Online
LHCP2021
The Ninth Annual Conference on Large Hadron Collider Physics
7-12 June 2021 ~~Paris (France), Sorbonne Université (IN2P3/CNRS,IRFU/CEA)~~
D. Longieras IJClab 2021

ALICE Upgrades

C. Lippmann
for the ALICE collaboration

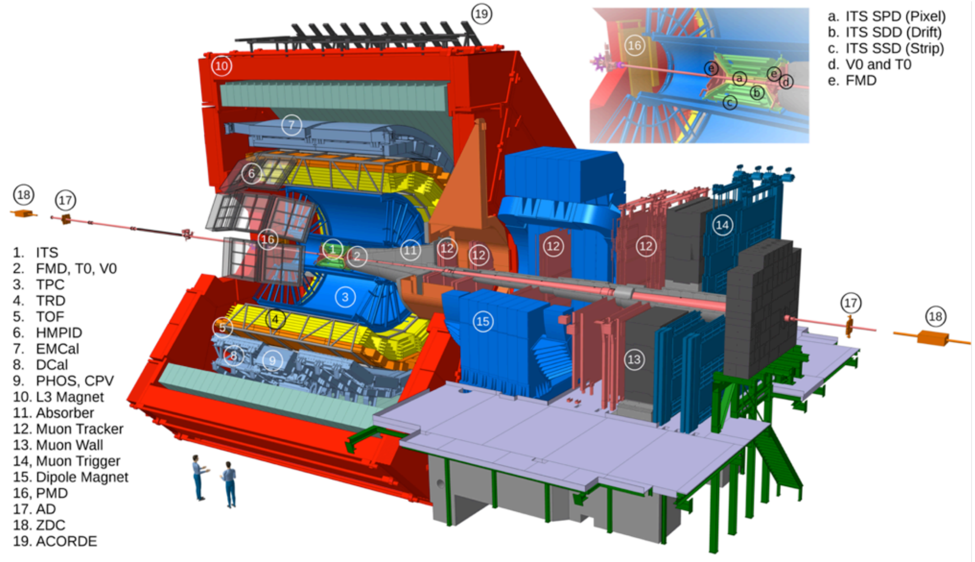
ALICE

GSI

ALICE in Run 1 and Run 2

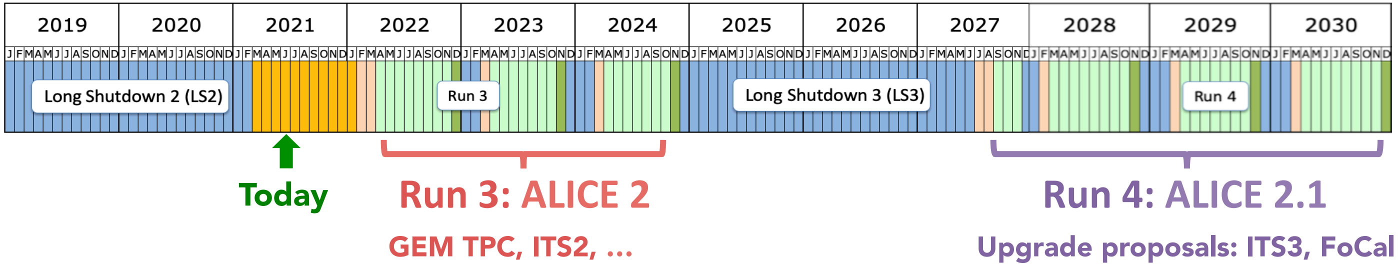
Run 1 (2009 – 2013)
Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV
pp @ $\sqrt{s}$ = 0.9, 2.76, 7 and 8 TeV

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



- 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 upgrade roadmap (1)



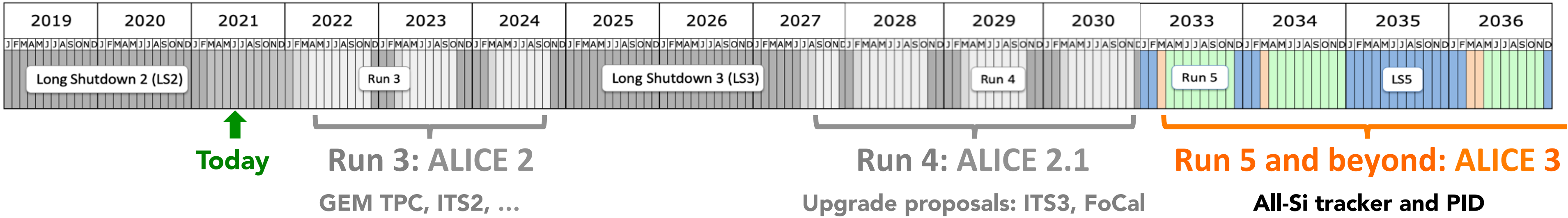
ALICE strategy for Run 3 and Run 4

- 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	$\mathcal{L}_{Pb-Pb}$ = 13 nb^{-1}	Plus pp reference data
p-Pb @ $\sqrt{s_{NN}}$ = 8 – 8.8 TeV	$\mathcal{L}_{p-Pb}$ = 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

Programme is presented in CERN Yellow Report (link)
LHC schedule (link),
Future high-energy pp programme with ALICE (link)

ALICE upgrade roadmap (2)



ALICE 3: Proposal for a new generation heavy-ion experiment for LHC Run 5

- **See slide 36**

Runs 3 and 4: Physics goals

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

Runs 3 and 4: Implementation (1)

Runs 3 and 4: Physics goals

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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

Runs 3 and 4: Implementation (2)

Runs 3 and 4: Physics goals

- Heavy-flavour mesons and baryons (down to very low p_T)
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1. **Untriggered data sample**
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   ➔ 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

Runs 3 and 4: Implementation (3)

Runs 3 and 4: Physics goals

- Heavy-flavour mesons and baryons (down to very low p_T)
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3. **Preserve particle identification (PID)** ➔ **Consolidate and speed-up main ALICE PID detectors**

Runs 3 and 4: Implementation (4)

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

Implementation

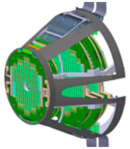
1. **Untriggered data sample**
   - **Record all Pb-Pb interactions at 50 kHz through continuous readout**
   - **Collect a factor 50 – 100 more min bias data wrt Run 2**

   → 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**

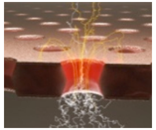
   → New Inner Tracking System ITS2 and Muon Forward Tracker MFT
3. **Preserve particle identification (PID)** **→ Consolidate and speed-up main ALICE PID detectors**
4. **Synchronous data processing (reconstruction, calibration) → New Online/Offline (O^2) farm**

Detector upgrades for Run 3

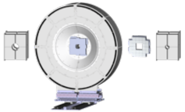
Inner Tracking System 2 (ITS2)
- CMOS pixel, Monolithic Active Pixel Sensor (MAPS) technology
- Improved resolution, less material, faster readout



New Muon Forward Tracker (MFT)
- CMOS pixel, MAPS technology
- Vertex tracker at forward rapidity



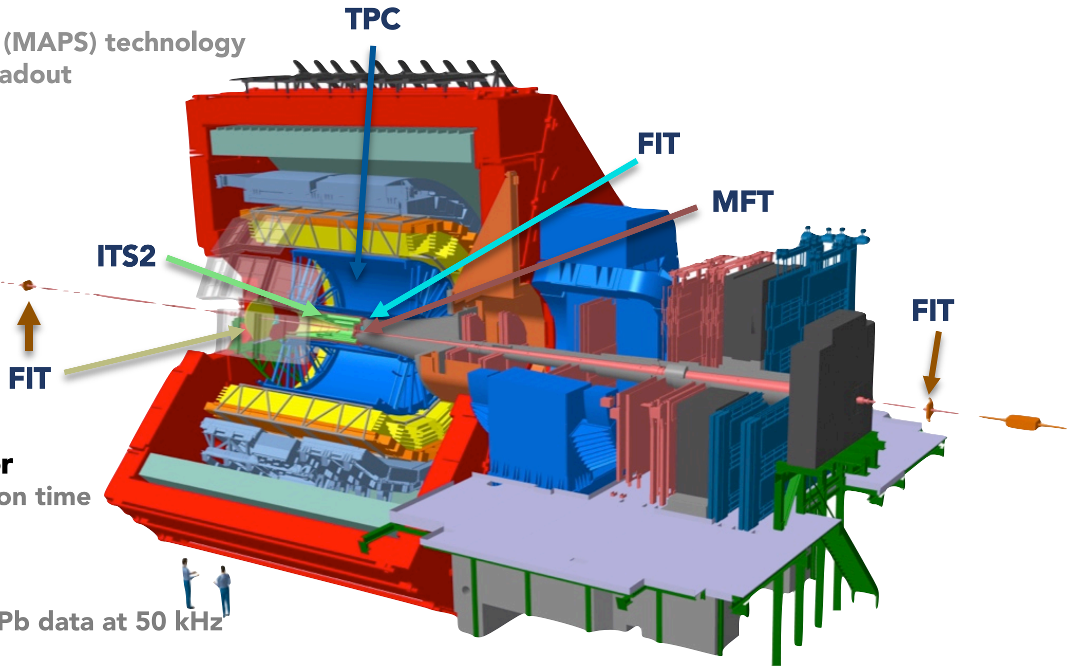
New TPC Readout Chambers (ROCs)
- Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout



New Fast Interaction Trigger (FIT) Detector
- Centrality, event plane, luminosity, interaction time

Integrated Online-Offline system (O^2)
- Calibrate and reconstruct minimum-bias Pb-Pb data at 50 kHz

Readout upgrade for all other detectors
- TOF, TRD, MUON, ZDC, calorimeters



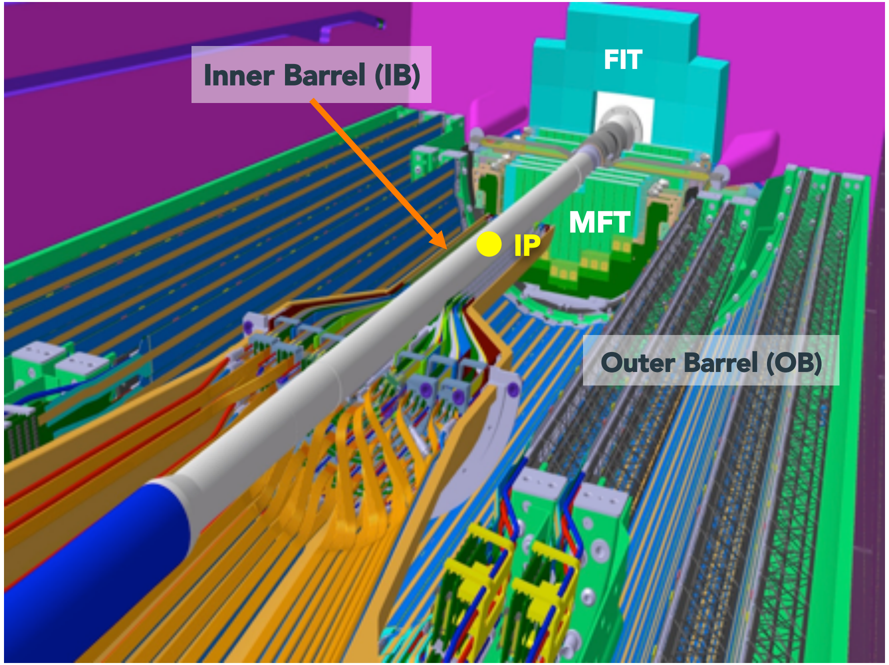
Inner Tracking System (ITS2)

ITS2 in CERN Courier

With permission. Article online (link)

- Largest pixel detector so far
- Article in July/August 2021 issue

ITS2 layout and specifications

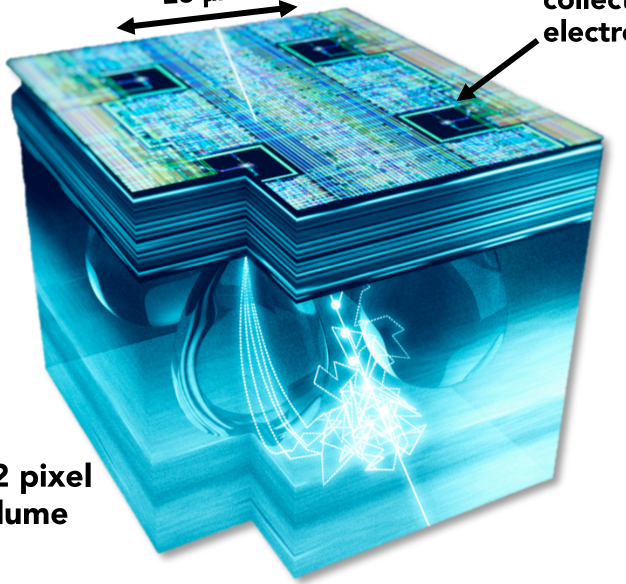


- 10 m^2 active silicon area, 12.5×10^9 pixels
  - 7 layers (3 inner, 4 outer)
  - 192 staves (48 inner, 144 outer)

	ITS1	ITS2
Distance to IP (mm)	39	22
X_0 (innermost layer) (%)	~ 1.14	~ 0.35
Pixel pitch (μm^2)	50 x 425	27 x 29
Spatial resolution ($r\varphi$ x z) (μm^2)	11 x 100	5 x 5
Readout rate (kHz)	1	100

➔ **Improved resolution, less material, faster readout**

ITS2 sensors

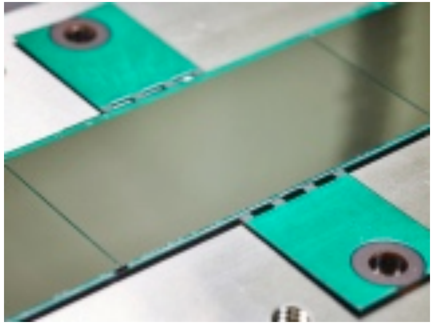


Artistic view

- Based on the ALPIDE chip (Monolithic Active Pixel Sensor, MAPS)
  - In-pixel amplification, shaping, discrimination and multi-event buffers (MEB)
  - In-matrix data sparsification
  - High detection efficiency: > 99%
  - Low fake-hit rate: << 10^{-6}/pixel/event
  - Radiation tolerant: > 270 krad total ionising dose (TID), > 1.7×10^{12} 1 MeV/n_{eq} non-ionising energy loss (NIEL)

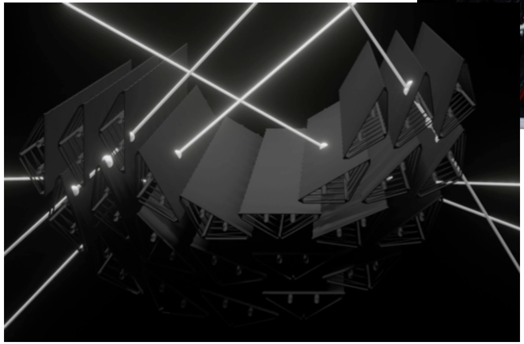
ITS2 timeline

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



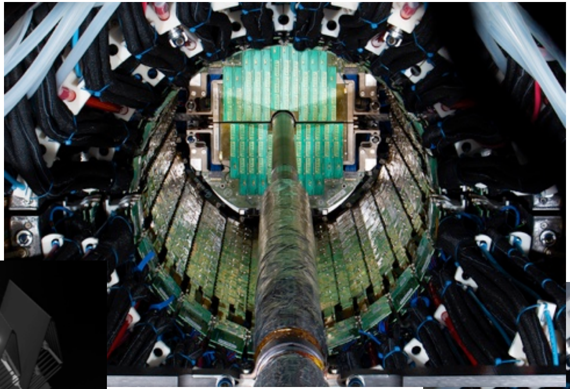
Start detector construction and assembly

Dec 2016



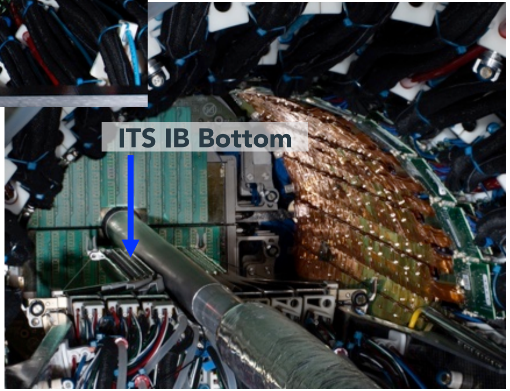
Start on-surface commissioning with final services

May 2019



ITS outer barrel installation

Mar 2021

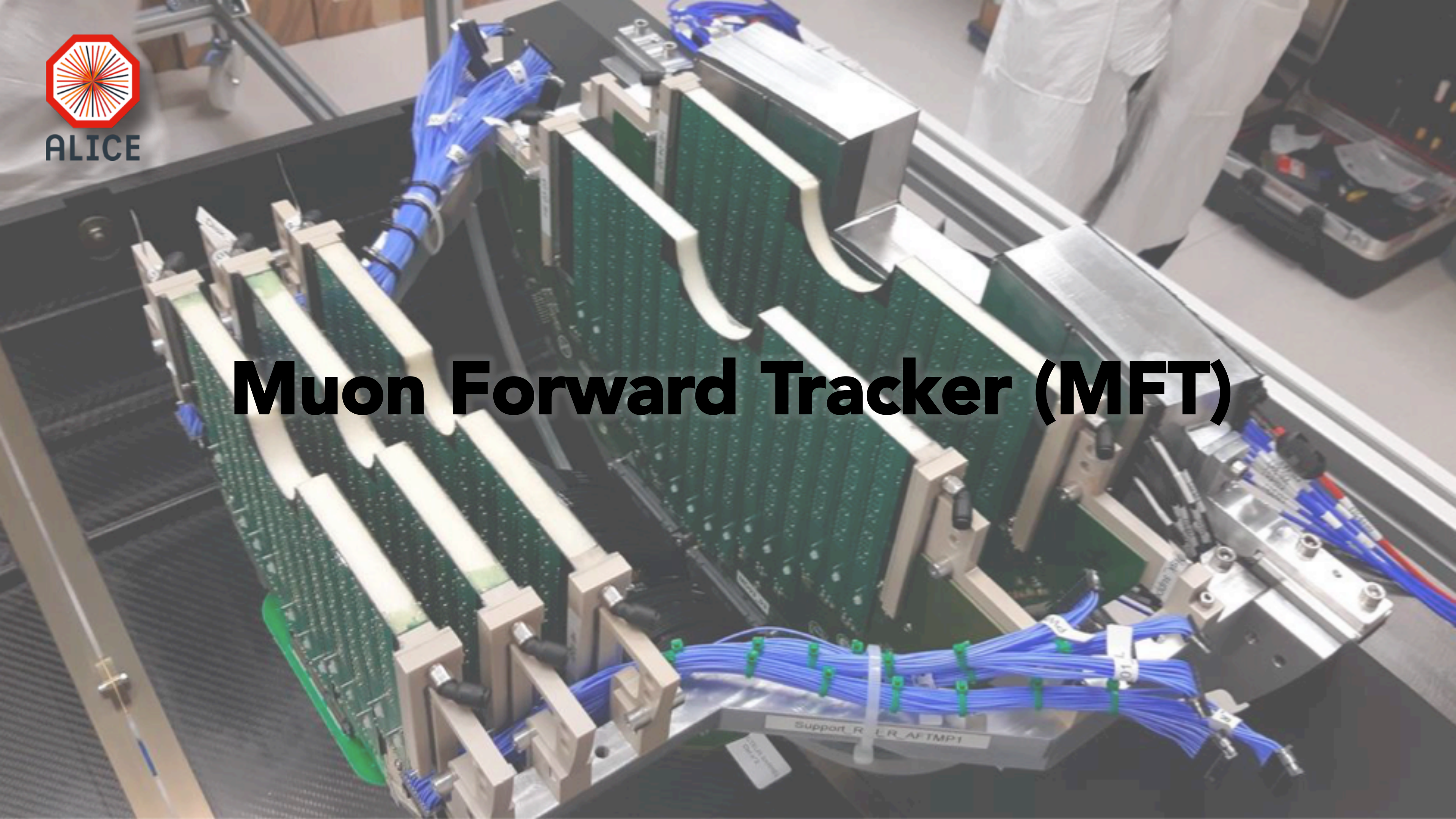


ITS inner barrel installation

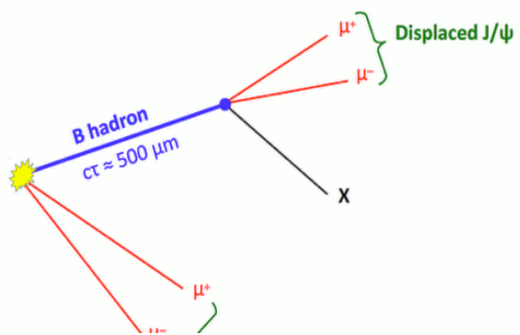
May 2021

ALICE

Muon Forward Tracker (MFT)

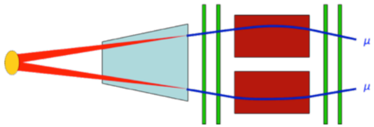


Muon Forward Tracker (1)

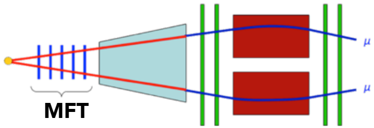


High pointing accurancy

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

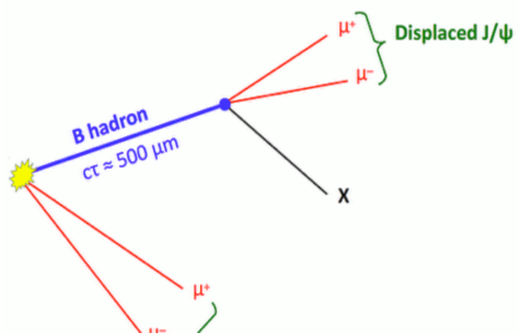


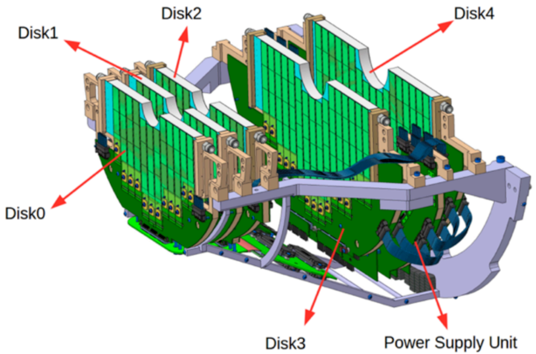
MUON spectrometer only

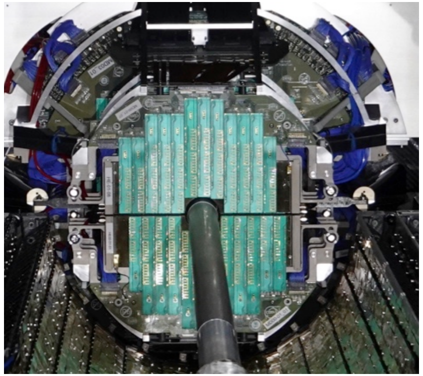


MUON + MFT

Muon Forward Tracker (2)



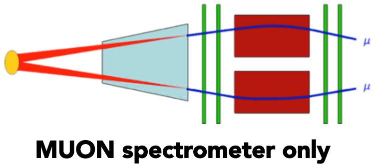


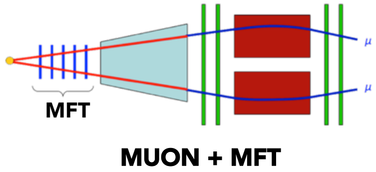


MFT in its final position

High pointing accurancy

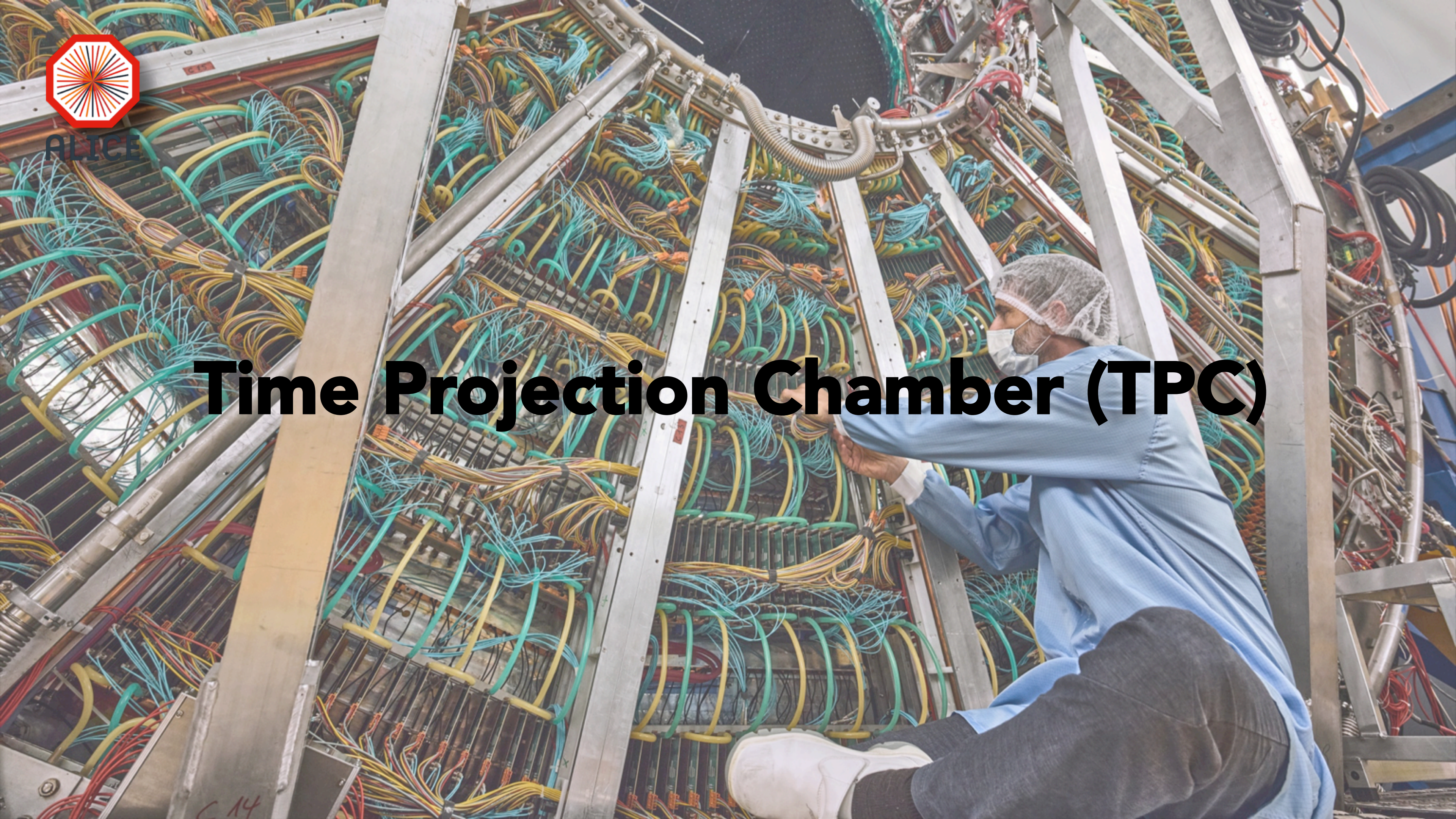
- Matching muon tracks with MFT tracks
- Charm/beauty separation via secondary vertex reconstruction



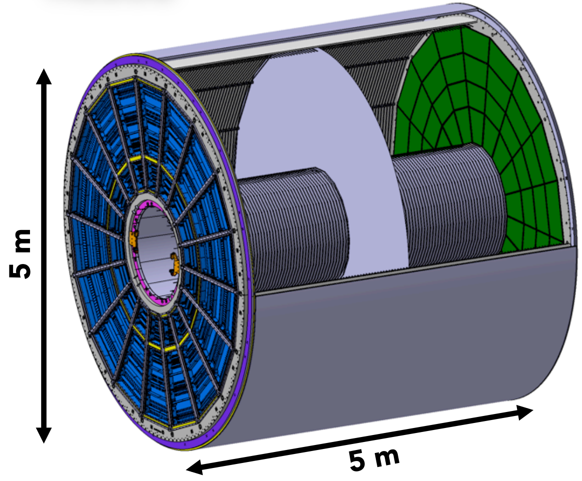


- A new high-resolution Si tracker ($2.5 < \eta < 3.6$) based on ALPIDE chips
  - 5 disks, 0.4 m^2
- Detector installed in Dec 2020
- Excellent noise performance: $< 10^{-8}$ fake hits / pixel / event

Time Projection Chamber (TPC)



TPC readout chambers



TPC upgrade specifications

- **Continuous readout**
- **Nominal gain = 2000 in Ne-CO_2-N_2 (90-10-5)**
- **Ion back-flow (IBF) < 1%**
- **Preserve dE/dx performance**
- **Stable operation under LHC Run 3 conditions**

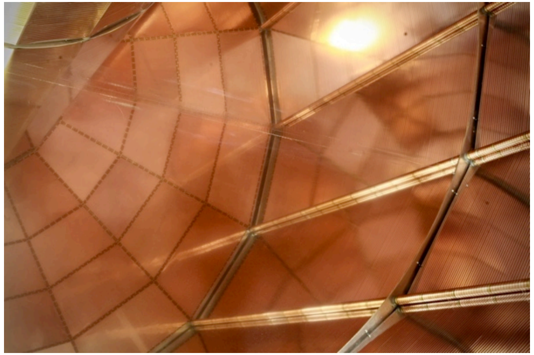
➔ **Adopted solution: 4–GEM stack, combination of standard (140 µm) and large hole pitch (280 µm) GEM foils, optimized HV configuration**

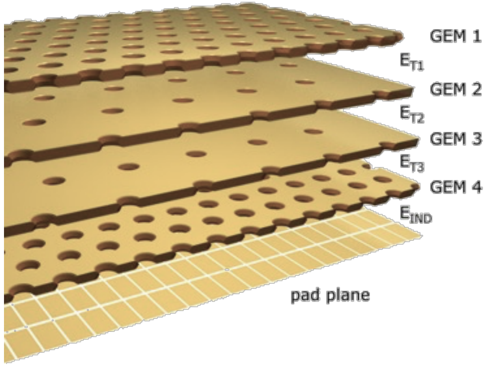
➔ **Unprecedented challenges: e.g. distortions from remaining space charge**

Max. drift time: ~100 µs

Previous detector (Run 1, Run 2):

- 72 MWPCs
- Wire gating grid (GG) to minimize Ion Back-Flow (IBF)
- Rate limitation: few kHz





The upgrade of the ALICE TPC with GEMs and continuous readout (link)

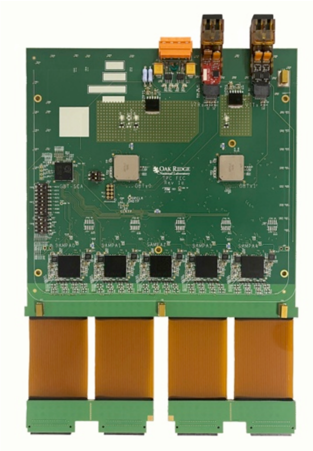
TPC readout electronics

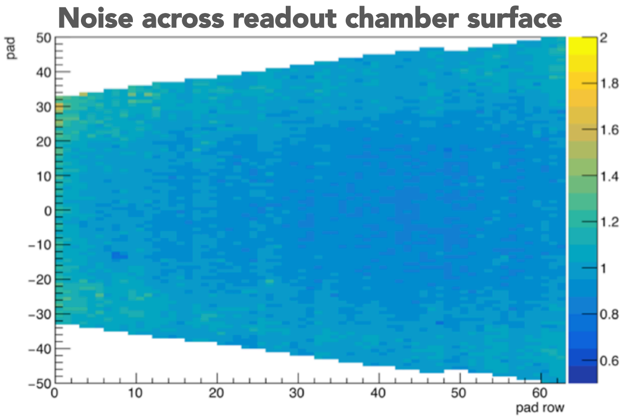
Newly developed FE ASIC SAMPA (130 nm TSMC CMOS)

- 32 channels with preamplifier, shaper and 10 bit ADC
- Readout mode: continuous or triggered
- Also used in the ALICE Muon spectrometer

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
- Readout link: CERN GBT / Versatile link system
- FPGA-based readout card receives the data: Common Readout Unit (CRU)

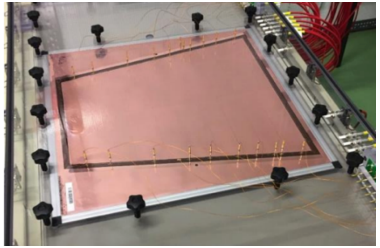




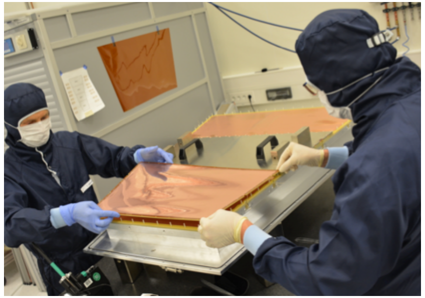
Excellent noise figure: 670 e^- @18 pF on detector

The upgrade of the ALICE TPC with GEMs and continuous readout (link)

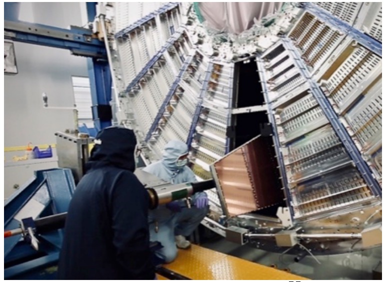
TPC upgrade timeline


Start GEM production

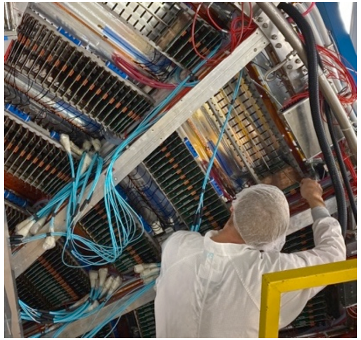
Aug 2016


Start GEM ROC production

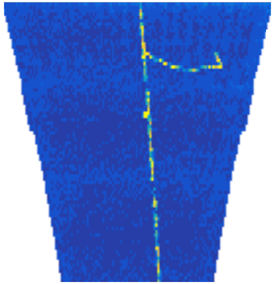
March 2017


Start GEM ROC installation

May 2019


Start installation FEE and services

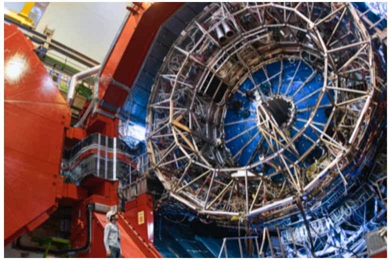
Sep 2019


Start pre-commissioning

Nov 2019

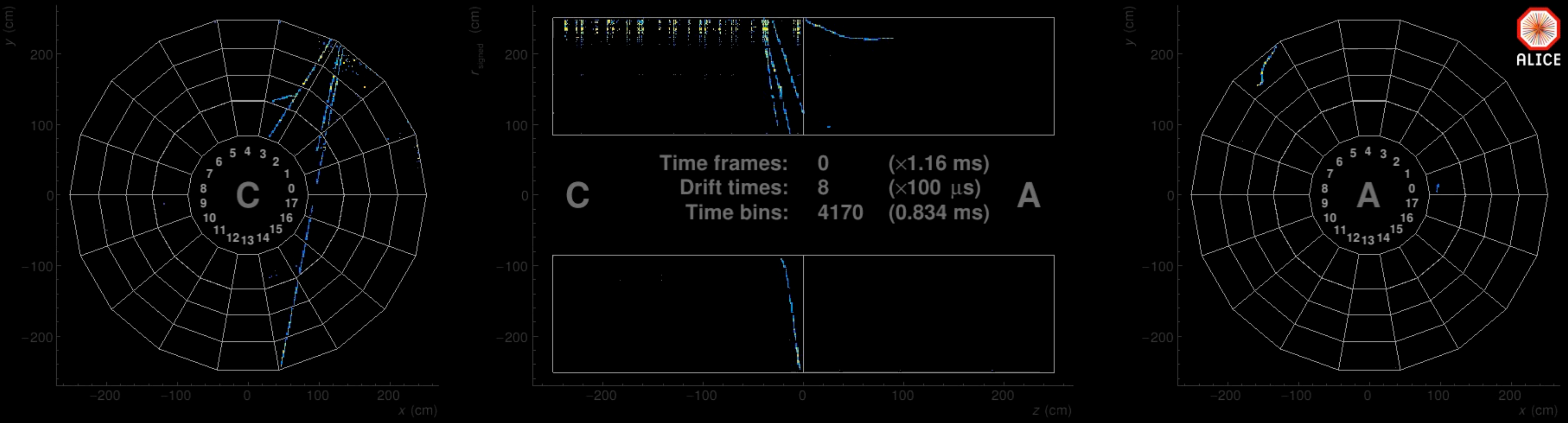

Transportation to LHC P2

Aug 2020


Connection and commissioning

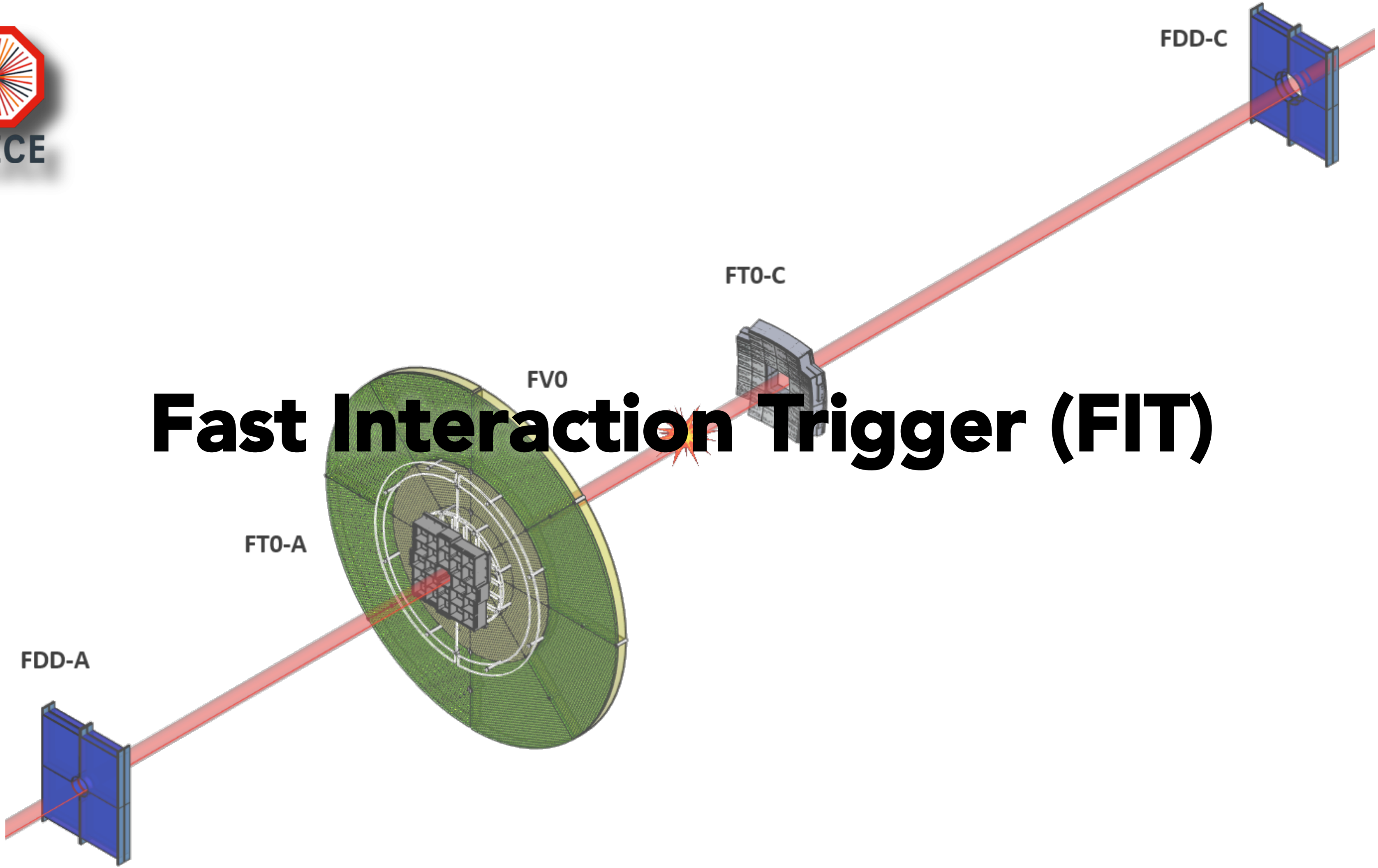
Dec 2020

TPC cosmic muon tracks



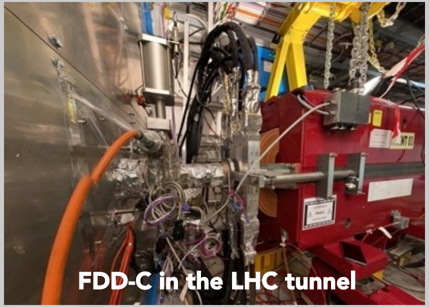
From TPC installed in cavern

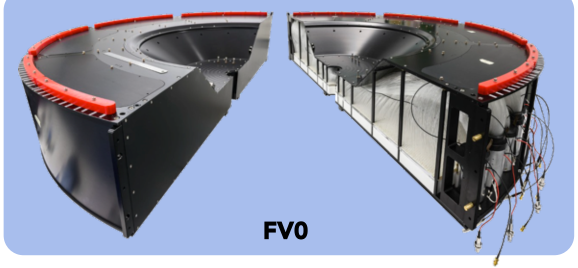
Fast Interaction Trigger (FIT)

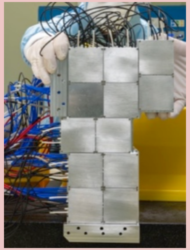


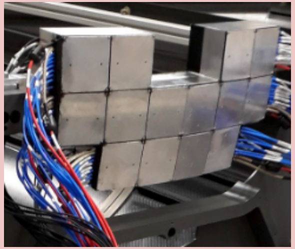
Fast Interaction Trigger

Detector	Purpose	Distance from collision point	Technology	Comment
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	To be installed mid July
FDD-C		-19.5 m		Installed
FV0	Min bias and multiplicity triggers, centrality and event plane measurement	3.2 m	EJ-204 scintillators, fibers, Hamamatsu R5924-70 PMTs	To be installed end of June
FT0-A	Minimum bias and multiplicity triggers (together with FV0), collision time	3.3 m	Quartz Cherenkov radiators, Photonis XP85002/FIT-Q MCP photomultipliers	To be installed end of June
FT0-C		-0.8 m		Installed


FDD-C in the LHC tunnel

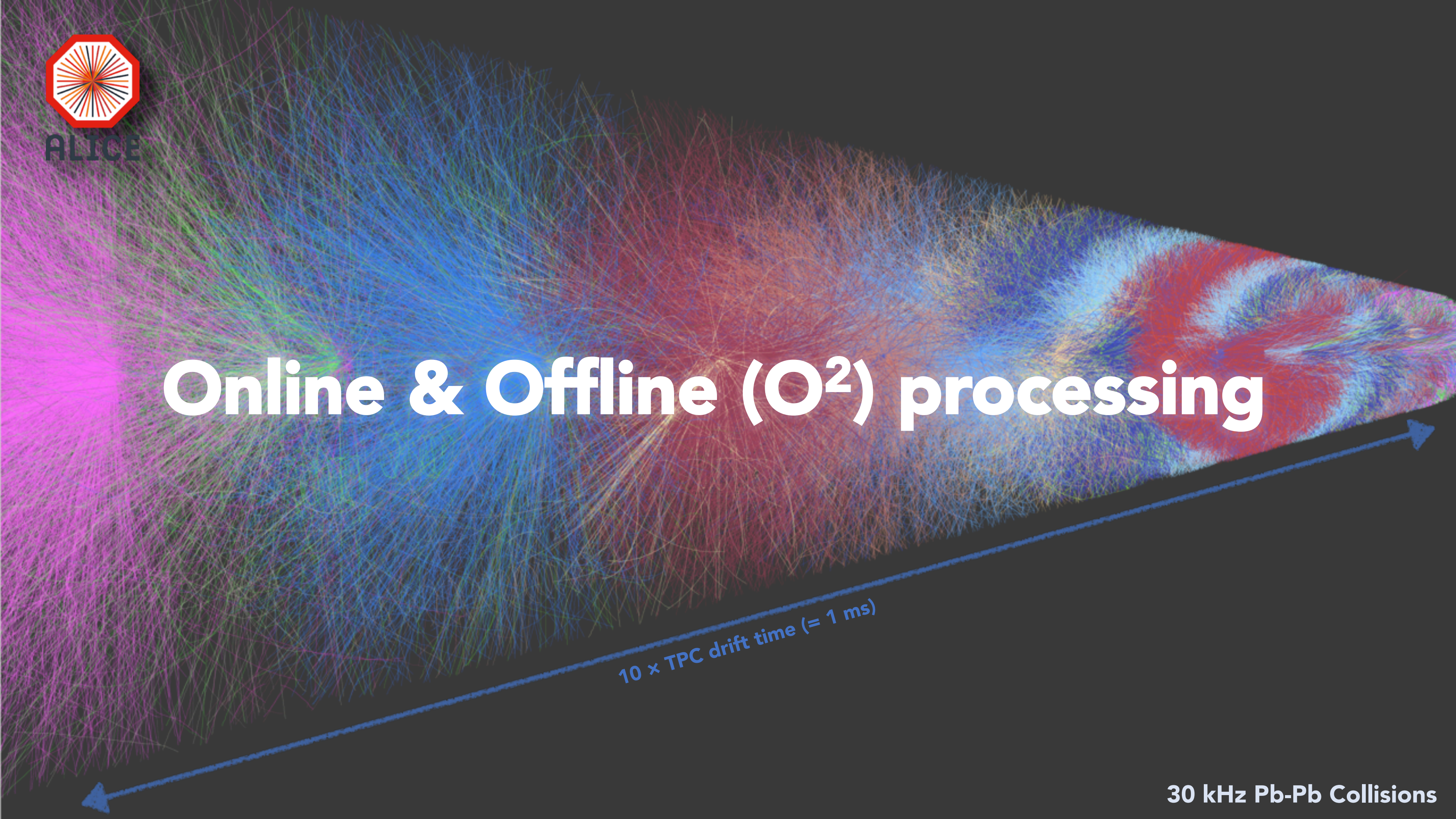

FV0


Half of FT0-A


Half of FT0-C

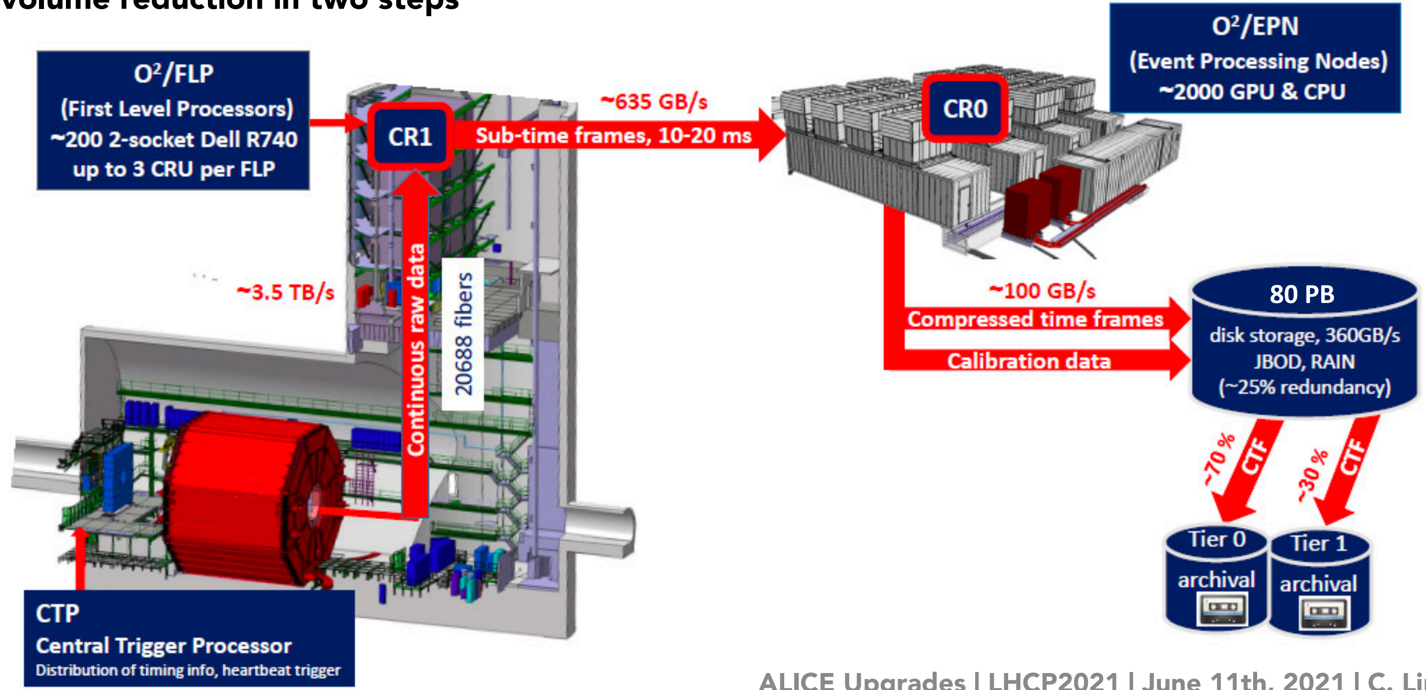
ALICE

Online & Offline (O^2) processing



O² processing

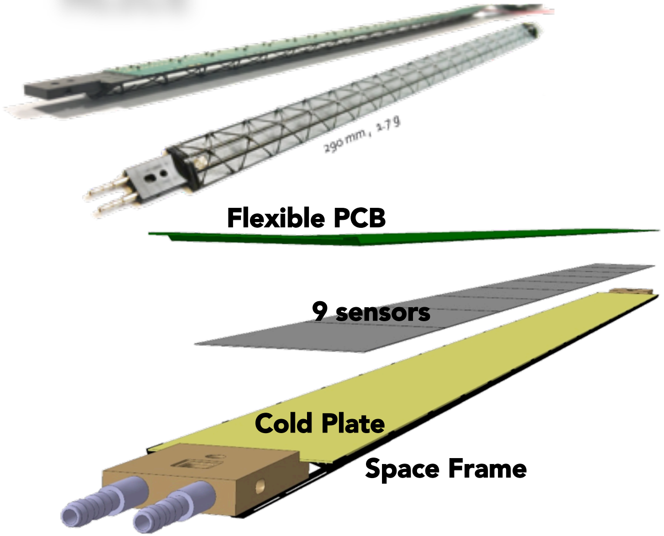
- 50 kHz Pb-Pb collisions ➔ ~ 3.5 TB/s continuous raw data flow
- Continuous data flow is chopped into (sub-)time frames on the FLPs
- Data volume reduction in two steps



ITS3 for Run 4

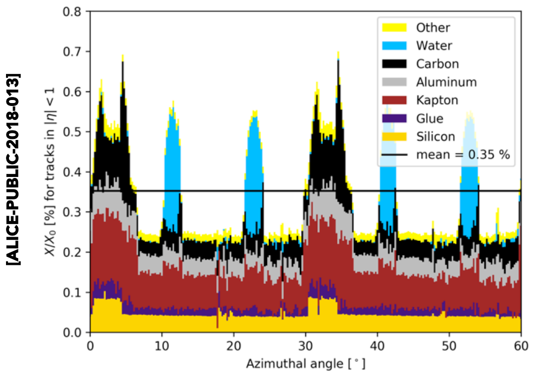
(from 2027)

ITS3 material budget

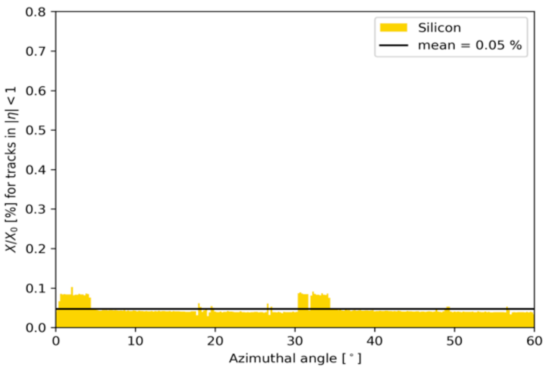


ITS2 stave structure

Material budget ITS2 inner-most layer



Material budget Si only



- Only about 15% of the total material is silicon!
- Irregularities due to support and services

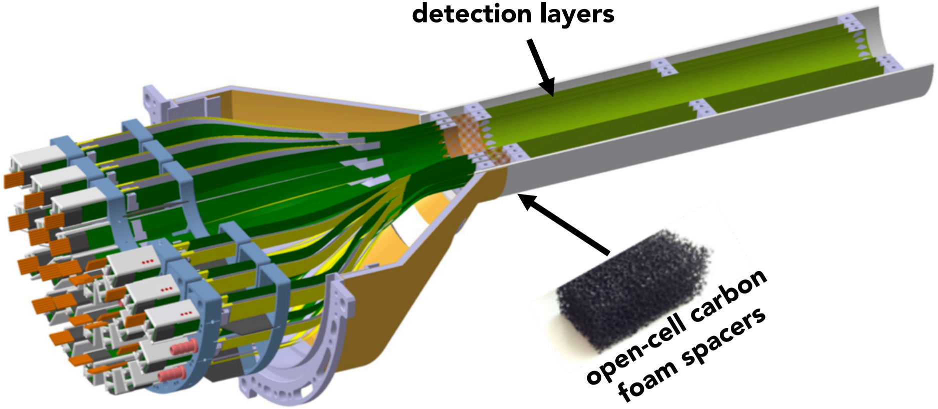
Removal of water cooling ➔ power consumption below 20 mW/cm^2 (➔ 65 nm technology)

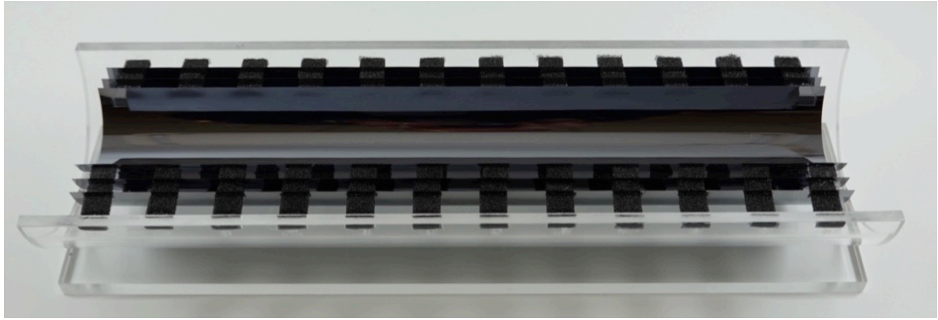
Removal of circuit board ➔ Integrate power and data buses on chip

Removal of mechanical support: Benefit from increased stiffness of bent Si wafers

LOI: CERN-LHCC-2019-018

ITS3 detector concept





Full-size mechanical prototype. 3 layers with carbon foam spacers

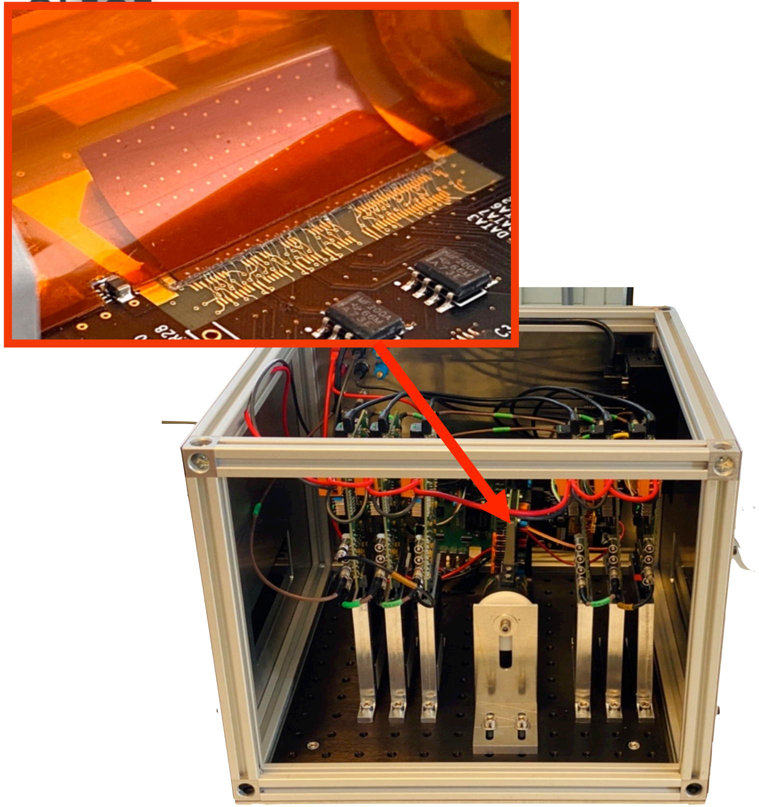
New inner layers (3 out of 7) for the ITS

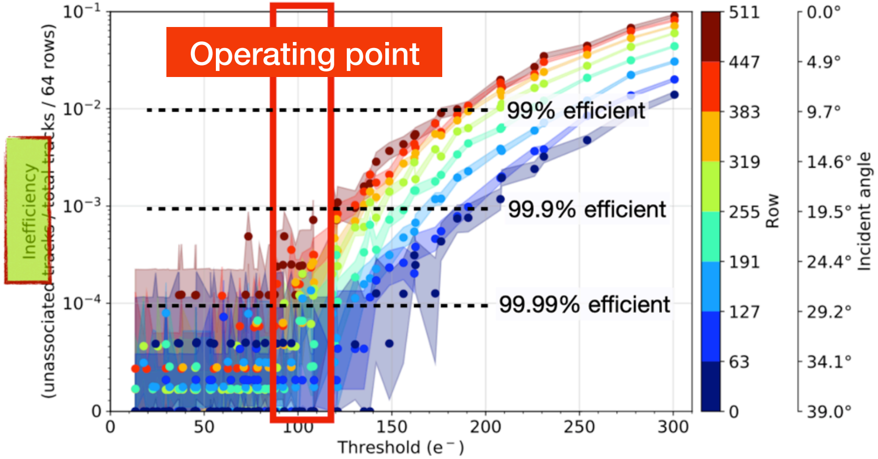
Key ingredients:

- 300 mm wafer-scale chips, 65 nm CMOS process
- thinned down to 20-40 µm, making them flexible
- bent to the target radii
- mechanically held in place by carbon foam ribs

The whole detector will comprise six chips (current ITS2 inner barrel: 432) – and barely anything else!

Proof of concept (1)



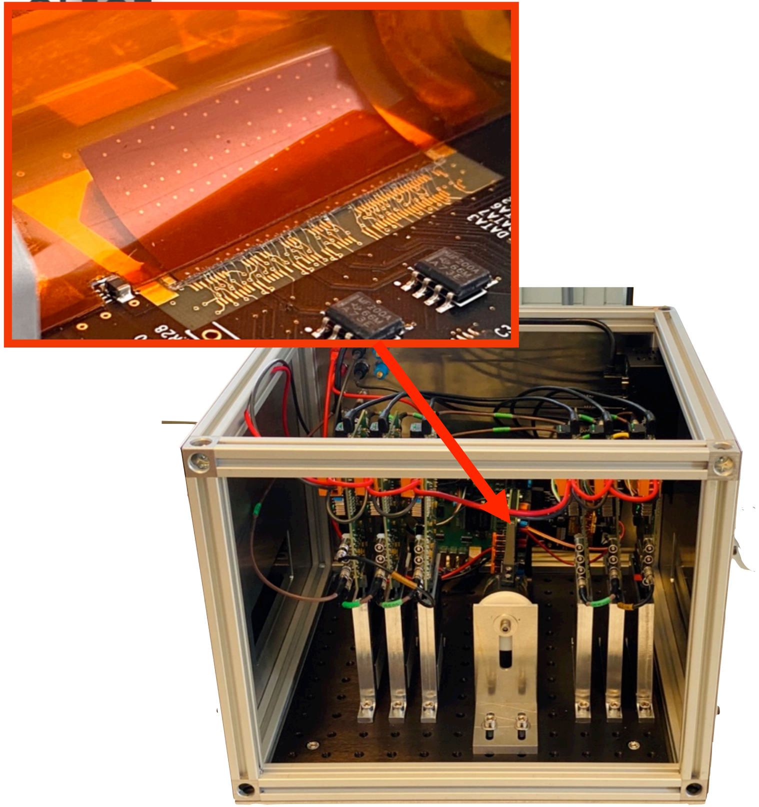


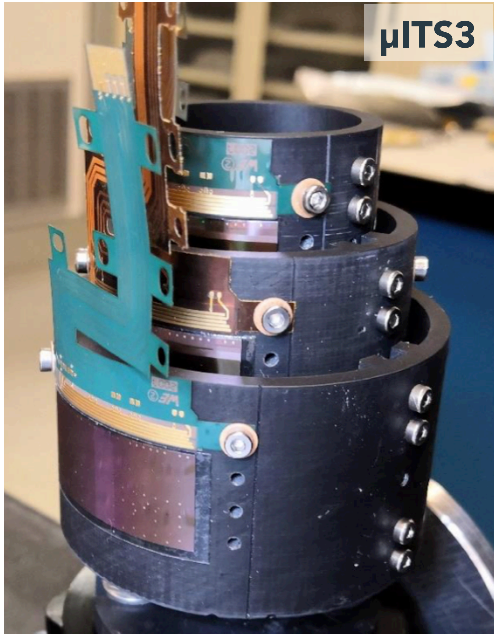
- **Data based on analysis of test beam data using bent, 50 μm thick ALPIDEs from ITS2**
- **No deviation from flat performance observed**
- **Important milestone for ITS3**

Bent chips just continue to work!

See also link

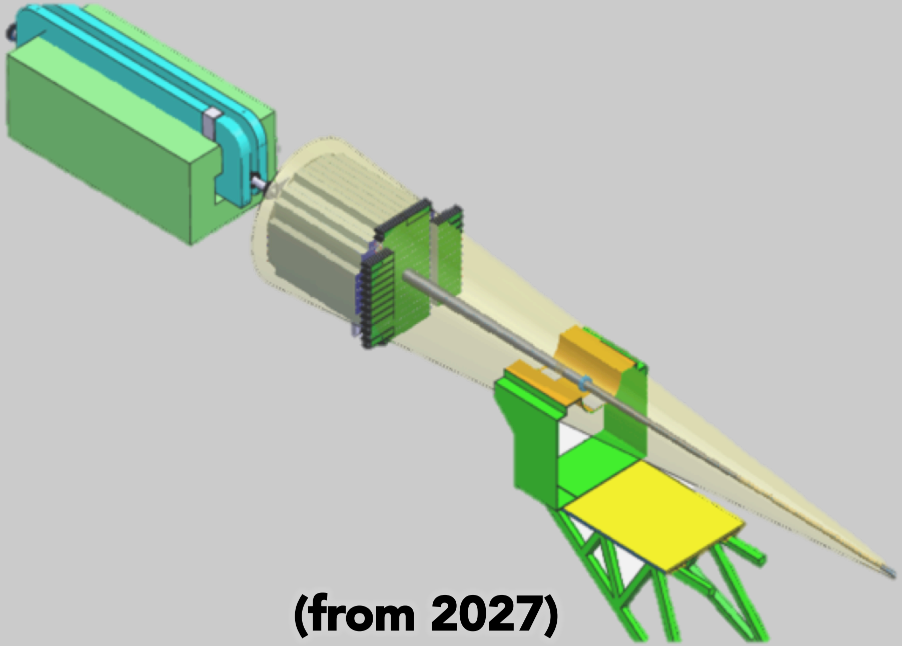
Proof of concept (2)





- Three layers with bent ALPIDEs
- Mimics ITS3 (same radii)

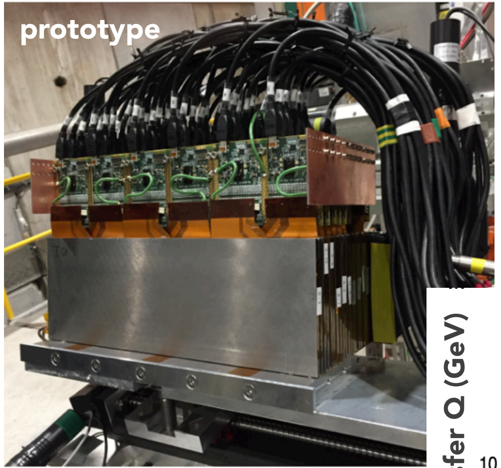
FoCal for Run 4



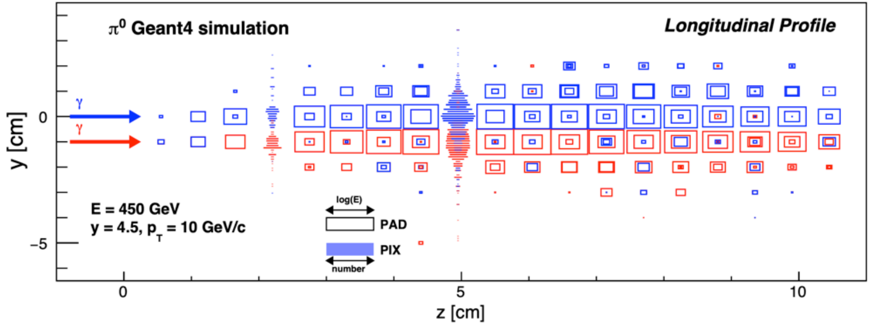
(from 2027)

FoCal (from 2027)

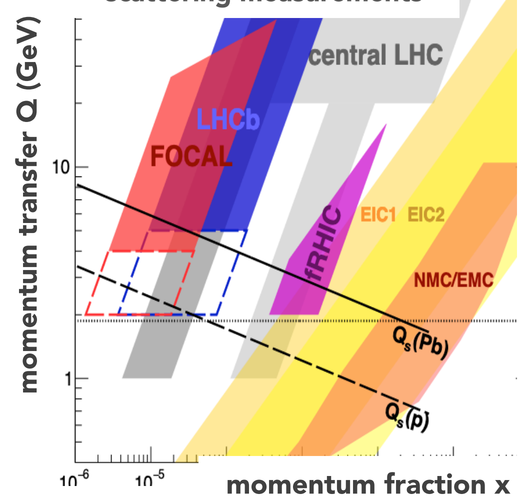
- **A new high granularity Forward Calorimeter**
  - High-precision inclusive measurement of direct photons and jets
  - Coincident γ-jet and jet-jet measurements
- **7 m from interaction point, 3.4 ≤ η ≤ 5.8**
- **FoCal-E:** Si-W electromagnetic calorimeter (w/ pads and 2 high-granularity pixel layers)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



Simulated longitudinal shower profile for 2 photons



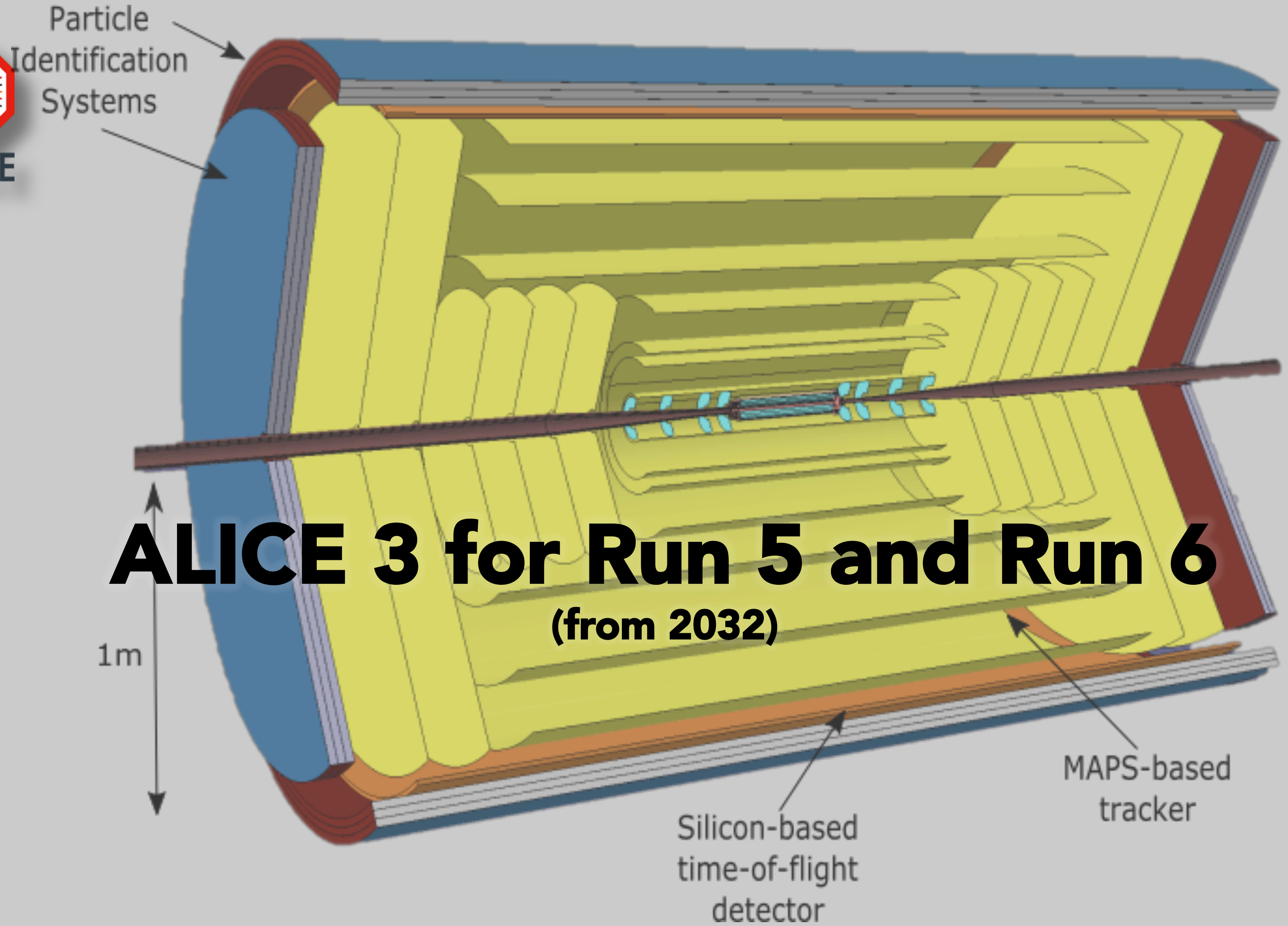
Approximate (x,Q) coverage of various experiments for regions probed by deep inelastic scattering measurements



LOI: CERN-LHCC-2020-009

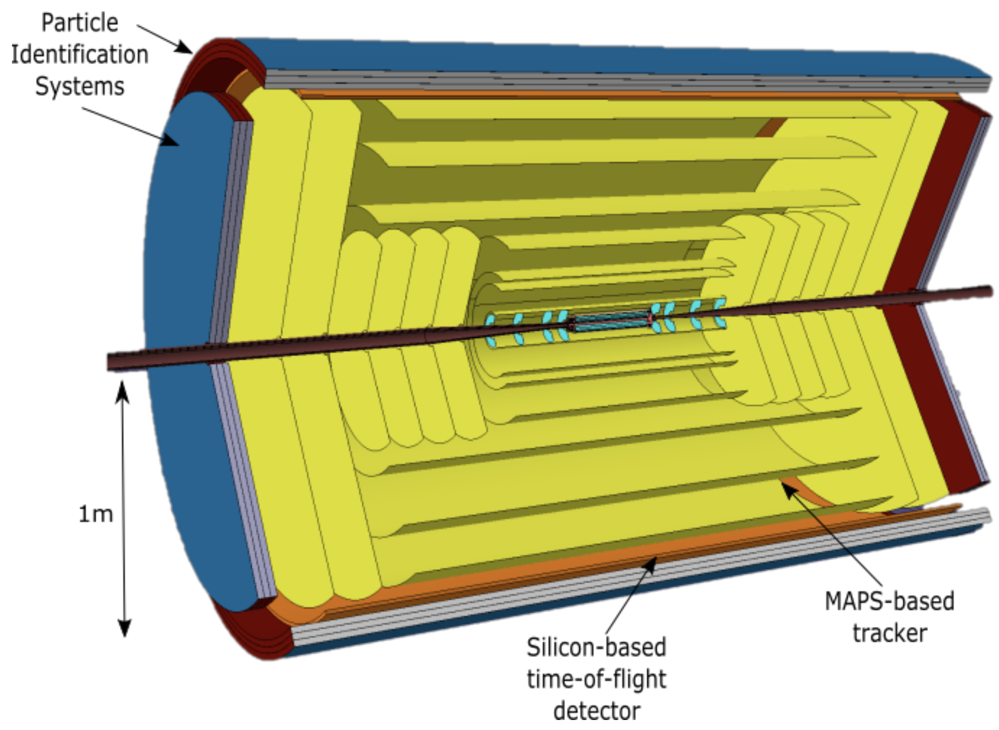
ALICE 3 for Run 5 and Run 6

(from 2032)



ALICE 3 (from 2032)

- **A next-generation HI experiment**
- **Ultra-lightweight silicon tracker: ~12 tracking barrel layers + disks based on CMOS sensors**
- **New physics opportunities due to improved detector performance + increased luminosity**
- **Kinematic range down to very low p_T: 50 MeV/c (central barrel), 10 MeV/c forward (dedicated detector)**
- **Different options for PID under study**
- **LOI under preparation**

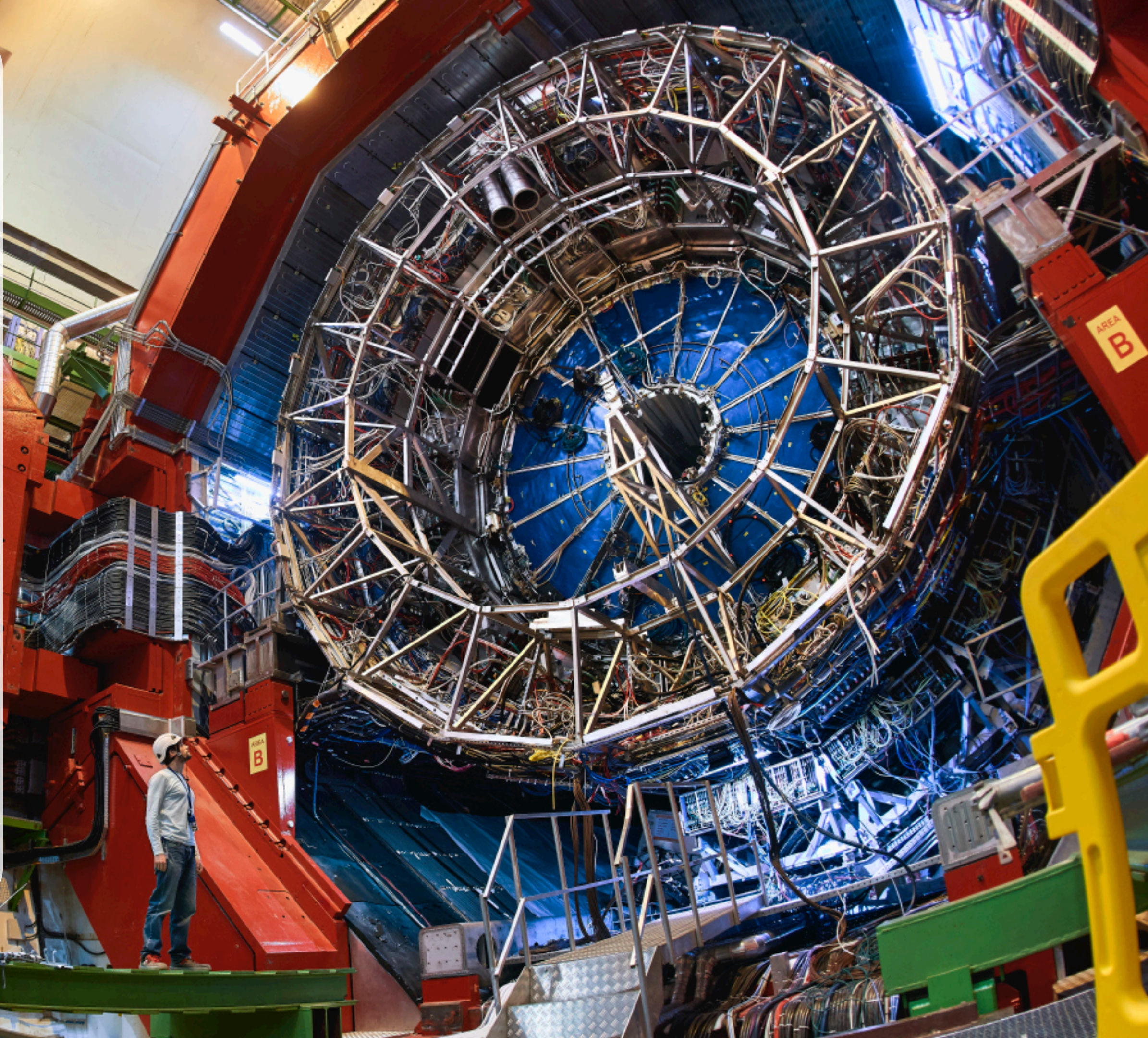


Expression of interest: link

Summary

- Major ALICE upgrade for Run 3 in its final steps: ITS2, MFT, TPC, FIT, O^2 and readout electronics
- Last detector installation to be completed in July
- ALICE global commissioning from July
- New upgrade proposals for Run 4: ITS3, FoCal
- Preparation for a new generation, heavy-ion experiment for Run 5 ongoing

Thank you for your attention!



ALICE

Summary

- Major ALICE upgrade for Run 3 in its final steps: ITS2, MFT, TPC, FIT, O^2 and readout electronics
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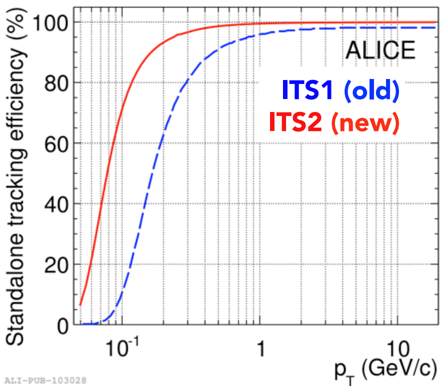
Thank you for your attention!

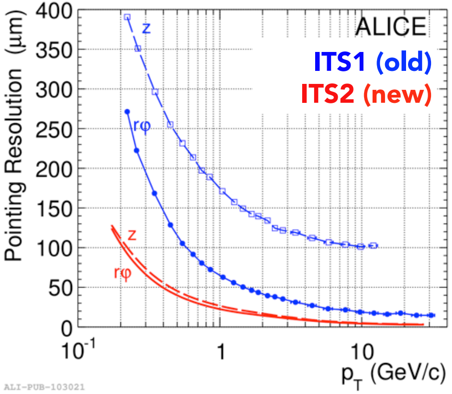
See also (at this conference):

- Ivan Ravasenga: *New ITS commissioning and impact on vertexing in Run 3*. Thursday
- Ernst Hellbär: *Reconstruction and TPC calibration in Run 3*. Monday
- Giacomo Contin: *Novel detector concepts for ALICE for Run 4 and beyond*. Wednesday
- Stefania Bufalino: *PID and tracking with timing detectors in ALICE and LHCb in Run 5*. Tuesday
- Antonio Uras: *Physics prospects for ALICE in Run 5 and beyond*. Monday

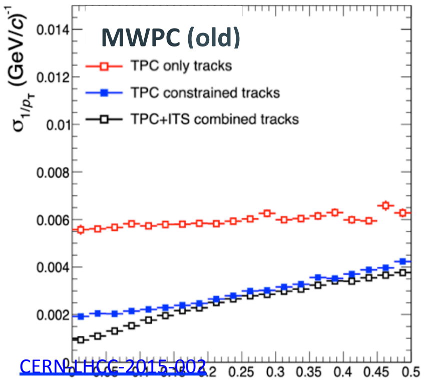
Detector performance in Runs 3 and 4

Tracking efficiency vs p_T

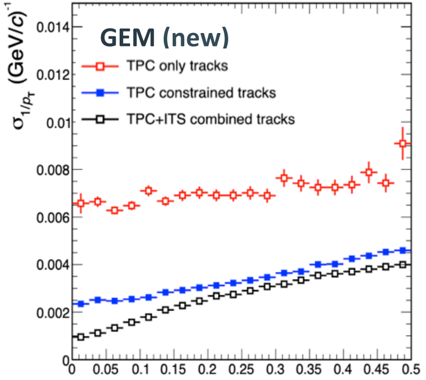




Momentum resolution vs p_T



CERN-LHCC-2015-002



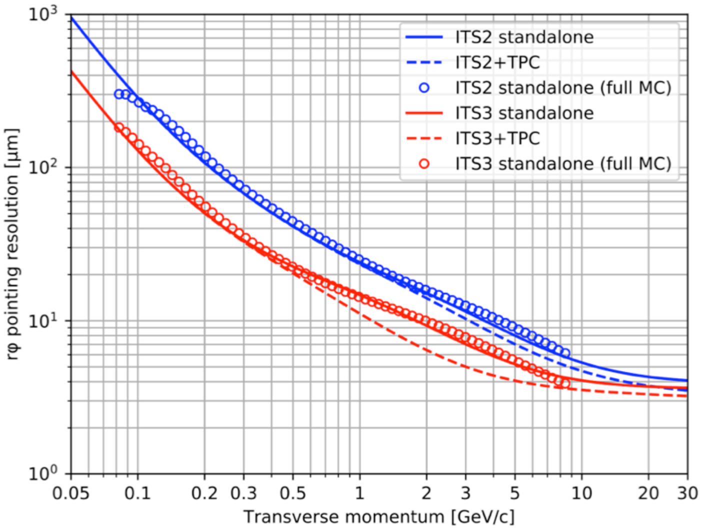
ITS2

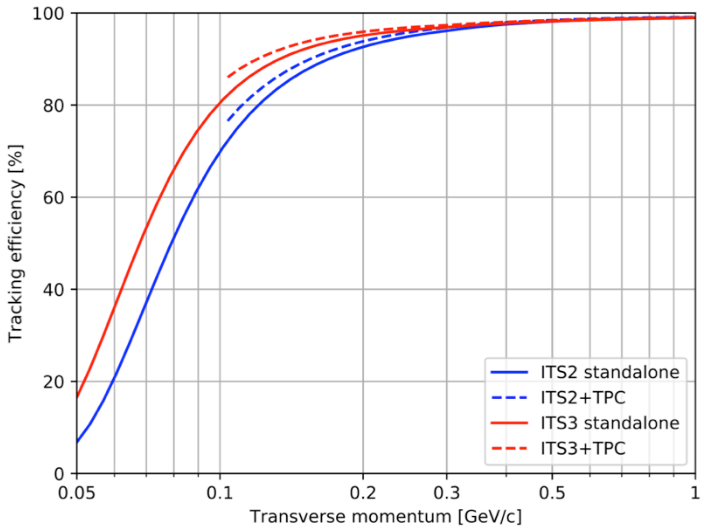
- **Improved tracking efficiency**
- **Improved tracking resolution**
- **Pointing accuracy 3 times better in transverse plane (6 times along beam axis)**

GEM TPC

- **Preserve momentum resolution for TPC+ITS tracks**
- **Preserve particle identification (d*E*/d*x*)**

Performance gain with ITS3





- Pointing resolution 2x better
- Improved tracking efficiency for low momenta
- Improved physics performance for heavy-flavour baryons and low-mass dielectrons

EOI: ALICE ITS Upgrade in LS3, ALICE-PUBLIC-2018-013