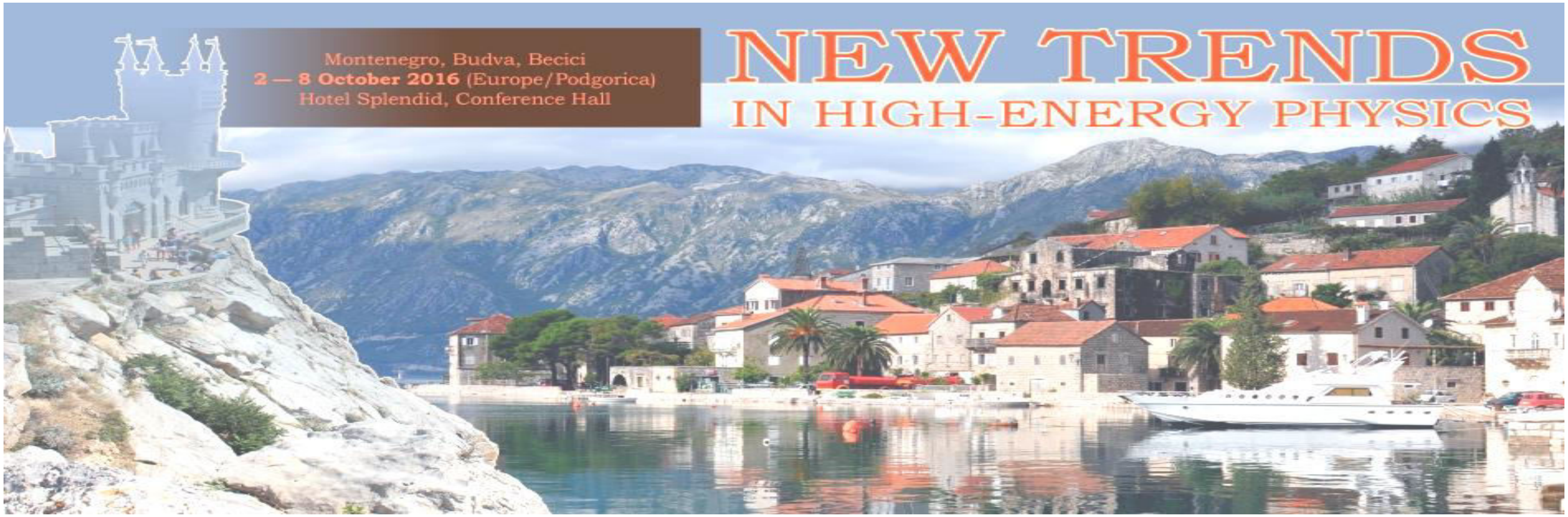
Recent results from PHENIX experiment at RHIC

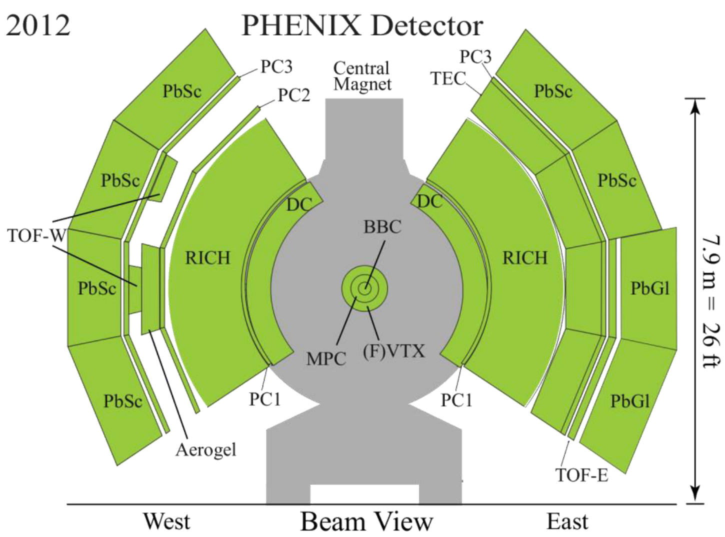
Viktor Riabov, PNPI, Gatchina, Russia
(for the PHENIX collaboration)



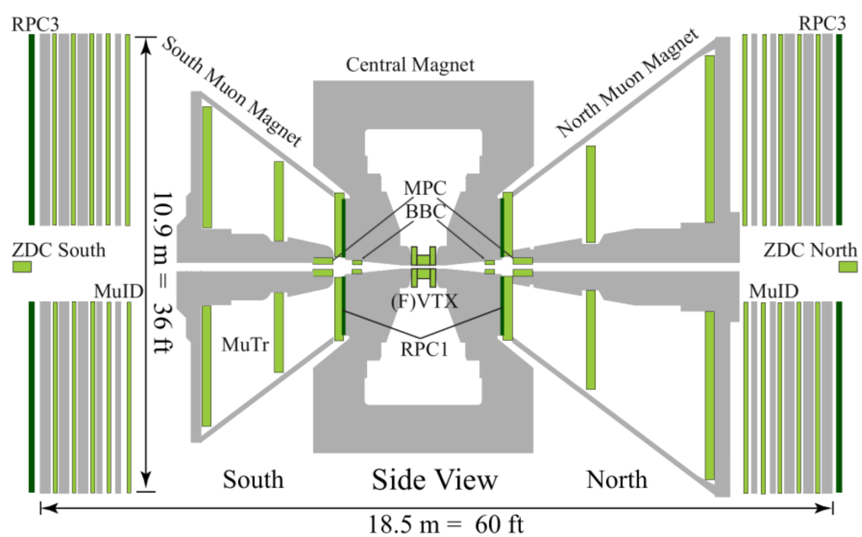
Outline

- Hard probes (jets and leading hadrons at high-p_T):
  - ✓ Jets and π^0 in pp, d(^{3}He)+Au and Cu+Au
  - ✓ γ_{direct} - hadron correlations in pp, d+Au and Au+Au
- Collectivity in small systems:
  - ✓ Long-range correlations and flow in p(d, ^{3}He) + Au
- Quarkonia:
  - ✓ J/Ψ and Ψ' production in p(d, ^{3}He) + A (Al, Au)
  - ✓ B → J/Ψ in pp and Cu+Au

Experimental setup

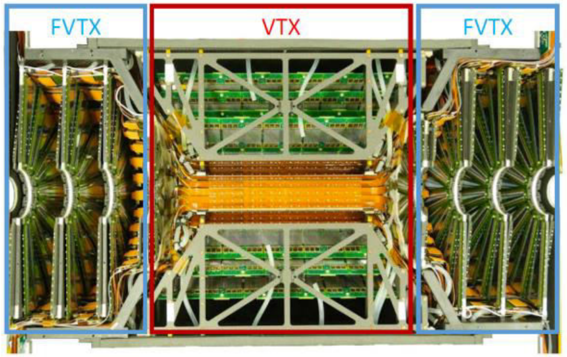


|η|<0.35, Δφ – 2x90°



1.2< η <2.2, Δφ – 360°

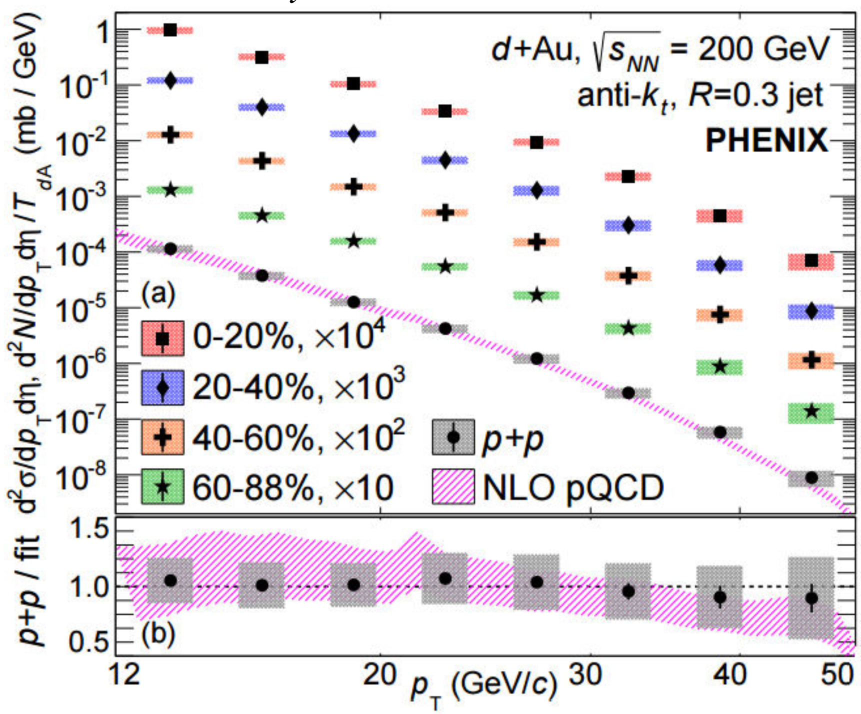
- Vertex and centrality: BBC
- Charged particle tracking: DC and PC
- Calorimetry: EMCal consisting of PbSc and PbGl
- Vertex silicon detectors:
  - ✓ VTX (from 2011): 4 layers (2 pixels + 2 strips), $\Delta\varphi = 2\pi$, $|\eta| < 1.2$
  - ✓ FVTX (from 2012): 4 layers (mini-strips), $\Delta\varphi = 2\pi$, $1.2 < |\eta| < 2.2$
  - ✓ Improve tracking; DCA measurement to separate charm and bottom



Hard probes in PHENIX

Jets in pp and d+Au at $\sqrt{s_{NN}}$ = 200 GeV

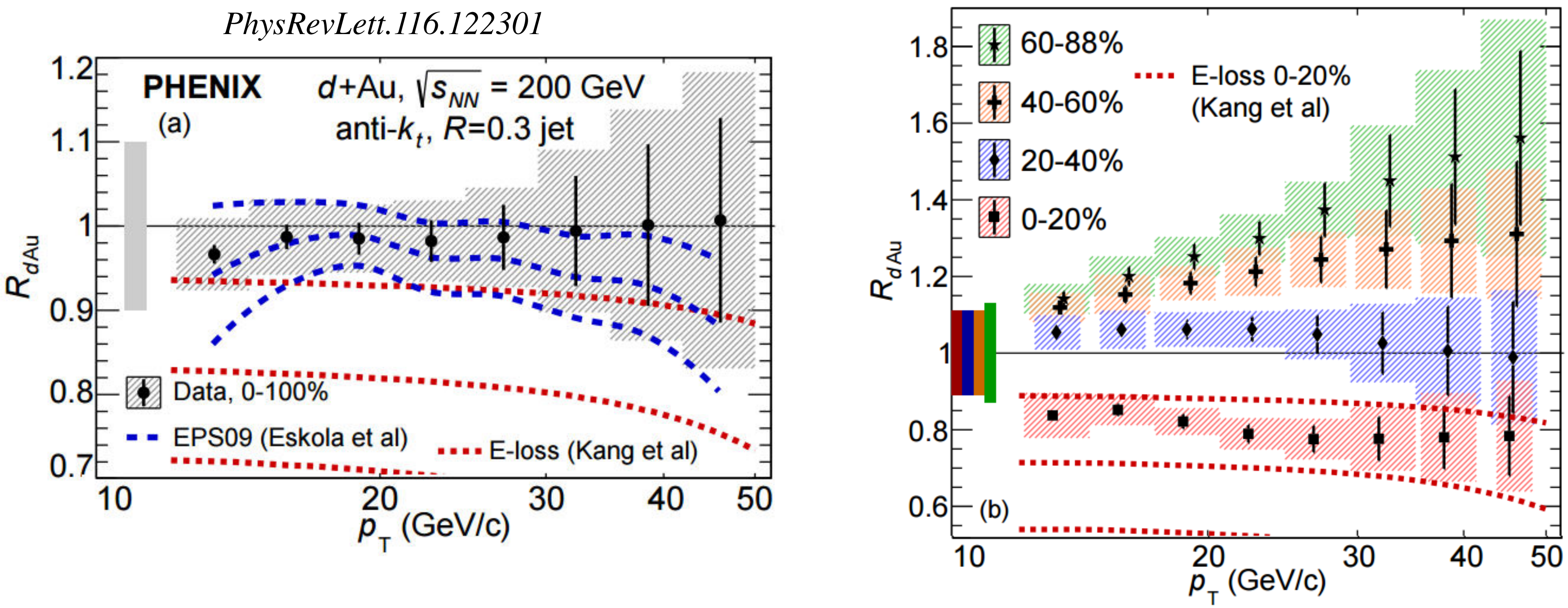
PhysRevLett.116.122301



- Jets are measured using anti-k_T algorithm with R = 0.3 using central arm tracking (DC-PC) and calorimetry (EMCal)
- Results in pp are well reproduced with NLO pQCD (NLOJET++ with NNPDF2.3)
- Understand jet production in elementary collisions

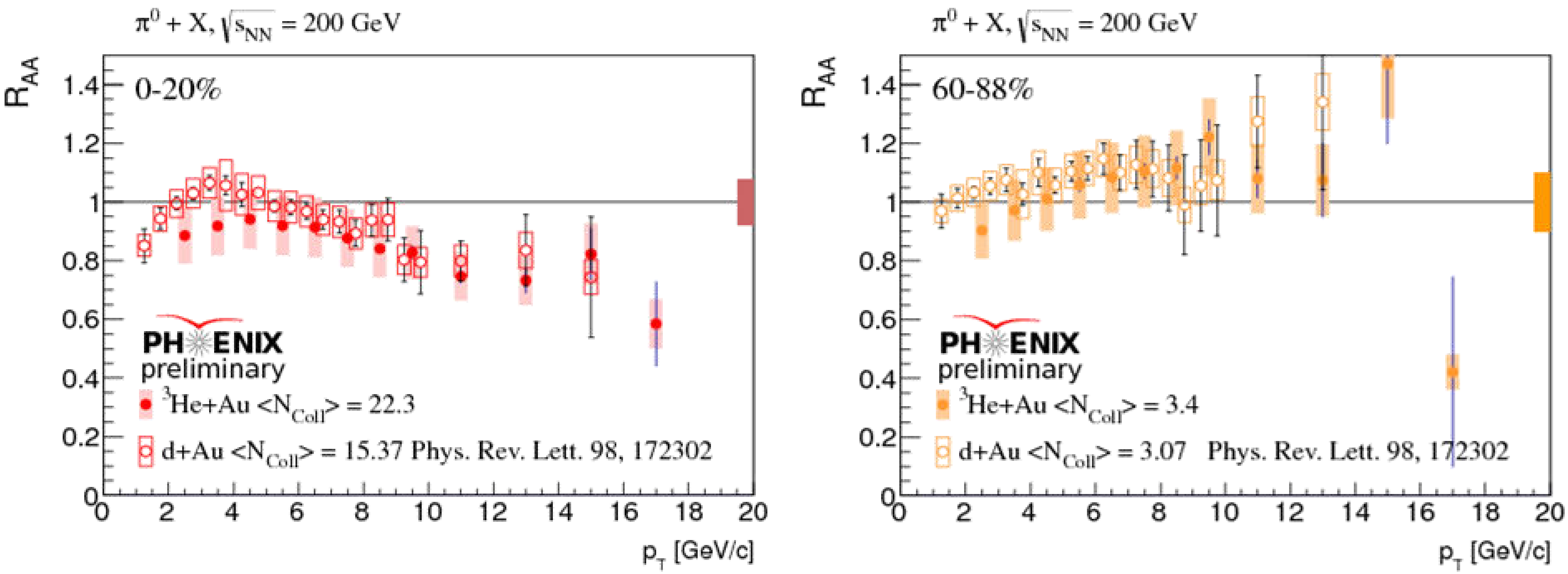
Jets in d+Au, $\sqrt{s_{NN}}$ = 200 GeV

PhysRevLett.116.122301



- Nuclear effects are studied with $R_{AA}(p_T) = \dfrac{Yield_{A-A}(p_T)}{Yield_{pp}(p_T) \cdot N_{coll}}$
- Jets scale with N_{coll} in minbias collisions, no sign of energy loss
- Surprising centrality dependence, R_{dAu} changes from suppression to enhancement
- Similar to ATLAS observations in p+Pb @ 5.02 TeV (PLB 748 (2015) 392)

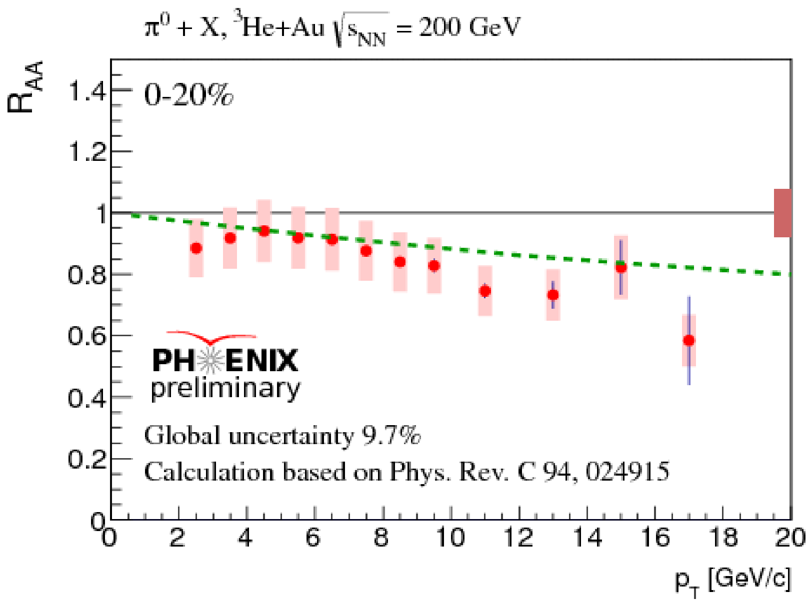
π^0 in d+Au and ^{3}He+Au, $\sqrt{s_{NN}}$ = 200 GeV

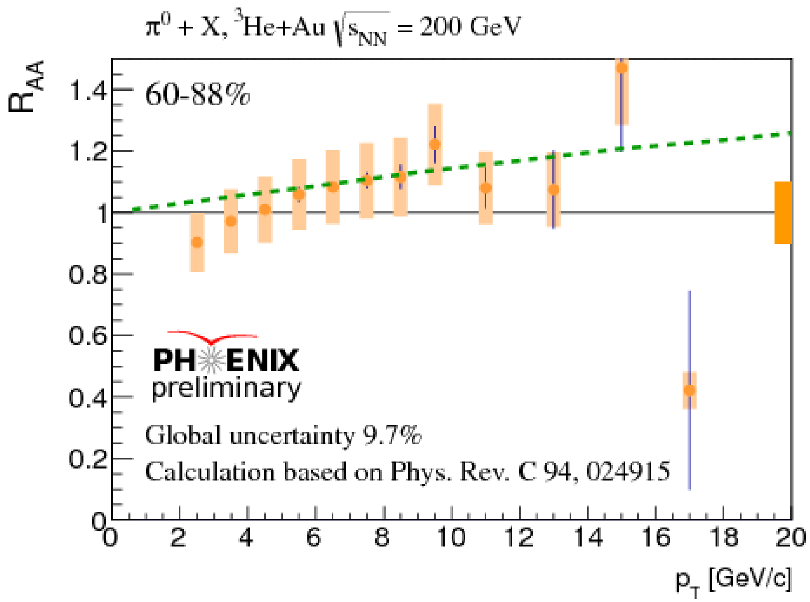


- R_{AA} values measured for π^0 in ^{3}He+Au and d+Au are consistent
- R_{AA} for π^0 at high p_T shows a similar trend as jets in d+Au:
  - ✓ R_{AA} (central) < R_{AA} (peripheral)

Centrality dependence of R_{pA}

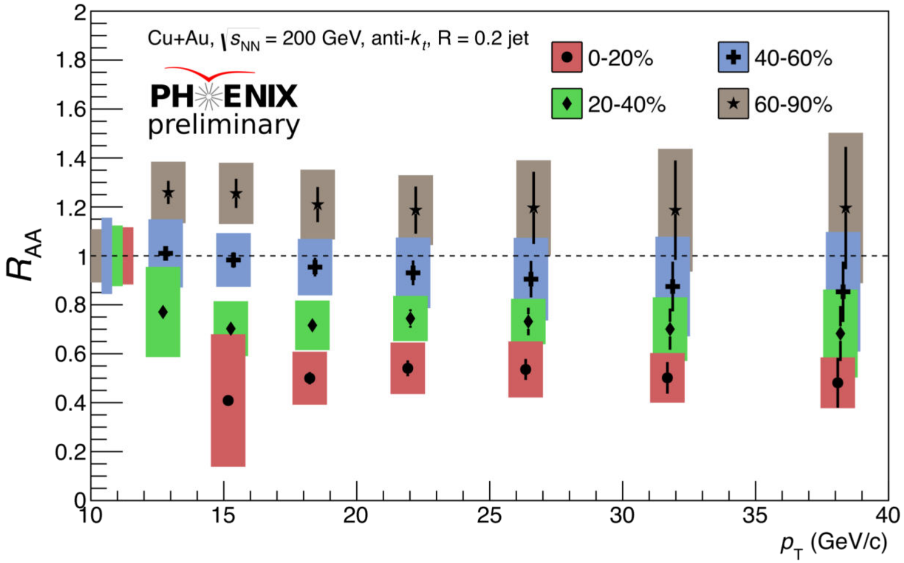
- Centrality dependence of R_{pA} results for jets and π^0 presents a challenge for conventional models
- Dispersion can be explained as a bias in centrality determination from "smaller" protons with a high-x parton.

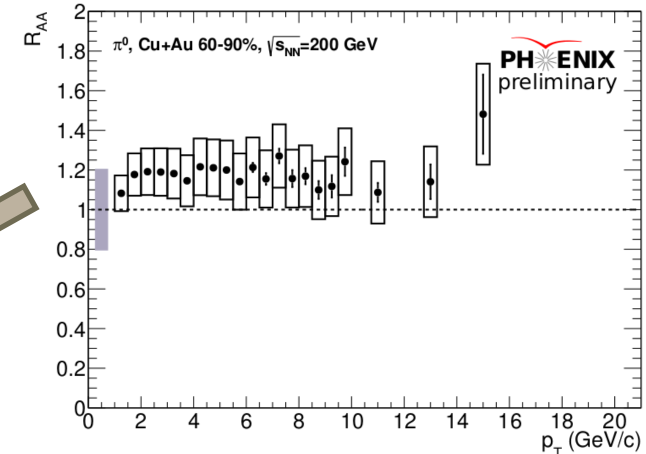


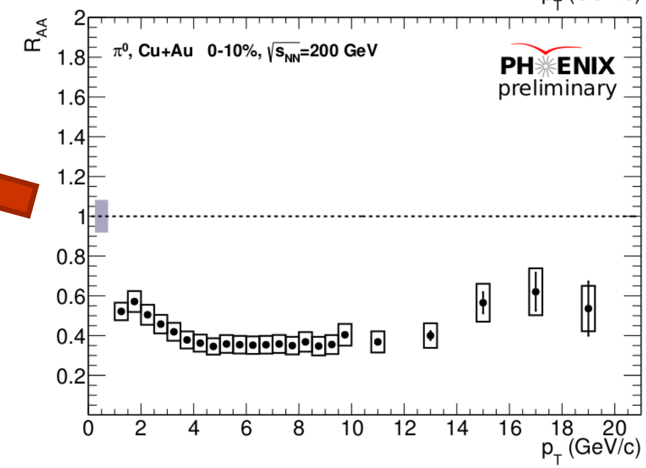


Jets and π^0 in Cu+Au, $\sqrt{s_{NN}}$ = 200 GeV

See talk by D. Kotov: "PHENIX Results on Leading Particles and Jets Measured in Cu+Au Collisions at RHIC"

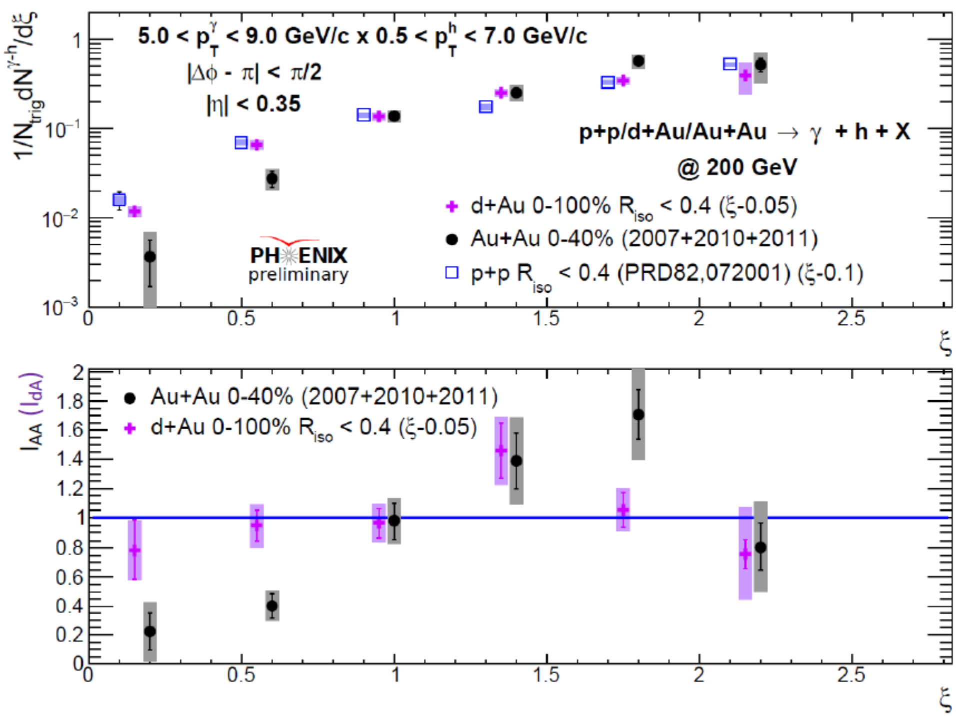






- Production of jets and π^0 is suppressed by a factor of two in central collisions
- Hint of enhancement in most peripheral collisions for both observables
- Very weak p_T dependence of R_{AA} for jets;
  similar to the LHC results in Pb-Pb @ 2.76 TeV (Phys.Lett. B746 (2015) 1-14)

γ_{direct}-h correlations: pp, d+Au and Au+Au, $\sqrt{s_{NN}}$ = 200 GeV



- γ_{direct}-h correlations:
  - ✓ no surface bias
  - ✓ trigger γ_{direct} is the most direct measure of the initial parton energy

$$z_T = \frac{p_T^h}{p_T^\gamma} \qquad \xi = \ln\left(1/z_T\right)$$

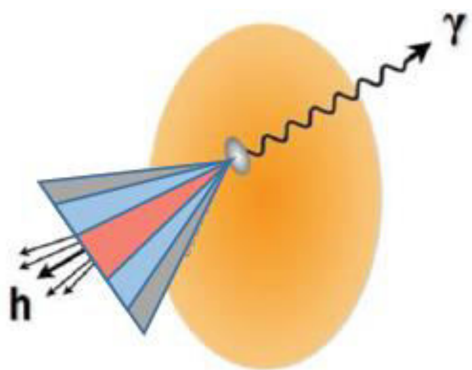
$$D_q(z_T) = \frac{1}{N_{evt}} \frac{dN(z_T)}{dz_T}$$

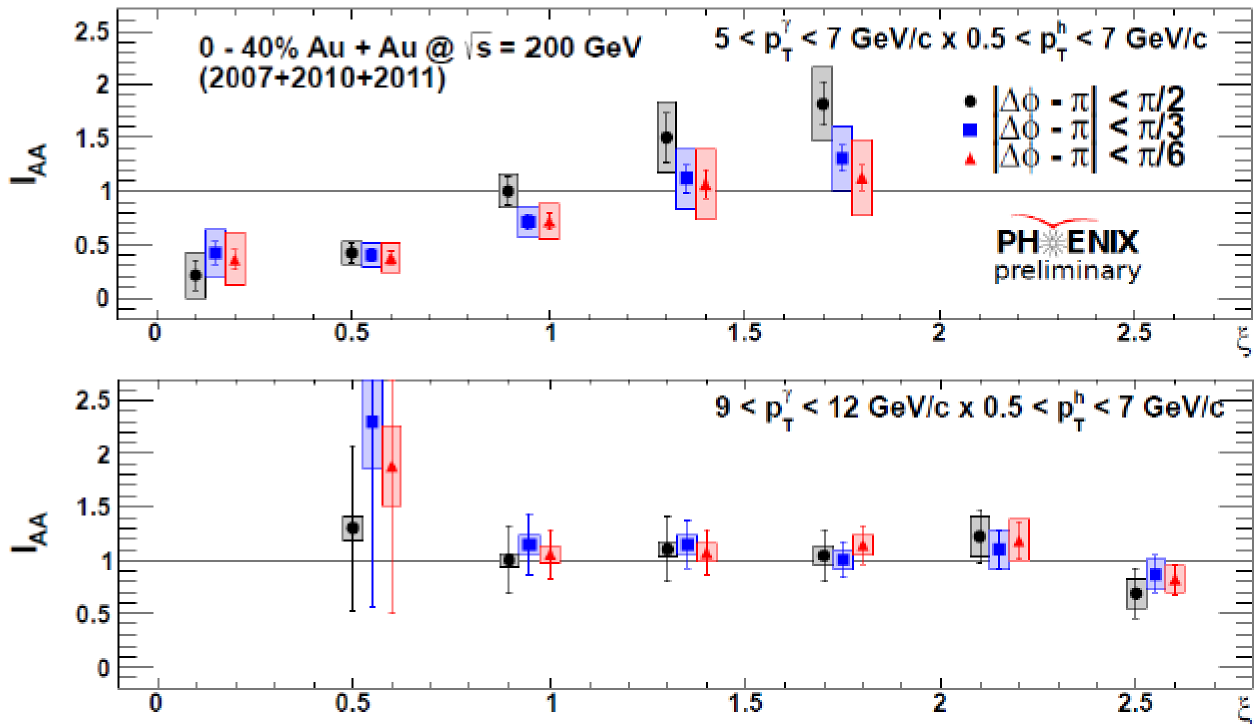
- Experimentally measure:

$$Y_{AA}(\Delta\varphi) = \frac{1}{N_{trig}^\gamma} \frac{dN^{\gamma-h}}{d\Delta\varphi} \qquad I_{AA} = \frac{Y_{AA}}{Y_{pp}} \sim \frac{D_{AA}(z_T)}{D_{pp}(z_T)}$$

- In d+Au no modification is observed within uncertainties
- In Au+Au observe suppression at low-ξ and enhancement at high-ξ
- Transition from suppression to enhancement occurs at ξ ~ 1.2

γ_{direct}-h correlations: Au+Au, $\sqrt{s_{NN}}$ = 200 GeV



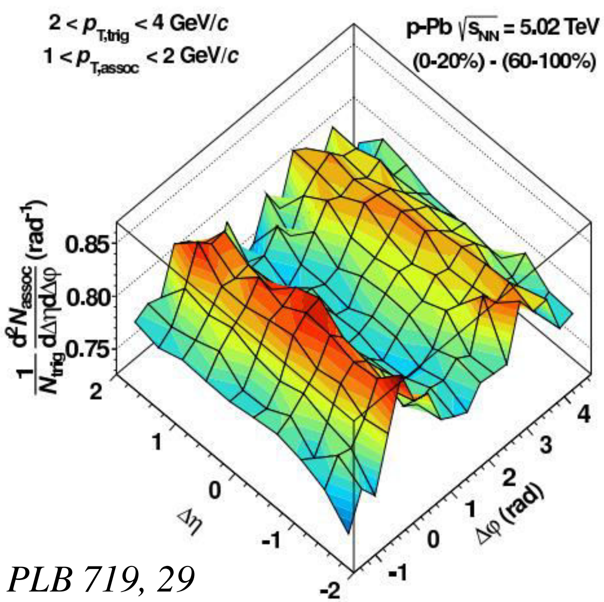


- Observed modifications in Au+Au are specific to the softest jets; modifications are most prominent for wider away-side integration region
- For hard jets observe no significant dependence on integration region; consistent with minimal jet shape modifications in Pb+Pb collisions @ 2.76 TeV (JHEP 1403 (2014) 013)

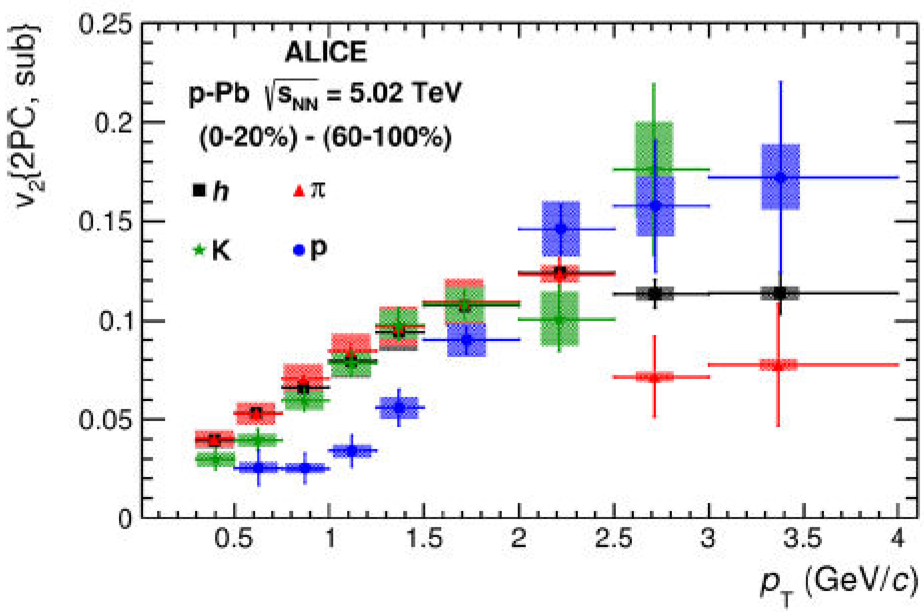
Collectivity in small systems

Paradigm of small systems

- Observation of flow in heavy-ion collisions became one of the most convincing evidences for the formation of strongly coupled Quark-Gluon Plasma (sQGP)
- Small systems were considered as “too small” to produce QGP and were used to establish a reference baseline (p+p) or study cold nuclear matter effects (p+A)
- Observation of long range correlations and mass dependent elliptic flow for identified hadrons in p+p/p+Pb collisions at the LHC changed this paradigm

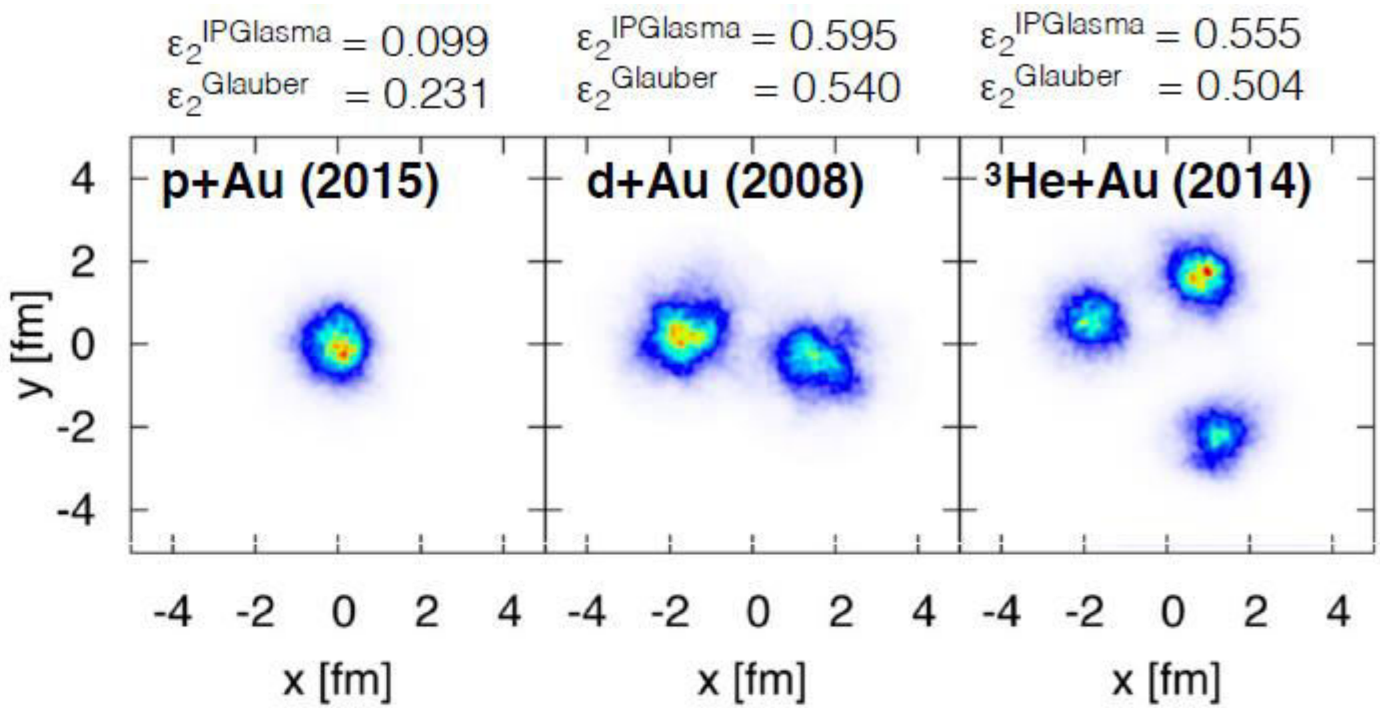


PLB 719, 29

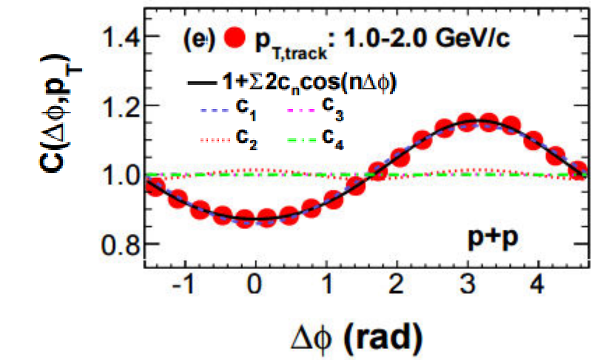


Geometry engineering

- Interpretation of long-range correlations in small systems requires understanding of how initial geometry is transformed into final state momentum correlations
- Geometry engineering is a unique capability of the RHIC



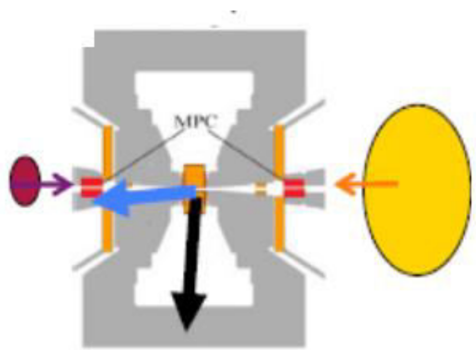
Long-range correlations at RHIC: p+Au, d+Au, ^{3}He+Au at $\sqrt{s_{NN}}$ = 200 GeV

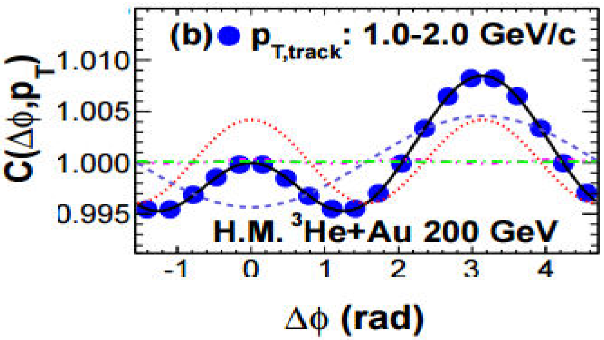


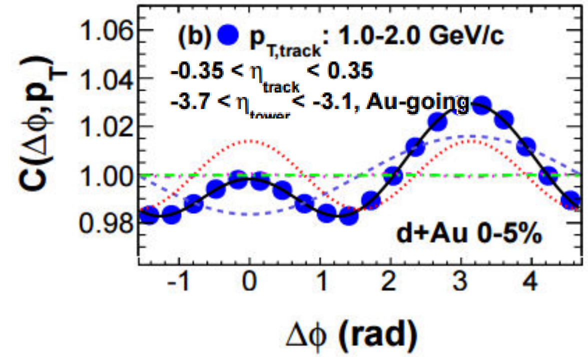
Phys.Rev.Lett. 114, 192301

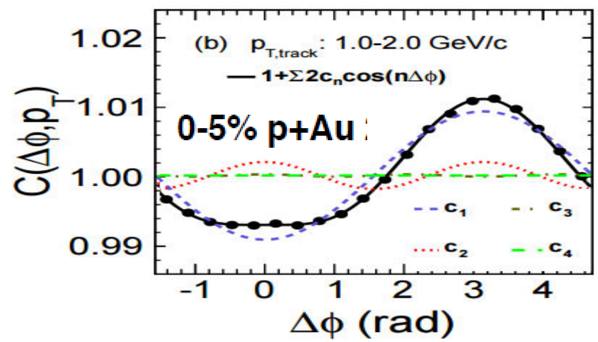
Phys.Rev.Lett. 115, 142301

arXiv:1609.02894



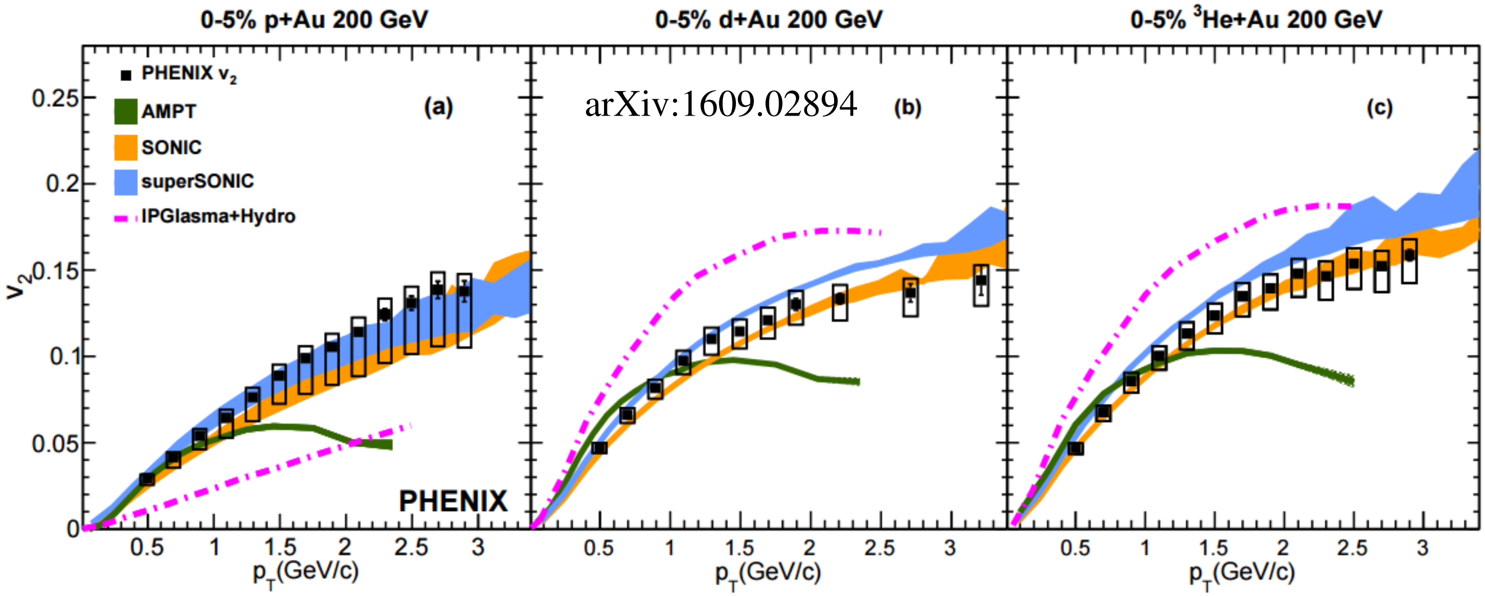






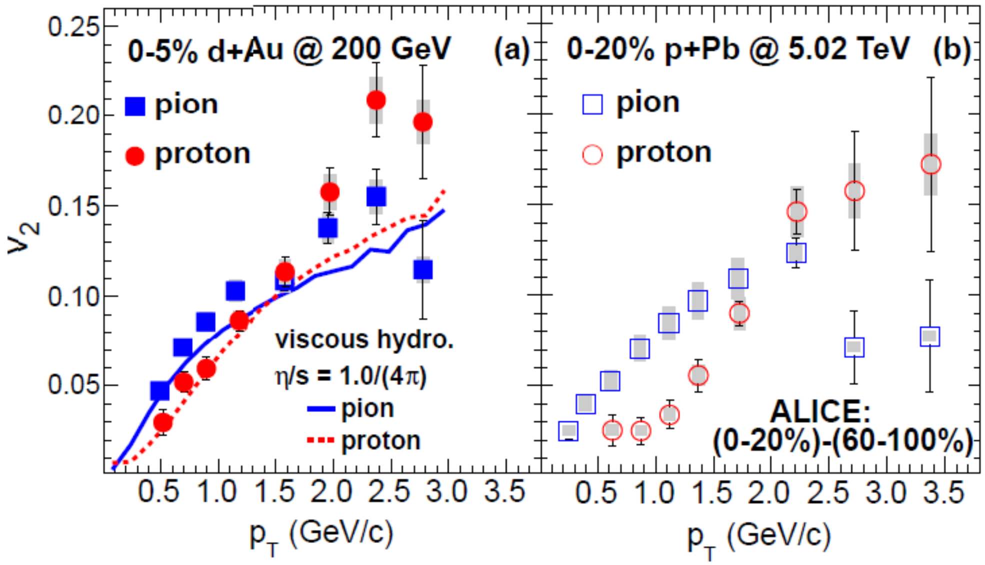
- The azimuthal correlation functions $C(\Delta\phi, p_T)$ between charged tracks ($|\eta|<0.35$) and signals in forward detectors ($|\eta| > 3$)
- Fit to four-term Fourier cosine expansion: $f(\Delta\phi) = 1 + \sum_{n=1}^{4} 2c_n(p_T)\cos(n\,\Delta\phi)$
- Long-range ($|\Delta\eta| > 2.75$) correlations are observed in 5% top-multiplicity p+Au, d+Au and ^{3}He+Au collisions but not in minbias p+p

Elliptic flow, model comparison

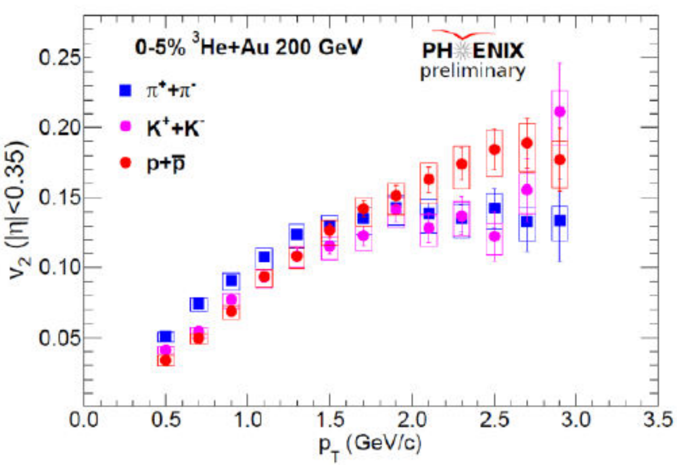


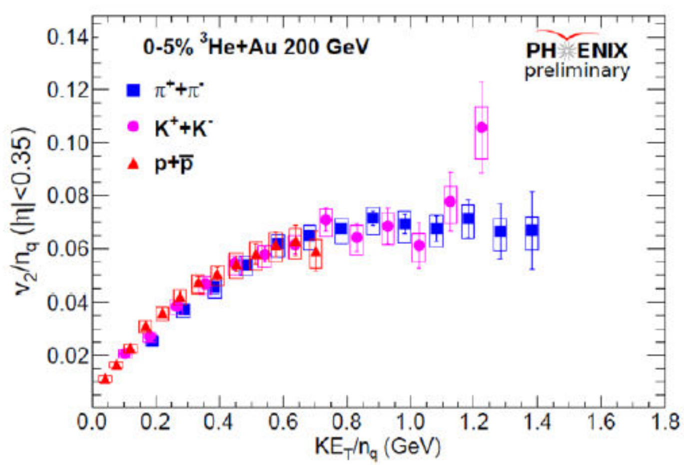
- Substantial v_2 is measured for charged hadrons in 0-5% p+Au, d+Au and ^{3}He+Au
- Asymmetric systematic uncertainties account for non-flow contributions
- Model comparison:
  - ✓ ***SONIC***: hydrodynamic model, standard Monte Carlo Glauber initial conditions followed by viscous hydrodynamics with $\eta/s = 0.08$, and a transition to a hadronic cascade at T = 170 MeV
  - ✓ ***superSONIC***: additionally incorporates pre-equilibrium dynamics
    → good description of data
  - ✓ ***AMPT*** (A-Multi-Phase-Transport Model): combines partonic and hadronic scattering
    → describes data up to 1 GeV/c
  - ✓ ***IP-Glasma + Hydro***:
    → overpredicts d+Au, ^{3}He+Au while underpredicts p+A

Elliptic flow, identified hadrons



- Observe mass ordering of elliptic flow for identified hadrons in d+Au and ^{3}He+Au similar to that previously observed in p+Pb at the LHC (Phys.Lett. B726 (2013) 164-177)
- Elliptic flow follows n_q-scaling similar to that in A+A
- Measurements are consistent with predictions of hydrodynamic models



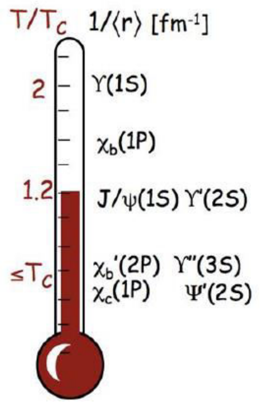


Another strong indication of collectivity in small systems at RHIC

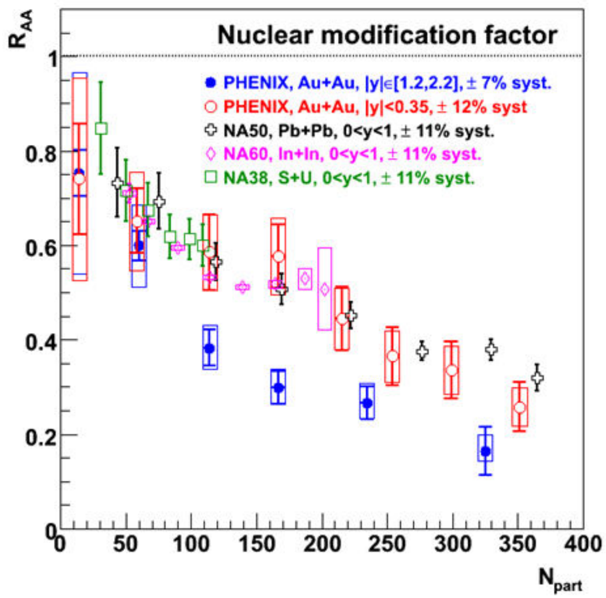
Quarkonia

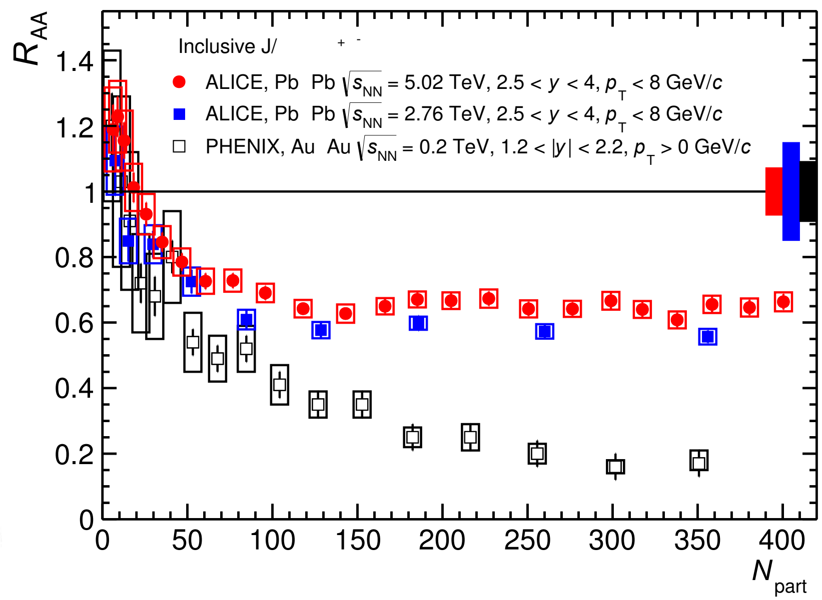
Quarkonia as probes of deconfinement

- Original idea of color screening by Matsui and Satz, 1986:
  - ✓ sequential melting of quarkonium states
  - ✓ relative yield measurements can be used as QGP thermometer



- Real life turned out to be more complicated:
  - ✓ J/Ψ suppression does not increase with collision energy SPS → RHIC → LHC





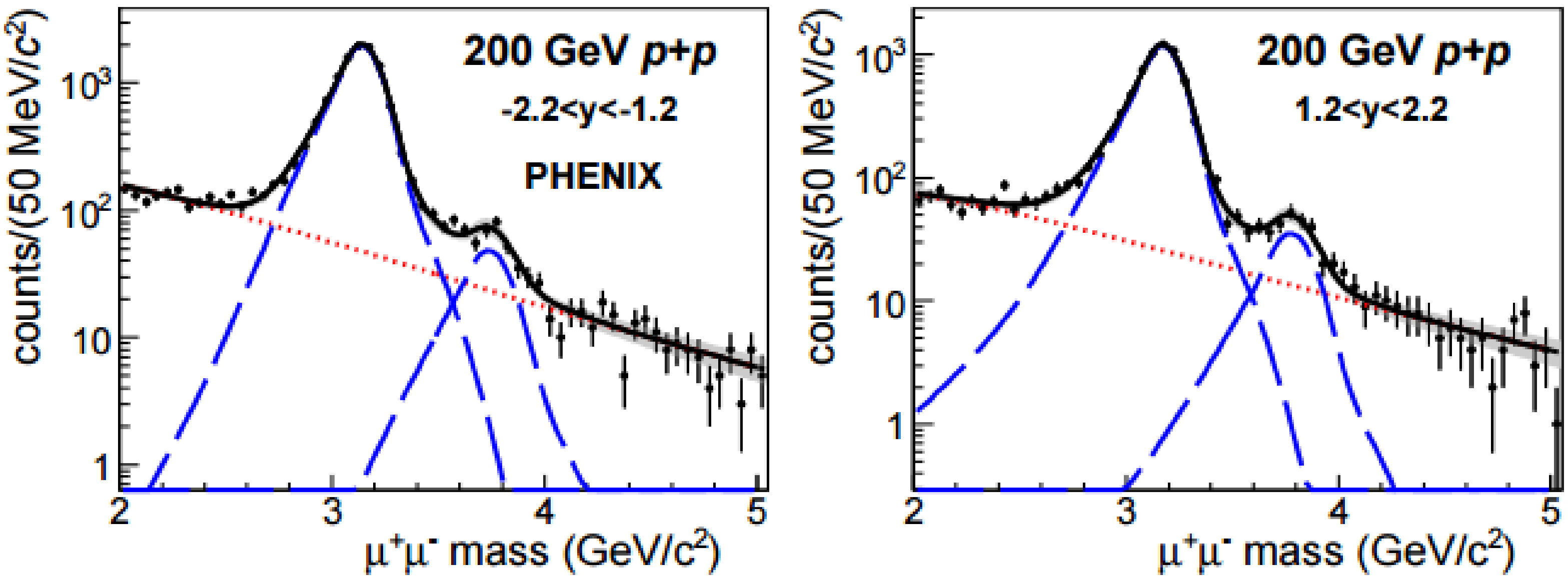
- Need to account for many effects:
  - ✓ recombination of open charm; the higher the energy the larger the contribution
  - ✓ nPDF, nuclear absorption and co-mover dissociation

- So far no agreed interpretation of results

Charmonium in pp at $\sqrt{s}$ = 200 GeV

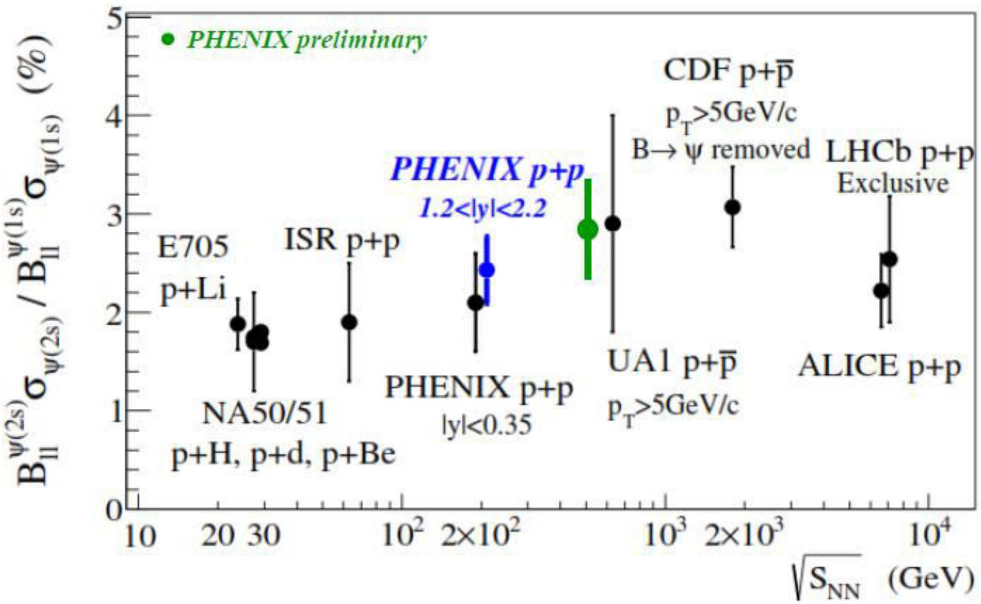
- Measurements at forward rapidity in $\mu^+\mu^-$: $1.2 < |y| < 2.2$
- Mass resolution with FVTX is good enough to resolve J/Ψ and Ψ’
- J/Ψ and Ψ’ yields are consistent between forward and backward rapidity

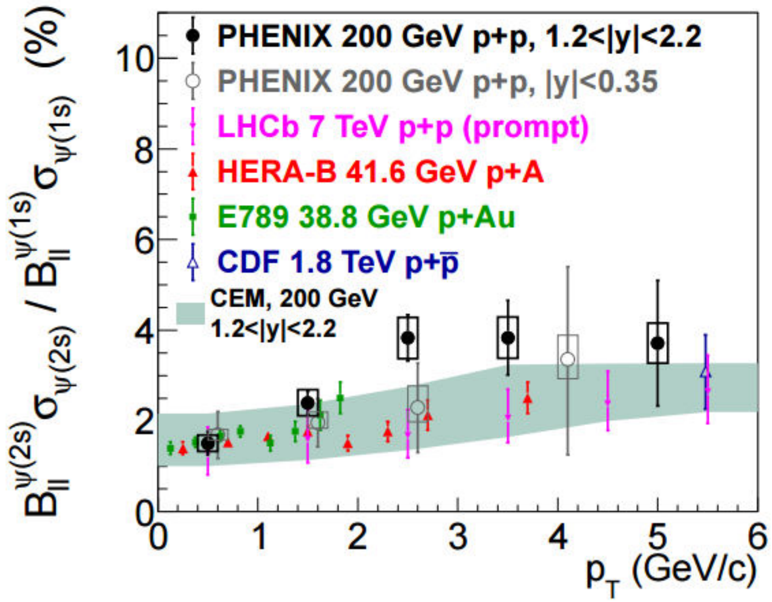
arxiv:1609.06550



J/Ψ to Ψ’ ratio in pp at √s = 200 GeV

arxiv:1609.06550



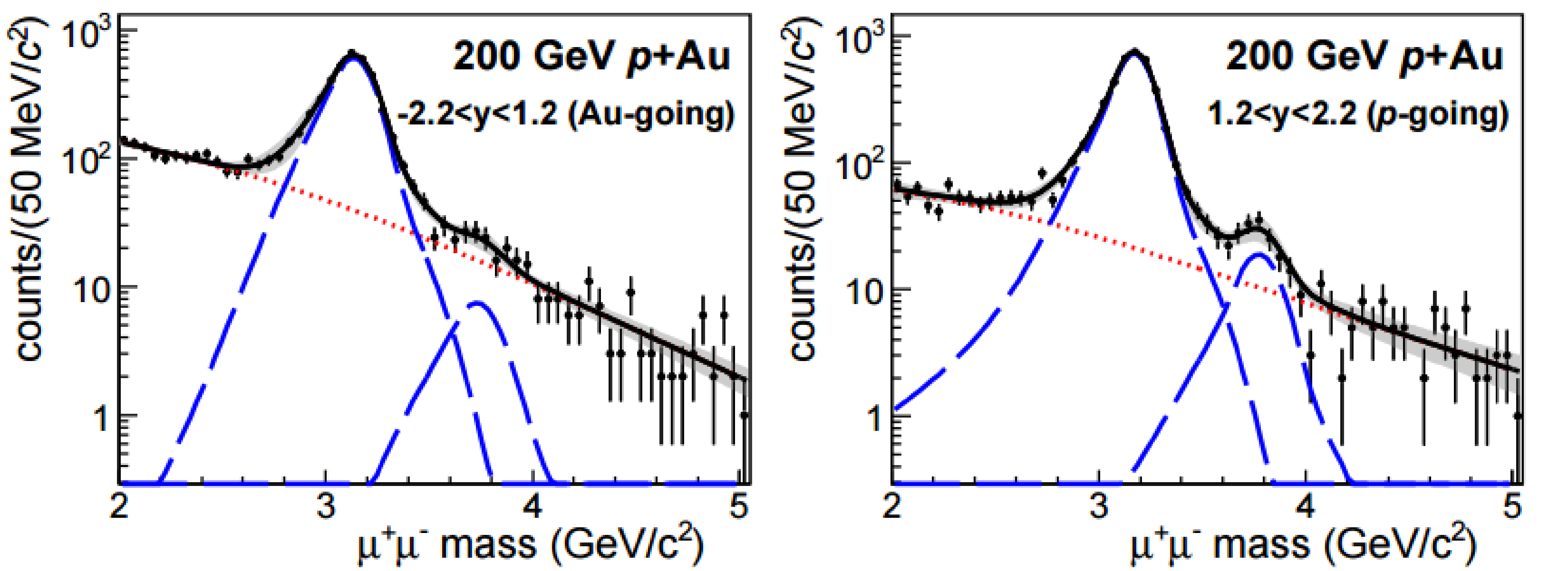


- Baseline measurements for p+Au p+Al and ^{3}He+Au
- Ratio agrees to the world data
- Weak dependence on collision energy, rapidity and p_T
- Small deviation in p_T dependence at 2-3 GeV/c could be related to bottom feed down

Charmonium p+Au at √s = 200 GeV

- Measurements at forward rapidity in $\mu^+\mu^-$: $1.2 < |y| < 2.2$
- J/Ψ yields are consistent between forward and backward rapidity
- Ψ' yield is suppressed at backward (Au-going) rapidity
- Similar situation in p+Al and ^{3}He+Au collisions

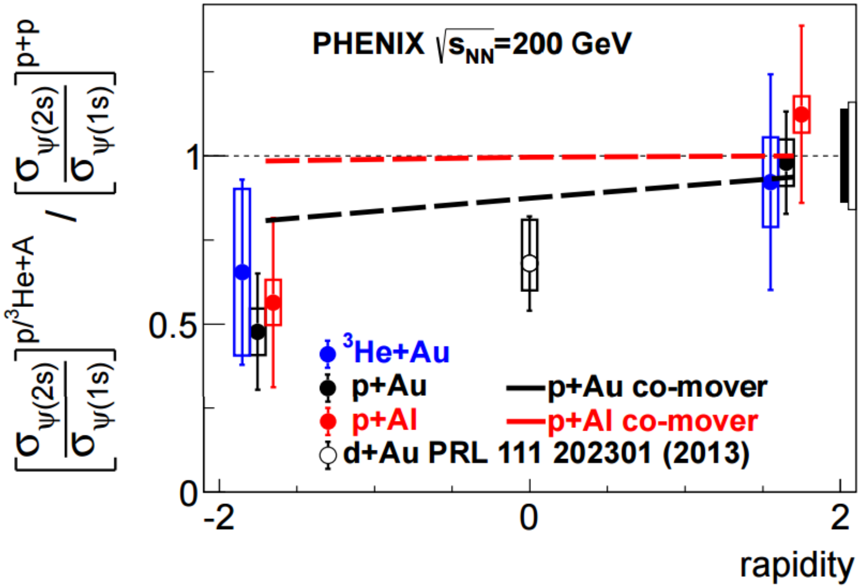
arxiv:1609.06550

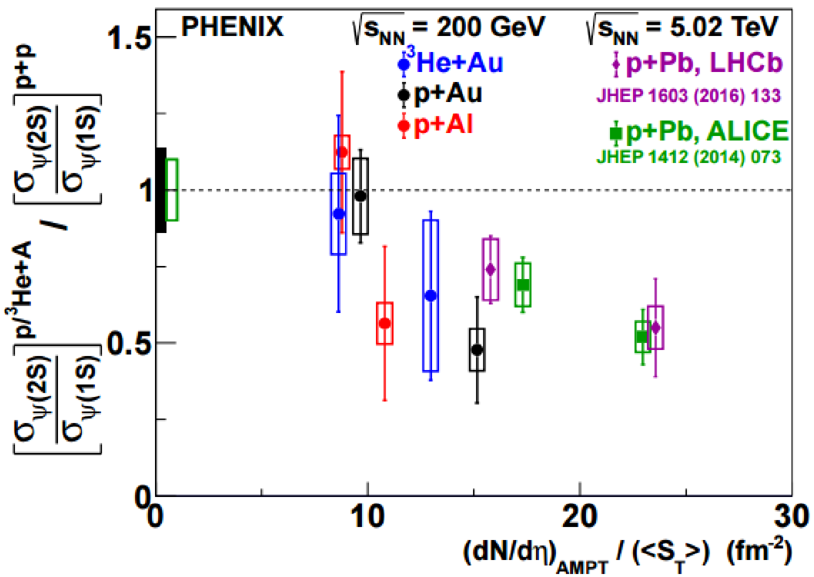


Ψ' to J/Ψ ratio in small systems at √s = 200 GeV

- Double ratio, $[\Psi'/ J/\Psi]_{p+A}$ to $[\Psi' / J/\Psi]_{p+p}$ cancels out systematic uncertainties
- Ψ' / J/Ψ ratio is unchanged in p(^{3}He)-going direction
- Ψ' / J/Ψ ratio is suppressed by a factor of ~2 in Au-going direction
- J/Ψ and Ψ' are $c\bar{c}$ pairs with different binding energies of ~ 640 and ~ 50 MeV
- Plotted vs. co-moving particle density shows common behavior at RHIC and the LHC
- Note suppression in p-going direction in p+Pb
- Understanding suppression due to co-movers could play a critical role in interpreting quarkonia data from A+A collisions.

arxiv:1609.06550





Summary

- ✓ R_{AA} for jets shows surprising centrality dependence in small systems: enhancement in peripheral collisions and suppression in central
- ✓ Modification of effective fragmentation function is observed in Au+Au collisions using γ_{direct} – h correlations. No modification is observed in d+Au collisions
- ✓ Ψ' / J/Ψ ratio show a factor of two suppression in Au-going direction in small systems. Stronger Ψ' suppression is consistent with co-mover dissociation.
- ✓ Observed long-range correlations and flow in small systems provide strong indication of collectivity

Backup slides