Differential π^{\vee} and **photon modification in** *d***+Au collisions** *π*0 **[based on nucl-th/2404.17660]**

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Letter

Contribution to differential π^0 and γ_{dir} modification in small systems from color fluctuation effects

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presence of physical effects which influence the experimental determination of collision centrality in the presence parton interact more weakly with the nucleons in the nucleus, leading to a smaller (larger) than expected yield in large (small) activity events. A recent measurement by the PHENIX Collaboration compared the yield of neutral pion and direct photon production in $d + Au$ collisions, under the argument that the photon yields correct for such

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- PHENIX measures the double ratio in small systems $R_{\rm dAu}(\pi^0)/R_{\rm dAu}(\gamma_{\rm dir})$ ing *N* GL coll within the GLM framework. The *N*EXP zio ratit $R_{\text{aux}}(\pi^{\vee})/R_{\text{aux}}(\gamma_{\text{aux}})$ in small syste a more accurate and the scattering of the hard-scattering of the scattering of
- ➡ Argument: the normalization to the number of photons takes out all centrality bias effects, and any modification is a **final-state effect** contribution. Using *N*EXP coll eliminates the enhancement, **Weighthally mail in the mormalization to the paint of the paint o** UUITERIILY NICO UNUULU, CHU CHIY modification is a final-state eife

• For centrality averaged events, $R_{dAu}(\pi^0)/R_{dAu}(\gamma_{dir}) = 0.92 \pm 0.02$ (stat) \pm 0.15 (syst) sion. Furthermore, α is dependence, $R_{dAu}(\pi^{\circ})/R_{dAu}(\gamma_{dir}) = 0.92 \pm 0.02$ (stat) \pm

• In the **most central** events, $R_{dAu}(\pi^0)/R_{dAu}(\gamma_{dir}) = 0.77 \pm 0.03$ (stat) \pm 0.13 (syst) \mathbf{b} be larger \mathbf{b} in the larger \mathbf{b} in the larger \mathbf{a} $\Lambda_{dAu}(n)$ *p* $\Lambda_{dAu}(n)$ in $\rho = 0.77 \pm 0.03$ (stat) \pm

Measurement of π^0/γ **modification in** *d***+Au d** *z***iic v** $\frac{1}{2}$ summary, which the simultaneous measurement of $\frac{1}{2}$ and dir at high *p^T* in *d*+Au collisions at p*sNN* = 200 $G_{\rm eff}$ is the periodic that the previously obes that the previously ob-

*N*EXP $\frac{1}{2}$ $\frac{1}{2}$ *Y* dir *T. Hachiya, PHENIX Overview, nucl-ex/2303.12899*

The PHENIX results would require $\delta p_{\rm T}/p_{\rm T} \approx$ 1-2% in 0-5% *d*+Au collisions

At LHC energies, limit of $\delta p_\text{T}/p_\text{T}$ < 1.4% at 90% CL (in 0-20% ZDC-selected *p*+Pb events)

- Increased event activity in the presence of a hard-scattering
	- ➡ overestimate hard scattering yields in high-multiplicity events, underestimate them in low-multiplicity events
- This particular bias does not have a strong process $(\gamma_{\rm dir}$ vs. π^0) or kinematic dependence *γ*dir *π*⁰
	- ➡ the PHENIX strategy likely eliminates this particular bias ✅

Well-known "multiplicity" bias J. ADAM *et al.* PHYSICAL REVIEW C **91**, 064905 (2015)

centrality estimators explained in the text. The lines are from G-PYTHIA calculations. The systematic error on the spectra is only shown for the *ALICE, PRC 91 (2015) 064905* + much work by PHENIX, Steinberg, 1 around units internet unity of the system system is system in the system in the system is shown and uncertainty
Moreoby a light blue boxe at high *p*T. *Morsch, Loizides, others*

A different bias for extremely high- $x_{\overline{\rho}}$ process ich iciy ingil λ_n process \blacksquare

- For hard-scattering processes with Bjorken-*x* in the proton, $x_p \gtrsim 0.1$:
	- ➡ data at RHIC and LHC: there is an **anti**-correlation between increasing x_p and the backward multiplicity (i.e. in the nucleus-direction)
	- ➡ i.e. relative movement of events from "central" to "peripheral" category
	- \blacktriangleright observed indirectly as an $R_{\mathrm{CP}} < 1$

- FIG. 1. Schematic representation of ^a proton-nucleus collision • One compelling explanation: **proton** color fluctuations **color fluctuations**
- transverse size through the nucleus, with interesting in the nucleus, with impacted nucleus, with impacted nucleons in \blacktriangleright protons with a large- x_p parton are quite different than "average" weakly formed cases (protons, and strike fewer nucleons in the nucleus

M. Alvioli et al PRD 98 (2018) 071502(R)

shitt of strong LIF dependence of Strong UE-dependence of and Strongly suppressed by Strong and Strong are normalized by Strong and Strong are no y distribution the yield of jets, **increasing** Fig. **Property in the statistical uncertainty** and was dominated at all property R_{CP} for jets, and the dashed the data points are designed to guide the executive the eye. the combined tracker and calorimeter information. Events containing a leading \mathbf{x}_p and \mathbf{y}_p is a property \mathbf{x}_p is a leading \mathbf{x}_p is a leading \mathbf{x}_p is a leading \mathbf{x}_p is a leading \mathbf{x}_p is a leadi 120 GeV/*c* and a subleading jet with *p*T,2 *>* 30 GeV/*c* in the pseudorapidity range *|h| <* 3 were **creasingly with more forward** (higher-Strong UE-dependence of the yield of jets, **increasing** xp) selections

and and normalization uncertainties are shown as shown a asing and R_{CP} for jets, gher-
increasing with p **T** between adjusted so that both are visible. Dashed lines show that both are visible. Dashed lines show the show
Dashed lines show the show th Strongly suppressed

Evidence for x_p -UEbackward anti-correlation ide idi appolential distance distance distance distance of the edges of the edge of the edge of the edge of the e the detector, and by restricting the vertex z position to a $\overline{}$

Evidence for *xp***-UEbackward anti-correlation** PHYSICAL REVIEW LETTERS 132, 102301 (2024)

- Recent ATLAS measurement of the *RcP* for dijet events
	- ➡ event-level parton kinematics (x_{n}, x_{A}, Q^{2}) estimated via the dijet kinematics (x_p, x_A, Q^2)
- Modification is (mostly) a universal function just of *x*p
	- ➡ strongly supportive of color fluctuation picture

Quantifying color fluctuation effects

- An analysis of earlier ATLAS & PHENIX data quantitatively extracted the magnitude of the proton's "shrinking"
- 3 104 Davey Lab, The Pennsylvania State University, University, Diversity Park, Pennsylvania 16803, USA
 \blacksquare The effective \blacksquare Nucleon-nucleon-nucleon crosssection for a proton depleted by a high- \mathcal{X}_p parton is $\lambda(\mathcal{X}_p) \times \sigma_{NN}$ \sim_p parconno \sim_p is \sim_{NN}
	- $\rightarrow \lambda(x_p) < 1$ and decreases quickly with x_p t riggers with different ranges of \mathcal{A} \mathbf{r}
	- ➡ I use the results of this Color Fluctuation Model (CFM) with no changes to the parameters or introduction of **additional physics** \rightarrow Luse the results of this Color Fluct the additional projection in the additional projection of the additional projection in the set of the set of t
The additional projection in the set of the s an xp-dependent decrease in the interaction strength of the interaction strength of the interaction strength o
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Global analysis of color fluctuation effects in proton– and deuteron–nucleus collisions at RHIC and the LHC

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Rapid Communications

- MC simulation, matching specific PHENIX acceptance & kinematics
- For **direct photons**, typical x_p values probed are *xp* $\sim p_T^{\gamma}$ $T/T_{\text{beam}} \sim 0.11$
- However, **neutral pions** carry only a fraction of the fragmenting parton's $p_{\rm T}$
	- \rightarrow <x_p> ≈ 0.17, with long tail to large x_p values (28% from $x_p > 0.2$)
	- ➡ they will incur stronger CFM effects

x_p ranges probed by PHENIX measurement

Color fluctuation effect for γ_{dir} **vs.** π^{\vee}

- I apply the CFM to these x _p distributions and the PHENIX Glauber+NBD centrality model
	- ➡ The CFM has no physics to change the minimum-bias R_{dAu} – all results are only relative enhancements/suppressions
- Note the stronger effect for **pions** (higher $\langle x_p \rangle$ than direct photons (lower $\langle x_p \rangle$)
	- $F = \frac{1}{2}$ u_{p} -dependent enect $\frac{1}{2}$ ➡ These **only partially cancel** - the PHENIX $\pi^{0}/\gamma_{\text{dir}}$ observable is sensitive to this $x_{p}^{}$ -dependent effect \blacksquare $\pi^0/\gamma_{\rm dir}$ *xp*

Benchmarking: direct photon R_{dAn}

- Compare the CFM to PHENIX direct photon $R_{\rm dAu}$ data vs. centrality
	- ➡ The data has a modest enhancement at low N_{coll} , suppression at high $N_{\rm coll}$, and min-bias $R_{\rm dAu} \approx 10$
- The **Color Fluctuation Model** predicts a modification pattern exactly like this
	- The predicted modifications are modest since x_p is not too high

Comparison to $\pi^{0}/\gamma_{\text{dir}}$ **data** DENNIS V. PEREPELITSA PHYSICAL REVIEW C **110**, L011901 (2024)

- Compare the CFM to the PHENIX $_{\rm dAu}(\pi^0)/R_{\rm dAu}(\gamma_{\rm dir})$ vs. $N_{\rm coll}$ results α as α , α , α , α $R_{\rm dAu}(\pi^0)/R_{\rm dAu}(\gamma_{\rm dir})$
	- ➡ The dashed red line is the CFM $\frac{1}{2}$ $\frac{1}{2}$ assuining all fillit-bias $N_{\rm dAu} - 1$ assuming all min-bias $R_{\rm dAu} = 1$
	- n_{u} σ but the PHENIX measurement in MB nas $R_{dAu}(\pi^0)/R_{dAu}(\gamma_{dir}) = 0.92 \pm 0.02$ (stat) \pm 0.15 (syst) ➡ But the PHENIX measurement in MB has
- The solid red line is the CFM with x0.90 MB normalization to better match what is observed in data
	- in G reat a greement we N a without any orde dynomione **ICCU IOI IIIIal-State priysics enects!** \rightarrow Great agreement vs. N_{coll} without any need for final-state physics effects!

How to take out the color fluctuation effect?

- **Final-state energy loss** should **increase** from *p*+Au to *d*+Au to 3He+Au, etc.
- The impact of **color fluctuations** in one nucleon is **diluted** as one increases the projectile size

■ Change projectile size \rightarrow Choose matching $\langle x_p \rangle$ selections

- Example ranges of p_T^{γ} and $p_T^{\pi^0}$ with similar sampled x_p distributions
- Use *γ*'s and full jets in, e.g., sPHENIX *p*+Au sPHENIX

Major bias to the **backward multiplicity** from a high- x_p process

Study by ATLAS presented at HP'24 on sensitivity of FCal vs. ZDC to large- x_p selections

Bias to the **spectator neutrons** from a high- $x_p^{}$ process is smaller by a factor of 6!

Downside: loss of sensitivity to very central events

Spectator neutrons are much less biased

Conclusion

- Some centrality bias effects are processor kinematics-dependent
- The PHENIX $\pi^{0}/\gamma_{\text{dir}}$ ratio is moderately sensitive to color fluctuation effects, due to the different $x_p^{}$ distributions $\pi^0/\gamma_{\rm dir}$
	- \rightarrow the data are quantitatively reproduced by a previous Color Fluctuation Model with no new parameters or retuning
	- ➡ **no additional final-state effects needed to explain the PHENIX data**

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tic proton- or deuteron-nucleus (*p/d* + *A*) collisions at the BNL Relativistic Heavy International European International E \blacksquare purposes including a purpose including a precision of the theorem in the theorem in the theorem in the theorem parton densities in nuclei (see Ref. [3] for a recent example), constraints on dynamical processes in the initial state of $\frac{1}{2}$ the cold at lower energies observed at lower energ \mathbf{r} sensitive to upward multiplicity fluctuations (multiplicity fluctuations (multiplicity fluctuations \mathbf{r} More information: $(100A)$ is peripheral. DVP, PRC 110 (2024) L011901 lisions, !*N*coll", in the events [13–16]. 4.17660 nucl-th/2404.17660

A major complication in the search for jet quenching in proton- or deuteron-nucleus collision systems is the presence of physical effects which influence the experimental determination of collision centrality in the presence of a hard process. For example, in the proton color fluctuation picture, protons with a large Bjorken- x ($x \ge 0.1$) parton interact more weakly with the nucleons in the nucleus, leading to a smaller (larger) than expected yield in large (small) activity events. A recent measurement by the PHENIX Collaboration compared the yield of neutral pion and direct photon production in $d + Au$ collisions, under the argument that the photon yields correct for such biases, and the difference between the two species is thus attributable to final-state effects (i.e., jet quenching). The main finding suggests a significant degree of jet quenching for hard processes in small systems. In this paper, I argue that the particular photon and pion events selected by PHENIX arise from proton configurations with significantly different Bjorken-*x* distributions, and thus are subject to different magnitudes of modification in the color fluctuation model. Using the results of a previous global analysis of data from the BNL Relativistic Heavy Ion Collider (RHIC) and the CERN Large Hadron Collider (LHC), I show that potentially all of the pion-to-photon difference in PHENIX data can be described by a proton color fluctuation picture at a quantitative level before any additional physics from final-state effects is required. This finding reconciles the interpretation of the PHENIX measurement with others at RHIC and LHC, which have found no observable evidence for jet quenching in small systems.

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➡ **Not really.**

ATLAS, PLB 756 (2016) 10

Is there a x_p **-UE**backward **anti-correlation just in** *p***+***p* **collisions?** *xp* -∞ ← ^η ^η → +∞ **s** tl α_p \rightarrow \rightarrow a *y* - I JFback ed. 2 η

 $-\infty \leftarrow \eta$ $\eta \rightarrow +\infty$

