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# Simulation Study on the Splitting Effect of Transverse Mass Spectra in p+p Collisions at $\sqrt{S}=200$GeV Using PYTHIA *

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**Abstract** In proton-proton (p+p) collisions at $\sqrt{S}$=200GeV , it is found that the previously observed universal shape of transverse mass spectra of hadron production seems to break down into two species of baryons and mesons at higher transverse mass region. In order to understand the underlying physics mechanism, a Monte Carlo study is done using the PYTHIA event generator. The simulation results demonstrate that this difference exists not only within string fragmentation scheme but also within independent fragmentation scheme, and comes primarily from gluon jets within string fragmentation scheme at RHIC energy. The new introduced physics mechanisms in PYTHIA version6.3 indicate that the complicated string junction may contribute to this splitting effect between mesons and baryons.

**Key words** transverse mass spectrum, string fragmentation, independent fragmentation, multiple-parton interleaved interaction

## 1 Introduction

The interaction processes in p+p collisions can be roughly categorized into two dominating mechanisms, soft and hard processes. The soft process populates the low momentum region of the particle spectra (the underlying event), while the high momentum region is dominated by hard process described by fragmentation as in the leading order models[1]. Interesting enough in the transverse mass ($m_{\mathrm{T}}$) spectra, observed in p+p collisions at both ISR energies ($20 \leqslant \sqrt{S} \leqslant 63$GeV)[2, 3] and RHIC energy ($\sqrt{S}$=200GeV) as shown in Fig. 1[1], is that the change trend of mesons is distinctly different from that of baryons in the up $m_{\mathrm{T}}$ region. It is clearly seen from Fig. 1(a) that the $m_{\mathrm{T}}$ spectra of identified particles have similar shapes, but their yields are quite different. However, a set of scaling factors (summarized in Table 1) may be introduced to bring the spectra onto a single curve in low $m_{\mathrm{T}}$ region, ($\sim$1GeV/$c^2$) as in Fig. 1(b), but there exists a clear splitting effect in the region above $m_{\mathrm{T}} \approx 2\mathrm{GeV}/c^2$. The meson spectra appear to be higher than the baryon spectra with as much as an order of magnitude difference around 4.5GeV in $m_{\mathrm{T}}$[1] . In order to further understand the underlying physics and hadron production mechanism in these p+p collisions behind the scaling factors listed in Table 1, simulation study is performed at $\sqrt{S}$=200GeV using PYTHIA version6.3[4] and version6.2[5] respectively.

Table 1. A summary of scaling factors applied to the $m_{\mathrm{T}}$ spectra in Fig. 1(b).

| | $\pi$ | k | p | $\Lambda$ | $\Phi$ |
|---|---|---|---|---|---|
| scaling factor | 1.0 | 2.0 | 0.64 | 0.2 | 3.43 |

In section 2, $m_{\mathrm{T}}$ spectral shapes and the yields of identified hadron spectra from PYTHIA simulation are studied and the effect of different fragmentation

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schemes in the high $m_{\rm T}$ region is compared. In section 3, different result from PYTHIA v6.2 and v6.3, and the new physics mechanism indicated in v6.3 are discussed. Conclusion will be given in section 4.

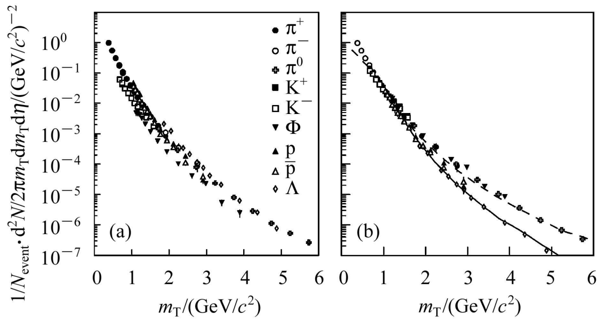


Fig. 1. Comparisons of (a) un-scaled and (b) scaled $m_{\rm T}$ spectra from p+p collisions in STAR and PHENIX at $\sqrt{S}$=200GeV. π, K, p spectra are from Ref. [6,7], while the PHENIX $\pi^0$ spectrum is from Ref. [8]. In the right plot, the superimposed dashed (real) line is the $\pi({\rm p}/\overline{\rm p})$ spectrum scaled by 0.4 (0.5) from simulation, which show the consistencies with experimental shapes of meson and baryon spectra respectively. (a) $m_{\rm T}$ spectra in mid-rapidity ($|y|<0.5$) for π, $K^{\pm}$, ρ, $p(\overline{p})$, Λ, Ξ. (b) $m_{\rm T}$ spectra in mid-rapidity ($|y|<0.5$)for π, $K^{\pm}$, ρ, $p(\overline{p})$, Λ, Ξ after scaling.

## 2 Simulation with different fragmentation scheme

The PYTHIA is commonly used for event generation in high-energy physics. It introduces several fragmentation mechanisms to describe the outgoing quarks and gluons: string fragmentation (SF) scheme, independent fragmentation (IF) scheme and some other fragmentation mechanisms. Both SF and IF mechanisms are used in this study. A comparison between simulation and experiment was made to ensure validity of the simulation. The superimposed dashed (solid) line in Fig. 1(b) are the scaled $m_{\rm T}$ spectra of pion (proton) from simulation of PYTHIA v6.3, which are consistent with what obtained from experiment, therefore the PYTHIA simulation is suitable in this $m_{\rm T}$-spectra shape study.

### 2.1 String fragmentation (SF)

Figure 2 shows the results of PYTHIA simulation within SF scheme according to the final state parton content. As we know, there are six modes in the hard process, which are (1) $q_iq_j\rightarrow q_iq_j$, (2) $q_i\overline{q}_i\rightarrow q_k\overline{q}_k$, (3) $q_i\overline{q}_i\rightarrow gg$, (4) $q_ig\rightarrow q_ig$, (5) $gg\rightarrow q_k\overline{q}_k$ and (6) $gg\rightarrow gg$. In Fig. 2(a) only the events from quark jets in the final states are chosen by setting parameters $MSEL$=0, $MSUB$=11,12,53, $MSTP(33)$=1, and $PARP(31)$=3 (namely $K$=3 instead of the default $K$=1.50 ), which is a common factor multiplying the differential cross section for hard parton-parton processes in the model and is expressed to the Next-to-Leading Order in PYTHIA. In Fig. 2(b) only the events from gluon jets in the final states are chosen by setting parameters $MSEL$=0, $MSUB$=13,68, and $K$=3. In Fig. 2(c) the events from both quarks and gluons in the final states are chosen by setting parameters $MSEL$=0, $MSUB$=28, $K$=3, while in Fig. 2(d) all the processes are contained by setting $MSEL$=1 (default). Particles selected in the simulation are $\pi^{\pm}$, $K^{\pm}$, $p(\overline{p})$, Λ and $\Xi^-$. All the particle yields are scaled to the pion's at the point of $m_{\rm T}=1.25{\rm GeV}/c^2$ using the same scaling method as in Ref. [1].

In Fig. 2(a), only a weak mass splitting in the high $m_{\rm T}$ region is observed, while in (b—d) more obvious splitting meson and baryon bands are seen, and the band of mesons is above that of baryons. This phenomenon could reflect the fact that the fragmentation process could endow more momentum to a produced meson than baryon as meson and baryon have different quark contents. The formation of a baryon requires the creation of a di-quark pair, which is suppressed by 10 comparing with that of a quark pair. The weaker splitting effect of (a) comparing with (c—d) demonstrates that the splitting effect is mainly attributed to gluon jets.

### 2.2 Independent fragmentation (IF)

Figure 3 shows the results of PYTHIA within IF scheme based on final state parton content. The same scaling method as above is used. Some parameters are changed as following: $MSTJ(1)$=2 (choice of IF scheme), $MSTJ(2)$=3 (a gluon is assumed to fragment like a pair of u, d or s quark and its anti-quark), $MSTJ(3)$=5 (only flavor is explicitly conserved).

The splitting also exists in the IF scheme, but a bit different from that in the SF scheme. The splitting

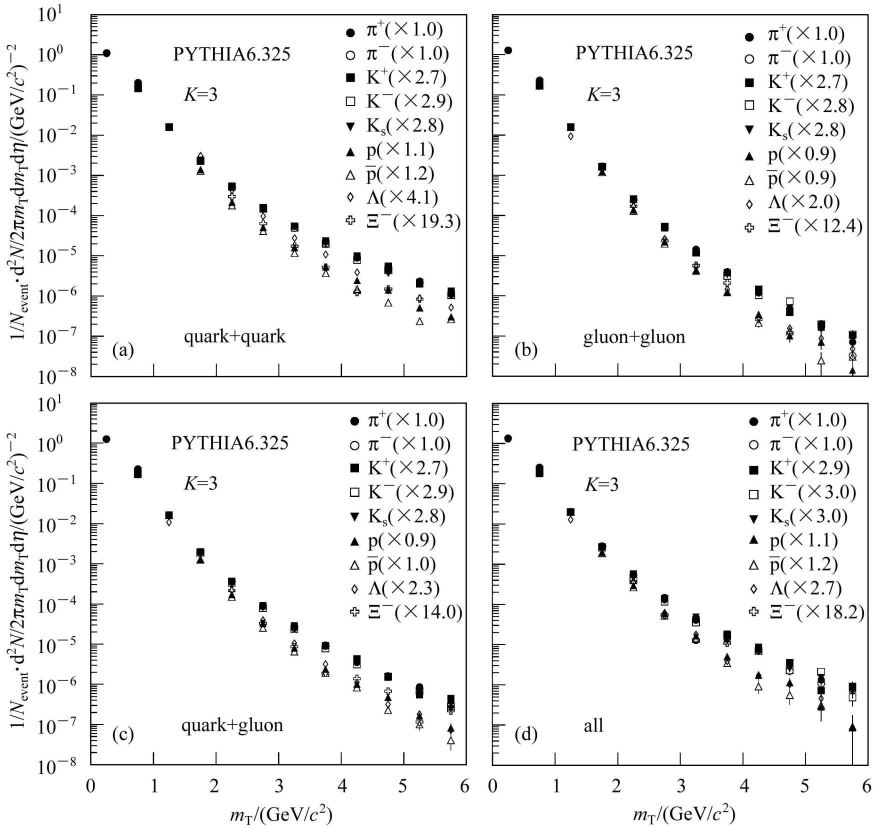


Fig. 2. $m_{\mathrm{T}}$ spectra from PYTHIA v6.3 with SF scheme & $K$=3 scaled at 1.25GeV/$c^2$ for the final states of different parton.

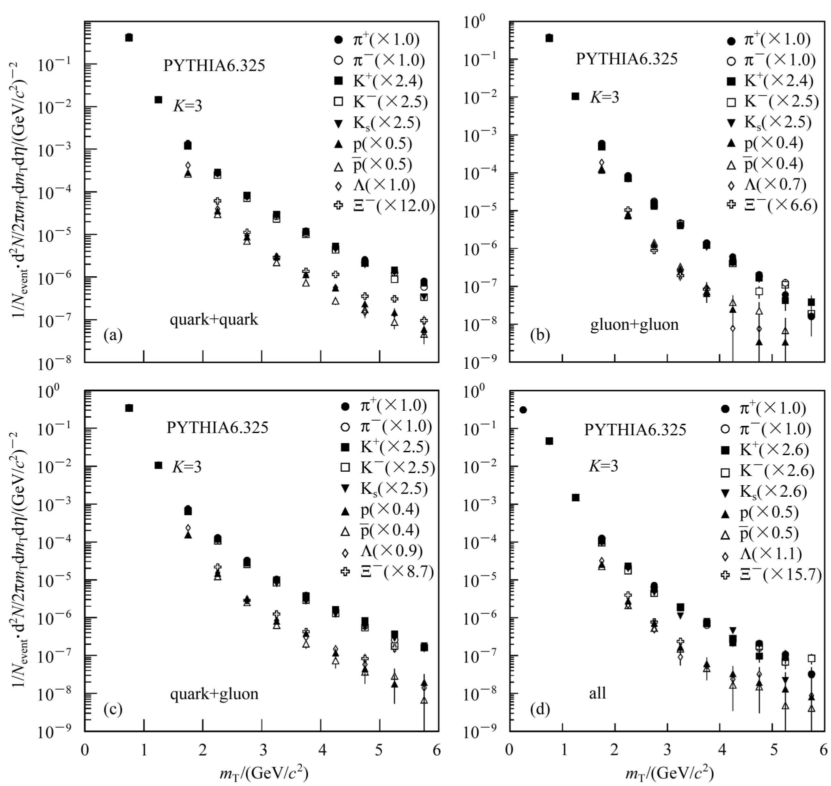


Fig. 3. $m_{\mathrm{T}}$-scaling results are from PYTHIA v6.3 with independent fragmentation and $K$=3, and each spectrum is scaled at 1.25GeV/$c^2$. The final state parton contents on each plot are the same as those in Fig. 2.

between mesons and baryons is significantly larger than that in SF, and clearly appears in the processes of both quark and gluon final states.

Within the IF scheme, there is no unique recipe for how gluon jet fragmentation should be handled. A gluon jet is assumed to fragment like a pair of u, d or s quark and its anti-quark, sharing the gluon energy according to the Altarelli-Parisi splitting function, i.e. $f(z)\propto z^2+(1-z)^2$. Therefore, all processes contribute to the final states equally. Besides, as di-quarks excited from single quark are less than those from quark string, the splitting phenomena are more distinct than those in SF scheme.

## 3 The new physics introduced in PYTHIA v6.3 comparing with v6.2

In order to further understand the new physics of above splitting phenomenon, different PYTHIA versions are compared within SF scheme. Since the non-trivial interplay between multiple parton-parton interactions and initial-state parton showers are considered in the new version v6.3, an extended model for multiple interactions (for underlying events and mini-bias)[9] and a newly developed model, i.e. interleaved model[10] (for $p_T$-ordered initial- and final-state parton showers) are introduced. To find out the influence and contribution from these new models, the processes of p+p collisions at 200GeV are simulated again using PYTHIA v6.2. Shown in Fig. 4 are the $m_T$ spectra which demonstrate a negligible splitting effect in v6.2.

From Fig. 4，it can be seen that within the same SF scheme the results from different version (v6.2 and v6.3) are quite different. The new model introduced in v6.3 to improve the underlying event (including multiple interaction and beam remnants) allows more than one valence quark to be kicked out, and also takes into account the fact that sea quarks come in pairs. Therefore the beam remnant structure and color flow topologies can become quite complicated, and the so-called string junctions, e.g. junction fragmentation, are handled in the v6.3. For instance, if two valence quarks have been knocked out of the same baryon in different directions, there will be three quarks being knocked out from the same baryon in different directions, which are widely separated in momentum space, two of them may not naturally be collapsed to form a di-quark system, so the number of di-quark is decreased. But in the old model implemented in the v6.2, technical limitations in the way the fragmentation was handled made it impossible to address such remnant systems. Consequently, it is impossible to associate beam remnant with the splitting effect between mesons and baryons in PYTHIA v6.2.

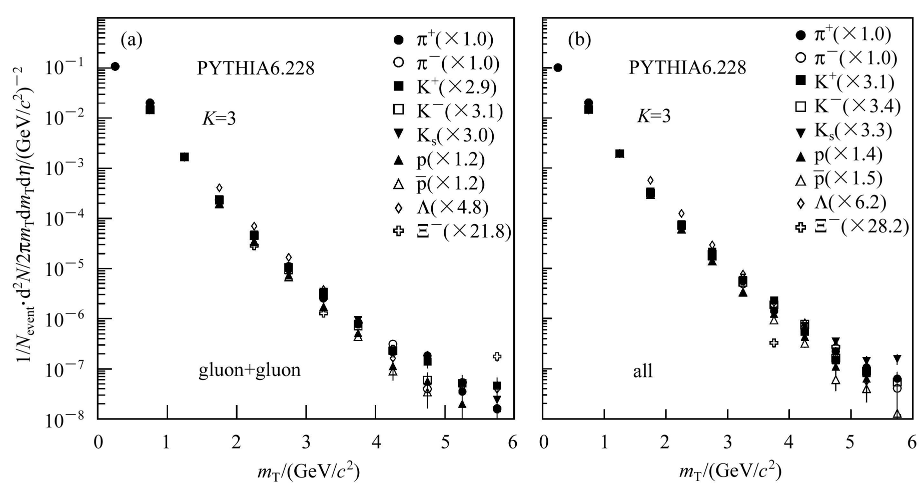


Fig. 4. $m_T$-scaling results from PYTHIA v6.2 with $K$=3 (other parameters are default). These events with the final states of gluon-gluons or all processes are simulated. No clear splitting phenomena are seen as comparing with that from PYTHIA v6.3.

## 4 Conclusion

We have presented a simulation study of the $m_{\mathrm{T}}$ spectra for $\sqrt{S}$=200GeV p+p collisions using PYTHIA. In order to understand the splitting effect between meson and baryon observed in RHIC data, different fragmentation models (SF and IF scheme) are tested in the simulation study. Both fragmentation schemes demonstrate similar splitting effects between mesons and baryons at high $m_{\mathrm{T}}$ region. The SF passes an information that the contribution to $m_{\mathrm{T}}$-spectra from p+p collisions at RHIC energies may come primarily from gluon jets, but IF does not as in it the gluon fragments into a pair of quarks. Due to the different fragmentation mechanism, the production of di-quarks from IF should be less than that from SF, thus the $m_{\mathrm{T}}$-spectra within IF show more clearly splitting effect than that within SF.

However, within the same SF scheme different versions (v6.2 and v6.3) of PYTHIA give different results. The splitting effect between mesons and baryons clearly seen in the new version v6.3 disappears in the v6.2. The reasonable explanation might be that a new and sophisticated model considering the multiple parton interactions is introduced in v6.3 and junction fragmentation is handled, which make more valence quarks kicked out at the same time, and reduce the production of di-quark. Therefore, the splitting effect is aroused in the v6.3.

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# $\sqrt{S}=200$GeV质子对撞中横质量谱劈裂效应的PYTHIA模拟研究*


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**摘要** 在质心系能量为200GeV的质子–质子对撞中, 高横质量区域产生的强子横质量谱分裂成两类——重子和介子. 应用PYTHIA产生器进行Monte Carlo分析其内在的物理机制. 模拟结果表明, 这种劈裂效应不仅在弦碎裂模型中出现, 而且独立碎裂模型中也有, 并且在RHIC能区(200GeV)下主要来源于胶子的贡献. 在PYTHIA6.3版本中引入的新的物理机制表明复杂的弦纠缠(string junction)形式可能是这种重子–介子差异的主要原因.



**关键词** 横质量谱 弦碎裂 独立碎裂 多重部分子交叉反应

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