# ALICE Upgrade

***CLHCP 2021***

裴 骅

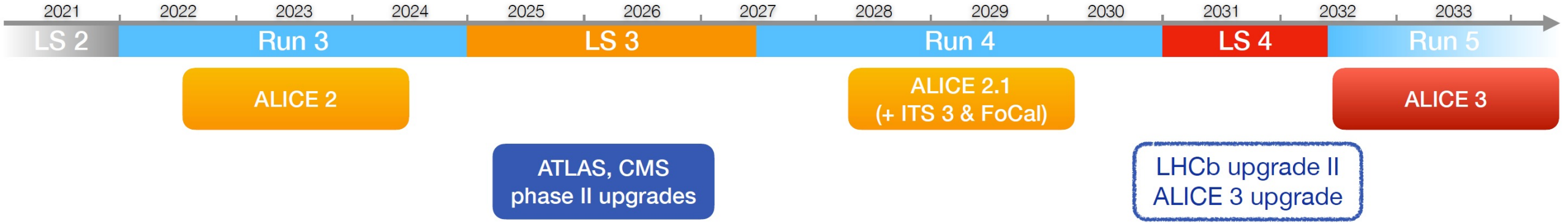
华中师范大学

# Outline

- Overview of ALICE Detector Upgrade program
- ALICE 2: LS2 and Run 3 pilot beam
- ALICE 2.1: Run 4
- ALICE 3: Run 5 and beyond
- Summary and outlook

# ALICE detector upgrade program

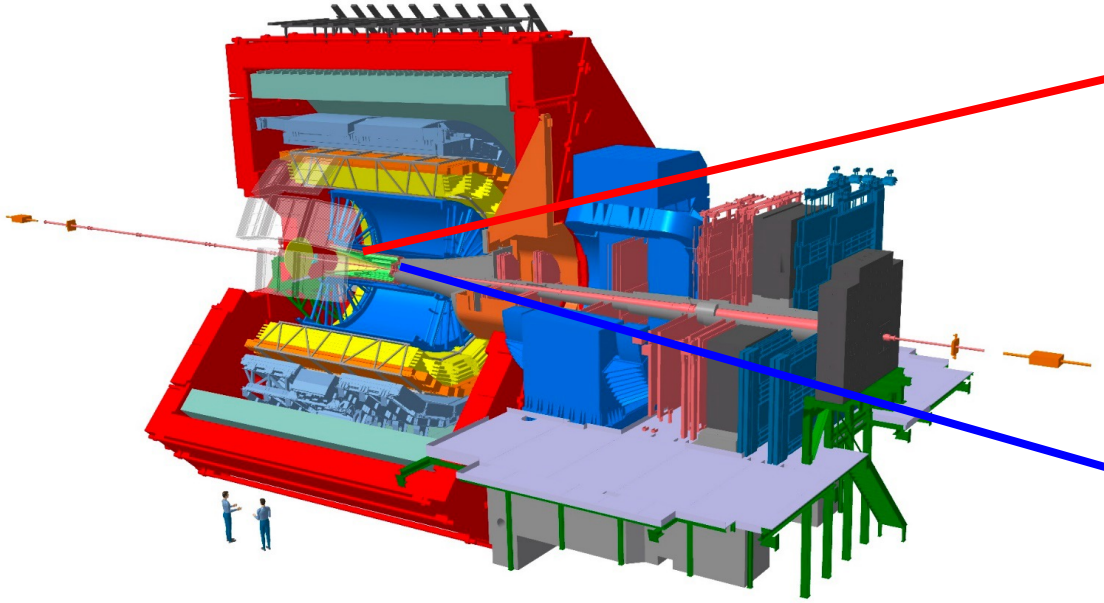
- ALICE 2: **Achievement today** (LS2 & Run 3, by 2021)
- ALICE 2.1: **New hope tomorrow** (LS3 & Run 4)
- ALICE 3: **The day after tomorrow** (Run 5 and beyond)

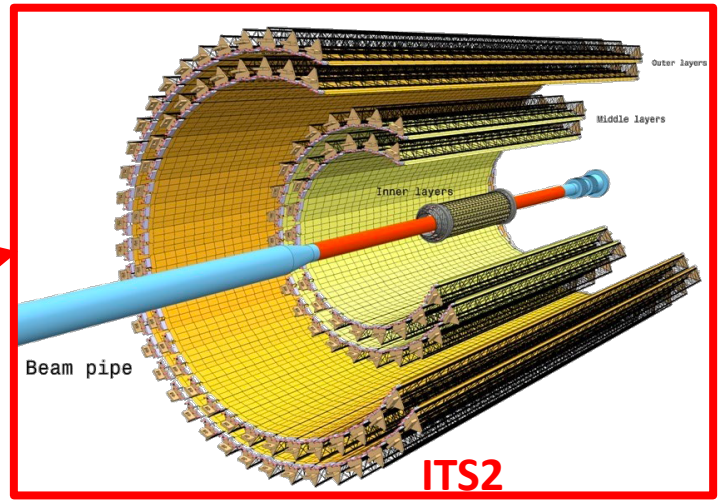


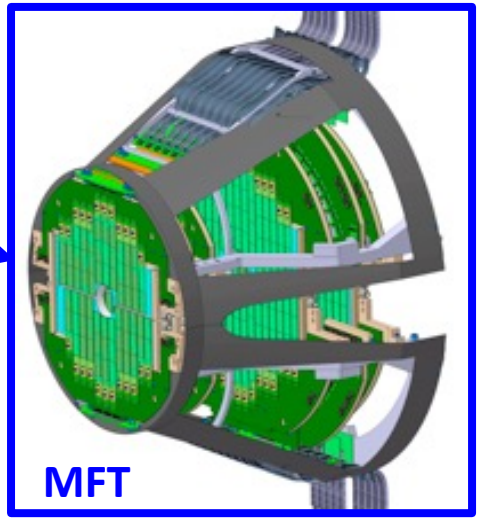
# ALICE 2: The upgrades ready for Run 3

- Chinese contribution in colored **text**

Tracking detectors upgraded: **Inner Tracking System (ITS2)**
Time Projection Chamber (GEM)
**Muon Forward Tracker (MFT)**



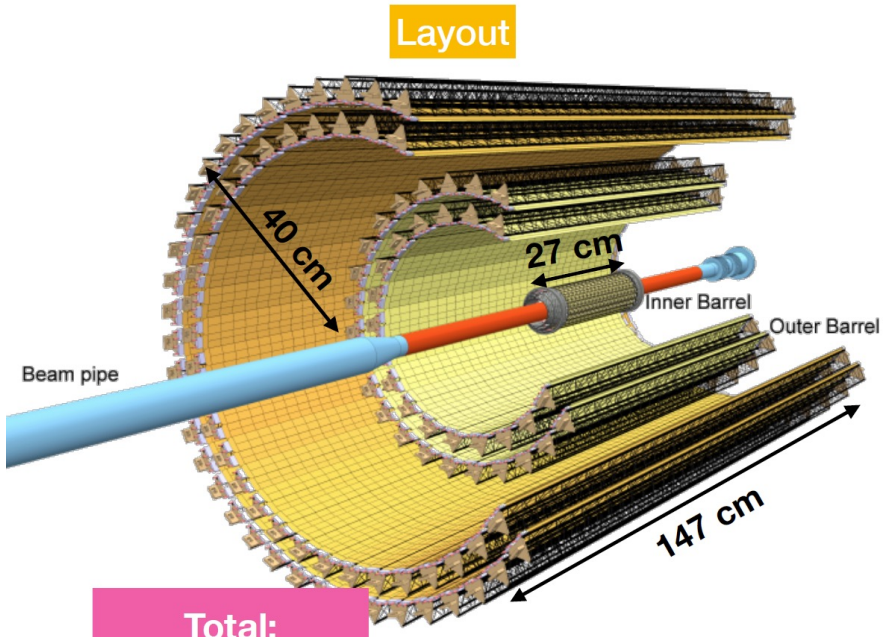



Other upgrades:
- Fast Interaction Trigger (FIT)
- Integrated Online-Offline system ($O^2$)
  → record minimum bias Pb-Pb data at > 50kHz
- Detector readout electronics

# ITS2: improve tracking at low $p_T$

- ITS2 fully commissioned 2021



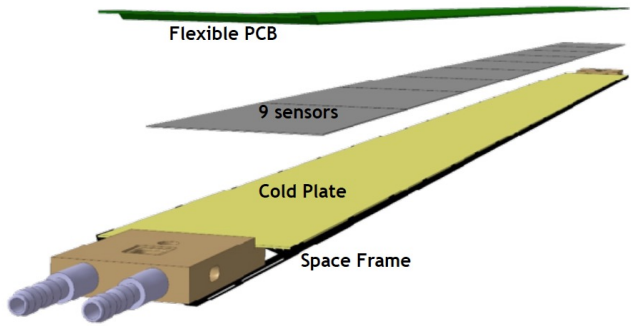

**Total:**
- 24k chips
- 10 m²
- 12.5 GPixel

**Inner Barrel (IB)**

3 Inner Layers: 12+16+20 Staves
1 Module / Stave

9 sensors per Module

96 Modules produced
(2 Inner Barrels + spares)

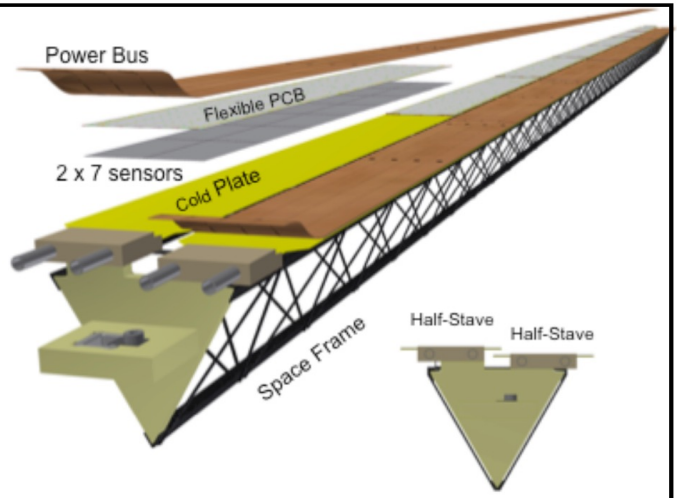



**Outer Barrel (OB)**

2 Middle Layers: 30+24 Staves
2×4 Modules / Stave
2 Outer Layers: 42+48 Staves
2×7 Modules / Stave

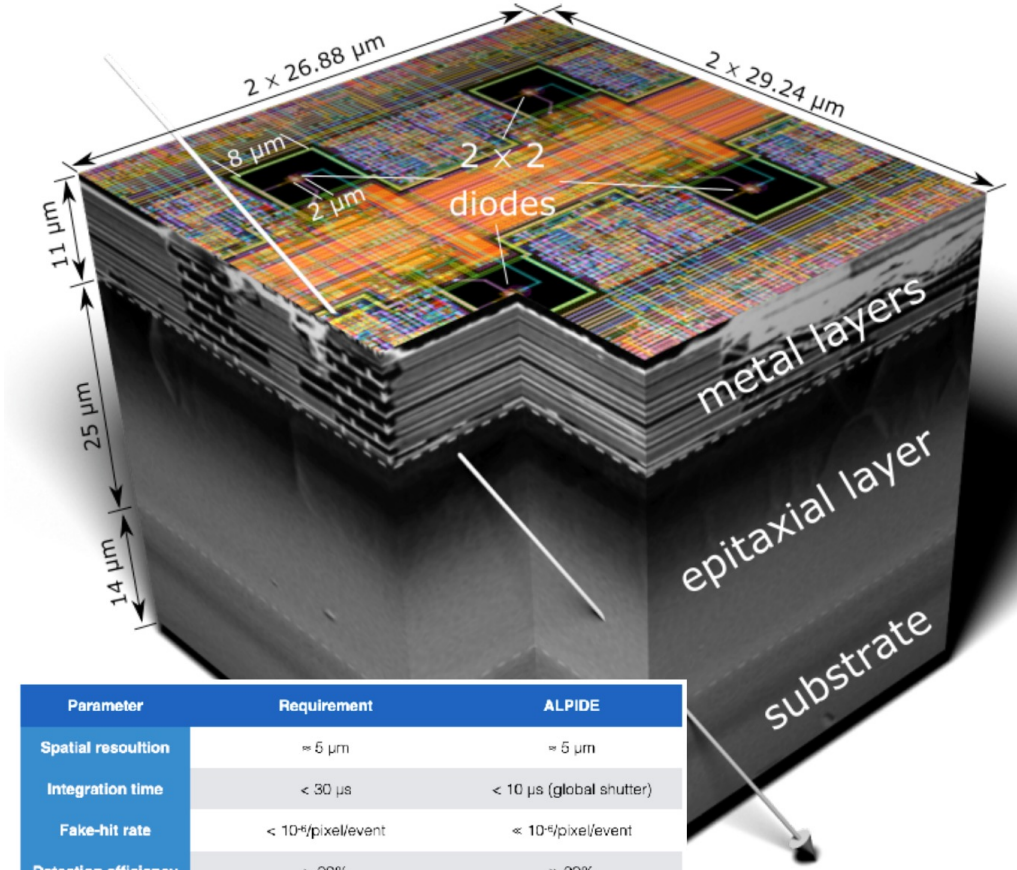
2×7 sensors / Module
(Middle and Outer Layers are equipped with the same Module Type)

1880 Modules produced
(including spares)



# ITS2 realization with ALPIDE

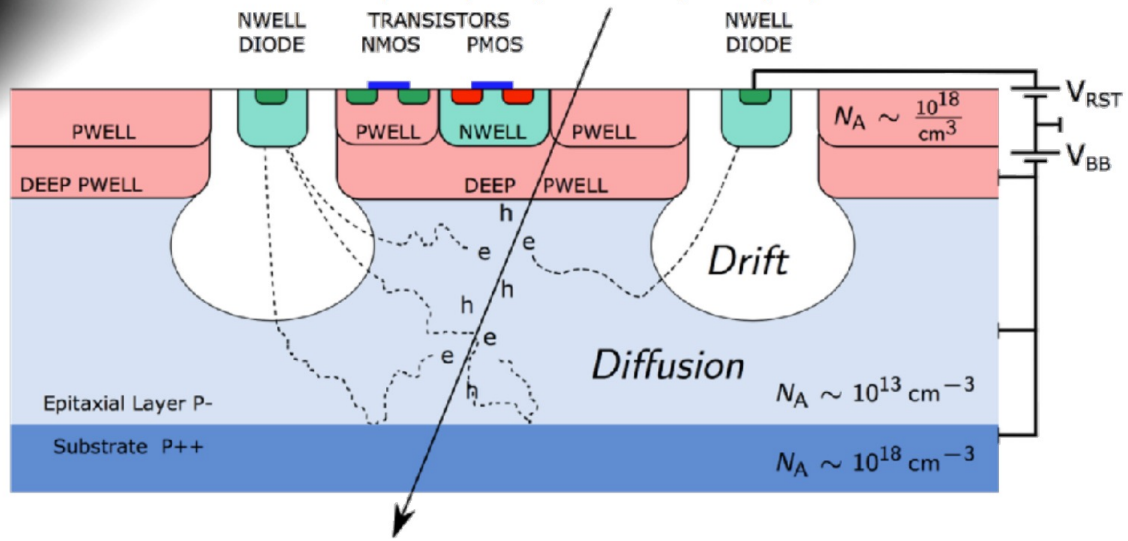
- ALPIDE technology




| Parameter | Requirement | ALPIDE |
|---|---|---|
| Spatial resolution | ≈ 5 µm | ≈ 5 µm |
| Integration time | < 30 µs | < 10 µs (global shutter) |
| Fake-hit rate | < $10^{-6}$/pixel/event | ≪ $10^{-6}$/pixel/event |
| Detection efficiency | > 99% | ≈ 99% |
| Power consumption | < 100 mW/cm² | < 40 mW/cm² |
| Radiation hardness* | > 2.7 Mrad (IB), 100 krad (OB) (TID)<br>> $1.7\times10^{13}$ 1 MeV $n_{eq}$ (NIEL) | OK |

* including safety factor of 10

- **Process:** TowerJazz 180 nm CIS
  - deep p-well to allow CMOS circuitry inside matrix
  - reverse-substrate bias
- **Detection layer:** 25 µm high-resistive (>1 kΩcm) epitaxial layer
- **Thickness:** 100 µm (OB) or 50 µm (IB)



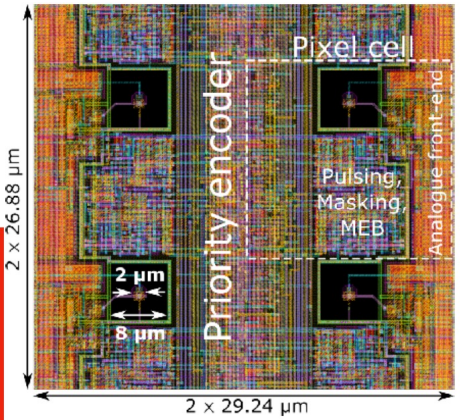
# ITS2 realization with ALPIDE

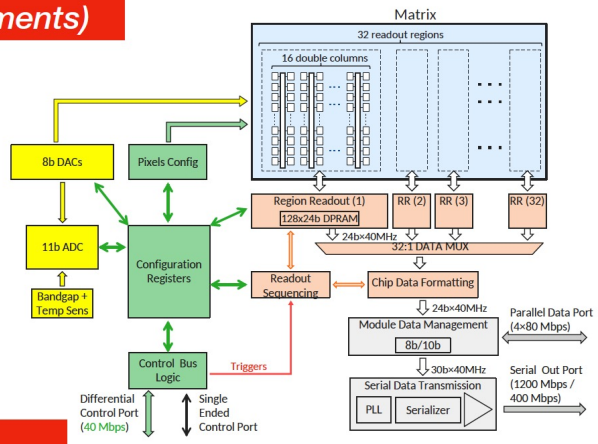
- ALPIDE functionality

  - **In-pixel circuitry**
    - continuously active, low-power (40 nW) front-end
    - 3-level multiple-event memory
    - masking and analog+digital testing circuitry (each pixel)
  - **Column readout**
    - priority encoder, asynchronous, hit-driven
  - **Periphery**
    - event handling (global shutter)
    - data transmission, directly drives 8 m-long cables

O(200) transistors/ pixel

*(wrt. traditional 3T/4T arrangements)*



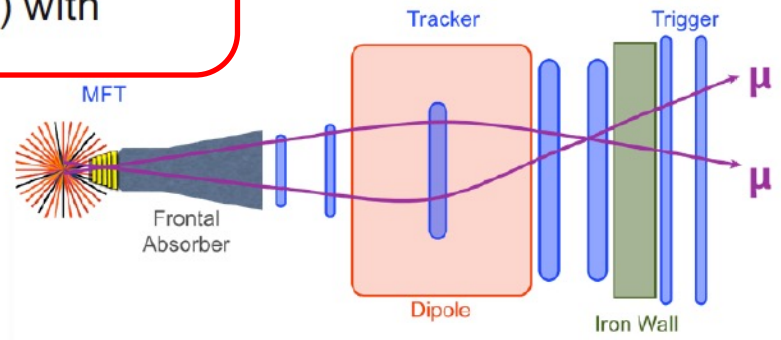

This marks a new level of integration density for MAPS

# MFT: precise vertexing of forward muons

- New detector: the **Muon Forward Tracker**
- Vertex tracker for the Muon Spectrometer, to be installed between the interaction point and the hadron absorber ($-3.6 < \eta < -2.5$)
- 920 silicon pixel sensors (0.4 $m^2$) in 280 ladders of 2 to 5 sensors each

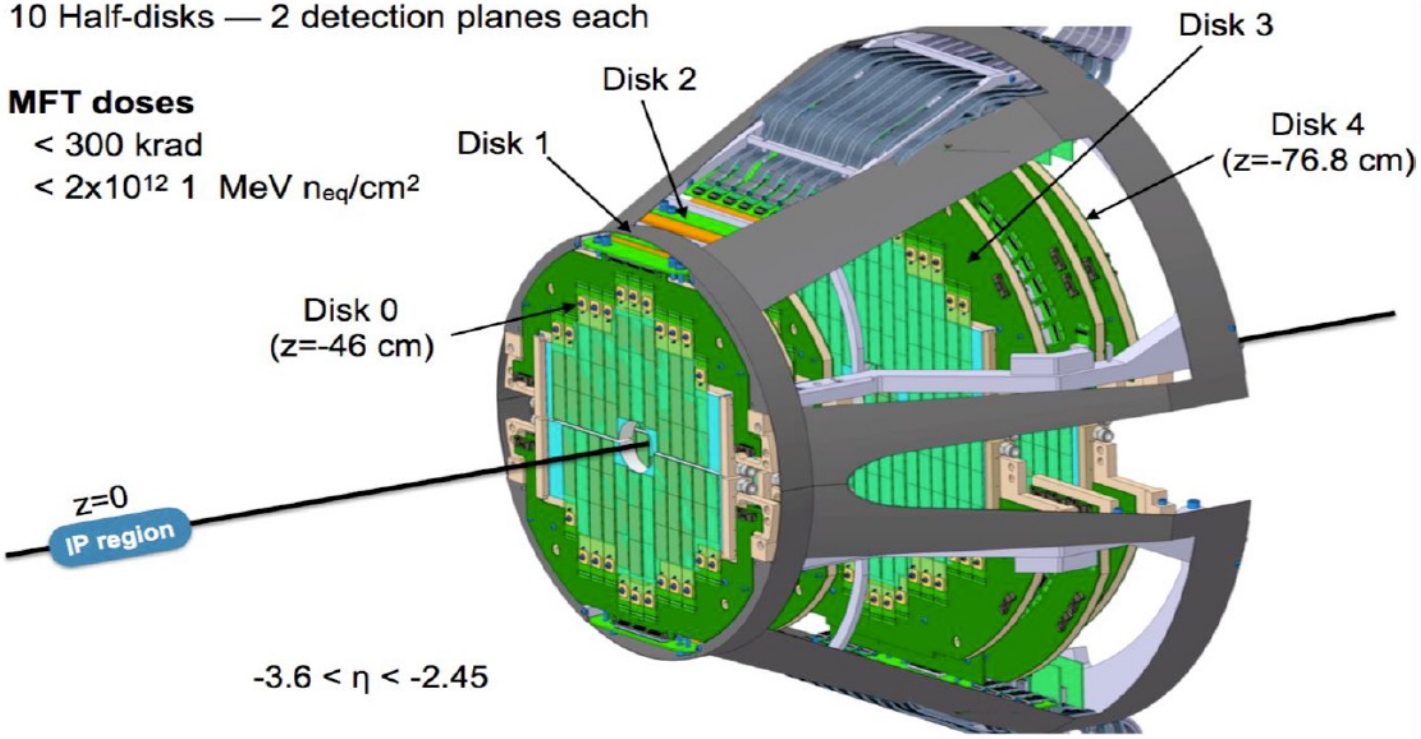
**Continuous readout for all systems** (Common Readout Unit), for muons:

- **MCH** upgrade with SAMPA ASIC
- **MID** (upgrade of MTR) with FEERIC ASIC




10 Half-disks — 2 detection planes each

**MFT doses**
< 300 krad
< $2 \times 10^{12}$ 1 MeV $n_{eq}/cm^2$



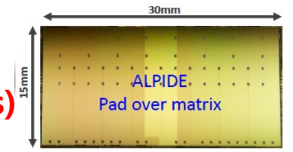

- **Based on same MAPS as ITS upgrade**
- 2212 chips in total
- 5 disks with 2 planes on each disk
- Enables better matching to vertex

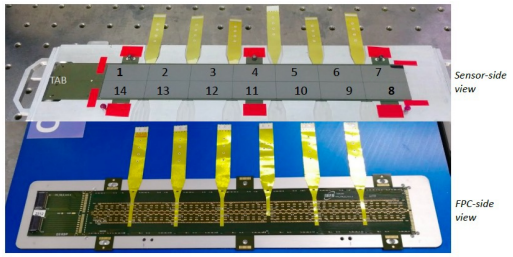
- **Charm/beauty separation possible**
- **Improved mass resolution**

# Chinese contribution to ALICE 2

- Role in ALICE/ITS2 Silicon Pixel Detector Upgrade
  - ➢ Joint R&D plus testing of ALPIDE chip
  - ➢ Production and testing of ALICE/ITS2 Hybrid-IC
    - ✓ 450 HIC modules produced and tested by China group ( **error < 5 mm, qualified > 85%** )
    - ✓ ITS2 commission run and on-site shift, readout testing, setup of data QA framework
  - ➢ **Build a silicon pixel chip factory of high precision IC, testing and mass production**
  - ➢ **Form a team holding core technologies**

**HIC (2x7 ALPIDE chips)**

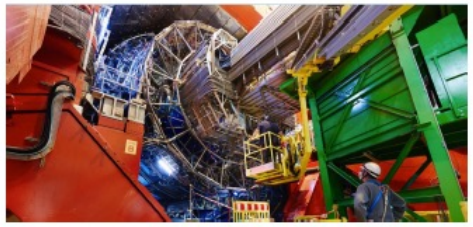


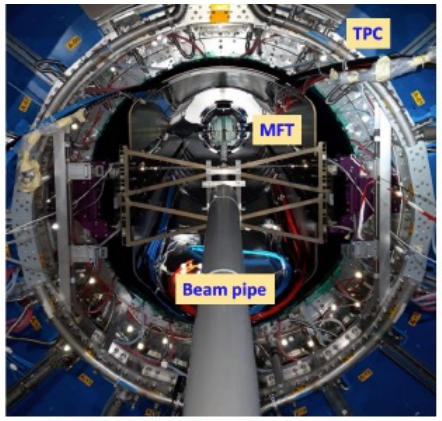

- Role in ALICE/MFT Detector R&D
  - ➢ Readout PCB, including **design, production and testing** (5 MFT Discs)

**Half MFT Disc**

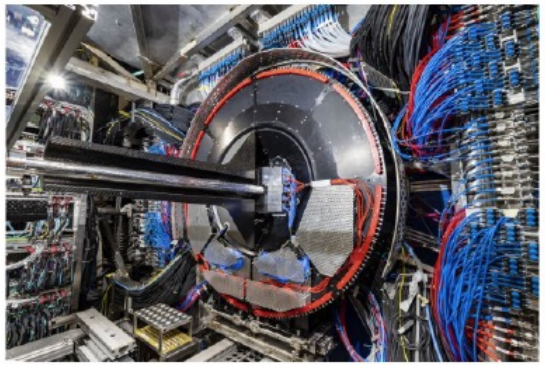
# Installation during LS2



Reinstall Miniframe

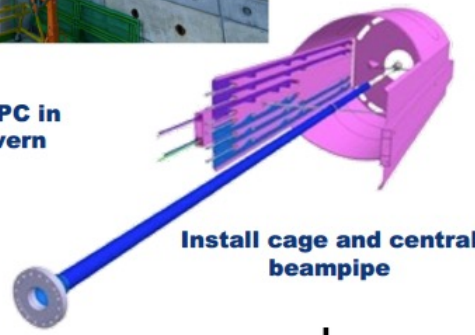



Install MFT and FIT-C



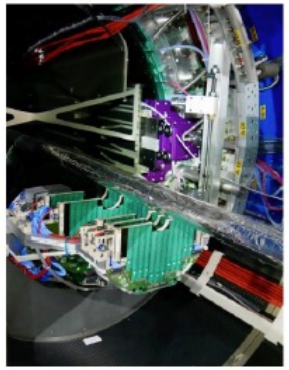
Install FIT-A

Standalone commissioning
Milestone weeks



Reinstall TPC in ALICE Cavern

Install cage and central beampipe



Install ITS2

Global Commissioning
Pilot beam tests

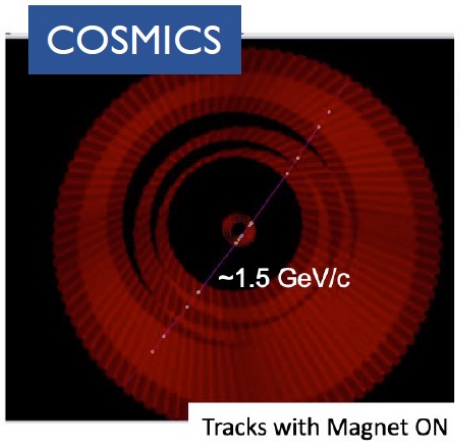
LS2 ends

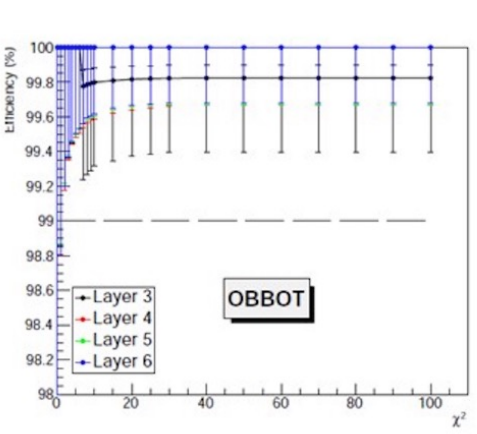
Jul-Aug '20 | Aug-Sep '20 | Oct-Nov | Dec-Jan'21 | Feb-June | July | Feb? 22

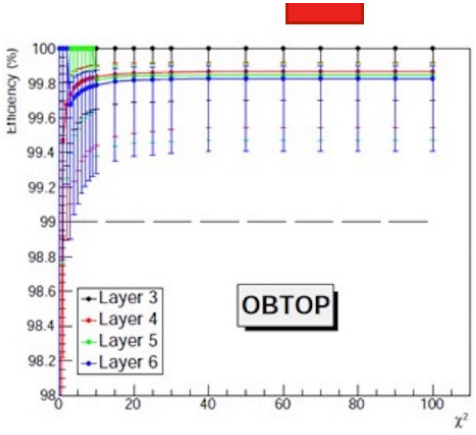
# Global commissioning: ITS2 and MFT

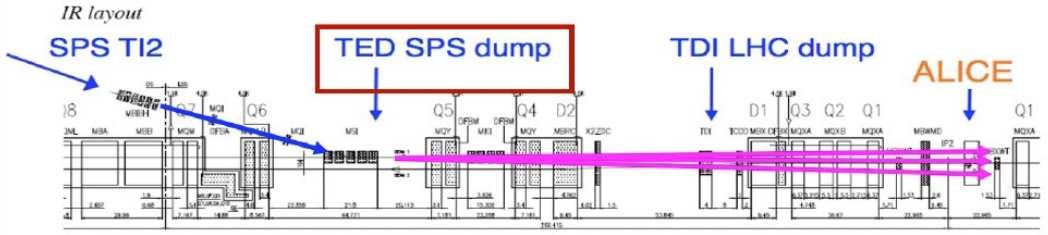
## ITS2

- Noise calibration
  - fake-hit rate: $10^{-8}$/pixel/event
- Cosmic data taking
  - Online clustering and tracking
  - Offline analysis advanced
- Detector fully efficient
  - >99% of IB and OB

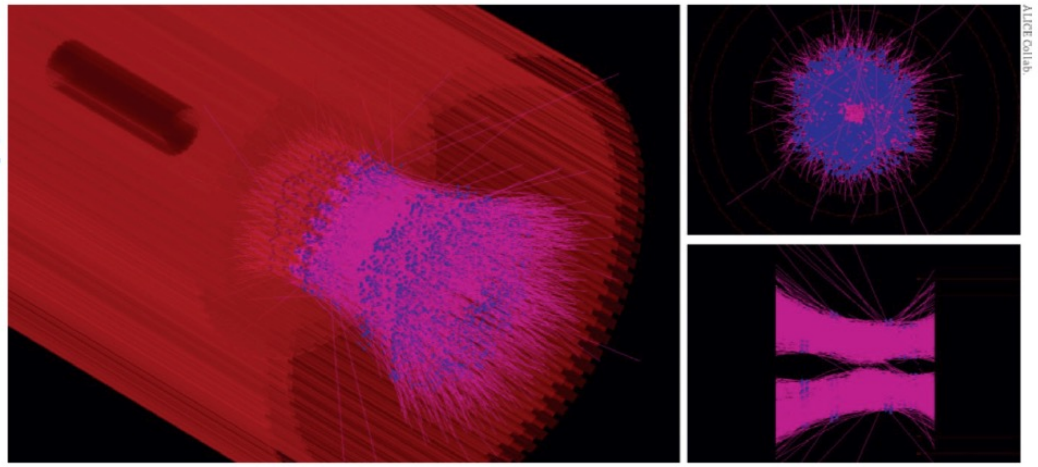



Splashes of muons from TED beam dump during TI2 tests

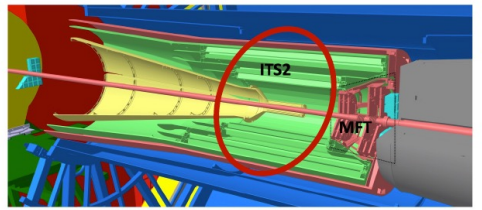


## MFT

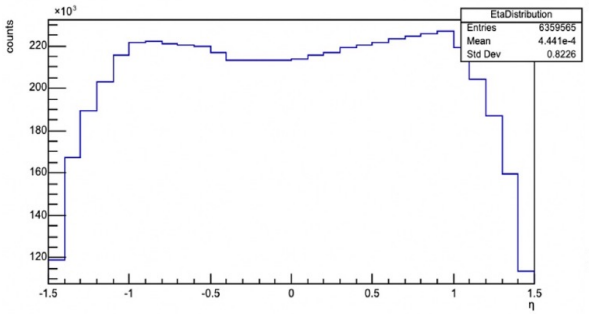
- Noise pixel masking
- Online clustering and online tracking validated using TED shots

# Run 3 pilot beam

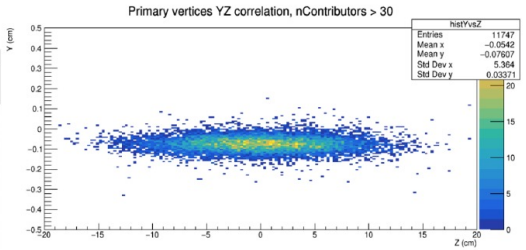
- **5 days: 27-31/10/2021**
- **12 fills with different filling scheme, solenoid with different configurations (0.2T, -0.2T, 0 T)**
- **19 good runs in total → 1455 mins (~58M events)**
  - QC on FLP/EPN + Sync Reco + Event Display + TF/CTF writing (→ data on grid)
- **Reconstruction experts available for quick checks on the first data on disk!**

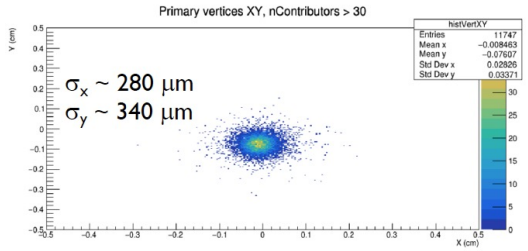


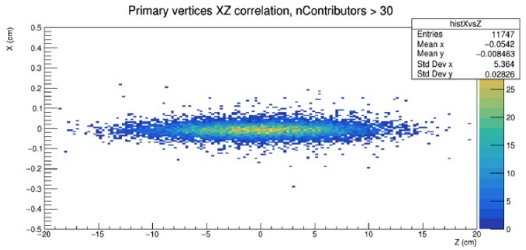

**ITS2 online tracking (η distribution)**

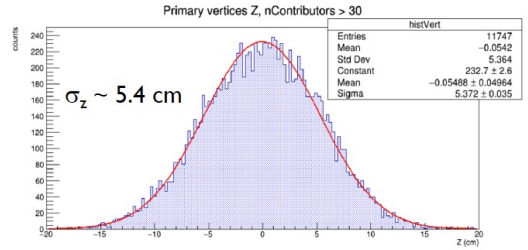



**ITS2 vertexing**



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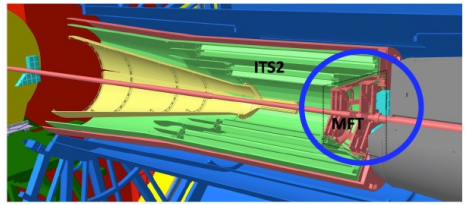
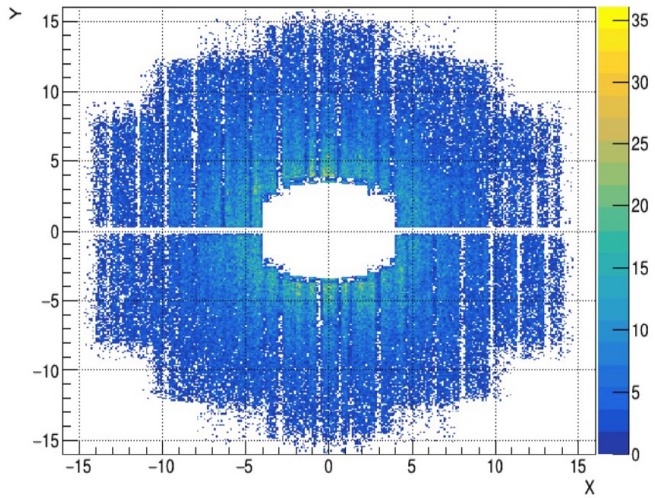
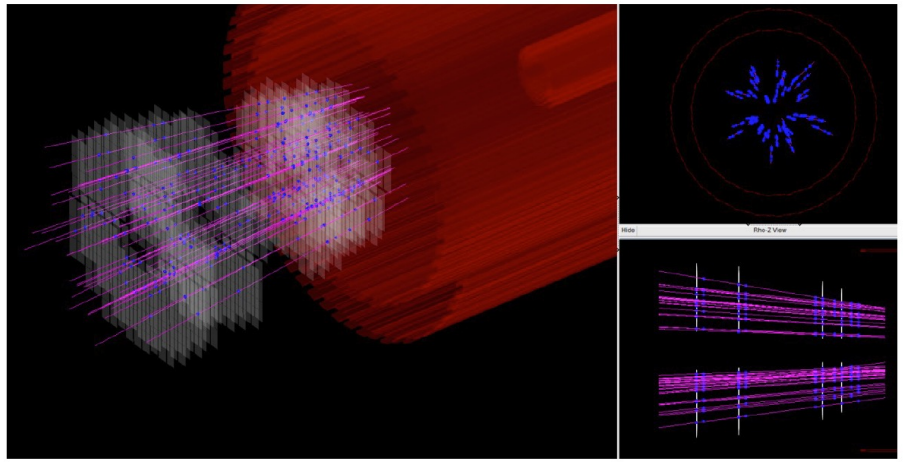



**MFT cluster distribution**




**MFT tracking**



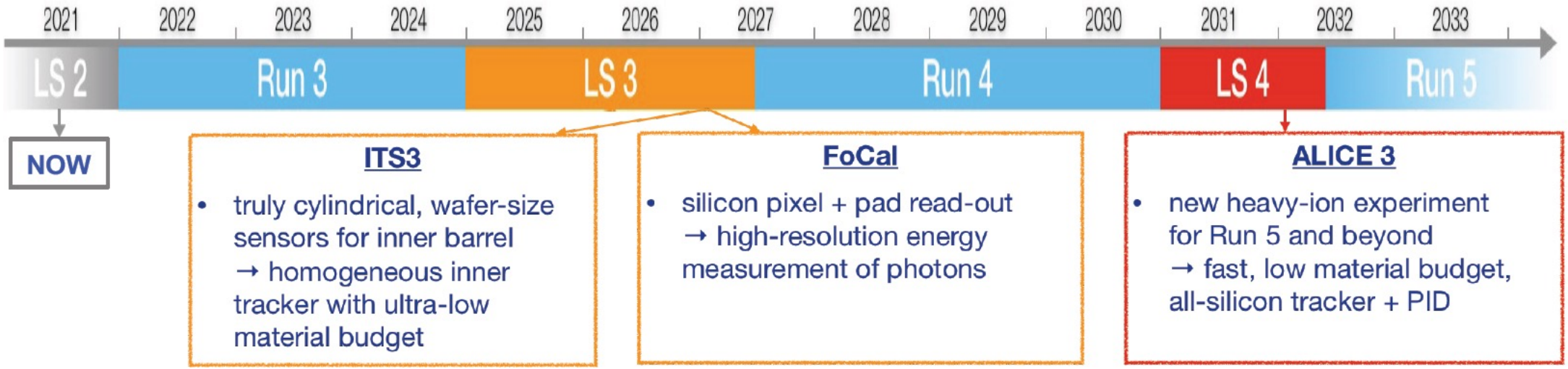
# Run 3 at the gate, and what's next?

**ALICE strategy for Run 3 + Run 4:**

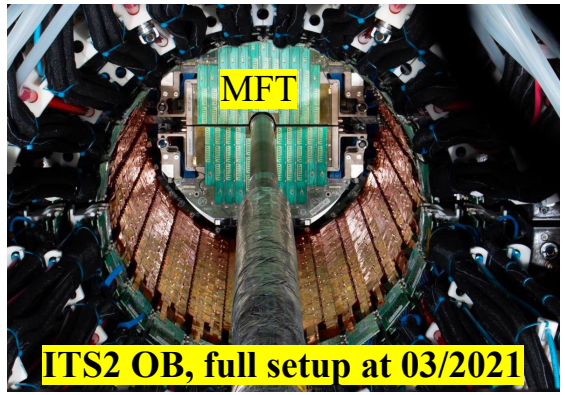
- Continuous readout and online data reconstruction

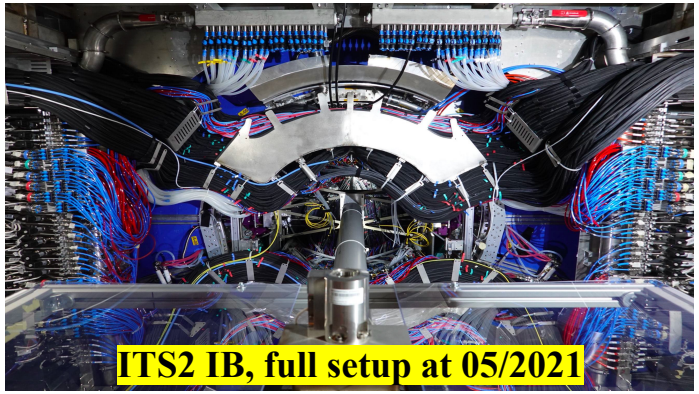
**→ Inspect all MB Pb-Pb collisions at 50 kHz. Collect $L_{Pb\text{-}Pb}$ = 13 $nb^{-1}$**

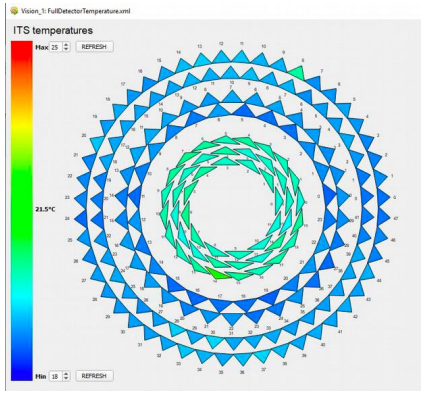
**x50 statistics increase for many observables compared to Run 1 and Run 2**



# Chinese participation in Run 3 & 4



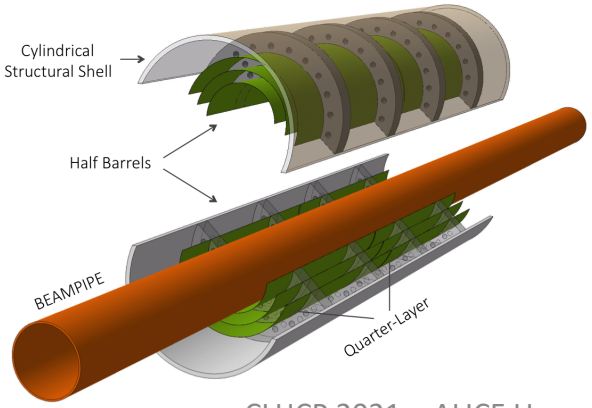




**ITS2**
**Full Commission**
**31/05/2021**

- Play an important role in ITS2 calibration, alignment, and analysis on physics highlights
- Part of the wafer-size ultra-thin silicon pixel detector R&D based on Stiching (**ITS3**)
- Part of the silicon layer R&D of **FoCal**

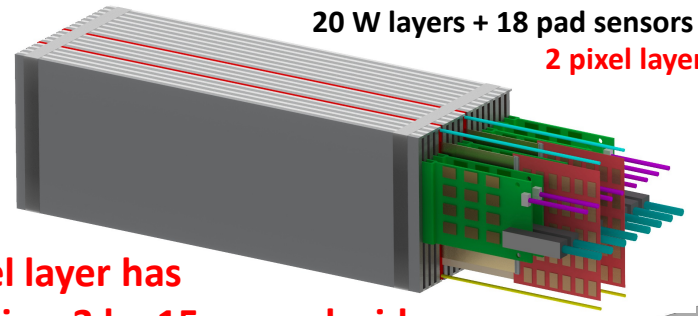
## ITS3

- Closer to beam pipe: ~18 mm
- Less material: < 0.05% $X_0$
- Stiching-based wafer-scale MAPS sensor (~28 x 10 cm)
- Ultra-thin (20-40 μm)
- Bent (R=18, 24, 30 mm)

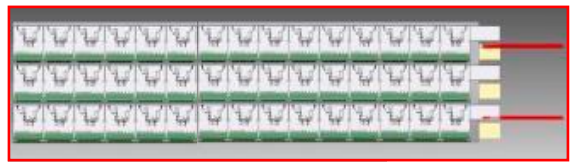


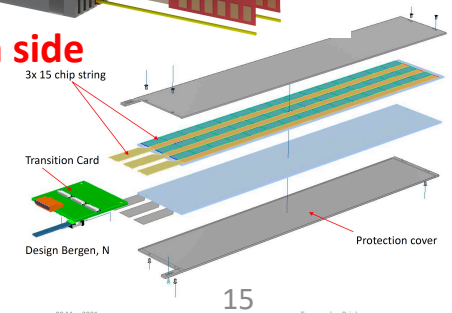

## FoCal

**20 W layers + 18 pad sensors +**
**2 pixel layers**



**Each full pixel layer has**
**30 ALPIDE chips, 3 by 15 on each side**

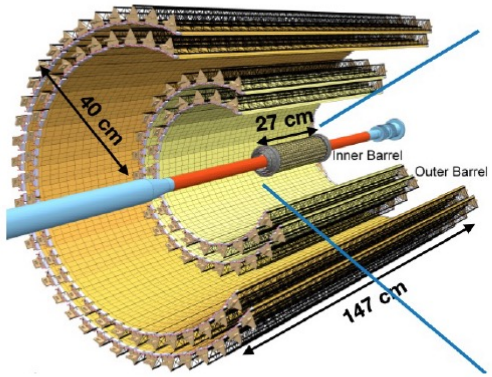


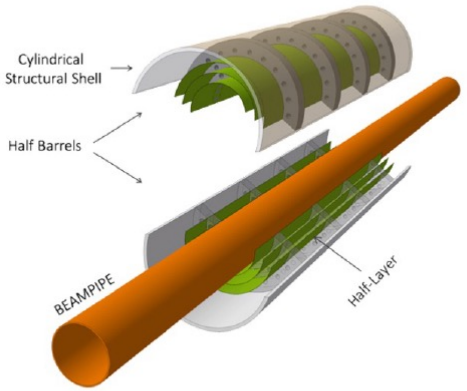


# ITS2 → ITS3 @ ALICE 2.1

**For Run 4 the inner barrel of the ITS2 will be replaced with bent chips ITS3** *LoI: CERN-LHCC-2019-018*

- Ultra-thin, wafer-scale, bent MAPS around the beam pipe
- **~6x** less material budget: ~ 0.02-0.04% $X_0$ per layer
  - Homogeneous material distribution
- First detection layer closer to the IP improved tracking performance
  - **2x** tracking precision and efficiency at low $p_T$

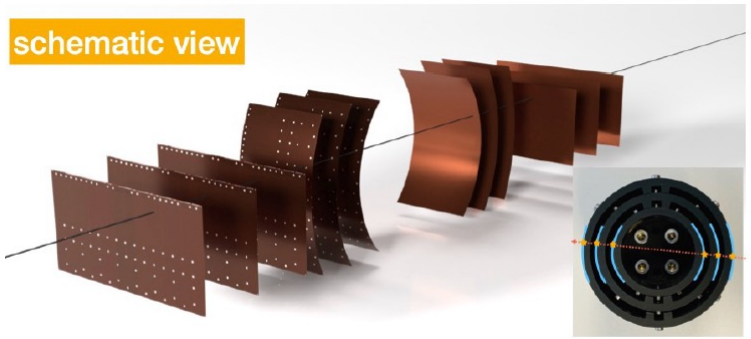


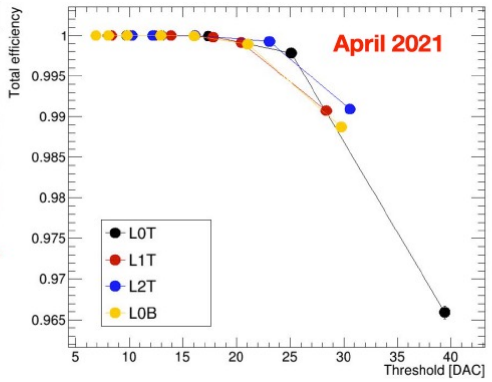



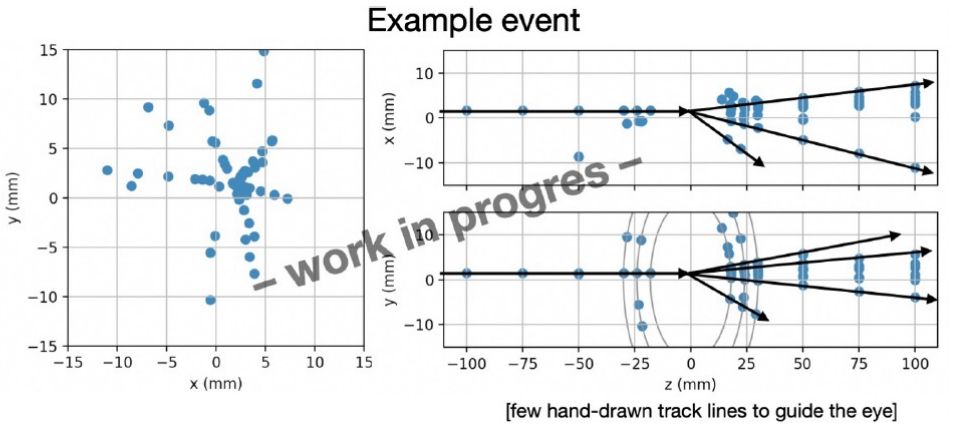

**R&D is underway and progressing rapidly:**

- Extensive in-beam tests for tracking performance of the bent MAPS
  - **Successful** verification of bent ALPIDE sensors
  - no effect on radius (18, 24, 30 mm) observed

arXiv:2105.13000



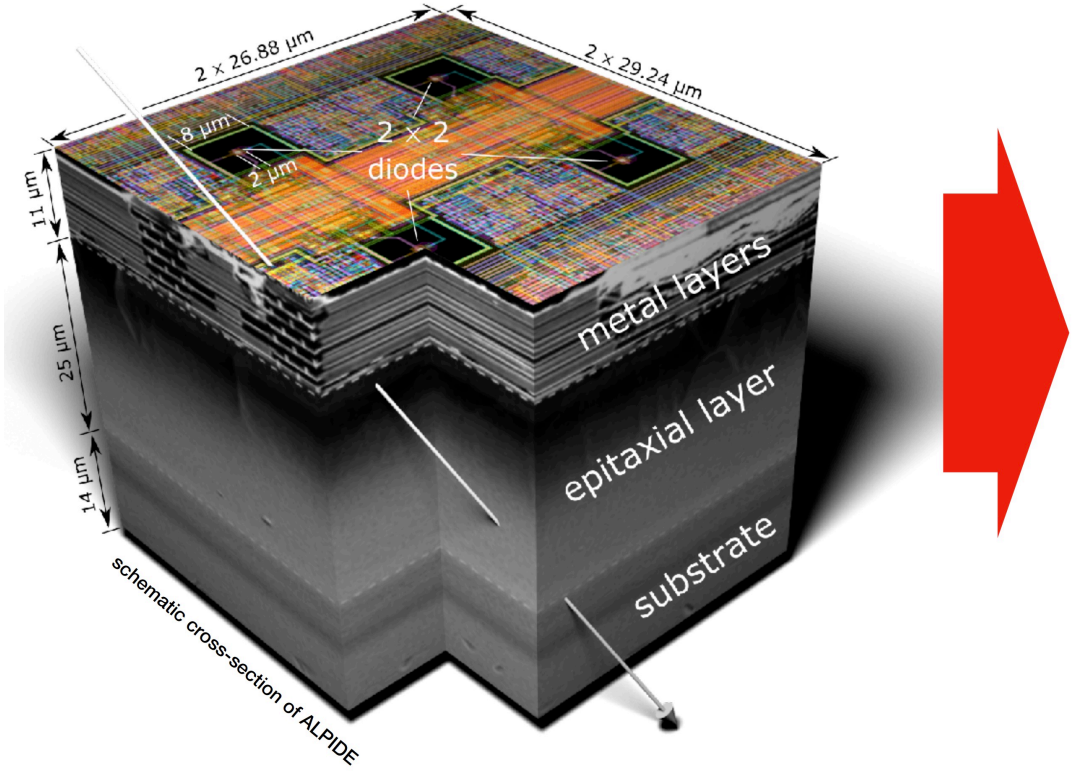



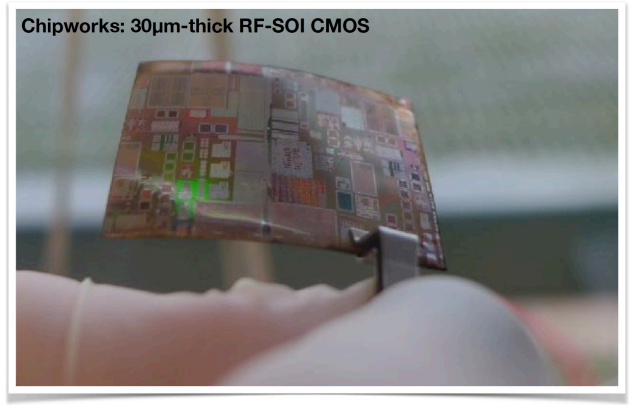
# ITS2 → ITS3 @ ALICE 2.1

## ITS3

**the idea (1): make use of the flexible nature of thin silicon**





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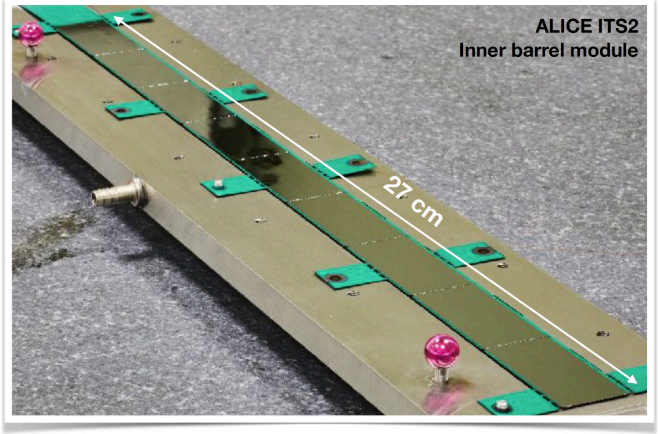
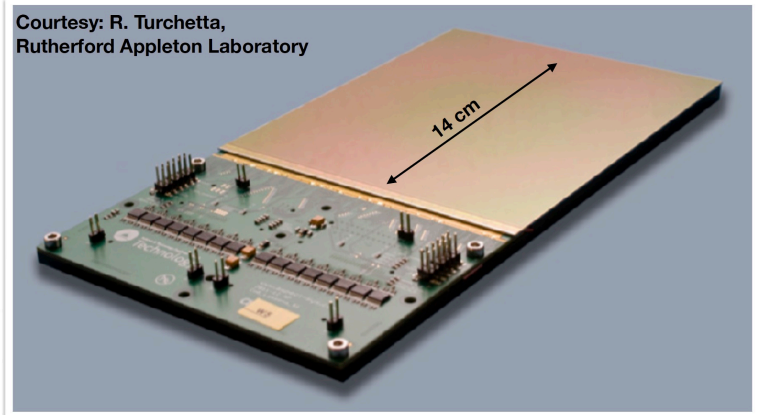
# ITS2 → ITS3 @ ALICE 2.1

## ITS3

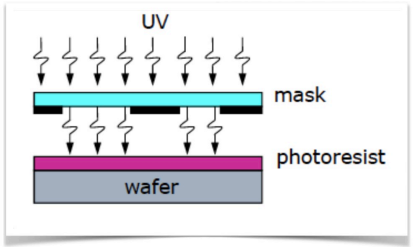
### the idea (2): build wafer-scale sensors




- Chip size is traditionally limited by CMOS manufacturing (“reticle size”)
  - typical sizes of few cm²
  - modules are tiled with chips connected to a flexible printed circuit board

- New option: stitching, i.e. aligned exposures of a reticle to produce larger circuits
  - actively used in industry
  - a 300 mm wafer can house a sensor to equip a full half-layer
  - ***requires dedicated sensor design***

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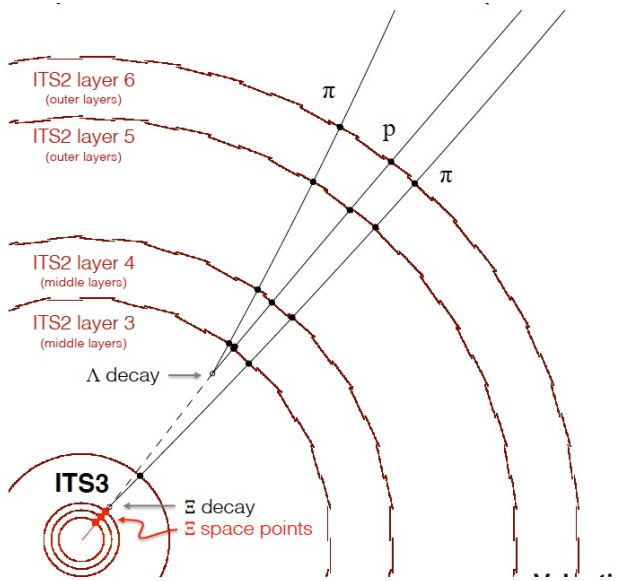
# ITS2 → ITS3 @ ALICE 2.1

## ITS impact on physics

- **Low-mass di-electrons**
  - Less conversions (x 1/3), one of the main “soft” backgrounds
  - Better low-$p_T$ standalone efficiency to reconstruct and reject conversions
  - Better precision to reject or subtract conversion and charm-decay electrons (displaced)
- **Heavy flavour** in particular those with small $c\tau$ ($\Lambda_c \approx 60$ μm, $D_s \approx 150$ μm)
  - Better precision to separate secondary vertex
  - Increased efficiency also helps in multi-prong decays
- **Much more**
  - $B_s^0$, non-prompt $D_s^+$, $\Lambda_b$, $\Xi_c$,
  - “c-deuteron”, $d\Lambda_c$
  - “strangeness tracking”
  - Anti-$^3$He production from anti-$\Lambda_b^0$

Letter of Intent

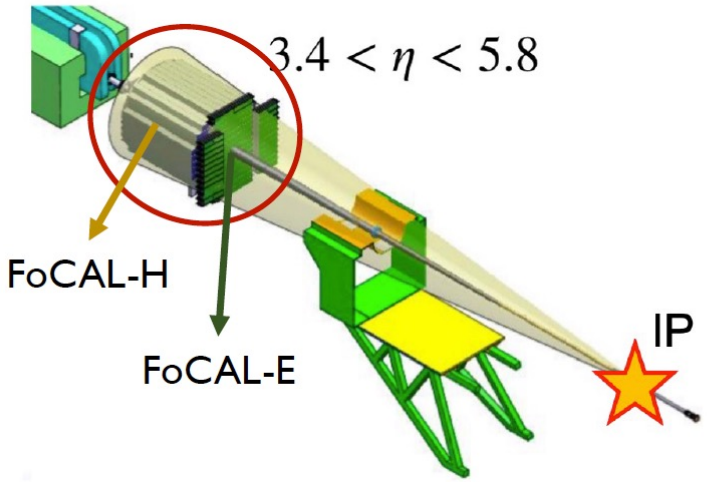


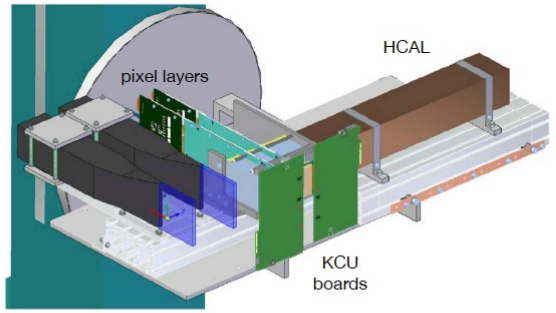
# FoCal @ ALICE 2.1

**FoCal: forward electromagnetic and hadronic calorimeters**

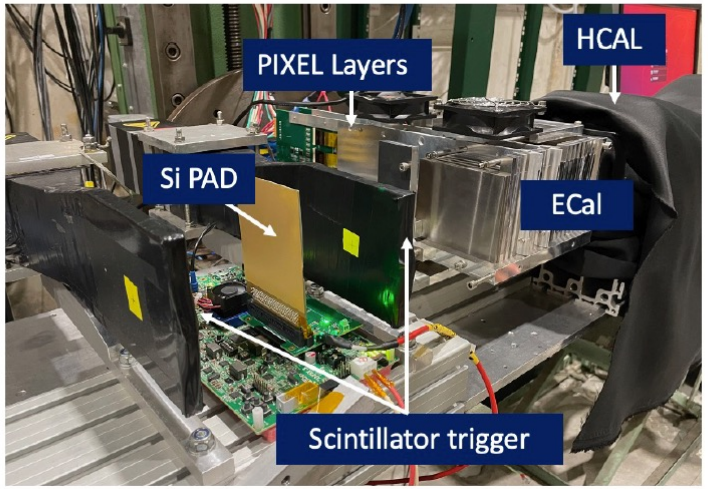
*LoI ALICE-PUBLIC-2019-005*

- **FoCal-E**: high-granularity Si (pad and pixel)-W sampling calorimeter for the measurement of direct $\gamma$ and $\pi^0$
- **FoCal-H**: metal-scintillator sampling calorimeter for photon isolation and jets

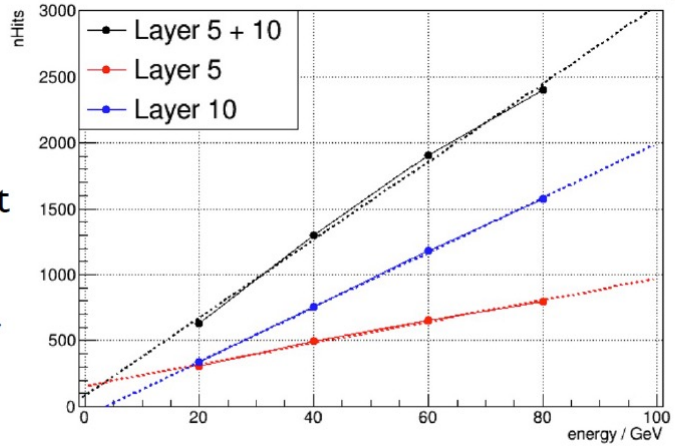


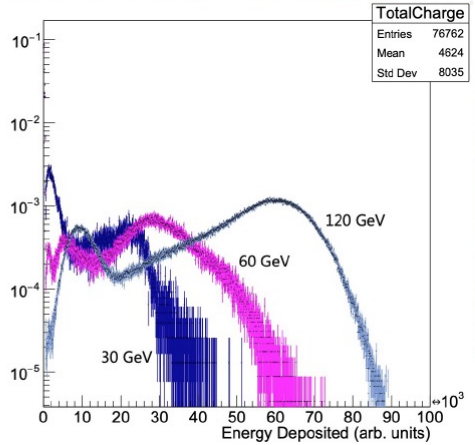



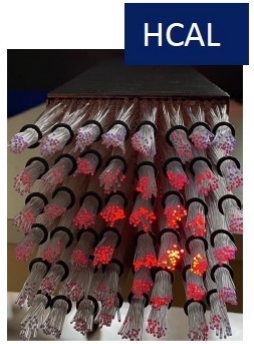

2 pixel layers
1 or 2 pad layers with KCU board(s)




nHits vs. energy




Good progress on R&D

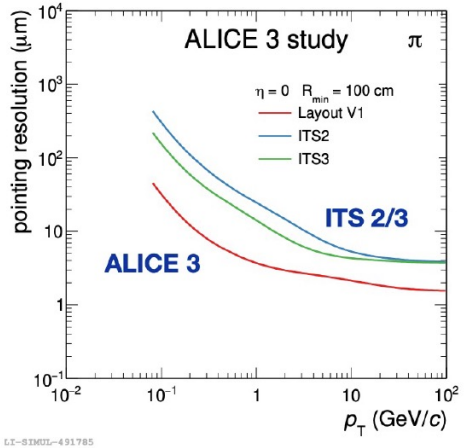
- prototypes of main components tested at **SPS test beam** in Sep/Oct 2021
- In-beam tests of full demonstrator tower planned for **May/June 2022**

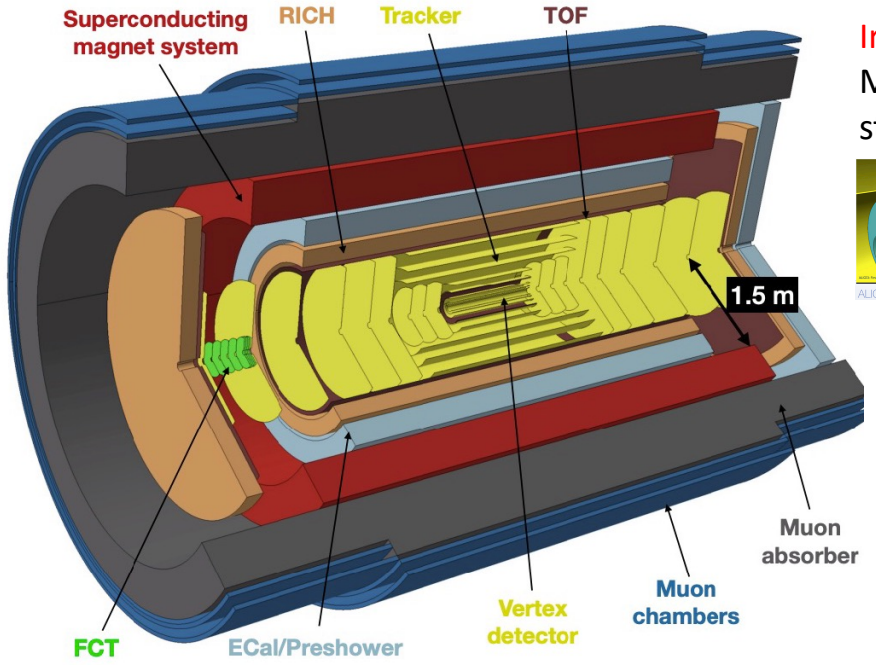
# ALICE 3 ➔ Run 5 and beyond

## A new dedicated heavy-ion detector for Run 5+ (> 2030)

Detailed chatacterization of the QGP (transport properties, electric conductivity), dynamics of pre-thermalization and hydrodynamization, hadronization and hadron chemistry, chiral symmetry restoration, …

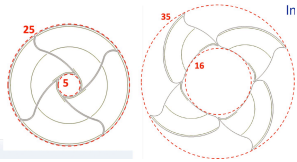
- **Compact all-silicon tracker with high-resolution vertex detector**
- **Superconducting magnet system**
- **Particle Identification over large acceptance**
- **Fast read-out and online processing**

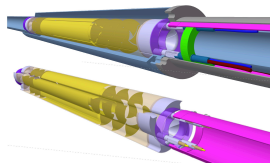


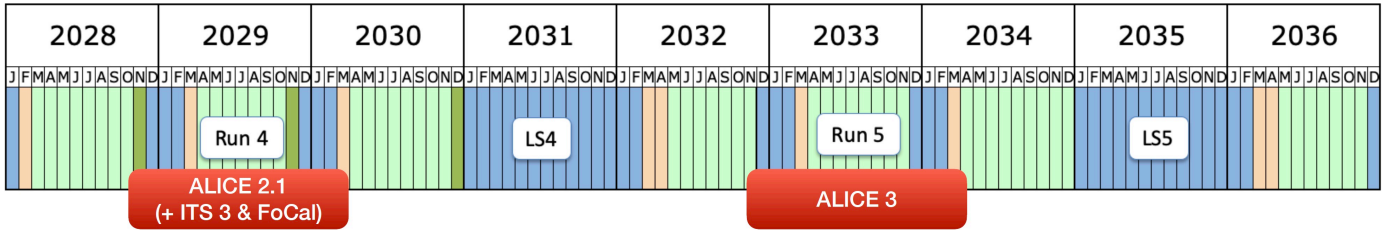




Iris tracker:

Monolithic active pixel sensors, stitched, **bended**, and **FOLDED**?



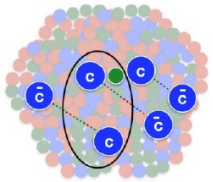


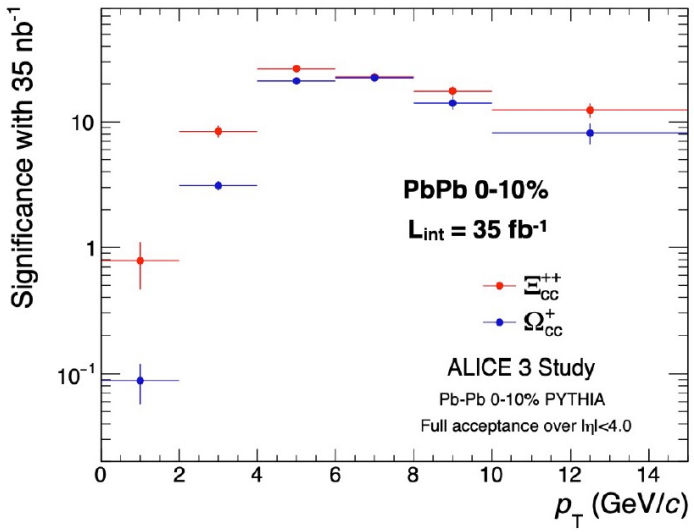


# ALICE 3 physics highlights

## Multi-charm flavor hadrons

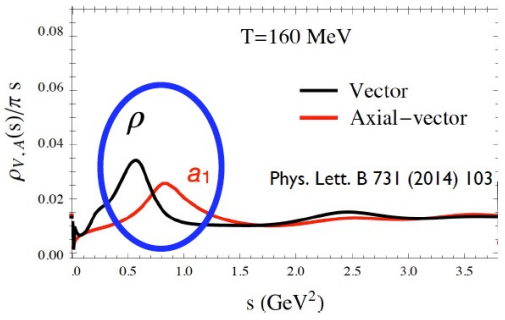
Large enhancement (up to x100 for $\Xi_{cc}$, $\Omega_{cc}$) w.r.t. pp predicted in presence of hadron production from uncorrelated charm quarks

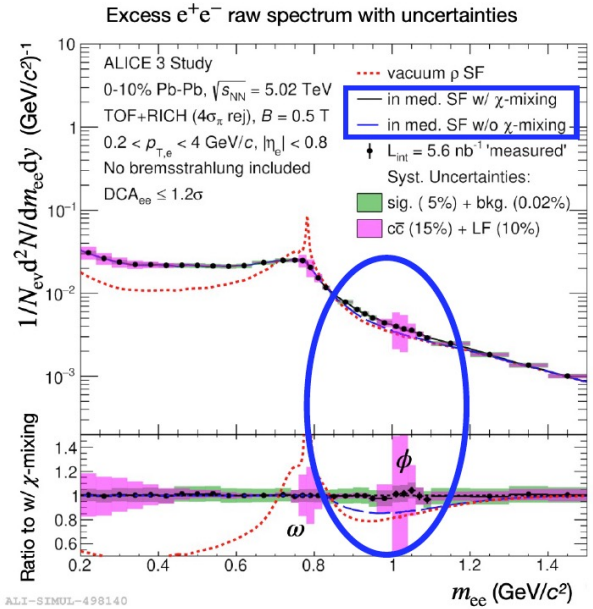


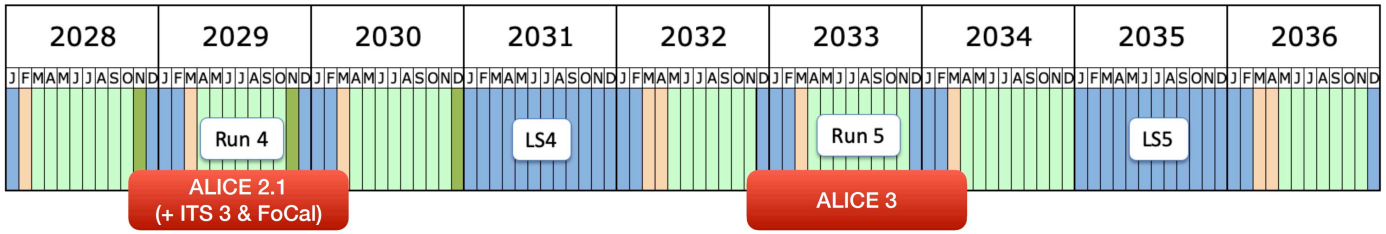




## Low mass dielectrons

- details of the ρ spectral function and chiral mixing with $a_1$
- Electric conductivity
- QGP temperature
- pre-thermalization



# Summary and outlook

- A long and lasting LS2...but ALICE China group were not sleeping

✓ Deep involvement of **ITS2** and **MFT** for Run 3 by ALICE China

- ALPIDE chip R&D on ITS2 and MFT
- OB HIC production and commission completed
- Pilot beam output encouraging

✓ ALICE 2.1 is on the way for Run 4, and ALICE China is active

- R&D of wafer-scale bended silicon sensor for ITS3
- R&D of pixel layers to FoCal-E

✓ Run 5 is on the horizon: **ALICE 3,** a nearly pure silicon detector

- ALICE China is part of the plan
  - ➢ multi-charm flavor hadrons
  - ➢ detector R&D