Quark Gluon Plasma Formation in Small Systems

Coleridge Faraday
Supervised by A/Prof. W. A. Horowitz

Based on CF, A. Grindrod, and W. A. Horowitz arXiv:2305.13182

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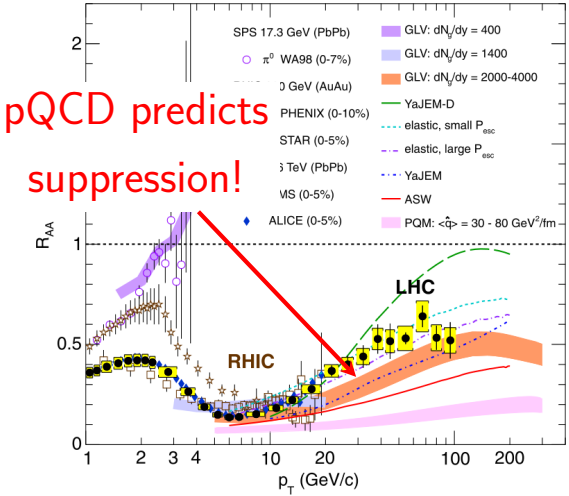
MSc candidate, University of Cape Town

The Quark Gluon Plasma (QGP)



Nuclear modification factor data
(CMS 2012, arXiv:1202.2554)

$$R_{AB}^{h} \equiv \frac{\mathrm{d}\sigma_{AB}^{h}}{N_{\mathrm{coll}}\,\mathrm{d}\sigma_{pp}^{h}}$$

- Divide out by **independent superposition** of $p+p$ collisions
- s.t. $R_{AA} = 1$ for no spectrum modifiication

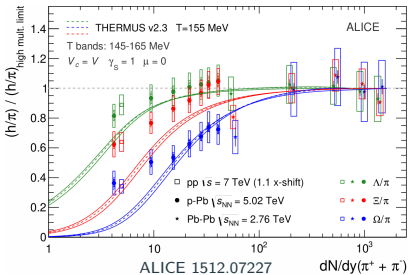
\+ other evidence for QGP in A+A: elliptic flow, quarkonium suppression, strangeness enhancement

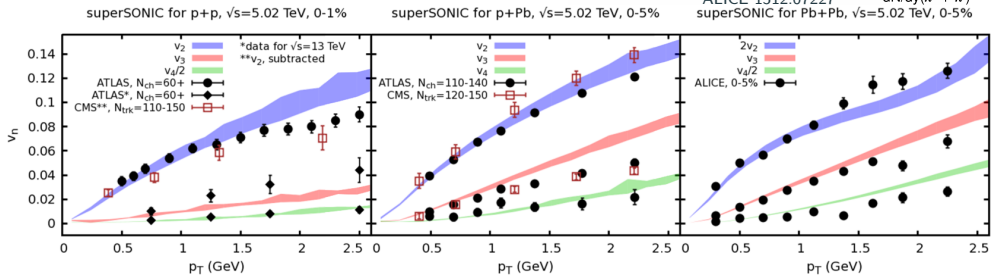
Solid evidence for QGP in $A + A$;
$p + A$ as a null control?

QGP Formation in Small Systems?

QGP signs in $p + A$ and high multiplicity $p + p$ collisions:

- Elliptic flow
- Quarkonium suppression
- Strangeness enhancement

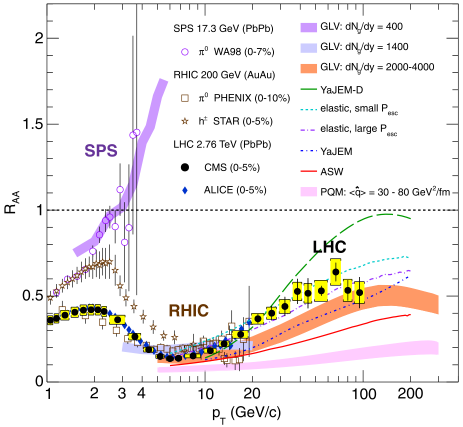




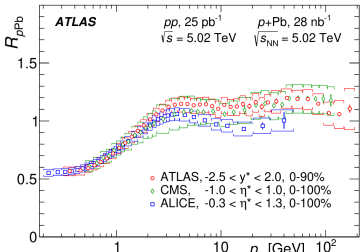
Weller et al. 2017, 1701.07145

Nuclear modification in Small Systems

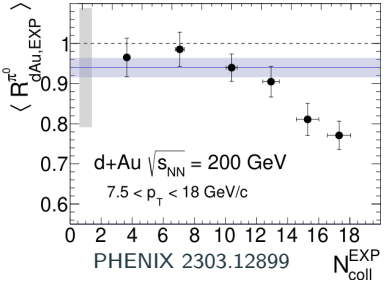
- Qualitative **success of pQCD** models in $A + A$



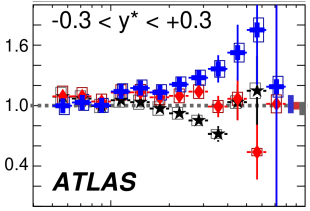
CMS 1202.2554



ATLAS 2211.15257



PHENIX 2303.12899



ATLAS 1412.4092

- Is there **nontrivial final state nuclear modification** in $p + A$?
- Theoretical control needed

Energy loss in Small Systems: Theory Challenges

Theoretical energy loss models conventionally assume

- Thermalized medium
- No pre-thermalization time effects
- Explicit dropping of $\mathcal{O}(e^{-\text{system size}})$ terms

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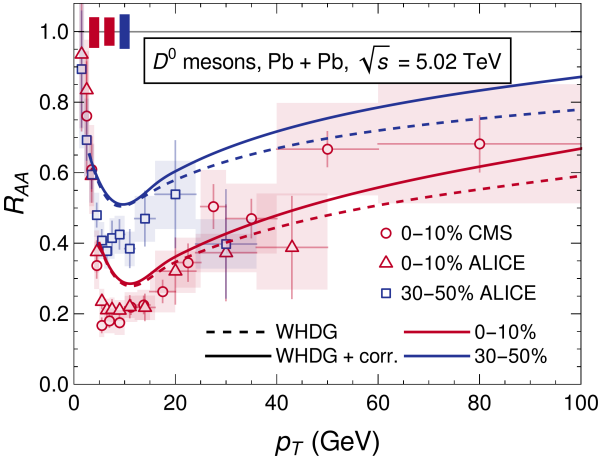
- Thermalized medium
- No pre-thermalization time effects
- Explicit dropping of $\mathcal{O}(e^{-\text{system size}})$ terms
  - These terms included in new **small system correction** to radiative energy loss
    Kolbé, Horowitz 2015, 1511.09313

Heavy flavour A+A



Pb + Pb suppression

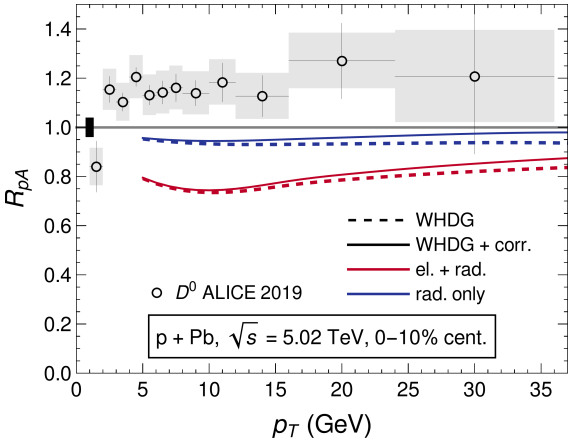
CF, Grindrod, Horowitz 2305.13182

Data: CMS 1708.04962 + ALICE 1804.09083

✓ Small system correction should be small in $A + A$

Heavy flavour p+A

- Is small system correction important in $p + A$?
- Shocking predicted suppression?
  - $\rightarrow$ Only $\mathcal{O}(1)$ scatter in $p + A$
  - $\rightarrow$ Central Limit Theorem (CLT) in el. E-loss breakdown $\Rightarrow$ small system elastic corr. needed (coming soon)

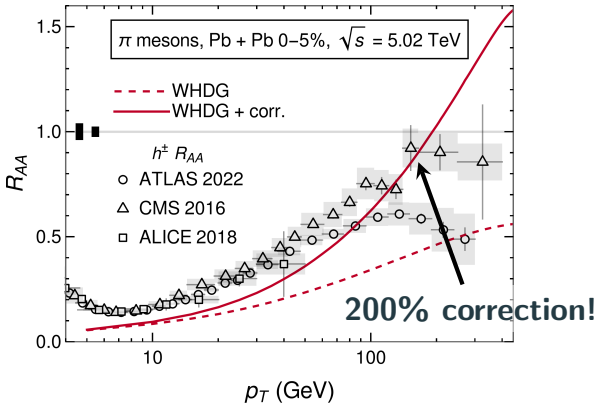


p + Pb suppression

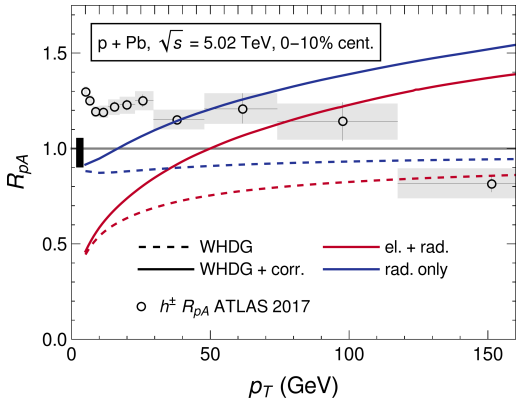
CF, Grindrod, Horowitz 2305.13182

Data: ALICE 1906.03425

Light flavour predictions



- Corrected R_{AA} consistent with data for $p_T \sim \mathcal{O}(10\text{–}100)$ GeV
- 200% "correction" at high-p_T!



- Potentially consistent with $R_{pA}^{h^{\pm}} > 1$?
- CLT breakdown in elastic E-loss

How physical are these results?

Is anything breaking?

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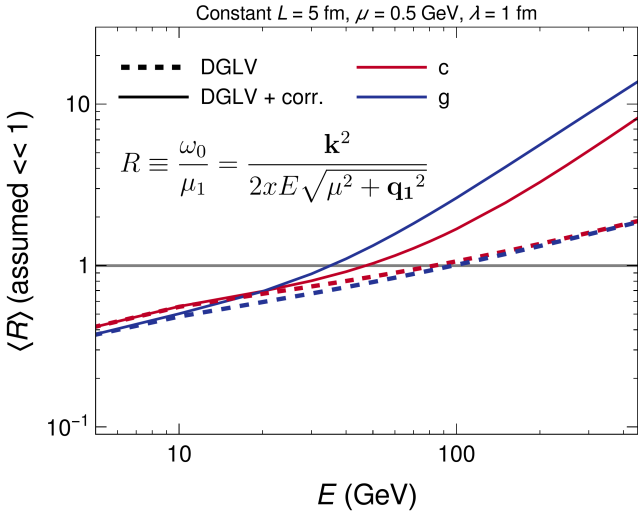
Is anything breaking?

$\longrightarrow$ **Investigate all assumptions in the model**

Consistency of Large Formation Time Assumption



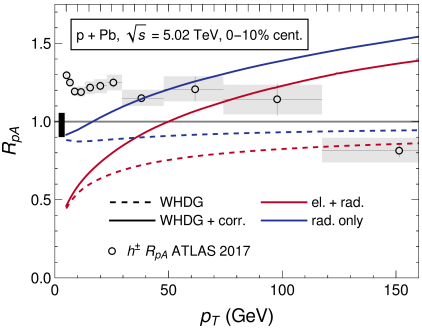
Disaster!

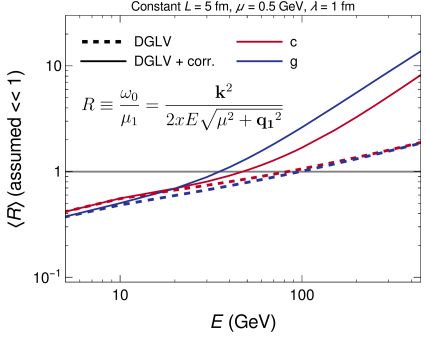
- Large Formation Time assumption **not** valid at high-p_T
- Plays a crucial role in derivation of energy loss models

Energy-weighted expectation of **large formation time** assumption

Summary

- **Elastic small system size correction** needed for quantitative $p + A$ predictions (coming soon)
- Final state radiation (potentially) affects **enhancement** in $p + A$?





- Large formation time assumption **violated** at high-p_T $\Rightarrow$ **short formation time corr. required**
- Potential impact on **all** energy loss models