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for the HADES Collaboration

Analysis of charged kaon flow in Ag+Ag collisions registered with HADES

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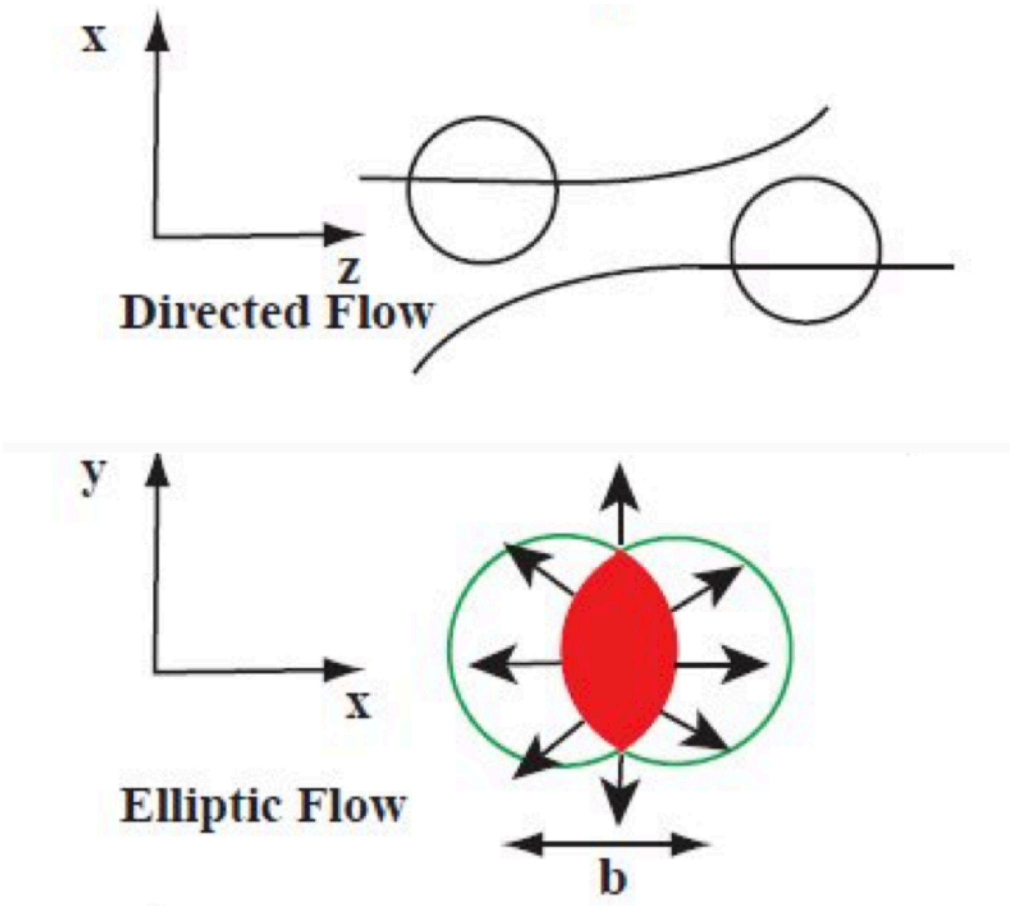
Overview

1. Transverse flow - introduction and motivation
2. The HADES experiment
3. Experimental details
4. Identification and $p_T : y$ distribution of $K^{\pm}$ mesons
5. Preliminary flow patterns of $K^{\pm}$ mesons
6. Summary and outlook

The ϕ azimuthal angle in heavy-ion collisions

- The azimuthal angle matters in describing momenta of particles emitted from heavy ion collisions
- The distributions in this angle are not isotropic!
- Anisotropies of these distributions are called the **transverse flow** (also called the anisotropic or the collective flow)
- Caused by non-spherical geometry of the collision and effects of collisions dynamics



S. Voloshin et al., arXiv:0809.2949 [nucl-ex] (2008)

Sensitivity of flow to physical effects

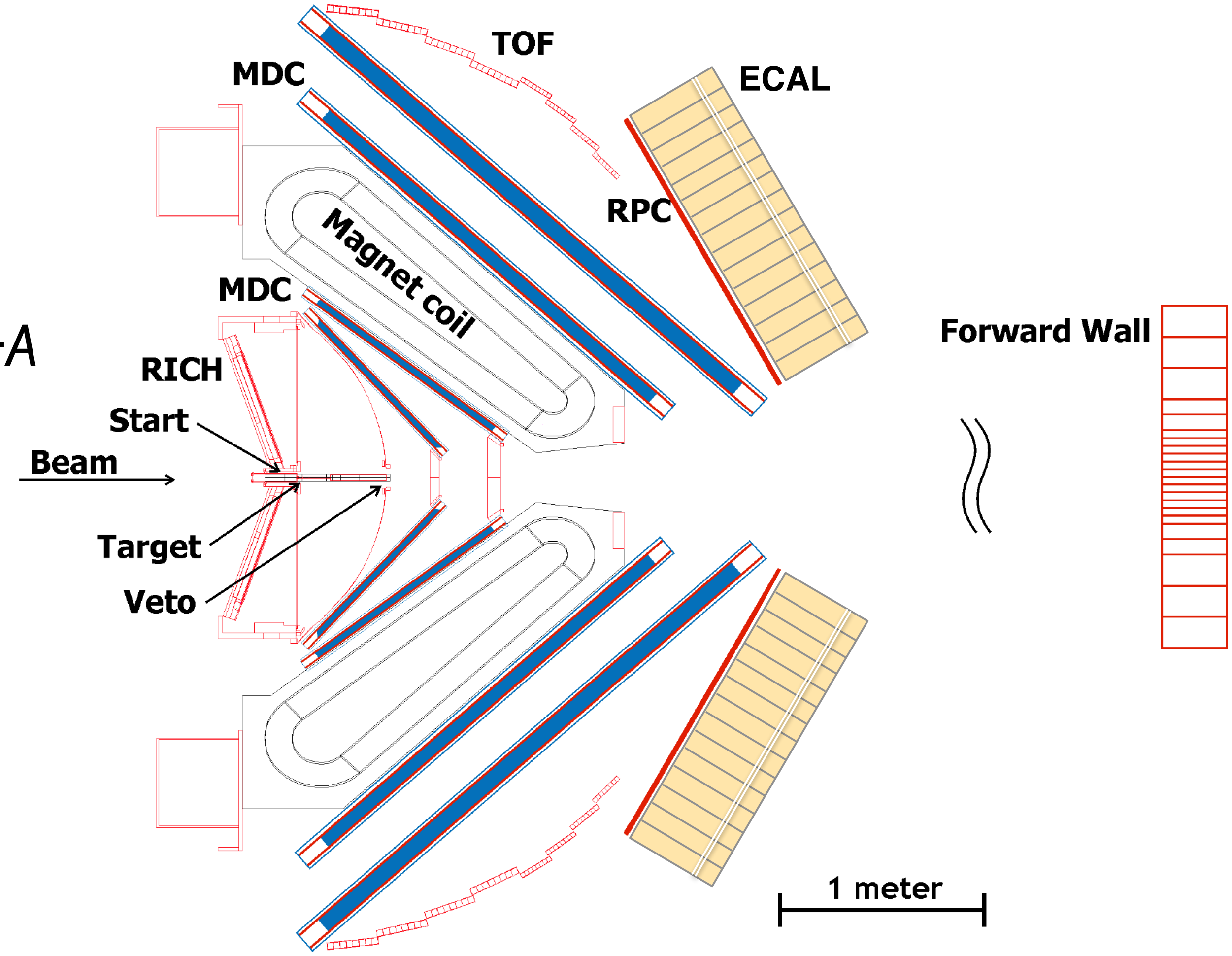
- Significant extension of our current understanding of RHIC's
  - v_n often reported in small or partly integrated phase space regions
  - **HADES provides large acceptance and statistics!**

- Azimuthal angle distribution sensitive to properties of nuclear matter (NM):
  - Equation of State of the NM
  - Interactions within NM, and its interaction with produced particles
  - **Good observable for transport models comparisons!**

- Why strange particles?
  - Near-threshold production → they act as probe particles
  - Strangeness conservation
  - Significant Kaon-Nucleon potential predicted

High Acceptance Di-Electron Spectrometer

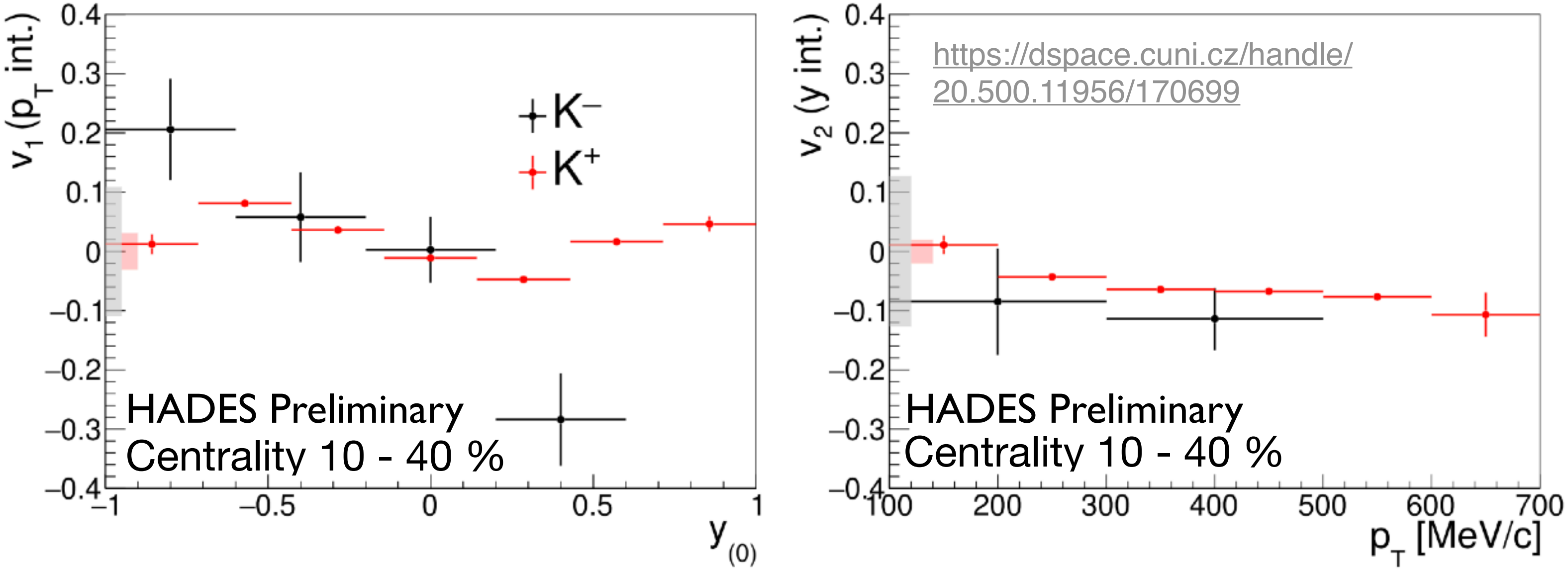
- Installed at the SIS18 accelerator at GSI (Darmstadt, Germany)
- Measures products of *A*+*A* as well as *p*+*A*, *p*+*p* and *π*+*A* collisions
- 0.2 - 4.5 GeV/nucleon energy regime;
- Part of FAIR Phase-0 program (SIS-100 accelerator under construction)



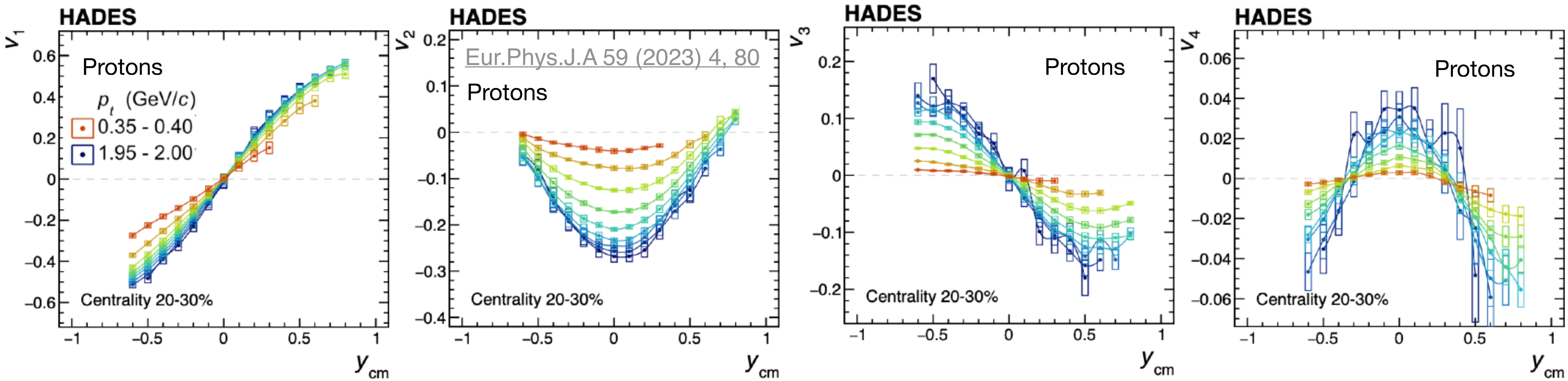
G. Agakichiev et al. (HADES Collaboration), Eur. Phys. J. A 41, 243 (2009)

Previous flow reports from HADES

$v_{1,2}$ of charged kaons
in Au+Au @ 1.23*A* GeV ↘



v_{1-4} of protons
in Au+Au @ 1.23*A* GeV ↓

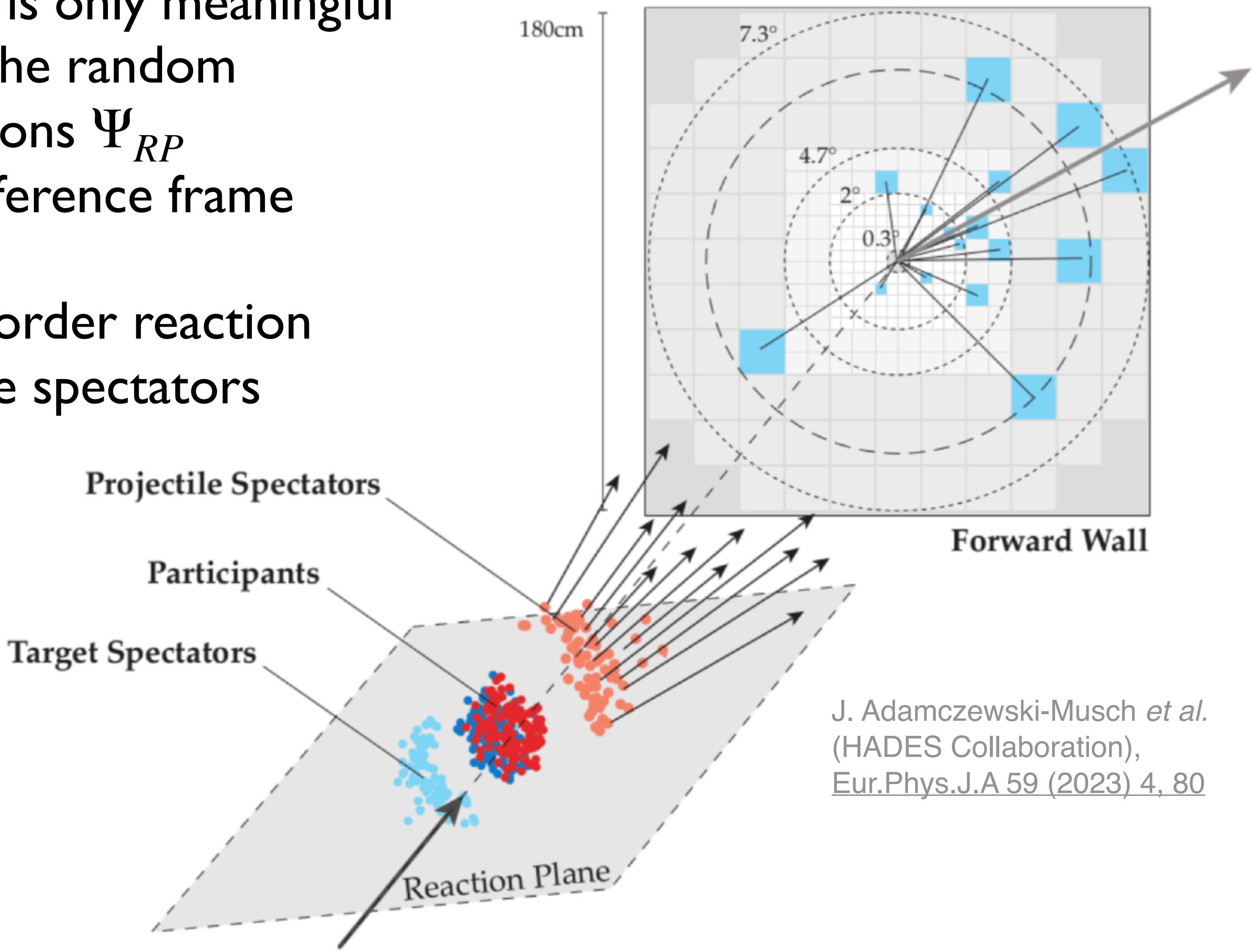


Event-plane reconstruction

- The azimuthal angle is only meaningful if we correct it for the random orientation of collisions Ψ_{RP} in the laboratory reference frame

- We obtain the first order reaction plane $\Psi_{EP,1}$ from the spectators measured in the Forward Wall

- We obtain
$$\Delta\phi = \phi_{Lab} - \Psi_{RP}$$



J. Adamczewski-Musch *et al.* (HADES Collaboration), Eur.Phys.J.A 59 (2023) 4, 80

Measurement of flow

- The azimuthal angle distribution can be described with a Fourier series:

$$\frac{dN}{d\Delta\phi} = \mathcal{N}\left(1 + 2\sum_n v_n \cos(n\Delta\phi)\right)$$

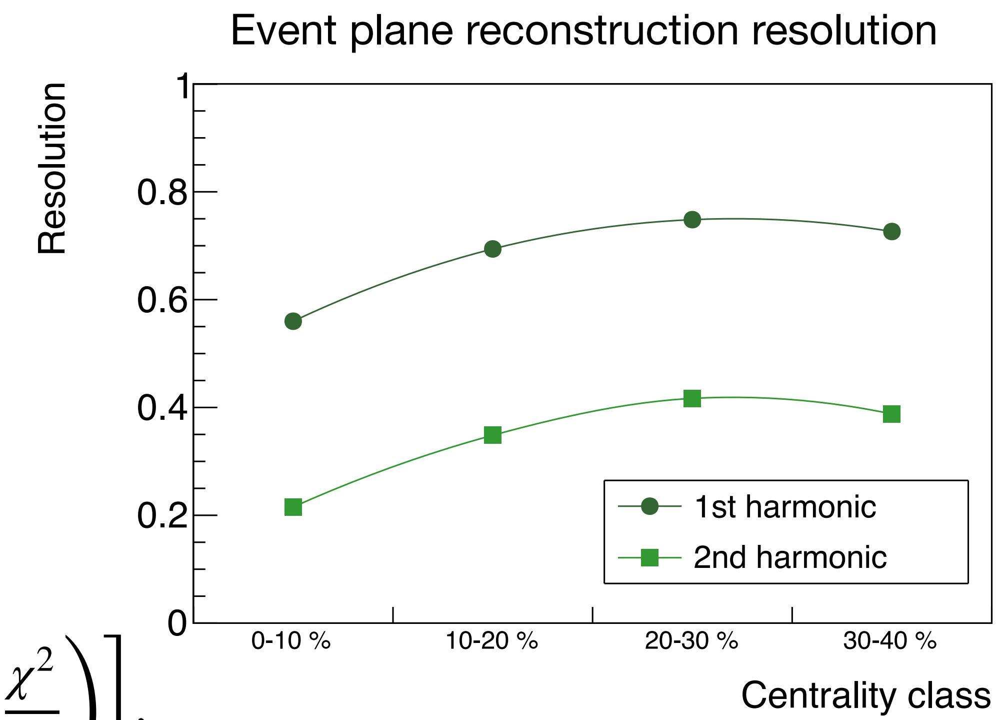
- The goal of flow analysis is to obtain maps of $v_{1,2,...}(p_t, y_0)$

- Notice:

  - v_1 is called directed flow and v_2 is called elliptic flow
  - collision symmetry enforces $v_1(y) = -v_1(-y)$
    from which follows that $v_1(y_{CM}) = 0$

Event-plane reconstruction resolution

- Standard method by J.-Y. Ollitrault was used to correct for the finite resolution of event plane reconstruction
(J.-Y. Ollitrault, arXiv:9711003 [nucl-ex])



- Divide the spectators into two random sub-events (A and B) and evaluate $\Delta\Psi_{AB} = \Psi_A - \Psi_B$

- Resolution for n-th harmonic is:

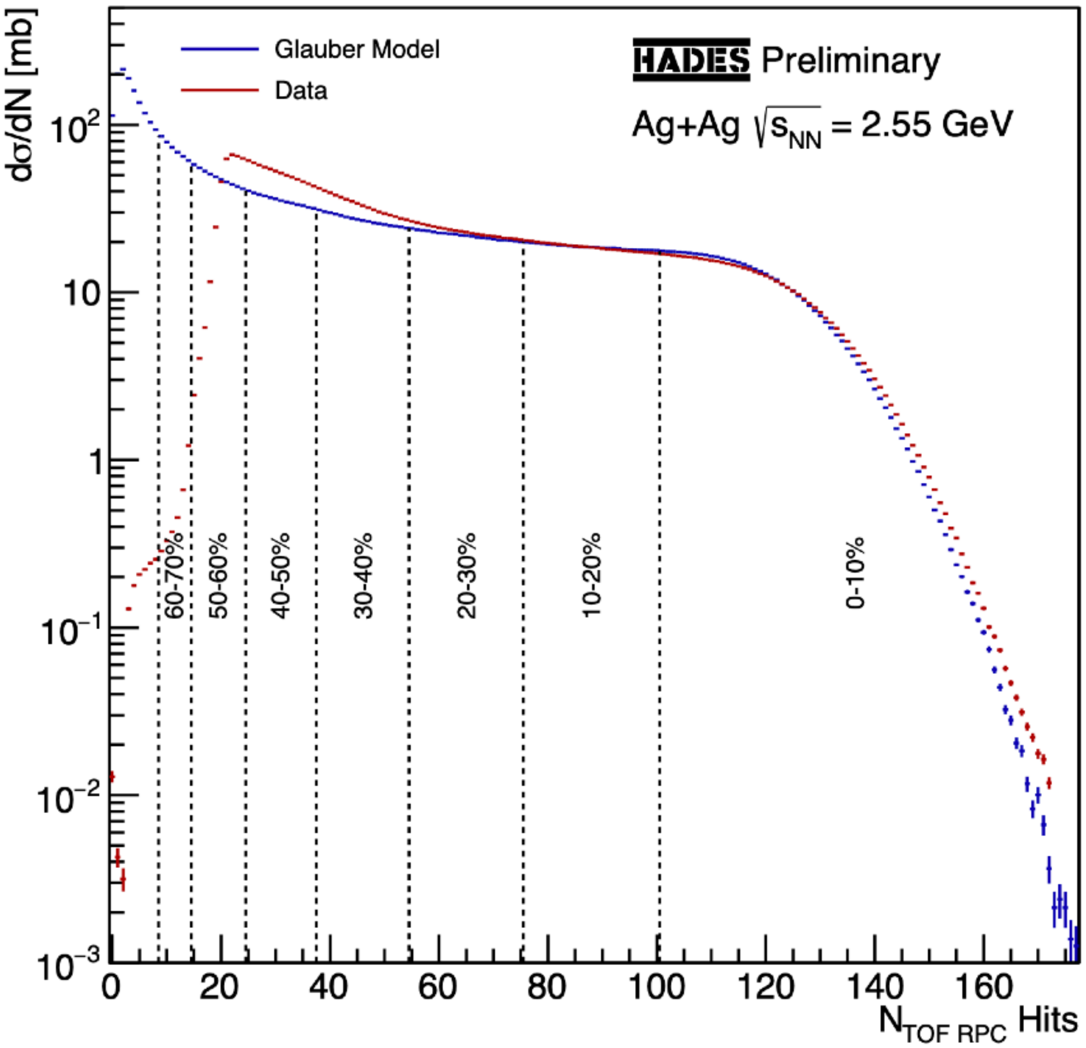
$$\mathscr{R} = \frac{\sqrt{\pi}}{2} \cdot \chi \cdot \exp\left(-\frac{\chi^2}{2}\right) \cdot \left[I_{\frac{n-1}{2}}\left(\frac{\chi^2}{2}\right) + I_{\frac{n+1}{2}}\left(\frac{\chi^2}{2}\right)\right],$$

where

$I_k(x)$ is the modified Bessel function of the first kind and $\chi^2 = -2\ln\left(\frac{2 \cdot \Delta\Psi_{AB}(90^\circ - 180^\circ)}{\Delta\Psi_{AB}(0^\circ - 180^\circ)}\right)$

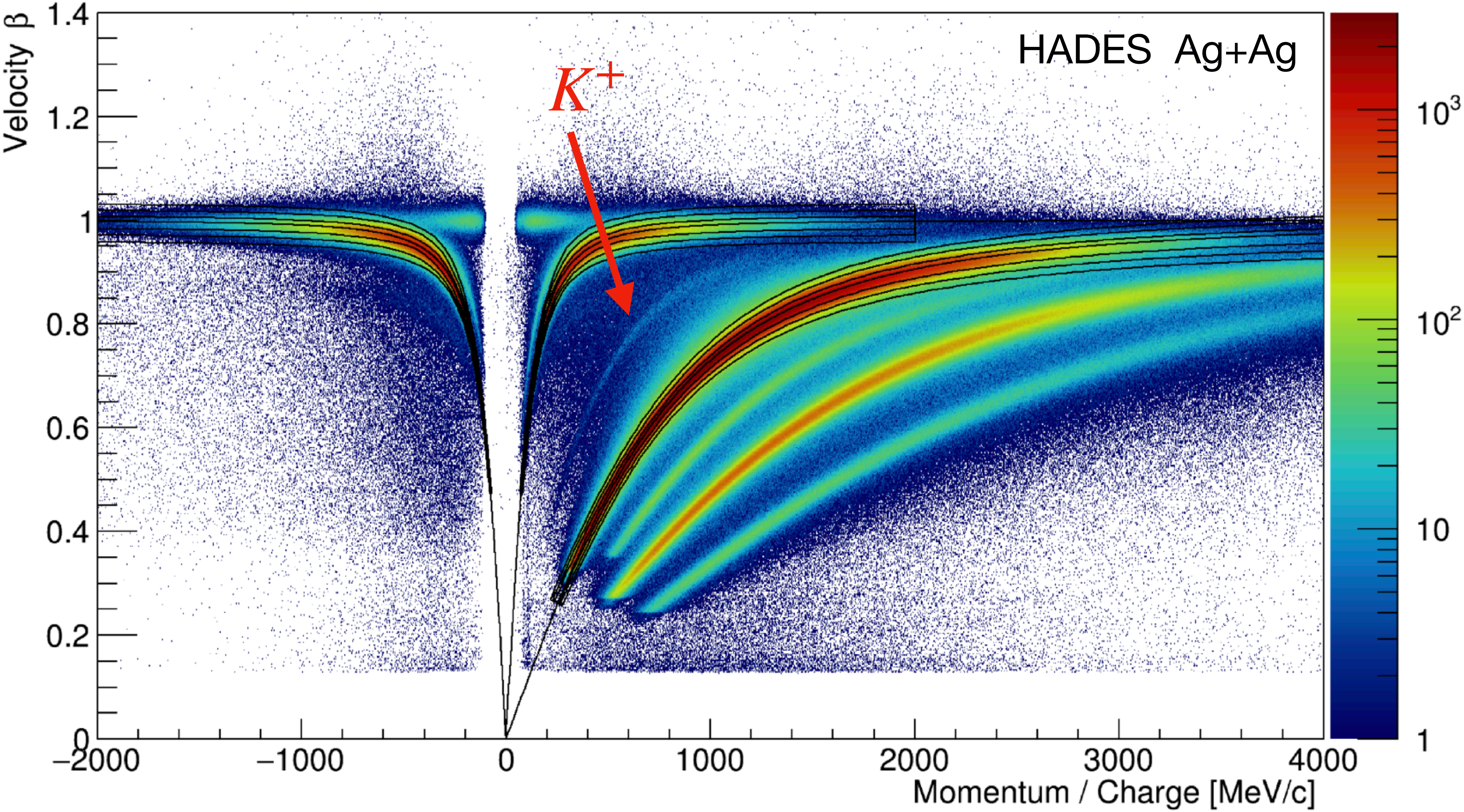
Ag+Ag dataset

- Ag+Ag collisions at 1.58*A* GeV energy – 30 days of statistics used;



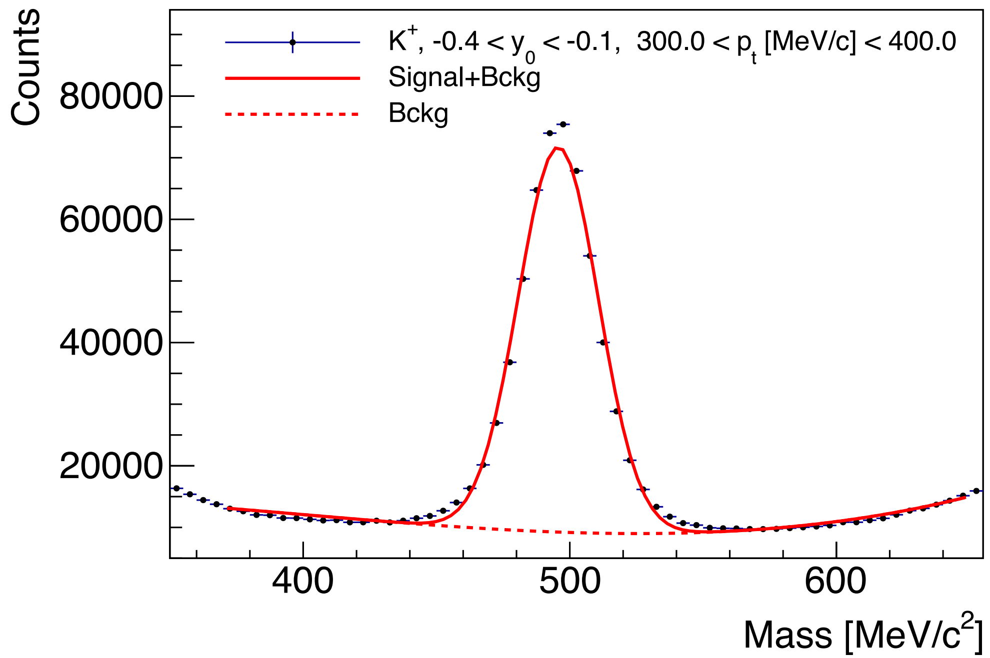
- Centrality determination based on number of hits in the ToF and RPC detectors
- Selected centrality class: 10-40 %
- About $2.6 \cdot 10^9$ collisions at disposal within this class
- Additional track cuts are used to purify the data (details in backup)

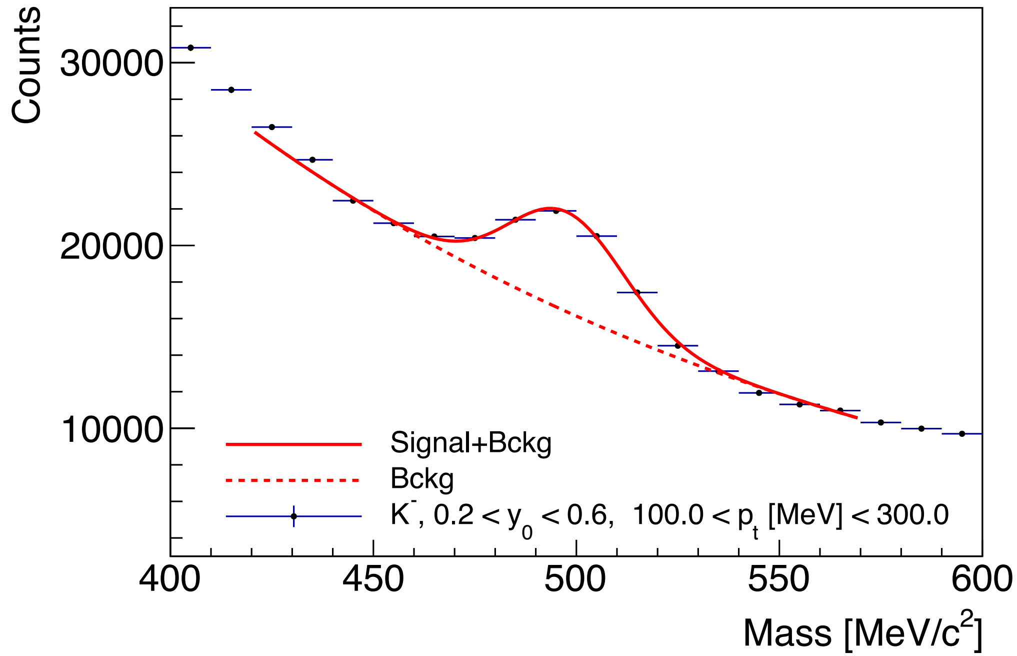
HADES p vs. β distribution



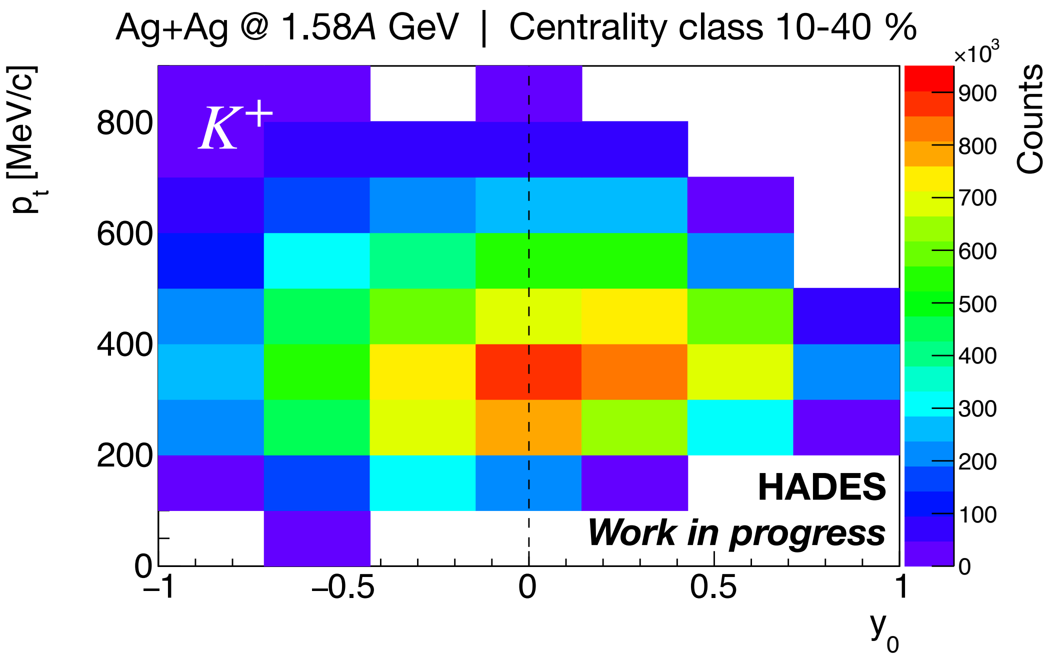
Identification of $K^{\pm}$

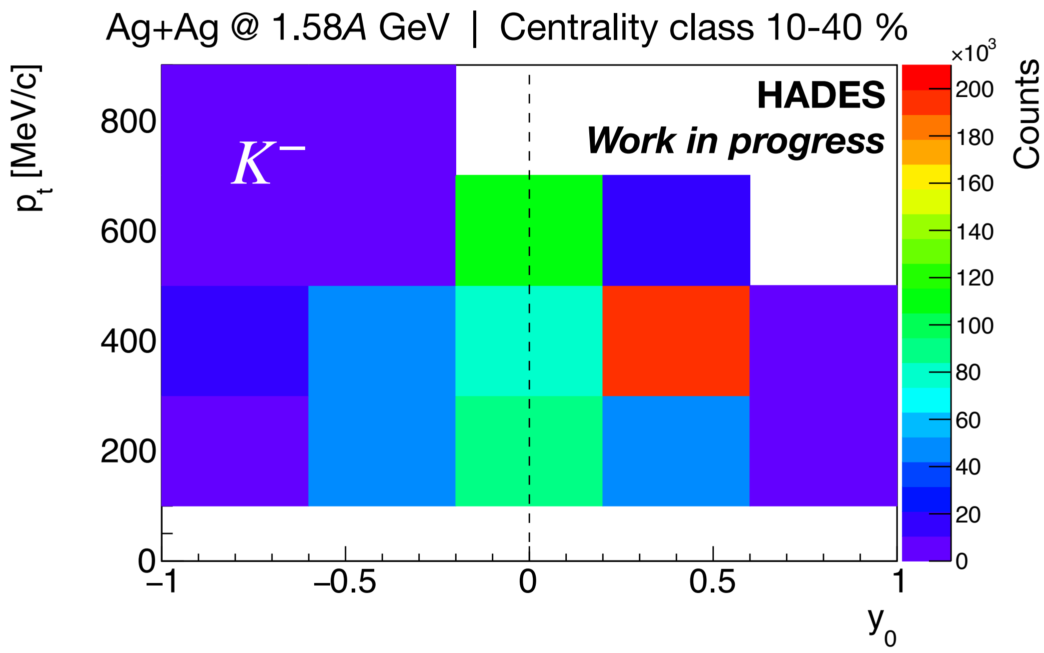
- Mass spectrum from time-of-flight measurement shows Gaussian peak around $K^{\pm}$ mass
- Background modelled with polynomial of 3rd degree (K^{+}) or exponential (K^{-})
- Independent fits in p_T , y_0 and $\Delta\phi$ bins yield a 3D phase-space distribution of K^{+} mesons
- **Signal measurement must be sensitive to small variations in kaon signal!**





Raw $p_t : y$ distributions of $K^{\pm}$ mesons

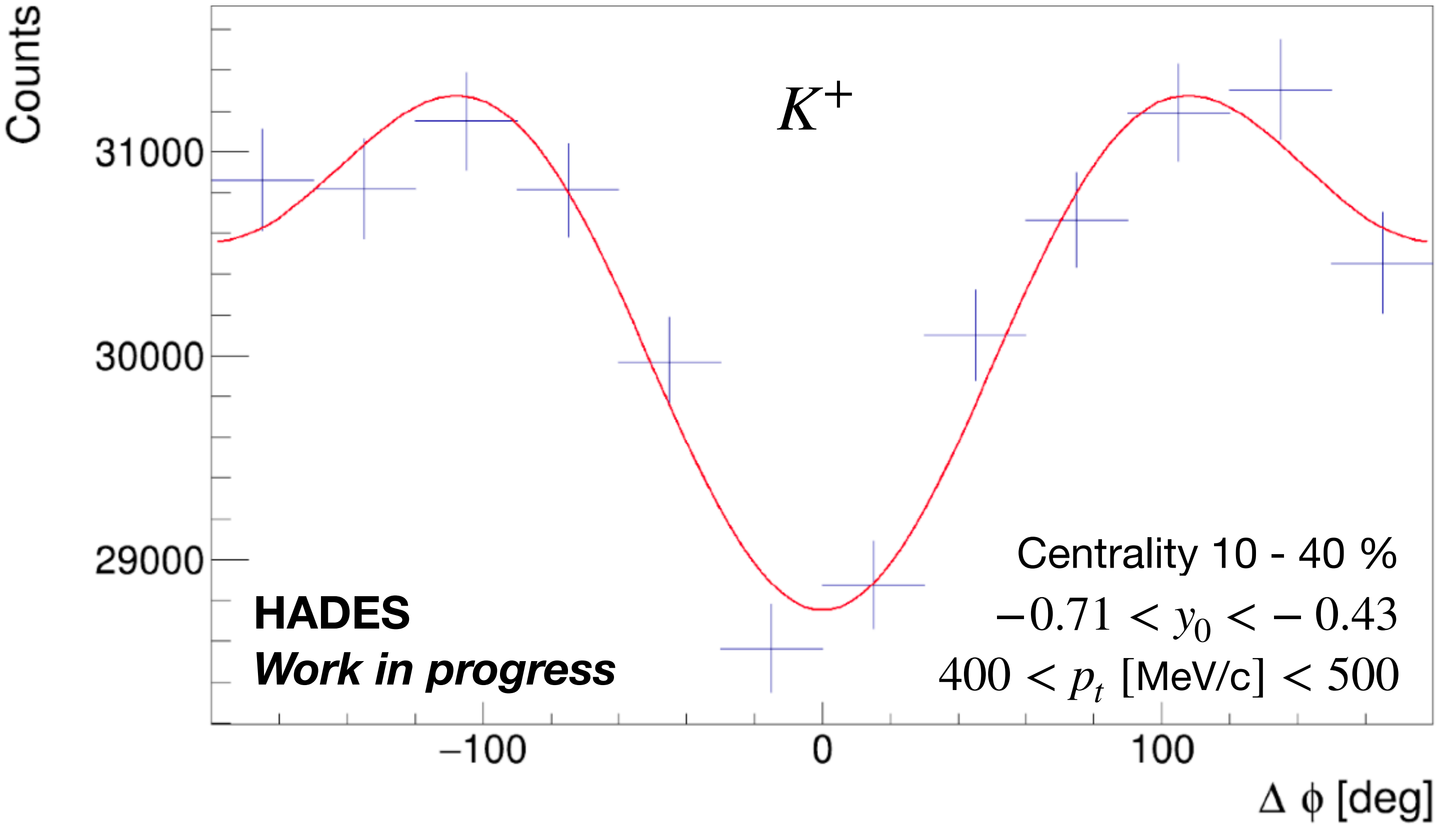




➠ $8.6 \cdot 10^6$ of K^+ and $6.7 \cdot 10^5$ of K^- reconstructed — no efficiency correction

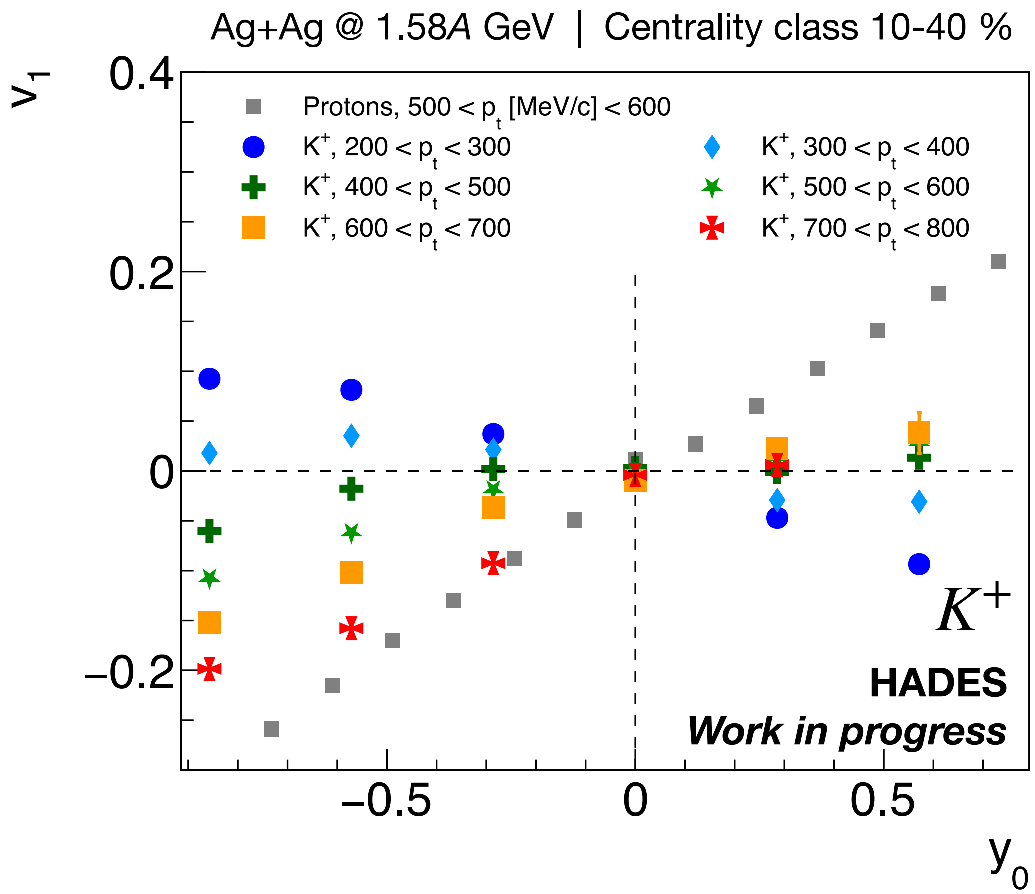
➠ HADES provides a very wide acceptance for both particles

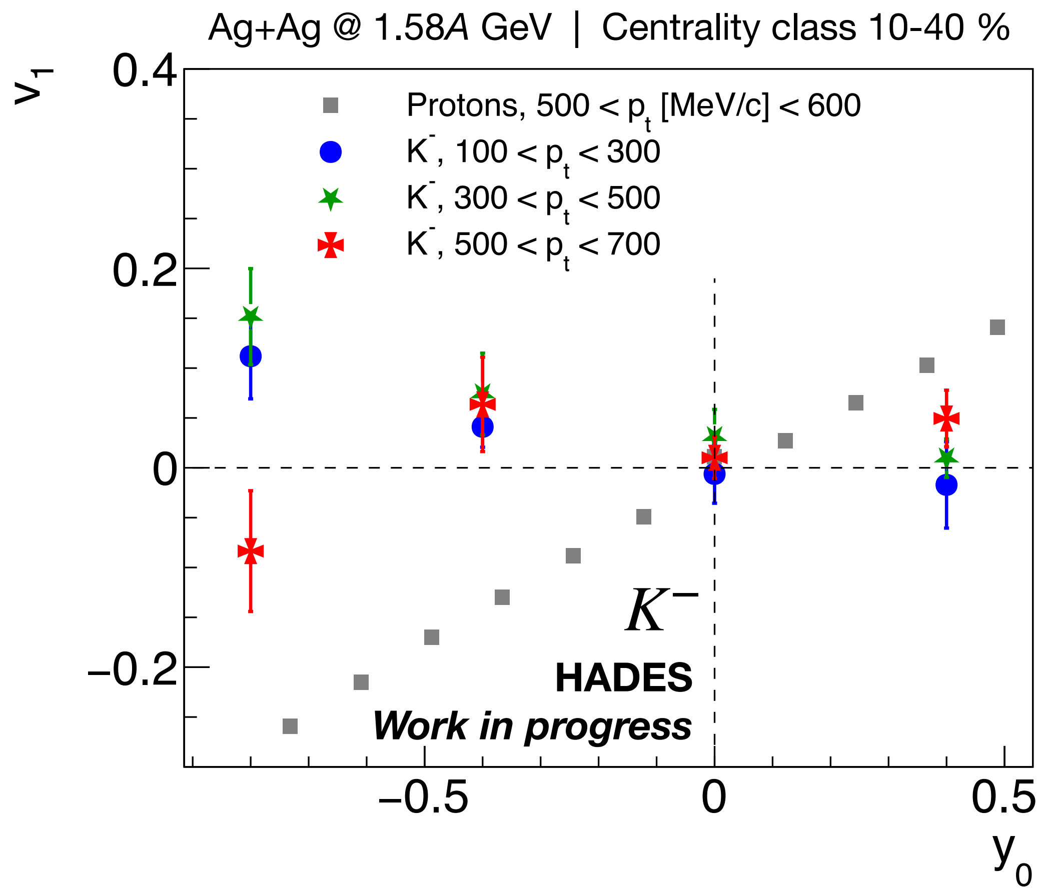
Fourier analysis



- The $\Delta\phi$ distribution for given p_t and y_0 is used to obtain flow coefficients
- For this cell, $v_1 = -0.0149 \pm 0.0015$ and $v_2 = -0.0122 \pm 0.0016$.

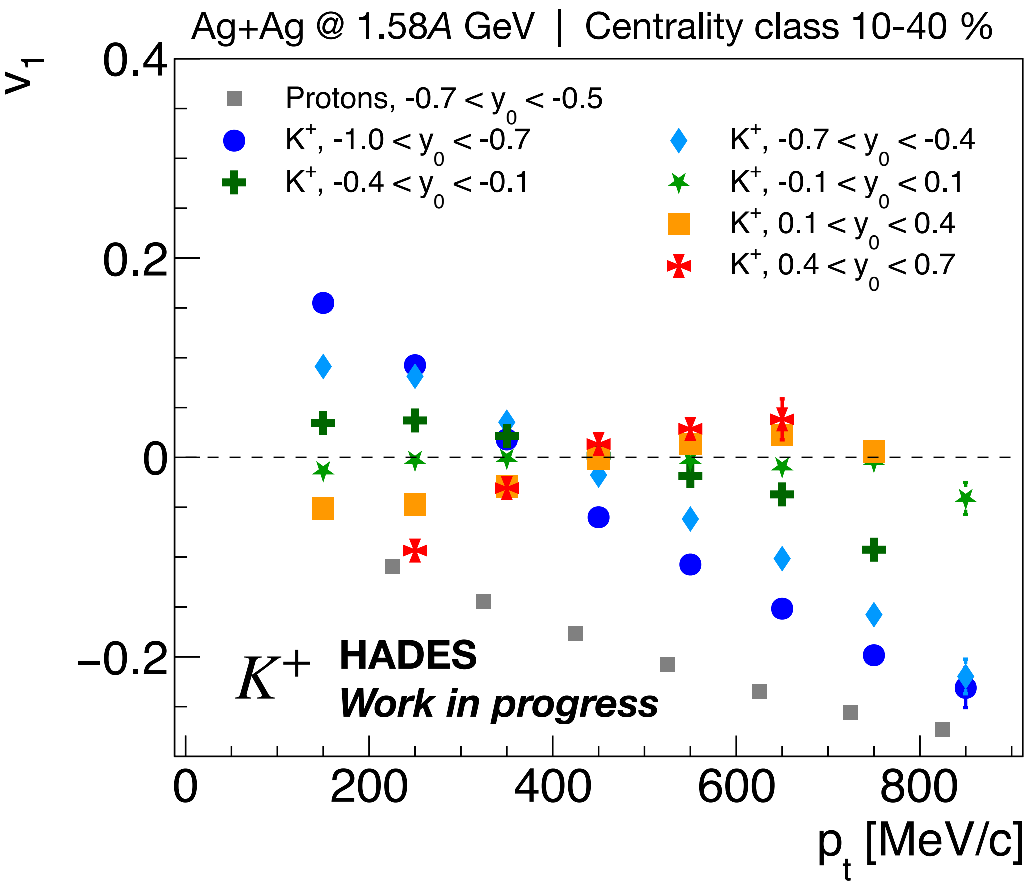
Directed flow (v_1) of $K^{\pm}$ as function of y_0

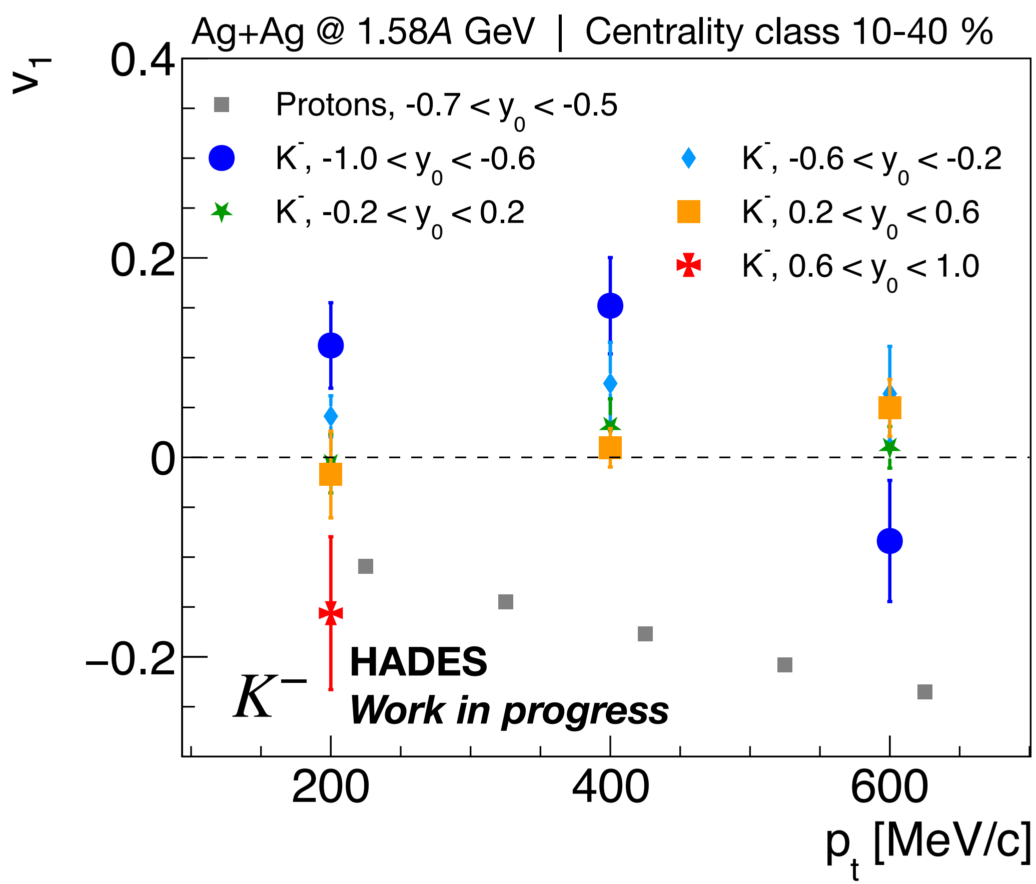




➠ Note: track occupancy effects are not yet corrected.

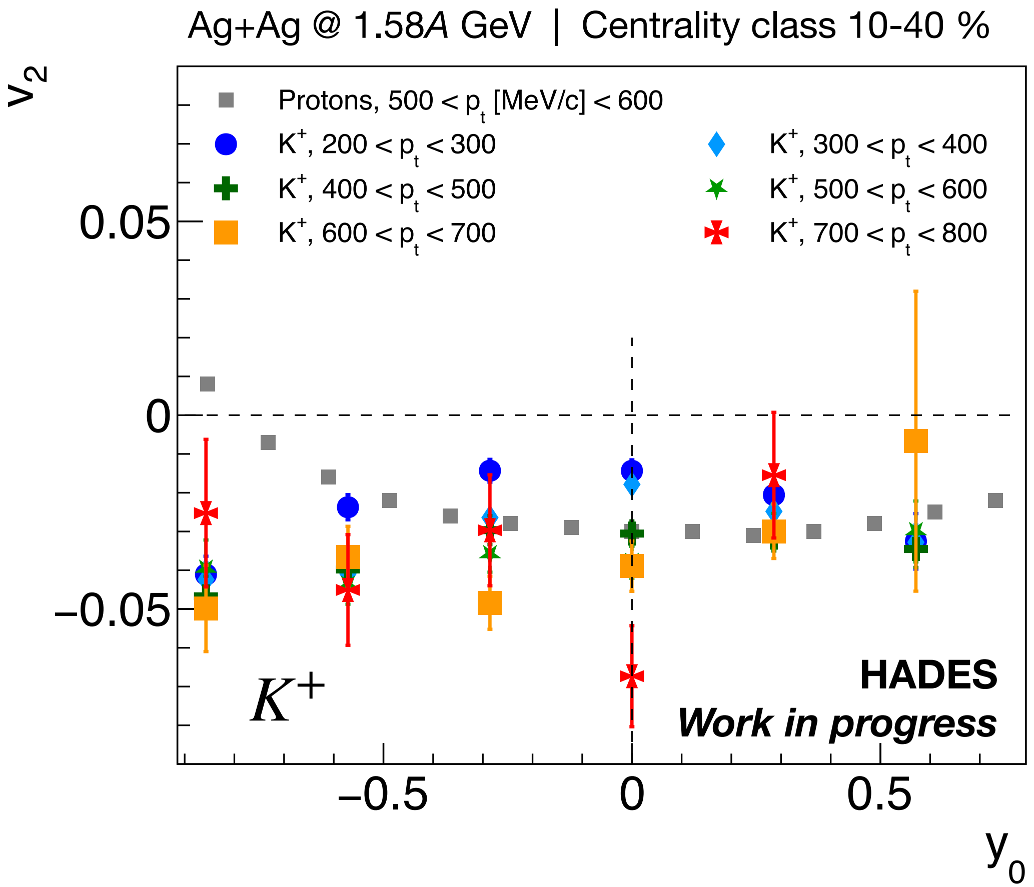
Directed flow (v_1) of $K^{\pm}$ as function of p_T

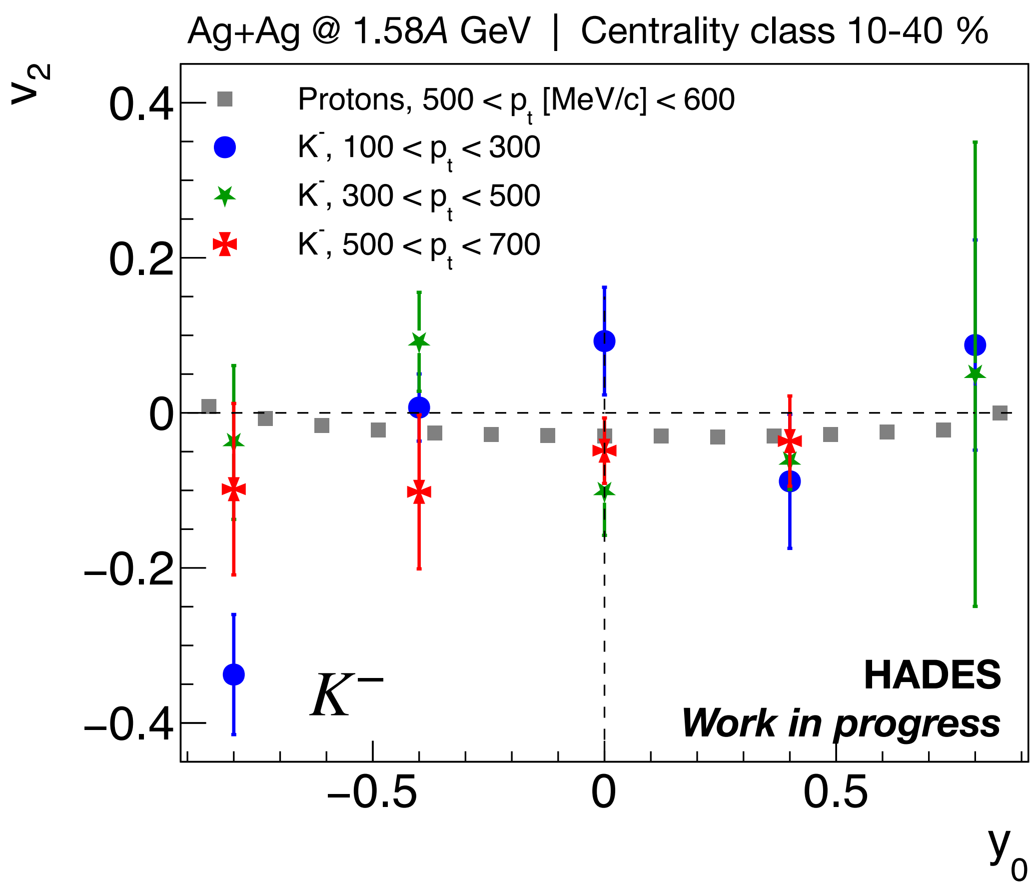




➠ Note: track occupancy effects are not yet corrected!

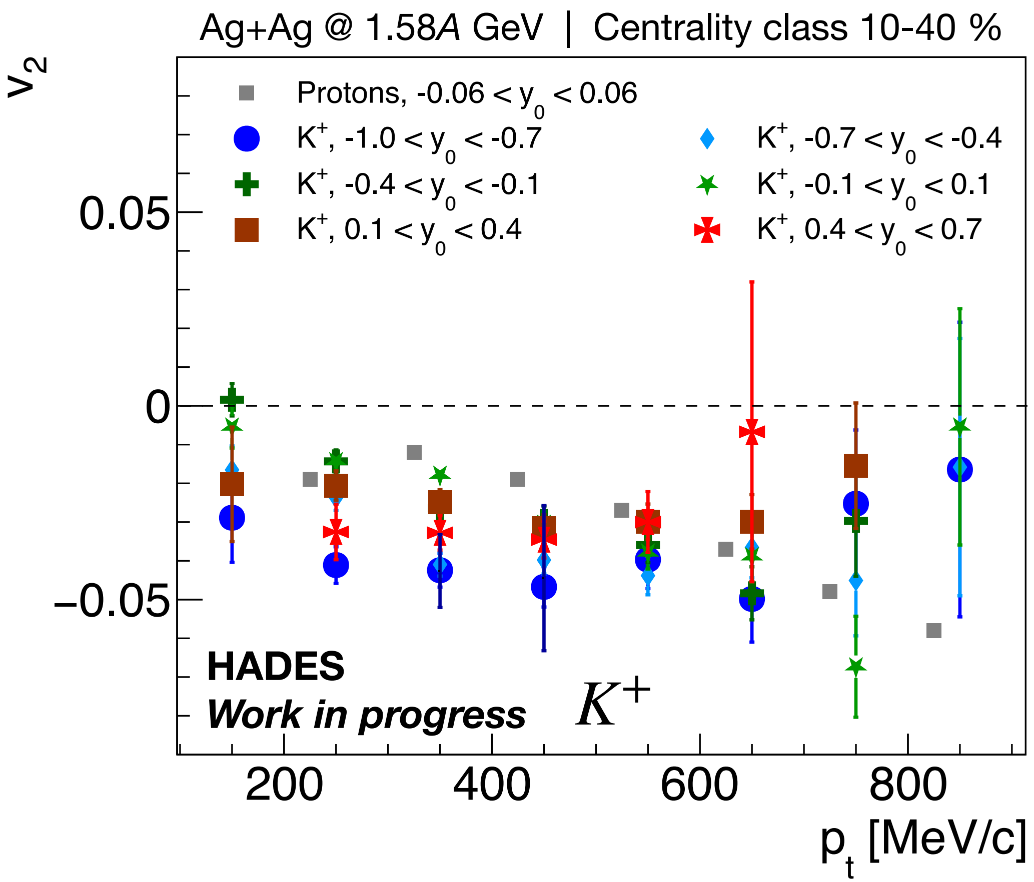
Elliptic flow (v_2) of $K^{\pm}$ as function of y_0

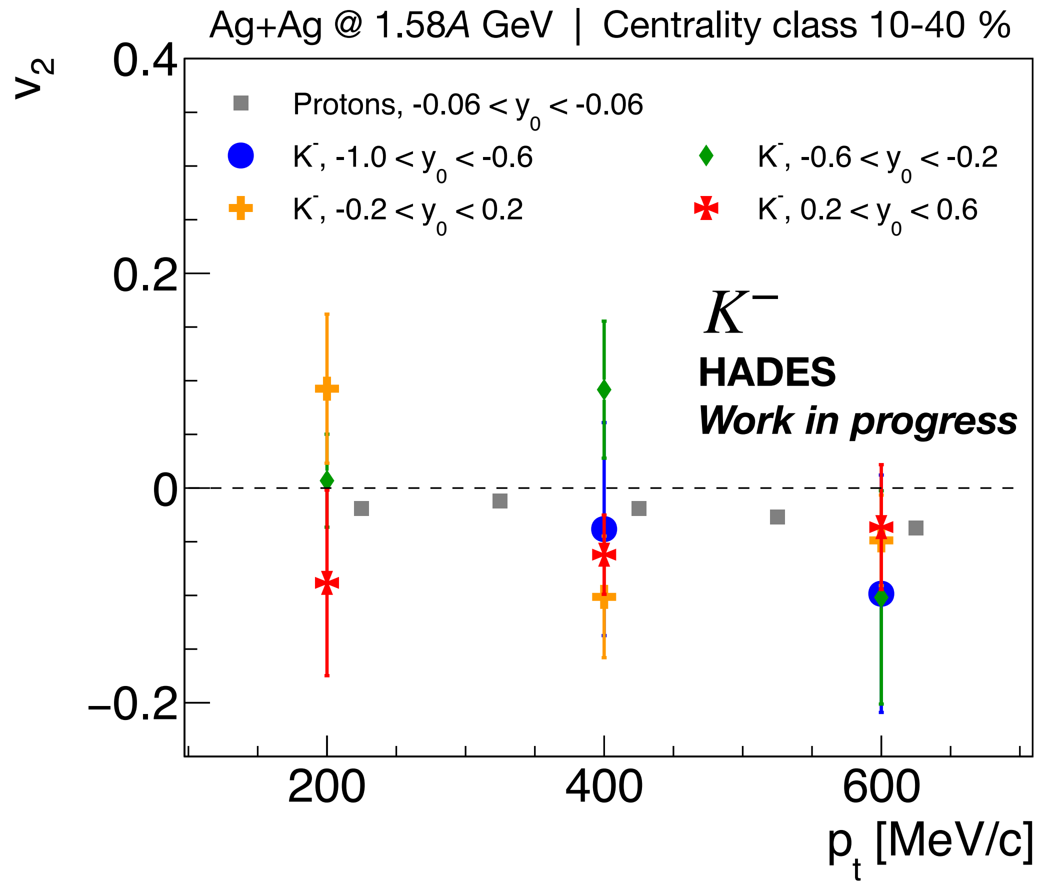




➠ Note: track occupancy effects are not yet corrected!

Elliptic flow (v_2) of $K^{\pm}$ as function of p_T





➠ Note: track occupancy effects are not yet corrected!

Summary and outlook

- Kinematic distributions of $K^{\pm}$ mesons were studied in three dimensions
- Distributions in the $\Delta\phi$ variable were used to study the transverse flow effect of these particles
- $v_1(y)$ for $K^{\pm}$ mesons with low transverse momenta shows strong 'antiflow' compared to protons - result of repulsion of kaons by nuclear matter...?
- PhD project in progress:
  - track occupancy correction and evaluation of systematic errors
  - compare the results to state-of-the-art transport models
  - extend analysis to other strange hadrons (K^0_S, Λ, ϕ)

Thank you for your attention!

BACKUP SLIDES

Relativistic momentum phase space

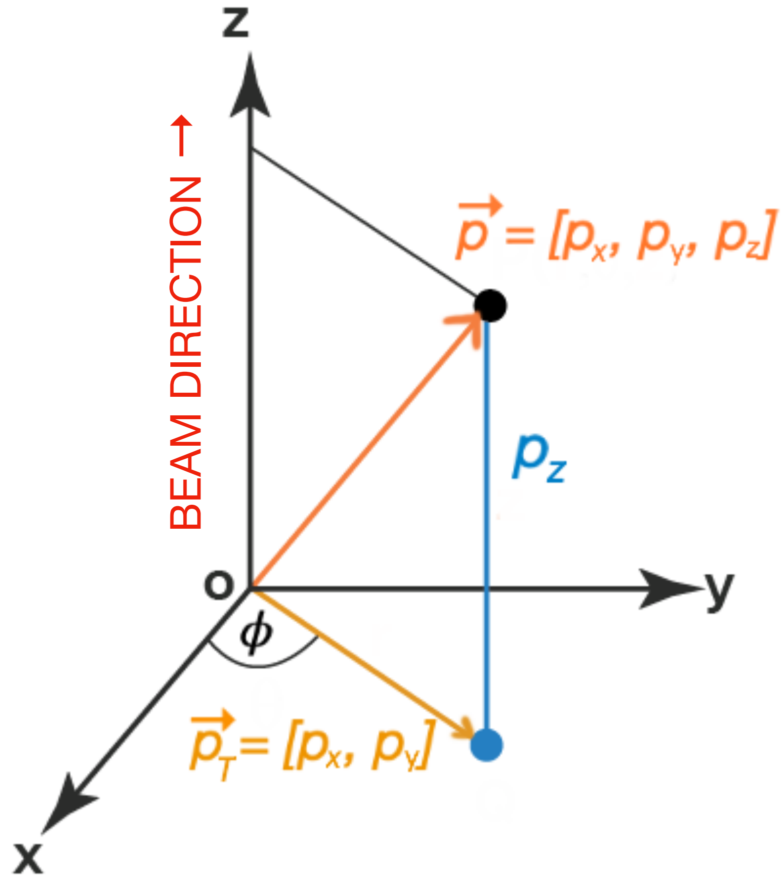
- Rapidity $y_i \equiv \text{atanh}(\beta_i)$, where $\beta_i = \dfrac{v_i}{c}$

- "Usual" description of spectra is two-dimensional:

$$p_T \equiv |\overrightarrow{p_T}|$$

$$y \equiv y_Z \qquad y_0 = \frac{y - y_{CM}}{y_{CM}}$$

- Notice! We collapse 3D → 2D. Information about the ϕ angle is lost in such an approach.



Track selection

Particle	K^+		K^-	
META detector	**RPC**	**ToF**	**RPC**	**ToF**
χ^2 **of** p **reconstr.** **Meta matching Q** **N. MDC Layers** **dist to vertex** ***m* [MeV/c²]**	≤ 100 ≤ 2 > 19 ≤ 20 ∈ (340, 660)			
***p* [MeV/c]**	∈ (200, 1200)	∈ (150, 900)	∈ (200, 950)	∈ (200, 800)
dE/dx (MDC) [a.u.] **dE/dx (MDC) * p [a.u.]** **dE/dx (ToF) *** $\beta\gamma$ **[a.u.]**	∈ (1, 9) - -	∈ (1.1, 17) ∈ (580, 3000) ∈ (0.25, 3.2)	- ∈ (800, 2500) -	∈ (2, 5) > 900 ∈ (1, 2.5)

FOPI results of $K^{\pm}$ flow

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