Triangular Emission due to Gluon Saturation and Tri-hadron Azimuthal Correlations

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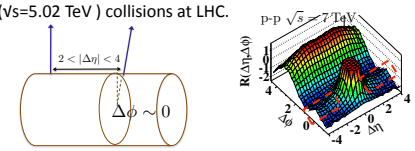
1 Puzzle: Near-side Ridge at p-p collisions!

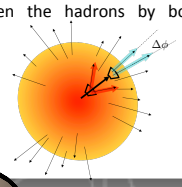
- A **near-side ridge** has been observed in **di-hadron azimuthal correlations** in p-p (√s=7 TeV) and p-Pb (√s=5.02 TeV) collisions at LHC.



- The near-side ridge corresponds to the situation where the measured hadron pair come out **collimated in azimuthal angle** $\Delta\phi \sim 0$ even though they are **separated in pseudorapidity** in many units $2 < |\Delta\eta| < 4$.

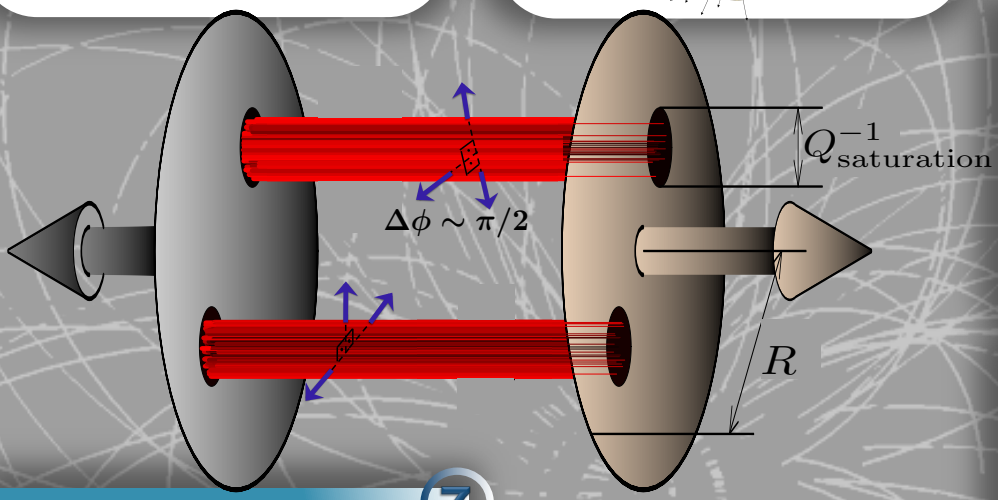
2 Known ridge in A-A collisions due to flow

•The near-side ridge has **never been predicted in p-p** collisions by event generators such as PYTHIA.
•However, it **was known from A-A collisions**, and the collimation of pair of hadrons in azimuthal angle was understood in terms of the **radial flow of the expanding quark gluon plasma** that would decrease the azimuthal separation between the hadrons by boosting them radially outward.



3 Radial flow and QGP in p-p collisions?

•The p-p ridge is somewhat **puzzling** because the formation of a quark gluon plasma in p-p collisions has never been anticipated due to the small system size.
• Application of **hydrodynamics** (radial flow) is somewhat successful for p-A collisions but the results are **not** conclusive for p-p collisions.
•Hydrodynamics is not the only current explanation of the ridge. The near-side ridge in p-p and p-Pb can be explained in terms of **interference** of the wavefunctions of hadron/nucleus that incorporate the semi-hard gluon **'saturation scale'** at high beam energy (or small-x). This is the **Glasma** approach.

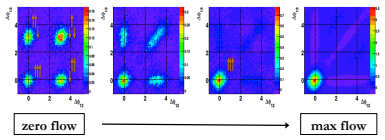


4 Glasma diagrams and azimuthal collimation

- At small-x, the wavefunction of the hadron/nucleus becomes dominated by **high number of gluons**, and due to the emergent saturation scale Q_{sat}, **glasma diagrams** that form classical gluon flux tubes between the colliding hadrons/nucleus become important.
- **Long-range correlations in rapidity** are intrinsic to the saturation physics at small-x. Glasma diagrams produce the azimuthal collimation naturally **without a radial flow**. They also explain the systematics of the data, i.e., the variation of the strength of the signal with different p_T and hadron multiplicities.

5 Suggesting Tri-hadron correlations

- The ridge seen in **di-hadron** correlations appears at **high multiplicity events**. From this, a **hydro person** can argue that high multiplicity leads to the equilibrated medium (fluid). On the other hand, a **glasma person** can argue that high multiplicity is due to a higher gluon saturation scale.
- To differentiate between these two scenarios, we have to look at the **tri-hadron** correlations.
- The main effect of the **radial flow** on tri-hadron correlations is **collimating** the three hadrons in the same azimuthal angle $\Delta\phi_{12} \sim \Delta\phi_{13} \sim 0$ and erasing the back-to-back correlations. The plots below show the effect of radial flow on simulated three particle correlations, where the axes are the azimuthal angle differences among the three hadrons (rapidity differences are not shown).

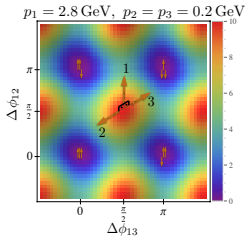


6 Novel correlation from Glasma: 90 degree emission of three hadrons

- We calculate **three gluon azimuthal correlation from Glasma** in terms of the unintegrated gluon distribution functions (UGD) **with full dependence on k_T and rapidity.** Using the UGD's from rcBK evolution gives a novel signal for certain p_T windows of the gluons where **the two hadron come out perpendicular to the third hadron.** (see window 7 and the central figure)
- This is the **anti-collimation** and it **cannot** be obtained from radial flow. We suggest that measurement of tri-hadron correlations in p-p and p-Pb may settle the discussion on the origin of the near-side ridge.

7 Tri-gluon correlation from Glasma: Peak at 90 degrees!

•The two gluons come out with **90 degrees** azimuthal angle difference with the third gluon. Radial flow **cannot** create such an anti-collimation.



•Calculation of the tri-hadron correlations from the tri-gluon correlations (shown above) via fragmentation functions, and predicting the systematics are now underway…

References

CMS Collaboration, *Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC*, JHEP 1009:091 (2010).
C. A. Pruneau, S. Gavin, S. A. Voloshin, *Transverse Radial Flow Effects on Two- and Three-Particle Angular Correlations*, Nucl.Phys. A802 (2008) 107-121

Acknowledgement

We thank Raju Venugopalan and Kevin Dusling for discussions. This work was supported by the U.S. DOE Grant No. DE-FG02-00ER41132.

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