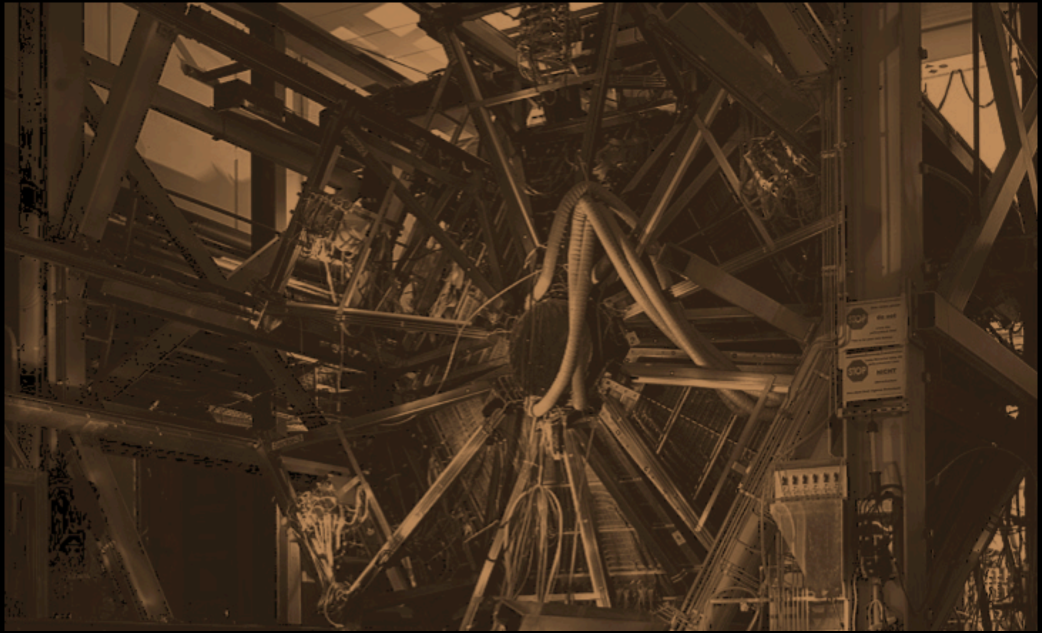
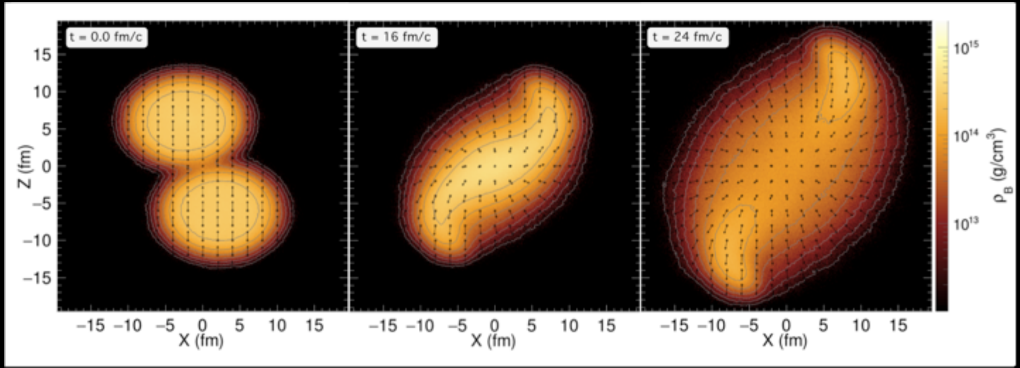
Strangeness production at HADES



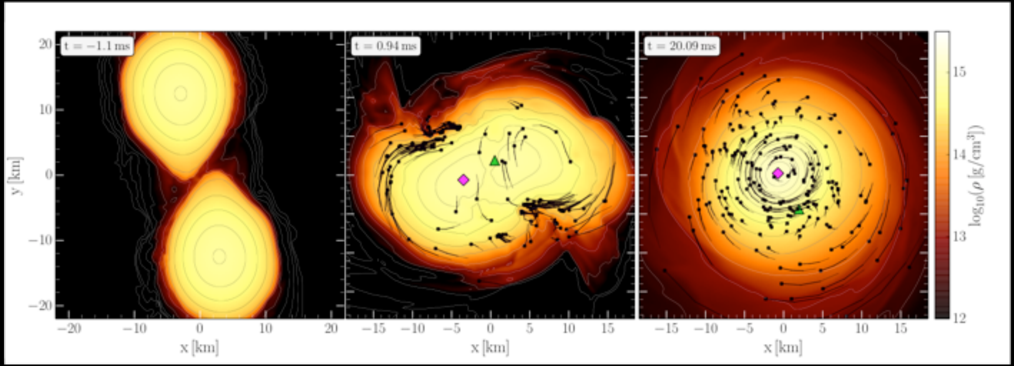
Manuel Lorenz
for the HADES collaboration
Goethe-University Frankfurt

Heavy-ion collisions at HADES

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



Merging Neutron Stars

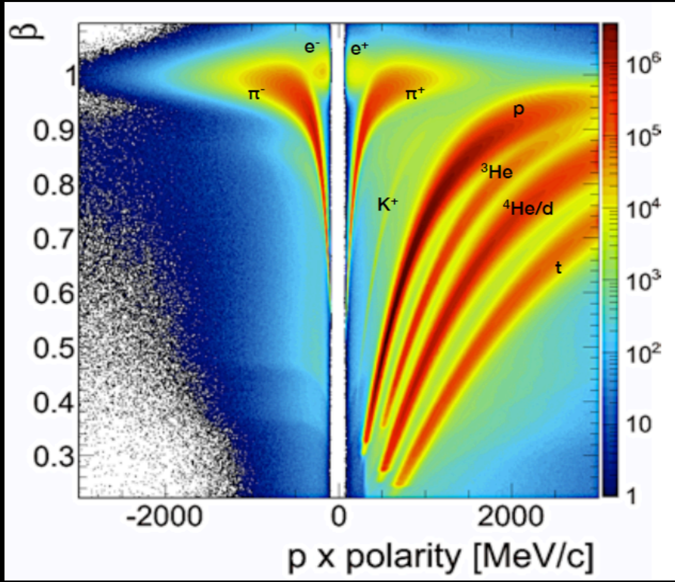


Nature Phys. 15 (2019) no.10, 1040-1045

Large stopping → baryon-dominated

Similar conditions as in merging NS

T < 70 MeV, $\rho \approx 3\rho_0$



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

Outline

- (Sub-Threshold) Strangeness Production

    KN- and YN-Potential in A+A and π+A

- The Bulk: Protons and Light Nuclei

    Coalescence Afterburner

    Macroscopic Description

- EM-Formfactors of Baryon Resonances
  Strangeness and FAIR-Phase0

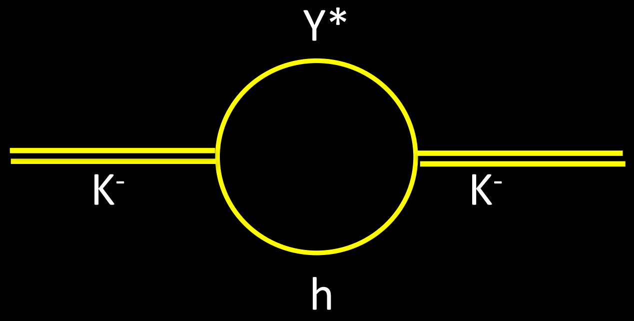
- Summary

(Sub-Threshold) Strangeness Production

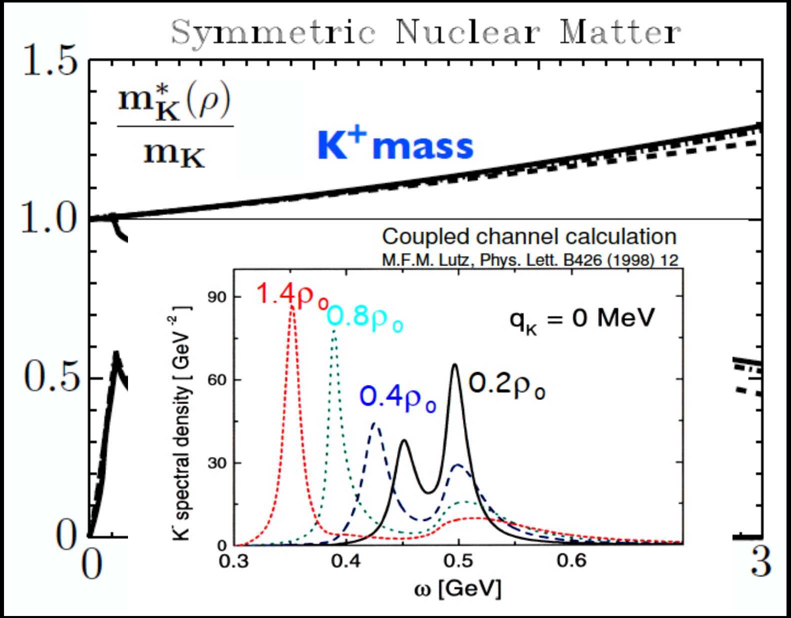
Unique observable:
Not produced in binary NN collisions at $\sqrt{s_{NN}}$= 2.4 GeV (no obvious elementary reference)

NN→NYK⁺: $\sqrt{s_{NN}}$= 2.55 GeV,
NN→NNK⁺K⁻: $\sqrt{s_{NN}}$= 2.86 GeV
(strong K⁻ suppression).

Energy must be provided from the system.



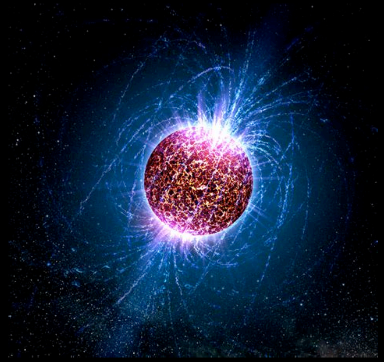
Coupling of K⁻ to baryons
and strangeness exchange reactions
e.g. πY→NK⁻.



Repulsive K⁺N potential
Attractive K⁻N potential → K⁻ condensation?
(complicated form due to resonances)

T. Waas, M. Rho and W. Weise Nucl. Phys. A617 (1997) 449-463
N. Kaiser et al. Nucl.Phys. A594 (1995) 325-345

Neutron Stars and Strangeness

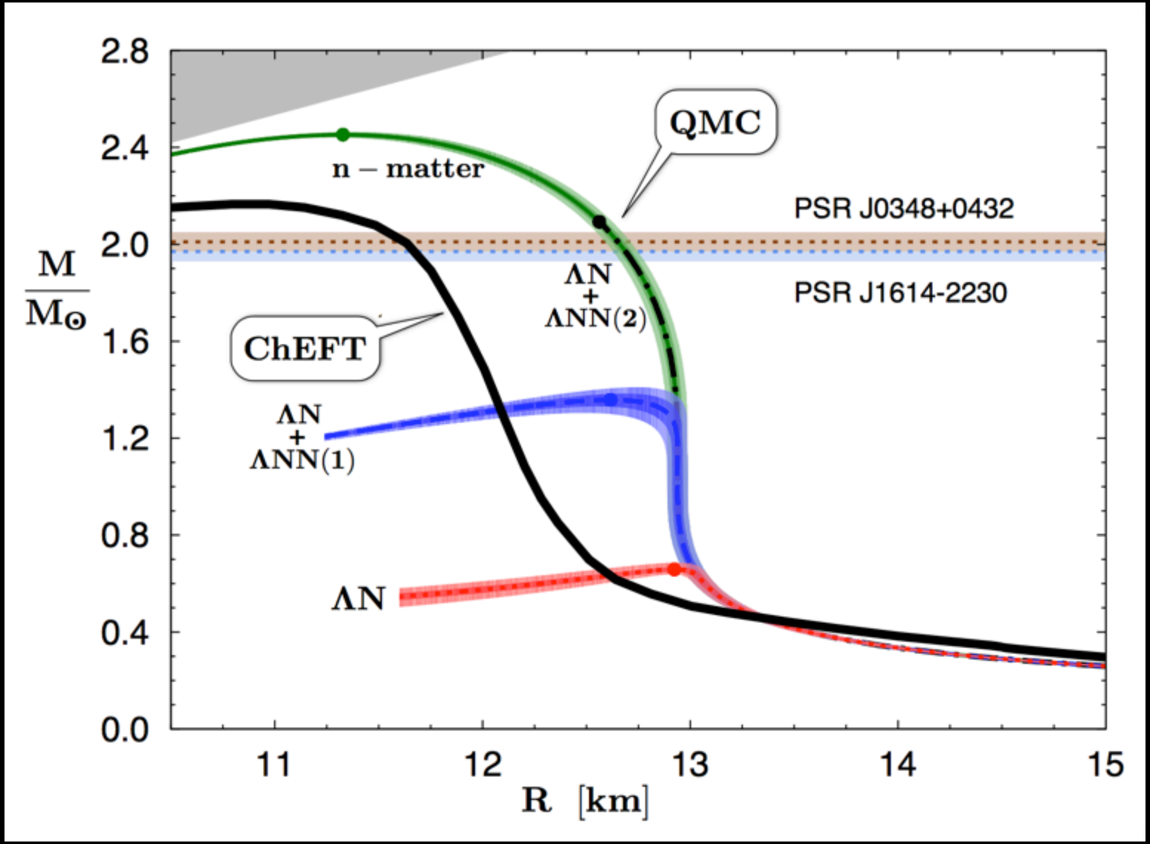


Stabilized by Fermi pressure

$p_{gravity} = p_{Fermi}$

High Fermi pressure can be reduced by strangeness.

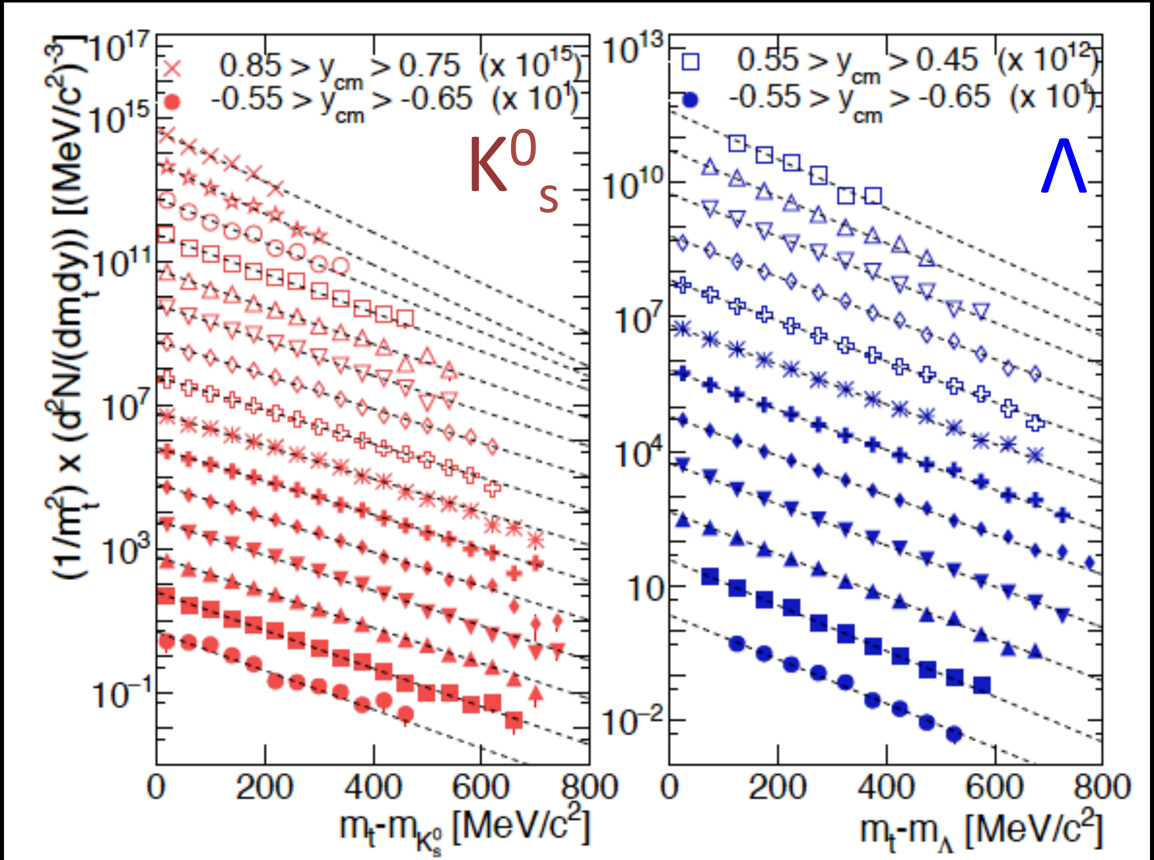
Important:
Hyperons
Many particle interactions



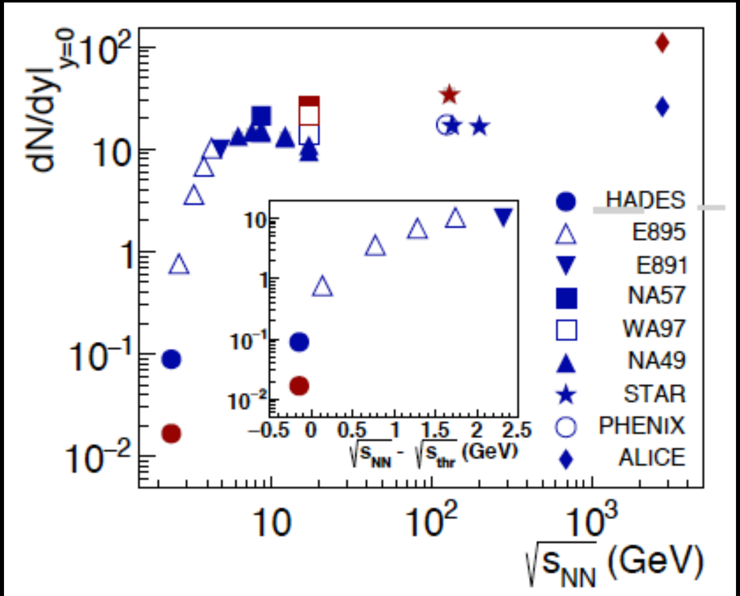
QMC: Attractive interaction + (phenom.) repulsive interaction

QMC: Lonardoni et al., Phys. Rev. Lett. 114, 092301 (2015) ChEFT: T. Hell et al., Phy. Rev. C 90, 045801 (2014)

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



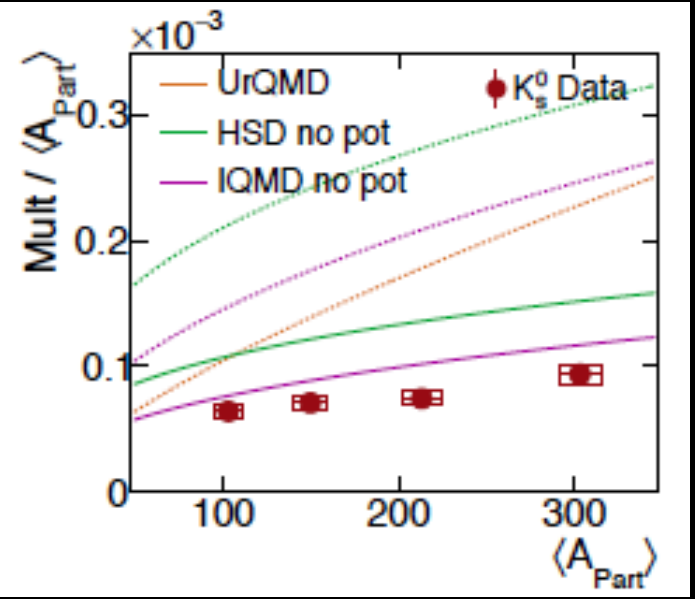
Phys.Lett. B793 (2019) 457-463

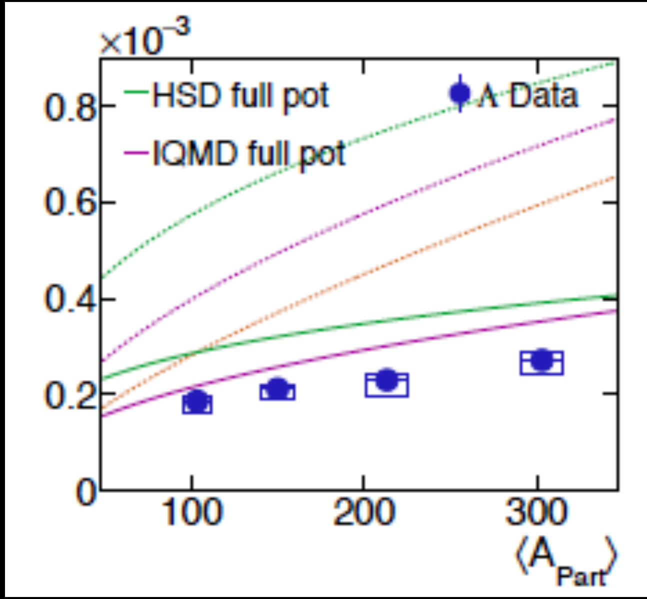


Steep excitation function

Strangeness Production in Transport Models

Phys.Lett. B793 (2019) 457-463





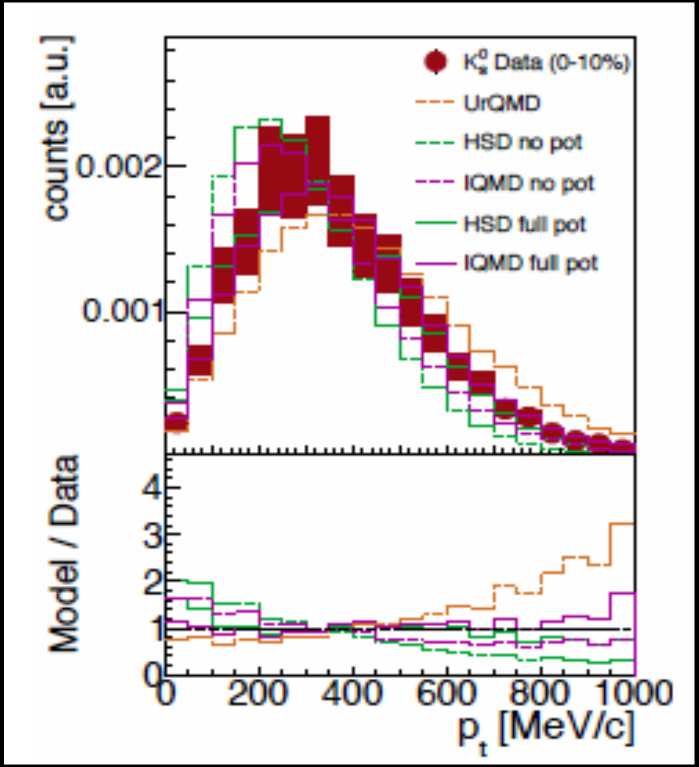
Model predictions: UrQMD 3.4, HSD 711n, IQMD c8, (full pot.= 40 MeV)

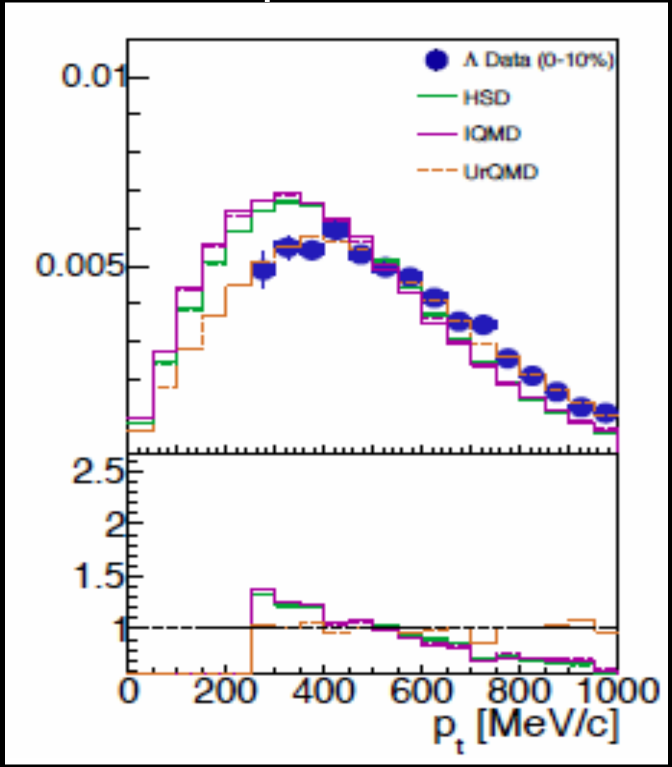
Large spread between different models, general trend to overshoot data.

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

Strangeness Production in Transport Models

Phys.Lett. B793 (2019) 457-463



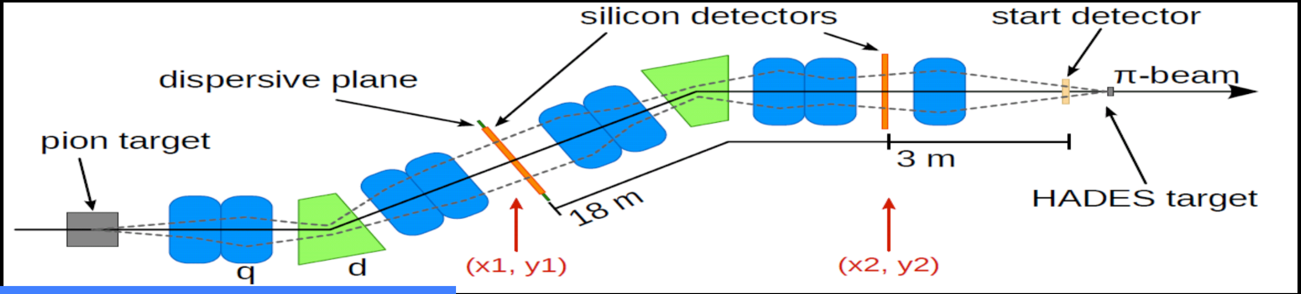


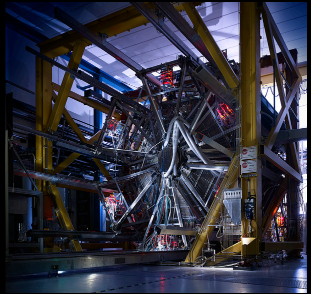
Large spread between different models, general trend to overshoot data.

Comparison of p_t-spectra shape: Ambiguities in description

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

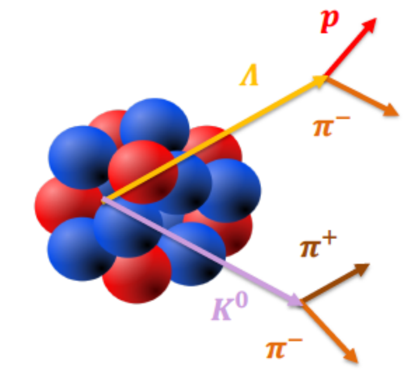
Strangeness in cold nuclear matter: π+A

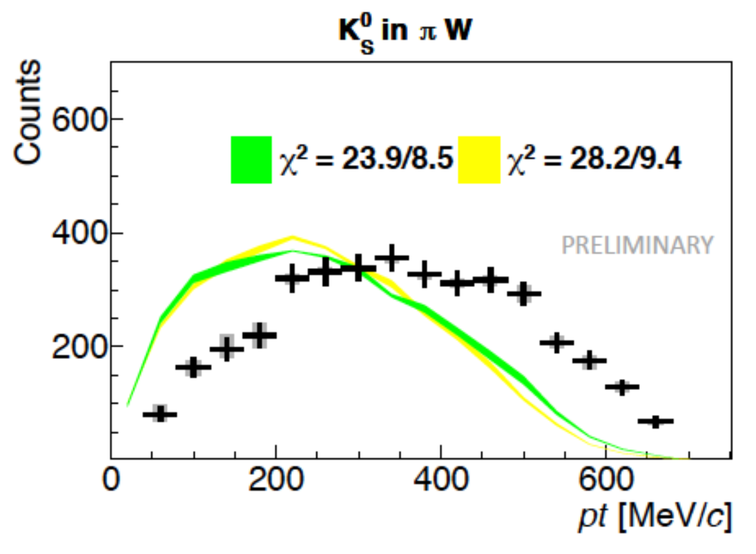




More controlled conditions, less pronounced effects. Semi-exclusive data analysis: $\pi^- + A \rightarrow K^0_s + \Lambda + X$

π beam momentum= 1.7 GeV/c



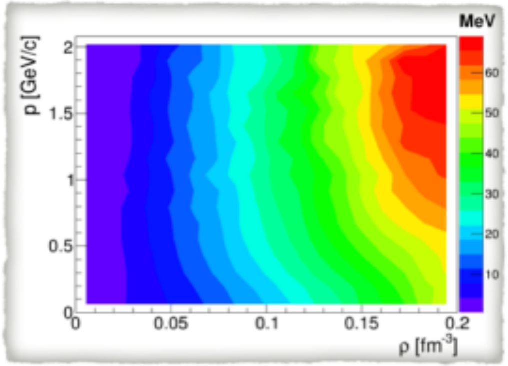


S. Maurus, J. Wirth, T. Gaitanos, L. Fabbietti

Transport Model: **GiBUU**

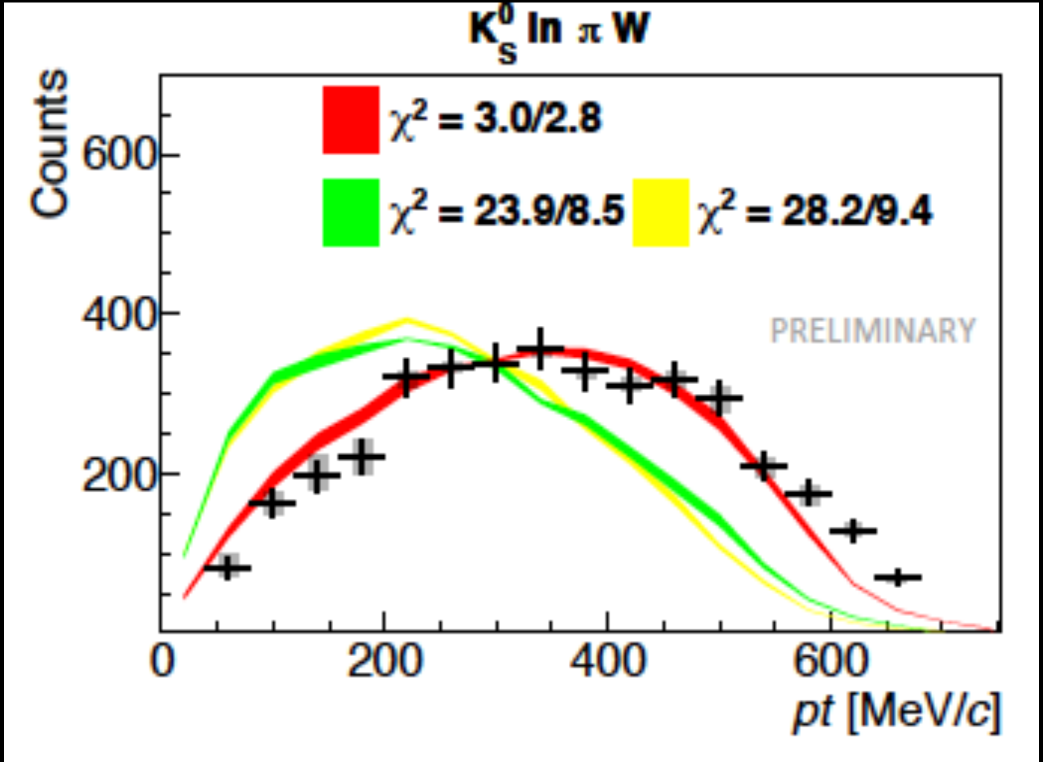
1. **No** $K^0/\Lambda/\Sigma^0 N$ **potentials (ES(Y,K))**
2. **No** $\Lambda/\Sigma^0 N$ **potentials (ES(Y))**

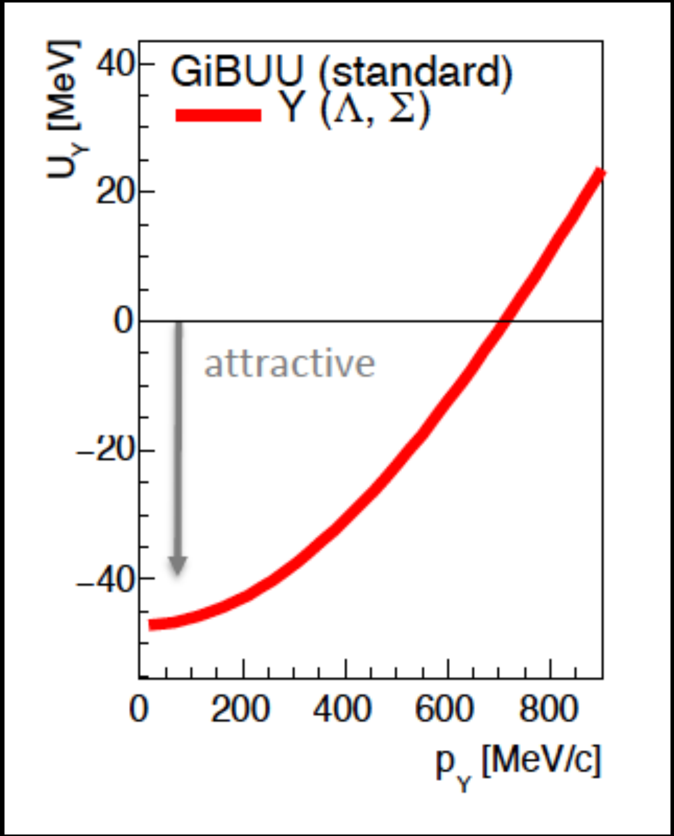
KN potential



Agakishiev et al., Phys. Rev. C 90, 054906 (2014)

Strangeness in cold nuclear matter: π+A

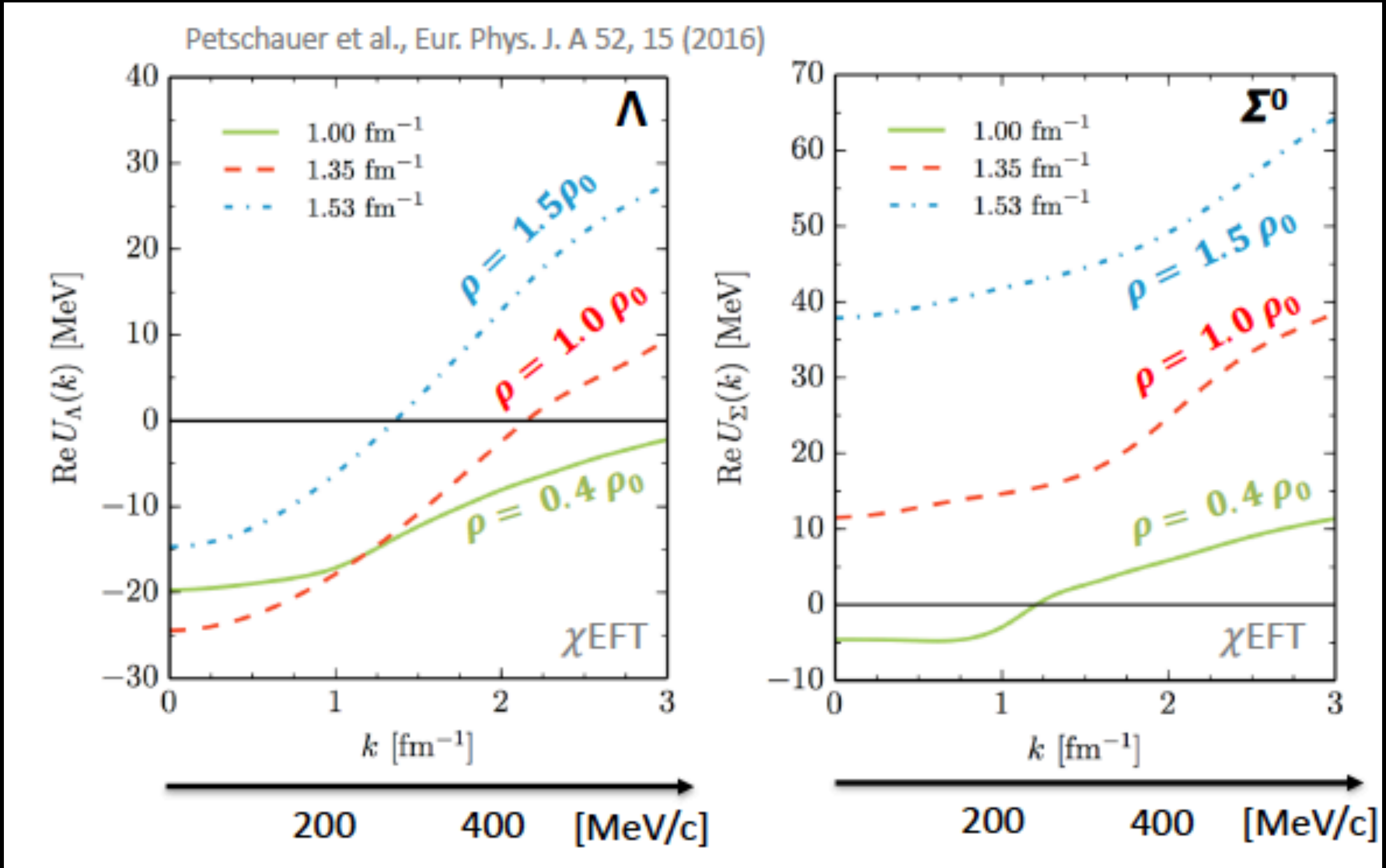




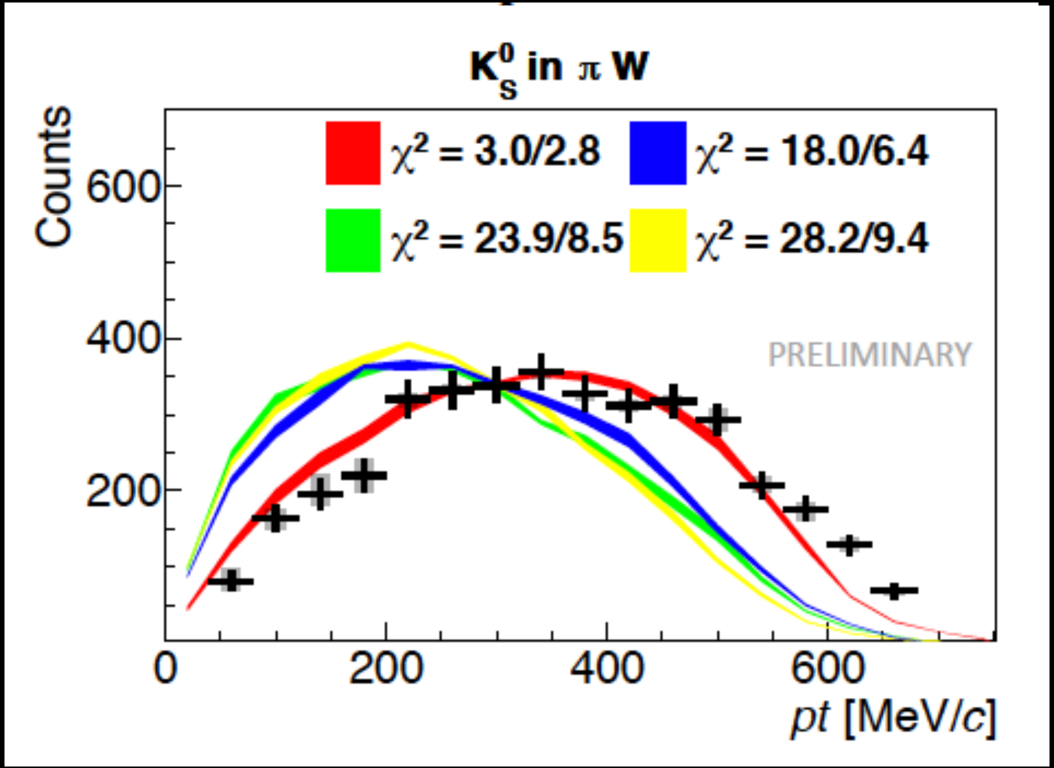
→ Do not stop if you are on the data.

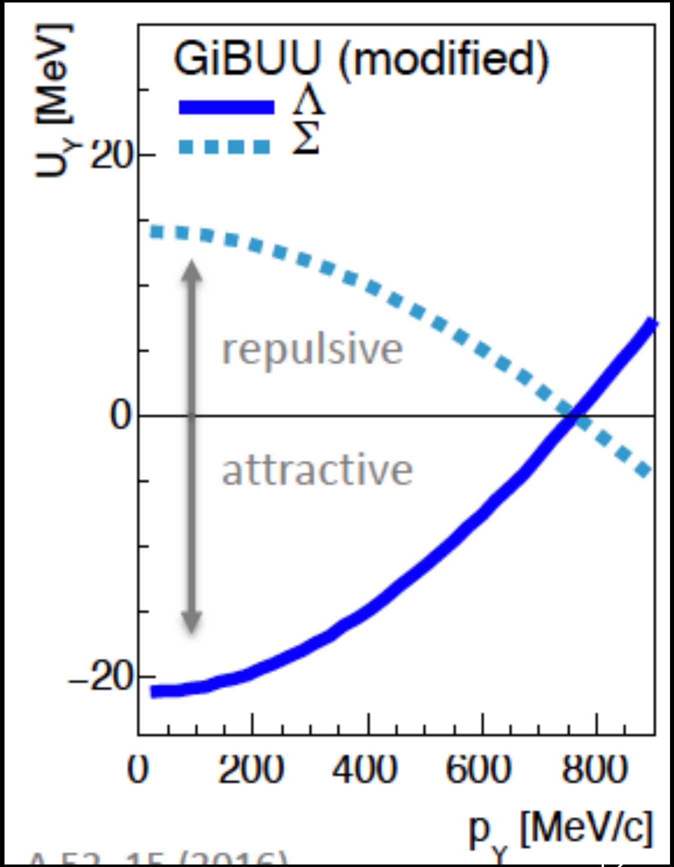
S. Maurus, J. Wirth, T. Gaitanos, L. Fabbietti

Strangeness in cold nuclear matter: π+A



Cold nuclear matter: π+A

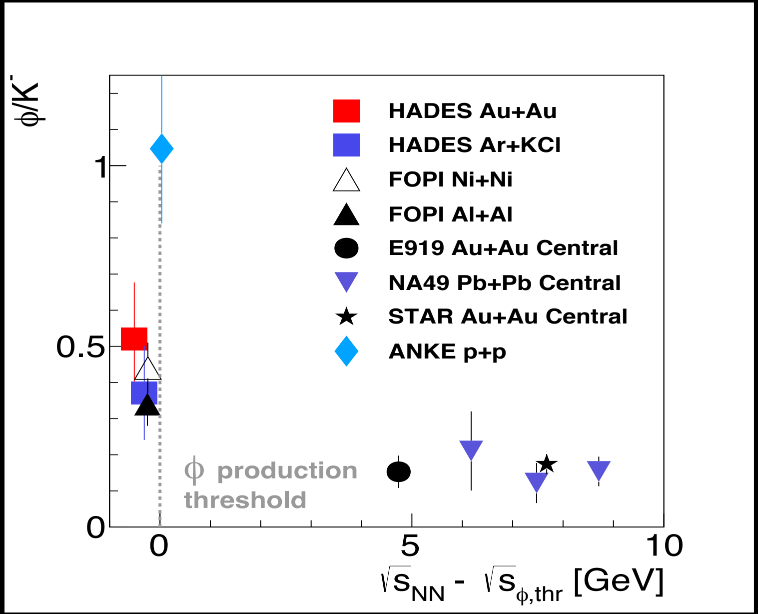


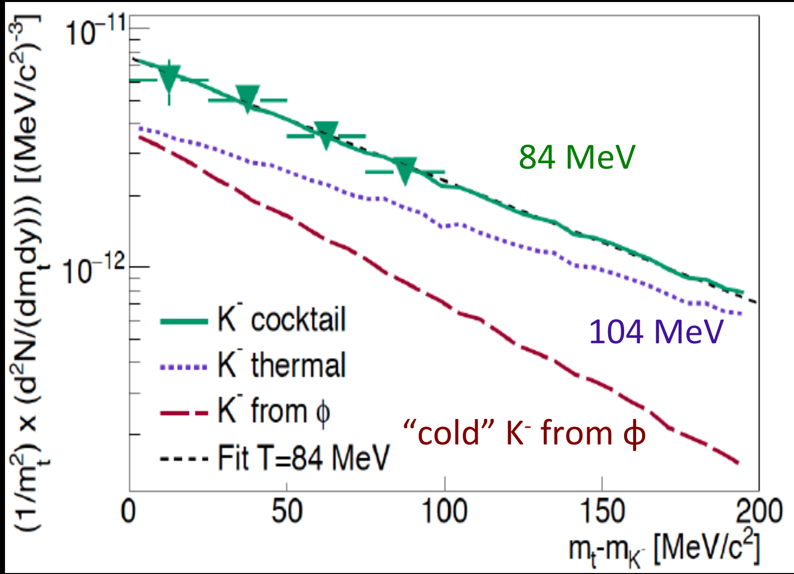


Not yet the complete picture.

S. Maurus, J. Wirth, T. Gaitanos, L. Fabbietti

Φ-AntiKaon Interplay in HIC





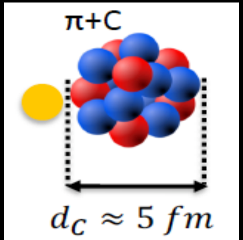
Phys.Lett. B778 (2018) 403-407

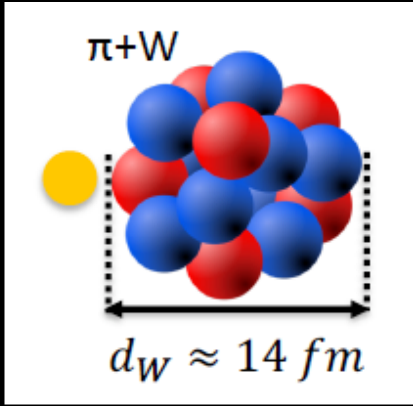
Increased in HIC at low $\sqrt{s_{NN}}$:
→ 25% of K^- result from Φ decays!

Φ feed-down can explain lower inverse slope parameter of K^- spectrum (T_{eff} = 84 ± 6 MeV) in comparison to the one of K^+(T_{eff} = 104 ± 1 MeV)

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

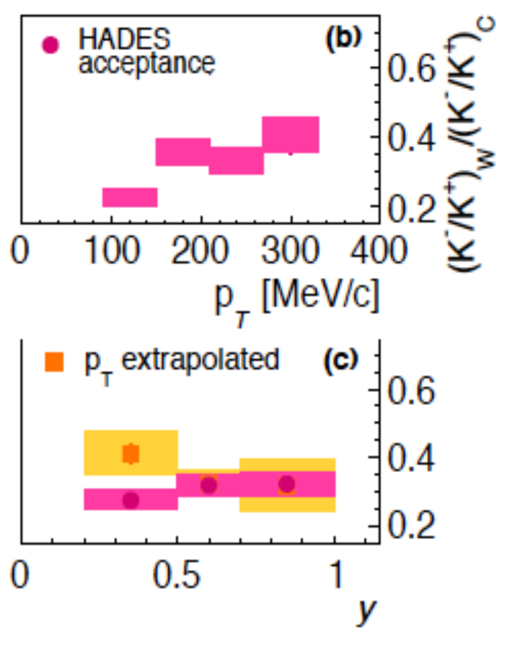
Φ-AntiKaon Interplay in Cold Matter

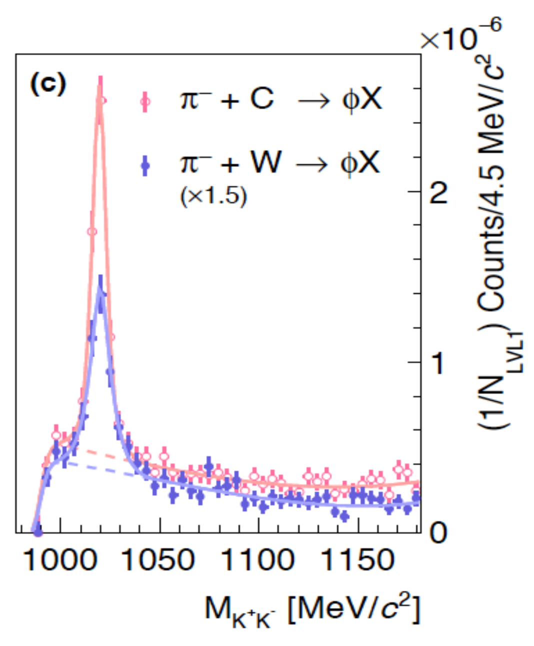




→ Mean free path $\lambda_\pi = 1.5\ fm$

$(p_\pi = 1.7\ GeV/c\ ,\rho_B \approx \rho_0)$





→ Suppression of K^- relative to K^+

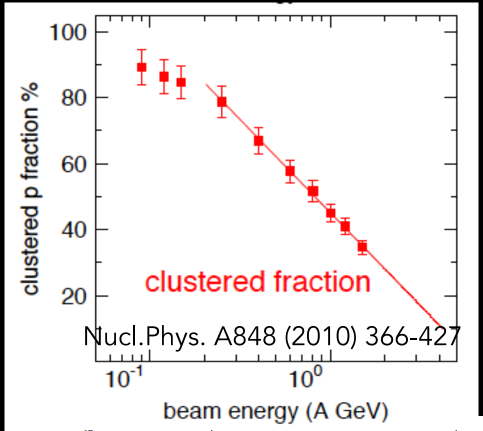
→ Similar suppression for ϕ like for K^-

In HADES acceptance:

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

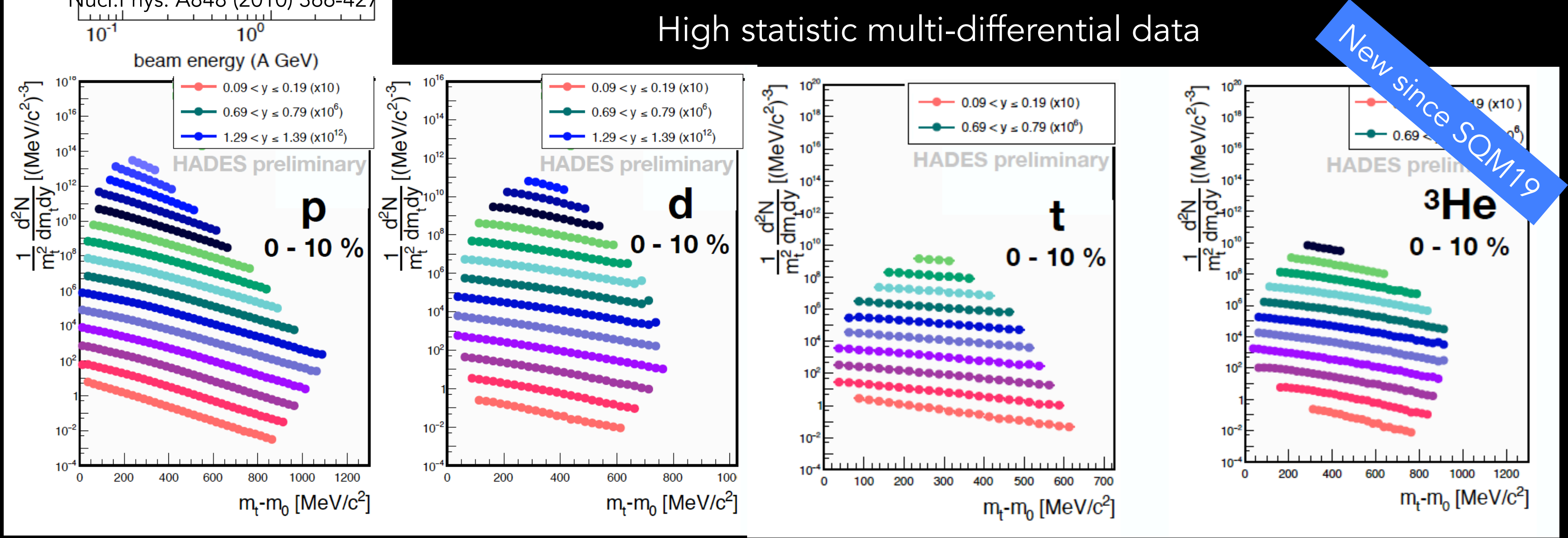
$$(\phi/K^-)_W = 0.63 \pm 0.06(stat) \pm 0.11(sys)$$

Phys.Rev.Lett. 123 (2019) no.2, 022002

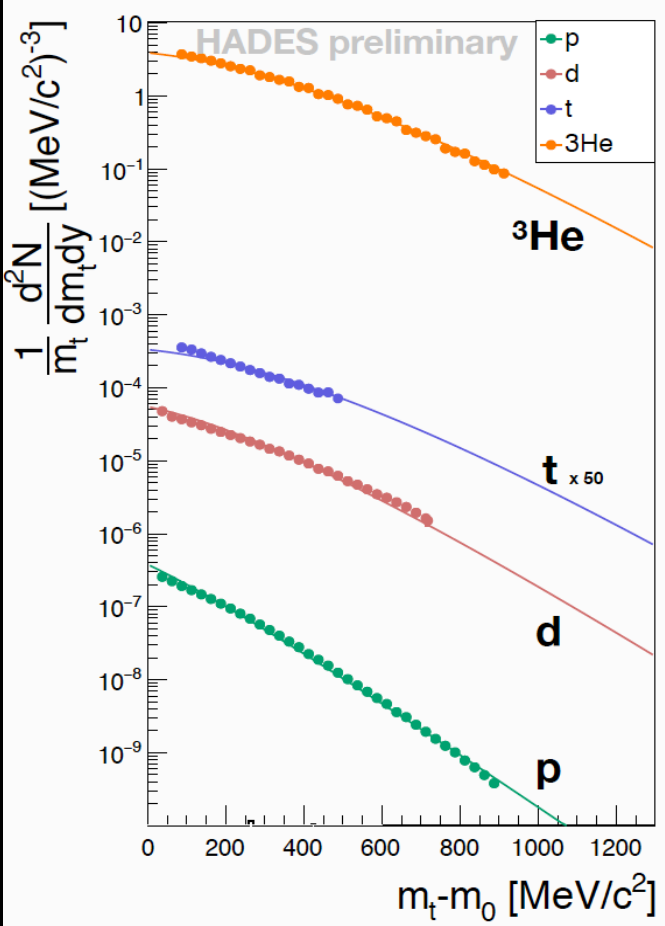


The Bulk: Protons and Light Nuclei

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}=71±8 MeV

$<\beta_r>$=0.30±0.04

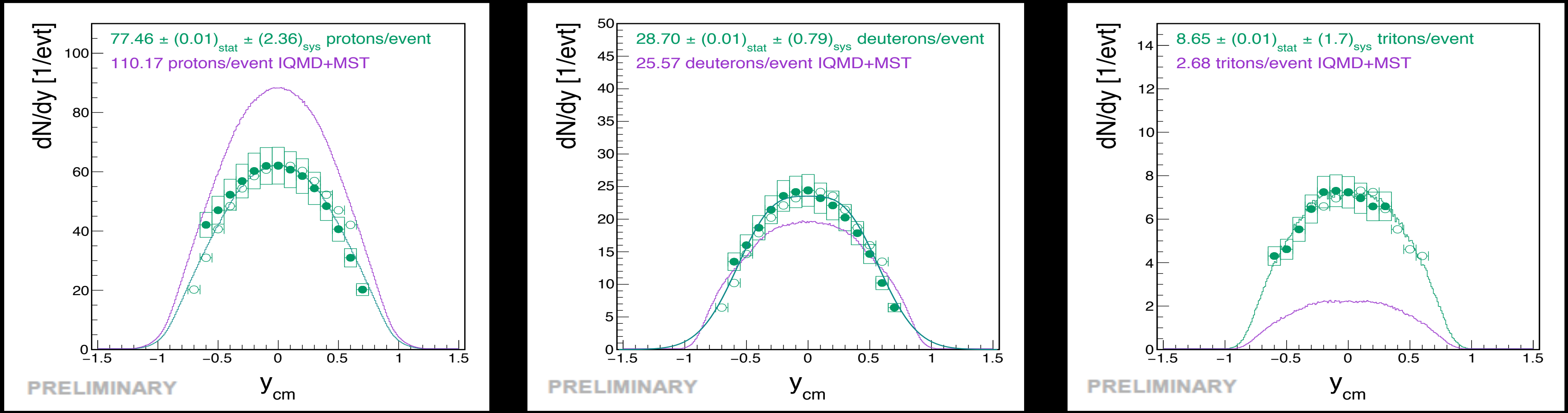
Shape of p and light nuclei spectra described with simple BW model (at most 20% difference)

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

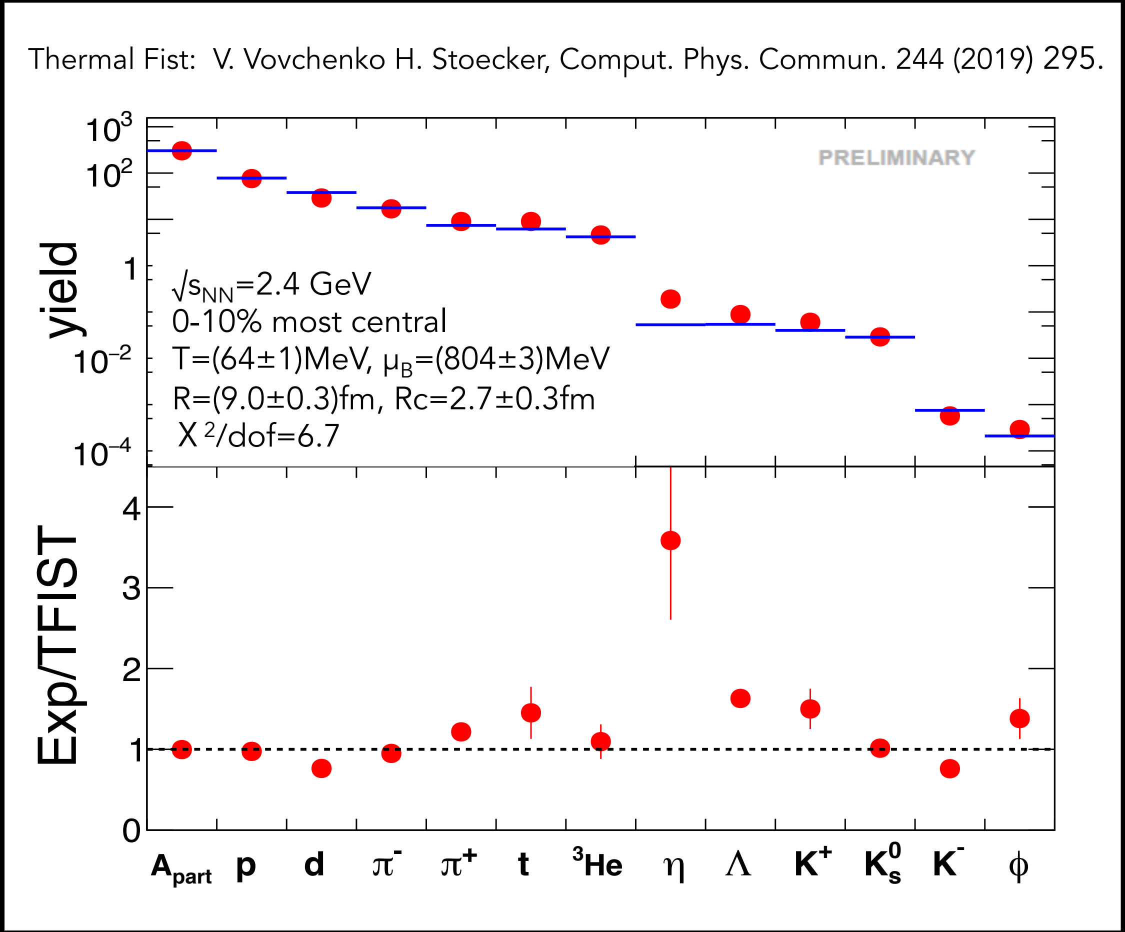


→ Challenge to reproduce light nuclei yields at mid-rapidity with simple coalescence.

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).
D. Oliinychenko, L. G. Pang, H. Elfner and V. Koch, Phys. Rev. C 99 (2019) no.4, 044907.
E. Bratkovskaya, J. Aichelin, A. Le Fevre, V. Kireyeu, V. Kolesnikov, Y. Leifels and a. V.Voronyuk, arXiv:1911.11892 [nucl-th].

Macroscopic description of yields



Momentum distribution not isotropic even in most central events.

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

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

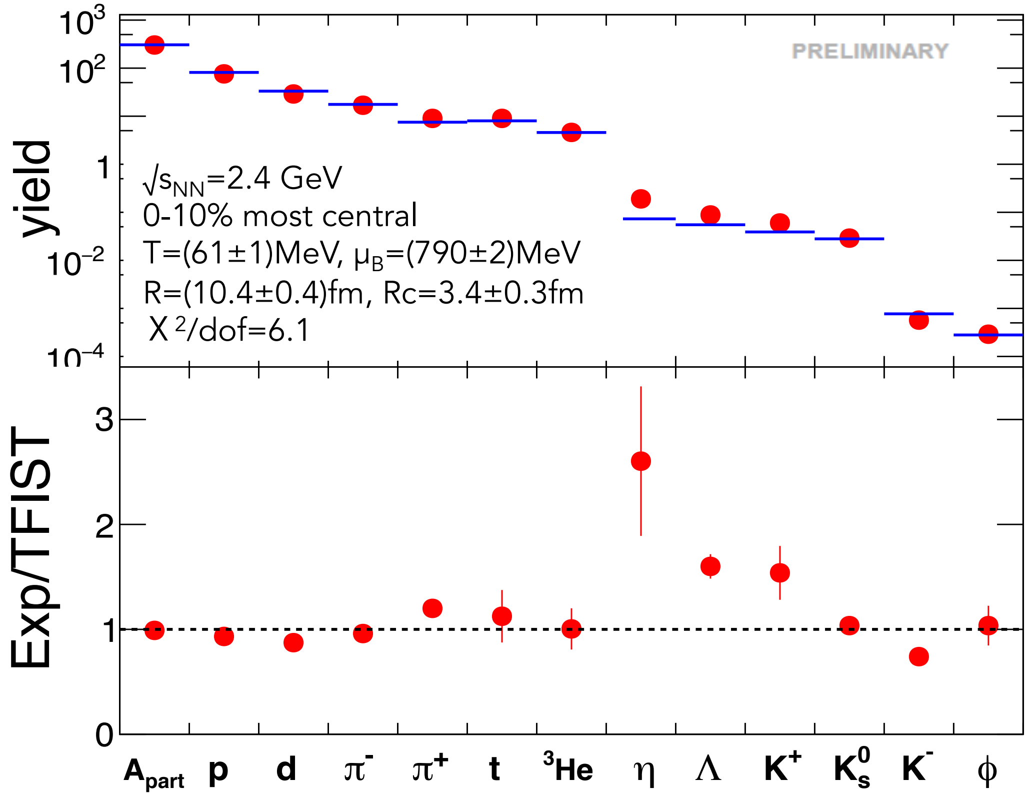
R. Averbeck, R. Holzmann, V. Metag, R.S. Simon. Phys.Rev. C67 (2003)

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

Inclusion of excited nuclei:
As proposed by e.g. E. Shuryak.

Macroscopic description of yields

Thermal Fist: V. Vovchenko H. Stoecker, Comput. Phys. Commun. 244 (2019) 295.



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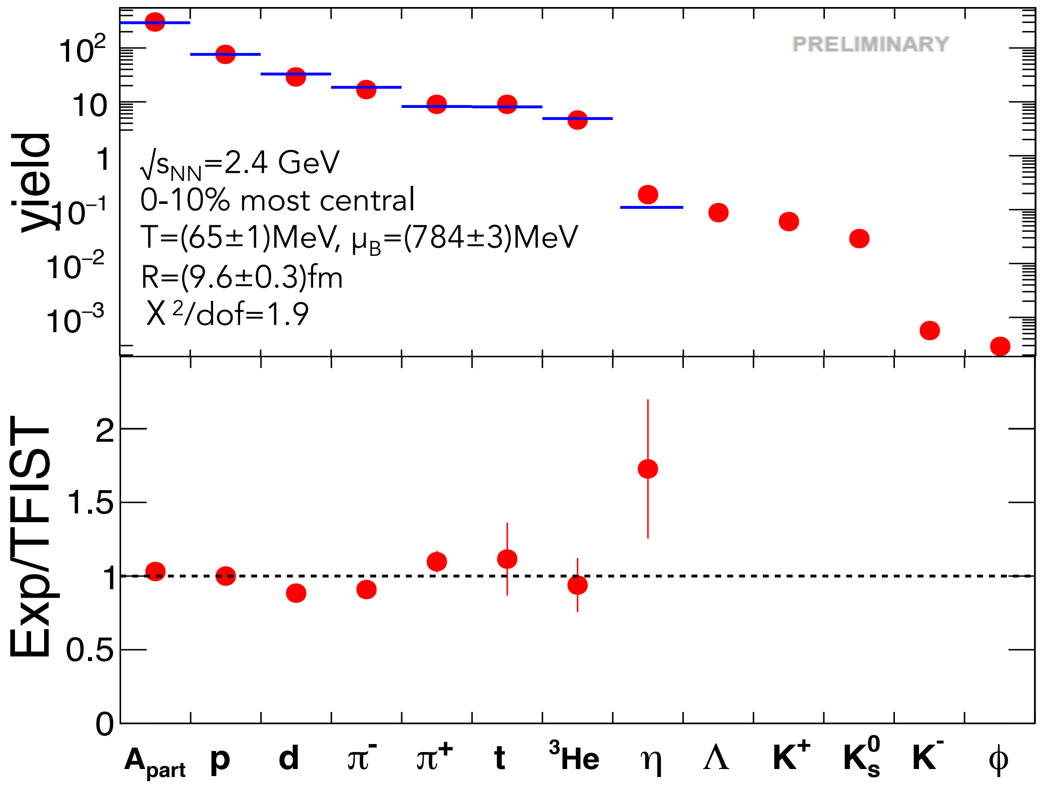
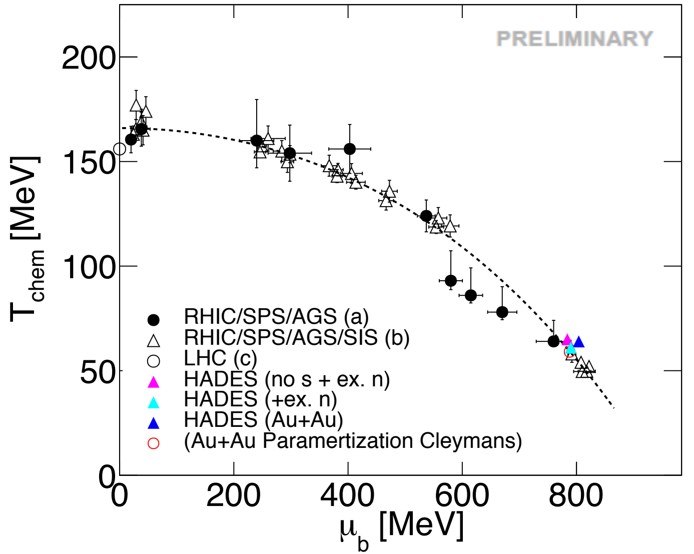
Fit to full hadron spectrum results in large χ^2 !

Inclusion of excited nuclei:
As proposed by e.g. E. Shuryak.
→ Small improvement in χ^2.

Macroscopic description of yields

Thermal Fist: V. Vovchenko H. Stoecker, Comput. Phys. Commun. 244 (2019) 295.

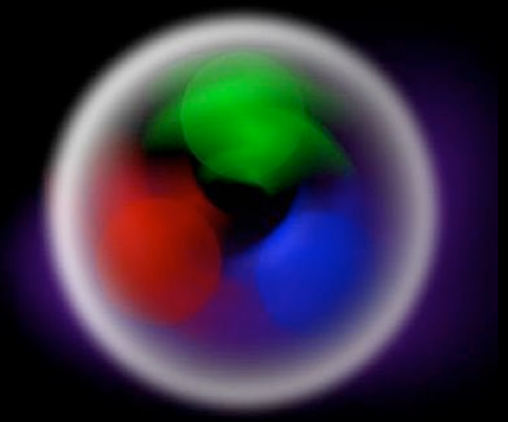




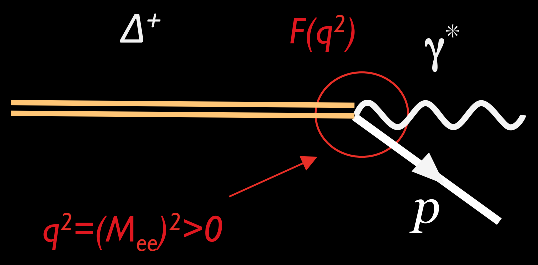
Fit excluding strangeness and but including excited nuclei states results small χ^2 !

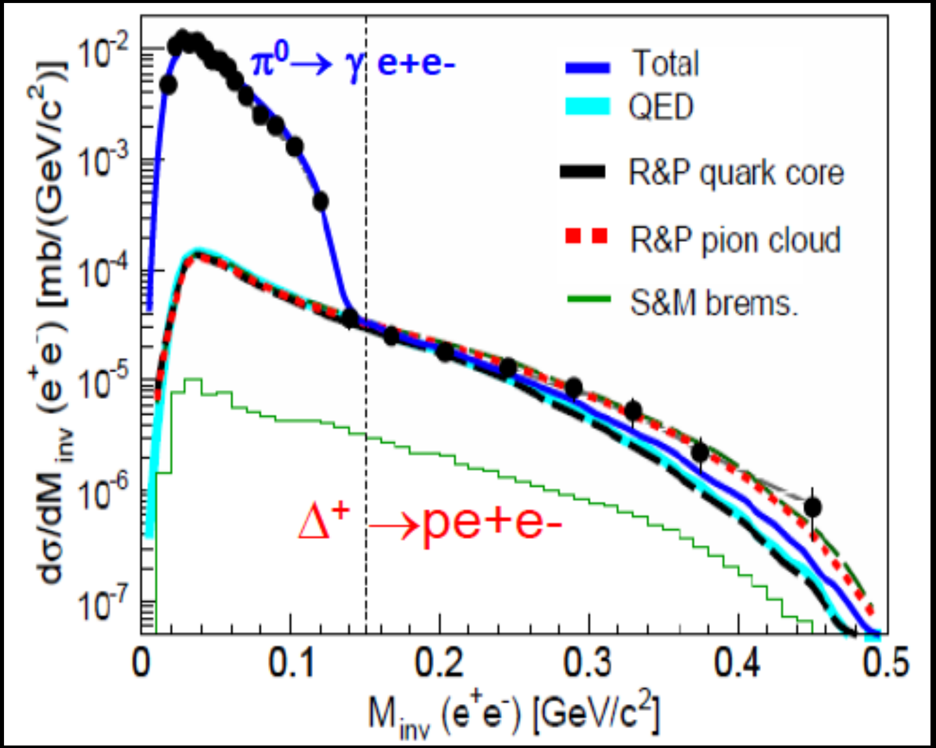
Andronic et. al. (Grand canonical T, μ_B)
Nucl.Phys. A789 (2007) 334-35
Cleymans, Becattini (Strangeness canonical+ γ_S)
Phys.Rev. C73 (2006) 034905

EM Formfactors of baryonic resonances



$p+p(1.25\ GeV) \rightarrow p+p+e^-+e^+$

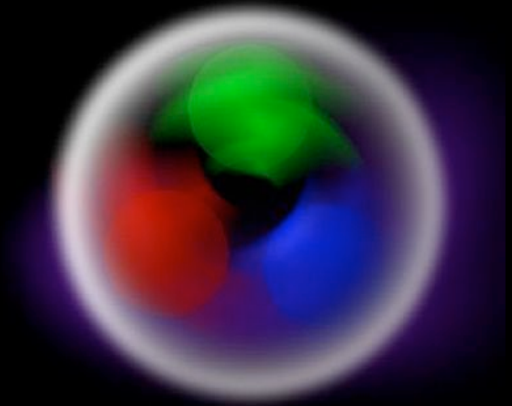




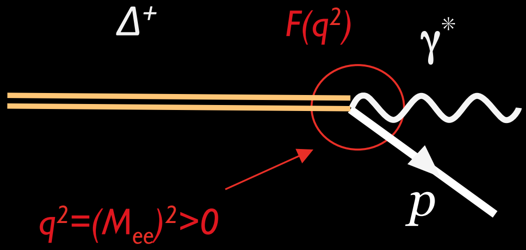
Phys. Rev. C95 (2017) no.6 065205

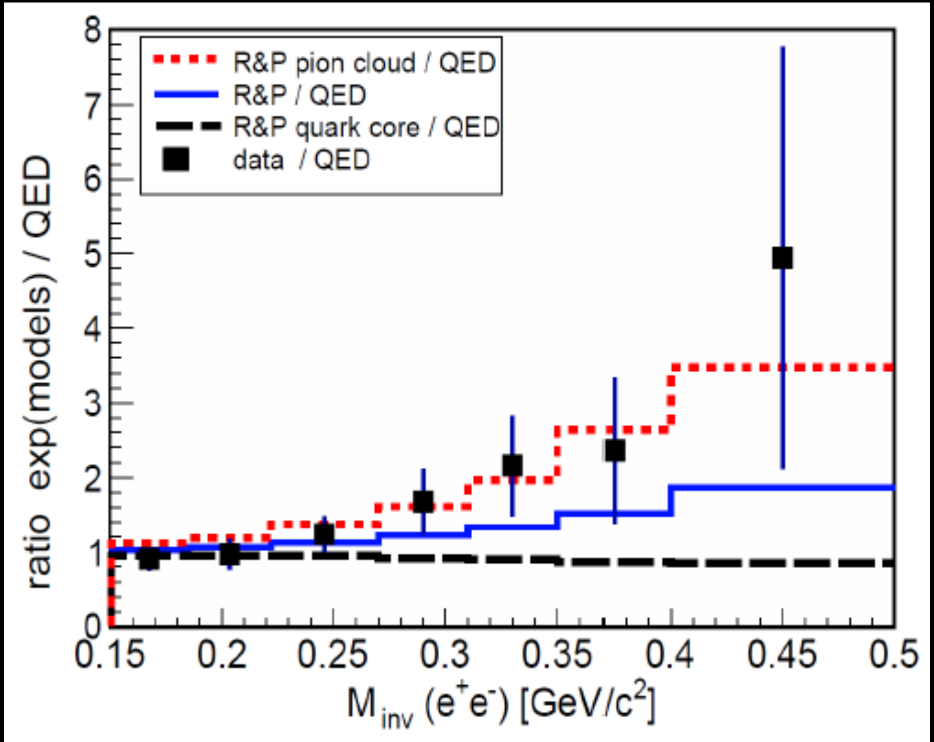
Good agreement with model of Ramahlo & Pehna if pion cloud is taken into account

EM Formfactors of baryonic resonances



$p+p(1.25\ \text{GeV}) \rightarrow p+p+e^-+e^+$

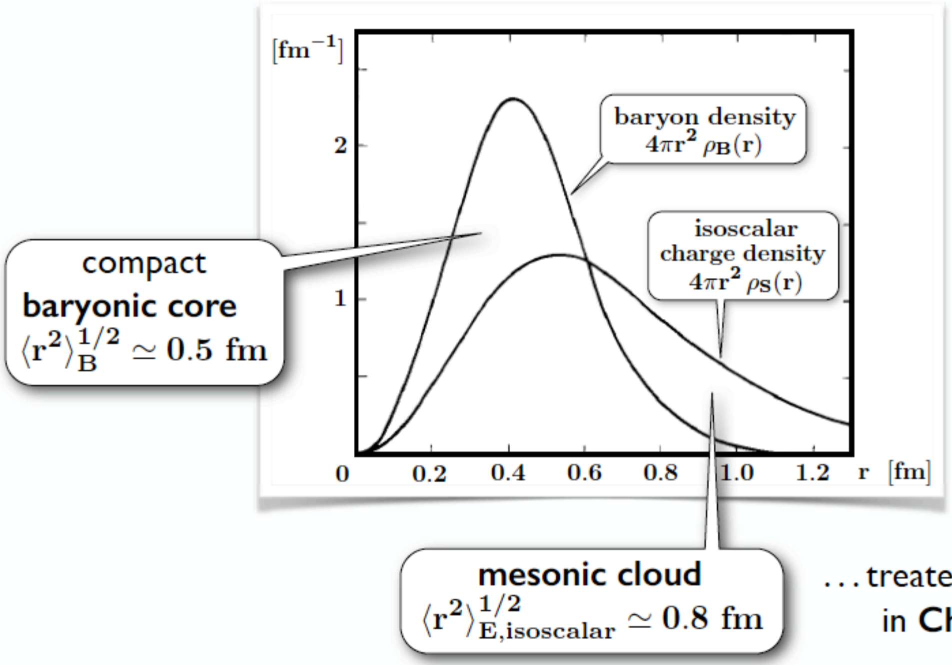




Good agreement with model of Ramahlo & Pehna if pion cloud is taken into account

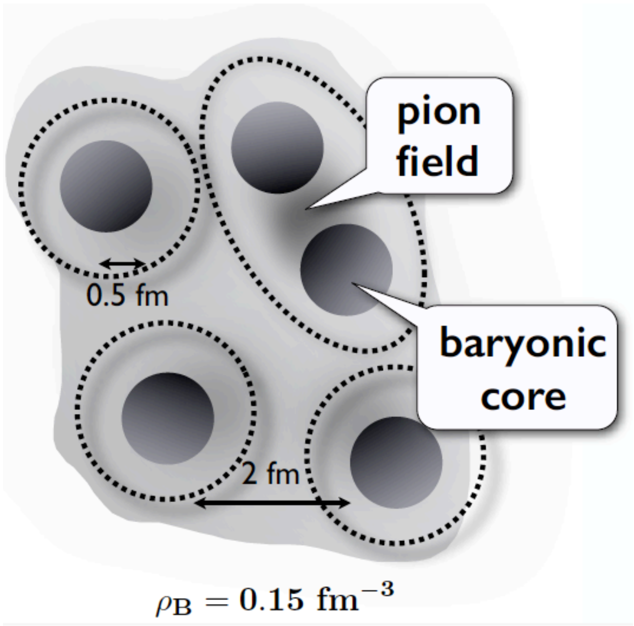
Phys. Rev. C95 (2017) no.6 065205

Consequences for the created system?



N. Kaiser,
U.-G. Meißner,
W.W.
Nucl. Phys.
A466 (1987) 685

...treated properly
in **Chiral EFT**



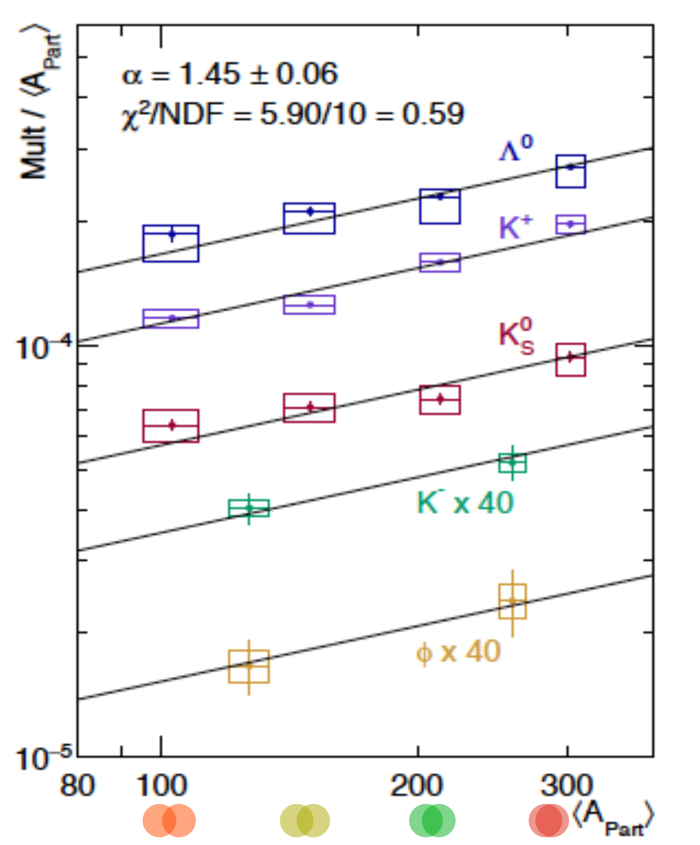
Can we connect this to an observable?

Figures from W. Weise

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.

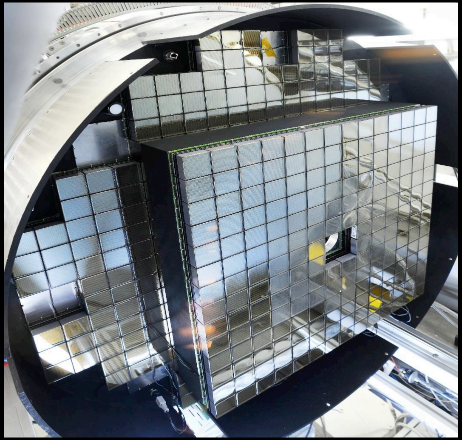
Strange particle yields rise stronger than linear with

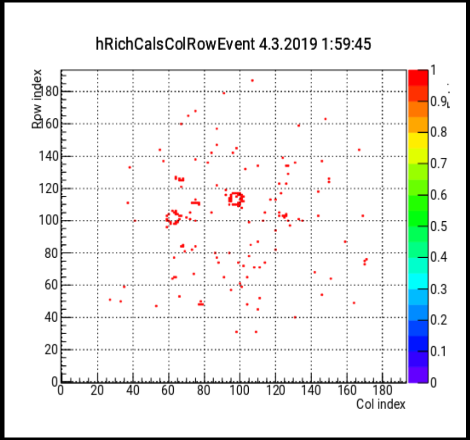
$<A_{part}>$ ($M \sim <A_{part}>^{\alpha}$)

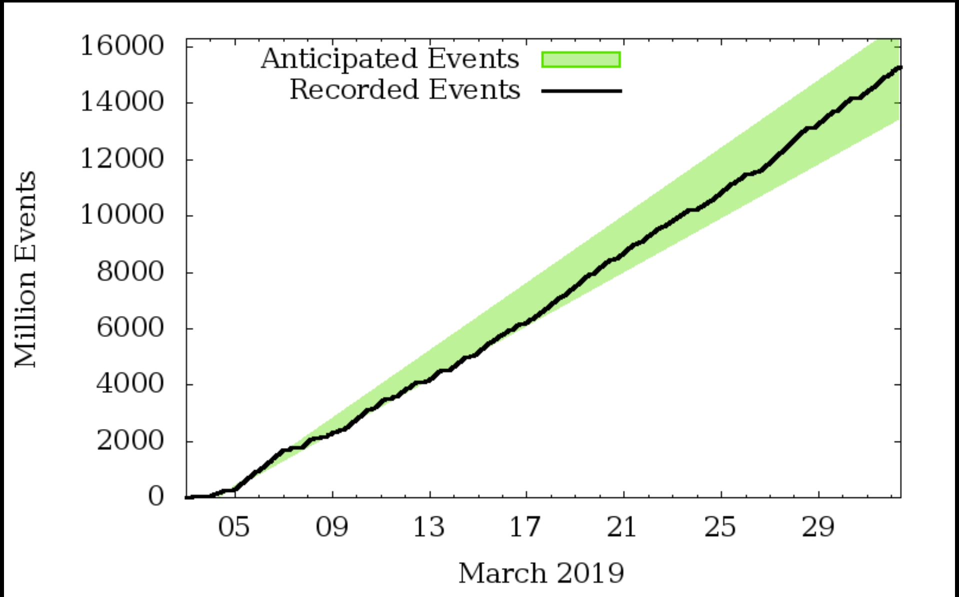
Universal $<A_{part}>$ dependence of strangeness production

→ Hierarchy in production threshold not reflected
Scaling with absolute amount of strangeness not with individual hadron states:
ssbar excitation in overlapping clouds?

FAIR Phase 0: Ag+Ag $\sqrt{s_{NN}}$= 2.6 (2.4) GeV







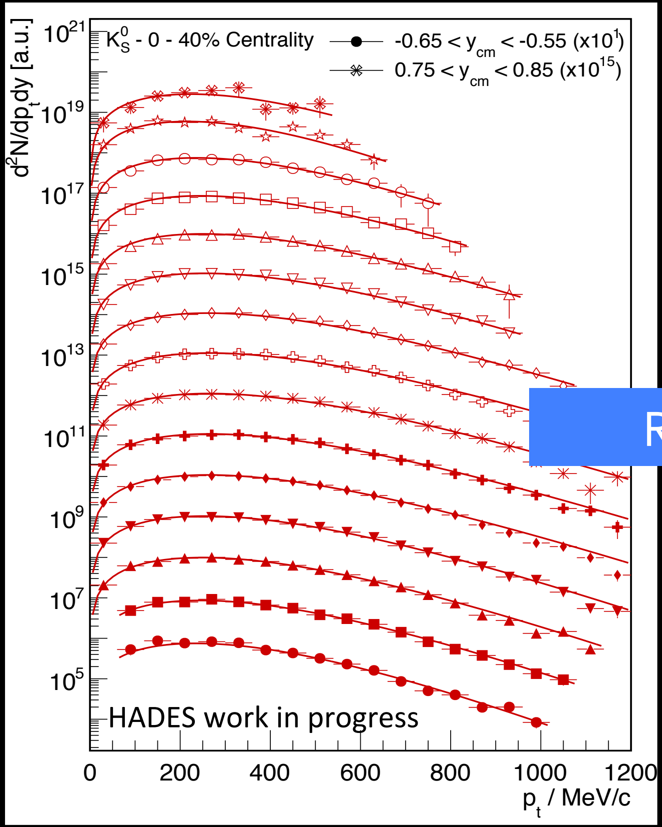
½ of the CBM RICH photon detector

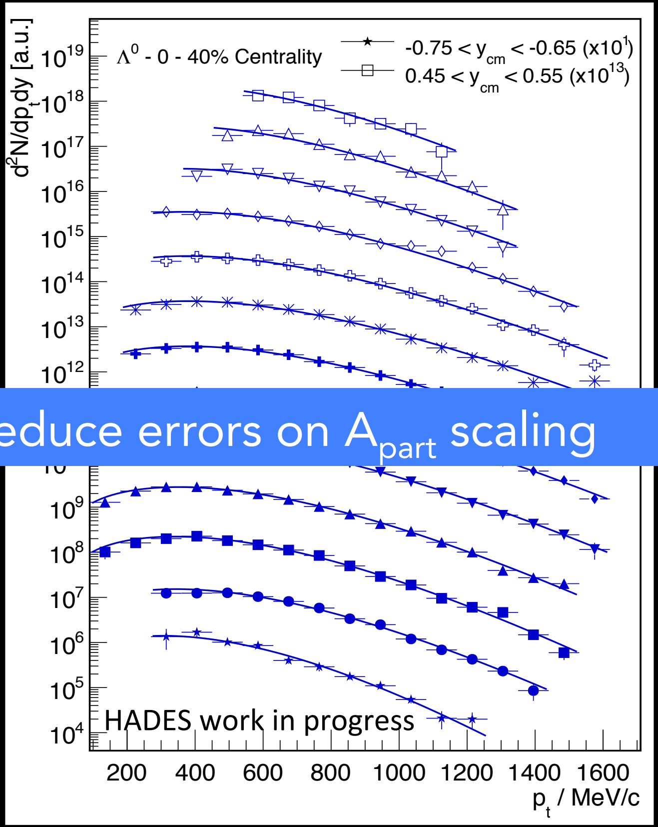
Stable operation during 4 weeks of beamtime

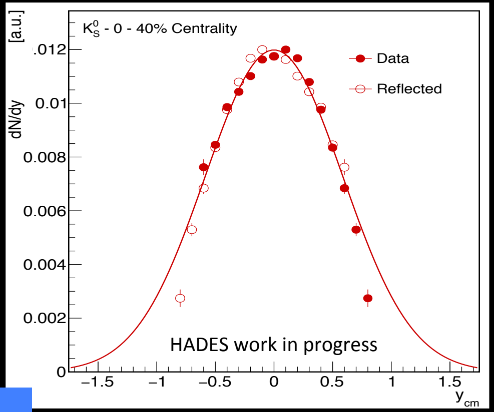
~ 15 billion events collected during March 2019

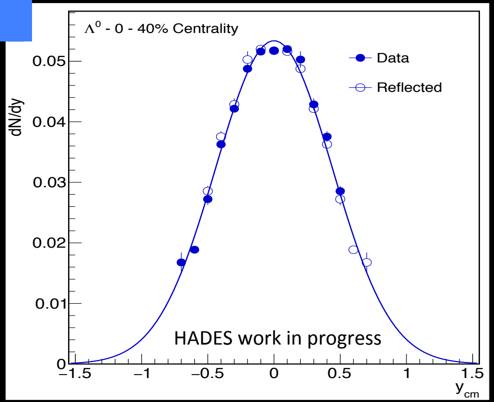
Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Strangeness

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



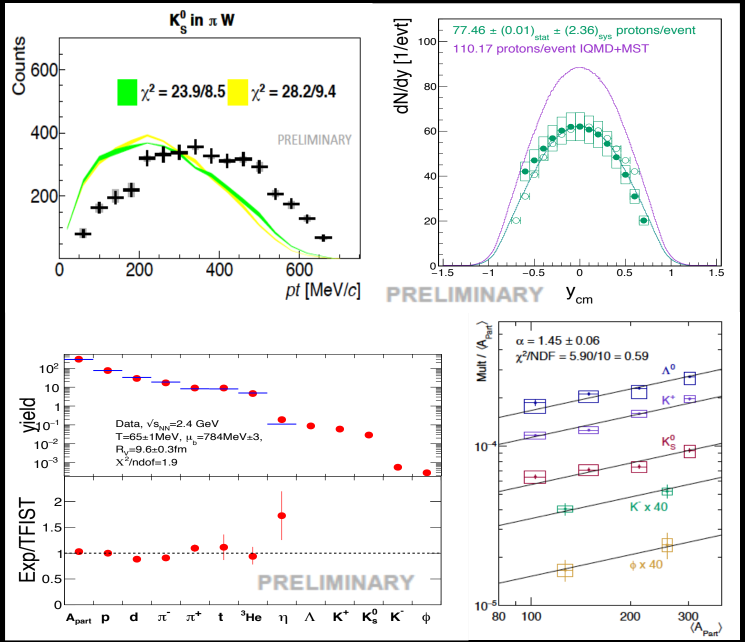






Reduce errors on A_{part} scaling

Summary



- (Sub-Threshold) Strangeness Production

  KN- and YN-Potential in A+A and π+A

→ Not there but progress is made.

- The Bulk: Protons and Light Nuclei

  Coalescence Afterburner

→ Challenge to reproduce yields at mid-rapidity.

  Macroscopic Description

→ Fit excluding strangeness and but including excited nuclei results in small χ^2 .

- EM-Formfactors of Baryon Resonances
  Strangeness and FAIR-Phase0

→ Universal $\langle A_{part} \rangle$ dependence of Strange hadrons will be tested with new data

The HADES collaboration

Thank you for your attention!