Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

SURGE COLLABORATION

IS THE UNDERLYING PHYSICS OF COLLECTIVE FLOW IN SMALL&DILUTE "IN ESSENCE" THE SAME AS IN LARGE&DENSE SYSTEMS?

"YES" (MAYBE, DON'T KNOW)

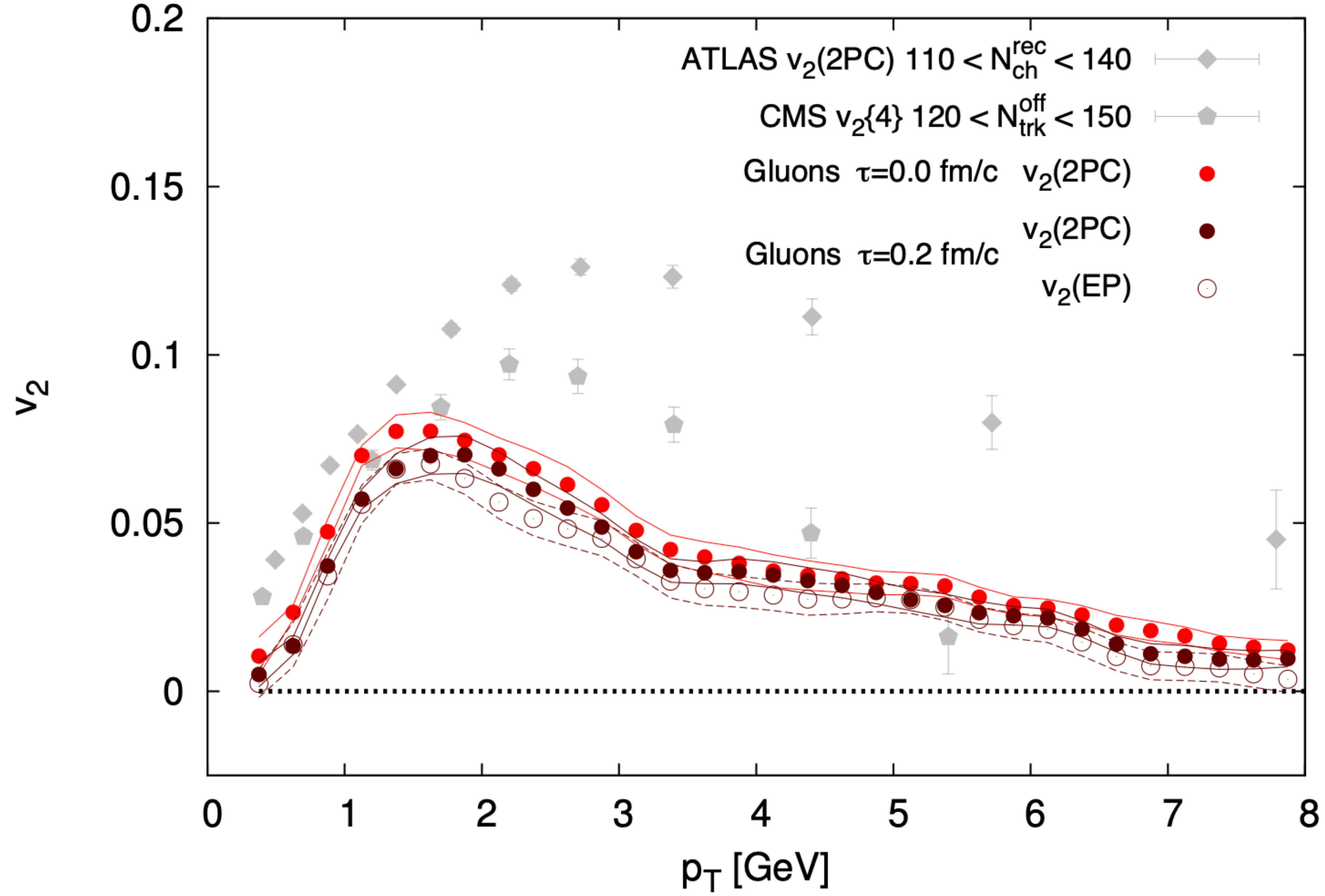
BJÖRN SCHENKE, BROOKHAVEN NATIONAL LABORATORY

Initial Stages 2023
Copenhagen, Denmark
06/22/2023

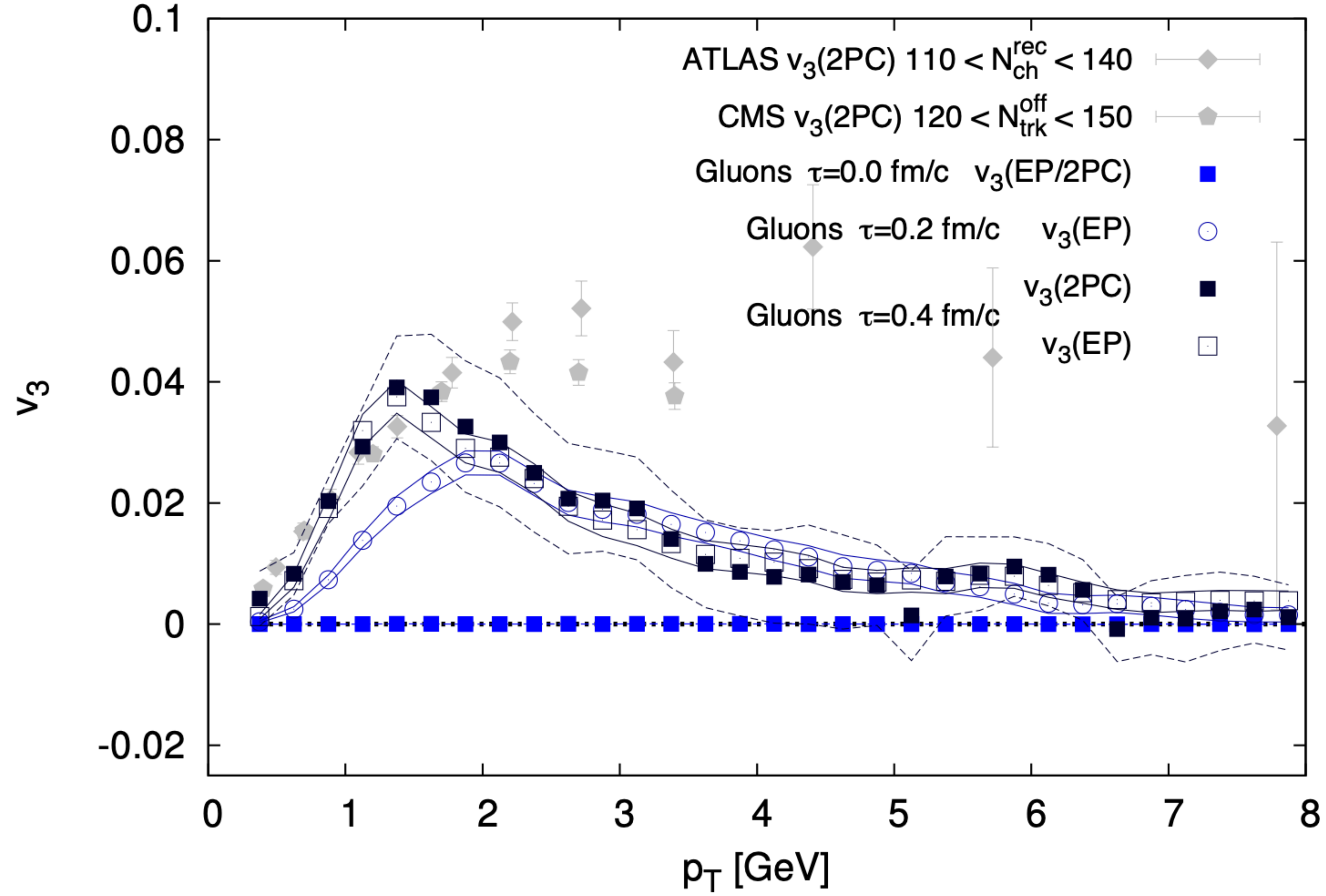
2015: Boost-invariant dense-dense calculation of initial gluon v_n

B. Schenke, S. Schlichting, R. Venugopalan, Phys.Lett.B 747 (2015) 76-82, 1502.01331

- Compute single and double inclusive gluon distributions in classical Yang-Mills simulations (dense-dense)
- Gluons have a large v_2 in the initial state, while odd harmonics vanish identically at the initial time $\tau = 0+$.
- Yang-Mills evolution generates v_3
- p_T dependence not quite like the data



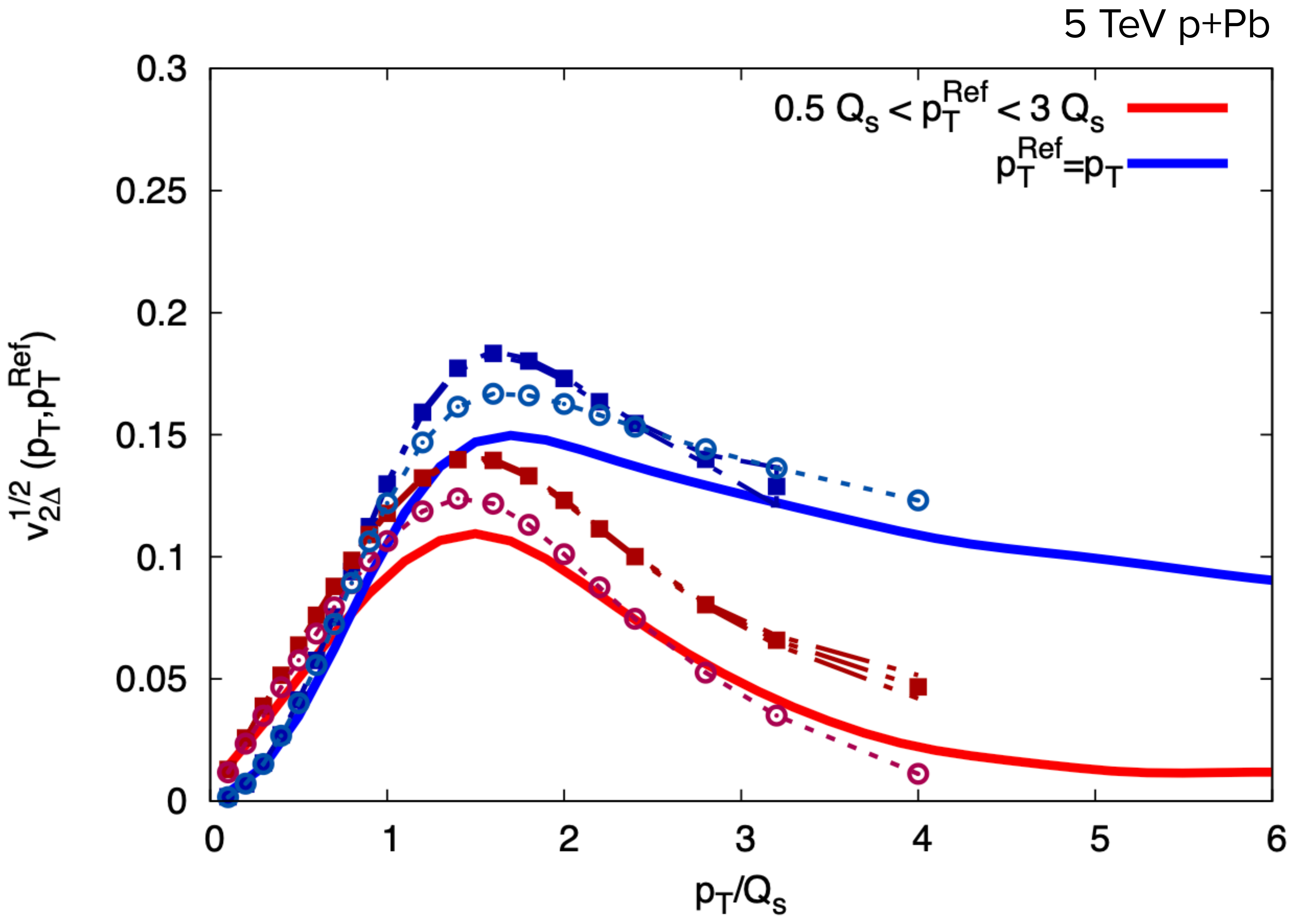
5 TeV p+Pb



2015: Strong dependence on p_T difference in two-particle correlations

T. Lappi, B. Schenke, S. Schlichting, R. Venugopalan., JHEP 01 (2016) 061, 1509.03499

- Decorrelation in p_T stronger than in the data



- Solid lines: lattice simulation without additional approximation
- Dash-dotted lines (with squares): non-linear Gaussian approximation
- Dotted line (with circles): Glasma graph approximation

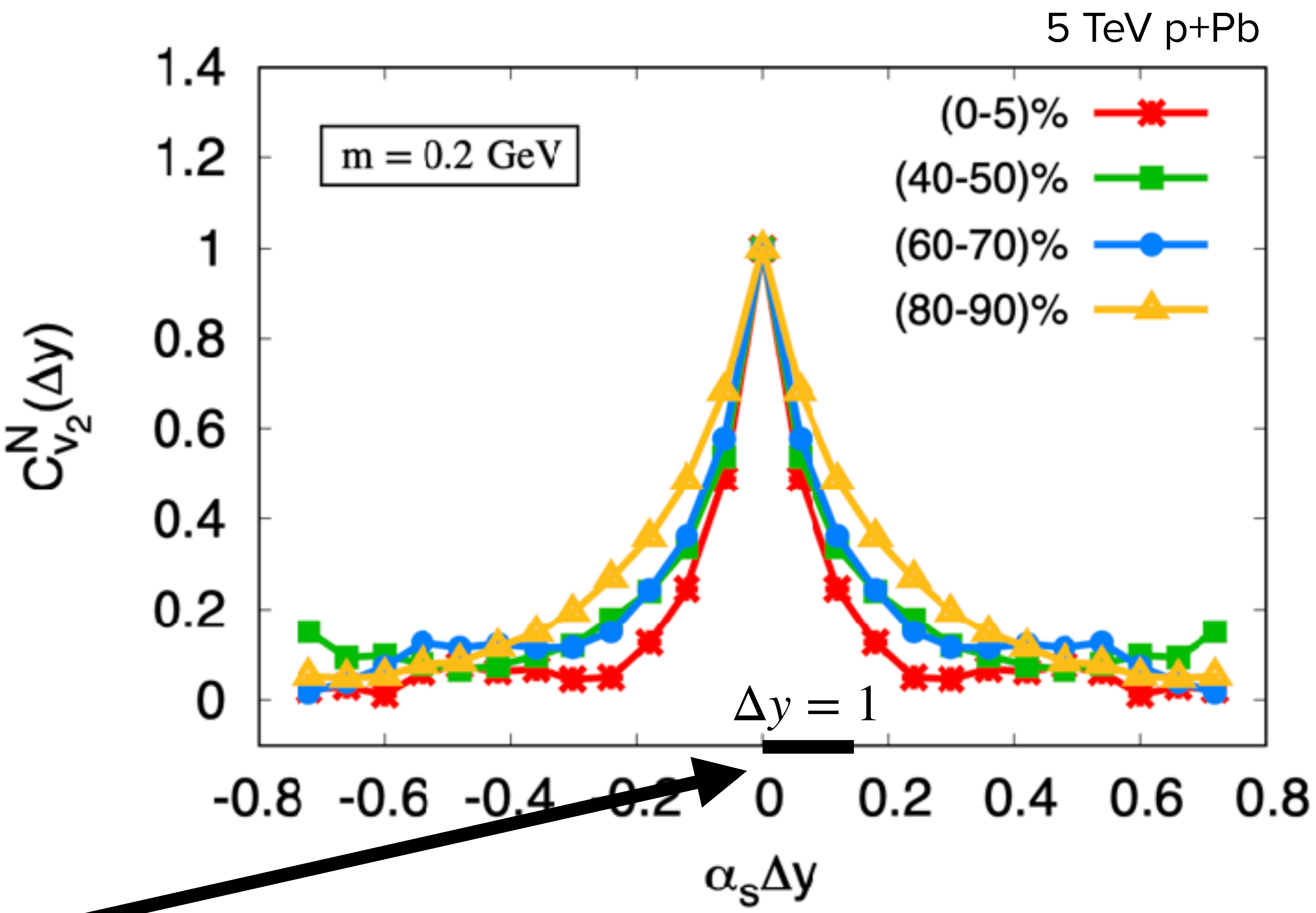
2022: Rapidity decorrelation of the initial momentum anisotropy

B.Schenke, S. Schlichting, and Pragya Singh, Phys.Rev.D 105 (2022) 9, 094023, e-Print: 2201.08864 [nucl-th]

$$v_2^g(y) = \frac{\int d^2\mathbf{k}_\perp |\mathbf{k}_\perp| \frac{dN_g}{dyd^2\mathbf{k}_\perp}(y) e^{2i\phi_{\mathbf{k}_\perp}}}{\int d^2\mathbf{k}_\perp |\mathbf{k}_\perp| \frac{dN}{dyd^2\mathbf{k}_\perp}(y)}$$

The initial anisotropy of the gluons decorrelates quickly (like typical non-flow)

$$C_{\mathcal{O}}^N(\eta_1, \eta_2) = \frac{\left\langle \mathrm{Re}\left(\mathcal{O}(\eta_1)\mathcal{O}^*(\eta_2)\right)\right\rangle}{\sqrt{\langle |\mathcal{O}(\eta_1)|^2\rangle\langle |\mathcal{O}(\eta_2)|^2\rangle}}$$

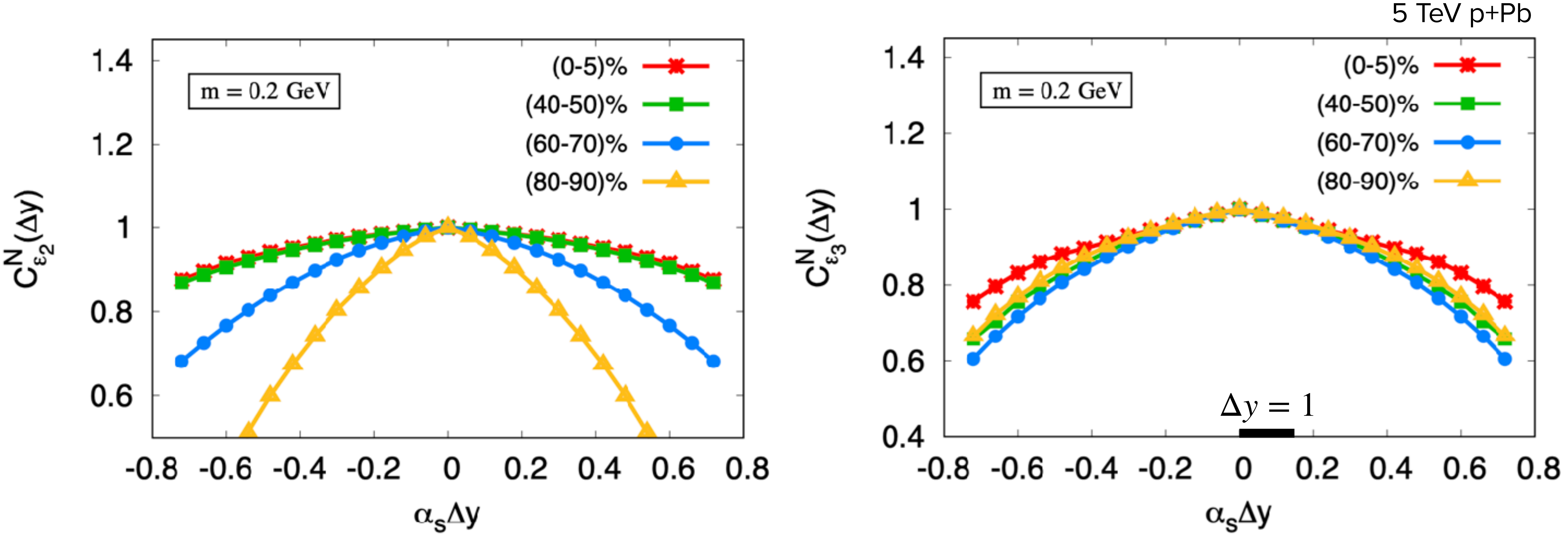


Plug in $\alpha_s = 0.15$, which works well for the rapidity dependence of the charged hadron distribution

If experiments employ large rapidity gaps, this effect could remove the initial momentum anisotropy like any other non-flow

2022: Rapidity decorrelation of the geometry

B.Schenke, S. Schlichting, P. Singh, Phys.Rev.D 105 (2022) 9, 094023, e-Print: 2201.08864 [nucl-th]

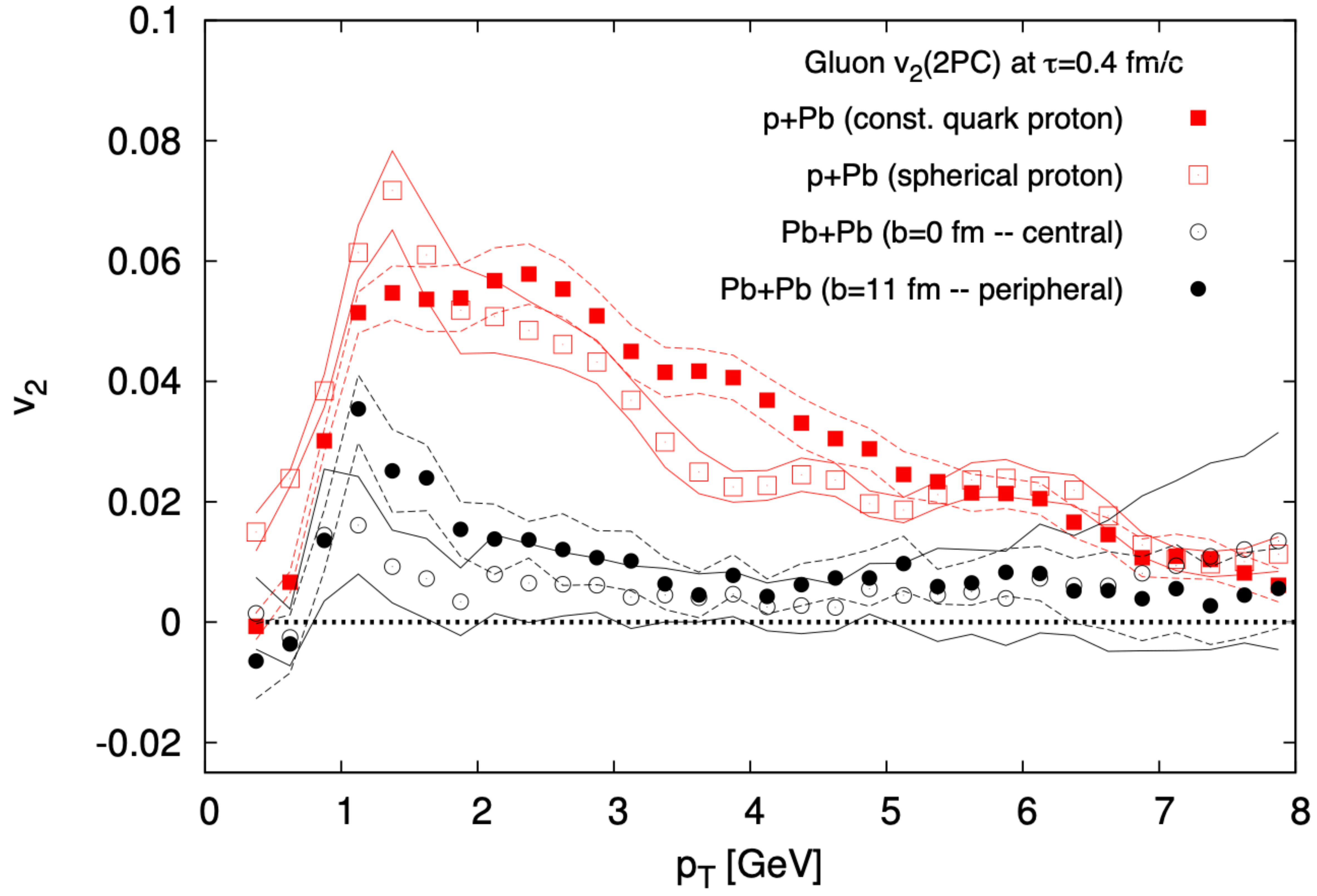


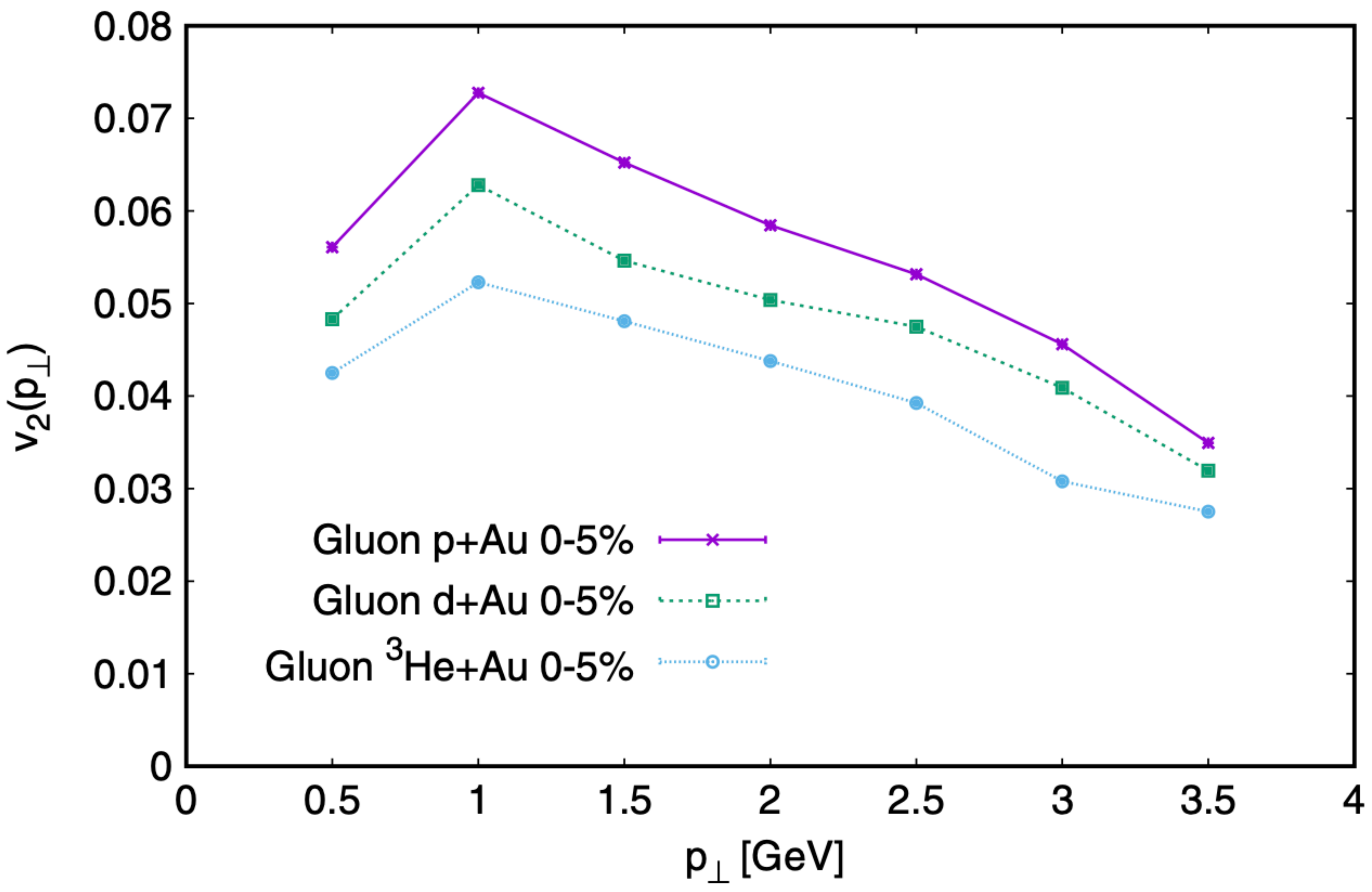
The geometry, quantified here with ε_2 and ε_3, decorrelates slowly, at least for not too peripheral events

$$C^N_{\mathcal{O}}(\eta_1, \eta_2) = \frac{\left\langle \mathrm{Re}\left(\mathcal{O}(\eta_1)\mathcal{O}^*(\eta_2)\right)\right\rangle}{\sqrt{\langle |\mathcal{O}(\eta_1)|^2\rangle\langle |\mathcal{O}(\eta_2)|^2\rangle}}$$

Systematics with system size

B. Schenke, S. Schlichting, R. Venugopalan, Phys.Lett.B 747 (2015) 76-82, 1502.01331
M. Mace, V. V. Skokov, P. Tribedy, R. Venugopalan, Phys. Rev. Lett. 121, 052301 (2018), PRL123, 039901(E) (2019)





- Trend with system size is opposite to the data (when using large rapidity gaps)

Discussion

- CGC initial state momentum distributions:
  Systematics with system size and p_T **do not agree with data**
- Full 3+1D Yang Mills will evolve towards isotropization at early times
  This would reduce the initial anisotropy even more
- At small $p_T \lesssim Q_s$ and large rapidity separation, **we will not observe a momentum anisotropy that is not driven by geometry and strong final state effects**
- **Short range rapidity correlations** may be there but mixed with other non-flow
- Note: Remember that the CGC does also predicts how energy and momentum is deposited. Along with sampled nucleon positions, it provides the initial geometry that, in combination with hydrodynamics, successfully describes a lot of data
- Hydrodynamics has issues in small systems - very large viscous corrections/problems with causality

BACKUP

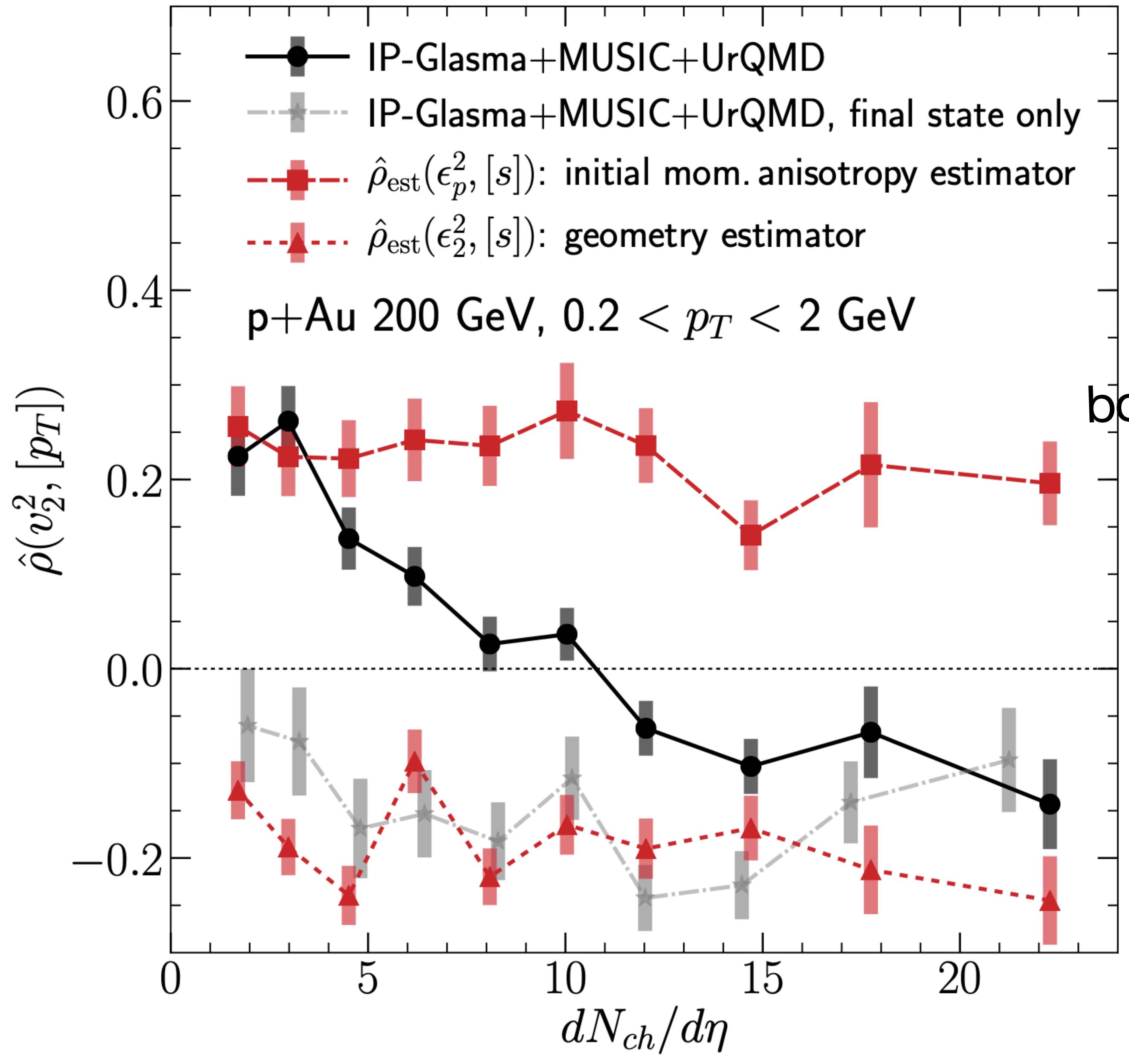
Initial pressure anisotropy

B.Schenke, S. Schlichting, and Pragya Singh, Phys.Rev.D 105 (2022) 9, 094023, e-Print: 2201.08864 [nucl-th]

$$\varepsilon_p(y) = \frac{\int d^2\mathbf{r}_\perp\ T^{xx}(y,\mathbf{r}_\perp) - T^{yy}(y,\mathbf{r}_\perp) + 2iT^{xy}(y,\mathbf{r}_\perp)}{\int d^2\mathbf{r}_\perp\ T^{xx}(y,\mathbf{r}_\perp) + T^{yy}(y,\mathbf{r}_\perp)}$$

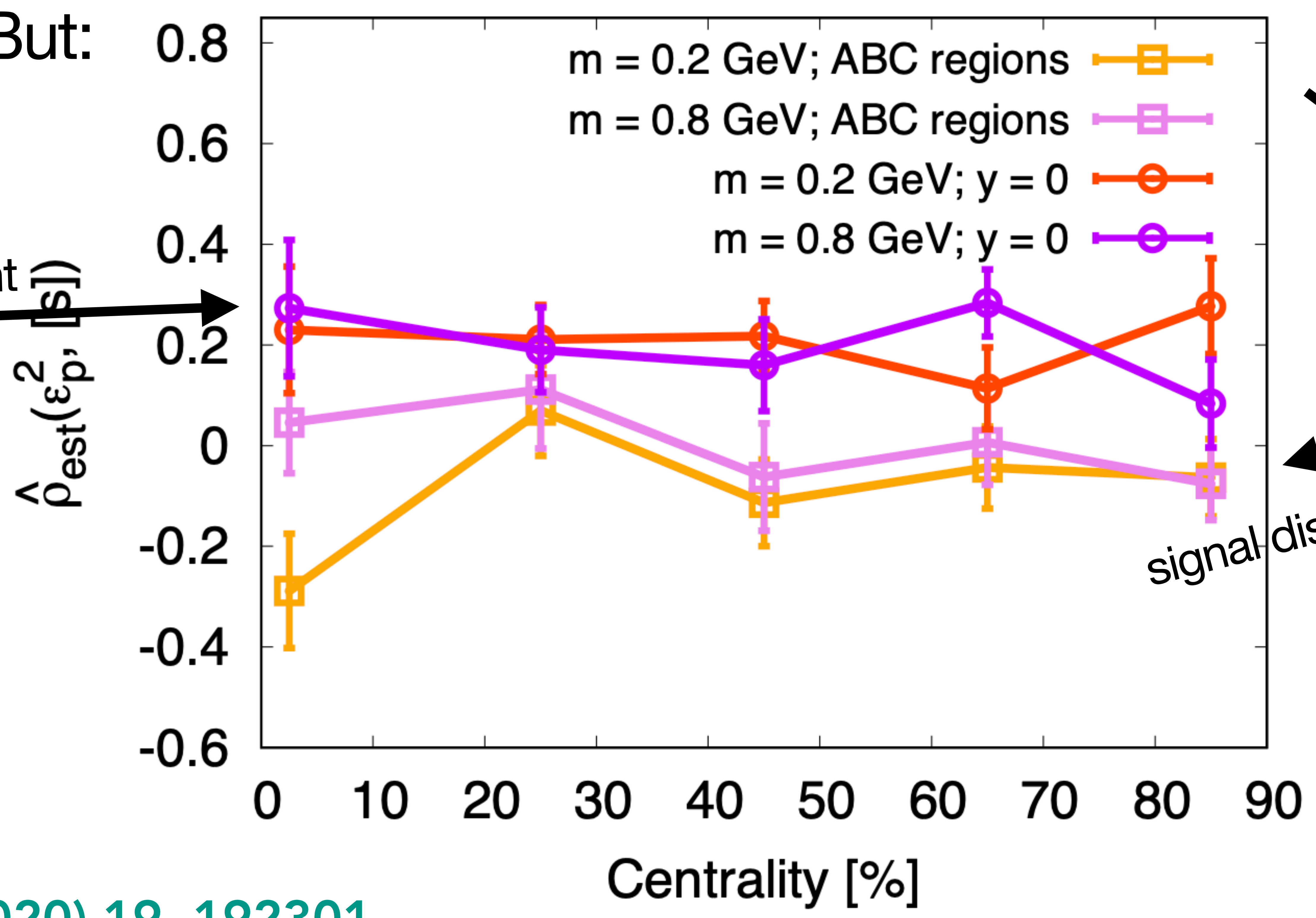
in the quasi-particle picture this is equivalent to the v_2^g definition

This anisotropy is present in the initial condition for hydrodynamics $T^{\mu\nu}$:



boost invariant

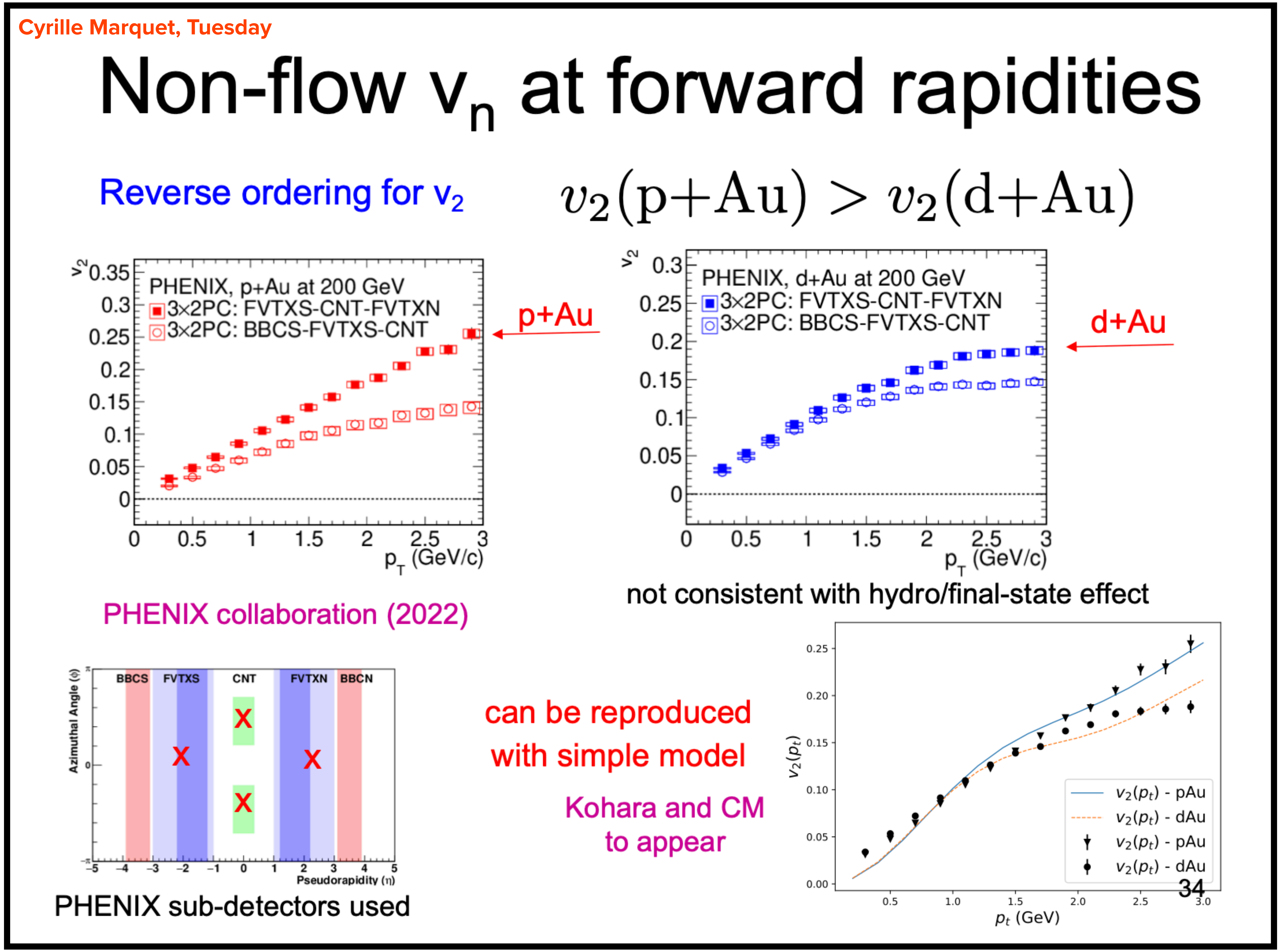
But:



experimental rapidity regions

signal disappears

G. Giacalone, B.Schenke, C. Shen, Phys.Rev.Lett. 125 (2020) 19, 192301



But this could be other non-flow as well should check PYTHIA