Characterising the hot and dense fireball via dilepton polarization and flow in HADES

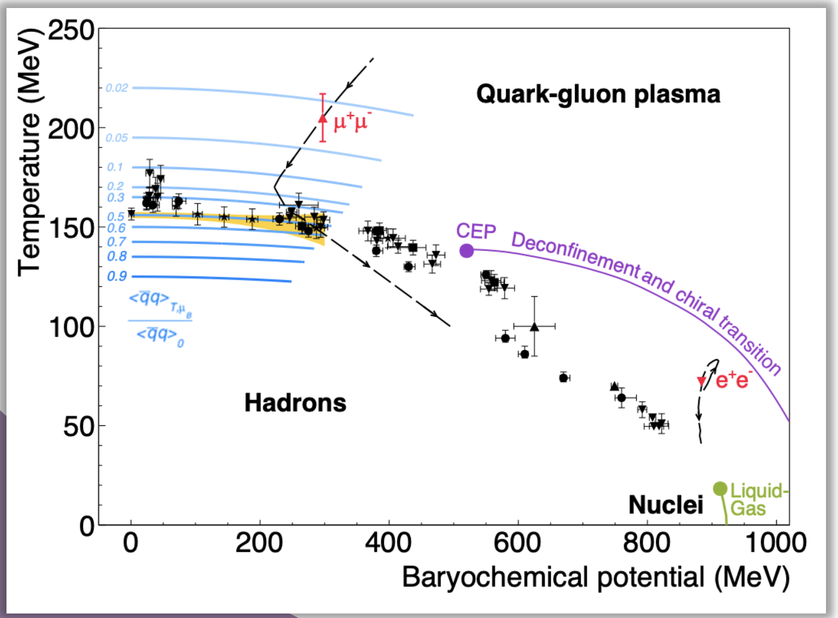
Niklas Schild

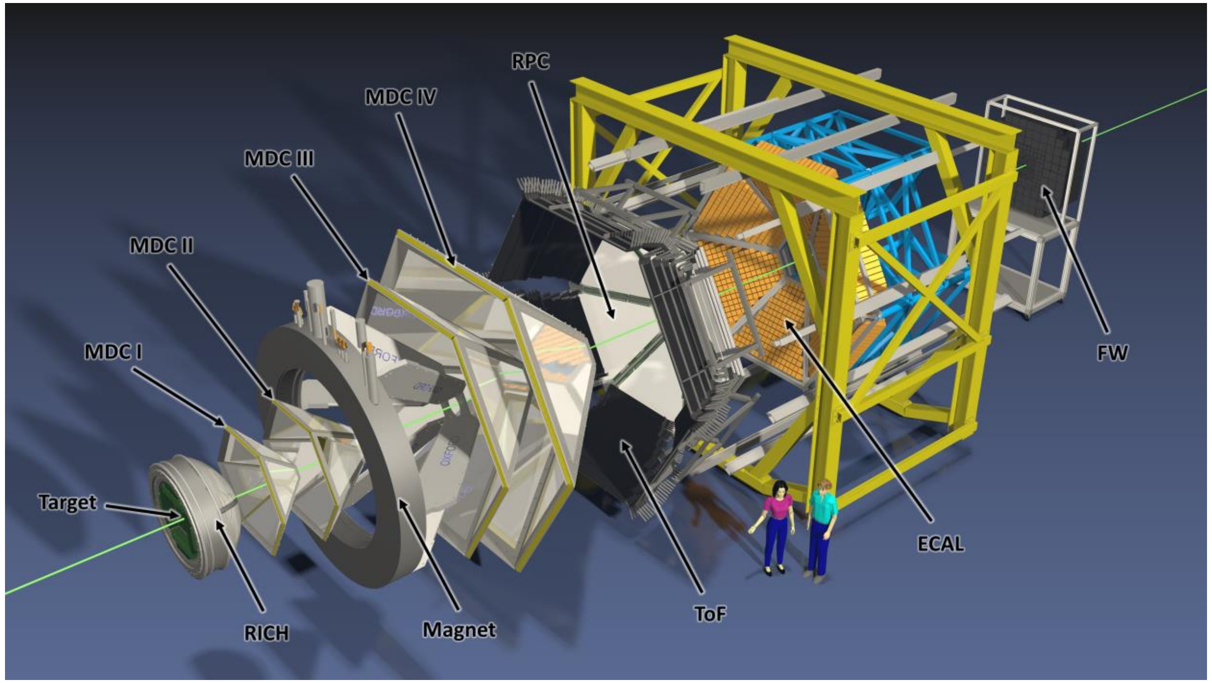
This work is supported by the State of Hesse within the Research Cluster ELEMENTS (Project ID 500/10.006)

Motivation - The HADES

- **H**igh-**A**cceptance-**D**i-**E**lectron-**S**pectrometer
- Fixed target experiment at GSI, Darmstadt
- Study heavy ion collisions in few GeV range

➡ Explores region of high densities μ_B and moderate temperaures T





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

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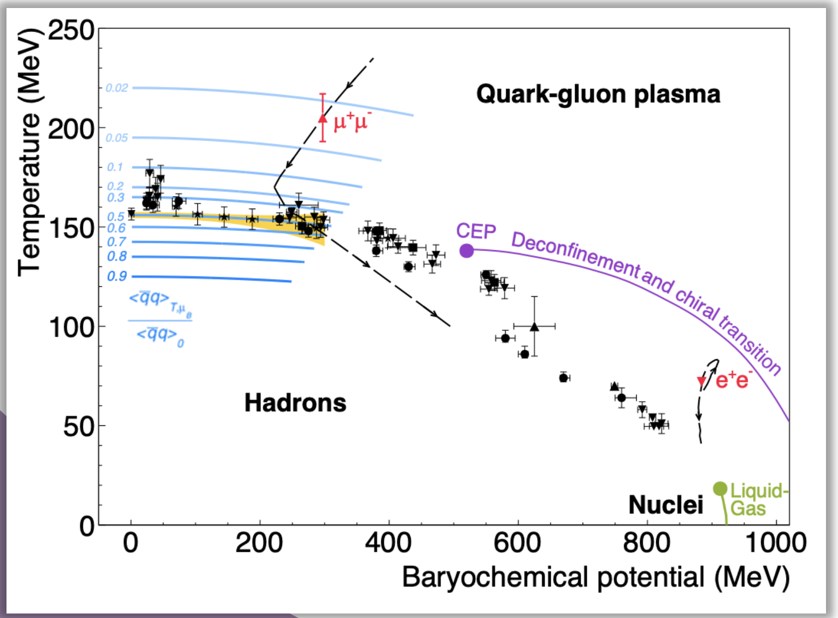
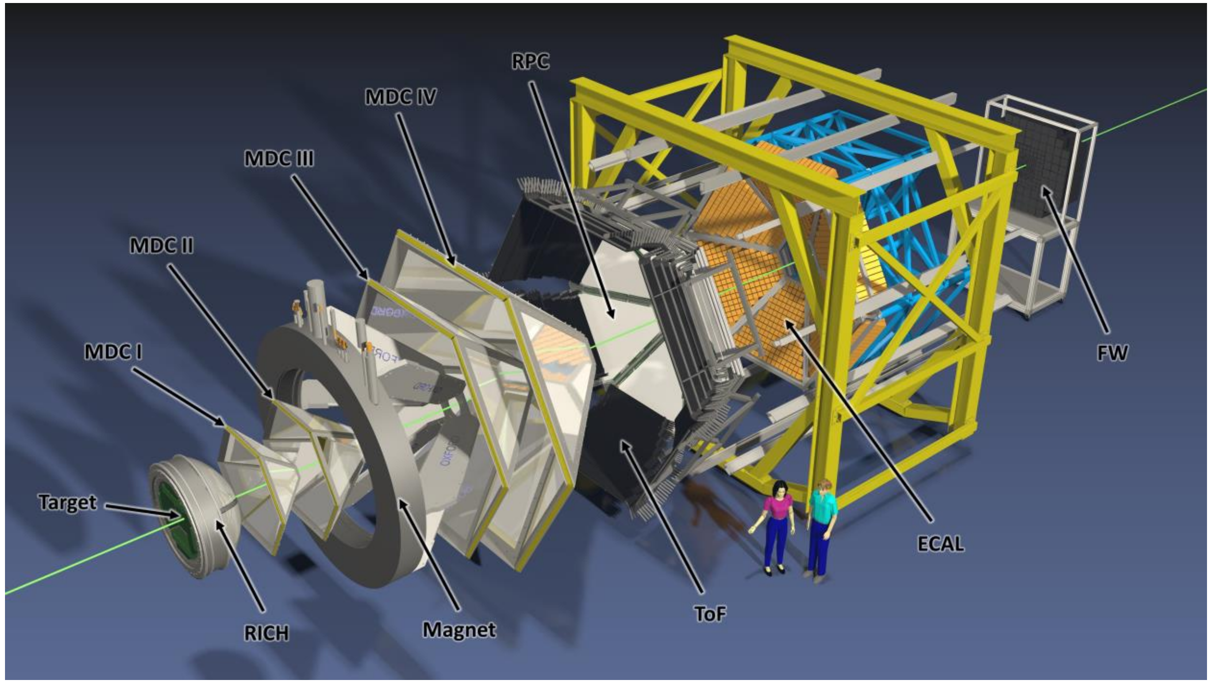
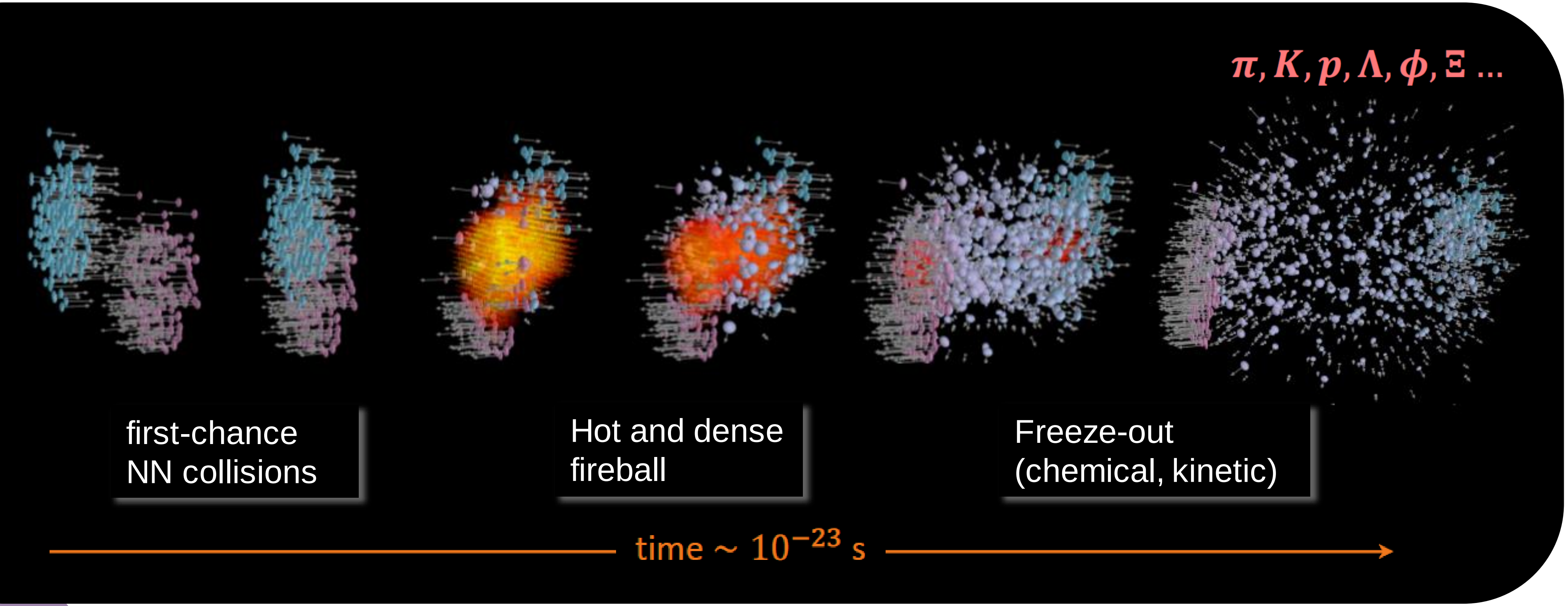




Create and study conditions in the laboratory which resemble those in neutron star mergers

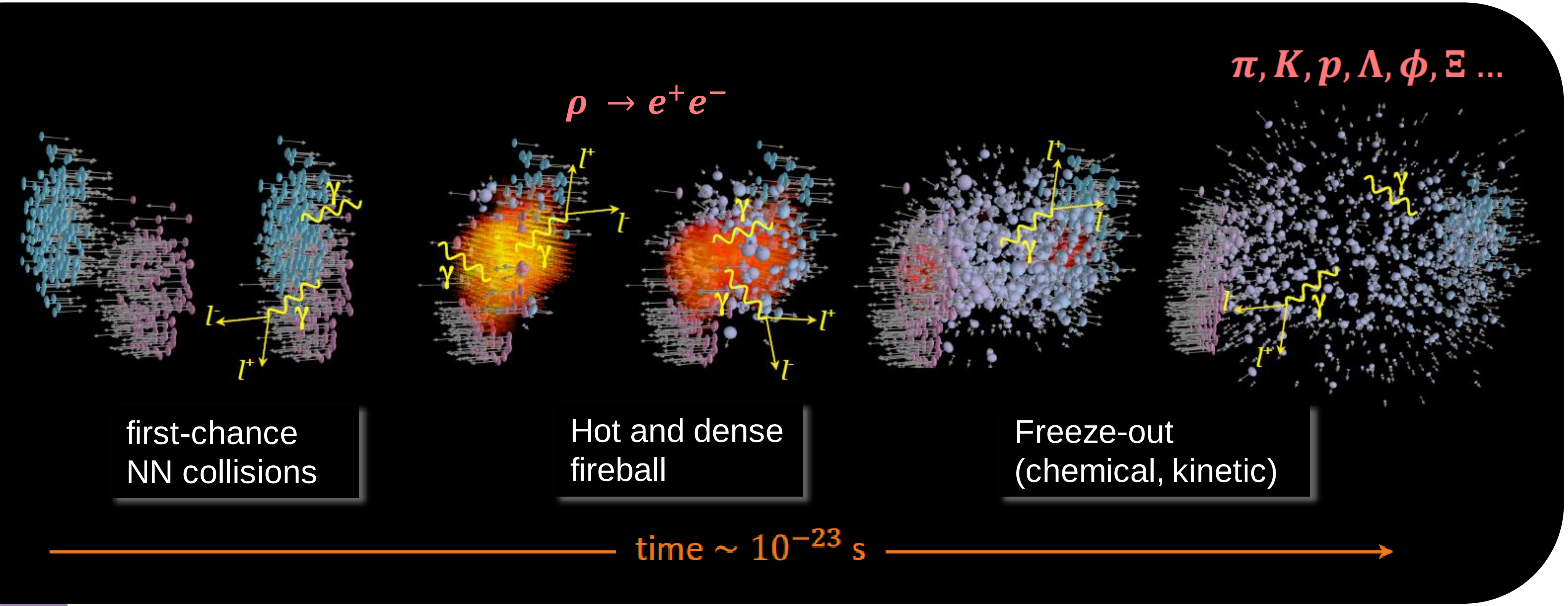
The HADES Collaboration, *Nat. Phys.* **15,** 1040–1045 (2019)

Motivation - Dileptons



All strongly interacting particles heavily influenced by freeze-out

Motivation - Dileptons



All strongly interacting particles heavily influenced by freeze-out

- Dileptons as electromagnetic, direct probes
- Carry additional information in their invariant mass M_{ee}

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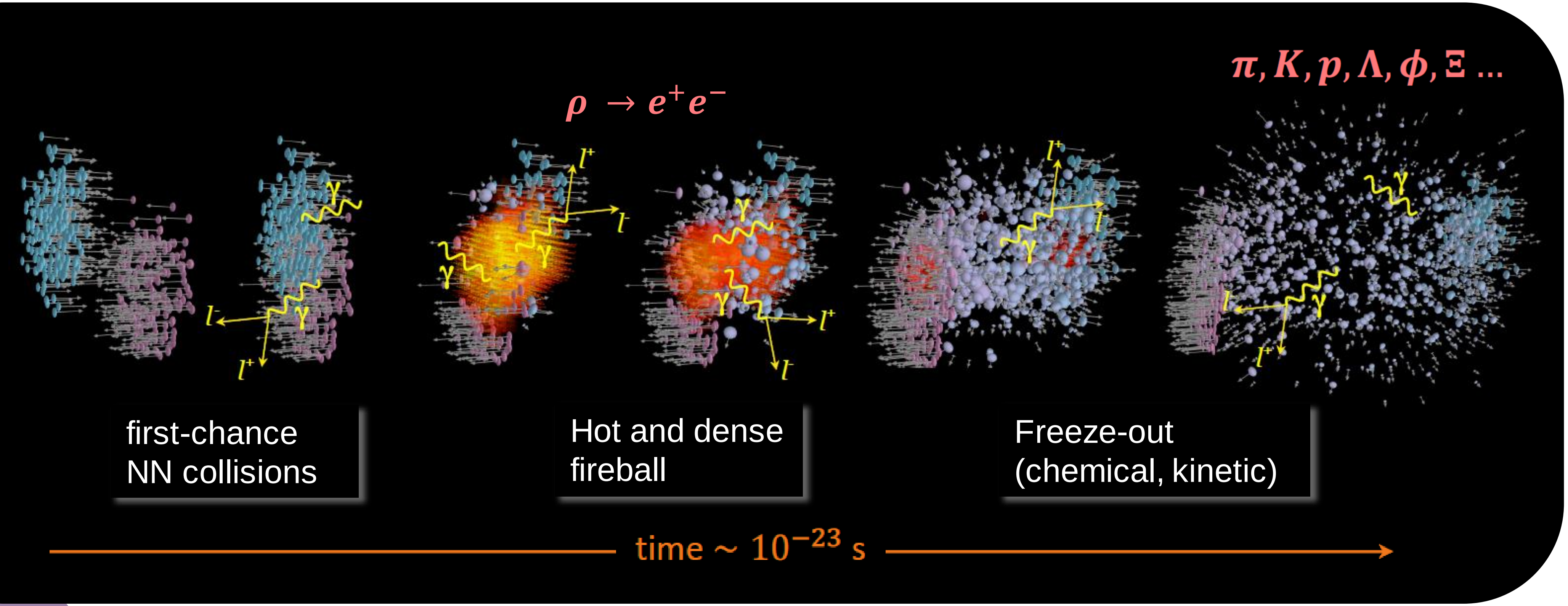

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Lifetime

Temperature

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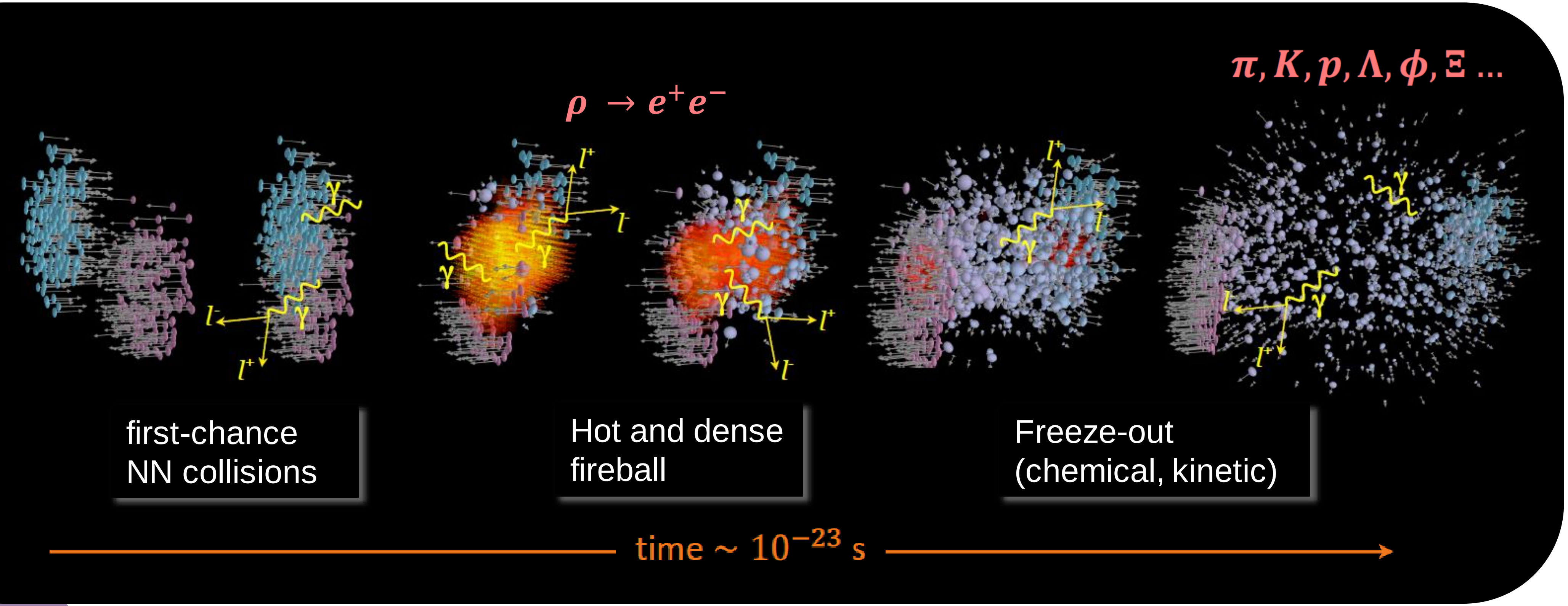


All strongly interacting particles heavily influenced by freeze-out

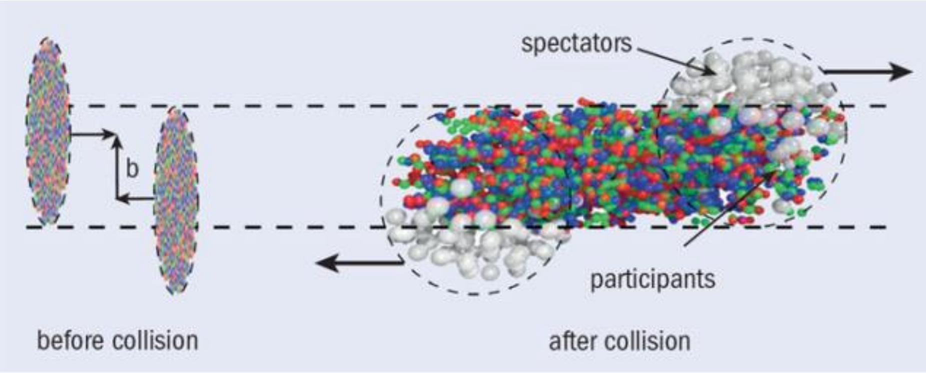
- Dileptons as electromagnetic, direct probes
- Carry additional information in their invariant mass M_{ee}
- Flow and polarization to investigate collectivity

Lifetime

Temperature

Important Defintions

Centrality



- Impact parameter b determines number of participants nucleons A_{part}

Periperhal Collision ← **Central** Collision

https://cerncourier.com/a/participants-and-spectators-at-the-heavy-ion-fireball/

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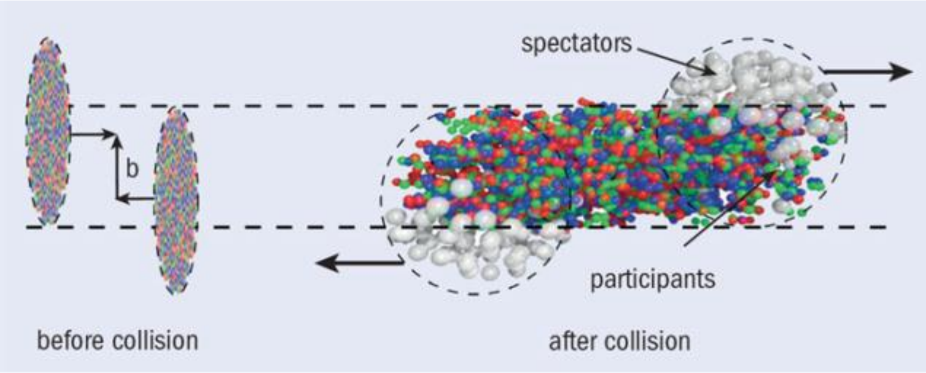

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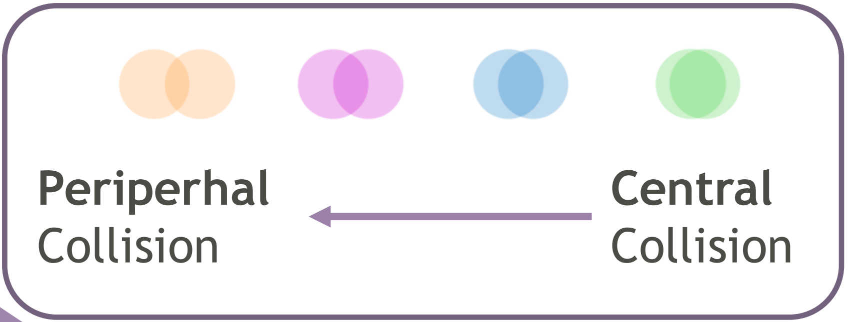

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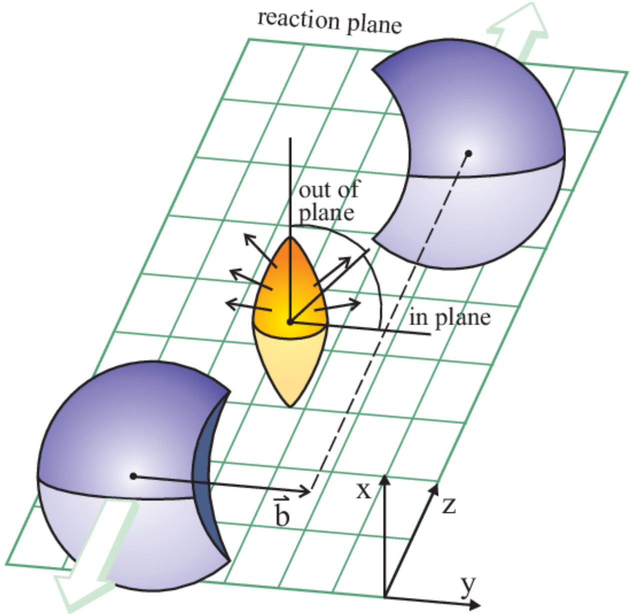
Reaction Plane

- Impact parameter b and beam direction define the **reaction plane** Ψ_{RP}



Barbara Betz, arXiv:0910.4114

Reconstructing the Invariant Mass Spectrum

Creation of Data Summary Tape

Translation from detector signals into physical quantities. Reconstruction of events and particle candiates.

Event Selection

Removal of unsuitable events, i.e. events with high background noise or pile-up events.

Lepton Identification

Selection of electrons and positrons from all particle candidates provided in the DST.

Combinatorial Background Estimation

Matching of individual leptons into dilepton pairs by estimation of the combinatorial background.

Efficiency Corrections

Correction of dilepton signal to account for imperfect reconstruction and particle identification.

Isolation of Excess Pairs

Isolation of excess pairs by subtraction of reference and η-spectrum.

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Correction of excess spectrum to account for the limited solid angle coverage of the detector.

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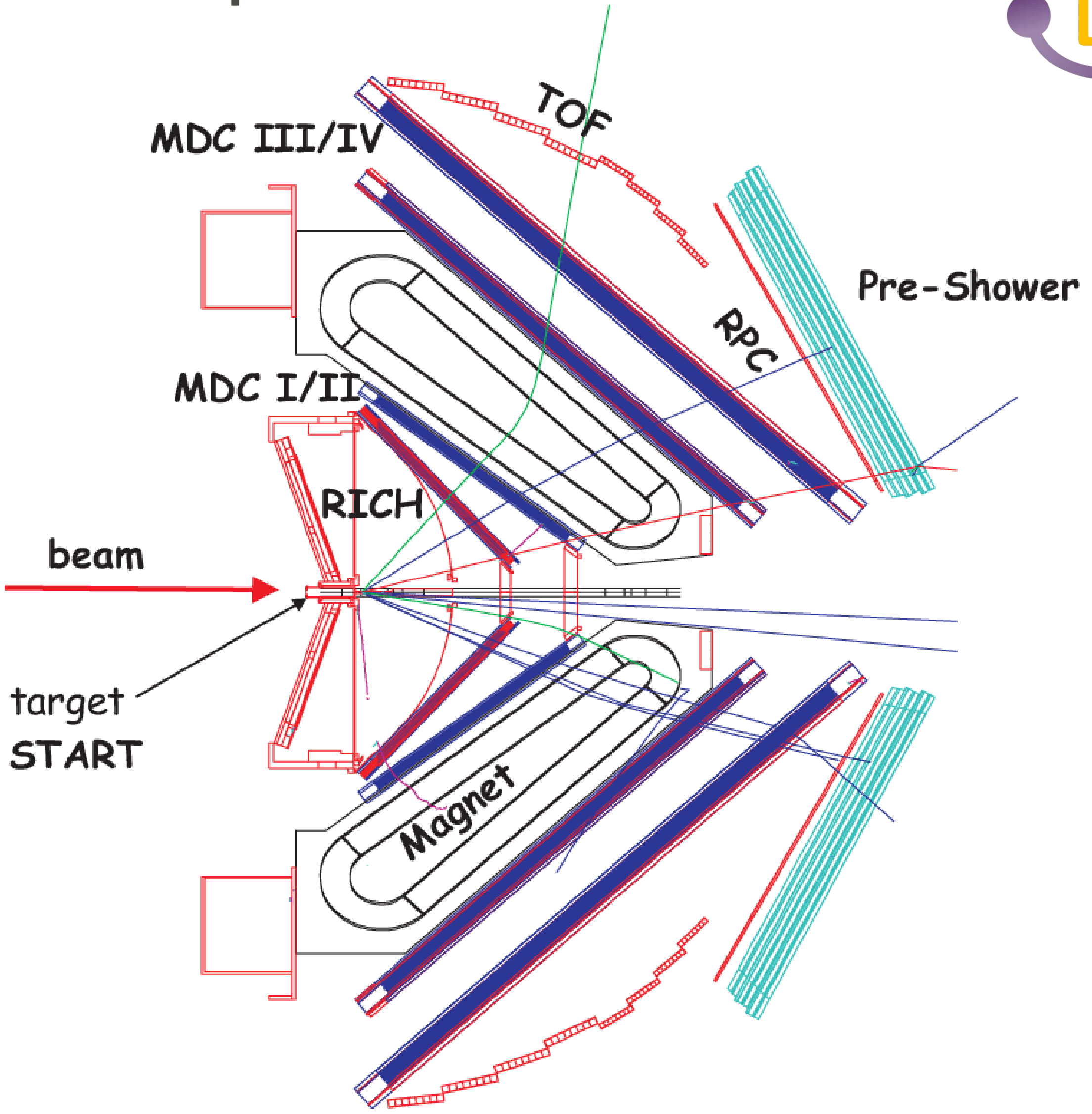

L. Chlad, 2016 J. Phys.: Conf. Ser. 742 012033

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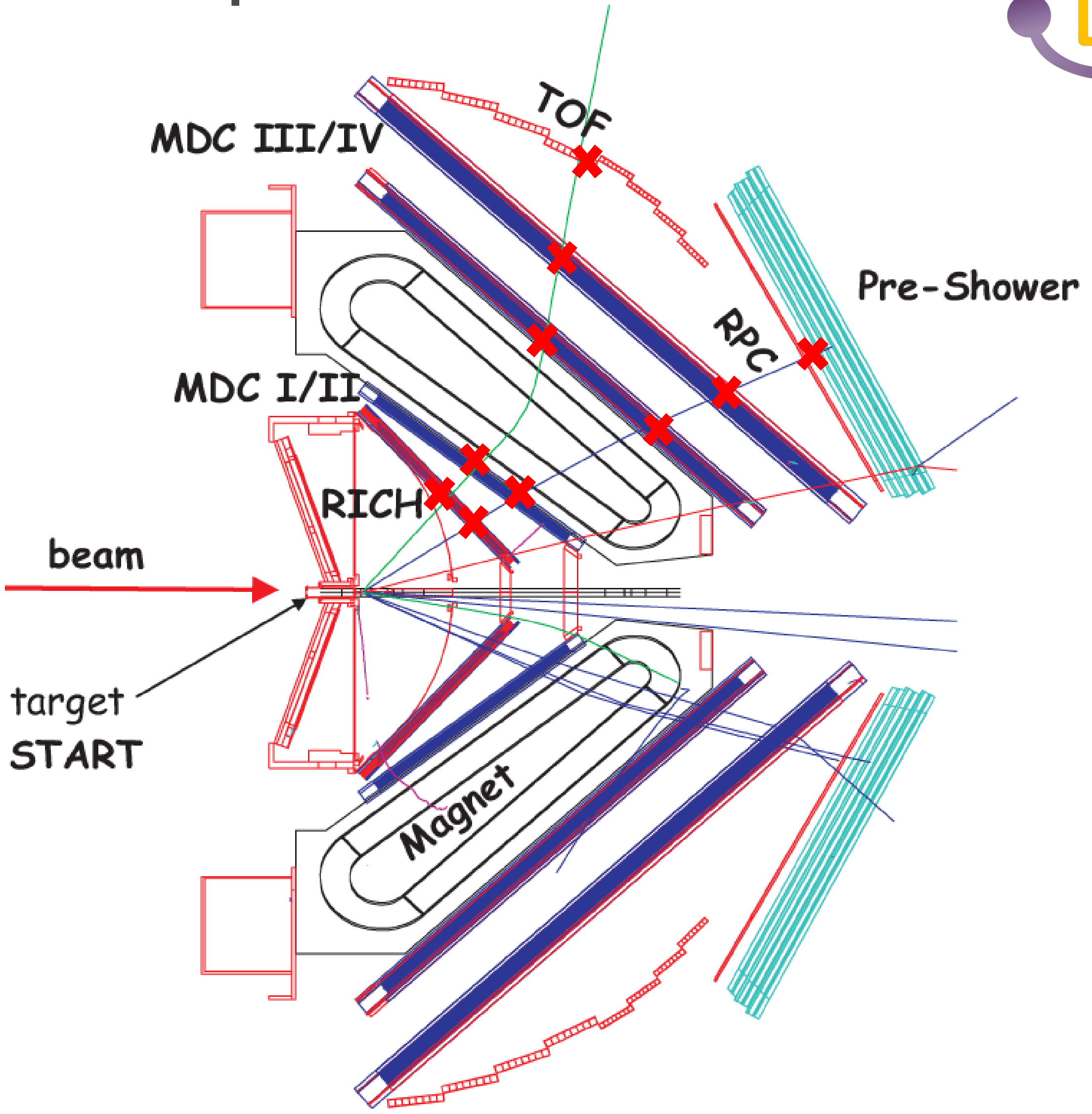

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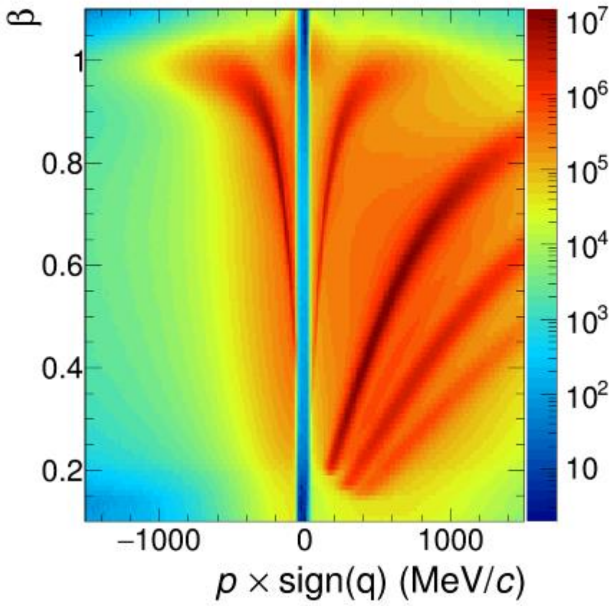
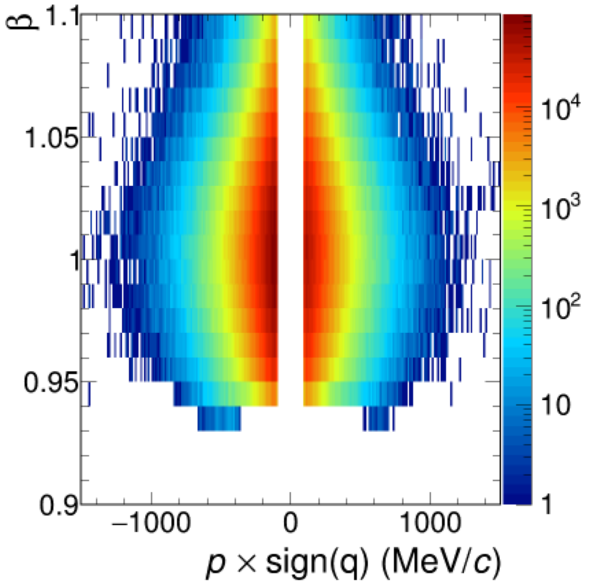
Dedicated detector components provide multiple e^+e^- selection criteria:

- Ring-Imaging-Cherenkov detector (RICH)
- Electromagnetic Calorimeter
- Velocity β





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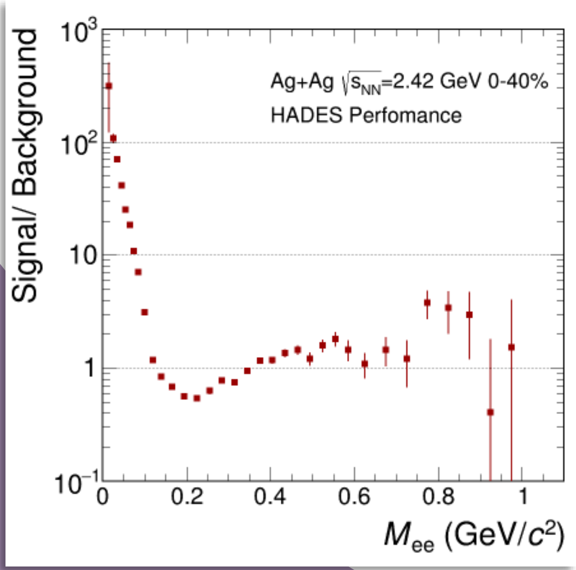
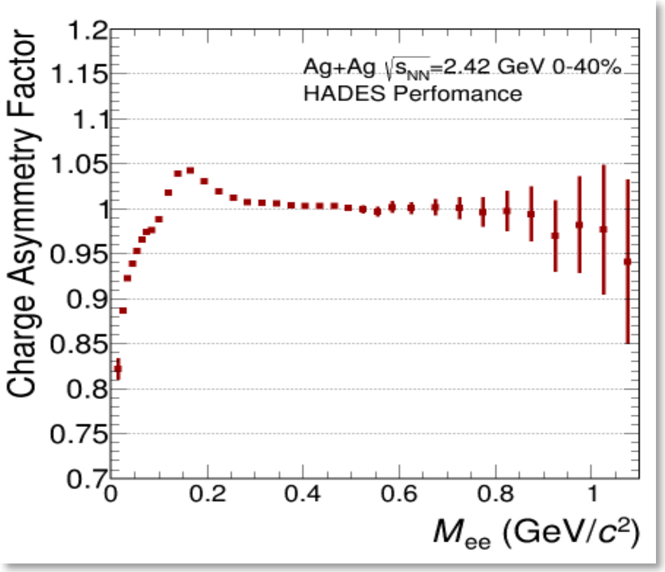
Matching into Dilepton Pairs

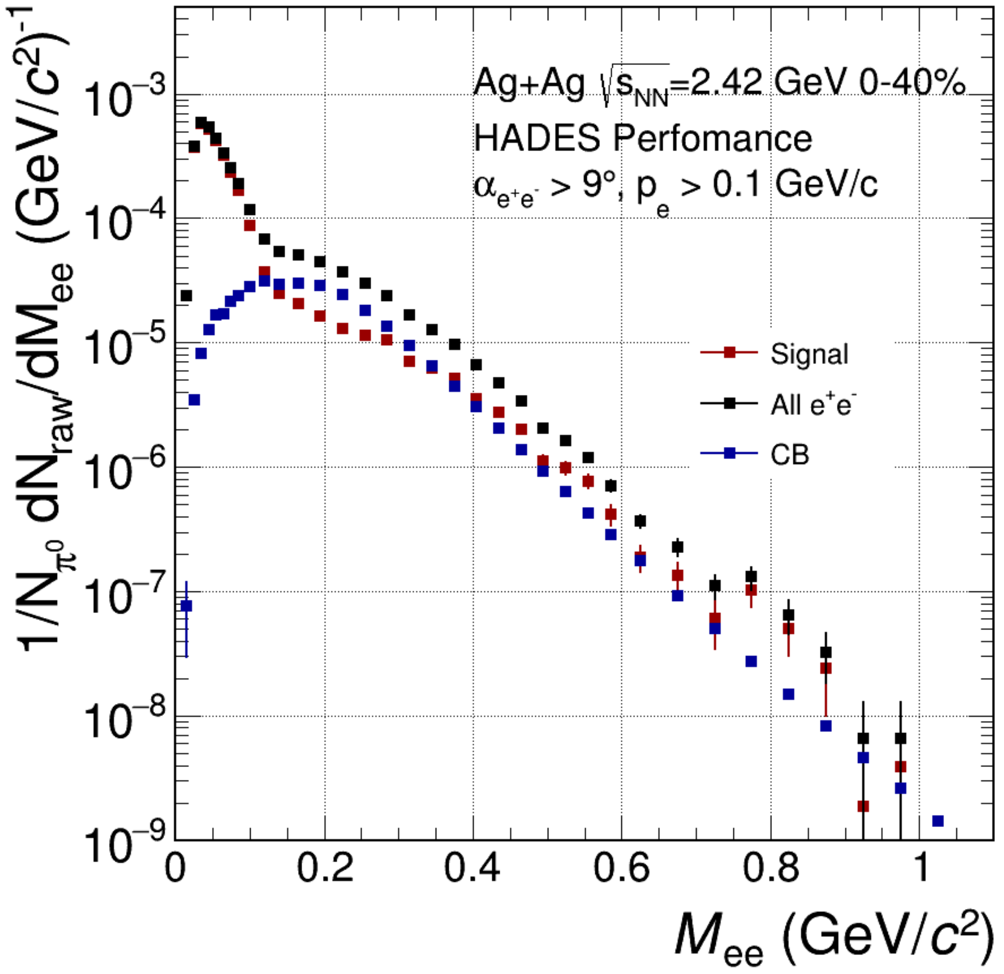
- Create mass spectrum $\frac{dN_{+-}}{dM}$ for all possible e^+e^- pairs
- Subtract combinatorial background to get true signal

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

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







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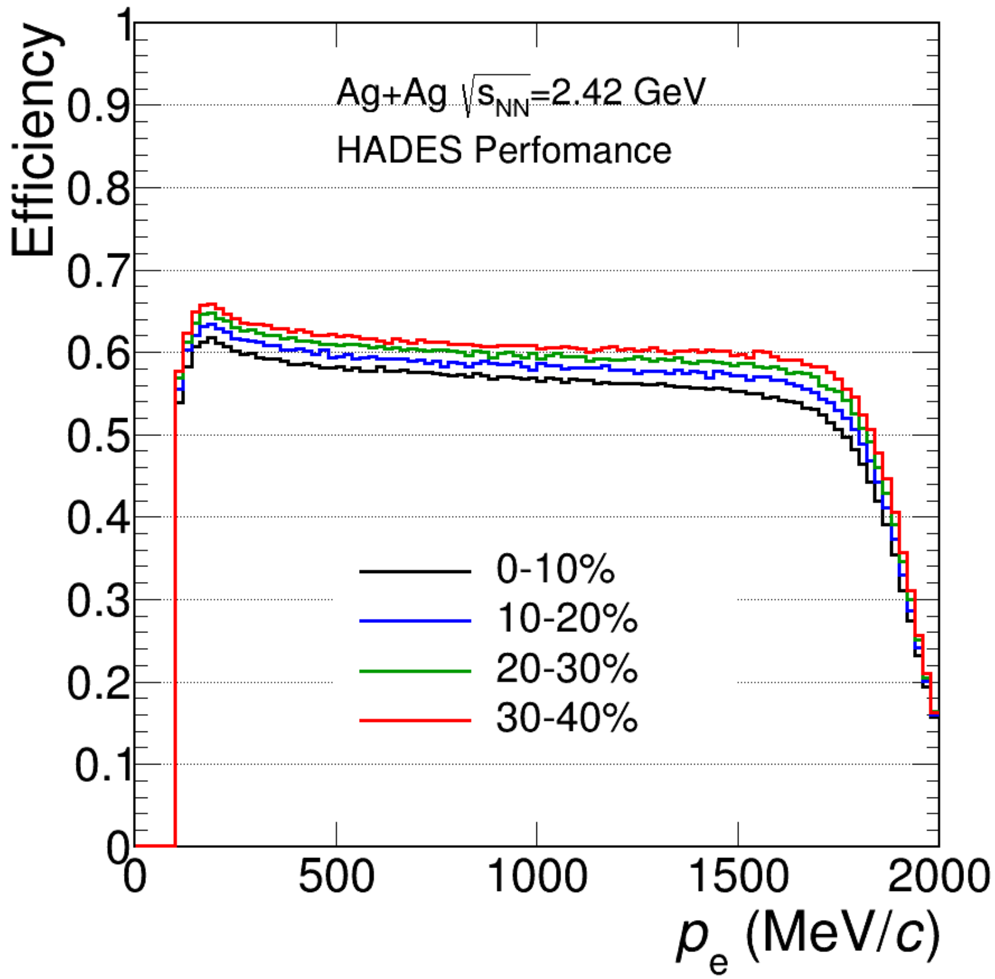
Efficiency Corecction

- Includes losses due to track reconstruction and particle identification
- Efficiency estimation based on embedding simulated $e^{\pm}$ to experimental data

Assume pair effciency ε_{Pair} is given by product of single particle efficiencies ε_e:

$$\varepsilon_{Pair} = \varepsilon_{e_1} \cdot \varepsilon_{e_2}$$

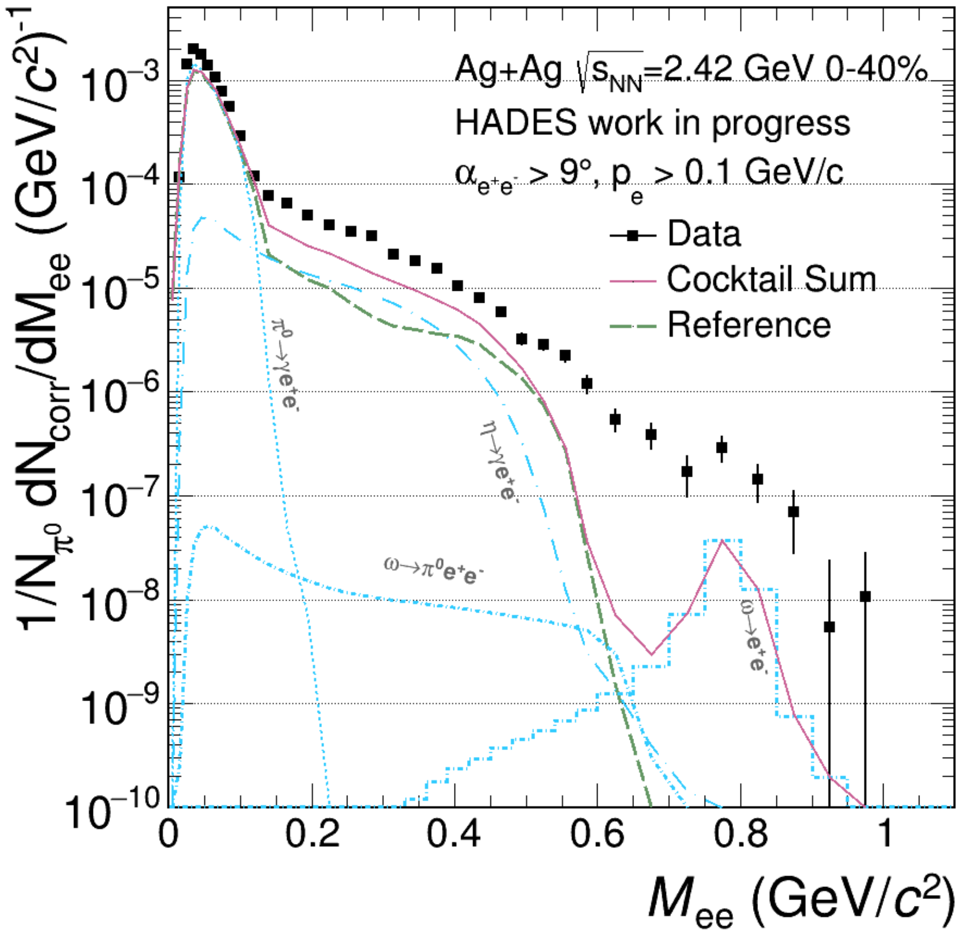
Fill raw spectra with weight $w = \frac{1}{\varepsilon_{Pair}}$ to apply correction



Efficiency Corrected Mass Spectrum

- Compare reconstructed spectrum with cocktail simulations
- Excess to Cocktail sum is from thermal contribution (thermal ρ)

- Isolate excess by subtraction of measured:
  - NN Refernce
  - $\eta \rightarrow \gamma\, e^{+}e^{-}$



Reconstructing the Invariant Mass Spectrum

ELEMENTS

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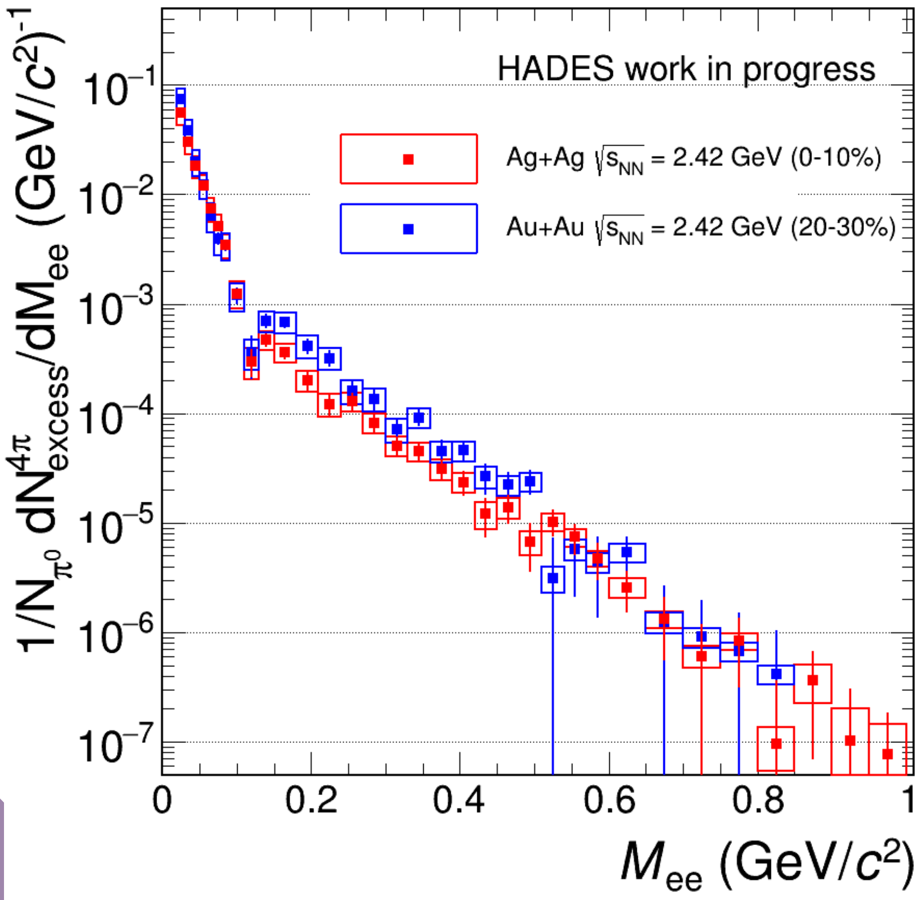
Resulting Excess Spectrum



$\langle A_{part} \rangle \approx 150$

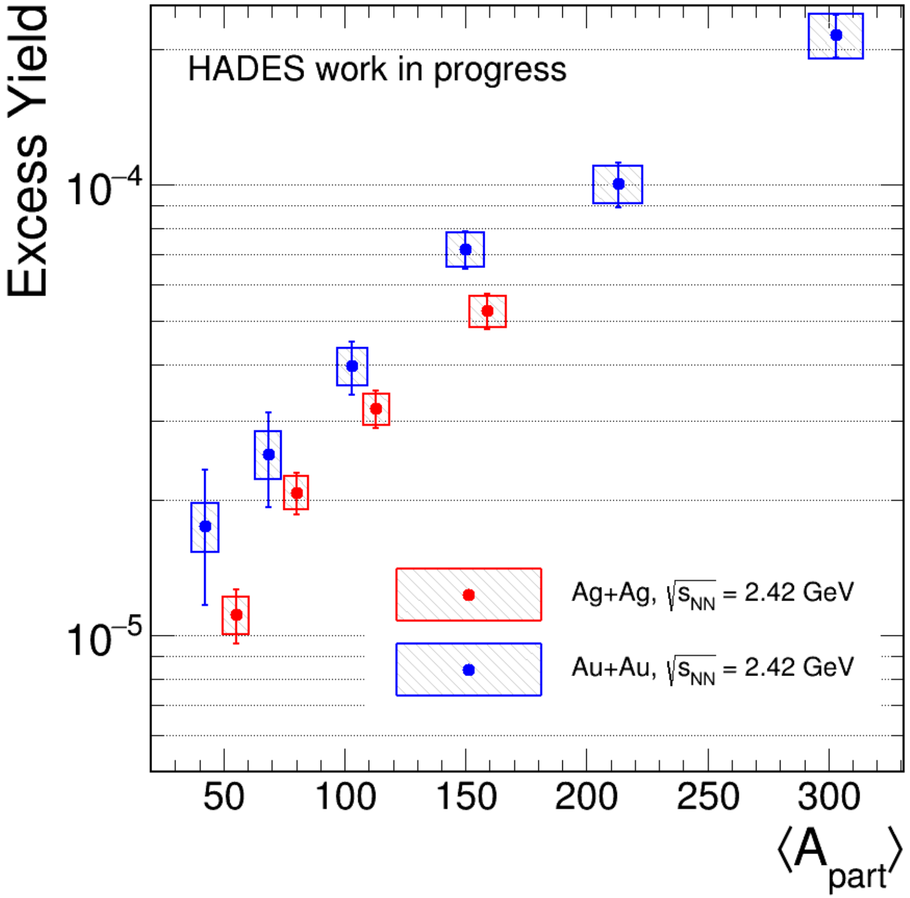
Chronometer

$$N_{excess} = \int_{0.3\ GeV/c^2}^{0.7\ GeV/c^2} \frac{dN}{dM}\, dM$$

Thermometer

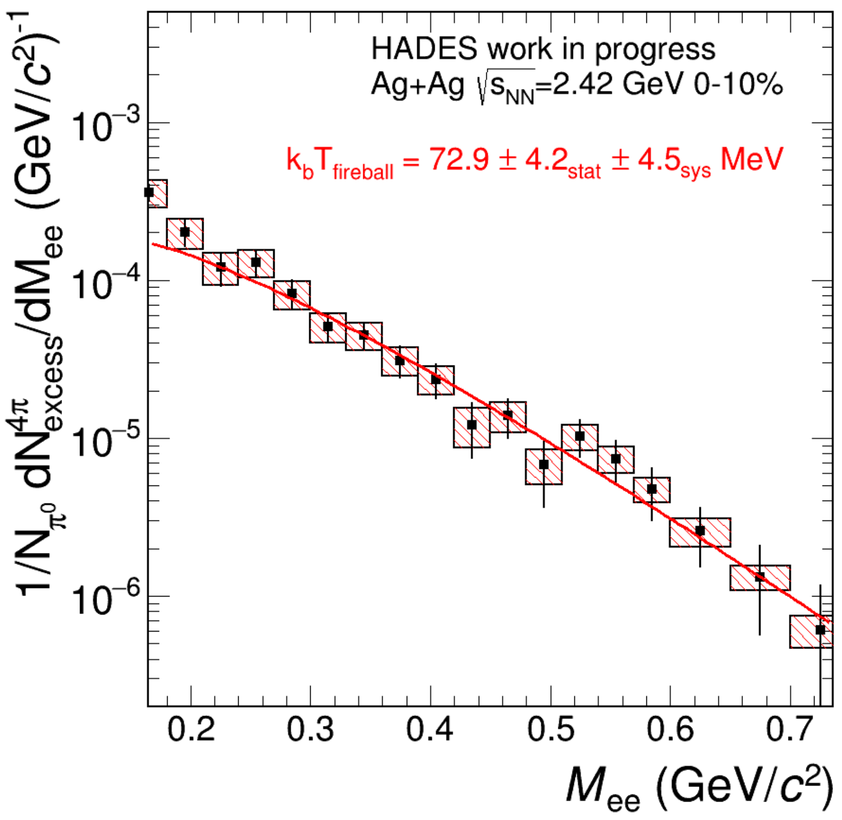
$$\frac{dN}{dM} \propto M^{\frac{3}{2}} \exp\left(-\frac{M}{T}\right)$$

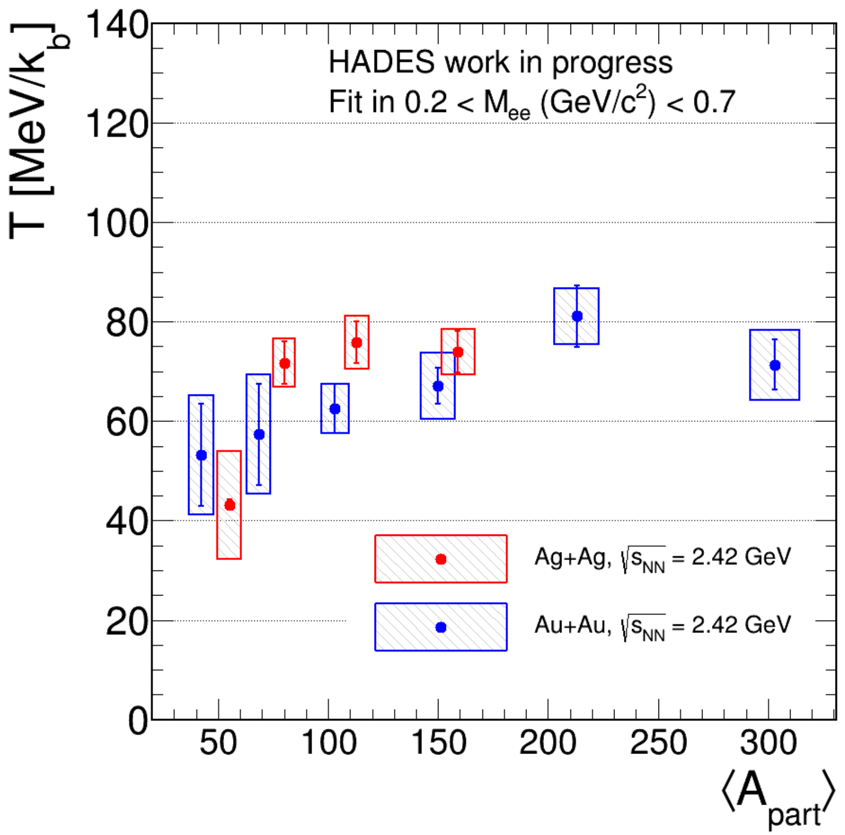
Excess Yield



- Current results indicate higher yield for the overall larger system
  ⇨ System Size Dependence?
- Fit of $\propto \langle A_{part} \rangle^{\alpha}$ gives:
  - $\alpha^{Au+Au} = 1.34 \pm 0.09$
  - $\alpha^{Ag+Ag} = 1.42 \pm 0.14$
- Still under investigation:
  - Possible carbon contamination from collisions with structure material around target
  - Cocktail subtraction

Fireball Temperature

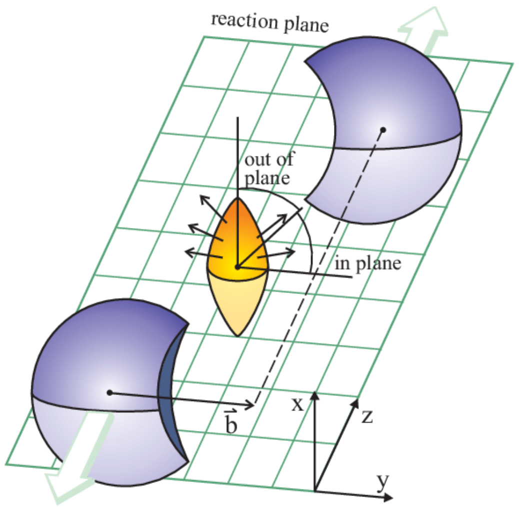




- Subject to significant systematic uncertainties
  - $\langle A_{part} \rangle$ and overall system size less pronounced

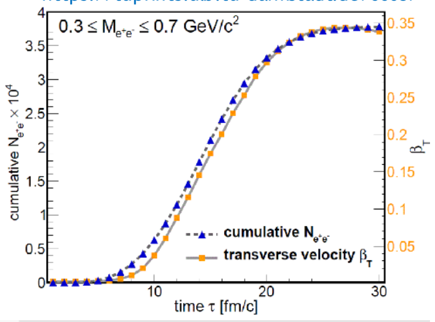
Collective Observables

Collectivity

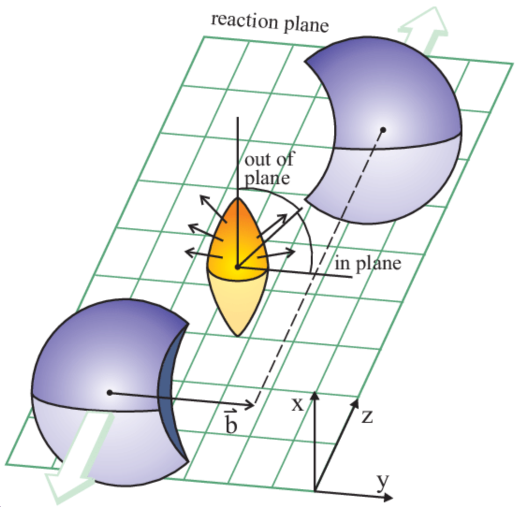


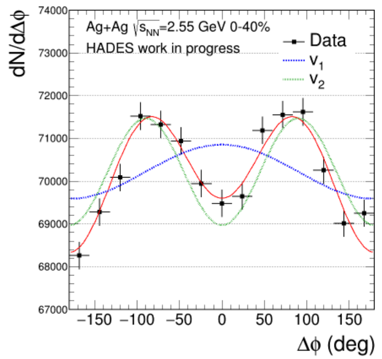
Collective Observables

https://tuprints.ulb.tu-darmstadt.de/6605/



Barbara Betz, arXiv:0910.4114





Collectivity

Radial Flow

- Radial expansion velocity $\langle \beta_t \rangle$
- Analysis of p_t spectra for various mass bins

$$T_{kin} = T_{eff} - m \cdot \langle \beta_t \rangle^2$$

Anisotropic Flow

- „Direction", azimuthal distribution
- Defined through the fourier coefficients

→ v_1: Directed Flow

→ v_2: Elliptic flow

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

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

Polarization

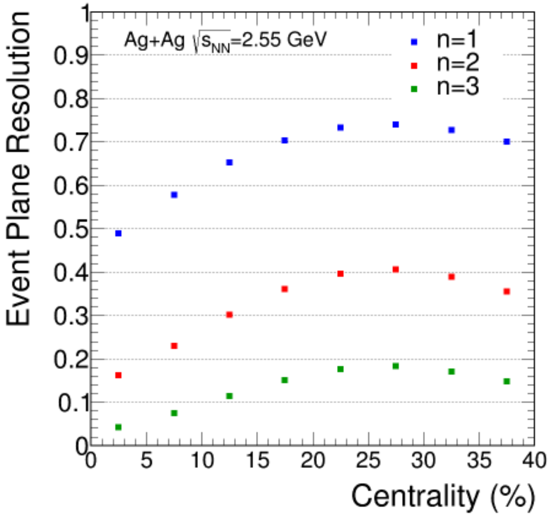
Flow Analysis

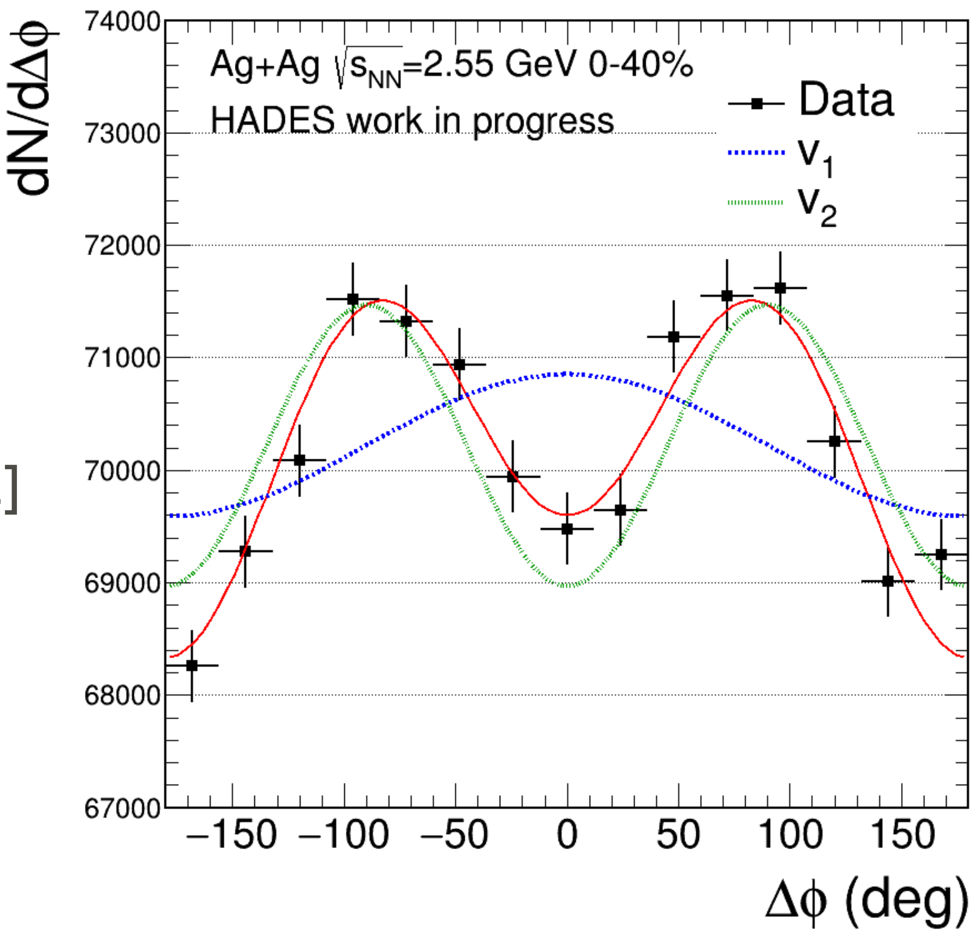
$$\frac{dN}{d\Delta\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n\,\Delta\varphi)$$

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

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

- Reaction plane Ψ_{RP} reconstructed from total tranverse momentum in forward wall detector [1]
- Event plane resolution R_n via Ollitrault method [2]

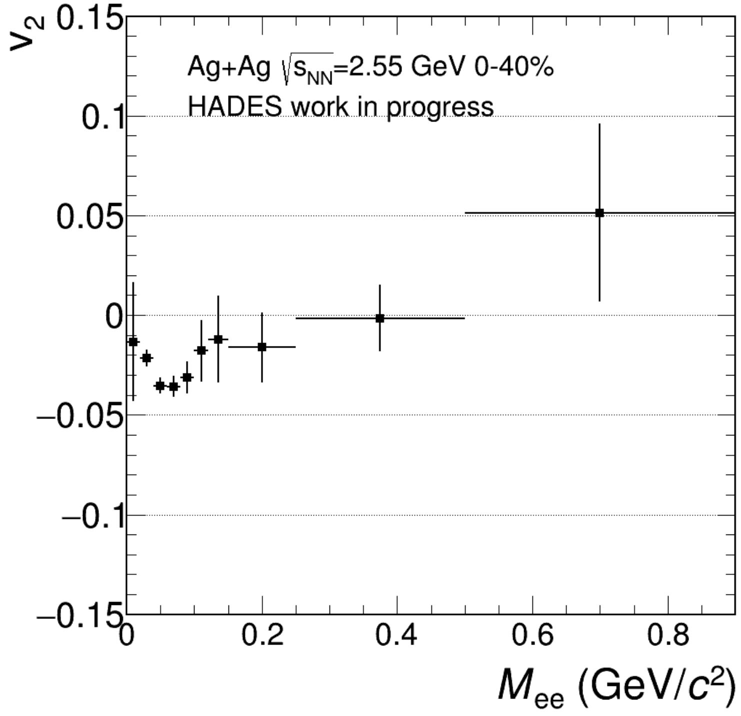




[1] Andreeva *et al.*, 2014 Inst. and Exp. Techniques 57 103–19
[2] Jean-Yves Ollitrault, arXiv:nucl-ex/9711003

Flow Analysis

Fill $\Delta\varphi$ Distributions



- Low masses dominated by π^0 Dalitz decay
- Otherwise v_2 close to zero

Flow Analysis

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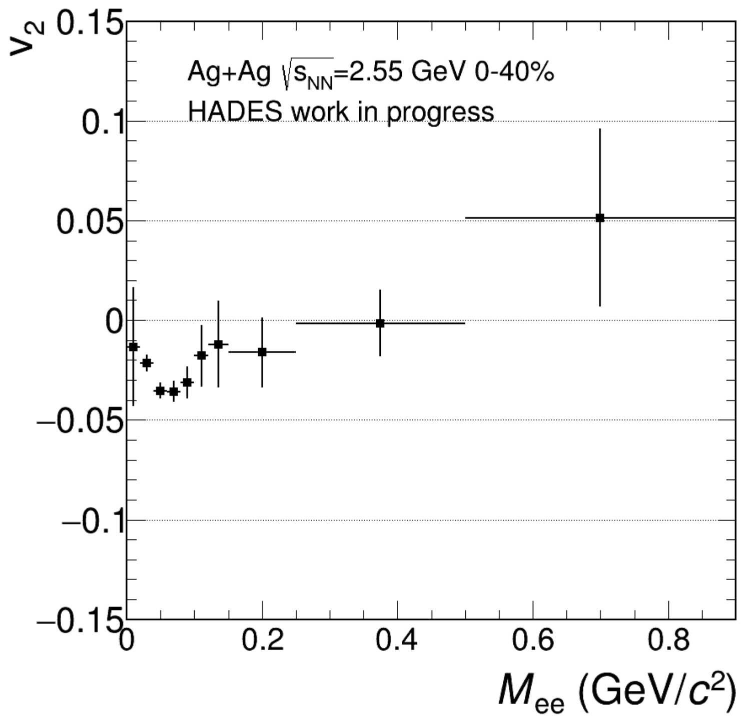
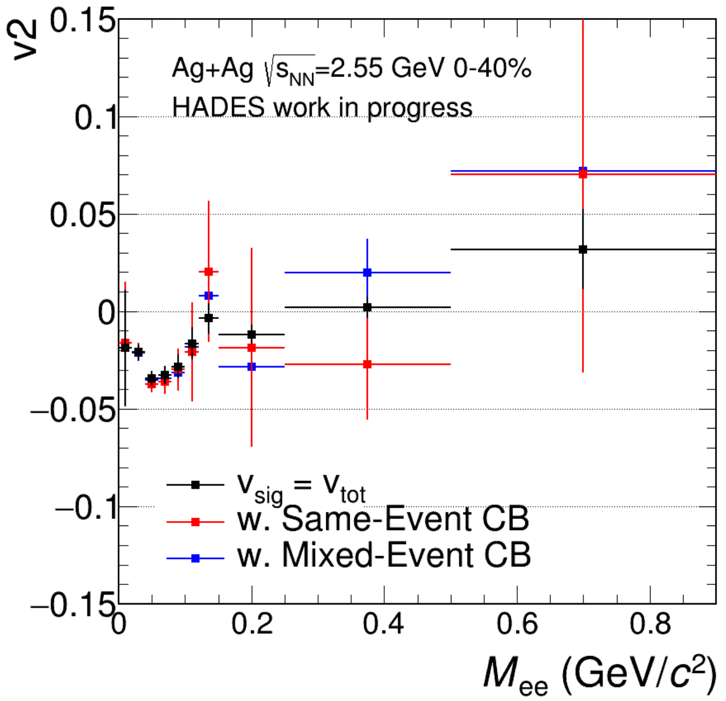


Fill Profiles



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

1) Pair all possible e^+e^- combinations
2) Subtract combinatorial background
   - Same-Event
   - Mixed-Event

$$v_n^{sig} \approx v_n^{tot}$$

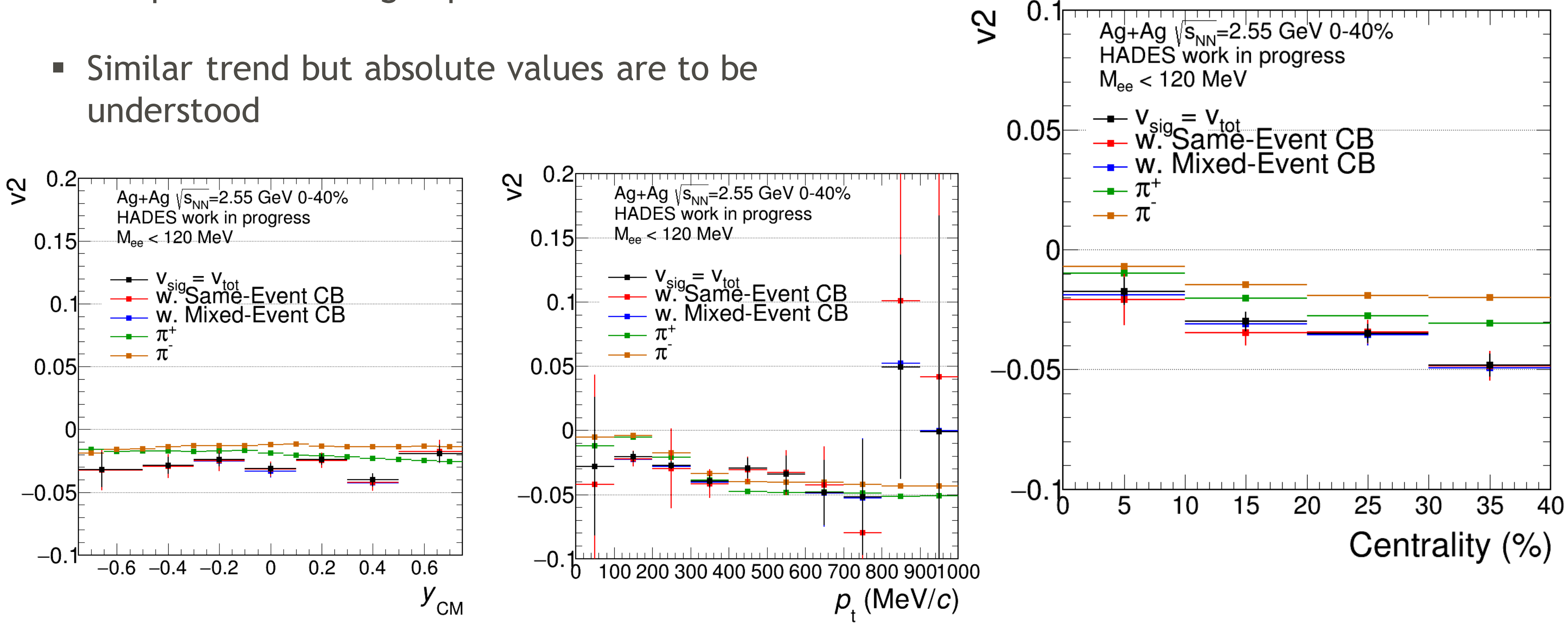
$$v_n^{sig} = v_n^{tot} + \frac{N_{bg}}{N_{sig}} \left(v_n^{tot} - v_n^{bg}\right)$$

https://doi.org/10.1016/j.nuclphysa.2013.01.062

- Low masses dominated by π^0 Dalitz decay
- Otherwise v_2 close to zero

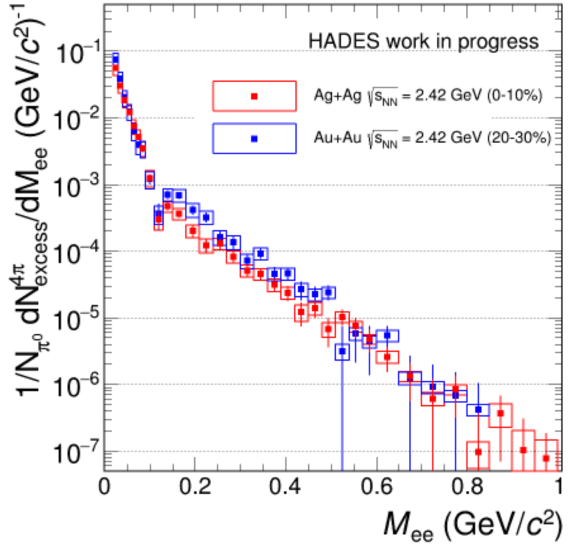
Flow Analysis

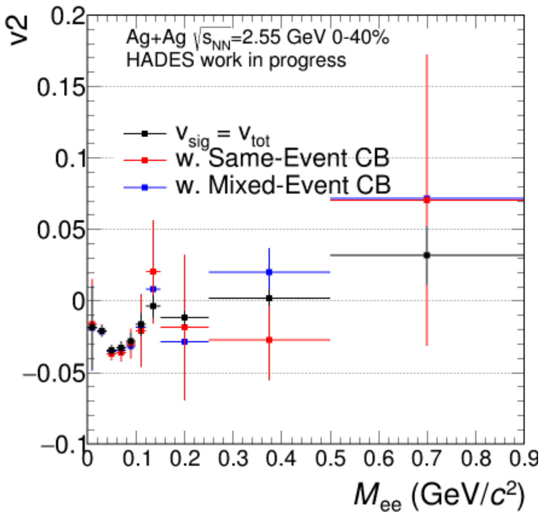
- Look at dilepton pairs with $M_{ee} < 120\ \text{MeV/c}^2$ to compare with charged pion flow
- Similar trend but absolute values are to be understood



Summary and Outlook

- HADES probes regions similar to neutron star mergers
- Dilepton excess invariant mass spectrum serves as thermo- and chronometer
- Comparison of Au+Au and Ag+Ag data at same energy allows insights into system size dependence





- First values for dilepton anisotropic flow coefficients have been extracted
- **Outlook:**
  - Isolation of thermal contribution
  - Detailed investigation into systematic uncertainties
  - Reconstruction of radial flow and polarization