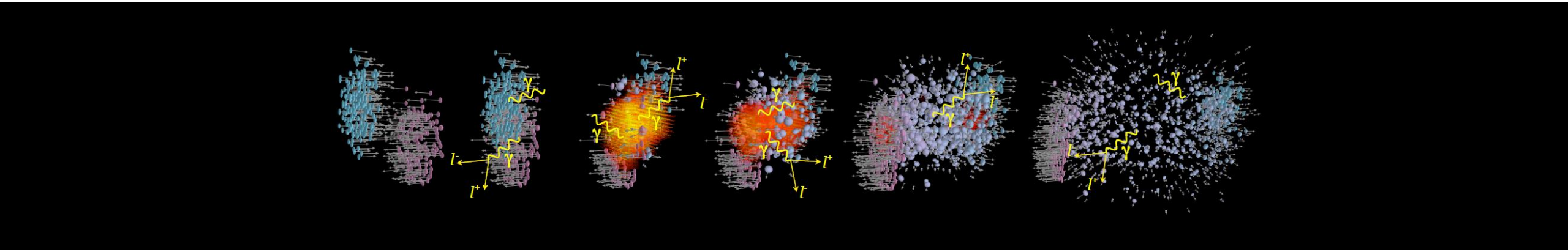
Characterising the hot and dense fireball via virtual photons in HADES

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)

Motivation

Electromagnetic probes (γ, γ^*) penetrate strongly-interacting medium and can bring direct information to the detector



Allows many unique measurements

Transport properties

Degrees of freedom of the medium

Restoration of chiral symmetry

Lifetime/Temperature/Acceleration/ Polarization of the fireball

Yet brings own set of challenges

Need to isolate contribution of interest

Rarity of events (BR ~ 10^{-5})

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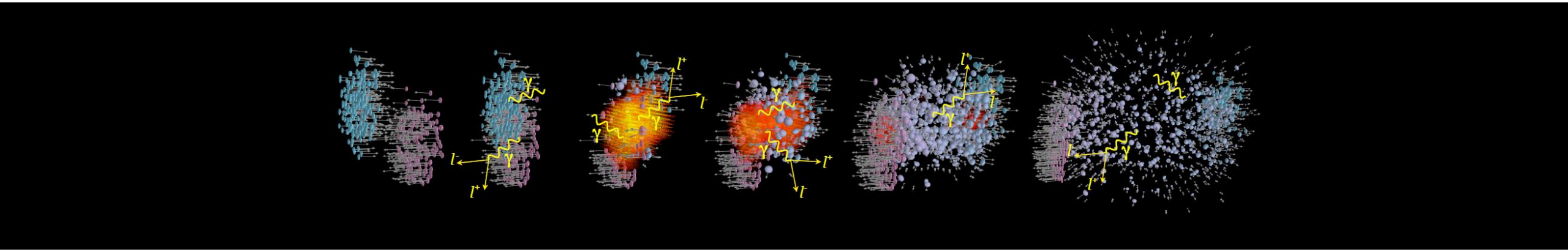

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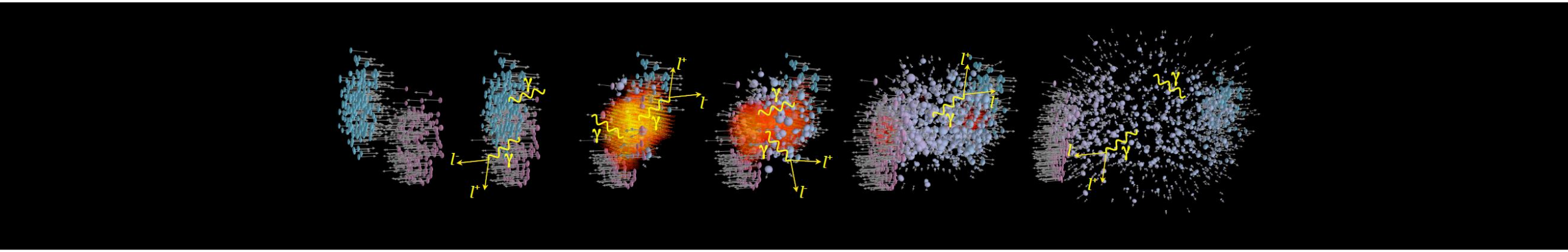

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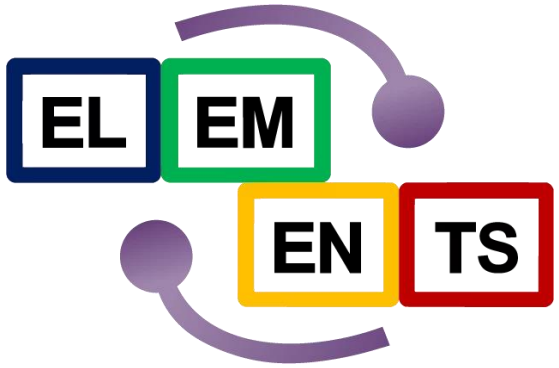
1 **The HADES**

2 **Invariant mass spectrum**

3 **Flow analysis**



The High-Acceptance-Di-Electron-Spectrometer

1

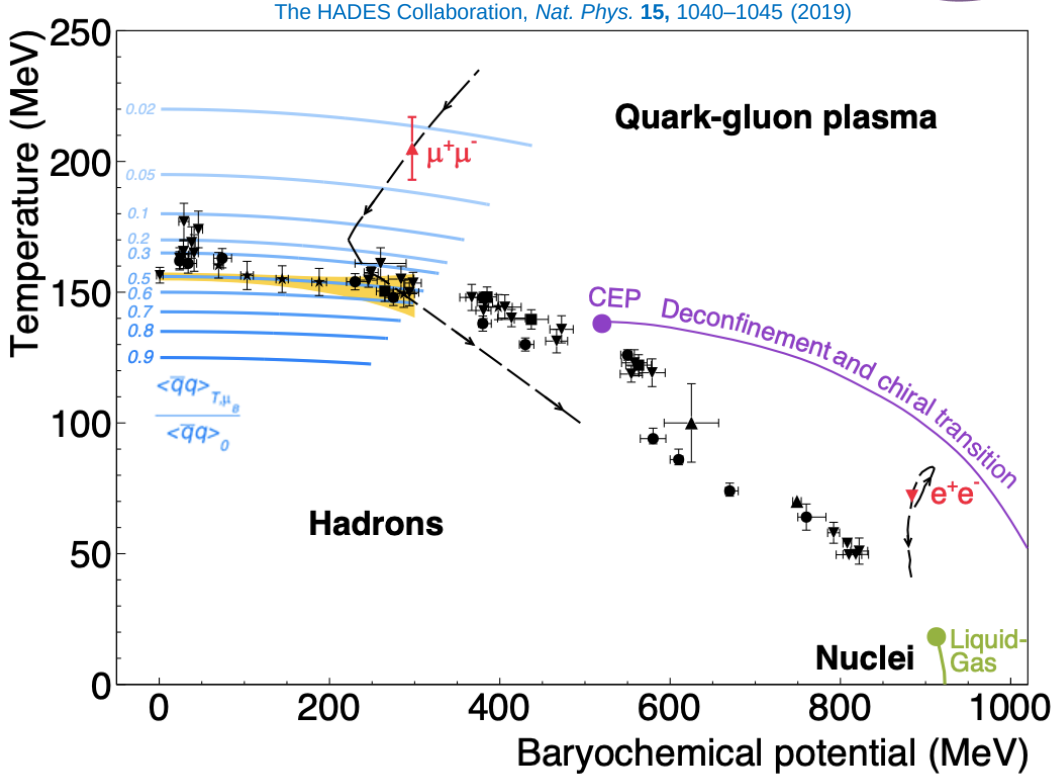
HADES
GOETHE UNIVERSITÄT FRANKFURT AM MAIN
TECHNISCHE UNIVERSITÄT DARMSTADT
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
GSI

The HADES – Probing the QCD phase diagram

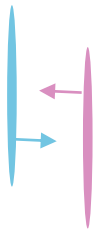
- **Heavy ion collisions** at $\sqrt{s_{NN}} = 2 - 3$ GeV
  - ➡ Different collision dynamics compared to higher energies
- **Pion and nucleon beams**
  - ➡ Reference measurements
  - ➡ Inclusive and exclusive measurements

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

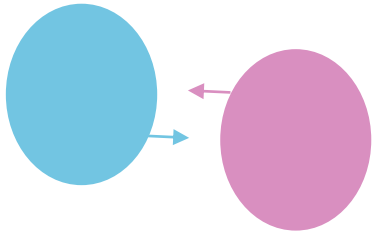
The HADES Collaboration, *Nat. Phys.* **15,** 1040–1045 (2019)



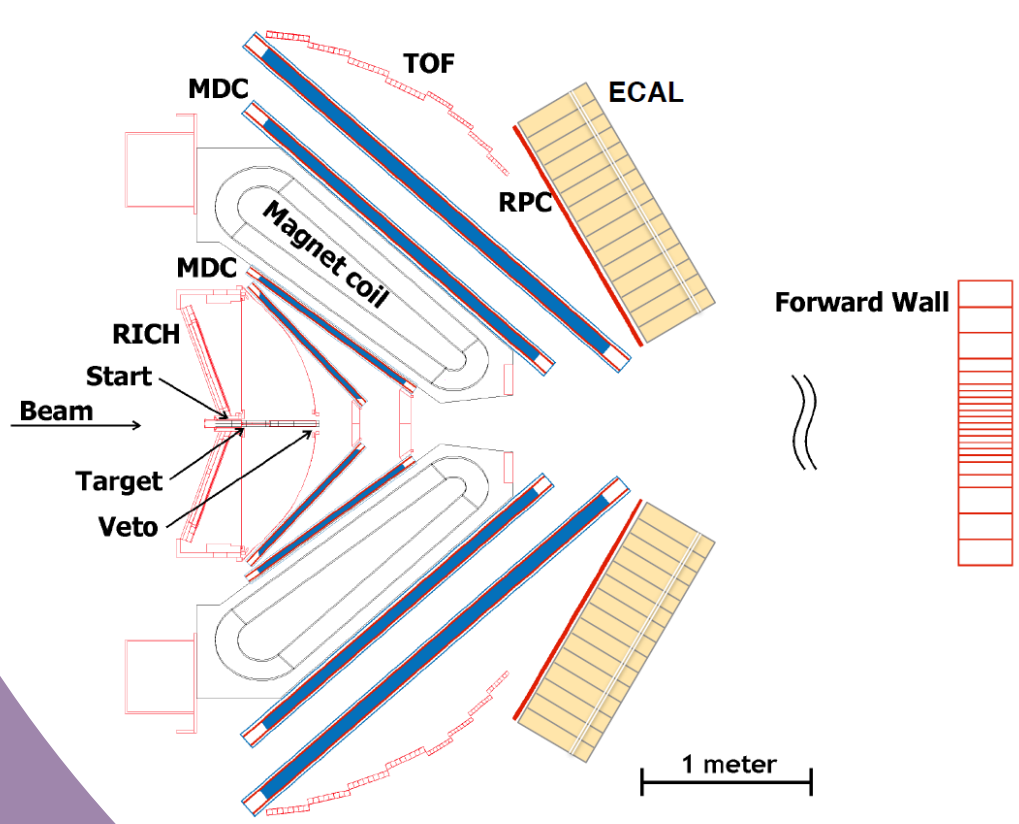
LHC energies $\sqrt{s_{NN}} = 2$ TeV
parton+parton collisions
Early Universe in the laboratory



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



The HADES – Performance $e^{\pm}$ identification



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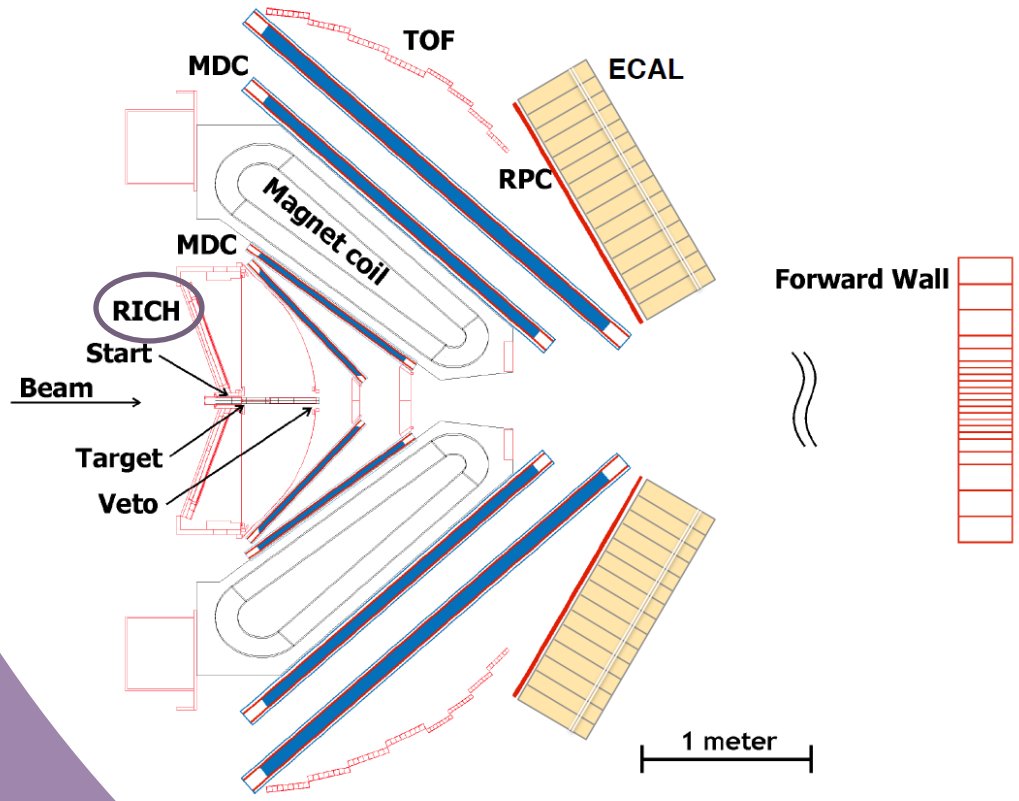
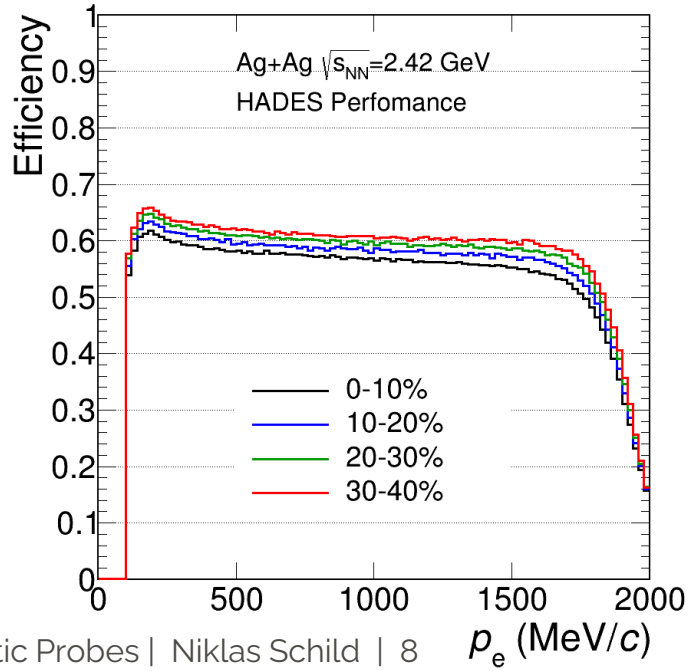
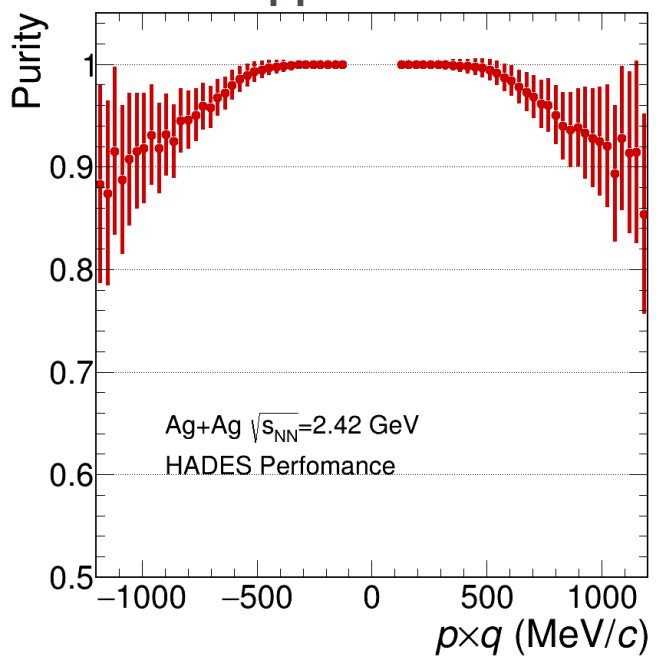


Reconstruction of $e^{\pm}$ with high efficiency and high purity

Reconstruction efficiency ~ 60%



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



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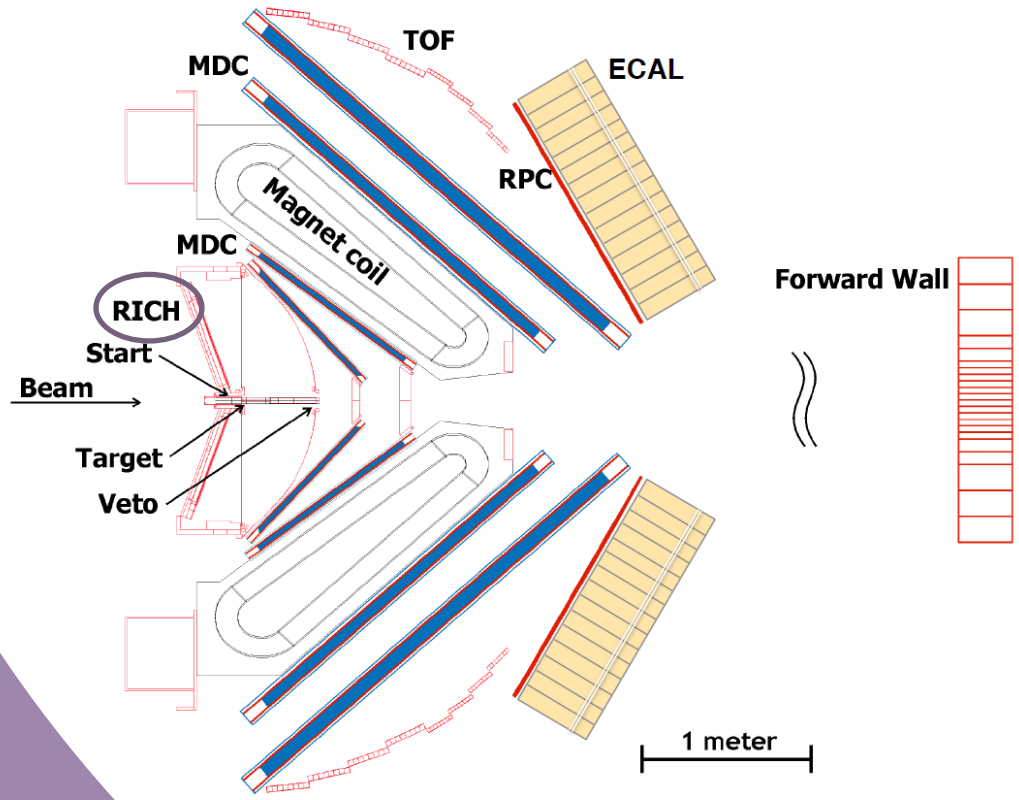
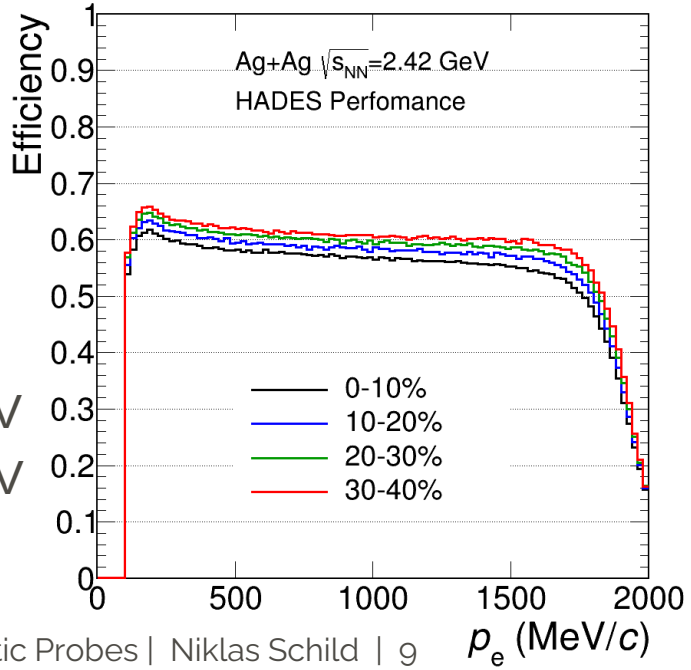


Reconstruction of $e^{\pm}$ with high efficiency and high purity

- Upgraded RICH photodetection plane
- Large acceptance $18° < \theta < 85°$, $0° < \varphi < 360°$
- Conversion rejection
- Accepted trigger rate 16 kHz for HIC

Reconstruction efficiency ~ 60%



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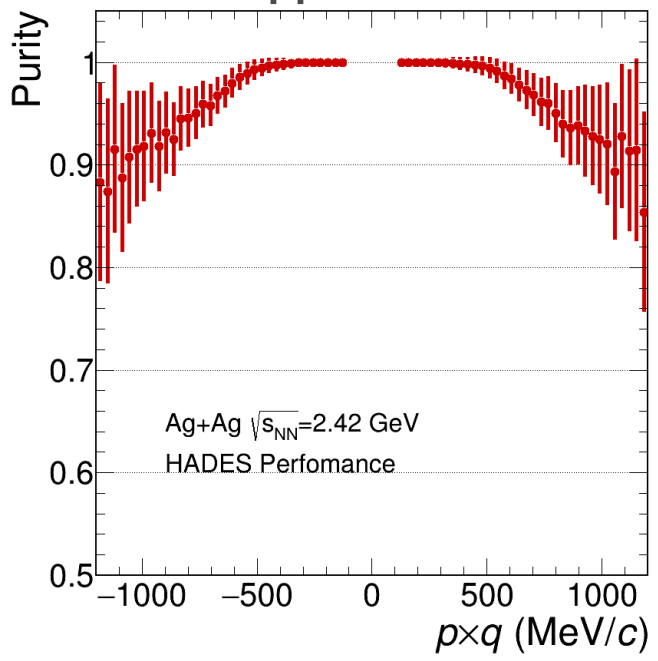


Ag+Ag run in 2019

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

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

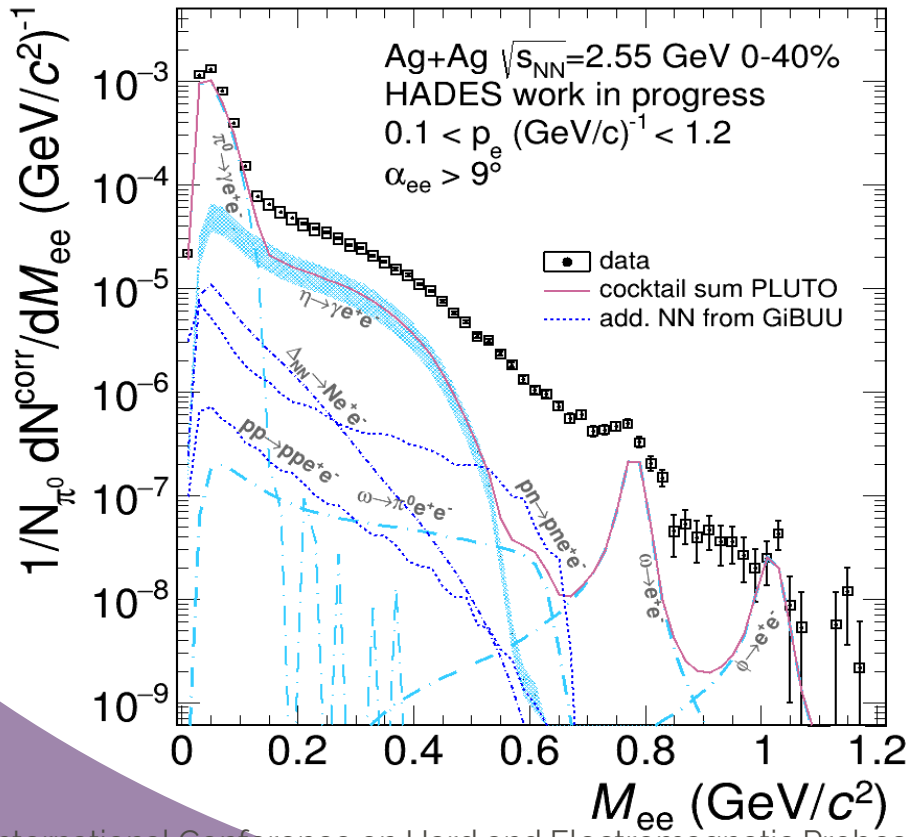
(28 and 3 days of beam)

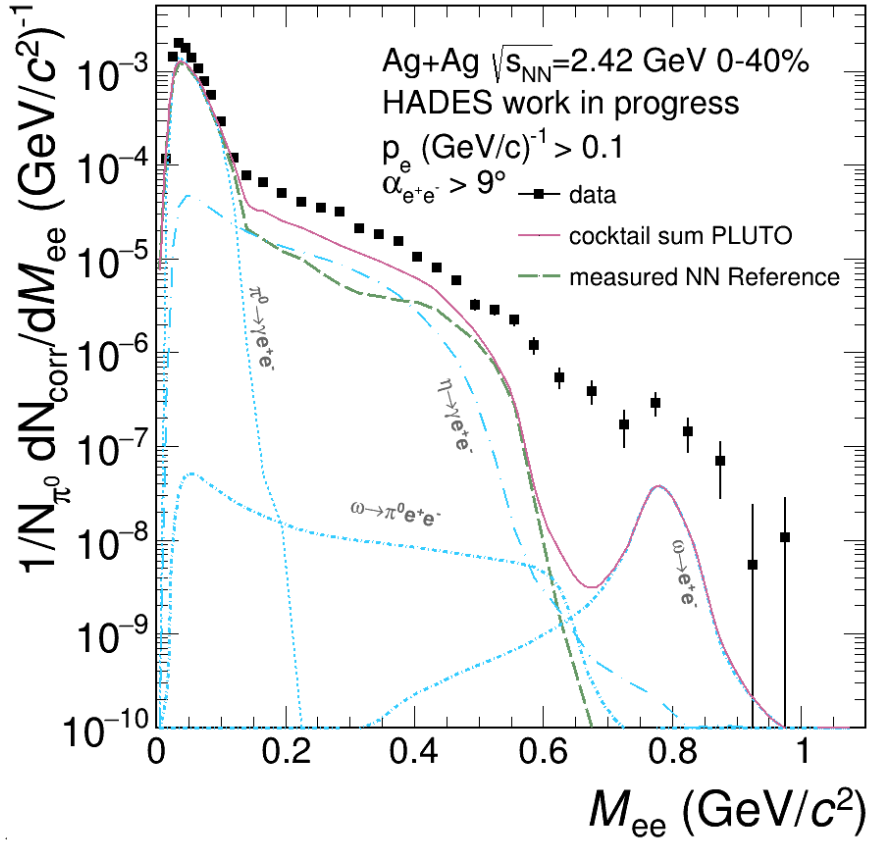
Reconstruction of the invariant mass spectrum

2

Invariant mass spectrum

Measured mass spectrum serves as integral over whole evolution





Invariant mass spectrum

Measured mass spectrum serves as integral over whole evolution

Initial NN contribution

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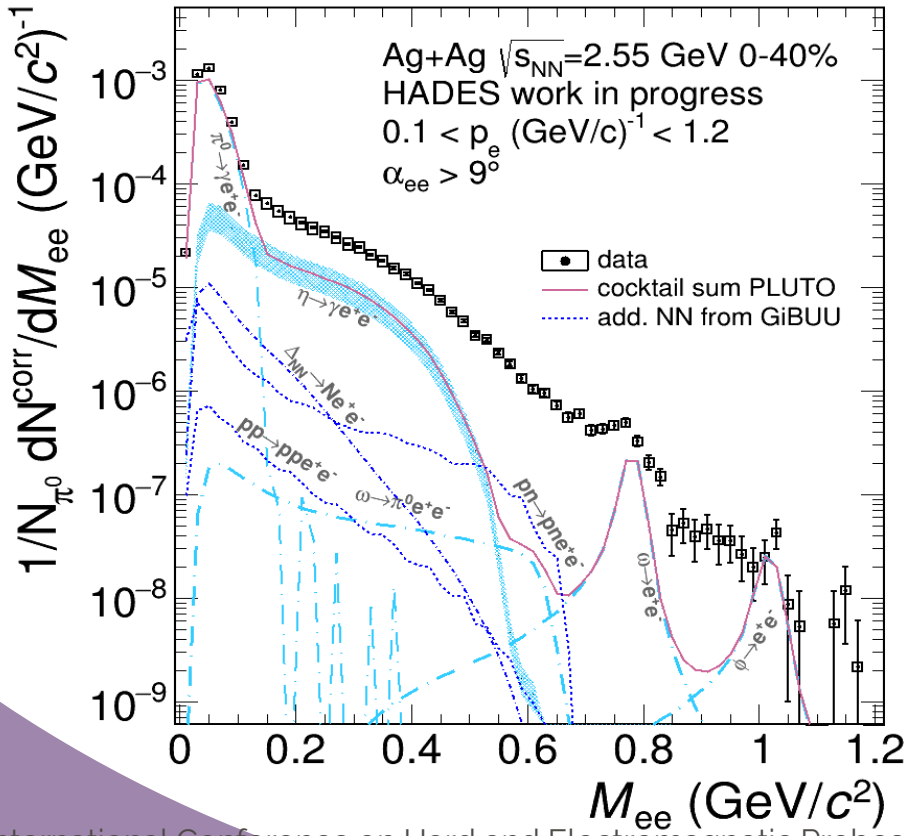
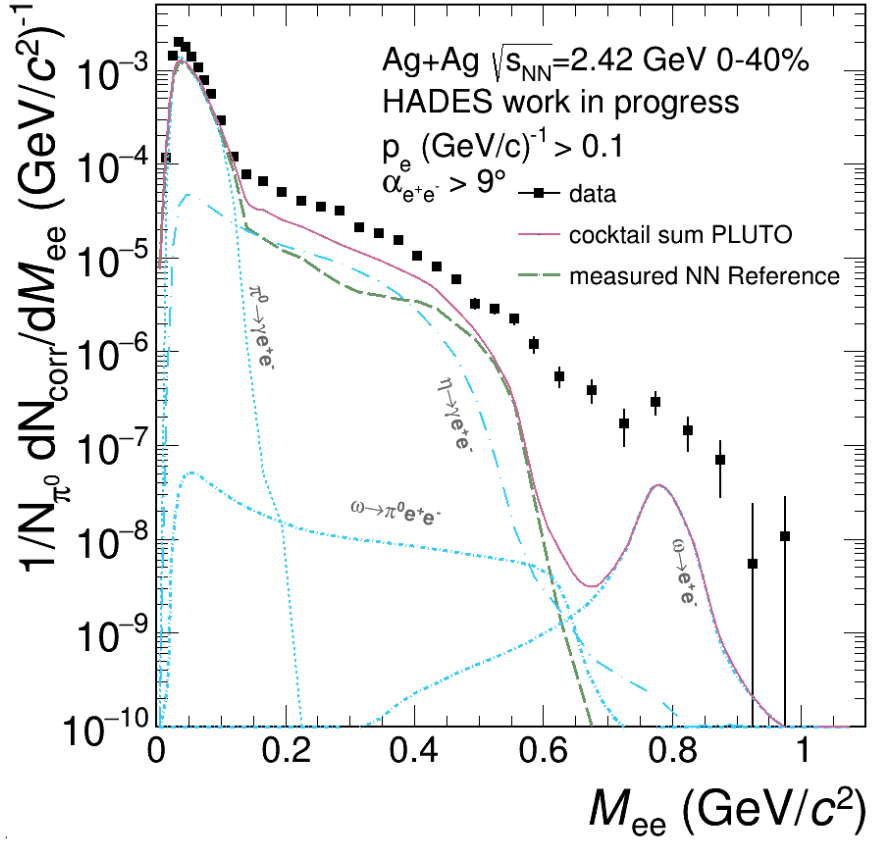
- For $\sqrt{s_{NN}} = 2.55$ GeV currently estimated using GiBUU 2021 release



Freeze-out cocktail

- Simulated using Pluto event generator
- Multiplicities to be measured from same dataset



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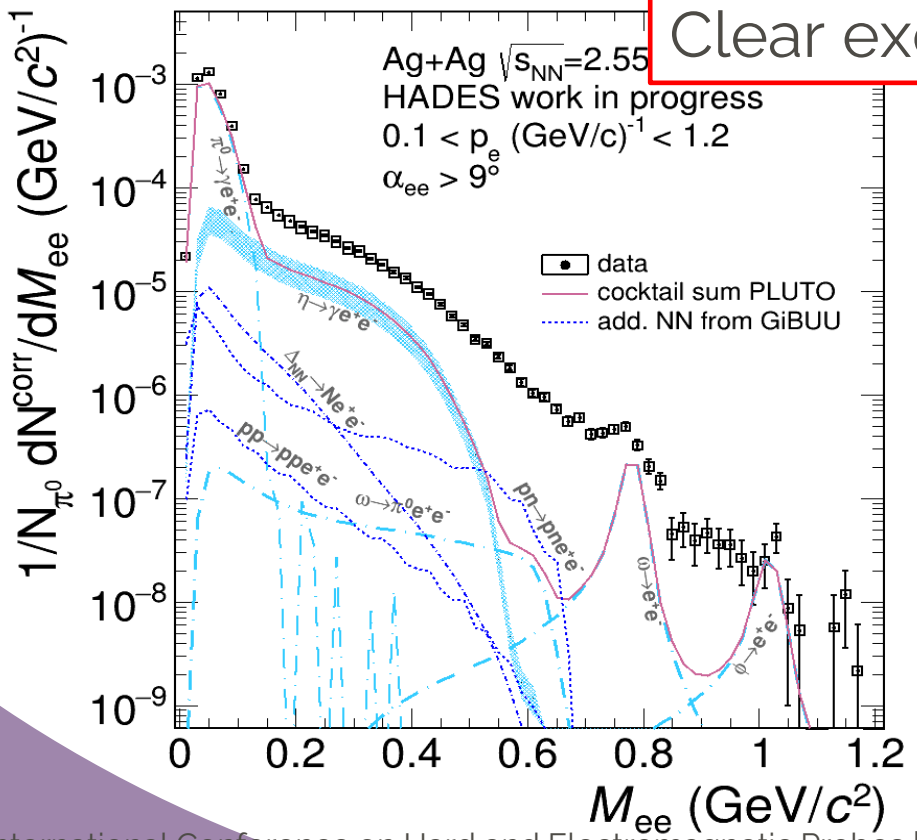
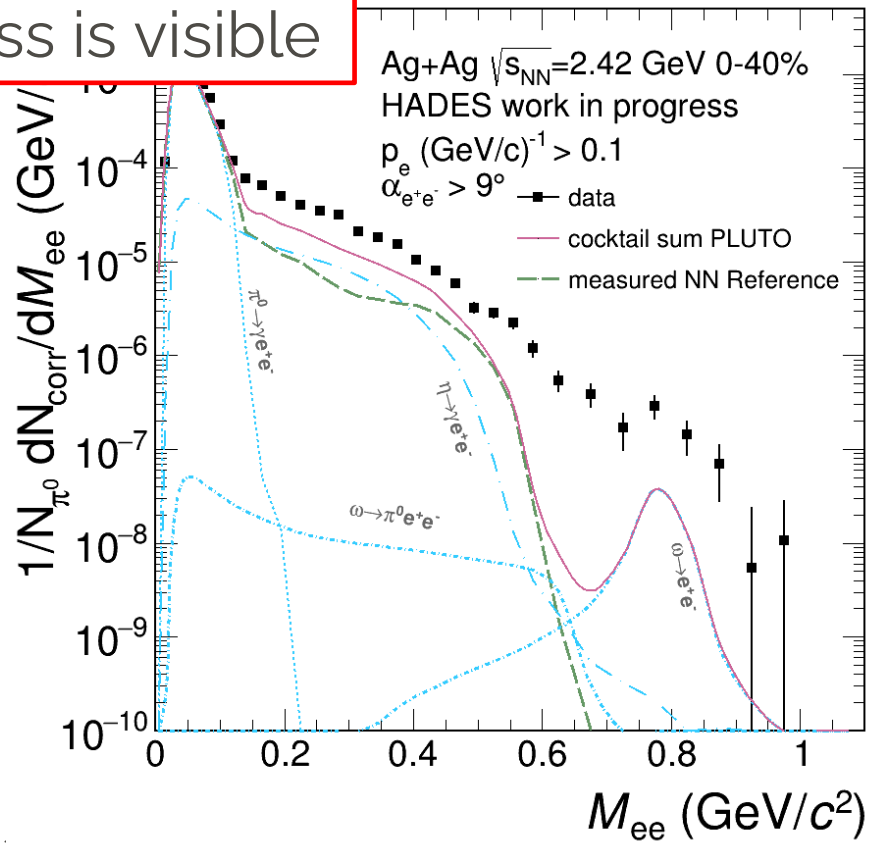
Clear excess is visible





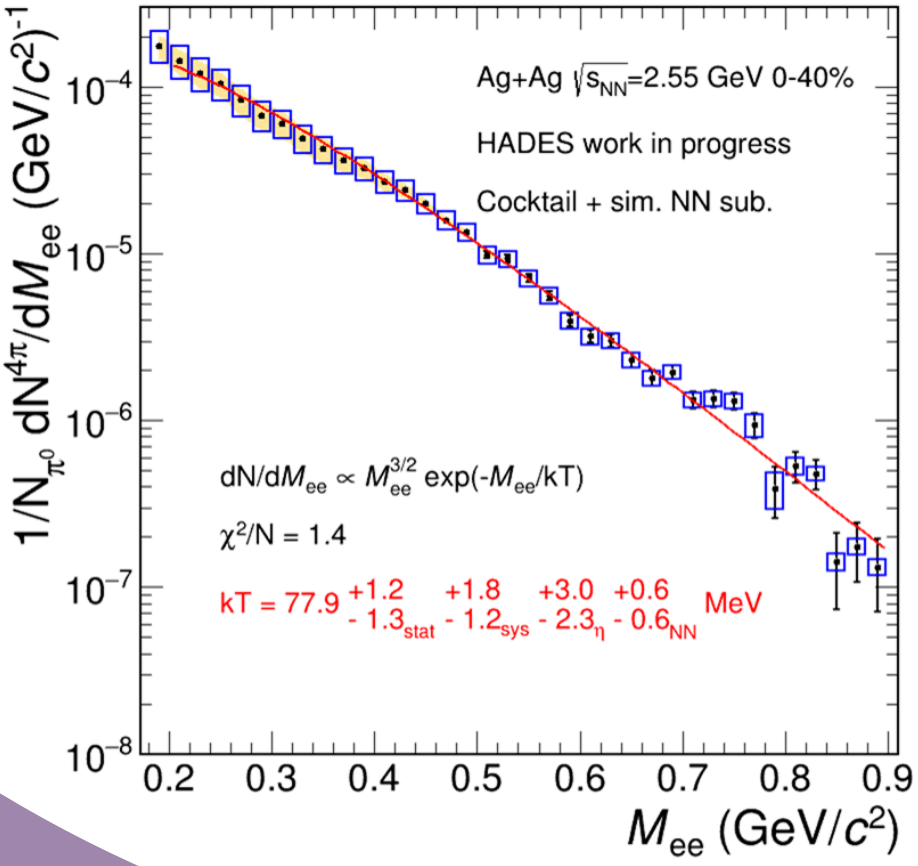
Temperature determination

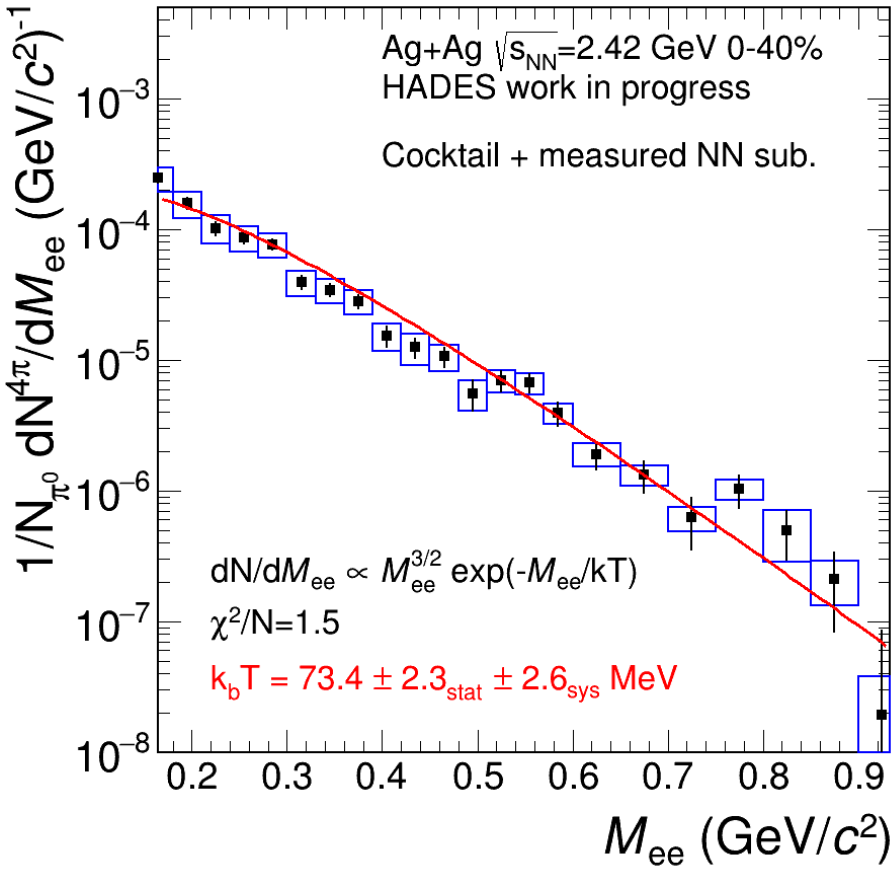
$$\frac{dN}{dM} \propto M^{\frac{3}{2}} \exp\left(-\frac{M}{T}\right)$$

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

Compare with*:

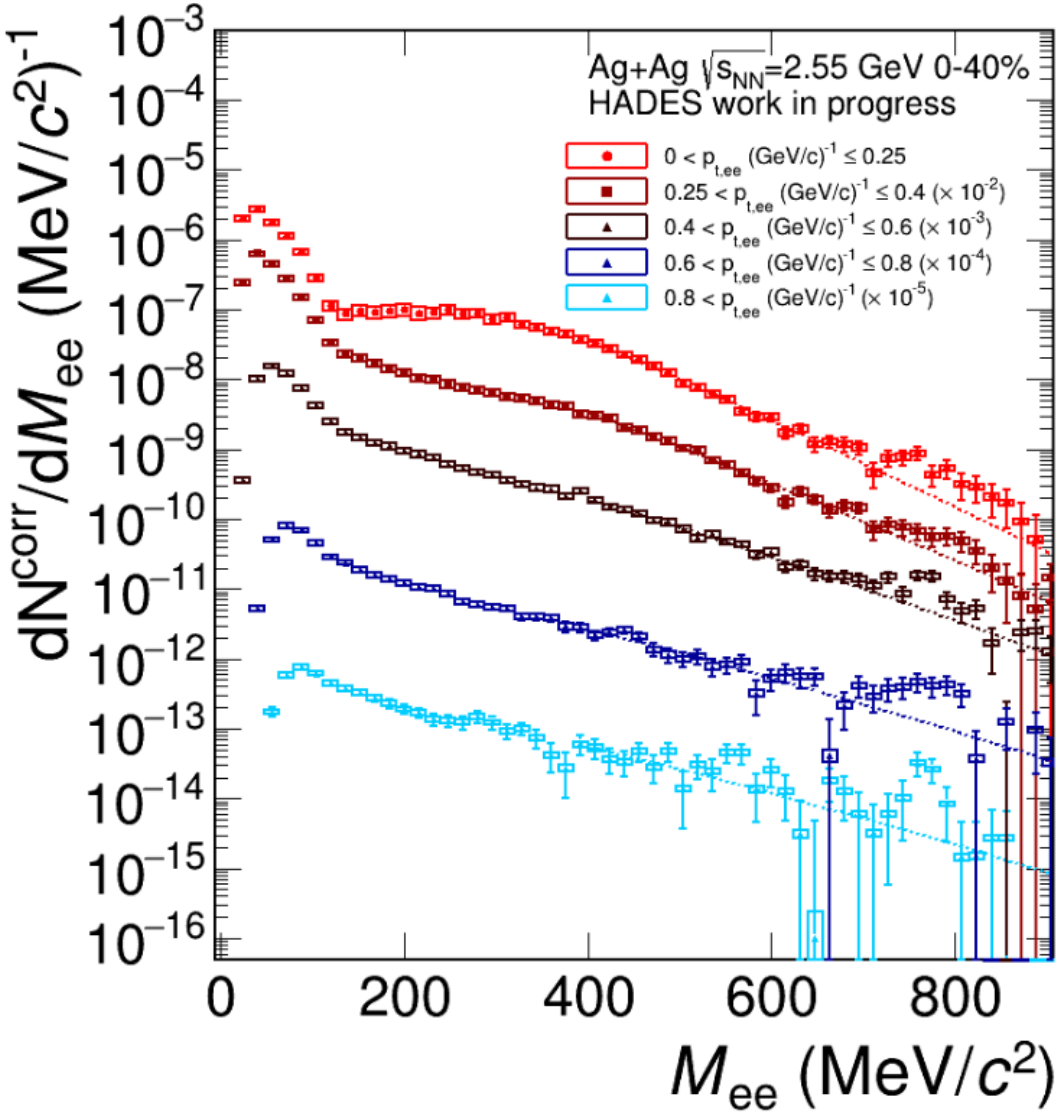
$kT_{Au+Au}\ (\sqrt{s_{NN}} = 2.42\ \text{GeV}) = 74.5 \pm 3.3\ \text{MeV}$





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

Differential analysis of dielectron spectra



- Sufficient number of lepton pairs and high purity 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

3

Investigating collectivitiy

Collectivity Observables

- Radial (isotropic) flow
- Polarization
- Anisotropic flow

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

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

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- Radial (isotropic) flow
- Polarization
- **Anisotropic flow**

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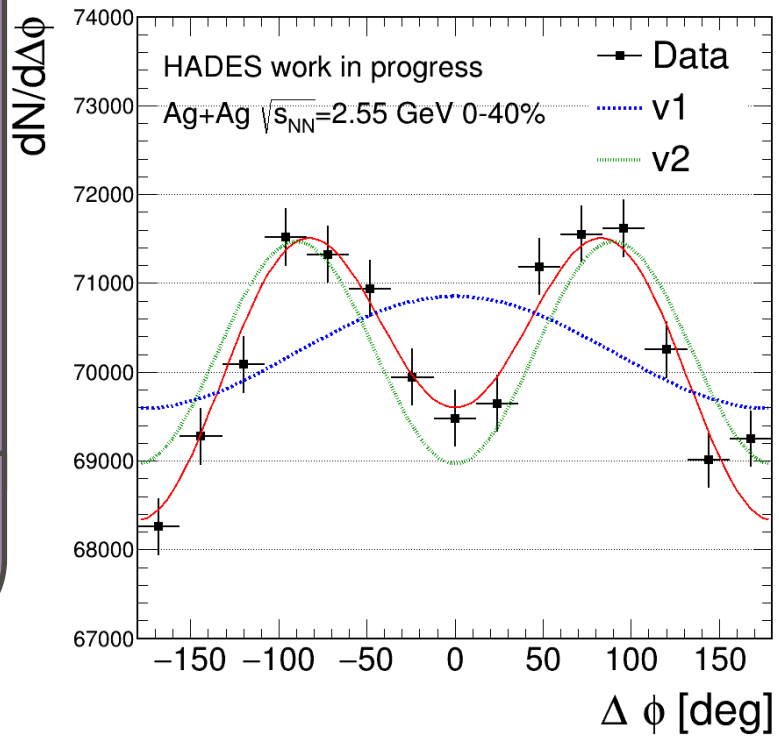
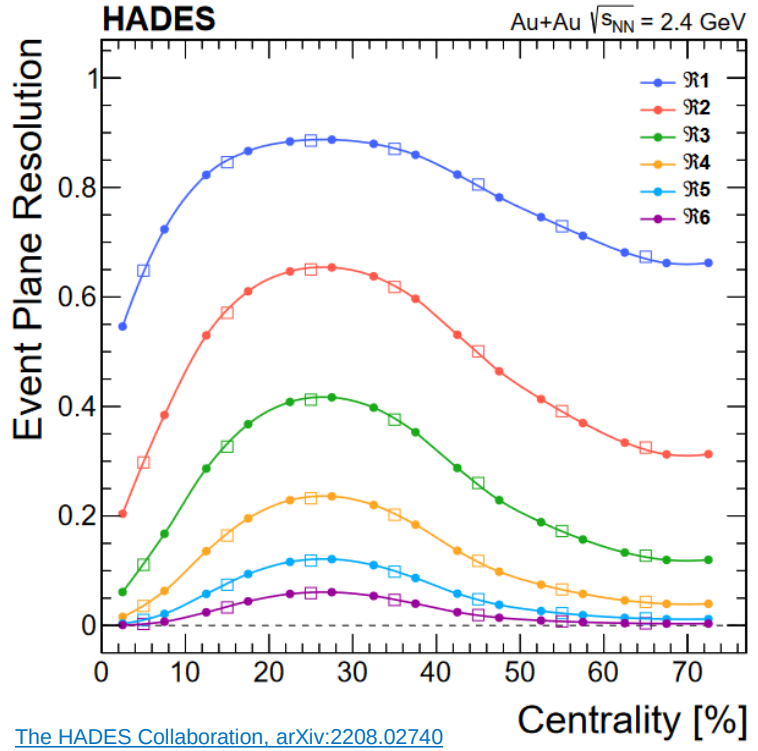
$$\Delta\varphi = \varphi_{ee} - \Psi_{RP}$$

Flow analysis procedure

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

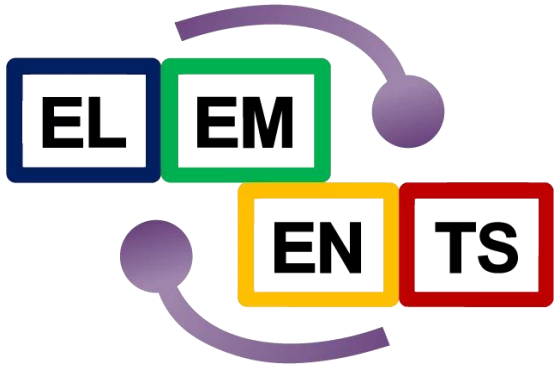
$$v_n = \frac{v_n^{obs}}{\Re_n}$$





The HADES Collaboration, arXiv:2208.02740

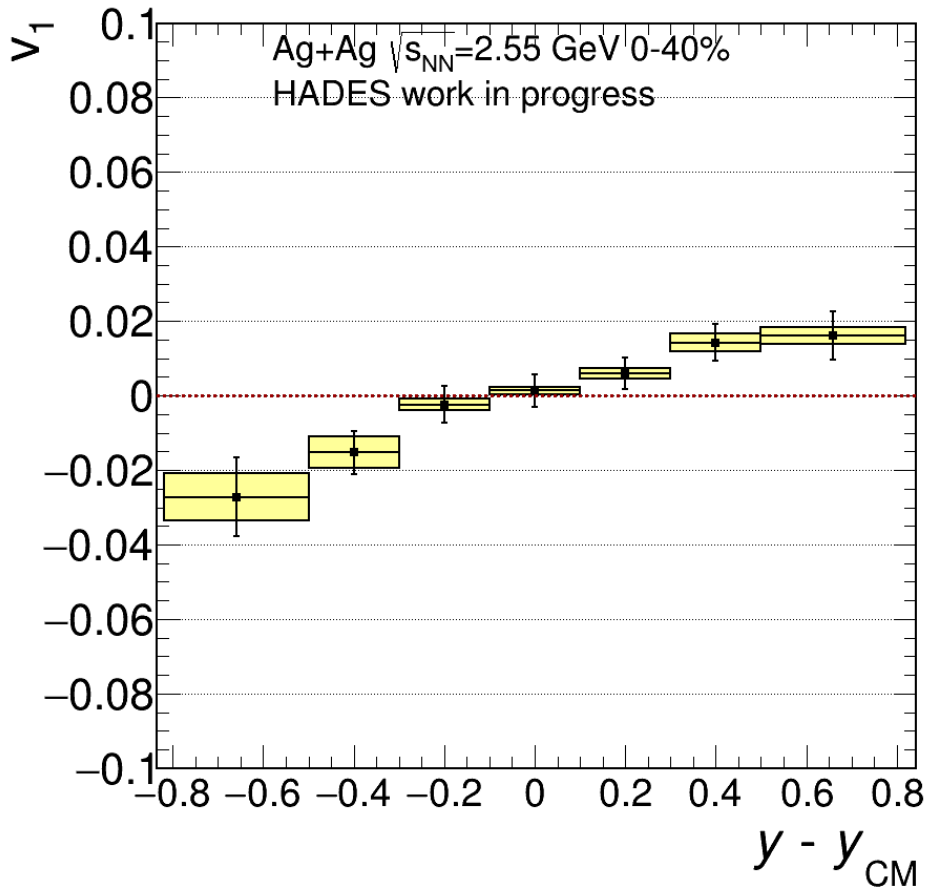
[1] Andreeva *et al.*, 2014 Inst. and Exp. Techniques 57 103–19
[2] Jean-Yves Ollitrault, arXiv:nucl-ex/9711003

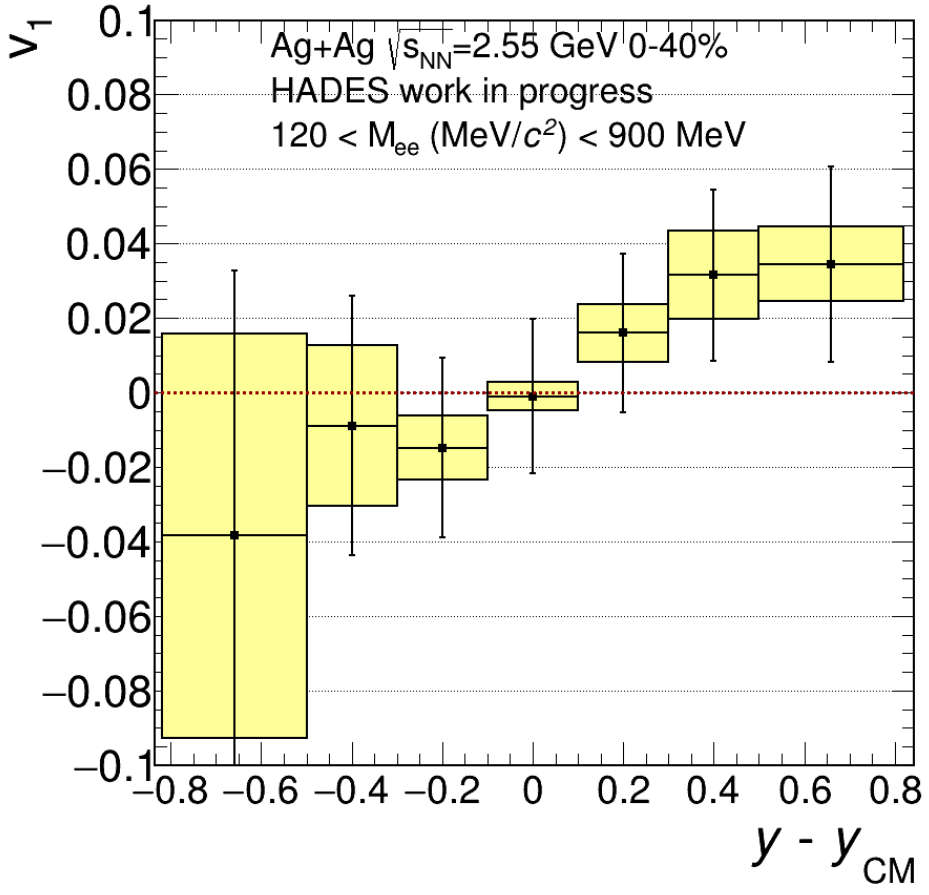


Directed Flow v_1

Rapidity dependence

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

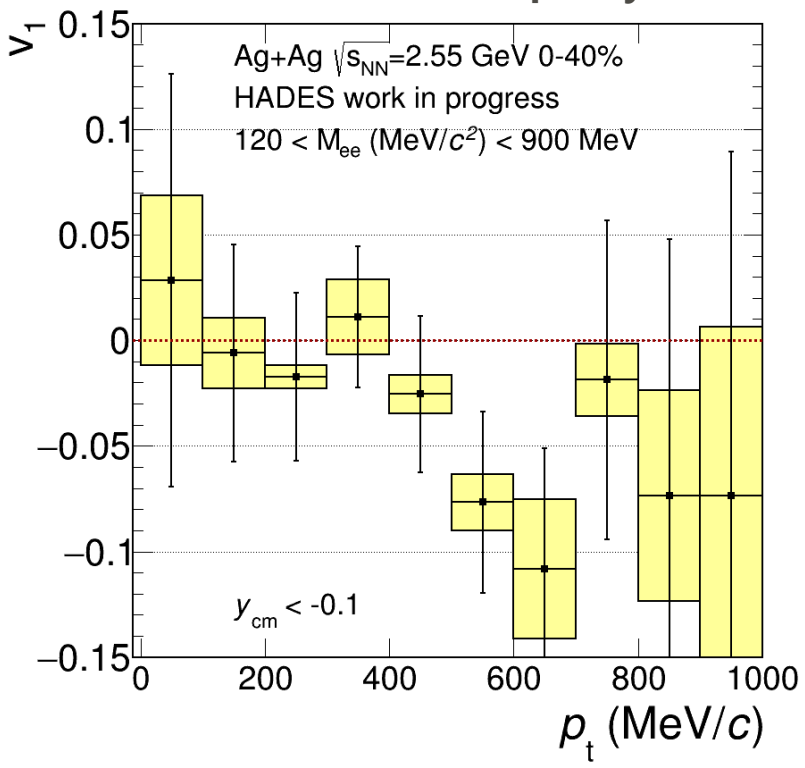




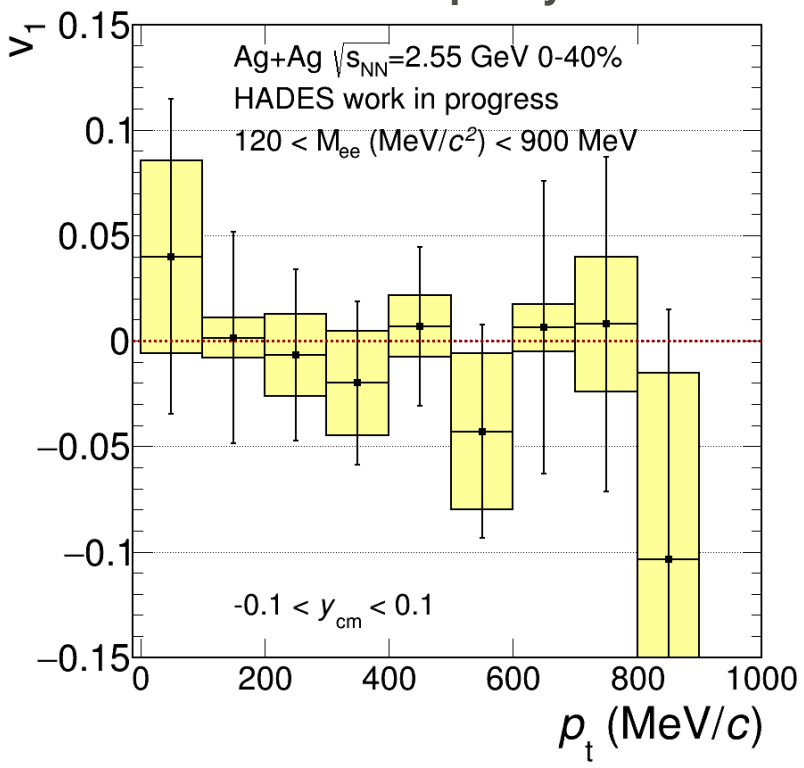
Transverse momentum dependence

➡ Larger v_1 found at higher p_t

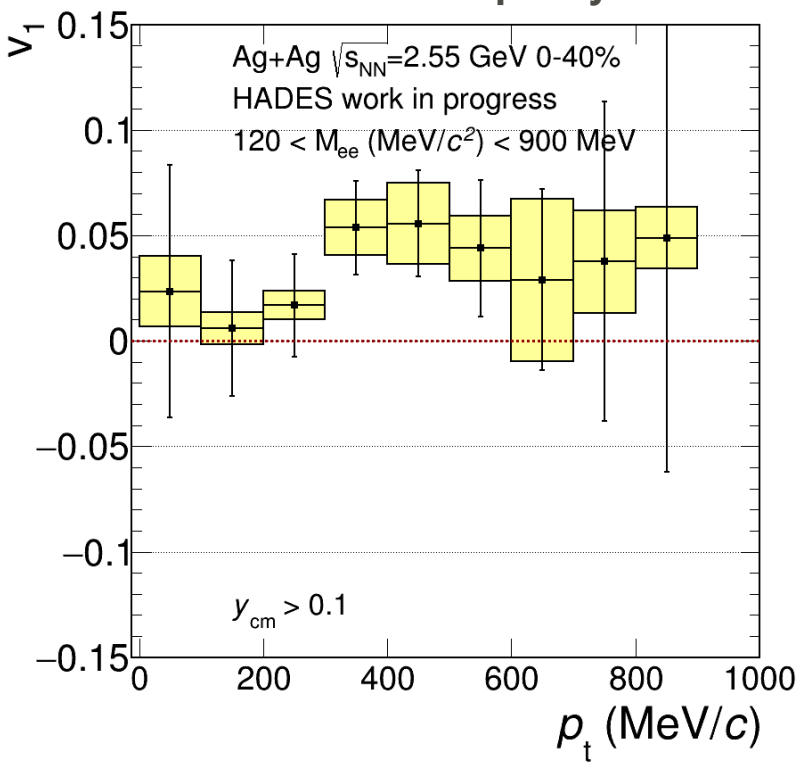
Backward rapidity

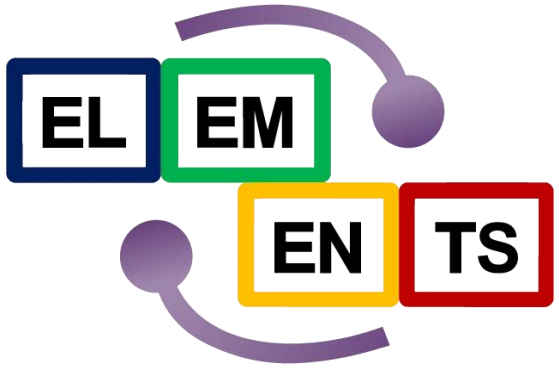


Midrapidity



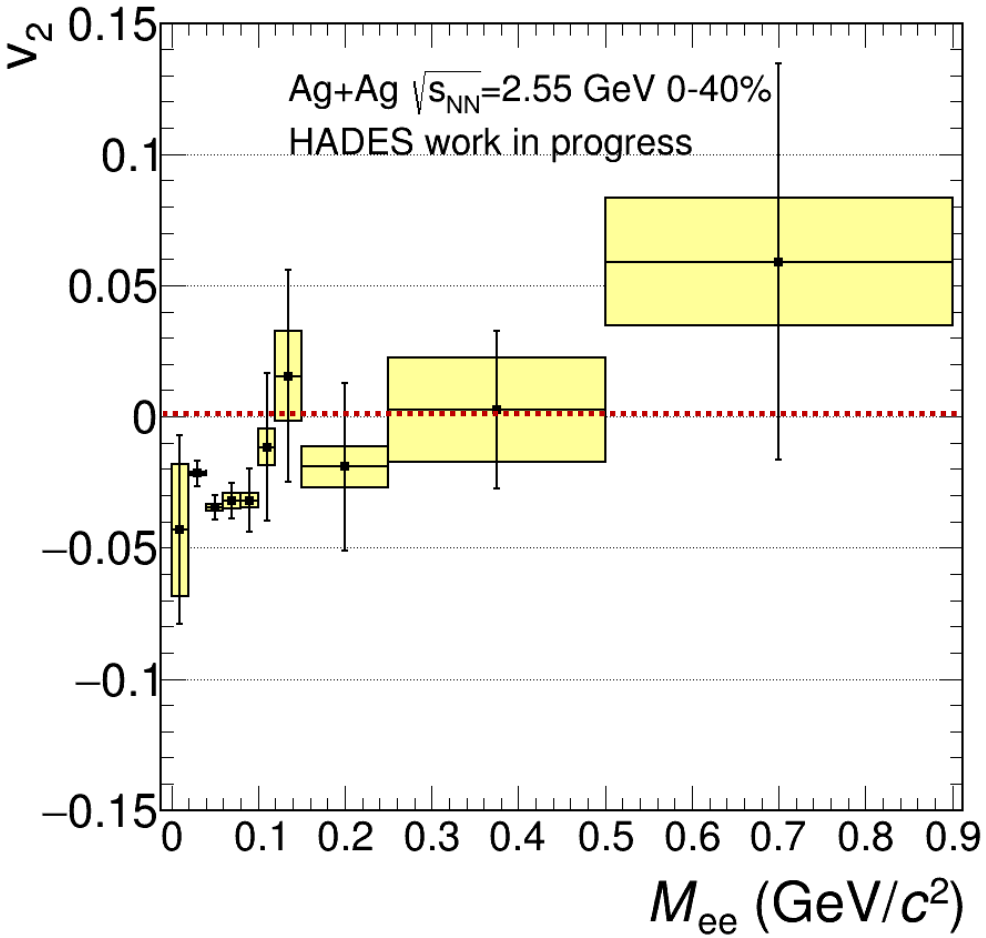
Forward rapidity



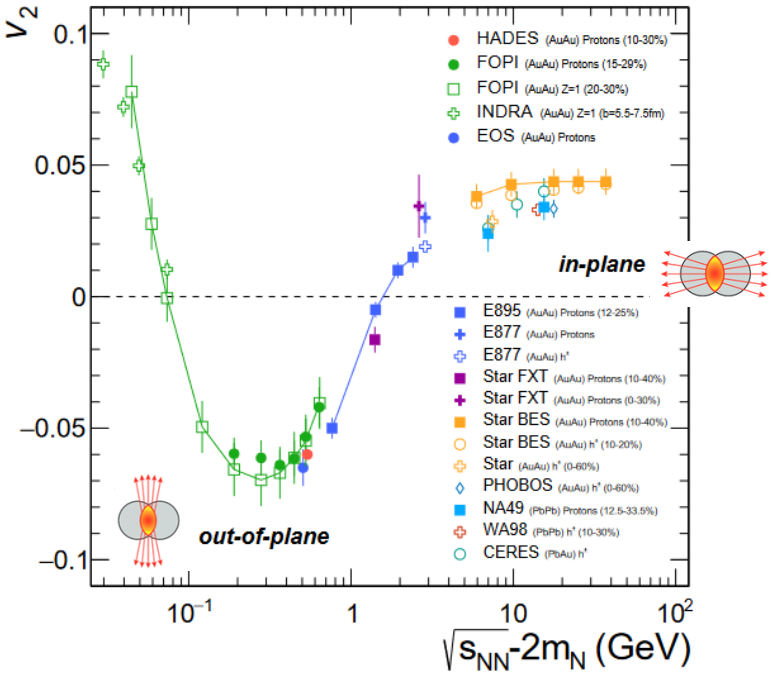


Elliptic Flow v_2

Elliptic flow



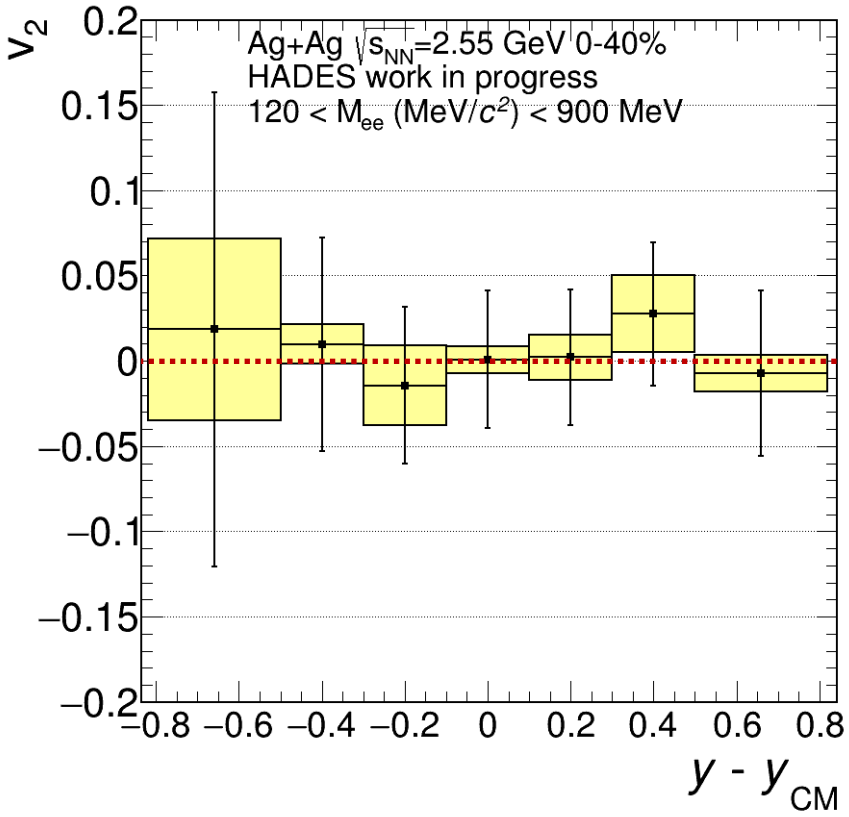
- Low masses dominated by π^0 Dalitz decay
  - ➡ Negative v_2 consistent with pions
- Beyond π^0 mass v_2 consistently around zero for $\mathbf{120 < M_{ee}\ (GeV/c^2) < 900}$

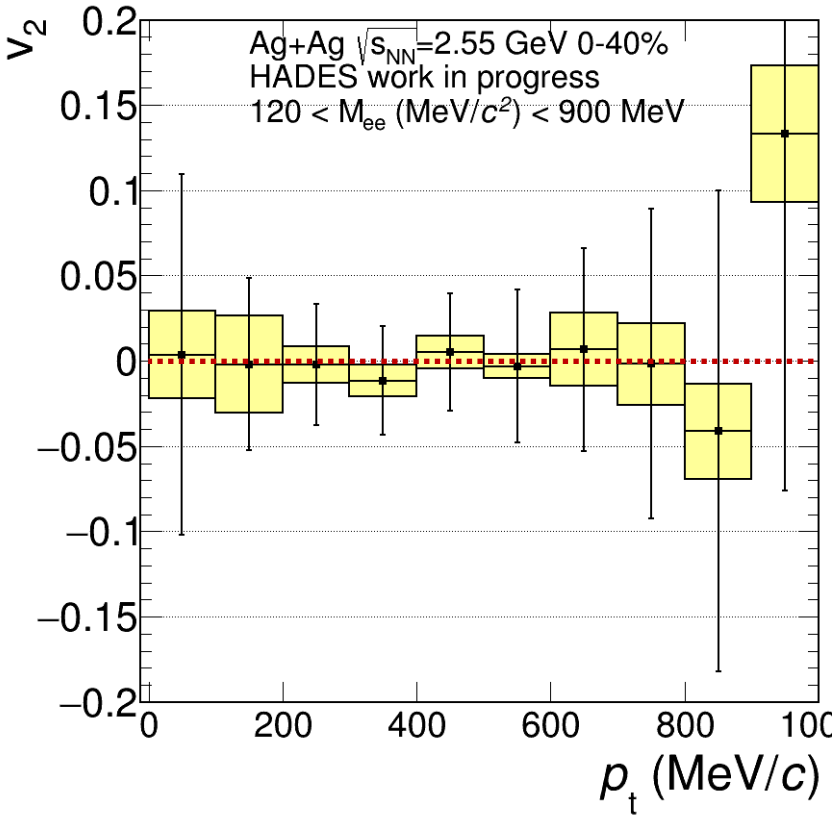


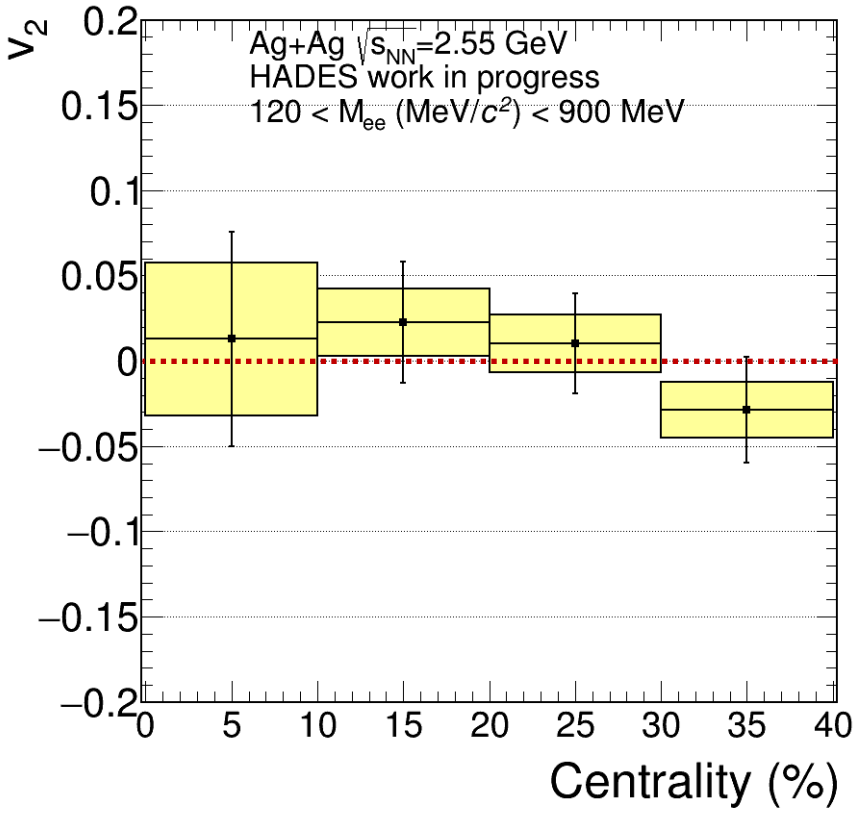
The HADES Collaboration, arXiv:2208.02740

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

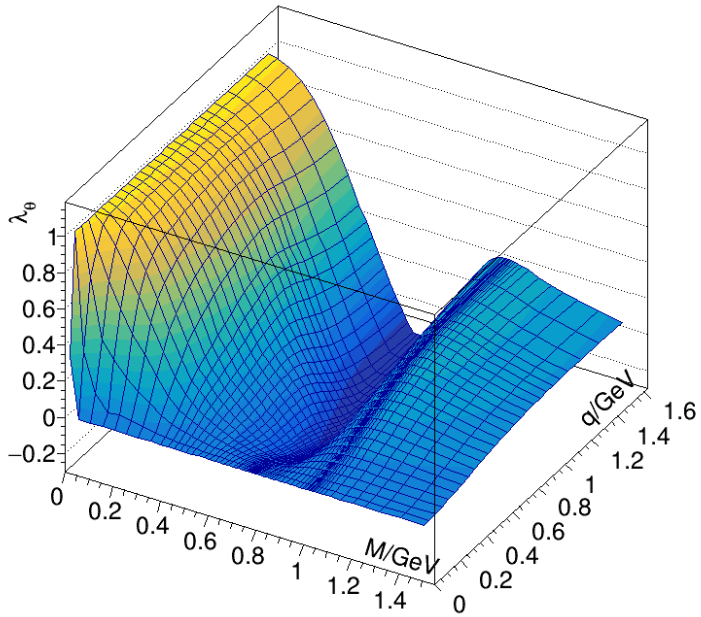
$$v_n^{sig} = v_n^{tot} + \frac{N_{bg}}{N_{sig}} \left(v_n^{tot} - v_n^{bg}\right)$$

Determine radial flow

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

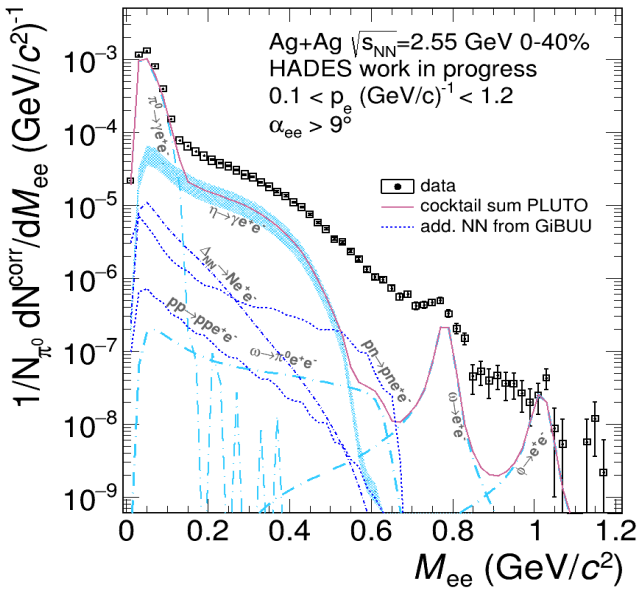
Determine polarization of virtual photons

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

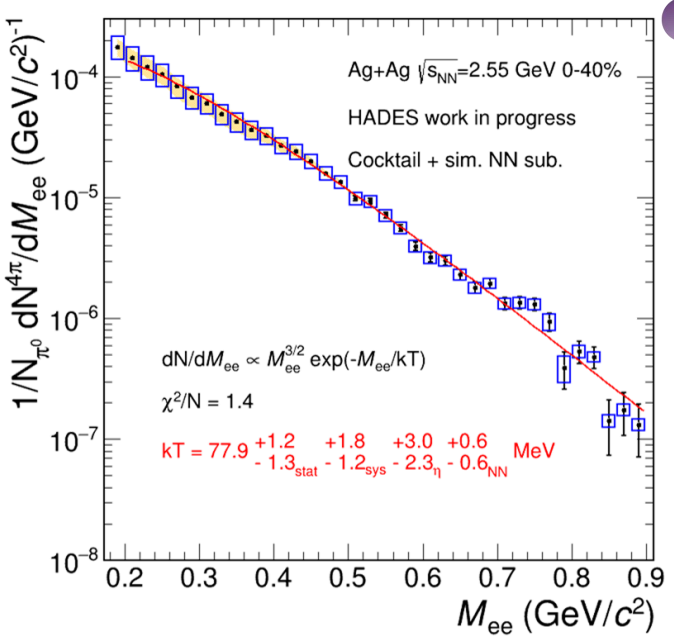


Estimation of virtual photon polarization from spectral functions (N. Schwarz)

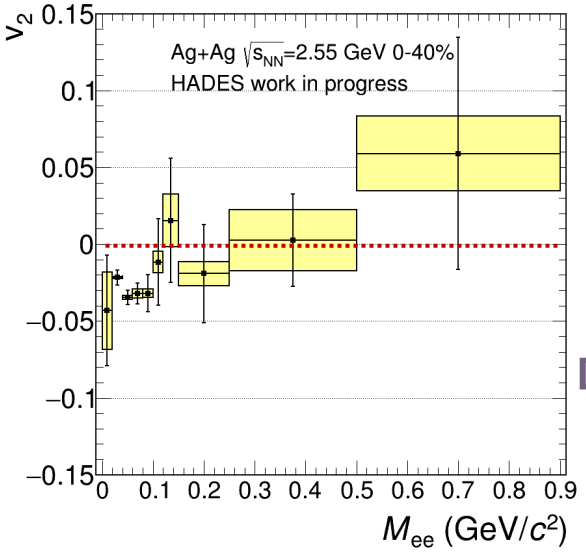
Summary



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 elliptic flow for thermal dileptons shows difference in v_2 from hadron measurements