Study of identified particles originating from quark and gluon jets in proton-proton collisions

Outline:
- Introduction
- Q/G contribution to individual spectra
- Particle spectra in different event shapes

PhD. studies in collab with

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**Introduction**

**Jets** are produced in hard scatterings of partons of colliding particles/ions. Emerging from the very early stages of collisions they are ideal to study.

Early stages of collisions Hadronisation processes Particle production

These questions can be addressed through the **study of fragmentation properties of quark and gluon jets** in different event shapes (2- and 3-jet events).
Quark and Gluon Jets

Quark and gluon jet carry different colour factors

\[
\frac{C_A}{C_F} = \frac{9}{4} = 2.25 (Q \to \infty)
\]

The colour factors are proportional to the probability a parton radiates soft gluon

Gluons branch more easily and are expected to form

Higher multiplicity jets
Broader jets
Jets with softer fragmentation function
Quark and Gluon Jets

Particle production differences:

- **Gluons**
  - Baryon production
- **Quarks**
  - Meson production

Higher multiplicity jets
Broader jets
Jets with softer fragmentation function
Experimentally, jets are observed as showers of high-momentum particles in the detectors.

To identify such showers, one uses various jet-finding algorithms:
- Cone
- KT
- Anti-κT

Event shape study:
- anisotropical/isotropical events
- Di-Jet/Multi-Jet events
Historical outlook

- First studies looking at properties of jets were conducted in $e^+e^-$ (LEP)
- Tevatron – pp @ 2 TeV

Qualitatively, differences were observed, however, asymptotic limit was not.
**Away side jet suppression**

→ Dramatic softening of jet fragmentation through rapid energy loss while traversing the medium – **soft gluon radiation**. Particle spectra are sensitive to such behaviour.
mid $p_T$ hadron yield enhanced
$\Rightarrow$ Coalescence of hard partons from jets with soft partons from medium


The observed ordering of $R_{AA}$ of identified hadrons is consistent with predictions from calculations including jet flavor conversion in the hot dense medium

Wei Liu, Che Ming Ko, Ben-Wei Zhang
Aim of our work:

- We are looking at identified particle production based on whether these are coming from quarks or gluons
- We compare collision energies (RHIC, CDF, LHC)
- Simulations – PYTHIA Tune P0

- **QCD processes:**
  - \(\text{QQ} (+G)\)
    - \(qq \rightarrow qq\)
    - \(q\bar{q} \rightarrow q\bar{q}\)
    - \(gg \rightarrow q\bar{q}\)
  - \(\text{GG} (+G)\)
    - \(q\bar{q} \rightarrow gg\)
    - \(gg \rightarrow gg\)
  - \(\text{QG} (+G)\)
    - \(qg \rightarrow qg\)

- Look at production w/o jet finding algorithm
- We distinguish between 2- and 3-jet events using the thrust variable
Identified particle spectra
• Higher collision energy
• QQ channel becomes suppressed
• GG becomes dominant

<table>
<thead>
<tr>
<th>√sNN [TeV]</th>
<th>QQ/Jet</th>
<th>GG/Jet</th>
<th>QG/Jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>27.3%</td>
<td>17.7%</td>
<td>55%</td>
</tr>
<tr>
<td>1.8</td>
<td>7.6%</td>
<td>49.7%</td>
<td>42.7%</td>
</tr>
<tr>
<td>7</td>
<td>5.3%</td>
<td>60%</td>
<td>34.7%</td>
</tr>
</tbody>
</table>
Particle ratios
Antiparticle/particle ratios
Antiparticle/particle ratios

\[ \text{Antiparticle/particle ratio drops} \]

\( \bar{u} \) and \( s \) suppressed w.r.t \( u \)

\( \Rightarrow \) towards higher \( p_T \)

QQ, QG:

[Graph showing data points and lines for various categories: QQ, GG, QQ, K/\bar{K}, and All channels, with annotations for the antiparticle/particle ratio dropping as \( p_T \) increases.]
Antiparticle/particle ratios

Gluon production dominates spectra, difference in quark production vanish

⇒ ratios levels at 1
p/π, p/K
p/π, p/K

- p/π, p/K ratios highest for GG channel (mid-pₜ)
- All production channels combined
- Follow QG channel
- Merging to GG value with collision energy

Which is consistent with GG channel contribution to individual hadron spectra:

GG channel mainly contributes to proton spectra
Going higher in pₜ the differences vanish
Different point worth mentioning:

Monday; J-P Revol – \( p/\pi \) ratio underestimated by PYTHIA when compared to data

7 TeV – Gluon domination – proton production enhance w.r.t to pions

? PYTHIA tunes parameters may lead to underestimation of proton production in the gluon channel when looking at the full event

The gluon contribution to the ratios changes to lower values with energy (0.3 - 0.25).

Ratio from all prod.channels on the other hand at ~ TeV energies stays the same (~ 0.25).

! Important to look at separate prod.channels for tuning purposes as well.
Jet algorithm implementation

7 TeV

Anti-kT algorithm (fastjet.fr)
R = 0.7

Separating jets from the surrounding event - ratio rises
Experimental study of Q/G jets

• Using variable cuts based on MC
  – Charged multiplicity (Herme's talk)
  – Average pT, radial energy distribution
  – All based on some prior assumptions in MC >> BIASED Q/G SELECTION

☆ Multi-jet events
  – Additional hard gluon radiation
  – Might provide cross-checks for selection based on MC
Event shapes

Event shape selection:

\[ T > 0.9 \quad \text{anisotropic (2-Jet like)} \]
\[ T < 0.9 \quad \text{isotropic (3-Jet like)} \]
Ratios for all production channels
3-Jet events – additional hard gluon radiation
Effect ~ 20-40 %
Effect stronger for pions
Selecting on QQ channel makes the effect bigger- up to 60 % for pions
3-Jet yield

\[ \frac{1}{\sigma_{\text{inel}}} \frac{d\sigma}{dp_T} = \frac{1}{N_{\text{trig}}} \frac{dN}{dp_T} \]

Ntrig: 700 M. Events
\( \sigma \) (inel): 69 mb

3-jet, \( p_T > 10 \) GeV/c \( \sim 10^5 \)

PYTHIA P0

Leading jet \( p_T \) in 3-Jet events

High pT at LHC 2010 Mexico
Summary

- The presented analysis is suitable to study fragmentation properties of quarks and gluons

Selection:

- $QQ$, $GG$, $QG$
- 2/3 Jet-like shape

Going to higher $\sqrt{s_{NN}}$

- Sample becomes gluon dominated
- differences between Antiparticle/particle production vanish

Additional gluon radiation

- baryon/meson ratio influenced