AIDA innova

Advancement and Innovation
for Detectors at Accelerators

CMOS Pixel Developments in AIDAInnova

3 July 2023

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for the ***AIDAinnova WP5 team***

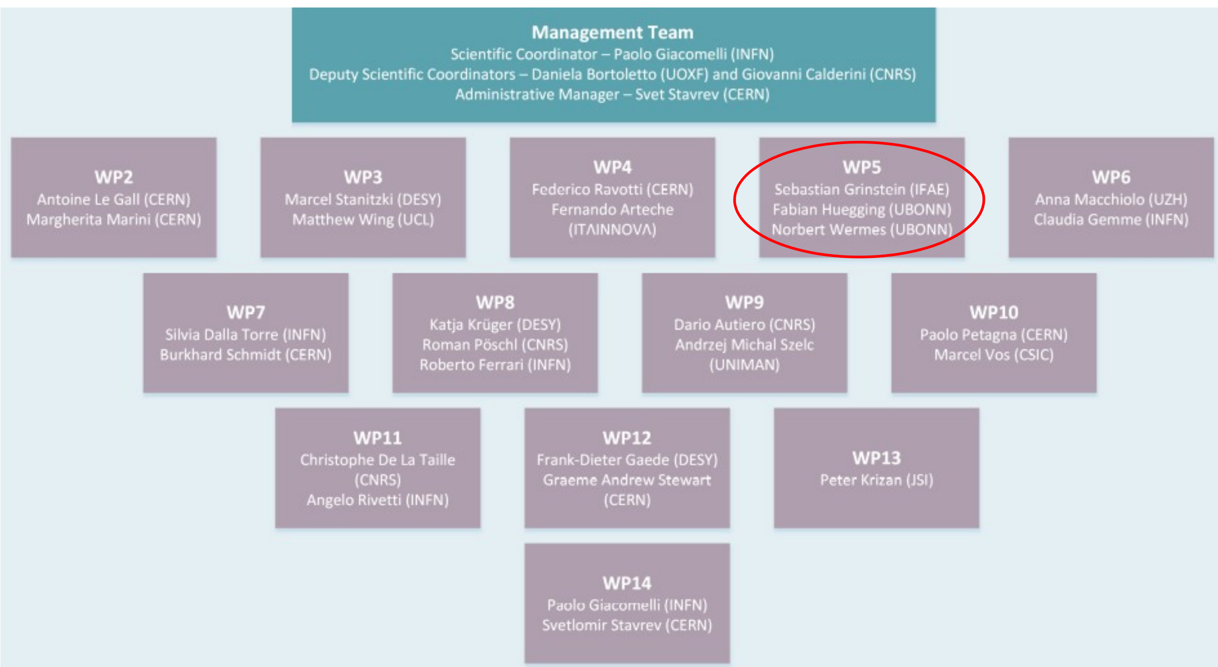
IFAE Institute for High Energy Physics

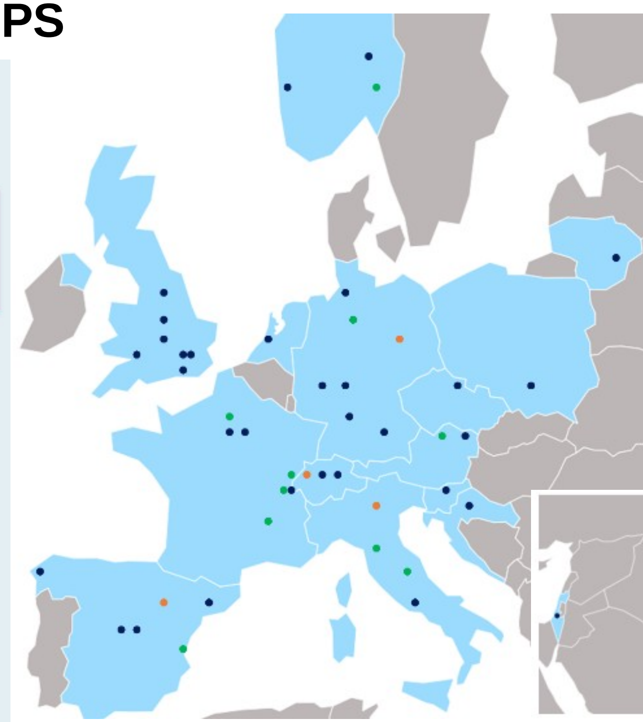
ICREA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

About AIDAInnova

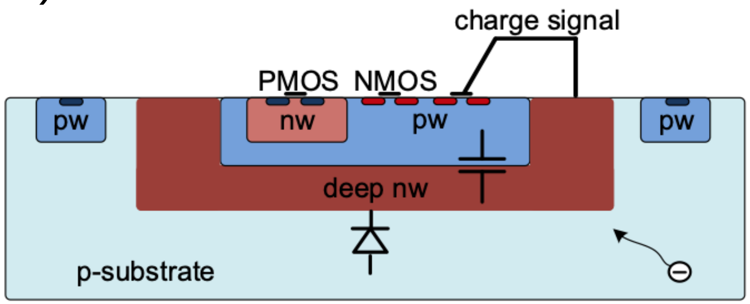
- AIDAInnova's goal is to enable **technology advances** mainly for particle physics (upgrades of research infrastructures)
- **European Commission** co-founded project through H2020 program (2021-2025)
- Project involves 8 industrial companies, 3 RTOs and 34 academic institutions in 15 countries, with main target of **common detector projects**
  - Several Work Packages... one dedicated to **DMAPS**

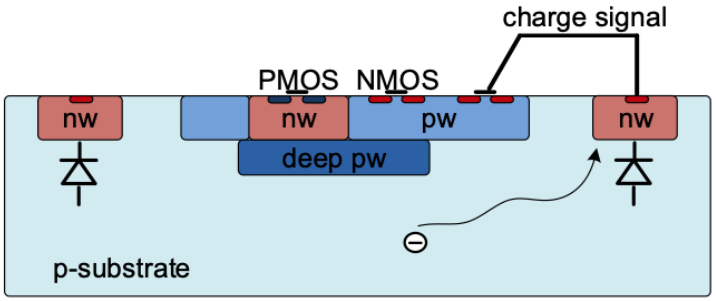




Geneal Approach

- Two basic approaches to Depleted Monolithic Active Pixel Sensors (DMAPS)
  - a) Large charge collecting electrode, with electronics inside n-well
  - b) Small electrode with the electronics separated





- Within the structure of the AIDAInnova effort (WP5)
  - a) Large electrode mostly targets *radiation hardness*
  - b) Small electrode primarily aims to *high granularity* lower noise and power
- *Categories are only an approximation:* large electrode efforts try to reduce pixel sizes while small electrode approach also targets large depletion regions
- The objective of the WP5 is to design, fabricate and test (before and after irradiation) DMAPS on both these lines

Activities and Submissions

Past and future submissions that will be, or have been, *partially* supported by AIDAinnova (several activities are mostly supported by **other** funds). These are core of WP5 activities.

Submission	Process	Time-scale	Target	Main Institute	Comment
LF-Monopix 2	LF 150 nm	v2 produced	rad. hard	Bonn/CPPM	Follow from ATLAS R&D
RD50-MPW 3/4	LF 150 nm	v4 in 0.5-1.0 yr	rad. hard, high granularity	Liverpool	R&D
CACTUS	LF 150 nm	mini-CACTUS v2 submitted	timing	CEA	LHC upgrade & beyond
TJ-Monopix 2	TJ 180 nm	v2 produced	high granularity	Bonn	Belle II, follow up by Obelix
MALTA 2/3	TJ 180 nm	v3 in ~0.5 yr	high granularity	CERN	LHC upgrade & beyond
ARCADIA	LF 110 nm	next version ~0.5 yr	high granularity	INFN	Demonstrator
TJ 65 nm	TJ 65 nm	2nd iteration just submitted	high granularity	IPHC	R&D, ALICE

Note:

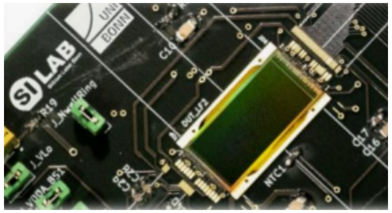
TJ: Tower

LF: LFoundry

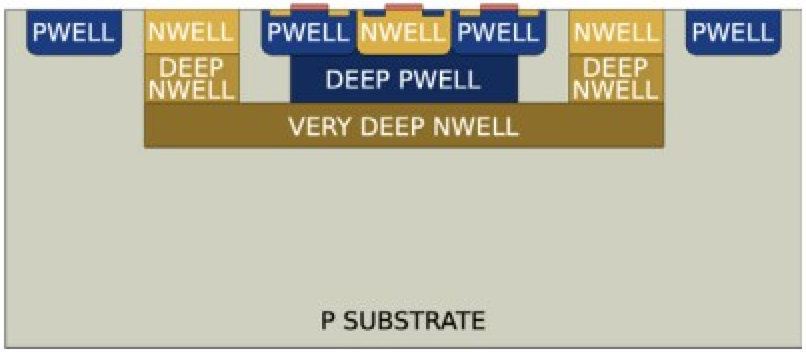
- All activities produced device/prototype during the first phase of the project
- Some lines/sub-projects more advanced than others

LF-Monopix 2
Large electrode, radiation hardness

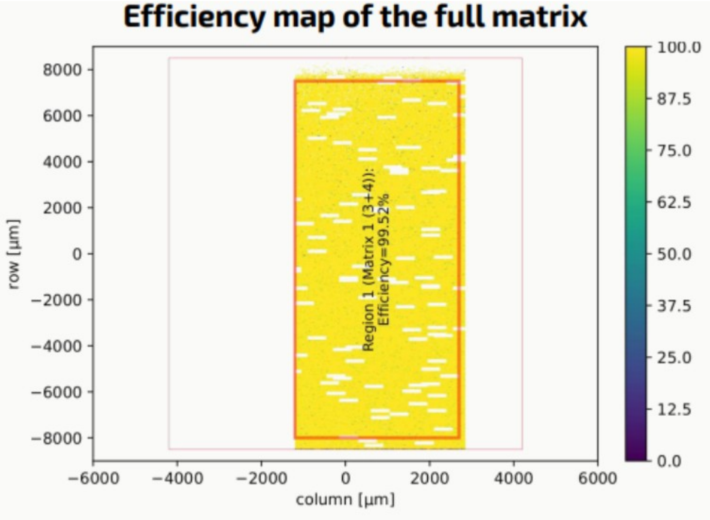
- Successor of LF-Monopix-1
- **LFoundry 150 nm**
- Column drain RO architecture
- 2 kOhm.cm, thinning & back-side processing
- Explored in-pixel circuit flavors
- Beam tests confirmed excellent efficiency before irradiation



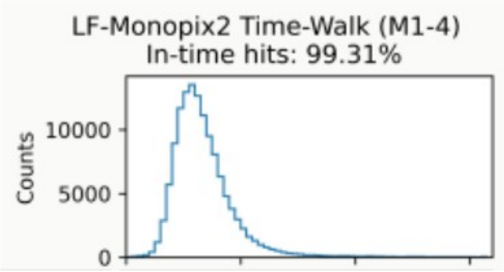
Pixel size: 50x150 μm^2



A cross section of the pixel layout. Deep n-implant forms the charge collection electrode.



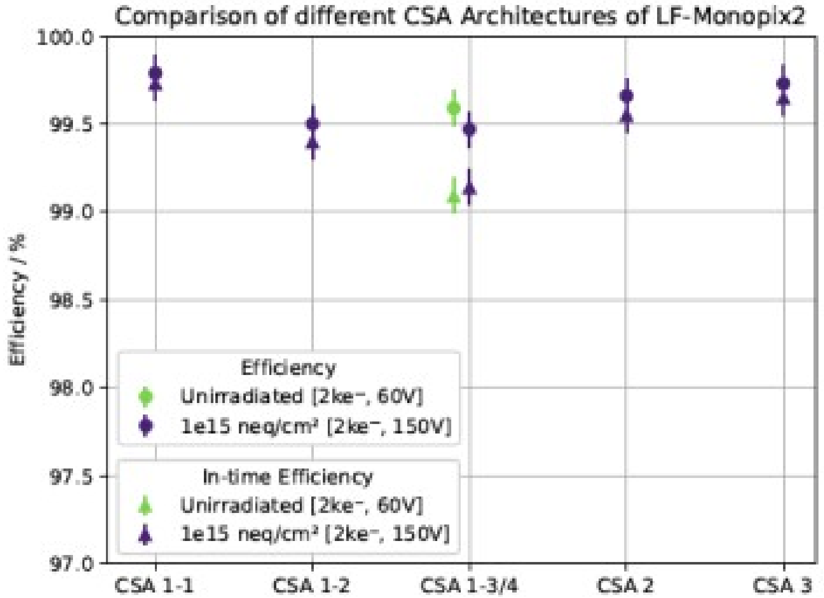
Dingfelder J., et al., NIMA 1034 (2022) 166747



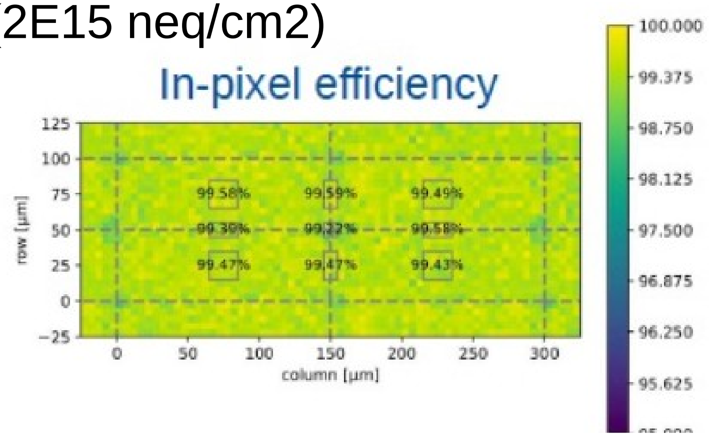
- Devices irradiated and tested with beam

LF-Monopix 2
Large electrode, radiation hardness

- Irradiated to 1E15 neq/cm2 @ Bonn Cyclotron
- Test-beam characterization followed
  - Very high eff in-time (>99%)
  - no efficiency degradation with respect to non-irradiated
  - Operation threshold ~2000 e^-
  - Plan to study higher fluencies (2E15 neq/cm2)



I. Caicedo-Sierra, L. Schall et al. See also Dingfelder J., et al., NIMA 1034 (2022) 166747



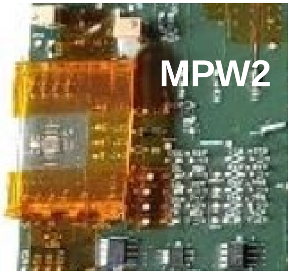
	ITk Outer Layer
Occupancy	1 MHz/mm²
Time Res.	25 ns
NIEL	10^{15} n_{eq}/cm^2
TID	80 Mrad
Area	O($10m^2$)

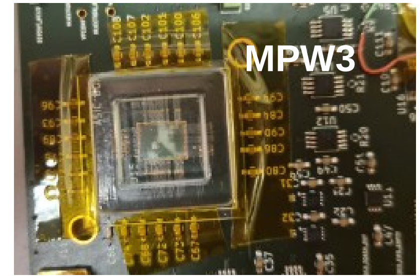
Compatible with outer layers of the HL-LHC pixel trackers

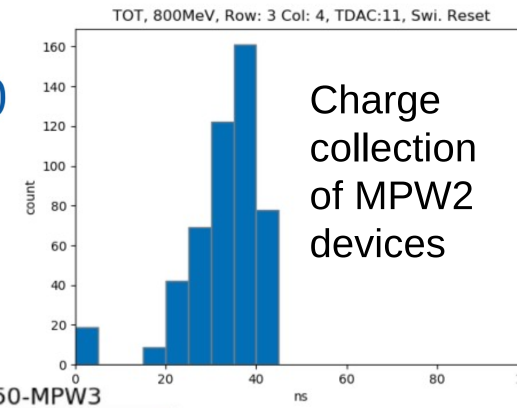
RD50-MPW2/3
Large electrode, radiation hardness

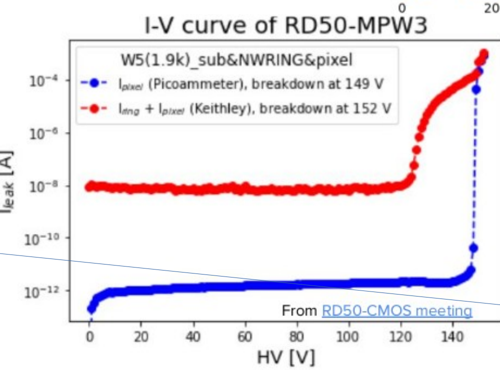
- **RD50-MPW2**: small prototype with several test structures
- On LF 150nm, 10-3k Ohm.cm
- Main matrix pixels: 60 x 60 μm^2
- In pixel CSA + discriminator, analog readout
- Initial beam tests (UK & Austria)
  - Results indicated expected results in terms of charge collection
- **RD50-MP3**: fabricated
  - add digital readout (column drain)
  - IV shows Vbd ~ 150V
  - High noise, studies on-going

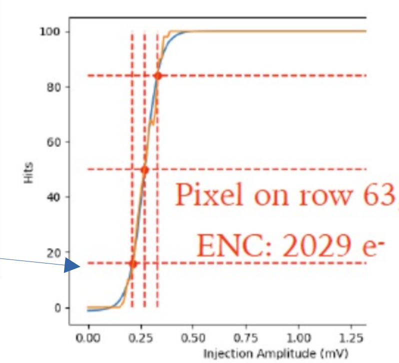
Next RD50-MPW4: with backside processing to improve radiation hardness







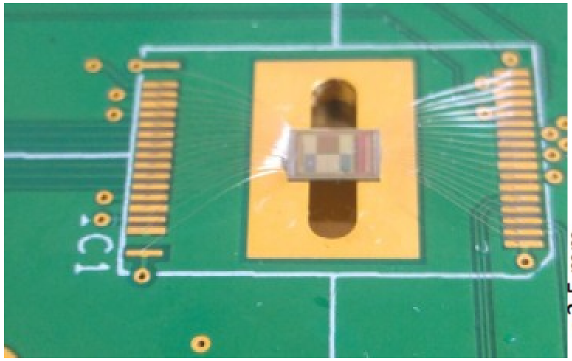


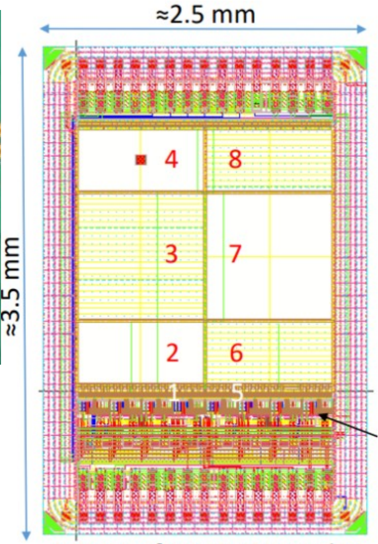


Vilella E., et al., NIMA 1034 (2022) 166826

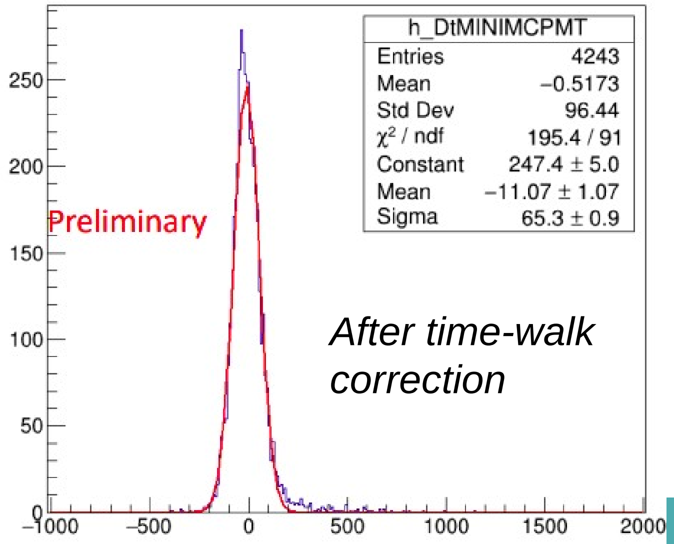
CACTUS
Large electrodes for Timing

- Target is monolithic device that can provide ~50 ps **timing resolution**
- LFoundry 150 nm, thinned to 100-200 µm
- Large (~1x1 mm^2) passive pixels with FE at column level
- **Mini-CACTUS**
  - Small prototype to address limitations of CACTUS (low S/N)
  - Implements different pixel flavors
  - Tested with beam (before irradiation)
    - Achieved ~ 65 ps resolution
- **Second iteration** of mini-cactus
  - Implement different amplifiers types
  - Improved front-end: better discriminator, etc





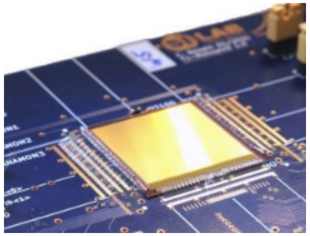
Layout of MiniCACTUS chip



Y. Dangleri et al., https://doi.org/10.1016/j.nima.2022.167022

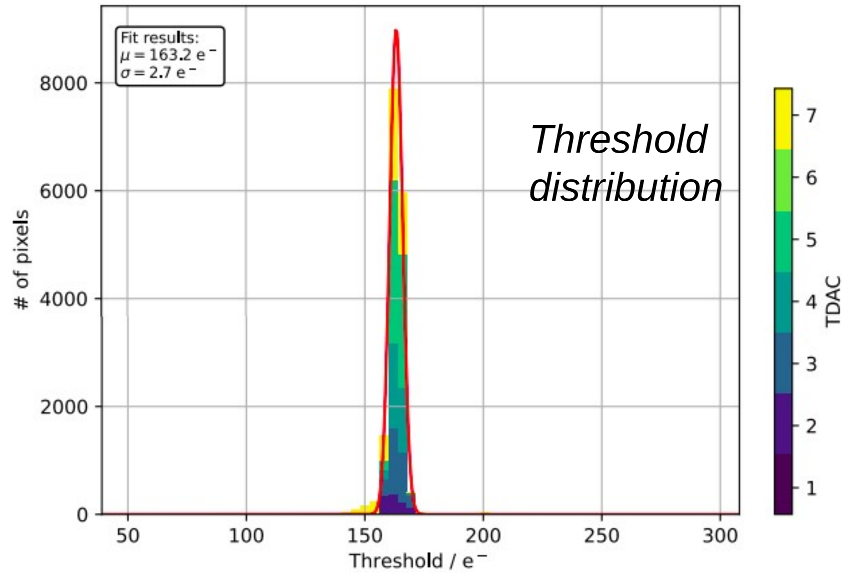
TJ-Monopix 2
Small electrode, High granularity

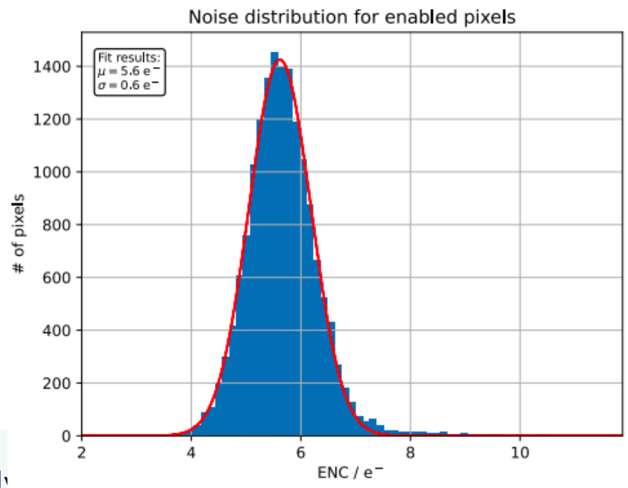
- Successor of TJ-Monopix-1, based on ALPIDE (ALICE ITS upgrade)
- **Tower 180 nm**, various sensing thicknesses (Cz-bulk, epi)
- Column drain RO architecture
- Implements four FE types
  - Cascode transistor to reduce threshold dispersion
  - Improved achievable threshold wrt previous iteration



Pixel size: 33x33 μm^2
Chip size: 2x2 cm^2

C. Bespin et al., NIMA 040 (2022) 167189

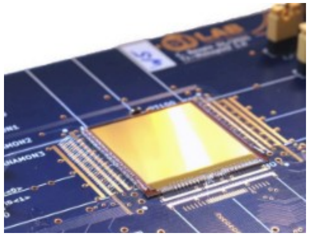




Clear noise reduction with respect to TJ-M1, which had ~30 e noise level.

TJ-Monopix 2
Small electrode, High granularity

- About 9 um position resolution (<cluster size> ~ 2, Cz)
- Excellent efficiency before irradiation
  - Testing of irradiated sensors on-going



Pixel size: 33x33 µm^2
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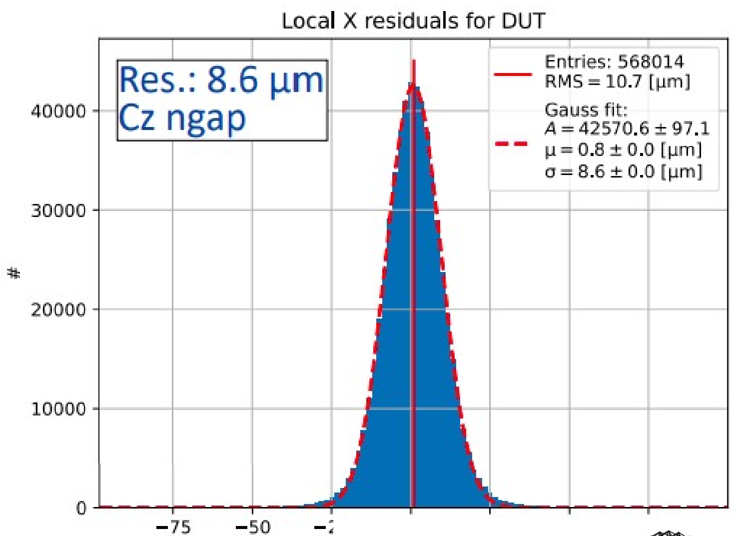
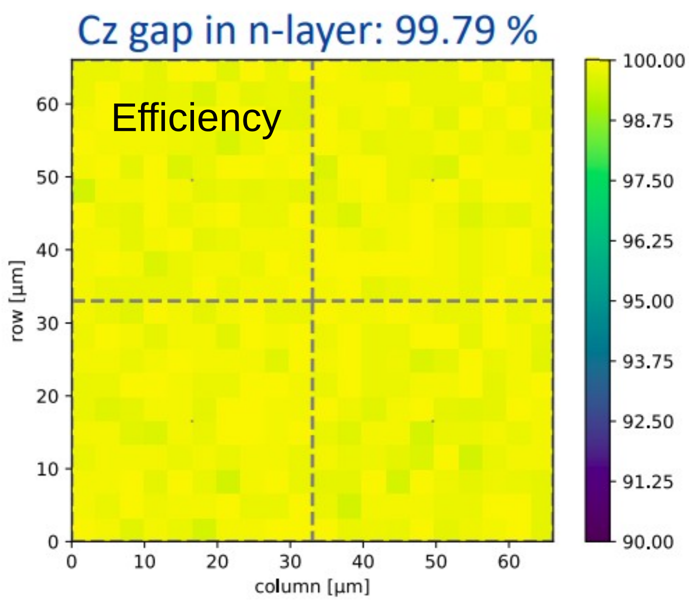
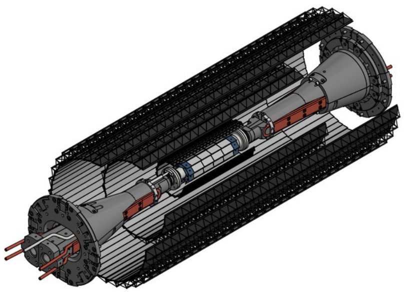
C. Bespin et al., NIMA 040 (2022) 167189



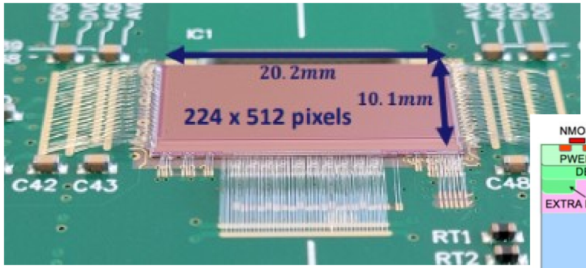




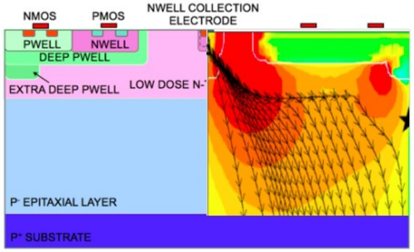
Basis of OBELIX, prototype for Belle-II VXD upgrade

MALTA 2
High granularity, rad hardness

- Follows previous MALTA prototypes
  - *Original target ATLAS ITk outer layer*
- **Tower 180 nm with process modification** to improve E field
- Fast asynchronous readout (low power)
- Different flavors in 2 substrates (epi, CZ)
- Irradiated up to **3E15 neq/cm2**

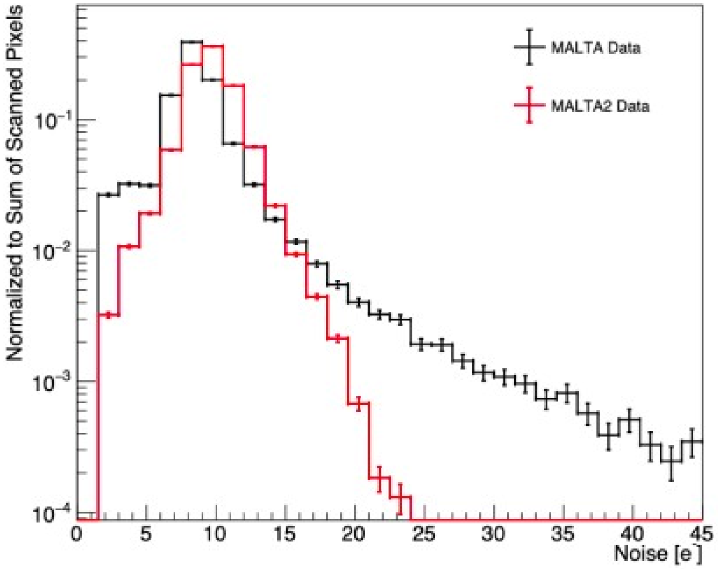


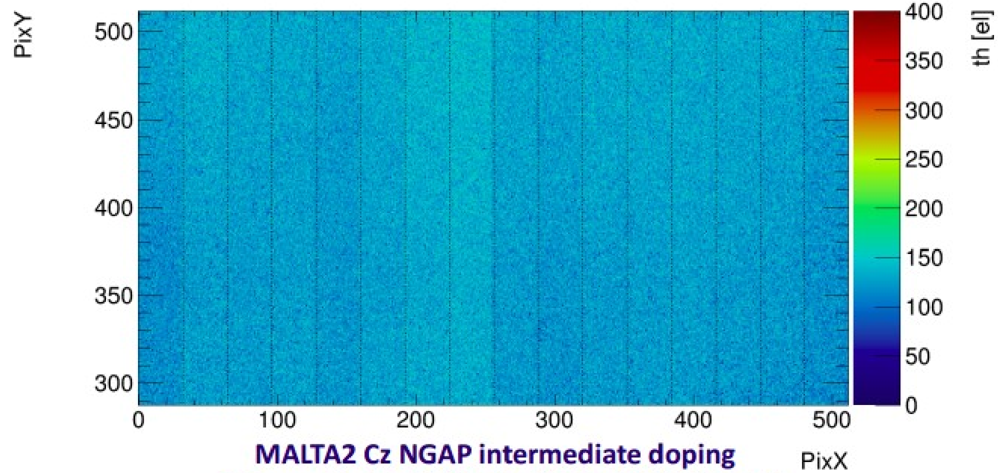
Pixels:
36.4 x 36.4 µm2



Modified process with extra deep p-well (XDPW).
Improved charge collection in the pixel edges.

LeBlanc M., et al., NIMA 1041 (2022) 167390



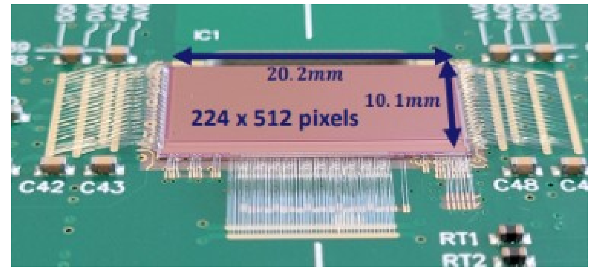


MALTA2 Cz NGAP intermediate doping
300 um thick 2×10^{15} n/cm^2 IDB: 120, ITHR=20

Improved noise wrt previous version and excellent threshold uniformity achieved

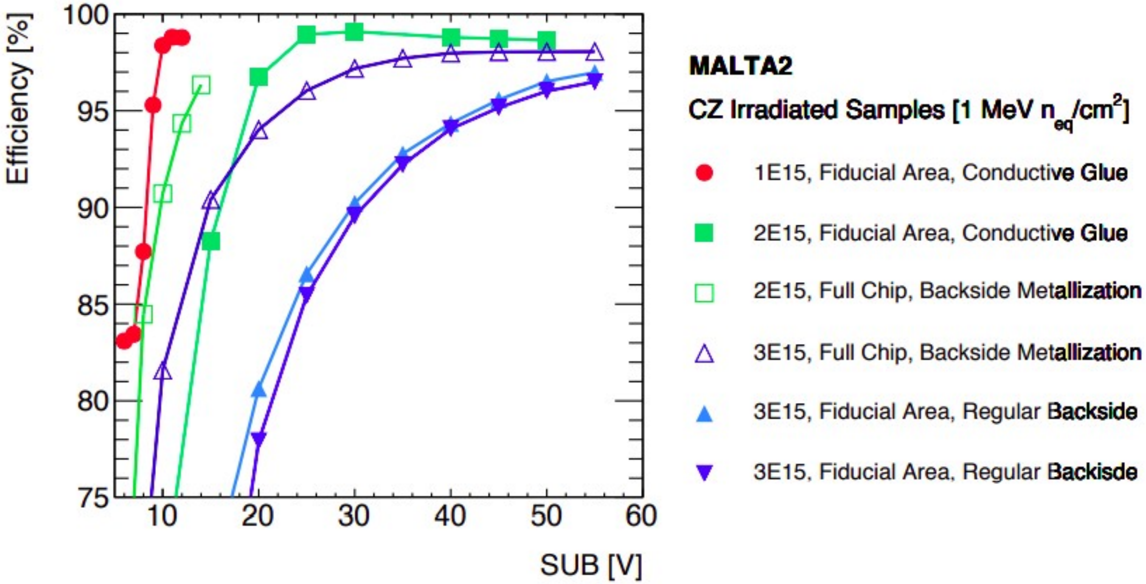
MALTA 2
High granularity, rad hardness

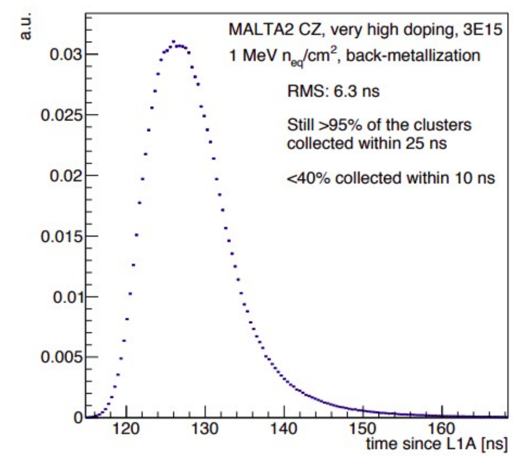
- Excellent results from beam tests after 3E15 neq/cm2
  - Efficiency (>95%)
  - In-time (>95% in 25ns)
- Dual and quad modules fabricated (with MALTA1)

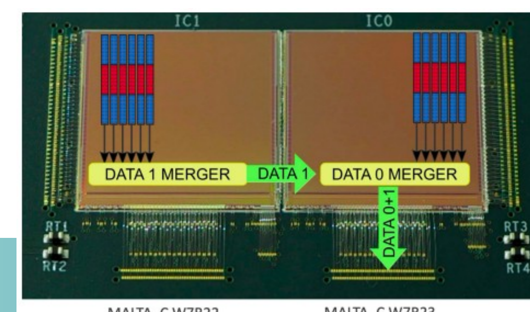


Pixels:
36.4 x 36.4 μm2

LeBlanc M., et al., NIMA 1041 (2022) 167390





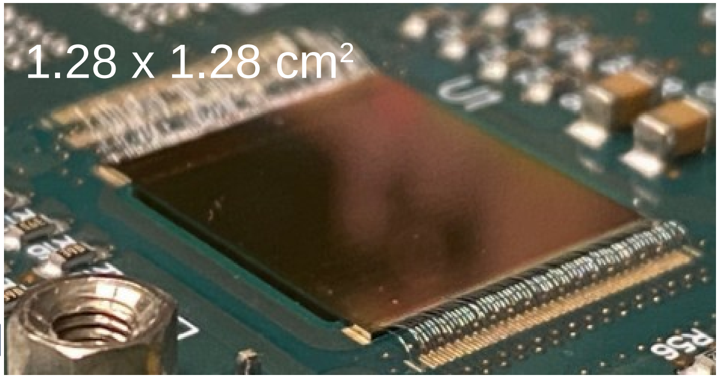


Full reticle MALTA3 design advanced, submission targeted for 2023

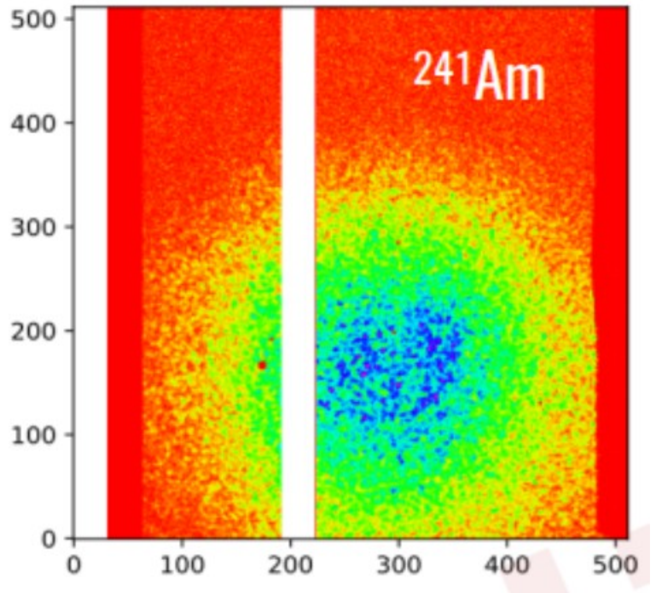
ARCADIA
High granularity

- Targets **very low power, small pixel**
- LFoundry 110 nm, largely founded by INFN
- Backside process, 50-500 µm thick
- Triggerless binary readout
- **First demonstrator fabricated**
  - 100 and 200 µm thick
  - Chip communication,injection, etc
  - Initial tests w/ radiation sources and cosmic rays
  - Higher power due to bug
- **MD2 already submitted** and being characterized
- Plan for next submission
  - System-grade main demonstrator chip
  - Gain layer being added for improved timing

INFN



MD1 pixels: 25 x 25 µm^2



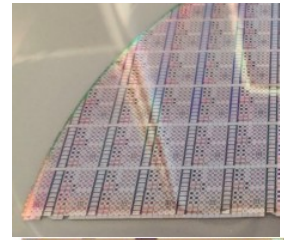
M. Rolo (INFN) VCI2022

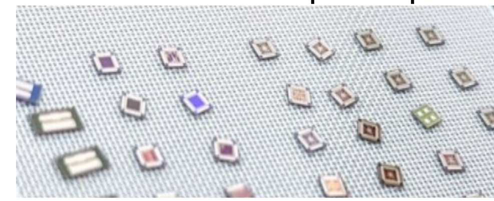
65 nm High granularity

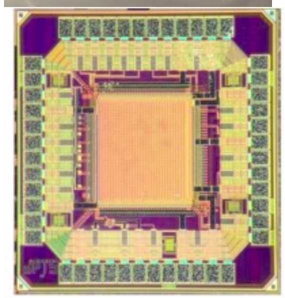
- Explore smaller size tech: **Tower 65 nm**
- Targets excellent position resolution, low mass, high rate, >1E15 neq/cm2
- 1st submission in July 2021 (MLR1)
  - Several test blocks included
  - Digital pixel test structure
    - Lab and beam tested
    - Excellent efficiency
- **Second submission**
  - Small prototypes (evolution of versions on MLR1)
  - Two large stitched sensors
    - 25 cm long, stitching
  - Submitted Dec 2022

Very encouraging results on 65 nm

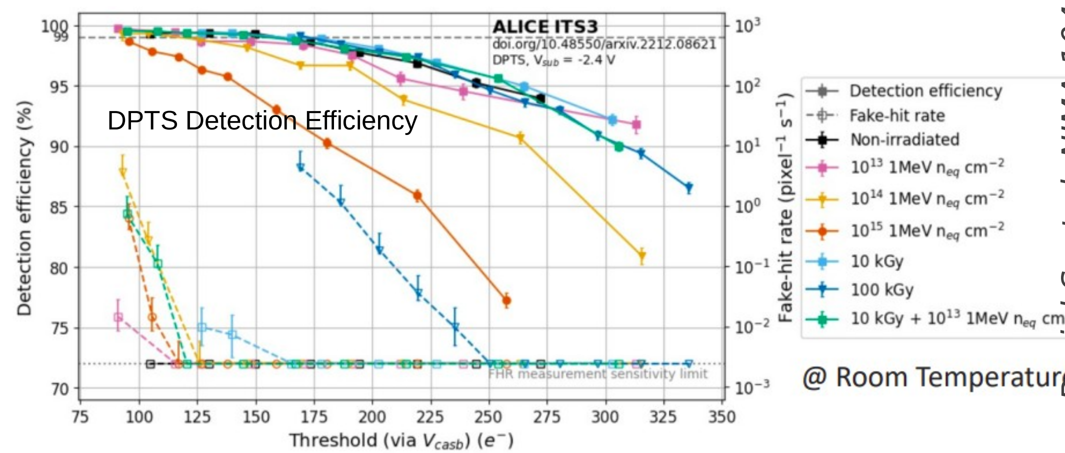
65 nm test structures and simple chips







DPTS
32 × 32 pixels
15 µm pitch
Asynchronous digital readout
ToT information



@ Room Temperature

Bugiel S. et al.,NIMA 1040 (2022) 167213

See talk of M. Mager on this workshop

Summary

- In the context of AIDAInnova, many institutions are collaborating in common DMAPS projects, mostly R&D, but some focused on applications
  - See *https://aidainnova.web.cern.ch/wp5*
- Effort focused on two main lines and two foundries *(LF and TJ)*
- Intense effort, not detailed here, DAQ development, irradiation and test-beam efforts, etc
- All research lines with devices to characterize
  - *High granularity, radiation hardness and timing*
    - *Overlap with TaichuPix effort (also in TJ)*
- Specially interesting for CEPC could be activities towards **65 nm** and **timing** with DMAPS

Back Up Slides

Group Contacts

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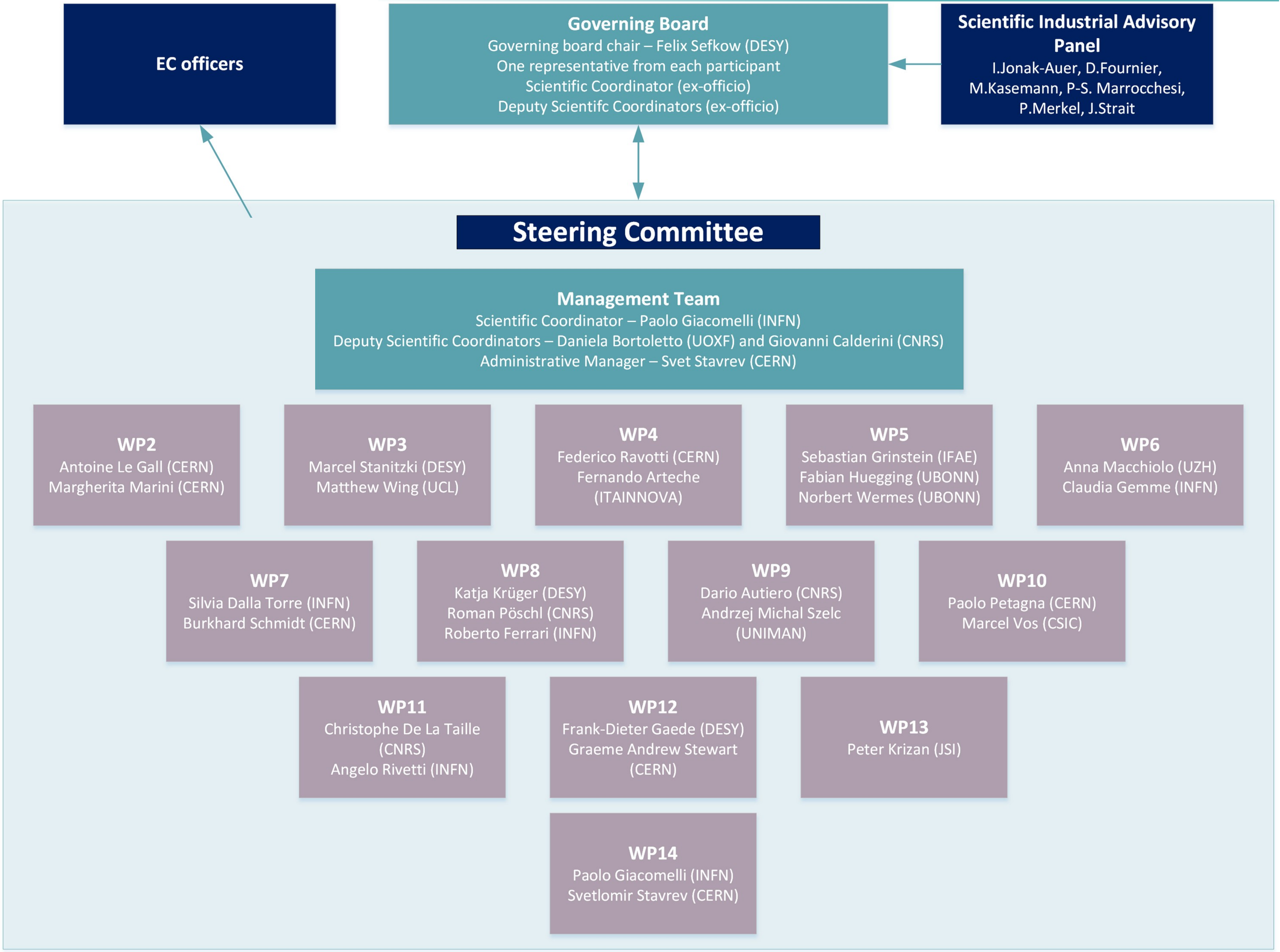
Thanks to all for providing input for this talk.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Governing Board
Governing board chair – Felix Sefkow (DESY)
One representative from each participant
Scientific Coordinator (ex-officio)
Deputy Scientifc Coordinators (ex-officio)
Scientific Industrial Advisory Panel
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Deputy Scientific Coordinators – Daniela Bortoletto (UOXF) and Giovanni Calderini (CNRS)
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WP9 Dario Autiero (CNRS) Andrzej Michal Szelc (UNIMAN)
WP10 Paolo Petagna (CERN) Marcel Vos (CSIC)
WP11 Christophe De La Taille (CNRS) Angelo Rivetti (INFN)
WP12 Frank-Dieter Gaede (DESY) Graeme Andrew Stewart (CERN)
WP13 Peter Krizan (JSI)
WP14 Paolo Giacomelli (INFN) Svetlomir Stavrev (CERN)