Statistical model analysis of hadron yields at SIS energies

Strangeness Workshop
Warszawa 2016

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for the HADES collaboration

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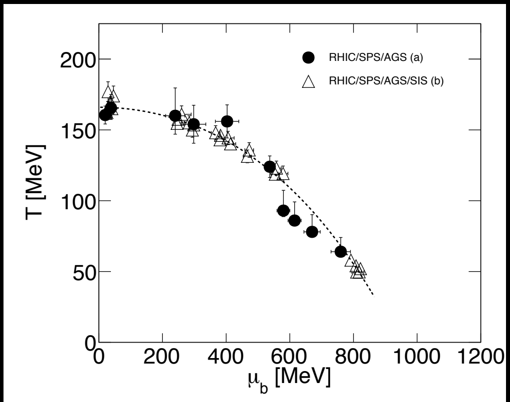
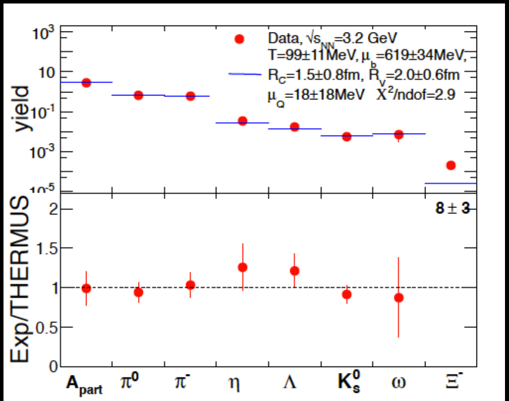
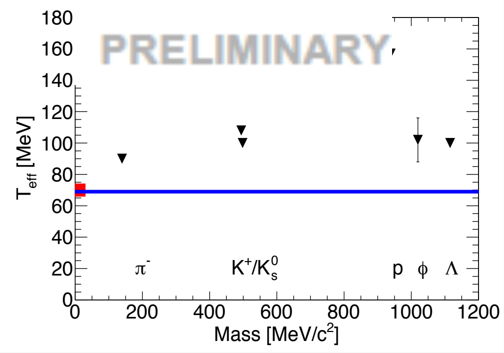
Outline:

- Introduction
  - Statistical particle production, Freeze-out and the Phase diagram
- Statistical model in small systems:
  - Ar+KCl @1.76 A GeV
  - p+Nb @ 3.5 GeV
  - Transport
- First results for central Au+Au @ 1.23 A GeV
  - Parameterization
  - Free fit
  - Kinetic vs. chemical freeze-out
- Summary and conclusion
- Outlook: What else to expect from Au+Au (and the future)







Statistical model

Particle production from a homogeneous source:

$$\sum_i M_{m_i} = \sum_i g_i V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_i}{T}\right) \times F_{Si},$$

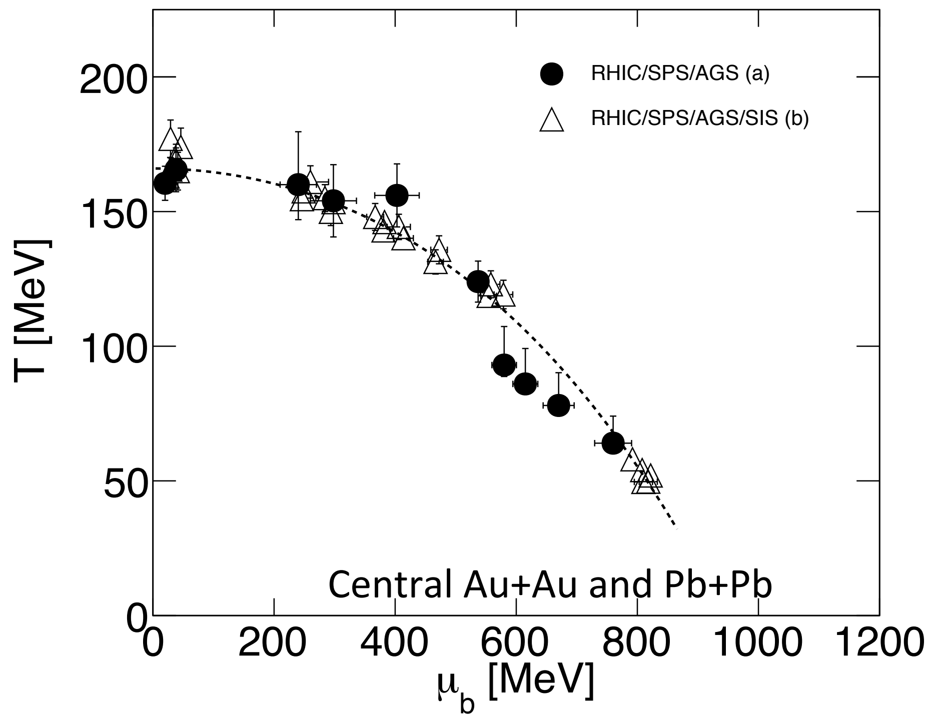
$$\sum_j M_{b_j} = \sum_j g_j V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_j - \mu_B}{T}\right) \times F_{Sj}$$

Grand canonical ensemble

Quantum numbers conserved on average using chemical potentials

Parameters: **T, $\mu = \mu_B\ \mu_s\ \mu_Q$, V**
(usually μ_s and μ_Q are fixed from initial conditions)

Eur. Phys. J., A 47(21)



Freeze-out points:

a) Andronic et. al. (Grand canonical T, μ_B)
Nucl.Phys. A789 (2007) 334-356

a) Cleymans, Becattini (Strangeness canonical+γ_S)
Phys.Rev. C73 (2006) 034905

Measurements at different √s line up in a common freeze-out curve (E/N≈1 GeV)

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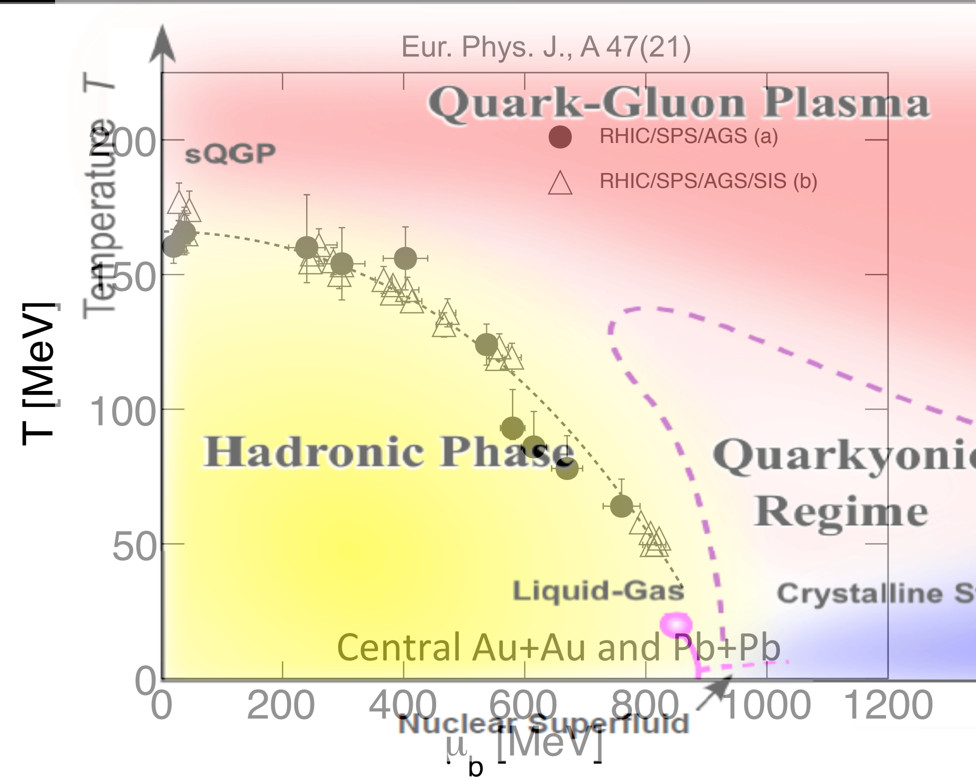

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Measurements at different √s line up in a common freeze-out curve (E/N≈1 GeV)

How to interpret this apparent equilibrium, especially at low energies?
Test model also in reference systems e.g. p+A

Statistical model at SIS energies

Strangeness canonical (exactly conserved)

Yields reduced (canonical suppression)

$$M_{m_K} \approx g_K V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_K}{T}\right) \times \left[g_Y V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_Y - \mu_B}{T}\right) + g_{\overline{K}} V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_{\overline{K}}}{T}\right)\right].$$

$$M_{m_K} \approx M^{GC}_{m_K} \times \left[M^{GC}_{m_Y} + M^{GC}_{m_{\overline{K}}}\right]$$

- Not enough to explain data:
- Strangeness has to be conserved exactly in a volume smaller than the volume of the system (radius: $R_C < R_V$)
- Empirical under-saturation parameter (γ_S)
- ϕ meson (hidden strangeness, not suppressed by R_C but strongly by γ_S)

In the strangeness canonical ensemble
μ_B constrained by:
π/p, K^+/K^-
(due to strangeness content in the Λ)

T constrained by:
K/π, ϕ/K (p/Λ) (usually R_c or γ_S is also involved, strong correlation between different parameters

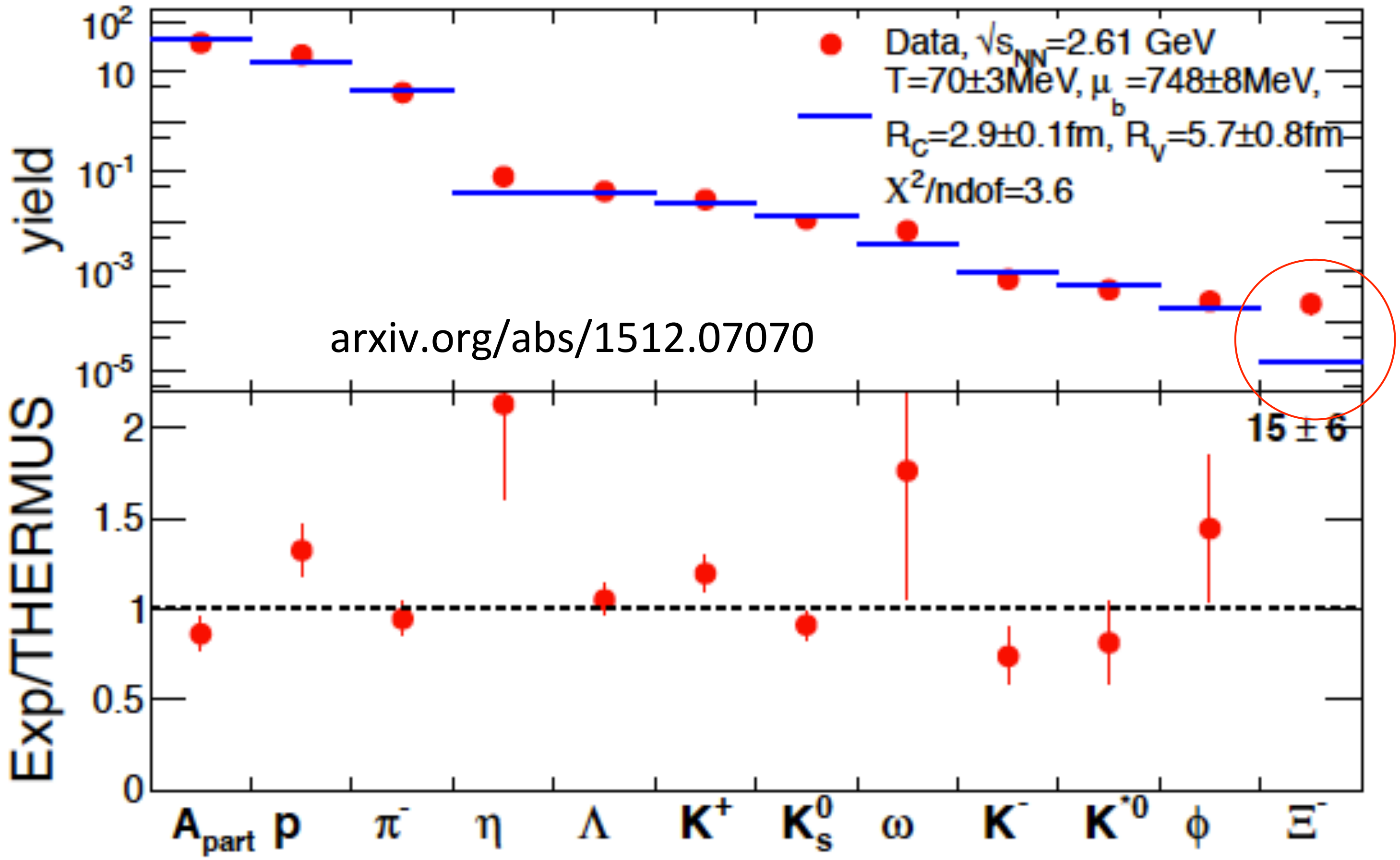
Additional input:
Hadron spectrum and BR to final states

Yields vs. ratios:
Cancellation of systematic errors
R and R_c determined

Limited number of hadron yields measured at low energies!

Light systems: Ar+KCl vs. p+Nb

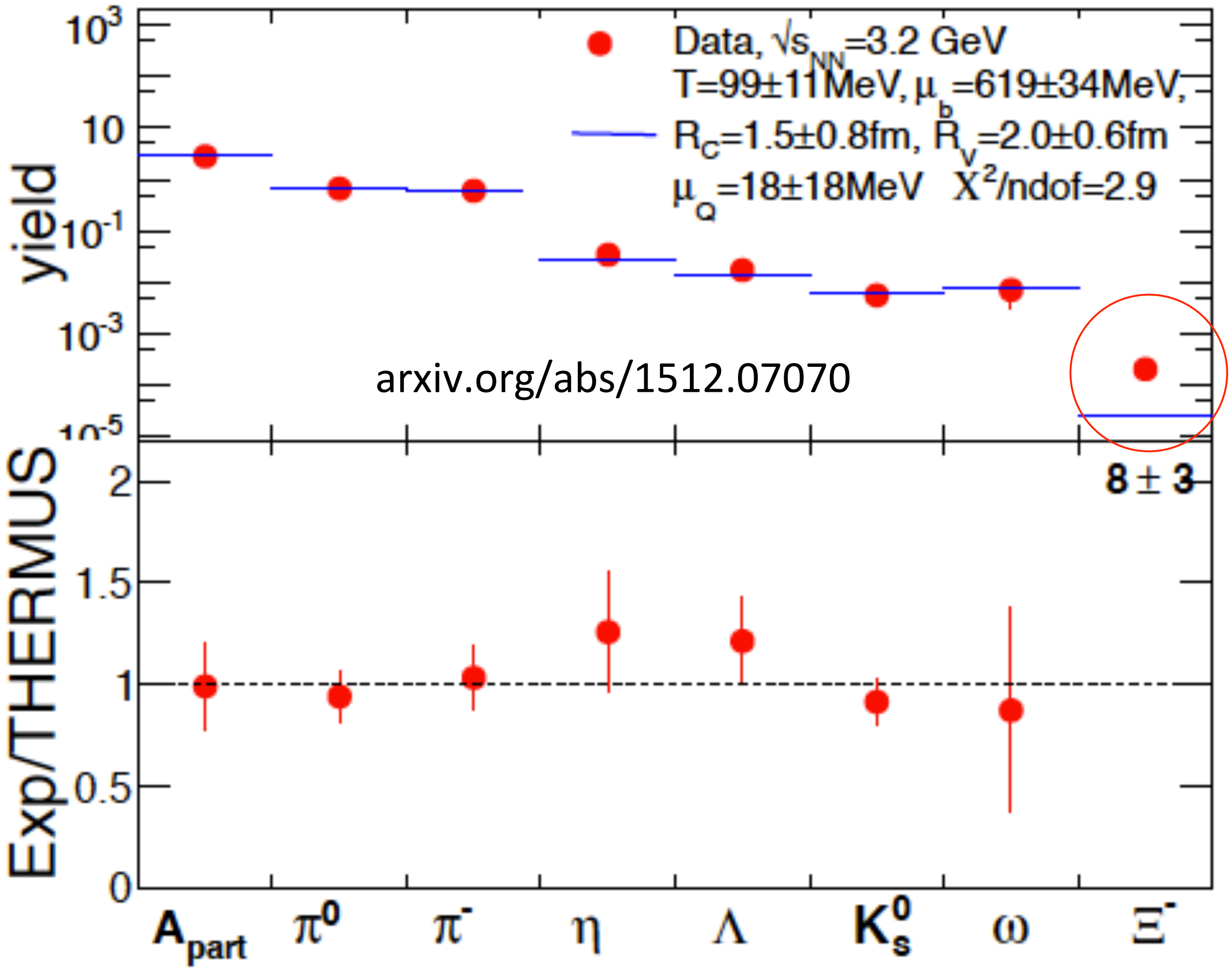
Ar+KCl @ 1.76 A GeV



- Statistical model works reasonably well at low energies for medium-sized system
- Strong excess of the Ξ^-
- Φ meson described without suppression (R_c)

THERMUS V3.0: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009
Eta meson interpolated from TAPS measurement at 1.5 and 2 A Gev in Ca+Ca

p+Nb @ 3.5 GeV



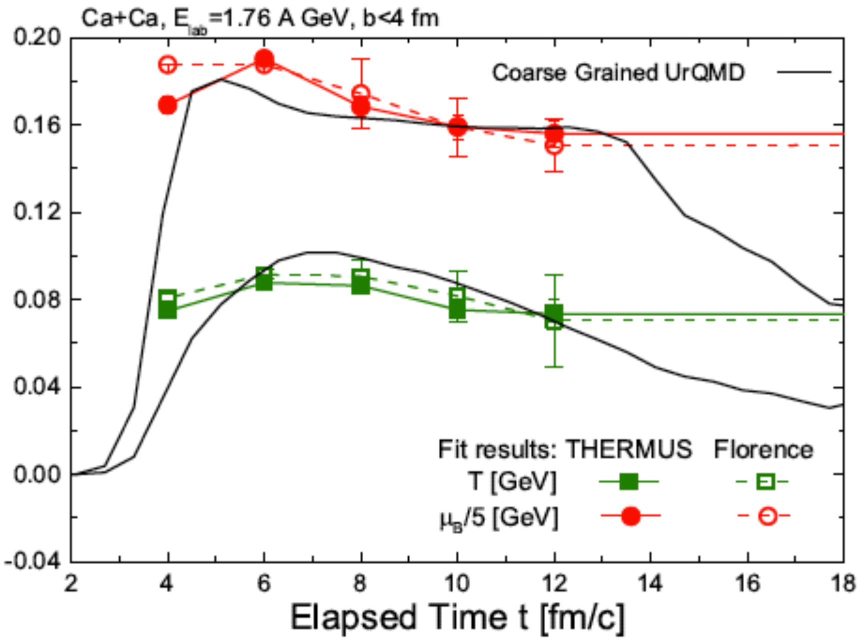
Very similar fit for p+Nb as for Ar+KCl!

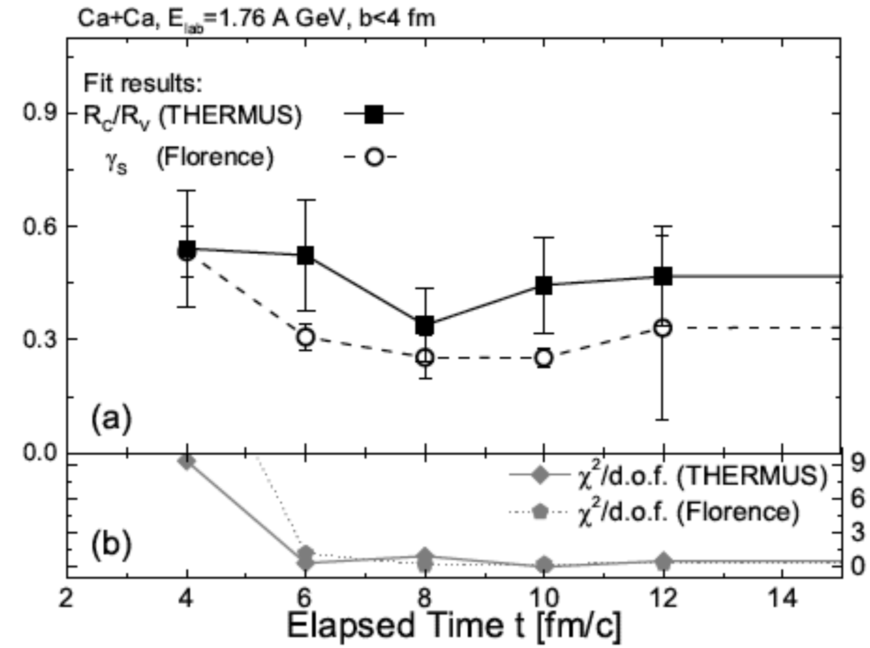
Strong excess of the Ξ^- already present in cold nuclear matter

Statistical model gives similar results for p+A and light A+A collisions!

THERMUS V3.0: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009

Apparent equilibrium in UrQMD

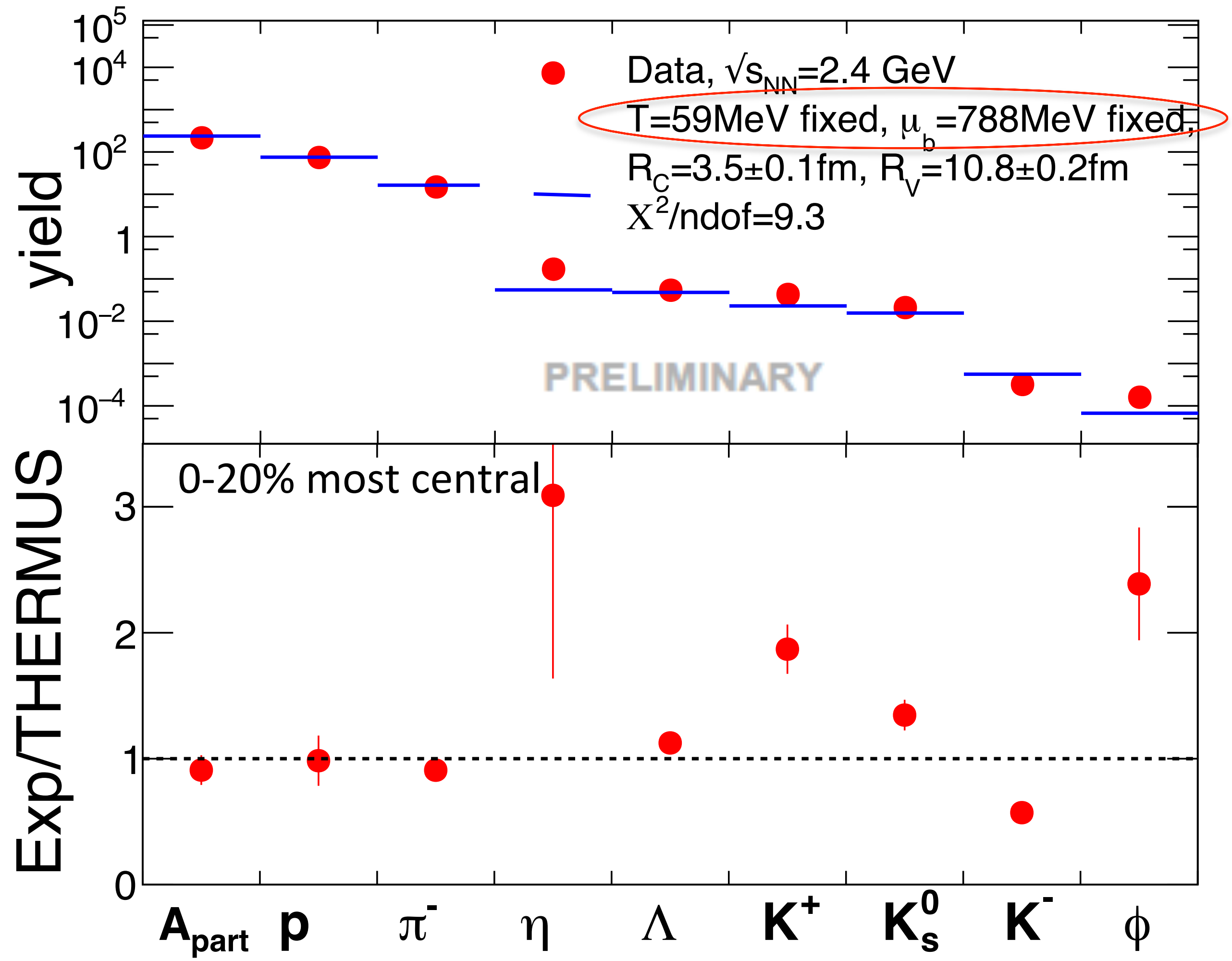




J. Steinheimer, M. Lorenz, F. Becattini, R. Stock, M. Bleicher arxiv.org/abs/1603.02051

Very first results for yields from central Au+Au collisions @1.23 A GeV

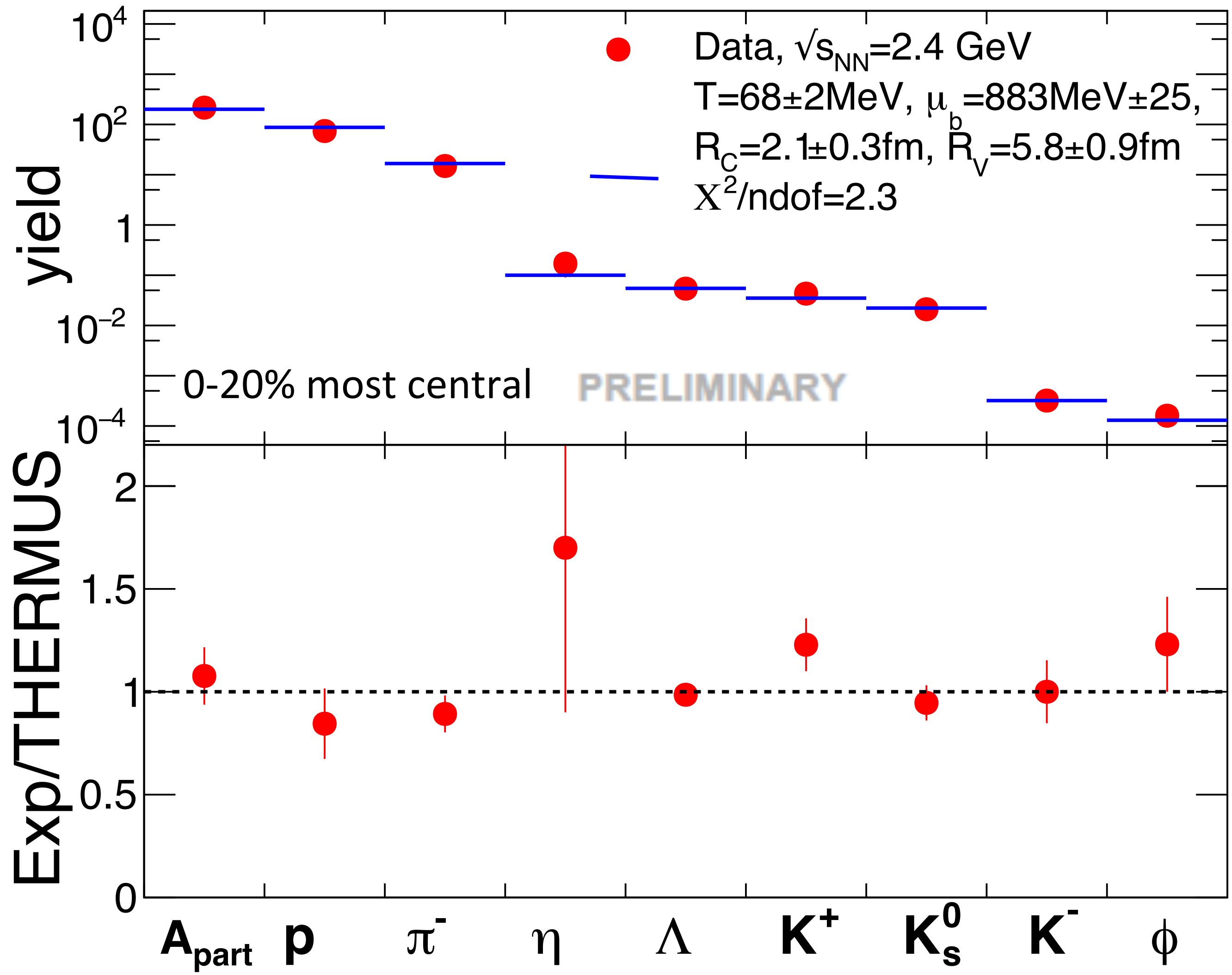
Au+Au data vs T and μ_B parameterized



Cleymans, Oeschler et al, Phys.Rev.C73:034905,2006

THERMUS V2.3: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009

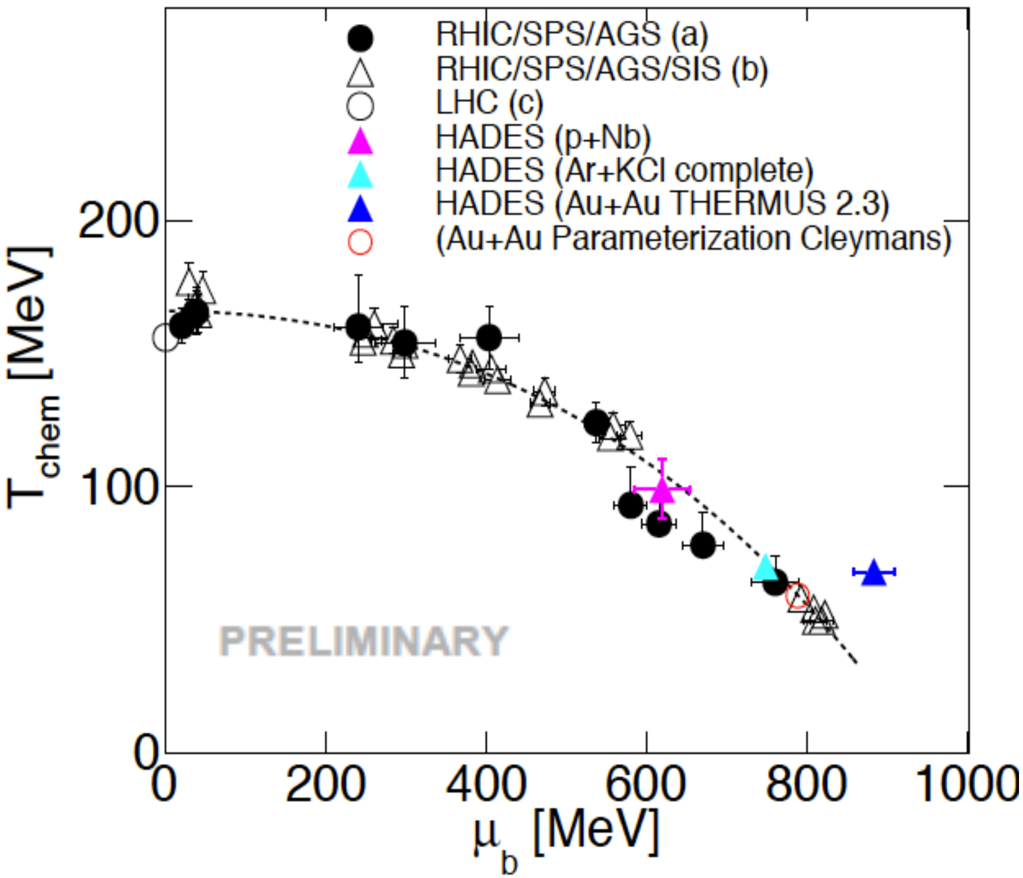
Au+Au data vs free fit



Good minimum, but rather high values for μ_B and T

THERMUS V2.3: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009

Chemical freeze-out



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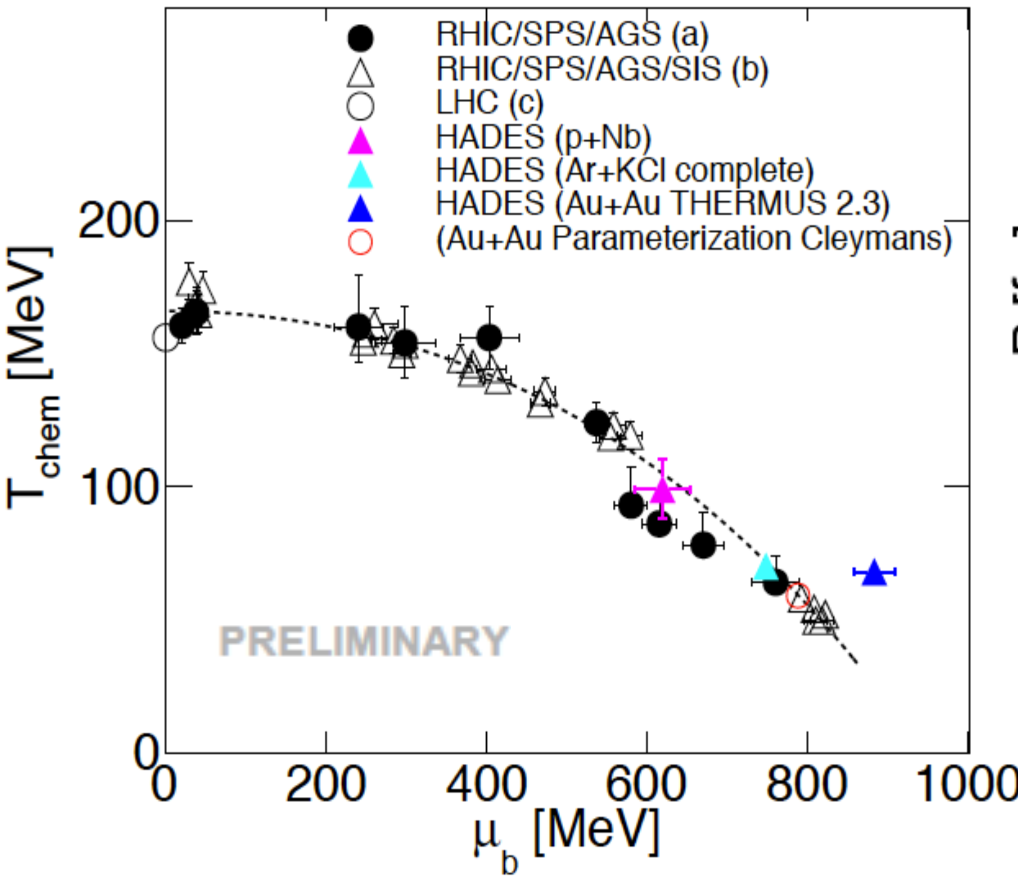
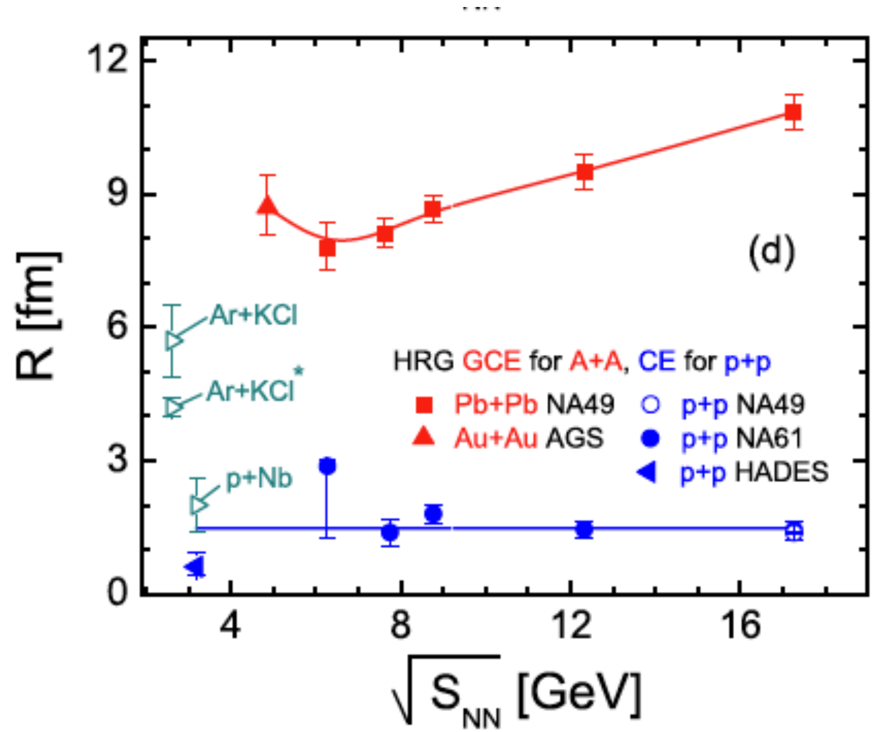
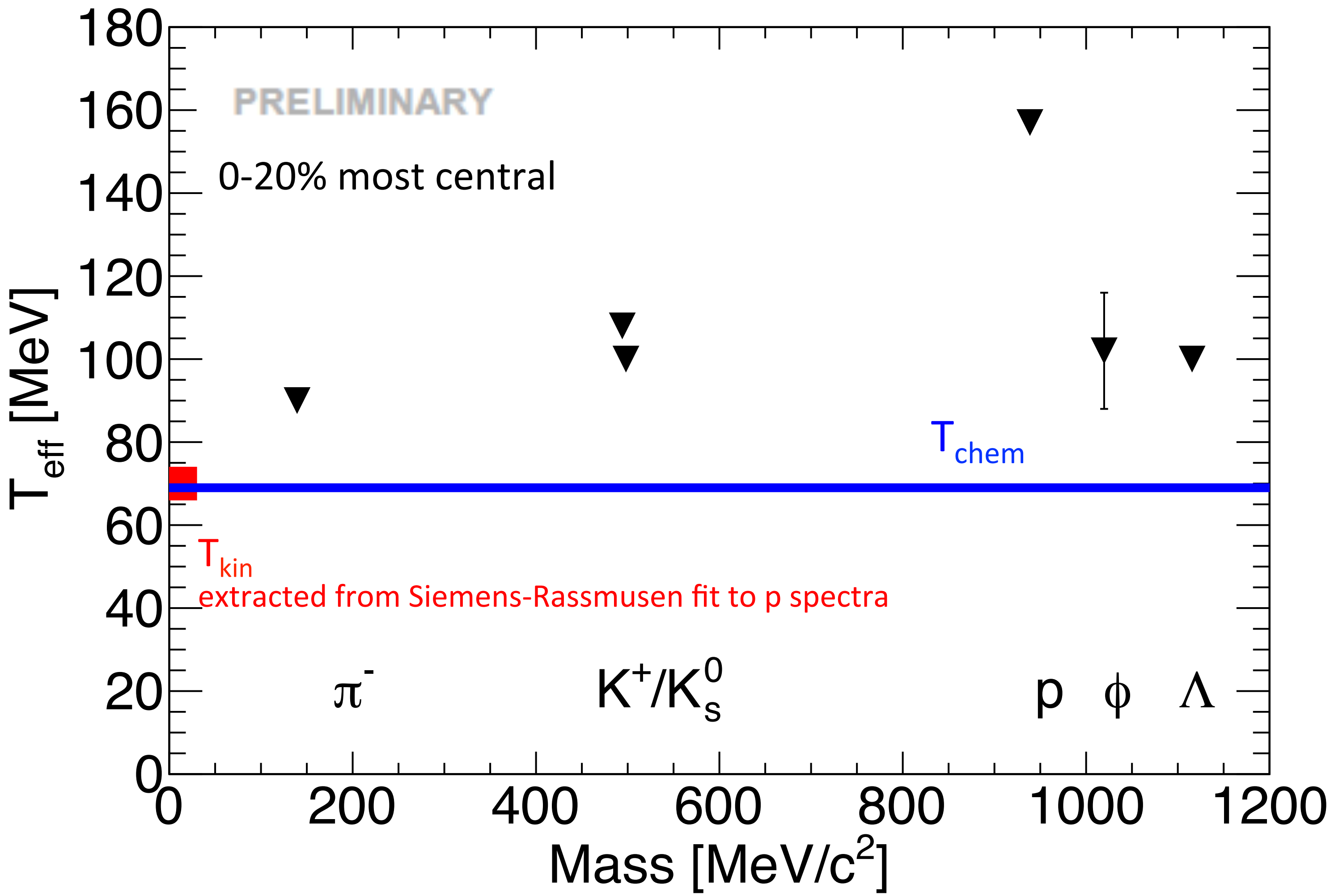




arXiv:1512.08025 [nucl-th]

Kinetic freeze out



Summary

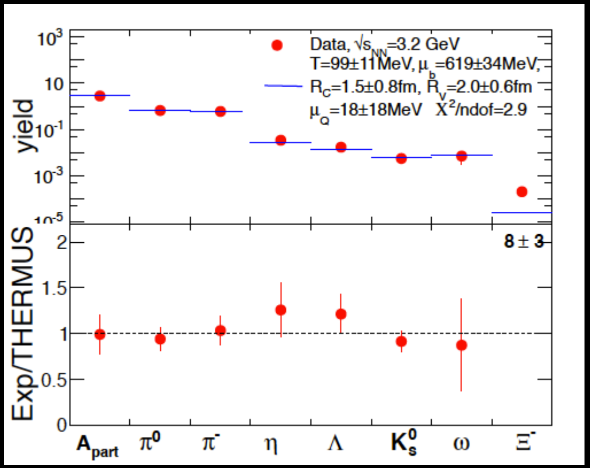
Excess of Xi already present in cold nuclear matter

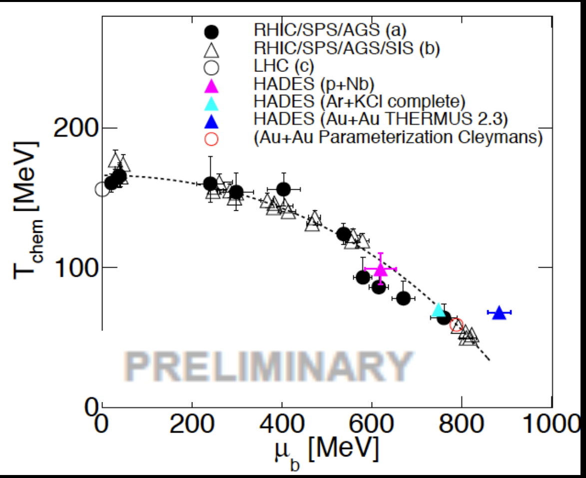
Description of p+A with a statistical model very similar to those for Ar+KCl
(and to Ca+Ca from UrQMD)

Implications and Interpretation!

First fit to Au+Au hadron yields shows higher T and μ_B than expected from parameterizations, to early to call!

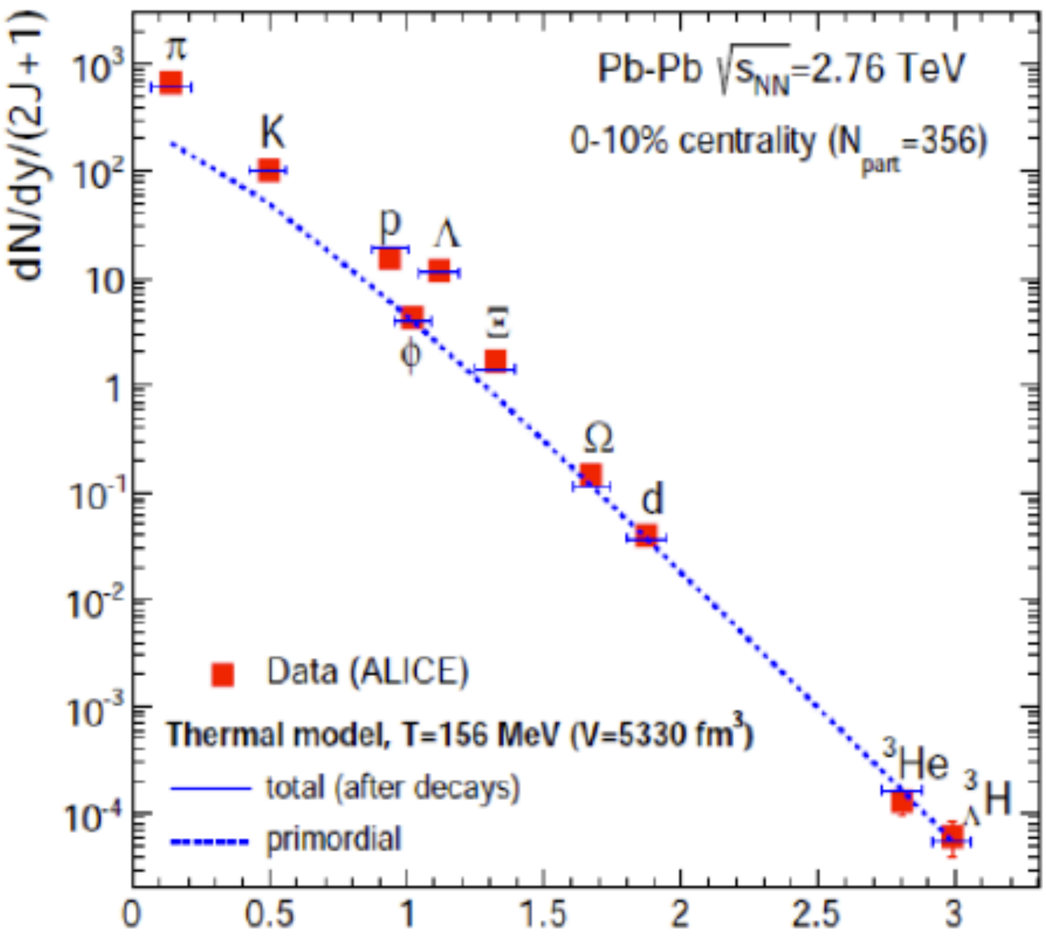
Systematic studies of models/parameters/yields/minimum/..





What else?

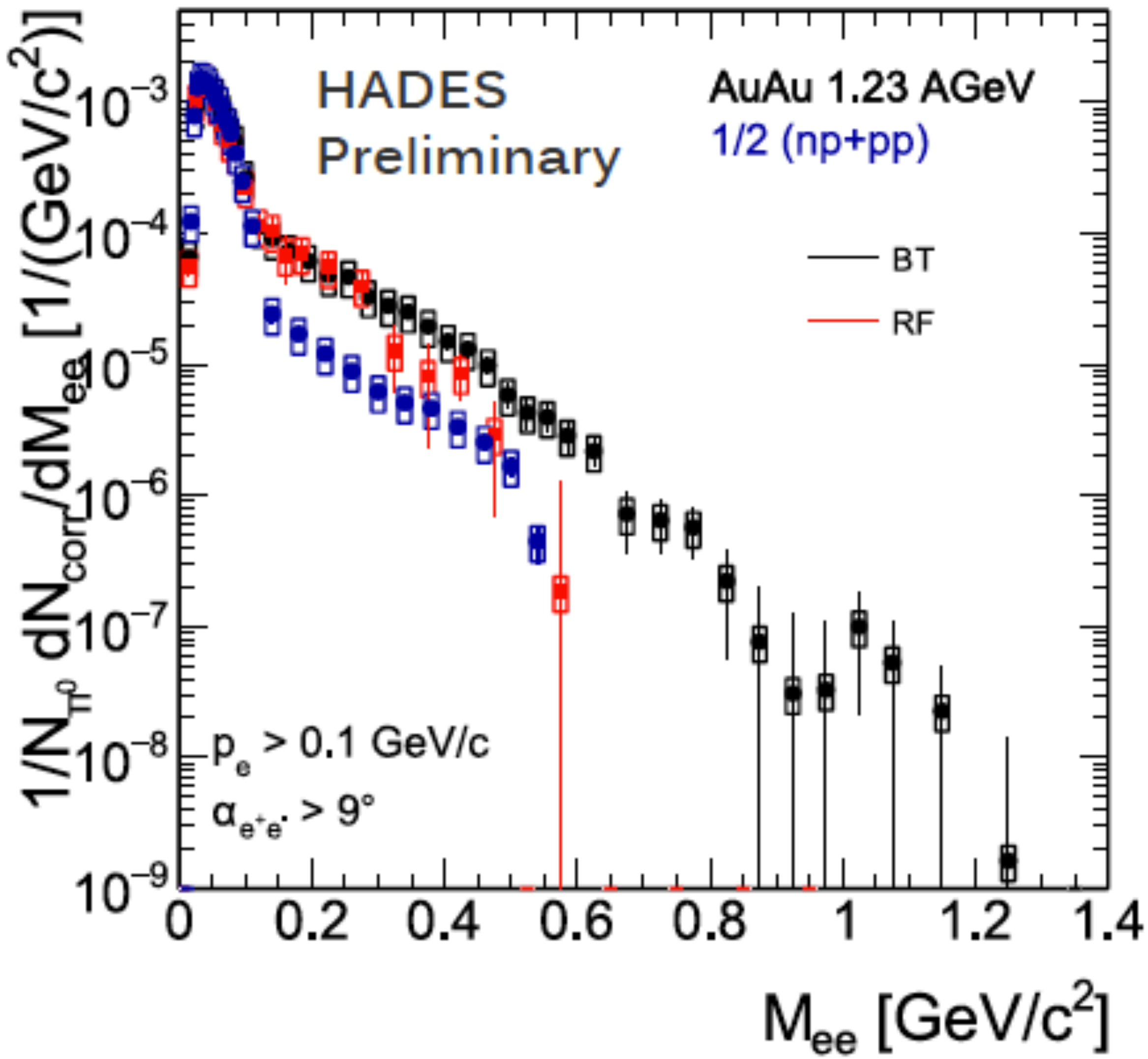
Light nuclei: perfectly described by SHM at LHC



Nucl.Phys. A904-905 (2013) 535c-538c

Very sensitive to muB at SIS 18 energies

Dileptons

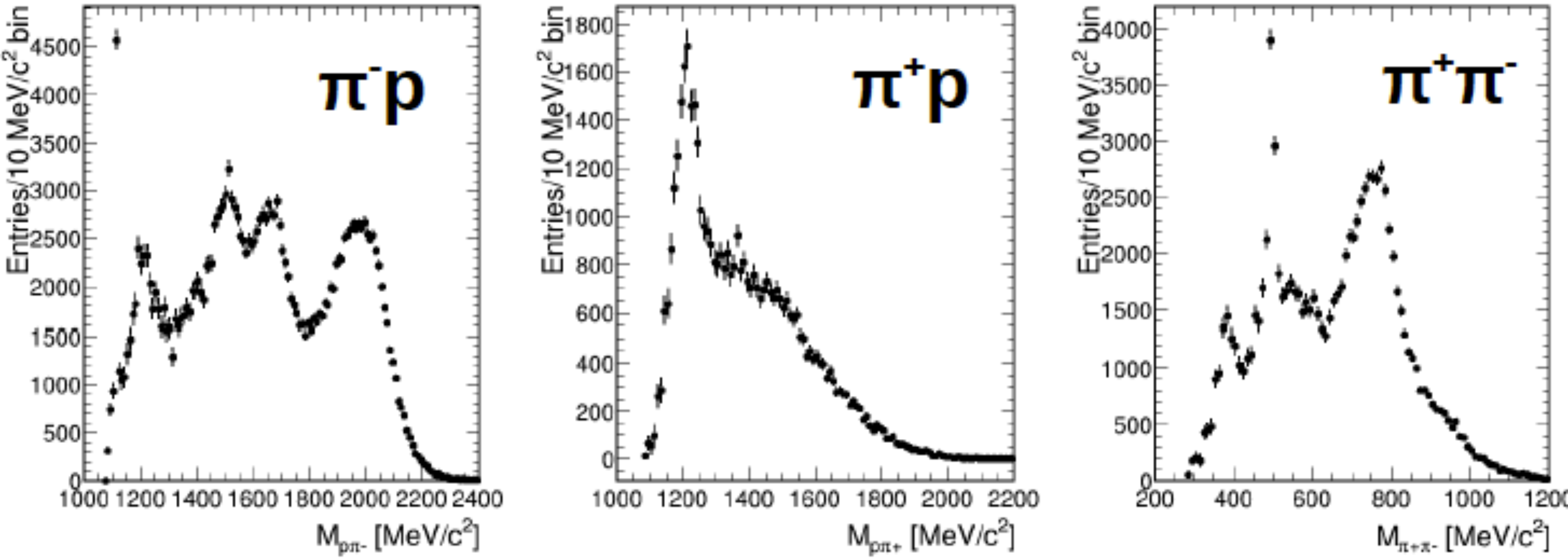


Szymon Harabaz, Patrick Sellheim

Constraining the resonance contributions

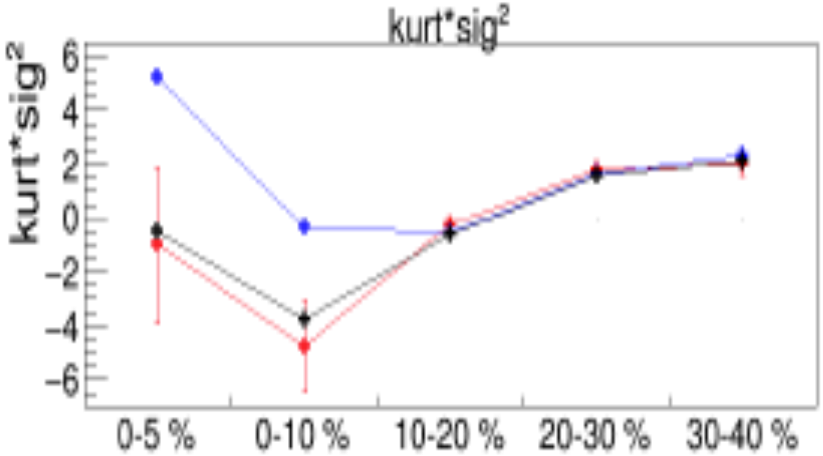
$\pi^- C$ @ 1.7 GeV/c

Validation of the reconstruction method using pion induced reaction data.



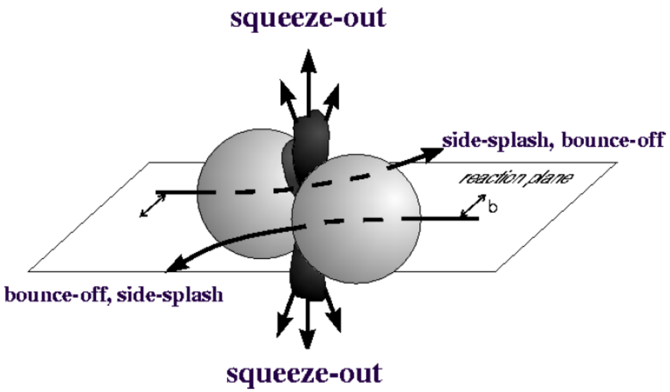
Iterative procedure

Fluctuations of conserved charges and much more

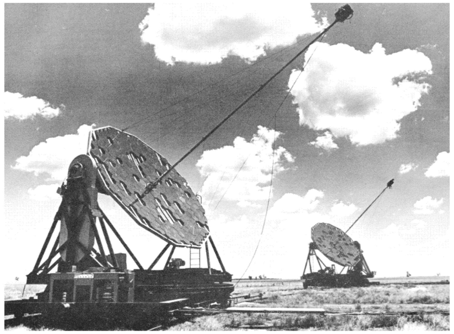


Melanie Szala, Romain Holzmann

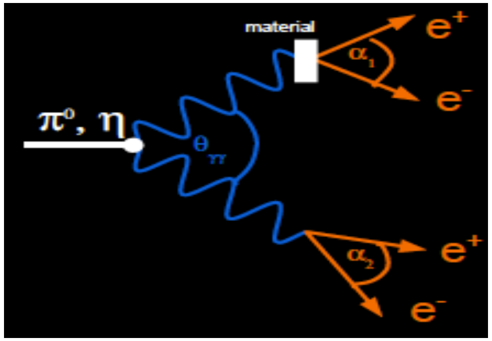
Flow anisotropies



HBT



Conversion analysis



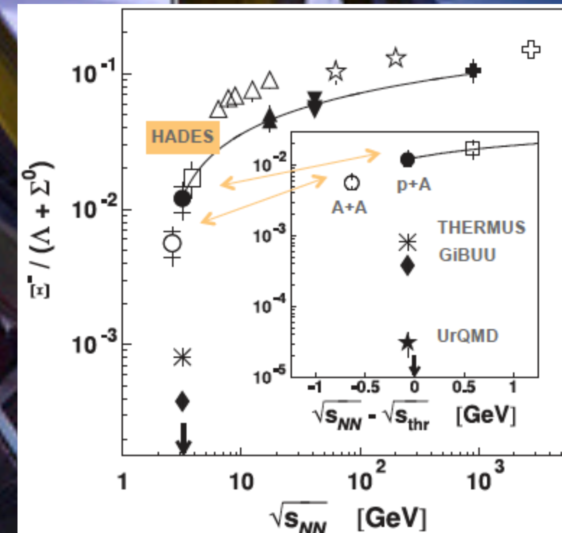
Sasha Sadovsky, Behruz Kardan, Frederic Kornas   Roland Kotte   Claudia Behnke, Christina Deveaux

Future beam time proposals

p+p @ 4 GeV:

Xi cross section

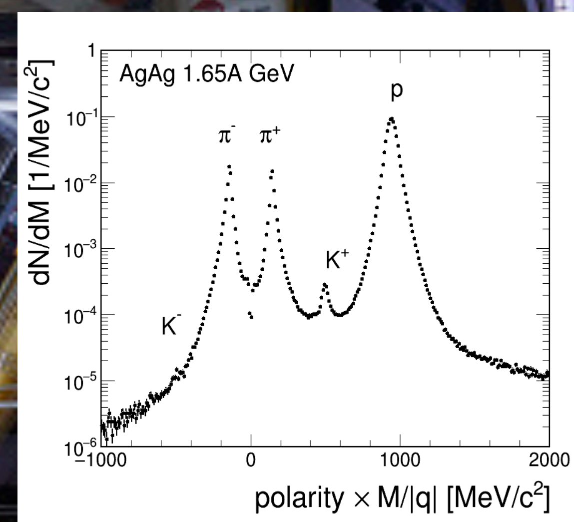
Reference measurement in NN



Ag+Ag @ 1.65 A GeV

Xi- spectra

Phi, K- differential

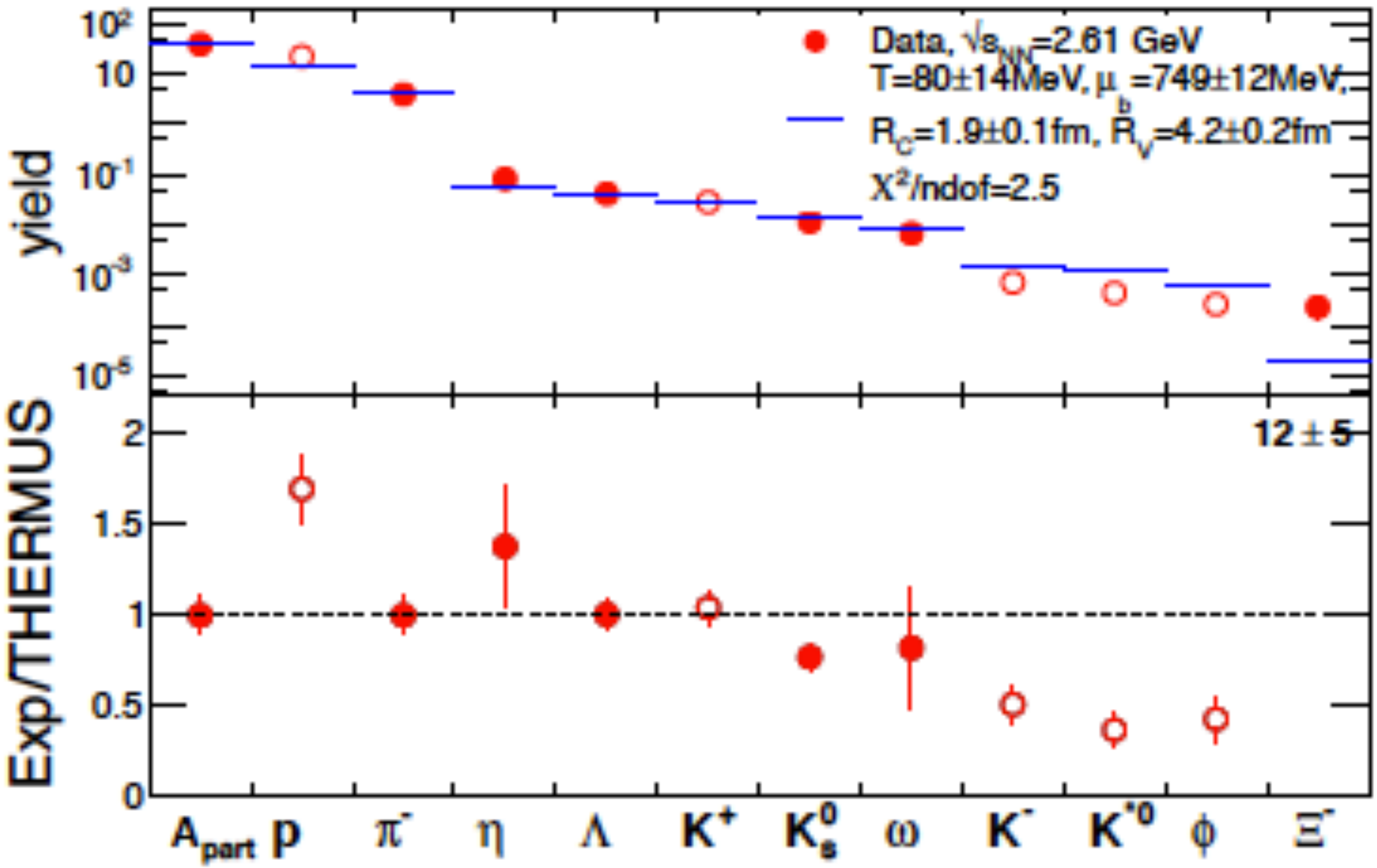


Pion induced reaction in addition

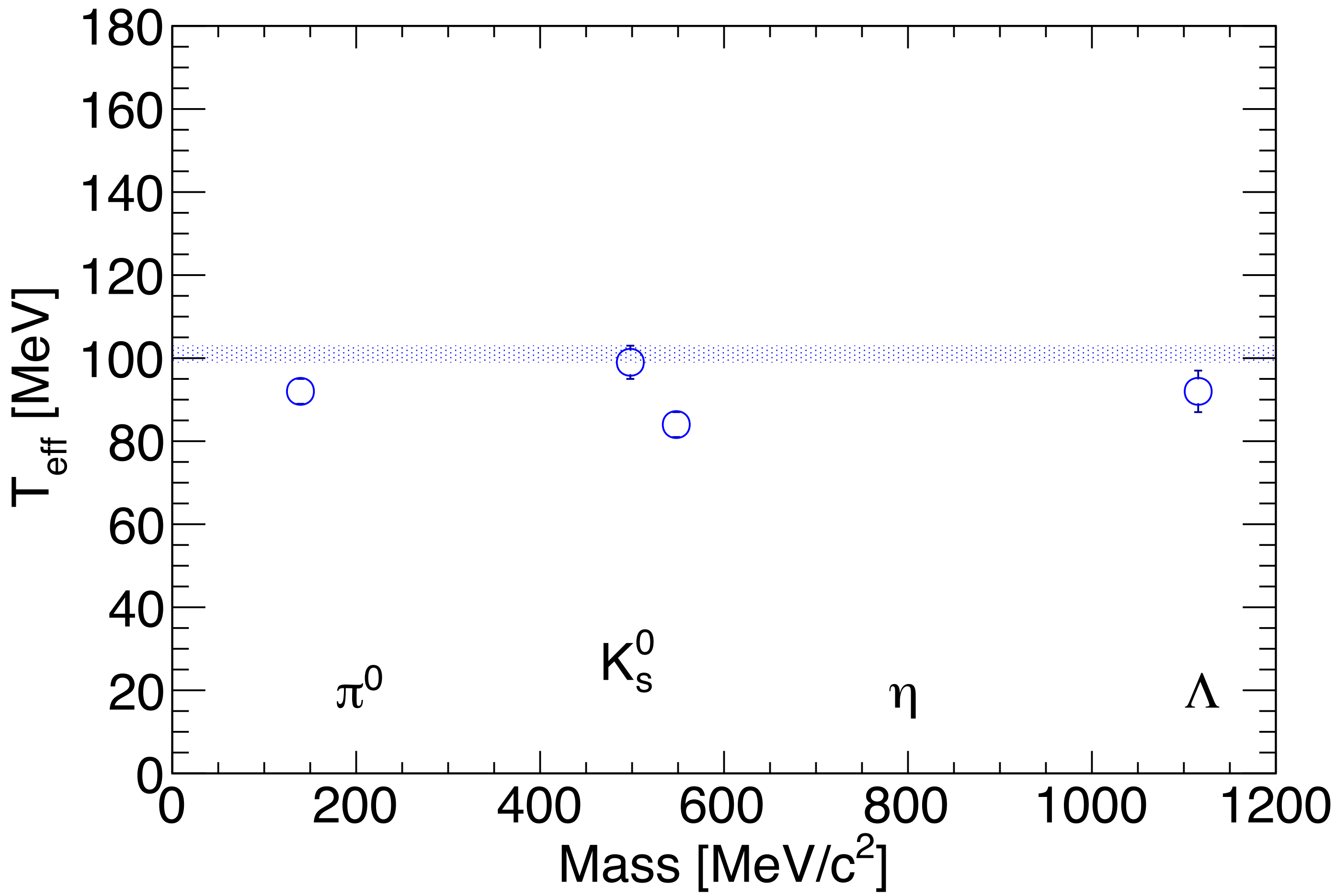
T. Galatyuk

Thank you!

Ar+KCl ala pNb



Kinetic freeze-out Ar+KCl



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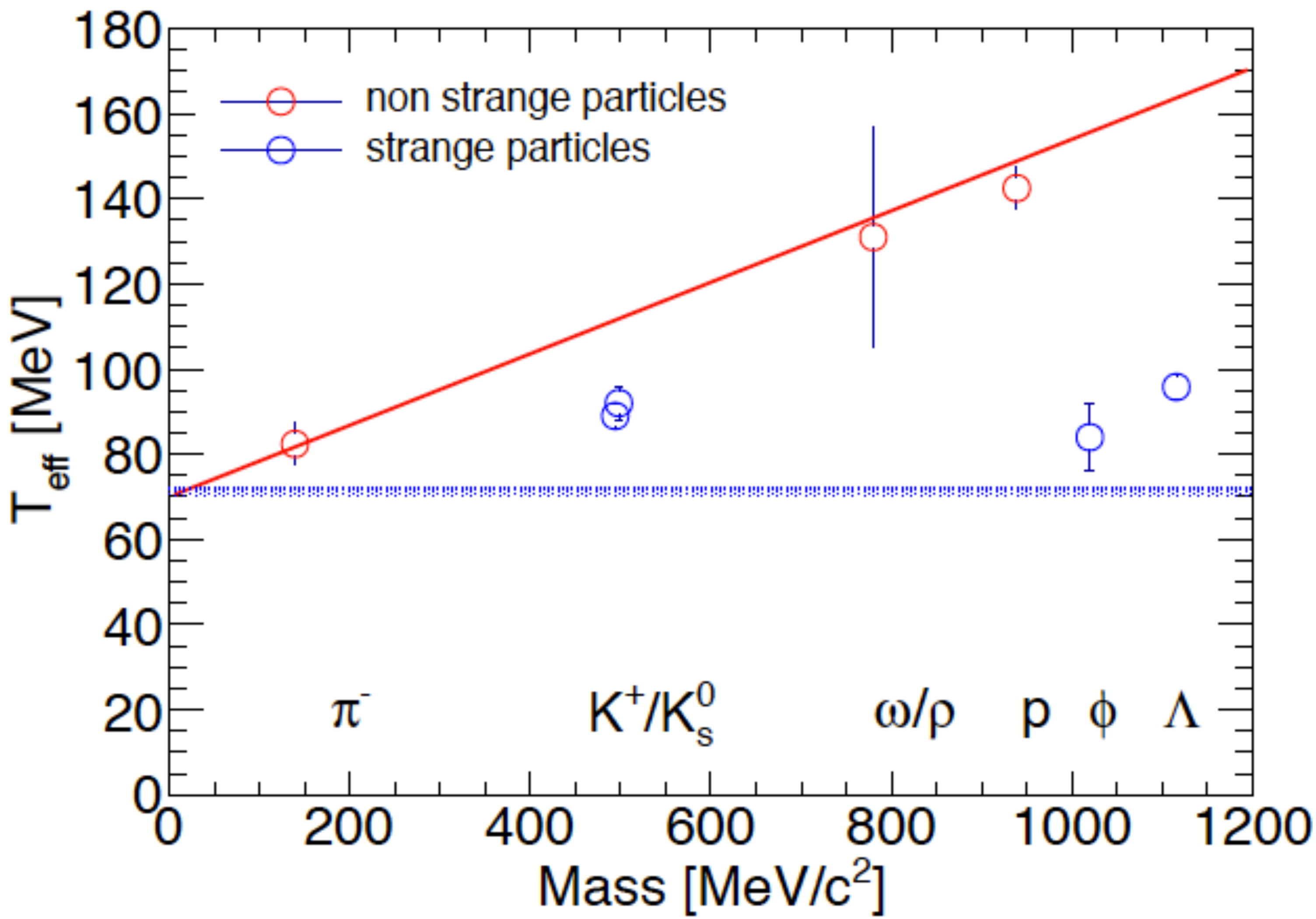
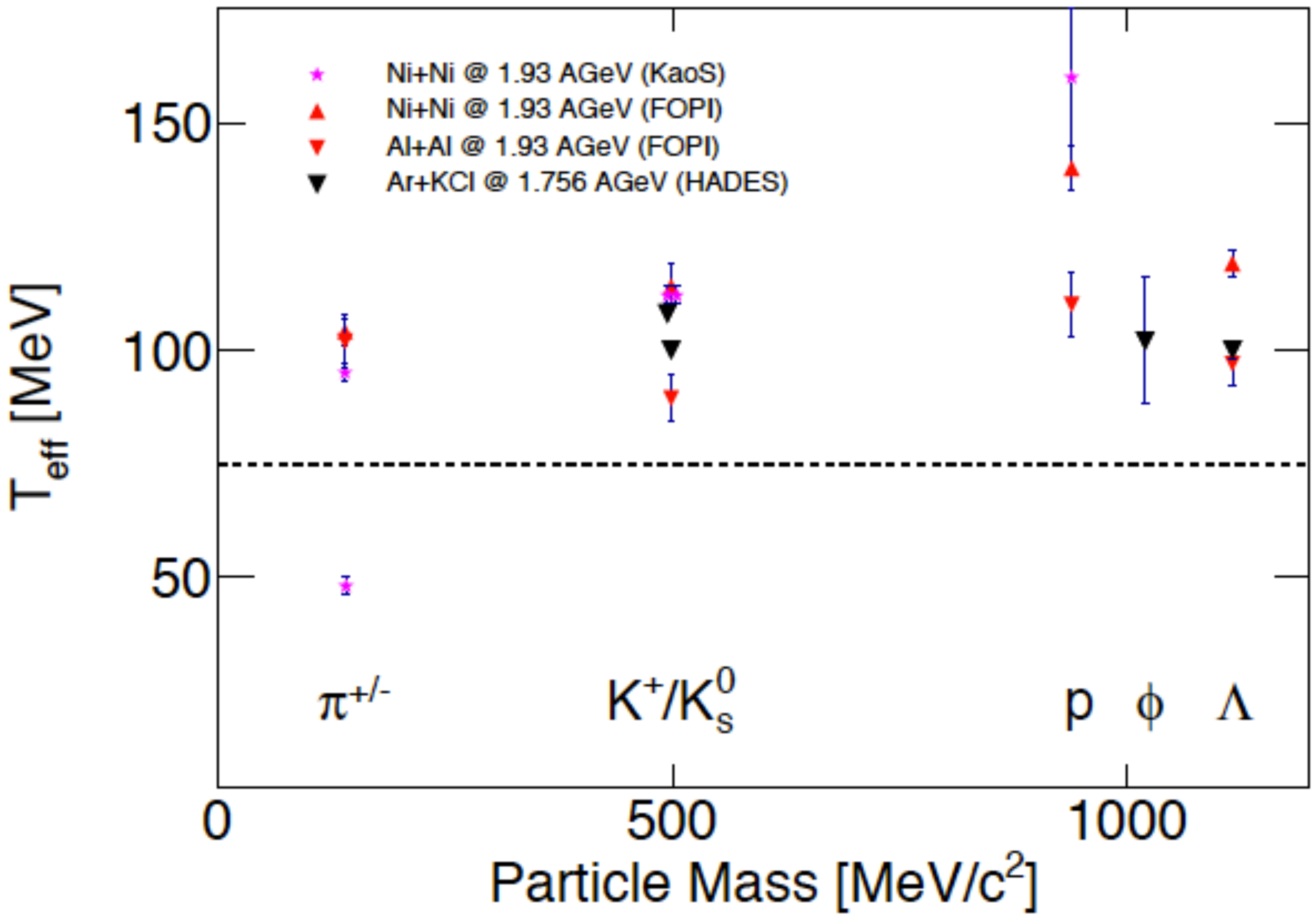


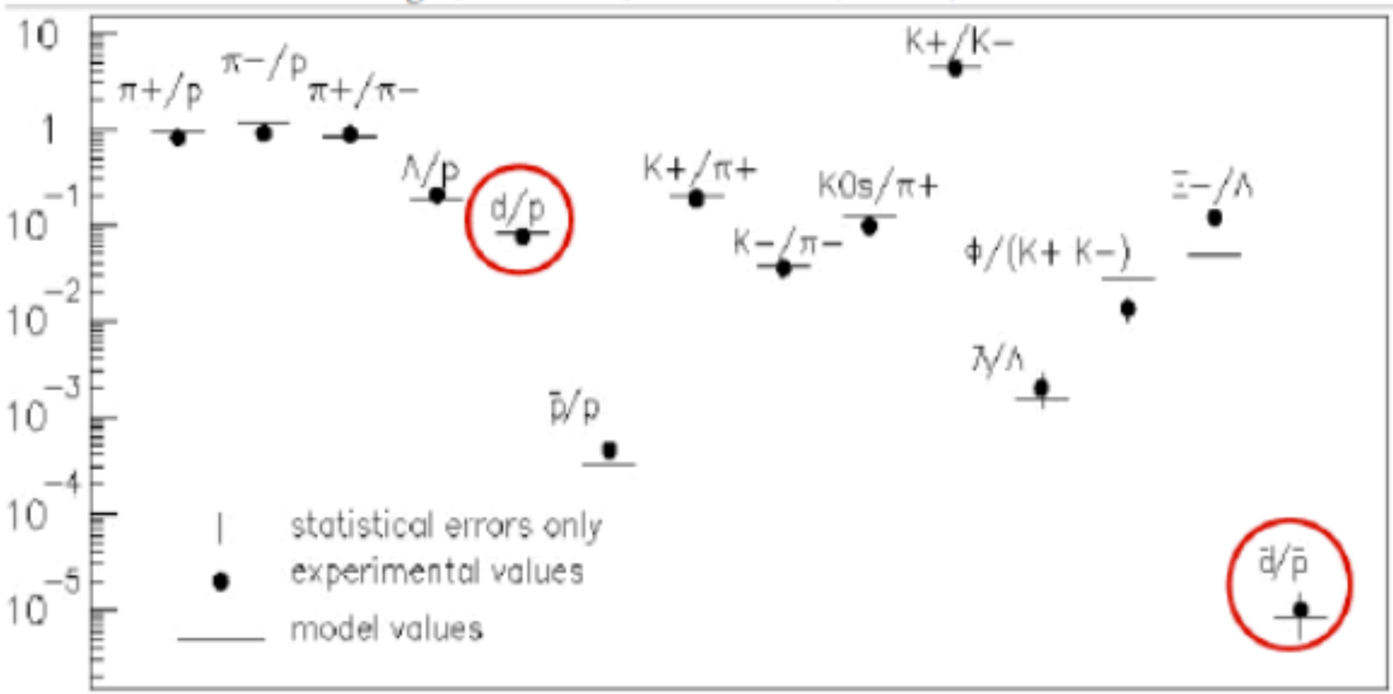
Kinetic freeze-out



AGS

14.6 A GeV/c central Si + Au collisions and GC statistical model

P. Braun-Munzinger, J. Stachel, J.P. Wessels, N. Xu, PLB 1994



dynamic range: 9 orders of magnitude! No deviation

Also at AGS deuteron to proton ratio fits nicely