

Collectivity in small systems

From LHC to EIC

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Stony Brook University & BNL

CFNS workshop



Who is this guy?

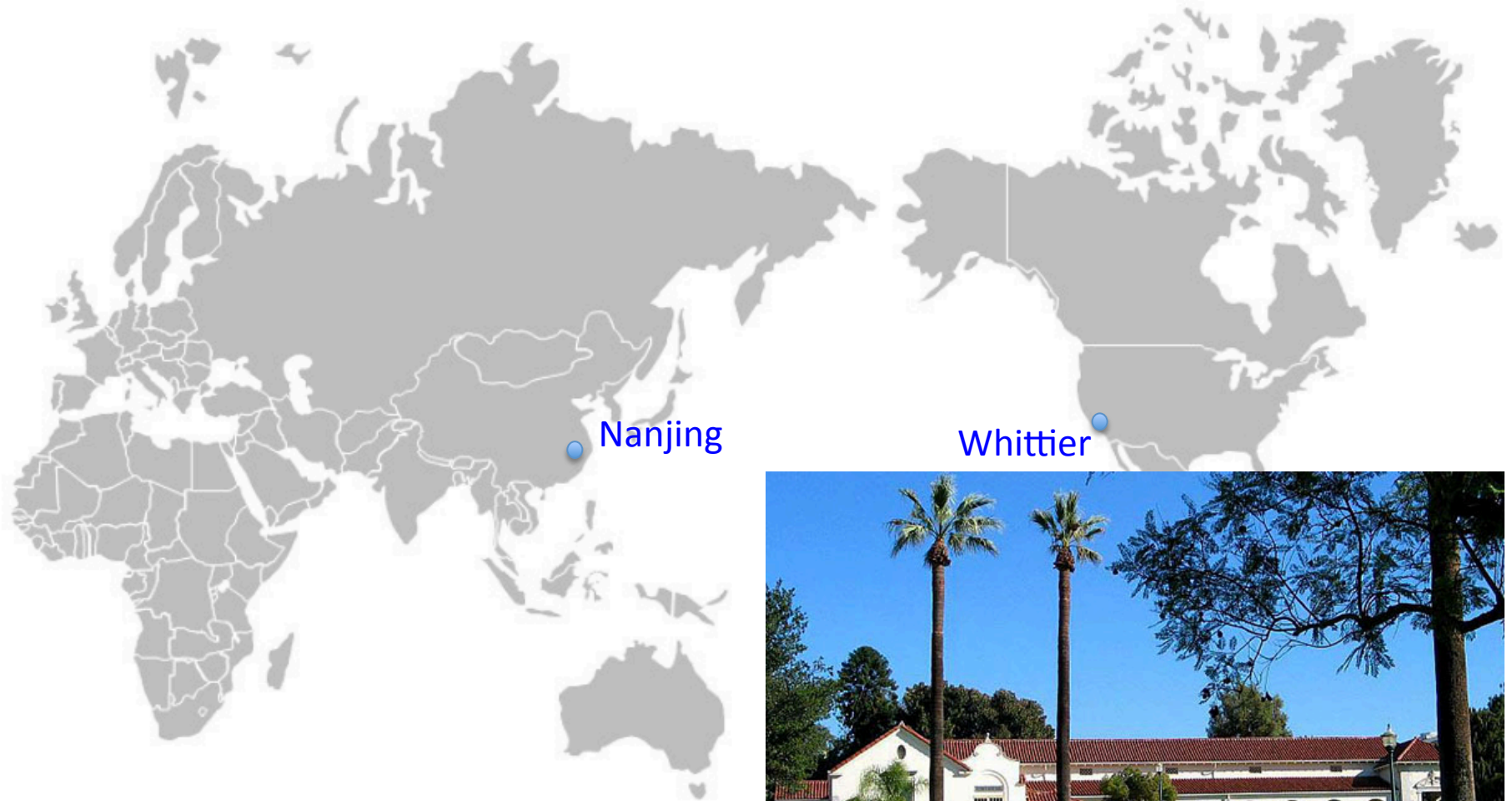


Who is this guy?

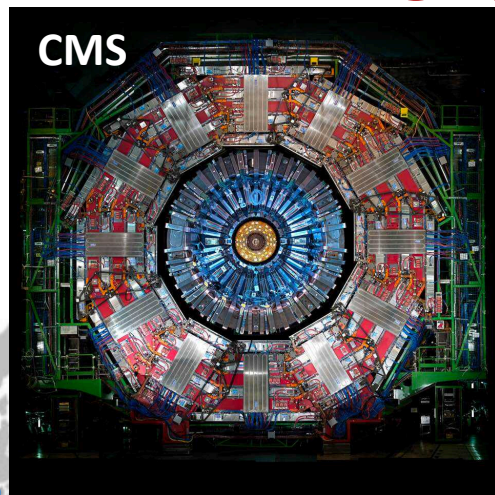


Nanjing

Who is this guy?



Who is this guy?



CERN

Nanjing

Whittier

Houston

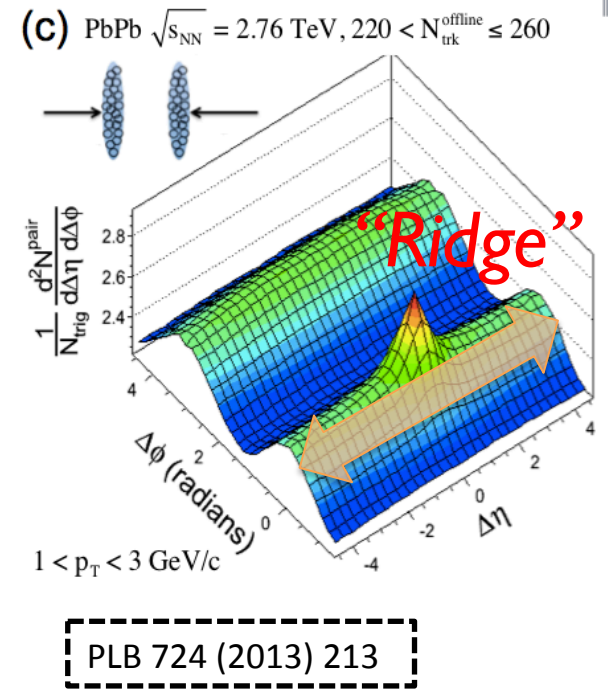


Rice University
PhD+postdoc
2012-2018

Who is this guy?

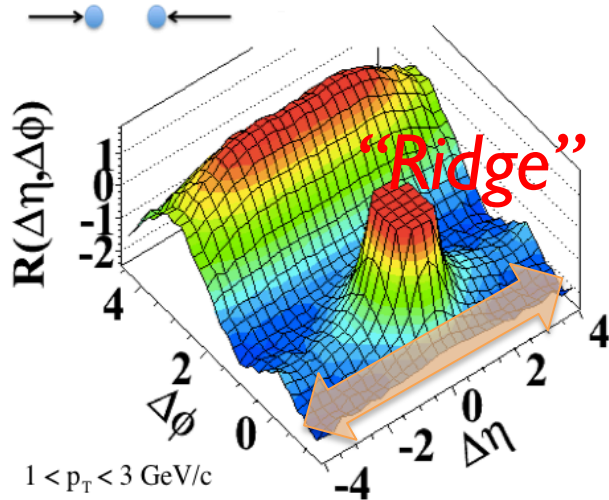


“Ridge” in small systems



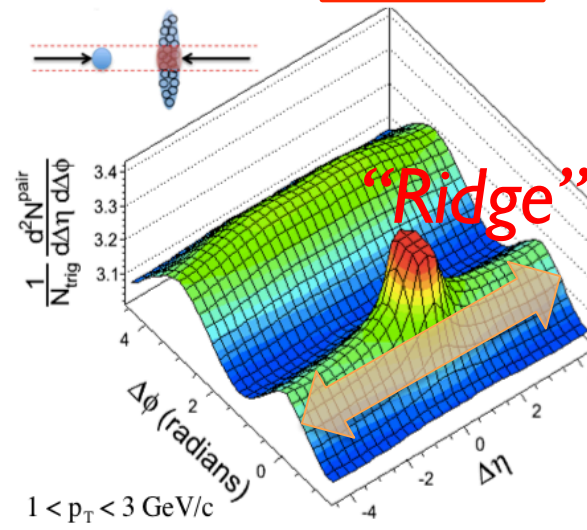
“Ridge” in small systems

(a) $pp \sqrt{s} = 7 \text{ TeV}$ $N_{\text{trk}}^{\text{offline}} \geq 110$



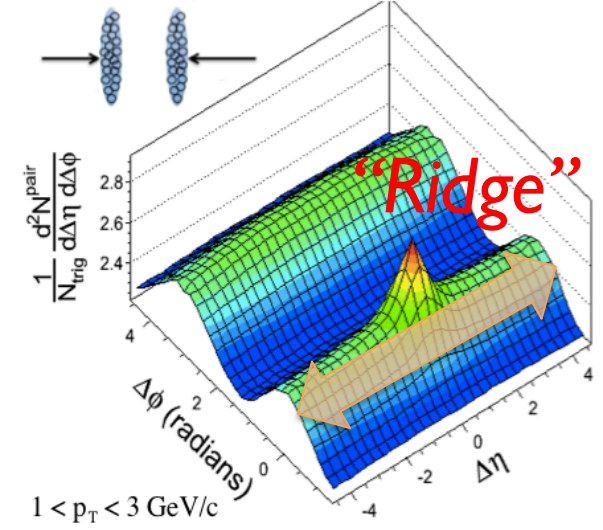
JHEP 09 (2010) 091

(b) $pPb \sqrt{s_{NN}} = 5.02 \text{ TeV}$ $220 < N_{\text{trk}}^{\text{offline}} \leq 260$



PLB 724 (2013) 213

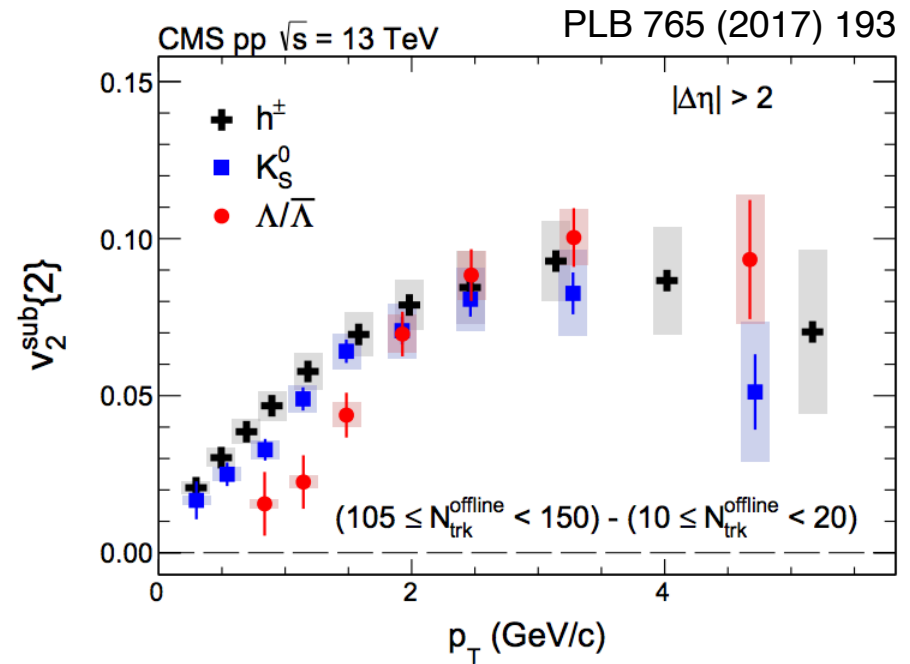
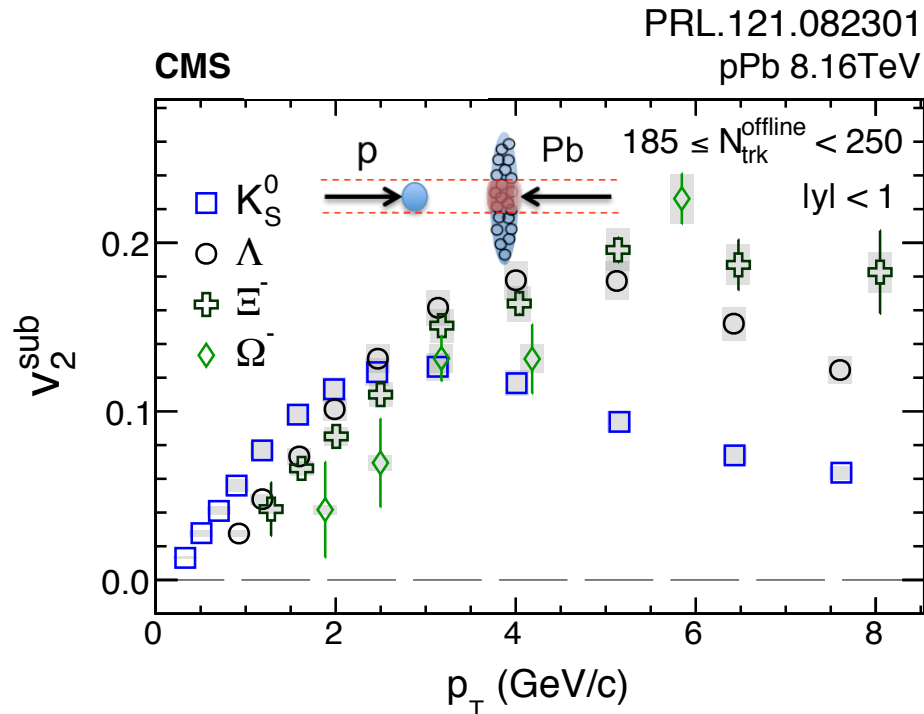
(c) $PbPb \sqrt{s_{NN}} = 2.76 \text{ TeV}$, $220 < N_{\text{trk}}^{\text{offline}} \leq 260$



PLB 724 (2013) 213

What is the origin of the “Ridge” in small system?
 A small droplet of QGP? Other novel QCD effect?
 Collectivity?

PID flow in small system



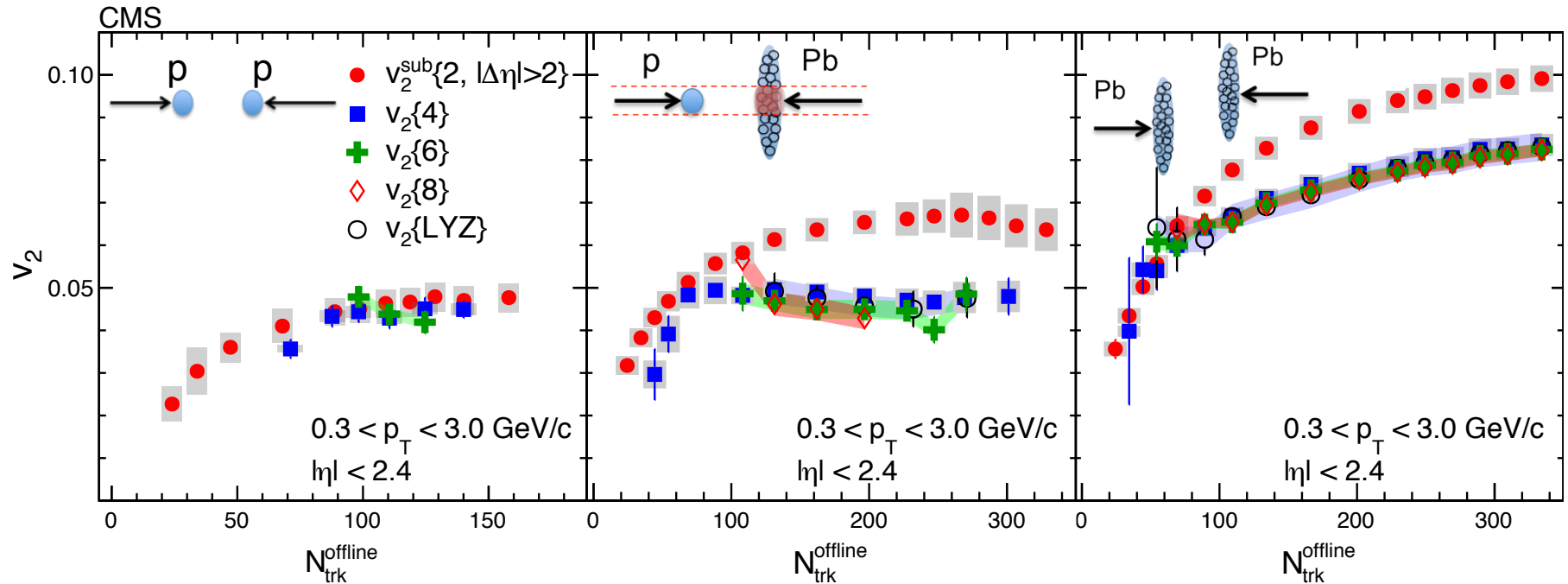
Mass ordering at low p_T -> Common velocity field

Similar observation in AA!!

Multi-particle correlation

PRL 115 (2015) 012301

PLB 765 (2017) 193

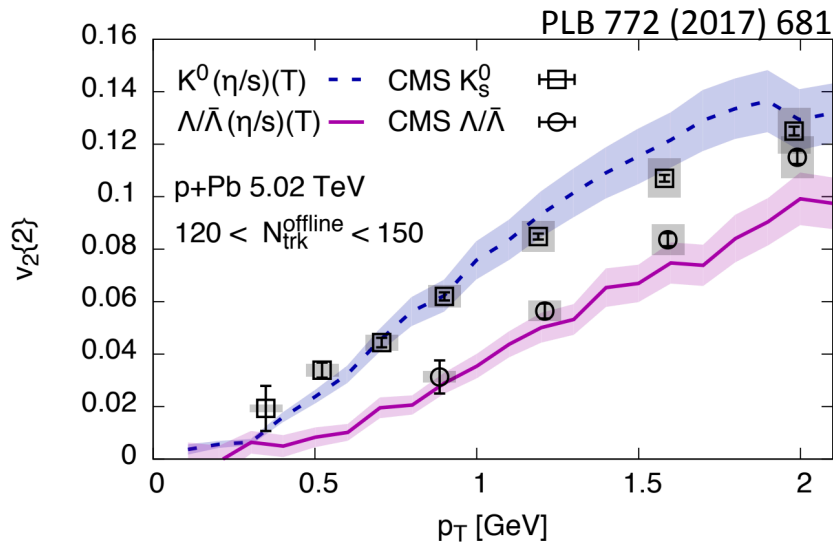


$$v_2\{4\} \approx v_2\{6\} \approx v_2\{8\} \approx \dots \approx v_2\{\infty\}$$

Direct confirmation of collectivity in all systems

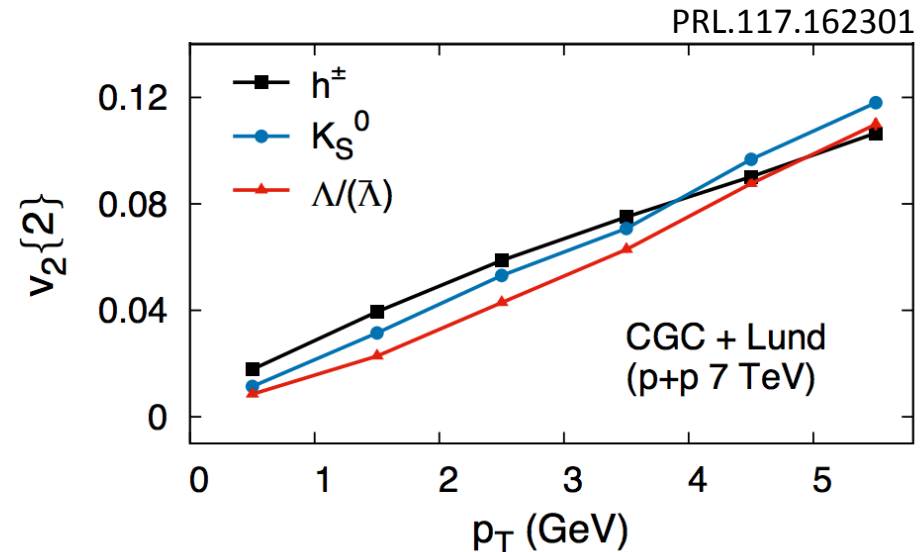
Origin of collectivity?

Final-state interactions
("Hydro" or few hits)



Extremely sensitive to
initial-state (not well constrained)

vs **Initial-state dynamics**
(Color-Glass-Condensate)

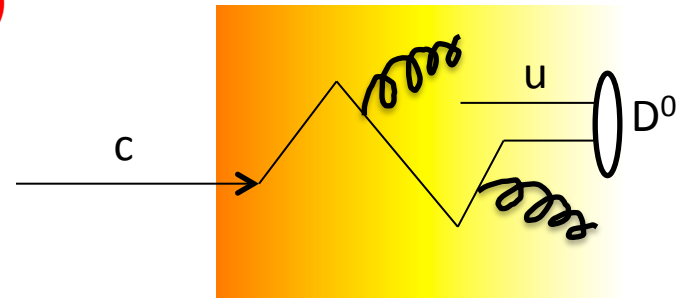
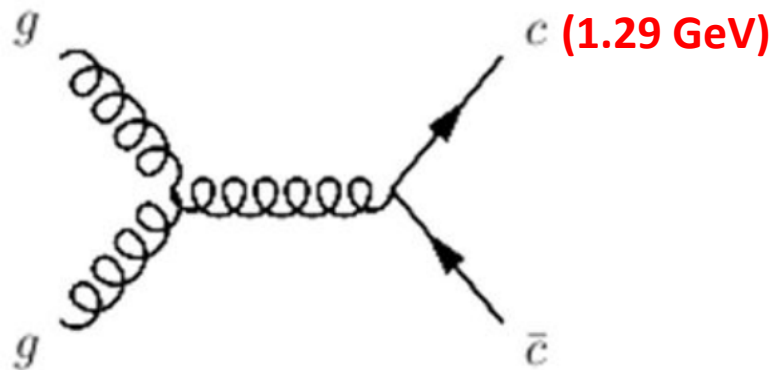
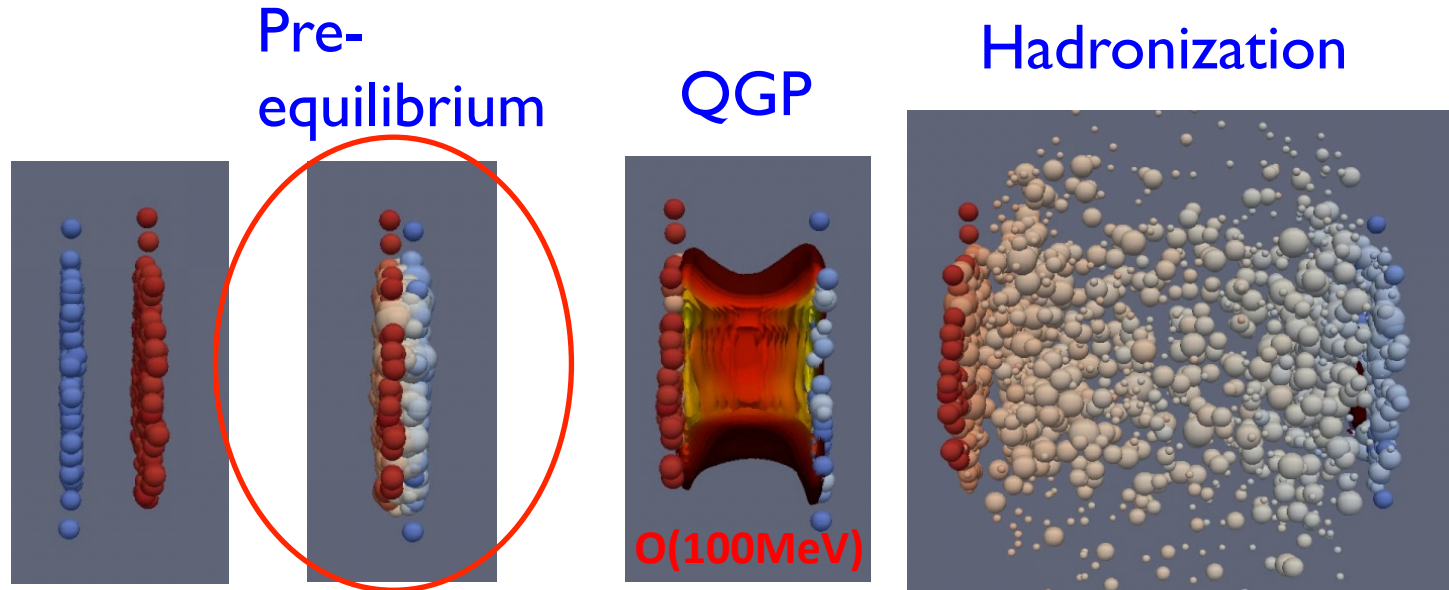


Quantitative comparison
not settled

What further measurements can distinguish them?

Parton-medium interaction

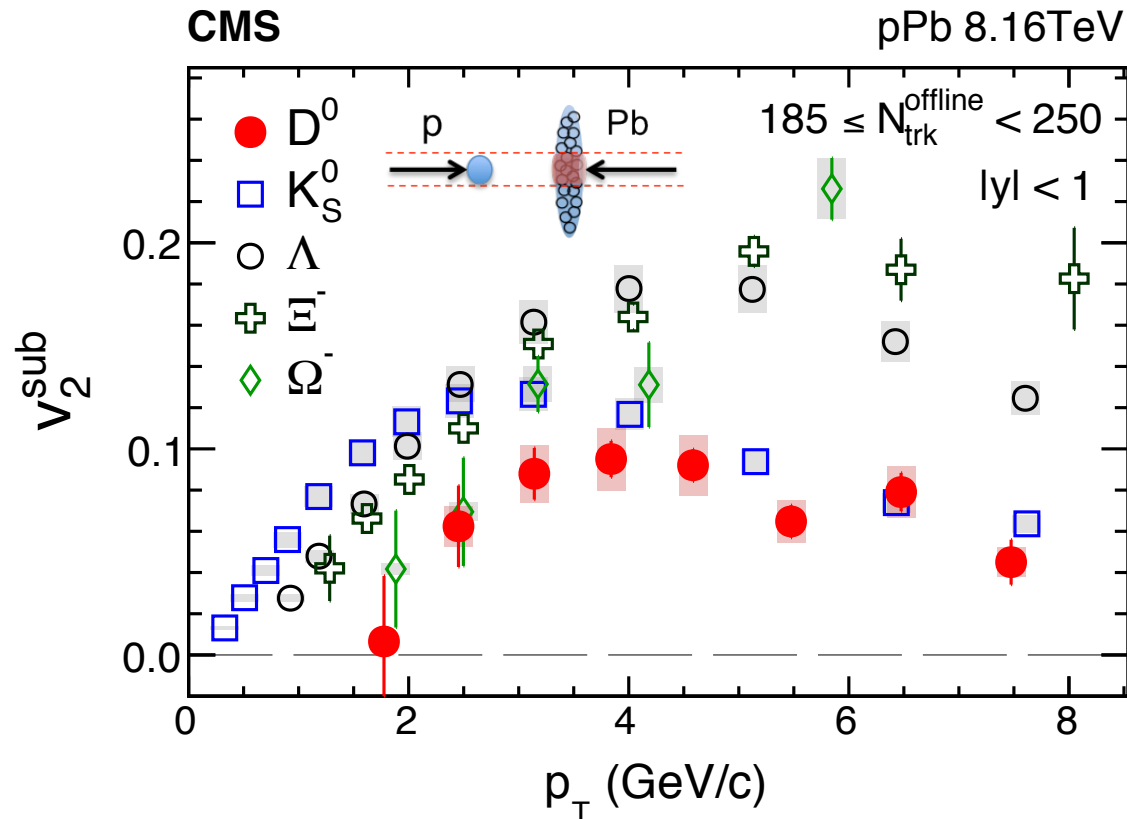
Heavy flavor quark as external probe



Expected to pick up medium flow!

D^0 meson v_2 in pPb

PRL.121.082301

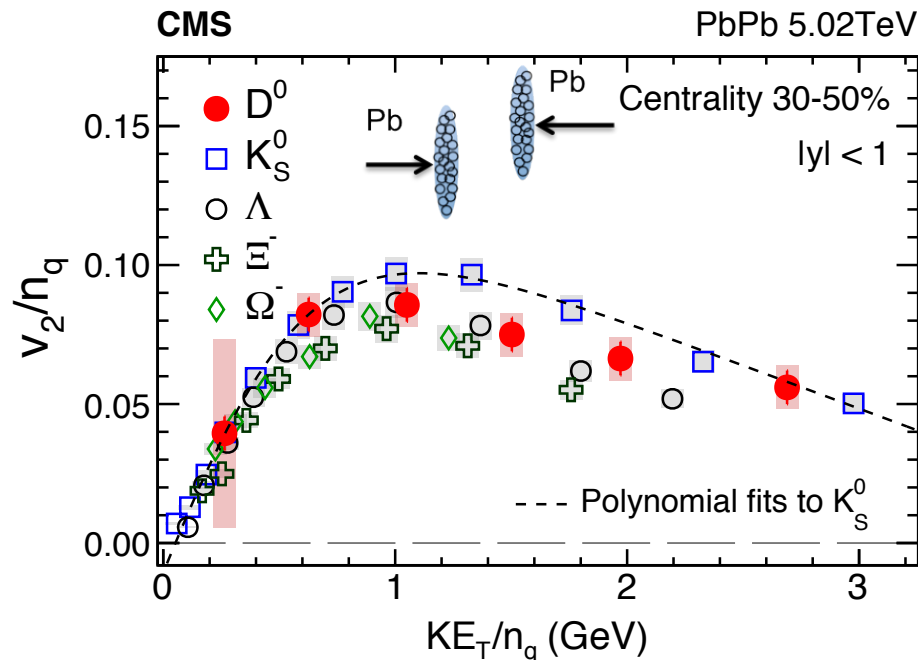
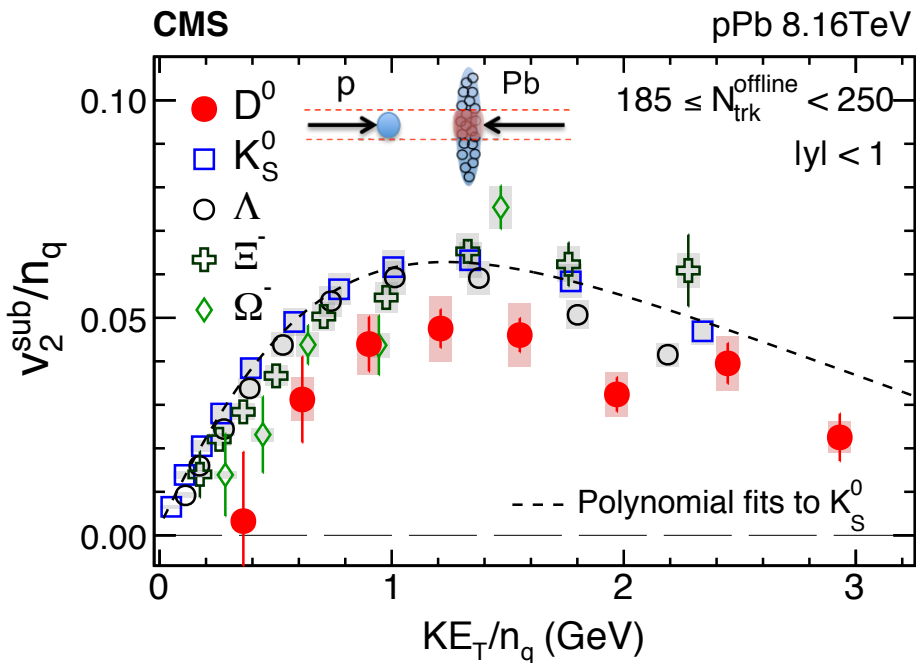


Significant $D^0 v_2$

D^0 share the common velocity field

D^0 meson NCQ in pPb

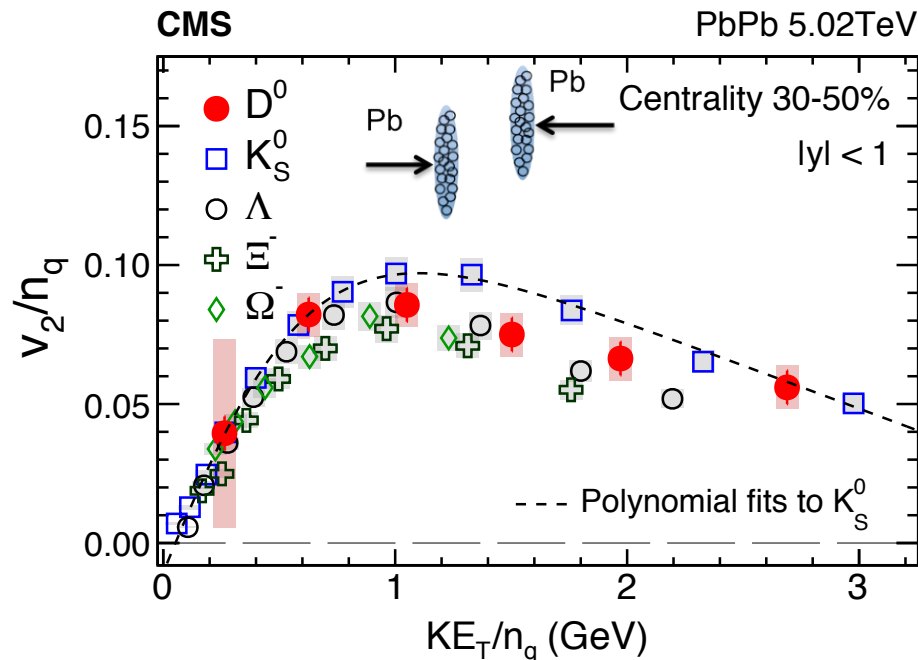
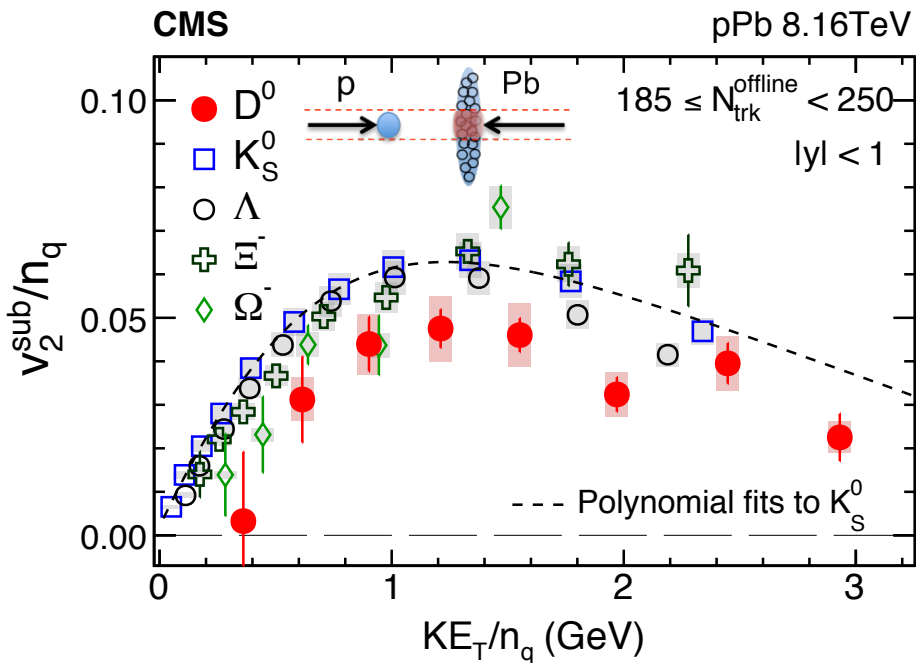
PRL.121.082301



D^0 results systematically lower
Different than observation in PbPb
Charm quark **less** thermalized in pPb than in PbPb?

D^0 meson NCQ in pPb

PRL.121.082301



D^0 results systematically lower

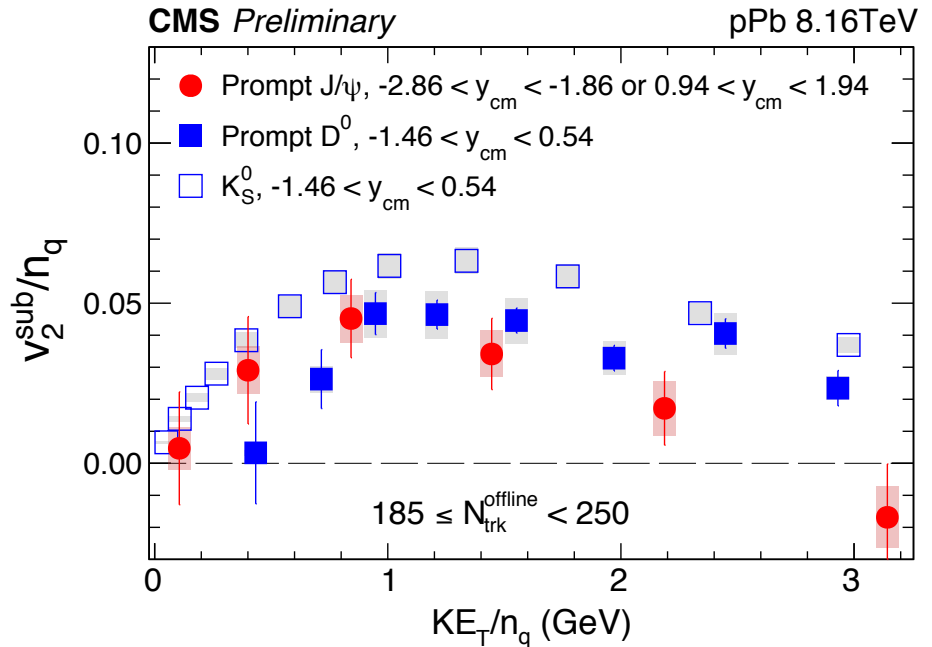
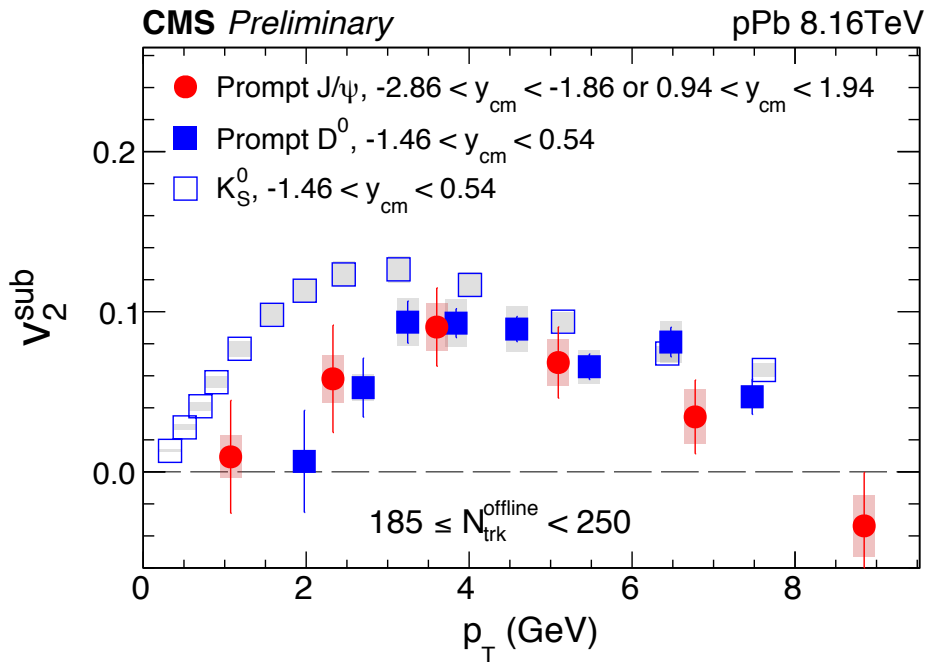
Different than observation in PbPb

Charm quark **less** thermalized in pPb than in PbPb?

At which stage does charm quark pick up the flow?

J/ψ flow in pPb

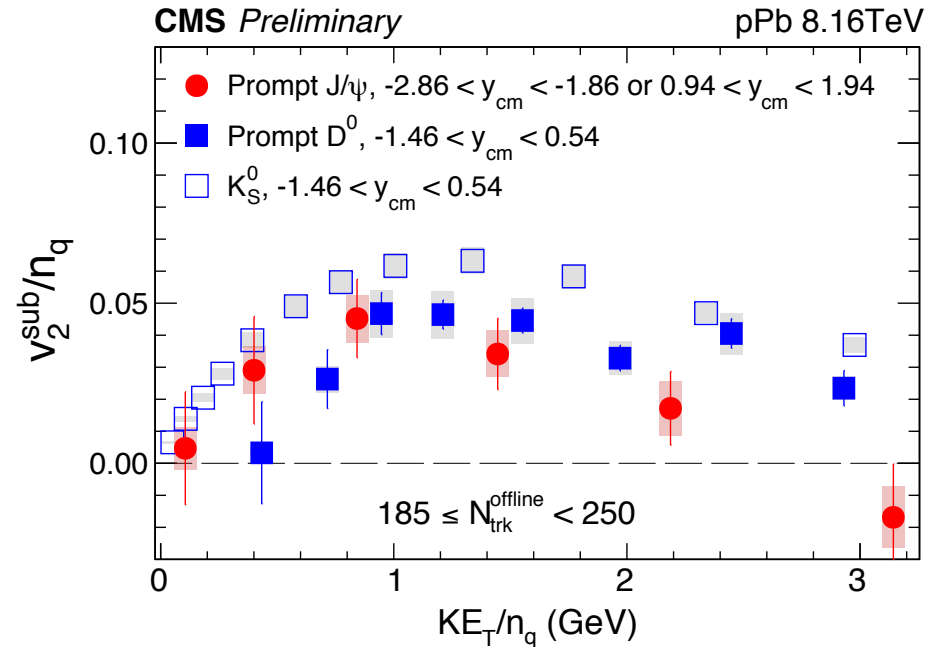
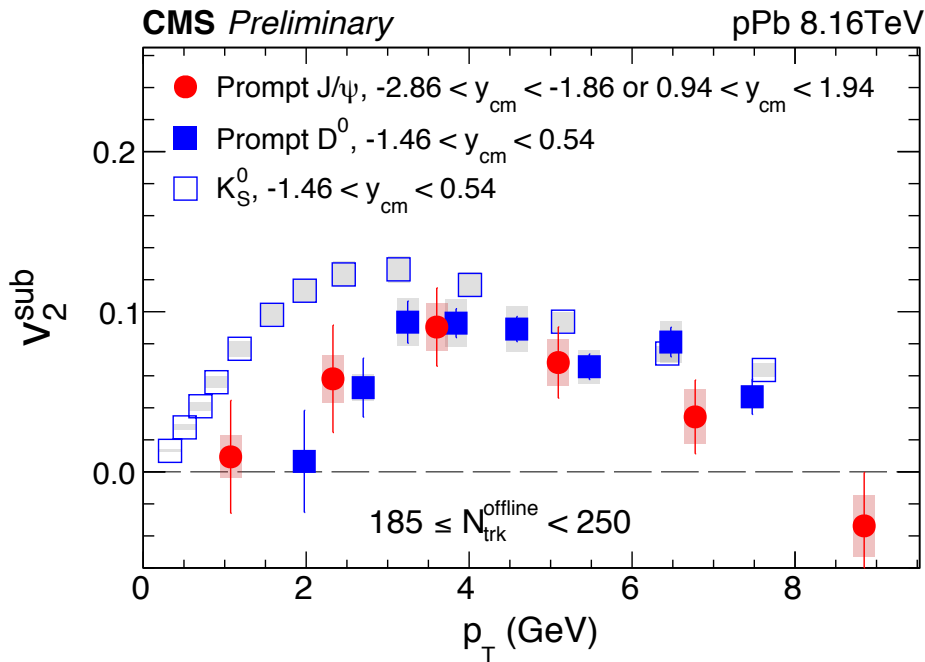
arxiv.1810.01473



Significant v_2 for J/ψ – **most** direct evidence of charm flow

J/ ψ flow in pPb

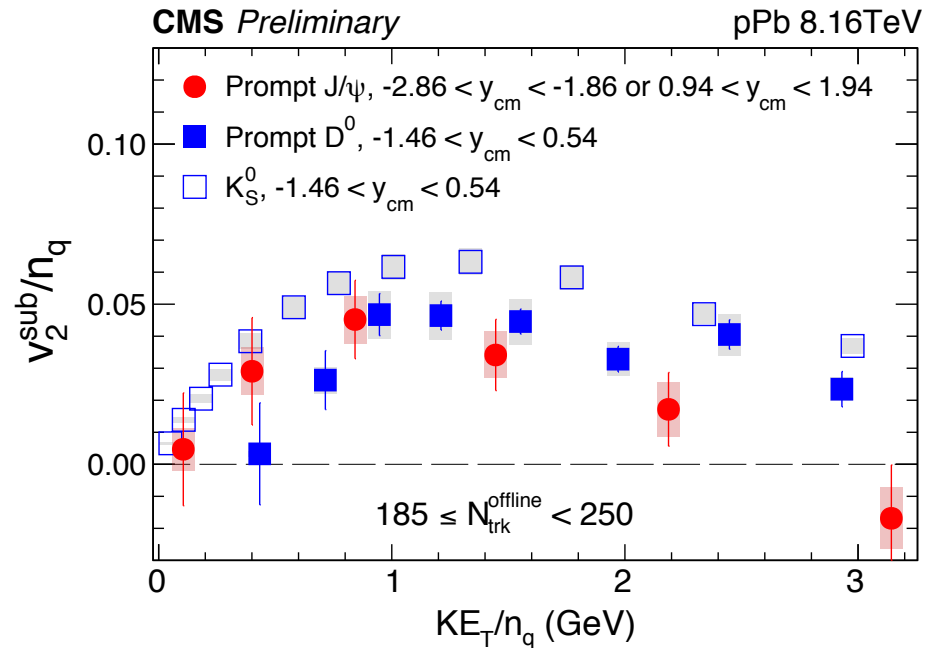
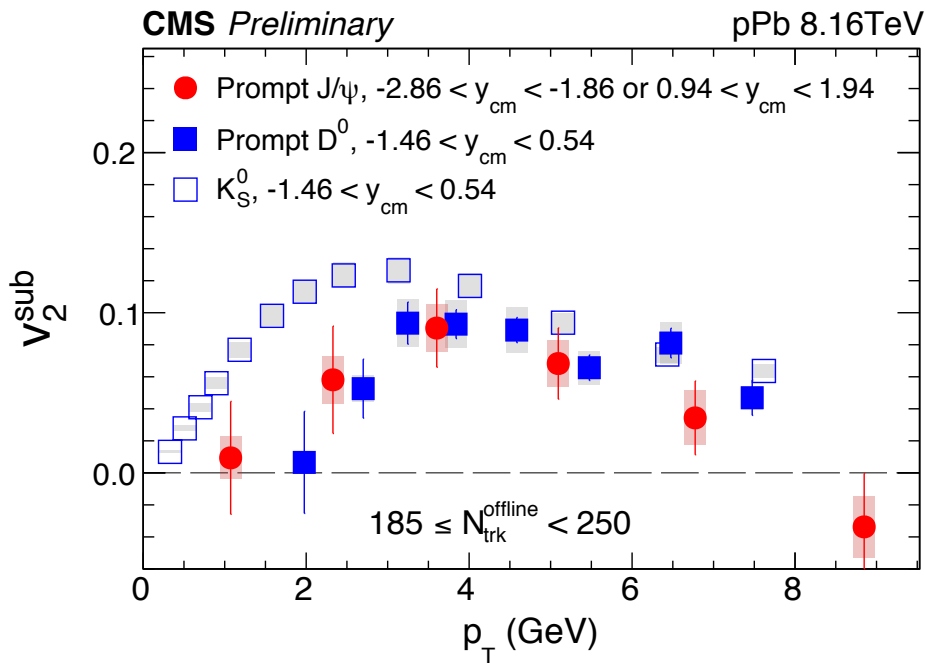
arxiv.1810.01473



Significant v_2 for J/ ψ – **most** direct evidence of charm flow
Challenge for hydro? Recombination expected to be low
What about CGC?

J/ ψ flow in pPb

arxiv.1810.01473



Significant v_2 for J/ ψ – **most** direct evidence of charm flow
Challenge for hydro? Recombination expected to be low
What about CGC?

Future: Detailed study of c and b collectivity vs multiplicity

New opportunity – STAR beyond-BESII

	Year	$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
Scheduled RHIC running	2023	$p^\uparrow p @ 200$	300 pb^{-1} 8 weeks	Subprocess driving the large A_N at high x_F and η	A_N for charged hadrons and flavor enhanced jets	Forward instrum. ECal+HCal+Tracking
	2023	$p^\uparrow \text{Au} @ 200$	1.8 pb^{-1} 8 weeks	What is the nature of the initial state and hadronization in nuclear collisions	R_{pAu} direct photons and DY	Forward instrum. ECal+Hcal+Tracking
	2023	$p^\uparrow \text{Al} @ 200$	12.6 pb^{-1} 8 weeks	Clear signatures for Saturation A-dependence of nPDF, A-dependence for Saturation	Dihadrons, γ -jet, h-jet, diffraction R_{pAl} direct photons and DY	Forward instrum. ECal+HCal+Tracking
Potential future running	2021	$p^\uparrow p @ 510$	1.1 fb^{-1} 10 weeks	TMDs at low and high x	A_{UT} for Collins observables, i.e. hadron in jet modulations at $\eta > 1$	Forward instrum. ECal+HCal+Tracking
	2021	$\vec{p} \vec{p} @ 510$	1.1 fb^{-1} 10 weeks	$\Delta g(x)$ at small x	A_{LL} for jets, di-jets, h/ γ -jets at $\eta > 1$	Forward instrum. ECal+HCal

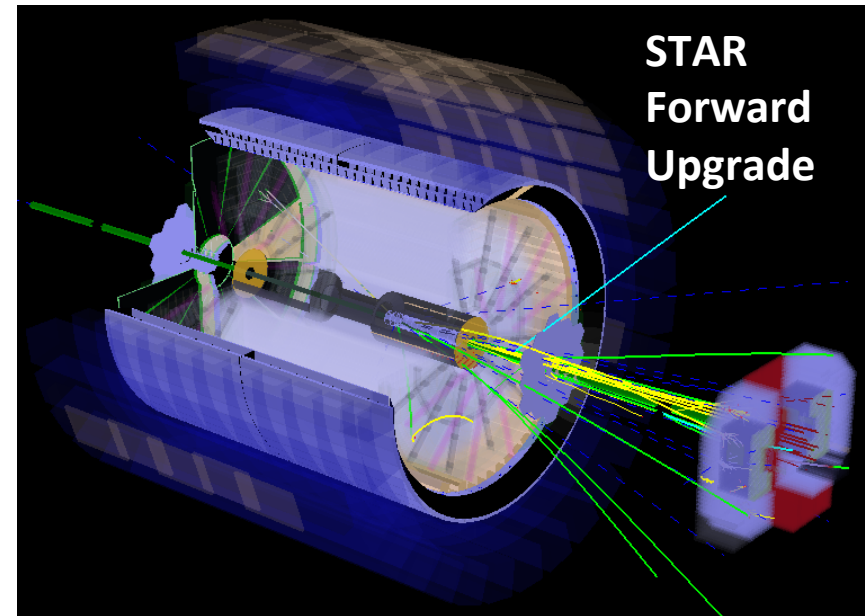
Golden window for collectivity in small system at RHIC energies and with polarized beams

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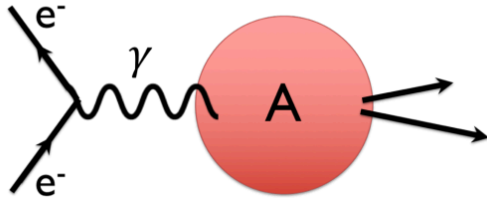
Golden window for collectivity in small system at RHIC energies
and with polarized beams

Forward upgrade crucial for long range correlations



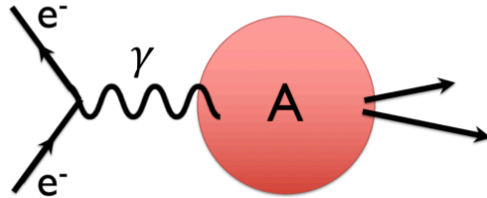
New opportunity – eA collision

Typical e+A

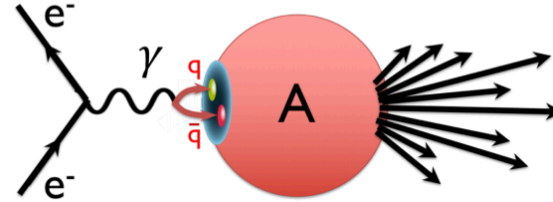


New opportunity – eA collision

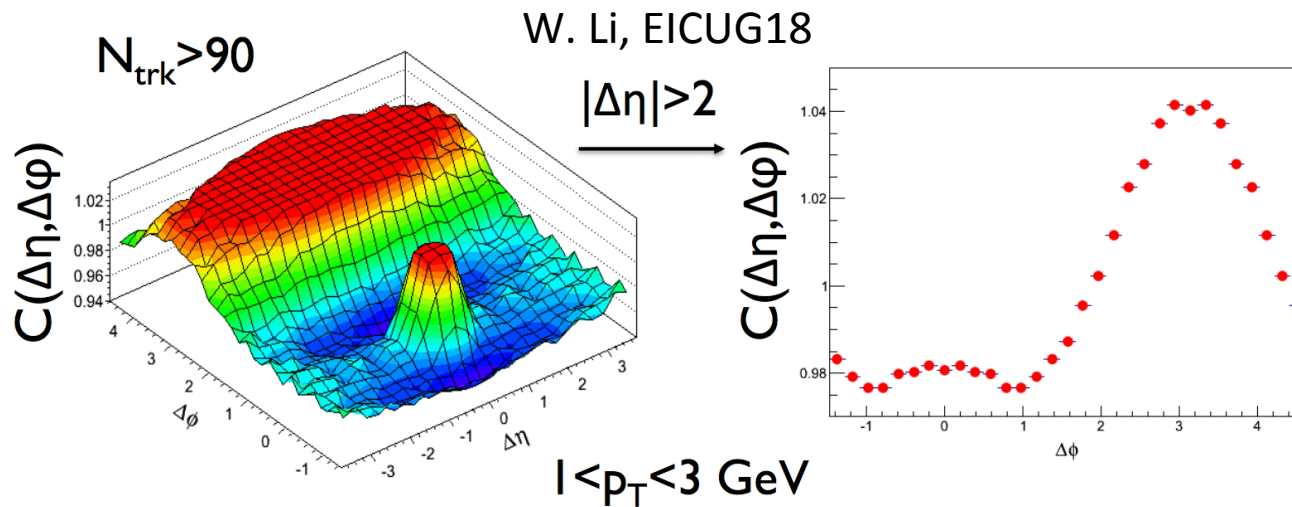
Typical e+A



High-multiplicity e+A = (q $\bar{q}$)+A

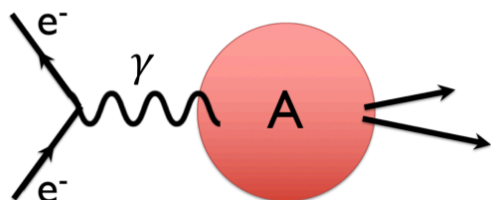


π^+ (30GeV) + **Au** (100GeV) from AMPT

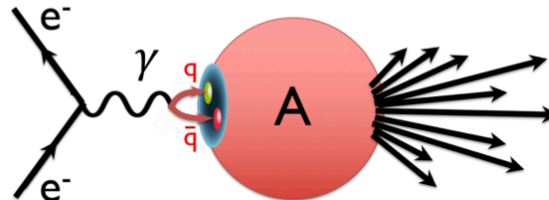


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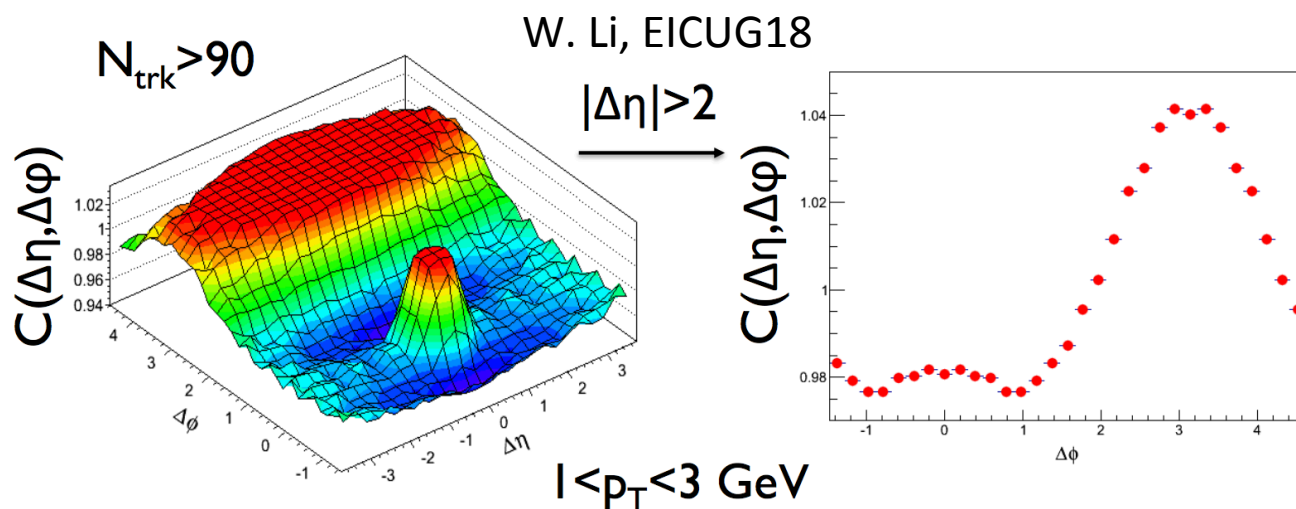
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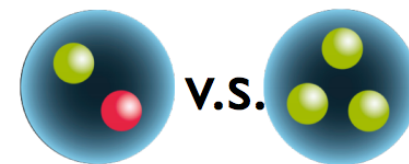
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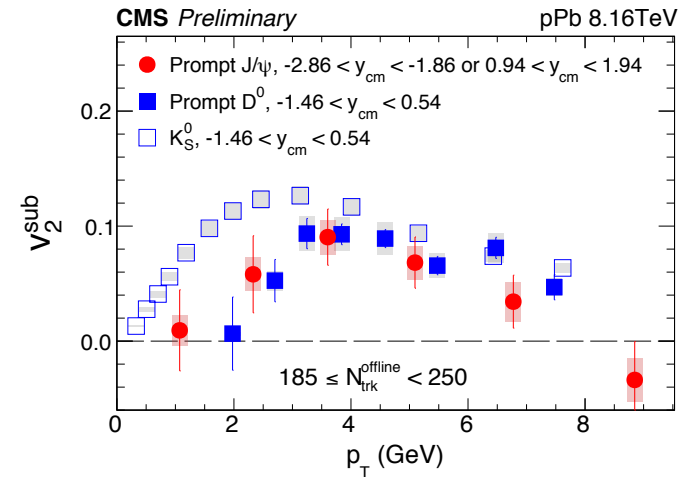
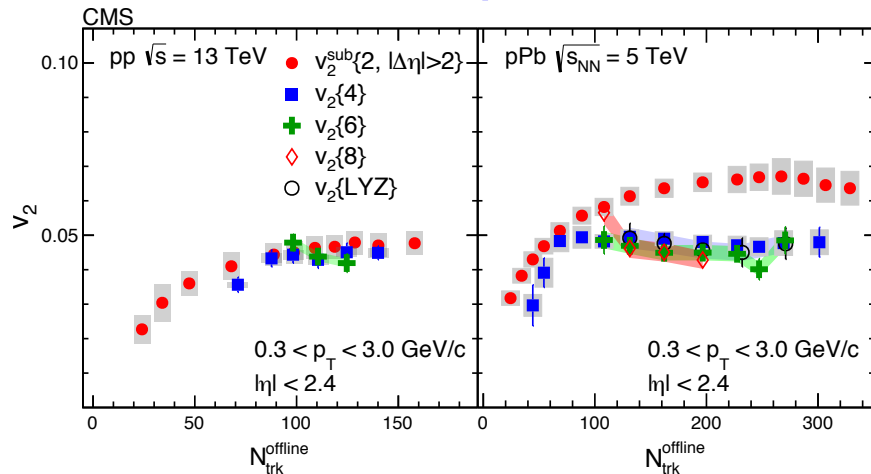
Insight on
sub-nucleonic
fluctuation



Disentangle “hydro” vs CGC?
Constrain sub-nucleonic structure?

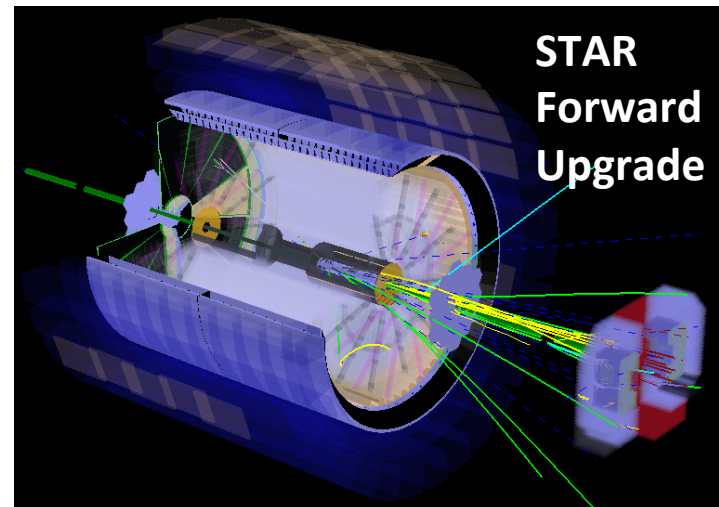
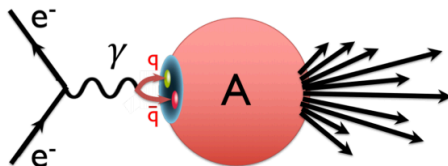
Summary

- Experimental observations in **high-multiplicity** small collisions confirm **collectivity** nature of the correlations



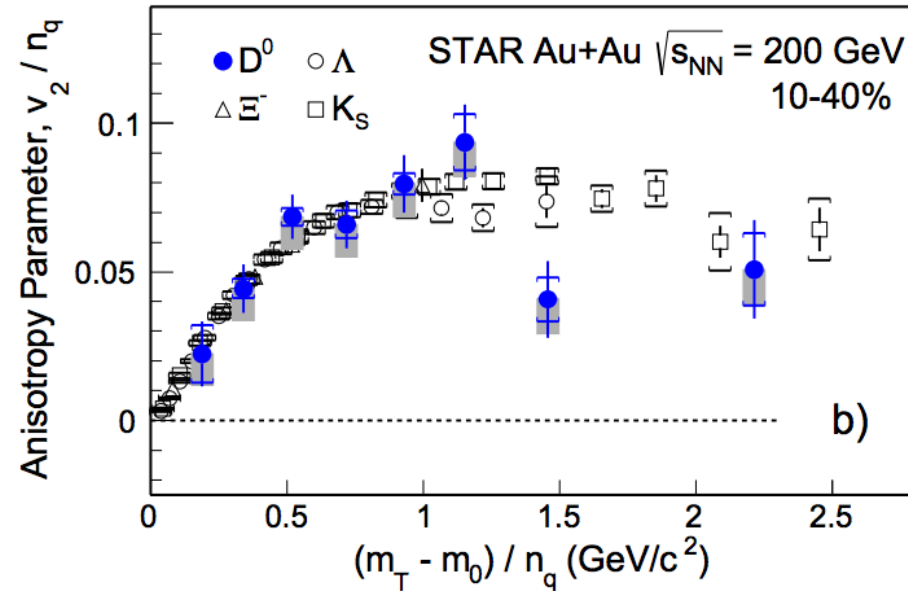
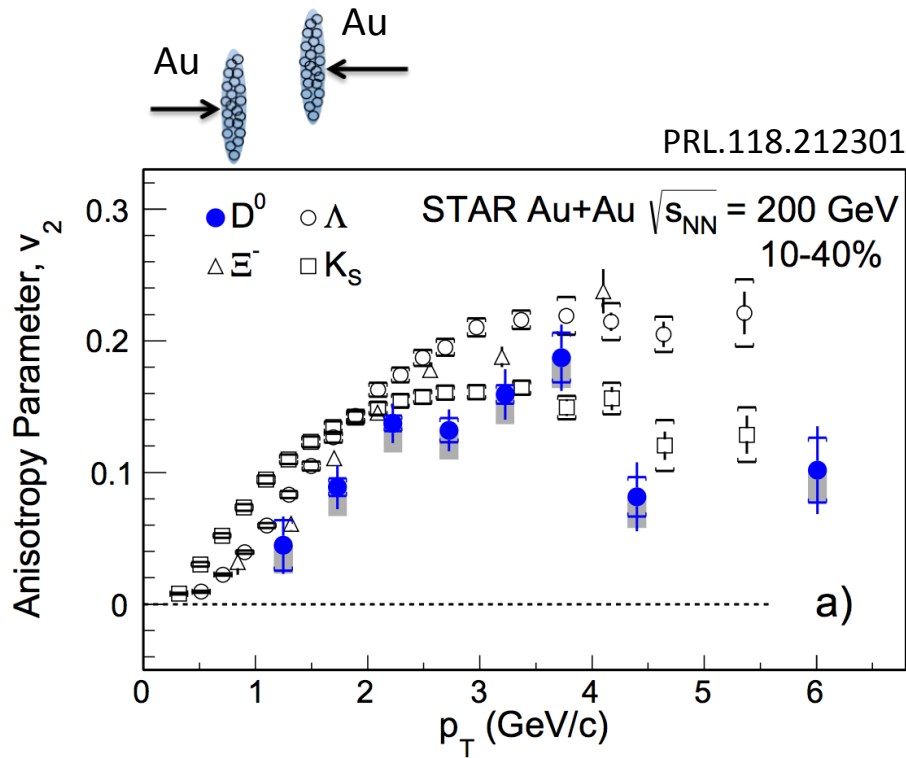
- New opportunities to understand the **origin of collectivity** at STAR and EIC

High-multiplicity $e+A = (q\bar{q})+A$



Back up

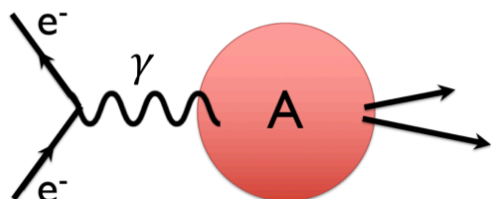
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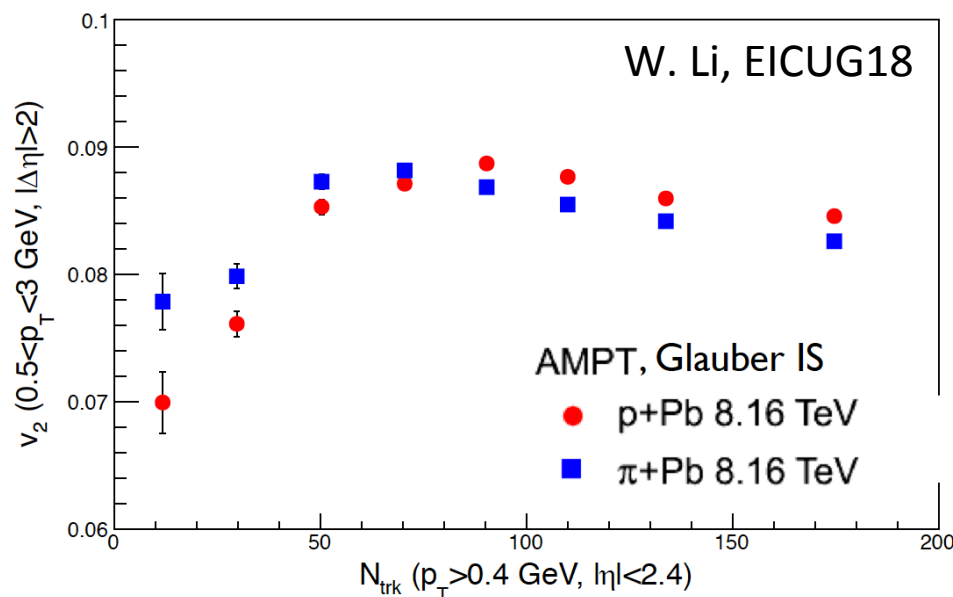
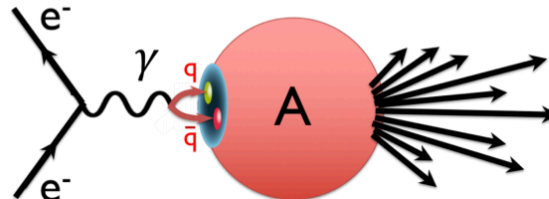
Significant interaction between charm quark and QGP
Charm quark fully thermalized with medium?
Do we see the same in small systems?

New opportunity – eA collision

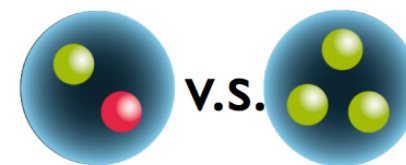
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