Particle identification in ALICE and LHCb

LHCP conference 2023 — Belgrade, Serbia

Christian Sonnabend on behalf of the ALICE and LHCb collaborations

25.05.2023
Introduction

Run 3 is in full swing - new challenges and opportunities!

- Major upgrades during LS2 for ALICE and LHCb, in particular for PID detectors
  - Completely new sensors and readout chain in RICH detectors of LHCb
  - New TPC readout in ALICE - GEMs replace the MWPCs
  - Replacing hardware triggers with software triggering — minimum bias data collection!
- Goals until LS4: ALICE — 200 pb$^{-1}$ pp and 13 nb$^{-1}$ Pb-Pb | LHCb — 50 fb$^{-1}$ pp and 1 nb$^{-1}$ in Pb-Pb
- New algorithms to cope with higher luminosities and data rates

1) LHCb event display: https://cds.cern.ch/images/LHCb-PHQ-GEN-2022-004-1
2) ALICE event display: https://cds.cern.ch/record/2841865?ln=en
Run 3 PID-detectors in ALICE and LHCb

1) LHCb schematic: https://cds.cern.ch/record/1087860
2) ALICE schematic: https://cds.cern.ch/record/2263642
Particle identification in LHCb

RICH - Ring Imaging Cherenkov Detector

- Release of Cherenkov radiation when charged particles pass $C_4F_{10}$ (RICH1) & $CF_4$ (RICH2)
- Focusing radiation using mirror system and detection using multianode photomultipliers (MaPMT)
- Ultimate physics performance: separation between charged hadron species ($\pi^\pm, K^\pm, p^\pm$ etc.) — purity vs. efficiency

1) & 2) PID performance of upgraded geometry: https://cds.cern.ch/record/1624074/files/LHCB-TDR-014.pdf
Particle identification in LHCb

Calorimeters (ECAL & HCAL)

- Identification of hadrons (HCAL), electrons and photons (ECAL)
- New graph-based clustering for Run 3: match performance of cellular automaton but much more efficient
- Neural network based classification for photon identification
- For Run 3 calorimeter PID is running in first level triggering

1) Graph based clustering: https://doi.org/10.1140/epjc/s10052-023-11332-1
2) & 3) Electron identification: https://cds.cern.ch/record/2773174
Particle identification in LHCb

Muon detectors

- 80 cm thick iron absorbers interleaved with sensitive readout panels (M2-M5)
- Run 3 readout upgrade allows to run with the full event rate — no hardware triggering
- Novel algorithms in Run 3 for HLT1 ($\chi_{corr}^2$) and HLT2 (CatBoost) for purification of muon identification

1) - 3) Performance HLT1 and 2: https://doi.org/10.1088/1748-0221/15/12/T12005
Reconstruction in LHCb

Computing throughput — HLT2 reconstruction

LHCb Simulation

- Seed tracking: 4.0%
- Downstream: 4.8%
- Converters: 5.6%
- Forward tracking: 5.9%
- Protoparticles: 8.6%
- RICH: 8.6%
- Calorimeter: 18.8%

Throughput = 153.7 events/s/node

Track fit: 41.5%

1) Performance graph: https://cds.cern.ch/record/2773174
Particle identification in ALICE

TPC - Time projection chamber

- Gaseous detector (Ne-CO$_2$-N$_2$, 90-10-5 gas mixture), collects 97.5% of all raw data in ALICE
- PID via specific energy loss per unit distance $dE/dx$ — Bethe-Bloch with secondary corrections
- Run 3: GEM-based readout $\rightarrow$ 50 kHz readout rate, raw-data stream of up to 3.5 TB/s
Particle identification in ALICE

**TPC - Time projection chamber**

- Novel PID procedure in Run 3
  - Hyperparameter optimisation for initial fit of Bethe-Bloch — a priori PID information not needed
  - Neural network corrections for secondary effects and sigma estimation
  - Fully data-driven 6D corrections and sigma estimation (Run 3)
Particle identification in ALICE

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Particle identification in ALICE

TOF - Time-of-flight detector

- 3.7 meters from IP, 1593 strips multigap resistive plate chambers, 141 m² and -0.9 < \( \eta \) < 0.9 of coverage
- Particle identification using particle velocity and measured momentum
- Requires event time, particle arrival time at TOF, track path length
Particle identification in ALICE

TOF - Time-of-flight detector

- Event time computed by forward detectors FT0 and TOF itself
- Comparison with FT0 detector — nominal performance of the ALICE TOF detector
Particle identification in ALICE

Specialized detector systems

- **TRD**
  - Electron PID for $\gamma > 1000$ by transition radiation, Xe-CO$_2$ mixture, excellent tracking capabilities

- **PHOS, EMCal, DCal** — Calorimetry
  - Electromagnetic and di-jet identification

- **HMPID**
  - RICH with liquid C$_6$F$_{14}$, used for high momentum PID
Particle identification in ALICE

Specialized detector systems

- **MFT, MCH, MID**
  - Muon identification at forward rapidity
  - MFT new in Run 3
  - Precision vertexing using ALPIDE MAPS silicon sensors

- **ITS**
  - Run 3: purely silicon pixels (ALPIDE MAPS)
  - Ongoing feasibility studies for PID
  - Excellent vertex resolution

- **FIT** — new in Run 3!
  - Event multiplicity, centrality, reaction plane
  - Determination of collision time with ~20 ps precision

1) Muon forward tracker - TDR: [https://cds.cern.ch/record/1981898](https://cds.cern.ch/record/1981898)
Conclusion

LHCb
- New algorithmic and hardware implementations for calorimeters and muon system
- PID efficiency is expected to match Run 2 and improve with higher statistics

ALICE
- New TPC readout and PID corrections will bring strong improvements compared to Run 2
- High precision of interaction vertex (space and time: ITS and FIT) will strongly enhance tracking

Thank you
Computing

- Completely new software framework — Combine detector operation, data processing and physics analysis
- Purely software triggering, online (synchronous) and offline (asynchronous) processing — O²
- Processing and compression of several events in timeframes (TF), PID selections in DPL

2) CHEP talk — David Rohr, Giulio Eulisse: https://indico.jlab.org/event/459/contributions/12432/attachments/9414/14116/alice_o2_gpu_eulisse_rohr.pdf
Event time determination

- Iterative procedure described in EPJP 132 (2017) 99

TOF event time determination – Run 2 and Run 3

![Histogram of TOF - t\_π (ps)](image1)

- LHC Run2 (2015)
  - Pb-Pb, \( \sqrt{s}_{NN} = 5.02 \) TeV
  - \( \sigma_{\text{event-time}} = 5 \) ps
  - \( \rho = 1.5 \) GeV/c

- ALICE Performance
  - Time-Of-Flight detector

- TOF calibration
  - standard
  - improved

- Gaussian model
  - \( \sigma = 56 \) ps

![Histogram of t\_exp(\pi) - t\_TOF (ps)](image2)

- Run3
  - pp, \( \sqrt{s} = 13.6 \) TeV
  - \( p_T = 1.50 \) GeV/c

- Gaussian model
  - \( \mu = 36.85 \) ps
  - \( \sigma = 76.61 \) ps