ALICE experiment at CERN

ALICE-India Collaboration
Virtual Visit

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14 March 2022
CERN

“Science without borders”
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?
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)

• Electric waves speed particles up
• Magnets bend them in a circle
27 km circumference
~ 100 m underground
Design Energy:
14 TeV (pp), 5.5 TeV (Pb-Pb)

World’s Most Powerful Accelerator:
The Large Hadron Collider

Lake Geneva

Jura mountains

12 Jan 2021
Phases of Nuclear Matter

1 eV is roughly 11605 Kelvin.
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
• Excellent track and vertex reconstruction capabilities in high multiplicity environment over a wide $p_T$ range

• Particle identification over a wide momentum range
Funded by DAE and DST, Indian scientists are involved since the conception of ALICE

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

- **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

Till 2018
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):
Performs data concentration, reconstruction and multiplexing.

Silicon-Tungsten Calorimeter

LHC GRID Computing

ALICE LS2 Upgrade

FOCAL
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:
Muon Tracking Chambers

Collaboration France, India, Italy, Russia:

• 5 stations of two Cathode Pad Chambers $\sim 100\, m^2$
• $1.1 \times 10^6$ channels, occupancy $< 5\%$ (in Pb+Pb) → Read out at 1 kHz
• Chamber thickness $\sim 3\% X_0$
• Beam test results for the spatial resolution: 50 $\mu m$
  for a required resolution $< 100\, \mu m$

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
Pb-Pb at 5.02 TeV: One PeV Collision
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

ITS

ALICE

\[ \eta < 0.9 \]

6 Layers of silicon detectors

Trigger, tracking, vertex, PID (dE/dx)

\( c (\text{GeV}/\text{p}^{-1}) \)

\[ \pm 1 \times 10^{1} \]

\[ 10^{1} \]

\[ 10^{2} \]

\[ 10^{3} \]

\[ 10^{4} \]

\[ 10^{5} \]

\[ 10^{6} \]

ITS standalone tracks

TOF

TPC

HMPID

TRD

ALICE performance

ALICE has at its disposal practically all known particle identification techniques in a broad pT range!
New Inner Tracking 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
New Inner Tracking System (ITS)

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

Based on CMOS Monolithic Active Pixel Sensors (MAPS)

10 Mar 2022
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: $10 \text{m}^2$ 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
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 increase 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

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.

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

CRU

50 kHz (1.5 MB/event)

Pb-Pb 5.5 TeV

90 GB/s (peak)

Online Offline (O²)

Storage
In January 2022, the schedule was updated with long shutdown 3 (LS3) to start in 2026 and to last for 3 years.

**New ALICE 3**

**ITS 3, FOCAL**
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 ....)

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

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

CMOS imaging technologies: high-precision spatial and time resolution
Recreating the Big Bang conditions at the LHC