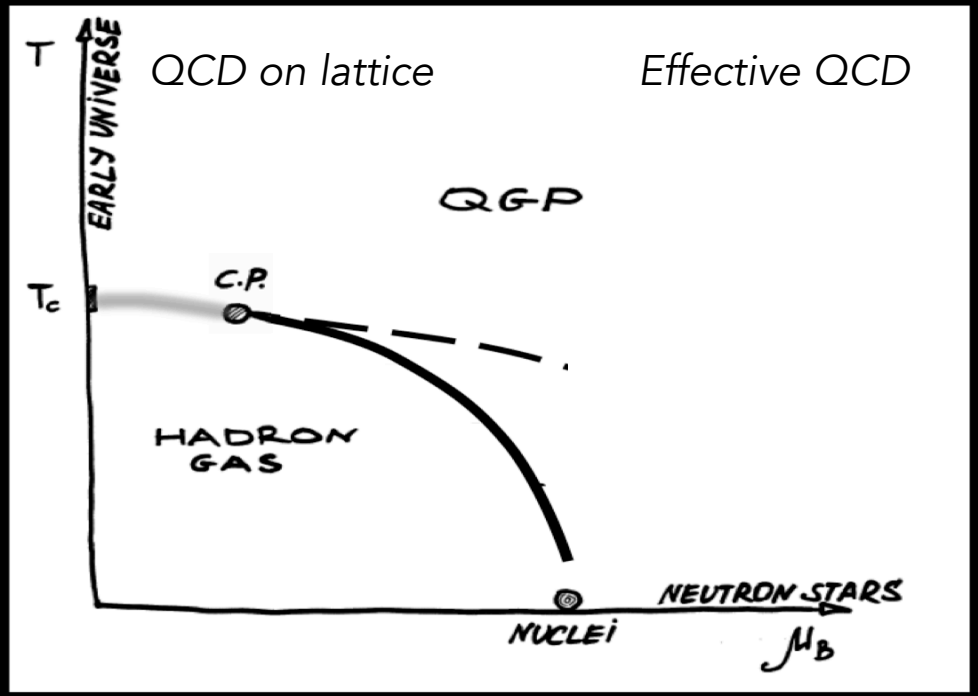
Recent Results from HADES

Manuel Lorenz

for the HADES collaboration

Goethe-University Frankfurt

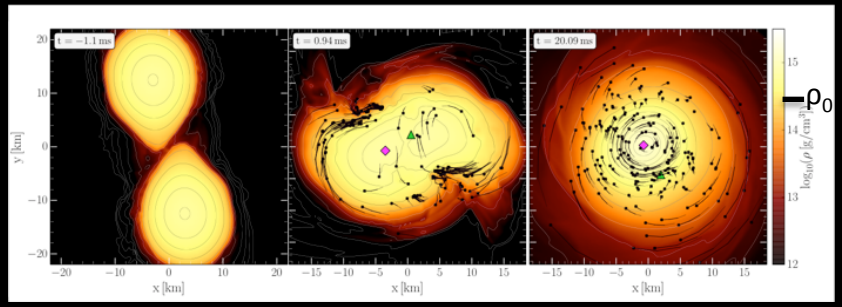
The Baryon-dominated Side of the Phase Diagram



HADES: Au+Au $\sqrt{s_{NN}}$=2.4 GeV,
Large stopping → baryon-dominated

Similar conditions as in merging Neutron Stars

Merging Neutron Stars



Central Au+Au $\sqrt{s_{NN}}$=2.4 GeV

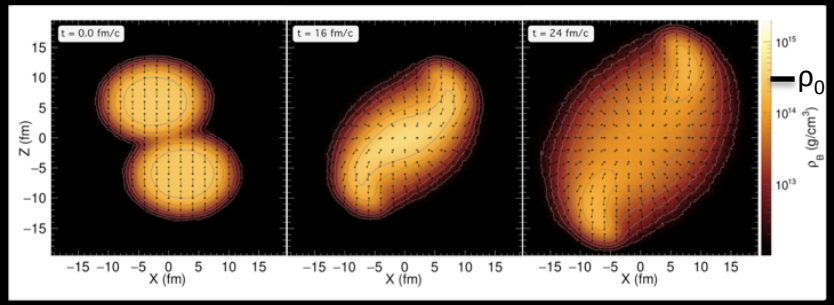
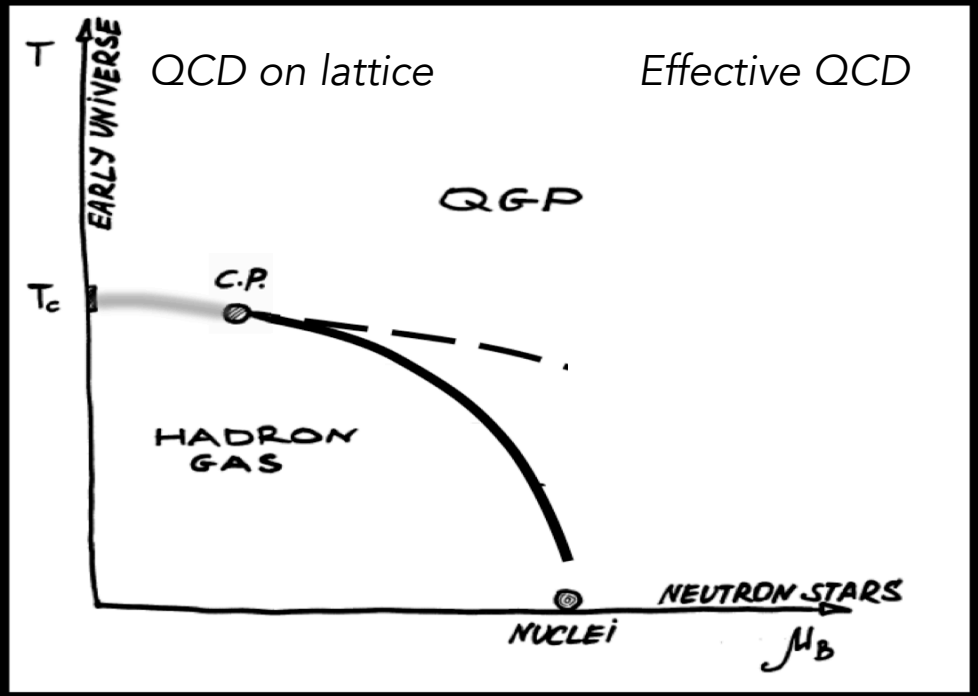


Fig. credit T. Galatyuk & F. Seck

T < 70 MeV, $\rho \approx 3\rho_0$ in both cases

M. Hanauske, J.Phys.: Conf. Series878 012031 (2017)
L. Rezzolla et. al. PRL 122, n0.6, 061101 (2019)
Au+Au simulation UrQMD: S. A. Bass et al., Prog. Part. Nucl. Phys. 41, 255 (1998).

The Baryon-dominated Side of the Phase Diagram



HADES: Au+Au $\sqrt{s_{NN}}$=2.4 GeV,
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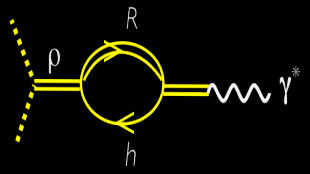
Similar conditions as in merging Neutron Stars

1. Virtual Photons:

Vector meson spectral functions modified by coupling to baryons



2. Strangeness:

Kinematical suppression of direct K^-

$NN \rightarrow NYK^+$ $\sqrt{s_{NN}}$= 2.55 GeV
$NN \rightarrow NNK^+K^-$ $\sqrt{s_{NN}}$= 2.86 GeV

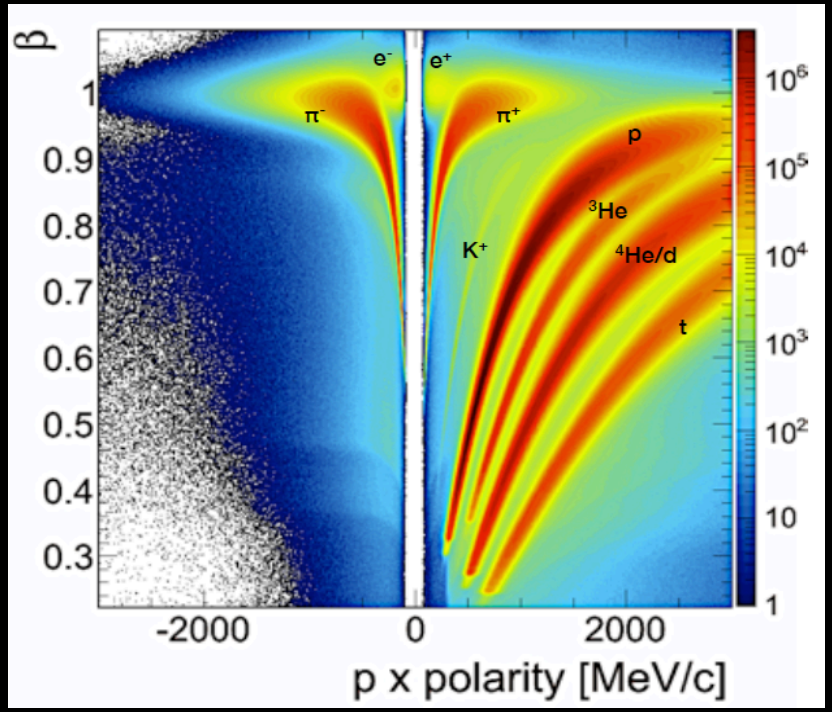
Coupling of K^- to baryons strangeness exchange reactions e.g. $\pi Y \rightarrow NK^-$

3. Bulk:

p, light nuclei and π, HBT-radii, flow anisotropies

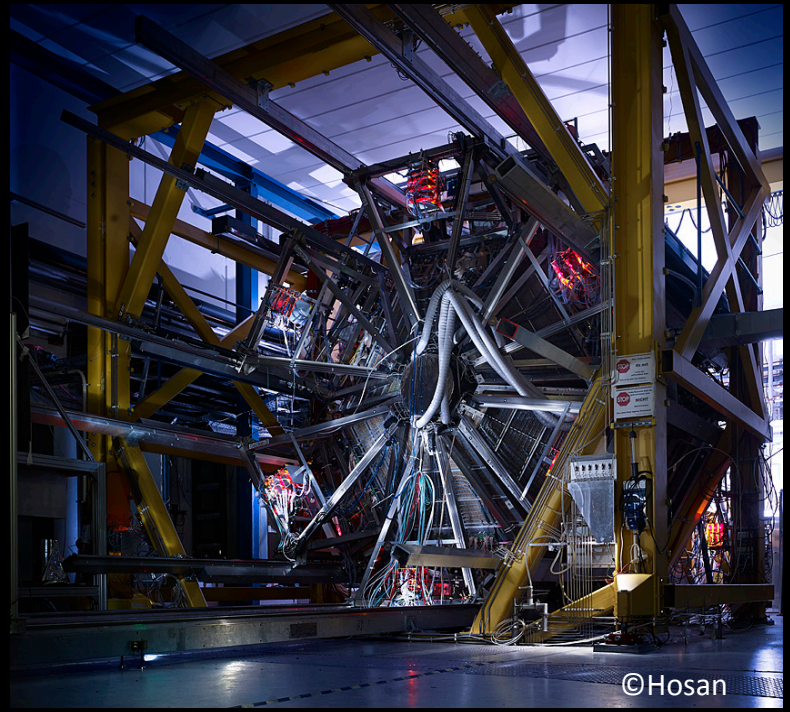
4. FAIR-Phase 0: new Ag+Ag data

The Baryon-dominated Side of the Phase Diagram



HADES: Au+Au $\sqrt{s_{NN}}$=2.4 GeV,
Large stopping → baryon-dominated

Clear hierarchy in hadron yields:
p ≈ 100, lt. nuclei ≈ 50 π ≈ 10, $K^+ \approx 10^{-2}$, $K^- \approx 10^{-4}$

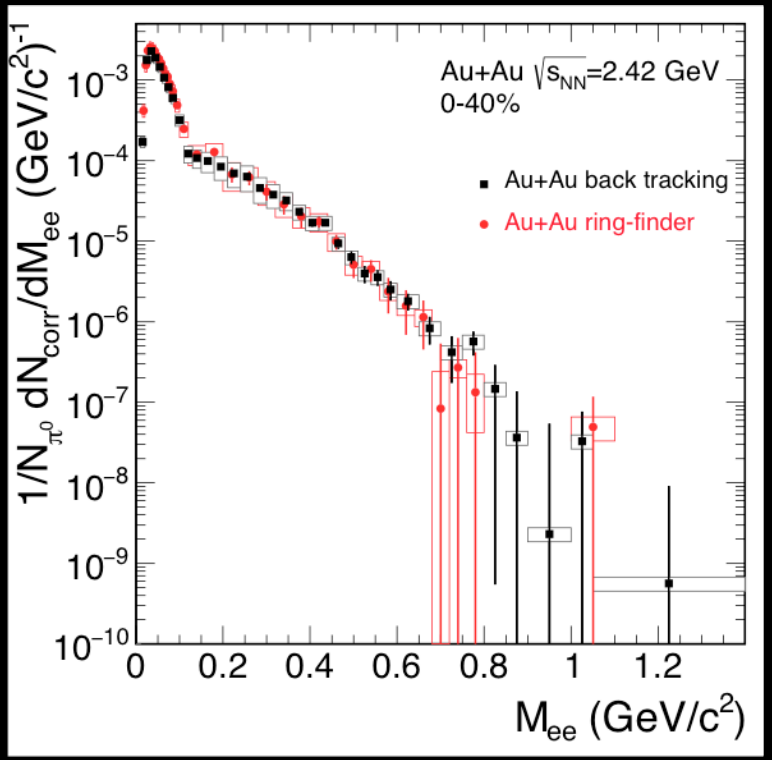


Fast detector: 8 kHz trigger rate (16 kHz Ag+Ag)
Large acceptance: Full azimuthal and polar angle coverage of Θ = 18° – 85°

2.2×10^9 events analyzed

Virtual Photons

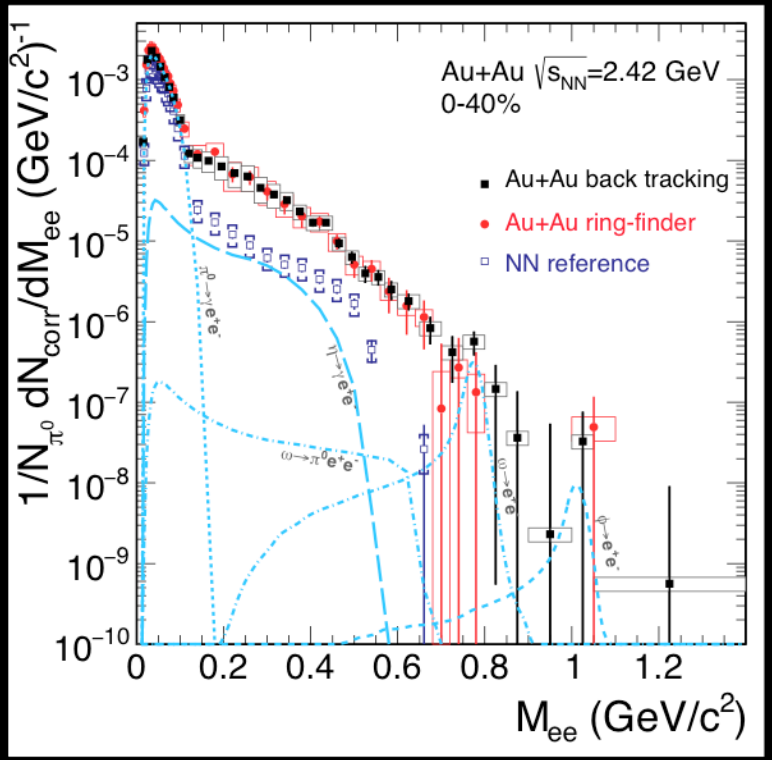
Virtual Photons



Accept. for publ. in Nature Physics

- First measurement for a heavy system at low $\sqrt{s_{NN}}$.

Virtual Photons



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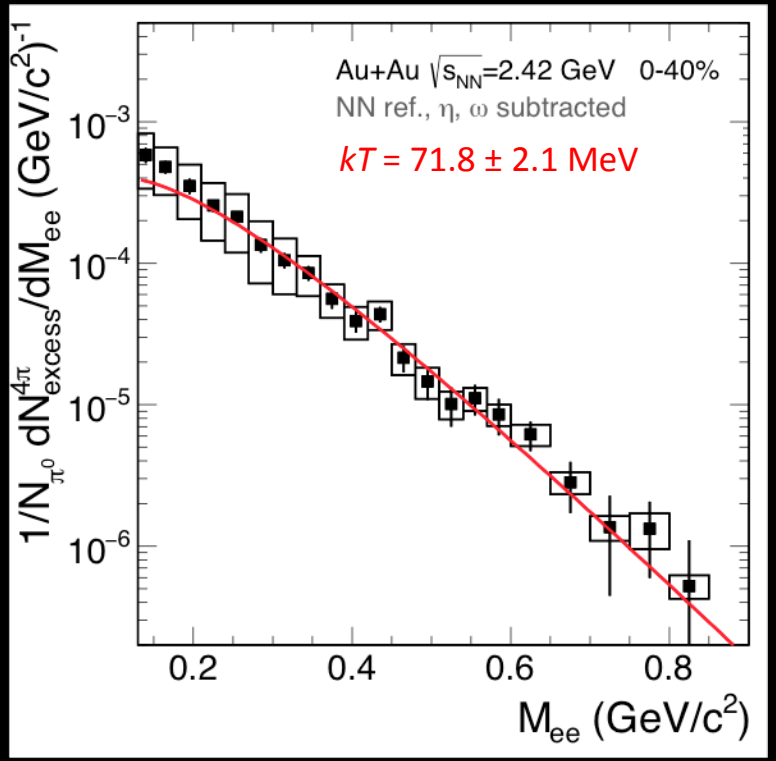
- Strong excess ($0.15<M<0.7$ GeV/c^2) above components of meson decays at freeze-out and elementary reference.
- Isolation of excess by subtracting the elementary reference.

Virtual Photons

Acceptance corrected excess yield.



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- Medium radiation: Strong broadening of the ρ due to direct ρ-baryon scattering
- Exponentially falling spectrum,
  → extraction of temperature $\langle T_{ee} \rangle$ = 72 MeV

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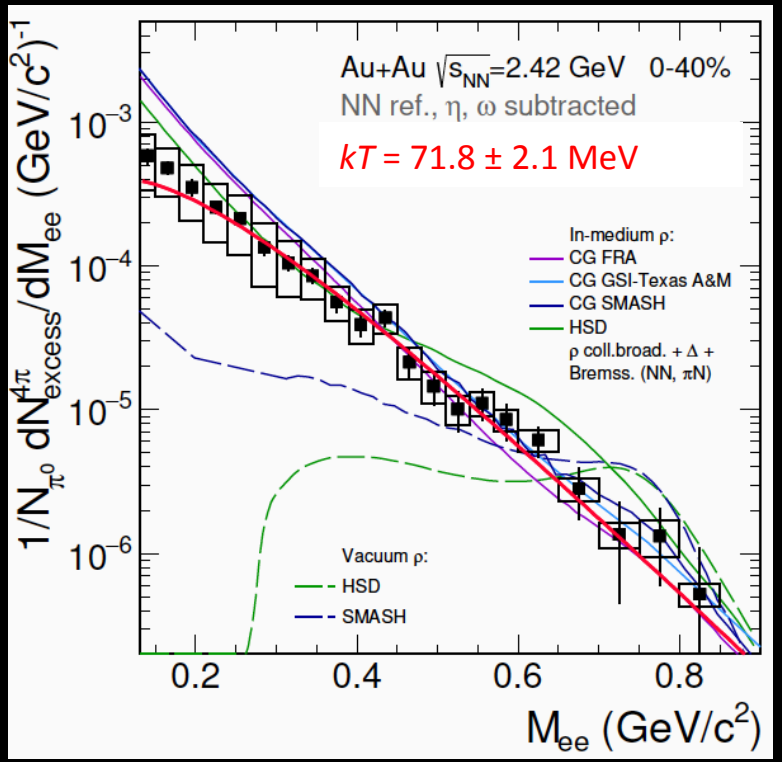

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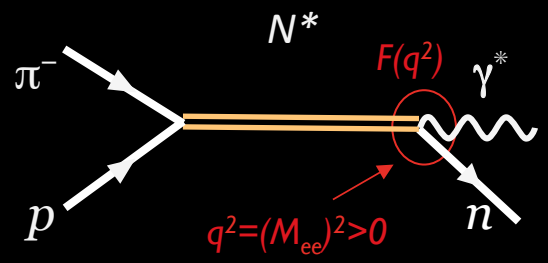
- Exponentially falling spectrum,
  → extraction of temperature $\langle T_{ee} \rangle$ = 72 MeV
- Thermal rates folded over coarse-grained transport medium evolution works at low energies
- Supports baryon-driven medium effects at SPS, RHIC (LHC)!

ρ-Baryon Coupling Mechanism

π^- beam $\sqrt{s_{\pi N}}$= 1.49 GeV

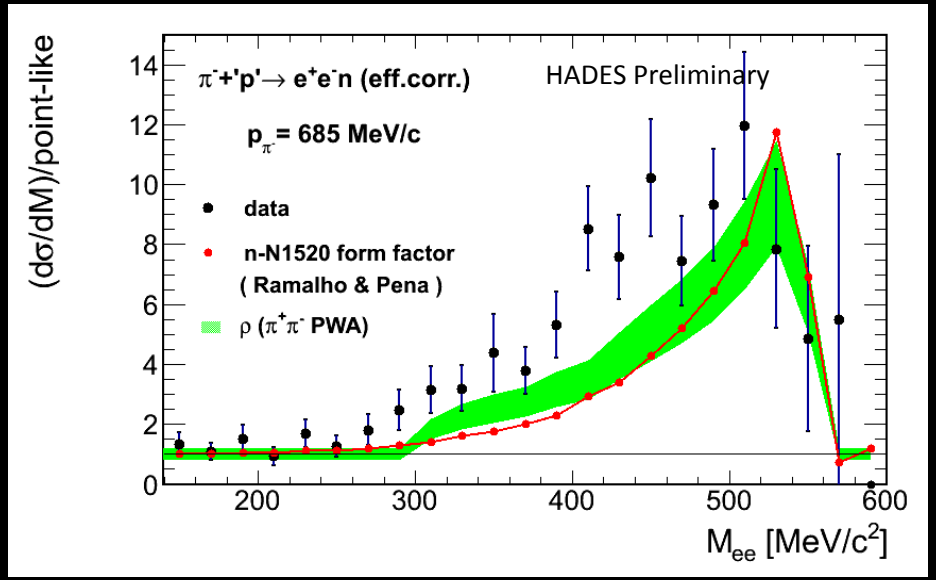
$\pi^-+p \rightarrow \pi^-+\pi^-+n$ (PWA)
$\pi^-+p \rightarrow e^+e^-+n$



Two consistent approaches:

- Vector-Meson dominance
  E. Speranza *et al.*, Phys.Lett. B764 (2017) 282
- Time-like form factor models with dominant meson cloud contribution
  G. Ramalho, T. Pena Phys. Rev. D95 (2017), 014003

e^+e^- invariant mass distribution ratio to point-like contributions

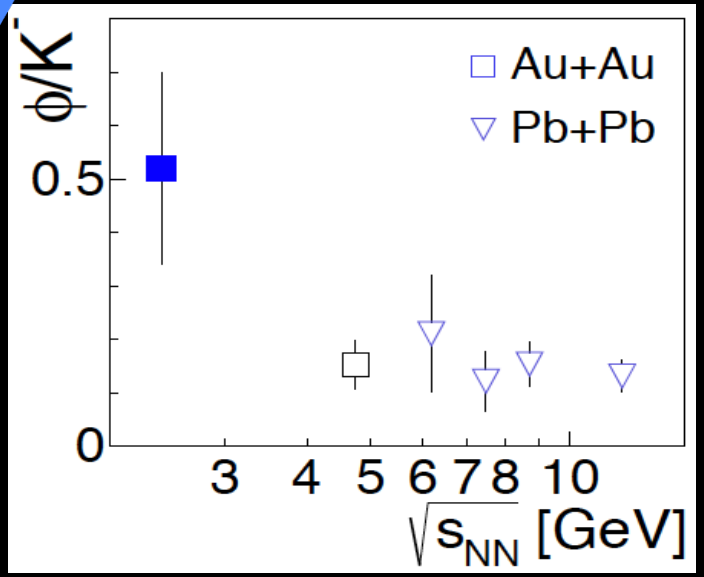


Invariant mass and angular distributions are consistent with ρ decay and VDM form factor models

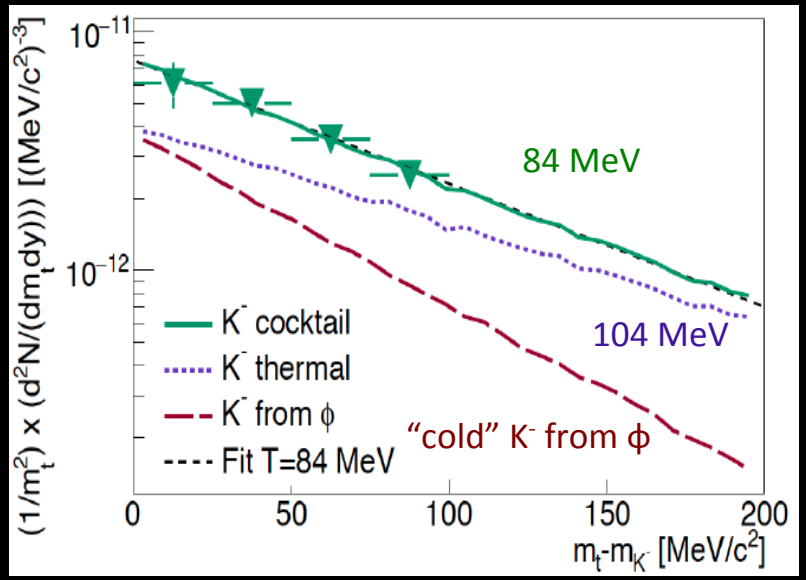
Strangeness

Reminder

Φ-AntiKaon Interplay in HIC



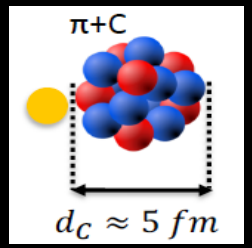
Increased in HIC at low $\sqrt{s_{NN}}$:
→ 25% of K^- result from Φ decays!

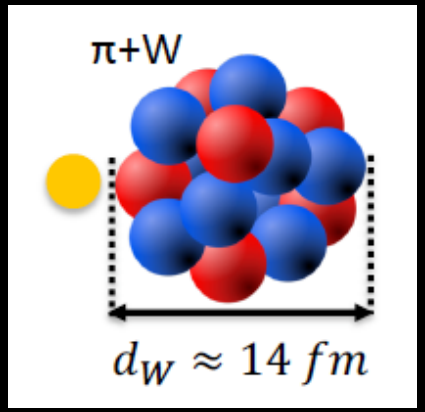


→ No indication from K^- spectrum for sequential K^+K^- freeze-out if corrected for feed-down.

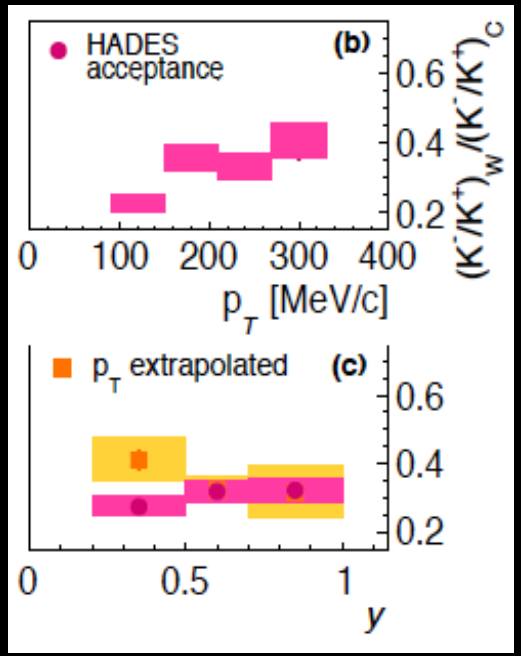
Phys.Lett. B778 (2018) 403-407

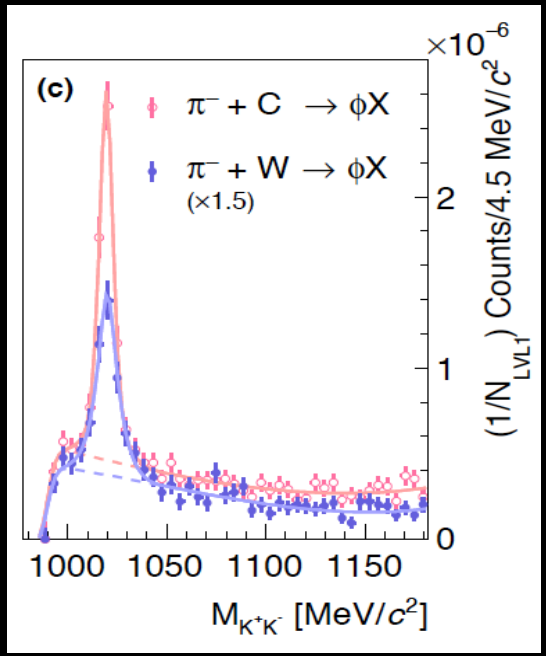
Φ-AntiKaon Interplay in Cold Matter





→ Mean free path $\lambda_\pi = 1.5\ fm$
$(p_\pi = 1.7\ GeV/c\,, \rho_B \approx \rho_0)$





→ Suppression of K^- relative to K^+

→ Similar suppression for ϕ like for K^-

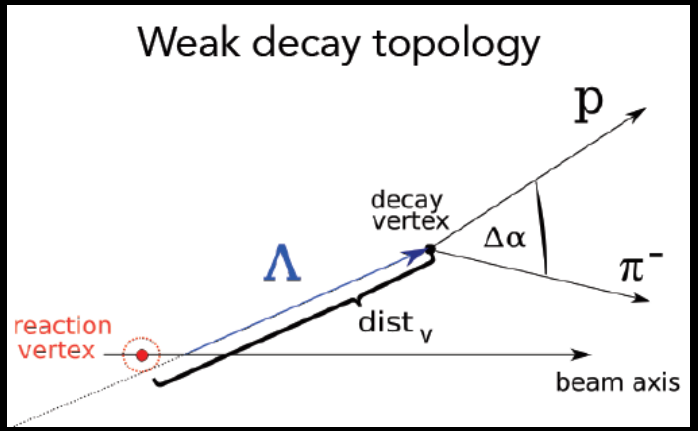
In HADES acceptance:

$$(\phi/K^-)_C = 0.55 \pm 0.04(stat)^{+0.06}_{-0.07}(sys)$$

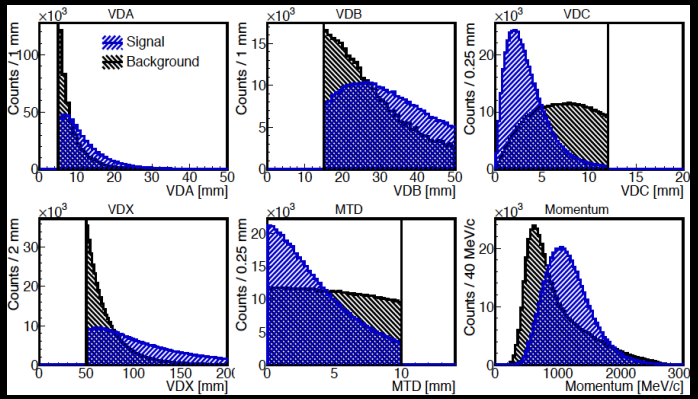
$$(\phi/K^-)_W = 0.63 \pm 0.06(stat) \pm 0.11(sys)$$

arXiv:1812.03728 [nucl-ex] accepted by PRL

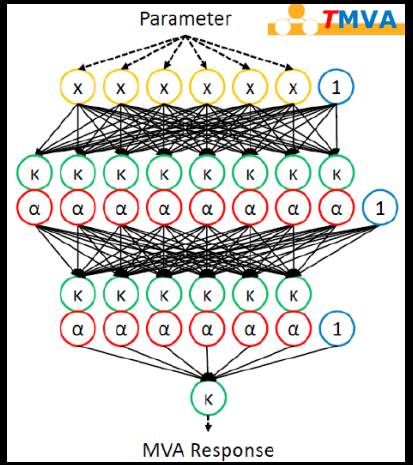
Weak decay topology recognition with neural networks



Results in several parameters

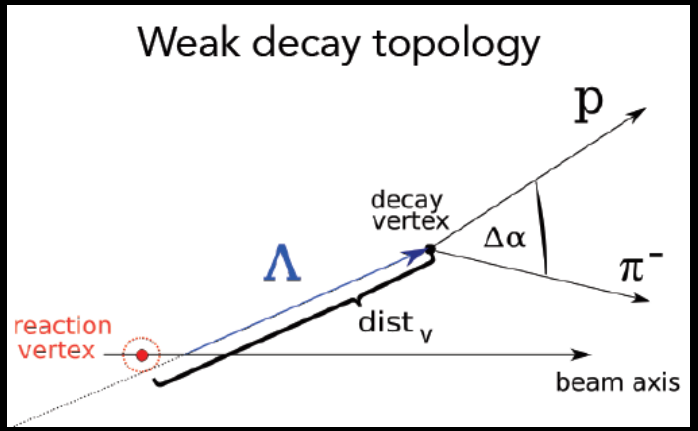


Which can be feed into an ANN



MA S. Spies, PhD F. Kornas, Phys.Lett. B793 (2019) 457-463

Weak decay topology recognition with neural networks



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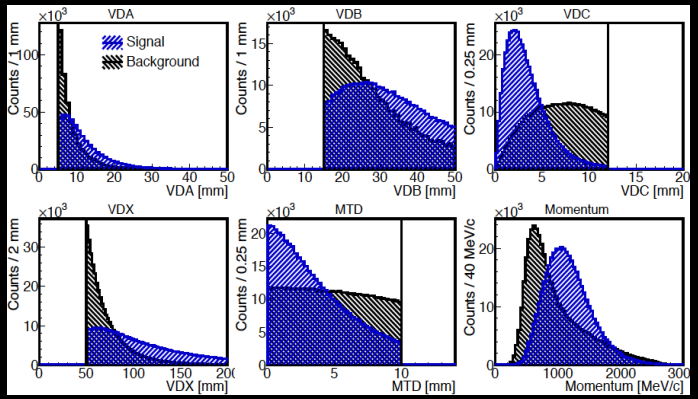
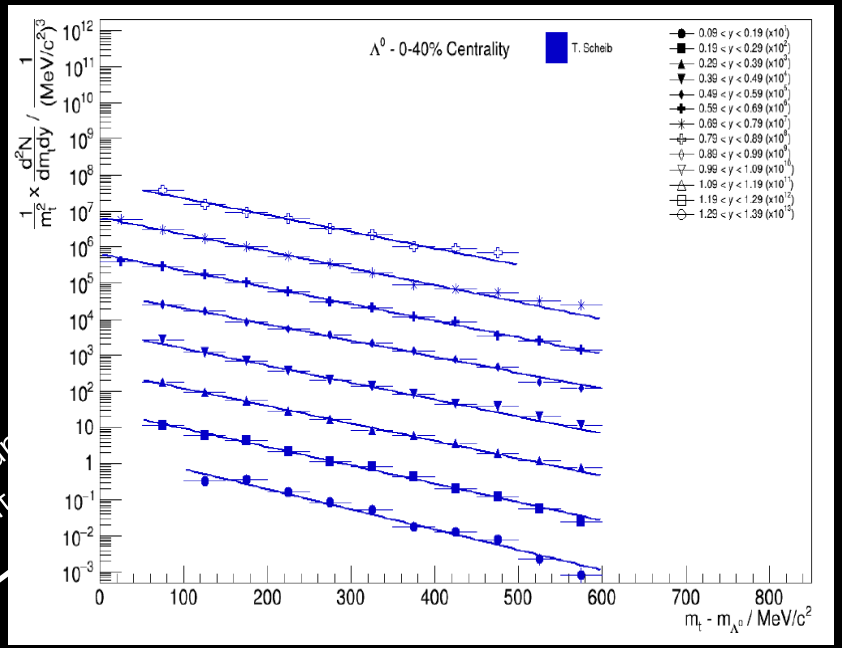


Which ca
feed int



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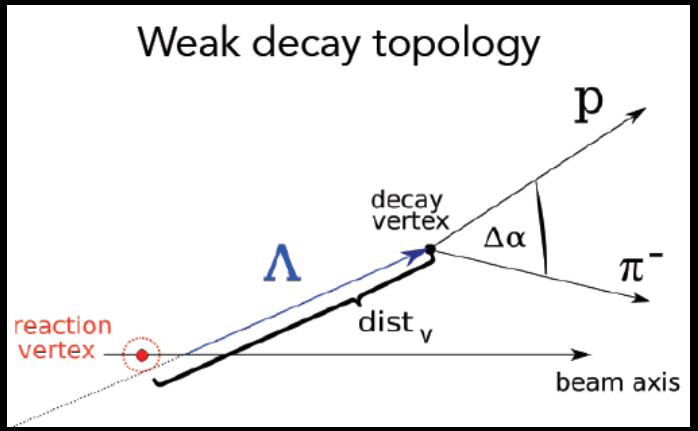

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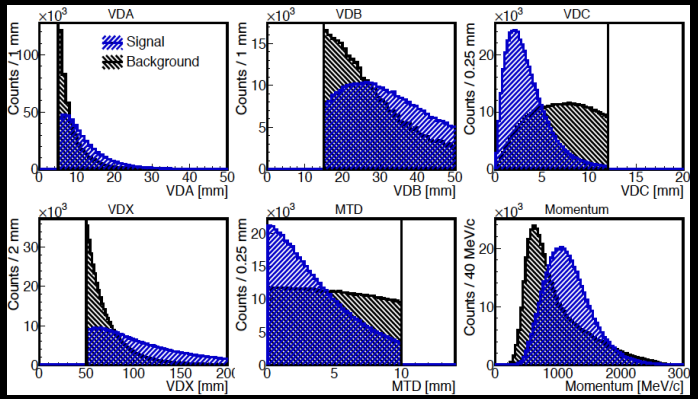

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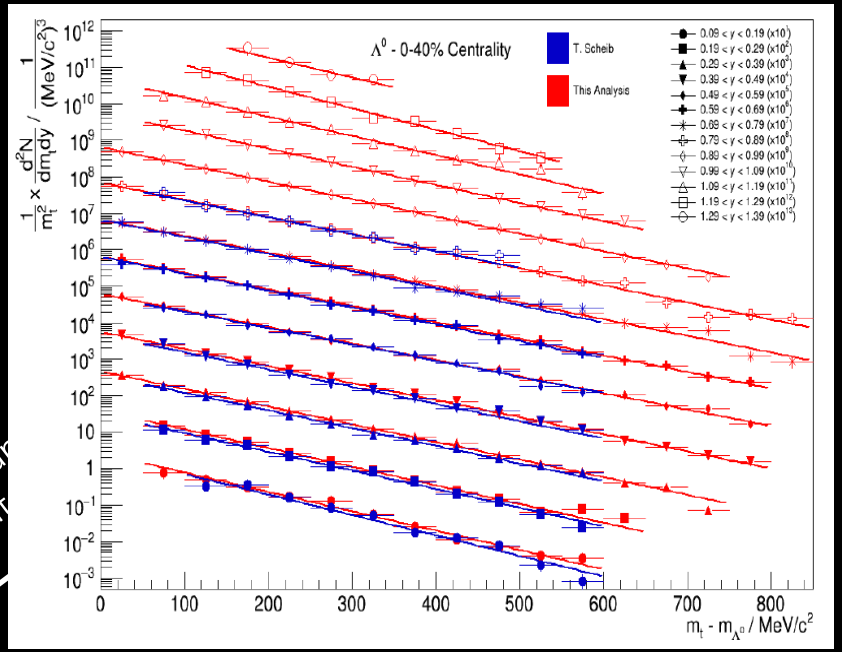
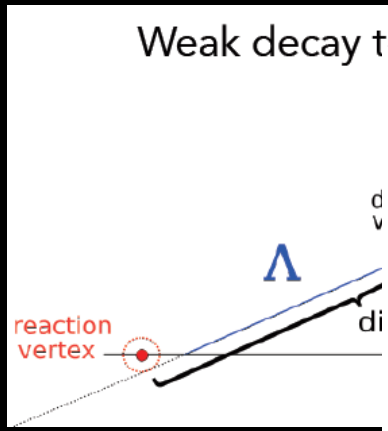


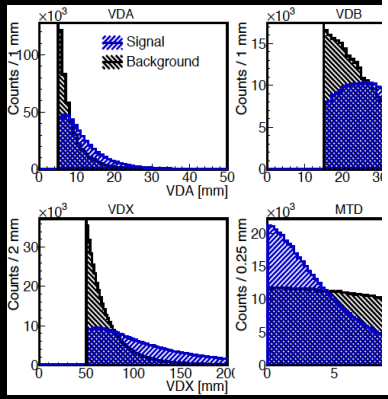
ANN in combination with pre-selection on topology parameters improves performance → reduction of uncertainty for 4π yield extraction.

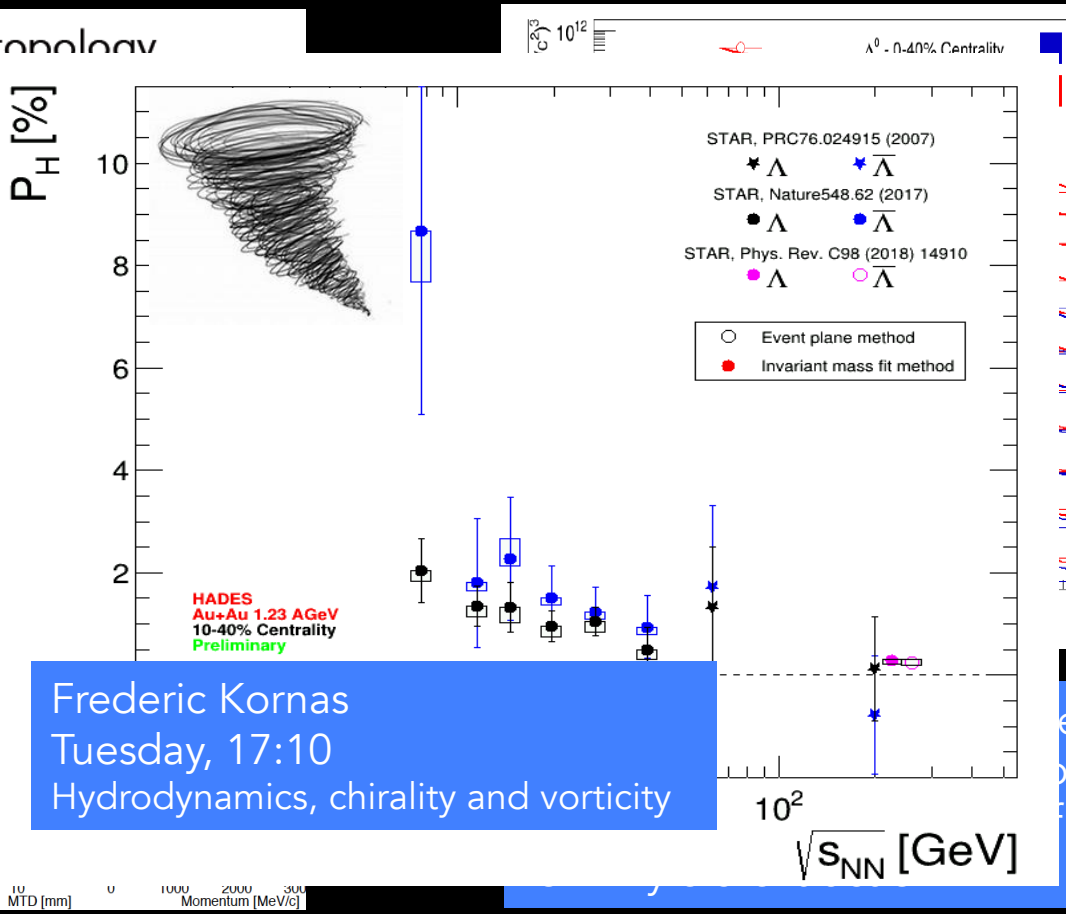
MA S. Spies, PhD F. Kornas, Phys.Lett. B793 (2019) 457-463

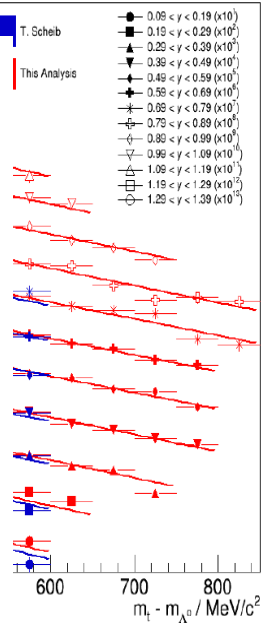
Weak decay topology recognition with neural networks



↓ Results in seve







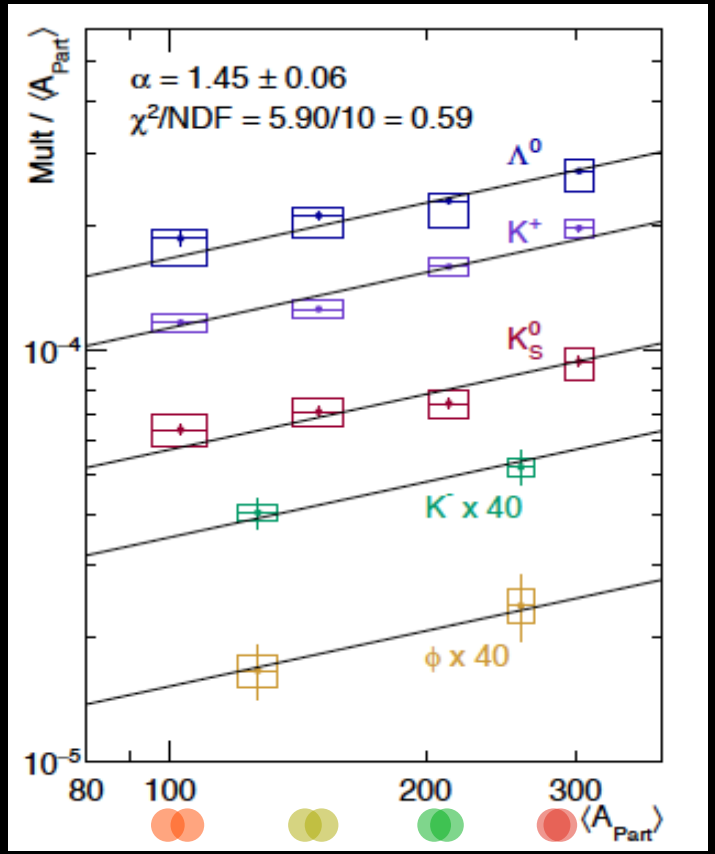
Frederic Kornas
Tuesday, 17:10
Hydrodynamics, chirality and vorticity

e-selection
proves
uncertainty

MA S. Spies, PhD F. Kornas, Phys.Lett. B793 (2019) 457-463

Strangeness in Au+Au @ $\sqrt{s_{NN}}$= 2.4 GeV

Complete set of strange hadrons produced below NN-threshold: NN→NYK$^+$: $\sqrt{s_{NN}}$= 2.55 GeV
NN→NNK$^+$K$^-$: $\sqrt{s_{NN}}$= 2.86 GeV



Phys.Lett. B793 (2019) 457-463

→ unique observable:

Energy must be provided from the system.

Strange particle yields rise stronger than linear with

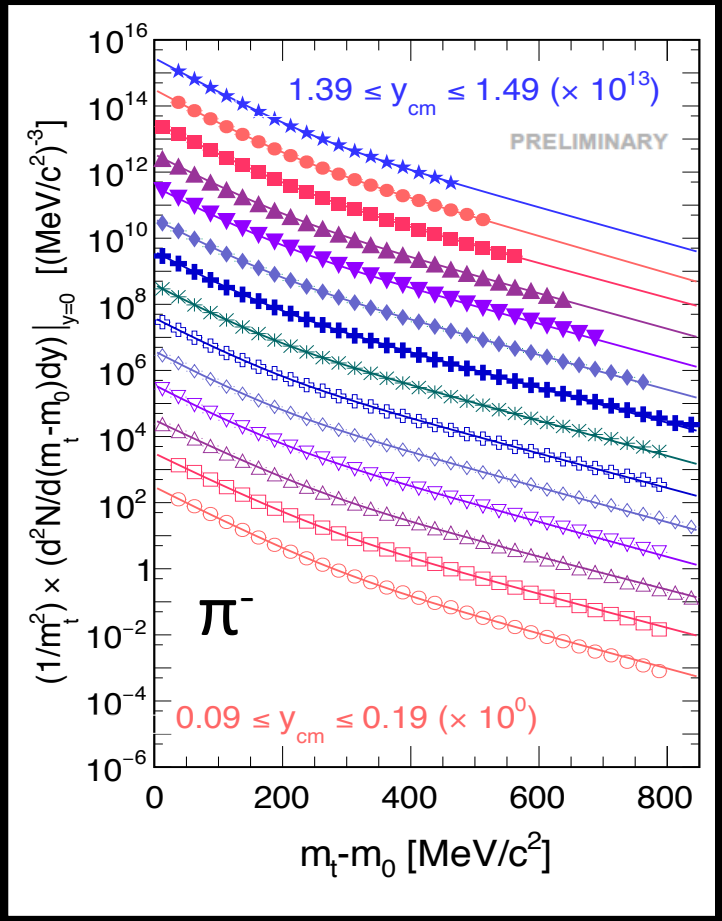
$\langle A_{part} \rangle$ ($M \sim \langle A_{part} \rangle^{\alpha}$)

Universal $\langle A_{part} \rangle$ dependence of strangeness production

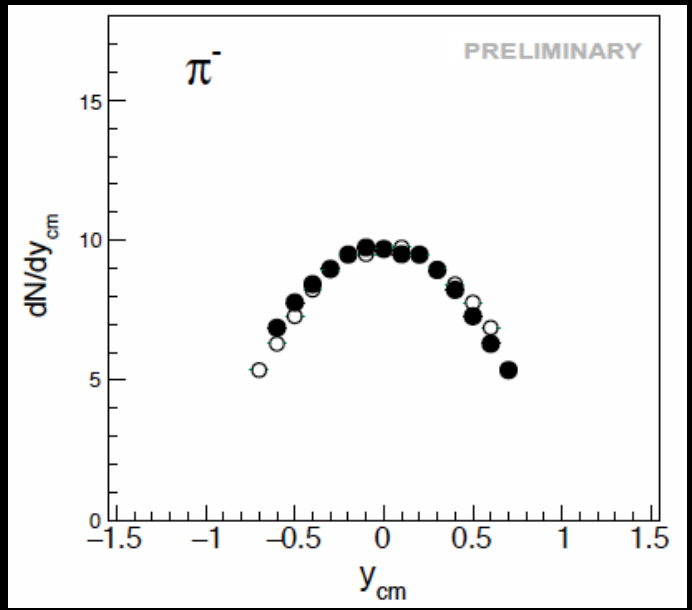
→ Hierarchy in production threshold not reflected

The Bulk

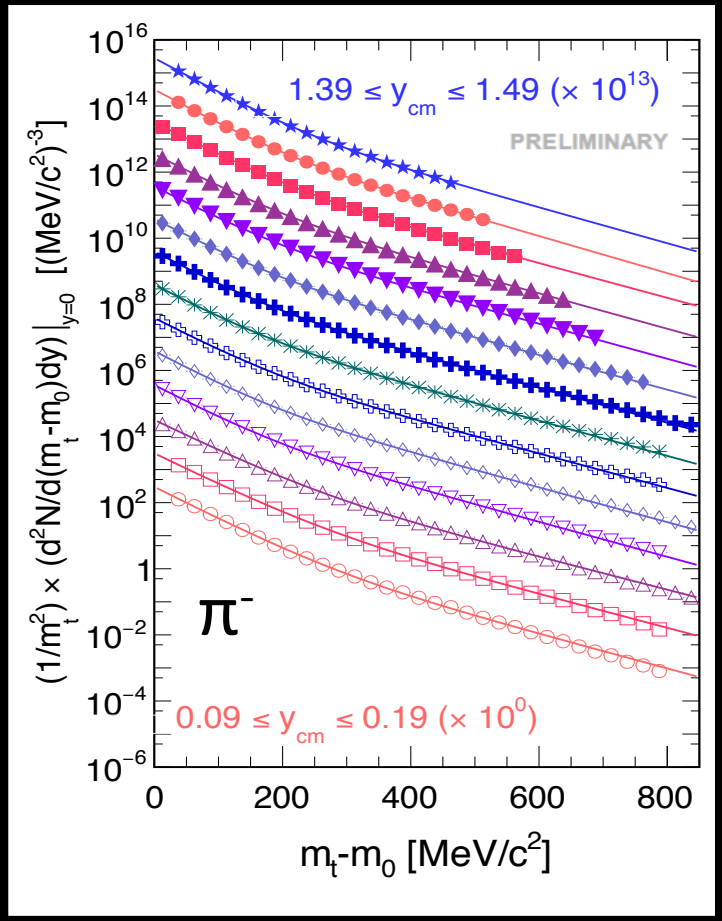
π Production:



- Most abundant meson: yield ≈ 10
- High statistic sample
- Large m_t-m_0 and y coverage



π Production:



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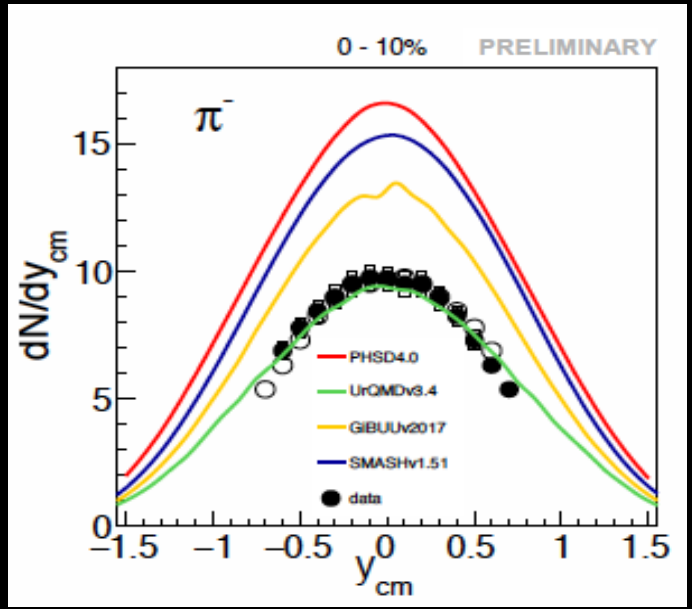
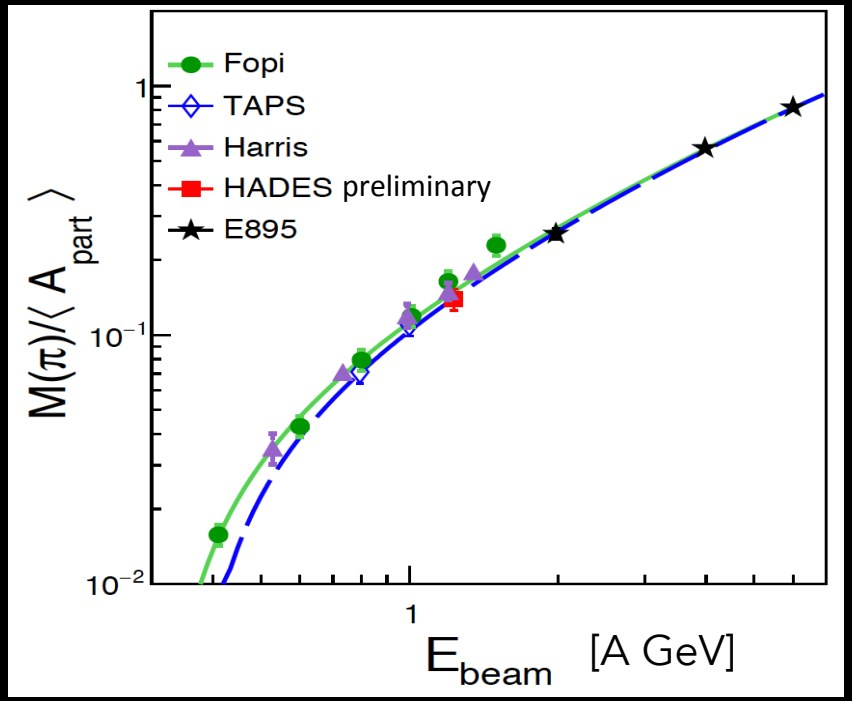
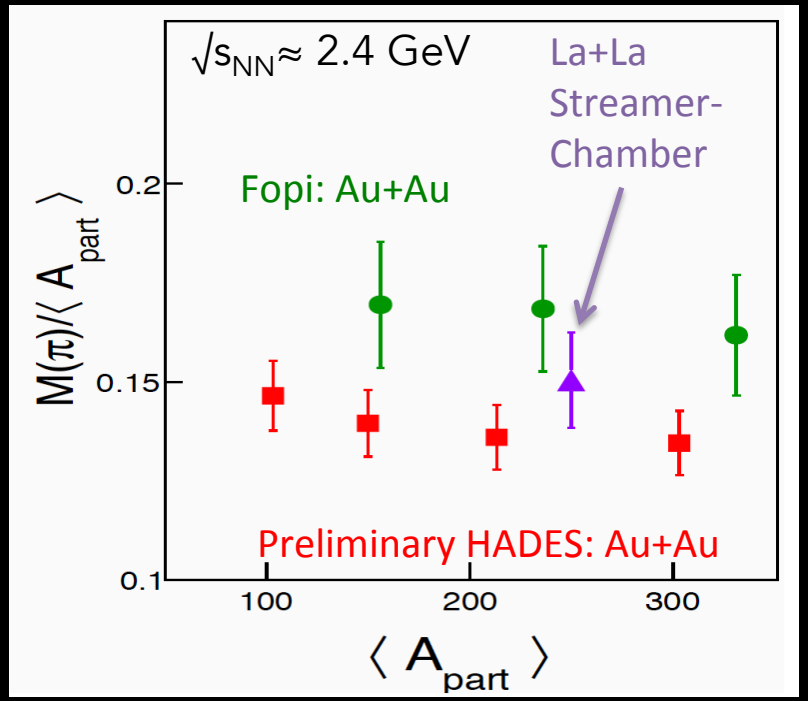


Microscopic models:
only UrQMD describes absolute yield

π Production: World data





Tension at low end of excitation function

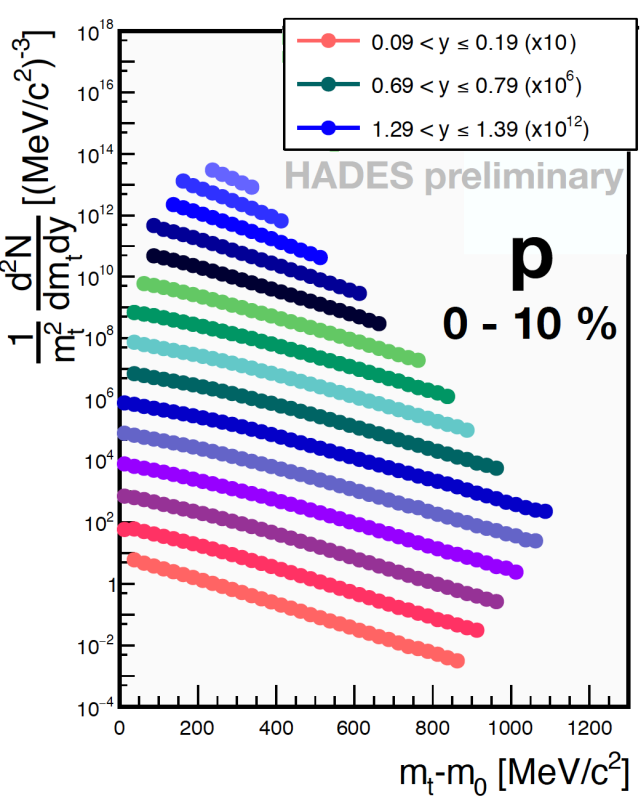
Green: all data; Blue: E895, HADES, TAPS

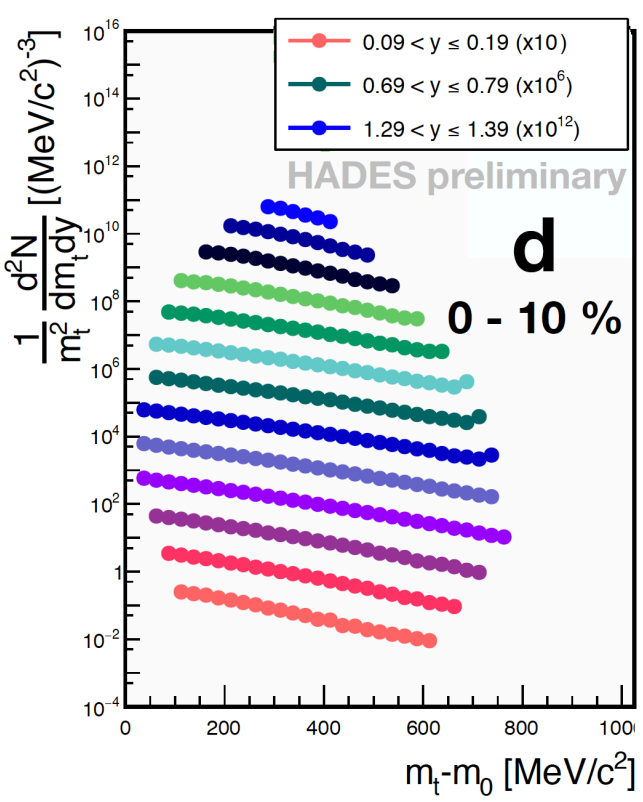
Comparison of data at $\sqrt{s_{NN}} \approx 2.4$ GeV

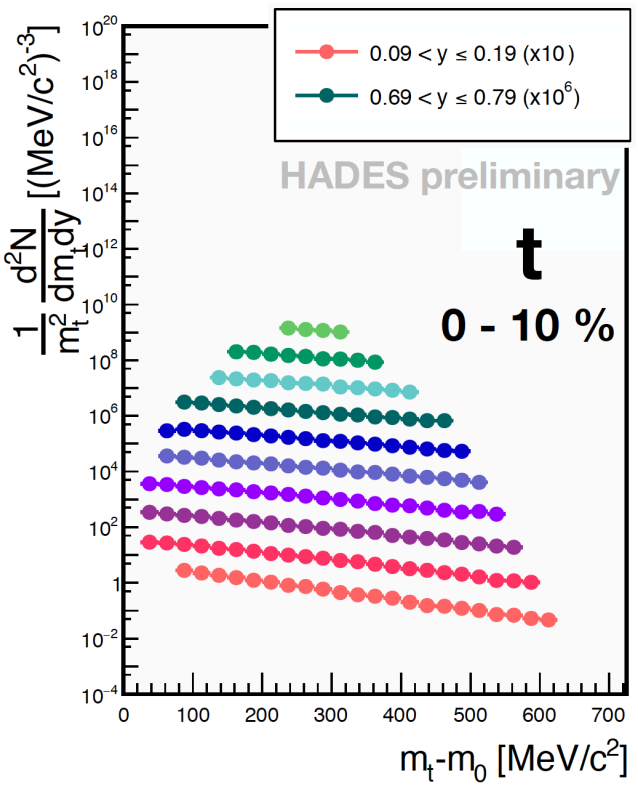
Malgorzata Gumberidze
Tuesday 18:45

J. W. Harris et al. , Phys. Rev. Lett. 58 (1987) 463, R. Averbeck et al. Phys. Rev. C 67 (2003), 024903
J. L. Klay et al. [E895 Collaboration], Phys. Rev. C 68 (2003) 054905, W.Reisdorf et al. [FOPI Collaboratio

Protons and light nuclei

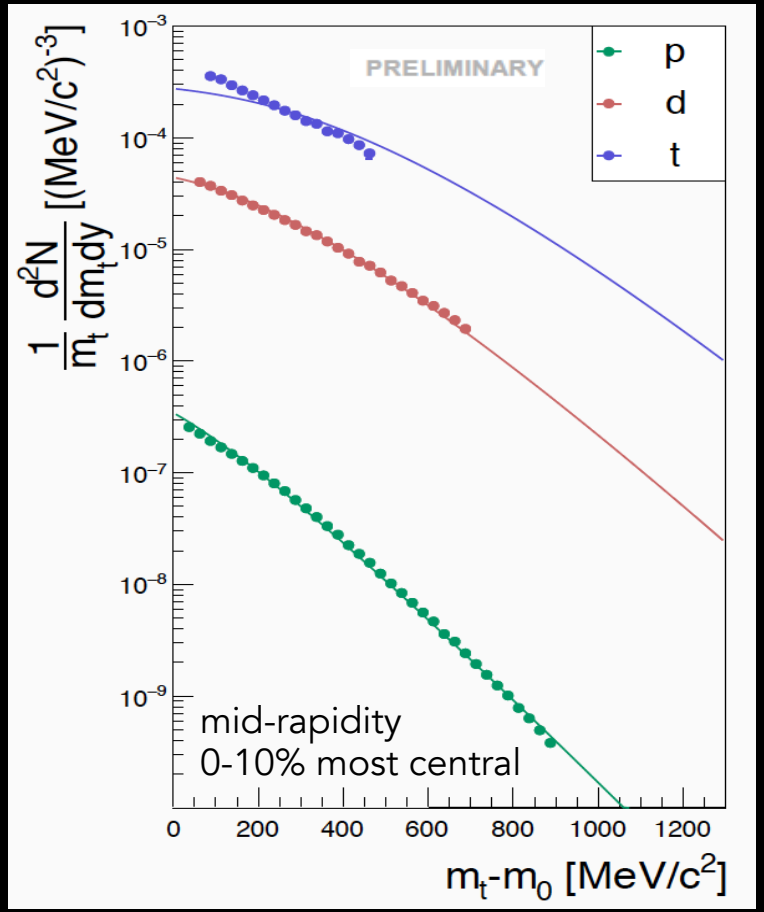






High statistic multi-differential data

Protons and light nuclei: kinetic freeze-out



Blast wave fit with linear velocity profile:

Phys.Rev.C48:2462-2475,1993

T_{kin}=66±8 MeV

$<\beta_r>$=0.34±0.02

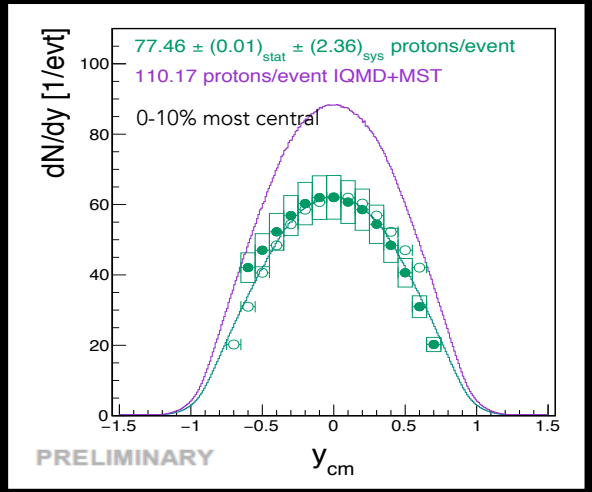
p and d described with simple BW model
shape of t more complicated

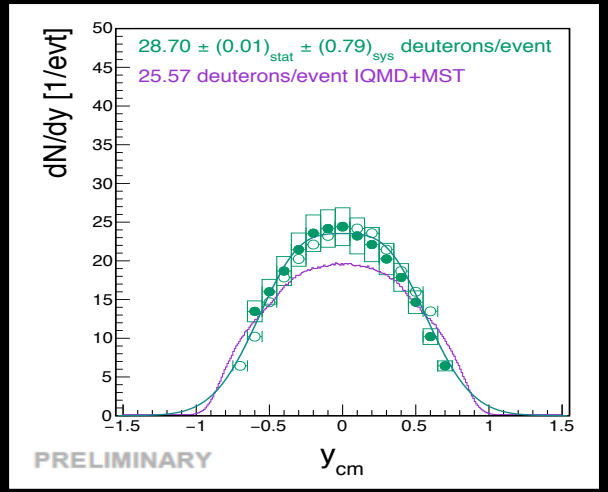
Protons and light nuclei: microscopic description

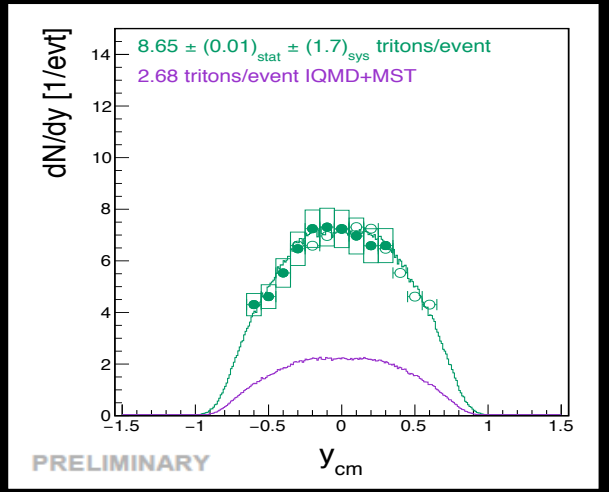
In a simple coalescence approach nuclei are "clustered" with the help of dedicated "afterburner".
Example: IQMD plus minimal spanning tree (MST) *

r = 5 fm in position space and t<140 fm/c

* Thanks to Y. Leifels







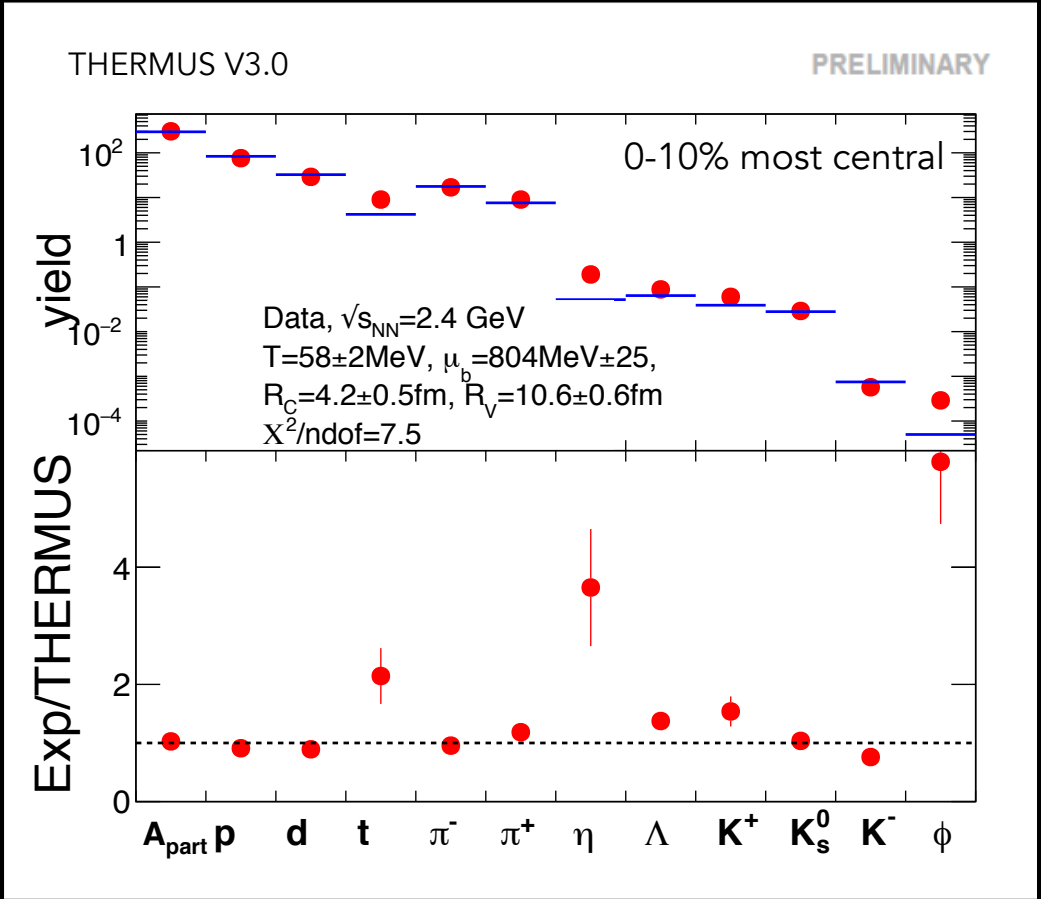
→ Challenge to reproduce light nuclei yields at mid-rapidity with simple coalescence.

More involved calculations:

P. Danielewicz and Q. Pan, Phys. Rev. C 46, 2002 (1992).
C. Kuhrts, M. Beyer, P. Danielewicz, and G. Ropke, Phys.Rev. C 63, 034605 (2001).
Akira Ono, EPJ Web of Conferences 122, 11001 (2016).
Le Févre, Y. Leifels, J. Aichelin, Ch. Hartnack, V. Kireyev, E. Bratkovskaya. J.Phys.Conf.Ser. 668

Melanie Szala
Tuesday 16:10
Hadronization and Coalescence

Macroscopic description of yields



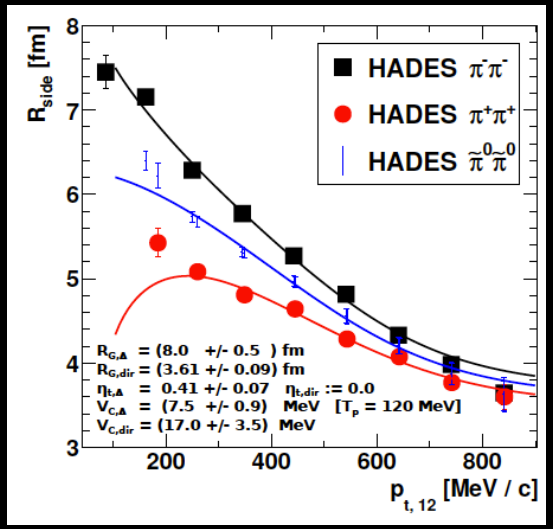
Fit to HADES data consistent with previous works when same selection of hardon species are used (p, d, π, K^+)

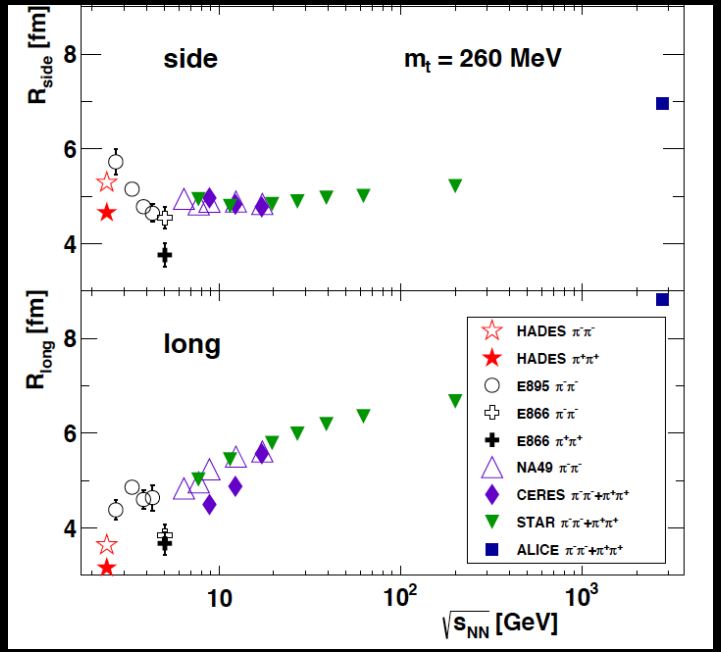
J. Cleymans, H. Oeschler, K. Redlich, Phys.Rev. C59 (1999)

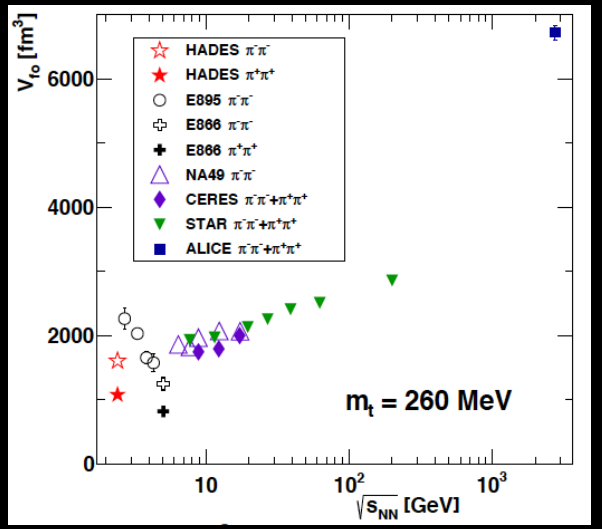
R. Averbeck, R. Holzmann, V. Metag, R.S. Simon. Phys.Rev. C67 (2003)

Fit to full hadron spectrum results in large χ^2 !

π-HBT radii







Indications for charge-sign differences reported previously:

E866 R. A. Soltz, M. Baker, J. H. Lee, Nucl. Phys. A 661, 439c (1999)
E877 D. Miskowiec et al., Nucl. Phys. A590, 473c (1995)
NA44 I.G. Bearden et al., Nucl. Phys. A638, 103c (1998)

First time observation of substantial differences!

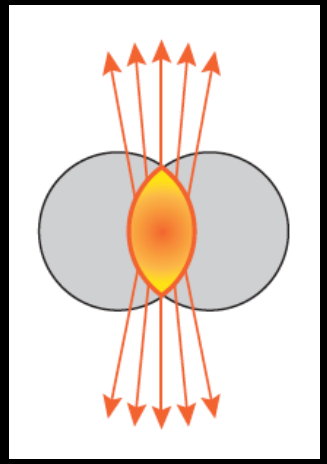
HADES follows trend from STAR/NA49 more than trend from E895
→ room for structures?

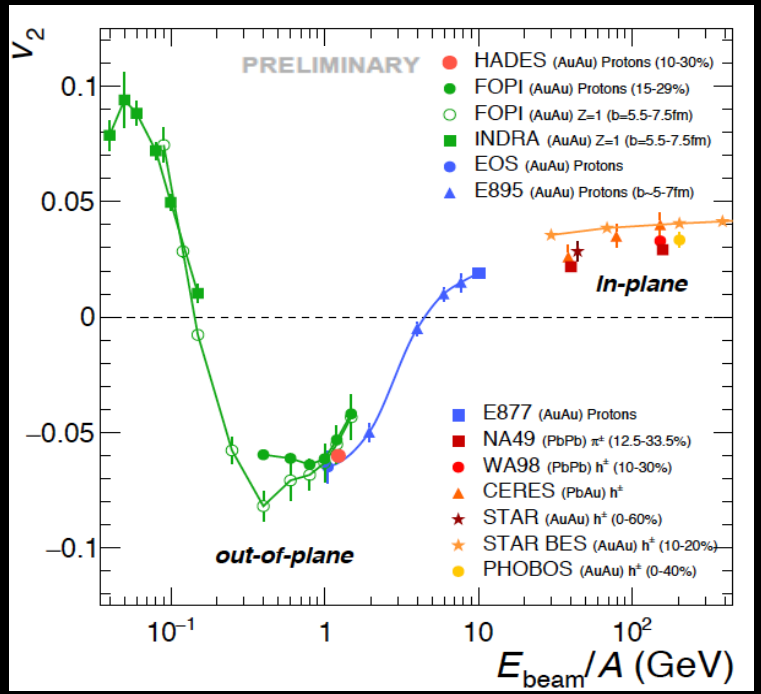
arXiv:1811.06213

Flow Anisotropies

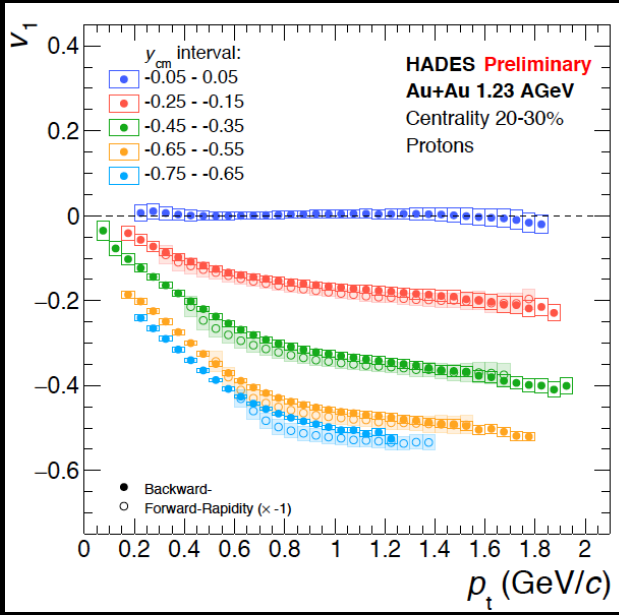
Out-of-plane v_2

- Long spectator passing time
  $\tau_{passing} \approx \tau_{expansion}$
- Squeeze-out

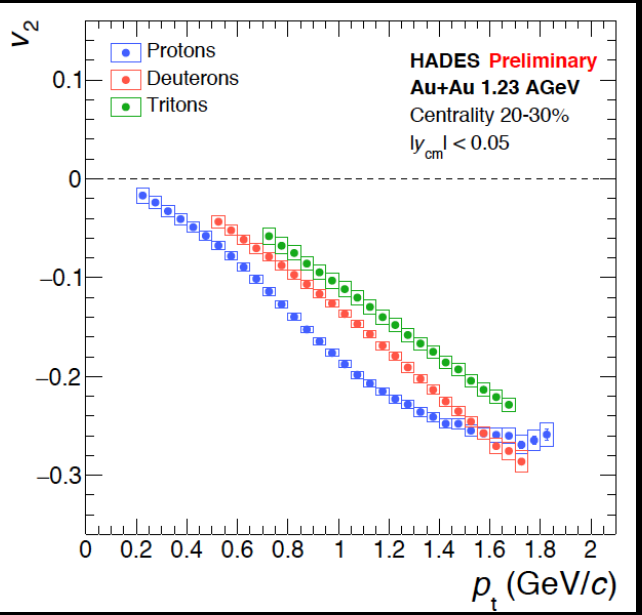




p, d, t v_1, v_2, v_3, v_4

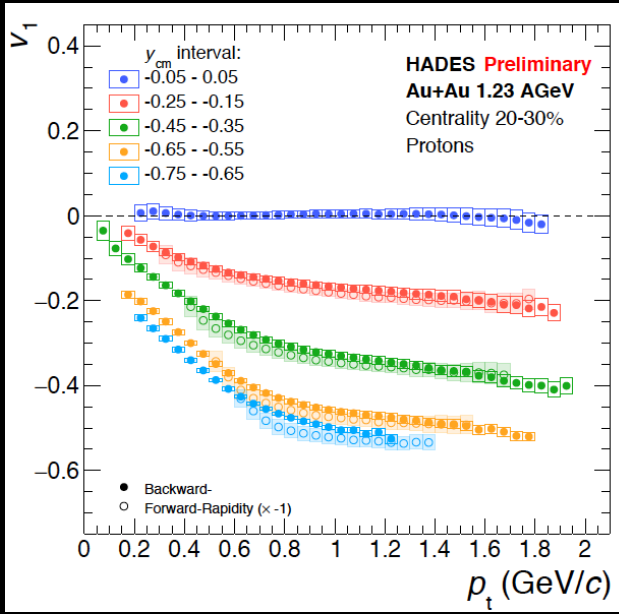


High statistic multi-differential data

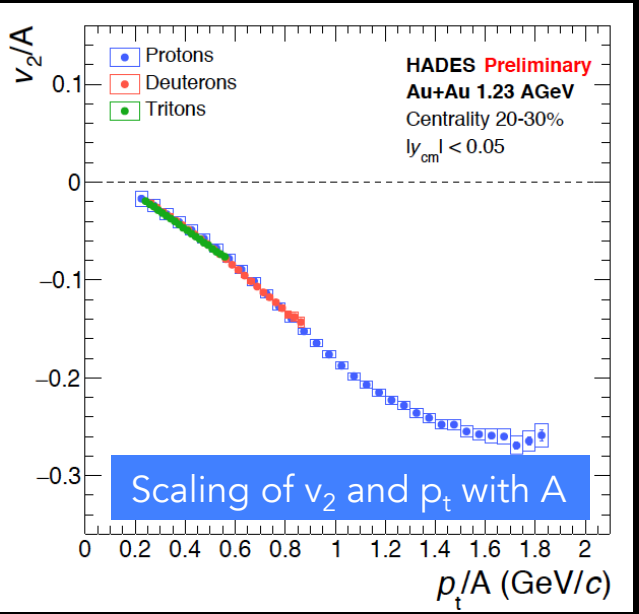


Comparison p,d,t at mid-rapidity

p, d, t v_1, v_2, v_3, v_4



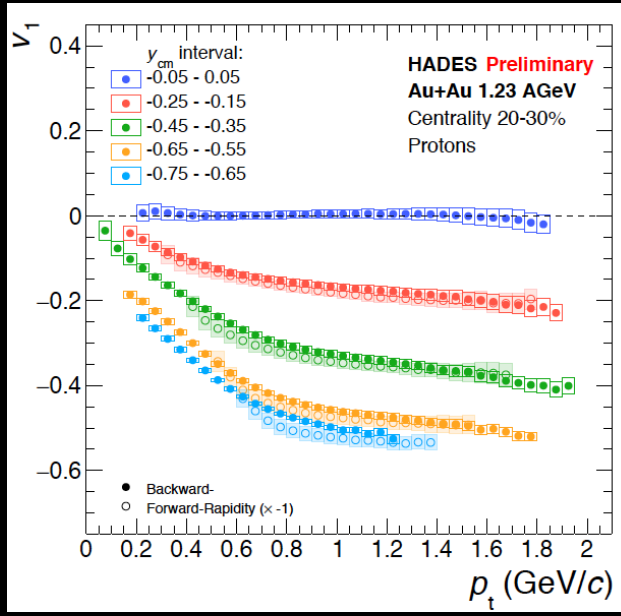
High statistic multi-differential data

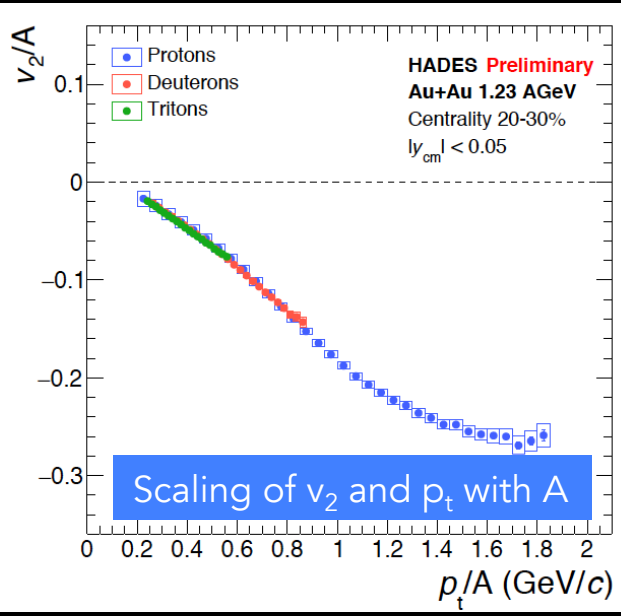


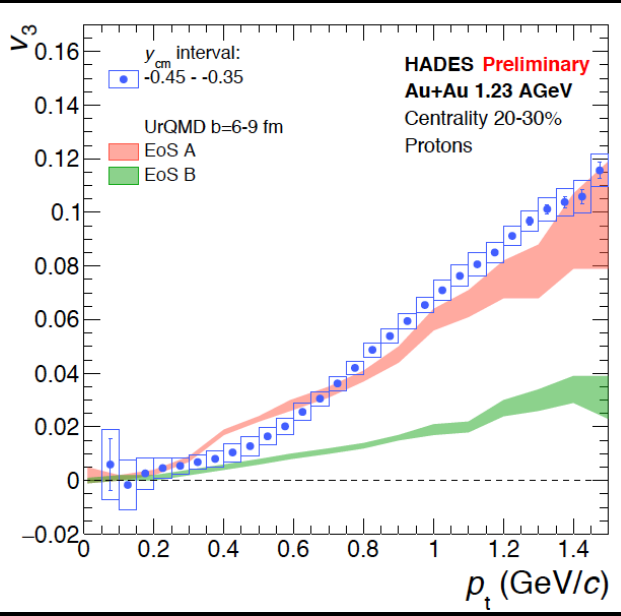
Comparison p,d,t at mid-rapidity

UrQMD prediction: P. Hillmann et al. J.Phys. G45 (2018) no.8, 085101

p, d, t v_1, v_2, v_3, v_4





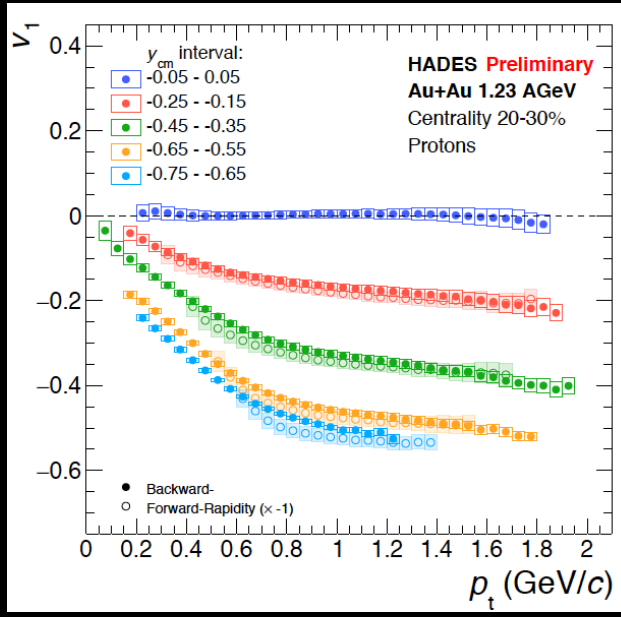


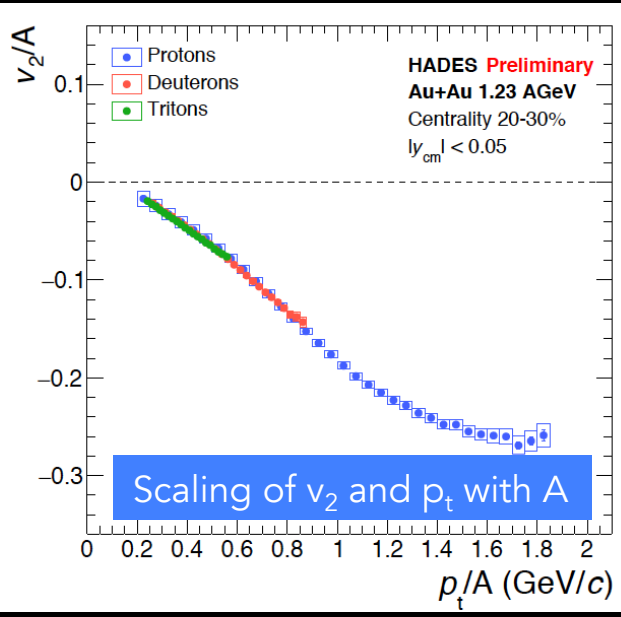
High statistic multi-differential data

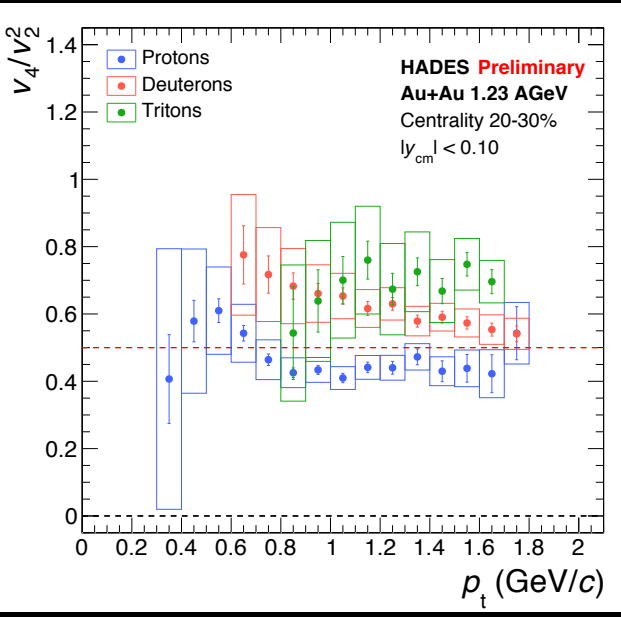
Comparison p,d,t at mid-rapidity

Sensitivity to EOS

p, d, t v_1, v_2, v_3, v_4







High statistic multi-differential data

Comparison p,d,t at mid-rapidity

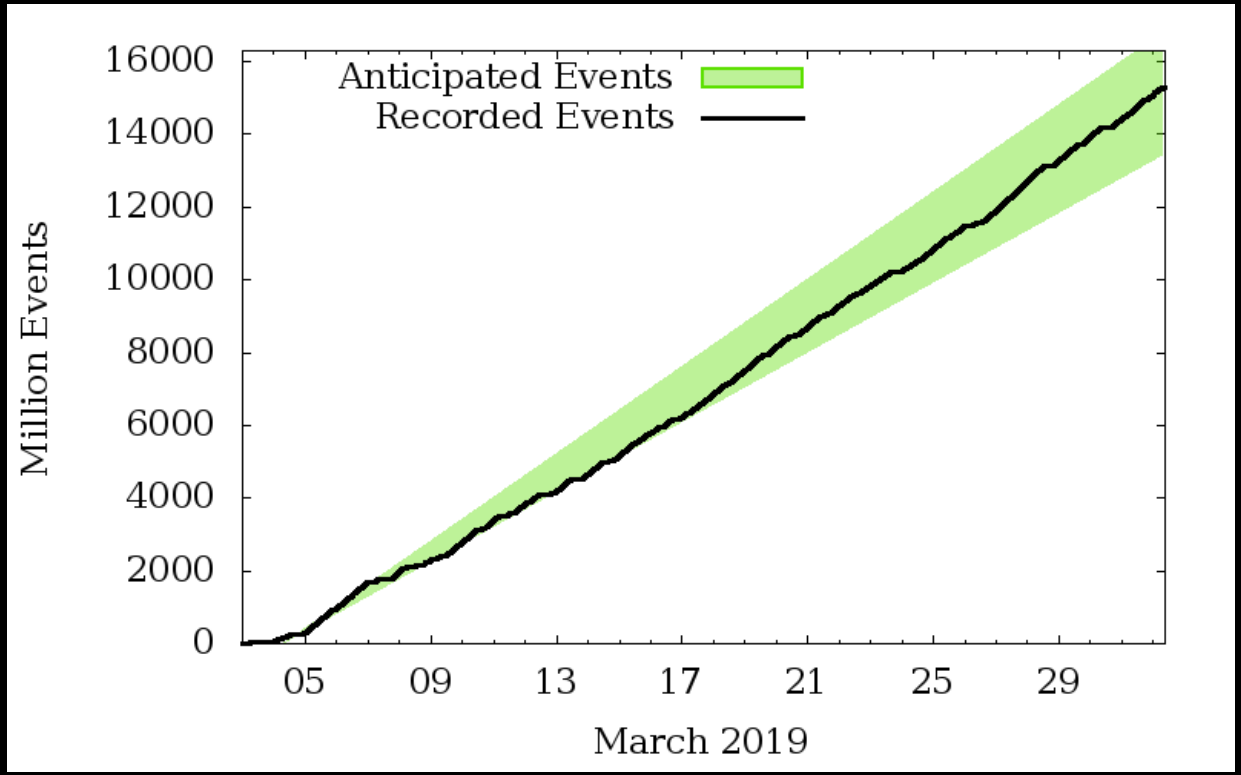
Description by hydrodynamics?

Behruz Kardan
Tuesday 18:45

Lukáš Chlad
Thursday 16:30

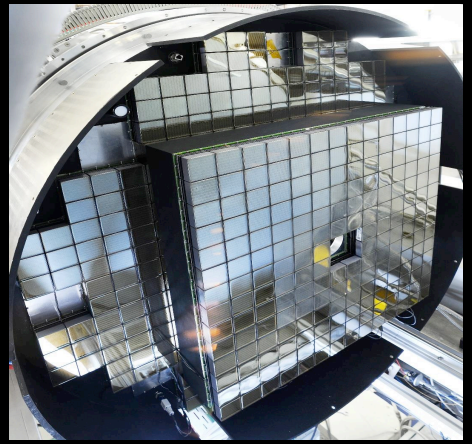
FAIR-Phase 0

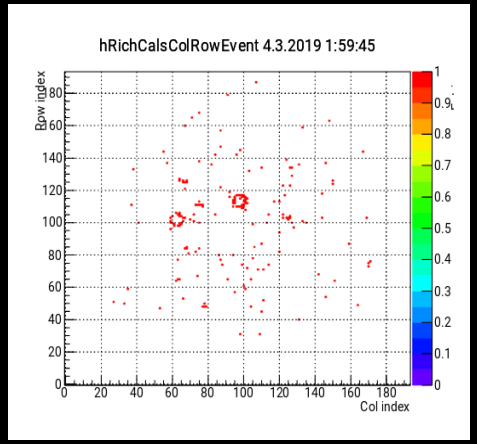
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV



~ 15 billion events collected during March 2019

Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Virtual Photons

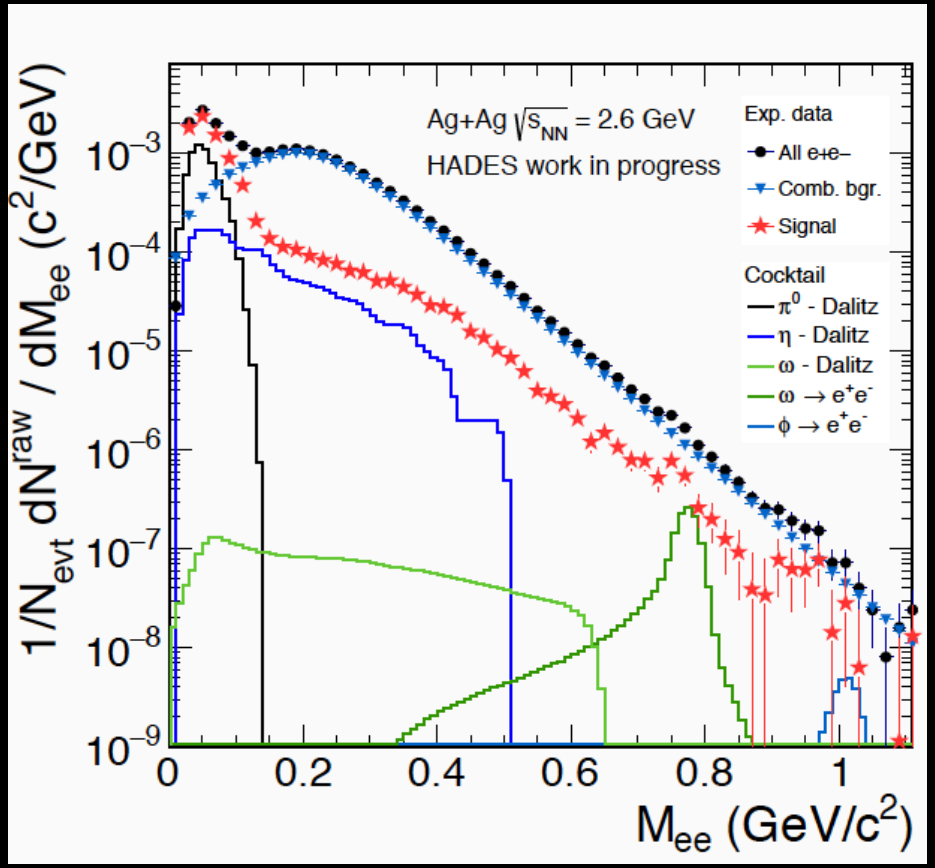




½ of the CBM RICH photon detector

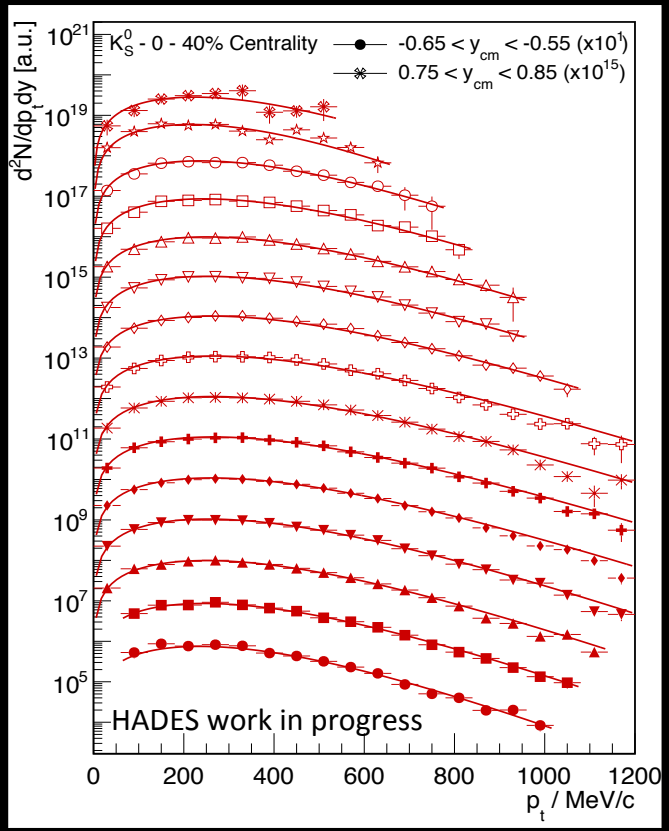
Stable operation during 4 weeks of beamtime

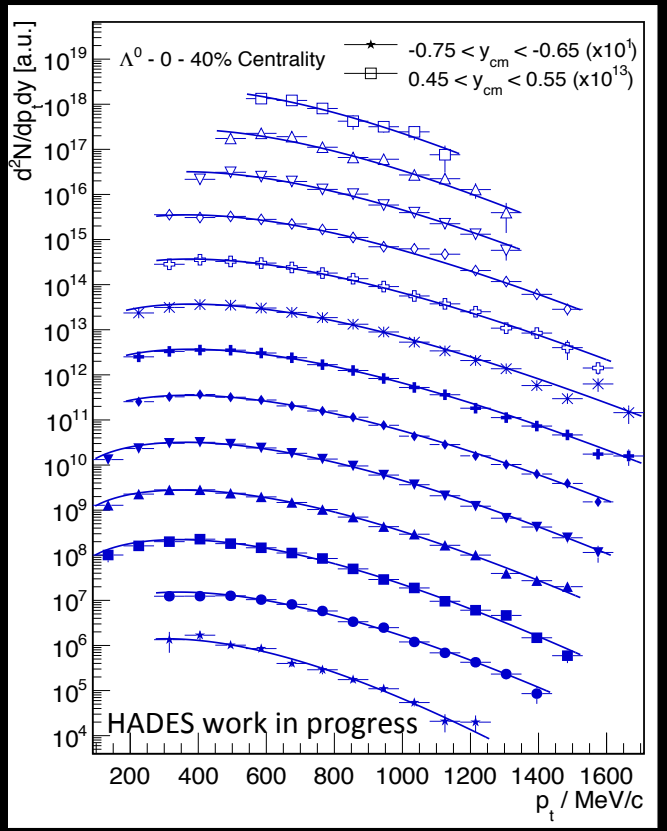
Resulting spectrum →

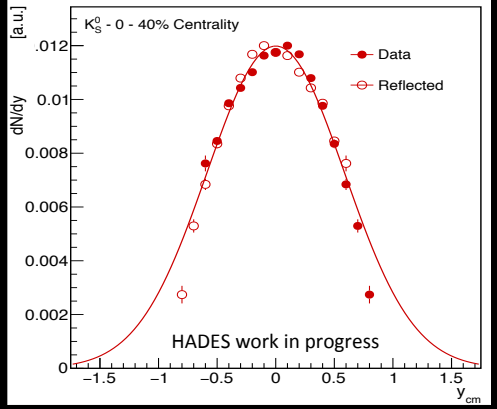


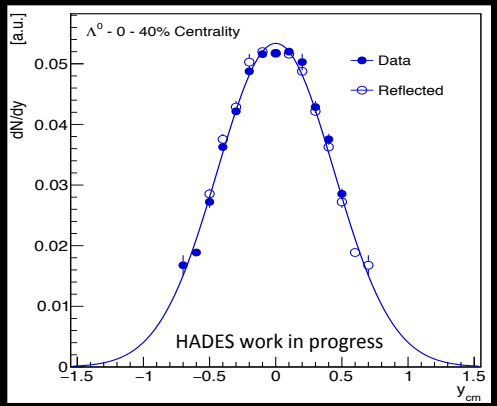
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Strangeness

K^0_s and Λ production at the NN-threshold









Summary

Virtual Photons:

Strong broadening of the ρ, exponentially falling spectrum,

→ extraction of temperature $\langle T_{ee} \rangle$ = 72 MeV

Strangeness:

Universal $\langle A_{part} \rangle$ dependence of strangeness production

π – beam:

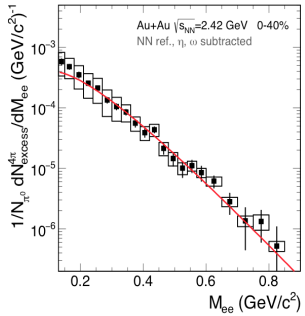
data for detailed investigation of the coupling to baryons

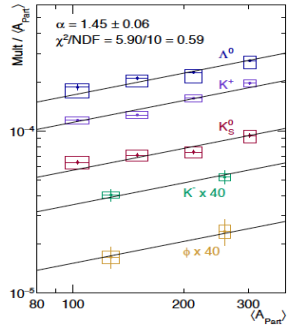
The Bulk:

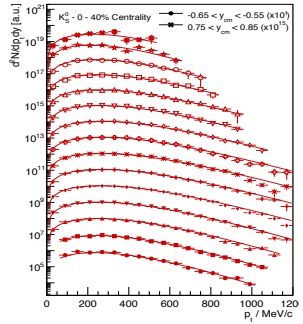
Multi-differential data on p, light nuclei, π
including flow anisotropies and HBT radii

FAIR-Phase0:

High quality data ~~to come~~ are here







The HADES collaboration