Dilepton anisotropy at low beam energies in a transport approach

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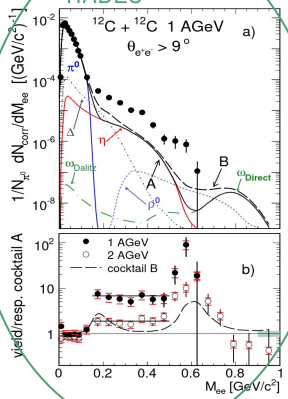
Dilepton as probes

Pairs of single-origin, opposite charge leptons

No interaction via strong force, therefore:

- Leave the hadronic medium undisturbed
- Multi-messenger for the whole evolution 👍
- Very rare: $\mathrm{BR}(h \to l^+l^-) \sim 10^{-5}$ 👎
- Large combinatorial background 👎

HADES



[PLB 663, 43 (2008)]

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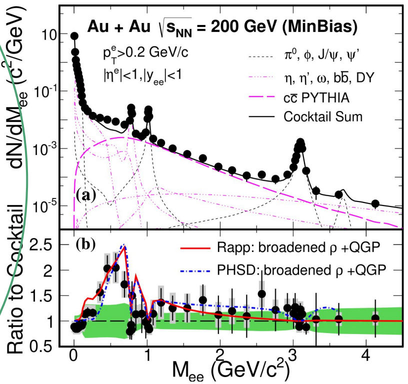
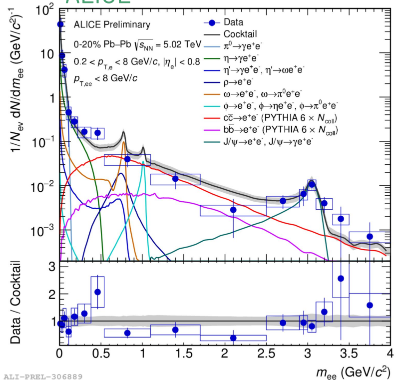
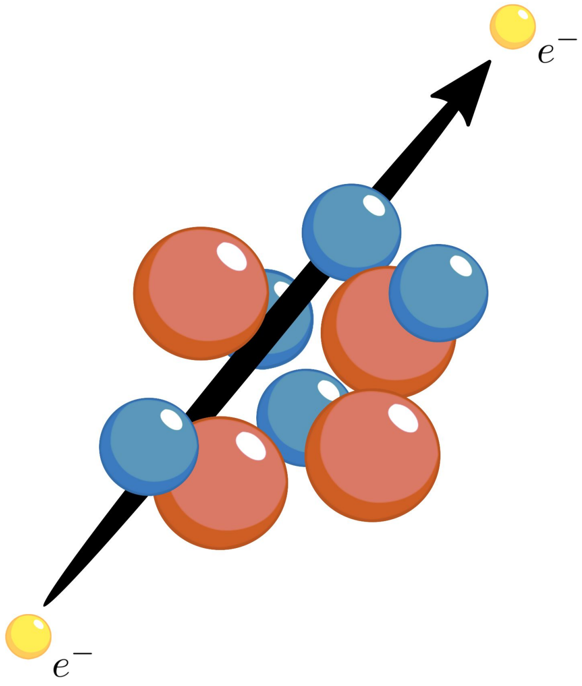


[PRL. 113, 022301 (2014)]

ALICE



[J.Phys.Conf. 1602, 012016 (2020)]



This work: Ag+Ag at $\sqrt{s_{NN}}$ = 2.55 GeV, 0-40%

SMASH approach

Simulating **Ma**ny **S**trongly-interacting **H**adrons

smash

https://smash-transport.github.io/

Hadrons

- Hadrons evolved with the relativistic Boltzmann equation

$$p^\mu \partial_\mu f_i(x,p) + m_i F^\alpha \partial^p_\alpha f_i(x,p) = C^i_{\text{coll}}$$

- Scatterings determined geometrically from "bottom-up" cross sections

$$\pi d^2_{\text{trans}}(a,b) < \sigma_{\text{tot}}(a,b) = \sum_R \sigma_{ab\to R} + \sum_{cd} \sigma_{ab\to cd}$$

- Mass-dependent width for hadronic decays

$$\frac{\text{Prob}(R \text{ decays in } \Delta t)}{\Delta t} = \Gamma^{\text{vac}}_R(m) = \sum_{ab} \Gamma_{R\to ab}(m)$$

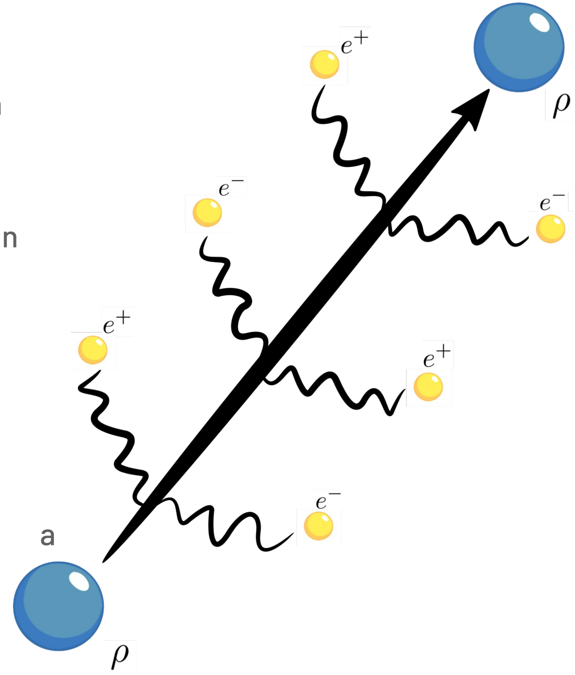
Dileptons

- Electromagnetic coupling is much smaller than strong coupling

- Perturbative treatment for dilepton emission

$$N_{R\to l^+l^-}(\tau) = \int_0^\tau \frac{\mathrm{d}t}{\gamma}\, \Gamma_{R\to l^+l^-}$$

- At every time step the particle radiates a lepton pair, carrying "shining" weight



Anisotropic flow

Particle yields can be Fourier decomposed in azimuthal momentum

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\phi - \Psi_R)\right]$$

In HADES: [Talks by Szymon Harabasz (Mon) and Niklas Schild (Thu)]

$v_n \approx v_n\{\mathrm{RP}\} = \langle \cos[n(\phi - \Psi_R)] \rangle$ + Ollitrault EP resolution correction

Ψ_R : reconstructed by spectators in Forward Wall Detector

Relatively large uncertainties. Can we improve with the **scalar product** method?

$$v_2^{ll}(X) = \frac{\langle |\mathbf{q}_n^h||\mathbf{q}_n^{ll}(X)| \cos[n(\Psi_n^h - \Psi_n^{ll})] \rangle_{\mathrm{ev}}}{\sqrt{\langle |\mathbf{q}_n^h|^2 \rangle_{\mathrm{ev}}}}$$

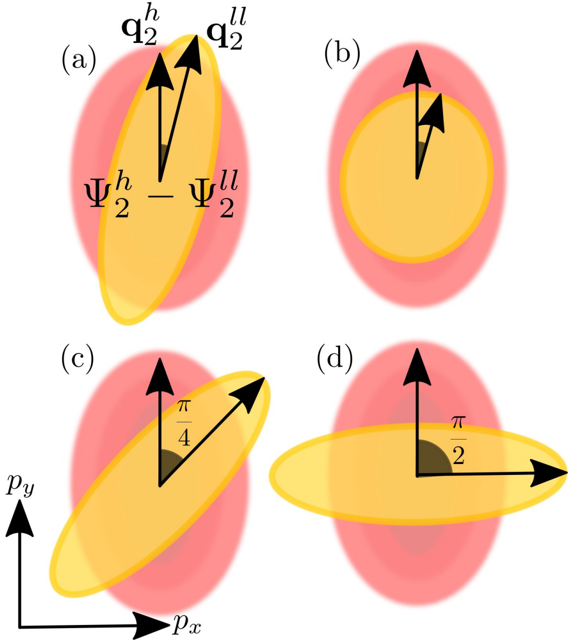
Used for LHC energies:
[Jean-François Paquet et al. PRC 93, 044906 (2016)]
[Gojko Vujanovic et al. PRC 101, 044904 (2020)]

Event flow vectors

$$\mathbf{q}_n^h = \frac{1}{N^h}\int d^3p \frac{dN^h}{d^3p}\begin{pmatrix}\cos n\phi \\ \sin n\phi\end{pmatrix} \xrightarrow{\mathrm{SMASH}} \frac{1}{N^h}\sum_j^{N^h}\begin{pmatrix}\cos n\phi_j \\ \sin n\phi_j\end{pmatrix}$$ final state

$$\mathbf{q}_n^{ll}(\mathrm{bin}) = \frac{1}{N^{ll}}\int_{\mathrm{bin}} dt\,dy\,p_T\,dp_T \int_0^{2\pi} d\phi \frac{dN^{ll}}{d^4p}\begin{pmatrix}\cos n\phi \\ \sin n\phi\end{pmatrix} \xrightarrow{\mathrm{SMASH}} \frac{1}{N^{ll}}\sum_{j\in\mathrm{bin}}^{N^{ll}}\begin{pmatrix}\cos n\phi_j \\ \sin n\phi_j\end{pmatrix}$$

full evolution

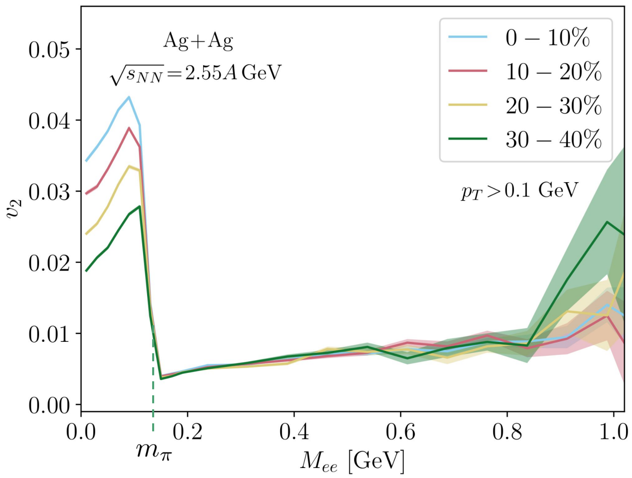


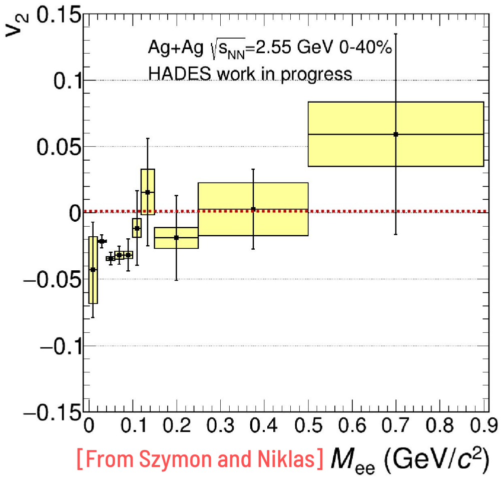
$v_2(\mathrm{a}) > v_2(\mathrm{b}) > 0$

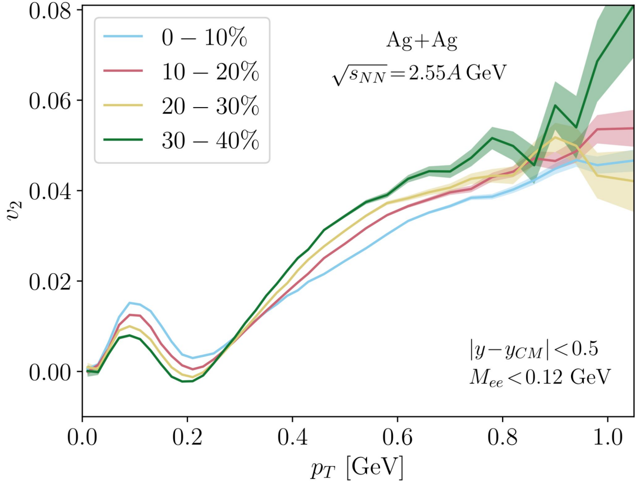
$v_2(\mathrm{c}) = 0 \qquad v_2(\mathrm{d}) < 0$

First results

Invariant mass, transverse momentum, rapidity







Consistency to HADES preliminary results: 👍

- Largest flow from Dalitz decays of π^0
- Resonance region has *almost* no flow

- Opposite centrality dependence: more *correlation* 👎 ?
- Peak structure at low p_T ?
- Do resonances themselves flow ?

Answerable with hadronic transport!

Time dependence

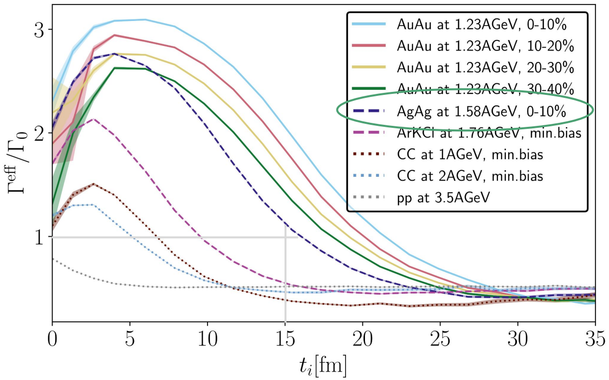
Of $v_2(p_T)$

- Larger flow overall in later stages
- No low-p_T peak while hot, dense medium is present

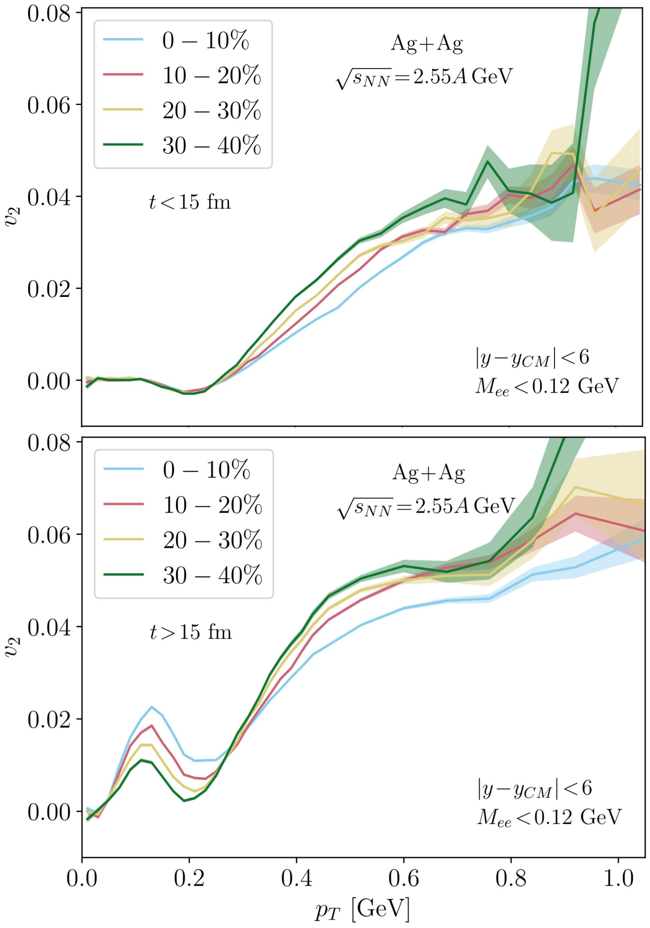
Non-flow effects:

- ★ Momentum conservation: Dalitz character of pion decay ?
- ★ p_T loss from decays of flowing Δ baryons?

Answerable with hadronic transport!

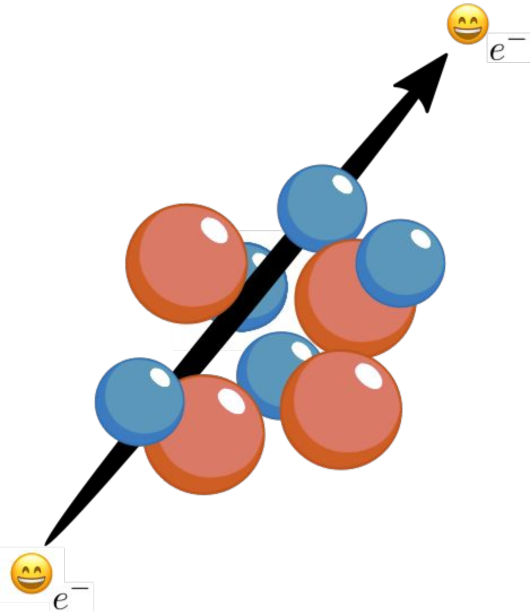


[RH et al., PRC 107, 025208 (2023)]



Conclusions

- *First* v_2 calculation of dileptons directly from hadronic transport
- Scalar product method can be used!
- Consistent to HADES results



Outlooks

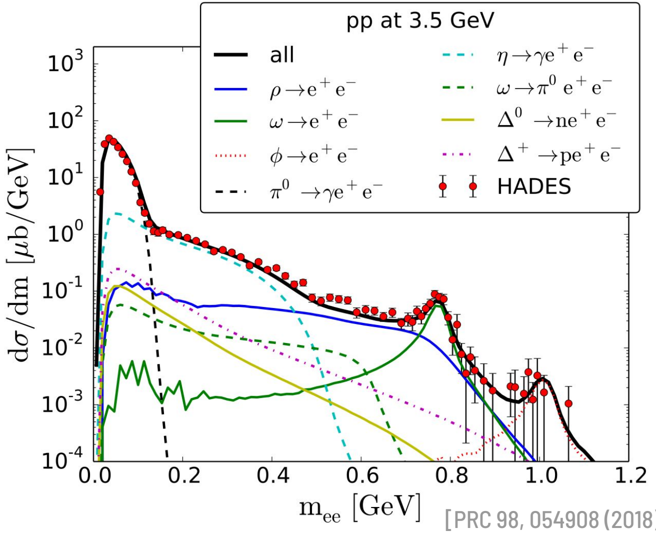
- ❑ Compare to reaction plane and pion flow
- ❑ Predictions of v_1 and v_3; other systems, etc.
- ❑ Thermal radiation w/ dynamic initialization of SMASH + vHLLE

[RH, HE, and Zuzana Paulinyova, coming soon!]

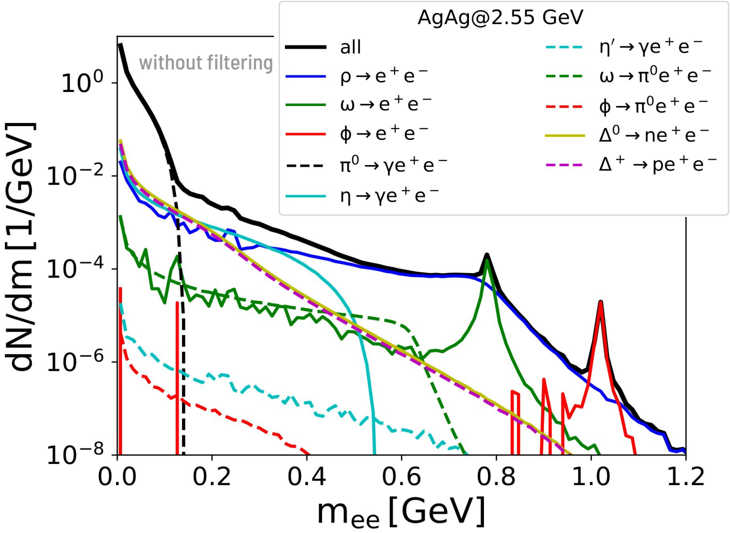
Thank you for the attention!

Backup slides

SMASH yields



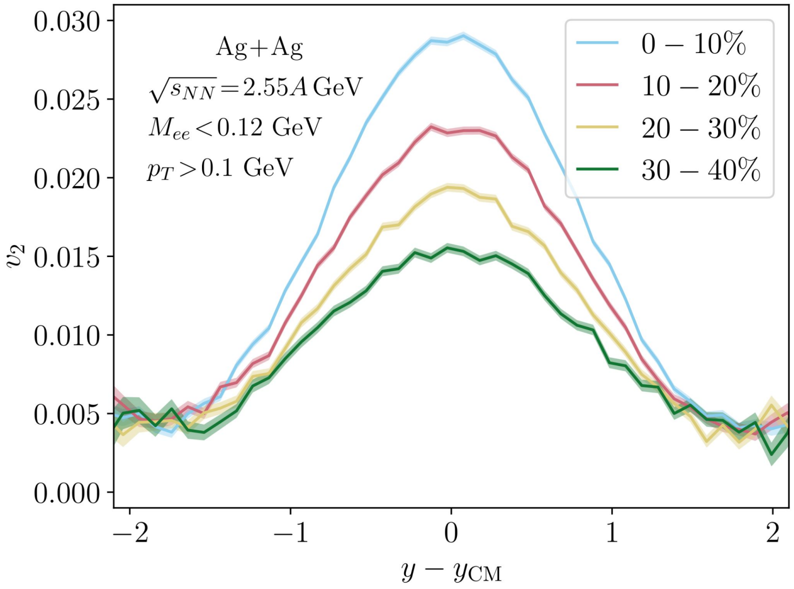
[PRC 98, 054908 (2018)]

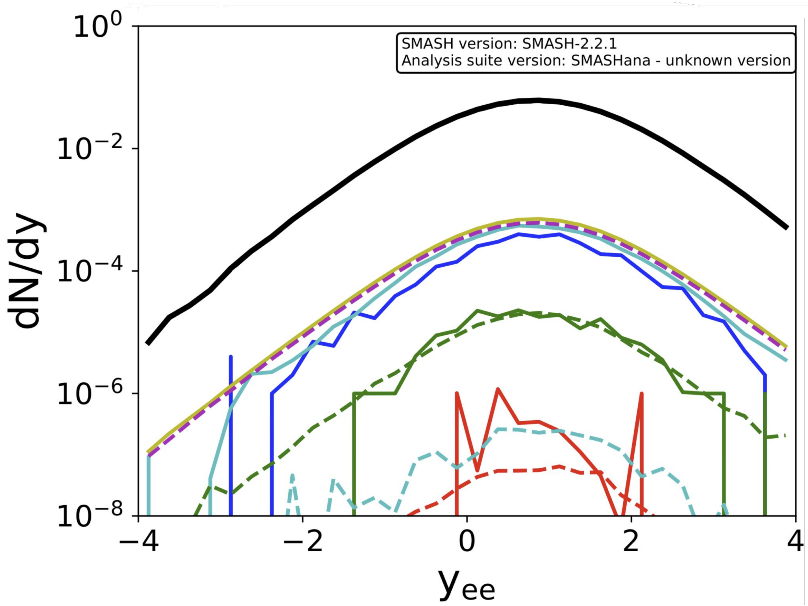


Caveat: collisional broadening not sufficient in a HIC!

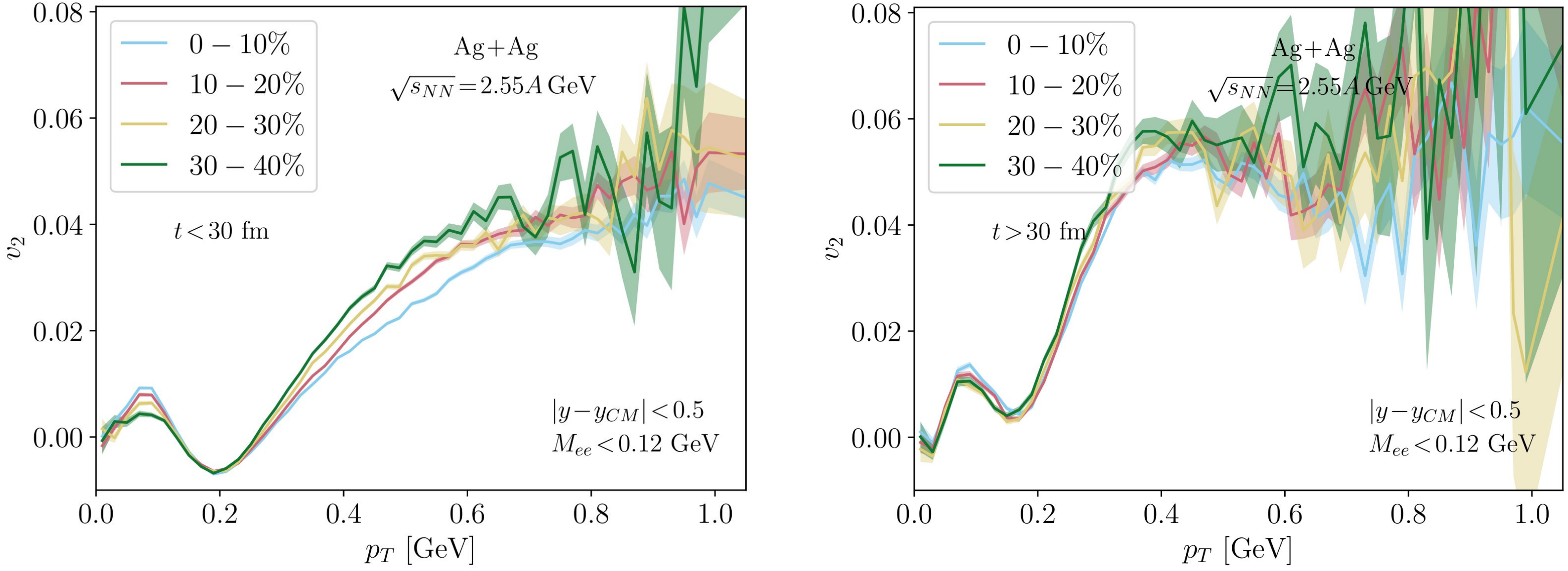
This work: Ag+Ag at $\sqrt{s_{NN}}$ = 2.55 GeV, 0-40%

Rapidity dependence





Another time cut



Transverse momentum yields