Future for Heavy Ions & ALICE 3

Paola La Rocca

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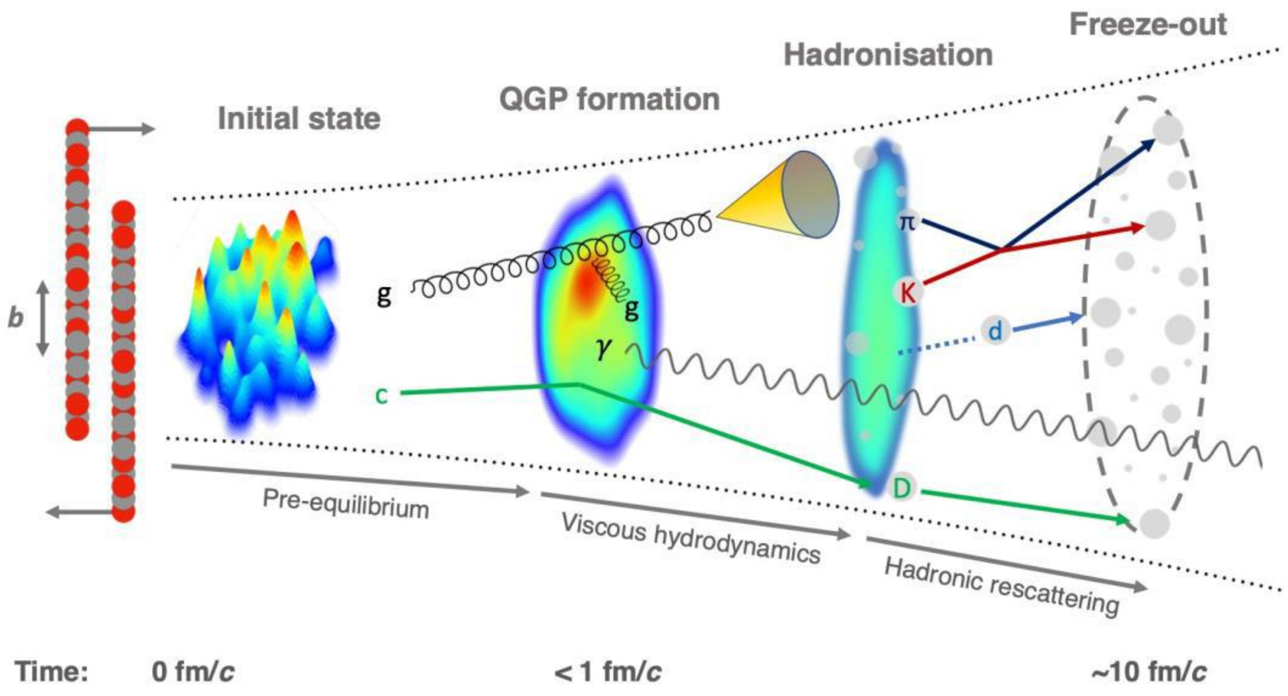
Upgrade motivation

ALICE is designed to study the quark-gluon plasma produced in heavy-ion collisions at the LHC

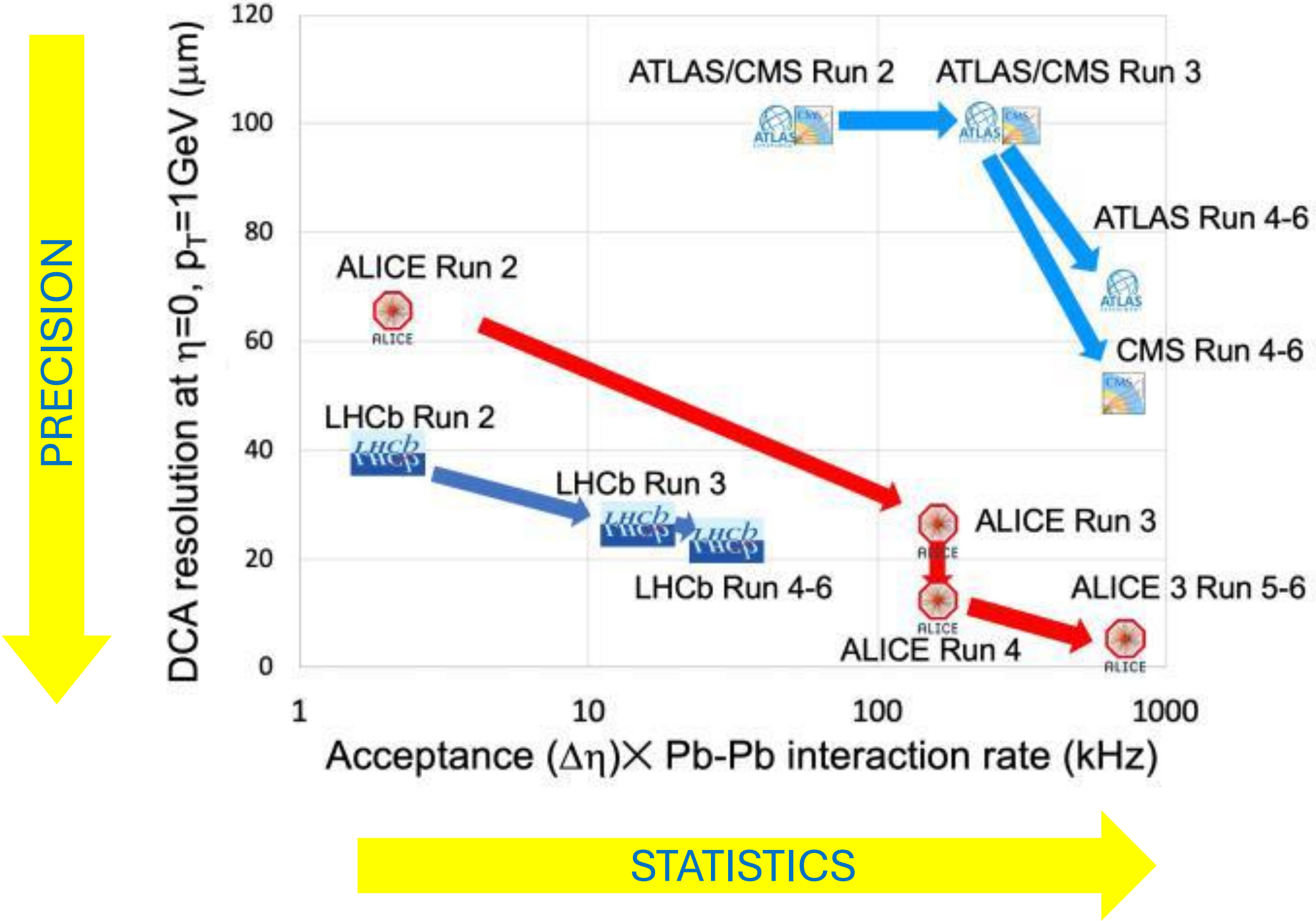
Two main physics goals driving the upgrade strategy:

- Heavy flavour (HF) transport and hadronization in the medium (down to vanishing p_T)
- Electromagnetic radiation from the medium down to zero p_T → mapping the evolution of the collision

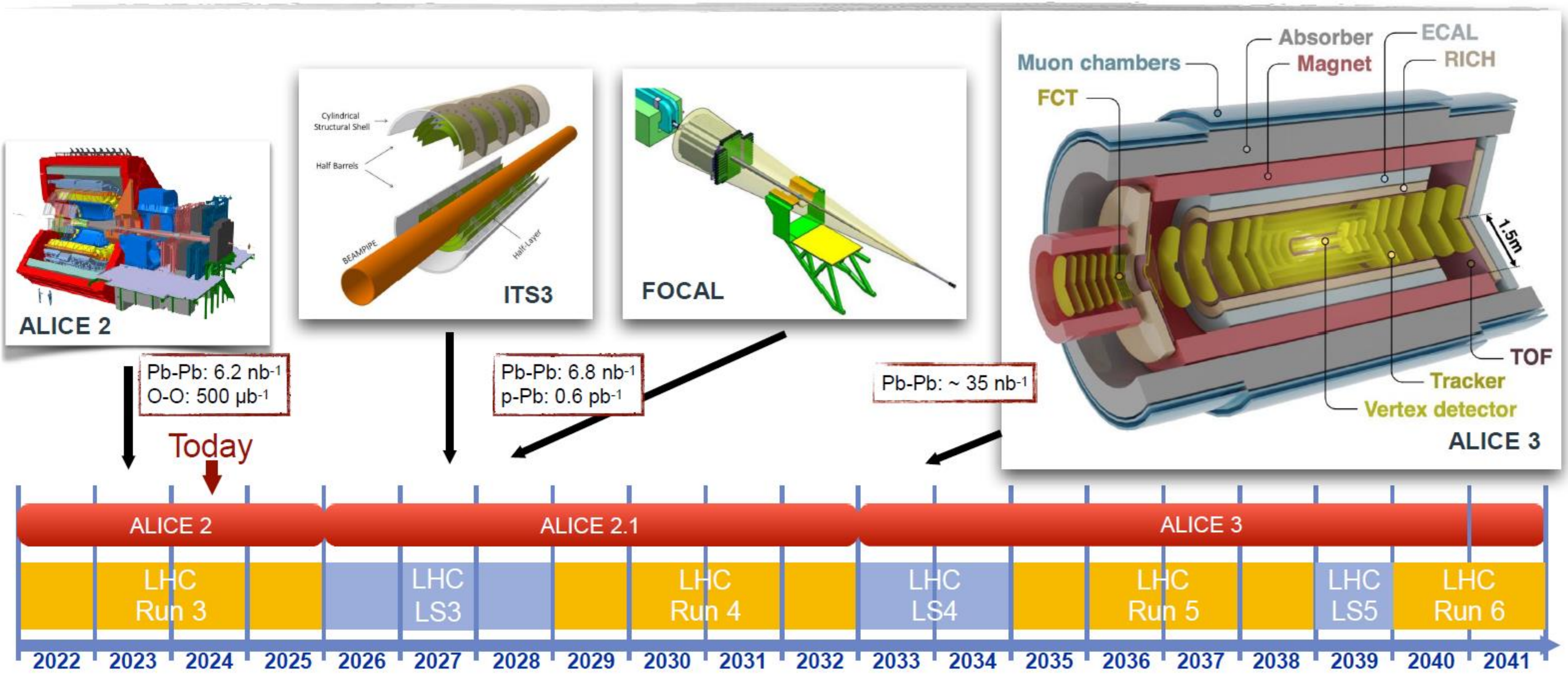


Upgrade requirements

- Increased effective acceptance (acceptance x readout rate)
- Improved tracking and vertexing performance at low p_T for background suppression
- Preserve in ALICE 2 and enhance in ALICE 3 particle identification (PID) capabilities



ALICE Upgrade Roadmap



Advancements in Silicon detectors

Improved tracking and vertexing performance

→ higher spatial resolution (smaller pixel size)

→ low material budget

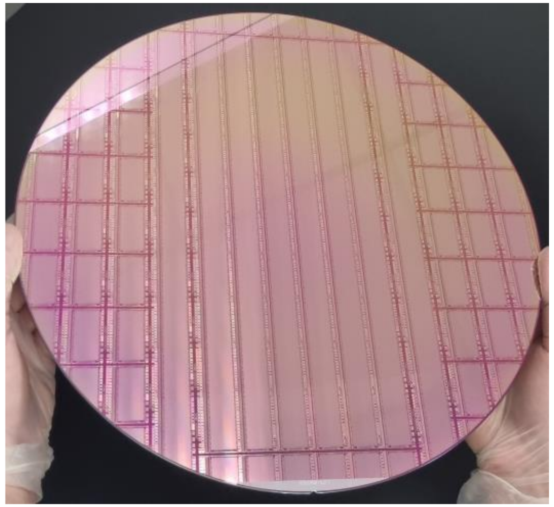
Down to vanishing p_T

→ detector closer to the interaction point

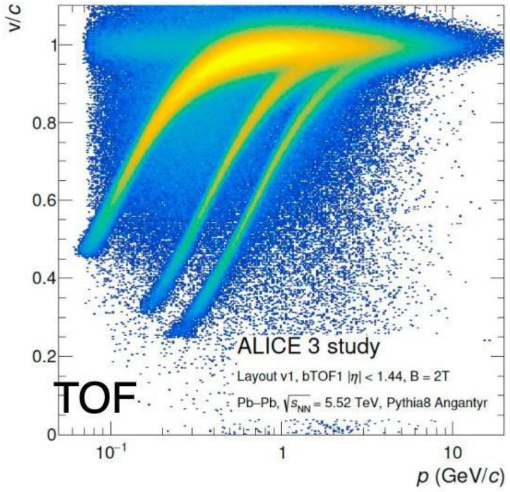
→ higher radiation tolerance

Preserve/improve PID

→ dE/dX, TOF

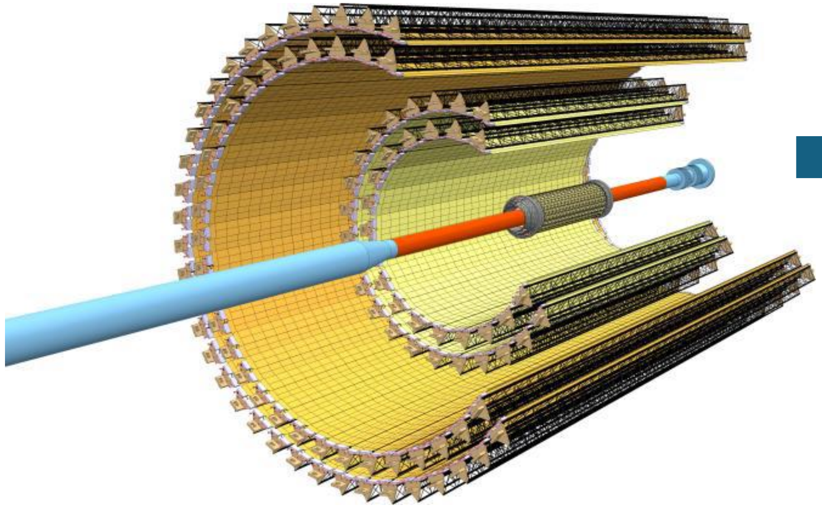


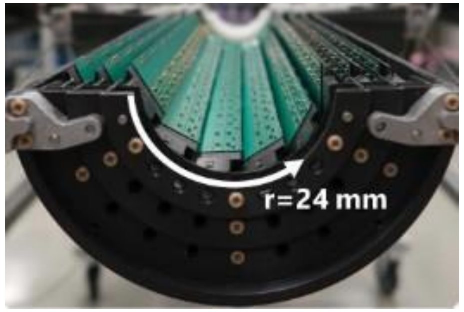
Silicon Stitched MAPS sensors

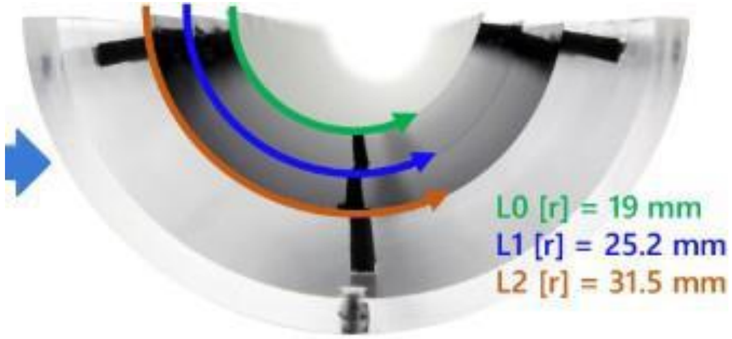


LGAD, CMOS and SiPM for TOF

ITS3 Project







- Replacement of ITS2 Inner Barrel with 3 layers of curved 50 μm thick wafer-scale MAPS
- Air cooling and ultra-light mechanical supports
- Reduced material budget of 0.09% X_0 instead of 0.36% X_0 per layer
- Smaller radius of the innermost layer: 19 mm instead of 23 mm

ITS3 Project – what's new?

- MAPS already used in ITS2 → MAPS in **65 nm technology**, improved charged collection efficiency and radiation hardness
- 65 nm technology → 300 mm wafer
- 300 mm wafer + **stitching** → large area sensors
- Flat sensors → curved sensor, **truly cylindrical geometry**

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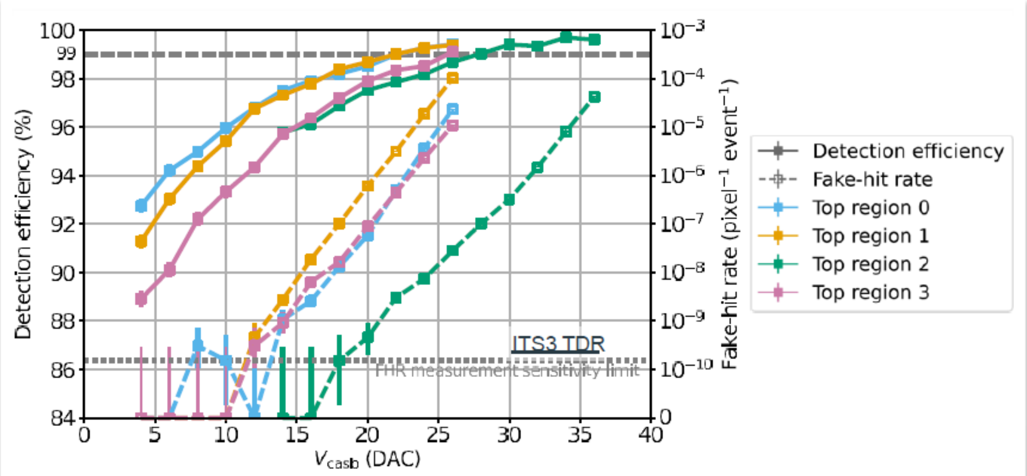
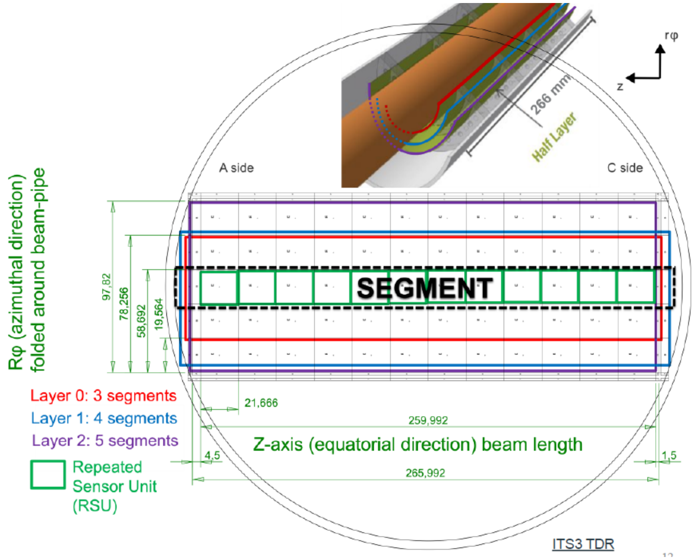
DONE!



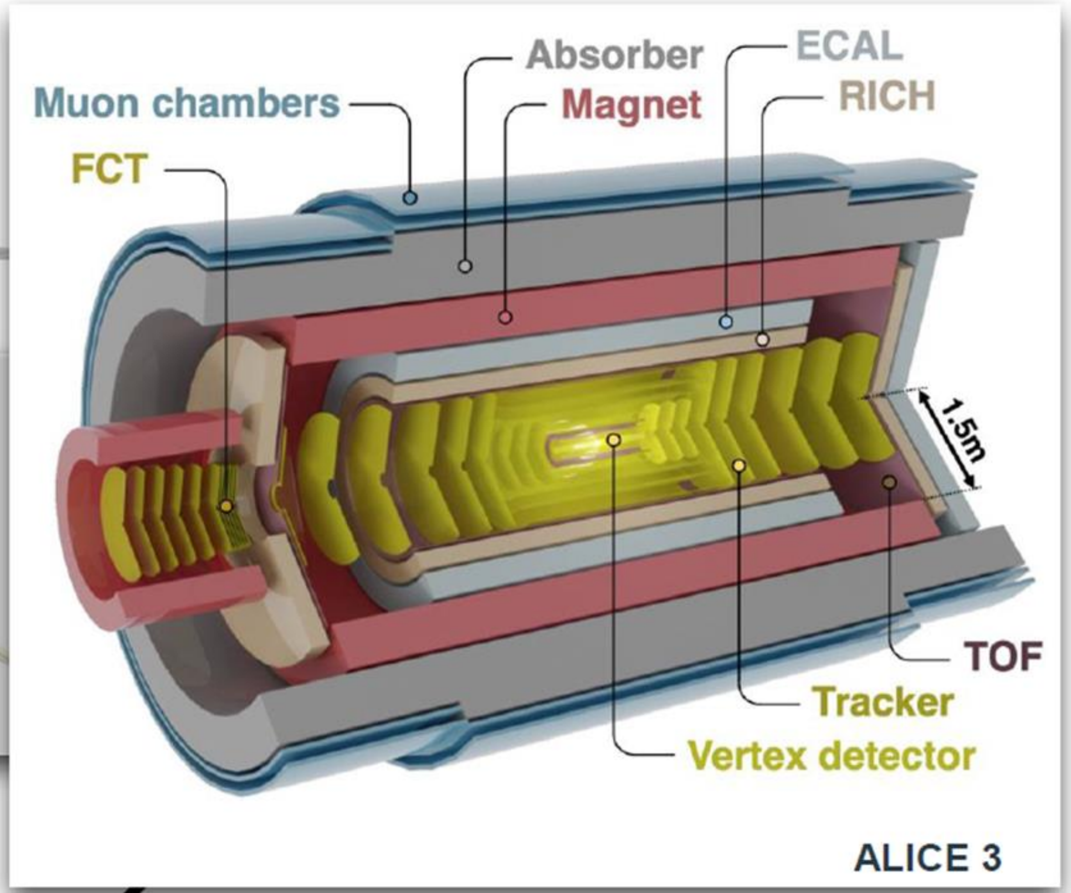
MOSS Detection efficiency and fake-hit rate

What next: production of the first fully operational prototype (MOSAIX)

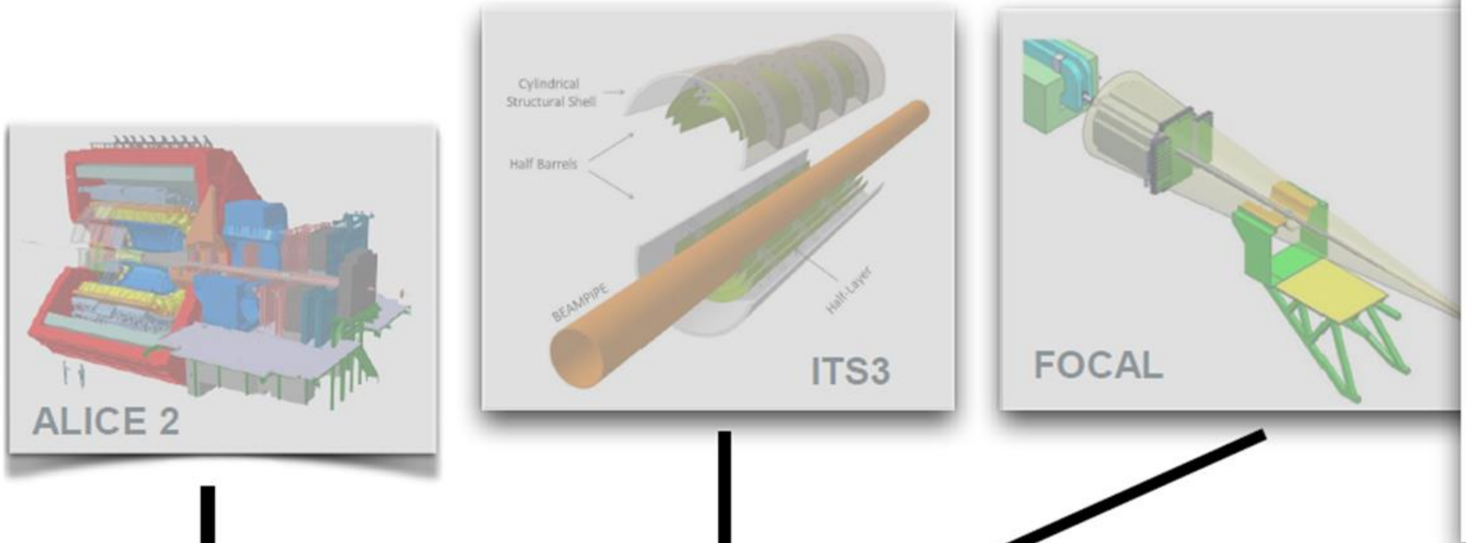


R&D for ALICE 3 will build upon ITS3 experience

ALICE 3



Absorber
ECAL
Muon chambers
Magnet
RICH
FCT
1.5m
TOF
Tracker
Vertex detector
ALICE 3



ALICE 2
Cylindrical Structural Shell
Half Barrels
BEAMPIPE
Half-Layer
ITS3
FOCAL

Today
ALICE 2
ALICE 2.1
ALICE 3
LHC Run 3
LHC LS3
LHC Run 4
LHC LS4
LHC Run 5
LHC LS5
LHC Run 6
2022
2023
2024
2025
2026
2027
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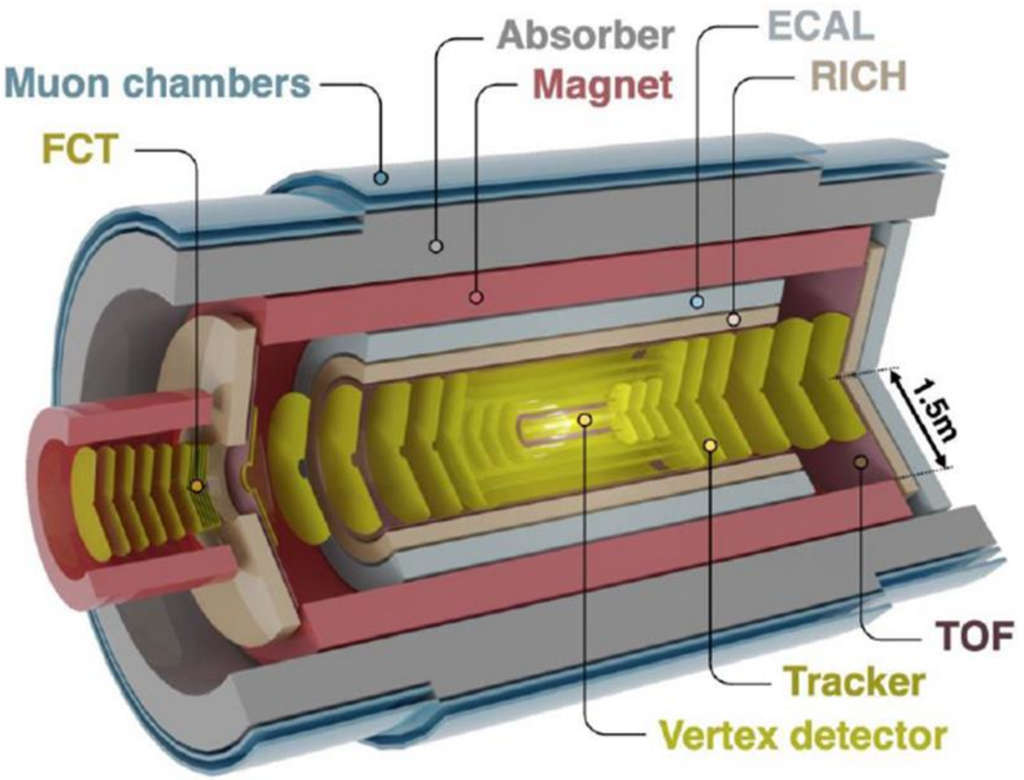
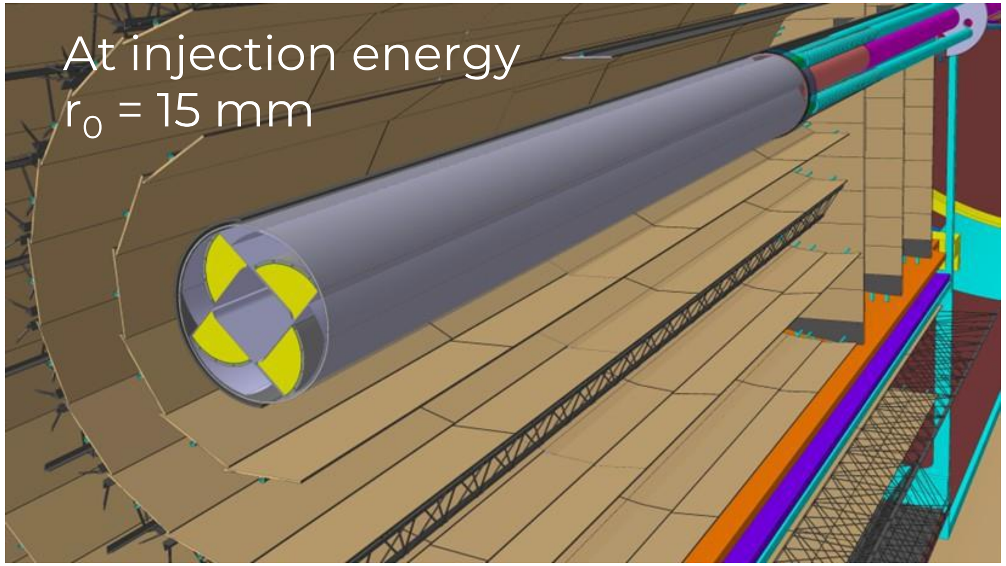
2041

ALICE 3 in a nutshell

- **Compact and lightweight all-silicon tracker**
  p_T resolution better than 1% @1 GeV/c and
  ~1-2% over large acceptance
- **Retractable vertex detector with excellent pointing resolution**
  About 3-4 μm @ 1 GeV/c
- **Large acceptance: $-4 < \eta < 4$, $p_T > 0.02$ GeV/c**
  e/π/K/p particle identification over large acceptance
  Superconducting magnet system
- **Continuous readout** and online processing
  Large data sample to access rare signals
- Muon Identification system
- Large-area ECal for photons and jets
- Forward Conversion Tracker for ultrasoft photons

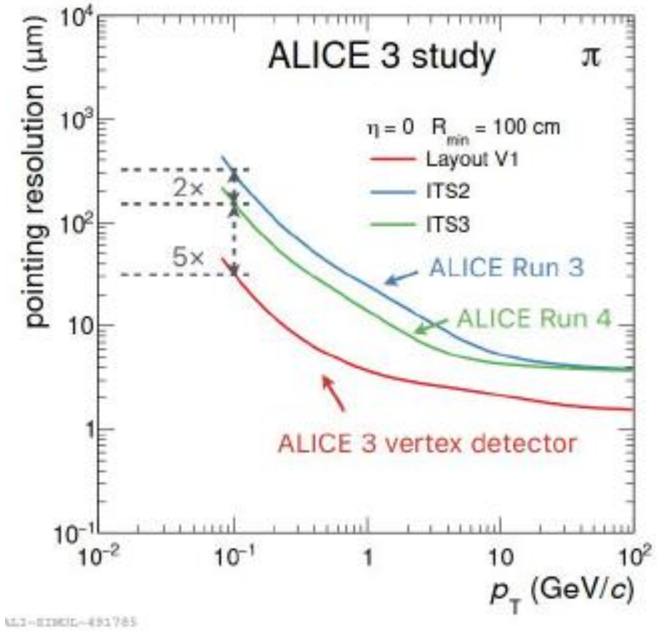


Vertex detector



Requirements:
- Hadron identification over a wide p_T range
- Tracking close to interaction point (5 mm)
- High readout rates (>100 kHz Pb-Pb and 24 MHz pp)
- Large acceptance ($|\eta| < 4$)

Specifications:
- 3 detection layers (barrel + disks)
- Retractable: $r_0 = 5$ mm (inside the beam pipe)
- Material budget: 0.1% X_0 / layer
- Unprecedented spatial resolution: 2.5 μm



Vertex detector

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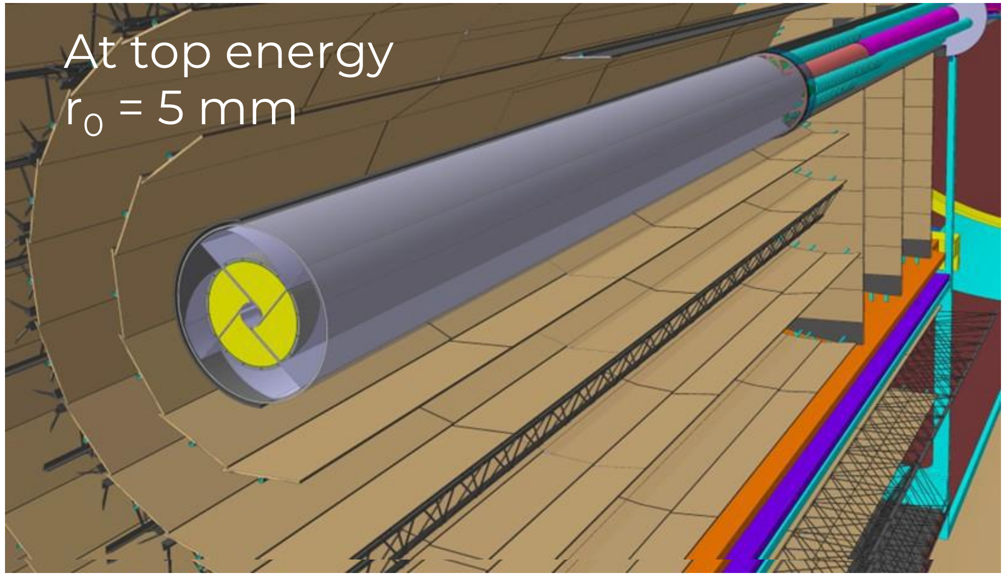
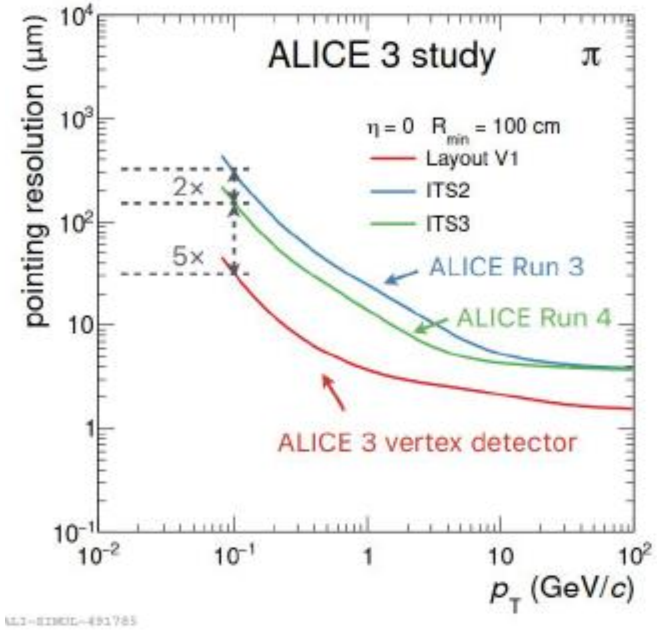
Main R&D challenges
- Light-weight in-vacuum mechanics and cooling
- Radiation hardness* (10^{16} 1 MeV neq/cm^2 + 300 Mrad)
- Pixel pitch of 10 µm

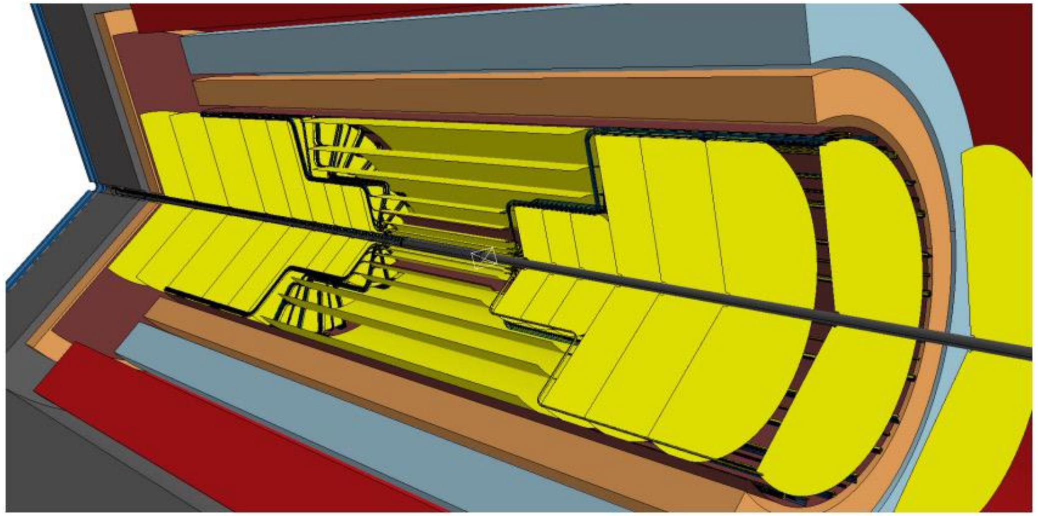
→ **Sensor R&D leverages on ALICE ITS3 upgrade**





Tracking detectors

Key detector characteristics
- 8 barrel layers (3.5 cm < R < 80 cm)
- 2 x 9 forward disks
- Total surface: ~ 60 m^2
- Material budget: 1% X_0 / layer
- Spatial resolution: 10 µm / 50 µm pixel pitch
- Low power consumption: 20 mW/cm^2
- 100 ns time resolution



Main R&D challenges
- Module design for high yield industrial mass production
- Low power consumption while maintaining timing performance

Particle identification

Time of Flight

- Time resolution target: 20 ps
- Low material budget 1-3% X_0/layer
- Total surface: ~45 m^2

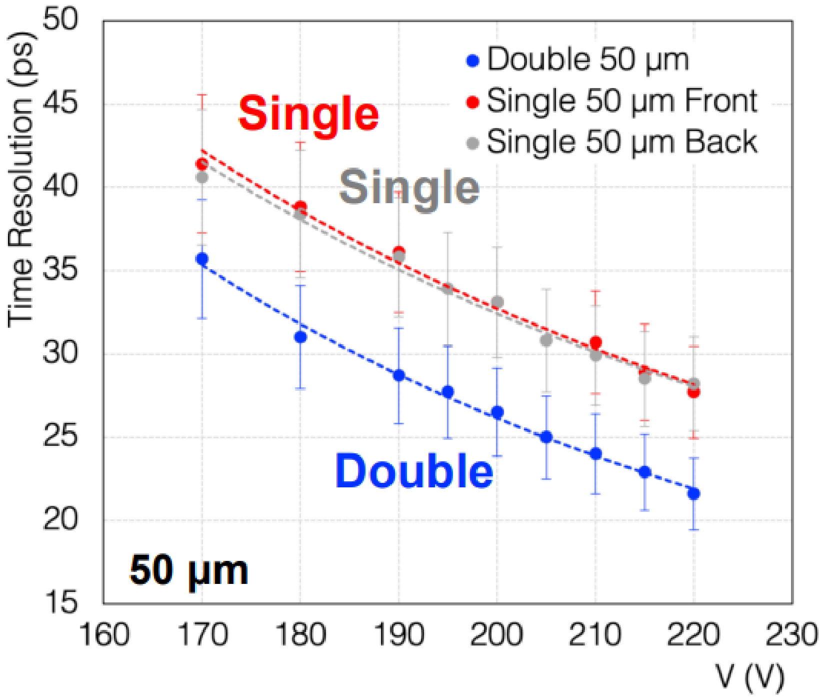
R&D streams:

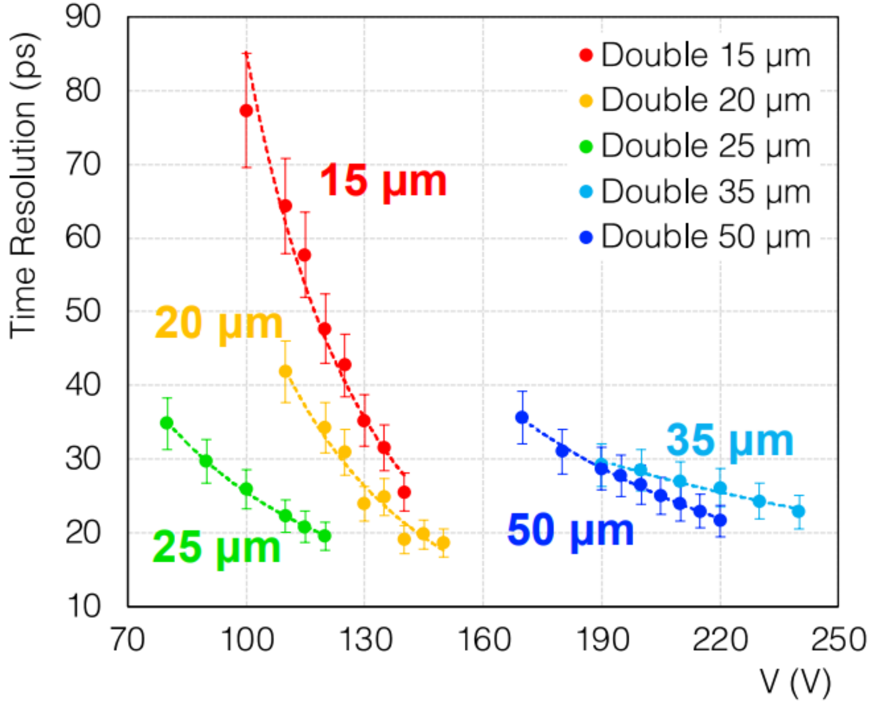
- Single and double LGADs
- SiPM coated with different resins (type, thickness)
- 50 μm thick CMOS-LGAD (ARCADIA / MADPIX)

Particle identification

Single and double LGADs

- double-LGAD introduced and tested for the first time
- signals of both layers sum up resulting in a larger signal (charge) using a single front-end amplifier
- consistent improvement of the time resolution for the double-LGAD w.r.t. single LGAD
- better timing by going to thinner LGAD design

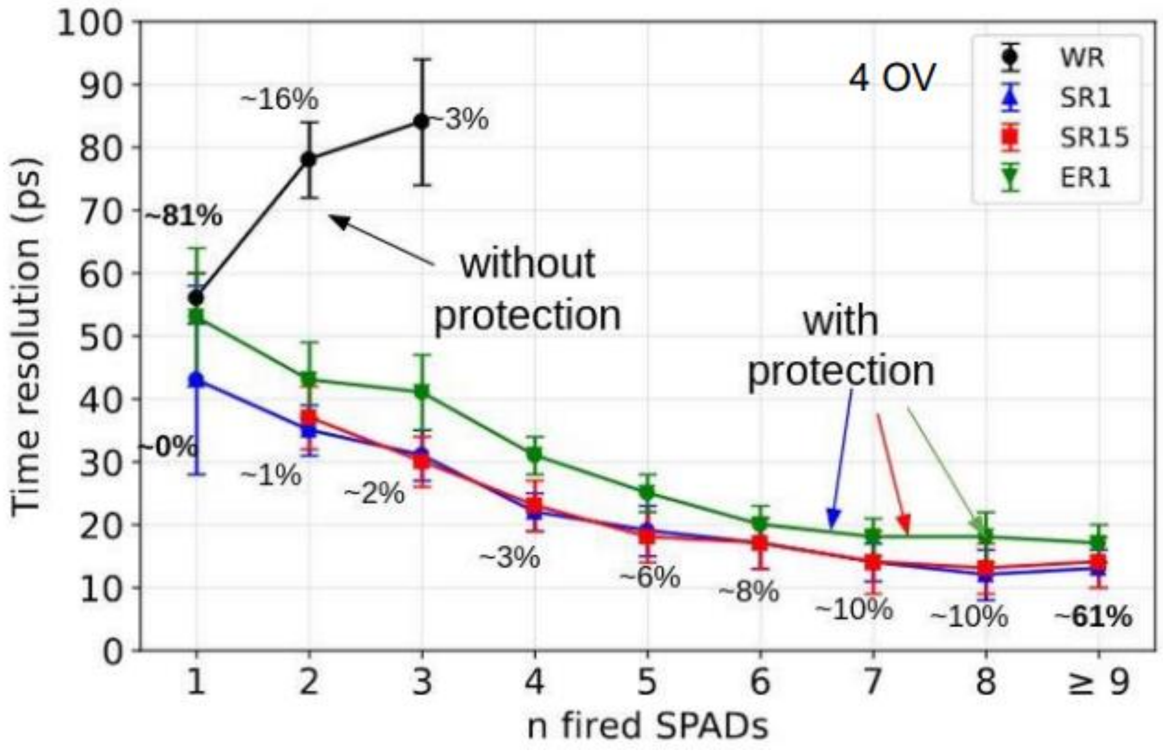




Particle identification

SiPM coated with different resins (type, thickness)

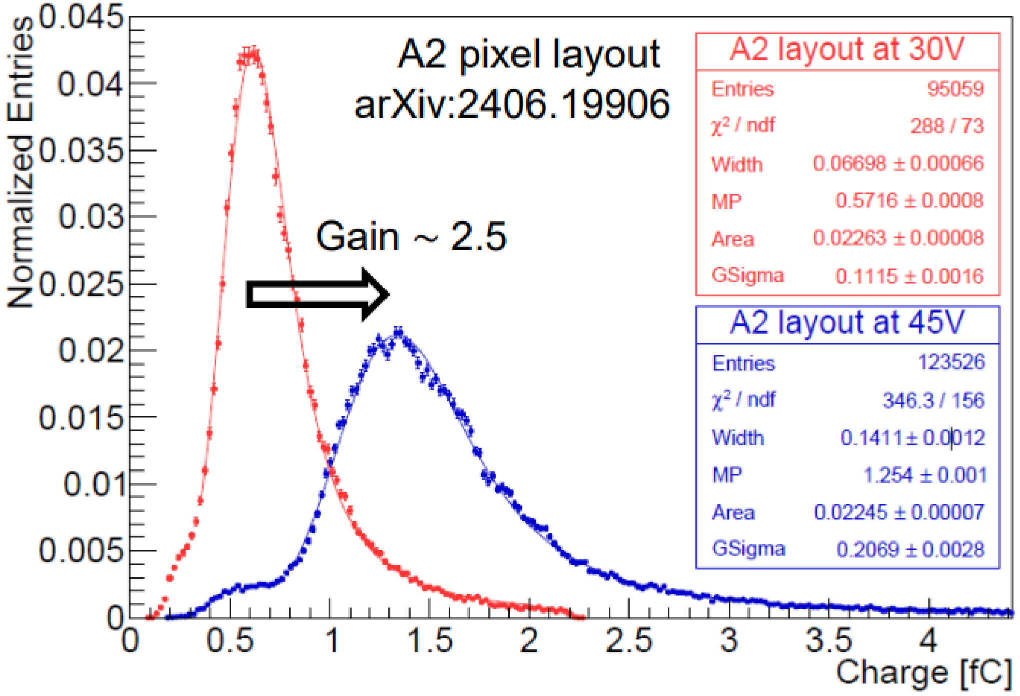
- Direct response of SiPMs to the passage of charged particles was studied for the first time
- high crosstalk with the protection resin (large contribution of the Cherenkov light produced in the resin) → huge noise rejection w.r.t. standard SiPMs
- The increased number of firing SPADs improves significantly the time resolution



Particle identification

CMOS-LGAD (ARCADIA / MADPIX)

- Advantages of a monolithic approach: lower material budget, cheap and easier assembly, lower power consumption
- LGAD technology has been integrated in INFN-ARCADIA production of MAPS
- First prototype (MadPix) with integrated electronics and gain layer produced
- Work in progress to achieve the expected gain



Summary

ALICE has an ambitious upgrade program, aiming at furthering our understanding of the QGP in particular with precise measurements of heavy flavour and electromagnetic radiation.

ITS3: replacement of inner barrel of ITS2 with **stitched wafer-scale 65 nm CMOS sensors** to reduce material budget and improve pointing resolution
→ ITS3 project is on track for installation in LHC LS3

ALICE 3: innovative detector concept **focusing on silicon technology**
→ R&D activities started on several strategic areas

ITS3 and ALICE 3 pioneer several R&D directions that can have a broad impact on future HEP experiments (e.g., EIC, FCC-ee)