Characterising collectivity with virtual photons at HADES

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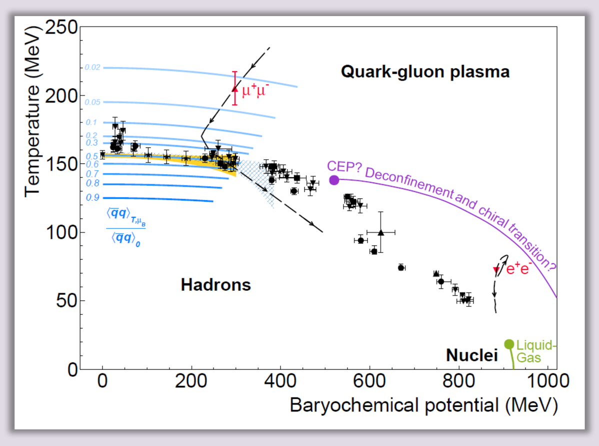
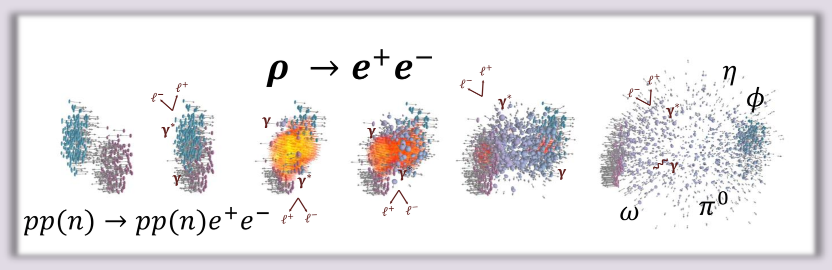
Motivation

- Explore region of QCD phase diagram at high net-baryon density and moderate temperatures with electromagnetic radiation (γ, γ^*)
- No strong final state interaction → leave reaction volume undisturbed
- Encodes information on matter properties



Challenges:

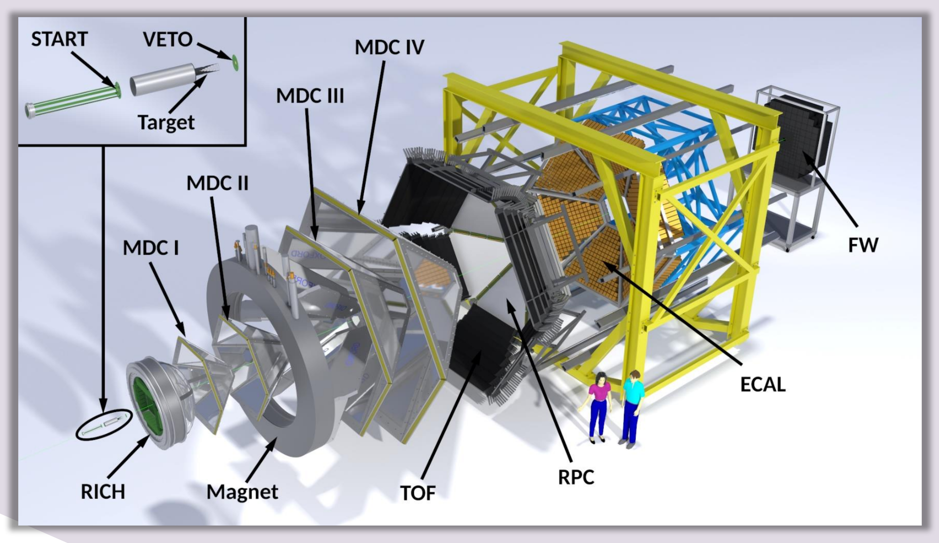
- Rare probes ($BR \sim 10^{-5}$)
- Isolation of in-medium contribution



HADES

The **H**igh-**A**cceptance-**D**i-**E**lectron-**S**pectrometer at GSI, Darmstadt, enables study of heavy-ion collsions at energies of $\sqrt{s_{NN}} = 2$ - 3 GeV

- Large acceptance: $0° < \varphi < 360°$ | $18° < \theta < 85°$
- Trigger rate up to 16 kHz
- Lepton identification with RICH, ToF, ECAL



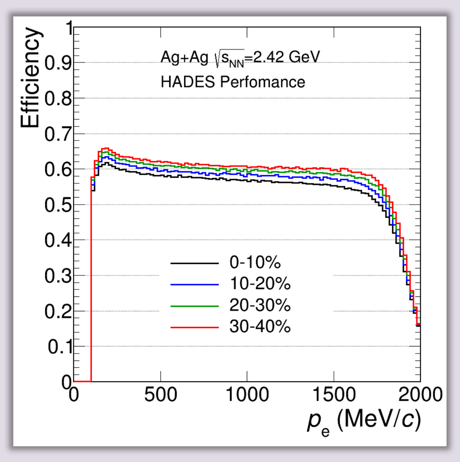
Reconstruction of e^+/e^- with high efficiency and high purity

Ag+Ag run in 2019

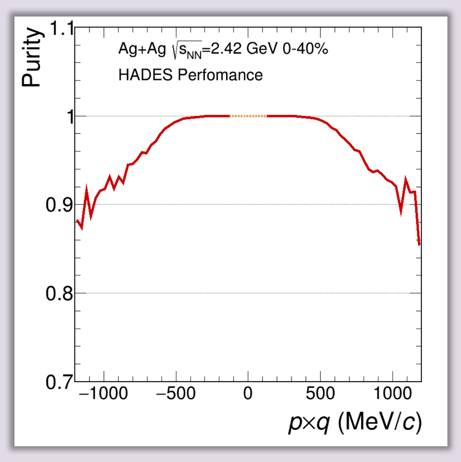
$N^{rec}_{\gamma^*} \approx 1.5 \cdot \mathbf{10^6}$ for $\sqrt{s_{NN}} = 2.55$ GeV

$N^{rec}_{\gamma^*} \approx 1.5 \cdot \mathbf{10^5}$ for $\sqrt{s_{NN}} = 2.42$ GeV

Reconstruction efficiency ~ 60%

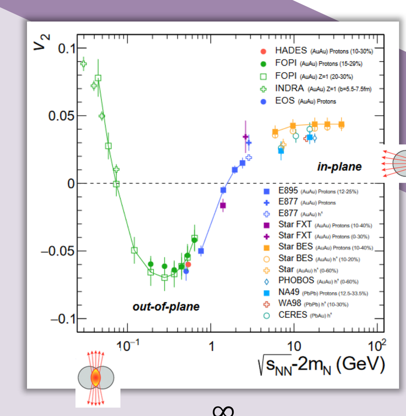


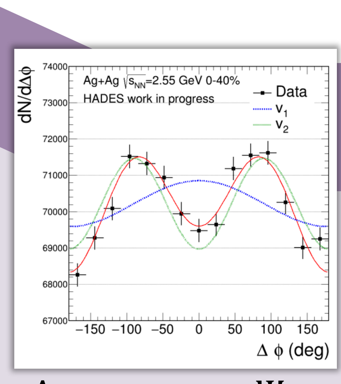
Purity above 90%
Pion suppression of ~ 10^{-5}



Anisotropic Flow

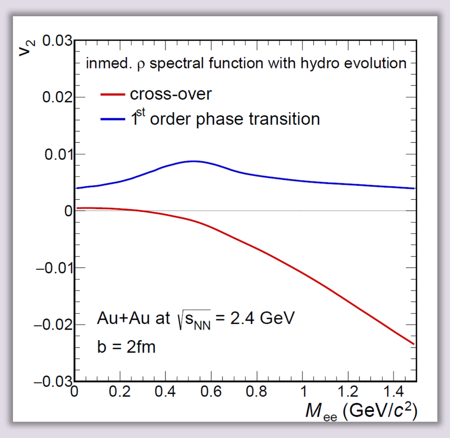
- Flow measurement of virtual photons allows insights into the time evolution of the systems collectivity [1]
- Anisotropic flow v_n at SIS18 energies subject to squeeze-out effect from spectators
- Sensitive to equation of state and potential phase transititon [2]

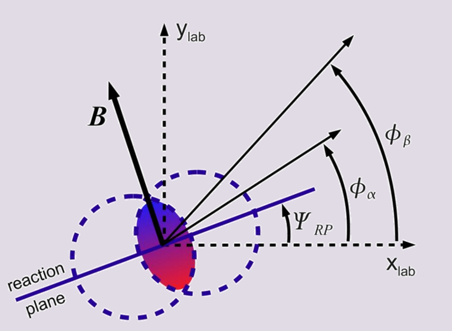




$$\frac{dN}{d\Delta\varphi} \propto 1 + 2 \sum_{n=1}^{\infty} v_n \cos(n\,\Delta\varphi)$$

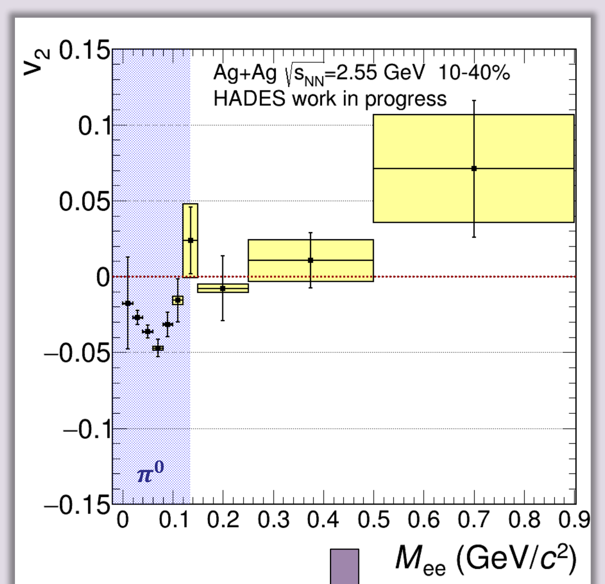
$$\Delta\varphi = \varphi_{ee} - \Psi_{RP}$$

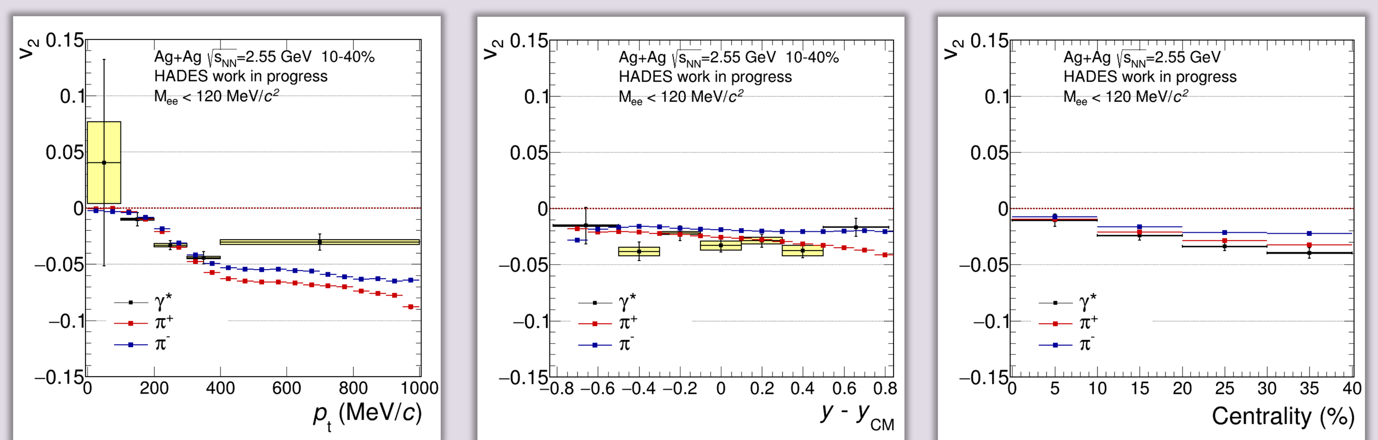




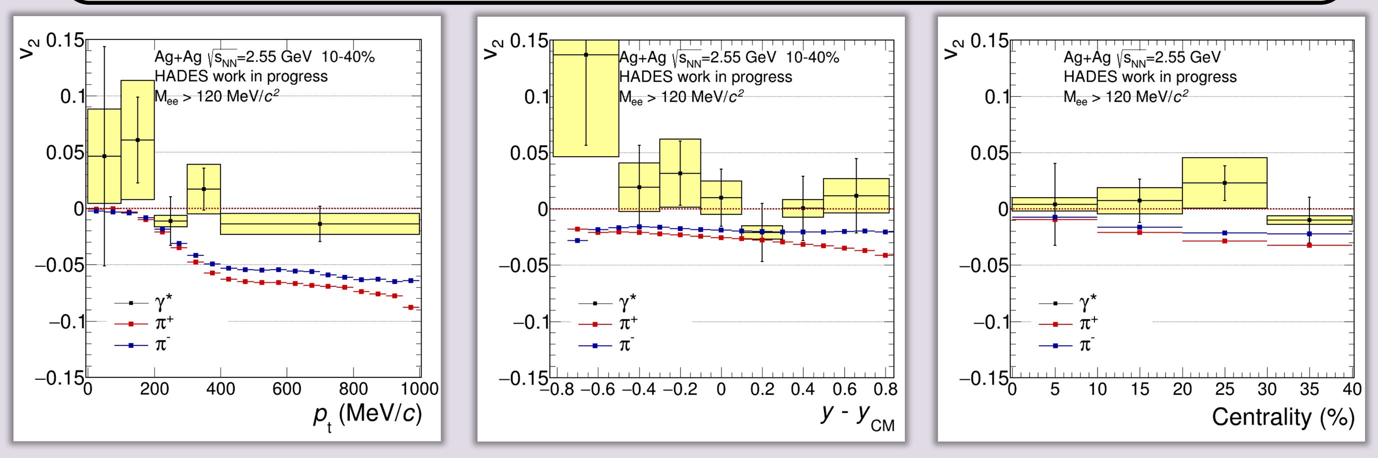
- Event Plane Ψ_{EP} [3] reconstructed from total tranverse momentum in forward wall detector [4]
- Event plane resolution $\Re_n$ estimated via Ollitrault method [5]

v_2 in π^0 Dalitz range is negative, consistent with $\pi^{-/+}$





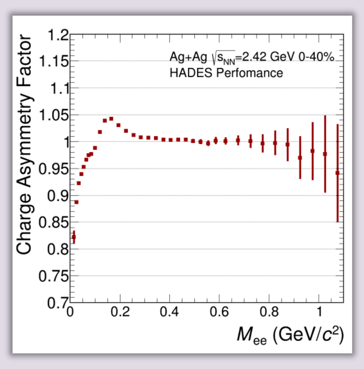
v_2 shows differences in mass regions dominated by π^0 vs regions dominated by thermal contribution, demontrating penetrating nature

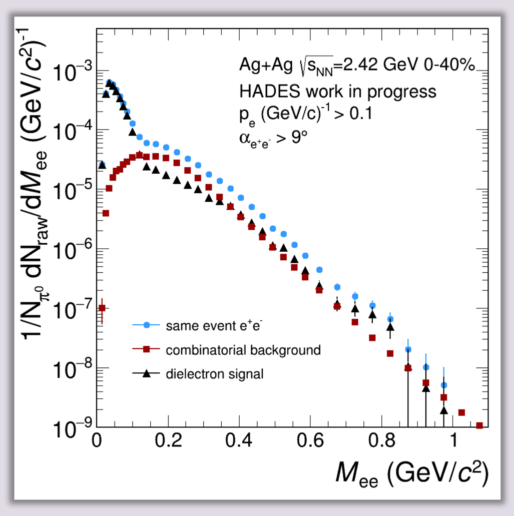


v_2 consistent with zero for $M_{ee} > m_{\pi^0}$

→ thermal contribution dominant

Signal Reconstruction

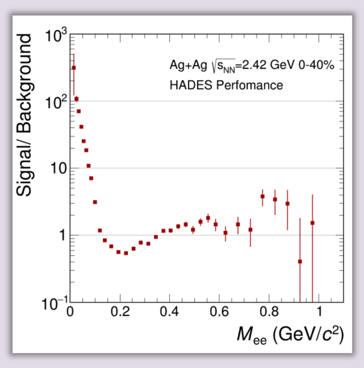




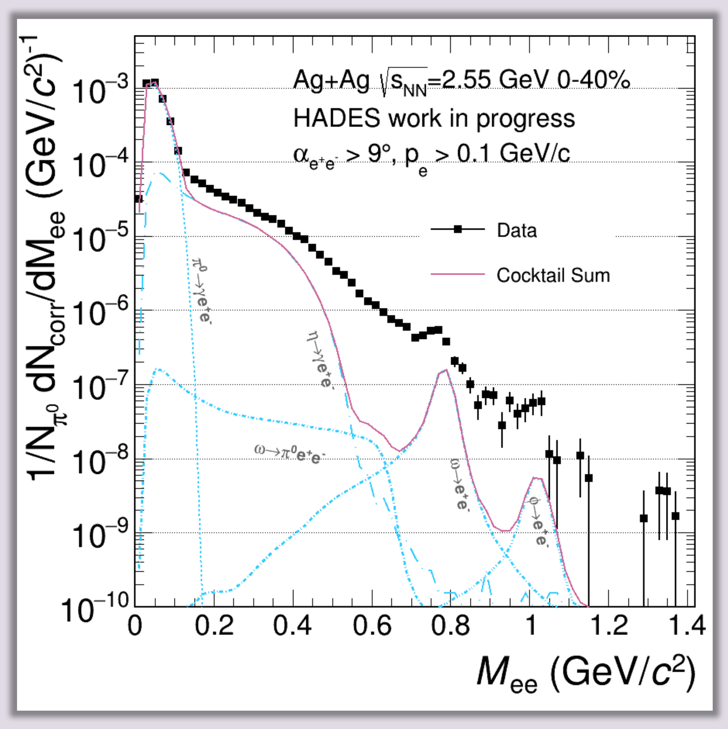
$$\frac{dN_{Signal}}{dM} = \frac{dN_{+-}}{dM} - \frac{dN_{CB}}{dM}$$

$$\frac{dN_{CB}}{dM} = 2k\sqrt{\frac{dN_{++}}{dM}\frac{dN_{--}}{dM}}$$

$$k = \frac{\frac{dN^{mix}_{+-}}{dM}}{\sqrt{\frac{dN^{mix}_{++}}{dM}\frac{dN^{mix}_{--}}{dM}}}$$

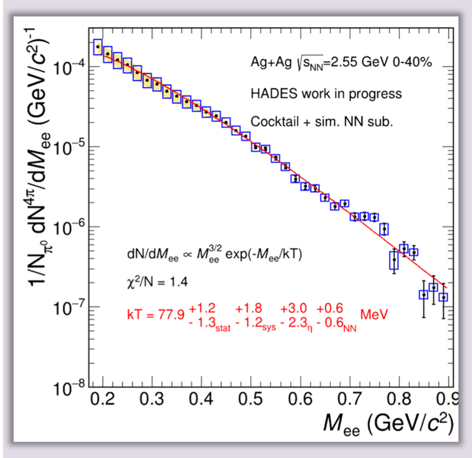


- Combinatorial background (CB) estimated via same-event and mixed-event methods
- Conversion rejection, based on opening angle, leads to significant improvement in signal/background ratio



- Correct for efficiency by embedding simulated $e^{\pm}$ into experimental data
- Detector response simulated with GEANT [6]
- Freeze-out cocktail simulated with Pluto [7]
- NN Reference measured in pp/pn collisions at the same energy (Feb - Mar 2022)
- Excess over freeze-out and initial contribution from thermal ρ

Fireball Temperature



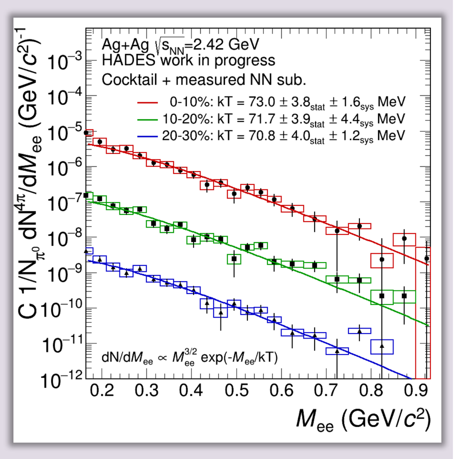
Shape of the excess mass spectrum reveals integrated fireball temperature T

$$\frac{dN}{dM} \propto M^{\frac{3}{2}} \exp\left(-\frac{M}{T}\right)$$

$kT_{Ag+Ag}\,(\sqrt{s_{NN}} = 2.55 \text{ GeV}) = 77.9 \pm 1.3_{stat}$ MeV

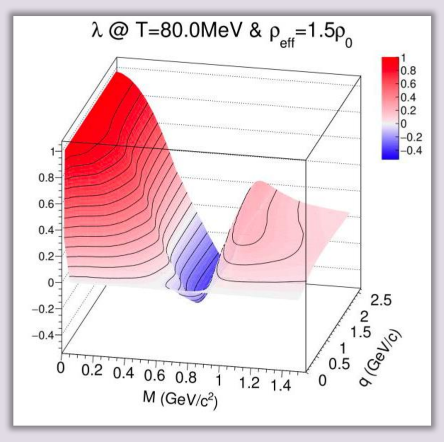
$kT_{Ag+Ag}\,(\sqrt{s_{NN}} = 2.42 \text{ GeV}) = 73.4 \pm 2.6_{stat}$ MeV

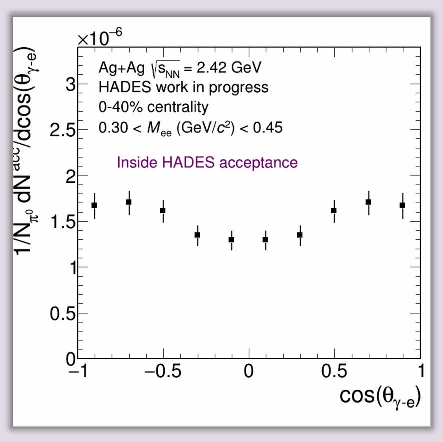
$kT_{Au+Au}\,(\sqrt{s_{NN}} = 2.42 \text{ GeV}) = 74.5 \pm 3.3_{stat}$ MeV

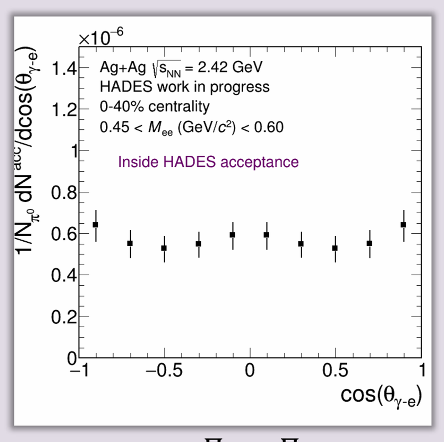


Prospects

- Isolation of thermal dileptons from freeze-out and initial contribution
- Comparison with simulation to learn about EoS
- Combine γ^* polarization and anisotropy to learn about production mechanism [8][9]







Polarization analysis ongoing

For thermal dileptons in helicity frame: $\lambda_\theta = \frac{\Pi_T - \Pi_L}{\Pi_T + \Pi_L}$

Quark Matter 2023

[1] T. Reichert *et al.*, Phys.Lett.B 841 (2023) 137947
[2] F. Seck *et al.*, Phys.Rev. C 106 (2022) 1, 014904
[3] B. I. Abelev *et al.*, Phys. Rev. Lett. 103, 251601
[4] Andreeva *et al.*, 2014 Inst. and Exp. Techniques 57 103–119
[5] Jean-Yves Ollitrault, arXiv:nucl-ex/9711003
[6] S. Agostinelli *et al.*, Nucl. Instrum. Meth. A 506 (2003)
[7] I. Froehkich *et al.*, arXiv:0708.2382
[8] Speranza *et al.*, Phys. Lett. B 782, 395 (2018)
[9] Baym *et. al.*, Phys. Rev. C 95, 044907 (2017)