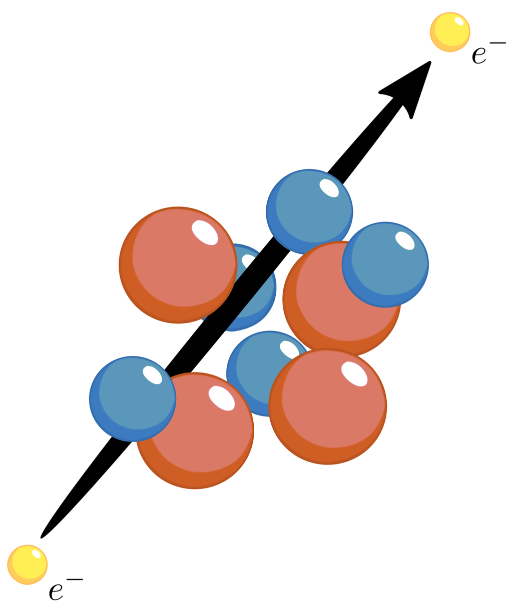
Dilepton anisotropy at low beam energies in a transport approach

Renan Hirayama[123] and Hannah Elfner[1234]

[1]Helmholtz Research Academy Hesse (HFHF), GSI Helmholtz Center, Campus Frankfurt, Max-von-Laue-Str. 12, 60438 Frankfurt am Main
[2]Frankfurt Institute for Advanced Studies (FIAS), Ruth-Moufang-Straße 1, 60438 Frankfurt am Main
[3]Institute for Theoretical Physics, Goethe University, Max-von-Laue-Strasse 1, 60438 Frankfurt am Main, Germany
[4]GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt

Dileptons

- Lepton-antilepton pair from the same origin
- No interaction via strong force, therefore:
  - ⋆ Leave the hadronic medium undisturbed 👍
  - ⋆ Multi-messenger for the whole evolution 👍
  - ⋆ Very rare: $\mathrm{BR}(h \to l^+l^-) \sim 10^{-5}$ 👎
- Combinatorial background 👎



SMASH

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

- Hadronic transport: evolve hadrons w/ relativistic Boltzmann equation

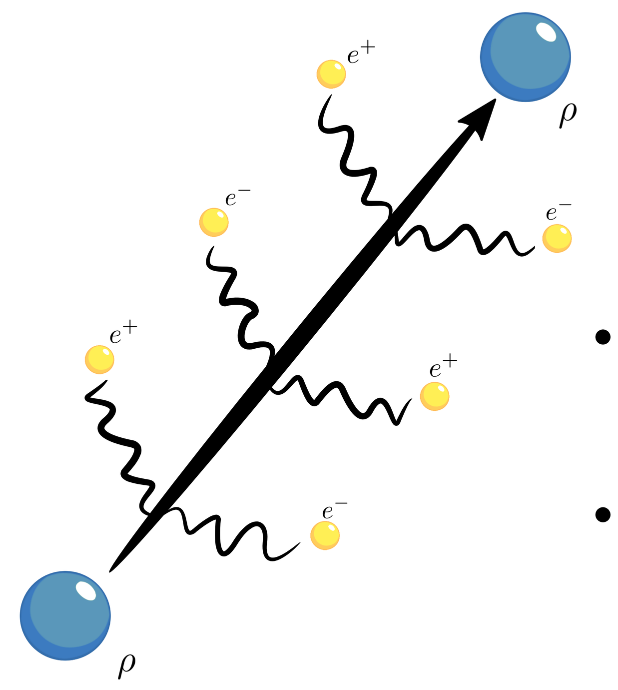
$$p^\mu \partial_\mu f_i(x,p) + m_i F^\alpha \partial^p_\alpha f_i(x,p) = C_i^{\mathrm{coll}}$$

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

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

- Rate for *hadronic* decays corresponds to mass-dependent vacuum width

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



- Dileptons are rare ⇒ Perturbative emission [1]

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

- At every timestep, R emits a dilepton with the corresponding *shining weight*
- Caveat: collisional broadening does not account for full medium modification in the resonance region [2]

Anisotropic flow

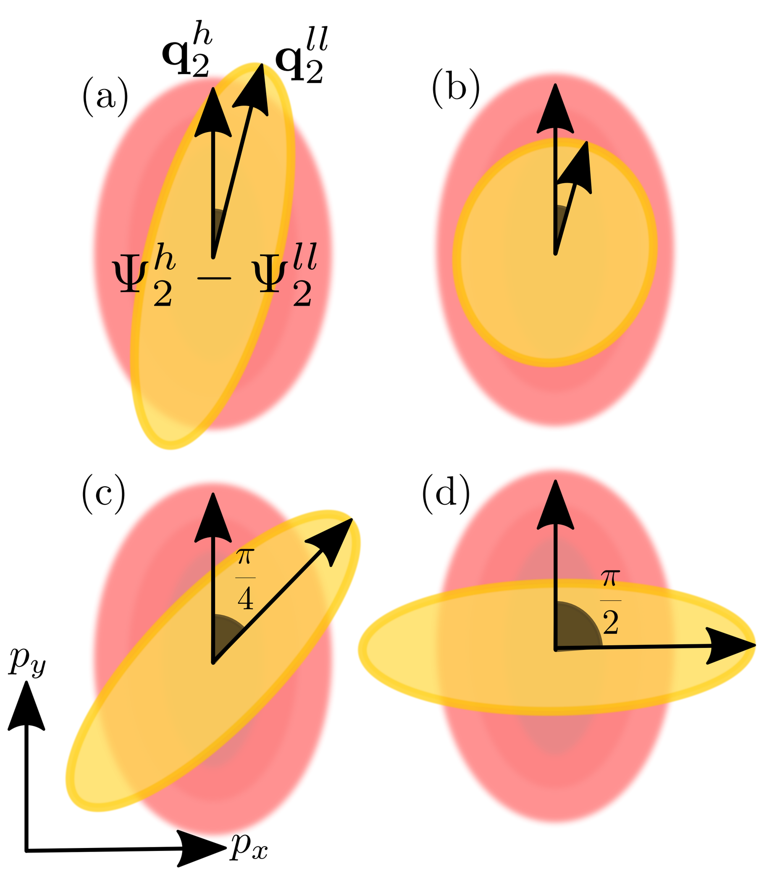
- Particle yields can be Fourier decomposed in azimuthal momentum:

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

- Anisotropic flow coefficient $v_n = \langle \cos[n(\phi - \Psi_R)] \rangle$
- Reaction plane angle Ψ_R: span { impact parameter, beam direction }
  - ⋆ Sometimes cannot be reconstructed ⇐ **scalar product** method
  - ⋆ In each event the momentum of each particle is correlated with an event flow vector $\mathbf{q}_n$, computed with the remaining particles
- Dileptons: rare + combinatorics
- Measuring correlations between two dileptons may be unfeasible
- Correlate the dilepton flow with the hadron flow! [3]

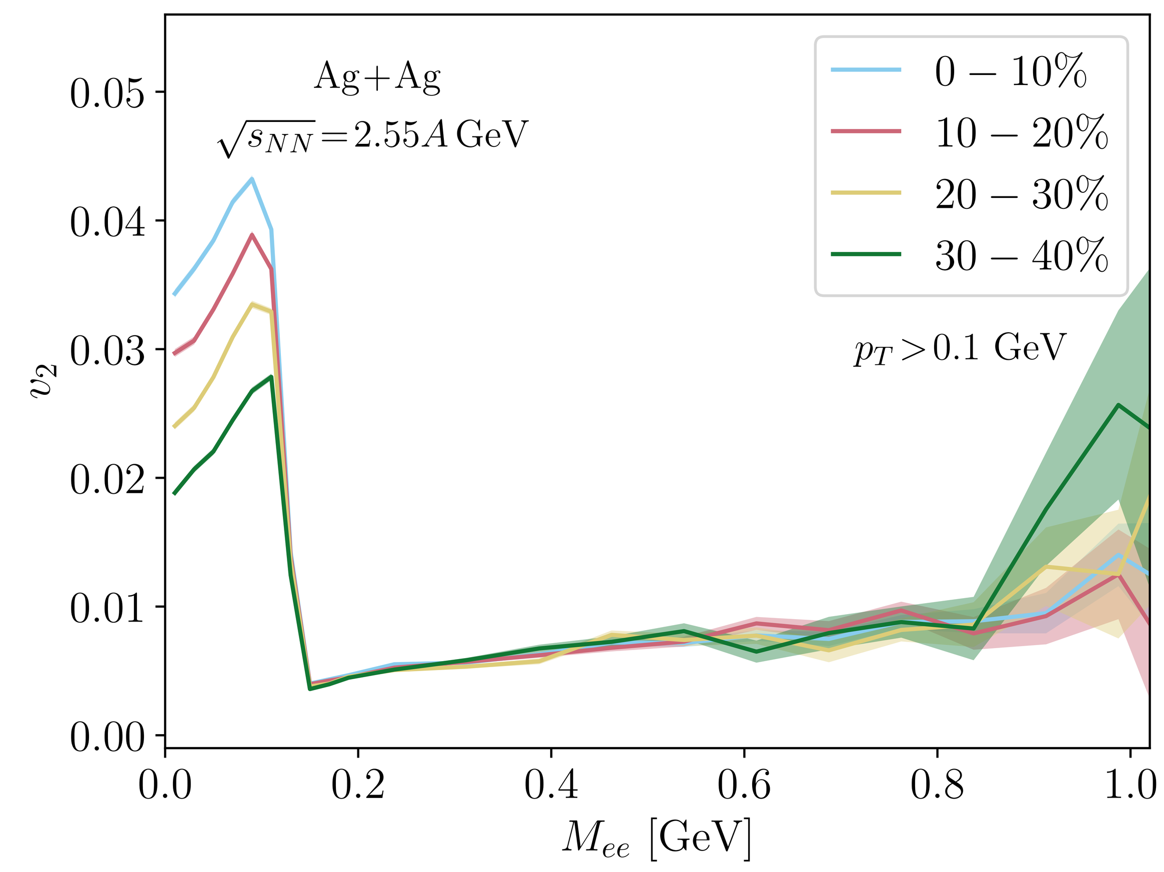
$$v_2^{ll}(X) = \frac{\langle |\mathbf{q}_n^h||\mathbf{q}_n^{ll}(X)| \cos[n(\Psi_n^h - \Psi_n^{ll})] \rangle_{\mathrm{ev}}}{\sqrt{\langle |\mathbf{q}_n^h|^2 \rangle_{\mathrm{ev}}}}$$

- Dileptons in bin X (time integrated), hadrons in large bin (final state)
- Smaller dilepton statistic needed 👍
- Sign can be recovered from hadron flow
- Usual geometric interpretation lost

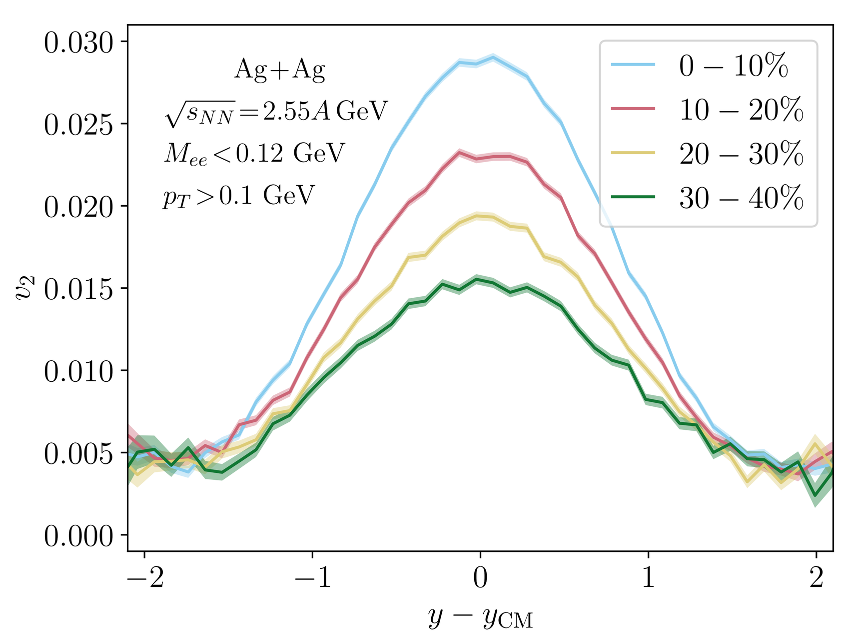


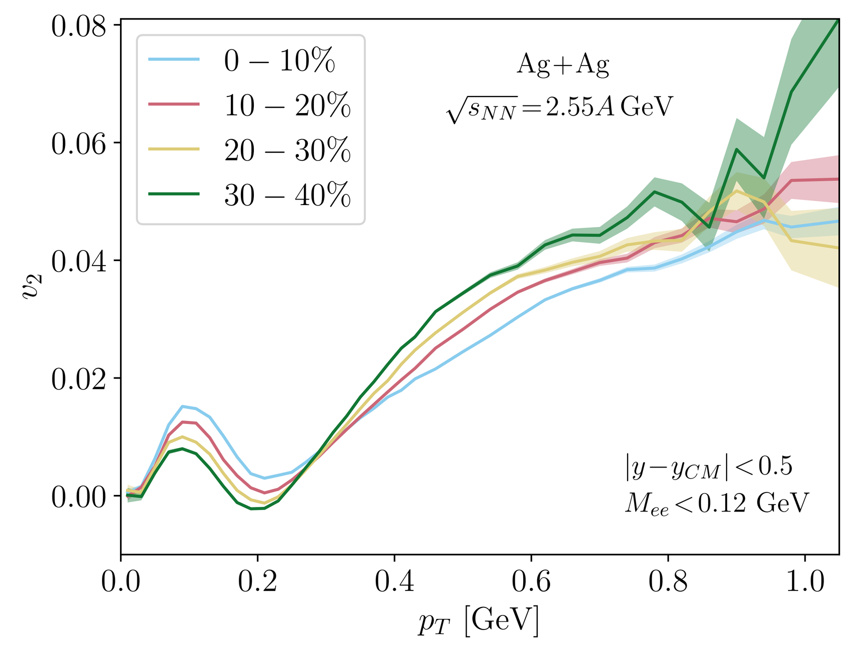
$v_2(a) > v_2(b) > v_2(c) = 0 > v_2(d)$

Initial results



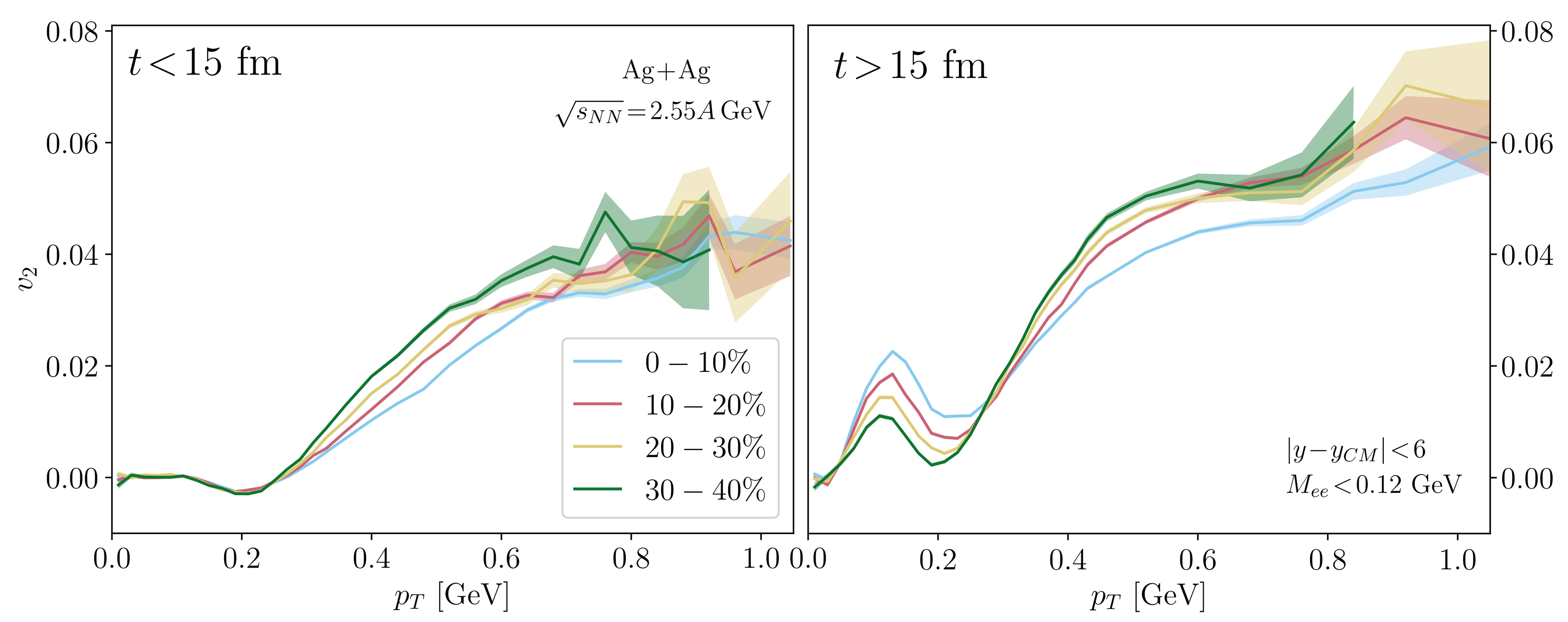
- Significant flow below the pion mass, from Dalitz decays $\pi^0 \to \gamma e^+ e^-$
- Little to no flow in resonance region
- Overall consistency to HADES preliminary results 👍
- Reverse centrality dependence from expected 👎





- Proportional to dilepton yield at midrapidity
- No pions beyond $|y - y_{\mathrm{CM}}| \sim 2$ (HADES preliminary)
- Peak structure at low p_T
- Centrality dependence flips at $p_T \sim 0.3$ GeV
- No impact by cut in midrapidity

Time dependence



- This system becomes dilute at around $t \sim 15$ fm [2]
- In the dense stage, there is no peak
- In the dilute stage, the peak arises and flow is higher at all p_T
- Non-flow (momentum conservation; $\Delta \to N\pi$) or spurious correlation?

Outlook

- First v_2 result from hadronic transport
- Dilepton-hadron correlation may reduce needed statistical power
- Compare to pion flow, dilepton-dilepton correlations, and reaction plane
- Predictions! Other systems, v_1, v_3, etc.

References

[1] Jan Staudenmaier, *et al.* (2018). Phys. Rev. C 98(5), 054908. [1711.10297]
[2] Renan Hirayama, Jan Staudenmaier, and Hannah Elfner (2023). Phys. Rev. C 107(2), 025208 [2206.15166]
[3] Jean-François Paquet, *et al* (2016). Phys. Rev. C 93(4), 044906.[1509.06738]
[4] Alexandr Prozorov for HADES (2022). *"Neutral mesons flow and yields in AgAg@1.58 A GeV at HADES"*. FAIRness workshop, Greece.