32nd RD50 Workshop

4 – 6 June 2018 Hamburg

High – Density Low Gain Avalanche Detectors (HD-LGAD)

an RD50 common project proposal

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Summary

1. Thin-LGAD: technology development status
2. LGAD segmentation: Fill Factor losses
3. Segmentation strategies of LGAD sensors
4. New strategies to improve the Fill Factor
   - Optimized JTE
   - Narrow Trench isolation
5. RD50 proposal for HD-LGAD developments

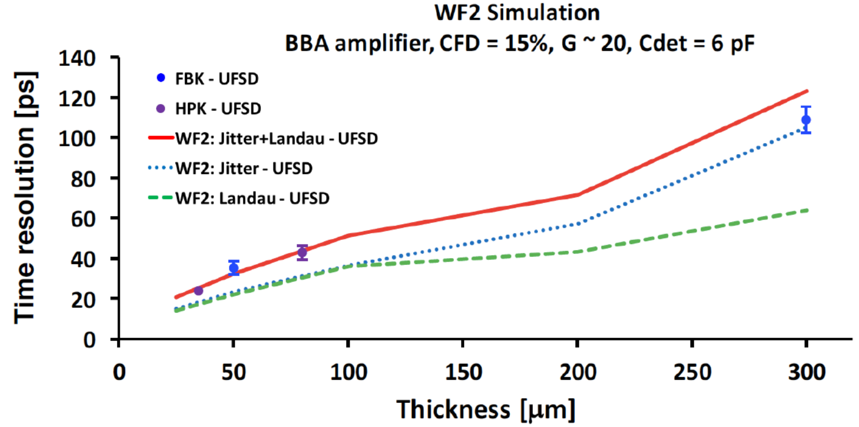
Low Gain Avalanche detectors

Ultra Fast Silicon Detectors = a candidate for 4-D tracking

Desired Features

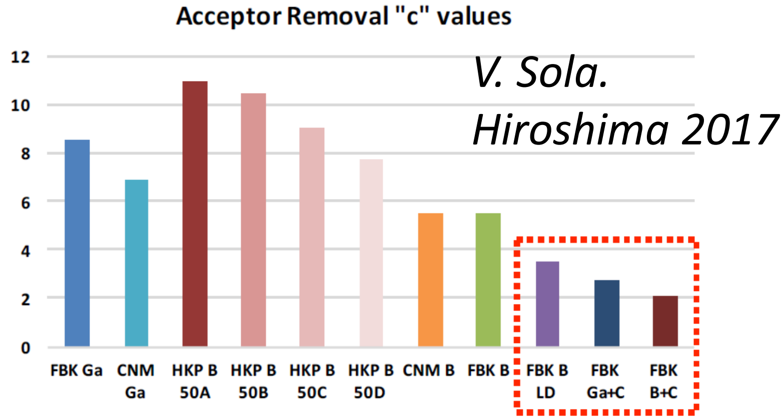
1. Ultra **Fast timing** resolution ≈ 10 - 20 ps

   Time resolution < 30 ps recently demonstrated



2. **Radiation hardness** at high fluences

   Promising Results with Boron Carbonated recently obtained up to fluences of 1.5 10^{15} n_{eq}/cm^2



Receipt for a high radiation resistant detector:

- Continue using **Boron**
- Add **Carbon**
- Make the gain layer thin (**LD**)

preliminary

3. High **spatial resolution**: ≈ 10's -100's of µm

   Small pixels

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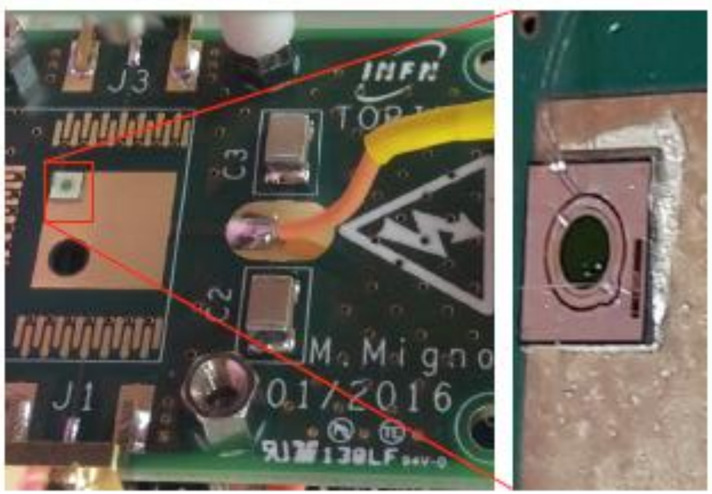
Low Gain Avalanche detectors

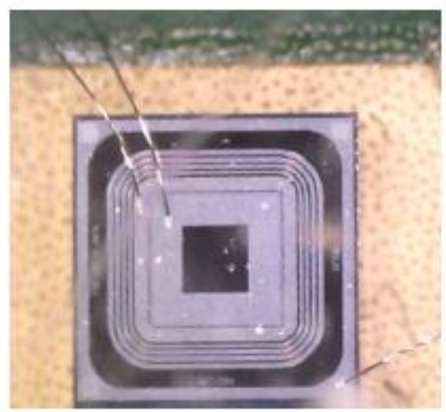
The "perfect" detector should feature at the same time:

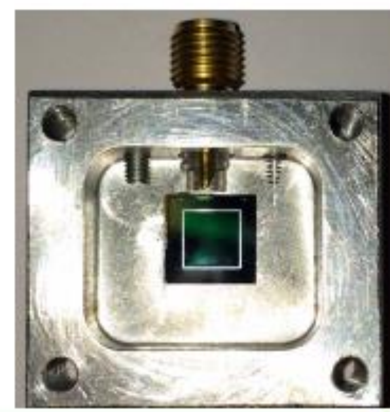
- **Thin substrate (< 50 um)**
- **Small Pixel (~100 um)**
- **Carbonated gain layer and thin multiplication layer**

not easy to produce thin LGAD with small pixels at the same time

Typical Pixel size ≈ 500 um - 1 mm.
There is still some work to do …

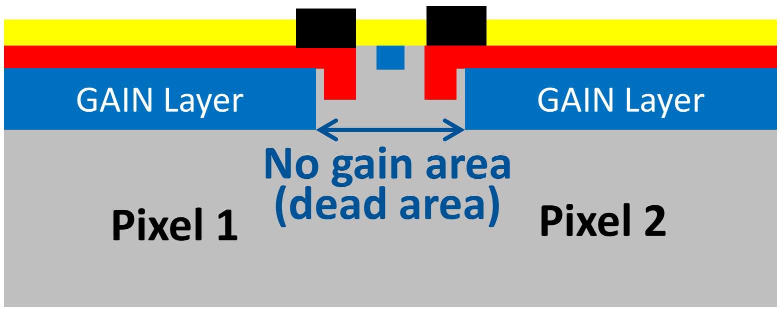






LGAD Segmentation problem: Fill Factor losses

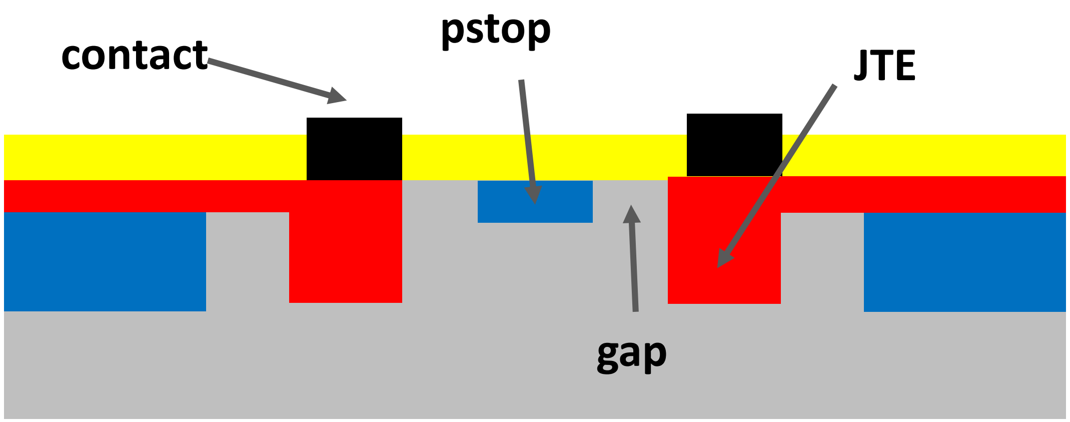
Current technology (FBK UFSD2)



- Detectors with internal gain are typically affected by Fill Factor reduction.
- Two regions are present :
  - i) GAIN region (pixel core)
  - ii) NO-GAIN region (pixel border)

$$\text{Fill Factor} = \frac{\text{gain area}}{\text{total area}}$$

- The pixel border is a dead-region. The carriers generated in this area are not multiplied.



- The pixel border region is necessary to host all the structures to control the E field (JTE, p-stop, etc..). Its dimensions are due to design and technology constraints

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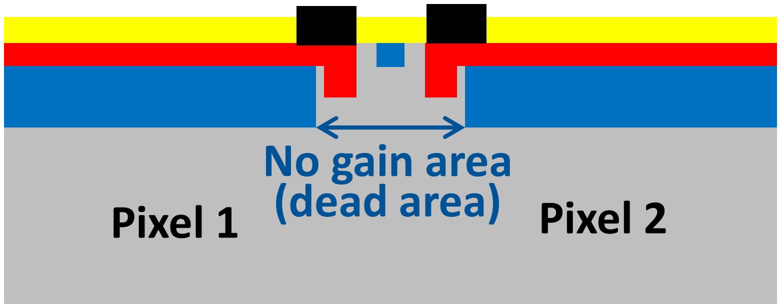
LGAD Segmentation problem : Fill Factor losses



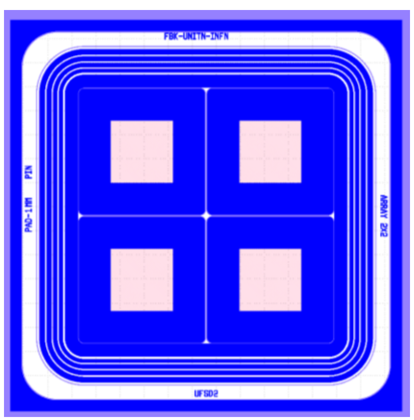
Current technology (FBK UFSD2)

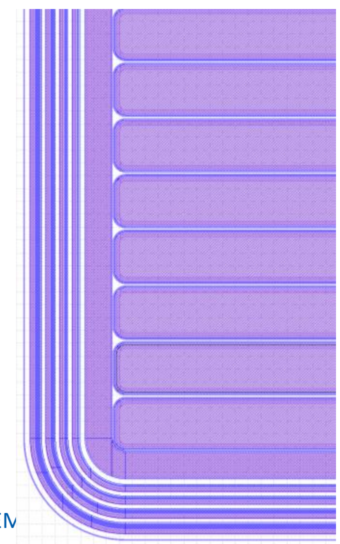
Nominal No gain area width ≈ 66 μm

FBK – UFSD2 Pad Array and Strips

1x1 mm² pixels
- > FF = 87%

200 μm Strips
- > FF = 66%





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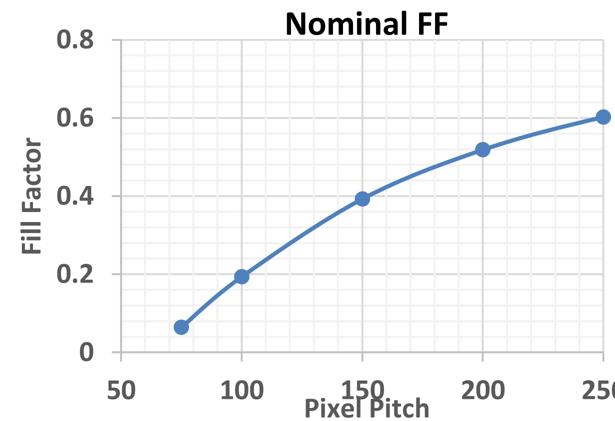
The minimum pixel (strip) dimension are dominated by the Fill Factor. Small pixels are not feasible.



Measured no-gain area width:

- HPK: 100 μm
- FBK: 70 μm
- CNM: 70 μm

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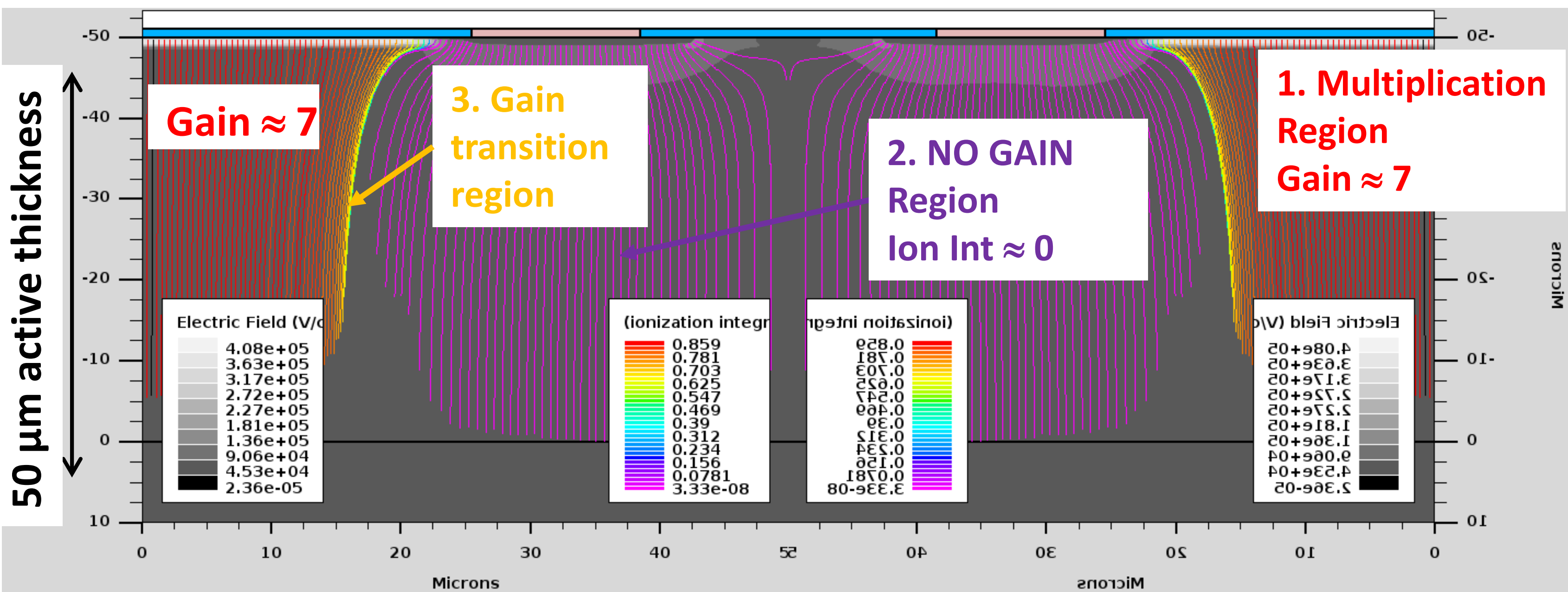
LGAD Segmentation: Fill Factor losses

TCAD Simulations. Standard technology (UFSD2)

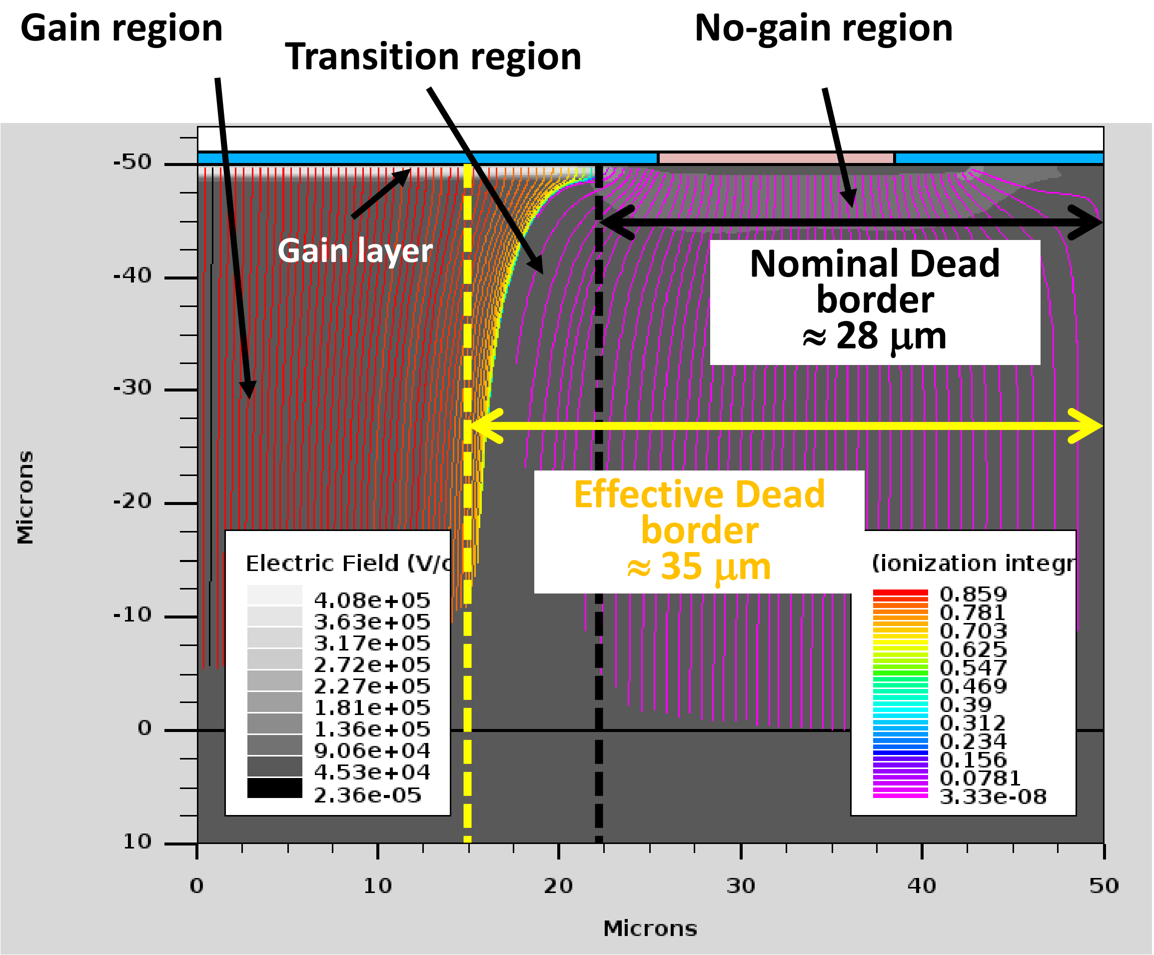
Electric Field Lines. Line color = Ionization integral



Reverse Bias = 200 Volts

LGAD Segmentation: Fill Factor losses

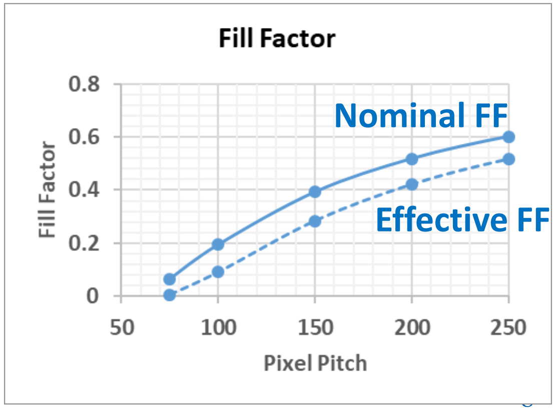
TCAD Simulations.



Nominal dead border: layout distance from gain layer to the pixel edge

Effective dead border effective distance from maximum gain region (at the detector bottom) to pixel edge

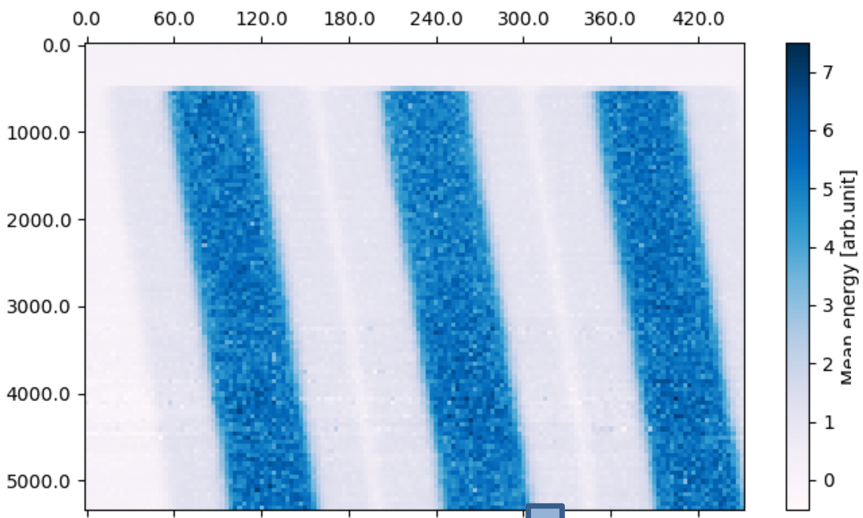
The charges generated in the **transition region** wrap up the multiplication layer and "skip it" . → The Gain depends on the depth where the charges are generated.



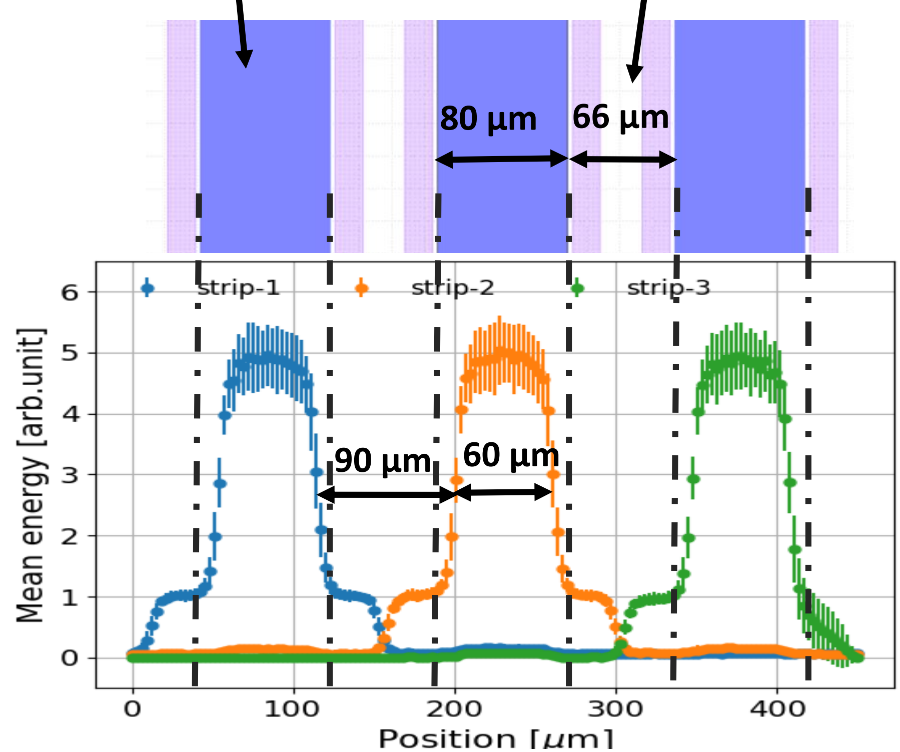
LGAD Segmentation: Fill Factor losses

Experimental measurements

X-ray beam 20 keV focused ~ 3 µm



150 µm strips (UFSD2)



Nominal FF: 55%

Effective FF (Sim): 45%

Measured FF (50% signal amplitude) ≈ 40%

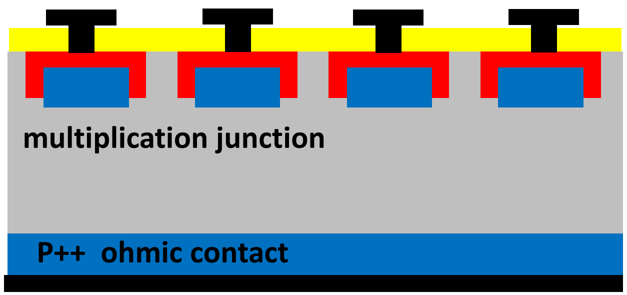
The measured energy/charge as function of beam position crossing three strips

Curtesy of Zhang Jiaguo (PSI).

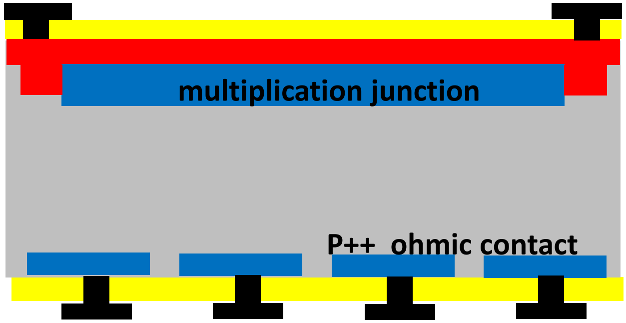
Unpublished results

Other LGAD Segmentation Strategies

Standard: N-side segmentation:
both n+ and the gain layers are segmented



1. P-side segmentation (i-LGAD): uniform gain layer. the p-layer is segmented (produced at both FBK and CNM)

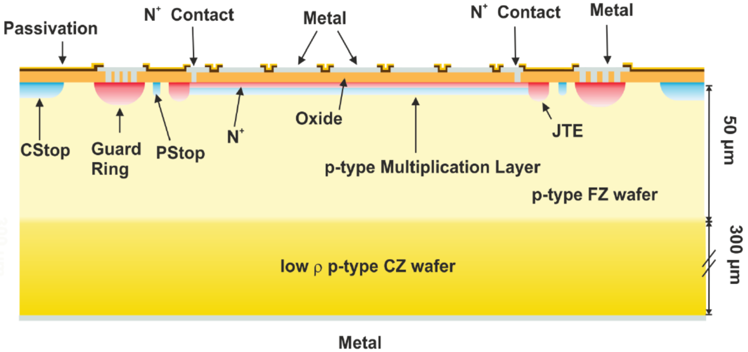


2-sides process. Not feasible on thin silicon wafers (not good for timing)

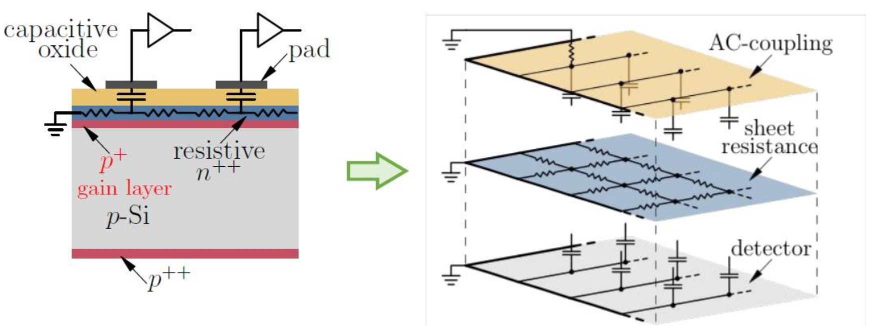
2. AC coupling readout of segmented LGAD

Uniform multiplication layer. Only metal is segmented. No dead border regions among pixels

1tst project : AC LGADs RD50 project
(UC Santa Cruz, CNM, INFN, Brookhaven Nat. Lab, CERN)



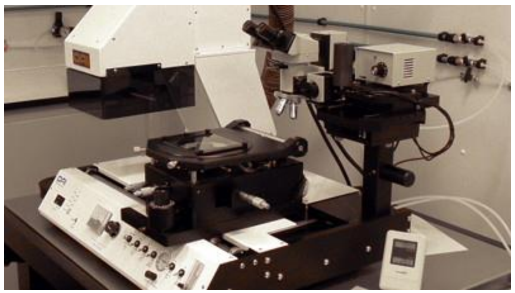
2nd project: RSD Resistive AC-Coupling
(M. Mandurrino INFN To)



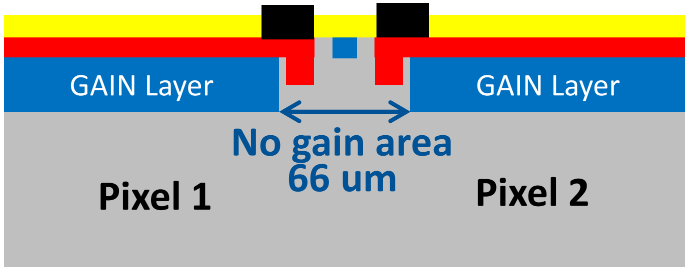
New strategies to improve FF on n-side segmentation

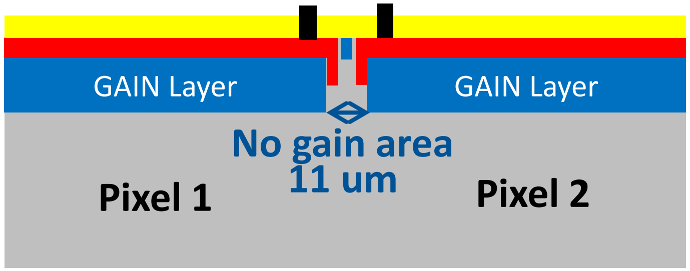
First option: Optimized border region

Standard technology (UFSD1 & 2 batches)
Based on Mask Aligner



Resolution=1um.
Critical Size = 2um
Border width = 66um



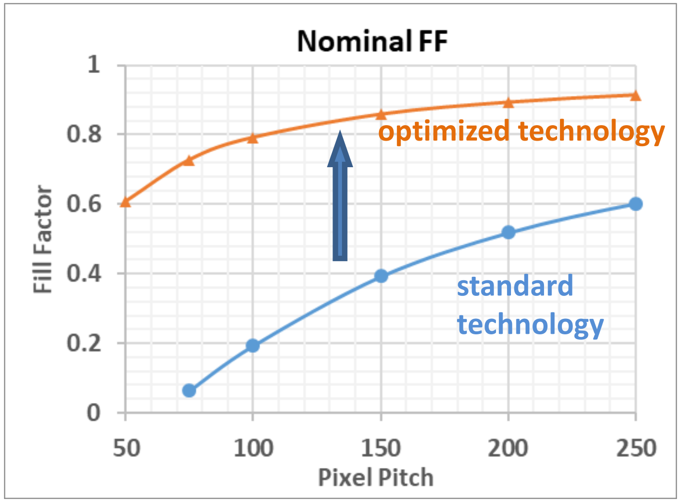


New technology (UFSD 3 batch)
Based on Stepper

New batch UFSD3 is ongoing. Expected in Q3-2018

Resolution = 0.35 um
Critical Size = 0.5 um

Layouts with Border width down to 5.5 um are going to be tested



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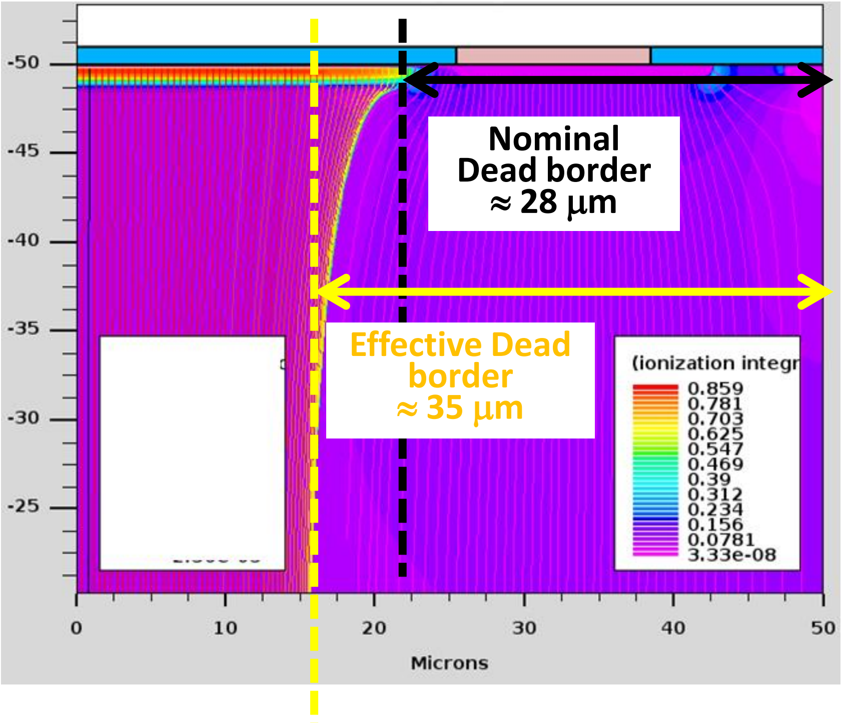
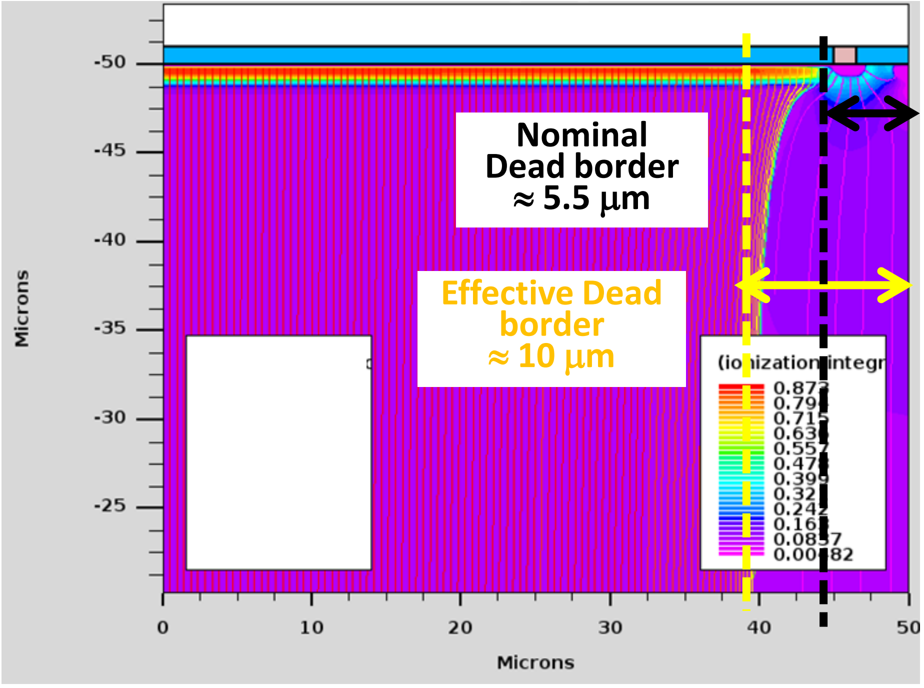
New strategies to improve FF

First option: Optimized border region

standard technology (Mask Aligner)



improved technology (Stepper)

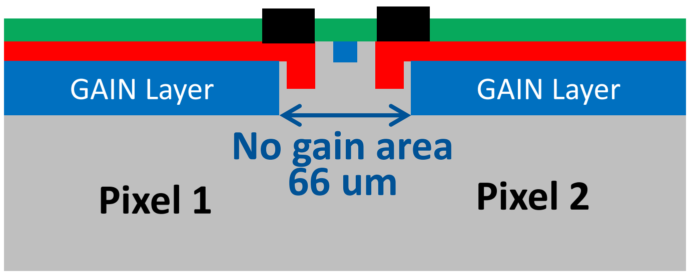


x6 reduction in nominal dead border region
but only a x3 reduction in the effective dead boarder Region. The transition region width is an intrinsic limit of this design

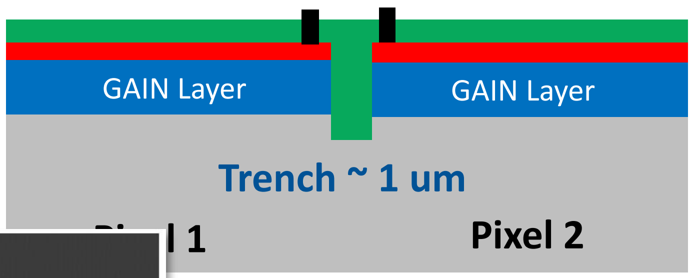
New strategies to improve FF

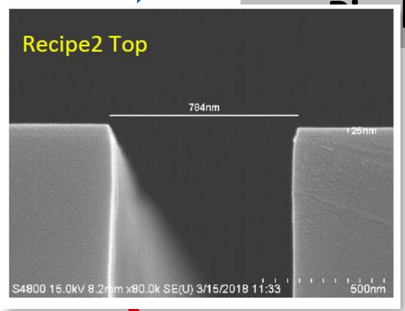
2nd Option: Trench isolation LGAD

Standard JTE + p-stop isolation

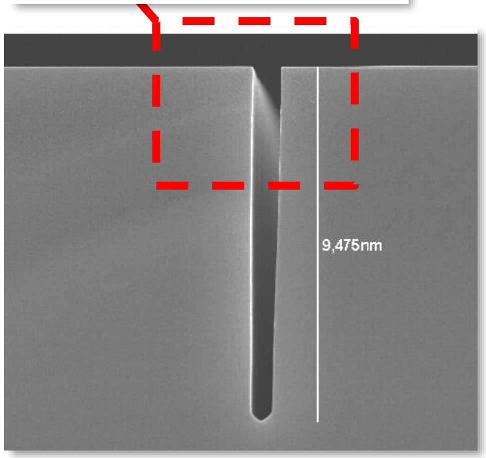


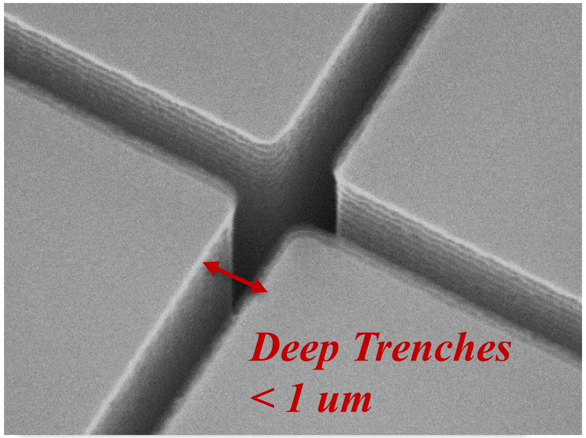
Trench Isolation





- Trench isolation could drastically reduce the inter-pixel border region down to few microns



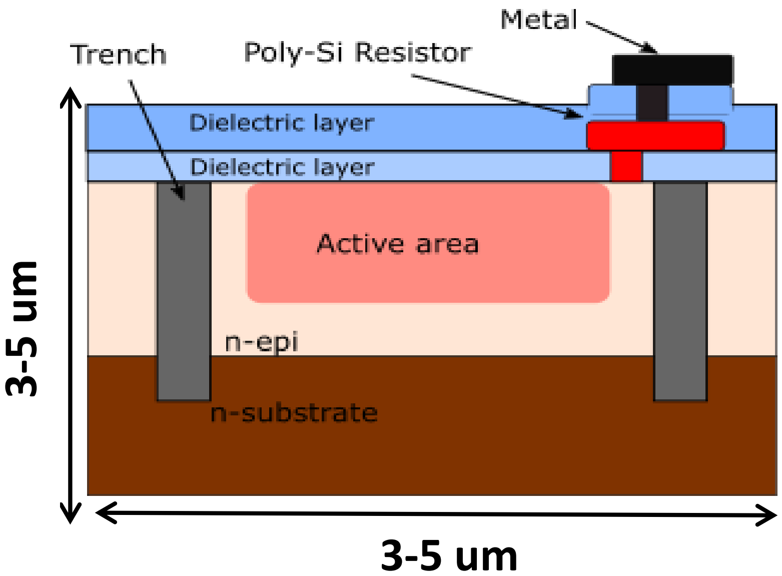


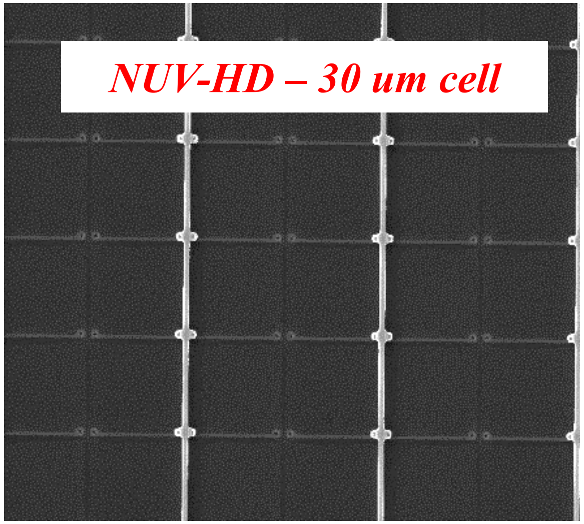
Trench isolation technology

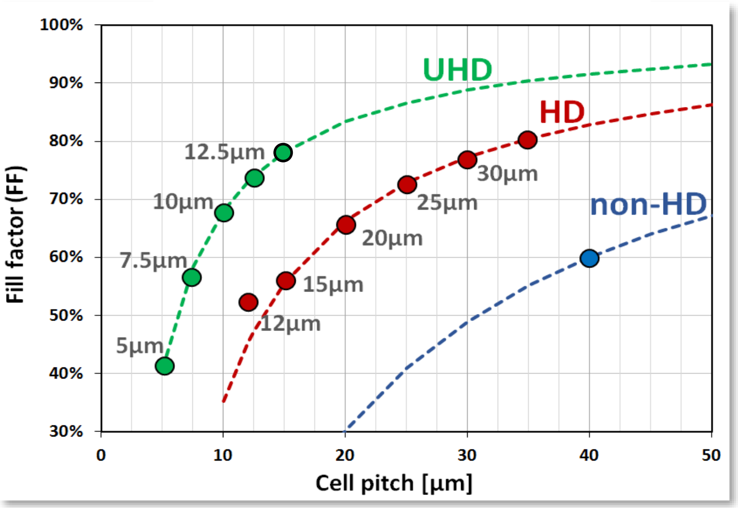
- Typical trench width < 1 um
- Max Aspect ratio: 1:20
- Trench filling with: SiO_2, Si_3N_4, PolySi

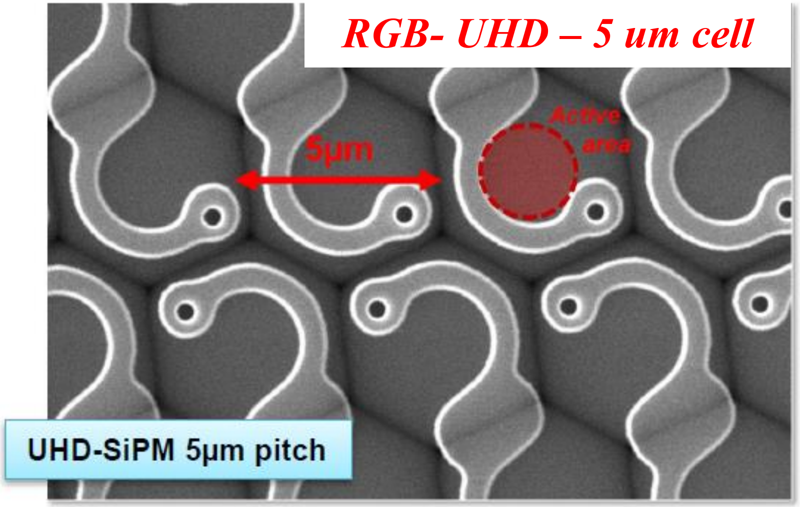
New strategies to improve FF

Trench isolation: successfully used in FBK HD-SiPM



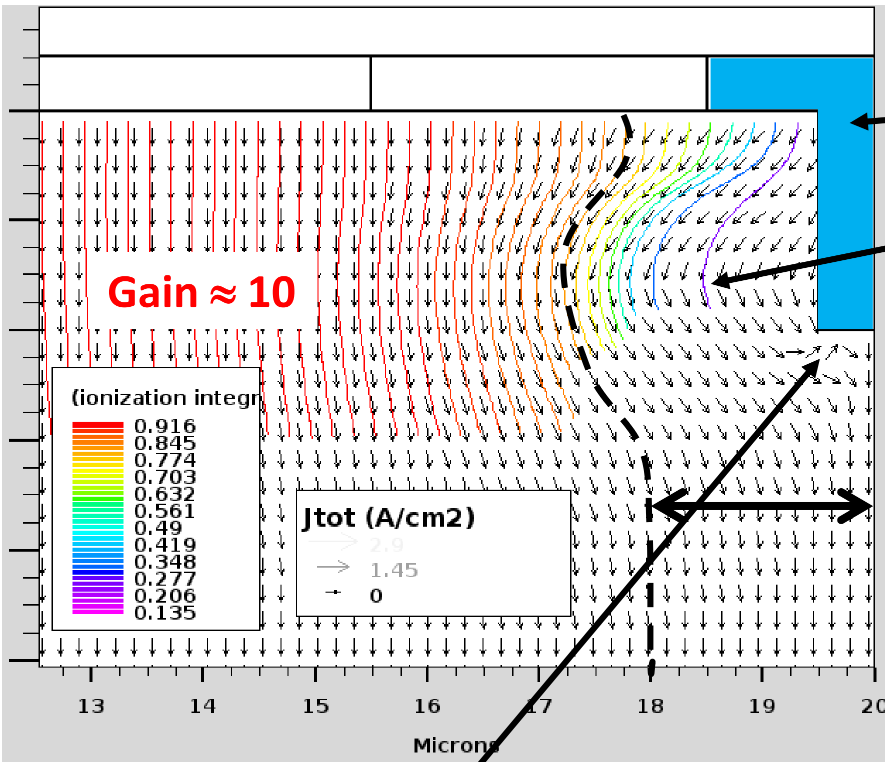






New strategies to improve FF

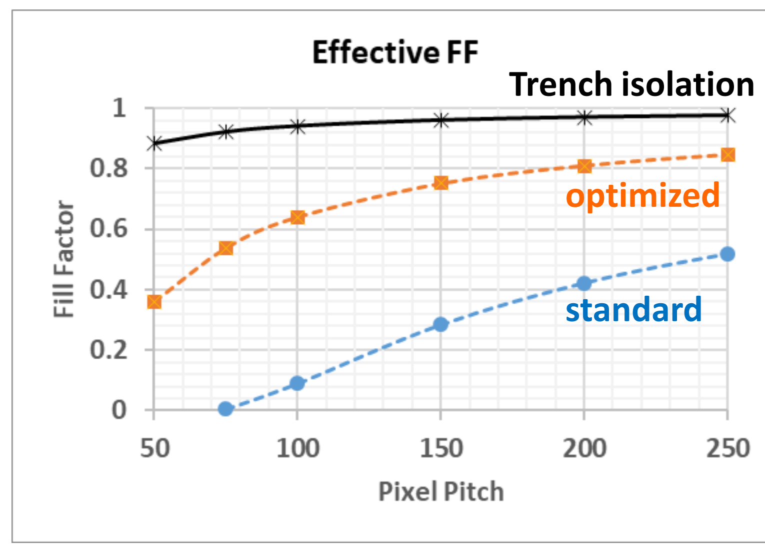
2nd Option: Trench isolation LGAD



Isolation trench

The Electric field lines wrap up the trench. → the charges are collected and pushed through the multiplication region

Dead border ≈ 2-3 μm



Possible risk:

Charge Collection from trenches surface (high defectiveness), even if no multiplication occurs at trenches interface

RD50 Proposal - HD-LGAD

TITLE: Segmented LGAD with small pixels and high Fill-Factor (High Density LGAD, HD-LGAD)

GOAL: Design and production of thin segmented LGAD sensors with small pixels (<= 100 um) and high Fill Factor (> 80%)

ACTIVITIES:

Activity	Involved Institutes	Duration
Numerical simulation and structure definition	FBK	3 months
Detector Layout and reticle production	FBK, UniTo, UniTN	2 months
Detector Manufacturing	FBK	4 months
Electrical Characterization	UniTo, others…	1 month
TCT Characterization	UniTo, others…	3 months

- **35 – 50 um substrates**
- **Carbon co-implantation**
- **Trench isolation**

Involved institutes:

FBK,
University Turin,
University of Trento and TIFPA

Other institutes shown interest…..

Thank you for your attention!

Giovanni Paternoster
Fondazione Bruno Kessler

(INFN Torino, Univ. Torino, Univ. Trento, TIFPA, FBK)