Gluon saturation: Forward dijets in p-p and p-Pb collisions

Based on arXiv:2306.17513, arXiv:2210.06613.

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NCN GRANT 2021/41/N/ST2/02956

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EIC Early Career (EC) Workshop

July 23-24, 2023

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Gluon saturation from forward dijets

One of the long-standing problems is finding clear experimental signals of gluon saturation.

Gluon saturation @ EIC EIC Yellow report : [arXiv :2103.05419]
[Rolf Ent's talk !] [Andrea Signori's talk !]

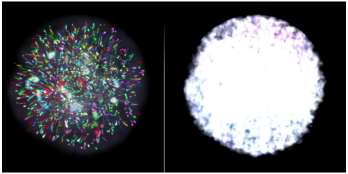
Motivation

C. Marquet [0708.0231], A. van Hameren et. al. [1402.5065].

1) Forward region allows us to probe parton densities of one of the colliding hadrons at very small longitudinal fractions x. [Ishita Ganguli's talk !]

2) Comparisons of p-p and p-Pb cross sections for the same observables can provide some evidence for saturation since such effects are further enhanced by increasing the atomic number of one of the colliding particles.

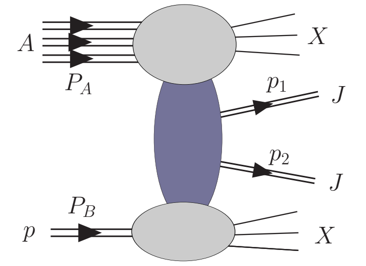
large-x small-x



https://l1nq.com/dDfzH

Diagrammatic representation

Momentum assignment in the inclusive dijet production in p+A collision



1) J are jets with momenta p_1, p_2.

2) X denotes arbitrary final states.

Theoretical framework

Kinematics

1) $A(P_A) + p(P_B) \rightarrow J(p_1) + J(p_2) + X$.
2) $P_A^\mu = (E_A, 0, 0, -E_A) = E_A n_+^\mu$.
3) $P_B^\mu = (E_B, 0, 0, E_B) = E_B n_-^\mu$.
4) Longitudinal momentum fractions :

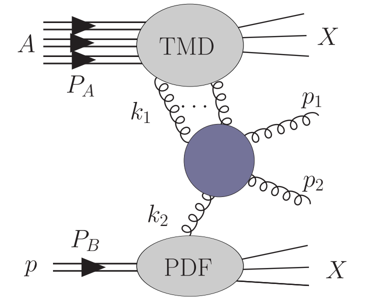
$$x_A = \frac{k_1 \cdot P_B}{P_A \cdot P_B}, \qquad x_B = \frac{k_2 \cdot P_A}{P_B \cdot P_A},$$

k_1 is the momentum transferred to the target A and k_2 is the momentum transferred to the proton target.

5) $x_A \ll x_B$.

ITMD factorization

pure gluon channel



The ITMD factorization formula for the production of two jets [arXiv :1503.03421]

$$\frac{d\sigma^{\mathrm{pA}\rightarrow j_1 j_2 + X}}{d^2 P_T d^2 k_T dy_1 dy_2} = \sum_{a,c,d} x_{\mathrm{p}} f_{a/\mathrm{p}}(x_{\mathrm{p}}, \mu) \sum_{i=1}^{2} \mathcal{K}^{(i)}_{ag^* \rightarrow cd}(P_T, k_T; \mu)\, \Phi^{(i)}_{ag \rightarrow cd}(x_{\mathrm{A}}, k_T),$$

$\vec{P}_T = \vec{p}_{T1} - \vec{p}_{T2}$ and $\vec{k}_T = \vec{p}_{T1} + \vec{p}_{T2}$ for jets with transverse momenta $\vec{p}_{T1}$ and $\vec{p}_{T2}$, with y_1 and y_2 being the jet rapidities.

Sudakov resummation

A.H. Mueller, Bo-Wen Xiao, and Feng Yuan. [arXiv :1308.2993]

A.H. Mueller, Bo-Wen Xiao, and Feng Yuan. [arXiv :1210.5792]

Impact parameter space – full b-space

$$\frac{d\sigma^{\mathrm{pA}\to j_1 j_2+X}}{d^2P_T d^2k_T dy_1 dy_2} = \sum_{a,c,d} x_{\mathrm{p}} \sum_{i=1}^{2} \mathcal{K}^{(i)}_{ag^*\to cd}(P_T, k_T; \mu)$$
$$\times \int db_T b_T J_0(b_T k_T) f_{a/\mathrm{p}}(x_{\mathrm{p}}, \mu_b)\, \widetilde{\Phi}^{(i)}_{ag\to cd}(x_{\mathrm{A}}, b_T)\, e^{-S^{ag\to cd}(\mu, b_\perp)},$$

Numerical Results

A. van Hameren [1611.00680].

KaTie can be downloaded from https://bitbucket.org/hameren/katie/downloads/

1) Jets were defined using the anti-k_T jet clustering algorithm with a radius of $R = 0.4$.

M. Cacciari, G. P. Salam and G. Soyez [0802.1189].

2) Kinematic cuts

ATLAS

Rapidity range : $2.7 < y_1^\star, y_2^\star < 4.0$.
Energy : $\sqrt{s} = 8.16\,\mathrm{TeV}$.

i) $28\,\mathrm{GeV} < p_{T1}, p_{T2} < 35\,\mathrm{GeV}$,

ii) $35\,\mathrm{GeV} < p_{T1}, p_{T2} < 45\,\mathrm{GeV}$,

iii) $35\,\mathrm{GeV} < p_{T1} < 45\,\mathrm{GeV}$
$28\,\mathrm{GeV} < p_{T2} < 35\,\mathrm{GeV}$.

FoCal - ALICE

Rapidity range : $3.8 < y_1^\star, y_2^\star < 5.1$
Energy : $\sqrt{s} = 5.02\,\mathrm{TeV}$, $8.16\,\mathrm{TeV}$ and $8.8\,\mathrm{TeV}$.

i) $p_{T1}, p_{T2} > 10\,\mathrm{GeV}$,

ii) $p_{T1}, p_{T2} > 20\,\mathrm{GeV}$.

p-p cross section for $\sqrt{s} = 14\,\mathrm{TeV}$.

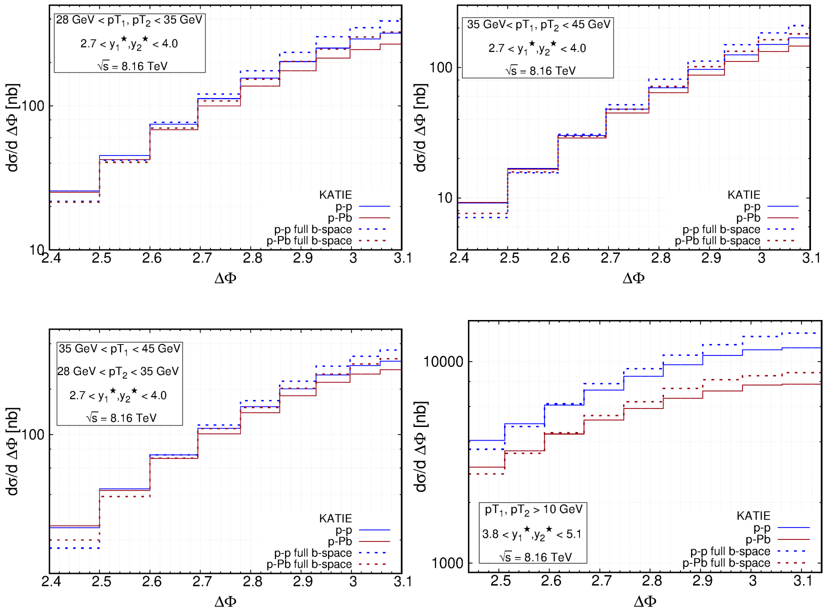
3) The factorization and renormalization scales : $\mu = (p_{T1} + p_{T2})/2$.

4) TMD gluon distributions : calculated in *A. van Hameren et. al. [1607.03121]* based on the Kutak-Sapeta (KS) fit of the dipole gluon density *[1205.5035]*.

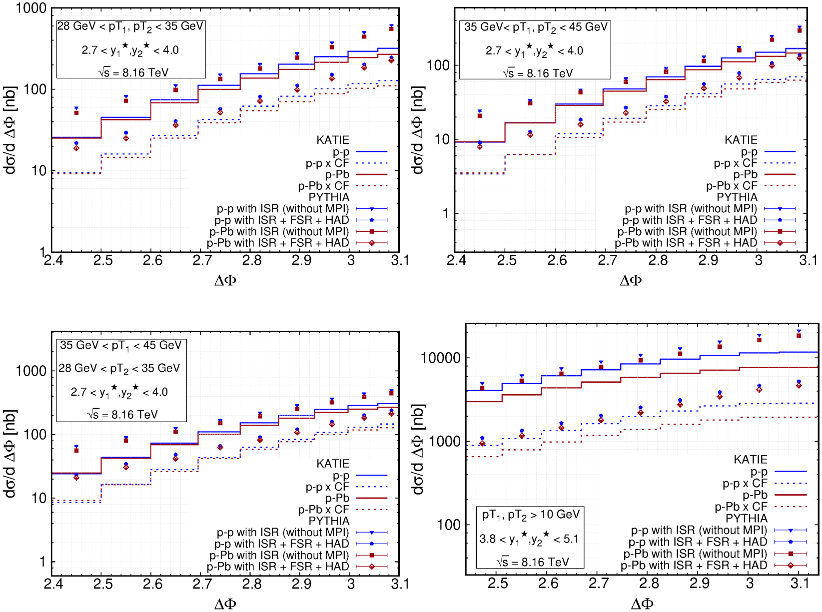
5) Collinear PDFs : CTEQ10NLO PDF set from LHAPDF6.

6) Channels : $qg^* \to qg$, with five quark flavours, and $gg^* \to gg$. The channel $gg^* \to \bar{q}q$ was neglected because its contribution, for the considered kinematic domain, is quite small.

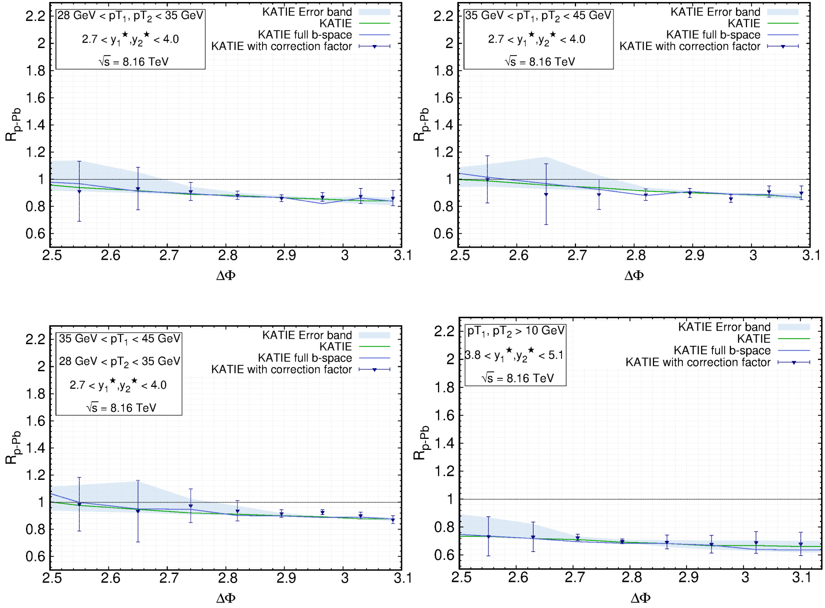
Results : Azimuthal Correlators KaTie [arXiv :2210.06613]

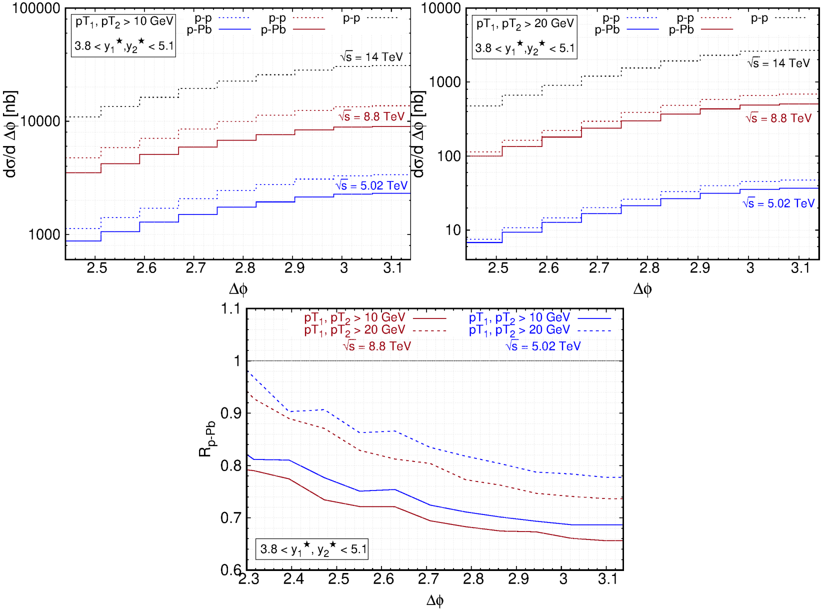


Results : Azimuthal correlators KaTie and PYTHIA [arXiv :2210.06613]



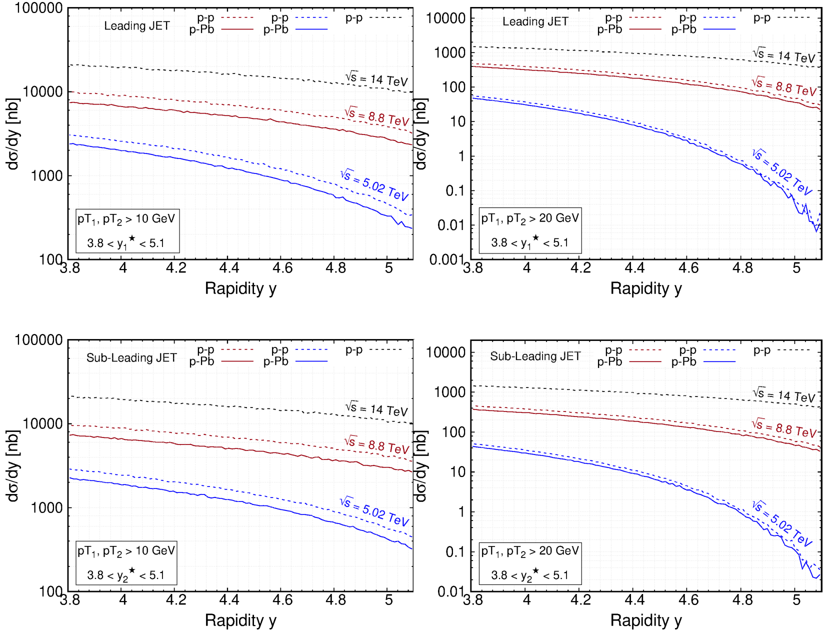
Results : Nuclear modification ratio [arXiv :2210.06613]





pT1, pT2 > 10 GeV
3.8 < y1*,y2* < 5.1
p-p
p-Pb
√s = 14 TeV
√s = 8.8 TeV
√s = 5.02 TeV
dσ/d Δϕ [nb]
Δϕ
pT1, pT2 > 20 GeV
3.8 < y1*,y2* < 5.1
pT1, pT2 > 10 GeV
pT1, pT2 > 20 GeV
√s = 8.8 TeV
√s = 5.02 TeV
R p-Pb
3.8 < y1*, y2* < 5.1
Δϕ

Latest results for FoCal kinematics [arXiv :2306.17513]



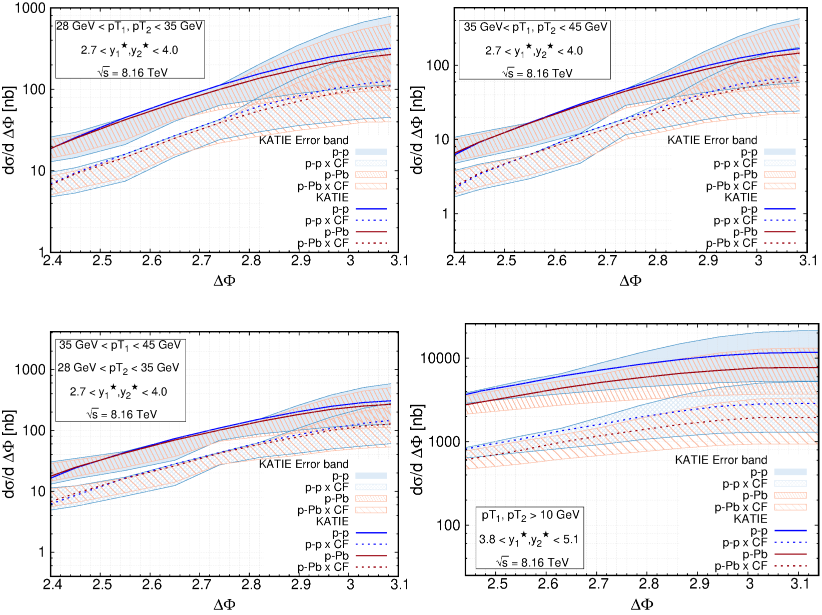
Summary

1) Dijets have the advantage of providing the azimuthal correlations, which in the back-to-back kinematics are sensitive to saturation even for relatively hard jets.
2) We provided predictions for the cross sections and the nuclear modification ratio R_{pA} for forward dijet production in kinematic domains covered by the FCal ATLAS detector and the planned FoCal upgrade of the ALICE experiment based on the application of the ITMD factorization together with the Sudakov resummation necessary for realistic description.
3) The Sudakov form factor was implemented using two approaches : a simplified approach, where the collinear PDF describing the dilute projectile is factorized, and the full b-space resummation. Both frameworks give results that are close to each other for the considered kinematic domain.
4) The ITMD calculation is a parton level calculation. We therefore used PYTHIA in order to estimate corrections for hadronization, FSR shower and MPI effects.
5) The measurement of the nuclear modification ratio will allow to determine the suppression due to saturation effects.

Thank You for your Time !

Back-up

Results : Error bands [arXiv :2210.06613]



Sudakov

Simplification – $\mu_b = \mu$

$$\Phi^{(i)}_{ag\to cd}(x,k_\perp,\mu) = \int db_\perp \int dk'_\perp\, b_\perp\, k'_\perp\, J_0(b_\perp\, k'_\perp)\, J_0(b_\perp\, k_\perp) \times \mathcal{F}_{g^*/B}(x,k'_\perp)\, e^{-S^{ag\to cd}(\mu,b_\perp)}\,.$$

Reweighting procedure for full b-space computation

Compute

$$\left(f_{a/\mathrm{p}}\otimes\Phi^{(i)}_{ag\to cd}\right)(x_\mathrm{p},x,k_\perp,\mu) = \int db_\perp \int dk'_\perp\, b_\perp\, k'_\perp\, J_0(b_\perp\, k'_\perp)\, J_0(b_\perp\, k_\perp) \times f_{a/\mathrm{p}}(x_\mathrm{p},\mu_b)\, \mathcal{F}_{g^*/B}(x,k'_\perp)\, e^{-S^{ag\to cd}(\mu,b_\perp)}\,.$$

Reweight using the following

$$\frac{\left(f_{a/\mathrm{p}}\otimes\Phi^{(i)}_{ag\to cd}\right)(x_\mathrm{p},x,k_\perp,\mu)}{f_{a/\mathrm{p}}(x_\mathrm{p},\mu)\,\Phi^{(i)}_{ag\to cd}(x,k_\perp,\mu)}\,.$$

PYTHIA

Torbjörn Sjöstrand, Stephen Mrenna, and Peter Z. Skands [arXiv :hep-ph/0603175].

Torbjörn Sjöstrand, Stefan Ask, Jesper R. Christiansen, et al. [arXiv :1410.3012].

PYTHIA computation

PYTHIA Monte Carlo event generator version 8.307 with default tunes.

1) We used NNPDF23NLO set to describe the proton structure.

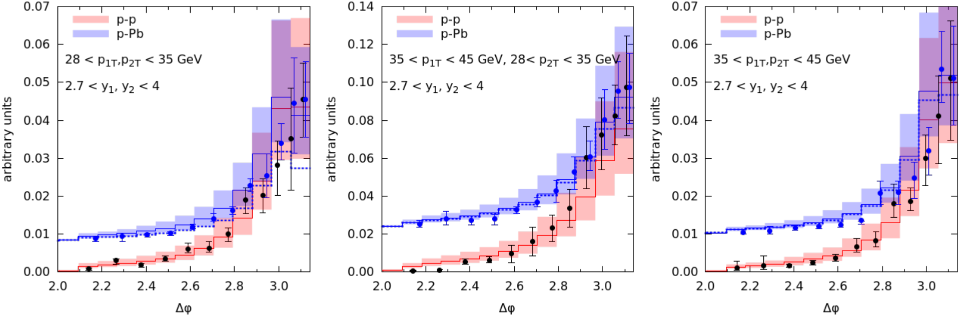
2) We used nCTEQ15WZ set for the nuclear PDF in the simulation of p-Pb collisions.

3) We simulated p-p collisions at parton level using PYTHIA with the Initial State (IS) showers only ; such setup is supposed to include similar physics as in the KaTie simulation because the TMD gluon distributions mimic the IS showers.

4) We turned on the Final State (FS) shower, hadronization, and MPI effects ; by comparing this with the previous calculation we estimate the correction factors.

5) We used the same procedure for p-Pb collisions,

6) We applied the correction factors to the KaTie results to obtain hadron-level cross sections.


p-p
p-Pb
28 < p1T,p2T < 35 GeV
2.7 < y1, y2 < 4
arbitrary units
Δφ
35 < p1T < 45 GeV, 28< p2T < 35 GeV
35 < p1T,p2T < 45 GeV

THE END !