



Probing collision dynamics of small system collisions via high p_T hadrons and direct photons by the PHENIX experiment at RHIC

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Dynamics of small system collisions

• Finding of collectivity in small system collisions both at LHC and RHIC casted a question:

Is it **mini-QGP** or **anomalous initial state effect?**

Mini-QGP



Anomalous initial state









Two key probes for probing dynamics

- Final products of collisions: hadrons
- Products throughout collisions: photons (penetrating probe)







Identified hadrons in small systems

- π^0 are measured at mid-rapidity in p+Au, d+Au and ³He+Au collisions
- Enhanced "Cronin"-peak in smaller system collisions
 - Still consistent with each other, and with unity within quoted uncertainties



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Identified hadrons in small systems

- Nuclear modification in centralities:
 - Centrality determined similarly as for large systems (PRC90,034902)
- System-size dependent R_{AB} is seen for $p_T < 10 \text{GeV/c}$, while R_{AB} merge at high p_T
- Larger enhancement is seen in central collisions





A-dependent jet modification

- π^0 -hadron correlation in p+p, p+Aland p+Au collisions (mid-rapidity)
- Near-side width is consistent over all the systems
- Away-side width becomes larger in larger A
 - Broadening due to pathlength dependent nuclear effect? (e-loss, mult. scatt.)





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A-dependent jet modification

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η and A-dependent hadron production

- Charged hadrons are measured at forward and backward rapidities
- Hadrons in p-going side are well described by PDF+PYTHIA

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• Hadrons in A-going side are better described by a pQCD calculation considering incoherent multiple scattering (final state) PLB740(2015)23

arXiv:1906:09928





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η and A-dependent hadron production

- Clear A-dependence increase is seen in A-going direction
 - pQCD calculations considering incoherent multiple-scattering well describe the data (final state effect) PLB740(2015)23
- Suppression in *p*-going direction suggests the presence of initial state effects





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A-dependence in polarized *p*+A collisions

- Positively-charged hadrons is sensitive to A-dependent TSSA
- $A^{1/3}$ dependence may be from gluon saturation effect (at low p_T)
 - Additional evidence for presence of initial state effects in *p*-going direction
 - A new way to look at gluon dynamics.

arXiv:1903:07422





PH^{*}ENIX Thermal photons in A+A collisions

- Photons are emitted from all stages of of the system evolution and give thermodynamical information, like temperature. $E\frac{dR_{\gamma}}{d^{3}p} = -\frac{\alpha_{em}}{\pi^{2}} \operatorname{Im}\Pi_{em}(\omega,k) \frac{1}{e^{E/T}-1}$
- Soft direct photon yields scaled by $(dN_{ch}/d\eta)^{1.25}$ are found to align on a line, independent of collision energy or centrality.





PH*ENIX Thermal photons in p+A

- Soft direct photons are successfully measured in p+Au collisions.
- Yield is higher than those expected from p+p collisions.





arXiv:1805.04084,

Accepted in PRL

Thermal photons show "bridge"

- Integrated soft photon yields as a function of $dN_{ch}/d\eta$ is shown.
- A+A are all on the universal line: dN_{γ}/dy = $\alpha(dN_{ch}/d\eta)^{1.25}$
- *p*+*p* points are on a different line, but parallel to A+A.



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Thermal photons show "bridge"

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- A+A are all on the universal line: dN_{γ}/dy = $\alpha (dN_{ch}/d\eta)^{1.25}$
- *p*+*p* points are on a different line, but parallel to A+A.
- *p*+Au and *d*+Au data fill the gap smoothly between A+A and *p*+*p* collisions.
- Onset of QGP'nization in *p*+Au and *d*+Au.







Summary

- Hadrons and photons are powerful tools to study small system collisions.
- Mid-rapidity hadron production demonstrated:
 - Cronin-like enhancement in R_{AB} at mid- p_T increases as projectile mass increases, while they merge at high p_T .
 - Angular widths of jets broaden as target mass increases (multiple scattering?).
- Forward/backward hadron production demonstrated:
 - Clear A-dependence increase is seen in A-going direction.
 - pQCD calculations with incoherent multiple-scattering describe the data (final state effect).
 - Suppression in *p*-going direction suggests presence of initial state effects (CGC?)
 - Also seen in Transverse Single Spin Asymmetry result in polarized p+A collisions.
- Thermal photon production at mid-rapidity demonstrated:
 - Yield scales with $(dN/d\eta)^{1.25}$ for A+A and p+p collisions, within themselves.
 - p/d+A are found to bridge A+A and p+p, providing strong evidence for the onset of QGP.





High pT hadrons in Au+Au collisions





Inclusive measurement of hadrons



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