Measurement of hadron composition in charged jets from pp collisions with the ALICE experiment

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Motivation

- Jets are phenomenological objects constructed to represent partons originating from hard scattering processes.

- Inclusive charged jet fragmentation in pp collisions measured by ALICE

  \[ p_T^{\text{jet}} > 20 \text{ GeV}/c, \text{jet } p_T \text{ scaling for } z = \frac{p_T^{\text{track}}}{p_T^{\text{jet}}} > 0.1 \ (\xi = -\log z < 2.3) \]
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- Jets are phenomenological objects constructed to represent partons originating from hard scattering processes.

- Inclusive charged jet fragmentation in pp collisions measured by ALICE

  $\rightarrow$ Above $p_{T}^{\text{jet}}$ 20 GeV/c, jet $p_{T}$ scaling for $z=p_{T}^{\text{track}}/p_{T}^{\text{jet}}>0.1$ ($\xi = -\log z < 2.3$)
Motivation

- Identified particle spectra in pp and Pb-Pb collisions measured by ALICE
  → large $p/\pi$ in intermediate $p_T$

- ALICE Particle IDentification capability allows to identify particle types in jets
  → first measurement of particle type dependent jet fragmentation at hadron colliders
  → unique measurement to provide constraint on fragmentation models
  → baseline technique for PID in jets from Pb-Pb collisions

ALICE PREL-67047

\[ \text{ALICE} \]

$S_{NN} = 2.76 \text{ TeV}$

- 0-5\% Pb-Pb
- 60-80\% Pb-Pb
- pp

$p_T < 3 \text{ GeV}/c$
- pp, preliminary
- Pb-Pb, PRC88, 044910 (2013)
- $p_T > 3 \text{ GeV}/c$
- arXiv:1401.1250

\[
\frac{p+\bar{p}}{(\pi^+ + \pi^-)}
\]

$p_T (\text{GeV}/c)$

20-May-2014

X.-G. Lu, U. Heidelberg
The ALICE Experiment

ALICE: A Large Ion Collider Experiment

- High multiplicity environment
  - High granularity
- Very low $p_T$ cut-off ~ 100 MeV/c
  - Very low material budget ~10%$X_0$
- Moderate B-field 0.5 T
- PID: large momentum range
  - $dE/dx$, Transition Radiation, TOF, Cherenkov ...

For π/K/p yields in charged jets from pp collision at 7 TeV:
- FastJet anti-$k_T$ with $R=0.4$
- $p_T^{\text{jet}}$ 5-10, 10-15, 15-20 GeV/c
- Advanced statistical PID methods (next slides):
  - TPC Coherent Fit
  - TPC Multi-Template Fit

http://www.jamin86.com/cern/
PID in jets – TPC Coherent Fit

- Most abundant particle types: $\pi$, K, p, e
- Gaussian signal shape ($dE/dx$ truncated mean)
- Continuous signal mean and width $\rightarrow$ models
- Continuous particle fractions
  - Allowing only statistical deviation from neighbor interpolation

Likelihood function built from signal models and fractions – **Coherence**: full-range constraint on $dE/dx$ model

Regularization on continuity condition of particle fractions: maximal use of information

Maximum likelihood estimation

$$l = l_{\text{stat}} + l_{\text{reg}}$$

1 distribution
1 regularized likelihood function
1 optimization
Calibration of TPC signal
Particle yield extraction

Feedback

http://archiv.ub.uni-heidelberg.de/volltextserver/15651/
Particle fraction at high $p_T (>4 \text{ GeV}/c)$ very sensitive to $dE/dx$ mean

- 5% $dE/dx$ K-p separation
  - 1 per mil $dE/dx$ bias
    - $0.1\%/5\% = 2\%$ fraction bias

Major systematics on PID in jets

- TPC $dE/dx$ model uncertainty
- Change of TPC $dE/dx$ quality
- Particle type dependence of $dE/dx$
  - Negligible: $-0.1\% \pm 0.3\%$
  - $Jet p_T$ dependence of $dE/dx$
    - Critical: $0.3\%$ $dE/dx$ increase per 5 GeV/c $p_T^{jet}$ increase due to enhanced track density
    - *Automatically taken into account*
TPC Multi-template Fit
(Poster: Benjamin Andreas HESS, 20/5 14:30)

- Model TPC dE/dx response in detail (function of number of ionization clusters, track phase space, etc.) with pure particle samples selected via
  - TPC dE/dx, TOF and V0 daughters (K^0/s/ Λ decays, γ conversions)
- High \( p_T \) dE/dx determined by dE/dx model fit to clean samples
- Generate TPC dE/dx templates for a given track sample and for each particle species with parametrized yield fractions - done directly in \( z \) bins
- Minimize template-data difference

Two independent methods with different systematics give consistent results.

3 orders of mag.

![Graph showing data and fits for different particle species](ALI-PREL-70018)

![Graph showing data and fits for different particle species](ALI-PREL-68942)
The following results are shown for the first time in conferences.
Jet constituent spectra – all charged particles

disappearance of scaling at lowest jet $p_T$

description improves with jet and particle $p_T$
π/K/p yields in charged jets from pp collisions at 7 TeV

PID up to $p_T = 20$ GeV/c

- $p_T$ dependence
  - Span 3-4 orders of mag.
  - Harder spectra at high jet $p_T$
  - Crossing at $p_T^{track} \approx 0.4 \pm 0.2$ GeV/c for π (K,p)
- ln(N) parabolic in ln($p_T$)
  - $\xi$-spectra Gaussian shape

- $z$ dependence
  - Span 1-2 orders of mag.
  - Jet $p_T$ ordering opposite
  - Crossing at $z \approx 0.3-0.4$
  - Exponential especially for light hadron

$\rightarrow$ disappearance of scaling at lowest jet $p_T$
**K/π and p/π in charged jets from pp collisions at 7 TeV**

No scaling with particle $p_T$ observed

- **Scaling at $z>0.2$**
  - Kaon 5-10, 10-15, 15-20 GeV/c jet
  - Proton 10-15, 15-20 GeV/c jet

Monotonic increase to 0.5-0.6

Strangeness fraction increases with $z$

Maximum 0.15-0.2 at $z$ 0.5-0.6

$z \to 1$: Leading baryons suppressed
Comparison of $\pi/K/p$ $p_T$ spectra with PYTHIA

PYTHIA describes data to first order
Largest deviation at lowest $p_T$ jet (5-10 GeV/c) and particle $p_T$

Low $p_T$ PYTHIA undershoots pions, consistent with kaons but overshoots protons.

Better agreement at high jet $p_T$ and particle $p_T$

PYTHIA reproduces the proton maximum, but fails to describe the width and high $p_T$ slope
Comparison of $K/\pi$ and $p/\pi$ $p_T$ with PYTHIA

- Kaons favor *PerugiaNoCR* (tune ID 324: no color reconnection, re-tuned to pre-LHC data)
  - strangeness fraction increases with $z$ and leading baryon suppression at high $z$
  - **trends described by PYTHIA**
Summary

First measurement of identified jet fragmentation at hadron colliders

- Particle yields and ratios as functions of $p_T$, $z$ of primary hadrons ($\pi/K/p$) in jets of $p_T$ 5-20 GeV/c with advanced PID techniques
- Disappearance of scaling at lowest jet $p_T$
- Strangeness fraction increases with $z$ and leading baryon suppression at high $z$
  - trends described by PYTHIA
- Compared to PYTHIA, challenges:
  - low jet $p_T$
  - pions and protons at low particle $p_T$

Poster: Benjamin Andreas HESS, 20/5/2014 14:30 – 18:30
Particle identification techniques for measuring the hadron composition in charged jets from pp collisions with the ALICE experiment

Talk: Xiaoming ZHANG, 20/5/2014 15:20 – 15:40
Production of strange particles in charged jets and underlying event in p–Pb collisions with ALICE
Analysis details

- $\pi/K/p$ yields in charged jets from pp collision at 7 TeV
  - 200M minimum bias events
  - FastJet anti-$k_T$ with $R=0.4$, $|\eta^{\text{jet}}| < 0.5$, $|\eta^{\text{track}}| < 0.9$
  - $p_T^{\text{jet}}$ 5-10, 10-15, 15-20 GeV/c, $p_T^{\text{track}} > 0.15$ GeV/c
  - Corrected to the particle level
Weighted mean

\[ f_k(u) = \frac{\sum_i N_k(p_i; u)}{\sum_j N_{all}(p_j; u)}, \quad u = p_T, z, \]

\[ = \frac{\sum_i N_{all}(p_i; u) f_k(p_i; u)}{\sum_j N_{all}(p_j; u)} \]

\[ = \sum_i w(p_i; u) f_k(p_i; u) \]

\[ \Re \sum_i w(p_i; u) f_k(p_i), \]
TPC Coherent Fit – coherence and regularization

Incoherent fit: individual fit in each momentum bin

Coherence:
- Global constraint to $dE/dx$ model
- $dE/dx$ model constraint fed back to fraction constraint

Regularization:
- Maximal use of information – continuity condition

http://archiv.ub.uni-heidelberg.de/volltextserver/15651/
- Model TPC $dE/dx$ response in detail:
  momentum $p$, mass, pseudorapidity $\eta$, $dE/dx$, $N_{PID\, cluster}$, shape asymmetry

- Determine response from pure track samples selected via
  → TPC $dE/dx$, \textit{Time of flight (TOF)}
  → \textit{track topology ($K_0^/$, $\Lambda$ decays, $\gamma$ conversions)}
- Binned log-likelihood fit:
  Minimize difference between measured $dE/dx$ distribution and template sum weighted by species fractions is
  → Fit parameters: Particle fractions as function of ($p_T$, track $p_T / z$)

- Regularisation:
  Ensure continuity of fractions versus $\ln(p_T) / z$

- Excellent description of data over 2-3 orders of magnitude

![Graph showing fit results](image-url)
PID in jets – TPC Multi-template Fit – Modelling the TPC $dE/dx$ Response

TPC $dE/dx$ of track depends on: momentum, mass, $\theta$, $dE/dx$, #PID clusters, shape asymmetry

Extract dependencies with data driven methods:
- Clean samples from TPC, TOF and V0's
- Fit $<dE/dx>$ ($\theta$ averaged) with Bethe-Bloch model
- Extract dependence on $\theta$ (vs. $1/<dE/dx>$)
- (Rel.) resolution map in ($\theta$, $1/<dE/dx>$)-bins as function of #PID cluster
- Parametrise asymmetric shape

Track parameters from sample of TPC tracks at given $p_T$ to generate templates for each species
**Goal**: Confirm method with MC
- Take same uncertainties as in data, vary templates
- Do not use any MC information for the fit => “blind” as in data
- Use PDG instead of pure samples to extract splines and maps (“semi-blind”)

- **MC truth reproduced** within typically 10%
- **Sys. errors confirmed**: follow size of deviations between truth and fit
PID in jets – TPC Multi-template Fit – Systematic Uncertainties: Raw Fractions

- Uncertainties of dEdx response change template shapes
- Propagate uncertainties to fractions by varying shape with systematic error and assigning sigma of resulting fractions as systematic error
- Sum up all error sources in quadrature

<table>
<thead>
<tr>
<th>Template input</th>
<th>Variations</th>
</tr>
</thead>
</table>
| Mean dE/dx (Splines)                  | ±0.2% for \( \beta \gamma \lesssim 50 \)
|                                       | +1.3% and −0.6% for \( \beta \gamma \gtrsim 50 \)                          |
| \( \sigma(dE/dx) \)                    | ±3% for \( dE/dx \lesssim 250 \)
|                                       | ±50% for \( dE/dx \gtrsim 250 \)                                           |
| \( \eta \)-dependence of mean dE/dx   | ±3% for \( p \lesssim 0.45 \text{ GeV/c} \)
|                                       | ±0.5% for \( p \gtrsim 0.45 \text{ GeV/c} \)                               |
| PID weighting                         | Default: Combined PID from ITS, TPC, TOF with default priors
|                                       | Flat                                                                       |
| Shape of detector response            | Default: Asymmetric shape
|                                       | Pure Gaussian                                                             |

- First 3 variations:
  - Global scaling with corresponding percentage
  - Uncertainties estimated from clean sample + dE/dx model comparison (high pT)
  - Note: Possible jet Pt dependence of splines as estimated by coherent fit covered by variations
Corrections

- Efficiency, acceptance and $p_T^{\text{jet}}$, $p_T^{\text{track}}$ resolution
- Secondary particle contamination
- Muon contamination (species cannot be separated with given $dE/dx$ resolution)

### Table 1

<table>
<thead>
<tr>
<th>jet $p_T$ (GeV/c)</th>
<th>5–10</th>
<th>10–15</th>
<th>15–20</th>
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<th>5–10</th>
<th>10–15</th>
<th>15–20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi$</td>
<td>1.8</td>
<td>1.8</td>
<td>2.4</td>
<td>$\pi$</td>
<td>1.9</td>
<td>1.5</td>
<td>1.7</td>
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<tr>
<td>$K$</td>
<td>8.5</td>
<td>8.6</td>
<td>13</td>
<td>$K$</td>
<td>8.8</td>
<td>5.8</td>
<td>8.5</td>
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<tr>
<td>$p$</td>
<td>12</td>
<td>12</td>
<td>16</td>
<td>$p$</td>
<td>13</td>
<td>11</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table 1**: Averaged systematic errors in % of raw particle yields as functions of $p_T$ (left) and $z$ (right).

### Table 2

<table>
<thead>
<tr>
<th>jet $p_T$ (GeV/c)</th>
<th>5–10</th>
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<tr>
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<td>10</td>
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<td>$K$</td>
<td>11</td>
<td>8.7</td>
<td>12</td>
</tr>
<tr>
<td>$p$</td>
<td>18</td>
<td>18</td>
<td>21</td>
<td>$p$</td>
<td>17</td>
<td>16</td>
<td>21</td>
</tr>
</tbody>
</table>

**Table 2**: Averaged systematic errors in % of corrected particle yields as functions of $p_T$ (left) and $z$ (right).
Model comparison – z spectra direct comparison

\begin{align*}
\frac{1}{N_{\text{jets}}} \frac{dN}{dz_{\text{ch}}} & \quad \pi^+\pi^- \\
\rho_{r,\text{jet}}^{ch} & \quad 5-10 \text{ GeV/c} \\
\text{pp } \sqrt{s} = 7 \text{ TeV} & \quad \text{ALICE Preliminary} \\
\frac{1}{N_{\text{jets}}} \frac{dN}{dz_{\text{ch}}} & \quad K^+K^- \\
\rho_{r,\text{jet}}^{ch} & \quad 10-15 \text{ GeV/c} \\
\frac{1}{N_{\text{jets}}} \frac{dN}{dz_{\text{ch}}} & \quad \rho_{r,\text{jet}}^{ch} 15-20 \text{ GeV/c} \\
\text{anti-}k_T; R=0.4; |\eta^{\text{jet}}|<0.5 & \quad \rho_T^{\text{track}}>0.15 \text{ GeV/c}; |\eta^{\text{track}}|<0.9 \\
\end{align*}
Model comparison – MC/Data z spectra

Largest deviation at 5-10 GeV/c jet low z
Better agreement at high jet $p_T$ and z

Kaons favor *PerugiaNoCR* (pre LHC tune, no color reconnection)

Models *reproduce the proton maximum and its position*,
but *fail to describe the width and high z slope*
Model comparison – $K/\pi$, $p/\pi$ direct comparison

![Graphs showing particle ratio for $K^+/K^-$ and $p/p$ comparisons across different $p_T$ bins.](image)

- Data and predictions from PYTHIA Perugia0, PYTHIA Perugia0NoCR, and PYTHIA Perugia2011.
- $pp$ at $s=7$ TeV, $\rho_{\text{track}} > 0.15$ GeV/c; $|\eta_{\text{track}}| < 0.9$.
Model comparison – \( K/\pi, p/\pi \) MC/Data

Consistency pattern similar to particle yields, especially for high jet \( p_T \) due to good consistency for pions.