Production of Σ baryons in p–Pb and pp collisions at the LHC with ALICE

Pavel Gordeev on behalf of the ALICE Collaboration
National Research Centre "Kurchatov Institute"

LXXIV International conference Nucleus-2024: Fundamental problems and applications

1. Motivation

- The strangeness content of the final state in ultrarelativistic heavy-ion collisions has been studied through measurements of kaons ($K^{\pm}, K^0_S$), Λ, Ξ and Ω, but not yet Σ
- Σ-hyperons carry a significant fraction of the strangeness produced in the collision and are a useful probe of QGP formation [1]
- For the moment only Σ^0 was measured by ALICE at the LHC
- Measurement of N–Σ correlation should shed a light on the presence of Σ-hyperons in neutrons stars and constrain the Equation-of-State [2]

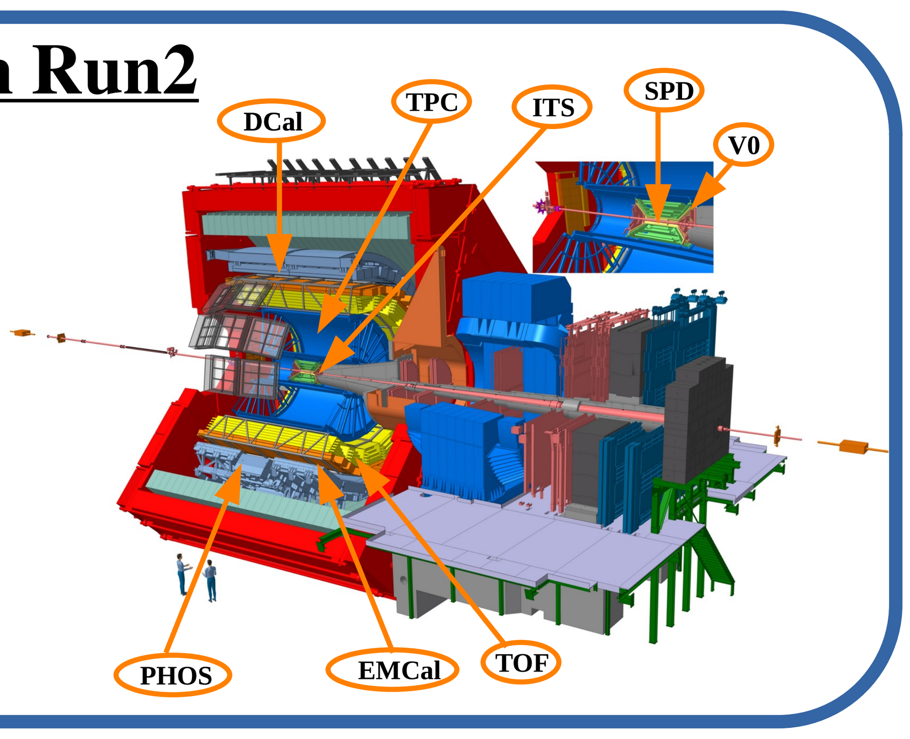
$\Sigma^+ = \mathrm{uus}$
$m = 1189.37 \pm 0.07$ MeV/c^2
$\Sigma^+ \to p\pi^0 (51.57 \pm 0.30)$ %
$\Sigma^+ \to n\pi^+ (48.31 \pm 0.30)$ %

$\Sigma^- = \mathrm{dds}$
$m = 1197.449 \pm 0.030$ MeV/c^2
$\Sigma^- \to n\pi^- (98.848 \pm 0.005)$ %

$\Sigma^0 = \mathrm{uds}$
$m = 1192.642 \pm 0.014$ MeV/c^2
$\Sigma^0 \to \Lambda\gamma (100)$ %

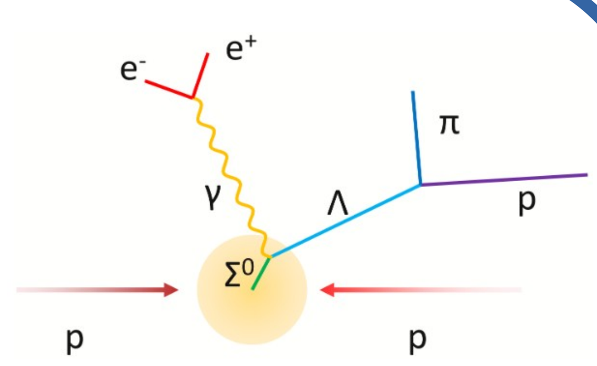
2. The ALICE detector in Run2

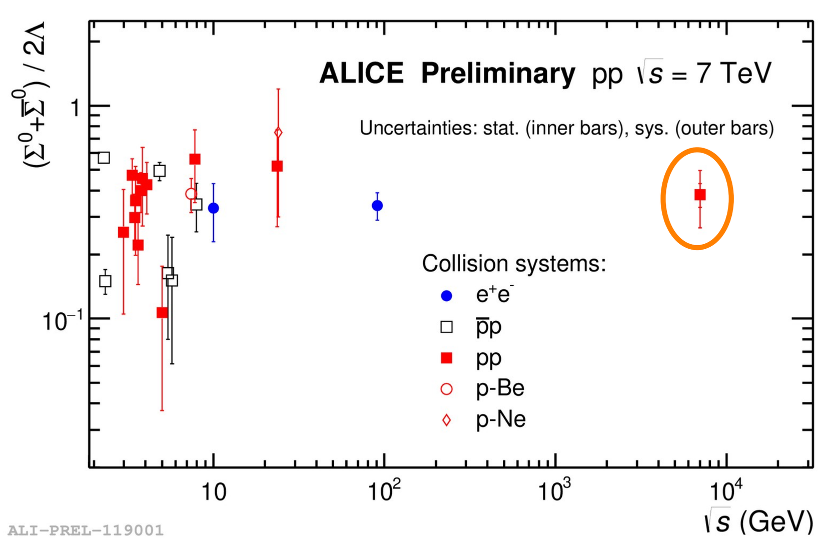
- Tracking down to low p_T is provided by the Inner Tracking System (ITS) and Time Projection Chamber (TPC)
- Charged particle identification is done with Time Projection Chamber (TPC) and Time-of-Flight (TOF)
- Electromagnetic calorimeters: PHOS, EMCal and DCal
- V0 and SPD are used for multiplicity estimation

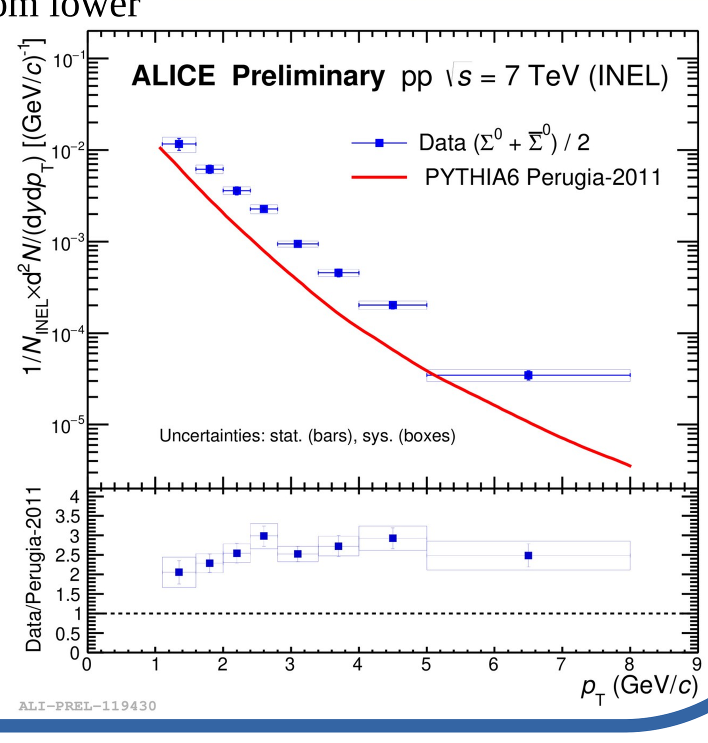


3. Σ^0 and $\bar{\Sigma}^0$ measurement

- Λ is reconstructed via the decay into proton and pion
- γ is reconstructed via Photon Conversion Method (PCM)
- PYTHIA6 [3] underestimates the production of Σ^0
- $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio complements world data from lower energies

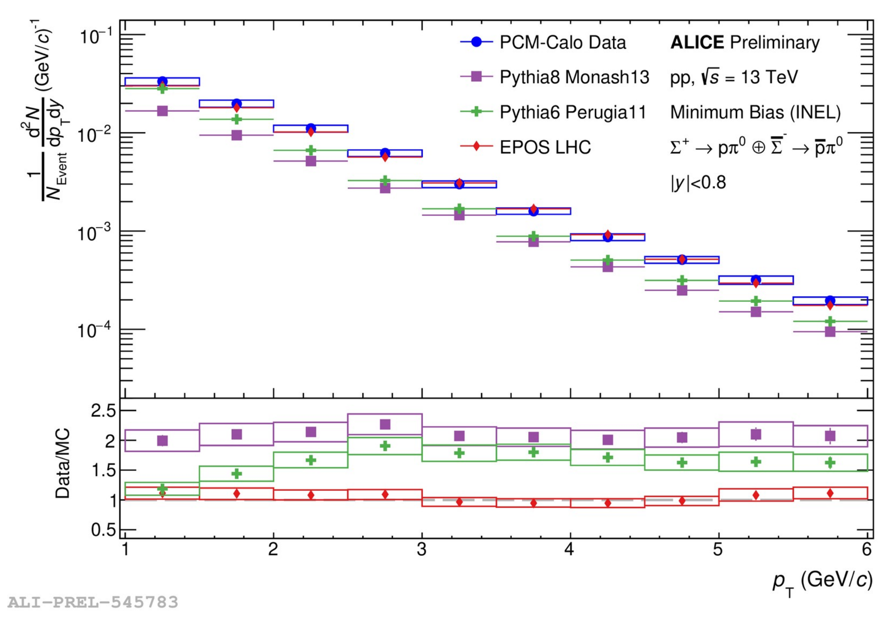


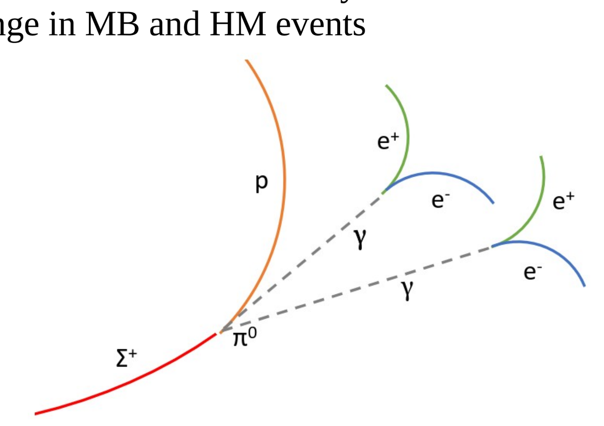


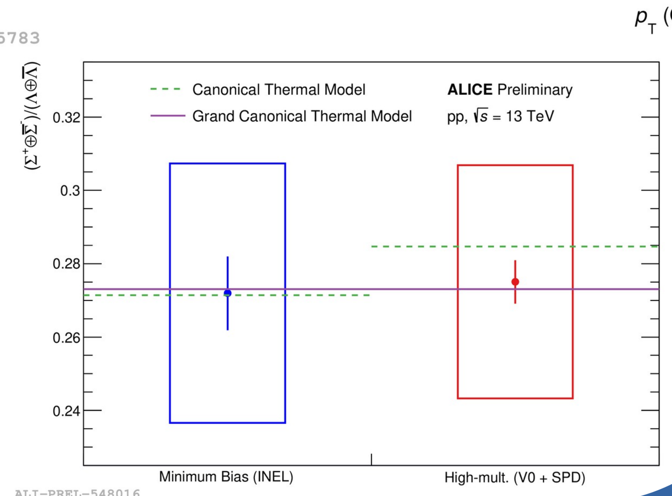


4. Σ^+ and $\bar{\Sigma}^-$ measurement with PCM

- Spectrum is measured both in Minimum Bias and High Multiplicity collisions
- Spectrum is well reproduced by EPOS LHC generator [4], while PYTHIA8 [5] catches the shape, but underestimates the yield
- PYTHIA6 [3] does not describe the shape of the spectrum at low transverse momentum and underestimates the yield
- $(\Sigma^+ \oplus \bar{\Sigma}^-)/(\Lambda \oplus \bar{\Lambda})$ ratio is in good agreement with canonical and grand-canonical thermal-model calculations
- Within the uncertainties the yield ratio do not change in MB and HM events



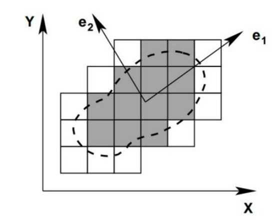




5. $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ measurement with PHOS

How can we identify antineutrons?

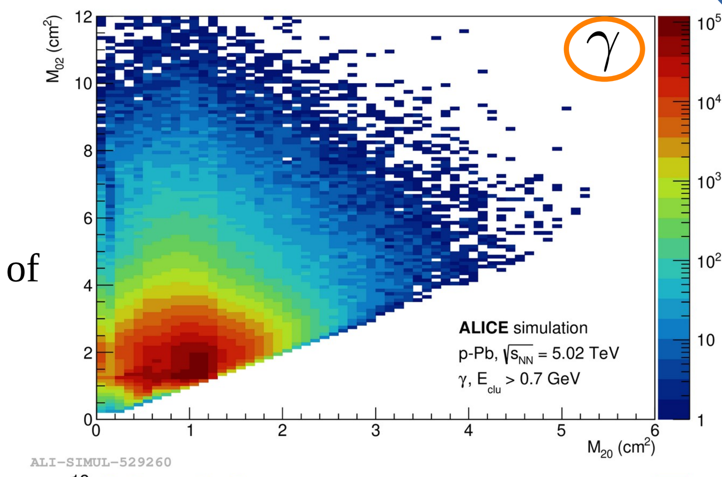
- Deposited energy of annihilation
- Neutrality (charged particle veto)
- Dispersion of cluster (M20, M02 – eigenvalues of S matrix)

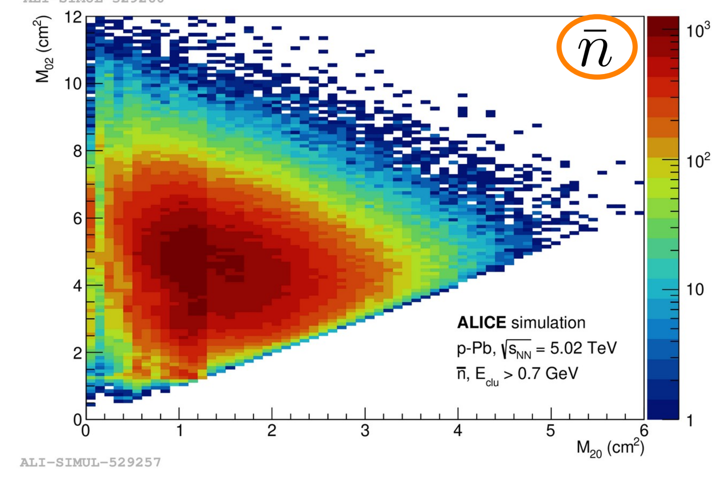


$$S = \begin{pmatrix} s_{xx} & s_{xz} \\ s_{zx} & s_{zz} \end{pmatrix}$$
$$s_{xx} = \langle (x - \bar{x})^2 \rangle$$
$$s_{xz} = \langle (x - \bar{x})(z - \bar{z}) \rangle$$

But:

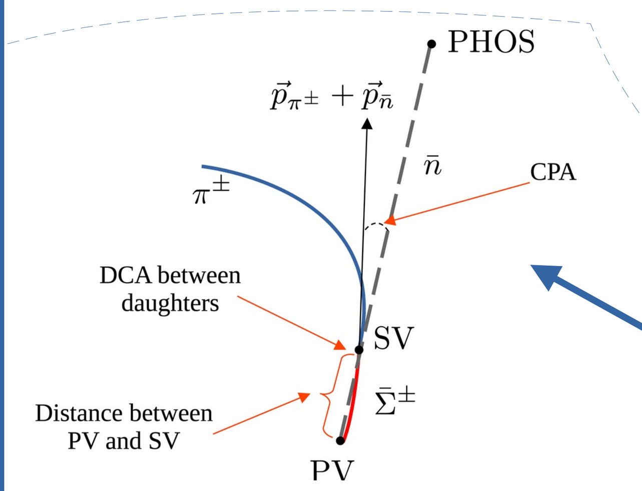
- Cannot measure momentum based on deposited energy
- Use time-of-flight information from PHOS to reconstruct antineutron momentum
- After applying PID cuts the fraction of antineutron clusters reaches ~50-60%



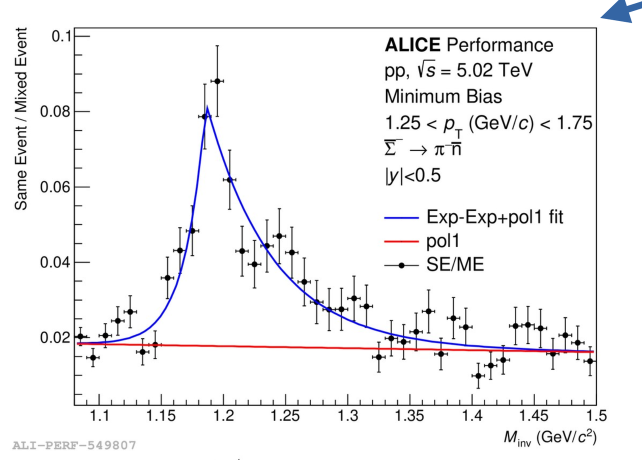


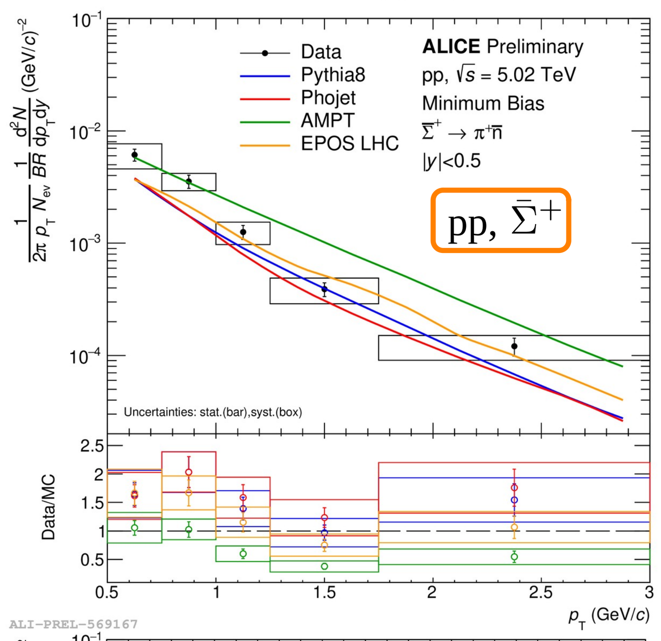
$$p_{\mathrm{rec}} = \frac{m_{\bar{n}}}{\sqrt{\left(\frac{t_{\mathrm{TOF}} \cdot c}{L}\right)^2 - 1}}$$

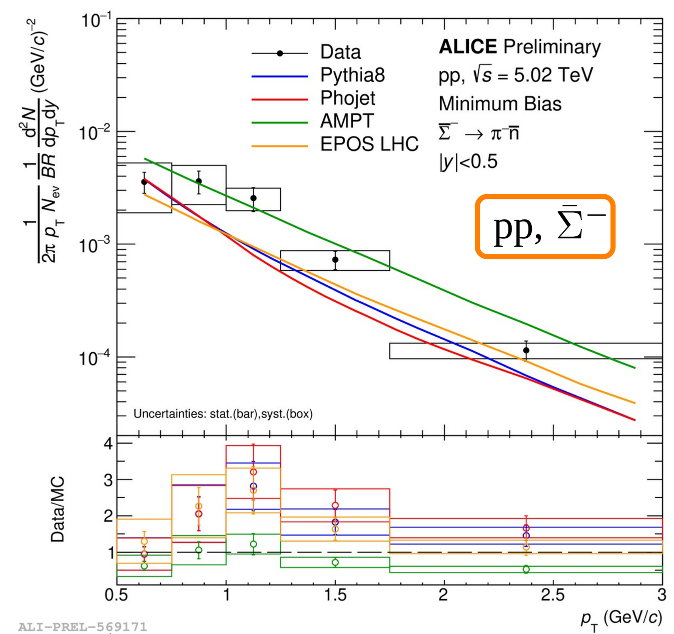
L - distance between primary vertex and cluster coordinate in PHOS, m (~4.6 m)
$m_{\bar{n}}$ - antineutron mass, 0.939485 GeV/c^2
t_{TOF} - time of flight, s

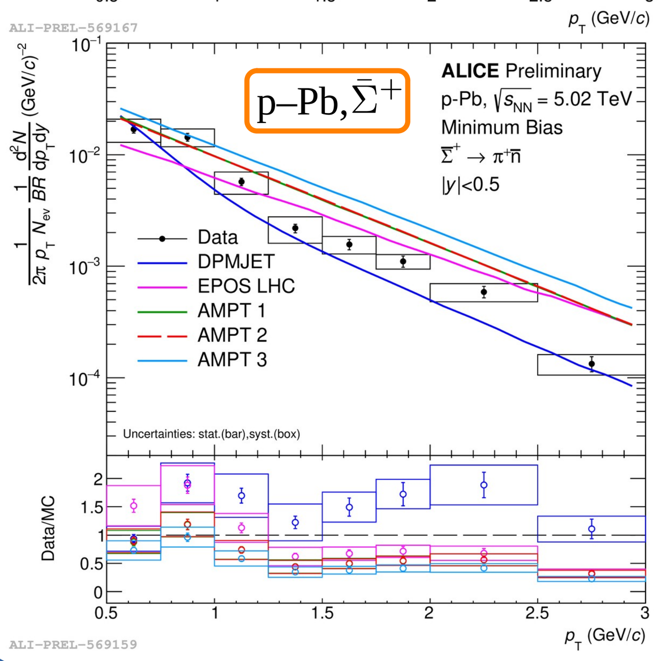


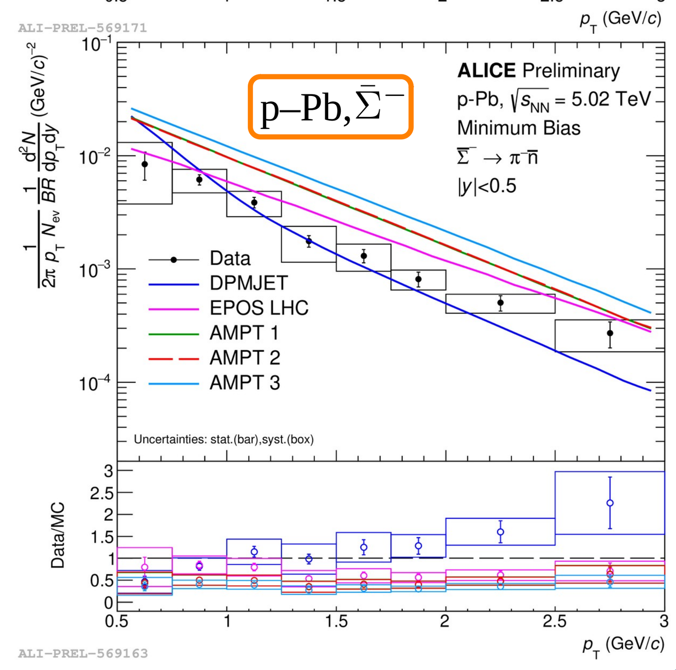
- Secondary vertex is reconstructed and topological selections are used to increase signal to background ratio
- Signal peak has non-gaussian shape due to finite time resolution of PHOS
- EPOS LHC [4], PYTHIA8 Monash13 [5] and Phojet [6] show good agreement with data points within large uncertainties
- AMPT [7] generator options tend to overestimate the yield
- DPMJET [8] shows good agreement at high p_T but have a rise at low p_T, which is not common to other models











6. Conclusion

- For the first time at the LHC, production of charged Σ-hyperons was measured
- Method for antineutron reconstruction was proposed, which opens up a variety of new observables
- Obtained results are more or less consistent with EPOS LHC [4] predictions, and can be used to constrain other MC generators
- Σ was studied both in High Multiplicity and Minimum Bias pp collisions and Σ/Λ ratio is consistent with thermal-model prediction
- More precise measurement of Σ-hyperons, Σ-hypernuclei search and hadron-Σ interactions measurement is foreseen at LHC with ALICE in Run 3 in 2022–2025

[1] - Bellwied, Rene, et al. "Off-diagonal correlators of conserved charges from lattice QCD and how to relate them to experiment." Physical Review D 101.3 (2020): 034506.
[2] - Acharya, Shreyasi, et al. "Investigation of the p–Σ0 interaction via femtoscopy in pp collisions." Physics Letters B 805 (2020): 135419.
[3] - Sjöstrand, Torbjörn, Stephen Mrenna, and Peter Skands. "PYTHIA 6.4 physics and manual." Journal of High Energy Physics 2006.05 (2006): 026.
[4] - Pierog, T., et al. "EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider." Physical Review C 92.3 (2015): 034906.
[5] - Bierlich, Christian, et al. "A comprehensive guide to the physics and usage of PYTHIA 8.3." SciPost Physics Codebases (2022): 008.
[6] - Bopp, Fritz W., R. Engel, and J. Ranft. "Rapidity gaps and the PHOJET Monte Carlo." arXiv preprint hep-ph/9803437 (1998).
[7] - Lin, Zi-Wei, et al. "Multiphase transport model for relativistic heavy ion collisions." Physical Review C 72.6 (2005): 064901.
[8] - Roesler, Stefan, Ralph Engel, and Johannes Ranft. "The monte carlo event generator dpmjet-iii." Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications: Proceedings of the Monte Carlo 2000 Conference, Lisbon, 23–26 October 2000. Springer Berlin Heidelberg, 2001.