Hot results from PHENIX

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for the PHENIX collaboration

15 papers published since the last User meeting

Two pillars in the PHENIX experimental program: Spin and Heavy-ions

Today's talk:

Spin:

- Zoom in on gluons' contribution to proton spin with A_{LL} measurements
- The polarized sea quark and anti-quark distributions from $W^{+/-}$ A_L
- A_N of forward neutrons: surprises from first polarized p+A collisions !

Heavy-ion physics:

- Microscopic structure probed with charm, bottom, and jets
- System evolution puzzles:
  - Large direct photon flow in Au+Au
  - Flow in small systems

The proton spin puzzle

Know very little

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \boxed{\Delta L_q + \Delta L_g}$$

~0.33 (small)

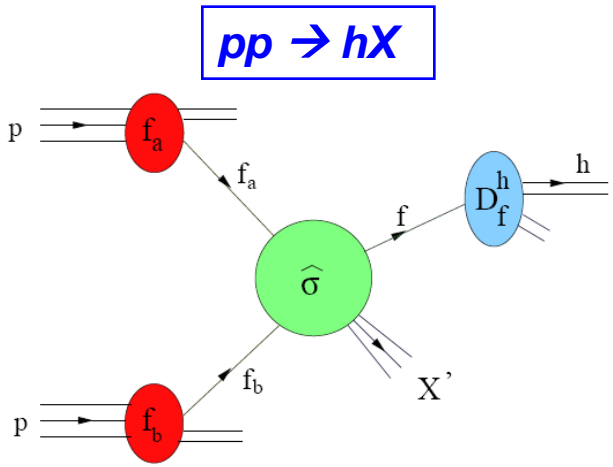
Poorly constrained

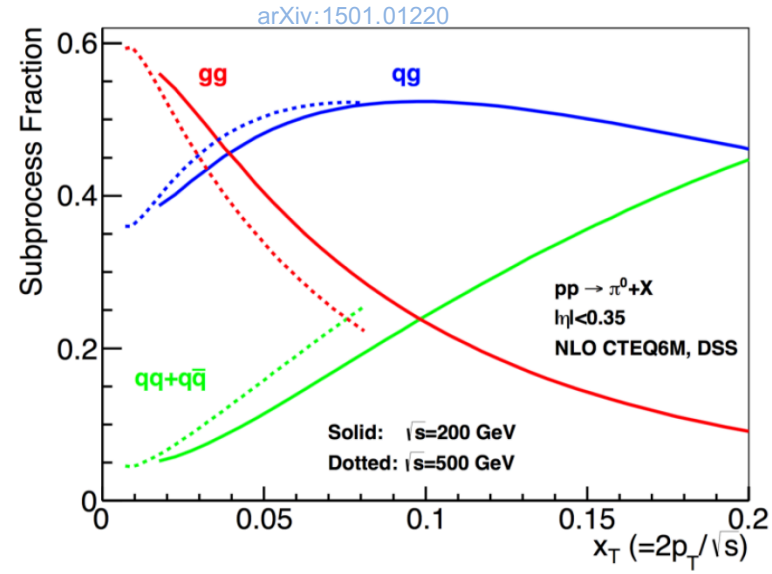
$$\Delta\Sigma = \Delta u + \Delta d + \boxed{\Delta\bar{u} + \Delta\bar{d} + \ldots}$$

Poorly constrained

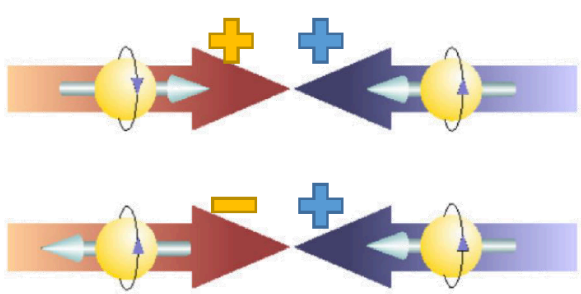
How much of the proton spin is carried by gluons ?

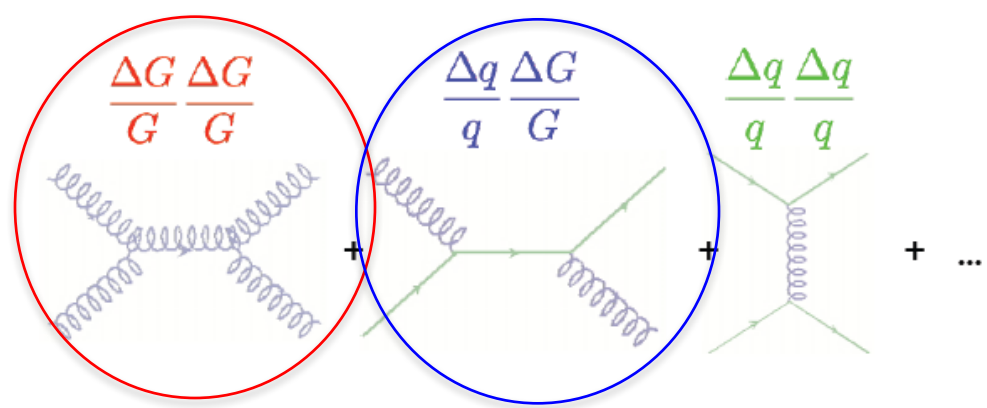
Probing ΔG in polarized pp collisions with π^0 A_{LL}



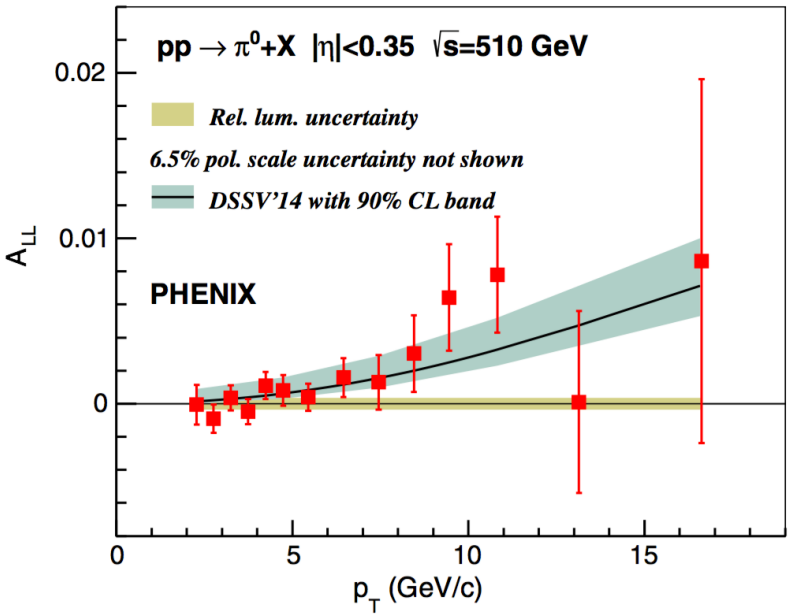


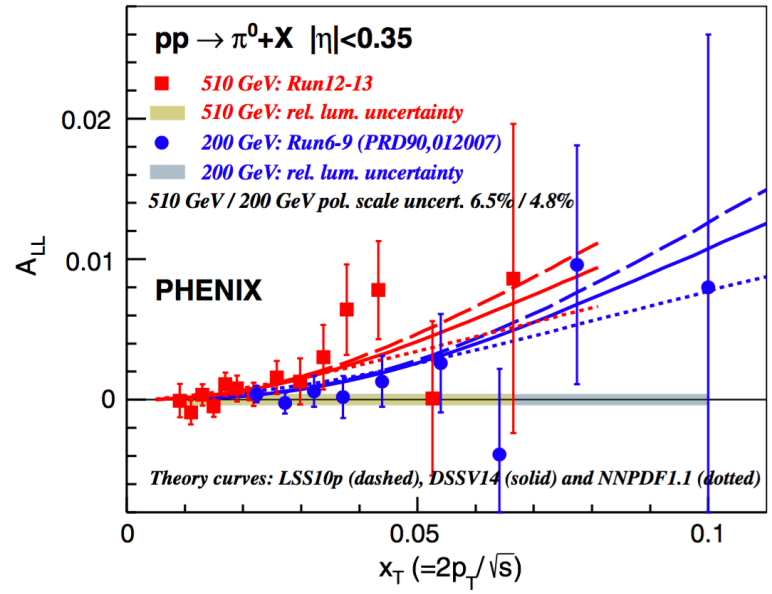
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \cdot \hat{a}_{LL}^{f_a f_b \to fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$$





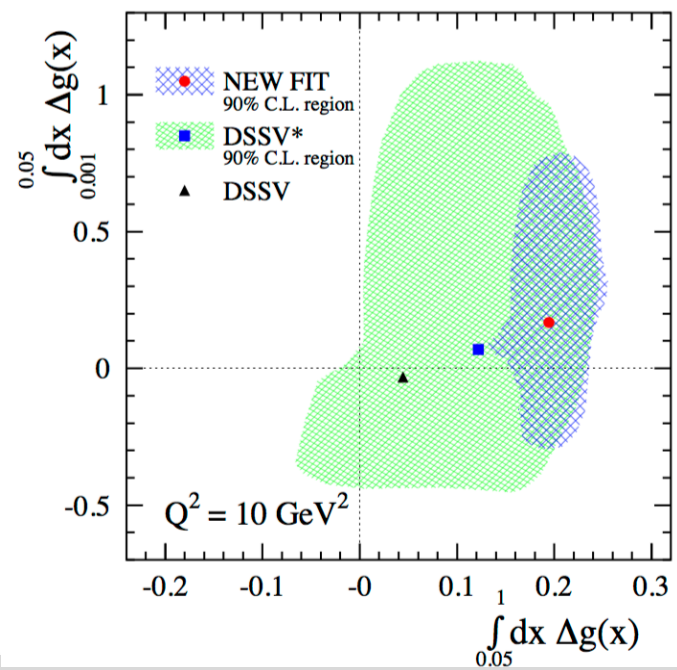
Zooming in on Δ G: π^0 at |η|<0.35





Phys. Rev. D 93, 011501(R) (2016)

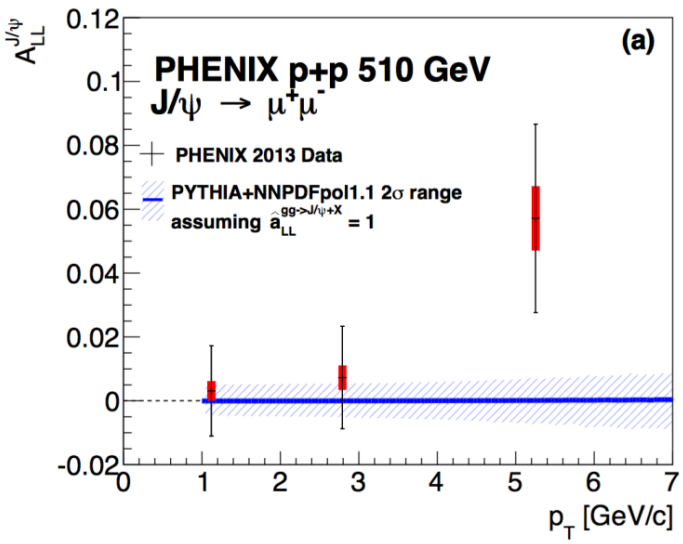
- Non-vanishing A_{LL}
- Increasingly positive with p_T and $\sqrt{s}$
- Global fits do not yet include $\sqrt{s}$=510 GeV data, but suggest that gluons contribute a significant fraction of the proton spin
  - Small x still not fully explored
- New data provides contraint down to x ~ 10^{-2}

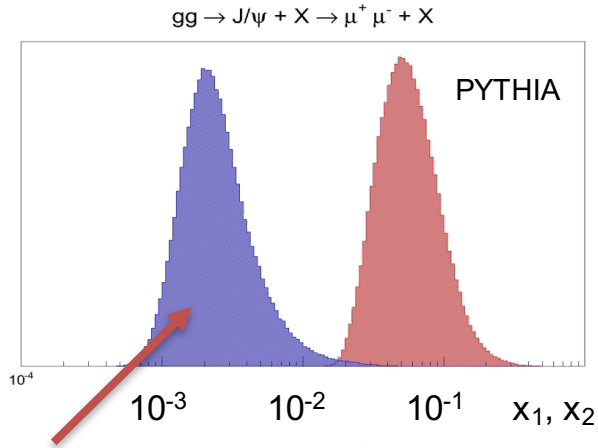


Δ G: towards lower x at forward rapidity

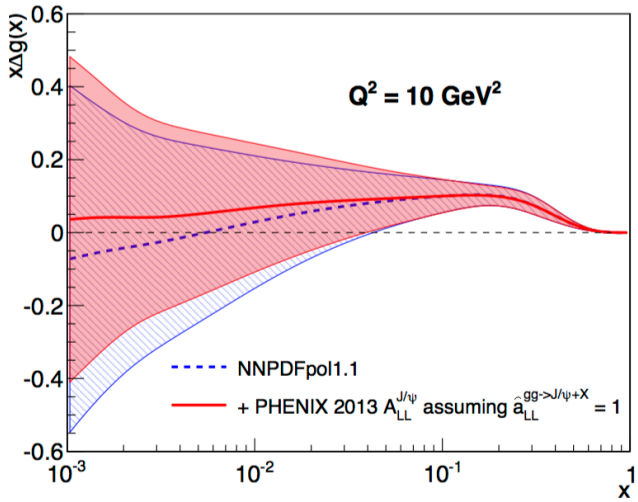
J/ψ @ 510 GeV ,1.2<|y|<2.2

Just submitted to PRD: arXiv:1606.01815





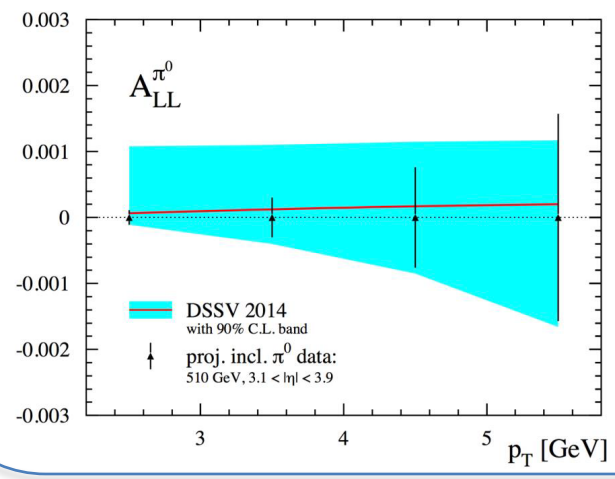
accesses down to x~2×10^{-3}



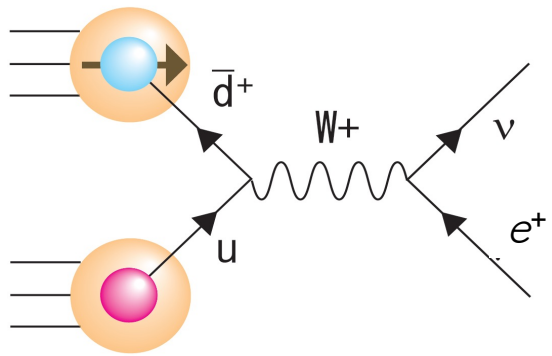
Coming soon:

π^0 A_{LL} @ 510 GeV, 3.1 < |η| <3.9

Projection: arXiv: 1501.01220



The missing pieces in ΔΣ through $W^{+/-}$ A_L



$$A_L = \frac{N^+(e) - N^-(e)}{N^+(e) + N^-(e)}$$

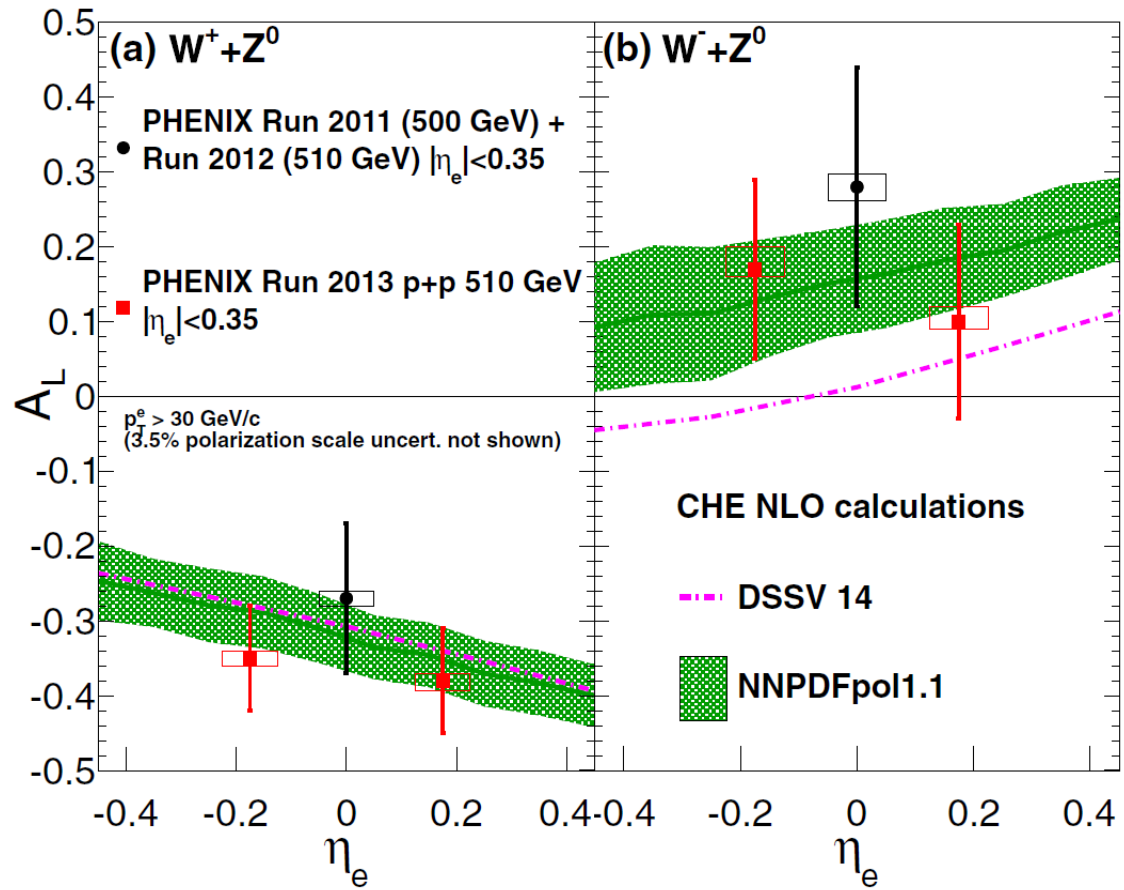
- Parity violating W production:

  Fixes quark helicity and flavor

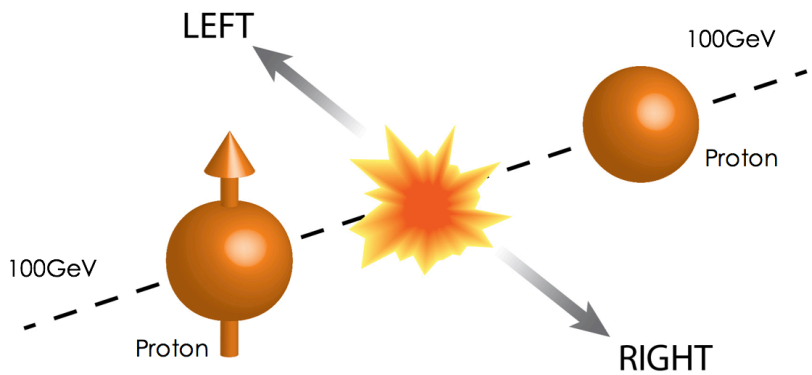
  $u_L \bar{d}_R \rightarrow W^+ \qquad d_L \bar{u}_R \rightarrow W^-$
- measure A_L of the outgoing leptons
- no fragmentation involved
- $x \sim M_W / \sqrt{s} \sim 0.16$
- extract $\Delta\bar{u}$, $\Delta\bar{d}$

$$A_L^{W^+} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

PRD 93, 051103(R)(2016)



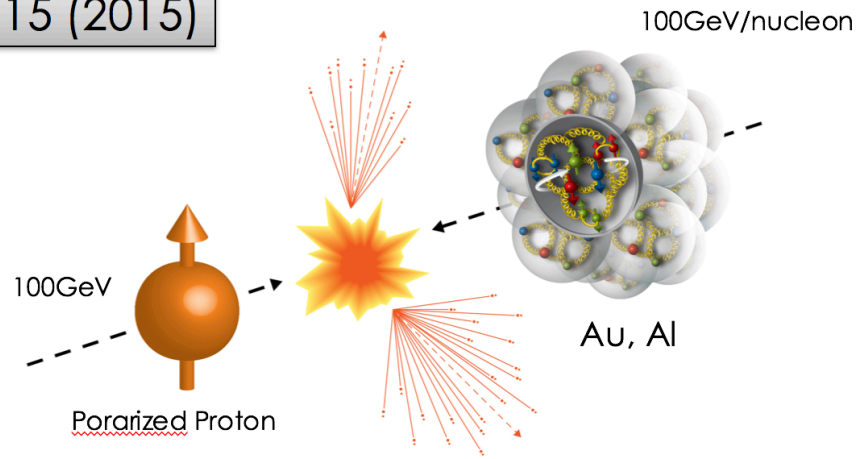
Preference for larger $\Delta\bar{u}$ than in DSSV



$$A_N = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$$

Many topics: both initial and final state effects

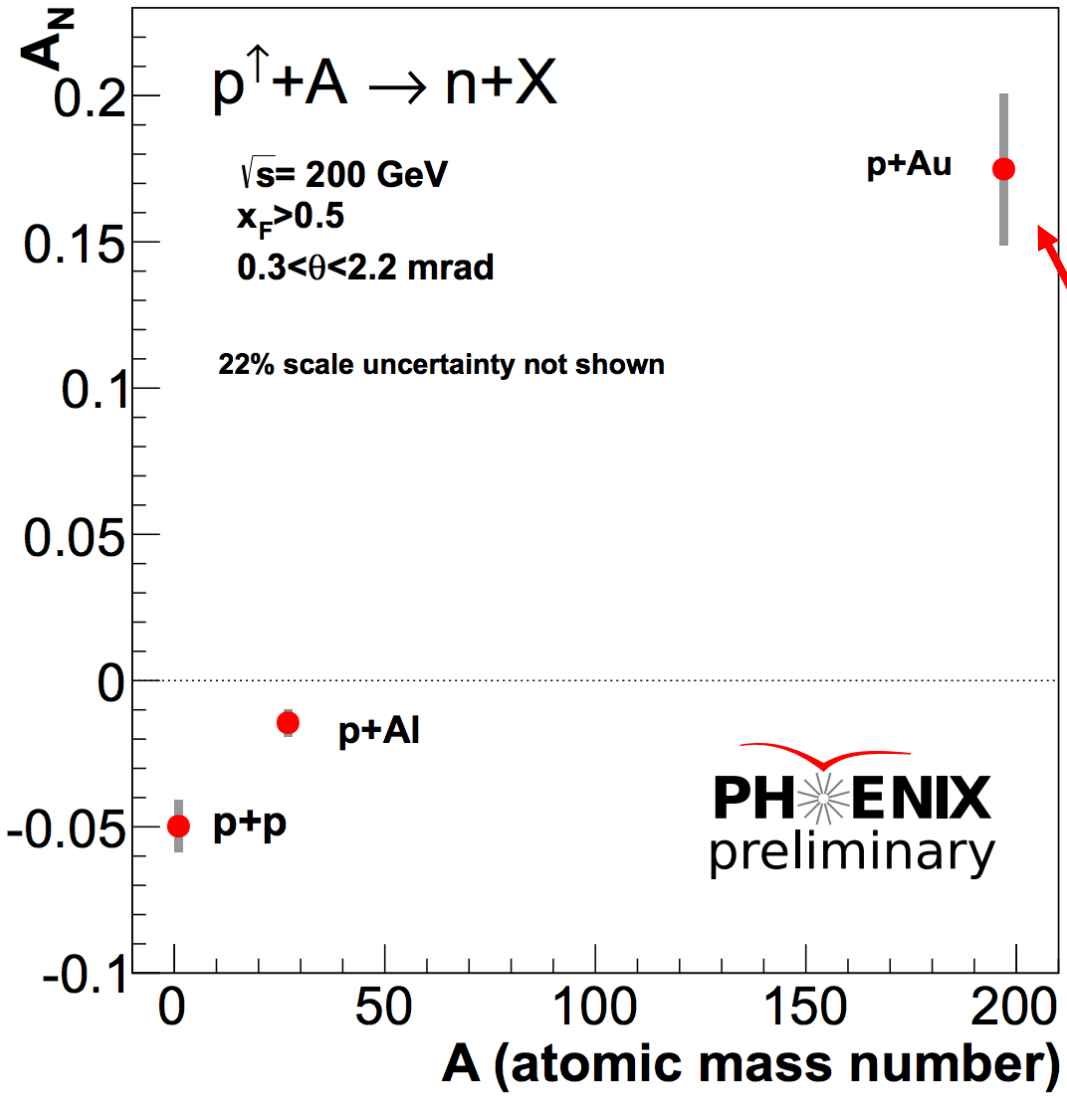
Run15 (2015)



The first-ever $p^{\uparrow}$+A collisions:

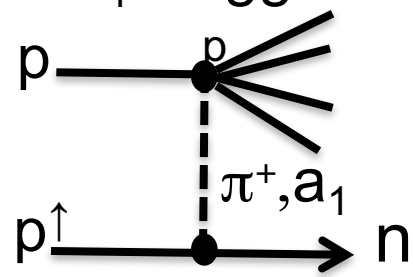
Huge nuclear effect in forward neutron A_N !

Forward neutron A_N



Known effect in p↑p

Well described by interference between π and a_1 Reggeon



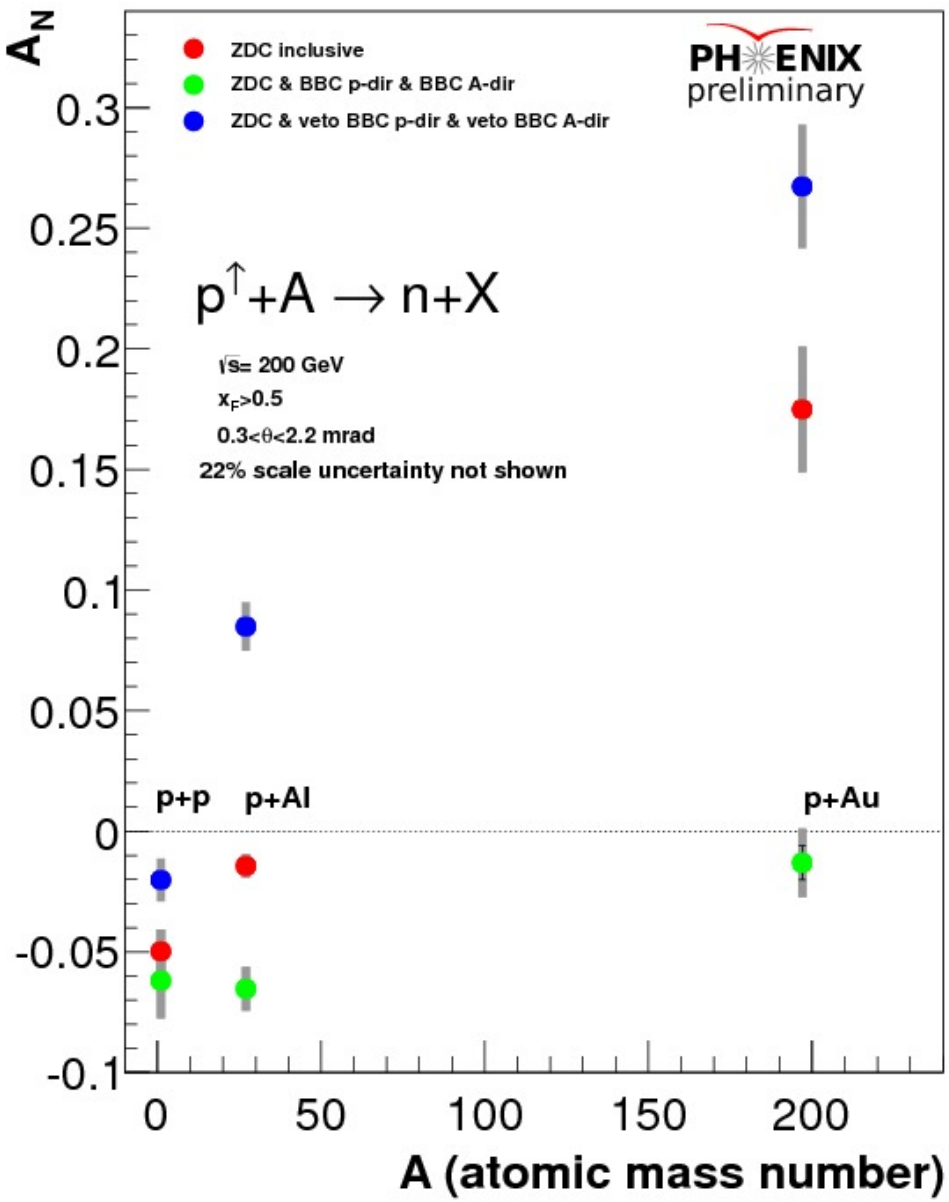
Surprise — huge A dependence:

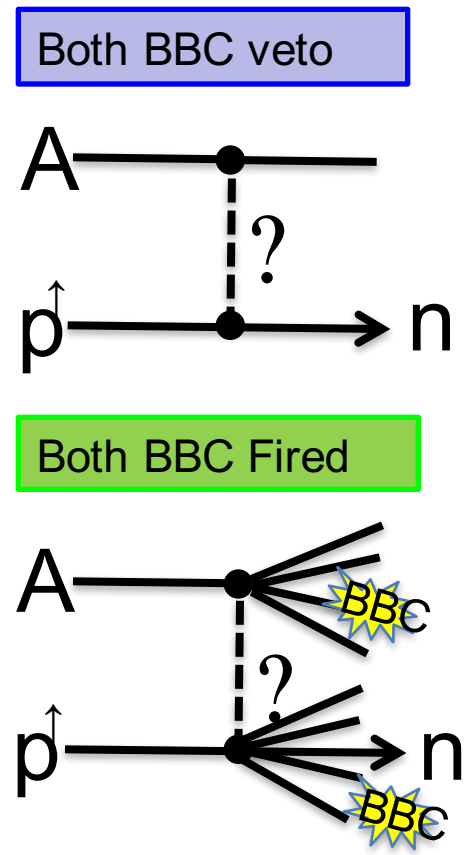
factor of ~ 3 increase in magnitude

Even the sign changes

Simple π -a_1 interference predicts small dependence

Investigating nuclear effects in forward neutron A_N





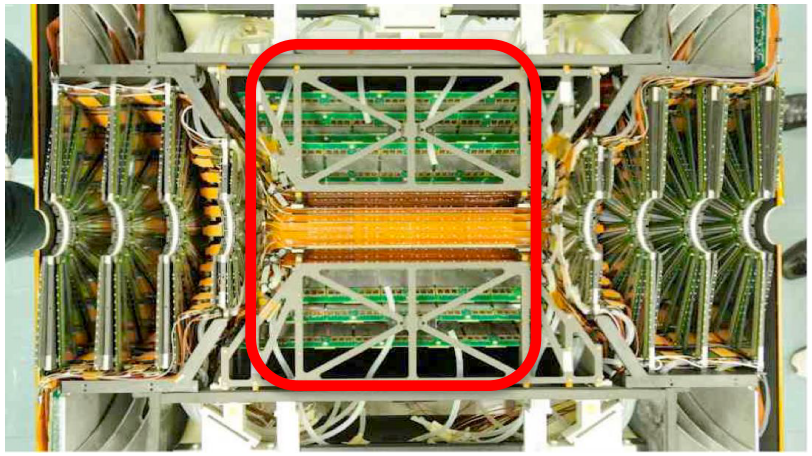
- Multiple mechanisms contribute?
- UPC or/and high parton density effect?

Need theoretical input !

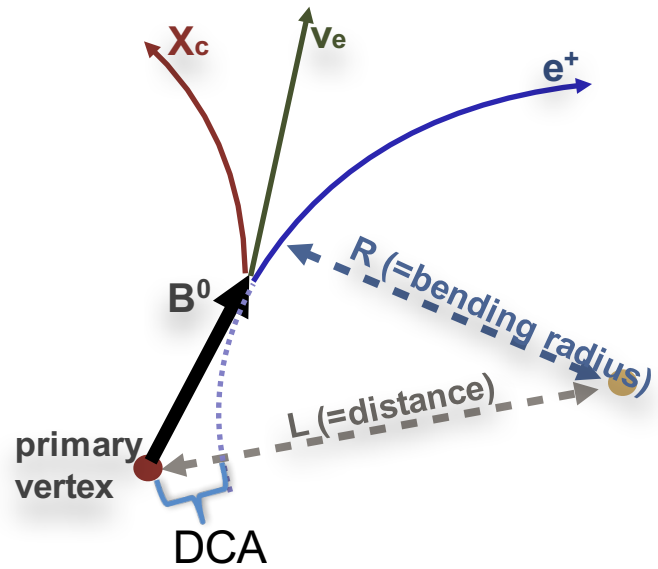
HOT TOPICS IN HEAVY IONS

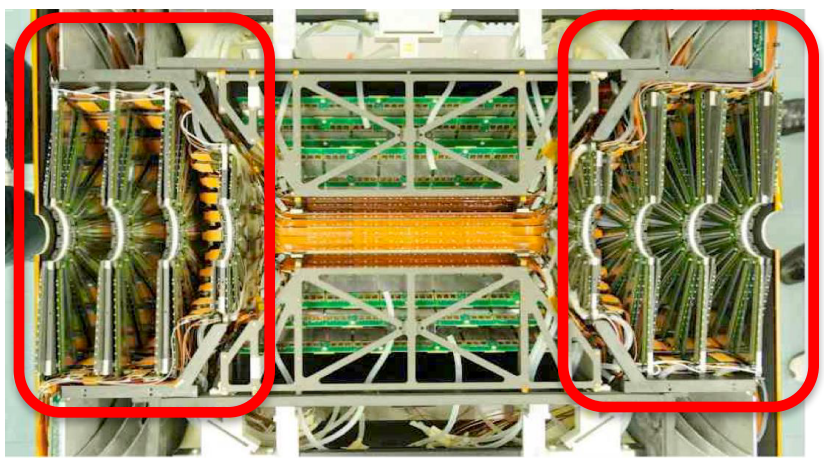
QGP	A+A , A+B	p/d/^{3}He +Au
Microscopic structure	E_{loss} in separated charm and bottom Jets	 Jets
System evolution	Direct photon flow	Collective flow of hadrons

c/b separation by secondary vertex

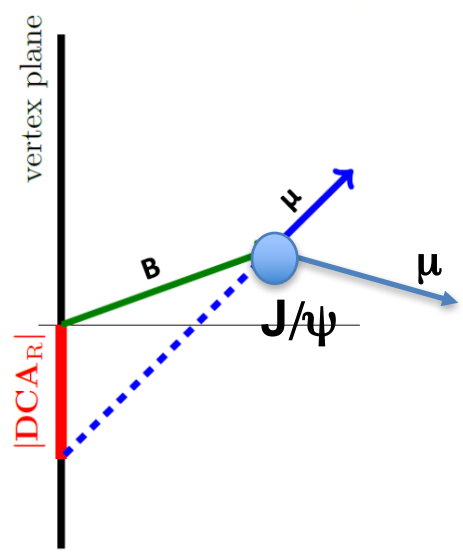


VTX detector

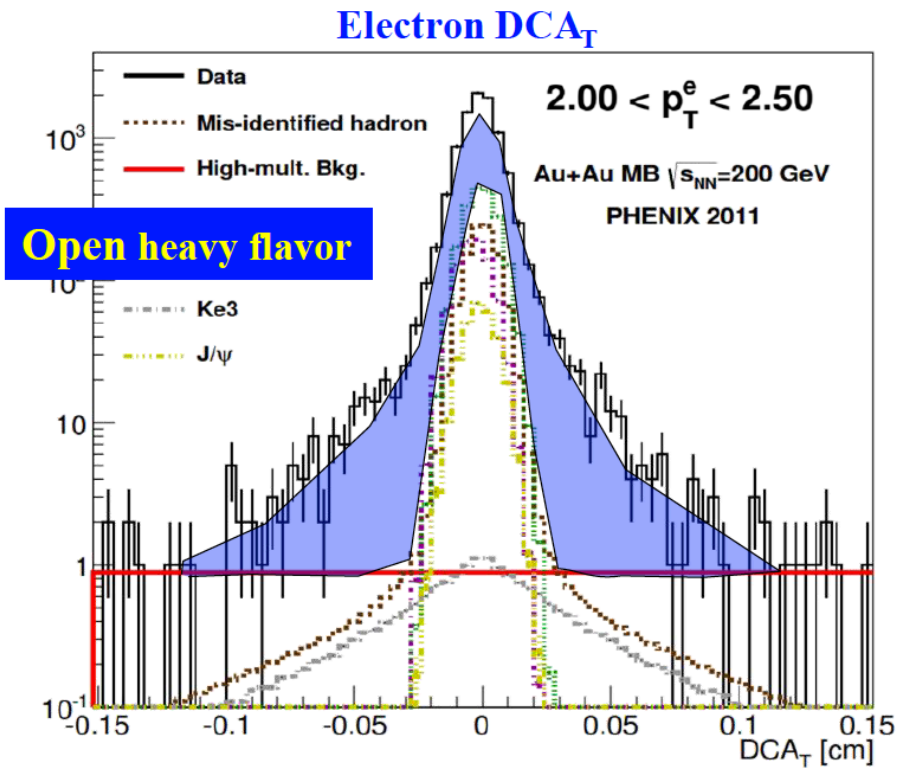




FVTX detector



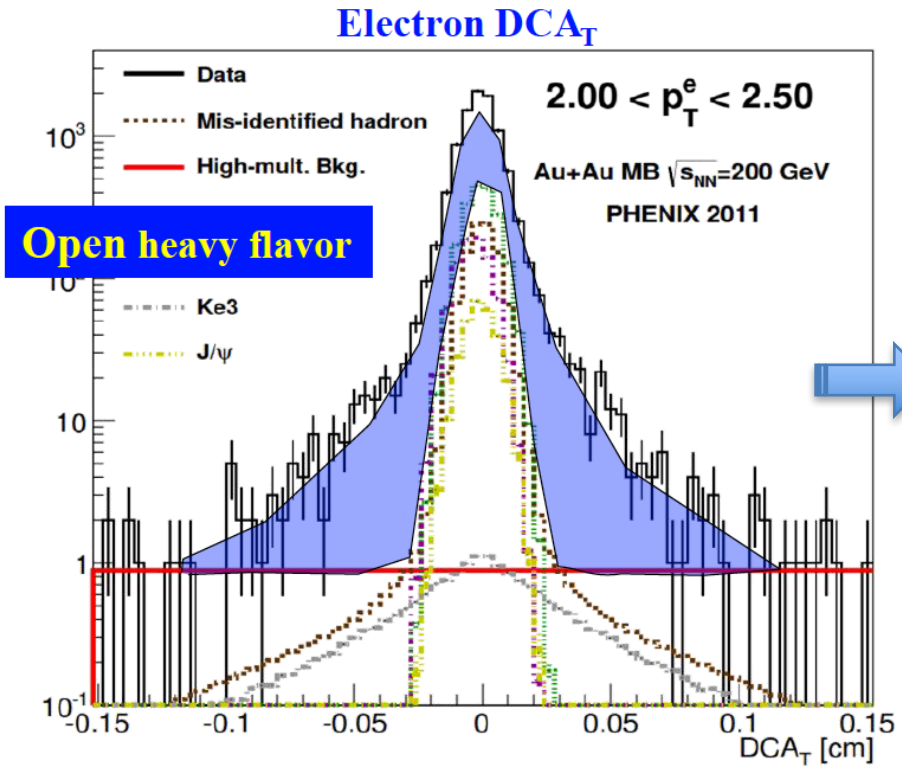
R_{AA} for electrons from charm and bottom

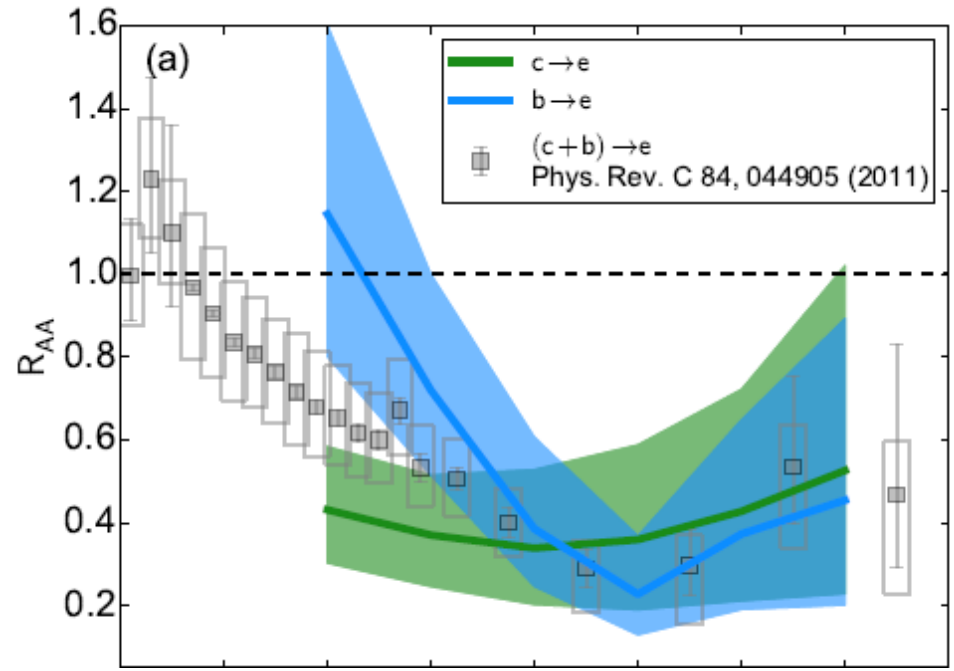


Phys. Rev. C93, 034904 (2016)

R_{AA} for electrons from charm and bottom

Unfolding to obtain b/(c+b) electron fraction in Au+Au
Combine with previous results in pp from correlation analysis
→ R_{AA} for c→ e and b→ e separately!

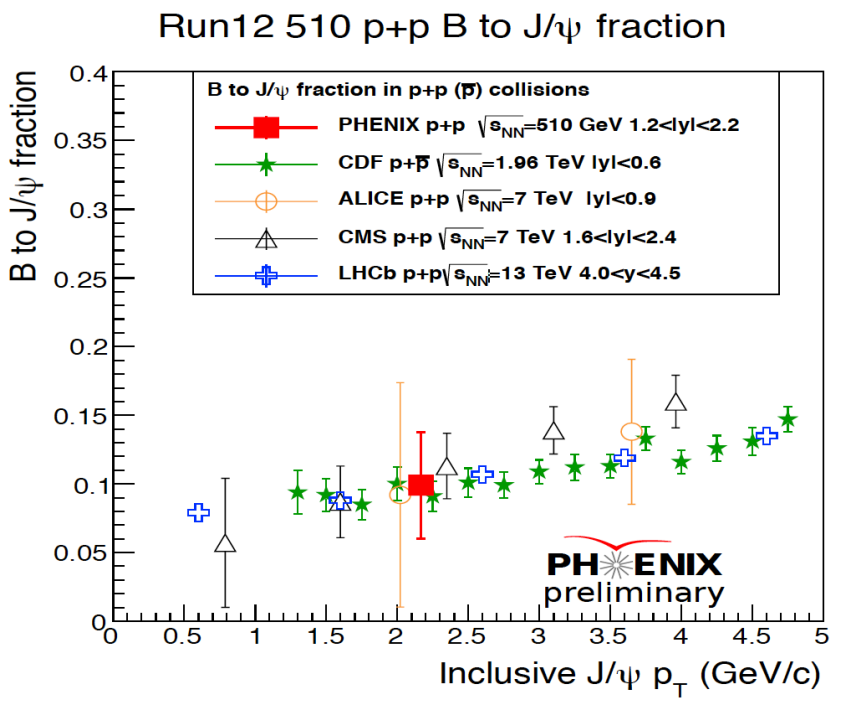




Phys. Rev. C93, 034904 (2016)

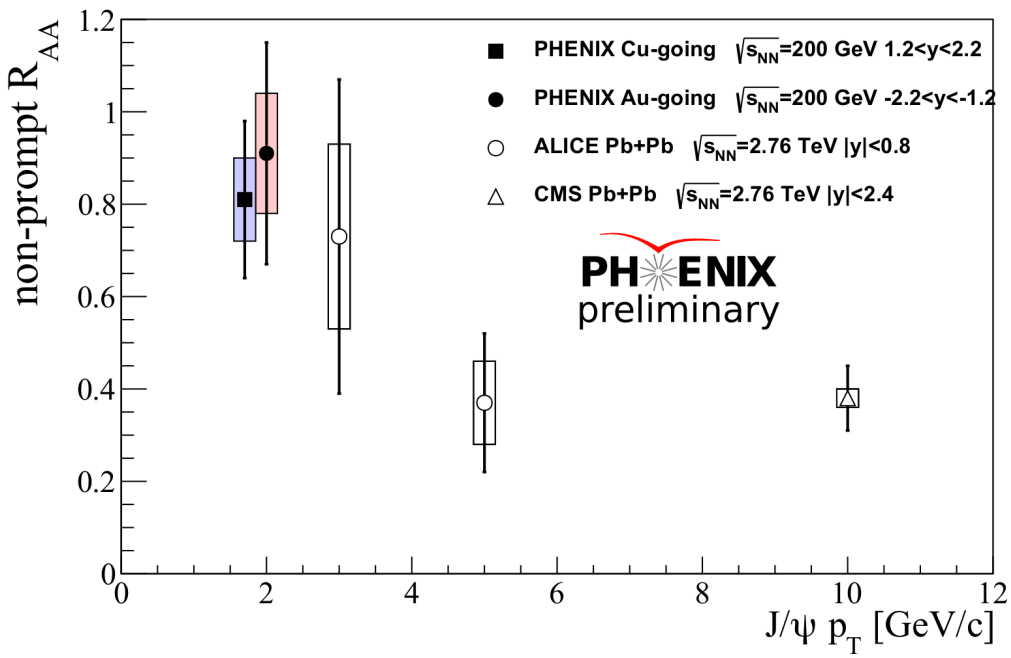
Charm and bottom similarly suppressed at high p_T
Bottom less below ~ 3 GeV/c !
A factor of ~ 20 more statistics from Run 14 & 16 !
Stay tuned for future updates !

B->J/ψ in pp (510 GeV) and CuAu (200 GeV)



NEW Release for Users' meeting !

$$R_{AA}^{B\to J/\psi} = \frac{F_{B\to j/\psi}^{AA}}{F_{B\to j/\psi}^{pp}} R_{AA}^{J/\psi} = \frac{F_{B\to j/\psi}^{AA}}{0.1} R_{AA}^{J/\psi}$$

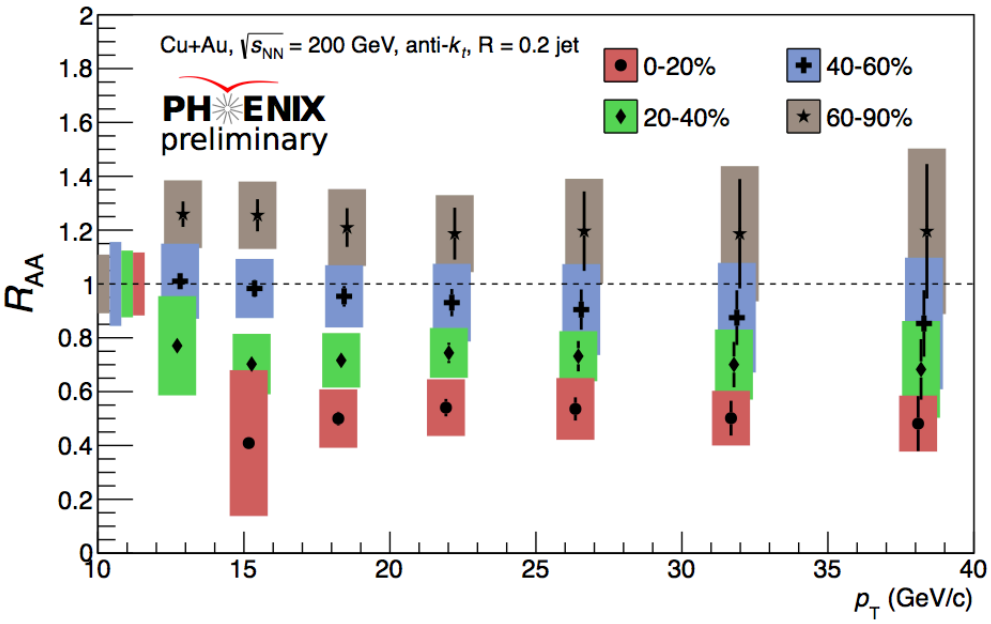


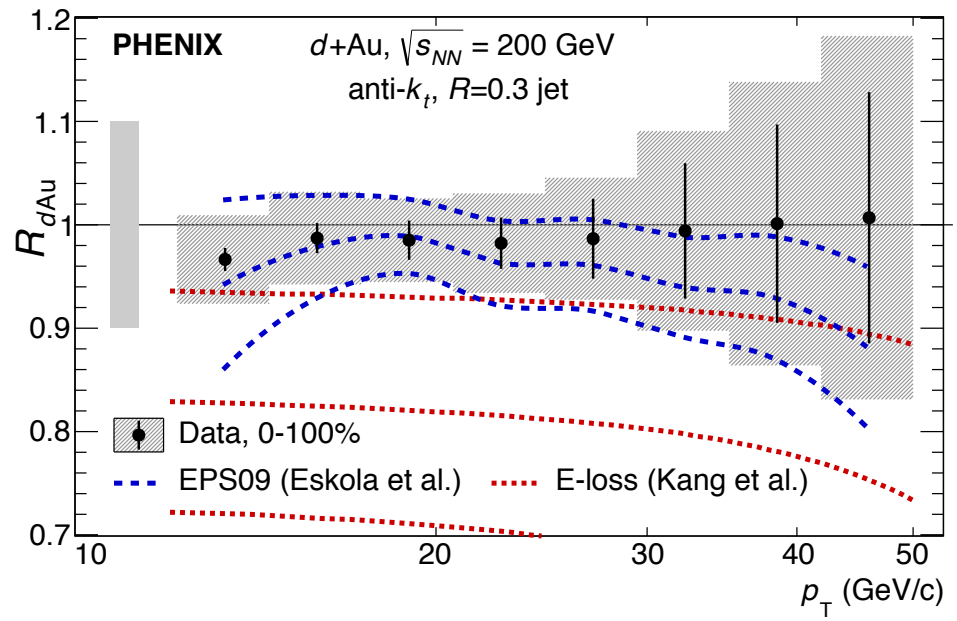
B less suppressed than J/ψ

Jets in Cu+Au and d+Au

2016 RHIC/AGS Thesis award !
Arbin Timilsina

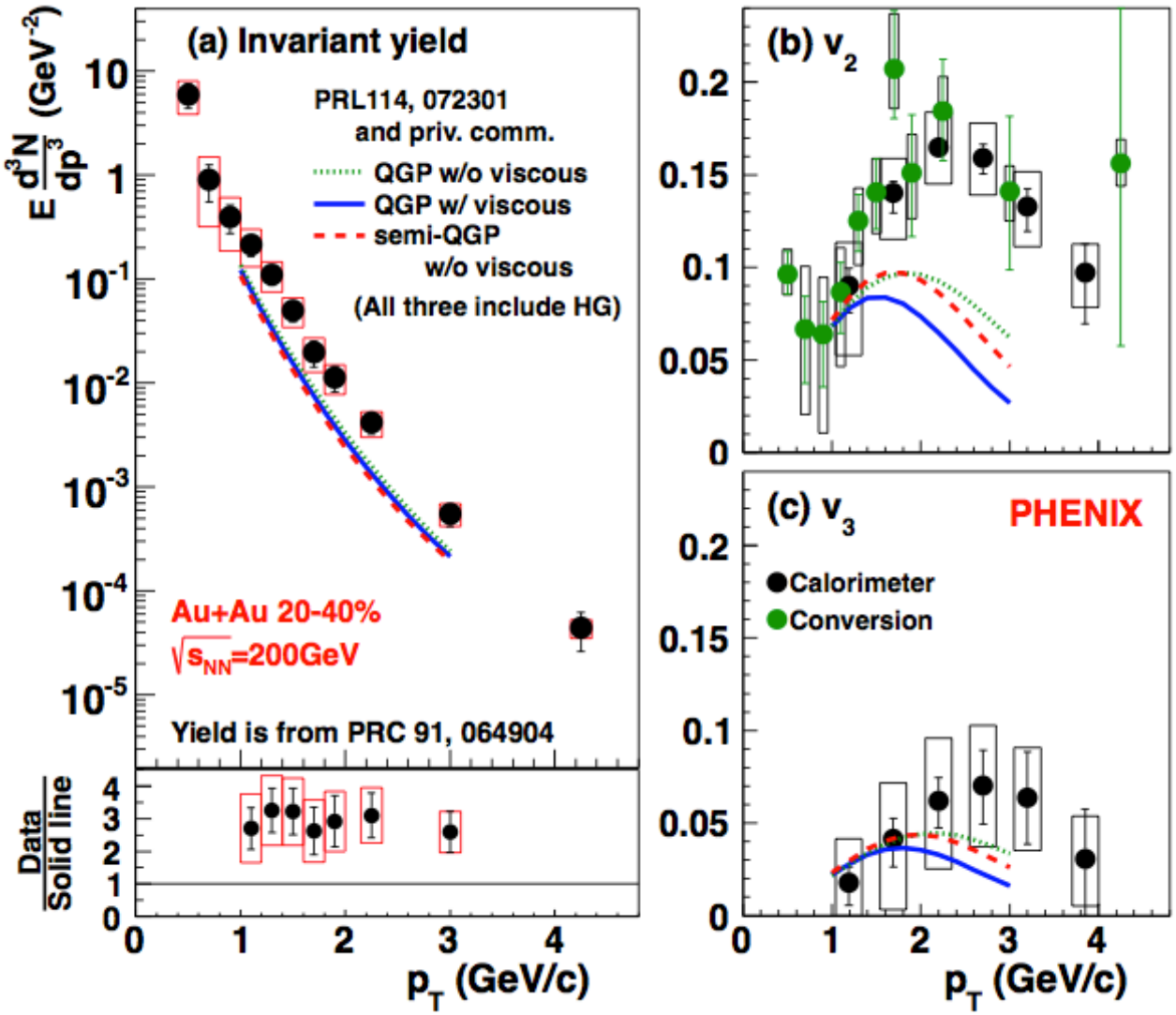
Phys. Rev. Lett. **116**, 122301 (2016)





- jets suppressed by ~factor of 2 in central Cu+Au collisions
- suppression shows no p_T dependence
- In d+Au:
  - no suppression in minimum bias events
  - surprising centrality dependence

Large system evolution: Au+Au probed with direct photons



arXiv:1509.07758

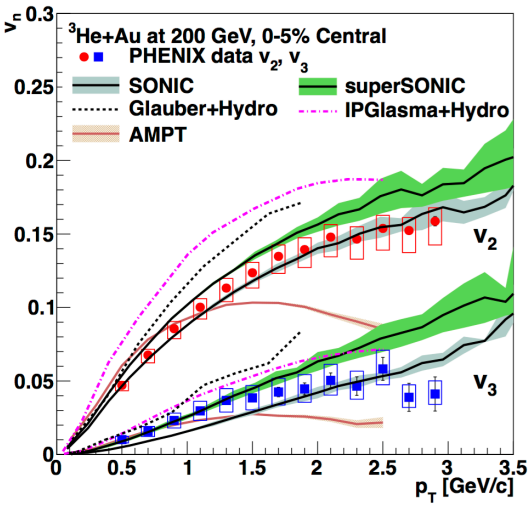
Simultaneous description of large yield and large flow difficult

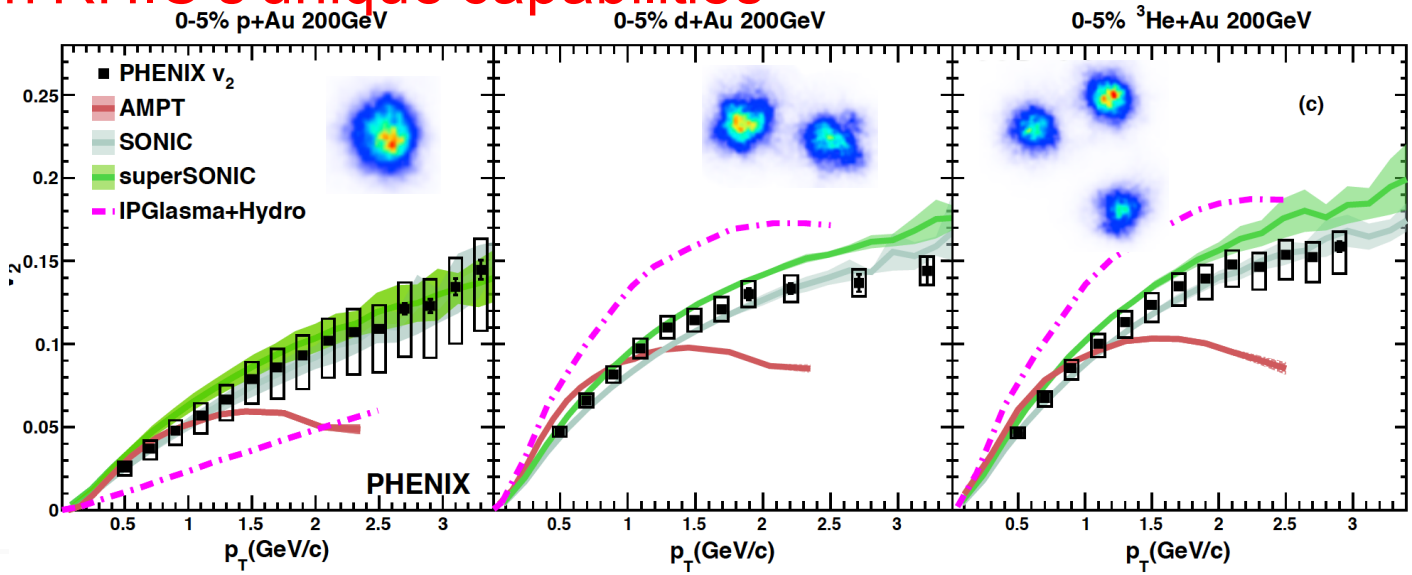
Late emission important

Shining sQGP

Collectivity in small systems

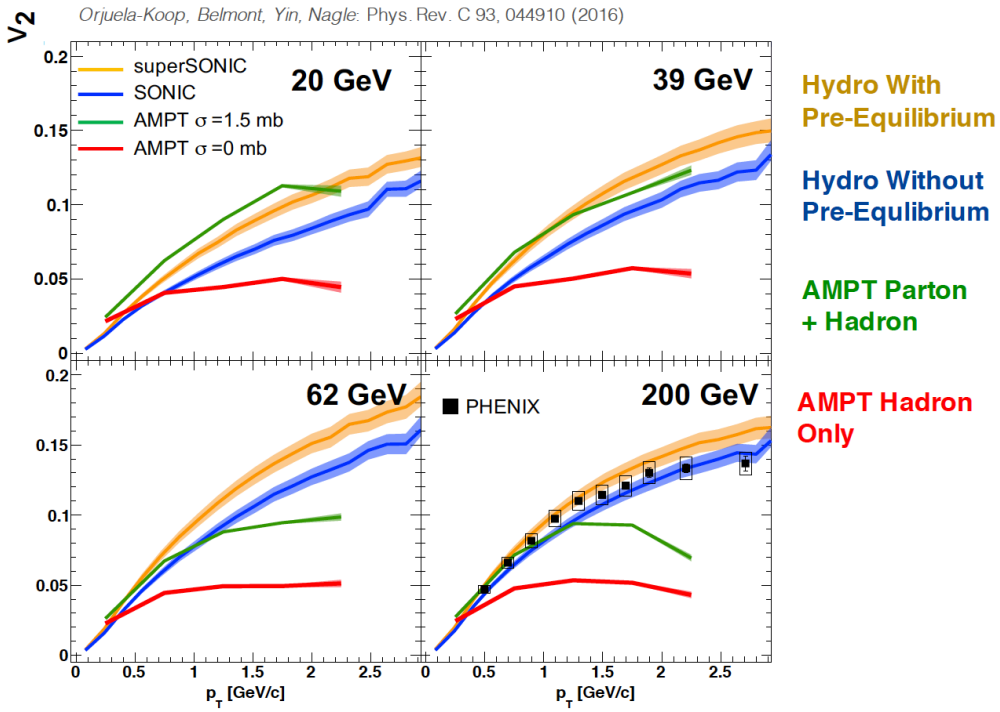
- Ample experimental evidence for collective effects in small systems at top RHIC energy and at the LHC
  - Ridges, multiparticle correlations
  - Particle species dependence in v_2 and spectra (dAu, pPb)
  - Yet, many competing explanations
  - Geometry controlled experiments: pAu, dAu, ^{3}HeAu => capitalize on RHIC's unique capabilities

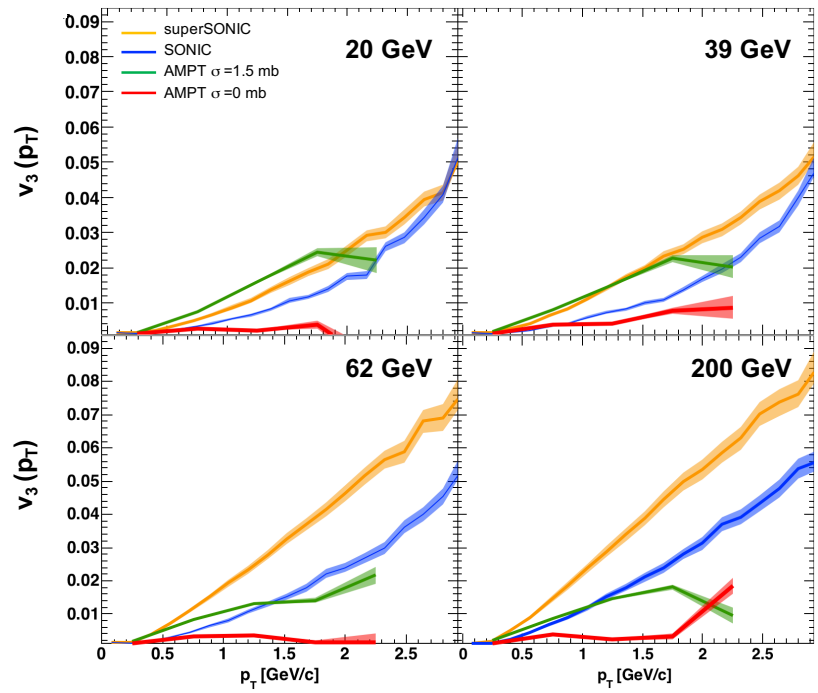




- Strong constraints on the initial state

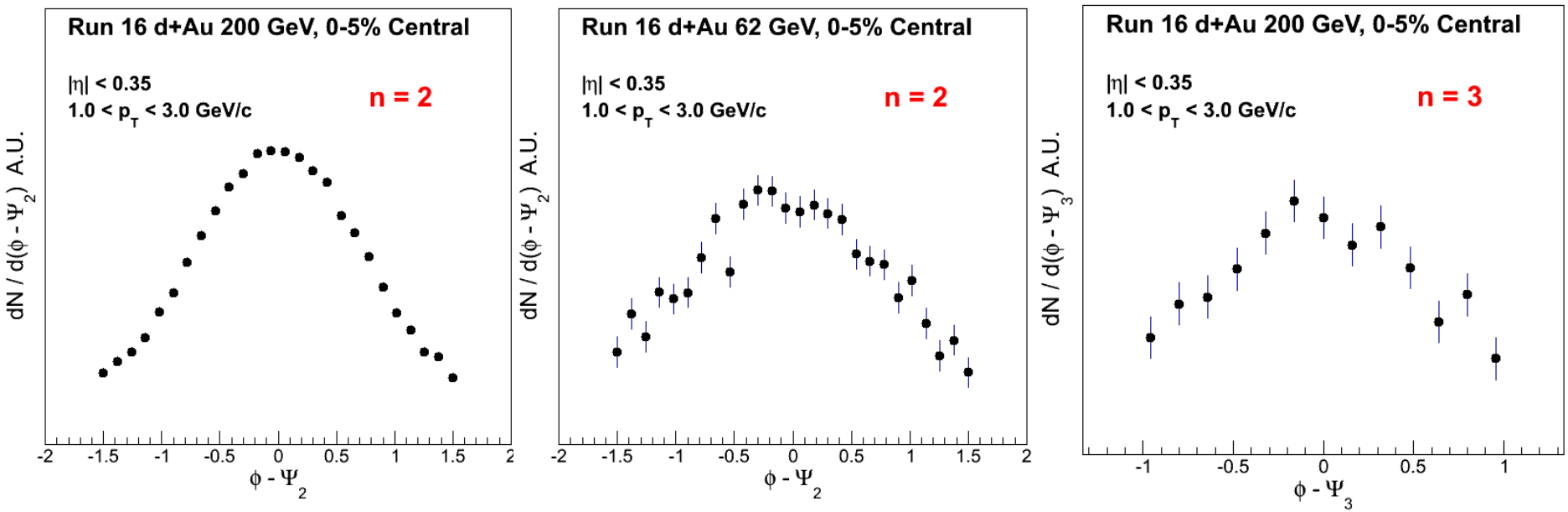
Model predictions for v_2 and v_3





- v_2 : weak energy dependence
- hadronic **only** flow **ruled out at 200 GeV**
- triangular flow takes a longer time to develop => much more sensitive to the shorter and shorter QGP lifetime at the lower energies
- Large difference between SuperSONIC, SONIC and AMPT
- v_3 collapses if the system is hadronic

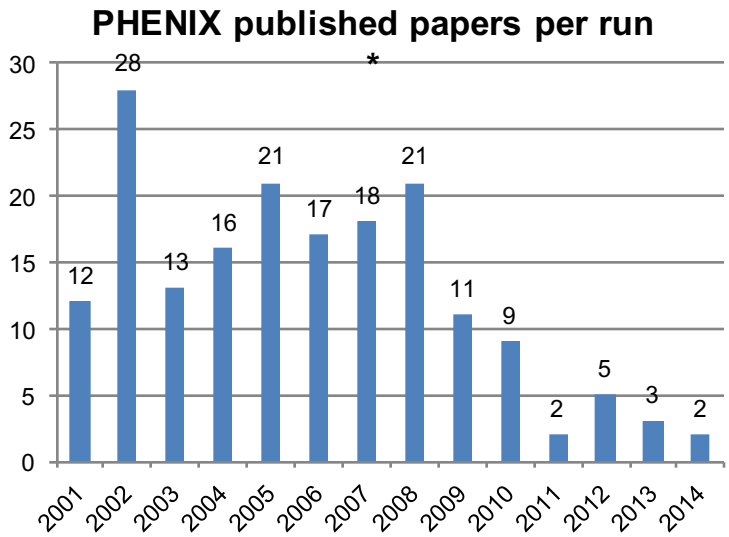
PHENIXians hard at work checking and analyzing Run 16 d+Au data!



- Great enthusiasm for the d+Au BES physics
- Online data production, and online analysis !
- First signs of v_2 at 200 GeV and 62 GeV
- First indication of non-zero v3 in d+Au at 200 GeV!

What's next for PHENIX ?

- Data taking ends with Run 16, but this is not the end of PHENIX !
- >300 active collaborators



- A lot of physics topics in
  - pp at 500/510 GeV
  - pp at 200 GeV
  - p+Al and pAu at 200 GeV
  - Cu+Au at 200 GeV
  - Au+Au at 200 GeV
  - U+U at 193 GeV
  - d+Au at 200,62,39,20 GeV

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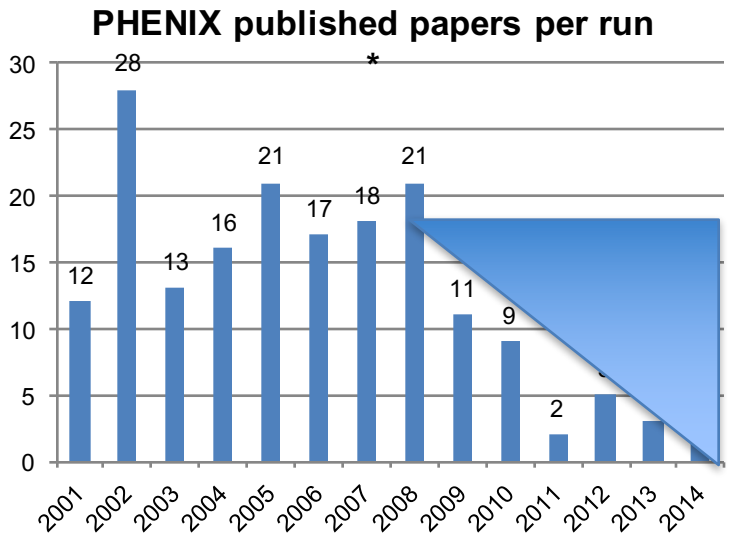

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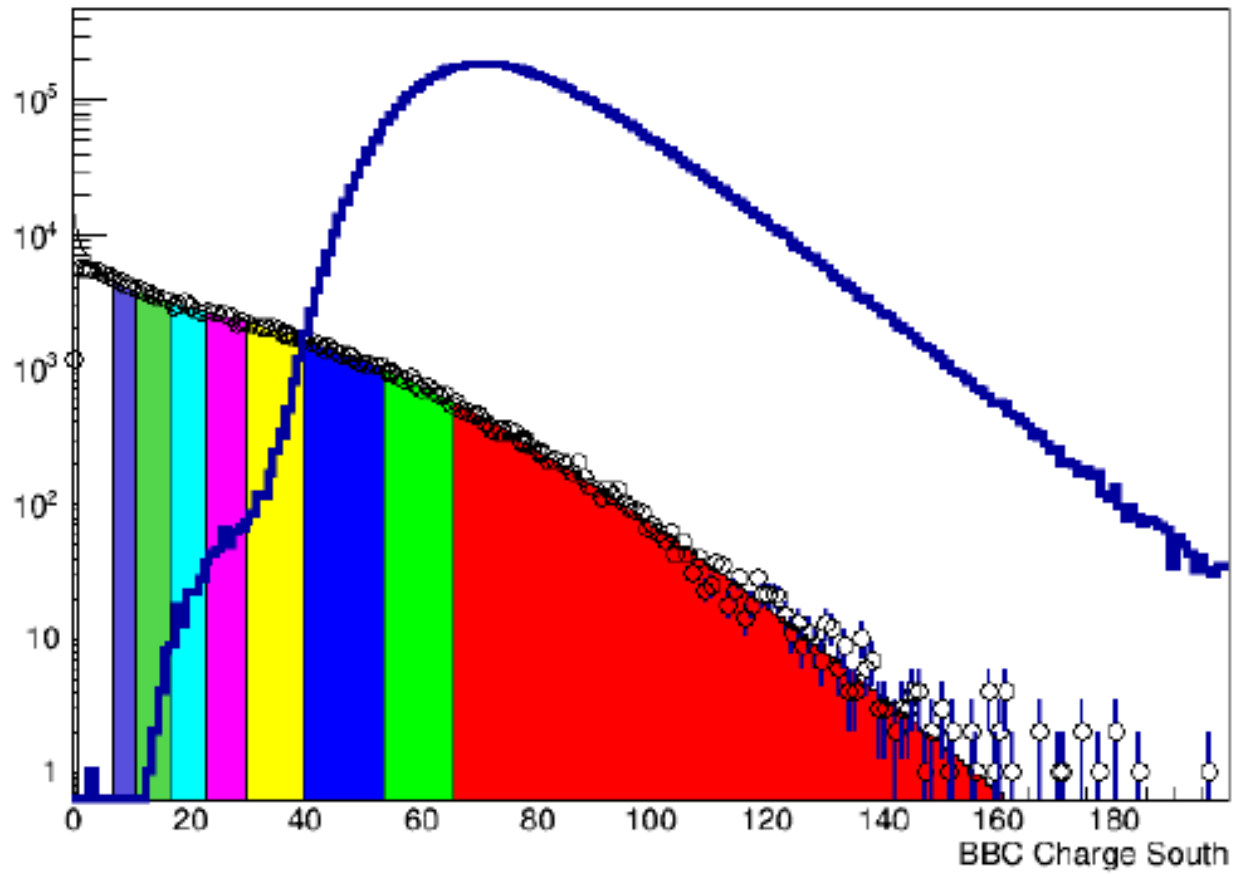
  - d+Au at 200,62,39,20 GeV

BACKUP

Trigger at 200 GeV dAu



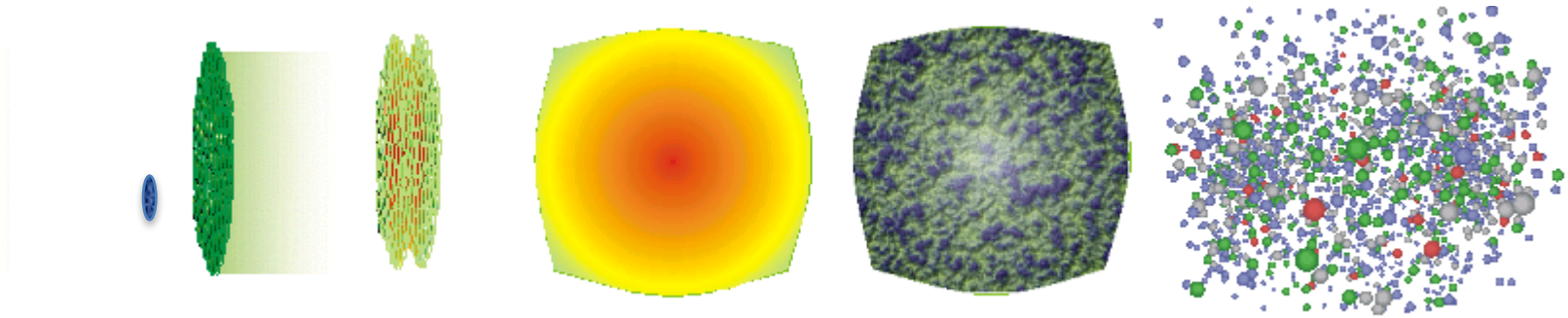
Collectivity in small systems: challenges remain

- Challenge for our understanding of perfect fluid hydrodynamics and the minimal conditions necessary for quark-gluon plasma formation
  - How is equilibration achieved ?
  - Role of pre-equilibrium dynamics ?
  - Is there a smallest QGP droplet ?
  - Role of hadronic flow?
- BES with d+Au collisions (well controlled geometry) aims to disentangle different stages of the system evolution
  - as system spends less and less time in hydrodynamic equilibrium, pre-equilibrium and hadronic contributions gain importance with decreasing beam energy

Small system evolution: confront models with data

Pre-equillibrium flow ?

Hadronization via coalescence?



Initial state

Quark Gluon Plasma?
thermally equilibrated?
Hydrodynamic collective flow ?

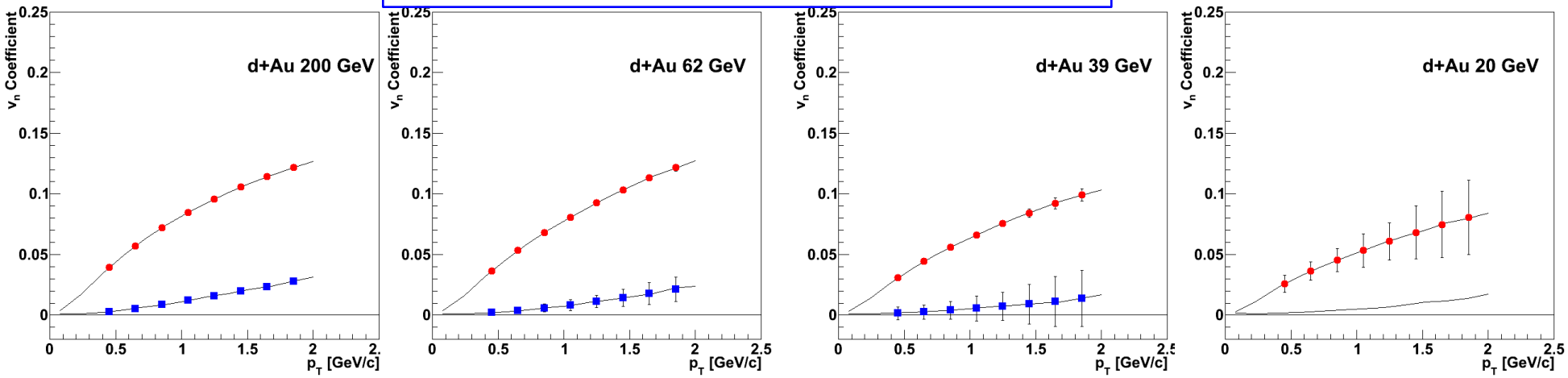
Hadronic phase flow ?

SuperSONIC:	preequilibrium + QGP hydro + hadronic cascade
SONIC:	QGP hydro + hadronic cascade
AMPT(σ = 1.5 mb):	partonic cascade + coalescence + hadronic cascade
AMPT(σ = 0 mb):	hadronic cascade

- The role of different stages of the system evolution can be assessed in a BES through model comparisons

Projections (based on SONIC) for 5 weeks BES

0-5% central events within $|z_{vtx}|< 10$ cm



1 week, 1.6 B evts	1 week, 160 M evts	1.5 weeks, 110M	1.5 weeks, 9M
robust baseline v_2 and v_3 measurements	All 3 lower energies for robust v_2 measurements to establish • role of pre-equilibrium stage • role of hadronic stage		
Factor of ~20 stat increase from Run8 FVTX improved EP	v_3 at lower energy: more sensitive to time spent in QGP	Does v_3 collapse at lower energy ? upper limits of v_3 can be established	
same detector conditions=> systematics control in the BES	Statistically significant measurements for both v_2 and v_3	Transition region for v_3 collapse	Largest lever arm for v_2 measurements

Projected EP resolution in BES

He3 +Au at 200 GeV: FVTX crucial for v_3 measurement

TABLE II. The resolution of nth-order event-plane angles measured by the BBC-S and FVTX-S detectors.

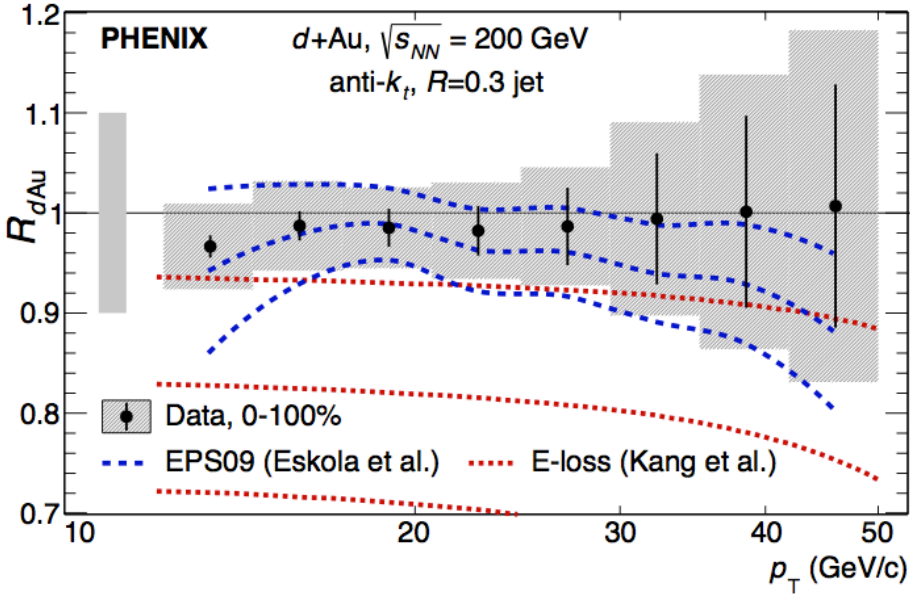
Subsystem	$\mathrm{Res}(\Psi_2^{\mathrm{Obs}})$	$\mathrm{Res}(\Psi_3^{\mathrm{Obs}})$
BBC-S (-3.9 $< \eta <$ -3.0)	0.110	0.034
FVTX-S (-2.5 $< \eta <$ -1.5)	0.232	0.052
FVTX-S (-3.0 $< \eta <$ -1.0)	0.274	0.070

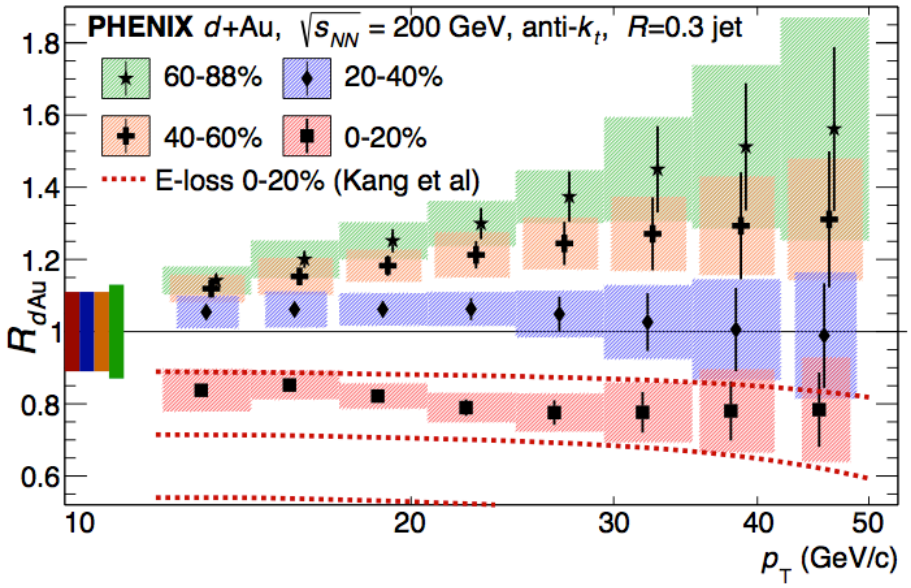
energy	Res (Ψ_2)	Res (Ψ_3)
200 GeV	0.249	0.070
62 GeV	0.187	0.041
39 GeV	0.136	0.025
20 GeV	0.093	0.022

Both resolution and statistics improved at 200 GeV compared to Run 8 dAu:
BBC -> FVTX; 80 M evts -> 1.6 B events

Jets in d+Au

arXiv:1509.04657





minimum bias jets show no energy loss

Strong centrality dependence

But different from that in Au+Au

Explanation would be anti-correlation between hard and soft particle production