LGAD: a Little bit of the early history

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Salvador Hidalgo

Centro Nacional de Microelectrónica IMB
CSIC
Consejo Superior de Investigaciones Científicas

RD50

RDG Radiation Detectors Group

Outline

Why LGADs became such a hot topic in the last decade?
My recall of how the whole thing started and continues....

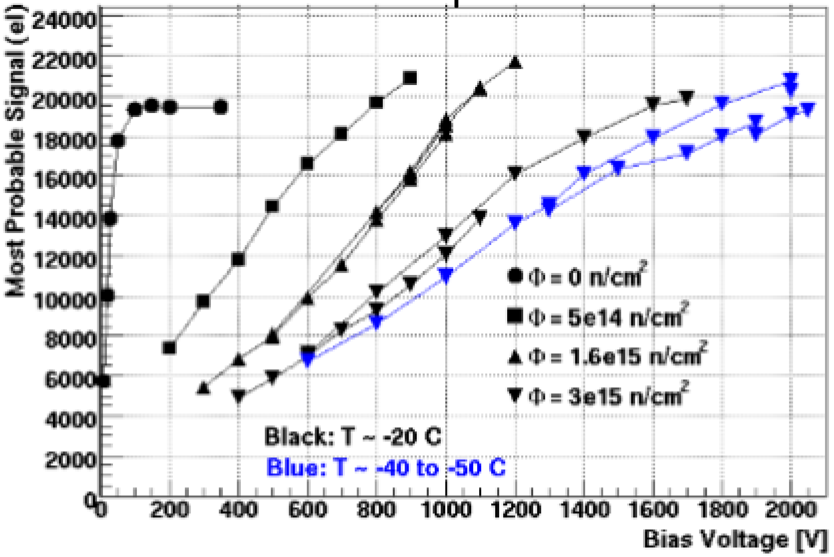
I apologize for omission or forgetting names and fact…
I will appreciate any correction or comment.

Charge multiplication (<2010)

It was clear in 2010 the charge Multiplication effect in Highly Irradiated Planar Sensors -> mainly strips.

A considerable R&D activity for improving the radiation tolerance of finely segmented silicon detectors has been stimulated by the requirements of the future upgrade of the LHCaccelerator at CERN.

microstrip detectors

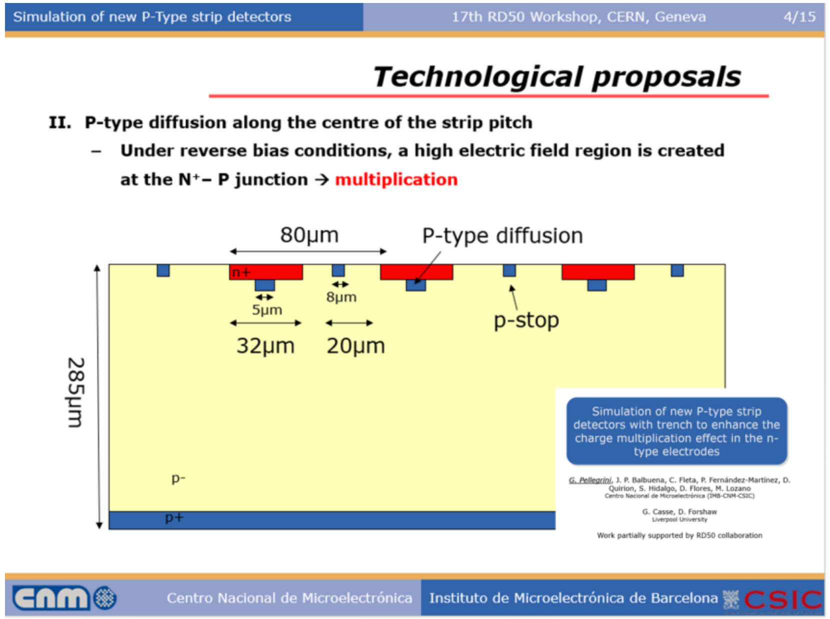


RD50 has shown that irradiated sensors were capable to recover at least the same charge as before irradiation, or even more if biased to sufficiently high voltages.

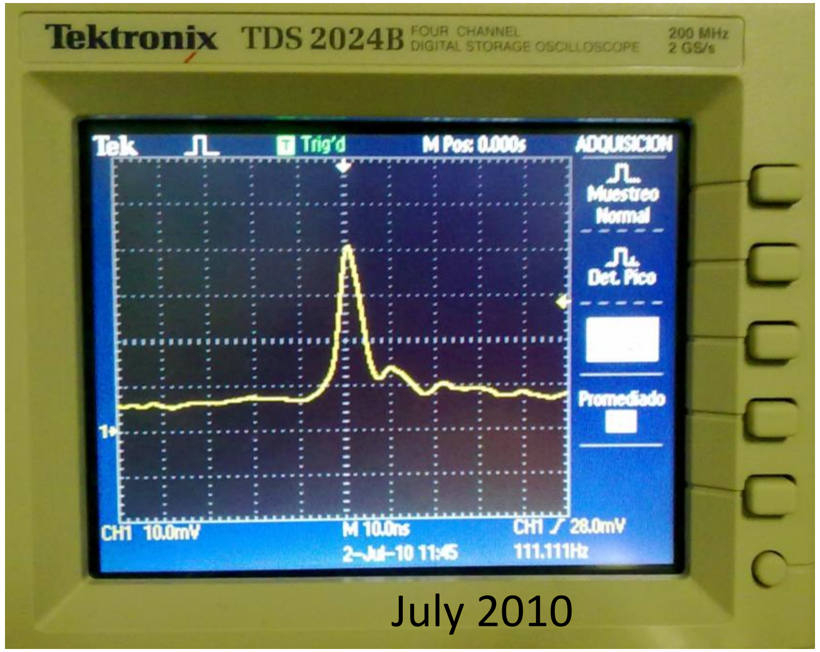
2010

First idea of a detector with a moderate Gain

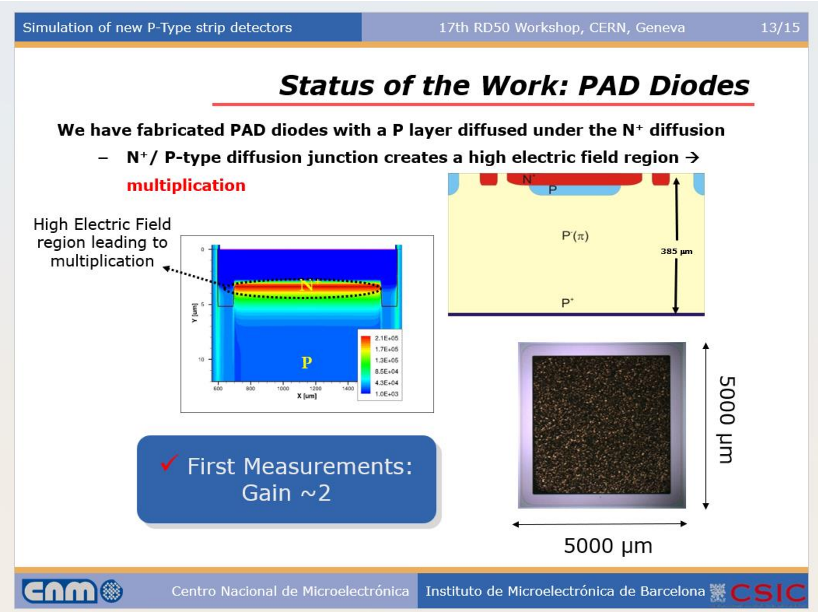
Strip detector



PhD thesis of Pablo Fernandez

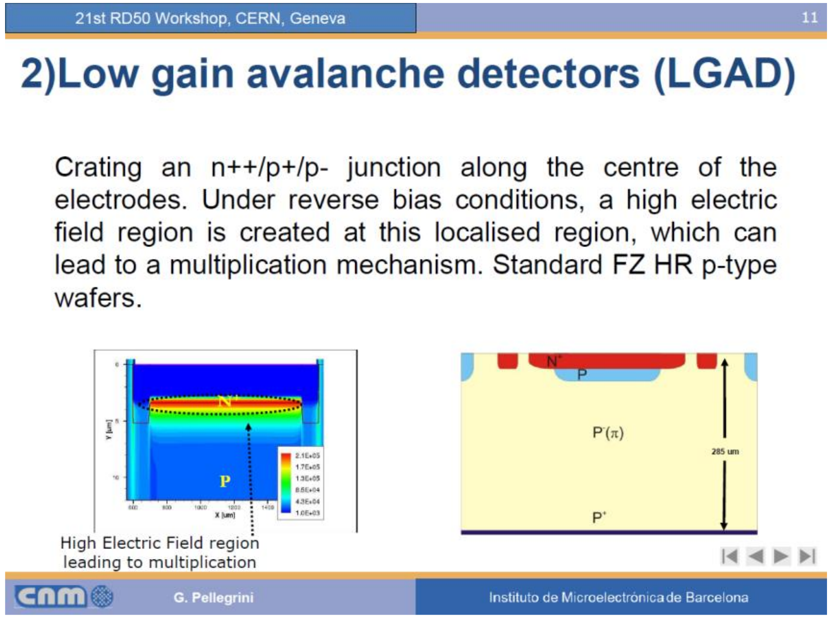


July 2010



Early Historical developments : The first appearance on scene of the LGAD (2011-2012)

Status of the RD50 funding request for "detectors with enhanced multiplication”



RD50 funding request

- November 2012-

Title of project: Fabrication of new p-type pixel detectors with enhanced multiplication effect in the n-type electrodes.

Contact person: *G. Pellegrini*
CNM-Barcelona
(+34) 93 594 77 00 ext. 2204
Giulio.Pellegrini@cnm-imb.csic.es

RD50 Institutes:

1. CNM-Barcelona, G. Pellegrini, Giulio.Pellegrini@cnm-imb.csic.es
2. Liverpool University, Gianluigi Casse, gcasse@hep.ph.liv.ac.uk
3. UC Santa Cruz, Hartmut Sadrozinki, hartmut@ucsc.edu
4. IFAE, Barcelona, Sebastian Grinstein, sgrinstein@ifae.es
5. KIT, Karlsruhe, Prof. Wim de Bôer, wim.de.boer@kit.edu
6. IFCA Santander, Ivan Vila, ivan.vila@csic.es
7. University of Glasgow, Richard Bates, richard.bates@glasgow.ac.uk

Who requested the LGAD? A few months before in Bari (2012)

Great interest of Atlas and CMS for HGTD and ETL

Great vision!

Ultra-Fast Silicon Detectors

Hartmut Sadrozinski, Abe Seiden (UCSC)
Nicolo Cartiglia (INFN Torino)

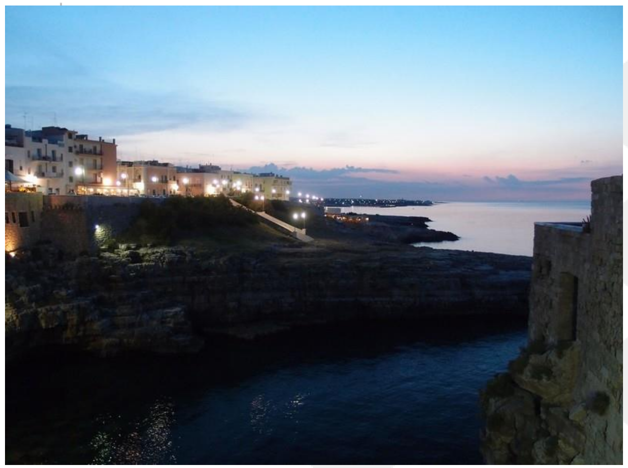
Ultra-Fast Silicon Detectors (UFSD)
provide in the same detector and readout chain
- ultra-fast timing resolution [10's of ps]
- precision location information [10's of μm]

Benefits of Gain in Detectors

⊕ Charge multiplication (CM) in silicon sensors (discovered by RD50 institutions) might have applications beyond off-setting charge lost due to trapping during the drift of electrons or holes.

⊕ Charge multiplication makes silicon sensors similar to drift chambers (DC) or Gas Micro-strip Detectors (GMSD), where a modest number of created charges drift to the sense wire, are amplified there (by factors of > 10^4) and are then used for fast timing.

⊕ We propose considering silicon detectors for simultaneous precision position and fast timing measurements.



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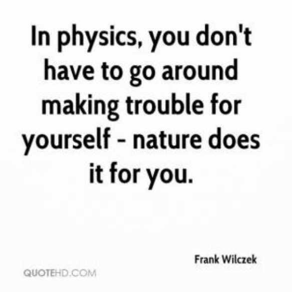
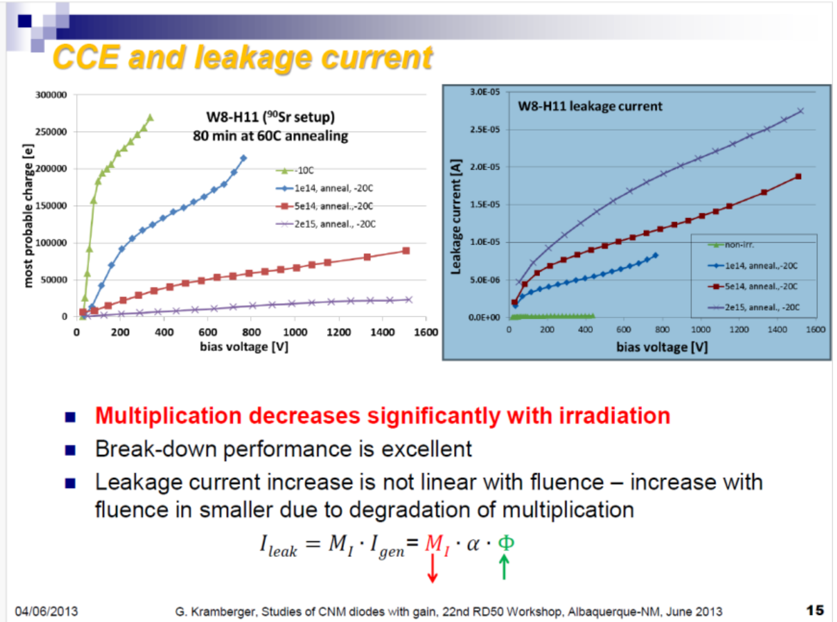
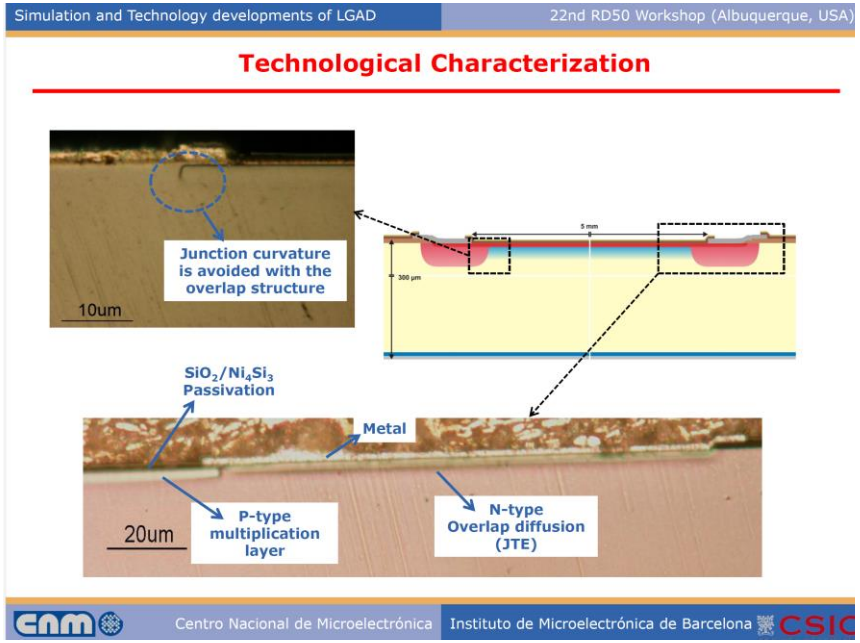
2013

- **Devices available to all interested groups**
- **First irradiations studies Boron Removal**







Centro Nacional de Microelectrónica IMB

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

RD50

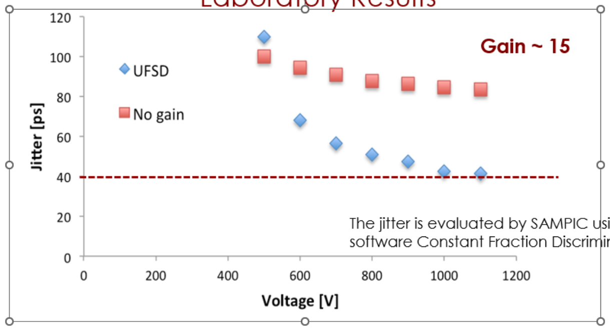
2014

- **Thin LGAD**
- **C and G doping**

Discussion session

Time Resolution vs Vbias

Laboratory Results



This result is consistent with the simulation predictions:
300-micron thick UFSDs with gain of ~ 15 improve by ~ 2 the timing resolution

Nicolo Cartiglia, INFN, Torino - UFSD - RD50, Bucharest, 13 June 2014

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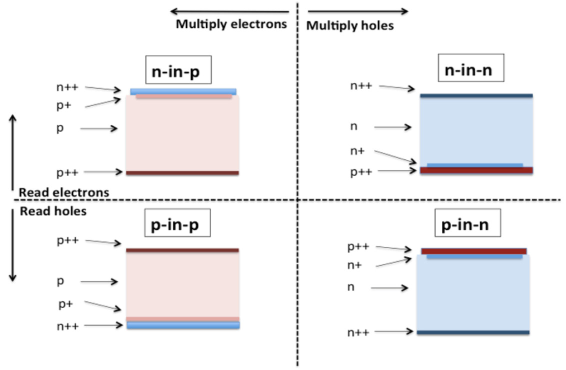
New directions

- New designs for the gain layer position/doping under investigation



In backup slides

Nicolo Cartiglia, INFN, Torino - UFSD - RD50, Bucharest, 13 June 2014

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SCIPP

Experience with 50um thick epi LGAD

Hartmut F.W. Sadrozinski

with

Caitlin Celic, Scott Ely, Vitaliy Fadeyev, Patrick Freeman, Zachary Galloway, Zhijun Liang, Colin Parker, Abe Seiden, Andriy Zatserklyaniy
SCIPP, Univ. of California Santa Cruz, USA

Marta Baselga, Pablo Fernández-Martínez, David Flores , Virginia Greco, Salvador Hidalgo, Giulio Pellegrini, David Quirion,
IMB-CNM, Barcelona, Spain

Nicolo Cartiglia, Francesca Cenna
INFN Torino, Torino, Italy

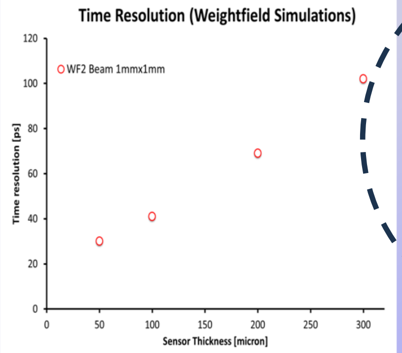
Why LGAD, why thin?
CCE (IR Laser, α top)
Gain thin-thick
Doping Profile

Hartmut F.-W. Sadrozinski, thin LGAD, 25th RD50, Nov. 2014

SCIPP

Time Resolution for thin LGAD

For the 300 µm thick large LGAD pads (C ≈ 10 pF), the time resolution measured in the beam test (BT) at Frascati, is predicted by the **Weightfield (WF2)** simulation –(see N. Cartiglia talk)



The time resolution is predicted to improve for smaller LGAD (1mmx1mm) and optimized electronics.
Reduced the thickness also improves the time resolution.

Expect for 50 µm thick LGAD (C~2pF):

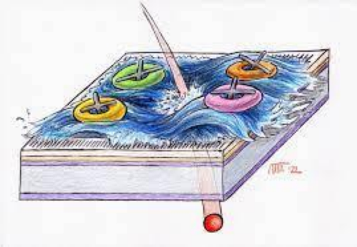
σ_t = 30 ps (requires ASIC)

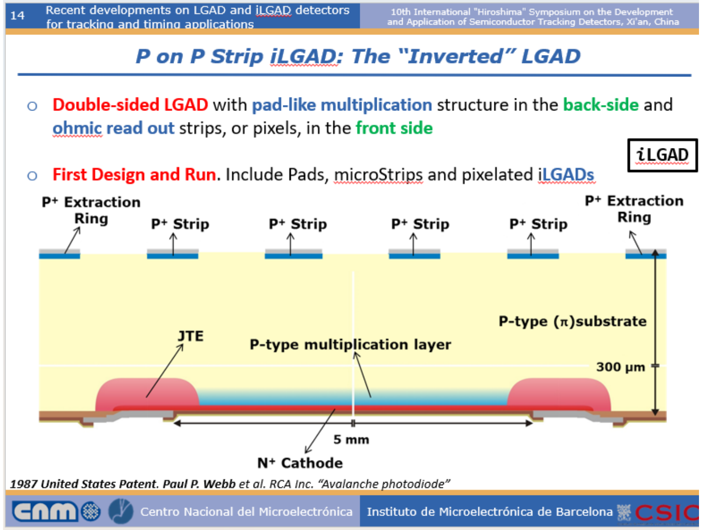
N. Cartiglia, F. Cenna et al. "Weightfield", 2014 IEEE NSS-MIC

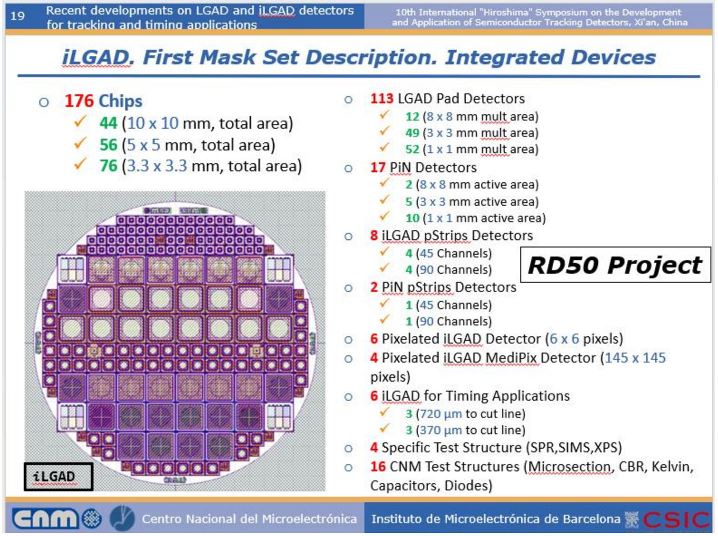
Hartmut F.-W. Sadrozinski, thin LGAD, 25th RD50, Nov. 2014

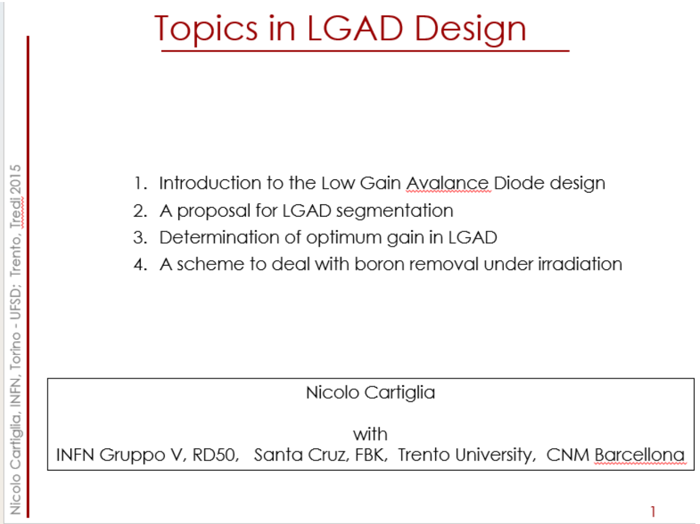
2015

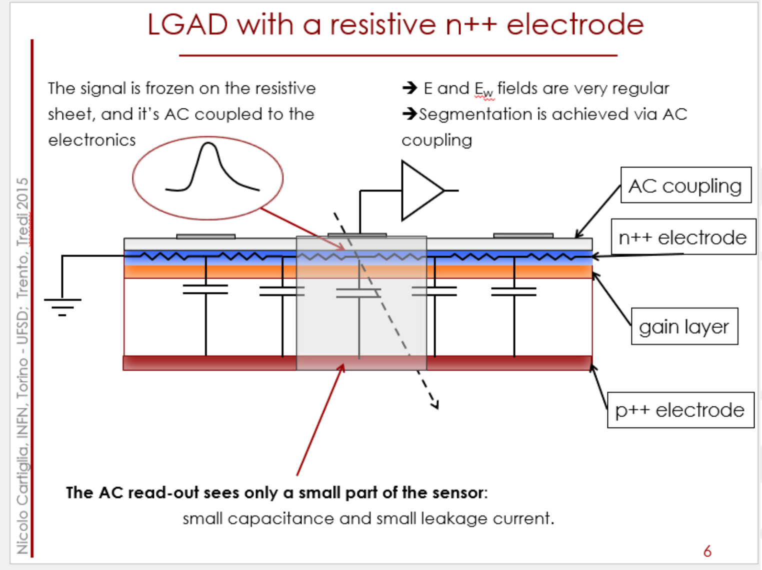
- **Fill Factor**
- **iLGAD & AC-LGAD**











2016

Time resolution before and after irradiation on 50um thick detectors.

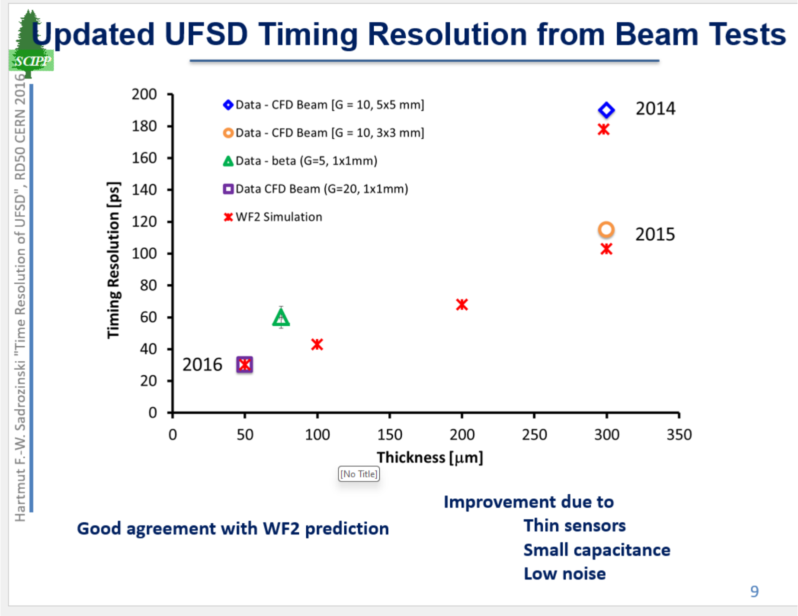
Head of Production and Development at X-Spectrum GmbH

Gain and time resolution of 50 µm LGADs before and after irradiation

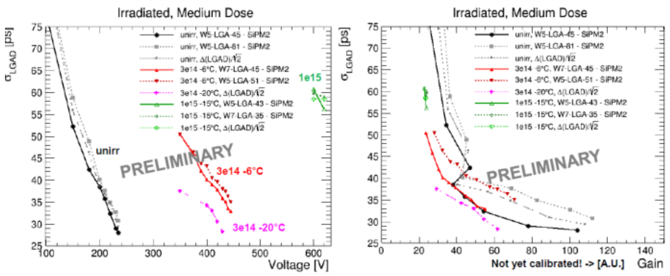
J. Lange, E. Cavallaro, F. Förster, S. Grinstein
IFAE Barcelona
M. Carulla, D. Flores, S. Hidalgo, G. Pellegrini, D. Quirion
CNM-IMB-CSIC Barcelona
L. Chytka, T. Komarek, L. Nozka, T. Sykora
Palacky University Olomouc and Charles University Prague
P. Davis
University of Alberta, Edmonton
G. Kramberger, I. Mandic
JSI Ljubljana

22 November 2016,
29th RD50 Workshop, CERN

IFAE Institut de Física d'Altes Energies



Time Resolution (irr)



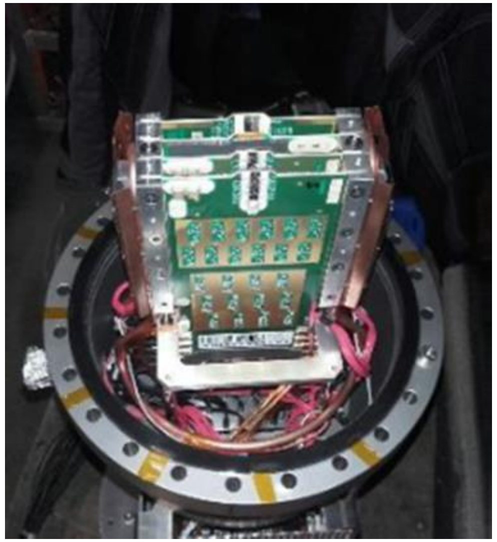
- At 3e14 similar time resolution achieved as before irradiation (at higher V)
  - -6°C: 33 ps at 445 V
  - -20°C: 28 ps at 430 V
- At 1e15 gain is highly reduced and voltage stability not high enough to compensate for it
  - 55-60 ps at 620 V
- Gain dependence in all cases similar to before irradiation
  -> "universal"

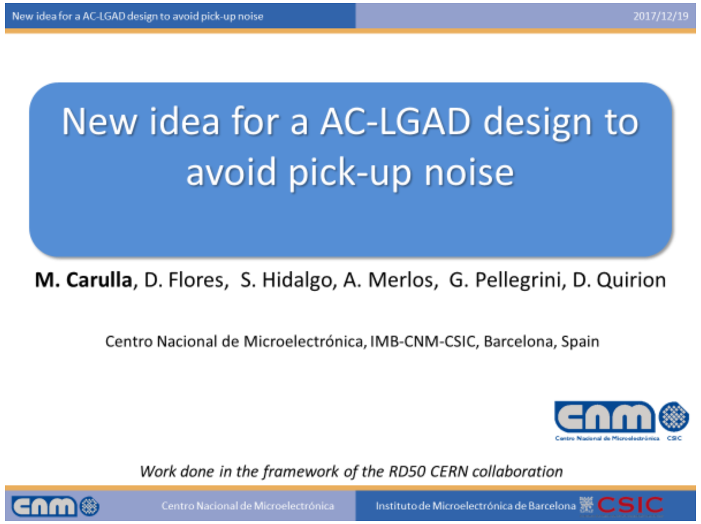
22/11/2016 Jörn Lange - 50 µm LGAD Gain+Resolution 18

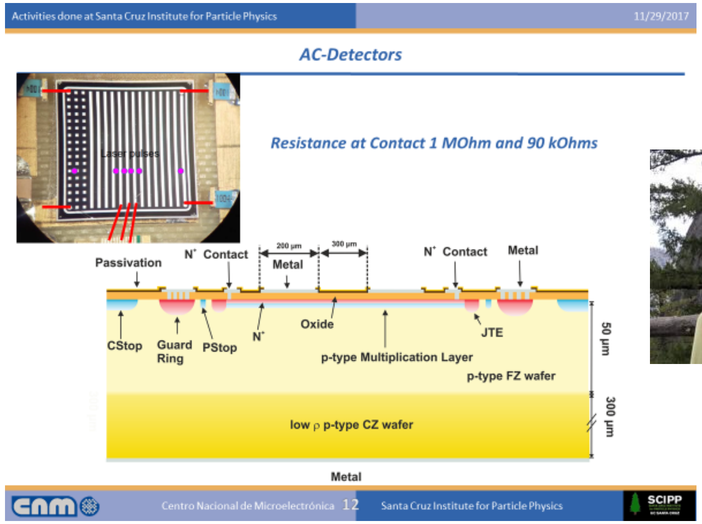
2017

- **First CERN experiment**
- **First measurements of AC-LGAD**

TOTEM CT-PPS

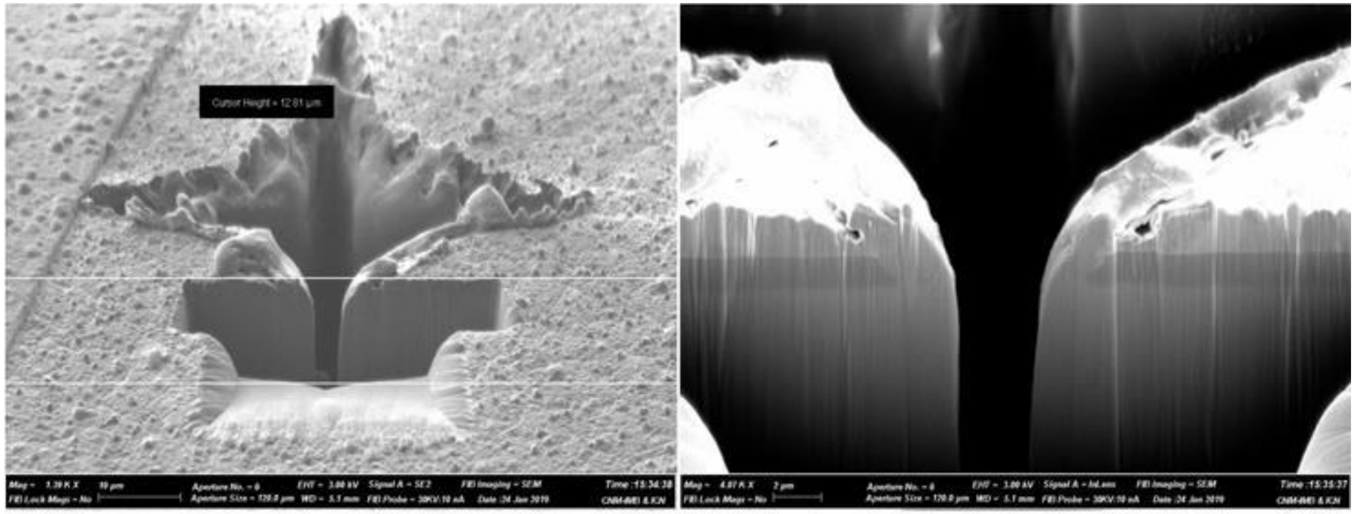




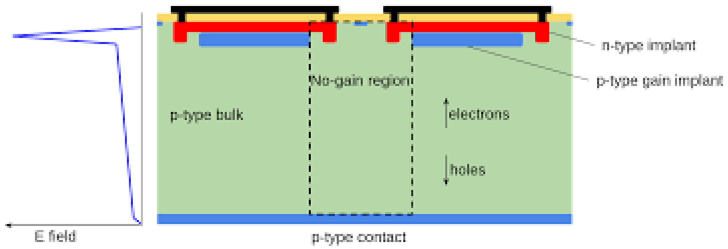


2018

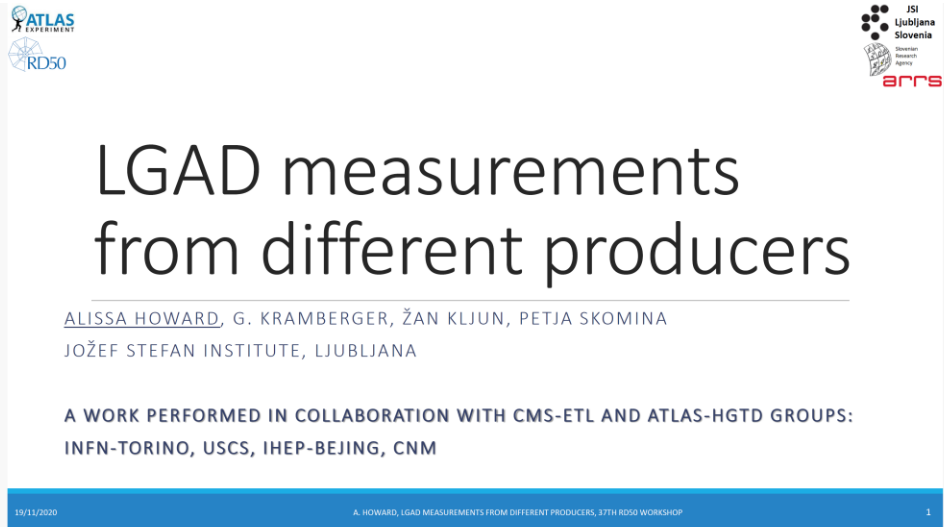
Single Event Burnout

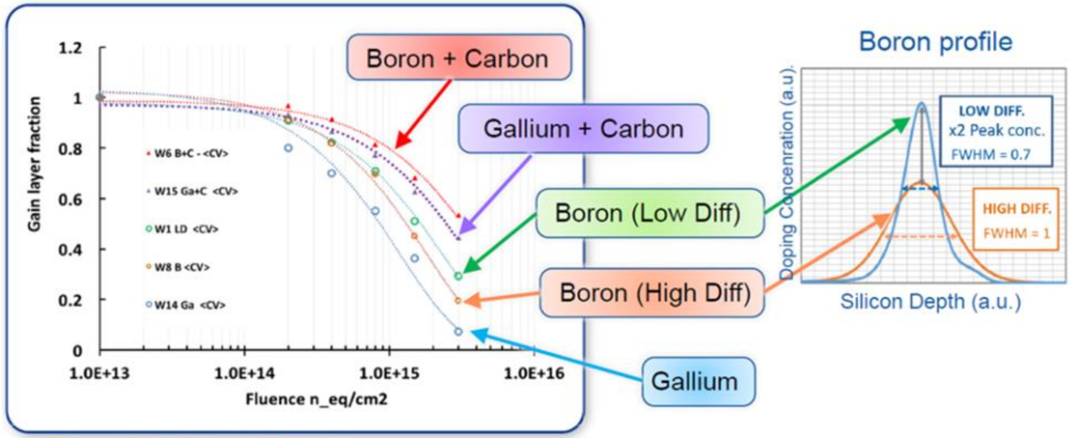


2020



Mattero Centis





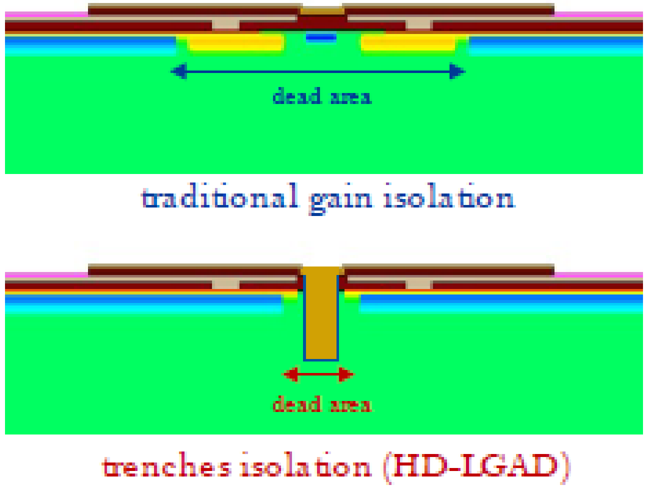
[G.Paternoster, FBK, Trento, Feb.2019]

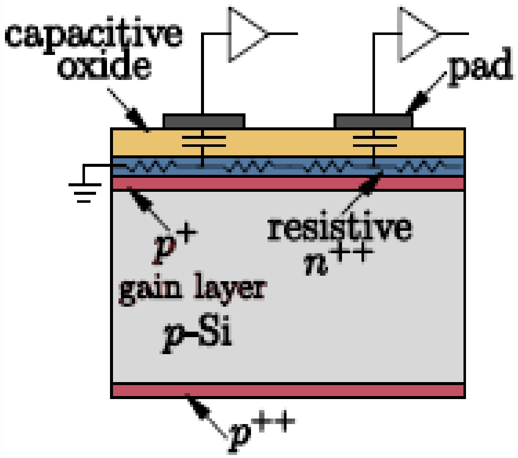
LGAD: Fill factor & performance improvements

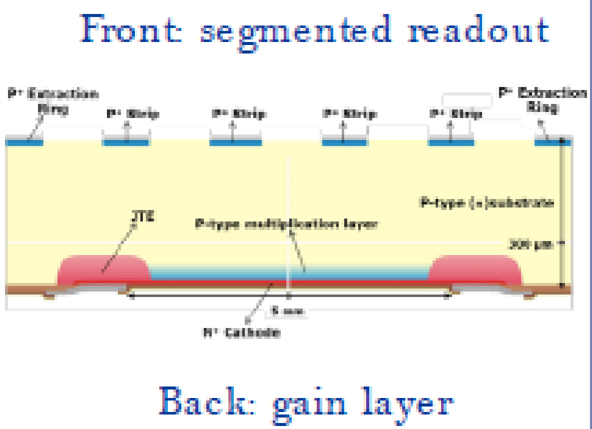
RD50

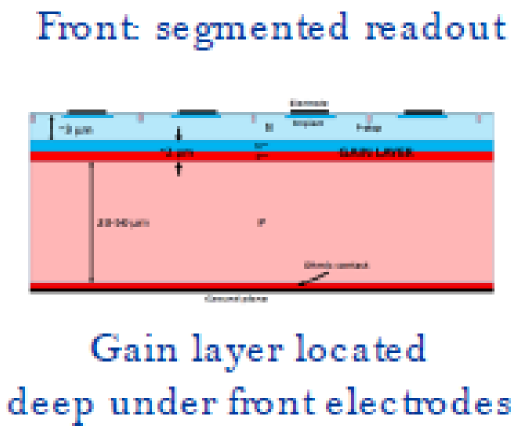
- Two opposing requirements:
  - Good timing reconstruction needs homogeneous signal (i.e. no dead areas and homogeneous weighting field)
  - A pixel-border termination is necessary to host all structures controlling the electric field
- Several new approaches to optimize/mitigate followed:

Trench Isolation LGAD | AC-LGAD | Invers LGAD | Deep Junction LGAD









N. Cartiglia

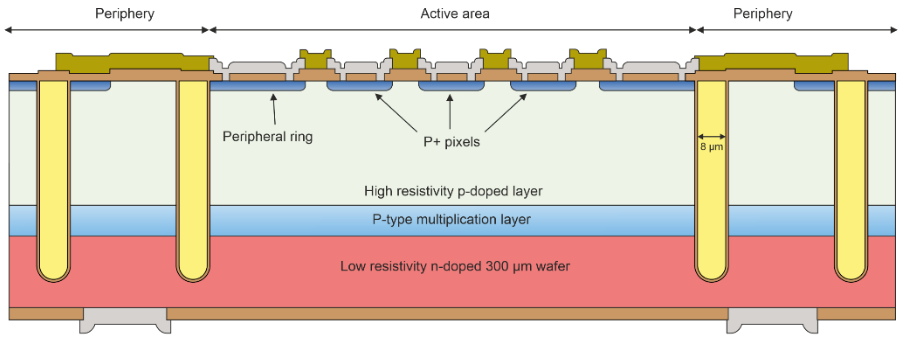
Concepts simulated, designed, produced and tested in 2018/19

..new concept 2020

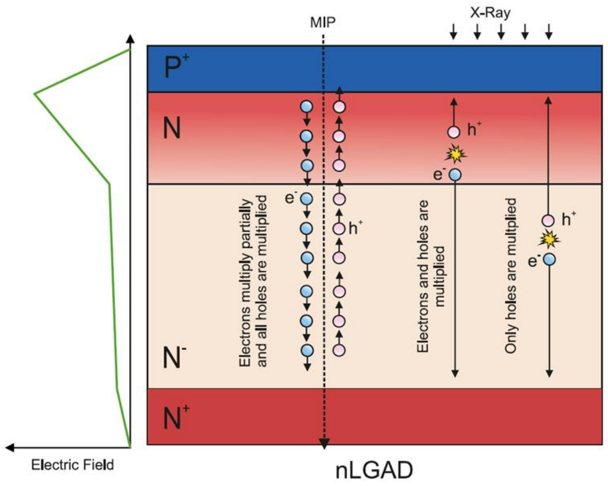
Example 2

Fill factor, low penetrating particles and large area devices

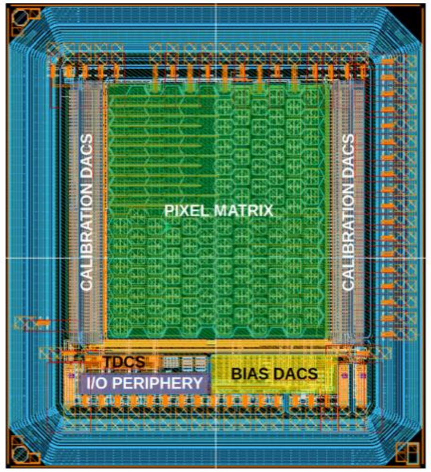
Trenches iLGAD



pLGAD



LGAD-in-CMOS Design

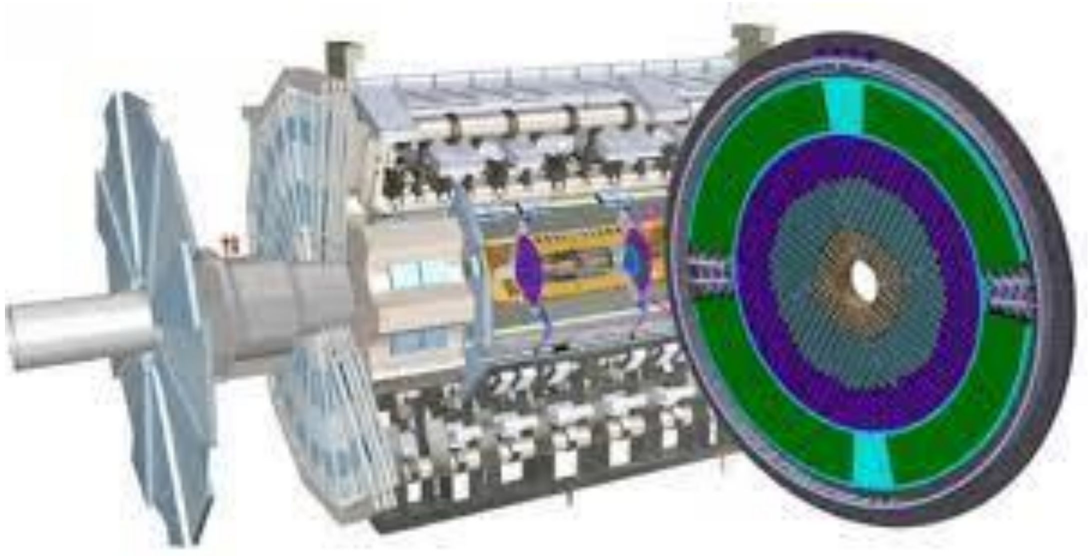


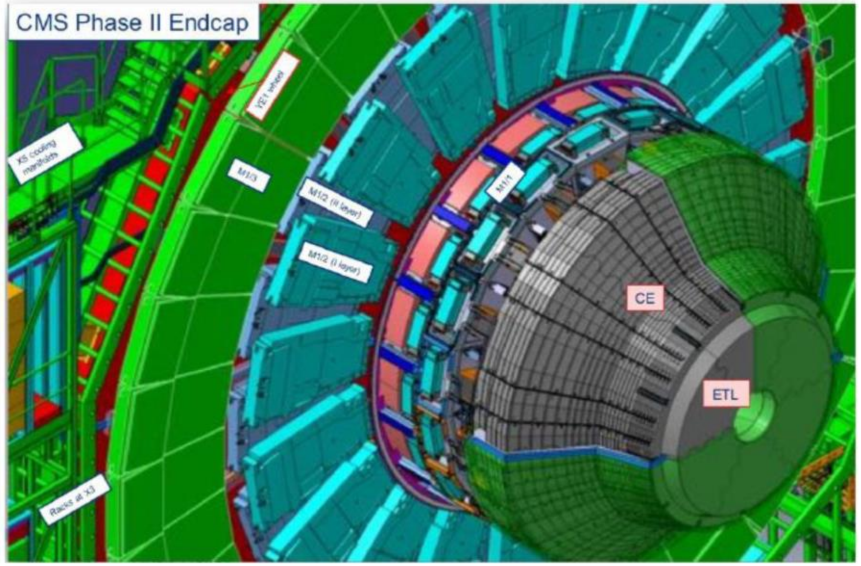
Picosecond Avalanche Detector

- Picosecond Avalanche Detector — working principle and gain measurement with a proof-of-concept prototype: DOI 10.1088/1748-0221/17/10/P10032
- **Effects of Shallow Carbon and Deep N++ Layer on the Radiation Hardness of IHEP-IME LGAD Sensors : DOI: 10.1109/TNS.2022.3161048**
- Trench-Isolated Low Gain Avalanche Diode, DOI: 10.1109/LED.2020.2991351
- First results for the pLGAD sensor for low-penetrating particles, https://doi.org/10.1016/j.nima.2022.167220
- Inverse LGAD (iLGAD) Periphery Optimization for Surface Damage Irradiation, https://doi.org/10.3390/s23073450
- **Fabrication and performance of AC-coupled LGADs, https://doi.org/10.48550/arXiv.1906.11542**
- **A new approach to achieving high granularity for silicon diode detectors with impact ionization gain, https://doi.org/10.48550/arXiv.2101.00511**

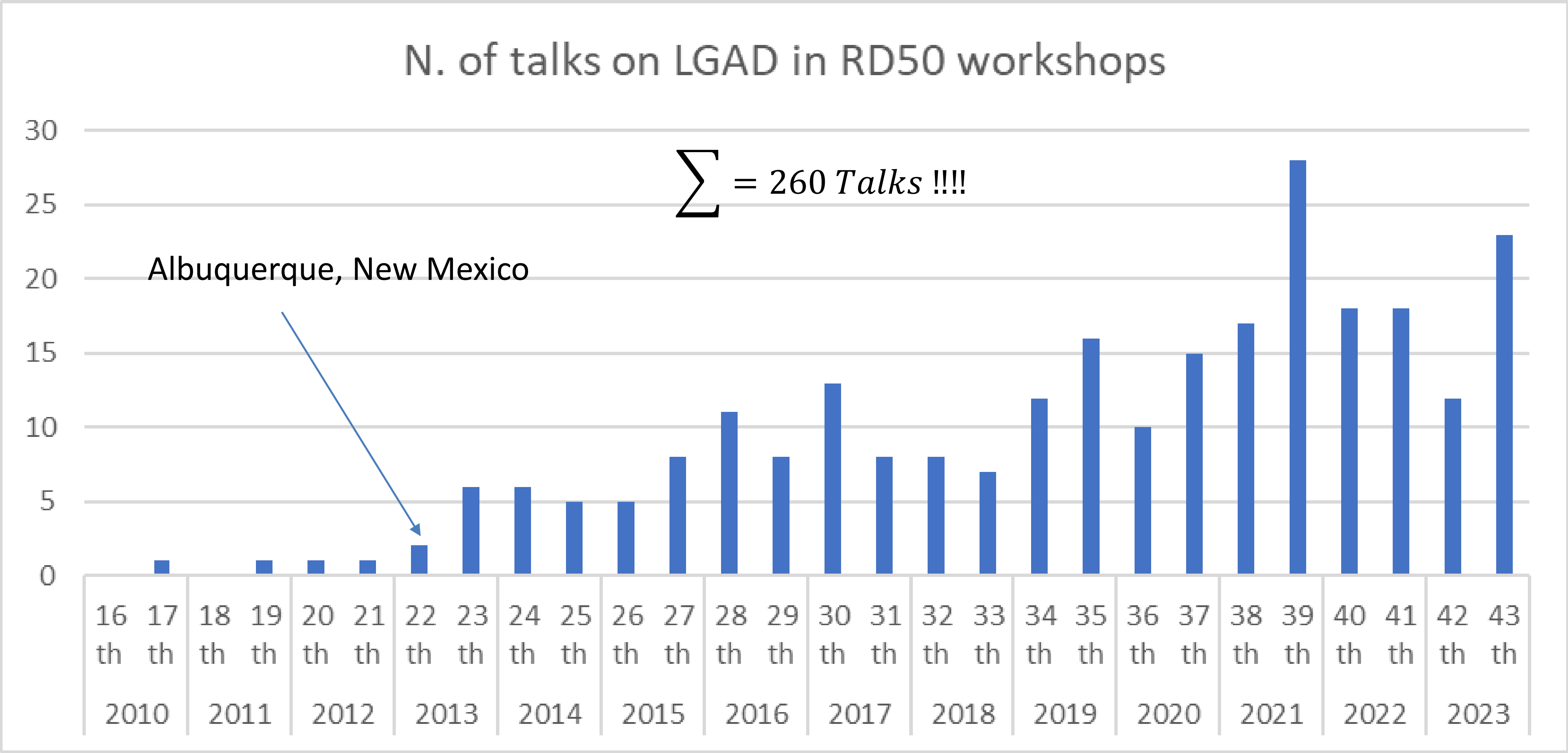
Atlas and CMS….

- Radiation hardness improvement
- Large area detectors
- Fabrication in 200mm wafers
- High yield
- …





DRD3



LGAD/UFSD/iLGAD/RSD/etc…

RD50 LGAD projects

1. 2013-01:Fabrication of p-type pixel detectors with enhanced multiplication (Giulio Pellegrini, CNM)
2. 2014-02:Fabrication of 200 um p-an n-type pad detectors with enhanced multiplication(Giulio Pelegrini, CNM)
3. 2014-05:Thin LGAD devices (Nicolo Cartiglia, Torino)
4. 2015-04:Doping profiling of LGAD and other devices, SIMS (Hartmut Sadrozinski, SCIPP, USA)
5. 2016-02:Gallium doping (David Fores, CNM, Barcelona)
6. 2016-03:Acceptor Removal in boron doped silicon wafers (Giulio Pelegrini, CNM)
7. 2017-01:LGAD based on EPI wafers (G.Pellegini, CNM, Barcelona)
8. 2017-03:LGAD fabricated with epitaxial layer (G.Pellegrini, CNM, Barcelona)
9. 2017-05:50 µm thin LGAD fabricated with Ga multiplication layer (Joern Lange, IFAE Barcelona)
10. 2017-06:Thin LGADs characterization using IBIC and time-resolved IBIC at CAN (Carmen Jiménez-Ramos, Sevilla)
11. 2017-08:50 µm thin AC-LGAD (Mar Carulla, CNM Barcelona)
12. 2018-01:Development of Segmented LGAD with small pixels and high Fill-Factor (Giovanni Paternoster, FBK)
13. 2020-02:Proof-of-concept and radiation tolerance assessment of thin pixelated Inverse Low Gain Avalanche Detectors (ILGAD) (Ivan Vila, UC-CSIC, Santander)
14. 2021-03:Defect engineering for sensors with intrinsic gain(Gkougkousis Evangelos, CERN)
15. 2022-01: Defect engineering in PAD diodes mimicking the gain layer in LGADs (Ioana Pintilie, NIMP)
16. 2023-01: SiC-LGAD, (Thomas Bergauer,HEPHY Vienna)
17. 2023-03: DeepJunction-LGAD and adaptive gain layer, (Simone M.Mazza, SCIPP, UC Santa Cruz)
18. 2023-05: Partial Activation of Boron (PAB) to enhance radiation tolerance (Valentina Sola, Torino)

From lab to companies

Clean Rooms that develop LGAD technology

2013 — Centro Nacional de Microelectrónica CSIC

2016 — Centro Nacional de Microelectrónica CSIC; Fondazione Bruno Kessler

2017 — Centro Nacional de Microelectrónica CSIC; Fondazione Bruno Kessler; Hamamatsu

2018 — Centro Nacional de Microelectrónica CSIC; Fondazione Bruno Kessler; Hamamatsu; Institute of Microelectronics of the Chinese Academy of Sciences; Micron Semiconductor Limited; Brookhaven National Laboratory

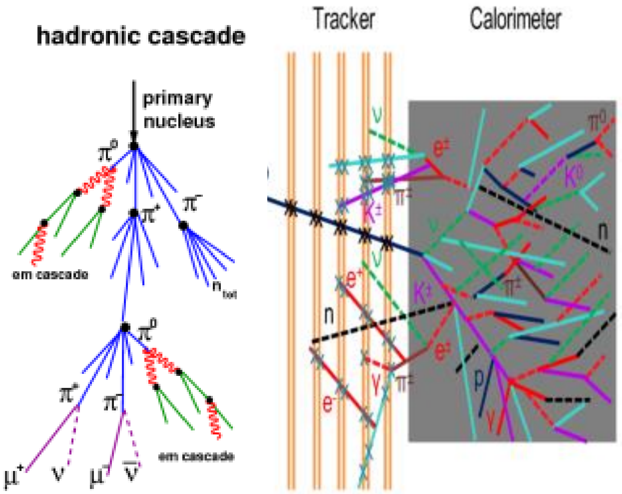
2021 — Centro Nacional de Microelectrónica CSIC; Fondazione Bruno Kessler; Hamamatsu; Micron Semiconductor Limited; Brookhaven National Laboratory; Institute of Microelectronics of the Chinese Academy of Sciences; CiS Forschungsinstitut für Mikrosensorik GmbH; Teledyne Technologies

First time used in TOTEM CT-PPS at CERN

LGAD is the baseline technology of the timing detectors for the high-luminosity upgrade of the ATLAS (HGTD) and CMS (ETL) experiments.

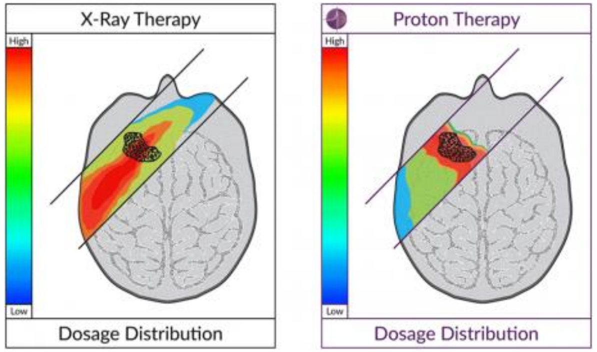
LGAD and timing beyond HEP

Space Applications
(Time resolved tracking)

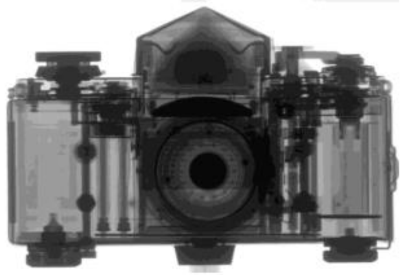


Synchrotron Applications
(LGAD tailored for X-ray detection)

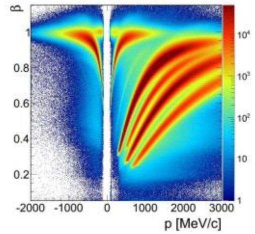
Medical Physics
(4D tracking, X-ray detection...)

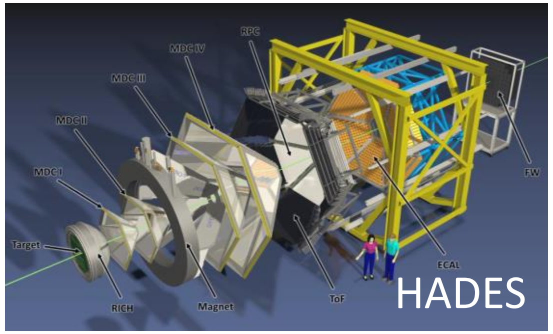


Neutron Imaging
(Combining timing LGAD with a conversion layer)



Nuclear Physics
(Particle identification)

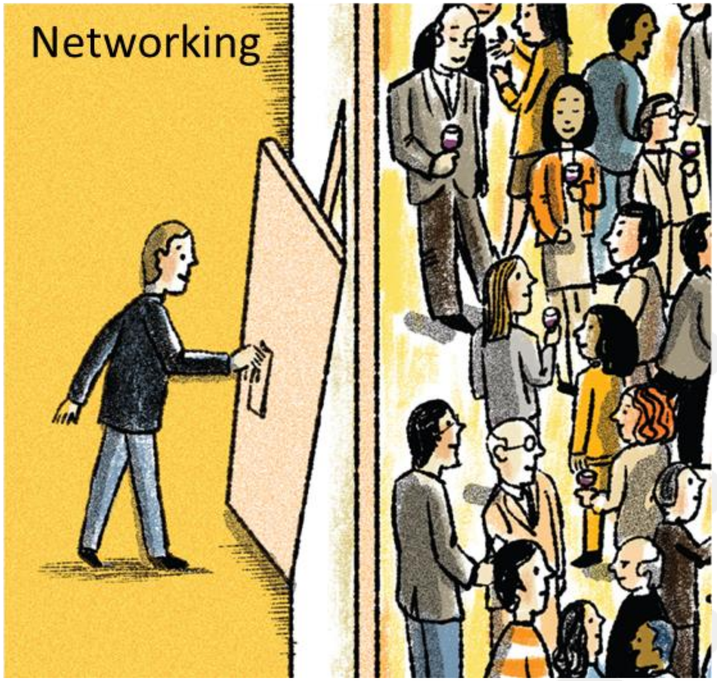




Please check dedicated sessions at:
RD50 Workshops
TREDi workshops
VERTEX
Vienna conference on Instrumentation
Etc…

Conclusions

Lesson I learned in RD50 meeting:



Congratulation to Valentina!

erc

European Research Council (ERC)

-Doping Compensation in Thin Silicon Sensors: the pathway to Extreme Radiation Environments

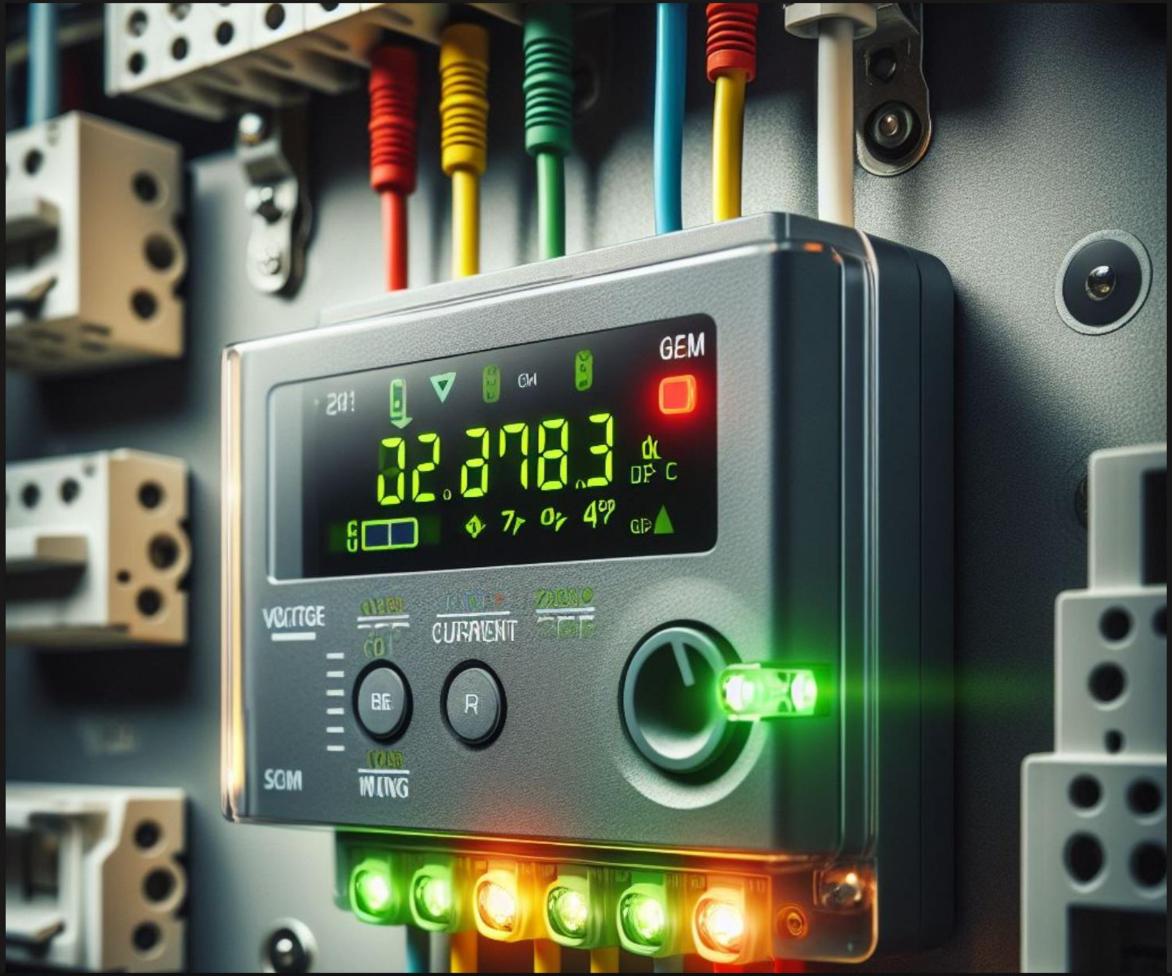
Centro Nacional de Microelectrónica IMB

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

RD50

Microsoft Bing | **Image Creator** da finestra di progettazione PREVIEW

Prova



An LGAD detector

Designer | 1024 × 1024 jpg | 2 giorni fa

Condividi Scarica Feedback

Credenziali del contenuto
Generato con intelligenza artificiale · 25 Novembe