Characterising the hot and dense fireball via virtual photons in HADES

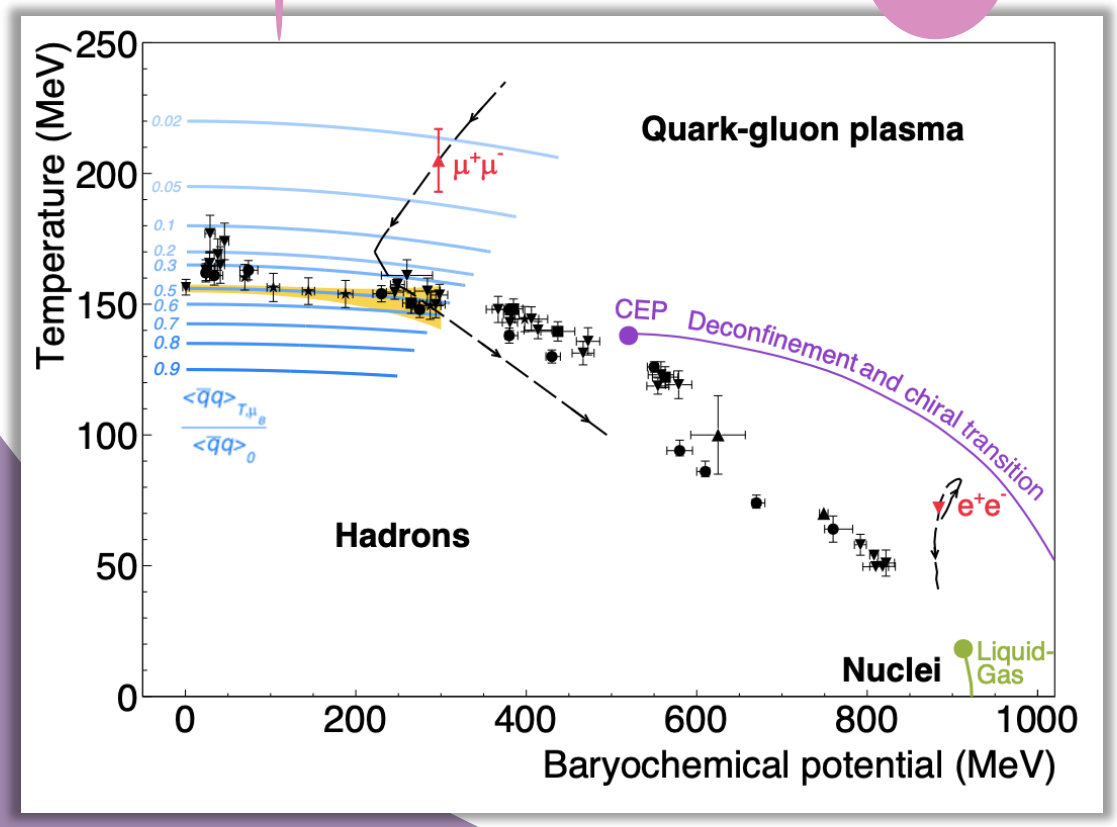
Niklas Schild for the HADES Collaboration

This work is supported by the State of Hesse within the Research Cluster ELEMENTS (Project ID 500/10.006)

Exploring the QCD matter phase diagram

LHC energies $\sqrt{s_{NN}} = 2\ \mathrm{TeV}$
parton+parton collisions
Early Universe in the laboratory

Energies $\sqrt{s_{NN}} \cong 2 * m_N\ \mathrm{GeV}$
nuclear stopping
NS merger matter in the laboratory



The HADES Collaboration, *Nat. Phys.* **15,** 1040–1045 (2019)

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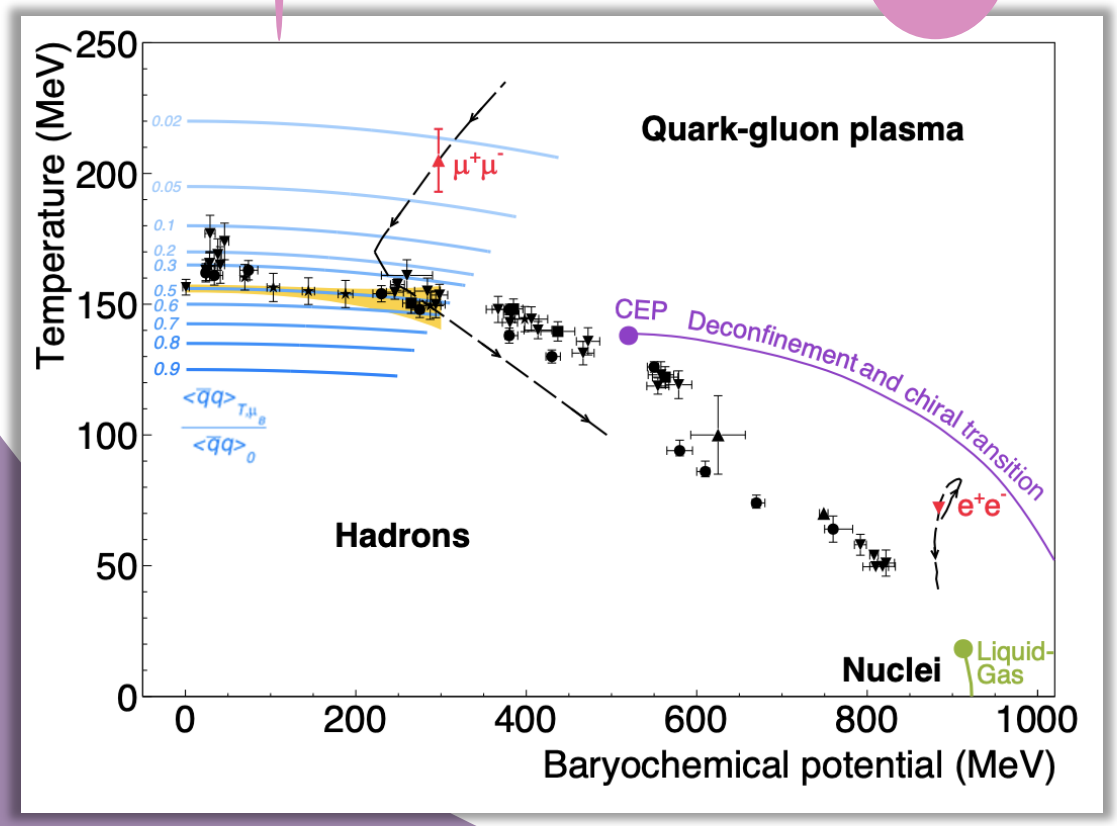
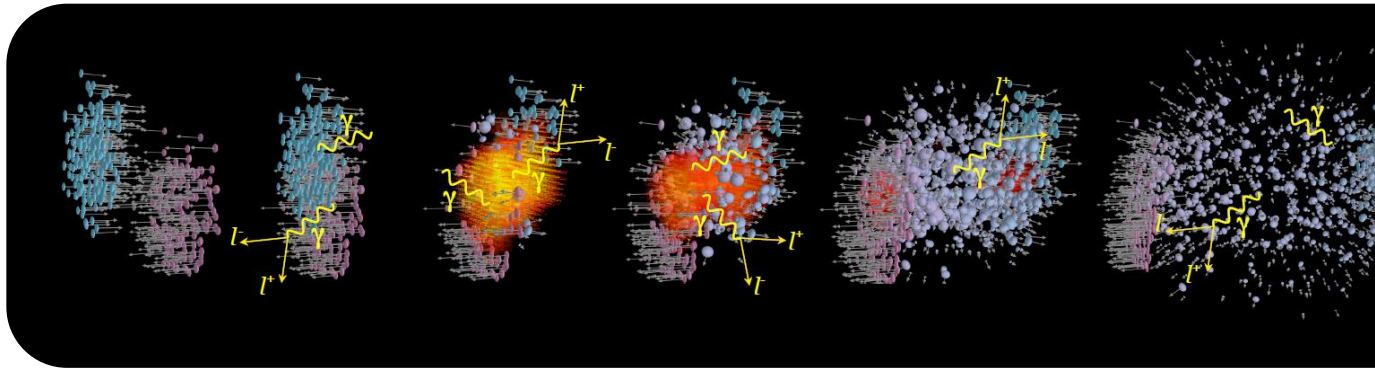


Focus on **virtual and real photons**



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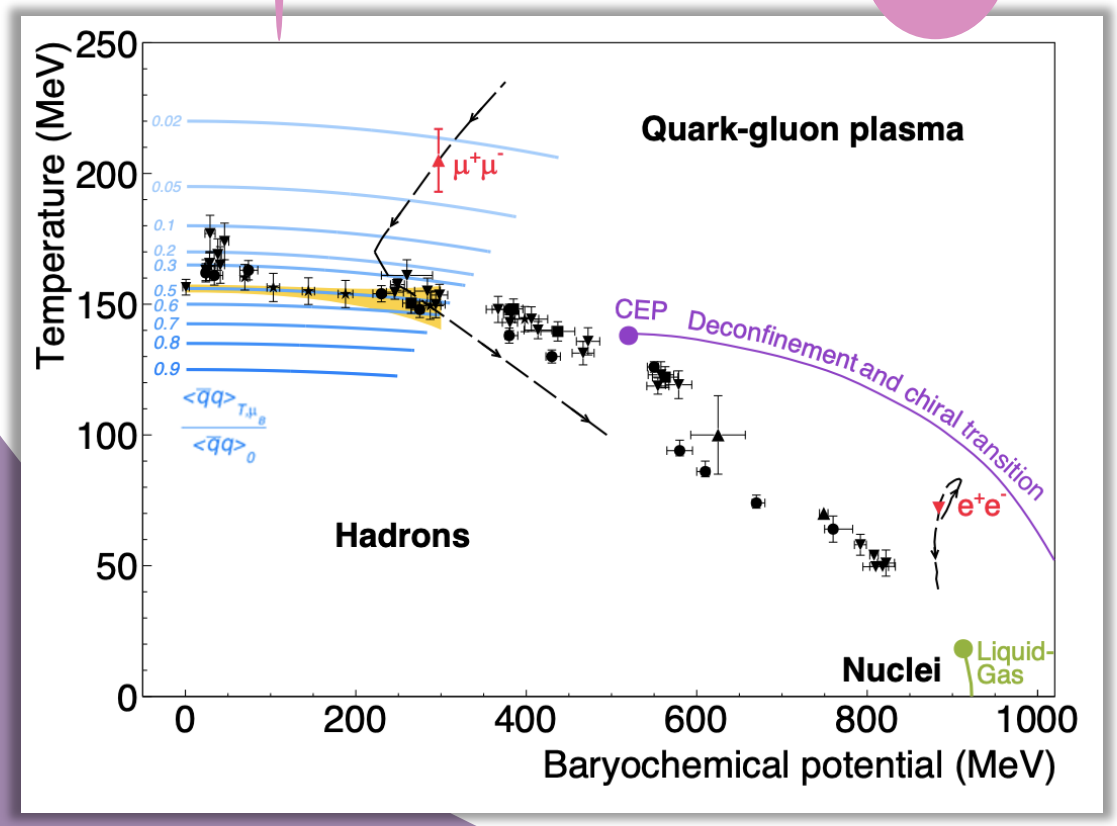

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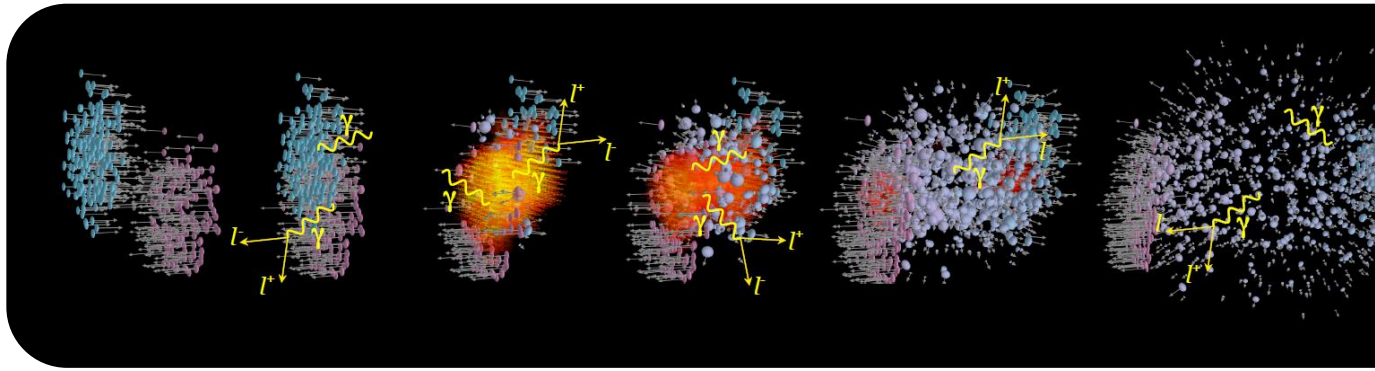
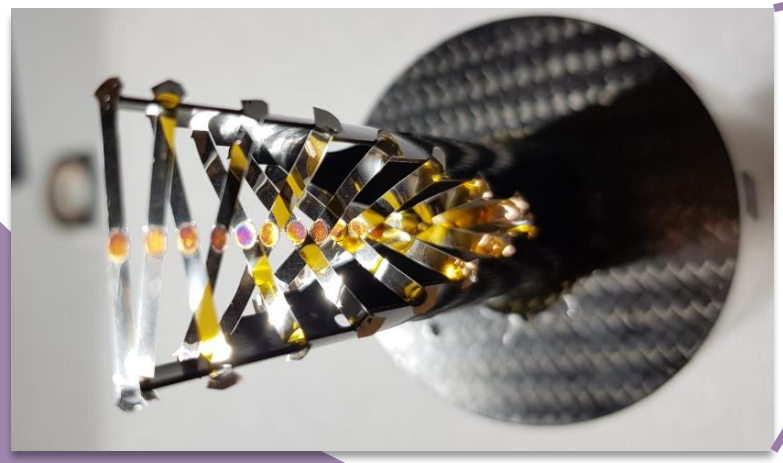


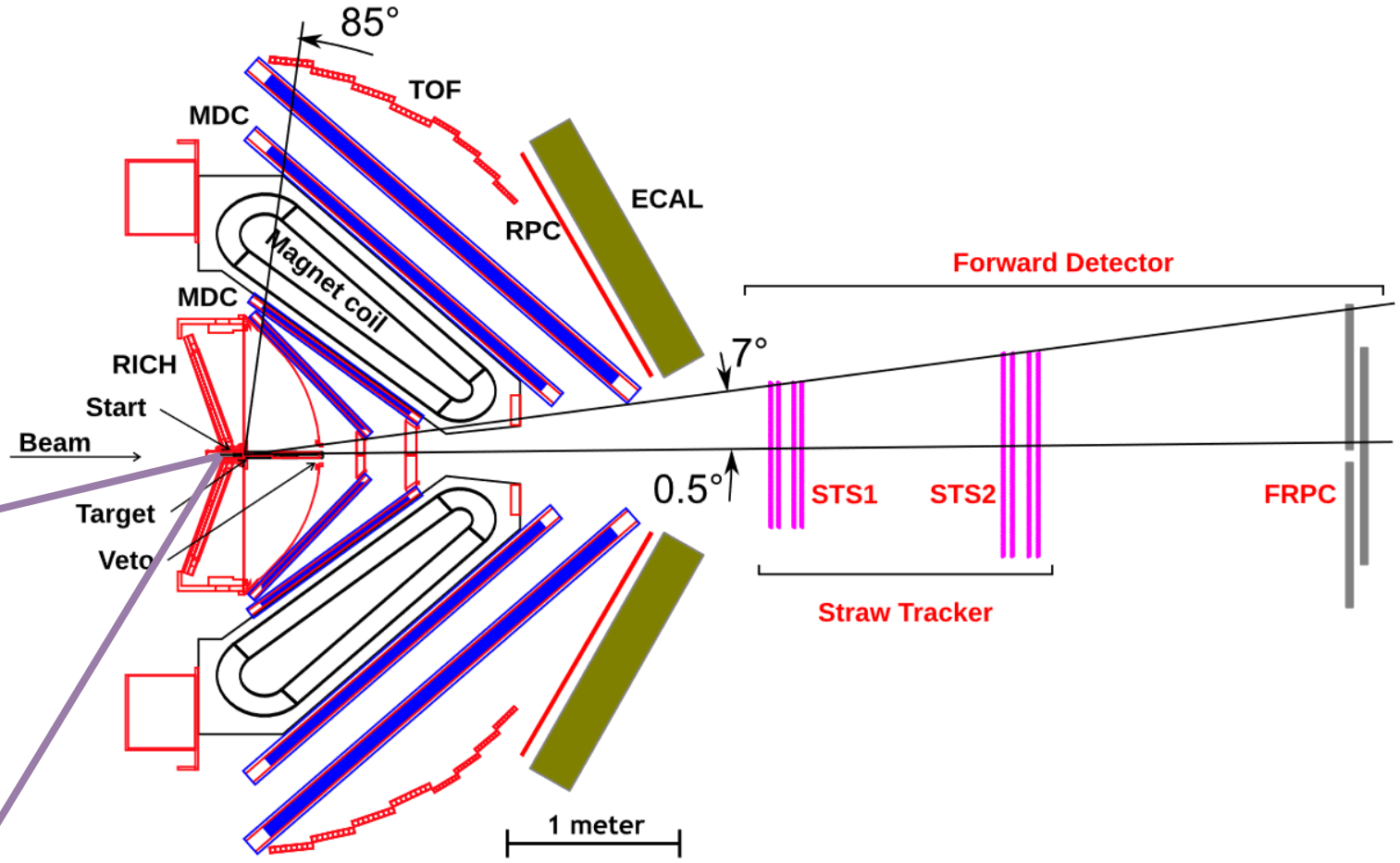
- **Heavy ion collisions** at $\sqrt{s_{NN}} = 2 - 3\ \mathrm{GeV}$
  - Different collision dynamics compared to higher energies
- **Pion and nucleon beams**
  - E.g. for reference measurements

Explore region of QCD phase diagram with high net-baryon density and moderate temperatures

The High-Acceptance-Di-Electron-Spectrometer

- Almost full azimuth angle coverage and polar angles between 18°-85° (0.5°-7°)
- Accepted trigger rate 16 kHz for HIC, 50 kHz for elementary reactions
- **New installments and upgrades:**
  - RICH photon detection plane
  - ECal
  - Forward detector
- 15-fold segmented target

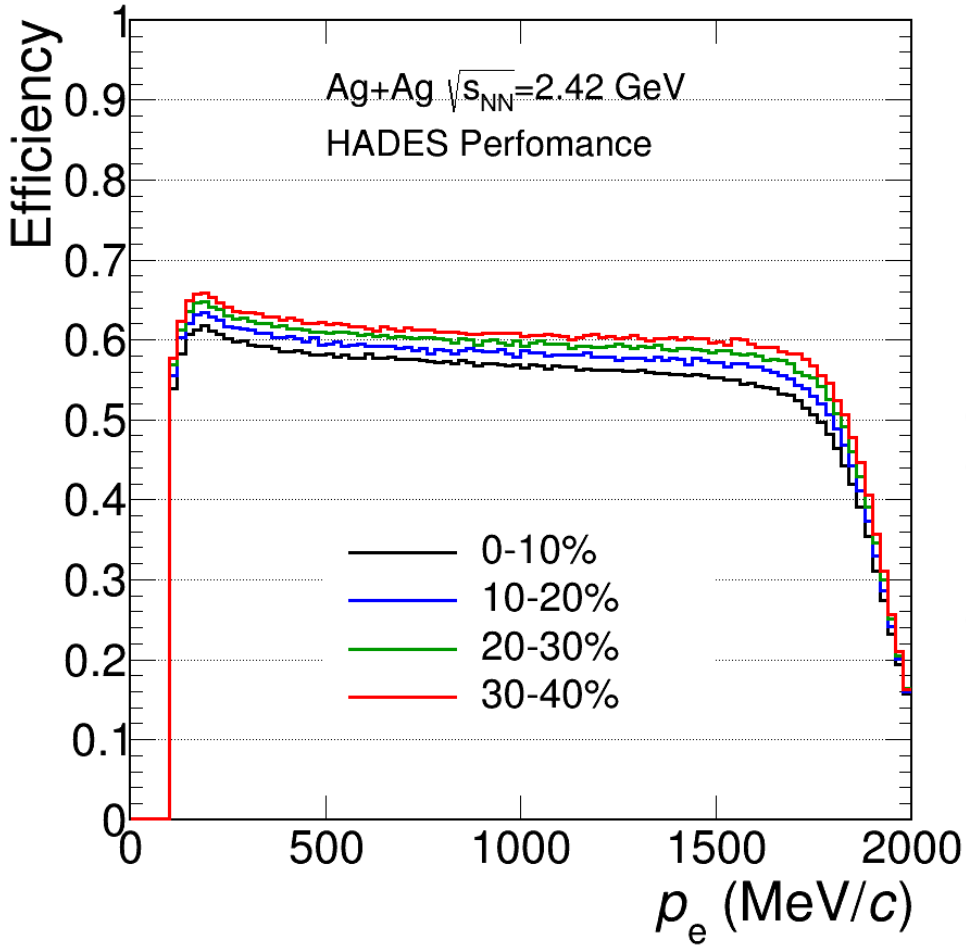




The HADES Collaboration, Eur. Phys. J. A **57**, 138 (2021)

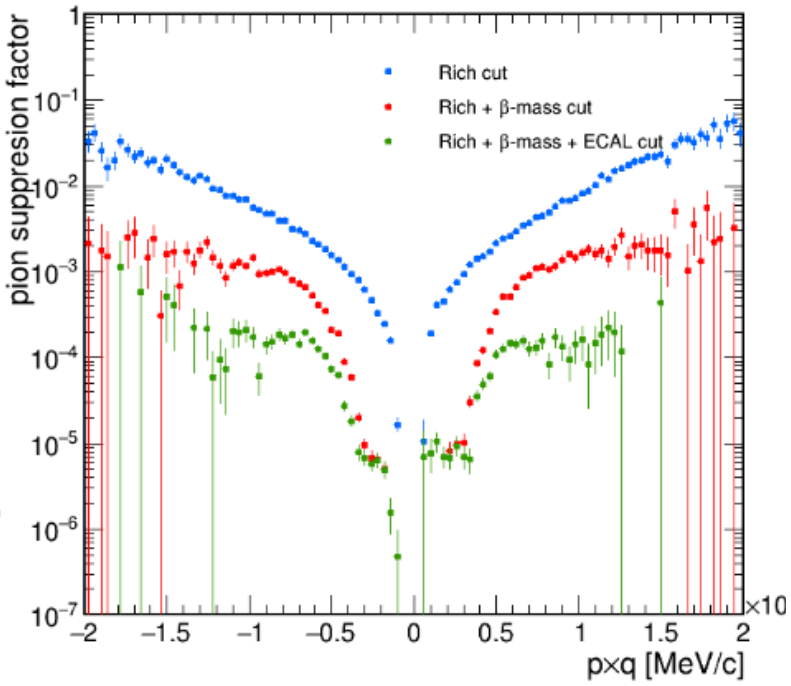
HADES perfomance for electron identification

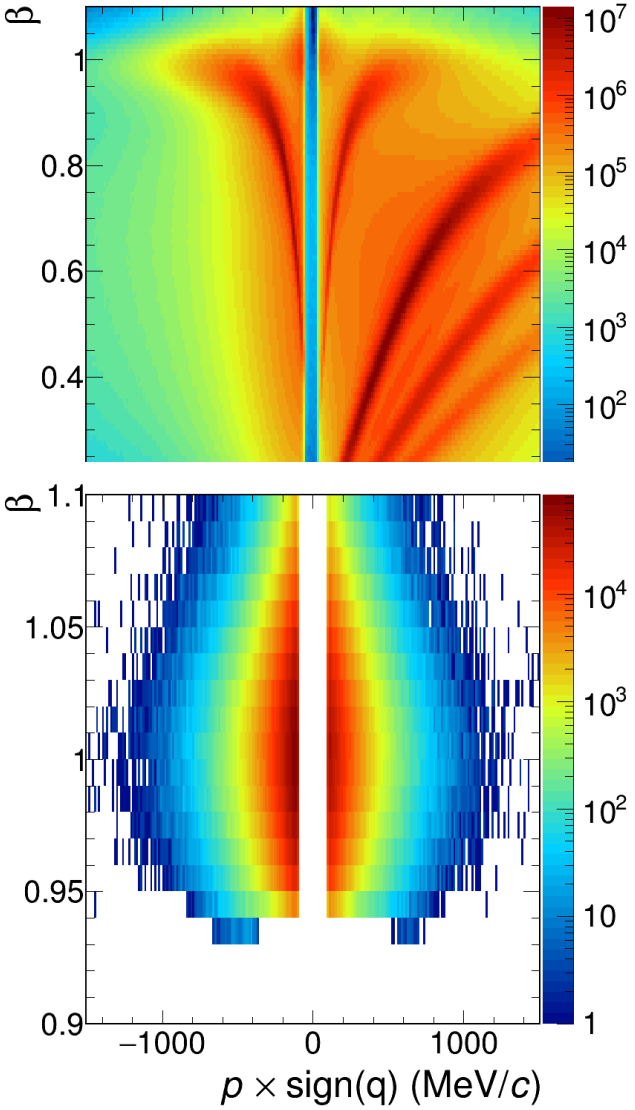
Reconstruction efficiency ~ 60%



Upgrades in RICH detector allows for **high effifiency** and **high purity** electron sample

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





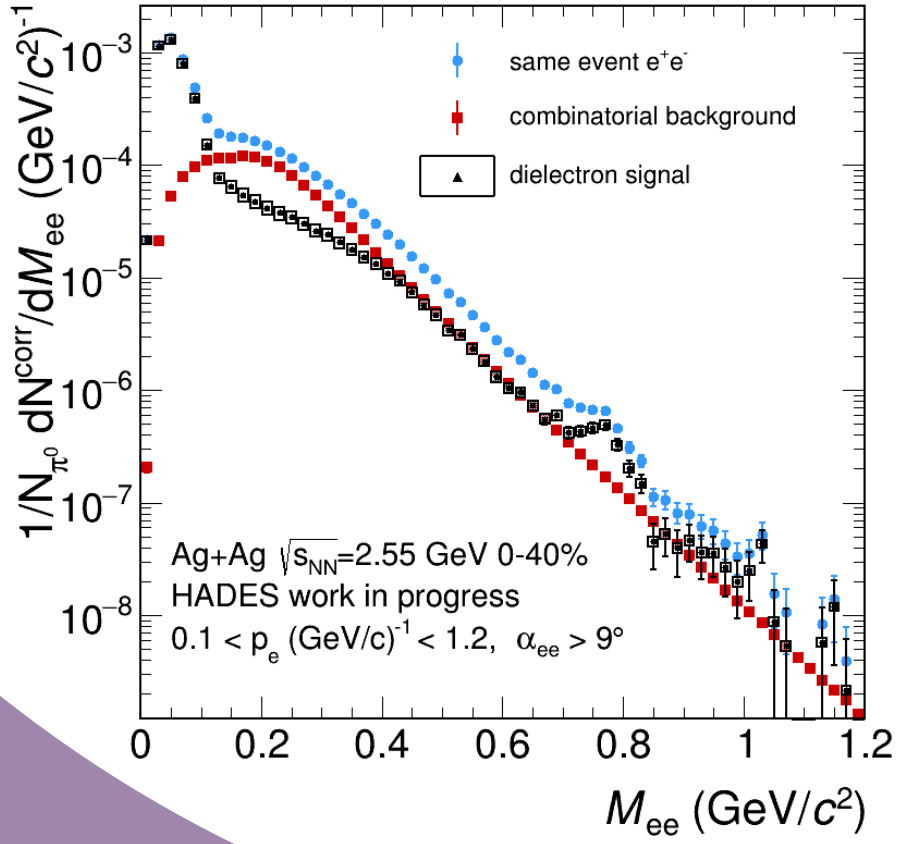
Outline

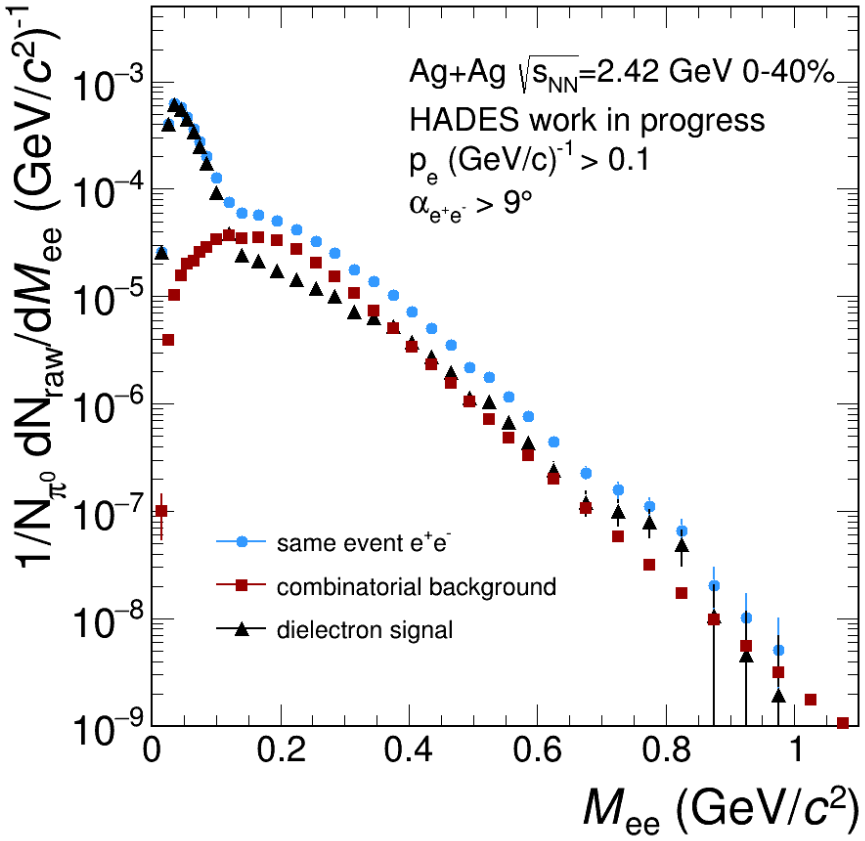
1. Reconstruction of (invariant mass) spectra
2. Dilepton flow analysis
3. Prospects/Outlook

Reconstruction of the dilepton spectra

Reconstruction of e^+e^- signal

- Conversion rejection with RICH detector:
  - Pair opening angle > 9°
  - Maximum number of photons per ring





Reconstruction of e^+e^- signal

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

- Conversion rejection with RICH detector:
  - Pair opening angle > 9°
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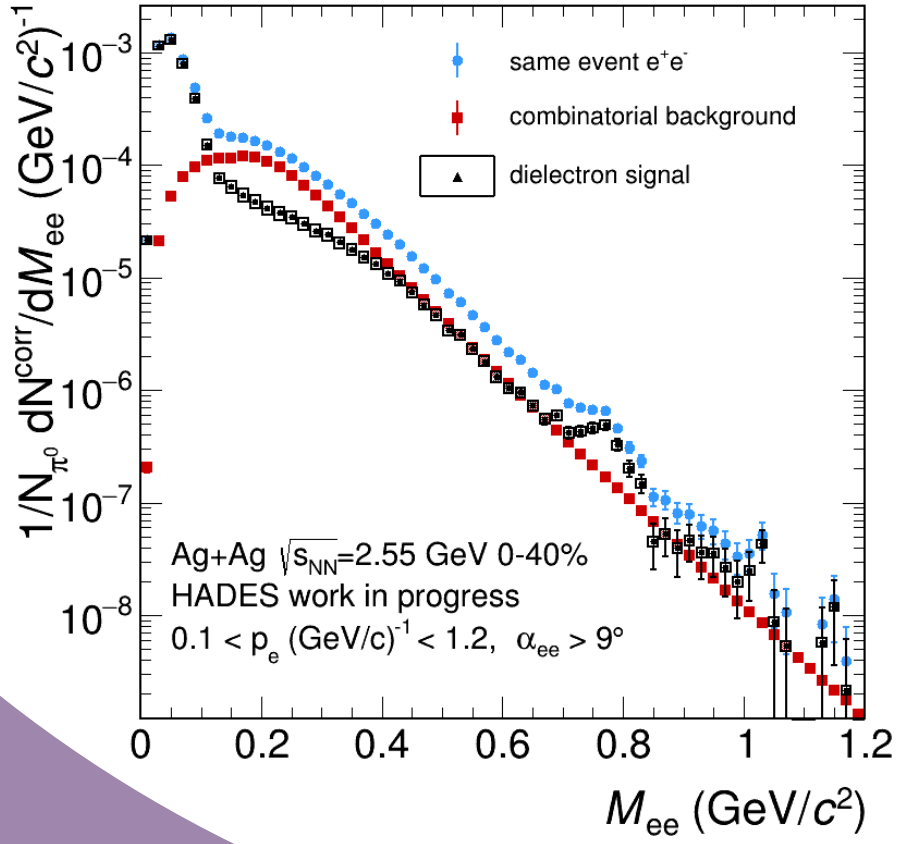
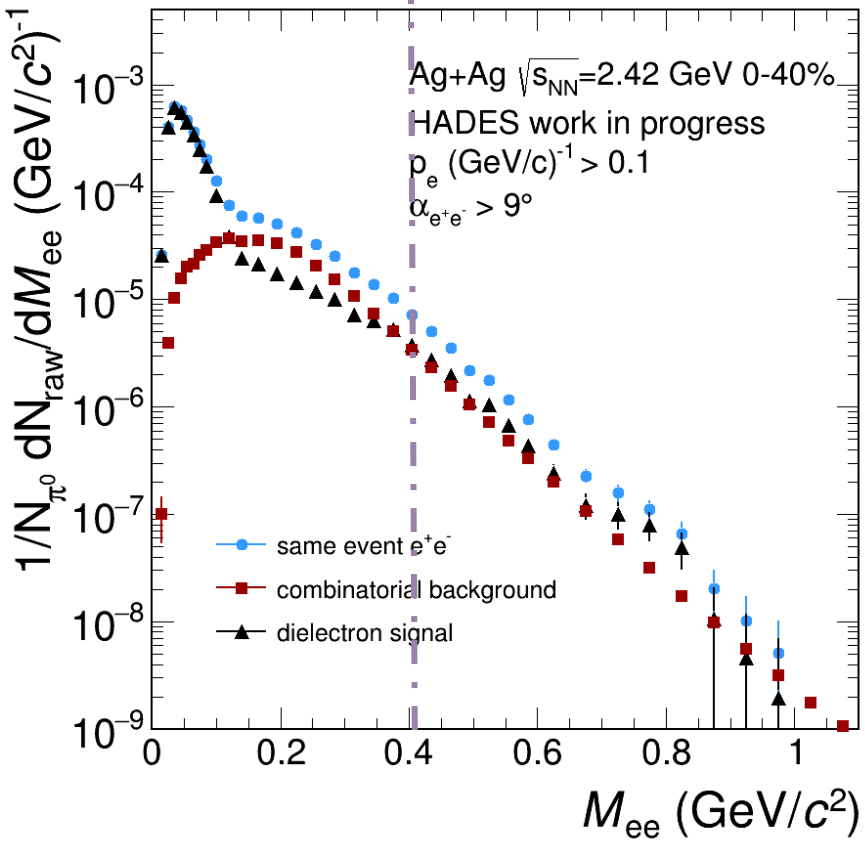
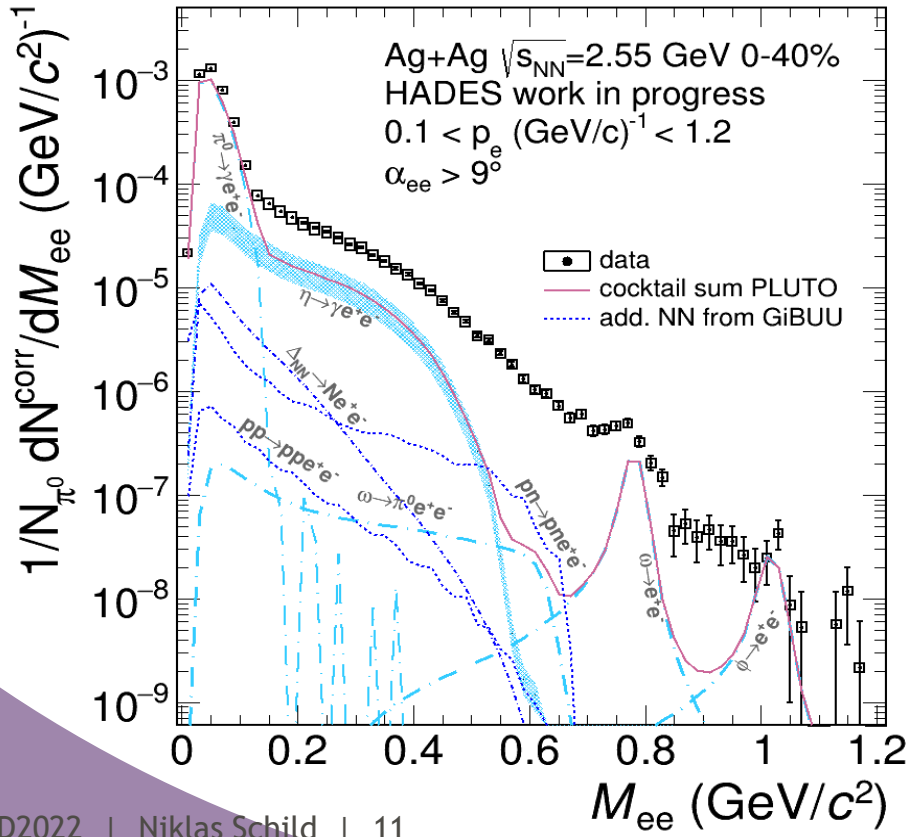


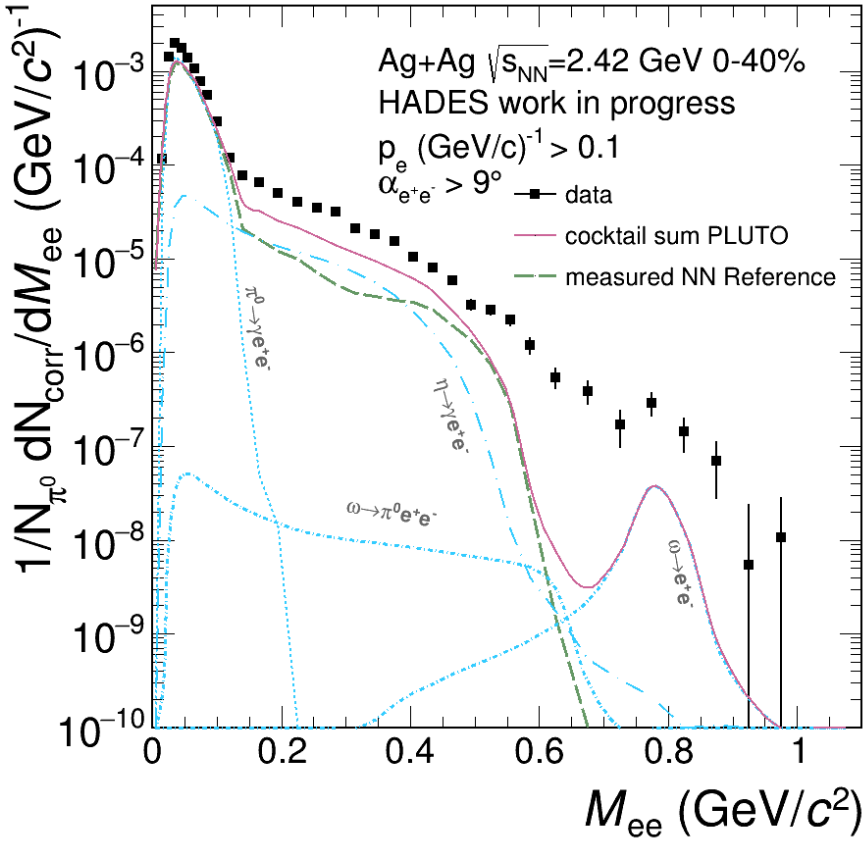
Same-event method (1) | Mixed-event method



Extracting the in-medium contribution

- **Freeze-out cocktail:**
  - Simulated using Pluto event generator
  - Multiplicities to be measured from same dataset
- **Initial NN contribution:**
  - Reference measured for $\sqrt{s_{NN}} = 2.42$ GeV
  - For $\sqrt{s_{NN}} = 2.55$ GeV currently estimated using GiBUU 2021 release





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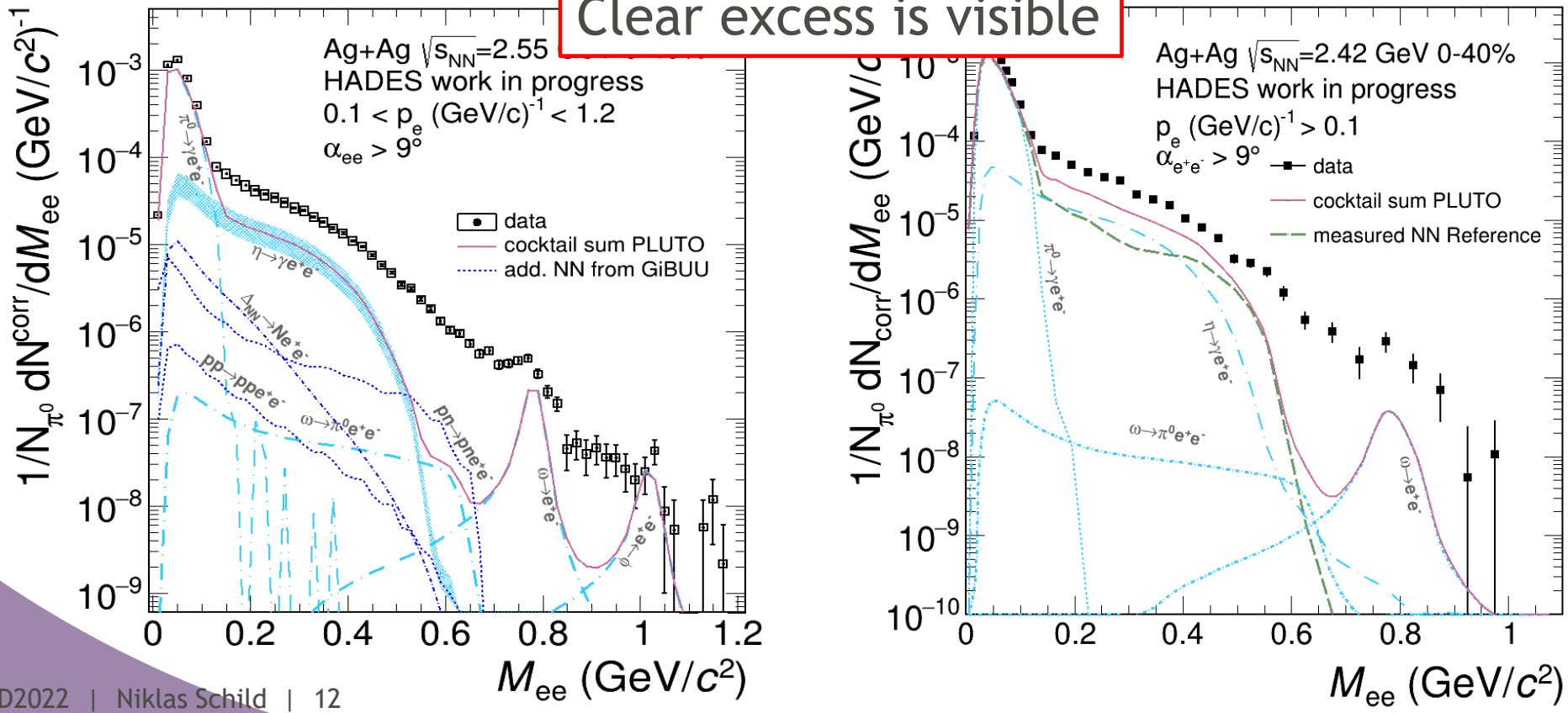
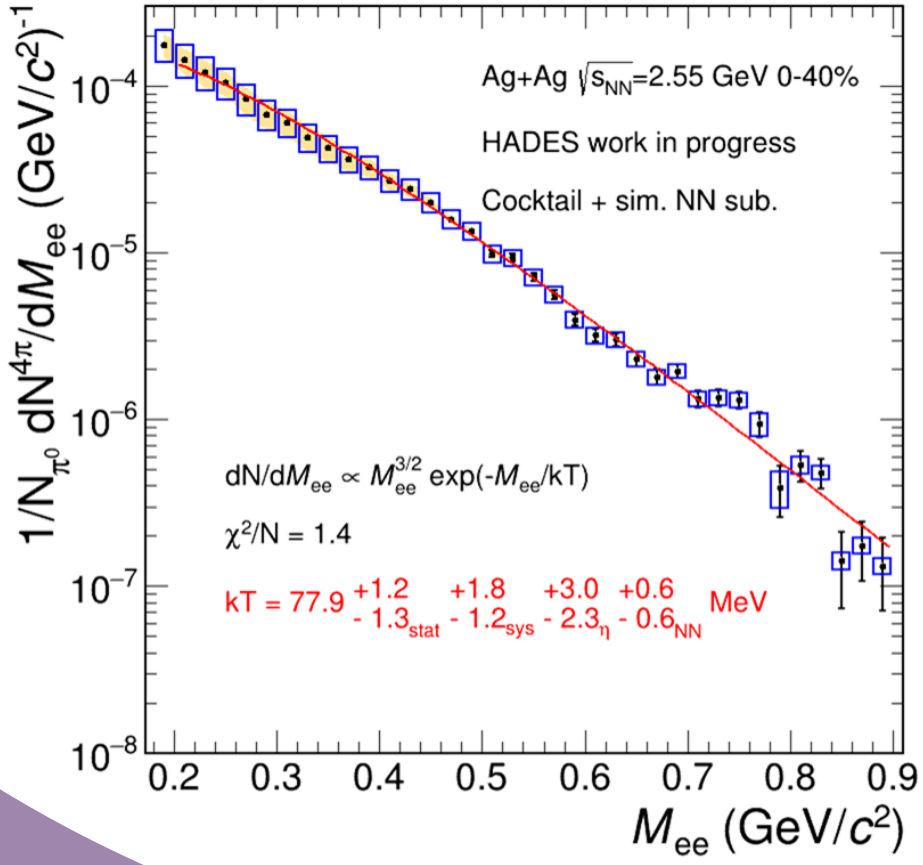
Clear excess is visible



Temperature determination

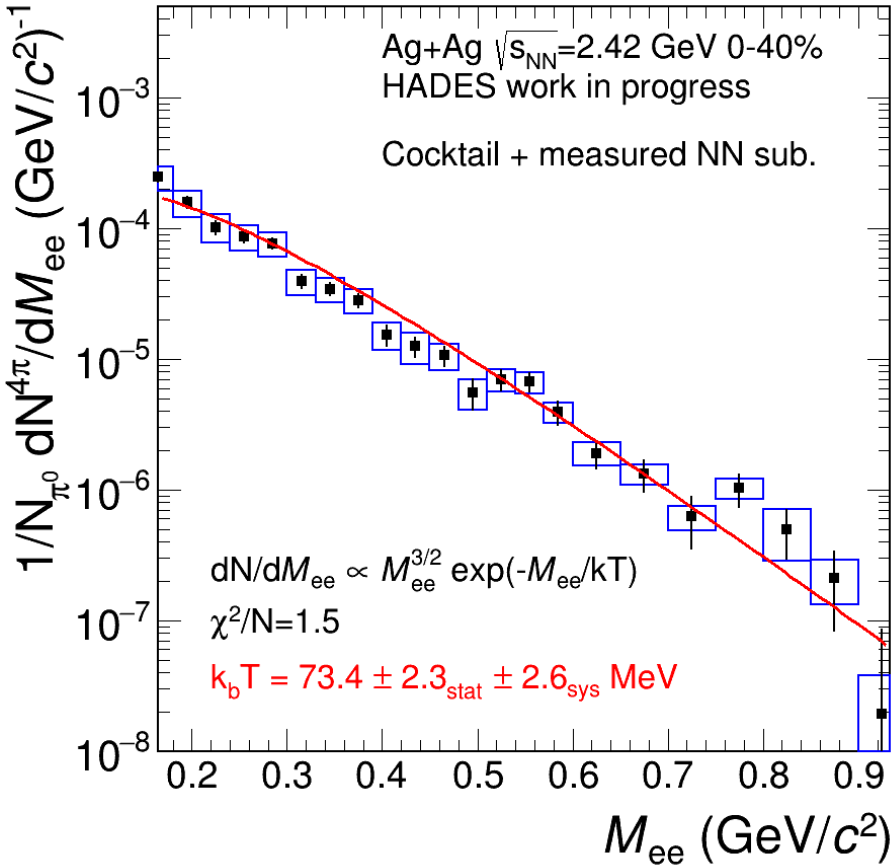
$$\frac{dN}{dM} \propto M^{\frac{3}{2}} \exp\left(-\frac{M}{T}\right)$$

- Subtraction of freeze-out and initial contributions reveals **excess of thermal nature**
- Higher temperature for higher collision energy



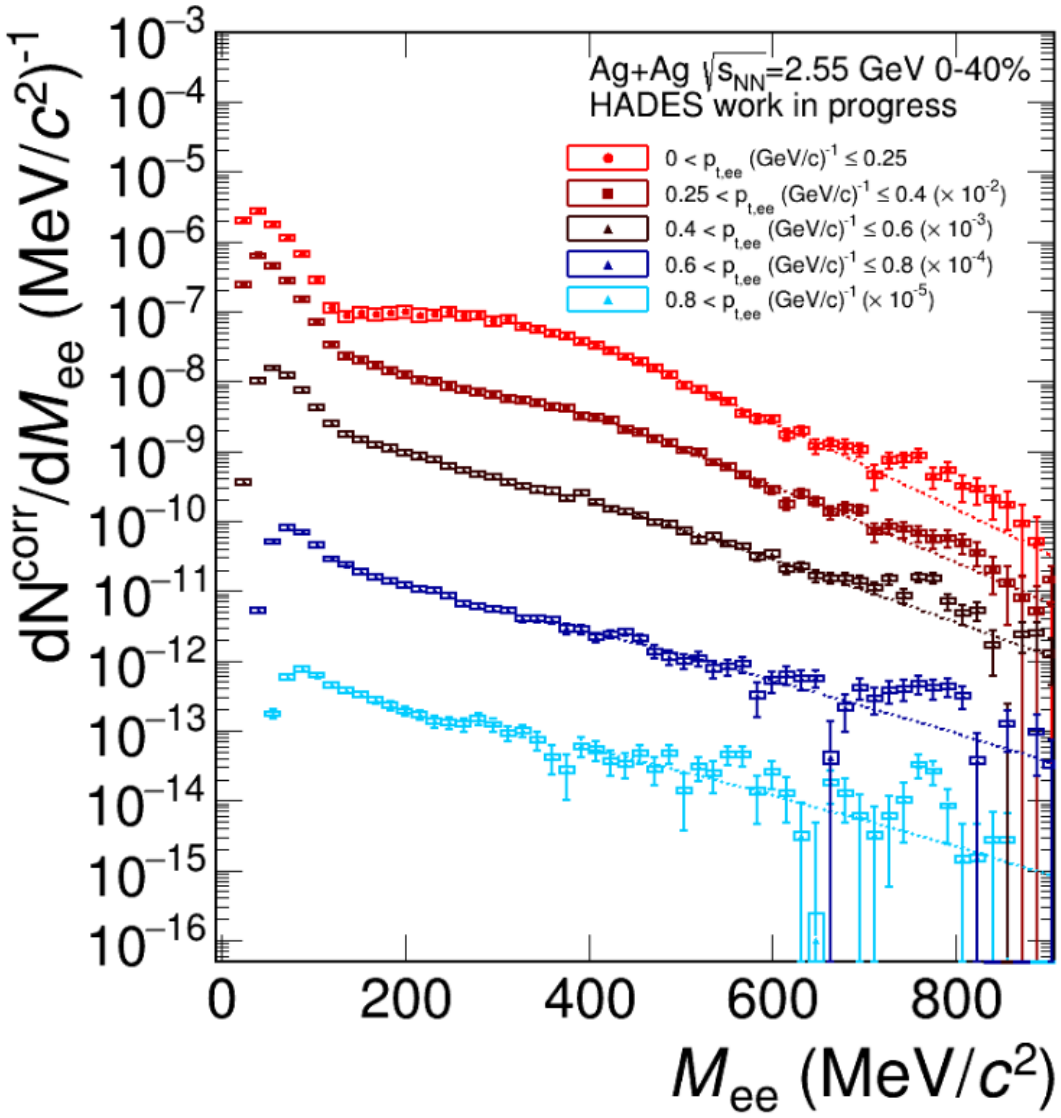
Compare with*:

$kT_{Au+Au}\,(\sqrt{s_{NN}} = 2.42\ \text{GeV}) = 71.8 \pm 2.8\ \text{MeV}$



* The HADES Collaboration, *Nat. Phys.* **15,** 1040–1045 (2019)

Differential analysis of dielectron spectra



- Large number of lepton pairs and high efficiency allows for multidifferential analysis, e.g.:
  - Centrality-dependent*
  - Angular distributions
  - Reconstruction of p_t and y spectra for varying mass bins

Analysis in bins of tranverse momentum p_t

- ω-peak clearly visible at high p_t
- Disapperance of ω-peak at small p_t
- Model comparison ongoing

* https://indico.cern.ch/event/895086/contributions/4721205/

Flow analysis

Flow analysis procedure

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

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

$$v_n = \frac{v_n^{obs}}{\Re_n}$$

- Event Plane Ψ_{EP} reconstructed from total tranverse momentum in forward wall detector [1]
- Event plane resolution $\Re_n$ via Ollitrault method [2]

[1] Andreeva *et al.*, 2014 Inst. and Exp. Techniques 57 103–19
[2] Jean-Yves Ollitrault, arXiv:nucl-ex/9711003

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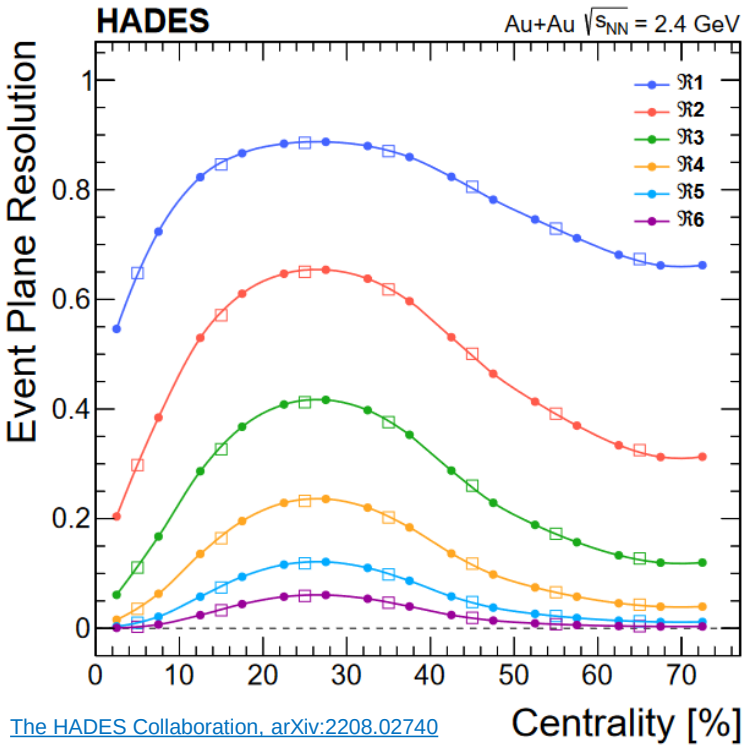

The HADES Collaboration, arXiv:2208.02740

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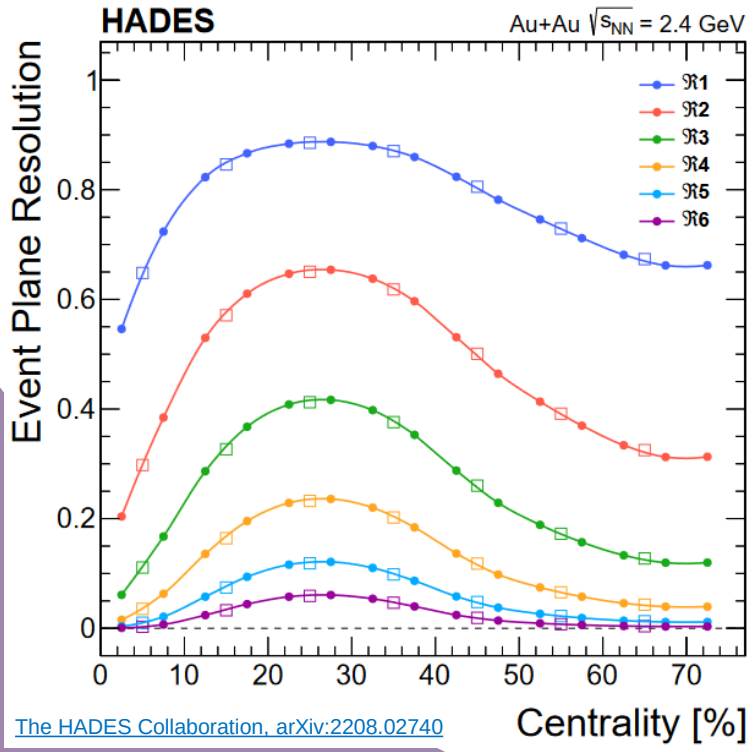

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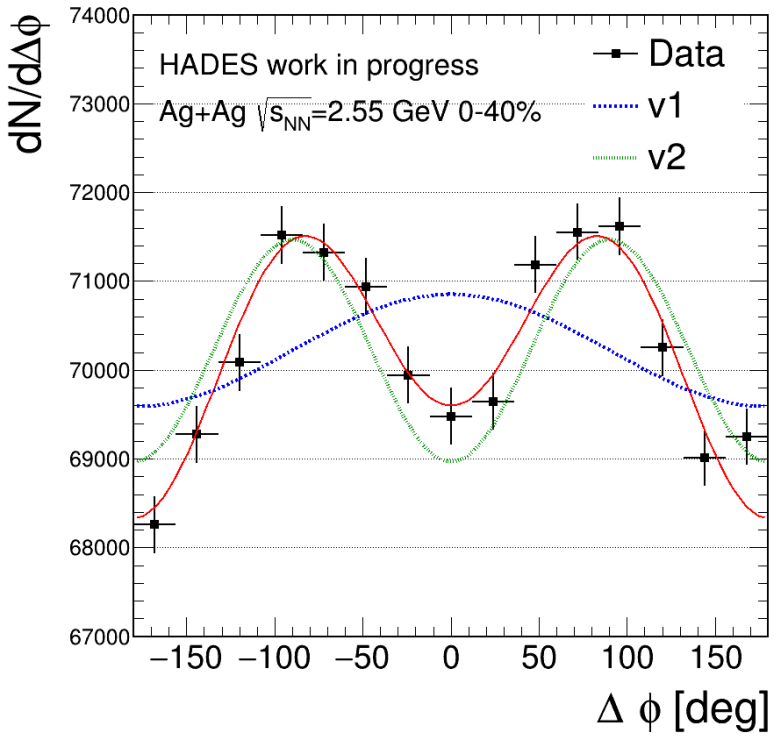

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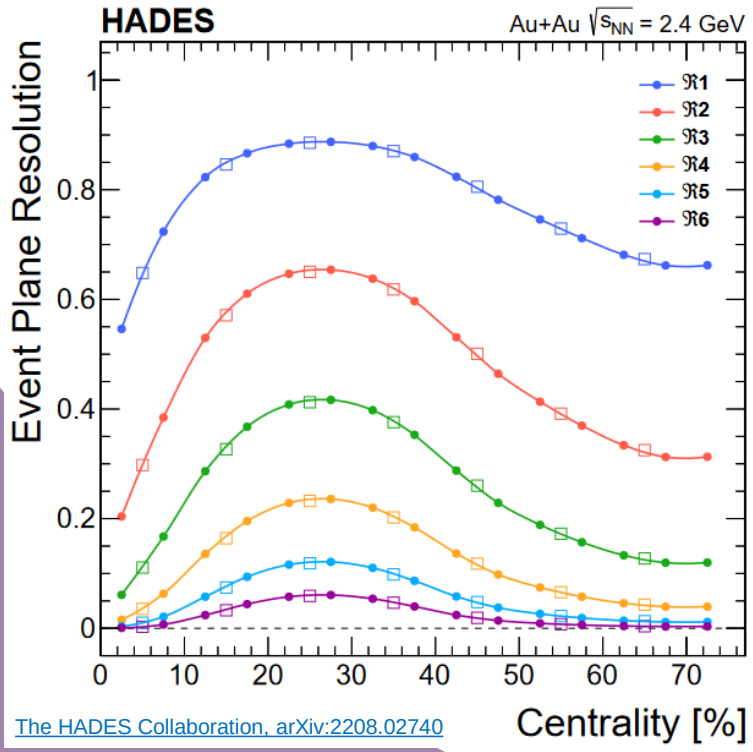

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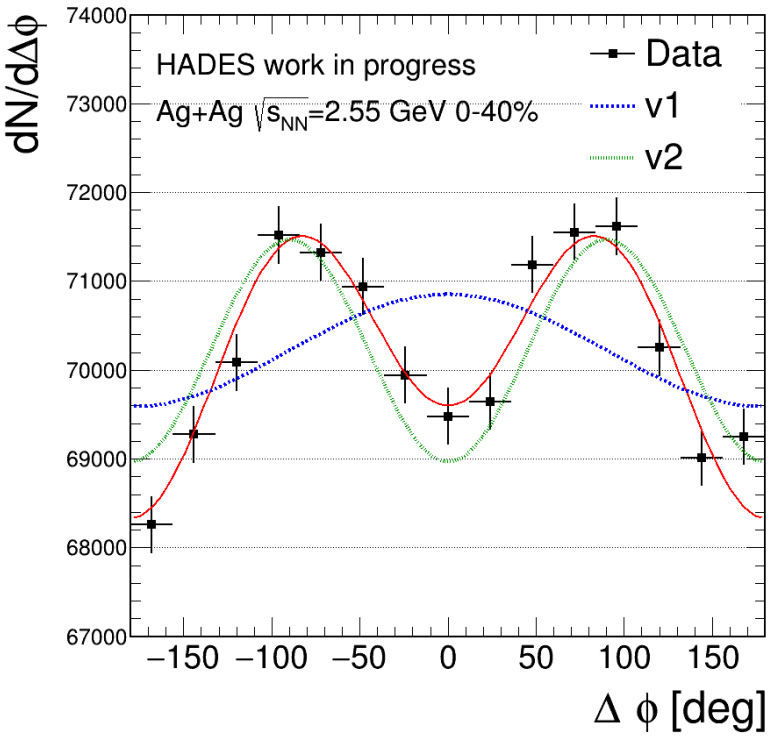

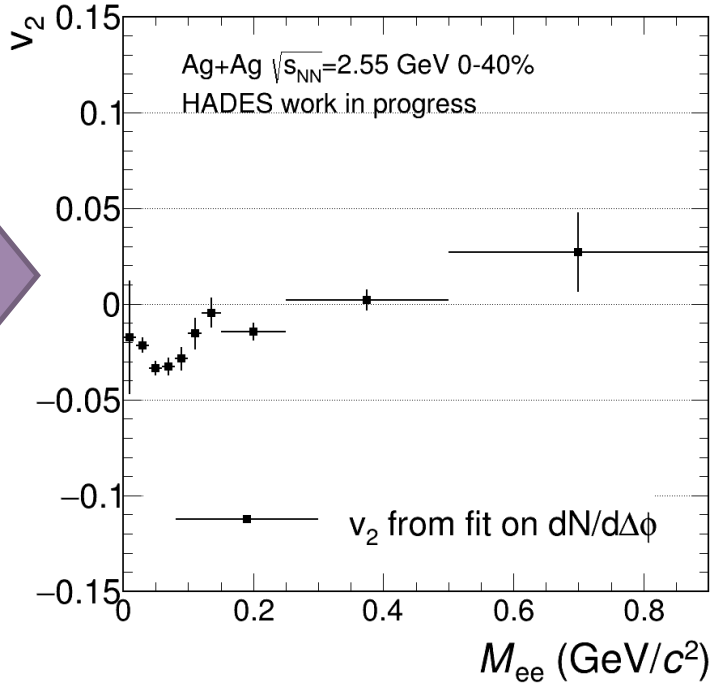

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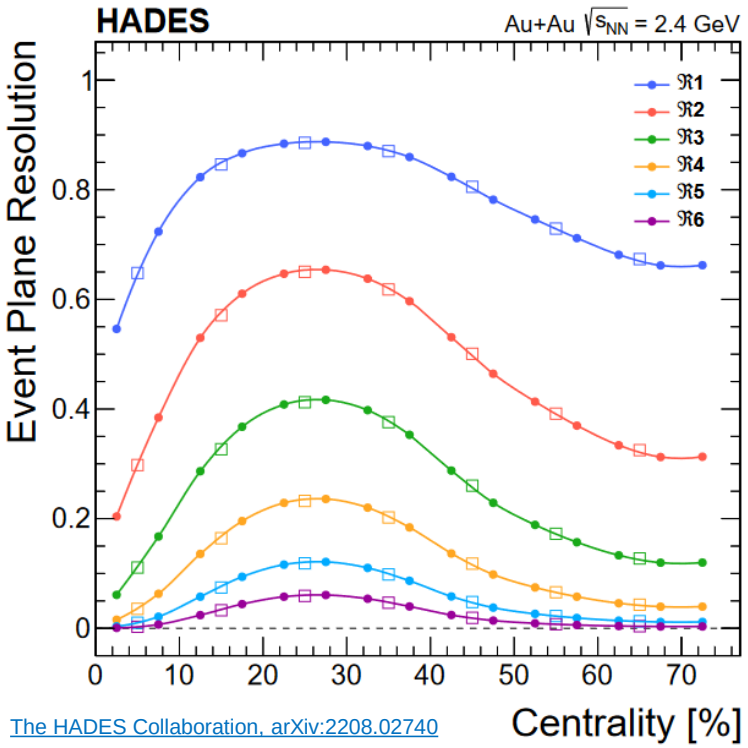

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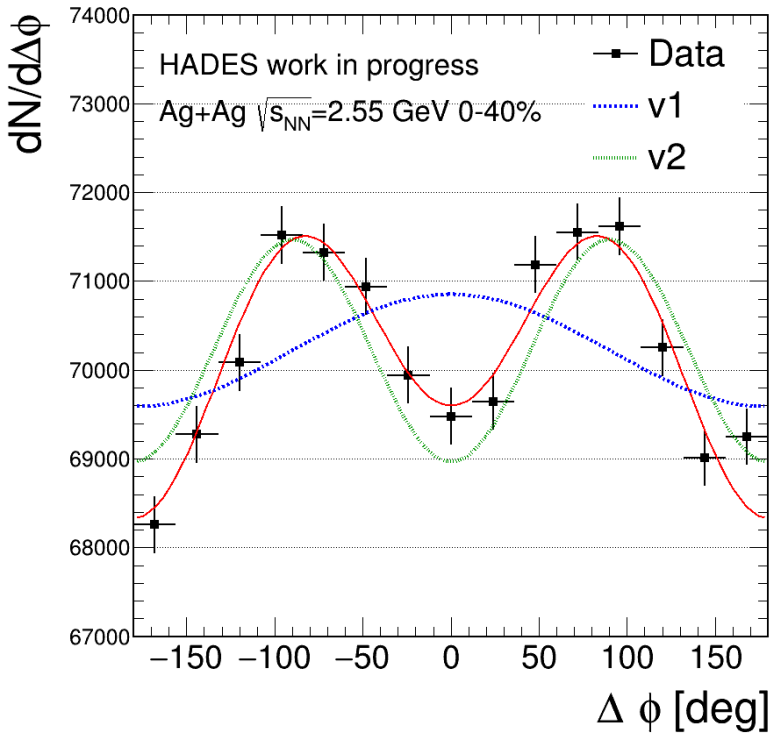
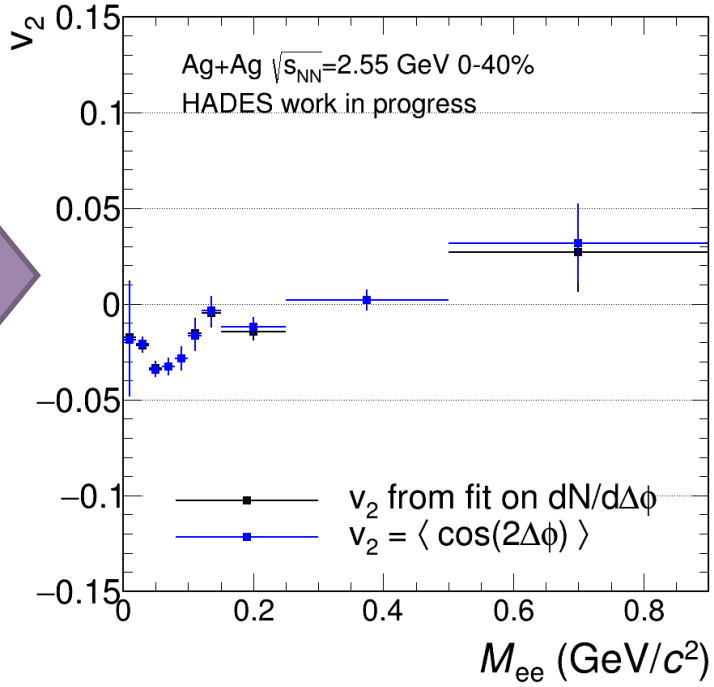


$$v_n = \langle \cos(n(\Delta\varphi)) \rangle$$



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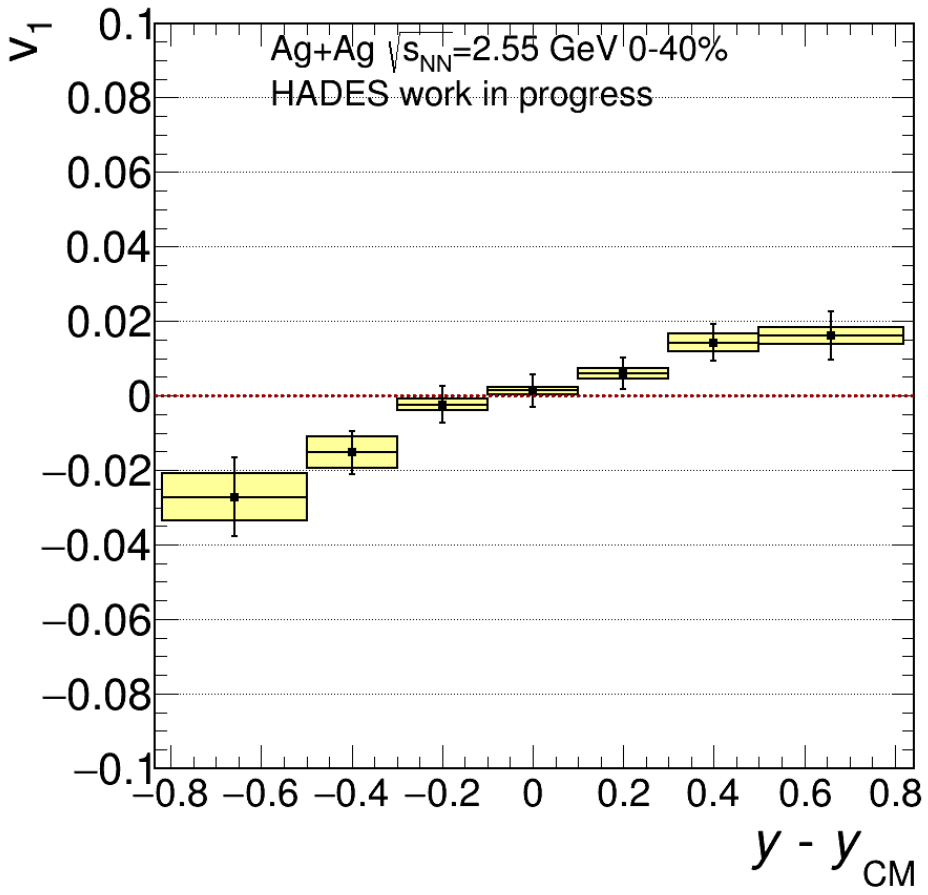
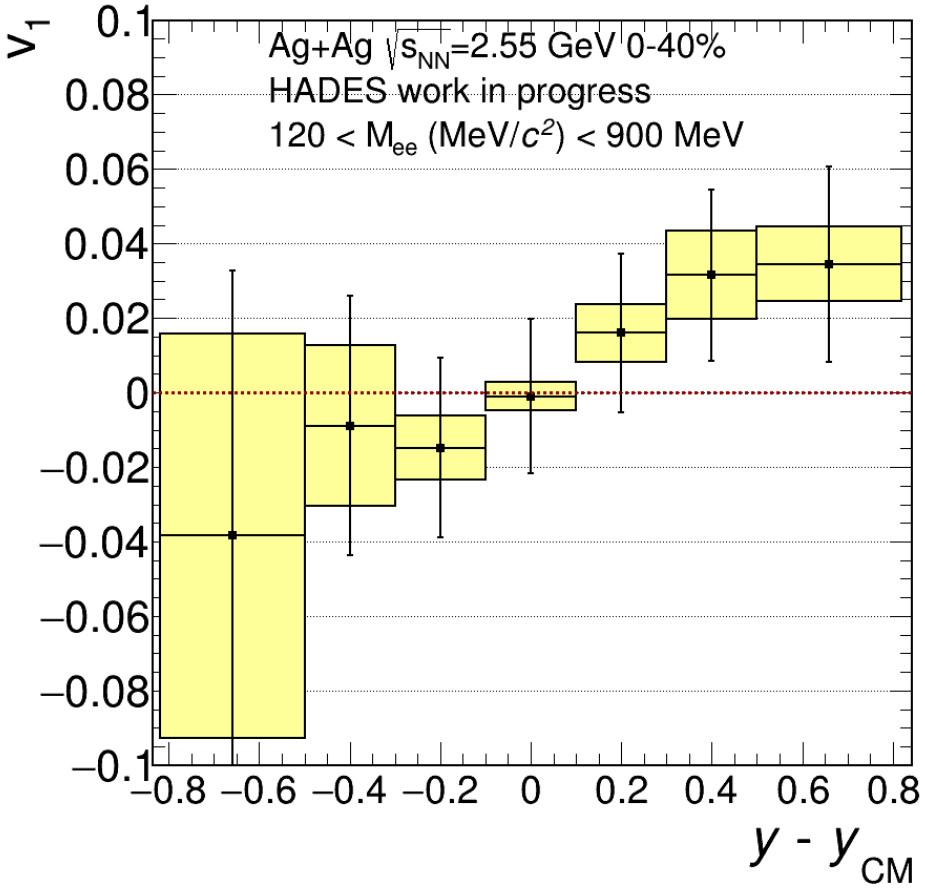
Directed Flow v_1

Rapidity dependence

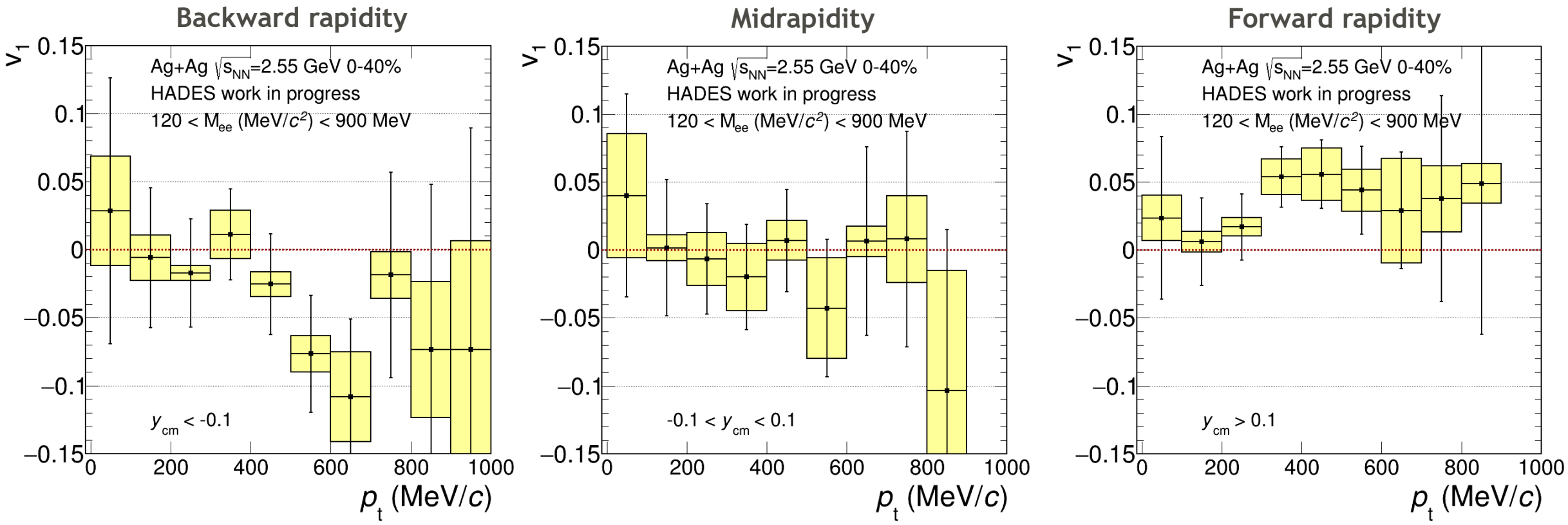
- Focus on mass region beyond π^0 mass ⟺ Otherwise π_0 signal dominant
- Point symmetry around v_1 at midrapidity within uncertainties





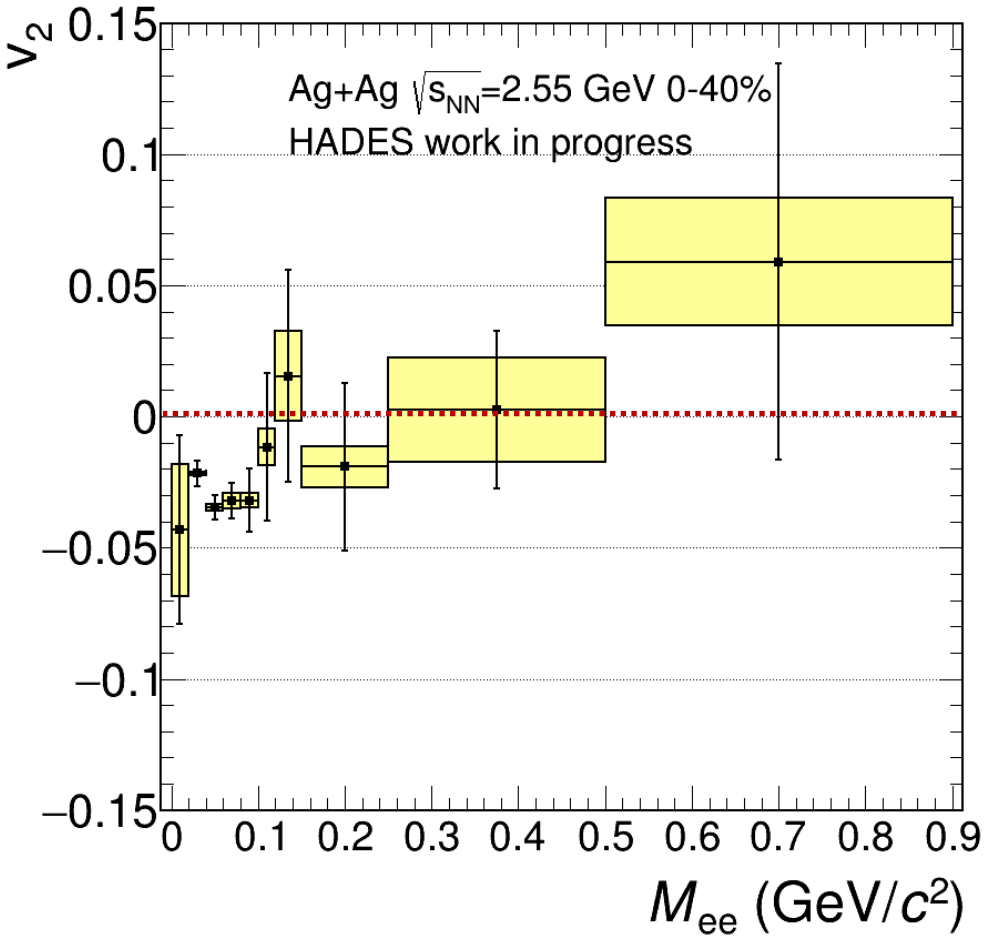
Transverse momentum dependence

➡ Larger v_1 found at higher p_t

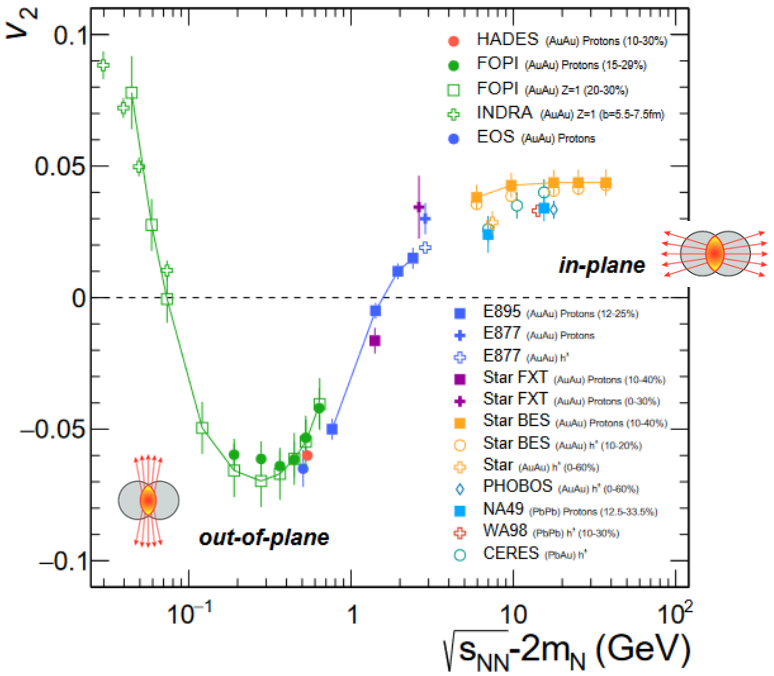


Elliptic Flow v_2

Elliptic flow over invariant mass



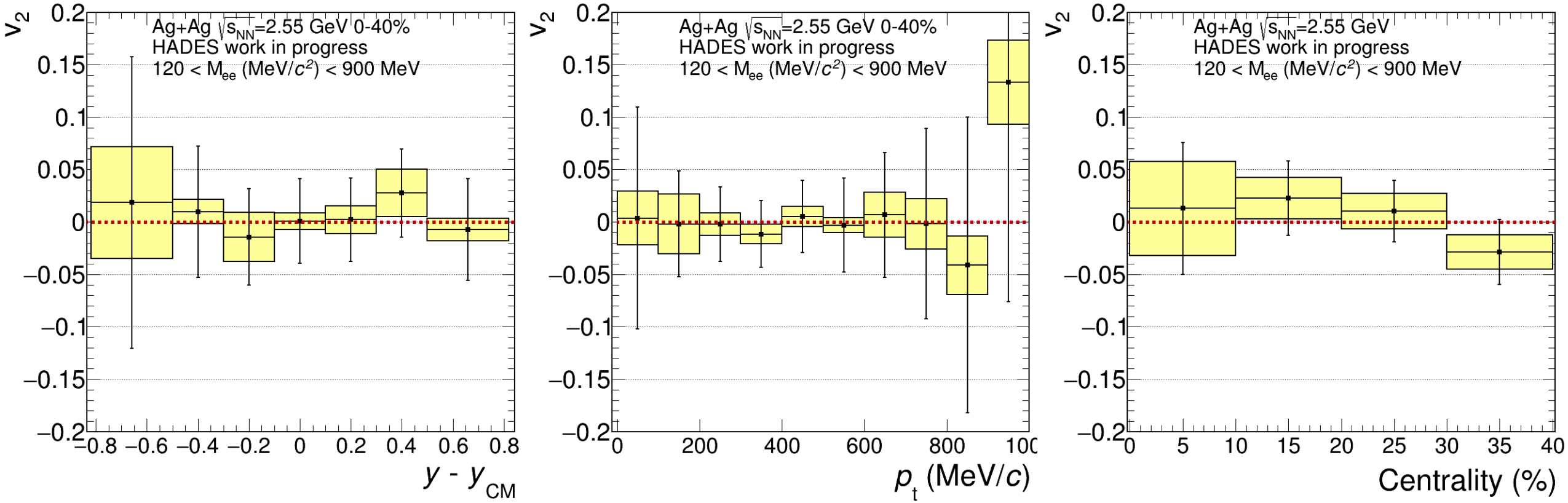
- Low masses dominated by π^0 Dalitz decay
  - ⇒ Negative v_2 consistent with pions
- Beyond π^0 mass v_2 consistently around zero for $\mathbf{120 < M_{ee}\ (GeV/c^2) < 900}$



The HADES Collaboration, arXiv:2208.02740

Multidifferential elliptic flow

- v_2 consistently around zero for $\mathbf{120 < M_{ee}\ (GeV/c^2) < 900}$
- Would agree with picture of dileptons as penetrating probes



Prospects

Isolate in-medium dilepton contribution

- Ongoing analyses to find v_n and multiplicities of freeze-out hadrons
- Analysis of p+p collisions at $\sqrt{s_{NN}} = 2.55\ \mathrm{GeV}$ (taken Feb2022) will provide NN reference

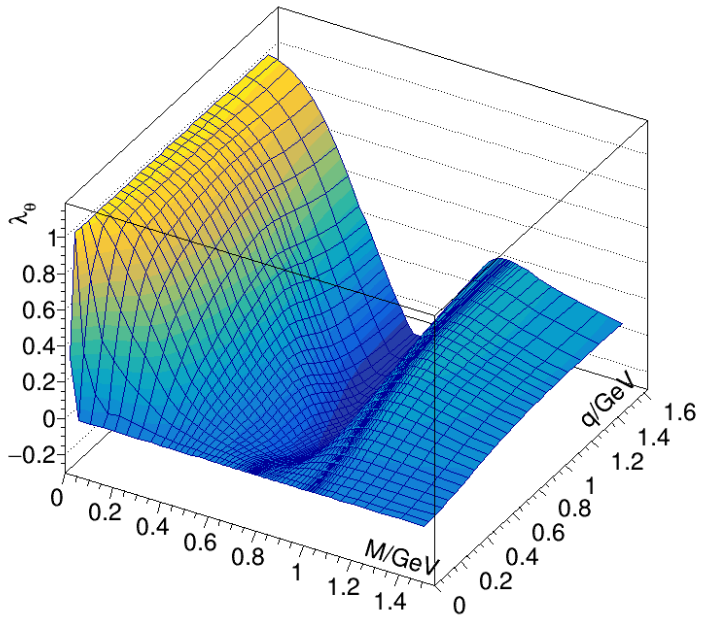
$$v_n^{sig} = v_n^{tot} + \frac{N_{bg}}{N_{sig}} \left(v_n^{tot} - v_n^{bg}\right)$$

Determine radial flow

- Reconstruction of dilepton p_t spectra as a function of invariant mass

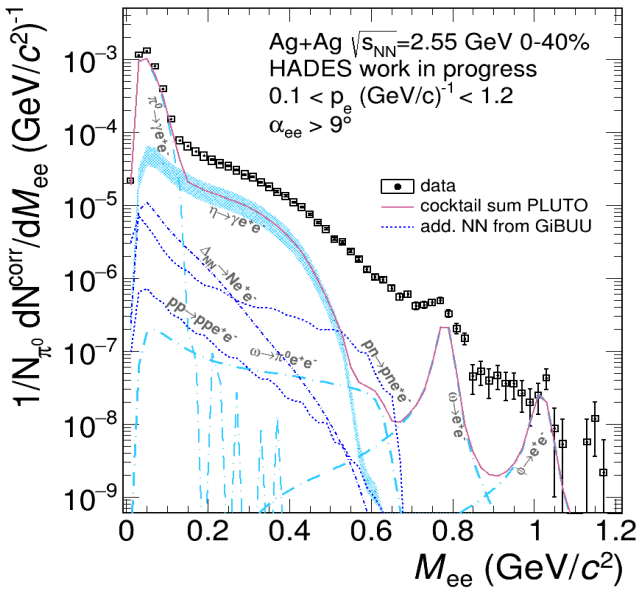
Determine polarization of virtual photons

- First strides are taken in data analysis and preparation of theory predictions



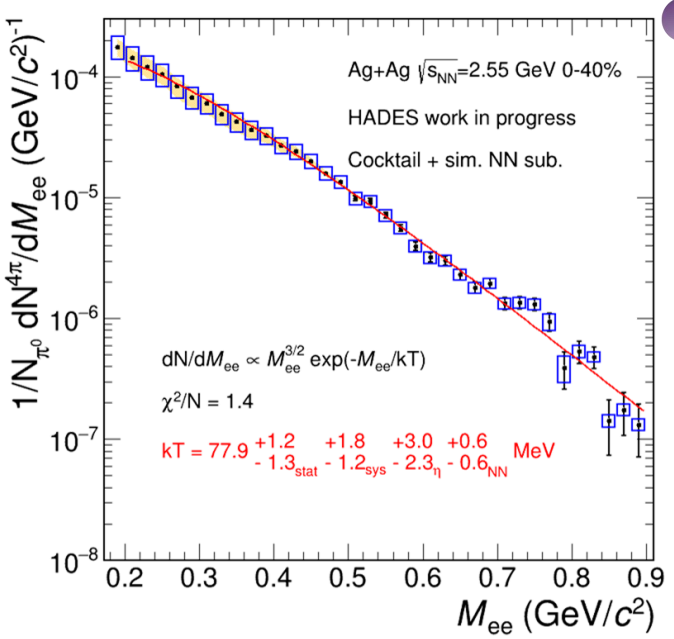
Estimation of virtual photon polarization from spectral functions (N. Schwarz)

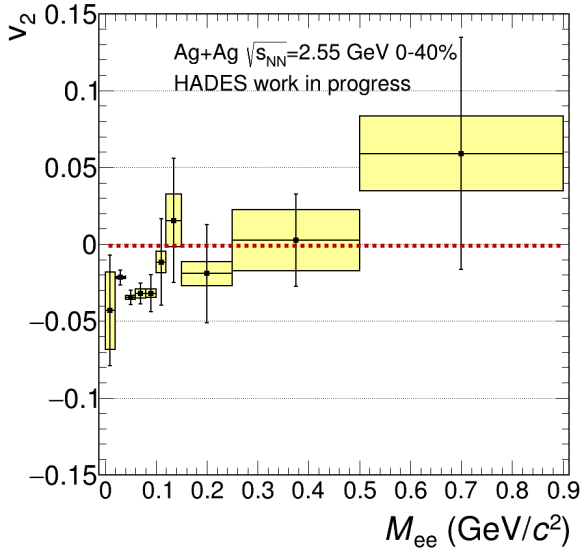
Summary



Dilepton spectra are reconstructed for center-of-mass energies of 2.42 GeV and 2.55 GeV

Study of numerous fireball characteristics (e.g. temperature)





Collectivity is under investigation

Reconstruction of flow suggests no elliptic flow for thermal dileptons