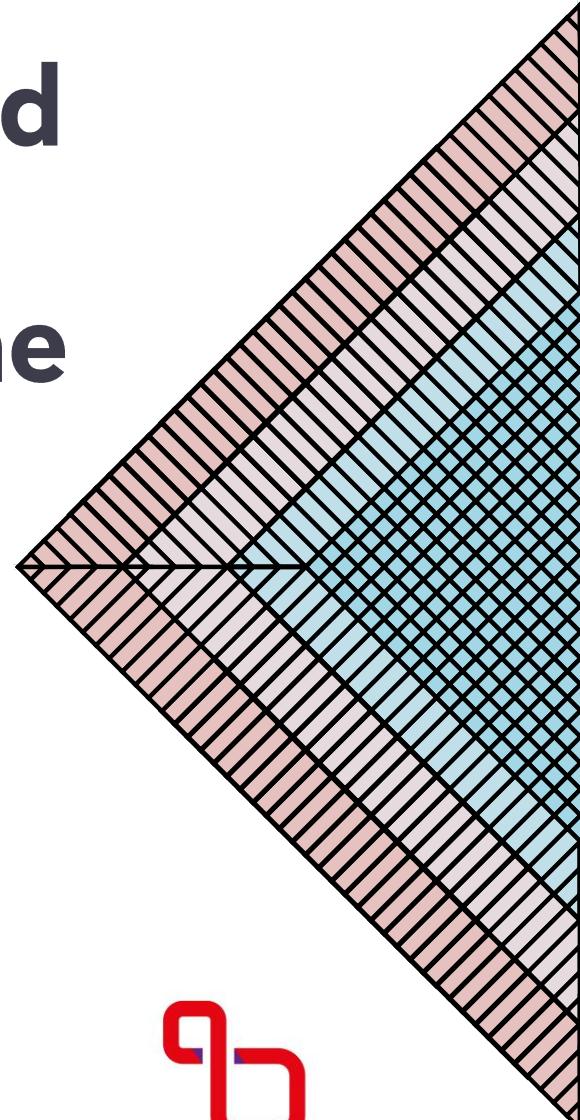


Spheroidal expansion and freeze-out geometry of heavy-ion collisions in the few-GeV energy regime

Author: Jędrzej Kołaś

In collaboration with: Wojciech Florkowski, Tetyana Galatyuk, Małgorzata Gumberidze, Szymon Harabasz, Małgorzata Kurach, Radosław Ryblewski, Piotr Salabura, Joachim Stroth, and Hanna Zbroszczyk



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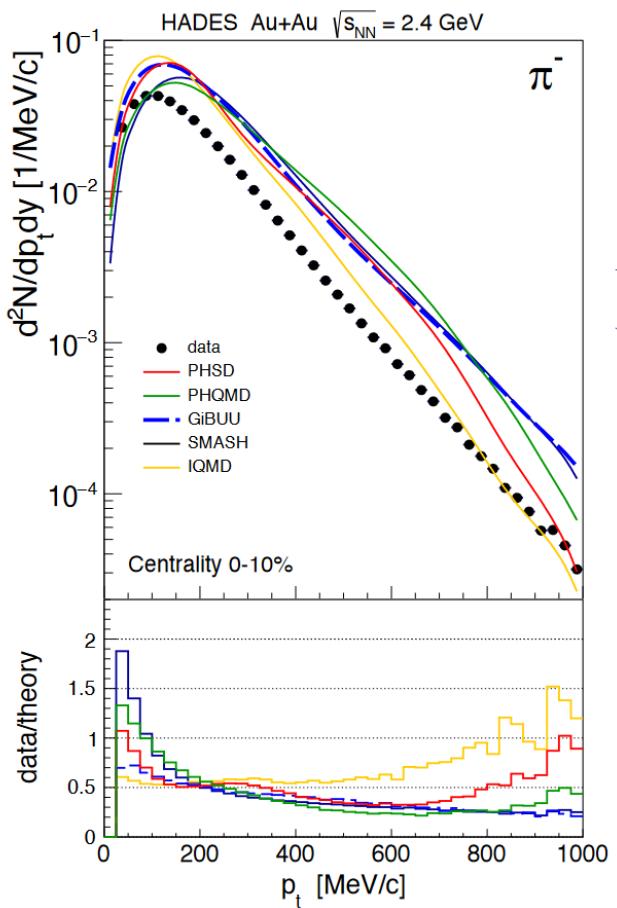
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Motivation

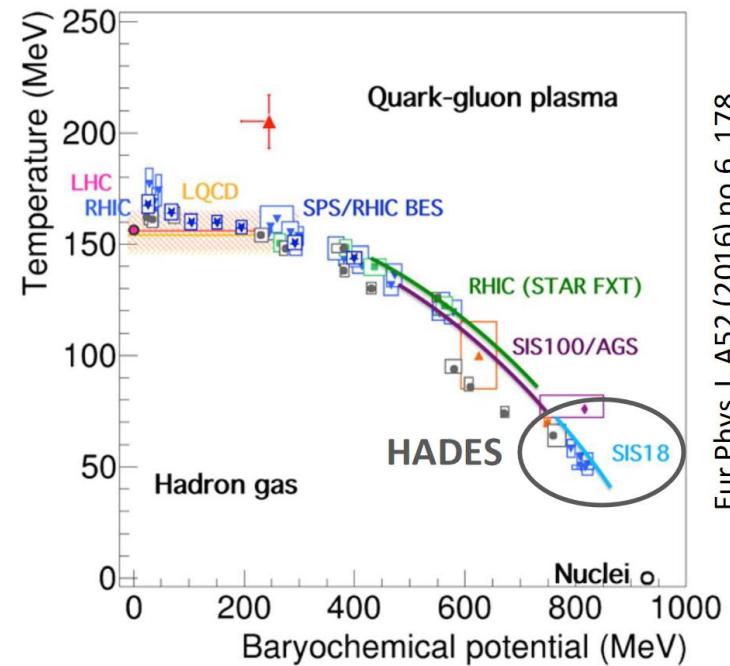
- Transport models failed to reproduce HADES data
- The prompt for „alternative” approaches
- Our take: THERMINATOR 2



HADES Collaboration, Eur.Phys.J.A 56 (2020) 10,259

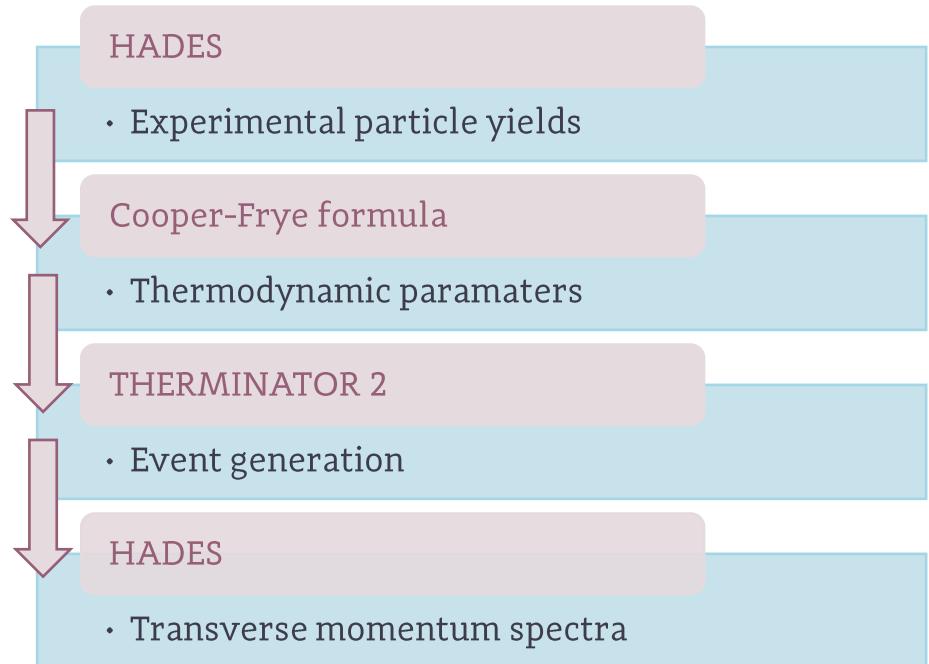
The Area of Study

- Low collision energy
- High baryochemical potential
- Experiment of choice: HADES
- System:
 - Au+Au
 - $\sqrt{s_{NN}} = 2.4 \text{ GeV}$
 - 0-10% centrality
- Thermalisation?



THERMINATOR 2

- SHM-based model
(Cooper-Frye)
- Single freeze-out
- Decay list: standard SHARE package + excited states of nuclei
- Femtososcopic afterburner
(Adam Kisiel's weights algorithm)



The Siemens-Rasmussen Spheroidal Model

➤ Based on the blast wave model of Siemens and Rasmussen (*Physical Review Letters* 42.14 (1979): 880)

➤ Includes following changes:

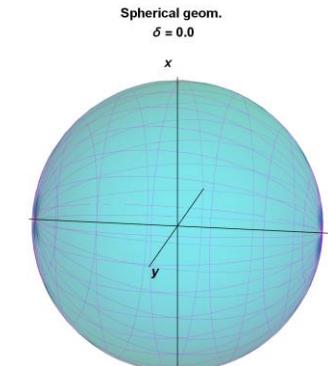
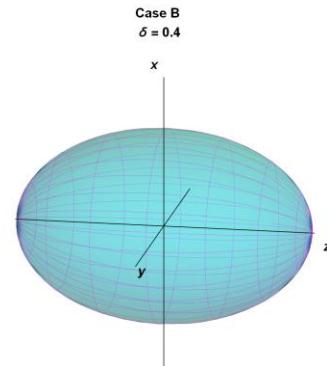
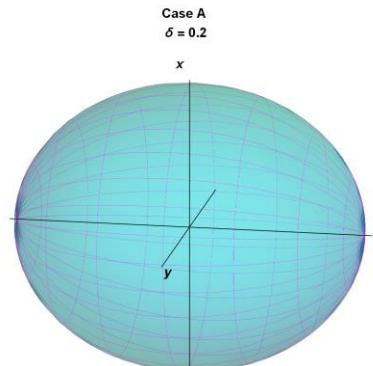
➤ Radial flow profile:

$$v(r) = \tanh(H r)$$

➤ Spheroidal symmetry:

$$x^\mu = (t, r\sqrt{1 - \epsilon} \cos \phi \sin \theta, r\sqrt{1 - \epsilon} \sin \phi \sin \theta, r\sqrt{1 + \epsilon} \cos \theta)$$

$$u^\mu = \gamma(\xi)(t, v(\xi)\sqrt{1 - \delta} \cos \phi \sin \theta, v(\xi)\sqrt{1 - \delta} \sin \phi \sin \theta, v(\xi)\sqrt{1 + \delta} \cos \theta)$$



Physical Review C 107.3 (2023): 034917

Jędrzej Kołas, XVI Polish Workshop on Relativistic Heavy-Ion Collisions

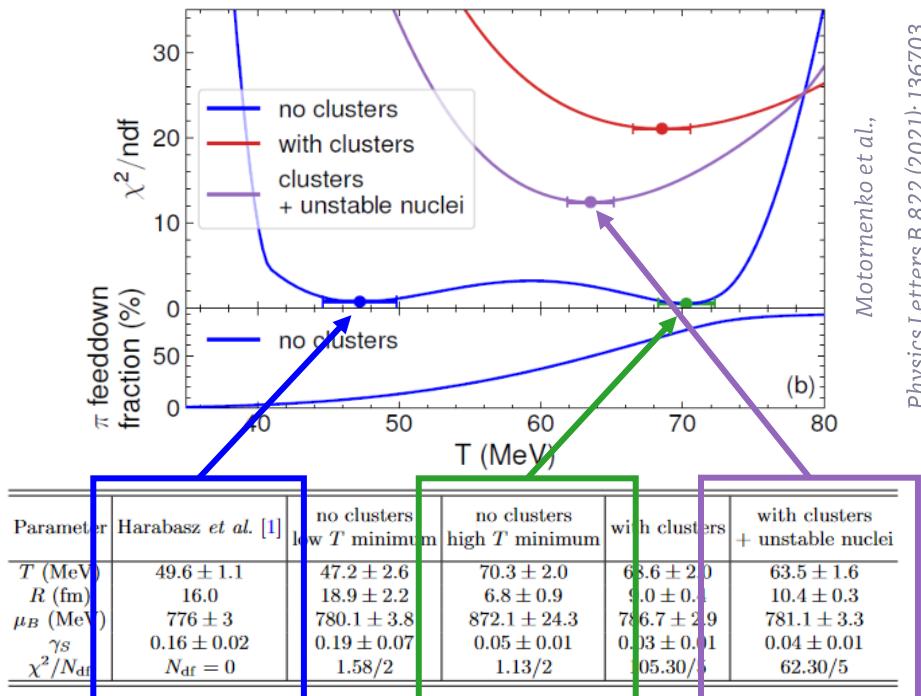
„Kinematic” Parameters Estimation



$$Q^2 = \sqrt{\frac{1}{N} \sum_{i=1}^N \frac{(Y_{i,model} - Y_{i,exp})^2}{{Y_{i,exp}}^2}}$$

Thermodynamic Landscape of HADES

- Our model was tested with results from Motornenko *et al.*
- Later denoted as:
 - Case A
 - Case B
 - Case C
- Different approach to light nuclei production:
 - Cases A and B – coalescence
 - Case C - thermal



Spherical vs Spheroidal

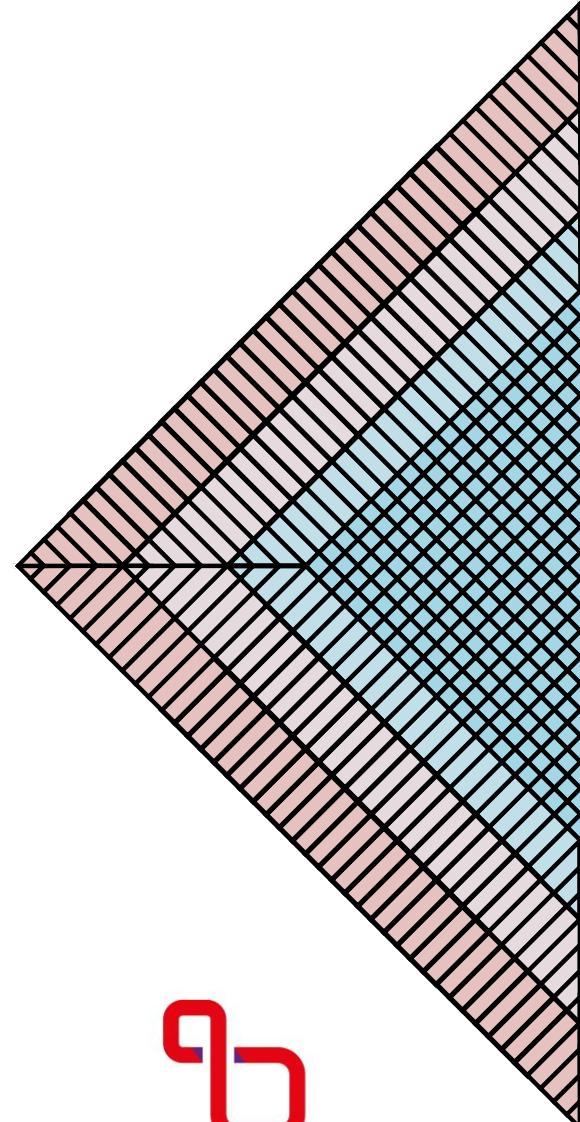


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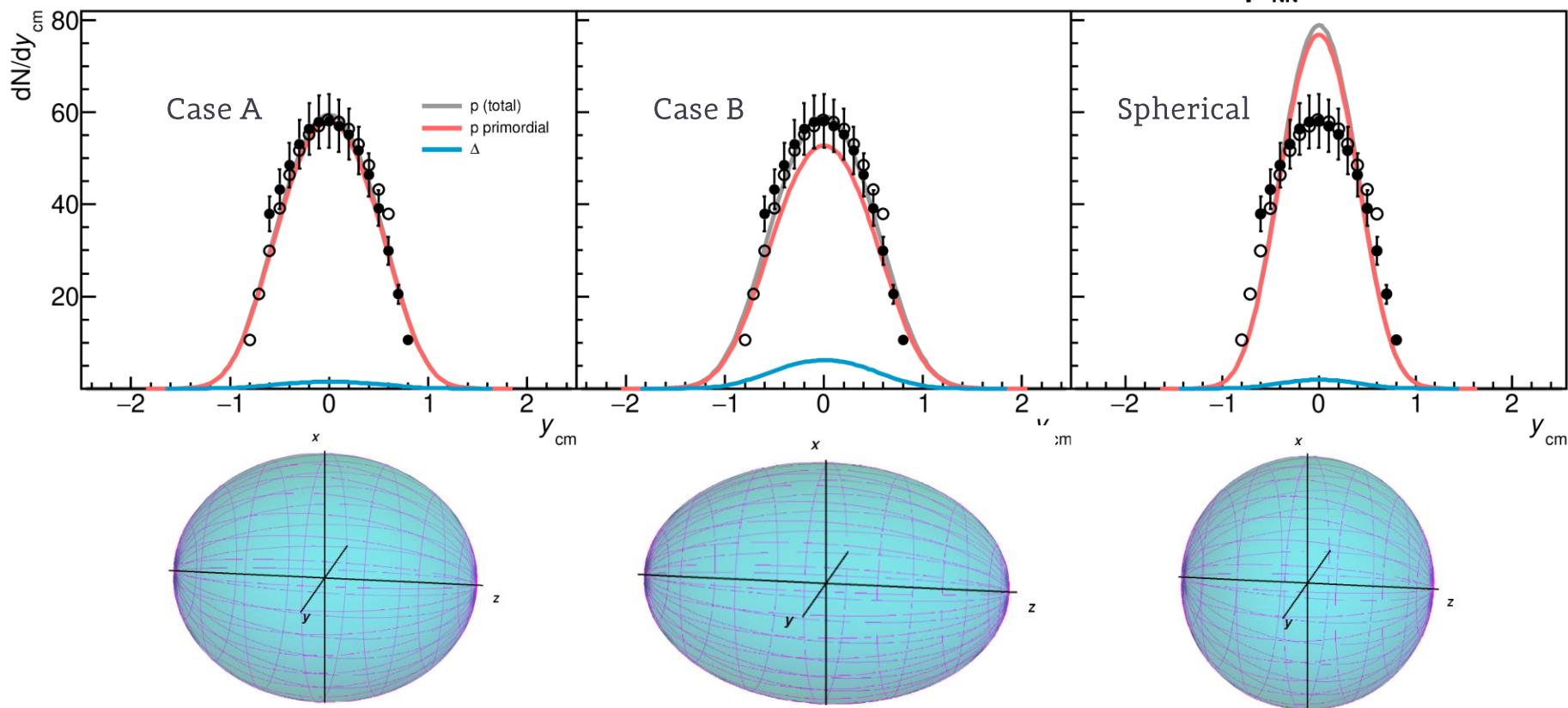


Rapidity Distribution (proton)

Physical Review C 107.3 (2023): 034917

Szala, Melanie. "Proton and Light Nuclei from Au+ Au Collisions at." Domenico Elia Giuseppe E. Bruno Pietro Colangelo (2020): 297

Au + Au $\sqrt{s_{NN}} = 2.4 \text{ GeV}$ (0 - 10%)

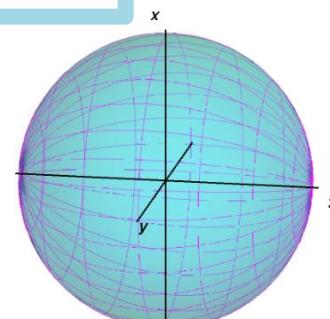
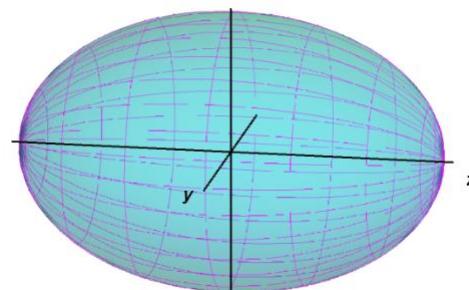
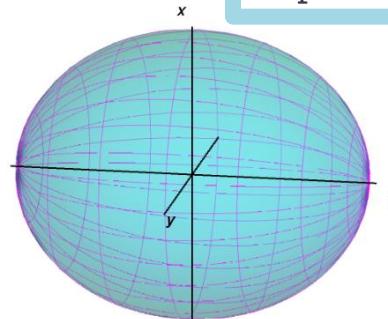
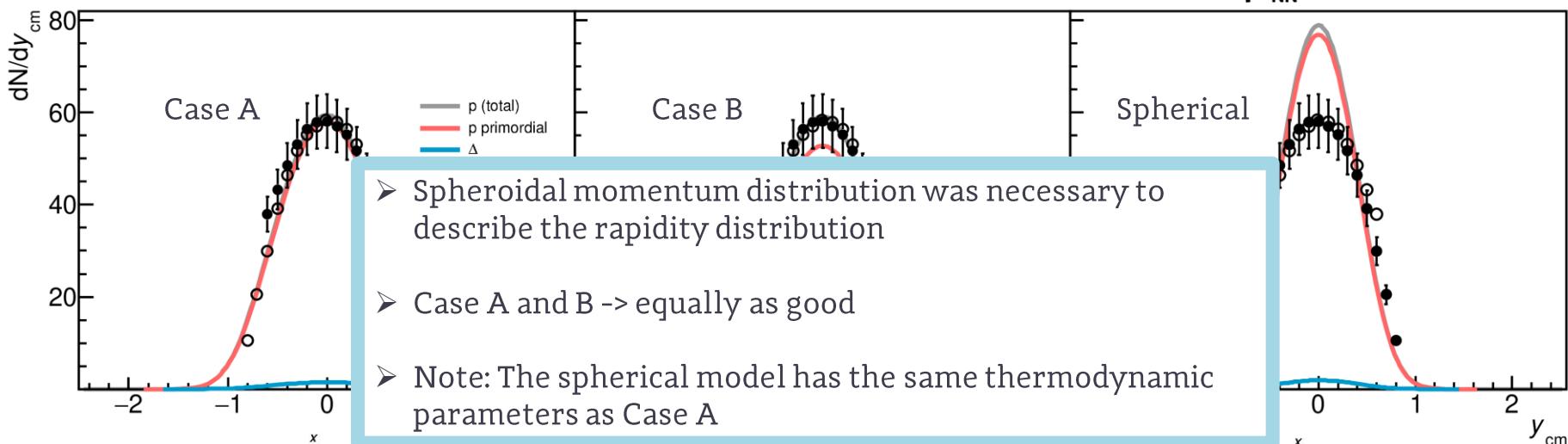


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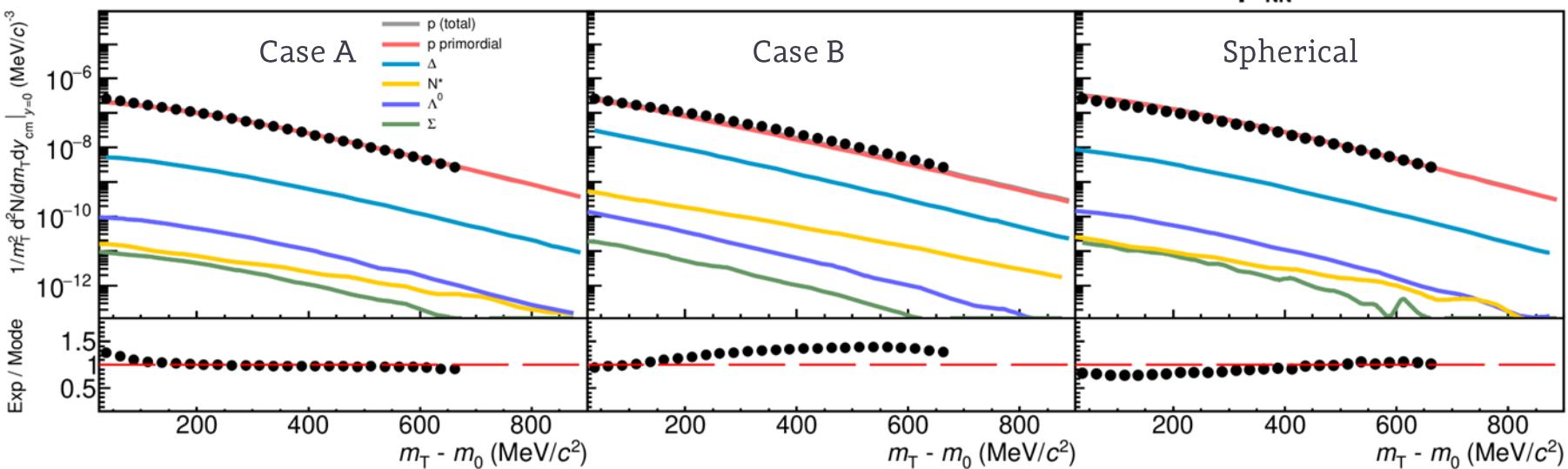
Transverse Momentum Spectra (proton)

Physical Review C 107.3 (2023): 034917

Szala, Melanie. "Proton and Light Nuclei from Au+ Au Collisions at." Domenico Elia

Giuseppe E. Bruno Pietro Colangelo (2020): 297

Au + Au $\sqrt{s_{NN}} = 2.4 \text{ GeV}$ (0 - 10%)

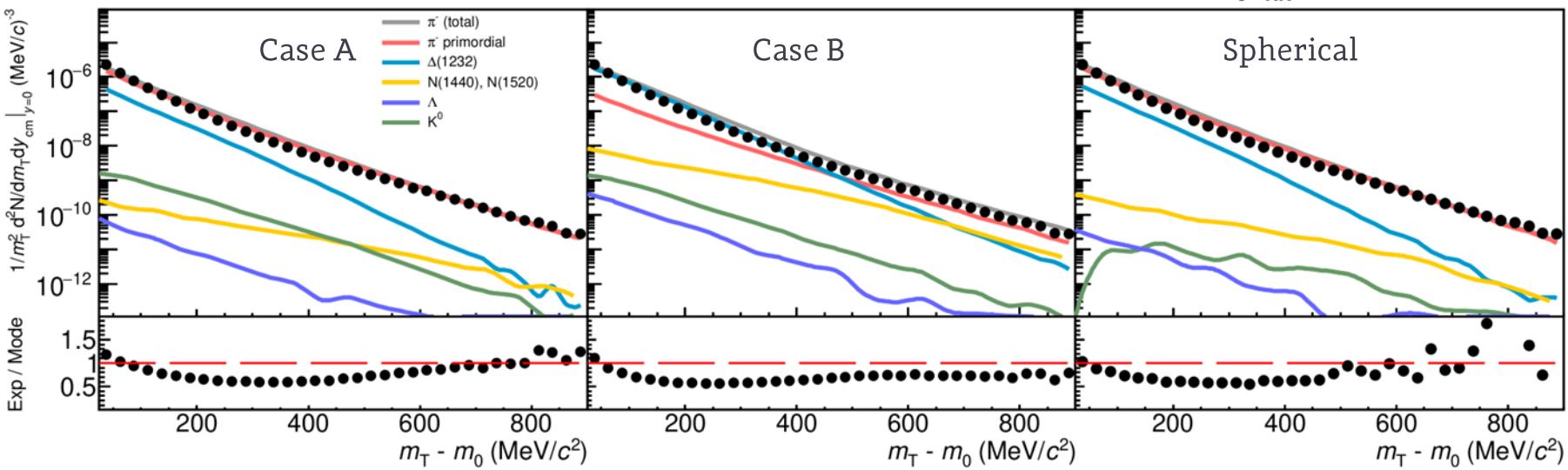


- Similarly good agreement
- Thermal protons → dominant contribution
- Spherical is just as good as spheroidal → no noticeable difference without looking at the rapidity

Transverse Momentum Spectra (negative pion)

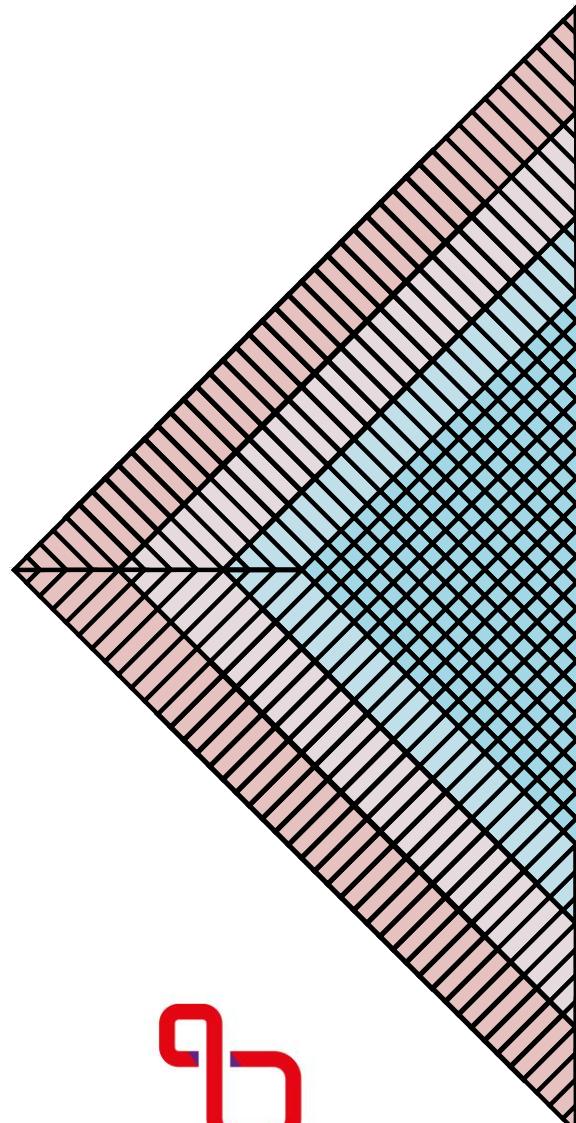
Physical Review C 107.3 (2023): 034917
Eur.Phys.J.A 56 (2020) 259

Au + Au $\sqrt{s_{NN}} = 2.4 \text{ GeV}$ (0 - 10%)



- Similarly good agreement
- Case B shows a „double slope“ ($\Delta(1232)$ + primordial decay)
- $\Delta(1232)$ decay becomes a dominant contribution below 500 MeV for Case B
- Coulomb effect is visible (< 100 MeV)

Coalescence vs Thermal



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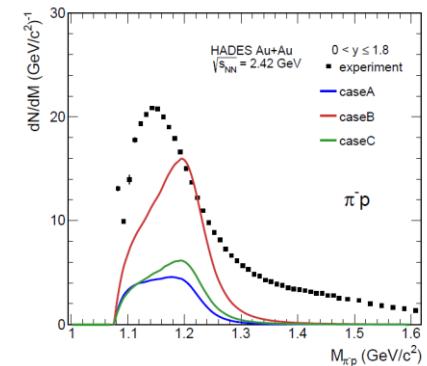
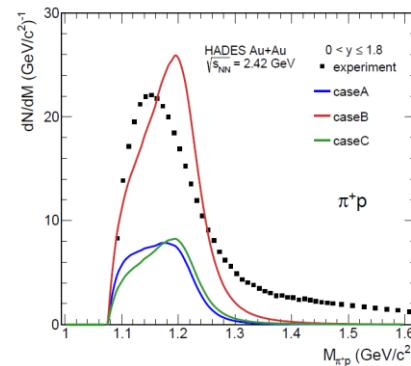
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The Delta(1232) and Other Resonances

- Originally, resonance mass = fixed PDG value
- Idea: use finite width for all resonances
- For $\Delta(1232)$, derivative of the scattering phase shift was used (Phys. Rev. C 96, 015207 (2017))
- For other resonances, Breit-Wigner parametrisation with mass-dependent width was used ([arXiv:0708.2382](https://arxiv.org/abs/0708.2382) (2007))

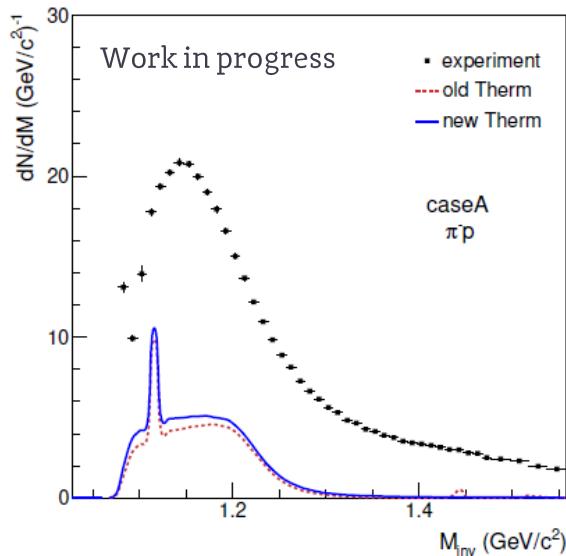
True MC $\Delta(1232)$ vs correlated pairs of protons and pions:



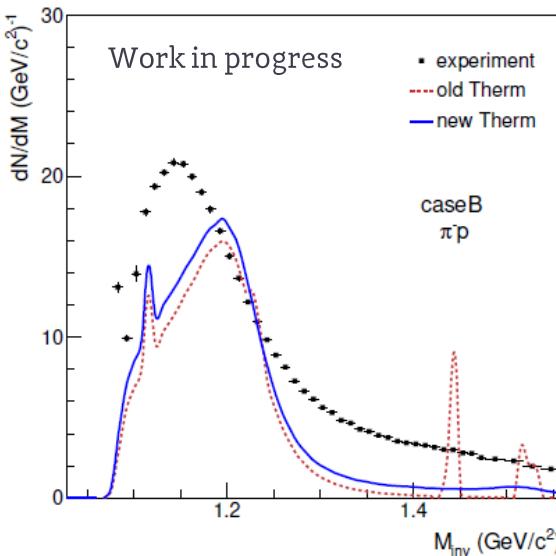
M. Kurach „Phase-space distributions of Delta resonances reconstructed from Therminator events”, Get_Involved internship

The Delta(1232) and Other Resonances

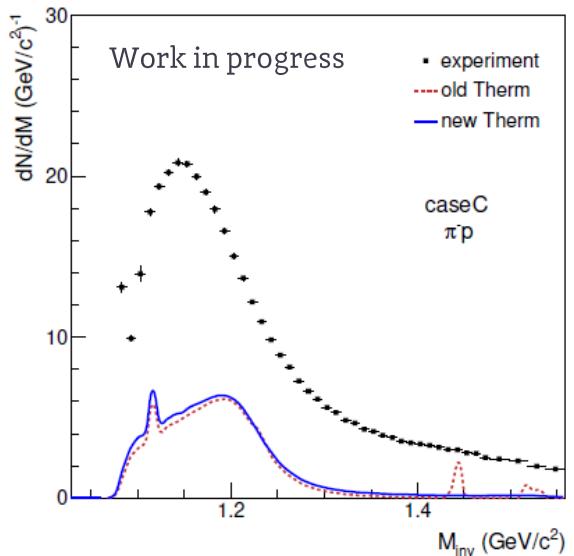
M. Kurach „Study of resonance production Au+Au collisions at HADES with Therminator”, Get_Involved internship



(a) Case A.



(b) Case B.



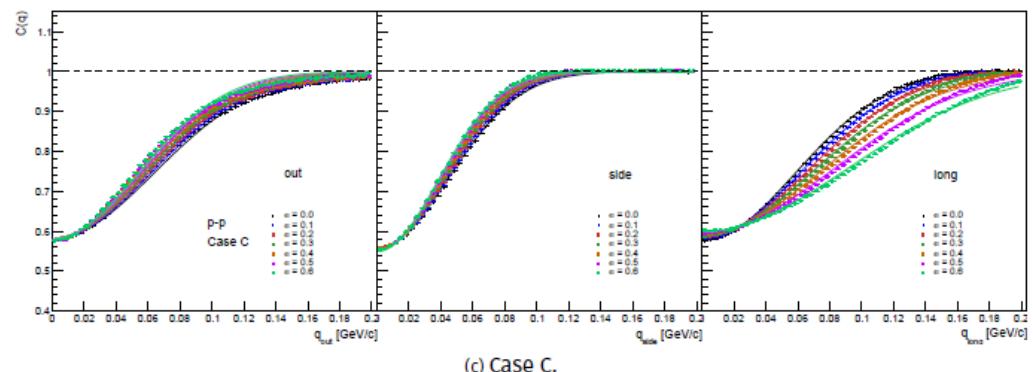
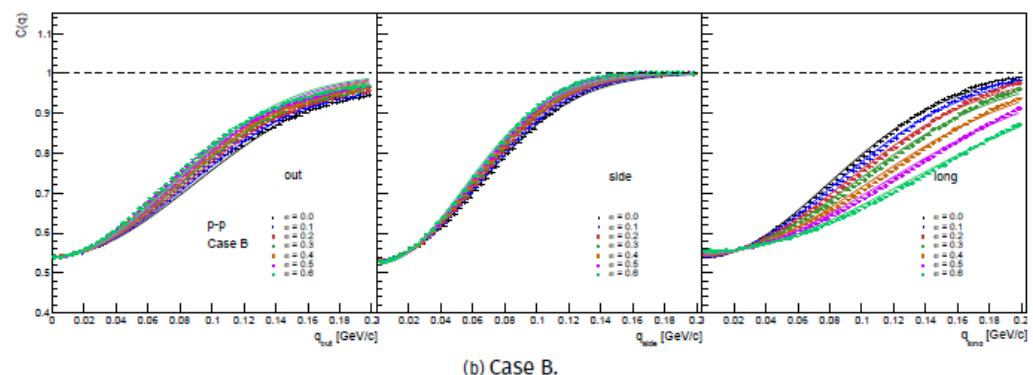
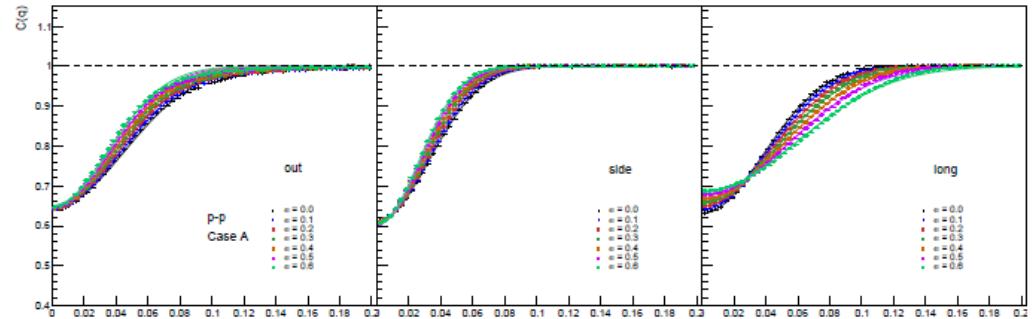
(c) Case C.

➤ Smeared peaks of heavy resonances

➤ Work in progress

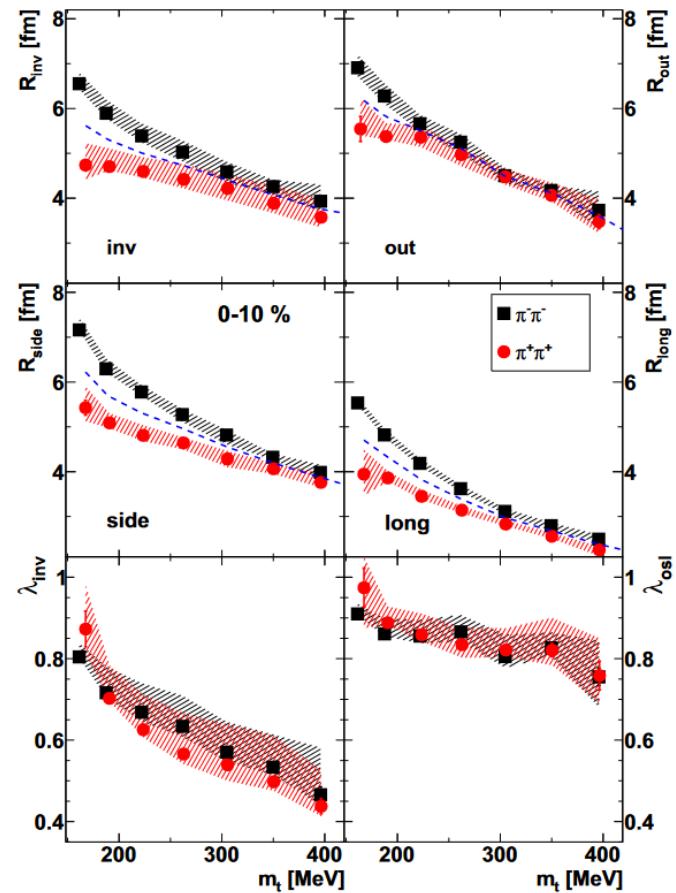
Position Deformation Sensitivity of Correlation Functions

- No final-state interactions included
- Long direction → the most sensitive to the eccentricity parameter
- Negligible sensitivity of H and δ



Pion HBT @ HADES

- Original work from R. Griefenhagen, PhD Thesis (2020), Dresen Technical University, published in Eur.Phys.J.A 56 (2020) 4, 140 and Phys.Lett.B 795 (2019) 446-451
- Noticeable radii separation at low m_T → Coulomb effect
- Pion correlation → „simplest” of correlations → best for my study



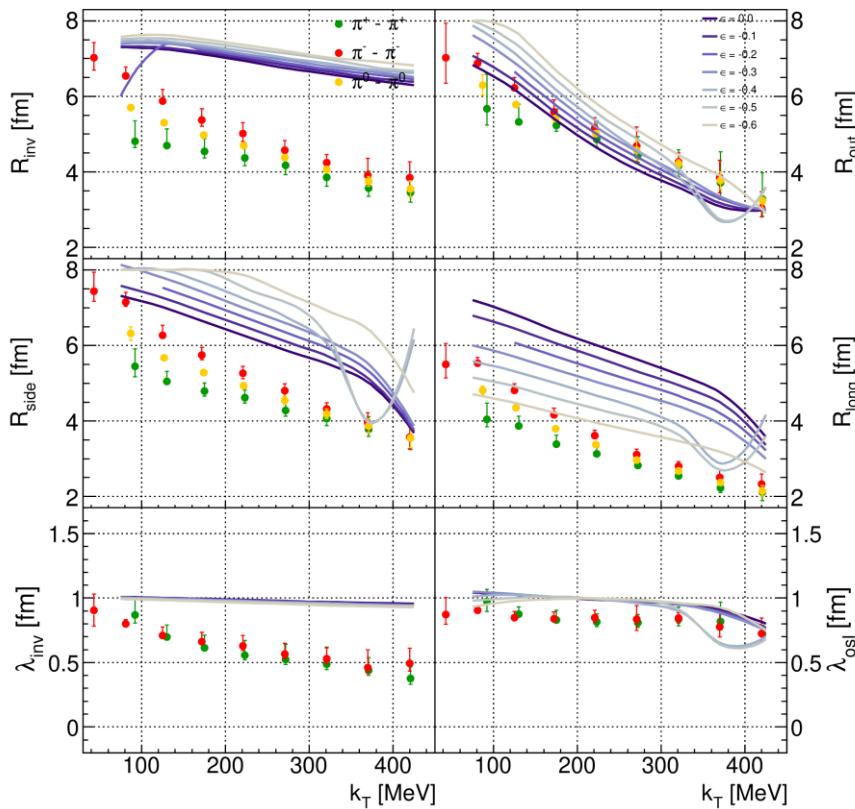
Eur.Phys.J.A 56 (2020) 5, 140
Phys.Lett.B 795 (2019) 446-451

Jędrzej Kołaś, XVI Polish Workshop on Relativistic Heavy-Ion Collisions

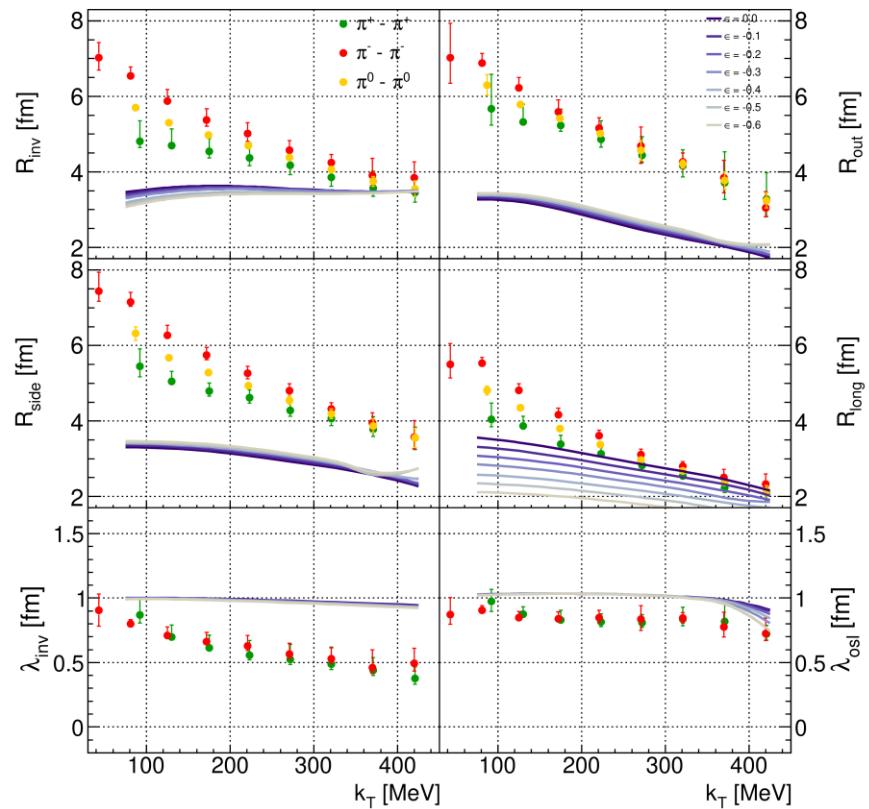
Femtoscopy in Coalescence Approach

J. Kołas, MSc Thesis (2022), Faculty of Physics, WUT
Eur.Phys.J.A 56 (2020) 5, 140
Phys.Lett.B 795 (2019) 446-451

Case A



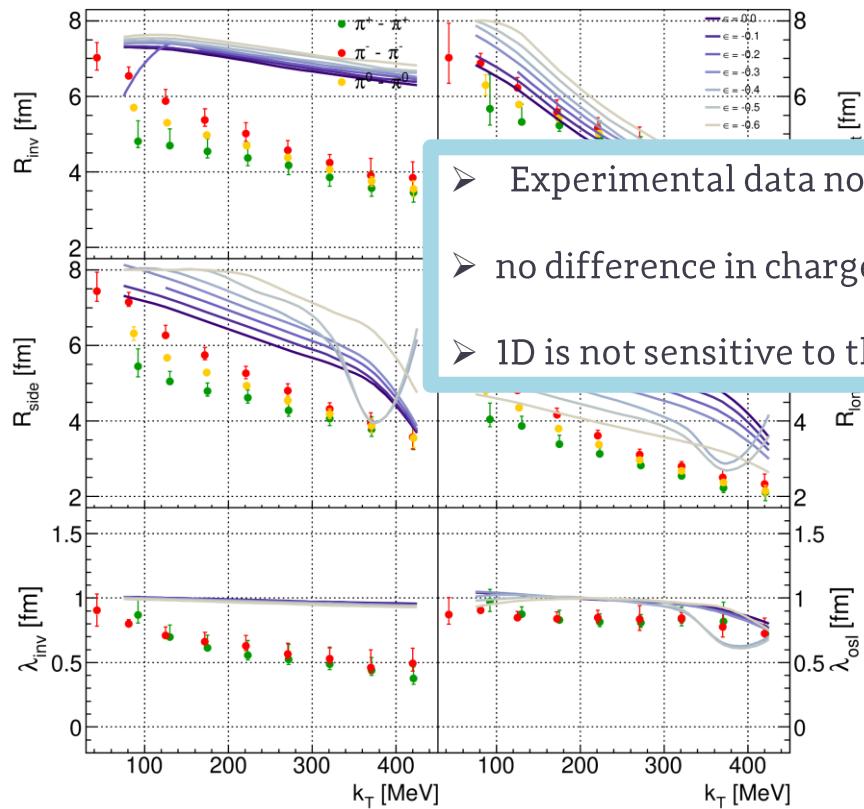
Case B



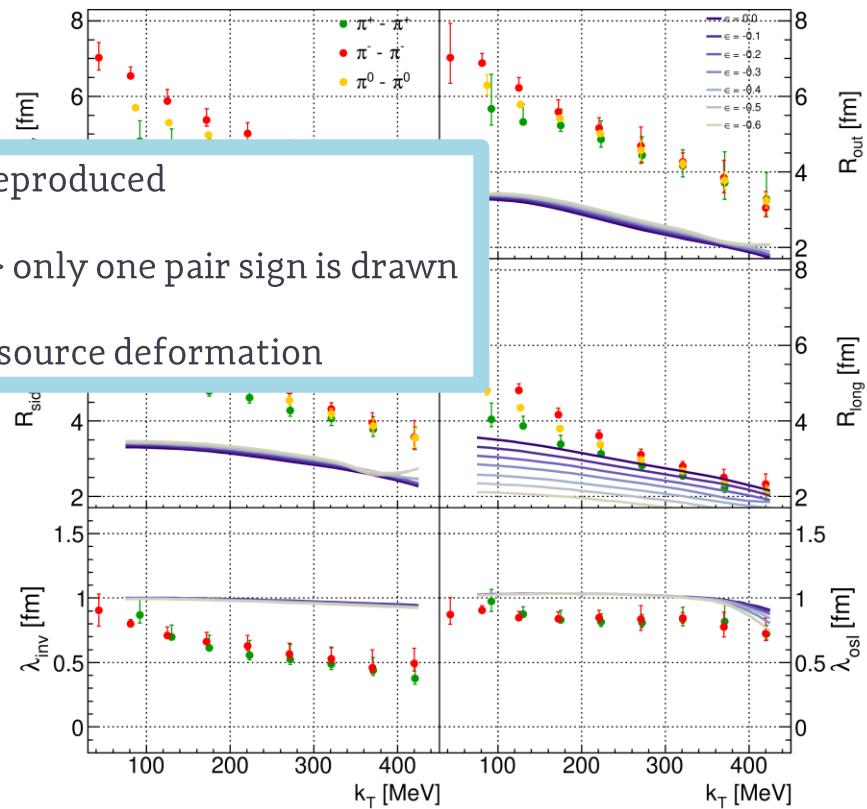
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Case A



Case B

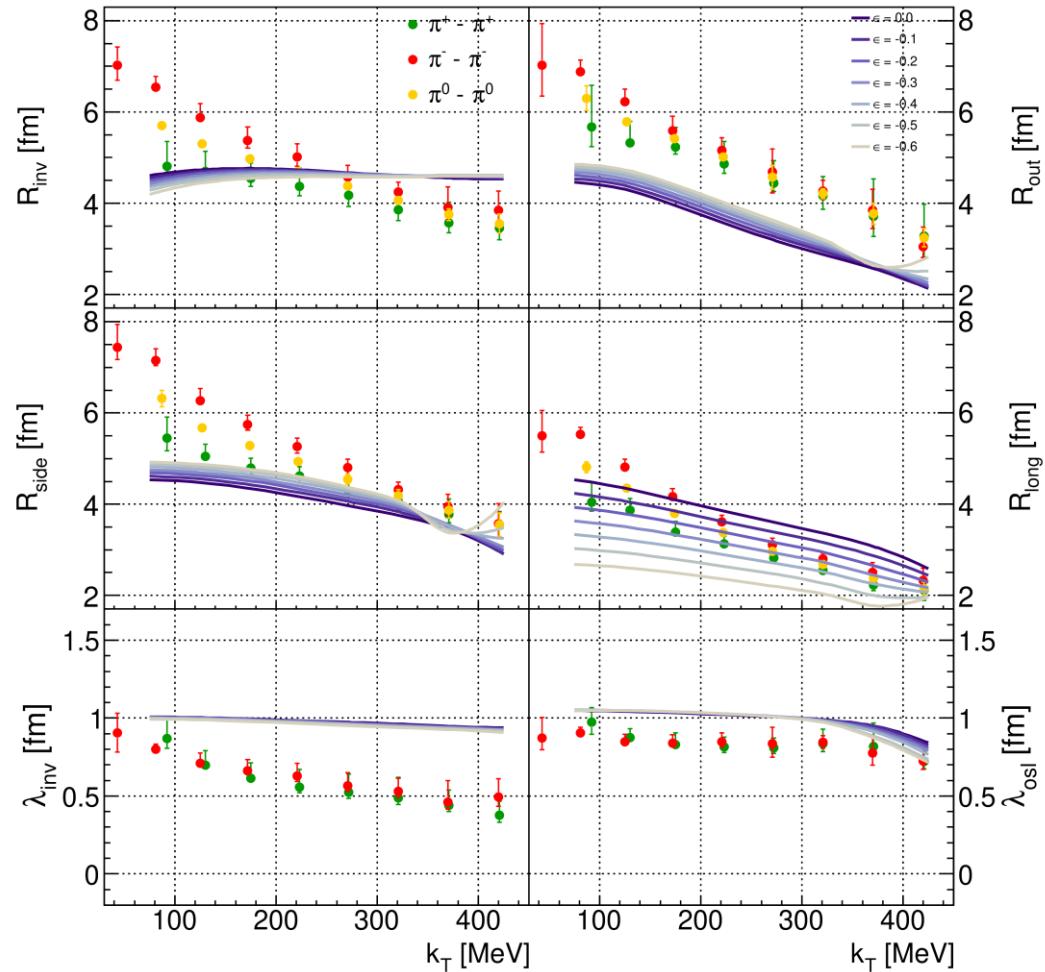


- Experimental data not reproduced
- no difference in charge \rightarrow only one pair sign is drawn
- 1D is not sensitive to the source deformation



Femtoscopy in Thermal Approach

- Closest reproduction (of all three) of the invariant radius
- Strong position eccentricity dependence in the long direction
- Simple afterburner, only QS included



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Eur.Phys.J.A 56 (2020) 5, 140
Phys.Lett.B 795 (2019) 446–451

Summary

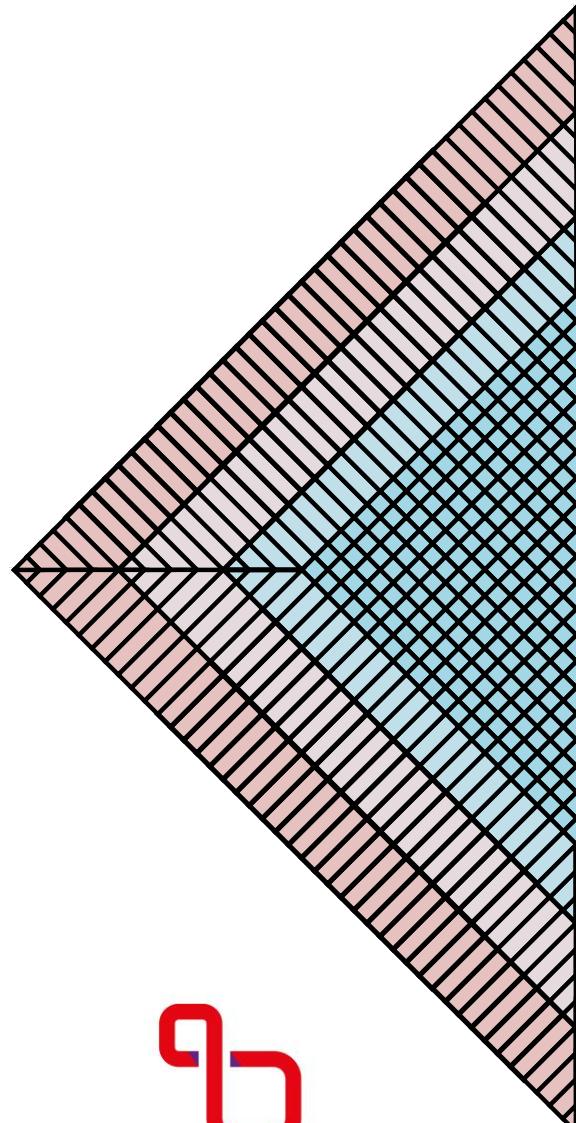
Spherical vs Spheroidal

- The spheroidal model is necessary to reproduce spectra
- It works well for abundant particles (protons and charged pions)

Coalescence vs Thermal

- Resonances play a significant role (for momentum distribution)
- R_{inv} and R_{long} HBT radii are best reproduced in the thermal approach (Case C)
- Proton and pion m_T and y spectra are well reproduced by both Case A and Case B
- Delta resonance favours Case B

Thank You For Your Attention



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Backup

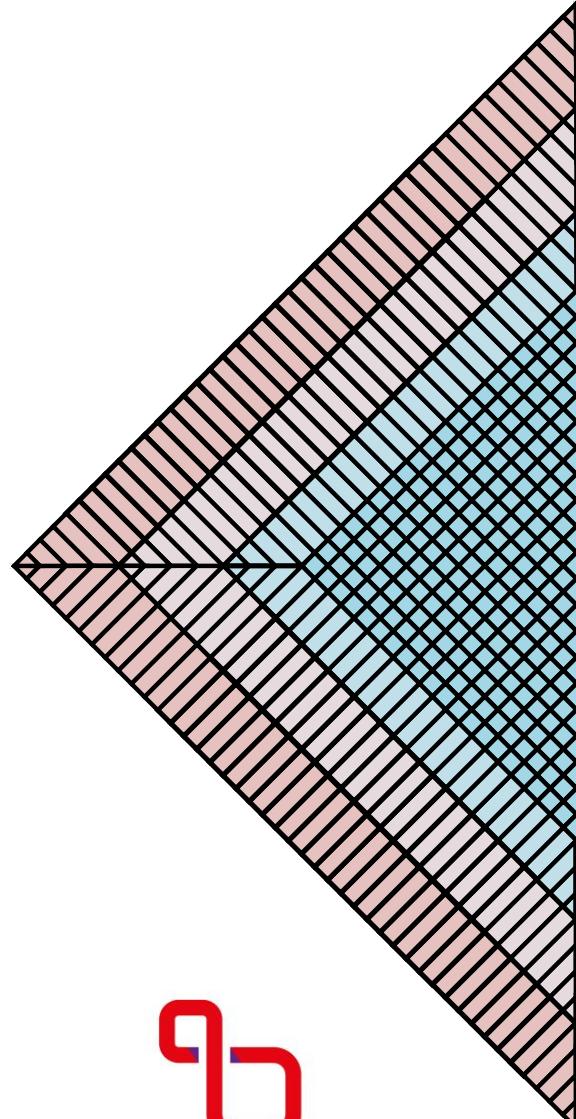


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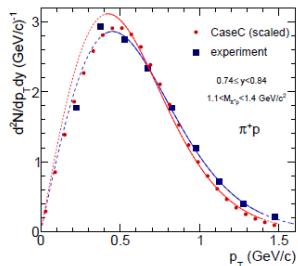
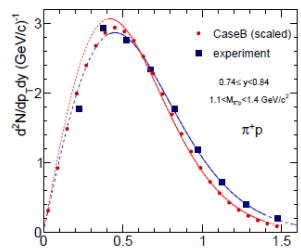
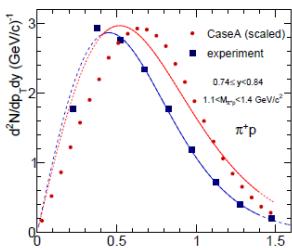


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The Delta(1232) and Other Resonances



Case A is not as good...

