Electromagnetic probe Experiment

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Hiroshima, Japan

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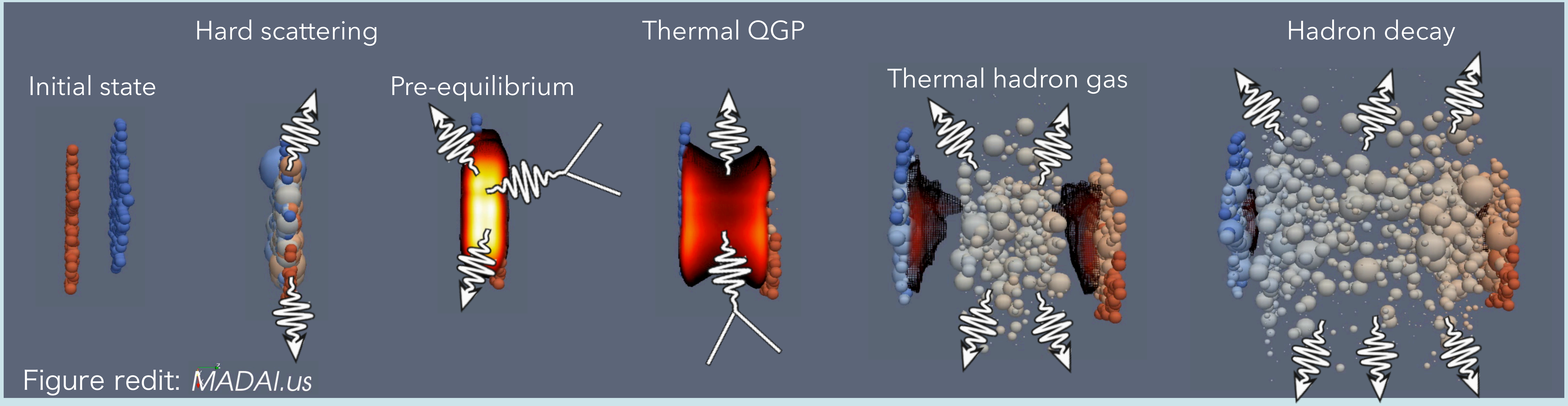

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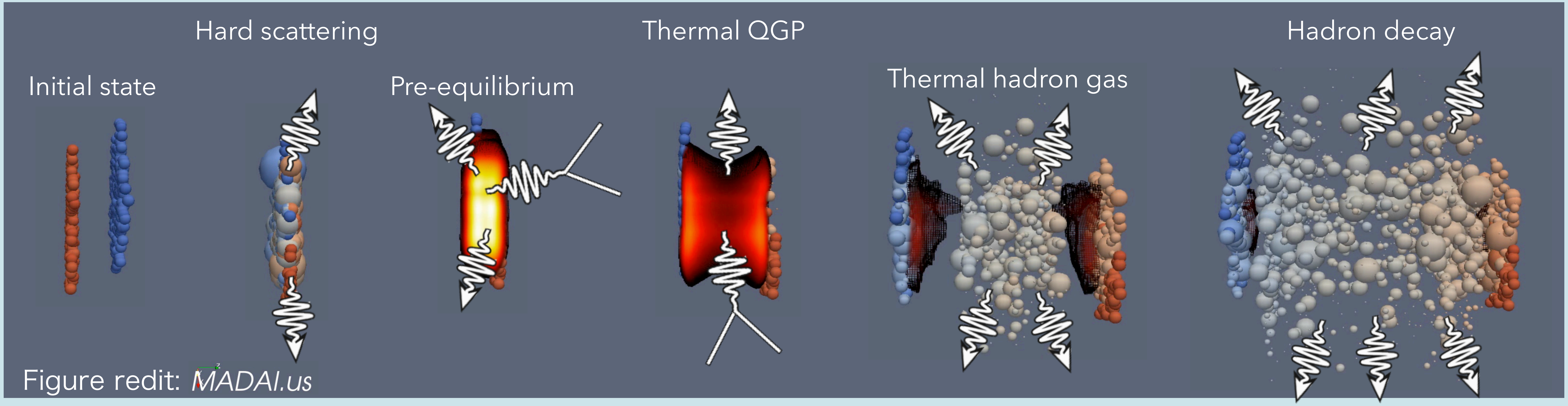
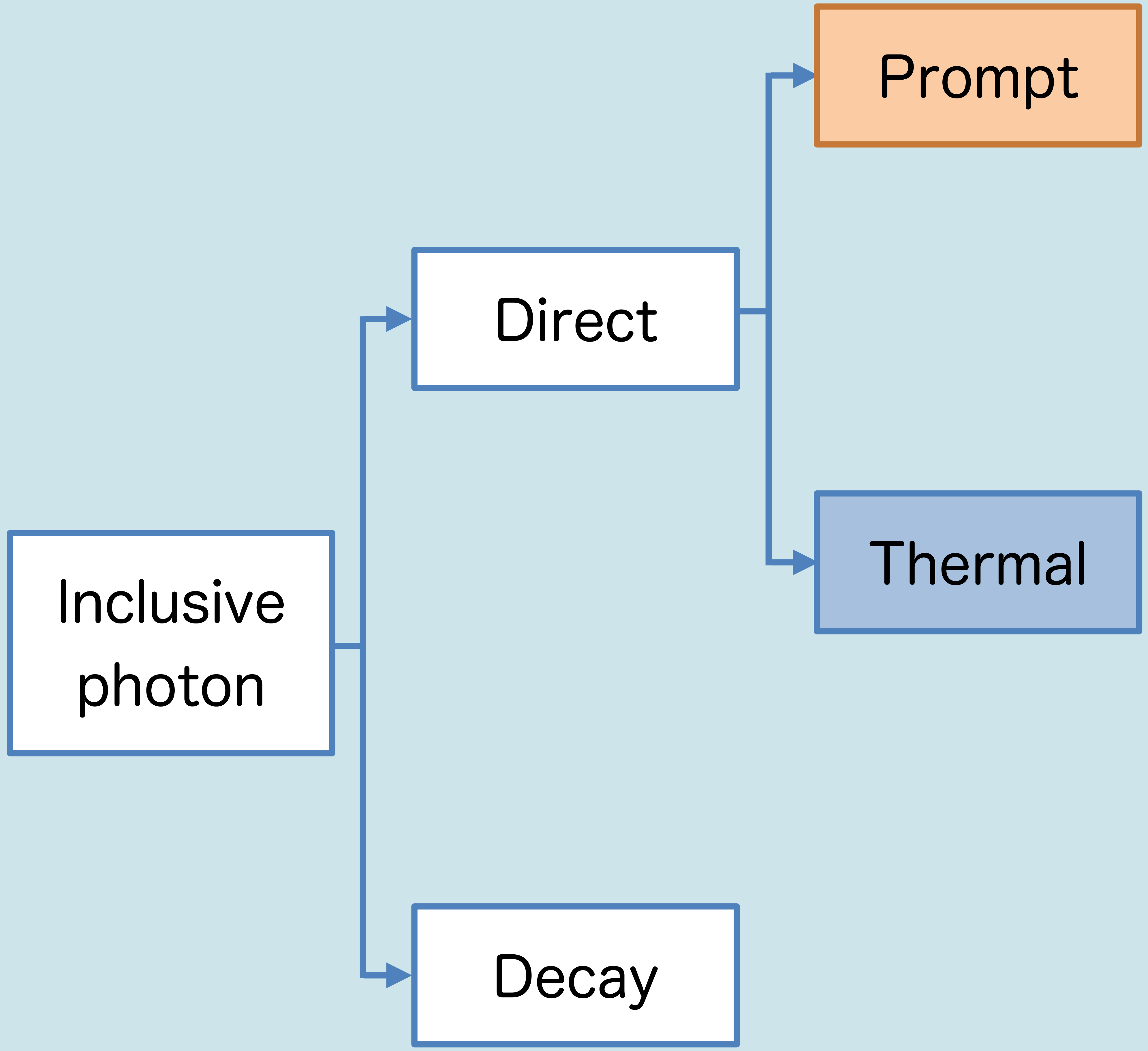


It is a very clean probe to investigate the space-time evolution of the collision

Photon sources in HIC

Photon sources in HIC (a few years ago)



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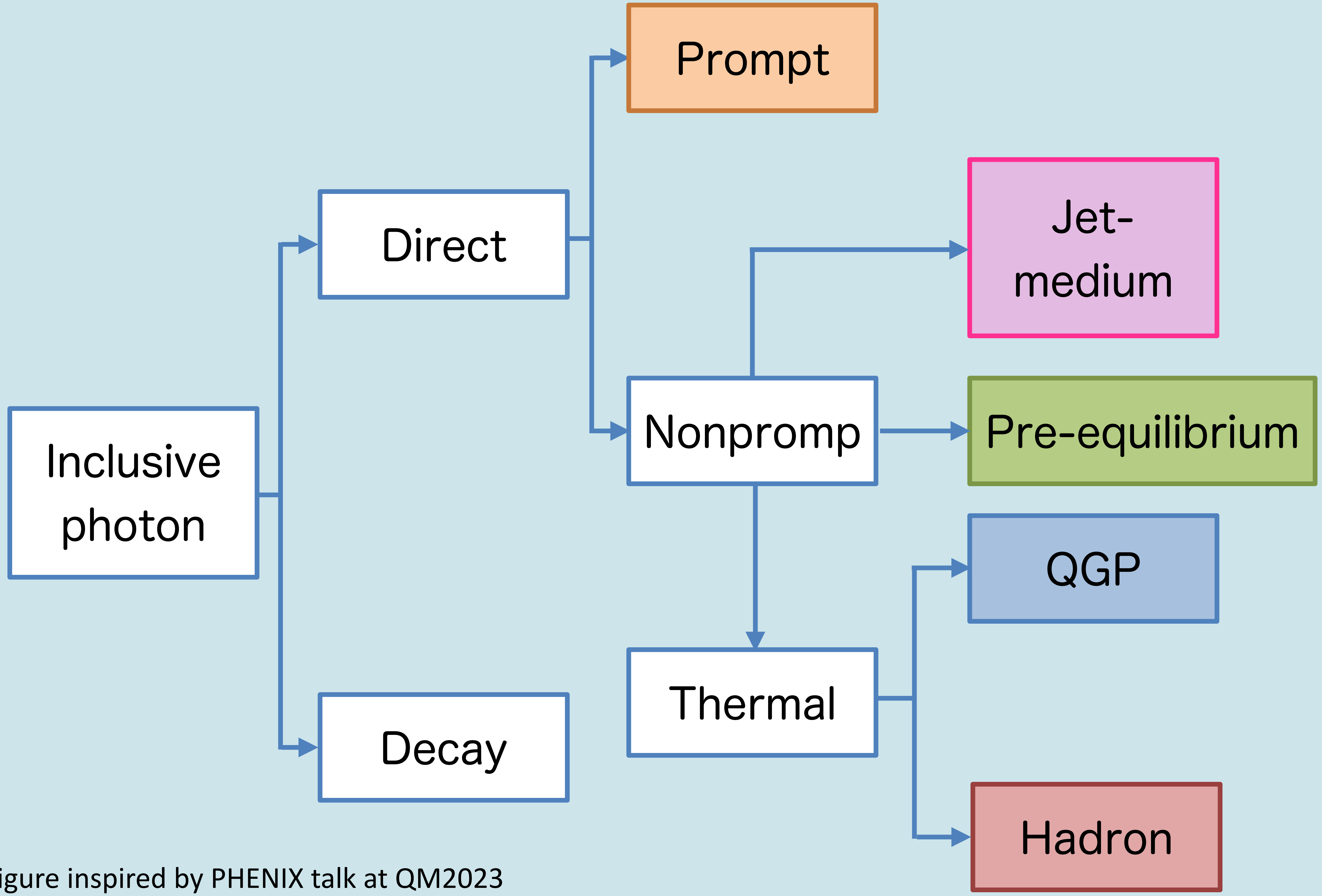

Figure inspired by PHENIX talk at QM2023

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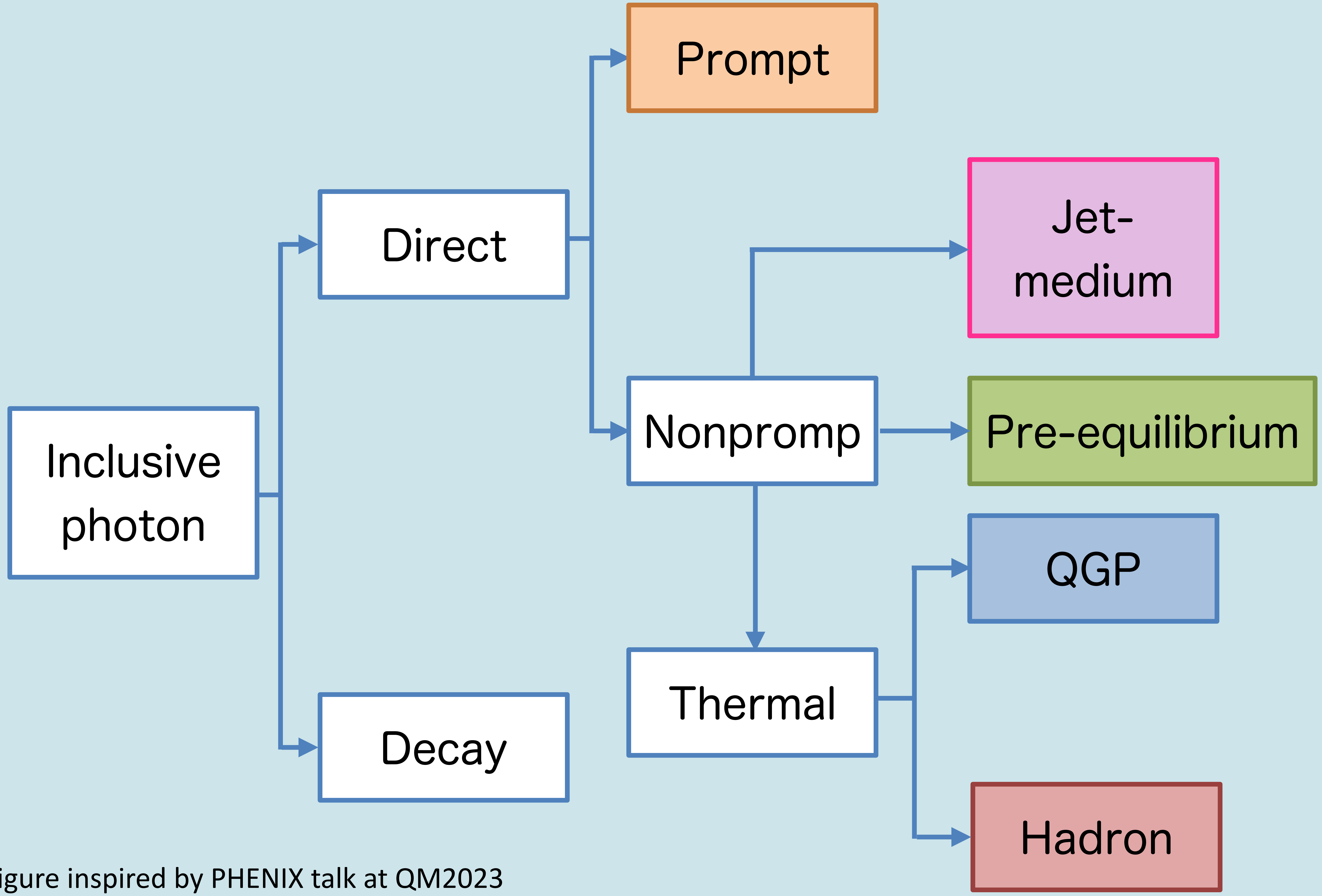

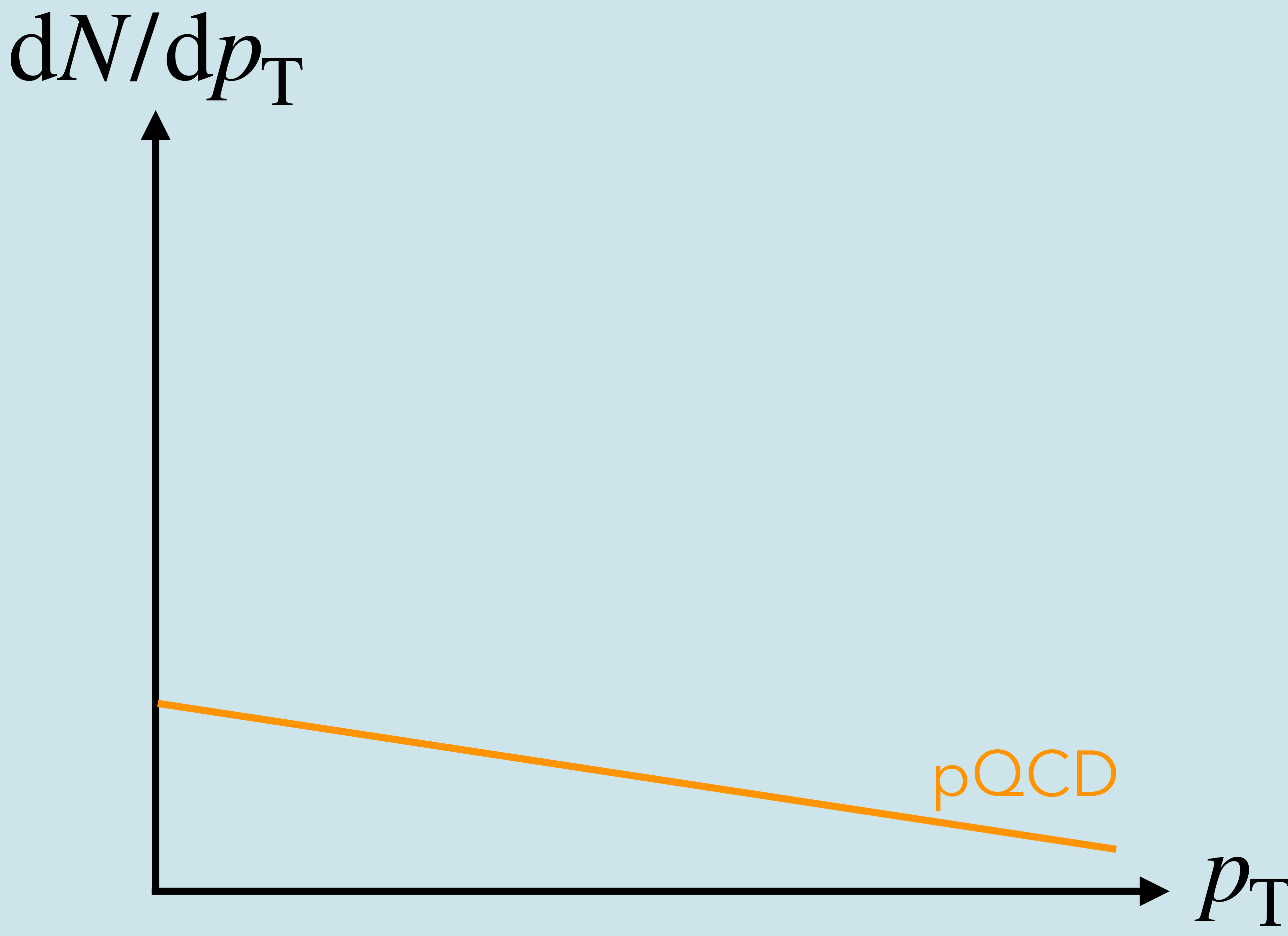

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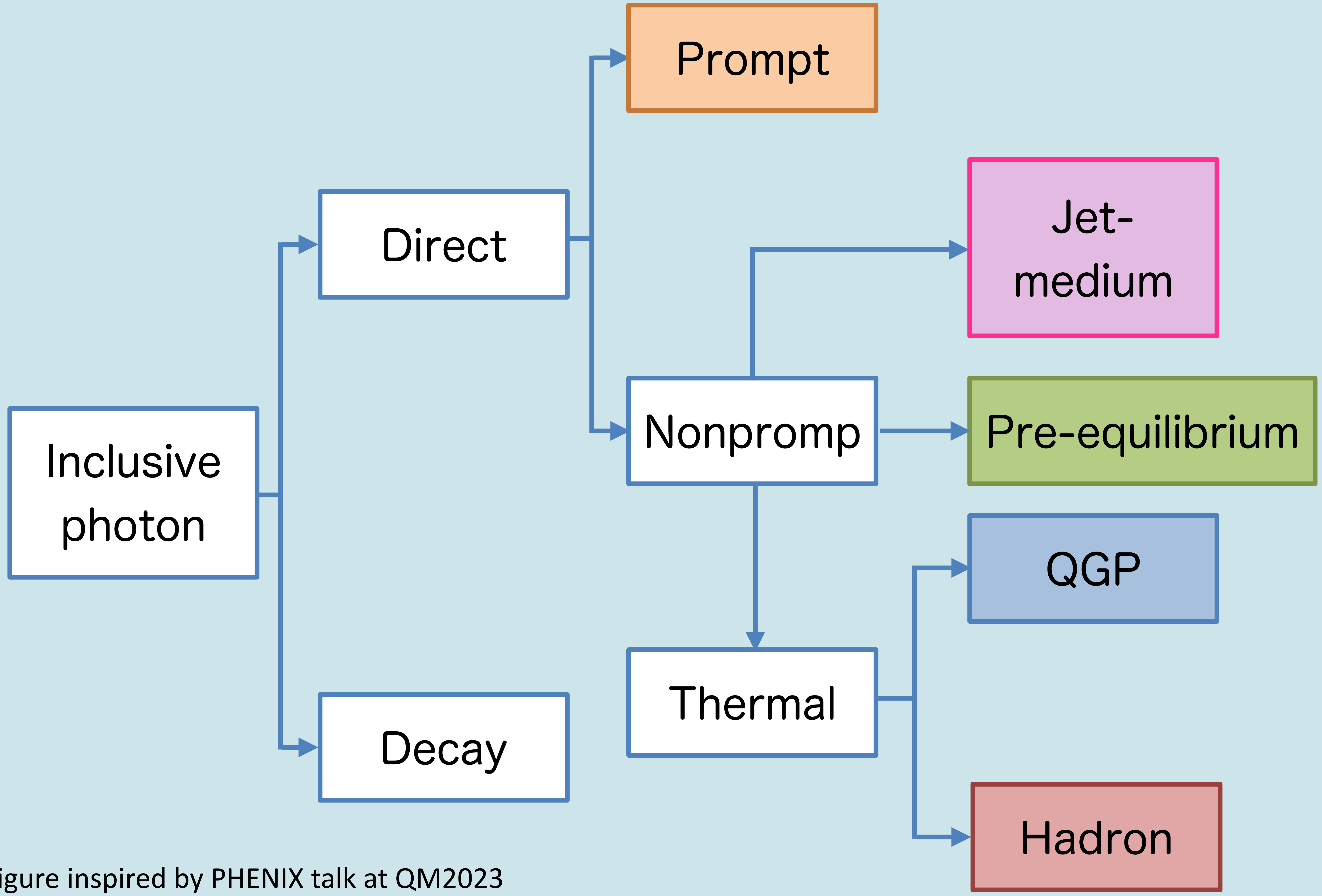

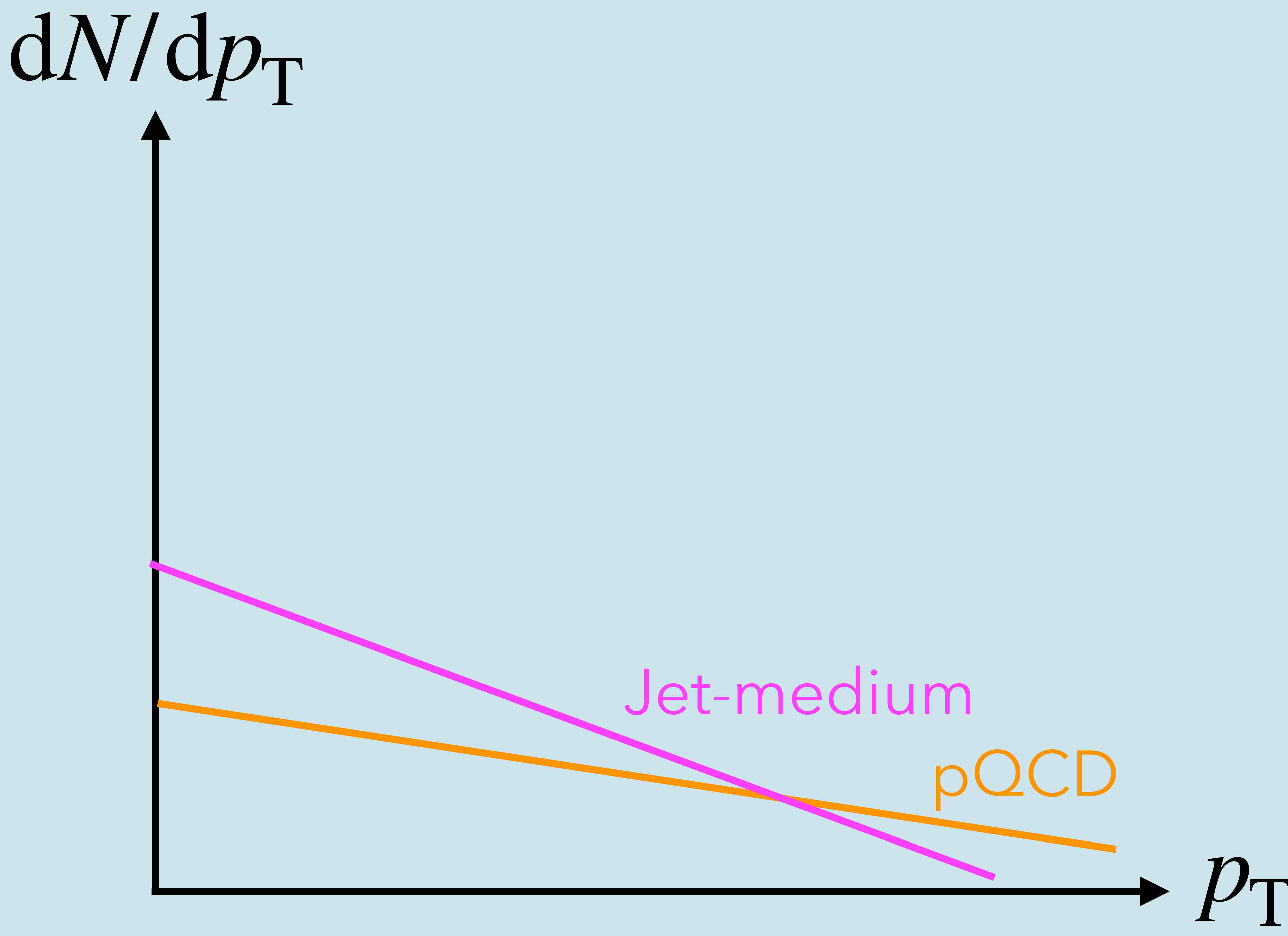

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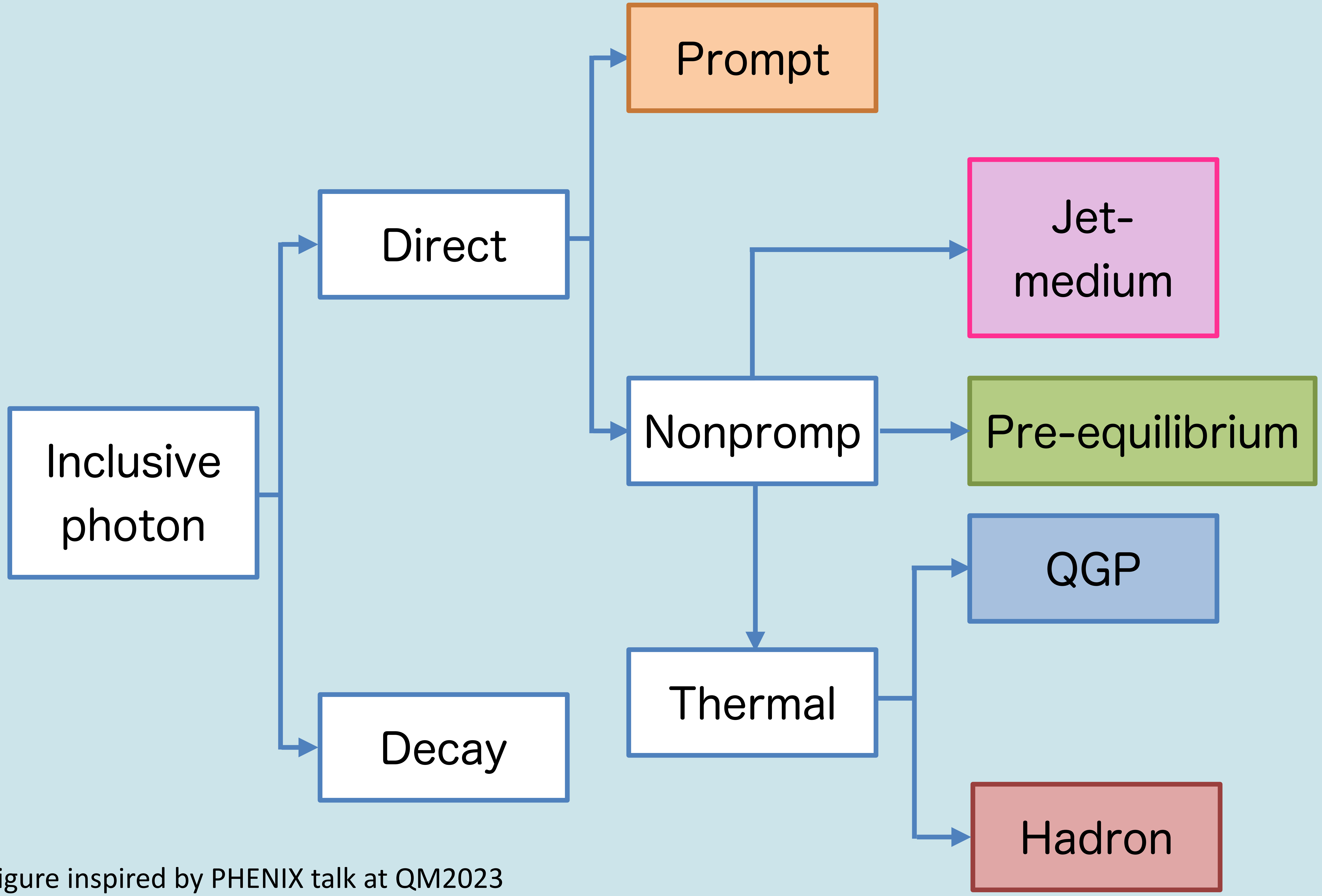

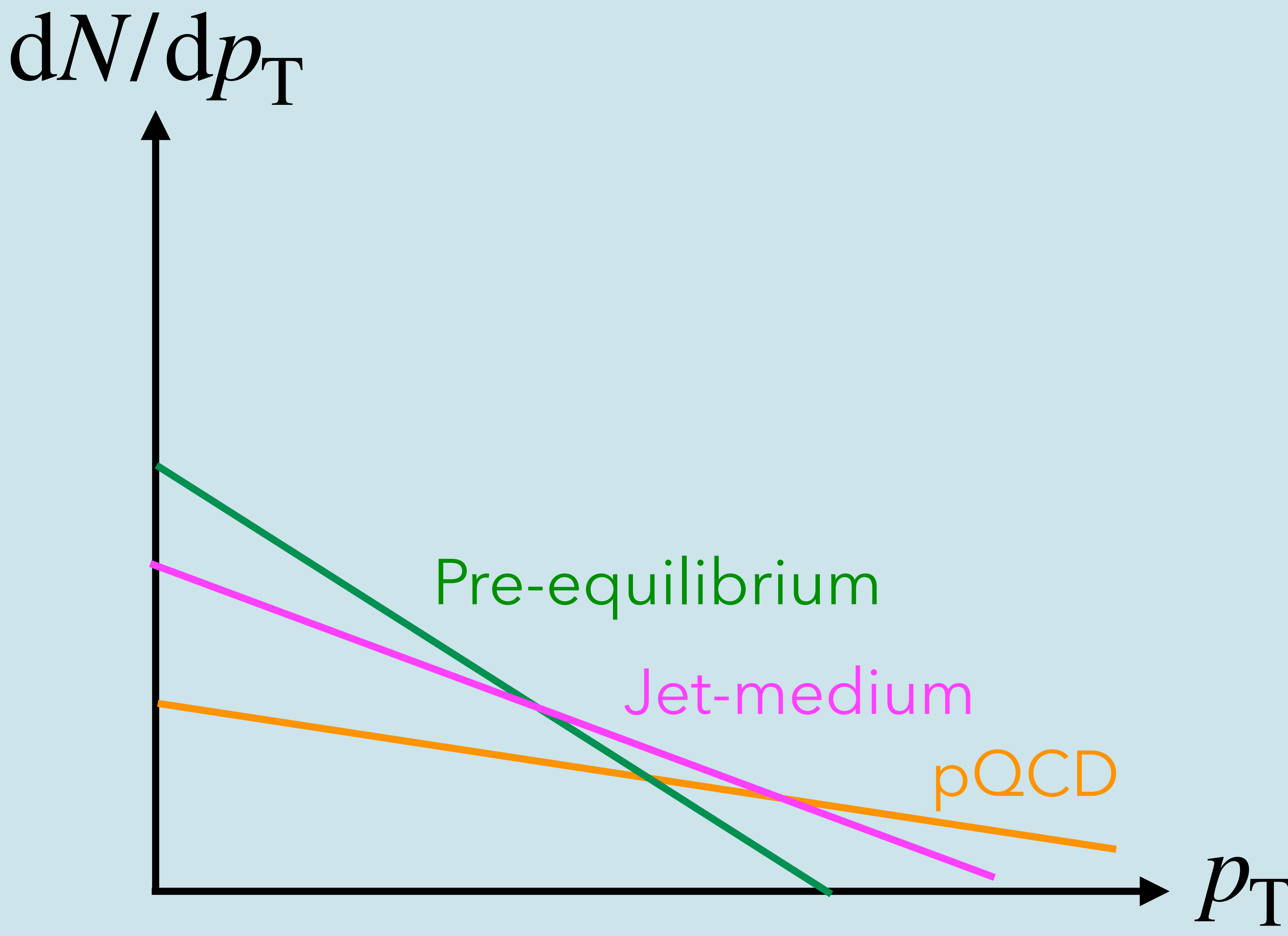

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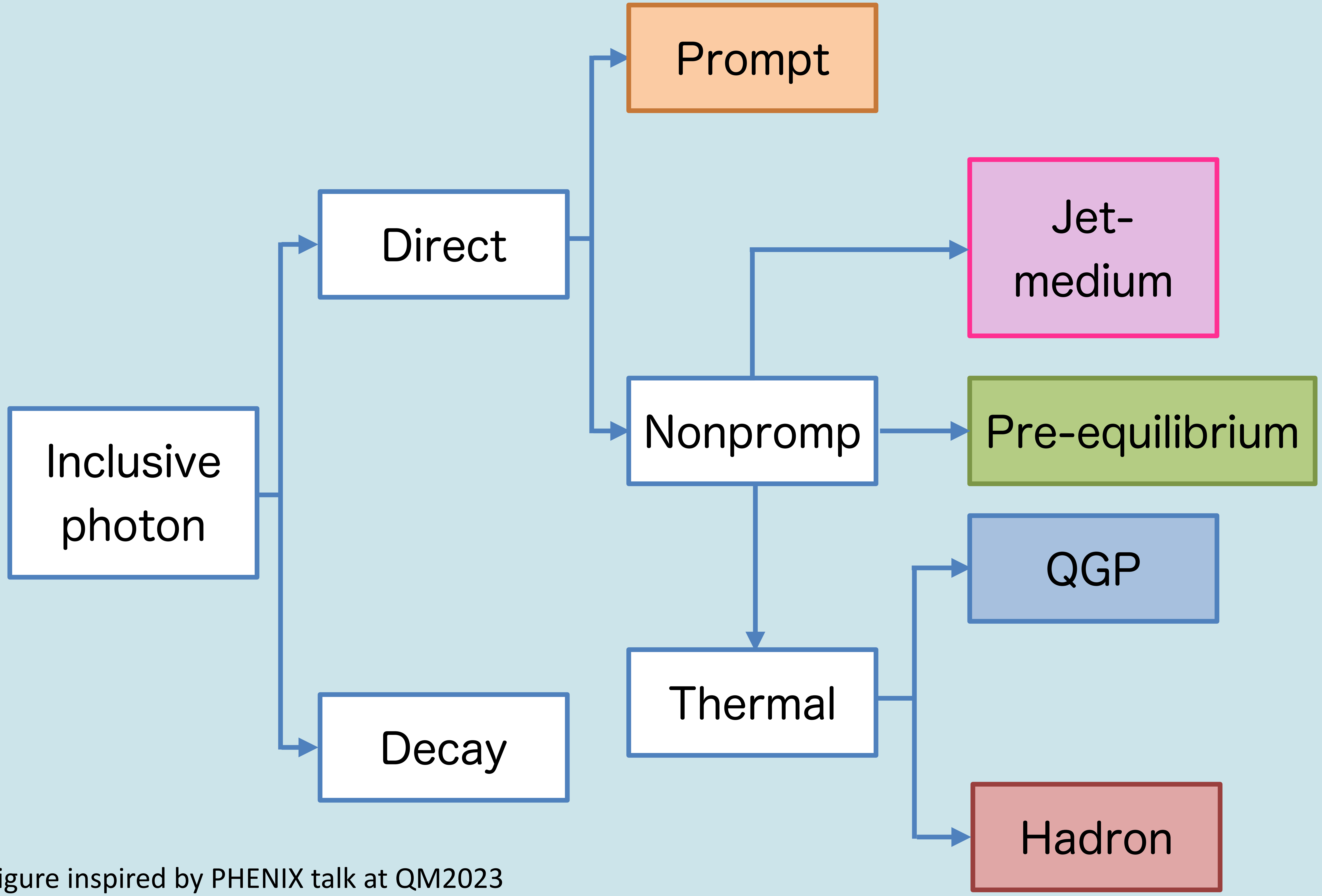

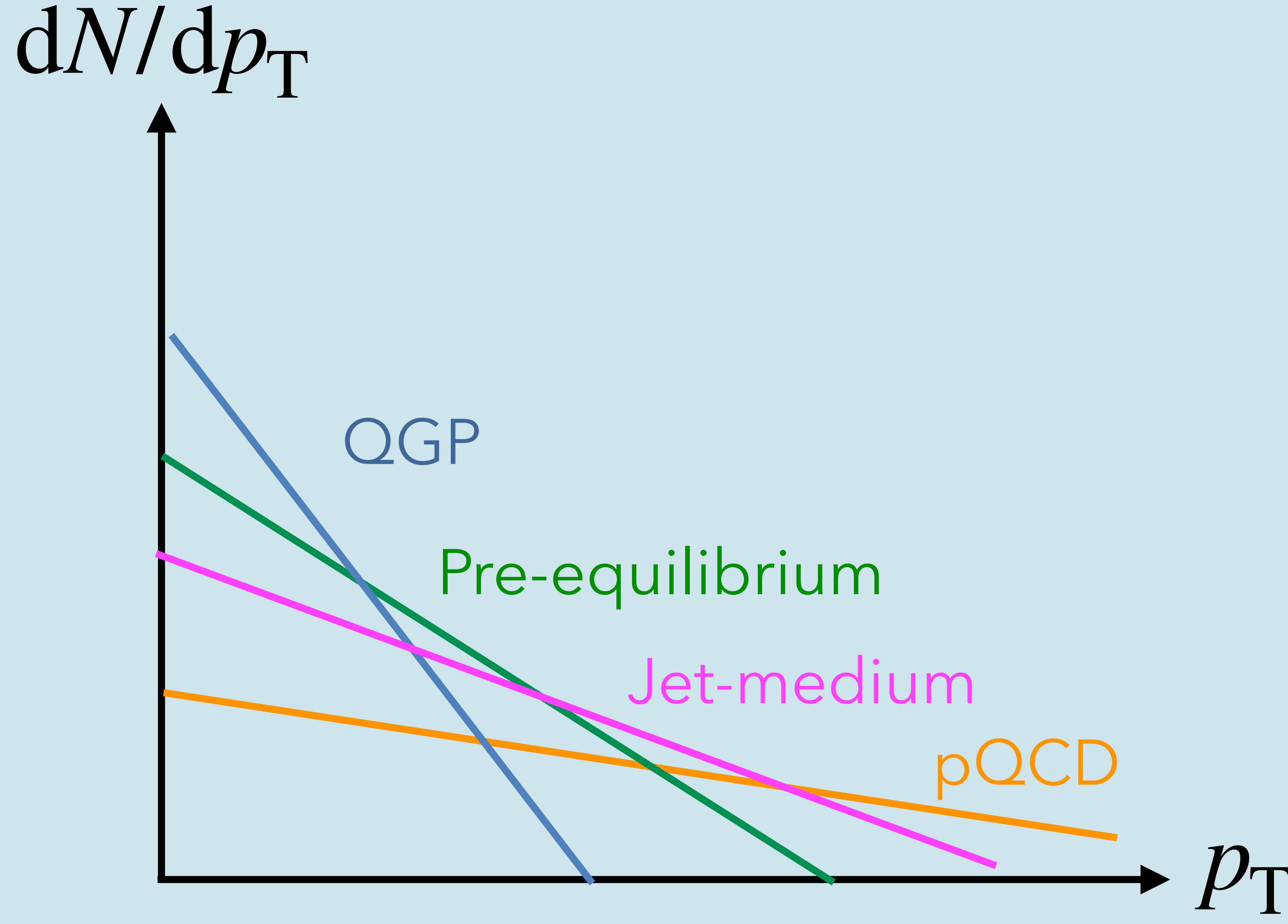

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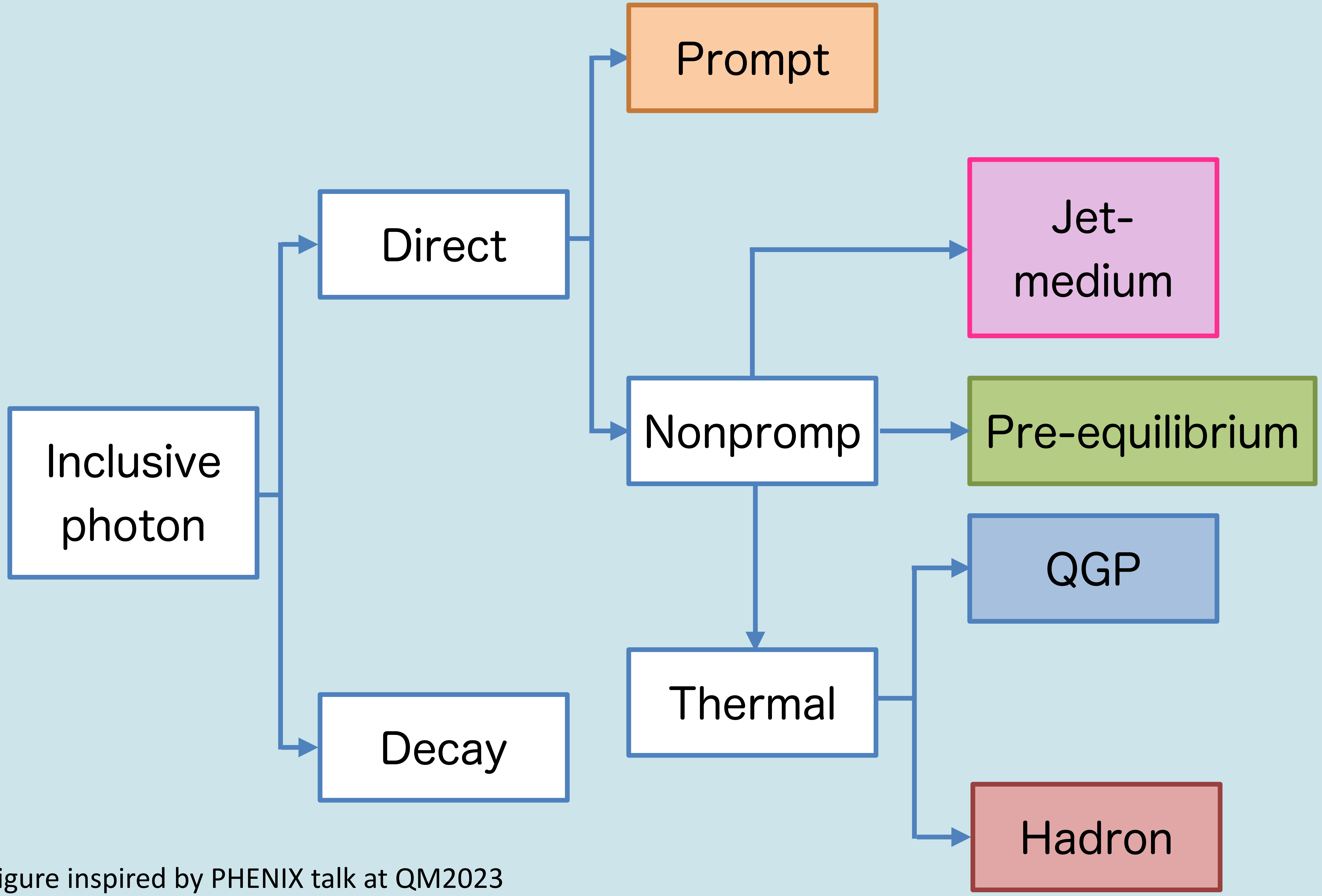

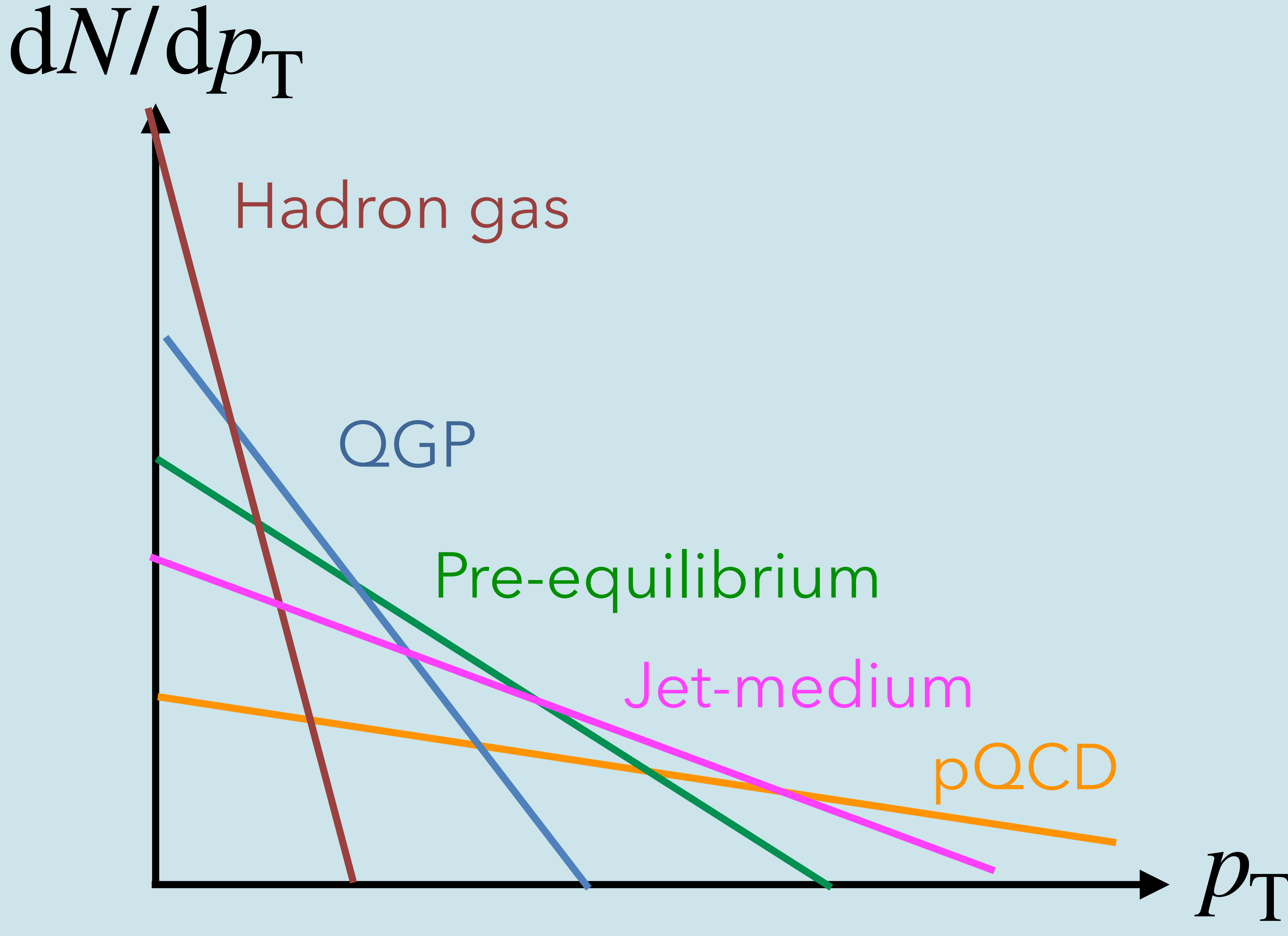

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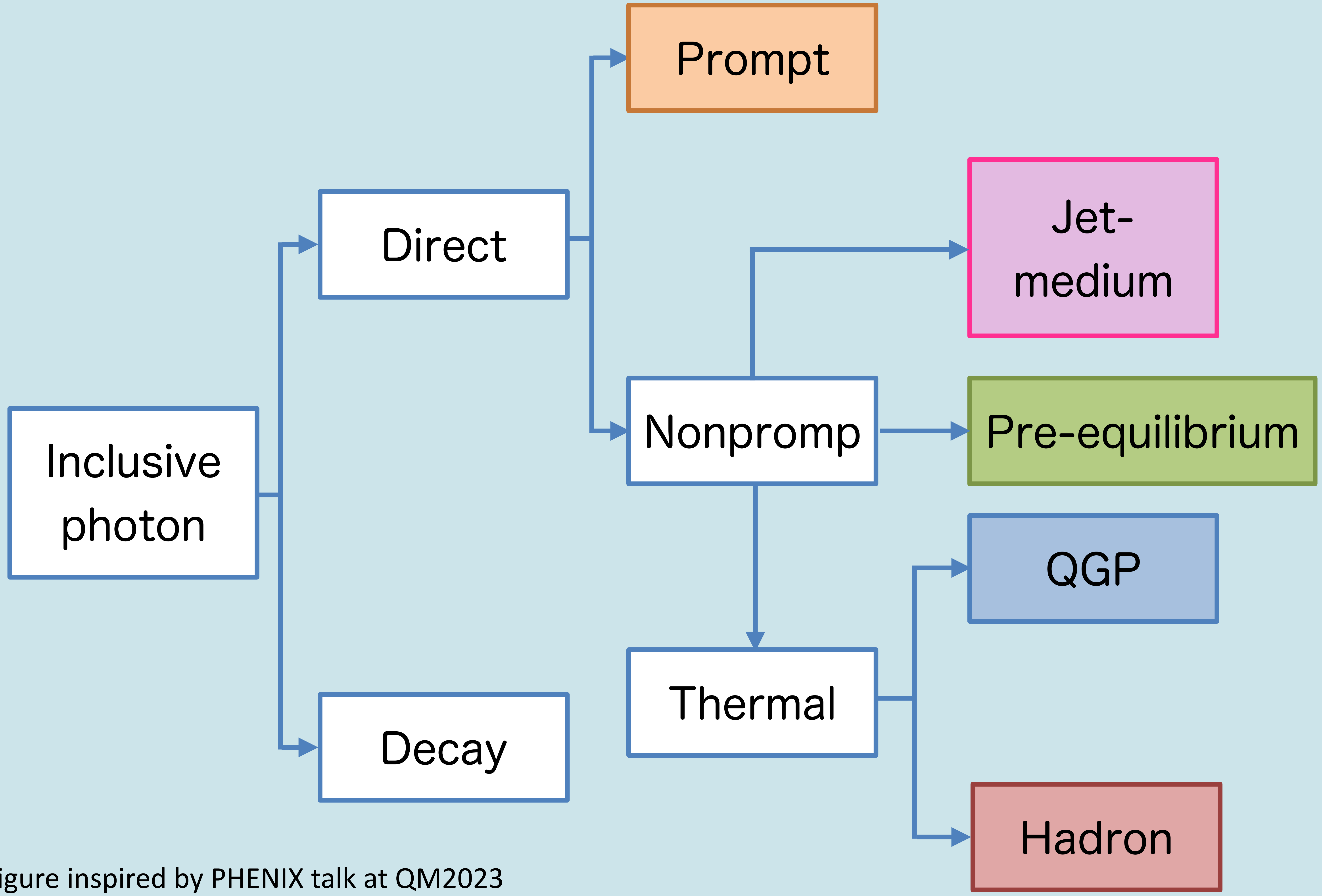

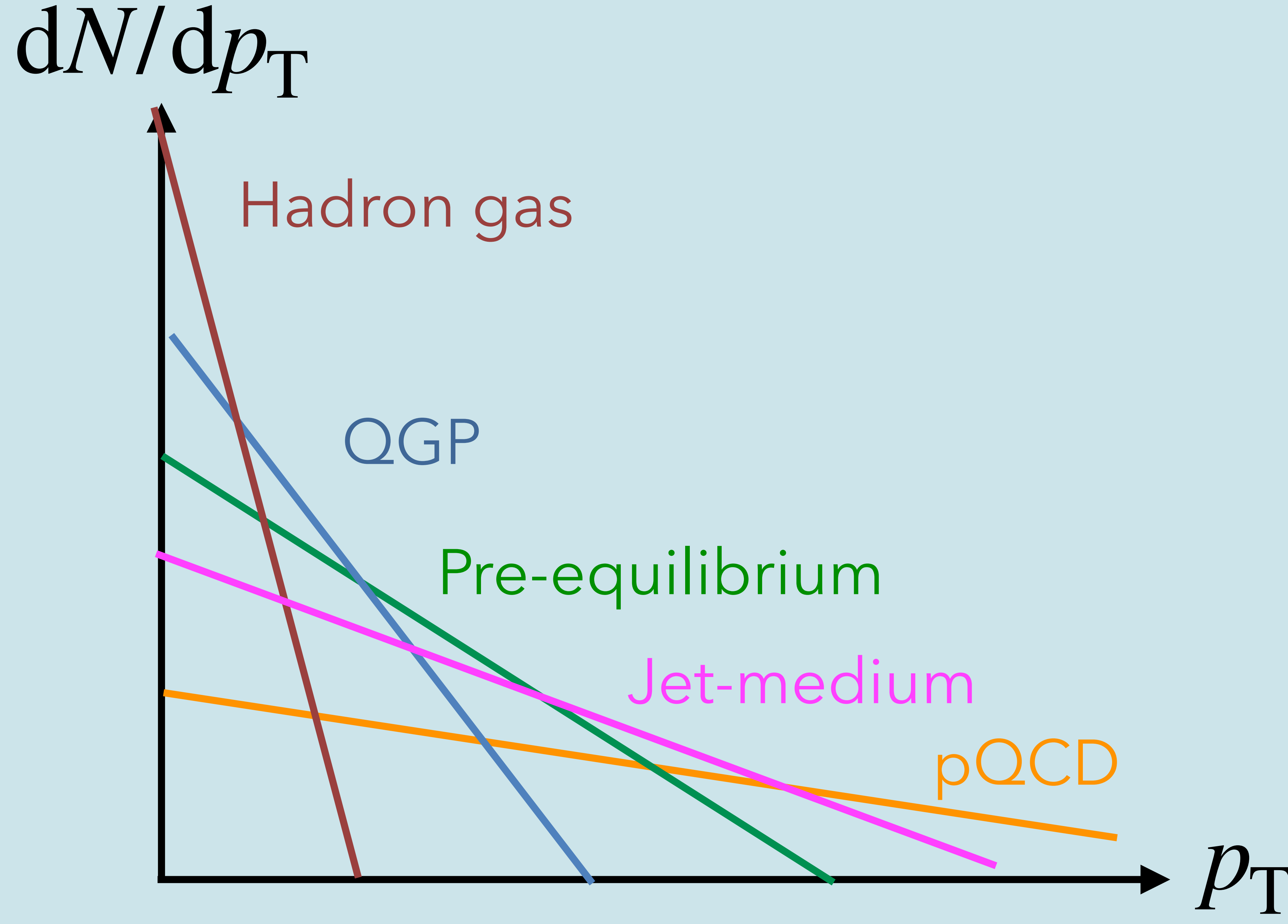

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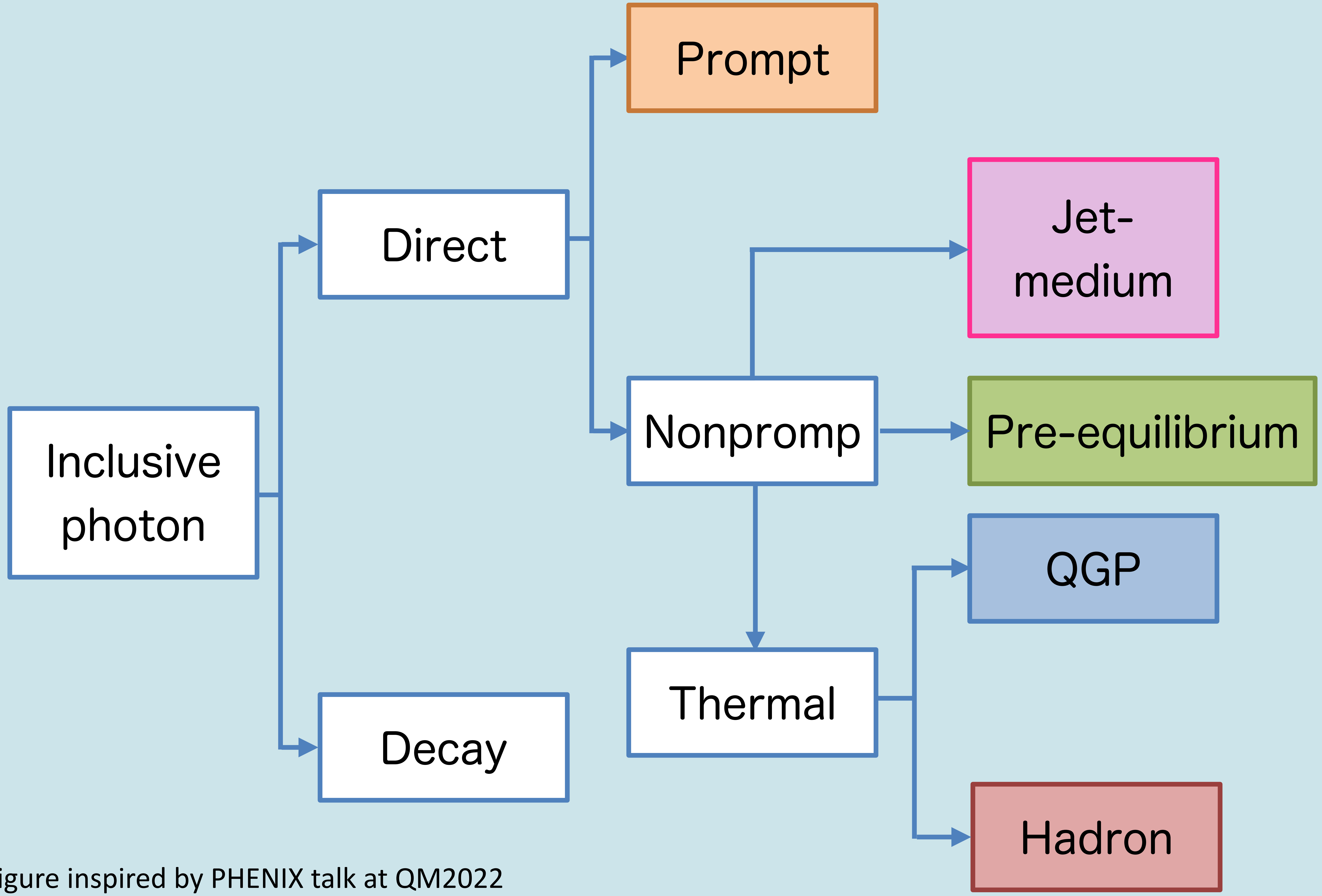

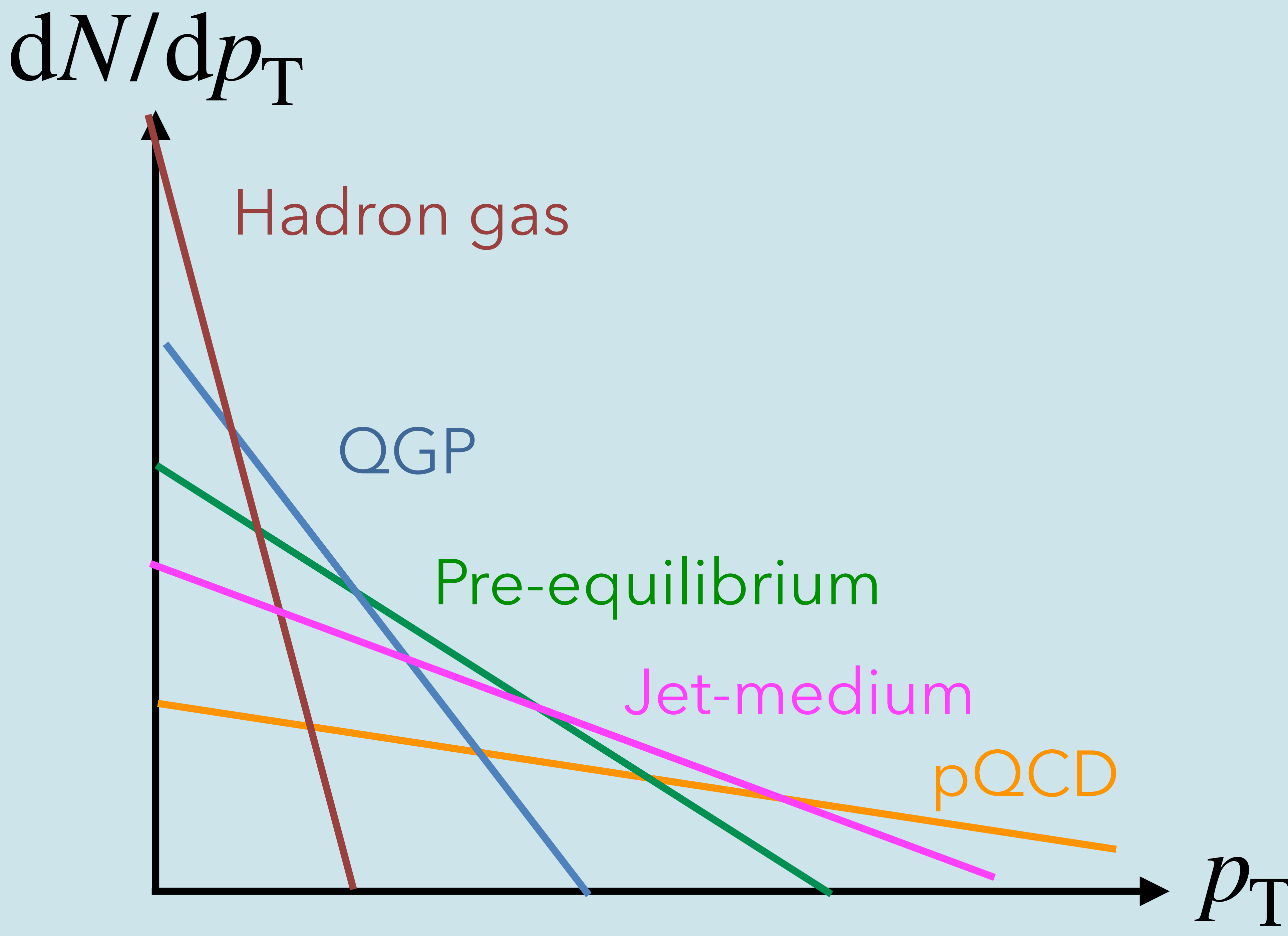

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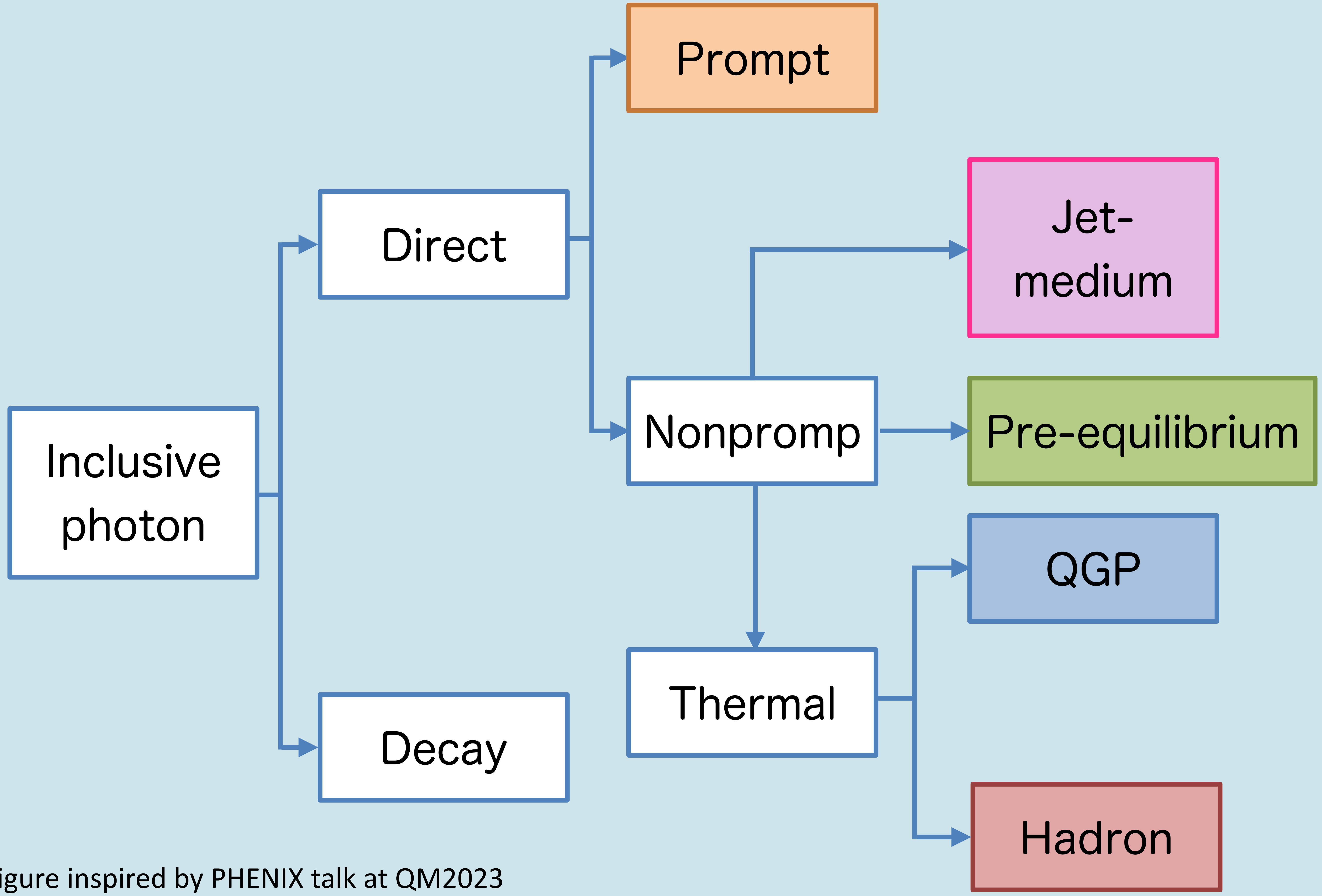

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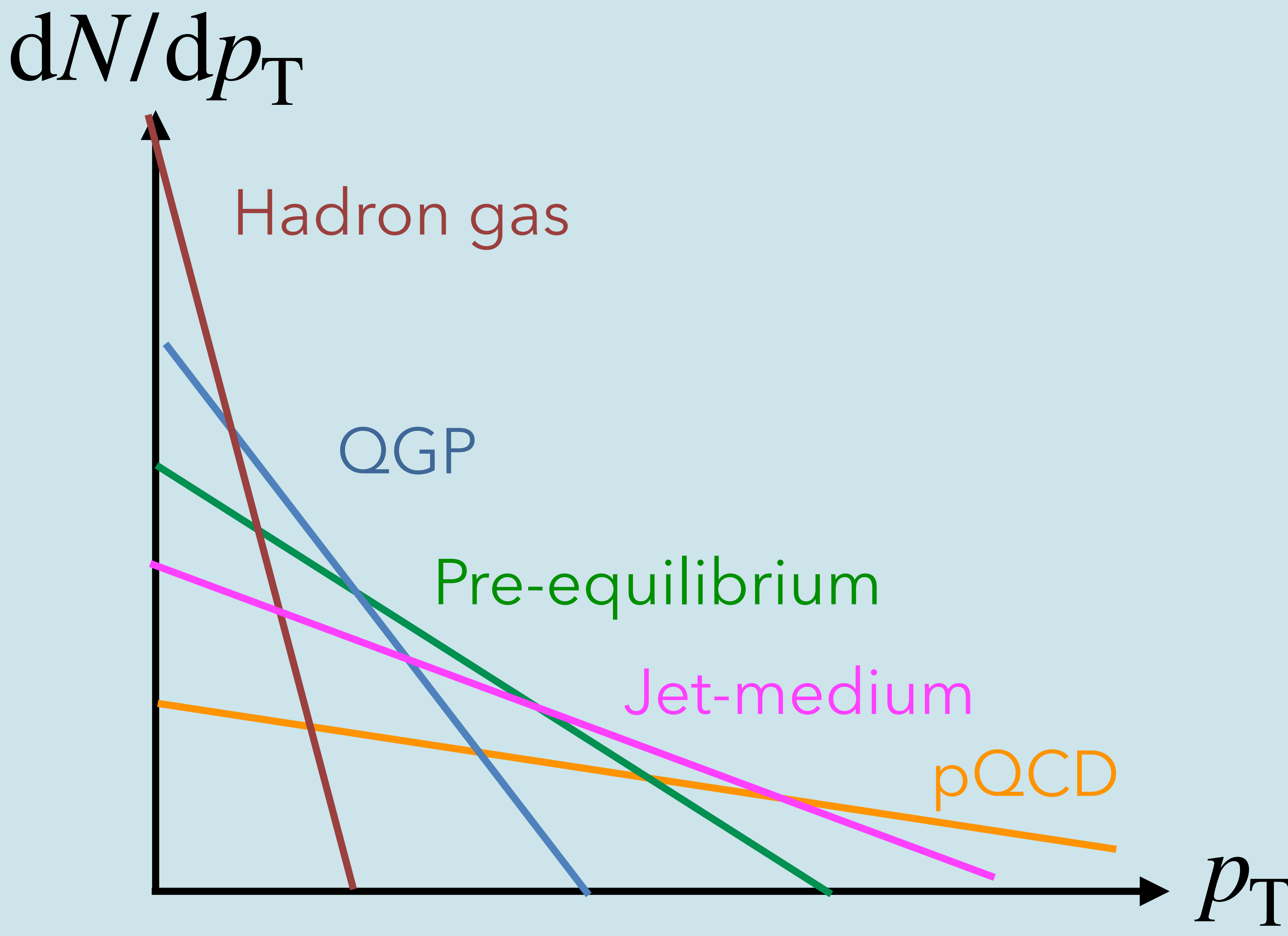

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- Only the total spectrum is observable
- Dominant p_T region of each source is different

Direct photon puzzle (1)

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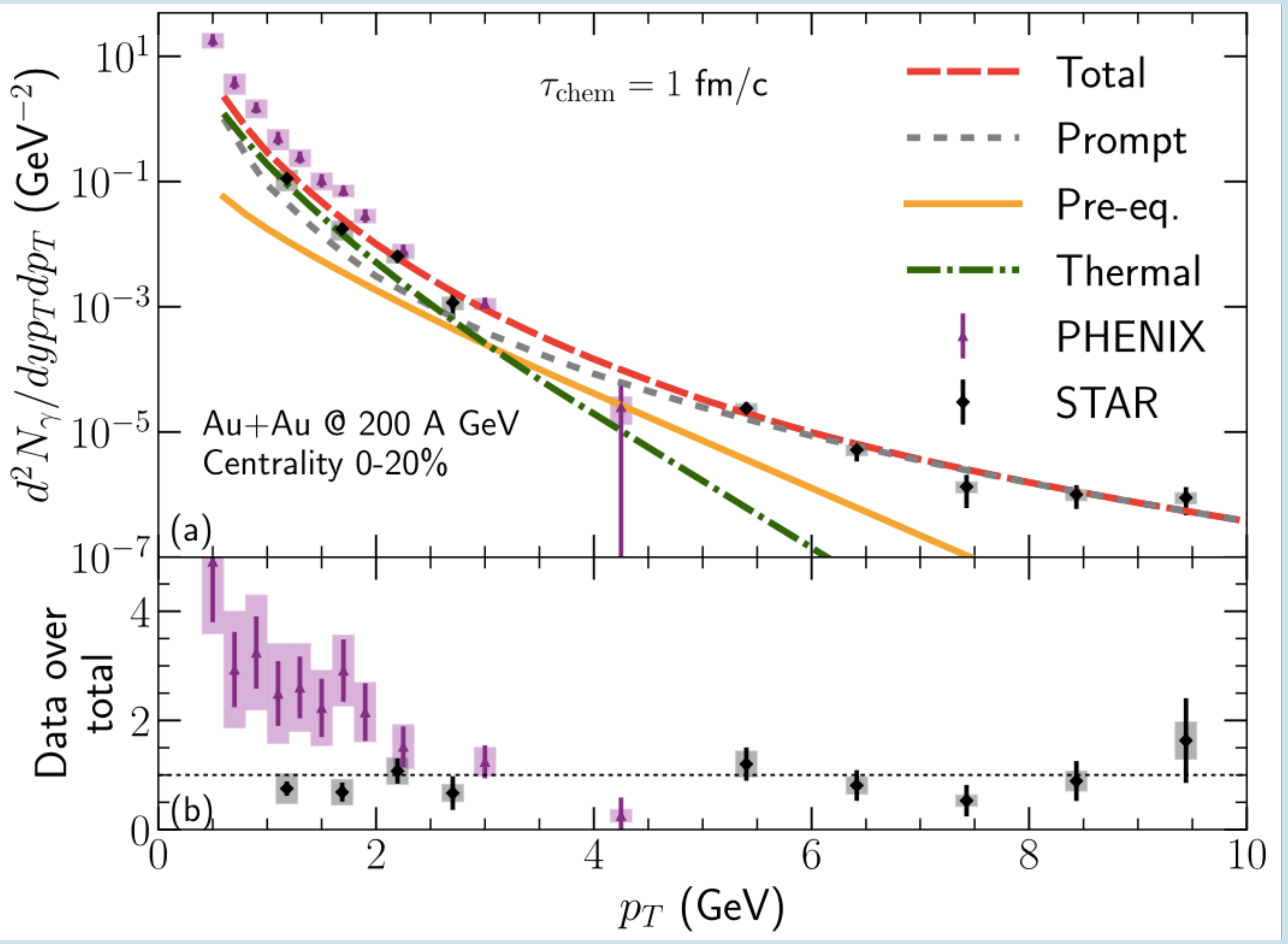
Underestimate yield by the state-of-art model at low p_T

Direct photon



C. Gale, J-F. Paquet, B. Schenke, C. Shen
Phys.Rev.C 105 (2022) 1, 014909

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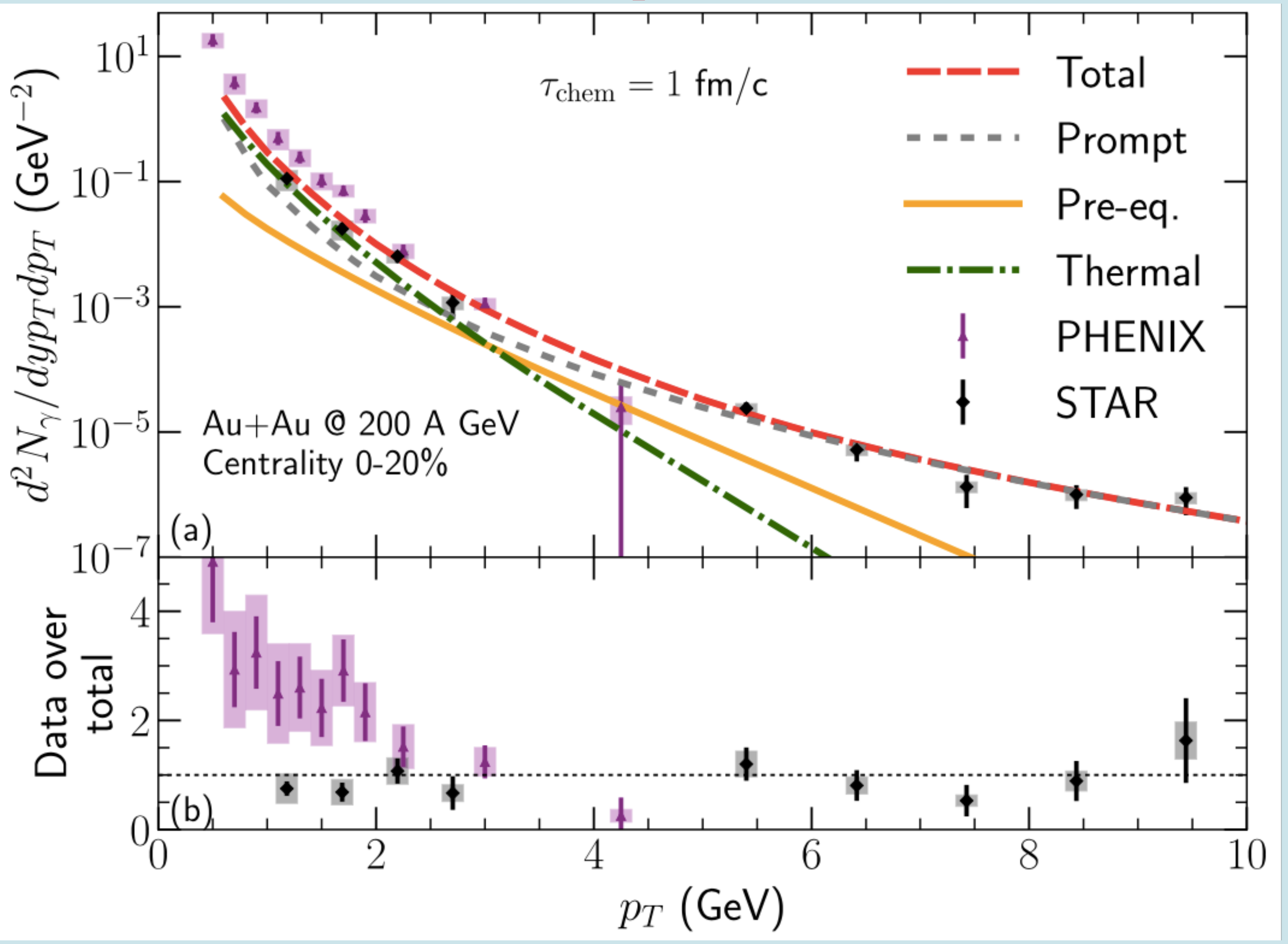

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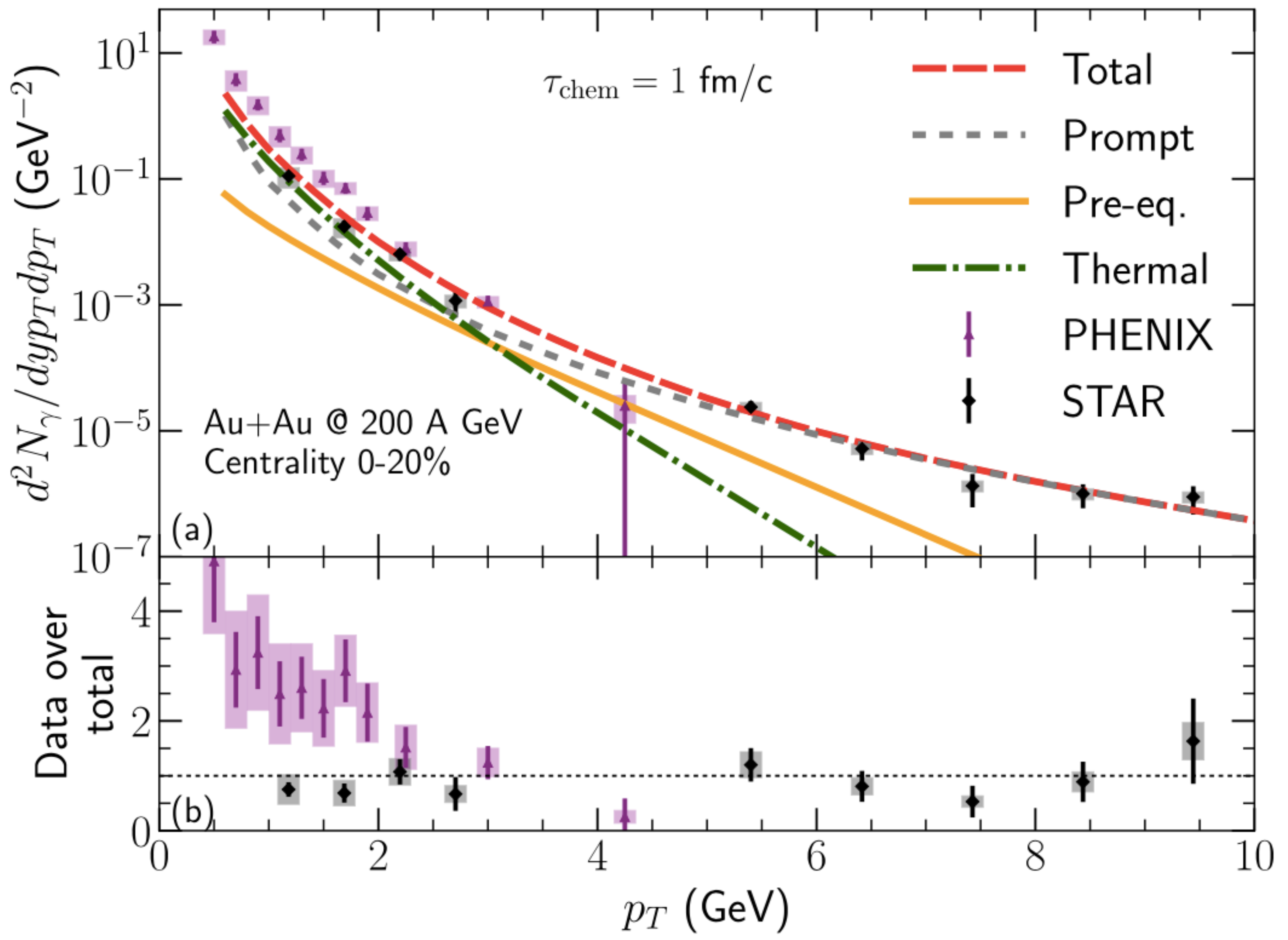

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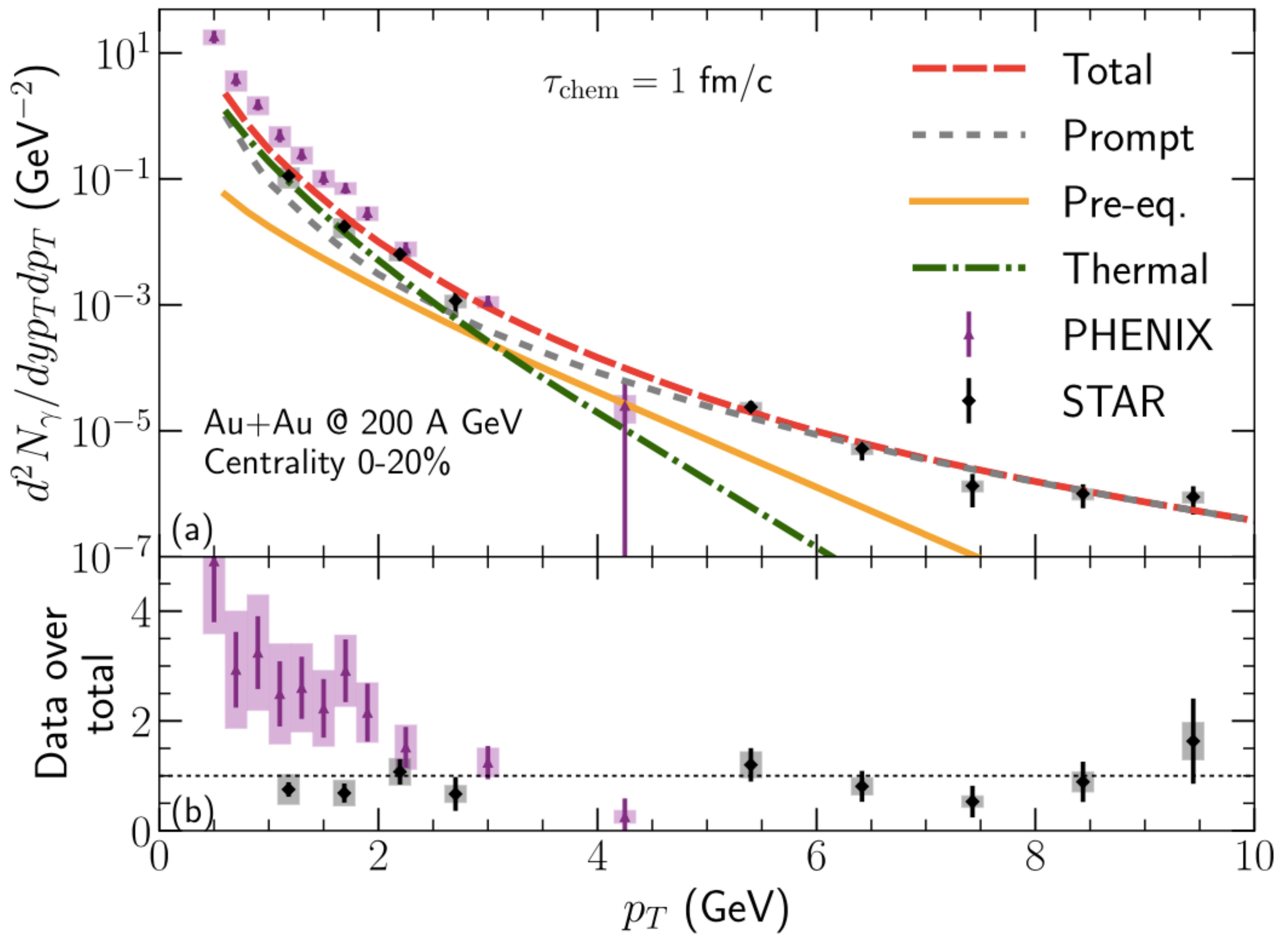

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Missing something in the model? Experimental uncertainties?

Direct photon puzzle (2)
Unexpected large direct photon v_2 ~ pion v_2

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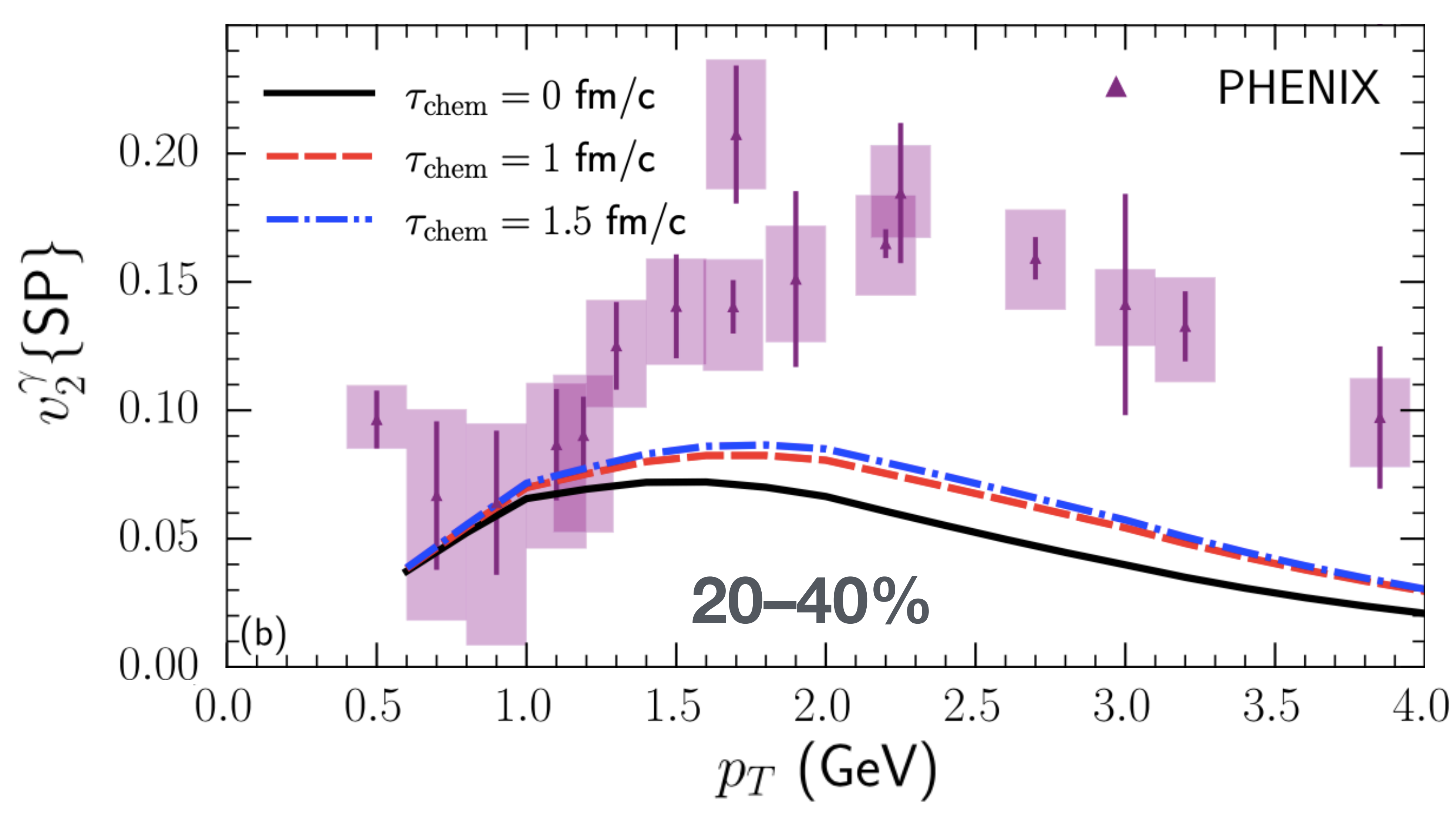

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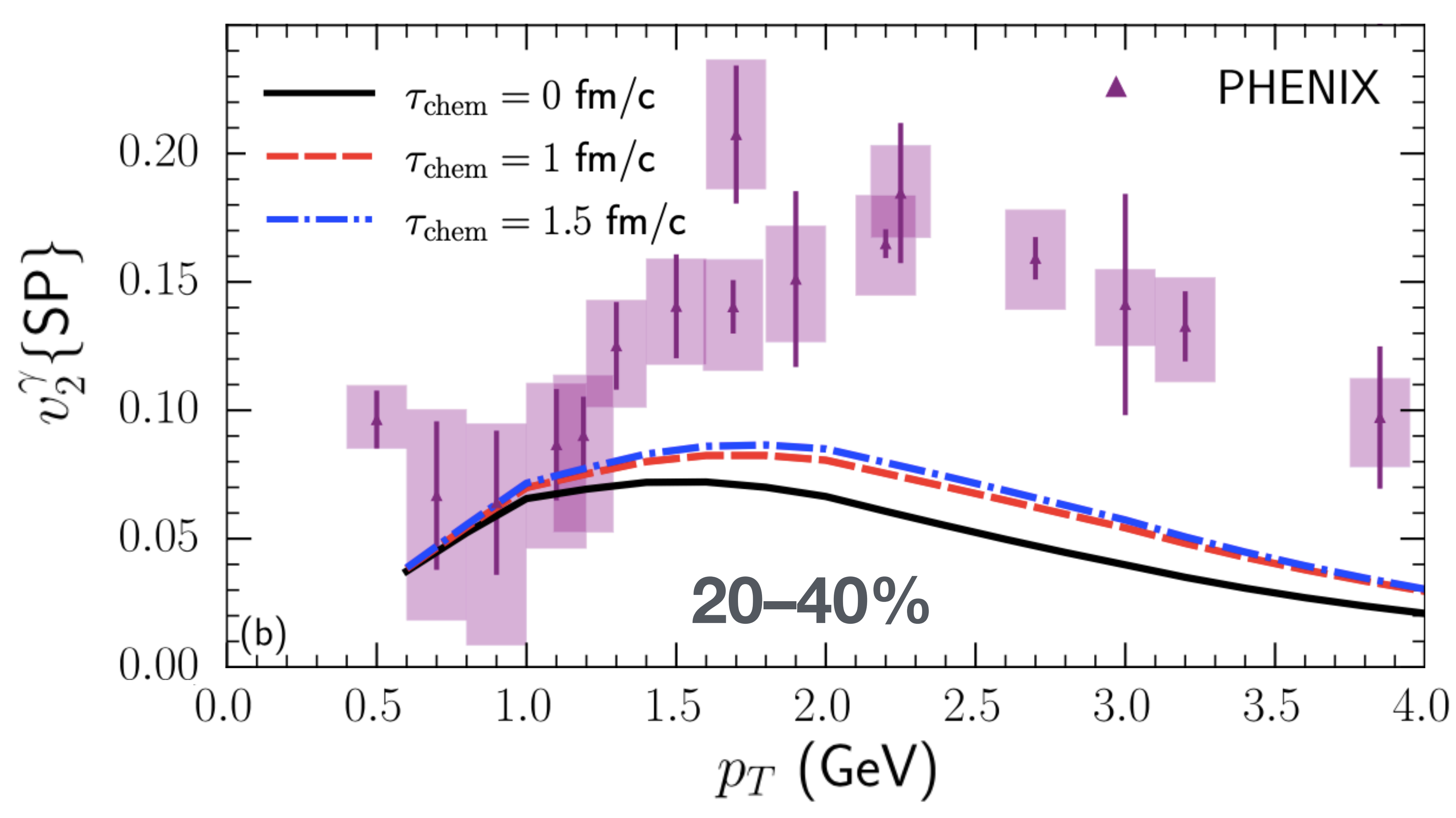

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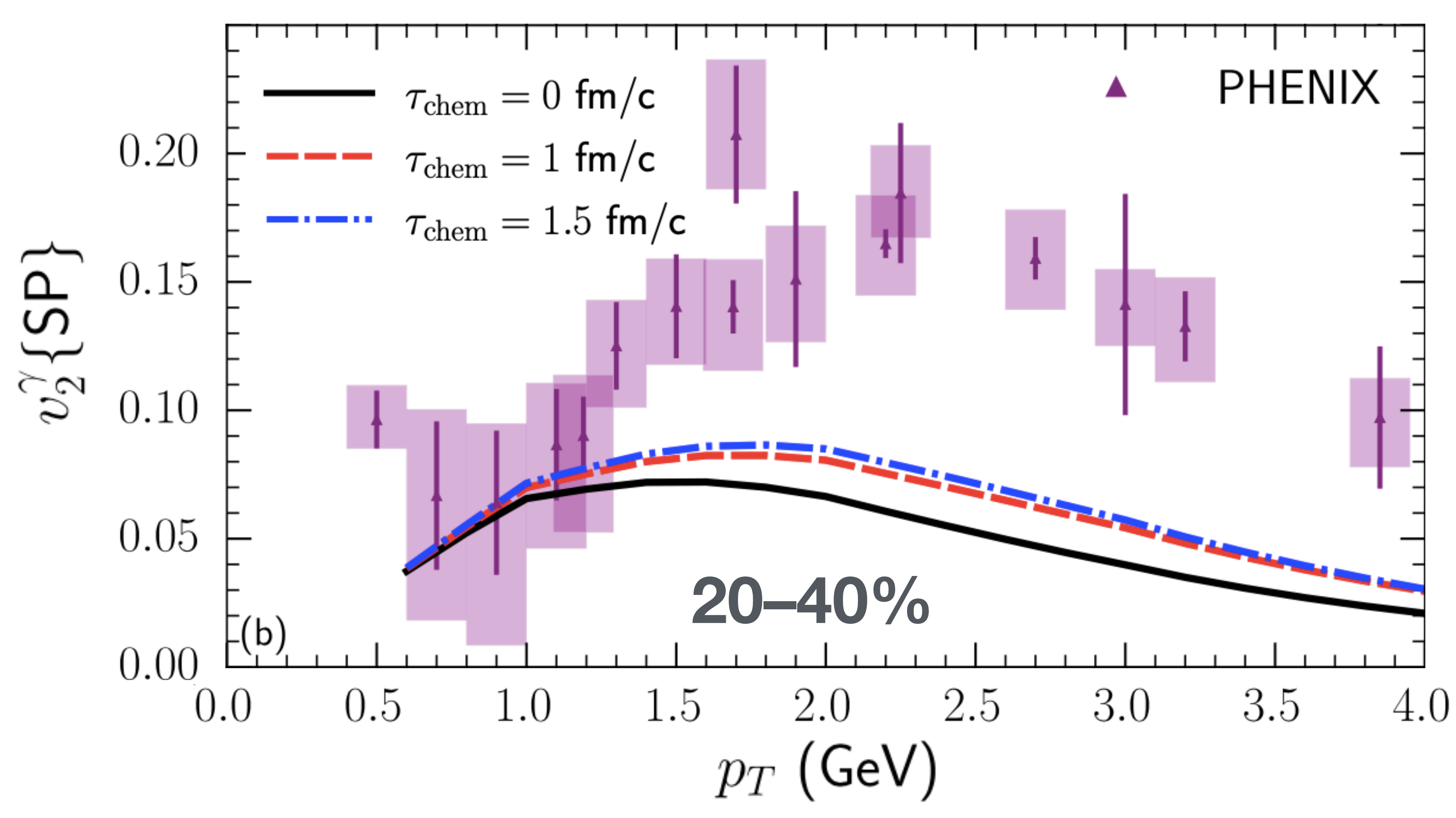

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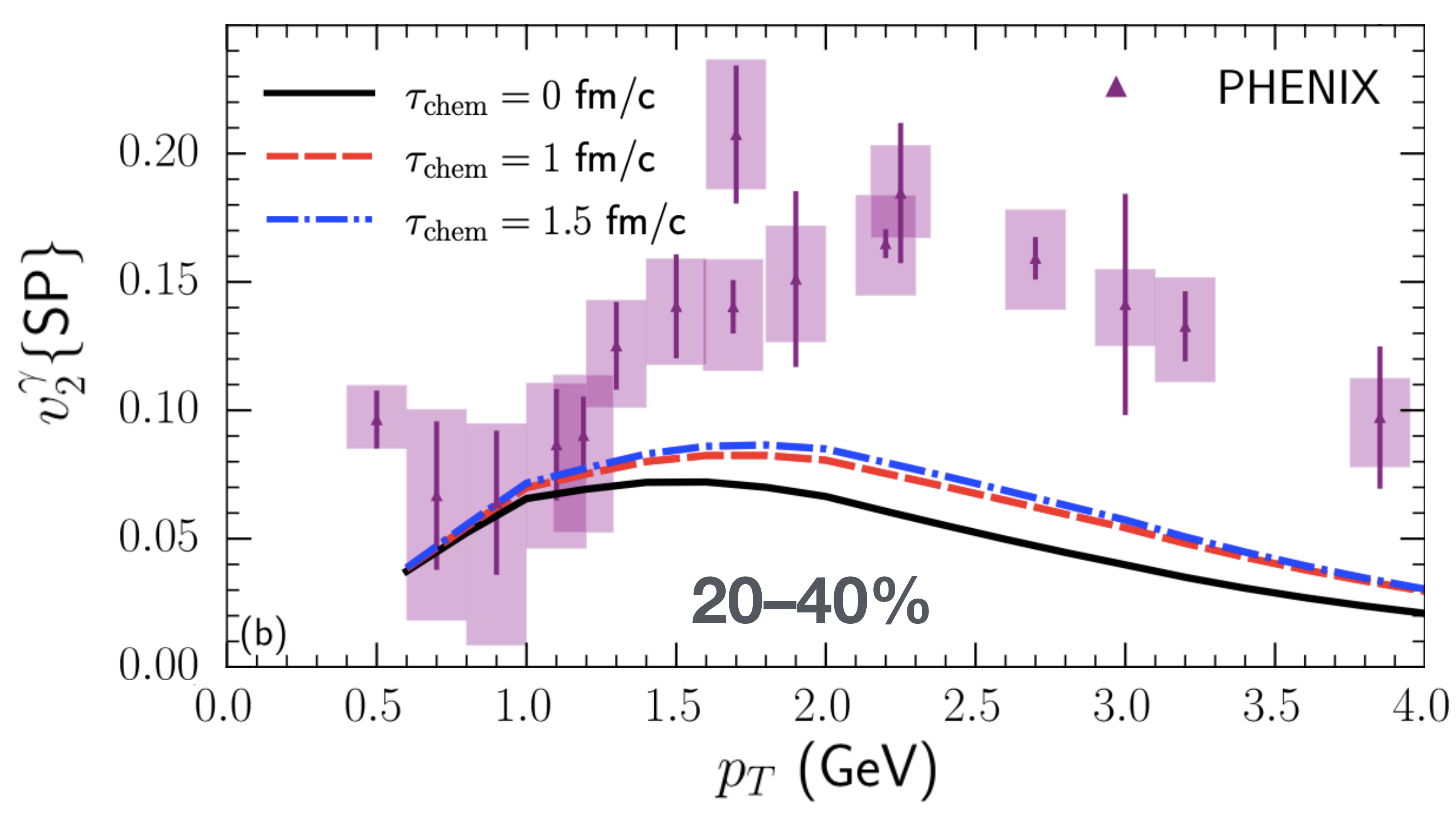

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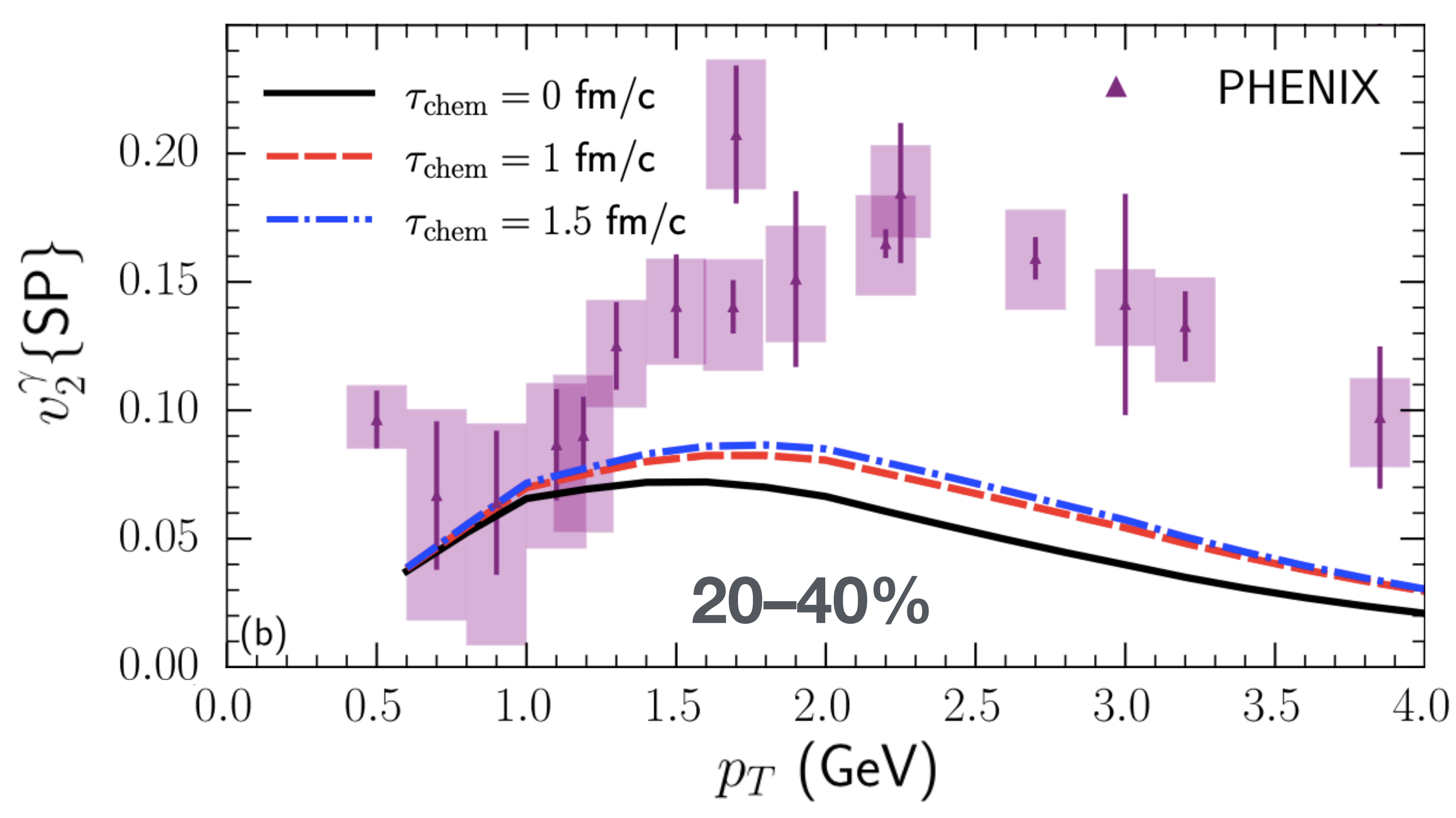

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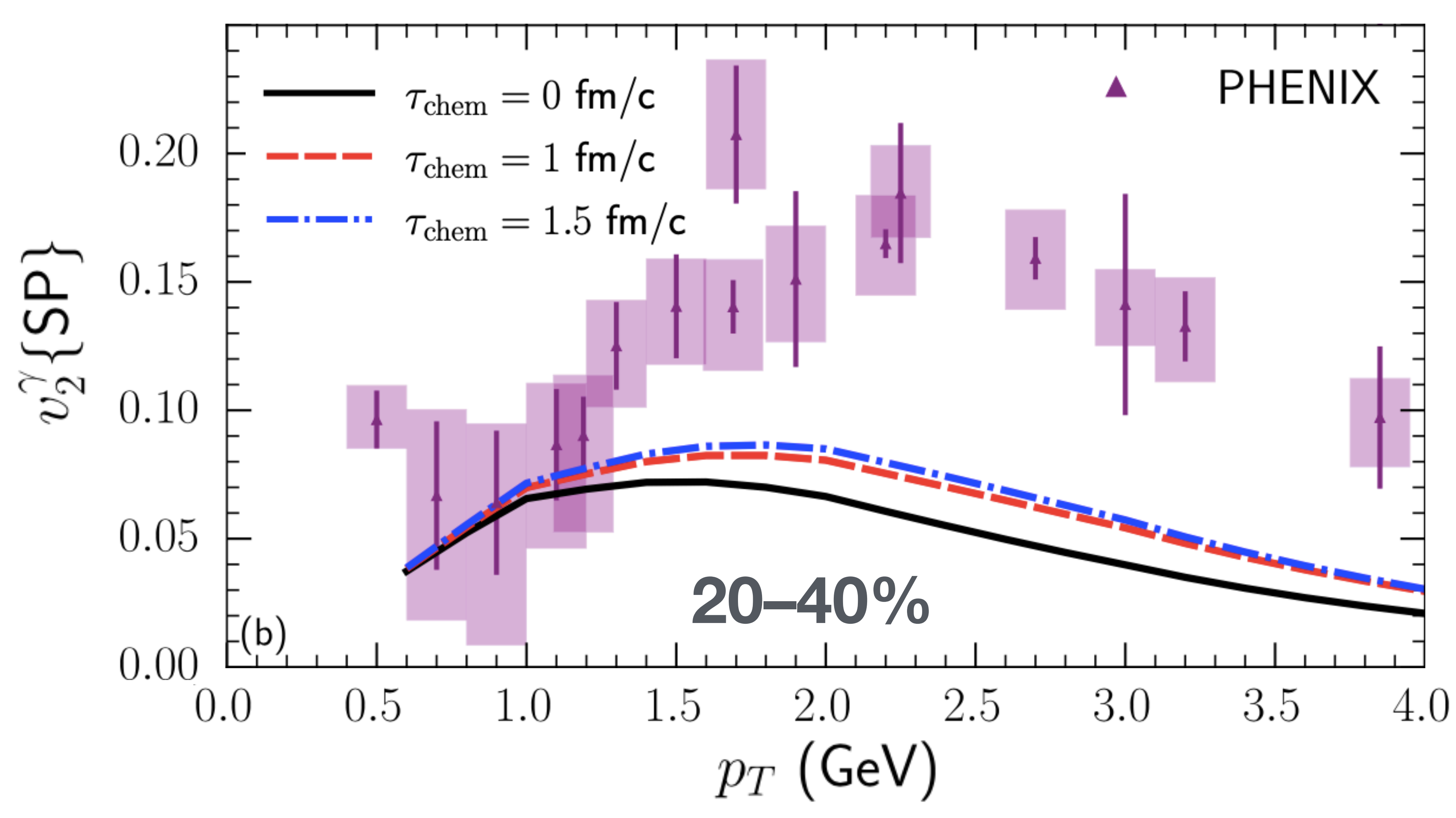

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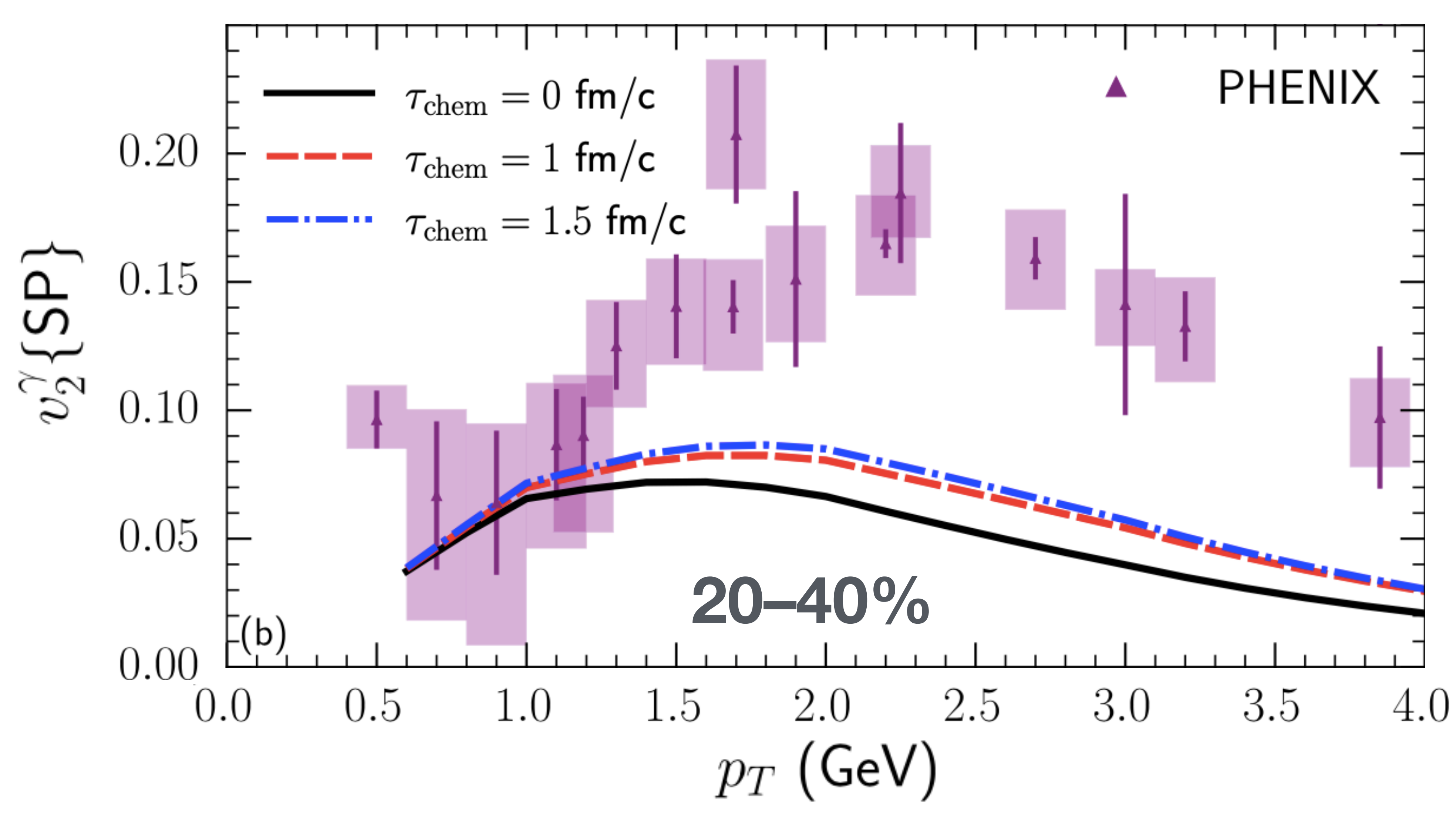

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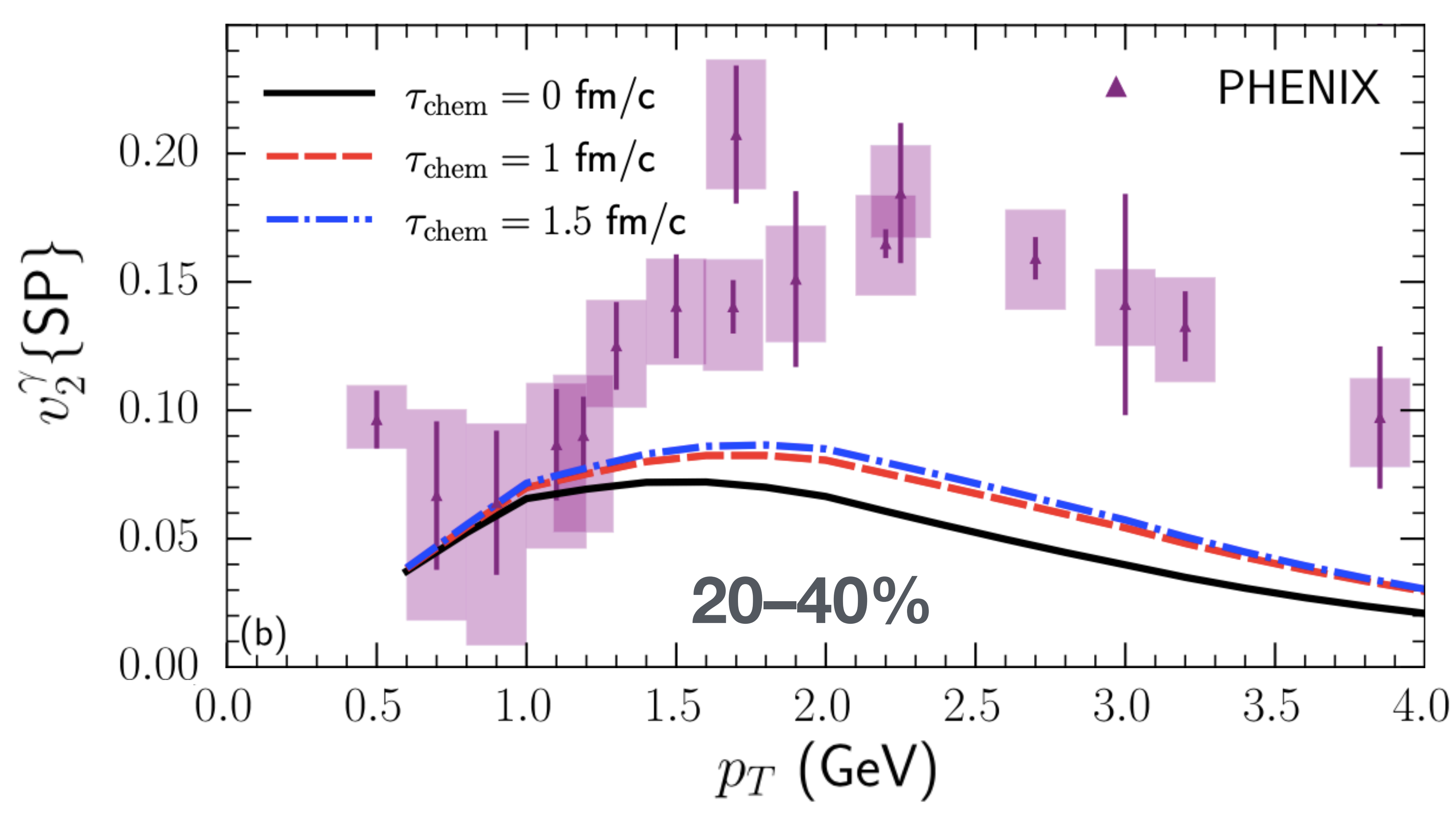

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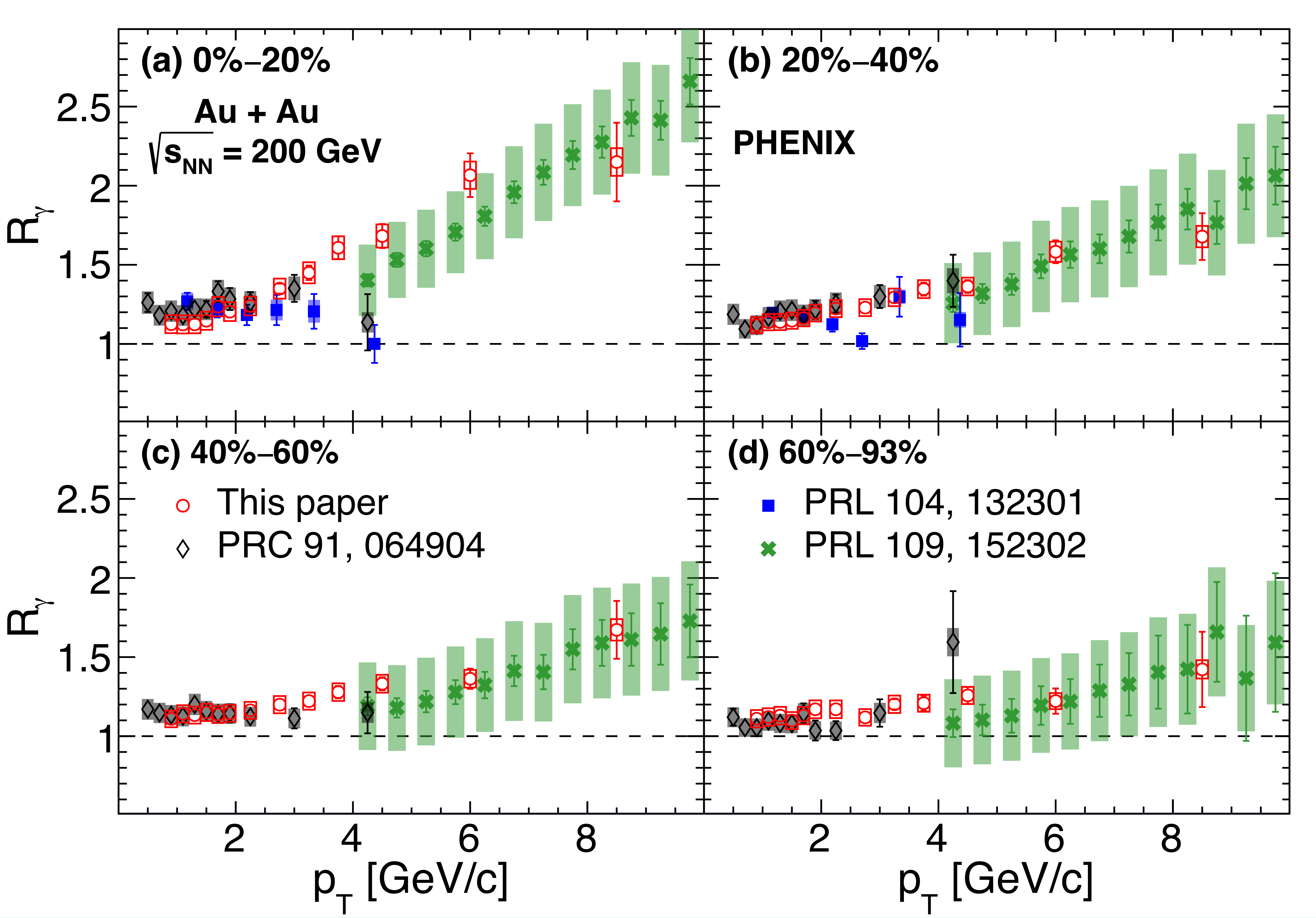
  - Systematic comparison across different collision systems and energies

Consistent results across different methods

- PHENIX measured direct photon with different methods



arXiv:2203.17187

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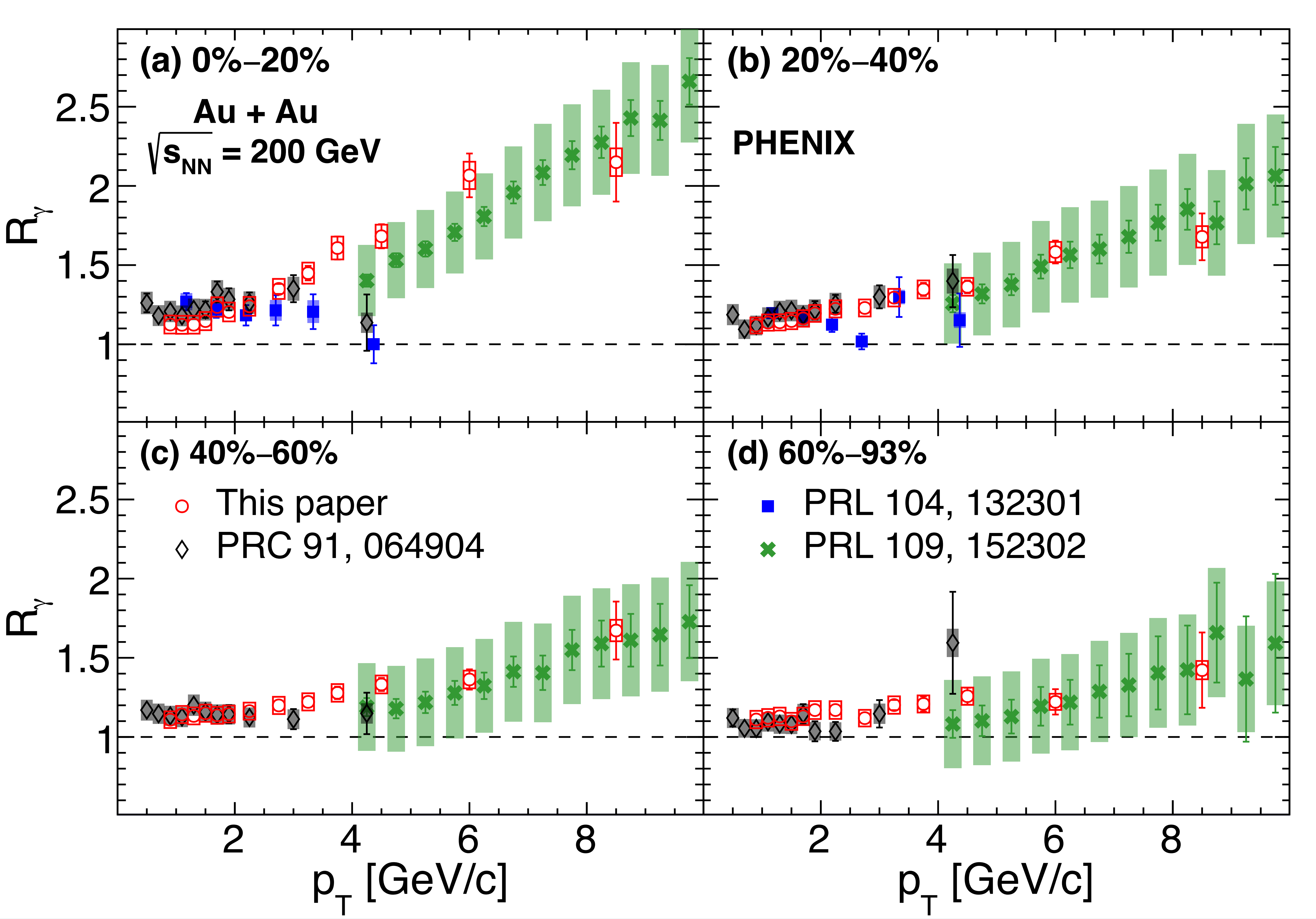

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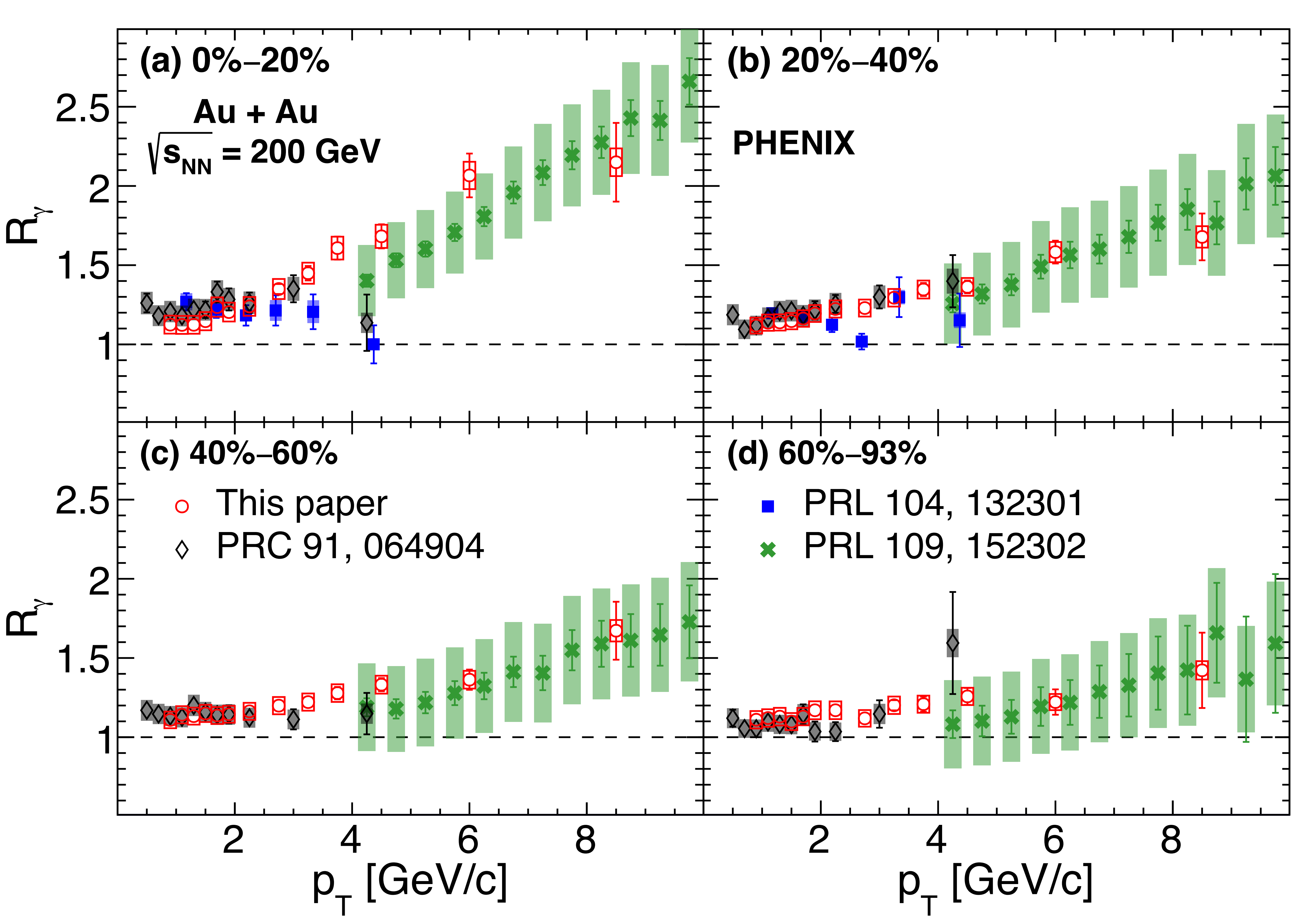

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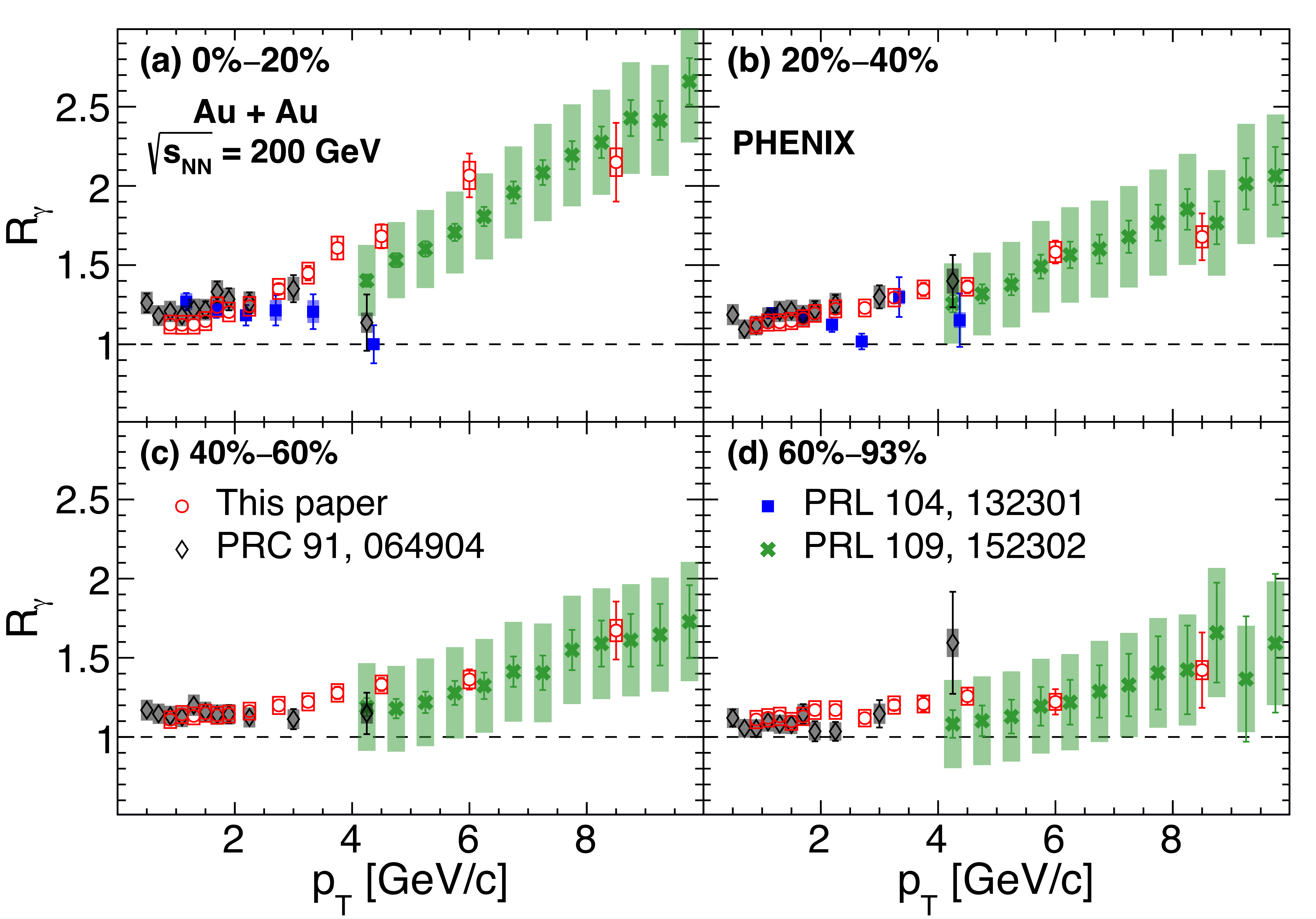

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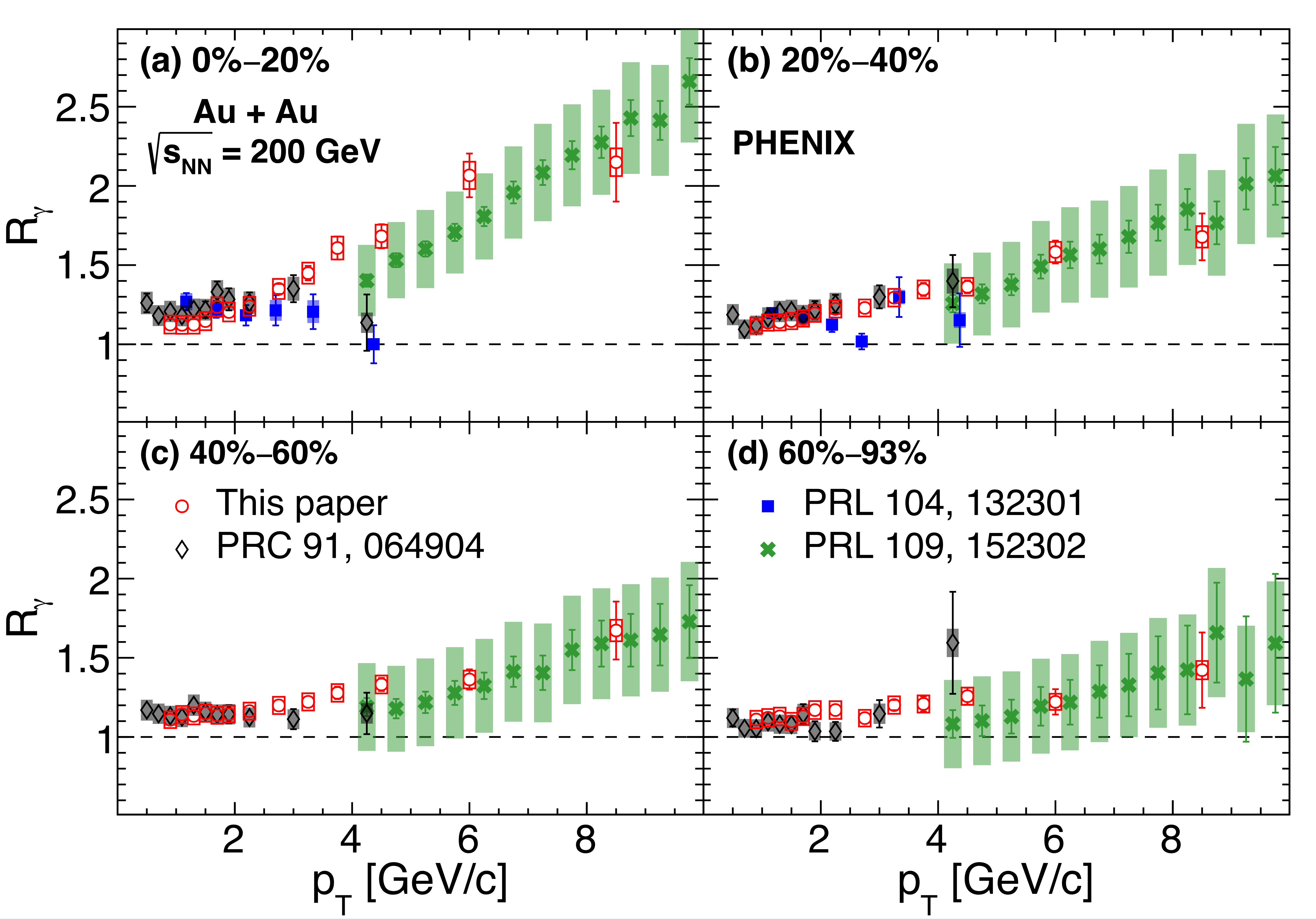

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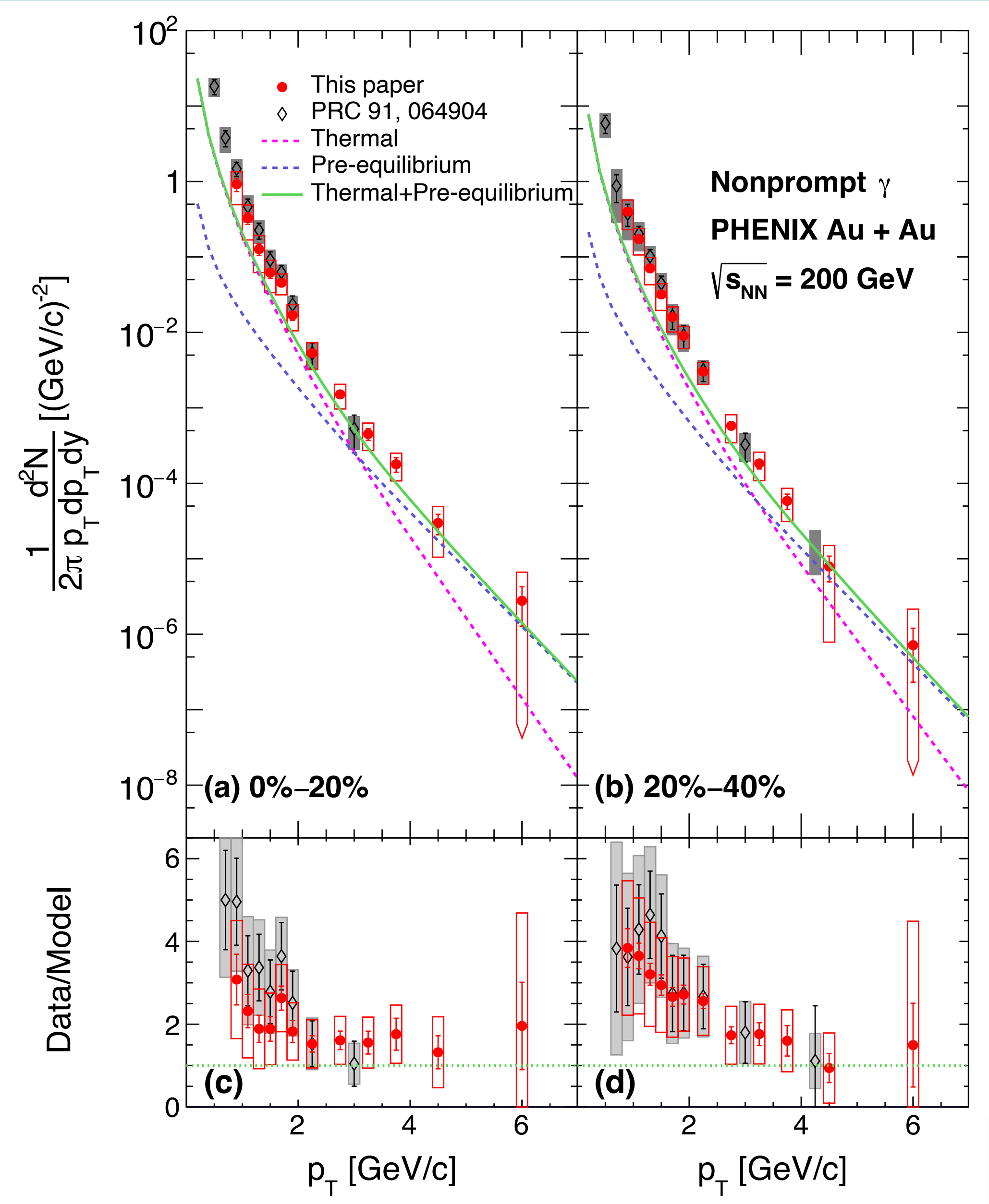

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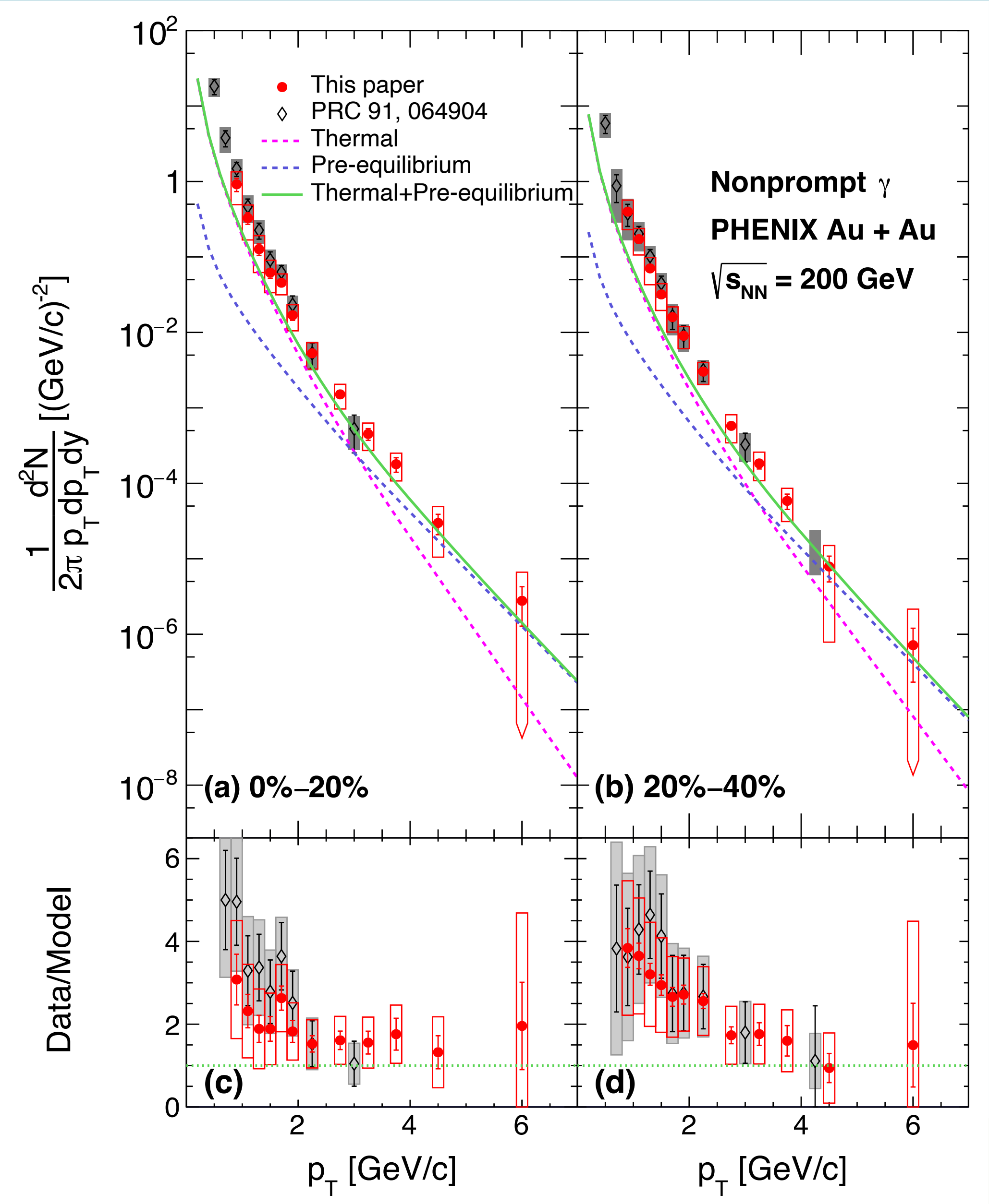

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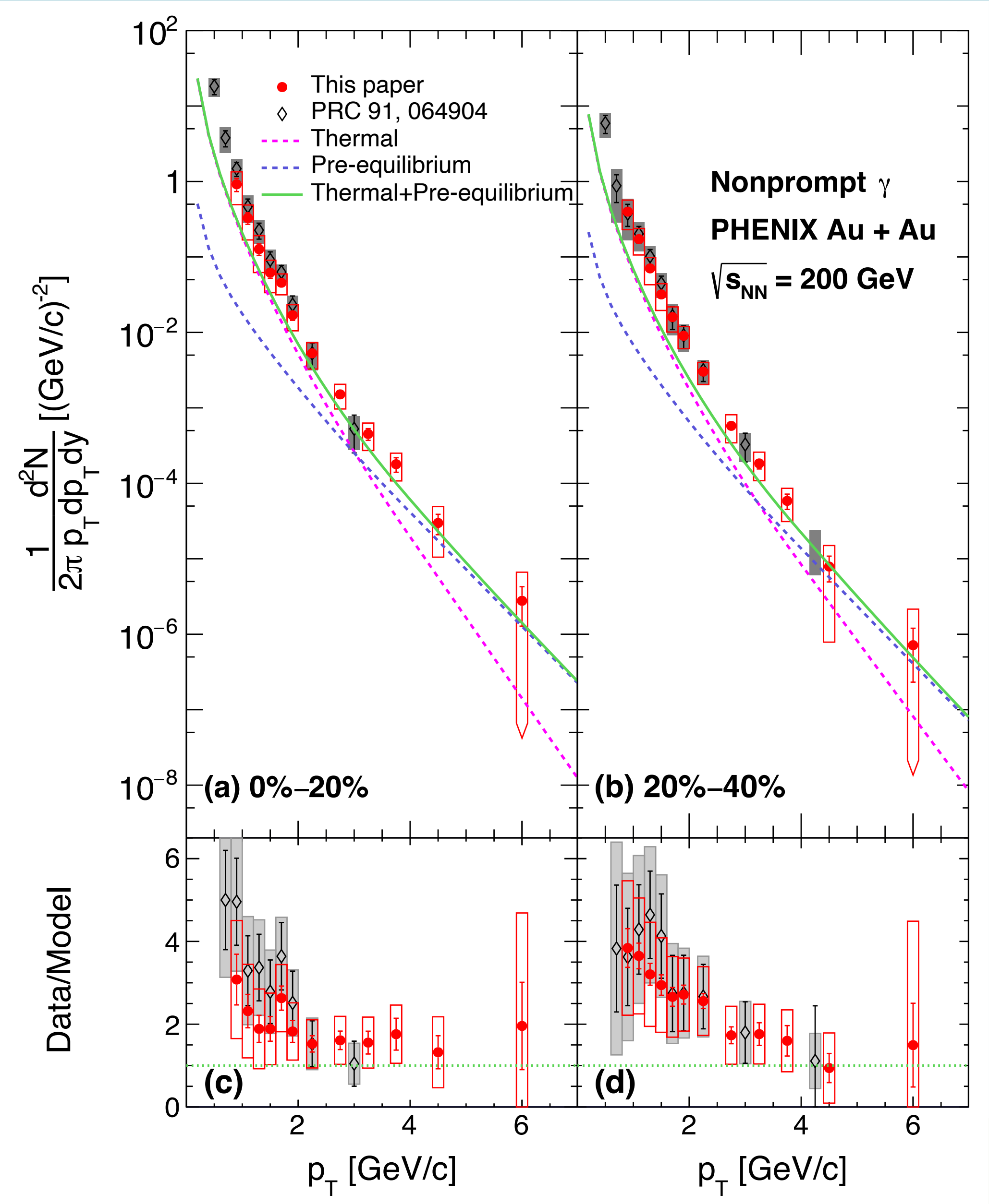

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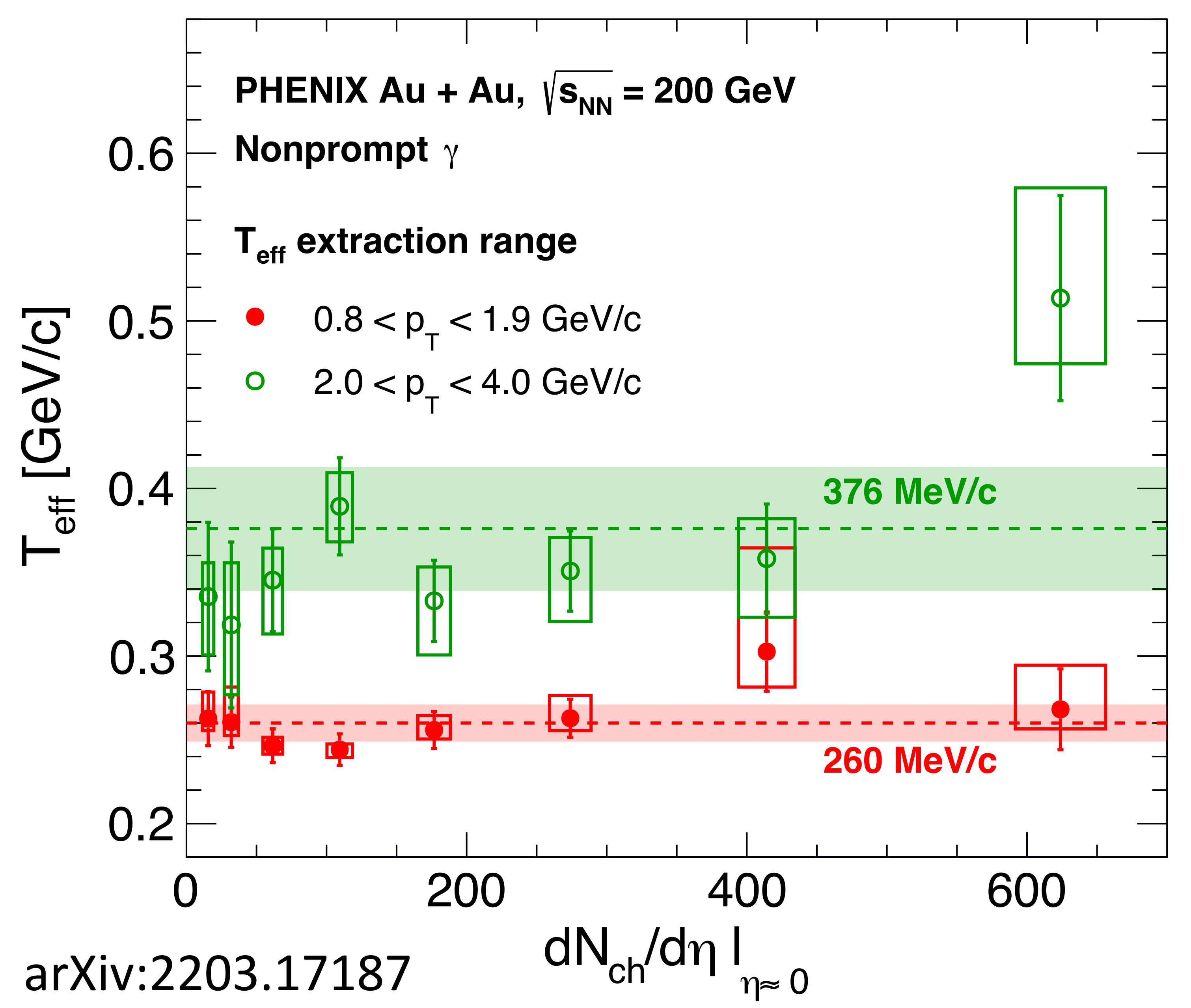

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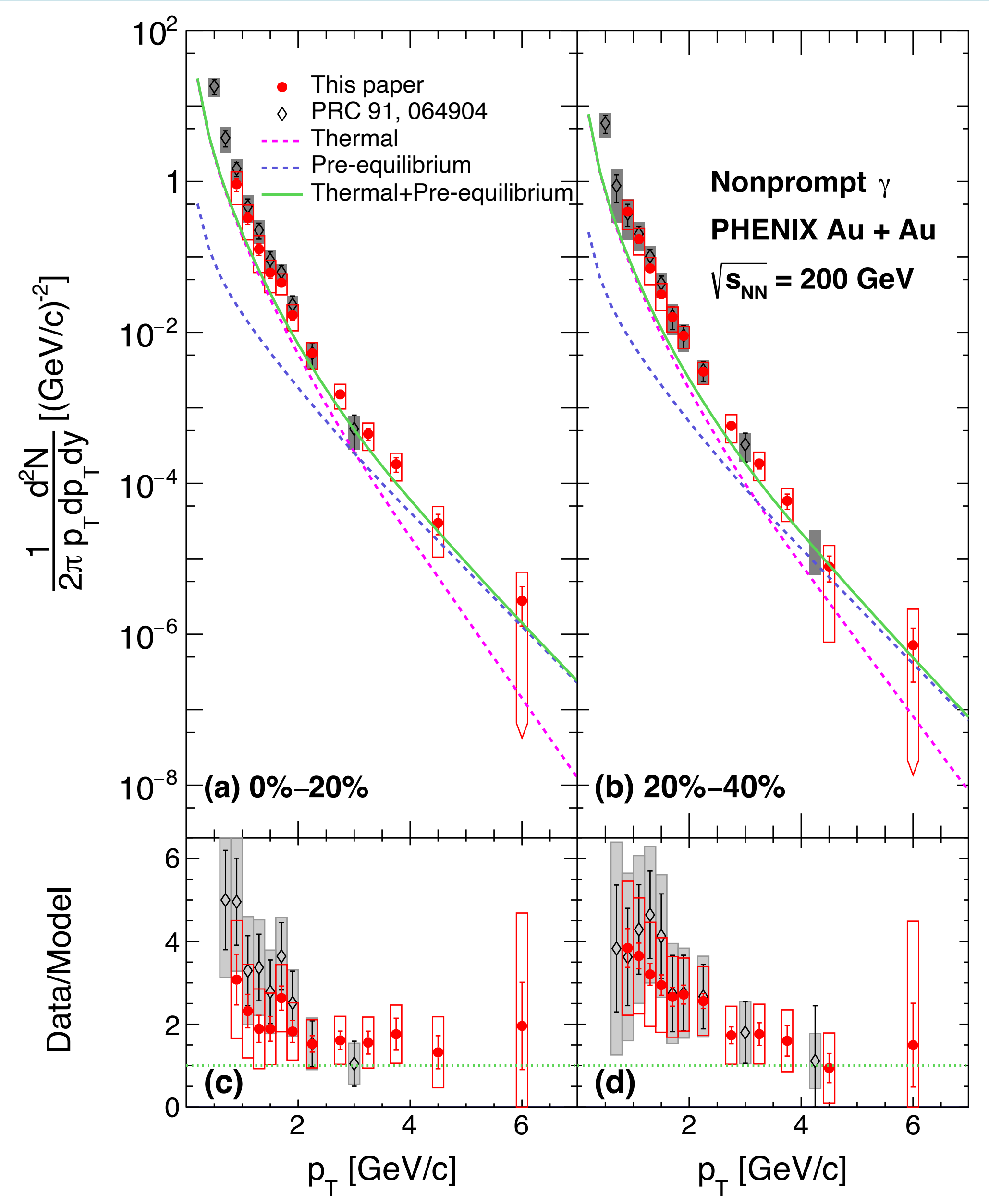

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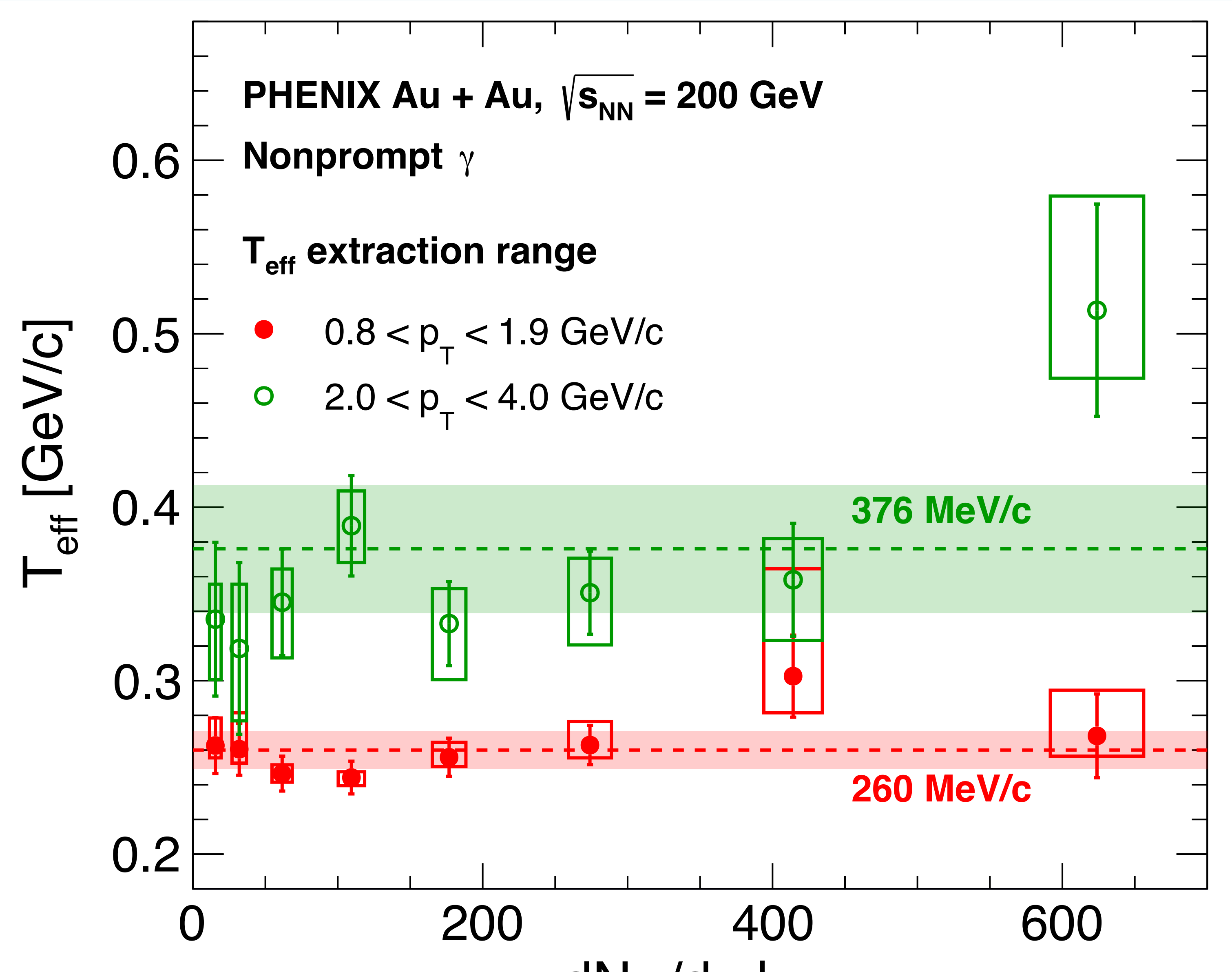

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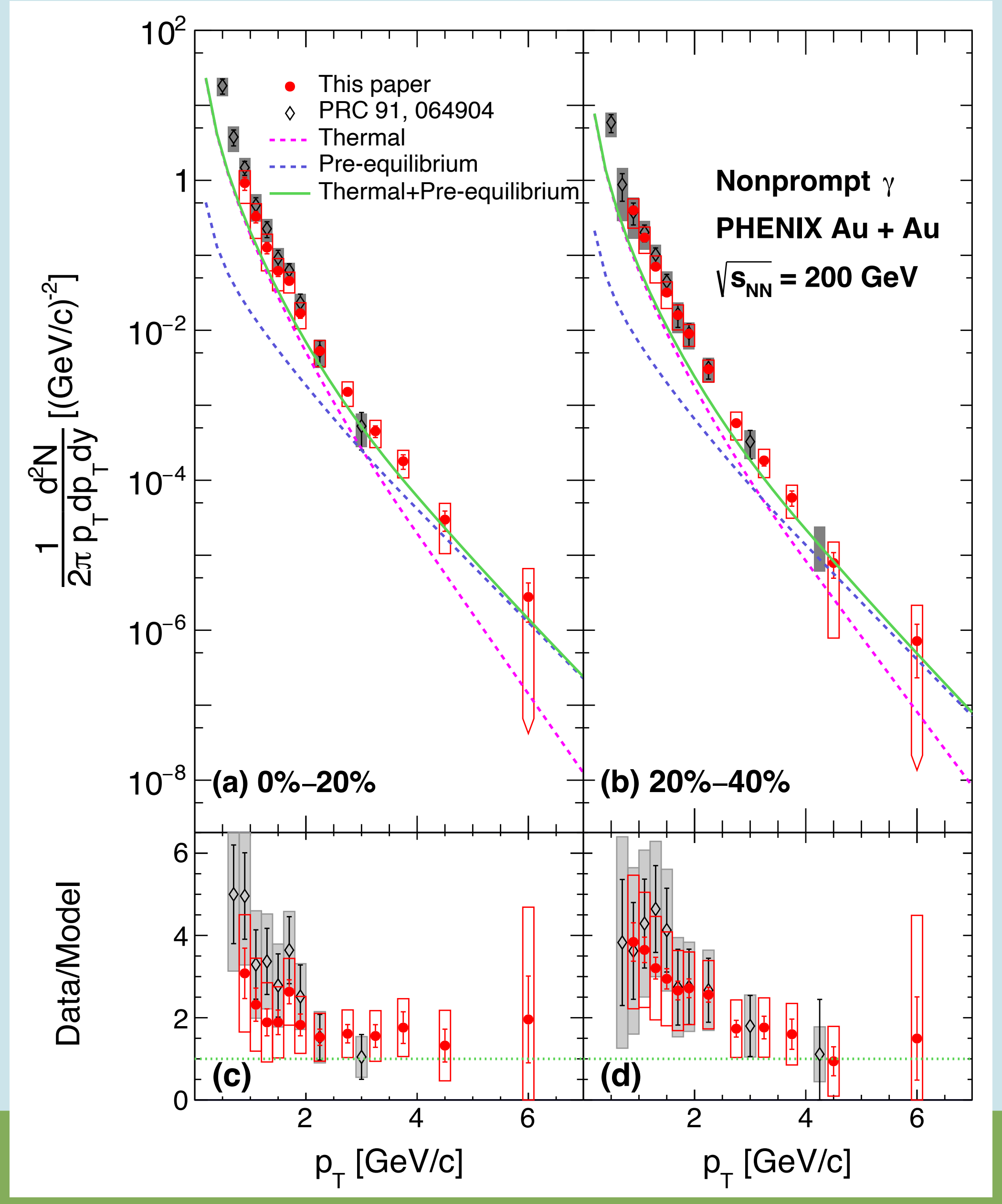

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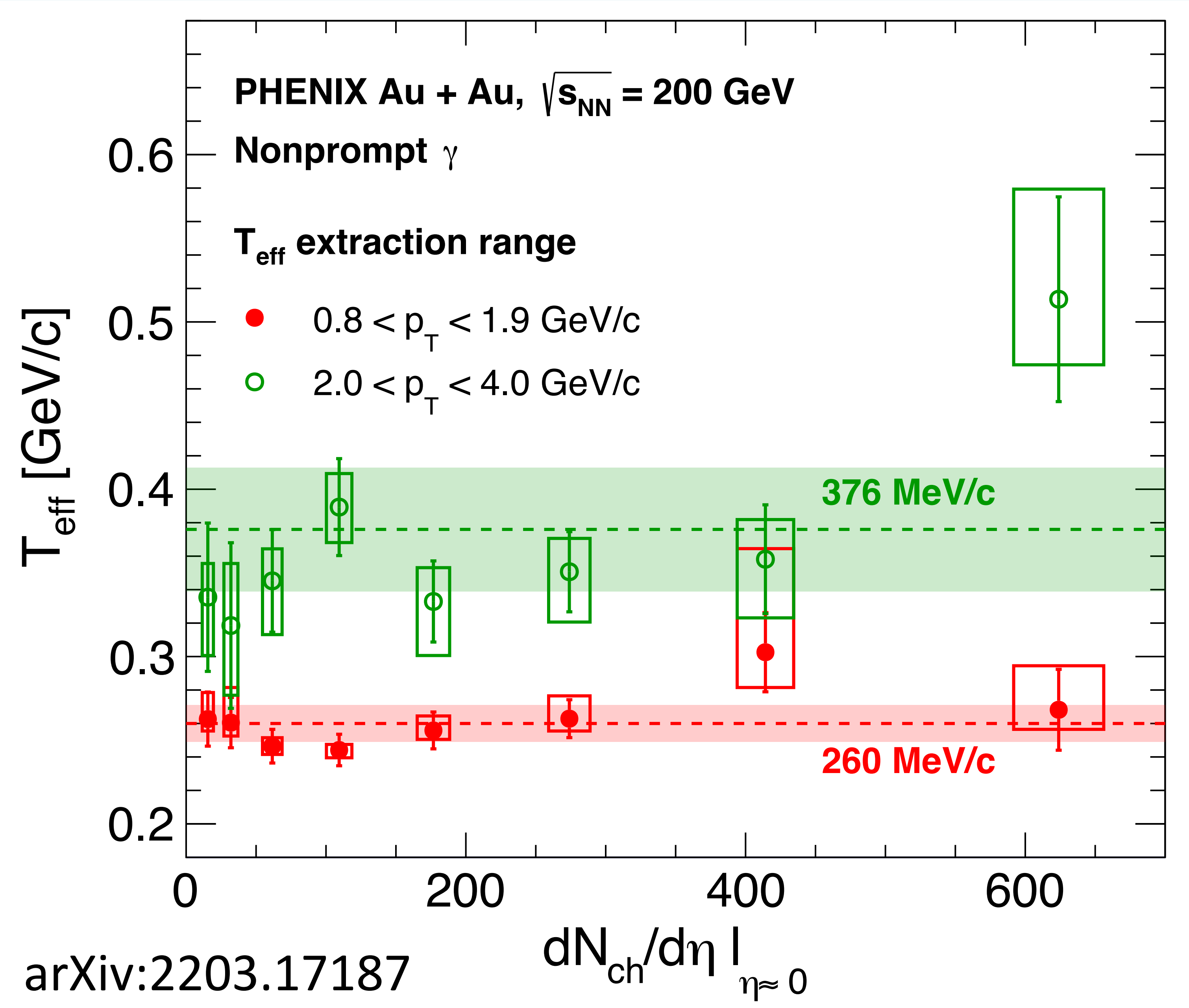

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- Caveat: $T_{eff} > T$ is affected by the blue-shift effect

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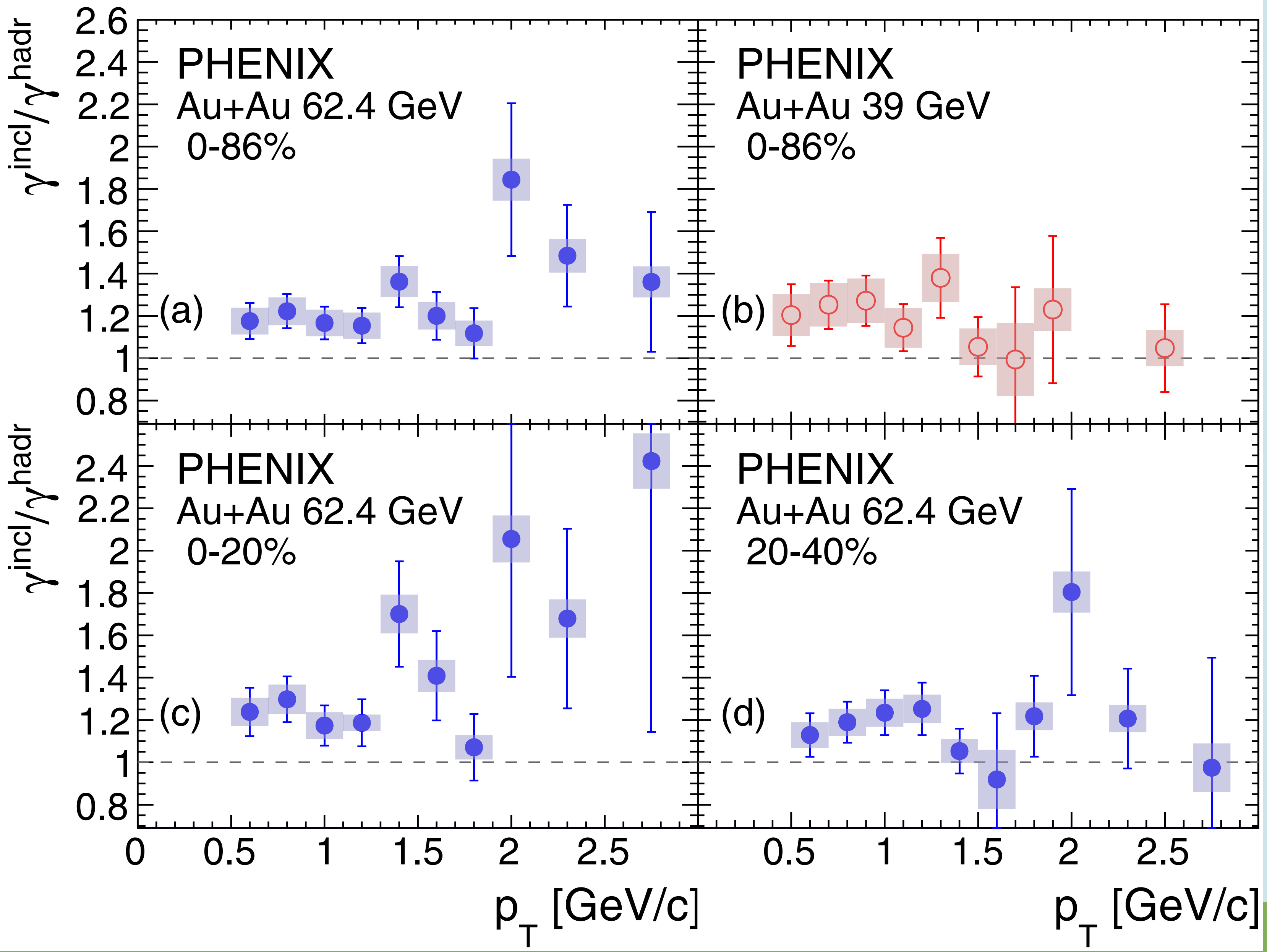

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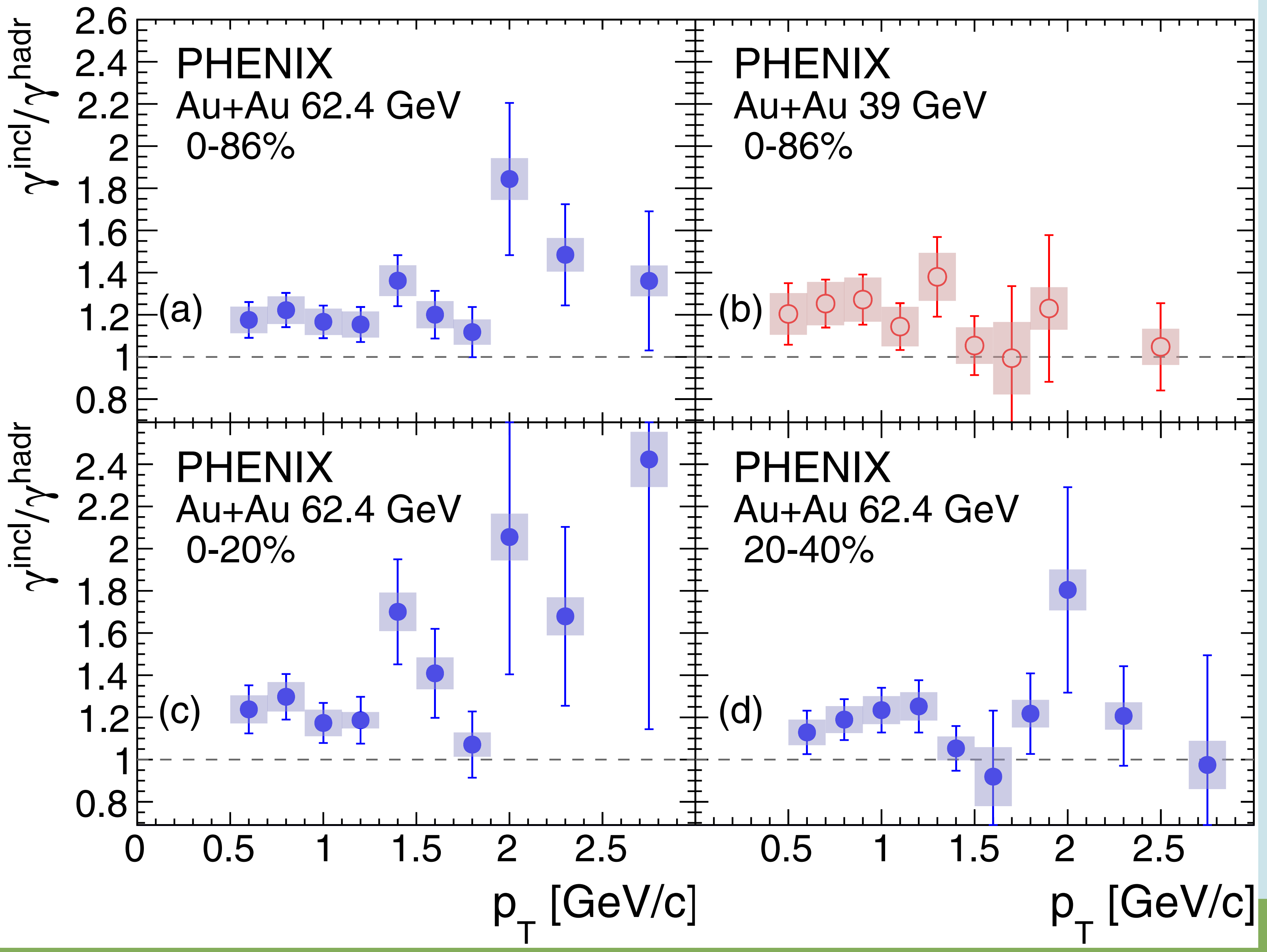

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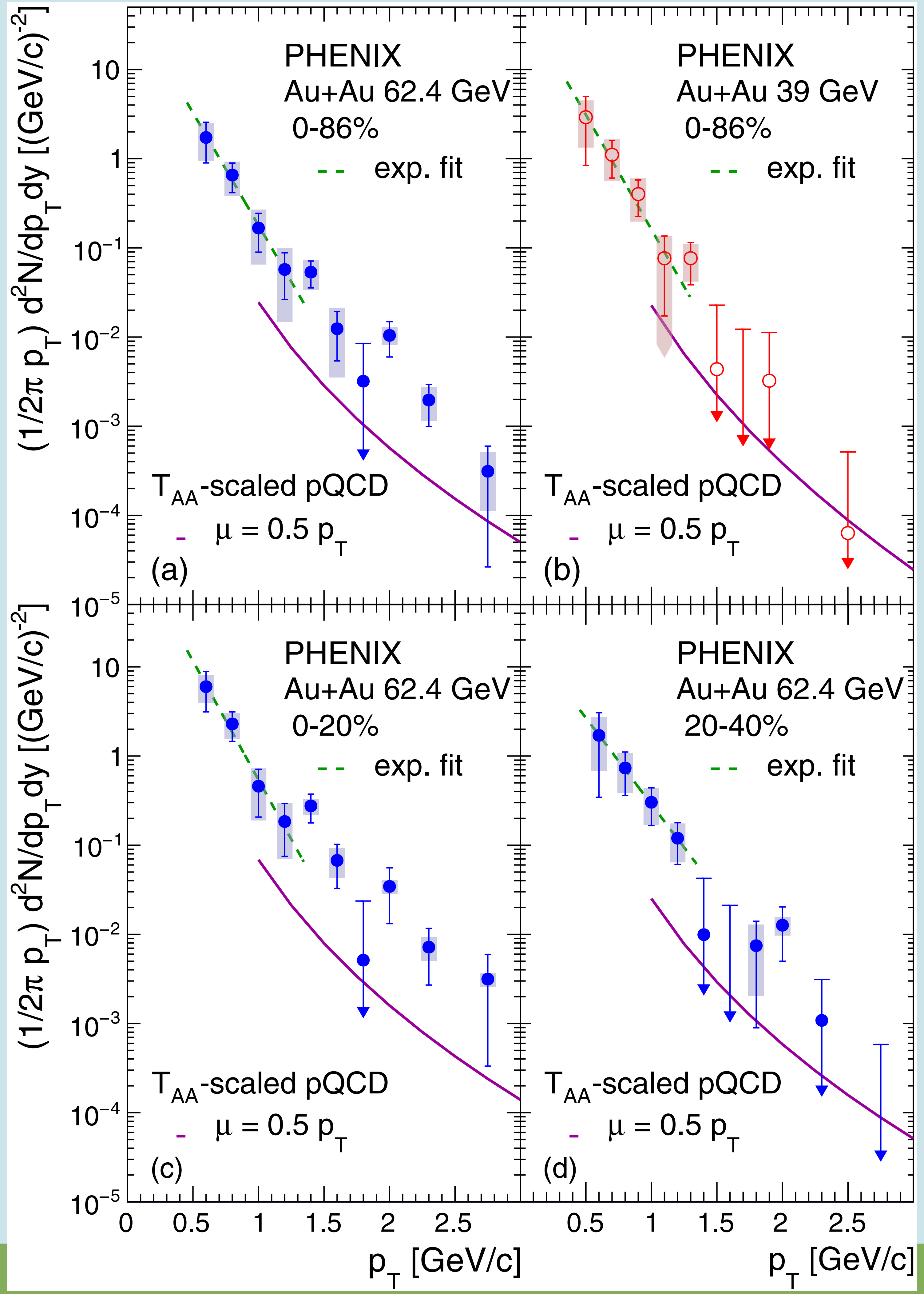
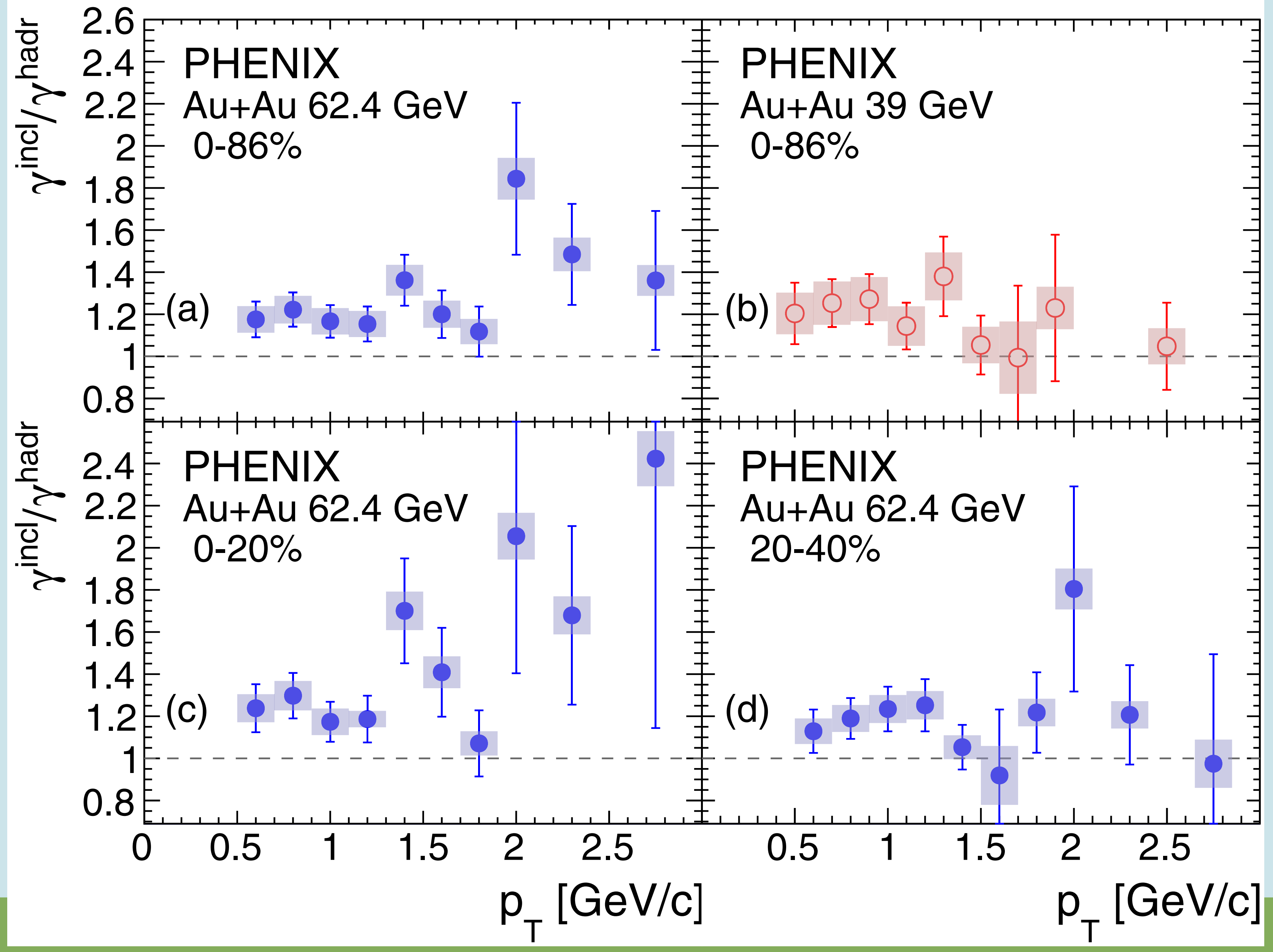


Phys. Rev. C **107**, 024914

Direct photon production at lower collision energies

- PHENIX has measured direct photon at $\sqrt{s_{NN}}$ = 39 and 62.4 GeV
- Excess (~ 20%) above decay photon has been observed
- T_{eff} achieves ~170 MeV at both energies
- No dependence on collisions energies and system size has been observed

Direct photon



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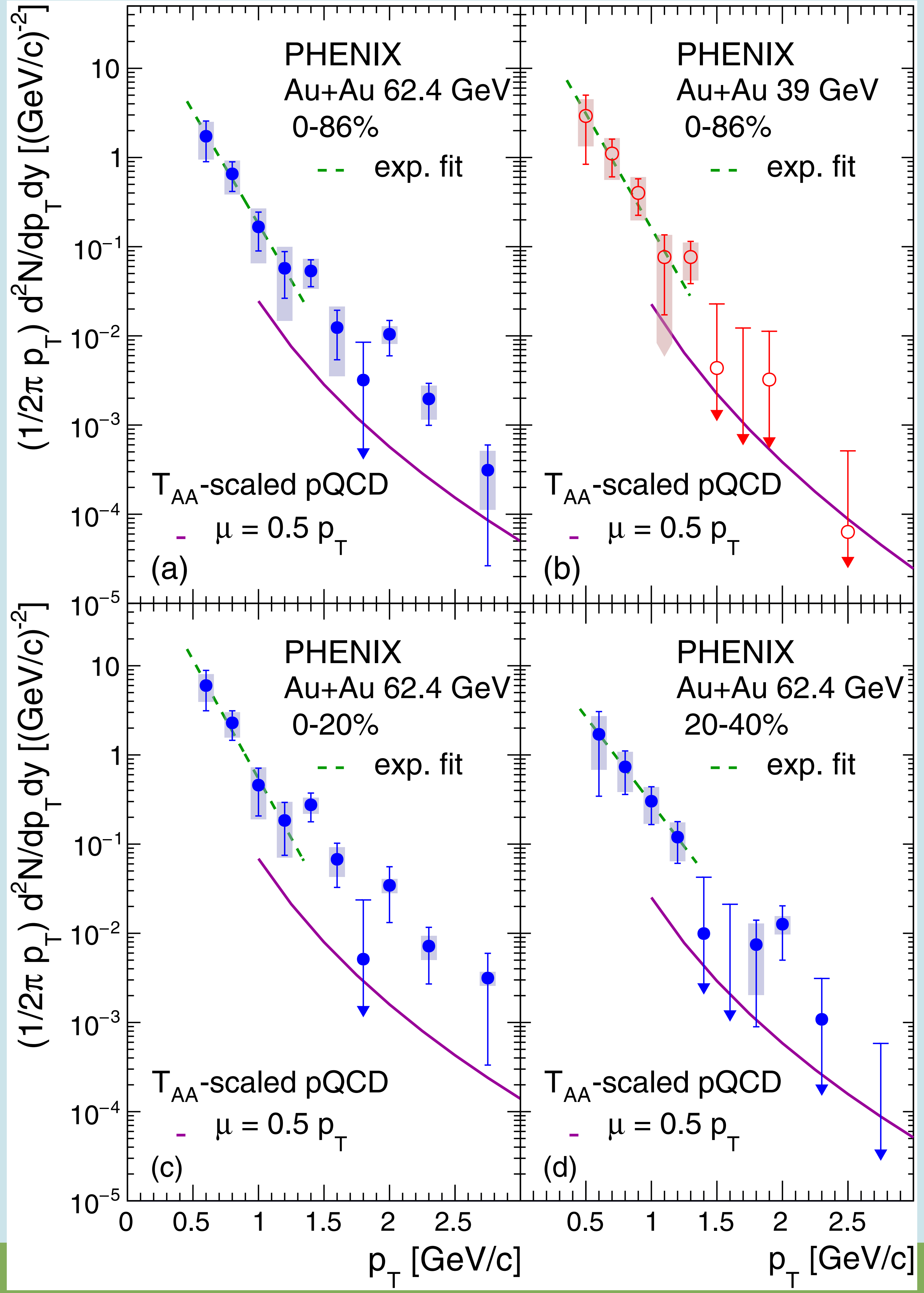

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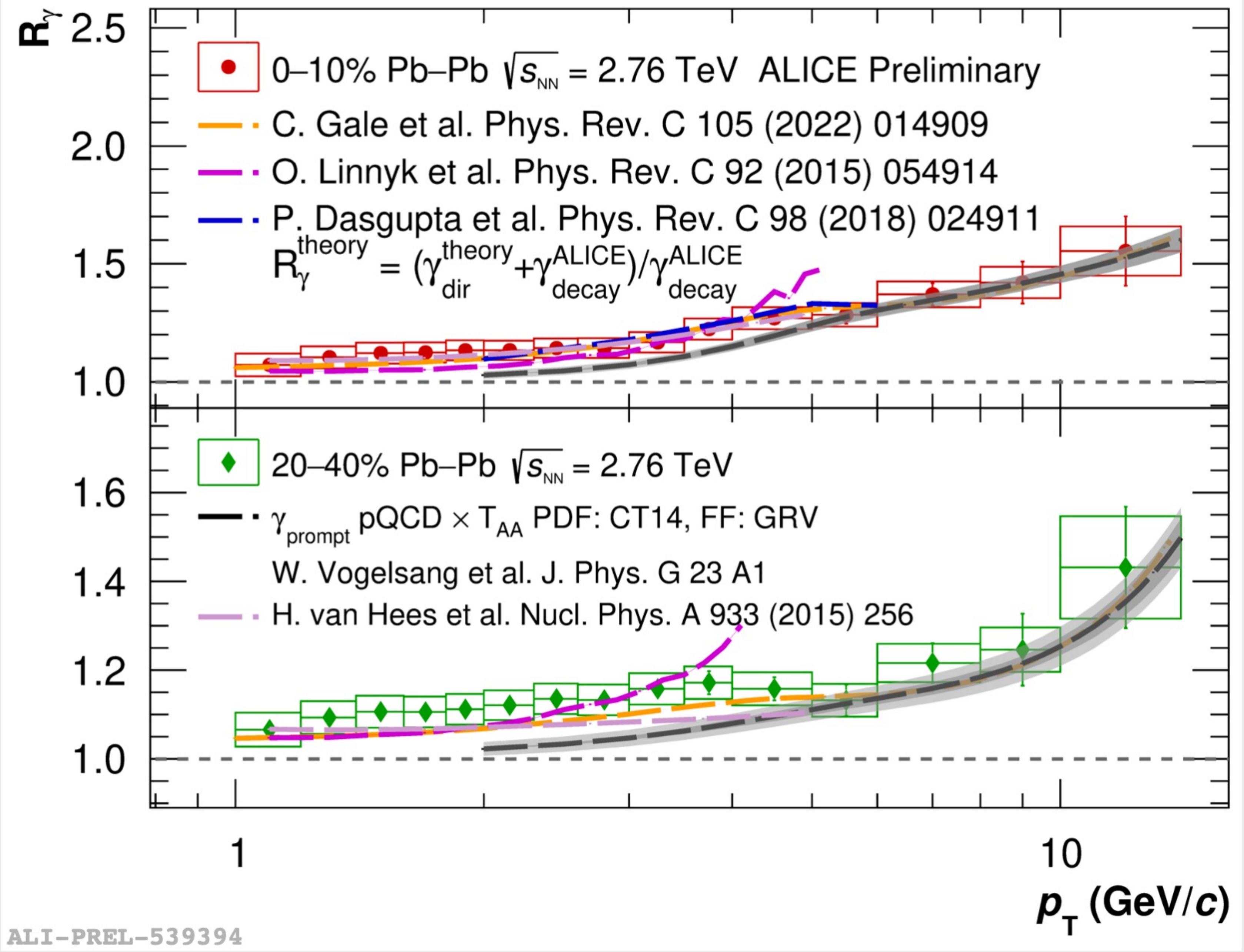

Talk at HP2023

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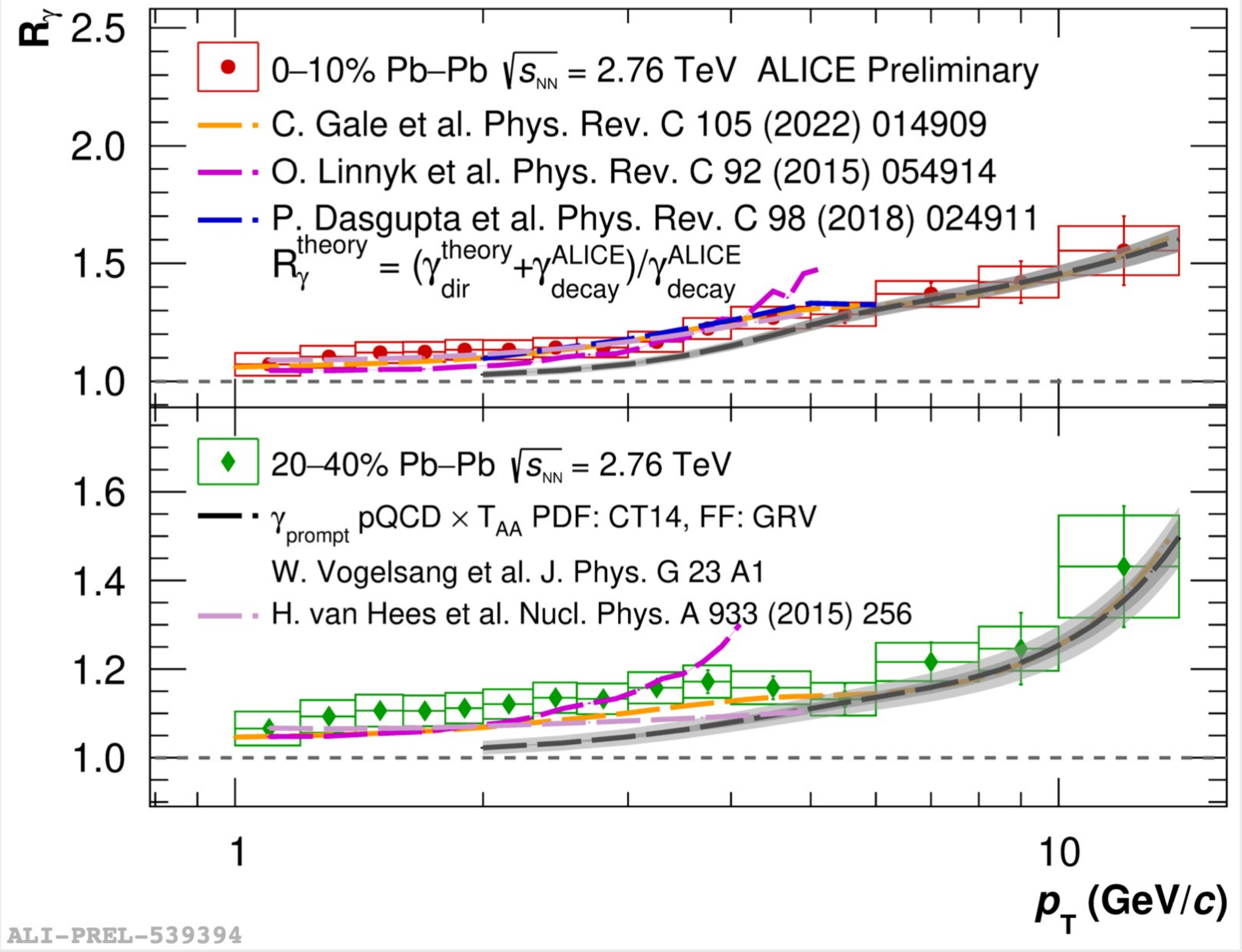
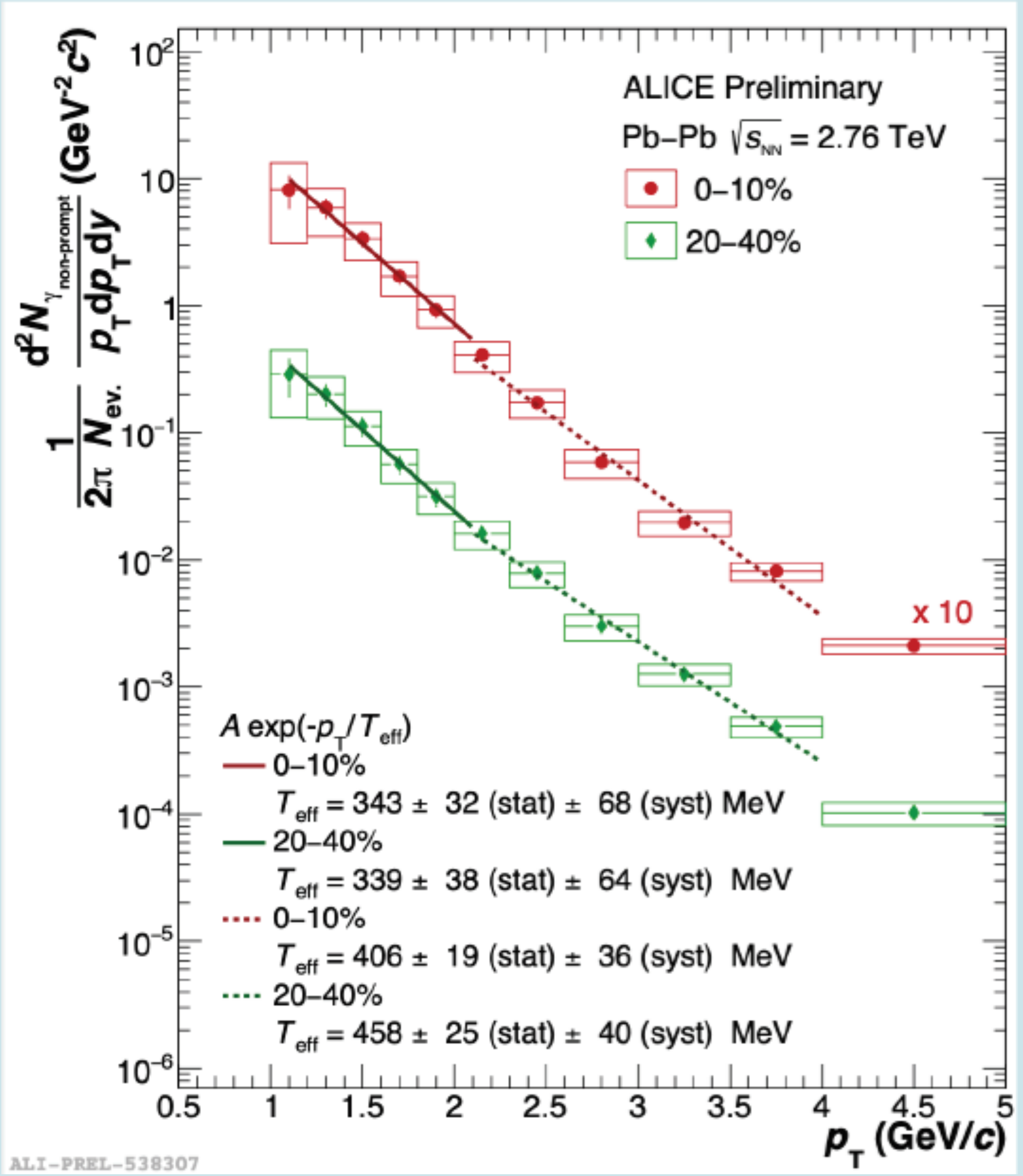


Non-prompt photon



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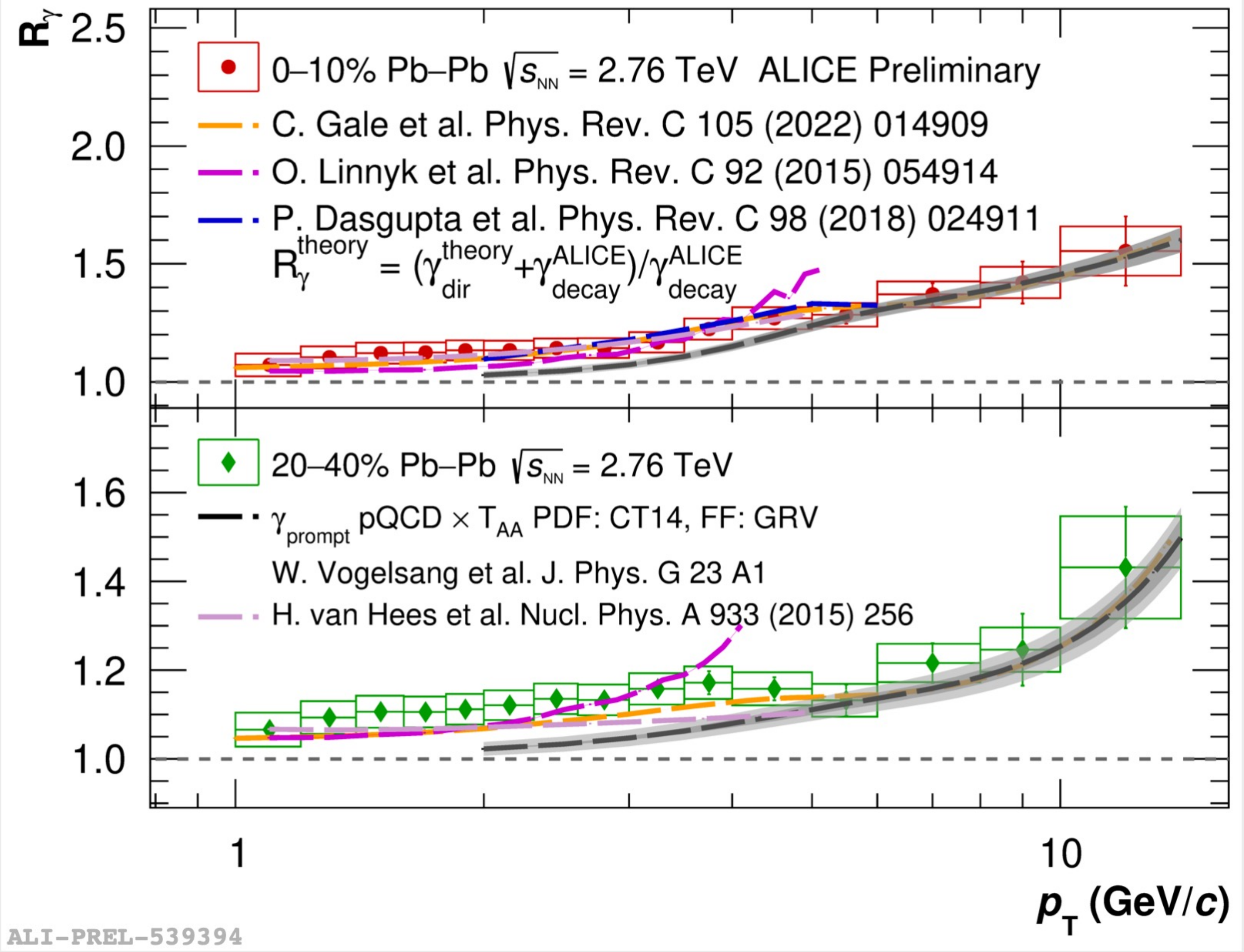

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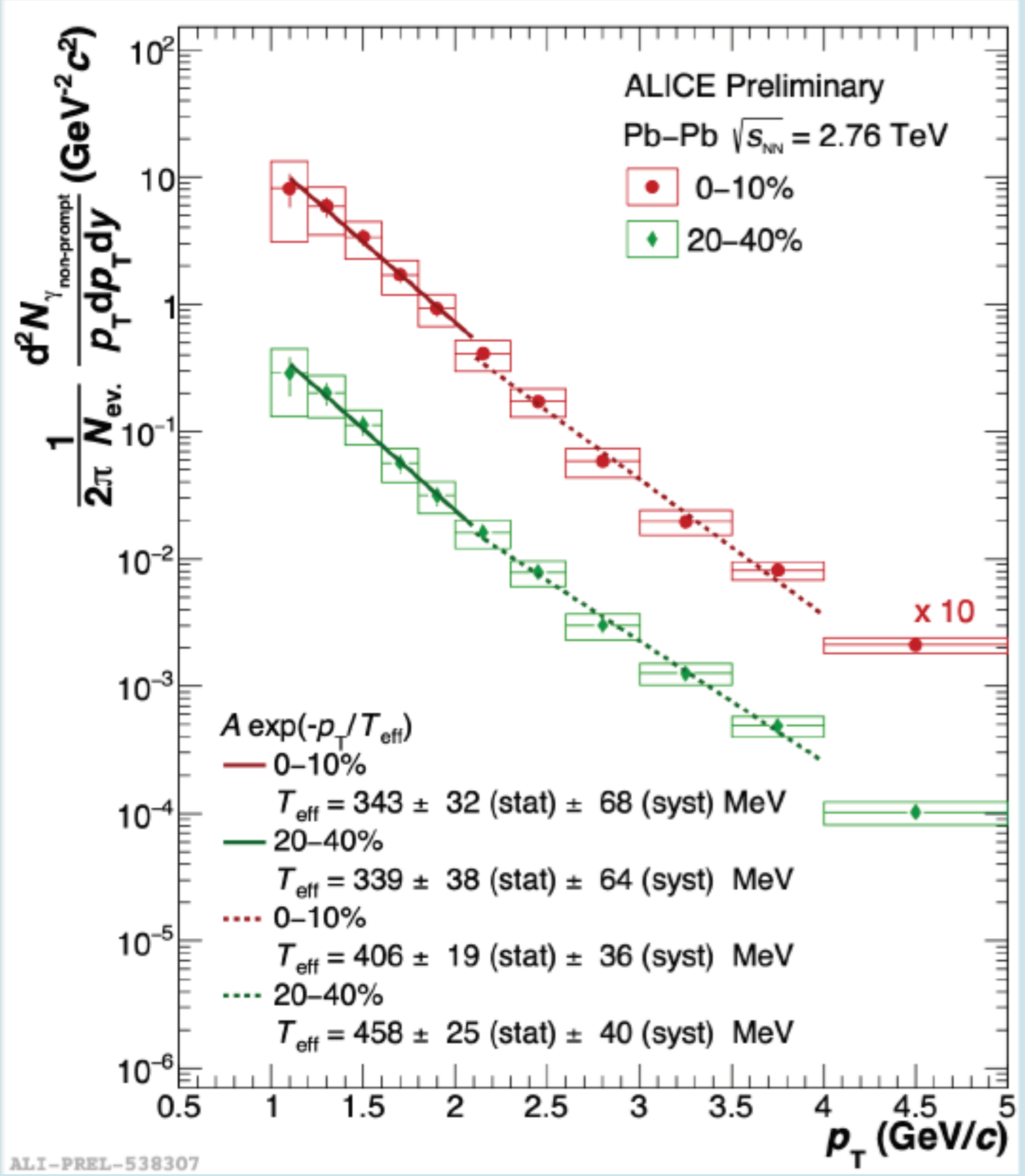


Low p_T (1-2 GeV/c)

T_{eff} = 343 ± 32 ± 68 MeV (low p_T)

T_{eff} = 339 ± 38 ± 64 MeV (low p_T)

High p_T (2-4 GeV/c)

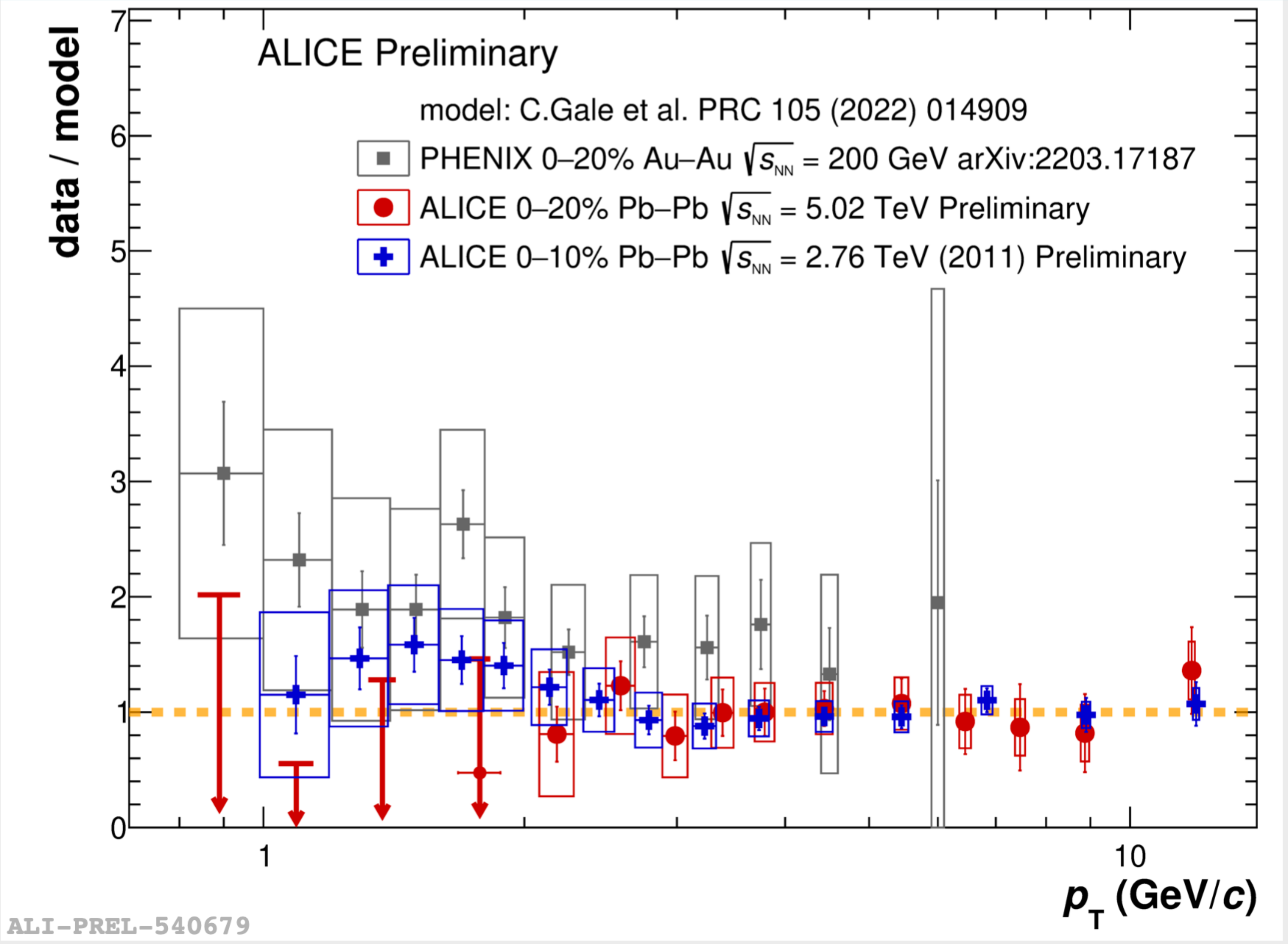
T_{eff} = 406 ± 19 ± 36 MeV (high p_T)

T_{eff} = 458 ± 25 ± 40 MeV (high p_T)

Re: Direct photon puzzle
Underestimate state-of-art model at low-p_T?

- New ALICE results are in agreement with the state-of-art model within experimental uncertainties, but systematically larger than the model

Non-prompt photon



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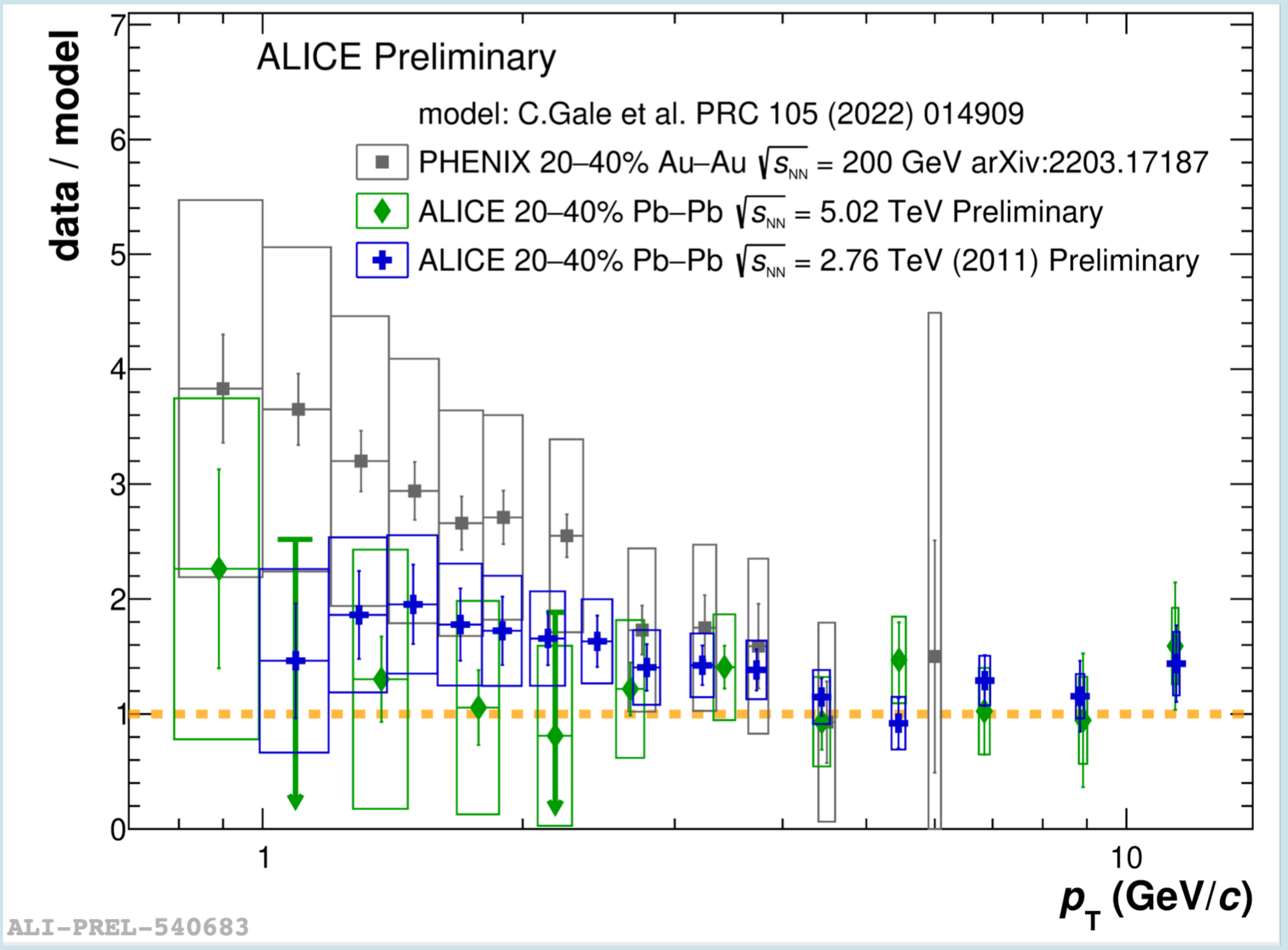

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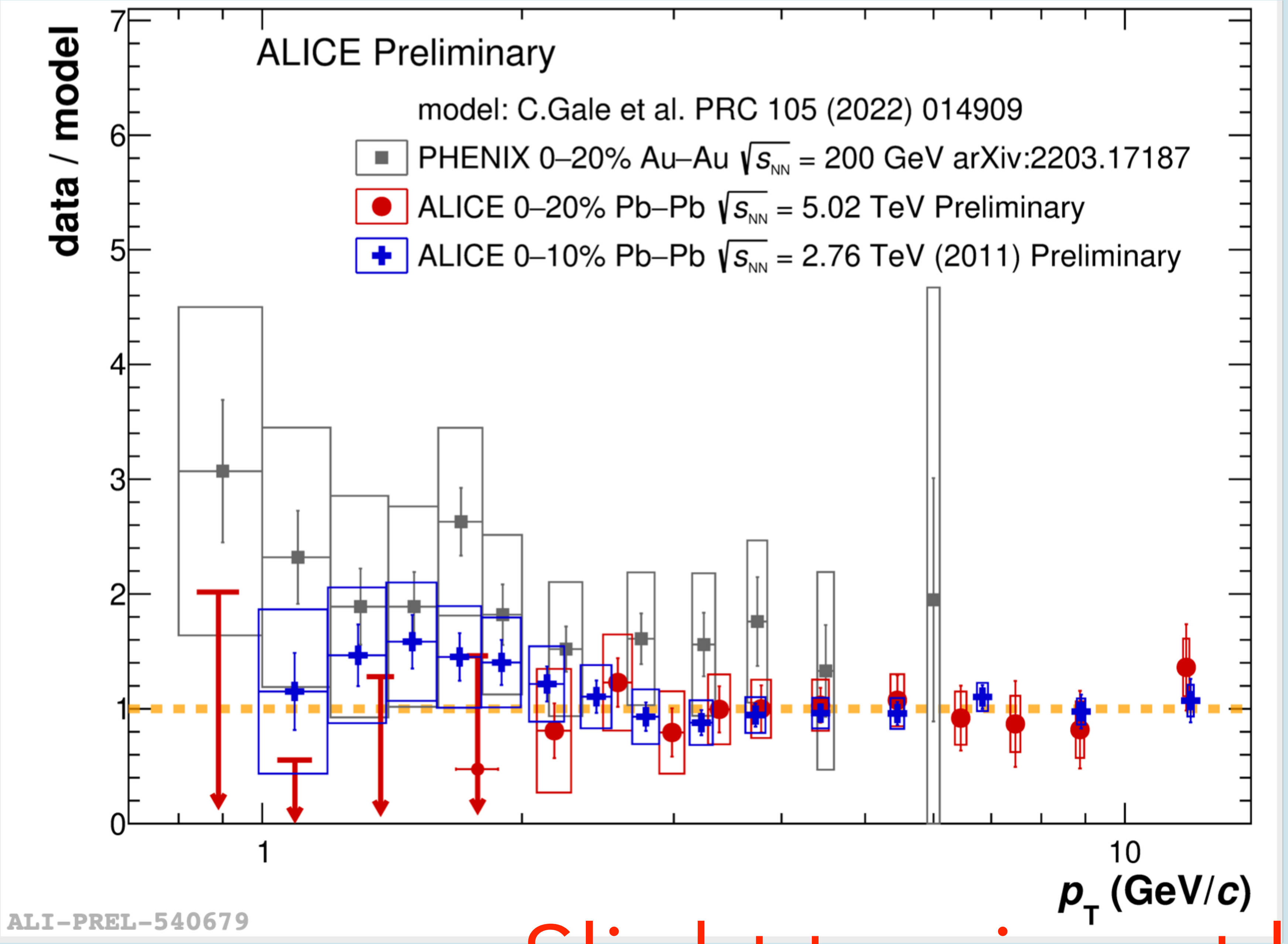

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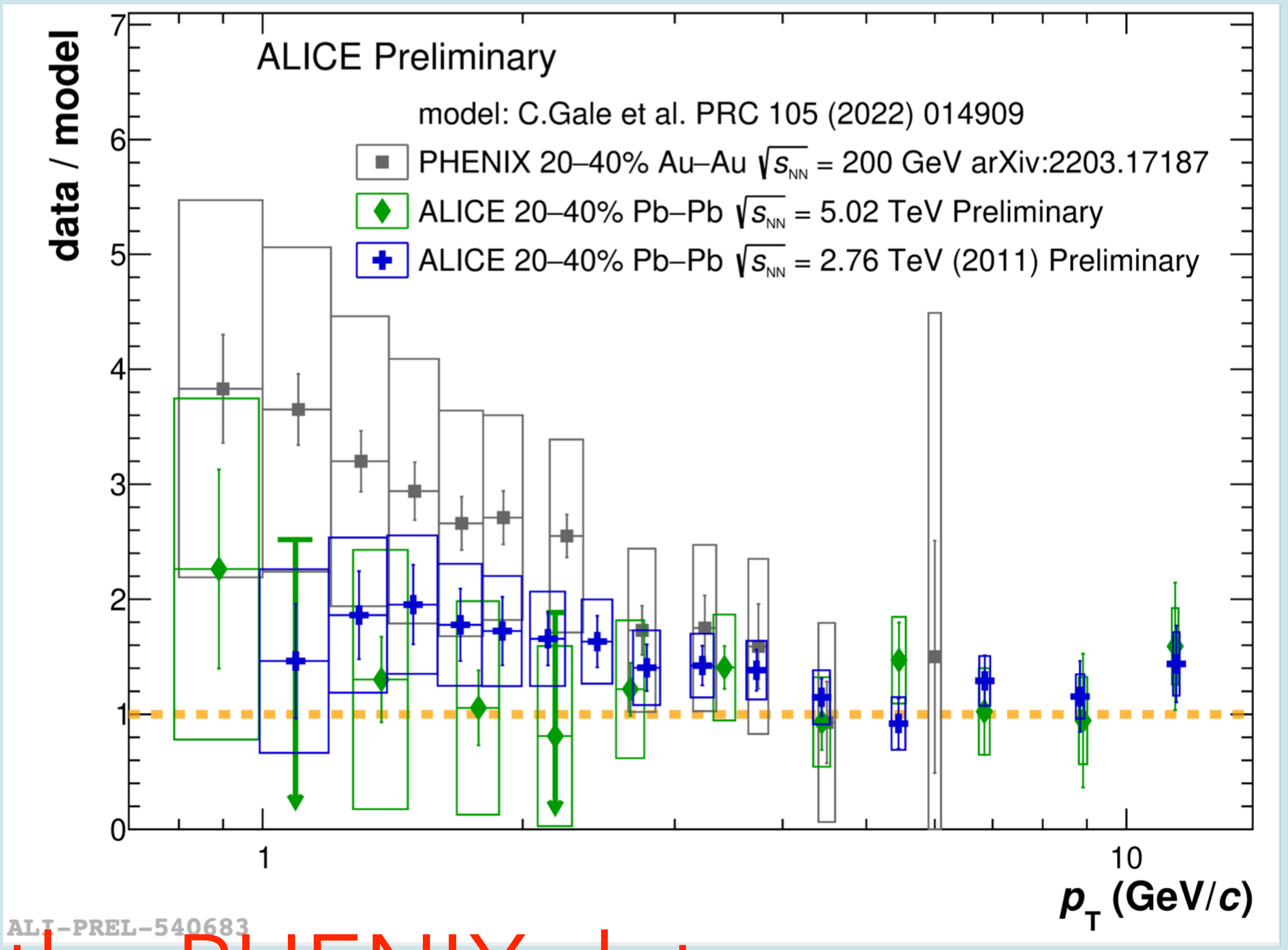

Talk at HP2023

Slight tension at low p_T for the PHENIX data

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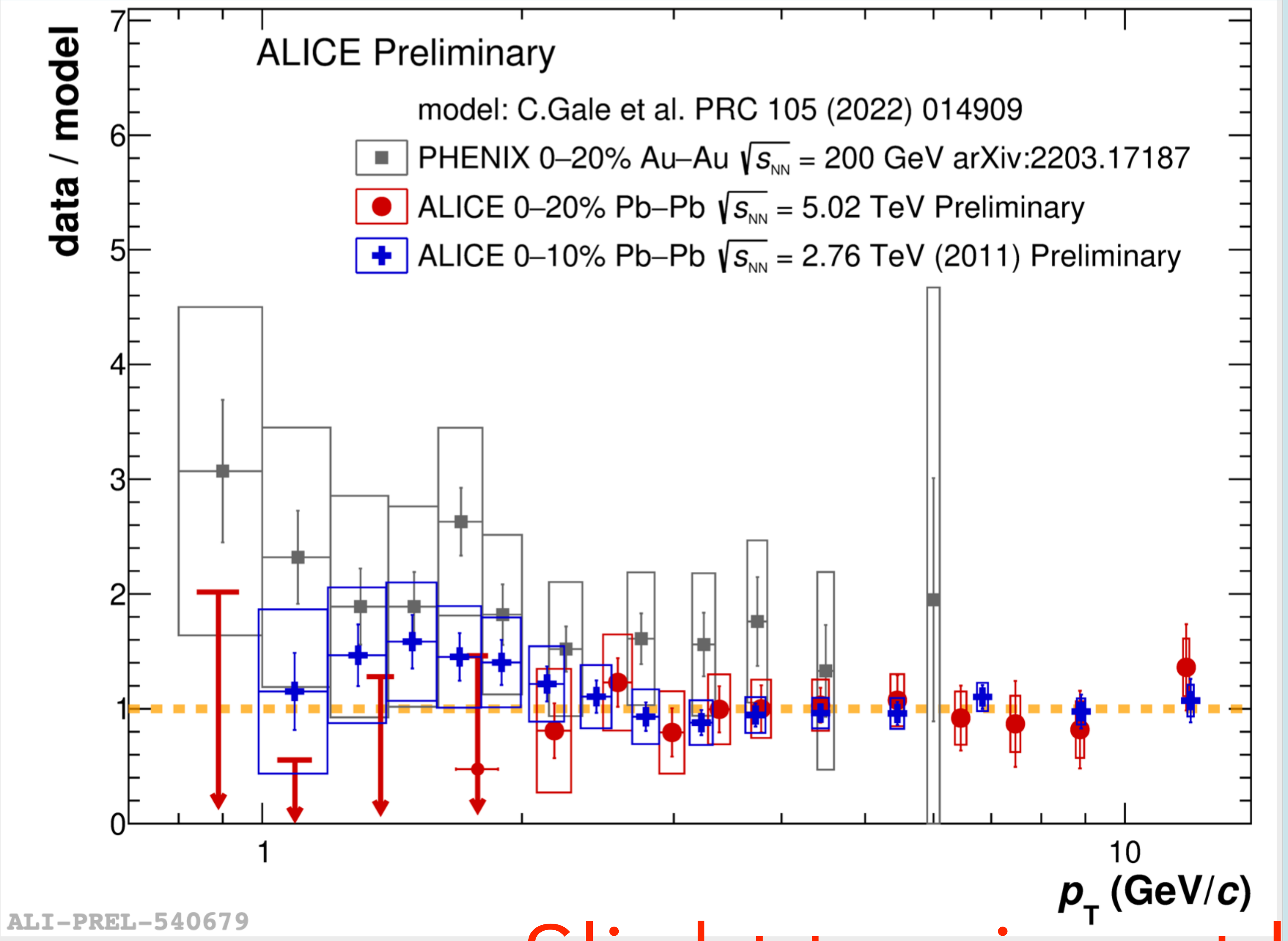

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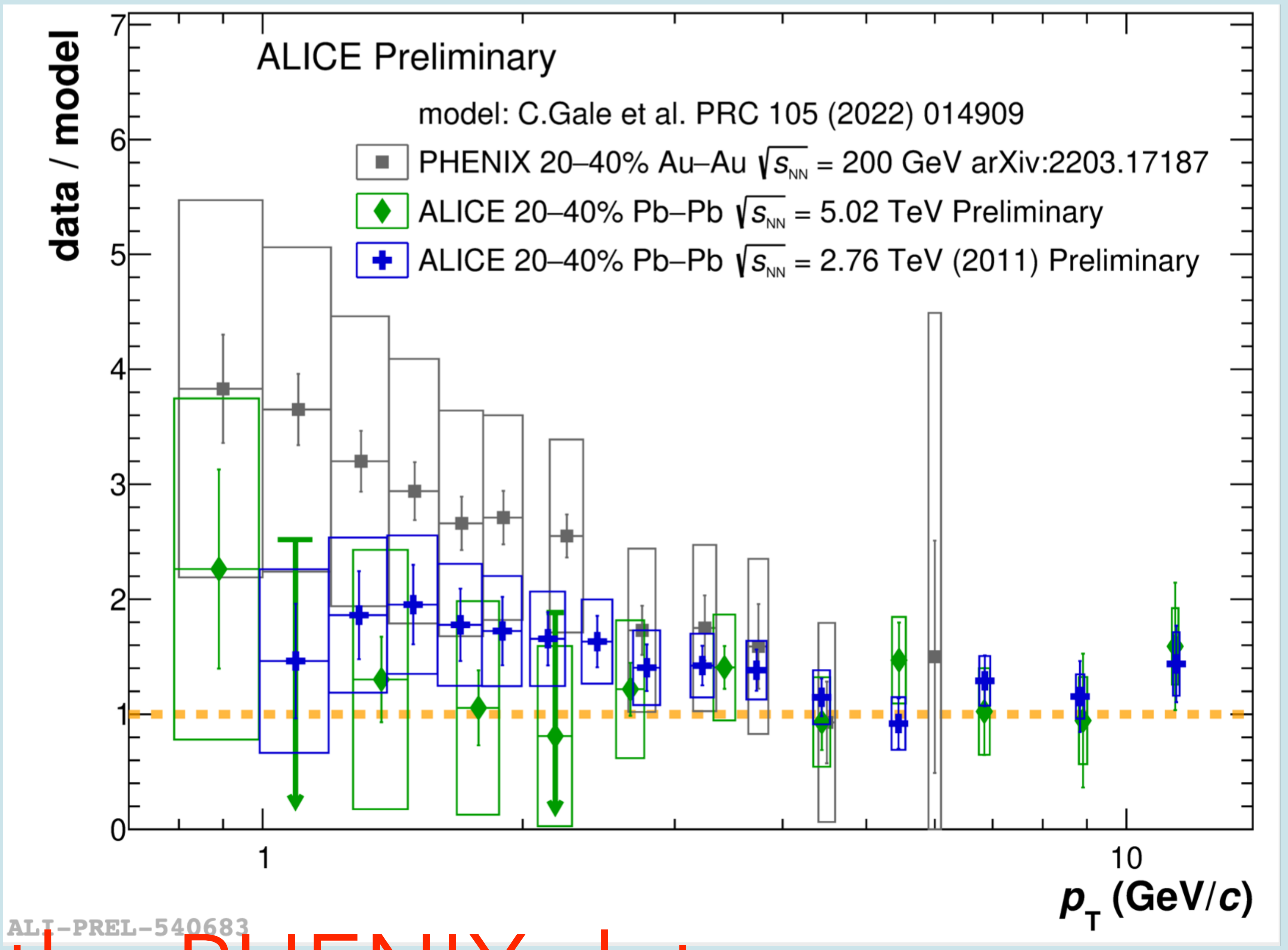

Talk at HP2023

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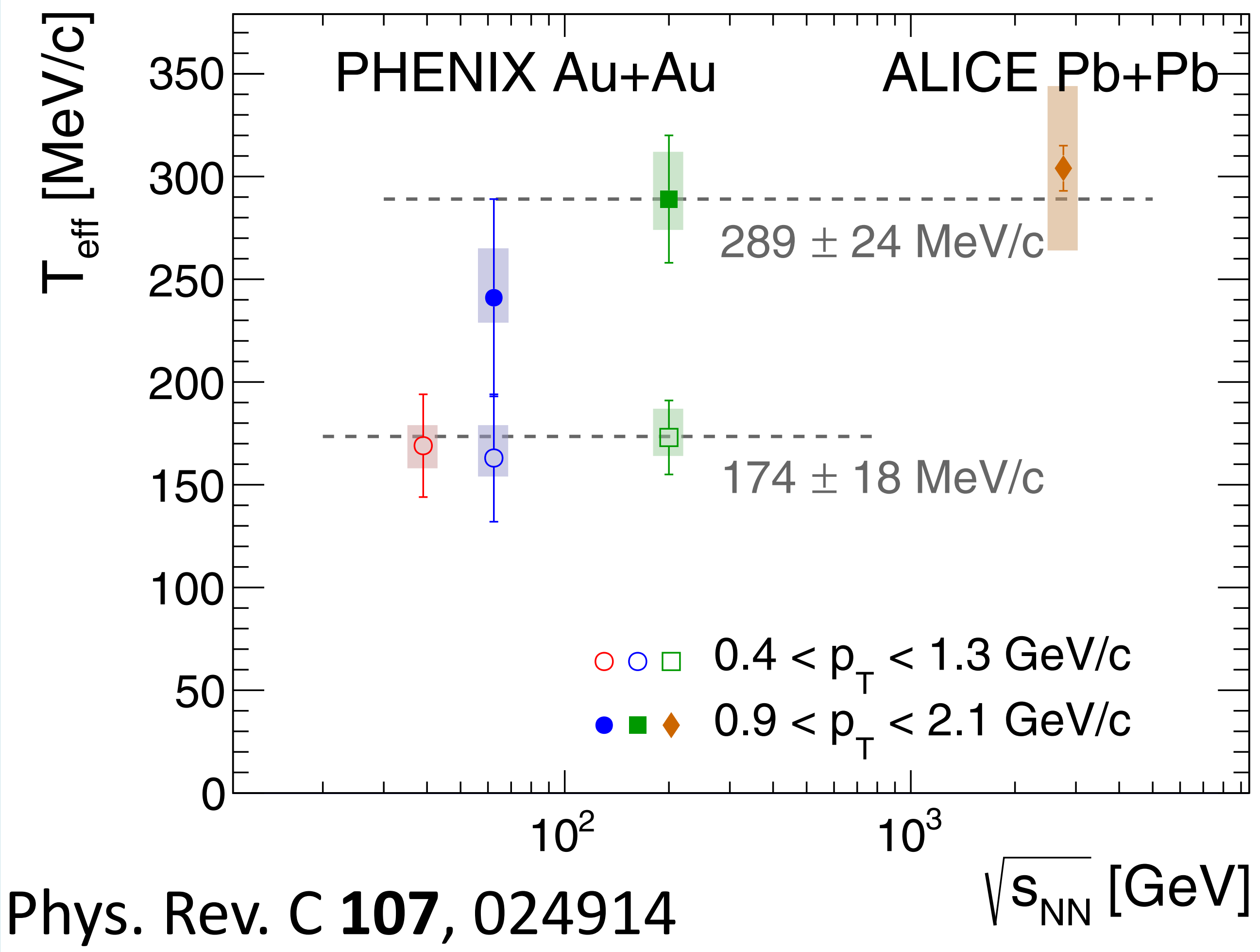
Update from the STAR experiment is eagerly awaited

Energy and system size dependence of direct photon

- No $\sqrt{s_{NN}}$ dependence of T_{eff} has been observed

Non-prompt photon



Phys. Rev. C **107**, 024914

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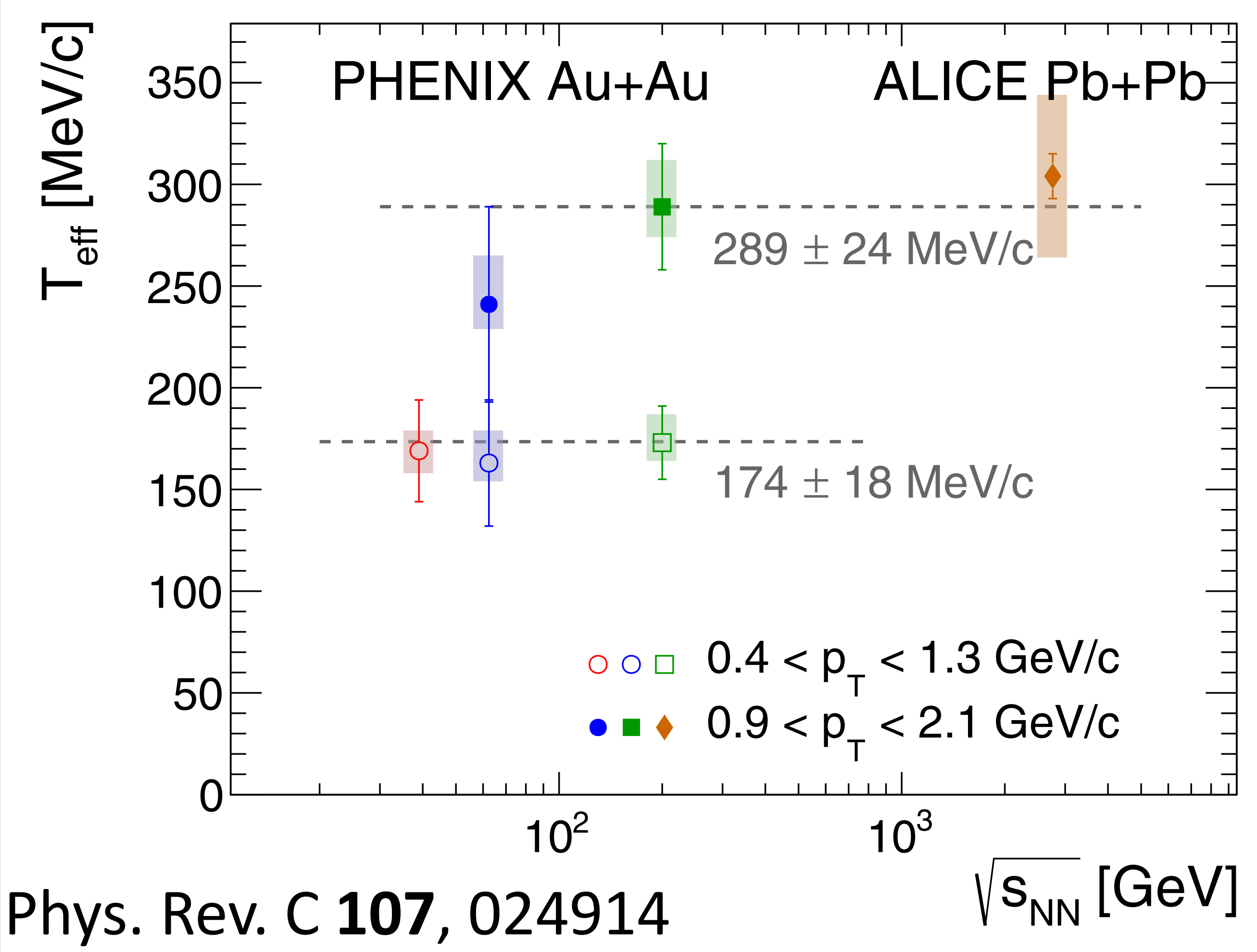

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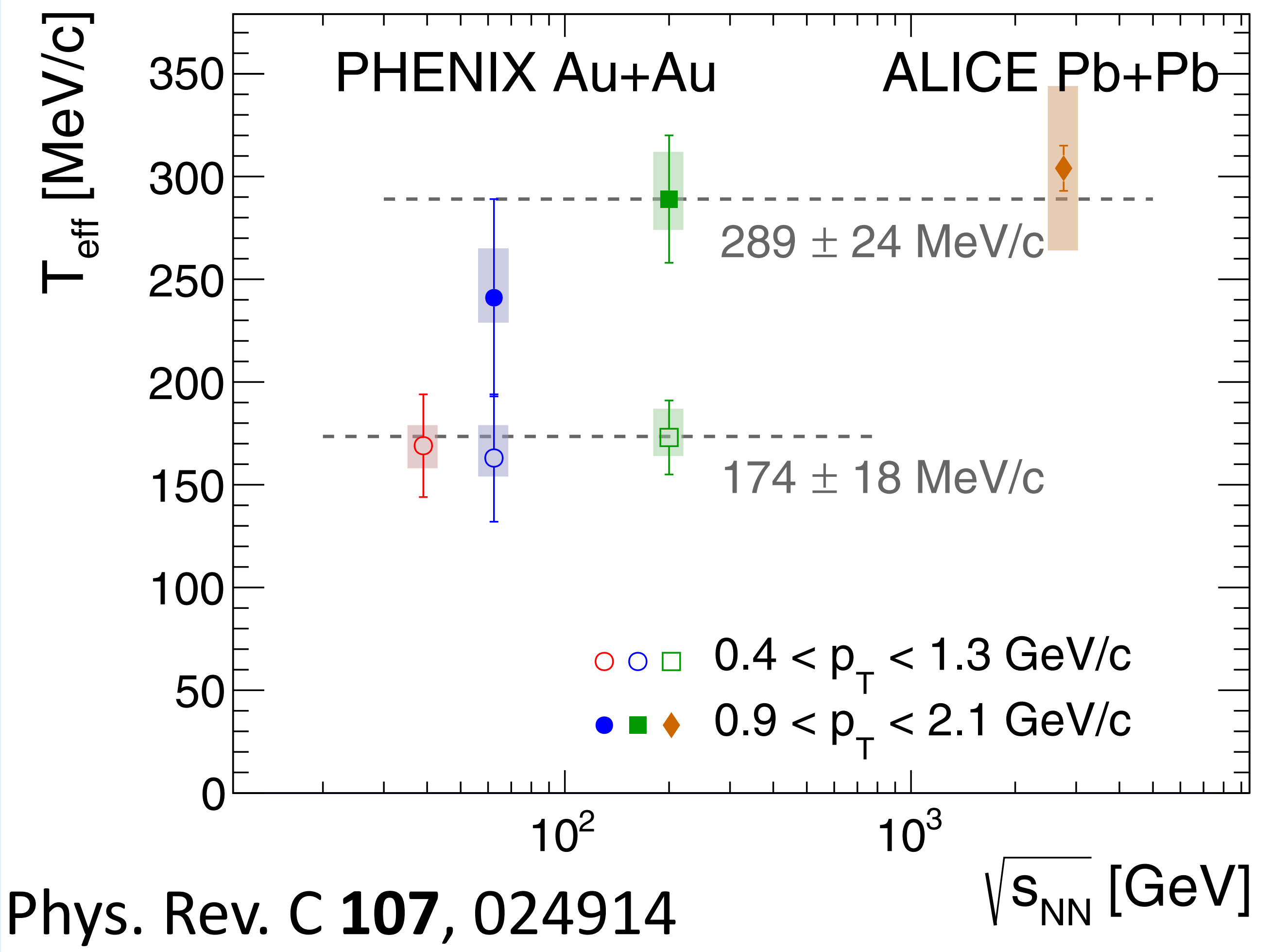

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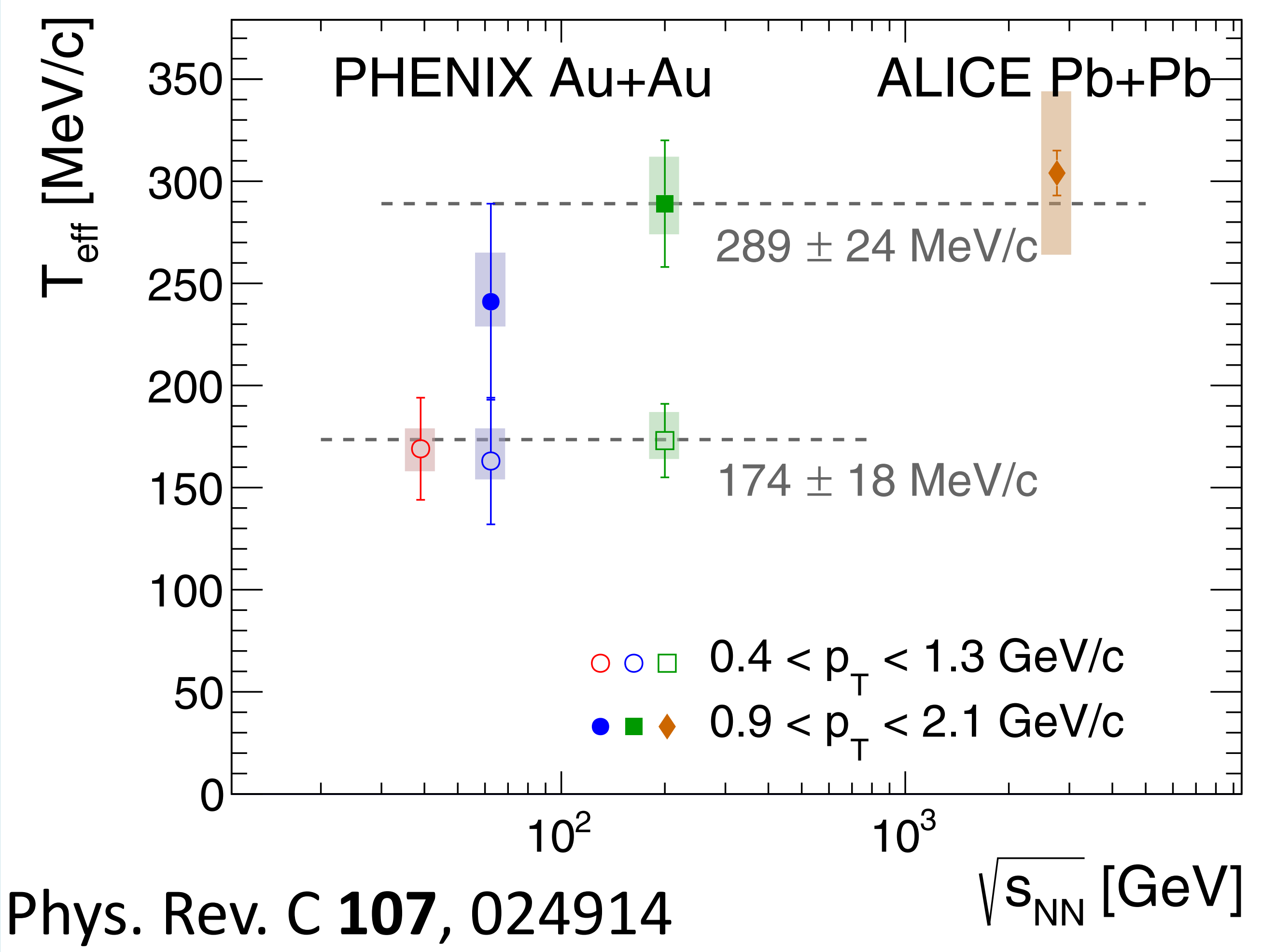

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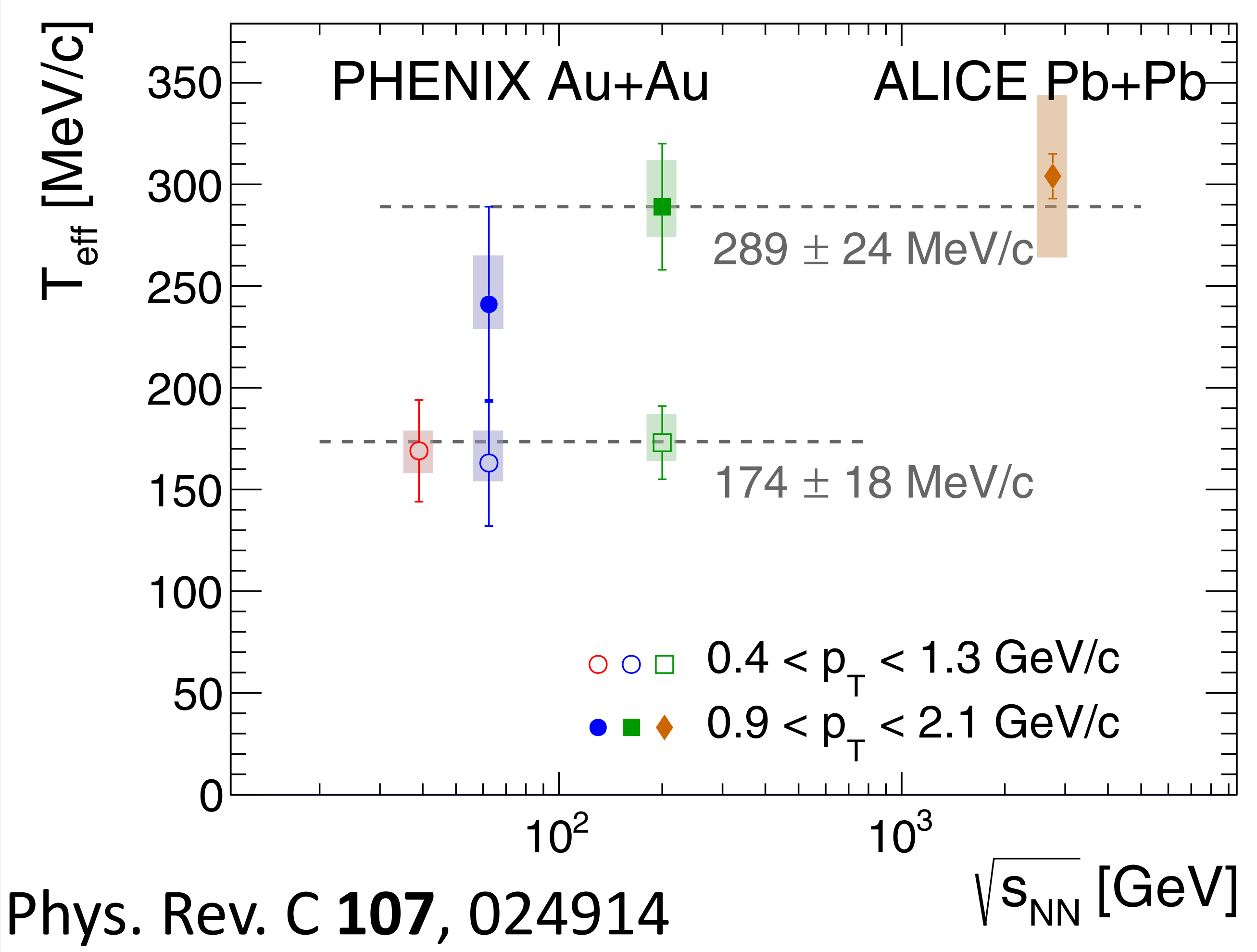

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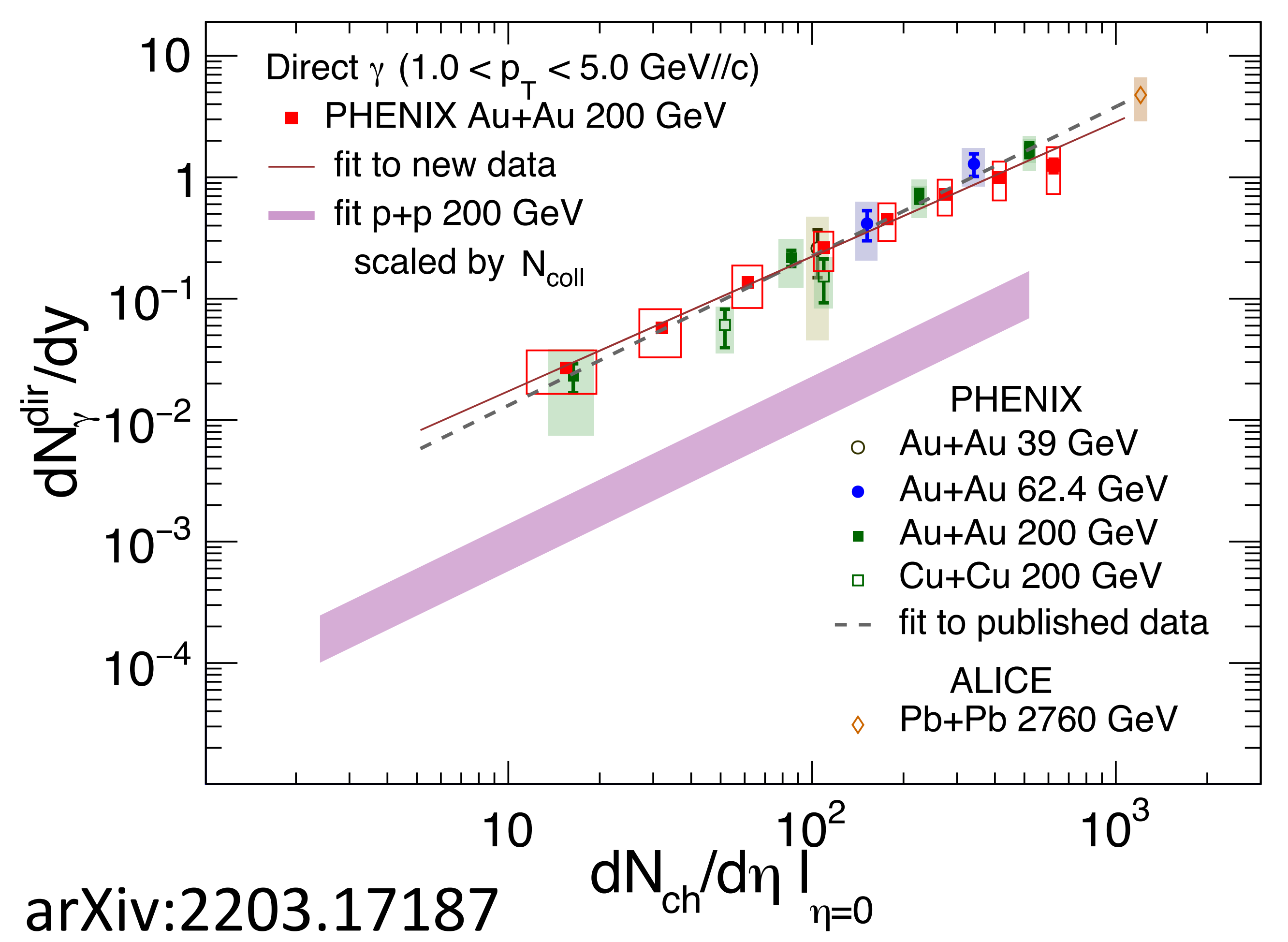

arXiv:2203.17187

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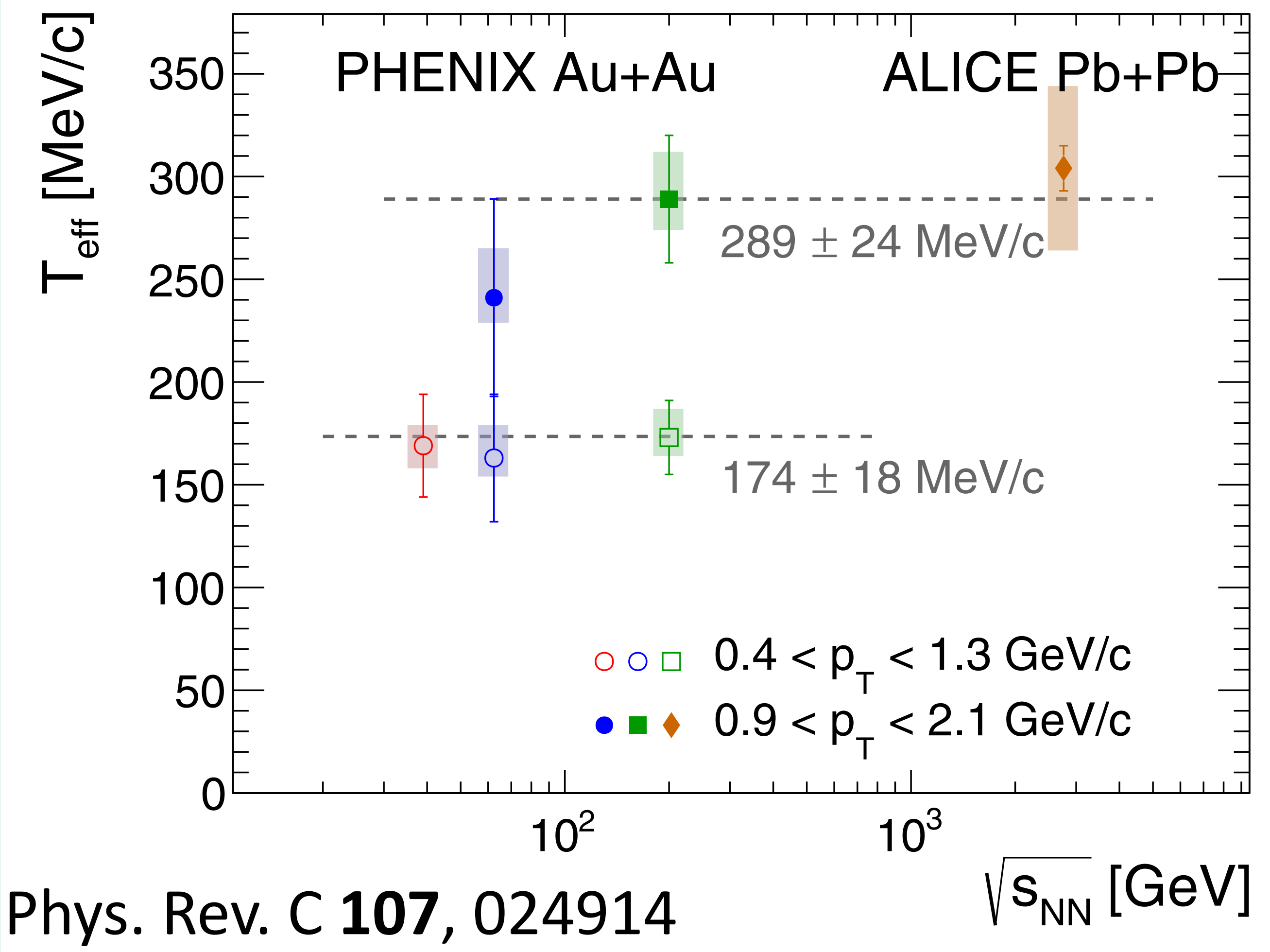
  - HG (p_T<1 GeV) ~ 1.23
  - QGP (1<p_T<4 GeV) ~ 1.83

Non-prompt photon



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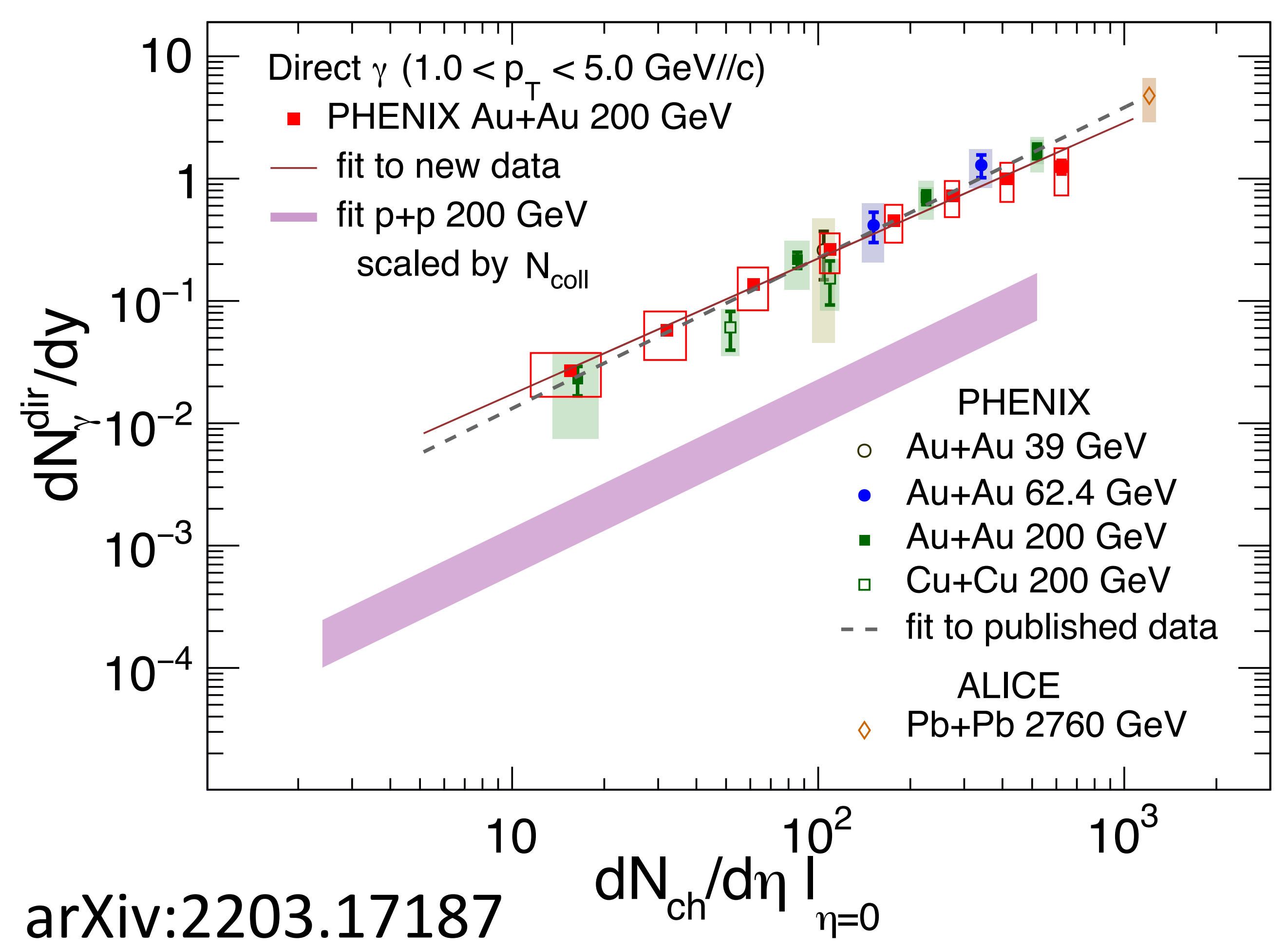

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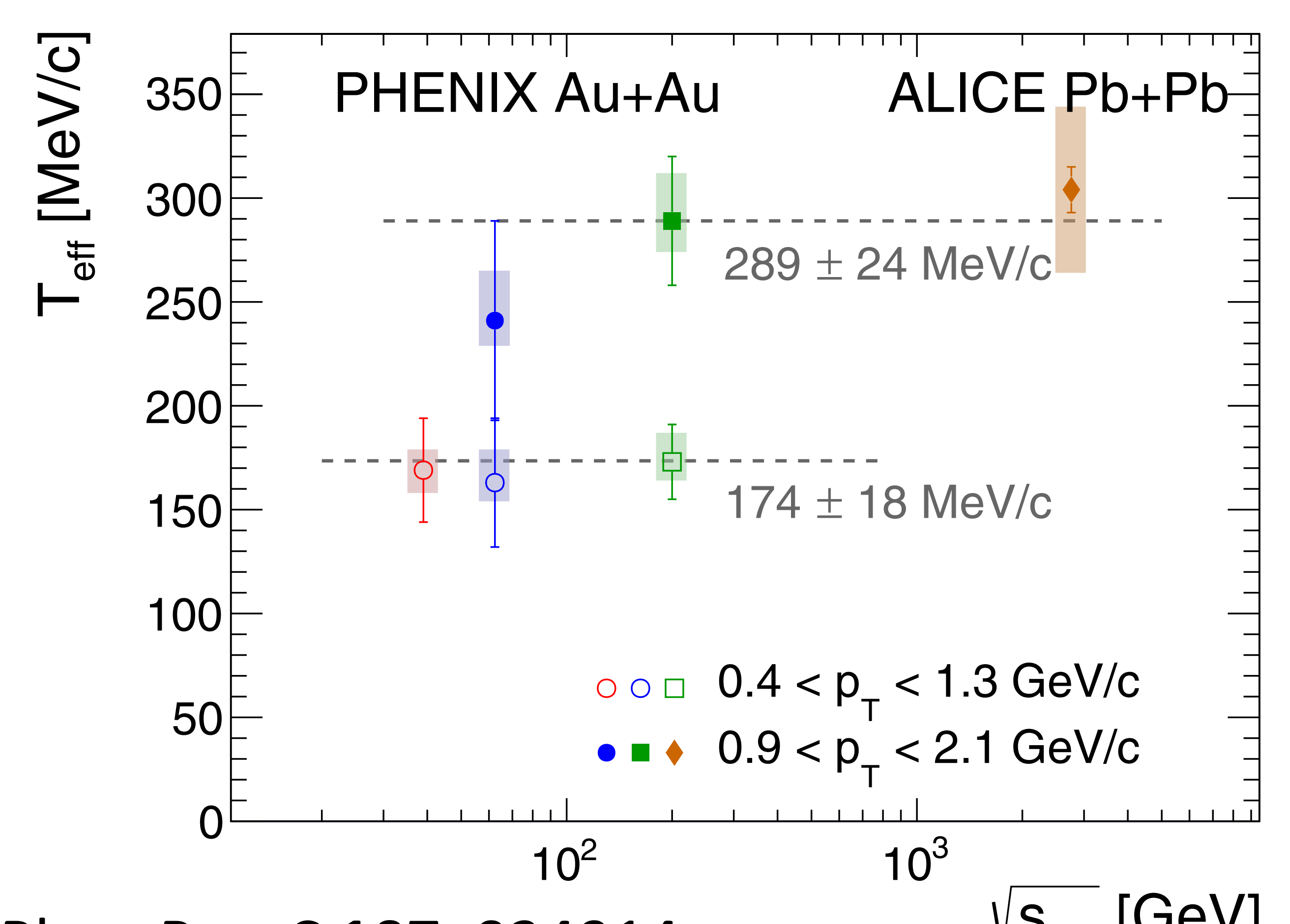
More insight into the origin of photons is needed

Non-prompt photon



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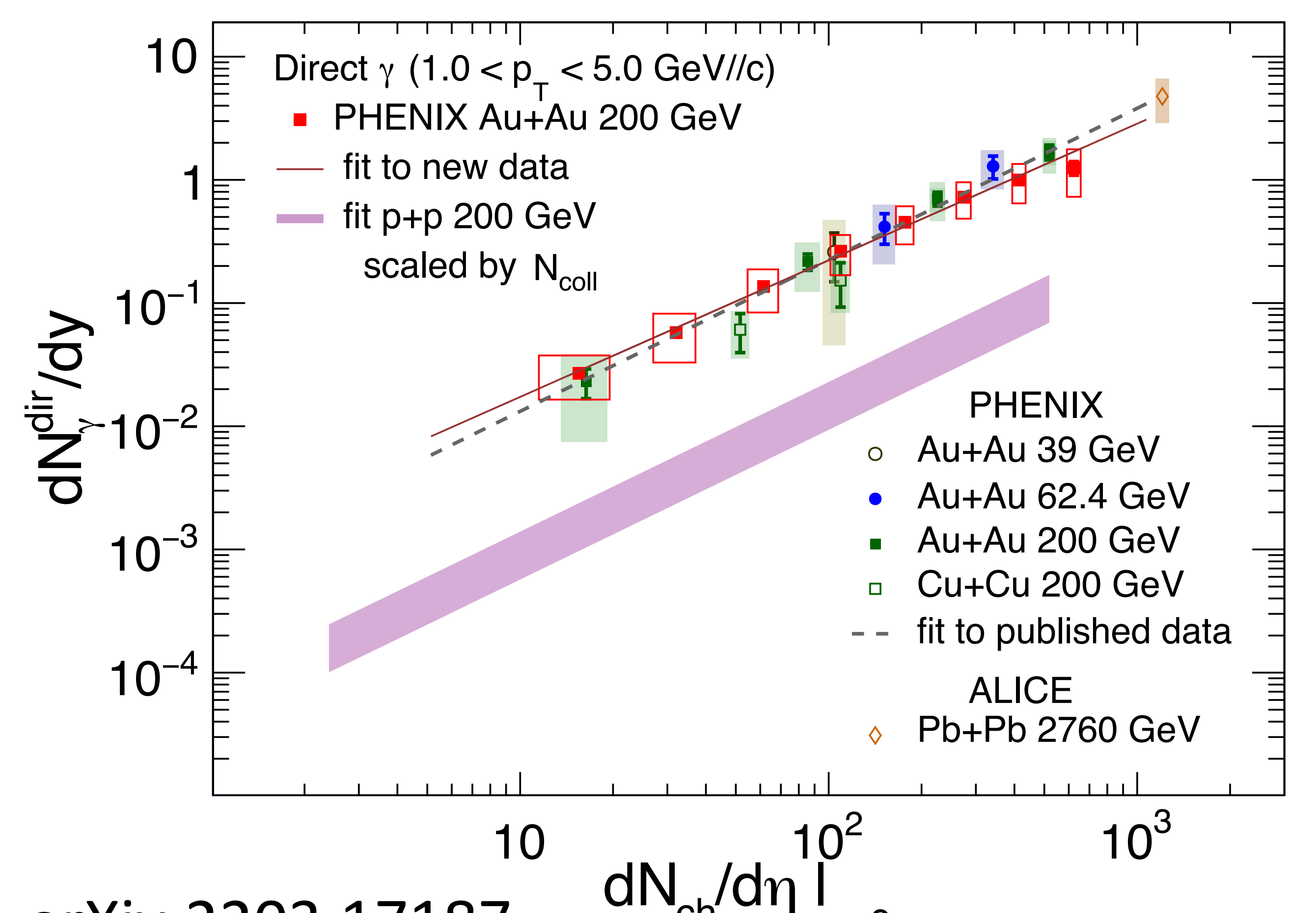

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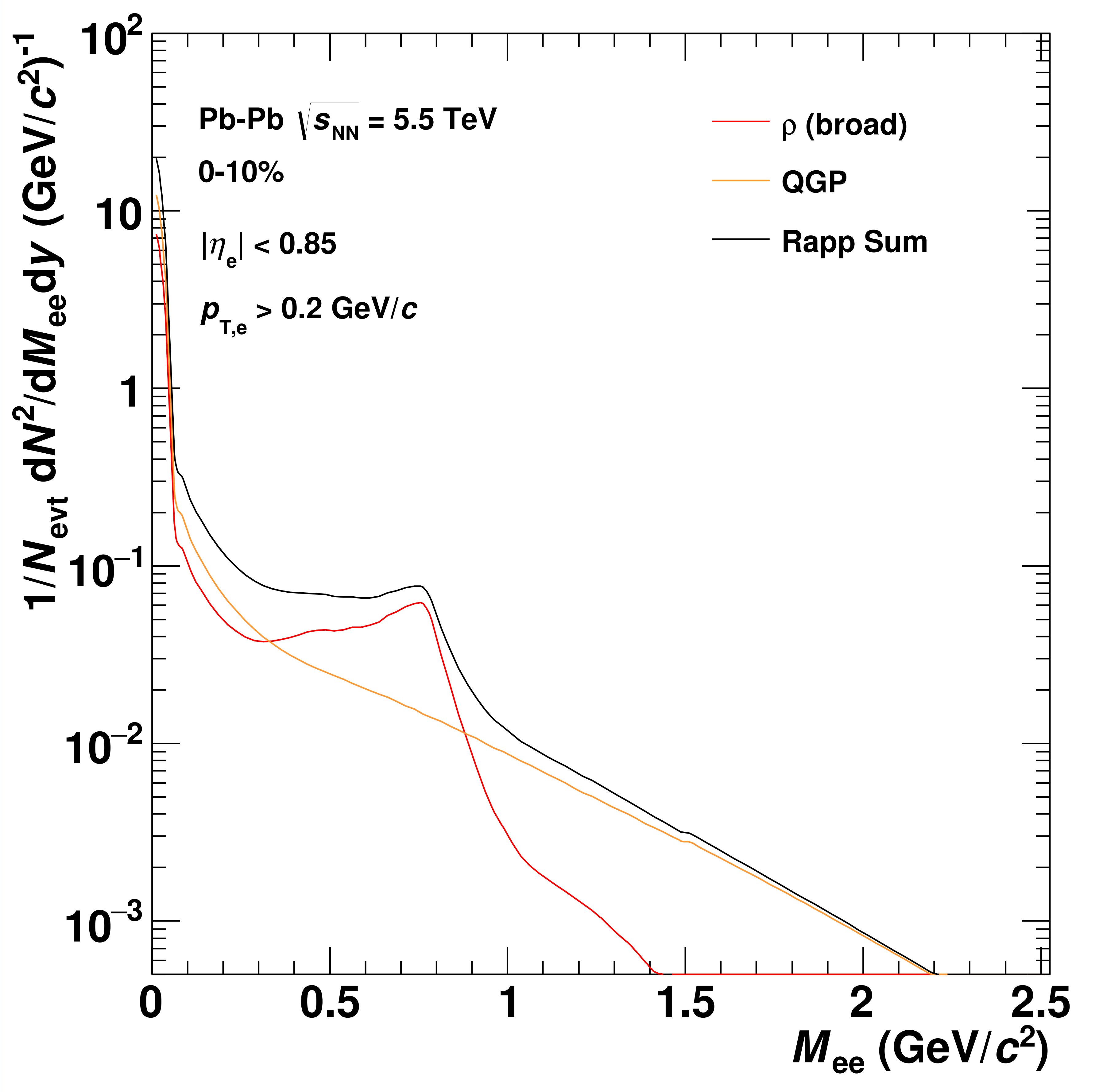
Dileptons

Dileptons in HIC

- Low mass region (IMR), $M_{ll} < 1.5$ GeV/c^2, is sensitive to the late-stage temperature



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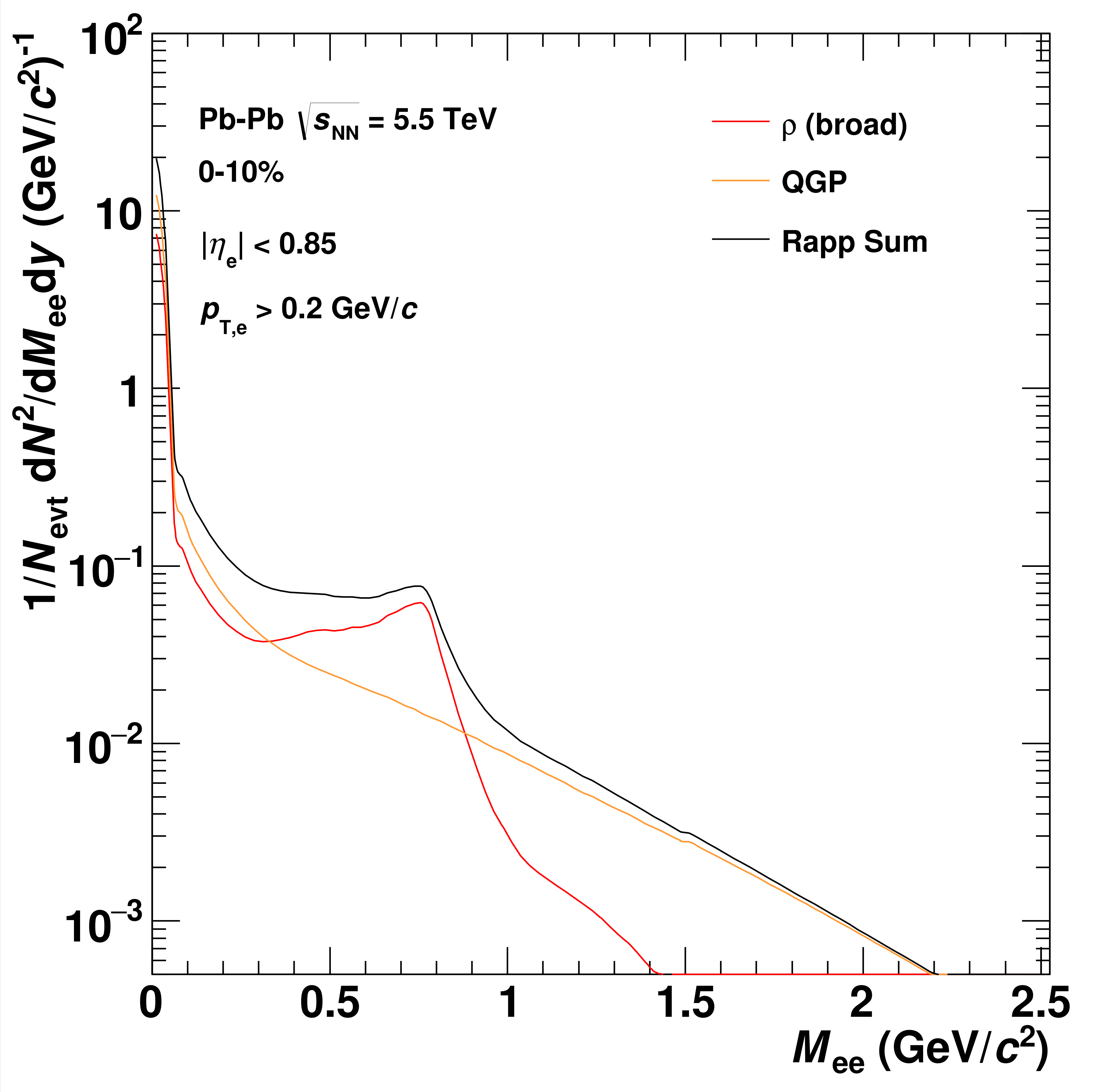

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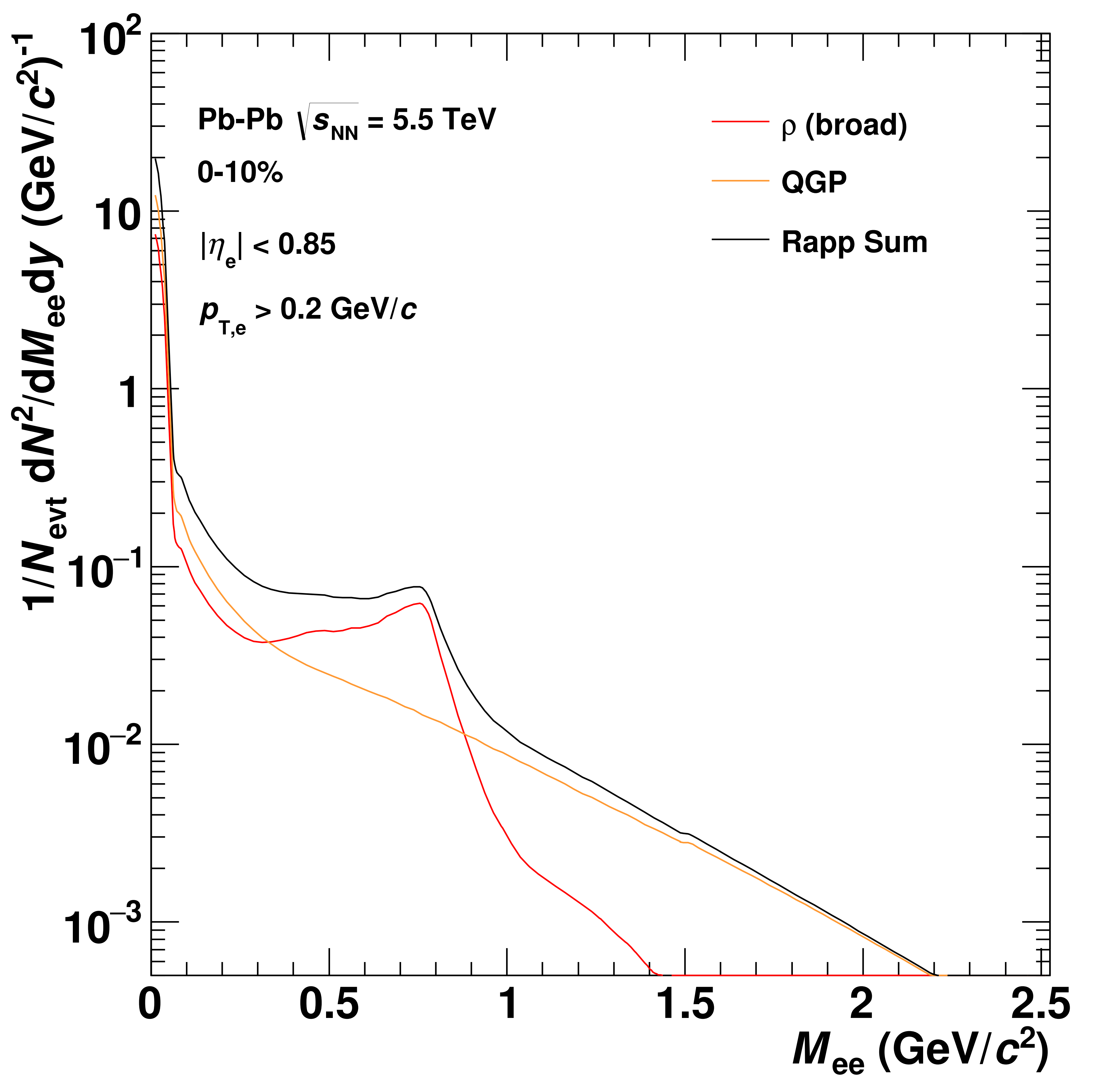

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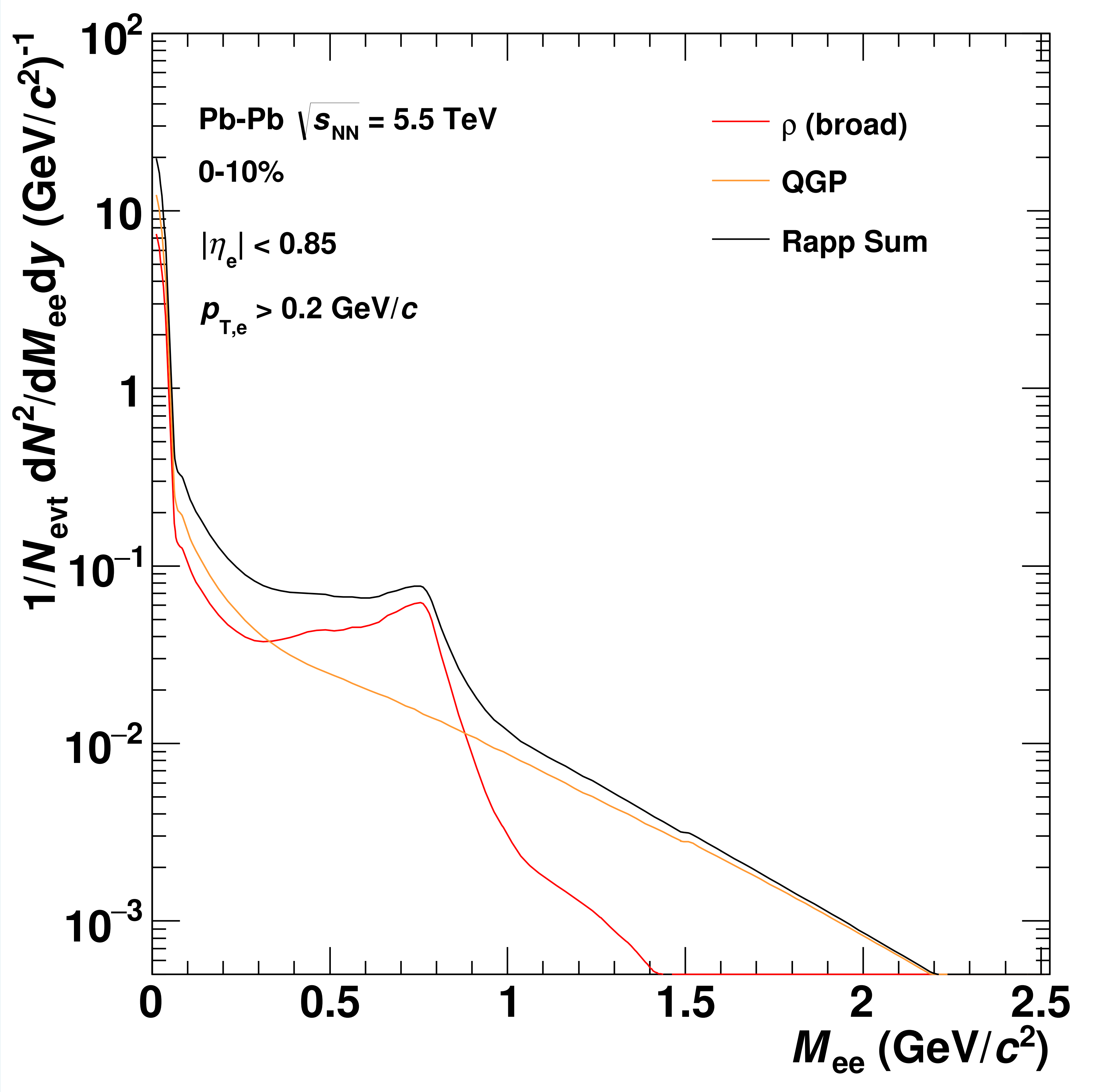
  - Mass modification is sensitive to chiral symmetry restoration (CSR)



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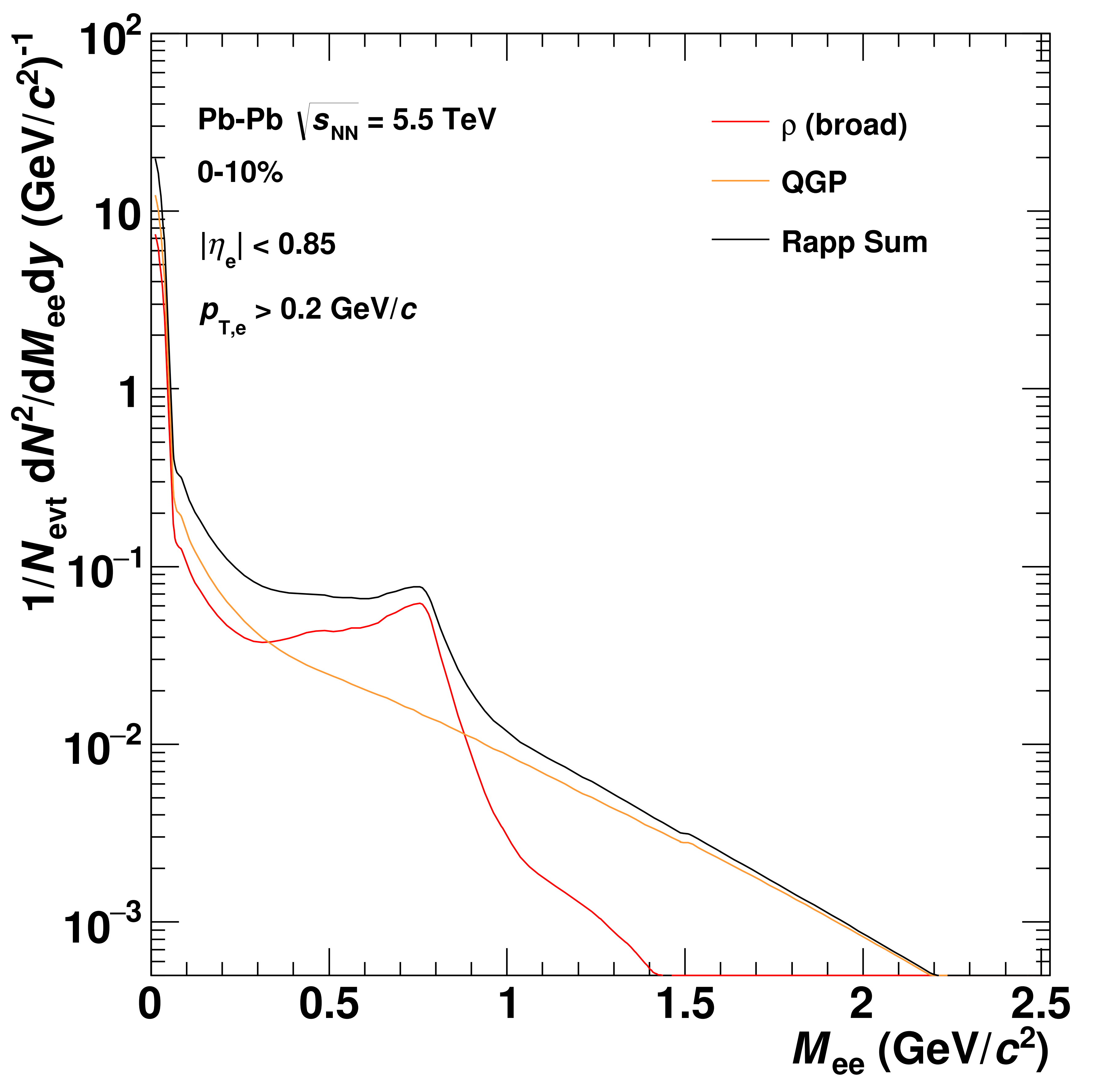
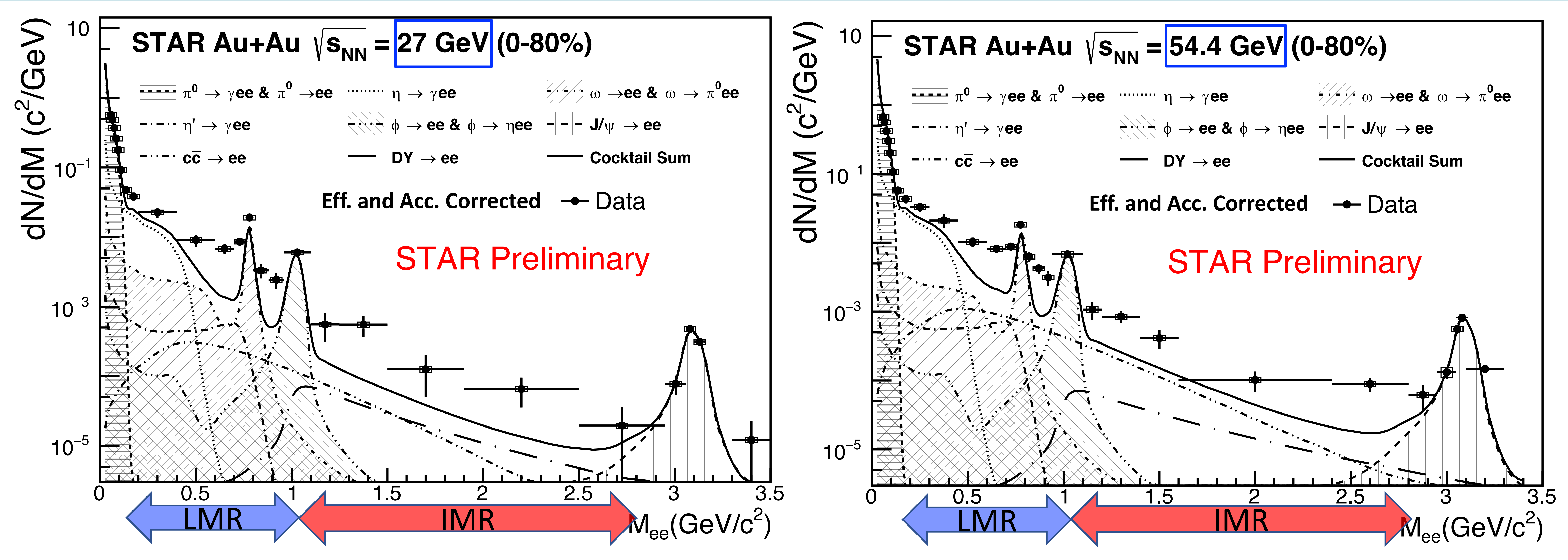


Inverse slope T_{eff} in the mass spectrum is **NOT** affected by the blue-shift

Dielectrons from BESII

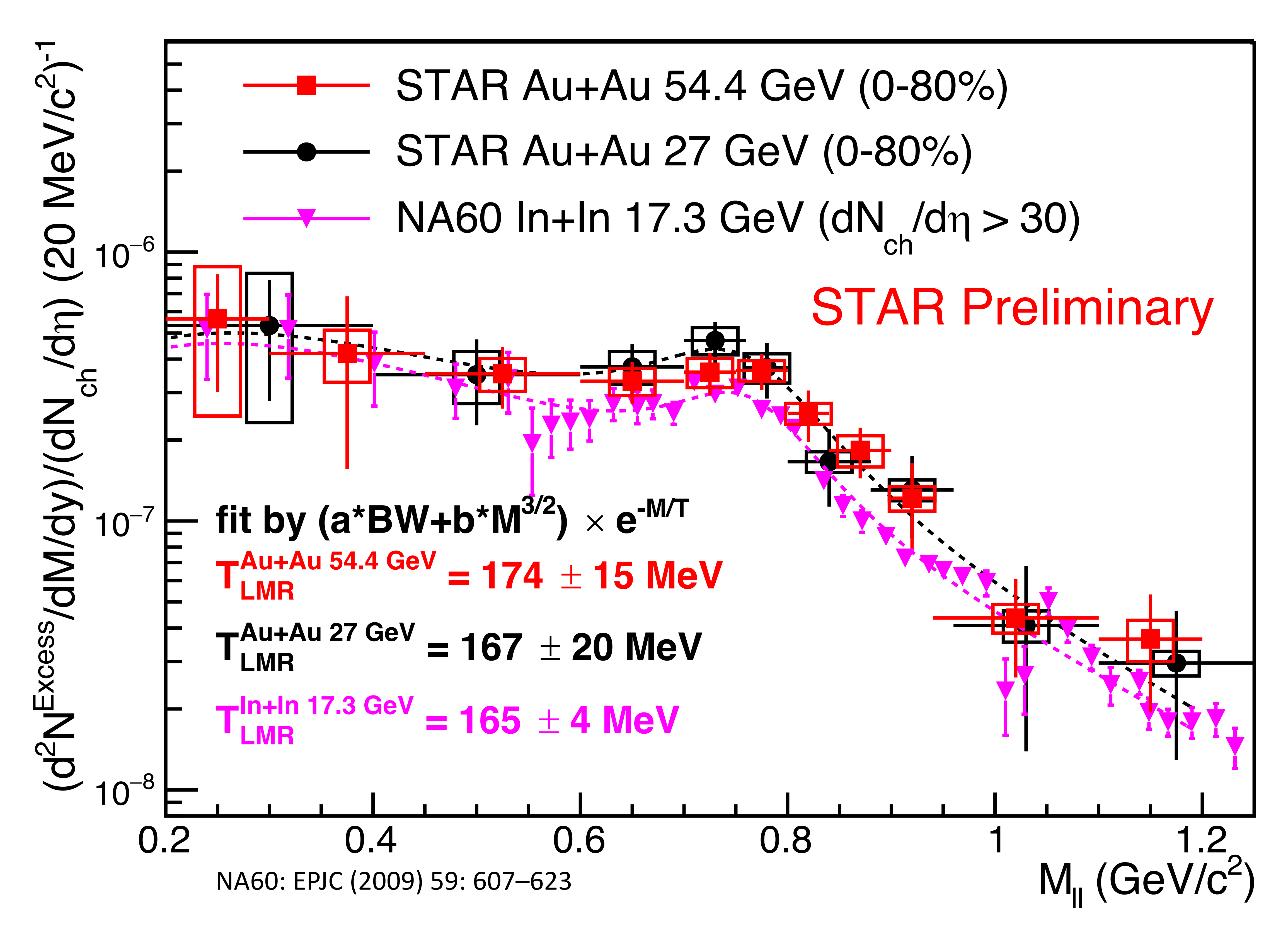
Talk at QM2022



- Clear enhancement compared to cocktail contribution in both low mass region and intermediate mass region at 27 and 54.4 GeV have been observed

Temperature from excess dilepton from BESII
Low mass region (LMR) = late stage

Talk at QM2022



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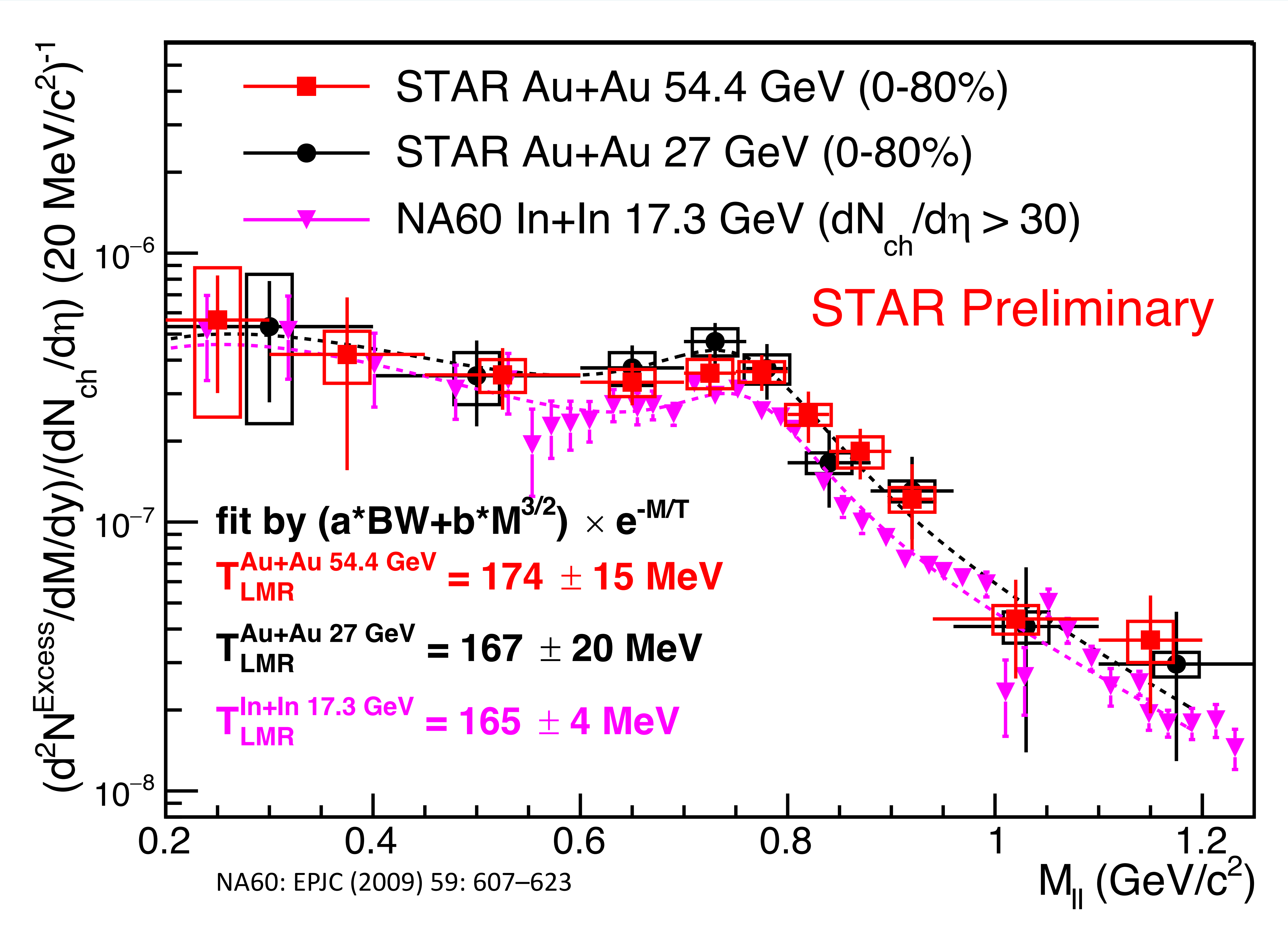

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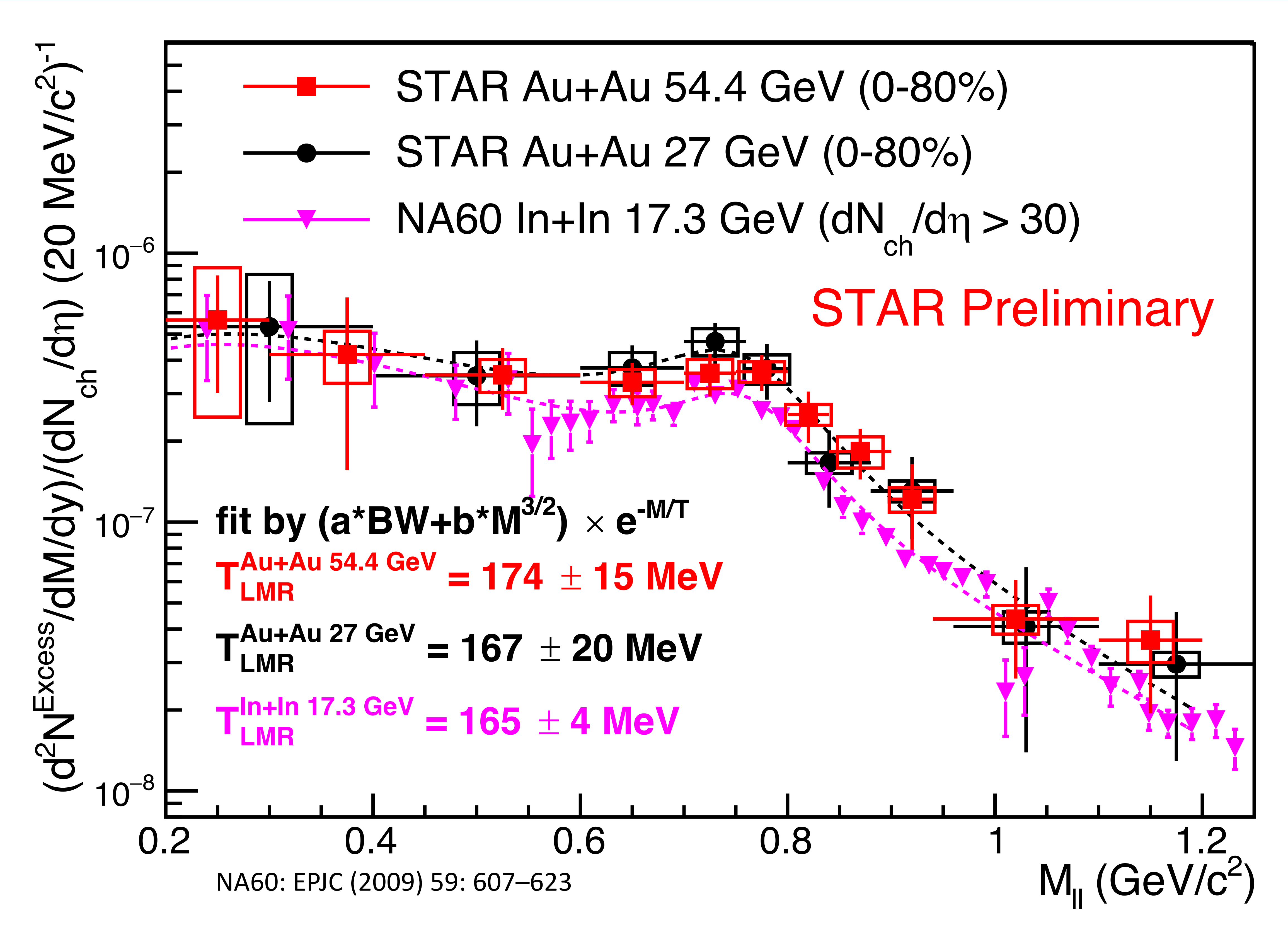

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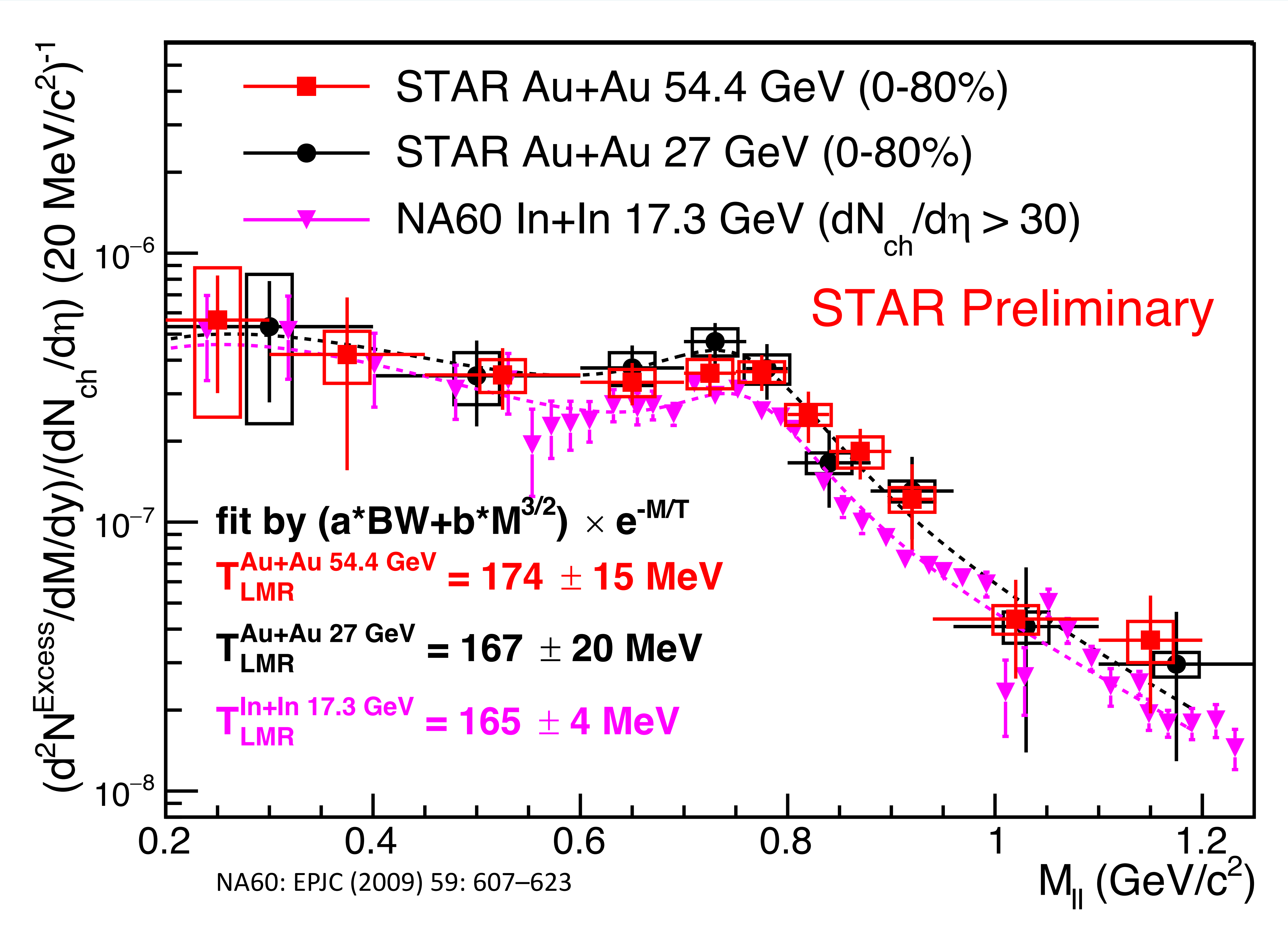

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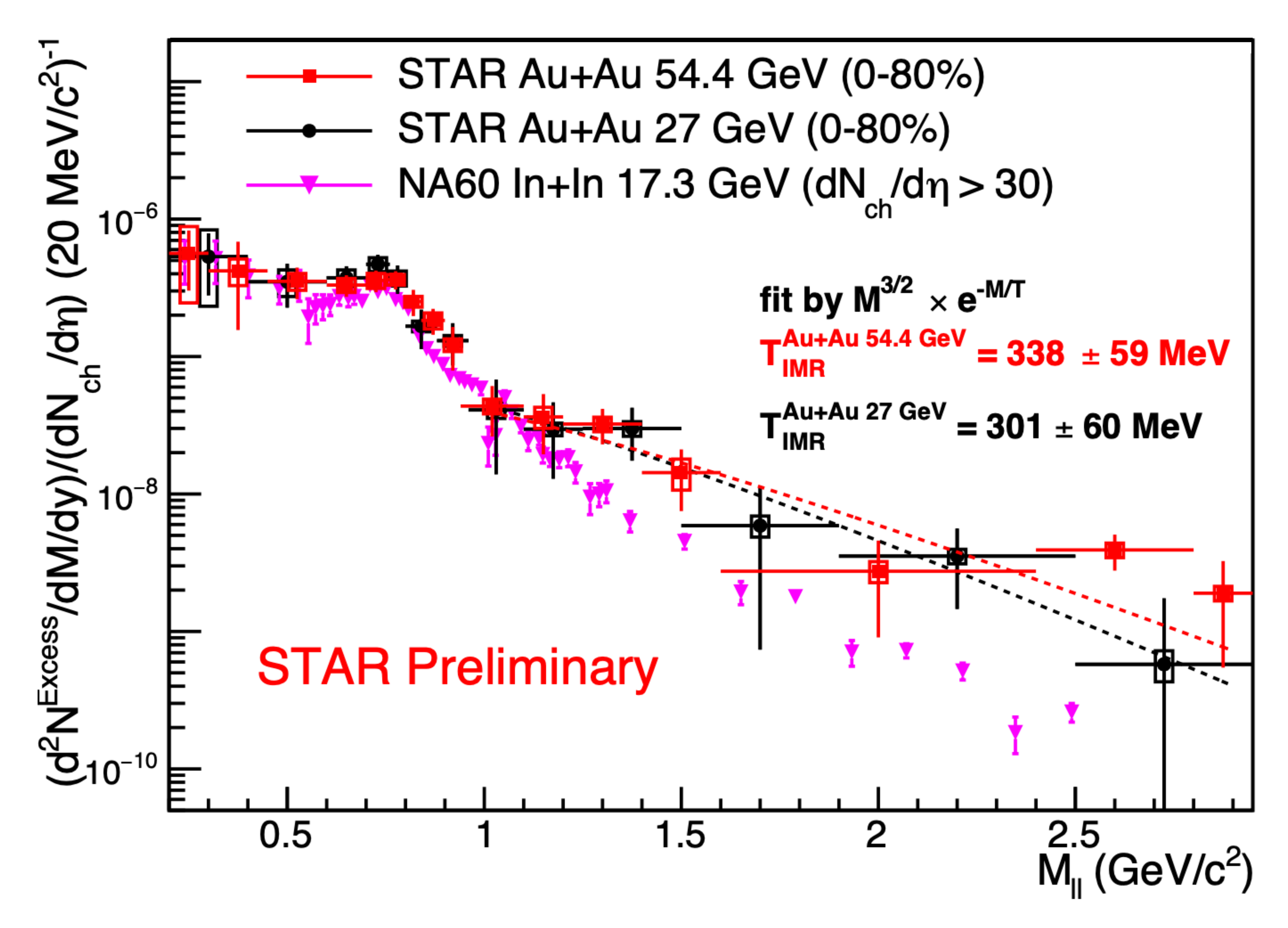
Same temperature at the late stage, but a longer lifetime medium than SPS

Temperature from excess dilepton from BESII
Intermediate mass region (IMR) = early stage

Talk at QM2022



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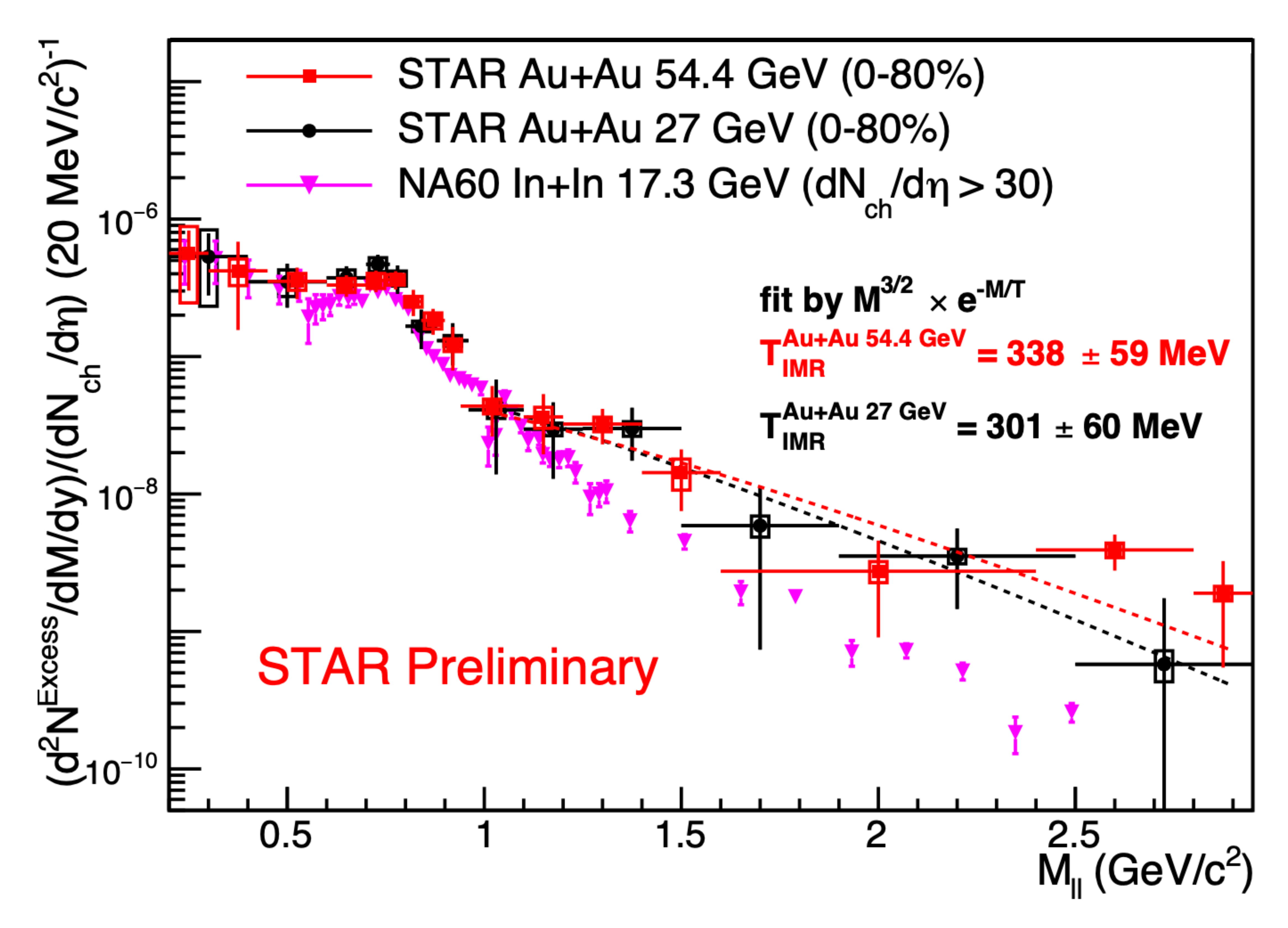
Talk at QM2022



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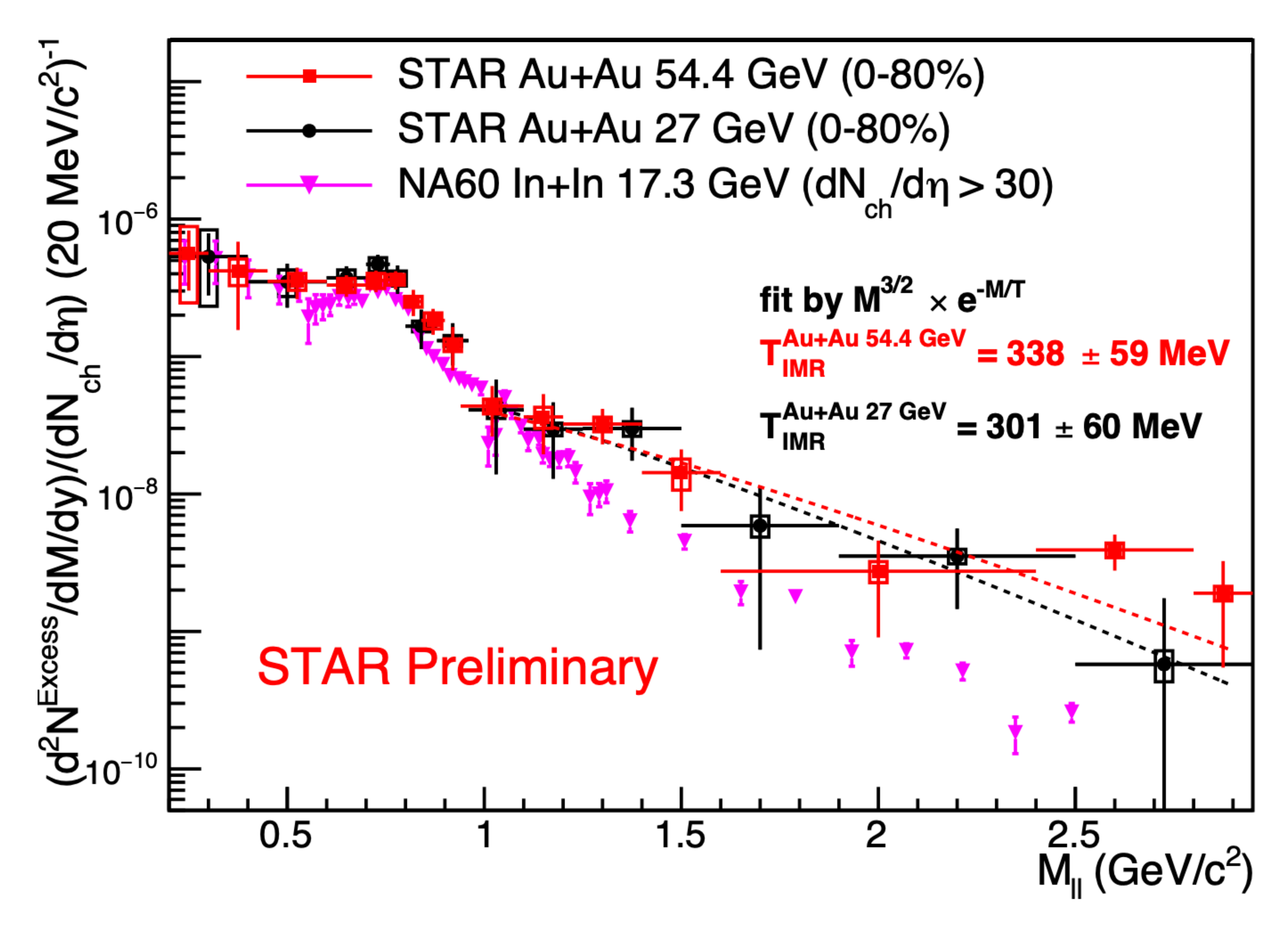
Talk at QM2022



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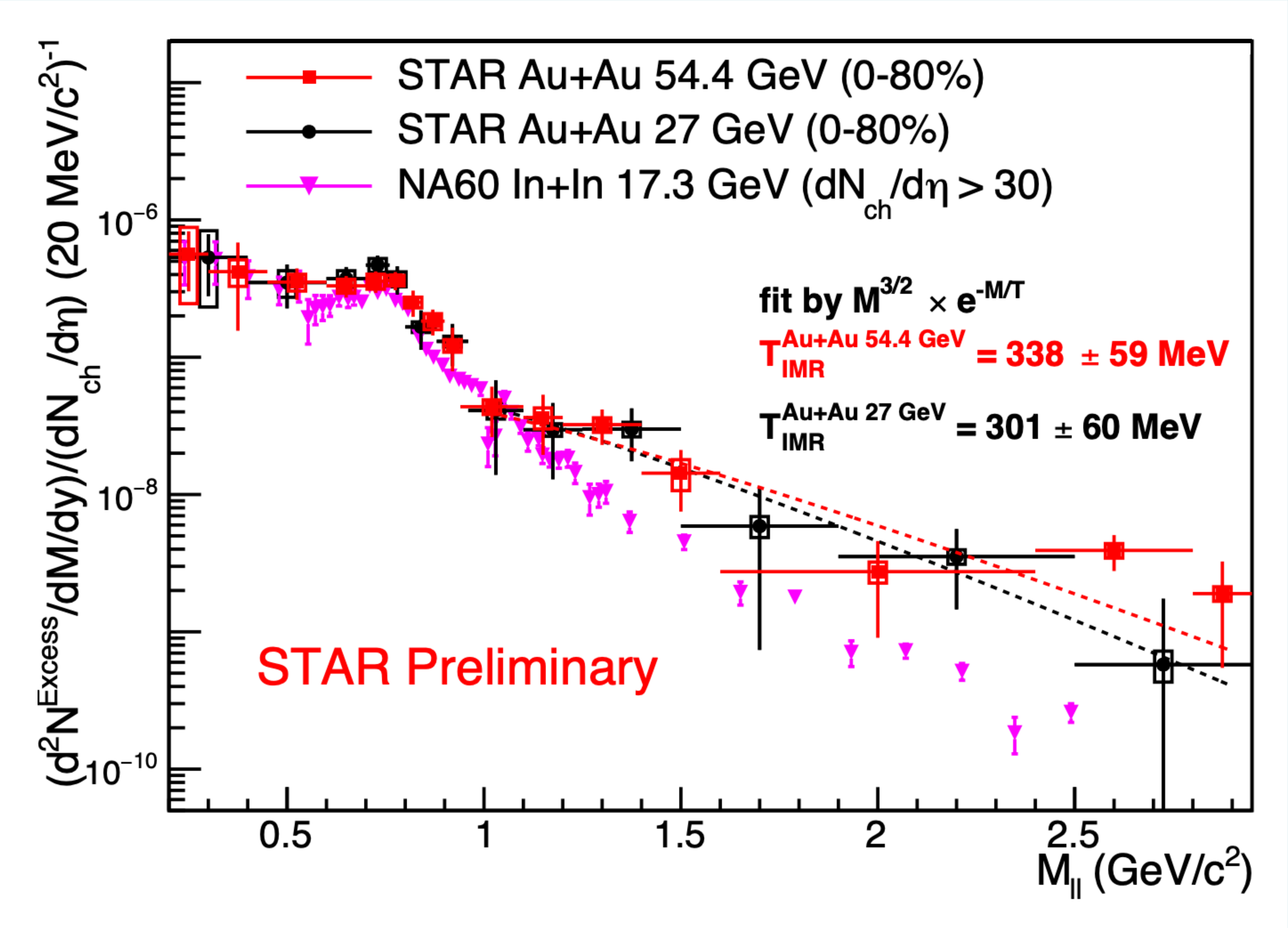

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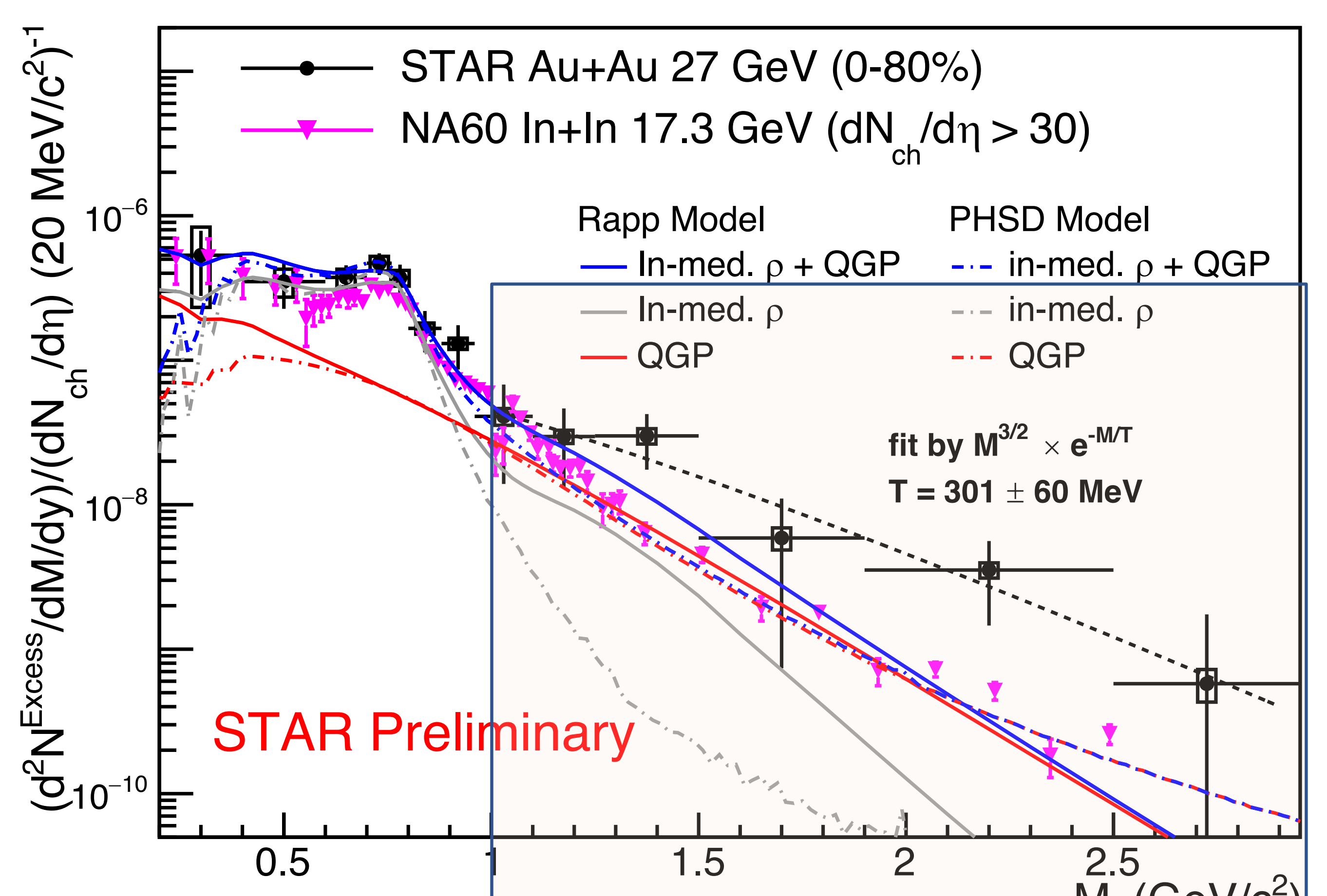
} Higher than LMR

Initial temperature depends on collision energy

System size and μ_B dependence

- The models describe LMR (late-stage) thermal dilepton, but IMR (early-stage) is underestimated
  - This is the opposite result of non-prompt direct photon measured by the PHENIX experiment at 200 GeV



Talk at QM2022

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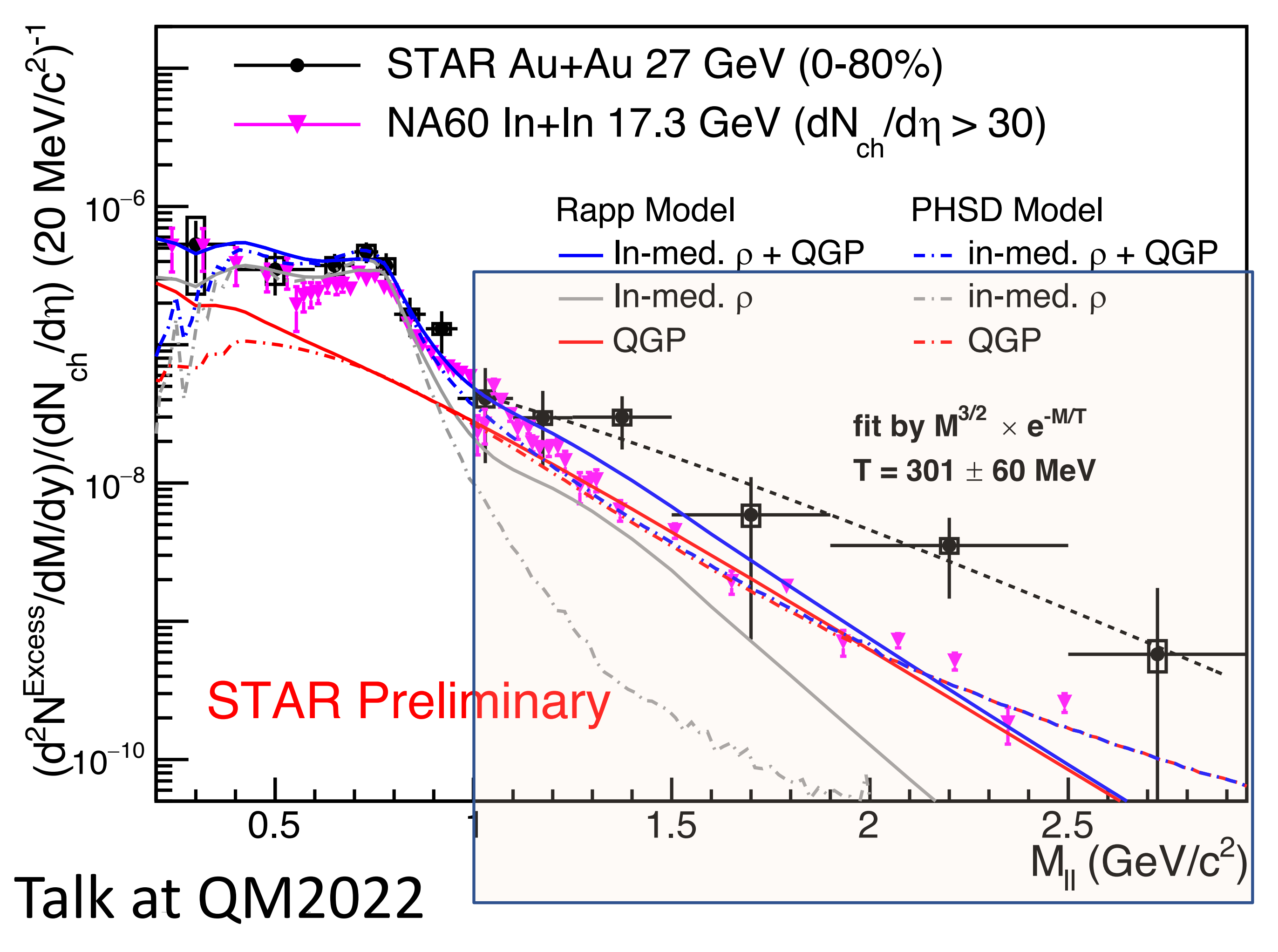
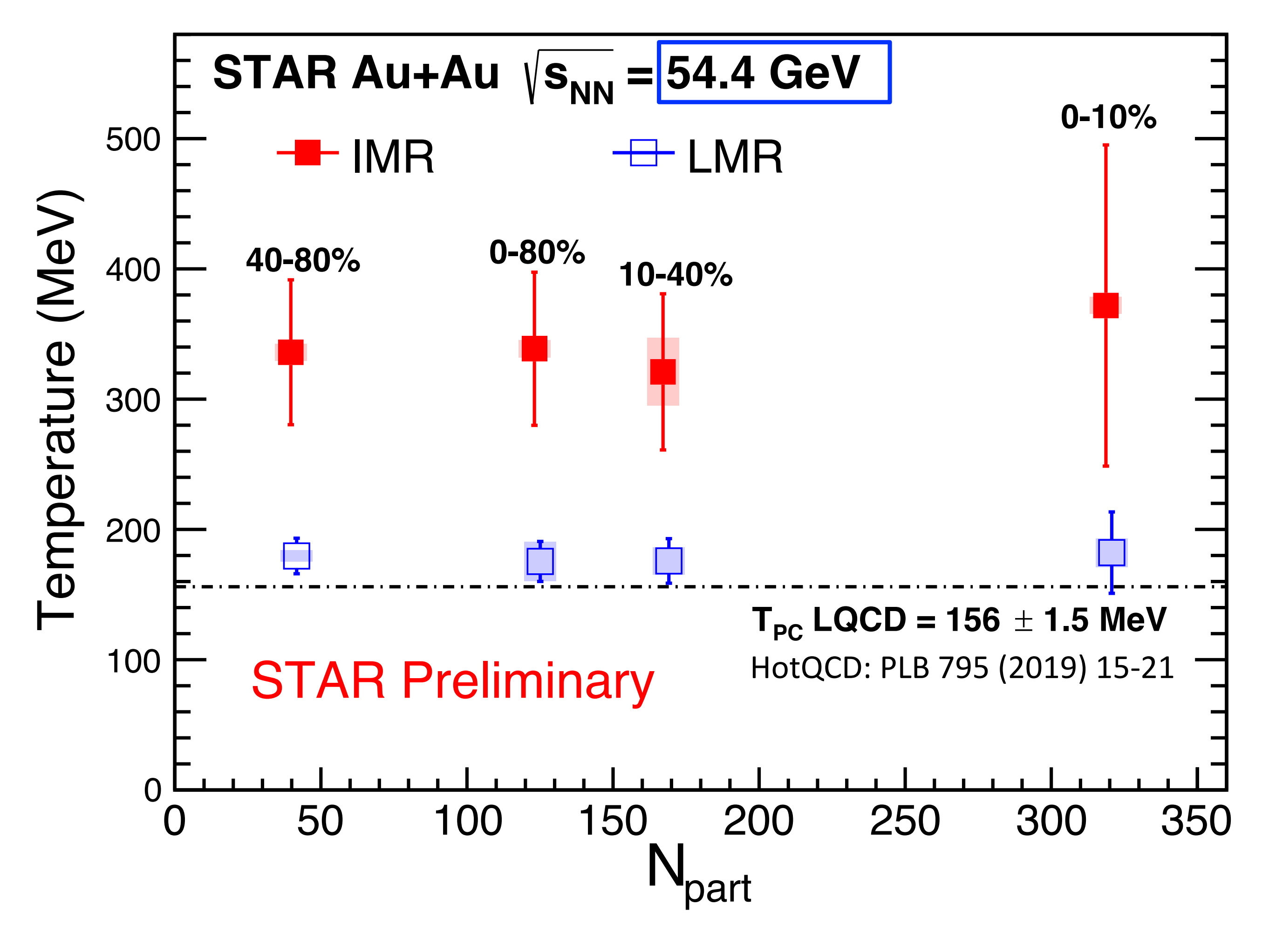
- Temperature from dilepton doesn't depend on the system size
  - Temperature of the early stage is expected to depend on
  - Late-stage LMR temperature is nearly at the phase transition temperature





System size and μ_B dependence

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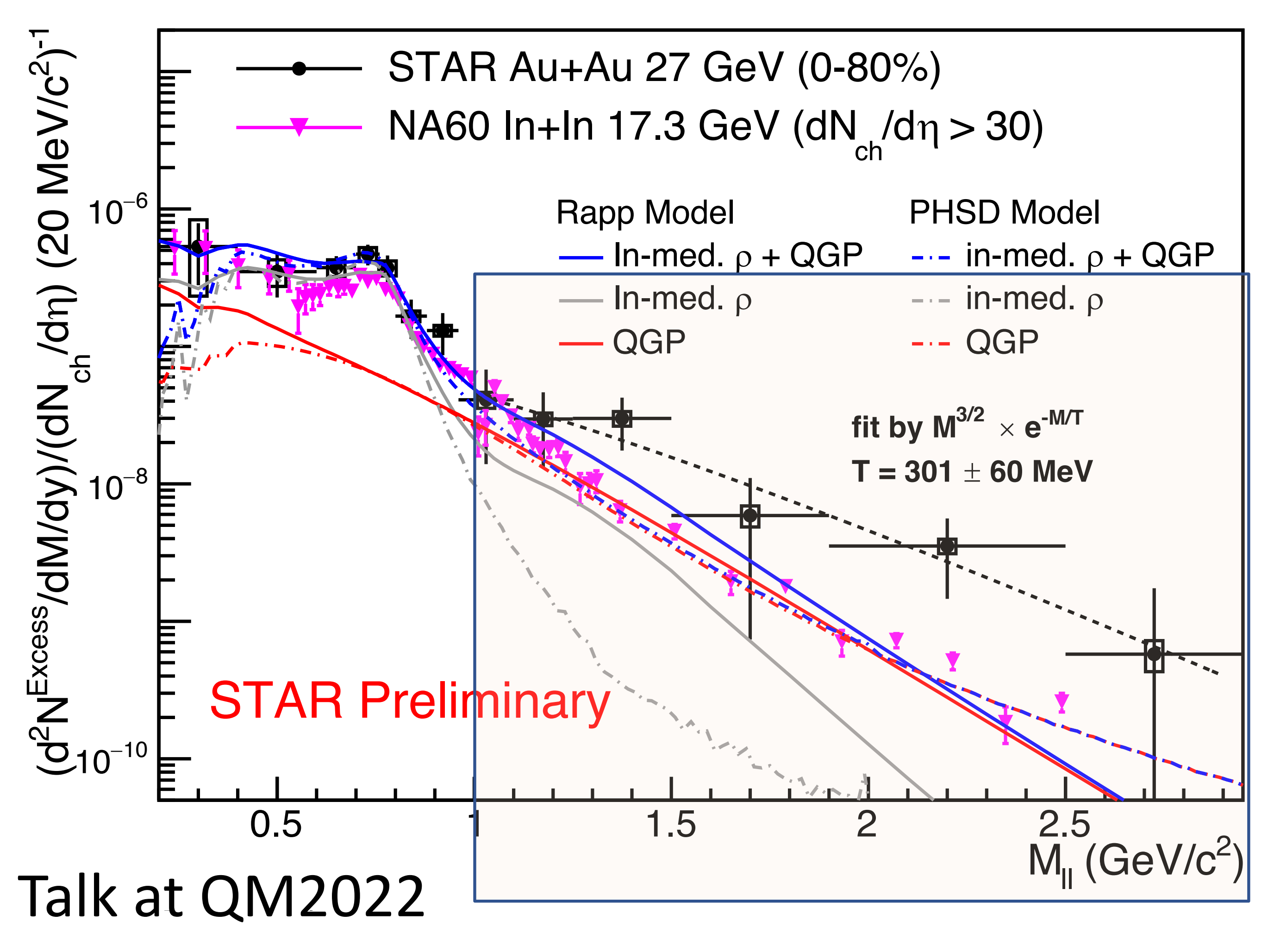
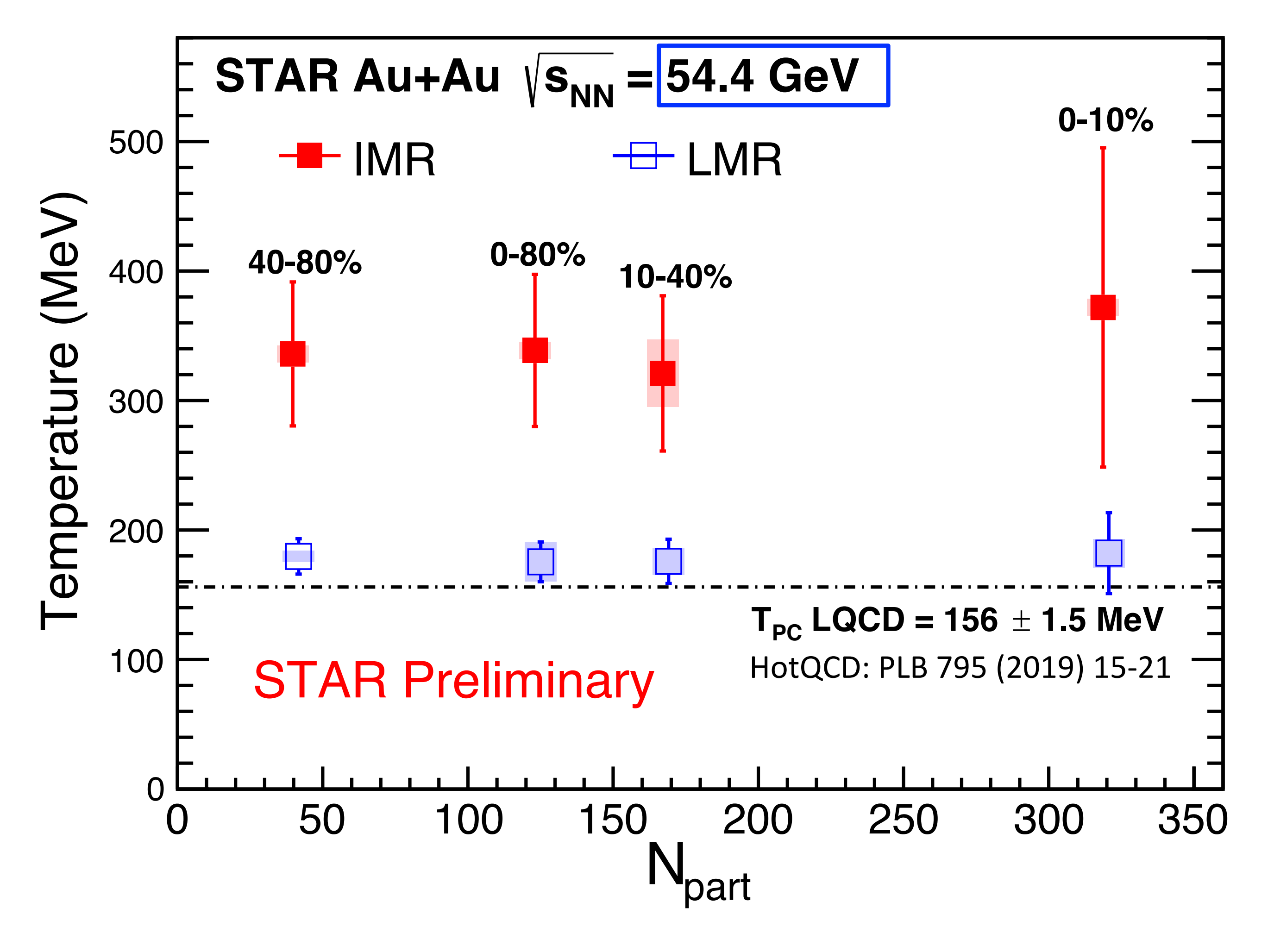
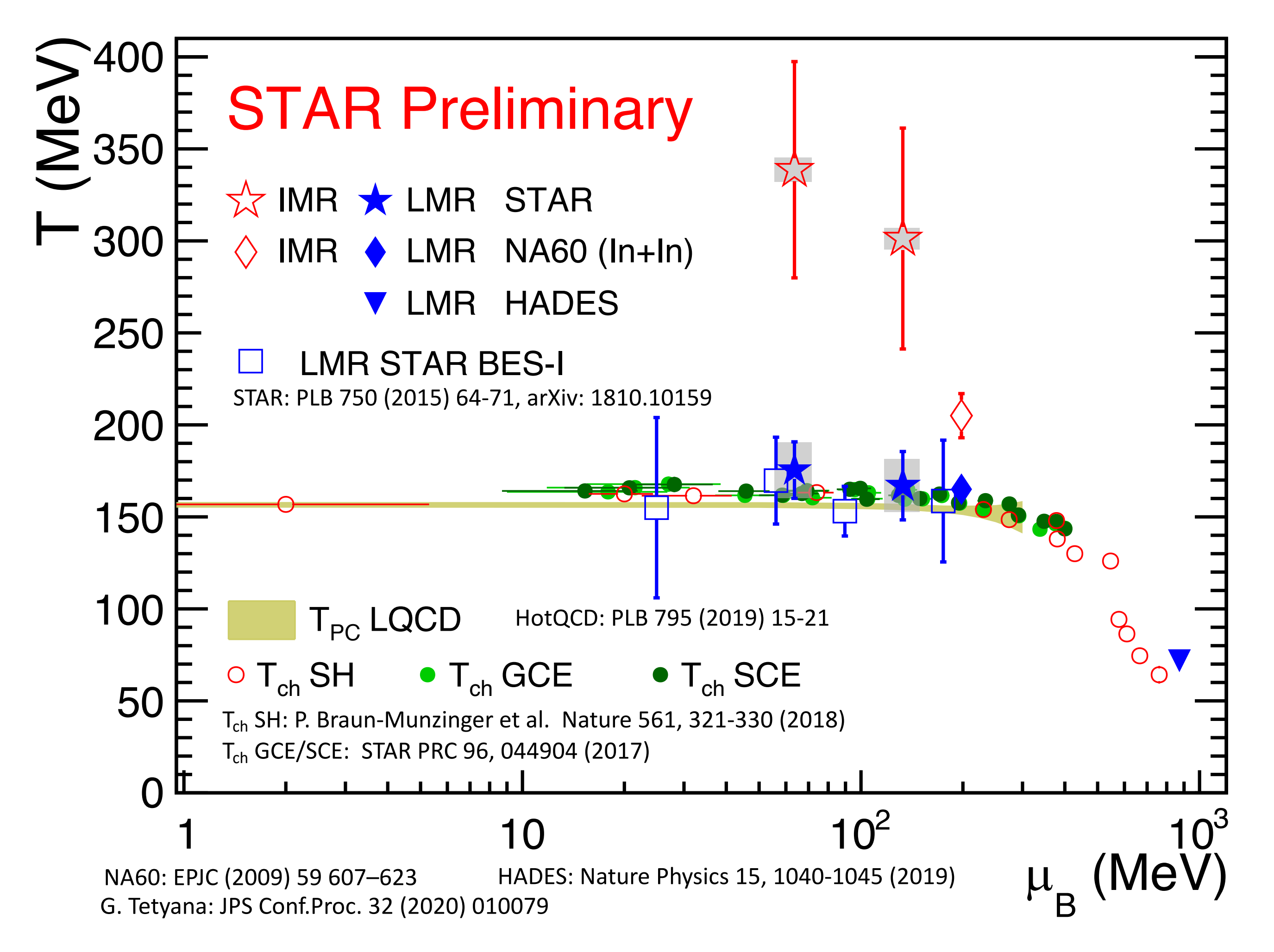
  - This is the opposite result of non-prompt direct photon measured by the PHENIX experiment at 200 GeV
- Temperature from dilepton doesn't depend on the system size
  - Temperature of the early stage is expected to depend on
  - Late-stage LMR temperature is nearly at the phase transition temperature





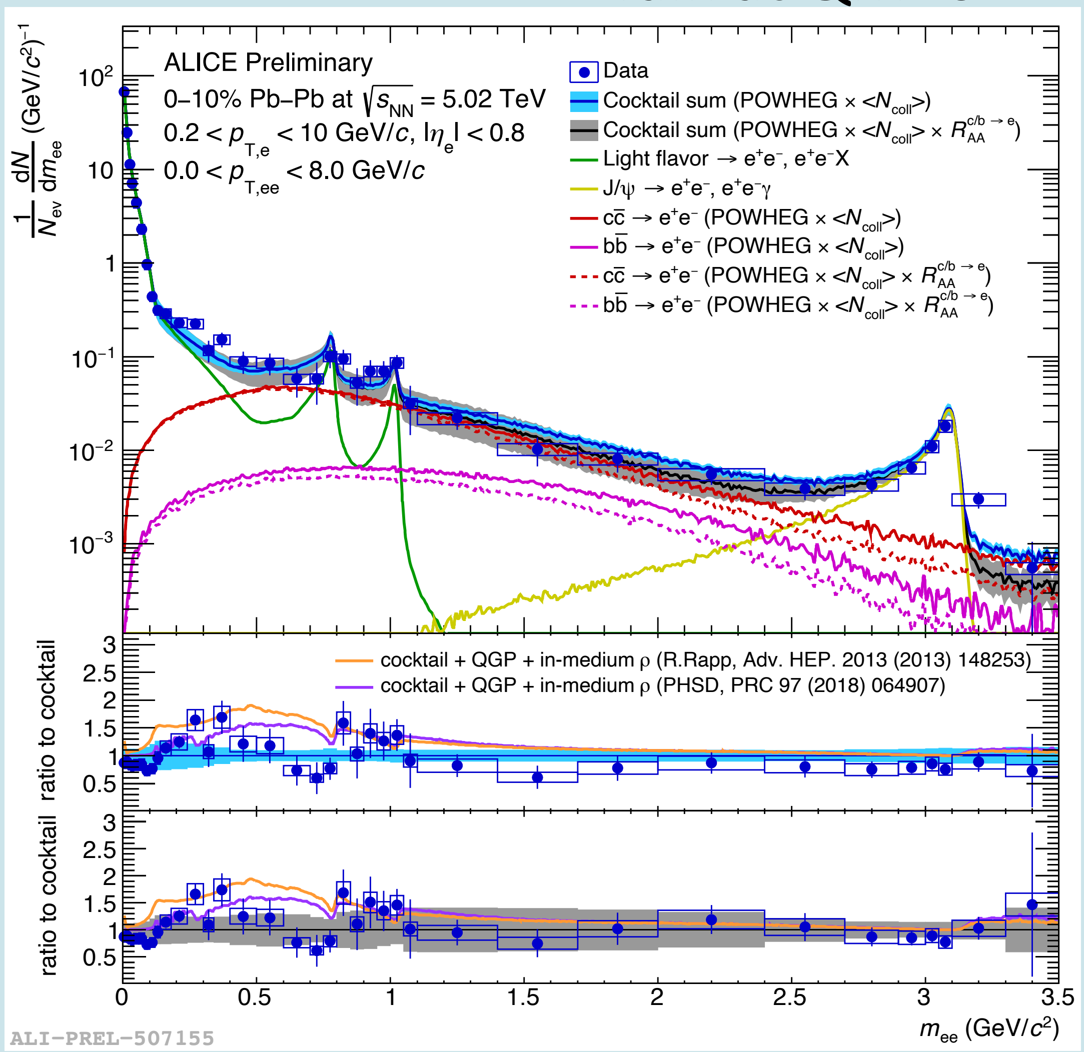


The information to reveal the QCD phase diagram is gradually being gathered

Dilepton measurement at LHC energies

- It is challenging to extract the dielectron excess at LHC energy due to the huge background
  - Contribution from light flavors and heavy flavors are dominant contributions for LMR and IMR, respectively

Talk at QM2022



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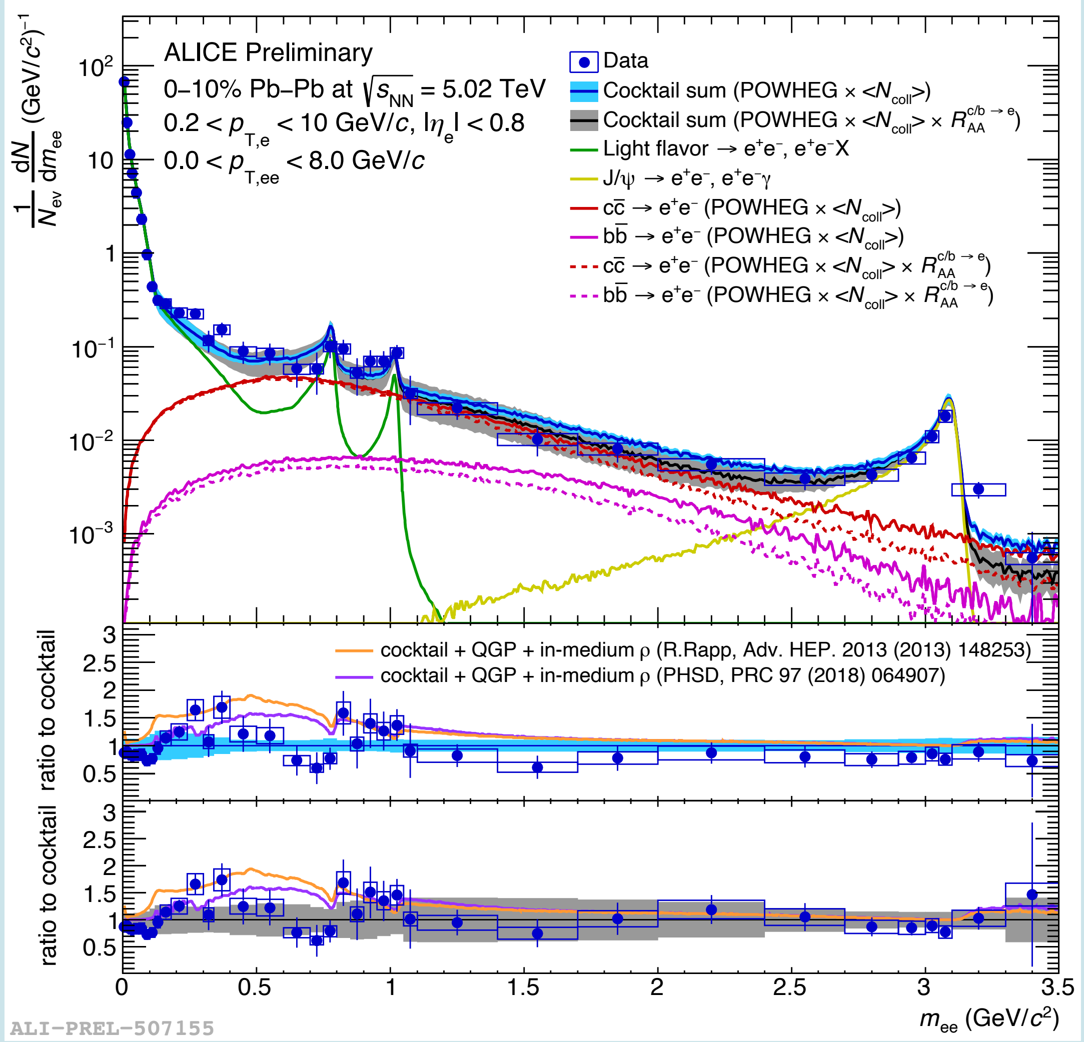

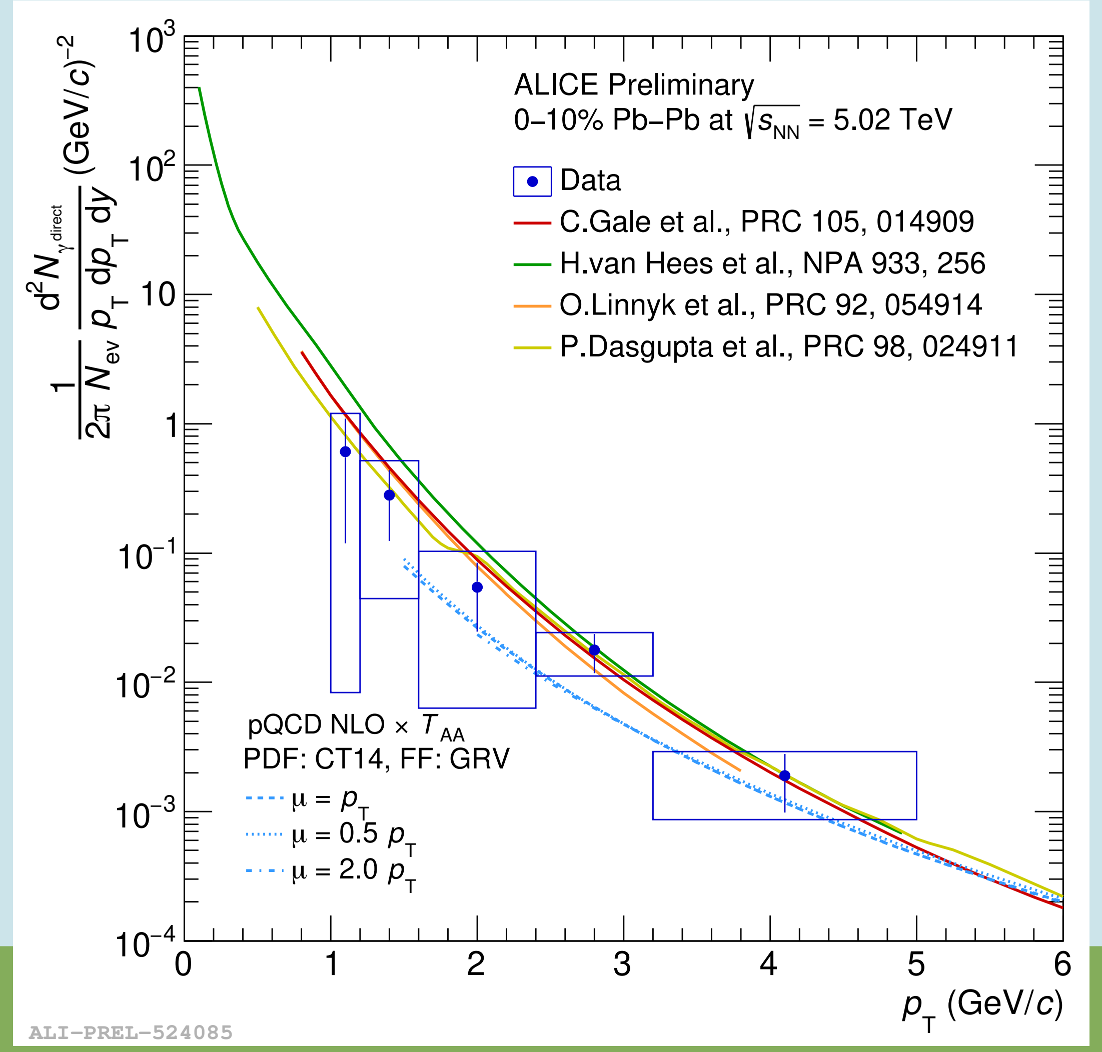

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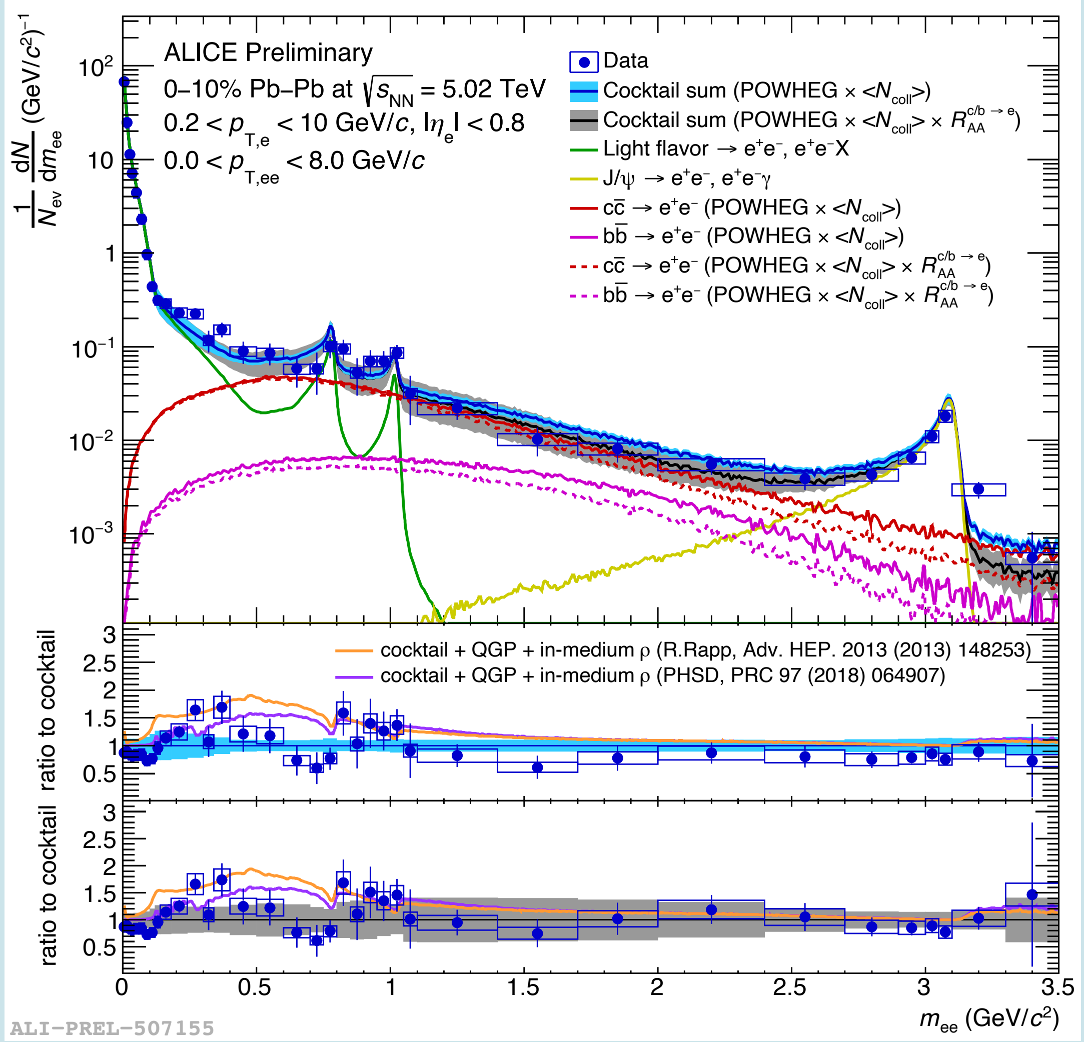

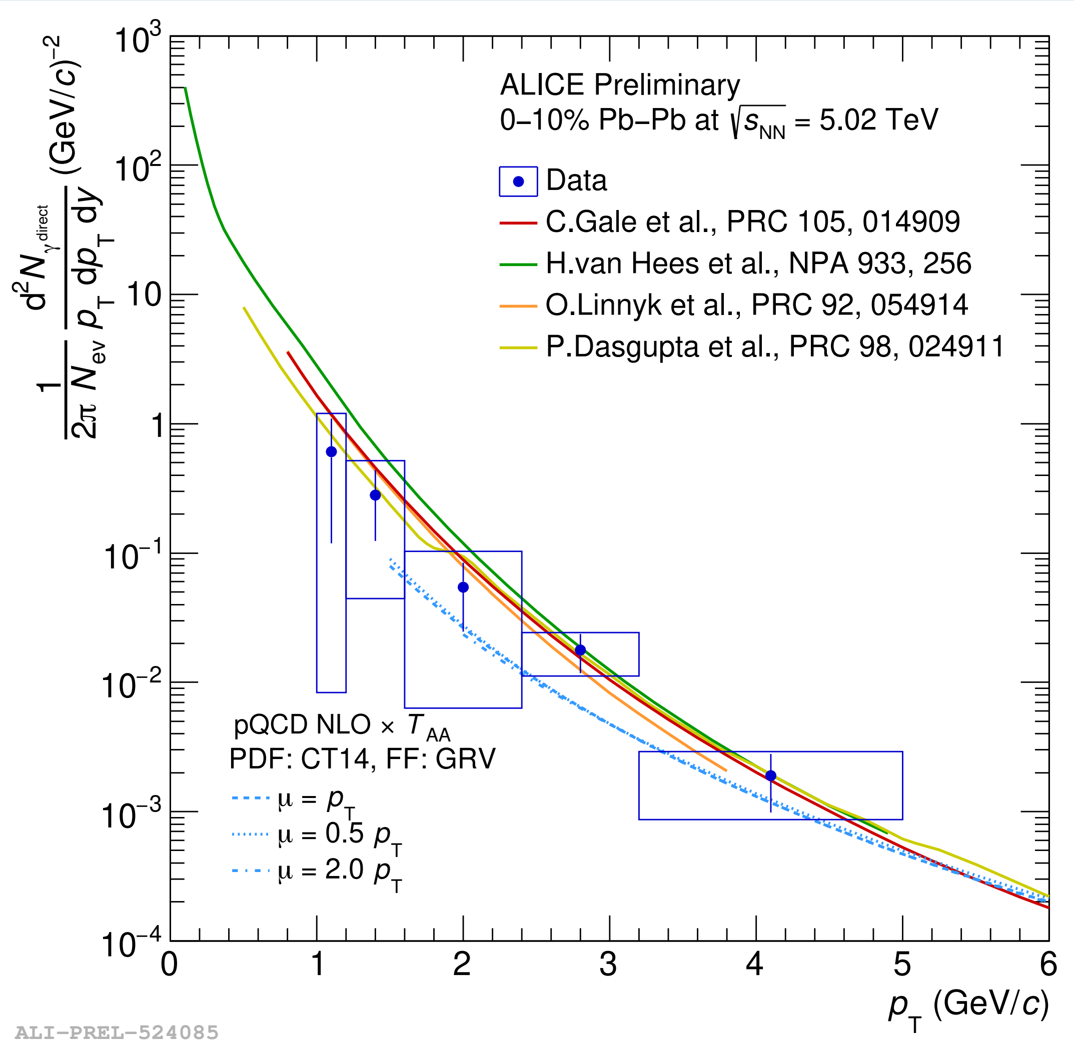

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It is very difficult and challenging measurement at LHC due to huge huge background

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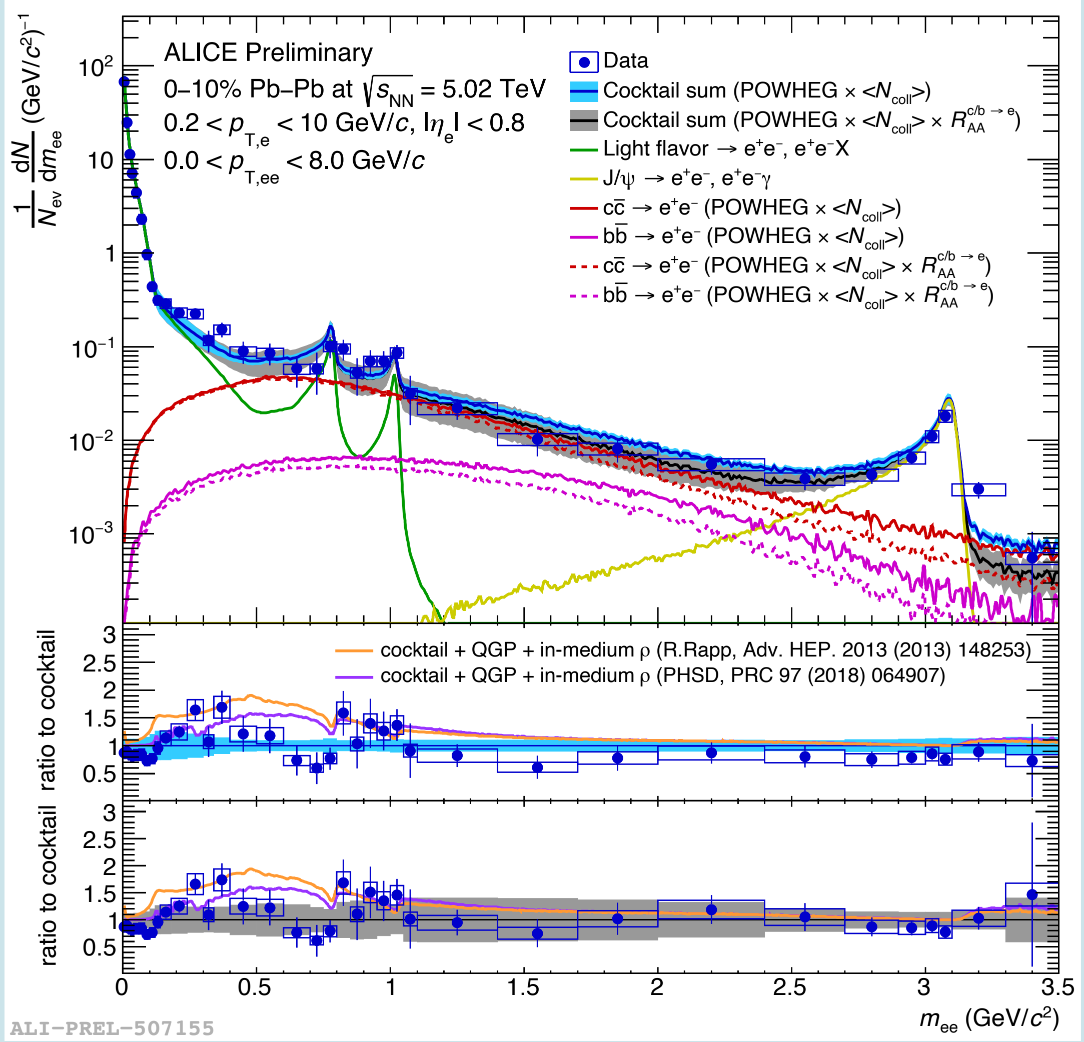
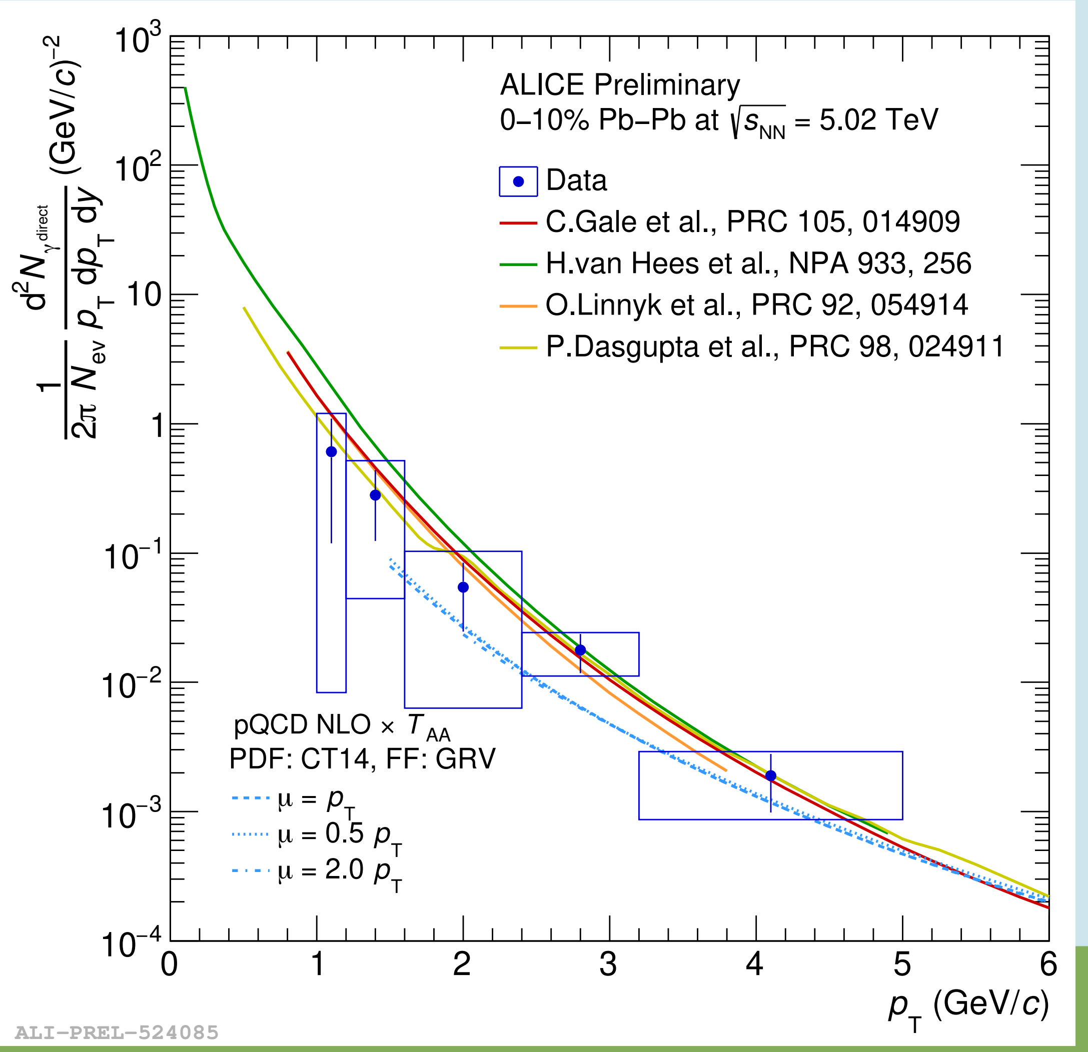
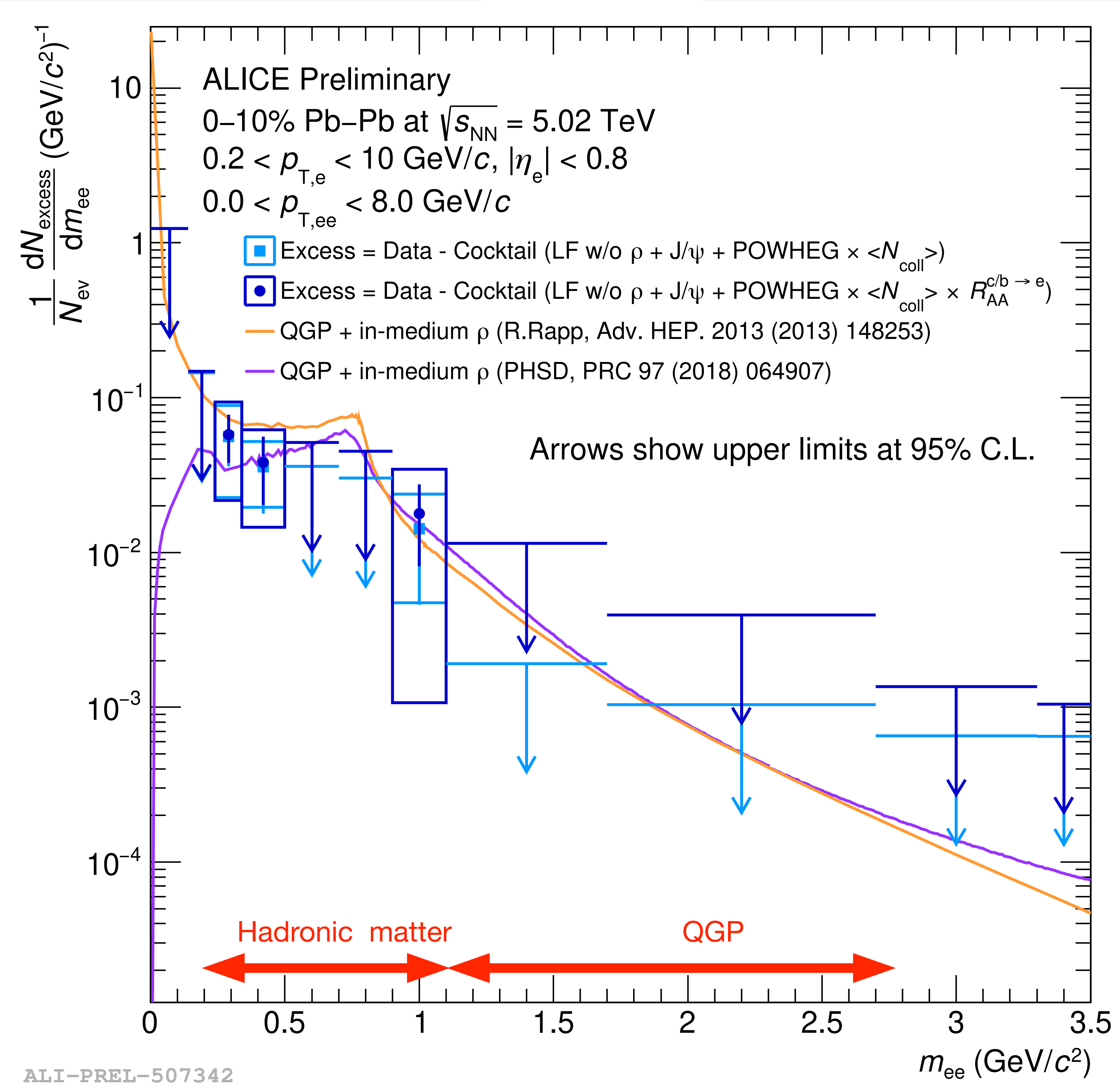




Dilepton excess at LHC energies

- Dielectron excess has been extracted
  - LFs are measured results, but N_{coll} scaled HF contribution w/ and w/o R_{AA} effect is used



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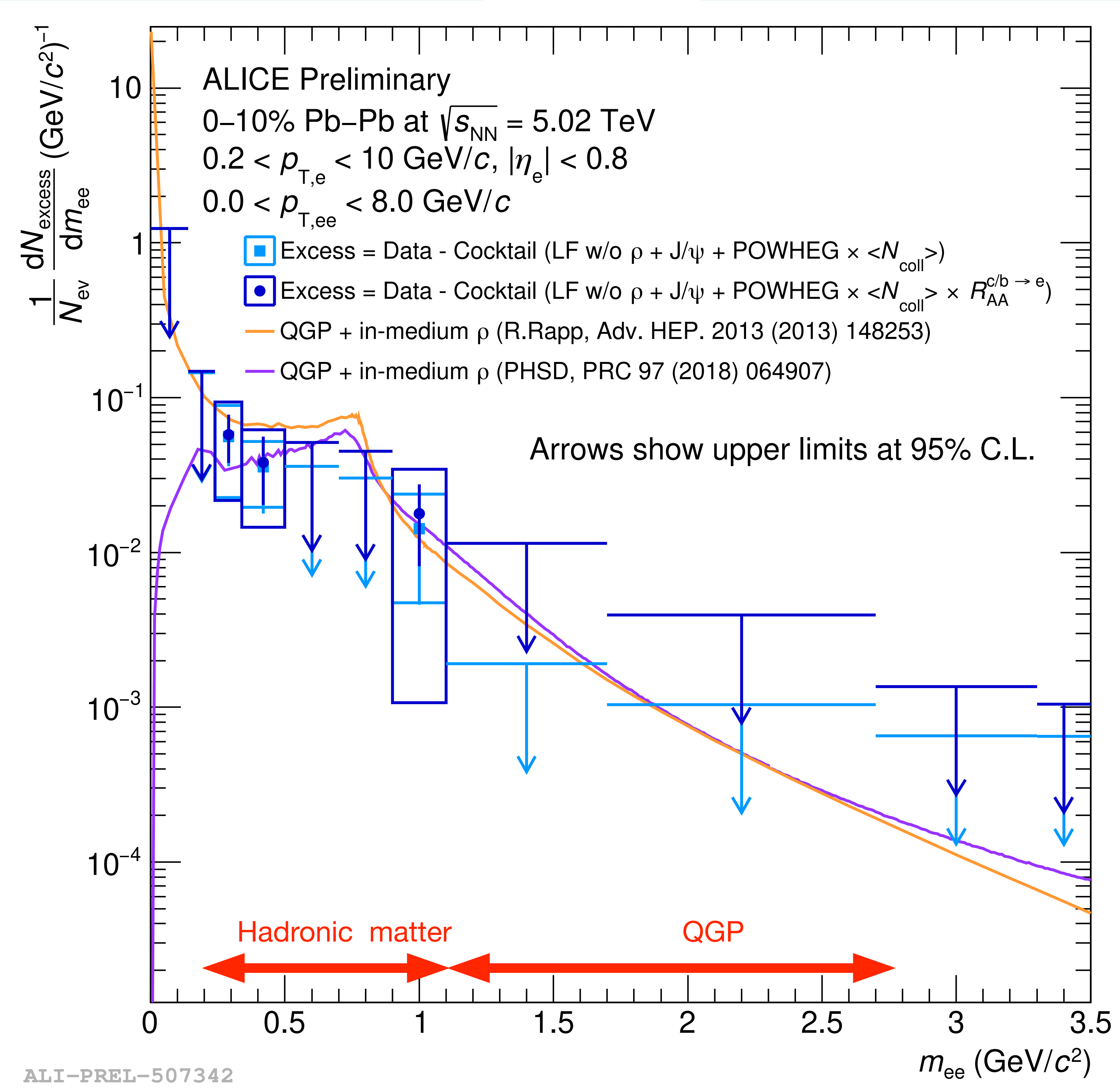
  - LMR: Combinatorial electrons
  - IMR: Contribution from HF ($\sigma_{cc}^{LHC} \sim 10 \times \sigma_{cc}^{RHIC}$)



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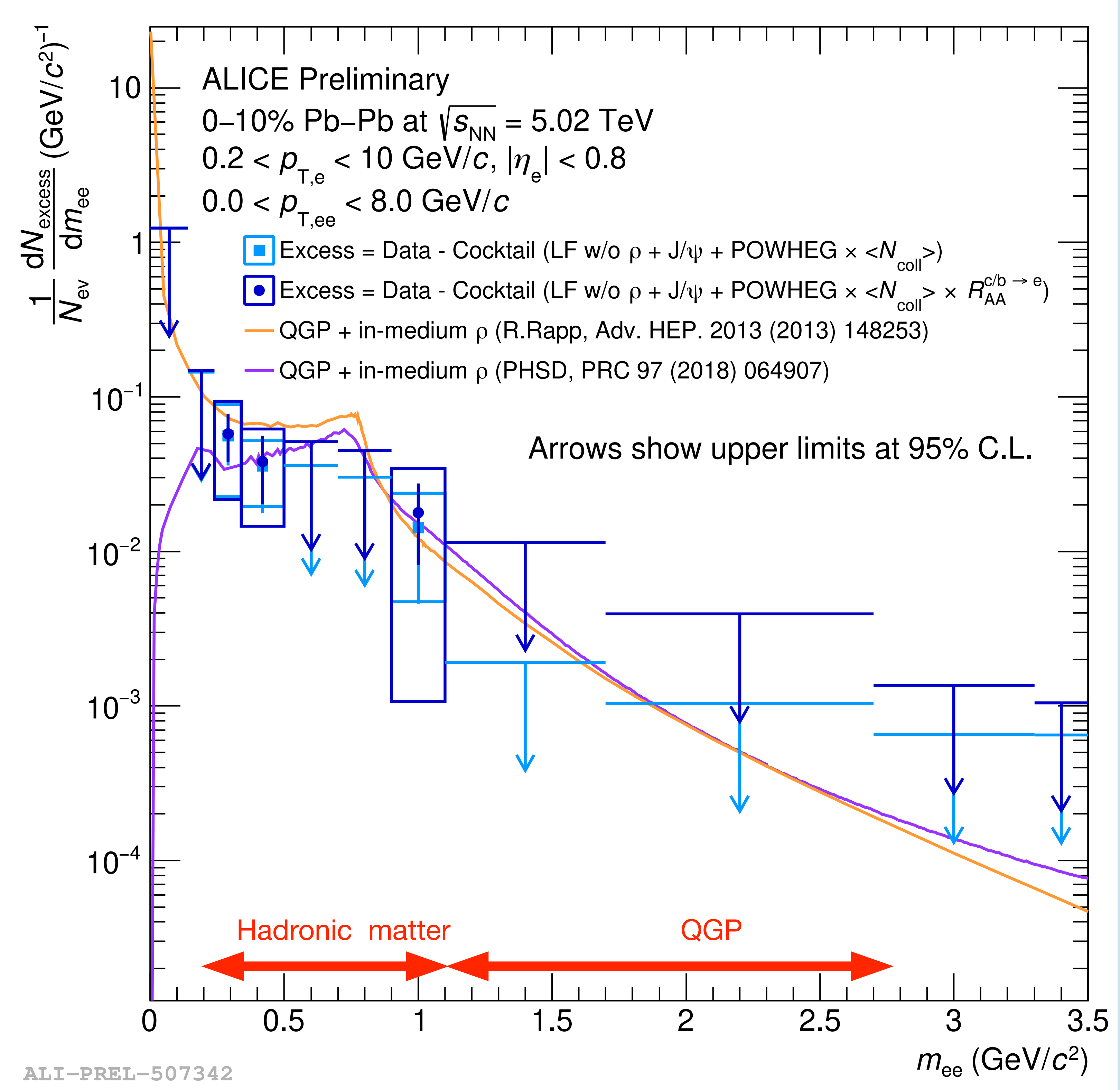

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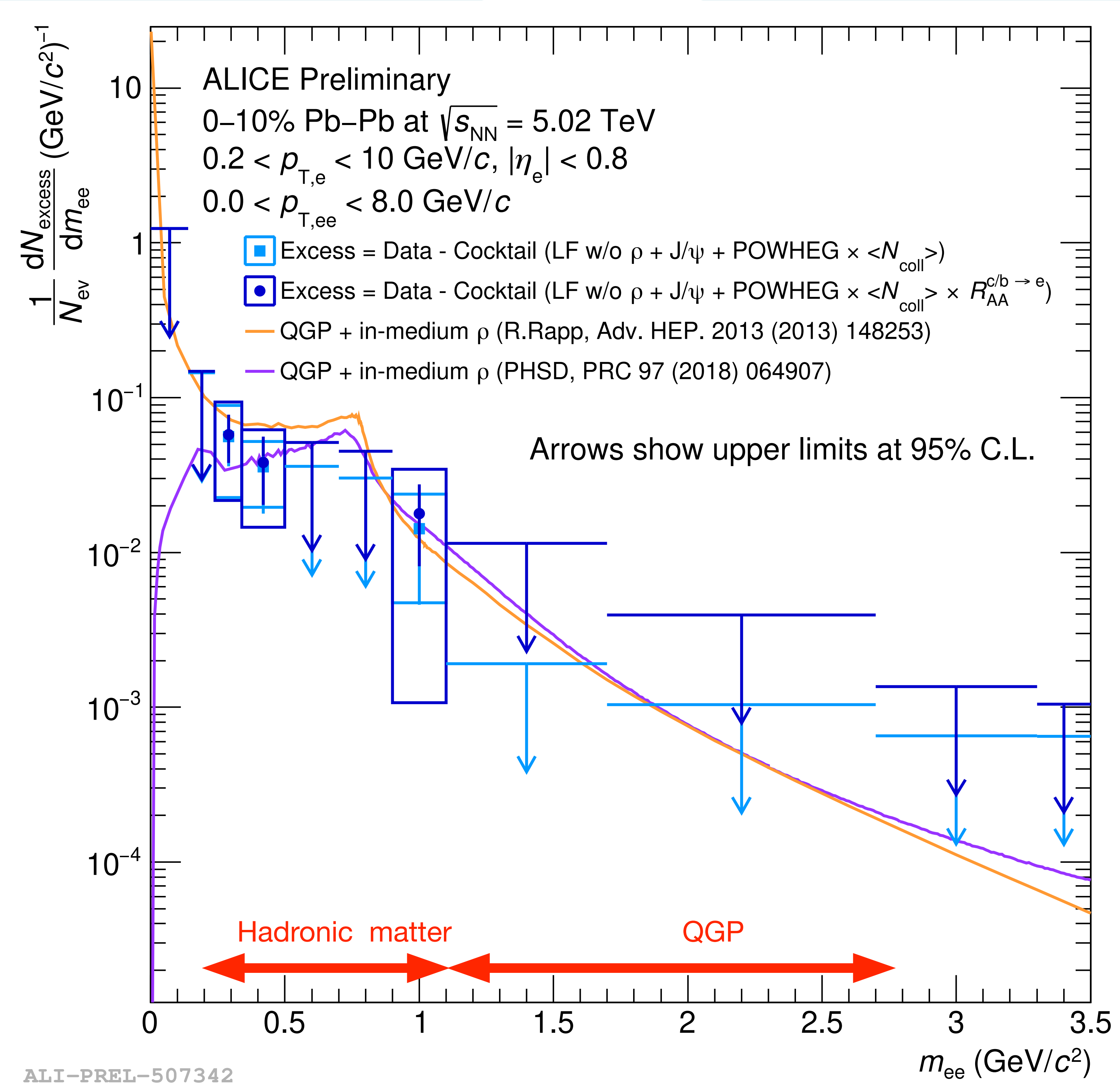

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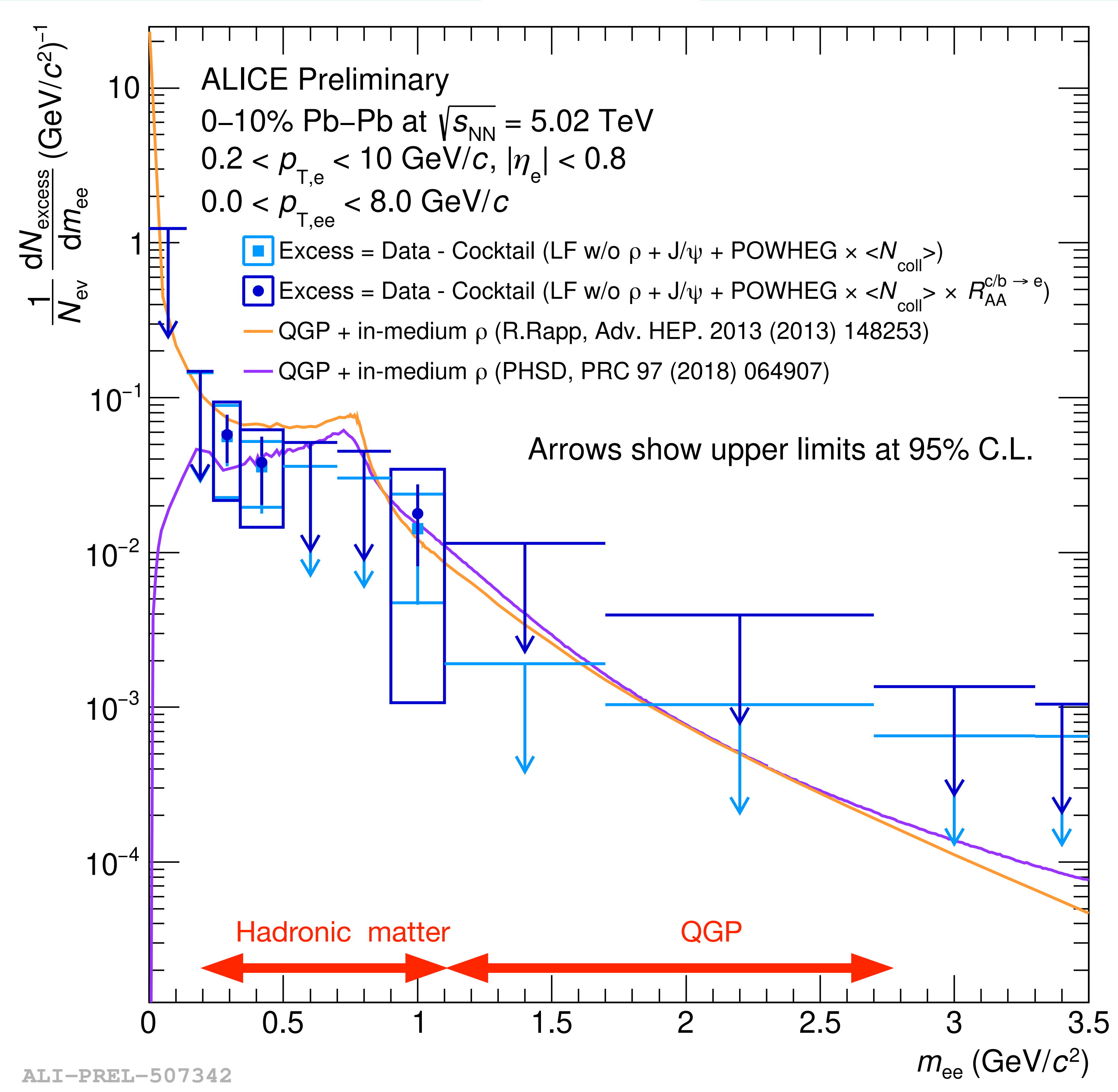

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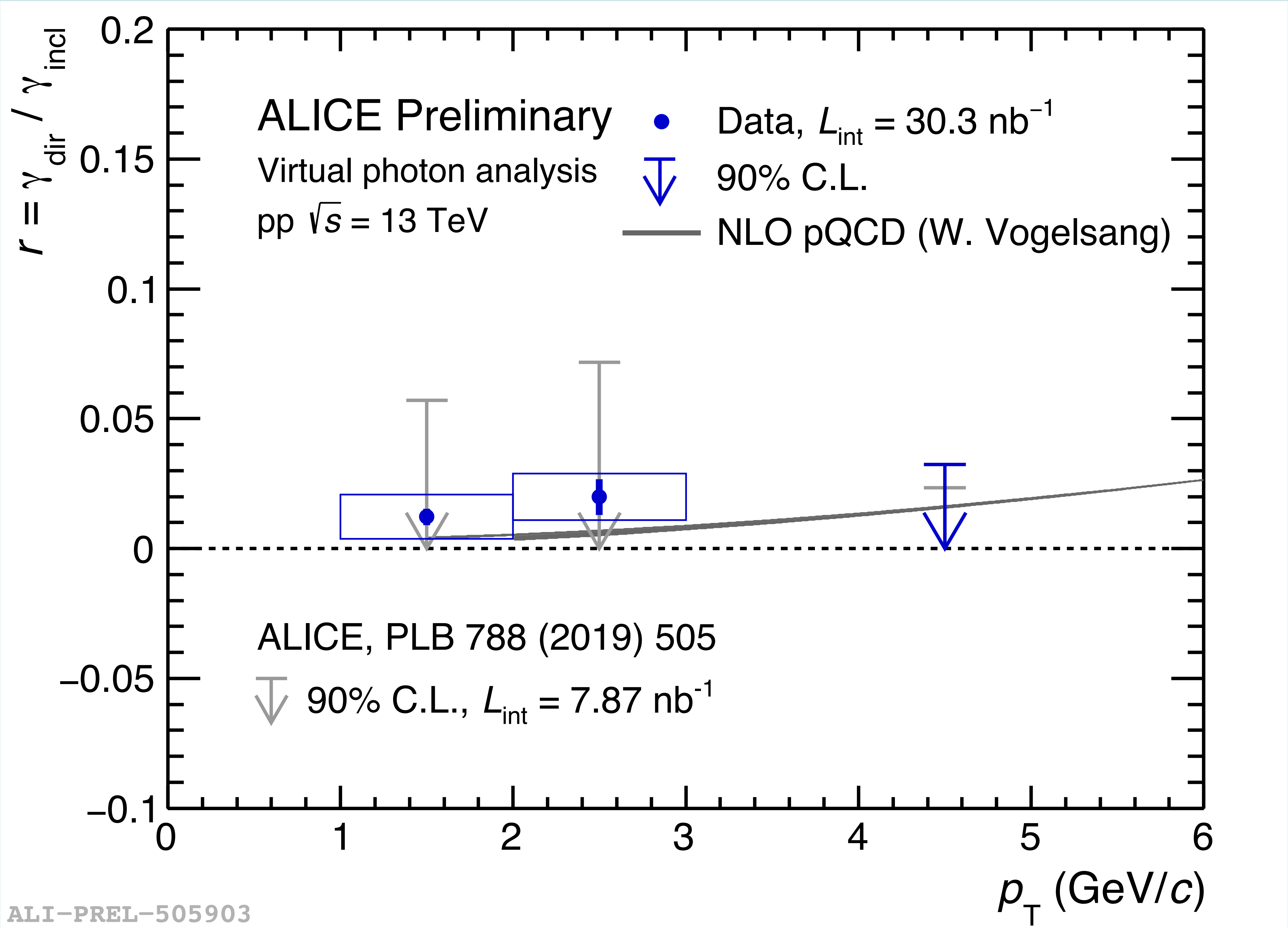
  - IMR: Improving HF determination by excellent detectors, or altering measuring rapidity

Direct photon production in high-multiplicity pp



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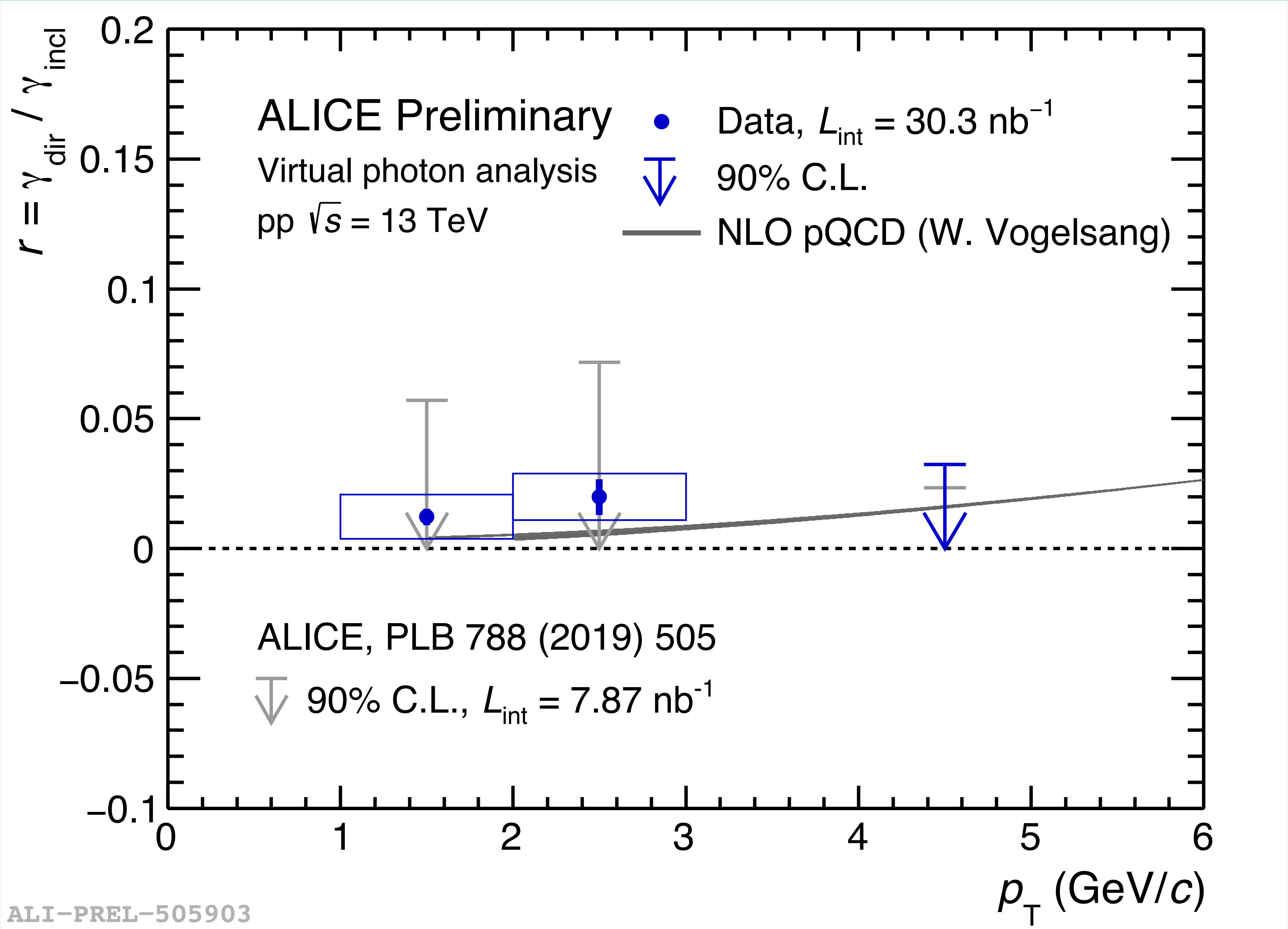
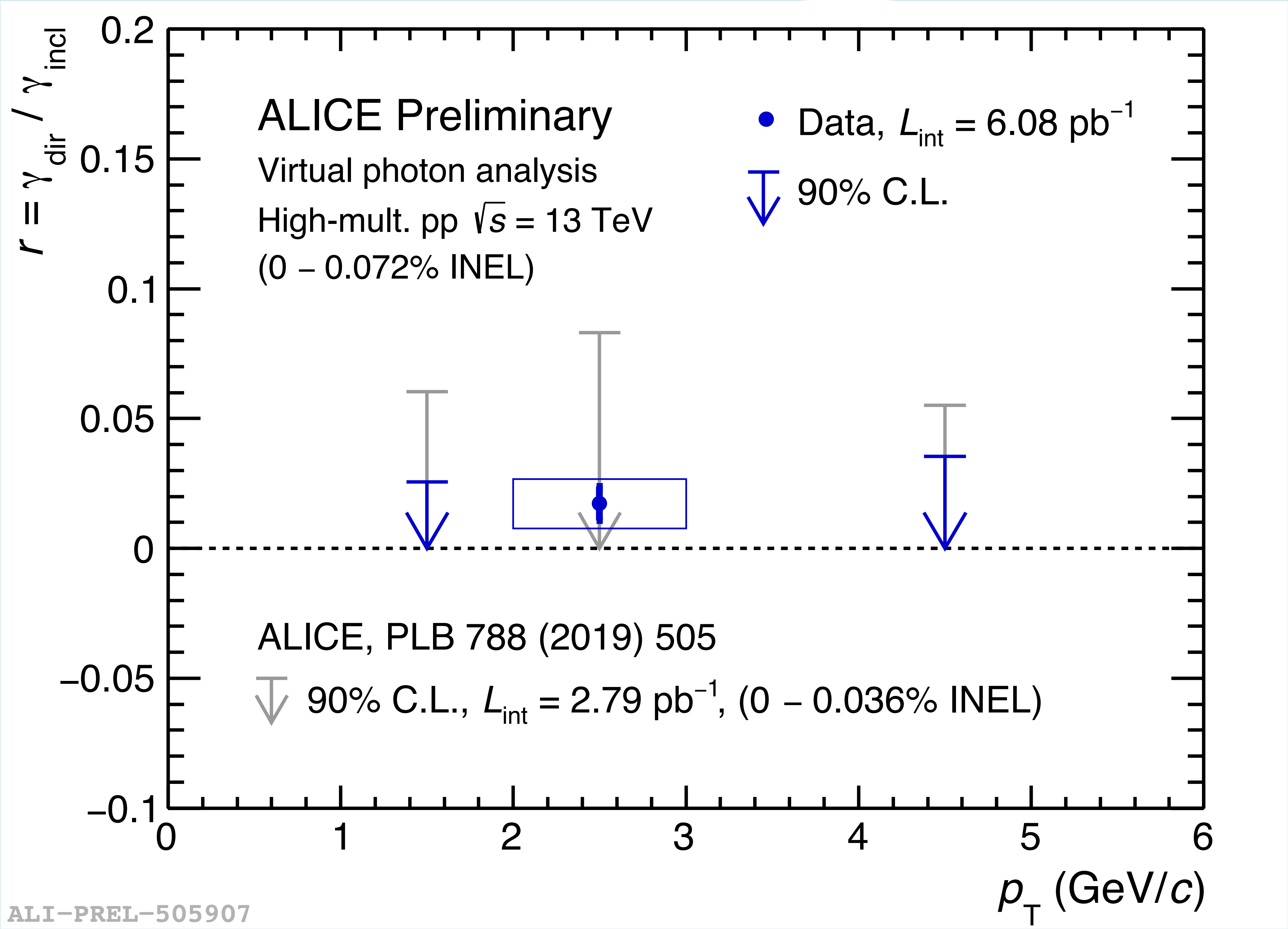
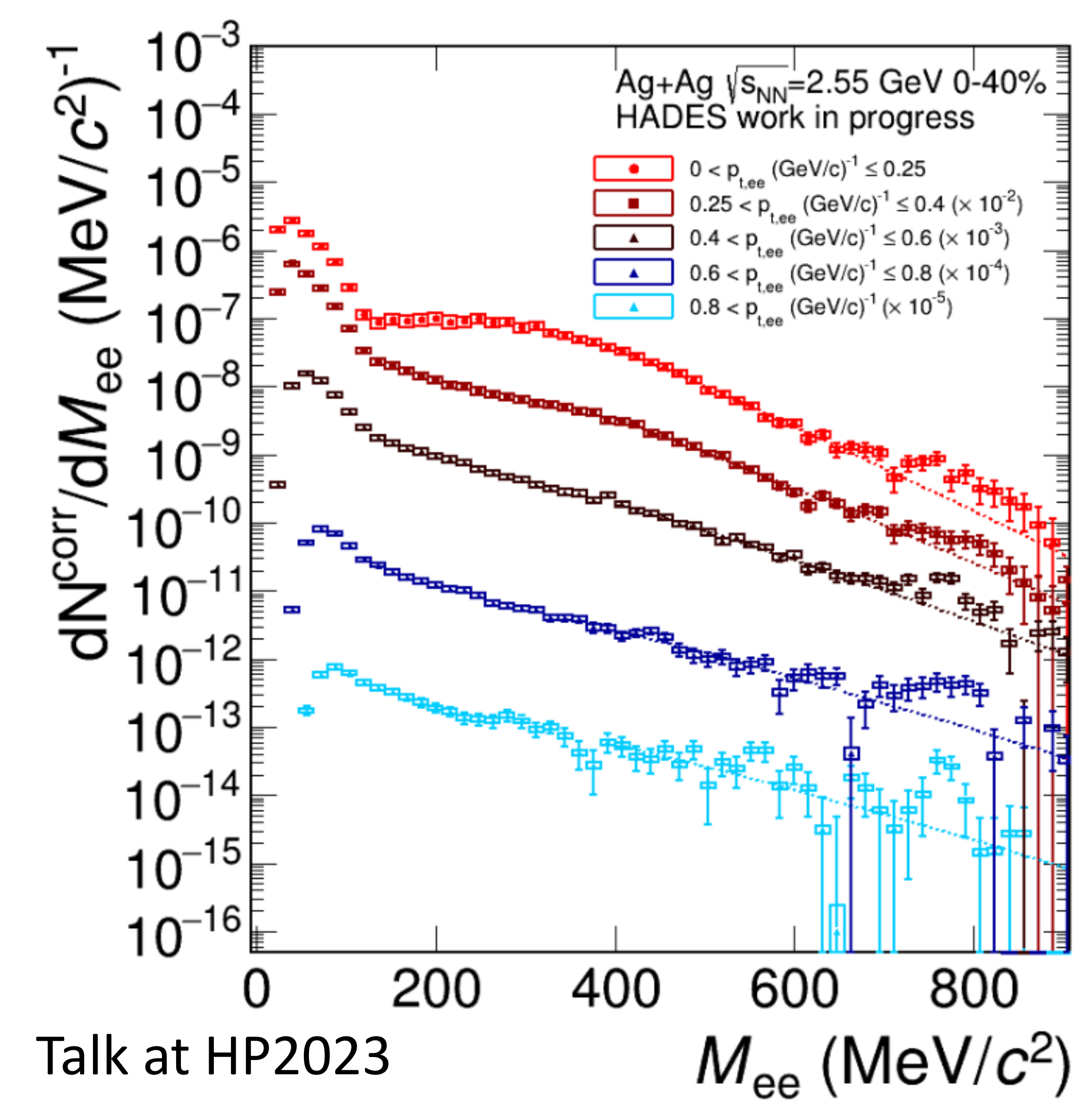




- Significant reduction of uncertainties compared to the previous ALICE paper
- Similar direct photon fraction in MB and HM pp collisions has been observed

Chance meet of high μ_B and high multiplicity pp collisions

- HADES claims ω meson is clearly visible at high p_T but disappeared at low p_T



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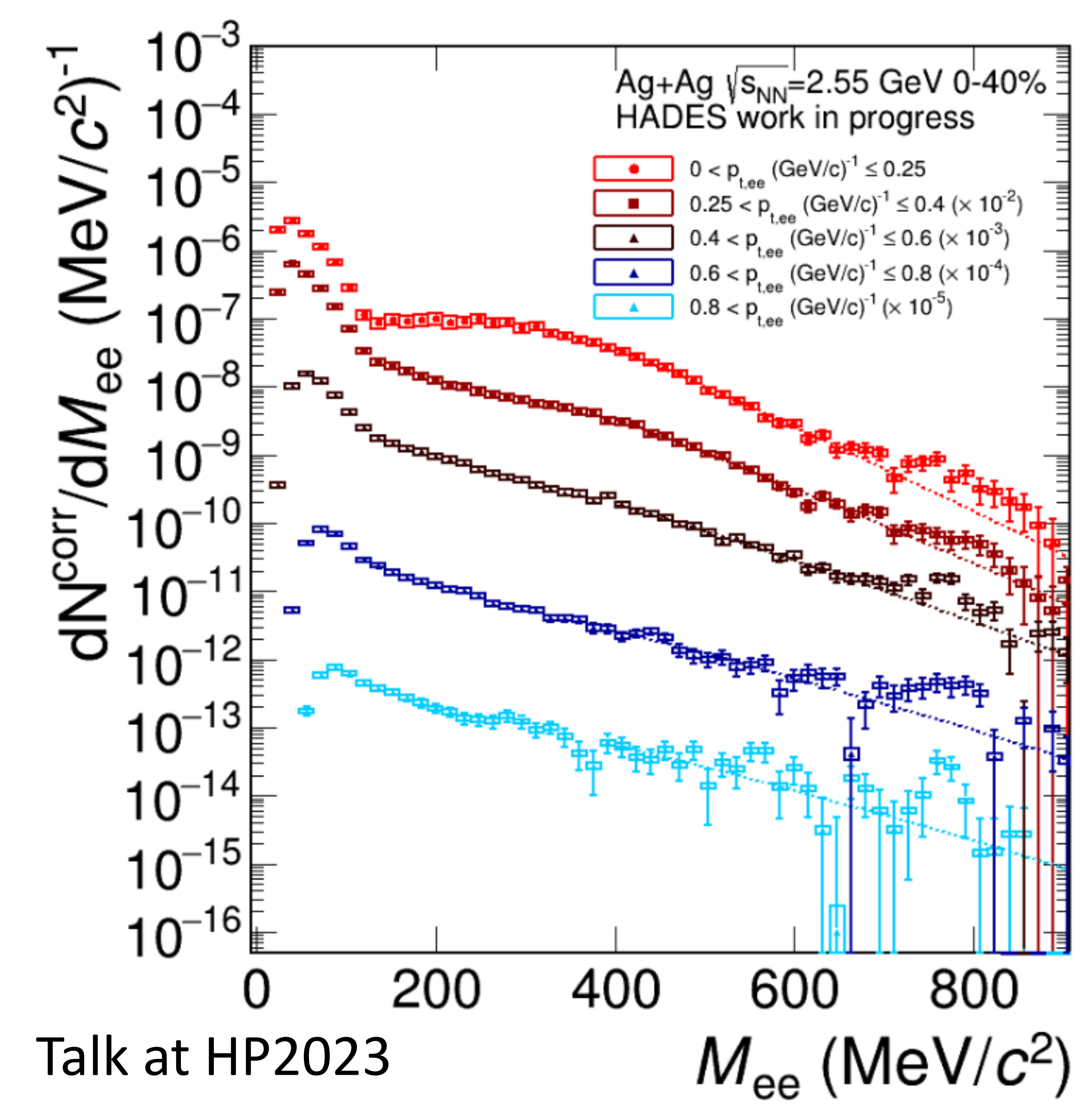

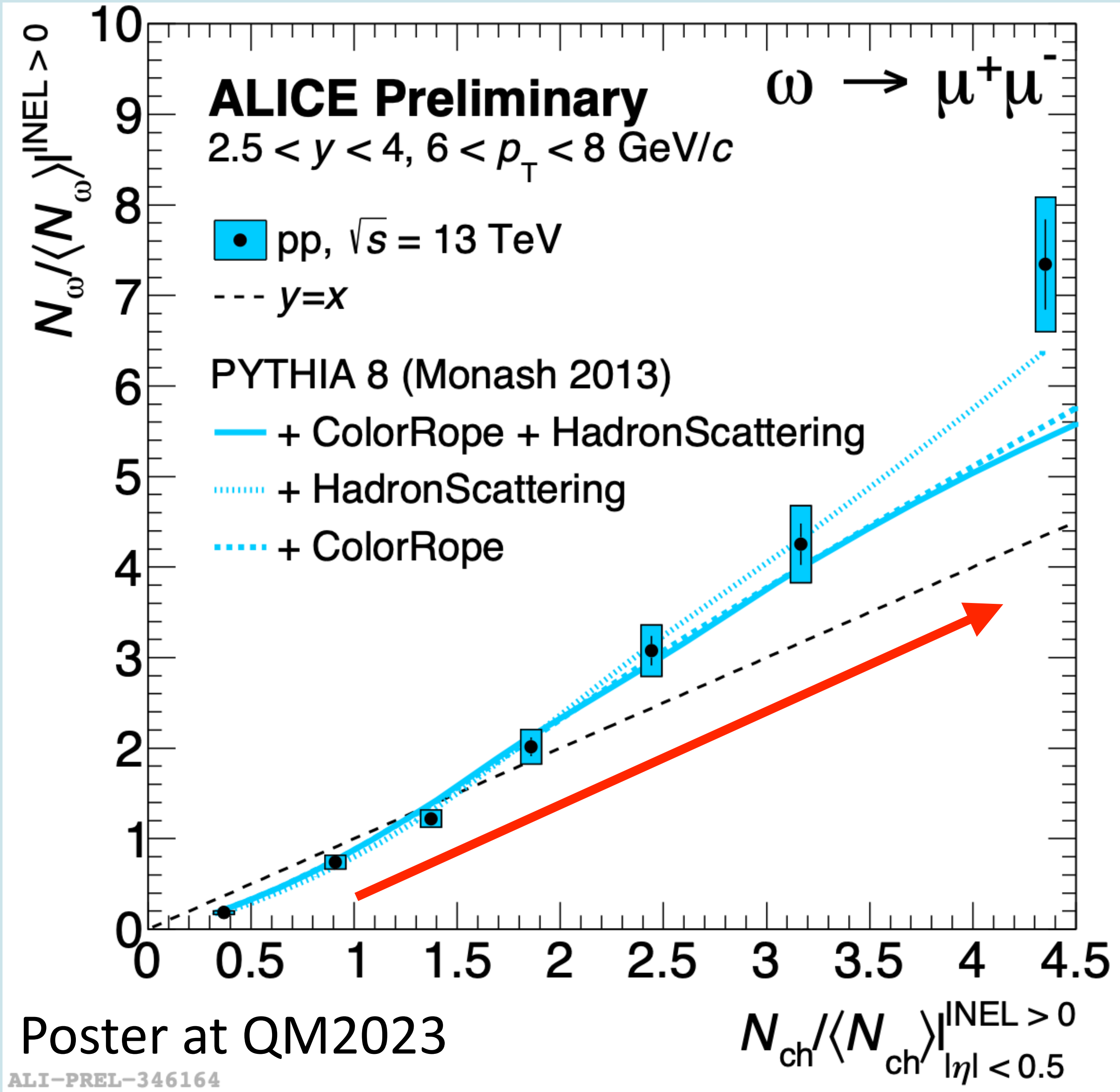

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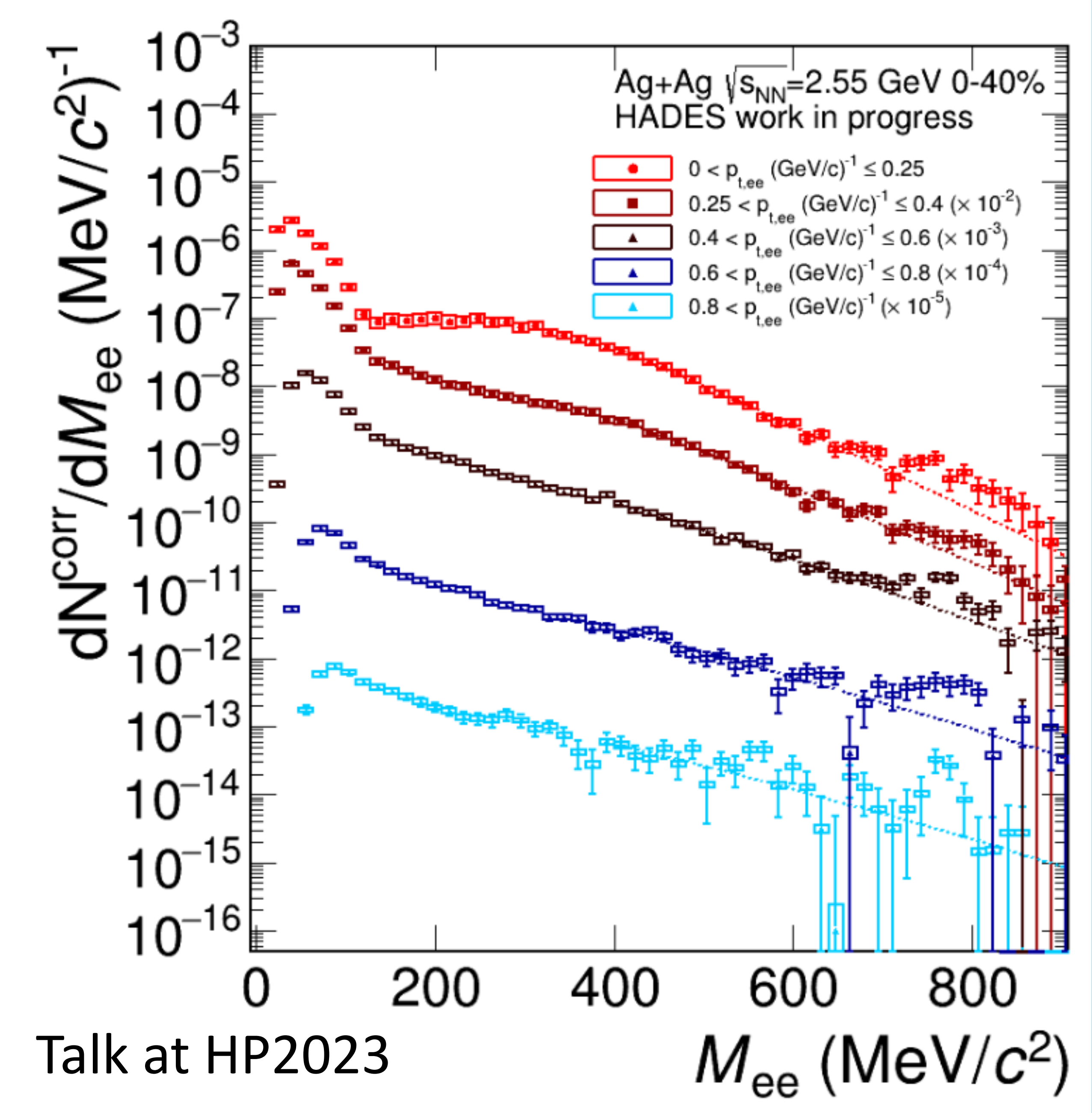

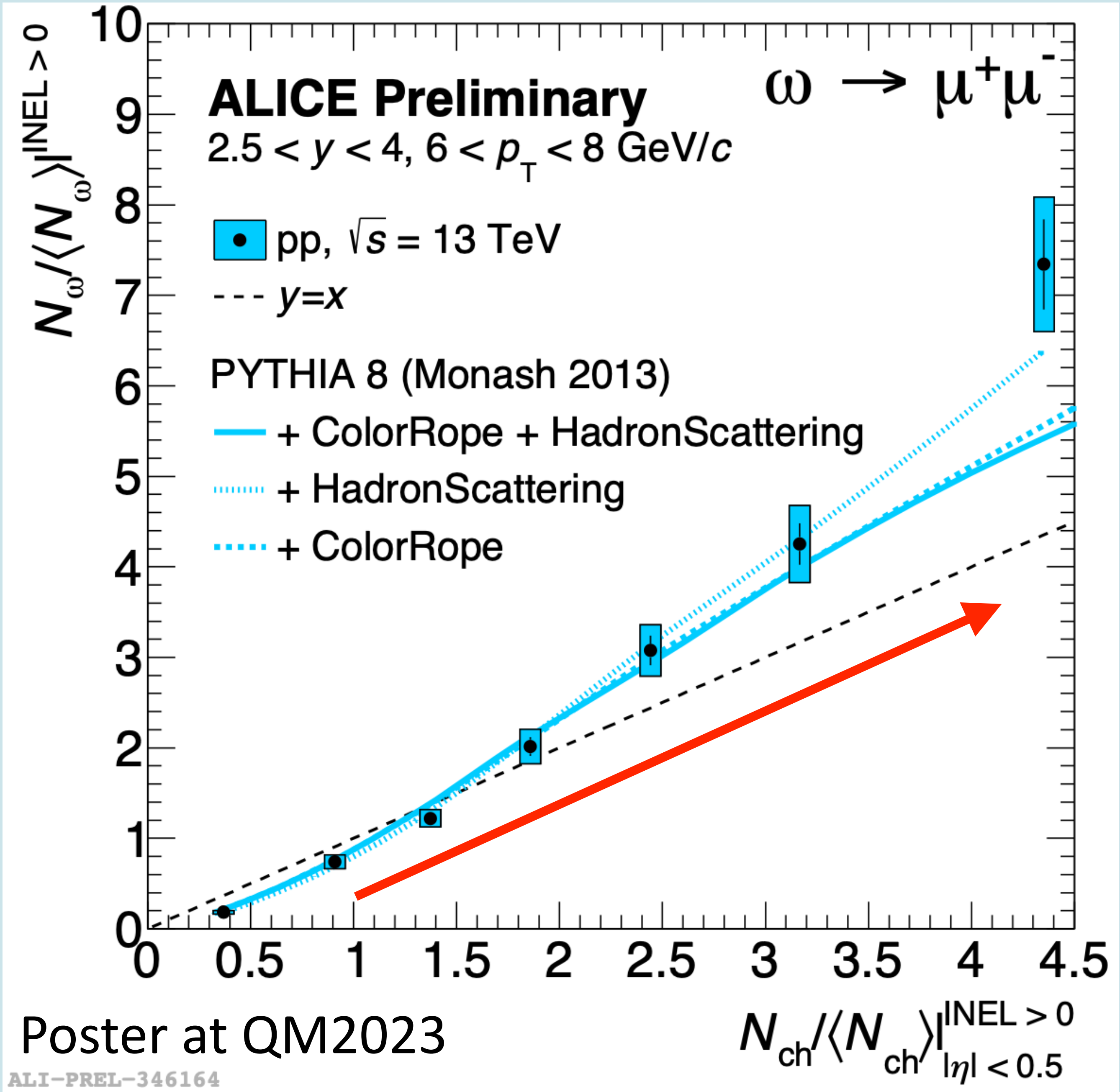

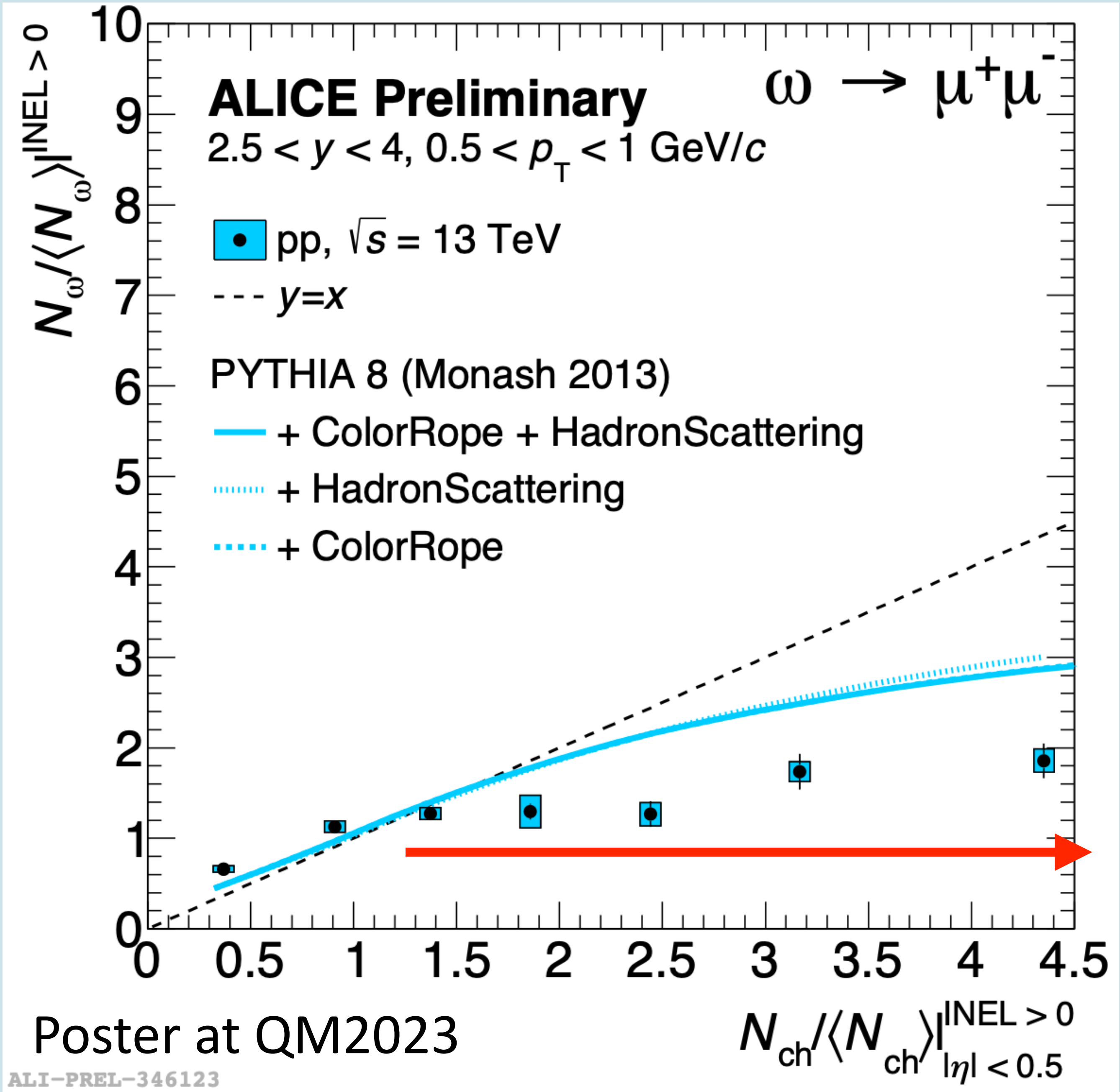

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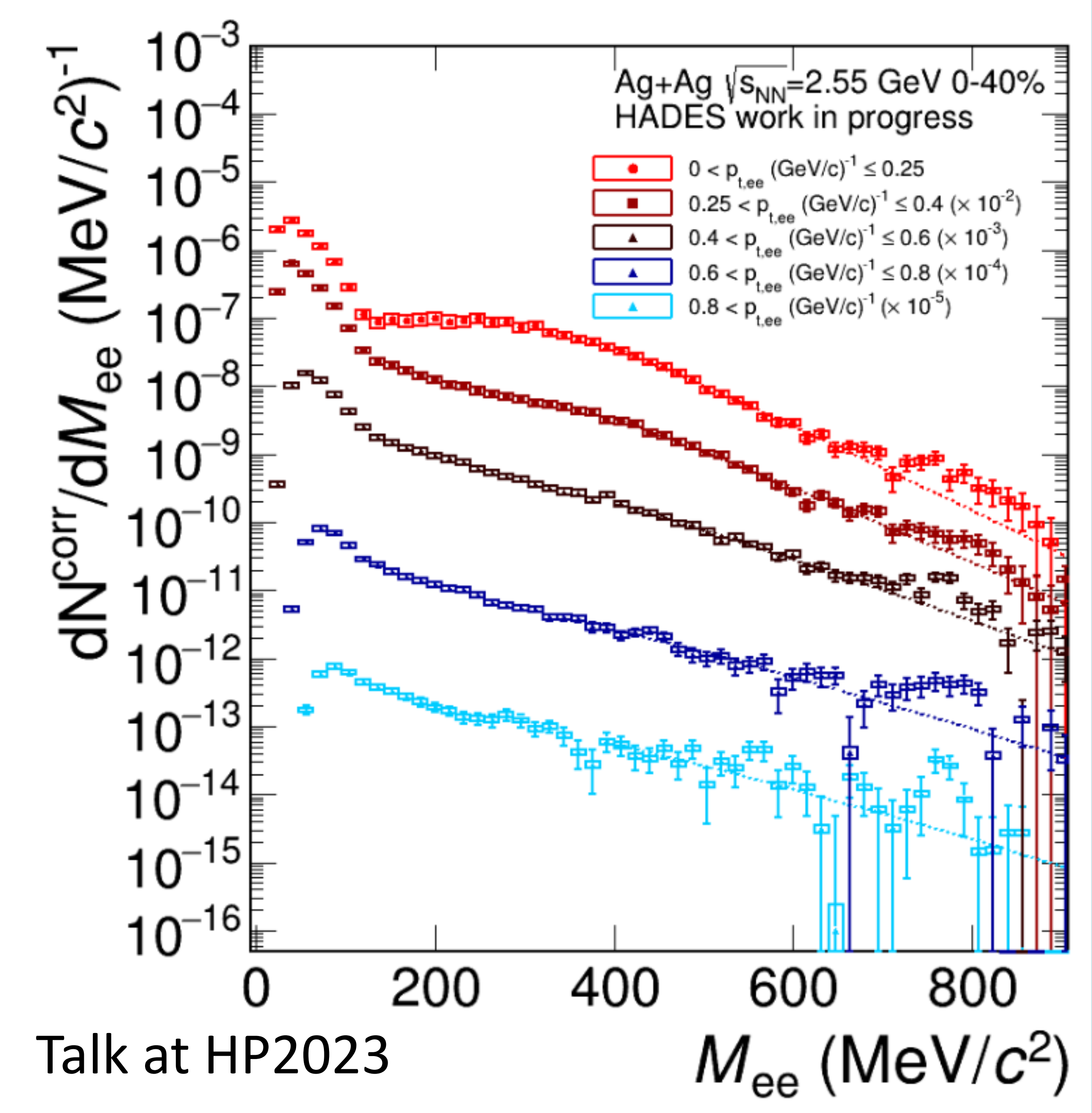

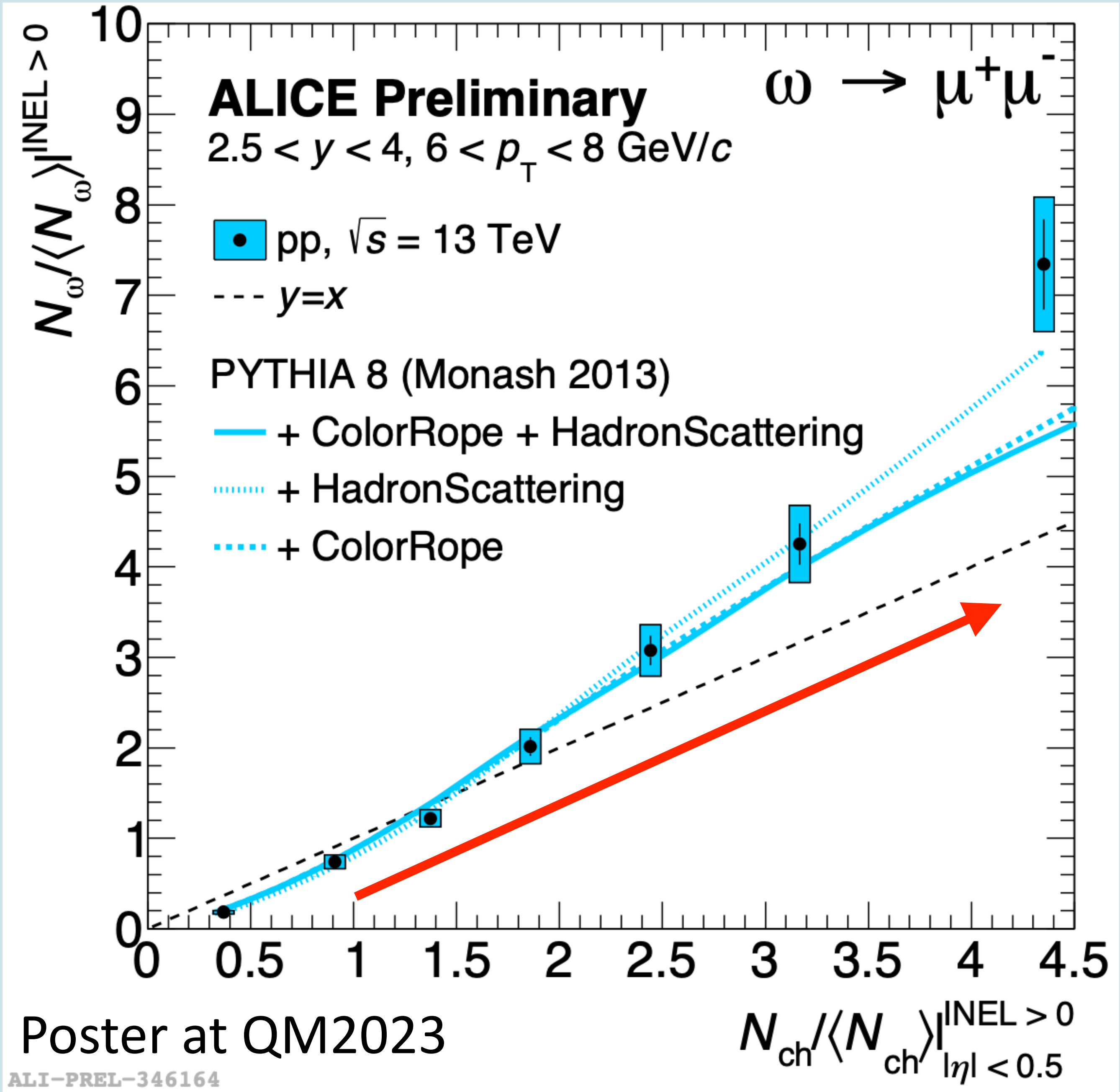

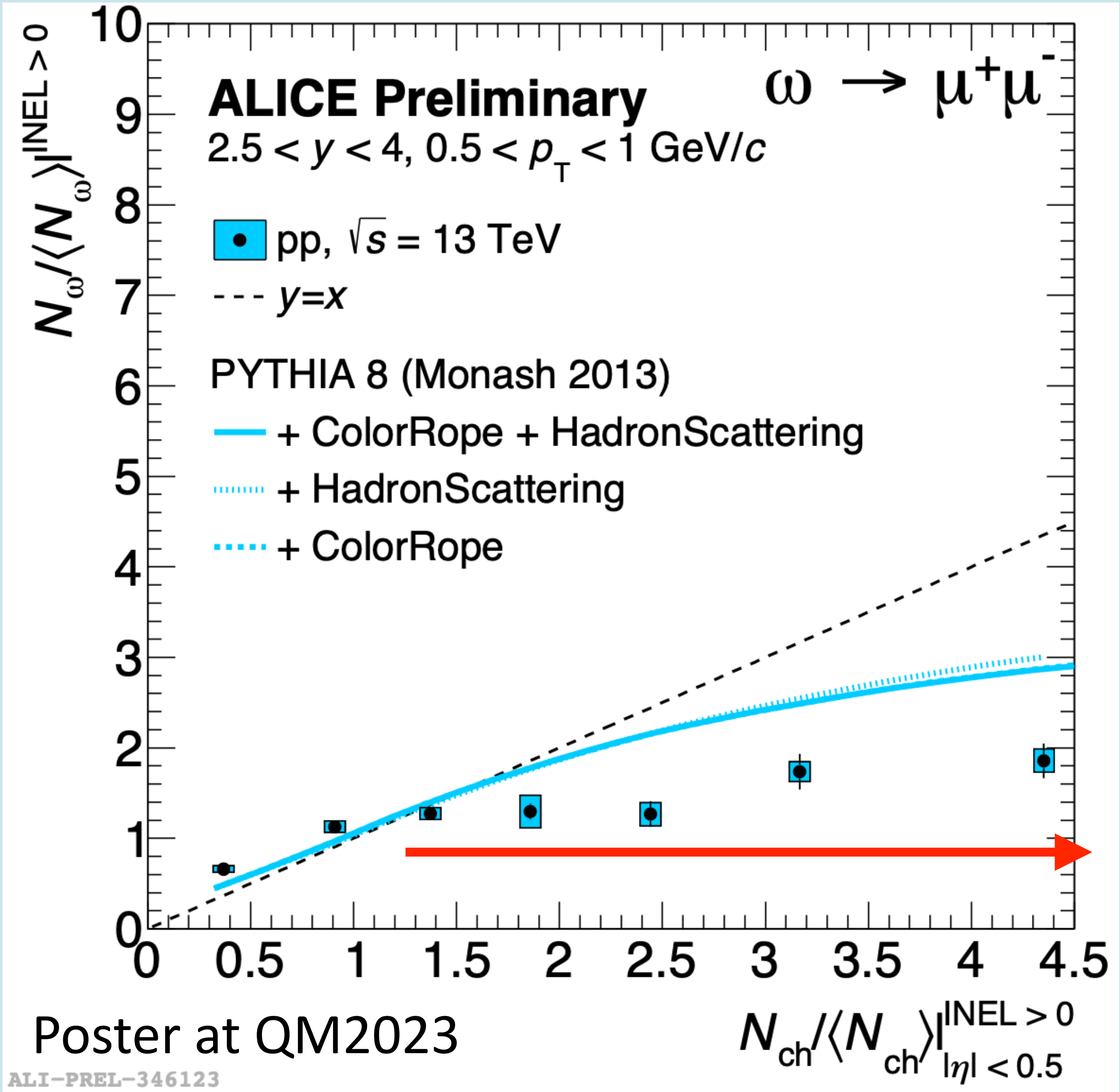

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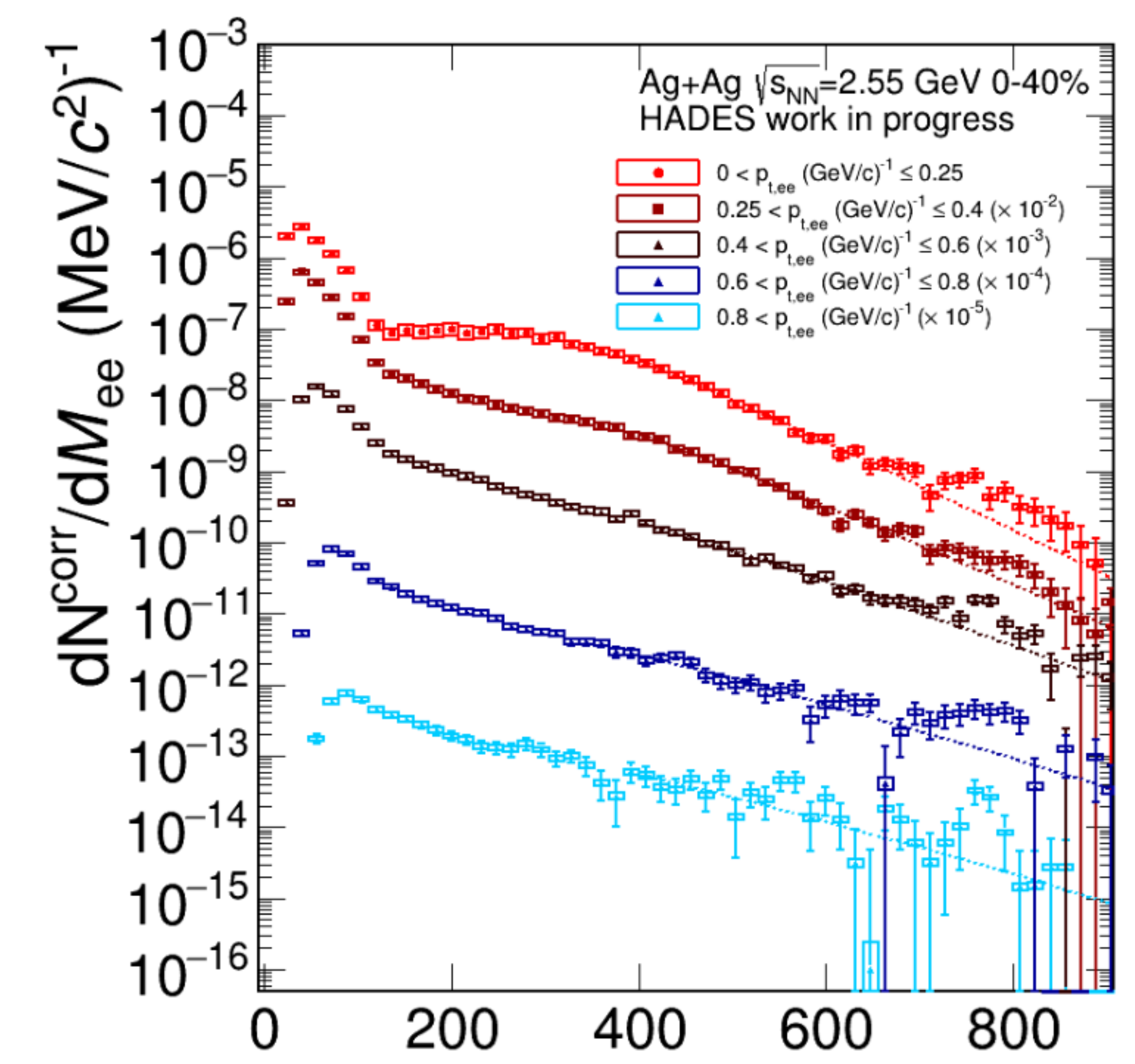

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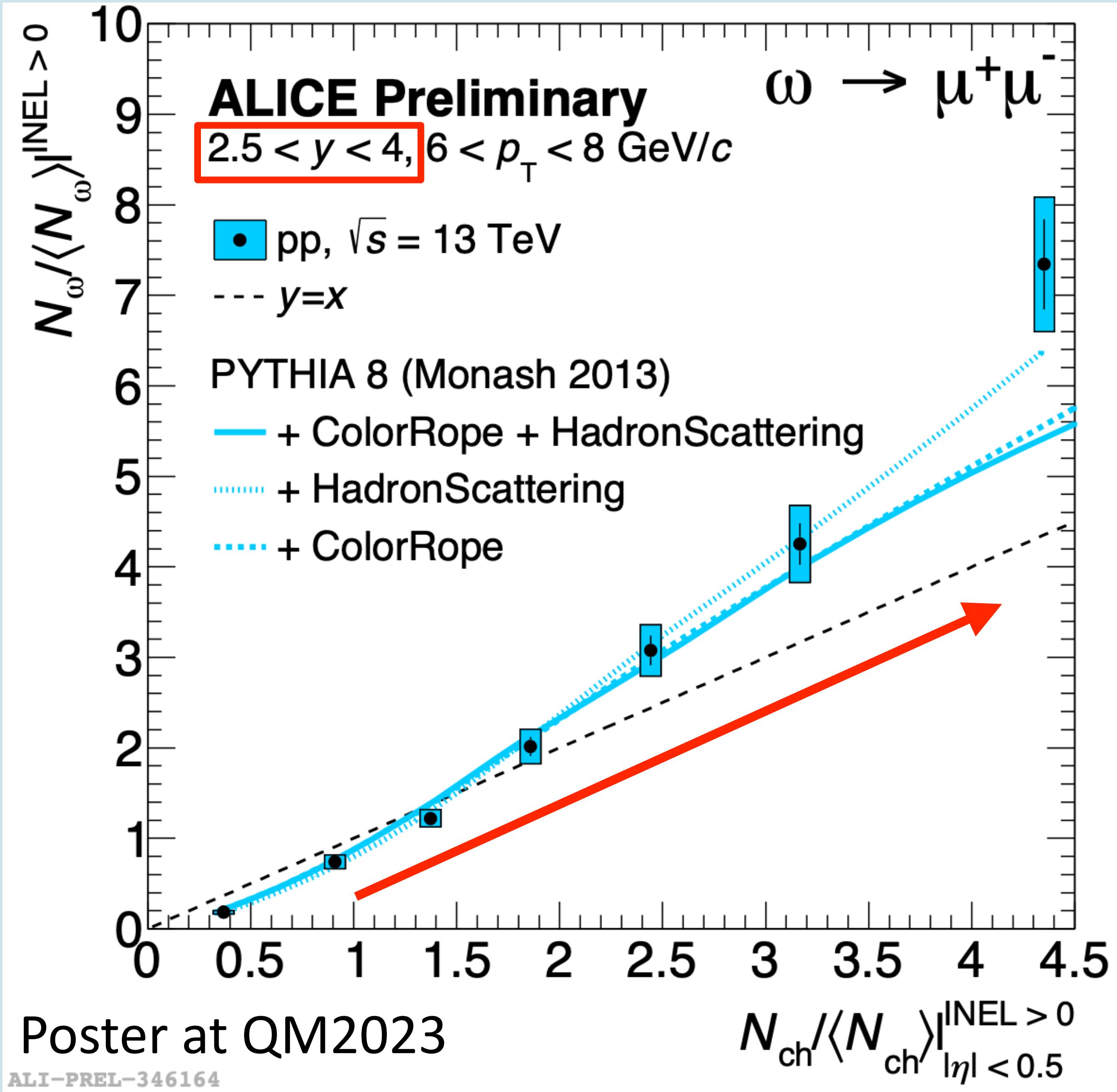
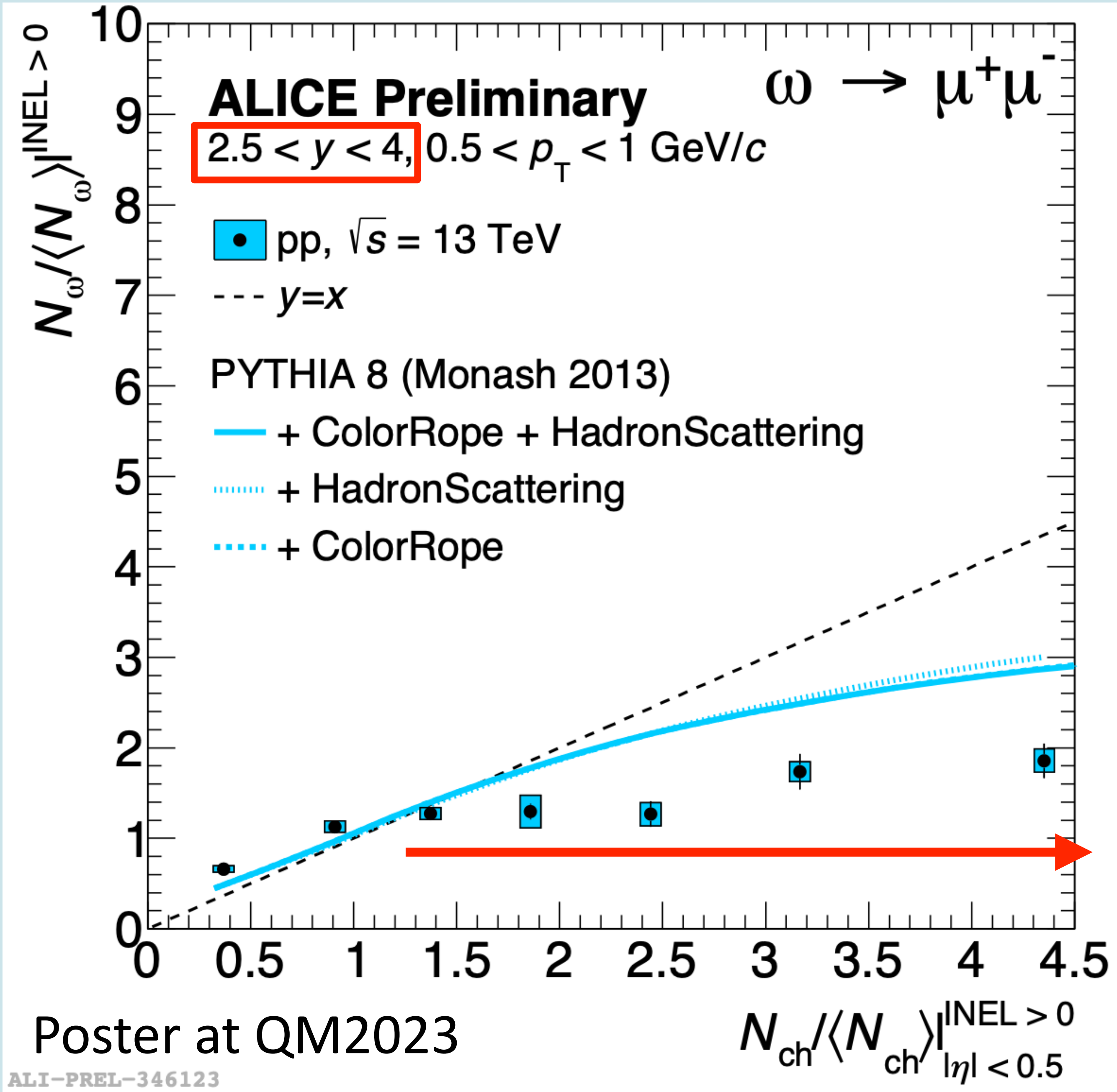


Poster at QM2023



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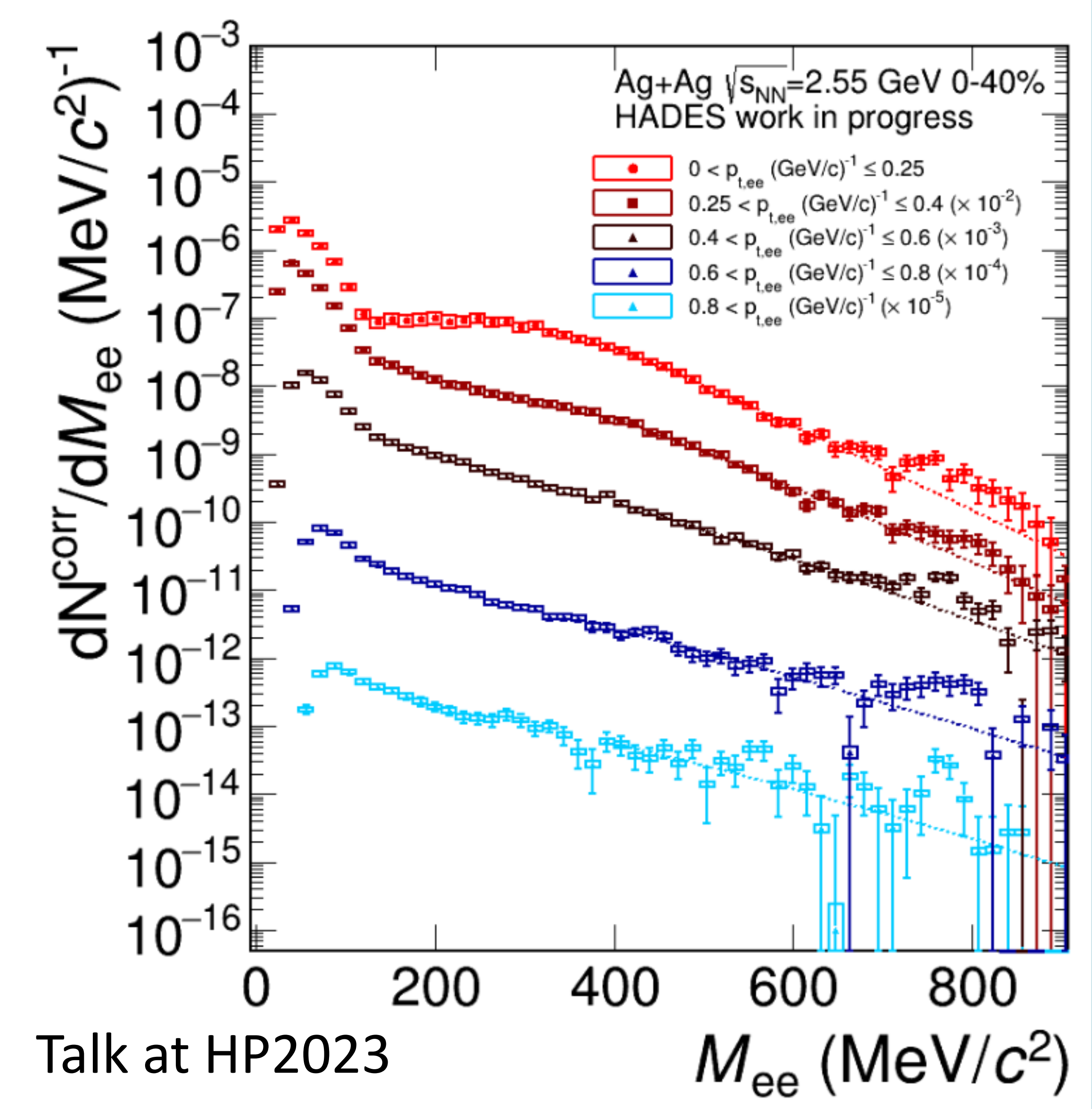

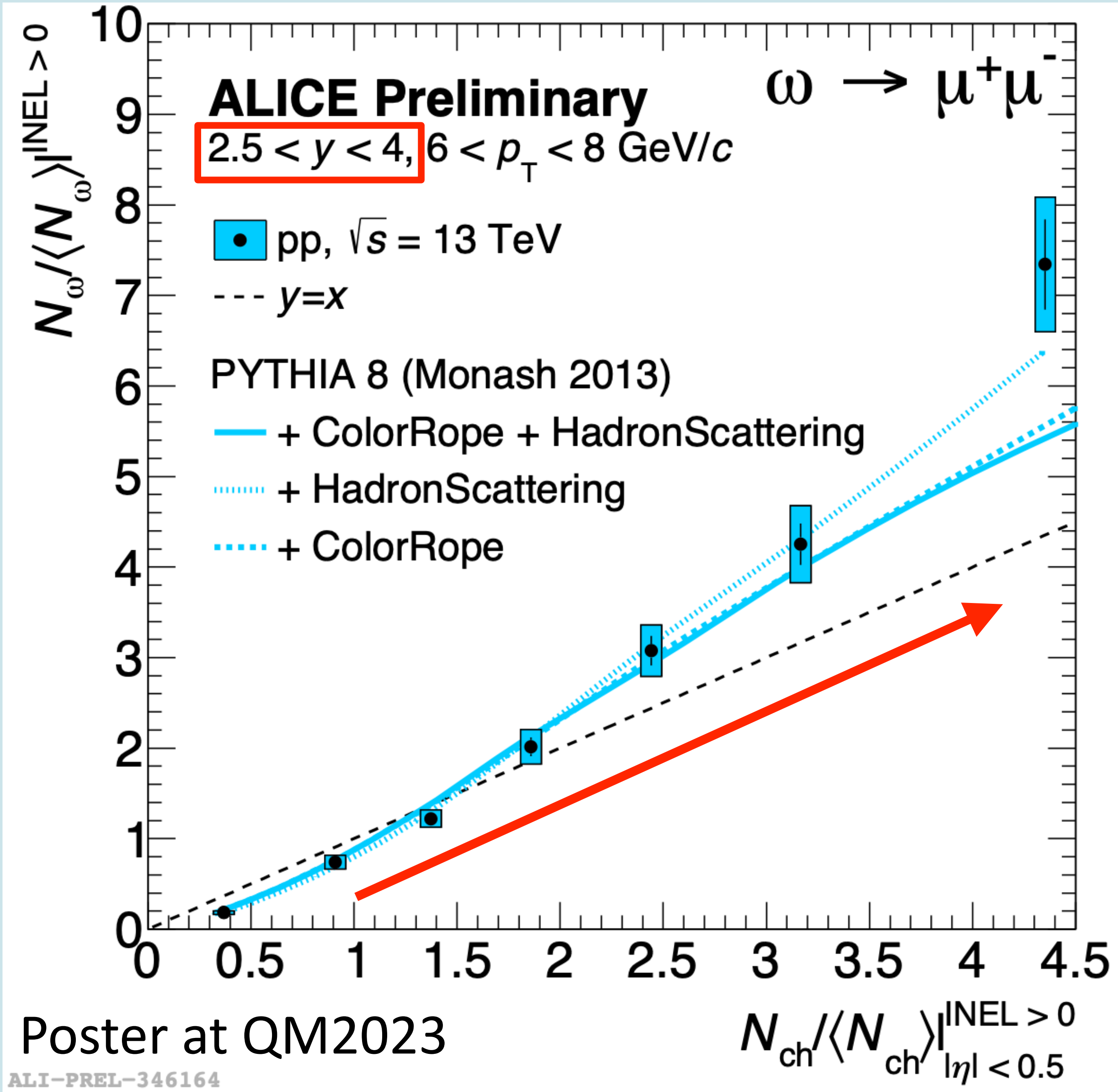

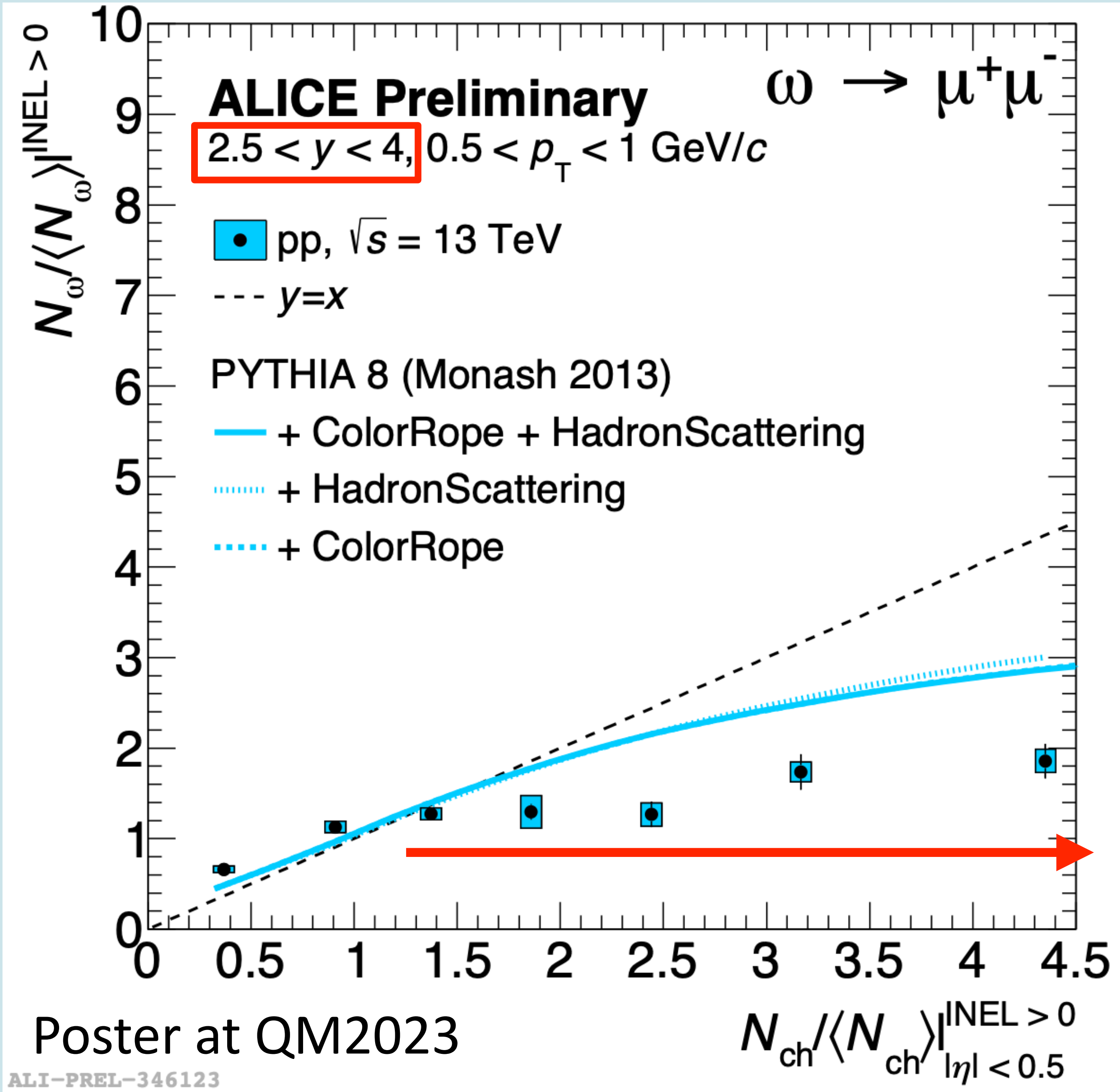

Same phenomenon in high multiplicity pp (forward) as in the high μ_B environment?
Look forwarding to updates from HADES

(My) summary

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  - Temperature measurement, space-time evolution, and chiral symmetry restoration

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  - New photon puzzle at early stage photon yield in real photon and virtual photon (dilepton)?
- There could be interesting relationships between low energy HIC and high multiplicity small system

Backup

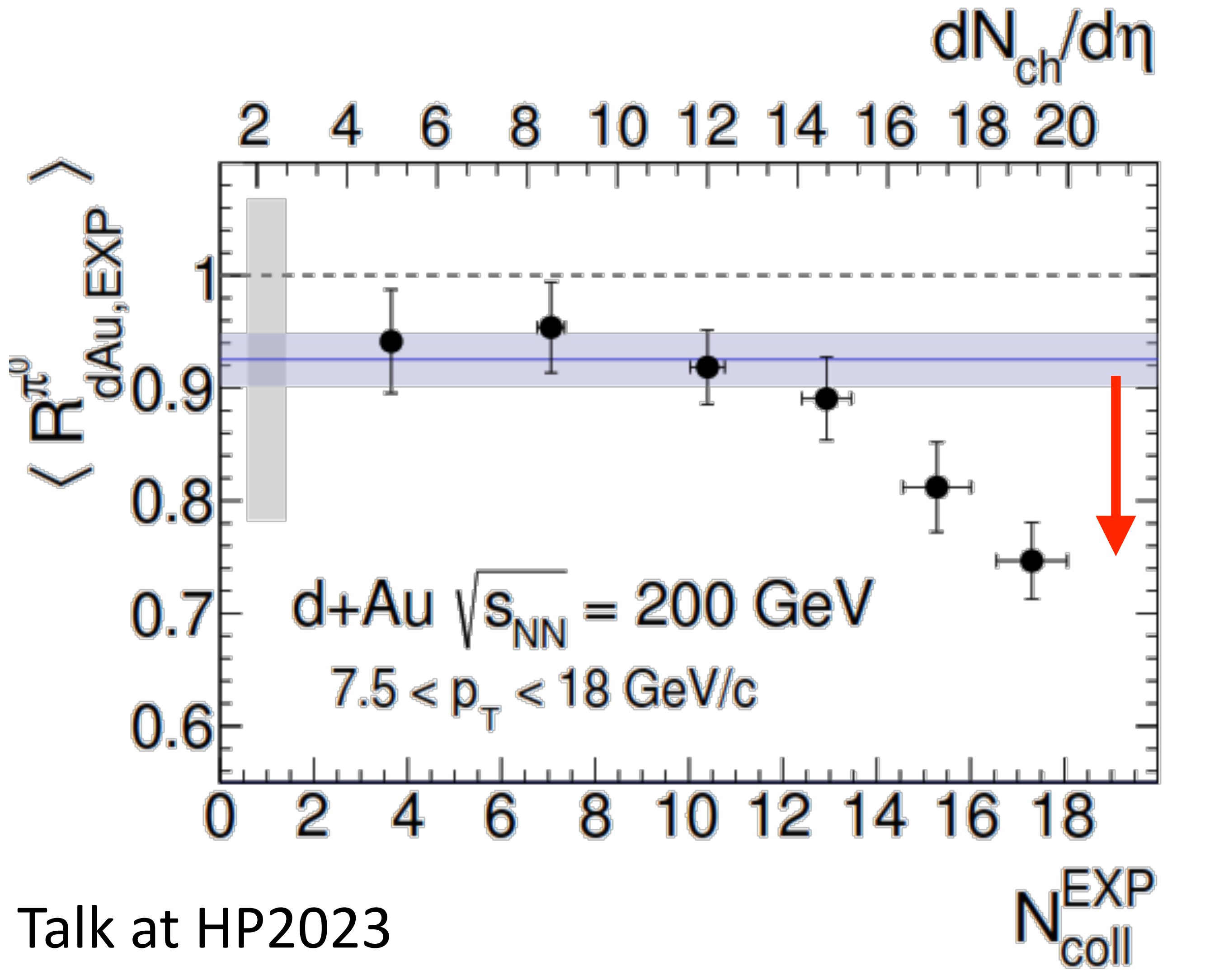
Event classification by prompt photon

- PHENIX has reported the existence of event selection bias with high p_T particles in d+Au collisions
- PHENIX has proposed a method to evaluate N_{coll} with direct γ data in each centrality

$$R^{\gamma}_{pA} = \frac{Y^{\gamma}_{pA}(p_T)}{< N_{coll} >_{Exp.}\ Y^{\gamma}_{pp}(p_T)} = 1 \quad \rightarrow \quad < N_{coll} >_{EXP} (p_T) = \frac{Y^{\gamma}_{pA}(p_T)}{Y^{\gamma}_{pp}(p_T)}$$

- 20% high p_T π^0 suppression has been observed with 4.5 σ significance in d+Au collisions at 200 GeV

- Study of system size dependence, p+Au, ^{3}He+Au, is mandatory



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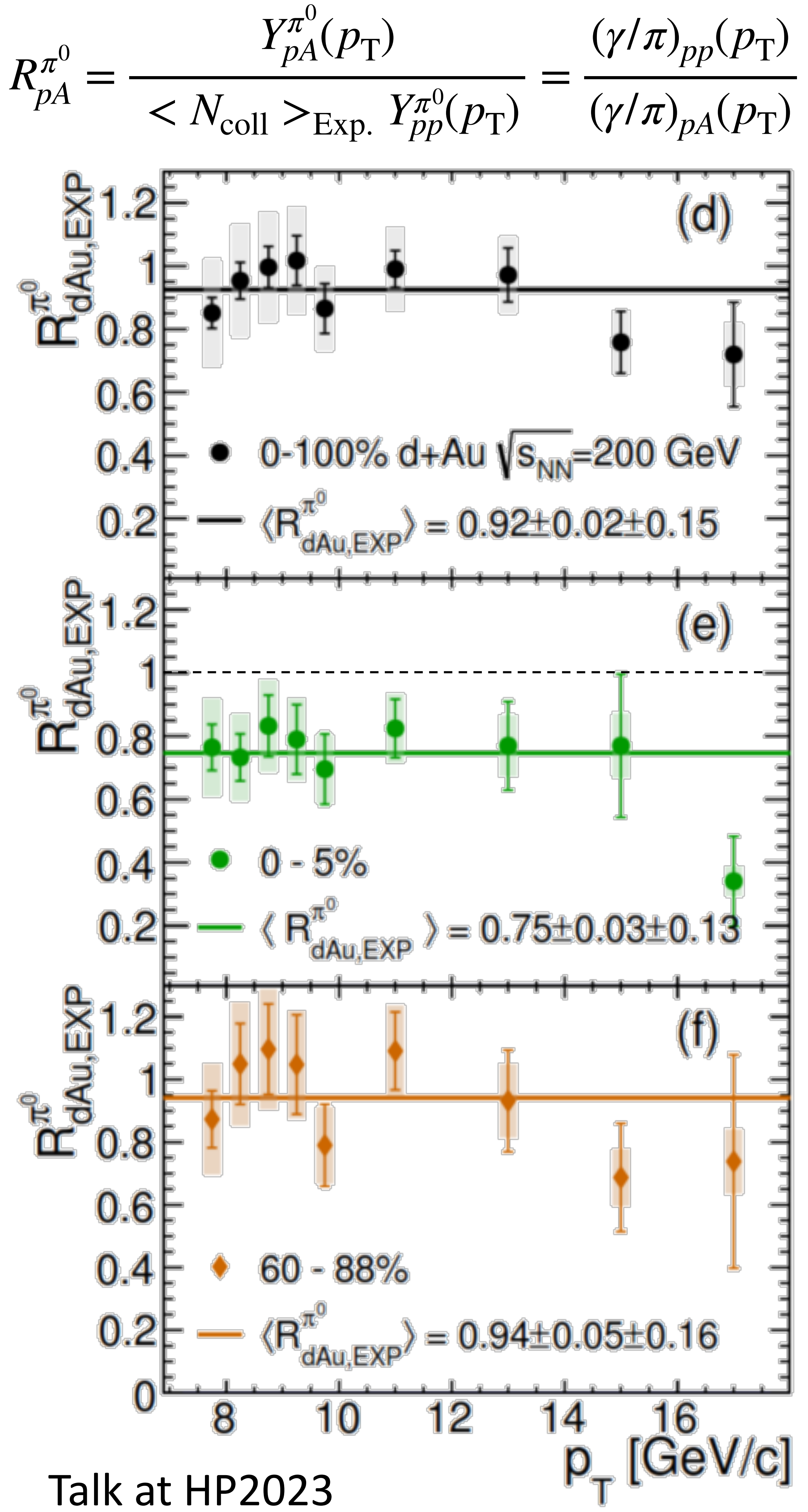

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Hydrodynamics + chiral mixing model

- The new model has been created with chiral mixing phenomena in the viscous hydrodynamics
- 3 scenarios have been demonstrated,