Multiplicity and rapidity dependence of strange hadron production in pp, pPb, and PbPb collisions at LHC energies

Hong Ni
Vanderbilt University
for the CMS Collaboration

Quark Matter conference, Kobe
28th September, 2015
Motivation

In smaller systems with high multiplicity:
- Similar ridge structure as in AA collisions
- Also related to collective flow?

PbPb 2.76 TeV

- Ridge-like structure
- Collective flow

pPb 5.02 TeV

CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{\text{trk}} \geq 110$

$1 < p_T < 3$ GeV/c

pp 7 TeV

CMS $N \geq 110$, $1.0\text{GeV/c} < p_T < 3.0\text{GeV/c}$

This analysis analyzes identified particle.
If it is collective flow, can we see mass effect?
Motivation

From Pb-going side to p-going side:

- In hydrodynamics, \( <p_T> \) gets smaller
  - Number of particles decreases

- Opposite trend in CGC (only) model.
  - Saturation momentum increases

With the large acceptance of CMS detector, what will we see in our result?
Data Sample

- **pp**
  - Data set: 2010 7 TeV
  - Event Selection:
    - Minimum bias trigger
    - High multiplicity triggers

- **pPb**
  - Data set: 2013 5.02 TeV
  - Event Selection:
    - Minimum bias trigger
    - High multiplicity triggers

- **PbPb (50-100% Centrality)**
  - Data set: 2011 2.76 TeV
  - Event Selection:
    - Minimum bias trigger

---

**Track multiplicity distribution for different triggers in pPb**

- MinBias
- HLT $N_{\text{trk}}^\text{online} > 100$
- HLT $N_{\text{trk}}^\text{online} > 130$
- HLT $N_{\text{trk}}^\text{online} > 160$
- HLT $N_{\text{trk}}^\text{online} > 190$
**V₀ and Ξ⁻ (Ξ⁻ + Ξ⁺) Reconstruction**

**Decay Channel:**

- \( \bar{K}_s \rightarrow \pi^+ \pi^- \)
- \( \Lambda^0 \rightarrow \pi^- \, \rho \)
- \( \Xi^- \rightarrow \Lambda^0 \, \pi^- \)

\( V^0 \) s are reconstructed via combining a pair of oppositely charged tracks.

\( \Xi^- \) candidates are reconstructed via combining \( \Lambda^0 \) candidate with an additional charged track with the proper sign.

**Candidates Selection:**

For \( V^0 \) s:
- Decay length significance
- \( \cos(\text{pointing angle}) \)
- 2D impact parameter significance of daughter tracks wrt PV

For \( \Xi^- \) Candidates:
- 3D impact parameter significance of daughter tracks wrt PV
- 3D separation significance between \( \Xi^- \) or \( \Lambda^0 \) vertex wrt PV
- 3D impact parameter significance of \( \Xi^- \) candidate wrt PV

**Diagram:**

- **Primary Vertex**
- **V₀ momentum direction**
- **Pointing Angle**
- **Connect PV and V₀ Vertex**
- **V₀ Vertex**
Invariant Mass Peaks

- **Signal Function**: Double Gaussian (with a common mean)
- **Background Function**:
  - quadratic function for $K_S^0$
  - $Aq^{3/2} + Bq^{1/2}$ for $\Lambda$, where $q = m - (M_\rho + M_\pi)$
  - $Aq^B$ for $\Xi$, where $q = m - (M_\Lambda + M_\pi)$

### Yield Extraction

1. Implement Signal Fitting Function
2. Obtain signal counts and statistical error from fitting parameters
Mid-rapidity Spectra

CMS Preliminary pp
\( \sqrt{s} = 7 \text{ TeV}, L_{int} = 6.2 \text{ pb}^{-1} \)

\( |y|_{CM} < 1.0 \)

\( \kappa_s^0 \) pp

\( \Lambda^+ \Lambda \)

\( \Xi^+ \Xi^- \)

CMS Preliminary pPb
\( \sqrt{s_{NN}} = 5.02 \text{ TeV}, L_{int} = 35 \text{ nb}^{-1} \)

\( |y|_{CM} < 1.0 \)

\( \kappa_s^0 \) pPb

\( \Lambda^+ \bar{\Lambda} \)

\( \Xi^+ \Xi^- \)

CMS Preliminary PbPb
\( \sqrt{s_{NN}} = 2.76 \text{ TeV}, L_{int} = 2.3 \mu b^{-1} \)

\( |y|_{CM} < 1.0 \)

\( \kappa_s^0 \) PbPb

\( \Lambda^+ \bar{\Lambda} \)

\( \Xi^+ \Xi^- \)
Mid-rapidity Spectra

Evolution of Spectra Shape:
1. Spectra become harder as multiplicity increases
2. Heavier particles have harder spectra
For all multiplicity classes
- $\Lambda / K_s$ ratio reaches a maximum and then declines at higher $p_T$
- Location of the maximum in $p_T$ increases with multiplicity

At low $p_T$ region
- In each system, at a given $p_T$, $\Lambda / K_s$ ratio is smaller in higher multiplicity events
- Difference between high and low multiplicity events is larger for smaller system
For all multiplicity classes
  - $\Xi/\Lambda$ ratio increases with $p_T$ and then reaches a plateau at around 3 GeV

At low $p_T$ region
  - Don’t expect a large difference between high and low multiplicity events, because of small mass difference
<KE_T> versus Multiplicity

\[ KE_T = m_T - m_0 = \sqrt{(p_T^2 + m_0^2)} - m_0 \]

- At the lowest multiplicity bin, <KE_T> for all particles are similar (m_T scaling)
- For all particles, <KE_T> increases as multiplicity increases
- For each system, <KE_T> of heavier particle species increases faster with multiplicity
  - In PbPb collisions, m_T-scaling breaking is the effect of radial flow.
- At similar multiplicities, larger separation for pp / pPb than PbPb
Simultaneous Blast Wave Fit

**Simultaneous fit for \( K_s \) and \( \Lambda \)**

- **\( T_{\text{kin}} \):** kinetic freeze-out temperature
- **\( \langle \beta_T \rangle \):** average radial flow velocity

Simultaneous Blast-wave model assumes:
- common \( T_{\text{kin}} \)
- common \( \langle \beta_T \rangle \)
  for all particle species

- Meaning of \( T_{\text{kin}} \) and \( \langle \beta_T \rangle \) are model-dependent
- Provide a qualitative comparison of the spectra shape among three systems

**Larger radial flow velocity for smaller system**

### Data Points

- **pp** \( \sqrt{s} = 7 \text{ TeV}, L_{\text{int}} = 6.2 \text{ pb}^{-1} \)
- **pPb** \( \sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}, L_{\text{int}} = 35 \text{ nb}^{-1} \)
- **PbPb** \( \sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}, L_{\text{int}} = 2.3 \text{ \mu b}^{-1} \)
pPb Spectra in Different Rapidity Range

CMS Preliminary pPb
\( \sqrt{s_{NN}} = 2.76 \text{ TeV}, L_{\text{int}} = 2.3 \mu \text{b}^{-1} \)

\( N_{\text{trk}} \) offline [0,35]

\( \Lambda+\bar{\Lambda} \) ranges:
- (2.4,-1.5) (-1)
- (1.5,-0.8) (-2)
- (0.8,0) (-2)
- (0.8,1.5) (+2)

\( N_{\text{trk}} \) offline [120,150]

\( \Lambda+\bar{\Lambda} \) ranges:
- (2.4,-1.5) (-1)
- (1.5,-0.8) (-2)
- (0.8,0) (-2)
- (0.8,1.5) (+2)

\( N_{\text{trk}} \) offline [220,260]

\( \Lambda+\bar{\Lambda} \) ranges:
- (2.4,-1.5) (-1)
- (1.5,-0.8) (-2)
- (0.8,0) (-2)
- (0.8,1.5) (+2)
Comparing $\Lambda / K_s$ ratio in Pb-going side and p-going side:

- For low multiplicity events, two ratios mostly overlap within systematic uncertainties.
- For high multiplicity events, ratio in Pb-going side is larger at higher $p_T$. 

CMS Preliminary pPb

$\sqrt{s_{NN}} = 5.02$ TeV, $L_{int} = 35$ nb$^{-1}$

- Pb going side ($-1.5 < y_{cm} < -0.8$)
- p going side ($0.8 < y_{cm} < 1.5$)
$\langle KE_T \rangle$ versus $y_{cm}$

CMS Preliminary pPb
$\sqrt{s_{NN}} = 5.02$ TeV, $L_{int} = 35$ nb$^{-1}$

$<KE_T>$ (GeV)

$K^0_S$

$\Lambda+\bar{\Lambda}$

$y_{cm}$
Comparing $<KЕ_T>$ in Pb-going side and p-going side:
- Asymmetry develops as event multiplicity increases (Pb-going side larger)
- Trend of asymmetry is more evident for heavier particle species

The trend of data is similar as hydrodynamic model predicted.
Summary

- $K_s$, $\Lambda$, and $\Xi$ spectra are measured in three systems with high precision.

- At similar multiplicities, particle ratios at low $p_T$ show a larger difference between high- and low-multiplicity events in smaller system.

- At similar multiplicities, “$m_T$-scaling” breaking is more significant for smaller system.

- $<KE_T>$ asymmetry develops as multiplicity increases, with a larger value at Pb-going side, especially for heavier particles.

See Poster #0214 by Zhoudunming(Kong) Tu.
Blast Wave Fit Quality

- Fit quality is good at high multiplicity events
- Fit quality is not so good at low multiplicity events
  (No “radial” flow effect)

Fitting Range:
$K_s(0.1 \text{ to } 1.5 \text{ GeV/c}), \Lambda(0.6 \text{ to } 3 \text{ GeV/c})$

CMS Preliminary pPb
$\sqrt{s_{NN}} = 5.02 \text{ TeV}, L_{\text{int}} = 35 \text{ nb}^{-1}$
$0 \leq N_{\text{offline}}^{\text{trk}} < 35$

$185 \leq N_{\text{offline}}^{\text{trk}} < 220$
Simultaneous Blast Wave Fit with PYTHIA8

CMS Preliminary

$|y_{cm}| < 1.0$

- **pp** $\sqrt{s} = 7$ TeV, $L_{int} = 6.2$ pb$^{-1}$
- **pPb** $\sqrt{s_{NN}} = 5.02$ TeV, $L_{int} = 35$ nb$^{-1}$
- **PbPb** $\sqrt{s_{NN}} = 2.76$ TeV, $L_{int} = 2.3$ µb$^{-1}$

$T_{kin}$ (GeV) vs. $<\beta_T>$

PYTHIA8, $\sqrt{s} = 7$ TeV (with CR)
PYTHIA8, $\sqrt{s} = 7$ TeV (no CR)