PROCEEDINGS OF SCIENCE

# Monte Carlo simulations of Upsilon meson production

**Jaroslav Bielcik, Jakub Ceska,[*] Leszek Kosarzewski and Miroslav Myska**

*Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehova 7, 115 19 Praha 1, Czech Republic*

*E-mail:* ceskajak@fjfi.cvut.cz

$\Upsilon$ meson production dependence on charged particle multiplicity involves the interplay between soft and hard QCD processes. Normalised multiplicity dependence is a meaningful tool for understanding the particle production mechanisms. The observed strong increase may be explained by multi-parton interactions, string percolation or color glass condensate saturation effects. This paper presents Monte Carlo simulations of $\Upsilon$ meson production in proton-proton collisions at $\sqrt{s}$ = 500 GeV with PYTHIA and Herwig generators. The aim of the simulations is to explore the dependence of normalised $\Upsilon$ meson yield on normalised event multiplicity. Herwig with $k_\perp$ > 4 GeV/c shows a linear dependence of $N_\Upsilon/\langle N_\Upsilon \rangle$ vs. $N_{\mathrm{ch}}/\langle N_{\mathrm{ch}} \rangle$ for Upsilon $p_{\mathrm{T}}$ > 0 GeV/c, while both PYTHIA 8 and Herwig with $k_\perp$ > 20 GeV/c show a stronger than linear dependence.

*40th International Conference on High Energy physics - ICHEP2020*
*July 28 - August 6, 2020*
*Prague, Czech Republic (virtual meeting)*

[*]Speaker





PoS(ICHEP2020)578

## 1. Introduction

This work focuses on PYTHIA and Herwig simulations of $\Upsilon$ production vs. charged particle multiplicity ($N_{\mathrm{ch}}$) in pp collisions at $\sqrt{s}$ = 500 GeV. Normalised multiplicity dependence is a meaningful tool for understanding the particle production mechanisms and the interplay between soft and hard QCD processes. Recent experimental results show stronger than linear increase [1, 2]. This may be explained by multi-partion interactions, string percolation or color glass condensate saturation effects.

The experimental observable $N_\Upsilon/\langle N_\Upsilon\rangle$ is calculated as $N_\Upsilon/\langle N_\Upsilon\rangle = (N_{\mathrm{MB}}/N_{\mathrm{MB}}^{\mathrm{bin}})(N_\Upsilon^{\mathrm{bin}}/N_\Upsilon)$, where $N_{\mathrm{ch}}/\langle N_{\mathrm{ch}}\rangle$ is the self-normalised particle multiplicity, $N_\Upsilon$ ($N_{\mathrm{MB}}$) is the total number of events containing $\Upsilon$ meson (minimum bias events) and $N_\Upsilon^{\mathrm{bin}}$ ($N_{\mathrm{MB}}^{\mathrm{bin}}$) is the number of $\Upsilon$ (minimum bias) events in the corresponding multiplicity bin.

## 2. Simulation

The simulation consists of two parts: minimum bias and $\Upsilon$ production. For minimum bias events non-single-diffractive soft QCD events were chosen. Criteria for particle selection are: $|\eta| < 1$, $p_{\mathrm{T}} > 0.2$ GeV/c (STAR cuts), stable particles ($\tau > 10$ mm/c to reject weak decay contribution). Only directly produced $\Upsilon$(1S) states within $p_{\mathrm{T}} > 0$ or 4 GeV/c in electron decay channel were selected. This study also includes comparison to STAR preliminary data [3].

The Monte Carlo generators used in this study are PYTHIA 8.240 [4] with STAR HF tune and Herwig 7.2.0 [5, 6]. The main features of PYTHIA include $p_{\mathrm{T}}$ ordered showers, Lund string hadronisation model and direct $\Upsilon$ production (dedicated matrix elements for Bottomonia). Herwig's main features are angular ordered showers, cluster hadronisation and $\Upsilon$ production during hadronisation phase ($b\bar{b}$ matrix element). The results from Herwig depend on b-parton $k_\perp$ cut (4 or 20 GeV/c) - the value of the $k_\perp$ cut influences the $N_{\mathrm{ch}}$ and $p_{\mathrm{T}}$ spectra.

The multiplicity and $p_{\mathrm{T}}$ distributions can be seen in Fig. 1. Both PYTHIA and Herwig minimum bias spectra describe real data reasonably well. For $\Upsilon$ containing events, Herwig with $k_\perp > 4$ GeV/c is in closest agreement in terms of multiplicity and PYTHIA in terms of $p_{\mathrm{T}}$ distributions [3].

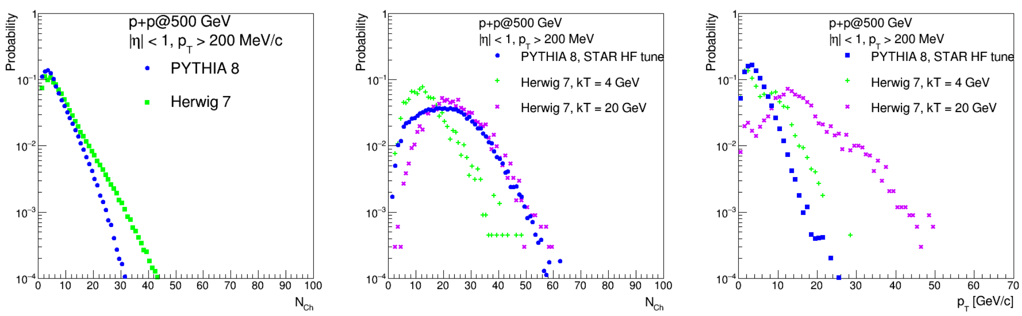


**Figure 1:** Charged particle multiplicity distributions for MB (left) and $\Upsilon$(1S) containing (middle) events and $p_{\mathrm{T}}$ distributions for $\Upsilon$ containing events (right).

## 3. Results and Conclusion

The results of both Herwig and PYTHIA simulation are compared to STAR preliminary data in Fig. 2.

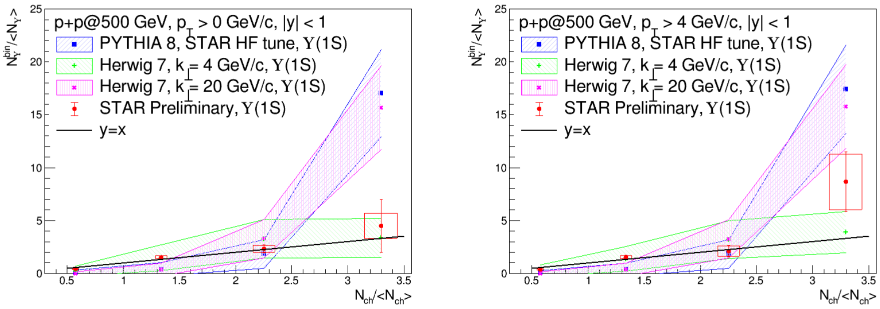


**Figure 2:** Normalised $\Upsilon(1S)$ yield dependence on normalised multiplicity. The PYTHIA simulations for direct $\Upsilon(1S)$ and Herwig simulations are compared to STAR preliminary data [3] for $p_T$-integrated (left) and $p_T$ > 4 GeV/c (right).

STAR $\Upsilon$ data with $p_T > 0$ GeV/c are better described by Herwig with $k_\perp > 4$ GeV/c, which is consistent with linear dependence. For $p_T > 4$ GeV/c, the STAR data indicate a stronger than linear rise, which is qualitatively reproduced by PYTHIA 8 and Herwig with $k_\perp > 20$ GeV/c. It may indicate that Upsilons are produced in multiple parton interactions [2]. However, higher precision measurement as well as dedicated Monte Carlo tunes are needed for a deeper insight.

### Acknowledgements

The work was supported from the project LTT18002 of the Ministry of Education, Youth, and Sport of the Czech Republic and from European Regional Development Fund-Project "Center of Advanced Applied Science" No. CZ.02.1.01/0.0/0.0/16-019/0000778.

### References

[1] J. Adam [STAR], Phys. Lett. B **786** (2018), 87-93

[2] J. Adam *et al.* [ALICE], JHEP **09** (2015), 148

[3] L. Kosarzewski [STAR], J. Phys.: Conf. Ser. **1667** (2020), 012022

[4] T. Sjöstrand, S. Mrenna and P. Skands, JHEP05 (2006) 026, Comput. Phys. Comm. 178 (2008) 852

[5] M. Bähr *et al.*, Eur. Phys. J. C **58** (2008), 639

[6] J. Bellm *et al.*, Eur. Phys. J. C **76** no.4 (2016), 196