‘The strong interaction at the frontier of knowledge: fundamental research and applications’

WP27

JRA9-TRACKING AND IONS IDENTIFICATIONS WITH MINIMAL MATERIAL BUDGET

Eleuterio Spiriti

INFN (National Institute of Nuclear Physics) - LNF (Frascati National Laboratory)

STRONG-2020 Kick-off meeting

October 23-25, 2019

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

TIIMM (JRA9 - Tracking and Ions Identifications with Minimal Material budget)

"**Objectives:** The JRA we propose concentrate in a **technological innovation** in the field of **tracking detectors** for experiments in the hadron physics area like the ALICE project at CERN, it is also easy to envisage possible applications in the more general area of LHC particle physics experiments and in the low energy range ion tracking and identification needed in the patient particle treatment in medical physics. Common needs to those applications is to combine at the same time a **precision tracking with energy loss measurement** to be used for **particle identification**, and **very low level of crossed material** to **minimize multiple scattering**. This should include also the easiness of the data readout produced by the sensor to cope with the specific need of all the different applications."

(From STRONG2020 proposal)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

1. Objectives
2. Tasks description
3. Update on progress
4. JRA9-WP27 **Deliverables**
5. JRA9-WP27 **Milestones**
6. Conclusion

JRA9 (TIIMM) objectives: main goal

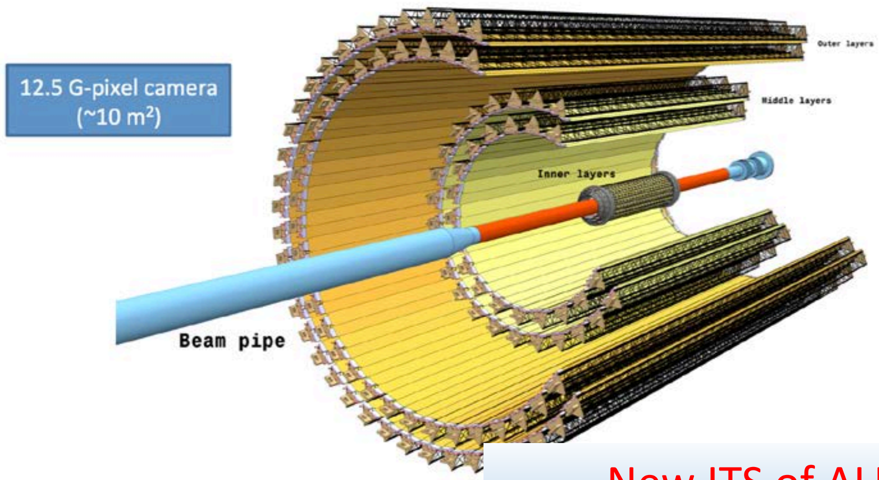
Precision Tracking
(few µm obtained)

+

Low material Budget
(0.3 % X_0 achieved)

+

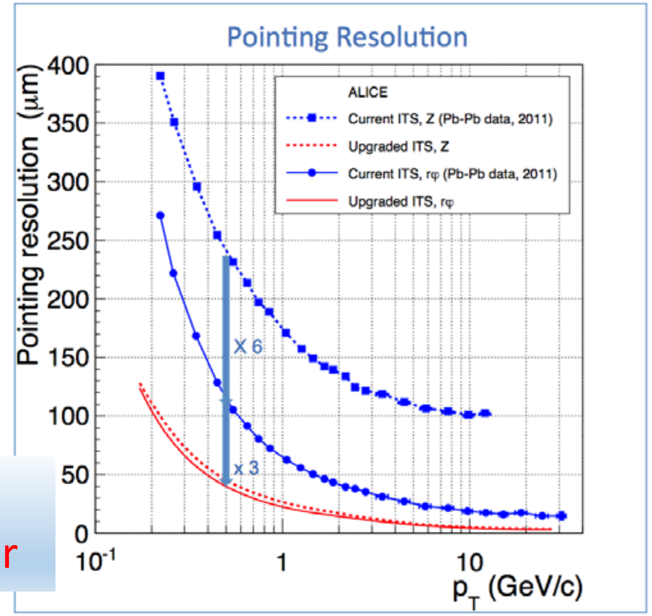
Energy loss measurement
(still missing on large area)



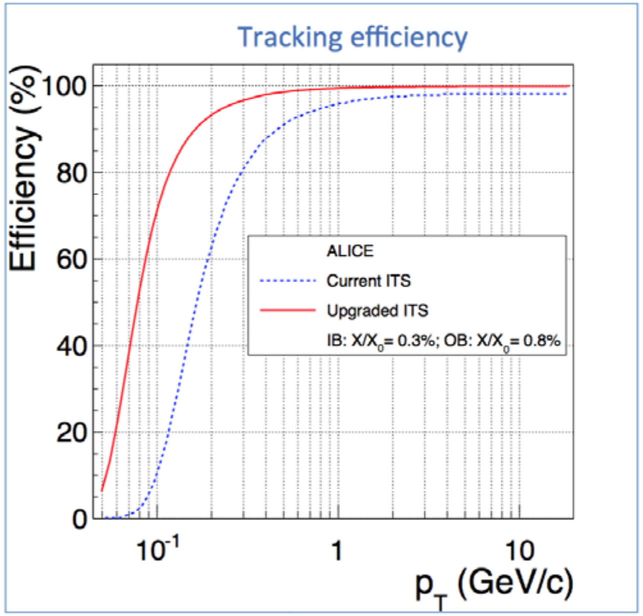
7-layer barrel geometry based on MAPS

New ITS of ALICE
x/X0~ 0.3% on inner layer

Impact parameter resolution



Tracking efficiency (ITS standalone)



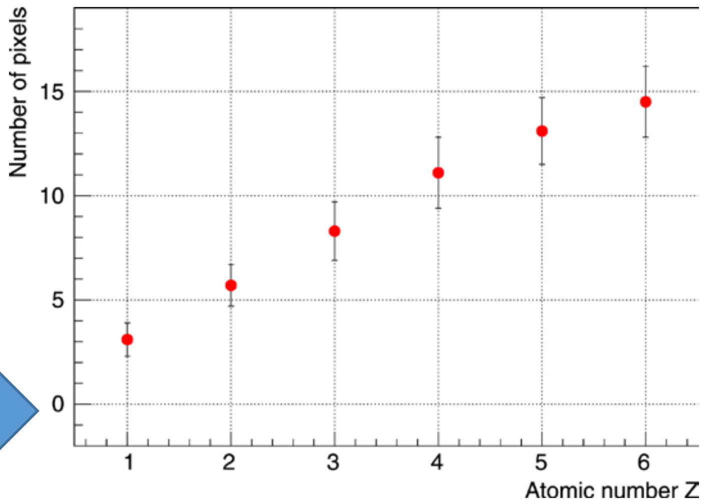
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

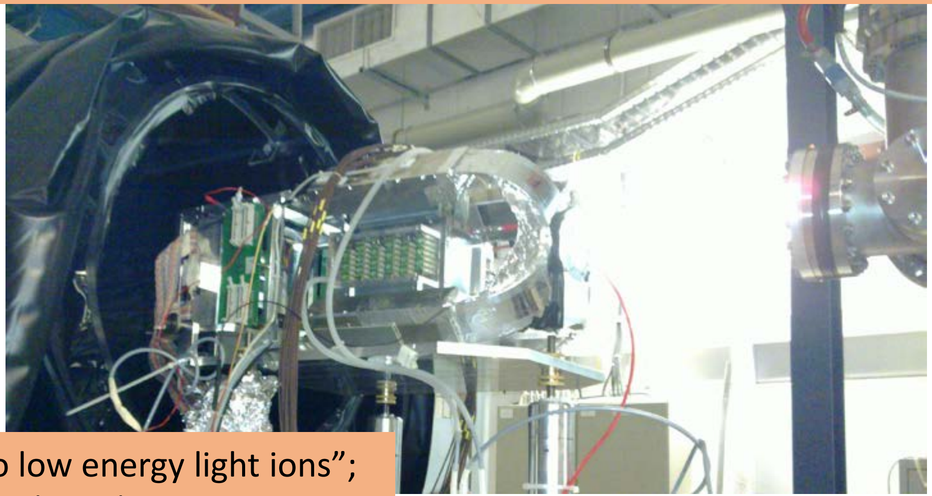
JRA9 (TIIMM) objectives

dE/dx in existing MAPS: where do we stand.

FIRST (Fragmentation of Ions foR Space and Therapy)

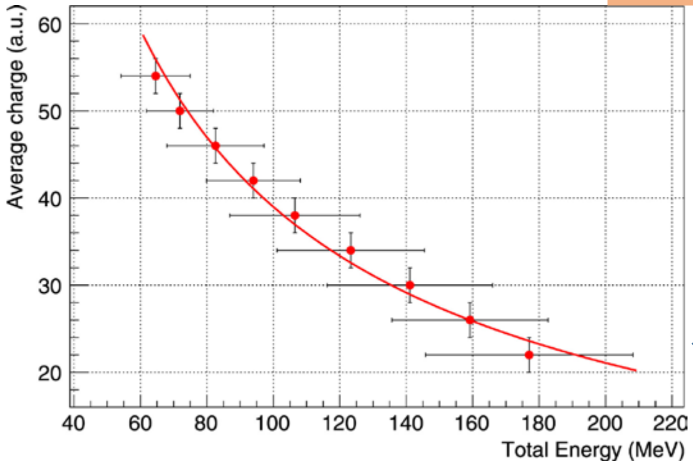
M. Toppi et al., "Measurement of fragmentation cross sections of C ions on a thin gold target with the FIRST apparatus," Phys. Rev. C, vol. 93, no. 6, p. 064601, 2016.





Number of pixel per cluster vs ion atomic number in FIRST data taking at GSI.
Measured in the MAPS (M26) vertex detector .

E. Spiriti et al.,"CMOS active pixel sensors response to low energy light ions"; Nuclear Inst. and Methods in Physics Research, A 875C (2017) pp. 35-40

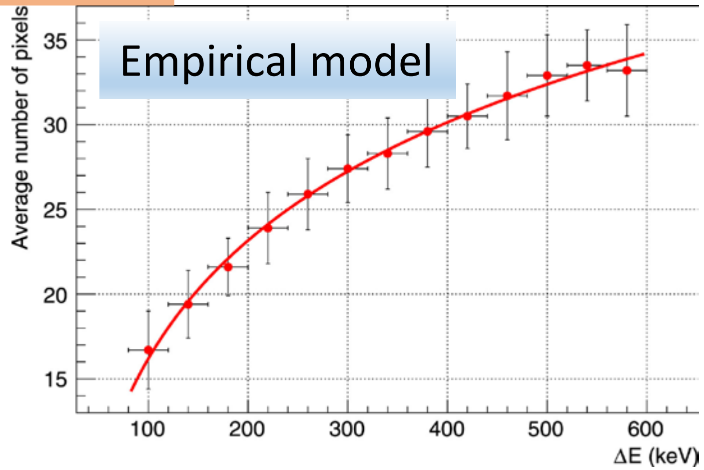


$$n_p = \frac{\pi r_T^2}{p^2} = 2\pi r_s \mathrm{Log}\left(\frac{\Delta E}{2\pi E_g T_s}\right)$$

$r_s = \sigma^2/p^2$ and $T_s = T\sigma^2$ (only two parameters)
σ = spread of Gaussian charge diffusion, T = single pixel charge threshold

Measured (M18 sensor) released charge in 14 μm thick silicon epitaxial layer *vs* total ion (Z=2) energy (measured in CsI telescope).

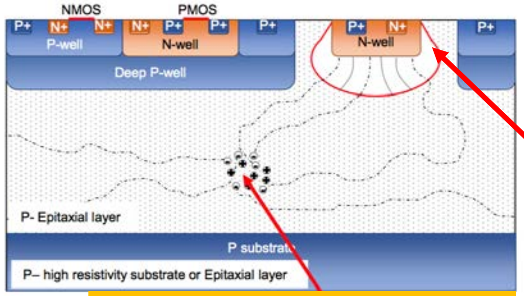
Empirical model



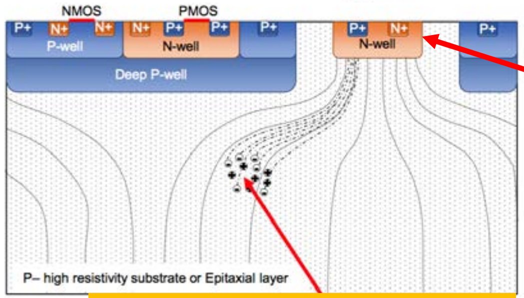
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 (TIIMM) objectives : fully depleted MAPS

J. Heymes ; "Performances of depleted Monolithic Active Pixel Sensor in a high-resistivity CMOS process for X-ray detection", slide, 11th International Conference on Position Sensitive Detectors PSD2017, Milton Keynes, the UK, 3-8 September 2017



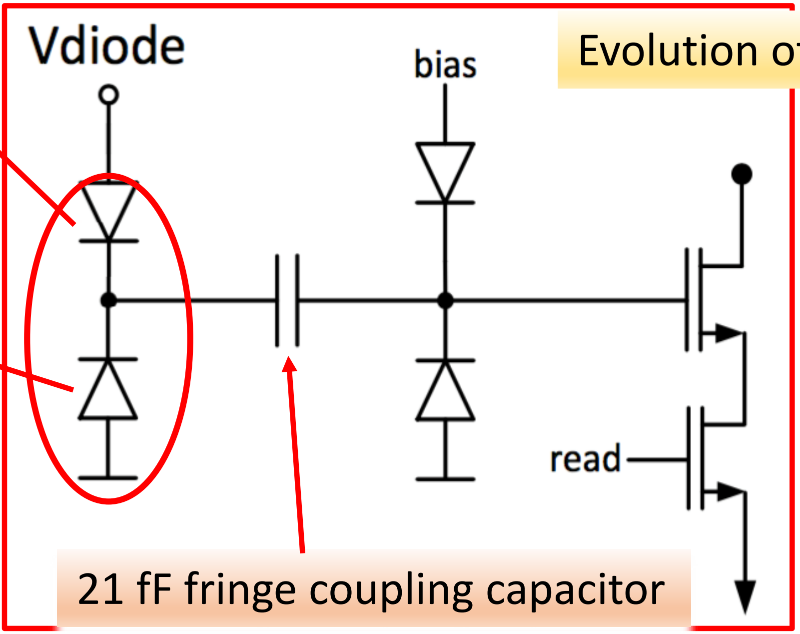
Charge produced by the photon conversion is collected by **diffusion**



Charge produced by the photon conversion is collected by **drift**

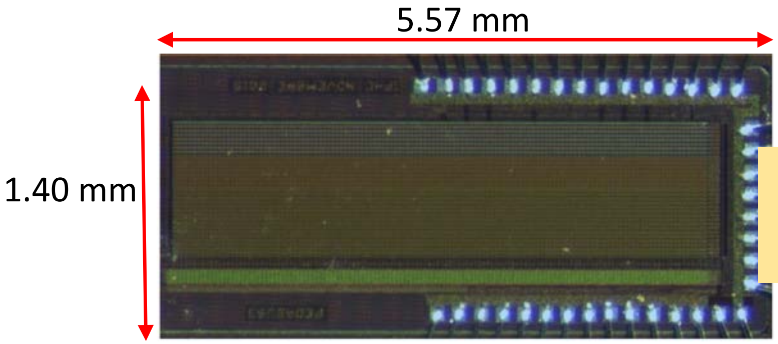
In both options we maintain MAPS solution advantages:

- low material budget
- low noise
- small pitch
- standard CMOS technology



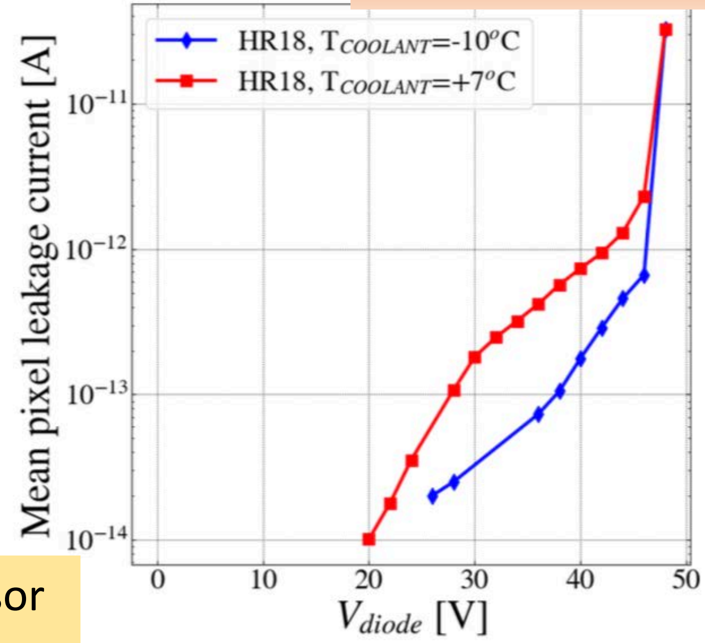
Evolution of standard self-biased 3T solution

21 fF fringe coupling capacitor



PIPPER-2 sensor Prototype picture

Leakage current in sensing diode



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

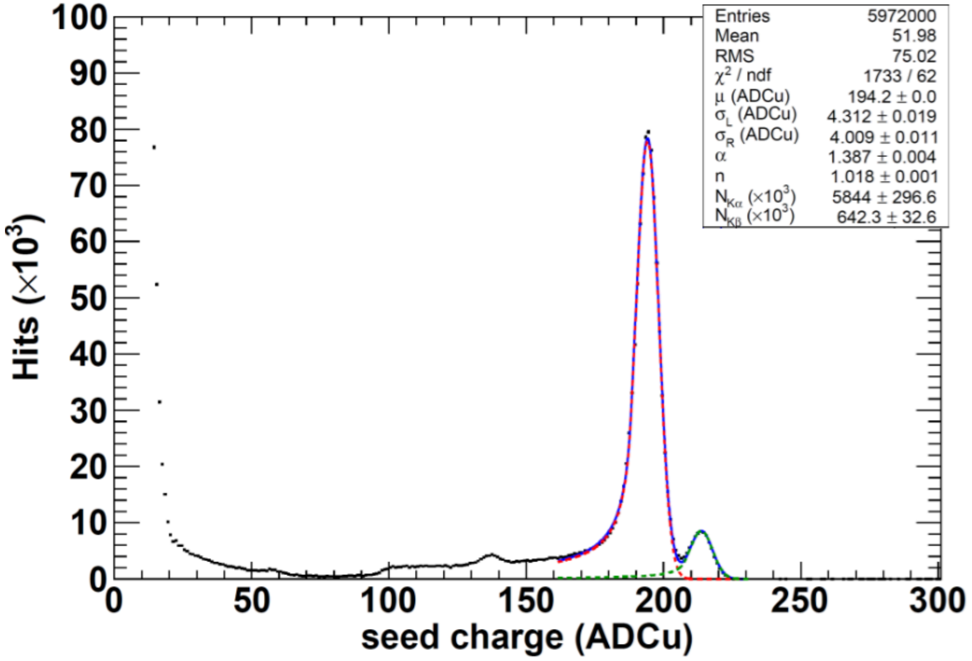
JRA9 (TIIMM) objectives: fully depletion results

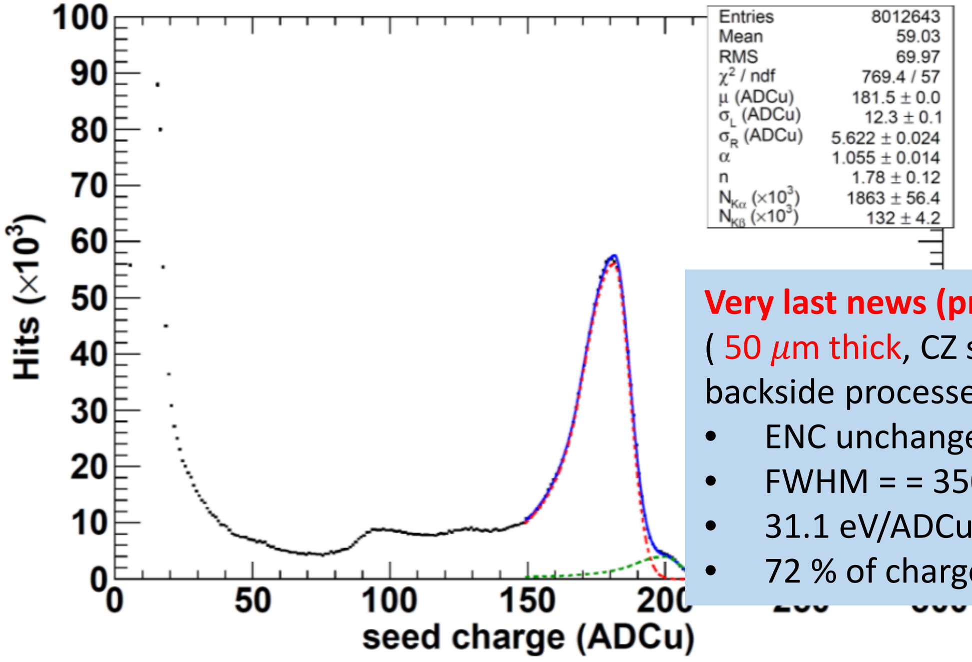
After clustering ➔ Seed pixel charge distribution

- **18 µm thick epitaxial layer (HR18)**
  - ❑ ENC = 24 e$^-$
  - ❑ FWHM (5.9 keV) = 298 eV
  - ❑ 30.38 eV/ADCu
  - ❑ Si escape peak visible (138 ADCu)
  - ❑ 75 % of the charges collected on the seed pixel on average

- **280 µm thick Czochralski (CZ)**
  - ❑ ENC = 26 e$^-$
  - ❑ FWHM (5.9 keV) = 686 eV
  - ❑ 32.51 eV/ADCu
  - ❑ Mn-Kα and Mn-Kβ merging
  - ❑ 68 % of the charges collected on the seed pixel on average

J. Heymes ; “Performances of depleted Monolithic Active Pixel Sensor in a high-resistivity CMOS process for X-ray detection”, slide, 11th International Conference on Position Sensitive Detectors PSD2017, Milton Keynes, the UK, 3-8 September 2017





Very last news (preliminar)!
(50 μm thick, CZ silicon, backside processed, 30V bias)
- ENC unchanged
- FWHM = = 350 eV
- 31.1 eV/ADCu
- 72 % of charge on seed pixel

Pipper-2 measurements (presc. 2, T°$_{cool}$=7 °C, V$_{diode}$=30V) ^{55}Fe irradiation – 400000 frames

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 (TIIMM) objectives

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

Which relevant innovations we target in the TIIMM project?

A proof of principle device integrating the MAPS good tracking performancies with the dE/dx measurements capabilities on large area sensors.

Still a lot of open questions:

- Analog or digital output?
- Power consumption?
- Pixel pitch (single point resolution)?
- In pixel discriminator?
- In pixel Analog to Digital Conversion (pipeline ADC)?
- Integration time?
- Sparse or full frame readout? (application dependen
- ……………………………

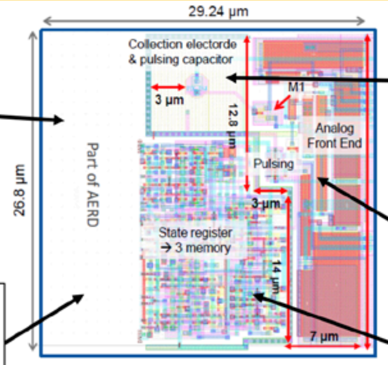
Common goal with TIIMM

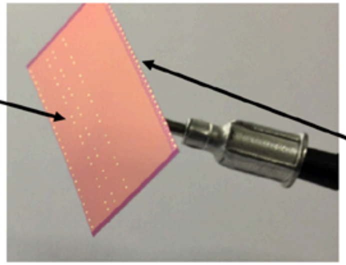
Example of similar questions in the MIMOSIS project for CBM

Pixel diode:
Add HV front biasing (More rad. hardness due to higher HV, suppress back bias effects on NMOS transistors).

Priority encoder:
Optimize layout, accelerate by factor 2x.

Eliminate bonding pads in pixel area (reduce integration challenge).





Preamp:
Understand ionizing radiation effects, add ELT transistors if needed.

Preamp:
Increase power, reduce noise, speed-up.

Pixel memory:
Simplify (increase robustness to SEU).

Costumize interface:
- Higher bandwidth
- Higher power /robustness
- Compatibility with GBTx

Which characteristics for the final instrument TIIMM is aimimg?
Incorporate **as much as possible** the functionalities existing in the hybrid sensors (Timepix3 ?!?!?!?!).
Most of the trade off choices are strongly dependent on the final application.
TIIMM goal zero: deliver a prototype to establish the feasibility at a large sensor scale size.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 (TIIMM) update on progress: fully depleted MAPS update!

Fully depleted MAPS – small electrodes with TJ modified process

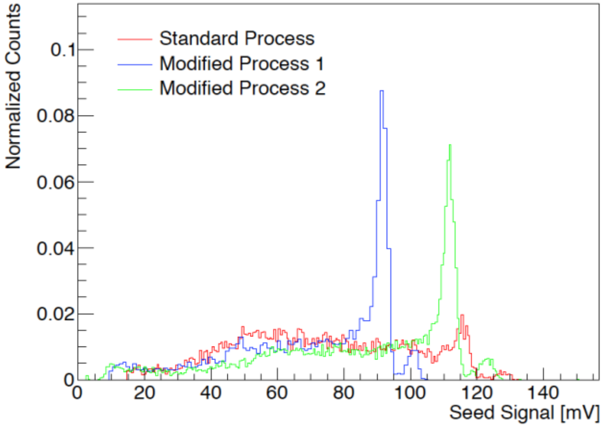
Signal and cluster distribution from a ^{55}Fe source for standard and modified process

Modified Process 1 = higher dose, Modified Process = lower dose

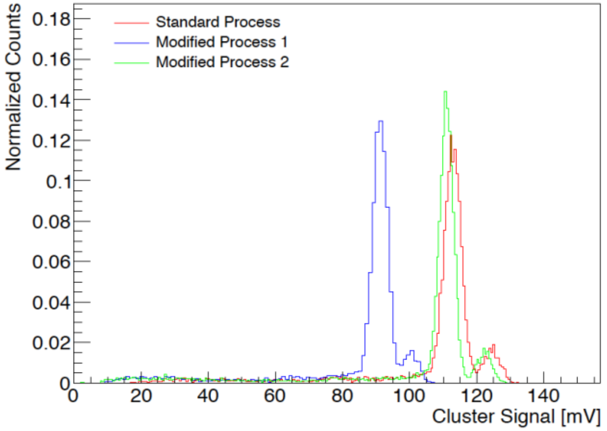
J. Van Hoorne et al., NSS 2016

Tests performed on investigator chip (same pixel as ALPIDE)

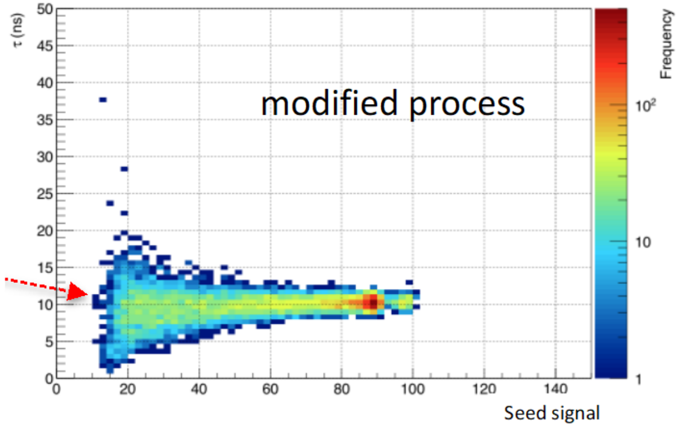
Pixel size: 28 x 28 αm², CE: 2 x 2 αm² centered in a 8 x 8 αm² opening, P-well & substrate @ -6V, CE @ 1V



(A) Seed signal



(B) cluster signal



Note: chip output buffer limits the rise time to 10ns

- For a lower dose (MP1) a no sensor capacitance penalty
- For modified process, larger fraction of single pixel clusters (see also fraction of signal within the peak in A)

L. Musa (CERN) – VCI, Vienna, Feb 2019 ← Credits to:

27

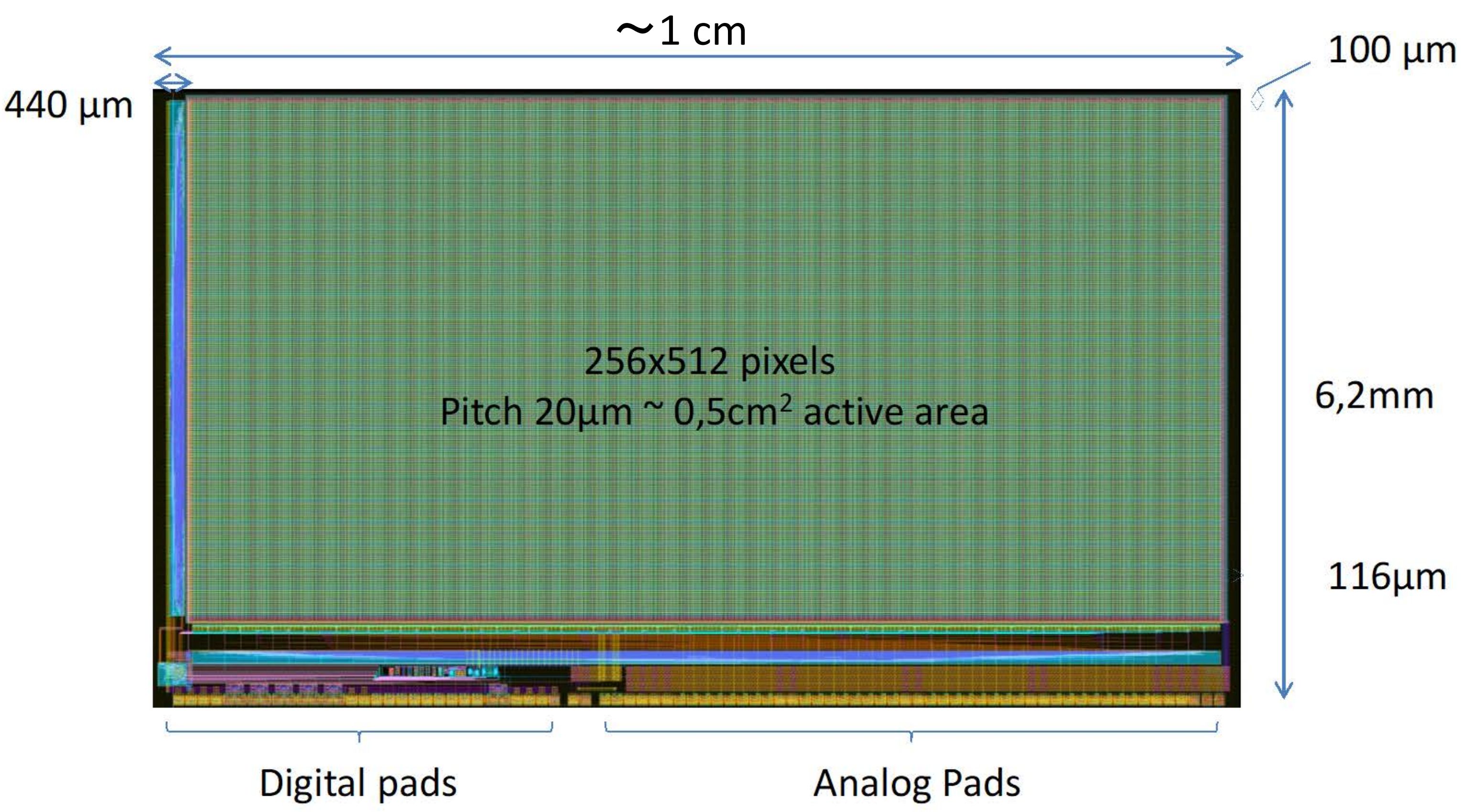
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 (TIIMM) update on progress

BigPipper large area pixel sensor

NOT FUNDED BY STRONG2020

Tower Jazz 180nm Strasbourg group submission



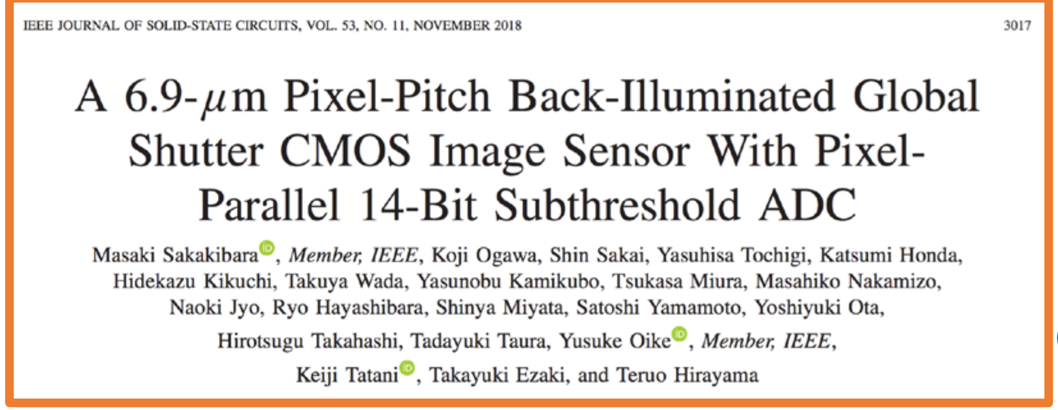
- **Modified process**
- Fully depleted
- Rolling shutter/Global shutter
- Analog output
- ROI (Region Of Interest) definition
- 20 μm pitch

Extremely useful to characterize the charge collection versus released energy in the sensor.

Important step before prototype with ADC on chip.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 (TIIMM) update on progress


IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 53, NO. 11, NOVEMBER 2018 3017

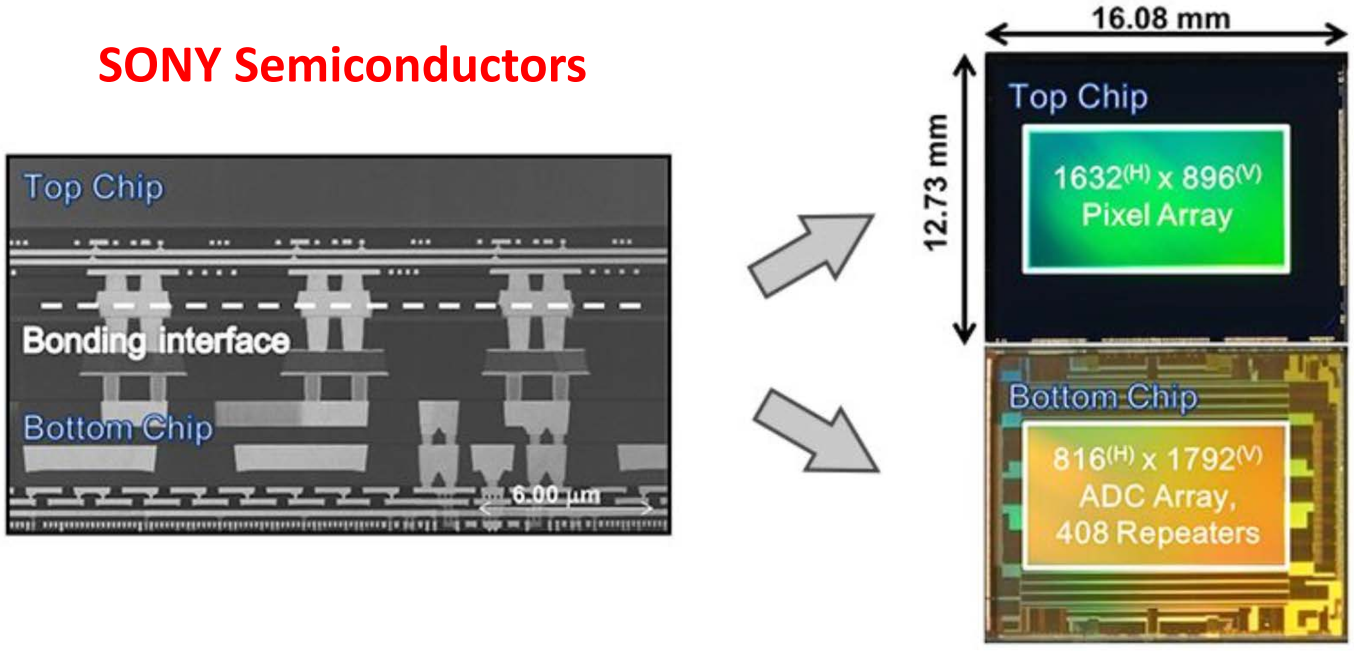
A 6.9-μm Pixel-Pitch Back-Illuminated Global Shutter CMOS Image Sensor With Pixel-Parallel 14-Bit Subthreshold ADC

Masaki Sakakibara, *Member, IEEE*, Koji Ogawa, Shin Sakai, Yasuhisa Tochigi, Katsumi Honda, Hidekazu Kikuchi, Takuya Wada, Yasunobu Kamikubo, Tsukasa Miura, Masahiko Nakamizo, Naoki Jyo, Ryo Hayashibara, Shinya Miyata, Satoshi Yamamoto, Yoshiyuki Ota, Hirotsugu Takahashi, Tadayuki Taura, Yusuke Oike, *Member, IEEE*, Keiji Tatani, Takayuki Ezaki, and Teruo Hirayama

State of the art

We do not even think to reach a fraction of such performances.
We don't have access to the technology
and its cost would be prohibitive
BUT we'll use it as reference

SONY Semiconductors



Left: cross-section of the Cu-Cu connection, Upper right: pixel substrate, Lower right: logic substrate

- 6.9 μm pitch
- 1632 x 896 pixel matrix
- CIS wafer: 90 nm, 1 Poly 4 Metal
- Logic wafer: 65 nm, 1 Poly 7 Metal
- ADC resolution: 14 bits
- 660 fps
- Dynamic range: 70.2 dB

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 (TIIMM) tasks structure

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

MS60

MS61

MS62

Deliverable D27.1

Deliverable D27.2

3.1.2 TIMING OF THE DIFFERENT WORK PACKAGES AND THEIR COMPONENTS

Work package number	JRAx
Work package acronym	TIIMM
Work package title	Tracking and Ions Identifications with Minimal Material budget

TASKS/Subtasks	Year 1				Year 2				Year 3				Year 4			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1 Sensors and final device requirements definition																
1.1 Sensors and final device requirements definition																
Task 2 Sensors design																
2.1 Design of the first sensor prototype																
2.2 Design of the second sensor prototype																
Task 3 Production of the sensors																
3.1 Production of the first sensor prototype																
3.2 Production of the second sensor prototype																
Task 4 Preparation of the test set-up																
4.1 Preparation of the first sensor test set up																
4.2 Preparation of the final device test set up																
Task 5 Testing and reporting of results																
5.1 Testing of the first prototype																
5.2 Report on the first prototype obtained performances																
5.3 Testing of the second prototype (multisensor device)																
5.4 Simulation and modelling of the performances																
5.5 Report on the possibilities for PID from the results																

(Timelines are indicate in grey, milestones with black boxes)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

The TIIMM team structure (expertise)

Group	Contact person	Hadron/particle Physics	Medical Physics	Detectors development
German Cancer Research Center (DKFZ), Heidelberg, Germany	Dr. Maria Martisikova			
INFN, Bari Section, Bari, Italy	Dr. Vito Manzari			
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany	Dr. Ulrich Weber			
INFN, Trento Institute for Fundamental Physics and Applications, Trento, Italy	Dr. Emanuele Scifoni			
IPHC (Institute Pluridisciplinaire Hubert Curien), In2p3, Strasbourg, France	Prof. Jerome Baudot			
LNF (Frascati National Laboratory), INFN, Frascati, Italy	Dr. Eleuterio Spiriti			

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 : Deliverables

There are no deliverables due for Reporting Period 1 (18 months, June 2019-November 2020)

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

JRA9 : Milestones

- MS60 has to be achieved M9 (February 2020)

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS60	Definition of the first prototype and final device characteristics.	30 - INFN	9	Report

- Advancement

MS60 on going

- Expected delivery date

End of February 2020

JRA9 (TIIMM) conclusion

- ***The bigPipper sensor will be submitted for production in few weeks***
- ***TCAD simulation of charge collection in “modified” process sensor started***
- ***A student started beginning of october to study possible new architectures***
- ***Designer of bigPipper available to contribute to the first TIIMM prototpe design***
- ***GEANT4 simulation of charge release is under way***

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.