Simulations of charged hadron and charmed meson production in Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with HYDJET++ generator

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ABSTRACT

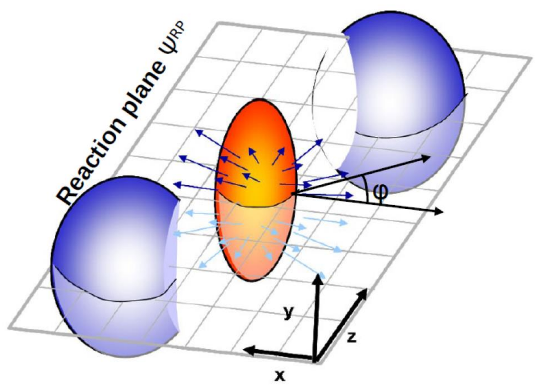
HYDJET++ is a Monte Carlo event generator merging parametrized soft part inspired by hydrodynamics with hard part containing jets. It has been successful to describe particle production in Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV energy. In this poster, particle spectra and collective flow for the top LHC energy $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV Pb+Pb collisions are presented for the first time. Specifically, the HYDJET++ model version 2.4 is used to simulate spectra of charged particles, D^0 and J/ψ mesons and related v_2 and v_3 azimuthal flow harmonics. The particle spectra and flow harmonics are studied in different centrality bins ranging from 0-10% up to 20-30% centrality in midrapidity region for charged particles and D^0 mesons and in forward rapidity in case of J/ψ mesons. The simulated results are compared to experimental data from the ALICE, ATLAS and CMS experiment in order to tune the HYDJET++ generator to get the most optimal agreement with the data.

MOTIVATION

- In central ultra-relativistic heavy ion collisions, **quark-gluon plasma (QGP)**, a novel phase of matter where quarks and gluons are deconfined, can be observed [1]
- QGP behaves as an almost perfect fluid and exists only for a short time ($\sim 10^{-20}$ s) during a collision
- The properties of the QGP can be deduced from energies and momenta of the outgoing particles
- Modified yields of particle species with regards to a proton-proton collision, collective behavior of nucleons participating in the collision and jet quenching can be recognized as **phenomena of QGP**
- Jet quenching is modification of a jet caused by the QGP medium
- In time evolution of a collision, transition between QGP and hadron gas happens at critical temperature, T_c, and at chemical freeze-out temperature, T_{ch}, particle species stop to change and finally, at **thermal freeze-out temperature, T_{th}**, momenta of all the particles are set

COLLECTIVE FLOW

- Particle production is anisotropic with respect to the reaction plane which is defined by the beam axis z and impact parameter $\vec{b}$
- Particle production in azimuthal angle φ can be decomposed into Fourier series



$$\frac{dN}{d\varphi} = \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \psi_n)]\right),$$

where n is order of the harmonic, ψ_n is reaction plane angle of the harmonic and $v_n = \langle \cos[n(\varphi - \psi_n)] \rangle$ is averaged over all the events

- v_2 and v_3 are called elliptic and triangular flows, respectively

HYDJET++ MODEL

- The HYDJET++ merges hydro-inspired blast wave parameterization (soft) with jet quenching (hard)
- In soft part, hadrons are generated at chemical freeze-out hypersurface and thermal equilibrium is assumed during the thermal emission
- Hard part is based on PYQUEN (PYthia QUENched) partonic energy loss model [2] which employs jet quenching in PYTHIA [3] generated jet events
- Production of charged hadrons and charmed mesons was **successfully described** in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV [4, 5] and in Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV energy [6]
- In Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV energy, correct model description has been achieved also for elliptic flow of charmed mesons [5] and triangular flow of different hadrons [7]

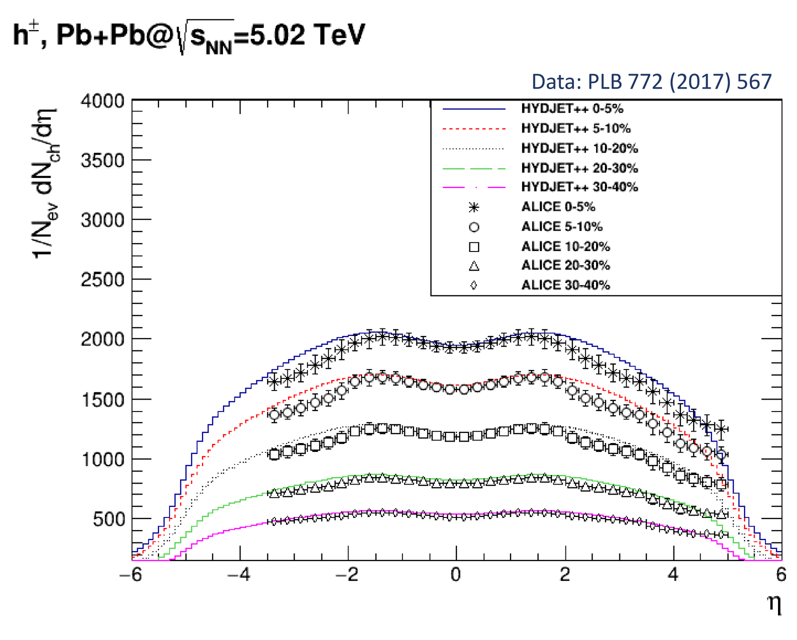
Simulation parameters

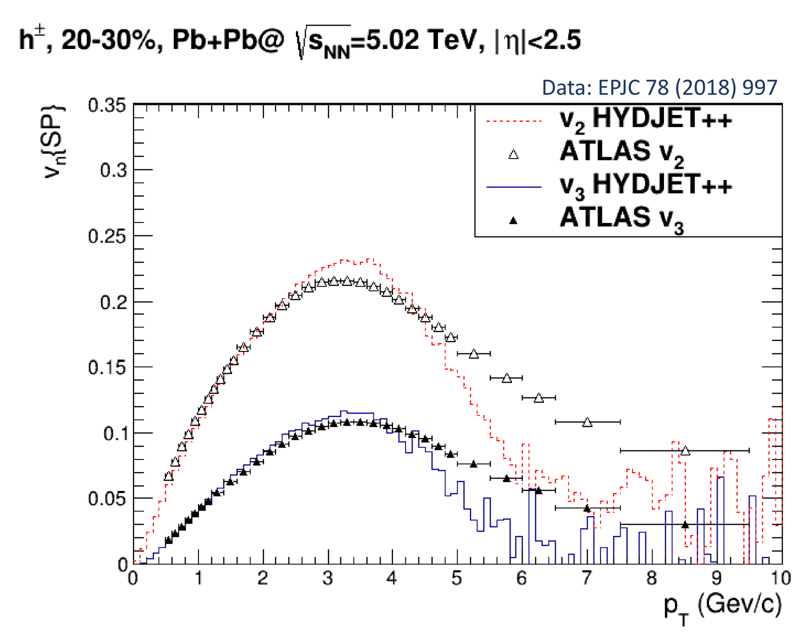
- Different thermal freeze-out temperatures T_{th} need to be used for correct description of charged hadrons $h^{\pm}$, open charm D^0 mesons and J/ψ meson at different collision energies as can be seen in the table

System	$\sqrt{s_{\mathrm{NN}}}$ [TeV]	Particle	T_{th} [MeV]
Au+Au	0.2	$h^{\pm}$	100
		$D^0, J/\psi$	165
Pb+Pb	2.76	$h^{\pm}, D^0$	105
		J/ψ	165
Pb+Pb	5.02	$h^{\pm}, D^0$	105
		J/ψ	165

CHARGED HADRONS $h^{\pm}$

- The same set of simulation parameters has been used for both charged hadrons and D^0 mesons
- v_2 and v_3 have been simulated by experiment adapted scalar product (SP) method





- **Pseudorapidity** η distribution is described well by HYDJET++ up to 30-40% centrality bin
- HYDJET++ correctly reproduces **elliptic and triangular flow** of charged hadrons in semi-central 20-30% events in $0 < p_{\mathrm{T}} < 4$ GeV/c region and underestimates the data in $4 < p_{\mathrm{T}} < 10$ GeV/c region

J/ψ MESON

- HYDJET++ parameter γ_c accounts for deviations of charm multiplicity from the complete thermal equilibrium value
- Parameter $\gamma_c = 15$ was tuned to achieve the best match with the experimental J/ψ p_{T} spectrum in 0-10% centrality range (Fig. 1)
- **Underestimation** of the experimental data in $4 < p_{\mathrm{T}} < 6$ GeV/c region is observed
- The underestimation was slightly eliminated by rising the maximal fluid flow transverse rapidity at thermal freeze-out $\rho_{\max}$ (Fig. 2)
- Qualitatively **good description of v_2** is observed in 0-10% centrality range regardless the $\rho_{\max}$ parameter (Fig. 3)

Fig. 1: J/ψ yield transverse momentum spectrum

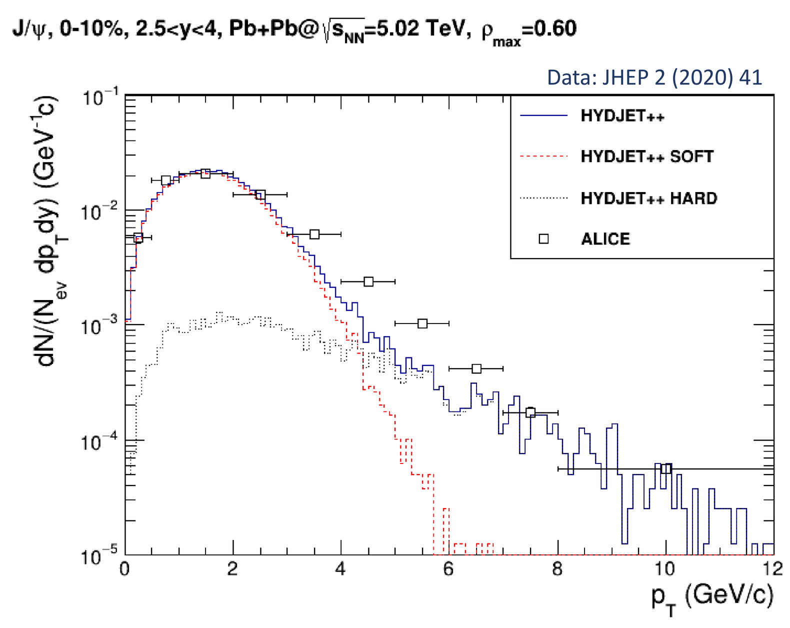


Fig. 2: Comparison of HYDJET++ model and experimental data for two $\rho_{\max}$ values

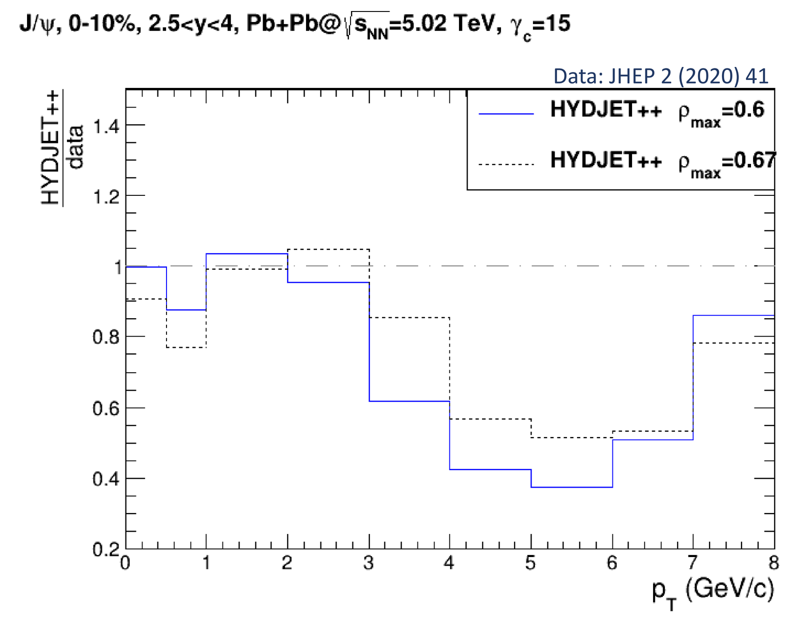
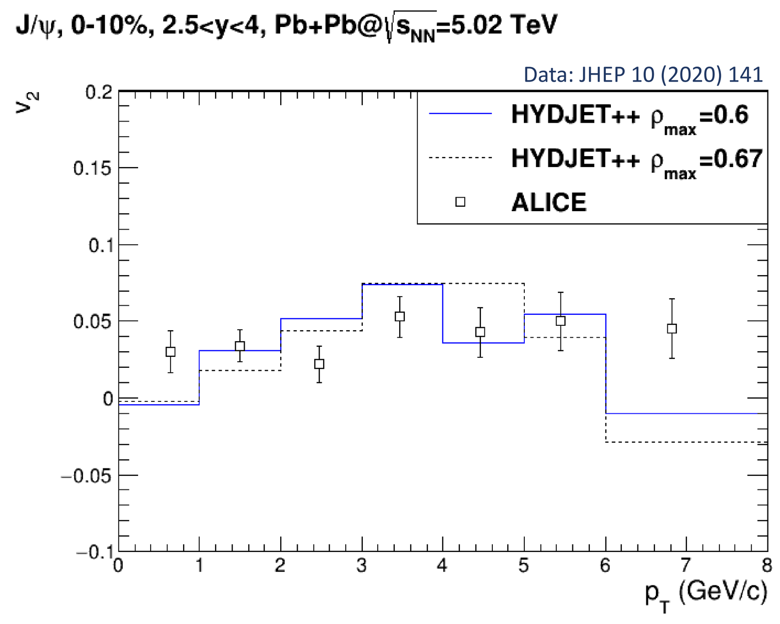
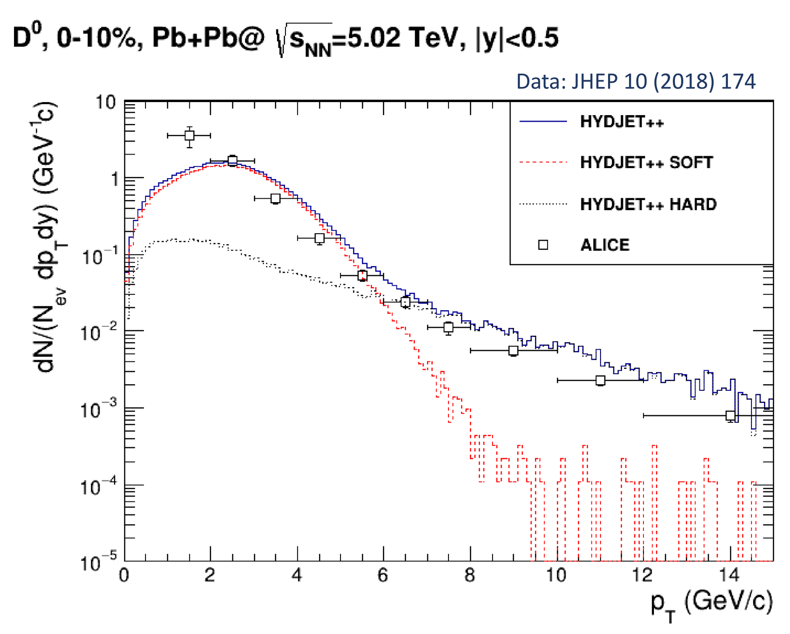


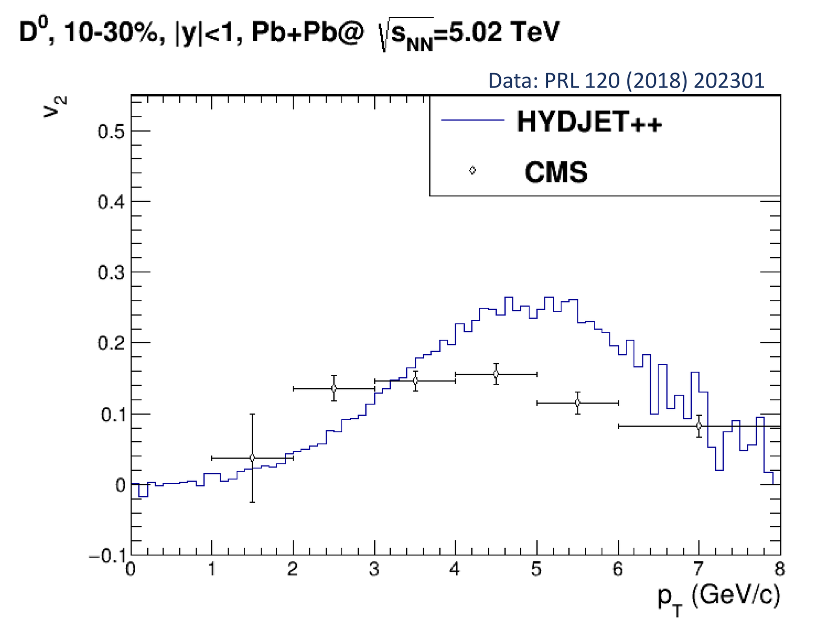
Fig. 3: Elliptic flow of J/ψ



D^0 MESONS

- Parameter $\gamma_c = 15$ used according to the J/ψ tuning





- Transverse momentum **p_{T} distribution** is described well by HYDJET++ in 0-10% centrality bin
- In 10-30% centrality, HYDJET++ generally follows the trend of the **elliptic flow** experimental data but overestimation in $4 < p_{\mathrm{T}} < 6$ GeV/c region is observed

CONCLUSIONS

- Raising collision energy from $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV to $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV does not have a significant impact on the thermal freeze-out temperature T_{th} which **is the same value for $h^{\pm}$ and D^0 meson and different value for J/ψ**
- Correct description of charm meson spectra has been achieved by tuning charm enhancement parameter $\gamma_c = 15$
- Elliptic flow of J/ψ is described qualitatively well regardless the maximal fluid flow transverse rapidity at thermal freeze-out $\rho_{\max}$ parameter

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