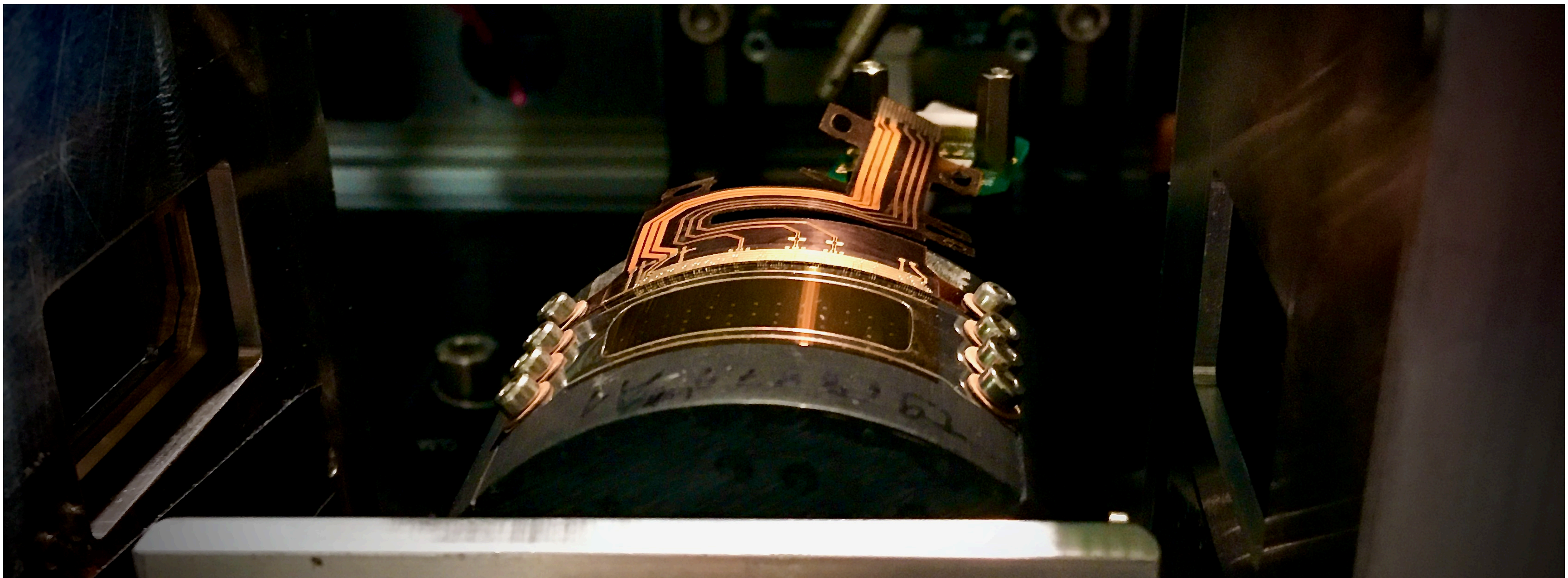
Congresso INFN 2022
Bari, 3-4 February 2022

Silicon trackers for CMS and ALICE

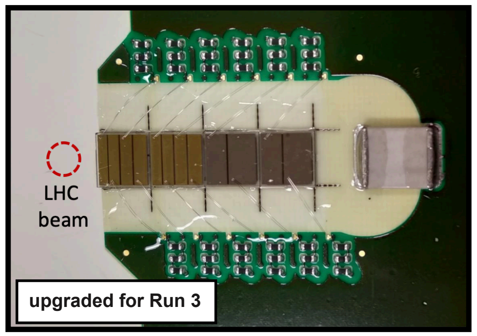


Bent ALPIDE silicon pixel sensor under investigation in a beam test setup. (Courtesy of ALICE ITS project)

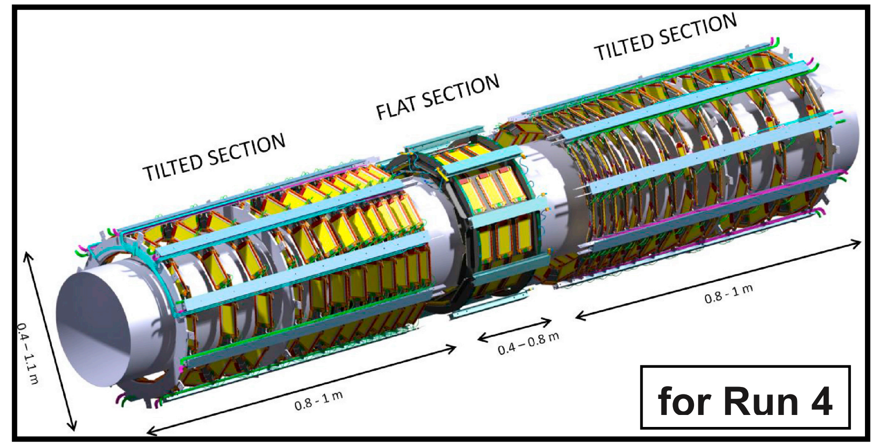
Domenico Colella
Politecnico and INFN Bari

LHC schedule and silicon tracker upgrades

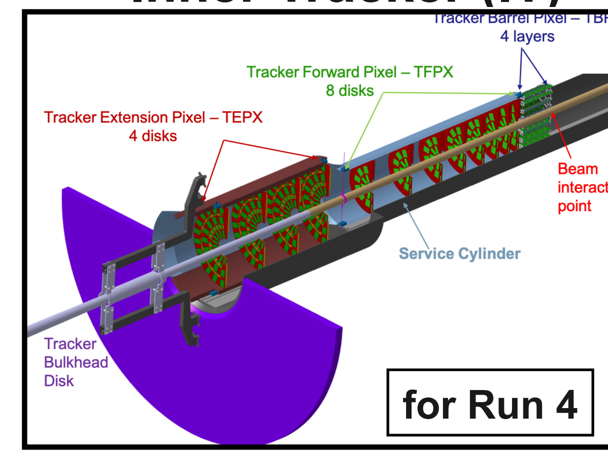
CMS-TOTEM
Precision Proton Spectrometer

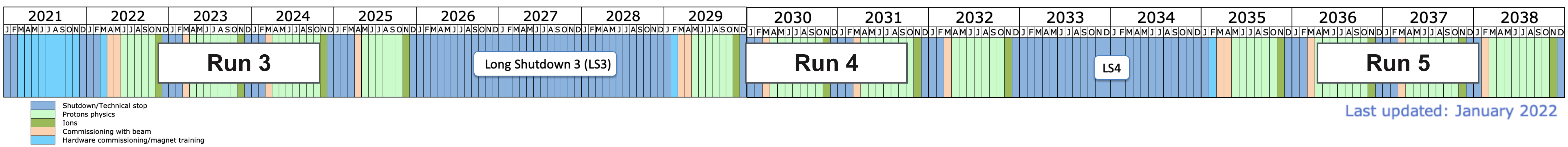


Outer Tracker (OT)

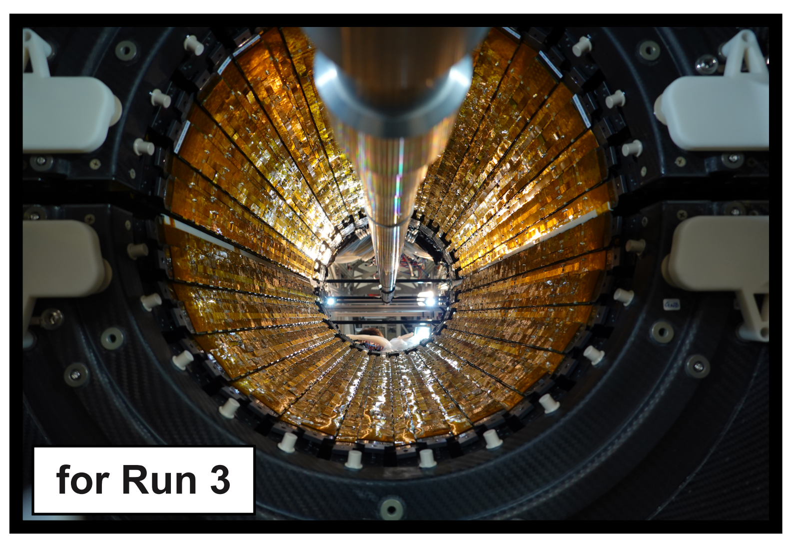


Inner Tracker (IT)

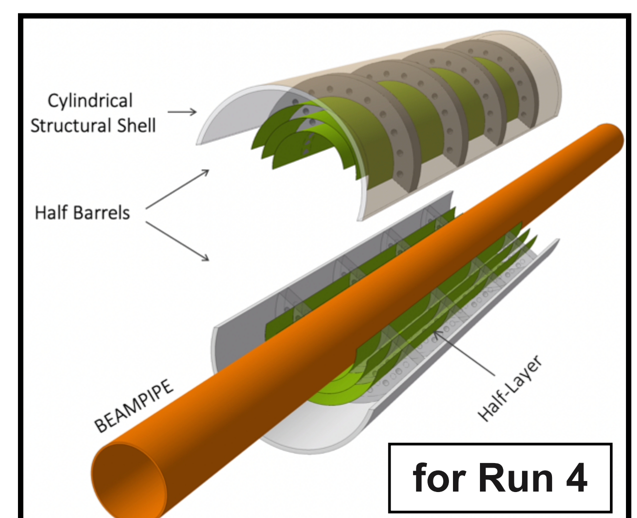




Inner Tracking System Upgrade (ITS2)



ITS3



CMS tracker upgrade for the HL-LHC

High Luminosity LHC

- Instantaneous luminosity: $5 - 7.5 \times 10^{34}\, cm^{-2} s^{-1} \rightarrow$ **High pileup** $(140 - 200)$
- Integrated luminosity: $3 - 4\, ab^{-1} \rightarrow$ **High irradiation** $(2 \times 10^{16}\, n_{eq}/cm^2)$

$\downarrow$

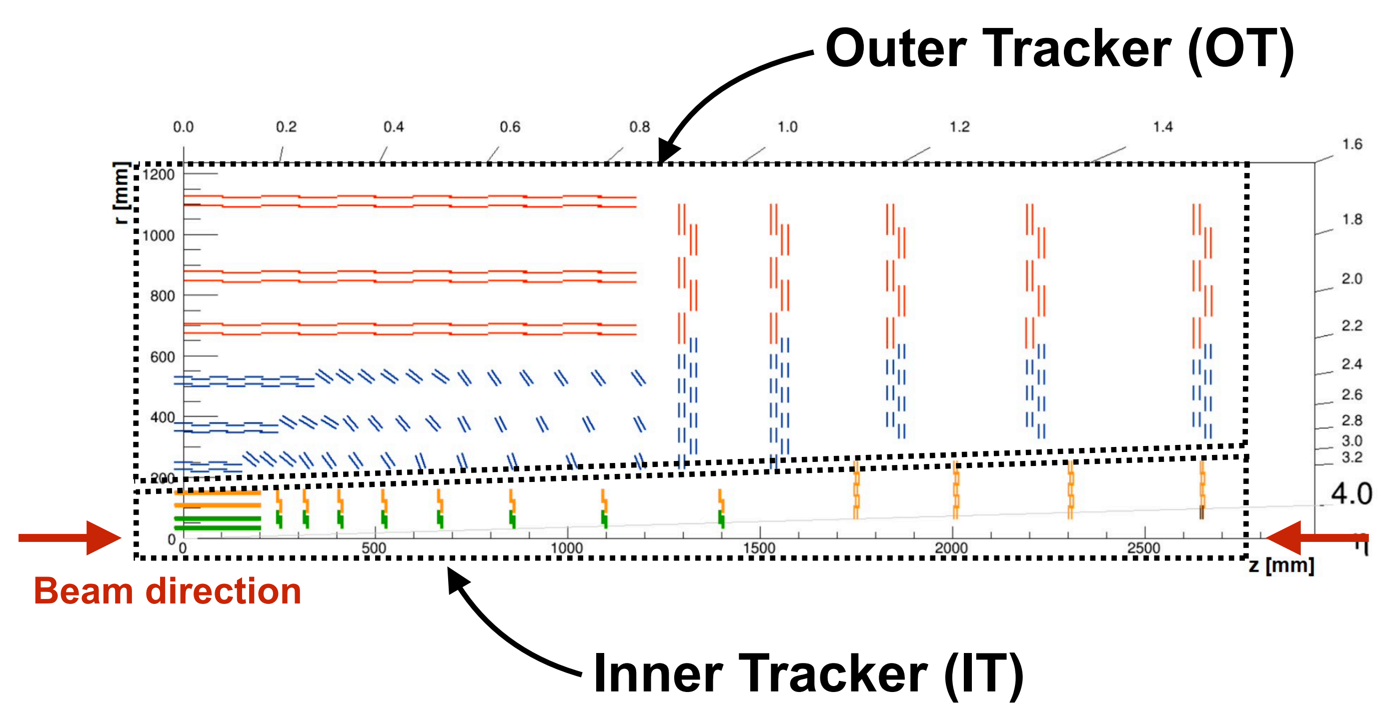
Current CMS Outer Tracker and Pixel Detector
will not survive the HL-LHC radiation conditions

$\downarrow$

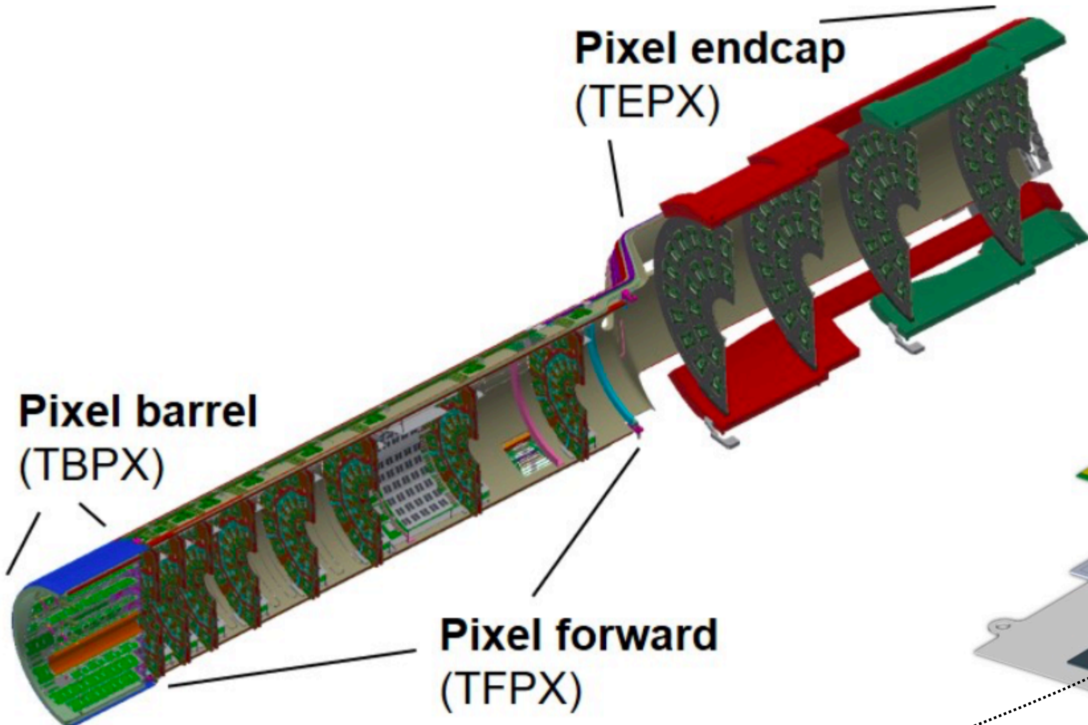
CMS Phase-2 upgrade

Requirements

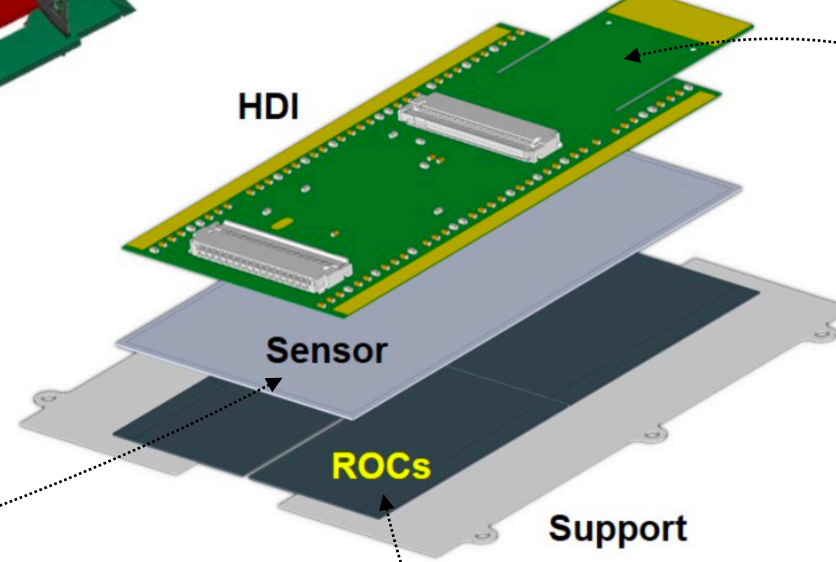
1. **Enhanced radiation tolerance**: sustaining a Total Integrated Dose (TID) up to ten times larger
2. **Ability to participate in first level trigger (L1) decisions**
3. **Higher granularity** in order to keep the channel occupancy below 1%
4. **Extended tracking coverage** (up to |η| = 4)
5. **Reduced material budget** for improved tracking performance



CMS tracker - Inner Tracker (IT)



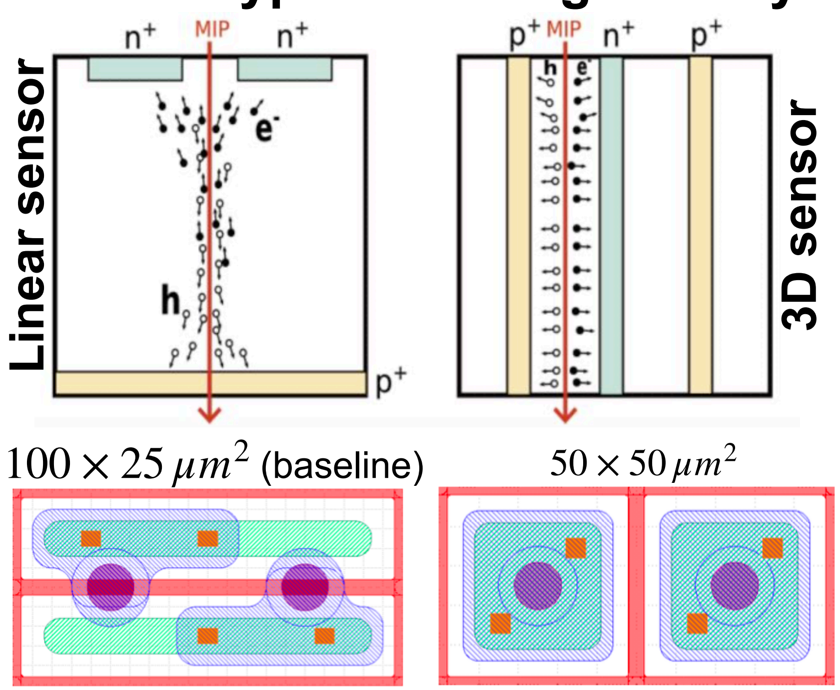
Hybrid pixel module



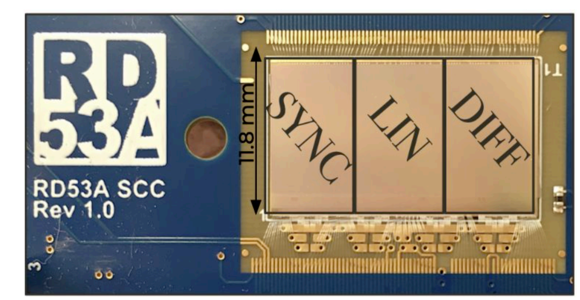
High-Density Interconnect

- Distribute signal and power to/ from module
- Contains only passive components

Sensor type and cell geometry



RD53 Collaboration development



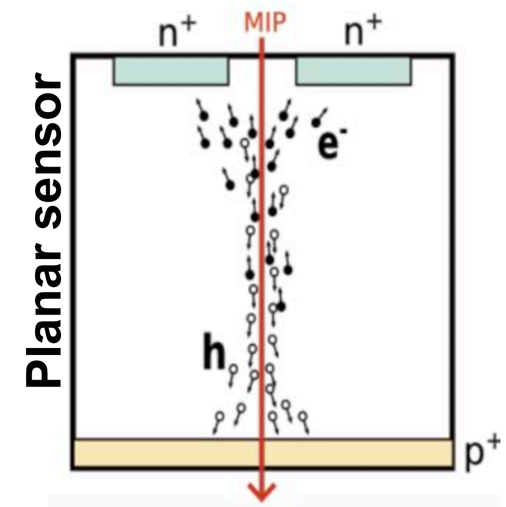
- Dead time ≤ 1% at $3.2\, GHz/cm^2$
- 0.5 Grad TID resistant
- 65 nm technology
- Pixel size $50 \times 50\, \mu m^2$
- Low threshold (≤ 1000 e^-)
- High hit and trigger rate (up to $4 \times 1.28\, Gb/s$ output links)
- CMS chip size $16.8 \times 21.6\, mm^2$
- First prototype RD53A
  - ½ total size of the final chip
  - 3 different analog front-end designs (Synchronous, Linear, Differential)
  - Compatible for the capacitance of both planar and 3D sensor
  - Time over Threshold counter to measure charge (4-bits)

→ dedicated talk by F. Loddo later today

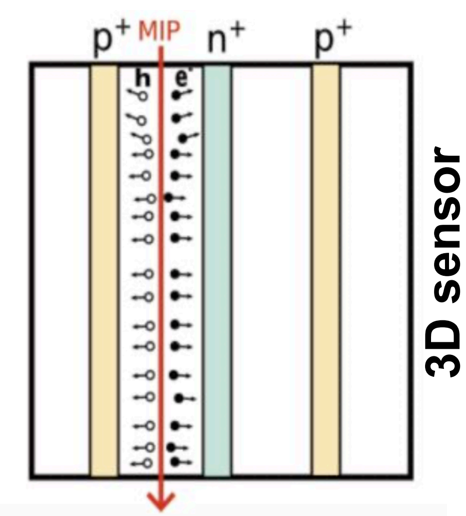
CMS tracker - Inner Tracker (IT)

- R&D project plan: design of thin, radiation tolerant, small pitch pixel sensors
- From 2015 several R&D submissions of prototype by HPK, FBK and CNM

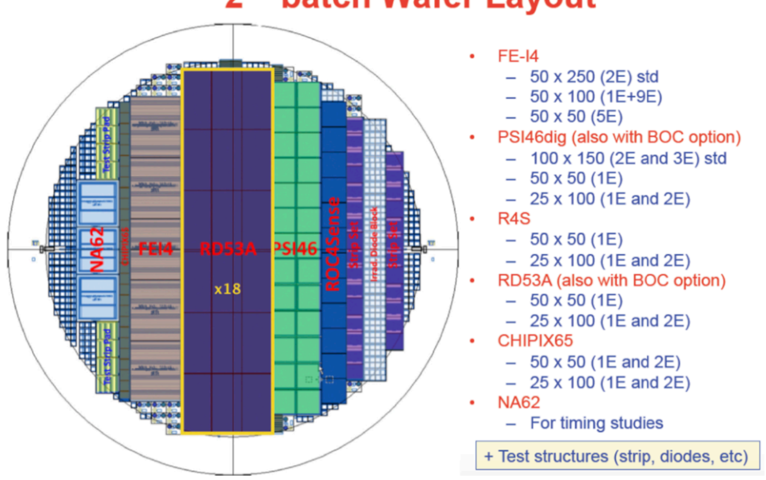
Planar Active Edge sensor
- Planar n-in-p pixel sensor
- Active edge technology
- Low active thickness
- Pixel size reduced by a factor 6.
- Two pixel cells: $50 \times 50\, \mu m^2$ and $100 \times 25\, \mu m^2$

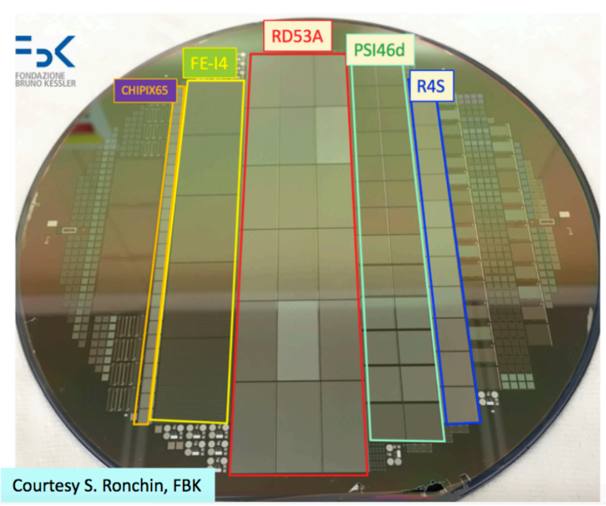


3D sensor
- Drift path perpendicular to the active depth: short drift distance
  3D sensor 30-50 μm vs planar sensor 100-150 μm
- Advantages vs plane sensors:
  - smaller bias sensor needed for efficient charge collection
  - less trapping expected in irradiated sensors

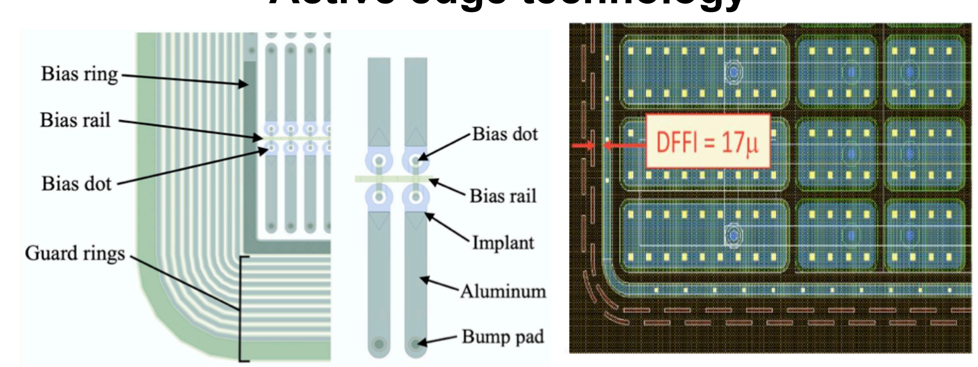


2nd batch Wafer Layout



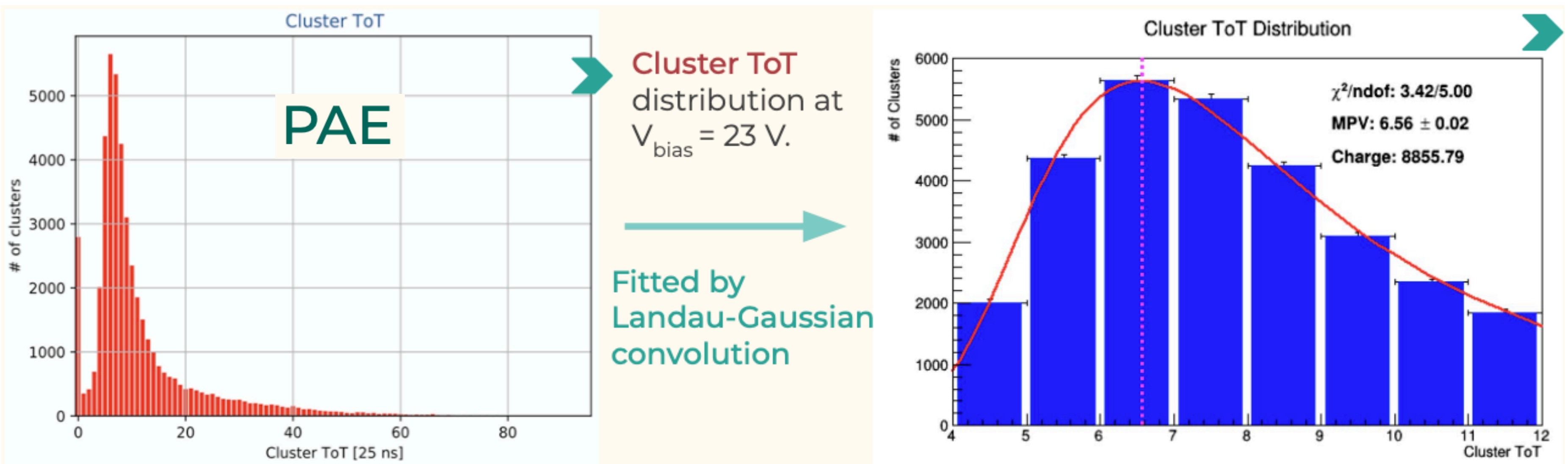


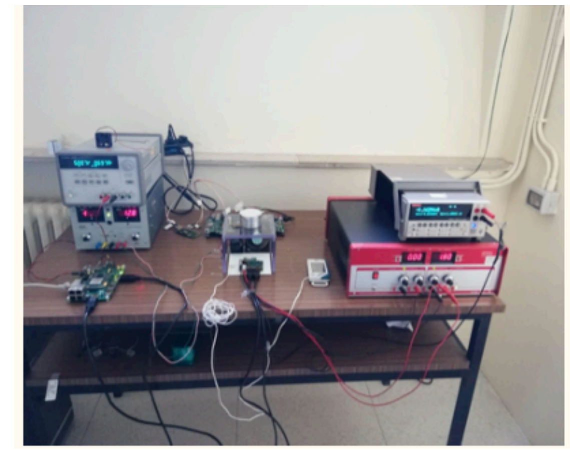
Active edge technology



CMS tracker - Inner Tracker (IT)

- <u>Activity done by a XXXII Cycle Ph.D. student</u>
- Charge collection efficiency study for sensors developed by INFN-FBK R&D
  - Planar AE (PAE) and 3D sensors investigated and compared
  - Usage of Sr-90 radioactive source and time-over-threshold technique
  - ToT signal measured in neighbouring pixels are clustered





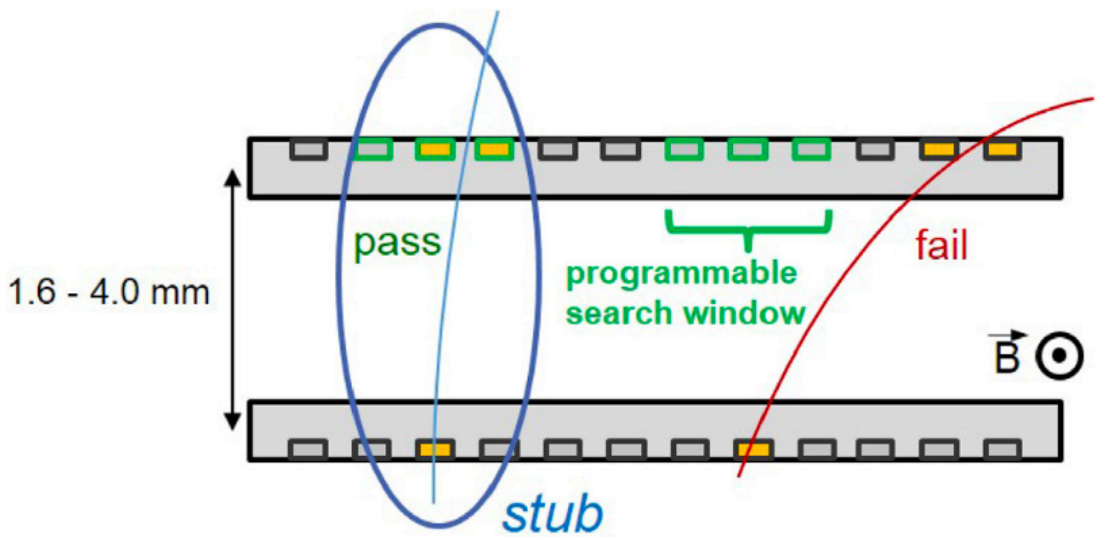
The collected charge is ~8856 e^- which translates to ~68 e^-/μm for the 130 μm sensor thickness.

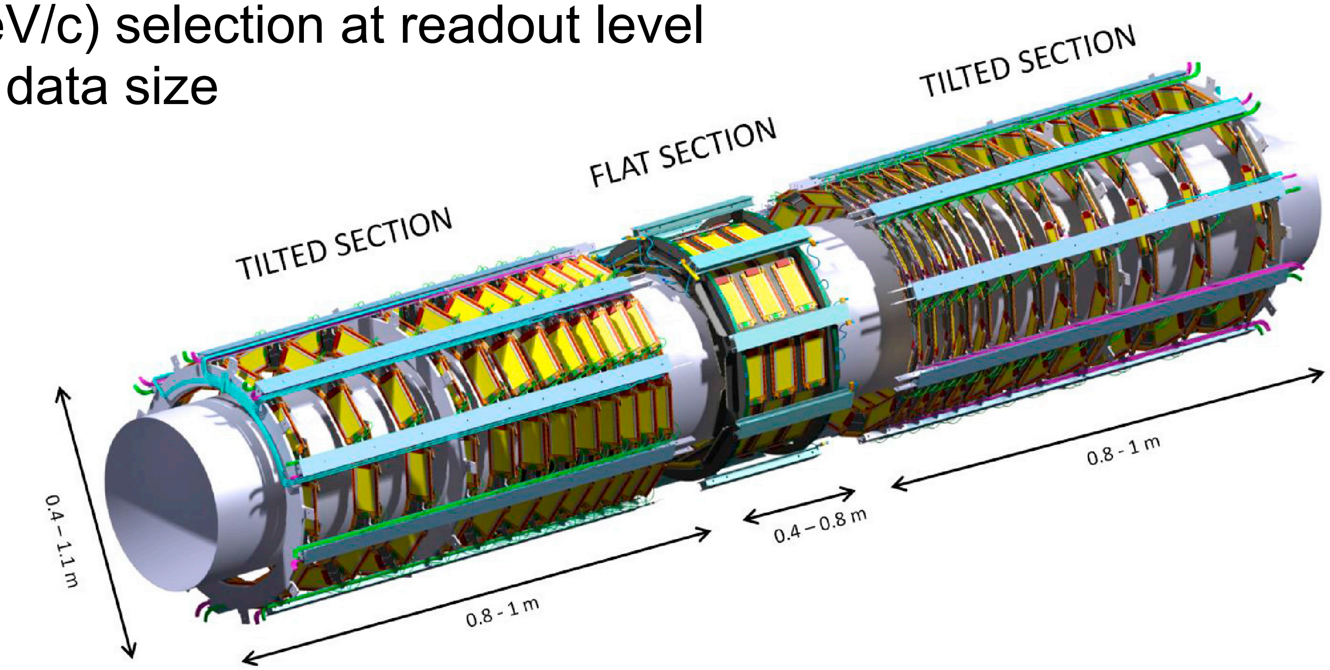
Compatible with expectations.

- Conclusions
  - The collection charge differences is around ~5% between 3D and PAE sensors for the same active and total thickness (130 and 200 μm, respectively)
  - Charge collection is penalised in the thicker 3D sensor (handle wafer thickness of 500 μm vs 70 μm)
  - The 3D sensor reach the plateau at Vbias ~ 5 V, while PAE sensor at Vbias ~ 20 V
  - In 3D pixel sensors the short inter-electrode distance and the lower operational bias voltage give an important advantage over the standard planar pixel sensors before and after irradiation
  - 3D sensor are safely operated with a large margin with respect to the depletion voltage. This is needed because of the fact that the upgraded CMS detector will be powered according to a serial powering scheme with up to eight modules in a serial chain.

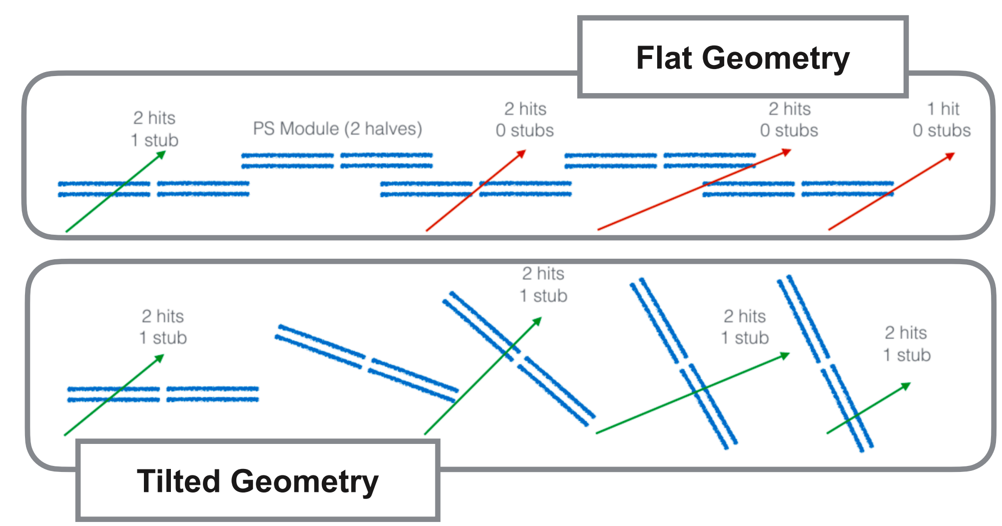
CMS tracker - Outer Tracker (OT)

- Given the high instantaneous luminosity during HL-LHC it is fundamental to keep data rate under control (more selective at L1 trigger)
- Most of charged particles have low p_T
- **Outer Tracker (OT)** must perform a p_T (> 2-3 GeV/c) selection at readout level (40 MHz) in order to reduce the L1 tracking input data size



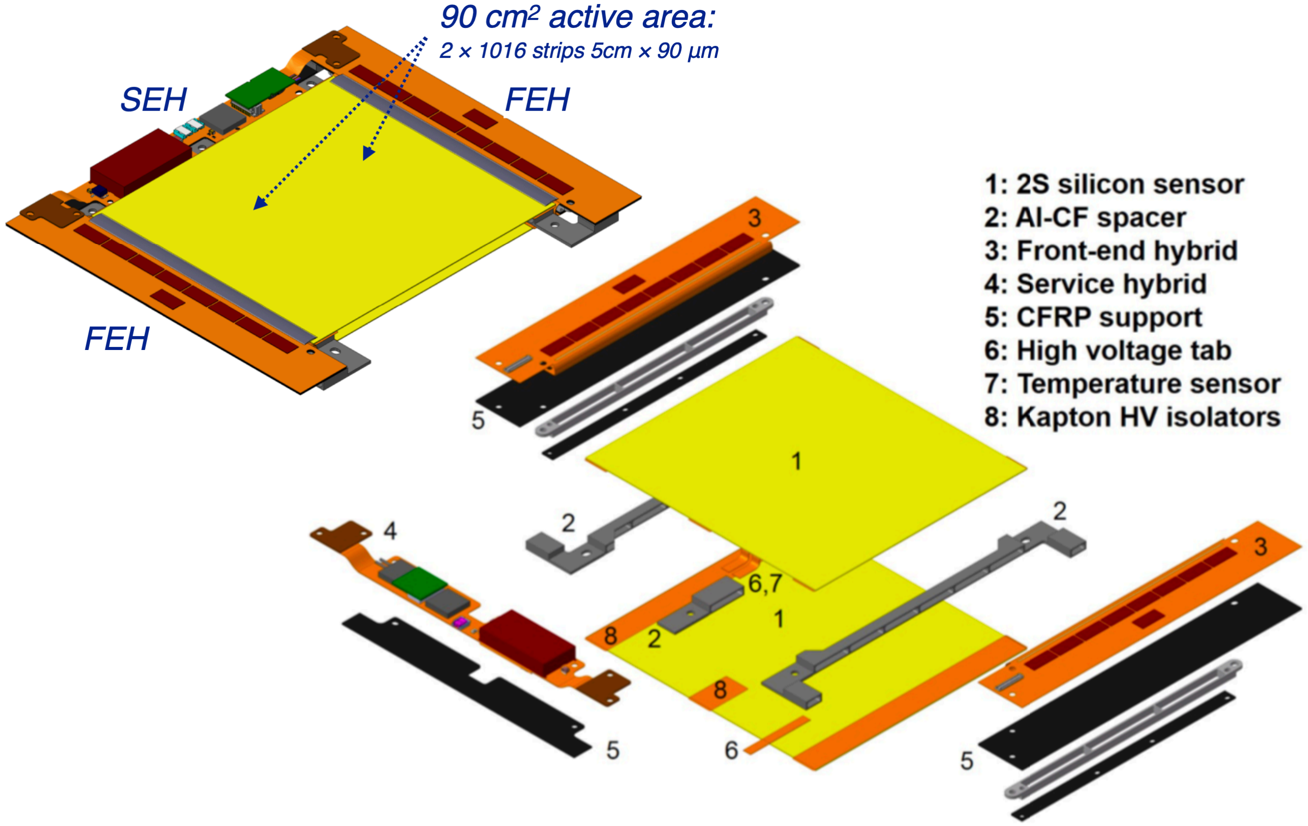


- OT module with **hardware integrated trigger**
  - Two parallel silicon sensors separated by few mm
  - Flex hybrid to get data from both sensors to one ASIC and **select track "stubs"**
  - Different sensor spacing for different detector region
  - Tunable correlation windows
  - Two geometrical configurations: *flat* and *tilted*
    - remove acceptance reduction due to not formed stubs (hits on uncorrelated module halves)
    - sizeable reduction of needed modules



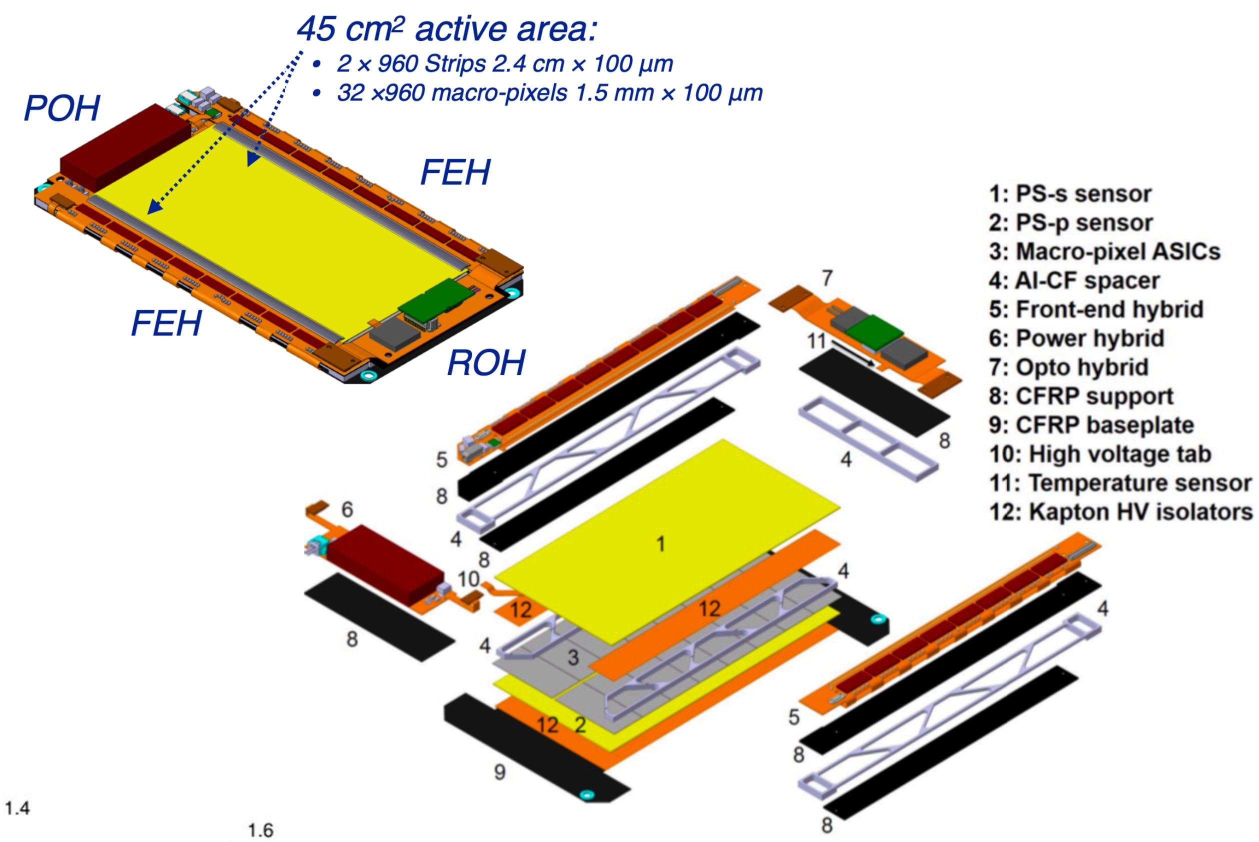
CMS tracker - Outer Tracker (OT)

Strip-Strip (2S) module

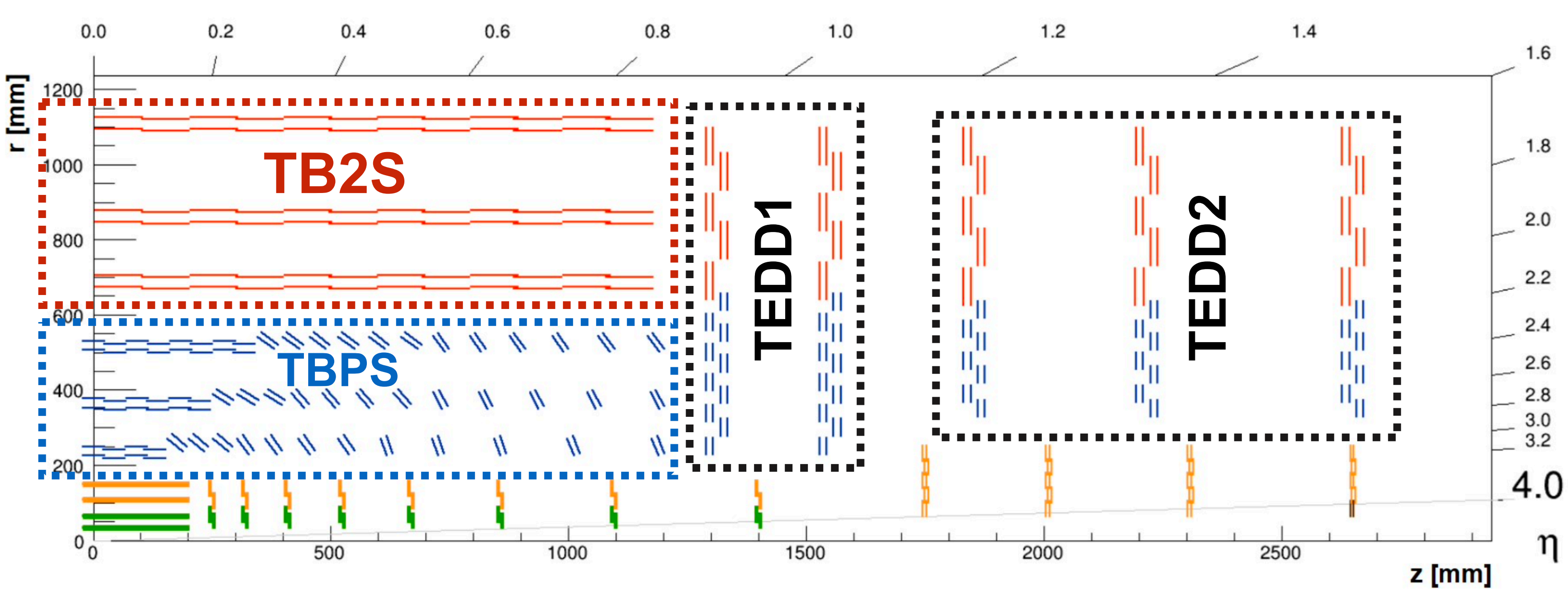


1: 2S silicon sensor
2: Al-CF spacer
3: Front-end hybrid
4: Service hybrid
5: CFRP support
6: High voltage tab
7: Temperature sensor
8: Kapton HV isolators

Pixel-Strip (PS) module



1: PS-s sensor
2: PS-p sensor
3: Macro-pixel ASICs
4: Al-CF spacer
5: Front-end hybrid
6: Power hybrid
7: Opto hybrid
8: CFRP support
9: CFRP baseplate
10: High voltage tab
11: Temperature sensor
12: Kapton HV isolators

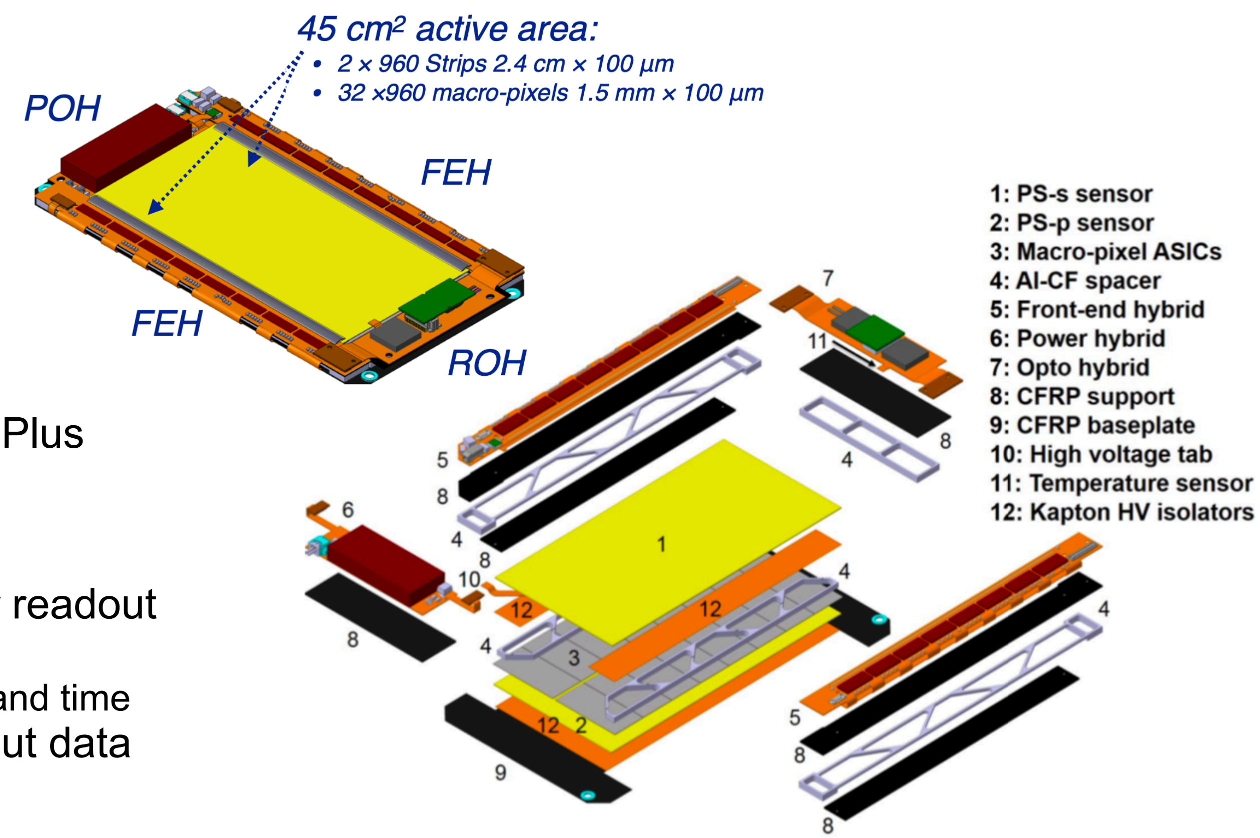


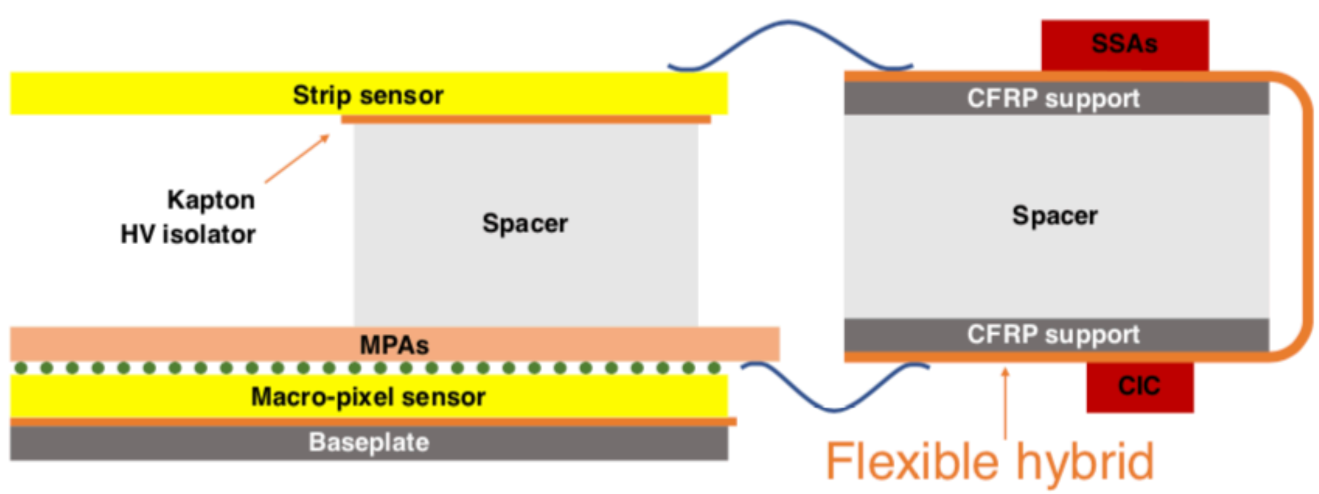
TBPS - Tracker Barrel with PS modules
TB2S - Tracker Barrel with 2S modules
TEDD - Tracker Endcap Double Disk

CMS tracker - Outer Tracker (OT)

Pixel-Strip (PS) module

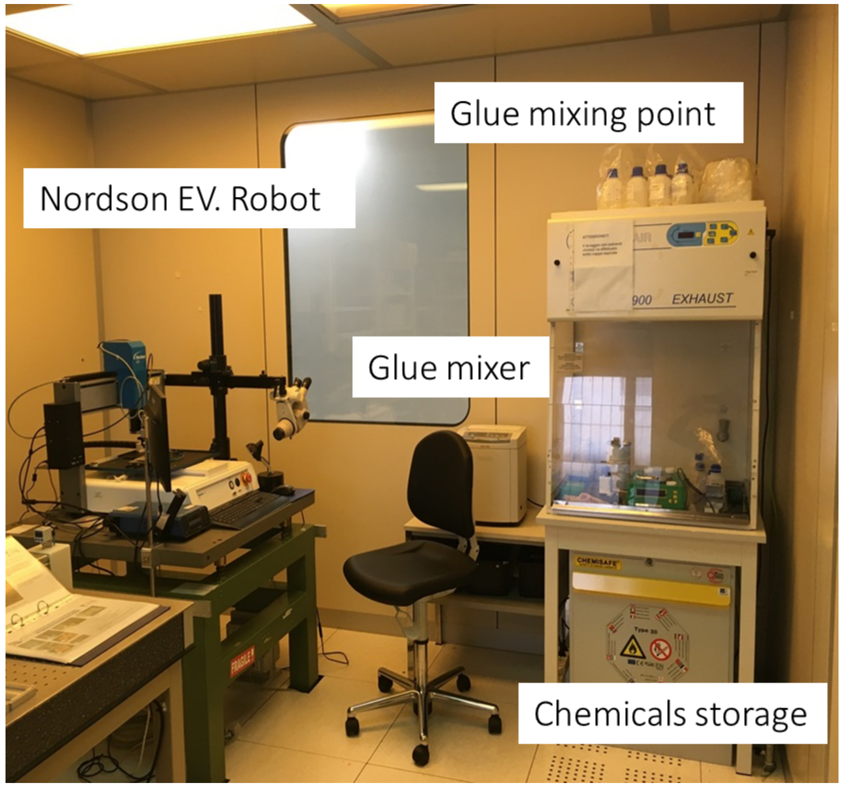
- Each PS module is a functional unit containing:
  - Silicon **strip sensor** + Macro **pixel sensor**
  - Power Hybrid (**POH**)
    - backend power system + DC-DC converters
  - Readout Hybrid (**ROH**)
    - DTC (Data, Trigger and Control) system via optical link
    - lpGBT (Low Power Gigabit Transceiver), VTRx+ (Versatile Link Plus Transceiver)
  - Frontend Hydrid (**FEH**)
    - Macro-Pixel ASIC (MPA) and Short-Strip ASIC (SSA) for sensor readout
    - Stub finding is performed by MPA
      SSA sends cluster and L1 information to MPA to enable match in space and time
    - Data concentrator (CIC) chip receives L1 information and readout data

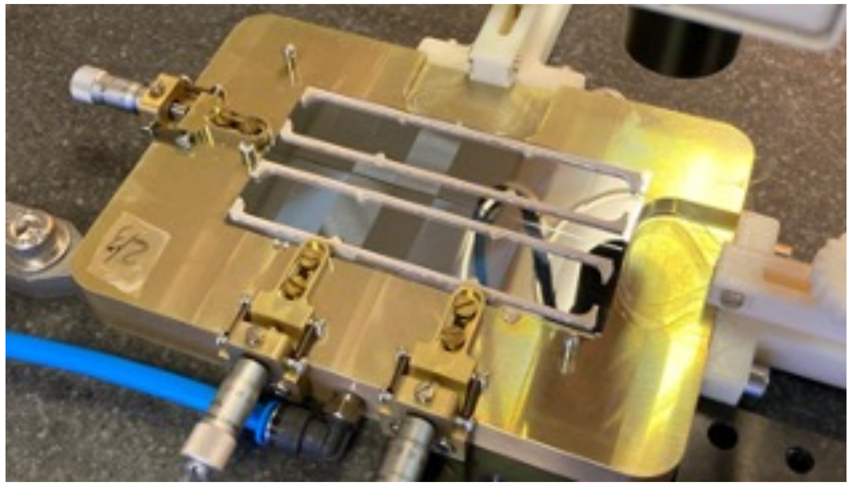


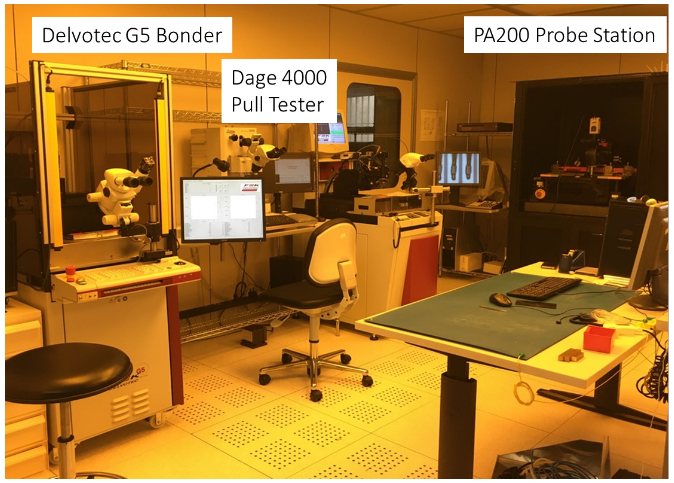


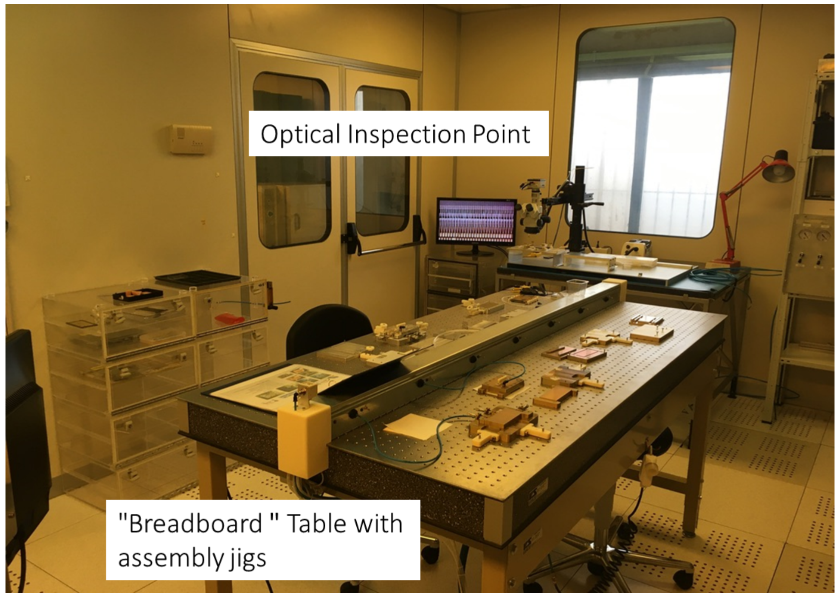
CMS tracker - Outer Tracker (OT)

- INFN strong commitment in the assembly of TBPS (1920 PS modules, ≈ 40 m^2 detector surface)
- Big effort in **Bari** and **Perugia** to complete the assembly line
  - New Glue dispensing robot, Nordson EV
  - New bonding machine
  - Vacuum line and assembly workflow optimisation
  - Jigs production and testing
- **2019** mainly dedicated to mechanical prototype construction
  - Alignment based and sensor dicing, lower precision obtainable with mechanical parts
  - Waiting for dummy sensors (MaPSA)
- **2020** mainly dedicated to build dummy modules and validate the procedures
  - Received 2 dummy sensors (MaPSA) per center
- **2021** first functional modules assembling
  - Foreseen in 2020 and delayed due to material procurement difficulties
  - Stringent constraints on sensor-to-sensor alignment and rotation

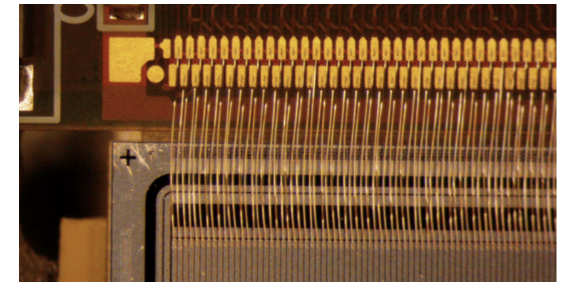


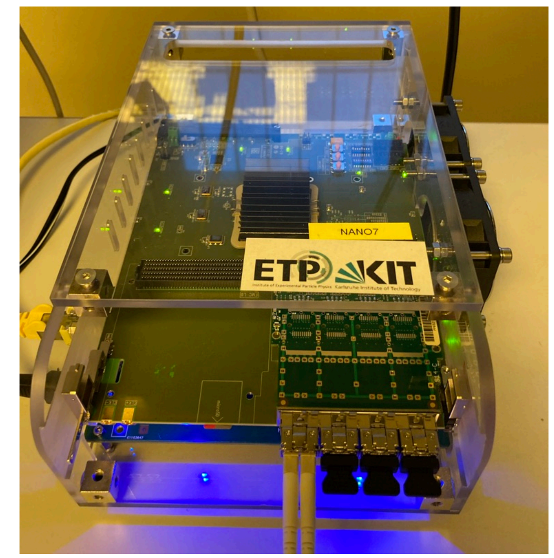


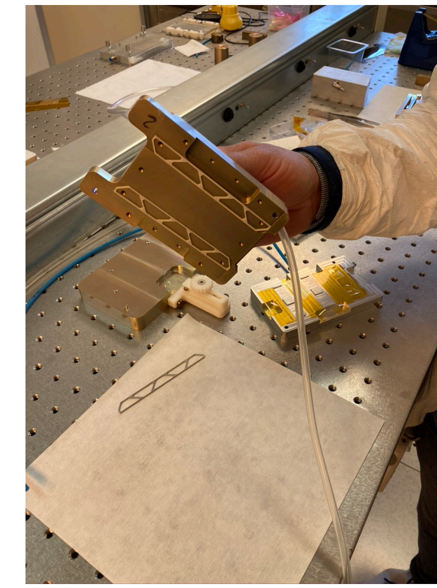


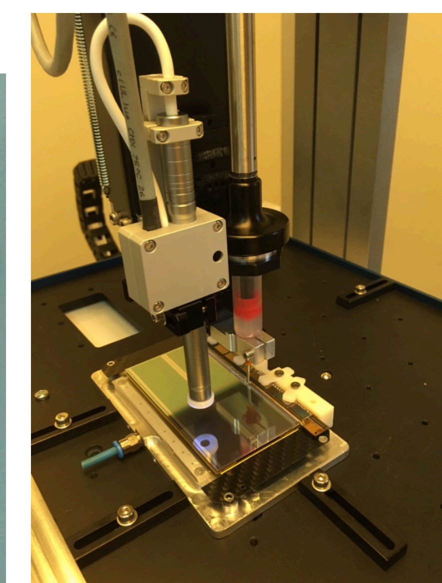


CMS tracker - Outer Tracker (OT)





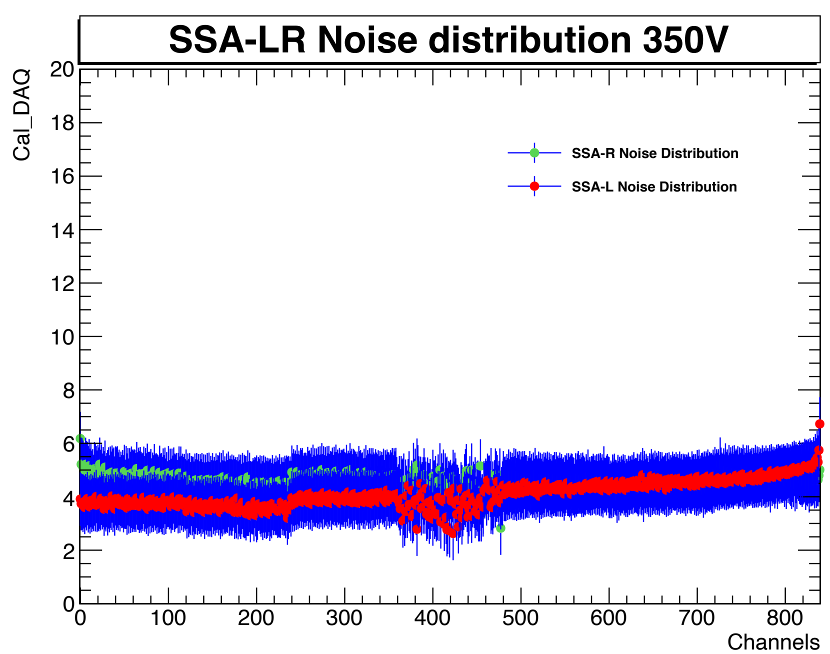


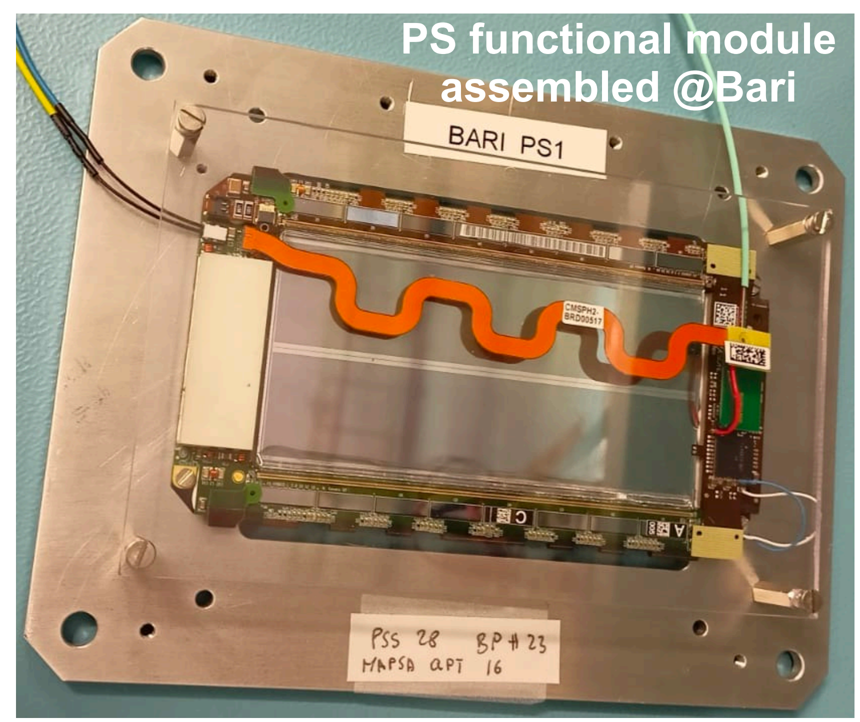


State of the art in Bari

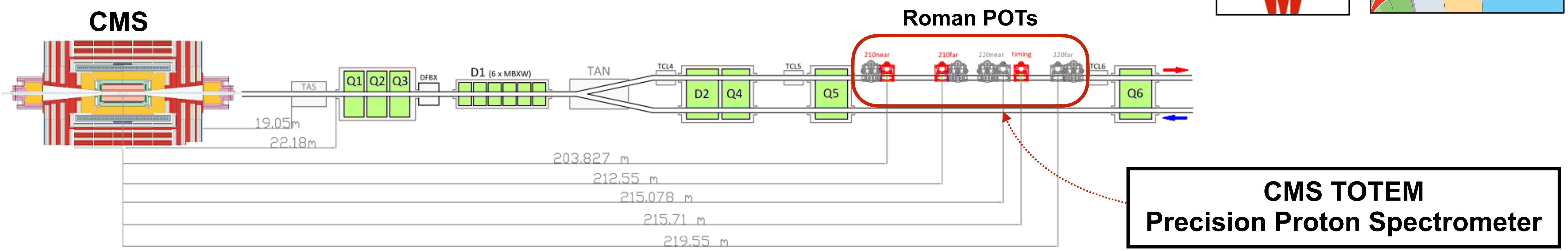
- 2 Mechanical prototypes built
  - Mechanical spacers (done by an external company) + Mechanical baseplate (done in Bari) + Mechanical sensors and MPA in stainless steel (done by an external company)
- 1 Semi-dummy module built
  - 1 dummy Hybrid, 1 PS-s dummy and 1 dummy backplane
  - no dummy MaPSA available → mechanical component
- Bonding and encapsulation studies performed on strip side
  - Real bonding loop: ~3 mm long and 215 μm tall
    - Pull results well within spec
- 3 functional modules assembled
  - At the moment under electrical verification
  - Missing components to complete the assembly of other two modules
- 1000 PS modules to be assembled

TEAM
P. Cariola,
D. Creanza,
M. de Palma,
L. Fiore,
I. Margjeka,
M. Mongelli,
S. My

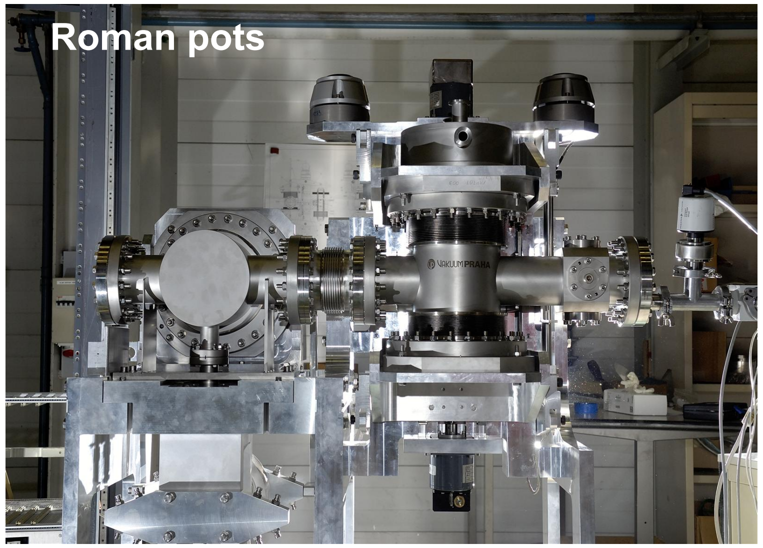




Precision Proton Spectrometer

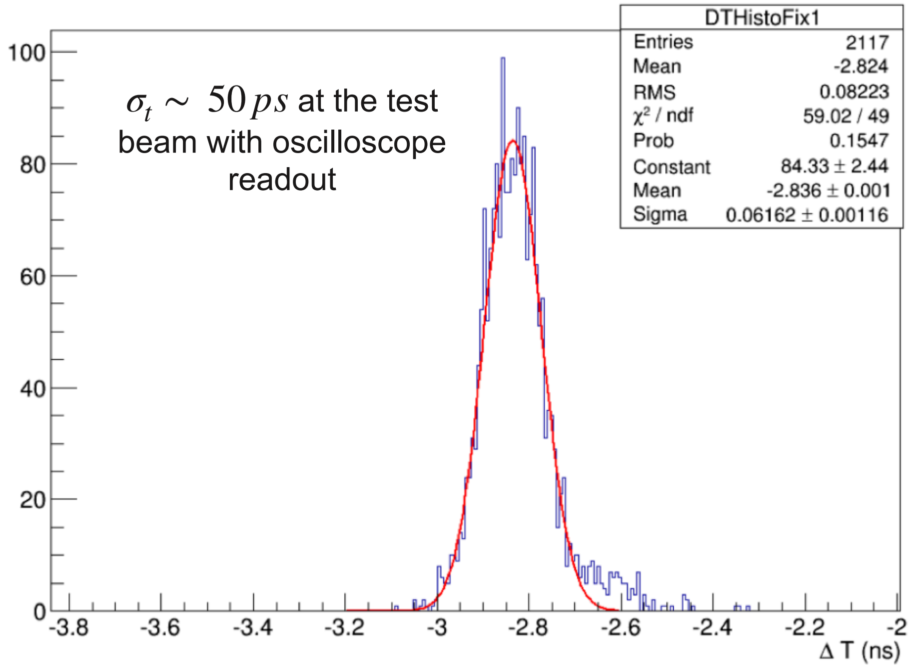


- Scientific objectives
  - Study of Central Exclusive Production (CEP) in p-p collisions during standard low-β^* runs at high luminosity
    - *EWK*: LHC used as photon-photon collider: measure $\gamma\gamma \rightarrow W^+W^-, e^+e^-, \mu^+\mu^-, \tau^+\tau^-$; search for AQGC with high sensitivity, search for SM forbidden $ZZ\gamma\gamma$, $\gamma\gamma\gamma\gamma$ couplings
    - *QCD*: exclusive two and three jet events, with M up to ~700-800 GeV; Test of pQCD mechanisms of exclusive production; gluon jet samples with small component of quark jets
    - *BSM*: Search for new resonances in CEP: clean events (no underlying pp event); independent mass measurement from pp system, J^{PC} quantum numbers 0^{++}, 2^{++}
- CT-PPS has been installed in the RP infrastructure and operated since 2016
- CT-PPS is now part of the CMS detector and has been renamed PPS → It will provide forward proton tagging capability to CMS



Precision Proton Spectrometer

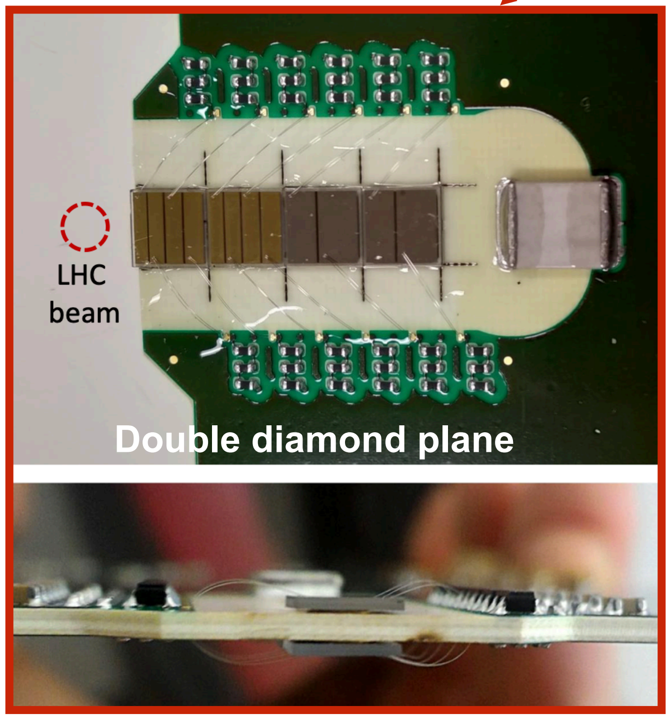
- **Diamond based timing detectors**, originally developed for TOTEM upgrade and the used in CT-PPS
- Detectors track the forward proton and measure the arrival time, to help the pile-up mitigation
- Each station is equipped with 4 **double diamond planes**
- A custom made front-end electronics, based on the NINO chip, design to reduce timing degradation in digitization phase
- The readout is based on the HPTDC chip and SAMPIC digitiser chip (fast sampler @ 7.8 Gsa/s). The latter will be available for commissioning phase and sensor monitoring
- A timing station for each arm was already present in Run 2 and two new stations, one per arm, are under installation for Run 3.

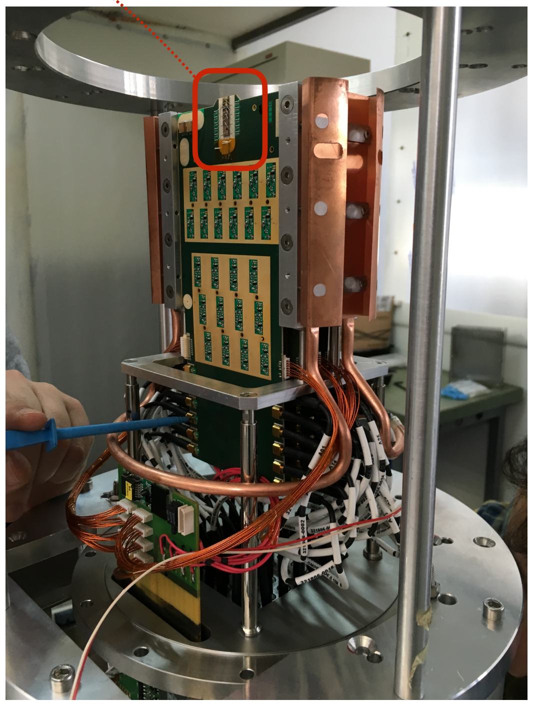


Bari team contributions

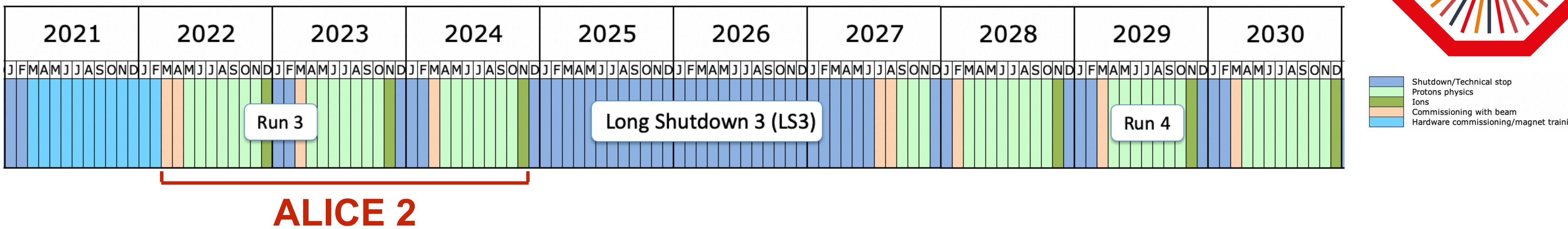
- Diamond detectors responsibility
- Readout system design
- Clock distribution system design

TEAM
F. Cafagna, E. Radicioni

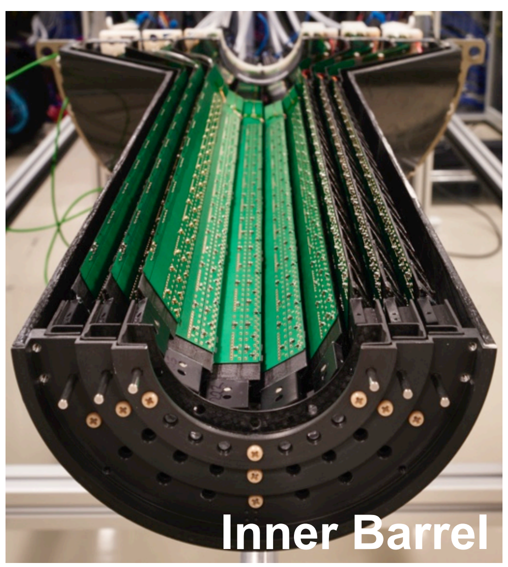




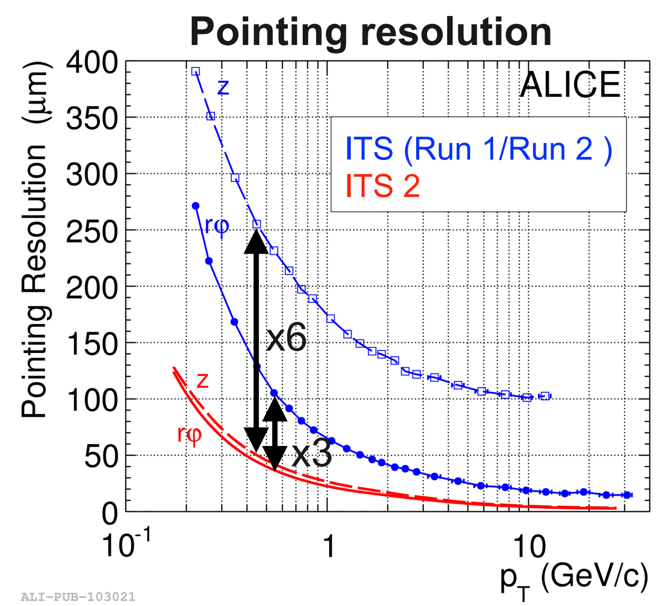
ALICE tracker - ITS2

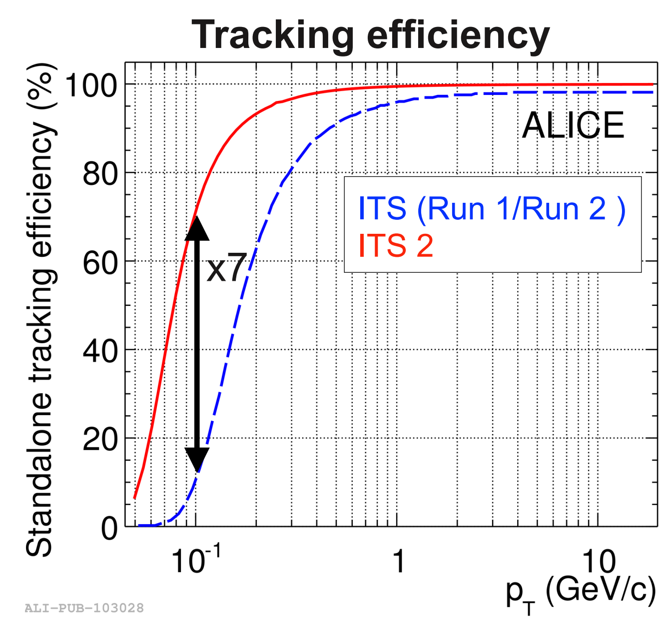


ITS2 for LHC Run 3



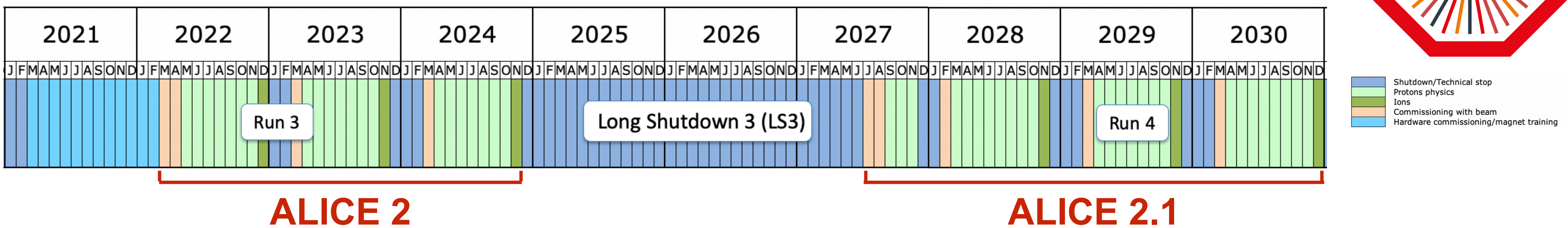
ITS2 installed and under commissioning



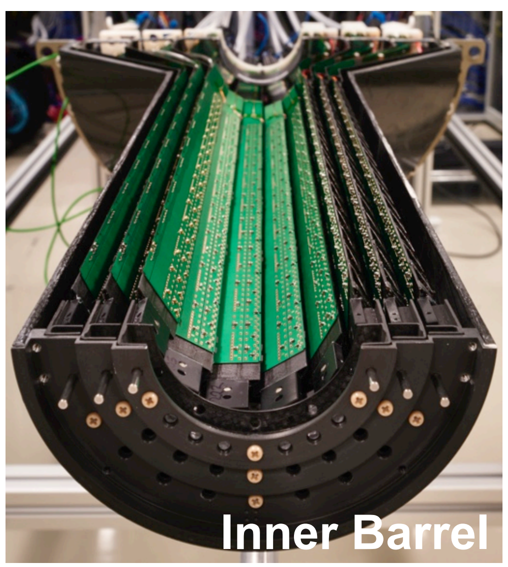


ITS2 will provide unprecedented performances
→ pointing resolution: 15 µm at p_T of 1 GeV/c
→ tracking efficiency: above 90% for p_T > 200 MeV/c

ALICE tracker - Motivation for ITS3



ITS2 for LHC Run 3

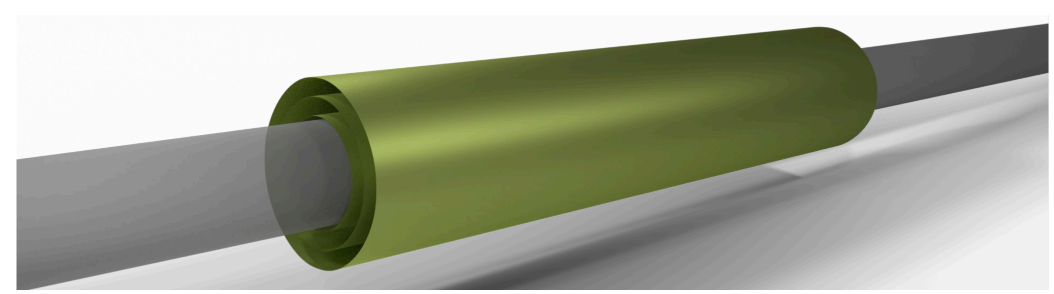


ITS2 installed and under commissioning

ITS3 for LHC Run 4

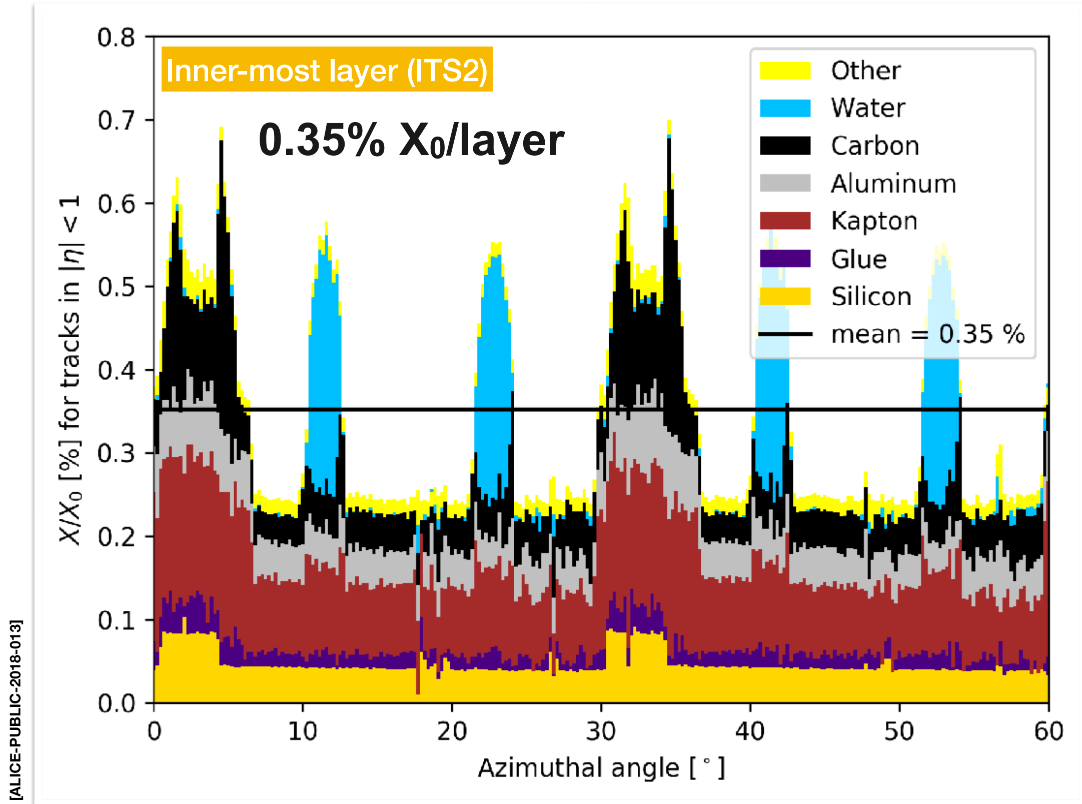
Can we get closer to the IP?
Can we reduce the material budget?

The way: replace detector staves (3 innermost layers) by wafer-scale sensors bent around the beam pipe



Joint effort with EIC_NET project and preparatory activity for ALICE3 (Run5 and beyond)

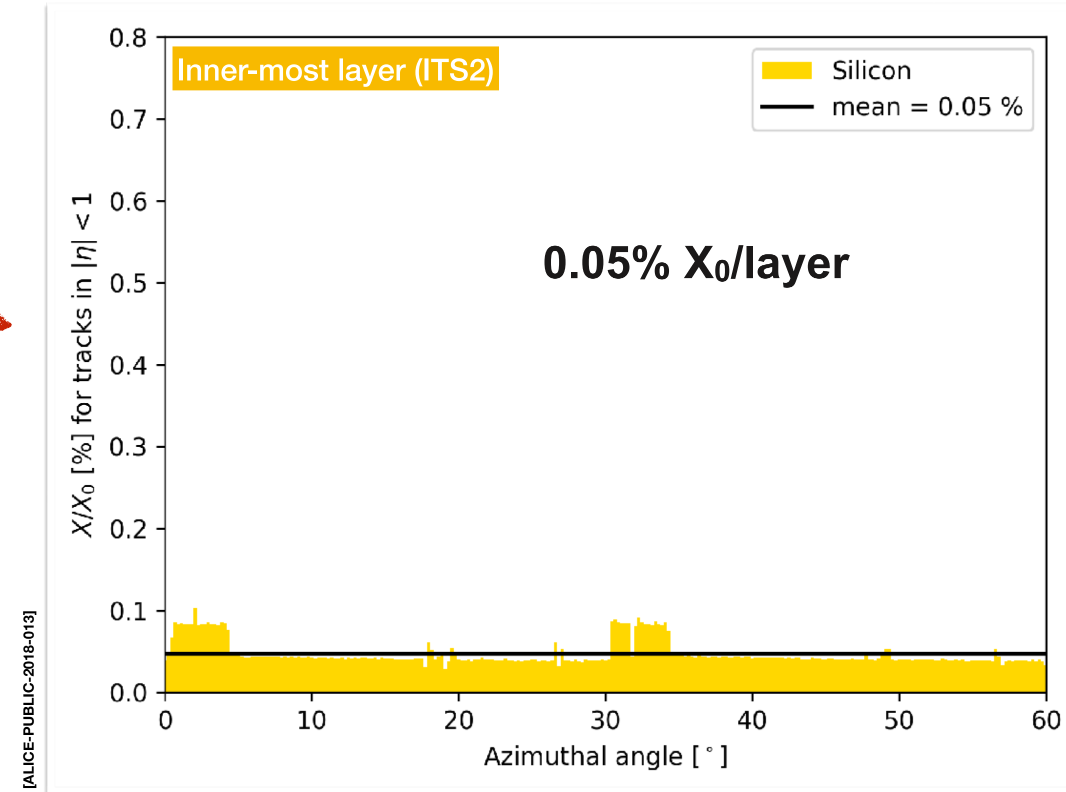
→ dedicated talk by A. Pastore tomorrow



Observations

» Silicon makes only about 15% of total material

» Irregularities due to support/cooling and overlap



Improvements

» *Removal of water cooling*

→ **possible** if power consumption stays below 20 mW/cm^2

→ move to (low flow) air cooling system

» *Removal circuit board* (power+data)

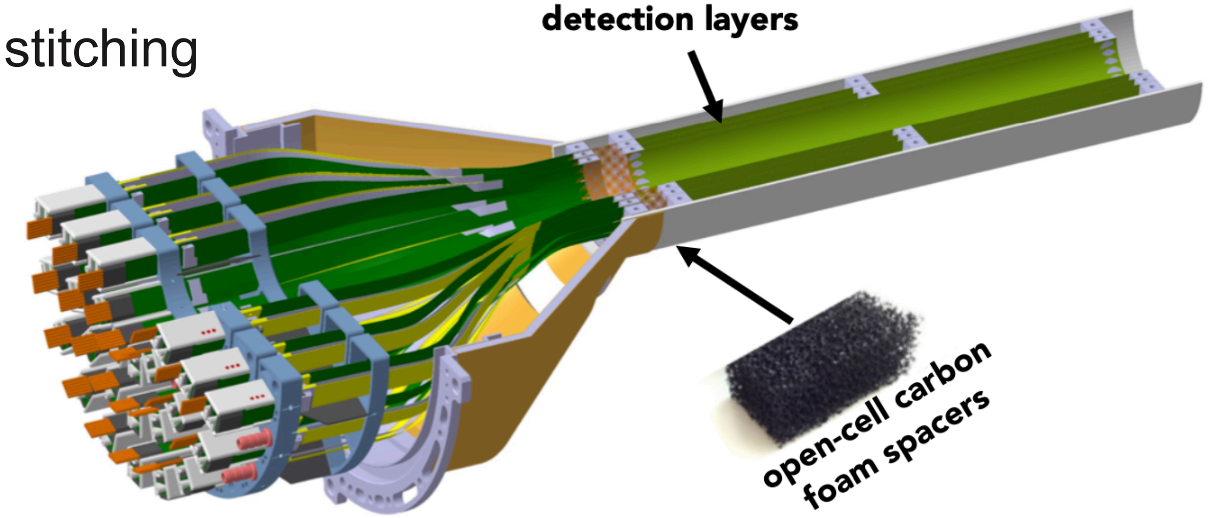
→ **possible** if integrated on chip

» *Removal of mechanical support*

→ **benefit** from increased stiffness by rolling Si wafers

ALICE tracker - ITS3 detector concept

Key ingredients
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Sensor thickness 20-40 μm
» Chips bent in cylindrical shape at target radii
» Si MAPS sensor based on 65 nm technology
» Carbon foam structures
» Smaller beam pipe diameter and wall thickness (0.14% X_0)



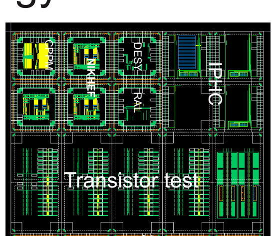
The whole detector will comprise six chips (current ITS IB: 432) and barely anything else!

Beam pipe inner/outer radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length of sensitive area (mm)	300.0		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active-area (cm²)	610	816	1016
Pixel sensor dimension (mm²)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm²)	O (10 x 10)		

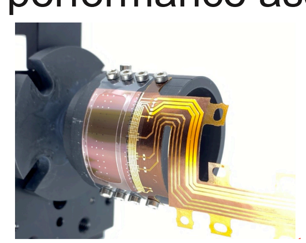
Key benefits
» Extremely low material budget: 0.02-0.04% X_0
» Homogeneous material distribution: negligible systematic error from material distribution

ITS3 project R&D lines

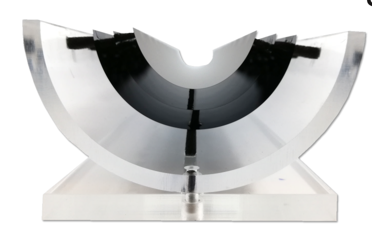
Chip design
New, stitched sensor in 65 nm technology on 300 mm wafers



Sensor performance
Tests with existing bent ALPIDE chips (ITS2) for (in-beam) performance assessment

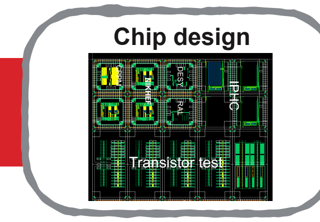


Detector Integration
Tests with wafer-scale dummy chips for mechanical integration



ALICE tracker - Chip design

MLR1 SUBMISSION AND TEST + ER1



» MLR1 is the first submission in the TowerJazz 65 nm technology
- scoped within CERN EP R&D WP1.2, but significant drive from ITS3
- this technology will allow to build larger sensors (300 mm wafers)

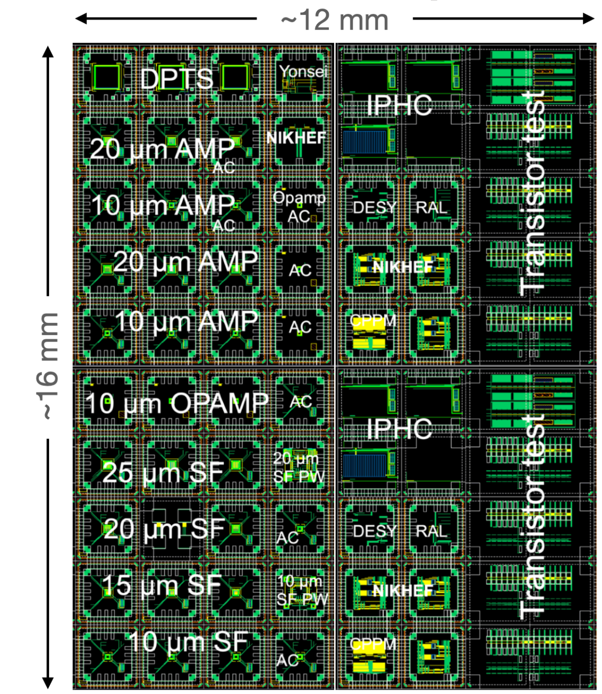
» More than just “first test structures”
- transistor test structures
- analog building blocks (band gaps, LVDS drivers, etc.)
- various diode matrices (small and large)
- digital test matrices

➡ Essentially covers the initial goals of MPW1 and MPW2

» First wafers received
- laboratory characterisation ongoing
- test beam campaign (PS, SPS and DESY) in Oct-Dec 2021
- characterisation of bent test structure

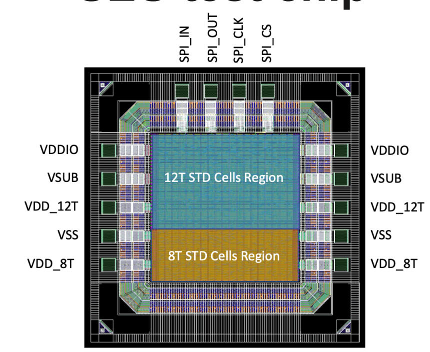
» ER1 Stitched Sensor prototype
- Key requirements and architectures defined (sensor, primary features, dimensions and floorpan, powering scheme, I/Os and global busses)
- <u>INFN Bari involvement in: SEU memory measurement chip design and characterisation</u> (**G. De Robertis**) and <u>development of Bias and Monitoring network of the MOSS chip</u> (**F. Loddo**)

MLR1 chip

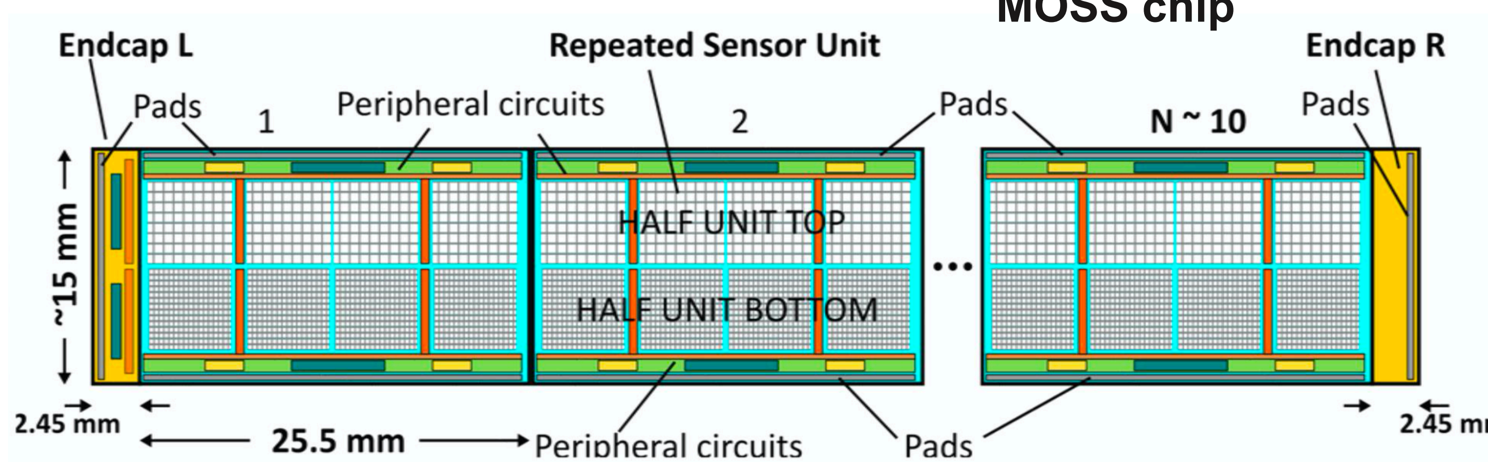


expect O(300) dies per wafer

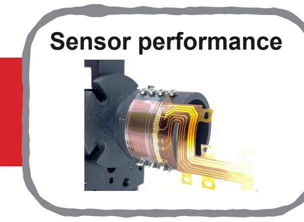
SEU test chip



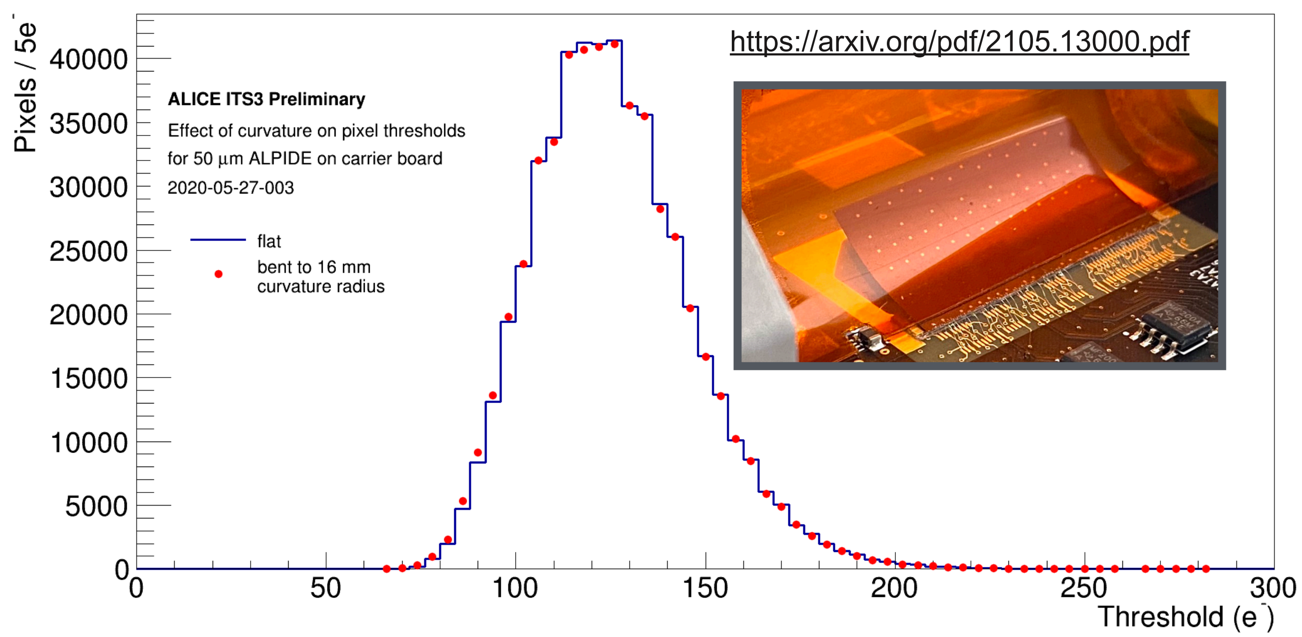
MOSS chip



ALICE tracker - Sensor performance



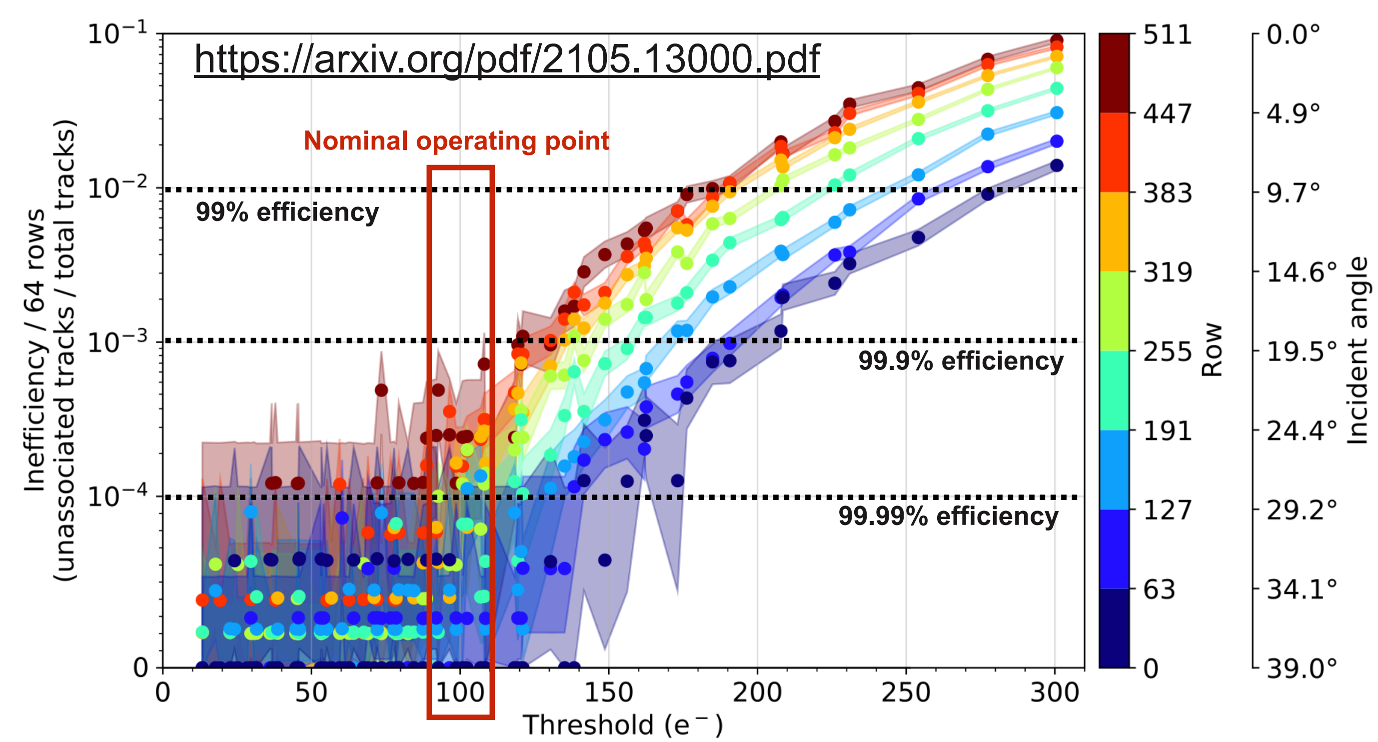
TESTS IN LAB AND IN BEAM



» Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip performance doesn't change after bending**
- Pixel matrix threshold distribution does not change when sensor is bent
- Efficiency above 99.9% at a threshold of 100 e⁻ (normal operating point)

▷ <u>Activity done by a XXXV Cycle Ph.D. student</u>
- Electrical and functional characterisation of bent ALPIDE chips
- Participation in test beam and data analysis

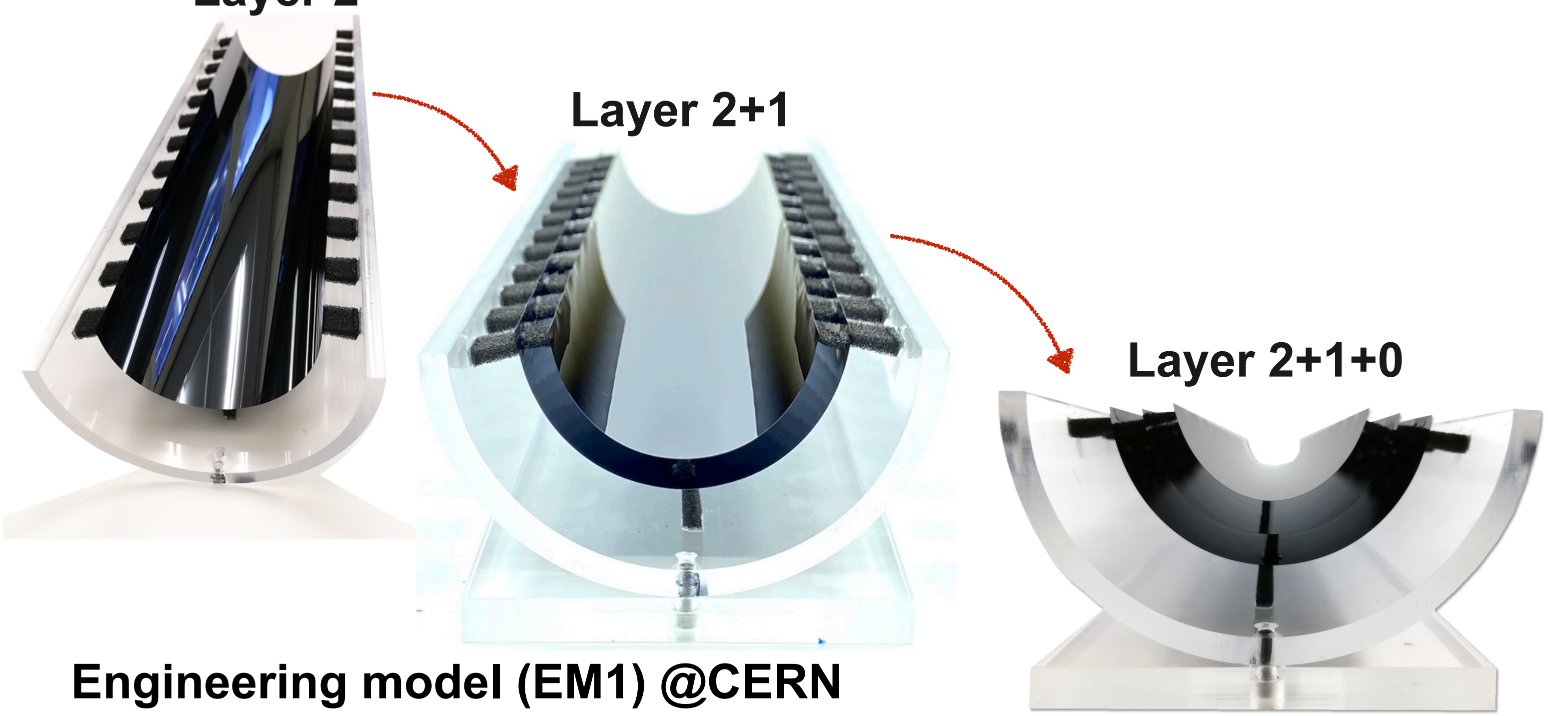
▷ Foreseen involvement in MLR1 APTS chip characterisation



ALICE tracker - Bending procedure

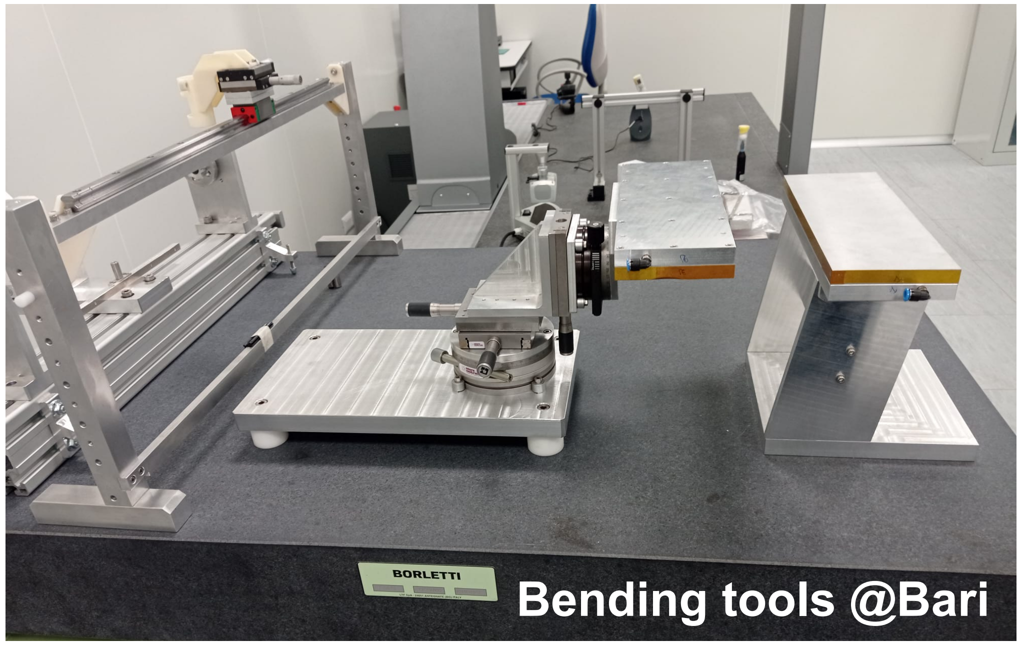
WAFER-SCALE CHIPS BENDING

- » CERN team developed procedure for silicon bending in a repeatable and reliable way
- » Bending tool: tensioned mylar foil wrapping around a cylindrical mandrel
- » <u>Bending tools available in Bari (produced in our workshop)</u>
  → Already contributing in procedure improvement



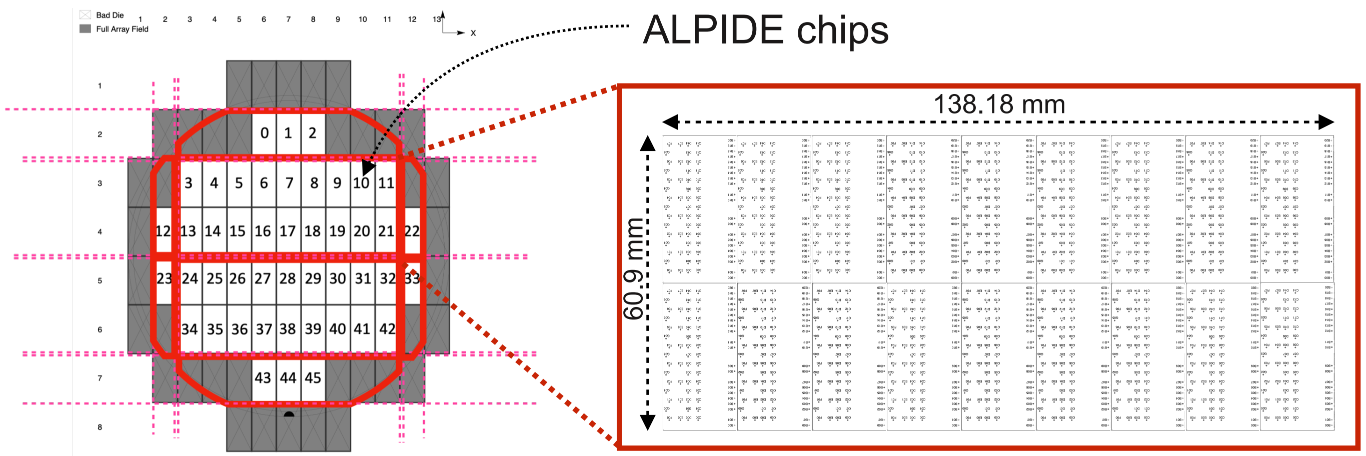
Engineering model (EM1) @CERN

Bending tools @CERN



Bending tools @Bari

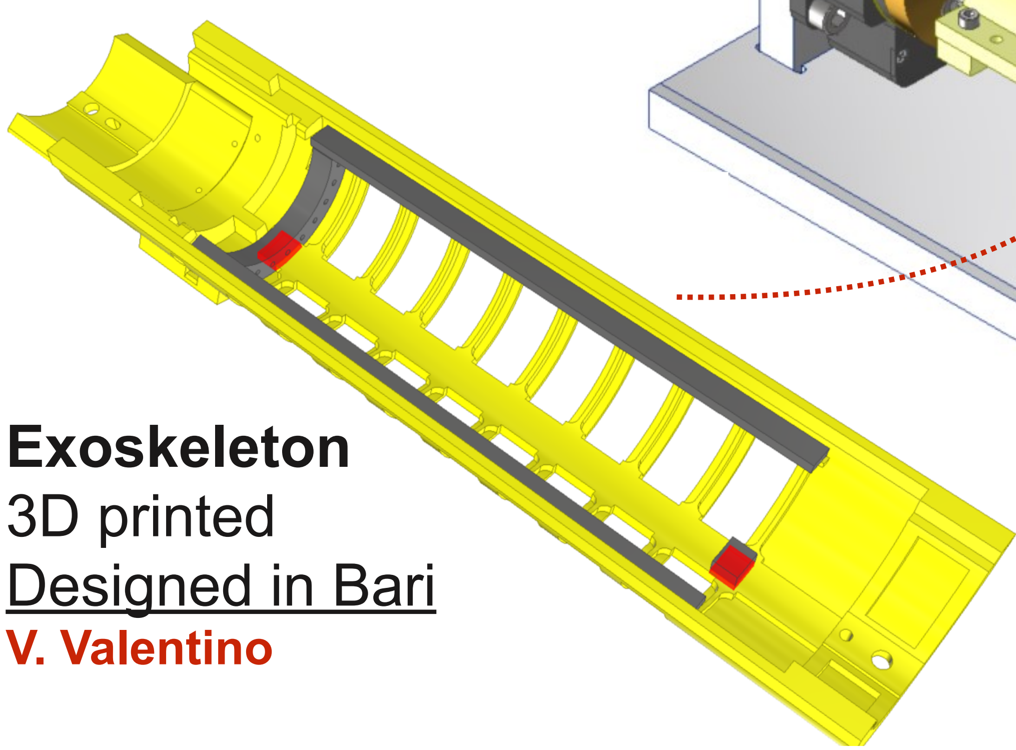
ALICE tracker - Super-ALPIDE

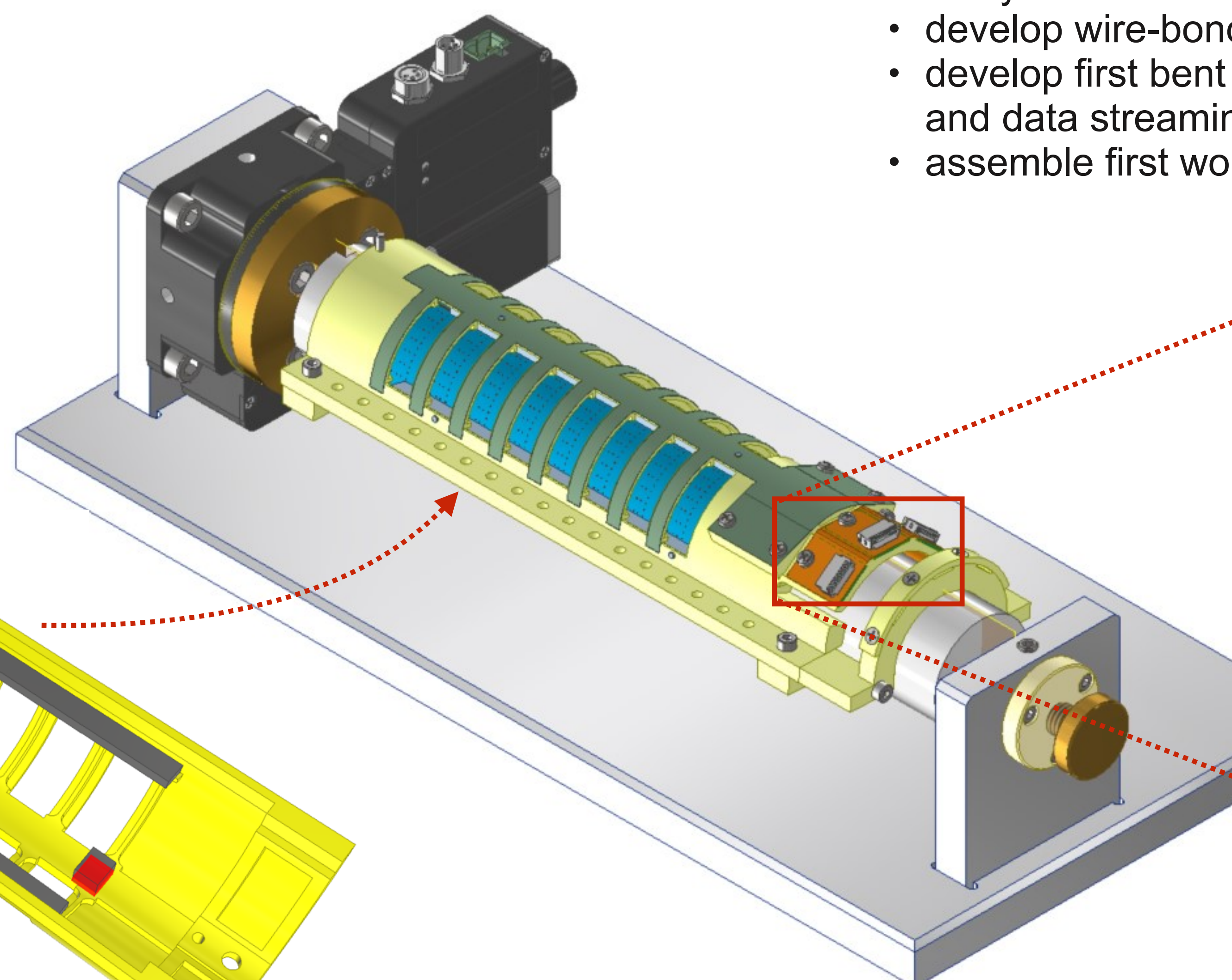


Super-ALPIDE: 18 not diced ALPIDE chips

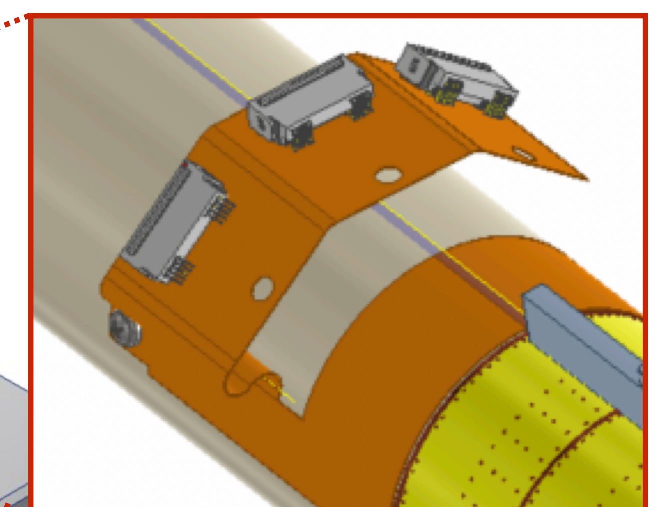
» Super-ALPIDE
- 18 not diced ALPIDE chips
- dimensions close to the ones for L0 sensor

» Goals
- verify bending tools for large-size working chips
- verify mechanical support alignment tools
- develop wire-bonding over bent surface tools
- develop first bent flex prototype (for powering and data streaming)
- assemble first working large dimension bent sensor



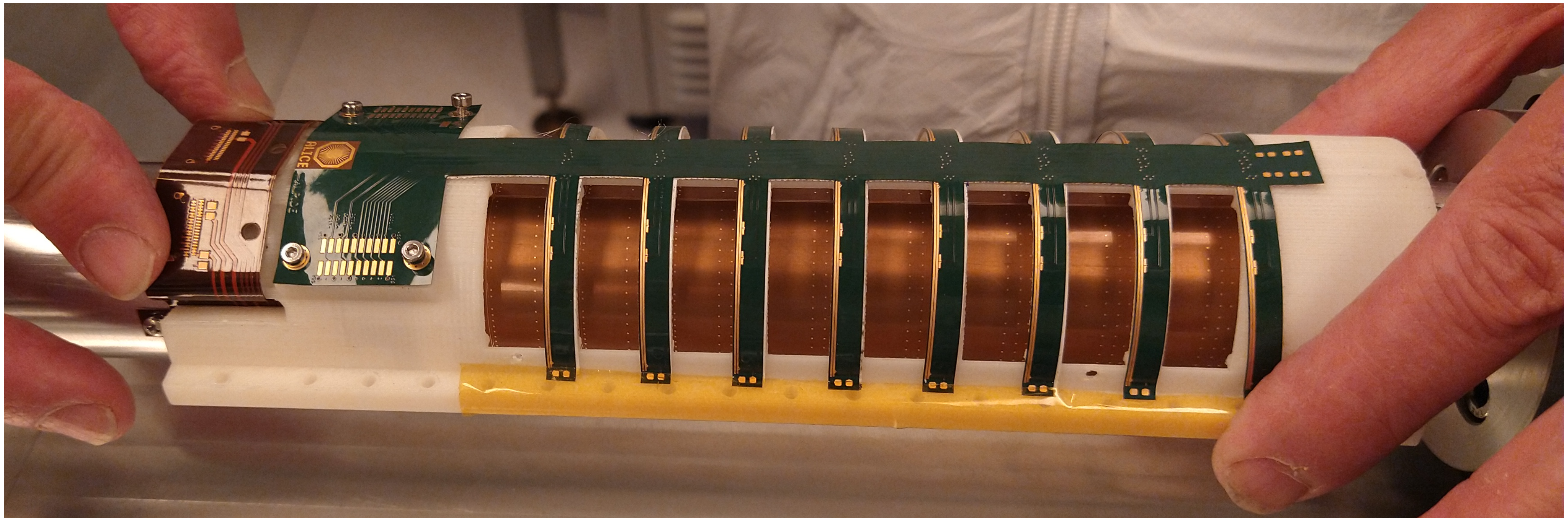


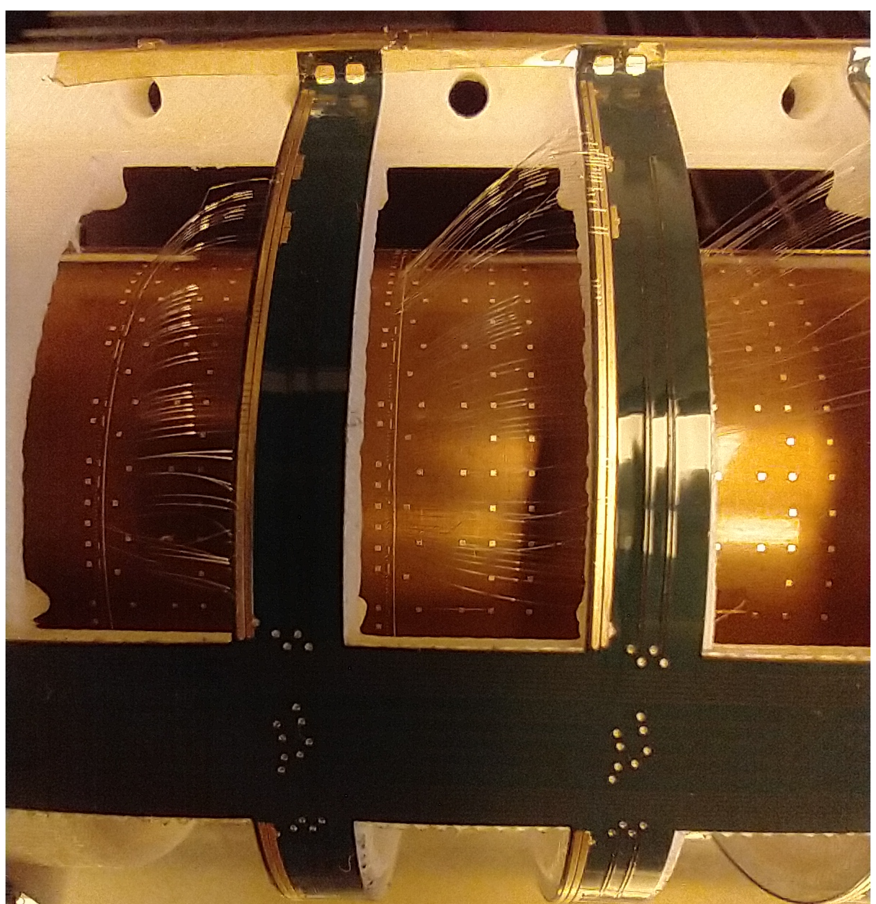
Exoskeleton
3D printed
<u>Designed in Bari</u>
V. Valentino



Edge-FPC
<u>Designed in Bari</u>
M. Rizzi, G. De Robertis

ALICE tracker - Super-ALPIDE

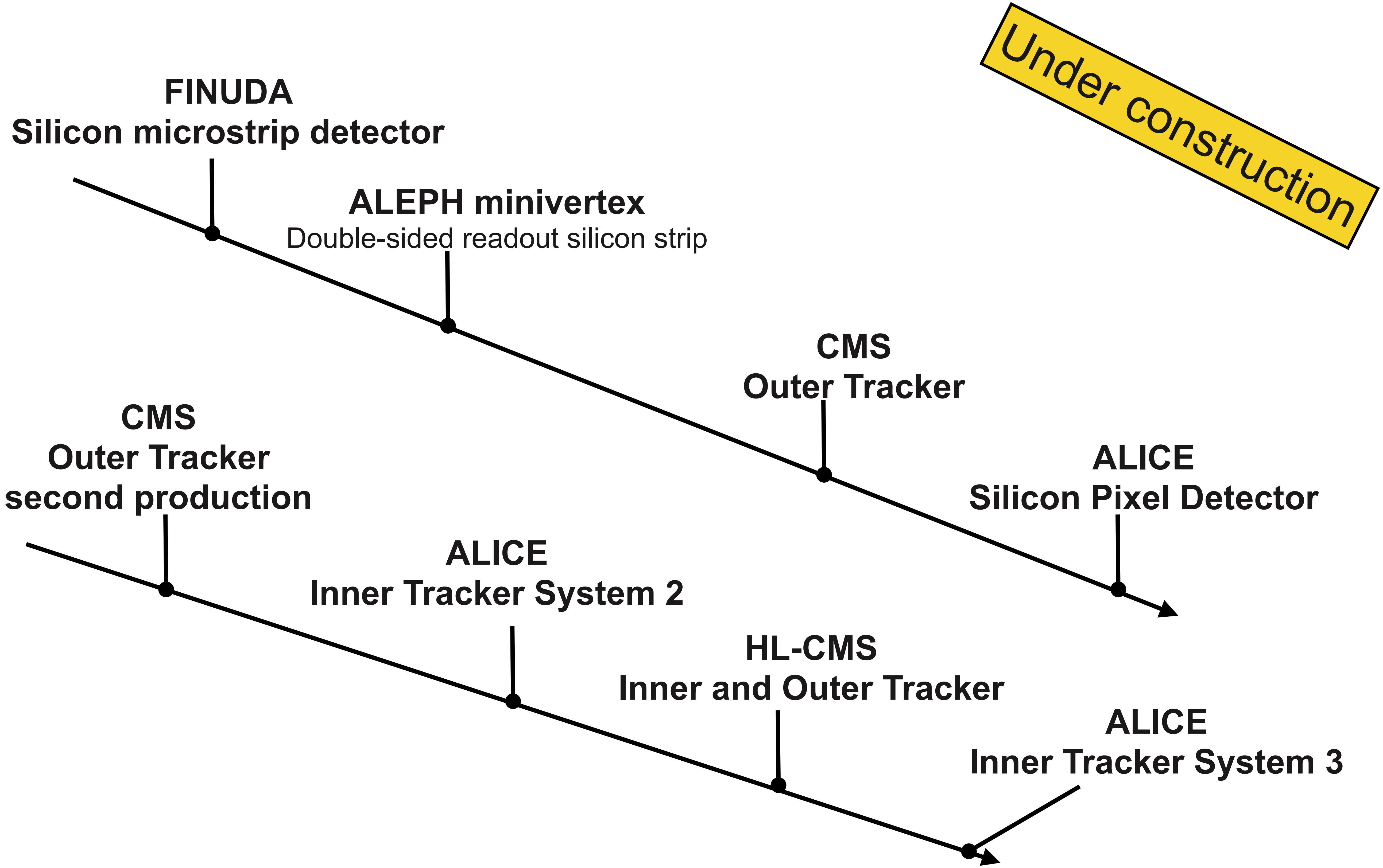




TEAM
G. E. Bruno, P. Cariola, D. Colella, V. Manzari, S. Martiradonna, C. Pastore, A. G. Torres Ramos, V. Valentino

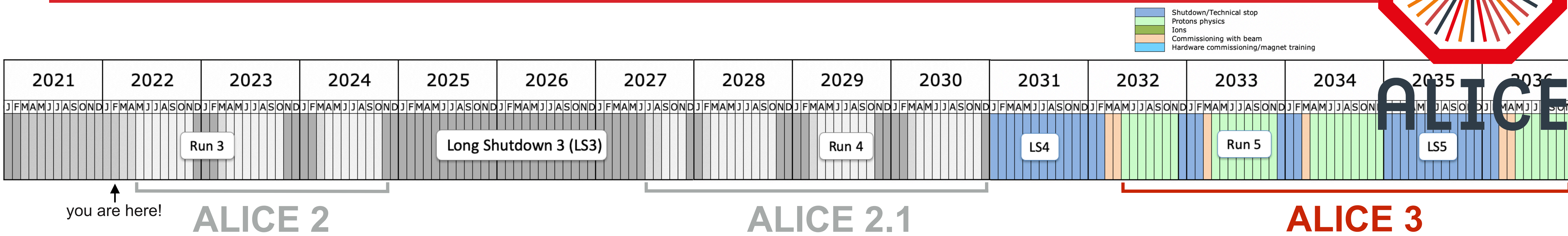
OTHER ALICE TRACKER RELATED ACTIVITIES AND EIC SYNERGY
F. Barile, F. Colamaria, D. Elia, A. Mastroserio, A. Palasciano, G. Tassielli

Timeline of silicon tracker assembly in Bari…



Backup

ALICE tracker

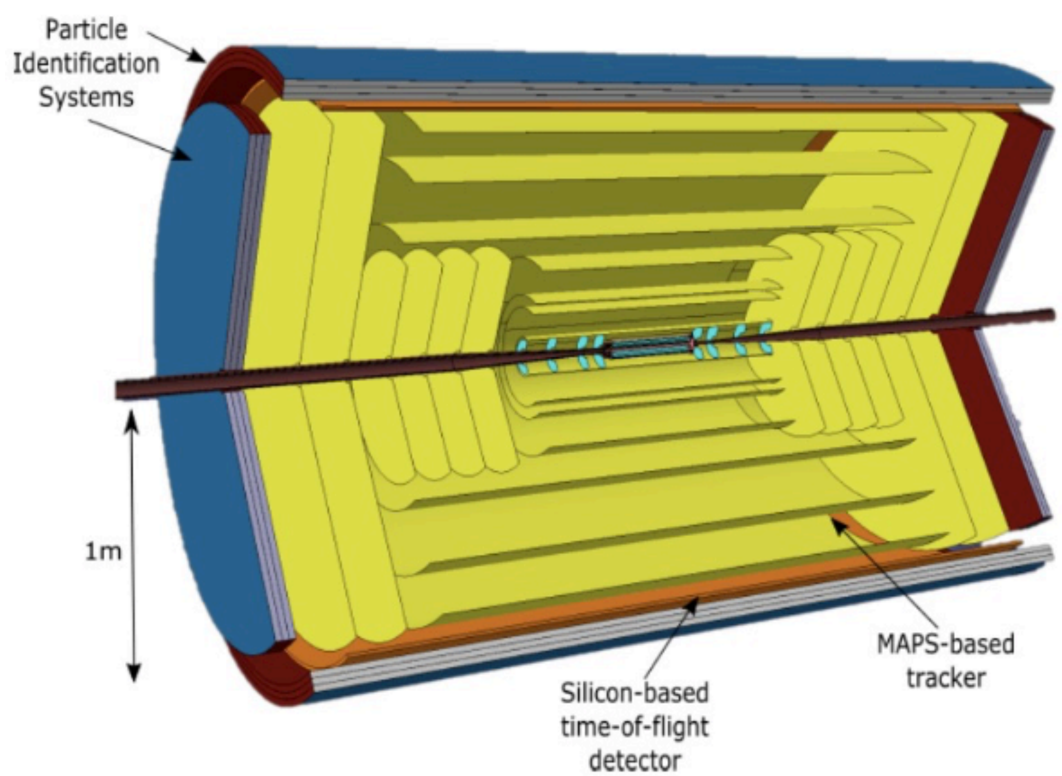


A next-generation LHC HI (soft-QCD) experiment

» Compact, all-silicon “nearly massless” detector with excellent low-p_T tracking performance

» Increase rate capabilities: luminosities x20-x50 higher

» **Unprecedented insight into QGP**



Expression of Interest (2019): https://arxiv.org/abs/1902.01211

LoI under preparation

ALICE tracker

Main R&D challenges

» *Inner tracker*

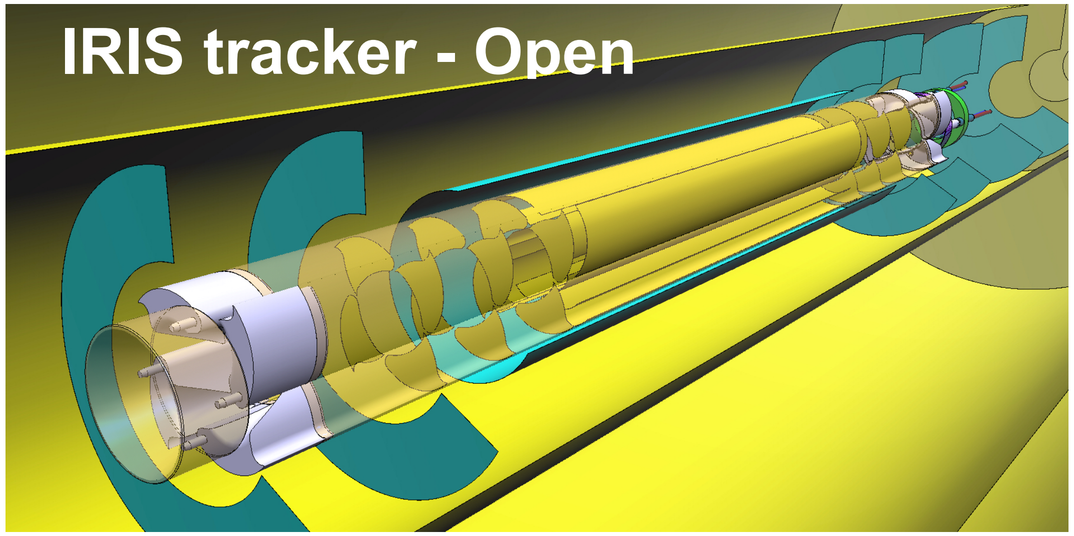
→ ultra-thin layout: flexible wafer-scale sensors (MAPS/ITS3)
→ minimal distance from IP requires retractable detector
→ position resolution O(1 μm) requires small pixel pitch

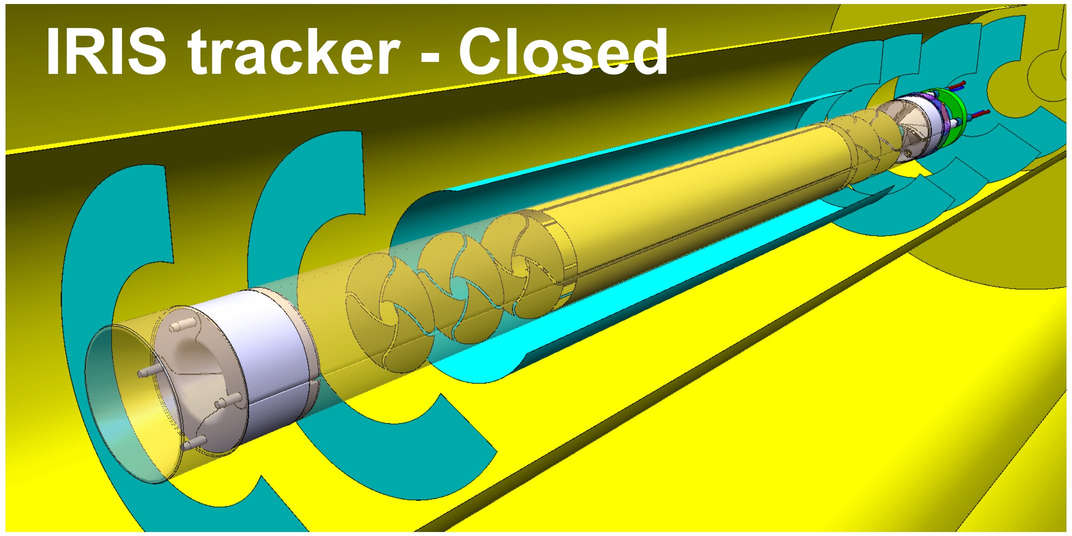
» *Outer tracker*

→ large areas to instrument O(100 m^2): develop cost-effective sensors
→ low material budget requires low-weight support and services

» *Time of Flight*

→ TOF resolution < 20 ps needed on the system level requires advances both on sensors and microelectronics
→ large areas to instrument: develop cost-effective sensors





Backup

INFN Outer Tracker (OT) Phase 2 contribution

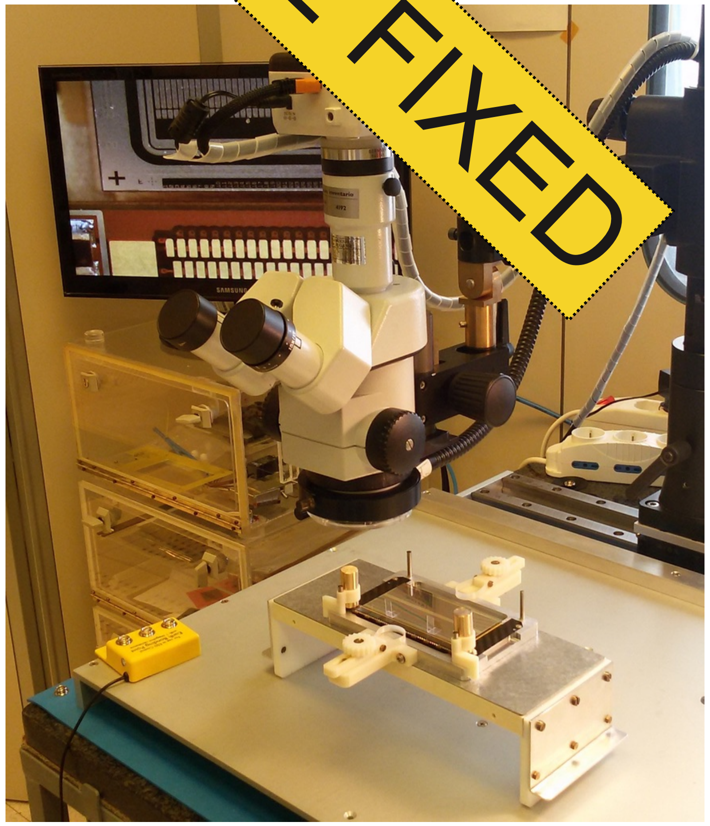
To deliver Tilted Barrel (TBPS) 72 rings (36 rings per side) mounted, integrated and tested with 1920 PS modules (≈ 40 m^2 surface detector) and contribute to Track Trigger. Production of necessary spares is implicit but not specified in this document. In summary:

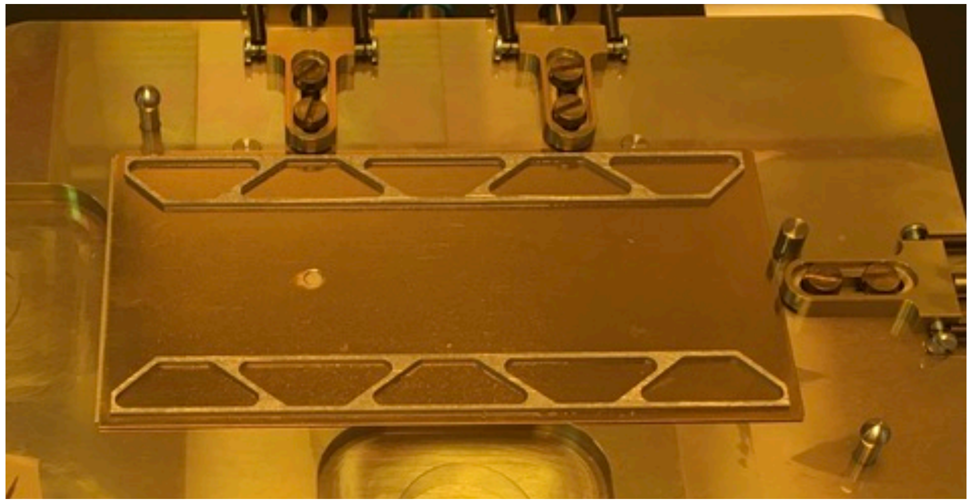
- Development and Qualification
  - Service (Power and Opto) Hybrids testing **(Genova)**
  - FE Hybrids testing **(Catania)**
  - Silicon Sensors Process Qualification and Sensor Testing **(Perugia)**
  - ASIC sample qualification and testing **(Padova)**
- Contribution to development, qualification of commons systems
  - Track Trigger electronics system **(Pisa)**
  - DAQ and Control Systems **(Pisa, Catania, Genova)**
  - Power supply backend **(Firenze, Perugia)**
  - Safety System **(Pisa)**
  - Silicon Sensors Process Qualification and Sensor Testing **(Perugia)**
- Construction and integration of PS Modules (1956 installed)
  - Module assembly, wire bonding and testing **(Bari, Perugia)**
  - Module Burn in and Calibration **(Pisa)**
  - Module mechanical integration and testing in 72 rings **(Pisa + all)**

CMS tracker - Outer Tracker (OT)

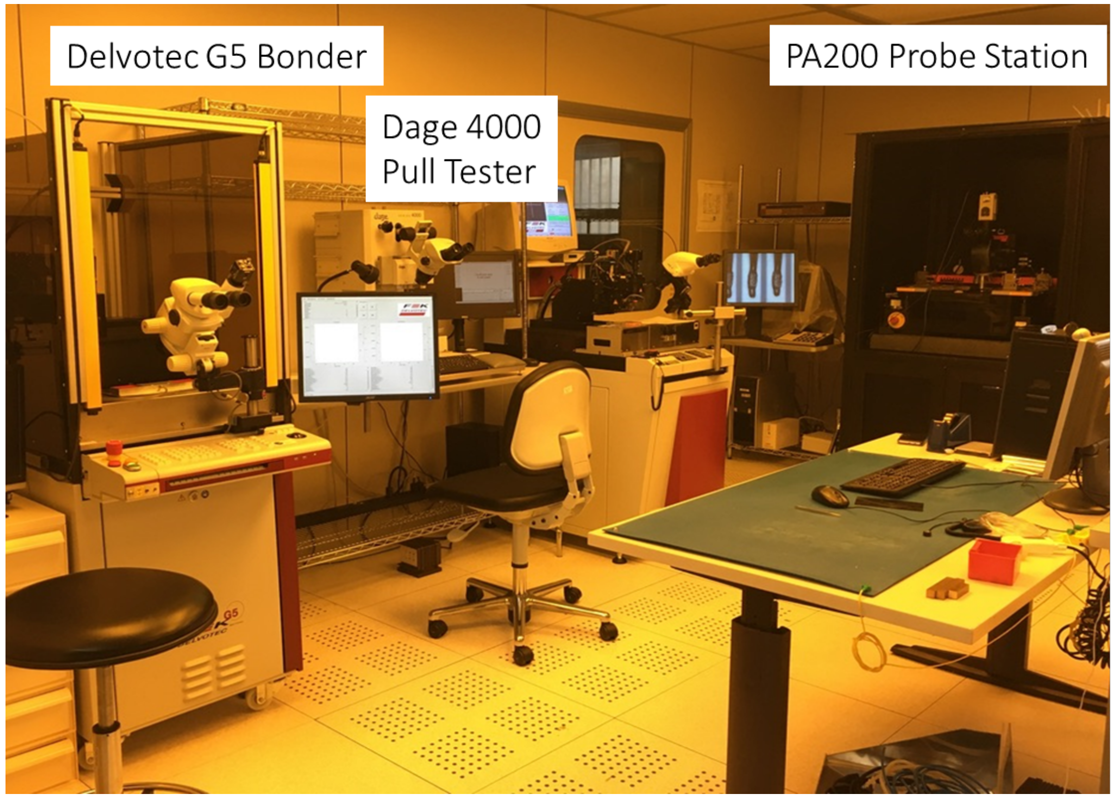
TO BE FIXED

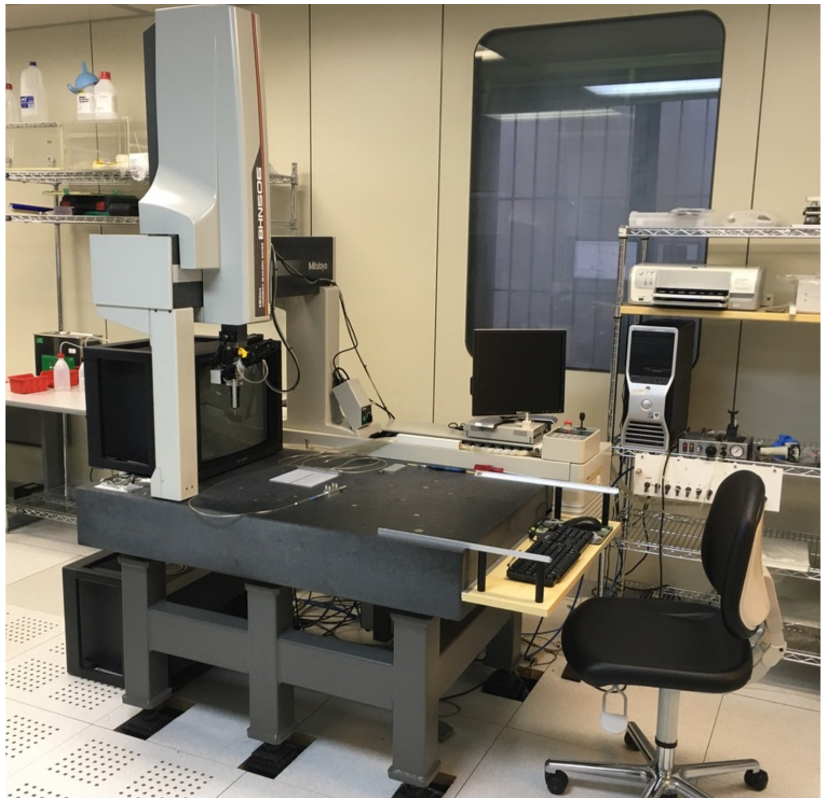
- INFN strong commitment in the assembly of TBPS (1920 PS modules, ≈ 40 m^2 detector surface)
- Big effort in **Bari** and **Perugia** to complete the assembly line
  - New Glue dispensing robot, Nordson EV
  - New bonding machine
  - Vacuum line and assembly workflow optimisation
  - Jigs production and testing
- 2019 mainly dedicated to mechanical prototype construction
  - Alignment based and sensor dicing, lower precision obtainable with mechanical parts
  - Waiting for dummy sensors (MaPSA)
- 2020 mainly dedicated to build dummy modules and validate the procedures
  - Received 2 dummy sensors (MaPSA) per center
- Delay in the center qualification (foreseen in 2020) with the production of 5 functional modules (procurement of MaPSA, hybrids…) → milestone moved to 2021
  - Stringent constraints on sensor-to-sensor alignment and rotation

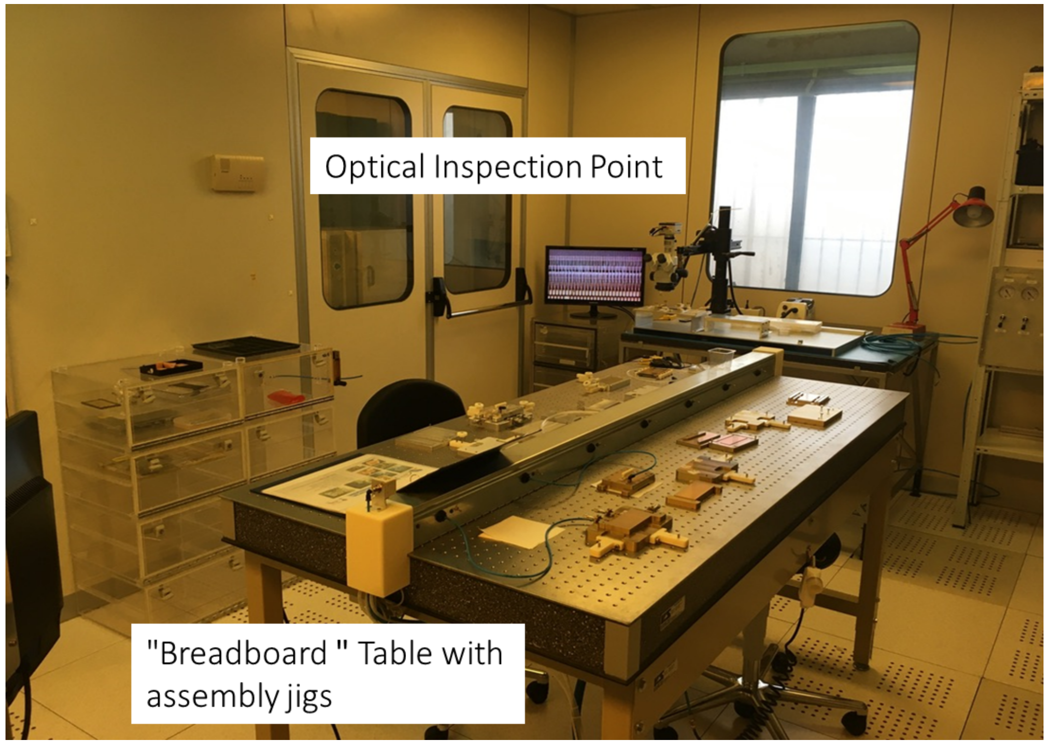


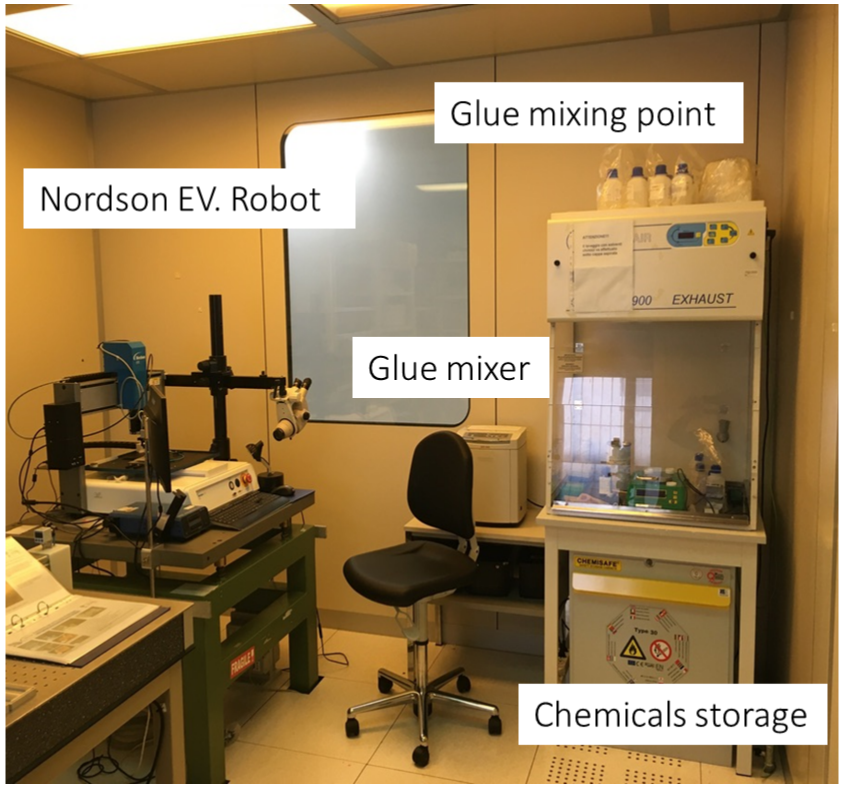


Backup

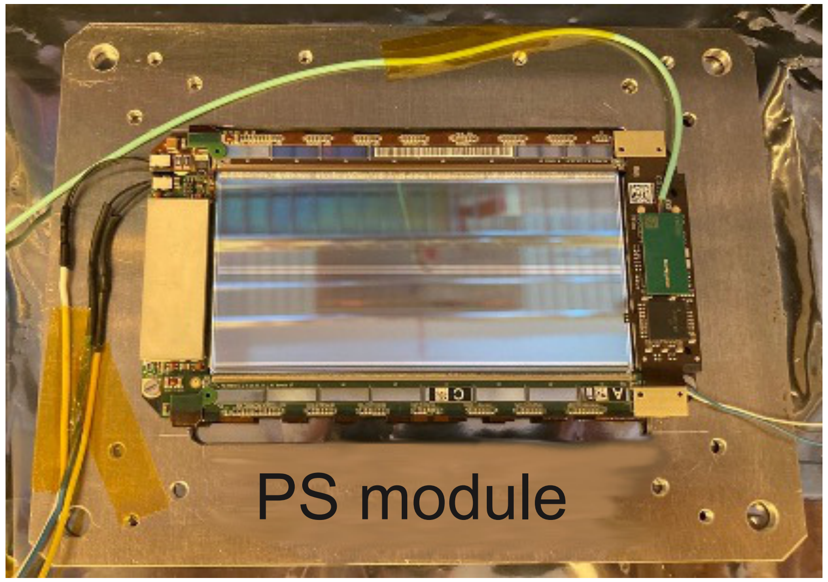

Delvotec G5 Bonder
Dage 4000
Pull Tester
PA200 Probe Station

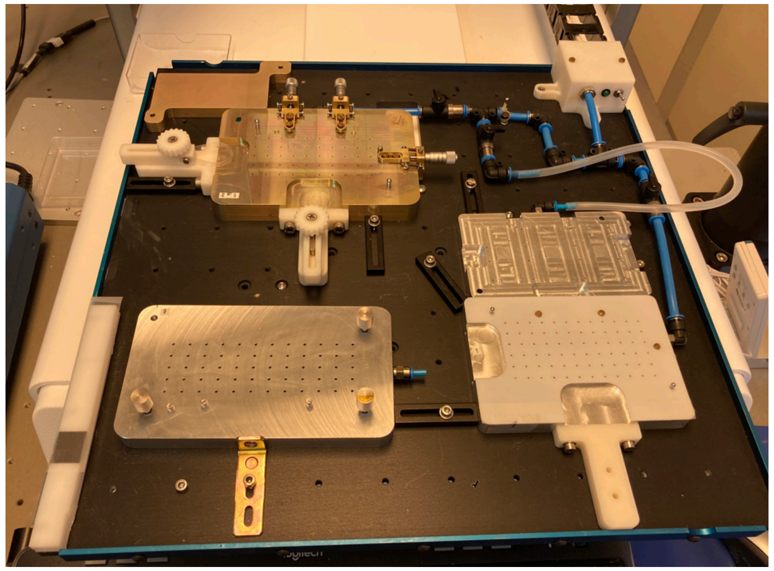


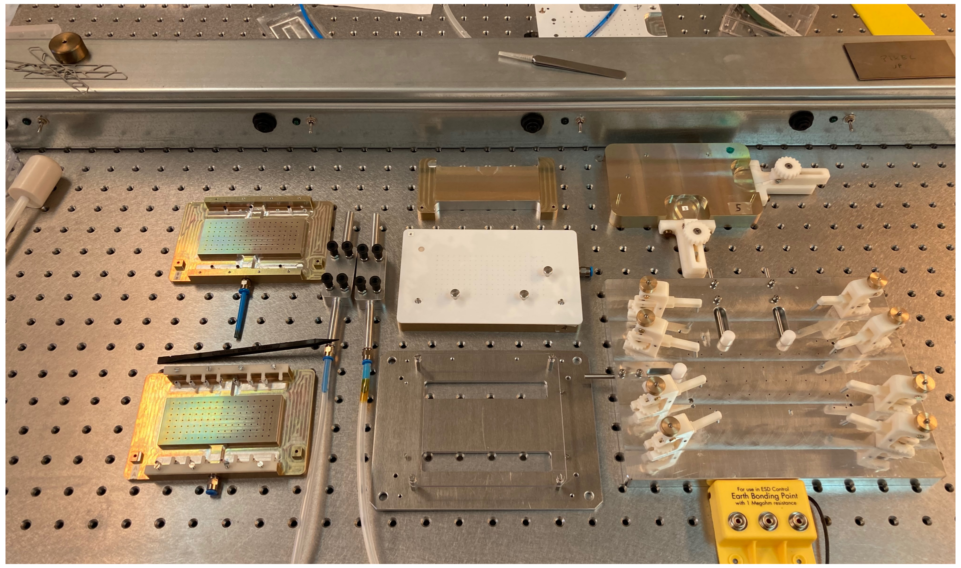

Optical Inspection Point
"Breadboard " Table with
assembly jigs


Glue mixing point
Nordson EV. Robot
Glue mixer
Chemicals storage

Backup







Precision Jigs designed and prototyped home for the module construction

Light flavour particle production in ALICE

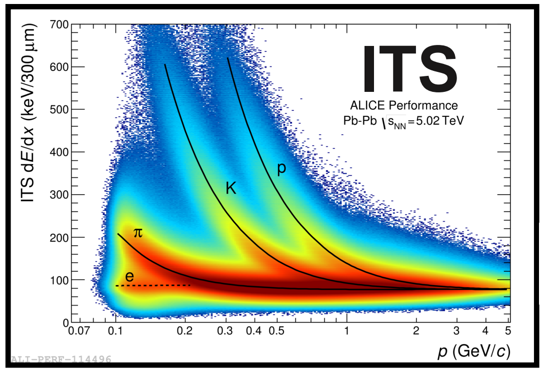
ALICE is designed to study the physics of strongly interacting matter under extreme temperature and energy densities to investigate the properties of the **quark-gluon plasma**

LHC Run1 and Run2 data taking		
Colliding System	**Year(s)**	**$\sqrt{s_{NN}}$ (TeV)**
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13
p-Pb	2013 2016	5.02 5.02, 8.16
Xe-Xe	2017	5,44
Pb-Pb	2010-2011 2015-2018	2.76 5.02

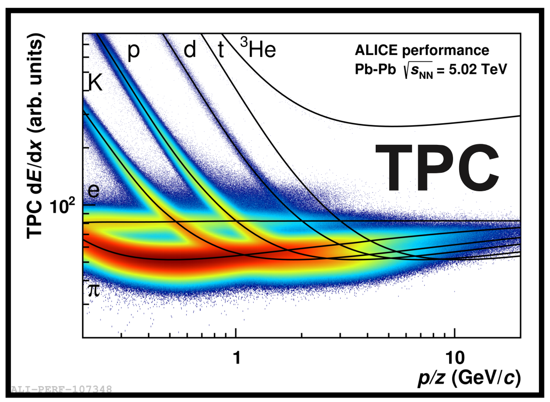
Published and Preliminary results available for most light-flavour and strange hadron species in all the colliding systems provided by LHC: π, $K^{\pm}$, p, K^{*0}, ϕ, Ξ^{*0}, $\Sigma^{*\pm}$, K^0, Λ, Ξ, Ω, d, t, ^{3}He, $^3_\Lambda$H.

The ALICE detector in LHC Run 1 and Run 2

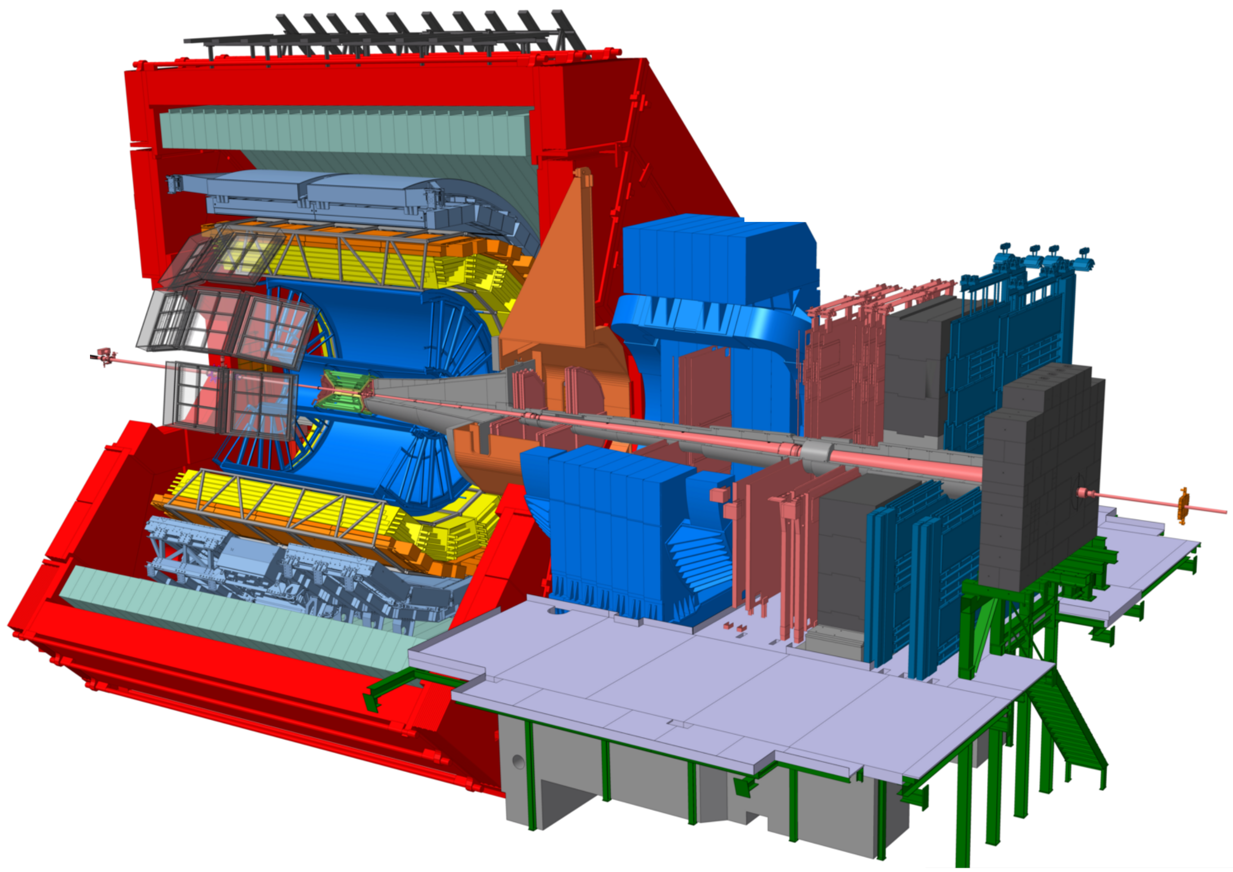
Multi-purpose detector at the LHC with unique particle identification capabilities and tracking down to very low momenta



ITS $\sigma_{dE/dx}$ ~ 10-15%



TPC $\sigma_{dE/dx}$ ~ 5%



Central Barrel Detectors (|η| < 1)

Inner Tracking System (**ITS**)

» Tracking, Vertexing, Triggering, Low momentum PID (dE/dx)

Time-Projection Chamber (**TPC**)

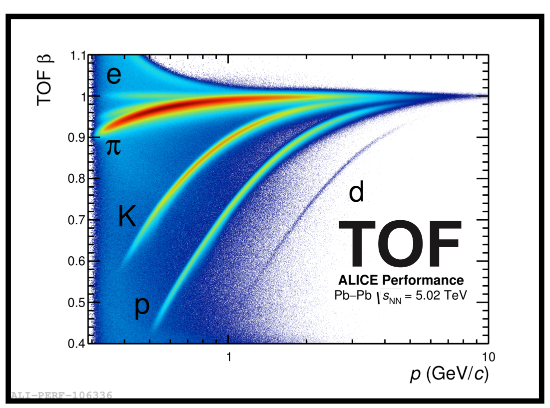
» Tracking, PID (dE/dx)

Time-of-flight detector (**TOF**)

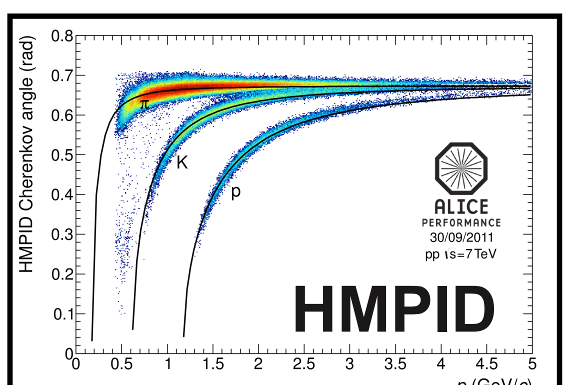
» PID (time-of-flight)

High Momentum PID (**HMPID**)

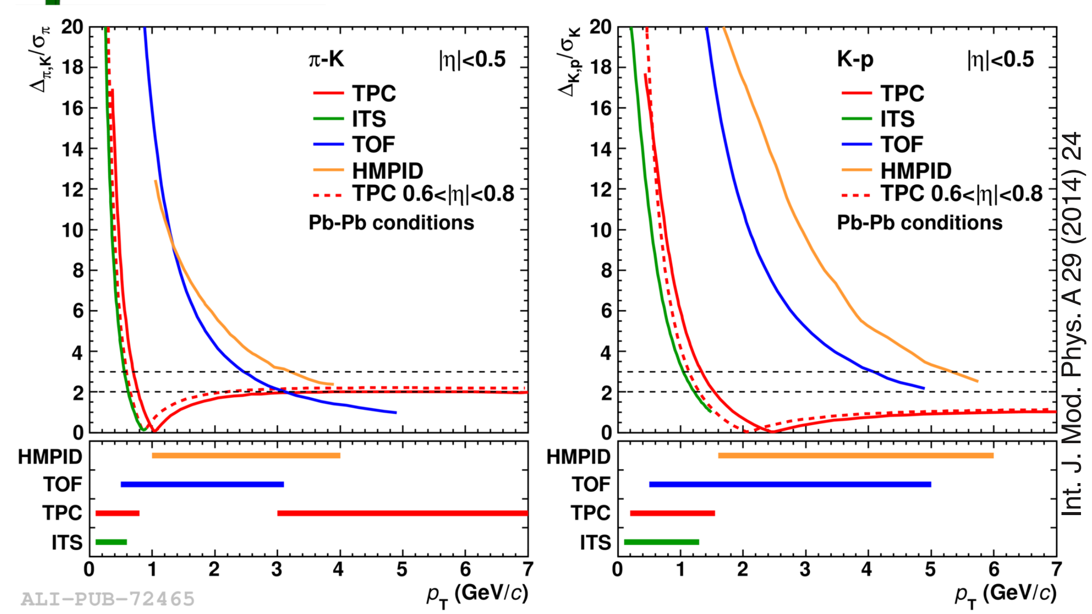
» PID (Cherenkov)



TOF $\sigma_{\text{Time Of Flight}}$ ~ 56 ps

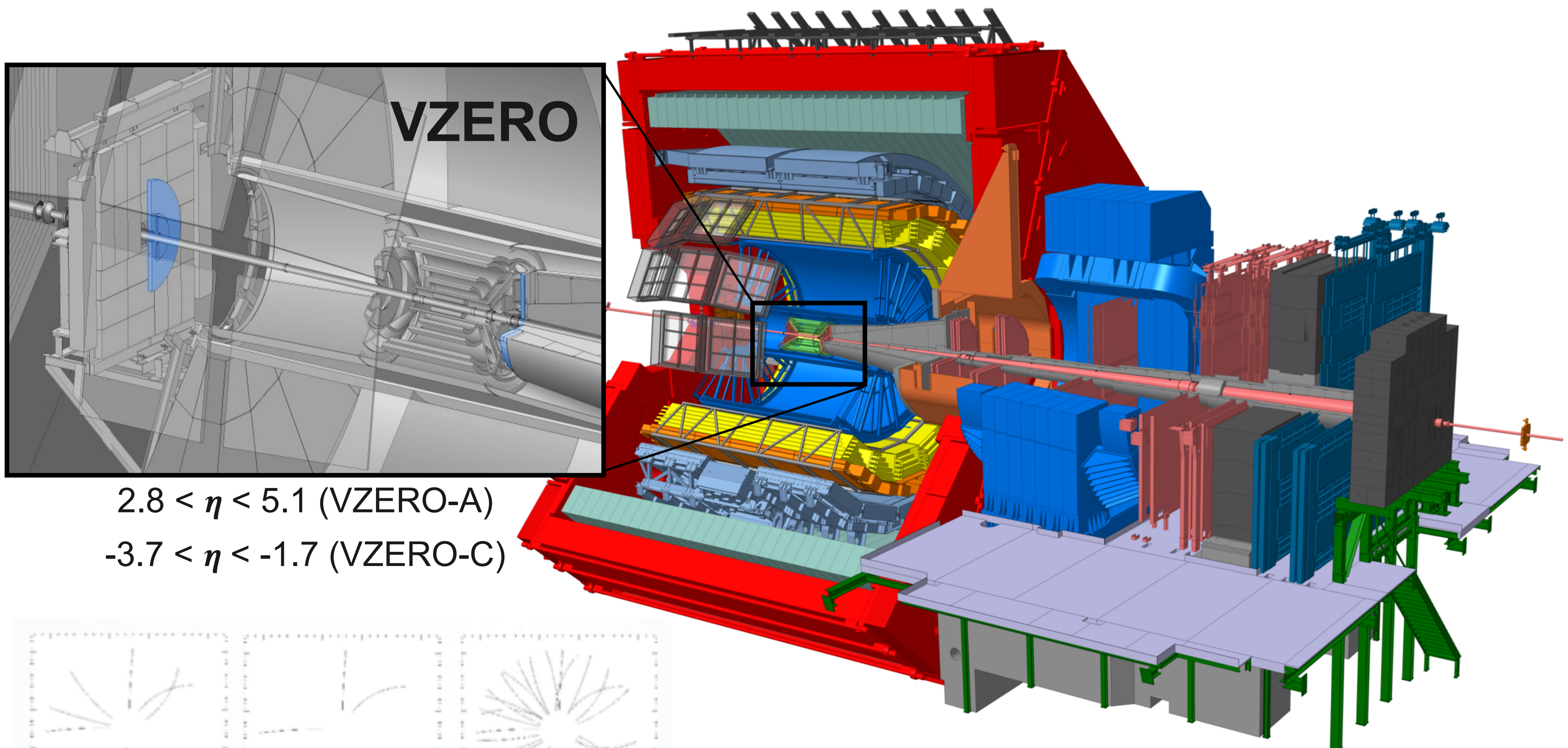


HMPID $\sigma_{\text{Cherenkov Angle}}$ ~ 3 mrad



The ALICE detector in LHC Run 1 and Run 2

Multi-purpose detector at the LHC with unique particle identification capabilities and tracking down to very low momenta



$2.8 < \eta < 5.1$ (VZERO-A)
$-3.7 < \eta < -1.7$ (VZERO-C)

<u>Central Barrel Detectors ($|\eta| < 1$)</u>

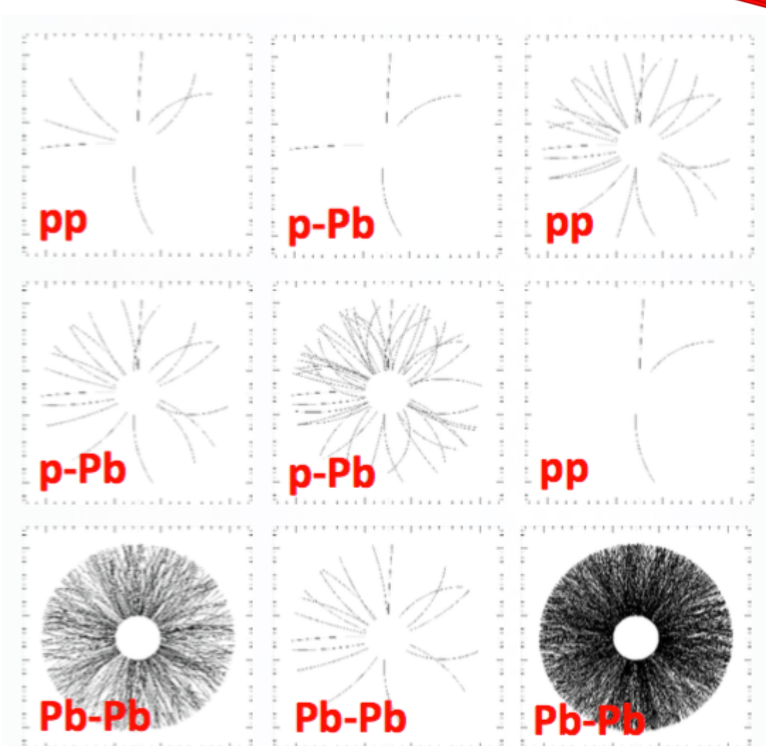
Inner Tracking System (**ITS**)
- » Tracking, Vertexing, Triggering, Low momentum PID (dE/dx)

Time-Projection Chamber (**TPC**)
- » Tracking, PID (dE/dx)

Time-of-flight detector (**TOF**)
- » PID (time-of-flight)

High Momentum PID (**HMPID**)
- » PID (Cherenkov)

VZERO
- » Triggering, Event multiplicity determination



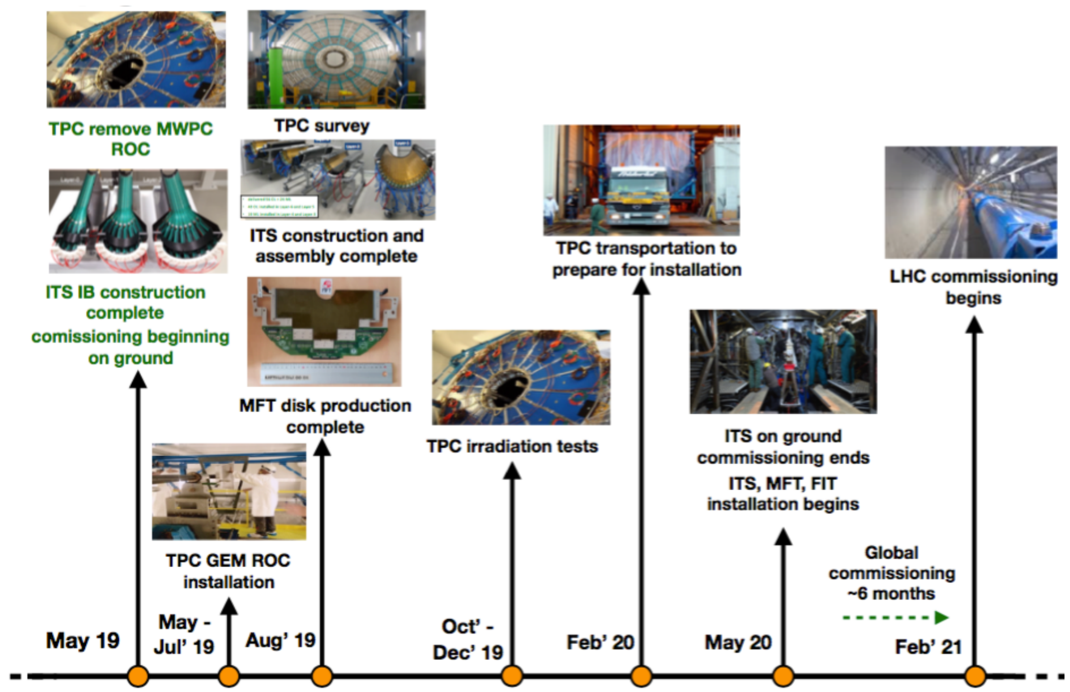
<u>Small and large system definition</u>

- » Commonly referred to the colliding system size (ee < pp < p-A < A-A)
- » In the following referred to the created medium size
  - ✓ Defined in terms of charge particle multiplicity
  - ✓ Correspondence to the previous true only on average
  - ✓ Multiplicity estimator used to categorise event according to its multiplicity (best if unbiased from particle under study)

LHC Run3/4 program and ALICE Upgrade strategy

4 key objectives identified by HL/HE-LHC working group 5 for high-density QCD at LHC after LS2

1. Characterising the microscopic long-wavelength QGP properties with unprecedented precision
2. Accessing the microscopic parton dynamics underlying QGP properties
3. Developing a unified picture of partial production from small (pp) to larger (p-A and A-A) systems
4. Probing parton densities in nuclei in a broad (x, Q2) kinematic range and searching for possible onset of parton saturation



Proposed run schedule for Run 3/4

System	$\sqrt{s}$, $\sqrt{s_{NN}}$	L_{int}	Note
Pb-Pb	5.5 TeV	13 nb^{-1}	3 nb^{-1} low B-field
p-Pb	8.8 TeV	1.2 pb^{-1}	
pp	14 TeV	200 pb^{-1}	High-multiplicity triggered
	8.8 TeV	3 pb^{-1}	
	5.5 TeV	6 pb^{-1}	
O-O	7 TeV	500 μb^{-1}	pilot run
p-O	9.9 TeV	200 μb^{-1}	

ALICE Upgrade strategy

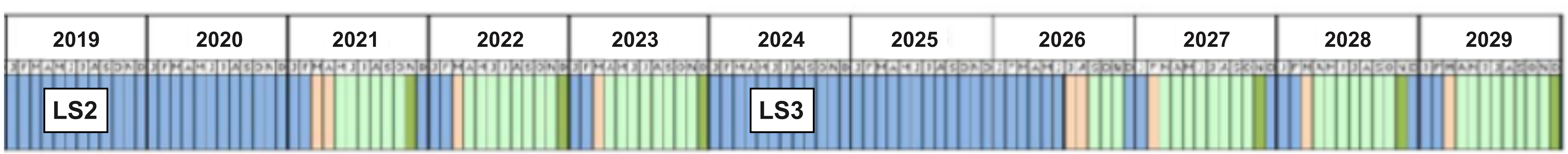
» New silicon trackers: ITS (mid-rapidity), MFT (forward rapidity)

» New TPC read-out chambers (GEMs) and electronics

» New Fast Interaction Trigger (FIT)

» New Read-out of other detectors (TOF, TRD, Muon arm, ZDC,…)

» Upgrade of Online and Offline systems (O^2 project)

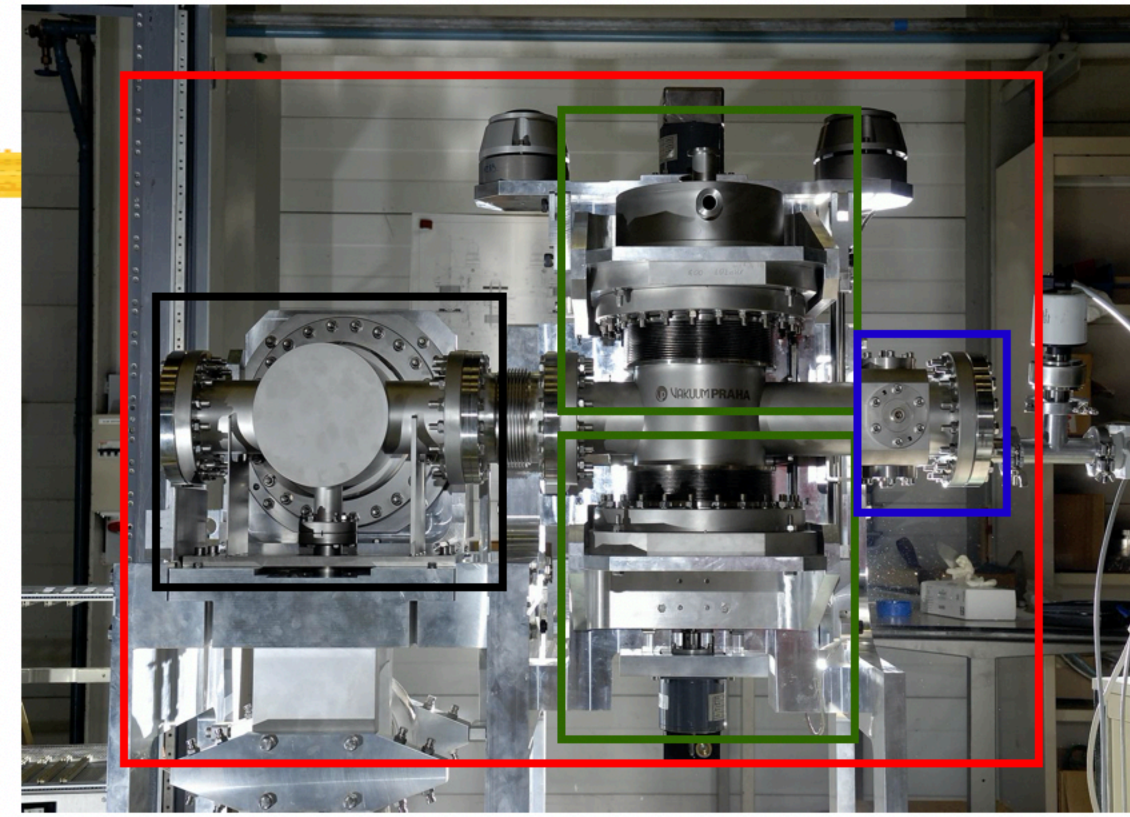


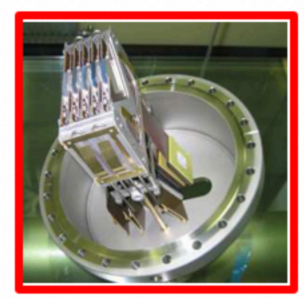
Run 3: L_{Pb-Pb} = 6.0 nb^{-1}

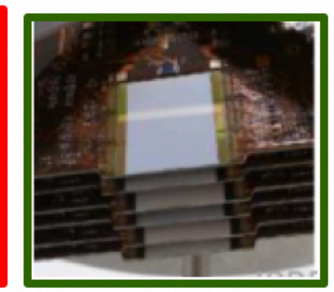
Run 4: L_{Pb-Pb} = 7.0 nb^{-1}

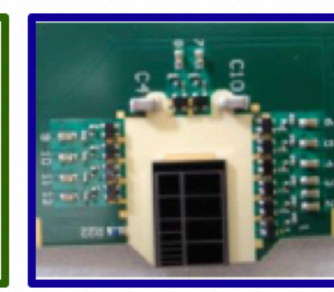
Roman pots in Run II & III

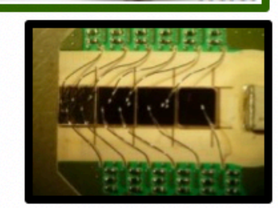
- In RunII the roman pots proven to be a "general purpose" dependable detector infrastructure able to host up to 4 different detectors types:
  - **Si strips**, TOTEM tracking detectors;
  - **Si 3D pixels**, CT-PPS tracking detectors;
  - **Diamond** base timing detectors, originally developed for TOTEM upgrade and then used in CT-PPS;
  - **UFSD** (Ultra Fast Silicon Detectors), originally developed for CT-PPS and then used in the last TOTEM special run.
- Tracking detectors time evolution (per arm):
  - 2016: All stations equipped with TOTEM Si strips;
  - 2017: 1 CT-PPS 3D pixel horizontal station;
  - 2018: 2 CT-PPS 3D pixel horizontal stations.
  - Run III: Configuration will remain the latest used for Run II. 3D pixel consolidation and mechanical upgrades.
- Timing detectors time evolution (per arm):
  - 2016: TOTEM 4 single diamond plane detectors (SD), designed for the vertical pots, moved to the horizontal to boost CT-PPS start of operations;
  - 2017: TOTEM 3 SD and 1 CT-PPS UFSD planes, in one horizontal RP;
  - 2018: TOTEM 2 SD and 2 double diamond sensor (DD) planes in the horizontal RP, 4 Ct-PPS UFSD planes in the vertical, used for TOTEM special runs.
  - Run III: Consolidation and electronics upgrades of the SD detectors and a new timing horizontal pot equipped with 4 DD planes.











3/02/2022 PPS 4

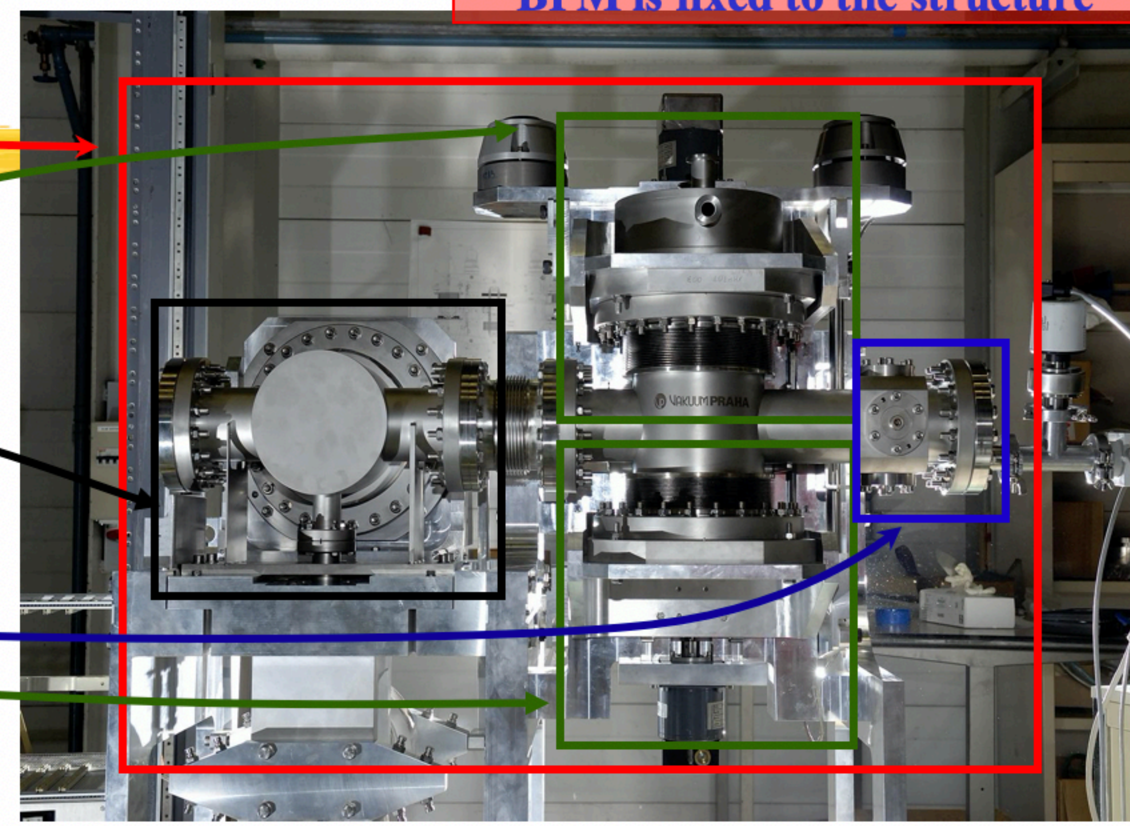
Backup

Roman pots

One RP station:
- 2 units

One unit:
- 2 vertical pot
- 1 horizontal pot
- 1 Beam Position Monitor (BPM)

BPM is fixed to the structure



- During **LHC RunI**, **12** Roman pots, distributed in **4 stations** at ±220 and ±147 m.
- Each RP was equipped with a stack of 10 silicon strip detectors, designed with the specific objective of reducing the insensitive area at the edge facing the beam to only a few tens of μm