A Large Ion Collider Experiment

ALICE

ALICE ITS3

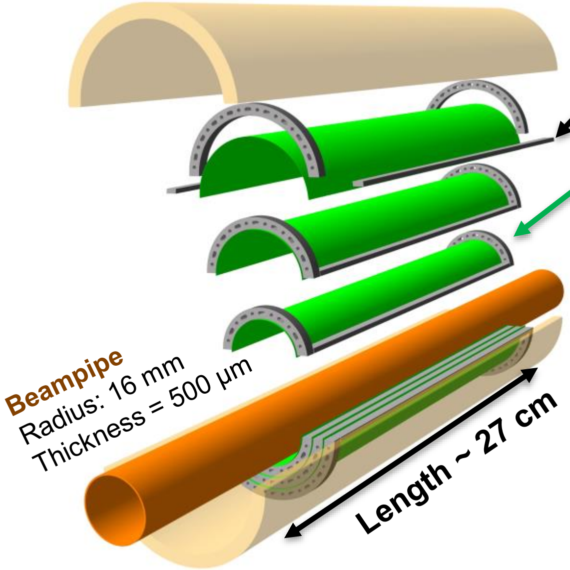
Status Report 2024-2025

P. La Rocca

NB: Info and plots from ITS3 Plenary meetings, WP meetings, conference talks, …

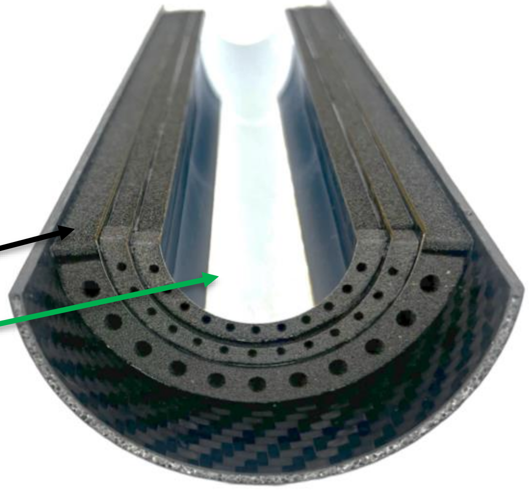
Inner Tracking System (ITS3)

- ITS2 → ITS3: 3 innermost layers replaced
- Basic idea: minimize material budget (0.09 % X_0) and distance to interaction point



Carbon foam

Half-layer sensor
Radii: ~ 31 mm
~ 25 mm
~ 19 mm



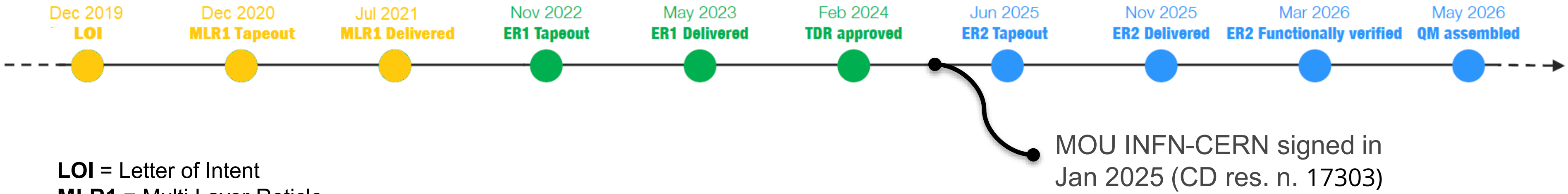
- **Key technologies:**
  - 1 sensor per half layer → wafer scale stitched
  - Total of 6 bent 65 nm Monolithic Active Pixel Sensors (MAPS)
  - Mechanically held in place by carbon foam ribs
  - Air cooled (Tair~ 20 °C)

ITS3 Project Organization

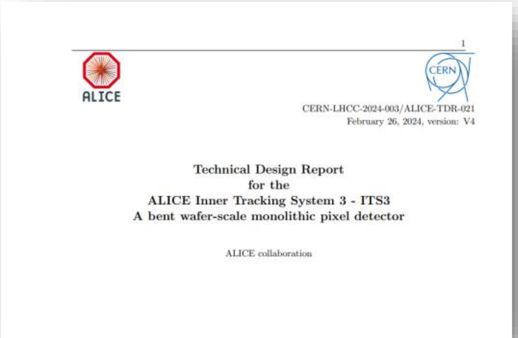
ITS3 Project leaders
A. Kluge, M. Mager

WP1 Physics, Simulation, Reconstruction	**WP2** Pixel Sensor ASIC Design	**WP4** Thinning, Bending, Interconnection	**WP5** Mechanics and Cooling
F. Grosa, A. Rossi	G. Aglieri Rinella, W. Snoeys	D. Colella, G. Contin	M. Angeletti, C. Gargiulo
WP3.1 Technology Demonstrator Characterisation and Qualification	**WP3.2** Stitched Sensor Characterisation and Qualification	**WP3.3** Qualification System & Detector Control System Design	**WP6** Readout electronics, Power Supply and Services
S. Senyukov	M. Suljic, H. Hillemanns	M. Keil, V. Sarritzu	O. Bourrion, S. Siddhanta/P. Giubilato

ITS3 Milestones



LOI = Letter of Intent
MLR1 = Multi Layer Reticle
ER = Engineering Run
TDR = Technical Design Report
QM = Qualification Model



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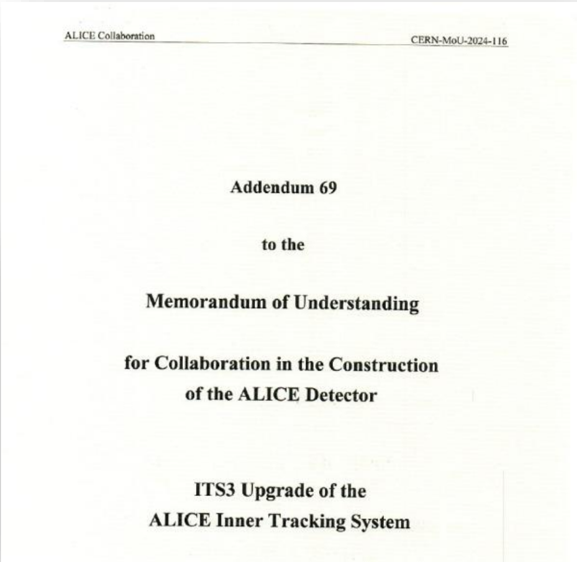
ALICE

CERN

CERN-LHCC-2024-003/ALICE-TDR-021
February 26, 2024, version: V4

Technical Design Report
for the
ALICE Inner Tracking System 3 - ITS3
A bent wafer-scale monolithic pixel detector

ALICE collaboration



ALICE Collaboration CERN-MoU-2024-116

Addendum 69

to the

Memorandum of Understanding

for Collaboration in the Construction
of the ALICE Detector

ITS3 Upgrade of the
ALICE Inner Tracking System

ALICE

MOU: Costs, Contributions and Responsibilities

01.07.24	2024	2025	2026	2027	2028	Total
	C&I	C&I	C&I	C&I	C&I	C&I
Total	1470	1671	480	100	180	**3901**
CMOS Sensor ASIC						**2280**
CMOS Sensor Fabrication	900	900				1800
Sensor Characterisation	180	150				330
Thinning/Dicing & Bending/Interconnect	75	75				150
Integration						**930**
Mechanics, Assembly & Test	100	150	100			350
Installation & Alignment	50	50	100	100		300
Air cooling	50	50				100
Installation & comissioning infrastructure					180	180
Readout Electronics						**431**
Common readout unit (CRU)		70				70
Detector Service Electronics (DSE)	40	50	100			190
Optical cables	5	6	30			41
Flexible Printed Circuit	70	60				130
Power Distribution						**210**
Power Supplies & Regulation		50				50
Power Cables		60	100			160
DCS (Detector control system)			50			**50**

Annex 5: Contributions and Responsibilities

03.07.24	CERN	CZ	FR	IT	KR	NL	NO	SE	SK	TH	Total
Funding (kCHF)											
ITS3 C&I	947	145	420	850	284	660	250	245	80	20	**3901**

03.07.24	CERN	CZ	FR	IT	KR	NL	NO	SE	SK	TH
CMOS Sensor ASIC										
CMOS Sensor Fabrication	X	X	X	X	X	X	X	X		
Sensor Characterisation	X	X	X	X	X	X	X	X		X
Thinning/Dicing & Bending/Interconnect	X			X	X					
Integration										
Mechanics, Assembly & Test	X			X						
Installation & Alignment	X									
Air cooling	X									
Installation & comissioning infrastructure	X		X	X						
Readout Electronics										
Common readout unit (CRU)			X	X			X			
Detector Service Electronics (DSE)			X	X		X	X			
Optical cables				X						
Flexible Printed Circuit	X		X	X		X				
Power Distribution										
Power Supplies & Regulation			X	X						
Power Cables				X						
DCS	X								X	
Physics performance & reconstruction	X		X	X						
Commissioning	X	X	X	X	X	X	X	X	X	X

Table 5.2: Field of responsibilities of contributors for the ALICE ITS3 upgrade describing the technical involvement of contributor person power.

WP1: Physics, simulation and reconstruction

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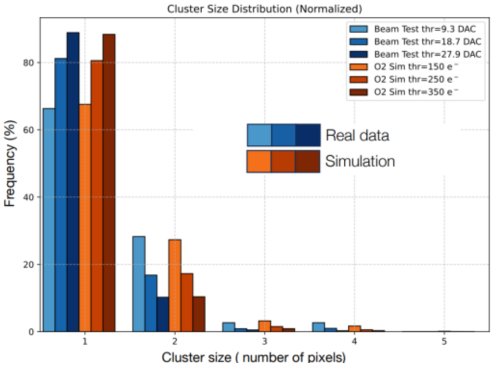
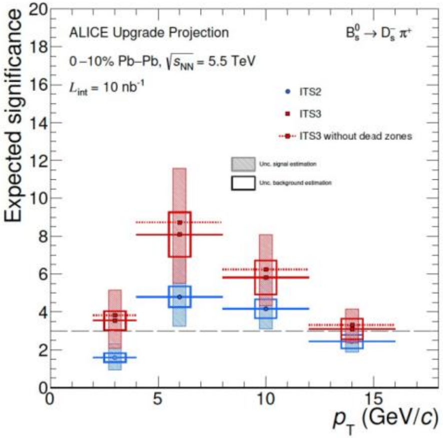
- Conveners: **A. Rossi**, F. Grosa
- Great effort in the preparation of the TDR
  - Detector layout
  - Heavy-flavour physics studies
  - Hypernuclei and c-deuteron
  - Strangeness tracking
- A good summary in: TDR CERN-LHCC-2024-003 and ALICE-PUBLIC-2023-002
- Complete ITS3 geometry implemented in the ALICE O2 framework
- New simulations with detailed geometry and precise dead zones inclusion done
- Realistic chip's response implemented
- **ITS3 WP1 meeting merged with ITS2 software (WP2) meeting** (from July 2024)





WP2: Pixel Sensor ASIC design
and
WP3: Sensor Characterisation and Qualification

WP2: Pixel Sensor ASIC design
and
WP3: Sensor Characterisation and Qualification

INFN Contribution (BA, BO, CA, CT/ME, PD, TO, TS)

- Contribution to sensor design
- Contribution to sensor fabrication (330 kEUR in 2024, 110.5 in 2025 + 39.5 kEUR anticipated in 2024)
- Development of test systems (hardware and software)
- Sensor glueing and bonding
- Characterization of prototypes:
  - Distributed effort (several prototypes to be characterized)
  - Local lab measurements
  - Participation to testbeam and data analysis
  - Papers preparation
- Human resources:
  - INFN similfellows
  - PhD students, master students
  - Long-term presence at CERN…

Sensor roadmap

MLR1 (Multi Layer Reticle 1): qualification of the 65 nm CMOS

Dec 2019 **LOI** — Dec 2020 **MLR1 Tapeout** — Jul 2021 **MLR1 Delivered** — Nov 2022 **ER1 Tapeout** — May 2023 **ER1 Delivered** — Feb 2024 **TDR approved** — Jun 2025 **ER2 Tapeout** — Nov 2025 **ER2 Delivered** — Mar 2026 **ER2 Functionally verified** — May 2026 **QM assembled**

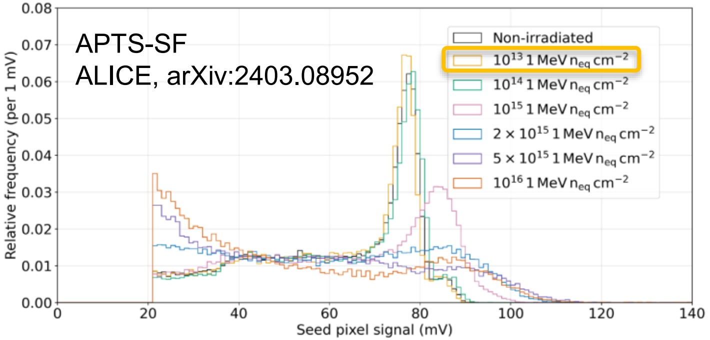
- Technology explored **beyond ITS3 requirements**:
  - Charge detection
  - Radiation hardness
- Several prototype sensors characterized
- **INFN contribution**: development of MLR1 test set-up, characterization of Analog (APTS) and Digital (DPTS) Test Structures
- **Papers** (INFN people in paper committees):

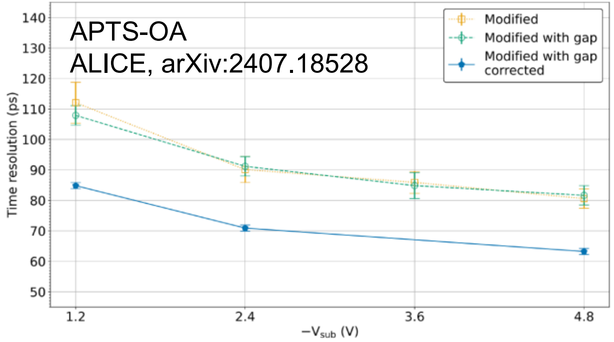
  DPTS: https://doi.org/10.1016/j.nima.2023.168589

  https://arxiv.org/abs/2505.05867

  APTS-SF: https://doi.org/10.1016/j.nima.2024.169896

  APTS-OA: https://doi.org/10.1016/j.nima.2024.170034





ER1 (Engineer Run 1): first stitched MAPS

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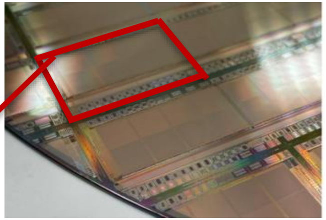
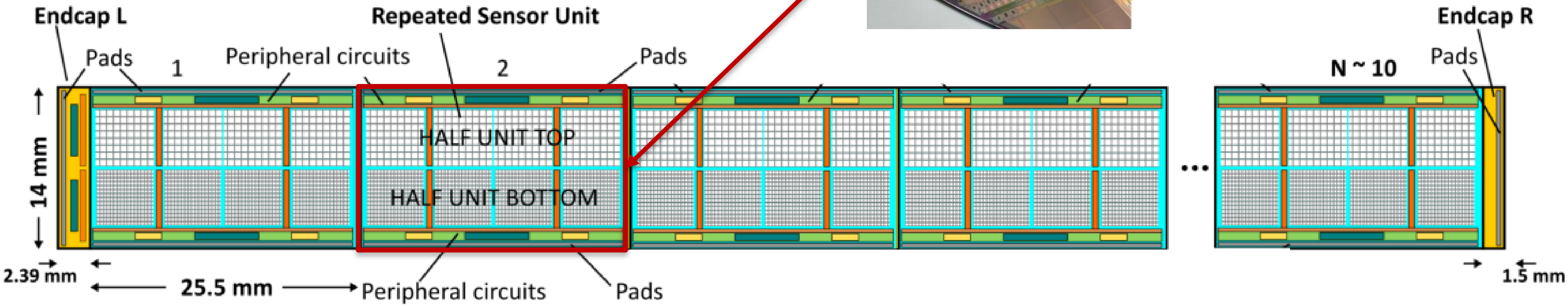
- First stitched MAPS
- First large-area prototypes
- Stitching validation





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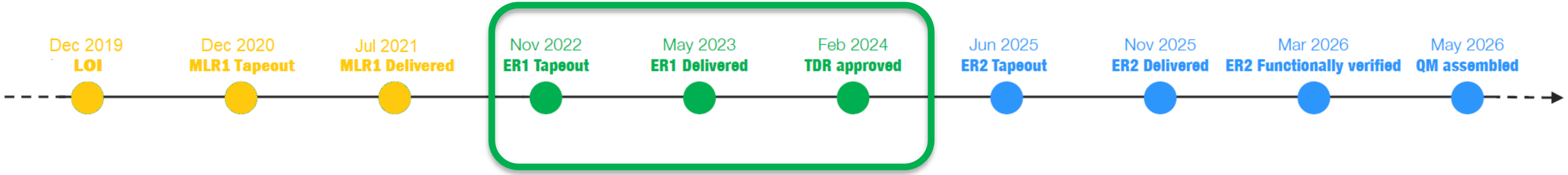
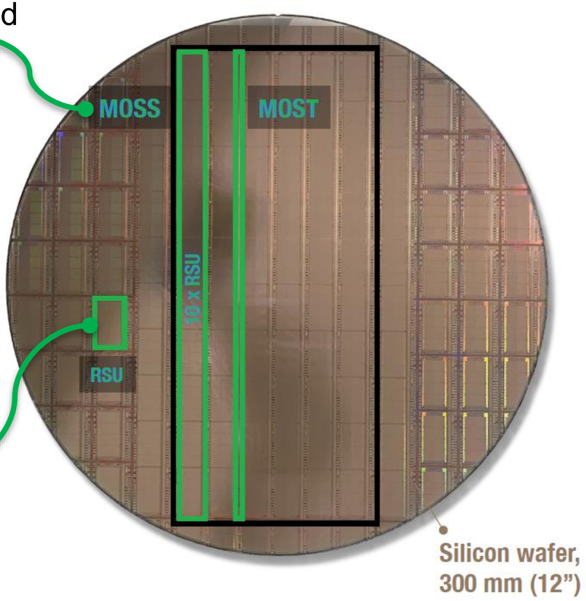


- Extensive tests on **MOSS** and **baby-MOSS**
- Yield, uniformity and performances established and reliable
  → fundamental for next submission design (ER2)
- BabyMOSS contains a single RSU:
  - Suitable for irradiation purposes
  - Suitable for distribution
  - Suitable for testbeam campaign



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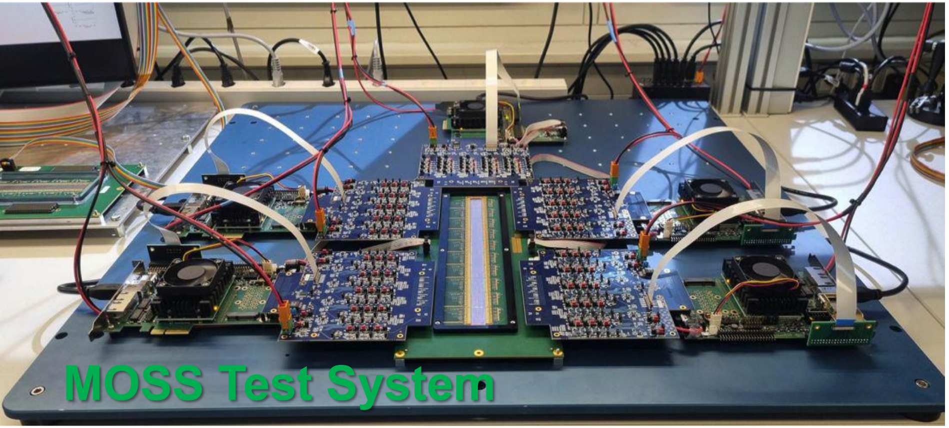

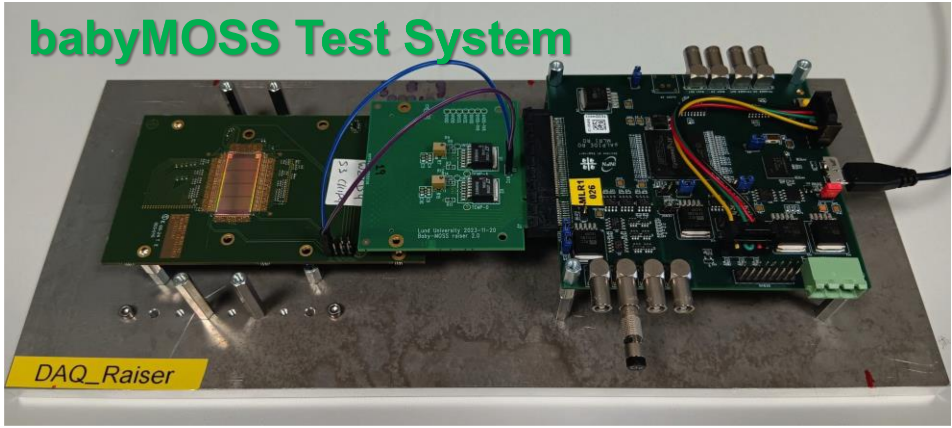

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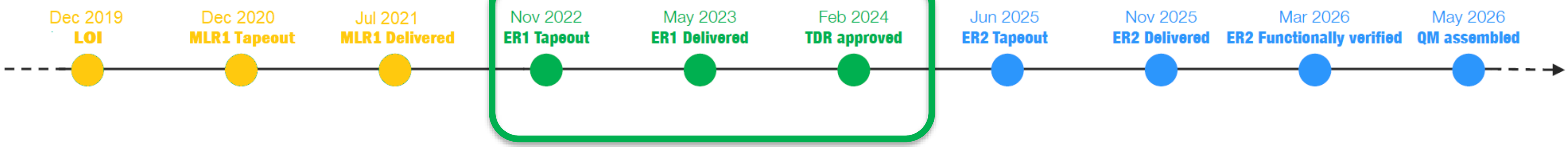
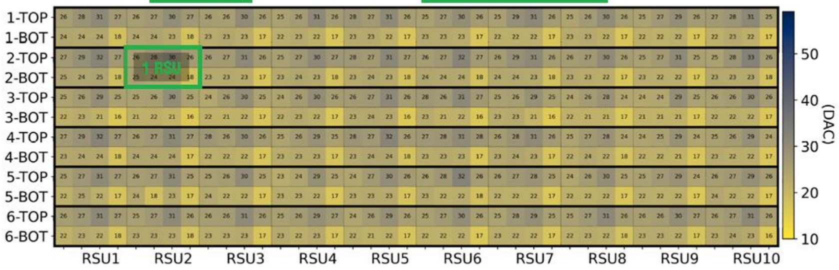


MOSS - functional tests

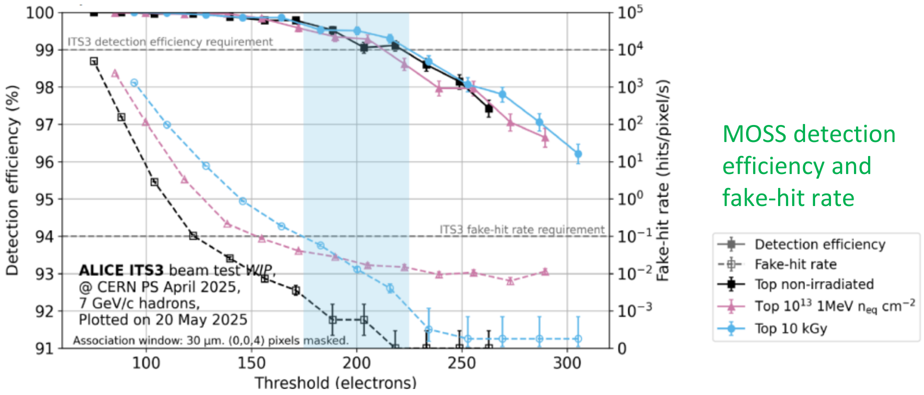
- Several functional tests on all 82 MOSS
  - Yield ~89 % (~98% excluding readout issues)
- Good performance and uniform behavior
  - NO wafer or sensor position dependence

all wafers - threshold scan - Threshold average per region



Beam test results

- Operational margin à confirmed performance from previous submissions



MOSS detection efficiency and fake-hit rate

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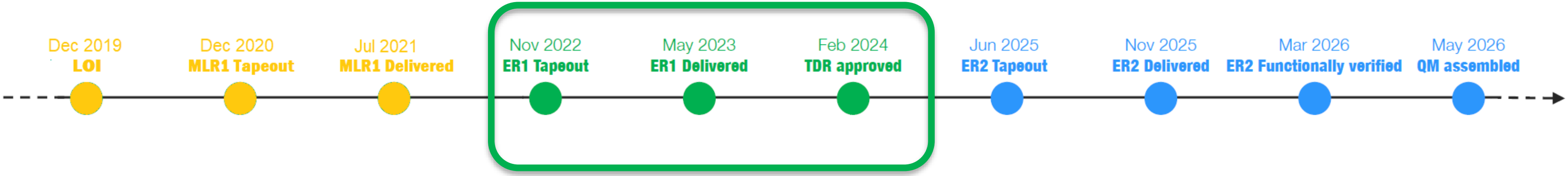
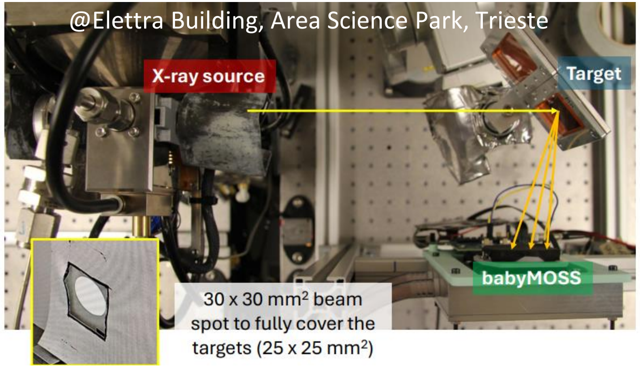
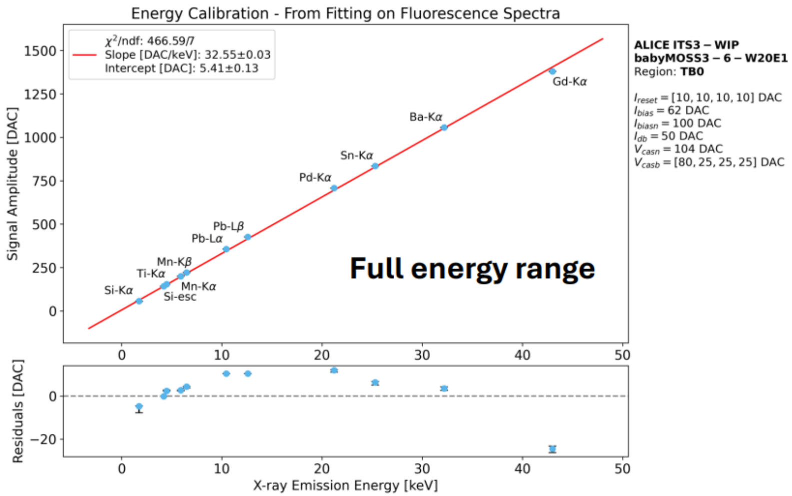


babyMOSS – Laboratory test

- Distributed characterization work
- Optimization of the FE settings
- Study of FHR, noise, threshold…
- Energy calibration (ToT) with X-ray sources + fluorescence targets





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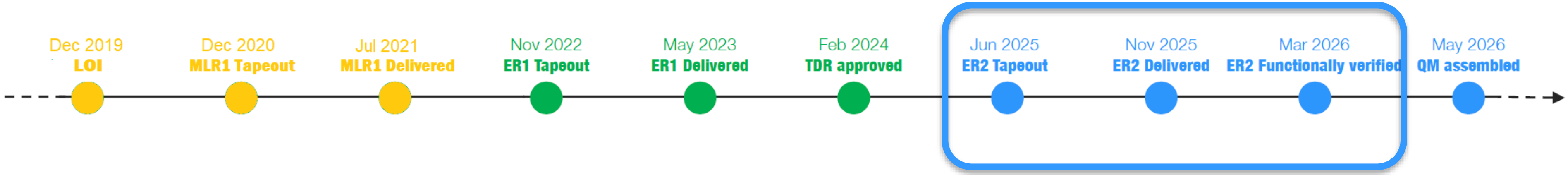
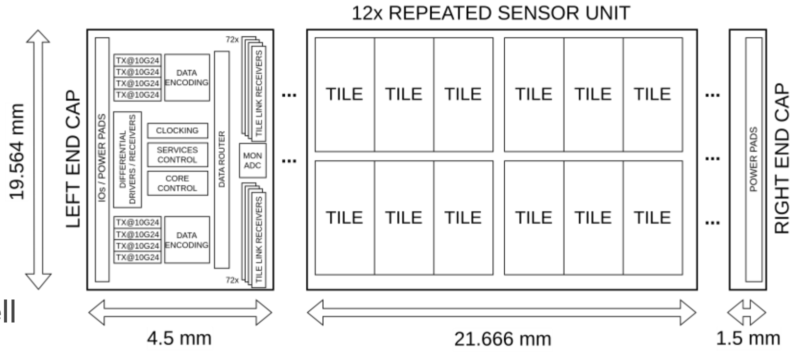
ER2 (Engineer Run 2): full size, full functionality sensor



MOSAIX: Final size 2D stitched sensor

- 12 RSU
- Each RSU is divided in turn in 12 fully independent tiles (powering, control and readout)
  - Different pixel variants for operational margins
- **Final ER2 submission → July 2025**
- **Very tight schedule** for MOSAIX testing
- Test system (hardware, firmware and software) to be ready well before chips arrive

+ CHIPLETS



ER2 (Engineer Run 2): full size, full functionality sensor

ALICE

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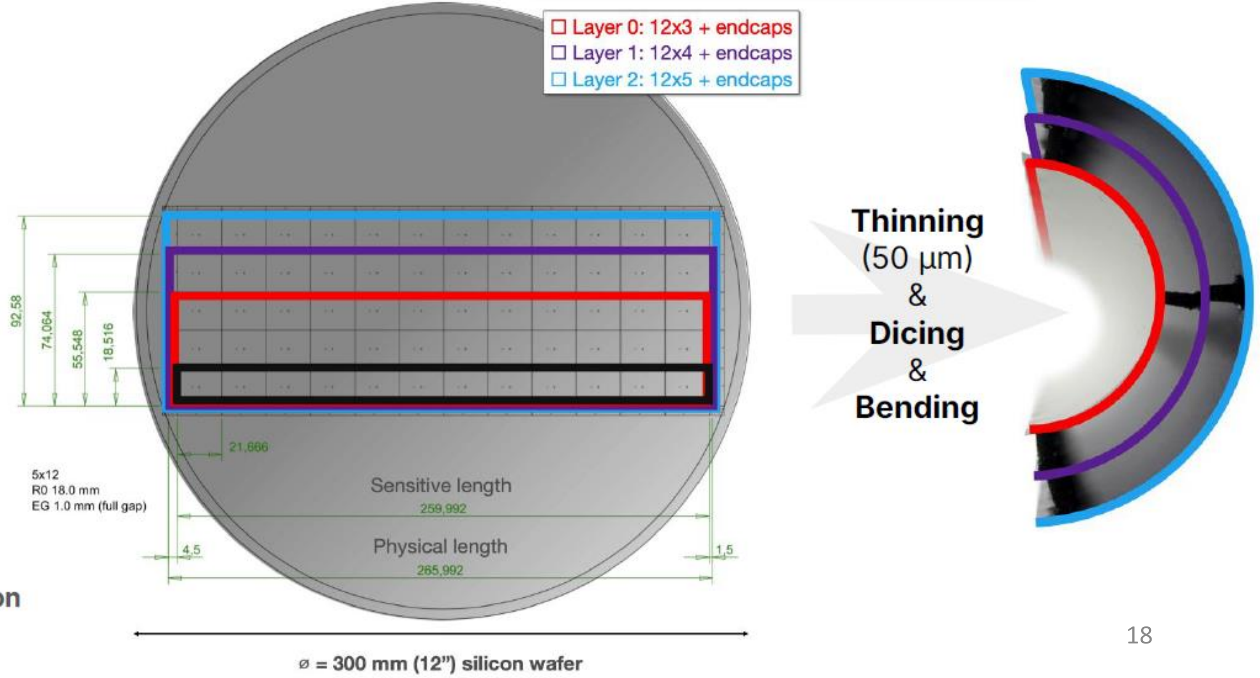
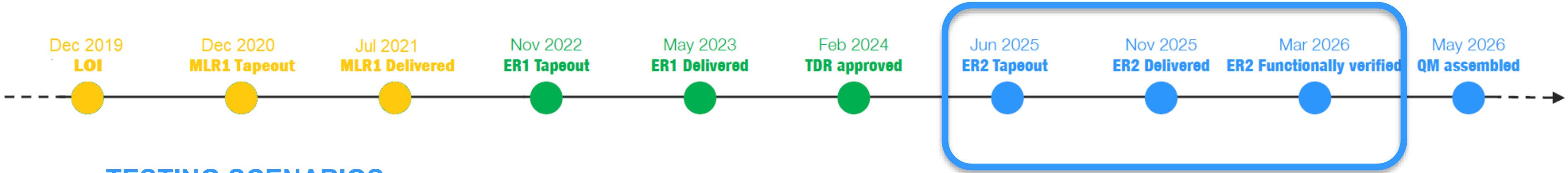
WAFER TO LAYERS

- **Modular design**: each sensor is divided into 3, 4, or 5 segments with 12 RSUs

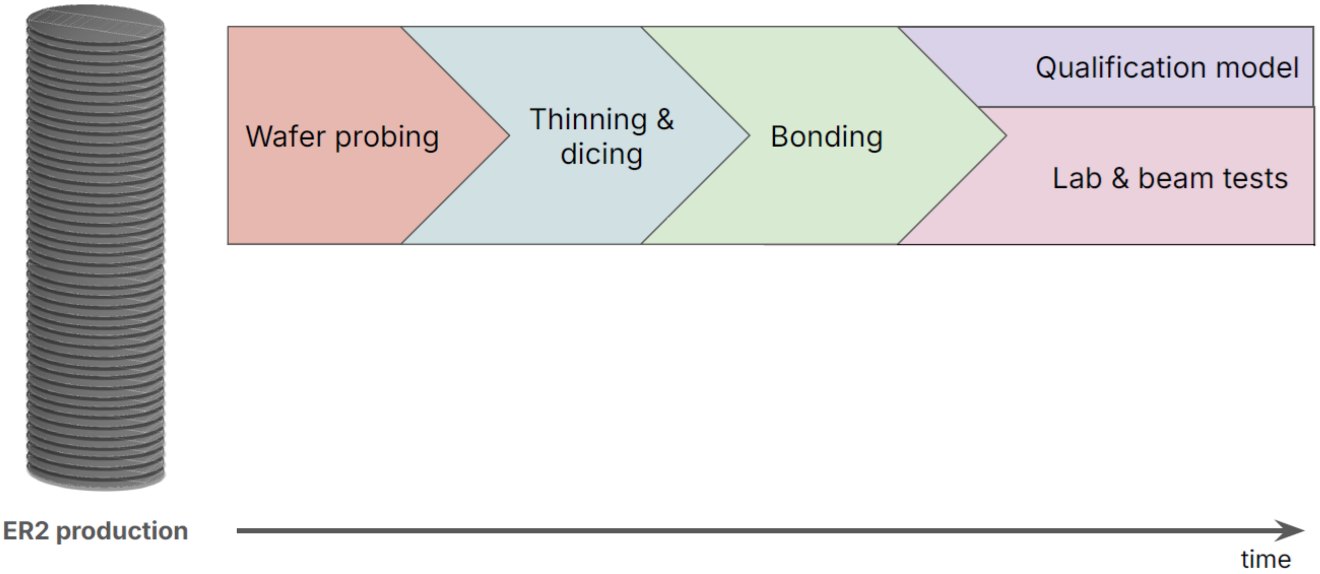
ER2 production



ER2 (Engineer Run 2): full size, full functionality sensor



TESTING SCENARIOS



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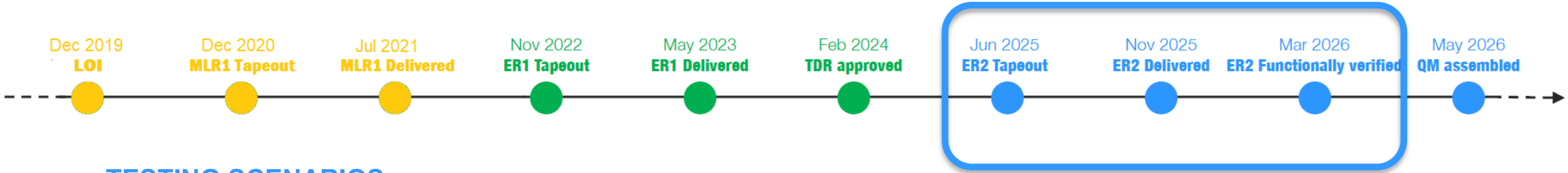

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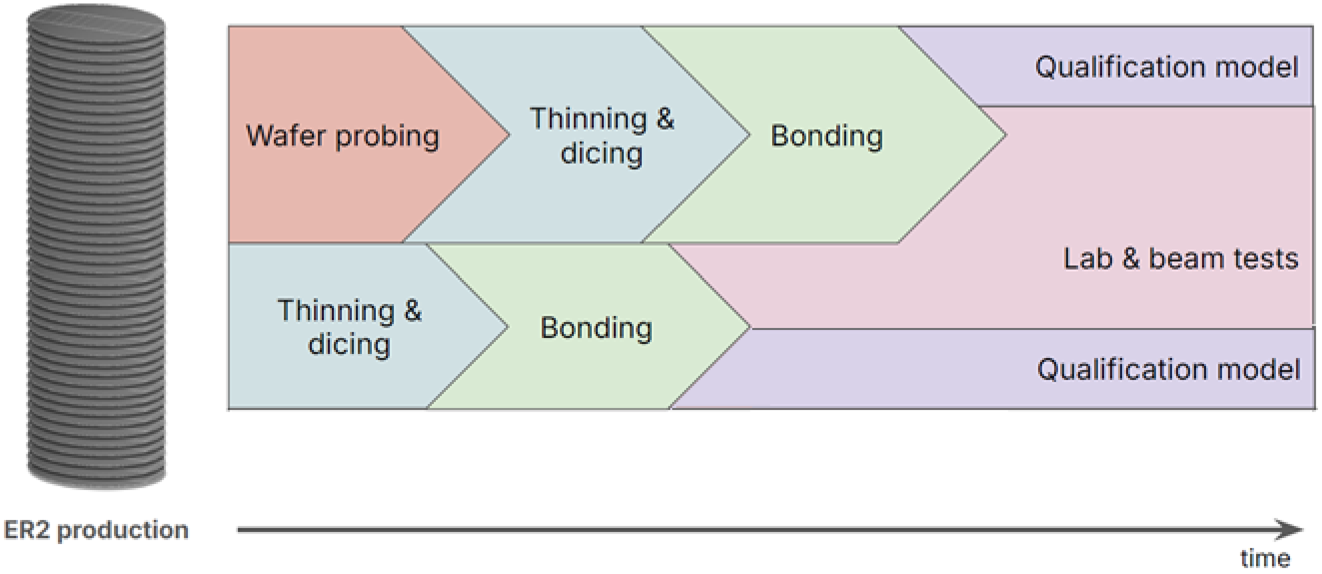
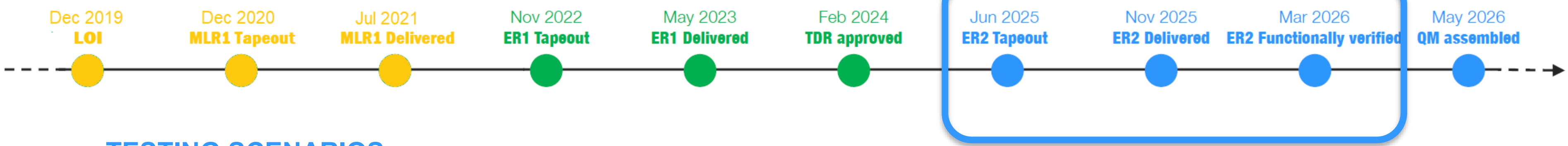


ER2 (Engineer Run 2): full size, full functionality sensor



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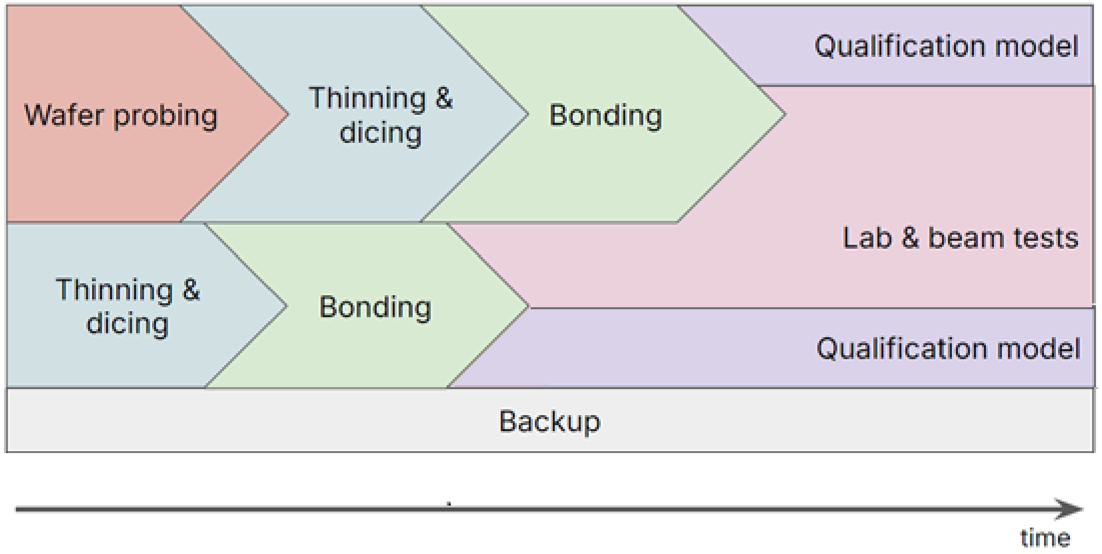

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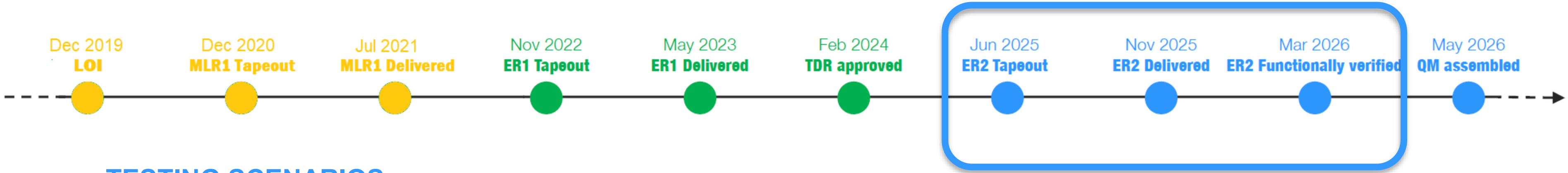

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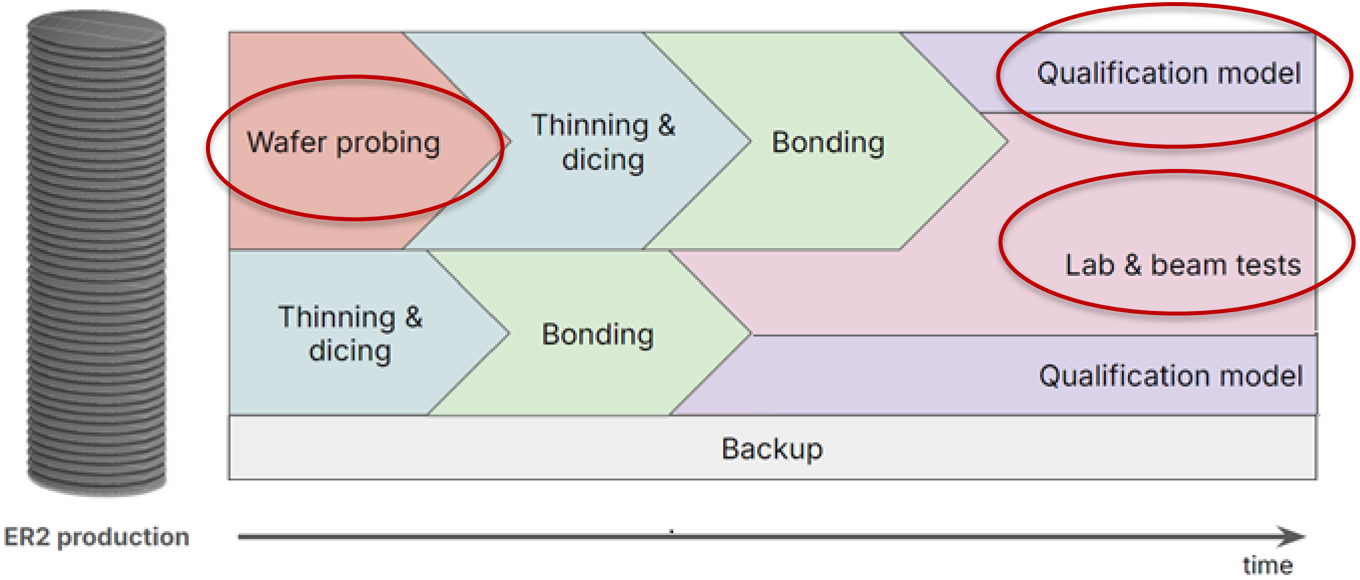

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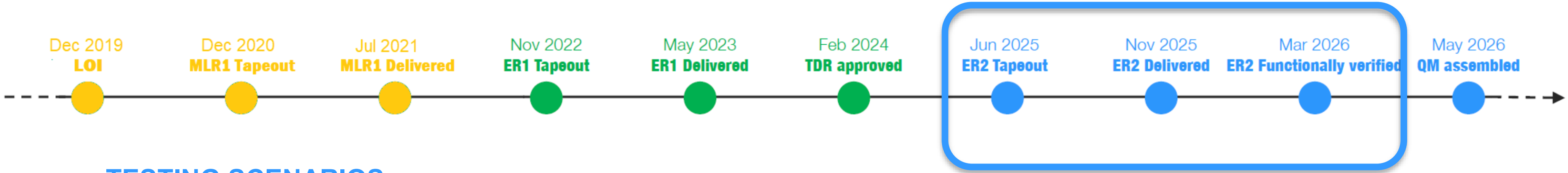
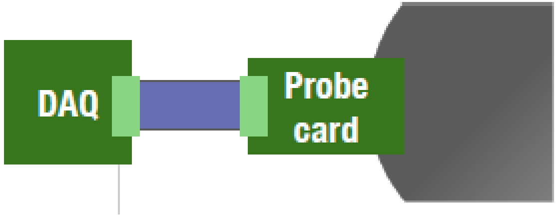


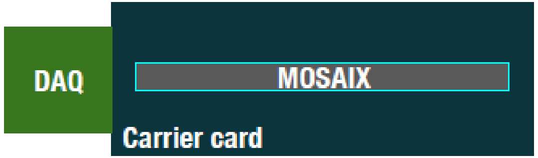
TESTING SCENARIOS

1) MOSAIX emulator → ready!

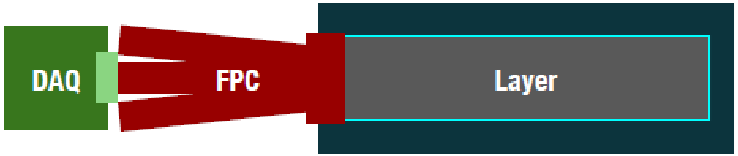
2) Wafer probing→ with different needle probe cards



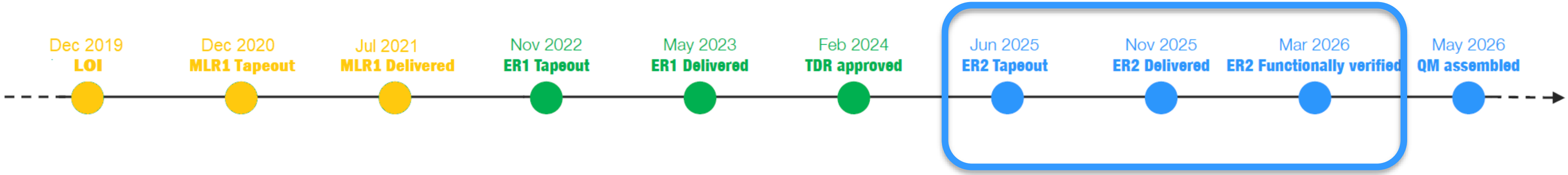
3) Lab & beam tests→ with options of sensor sizes and connections (e.g. FPC) → **distributed effort**



4) Qualification model → test of ITS3 layers

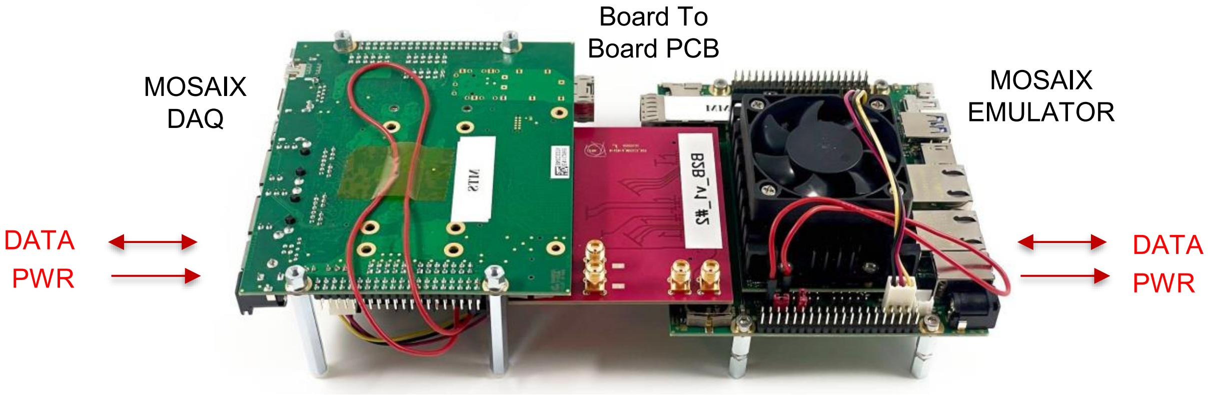


ER2 (Engineer Run 2): full size, full functionality sensor



MOSAIX EMULATOR

- Useful for HW/SW/FW **development** and testing
- **Training** tool for real chip characterization



ALICE

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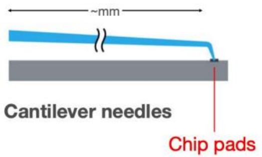
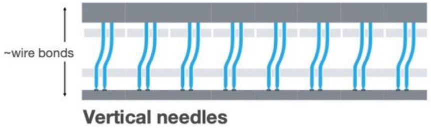
WAFER PROBING

- Facilities at CERN PH Department Silicon Facility
- 2 probe systems, to be re-tested with ER2 pad wafer
- Different needle probe cards



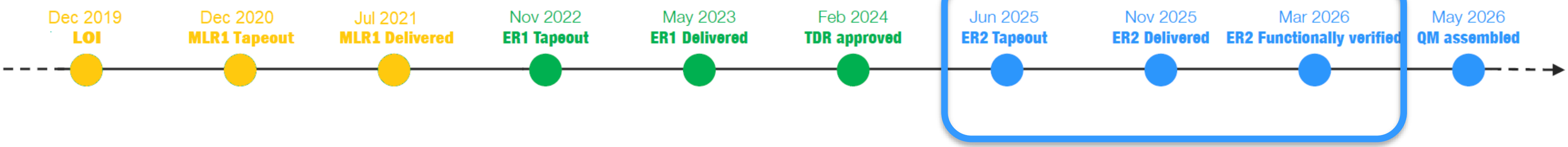


Backup option to

To learn how to use

	MOSAIX HS (cantilever)		MOSAIX HS (vertical)		NKF7 (vertical)	
Feature	**Status**	**Target date**	**Status**	**Target date**	**Status**	**Target date**
Design	Done	-	Ongoing	TBA	Done	-
Design validation	Done	-	Ongoing	TBA	Done	-
Production	Done	-	Not started	August	Done	-
Commissioning	Not started	End of May	Not started	August	Done	-
	✘ 5-10 Gbps		✔ 5-10 Gbps		✔ 5-10 Gbps	

ER2 (Engineer Run 2): full size, full functionality sensor

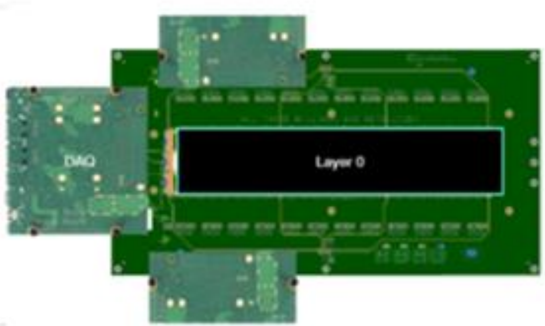


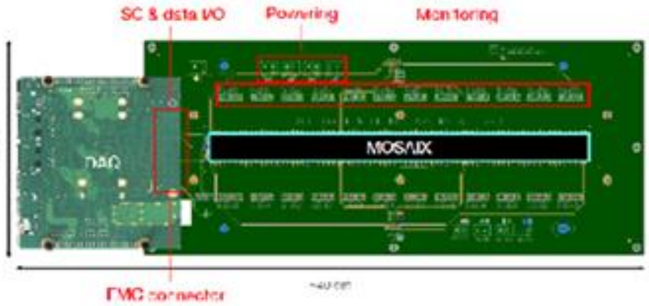
LAB & BEAM TESTS

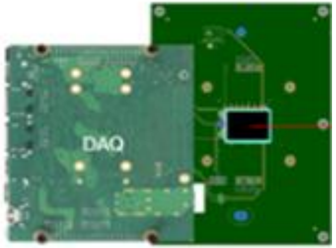
- INFN sites are being equipped with the setup to test the babyMOSAIX (+ emulator)
- Crucial contribution given the tight timeline for the ER3 submission

babyMOSAIX (1 RSU + ECs)

- Much more per wafer
- Much easier to pick
- Several sites practiced with babyMOSS
- Same test system as MOSAIX
- Ideal for distributed characterization







ER2 (Engineer Run 2): full size, full functionality sensor

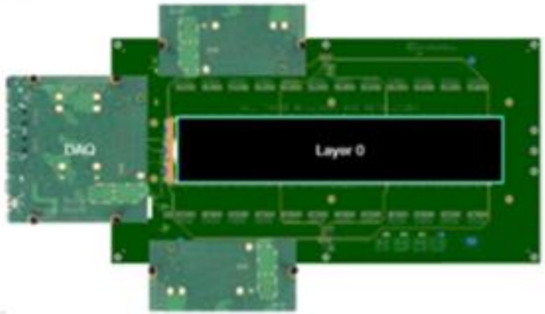
Dec 2019 LOI
Dec 2020 MLR1 Tapeout
Jul 2021 MLR1 Delivered
Nov 2022 ER1 Tapeout
May 2023 ER1 Delivered
Feb 2024 TDR approved
Jun 2025 ER2 Tapeout
Nov 2025 ER2 Delivered
Mar 2026 ER2 Functionally verified
May 2026 QM assembled

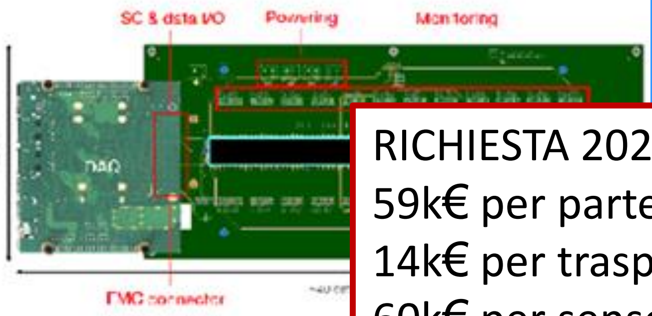
LAB & BEAM TESTS

- INFN sites are being equipped with the setup to test the babyMOSAIX (+ emulator)
- Crucial contribution given the tight timeline for the ER3 submission

babyMOSAIX (1 RSU + ECs)

- Much more per wafer
- Much easier to pick
- Several sites practiced with babyMOSS
- Same test system as MOSAIX
- Ideal for distributed characterization





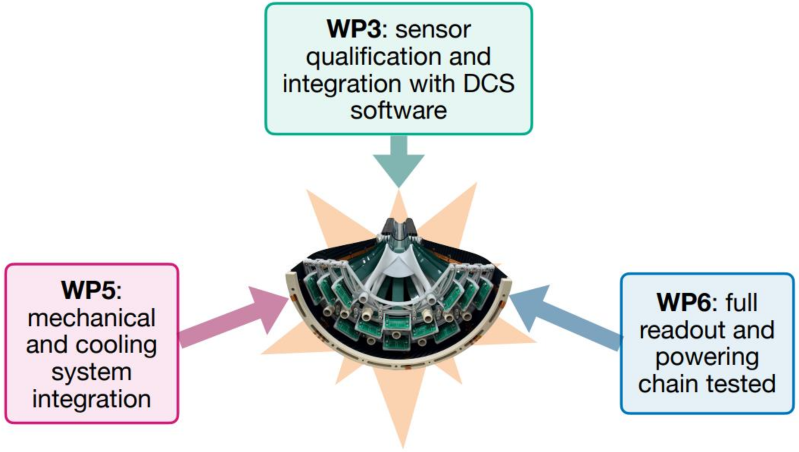
RICHIESTA 2026:
59k€ per partecipazione a beam tests
14k€ per trasporti
60k€ per sensore CMOS

ER2 (Engineer Run 2): full size, full functionality sensor

Dec 2019	Dec 2020	Jul 2021	Nov 2022	May 2023	Feb 2024	Jun 2025	Nov 2025	Mar 2026	May 2026
LOI	**MLR1 Tapeout**	**MLR1 Delivered**	**ER1 Tapeout**	**ER1 Delivered**	**TDR approved**	**ER2 Tapeout**	**ER2 Delivered**	**ER2 Functionally verified**	**QM assembled**

QUALIFICATION MODEL (QM)

- Validate the integration and functionality of all ITS3 components under realistic operating conditions
- Identify and resolve **integration**-related issues before final production and installation
- Detailed step-by-step plan and derivables defined
- 2 QMs will be produced
- A **unified effort** among different Work Packages
- **Key INFN contribution** to the development of testing systems and QM



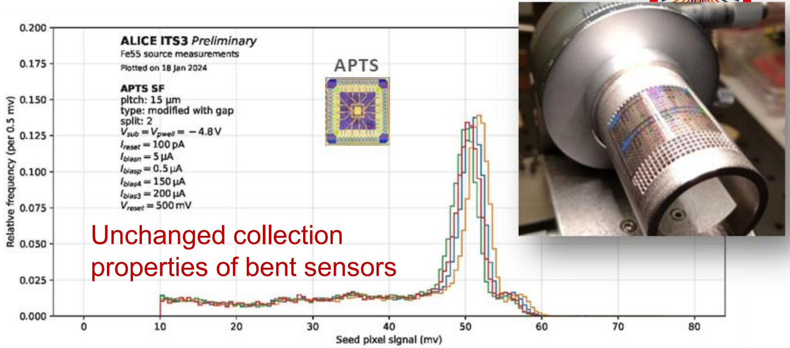
WP4: Thinning, Bending, Interconnection
and
WP5: Mechanics and cooling

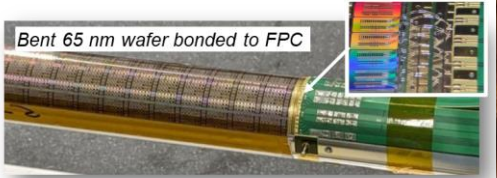
WP4: Thinning, Bending, Interconnection
and
WP5: Mechanics and cooling

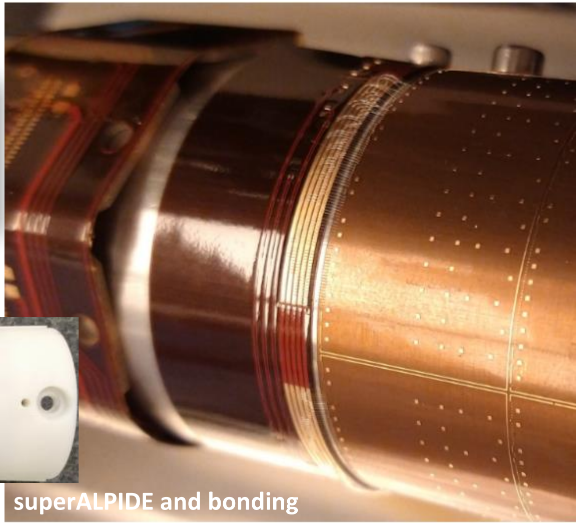
- Conveners WP4: **D. Colella, G. Contin**

Bending MAPS (past)

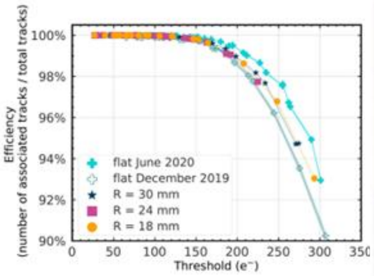
- Bending MAPS sensors (WP4)
  - Silicon becomes flexible below 50 µm thickness
  - Bend existing MAPS sensors (ALPIDE) and small test structures
  - Measure the bent sensor performance and compare with flat sensors
- R&D carried out within INFN:
  - Bending mechanics and procedures
  - Curvature precision measurements
  - Wire-bonding on curved surface
  - Laboratory characterization
  - In-beam performance measurements

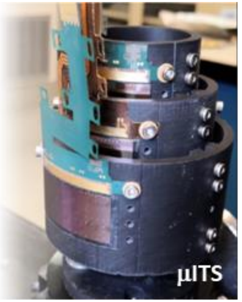






superALPIDE + eskeloton

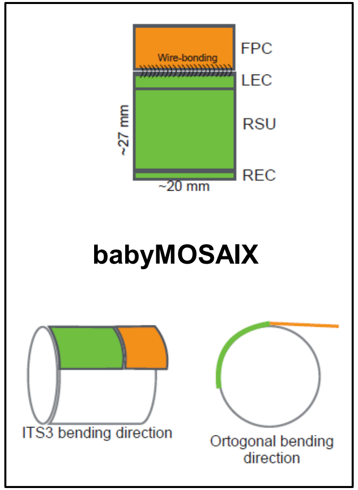




Bending MAPS (future)

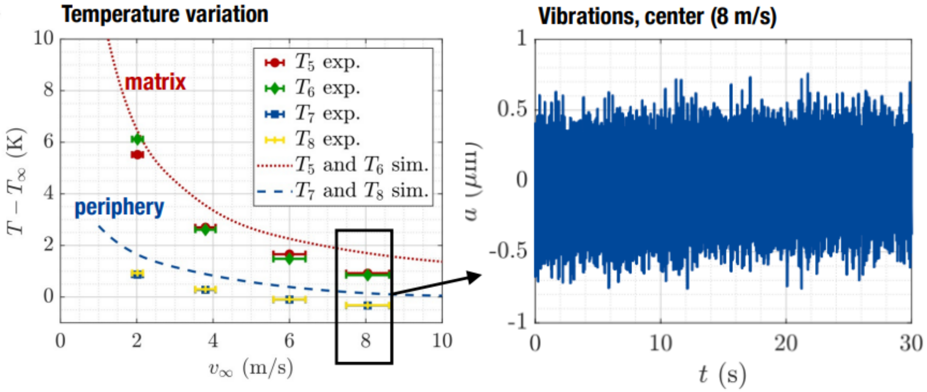
Bending large area sensors:

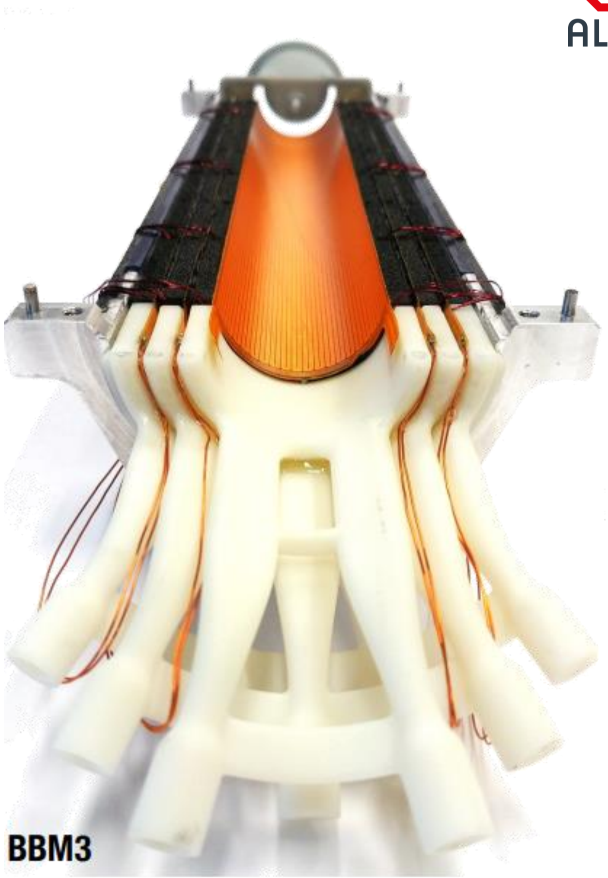
- babyMOSS
  - First effort started in 2024
  - Challange: wire bonding on all 4 sides → Flexible PCB
  - Work ongoing
- MOSS
  - Difficulties in handling and bending single segment
  - Under evaluation
- babyMOSAIX
  - Useful for lab testing, testbeam with telescope, study of ageing through thermal cycles
- MOSAIX
  - Qualification Models (mainly @CERN)
- INFN interest in baby sensor bending activities



Mechanics – Bread Board Models

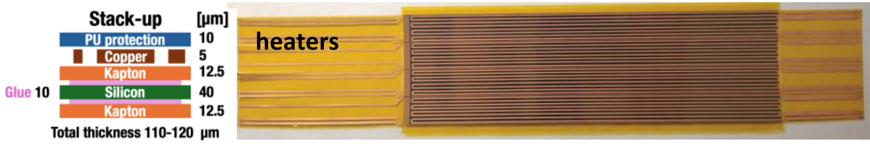
- Prototypes for air cooling
- Thermal and stability test:
  - Several Bread Board Models based on heating elements with carbon foam support structure
  - Placed in a custom wind tunnel, thermal and mechanical properties studied (BBM3)

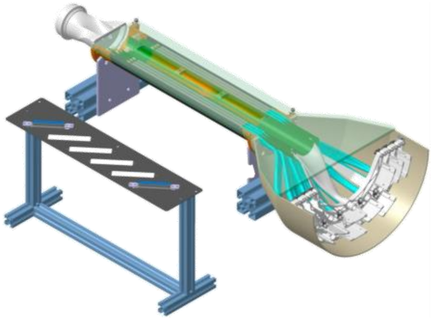


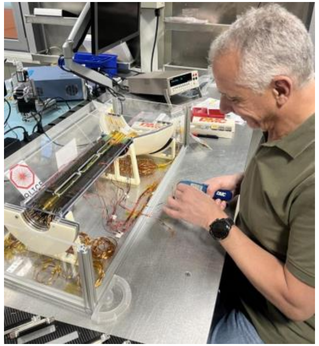


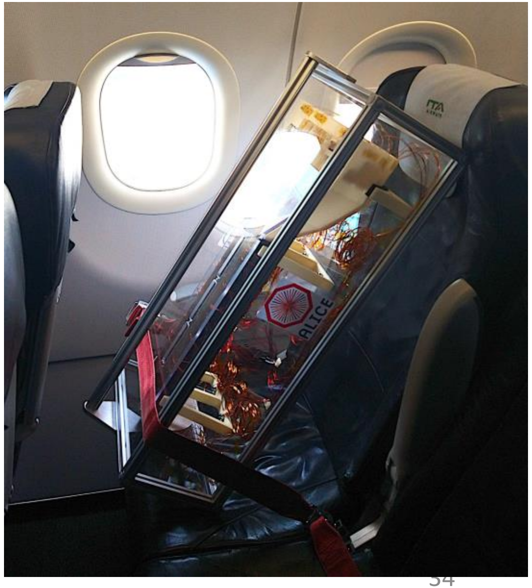
Mechanics – Bread Board Models

- New **BBM6 done in Bari**, now at CERN for integration in an upgraded wind tunnel
  - closer design to final
  - improved heaters design
  - improved mapping and temperature precision
- **Next INFN activity:** study of wire bond strength under air flow conditions
  - Realization of a wind tunnel, equipped with flow meters
  - Assembly of the prototype: bent sensors + FPC
  - Wire bonding and pull-force measures









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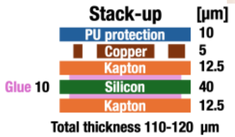
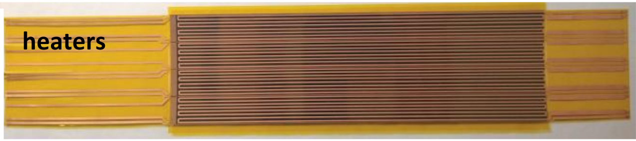
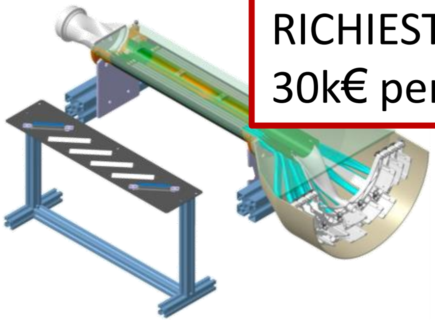
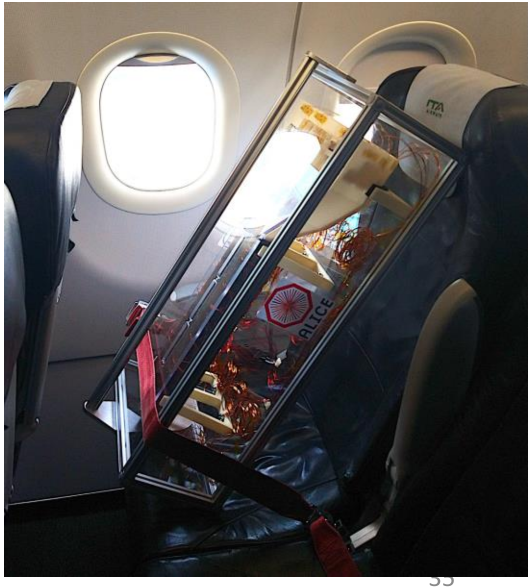






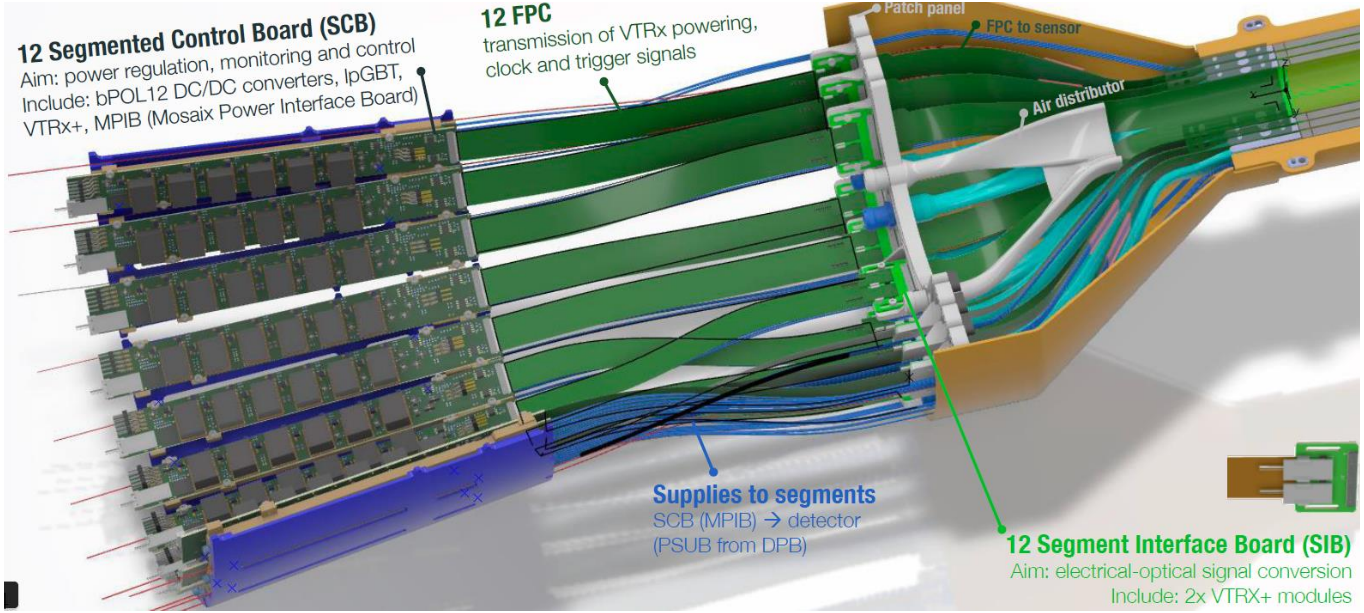
RICHIESTA 2026:
30k€ per attività WP5



WP6: Readout electronics, Power Supply and Services

WP6: Readout electronics, Power Supply and Services

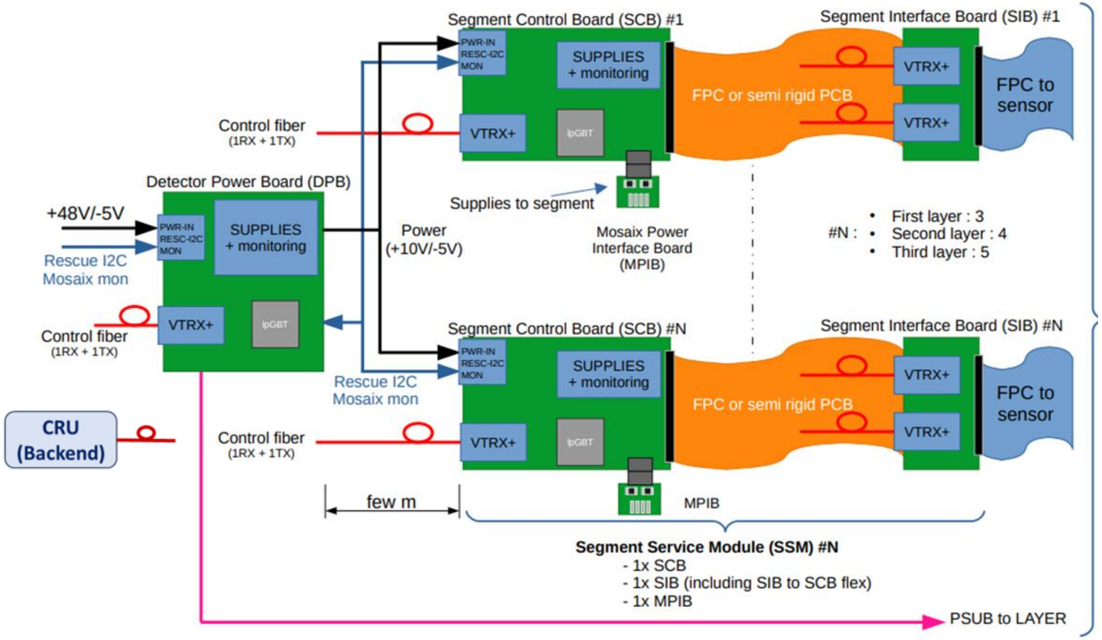
- Conveners: **S. Siddhanta, P. Giubilato**, O. Bourrion
- Full scale model realization ongoing



WP6: Readout electronics, Power Supply and Services

Detector Service Boards
- Design of the boards done at Grenoble
- First prototypes produced, **tests started**
- INFN will participate in the test and qualification as part of full system tests
- 2 testbenches (CERN and PD)

Common Readout Unit (CRU)
- CRU common logic is a central development
- ITS3 will have a new User Logic
- INFN (CA and PD) is involved in the User Logic development



Qualification model:
- Cross WP development
- Will integrate all the final WP components
- Study integration issues
- Study WP6 component performance and qualify them in realistic settings

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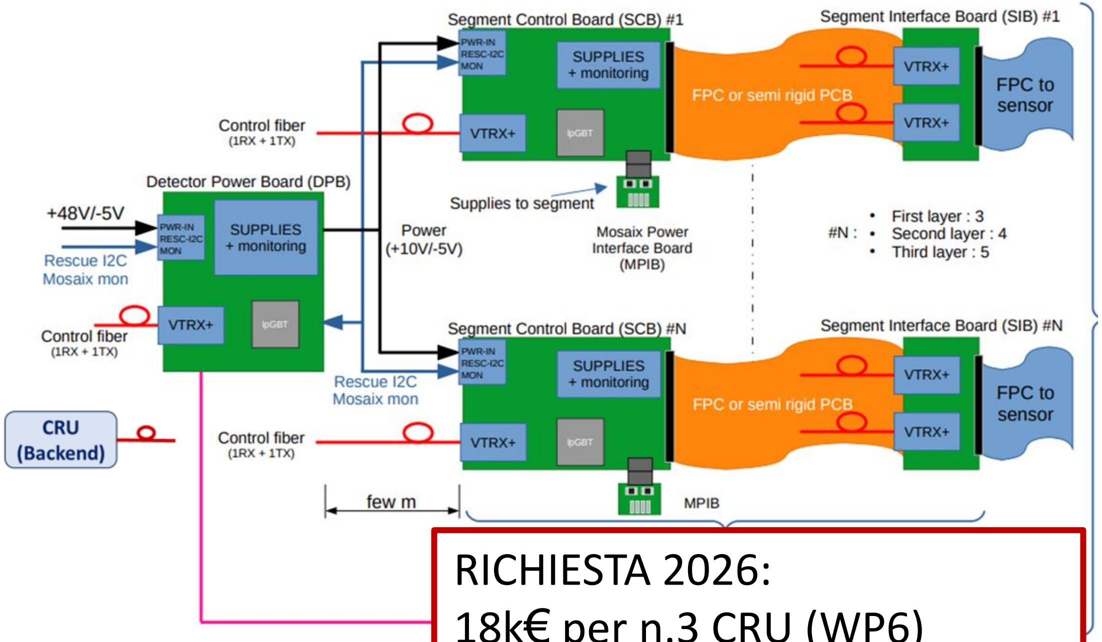
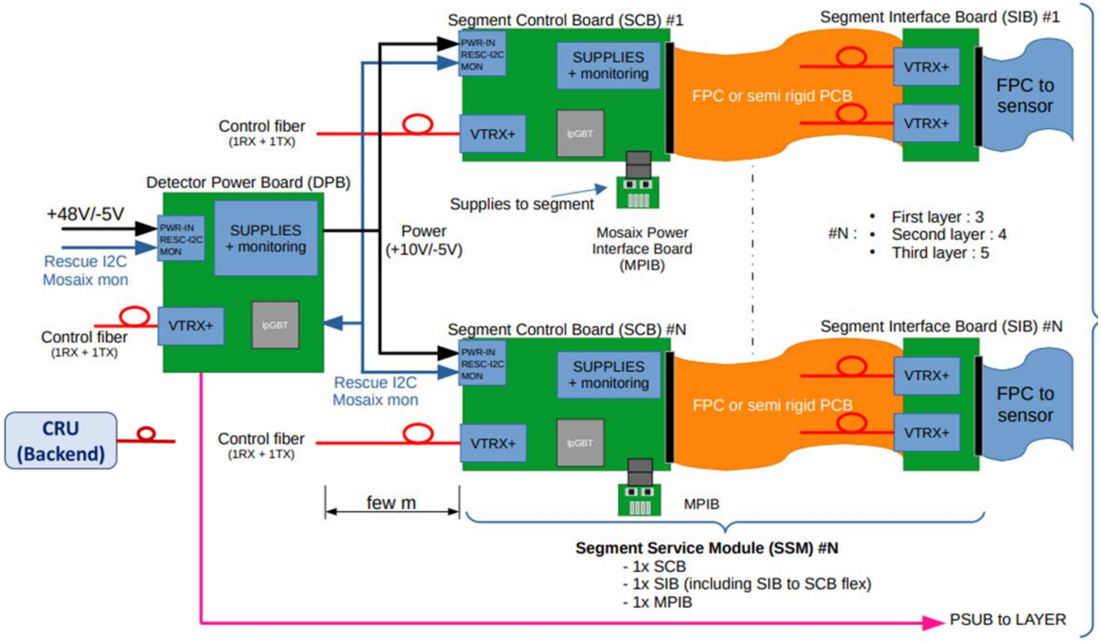


RICHIESTA 2026:
18k€ per n.3 CRU (WP6)
30k€ + 6k€ per missioni CERN

WP6: Readout electronics, Power Supply and Services

Flexible Printed Circuit (FPC)

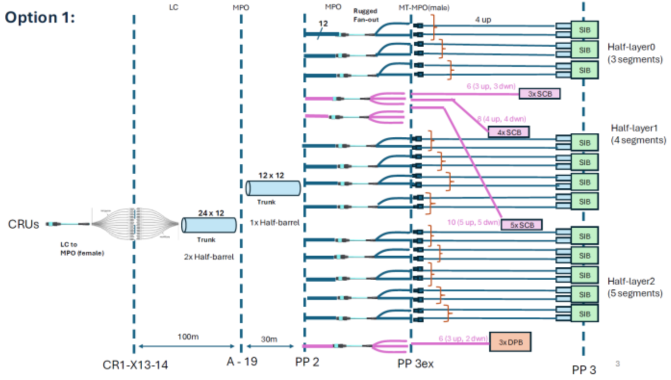
- Layout of a single segment is replicated multiple times depending on the layer
- Bonded on the sensor
- Design of FPC done at CERN, INFN (TS) involved in the characterization of FPC
- FPC prototype received, assembling the test system

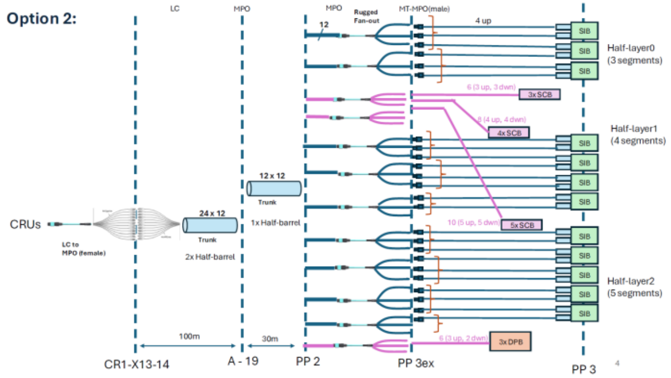


WP6: Readout electronics, Power Supply and Services

Optical Fibers

- Under **INFN responsibility**
- Fragile elements→ several optical link schemes under investigation
- Final choice based on mock-up evaluation
- The cost depends on the total fiber length
- Some fibers are custom-made





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WP6: Readout electronics, Power Supply and Services

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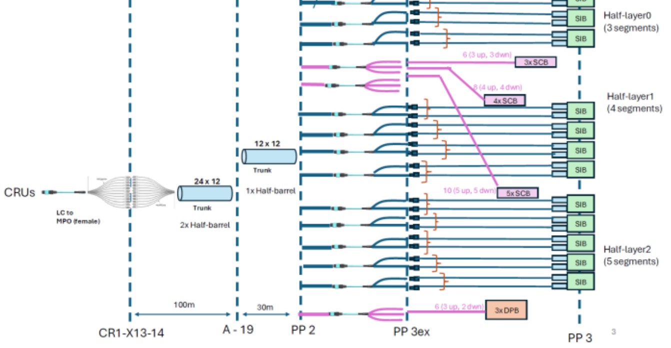
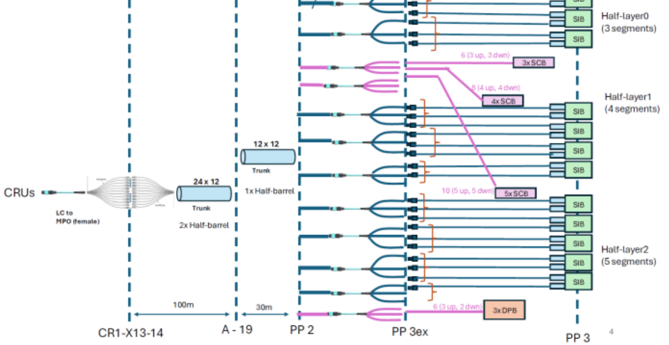
RICHIESTA 2026:
40k€ per optical fibers

Option 1:



Option 2:



WP6: Readout electronics, Power Supply and Services

POWER SUPPLIES

PSUB -5V to DPB

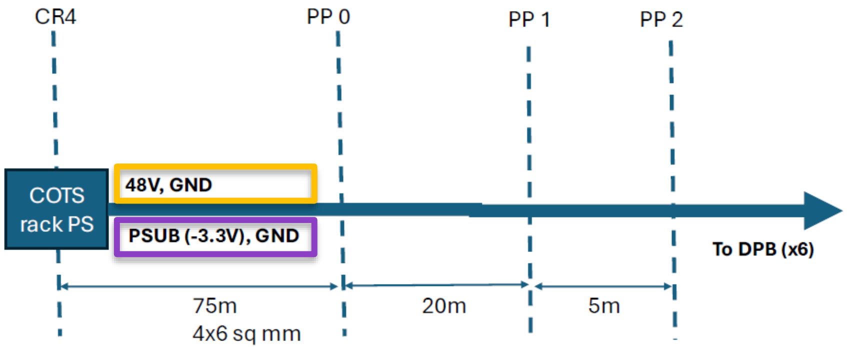
- CAEN A2518 – Obsolete but spares available from ITS2
- Alternative – CAEN 2551

48V to DPB

- CAEN A2554 – a new model received for tests
- Given the characteristics, we can use A2554 also for PSUB

LV cable integration study accomplished and first samples arrived

Under INFN responsibility



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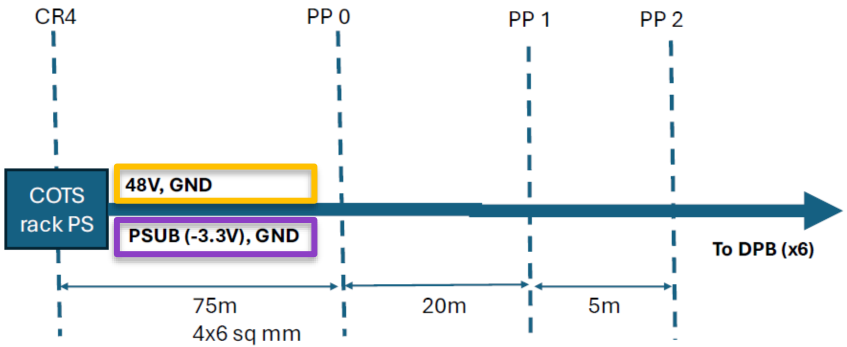

RICHIESTA 2026:
25k€ per power supplies

Financial requests 2026

Capitolo	Descrizione	Importo (kEUR)	Sede
Apparati	ITS3 CORE: contributo a meccanica	30	BA
Apparati	ITS3 CORE: acquisto 3 CRU (18keuro) + Optical cables (40keuro) + Power Supplies (25keuro)	83	CA
Apparati	ITS3 core: contributo alla produzione, caratterizzazione, thinning e dicing del sensore CMOS	60*	CT
Missioni	Partecipazione Beam Tests	59	BA/CT/LNF/PD/TO/TS
Missioni	Richiesta specifica per attività WP6 al CERN	30	CA
Missioni	Richiesta specifica per attività WP6 al CERN	6	PD
Trasporti	ITS3: spedizioni schede, chip ed assemblati	14	BA/CA/CT/LNF/PD/TO/TS
TOTALE		**282 (di cui 173 CORE)**	

*60 kEUR chiesti per il 2025 ma NDB

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Funding plan overview

tipo attività	2021 (k€)	2022 (k€)	2023 (k€)	2024 (k€)	2025 (k€)	2026 (k€)	2027 (k€)	totale richiesta INFN (k€)	totale ITS3 (k€)
R&D	200	300	150 WP3=100 WP4+5=50					700	2500
Costruzione CORE **(assegnato)**			ER2: 250	350* **(340)**	300 **(200.5 + 39.5**)**	100 **+70**	100	1100***	**3901 (MOU)**
Totale								1800	**6400**
Viaggi			50	50	70	**95**			

* 65k€ richiesta straordinaria a settembre 2024
** 39.5 k€ anticipati nel 2024
*** di cui 850 k€ secondo MOU

In grassetto voci aggiornate

Milestones 2024

		Data prevista per il completamento	Descrizione	Completamento al 30.06.2024 (%)	Commenti al 30.06.2024	Completamento al 31.12.2024 (%)	Commenti al 31.12.2024
4	ITS3	30/6/2024	ITS3 1: Partecipazione a beam test con sensori stitched	100	Risultati confermano i buoni risultati di efficienza di rivelazione ottenuti in test beam su test structures di piccola area. Altri test sono previsti nel corso dell'anno per completare la caratterizzazione	100	
5	ITS3	31/12/2024	ITS3 2: verifica performance sensore stitched curvato	30	Ricevuti mandrini high quality e piegato wafer non funzionante	80	Test sui sensori stitched curvati in fase di sviluppo, la veriifca delle performance è stata ritardata a seguito del prolungarsi dei test sui sensori stitched planari
6	ITS3	31/12/2024	ITS3 3: Invio alla fonderia del sensore stitched a grande area versione ER2	40	Disegno validato, ottimizzazioni finali in corso, alla luce di problemi rilevati durante i test su sensori MOSS (ER1)	80	Design del sensore ormai definito, in corso processi di verifica e ottimizzazione, con l'identificazione e la correzione di bug

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Milestones 2024

		Data prevista per il completamento	Descrizione	Completamento al 30.06.2024 (%)	Commenti al 30.06.2024	Completamento al 31.12.2024 (%)	Commenti al 31.12.2024
4	ITS3	30/6/2024	ITS3 1: Partecipazione a beam test con sensori stitched	100	Risultati confermano i buoni risultati di efficienza di rivelazione ottenuti in test beam su test structures di piccola area. Altri test sono previsti nel corso dell'anno per completare la caratterizzazione	100	
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100 %: bonding and bending procedure finalised. Performance studies on ER2 sensors

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Milestones 2024

		Data prevista per il completamento	Descrizione	Completamento al 30.06.2024 (%)	Commenti al 30.06.2024	Completamento al 31.12.2024 (%)	Commenti al 31.12.2024
4	ITS3	30/6/2024	ITS3 1: Partecipazione a beam test con sensori stitched	100	Risultati confermano i buoni risultati di efficienza di rivelazione ottenuti in test beam su test structures di piccola area. Altri test sono previsti nel corso dell'anno per completare la caratterizzazione	100 **100 %: bonding and bending procedure finalised, Performance studies on ER2 sensors**	**~100% imminent submission (July 2025)**
5	ITS3	31/12/2024	ITS3 2: verifica performance sensore stitched curvato	30	Ricevuti mandrini high quality e piegato wafer non funzionante	80	Test sui sensori stitched curvati in fase di sviluppo, la veriifca delle performance è stata ritardata a seguito del prolungarsi dei test sui sensori stitched planari
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Milestones 2025

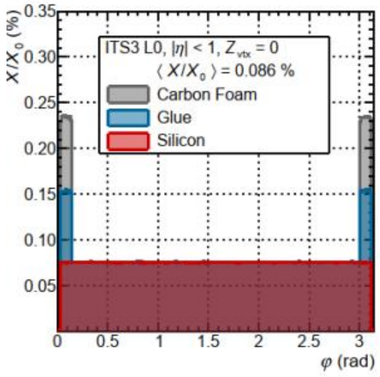
		Data prevista per il completamento	Descrizione	Completamento al 30.06.2025 (%)	Commenti al 30.06.2025	Completamento al 31.12.2025 (%)	Commenti al 31.12.2025
ITS 3	26	31/3/2025	Validazione sistema readout	20	Ricevuti i primi prototipi, test di validazione iniziati		
ITS 3	27	31/12/2025	Prima caratterizzazione di sensori MOSAIX	20	Sottomissione ER2 posticipata in base a nuova schedula LHC e arrivo dei sensori prevista a fine 2025. Sistemi di test validati e in fase di distribuzione		

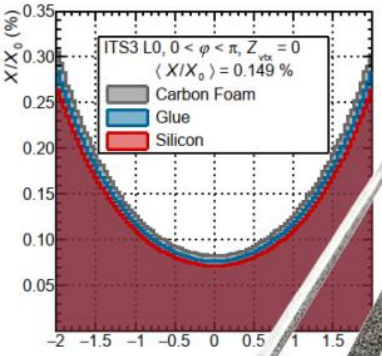
Milestones 2026

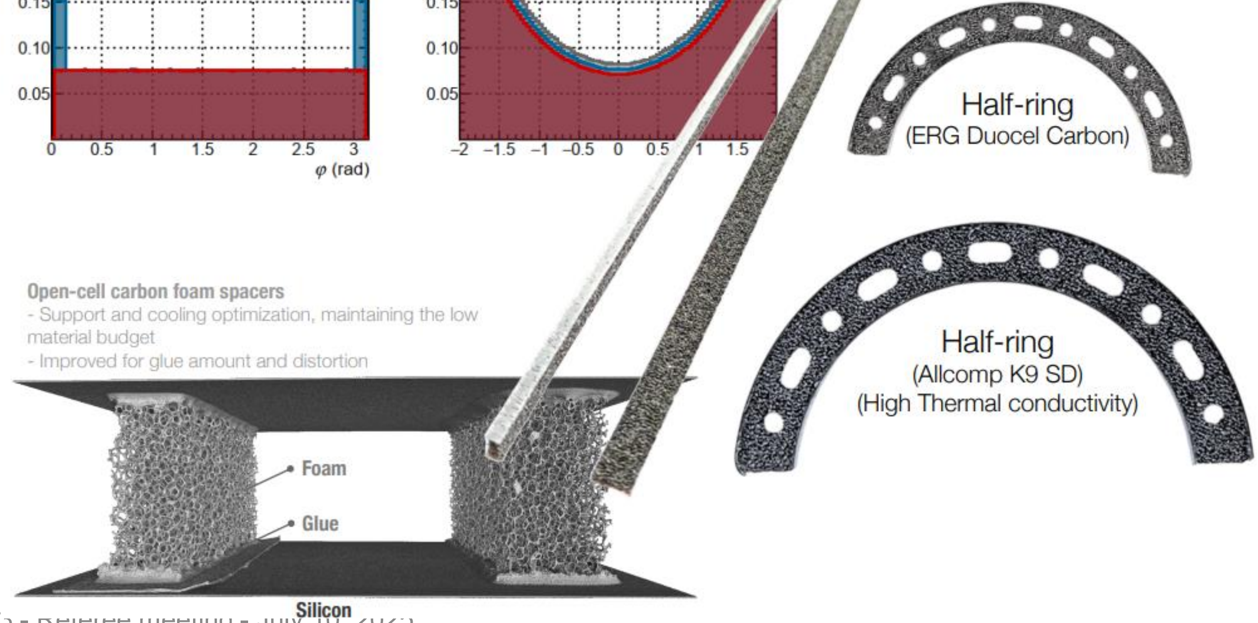
		Data prevista per il completamento	Descrizione	Completamento al 30.06.2026 (%)	Commenti al 30.06.2026	Completamento al 31.12.2026 (%)	Commenti al 31.12.2026
ITS 3		31/12/2026	Verifica resistenza bonding soggetto a flusso d'aria				
ITS 3		31/12/2026	Realizzazione Qualification Model				
ITS 3		31/12/2026	Definizione e prima implementazione della User Logic della CRU				
ITS 3		31/03/2026	Definizione schema fibre ottiche e scelta alimentatori				
ITS 3		31/12/2026	Caratterizzazione di sensori MOSAIX				

Backup slides

Mechanics – Carbon Foam







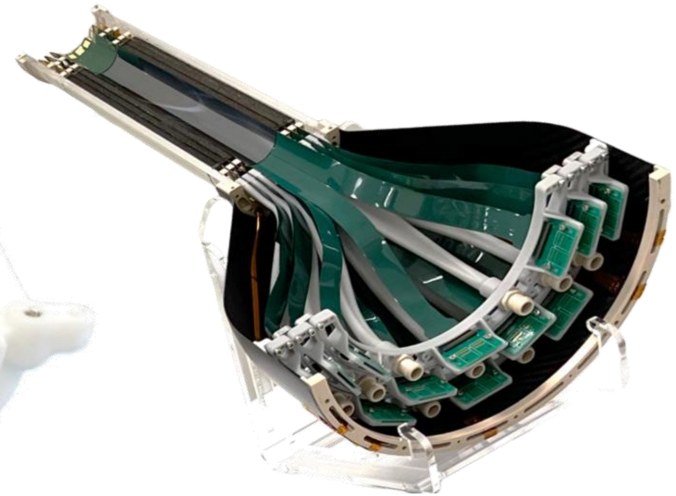
Mechanics – Engineering Model (EM)

Prototypes for layout, assembly and installation procedures validation

- 3 Ems completed + EM4 ongoing

EM1

EM2



EM3

MOSS Region variations

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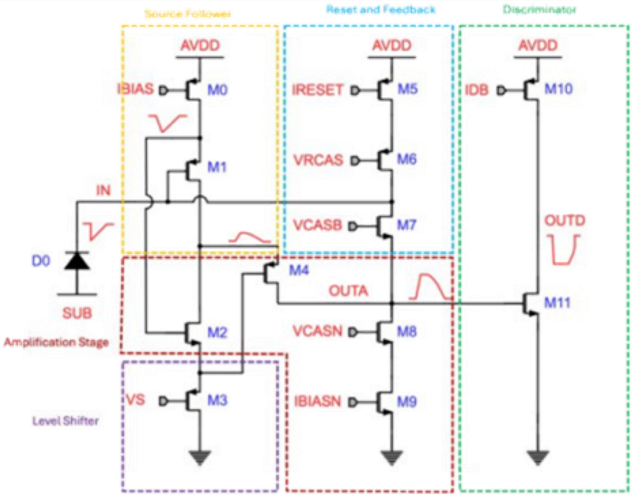
	Region 0	Region 1	Region 2	Region 3
TOP	Standard	Larger input transistor (M1)	Larger discriminator input transistor (M11)	Larger common-source transistor (M2)
BOTTOM	Standard	Standard	Standard	Slightly different layout

- Top region 1: Larger M1
  - less 1/f noise → less noisy pixels at larger thresholds
  - larger input C → worse S/N
- Top region 2: Larger L of M11
  - smaller threshold dispersion
  - larger capacitance OUTA → lower gain → worse S/N
- Top region 3: Larger W of M2
  - larger gain
  - Could push M1 out of saturation
- Bottom region 3: Smaller feedback capacitance
  - larger gain
  - more ringing



MOSS – testing campaign

Before picking and bonding on carrier:
- **Wafer-probing**

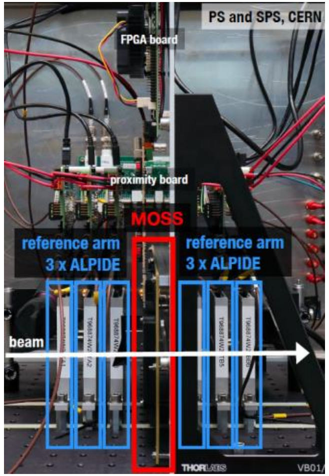
In laboratory, 3 main steps:
- **Impedance** tests between power nets
- **Power ramp** (slowly by domain)
- **Functional tests**

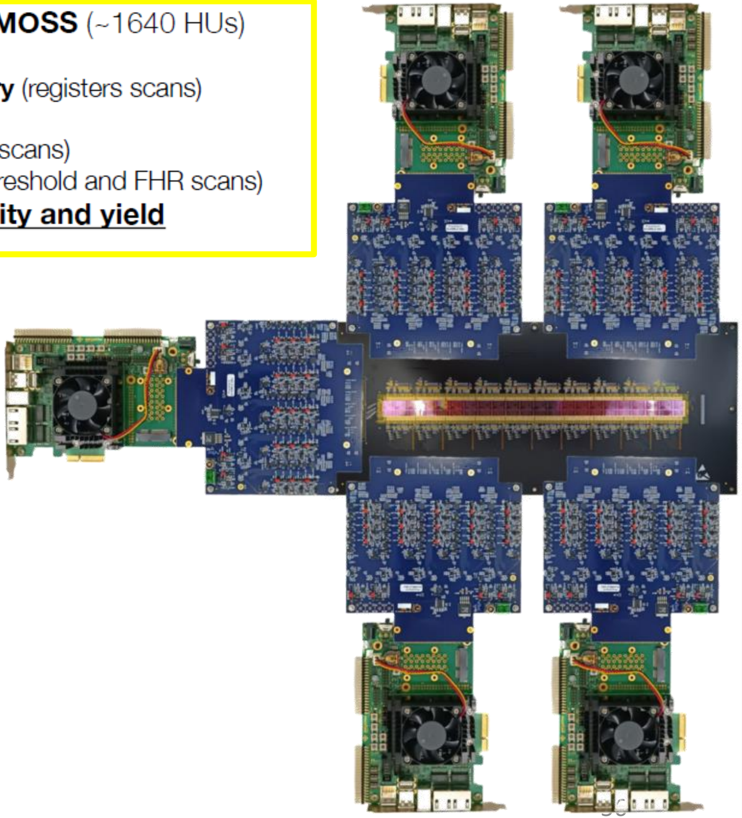
In **beam test**:
- detection efficiency and Fake-Hit Rate (FHR)

In **beam test**:
- detection efficiency and Fake-Hit Rate (FHR)
  - ~**80 days of data-taking** last year on several sensors (~17)

Several functional tests on all **82 MOSS** (~1640 HUs)
- **Power on** to check currents
- **Slow control and digital circuitry** (registers scans)
- **Analog biasing** (DAC scan)
- **Matrix readout** (digital, analogue scans)
- **Analog matrix performance** (threshold and FHR scans)

→ to get **performance, uniformity and yield**

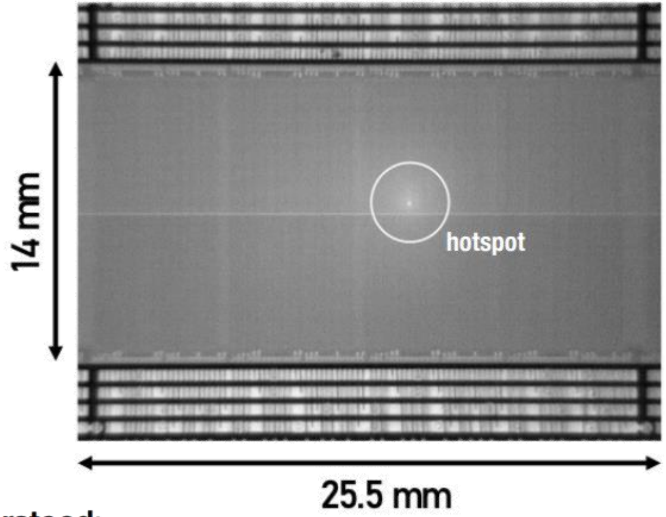


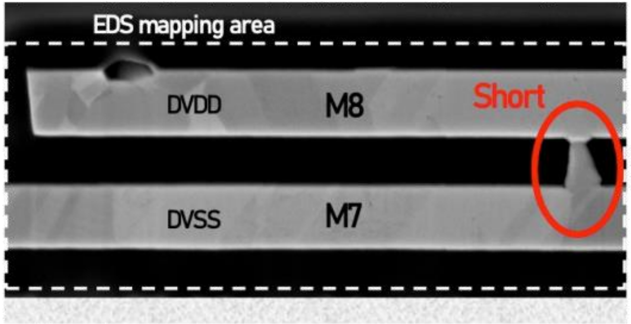


MOSS – power ramp

Large number of **shorts** observed during ramping:
- **Hotspot** appear
- Often they **disappear** (after some time or voltage)
- Position reconstructed O(50-100 μm)

1 RSU, thermal camera image

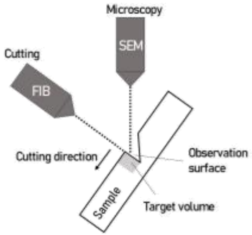




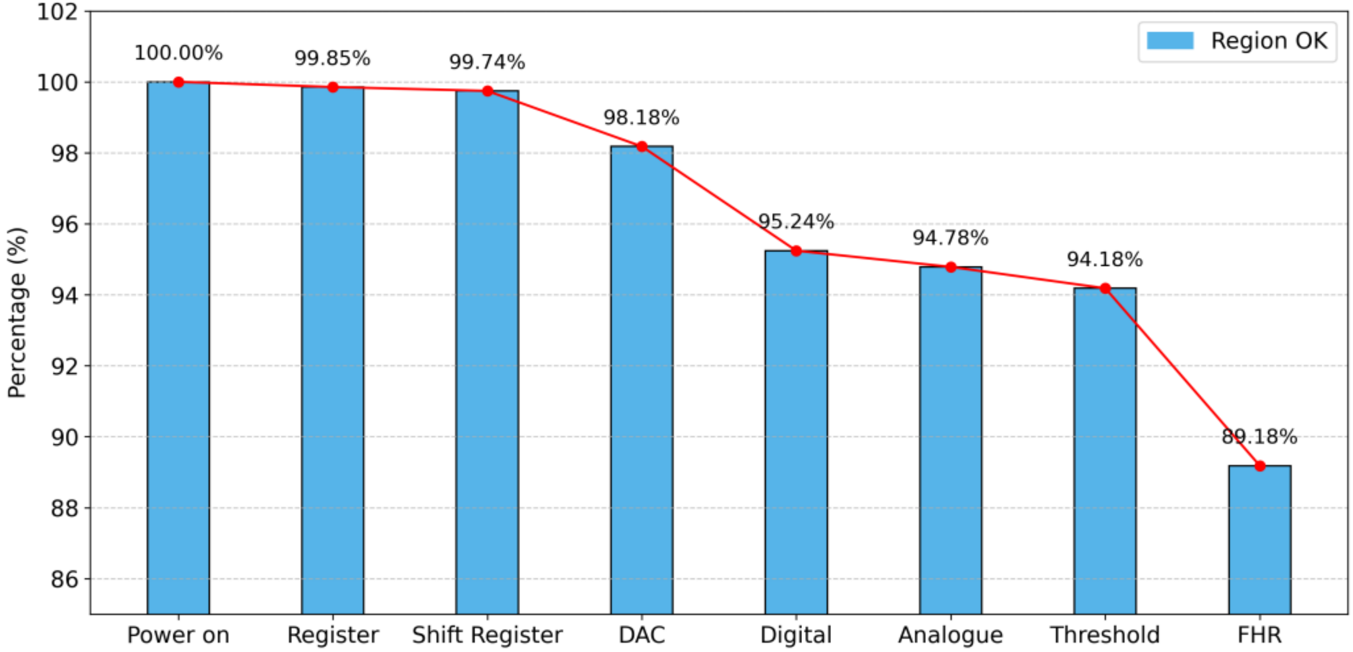
SEM (Scanning Electron Microscopy) cross section of the top two metal layers

Reason **understood**:
- Correlated with crossing of metal lines on the top two metal
- Communicated to foundry that confirmed the issue → will be fixed for future sensors

→ **Very important finding for yield next submission!**

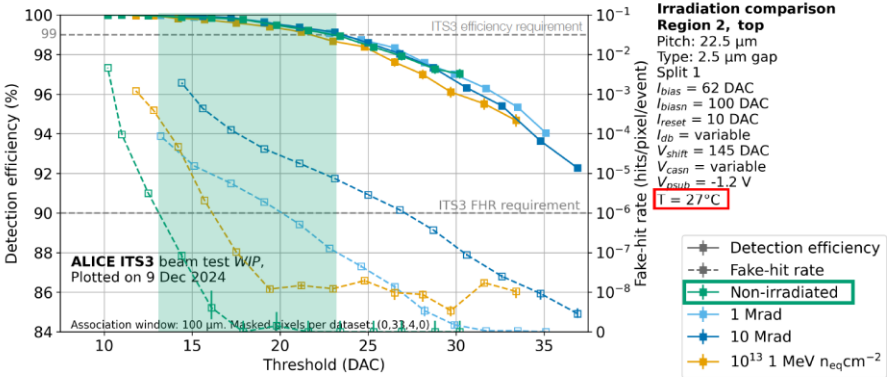


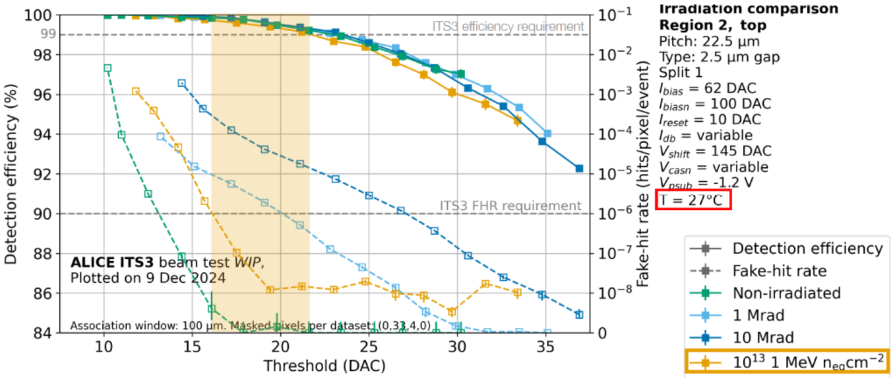
MOSS – Functional tests - Yield

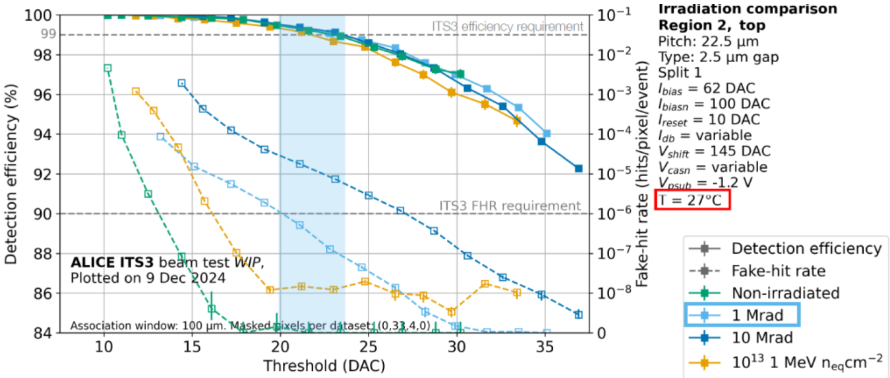


- Yield ~ 89 %
  - ~98% excluding readout architecture issues (not relevant for future MOSAIX)

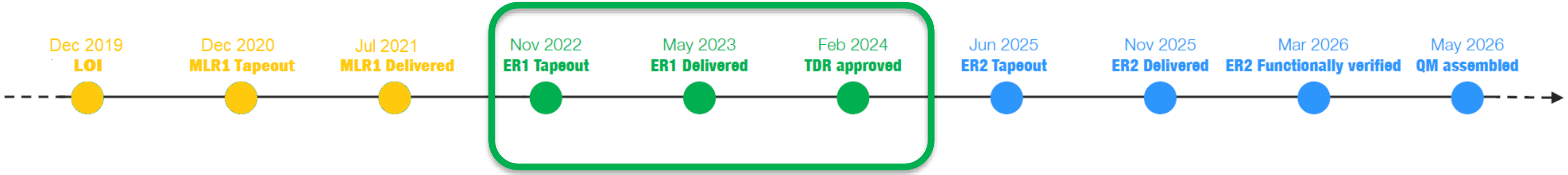
ER1 (Engineer Run 1): radiation tolerance studies





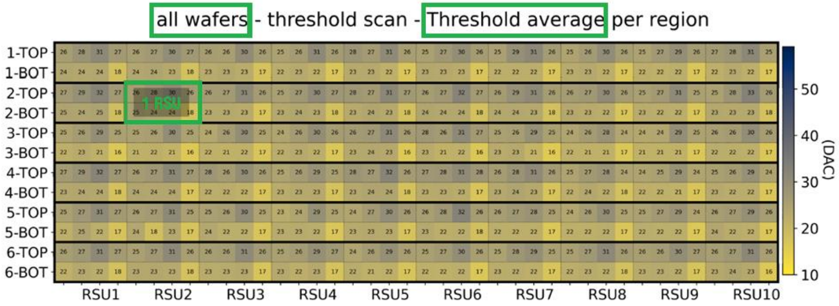


ER1 (Engineer Run 1): first stitched MAPS



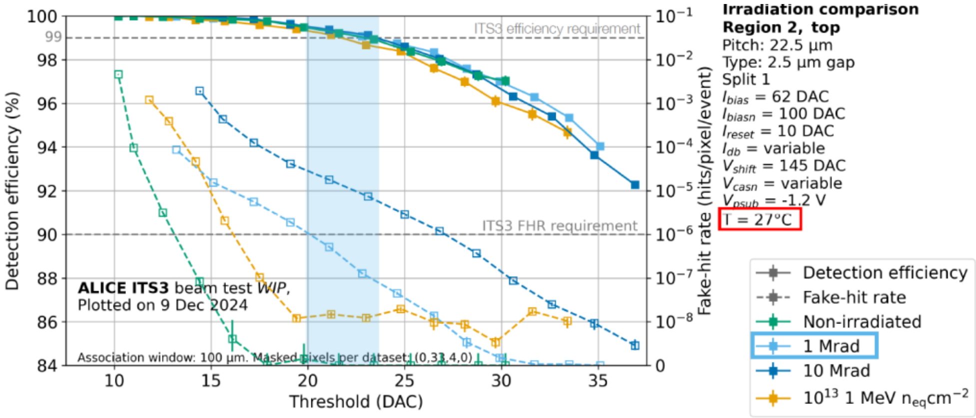
MOSS - functional tests

- Several functional tests on all 82 MOSS
  - Yield ~89 % (~98% excluding readout issues)
- Good performance and uniform behavior
  - NO wafer or sensor position dependence



Beam test results

- Operational margin à confirmed performance from previous submissions



ER1 (Engineer Run 1): first stitched MAPS

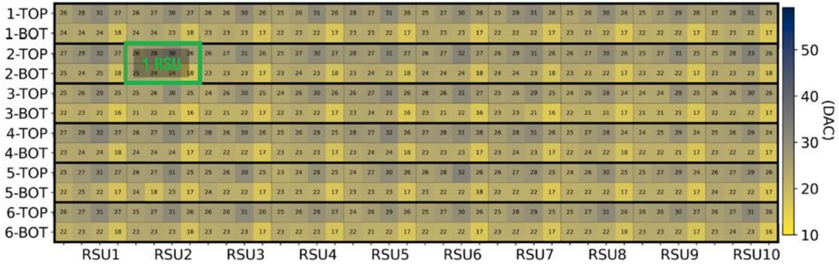
ALICE

Dec 2019 **LOI** — Dec 2020 **MLR1 Tapeout** — Jul 2021 **MLR1 Delivered** — Nov 2022 **ER1 Tapeout** — May 2023 **ER1 Delivered** — Feb 2024 **TDR approved** — Jun 2025 **ER2 Tapeout** — Nov 2025 **ER2 Delivered** — Mar 2026 **ER2 Functionally verified** — May 2026 **QM assembled**

MOSS - functional tests

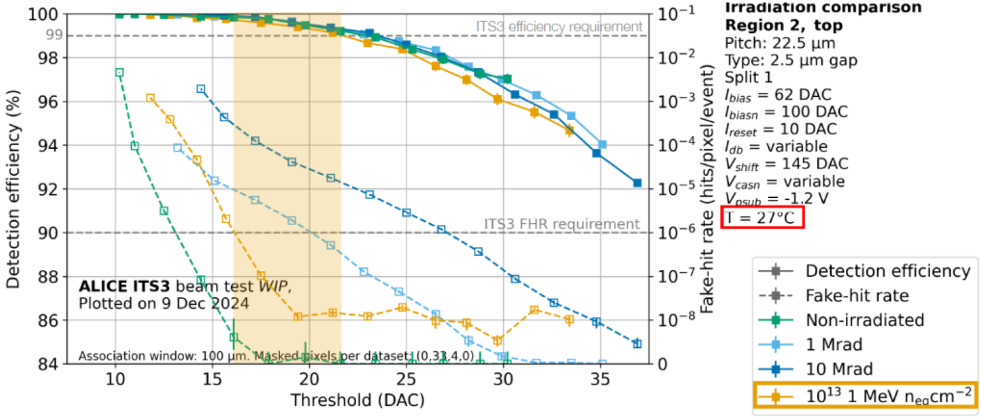
- Several functional tests on all 82 MOSS
  - Yield ~89 % (~98% excluding readout issues)
- Good performance and uniform behavior
  - NO wafer or sensor position dependence

all wafers - threshold scan - Threshold average per region



Beam test results

- Operational margin à confirmed performance from previous submissions



ER2 - specification

Simulation parameters	Value	Unit	Conditions
Particle Rates			
Pb-Pb Interaction Rate	164	kHz	Safety factor 2
Particle flux (Hadronic)	2.55	$\mathrm{MHz\,cm^{-2}}$	z=0 cm, all centralities.
Particle flux (QED)	3.20	$\mathrm{MHz\,cm^{-2}}$	z=0 cm.
Total particle flux	5.75	$\mathrm{MHz\,cm^{-2}}$	z=0 cm, all centralities.
Geometry, timing, encoding, data transfer capacity			
Pixel dimensions	20.8×22.8	$\mu m \times \mu m$	
Tile pixel array size	442×156		
Pixels per Tile	68952		
Sensitive Area of the tile	0.328	$\mathrm{cm^2}$	
Tiles per segment	144		
Readout regions per tile	3 or 4		
Frame Interval Duration (FD)	2 or 5	µs	
Minimum average cluster size	2.1		$\Delta z = 0\,\mathrm{cm}$, Fig. 3.43.
Pixel hit encoding time	25	ns	
Bits per pixel hit	16	bit	
Capacity of tile link	160	$\mathrm{Mbit\,s^{-1}}$	
Aggregated capacity (Segment)	23.04	$\mathrm{Gbit\,s^{-1}}$	
Simulation results			
Average pixel occupancy	$< 2.0 \times 10^{-4}$		z=0 cm.
Average pixel occupancy	$< 5.0 \times 10^{-4}$		z=0 cm, FD=5 µs.
Data throughput	120	$\mathrm{Mbit\,s^{-1}\,Tile^{-1}}$	z=0 cm.
Data throughput	15.55	$\mathrm{Gbit\,s^{-1}\,Segment^{-1}}$	
Data throughput per unit area	365	$\mathrm{Mbit\,s^{-1}\,cm^{-2}}$	z=0 cm.
Data throughput per unit area	329	$\mathrm{Mbit\,s^{-1}\,cm^{-2}}$	Average over z.
Data throughput per link	2.58	$\mathrm{Gbit\,s^{-1}}$	
Incomplete event probability	$< 6 \times 10^{-5}$		Layer 0 segment.
Incomplete event probability	$< 2 \times 10^{-4}$		Full layer 0.

ER2 – MOSAIX variants

144 power units, can be powered/tested independently

Per each RSU
- 12 different pixel variants to fine tune operational margins
  - 3 front-end circuit variation to improve S/N
  - 1 (antenna) to mitigate degradation with processing
  - 2 biasing variants, to reduce temperature sensititvity
- In addition → different splits to increase operational margin

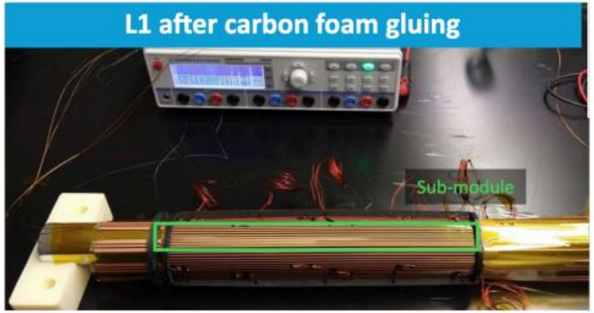
RSU

Baseline Biasing	Small input (-40%), with diodes	Standard (Baseline), with diodes	Standard (Baseline)	Small Input and Longer VCASB transistor	Small Input (-40%) and Longer VCASB transistor, with diodes	Longer VCASB transistor, with diodes
Biasing with Temperature Compensation	Standard (Baseline)	Small input (-40%)	Longer VCASB (+150%)	Small Input and Longer VCASB transistor	Small Input (-40%) and Longer VCASB transistor, with diodes	Longer VCASB transistor, with diodes

Qualification Model

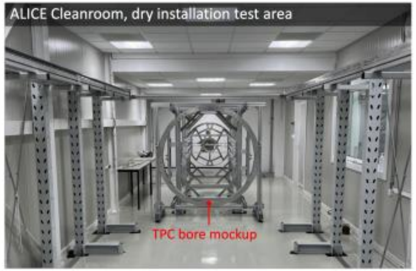
At the half-layer level

Before integration, and after wire bonding and carbon foam gluing, individual electrical testing.



At the half-detector level

Thermal and aeroelastic assessment using the wind tunnel setup at the ALICE Mechanics Lab.



At the detector barrel level

Installation and final cooling strategy assessment (thermal & vibrational aspects) with QMs in the ALICE Cleanroom