PARTICLE IDENTIFICATION WITH THE ALICE DETECTOR AT THE LHC

C. Zampolli – INFN Bologna
On behalf of the ALICE Collaboration
Outline

- The ALICE detector
- Particle Identification in ALICE
  - Barrel detectors
  - Single-arm detectors
  - Topological PID
- ALICE Particle Identification results
- Conclusions

See also:
- Recent results, P. Kuijer (4/6)
- HI at LHC, C. Loizides (5/6)
- PID in pp, A. Ortiz Velasquez (5/6)
- Correlations, D.J. Kim (5/6)
- Strangeness, B. Abelev (5/6)
- Soft QCD and Diffractive at LHC, E. Scapparone (5/6)
- HF in PbPb, Y. Pachmayer (5/6)
- HF in pp, P. Antonioli (7/6)
- Quarkonia in pp, L. Bianchi (5/6)
- Quarkonia in PbPb, H.D.A. Pereira Da Costa (5/6)
The ALICE Detector
The ALICE Experiment at LHC

- A Large Ion Collider Experiment is the experiment at the CERN Large Hadron Collider (LHC) dedicated for heavy-ion physics
  - Genuine interest also in pp and pA
- The ultimate goal is the study of the Quark Gluon Plasma (QGP)
- One of the key tools for the many observables ALICE is interested in is Particle Identification
- ALICE PID capabilities makes it unique wrt the other LHC experiments
  - It makes use of all known PID techniques
  - Covering a momentum range from 0.1 to ~100 GeV/c
ALICE Detectors - Setup

- **Detectors**: 18
- **Tracking**: 7
- **PID**: 6
- **Calo.**: 5

**Detectors**
- **EMCAL**
  - $\gamma$, $\pi_0$, jets
- **TPC**
  - Tracking, dE/dx PID
- **ZDC**
- **PMD**
  - $\gamma$, mult
- **ITS**
  - Vtx, low-$p_T$ trk, dE/dx PID
- **HMPID**
  - High-$p_T$ hadron PID
- **L3**
- **PHOS**
  - $\gamma$, $\pi_0$, jets
- **V0, T0**
  - Trigger, Centrality (V0)
- **FMD**
  - Forward mult
- **TRD**
  - e PID
- **ACORDE**
  - Cosmics
- **TOF**
  - Hadron PID
- **MUON Trk**
  - $\mu$
- **MUON Trig**
- **Dipole**
- **ZDC**
  - Centrality

**Detectors**

**C. Zampolli - ALICE**

**PLHC, 4 June 2012, Vancouver**
The ALICE PID techniques

Barrel Detectors
- Energy loss
  - ITS
  - TPC
- Transition radiation
  - TRD
- Time of Flight
  - TOF

Single-arm Detectors
- Calorimetry
  - PHOS
  - EMCAL
- Muon Spectrometry
  - MUON
- Cherenkov Radiation
  - HMPID
- Preshower
  - PMD
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Decay Topology
- Topological PID
  - ITS
PID in the barrel
PID with the ALICE ITS

The Inner Tracking System ($|\eta| < 0.9$)
- Six layers, three technologies: SPD, SDD, SSD
- Primary and secondary vertex reconstruction
- Tracking + standalone reconstruction
- PID via $dE/dx$ from SDD and SSD analog read-out
  - In the low $p_T$ region, down to 100 MeV for $\pi$ standalone tracking

- Truncated mean - (weighted) average – out of 3 or 4 layers

Resolution $\sigma_{dE/dx} \sim 10-15\%$
The ALICE TPC

- Large TPC optimized for high-multiplicity environment

- Efficient tracking (~80%) in $|\eta| < 0.8$, $\sigma(p_t)/p_t \sim 5\%$ (simulation, current performance within expectations)
- Momentum resolution (TPC+ITS) $\sigma(p_t)/p_t < 2.5\%$ up to 10 GeV/c
- Two-track resolution < 10 MeV
- PID (truncated mean over a max of 159 signals) with $\sigma_{dE/dx} \sim 5\%$ (isolated tracks, max number of clusters)
- Space-point resolution 0.8 (1.2) mm in xy (z)

- $L=5$ m, $\varnothing = 5$ m, 92 m$^3$ (inner radius ~80 cm)
- Material ($\eta=0$): 3% $X_o$
- Drift gas: Ne/CO$_2$/N$_2$ (86/9.5/4.5%)
- Drift time: 92 $\mu$s
- ~ 560000 pads
- Calibration with laser, krypton, cosmics, w/ and w/o B field
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PID with the ALICE TPC

- Wide dynamic range, up to ~26 MIP → light nuclei
- Track-to-Track ID (n-σ cut) in the 1/β² region
- PID in the relativistic rise using statistical approaches

**PbPb, 2.76 TeV**

**Negative tracks**

![Graph showing dE/dx signal in TPC](image)
The ALICE TRD

- 6 layer \textit{Transition Radiation Detector}, with 5 longitudinal stacks ($|\eta| < 0.9$ and full $\phi$)
- At the LHC energies, only electrons can emit TR ($\gamma > 1000$ needed)
  - Electron ID in the momentum range $p > 1$ GeV/c, with pion rejection factor \textasciitilde 100
- Signal shows:
  - Peak at early times $\rightarrow$ amplification region
  - Peak at late times (for electrons!) $\rightarrow$ Transition Radiation

![Diagram of Transition Radiation Detector]

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Test beam

- $p = 2$ GeV/c

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PID with the ALICE TRD

- 1d likelihood method used at present, using the different signal distributions for pions and electrons
  - 2d likelihood + neural networks under study
PID with the ALICE TRD

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  - 2d likelihood + neural networks under study
PID with the ALICE TOF

- **Time Of Flight detector** based on the MRPC technology (at 3.7 m, $|\eta| < 0.9$ and full $\phi$)
- Intrinsic (overall – no StartTime, no tracking) resolution of $40(90-80)$ ps (pp-PbPb)
- Excellent charged hadron PID performance in separating $\pi/K$ and $K/p$ over a wide momentum region in the intermediate range
- Mass determined from the measured time and momentum
  - Start time of the event provided by either the ALICET0 detector, or/and from an offline TOF algorithm
PID with the ALICE TOF

- **Time Of Flight detector** based on the MRPC technology (at 3.7 m, |η| < 0.9 and full φ)
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- Mass determined from the measured time and momentum
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![Graph showing TOF (Pb-Pb) 2.76 TeV, min. bias](image)
ALICE Single-Arm Detectors
PID with the ALICE HMPID

- Single-arm proximity focusing RICH (at 4.7 m, $|\eta| < 0.6$, $1.2^\circ < \phi < 58.8^\circ$)
- Hadron ID at higher momenta, $1<p_t<3$ GeV/c for $\pi$ and $K$, $1<p_t<5$ GeV/c for $p$
- Mass determined deducing $\beta$ measured from the Cherenkov angle and the momentum from TPC
- Track-to-track $\pi/K$ ($K/p$) separation up to $p_t \sim 3$ (5) GeV/c
The ALICE Calorimeters

- **PHOS**
  - Homogeneous EM calorimeter (at 4.6 m, |η| < 0.13, 260° < φ < 320°)
  - γ identification in 0 < E < 100 GeV
  - Energy resolution

- **EMCAL**
  - Sampling EM calorimeter (at 4.50 m, |η| < 0.7, 80° < φ < 180°)
  - γ identification in 0 < E < 250 GeV
  - Energy resolution
Hadron rejection for e-ID using the E/\rho distribution

- Electrons lose all their energy in the calorimeter, and have a small mass \( \Rightarrow E/\rho \sim 1 \)
The ALICE PMD

- In the forward region $2.3 < \eta < 3.7$, where the multiplicity density is too high, calorimetry cannot be used.
- The PMD uses the “preshower” method:
  - Converter (1.5 cm thick lead, 3 $X_0$) sandwiched between two planes of high granularity gas proportional counters
    - 1st plane $\rightarrow$ CPV
    - 2nd plane $\rightarrow$ shower for photon identification

![Graph]

- $\chi^2 / ndf = 1.615 / 54$
- Prob = 1
- $k_1 = 1.16 \pm 0.1497$
- $m_1 = 5.3 \pm 1.455$
- $k_2 = 4.23 \pm 1.19$
- $m_2 = 14.38 \pm 1.914$
- $w = 0.272 \pm 0.159$
- Constant $= 0.9964 \pm 0.03355$

**pp at $\sqrt{s_{NN}} = 7$ TeV**

Process INEL

$2.3 < \eta < 3.9$

Statistical and systematic uncertainties

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The ALICE MUON Spectrometer

- MUON Spectrometer in a dipole magnetic field (3 Tm) at -4 < \( \eta \) < -2.5
- Front absorber + tracking and triggering chambers + iron wall
- \( \mu \) identification for \( p > 4 \) GeV/c
- Hadron rejection making use of the iron wall + triggering chambers
Topological PID
Topological PID

- ALICE can exploit its excellent tracking and secondary vertex reconstruction to identify cascades, V0 and kinks.

\[ \Xi \rightarrow \Lambda \pi \rightarrow \pi p \pi \]
A few Physics Results with PID
Femtoscopy

- To measure the size and the shape of the source
  - TPC ($\pi$), TPC+TOF (charged K), Topological PID ($K_0$)

**Graphs:**

- ALICE pp @ 7 TeV
  - $\pi^+\pi^-\pi^+$: $k_T (0.2, 0.3)$
  - $\pi^+\pi^-\pi^-$: $k_T (0.4, 0.5)$

- ALICE pp @ 2.76 TeV
  - $\pi^+\pi^-\pi^+$: $k_T (0.2, 0.3)$
  - $\pi^+\pi^-\pi^-$: $k_T (0.4, 0.5)$

- ALICE pp @ 0.9 GeV
  - $\pi^+\pi^-\pi^+$: $k_T (0.2, 0.3)$
  - $\pi^+\pi^-\pi^-$: $k_T (0.4, 0.5)$

**Plots:**

- $R_{out}$ vs. $<dN_{ch}/d\eta>^{1/3}$
- $R_{side}$ vs. $<dN_{ch}/d\eta>^{1/3}$
- $R_{long}$ vs. $<dN_{ch}/d\eta>^{1/3}$
- $R_{inv}$ vs. $k_t$ (GeV/c)

**References:**

- Phys. Rev. D 84, 112004 (2011) for 0.9 and 7 TeV
Identified Particle Spectra

- Combination of different PID techniques in different $p_t$ regions
  - ITS, TPC, TOF
    - HMPID ongoing
  - $n-\sigma$ cut + unfolding
  - Extend $p_t$ coverage

![Graphs showing particle spectra](image)

**PP at $\sqrt{s} = 7$ TeV**

- Normalization Error 8.3%

**ALICE preliminary**

- MC/data comparison for $\pi^-$ and $K^+$

C. Zampolli - ALICE
Identified Particle Spectra

- Combination of different PID techniques in different $p_t$ regions
  - ITS, TPC, TOF
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  - Extend $p_t$ coverage

![Graph showing identified particle spectra](image)

**π^− + π^+**

ALICE Preliminary

$\sqrt{s_{NN}} = 2.76$ TeV

$0-5\%$ Pb-Pb

$20-40\%$ Pb-Pb

$40-60\%$ Pb-Pb

$60-80\%$ Pb-Pb

Normalization Error 8.3%
Open charm/beauty + quarkonia
- TPC, TOF, TRD, EMCAL, MUON
- PID fundamental to improve significance

Same analysis in pp and PbPb
Heavy Flavour

- Open charm/beauty + quarkonia
  - TPC, TOF, TRD, EMCAL, MUON
  - PID fundamental to improve significance

arXiv:1203.2160v2
Heavy Flavour

- Open charm/beauty + quarkonia
  - TPC, TOF, TRD, EMCAL, MUON
  - PID fundamental to improve significance

arXiv:1205.5423
Conclusions

- ALICE is endowed with powerful PID detectors...
  - ...covering different momentum ranges...
  - ...using all known PID techniques...
  - ...with high-level technology implementation

- The excellent ALICE PID performance makes it unique among the four main LHC experiments
  - It is an essential tool in exploring the hot dense medium created in HI collisions...
  - ...and to investigate pp collisions
    - as a fundamental reference for PbPb
    - per se
    - for MC tuning
“so many out-of-the-way things had happened lately, that Alice had begun to think that very few things indeed were really impossible.”

L. Carrol, Alice’s Adventures In Wonderland
Backup
ALICE Configuration

3/5 PHOS
13/18 TRD
18/18 TOF
7/7 HMPID
12/12 EMCAL

As in 2012
The ALICE ITS

- The Inner Tracking System
  - At $|\eta| < 0.9$
  - Six layers, three technologies:
    - $2 \times$ Silicon Pixel (SPD) – 3.9/7.6 cm
    - $2 \times$ Silicon Drift (SDD) – 15/23.9 cm
    - $2 \times$ Silicon Strip (SSD) – 38/43.0 cm
  - Primary and secondary vertex reconstruction
  - Tracking + standalone reconstruction (very low momentum tracks + high momentum tracks falling in TPC dead zones)
  - PID via $dE/dx$ from SDD and SSD analog read-out
    - In the low $p_T$ region, down to 100 MeV for $\pi$ standalone tracking
The ALICE TRD

- 6 layer Transition Radiation Detector, with 5 longitudinal stacks
  - $|\eta| < 0.9$ and full $\phi$
  - Fast trigger for high-$p_T$ particles
  - Electron ID in the momentum range $1 < p < 10$ GeV/c, with pion rejection factor $\sim 100$
  - Momentum reconstruction for $p_T \sim$ few tens GeV/c
The ALICE TOF

- **Time Of Flight detector** based on the MRPC technology

- At 3.7 m from the interaction point
- $|\eta| < 0.9$ and full $\phi$
- Intrinsic resolution of 40 ps
- Overall resolution of ~100 (90) ps in pp (PbPb) collisions
- Dedicated to **charged hadron Identification** in the intermediate momentum region

Diagram details:
- **Readout pads** $3.5 \times 2.5 \text{ cm}^2$
- **2x5 gas gaps** of **250 $\mu$m**

C. Zampolli - ALICE  PLHC, 4 June 2012, Vancouver
- **Excellent performance in separating π/K and K/p over a wide momentum region**
- **Mass determined from the measured time and momentum**
  - T0 of the event provided by either the ALICE T0 detector, or from an offline TOF algorithm
**The ALICE HMPID**

- Single-arm proximity focus RICH
  - 7 modules at 4.7 m, active area of 11 m²
  - $|\eta| < 0.6, 1.2^\circ < \phi < 58.8^\circ$ coverage
  - 15 mm layer of $C_6F_{14}$ liquid radiator ($n = 1.2989$ @ $\lambda = 175$ nm, $p_{th} = 1.21$ m (GeV/c, $m =$ mass))
  - CsI thin films deposited onto a cathode plane of MWPC ($O(10^5)$ readout channels)
  - Hadron ID @ high momenta, $1< p_T < 3$ GeV/c for $\pi$ and $K$, $1< p_T < 5$ GeV/c for $p$
The ALICE EMCAL

- **EMCAL**
  - Sampling EM calorimeter
  - 10 modules with 1152 towers of 77 layers of lead + scintillator each
  - At 4.50 cm from interaction point
  - $|\eta| < 0.7$, $80^\circ < \phi < 180^\circ$ coverage
  - $\gamma$ identification in $0 < E < 250$ GeV
  - Energy resolution

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ALICE performance

pp @ $\sqrt{s}=7$ TeV

EMCAL

16/05/2011
ALICE can exploit its excellent tracking and secondary vertex reconstruction to identify cascades, V0 and kinks.

- Using decay angle, $Q_t$ cut, $M_{inv}$
Elliptic Flow

- Anisotropic distribution of matter in the overlap region leads to anisotropies in the observed final particle spectra → **elliptic flow**

- It’s magnitude depends on the initial conditions, the EOS, and the system lifetime
  - TPC, TOF

![Graph showing ALICE preliminary, Pb-Pb events at $\sqrt{s_{NN}} = 2.76$ TeV centrality 10%-20%](graph.png)