Identified charged hadron production in Pb-Pb collisions at the LHC with the ALICE experiment

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On behalf of the ALICE Collaboration
Outline

- **PID in ALICE: detectors and techniques**
  ‣ some details on Particle Identification (PID) in ALICE

- **Identified particle spectra in central (0-5%) Pb-Pb collisions**
  ‣ \(\pi, K, p\) spectra in central (0-5%) Pb-Pb collision at \(\sqrt{s} = 2.76\) TeV
  ‣ comparison with different models and RHIC data

- **p_T-spectra as a function of event-by-event flow**
  ‣ flow vector definition
  ‣ jet contamination estimation
  ‣ spectra modification in events with high elliptic flow (30-40% centrality)

- **Thermal production of hadrons in central (0-20%) Pb-Pb collisions**
  ‣ comparison with RHIC and thermal model prediction
  ‣ thermal fit to integrated particle yields in ALICE

- **Summary**
PID in ALICE: detectors and techniques
Detector description


Detector components: ZDC, EMCAL, HMPID, TRD, PMD, V0, TPC, TOF, ITS, PHOS, Dipole magnet, Absorber, Tracking chambers, Muon filter, Trigger chambers.
Detector description

In this analysis:
- **Inner Tracking System (ITS)**
  - standalone tracker, extends low-$p_T$ reach
  - energy loss in the silicon
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  - VZERO C (-3.7<\(\eta\)<-1.7)
  - trigger, centrality selection, event plane calculation
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PID Analyses

Secondary subtraction
DCA fit*

\[ \text{counts} \]

\[ \text{pp @ } \sqrt{s} = 7 \text{ TeV} \]

\[ \pi^+ + \pi^- \]

\[ 1/\langle N_{xy}\rangle = (\text{GeV}/c)^{-2} \]

-3 -2 -1 0 1 2 3
dca

Identified particle spectra in central (0-5%) Pb-Pb collisions
Central (0-5%) Pb-Pb collisions

- Small extrapolation at low $p_T$
- Large radial flow
($<\beta_T> = 0.65 \pm 0.02 \sim 10\%$ higher w.r.t. RHIC)

Model comparison:
- **VISH2+1** (Viscous hydro)
- **HKM** (Hydro+ UrQMD)
- **Krakow** (viscous corrections that lower the effective $T_{ch}$)

Data/Model

Central (0-5%) Pb-Pb collisions

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**Hydro (with refined late fireball description) works at the LHC.**

\[\frac{d^2N}{dp_T^2} \times \frac{dN}{dy} = \text{constant} \]

\[\pi^+ + \pi^- (\times 100)\]

\[K^+ + K^- (\times 10)\]

\[p + \bar{p} (\times 1)\]

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- **MUSIC** (EbyE, 3+1D Hydro, UrQMD): 100 events

Hydro (with refined late fireball description) works at the LHC.

$p_T$-spectra as a function of event-by-event flow

...to further investigate the hydro behavior of $p_T$-spectra...
Flow vector definition:

\[ Q_{n,x} = \sum_i w_i \cos(n\phi_i), \]
\[ Q_{n,y} = \sum_i w_i \sin(n\phi_i), \]

- \( i = \) channels of VZERO detector
- \( w_i = \) multiplicity of channel \( i \)
- \( \Phi_i = \) angle of channel \( i \)

Flow vector is a powerful tool to select events with different \( v_2 \)

see Sergey Voloshin (13 August)
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large rapidity gap

centrality selected: 30-40%
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- Flow vector is a powerful tool to select events with different \( v_2 \)

- Integrated elliptic flow at the LHC is \( \sim 30\% \) larger w.r.t. RHIC*
- Event-by-event this increase can be much larger

- If we integrate \( \cos(2\Phi) \) in \( 2\pi \) we do not expect any modification of the \( p_T \)-spectrum
- We look at \( q_2 \) distribution: \( Q_2/\sqrt{\text{multiplicity}} \)

Flow vector distribution

\[ q_2 = \frac{Q_2}{\sqrt{\text{multiplicity}}} \]

We want to select the 10% highest (lowest) elliptic flow events

Keep potential biases under control:

- **multiplicity bias**
  - \( v_2 \) increases with decreasing centrality*

- **jet contribution**
  - Is the large \( q_2 \) due to an increased jet contribution?


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Quark Matter 2012
Checks on potential biases

- *Multiplicity bias*
- Centrality from tracks in the central barrel instead of VZERO
- Bin 30-40% obtained as the sum of 10 bins 1% wide

*shift negligible*
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- Multiplicity bias
  - centrality from tracks in the central barrel instead of VZERO
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- Jet contribution:

**Background:**

\[ p_{T\_tot} = \text{total } p_T \text{ in the event} \]
\[ \text{density} = \frac{p_{T\_tot}}{\text{acceptance}} \]

**Energy in a cone:**

- seed particle: \( p_T > 5 \text{GeV/c} \)
- \( p_{T\_sum} = \text{sum of } p_T \text{ in } R < 0.3 \)
- \( \text{area} = \pi \times R^2 \)
- \( p_{T\_jet} = p_{T\_sum} - \text{density} \times \text{area} \)
Checks on potential biases

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- \( p_{T_{jet}} = p_{T_{sum}} - \text{density} \times \text{area} \)

- method reliable only above \(~20 \text{ GeV/c}\)
- ratio is flat, “jet” contribution similar

![Cone Algorithm, Raw](image)

\( \text{charged raw jet } p_T \text{ (GeV/c)} \)
- Ratio of raw spectra, efficiency does not depend on $q_2$ selection

- Modification of the $p_T$-spectrum: large $q_2 \Rightarrow$ harder spectrum, opposite for small $q_2$

- Vanishing at high $p_T$: not due to jet contribution

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**$p_T$-spectra vs E-by-E flow**

- **Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV**
- Centrality 30-40%

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- **No $q_2$-selection**
- **10% highest $q_2$**
- **10% lowest $q_2$**

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**$p_T$ (GeV/c)**

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**$\eta$**

- **VZERO-C**
- **central barrel**
- **VZERO-A**

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**spectra**

**q-vector**
**p_T-spectra vs E-by-E flow**

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- Same effect for all the particles
- Hint of mass ordering?

Are $v_2$ and radial flow correlated?
Thermal production of hadrons
- Feed down correction: $p_{\text{STAR}}$ (-37%) $\pi_{\text{PHENIX}}$ (-10%)
- Decreasing ratios at the LHC?
- $p/\pi$ and $\Lambda/\pi$ different at the LHC
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Integrated yields at midrapidity:
- data are feed down corrected,
- $\phi$ and $K^{*0}$ not included in the fit

$T_{\text{ch}} = 152$ MeV from fit to LHC $dN/dy$

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- Possible extension*:
  - Hadronic interactions

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- Thermal production of hadrons
  - Particle ratios consistent with RHIC except for $p/\pi$ and $\Lambda/\pi$
  - Studies ongoing... improvement from experiments + feedback from theory
THANKS
- $\mu_B$ vanishing at the LHC
- $K/\pi$ similar to RHIC, in agreement with thermal model prediction
- $p/\pi$ below the expectations, same behavior observed in hydro model without explicit description of hadronic phase

Particle ratios

Data: ALICE, 0-20% (preliminary)
Thermal model
Best fit, $T=152$ MeV
Prediction, $T=164$ MeV
$\sqrt{s_{NN}}=2.76$ TeV

$\pi^+$

$K^+$

$K^-$

$p$

$\bar{p}$

$\Lambda$

$\Xi^-$

$\Xi^+$

$\Omega^-$

$\Omega^+$

$\phi$

$K^*$

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$v_2(p_T)$: SE (q$_2$ VZERO-A) vs unbiased

Cutting on q$_2$ from VZERO-A (2.8<$\eta$<5.1) and correlate tracks from TPC (-0.8<$\eta$<0.8) with EP from VZERO-C (-3.7<$\eta$<-1.7)

Cutting on q$_2$ from VZERO-C also investigated (see backup)

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events

- Non-flow contributions significantly reduced using $\eta$ gap
- Smaller ratios due to smaller flow and multiplicity → method sensitivity to the event shape
- $v_2 \sim$ shape (ratio almost constant) at least up to $p_T$=6 GeV/c
- Effect of event shape fluctuations becomes small for $p_T$>6 GeV/c

5% high q$_2$
10% low q$_2$
No q$_2$ selection