



LGAD: a Little bit of the early history

Giulio Pellegrini
Salvador Hidalgo



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)

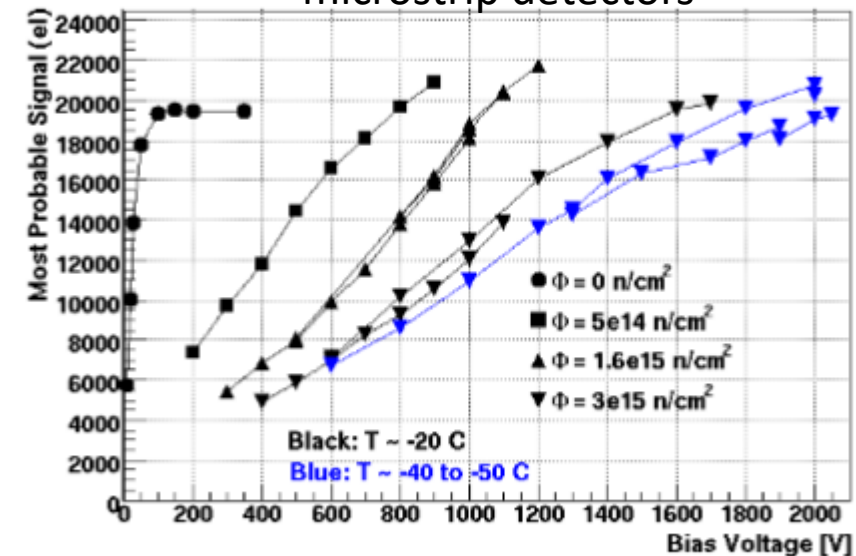
It was clear in 2010 the charge Multiplication effect in Highly Irradiated Planar Sensors -> mainly strips.

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.

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.



microstrip detectors



2010

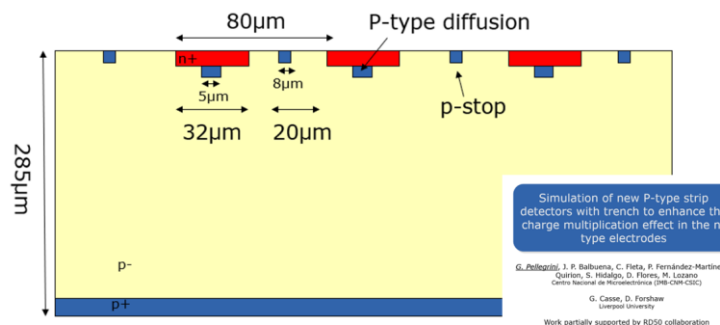
First idea of a detector with a moderate Gain

Strip detector

Technological proposals

II. P-type diffusion along the centre of the strip pitch

- Under reverse bias conditions, a high electric field region is created at the N⁺- P junction → **multiplication**

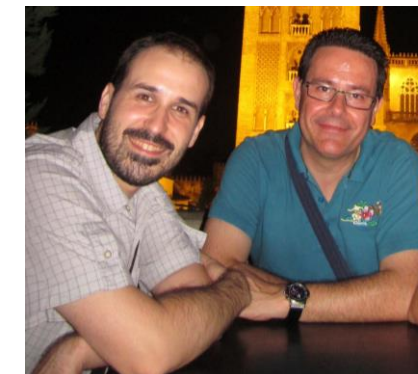


Simulation of new P-type strip detectors with trench to enhance the charge multiplication effect in the n-type electrodes.

G. Pellegrini, J. P. Balbuena, C. Fleta, P. Fernández-Martínez, D. Quiñón, S. Hidalgo, D. Flores, M. Lozano
Centro Nacional de Microelectrónica (2009-2012)

G. Casse, D. Forsham
Liverpool University

Work partially supported by RD50 collaboration



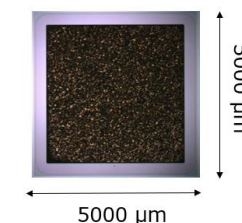
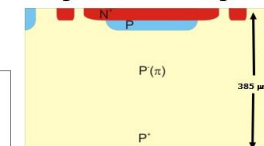
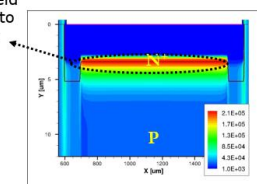
PhD thesis of Pablo Fernandez

Status of the Work: PAD Diodes

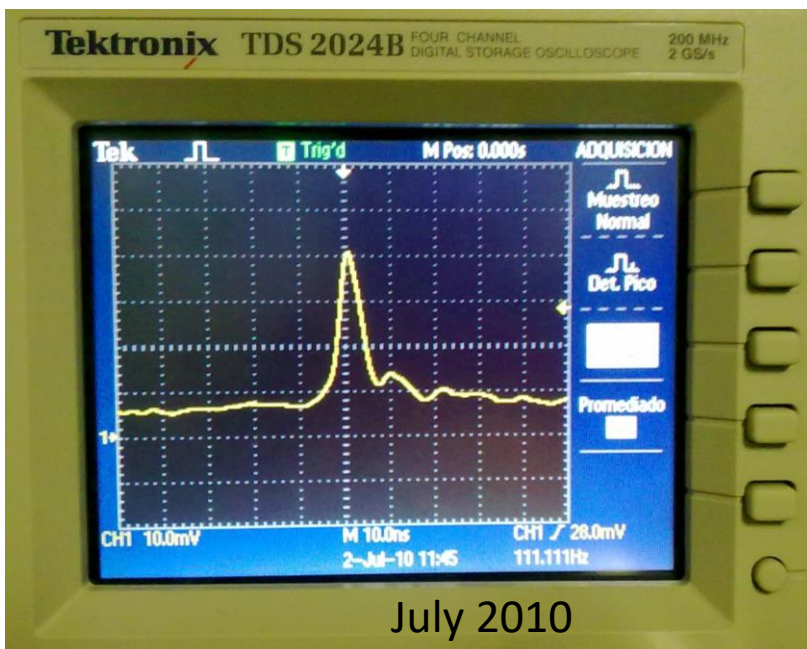
We have fabricated PAD diodes with a P layer diffused under the N⁺ diffusion

- N⁺ / P-type diffusion junction creates a high electric field region → **multiplication**

High Electric Field region leading to multiplication



✓ First Measurements:
Gain ~2



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

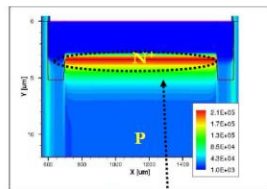
Status of the RD50 funding request for "detectors with enhanced multiplication"

21st RD50 Workshop, CERN, Geneva

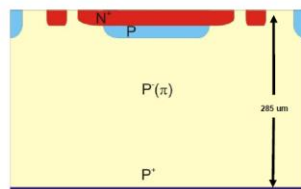
11

2) Low gain avalanche detectors (LGAD)

Crating an n⁺⁺/p⁺/p- junction along the centre of the electrodes. Under reverse bias conditions, a high electric field region is created at this localised region, which can lead to a multiplication mechanism. Standard FZ HR p-type wafers.



High Electric Field region leading to 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.

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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 Sadrozinski, hartmut@ucsc.edu
4. IFAE, Barcelona, Sebastian Grinstein, sgrinstein@ifae.es
5. KIT, Karlsruhe, Prof. Wim de Boer, 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

Ultra-Fast Silicon Detectors

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

Ultra-Fast Silicon Detectors (UFSD)

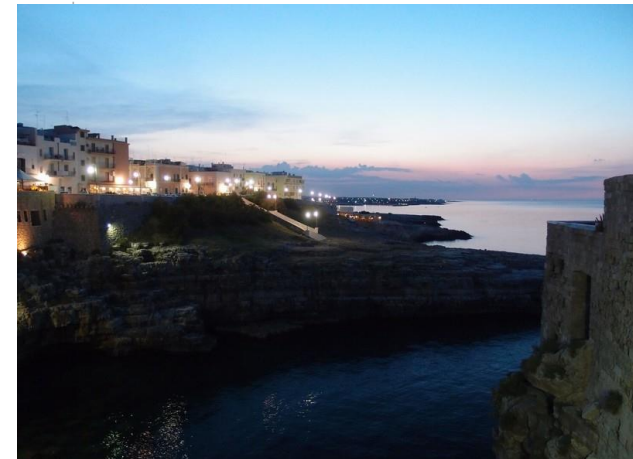
provide in the same detector and readout chain

- ultra-fast timing resolution [10's of ps]
- precision location information [10's of μm]



Great vision! 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.



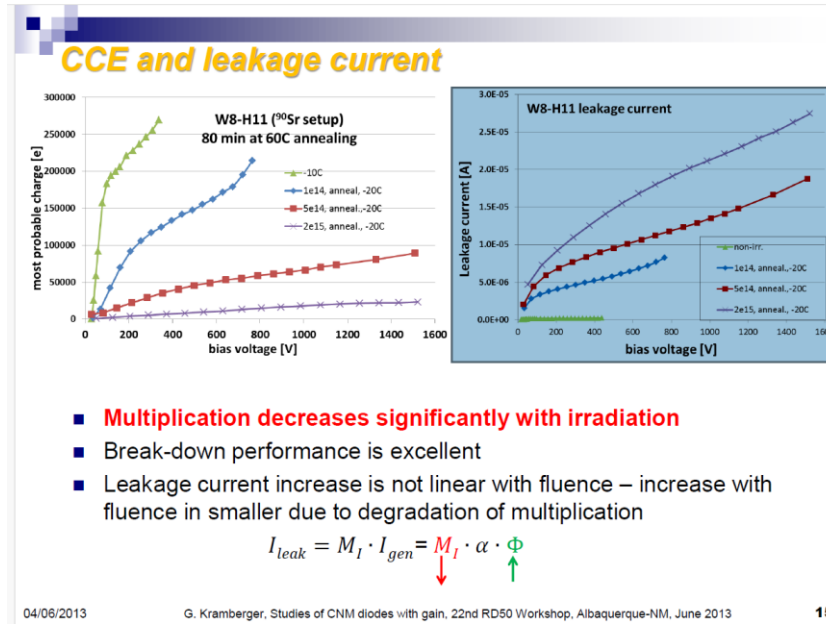
2013

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

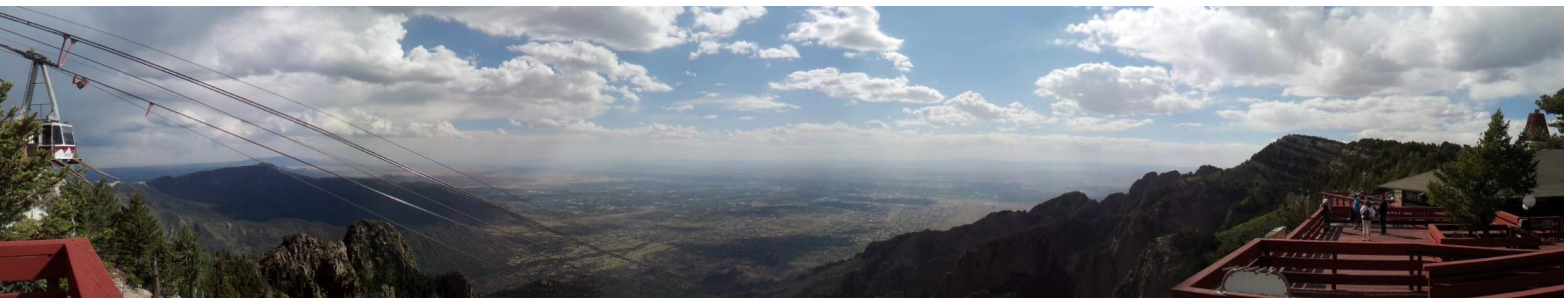
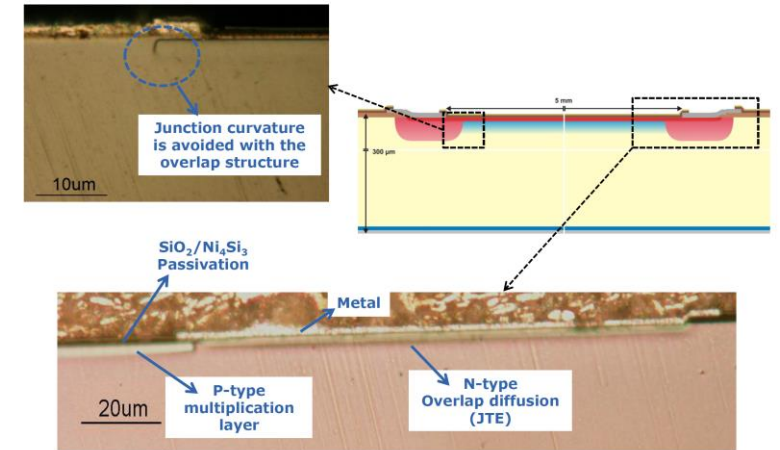
In physics, you don't have to go around making trouble for yourself - nature does it for you.

QUOTEHD.COM

Frank Wilczek



Technological Characterization



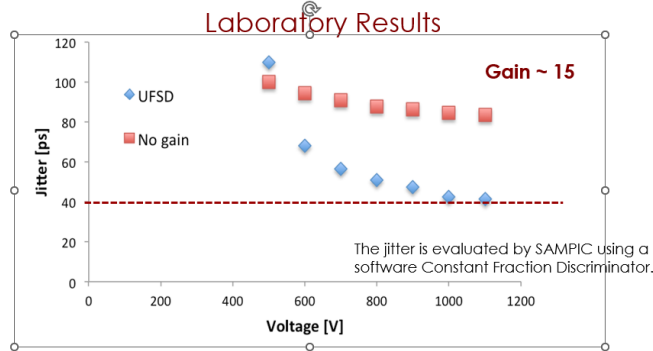
2014

- Thin LGAD
- C and G doping

Discussion session



Time Resolution vs Vbias



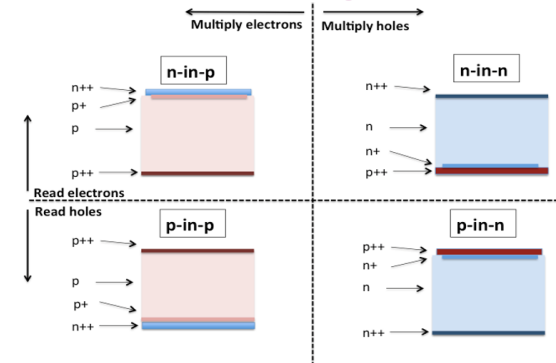
This result is consistent with the simulation predictions:
300-micron thick UFSDs with gain of ~ 15 improve by ~ 2 the timing resolution

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New directions

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



In backup slides

20

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

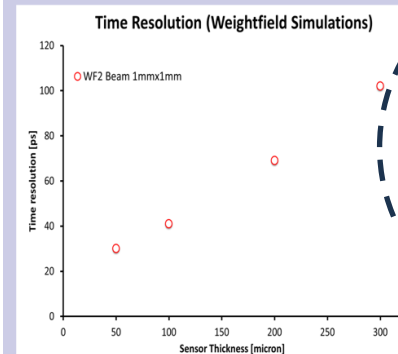
Marta Baselga, Pablo Fernández-Martínez, David Flores, Virginia Greco, Salvador Hidalgo, Giulio Pellegrini, David Quirion,
IMB-CNM, Barcelona, Spain

Nicolo Cartiglia, Francesca Cenna
INFN Torino, Torino, Italy

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

Time Resolution for thin LGAD

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

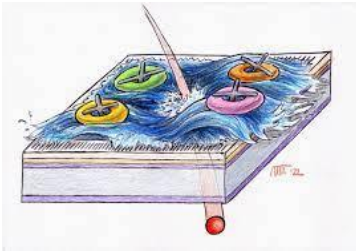


The time resolution is predicted to improve for smaller LGAD (1mmx1mm) and optimized electronics.
Reduced the thickness also improves the time resolution.

Expect for 50 μ m thick LGAD ($C \sim 2$ pF):

$\alpha = 30$ ps (requires ASIC)

2015



14 Recent developments on LGAD and iLGAD detectors for tracking and timing applications

10th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Xi'an, China

P on P Strip iLGAD: The "Inverted" LGAD

- Double-sided LGAD with pad-like multiplication structure in the back-side and ohmic read out strips, or pixels, in the front side
- First Design and Run. Include Pads, microStrips and pixelated iLGADs

1987 United States Patent. Paul P. Webb et al. RCA Inc. "Avalanche photodiode"

19 Recent developments on LGAD and iLGAD detectors for tracking and timing applications

10th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Xi'an, China

iLGAD. First Mask Set Description. Integrated Devices

- 176 Chips**
 - 44 (10 x 10 mm, total area)
 - 56 (5 x 5 mm, total area)
 - 76 (3.3 x 3.3 mm, total area)
- 113 LGAD Pad Detectors**
 - 12 (8 x 8 mm mult area)
 - 49 (3 x 3 mm mult area)
 - 52 (1 x 1 mm mult area)
- 17 PiN Detectors**
 - 2 (8 x 8 mm active area)
 - 5 (3 x 3 mm active area)
 - 10 (1 x 1 mm active area)
- 8 iLGAD pStrips Detectors**
 - 4 (45 Channels)
 - 4 (90 Channels)
- 2 PiN pStrips Detectors**
 - 1 (45 Channels)
 - 1 (90 Channels)
- 6 Pixelated iLGAD Detector (6 x 6 pixels)**
- 4 Pixelated iLGAD Medipix Detector (145 x 145 pixels)**
- 6 iLGAD for Timing Applications**
 - 3 (720 µm to cut line)
 - 3 (370 µm to cut line)
- 4 Specific Test Structure (SPR, SIMS, XPS)**
- 16 CNM Test Structures (Microsection, CBR, Kelvin, Capacitors, Diodes)**

RD50 Project

- Fill Factor
- iLGAD & AC-LGAD



Topics in LGAD Design

1. Introduction to the Low Gain Avalanche Diode design
2. A proposal for LGAD segmentation
3. Determination of optimum gain in LGAD
4. A scheme to deal with boron removal under irradiation

Nicolo Cartiglia
with
INFN Gruppo V, RD50, Santa Cruz, FBK, Trento University, CNM Barcellona

LGAD with a resistive n++ electrode

The signal is frozen on the resistive sheet, and it's AC coupled to the electronics

→ E and E_w fields are very regular
→ Segmentation is achieved via AC coupling

The AC read-out sees only a small part of the sensor: small capacitance and small leakage current.



2016

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

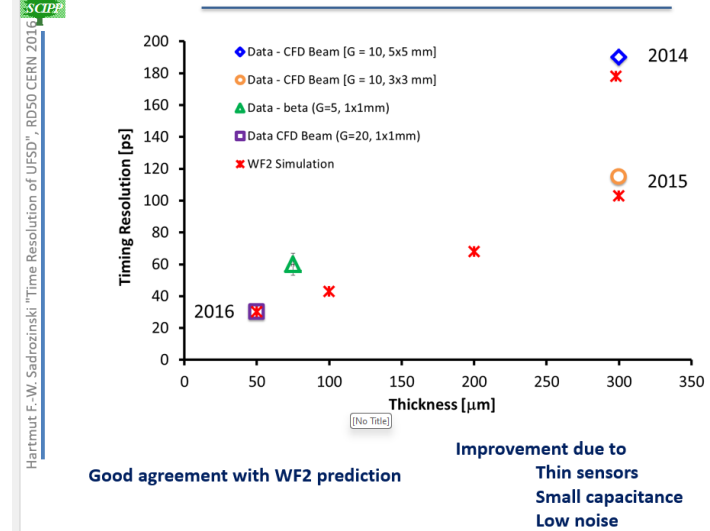


Gain and time resolution of 50 µm LGADs before and after irradiation

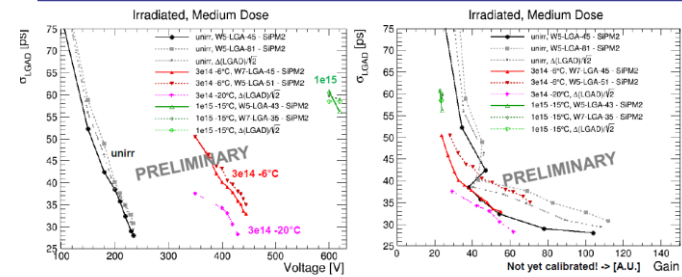
J. Lange, E. Cavallaro, F. Förster, S. Grinstein
 IFAE Barcelona
 M. Carulla, D. Flores, S. Hidalgo, G. Pellegrini, D. Quirion
 CNM-IMB-CSIC Barcelona
 L. Chytka, T. Komarek, L. Nozka, T. Sykora
 Palacky University Olomouc and Charles University Prague
 P. Davis
 University of Alberta, Edmonton
 G. Kramberger,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

22 November 2016,
 29th RD50 Workshop, CERN

Updated UFSD Timing Resolution from Beam Tests



Time Resolution (irr)

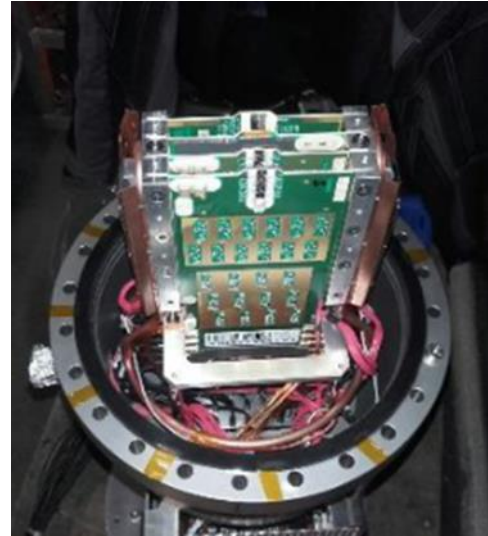


- At 3e14 similar time resolution achieved as before irradiation (at higher V)
 - -6°C: 33 ps at 445 V
 - -20°C: 28 ps at 430 V
- At 1e15 gain is highly reduced and voltage stability not high enough to compensate for it
 - 55-60 ps at 620 V
- Gain dependence in all cases similar to before irradiation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

2017

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

TOTEM CT-PPS



New idea for a AC-LGAD design to avoid pick-up noise

2017/12/19

Activities done at Santa Cruz Institute for Particle Physics

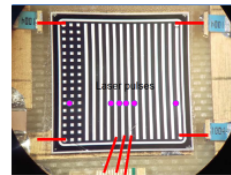
11/29/2017

New idea for a AC-LGAD design to avoid pick-up noise

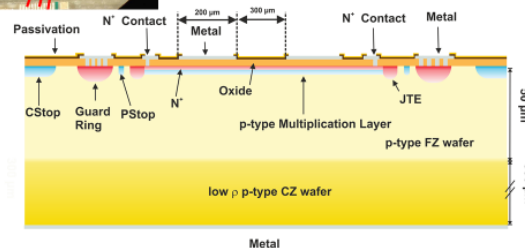
M. Carulla, D. Flores, S. Hidalgo, A. Merlos, G. Pellegrini, D. Quirion

Centro Nacional de Microelectrónica, IMB-CNM-CSIC, Barcelona, Spain

AC-Detectors



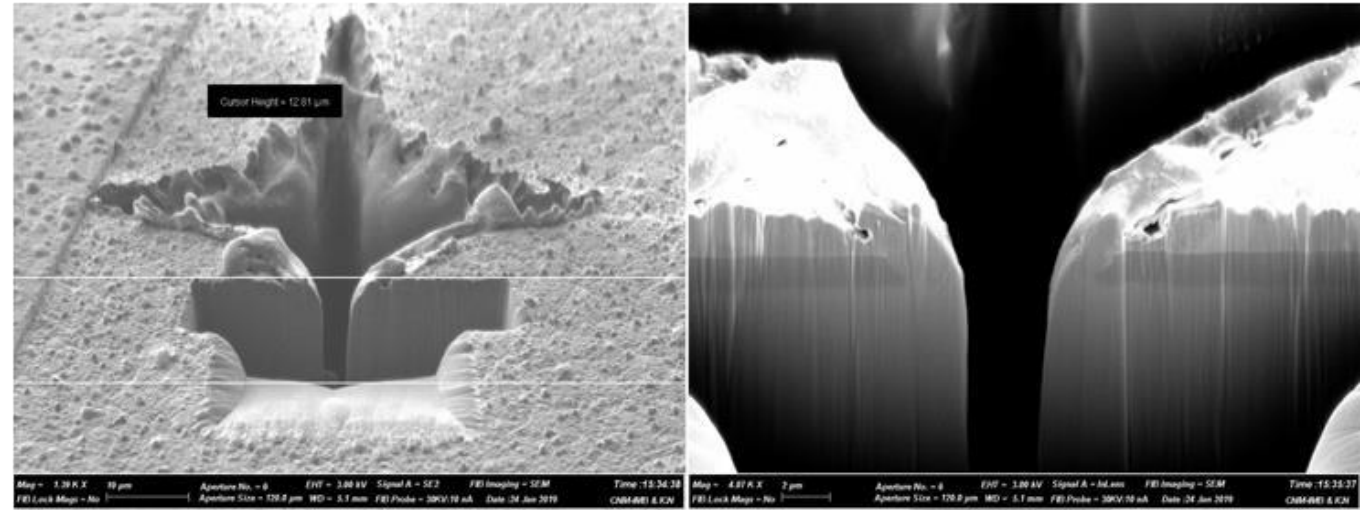
Resistance at Contact 1 MOhm and 90 kOhms



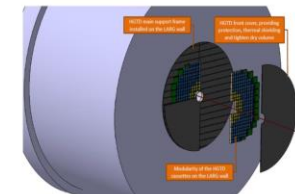
2018



Single Event Burnout



HGTD Test beam meeting – 30 / 5 / 2018



LGAD Safety and Stability Concerns
The art of (not) burning a sensor

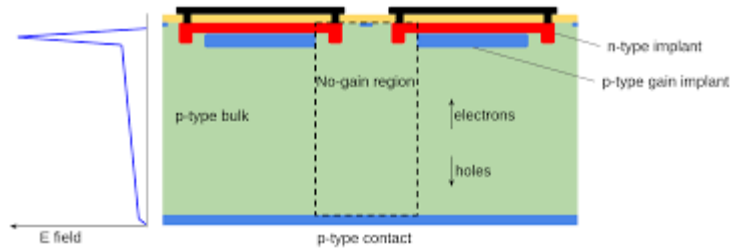
E. L. Gkougkousis^{1,2}

- 1: Institut de Física d'Altes Energies - IFAE
- 2: Conseil Européen de Recherche Nucléaire - CERN

2020



Mattero Centis



LGAD measurements from different producers

ALISSA HOWARD, G. KRAMBERGER, ŽAN KLJUN, PETJA SKOMINA
JOŽEF STEFAN INSTITUTE, LJUBLJANA

A WORK PERFORMED IN COLLABORATION WITH CMS-ETL AND ATLAS-HGTD GROUPS:
INFN-TORINO, USCS, IHEP-BEIJING, CNM

19/11/2020

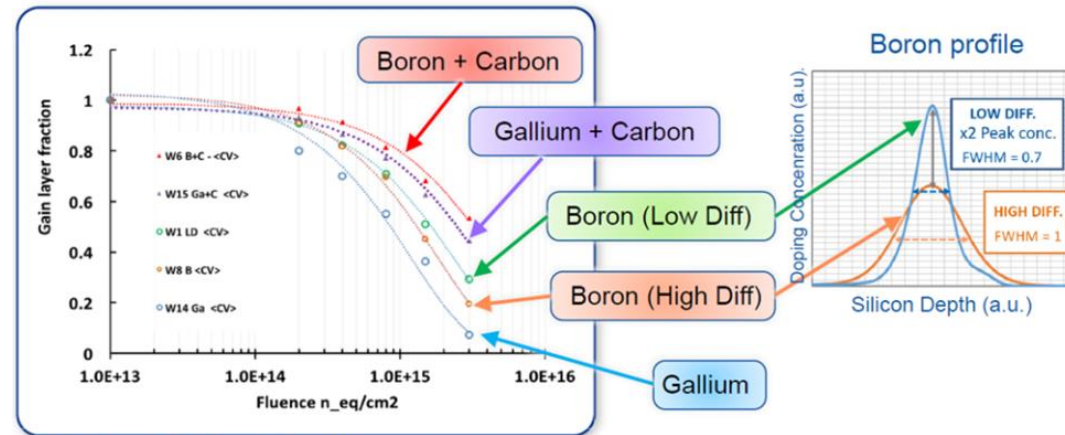
A. HOWARD, LGAD MEASUREMENTS FROM DIFFERENT PRODUCERS, 37TH ROSE WORKSHOP

1

Giovanni Paternoster
Principal Investigator
PLASMONIC ENHANCED SILICON PHOTOMULTIPLIERS FOR NEAR INFRARED LIGHT DETECTION (PLASIPM)

Detection of near infrared photons is a real key enabling technology in many scientific and industrial applications.

ATTRACT



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

LGAD: Fill factor & performance improvements



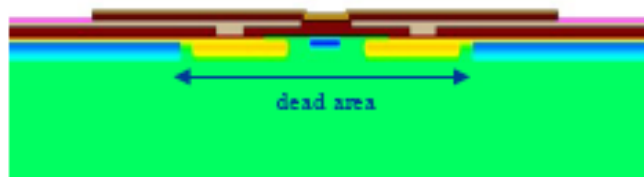
- Two opposing requirements:
 - Good timing reconstruction needs homogeneous signal (i.e. no dead areas and homogeneous weighting field)
 - A pixel-border termination is necessary to host all structures controlling the electric field
- Several new approaches to optimize/mitigate followed:

Trench Isolation LGAD

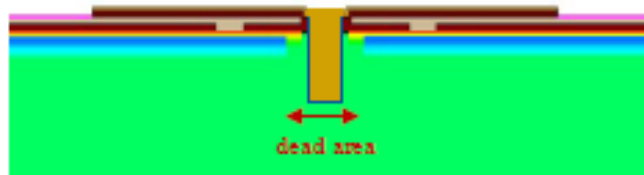
AC-LGAD

Invers LGAD

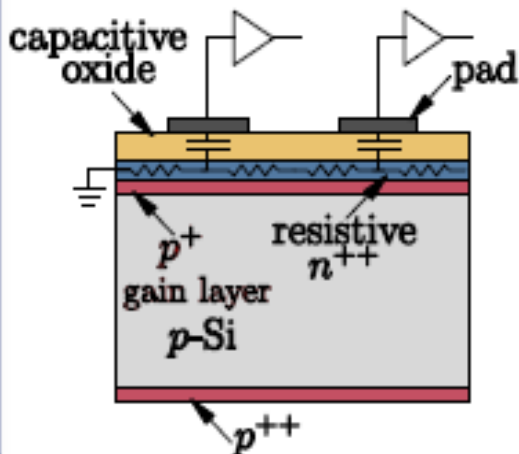
Deep Junction LGAD



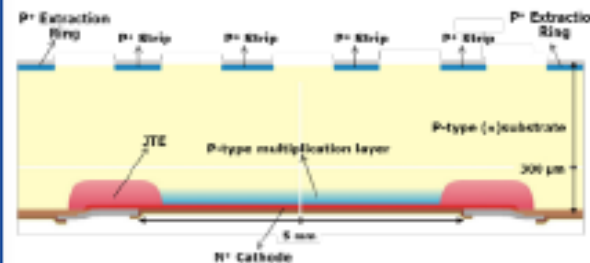
traditional gain isolation



trenches isolation (HD-LGAD)

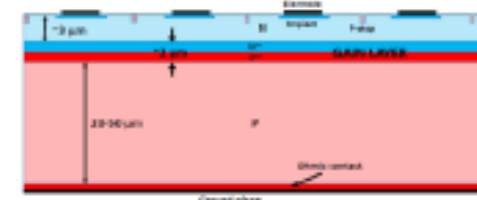


Front: segmented readout



Back: gain layer

Front: segmented readout

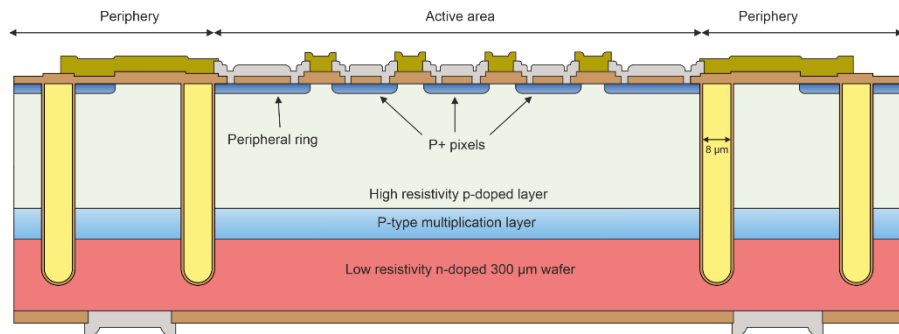


Gain layer located deep under front electrodes

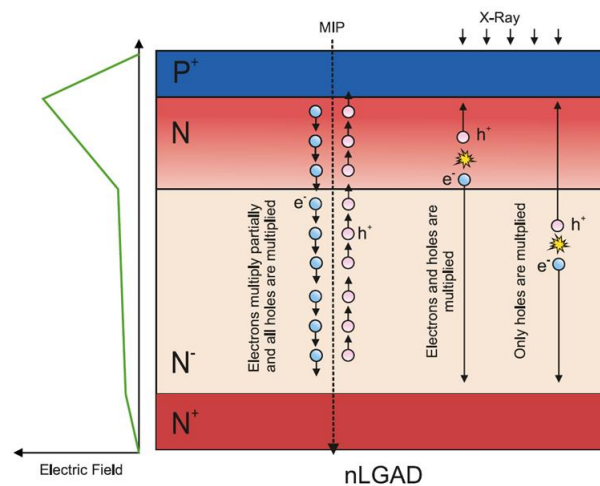
Example 2

Fill factor, low penetrating particles and large area devices

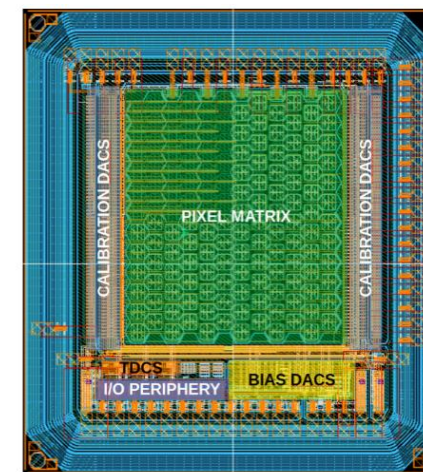
Trenches iLGAD



pLGAD



LGAD-in-CMOS Design

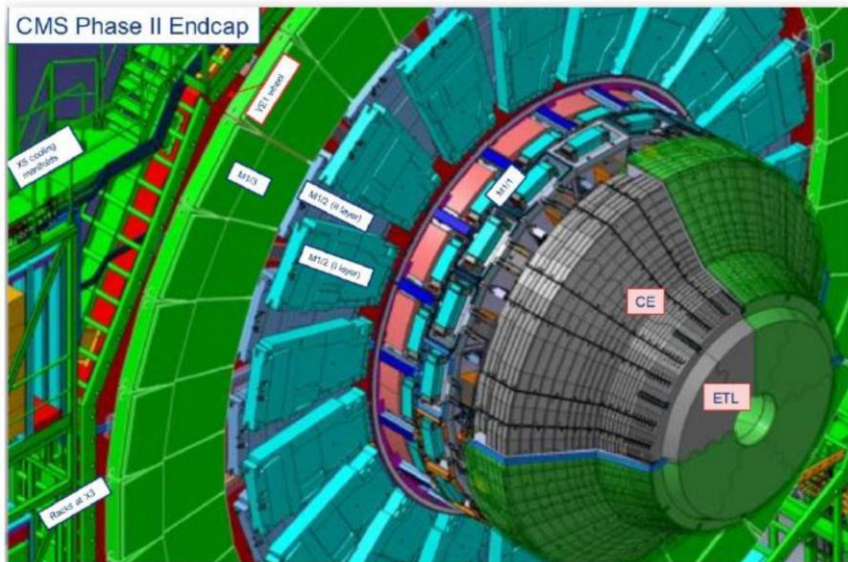
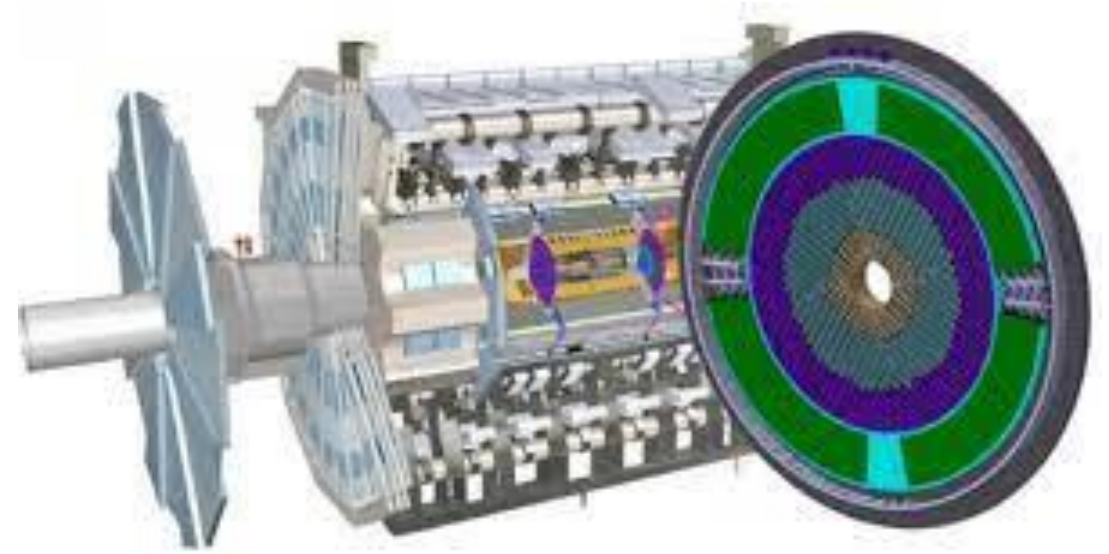


Picosecond Avalanche Detector

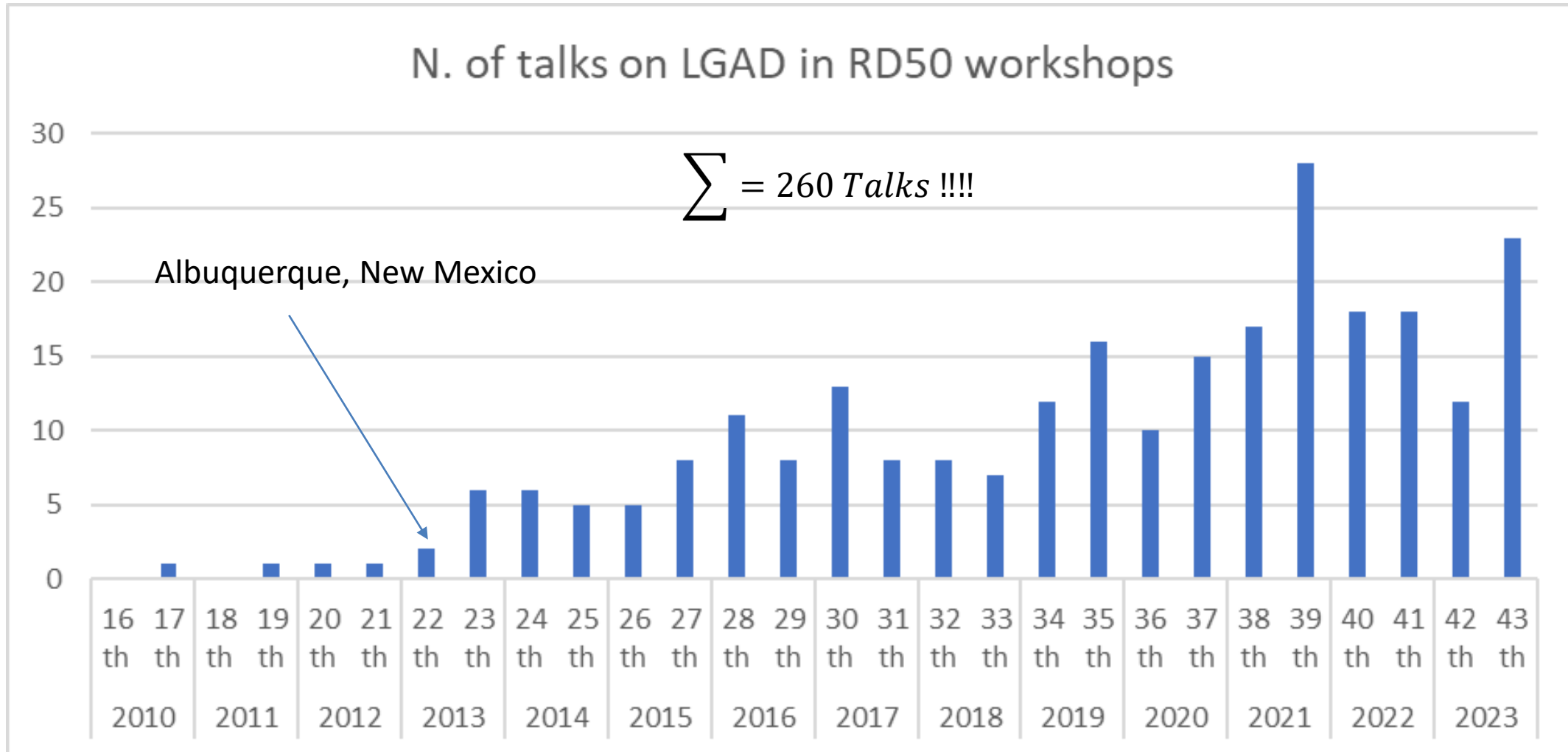
- Picosecond Avalanche Detector — working principle and gain measurement with a proof-of-concept prototype: DOI 10.1088/1748-0221/17/10/P10032
- **Effects of Shallow Carbon and Deep N++ Layer on the Radiation Hardness of IHEP-IME LGAD Sensors** : DOI: 10.1109/TNS.2022.3161048
- Trench-Isolated Low Gain Avalanche Diode, DOI: [10.1109/LED.2020.2991351](https://doi.org/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



RD50 LGAD projects

1. 2013-01: Fabrication of p-type pixel detectors with enhanced multiplication (Giulio Pellegrini, CNM)
2. 2014-02: Fabrication of 200 μm 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: Deep Junction-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



2016



2017



2018



2021

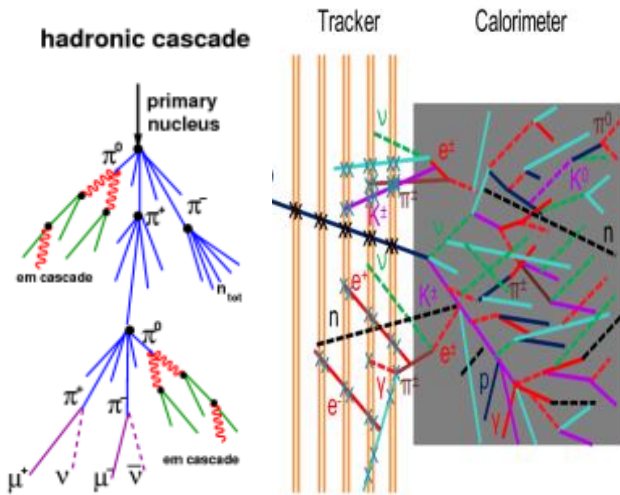


First time used in TOTEM CT-PPS at CERN

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

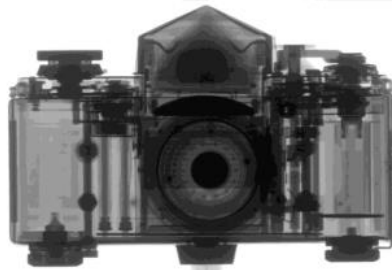
Space Applications (Time resolved tracking)



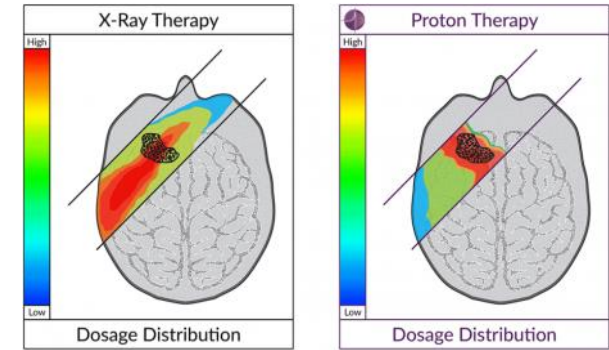
Synchrotron Applications (LGAD tailored for X-ray detection)



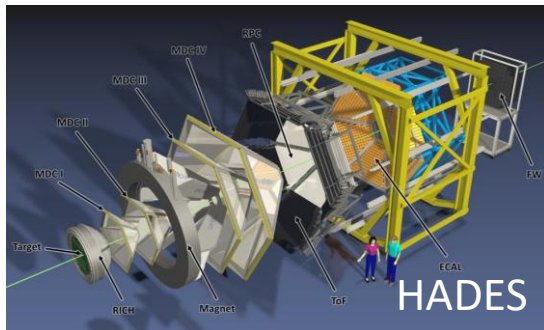
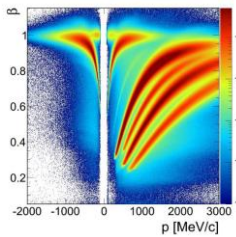
Neutron Imaging (Combining timing LGAD with a conversion layer)



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



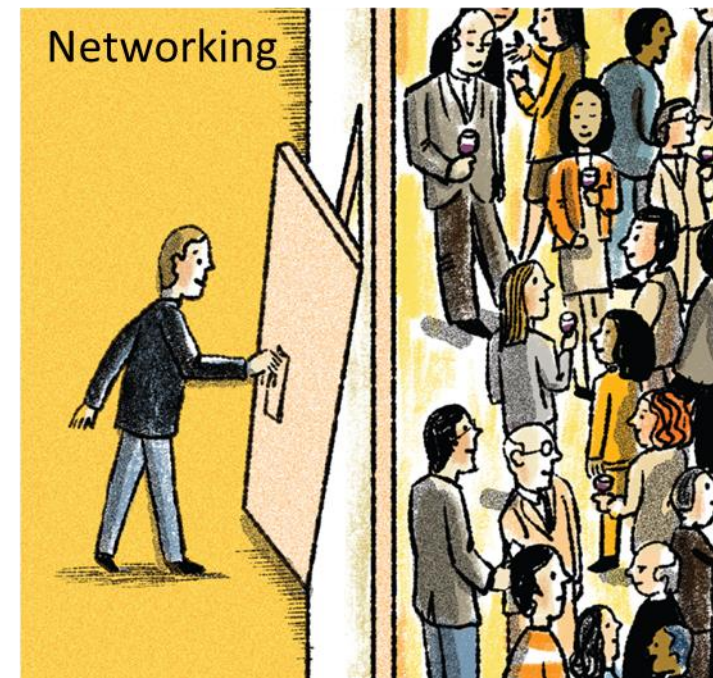
Nuclear Physics (Particle identification)



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!



European Research Council (ERC)

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

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 Novembre