Measurement of the Υ meson production in $p+p$ collisions at $\sqrt{s} = 510$ GeV at STAR

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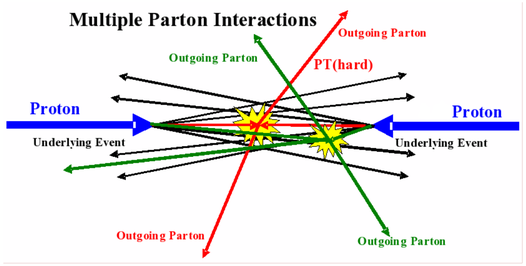
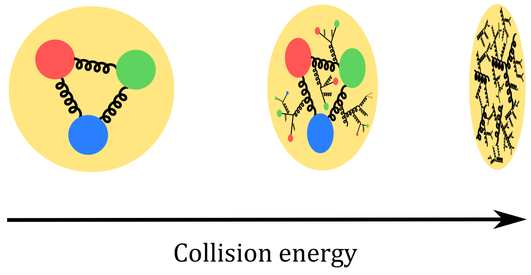
Motivation

Studies of normalised quarkonium yield in dependence on the self-normalised multiplicity in $p+p$ collisions at RHIC and the LHC exhibit a stronger than linear increase. Measurements help with understanding quarkonium production and modelling the formation of the bound states. Multiple effects may play a role in this behaviour:

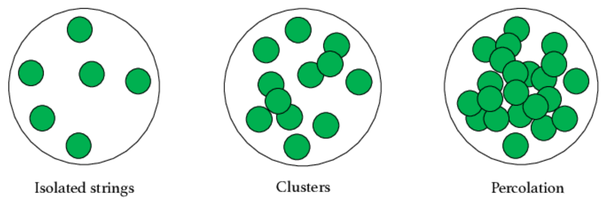
- **Multi-parton interactions (MPIs)** [1, 2, 3, 4]
  - Multiplicity proportional to energy density
  - Quarkonium yield proportional to # of MPIs



- **CGC/saturation effects** [5, 6]
  - Gluon density saturation @ low-x $\Rightarrow$ influence on soft-QCD particle production



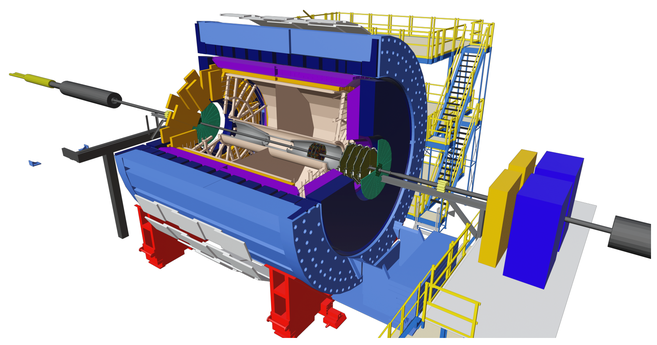
- **String percolation** [7]
  - Soft-QCD production suppression due to interactions of overlapping colour field strings



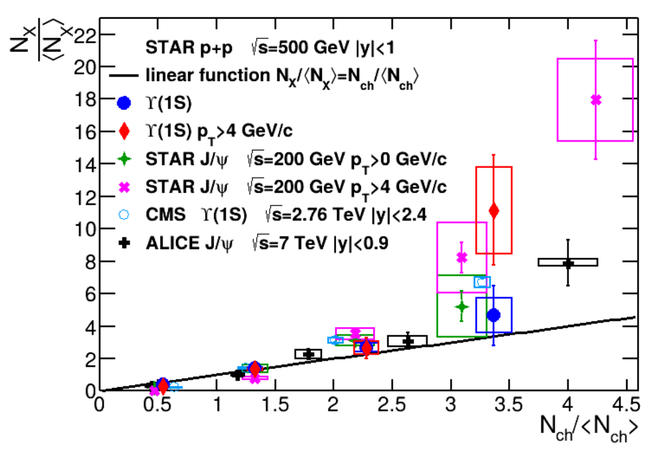
STAR Experiment

Located at the Relativistic Heavy Ion Collider in Brookhaven National Laboratory. Notable subdetectors used for this measurement are:

- **TPC** - tracking, particle identification based on $\mathrm{d}E/\mathrm{d}x$
- **BEMC** - electron ID, high tower trigger, high-p_{T} electron enhancement
- **TOF** - particle identification and charged particle multiplicity measurement
- **BBC** - instantaneous luminosity



Previous results



Recent measurements in $p+p$ at 500 GeV from Run11 [8] ($\mathcal{L}_{\mathrm{int}} \sim 22$ pb^{-1}) are consistent with the world trend. The 510 GeV $p+p$ data collected in 2017 used in this analysis offers up to 10 times the sampled integrated luminosity ($\mathcal{L}_{\mathrm{int}} \sim 340$ pb^{-1}) compared to the previous results. Expected to improve statistical uncertainty and extend multiplicity and p_{T} coverages.

References

[1] ALICE collaboration, Phys. Lett. B **712** (2012), 165-175
[2] CMS collaboration, JHEP **2014**, 103 (2014)
[3] STAR collaboration, Phys. Lett. B **768** (2018), 87-93
[4] T. Sjöstrand and M. van Zijl, PRD, **36** (1987) 2019
[5] C. Marquet, Nucl. Phys. A **904-905** (2013), 294c-301c
[6] E. Levin and M. Siddikov, Eur. Phys. J. C**79**, 376 (2019)
[7] E. Ferreiro and C. Pajares, Phys. Rev. C **86** (2012), 034903
[8] STAR collaboration, arXiv:2502.03769 **[hep-ex]**
[9] S. Navas et al. (Particle Data Group), Phys. Rev. D **110**, 030001 (2024)

Acknowledgements

The work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS25/159/OHK4/3T/14 and by the Ministry of Education, Youth and Sports of the Czech Republic through the projects LM2023034 Brookhaven National Laboratory - the participation of the Czech Republic, and INTER-ACTION, MSMT-355/2025-9.

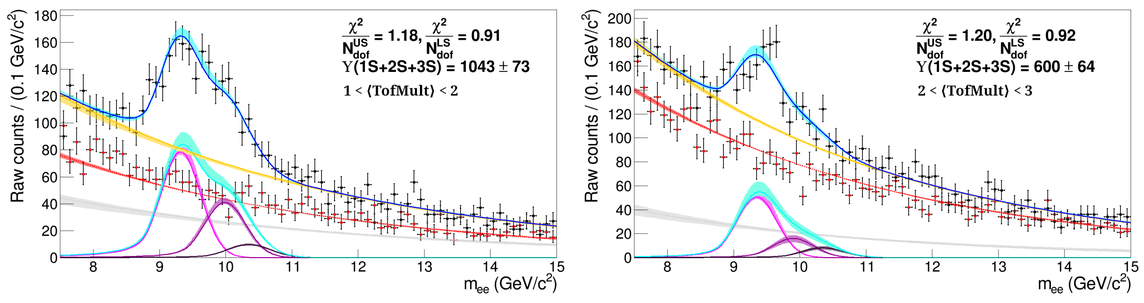
Analysis

The analysis uses $p+p$ collisions at 510 GeV recorded during Run17. Electron selection in $|\eta| < 1$ and full azimuth via TPC ($-1.2 < n\sigma_e < 3$ - based on $\mathrm{d}E/\mathrm{d}x$) and BEMC ($E_{\mathrm{TOW}}/E_{\mathrm{CLU}} > 0.5$, $0.55 < E_{\mathrm{CLU}}/p < 1.45$, where E_{TOW} is the energy of a BEMC tower and E_{CLU} is the energy from multiple BEMC towers associated to a cluster).

Dielectrons used to reconstruct Unlike-Sign (US) and Like-Sign (LS) pairs and calculate invariant mass (triggered electron satisfying high tower energy threshold of ~5.9 GeV, associated electron with $p_{\mathrm{T}} > 1$ GeV/c). The signal extraction uses unbinned likelihood simultaneous fitting of US and LS mass spectra. The **total fit** comprises of:

- **background**
  - **combinatorial background** - exponential, LS pairs
  - **residual background** (Drell-Yan, $b\bar{b}$) - exponential
- **signal** - 3 one-sided Crystal-Ball functions - (**Υ(1S)**, **Υ(2S)**, **Υ(3S)**)

The constraints used: mass separation of 500 MeV/c^2 and 400 MeV/c^2 for the Υ(1S) and Υ(2S), and Υ(2S) and Υ(3S) states, respectively [9]. The Υ signal widths linearly dependent on Υ state's mass. The fit is performed in normalised TOF multiplicity bins (0-1, 1-2, 2-3, 3-4, 4-8), which will be then used to obtain the dependence of the self-normalised Υ meson multiplicity on the self-normalised charged-particle multiplicity.



1-2 $\langle$TofMult$\rangle$ 2-3 $\langle$TofMult$\rangle$

Normalised quarkonium yield is defined as

$$N_\Upsilon / \langle N_\Upsilon \rangle = \left(N_{\mathrm{MB}}/N_{\mathrm{MB}}^{\mathrm{bin}}\right)\left(N_\Upsilon^{\mathrm{bin}}/N_\Upsilon\right)$$

- N_Υ - total yield of the Υ meson candidates
- $N_\Upsilon^{\mathrm{bin}}$ - Υ yield in the corresponding charged particle multiplicity bin
- N_{MB} - number of minimum bias events
- $N_{\mathrm{MB}}^{\mathrm{bin}}$ - number of minimum bias events in the corresponding bin

Conclusions

- Largest reconstructed Υ sample (2342 ± 116) in $p+p$ at $\sqrt{s} = 510$ GeV at STAR
- Expected improvement of signal extraction using lineshapes from embedded data
- Multiplicity dependence of normalised yield will be calculated
- Systematic uncertainty determination is on-going

The STAR Collaboration

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

Supported in part by:

U.S. DEPARTMENT OF ENERGY | Office of Science

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS