PHENIX overview

QGP – the fine print
or: is yesterday's calibration today's discovery?

Gabor David, SBU/BNL

Brookhaven™
National Laboratory

PHENIX – still many things to explore

Stopped data taking in 2016

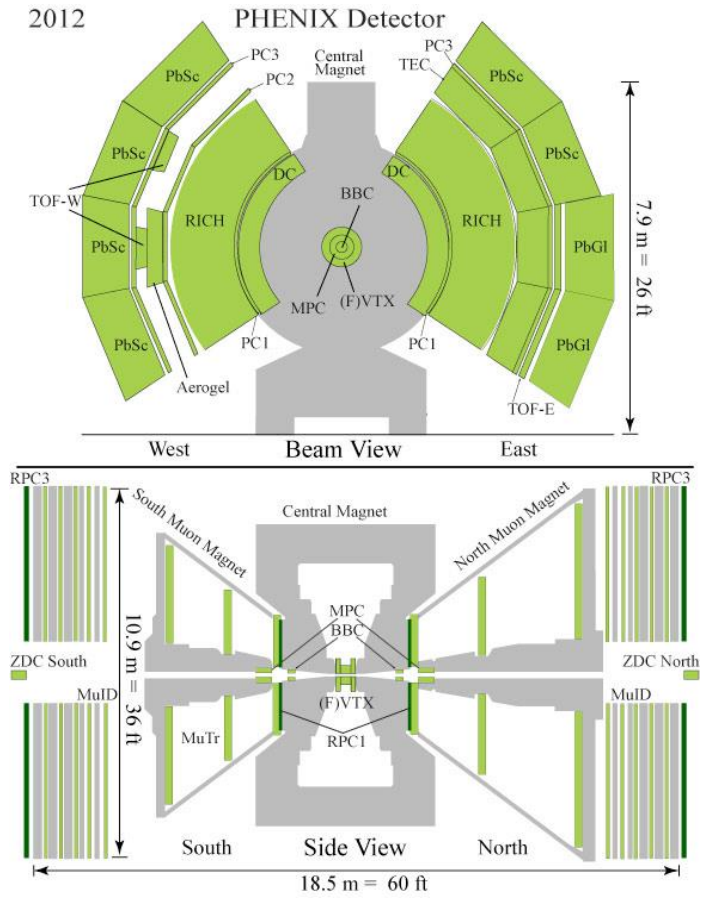
Some key ongoing or recently finished analyses:

c and b nuclear modification, flow
J/Ψ, Ψ(2S) nuclear modification and flow
high p_T direct photons in small systems
direct photons in large systems, including flow (archival, large dataset)
low p_T direct photons in small systems
direct photon – hadron correlations

p+p → some first-ever results, reference
x+A → ***small systems, currently maybe the most exciting***
A+A → "archival" papers based on the largest datasets, "photon puzzle"

Starting to ***read the "finer print"*** in heavy ion collisions

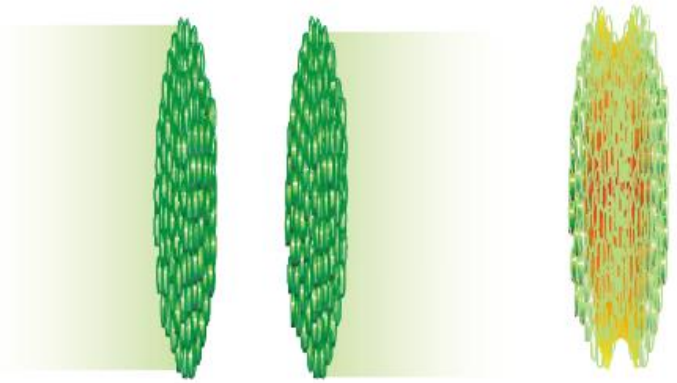
Data and Analysis Preservation – and we mean it!



Heavy ion collisions: the fine(r) print

nPDF?
Nucleon size?

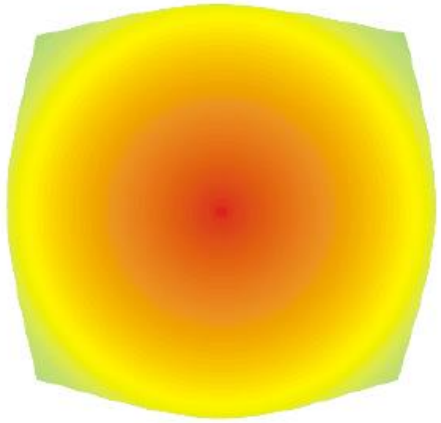
Initial State



MPI?
Preeq. photons?
N_{coll} bias?

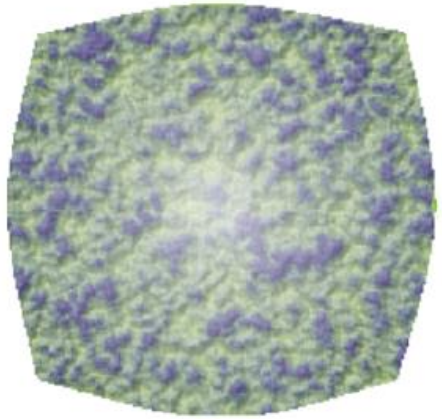
Incoming Nuclei

FS effects in p+A?
TSSA unchanged?
Scaling?

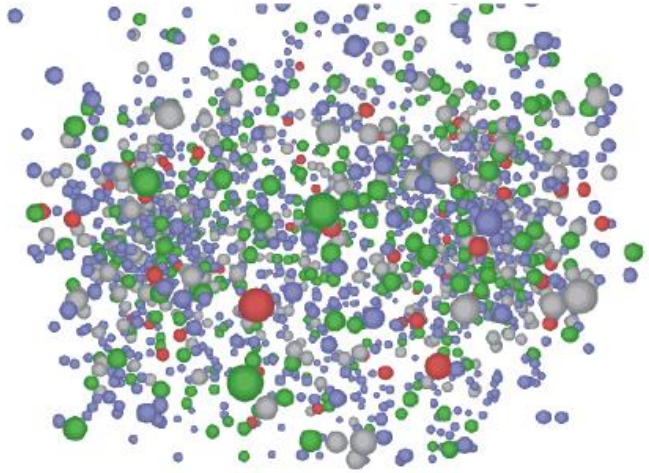


QGP

Hadronization



Recombination?



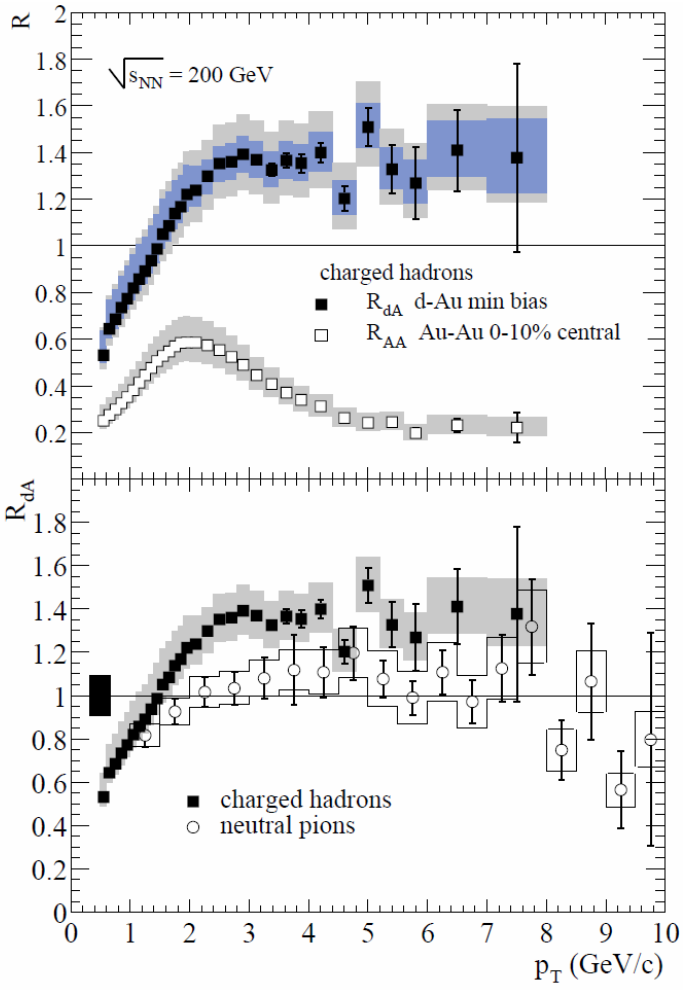
Freeze-out

Hydrodynamic expansion

Small systems: from “reference” to centerstage?

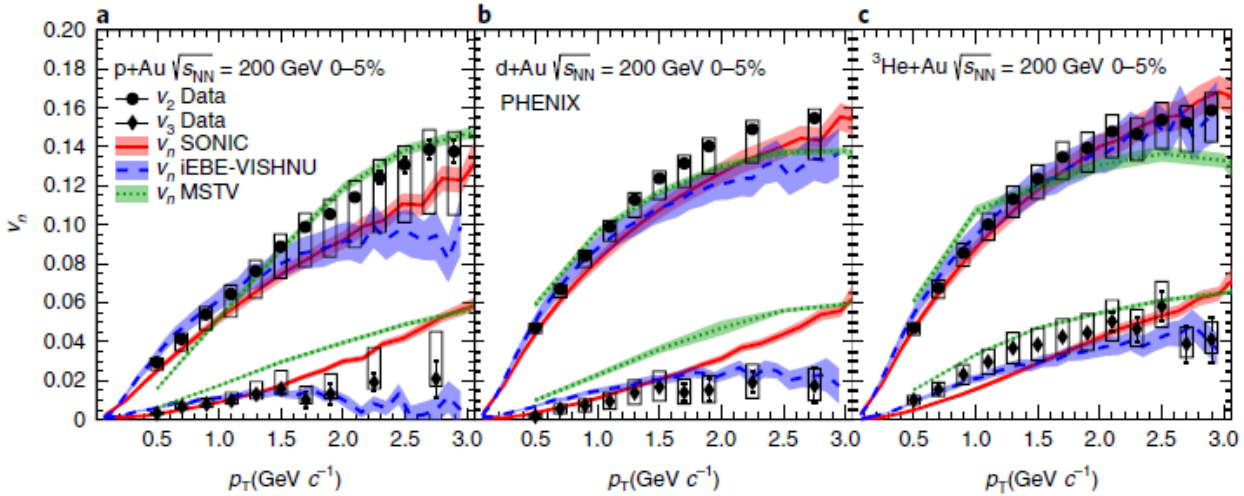
From…

PHENIX, PRL 91 (2003) 072303



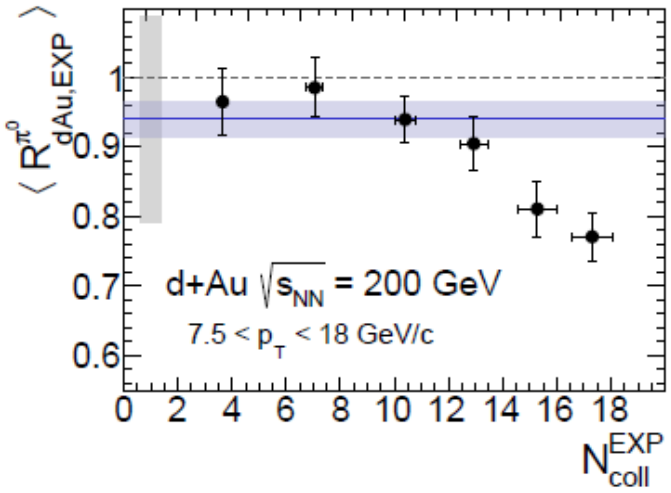
… to …

Nature Physics 15, (2019) 214-220



… and beyond..

arXiv:2303.12899



For details: Axel Drees, Tue March 28, 16:30

Small systems anisotropies cross-check

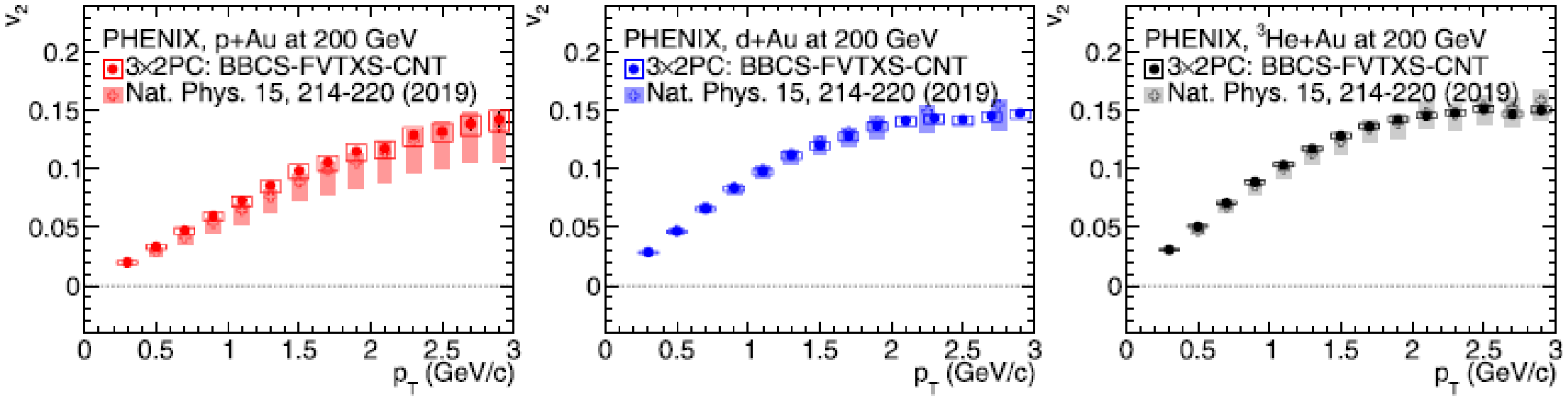
p+Au

d+Au

^{3}He+Au

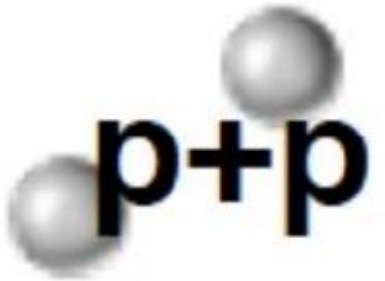
Nature Physics 2019:
found significant v_2, v_3 in small systems
Evidence for QGP droplets even is small system collisions

PRC 105, 024901 (2022)



Re-analyzing the data using 2-particle correlations
and different combinations of 3 subdetectors
→ earlier results confirmed
Differences for different subdetector-combinations,
but clean signal for all of them (η-dependence of v_2?)

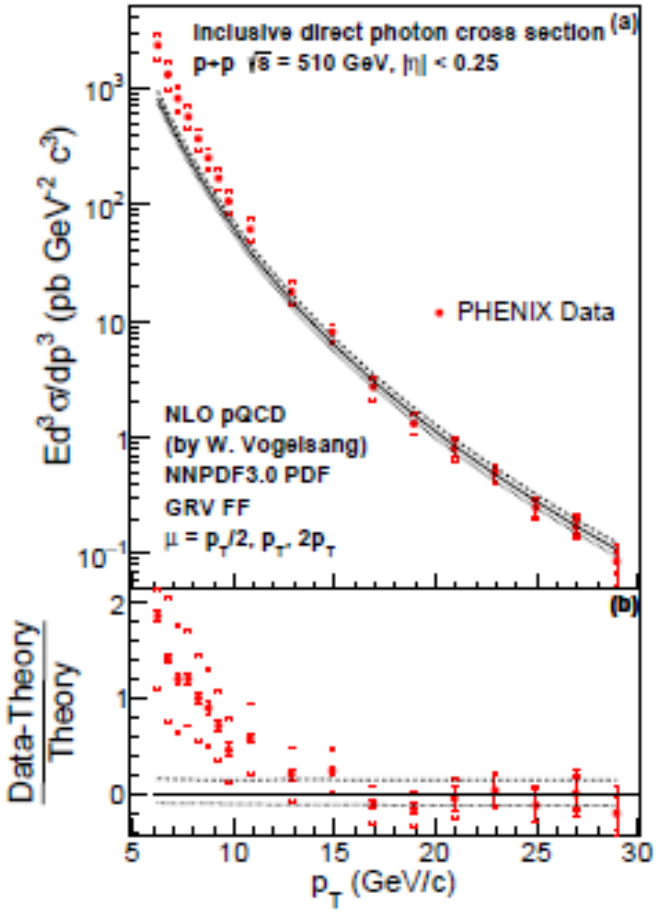
Nature Physics result confirmed
Other signs of QGP?


p+p

Direct photon cross sections, A_{LL}, p+p 510 GeV

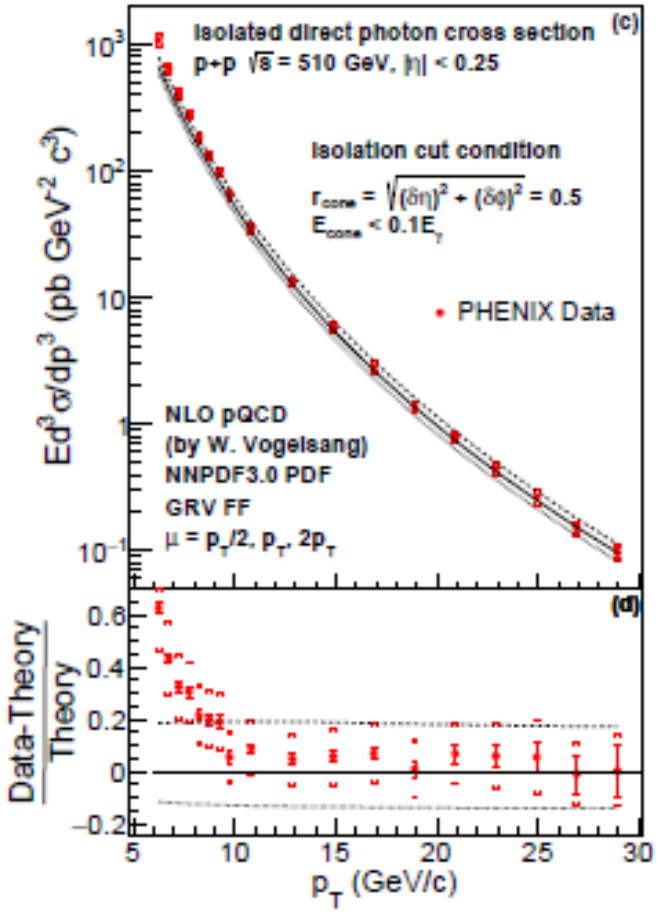
arXiv: 2202.08159

Inclusive



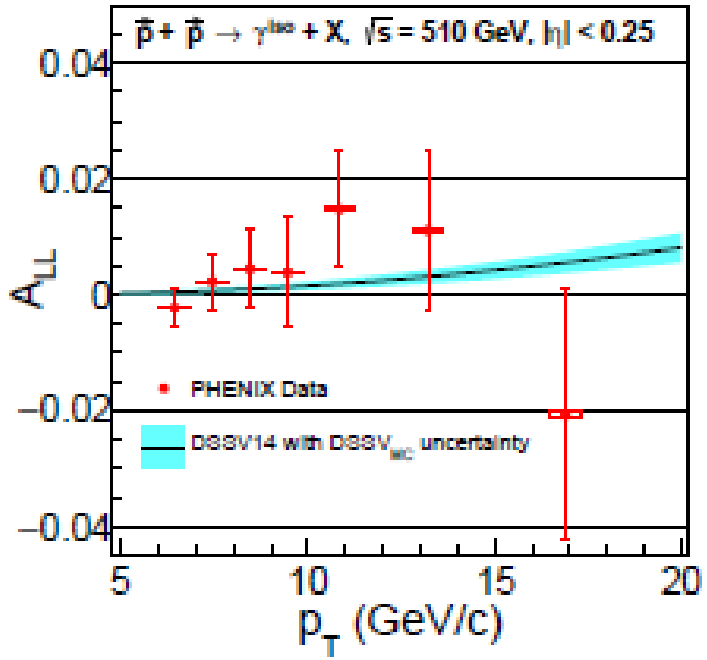
Large excess below 12 GeV/c
MPI? Parton showers?

Isolated



Still missing something at low p_T?

Double helicity asymmetry isolated direct photons

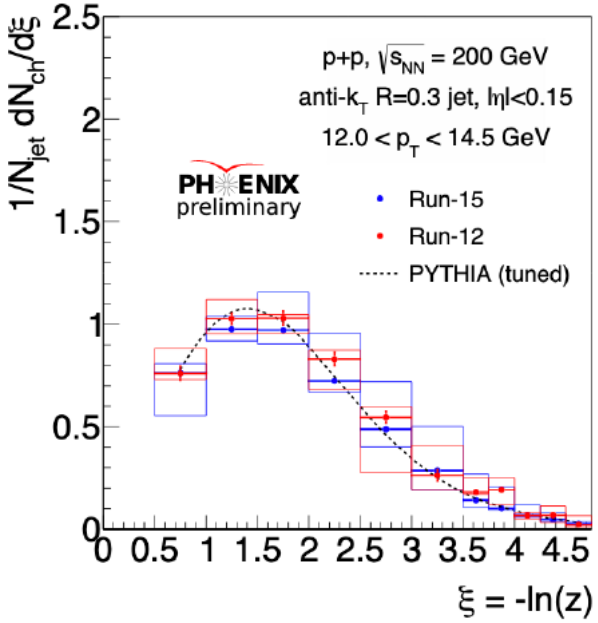


Dominated by qg → qγ
Sensitive to polarized gluon distribution

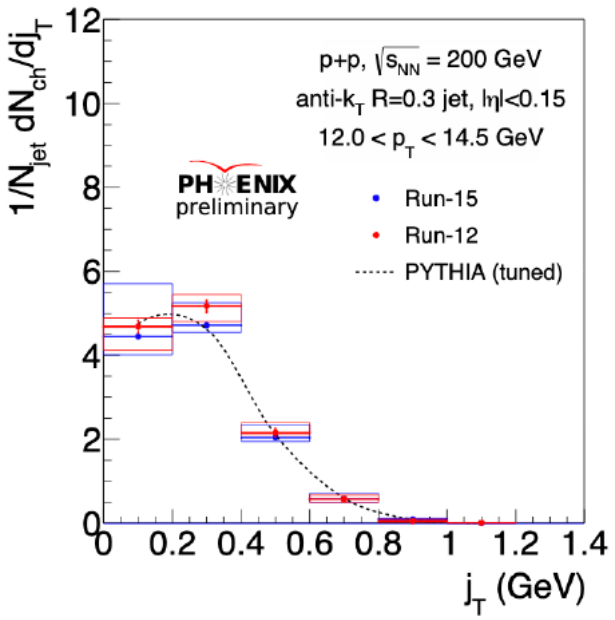
Jet substructure in p+p

p+p

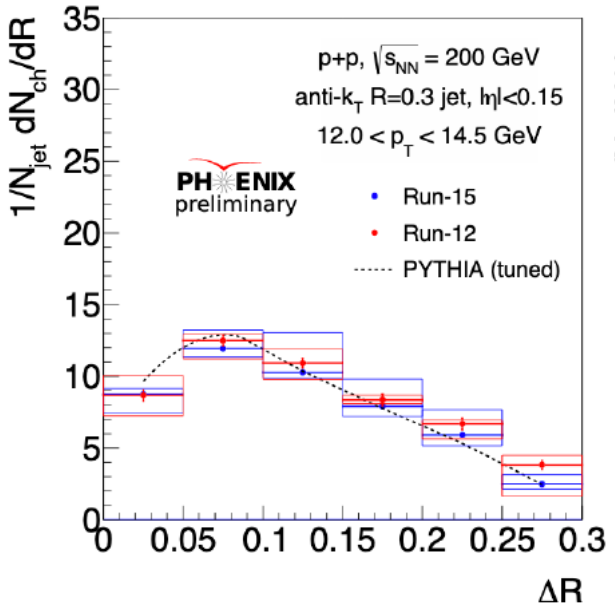
Fragmentation Function



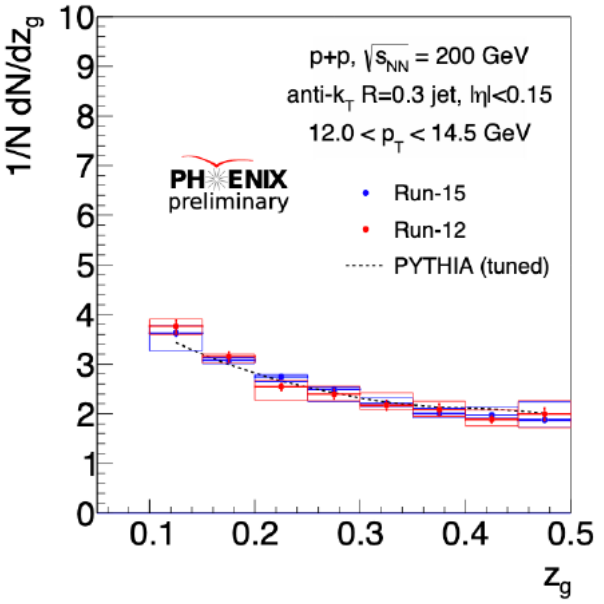
Transverse fragmentation



Radial profile



Jet splitting function



Z_g is consistent with published STAR result (PLB 811 (2020) 135846)

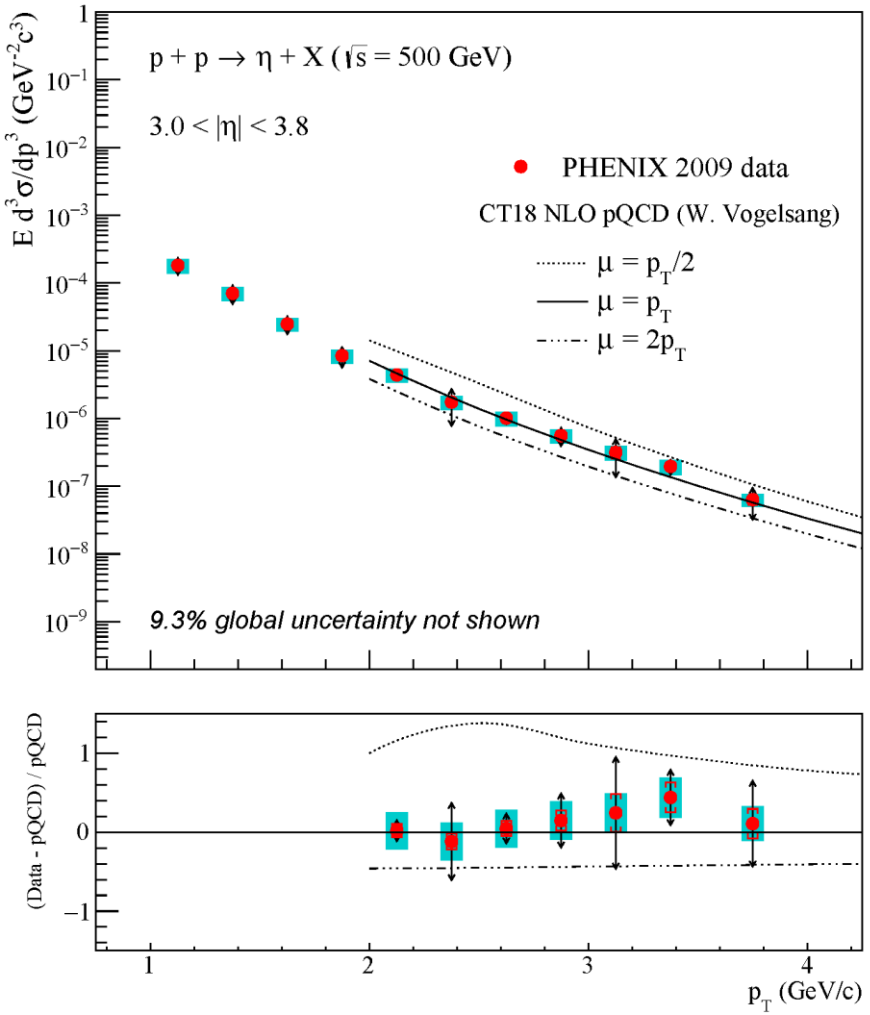
Baseline for ongoing analysis in p+Au

For details and more jet results including d+Au:
Julia Velkovska, March 29, 17:10

All quiet on the p+p front (?)

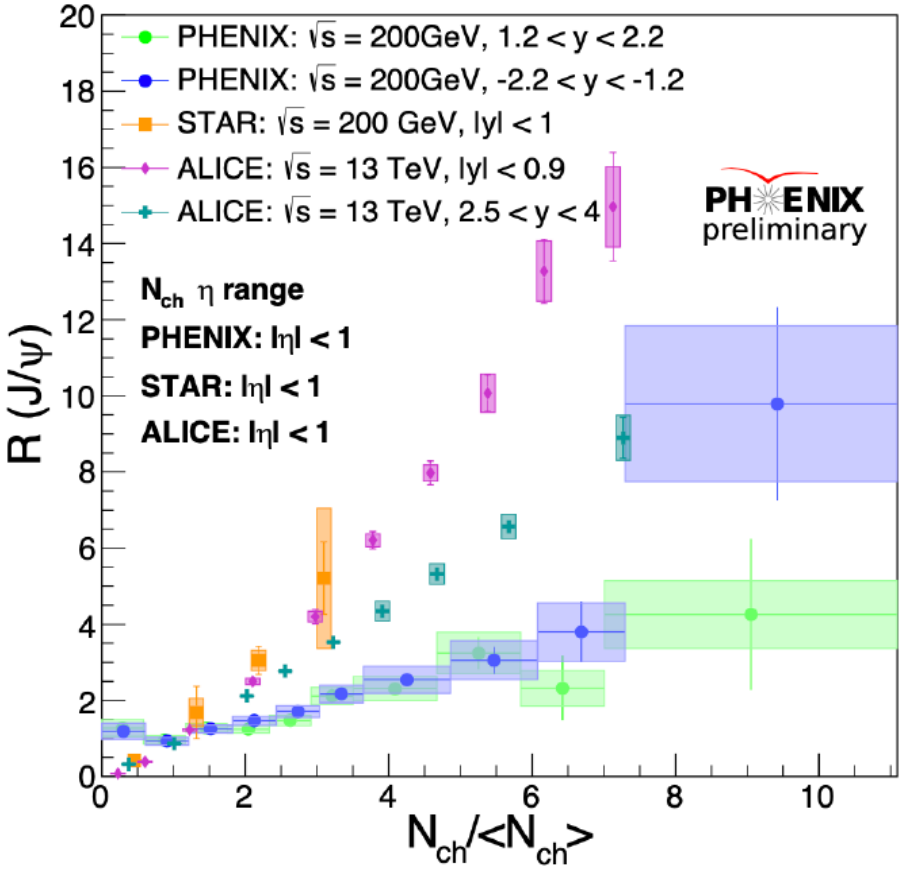
p+p

First measurement of forward
η production in 500 GeV p+p
Cross section agrees with NLO pQCD



J/Ψ / <J/Ψ> vs N_{ch} / <N_{ch}>

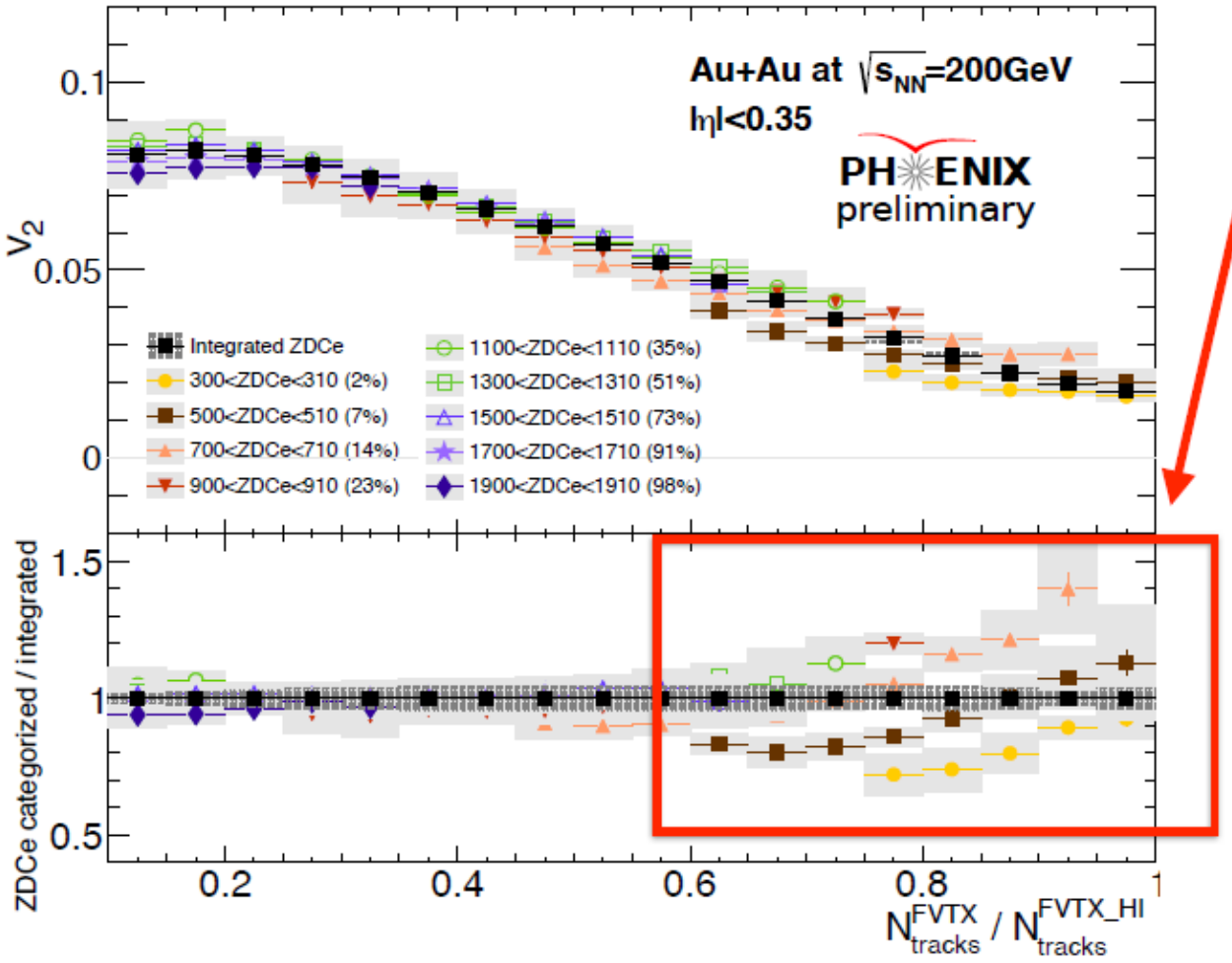
Important:
where is N_{ch} measured?
are J/Ψ tracks counted in N_{ch}?




Cu+Au
Au+Au

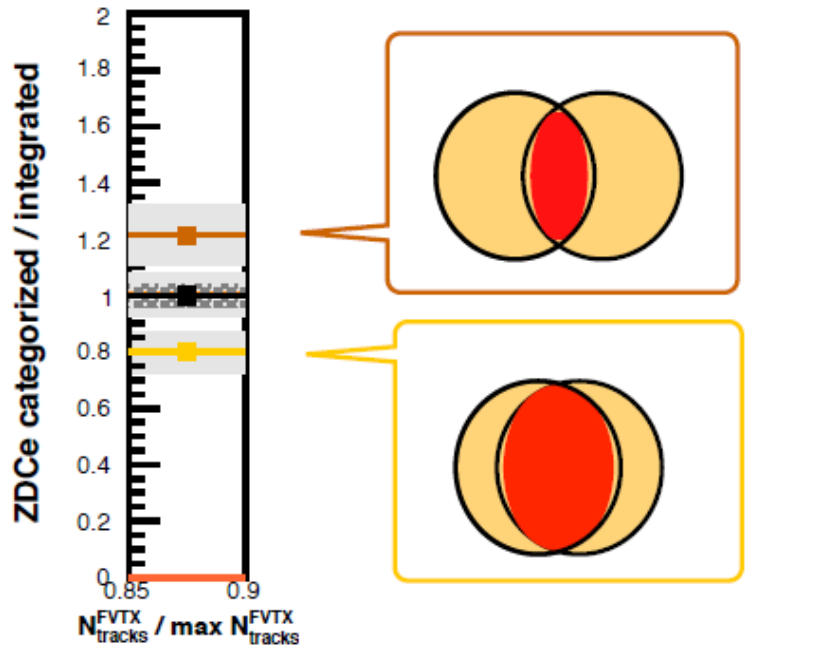
Event characterization – ambiguities even in Au+Au (?)

Central arm v_2 as a function of forward multiplicity and zero degree activity



Same multiplicity class (FVTX), different ZDC energy class → different N_{part}, event geometry

Image of the initial geometry



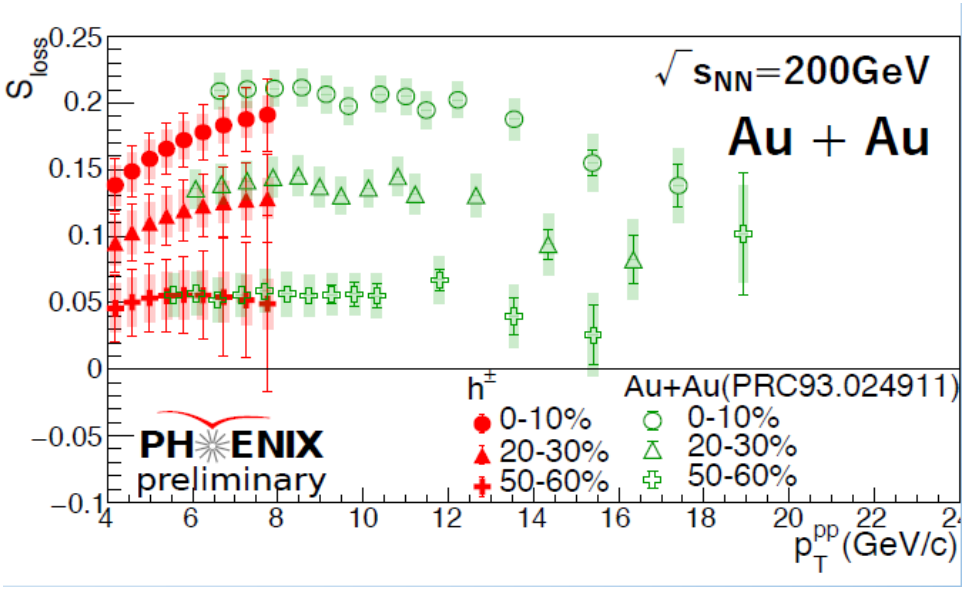
Hints of MPI in extreme events?

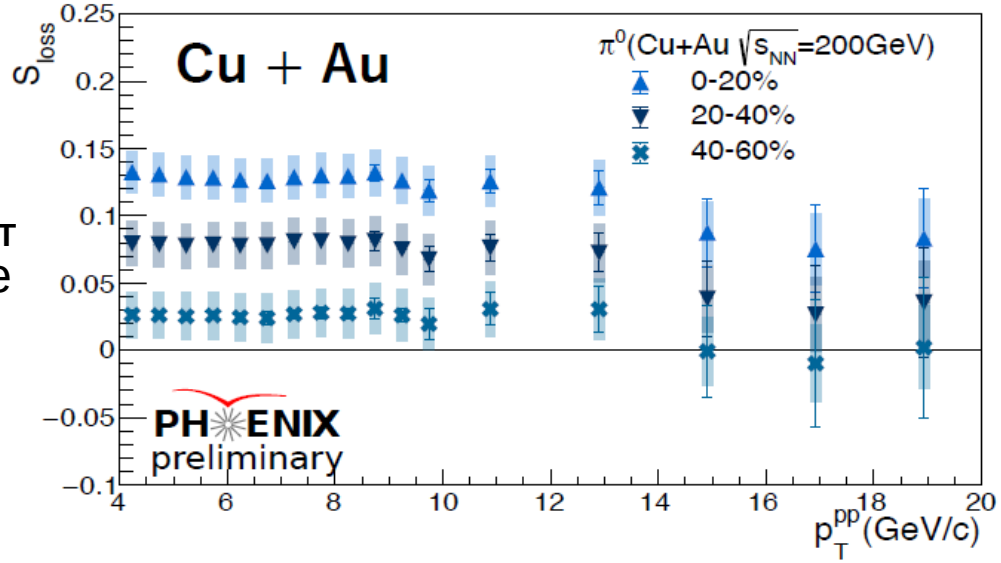
Charged hadron S_{loss} vs reaction plane in A+B

π^0 and h similar

π^0 only
No strong p_T dependence

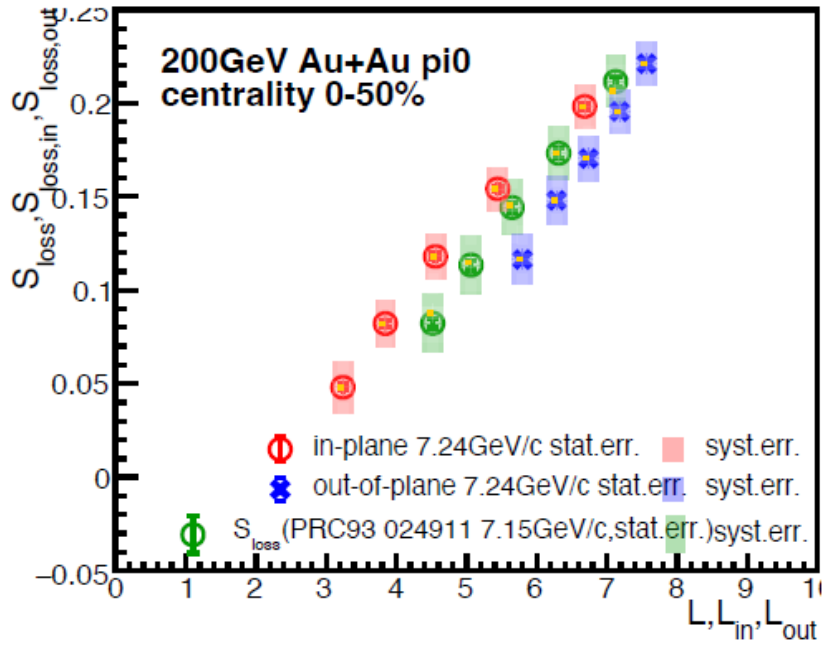
ϕ-integrated





$$S_{\rm loss} \equiv \delta p_T / p_T = \frac{p_T^{pp} - p_T^{AA}}{p_T^{pp}}$$

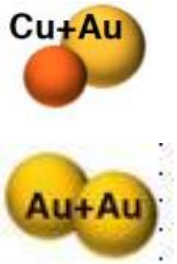
ϕ-differential (in-plane, out-of-plane)

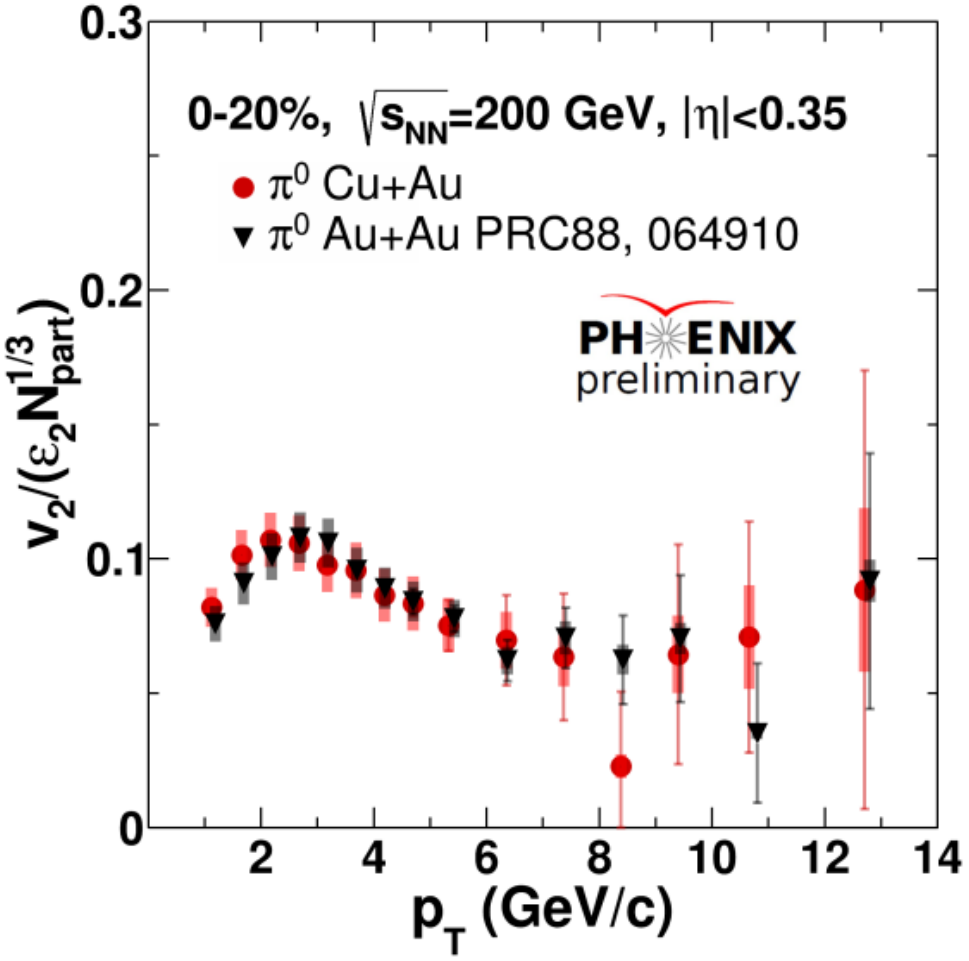


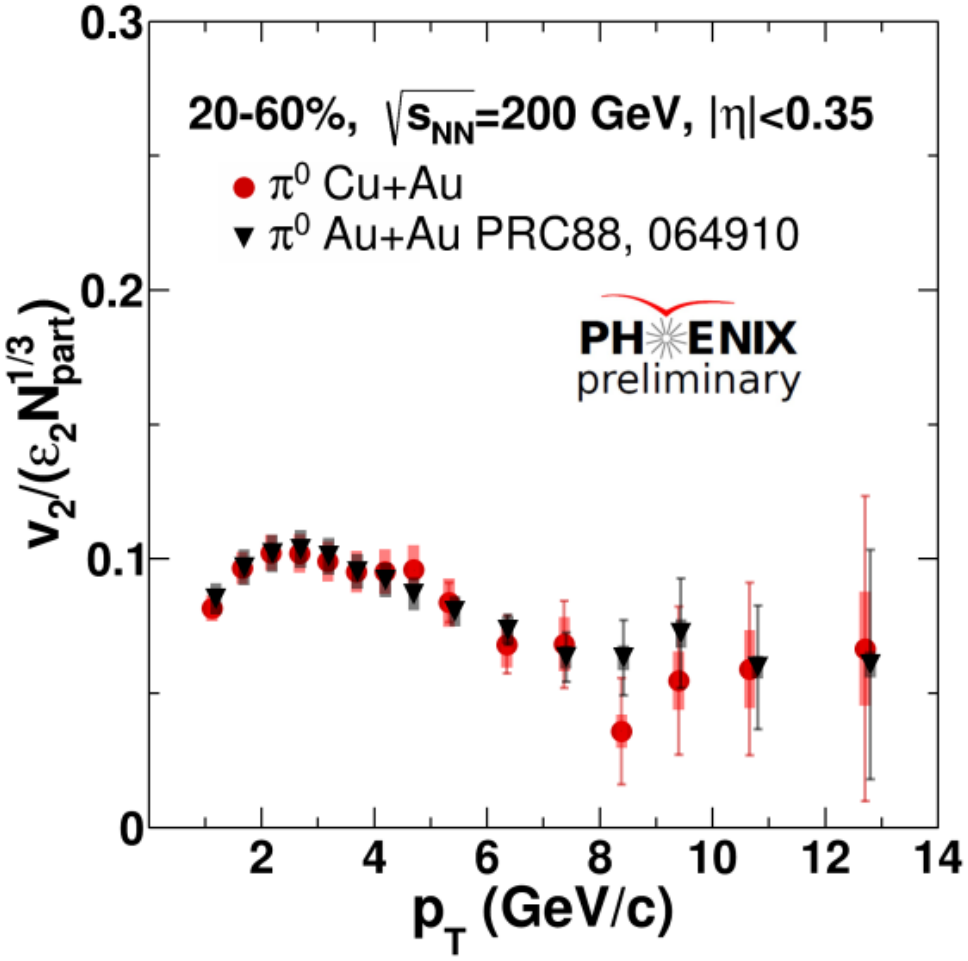
Different values and evolution with L in-plane and out-of-plane

For details: Maya Shimomura, Tue March 28, 16:50

π^0 flow in Cu+Au vs Au+Au





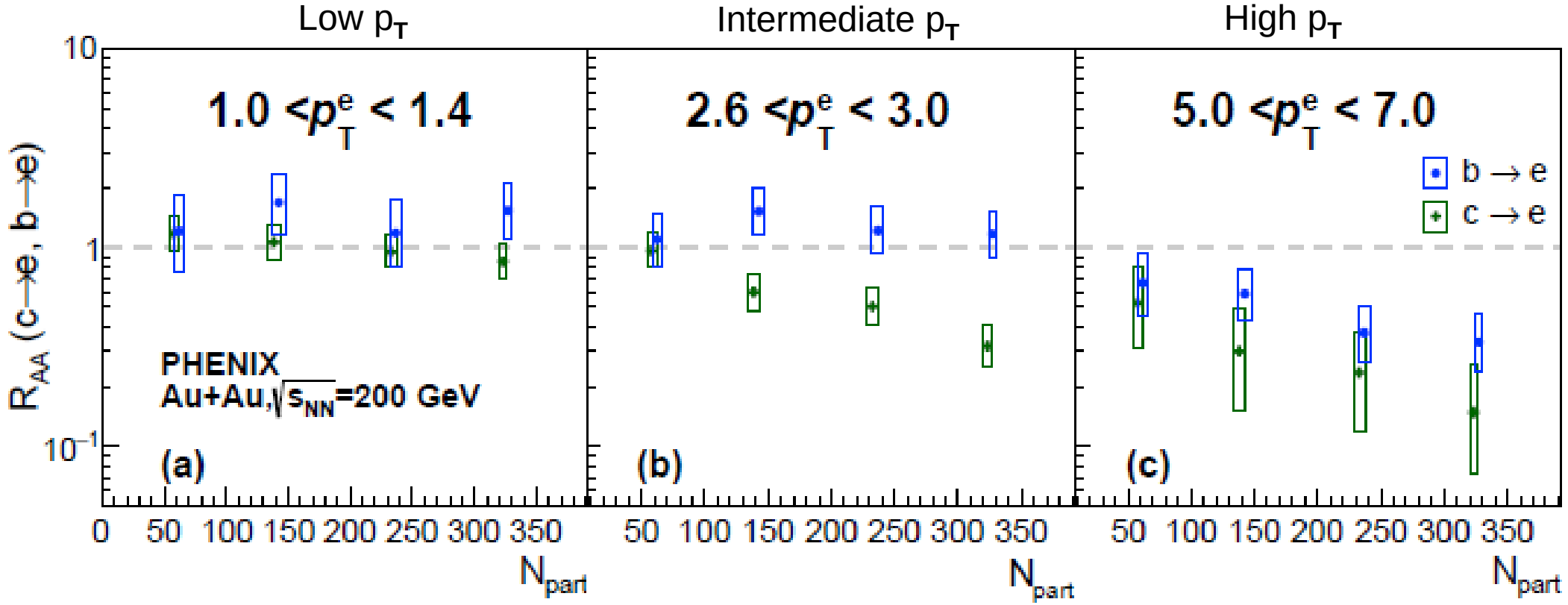


v_2 scales with eccentricity * system size (ε_2 * $(N_{part})^{1/3}$) even at high p_T, where this is not hydro…

Same ε_2 * $N_{part}^{1/3}$ scaling from soft to hard

Heavy flavor R_{AA} (charm vs bottom) vs N_{part}

arXiv:2203.17058

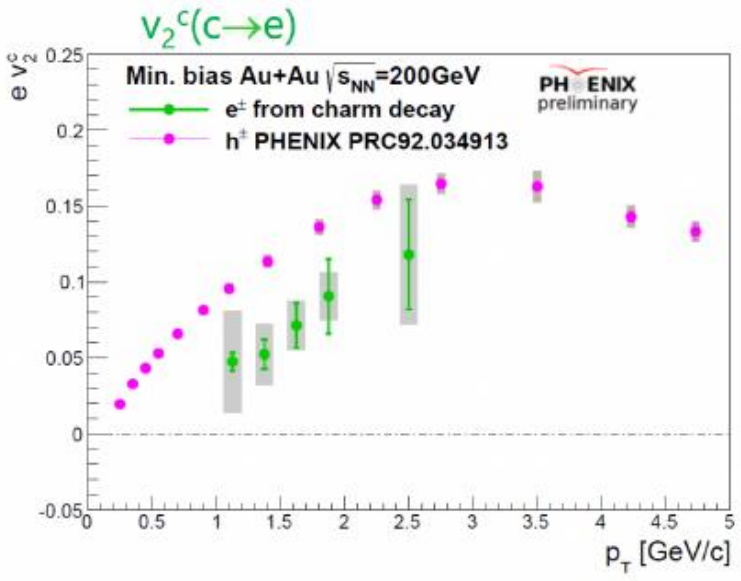


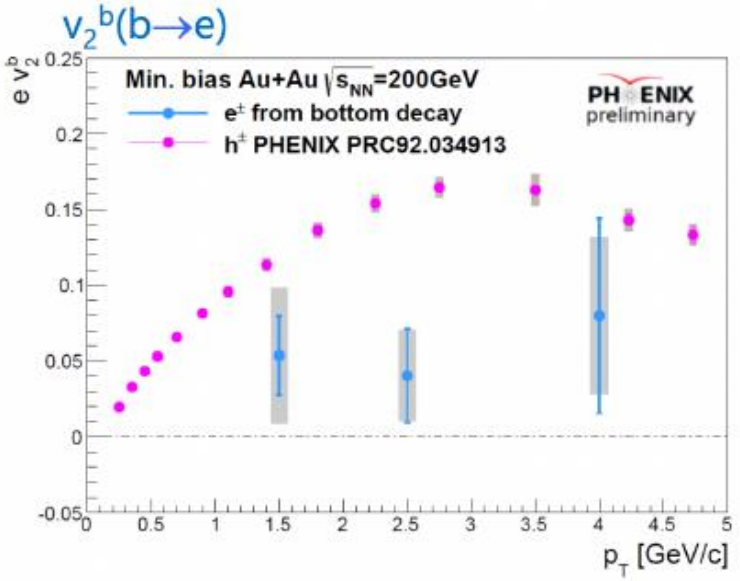
Suppression pattern very different at intermediate p_T

For details: Maya Shimomura, Tue March 28, 16:50

Heavy flavor flow

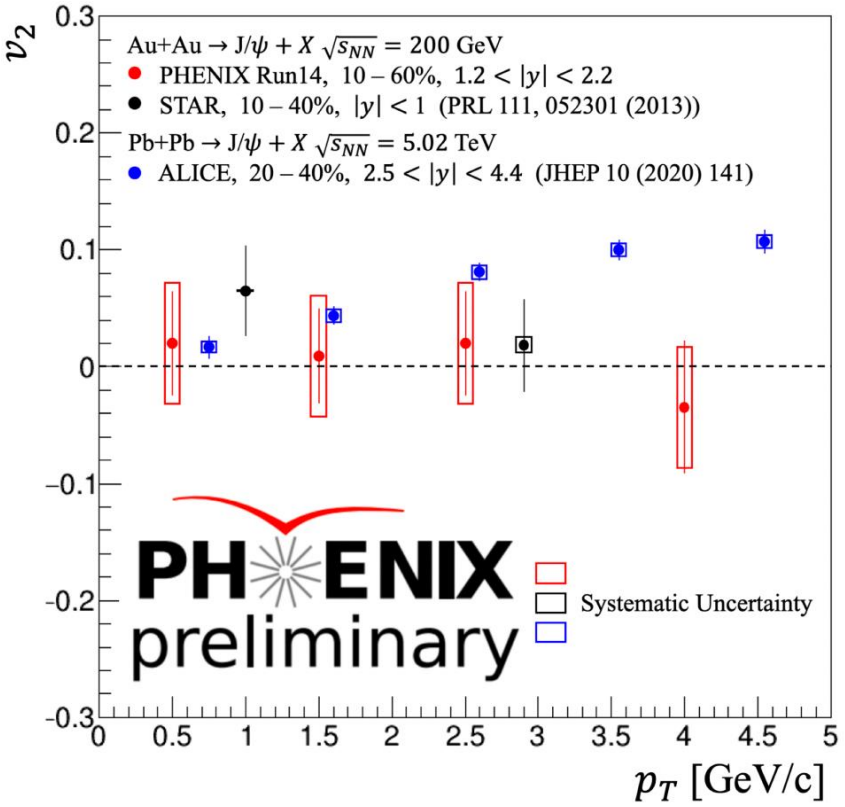
Charm and bottom at mid-rapidity





Charm follows the charged hadron trend (but smaller)

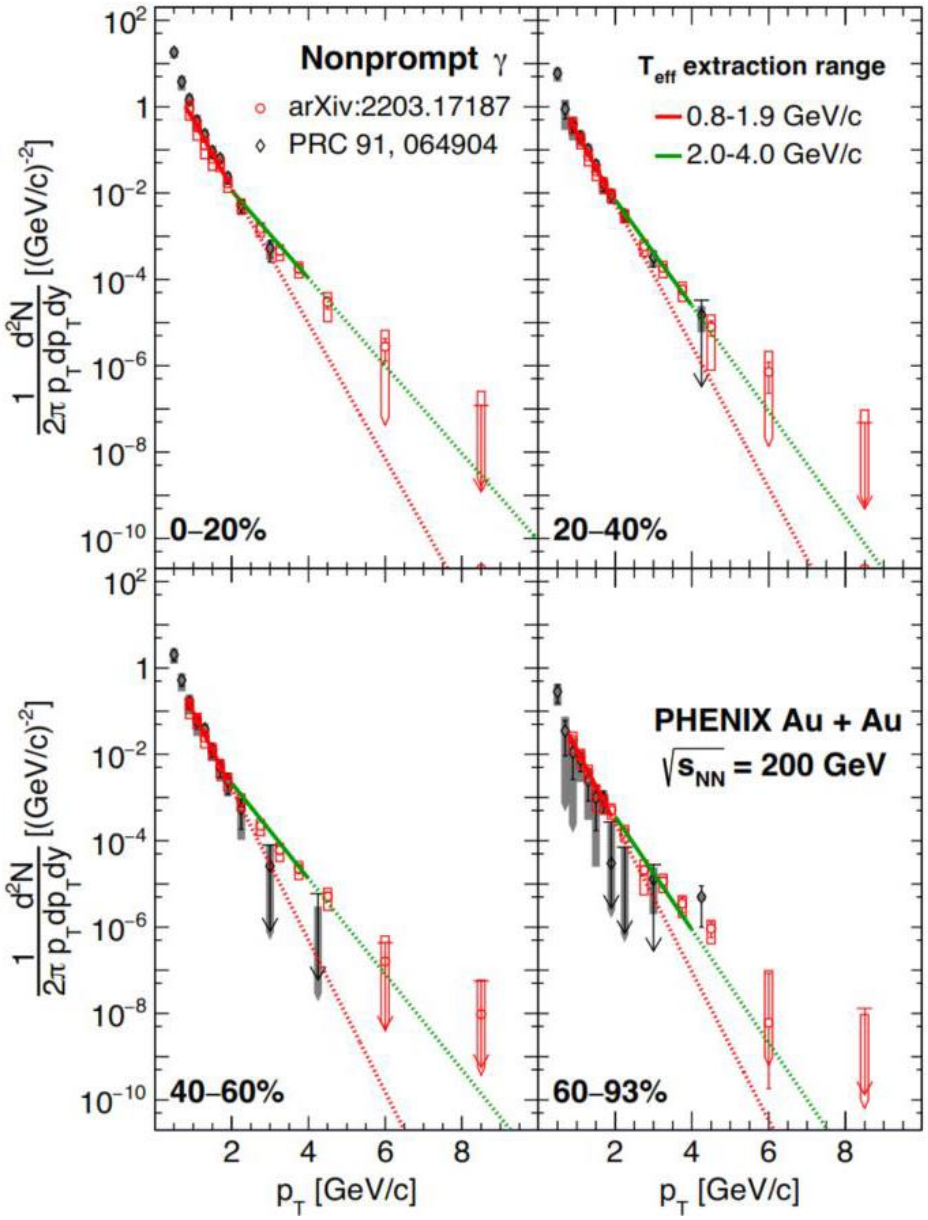
J/Ψ at forward rapidity

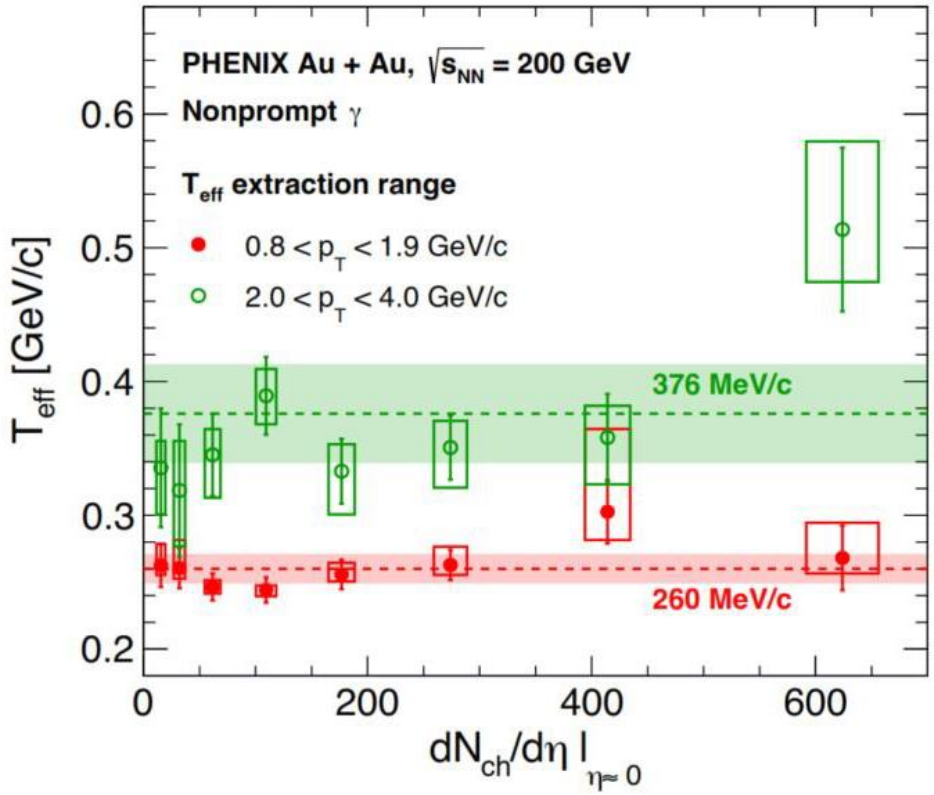


For details:
Brandon Blankenship,
Tue, March 28, 14:40

Mass ordering

Non-prompt direct photons in Au+Au





Increasing T_{eff} with p_T. Pre-equilibrium contributions?

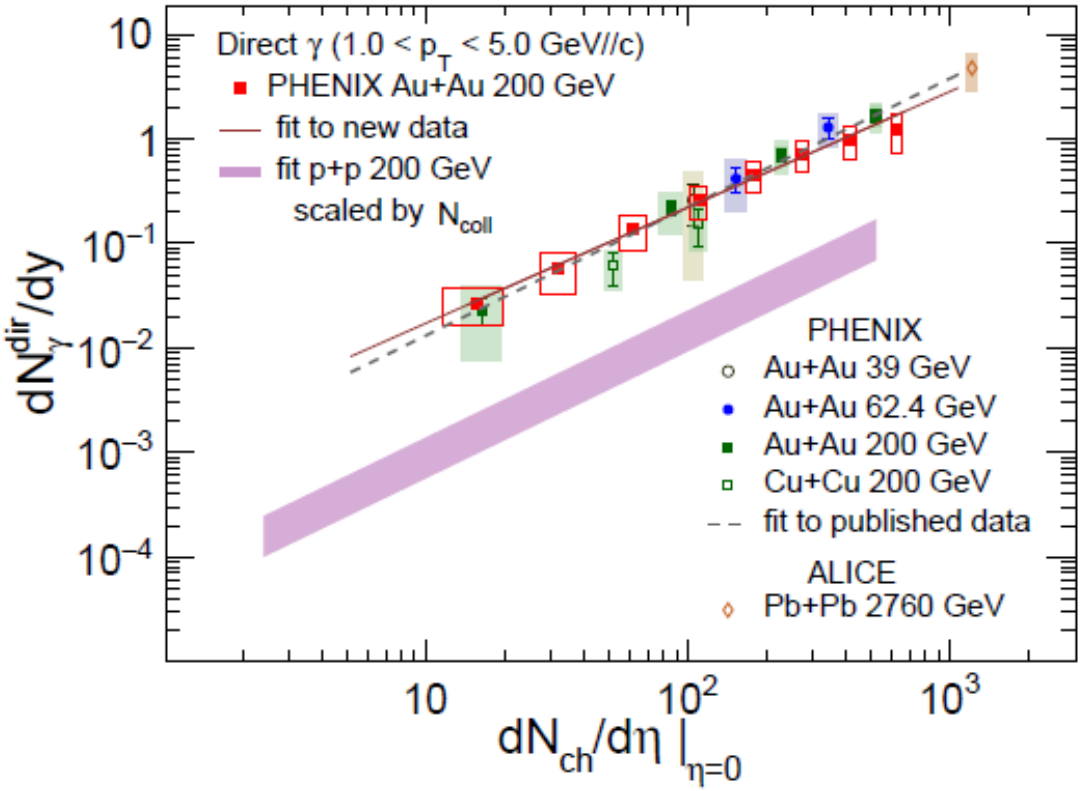
Pre-equilibrium photons?

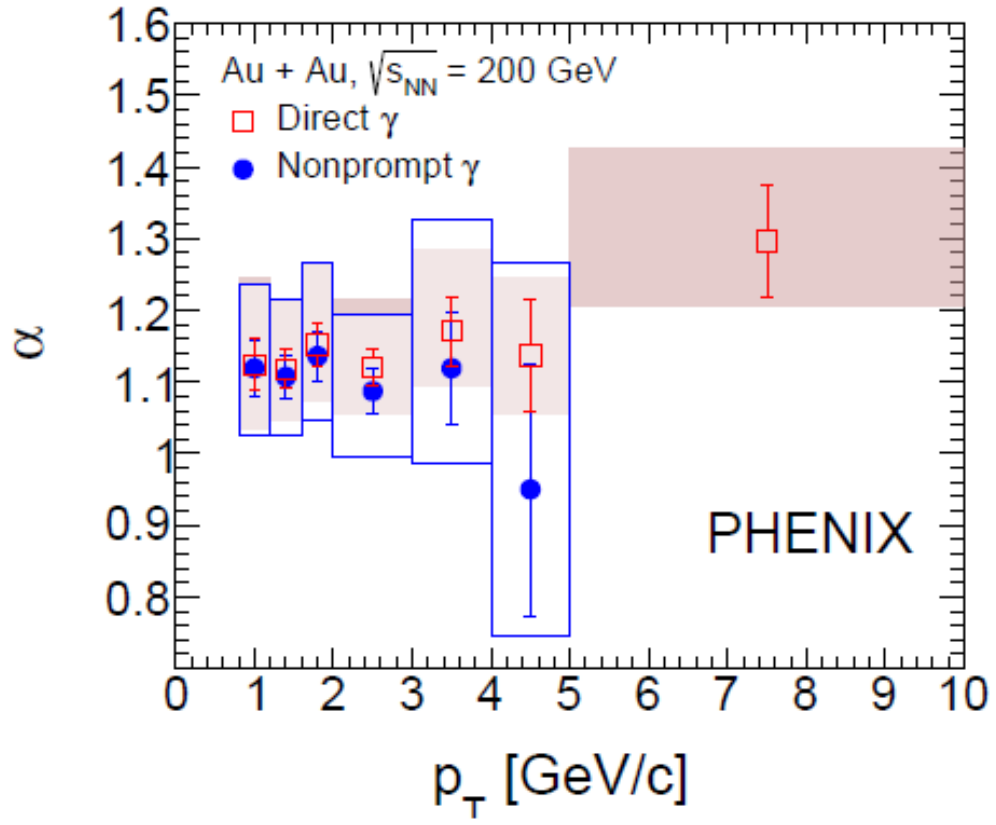
For details and more "thermal" photons:
Roli Esha, March 28, 17:10

Universal scaling of direct photon yields

In large systems low p_T photon yields scale with $dN_{ch}/d\eta$ over a large range of collision energies

arXiv:2203.17187



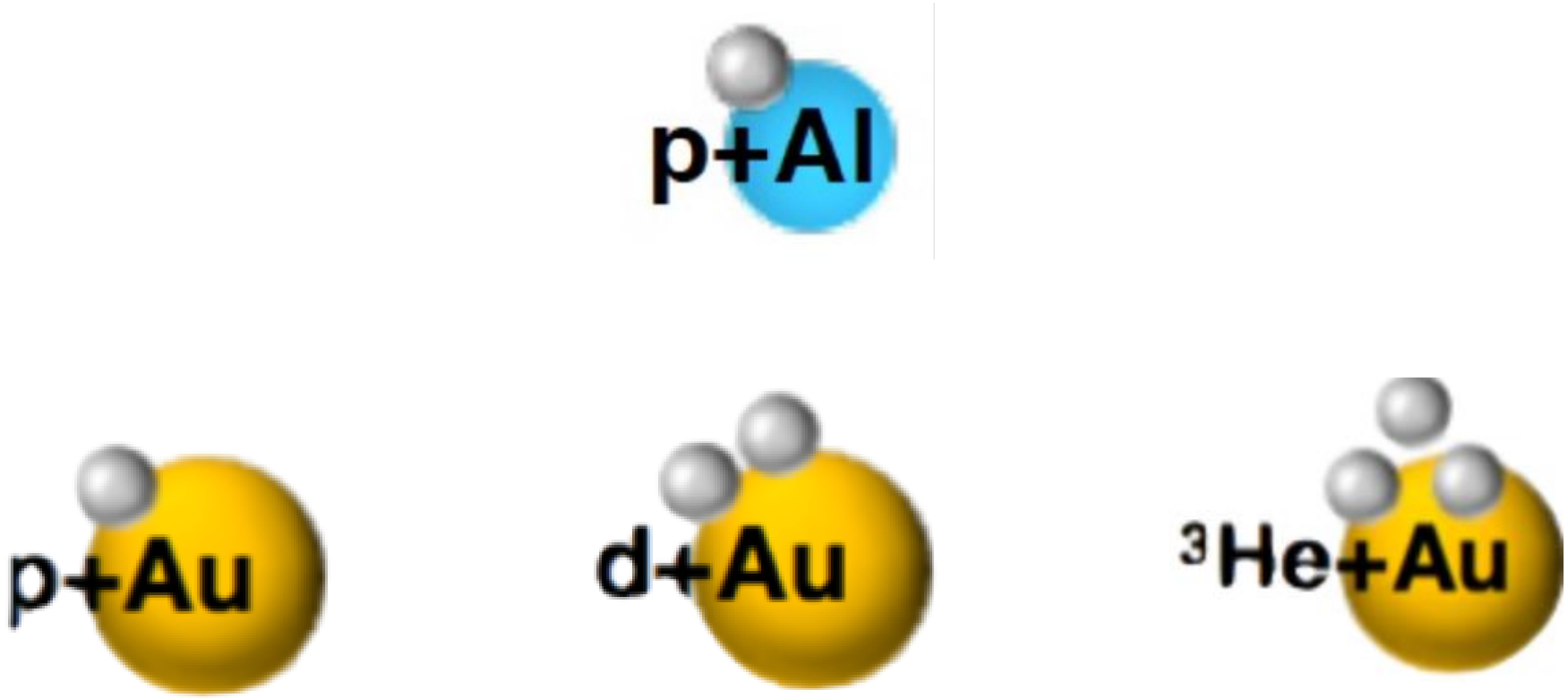


39 – 2760 GeV, all centralities

Same scaling power α both for 1-5 GeV/c range and for smaller p_T intervals

For details and more "thermal" photons: Roli Esha, March 28, 17:10

Universal α but too small for QGP / HG
Pre-equilibrium production?


p+Al
p+Au
d+Au
³He+Au

Mid-rapidity π^0 and η transverse single spin asymmetry in p+p, p+A

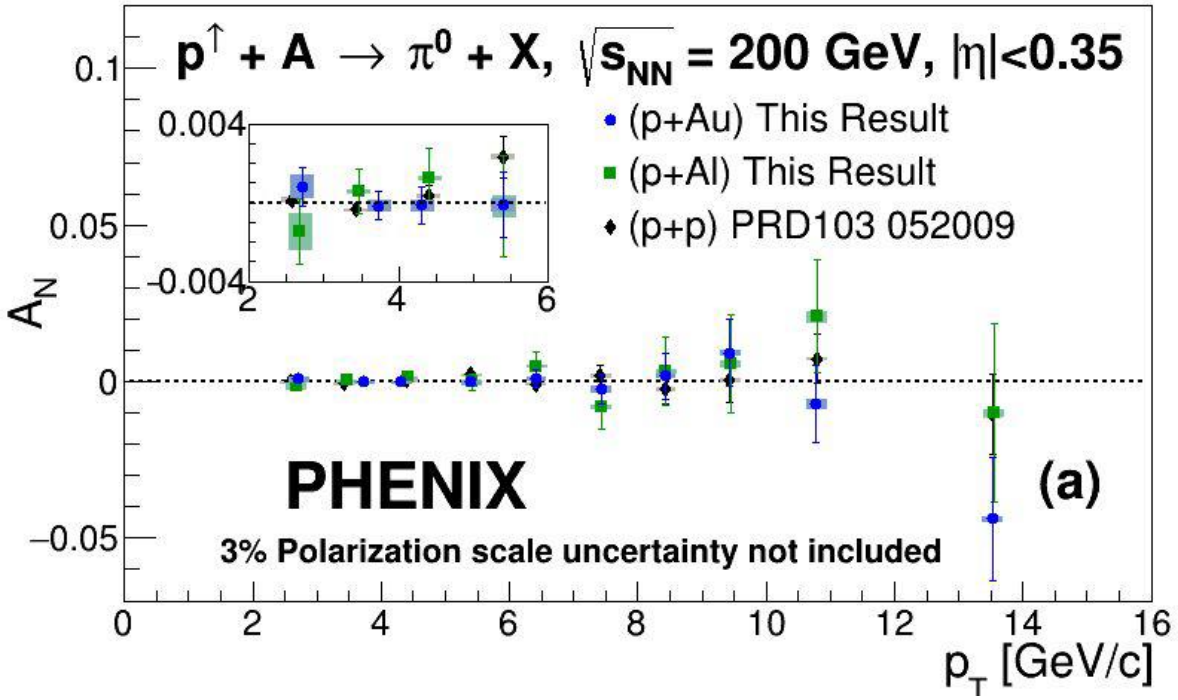
p+p

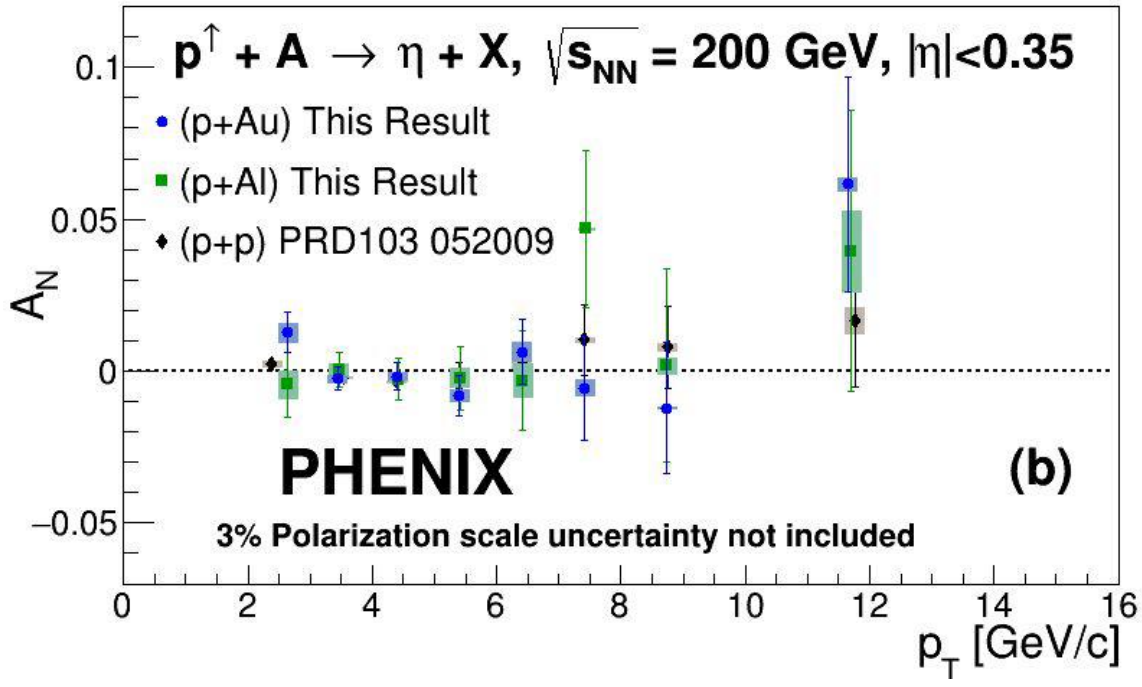
p+Al

p+Au

Two meson species, three colliding systems

arXiv: 2303.07190





Consistent with zero for all p_T across species and colliding systems.
No nuclear modification of the TSSA observed.

TSSA unchanged in p+A

Charged hadron forward/backward TSSA in p+p, p+A

p+p

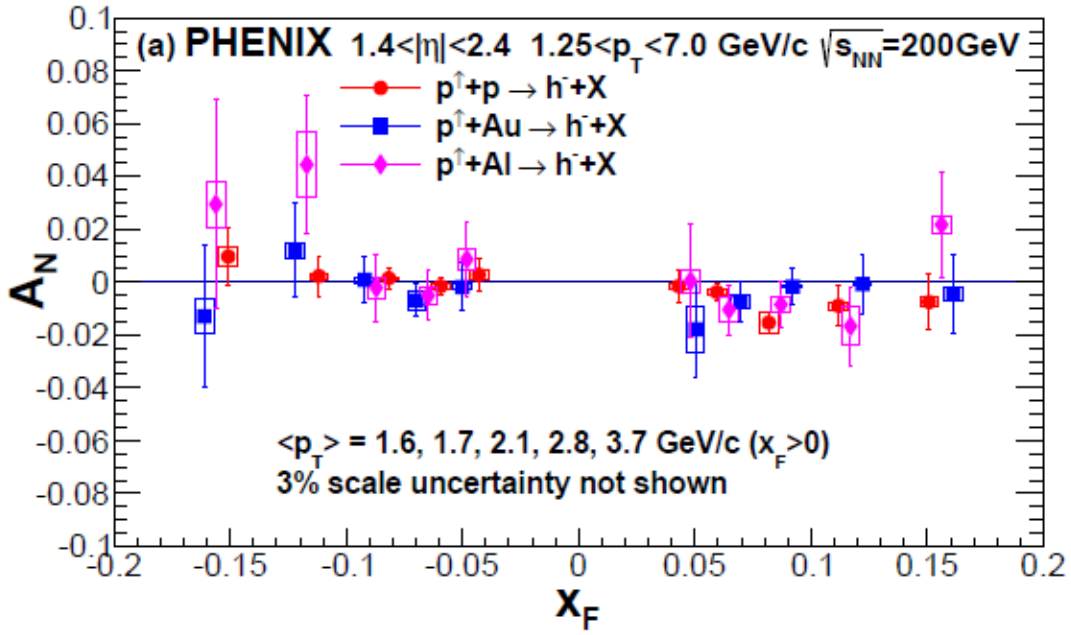
p+Al

p+Au

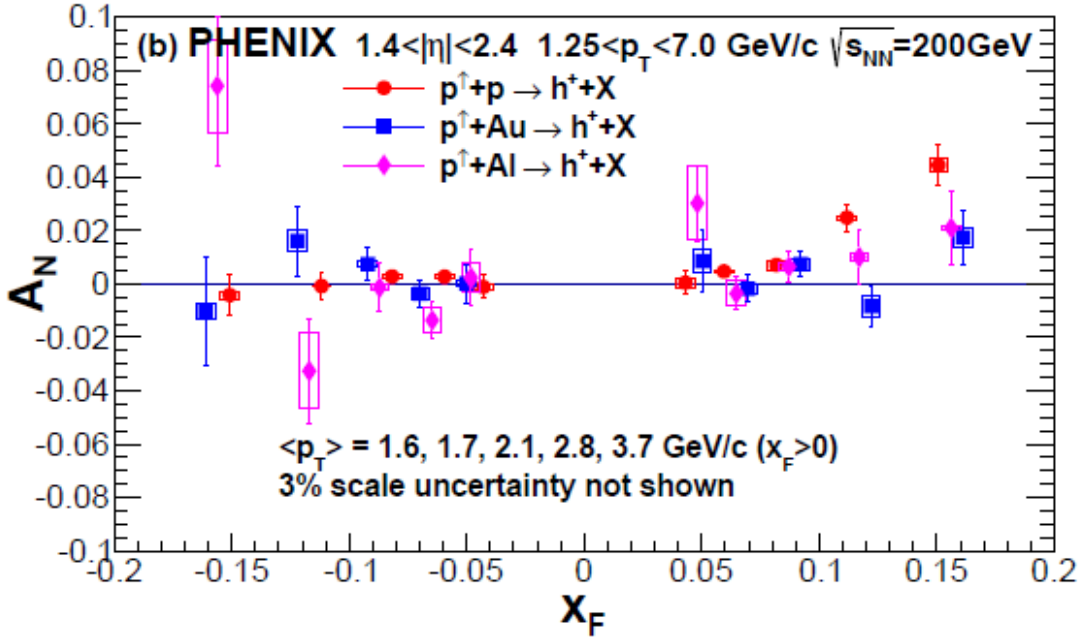
Positive and negative, three colliding systems

arXiv: 2303.07191

Negative



Positive



Independent of A within uncertainties
(measured range is above $\mathbf{Q_s}$)

All consistent with zero except for h^+ and $X_F>0$

ϕ and π^0 R_{xA} in small systems

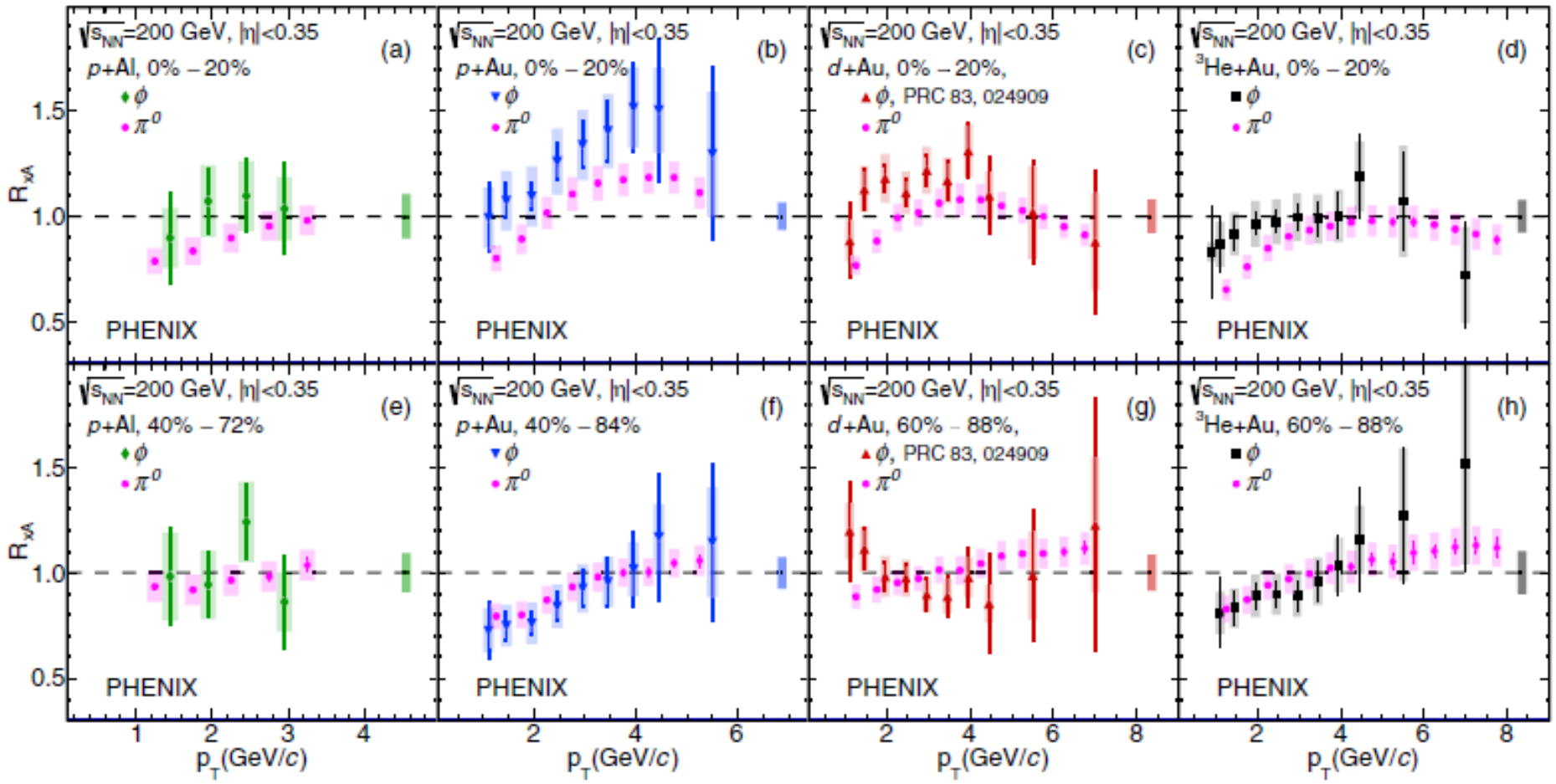
PRC 106, 014908 (2022)

p+Al

p+Au

d+Au

^{3}He+Au



Quark coalescence? → consistent
QGP, but too short lifetime?

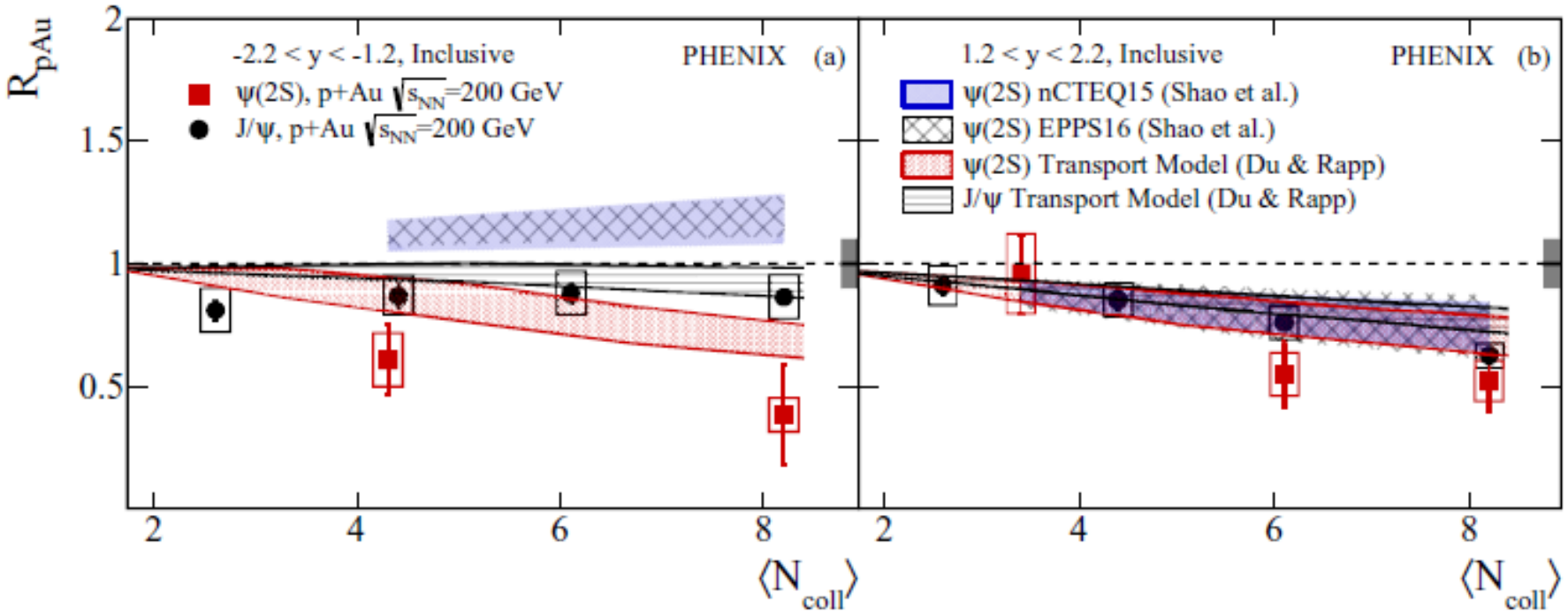
Strangeness enhancement? → inconclusive

J/Ψ and Ψ(2S) production in p+Au

PRC 105, 064912 (2022)

Au-going direction

p-going direction



Ψ(2S) more suppressed than J/Ψ in the Au direction –
similar to ALICE, LHCb.
Consistent with models (Du, Rapp) that include hot nuclear matter effects.
Final state effects at RHIC and LHC similar???

Final state effects in p+A ?

High pT π^0 in small systems (R_{xA})

p+p

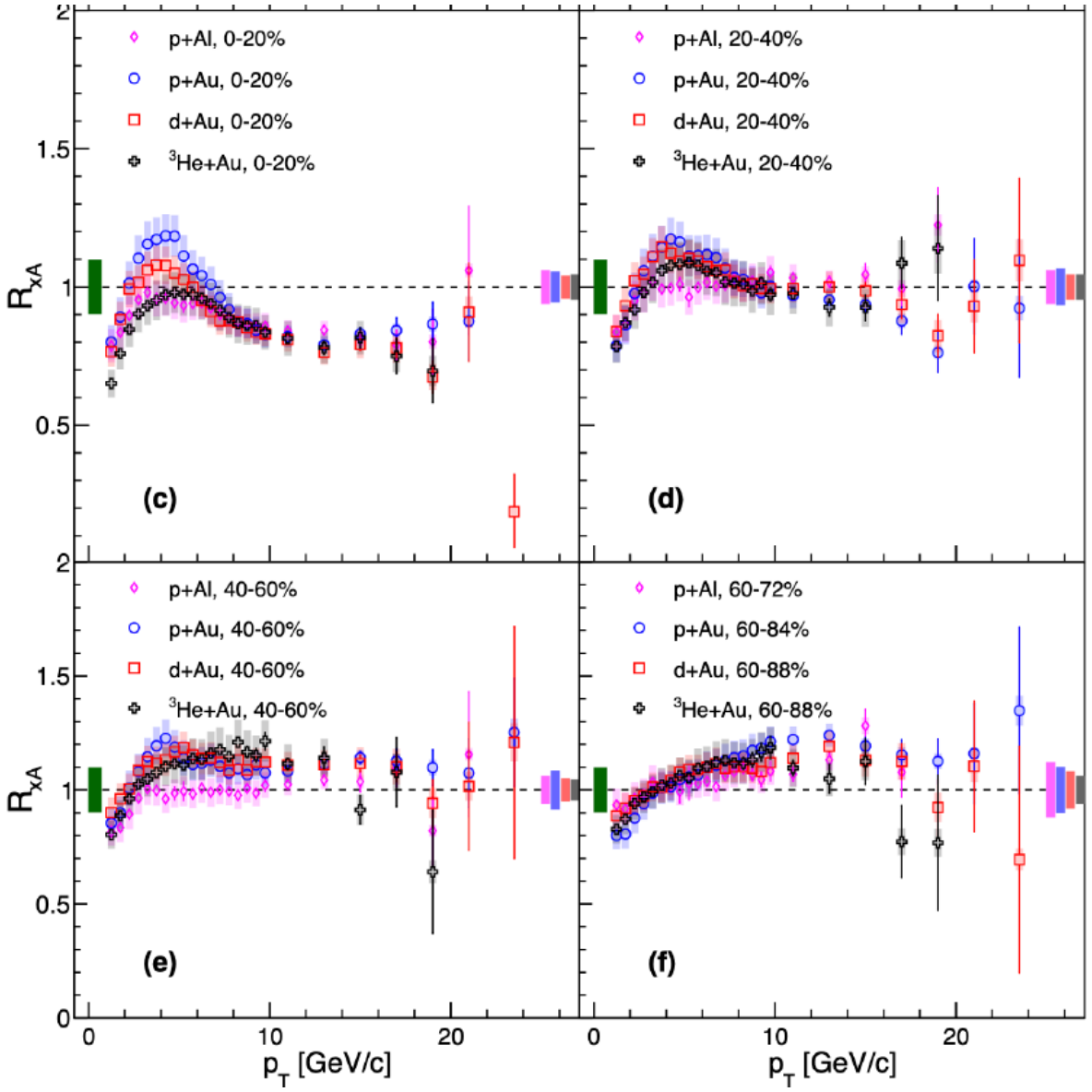
p+Al

p+Au

d+Au

^{3}He+Au

PRC 105, 064902 (2022)



The p+p reference is a combined result from 2005, 2008 and 2015 data

Ordering and some p_T shift of the Cronin peak (but reverse as nPDF would predict)

Same suppression at high p_T in centrals

Some enhancement in peripherals

Ordering with system size NOT seen at high p_T

Potential bias in centrality determination? Final state effect?

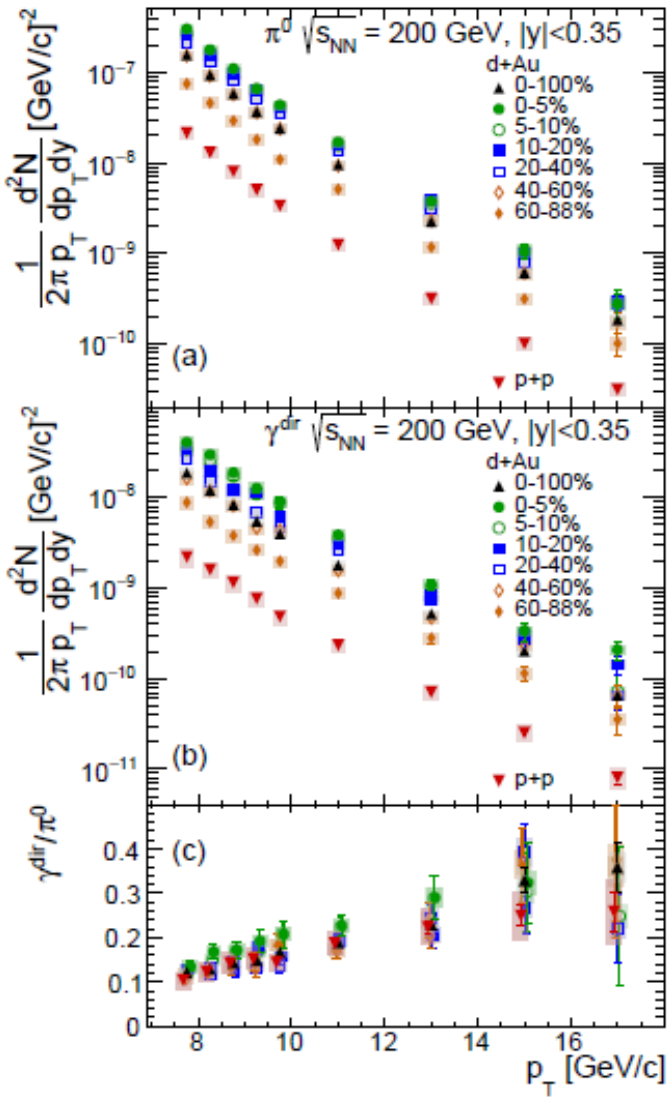
High and low p_T: quite different physics!

Bias in N_{coll} at high p_T ?

For details: Axel Drees, Tue March 28, 16:30

Experimental measure of N_{coll}

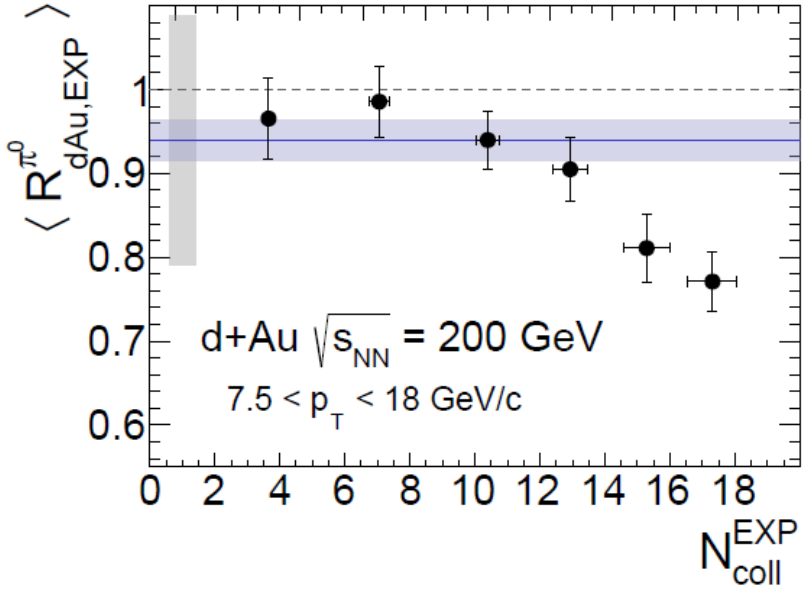
Centrality (b, theory) – event activity (experiment) → mapping is ambiguous in small systems



Use electroweak probes
(in our case photons)
to estimate N_{coll} experimentally

$$N_{\mathrm{coll}}^{\mathrm{EXP}}(p_T) = \frac{Y_{dAu}^{\gamma\,\mathrm{dir}}(p_T)}{Y_{pp}^{\gamma\,\mathrm{dir}}(p_T)}.$$

No enhancement in
peripherals, still
suppression in most
central collisions



arXiv:2303.12899

For details: Axel Drees,
Tue March 28, 16:30

E_{loss} in QGP droplets?
Something else?

DAP – Data and Analysis Preservation

New (public) PHENIX homepage:
https://www.phenix.bnl.gov/

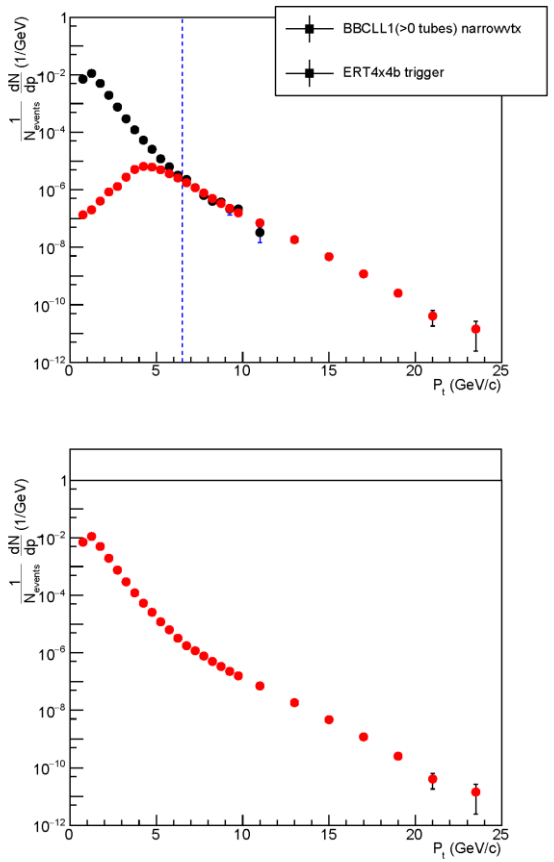
HEPData:
data tables for 75+ published papers

Zenodo:
>600 documents,
including all PHENIX theses
and talks since 2016

OPENData:
hands-on introduction to
photon and π^0 analysis

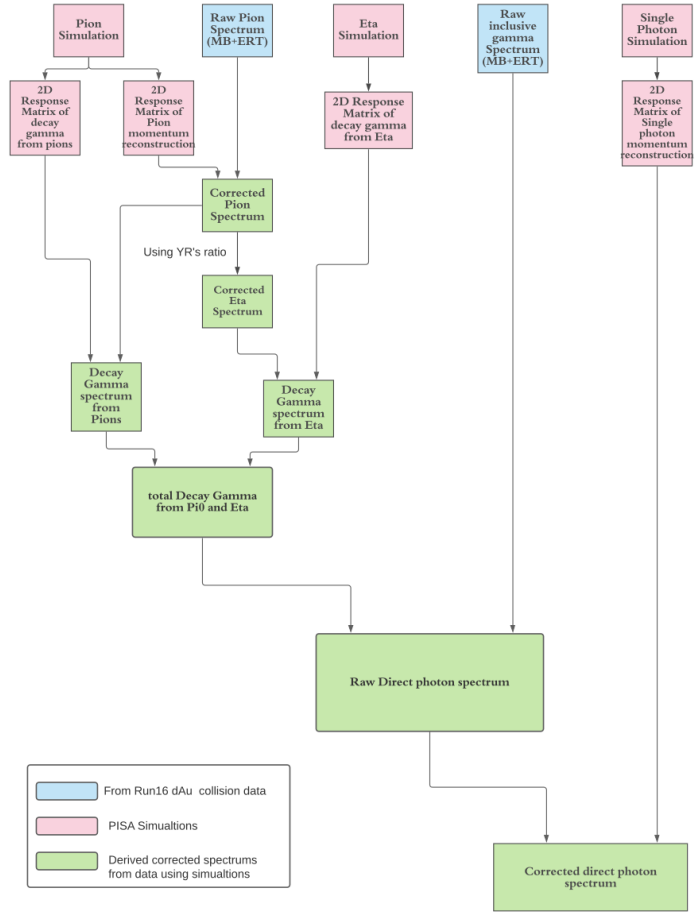
***REANA**: 2016 d+Au data*
π^0 MB spectrum reconstructed
by a non-PHENIX person (22/03/2023)

REANA



REANA

High p_T direct photon and π^0 analysis chain implemented



Summary

PHENIX: lively analysis program

Zeroing in on the “fine print”, soft-hard QCD transition

Small systems: from “reference” to the most exciting physics

Neutral probes, heavy flavor

Archival papers

Many more interesting things to come!

Making PHENIX data re-analyzable decades from now – and we mean it!

Thank you!

Backup