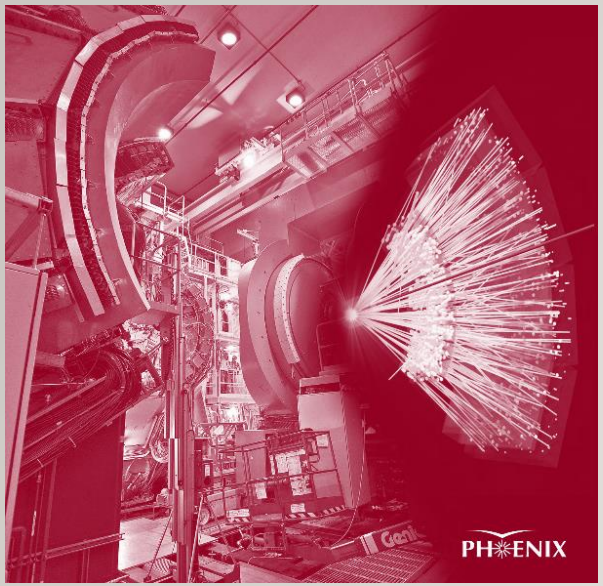


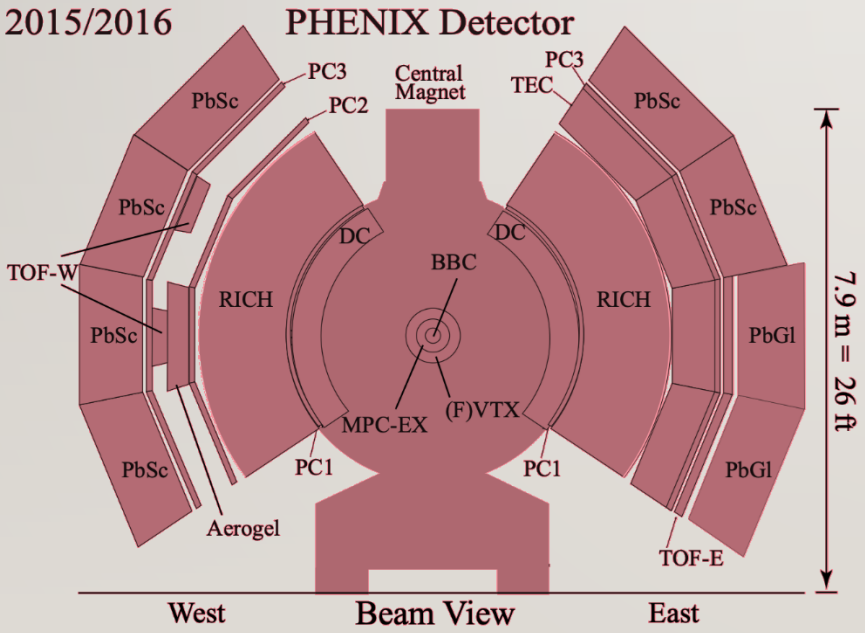
HIGHLIGHTS FROM THE PHENIX EXPERIMENT

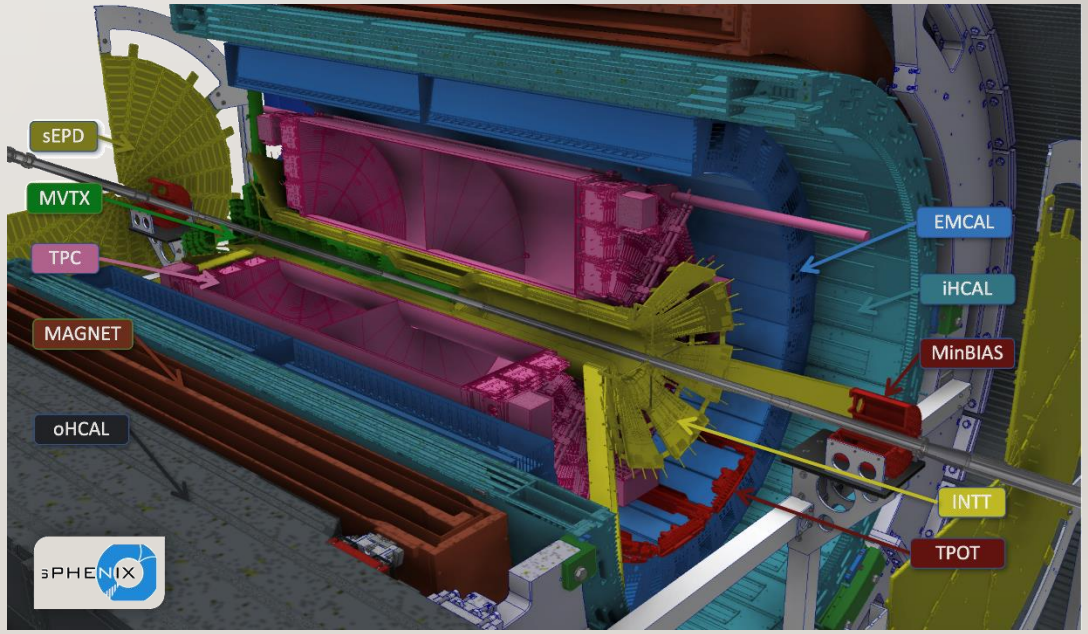
MÁTÉ CSANÁD (FOR THE PHENIX COLLABORATION) EÖTVÖS U, BUDAPEST

EUROPEAN NUCLEAR PHYSICS CONFERENCE 2022, SANTIAGO DE COMPOSTELA

THE PHENIX EXPERIMENT

- PHENIX: versatile detector identifying many different particles, recording large amount of collisions
- Dismantled in 2016, to give way to sPHENIX
- sPHENIX: to take data soon
  - Jets, jet correlations, Upsilon states
  - EM+Hadronic calorimetry, high resolution tracking, fast (~100 kHz) data aquisition

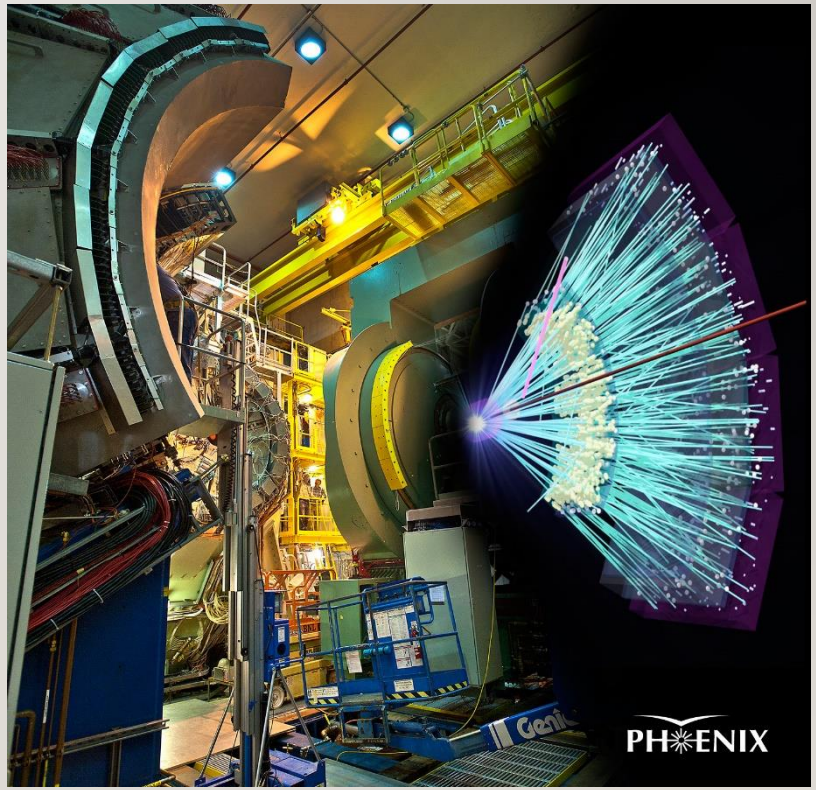




THE PHENIX EXPERIMENT AND THE BES

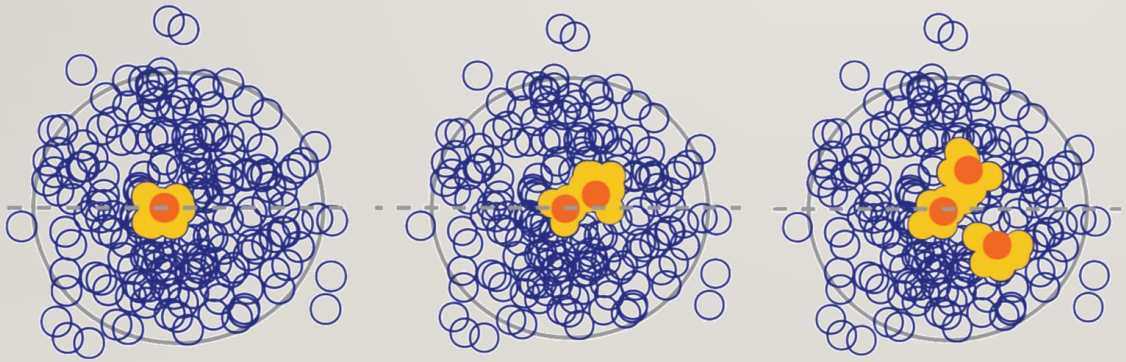
- Detector system allowing hadron, photon, muon etc. measurements, data taking until 2016
- Collision energies: 7.7 to 200 GeV (20-400 MeV in μ_B, 140-170 MeV in T)
- This talk: summary of small and large systems

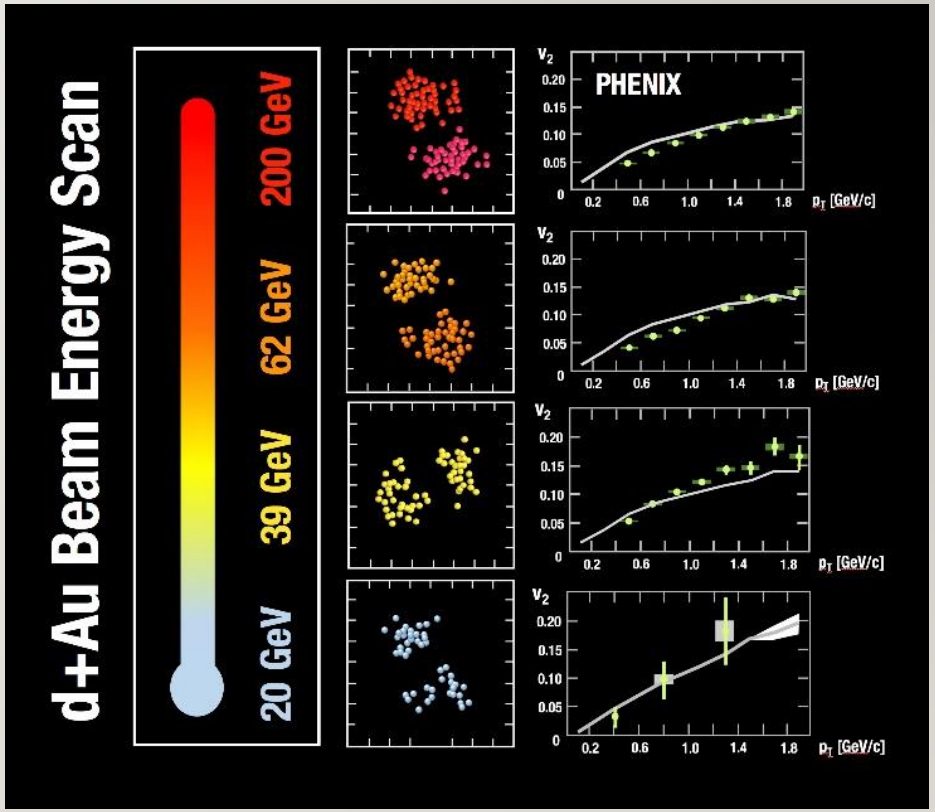
$\sqrt{s_{NN}}$ [GeV]	p	Al	Au	Au	Au	Cu	Cu	Au	Au	U	U
510	☑										
200	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
130									☑		
62.4	☑			☑		☑			☑		
39				☑					☑		
27									☑		
20				☑		☑			☑		
14.5									☑		
7.7									☑		



4/18 ORIGIN OF FINAL STATE COLLECTIVITY?

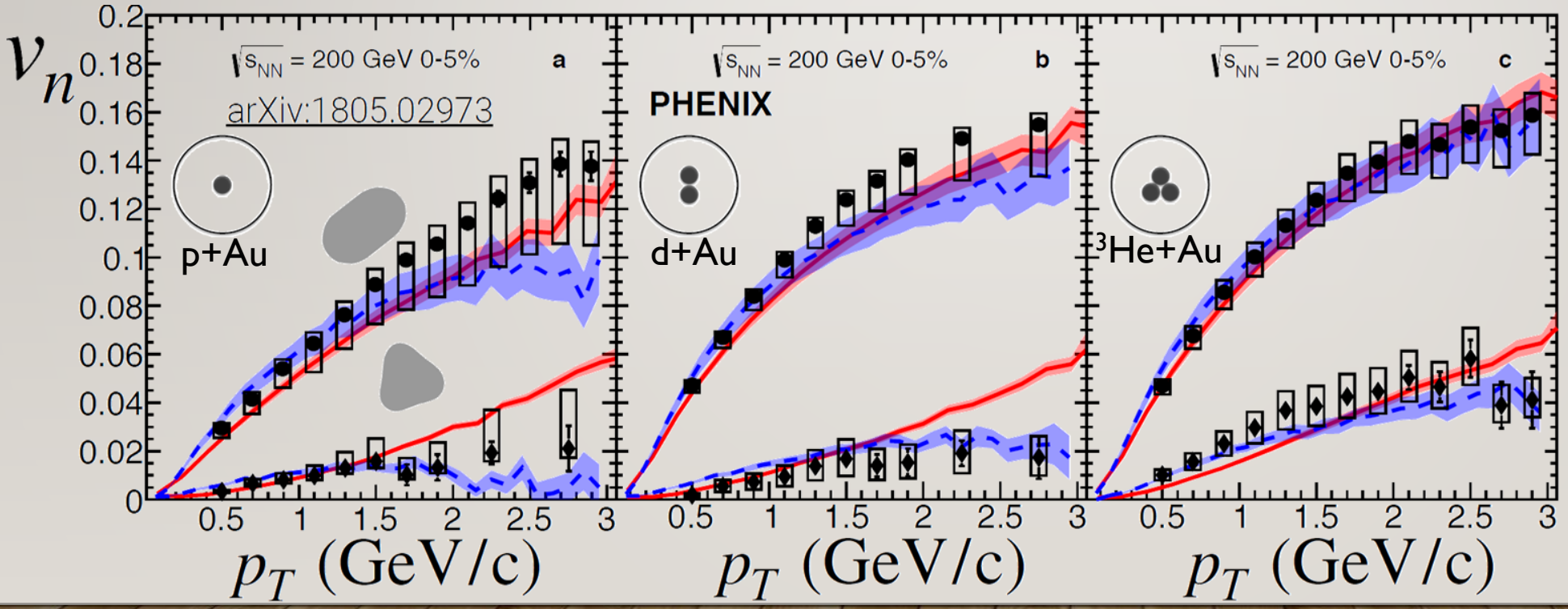
- Is it due to the appearance of the sQGP (i.e., a strongly coupled fluid)?
  - If yes, how much time is needed to spend in QGP phase?
  - Test: d+Au collisions from 20 to 200 GeV
- Is it due to initial geometry and hydro?
  - Hydrodynamics: initial spatial correlations
  - Alternative: initial momentum correlations
  - Test: p+Au, d+Au, ^{3}He+Au
  - How do v_2 and v_3 evolve with initial state geometry?





5/18 EVIDENCE FOR QGP DROPLETS IN SMALL SYSTEMS

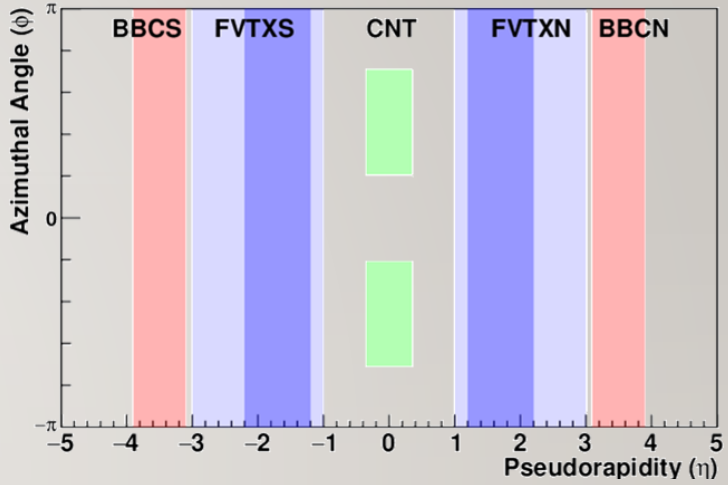
- Data: apparent geometrical ordering
  - v_2: p+Au < d+Au ~ ^{3}He+Au
  - v_3: p+Au ~ d+Au < ^{3}He+Au
- Hydro calculations (2+1D, η/s = 0.08, MCGlauber, different hadronic rescattering) match data

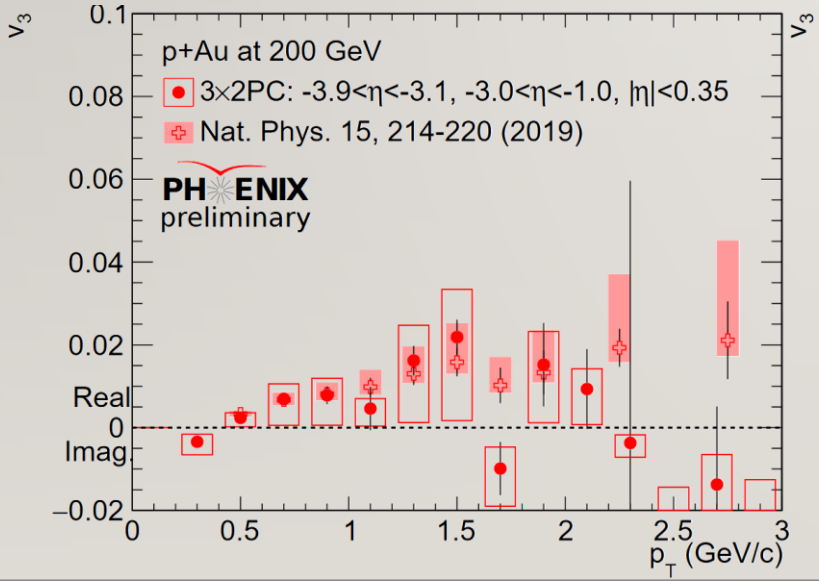


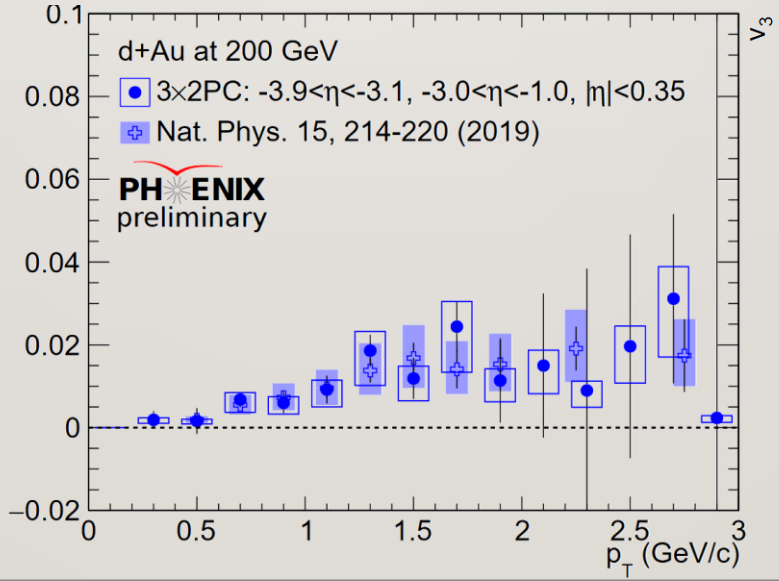
Nature Phys. 15, 214 (2019)
v_2 Data
v_3 Data
v_n SONIC Eur. Phys. J. C 75, 15 (2015)
v_n iEBE-VISHNU PRC 95, 014906 (2017)

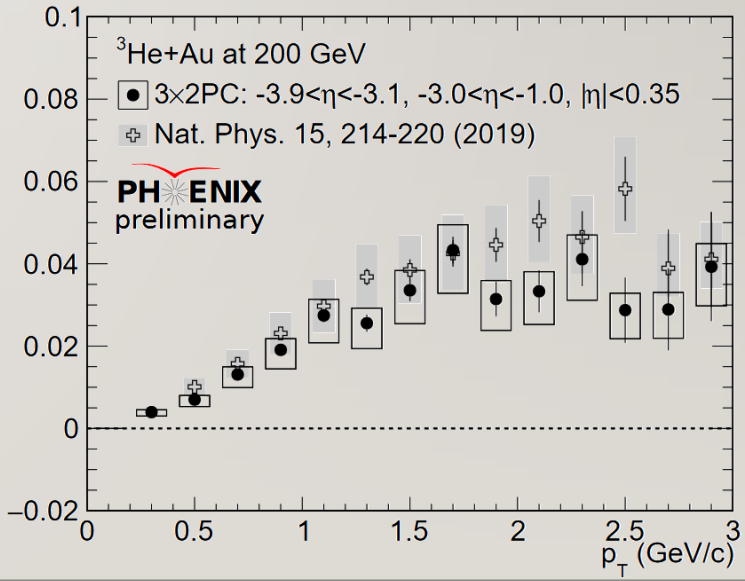
6/18 INDEPENDENT STUDY OF ANISOTROPIES

- Using two particle correlations over large rapidity range
  - PHENIX Nat. Phys. 15, 214 (2019): uses Event Plane, BBCS, FVTXS, CNT
  - Check done with 3x2PC method, BBCS-FVTXS-CNT & FVTXS-CNT-FVTXN
  - Different systematics, different sensitivity to non flow effects, different result!
- 3x2PC measurement confirms geometrical ordering of v_2 and v_3
- More details in arXiv:2203.09894



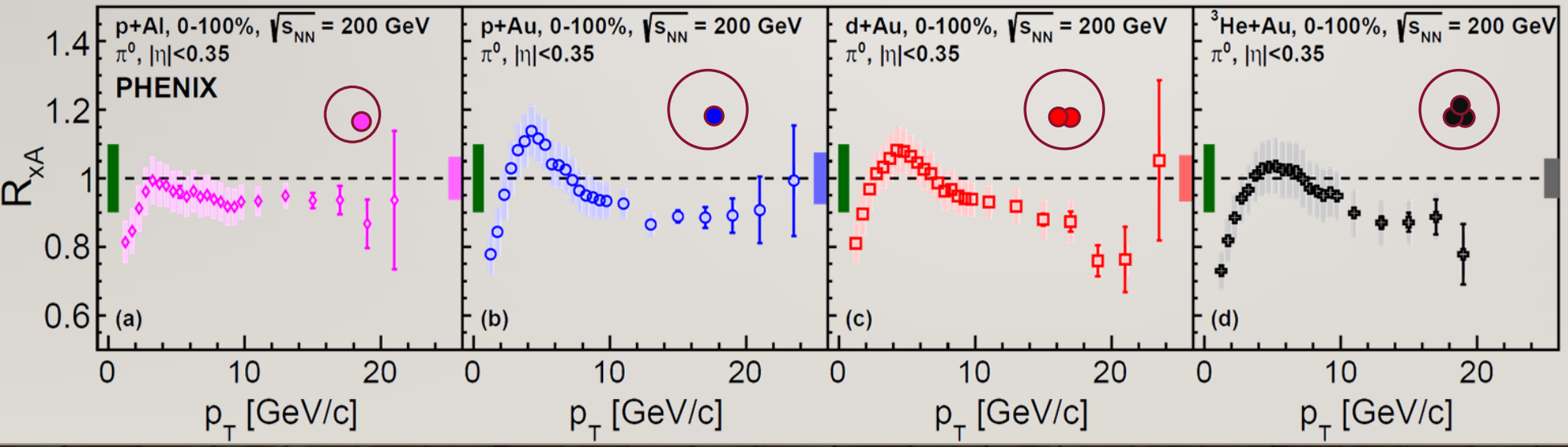


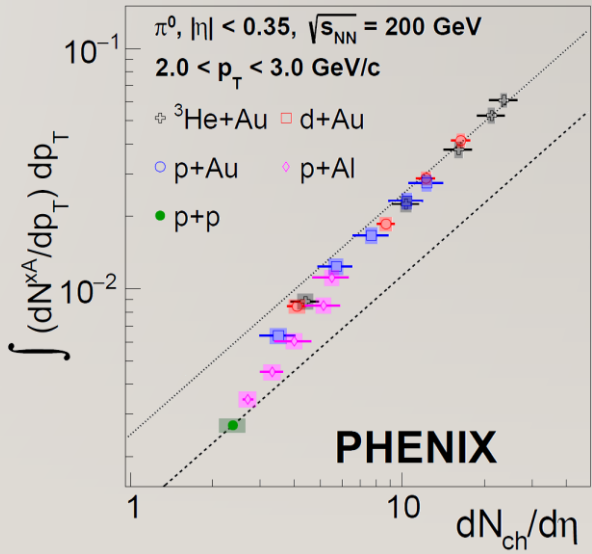




7/18 NUCLEAR MODIFICATION AT INTERMEDIATE PT

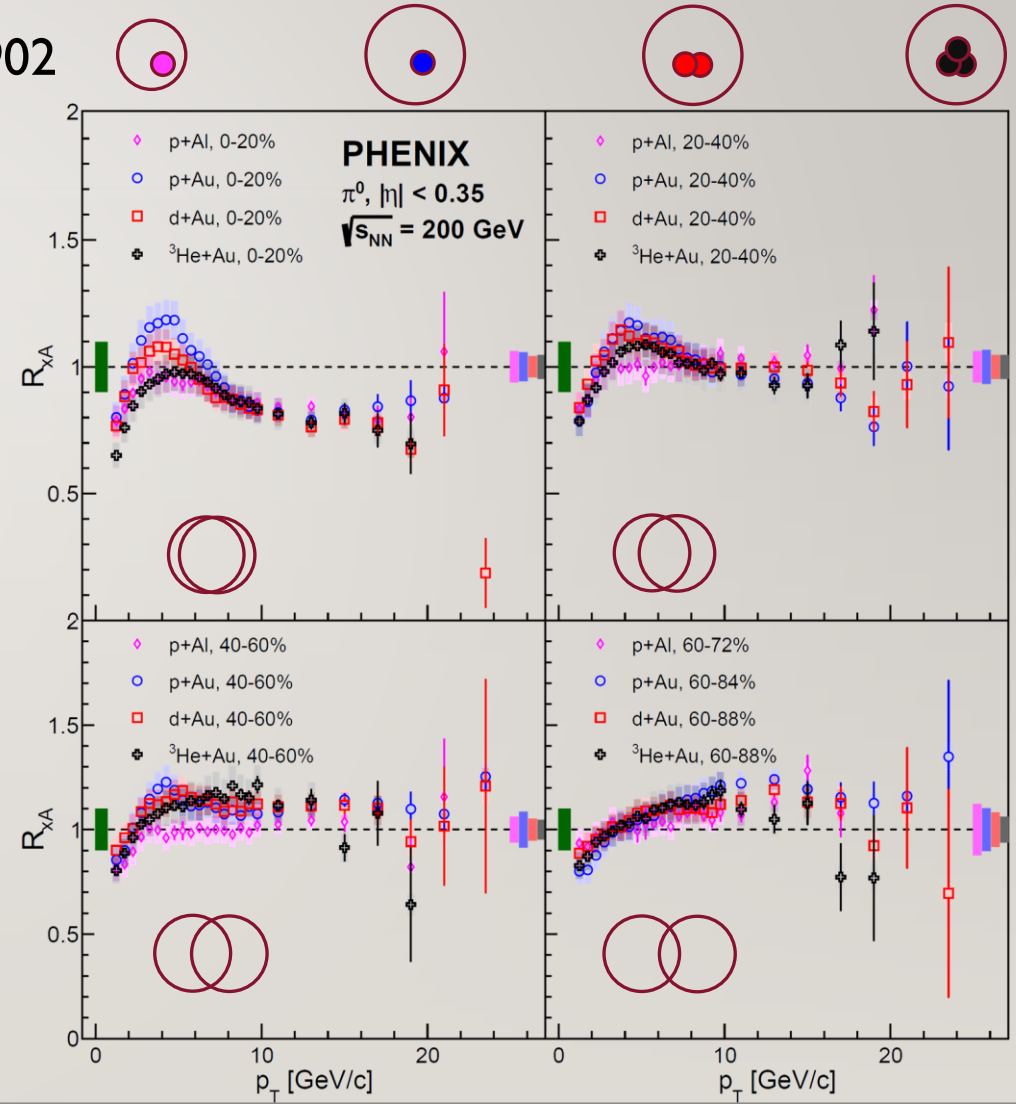
- Measurement of $R_{xA} = \frac{dN_{xA}/dp_T \times \sigma_{pp}^{\text{inel}}}{\langle N_{\text{coll}} \rangle \times d\sigma_{pp}/dp_T}$ (where x: p, d, ^{3}He) in PRC105 (2022) 6, 064902
- Especially interesting: intermediate range of $2<p_T<6$ GeV/c
  - "Cronin" peak indicating broadening
  - Shift of yield from scaled pp to scaled ^{3}He+Au starting around $dN_{ch}/d\eta$ of 4 to 5
- Broadening consistent with expectations for radial flow in small systems





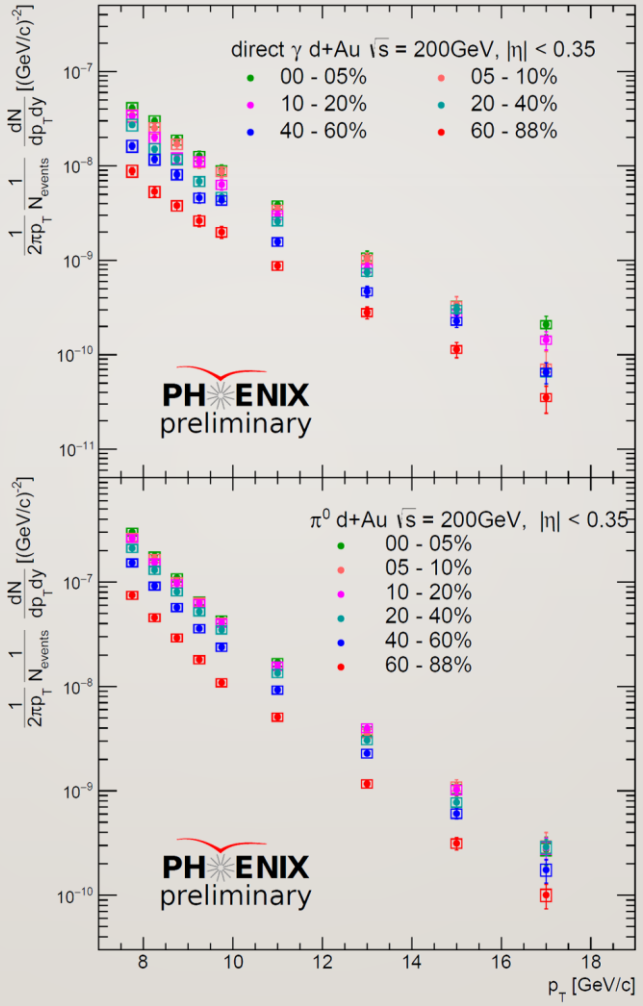
CENTRALITY DEPENDENCE OF SUPPRESSION

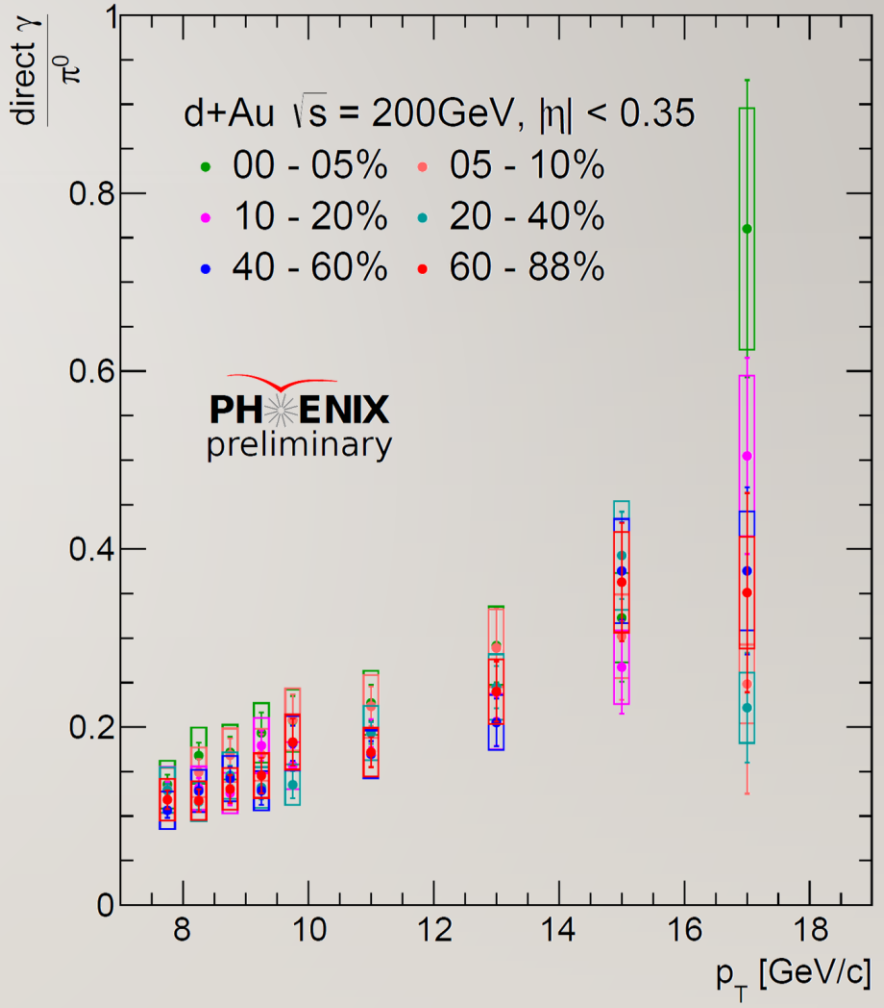
- p+Al, p+Au, d+Au, ^{3}He+Au compared, PRC105(2022)064902
- Centralities determined as for large systems
- Observations
  - New p+Au results show large centrality dependence
  - Systems of various size agree at high p_T
  - At moderate p_T, ordering seen
- Counterintuitive at high p_T:
  - 20% suppression in central collisions in all systems
  - 15% enhancement in peripheral collisions in all systems
  - Bias of centrality determination or final state effect?
- Model comparision:
  - Vitev, HIJING++ investigated
  - No full match of ordering, peak location, etc



DIRECT PHOTONS IN SMALL SYSTEMS

- High p_T direct γ at 8-18 GeV/c
  - produced in hard scattering,
  - have no final state effects,
  - yield proportional to N_{coll}
- Direct γ to π_0 ratio
  - No evident centrality dependence
- Centrality dependence of π_0: due to bias in centrality determination!

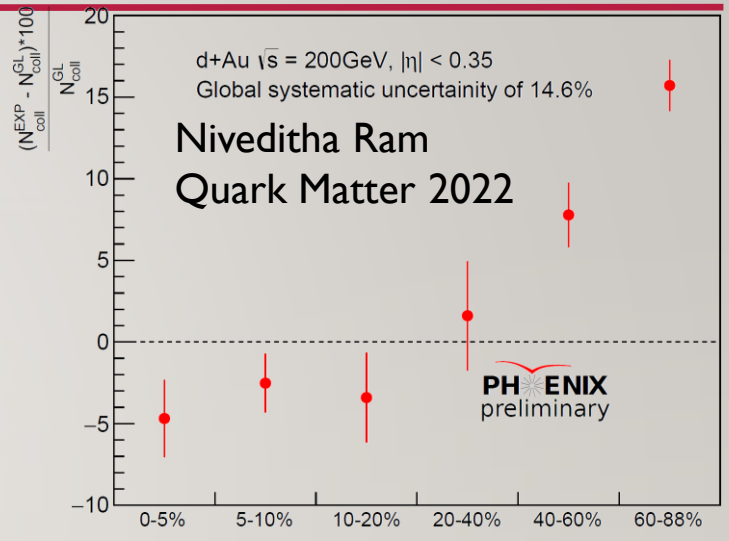


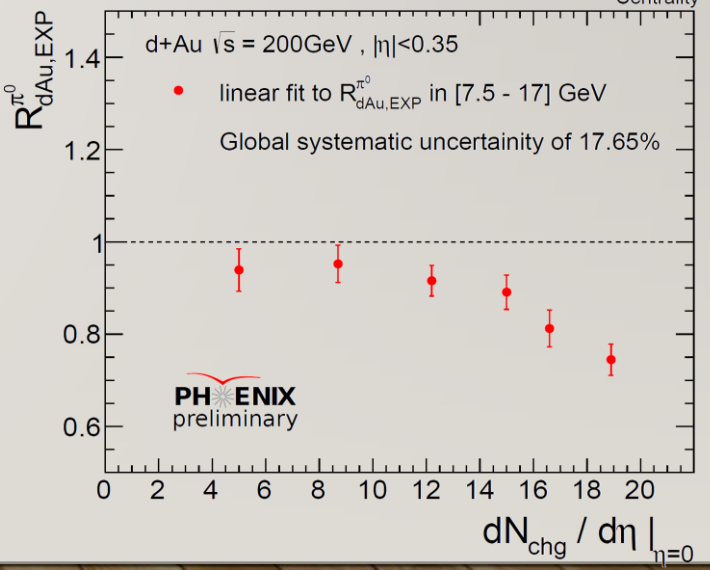


Niveditha Ram, Quark Matter 2022

REVISE R_{AA} VIA DIRECT PHOTONS

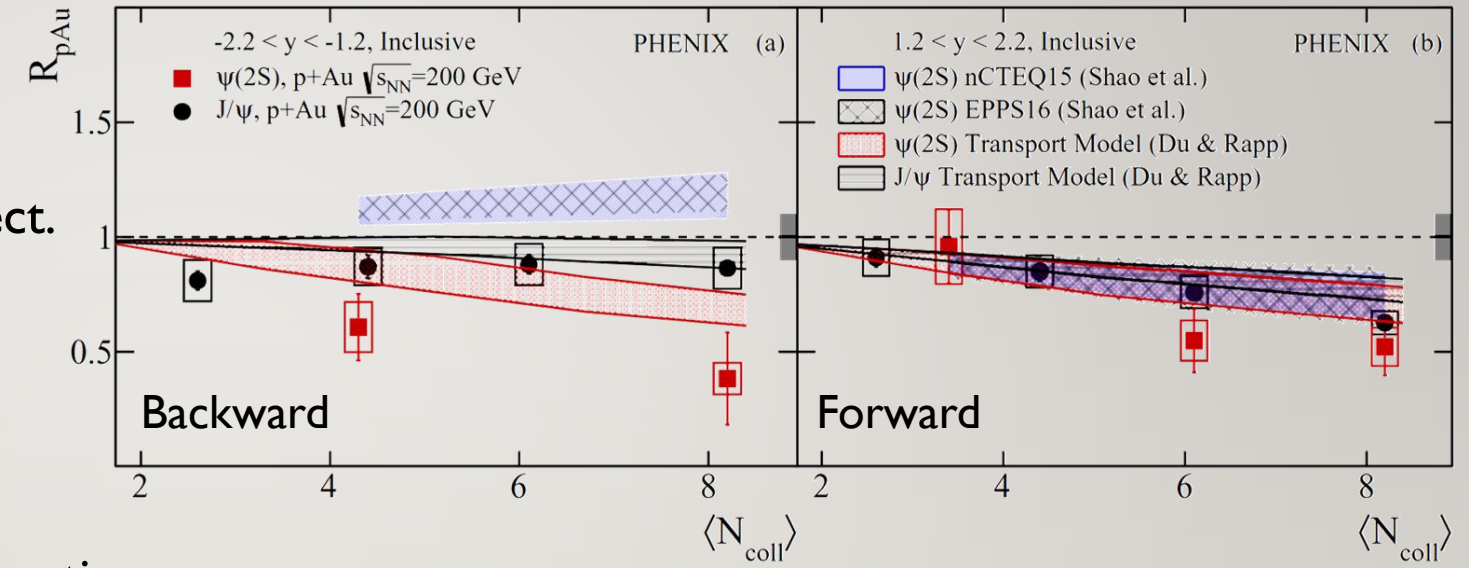
- Determine N_{coll} from experiment
  - Calculate dAu/pp ratio of direct γ
  - Fit constant
- Compare to Glauber Model
  - Good agreement in central collisions within 5%
  - 15% deviation in peripheral collisions
- Bias in Glauber calculation, event activity reduced if hard scattering
- Experimental π_0 R_{dAu}
  - Consistent with unit for peripheral collisions within scale uncertainties
  - Clear suppression in central collisions, ~15% relative to peripheral collisions
- Evidence for final state suppression of π_0 suppression at high p_T in d+Au events with high event activity
- Qualitatively consistent with energy loss?

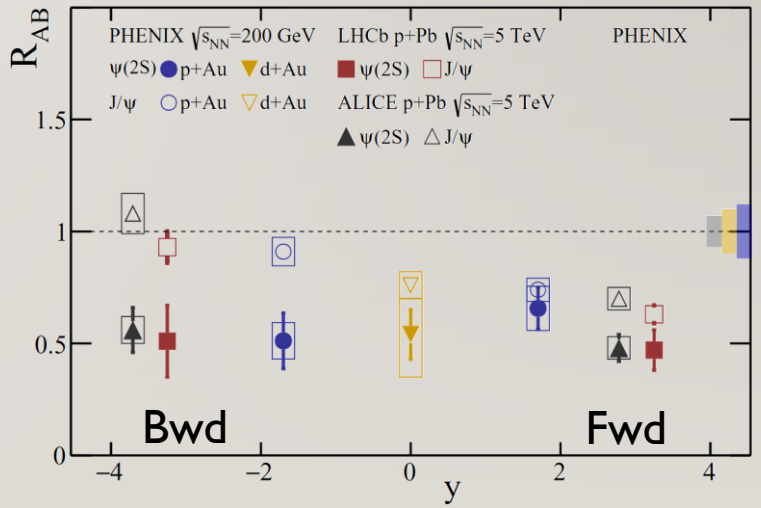




J/Ψ AND Ψ(2S) IN p+Au

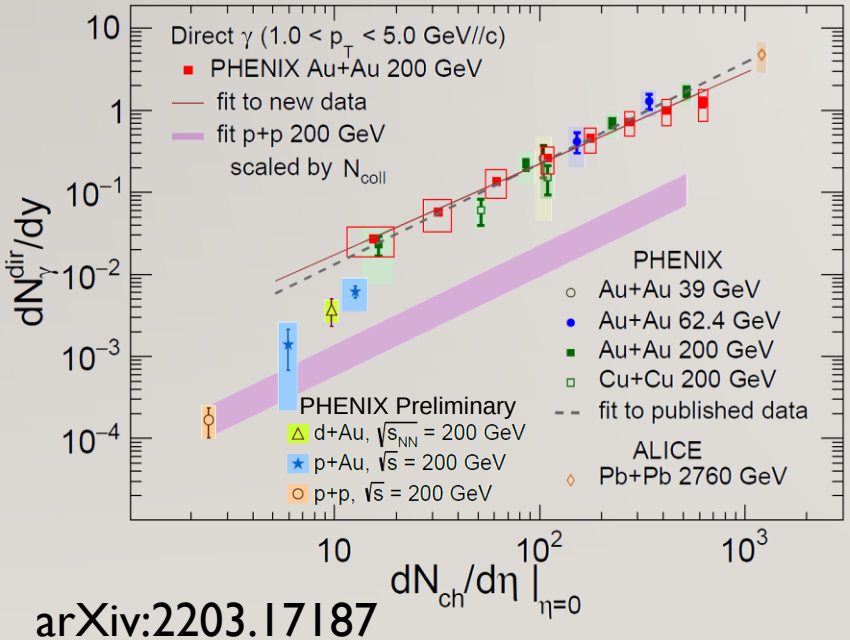
- Similar modification of J/ψ and ψ(2S) in p-direction
- Stronger ψ(2S) suppression in Au-direct.
- nPDF only can not describe the data
- Qualitatively agree with the transport model with final-state effects
- Qualitatively consistent with QGP formation
- Forward rapidity: J/ψ and ψ(2S) suppression similar, initial-state effects dominate
- Backward rapidity: J/ψ and ψ(2S) suppression different, increasing final-state effects in ion-going direction
- Details in Phys.Rev.C 105 (2022) 6, 064912 [arXiv:2202.03863]



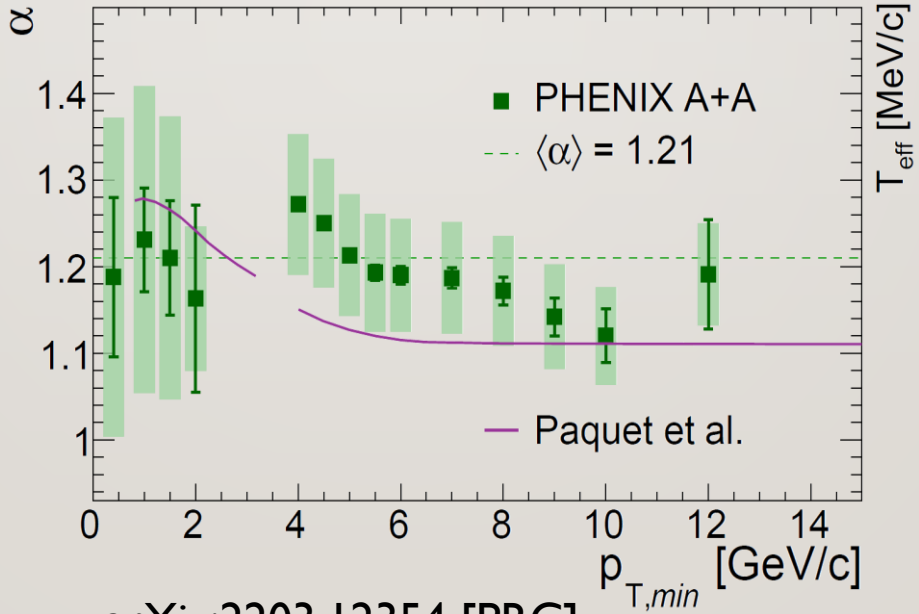


DIRECT PHOTONS IN SMALL AND LARGE SYSTEMS

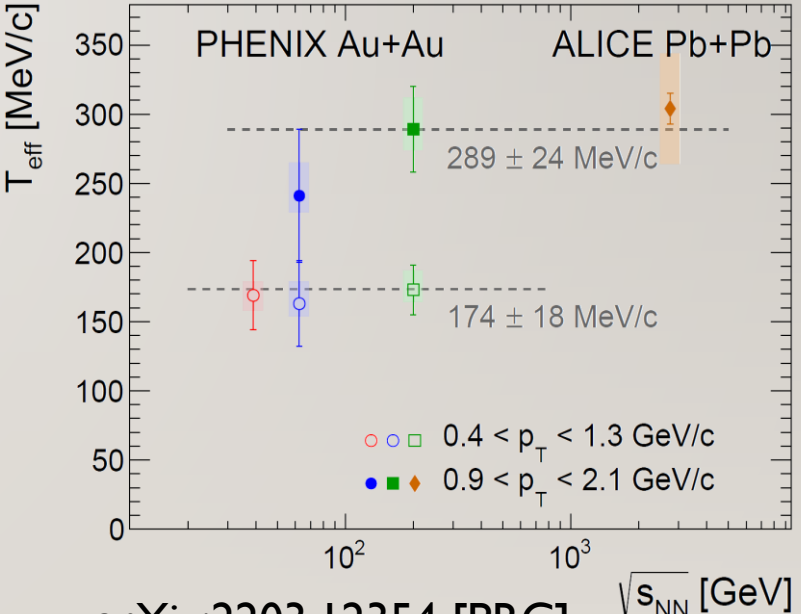
- Clear direct γ signal at all investigated energies
- Yield scaling from RHIC to LHC, transition from p+p, to A+A: p+Au, d+Au "bridge the gap"
- Slope α larger than one and independent of p_T
- Effective photon temperature similar from 39 to 2760 GeV, depend on p_T range
  - Note overlapping mechanisms: hadron gas, sQGP, jets, bremsstrahlung, hard scattering



arXiv:2203.17187



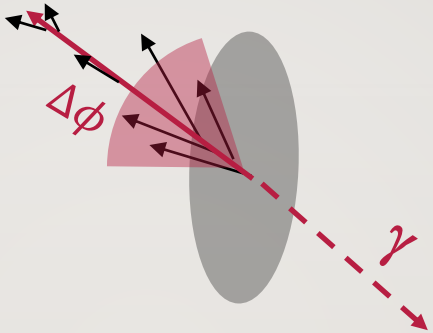
arXiv:2203.12354 [PRC]

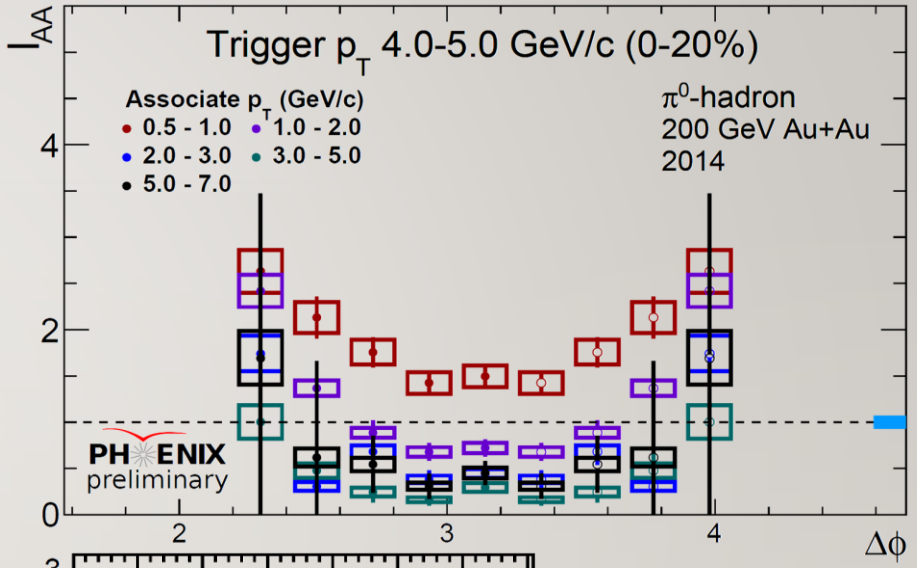


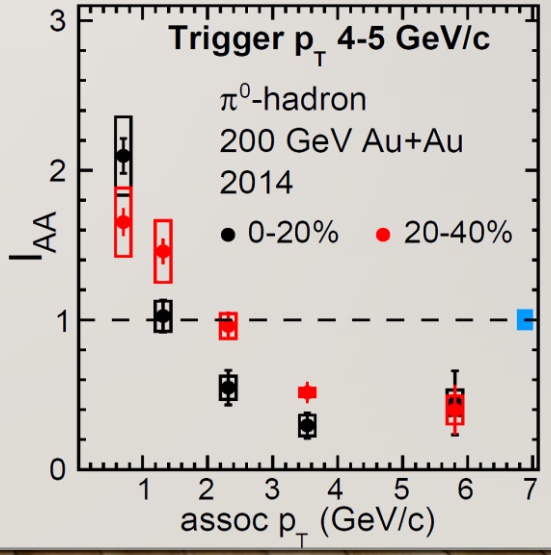
arXiv:2203.12354 [PRC]

13/18 JET BROADENING FROM π_0-h CORRELATIONS

- High statistics 200 GeV Au+Au data taken in 2014
- Jet-gamma correlations investigated
- I_{AA} = AA/pp away side yield ratio
- Modification of away-side jet particles
  - p_T > 3 GeV/c particles suppressed in jet core
  - 1 < p_T 3 GeV/c particles enhanced away from core
  - p_T < 1 GeV/c particles enhanced at all angles Δφ
- Evidence for broadening of jet
- Momentum transfer from core to low p_T
  - Over large Δφ



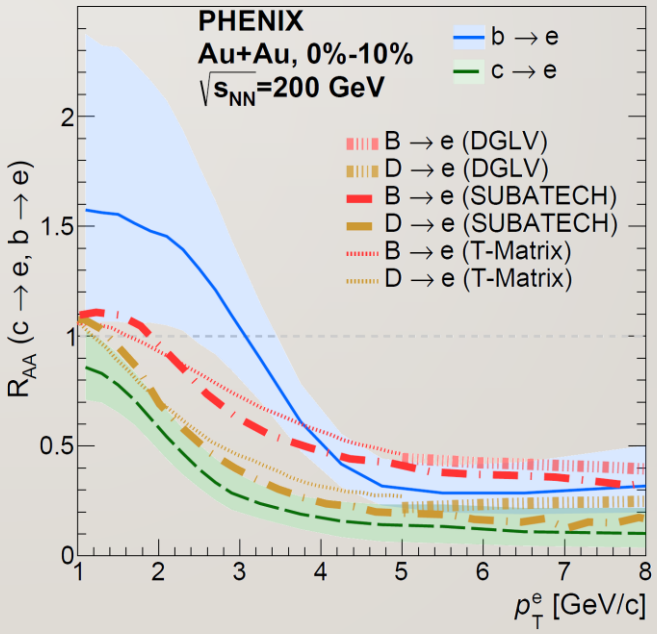


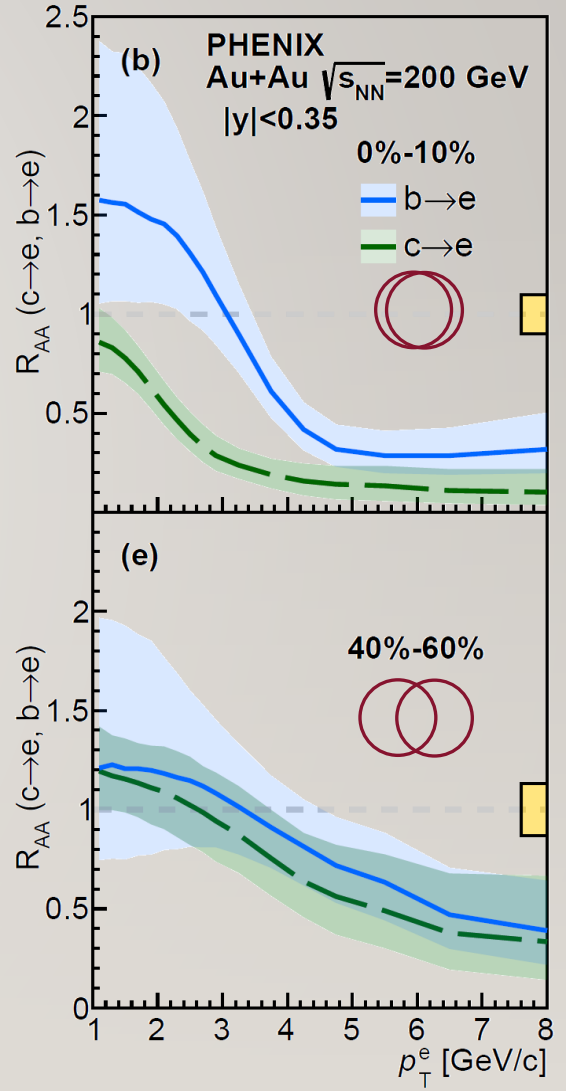


Anthony Hodges
Quark Matter 2022

ENERGY LOSS OF HEAVY QUARKS IN Au+Au

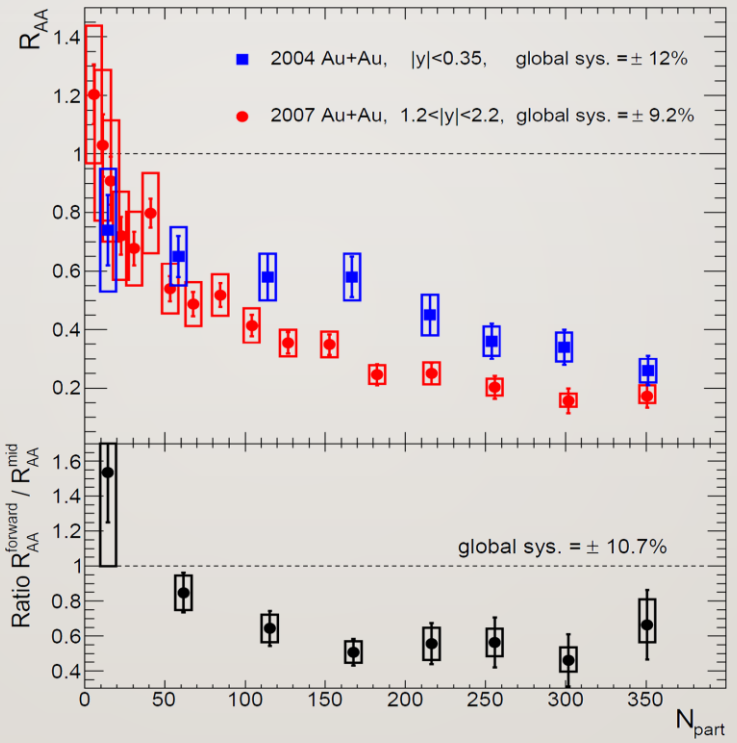
- Unfolding technique to separate electrons from semi-leptonic heavy flavor bottom and charm decays
- Centrality dependent suppression of charm and bottom in Au+Au collision
  - Both charm and bottom are suppressed
  - More suppression in central collisions
  - Charm and bottom similar in peripheral collisions
  - Stronger suppression of charm in central collisions
- Agreement to STAR for MinBias collisions
- Similar mass ordering as expected from models with energy loss in QGP
  - Probably very small diffusion coefficient
- Details in arXiv:2203.17058



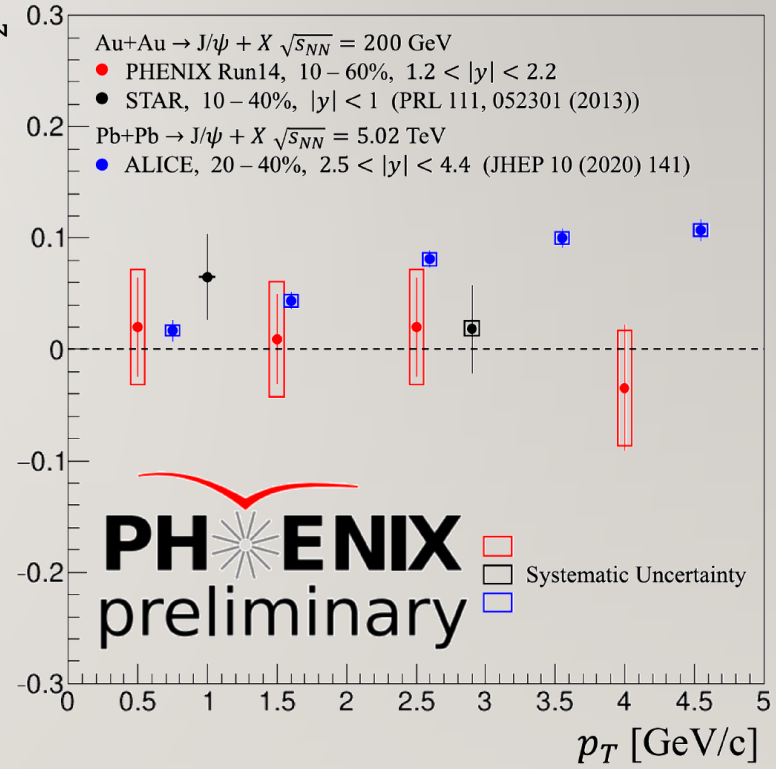


J/Ψ ELLIPTIC FLOW IN Au+Au

- J/ψ R_{AA} measured in 200 GeV Au+Au for midrapidity and forward rapidity, published in 2011
- Measured J/ψ suppression
  - Observed at all rapidities
  - Larger at forward rapidity
- Possible explanation:
  - Recombination at mid rapidity
- Expectation for recombination:
  Flow at midrapidity, but
  no flow in forward direction
- J/ψ v_2 at forward rapidity
  consistent with zero
  - Distinct difference from LHC



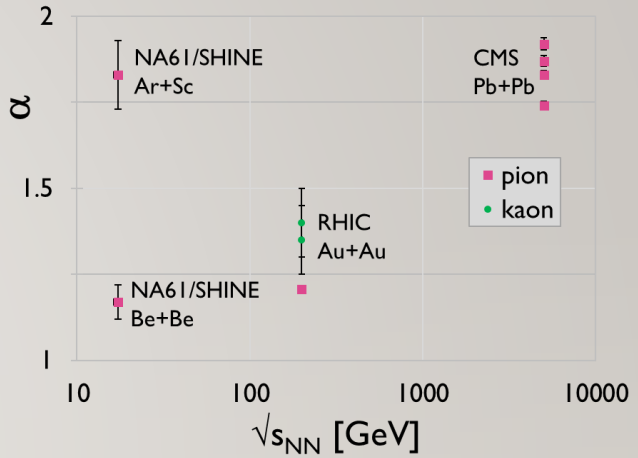
PHENIX PRC 84 (2011) 054912

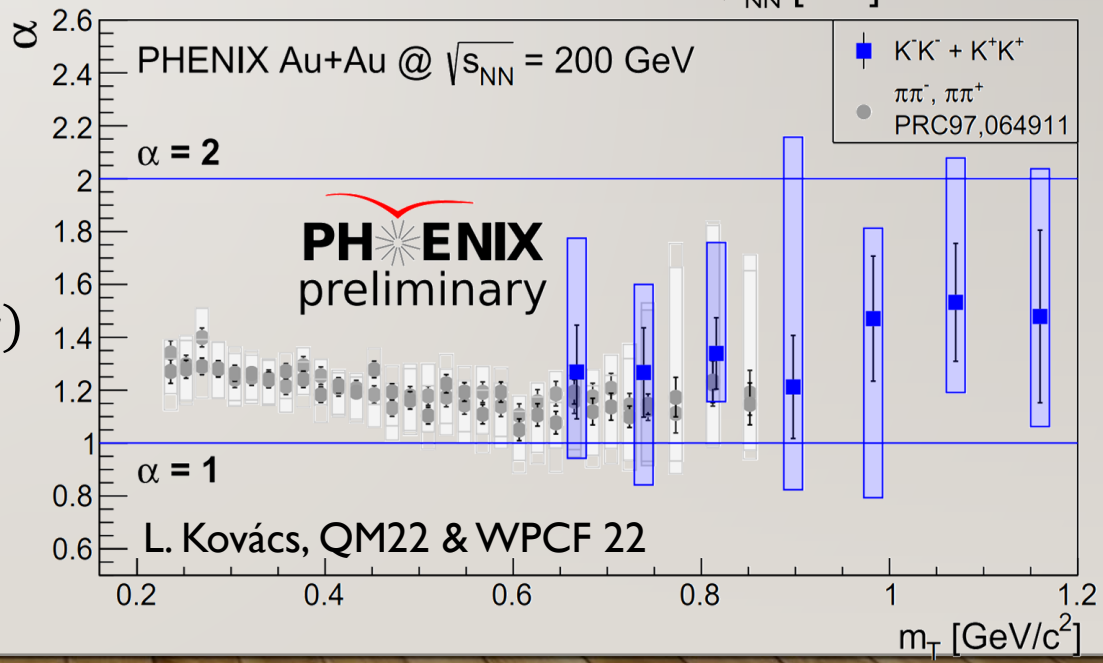


Luis Bichon, Quark Matter 2022

LÉVY HBT MEASUREMENTS

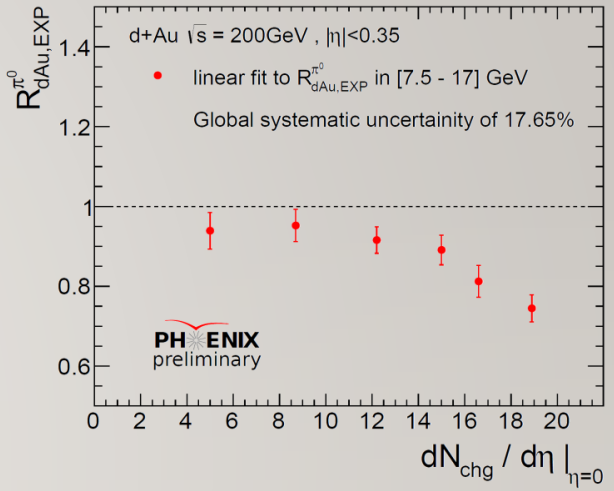
- HBT measurements test source homogeneity lenght and shape
- Lévy assumption with stability index α
  - Generalization of Gaussian ($\alpha = 2$) or Cauchy ($\alpha = 1$) source
  - Possible reasons: anomalous diffusion, critical behavior, QCD jets, resonances, …
- Tested from SPS through RHIC to LHC, also EPOS
- PHENIX measured Lévy α for pions and kaons
  - Pions: Phys. Rev. C97 (2018) 064911
  - Kaons: Preliminary at QM22
- Anomalous diffusion of hadrons suggests $\alpha(K) < \alpha(\pi)$
- Measurement does not confirm this so far
- Many other interesting details → see talk by T. Novák

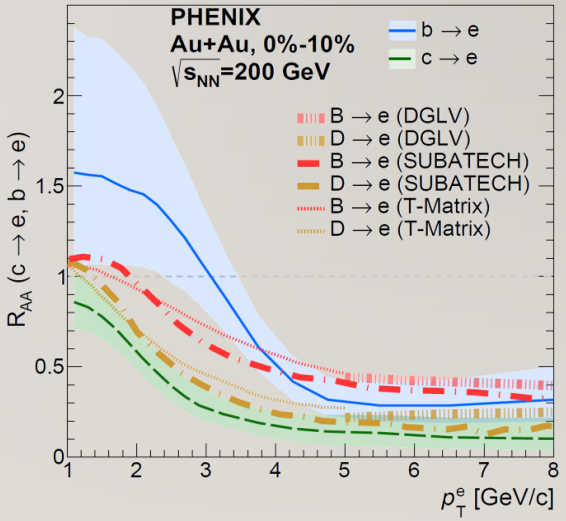


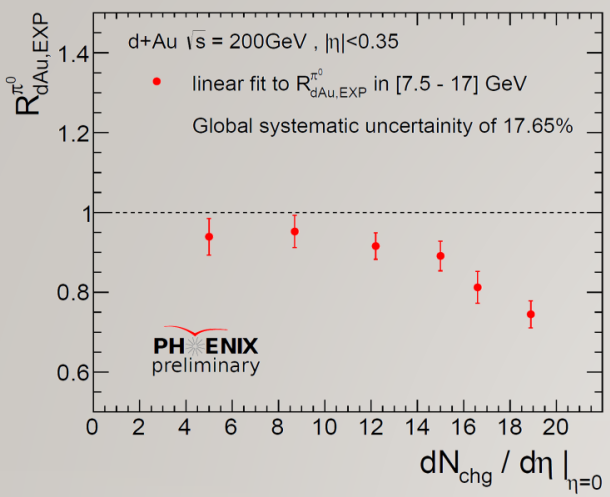


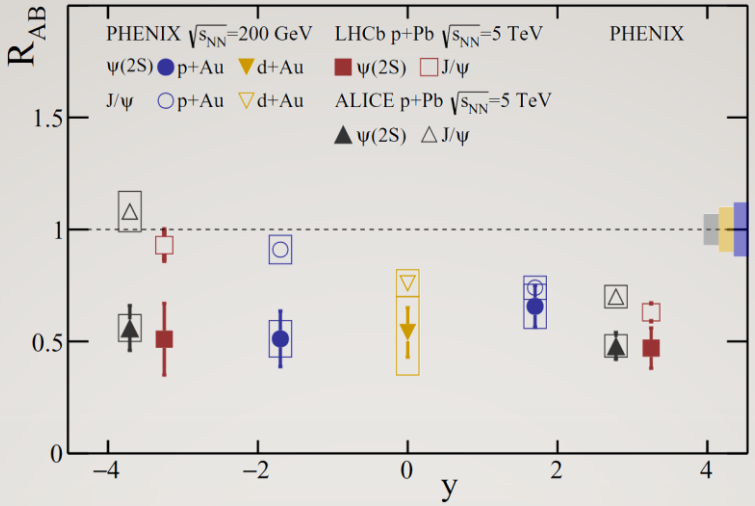
17/18 SUMMARY

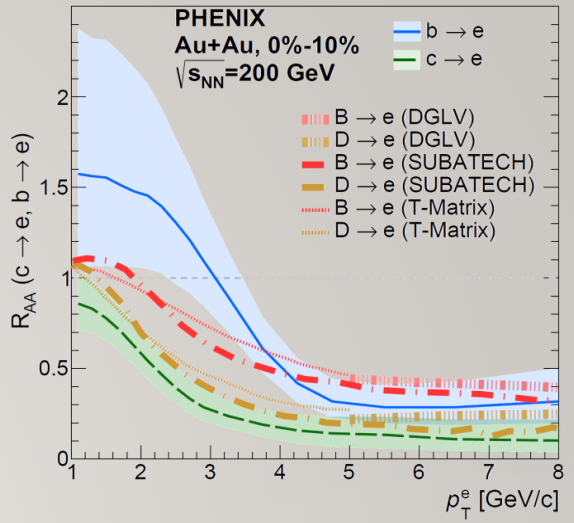
- Data consistent with QGP droplets in small systems with high event activity
  - Geometrical ordering of v_2 and v_3 as expected from hydro calculations, confirmed
  - Possible effect of radial flow seen in hadron spectra in small systems
  - Suppression of π_0 yield at high p_T, direct photon correction for centrality bias
  - Charmonium $\psi(2S)$ suppressed as expected from final state effects
- Detailed study of QGP properties in large systems
  - Quantitative description remains challenging
  - Direct "thermal" radiation: p_T yield scaling, similar T_{eff} from RHIC to LHC
  - Jet broadening & redistribution of energy from jet core
  - Hints of different energy loss for charm and bottom quarks
  - Charmonium J/ψ shows no flow at forward rapidity: recombination
- Numerous analysis ongoing and publications in preparation: thermal photons, heavy flavor, e^+e^-







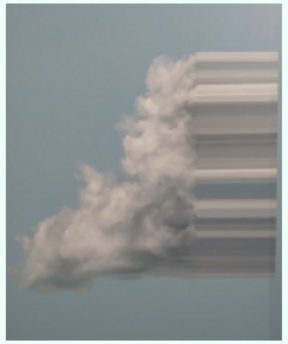




THANK YOU FOR YOUR ATTENTION

IF YOU ARE INTERESTED IN THESE SUBJECTS:

ZIMÁNYI SCHOOL 2022



Andrea Katalin Gulyás: Error 2

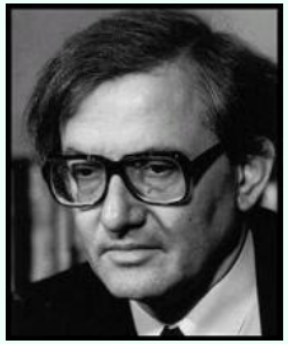
22nd ZIMÁNYI SCHOOL

WINTER WORKSHOP

ON HEAVY ION PHYSICS

December 5-9, 2022

Budapest, Hungary



József Zimányi (1931 - 2006)

http://zimanyischool.kfki.hu/22

BACKUP SLIDES