantum Technologies



Basic research:

Internal and cooperative research

Innovation:

Companies, Start-up’s

Joint laboratories

Society and industry:

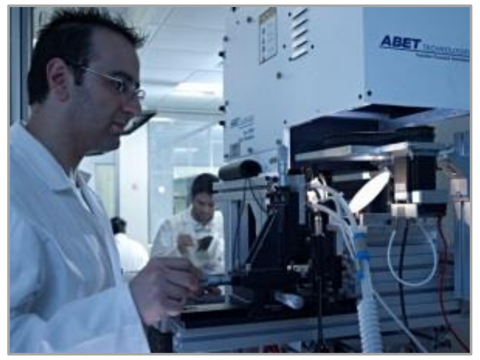
Service

and

education

CAPABILITIES





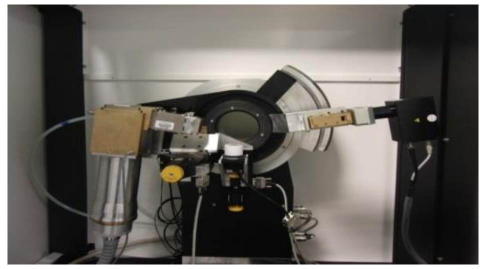

6” Microfabrication Area
Clean Room Detectors

Clean Room MEMS

Testing Area

Integration Area



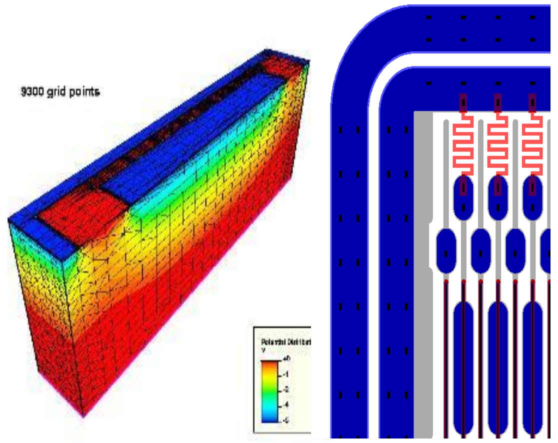
Analytical facility:

- D-SIMS Dynamic Secondary Ion Mass Spectrometry
- ToF-SMS Time of Flight Secondary Ion Mass Spectrometry
- XPS X-Ray Photoelectron Spectroscopy
- SEM-EDX-EBSD Scanning Electron Microscopy
- AFM Atomic Force Microscopy
- XRD/XRF X-ray Diffraction / X ray Fluorescence
- Raman spectroscopy

Overview of sensor activities

Detectors
Full Custom FBK Technology

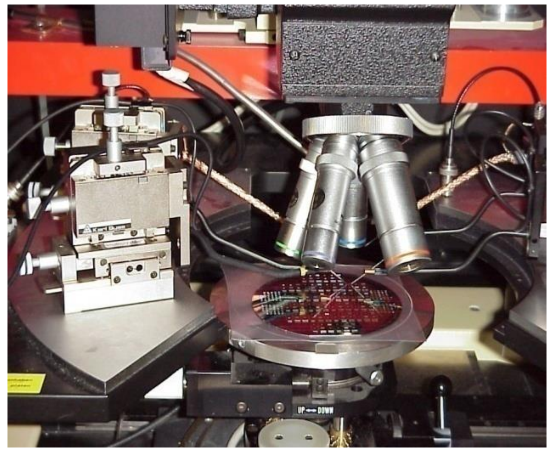
Image Sensors
Standard CMOS Technologies



Modeling & design

Custom production

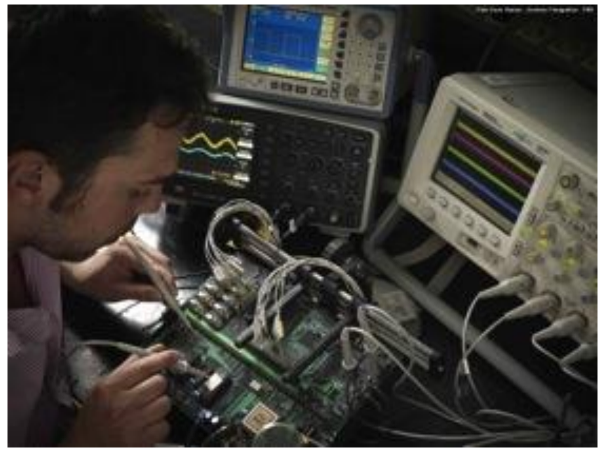
Testing



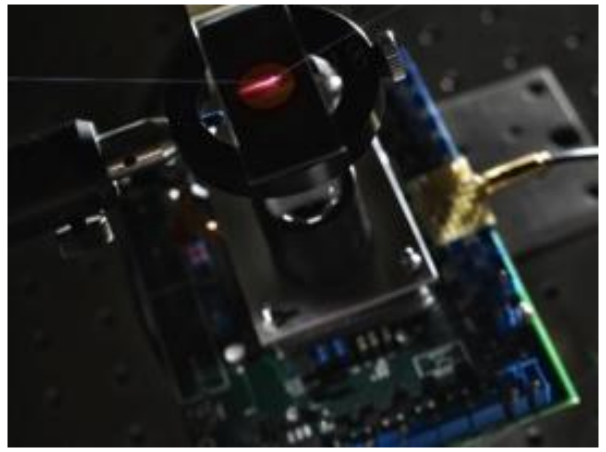
Analog and Digital IC Design

65nm-350nm CMOS Fab

EO Testing



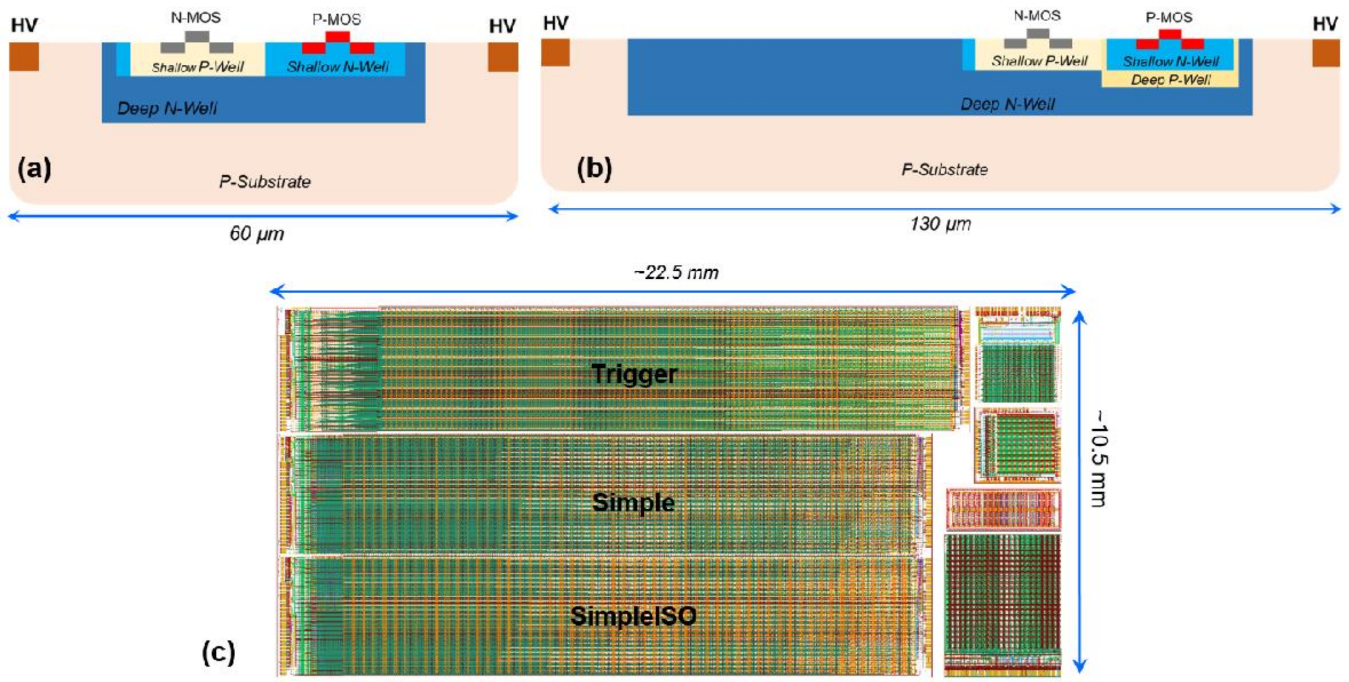
Prototyping

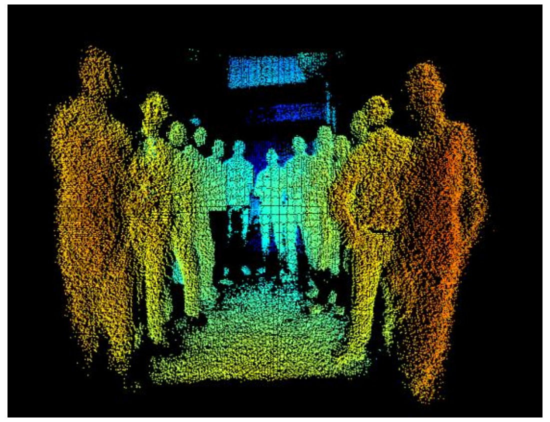


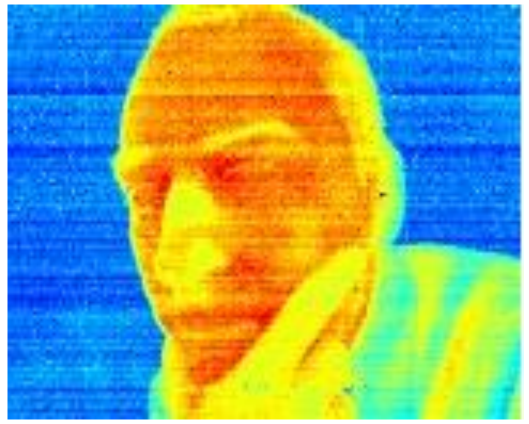
CMOS Sensors and imagers

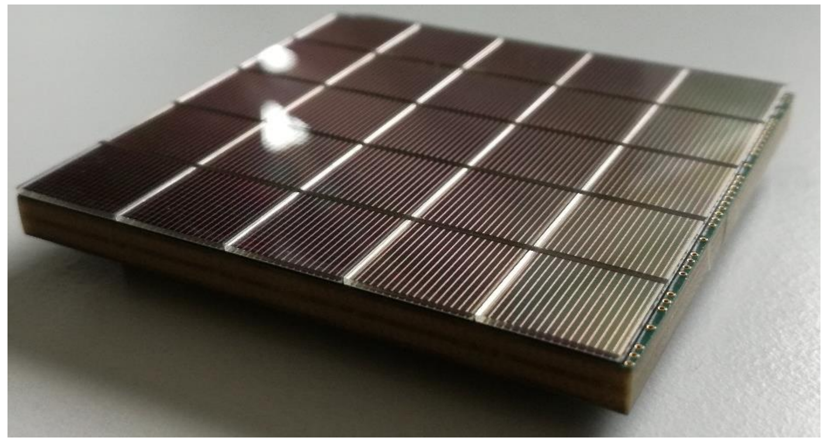
- ➢ Digital SiPM
- ➢ Pixelated HV-CMOS sensors (no bump-bonding, high resolution, rad-hard)
- ➢ Low power vision
- ➢ Multi-spectral and THz imagers
- ➢ SPAD Time resolved imaging
- ➢ TOF (3D) imaging

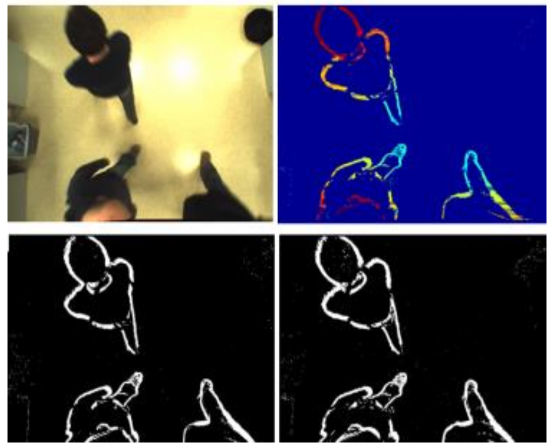
Process design

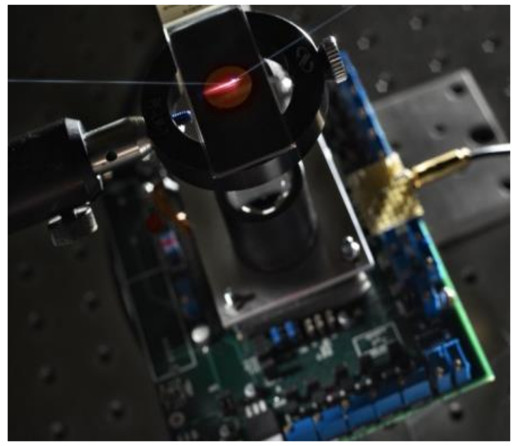






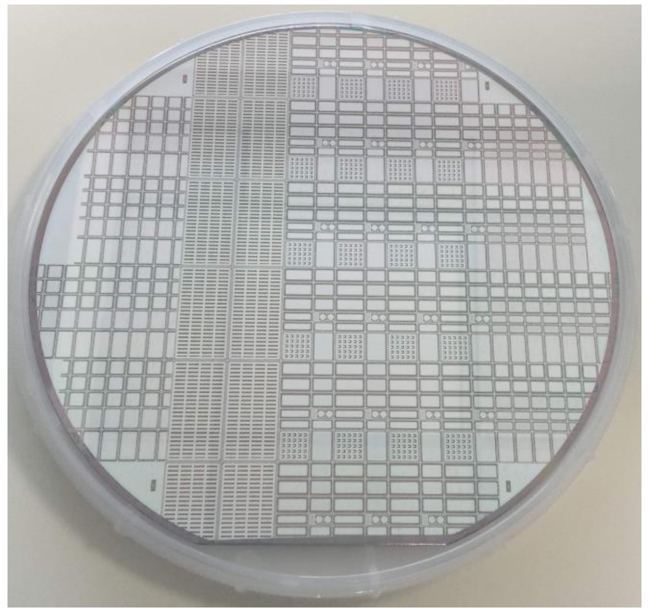


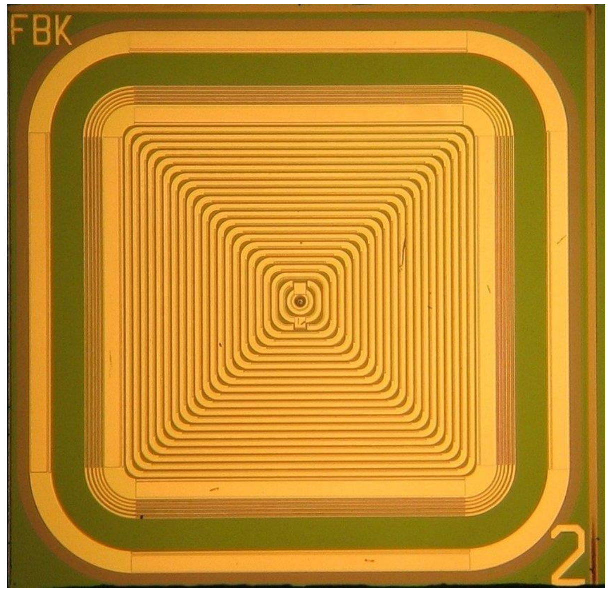


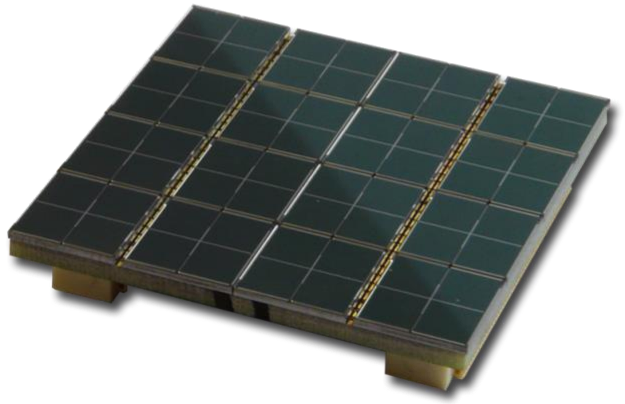


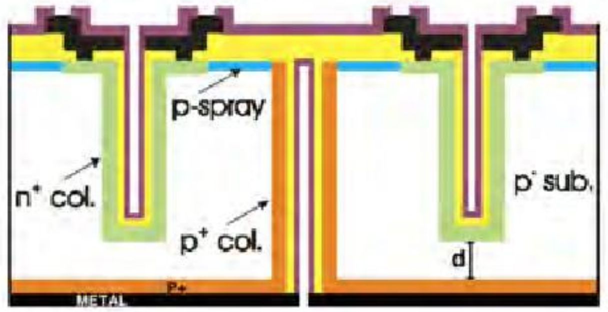
Custom Sensors

- ➢ Micro-strip (large area, low cost, rad-hard)
- ➢ Pixelated sensors (large area, high resolution, rad-hard)
- ➢ SDD (very high energy resolution)
- ➢ 3D column sensors (world record radiation tolerance)
- ➢ Low Gain Avalanche Detectors (radiation tolerant, world record 4D tracking)
- ➢ SiPM (best performance single photon sensors)

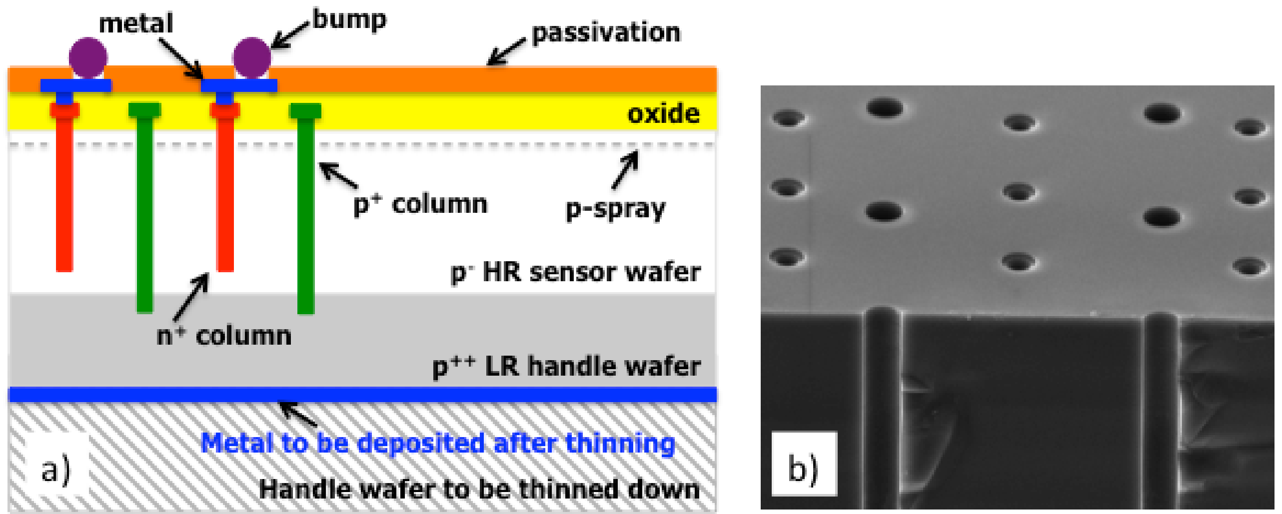




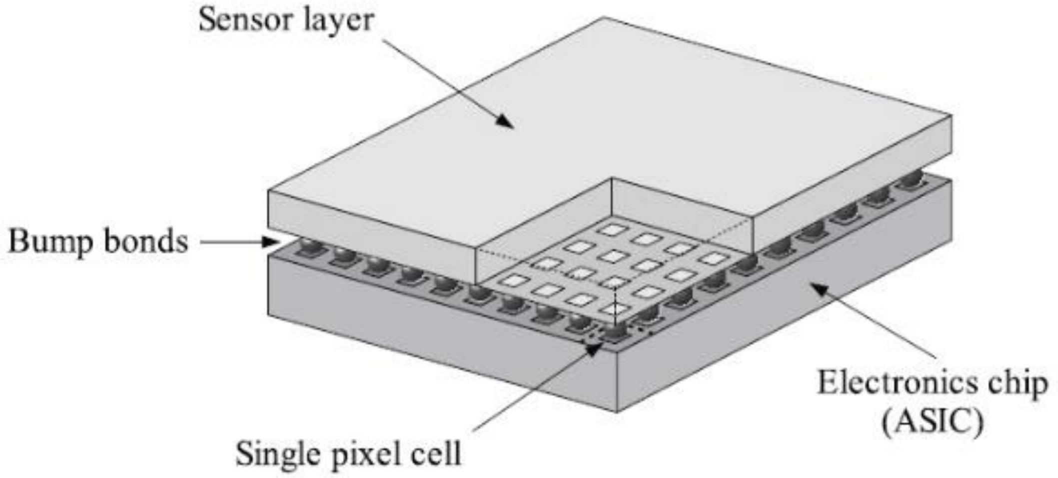




:hematic cross-section of a 3D-DDTC sensor with junction (n$^+$

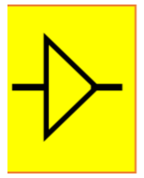


Silicon detectors for Particle Physics

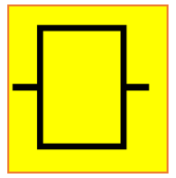


Detector functional blocks:

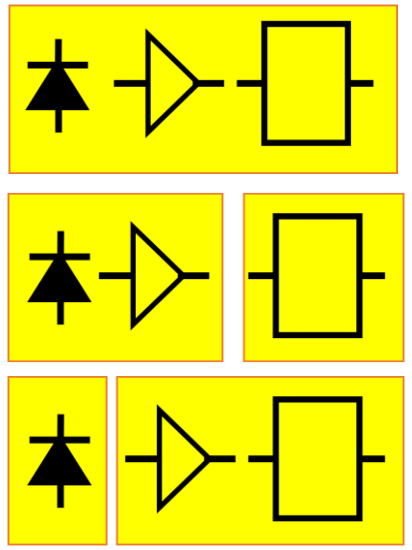
Diodes
(reverse biased)

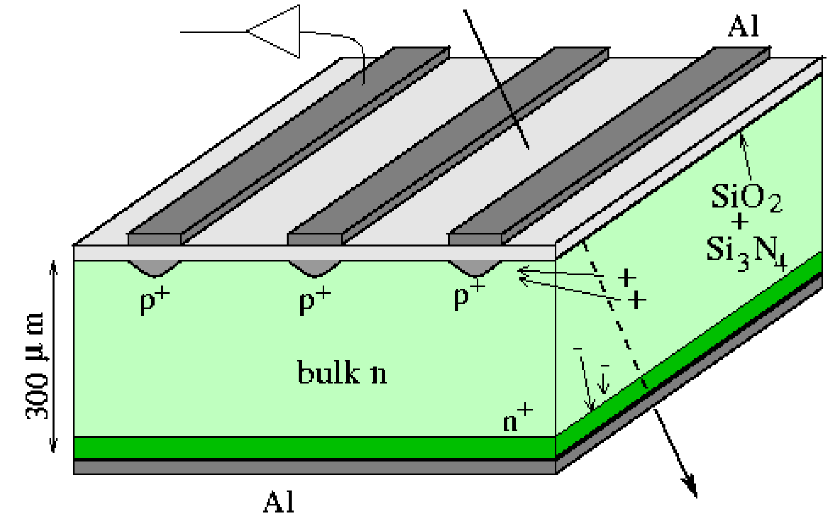


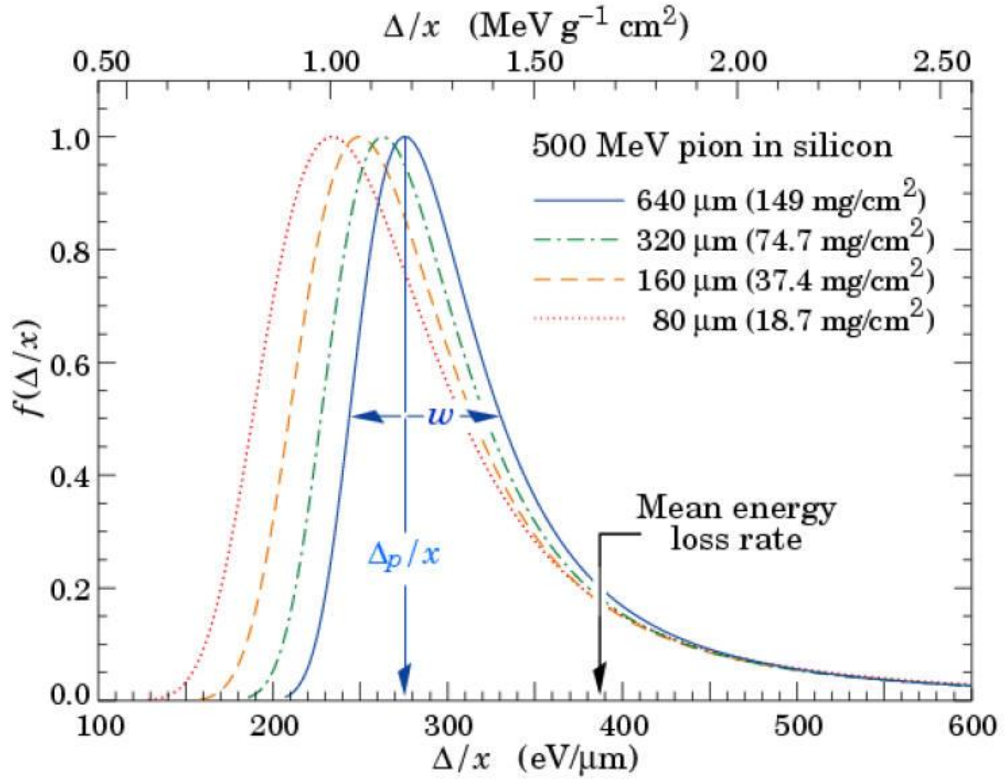
Analogue amplifiers

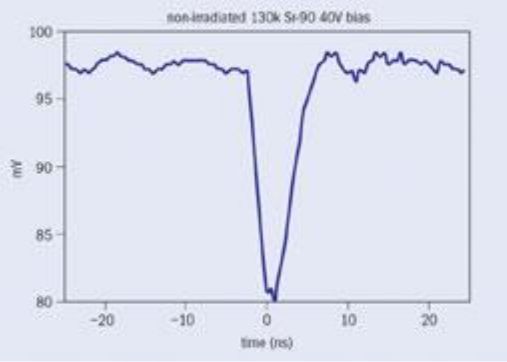


Digital readout







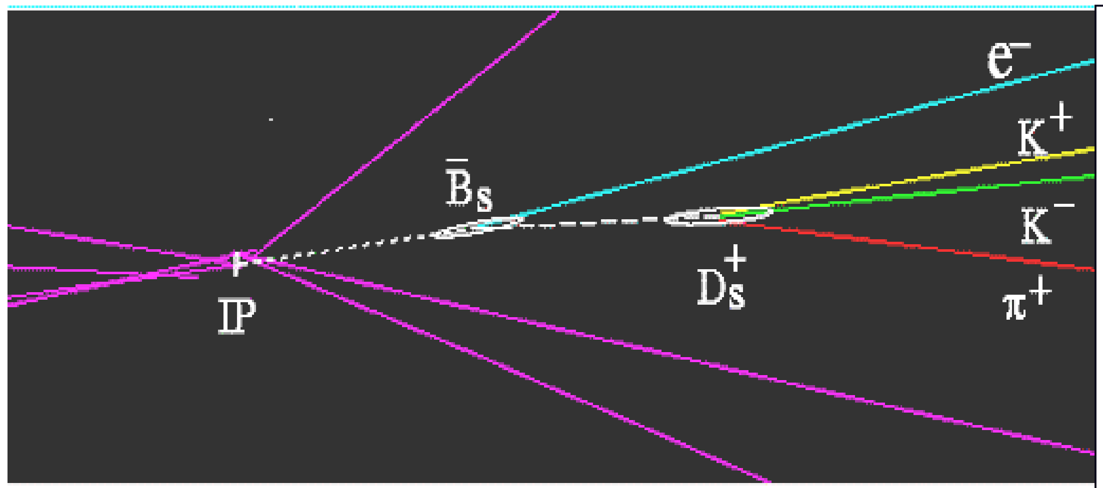


Silicon detectors in Physics Experiments: a spectacular success

Vertex identification, key to collider physics.

Needs for track reconstruction (late ‘80’s): high resolution, low mass (minimise multiple Coulomb scattering).

NA11 (1978 – 1988), fixed target experiment: first silicon micro-strip sensors inserted in 1983. Electronics ‘’remote’’ and ‘’discrete’’.



Example:

Mean decay length B_s ($\tau \approx 1.5$ ps):

in B_s-frame: $c_\tau \approx 450\ \mu m$

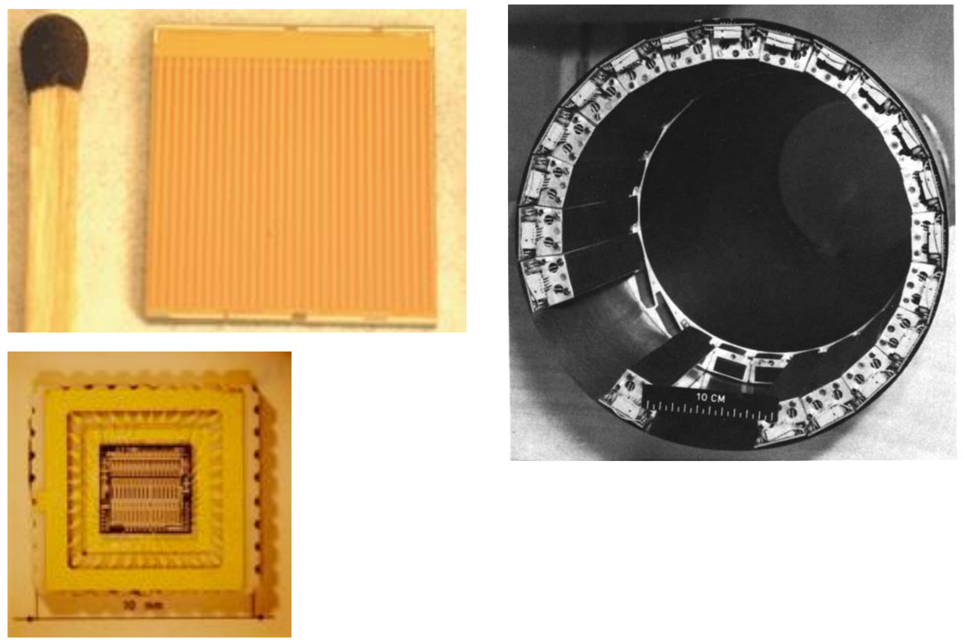
in lab frame $\beta\gamma c_\tau$ = few mm!

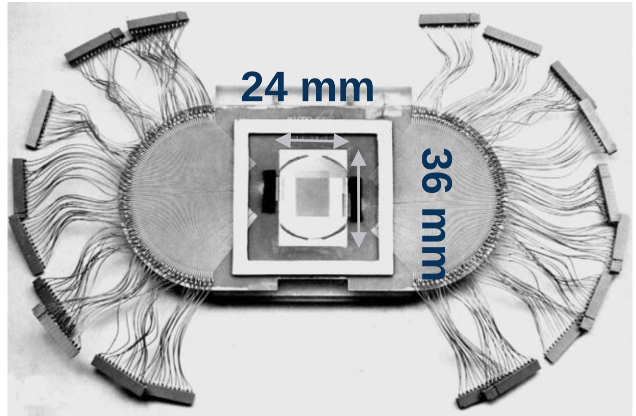
D_s ($\tau \sim 0.5$ ps):

in D_s-frame: $c_\tau \approx 150\ \mu m$

in lab frame $\beta\gamma c_\tau$ = few mm!

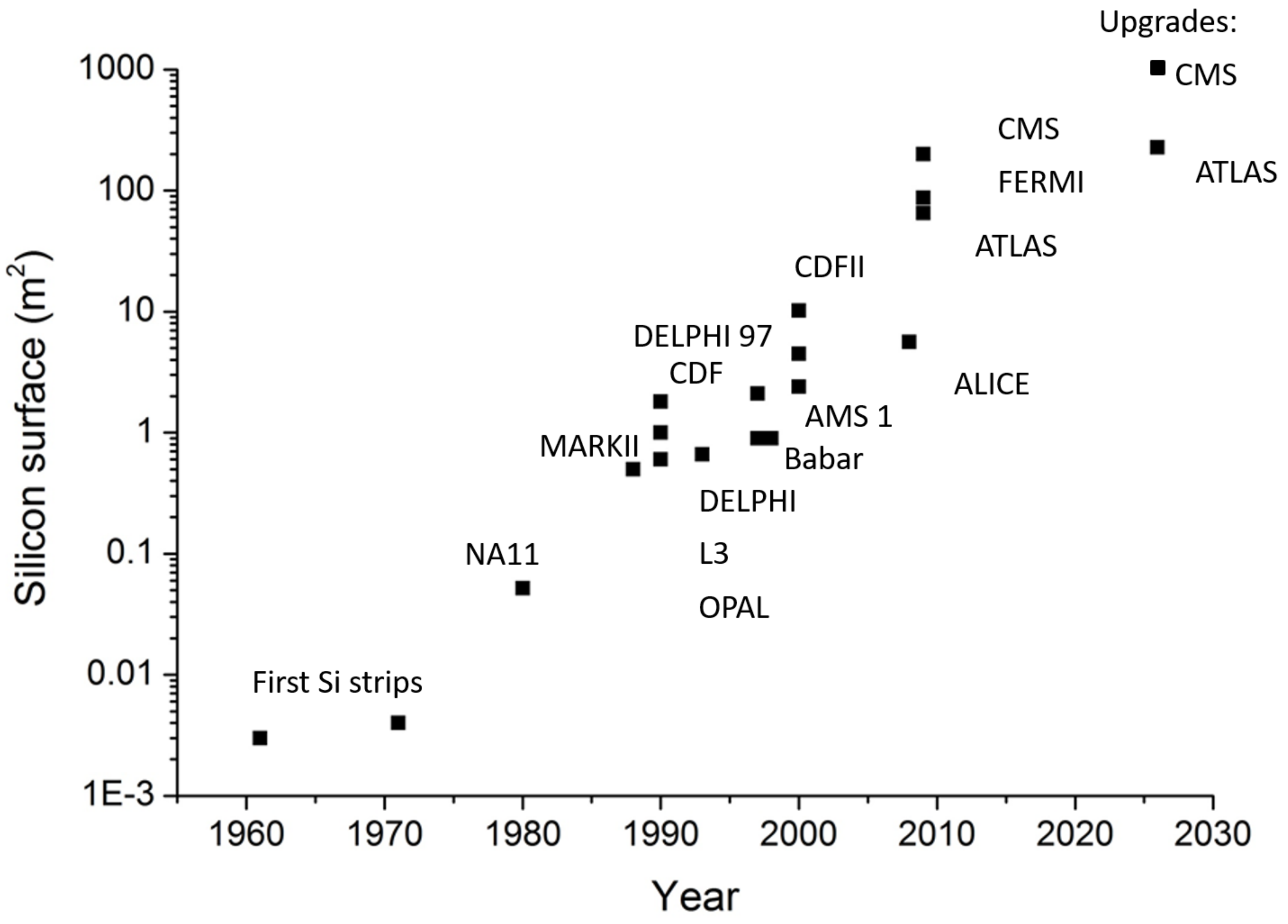
(lower mass $\Rightarrow$ more relativistic)

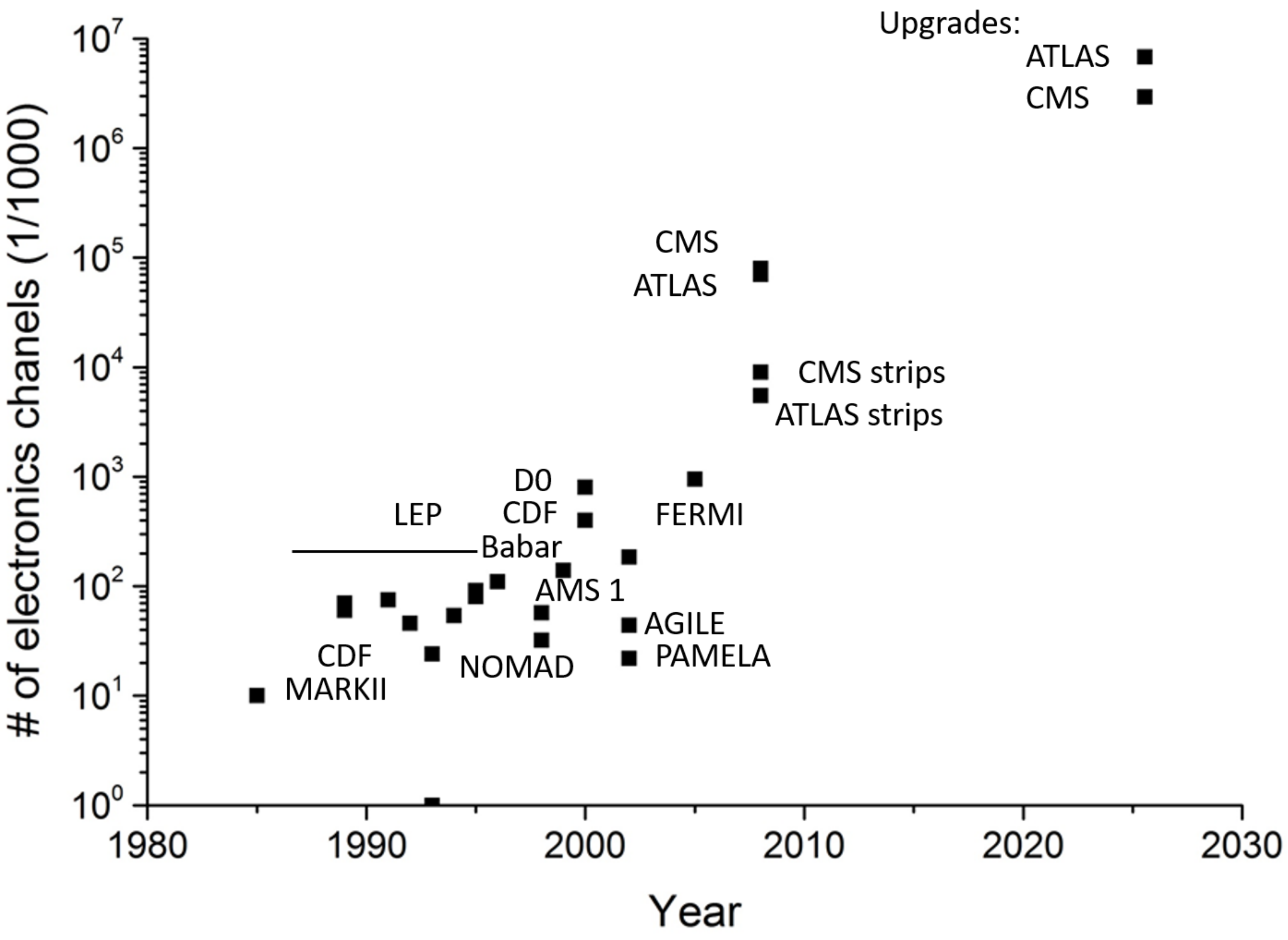




ASIC’s for silicon detector readout: 1988 (UA2 at the CERN/SPS): first collider experiment with silicon detectors with ASIC read-out, namely the AMPLEX, 16 channel, 3 μm Feature Size (S) CMOS chip for read-out and signal multiplexing (E. Heijne, P. Jarron).

Silicon detectors in Physics Experiments: a spectacular success



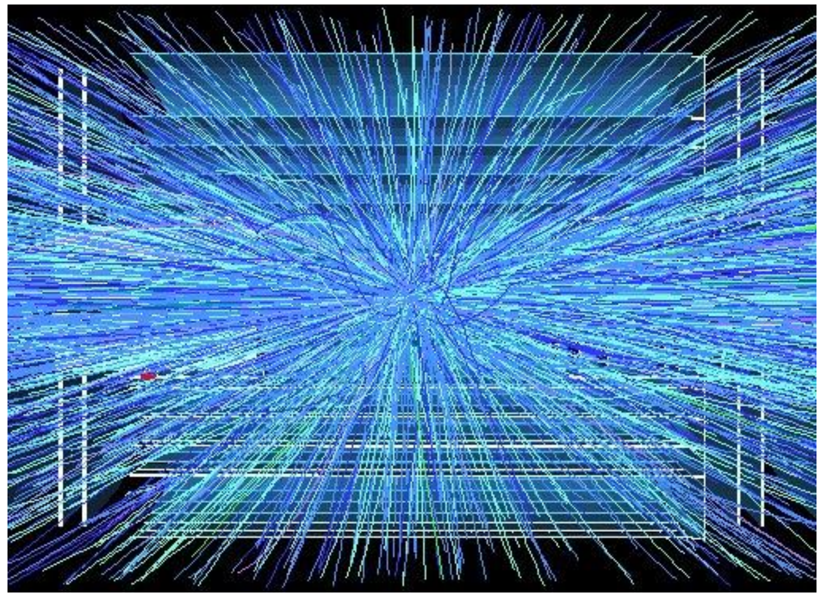


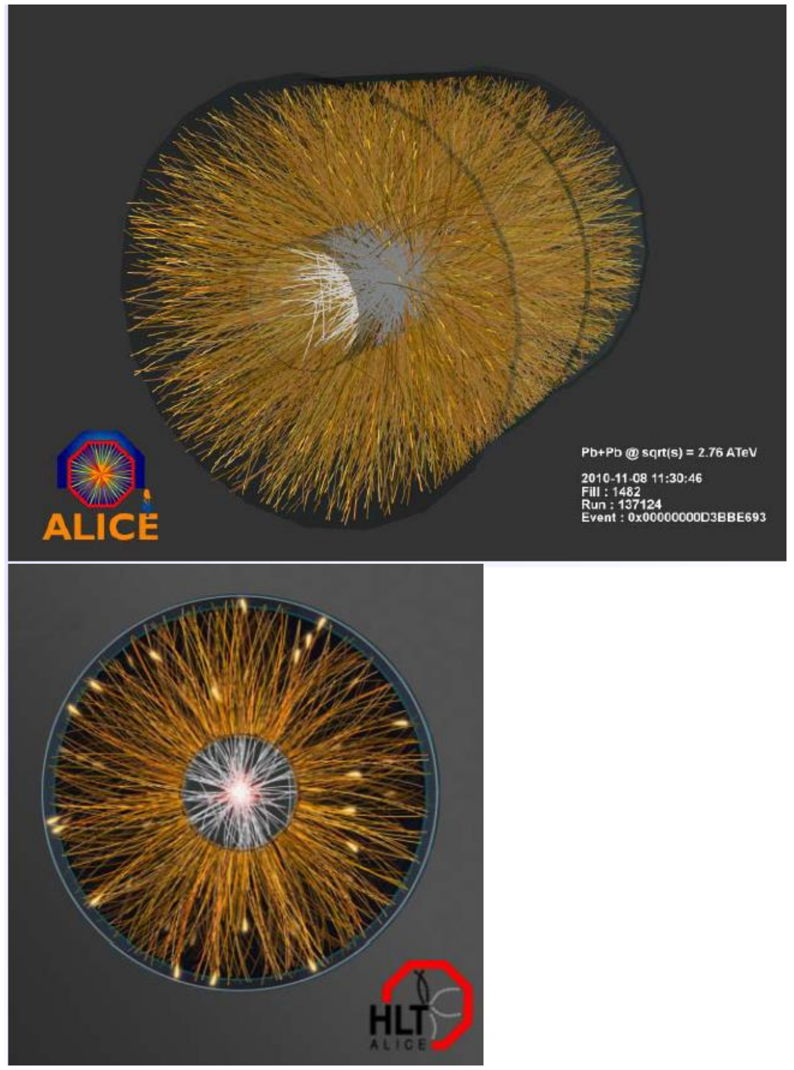
The sensing part can be produced in standard or custom technologies, available in mostly niche detector foundries.

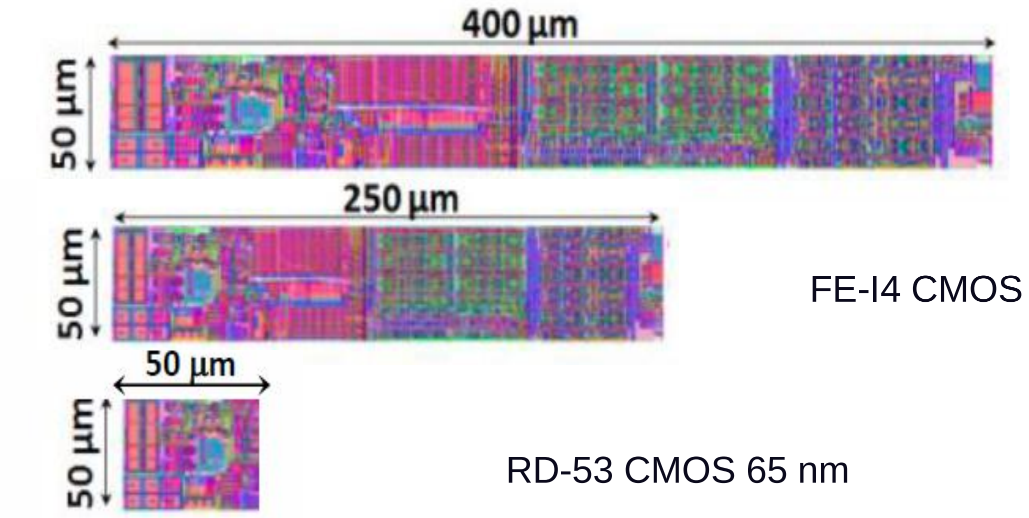
Central role of these niche silicon fabs in the success of silicon sensors in physics experiments.

Silicon detectors in Physics Experiments: a spectacular success

Sensor thickness (μm)	50/300
Spatial resolution (μm)	3/100
Cell Dimension (μm^2)	28 × 28
Power density (mW cm^{-2})	300/1000
Time resolution (ns)	0.06
Detection efficiency (%)	> 99
Fake hit rate	10^{-5}
TID radiation hardness (Grad)	1
NIEL radiation 1 MeV n_{eq} cm^{-2}	2.5×10^{16}







FE-I3 CMOS 250 nm

FE-I4 CMOS 130 nm

RD-53 CMOS 65 nm

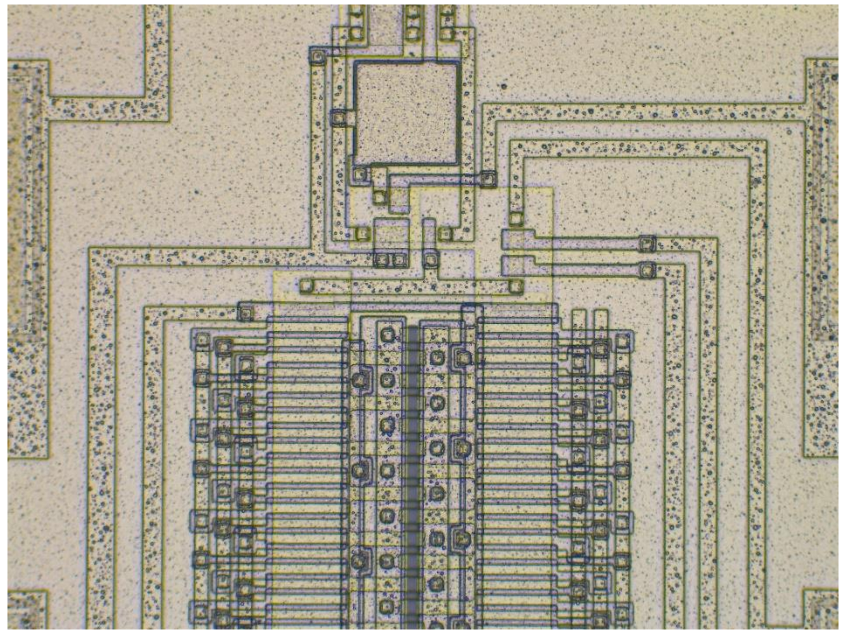
The sensing part can be produced in standard or custom technologies, available in mostly niche detector foundries.

Central role of these niche silicon fabs in the success of silicon sensors in physics experiments.

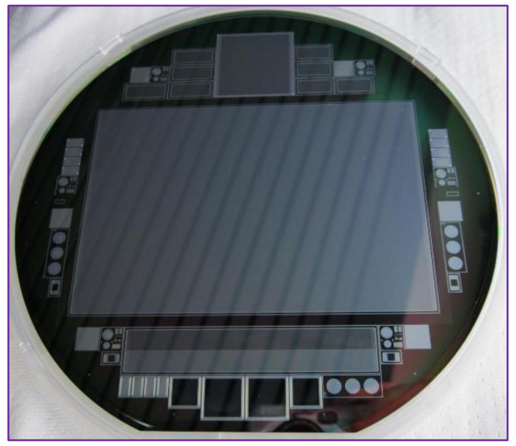
A bit of history:

Si CCD @ FBK-CMM
(our 1st technology)

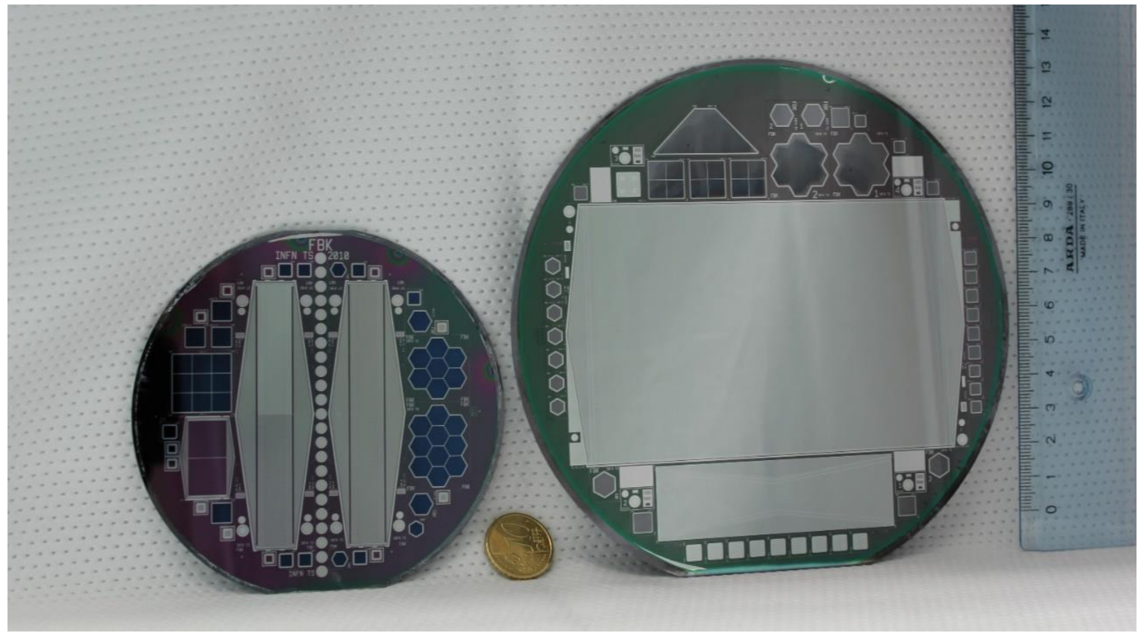
1990 -1991 Linear 4 µm CCD technology (project ISS)
1991-1992 4µm CMOS technology
1992-1993 4 µm CCD-CMOS technology



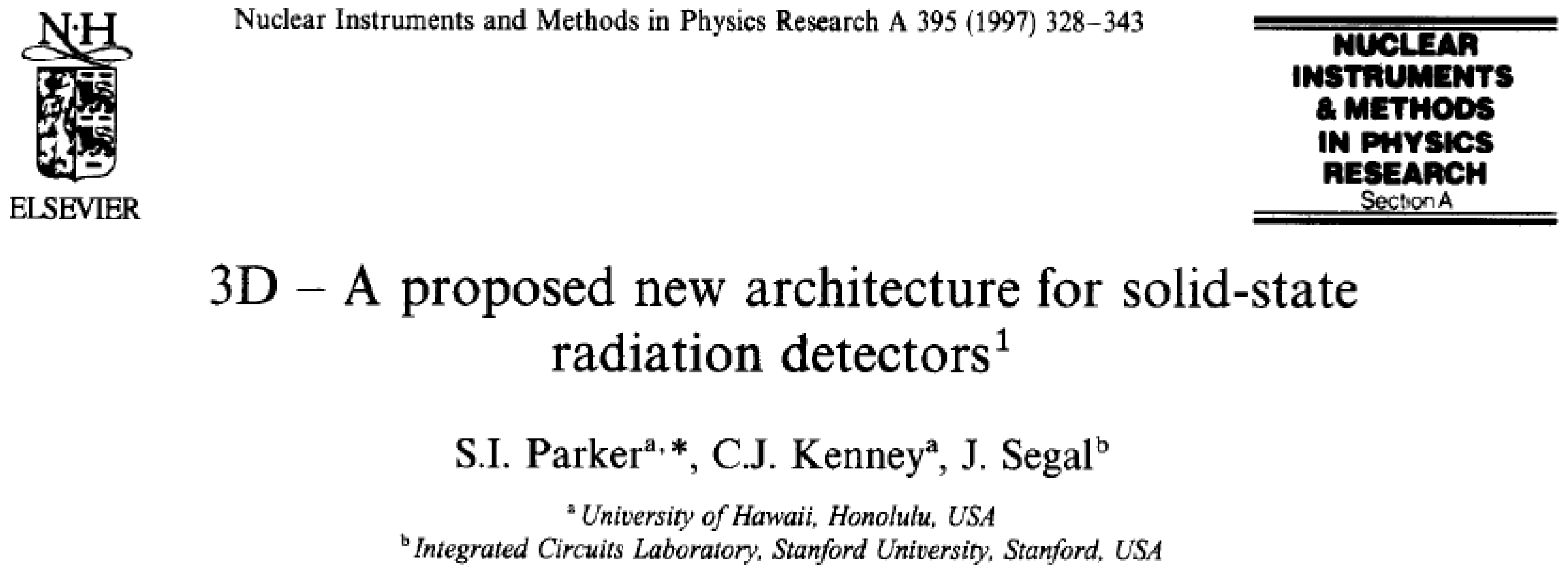
Planar technology (strip, pixels)
4” wafers: 1998
for AMS project ISS
ALICE (CERN-LHC)
On 150 mm wafers: 2014
2016 DS-Microstrip for
CSES (China Seismo-Electromagnetic Satellite)



Silicon Drift Detectors: 2009
Large area: 90 cm^2 SDD for Xray detection in Space (and Synchrotron applications)



A bit of history:



ELSEVIER

Nuclear Instruments and Methods in Physics Research A 395 (1997) 328–343

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

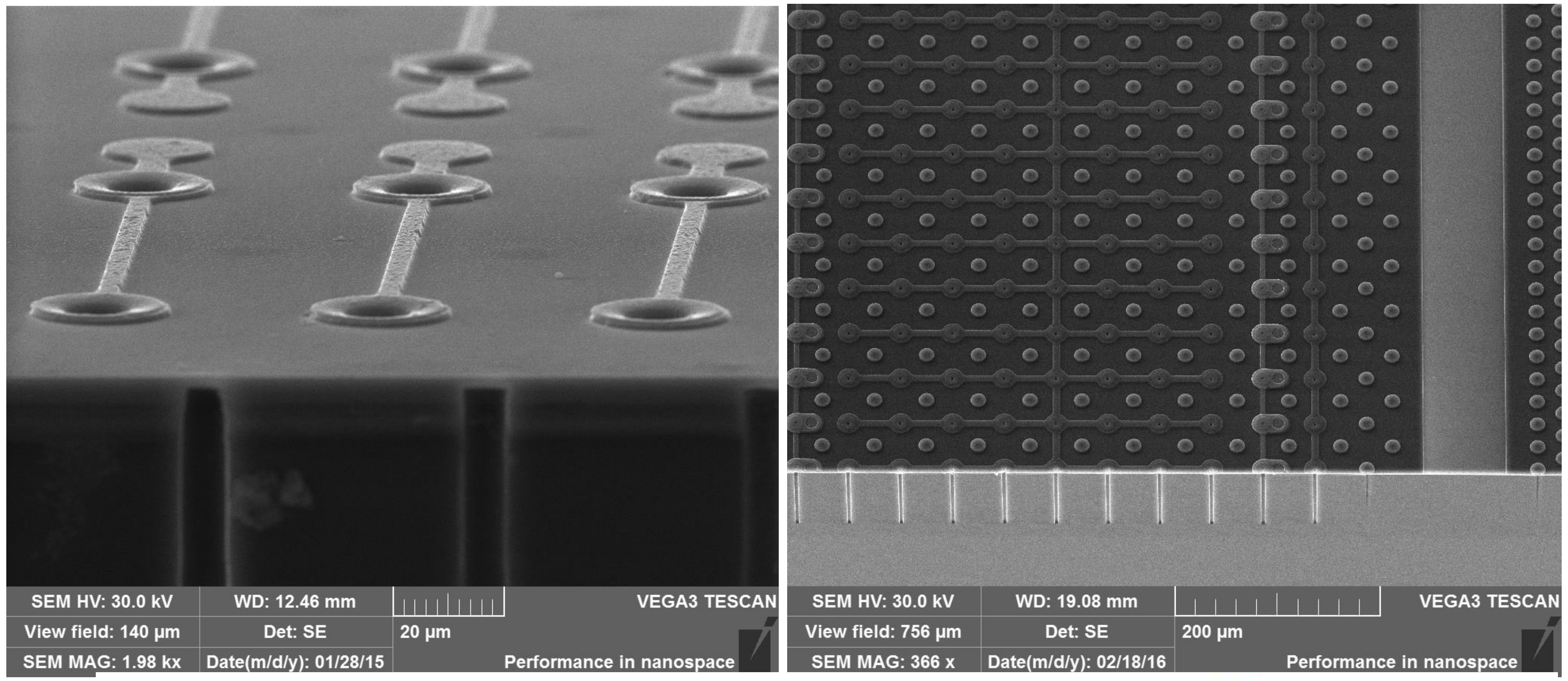
3D – A proposed new architecture for solid-state radiation detectors[1]

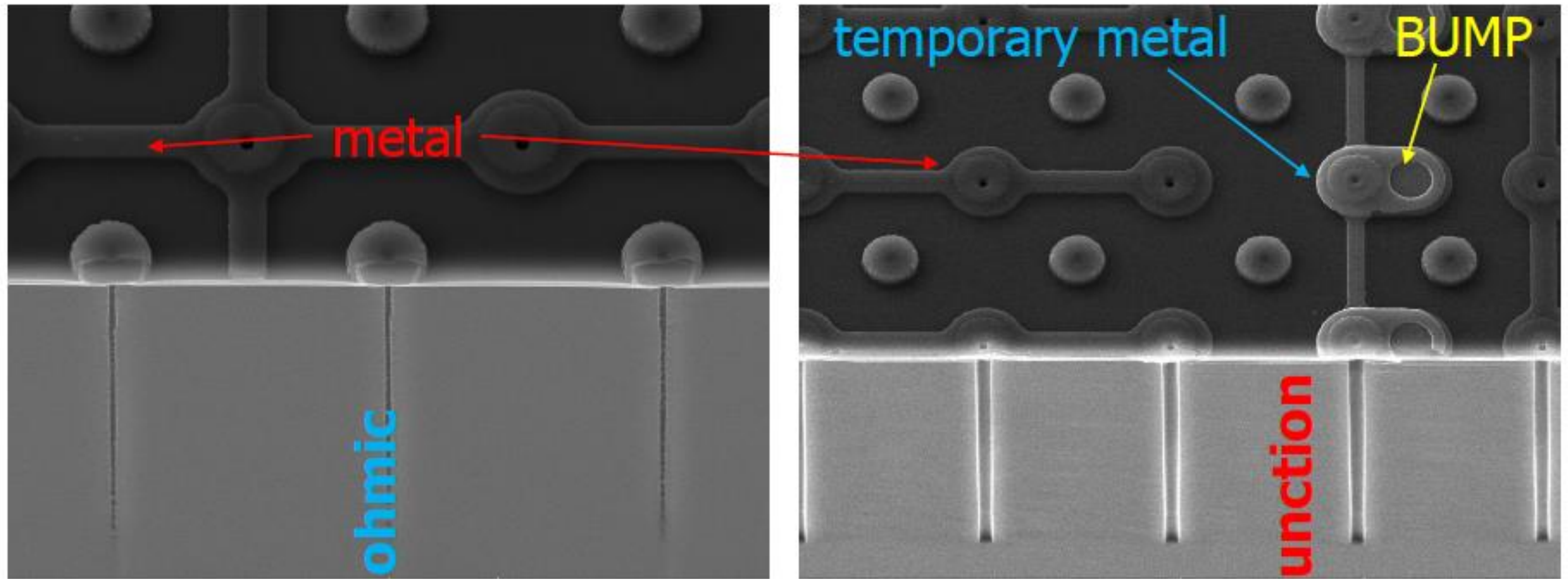
S.I. Parker[a,*], C.J. Kenney[a], J. Segal[b]

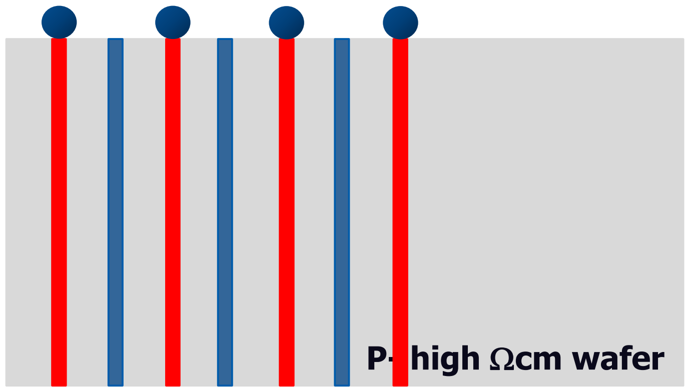
[a] *University of Hawaii, Honolulu, USA*
[b] *Integrated Circuits Laboratory, Stanford University, Stanford, USA*

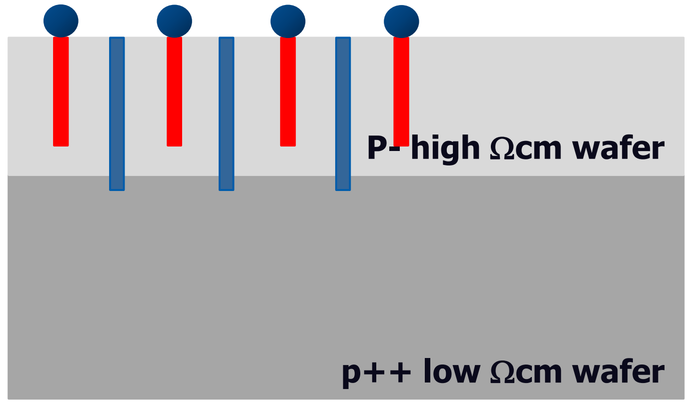
3D column technology (strip, pixels)
6” wafers: 2006, now in ATLAS IBL
Final R&D for ATLAS and CMS upgrade inner layers

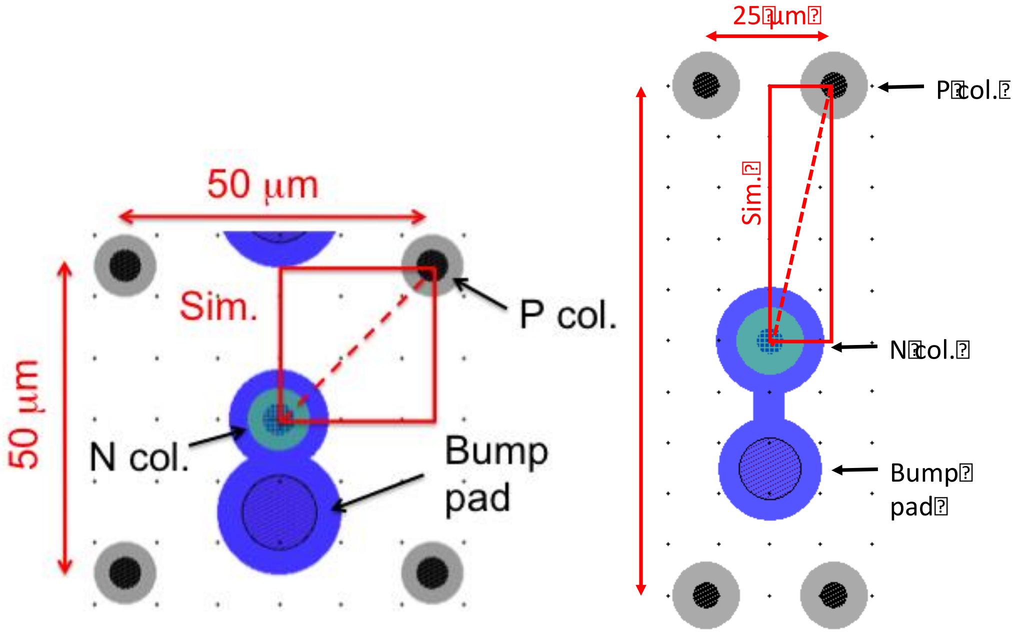
Strong reduction in pixel size (from 50 x 250 µm^2 to 25 x 100 µm^2)



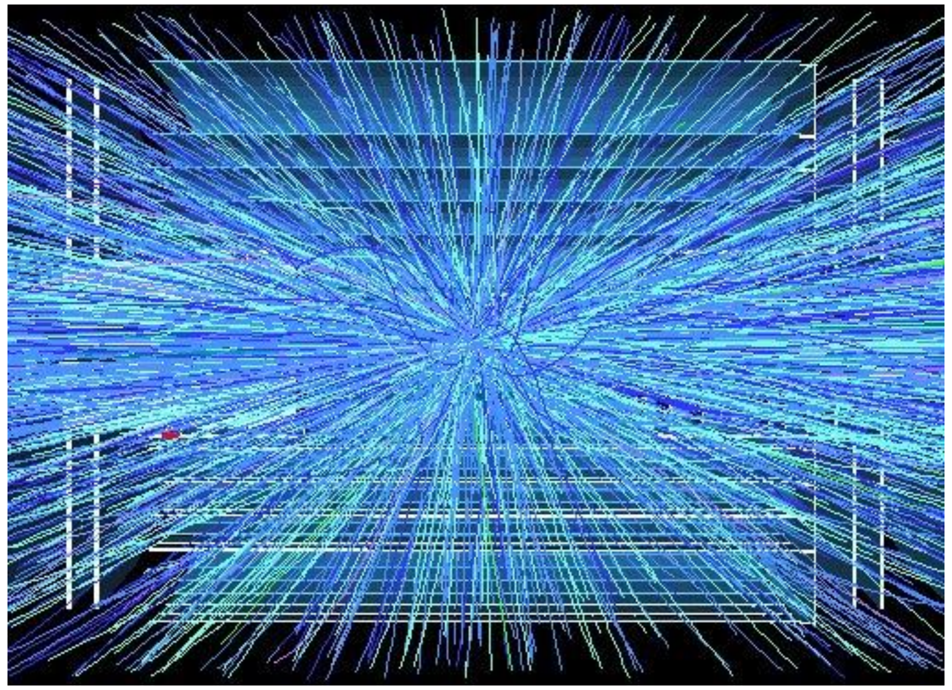




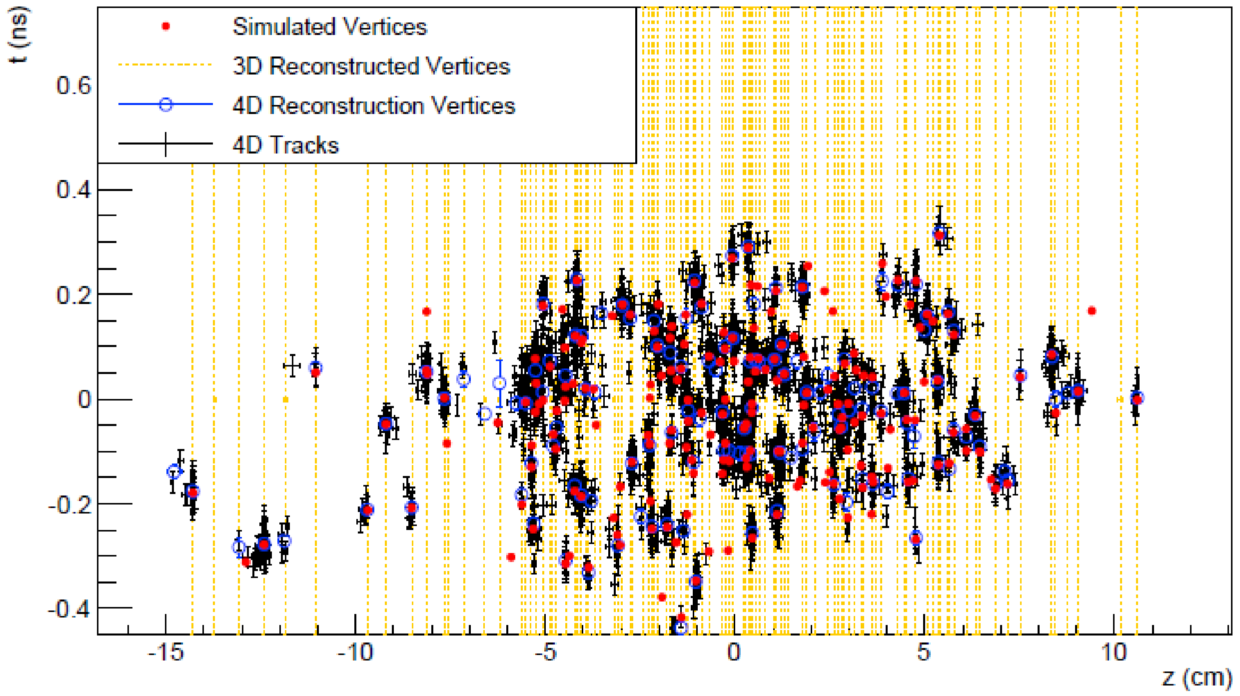




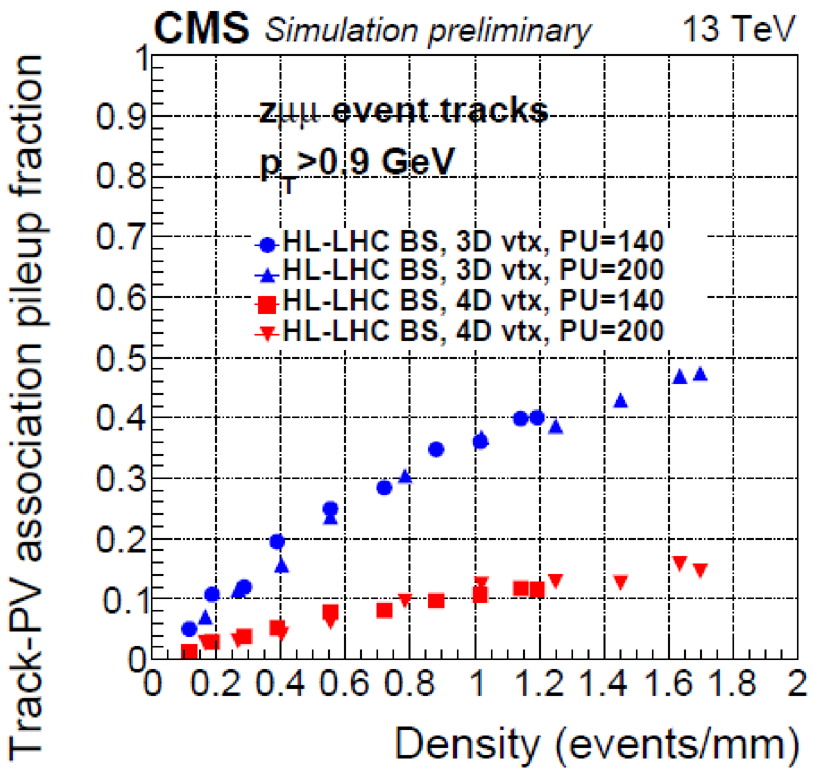
New concept for HL-LHC



4D silicon sensors developed before the expression of interest of experiments (within CERN RD50). Example of virtuous synergy between sensor R&D and physics needs.



Simulated and reconstructed vertices in a 200 pileup event with a MIP timing detector.



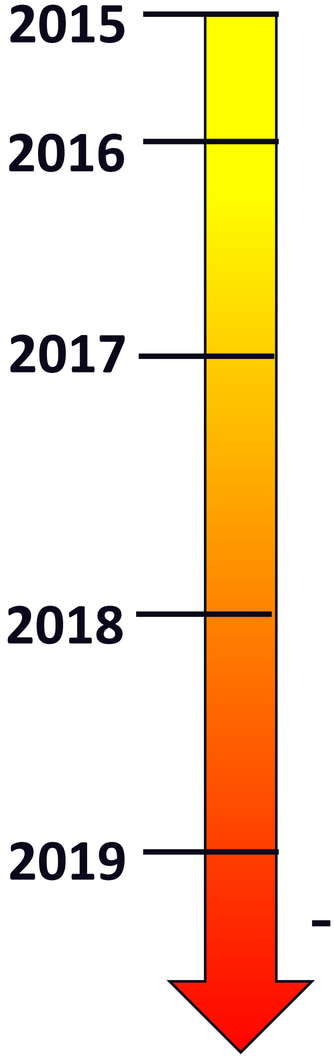
CMS Timing Detector TDR

Rate of tracks from pileup vertices incorrectly associated with the primary vertex.

To exploit the High Luminosity capability of the future accelerator, a 4D tracker is required!

LGAD Developments In FBK

- Since 2015 **FBK**, **INFN Torino** and **University of Trento** have been developing **LGADs** for **fast timing** and **4D-tracking** application in HEP experiments (Ultra Fast Silicon Detectors – **UFSD**)



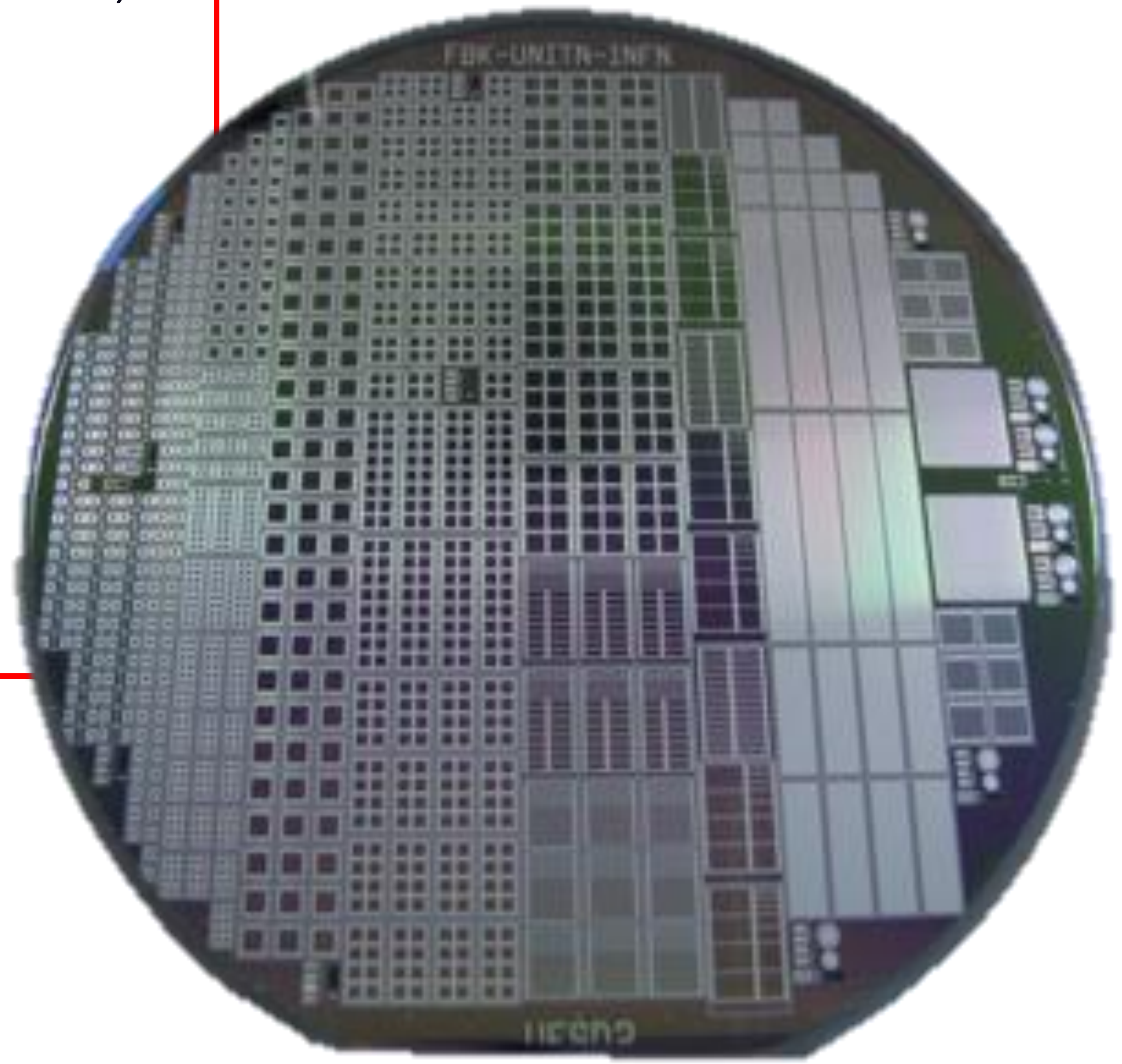
In 2015 FBK started to develop **UFSD** detectors, i.e. **LGADs** optimized for timing in HEP, in collaboration with INFN Torino, University of Trento and University of Turin

<u>Possible applications:</u>

ATLAS	→ High granularity timing detector
CMS	→ Endcap timing layer
……….	

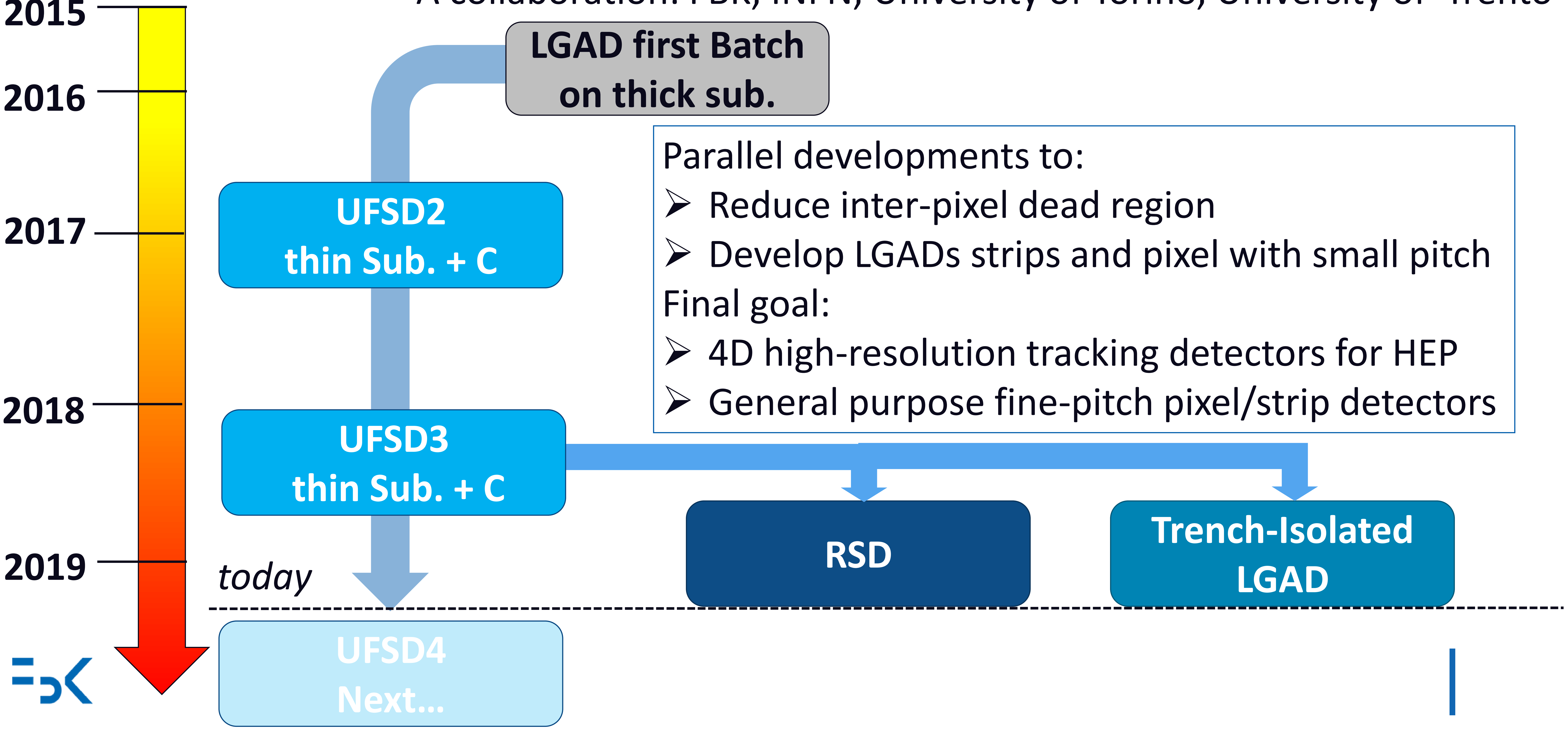
<u>Requirements:</u>

Fast timing	→ Time resolutions < 30-40 ps
Radiation Hard.	→ Fluences $> 10^{15}$ n_{eq}/cm^2
………….	



LGAD Technology Roadmap at FBK

A collaboration: FBK, INFN, University of Torino, University of Trento



Parallel developments to:

- Reduce inter-pixel dead region
- Develop LGADs strips and pixel with small pitch

Final goal:

- 4D high-resolution tracking detectors for HEP
- General purpose fine-pitch pixel/strip detectors

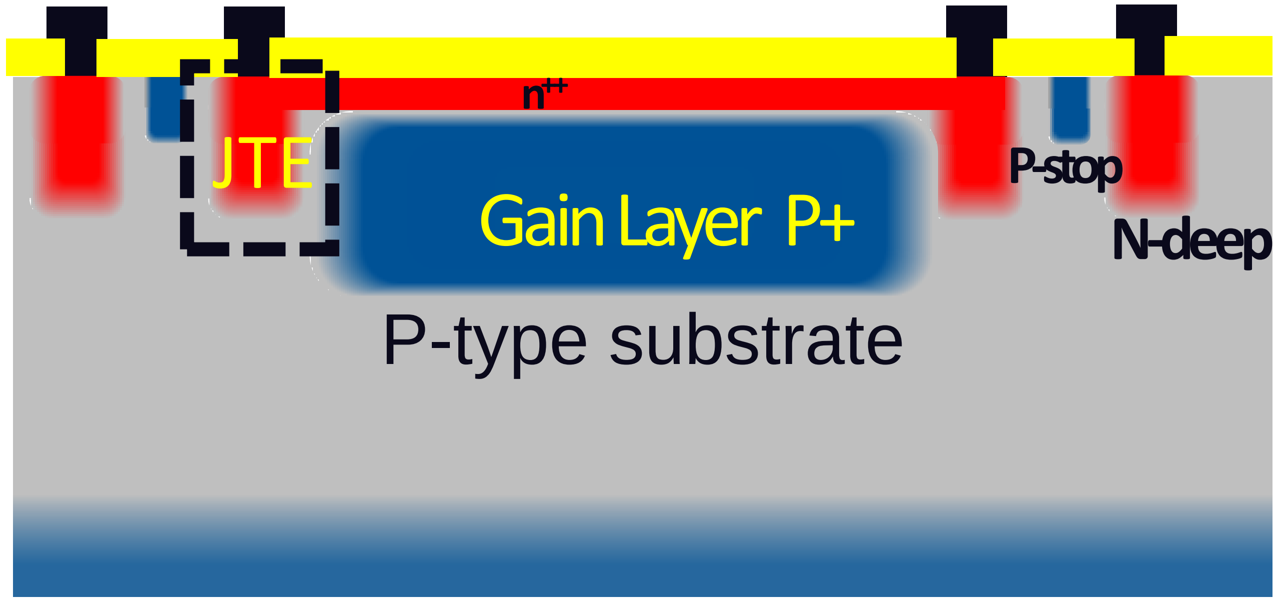
LGAD Technology

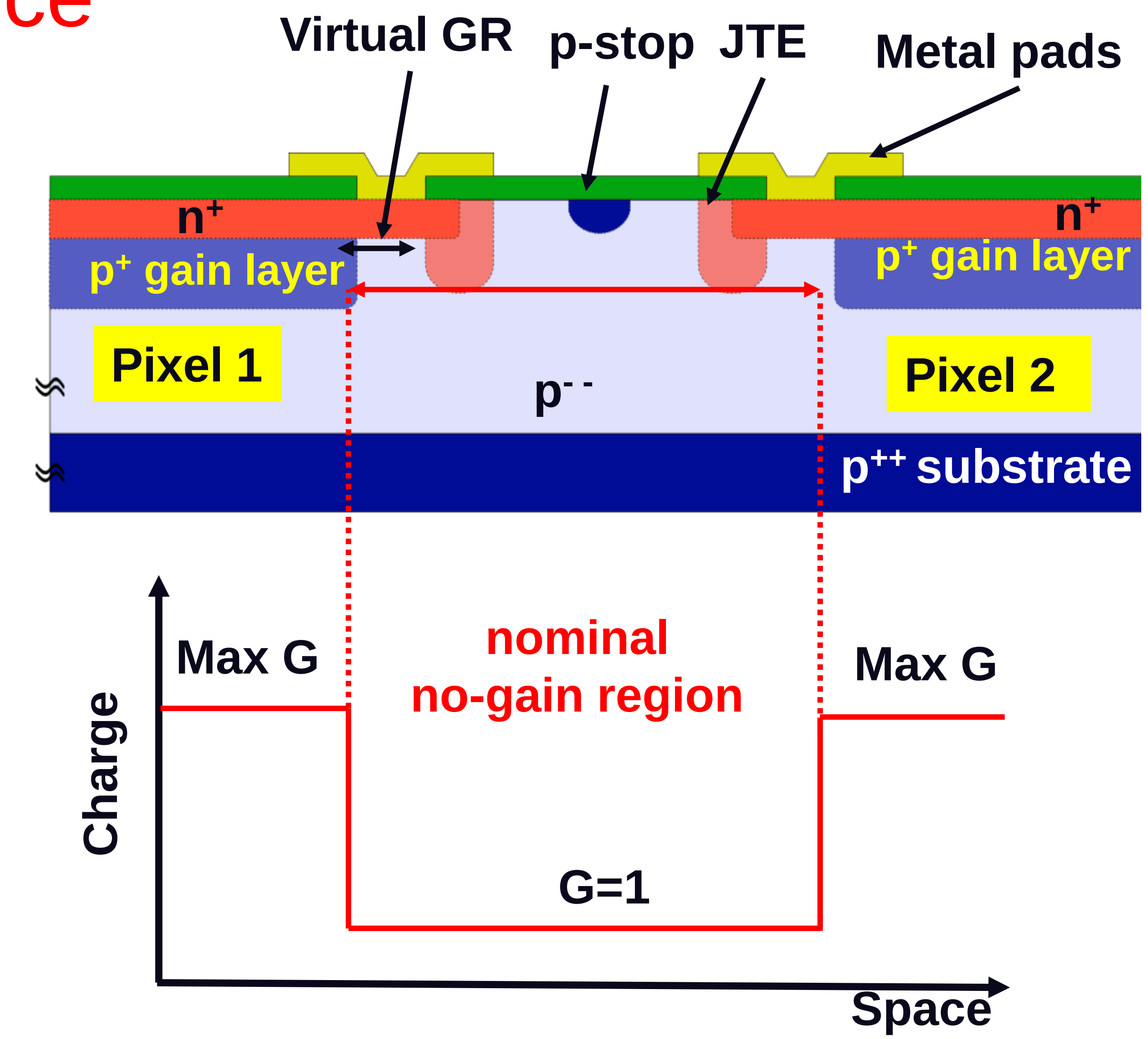
- Silicon detectors that look like a normal pixel or strip sensor, but with a **much larger signal** (internal Gain in the range ~ 10 – 20)
- High signals also with thin silicon substrates
- **Better timing performance**
- Easy to be segmented
- Low gain -> **low excess noise**

A "gain layer" is included in the structure (local doping enrichment with E > 2e5 to activate the impact ionization). Termination structure JTE for stability.

Two major challenges:

- Radiation tolerance
- Fill factor





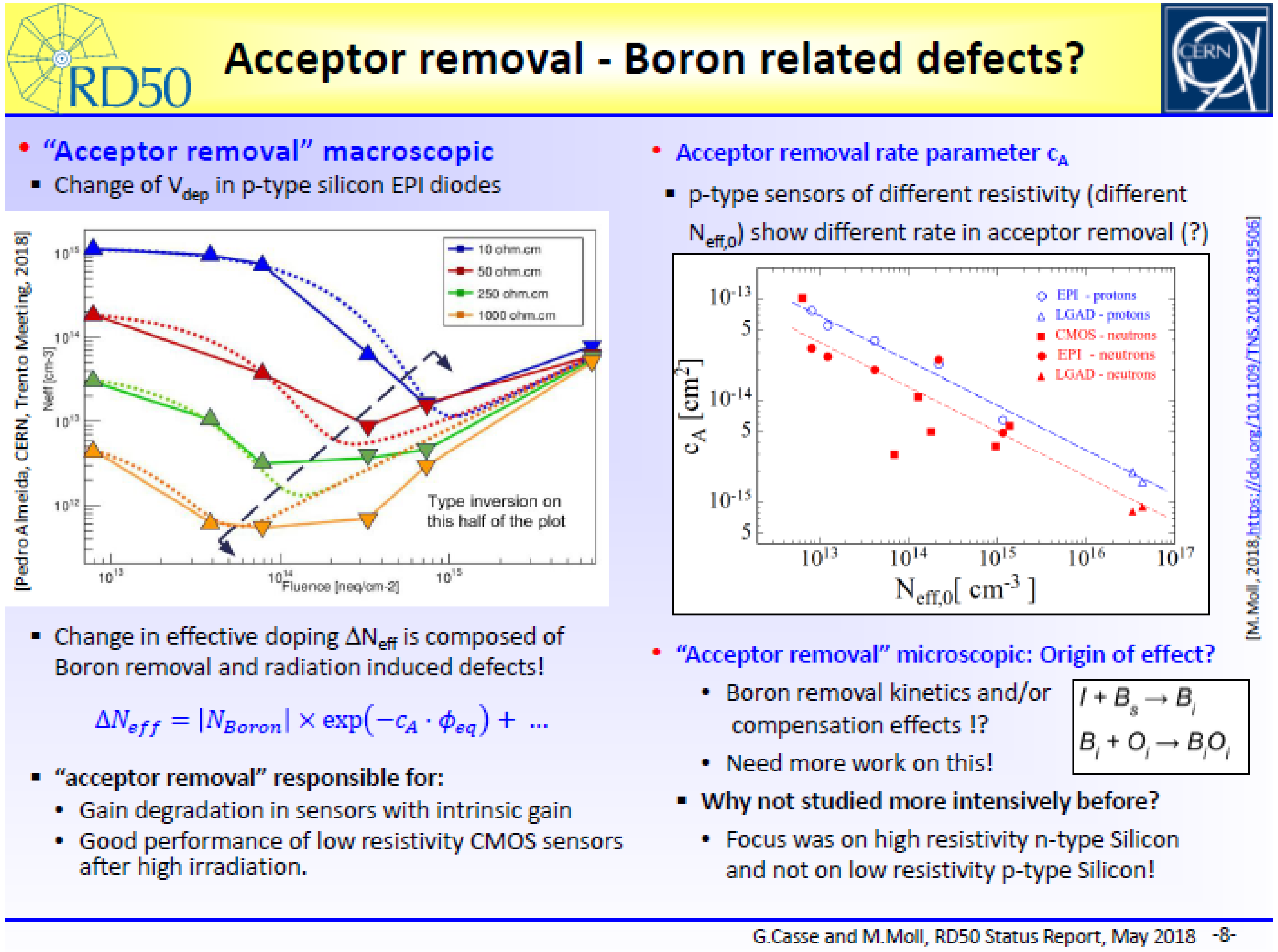
Radiation tolerance

Smaller c,
improved tolerance

Acceptor
Removal

$$\frac{N_A(\Phi)}{N_A(0)} = e^{-c(NA(0))\Phi/\Phi_0}$$

Radiation level changes the doping concentration of the gain layer, so it changes the way the device works



Acceptor removal - Boron related defects?

- **"Acceptor removal" macroscopic**
  - Change of V_{dep} in p-type silicon EPI diodes

[Pedro Almeida, CERN, Trento Meeting, 2018]

- Change in effective doping ΔN_{eff} is composed of Boron removal and radiation induced defects!

$$\Delta N_{eff} = |N_{Boron}| \times \exp(-c_A \cdot \phi_{eq}) + \ \ldots$$

- **"acceptor removal" responsible for:**
  - Gain degradation in sensors with intrinsic gain
  - Good performance of low resistivity CMOS sensors after high irradiation.

- Acceptor removal rate parameter c_A
  - p-type sensors of different resistivity (different $N_{eff,0}$) show different rate in acceptor removal (?)

[M.Moll, 2018, https://doi.org/10.1109/TNS.2018.2819506]

- **"Acceptor removal" microscopic: Origin of effect?**
  - Boron removal kinetics and/or compensation effects !?
  - Need more work on this!

$$I + B_s \rightarrow B_i$$
$$B_i + O_i \rightarrow B_iO_i$$

- **Why not studied more intensively before?**
  - Focus was on high resistivity n-type Silicon and not on low resistivity p-type Silicon!

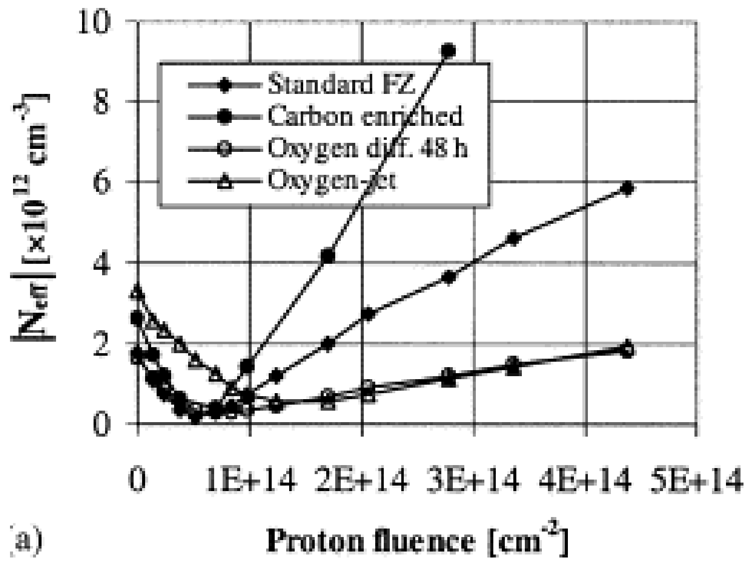
G.Casse and M.Moll, RD50 Status Report, May 2018 -8-

Radiation tolerance

Smaller c,
improved tolerance

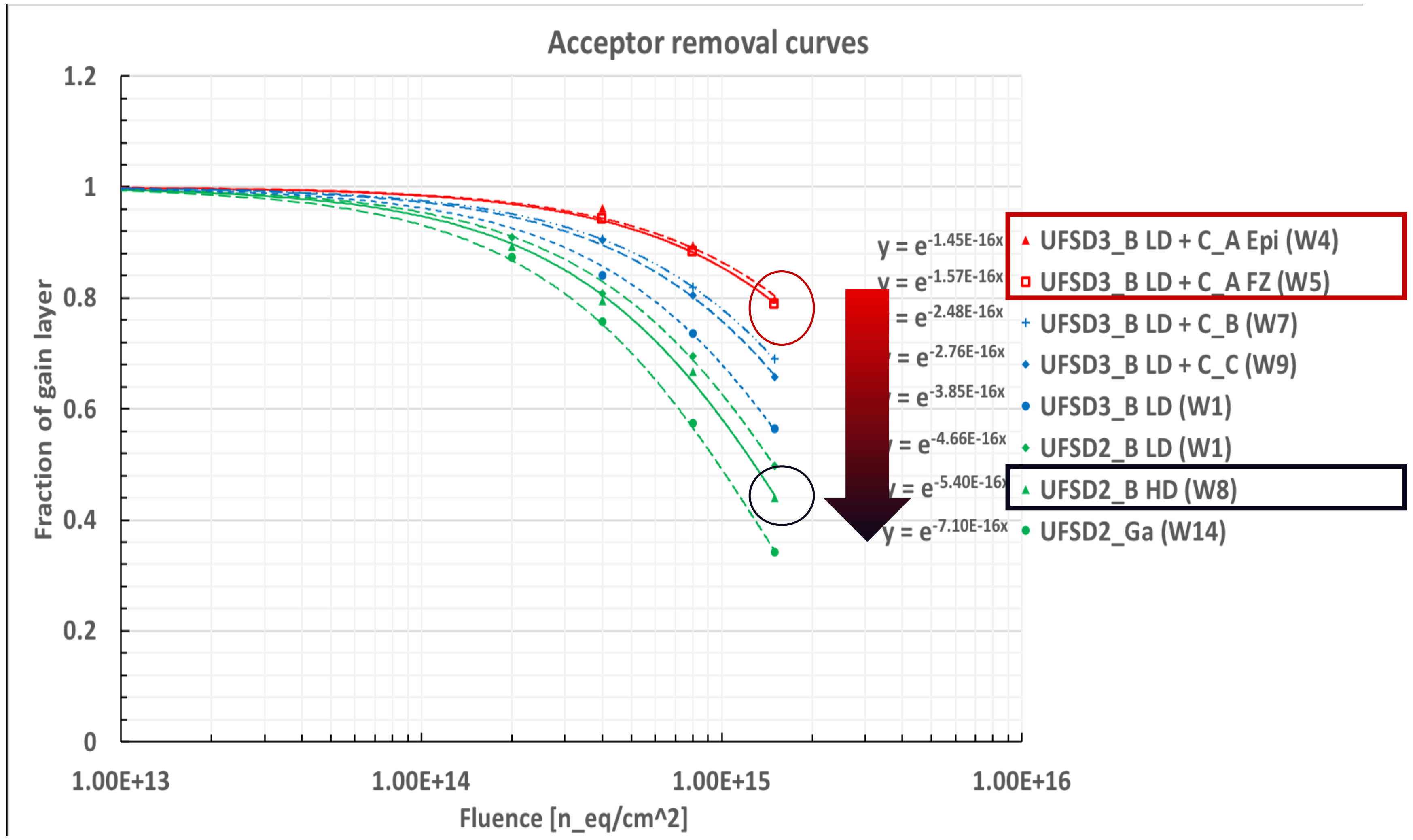
$$\frac{N_A(\Phi)}{N_A(0)} = e^{-c(NA(0))\Phi/\Phi_0}$$

Acceptor
Removal



Materials Science in Semiconductor Processing
Volume 3, Issue 4, 1 August 2000, Pages 257-261
Radiation effects in silicon detectors processed on carbon and oxygen-rich substrates
A. Ruzin, G. Casse, M. Glaser, F. Lemeilleur, J. Matheson, S. Watts, A. Zanet

Idea: Carbon
co-implantation

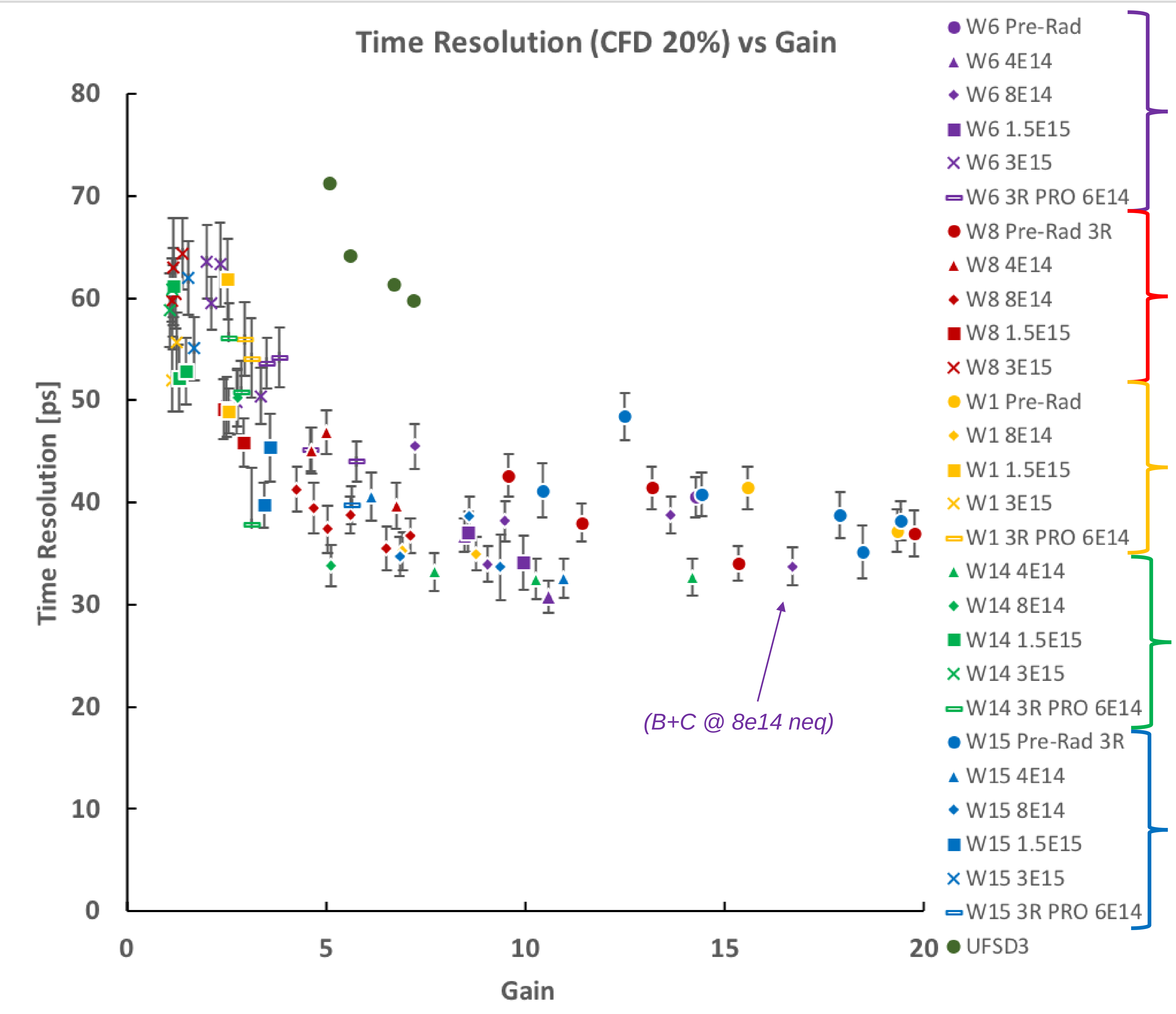


Addition of carbon improves by a factor ~2 the radiation tolerance.

Timing Resolution

Timing resolution depends on the gain value and on the holes drift velocity (∝Vbias)

Legend:
Wafer number
Fluence (1 MeV n_{eq}/cm^2)



Boron + Carbon co-impantation

Boron (wide Gain implant profile)

Boron (narrow Gain profile)

Gallium

Gallium + Carbon co-implantation

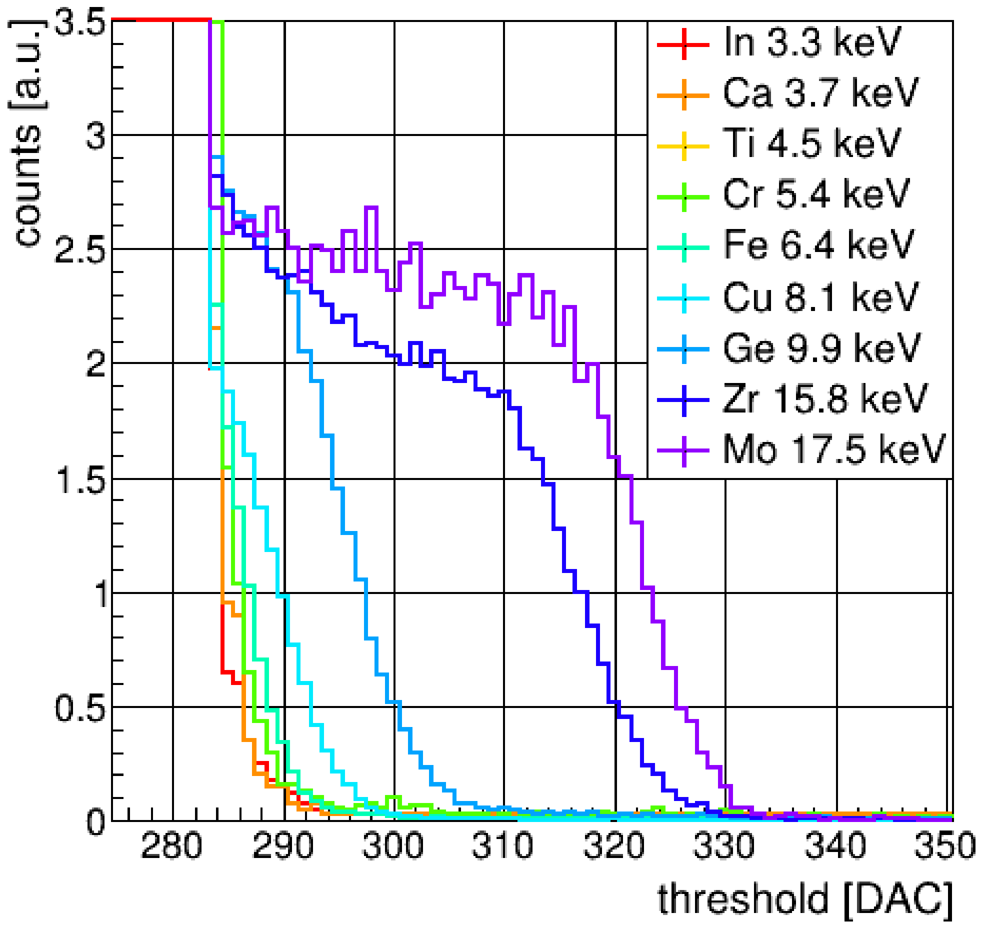
Timing resolution down to 30 ps for MIP detection

Other applications of LGAD

Low Energy X-ray Detection

Photon counting strip detectors, fluorescence X-rays

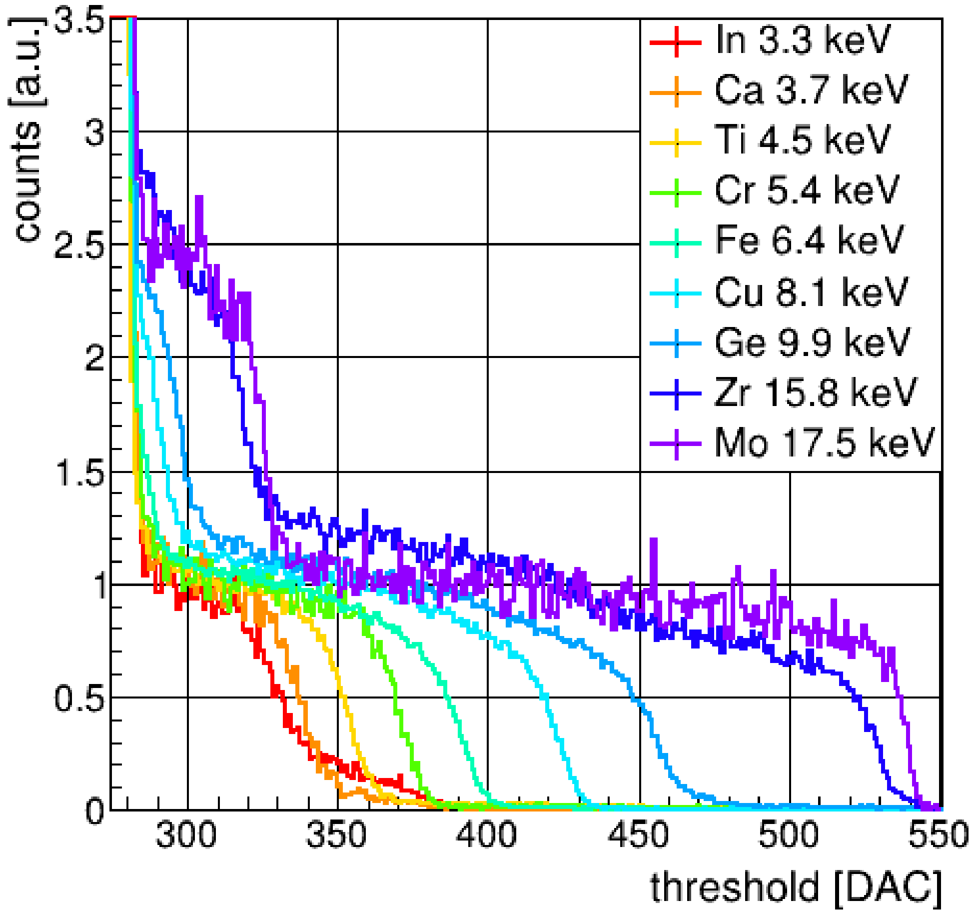
Planar sensor



Zoomed x-axis

E > 8 keV visible

LGAD sensor



E < 3.3 keV visible

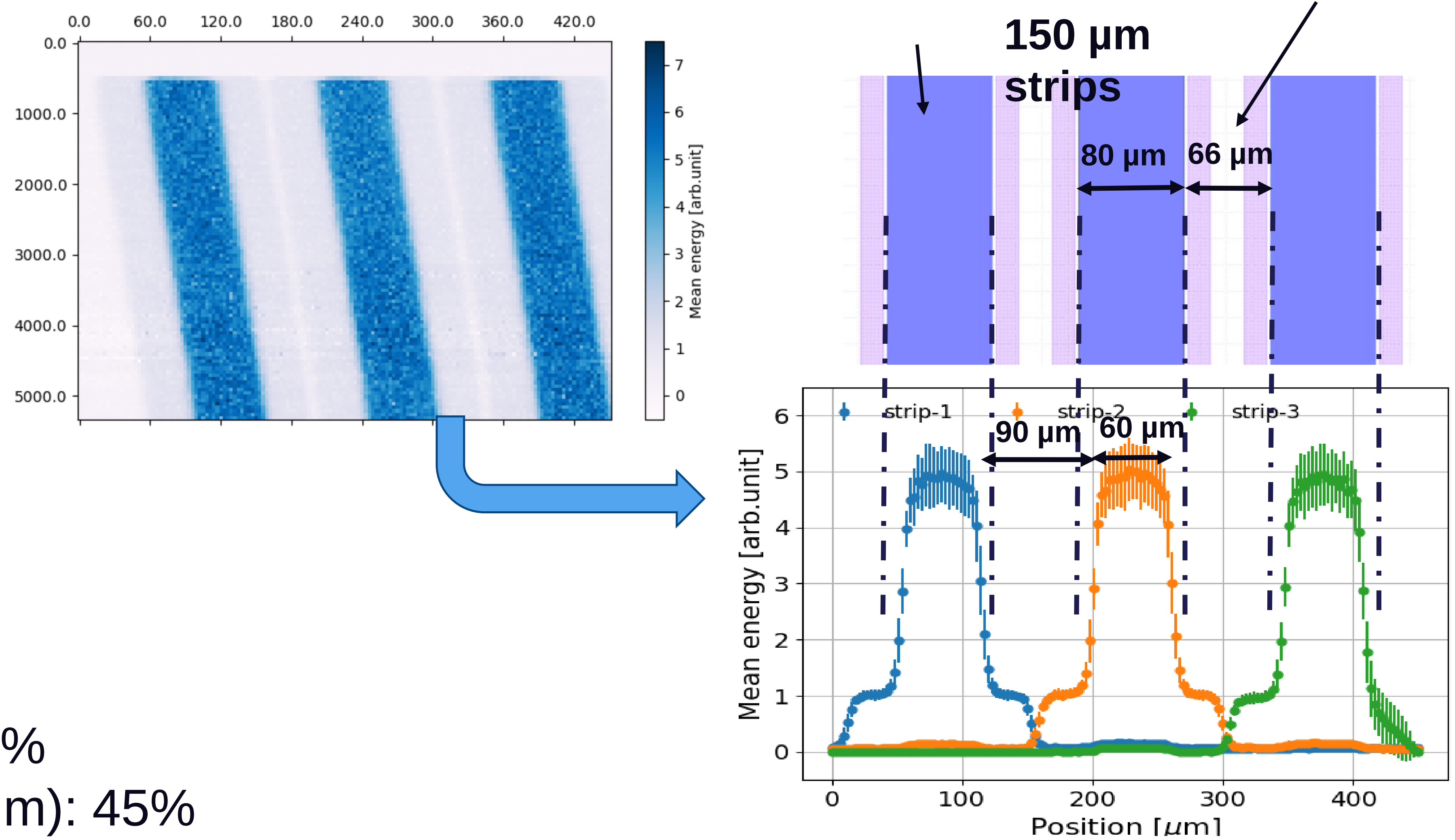
A. Bergamaschi, TREDI 2019

Andrae, Zhang, et al. J. Synchrotron Rad. (2019)

Other applications of LGAD

LGAD Segmentation: Fill Factor

Focused 20 keV X-ray beam



Nominal Gain region

Nominal FF: 55%
Effective FF (Sim): 45%
Measured FF (50% signal amplitude) ≈ 40%

Signal vs position for 3 strips

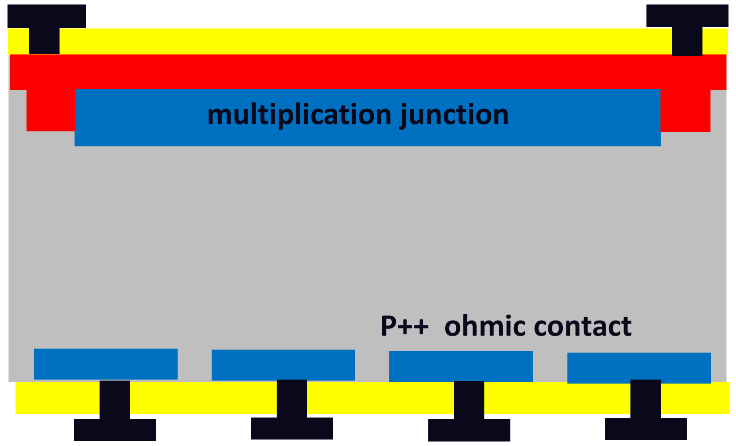
Andrae, Zhang, et al. J. Synchrotron Rad. (2019)

New Segmentation Strategies under development at FBK

iLGAD: P-side segmentation

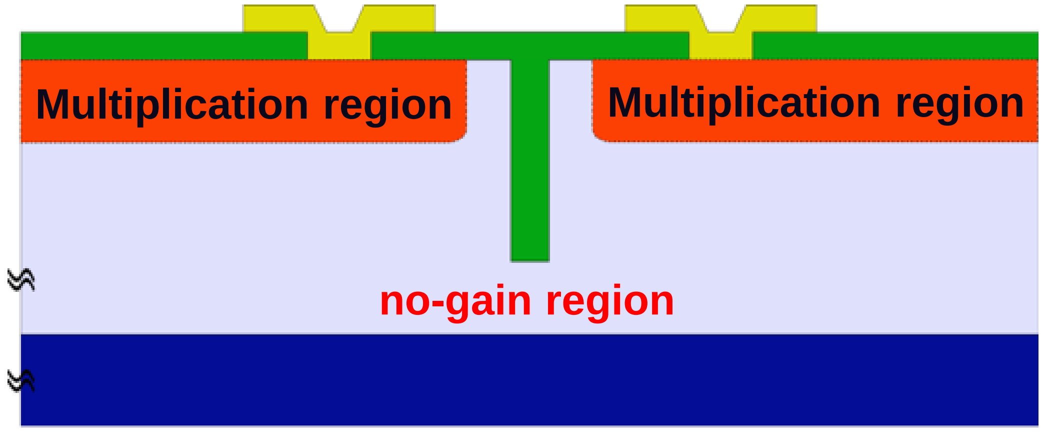
Uniform gain layer
The p-layer is segmented

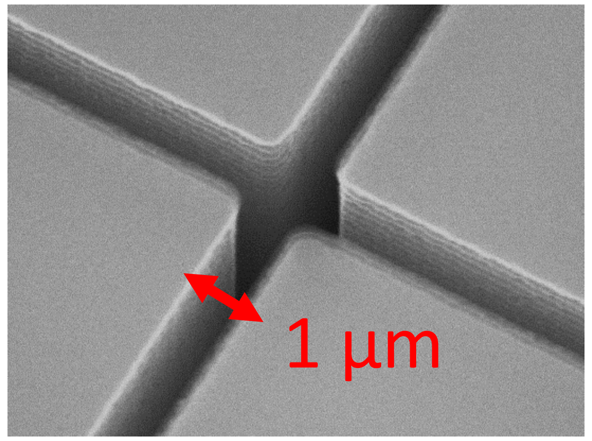
First trials CNM Barcelona.



- Metal Pads AC-coupled to the resistive n+ via dielectric coupling layer
- Not-segmented PGAIN -> virtually 100% FF

Trench-Isolated LGADs (TI-LGAD)

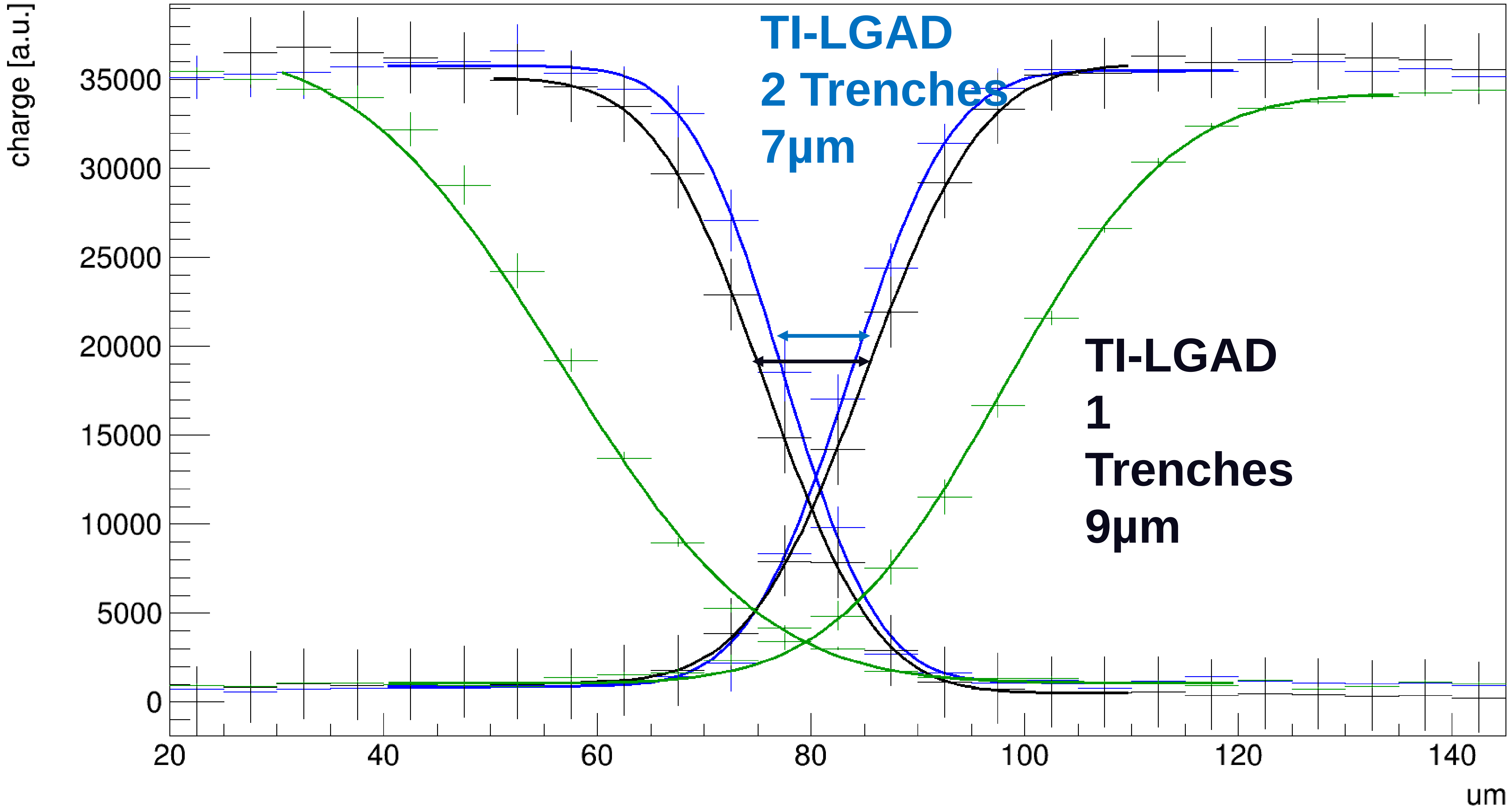




New **LGAD** technology proposed by FBK:

- **JTE and p-stop are replaced by a single trench.**
- Trenches act as a drift/diffusion barrier for electrons and isolate the pixels.
- The trenches are a few microns deep and < 1um wide.
- Filled with Silicon Oxide
- The fabrication process of trenches is compatible with the standard LGAD process flow.

TI-LGAD inter-pad Characterization (TCT laser Setup)

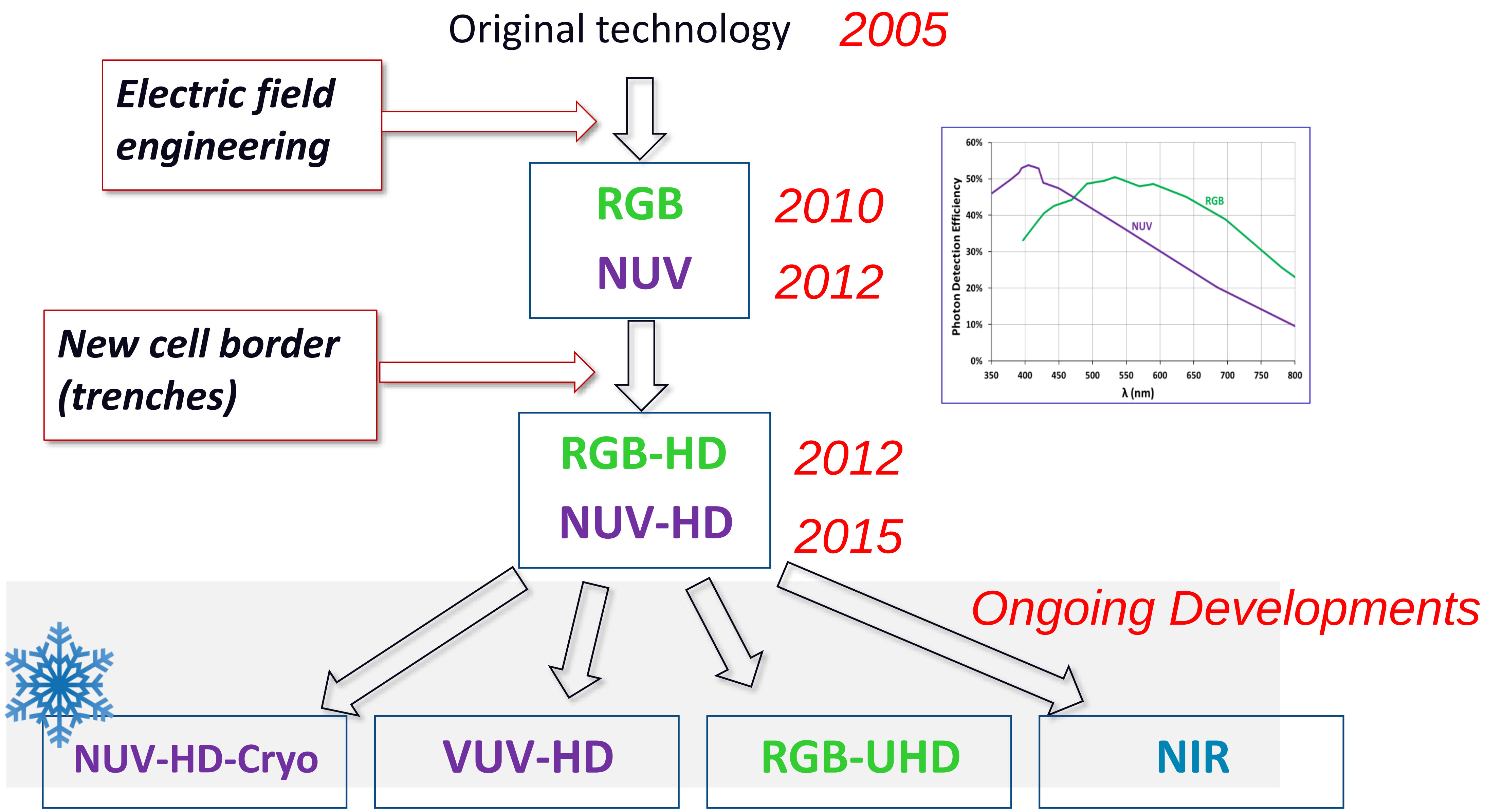


Layout	Effective inter-pad
STD-LGAD	~ 38 µm
1 Trench	9 ± 1 µm
2 Trenches	7 ± 1 µm

Measurements performed in Torino Silicon Lab (University of Torino - INFN)
F. Siviero – 35th RD50 Workshop, November 2019

SiPM, increasing use in science and technology

FBK SiPM technology roadmap



Original technology *2005*

Electric field engineering

RGB *2010*

NUV *2012*

New cell border (trenches)

RGB-HD *2012*

NUV-HD *2015*

Ongoing Developments

NUV-HD-Cryo

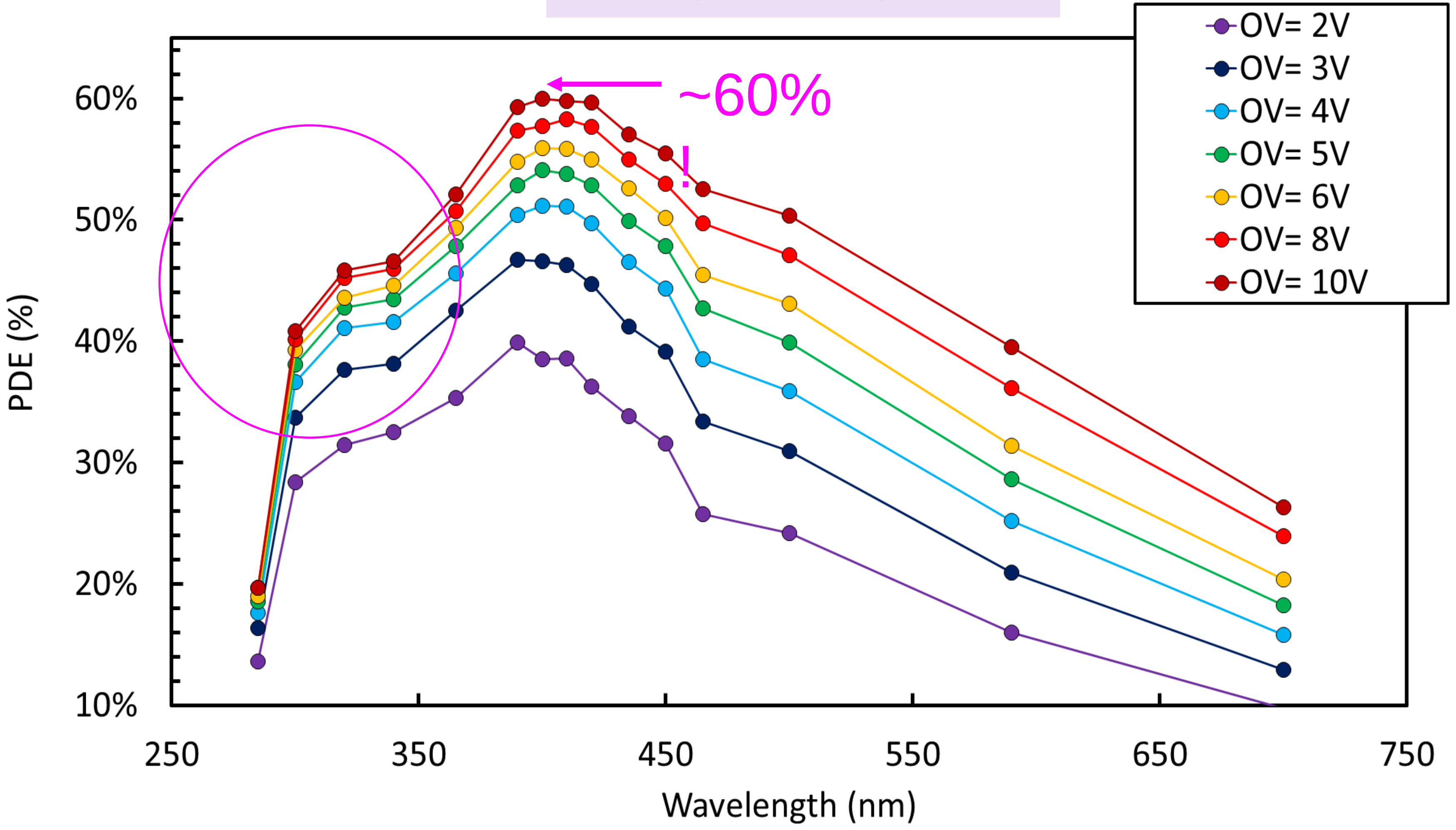
VUV-HD

RGB-UHD

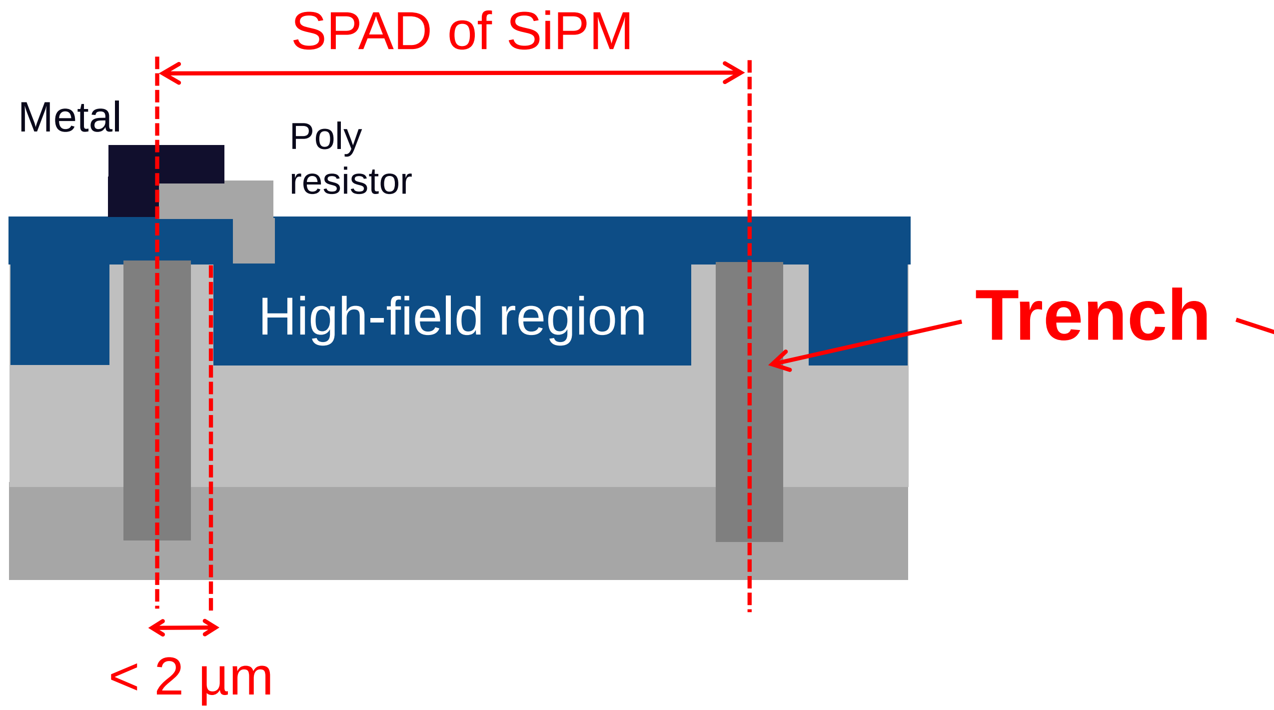
NIR

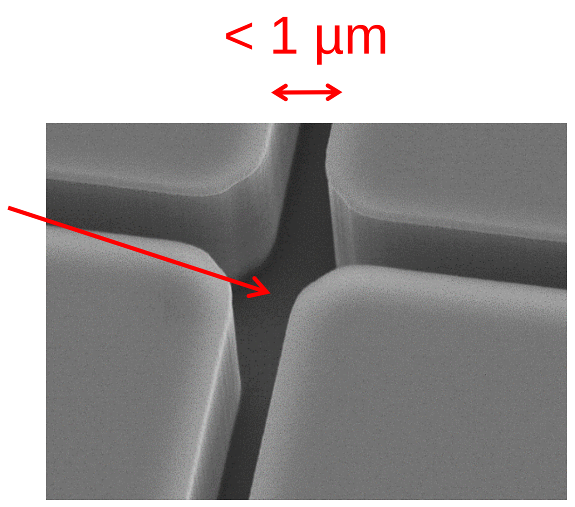
SiPM @ FBK: NUV-HD

35 µm cell pitch



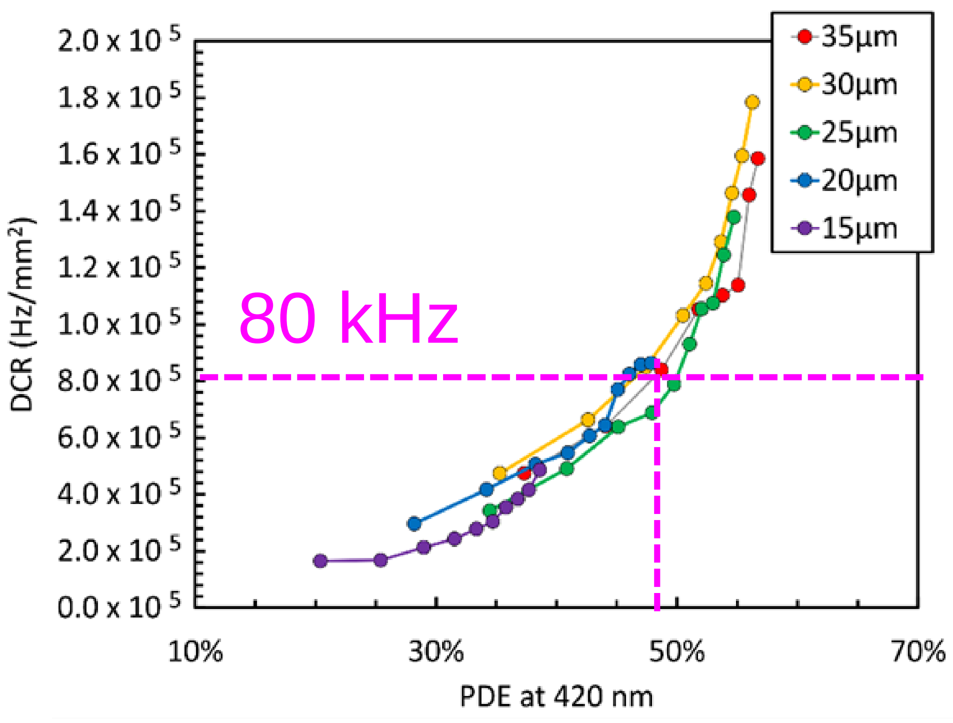
Gola, A et al. (2019). “NUV-Sensitive Silicon Photomultiplier Technologies Developed at Fondazione Bruno Kessler.” *Sensors*, *19*(2), 308.

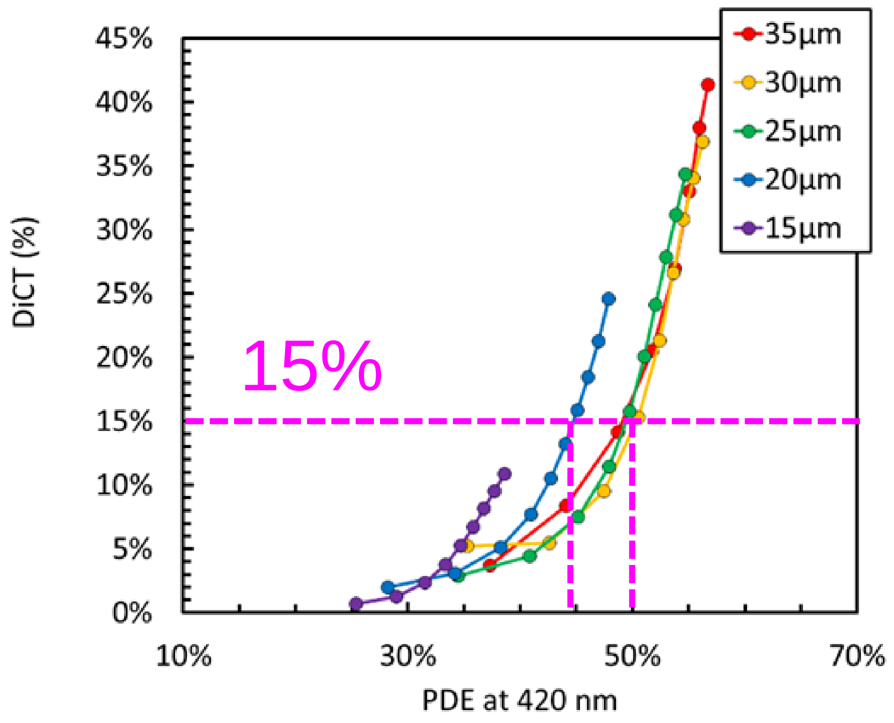




T = 20 C

Photon detection efficiency



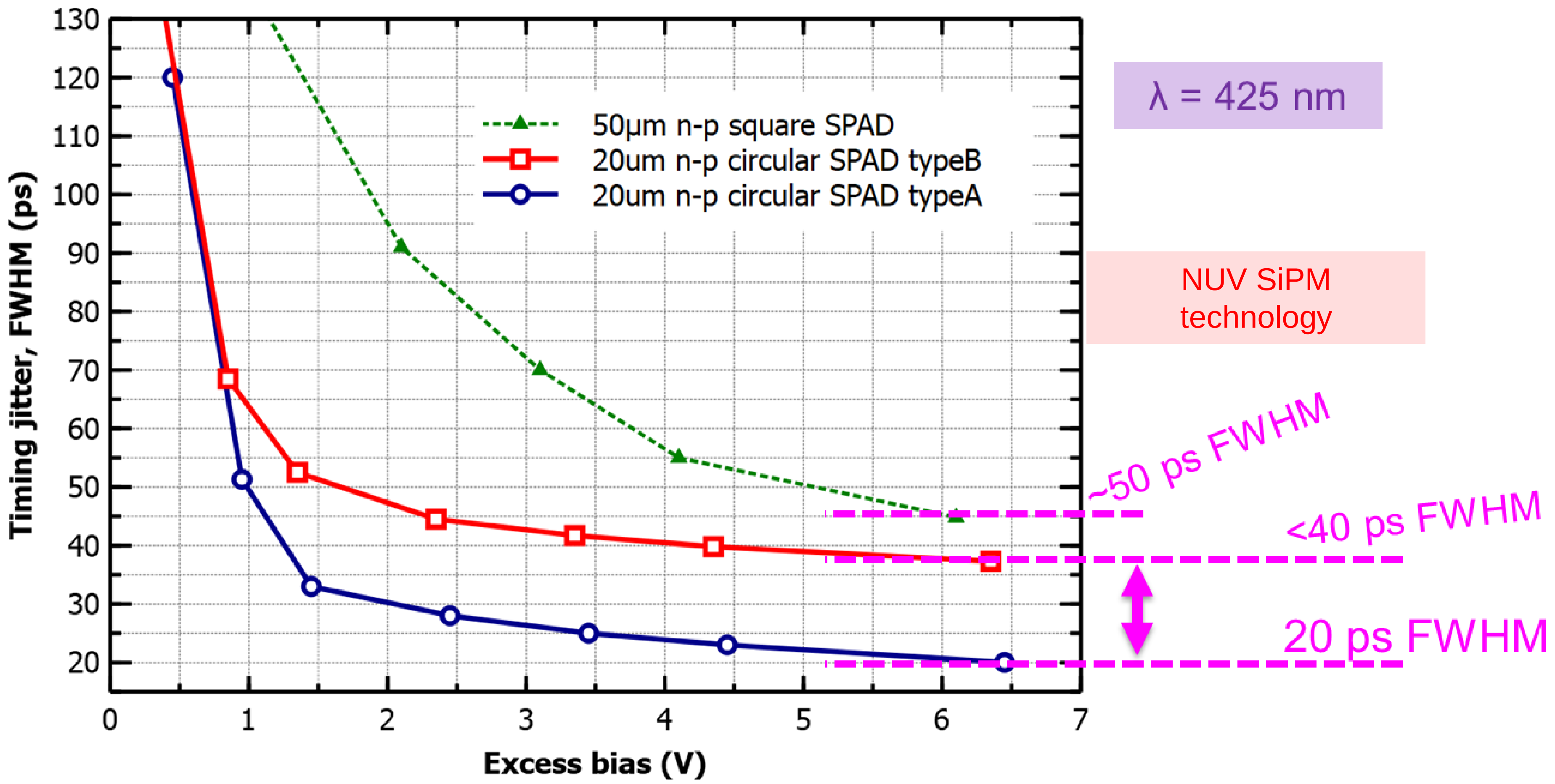


Dark Count Rate

Optical Crosstalk
(Correlated Noise)

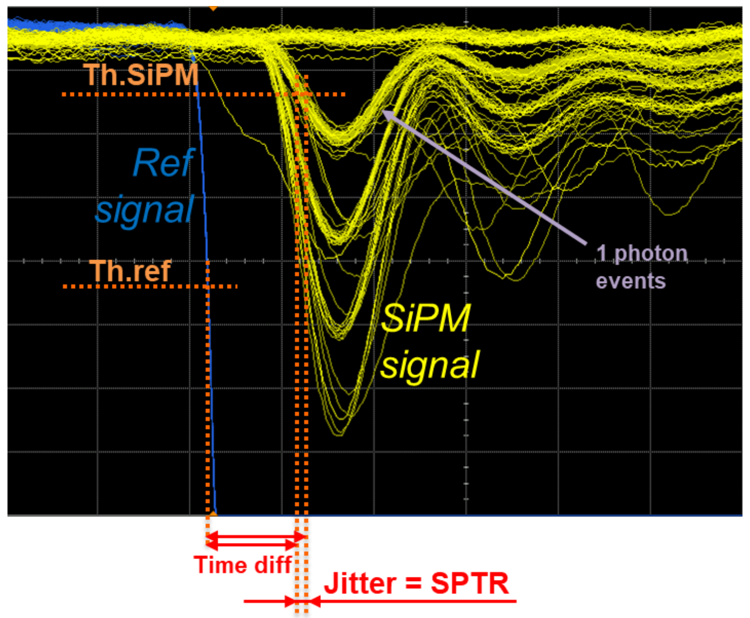
Timing performance of NUV-HD

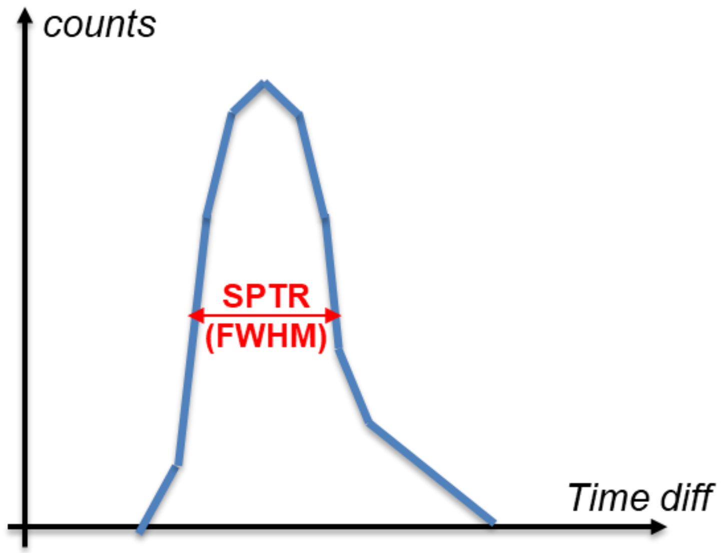
Single Photon Time Resolution (SPTR)

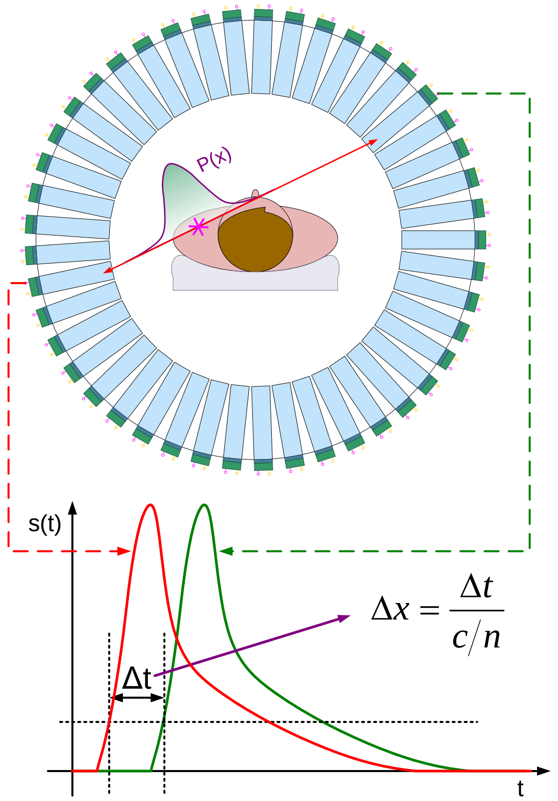


λ = 425 nm

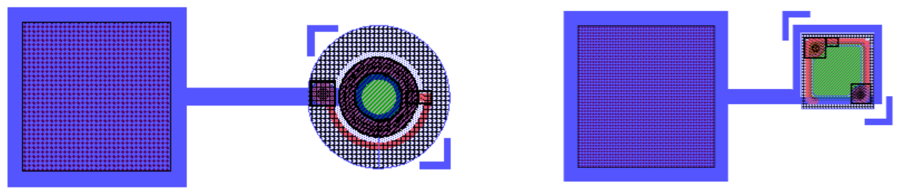
NUV SiPM technology







ACTIVE AREA LAYOUT	Diameter / side (µm)	Metallization
circular	20	Covered edges (A) with metal
circular	20	uncovered edges (B)
square	50	uncovered edges



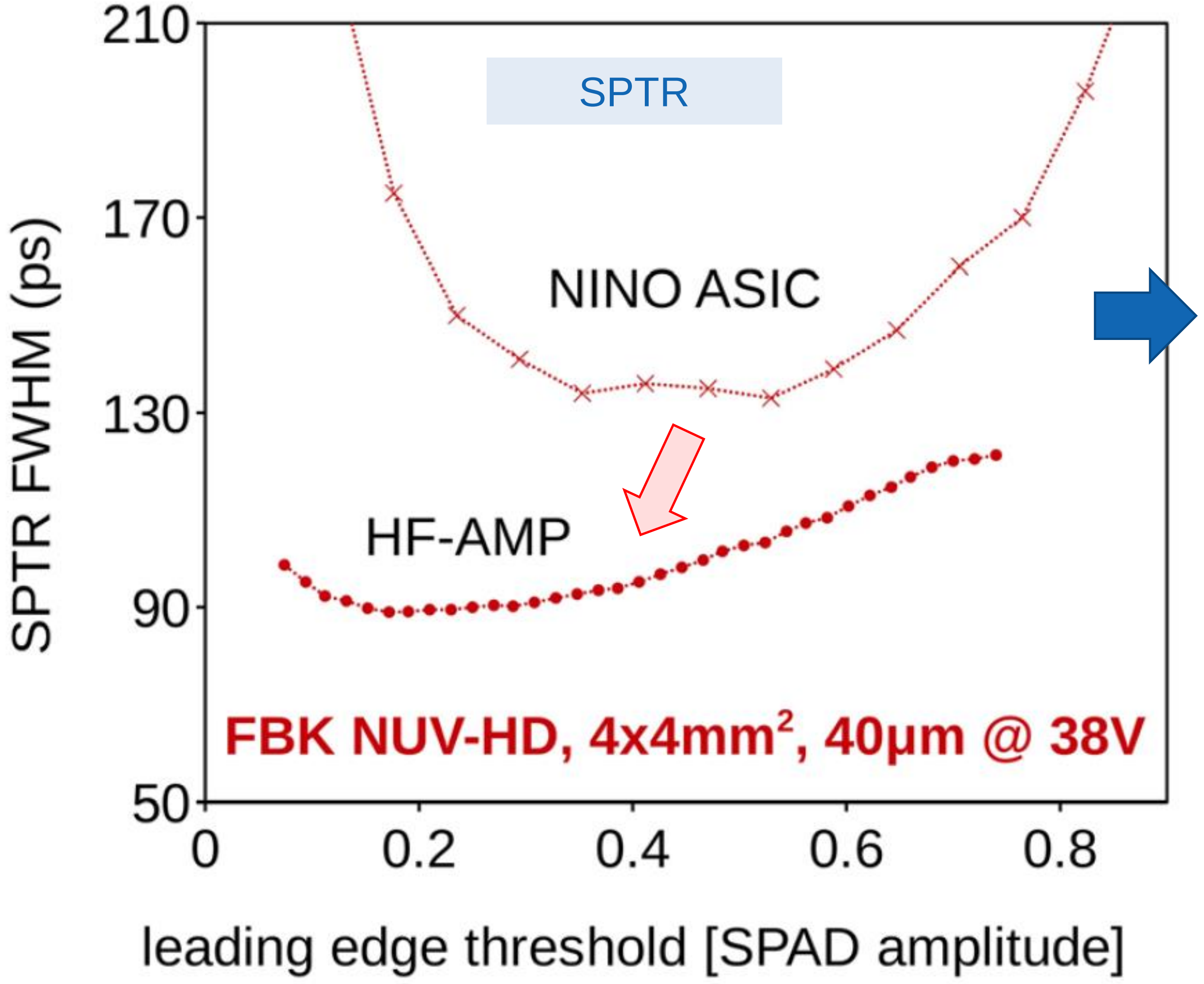
1) Worse charge collection at SPAD edges
2) Signal pick-up is also very important

Covering the SPAD edges with metal *reduces the SPTR to 20 ps*

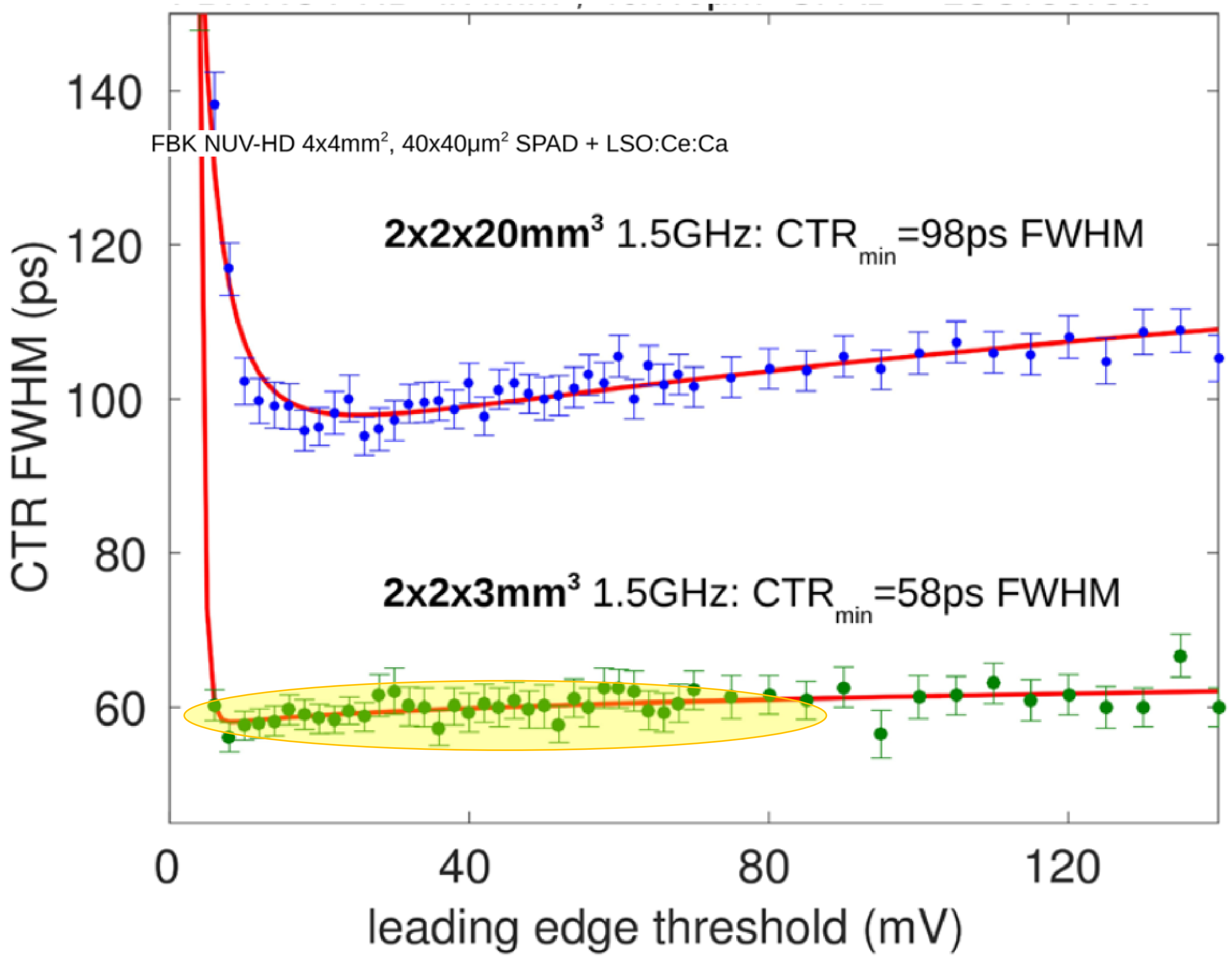
SPTR and CRT with LSO – 4x4 mm^2 SiPMs

Collaborations with:
- CERN (P. Lecoq, S. Gundacker)
- Stanford (Craig Levin, Joshua Cates)

SPTR

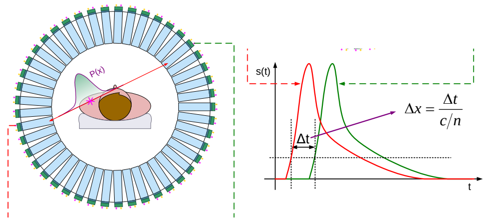


CRT with **LSO:Ce:Ca**

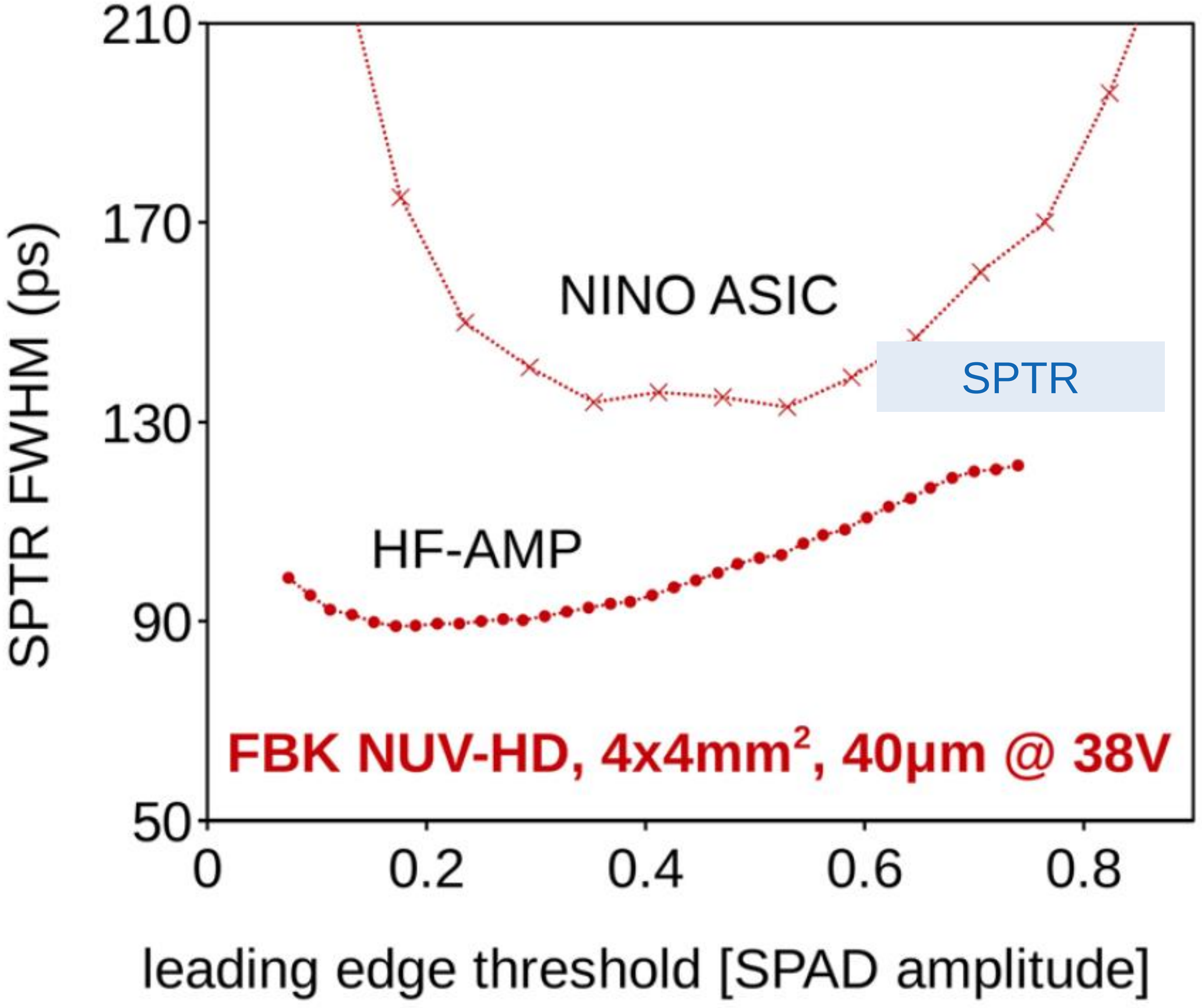


Excellent SPTR also with large-area SiPMs, employing improved electronics.

Coincidence Resolving Time (CRT) with 511 keV gamma photons

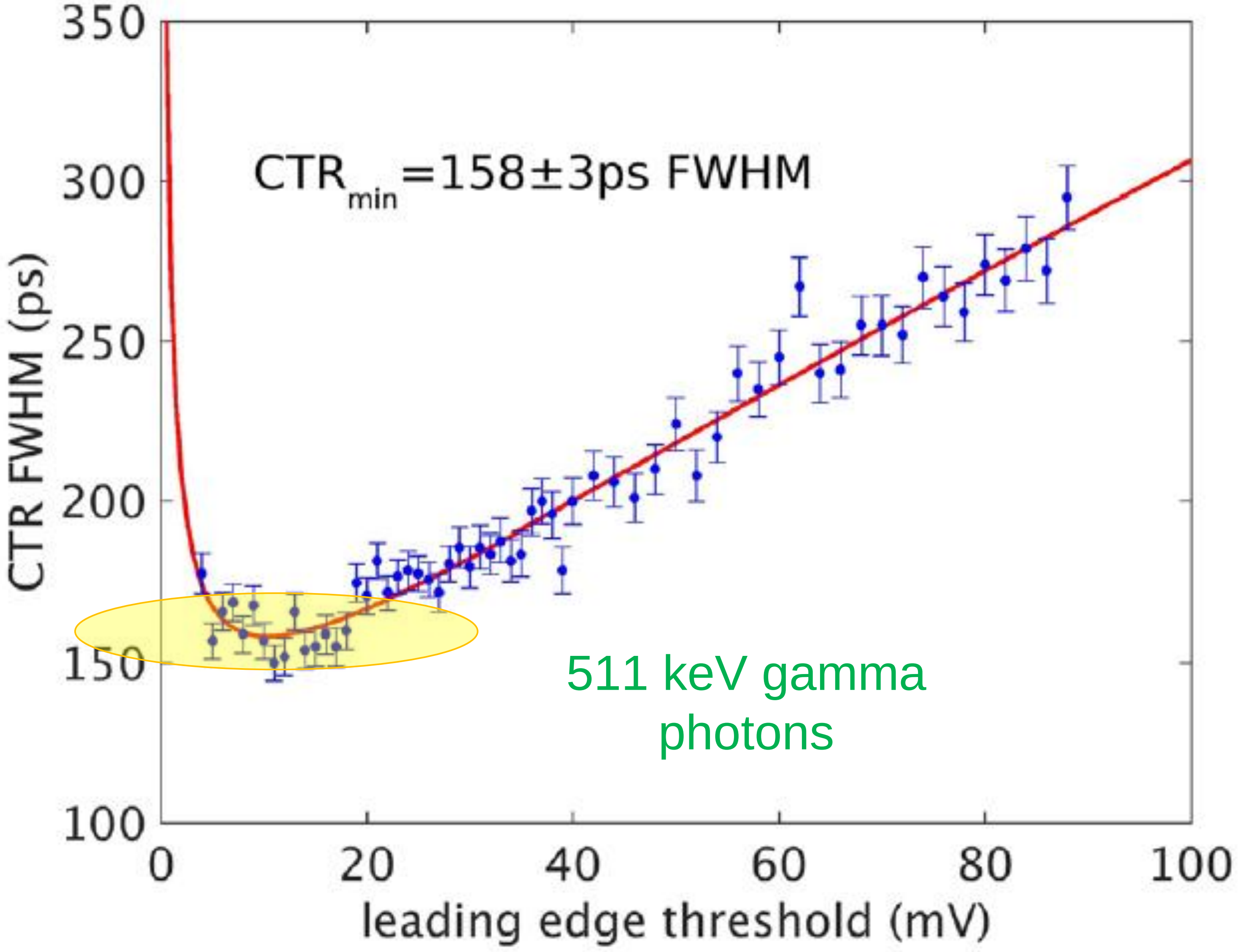


SPTR and CRT with BGO – 4x4 mm^2 SiPMs



SPTR

CRT with **BGO**



511 keV gamma photons

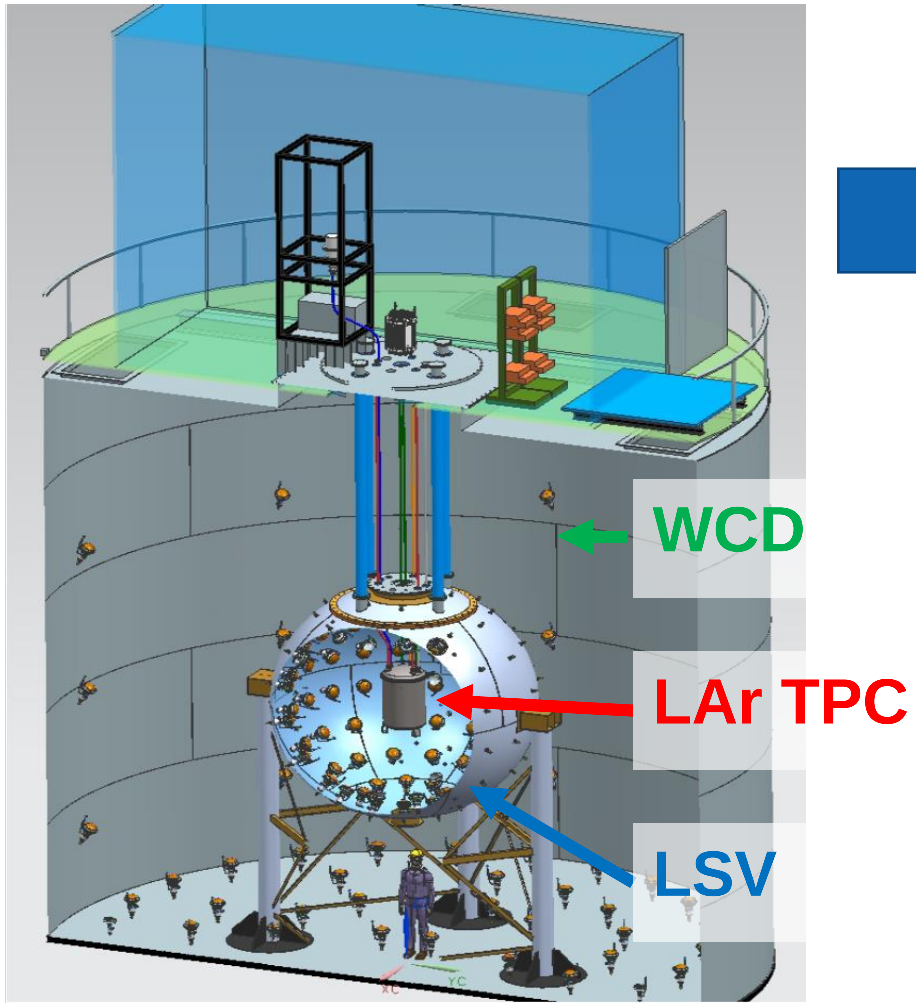
Improvement of SPTR is, possibly, even more important for BGO readout:
- Timing is improved with Cherenkov light detection

NUV-HD SiPMs for big science

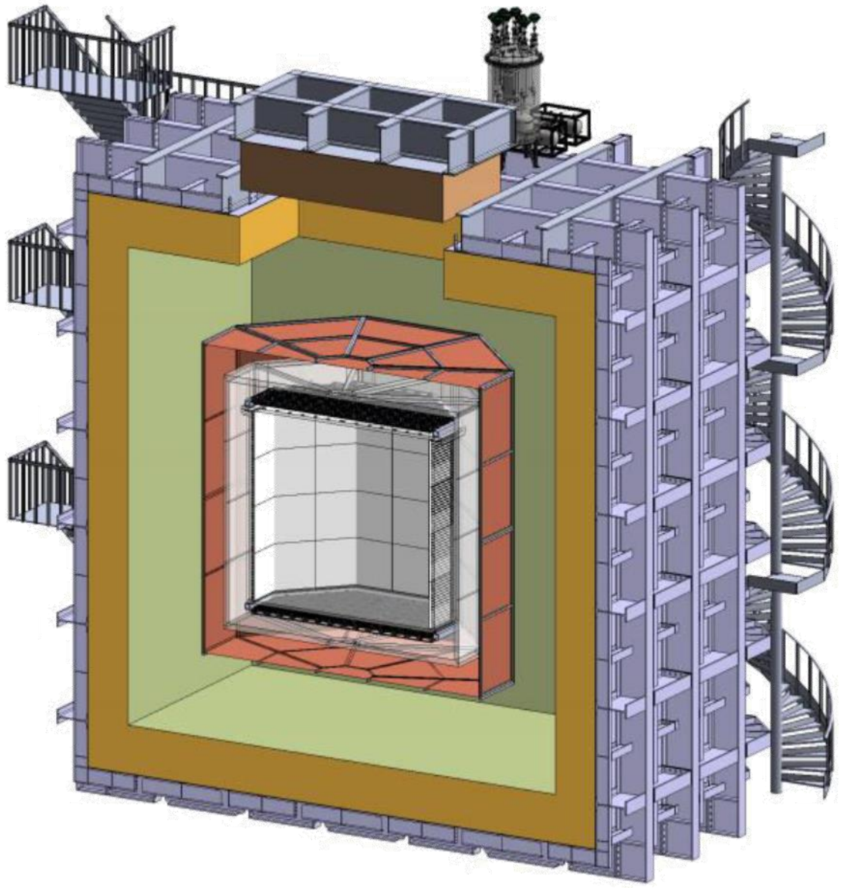
DarksSide-20k Experiment

> **3-year long collaboration** between FBK and DarkSide to **optimize performance** of the NUV-HD technology for the **specifications of the project**.

darkside
two-phase argon TPC for Dark Matter Direct Detection

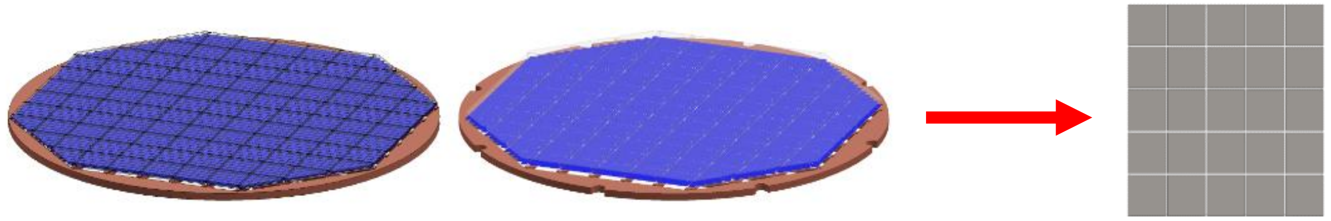


DarkSide-50
PMT-based TPC



~ 23t of UAr

TPB WLS: emission at 400 – 450 nm



2 light readout planes: 20 m^2 (+ veto)

SiPM tiles

DarkSide-20k
SiPM-based TPC

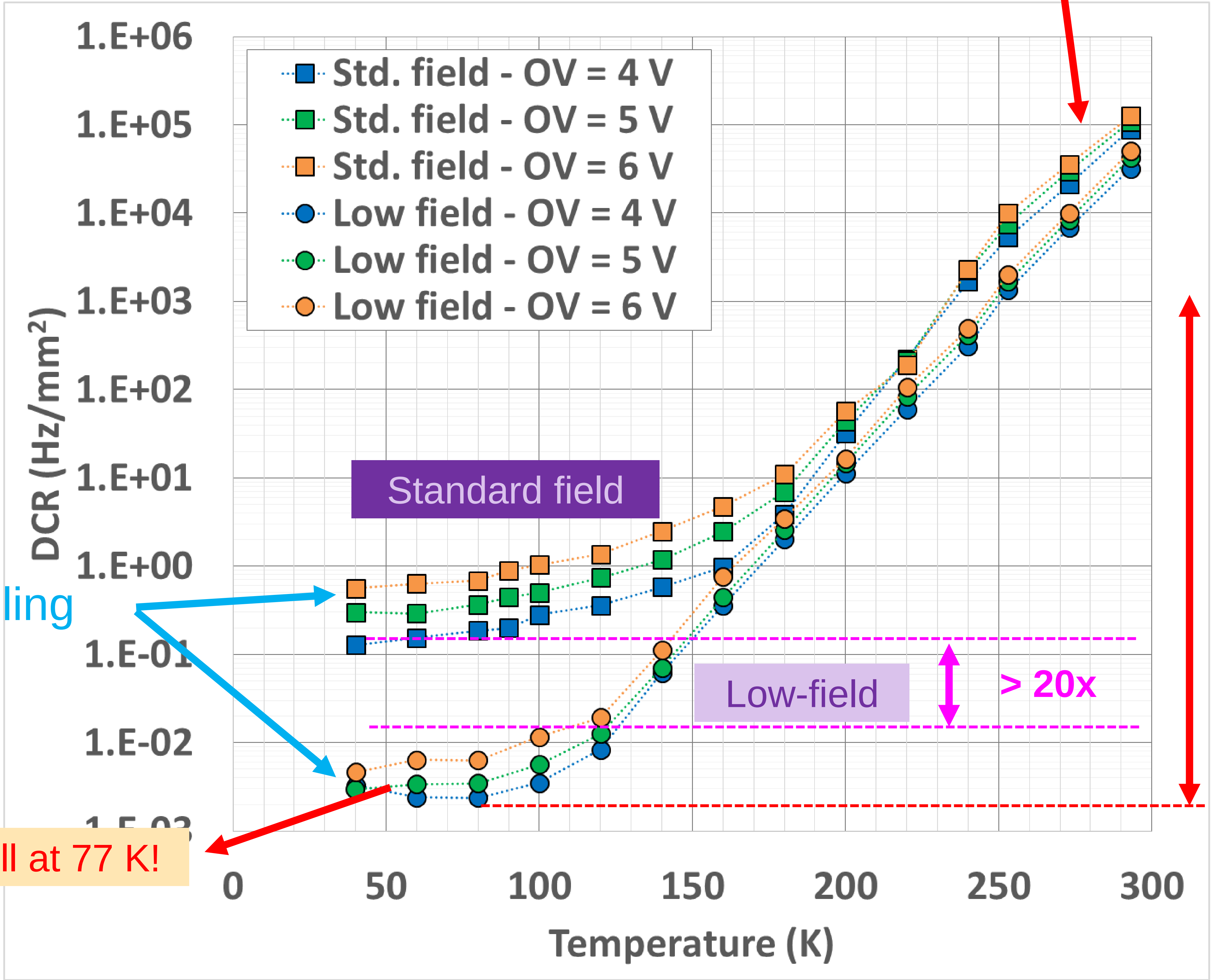
Satisfying DS specs

Primary DCR reduction

Thermal generation

25 µm cell

Tunneling



> 7 orders of magnitude !

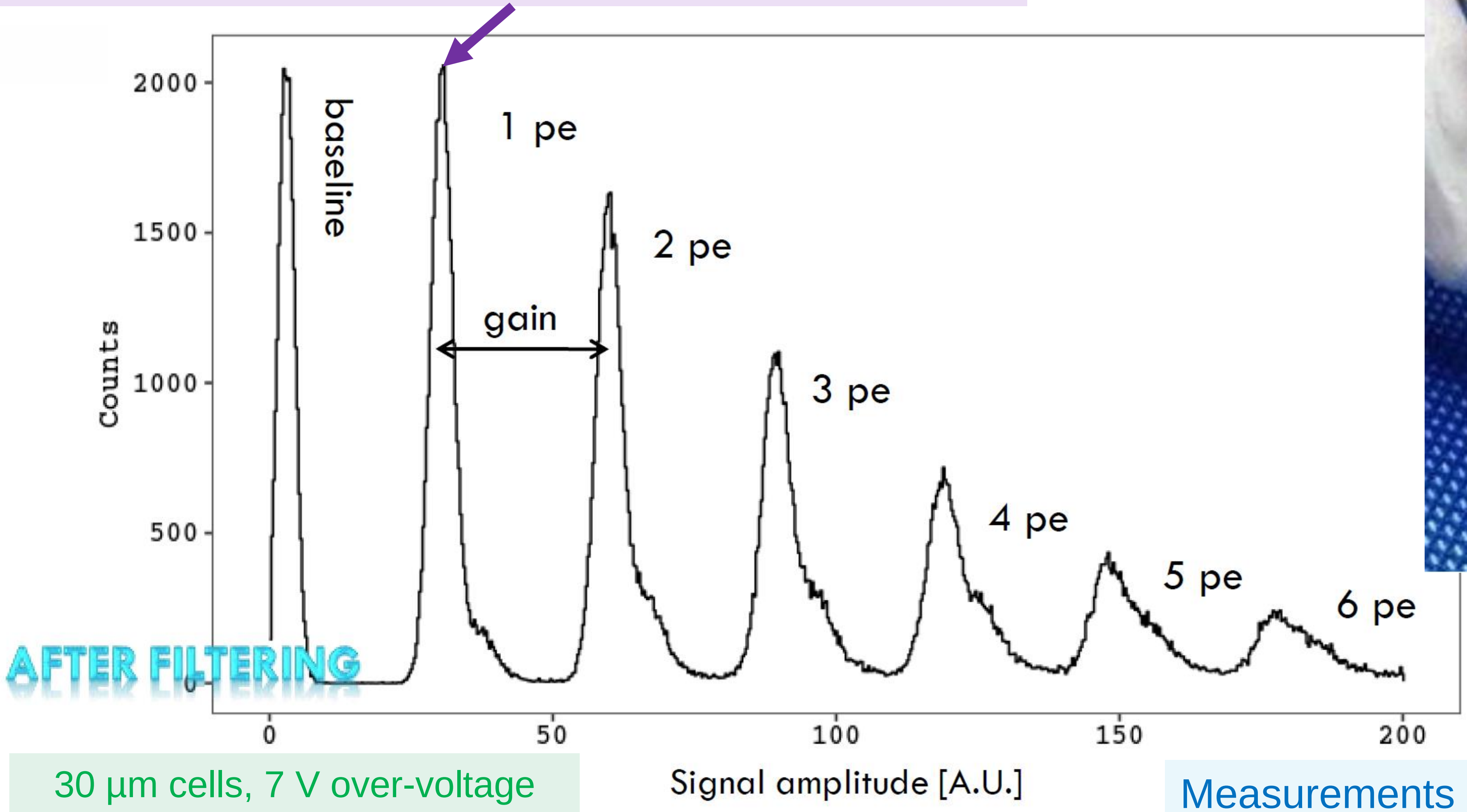
0.3 counts per day per cell at 77 K!

A 10x10 cm^2 SiPM array would have a total DCR < 100 cps!

DS-20k – Photo-detector module

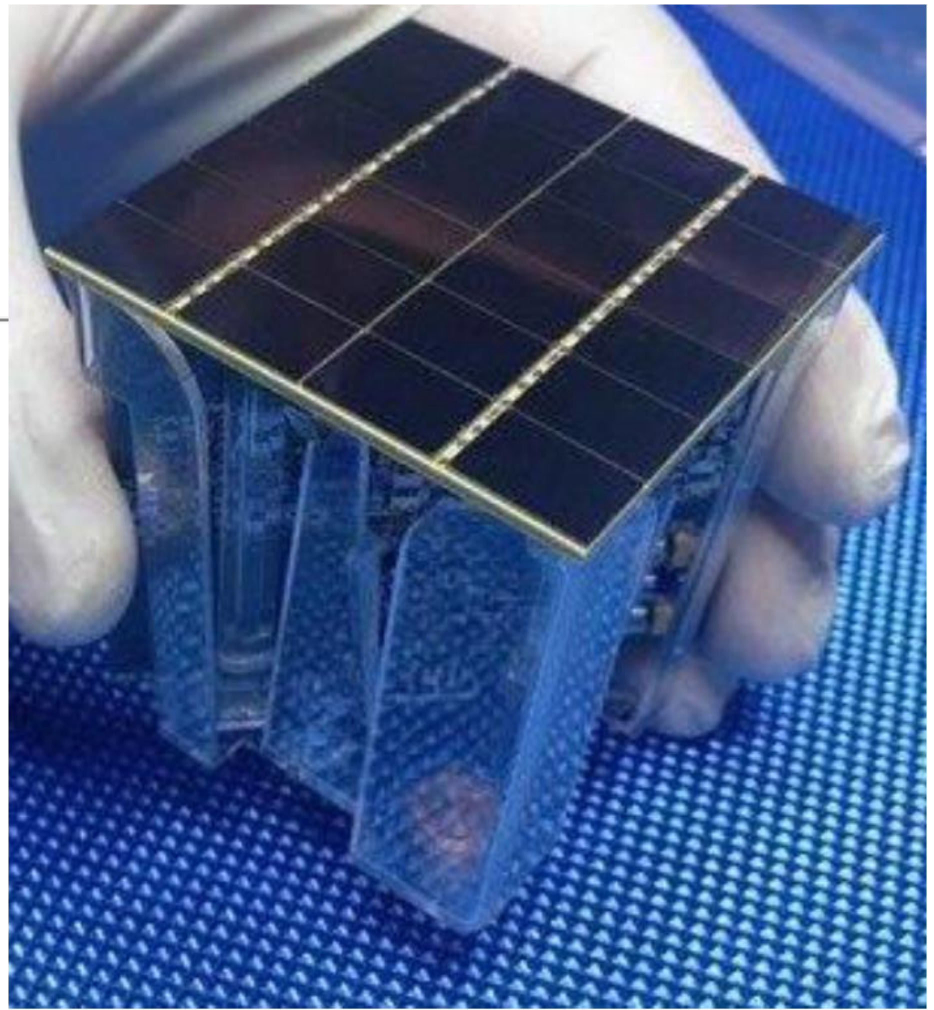
Photo Detector Module (PDM)

Good gain uniformity of ~ 3M SPADs at 77 K



30 µm cells, 7 V over-voltage
~500 ns recharge time

Measurements from LNGS



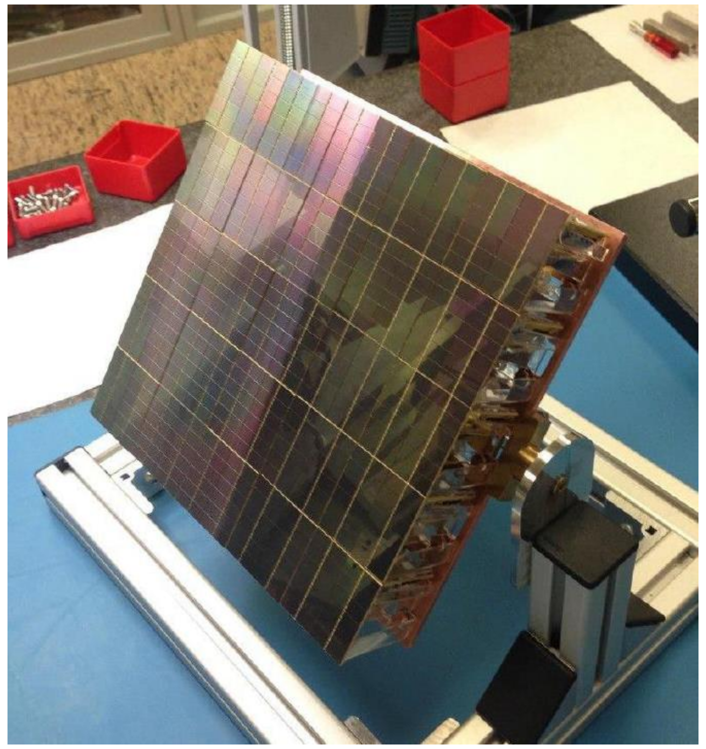
- 24x 12x8 mm^2 SiPMs (~ 1 cm^2)
- Front-end cryogenic pre-amplifier with differential output
- Sensitivity from single photon to few thousands photons

PDM Specifications:

- 5x5 cm^2 active surface
- PDE @ 420 nm > 40%
- DCR < 0.08 cps/mm2
- Baseline hit rate ≤ DCR ↔ SNR > 8
- Timing resolution ~ 10 ns

Integration window of 6 µs

- 20.7 m2 ◦ 6 µs ◦ DCR = 10 pe

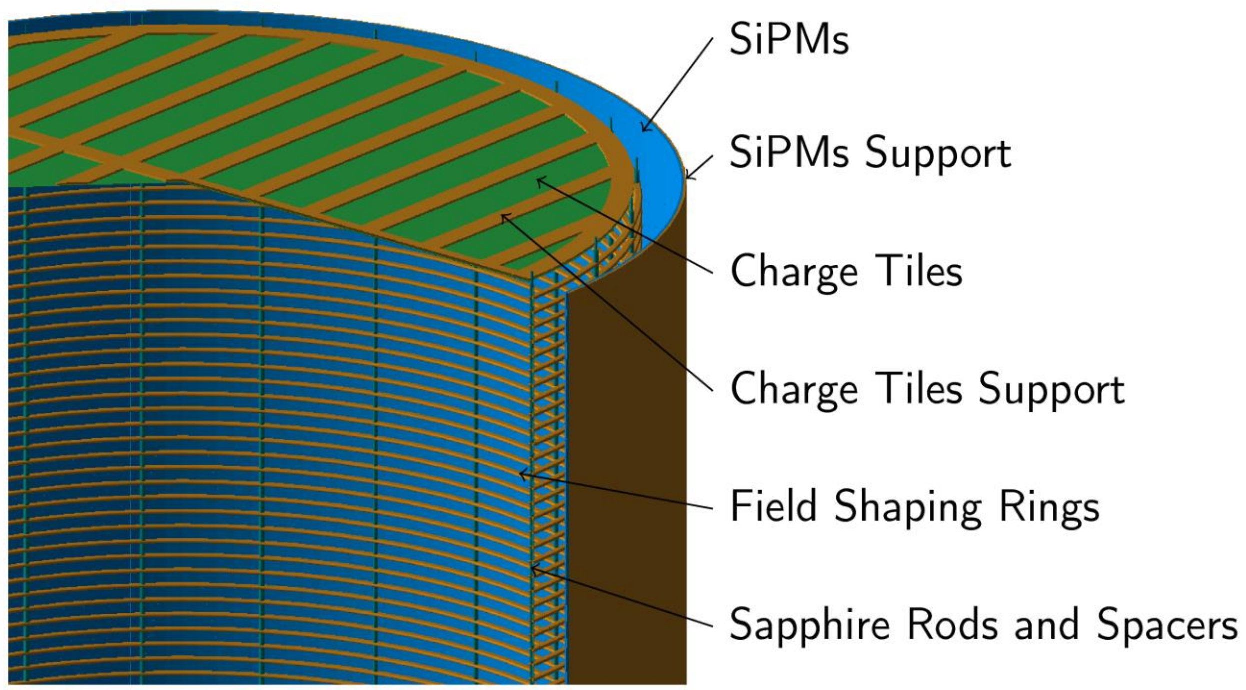


DS motherboard with 25 PDMs, power distribution and signal transmitter.

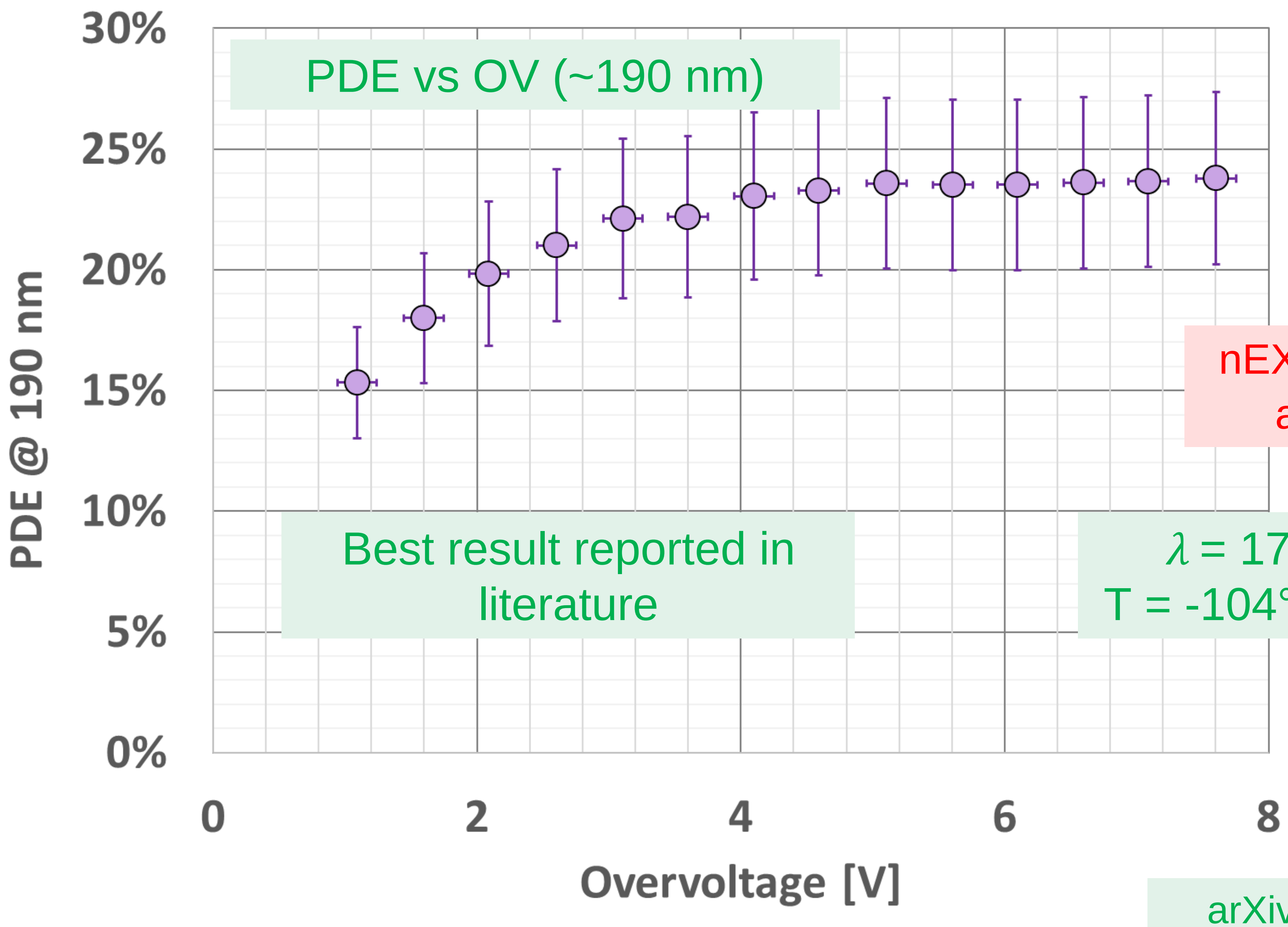
VUV–HD

0νββ with LXe

R&D carried out for nEXO to develop SiPMs capable of direct detection of photons at 178 nm and operation at -100°C



- TPC Filled with LXe
- 4-5 m² SiPM
- Single VUV photon sensitive (**178 nm**)
  - > 15% efficiency
  - < 20% correlated noise
  - < 50 mHz/mm² DCR
- Very low radioactivity
  - Silicon is generally very radio pure



PDE vs OV (~190 nm)

Best result reported in literature

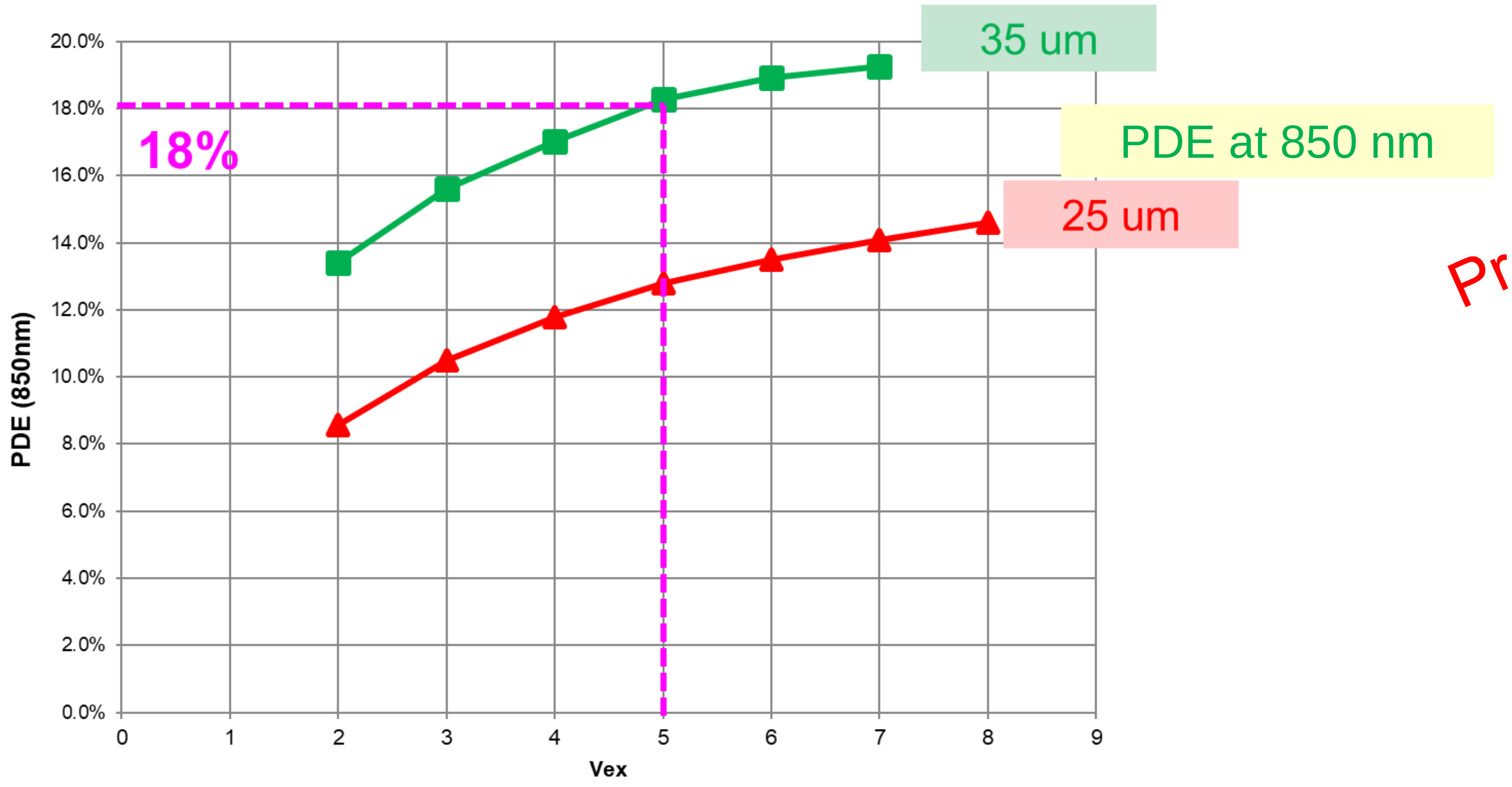
λ = 175 nm
T = -104°C (LXe)

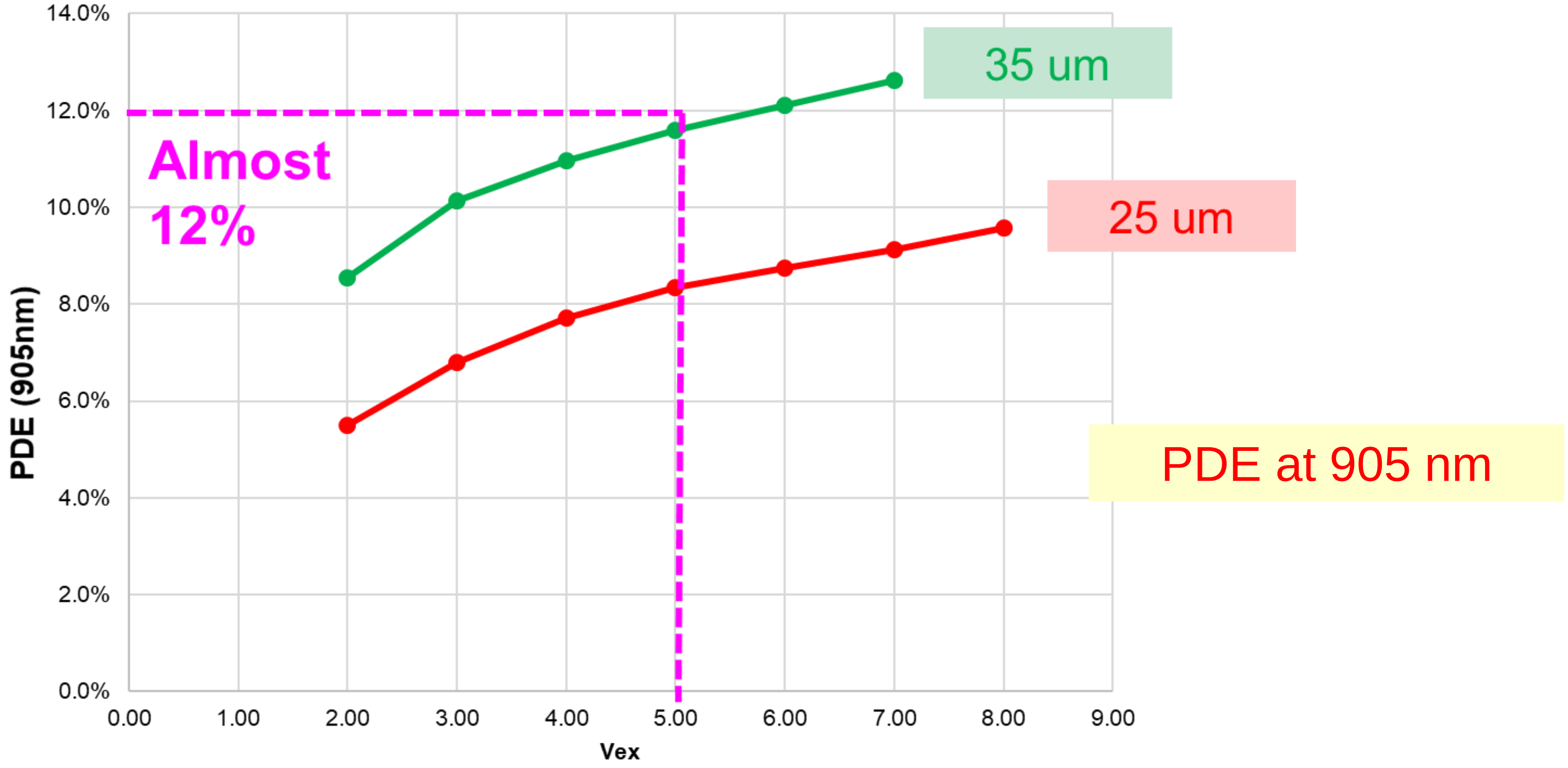
nEXO experiment at Stanford

arXiv:1904.05977

NIR-HD PDE

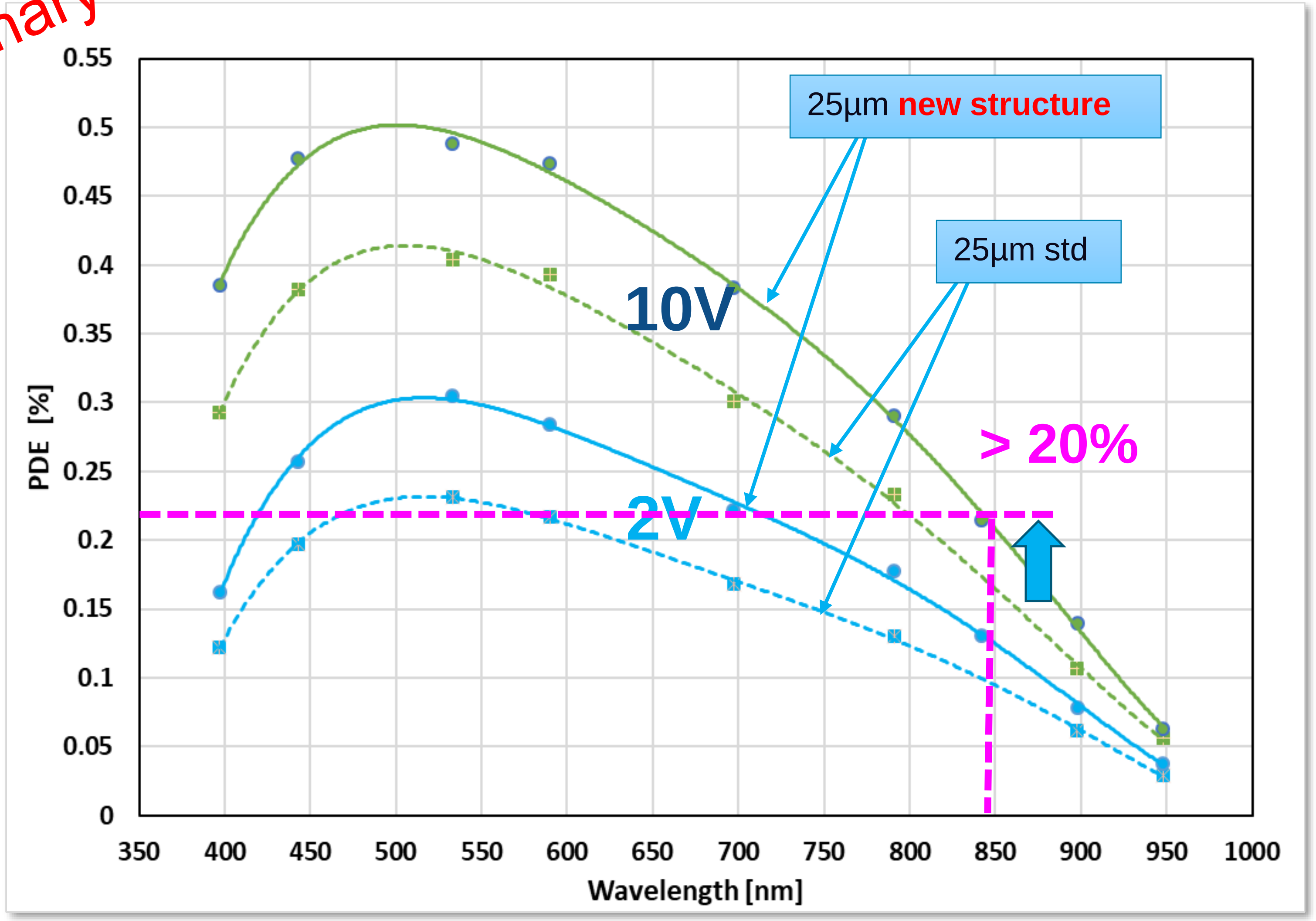
State of the art performance for silicon, single-photon detectors!





New NIR-HS developments

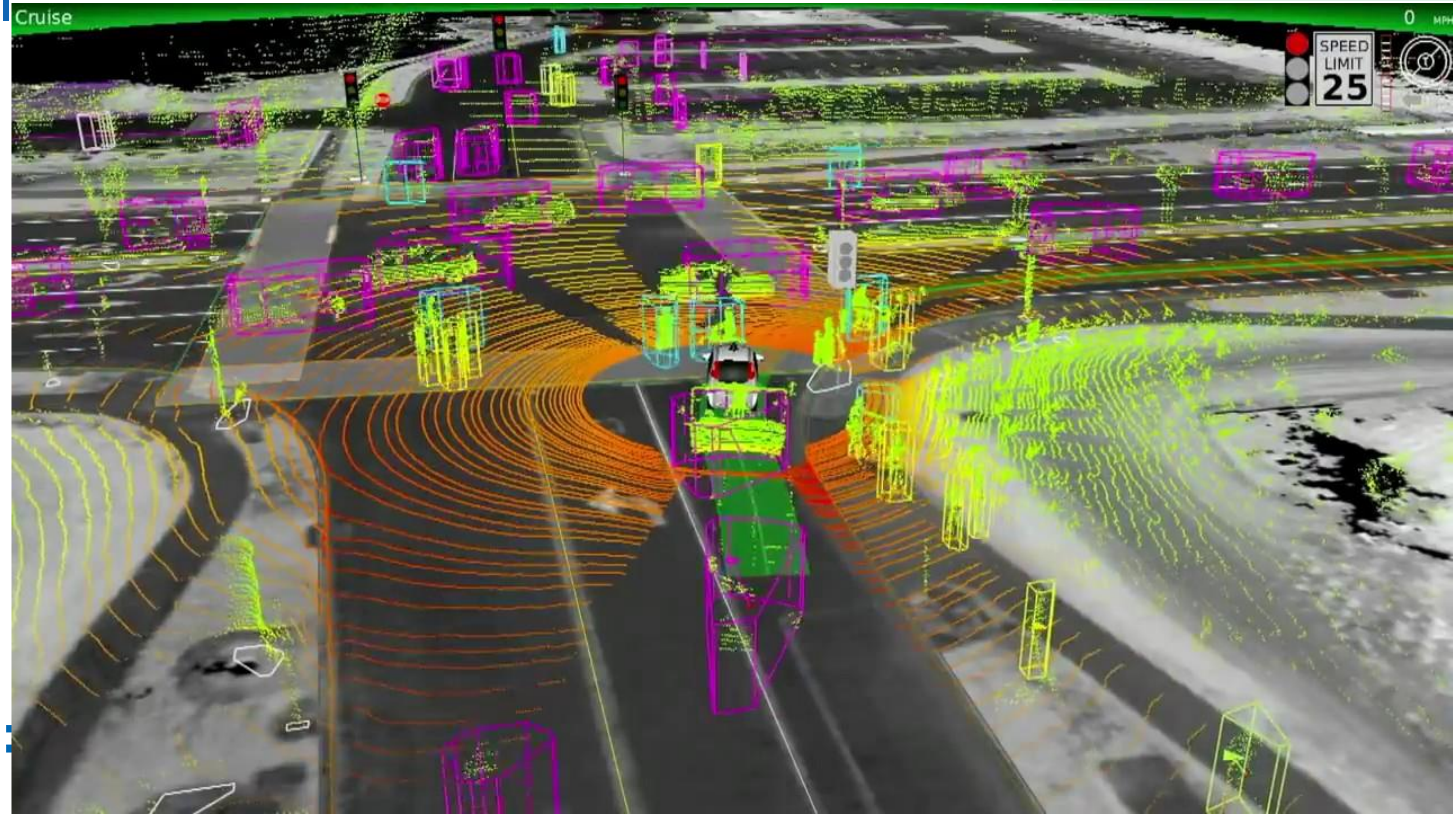
Preliminary results



With new cell termination structures, PDE is significantly improved in almost all the spectrum

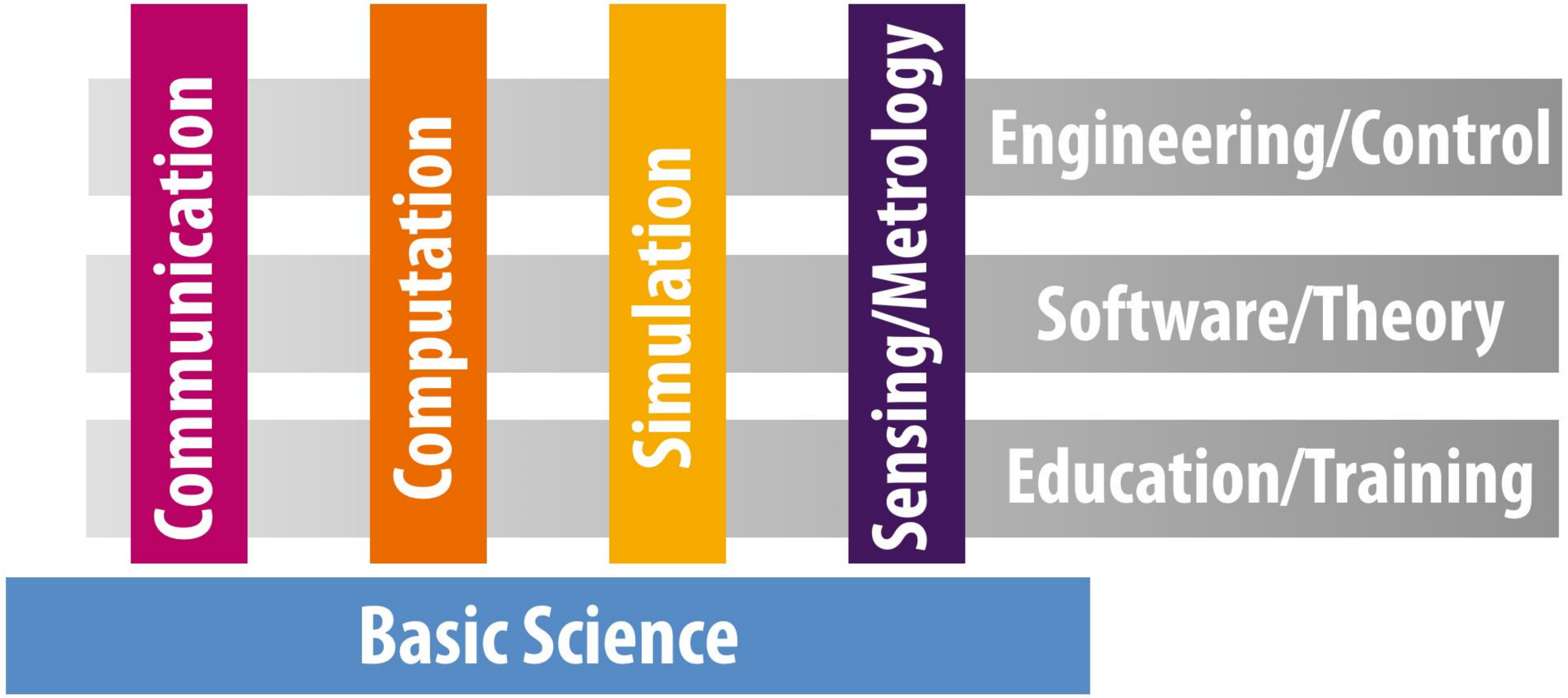
Application of NIR-SiPMs

LiDAR for Automotive



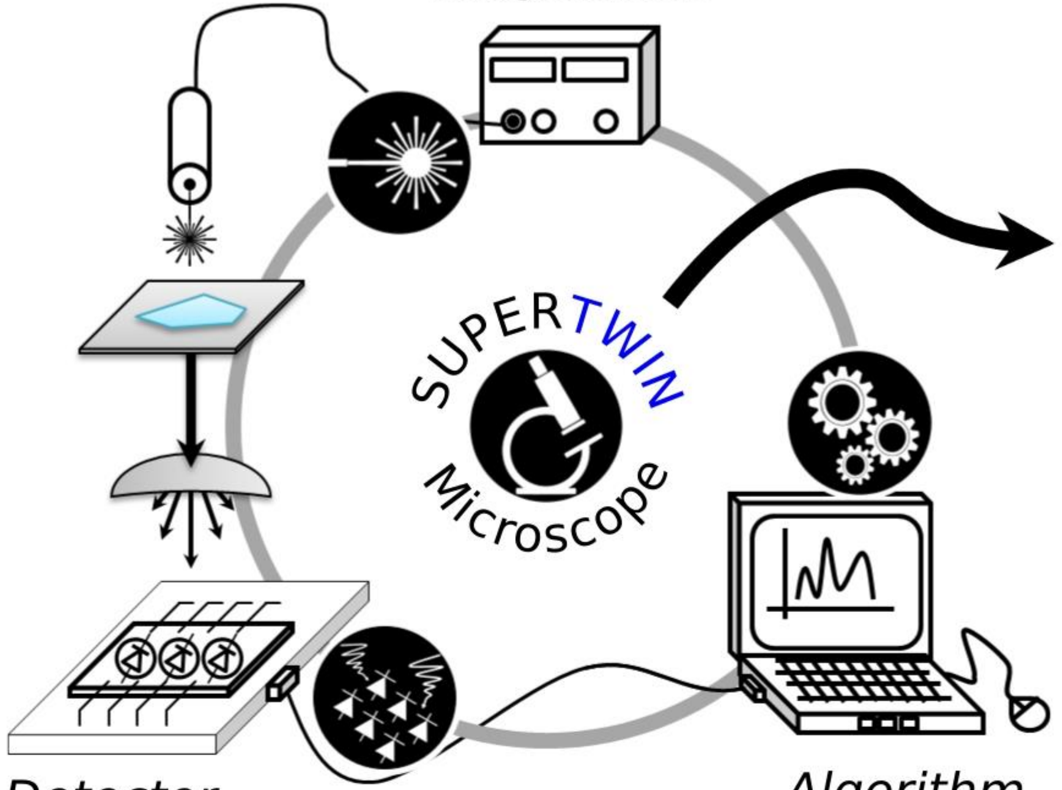
Quantum Technologies

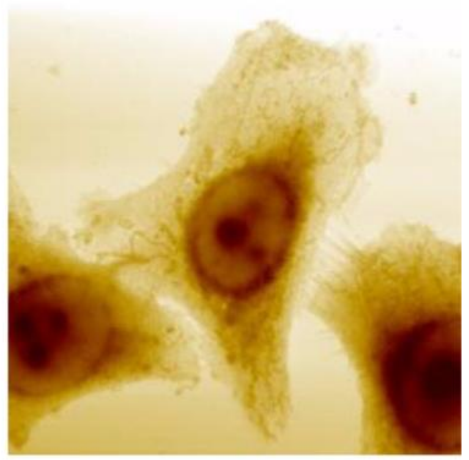
The pillars of the Quantum Flagship



Suitable novel devices will be in high demand for development in all of these fields!

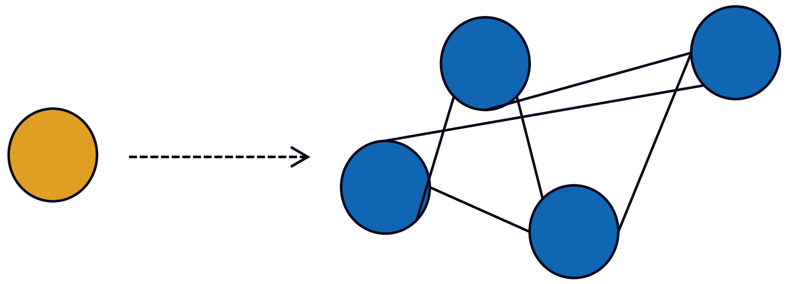
Quantum microscopy: SUPERTWIN



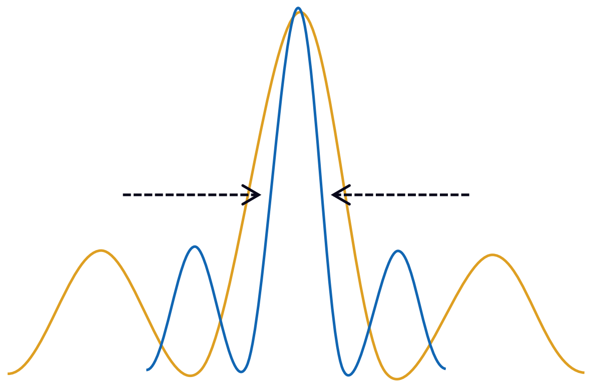


SUPERTWIN concept

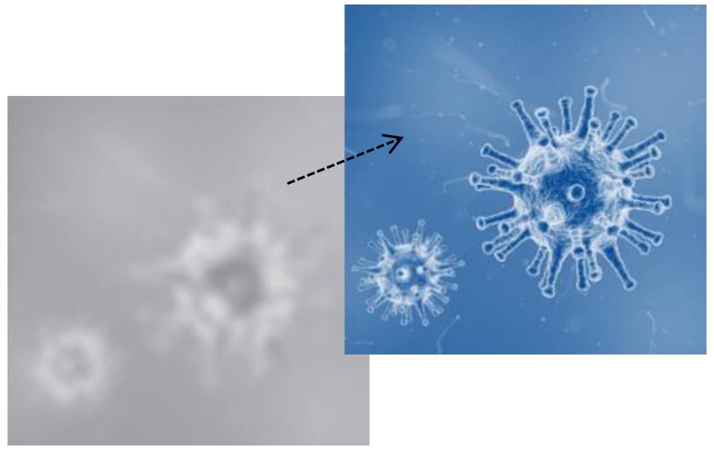
Nth entanglement



:N diffraction



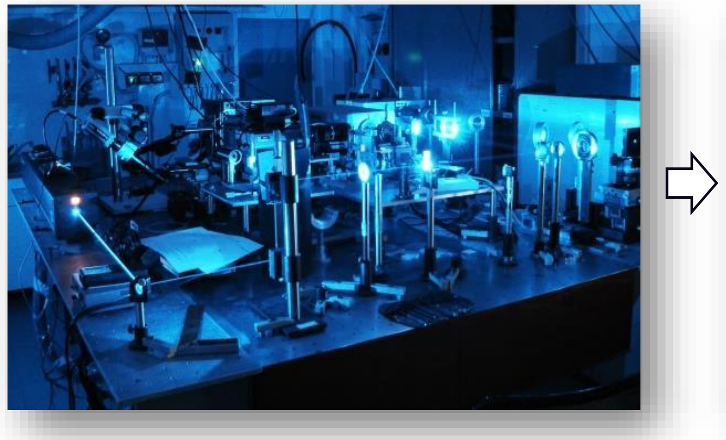
× N resolution



Quantum Optics and Photonics on Chip

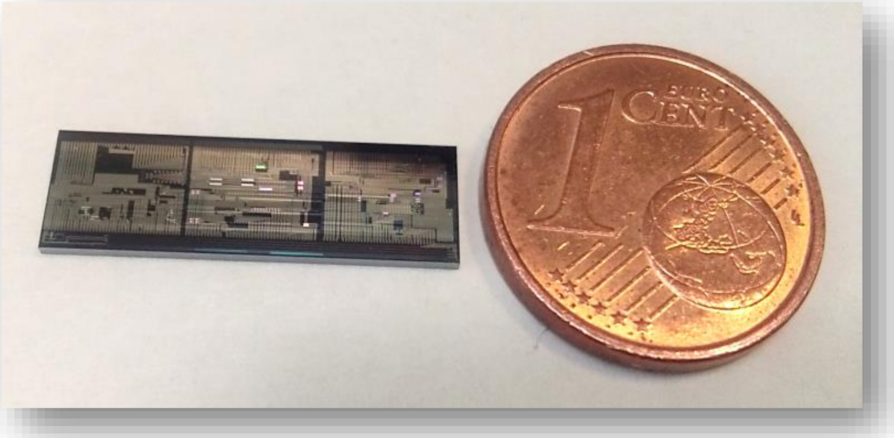
QIP (quantum information processing) – **photons** as **ideal candidates** (long coherence @ room temperatures)

Miniaturisation – **Photonic Integrated Circuits** (CMOS-compatibility)



Area: 10 m^2
Volume: 10 m^3

⇨



Area: 100 mm^2
Volume: 0.01 mm^3

Sqeesing the area by **million** times!

Volume reduction by **10^{11}** times!

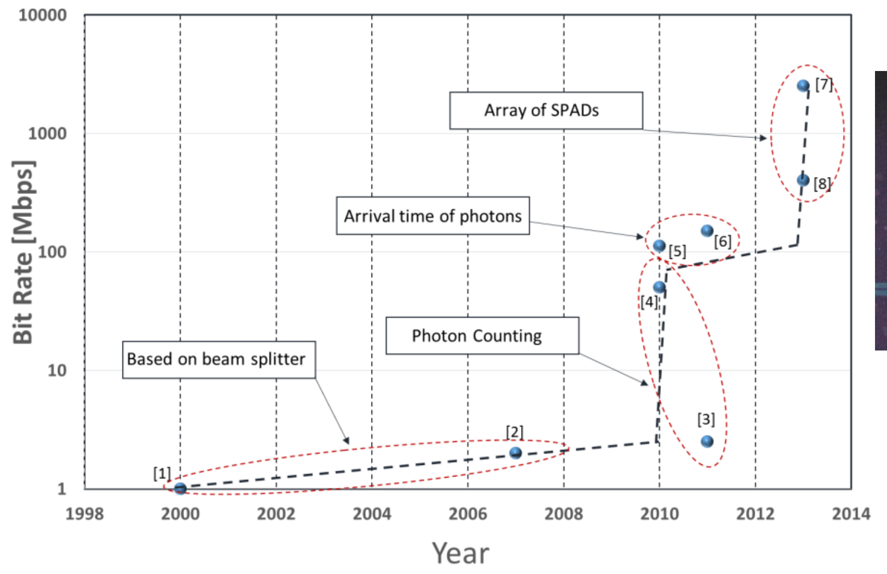
- **Silicon-on-Insulator SOI** (waveguiding layer c-Si, 250-500nm, $\lambda > 1\mu m$)
- **Silicon Nitride** ($\lambda > 0.3\mu m$, from VIS to MIR)
- **Hybrid-integrated** III-V on Si (light source, GaAs, InP and their ternary alloys)
- **ASIC** (application-specific integrated circuits)
    - SiN/SiO2 multilayered waveguides (optical nonlinearities and VIS-MIR transparency)
    - Si-nanocrystals in SiO2 host (VIS-NIR light emission)

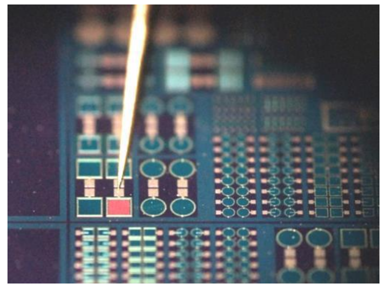
Quantum Random Number Generator

Important in
- ○ secure communications
- ○ stochastic simulations
- ○ gaming

QRNGs are a subset of hardware RNGs, in which randomness is obtained using quantum phenomena.

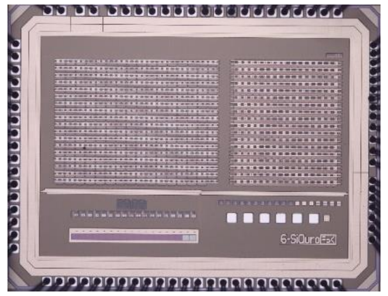
Project develops QRNG based on FBK's SPAD technology and LEDs in silicon developed by UniTN and FBK.





Si-LED

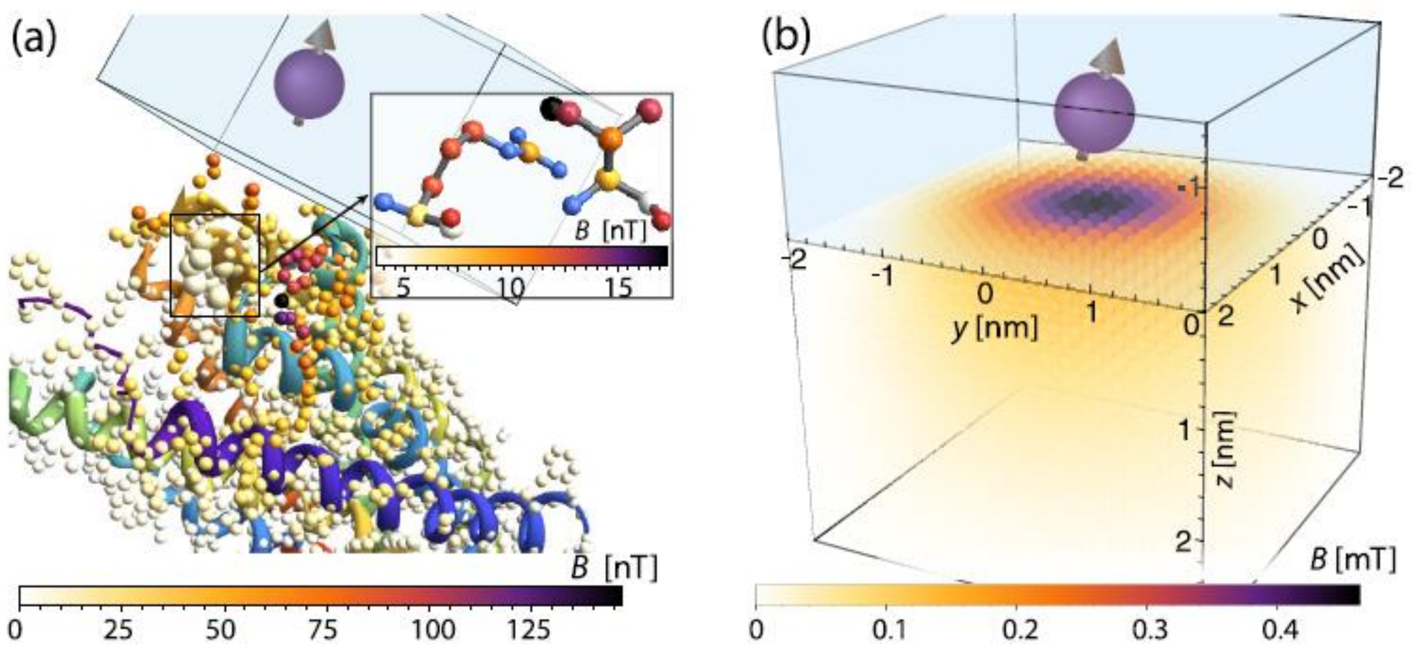
–



CMOS SPAD detector

Collaboration: UniTN: Nanosciencelab, Cryptolab, FBK-CMM and Telsy;

Cancer markers Quantum sensing with DIAmond DEfect MAgnetometry: Q-Diadema (Q@TN)

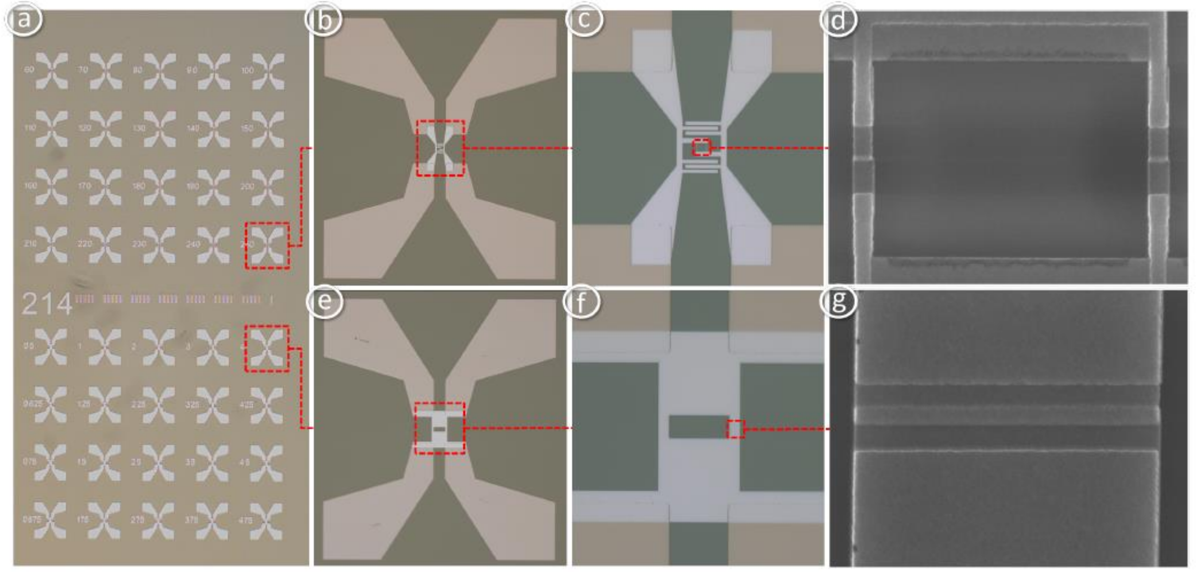


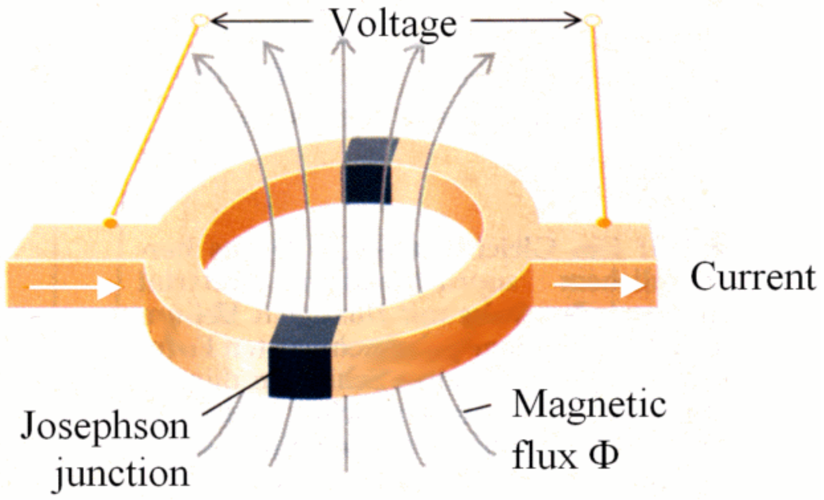
NV centres to detect the individual position of nuclear spins to reconstruct the structure of a protein accommodated on a bulk diamond sensor. In this domain, the frequency resolution of NMR instruments is too low. NV polarization leakage due to entanglements to specific nuclear spins under magnetic field gradients allows for the reconstruction of nuclear spin positions with unprecedented resolution.

SupercOnductive Circuits for Casimir Effect: SOCCEr

High sensitivity sensing:
Josephson junctions and SQUID’s

Fabrication of coplanar superconducting waveguides and resonators closed by a SQUID device to create a tunable mirror for quantum optics experiments to observe the Dynamical Casimir Effect (DCE) and related zero-point quantum fluctuation effects in the microwave spectral domain.





Hetero-integrated solid-state laser for optical traps LESSO

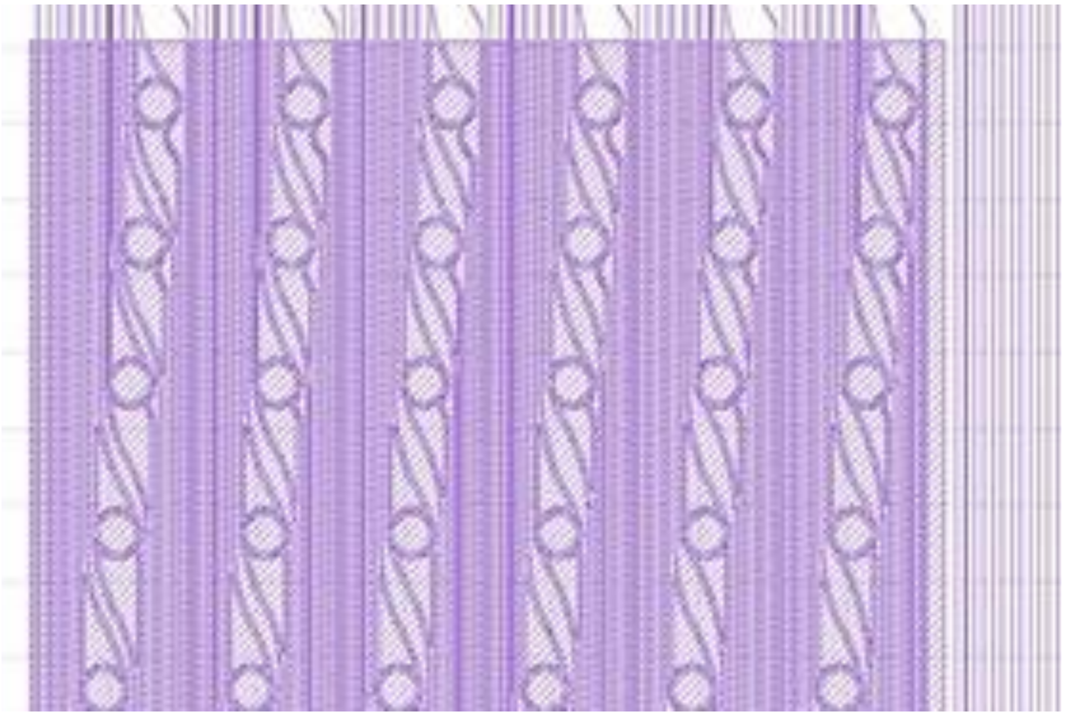
- Italian project funded by ASI
- Aim: development of a prototype of a 698nm miniaturized CW optical pumped laser, FWHM in the kHz regime,
- Vision: Application in the Sr^+ optical clock

UNIVERSITY OF TRENTO - Italy
Department of Physics

AtomSensors

DIPARTIMENTO DI FISICA
UNIVERSITÀ DI PISA

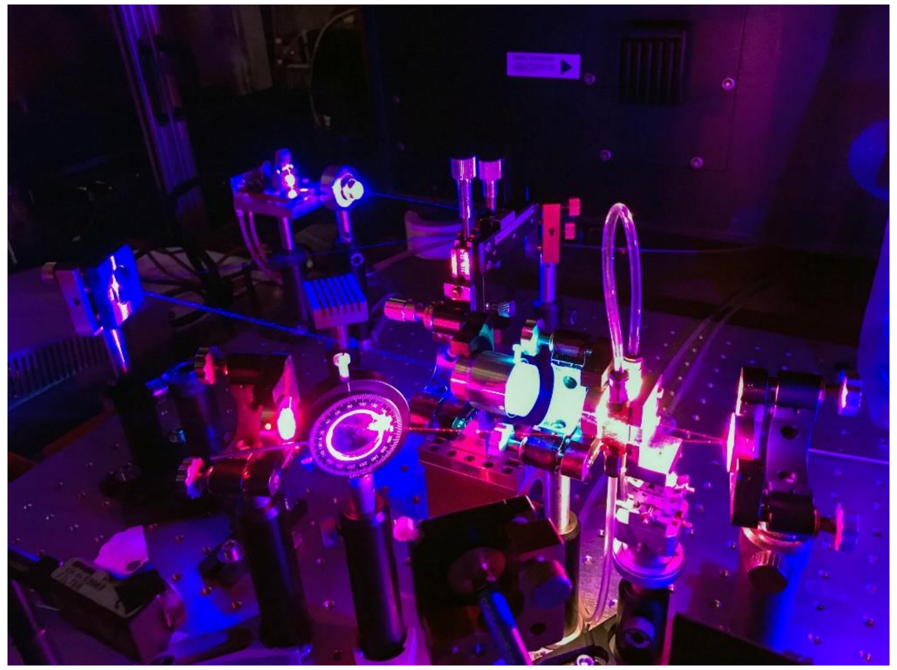
CMM CENTRO MATERIALI E MICROSISTEMI
FONDAZIONE BRUNO KESSLER



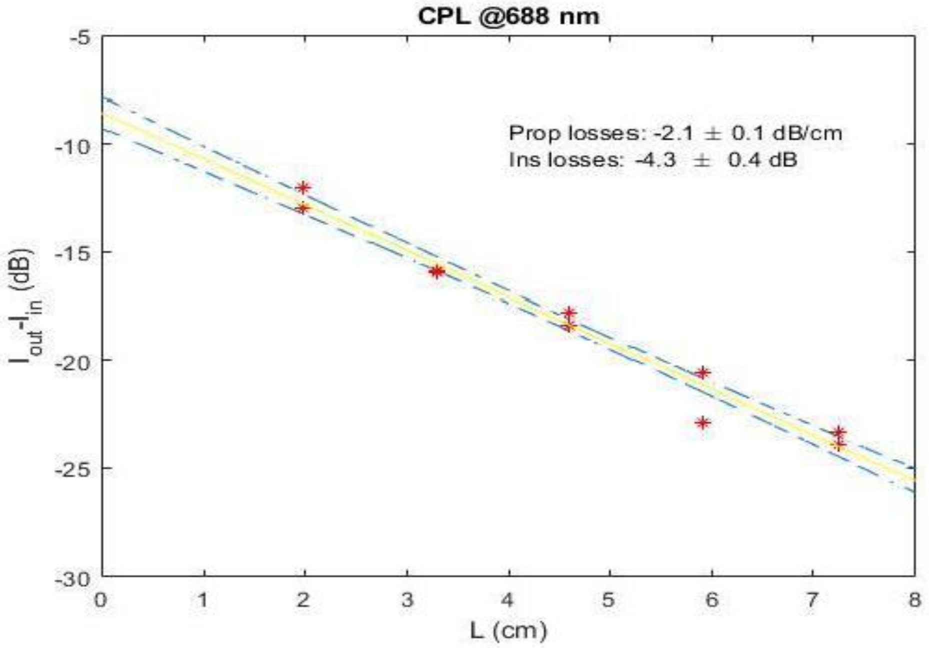
A high transparent silicon-oxynitride circuit is used which couples evanescently to the LiYF-crystal doped with praseodymium (P3+), CAD of array of microring cavities with input-and output coupler.

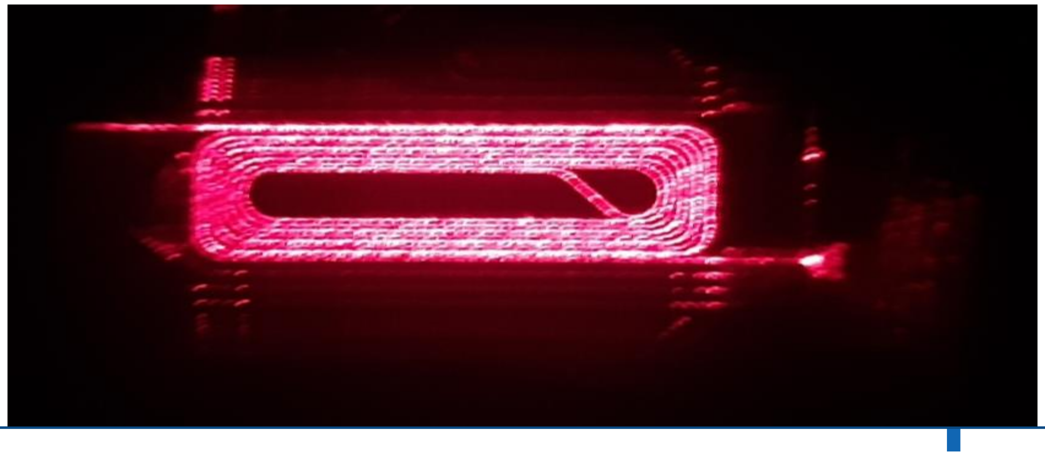
Lasing in the Red, Pr^{3+} doped YLiF-crystal, UniPisa

Testing of the laser-crystals on optical bench.



Development of low loss optical circuits in the blue and red spectral region





Infrastructure enhancement
FESR European Fund for Regional Development

8M€ for Nano-tech

Nanotechnology capabilities enabling QT R&D through submicron and deep submicron (350 nm - 50 nm) structure definition with state of the art E-beam and focused ion beam lithography and surface functionalization.

RAITH
NANOFABRICATION

FONDAZIONE
BRUNO KESSLER

Press Release

November X, 2019

Raith delivers its new FIB-SEM VELION to Fondazione Bruno Kessler (FBK)

Dortmund/Trento, August 2019

Raith, the world leading manufacturer of nanofabrication instrumentation, delivers its VELION to the Center for Materials and Microsystems of FBK - Fondazione Bruno Kessler in Trento, Italy, a Research Institute that aims for results of excellence in science and technology with particular emphasis on interdisciplinary approaches and their applicative dimension

The VELION is a Focused Ion Beam (FIB) centric FIB/SEM system for sophisticated nanofabrication applications on a lithography platform. Its FIB column is vertically mounted in order to keep the FIB always on target of the Laser Interferometer Stage. Thus, highest precision for demanding nanofabrication tasks is ensured. The high resolution FE-SEM is side mounted to serve in-situ process control, sample preparation and inspection as well as complementary Electron Beam Lithography (EBL).

"The Velion is a key instrument for the strategic investment that FBK is undertaking to significantly enhance its capabilities and strengthen its role as national reference point for Key Enabling Technologies (KET). This FIB system will enable us to implement advanced and novel integration of nanotechnological solutions on our traditional platforms (CMOS, MEMS) to boost our offer for frontier research activities as well as for innovative industrial products. Beside this, thanks to its characteristics, we will intensively use Velion, for our research in the strategic field of quantum technology" says Prof Gianluigi Casse, Director of the Center for Materials and Microsystems in FBK.

"The VELION is the perfect instrument for both, Focuced Ion Beam (FIB) experts and nanofabrication professionals. It has been recognized in the community as the most accurate and versatile system for challenging FIB nanofabrication applications across large areas. We are proud to deliver a fully equipped VELION to FBK that provides many techniques for FIB and EBL and supports numerous applications in the field of nanofabrication in one system. We are already looking forward to first results," says Torsten Richter, Product Manager.

All information around the VELION is available to the public at: www.raith.com/velion

Inquiries or questions of any kind can be sent to: sales@raith.com.

Infrastructure enhancement
Important Projects of Common European Interest (IPCEI)

FBK only full Italian partner.
Investments in the Clean-Rooms to **improve vertical integration capabilities** of silicon wafers and chips with different functionalities (e.g. stack of sensor, analogue, digital, photonic layers) significantly enhancing the abilities for heterogeneous integration of various technologies/chips. Heterogeneous integration already is a strength of FBK. This investment complements the one on nano-technologies (**FESR**) to enable a **large potential for future challenges** (e.g. Quantum Technologies).

UE: 1,75 miliardi di euro per la microelettronica europea (e anche italiana)

Luce verde della Commissione a un piano di investimenti integrato di Francia, Germania, Gran Bretagna e Italia a favore dell'innovazione microelettronica

La collaborazione fra Stati europei sarà magari pericolante su diversi piani, ma per quanto riguarda le iniziative a favore dell'innovazione tecnologica è ormai difficile considerare progetti massivi che non si svolgano sotto l'egida della UE. Accade anche nel campo della **microelettronica**: la Commissione Europea ha infatti appena approvato un progetto integrato proposto congiuntamente da **Francia, Germania, Gran Bretagna e Italia** per una serie di investimenti a favore dello sviluppo tecnologico in tale campo.

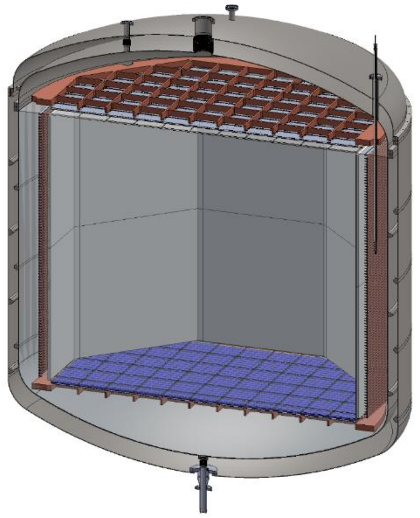
Il progetto presentato dai quattro Stati membri prevede il coinvolgimento di ben 29 realtà, di cui una sola completamente italiana (**Fondazione Bruno Kessler**) e una franco-italiana (**ST Microelectronics**). Altri nomi noti coinvolti sono Bosch, Infineon, Osram e Zeiss. A queste realtà della microelettronica, le quattro nazioni potranno erogare fino a un totale di 1,75 miliardi di euro per finanziare le loro ricerche.

Più in dettaglio, la Germania ha chiesto l'autorizzazione per finanziamenti fino a 820 milioni di euro, cifra che **per l'Italia passa a 524 milioni**, per la Francia a 355 milioni e per la Gran Bretagna a 48. L'autorizzazione delle Commissione era necessaria, altrimenti questi finanziamenti si sarebbero potuti considerare aiuti di Stato. Si stima poi che il piano sblocchi investimenti privati per altri sei miliardi di euro.

darkside
two-phase argon TPC for Dark Matter Direct Detection

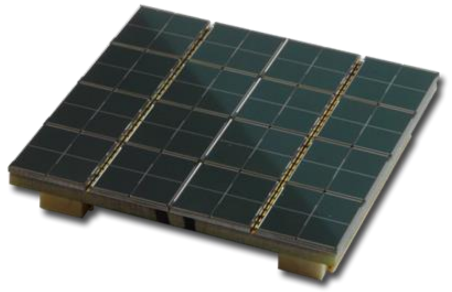
Examples: Big Science and space

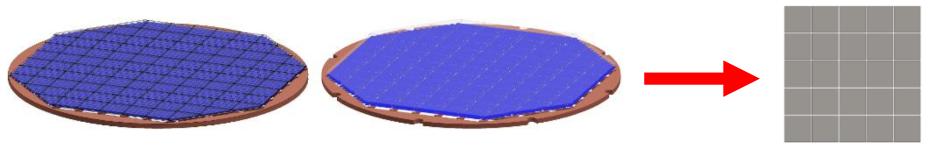
Beyond State of the art sensors and devices developed for Science, transferred to Industry.



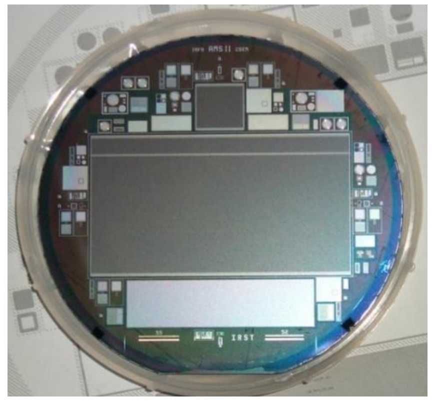
~ 23t of UAr

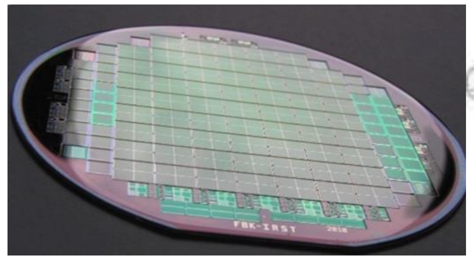
TPB WLS: emission at 400 – 450 nm

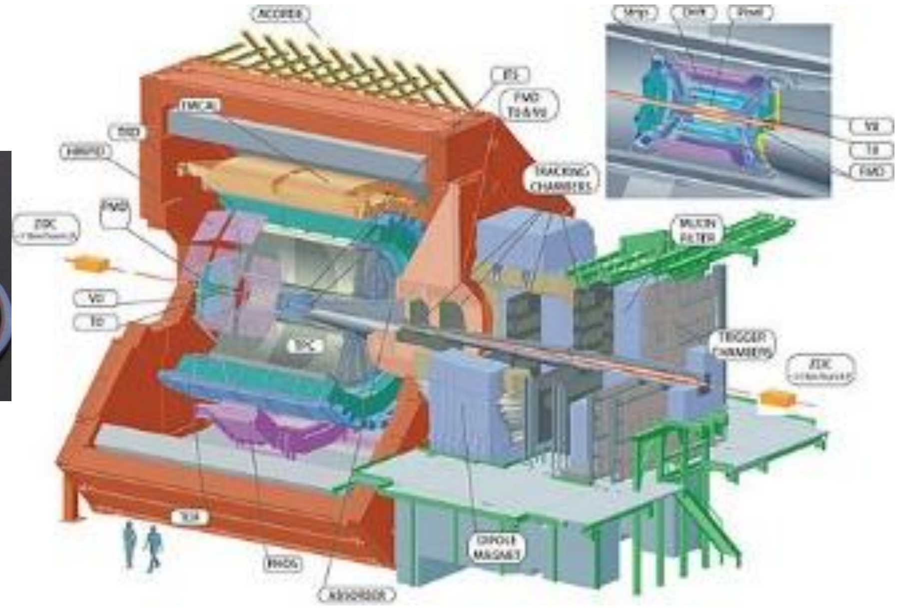


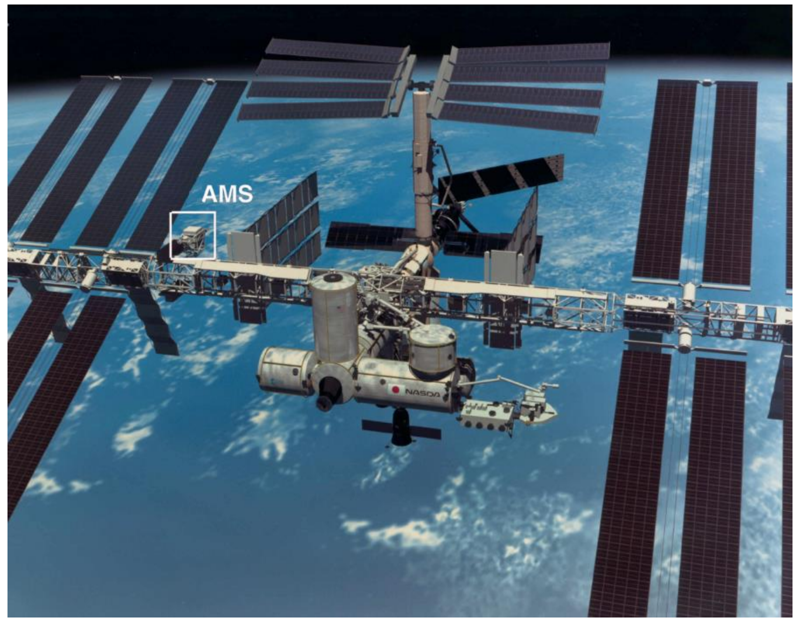


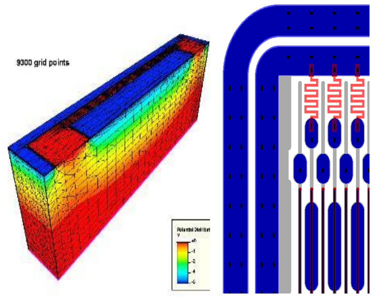
SiPM tiles

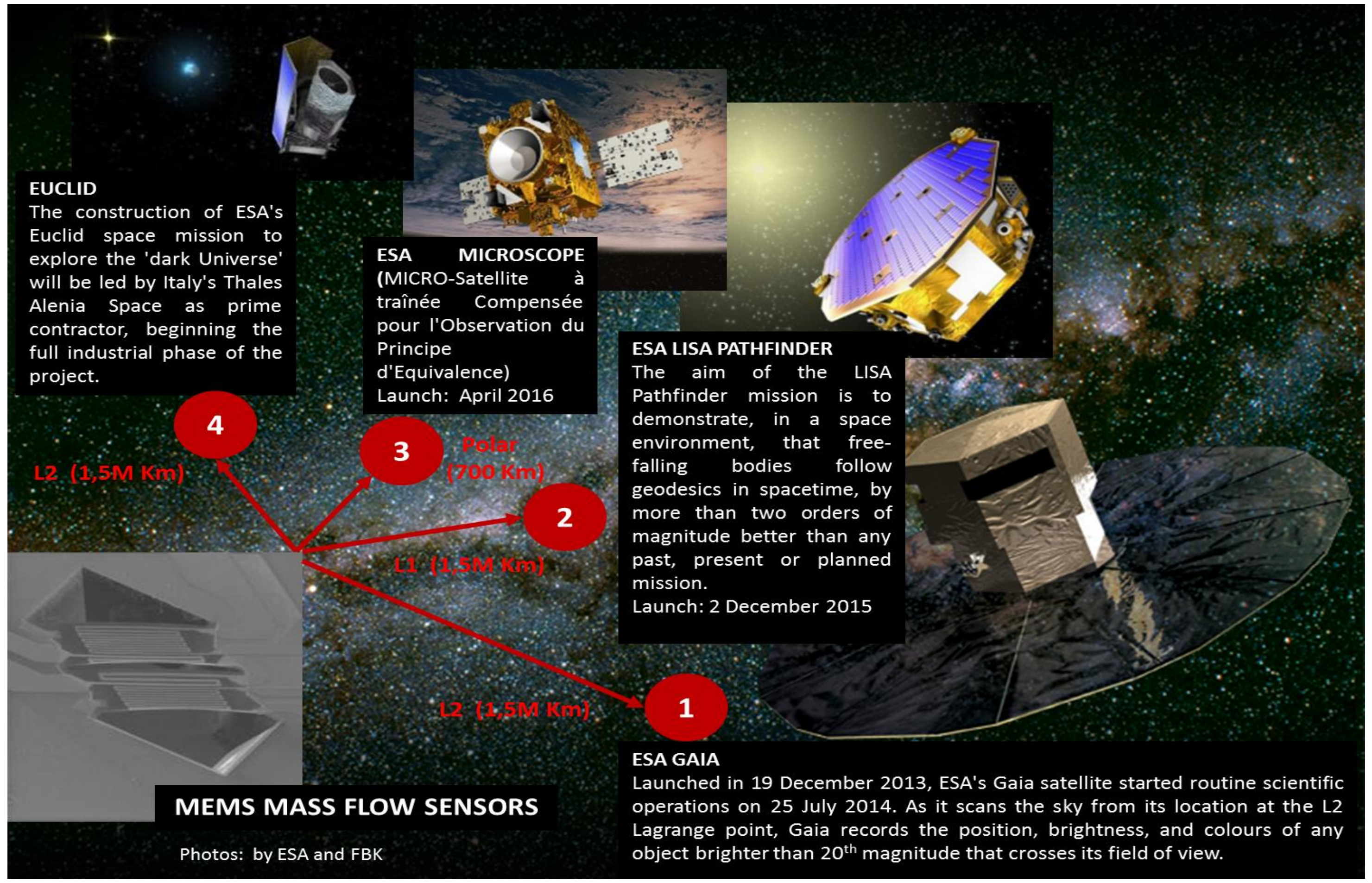












EUCLID
The construction of ESA's Euclid space mission to explore the 'dark Universe' will be led by Italy's Thales Alenia Space as prime contractor, beginning the full industrial phase of the project.

ESA MICROSCOPE (MICRO-Satellite à traînée Compensée pour l'Observation du Principe d'Equivalence)
Launch: April 2016

ESA LISA PATHFINDER
The aim of the LISA Pathfinder mission is to demonstrate, in a space environment, that free-falling bodies follow geodesics in spacetime, by more than two orders of magnitude better than any past, present or planned mission.
Launch: 2 December 2015

ESA GAIA
Launched in 19 December 2013, ESA's Gaia satellite started routine scientific operations on 25 July 2014. As it scans the sky from its location at the L2 Lagrange point, Gaia records the position, brightness, and colours of any object brighter than 20th magnitude that crosses its field of view.

MEMS MASS FLOW SENSORS

Photos: by ESA and FBK