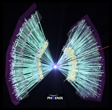
Centrality Dependence of γ^{dir} and π^0 Production in d+Au Collisions

21th Lomonosov Conference

Nour Jalal Abdulameer

Aug 29, 2023

Debrecen University & PHENIX Collaboration

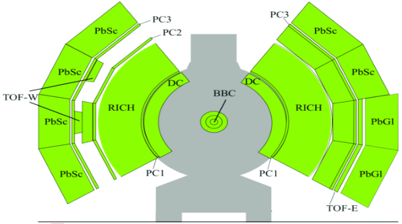


Outline

1. Introduction and the PHENIX Experiment
2. Centrality Determination and Correcting Biases
3. Insights and Future Directions

Introduction and the PHENIX Experiment

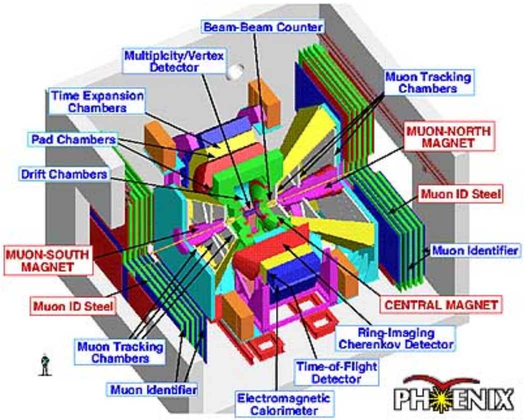
- The PHENIX experiment pioneered measurements of nuclear modification factor $R_{AB}(p_t)$ of π^0 and γ, providing strong evidence of the formation of Quark-Gluon Plasma (QGP)
- In small systems high p_T neutral hadrons are seen to be suppressed in central events , while enhanced in peripheral events.
- We study high p_T γ^{dir} and π^0 production in d+Au collisions to prove that biases in centrality determination using the standard Glauber model can be corrected by defining binary collisions using high p_T real photons.



3/4(PbSc): lead-scintillator sandwich sampling calorimeter, 1/4(PbGl): lead glass homogenous Cherenkov radiator.

PHENIX Experiment at RHIC

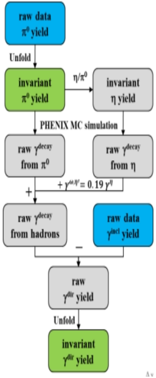
The PHENIX experiment at RHIC (BNL) took data 2000-2016 with various ion beams and collision energies. The primary goal of the PHENIX Electromagnetic Calorimeter (EMCal) is to identify photons and electrons and measure their energy and position of impact on the surface of the EMCal and to search for new phenomena such as the quark-gluon plasma in heavy ion collisions. It is also contributes to particle identification (PID).

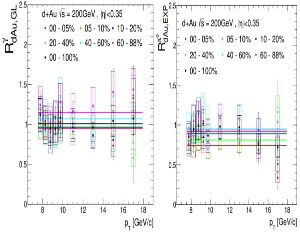


3D PHENIX detector

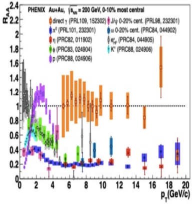
γ^{dir} and π^0 Invariant Yields and Nuclear Modification Factor

- Invariant yield of π^0s is measured at $|\eta| < 0.35$ from the $\pi^0 \to \gamma\gamma$ decay channel.
- Invariant yield of direct γs at $|\eta| < 0.35$ obtained by subtracting decay γ from inclusive photons and correcting with simulation at $\sqrt{s} = 200\,\mathrm{GeV}$.
- High p_T γ^{dir} generated during initial hard scattering are colorless and less affected by the surrounding medium (see the figure). Using them helps measure N_{coll} without bias.
- The ratio $\frac{\gamma^{dir}}{\pi^0}$ shows how π^0 centrality dependence might result from N_{coll} determination bias across centralities.





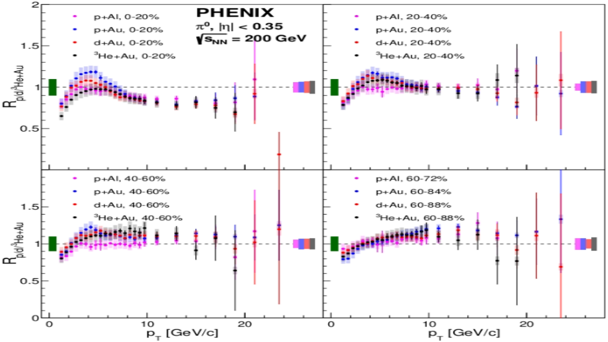
RdAu,EXP of π0 and γdir for all centrality with their first order polynomial fit function.



With RAB(pT) < 1, direct photon is transparent to the QGP.

π^0 in small system collisions

Run Number	π^0(MB)	π^0 (Centrality)	direct γ (MB)	direct γ (Centrality)
Run3	✓	✓	✓	✗
Run8	✓	✓	✗	✗
Run16	✓	✓	✓	✓

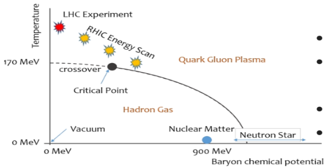


- PHENIX collected d+Au collision data at $\sqrt{s}$ = 200 GeV during three runs: 2003 (Run3), 2008 (Run8), and 2016 (Run16).
- The analysis notes published with the data grouped into 4 centrality classes ([0-20]%, [20-40]%, [40-60]%, [60-88%]), also the results published with categorization into 6 centrality classes ([0-5]%, [5-10]%, [10-20]%, [20-40]%, [40-60]%, [60-88%]).

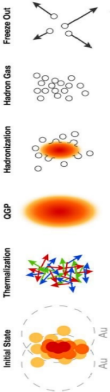
- PHENIX findings reveal distinct suppression in the R_AB of π0 at varying centralities for p+Au, d+Au, and He+Au collisions at high pT.
- While these outcomes align with the notion of QGP droplet formation in small systems, comprehending the enhancement present in peripheral collisions demands deeper consideration.

QGP Evidence and Importance

- Energy loss of partons in the QGP is revealed by high-momentum particles using hard parton scattering. At low p_T, the QGP's cooling and expansion manifests itself in azimuthal asymmetry of produced hadrons.
- Particles emitted at the end of a collision provide information on the QGP, temperatures, and initial conditions.

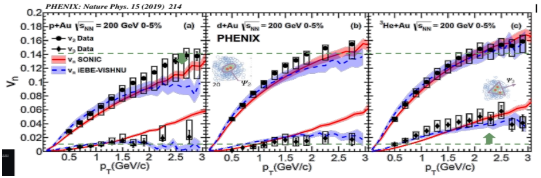


- QGP Journey :
- Probing phase transitions,
- hard scattering,
- and hadronization .



QGP evolution with time

Evidence for QGP Droplets in small Systems (p+Au, d+Au, He+Au)



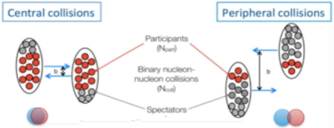
v_2 : p+Au $<$ d+Au $\approx$ 3He+Au, v_3 : p+Au $\approx$ d+Au $<$ 3He+Au

Centrality Determination and Correcting Biases

Centrality Concept

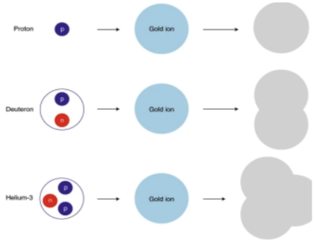
The event is defined by the overlap area, centrality(0-100%) quantifies the overlap, which dictates the participating nuclei count (N_{part}) and collisions (N_{coll}). These aspects shape the QGP size and event multiplicity. The overlap's orientation important because it govern the angular distribution of underlying event particles.

Two colliding nuclei with small and large impact parameters . The nucleons in red are the participants and those in grey are the spectators

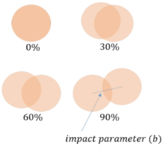


- The most central events are suppressed (<1) and peripheral events are enhanced (>1)

depiction of how the geometry of collision affects the momentum anisotropy of final state particles



Initial geometry of collision leads to spatial anisotropy which translates to momentum anisotropy of final state particles



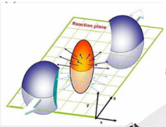
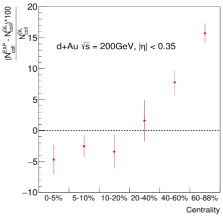


Table of Glaubermean Ncoll and Npart values for all centralities

%Centrality	$\langle N_{coll} \rangle$	$\langle N_{part} \rangle$
0% - 20%	15.10 ± 1.1	15.6 ± 0.9
20% - 40%	10.31 ± 0.7	11.1 ± 0.6
40% - 60%	6.65 ± 0.5	7.7 ± 0.4
60% - 88%	3.21 ± 0.4	4.2 ± 0.3
0% - 88%	7.59 ± 0.5	9.1 ± 0.4

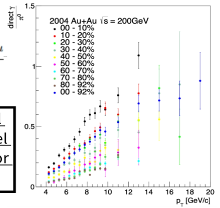
Standard Glauber model and normalizing with γ^{dir}

- Au+Au: Clear centrality dependence. The centrality dependence of π^0 is from final state effect.
- d+Au: First order, NO clear centrality dependence. The centrality dependence of π^0 is from bias in determination of N_{coll} in different centrality's.
- $N_{Expcoll}$ is dividing the invariant yield obtained in d+Au collisions over p+p collisions. Percentage difference between $N_{glaubercoll}$ and $N_{Expcoll}$.

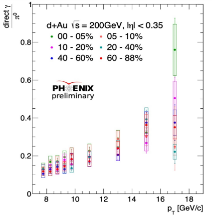


$$\langle N^{exp}_{coll} \rangle = \frac{\left(\frac{d^2N^{\gamma}}{dp_T d\eta}\right)_{dAu}}{\left(\frac{d^2N^{\gamma}}{dp_T d\eta}\right)_{pp}}$$

<u>Determination of Ncoll by using Glauber Model is biased specifically for peripheral events.</u>



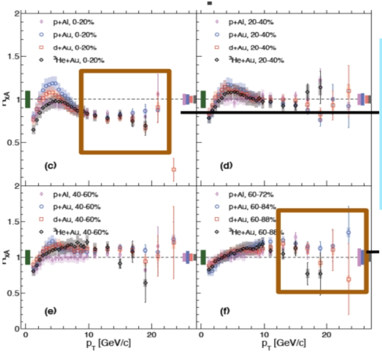
Centrality bin	N^{GL}_{coll}	N^{EXP}_{coll}
0-5%	18.115 ± 1.200	17.266 ± 0.733
5-10%	15.501 ± 1.000	15.110 ± 0.703
10-20%	13.397 ± 0.900	12.941 ± 0.516
20-40%	10.310 ± 0.700	10.476 ± 0.361
40-60%	6.650 ± 0.400	7.168 ± 0.289
60-88%	3.210 ± 0.200	$3.714 \pm 0.0.173$
0-100%	7.590 ± 0.400	7.702 ± 0.192



Glauber Model Approach Mapping Forward Charged Particles to Event's Binary Collisions.

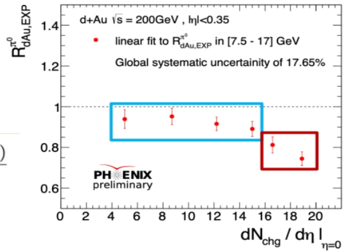
Correcting Biases with Color-Free Photon Production

- $R^{\pi^0}_{dAuExp}$ Does not show any improvement in peripheral collisions after bias correction.
- The correcting Centrality Biases via Photon-Based Binary Collisions $N^{exp}_{coll} = \frac{\gamma^{dir}_{xAu}}{\gamma^{dir}_{pp}}$.
- To determine whether the observed suppression is an initial or final state effect, one must understand the mechanism of π^0 and γ^{dir}.



- Observed supression in central collisions remains even after correcting for bias in Ncoll determination.
- Observed enhancement in peripheral collisions is an artifact of bias in the Ncoll determination using Glauber model for small systems

$$R^{\pi^0}_{dAu,EXP} = \frac{R^{\pi^0}_{dAu,GL}}{R^{\gamma}_{dAu,GL}} = \frac{(Y^{\pi^0}_{dAu}/Y^{\pi^0}_{pp})}{(Y^{\gamma}_{dAu}/Y^{\gamma}_{pp})} = \frac{(Y^{\pi^0}_{dAu}/Y^{\gamma}_{dAu})}{(Y^{\pi^0}_{pp}/Y^{\gamma}_{pp})}$$

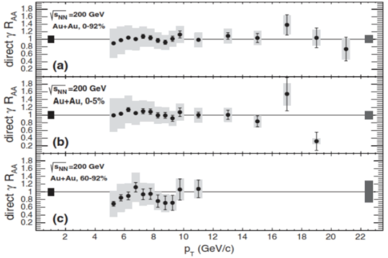


Insights and Future Directions

Bias from the Glauber model is evaluated using γ_{dir}

- determine scaling factor (N_{coll}) from the $\frac{\gamma^{dir}_{dAu}}{\gamma^{dir}_{pp}}$.
- Independent of p_T for 7.5 to 18 GeV/c.
- Good agreement in central collisions within 5%, 15% deviation in peripheral collisions.
- Bias in event selection: Event activity reduced in presence of hard scattering.

PHENIX: PRL109 (2012) 152302

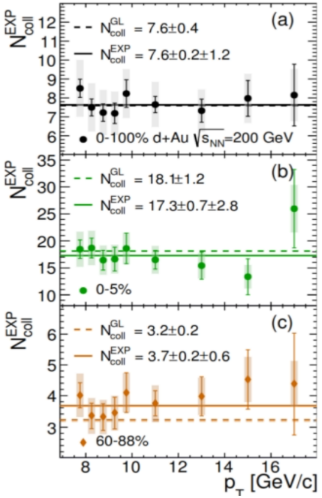


- Because of the color-neutral property, N_{coll} redefined by γ^{dir} yield experimentally

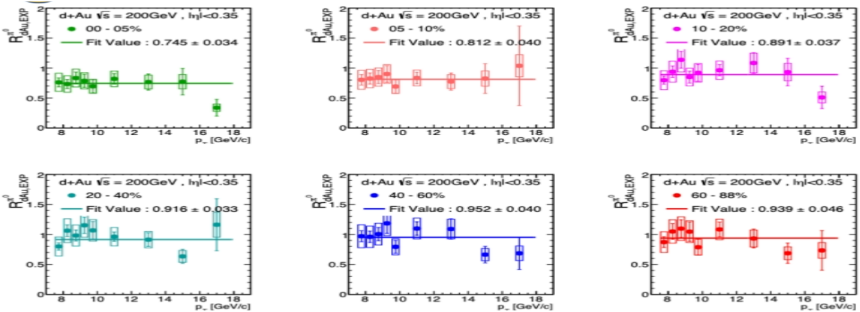
$$N^{\rm EXP}_{\rm coll}(p_T) = \frac{Y^{\gamma^{dir}}_{\rm dAu}(p_T)}{Y^{\gamma^{dir}}_{pp}(p_T)}$$

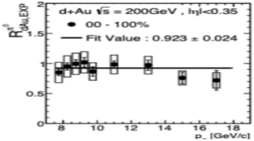
- Using the new N_{coll}, R_{dAu} for π^0 is written as following

$$R^{\pi^0}_{\rm dAu,EXP} = \frac{R^{\pi^0}_{\rm dAu,GL}}{R^{\gamma^{dir}}_{\rm dAu,GL}} = \frac{Y^{\pi^0}_{\rm dAu}/Y^{\pi^0}_{pp}}{Y^{\gamma^{dir}}_{\rm dAu}/Y^{\gamma^{dir}}_{pp}} = \frac{Y^{\pi^0}_{\rm dAu}}{N^{\rm EXP}_{\rm coll}\, Y^{\pi^0}_{pp}}$$



Nuclear Modification Factor (R_{dAu}) of π^0 and γ^{dir}





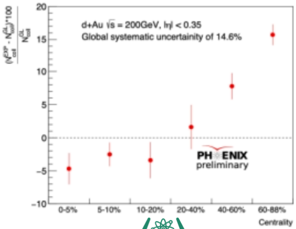
By using experimental Ncoll.Deriving unbiased $R^{\pi^0}_{dAu}$

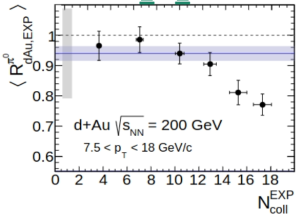
$$R^{\pi^0}_{dAu,EXP} = \frac{R^{\pi^0}_{dAu,GL}}{R^{\gamma}_{dAu,GL}} = \frac{(Y^{\pi^0}_{dAu}/Y^{\pi^0}_{pp})}{(Y^{\gamma}_{dAu}/Y^{\gamma}_{pp})} = \frac{(Y^{\pi^0}_{dAu}/Y^{\gamma}_{dAu})}{(Y^{\pi^0}_{pp}/Y^{\gamma}_{pp})}$$

- There is a clear centrality based ordering in both π 0 and direct γ.
- The most central events are suppressed (< 1) and peripheral events are enhanced (> 1).
- In central events, the suppression of π 0 s seem to be higher than those of direct γ.
- In most peripheral events, the degree enhancement of π 0 s matches that of direct γ.
- In the given p T range [7.5 – 18] GeV, to first order, both the π 0 and γ R dAu appear to be flat.

Conclusion & Future Directions

- Using direct photons to determine N_{coll} bias in the Glauber model for peripheral events.
- Experimentally determined N_{coll} with high p_T γ^{dir}.
- Further insight on the centrality bias's origin will be provided by further study of the p+Au and ^{3}He+Au systems.
- Indications that most central $R^{\pi^0}_{dAu}$ is suppressed.
- γ^{dir} are used to normalize R_{dAu} of π^0.
- Suppression in the extreme central events is around 15%.
- Models examining the initial state effect on the production of π^0 and γ^{dir} will shine light on the origin of the observed suppression.





Thank You for Your Attention

This Work is Supported by the OTKA 131991