ALICE experiment at CERN

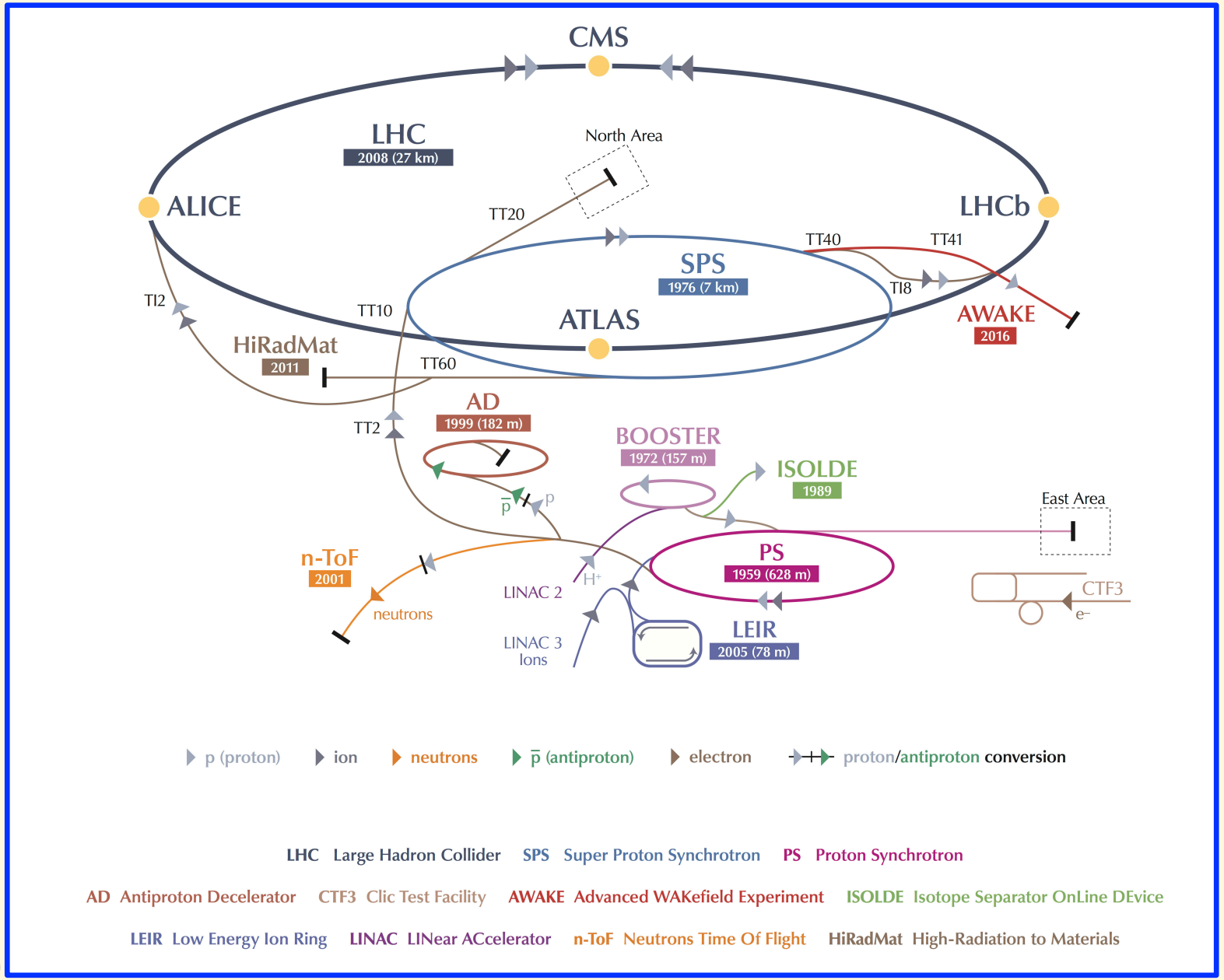
ALICE-India Collaboration
Virtual Visit

Tapan Nayak
14 March 2022

CERN

“Science without borders”

CERN Accelerator complex



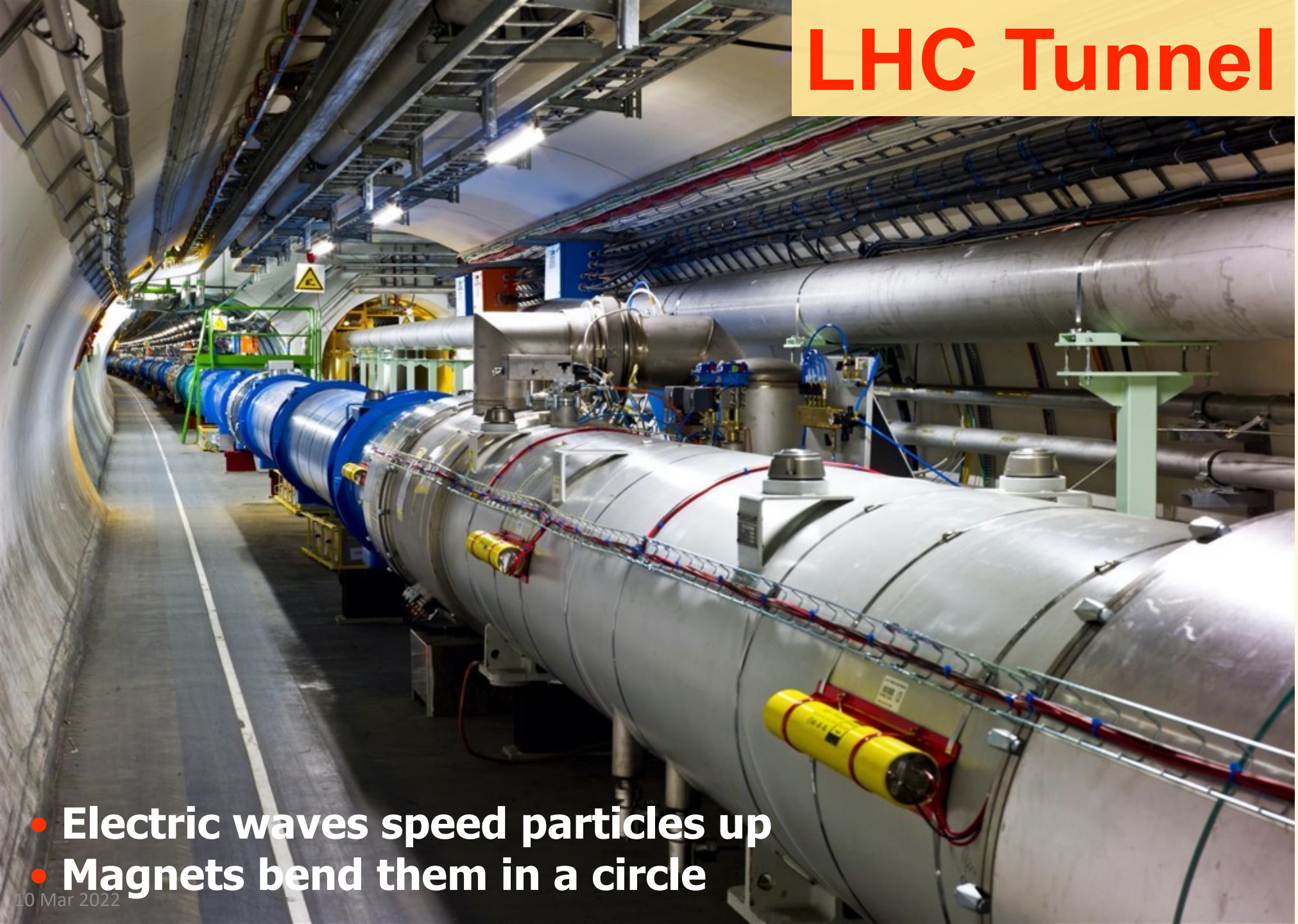
The LHC is the last ring in a complex chain of particle accelerators. The smaller machines are used in a chain to boost the particles to their final energies.

The LHC collides:

- proton on proton
- **Heavy-ions (lead on lead)**
- proton on lead
- ....

Why heavy-ions?

LHC Tunnel



- Electric waves speed particles up
- Magnets bend them in a circle

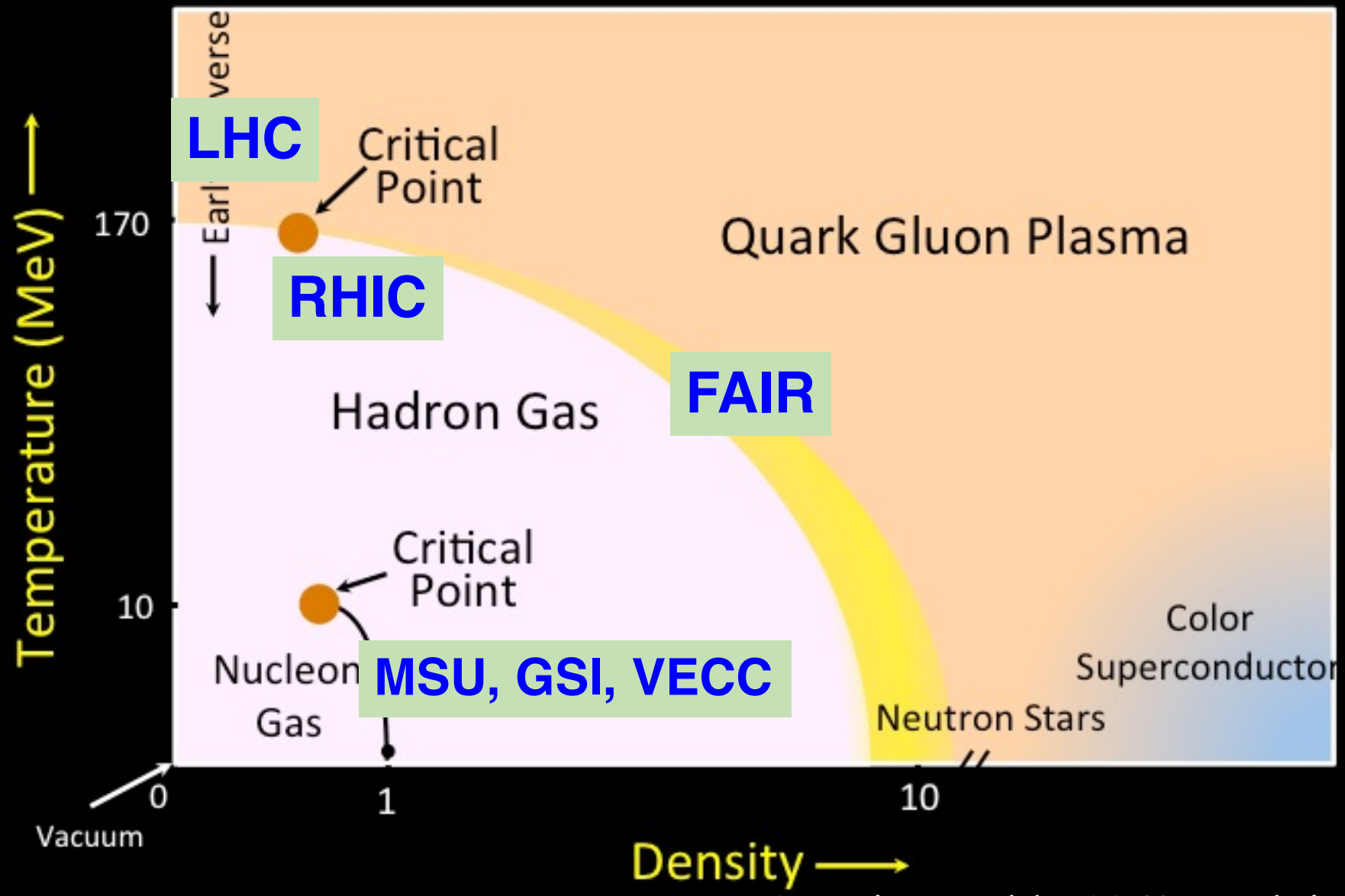
27km tunnel:

- 50-150m below ground
- Two beams circulating in opposite directions
- Total of 9300 magnets: beams controlled by 1800 superconducting magnets (up to 8T)

World's Most Powerful Accelerator:
The Large Hadron Collider

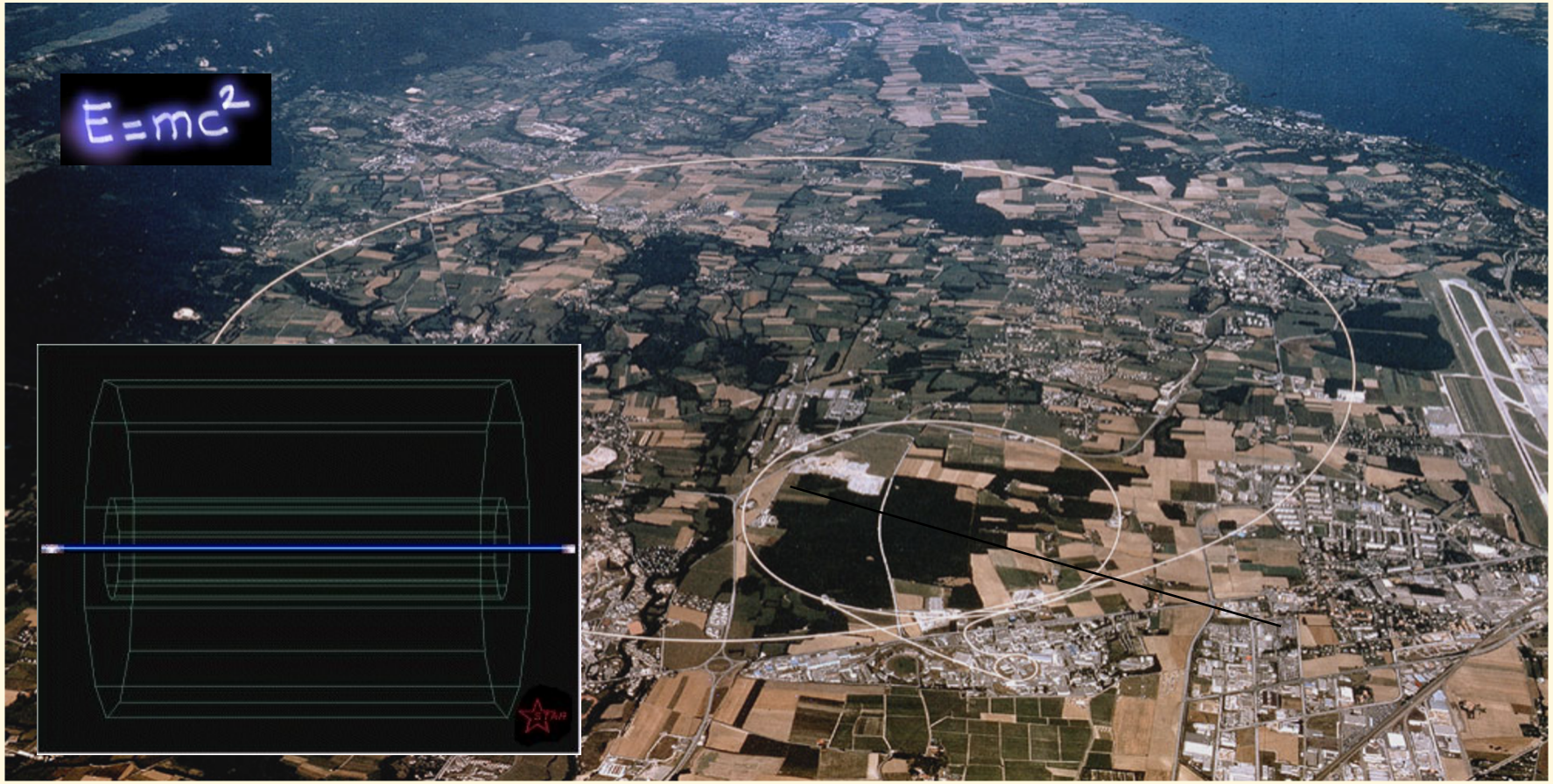
27 km circumference
~ 100 m underground
Design Energy:
14 TeV (pp), 5.5 TeV (Pb-Pb)

Phases of Nuclear Matter



1 eV is roughly 11605 Kelvin

Heavy-ion collisions



Accelerate Particles, Get them to Collide

Study the aftermath by specialized detector systems which surround the collision point ***=> Experiment***

Detect the particles produced in Experiments, store and analyze the data

Huge technological challenges

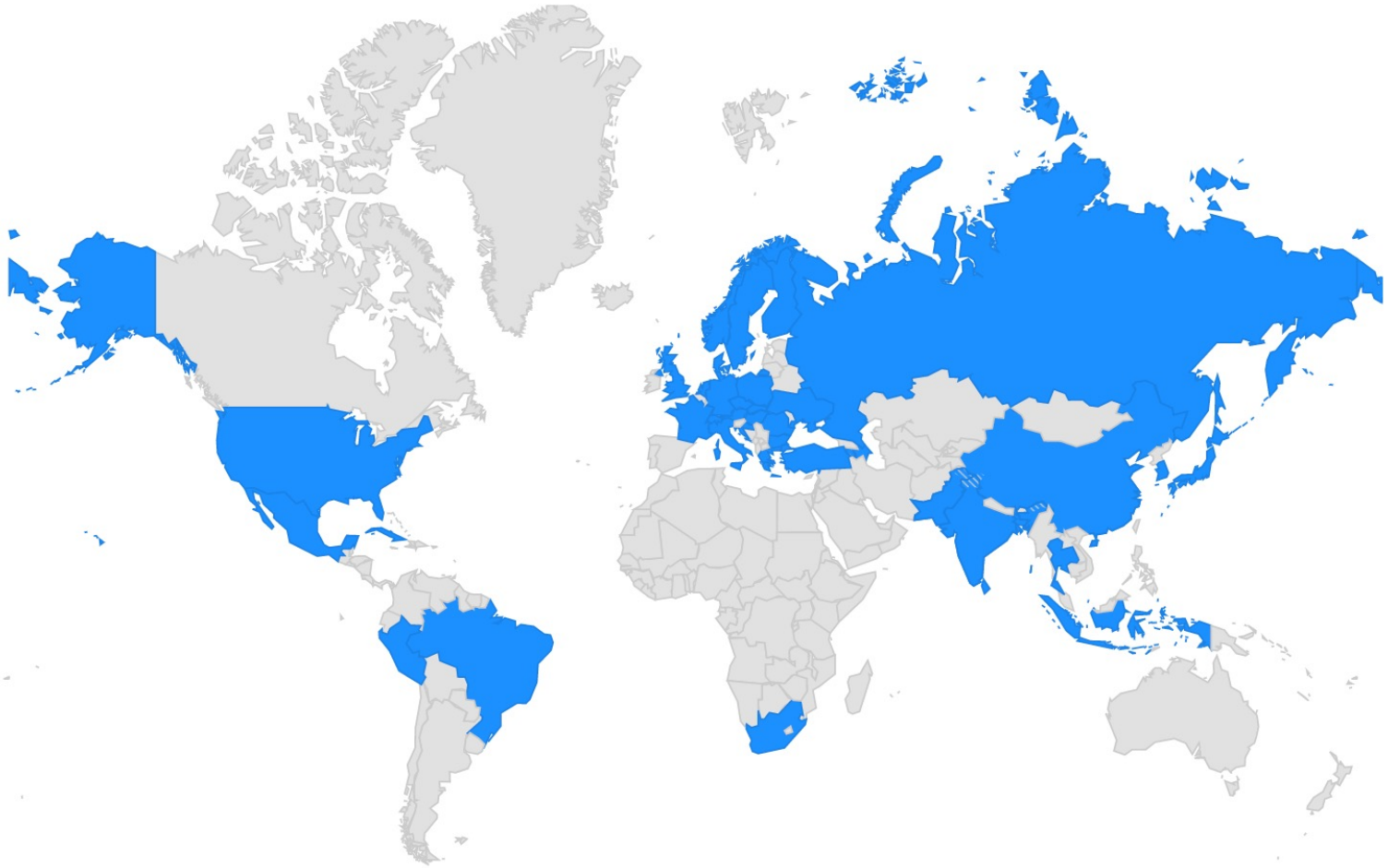
ALICE at Point-2 of the LHC

- Excellent track and vertex reconstruction capabilities in high multiplicity environment over a wide p_T range
- Particle identification over a wide momentum range

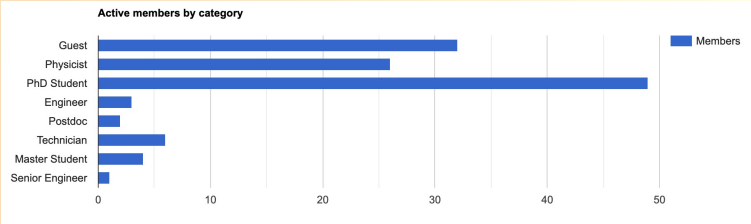
ALICE Collaboration

Funded by DAE and DST, Indian scientists are involved since the conception of ALICE

40 countries, 172 institutes, 1969 members



125 collaborators from India

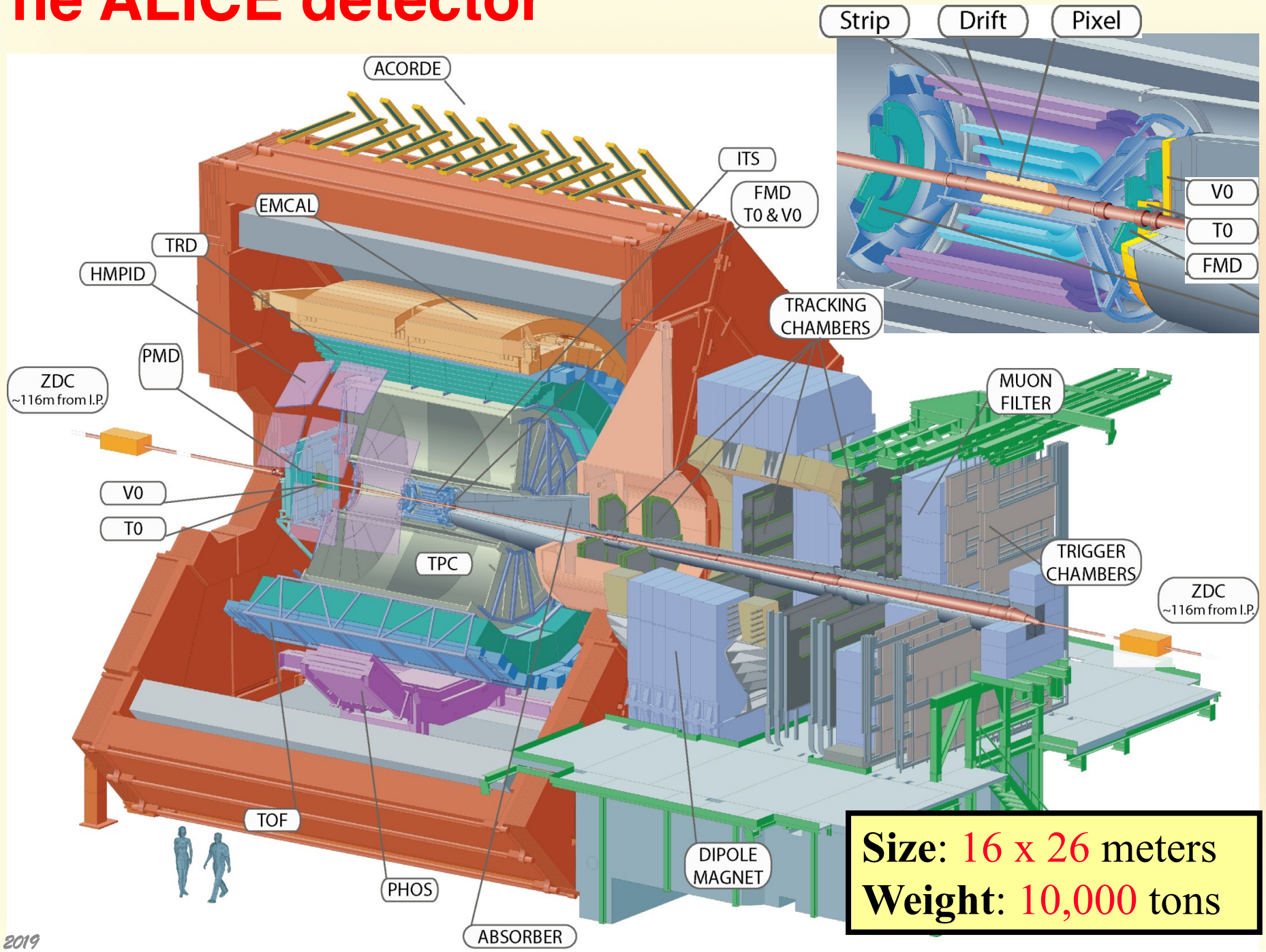


New Associate institute: Jadavpur University, Kolkata joined on 5 March 2022

https://alice-glance.cern.ch/alice/membership/

The ALICE detector

Till 2018



Size: 16 x 26 meters
Weight: 10,000 tons

CENTRAL BARREL

- Acceptance: $|\eta|<0.9$
- B=0.5 T
- **ITS:** High precision vertexing and centrality
- **ITS+TPC+TOF**: charged track reconstruction, PID
- **TRD:** electron ID
- **EMCAL:** calorimeter

Muon Arm: $-4<\eta<-2.5$

SPECIAL detectors:

- V0
- FMD
- PMD
- ADC
- ZDC

India in ALICE

Photon Multiplicity Detector (PMD)

Muon Tracking Chamber and MFT

MANAS: Multiplexed ANAlog Signal Processor

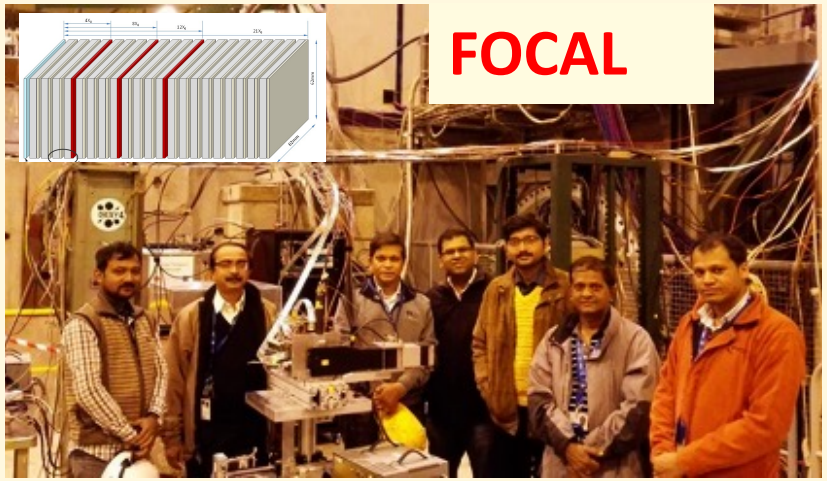
First large scale production of ASIC in India

Common Readout Unit (CRU):

ALICE LS2 Upgrade

Performs data concentration, reconstruction and multiplexing.

Silicon-Tungsten Calorimeter



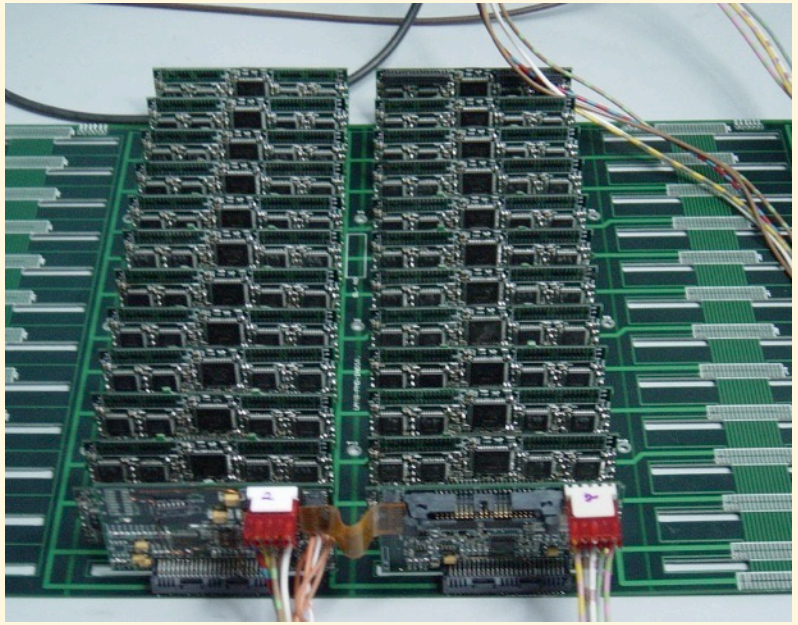
FOCAL

LHC GRID Computing

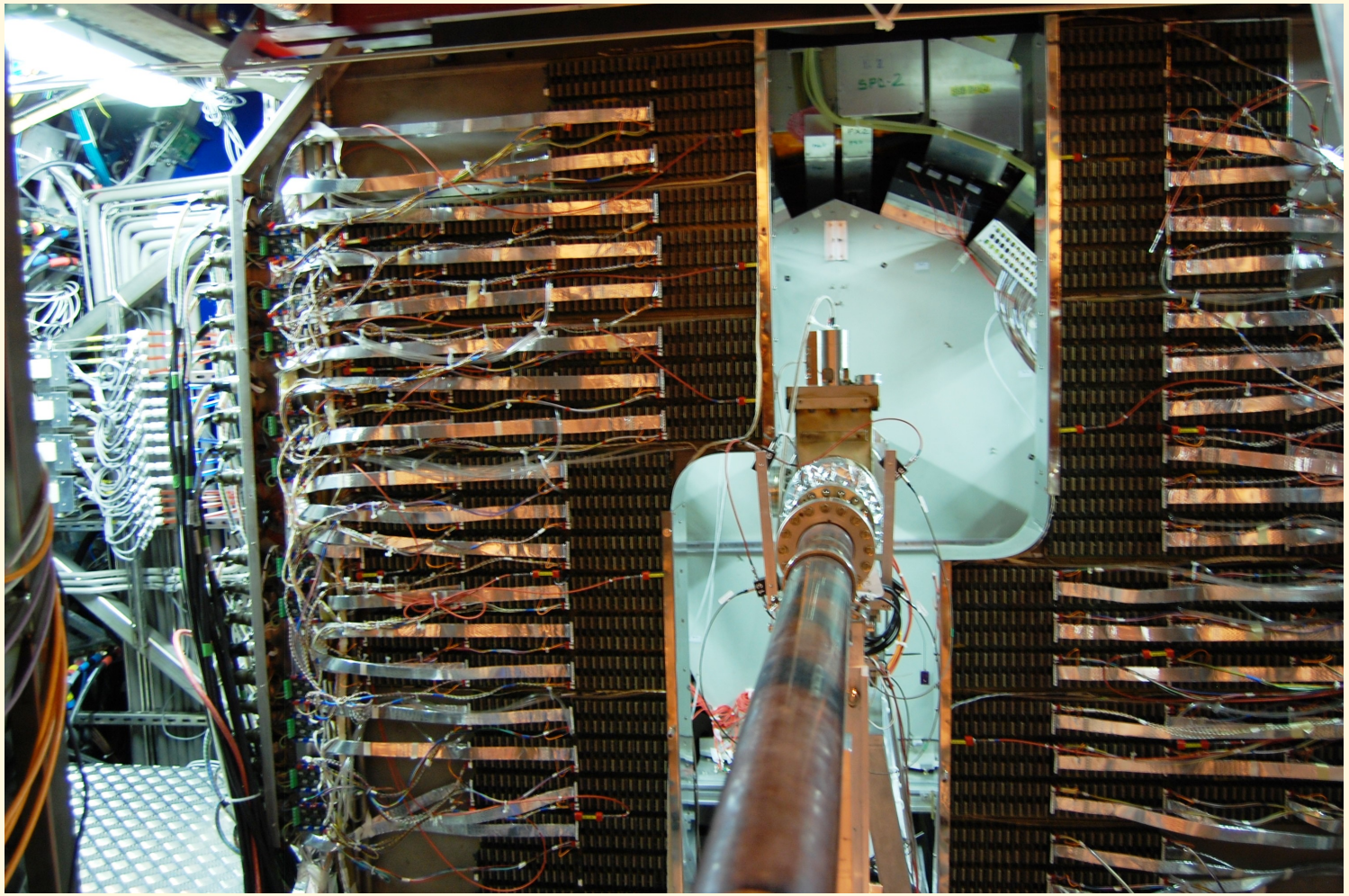
PMD: Photon Multiplicity Detector

100 % Indian effort: from conception to commissioning (Design, Fabrication, Installation, Detector Control, and DAQ)

48 Modules with 221,184 gas cells:



PMD in the ALICE cavern

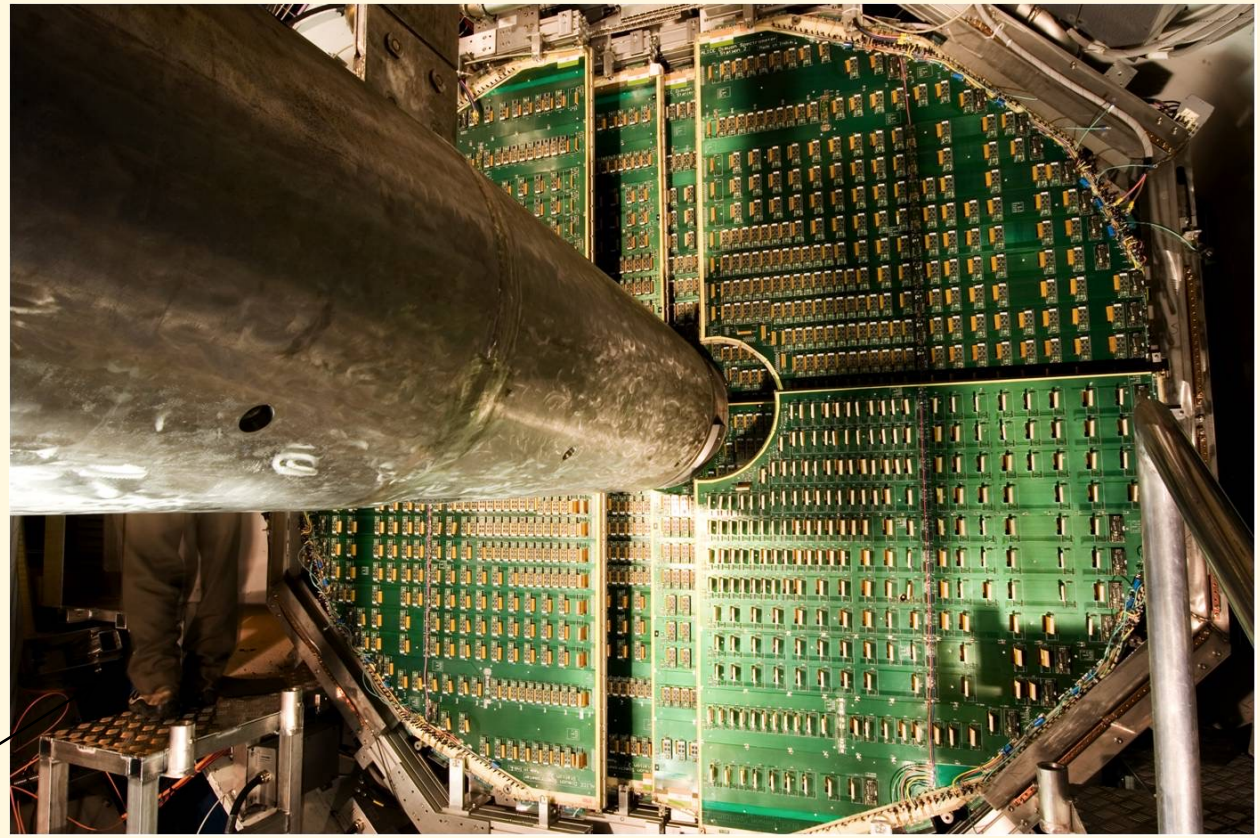


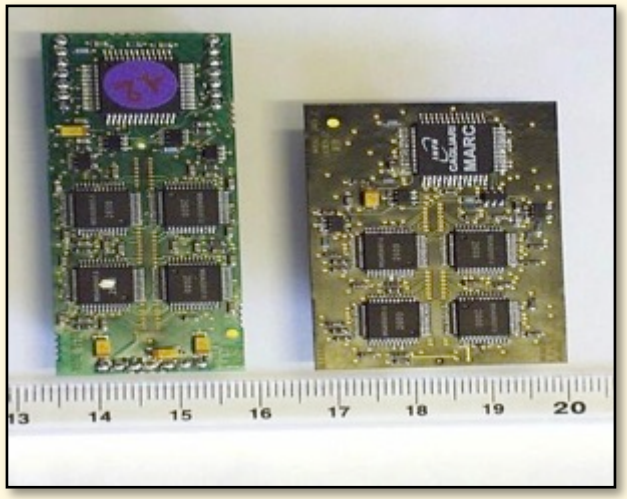
Muon Tracking Chambers

Collaboration France, India, Italy, Russia:

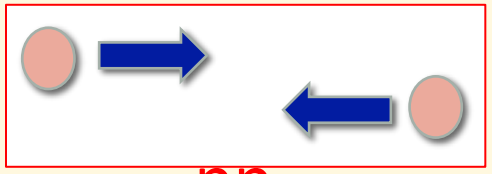
- 5 stations of two Cathode Pad Chambers ~ 100 m^2
- 1.1×10^6 channels, occupancy < 5% (in Pb+Pb)
  → Read out at 1 kHz
- Chamber thickness ~ 3% X0
- Beam test results for the spatial resolution : 50 μm for a required resolution < 100 μm

Station 2 of the Muon Tracking Chamber

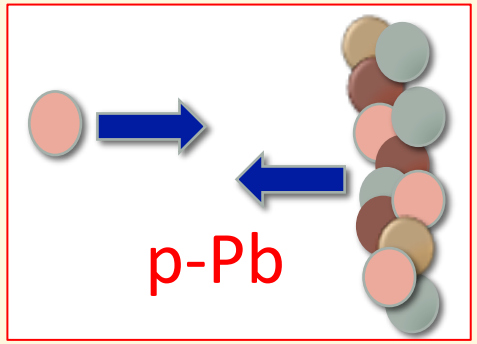




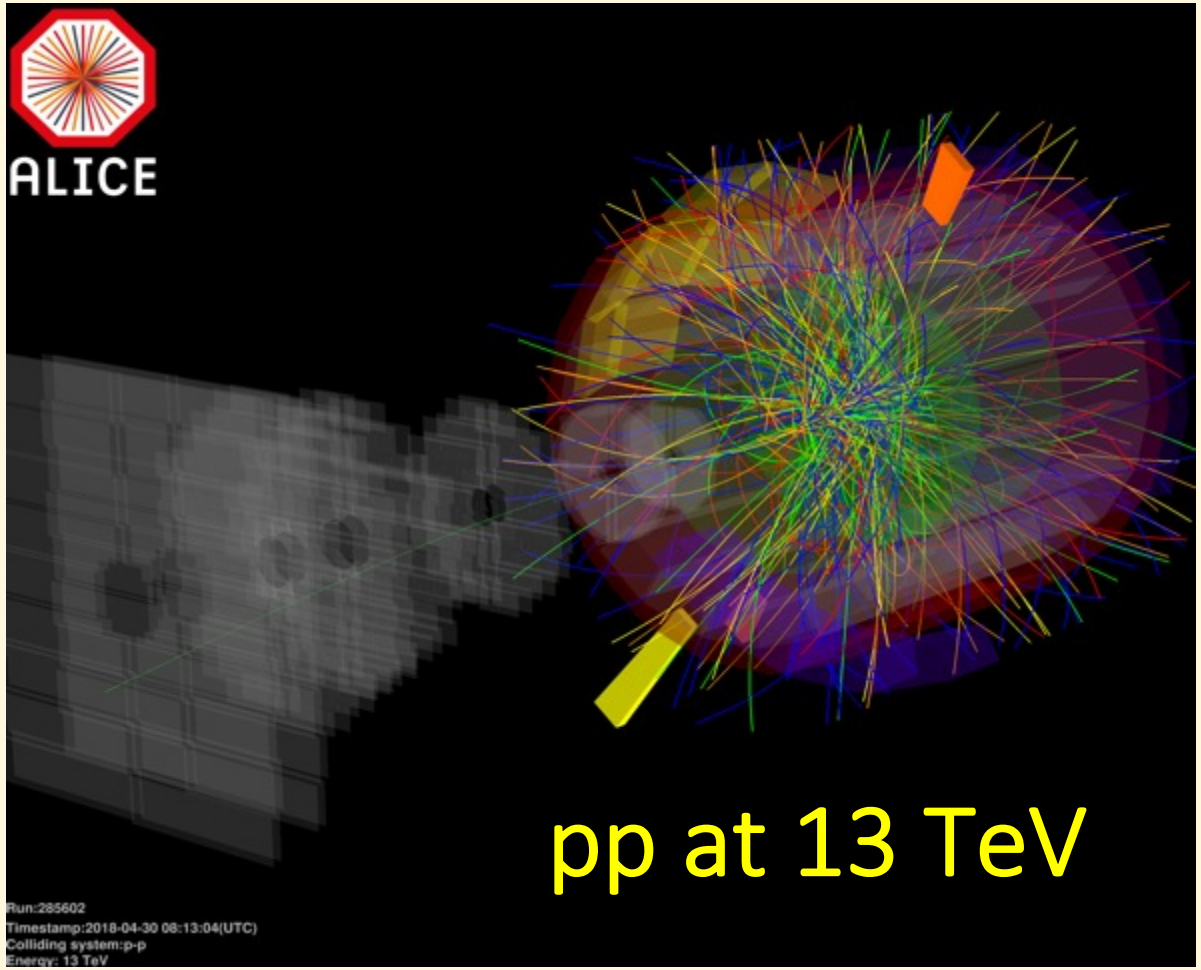
- **MANAS electronics chip: 16-channel Amplifier, shaper, track-and-hold**
- **MANU board: Reads 1.1 million pads of tracking chambers of ALICE**

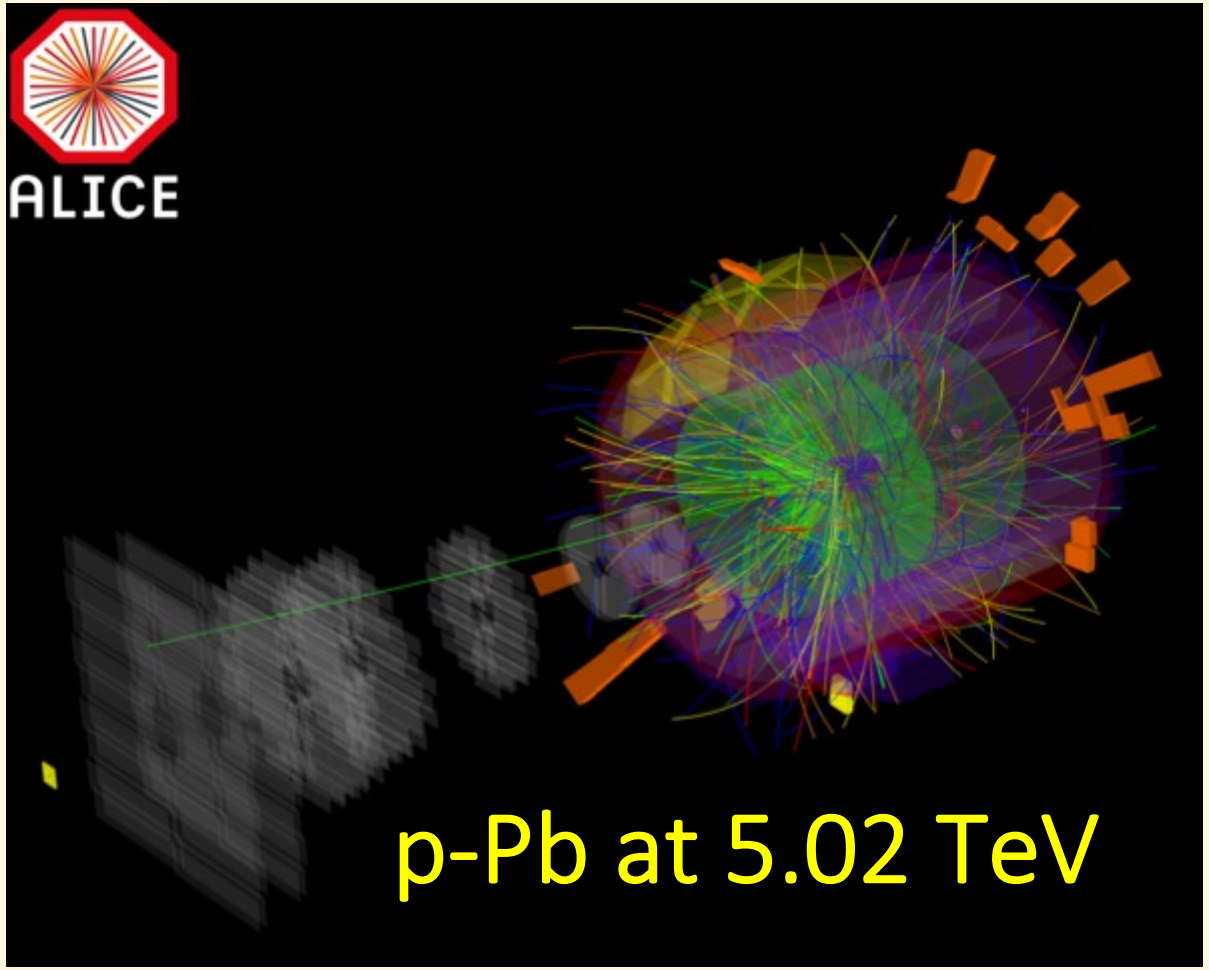


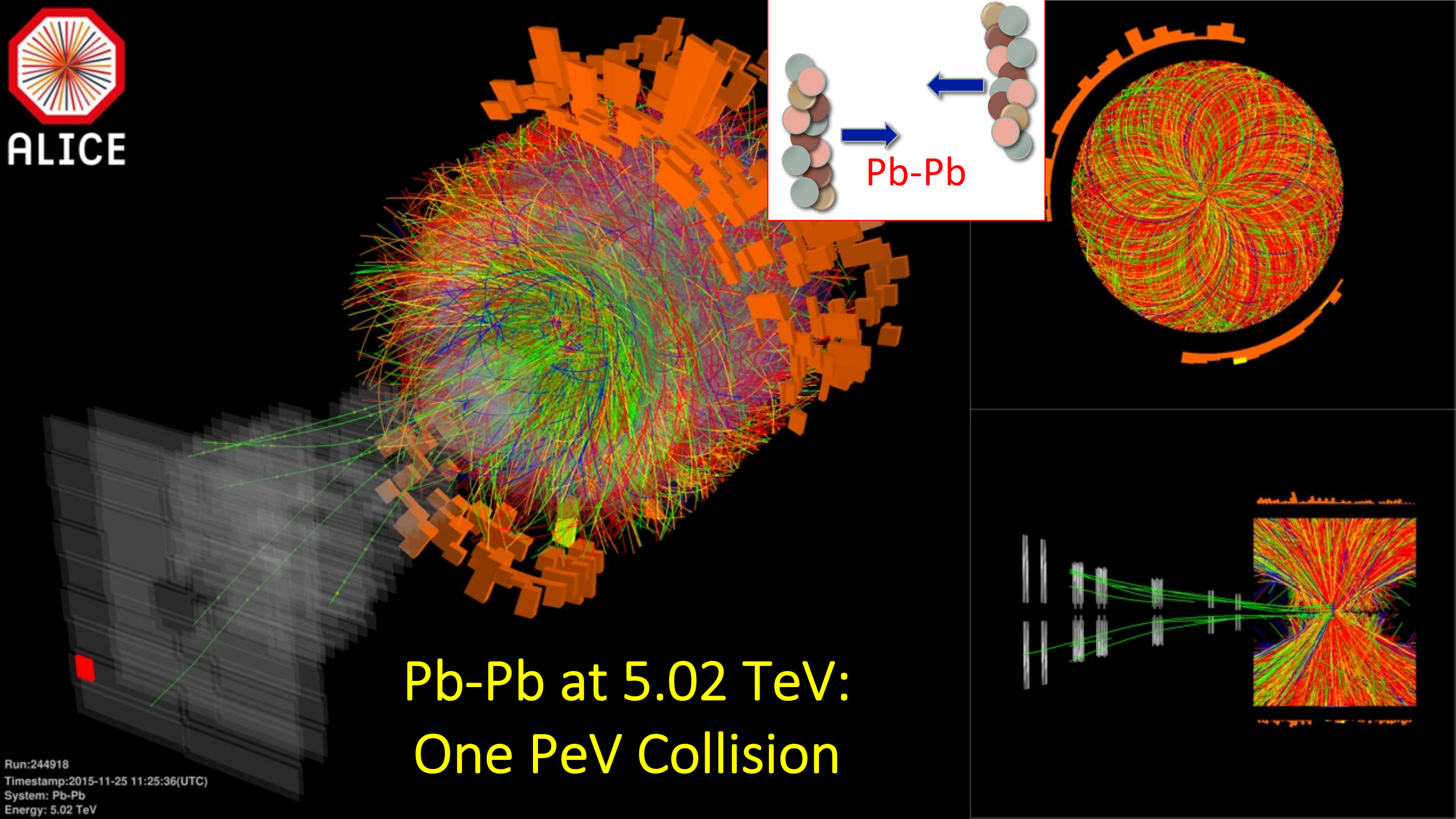
- Test of pQCD calculations from cross section measurements
- Provide reference for p-Pb and Pb-Pb collisions
- High multiplicity pp: what's the behaviour?



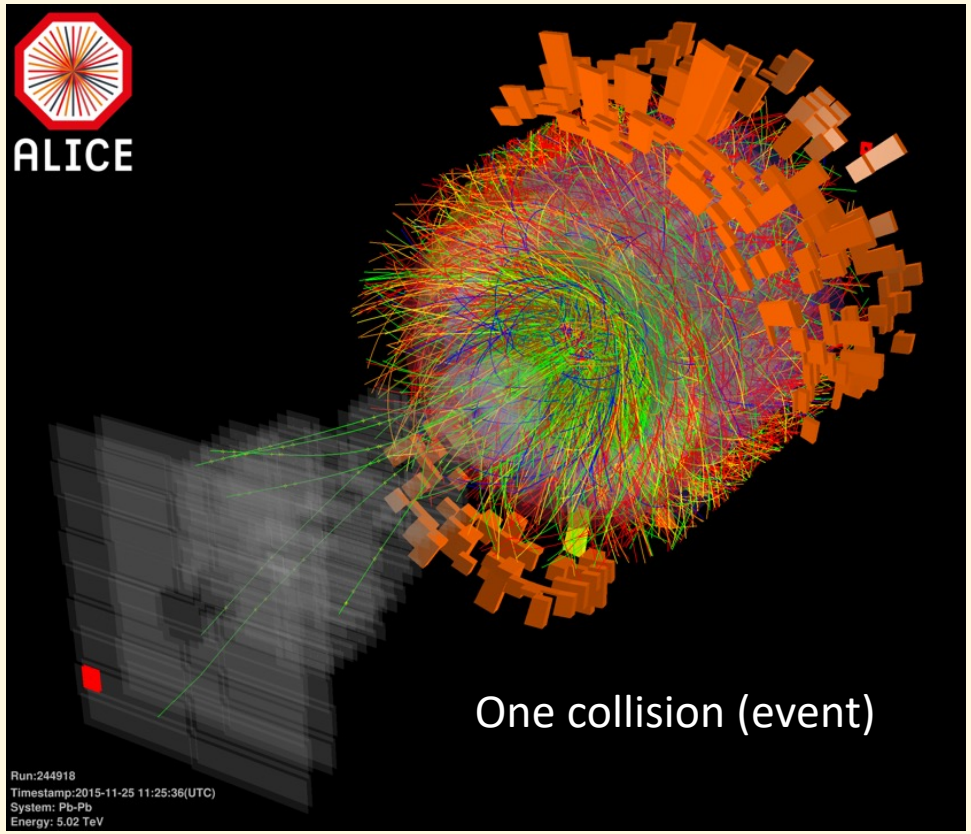
- Intermediary reference
- Address cold nuclear matter effects in initial and final states






ALICE
Pb-Pb
Pb-Pb at 5.02 TeV:
One PeV Collision
Run:244918
Timestamp:2015-11-25 11:25:36(UTC)
System: Pb-Pb
Energy: 5.02 TeV

Reconstructing the collision



What has just happened?

- What particles were created?
- Where were they produced?
- What were the parent particles?

=> Online (live):

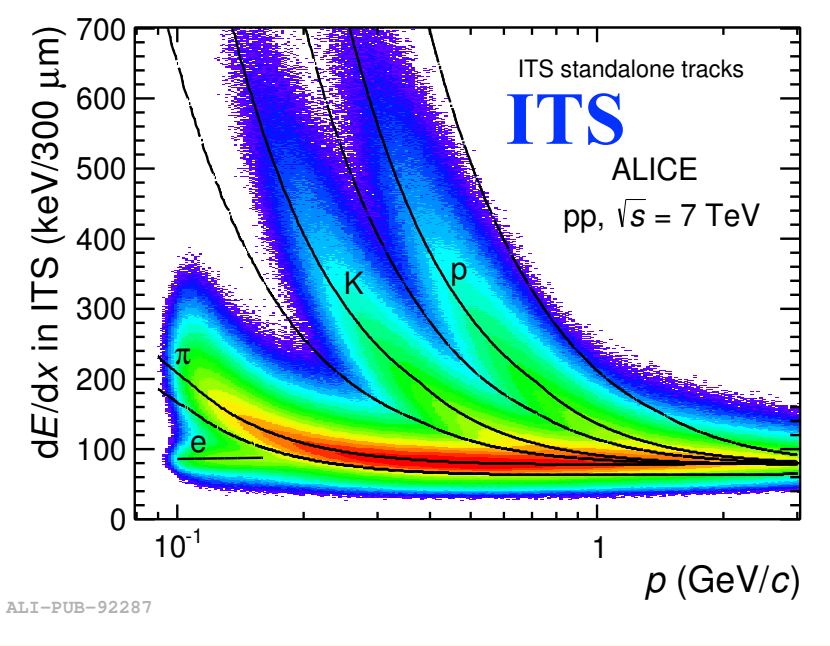
- Online data quality monitoring, calibrations.
- Using Triggers to keep events of interest and sends to storage.

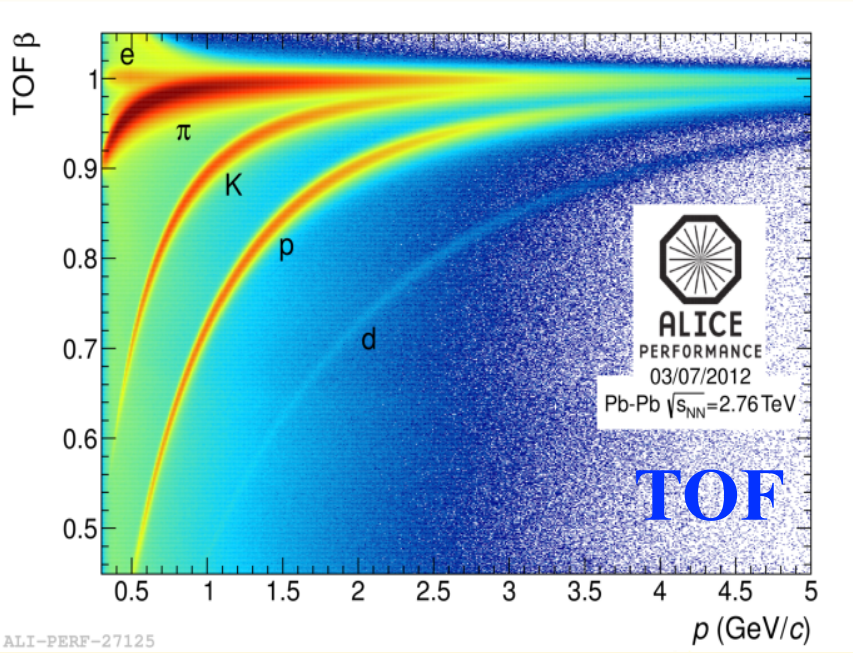
=> Offline: Event reconstruction:

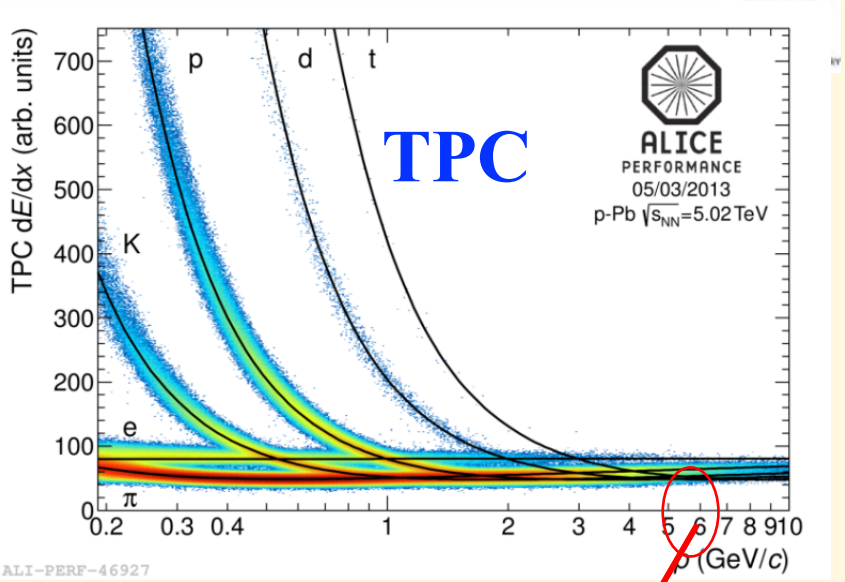
- Vertexing
- Tracking
- Particle identification of each of the tracks

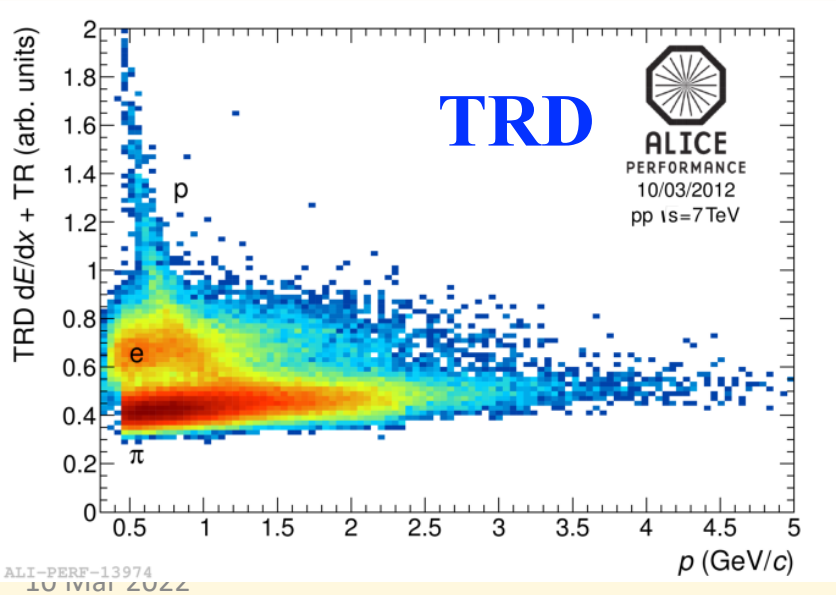
- The data flow from ALICE during Run2 was about 4 GB/second
- The data expected during next run (Run3) will be 3 TB/second

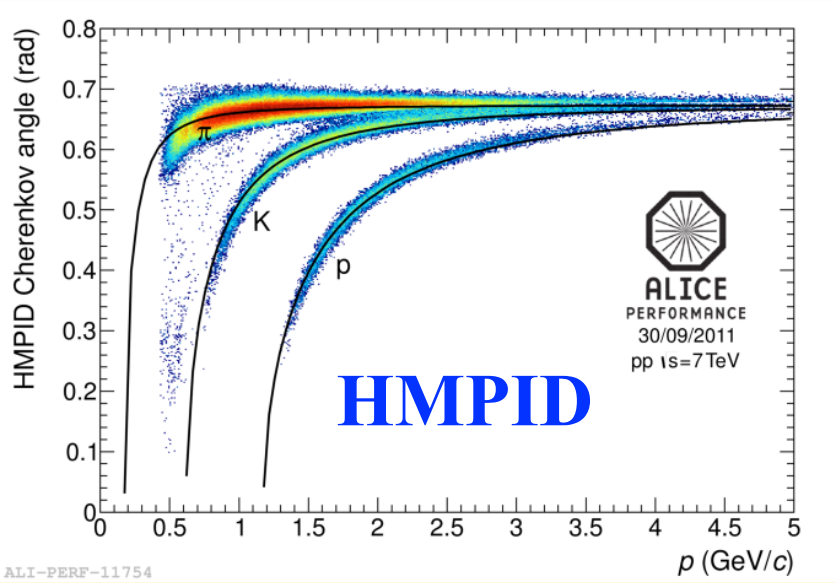
ALICE performance

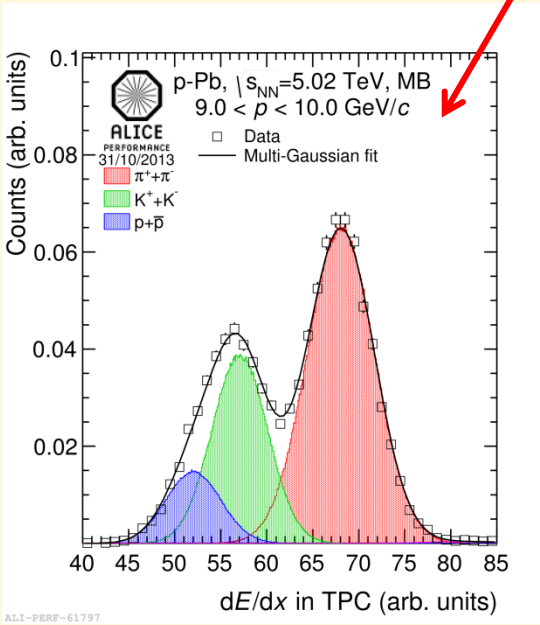




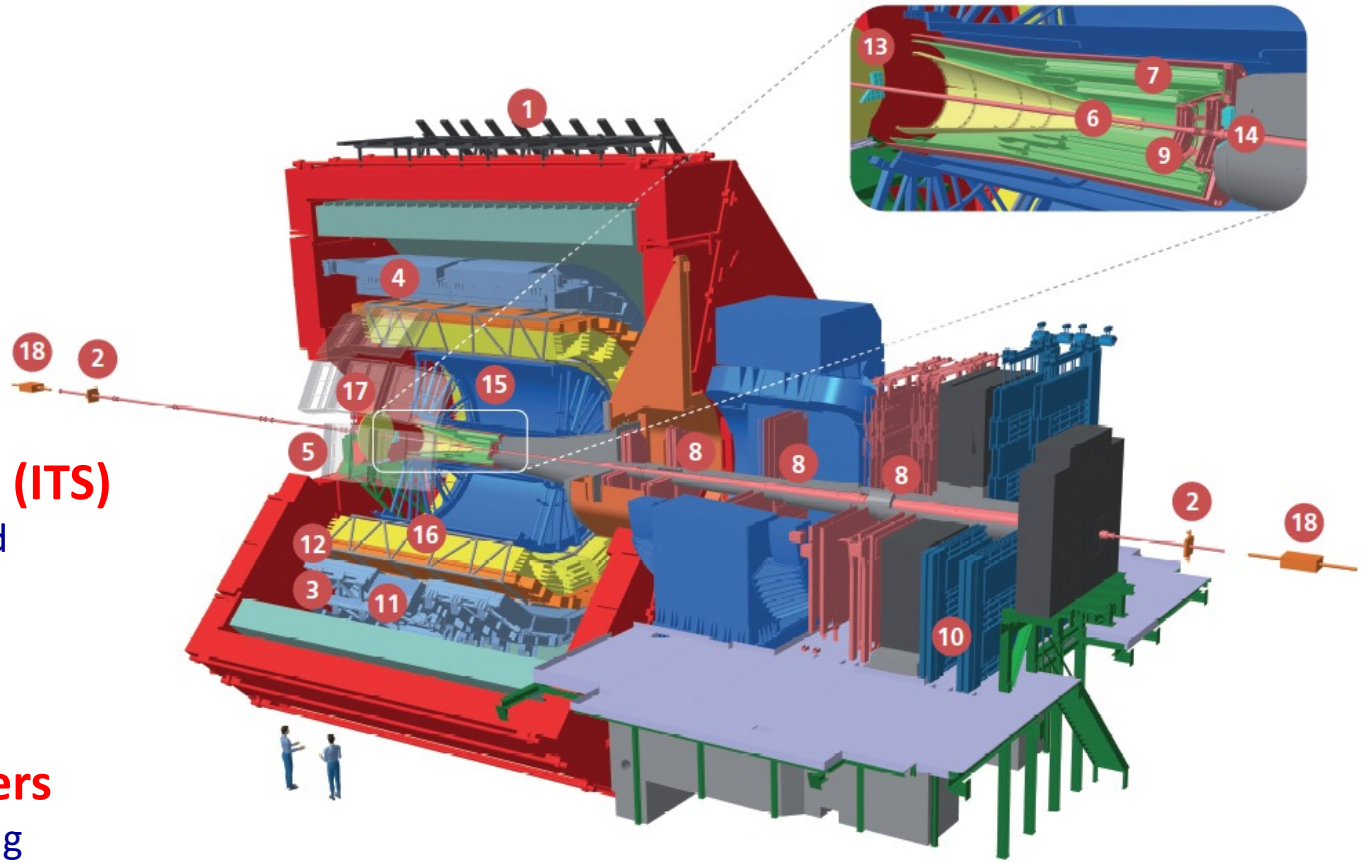








ALICE in (2022)



1 ACORDE | ALICE Cosmic Rays Detector
2 AD | ALICE Diffractive Detector
3 DCal | Di-jet Calorimeter
4 EMCal | Electromagnetic Calorimeter
5 HMPID | High Momentum Particle Identification Detector
6 ITS-IB | Inner Tracking System - Inner Barrel
7 ITS-OB | Inner Tracking System - Outer Barrel
8 MCH | Muon Tracking Chambers
9 MFT | Muon Forward Tracker
10 MID | Muon Identifier
11 PHOS / CPV | Photon Spectrometer
12 TOF | Time Of Flight
13 T0+A | Tzero + A
14 T0+C | Tzero + C
15 TPC | Time Projection Chamber
16 TRD | Transition Radiation Detector
17 V0+ | Vzero + Detector
18 ZDC | Zero Degree Calorimeter

New Inner Tacking System (ITS)

- MAPS technology: improved resolution
- Less material,
- Faster readout

New TPC Readout Chambers

- New readout chambers using 4-GEM technology
- New electronics for continuous readout (SAMPA)

New Forward Muon Tracker (MFT)

- Vertex tracker at forward rapidity

Muon Arm

- New electronics (SAMPA)
- New electronics for Muon Trigger

Online Offline (O2) system

- new computing facility
- on line tracking & data compression
- 50kHz Pb-Pb event rate

Common Projects:

Common Readout Unit (CRU)
SAMPA common FE chip

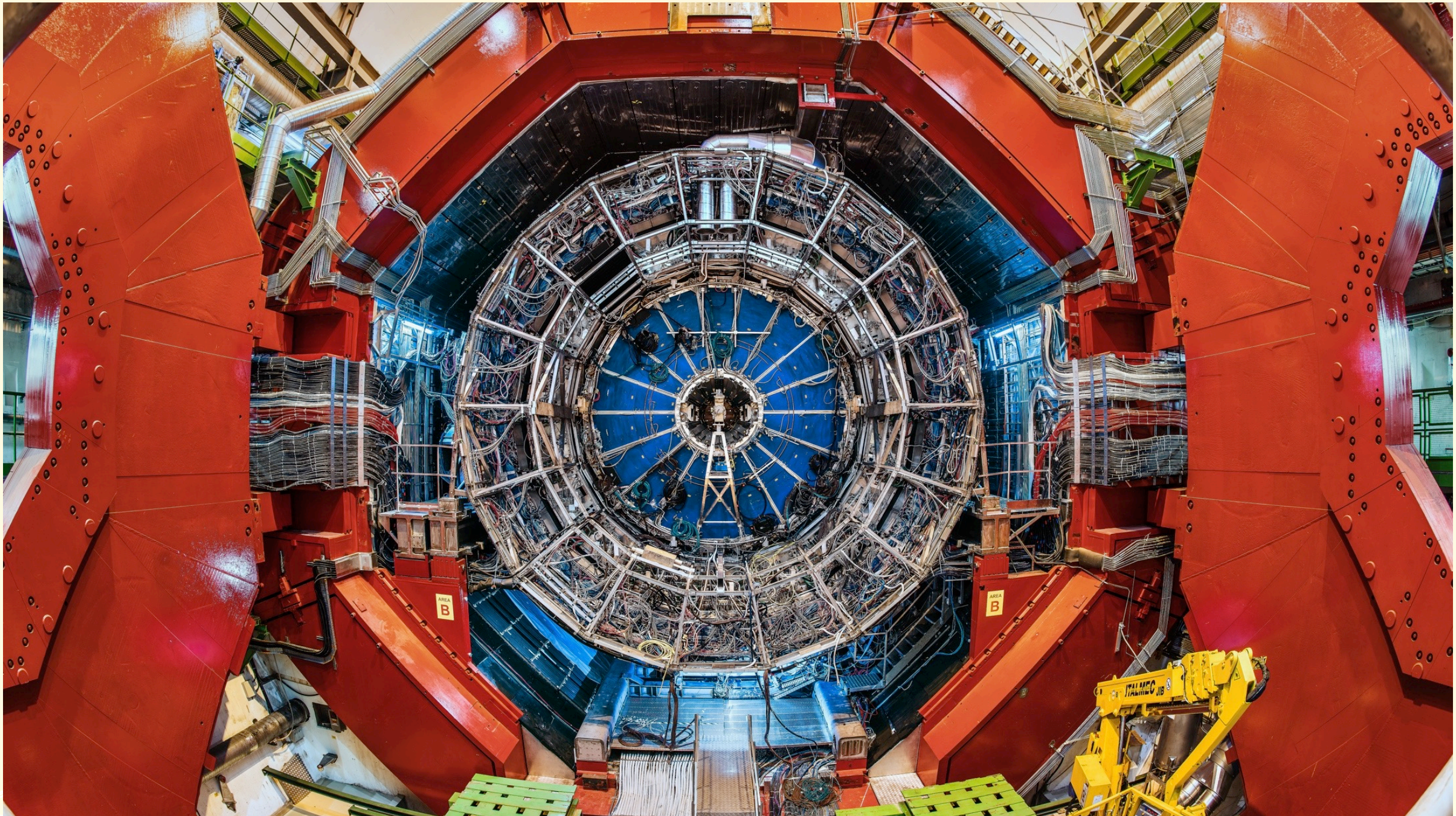
New Trigger Detectors (FIT, AD)

- + centrality, event plane

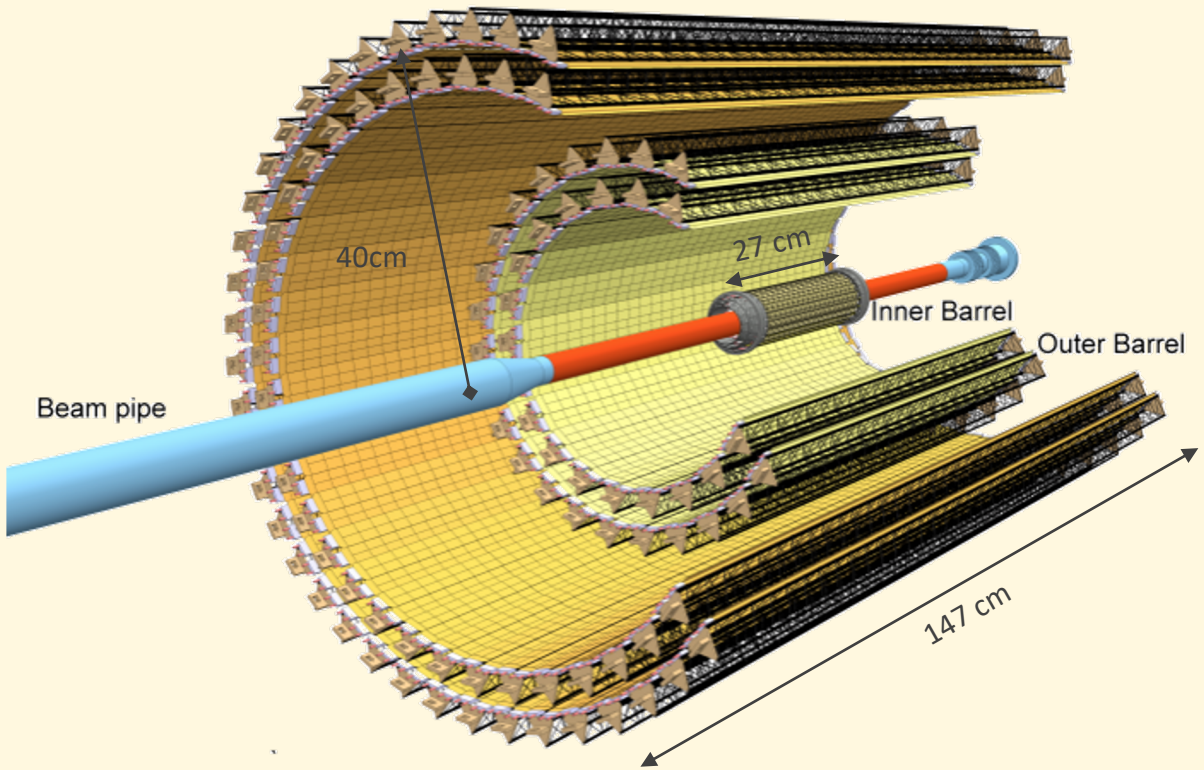
New Central Trigger Processor (CTP)

Upgraded readout for TOF, TRD, PHOS, EMCAL, CPV, HMPID

ALICE at Point-2 of the LHC

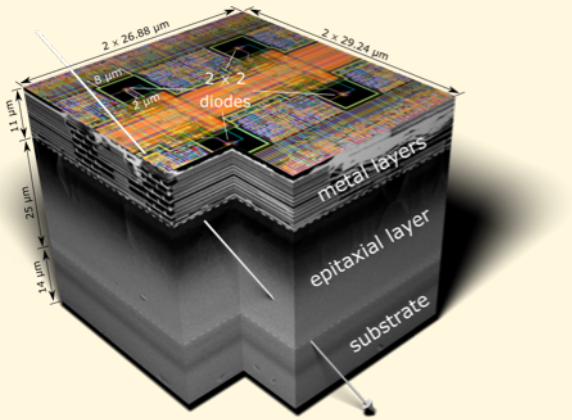


New Inner Tracking System (ITS)



- 7-layer geometry (23 – 400mm), $|\eta| \leq 1.5$)
- 10 m^2 active silicon area (**12.5 G-pixels**)
- Pixel pitch 28 x 28 μm^2
- Spatial resolution ~5μm
- Power density < 40mW / cm^2
- Material thickness: ~0.3% / layer (IB)
- Maximum particle rate: 100 MHz / cm^2

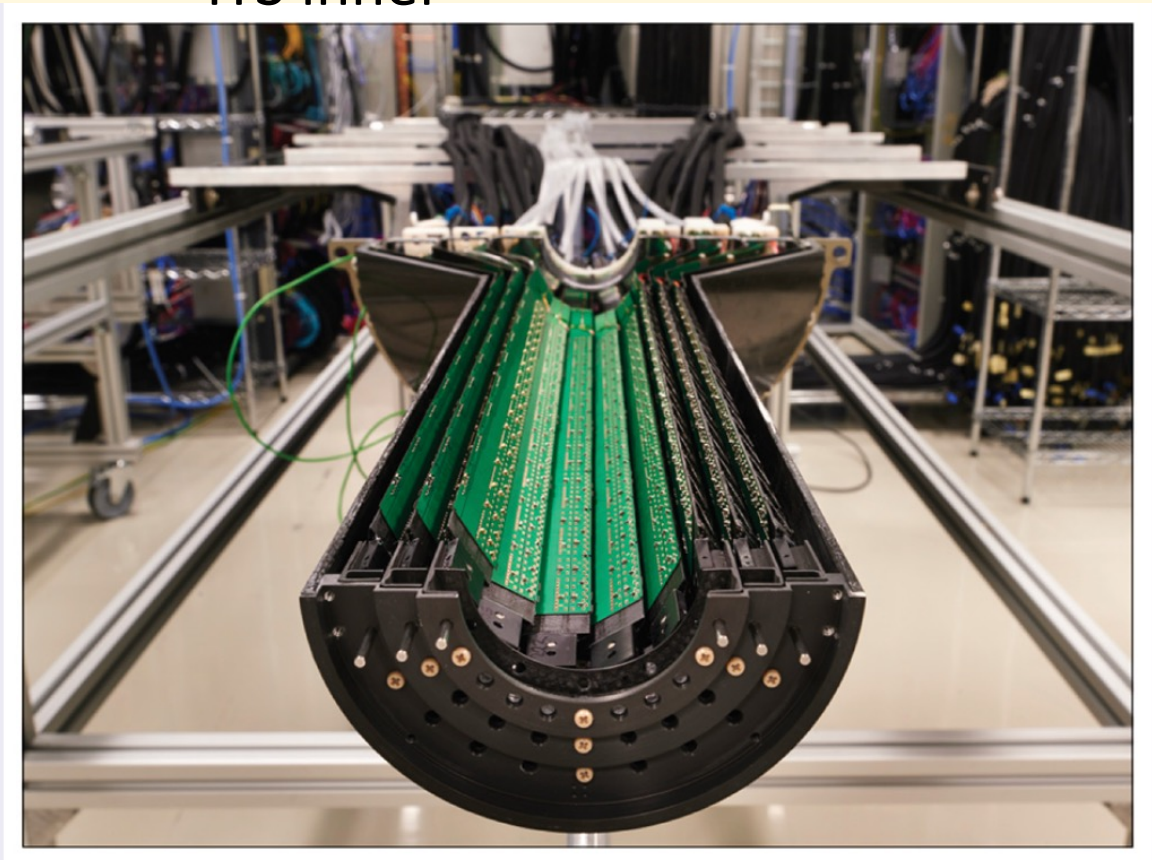
Based on CMOS Monolithic Active Pixel Sensors (MAPS)

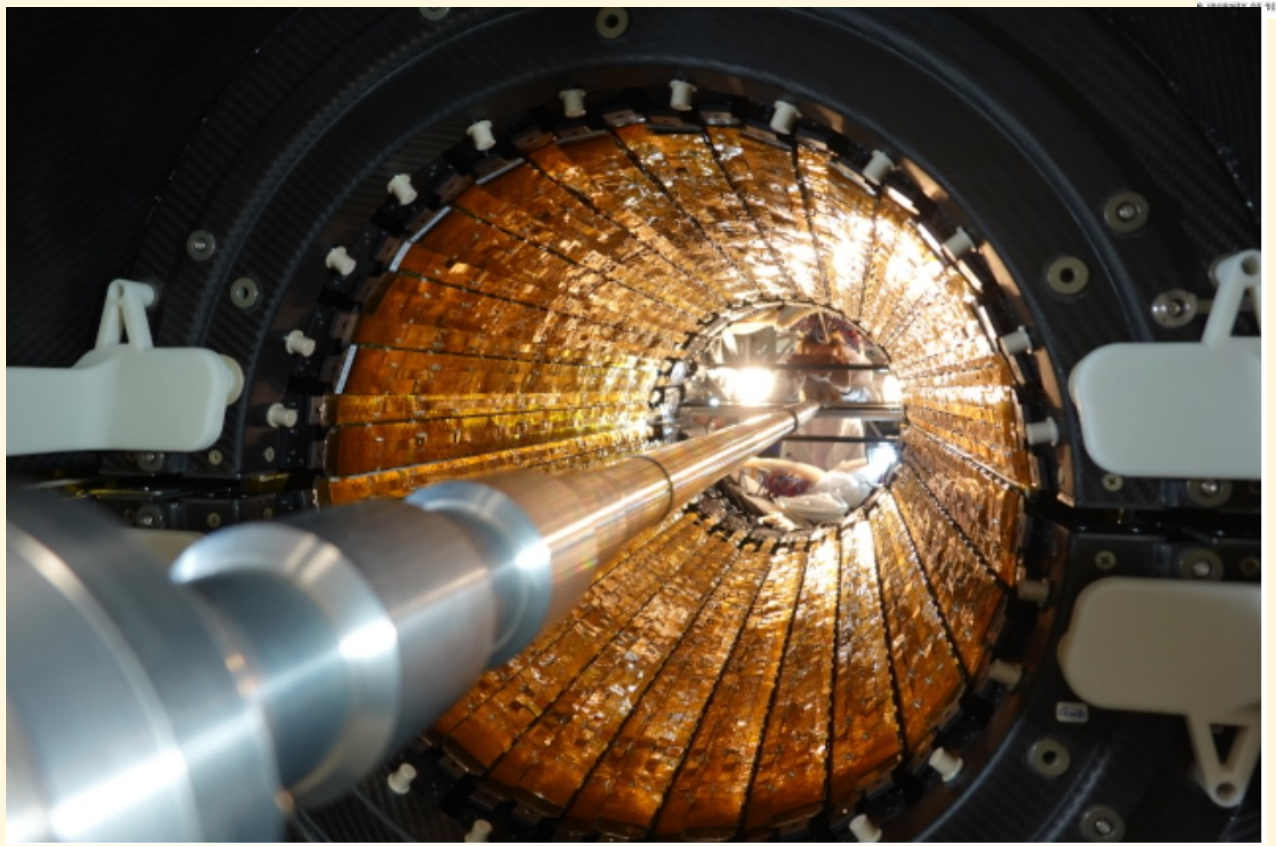


ITS inner

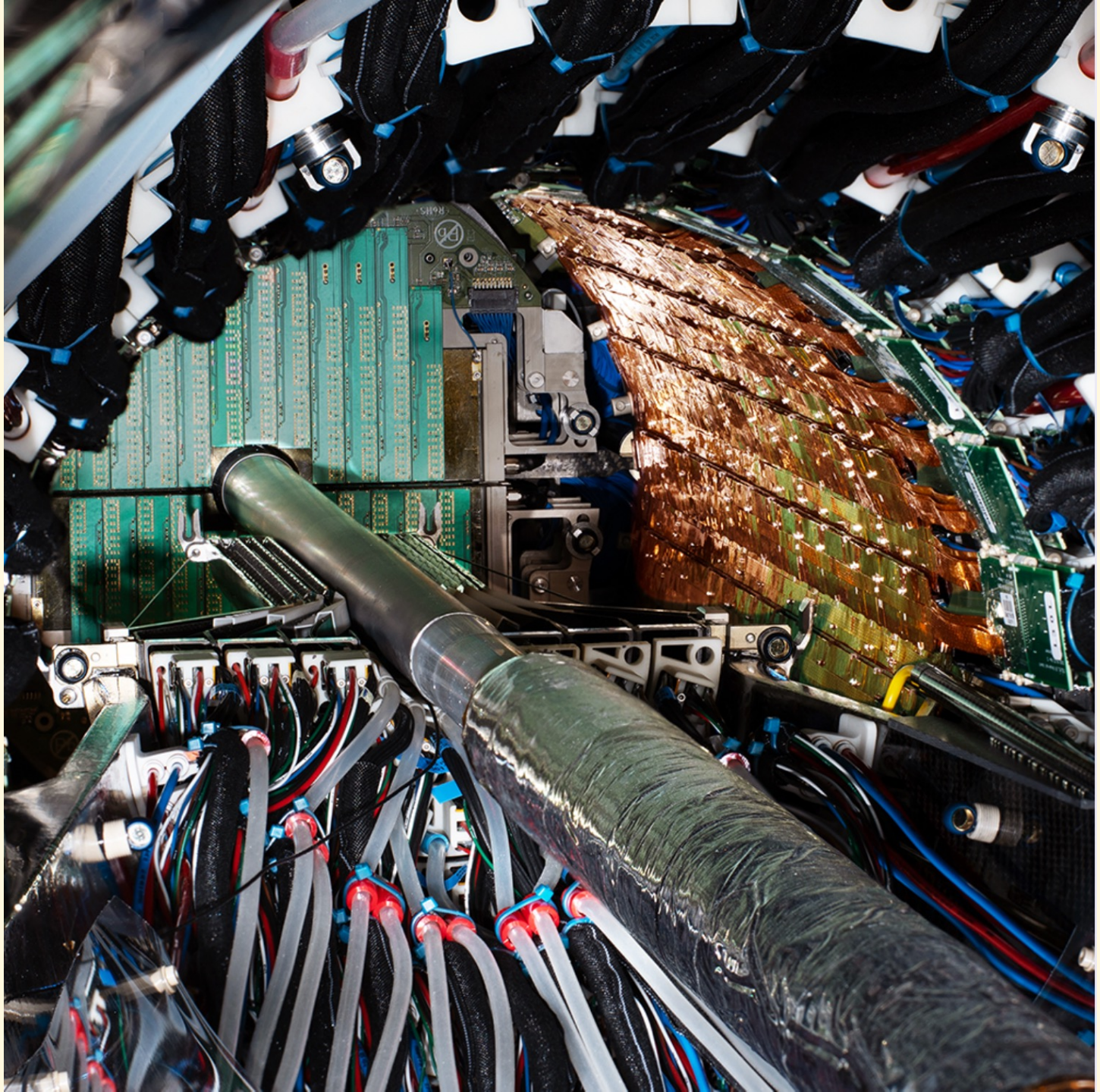
10 m^2 active silicon area (**12.5 G-pixels**)

ITS outer





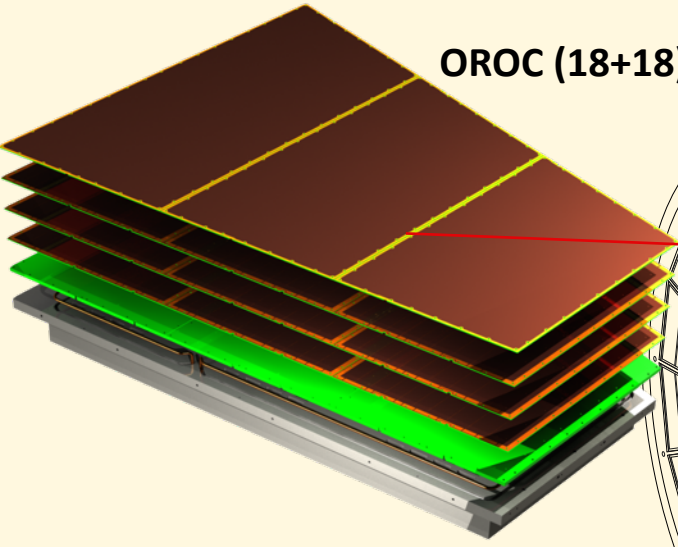
- In recent years, CMOS image pixel sensors have been widely used in digital cameras and smartphones. The ALICE ITS uses the same technology for detecting particles.
- In contrast to consumer applications, it is significantly larger: 10m^2 surface area (more than the sensors of 25000 cameras), and contains 12.5 billion pixels, a thousand times more than most consumer devices.
- On top of it, it takes 50000 pictures a second.



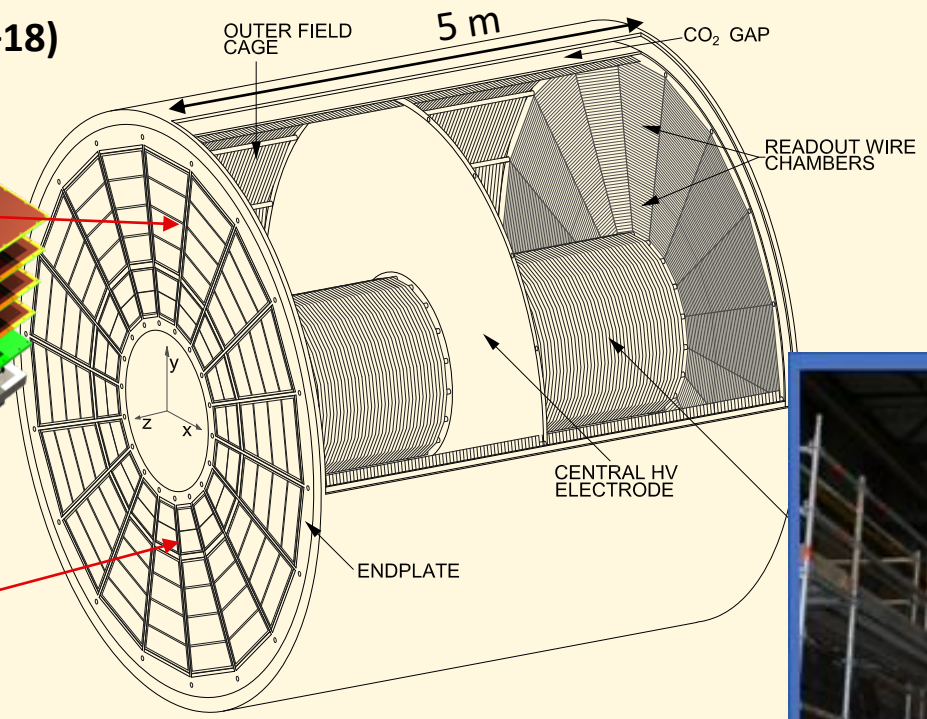
The inner (left, middle) and outer (gold colour) barrels of ALICE's state-of-the-art **Inner Tracking system (ITS)** along with the new **Muon Forward Tracker (MFT)** (green panel).

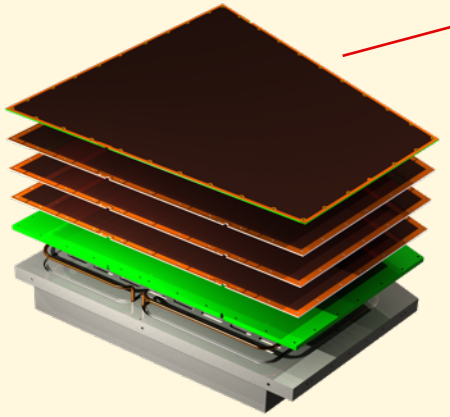
https://cerncourier.com/a/alice-tracks-new-territory/

Time Projection Chamber (TPC) with GEM detectors



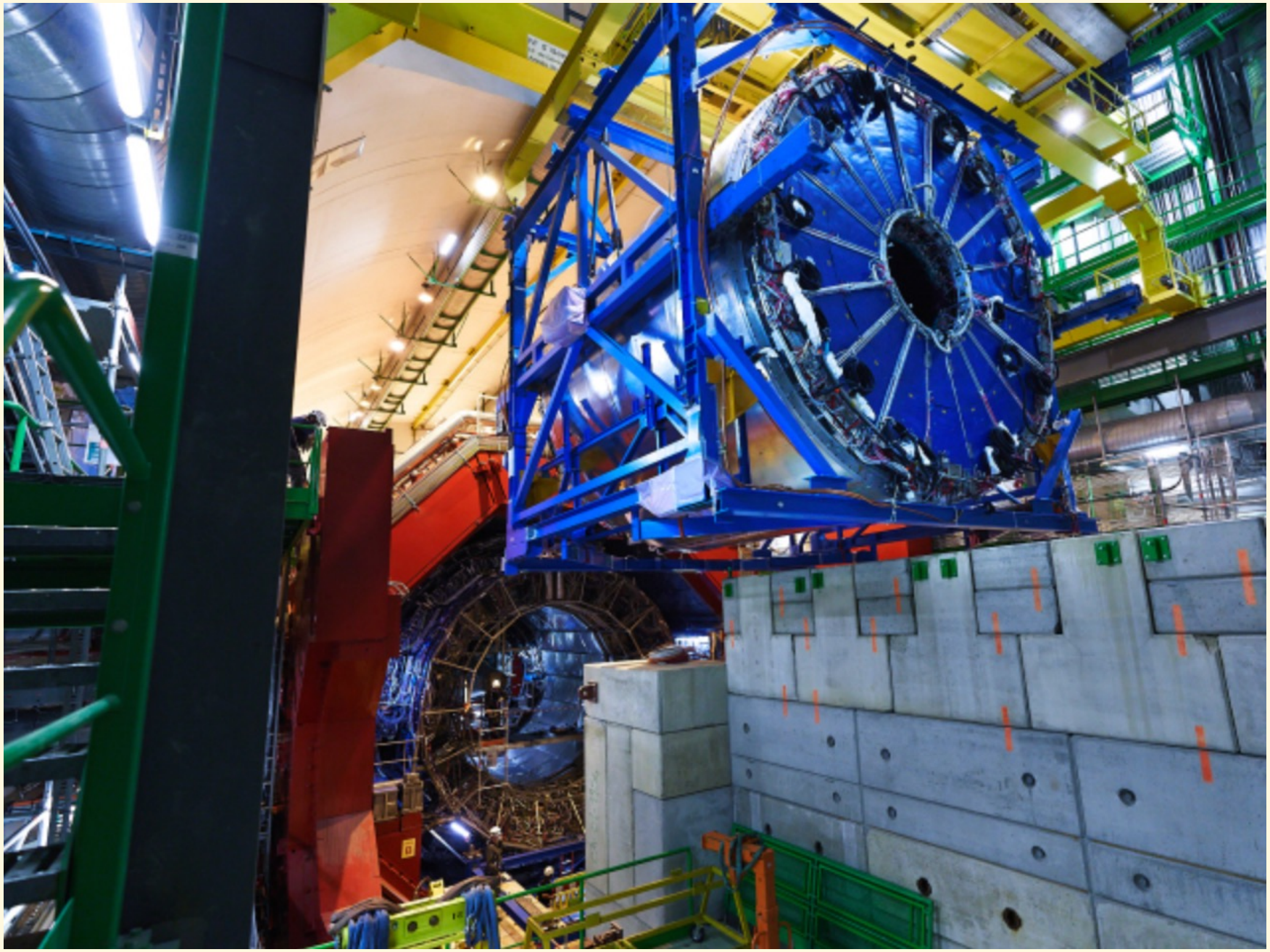
OROC (18+18)





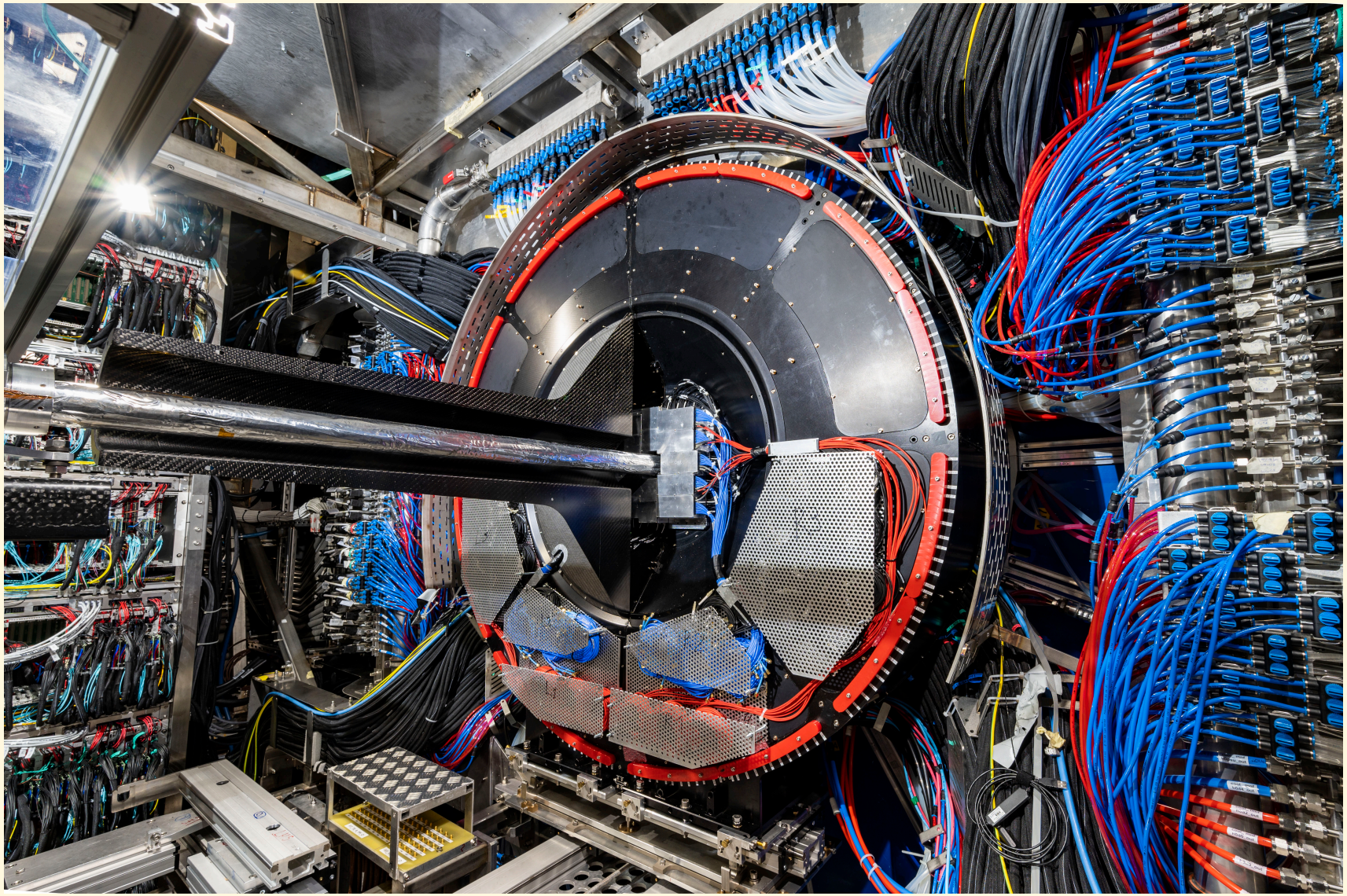
IROC (18+18)

TPC installation



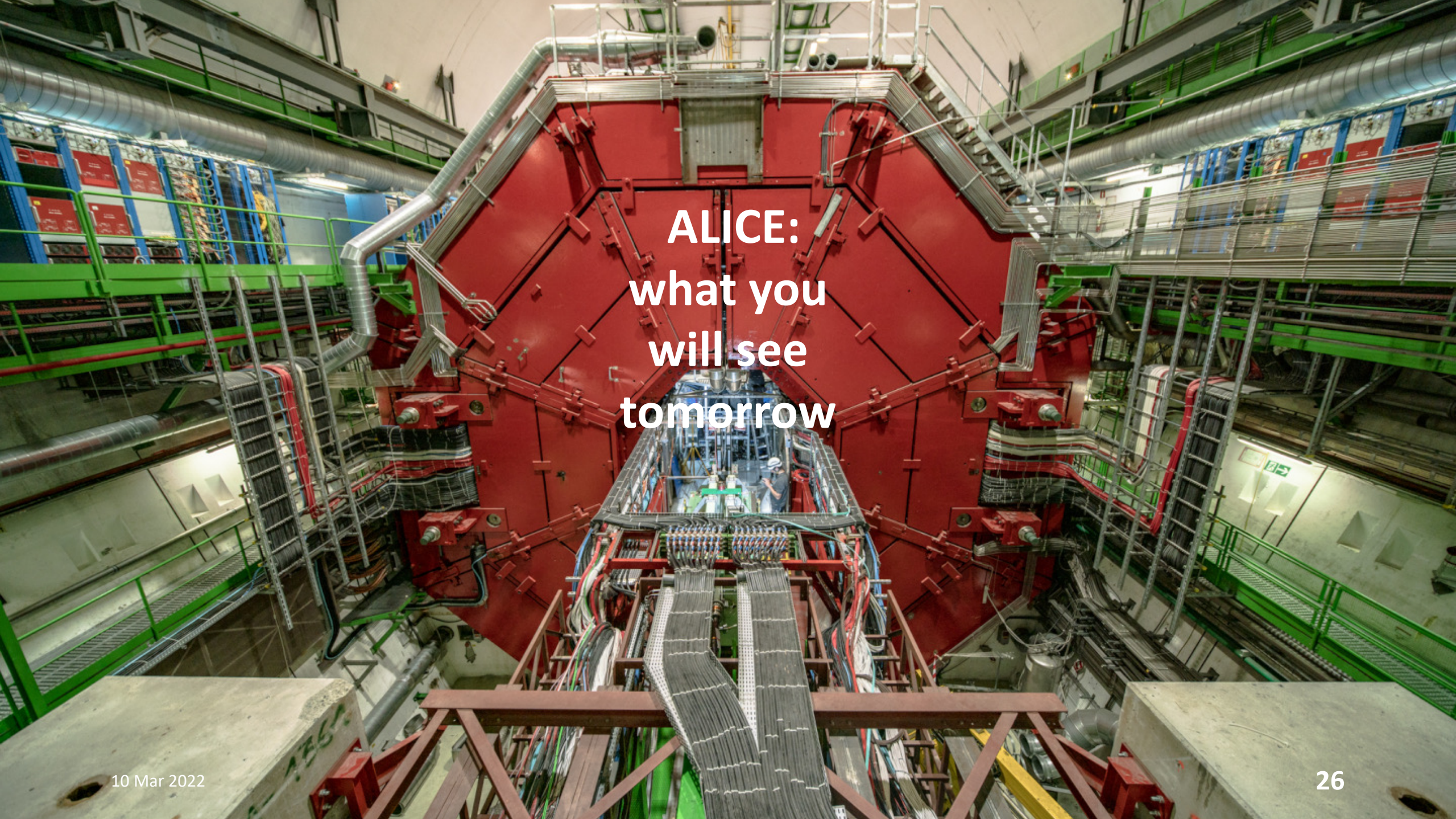
https://videos.cern.ch/record/2729677

Fast Interaction Trigger (FIT)



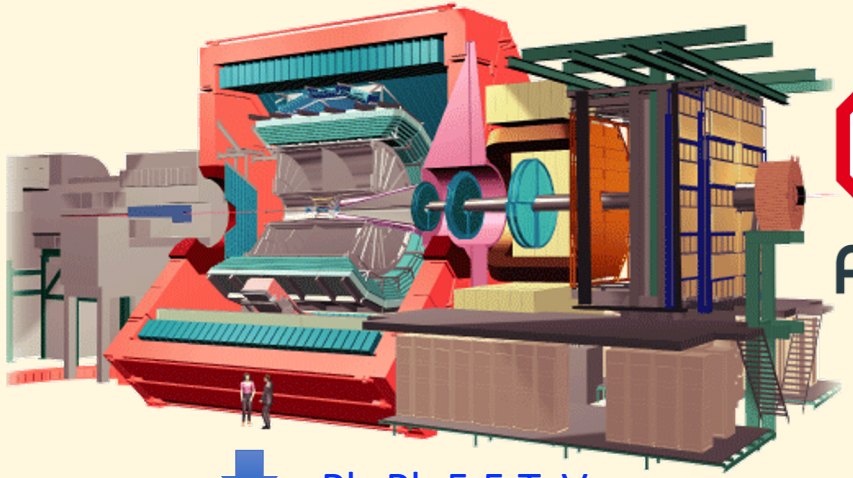
FIT is the

- fastest trigger,
- Online luminometer,
- initial indicator of the vertex position, and
- The forward multiplicity counter for ALICE.



ALICE: what you will see tomorrow

Common Readout Unit (CRU) in Run3



3: The total data volume from the front-end cards of the detectors will e significantly, reaching a sustained data throughput of up to 3 TB/s. The computing model is designed for a maximal reduction in the data volume

Pb-Pb 5.5 TeV

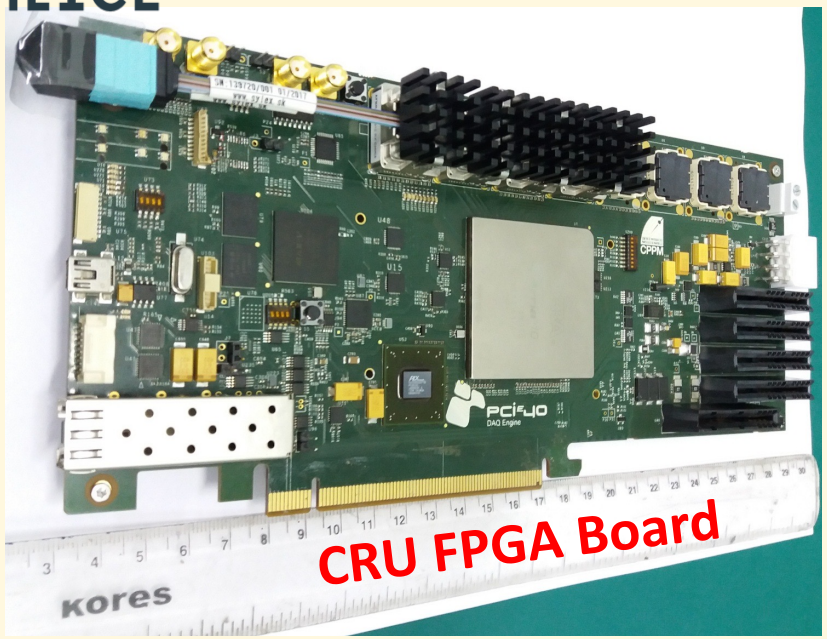
50 kHz (70 MB/event)
Total ~3 TB/s

Online
Offline
(O^2)

CRU

50 kHz (1.5 MB/event)

Storage **90 GB/s (peak)**



CRU is tasked to perform online data concentration, reconstruction and multiplexing.

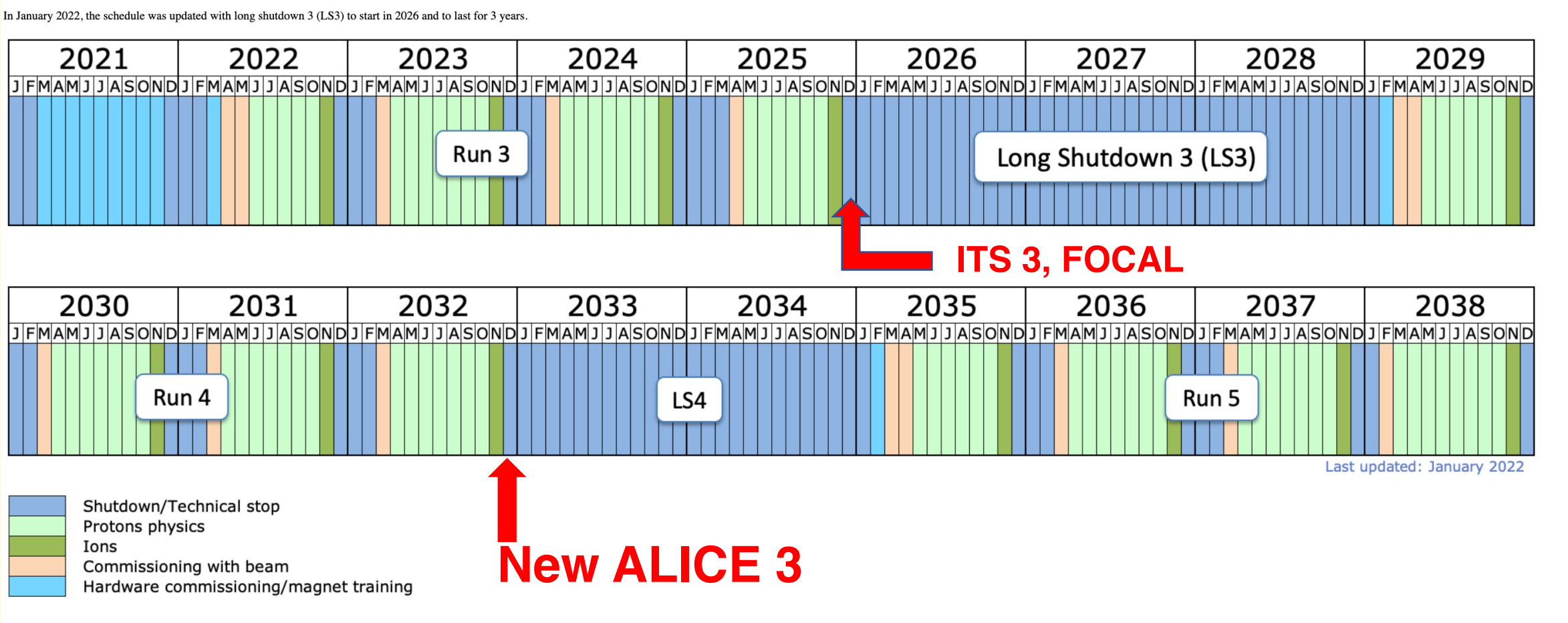
This makes CRU one of the most important components of ALICE.

India's Contribution:

400 CRU boards for TPC

Indian scientists and engineers have contributed to the design, prototyping and testing of the CRU over the last five years in collaboration with CERN, Wigner Institute, and CPPM, Marseille.

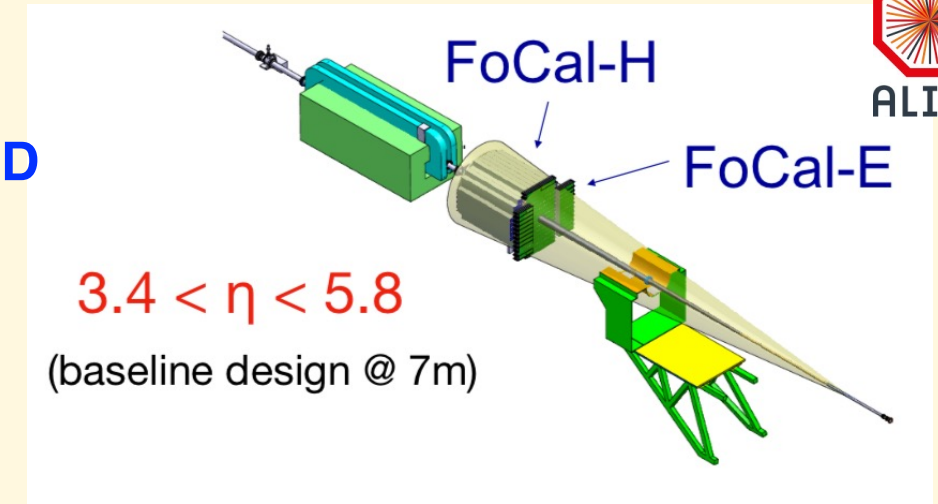
Large Hadron Collider: Schedule (Jan 2022)

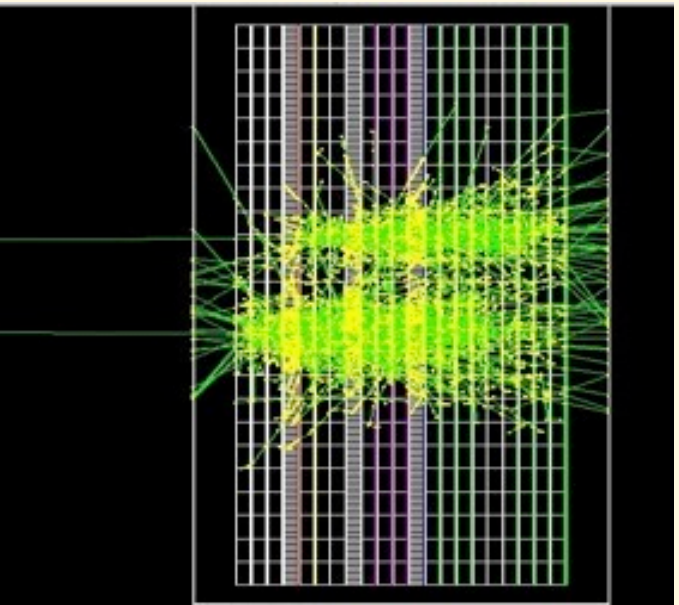


ALICE upgrade: FOCAL

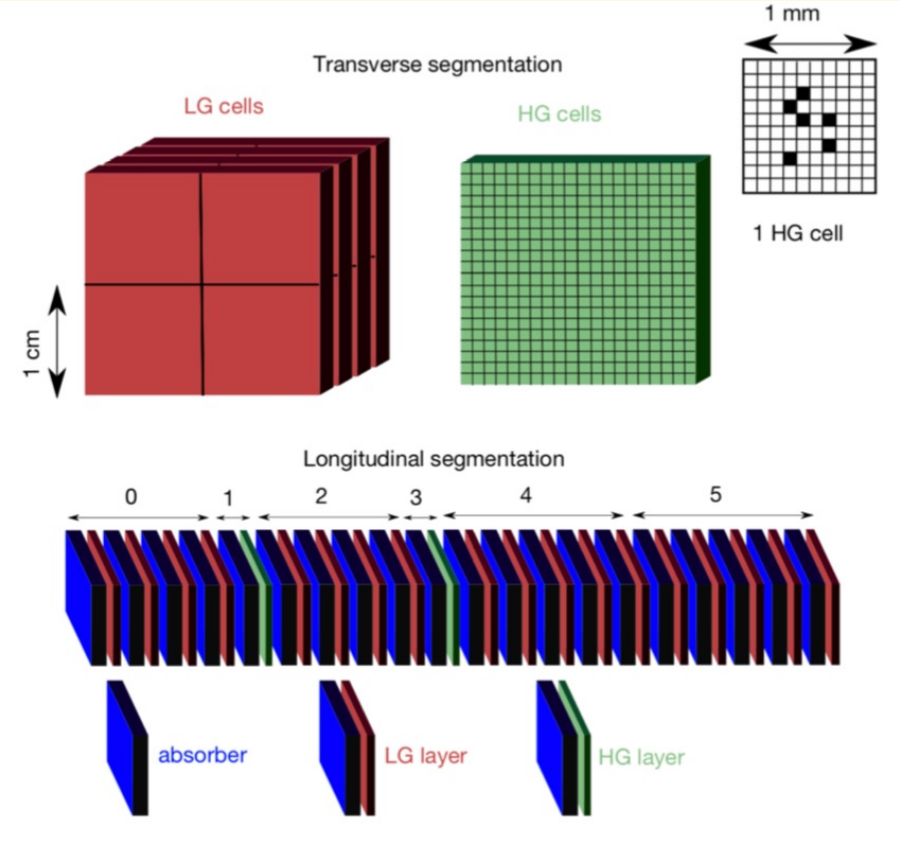
2008: First Proposal from India as a replacement for PMD

- **Physics:**
  - Initial State: Low-x Gluon Saturation
  - Initial State: Nuclear PDFs
  - Jet quenching, flow and correlations …
- **Detector R&D done in India**
- **All components from India:**
  - High resolution Silicon Pad Detector
  - Readout chips (MANAS, AnuIndra, AnuSanskar)

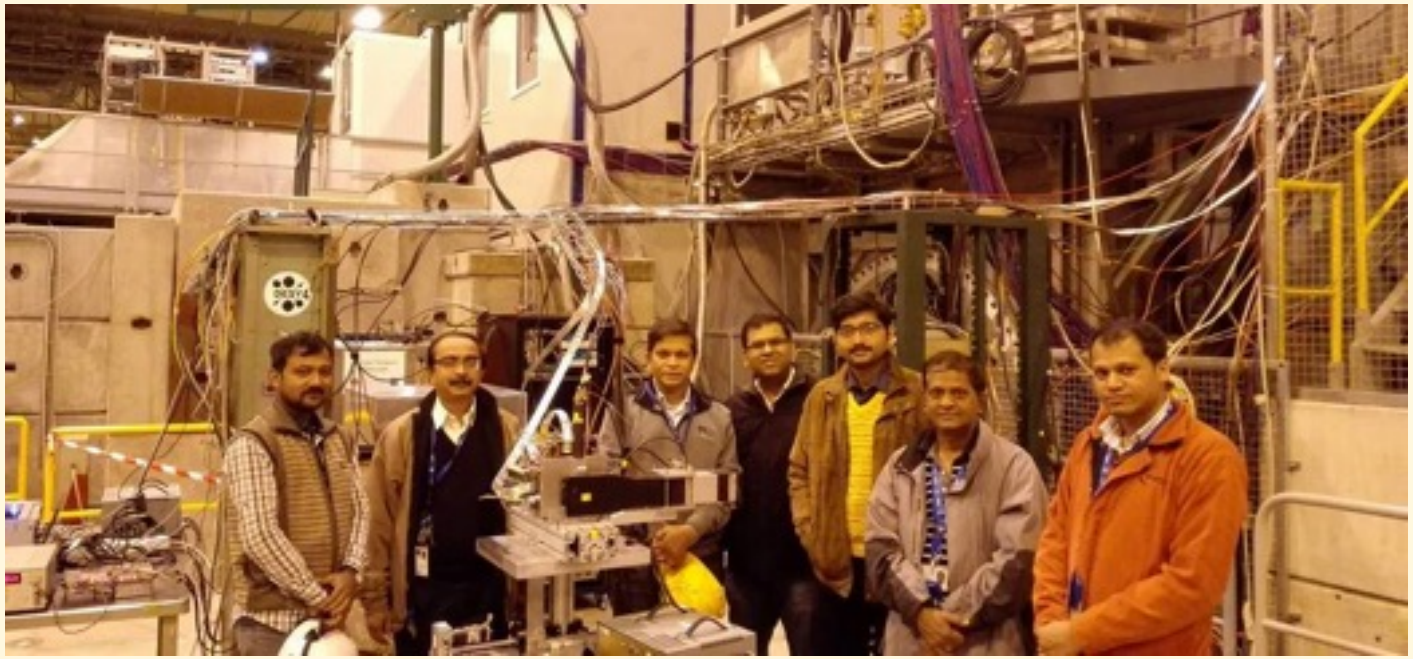


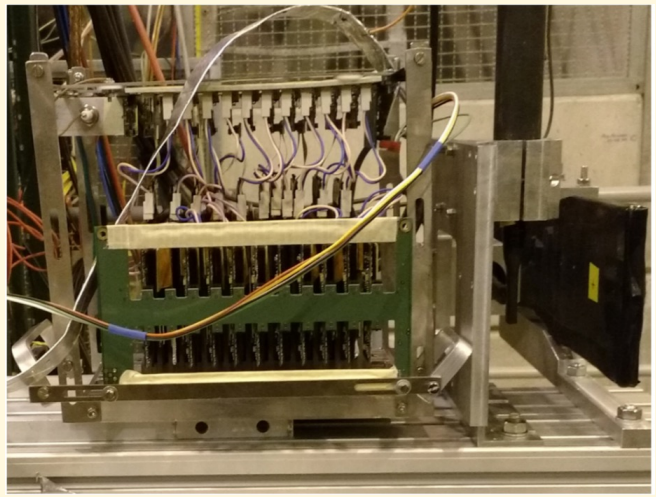


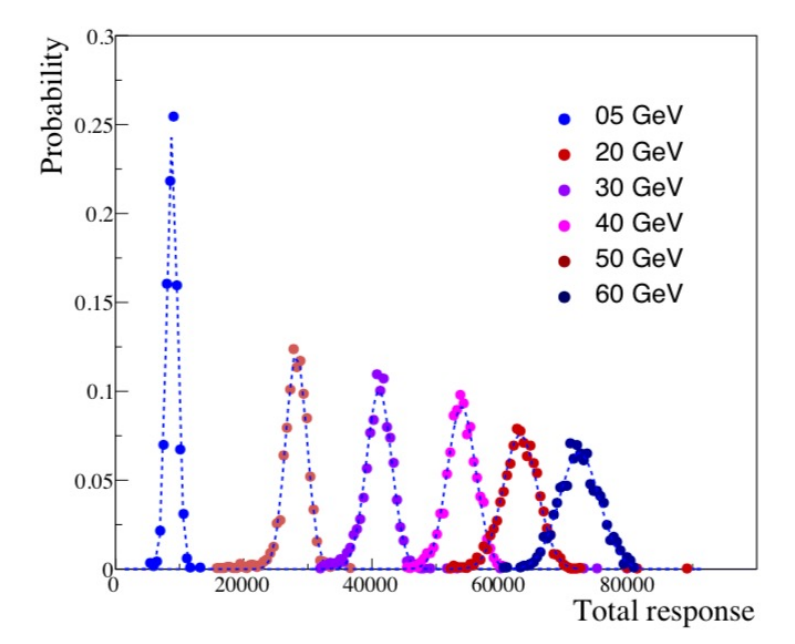
Simulation of a pi0 decaying to two photons



Silicon- Tungsten Calorimeter: 2015 test beam at CERN



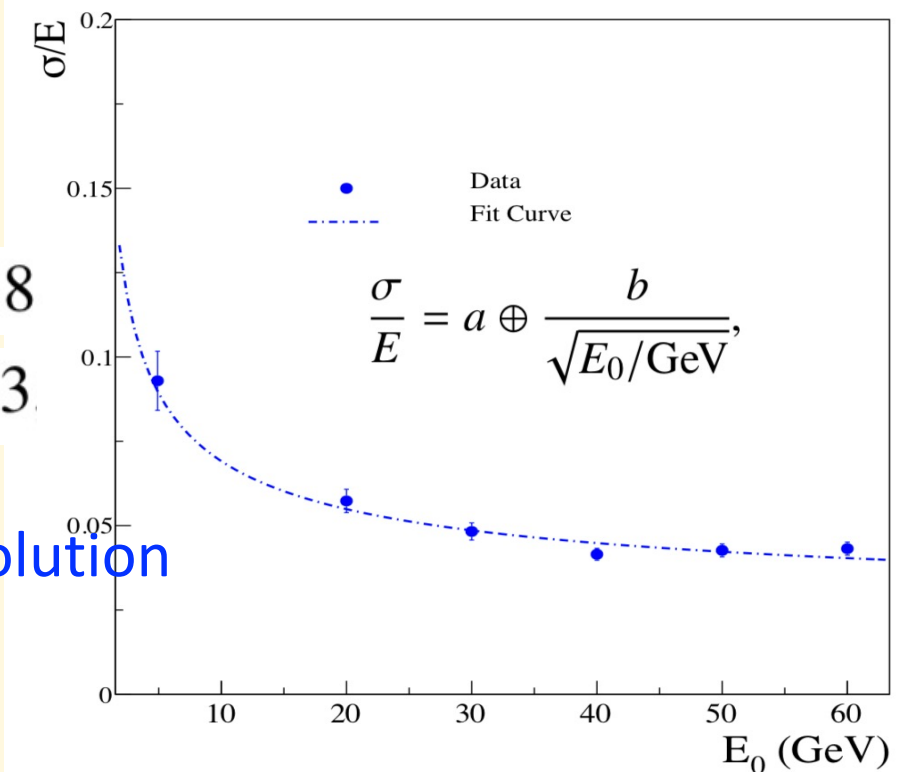




$$a = 0.020 \pm 0.0038$$

$$b = 0.1536 \pm 0.023$$

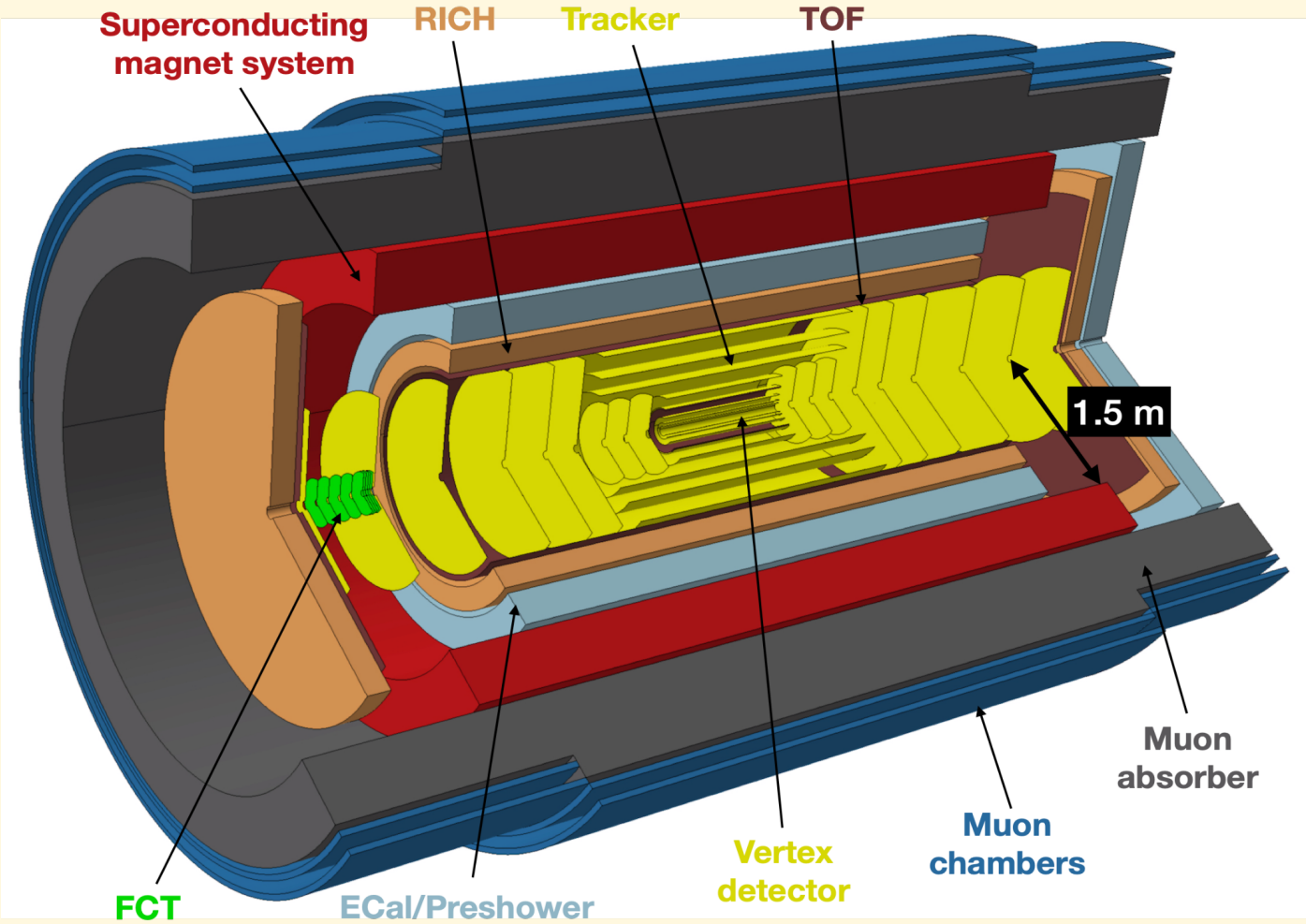
Excellent energy resolution



A "New ALICE 3" for LHC Run-5

https://arxiv.org/abs/1902.01211

(2035 onwards ....)



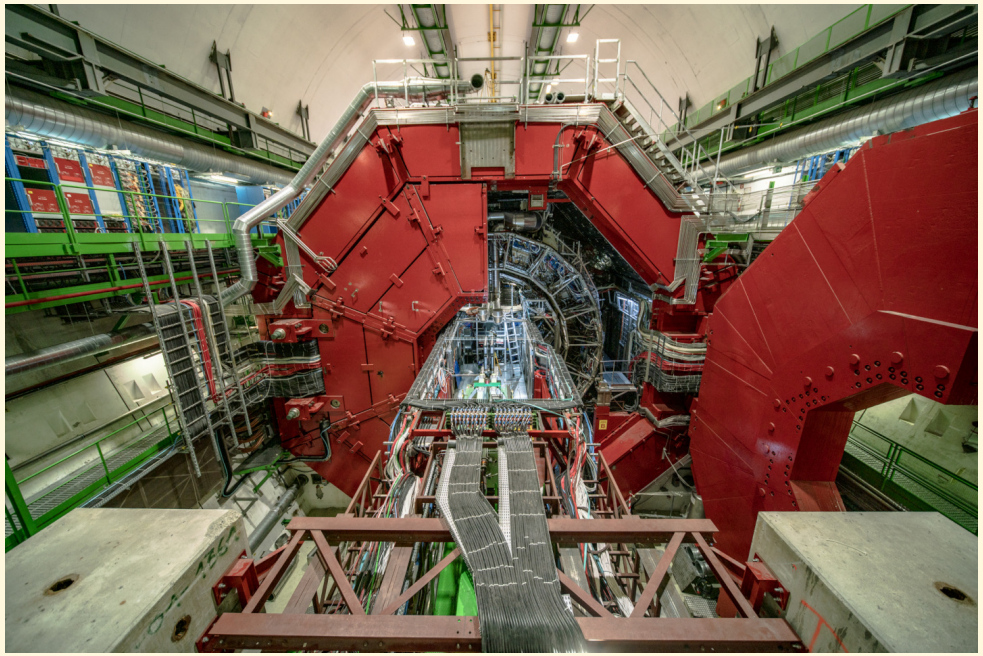
CMOS imaging technologies: high-precision spatial and time resolution

LHC Run-5:

- Tracker: ~10 tracking barrel layers
- Hadron ID: TOF with outer silicon layers
- Electron ID: pre-shower
- Conversion photons

Low p_T down to ~20 MeV/c

Extended rapidity coverage: up to 8 rapidity units + FoCal (Forward Calorimeters)



Recreating the Big Bang conditions at the LHC