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Projections for jet quenching measurements in O–O collisions at $\sqrt{s_{\mathrm{NN}}} = 6.37$ TeV during the LHC Run 3

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High-multiplicity events in small collision systems (pp, p–Pb) at LHC energies exhibit soft-physics phenomena that are associated with collective dynamics of the quark-gluon plasma (QGP) in large collision systems, e.g. azimuthal correlation between soft particles having large pseudo-rapidity separation. Jet quenching is likewise a necessary consequence of the QGP formation, however, within the precision of current measurements there is no significant evidence of jet quenching in small systems. Improvement of the experimental sensitivity to jet quenching in small collisions systems is therefore essential to address the question of the limits of QGP formation. In Run 3, the LHC will carry out a brief run with O–O collisions at $\sqrt{s_{\mathrm{NN}}} = 6.37$ TeV. The O–O system bridges the gap in system size between pp and p–Pb on one side and Pb–Pb on the other, and provides measurement channels in which quenching effects are expected to be both, observable experimentally and calculable theoretically. This article presents projections for high-precision measurements of jet quenching in the O–O run by ALICE.

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Final states of small collision systems like pp or p–Pb exhibit some signatures which are associated usually with quark-gluon plasma formation such as strangeness enhancement [1] or particle collectivity [2]. However, within precision of current experimental measurements these systems do not exhibit evidence of jet quenching. The measured nuclear modification factor in p–Pb is compatible with unity [3] and the estimated energy loss for $R = 0.4$ jets was found to be less than 400 MeV at the 90% confidence level [4]. This raises a question whether the observed phenomena are indeed associated with the quark-gluon plasma formation. Onset of jet quenching will be therefore searched for in a bit larger oxygen–oxygen system which bridges the gap in size between p–Pb and Pb–Pb and which has better control of collision geometry than p–Pb. As pointed out in Ref. [5], a short O–O run corresponding to 0.5 nb^{-1} should provide sufficient precision for detection of jet quenching in minimum bias collisions. The ALICE Collaboration has therefore investigated several systematically independent approaches for jet quenching measurements in the O–O system and assessed the corresponding sensitivity of the measurements [6].

The first approach is based on the measurement of the nuclear modification factor of inclusive charged hadrons in minimum bias O–O collisions. In this case, the Glauber theory [7] gives an exact value of the scaling factor for the pp reference spectrum, which equals A^2. In contrast, an analogous measurement of the nuclear modification factor from centrality biased O–O samples would require to scale the pp reference with nuclear overlap functions. These are known to have considerable uncertainties [5], which would cause considerable deterioration in the precision of the result.

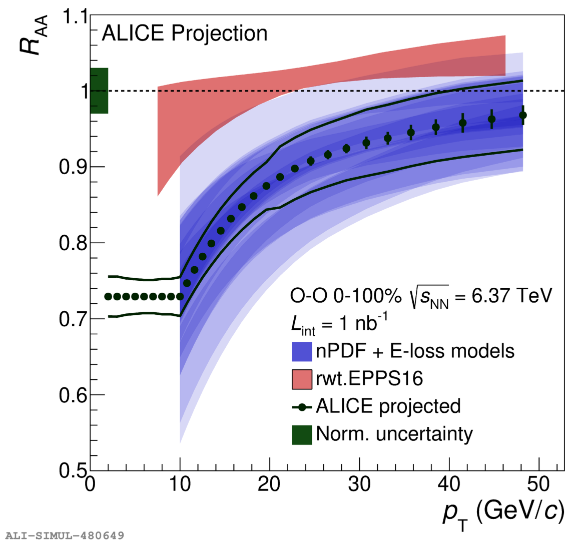

Figure 1: Projection of the nuclear modification factor for inclusive spectrum of charged hadrons in O–O collisions at $\sqrt{s_{\mathrm{NN}}}$ = 6.37 TeV. Taken from [6].

Figure 1 shows the ALICE projection of the charged hadron nuclear modification factor measurement in minimum bias O–O collisions at $\sqrt{s_{\mathrm{NN}}}$ = 6.37 TeV. The projection assumed for O–O collisions an integrated luminosity of 1 nb^{-1}. Central values of the ALICE projection are constructed to follow the mean of the blue band which represents theory calculations that account for parton energy loss using energy loss models that are on the market, see Ref. [5] for more details. The red band presents theory calculations of the nuclear modification factor which account just for nuclear parton distribution functions without considering parton energy loss. The error bars on the ALICE projection show the expected statistical precision of the measurement. The statistical uncertainty is better than 1.5%. The band bounded by the green lines represents a combined systematic uncertainty, which is about 4–6% large, and which comes from interpolation of the pp reference, cross section normalization, and other sources. Construction of the interpolated pp reference is necessary since it is not expected that there will be a pp run at the same center of mass energy. The projection suggests that 1 nb^{-1} of minimum bias O–O should provide sufficient precision to detect the expected magnitude of jet-quenching signal.

The other approach, which will be used to search for jet quenching, utilizes semi-inclusive transverse momentum (p_{T}) spectra of jets that recoil in azimuth from high-p_{T} trigger hadrons [4]. The method would be used to look for a p_{T} shift of the spectra measured in minimum bias O–O relative to pp collisions or in central O–O relative to peripheral O–O collisions. The technique enables on statistical basis in a data driven way to remove contribution of jets which are not associated with the trigger hadron. The left panel in Fig. 2 shows statistical projections of two semi-inclusive p_{T} distributions of jets, which are nearly back to back in azimuth w.r.t. high-p_{T} trigger hadrons from two exclusive p_{T} bins. The spectra are normalized per one trigger hadron and jet p_{T} was corrected for the expected mean underlying event density that was estimated on event-by-event basis. Close to zero jet p_{T}, the shape of the distributions is largely independent of trigger track p_{T}. In this region, the spectra are dominated by combinatorial background jets, which are not correlated with the trigger hadron. Subtraction of the distributions from one another removes this component. The subtracted spectrum is denoted Δ_{recoil}. Further it is assumed that the Δ_{recoil} distributions which are measured in O–O and pp collisions have locally exponential character, $\Delta^{\mathrm{OO}}_{\mathrm{recoil}} = a \exp\left[-(p^{\mathrm{ch}}_{\mathrm{T,jet}} + \bar{s})/b\right]$ and $\Delta^{\mathrm{pp}}_{\mathrm{recoil}} = a \exp\left[-p^{\mathrm{ch}}_{\mathrm{T,jet}}/b\right]$, with common parameters a and b. Their relative p_{T} shift, $\bar{s}$, can be extracted from the ratio $\Delta^{\mathrm{OO}}_{\mathrm{recoil}}/\Delta^{\mathrm{pp}}_{\mathrm{recoil}} = \exp\left[-\bar{s}/b\right]$. The statistical uncertainty on $\bar{s}$ corresponding to 1 nb^{-1} minimum bias O–O data set was combined with the expected systematic uncertainties [6] to obtain 90% confidence limits on the minimum size of $\bar{s}$ which can be measured. For the case of minimum bias O–O collisions with the pp reference it was found that $\bar{s} > 0.16\,\mathrm{GeV}/c$ whereas in the case when the shift is extracted from the ratio of central to peripheral O–O collisions $\bar{s} > 0.14\,\mathrm{GeV}/c$. Precision of the first measurement is affected by the uncertainty due to the necessity to extrapolate the $\Delta^{\mathrm{pp}}_{\mathrm{recoil}}$ spectrum measured at $\sqrt{s} = 5.02$ TeV to $\sqrt{s} = 6.37$ TeV. The limits on the shift can be translated to the following limit on the nuclear modification factor $R_{\mathrm{AA}} \gtrsim 0.98$. The semi-inclusive technique should therefore be more sensitive to the possible jet quenching when compared to the above mentioned nuclear modification factor measurement. The right panel in Fig. 2 then shows these projections in the context of other semi-inclusive measurements where ALICE Collaboration measured or where it plans to measure quenched energy which is transported out of jet cone.

In summary, the ALICE projections for the O–O run show that jet quenching detection should be within the reach of the experiment.

Acknowledgments

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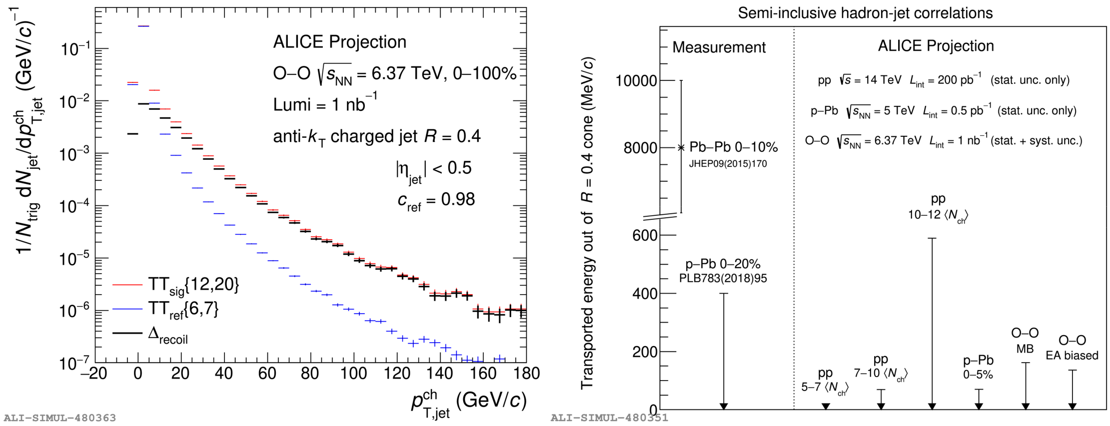

Figure 2: Left: Projections of semi-inclusive $p_{\rm T}$ spectra of jets which recoil from trigger hadrons with $p_{\rm T}$ in the range 12–20 GeV/c and 6–7 GeV/c. The projections were obtained using the PYTHIA 8 Monash event generator [8]. Right: Projected sensitivity of the semi-inclusive measurements to the quenched energy transported out of a jet cone in Run 3 and Run 4 for various systems compared to the measurements from Run 1. Taken from [6].

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