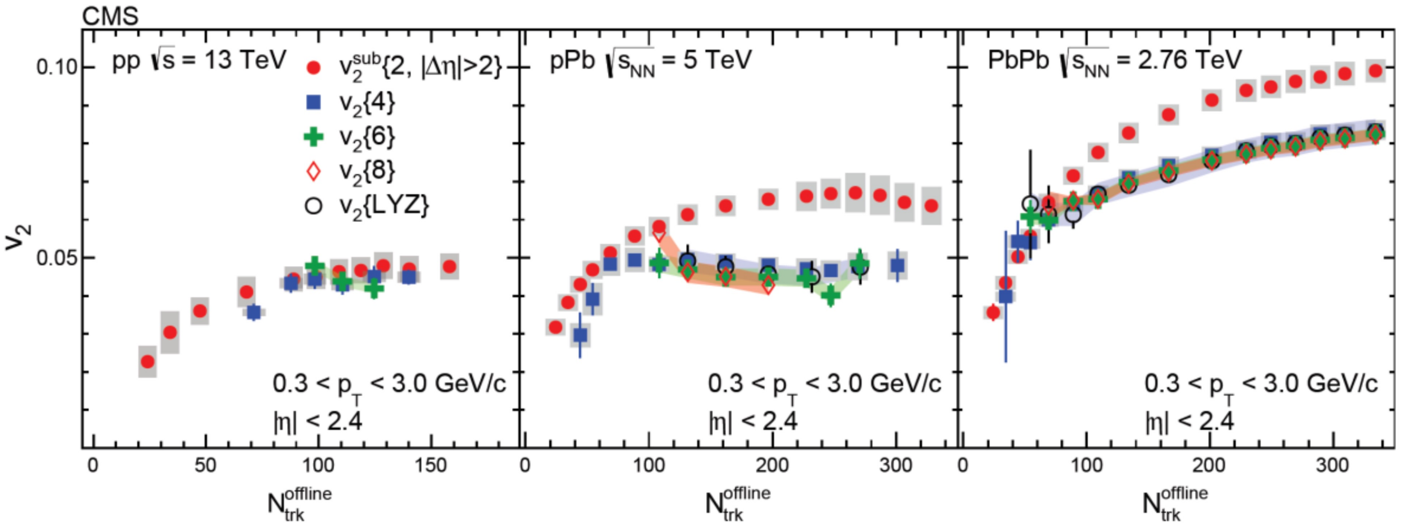
Proposal for p+Au data ~~at the end of this run~~

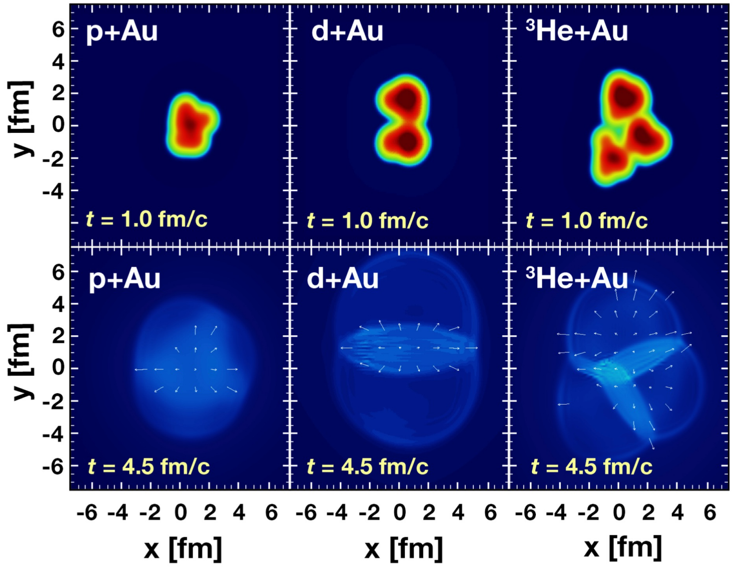
Mike Lisa

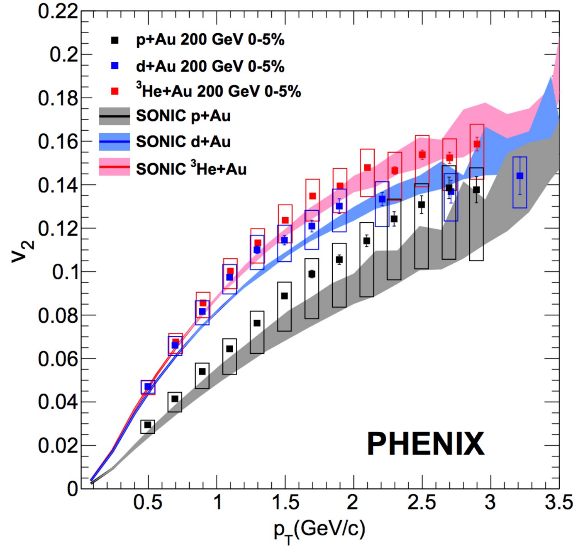
Does p+A make a hydro system?

Nagle & Zajc, Ann.Rev.Nucl.Part.Sci. 68 (2018)

- Anisotropic flow measures suggest hydro works for A+A, p+A. (p+p less clear)
- Alternative explanations for p+A have been proposed
- non-v_n-based evidence would be valuable!



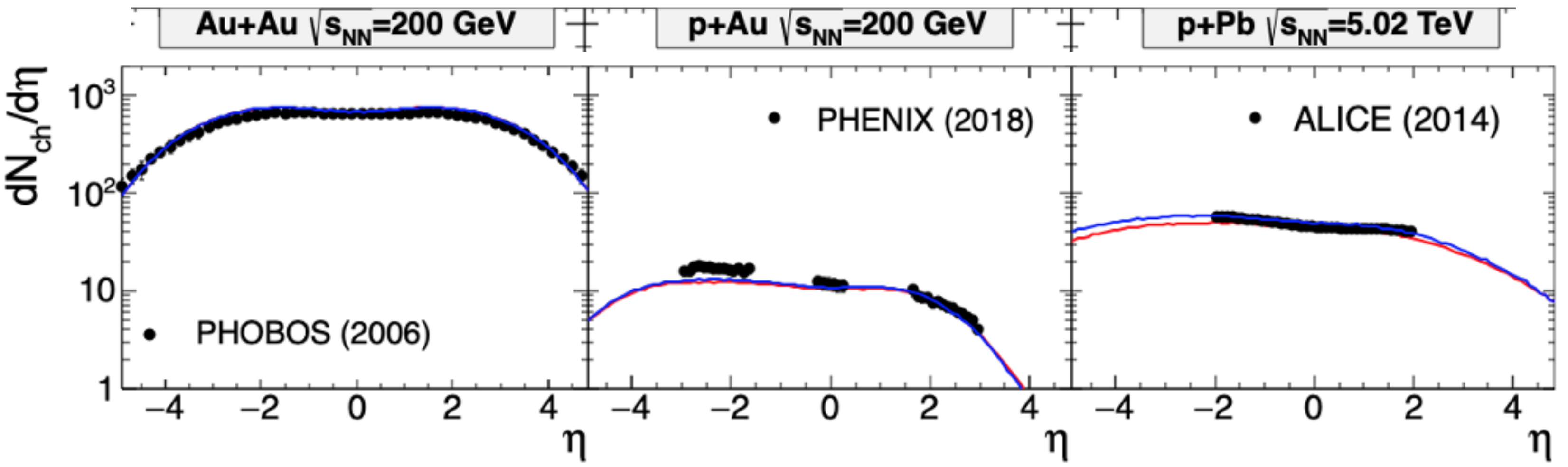


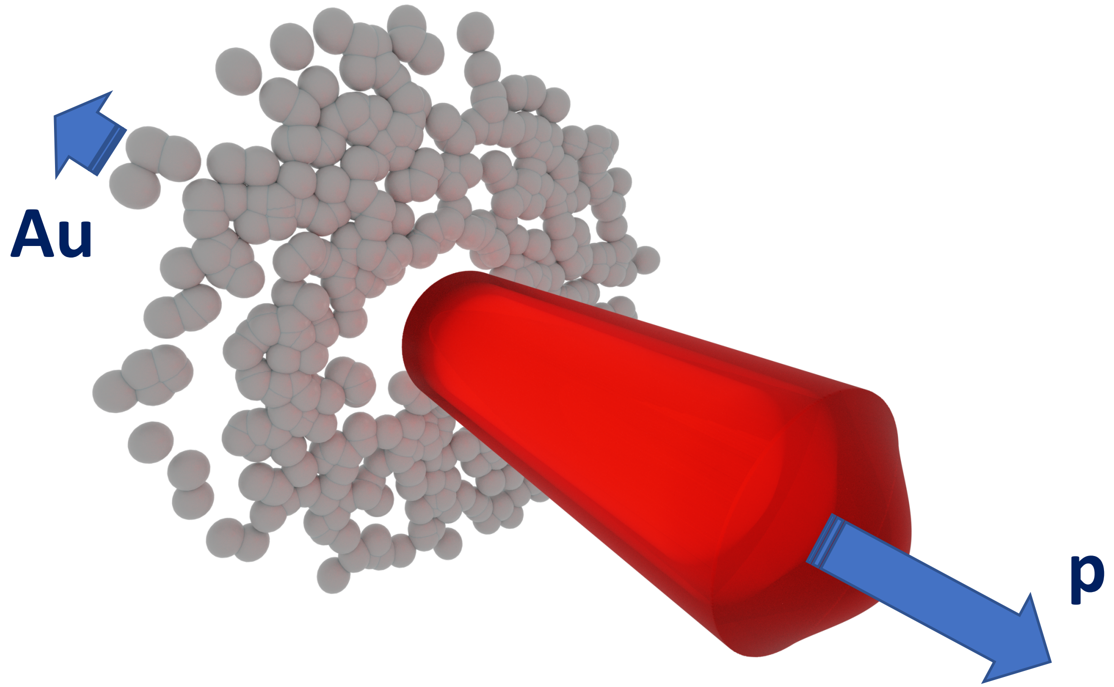


Does p+A make a hydro system?

MAL, Barbon, Chinellato, Serenone, Shen, Takahashi, Torrieri arxiv:2101.10872

MUSIC describes dN/d\eta well





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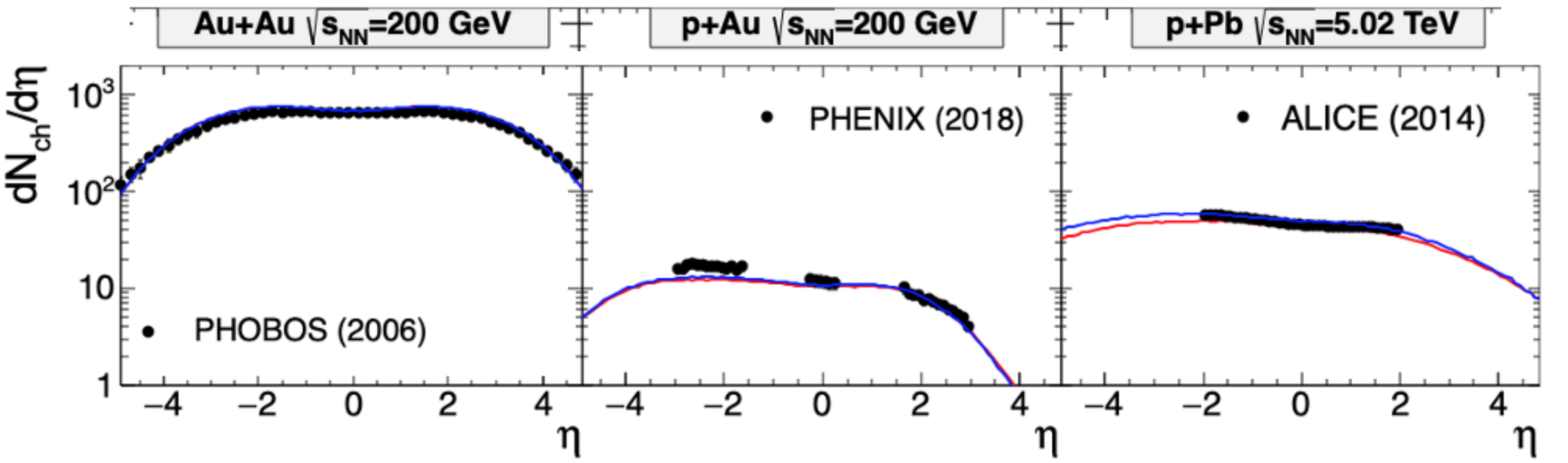
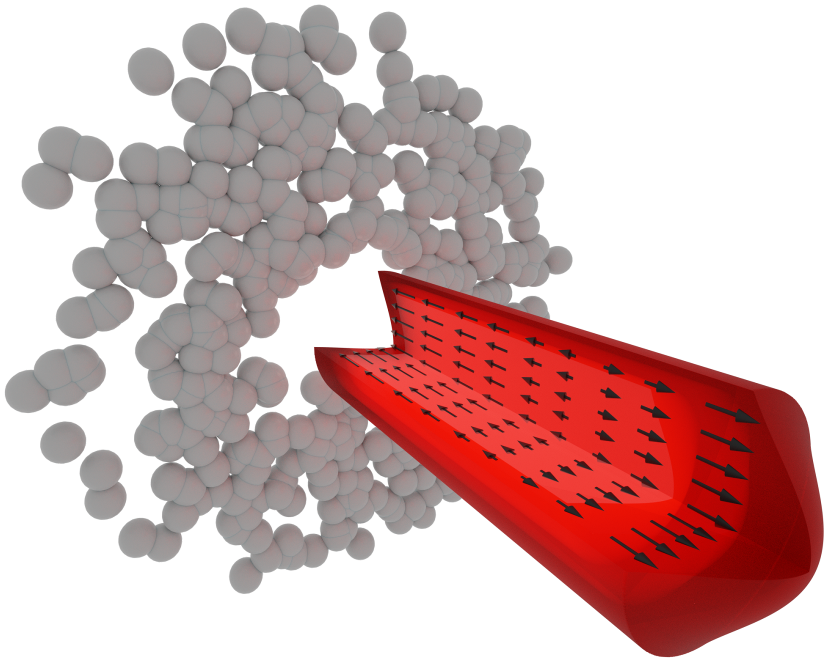
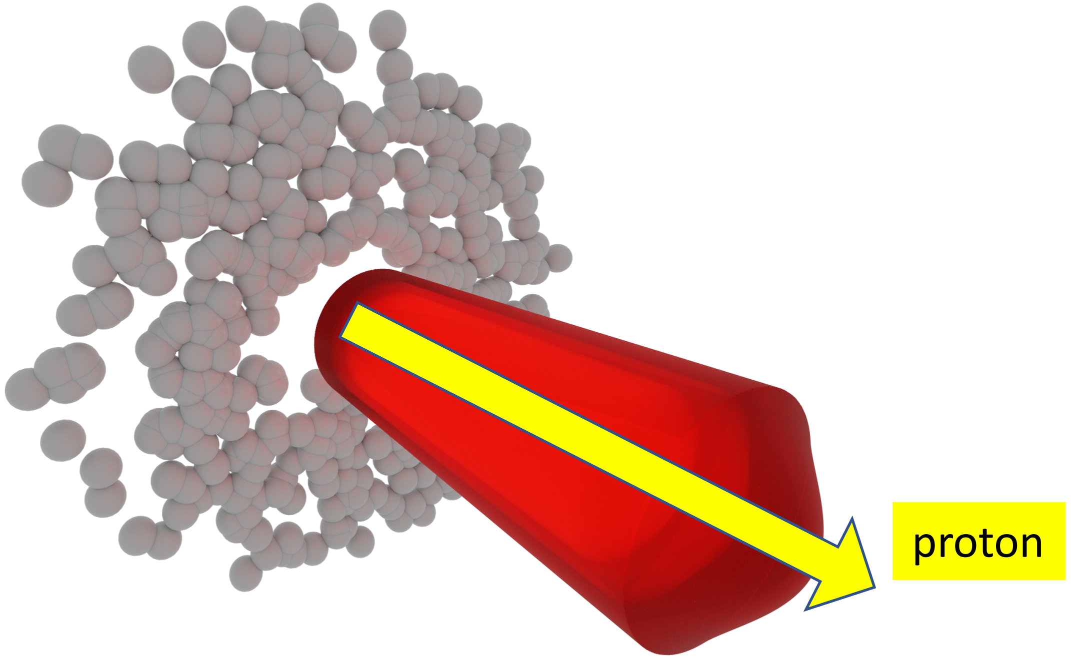




(a) Bjorken flow profile: $u_z = \eta_s$



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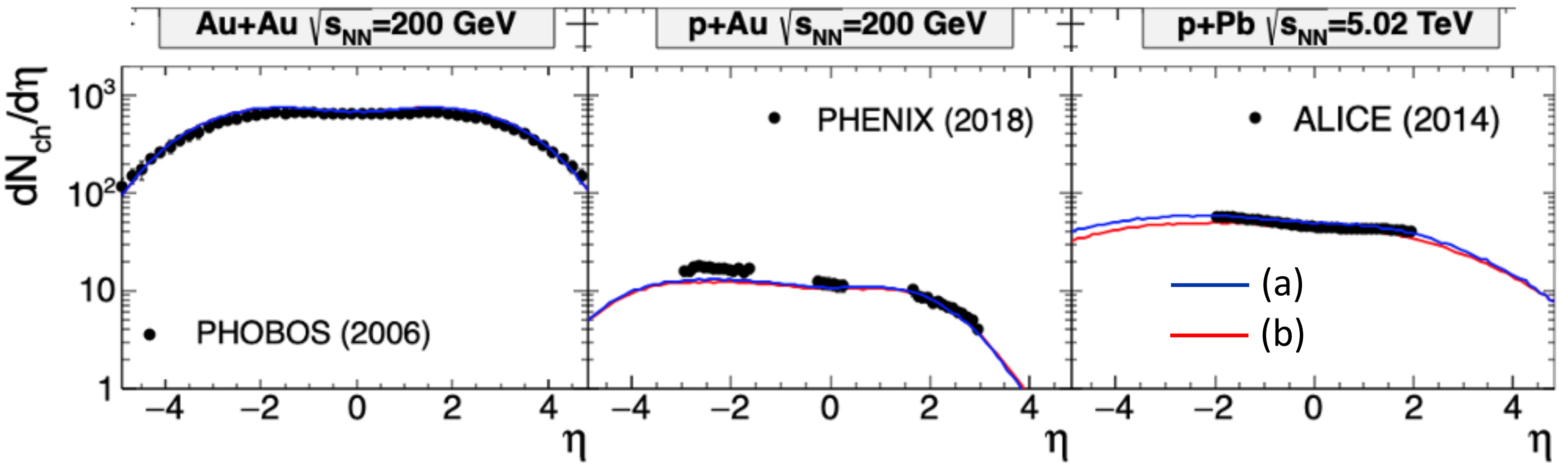
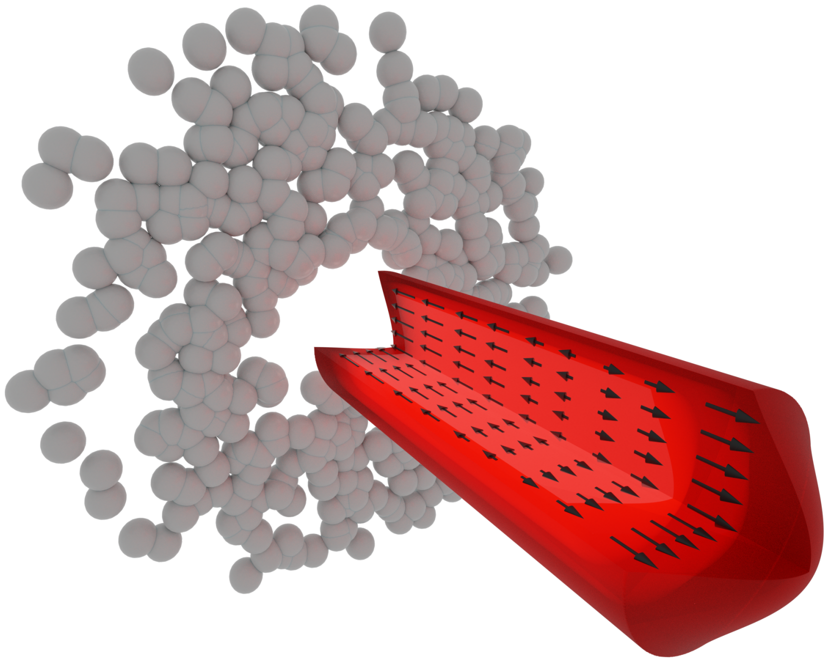
MUSIC describes dN/d\eta well

- default assumption: Bjorken flow
  - but is that "natural?"
- Radial-gradient profile also works
  - dN/d\eta insensitive to substructure



See also S. Voloshin, STAR BulkCorr, Hirschegg 2017



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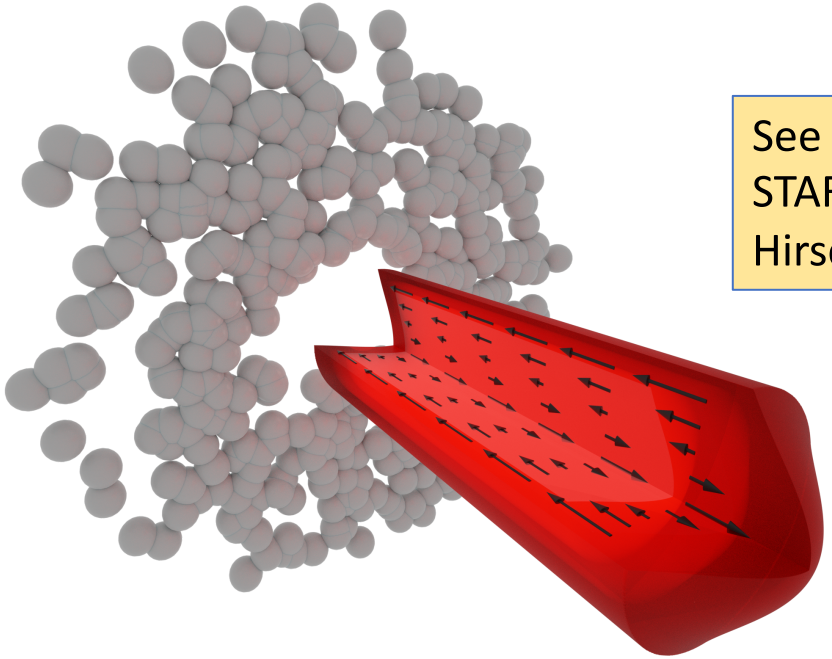

(b) Radial-gradient flow profile

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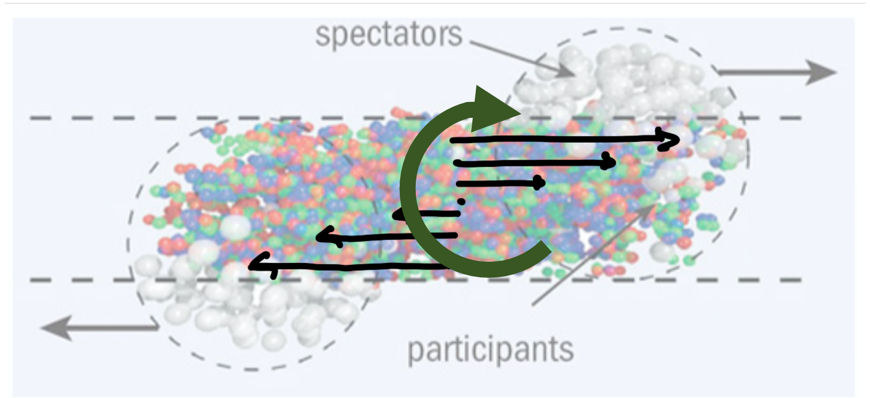
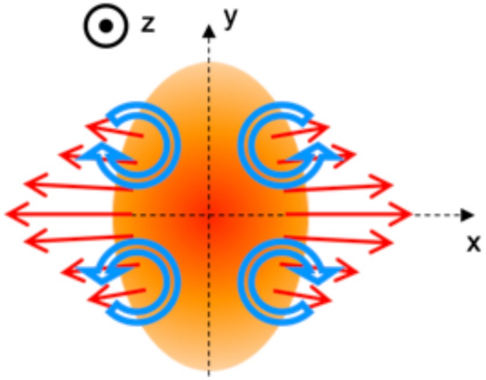
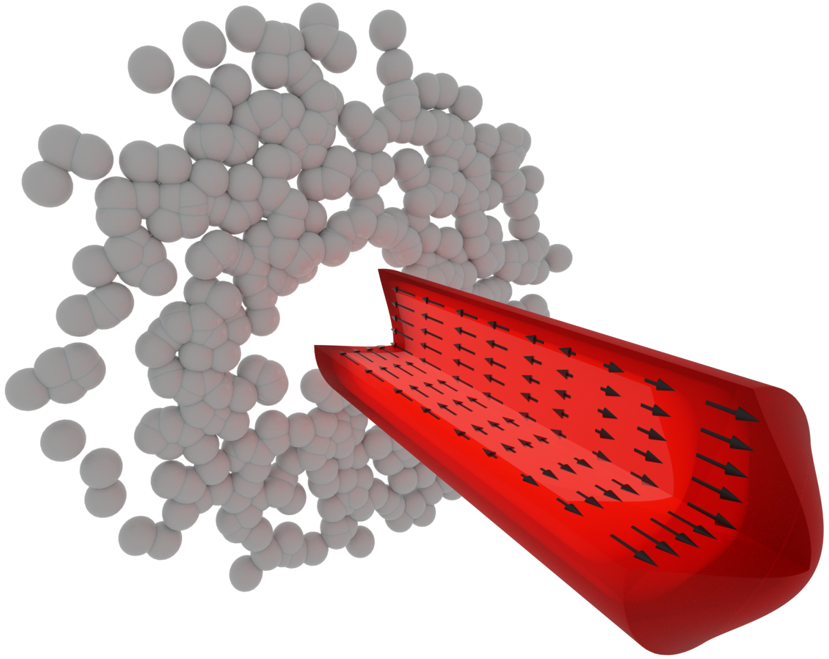
As in A+A collisions,
shear & continuity → vorticity







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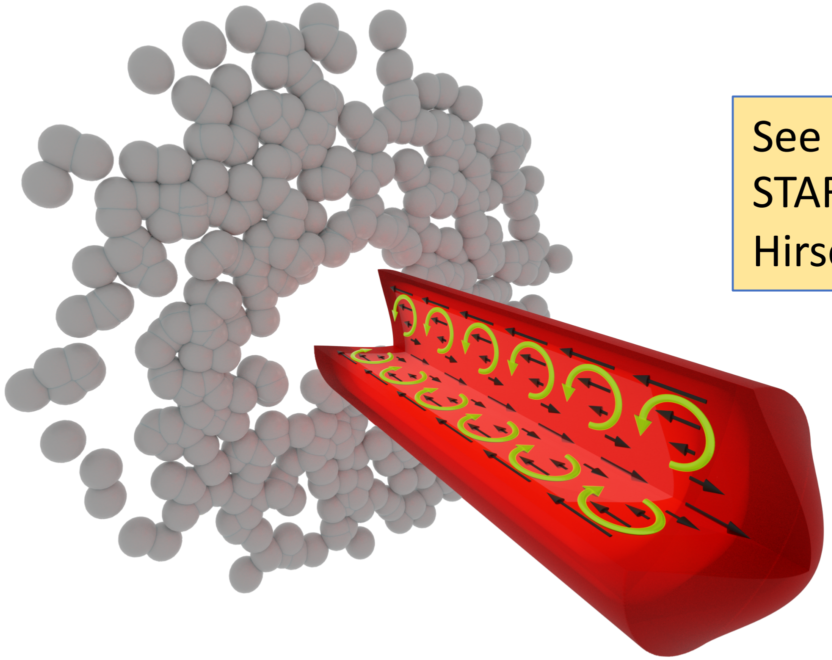

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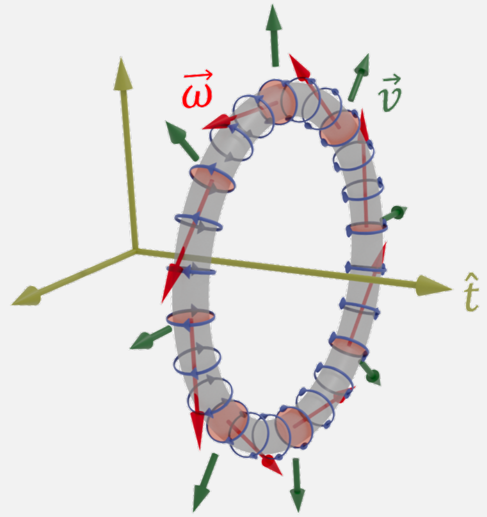
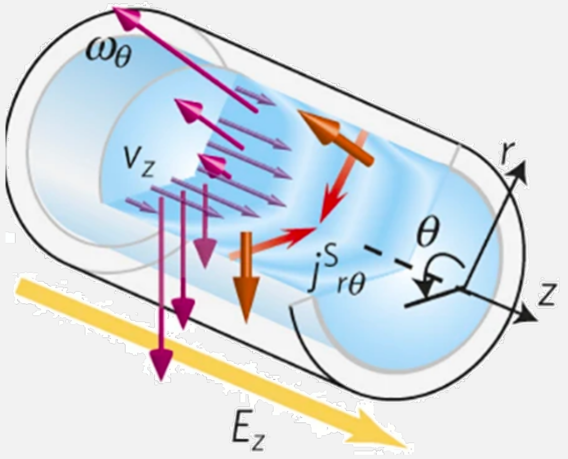


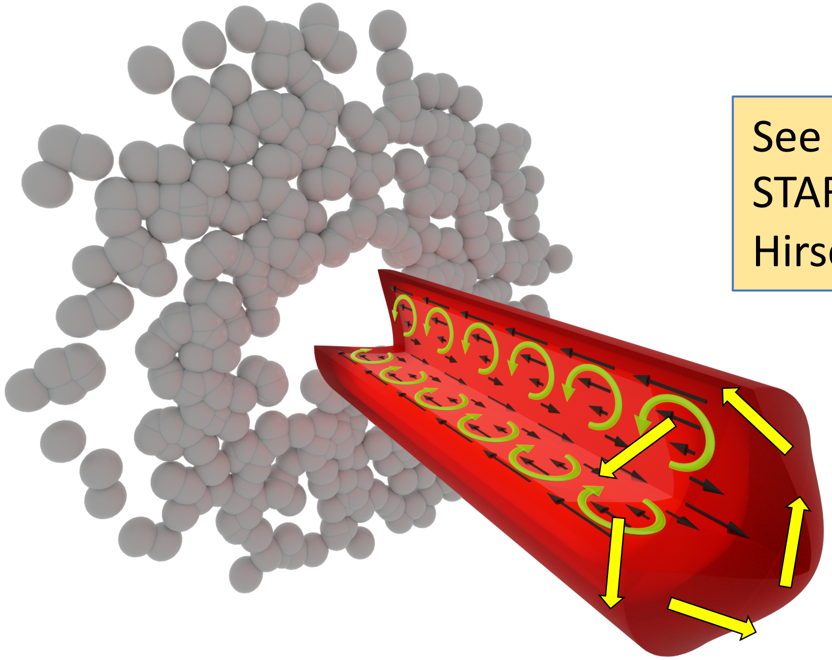
Smoke ring

Nature Phys. 12 (2016) 52-56



Fluid flowing in a tube

Classic fluid behavior with these initial conditions: toroidal vortex structure

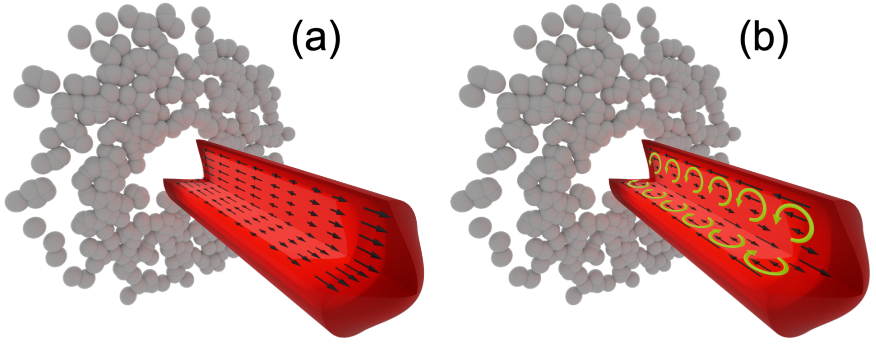


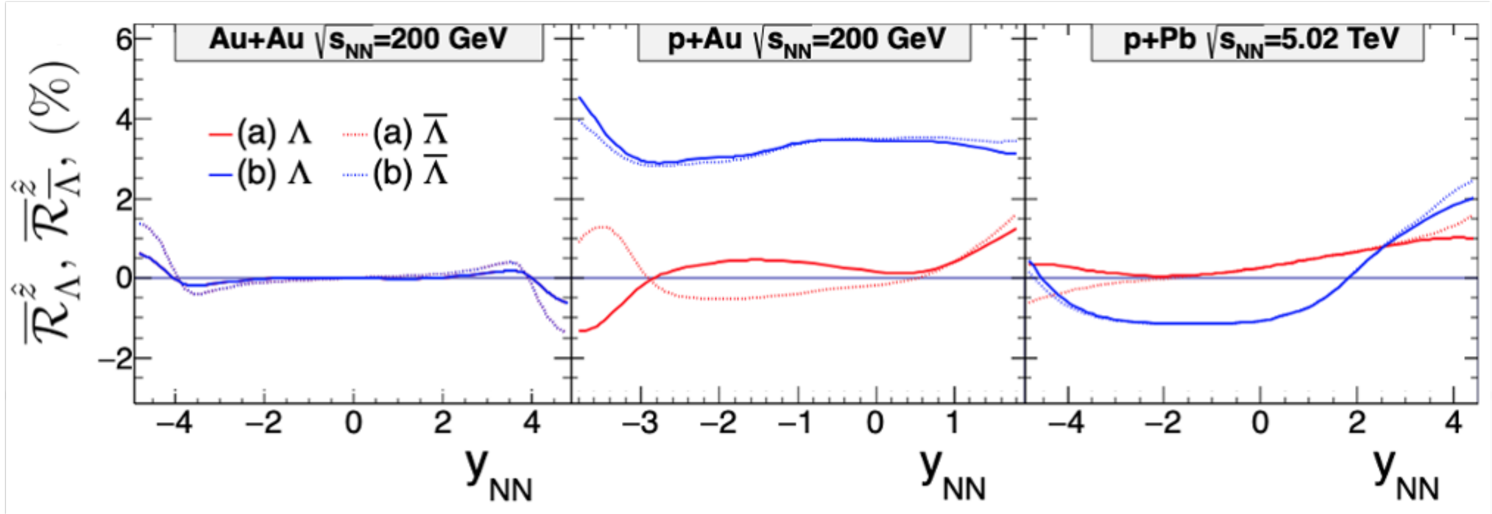
p+A collision?

See also S. Voloshin, STAR BulkCorr, Hirschegg 2017

How to measure?

MAL, Barbon, Chinellato, Serenone, Shen, Takahashi, Torrieri arxiv:2101.10872



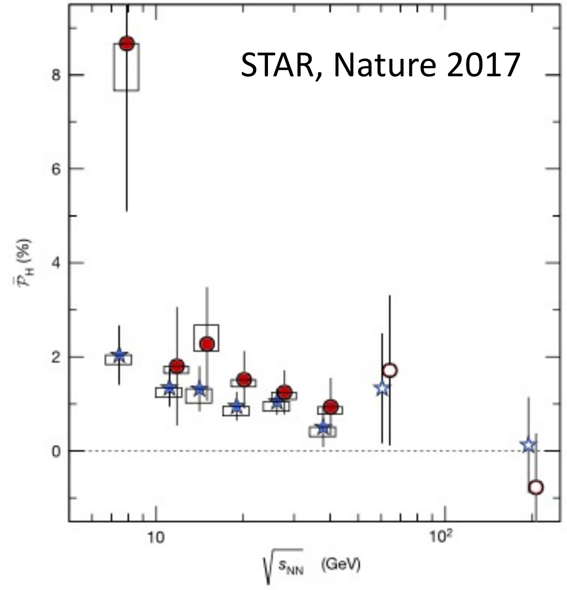


toroidal vorticity: $\overline{\mathcal{R}}^{\hat{z}}_{\Lambda} = 2\left\langle \frac{\vec{S}'_{\Lambda}\cdot(\hat{z}'\times\vec{p}_{\Lambda}')}{|\hat{z}'\times\vec{p}_{\Lambda}'|}\right\rangle_{\phi} = \frac{8}{\pi\alpha}\left\langle\cos\left(\phi_p-\phi_{\rm PP}\right)\right\rangle_{\phi}$ $\quad \delta\overline{\mathcal{R}}^{\hat{z}}_{\Lambda} \sim N_{\Lambda}^{-1/2}$

global polarization: $\overline{P}_H = \left\langle \vec{\mathcal{P}}_H\cdot\hat{J}_{\rm sys}\right\rangle = \frac{8}{\pi\alpha}\frac{\left\langle\cos\left(\phi_p-\phi_J\right)\right\rangle_{\phi}}{R^{(1)}_{\rm EP}}$ $\quad \delta\overline{P}_H \sim N_{\Lambda}^{-1/2}\times\left(R^{(1)}_{\rm EP}\right)^{-1}$

The hyperon statistics required to measure a 2% global polarization, should easily allow measurement of a 3% toroidal vorticity

Needed statistics… and…



Want central (say 0-10%) events

Estimate **0.02 reconstructed Lambdas/central event**. [backup slide]

Isaac's Nature analysis: 11 GeV sample had 6M Lambdas, measuring 1% signal with 3.5 sigma

→ Need 6M reco Lambdas/(0.02 reco Lambdas/central p+Au event) = **300M central p+Au events**

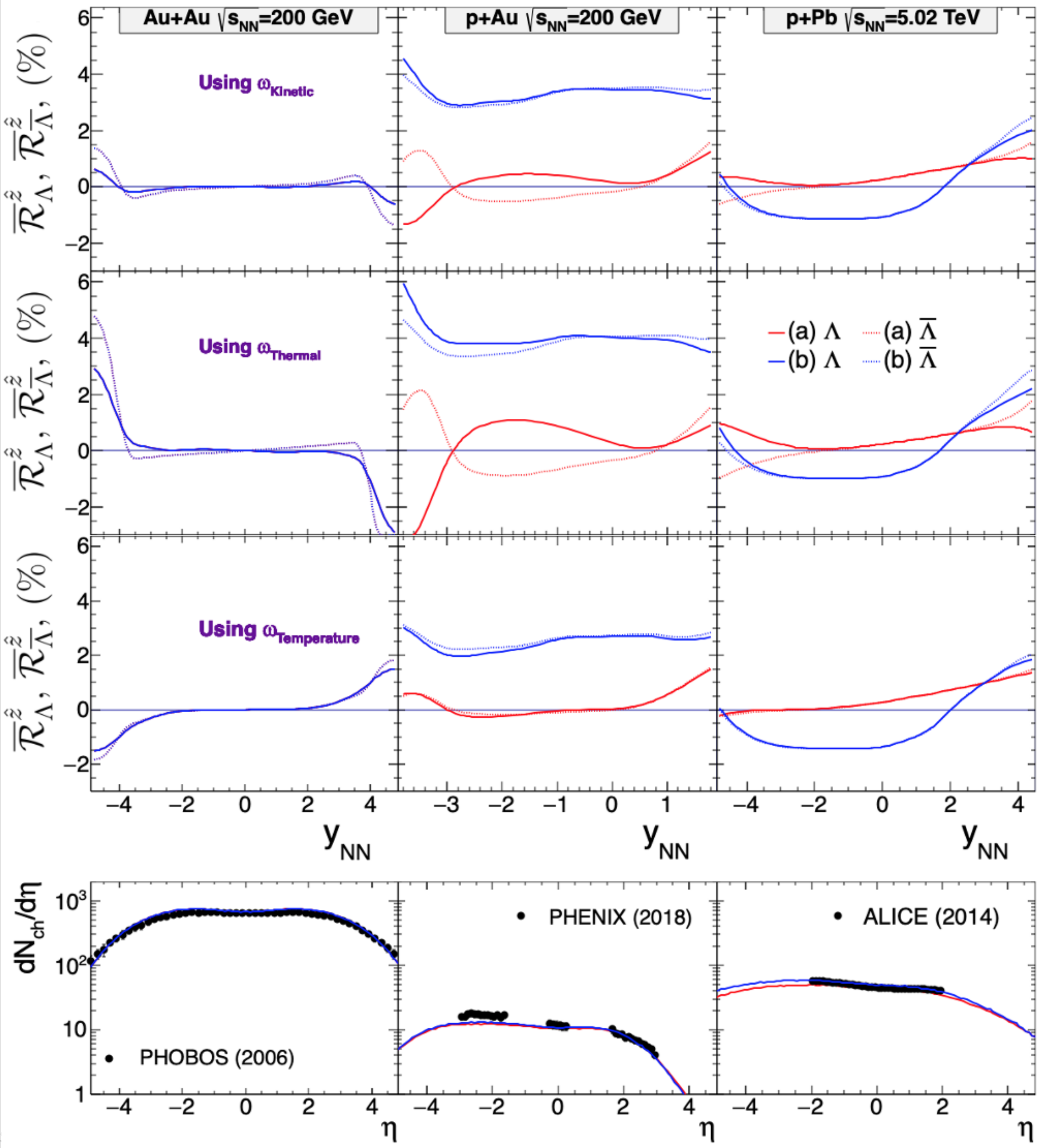
Furthermore, large and nontrivial acceptance effects (see Joey's "Azimuthal Emission Efficiency") will **produce a false signal**, even if there is no toroidal vorticity

- this artifact flips sign with a change in B-polarity (also shown by Joey)
  → want **~300M central p+Au events *at each field polarity***

This will need to wait for the 2024 run.

Summary

- A long p+Au run with STAR presents a unique opportunity
  - discover a novel vortical configuration in the subatomic fluid
  - novel light on the important question of hydrodynamics in the smallest systems
- for larger systems (e.g. He+Au) or higher energy collisions (e.g. LHC), the signal drops/reverses sign
  - p+Au @ RHIC is ~optimal
  - but, if discovered, an energy/system scan could be important
- "Helicity efficiency" and "AEE" cause large artifacts, which flip with B-field polarity
  - Need to take both FF and RFF data
- Likely need ~300M central events (300M FF + 300M RFF, *maybe* 150M+150M…)
  → this is for 2024.



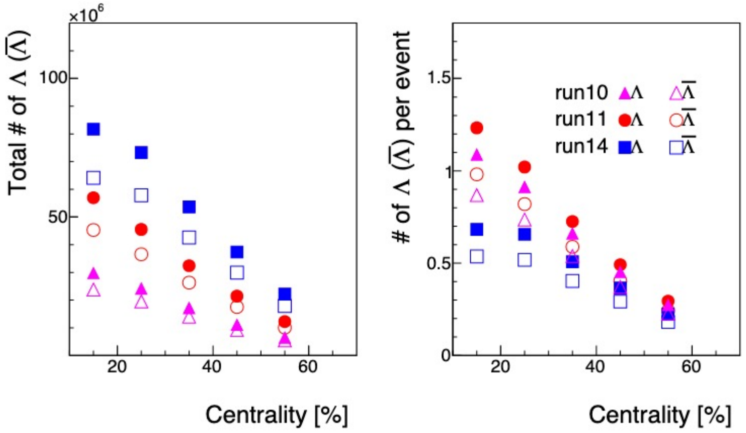
Au+Au $\sqrt{s_{NN}}$=200 GeV
p+Au $\sqrt{s_{NN}}$=200 GeV
p+Pb $\sqrt{s_{NN}}$=5.02 TeV
Using $\omega_{Kinetic}$
Using $\omega_{Thermal}$
Using $\omega_{Temperature}$
$\overline{\mathcal{R}}^{\hat{z}}_{\Lambda}$, $\overline{\mathcal{R}}^{\hat{z}}_{\overline{\Lambda}}$, (%)
(a) Λ
(b) Λ
(a) $\overline{\Lambda}$
(b) $\overline{\Lambda}$
y_{NN}
$dN_{ch}/d\eta$
PHOBOS (2006)
PHENIX (2018)
ALICE (2014)
η

estimated # Lambdas/central p+Au event

https://www.star.bnl.gov/protected/bulkcorr/taknn/2017/0816_BulkCorr_polSysStudy.pdf

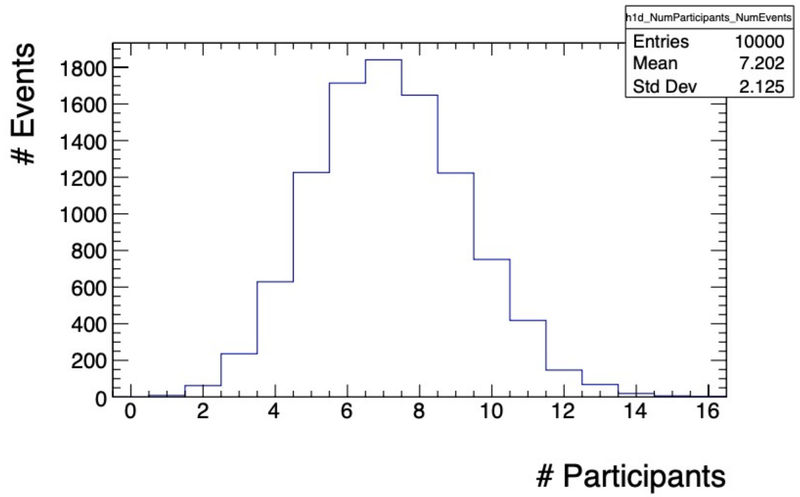
Data sets analyzed

	Run10	Run11	Run14
production	P10ik	P11id	P16id
trigger	Minimum Bias Triggers		
$\|v_z\|$	<30cm	<30cm	<6cm
$\|v_r-V_r^{center}\|$	<2cm	<2cm	<2cm
$\|v_z-v_z^{VPD}\|$	<3cm	<3cm	<3cm
# of events	~200M	~350M	~930M



T. Niida, BulkCorr PWG @Aug/15/2017

1 (reconstructed) Lambda/central Au+Au at 200 GeV



Joey Adams Glauber model: <Npart>~7

simplistic Npart scaling suggests
#Lambdas/central p+Au event = 1 * 7 / (2*197) ~ 0.02