The ALICE experiment upgrades

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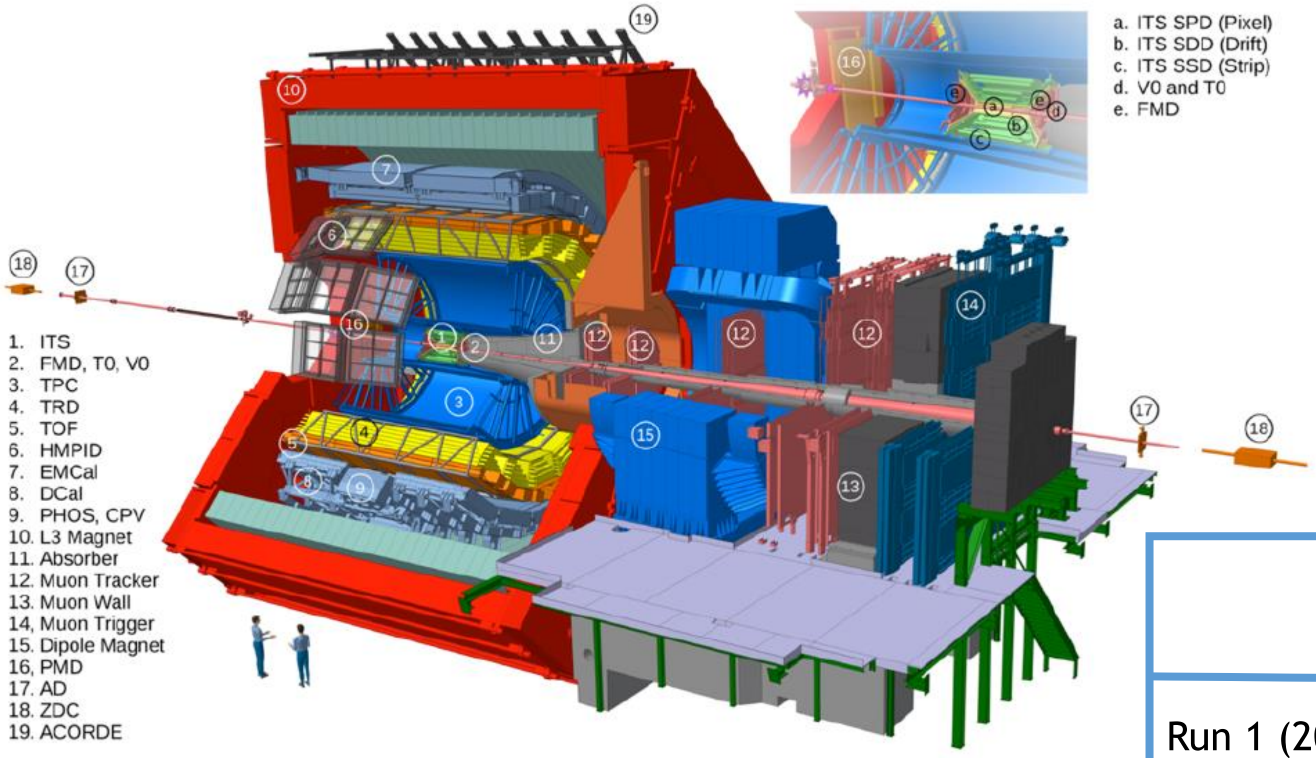
on behalf of the **ALICE collaboration**

Blois 2021: 32nd Rencontres de Blois on "Particle Physics and Cosmology"

ALICE in Run 1 and Run 2



- **ALICE** is one of the experiments at the LHC and it is mainly devoted to heavy-ion physics studies.
- Detailed characterization of strongly interacting quark-gluon plasma (QGP)
- **ALICE** is designed to carry out comprehensive studies of hadrons, electrons, muons, heavy flavors, photons and jets produced in the heavy-ion collisions

- Tracking and PID over large kinematic range
- High resolution vertex reconstruction
- Central barrel: -0.9 < η < 0.9
- Muon spectrometer: -4.0 < η < -2.5
- Forward detectors: trigger, centrality, luminosity, reaction plane

ALICE data taking history

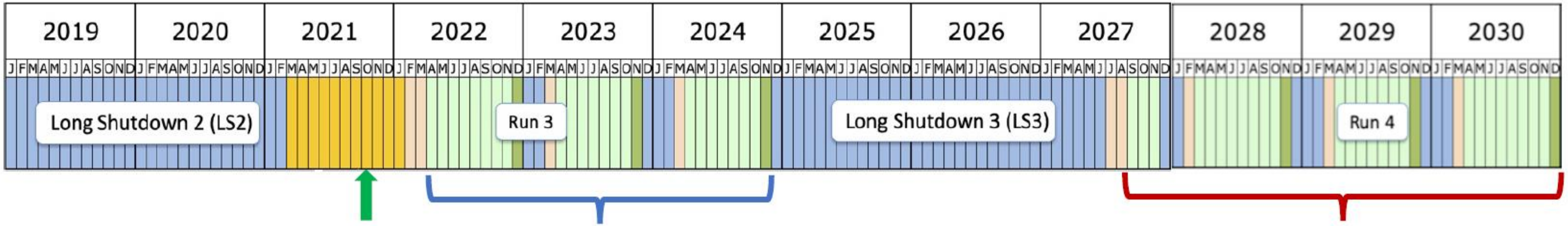
Run 1 (2009 – 2013):

- Pb-Pb @ $\sqrt{s_{NN}}$= 2.76 TeV
- p-Pb @ $\sqrt{s_{NN}}$= 5.02 TeV
- pp @ $\sqrt{s}$ = 0.9, 2.76, 7 and 8 TeV

Run 2 (2015 – 2018)

- Pb-Pb @ $\sqrt{s_{NN}}$= 5.02 TeV
- Xe-Xe @ $\sqrt{s_{NN}}$= 5.44 TeV
- p-Pb @ $\sqrt{s_{NN}}$= 5.02 and 8.16 TeV
- pp @$\sqrt{s}$= 5 and 13 TeV

ALICE in Run 3 and Run 4



Today

Run 3: ALICE 2
ITS2, MFT, FIT, GEM TPC, O^2

Run 4: ALICE 2.1
Upgrade proposals: ITS3, FoCal

ALICE strategy for Run 3 and Run 4

- 50 kHz Pb-Pb event readout rate (previously ~1 kHz in the central barrel)
- Integrated luminosity targets:

Collision system	Integrated luminosity	Comment
Pb-Pb @ $\sqrt{s_{NN}}$ = 5 – 5.5 TeV	$\mathcal{L}_{Pb\text{-}Pb}$ = 13 nb^{-1}	Plus pp reference data
p-Pb @ $\sqrt{s_{NN}}$ = 8 – 8.8 TeV	$\mathcal{L}_{p\text{-}Pb}$ = 0.6 pb^{-1}	Plus pp reference data
pp @ $\sqrt{s}$ = 14 TeV	$\mathcal{L}_{pp}$ = 200 pb^{-1}	With focus on high multiplicity and rare signals

ALICE physics goals in Run 3 and Run 4

ALICE

Runs 3 and 4: Physics goals

- Heavy-flavour mesons and baryons (down to very low p_T)
- Charmonium states
- Dileptons from QGP radiation and low-mass vector mesons
- High-precision measurement of light and hyper nuclei

No dedicated trigger possible!
→ Need minimum-bias readout at highest possible rate

Implementation

1. Untriggered data sample
- Record all Pb-Pb interactions at 50 kHz through continuous readout
- Collect a factor 50 – 100 more min bias data wrt Run 2

→ Continuous readout TPC

2. Improve tracking efficiency and momentum resolution at low p_T
- Increase tracking granularity
- Reduce material thickness
- Minimise the distance to IP

→ New Inner Tracking System ITS2 and Muon Forward Tracker MFT

3. Preserve particle identification (PID)

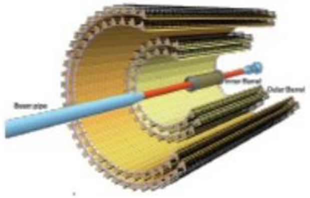
→ Consolidate and speed-up main ALICE PID detectors

4. Synchronous data processing (reconstruction, calibration)

→ New Online/Offline (O2)

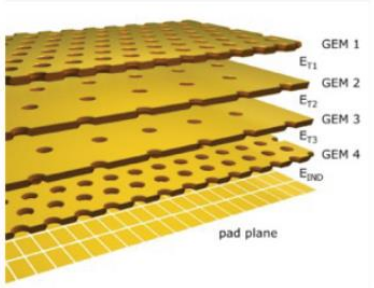
Evolution of the ALICE experimental set-up

Inner Tracking System



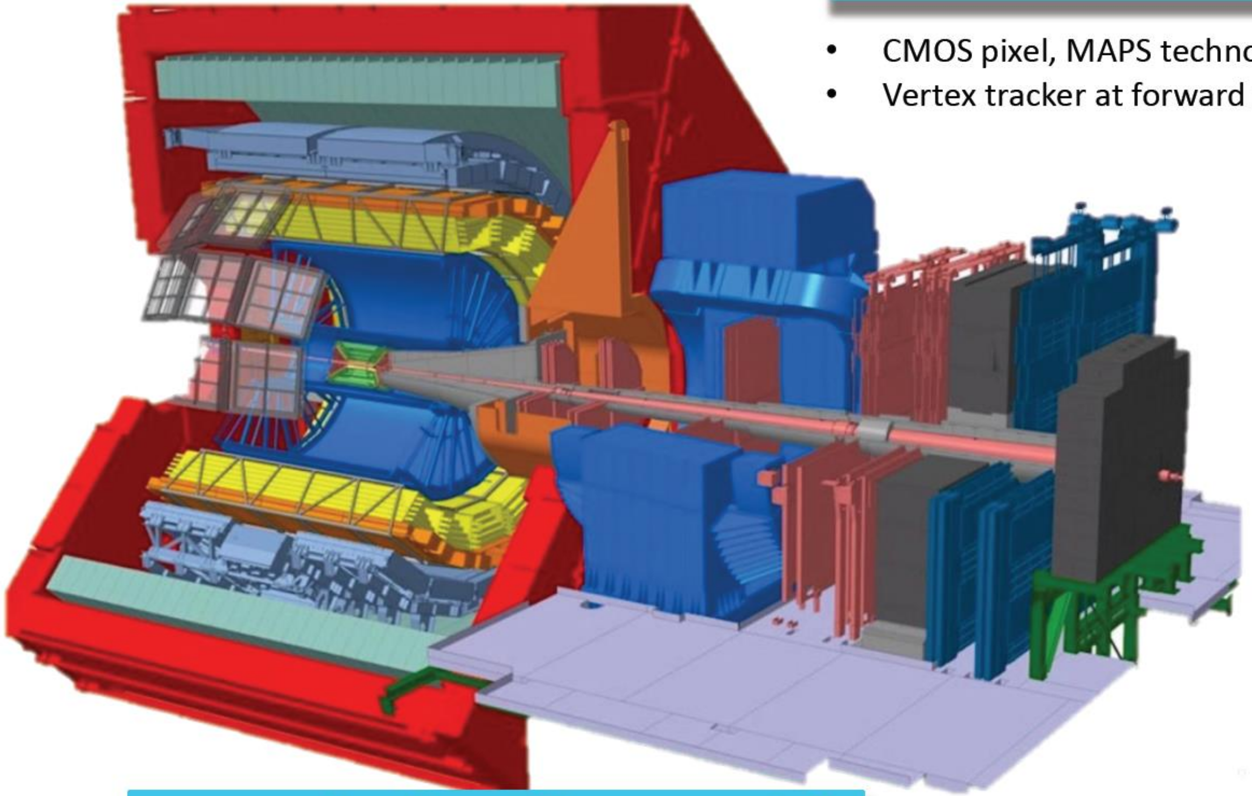
- CMOS monolithic active pixel sensors (10m² surface)
- Improved resolution, less material, faster readout

Time Projection Chamber



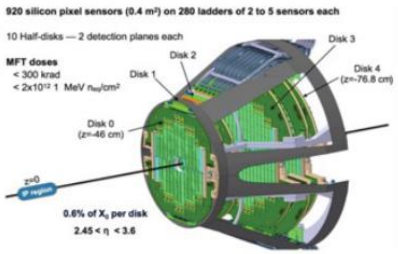
New Readout Chambers (ROCs)

- Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout



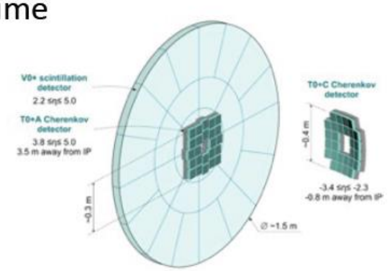
Muon Forward Tracker

- CMOS pixel, MAPS technology
- Vertex tracker at forward rapidity



Fast Interaction Trigger

- Centrality, event plane, luminosity, interaction time



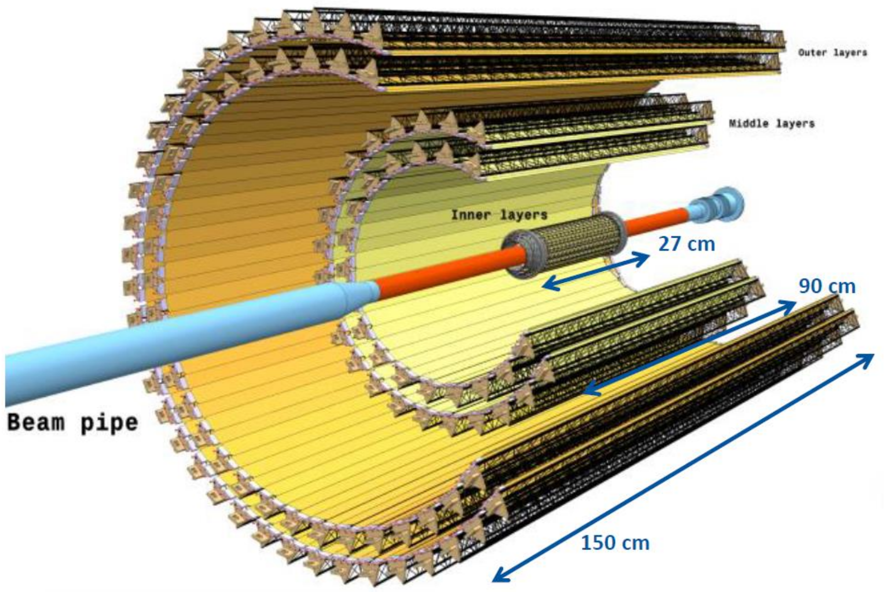
Integrated Online-Offline system (O²)

- Calibrate and reconstruct minimum-bias Pb-Pb data at 50 kHz

Upgrades readout for TOF, TRD, MUON, ZDC, Calorimeters


Inner Tracking System

ITS2 layout



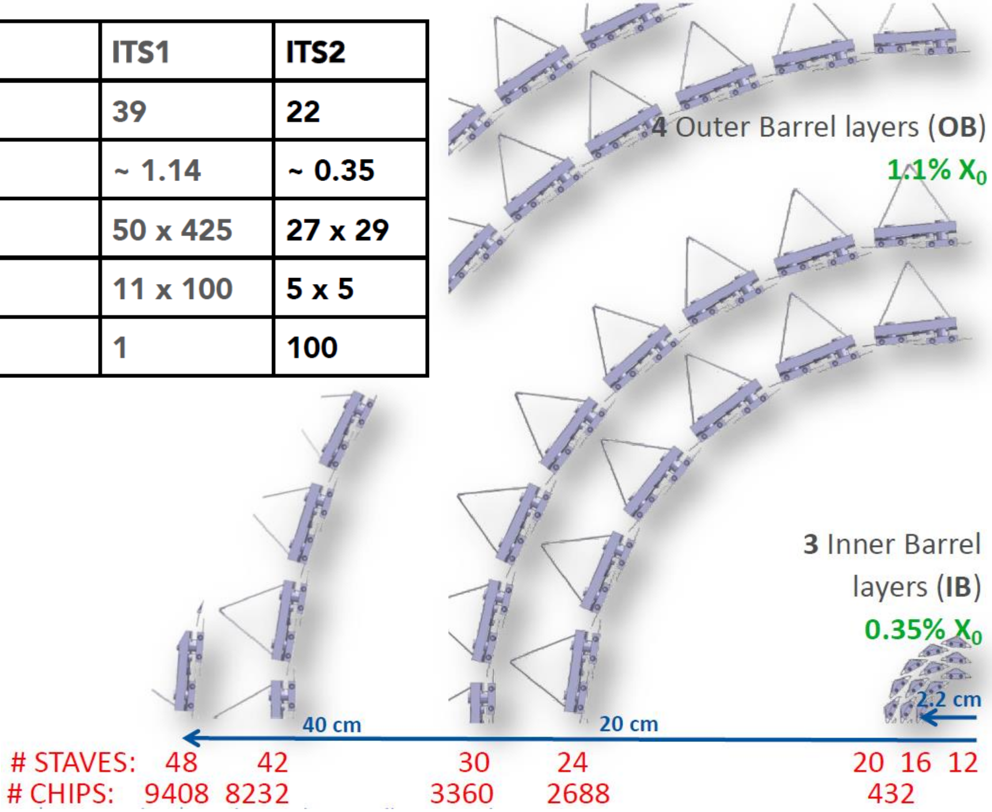
Motivations and goals:

Improved vertex and tracking precision

closer to IP, smaller pixels, less material

Faster readout

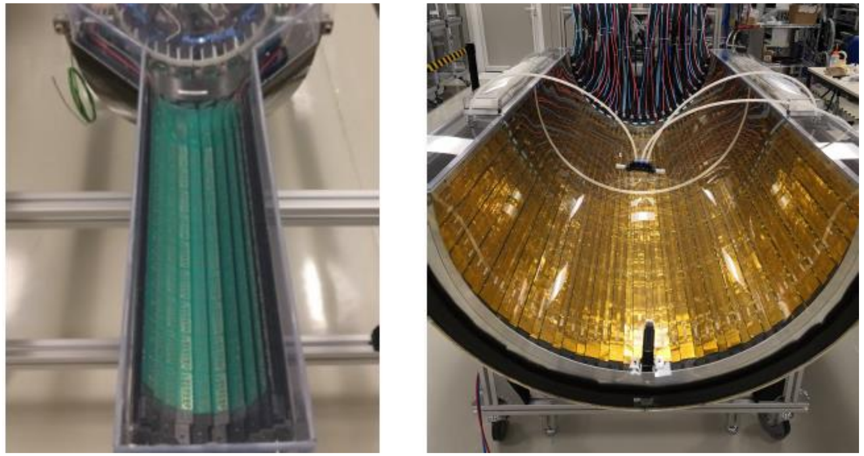
	ITS1	ITS2
Distance to IP (mm)	39	22
X_0 (innermost layer) (%)	~ 1.14	~ 0.35
Pixel pitch (μm²)	50 x 425	27 x 29
Spatial resolution ($r\varphi$ x z) (μm²)	11 x 100	5 x 5
Readout rate (kHz)	1	100



ITS2 (Run 3): 7 layers, all pixel
- Inner Barrel: 3 layers, 48 staves
- Outer Barrel: 4 layers, 144 staves

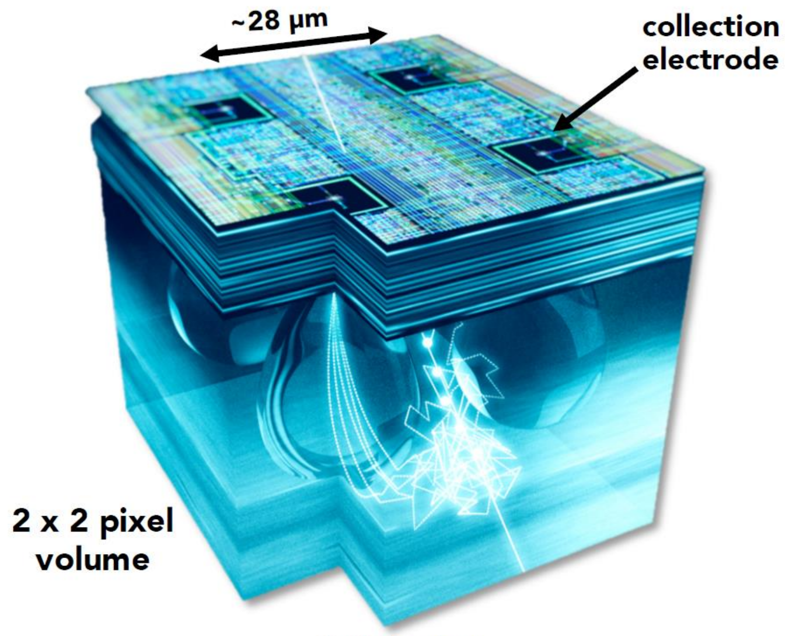
- 2 Middle Layers (54 staves)
- 2 Outer Layers (90 staves)

In total ~24000 chips = 12.5 Gpixels
~10 m² of ALPIDE silicon pixel sensors

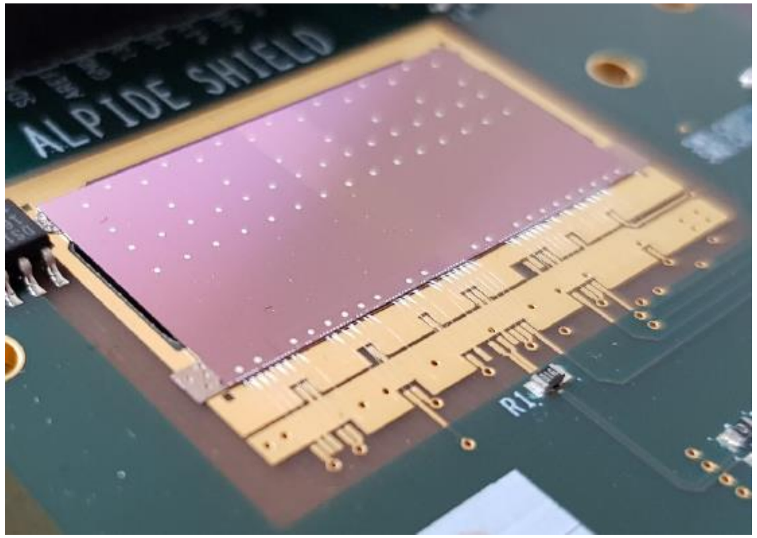


Inner and outer layer during commissioning

ITS2 sensors



Artistic view



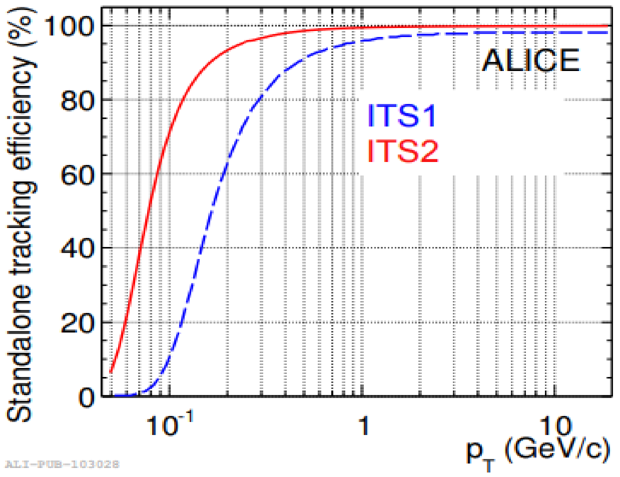
Chip area: 15x30 mm, 524288 pixels

Based on the ALPIDE chip (Monolithic Active Pixel Sensor, MAPS)
- **In-pixel:** Amplification, Shaping, Discrimination and multi-event buffers (MEB)
- **High detection efficiency:**> 99%
- **Low fake-hit rate:** <10^{-6}/pixel/event (<1Hz/cm^2)
- **Max particle rate:** ~100 MHz/cm^2 (without pile-up)

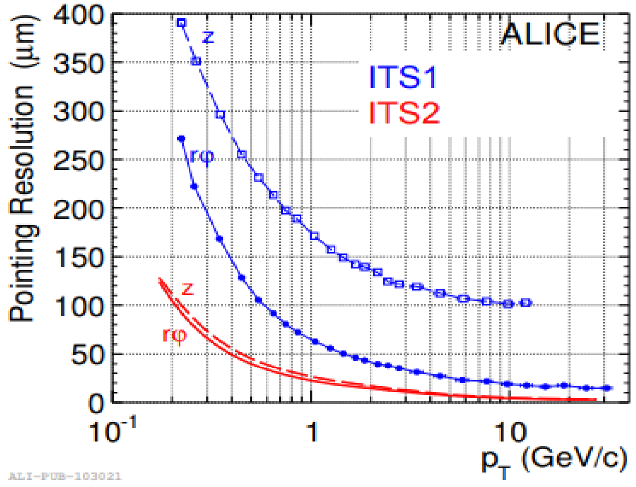
Sensor specification:
- TowerJazz 180 nm, full CMOS
- **Sensor size:** 1.5 cm x 3 cm
- **Thickness:** 50 μm (IB), 100 μm (OB)

Ultra-low power: < 40mW/cm^2
(< 140mW full chip)

ITS2 performances



Improved tracking efficiency at low p_T



Impact parameter resolution:
40 μm at p_T= 500 MeV/c

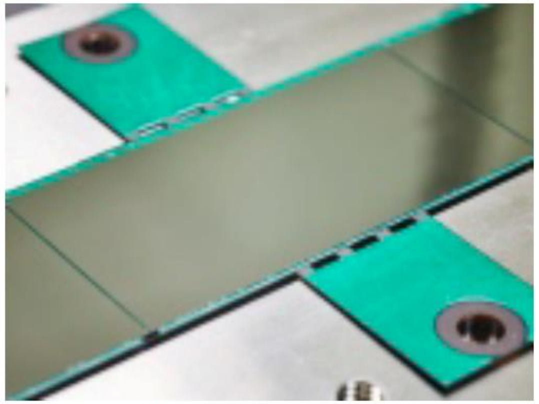
ITS2 will provide:

- High accuracy of secondary vertex determination due to the extremely low-material budget (below 0.35% X/X_0 for the 3 innermost layers).
- Impact parameter resolution will be better by a factor of 3.
- Low p_T detection starting from 50 MeV/c
- Charm and beauty mesons will be measured down to zero p_T.

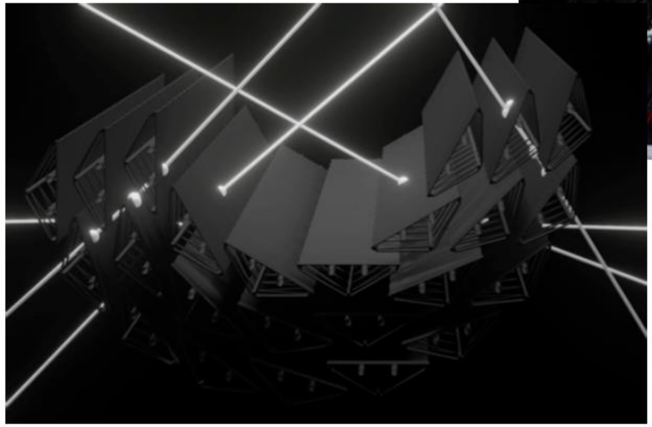
The rate of ALICE data taking in Pb–Pb collisions will be increased from 1 kHz to 50 kHz

ITS2 installation path

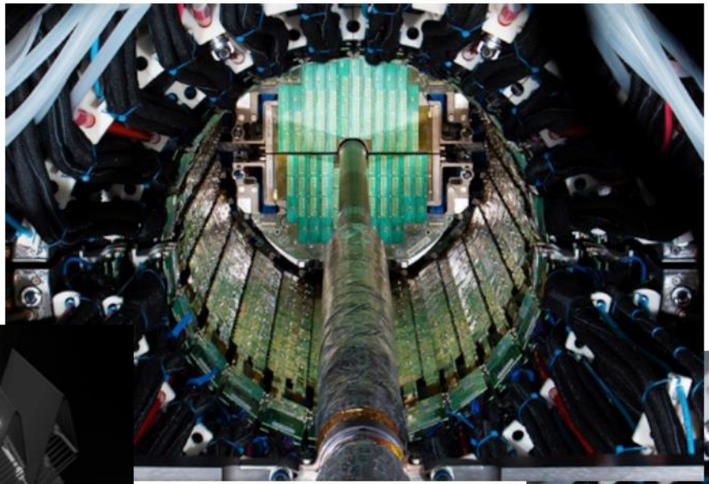
~72000 chips ~280 staves
>10 production sites worldwide
~ 30 institutes involved



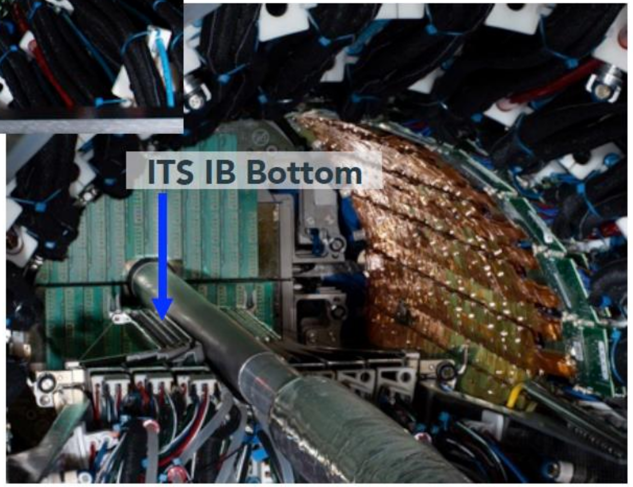
Start detector construction and assembly



Start on-surface commissioning with final services

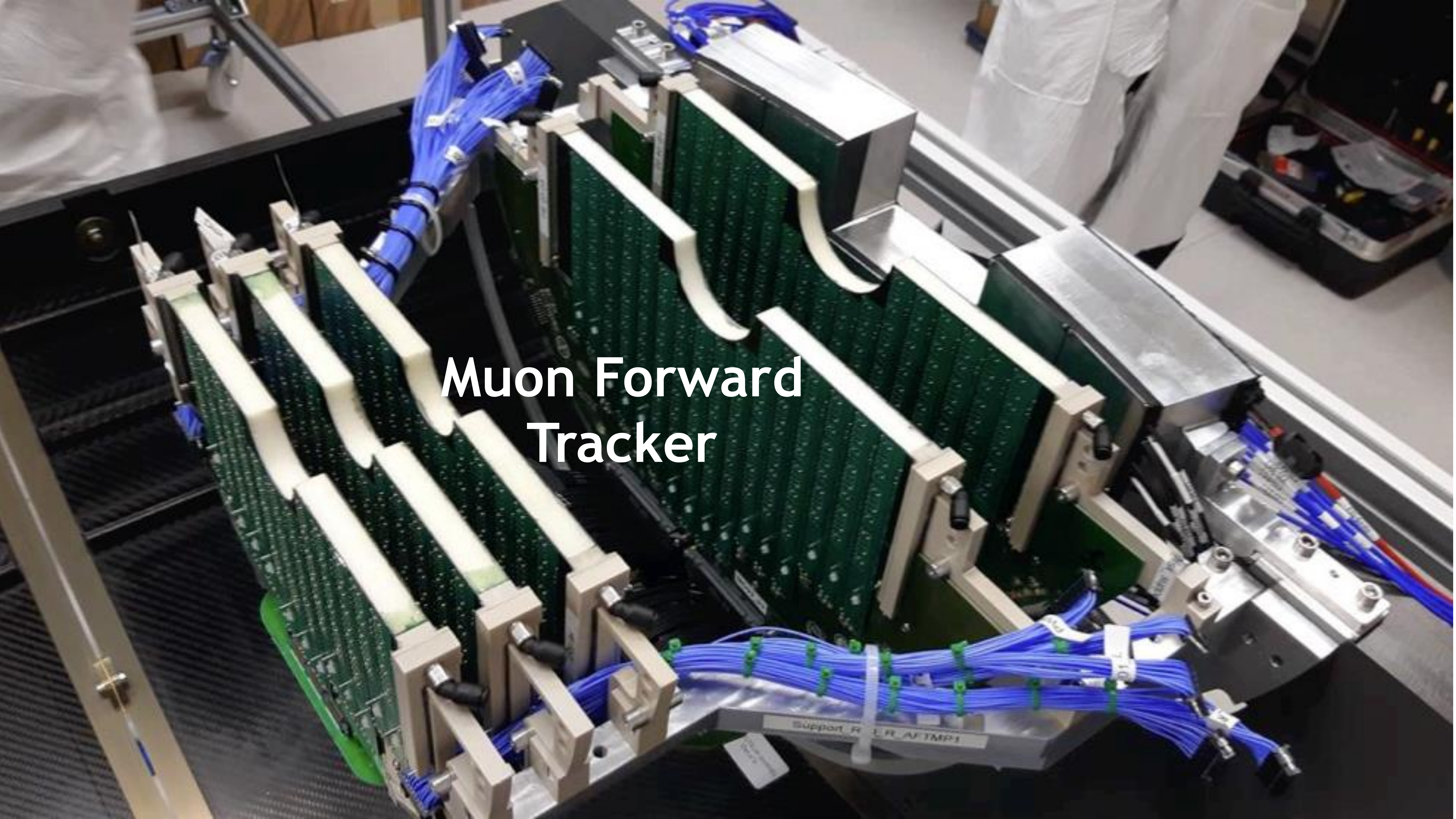


ITS outer barrel installation



ITS inner barrel installation

Dec 2016 — May 2019 — Mar 2021 — May 2021


Muon Forward
Tracker

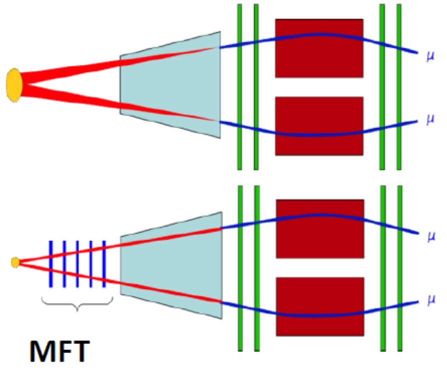
MFT layout

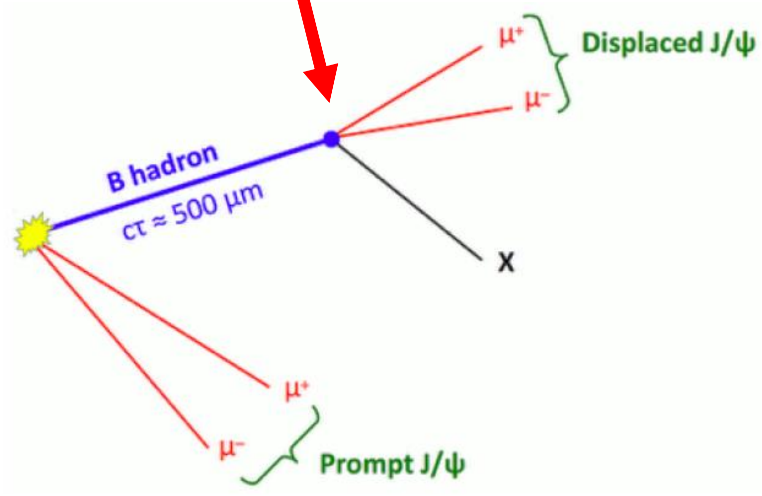
A new high-resolution Si tracker (2.5 < **η** < 3.6) which adds precise vertexing capabilities to muon tracking at forward rapidity

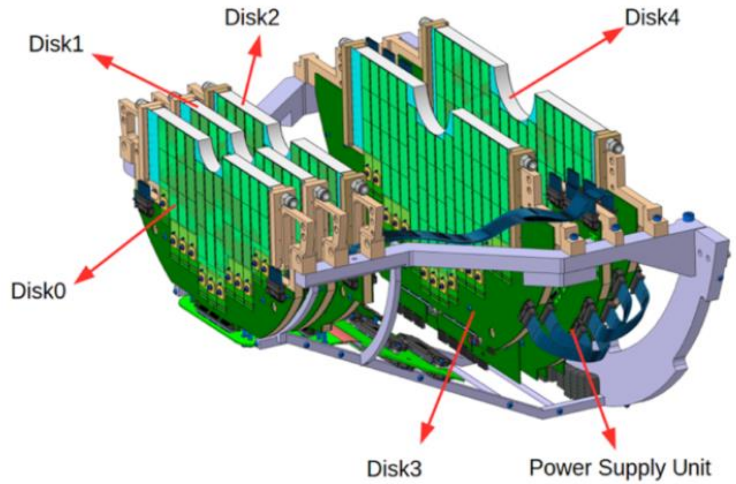
- Matching muon tracks with MFT tracks
- Charm/beauty separation via secondary vertex reconstruction

Run 2
MUON spectrometer→

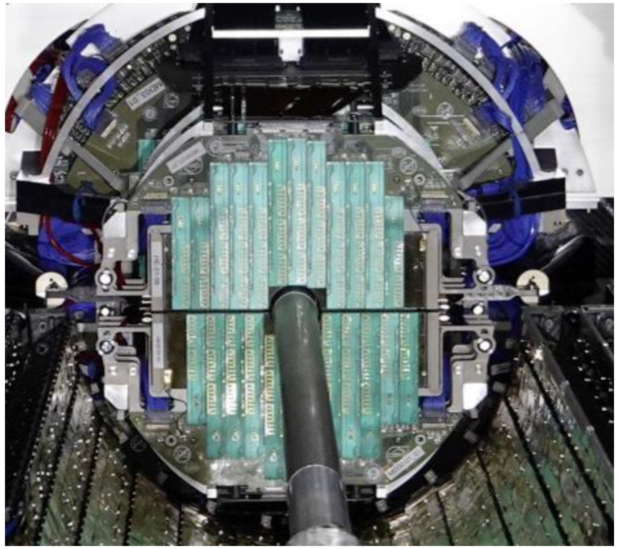
Run 3
MUON +MFT→





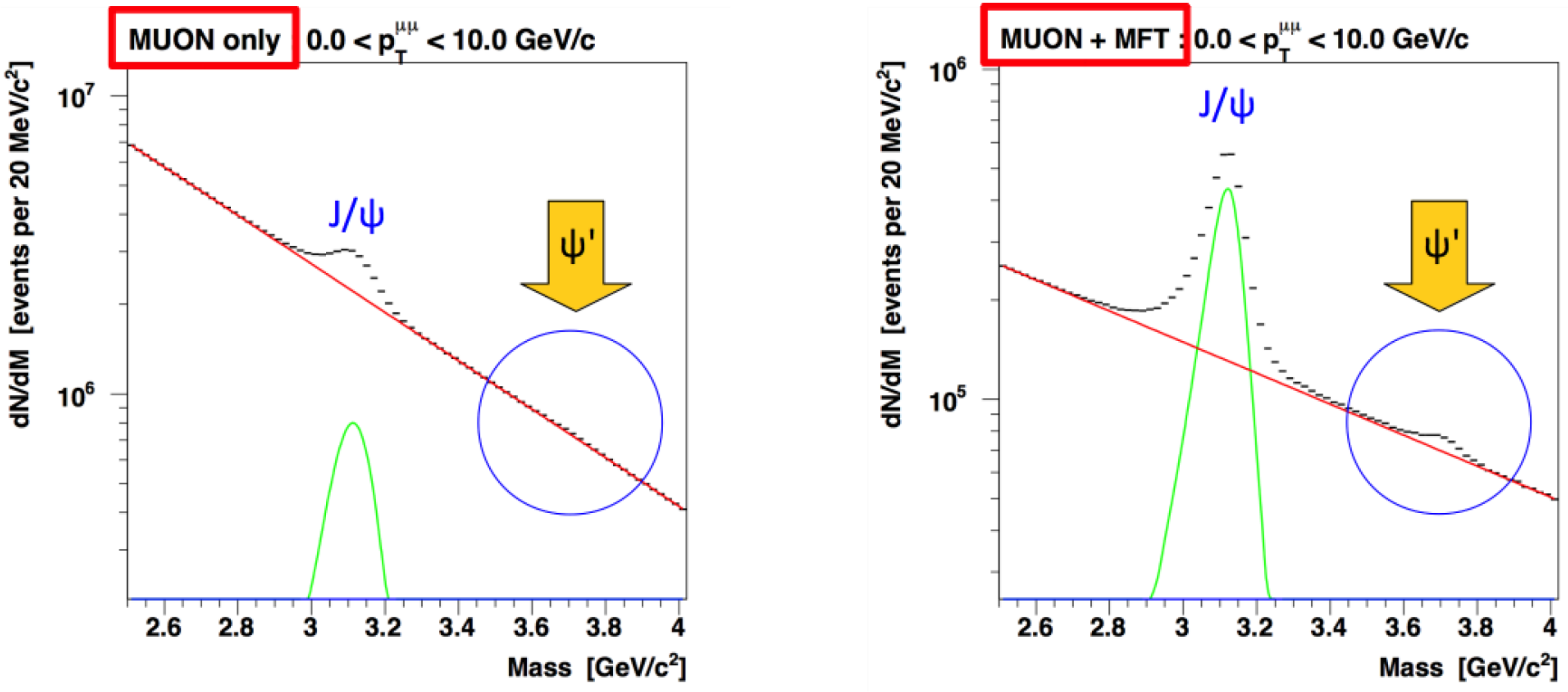


Based on ALPIDE chips as ITS2 (936 Si chips, 0.4 m^2)
10 half-disks, 2 detection planes each



MFT in its final position (installed Dec. 2020)

MFT performance



MFT will provide a robust ψ(2S) measurement by improving the S/B by a factor of 5 to 6


Time Projection Chamber

TPC readout chambers and electronics

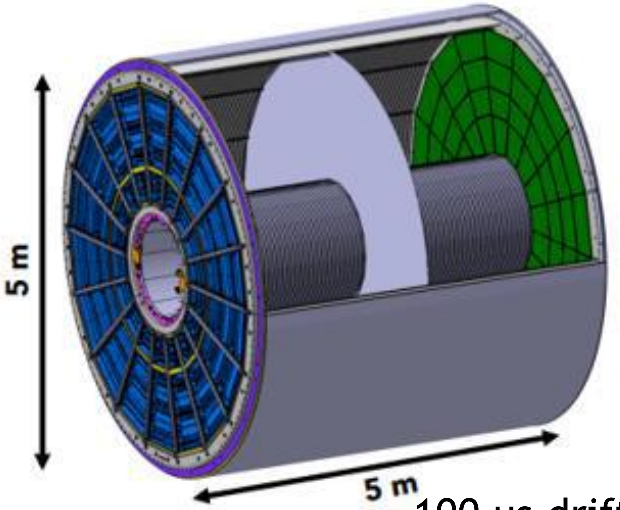
Previous readout with MWPC: readout rate limited to few kHz by need of wire gating grid, to minimize ion backflow

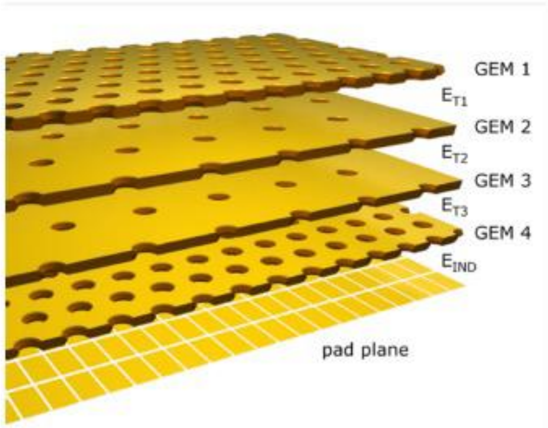
Goal:

- Continuous readout
- Nominal gain = 2000 in $Ne\text{-}CO_2\text{-}N_2$ gas
- Ion back-flow <1%
- Preserve dE/dx performance

Solution:

replace gated multiwire-proportional chambers with **quadruple GEM stack:** standard (140 µm) and large hole pitch (280 µm) GEM foils





100 µs drift time,
90 m^3 gas volume

Newly developed FE ASIC SAMPA
(130 nm TSMC CMOS)

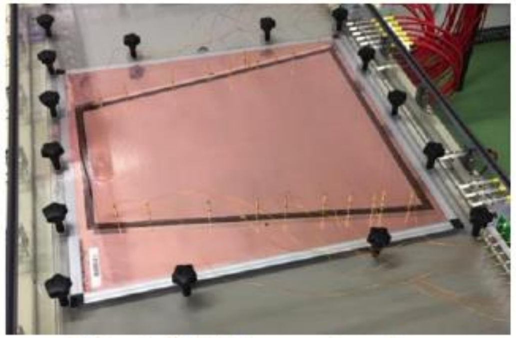
- 32 channels, preamplifier, shape and 10 bit ADC
- Readout mode: continuous or triggered

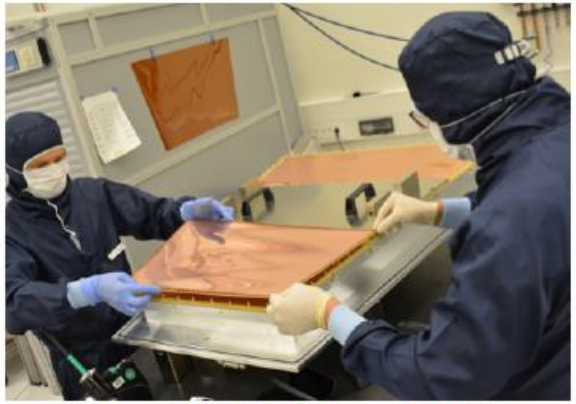
Front-End Cards (FECs)

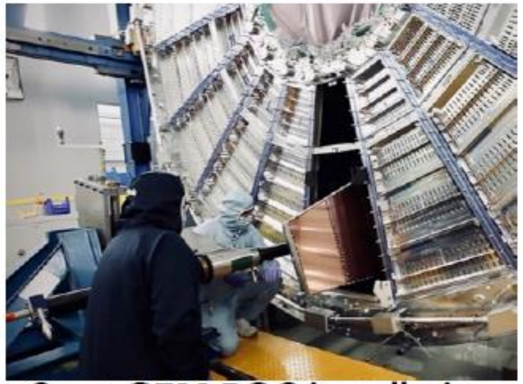
- 5 SAMPA chips per FEC (3276 FECs in total)
- Continuous sampling at 5 MHz
- All ADC values read out at 3.3 TB/s

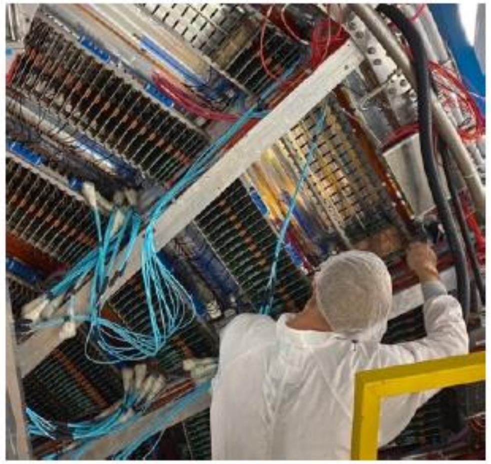
Online calibration, reconstruction and data compression needed (O2 project)

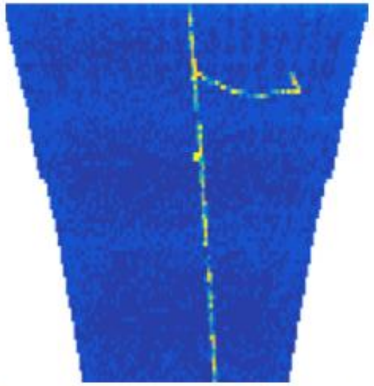
TPC production, installation and commissioning


Start GEM production


Start GEM ROC production


Start GEM ROC installation

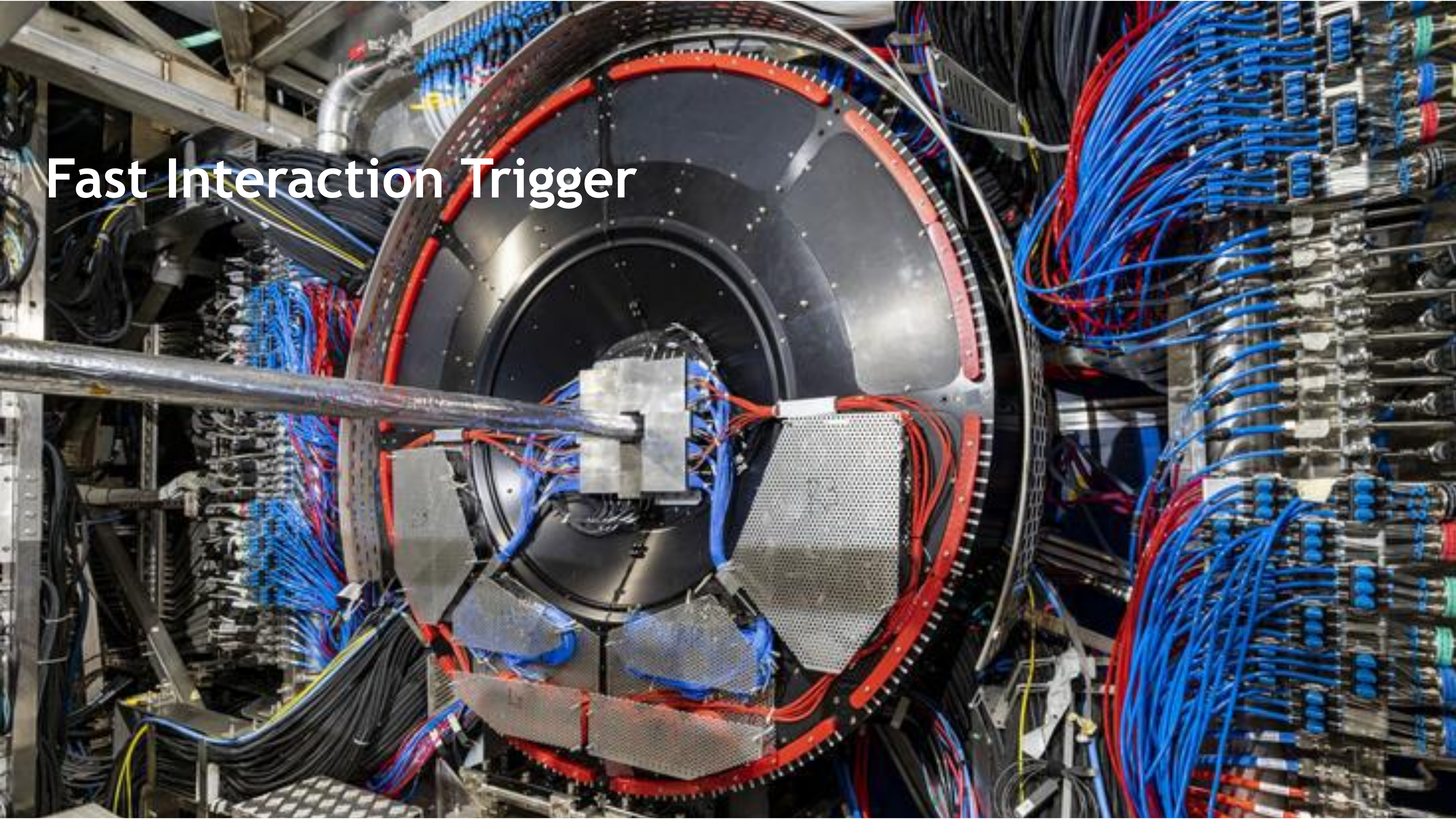

Start installation FEE and services


Start pre-commissioning

Transportation to LHC P2


Connection and commissioning

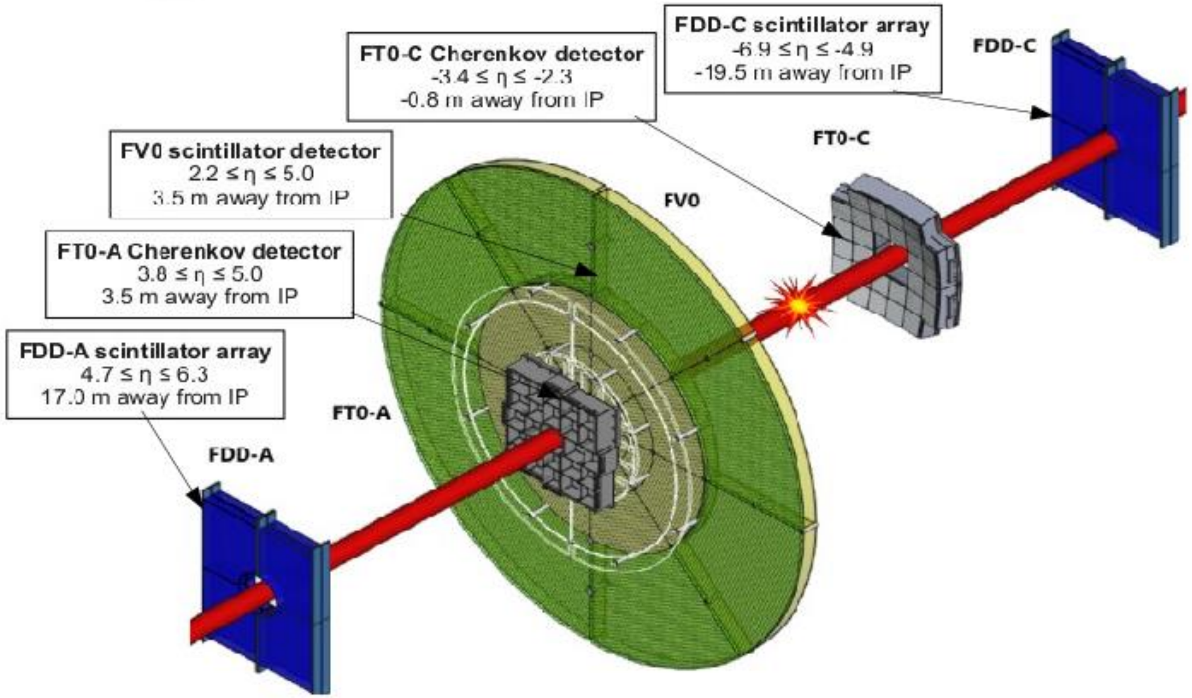
Fast Interaction Trigger



Fast Interaction Trigger

FIT functionality:

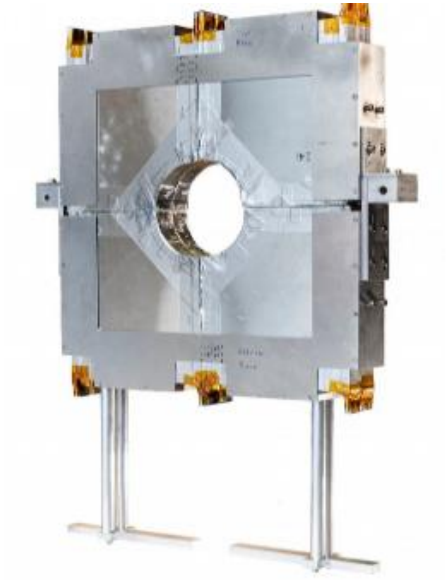
- **Luminosity** monitoring and feedback to LHC
  - Essential for the operation of ALICE
- Fast Interaction **Trigger** with **latency<425 ns**
  - Online Vertex determination
  - Minimum Bias and centrality selection
  - Rejection of beam/gas events
- **Collision time** for Time-Of-Flight particle ID
- **Multiplicity, Centrality** and **Event Plane** of the collision
- tags for **Diffractive** and **Ultra Peripheral Collisions**

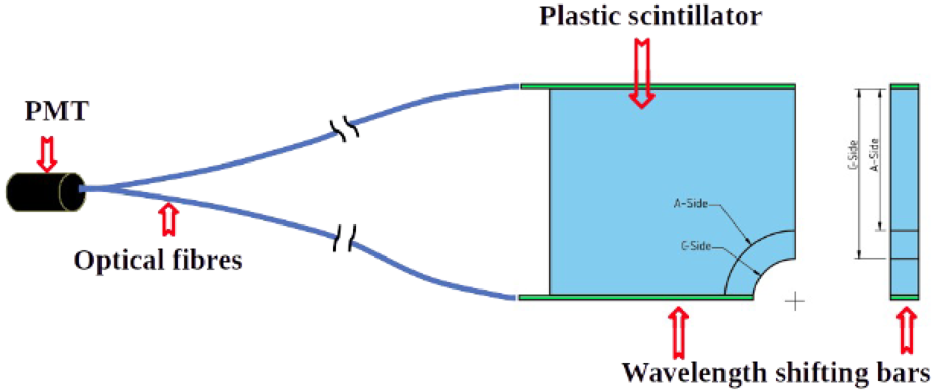


FV0

FIT Detectors

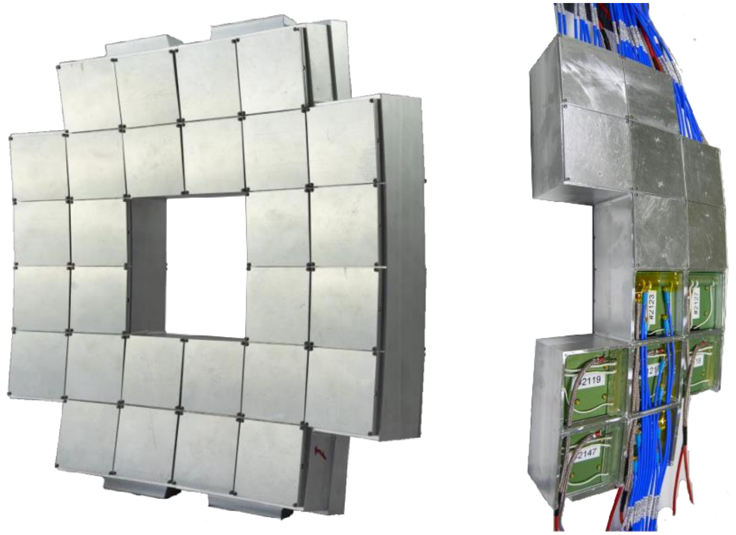
Detector	Purpose	Distance from collision point	Technology
FDD-A	Measurements of diffractive cross sections and studies of ultra-peripheral collisions	17 m	BC420 scintillator pads, wavelength shifters, fibers, Hamamatsu H8409-70 PMTs
FDD-C		-19.5 m	
FV0	Min bias and multiplicity triggers, centrality and event plane measurement	3.2 m	EJ-204 scintillators, fibers, Hamamatsu R5924-70 PMTs
FT0-A	Minimum bias and multiplicity triggers (together with FV0), collision time	3.3 m	Quartz Cherenkov radiators, Photonis XP85002/FIT-Q MCP photomultipliers
FT0-C		-0.8 m	



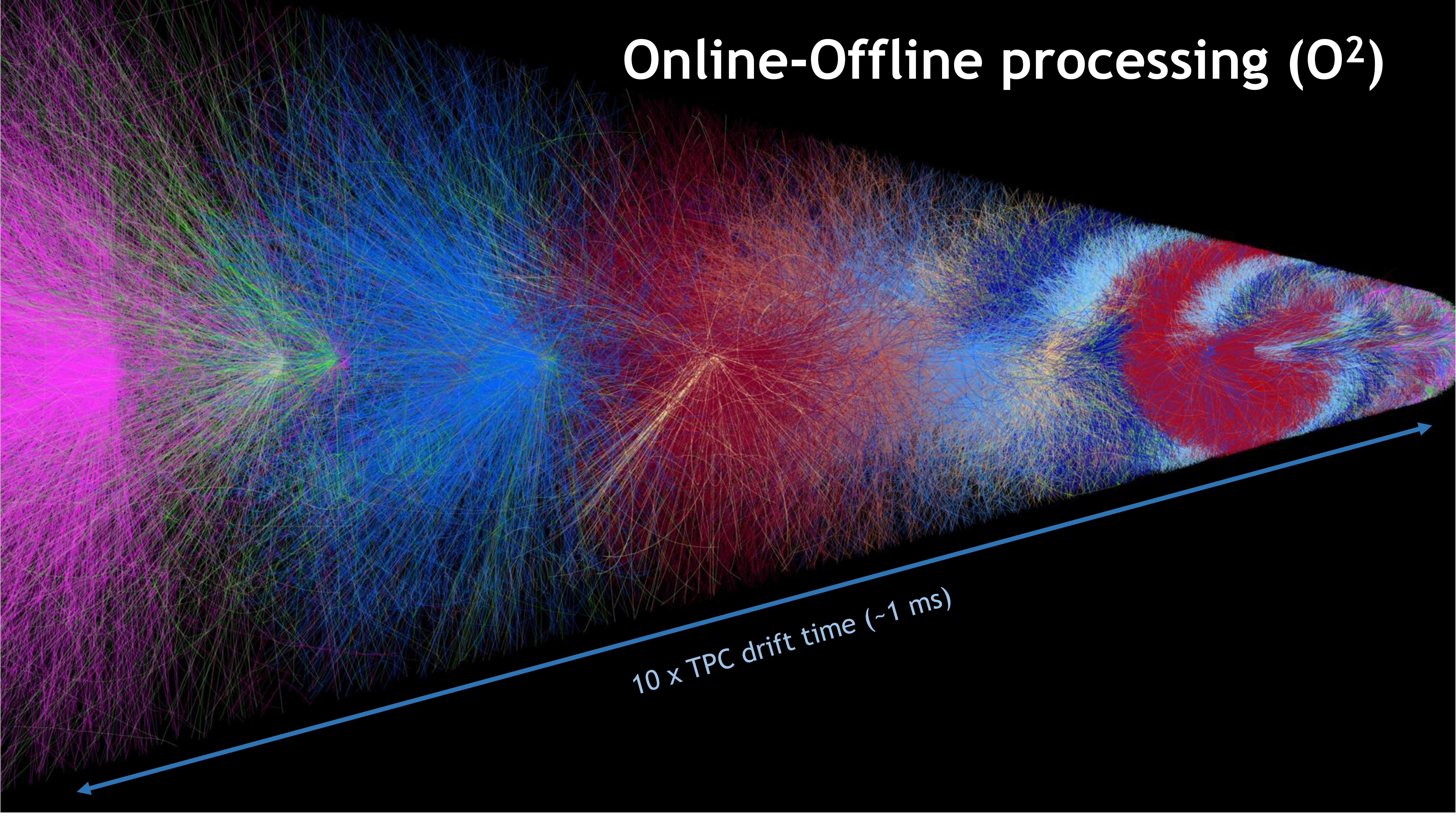


FDD-A

FT0

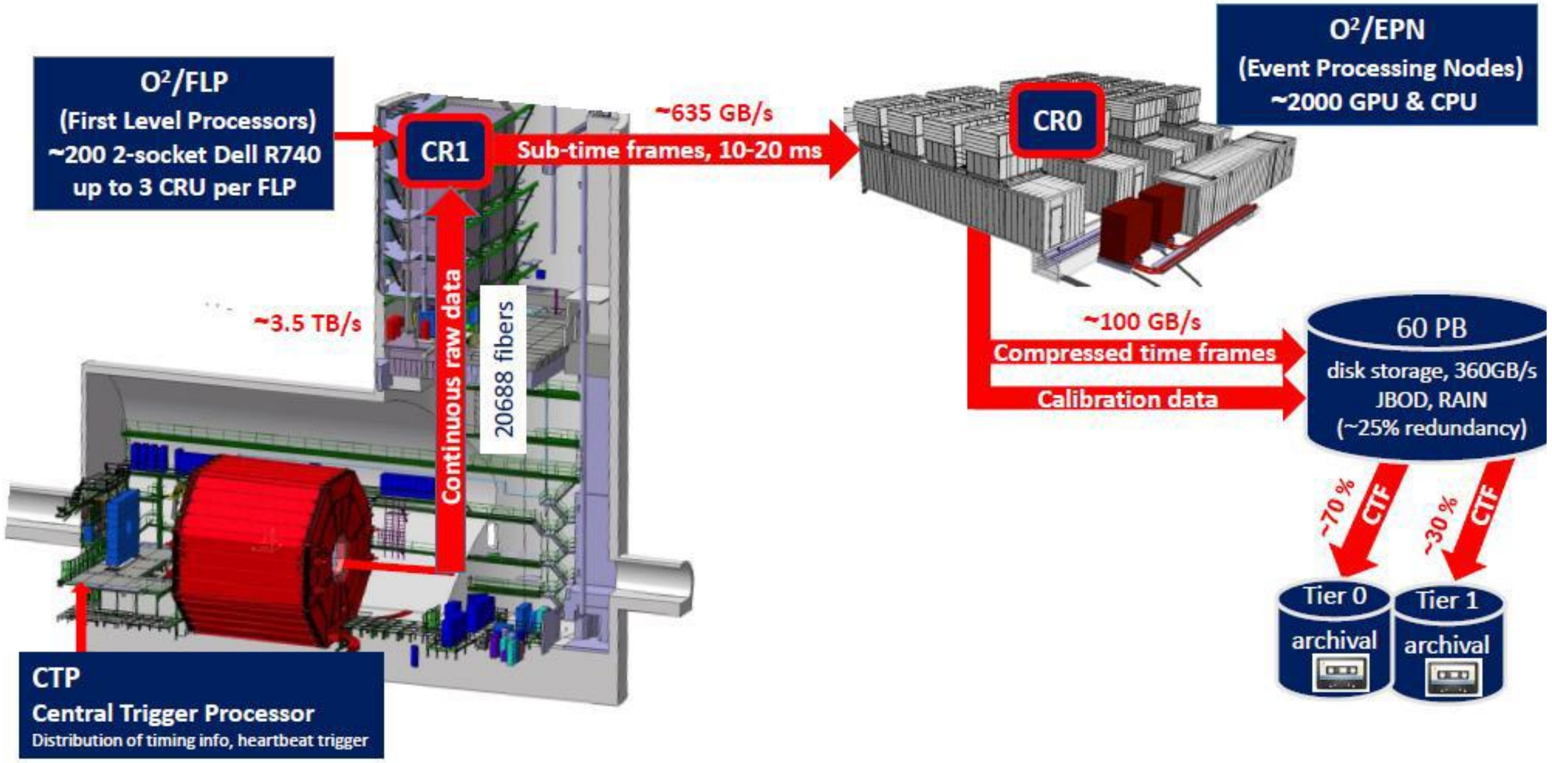


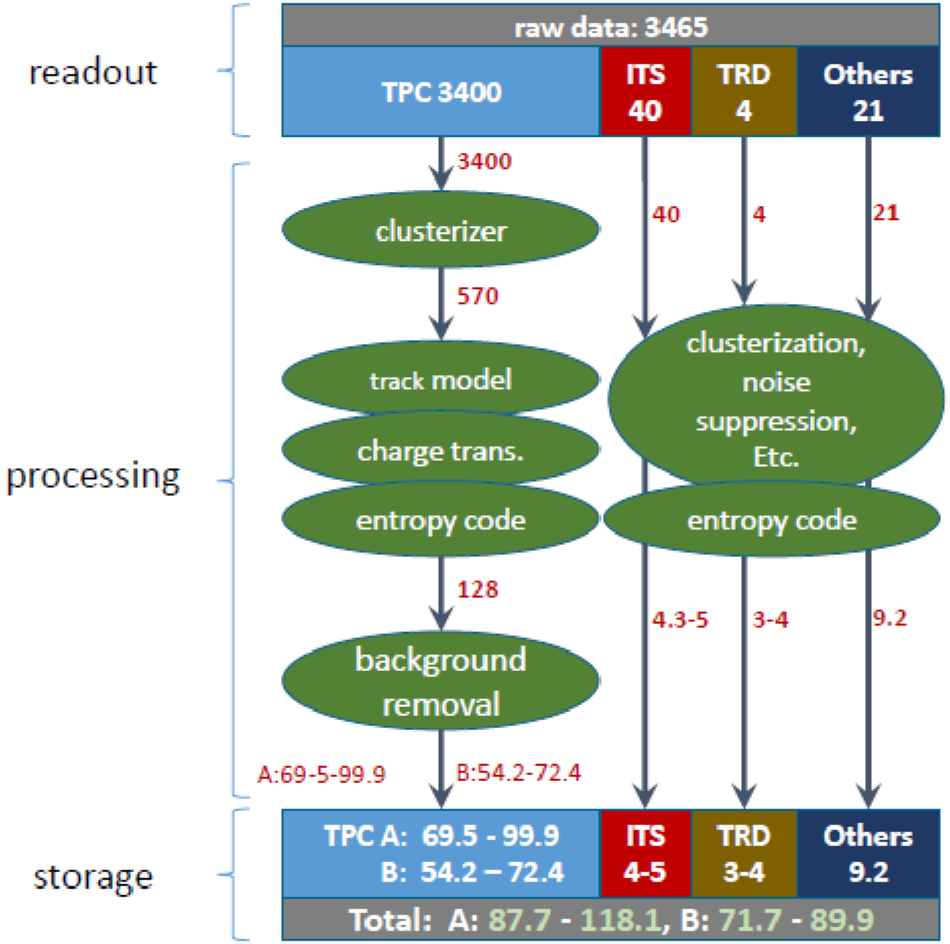
Online-Offline processing (O^2)



O² processing

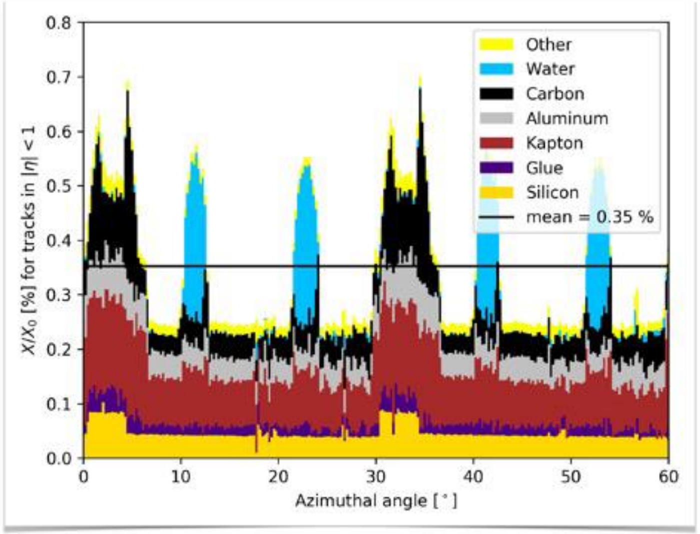
- **50 kHz Pb-Pb collisions**
- First Level Processors (FLPs) to receive detector data from detector
- Continuous data flow is chopped into (sub-)time frames on the FLPs
- Data volume reduction: input 3TB/s, output on storage 0.1TB/s

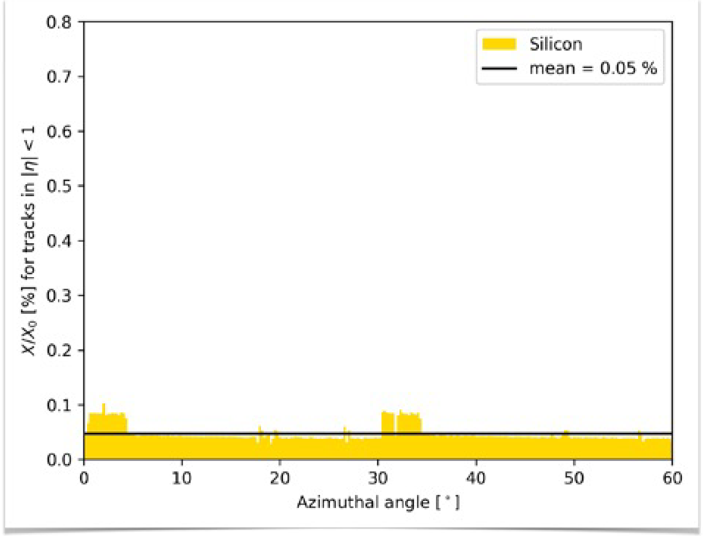





ITS3 for Run 4
(from 2027)

ITS3: future upgrade of the ITS for Run 4

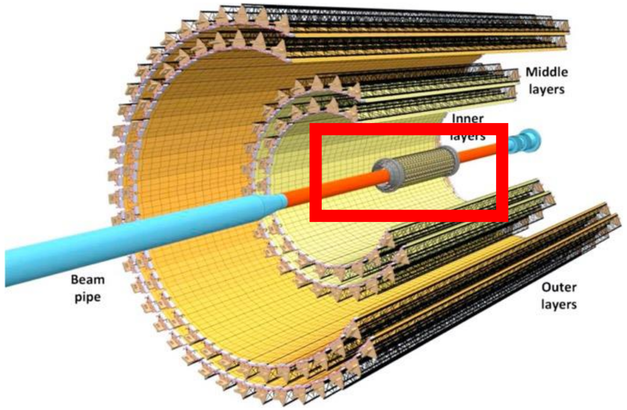


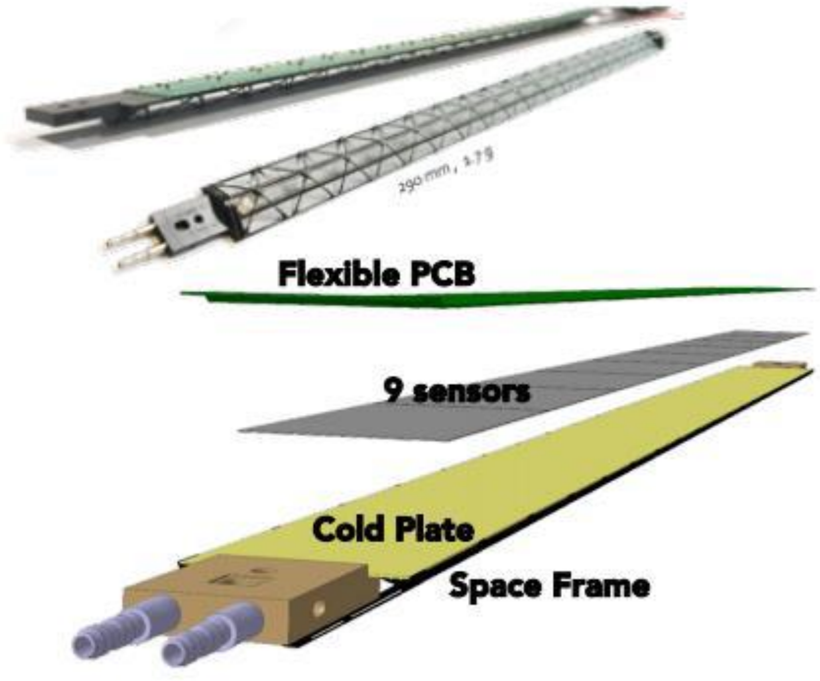


The performance of the upgraded ITS can be further improved essentially by modifying the Inner Barrel (IB):

- closer to the Interaction Point: beam pipe with smaller inner radius (18.2mm to 16mm and reduced thickness (800μm to 500μm)

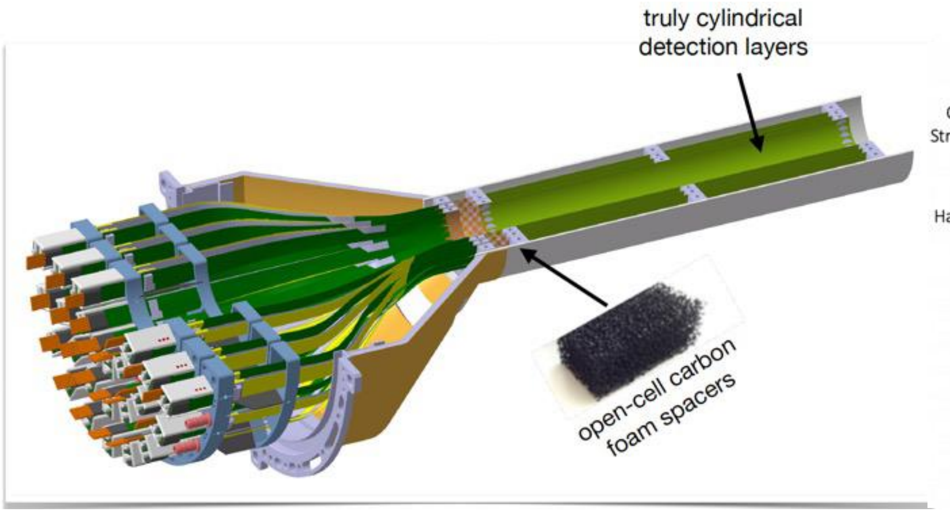
- reduced material budget

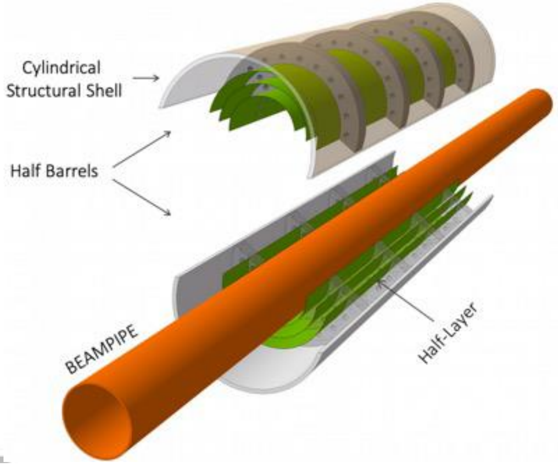




Removal of water cooling: power consumption below 20 mW/cm^2 (65 nm technology)
Removal of circuit board: Integrate power and data buses on chip
Removal of mechanical support: Benefit from increased stiffness of bent Si wafers

ITS3 detector concept





- **Key characteristics:**

- 65 nm CMOS, up to 300mm large sensors enabled through stitching technology, thinned down to (flexible) 20-40μm

- 6 sensors in total (1 for each half layer)

- bent to target radii

- mechanically held by low-density carbon foam ribs

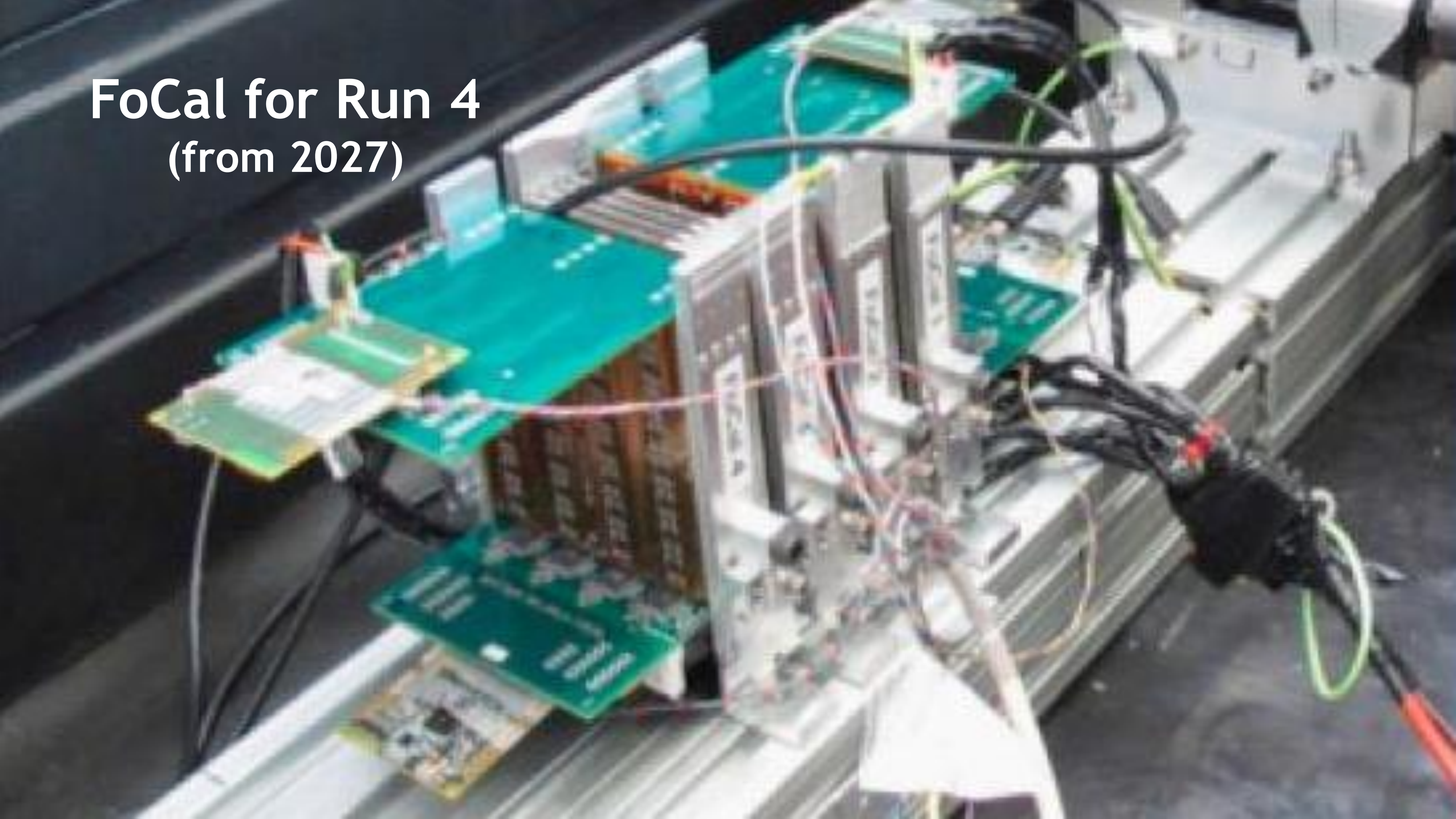
- **Main benefits:**

- very low material budget (0.04% X_0)

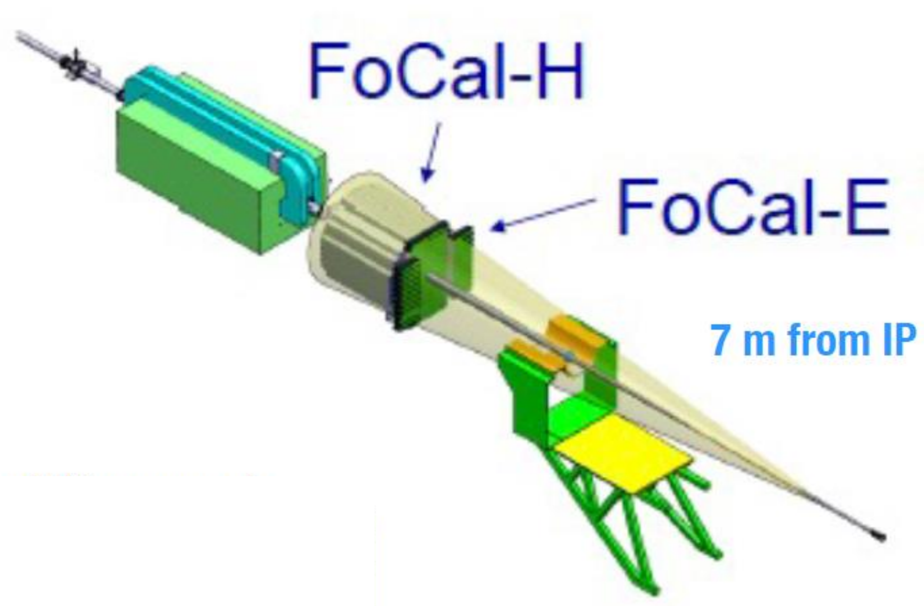
- very homogeneous material distribution (negligible systematic error)

IB Layer Parameters	L0	L1	L2
Radial Position [mm]	18	24	30
Length (sensitive area)[mm]	300		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active area [cm^2]	610	816	1016
Pixel sensor dimensions [mm^2]	280x56.5	280x75.5	280x94
Number of sensors per layer	2		
Pixels size [μm^2]	O(10x10)		
Beam Pipe Inner/Outer Radius [mm]	16/16.5		

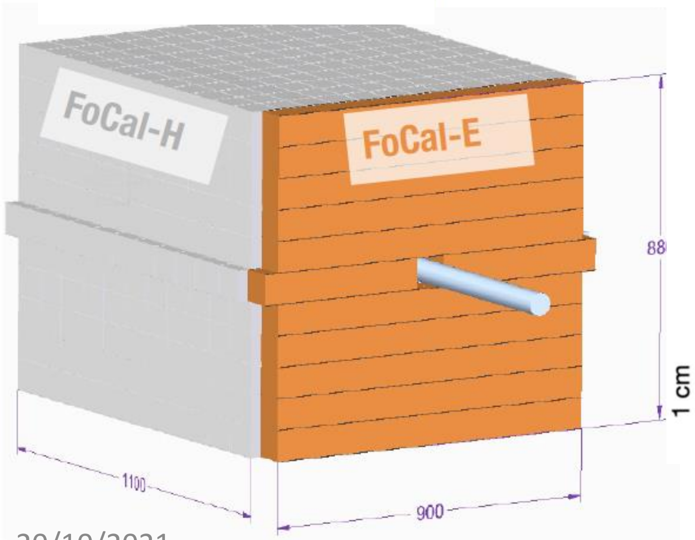
FoCal for Run 4
(from 2027)

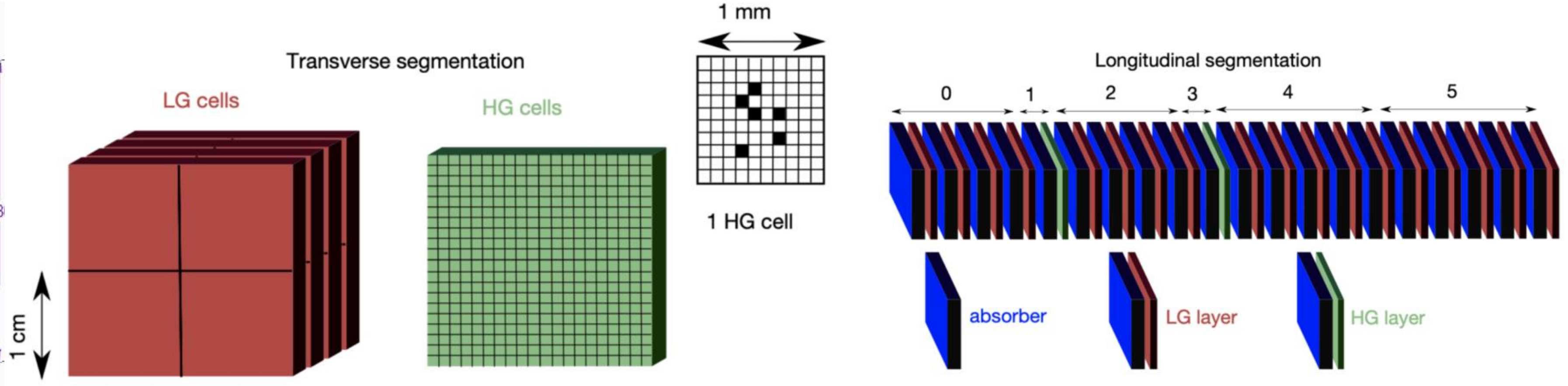


FOrward CALorimeter



- **A new high granularity Forward Calorimeter**
- High-precision inclusive measurement of direct photons and jets
- Coincident γ-jet and jet-jet measurements
- **7 m from interaction point, 3.4 ≤ η ≤ 5.8**
- **FoCal-E: high-granularity (~1 mm^2**) Si-W sampling sandwich calorimeter for photons and π^0 (w/ pads and 2 high-granularity pixel layers)
- **FoCal-H:** A conventional sampling calorimeter (Cu + scintillating fibres) for photon isolation and jets





Summary

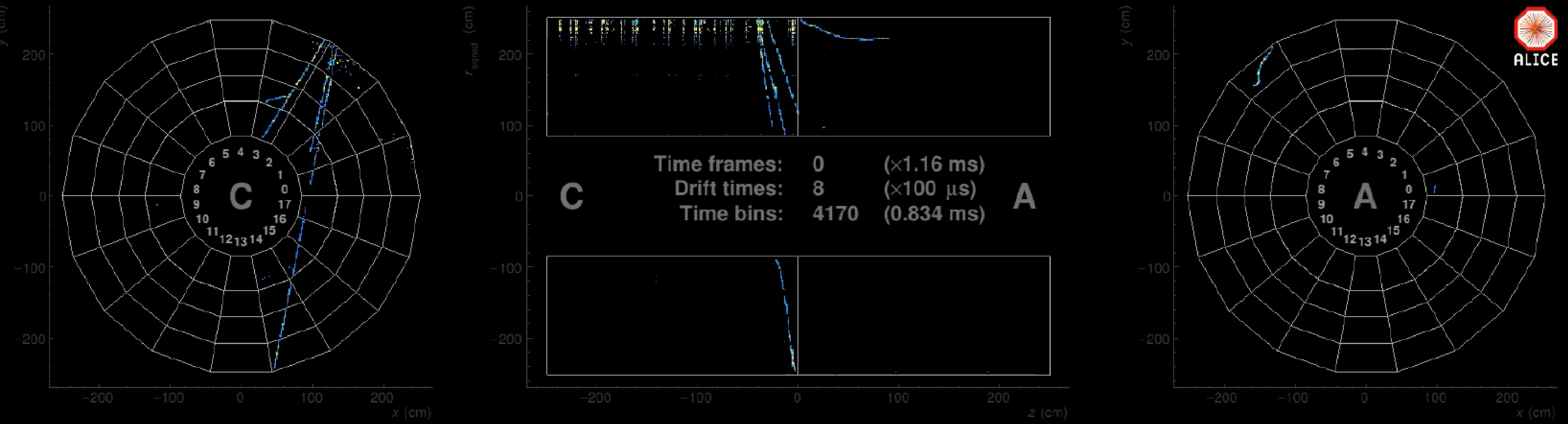
- Major ALICE upgrade for Run 3 on track
- Full upgrade of the detector readout architecture and computing
- Integrated Online-Offline system
- 3 new detectors have been installed
- Enhanced tracking and vertexing performance with the new ITS and MFT
- New, GEM-based TPC Readout Chambers
- New Fast Interaction Trigger

- In preparation: ITS3, FoCal for Run4

Thanks for your attention!

Backup slides

TPC cosmic muon track

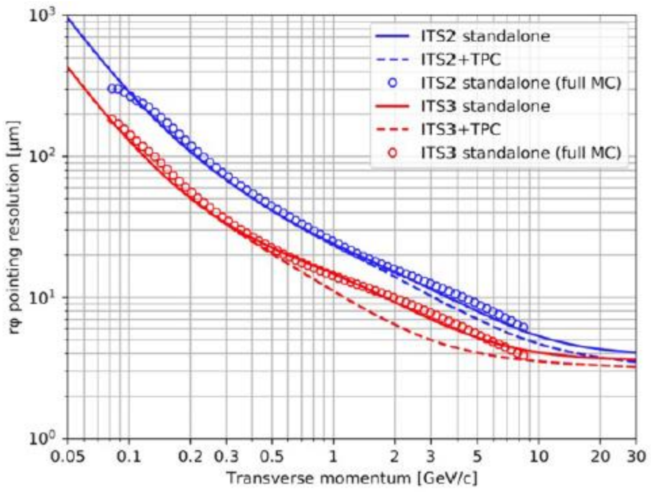


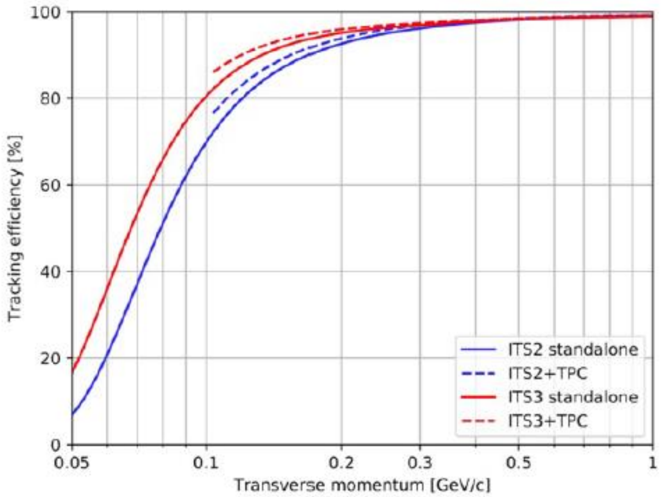
From TPC installed in ALICE cavern

ITS3 physics performance

Key improvements:

- Pointing resolution enhanced by a factor of 2 over all momenta
- Increase of tracking efficiency for low-p_T particles and extension of the low-p_T reach





Λ_c in Pb-Pb collisions

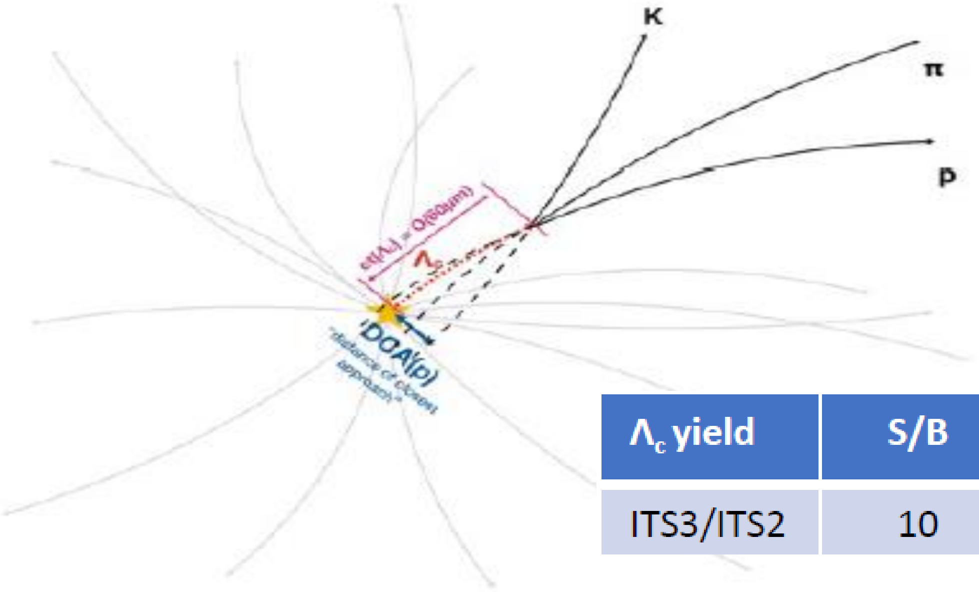
Analysis difficult due to large combinatorial background

- O(10k) charged particles in a central Pb-Pb collision

Discrimination of background via:

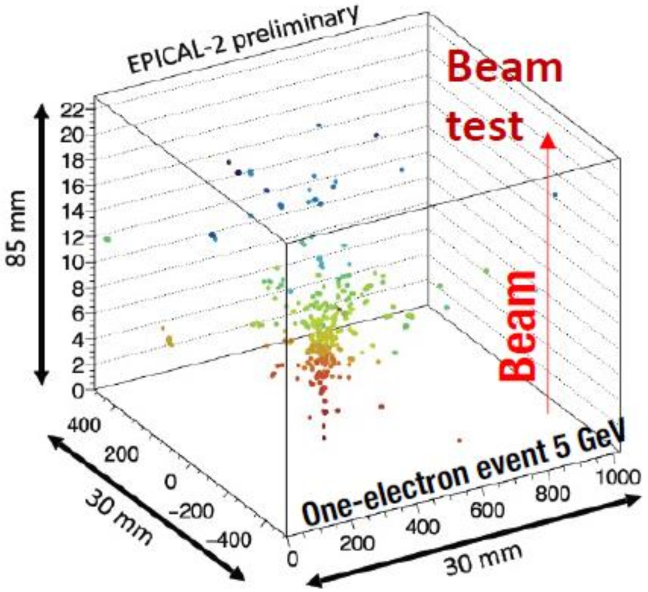
- Particle identification (relatively low yield of protons and Kaons wrt. pions

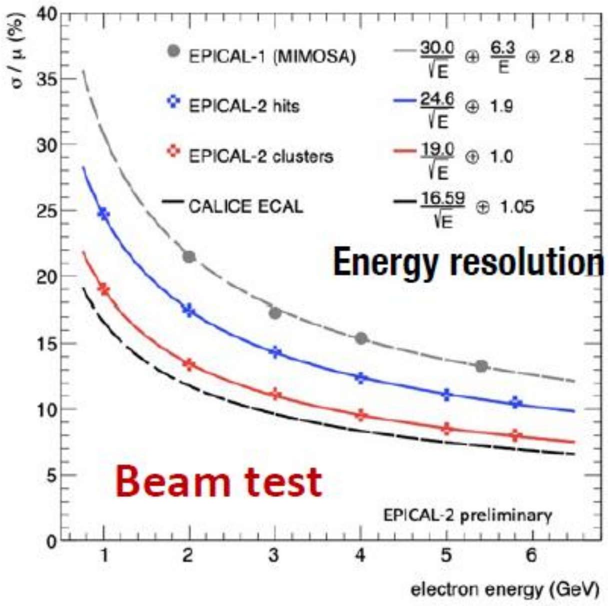
- Topology: cut on DCA of single tracks (before making the combinations) and decay vertex position (need combinations)

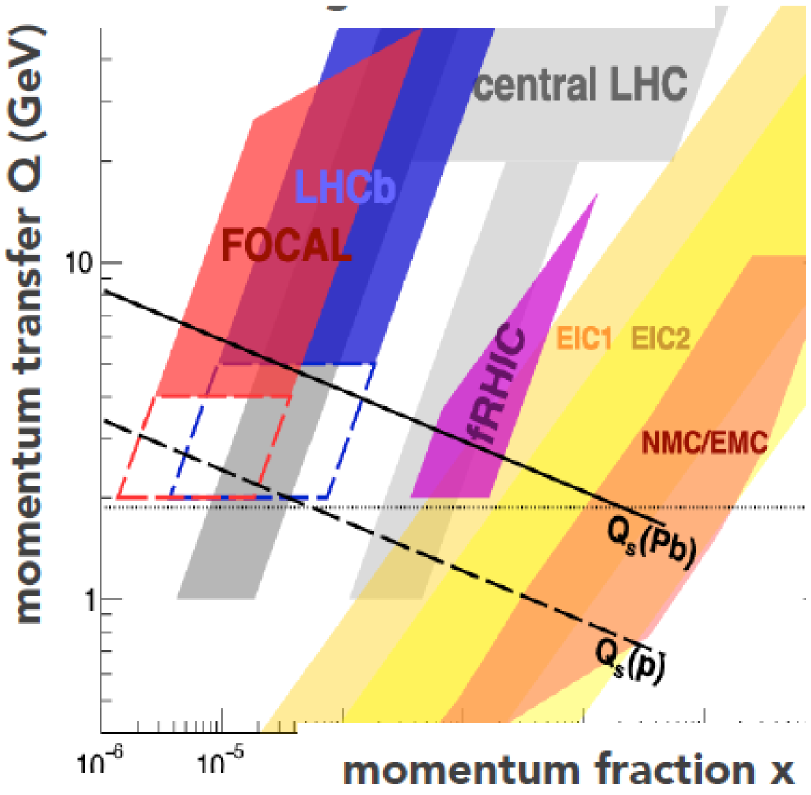


Λ_c yield	S/B	Significance
ITS3/ITS2	10	4

FOCAL beam test and physics domain







Beam test of EPiCAL2 (Electromagnetic Pixel CALorimeter, prototype 2

- 3x3 cm^2 cross section
- 24 layers, each with 2 ALPIDE CMOS MAPS and 3 mm W absorber

Results

ALPIDE sensor suitable for calorimeter use

Energy resolution improved wrt. previous prototypes

Reasonable longitudinal shower shape

Approximate (x,Q) coverage of various experiments for regions explored by deep inelastic scattering measurements and EM probes