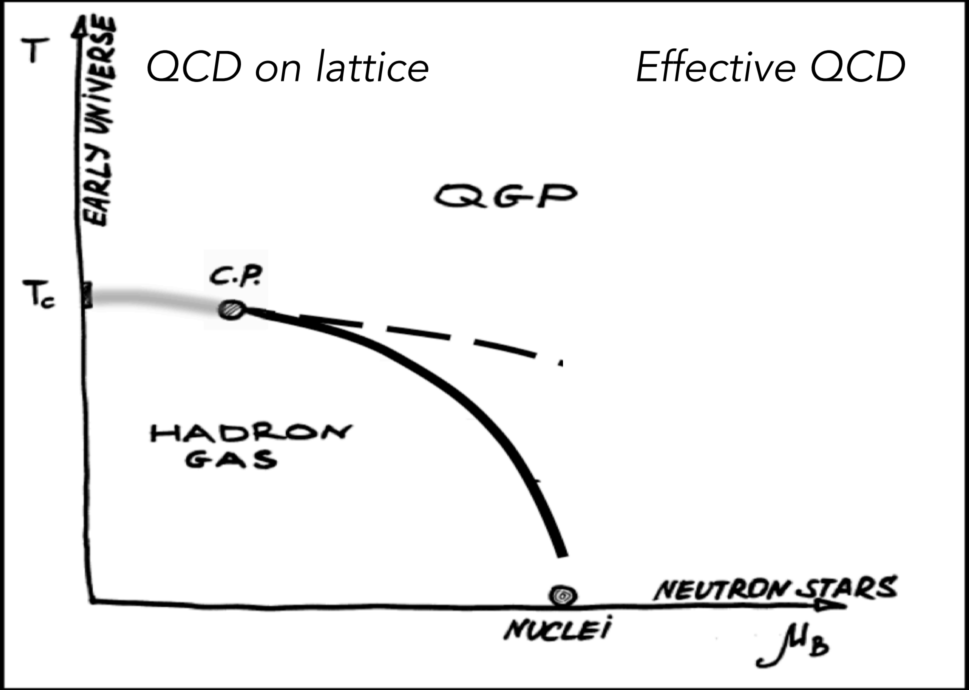
Recent Results from HADES

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

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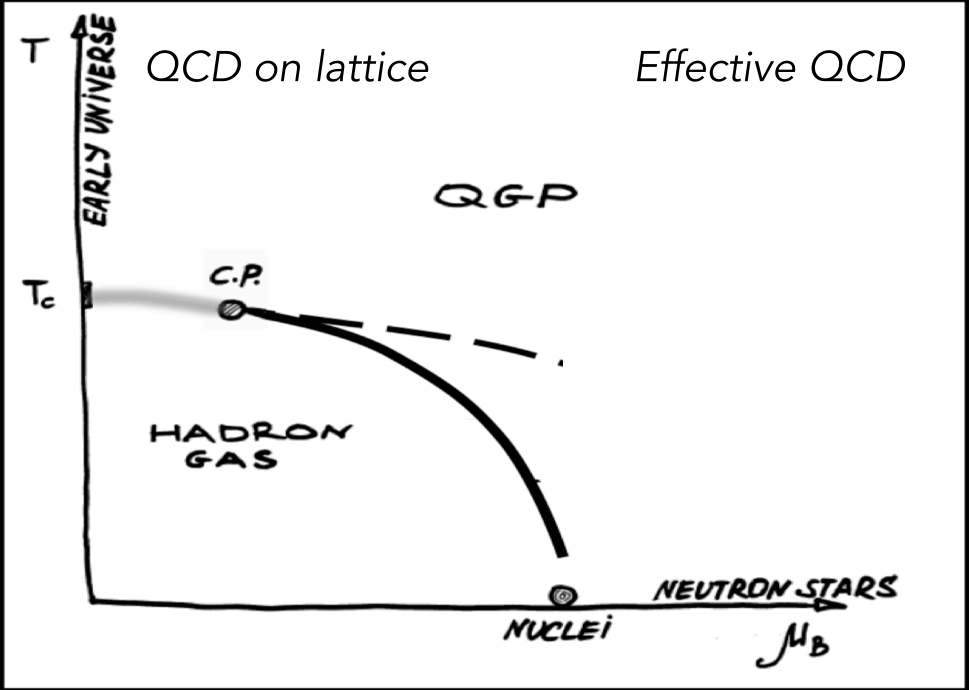

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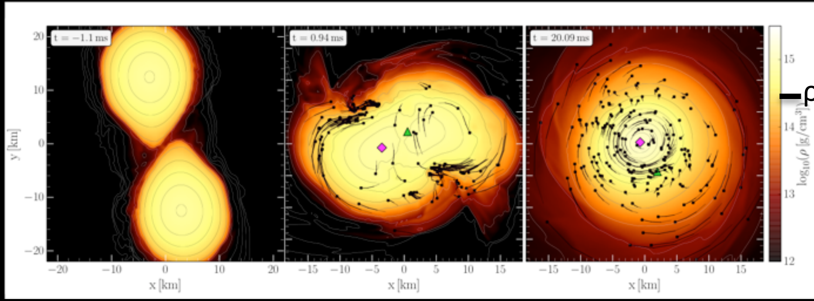
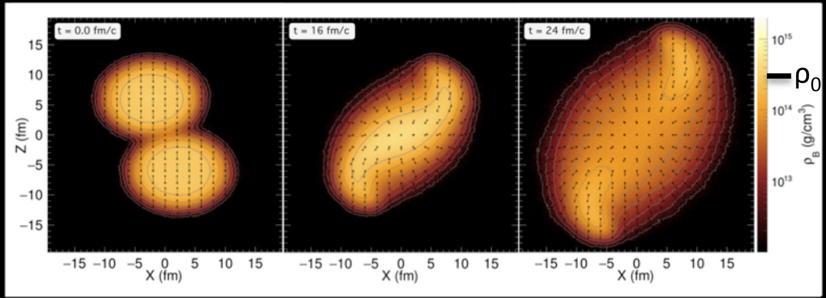
Similar conditions as in merging Neutron Stars

Merging Neutron Stars



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



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

Fig. credit T. Galatyuk & F. Seck

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).

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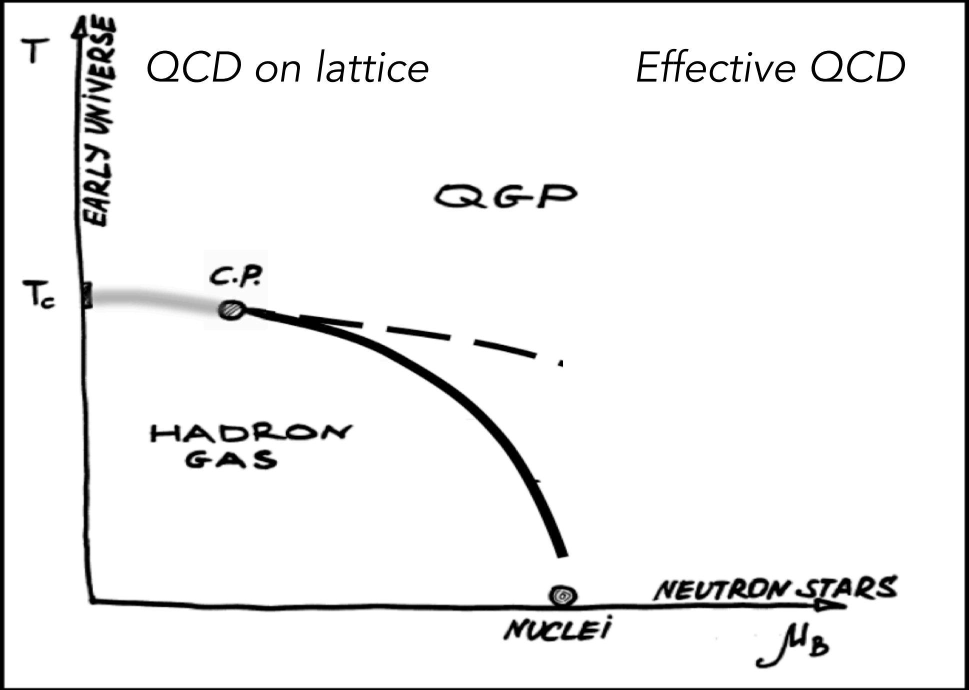

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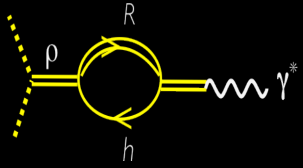
Similar conditions as in merging Neutron Stars

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

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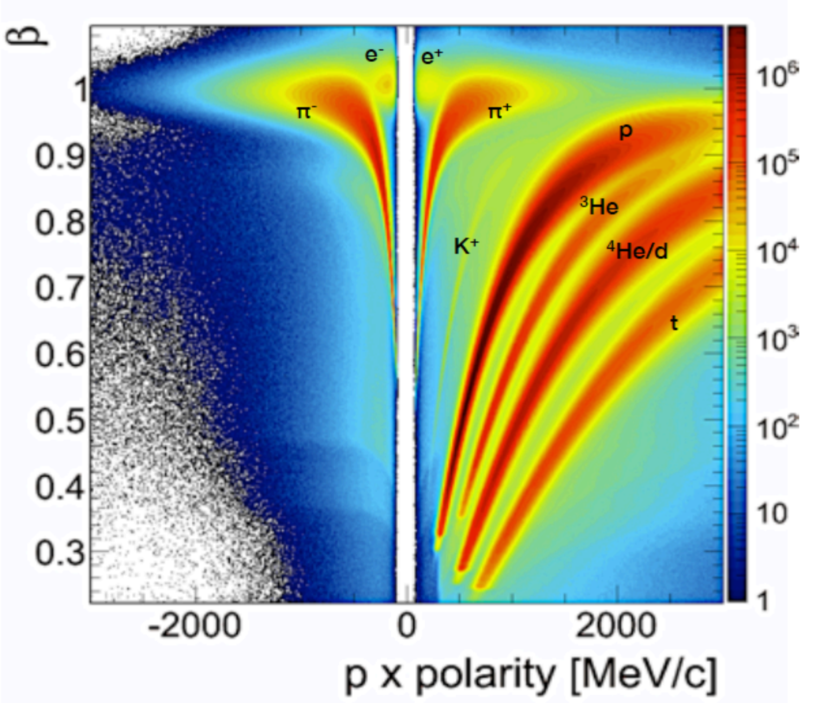

HADES: Au+Au $\sqrt{s_{NN}}$=2.4 GeV,
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Clear hierarchy in hadron yields:
p ≈ 100, lt. nuclei ≈ 50 π ≈ 10, K^+ ≈ 10^{-2}, K^- ≈10^{-4}

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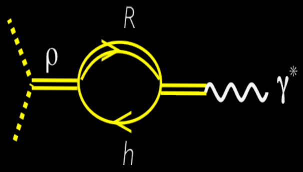

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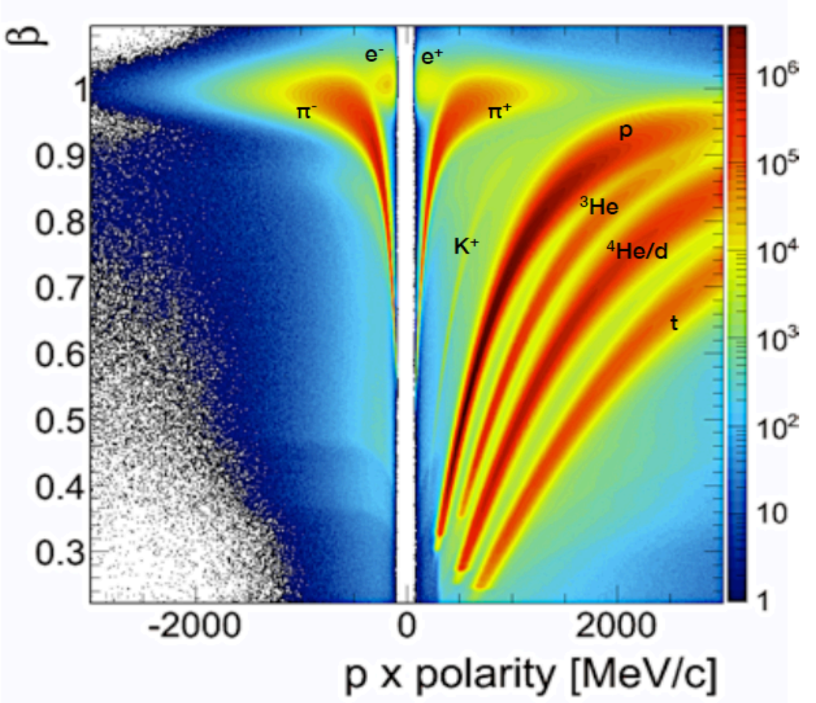

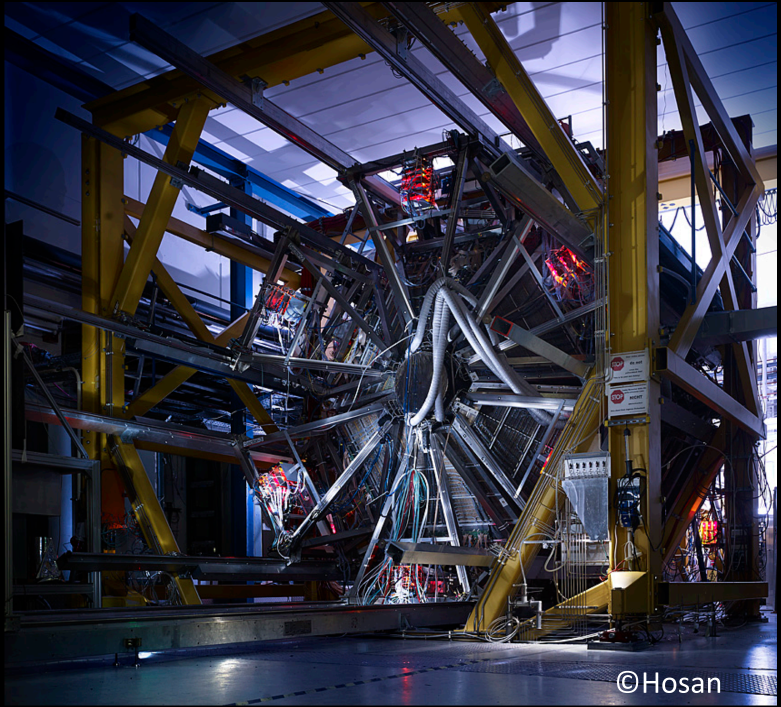

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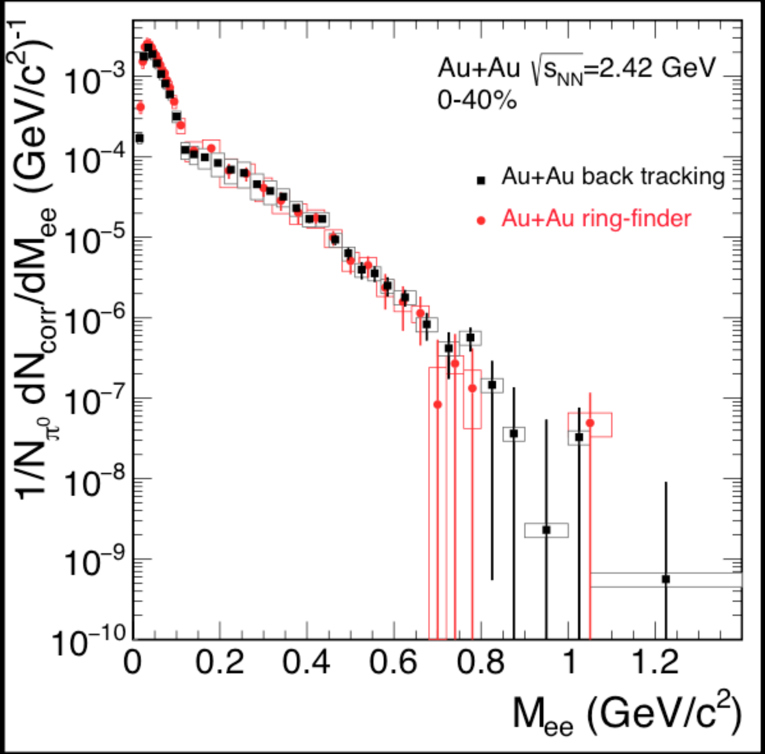
Clear hierarchy in hadron yields:
p ≈ 100, lt. nuclei ≈ 50 π ≈ 10, $K^+ \approx 10^{-2}$, $K^- \approx 10^{-4}$

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 $\sqrt{s_{NN}}$.

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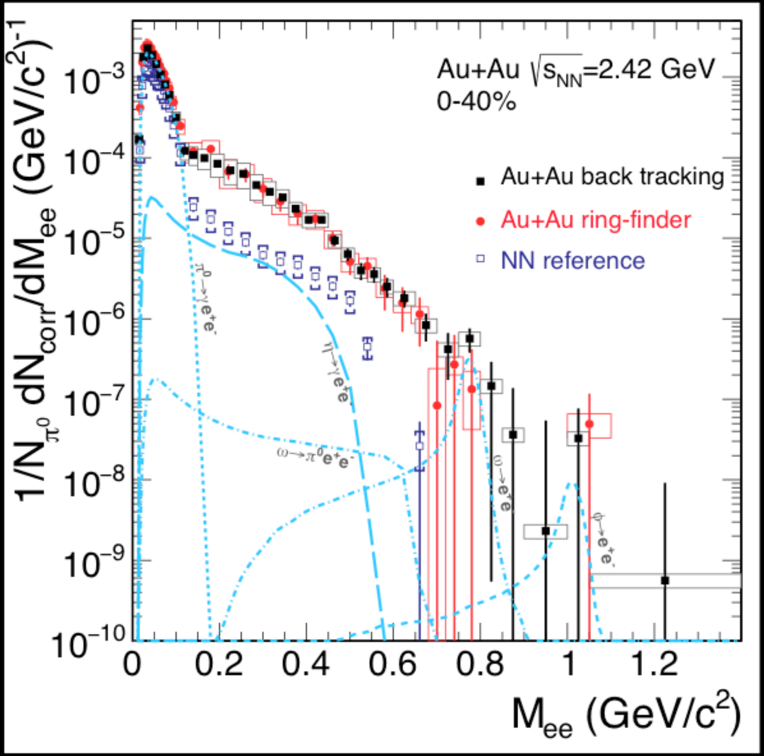

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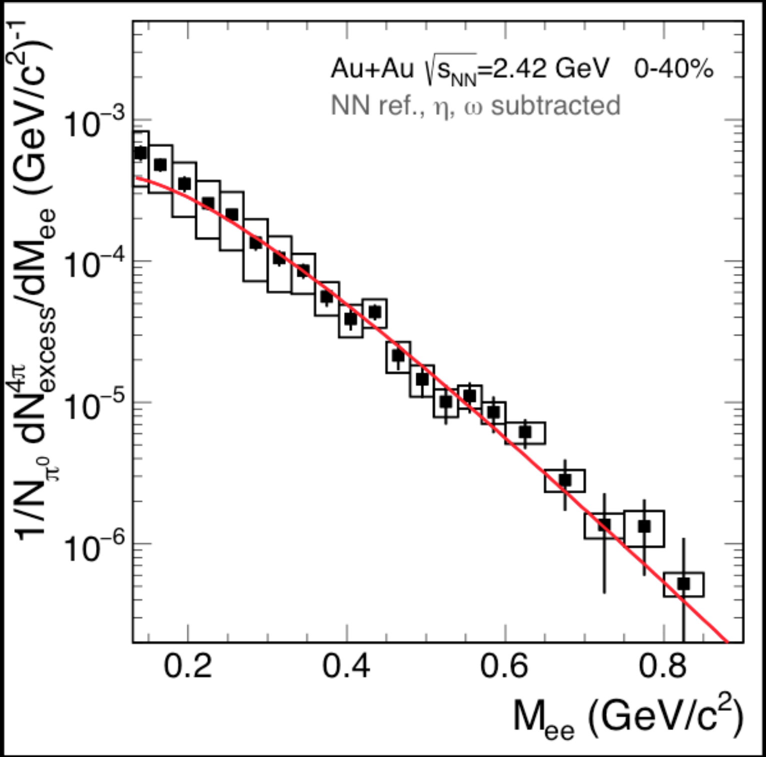
- Strong excess (0.15<M<0.7 GeV/c^2) above components of meson decays at freeze-out and elementary reference.
- Isolation of excess by subtracting the elementary reference.

Virtual Photons

Acceptance corrected excess yield.



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- Exponentially falling spectrum,

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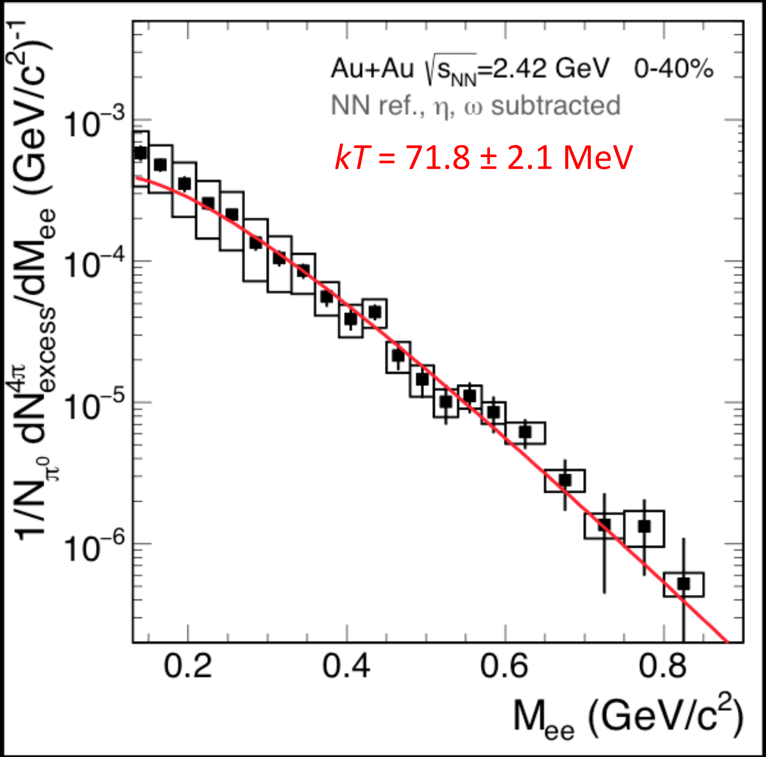

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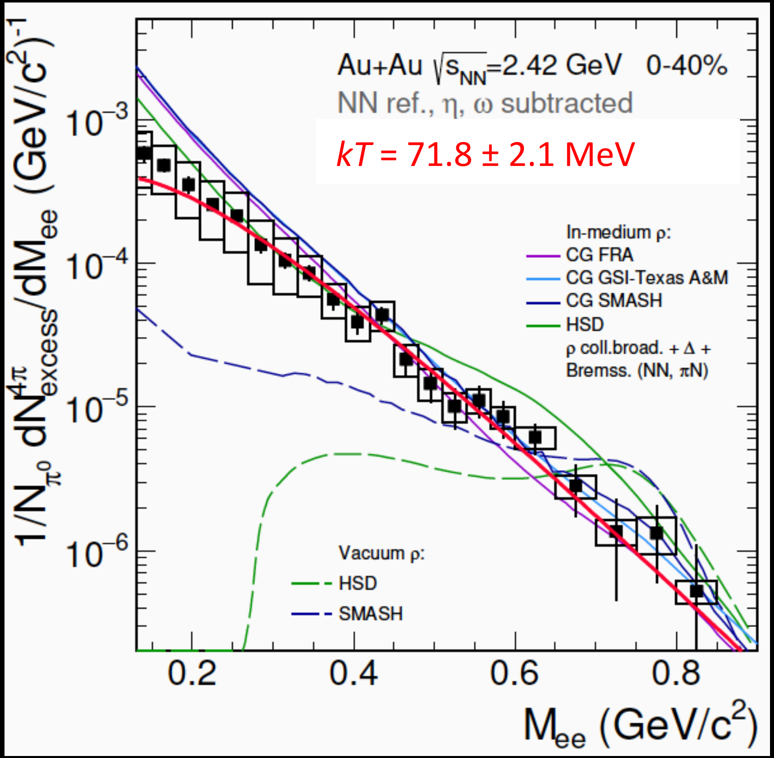

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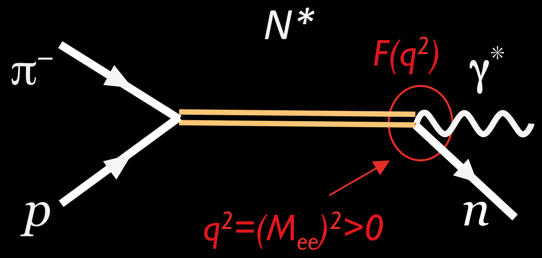
- Medium radiation: Strong broadening of the ρ due to direct ρ-baryon scattering
- Exponentially falling spectrum,
  → extraction of temperature <T_{ee}> = 72 MeV
- Thermal rates folded over coarse-grained transport medium evolution works at low energies
- Supports baryon-driven medium effects at SPS, RHIC (LHC)!

ρ-Baryon Coupling Mechanism

π^- beam $\sqrt{s_{\pi N}}$= 1.49 GeV

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



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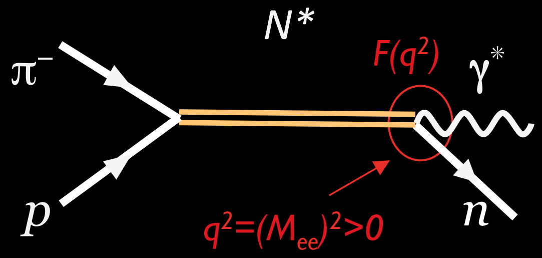
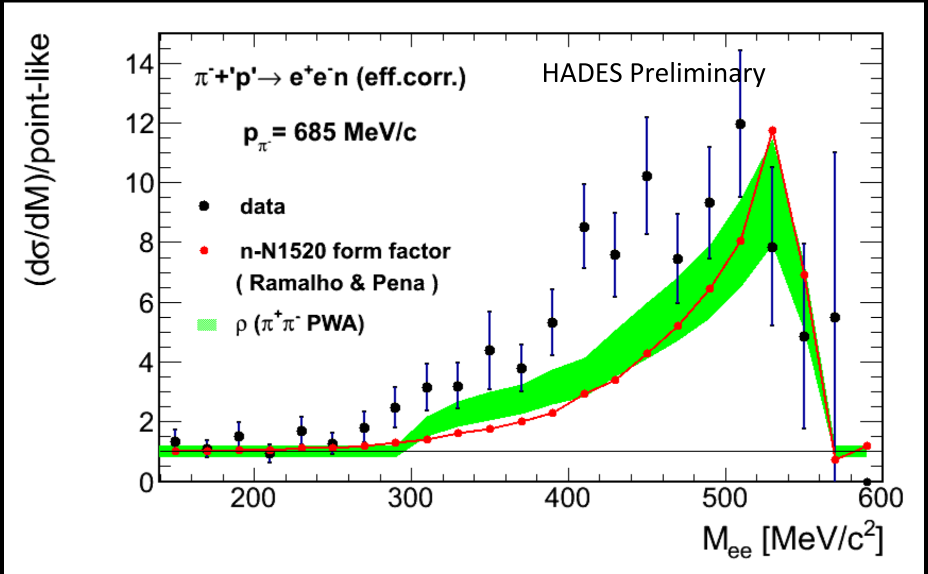


e^+e^- invariant mass distribution ratio to point-like contributions



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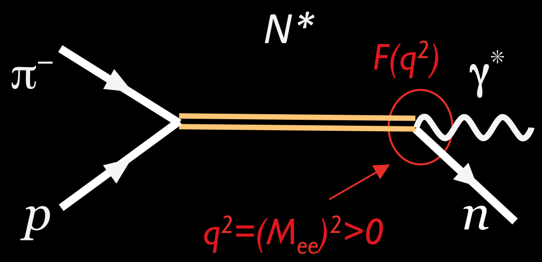
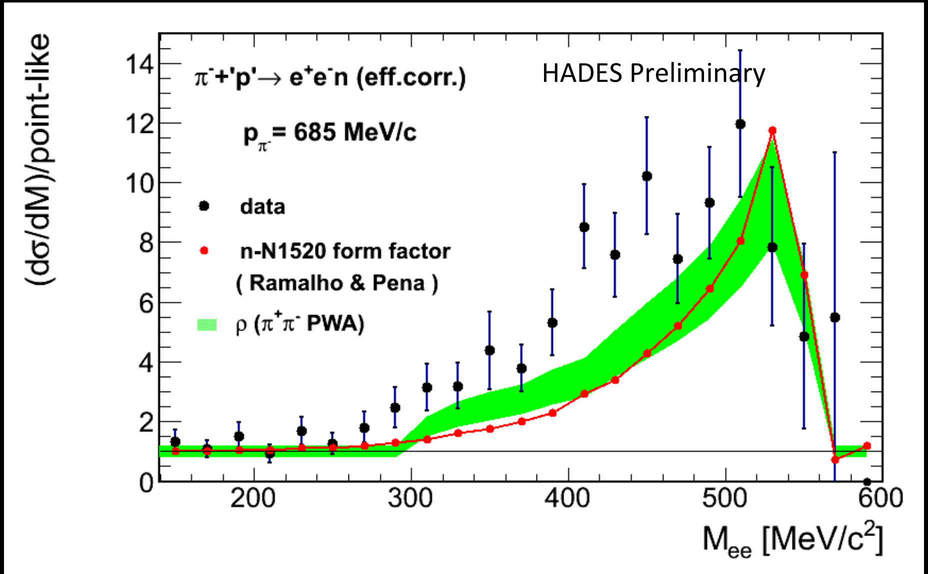


Two consistent approaches:

- 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

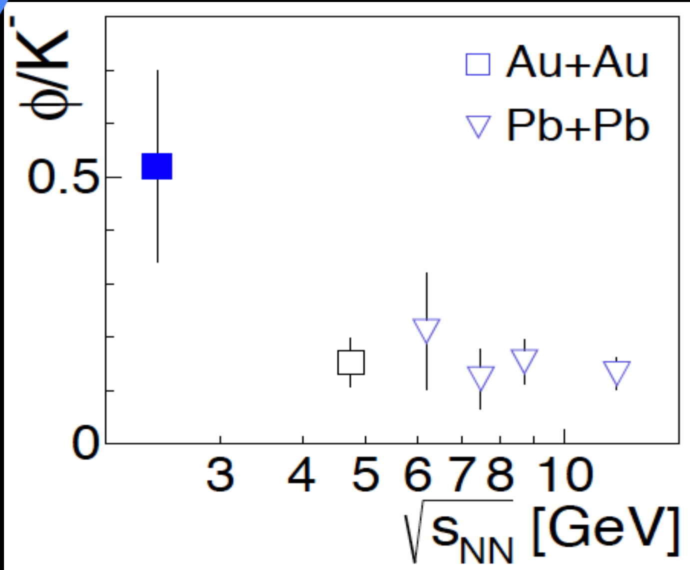


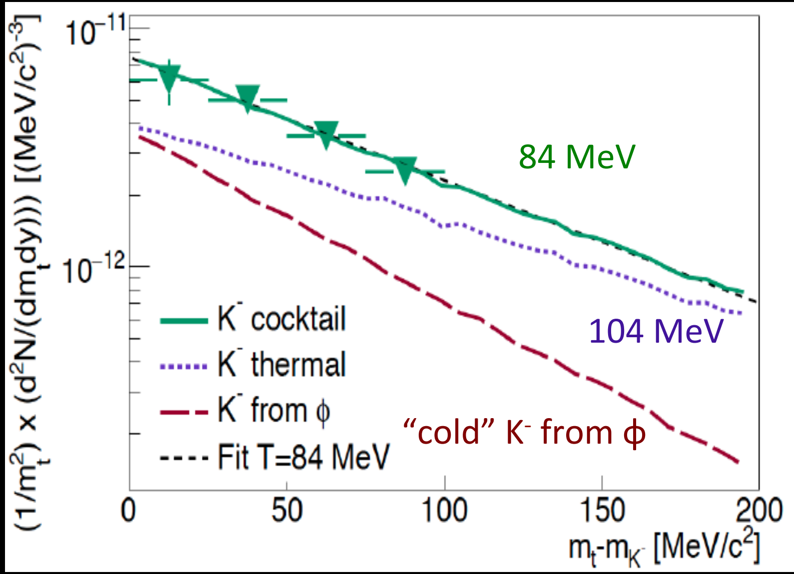
Invariant mass and angular distributions are consistent with ρ decay and VDM form factor models

Strangeness

Φ-AntiKaon Interplay in HIC

Reminder



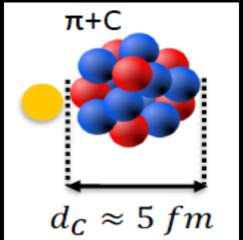


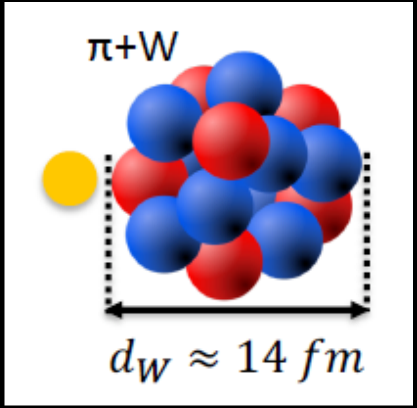
Increased in HIC at low $\sqrt{s_{NN}}$:
→ 25% of K^- result from Φ decays!

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

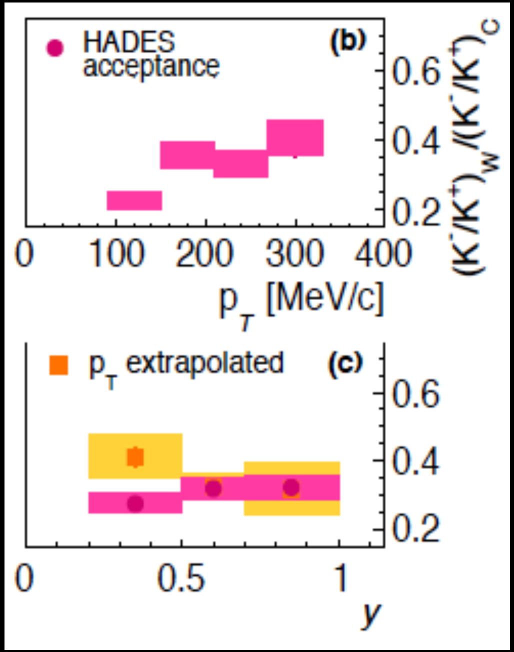
Phys.Lett. B778 (2018) 403-407

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^+

arXiv:1812.03728 [nucl-ex] accepted by PRL

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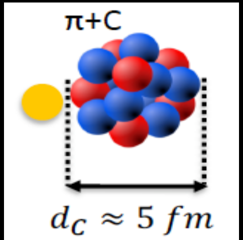

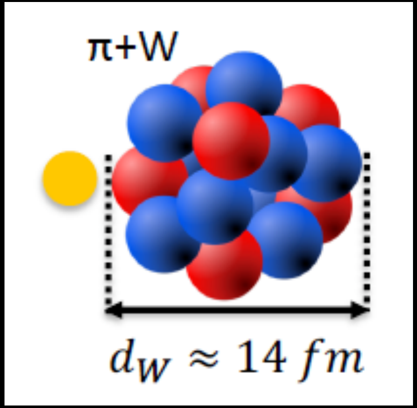

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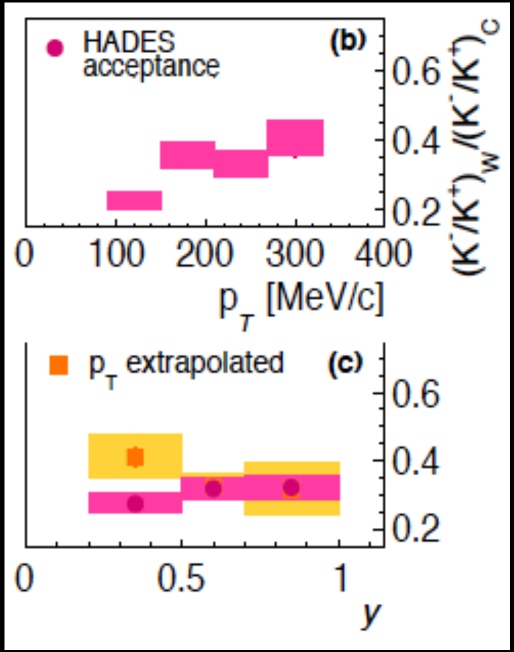

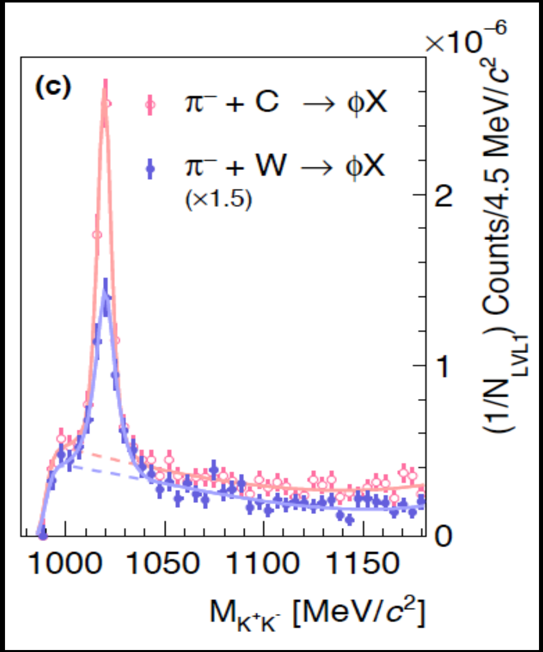

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In HADES acceptance:

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

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

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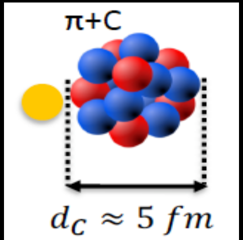
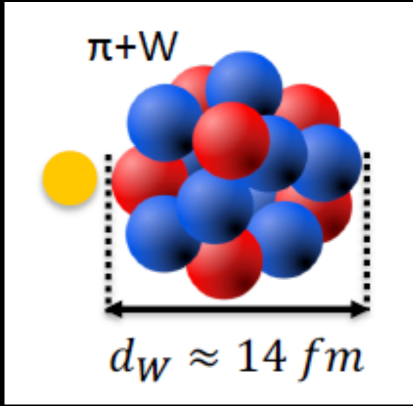
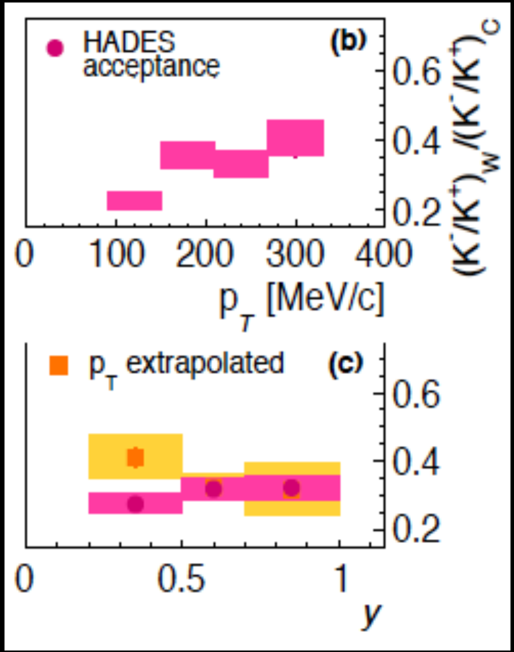
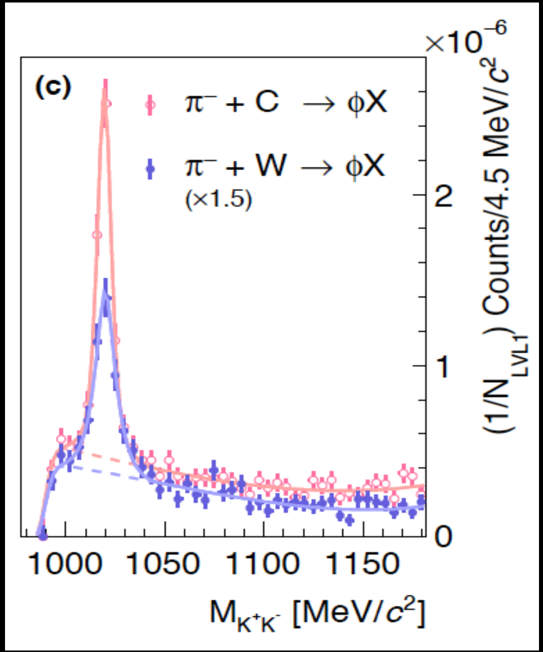
Φ-AntiKaon Interplay in Cold Matter









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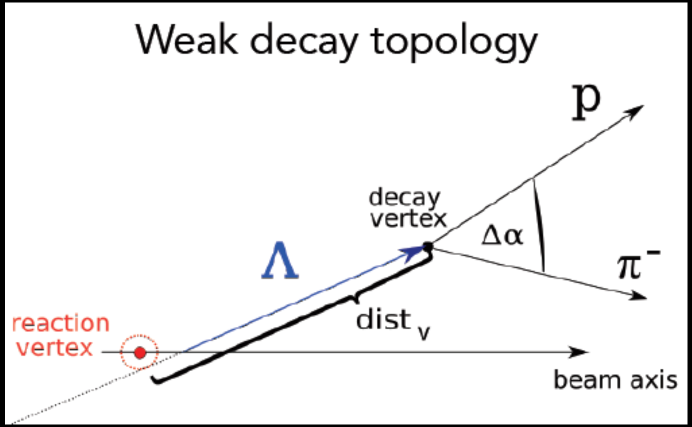
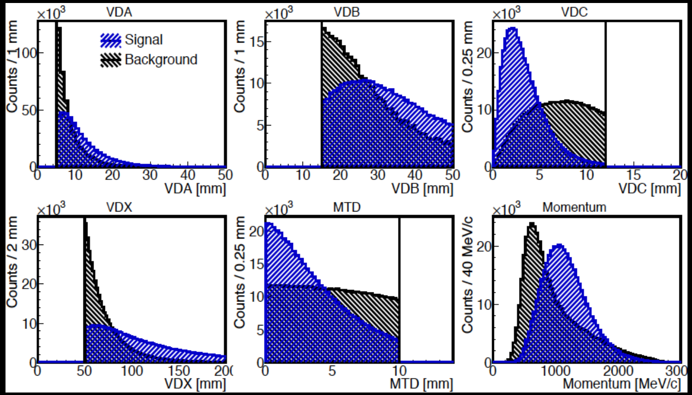
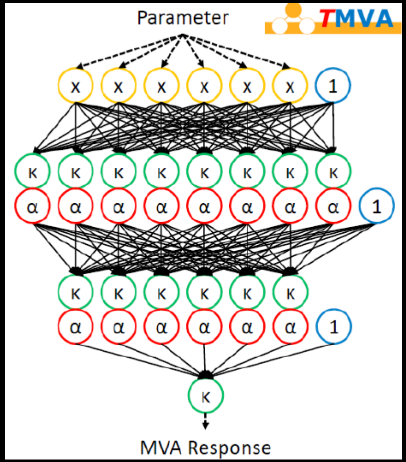
Weak decay topology recognition with neural networks



↓ Results in several parameters



Which can be feed into an ANN



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

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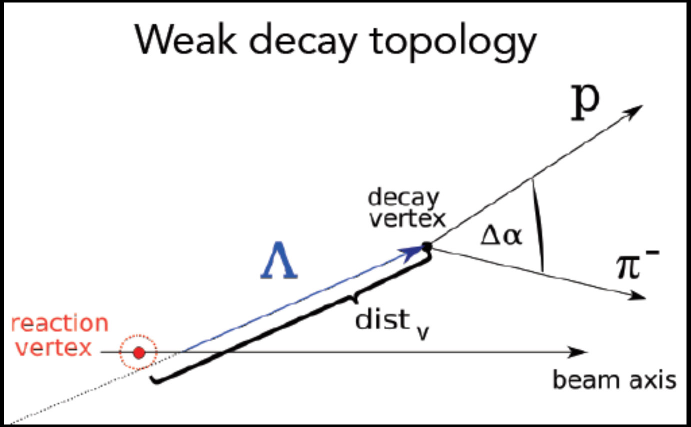

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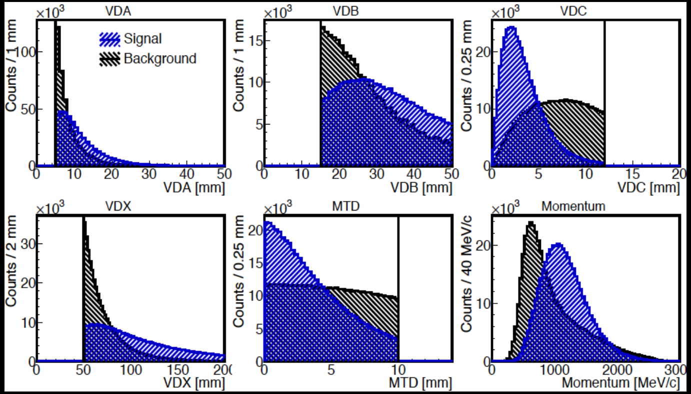

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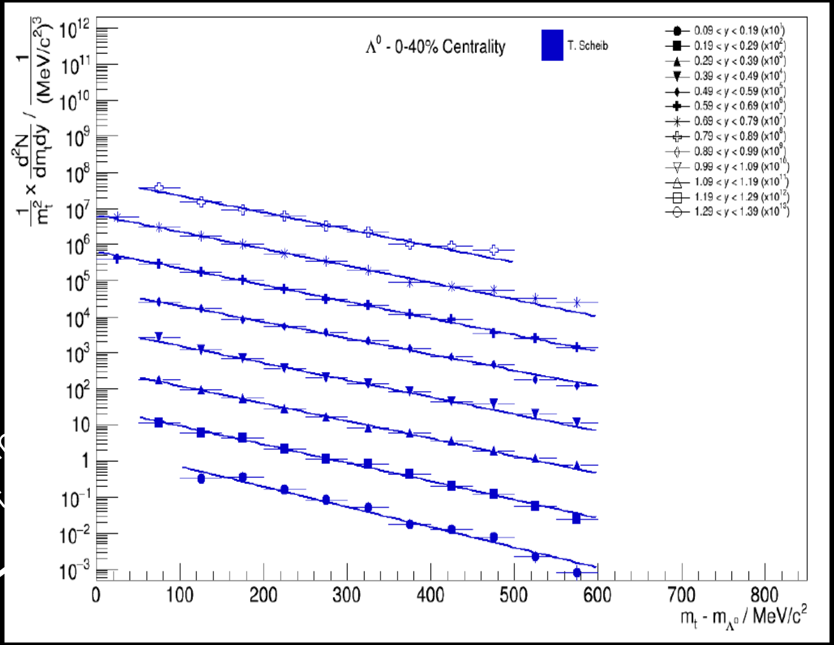

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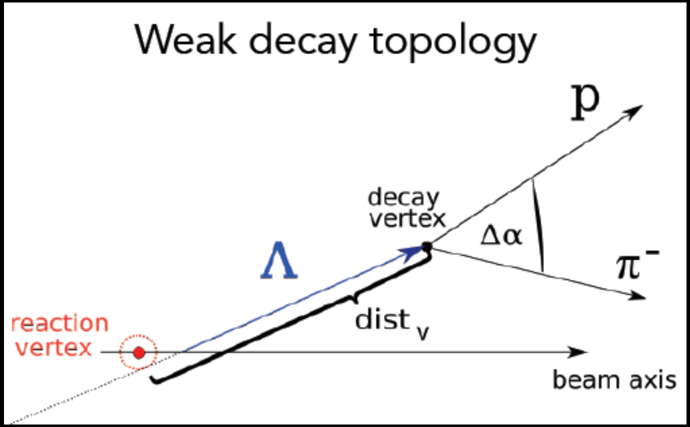

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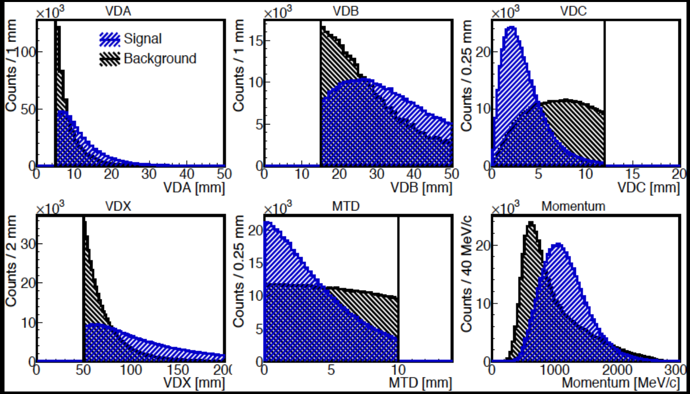

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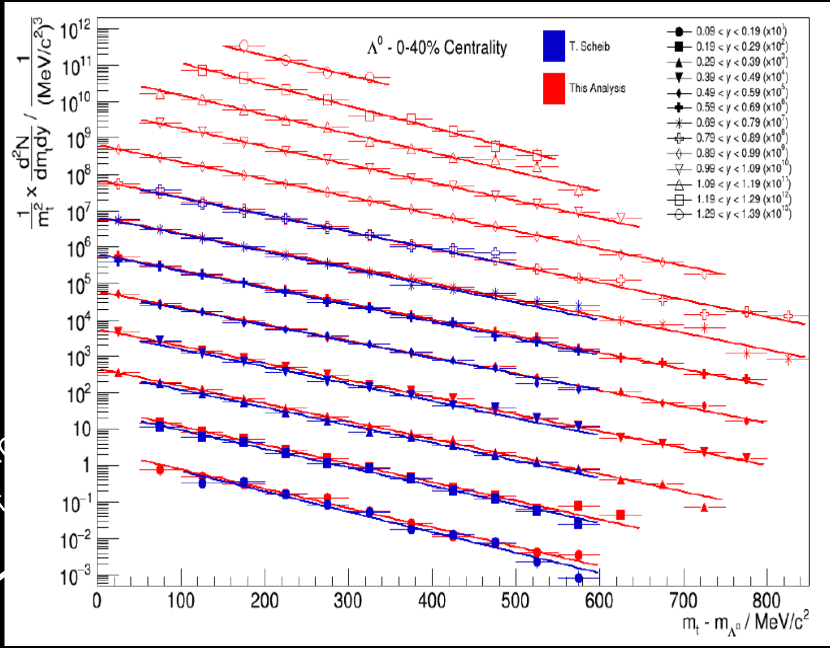

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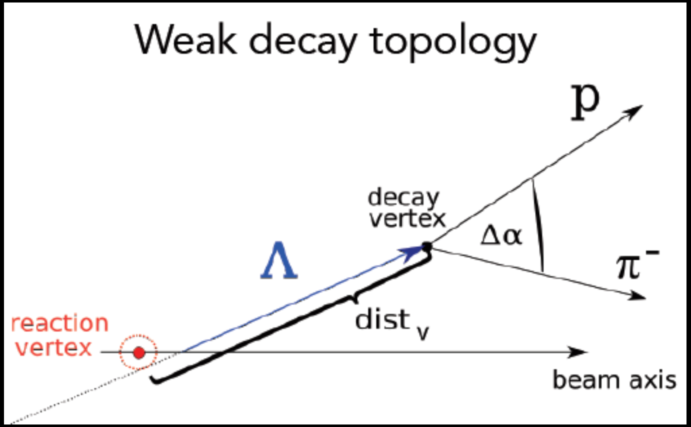

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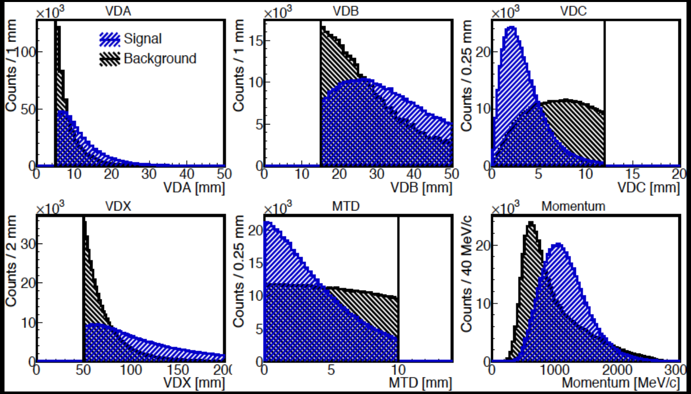
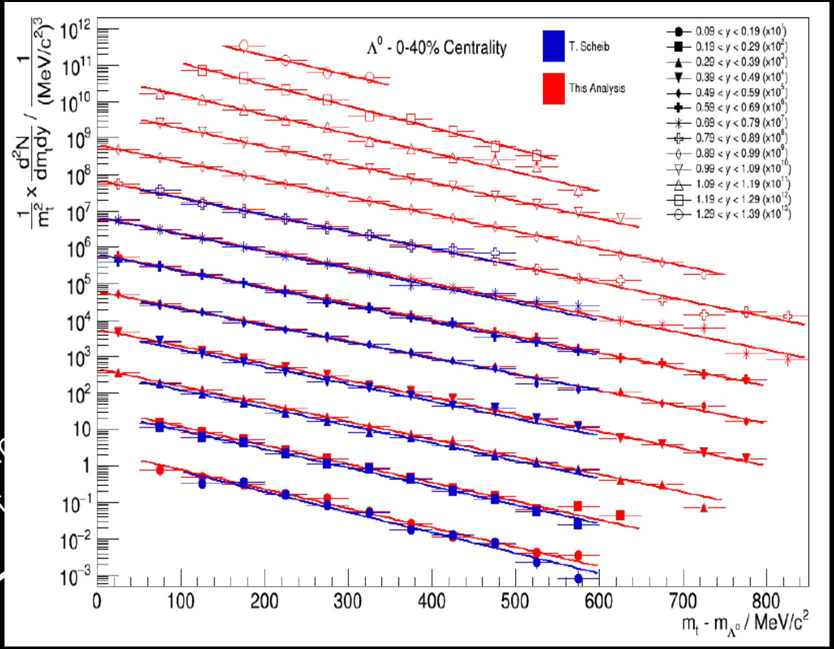


Which can feed int



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

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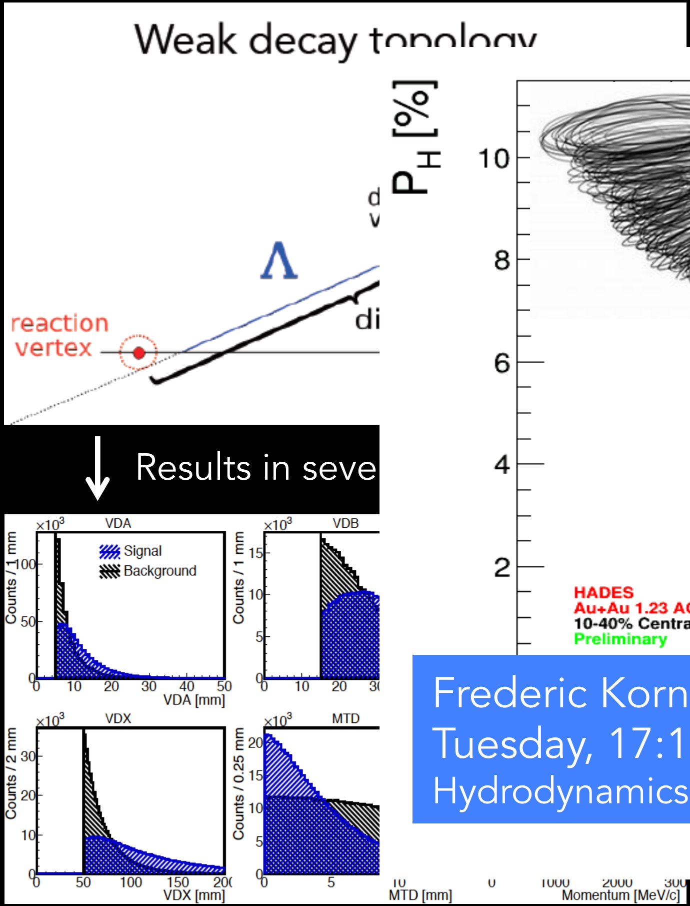

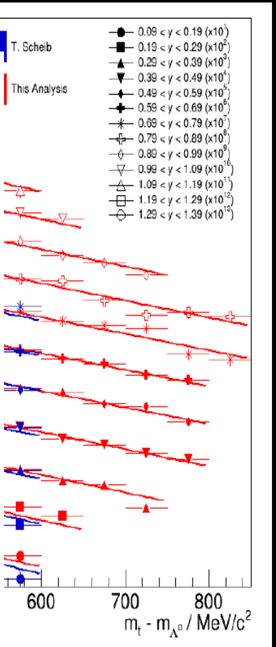

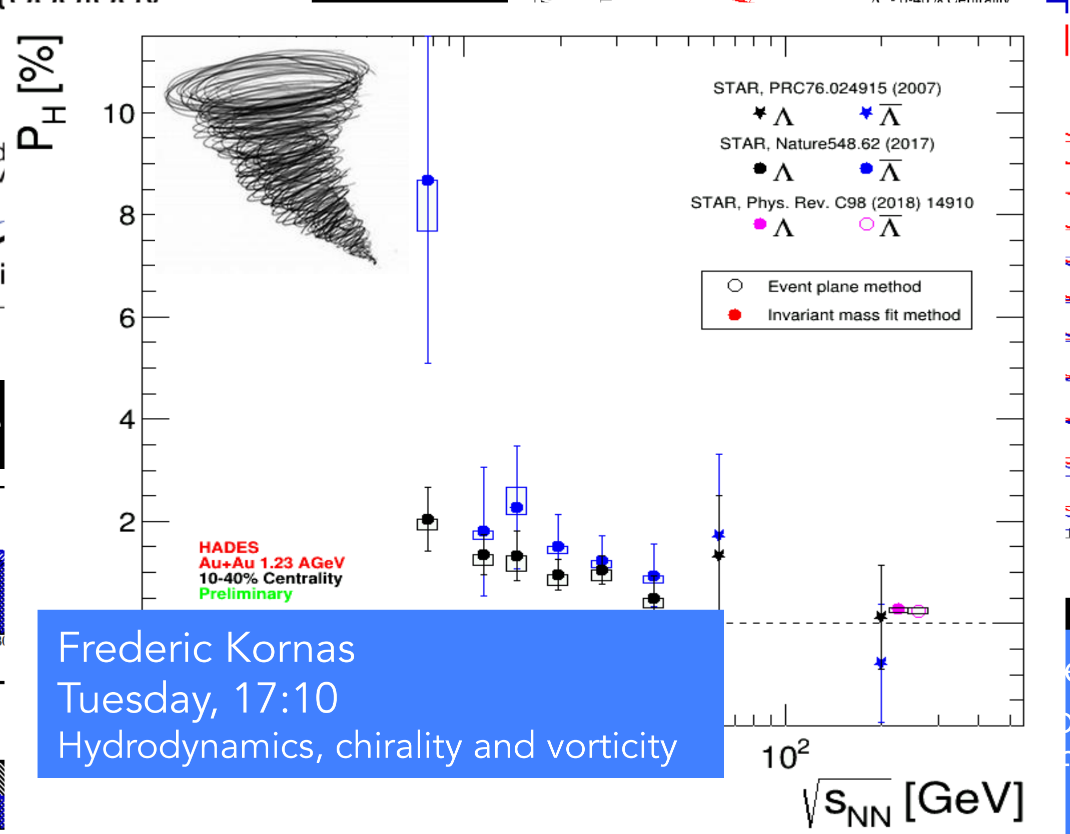

Frederic Kornas
Tuesday, 17:10
Hydrodynamics, chirality and vorticity

e-selection
proves
f uncertainty

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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

→ unique observable:

Energy must be provided from the system.

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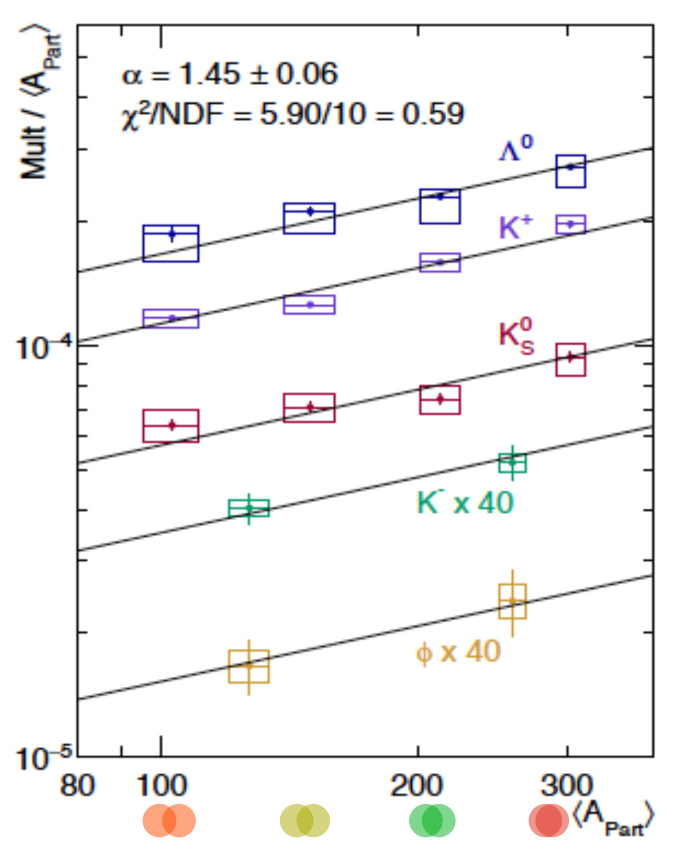

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Strange particle yields rise stronger than linear with

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

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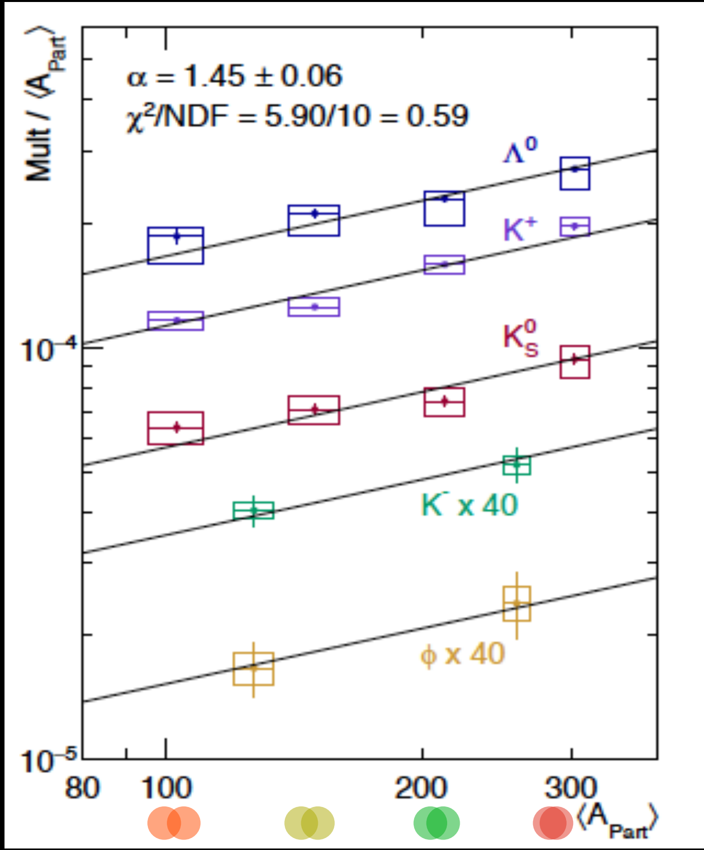

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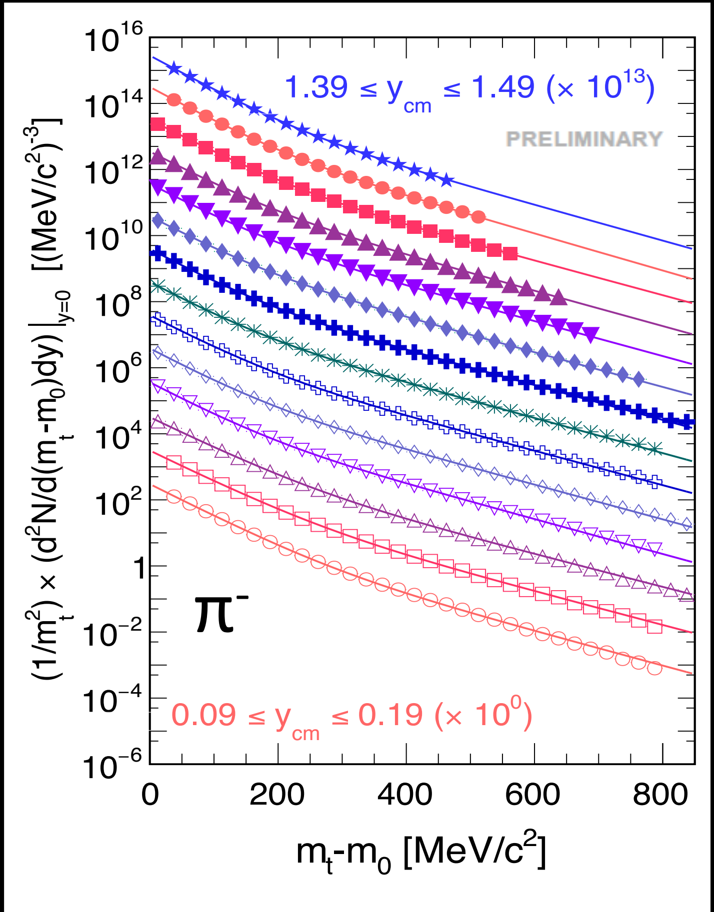
Universal $<A_{part}>$ dependence of strangeness production

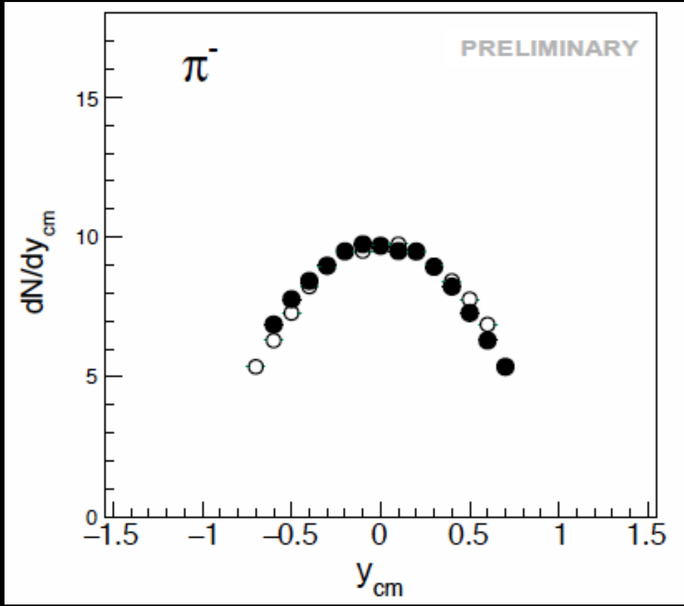
→ Hierarchy in production threshold not reflected

The Bulk

π Production:



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



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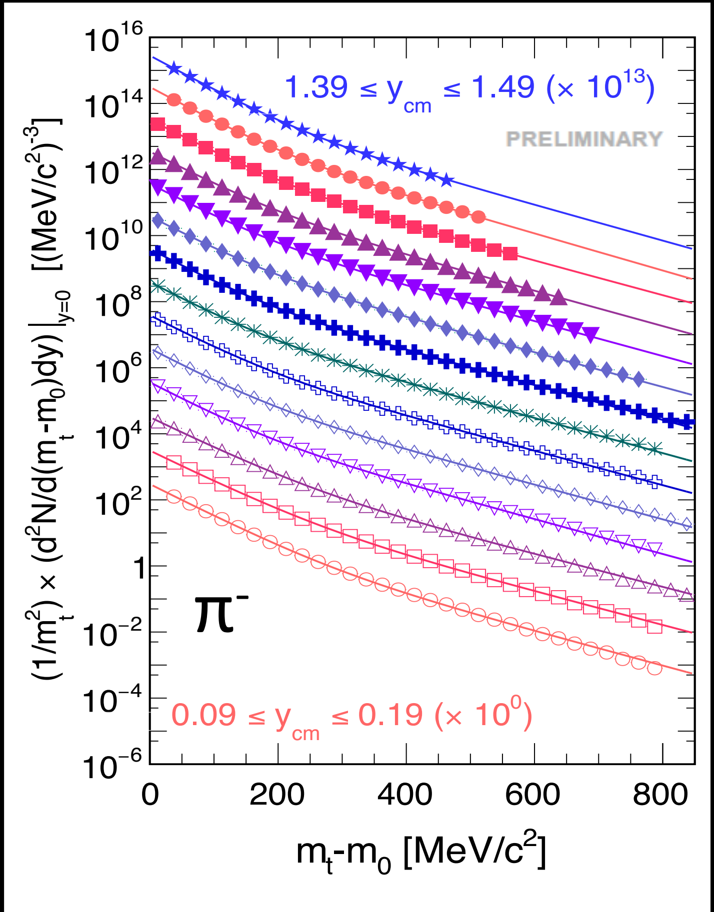

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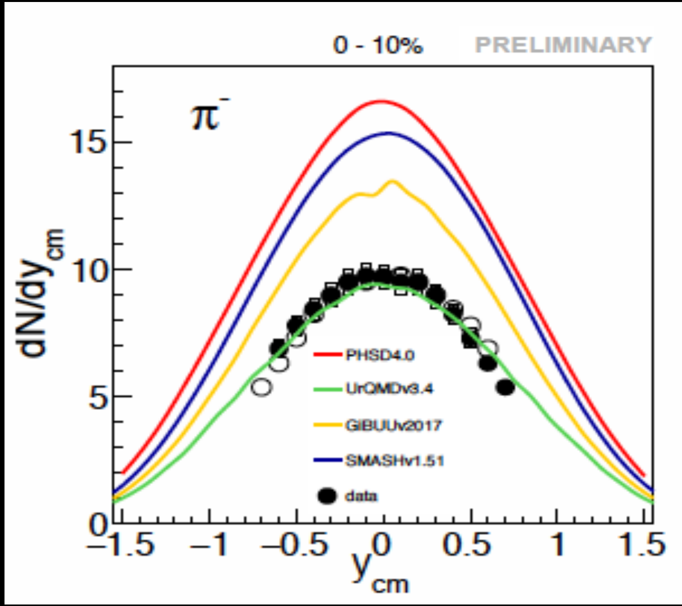
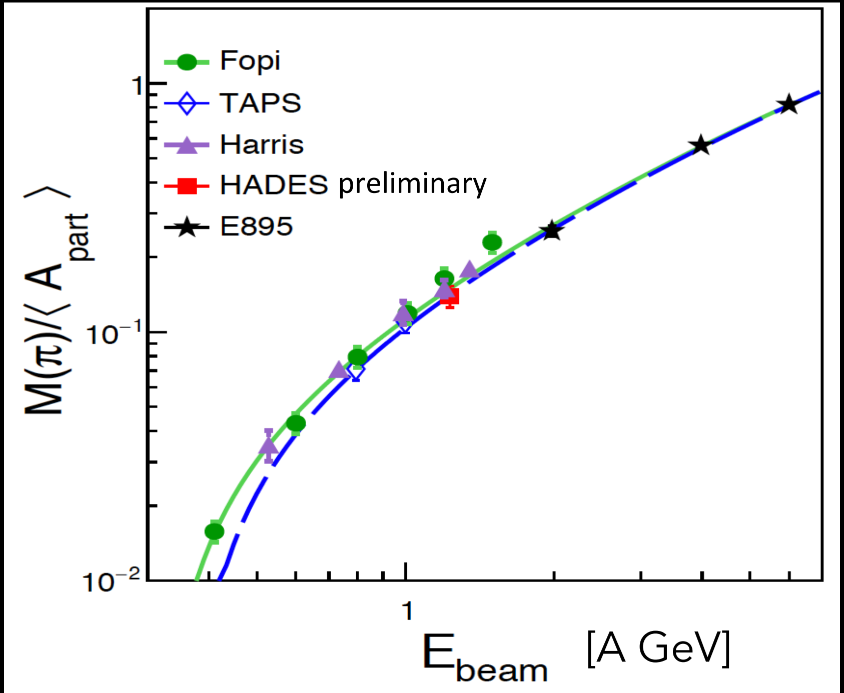
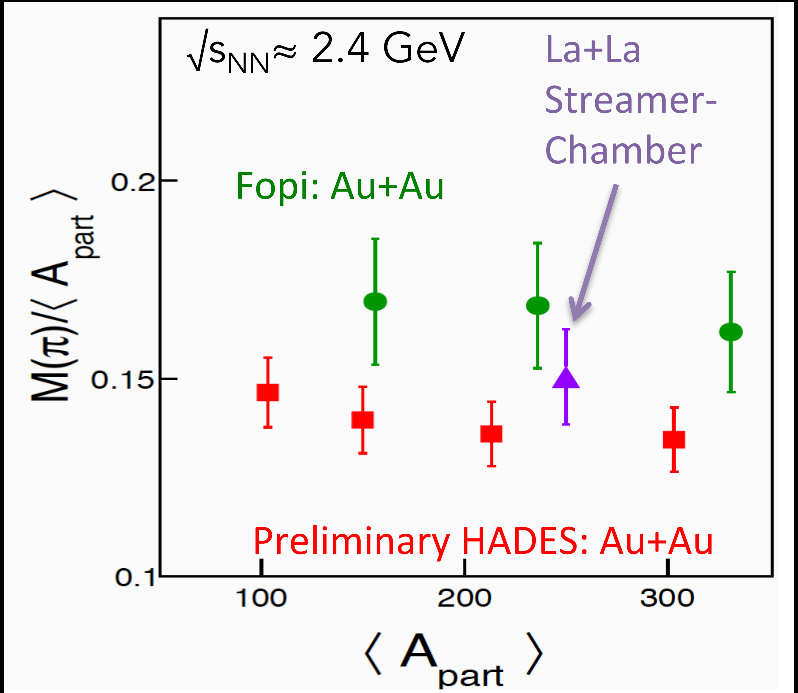


Microscopic models:
only UrQMD describes absolute yield

π Production: World data





Tension at low end of excitation function

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

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

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 Collaboration], NPA 781 (2007)

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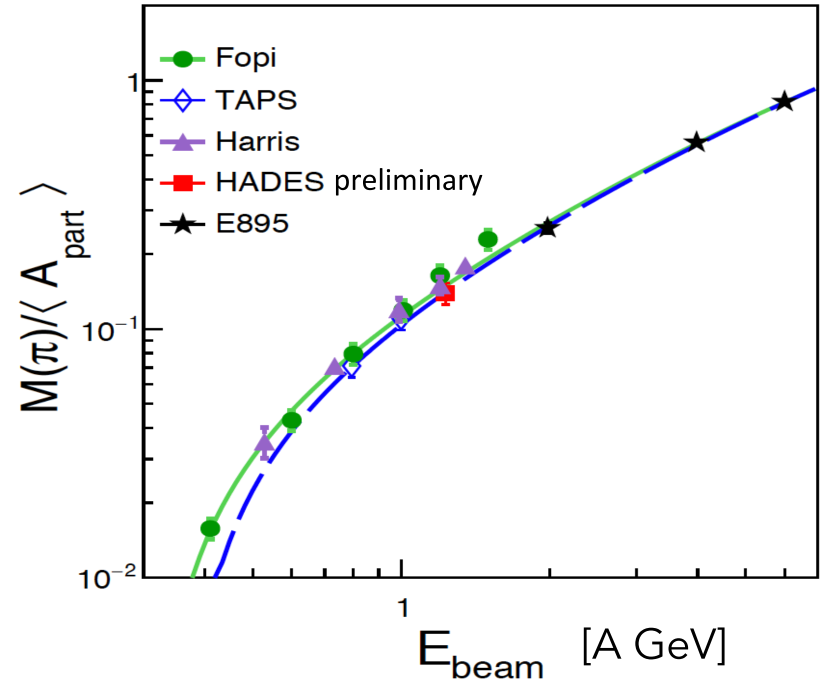

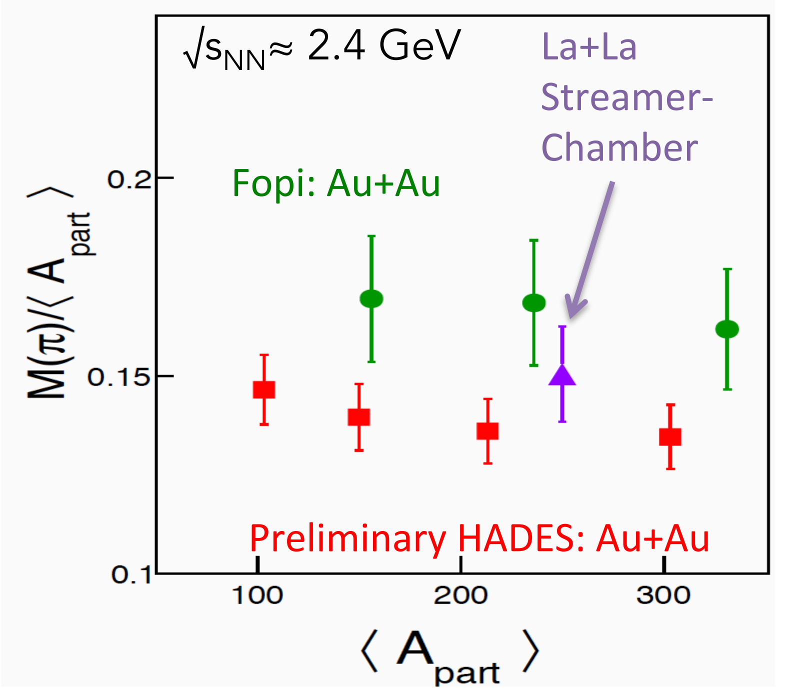

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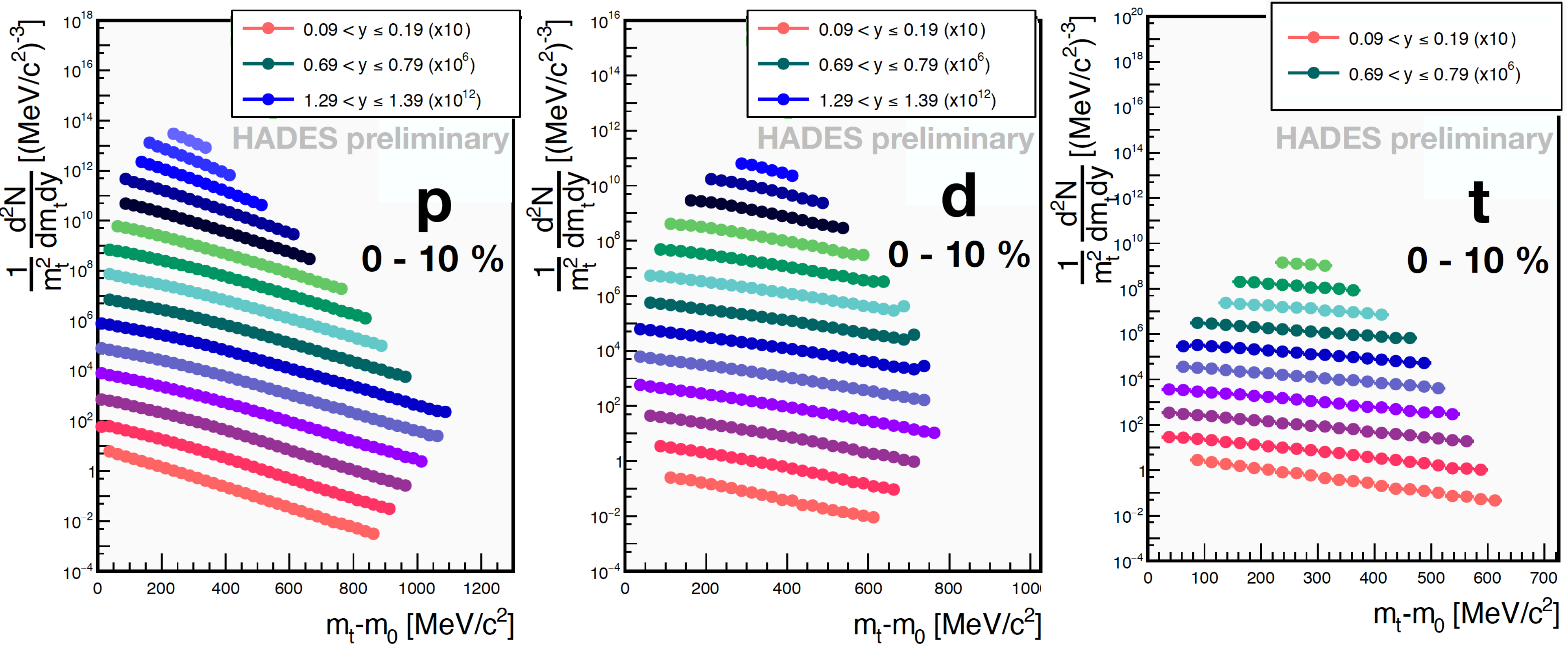
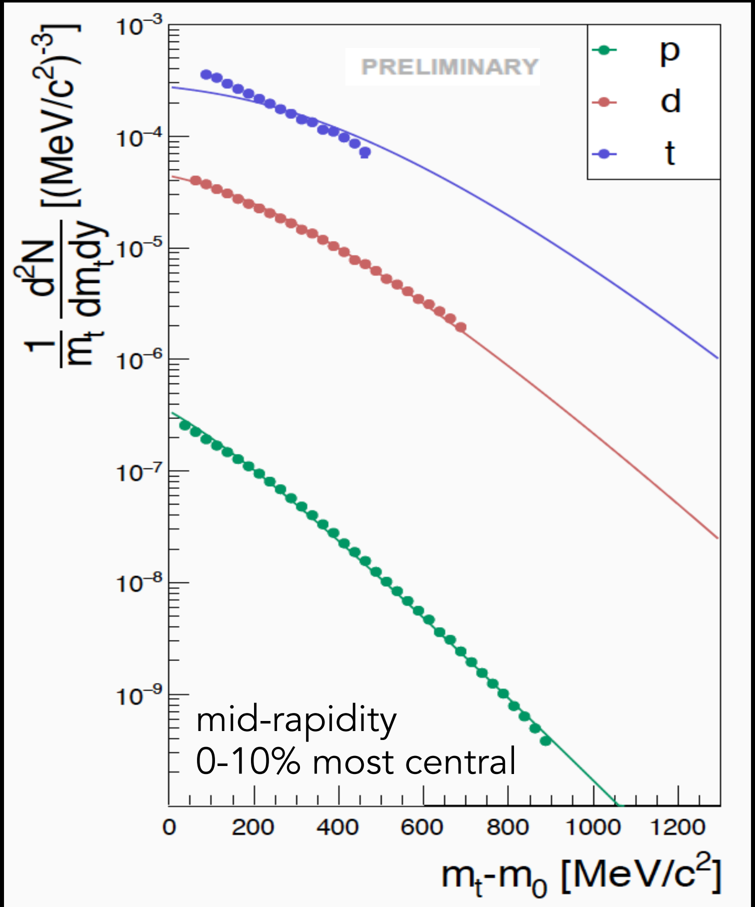
Malgorzata Gumberidze
Tuesday 18:45

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

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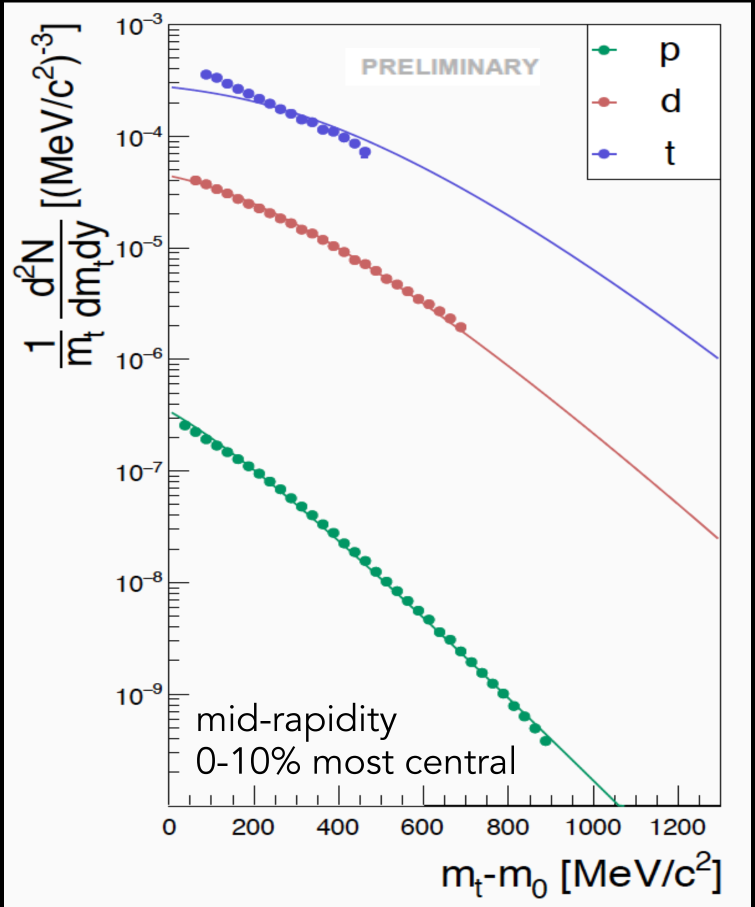

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$<\beta_r>$=0.34±0.02

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

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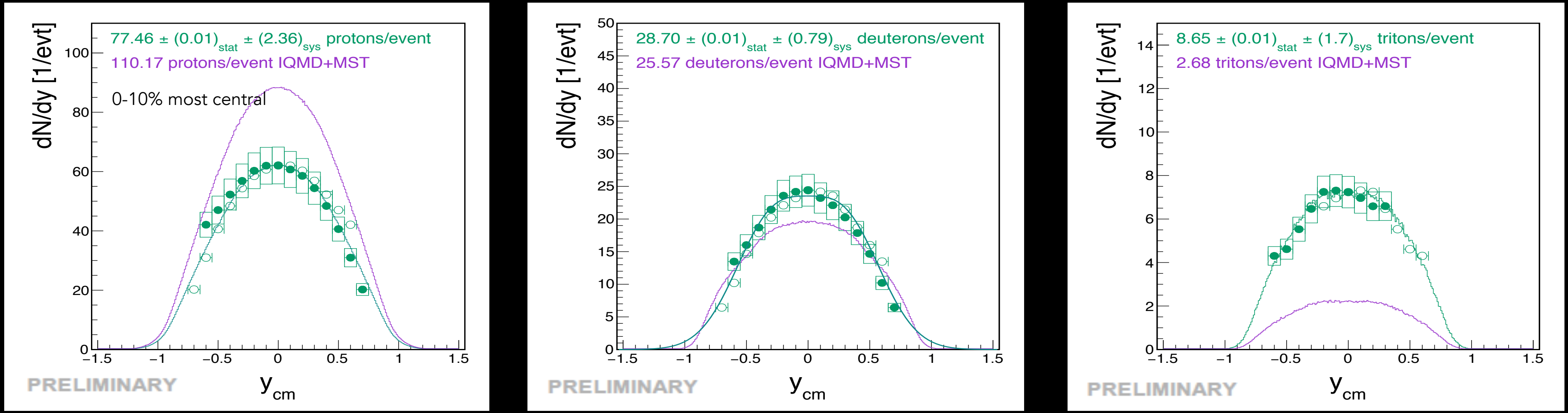

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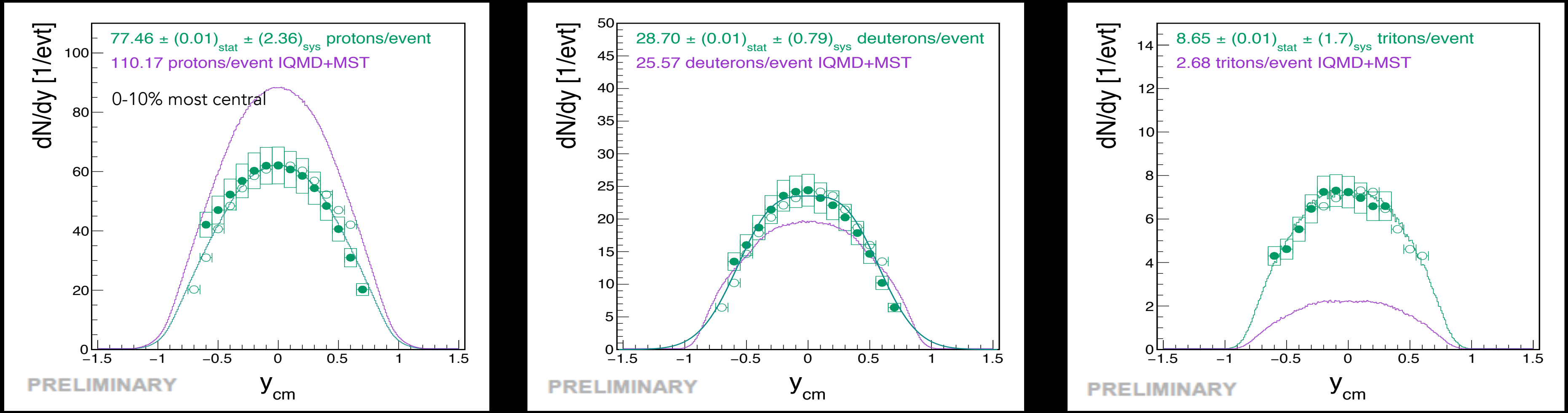

→ Challenge to reproduce light nuclei yields at mid-rapidity with simple coalescence.

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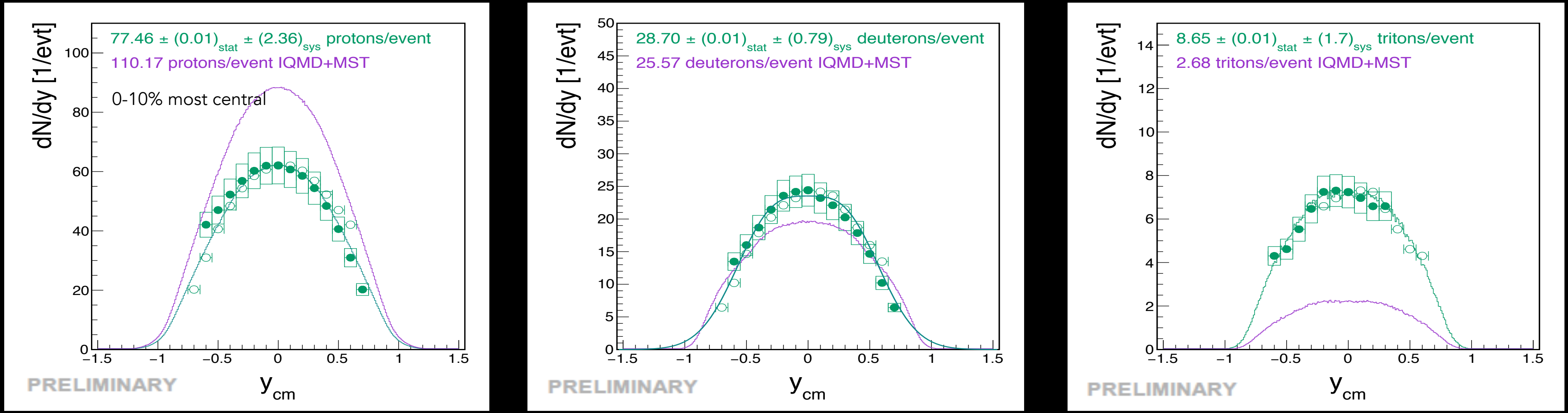

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Le Févre, Y. Leifels, J. Aichelin, Ch. Hartnack, V. Kireyev, E. Bratkovskaya. J.Phys.Conf.Ser. 668 (2016) no.1, 012021

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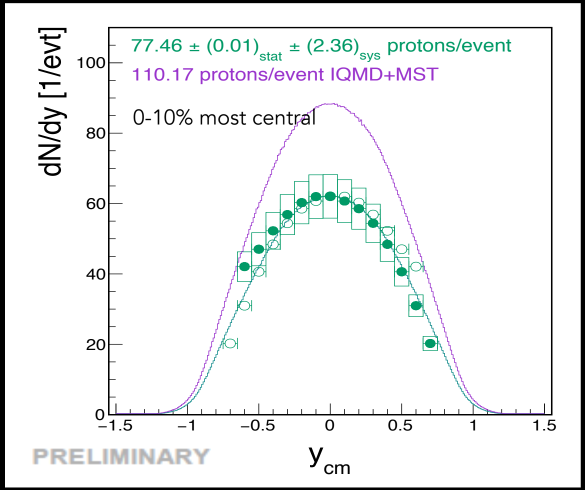

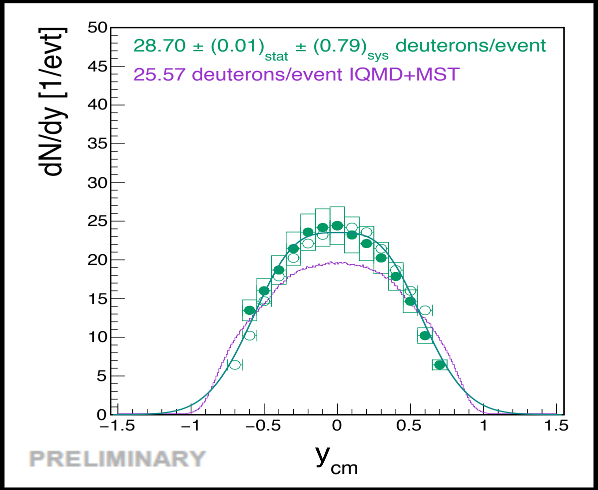

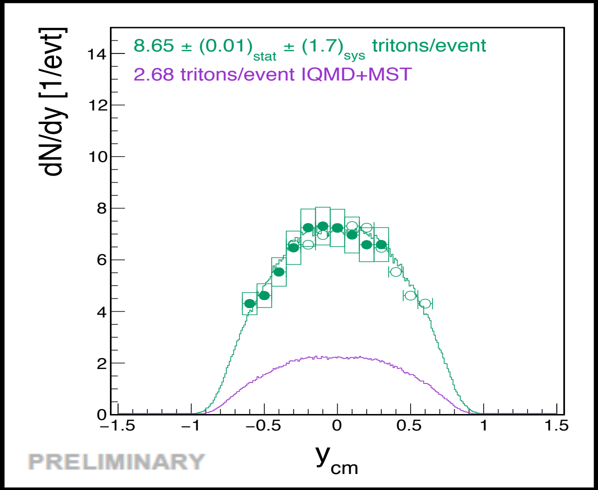

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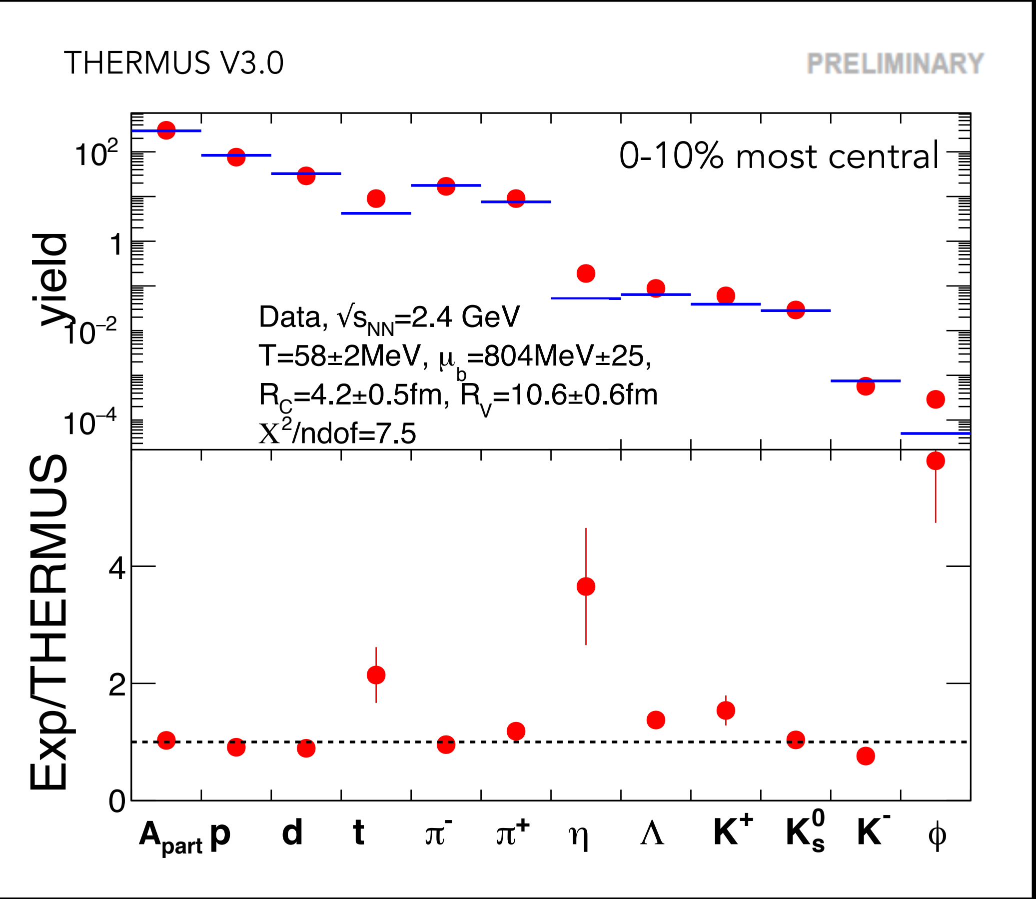
Melanie Szala
Tuesday 16:10
Hadronization and Coalescence

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)

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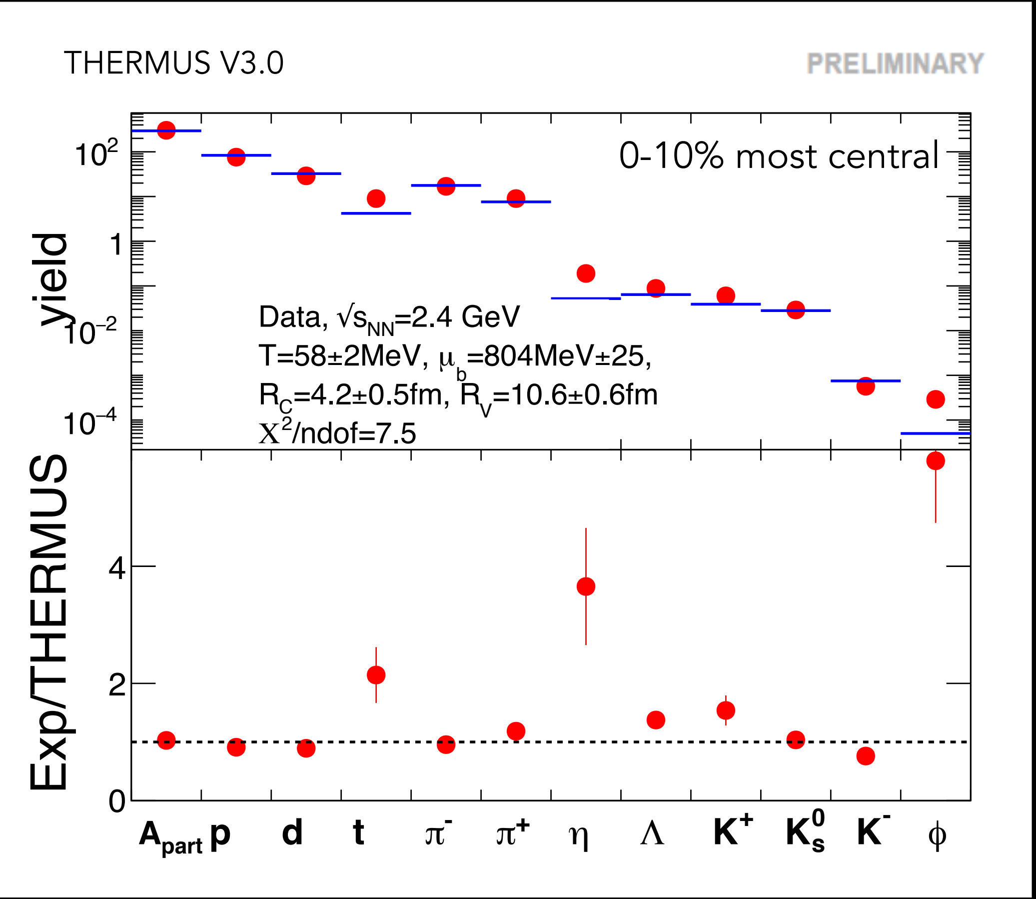

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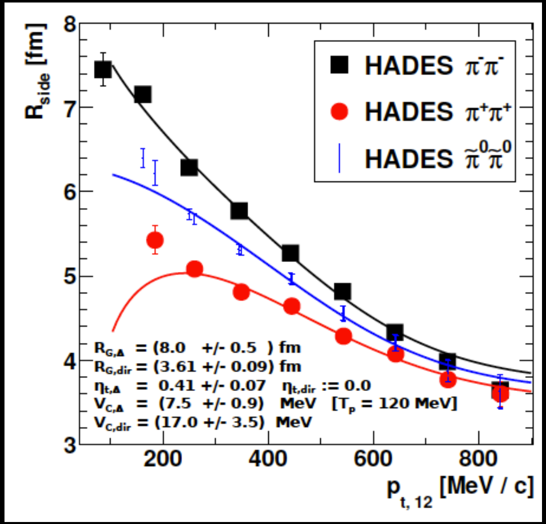
Fit to full hadron spectrum results in large χ^2 !

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)
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arXiv:1811.06213

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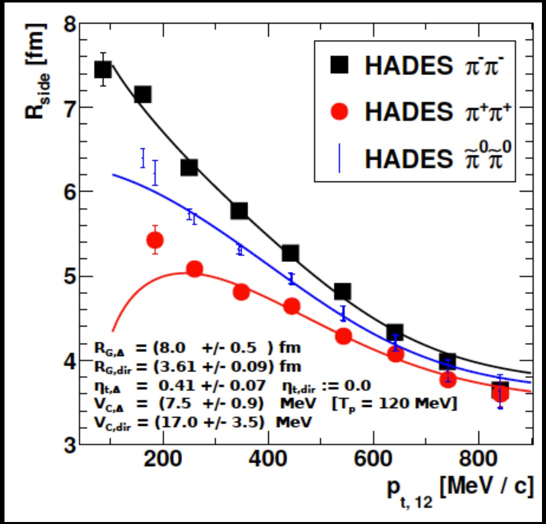

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First time observation of substantial differences!

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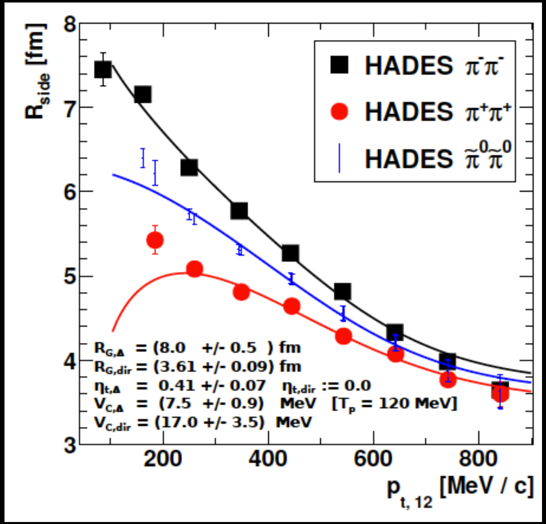

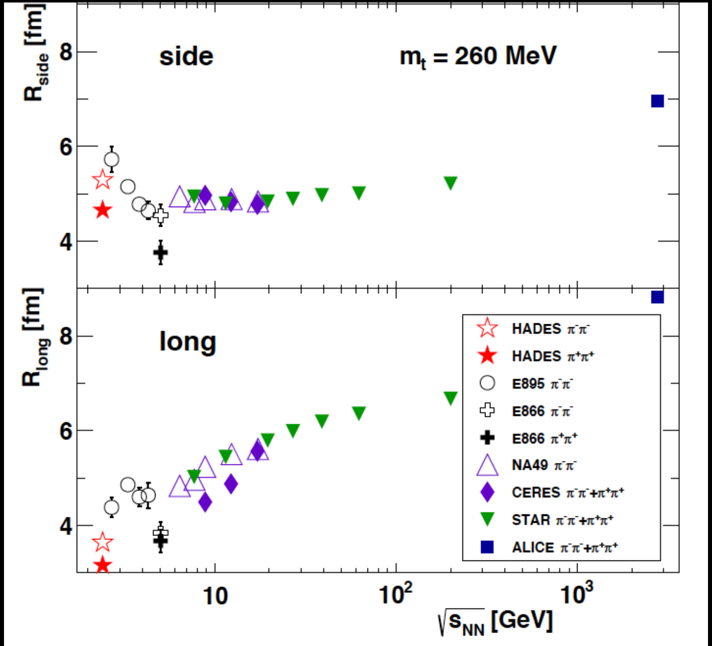

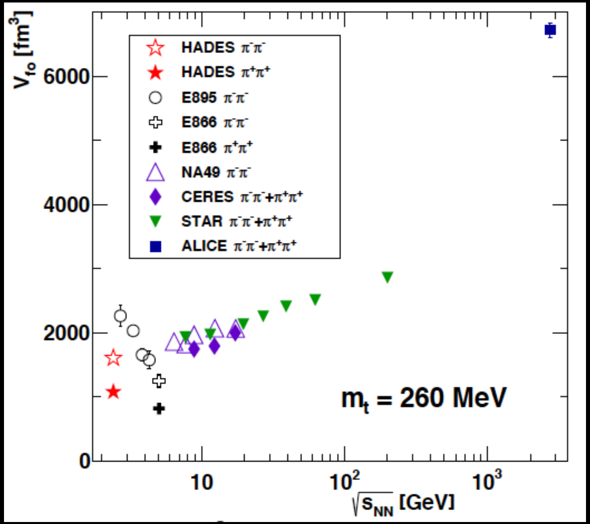

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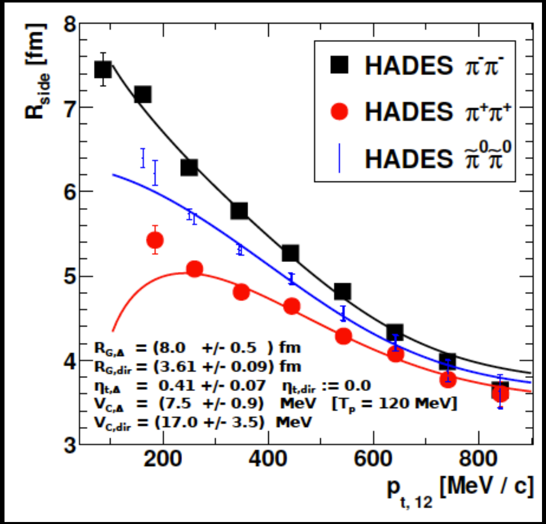

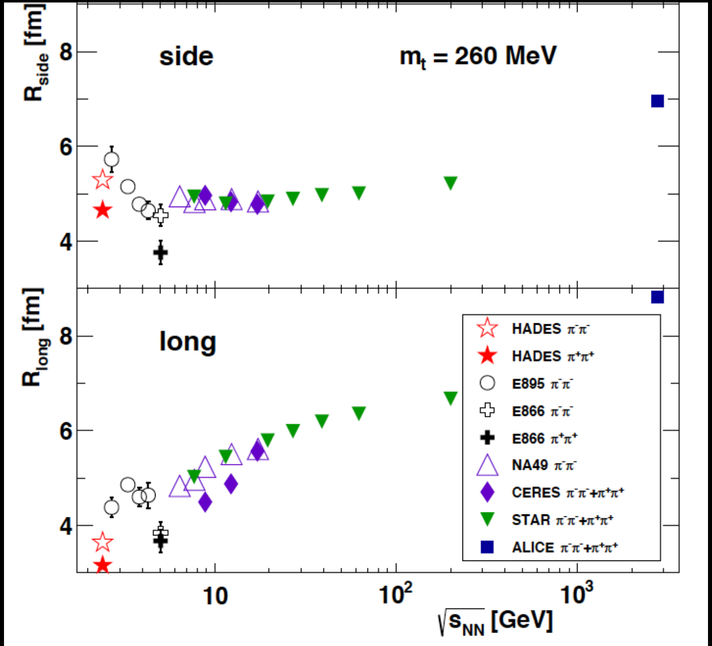

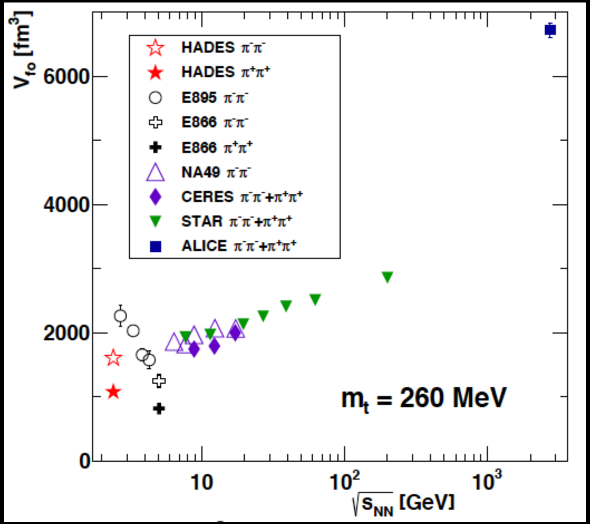

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First time observation of substantial differences!

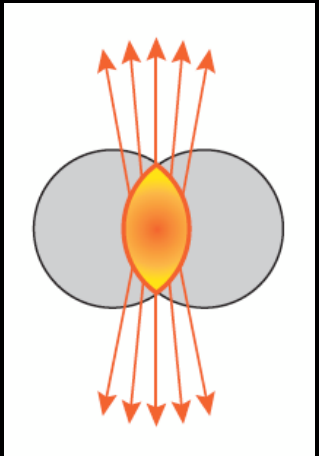
HADES follows trend from STAR/NA49 more than trend from E895
→ room for structures?

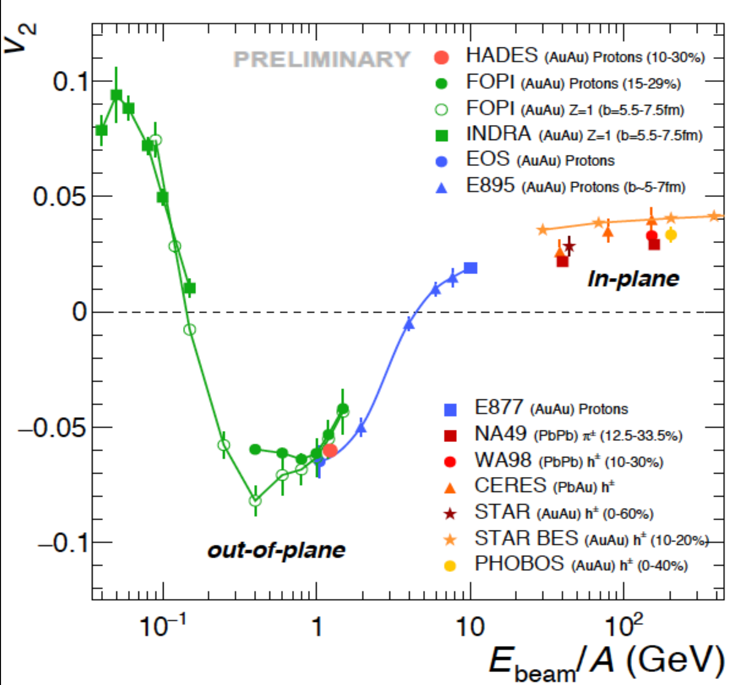
arXiv:1811.06213

Flow Anisotropies

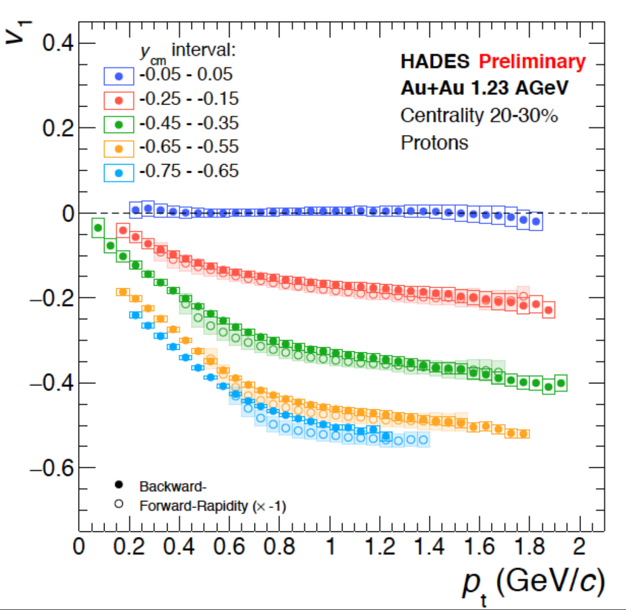
Out-of-plane v_2

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



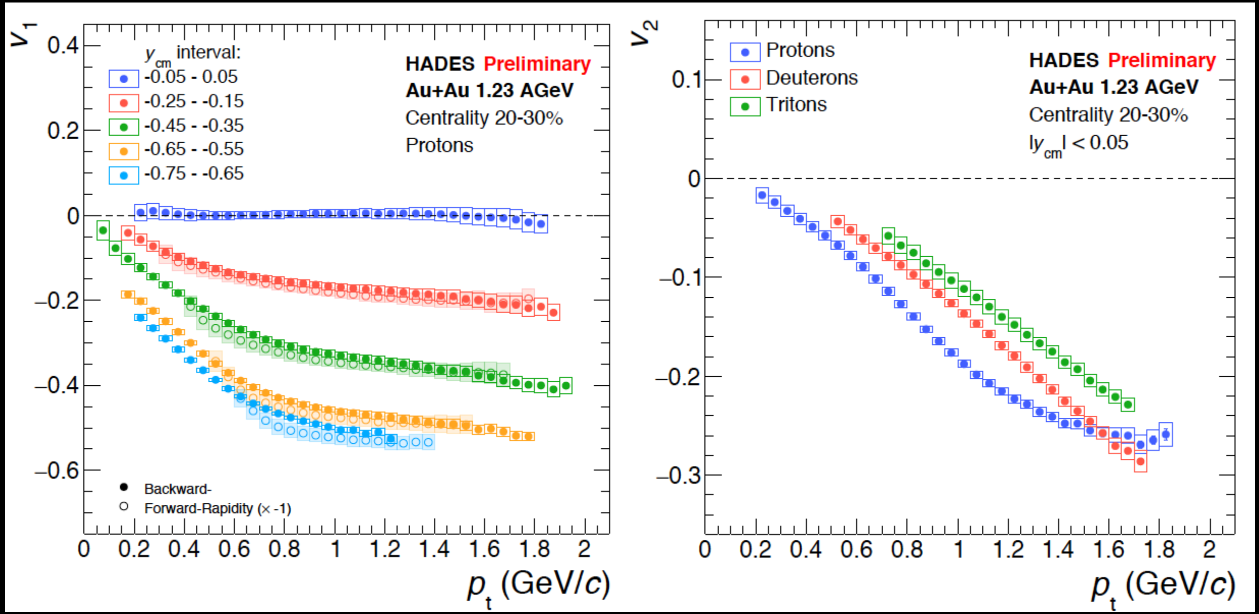


p, d, t v_1, v_2, v_3, v_4



High statistic multi-differential data

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



High statistic multi-differential data

Comparison p,d,t at mid-rapidity

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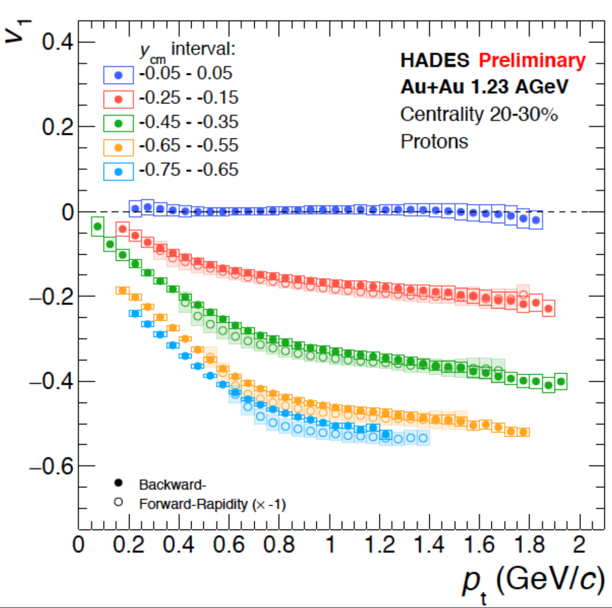

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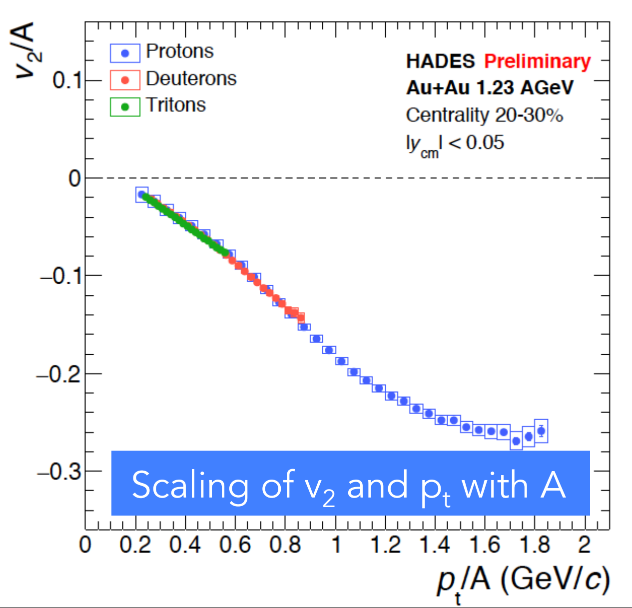

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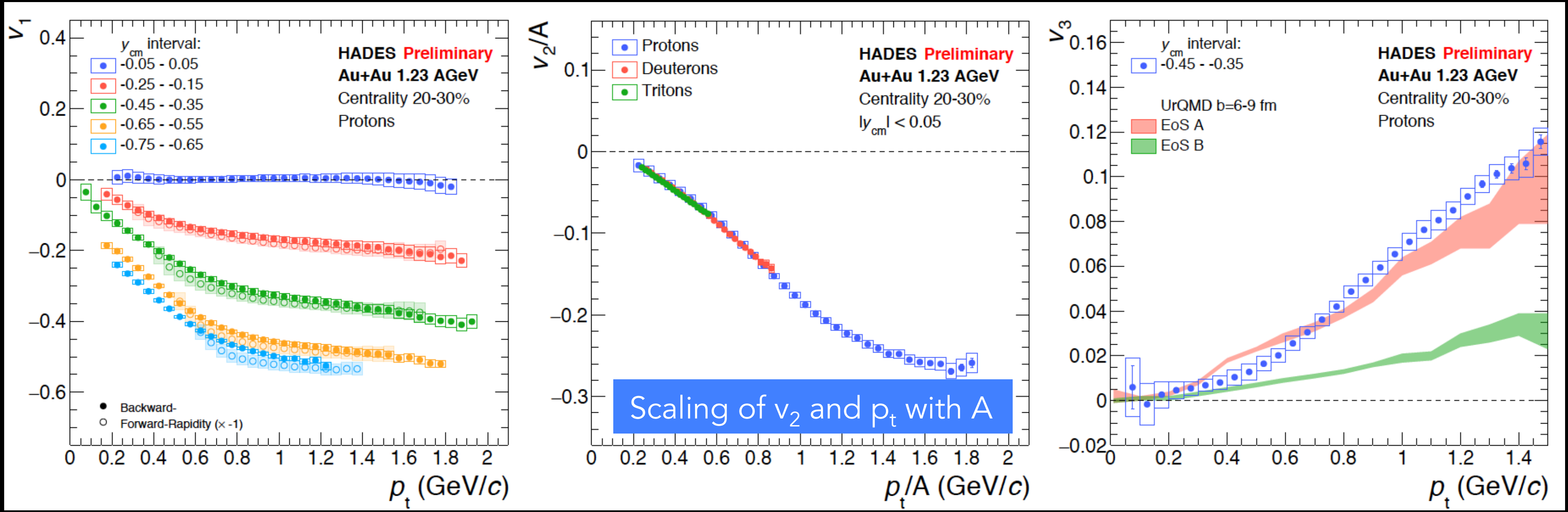
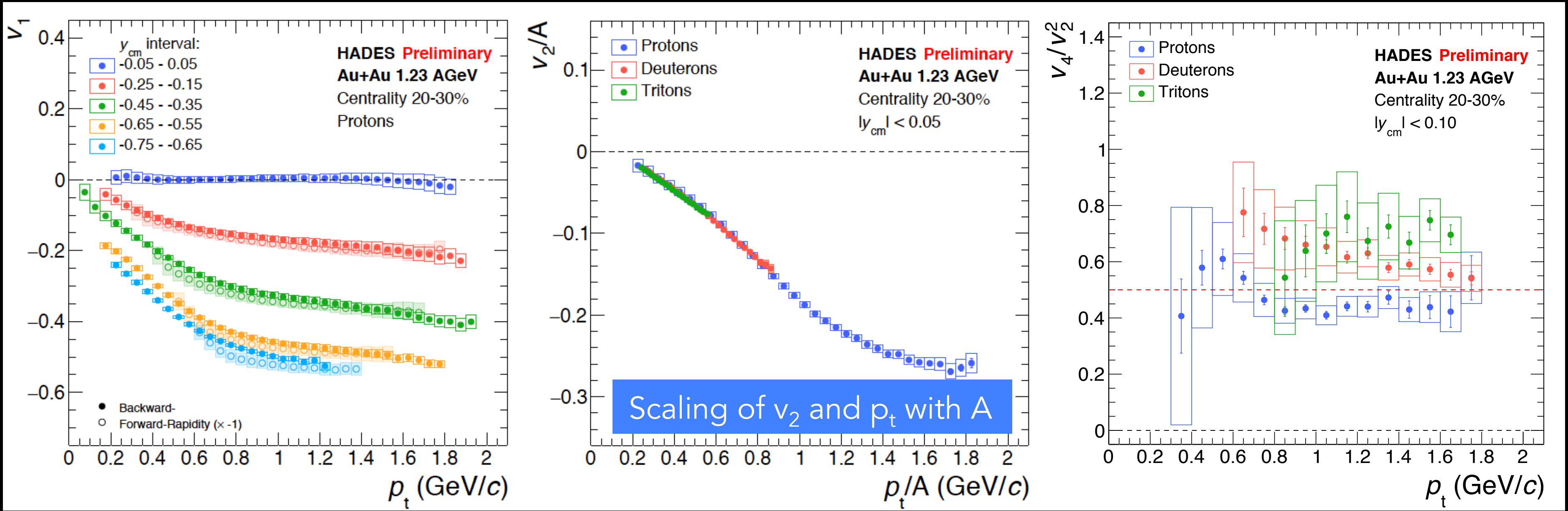


High statistic multi-differential data   Comparison p,d,t at mid-rapidity   Sensitivity to EOS

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

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



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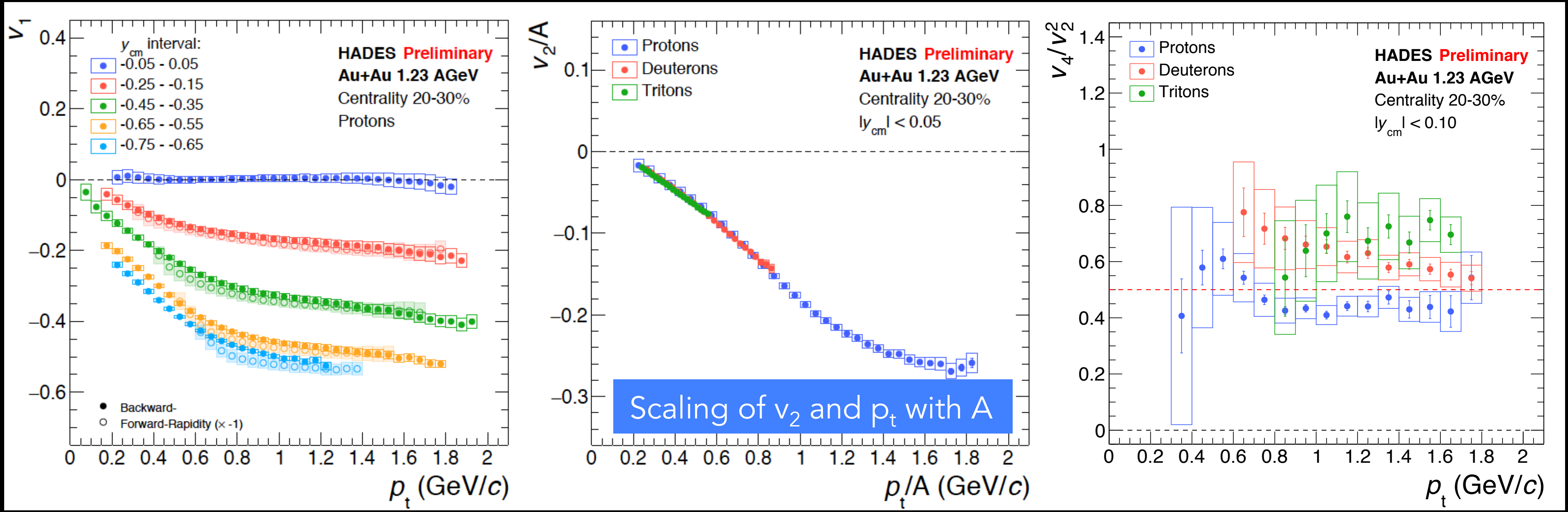
Description by hydrodynamics?

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



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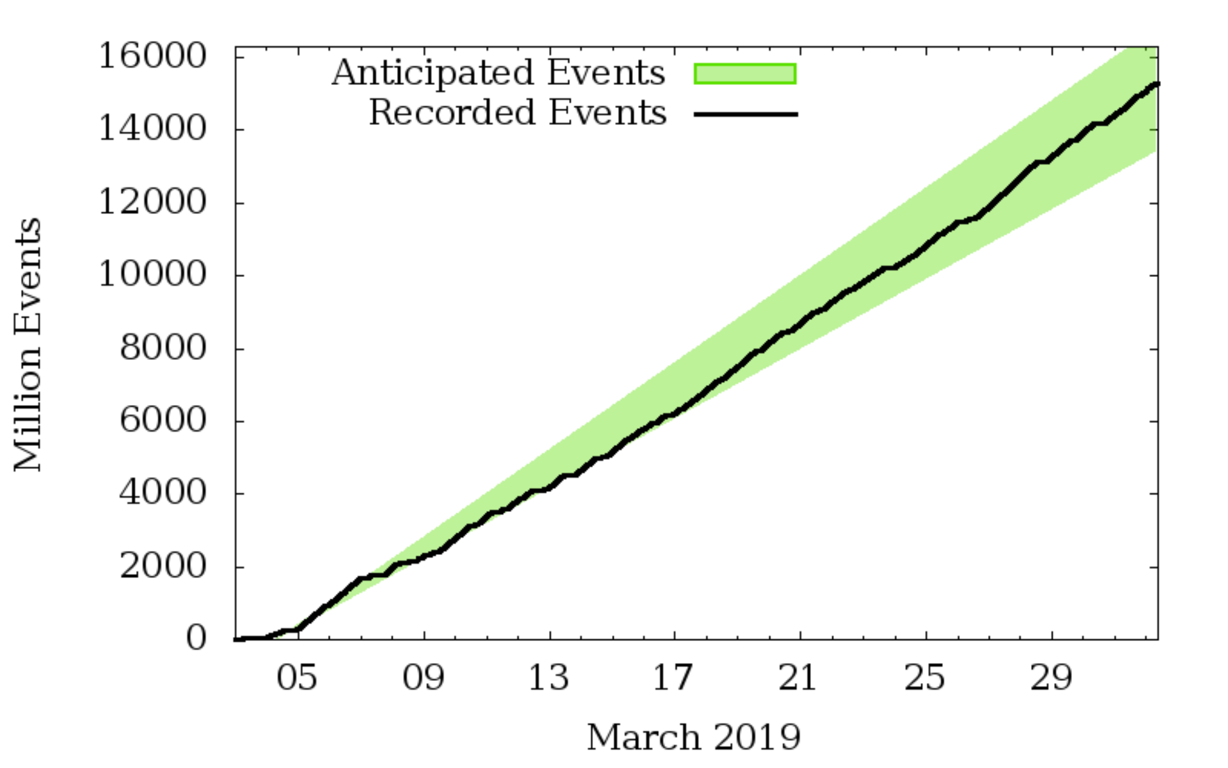
Description by hydrodynamics?

Behruz Kardan
Tuesday 18:45

Lukáš Chlad
Thursday 16:30

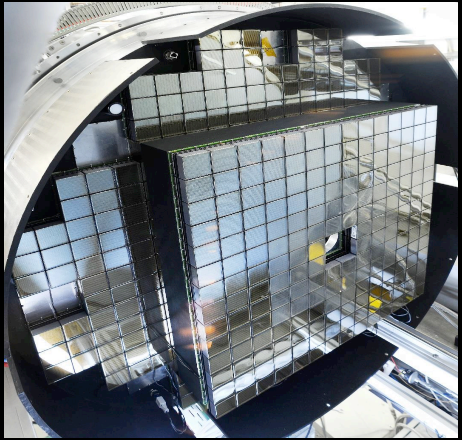
FAIR-Phase 0

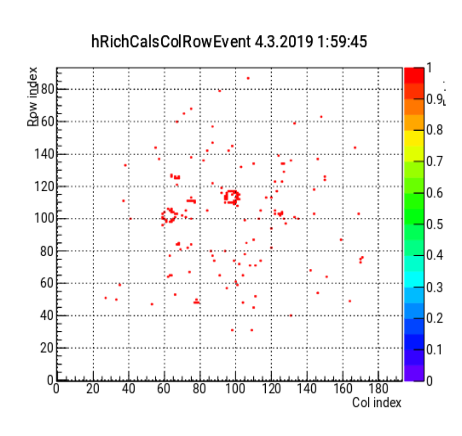
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV



~ 15 billion events collected during March 2019

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

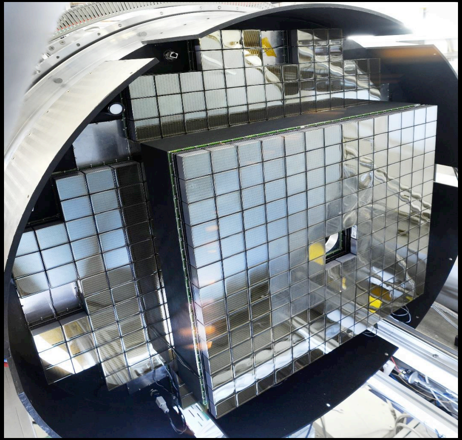


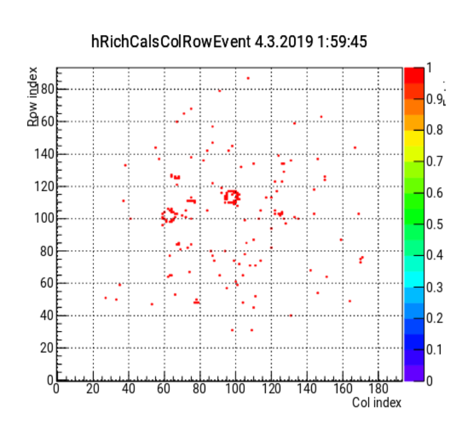


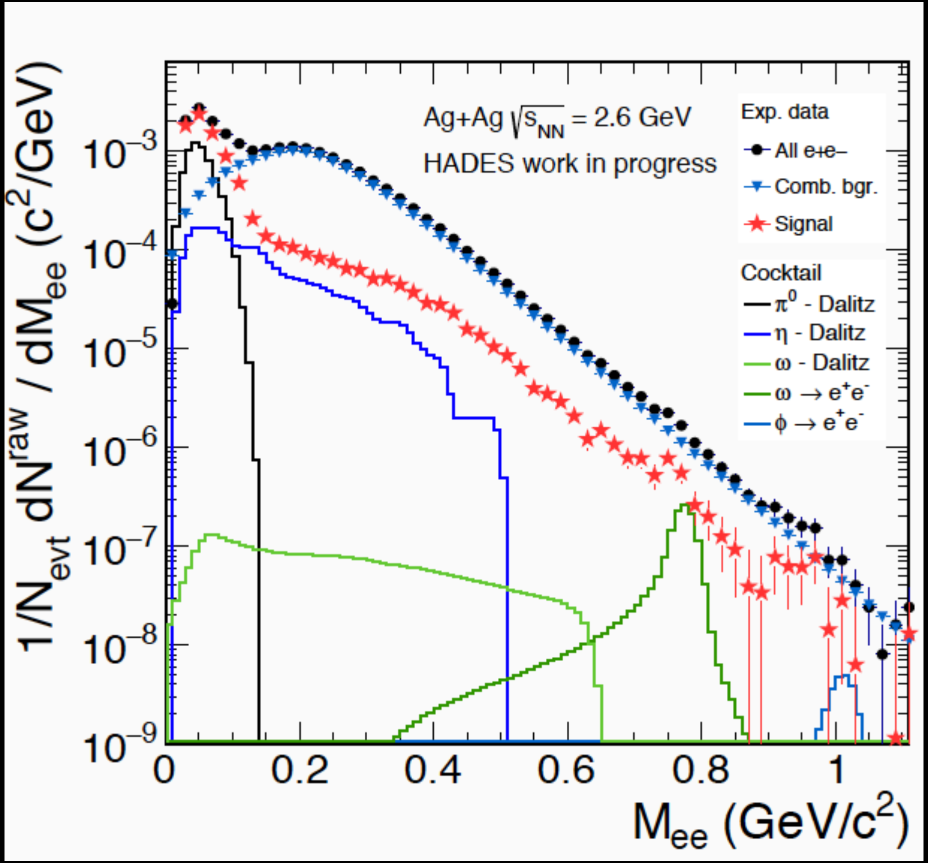
½ of the CBM RICH photon detector

Stable operation during 4 weeks of beamtime

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







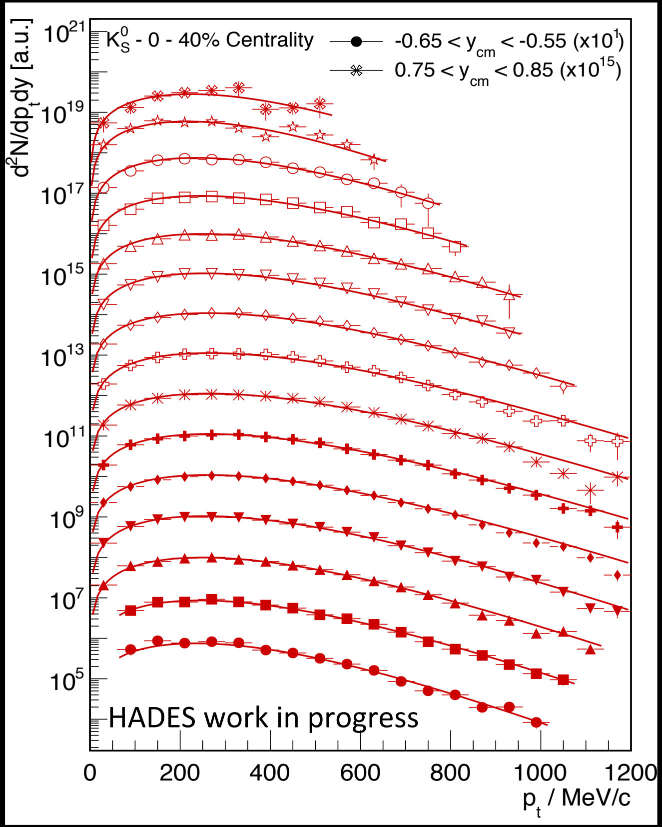
½ of the CBM RICH photon detector

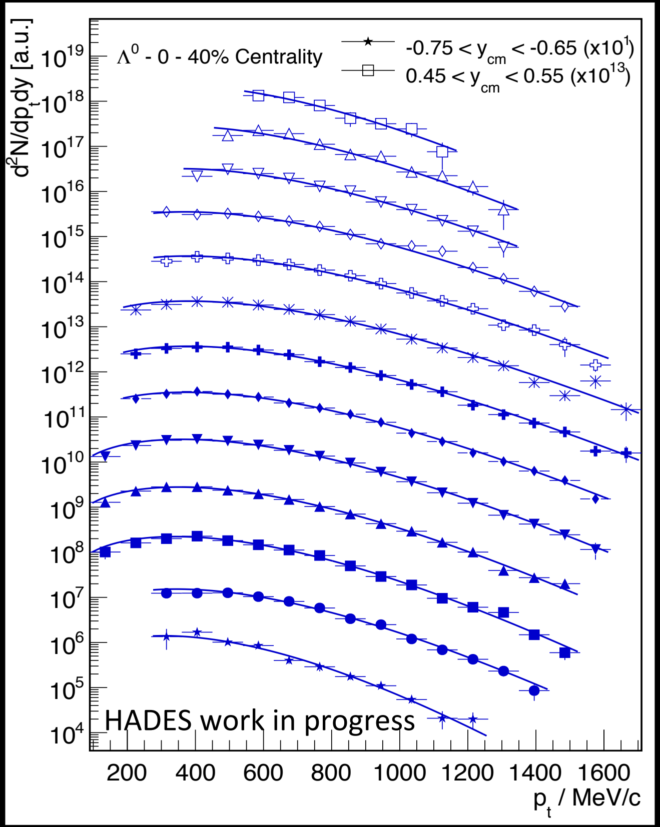
Stable operation during 4 weeks of beamtime

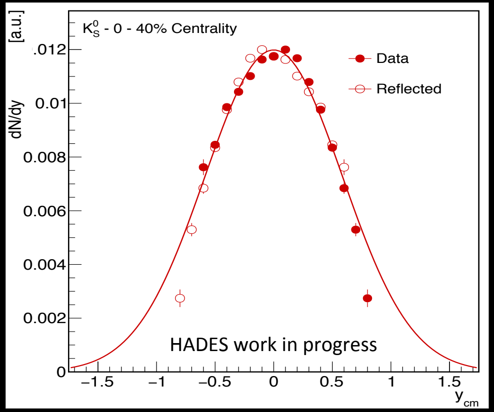
Resulting spectrum →

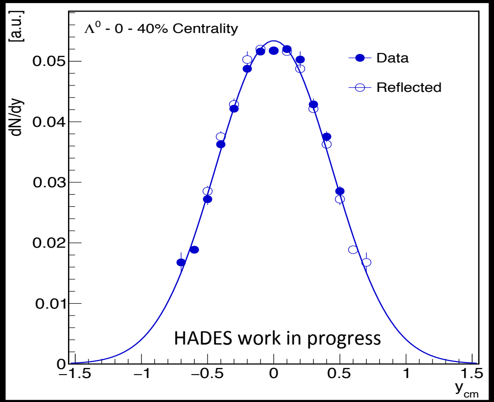
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Strangeness

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









Summary

Virtual Photons:

Strong broadening of the ρ, exponentially falling spectrum,

→ extraction of temperature $<T_{ee}>$ = 72 MeV

Strangeness:

Universal $<A_{part}>$ dependence of strangeness production

π – beam:

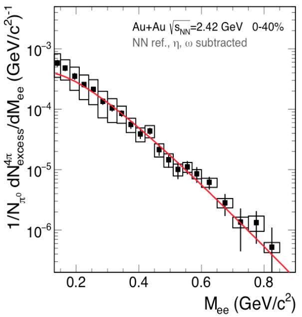
data for detailed investigation of the coupling to baryons

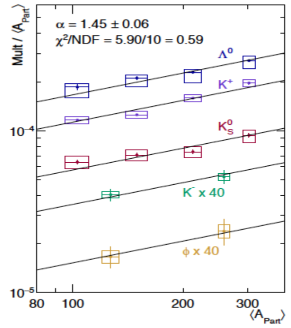
The Bulk:

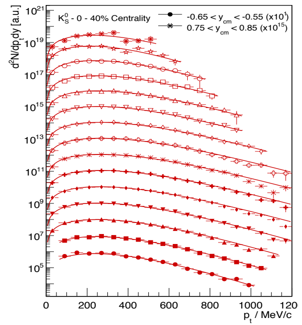
Multi-differential data on p, light nuclei, π
including flow anisotropies and HBT radii

FAIR-Phase0:

High quality data ~~to come~~ are here



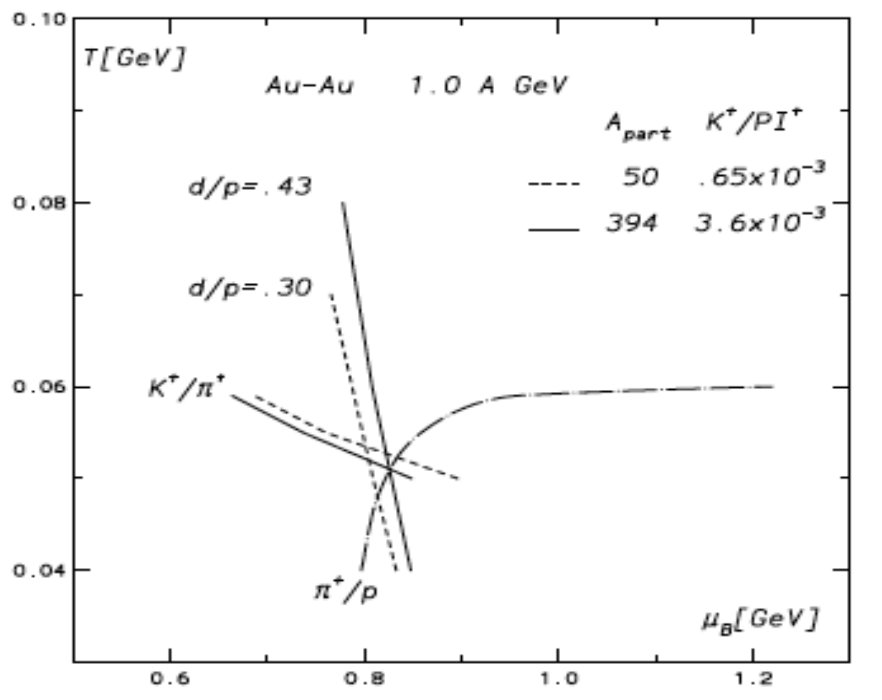


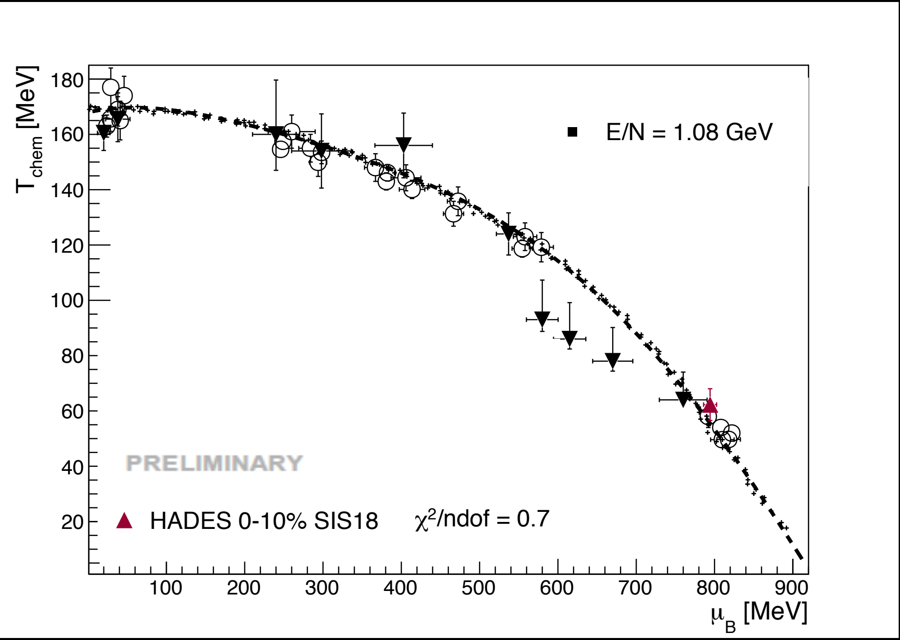


The HADES collaboration

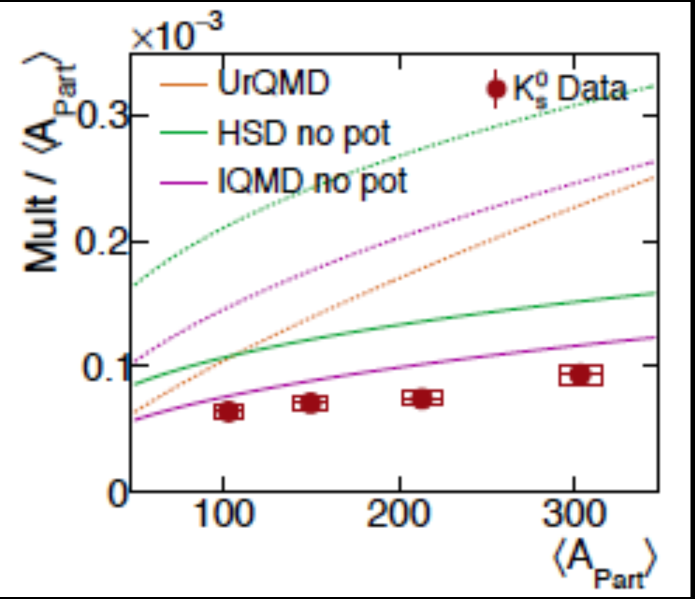
Macroscopic description

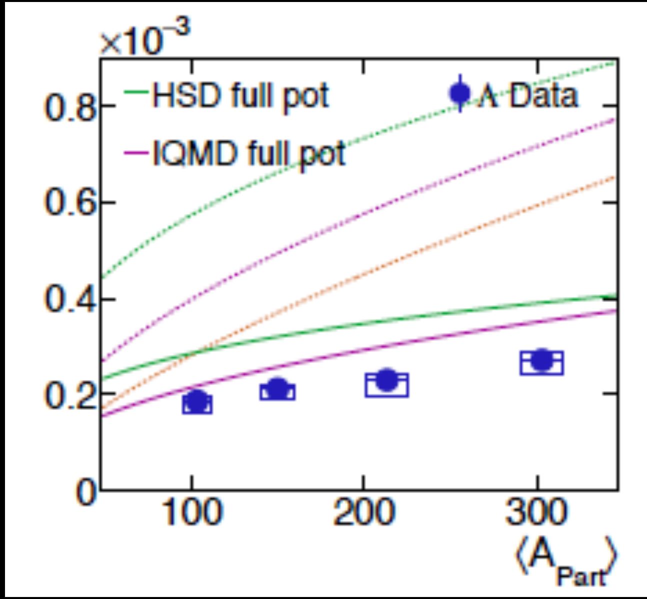
J. Cleymans, H. Oeschler, K. Redlich, Phys.Rev. C59 (1999))





Strangeness Production in Transport Models





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Model predictions: UrQMD 3.4, HSD 711n, IQMD c8, (full pot.= 40 MeV)

Large spread between different models, general trend to overshoot data.

Thanks to Y. Leifels, E. Bratkovskaya, C. Hartnack, J. Aichelin, J. Steinheimer and M. Bleicher

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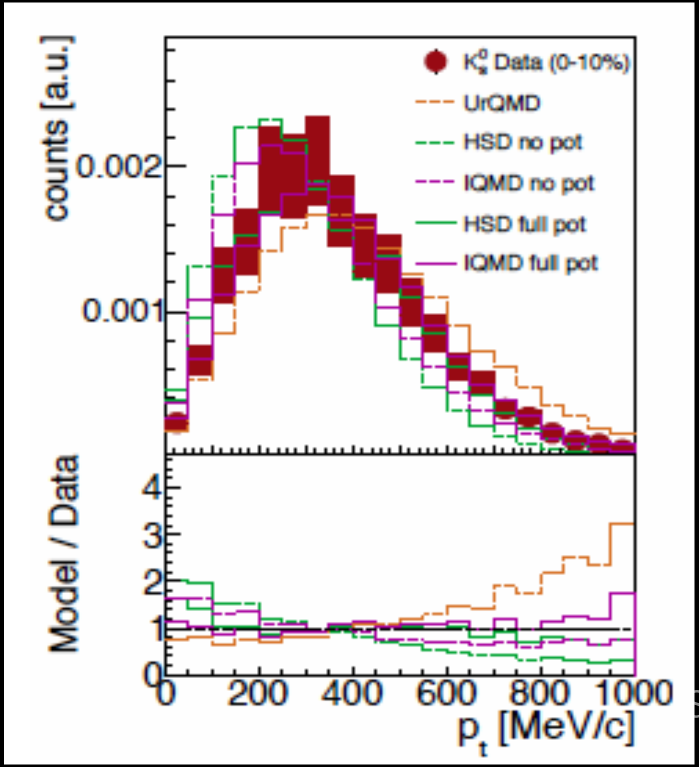

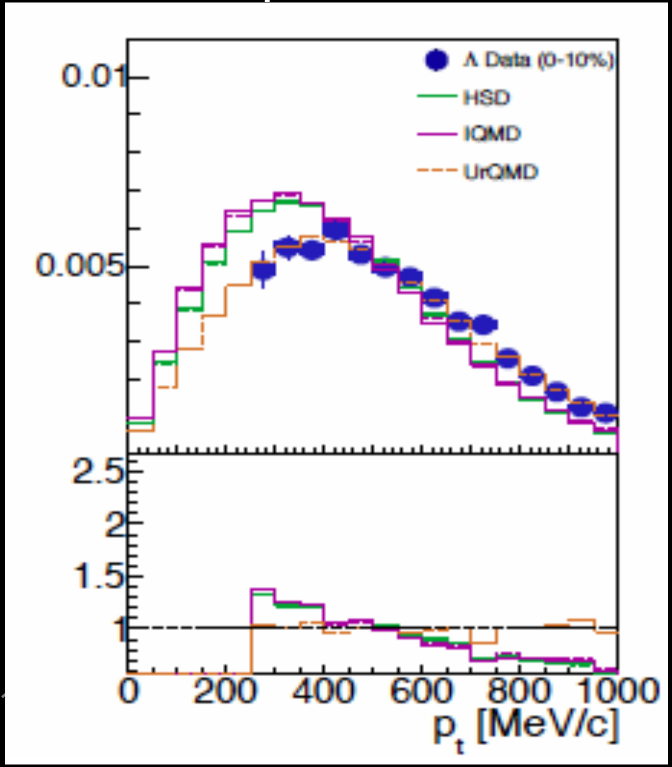

Large spread between different models, general trend to overshoot data.

Comparison of p_t-spectra shape: **Ambiguities in description**

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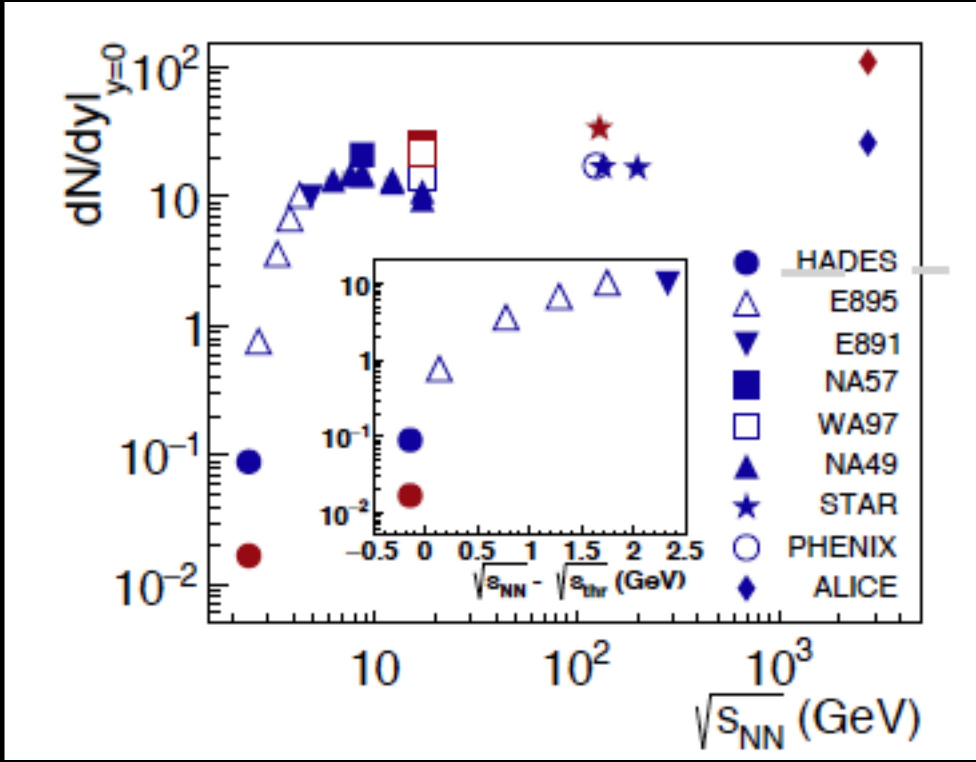
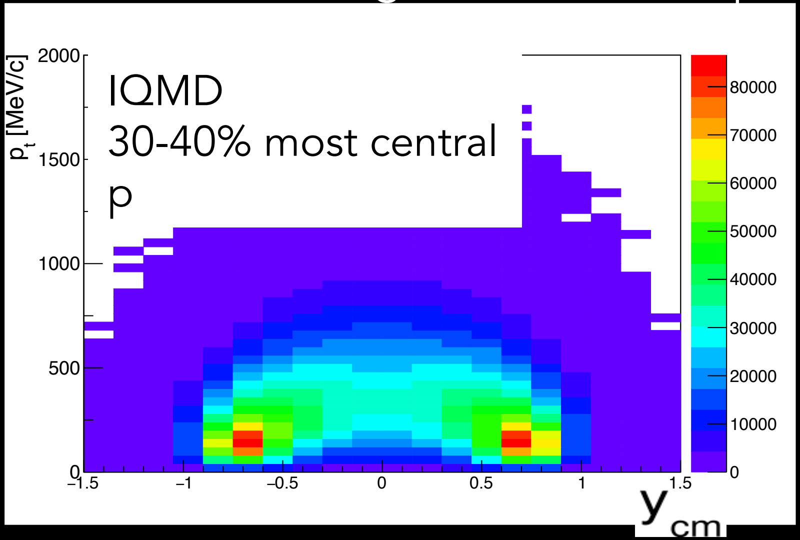
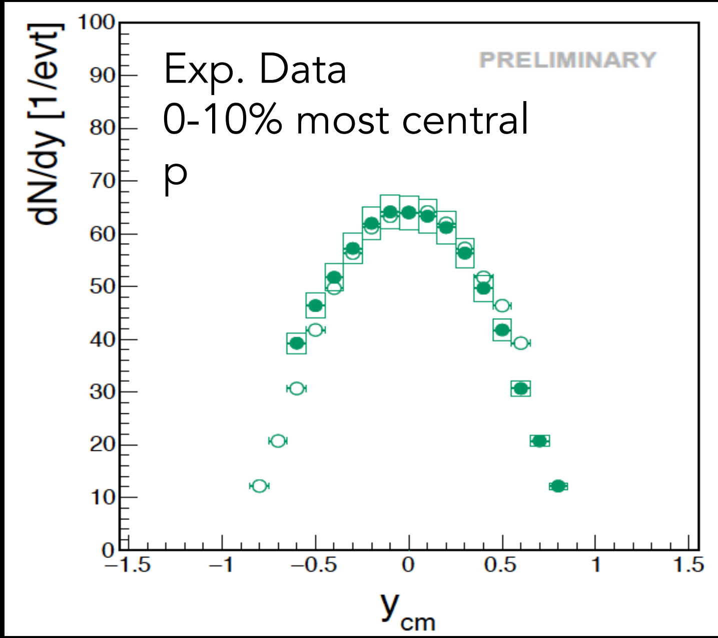


Protons and light nuclei at Au+Au $\sqrt{s_{NN}}$= 2.4 GeV

Spectator and fireball regions not well separated.





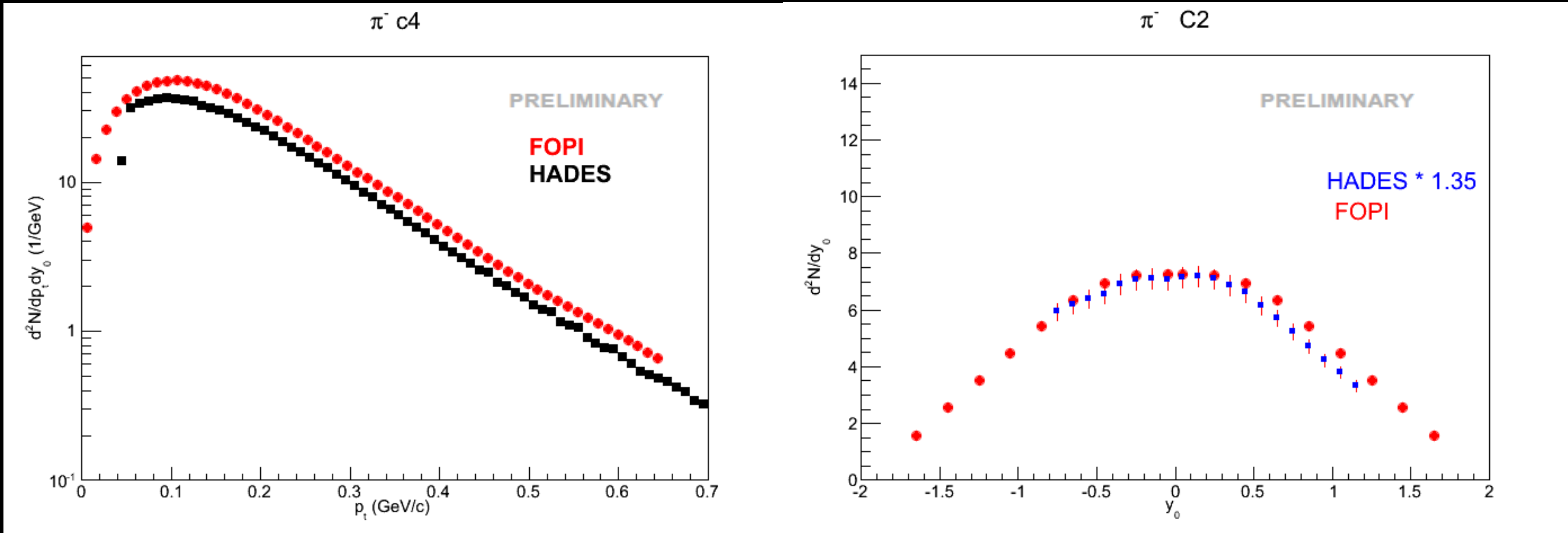
Careful analysis of protons:
Extension to high lab. momenta in order to cover forward hemisphere (no acceptance at low p_t)

→ Estimate spectator contamination by symmetry of the distribution

→ Minimize uncertainty due to extrapolation in y

Similar investigations for d and t are ongoing.

Pions



π⁻ c4
PRELIMINARY
FOPI
HADES
d²N/dp_t dy_0 (1/GeV)
p_t (GeV/c)
π⁻ C2
PRELIMINARY
HADES * 1.35
FOPI
d²N/dy_0
y_0