Heavy ion collisions at the LHC, last call for predictions

Investigating the extended geometric scaling region at LHC with polarized and unpolarized final states

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Abstract. We present predictions for charged hadron production and Λ polarization in \( p-p \) and \( p-Pb \) collisions at the LHC using the saturation inspired DHJ model for the dipole cross section in the extended geometric scaling region.

At high energy, scattering of a particle off a nucleus can be described in terms of a colour dipole scattering off small-\( x \) partons, predominantly gluons, in the nucleus. At very high energy (small \( x \)), the dipole amplitude starts to evolve nonlinearly with \( x \), leading to saturation of the density of these small-\( x \) gluons. The scale associated with this nonlinearity, the saturation scale \( Q_s(x) \), grows exponentially with \( \log(1/x) \).

The nonlinear evolution of the dipole amplitude is expected to be characterized by geometric scaling, which means that the dipole amplitude depends only on the combination \( r_T^2 Q_s^2(x) \), instead of on \( r_T^2 \) and \( x \) independently. Moreover, the scaling behaviour is expected to hold approximately in the so-called extended geometric scaling (EGS) region between \( Q_s^2(x) \) and \( Q_{gs}^2(x) \sim Q_s^2(x)/\Lambda \).

The small-\( x \) DIS data from HERA, which show geometric scaling, were successfully described by the GBW model [1]. To describe the RHIC data on hadron production in \( d-Au \) in the EGS region a modification of the GBW model was proposed by Dumitru, Hayashigaki and Jalilian-Marian (DHJ), incorporating scaling violations in terms of a function \( \gamma^\dagger \) [2]. This DHJ model also describes \( p-p \) data at forward rapidities [3].

DHJ model prediction for charged hadron production

Using the DHJ model we can make a prediction for the \( p_t \)-spectrum of charged hadron production in both \( p-Pb \) and \( p-p \) collisions at the LHC, at respectively \( \sqrt{s} = 8.8 \) TeV and \( \sqrt{s} = 14 \) TeV. Figure 1a shows the minimum bias invariant yield for an observed hadron rapidity of \( y_h = 2 \) in the centre of mass frame, which for 1 GeV \( \lesssim p_t \lesssim 10 \) GeV predominantly probes the EGS region. We note that at this rapidity the result is not sensitive to details of the DHJ model in the saturation region \( r_T^2 > 1/Q_s^2 \). Further, from ♠ We note that at central rapidities we cannot reproduce exactly the results of [2] for large \( p_t \). Therefore, a modification of the model may be needed to described all RHIC data.
we expect that $p_t$-independent $K$-factors are needed to fix the normalization. We conclude that the LHC data on hadron production in both $p$-$Pb$ and $p$-$p$ collisions will provide valuable data to further study the dipole scattering amplitude near the onset of saturation, particularly the behaviour of the function $\gamma$, which is discussed in e.g. [4].

**DHJ model prediction for $\Lambda$ polarization**

Another interesting small-$x$ observable is the polarization of $\Lambda$ hyperons produced in $p$-$A$ collisions, $P_\Lambda$. This polarization, oriented transversely to the production plane, was shown to essentially probe the derivative of the dipole scattering amplitude, hence displaying a peak around $Q_s$ when described in the McLerran-Venugopalan model [5]. If this feature persists when $x$-evolution of the dipole scattering amplitude is taken into account, $P_\Lambda$ would be a valuable probe of saturation effects. Using the DHJ model for the $x$-evolution of the scattering amplitude, we find that $P_\Lambda$ displays similar behaviour as in the MV model. This is depicted for fixed $\Lambda$ rapidities of 2 and 4 in figure 1b. The position of the peak scales with the average value of the saturation scale $\langle Q_s(x) \rangle$. In the plotted region, the peak is located roughly at $\langle Q_s(x) \rangle/2$.

The figure also shows that, like in the MV model, in the DHJ model $|P_\Lambda|$ scales approximately linearly with $x_F$, which means that at the LHC it is very small due to $\sqrt{s}$ being very large: rapidities around 6 are required for $P_\Lambda$ to be on the 1% level, although there is a considerable model uncertainty in the normalization.

We conclude that the polarization of $\Lambda$ particles in $p$-$Pb$ collisions is an interesting probe of $\langle Q_s(x) \rangle$, but is probably of measurable size only at very forward rapidities.

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**Figure 1.** a. Charged hadron production. b. $\Lambda$ polarization. In both plots, $A_{\text{eff}} = 20$, and parton distributions and fragmentation functions of [2] and [5] were used.

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