Identified Charged Hadron Production at High $p_T$
- in $\sqrt{s_{NN}} = 200$ GeV Au+Au Collisions at RHIC-PHENIX -

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for the PHENIX Collaboration
- Physics motivation
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- Comparison with models
- Summary
Physics motivation

Nuclear Modification Factor $R_{AA}$

High-$p_T$ suppression due to parton energy loss in the medium (jet quenching).

The suppression patterns depend on particle type. Protons are enhanced, while pions and kaons are suppressed.

$R_{AA} = \frac{Yield_{AA}}{\langle N_{binary} \rangle_{AA}} \over Yield_{pp}$
Physics motivation

Baryon Enhancement

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PRL 91, 172301 (2003)

- $p/\pi$ ratio $\sim 1$ for central Au+Au at intermediate $p_T$ (2-4 GeV/c).
- Larger than expected from fragmentation (measured in pp, $e^+e^-$).
- Baryon / Meson difference at intermediate $p_T$.
  (on $R_{AA}$ (nuclear modification factor), $v_2$ (elliptic flow) etc.)
Physics motivation

What is the origin of (anti-)proton enhancement at intermediate $p_T$?

Possible sources (medium effect):
- Strong radial flow
- Recombination
- Baryon junction

Transverse momentum spectra and particle ratios provide the most basic tool to investigate the mechanisms of hadron production.

To distinguish the different production mechanism for protons and pions at intermediate and higher $p_T$. 
PHENIX detector

- Central Arm Detectors (magnetic spectrometer)
- Event Characterization detectors

Aerogel Cherenkov Counter

Hadron Identification at High $p_T$
- $n = 1.0113$.
- Full installation in 2004.
- Proton separation from $\pi / K$ up to 8 GeV/c.

EMCal

TOF

Drift Chamber (momentum meas.)

Tracking detectors (PC1, PC2, PC3)

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Data analysis

- **High statistics** (440M events used)
- Charged Hadron PID:
  - TOF
  - Aerogel (for PID extension toward high $p_T$, Run4-)
- MC Simulations:
  - Acceptance, efficiency (occupancy) corrections
  - No feed-down correction

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**BG Subtraction**

Using residual bending in $\phi$ direction.

**Backgrounds:**
- random association
- electrons from photon conversion
- decayed products

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S/N~12  
3~4 GeV/c

S/N~5  
4~5 GeV/c

S/N~2  
5~6 GeV/c

S/N~1  
6~7 GeV/c

track matching residual (a.u.)
Results
$p_T$ spectra of (anti-)proton

$\frac{1}{2\pi p_T} d^2 N / dp_T dy$ [GeV$^{-2}$]

Identified with ACC

$p_T$ reach extended for (anti-)protons with fine centrality bins.
Precise measurement at high $p_T$ thanks to high statistics.

Identified with TOF
No significant centrality or $p_T$ dependence (up to 6 GeV/$c$).
\( \frac{p}{\pi} \) vs. \( p_T \)

\[ \frac{p}{\pi} \]

\[ \frac{p}{\pi} \]

\[ \frac{p}{\pi} \]

\[ \frac{p}{\pi} \]

\[ \frac{p}{\pi} \]

\[ \frac{p}{\pi} \]

- \( \frac{p}{\pi} \) (pbar/\( \pi \)) ratios seem to turn over at intermediate \( p_T \), and close to the value of fragmentation at higher \( p_T \).

- Indicating transition from soft to hard at intermediate \( p_T \).

* No feed-down correction.
$p/\pi$ vs. $p_T$ (centrality dep.)

- $p/\pi$ ratios look to have a peak at intermediate $p_T$ (2-4 GeV/c).
- Clear peak in central events than that in peripheral.

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- Centrality dependence seen in the magnitude.
- p/π ratio in peripheral lies slightly above the p+p ratio.

* No feed-down correction.
* p+p data (nucl-ex/0603010)
Proton $R_{CP}$

$$R_{CP} = \frac{\text{Yield}_{\text{Central}} / \langle N_{\text{binary}} \rangle_{\text{Central}}}{\text{Yield}_{\text{Peripheral}} / \langle N_{\text{binary}} \rangle_{\text{Peripheral}}}$$

- Proton $R_{CP}$ shows unity above 2 GeV/c.
- Peak structure at 2~3 GeV/c.
- Proton $R_{CP}$ seems to show decreasing above 3 GeV/c.
- Expected to merge to pion $R_{CP}$ at higher $p_T$.
- Need more statistics to look at high-$p_T$ points.
Collision system dep.
- Rapidly increasing with $p_T$ for 62 GeV.
- Weaker centrality dependences (62 GeV) than those of 200 GeV.
- Significant difference for $p$ and $p$bar at 62 GeV.
  (Indicating more baryon transport and less p-pbar pair production at 62 GeV than 200 GeV.)
- Observed a large $p, p\bar{p}$ contribution at intermediate $p_T$, as seen in 200 GeV data.
- $N_{\text{part}}$ dependences on particle ratios have similar trend as in Au+Au ($N_{\text{part}}$ scaling).

* No feed-down correction.
Comparison with models
Comparison with models

- Only look through several models (recombination, hydro+jet, ...).
- Novel mechanism of hadron production at intermediate $p_T$. 

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At intermediate $p_T$, recombination of partons may be a more efficient mechanism of hadron production than fragmentation.

Fries, R et al PRC 68 (2003) 044902
Greco, V et al PRL 90 (2003) 202302
Hwa, R et al PRC 70(2004) 024905
Scaling of elliptic flow

PHENIX Preliminary

Example of partonic degrees of freedom
Summary

- $p_T$ reach of PID (especially for $p$, $p\bar{p}$) extended with:
  - High statistics 200 GeV Au+Au data
  - New PID detector (Aerogel)

- **Results:**
  - $p\bar{p}/p$ ratio: No centrality or $p_T$ dependence
  - $p/\pi$ ratio: Indicating transition from soft to hard at intermediate $p_T$
  - $R_{CP}$ (Anti-)$p$ $R_{CP}$ shows decreasing above 3 GeV/c

- **Collision system dependence:**
  - Similar turnover curve on $p/\pi$ in 62 GeV Au+Au
  - $N_{part}$ scaling on particle ratios (Cu+Cu / Au+Au)

- **Comparison with models:**
  - Recombination models seem to be matched to the experimental data.

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Next

- Improve data analysis, reduce sys. errors for PID at high $p_T$
- Analyze Run5 $p+p$ (abundant) data to make $R_{AA}$ at higher $p_T$
- MRPC-TOF ($\sigma_{TOF}\sim100$ps) to be installed for PID upgrade