Strange Particle Production Mechanisms in Proton-Proton Collisions at RHIC

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\textbf{Abstract.} We present data on strange particle production in elementary proton-proton collisions at RHIC energies. Comparison to leading order and next-to-leading order (NLO) calculations shows that the fragmentation process is flavor dependent and that higher order corrections are needed to describe all spectra, in particular at these collision energies, which are modest compared to those at the Tevatron. A model (EPOS) which takes into account multiple scattering between projectile constituents seems to describe the data best.

\textit{Keywords:} proton-proton collisions, higher order calculations

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\section{1. Introduction}

Particle production in elementary proton-proton collisions is widely recognized as a well understood problem in the string fragmentation process. The universality of the fragmentation process between $e^+e^-$ and $p + p$ collisions has been recently confirmed by Kniehl, Kraemer and Poetter (KKP) in a detailed paper based on pion and charged hadron production \cite{1}. Using the factorization theorem with the proper next-to-leading order corrections, the calculation seems to describe the pion and charged hadron production in RHIC $p+p$ data well \cite{2,4}. We therefore expect the strange particle production to be also described by the standard fragmentation descriptions. The measurements presented here are based on two STAR Ph.D. theses \cite{4,5}.
2. Comparison to PYTHIA

The most commonly applied model available for the description of hadron-hadron collisions is PYTHIA. In Fig.1 we have used PYTHIA (v6.221 with default settings, MSEL=1) \[6\] for comparison to strange particle $p_T$ spectra measured in $p+p$ collisions at $\sqrt{s}=200$ GeV (solid line). The model describes neither the strange meson nor the baryon production. A more recent version of PYTHIA (v6.317), which includes an improved description of partonic multiple scattering processes, does well on the strange meson production (dashed line). The agreement of the model with the strange baryon spectra improved only when the K-factor was raised to three (dotted line).

![Fig. 1. $K_S^0$, $\Lambda$ and $\Xi$ $p_T$ spectra compared to PYTHIA calculations.](image)

The multiplicity dependence of the $<p_T>$ also could not be reproduced using the default setting, but only when the K-factor was raised (Fig.2).

Is this large value for K unphysical? Does it signal new physics in strangeness production? The K-factor, which quantifies the importance of next-to-leading order (NLO) effects, should increase from higher to lower collision energies, because the particle production is less and less dominated by the initial hard two-body scattering. Eskola et al. showed a K-factor excitation function in QM02 \[7\]. His calculation is in good agreement with the large K-factor necessary to describe our data. Therefore, one would expect actual NLO calculations to perform better than the default PYTHIA for strange particle production.

3. Comparison to NLO calculations

Werner Vogelsang used the KKP parametrization \[1\], which was successfully applied to the PHENIX $\pi^0$ and the STAR charged hadron spectra, plus a specific $\Lambda$ fragmentation function by Vogelsang and DeFlorian \[8\] in order to describe the strange particle data shown here. Fig.3 shows that these NLO calculations describe neither the shape nor the magnitude of the strange particle production very well,
Strange Particle Production in $p + p$ at RHIC

Fig. 2. $K^0_S$ and $\Lambda <p_T>$ as a function of measured charged particle multiplicity per unit pseudo-rapidity compared to PYTHIA calculations.

and that the disagreement is worse for the baryons. The systematic uncertainty of the calculation is taken into account through varying the renormalization factor, $\mu$.

Fig. 3. $K^0_S$ and $\Lambda p_T$ spectra compared to NLO calculations based on standard fragmentation functions [1, 8].

The agreement gets significantly better when quark-separated contributions to the fragmentation function are used according to Albino, Kniehl and Kraemer [9] and Bourelly and Soffer [10]. It is interesting to note that apparently the quark separation is more important at the lower (RHIC) energies than at the higher (CERN) energies [10]. In addition, the heavy quark contribution to the light baryon produc-
tion is not negligible [10], which can be interpreted as a higher order extension to the quark-separated contributions of the valence quarks.

4. Comparison to EPOS

Finally we compare to the new EPOS model [11], which takes into account soft and hard partonic interactions between the produced partons (inner contribution) and partonic remnants of projectile and target, i.e. diquarks in the case of proton-proton interactions (outer contributions). The agreement with the data is remarkable (Fig.4) and is mostly attributed to soft 'inner' parton cascading, which is a description of the multiple scattering process of the off-shell partons produced in the initial parton-parton collision. Surprisingly this soft contribution is more relevant to the heavy strange baryons than, for example, the pions [11].

![Fig. 4. K^0_S, Λ and Ξ p_T spectra compared to EPOS calculations.](image_url)

5. Summary

The good agreement between data and the most recent extended NLO calculations, as well as the EPOS calculations, points at the necessity of higher order corrections to the simple string fragmentation picture for the production of strange baryons and mesons in p + p collisions. The contributions of each quark flavor to the fragmentation has to be taken into account separately, and effects from partonic projectile remnants or cascading soft non-valence quarks are non-negligible. Therefore, strange particles, which are produced abundantly at RHIC in p + p collisions, provide a good test for the quantitative determination of the generation mechanism in elementary collisions, where apparently simple string fragmentation is not sufficient to describe all of the hadron production.

References

1. B.Kniehl et al., Nucl. Phys. B597 (2001) 337
Strange Particle Production in $p + p$ at RHIC

2. C.Adler et al., Phys. Rev. Lett.91 (2003) 241803
3. J.Adams et al., Phys. Rev. Lett.91 (2003) 172302
4. M.Heinz, Ph.D. thesis, University of Bern (2005)
5. J.Adams, Ph.D. thesis, The University of Birmingham (2005)
6. T.Sjostrand et al., hep-ph/0108264 and hep-ph/0308153
7. K.Eskola et al., Nucl. Phys. A713 (2003)
8. D.DeFlorian et al., Phys. Rev. D57 (1998) 5811
9. S.Albino et al., hep-ph/0502188
10. C.Bourrely and J. Soffer, Phys. Rev. D68 (2003) 014003
11. K.Werner et al., hep-ph/0506232