Probing resonance matter with HADES

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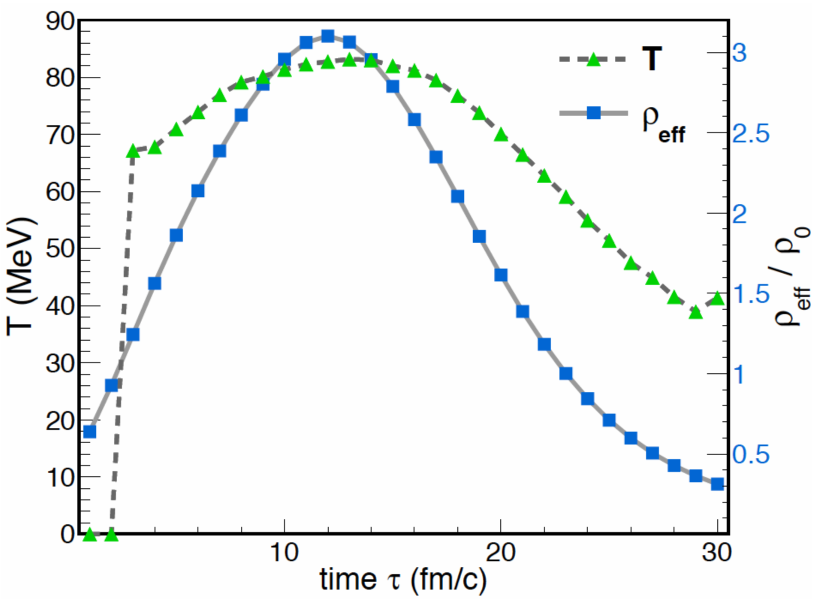
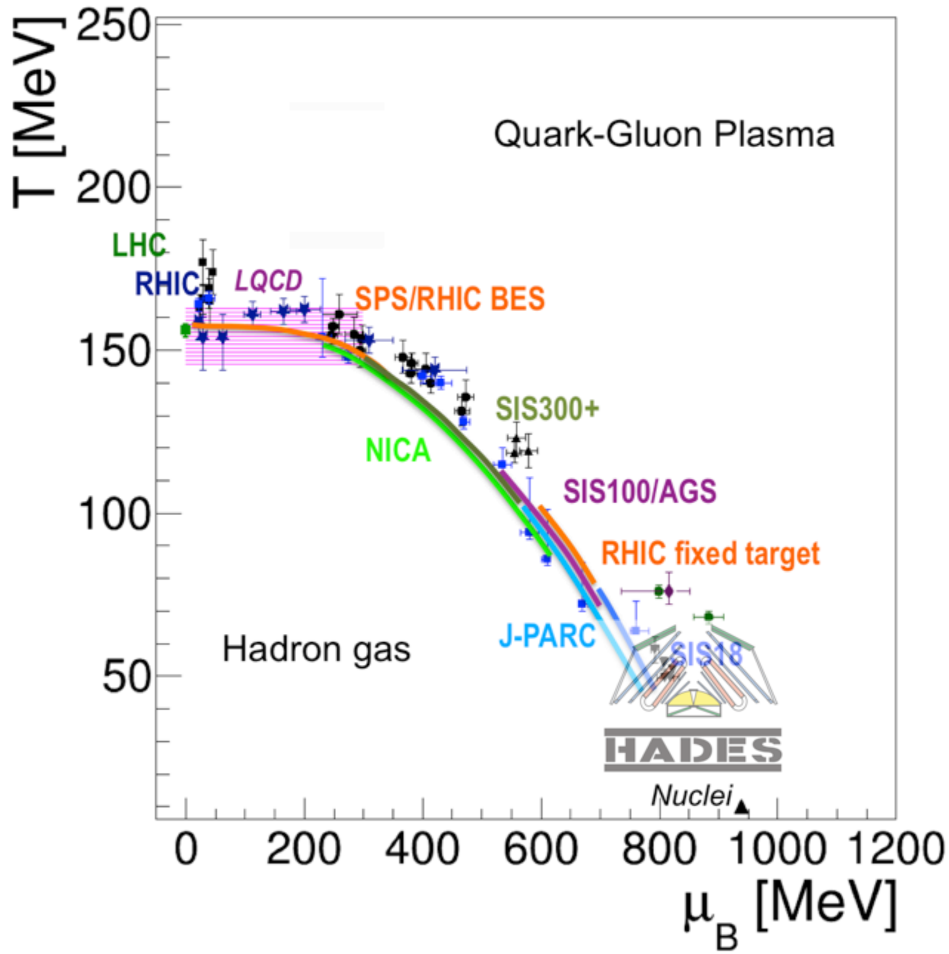
for the HADES collaboration

Technische Universität Darmstadt / GSI

Baryonic Matter at 1-2A GeV Beam Energy

Au+Au @ √s = 2.4 GeV

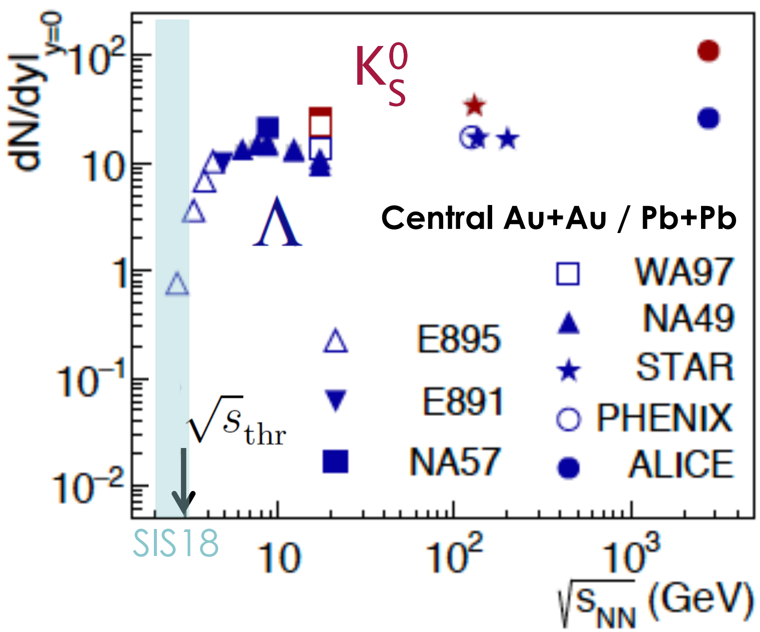




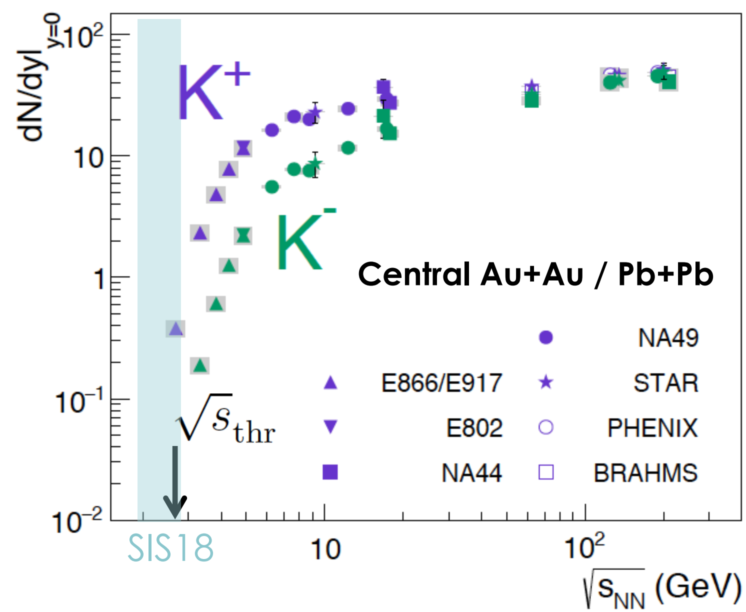
- High densities : ρ_{max} = 1-3ρ_0
- Moderate temperature : T = 50-100 MeV
- Relatively long lifetime of fireball
- Baryon dominated : $N_\pi/A_{part} \approx 10\%$

Strangeness Production at SIS18 Energies

NN → $NK^{+}\Lambda$
$\sqrt{s}$ = 2.55 GeV



NN → $NK^{+}K^{-}$
$\sqrt{s}$ = 2.68 GeV



Data compilation: Prog.Part.Nucl.Phys. 66 (2011) 834-879

- All strange hadrons produced below NN-thrshold
- Steep excitation function at SIS18
- Lower production yield of K^- (two order of magnitude)

Meet the HADES

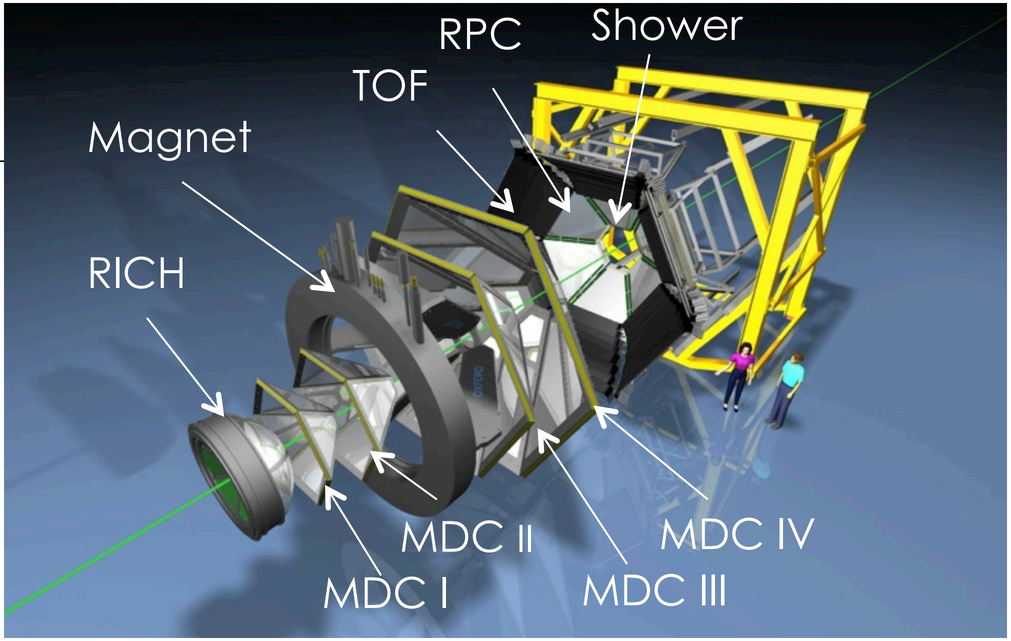
Measurements at SIS18
- Fixed target experiment

Fast detector
- 8 kHz trigger rate

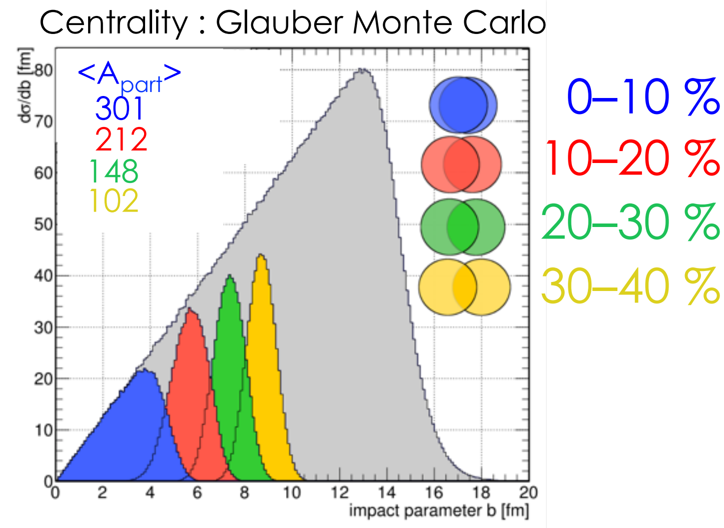
Large acceptance
- $18° < \theta < 85°$ (polar angle)
- Full azimuthal angle

Tracking system
- 4 drift chamber planes
- \+ superconducting magnet

Time-of-flight detectors
- RPC + TOF for precise hadron identification



Data sample: **Au+Au at $\sqrt{s}$ = 2.4 GeV**
- 40% most central collisions
- 5×10^9 LVL1 events



HADES Performance: Particle Identification

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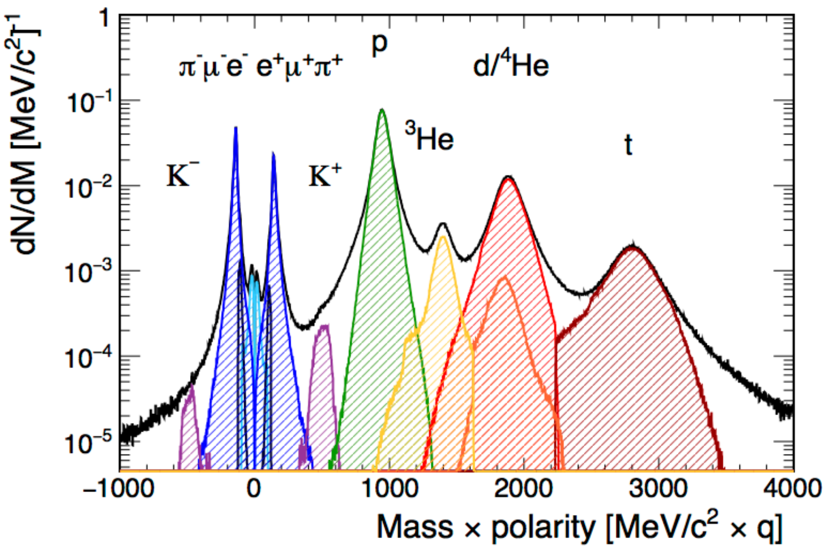
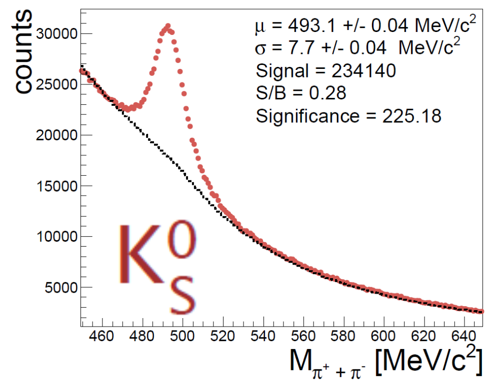
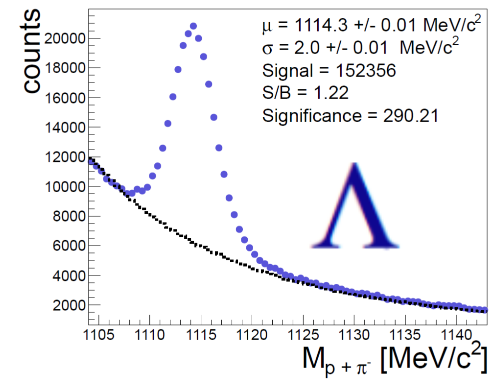
PID by means of :

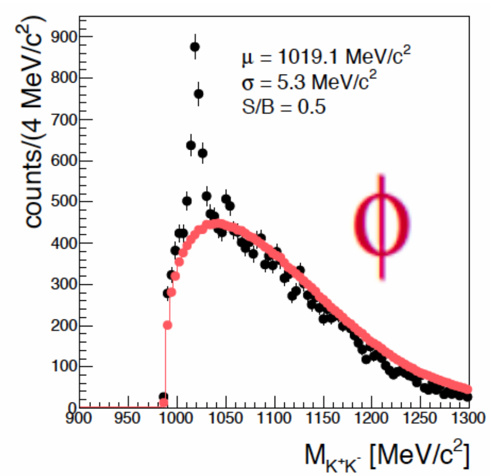
- Velocity
- Momentum
- dE/dx in MDC and ToF
- RICH information



Topological cuts applied
background obtained using mixed-event







Big statistics allows
multi-differential analysis
few 10% centrality classes

HADES

Reconstruction of Strange Hadrons

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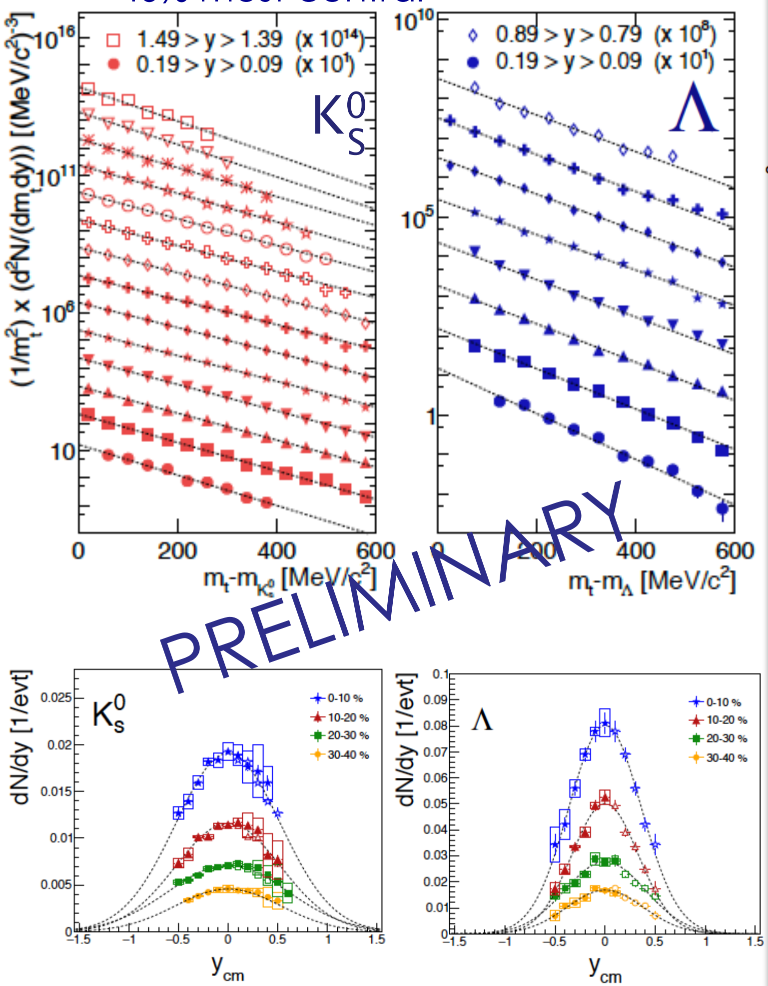
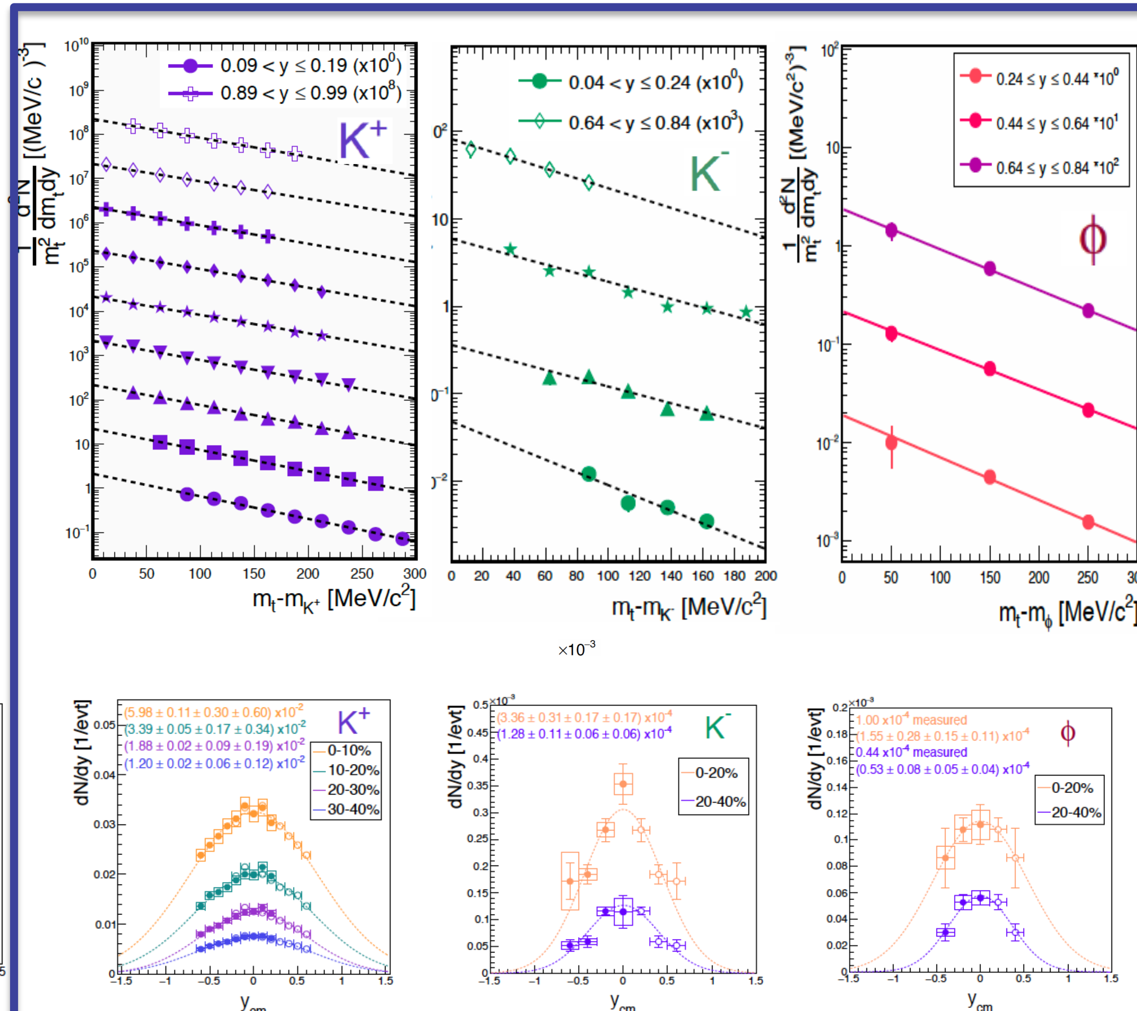
* 40% most central



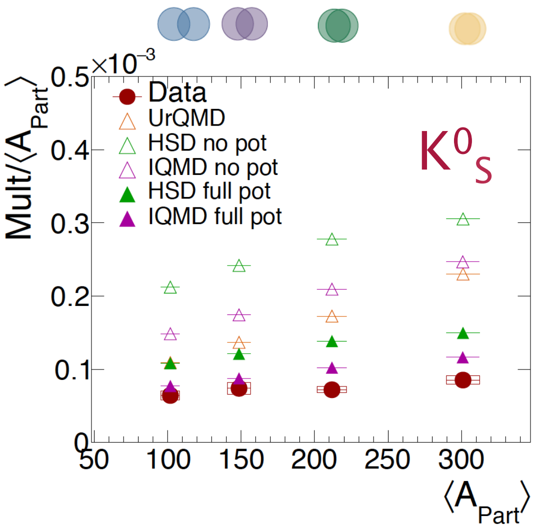


PLB accepted → arXiv:1703.08418

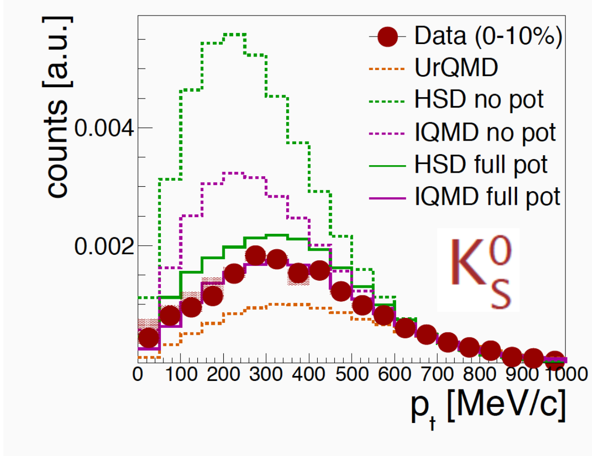
HADES

Microscopic Description : K^0_S and Λ

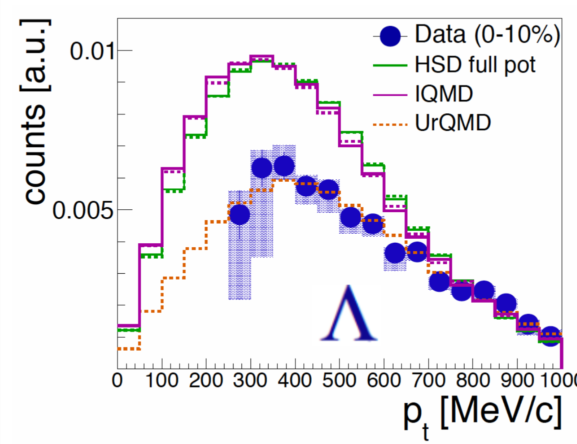
PRELIMINARY



(normalization: 600 < p_t <900 MeV/c)



(normalization: 700 < p_t <1000 MeV/c)



- Transport models overestimate yield and don't reproduce <A_{part}> dependence

- Including KN potential improves description of kaon spectra
- The effect is mimicked in UrQMD with resonance production

- No simultaneous description of kaon and Λ spectra

HSD v711n: Phys rep, 308:65–233, January 1999
IQMD c8: Eur.Phys.J.,A1:151–169, 1998
UrQMD 3.4: Prog.Part.Nucl.Phys., 41:255–369, 1998

K^-/K^+ Production : Comparison to KaoS

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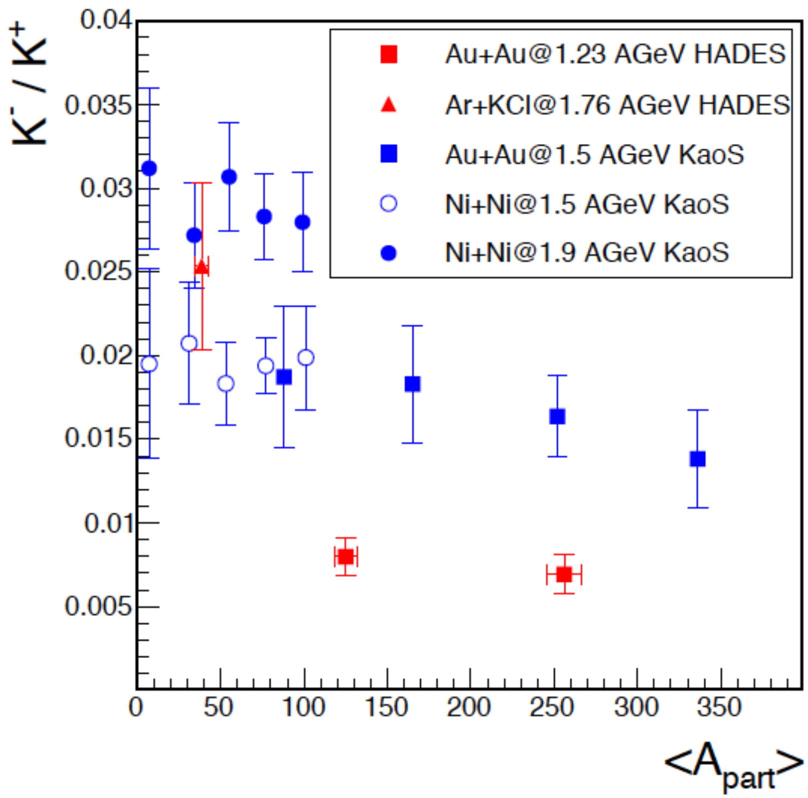
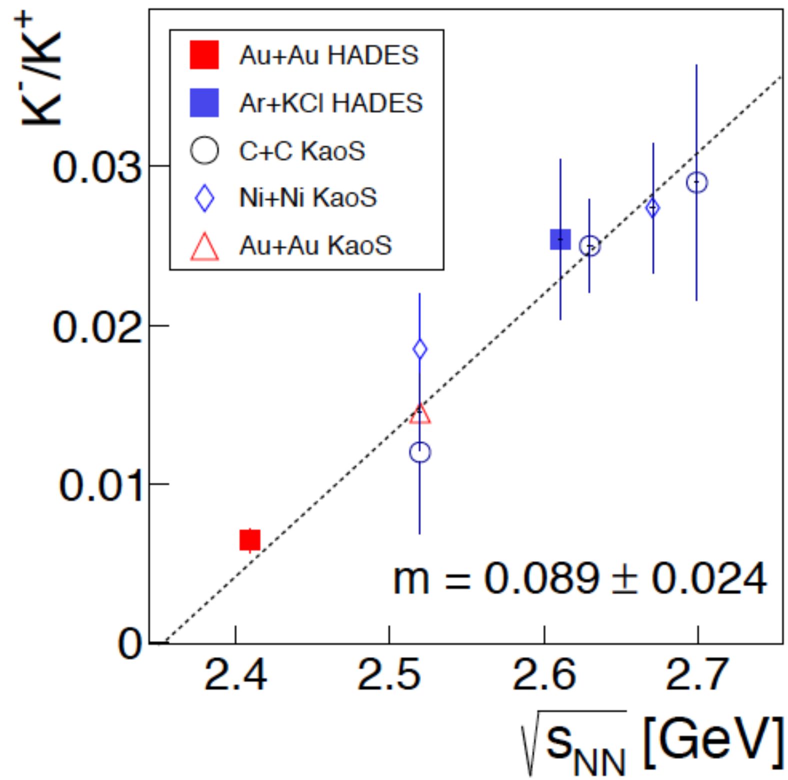
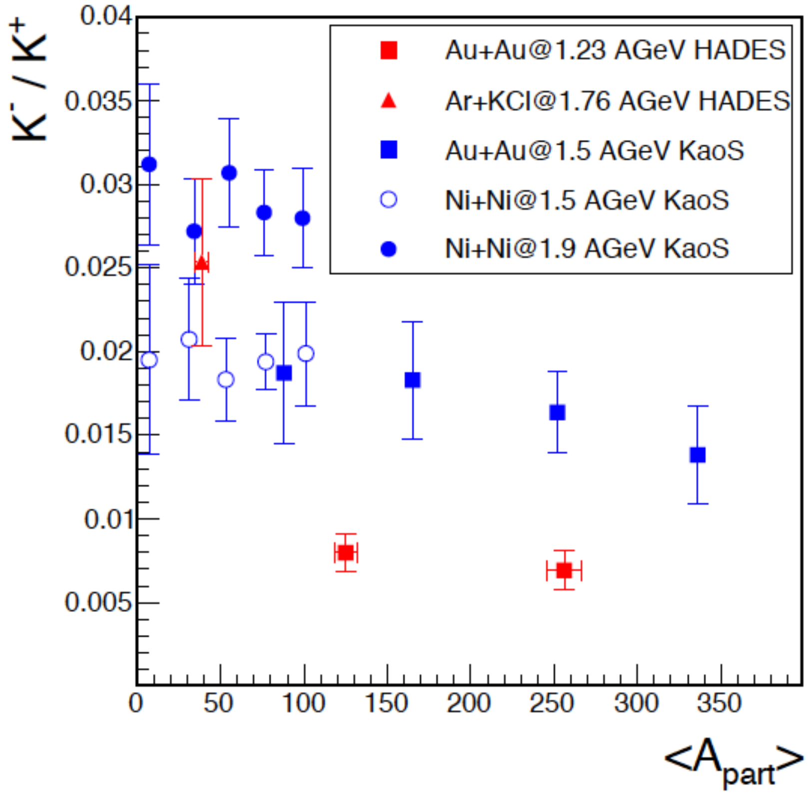
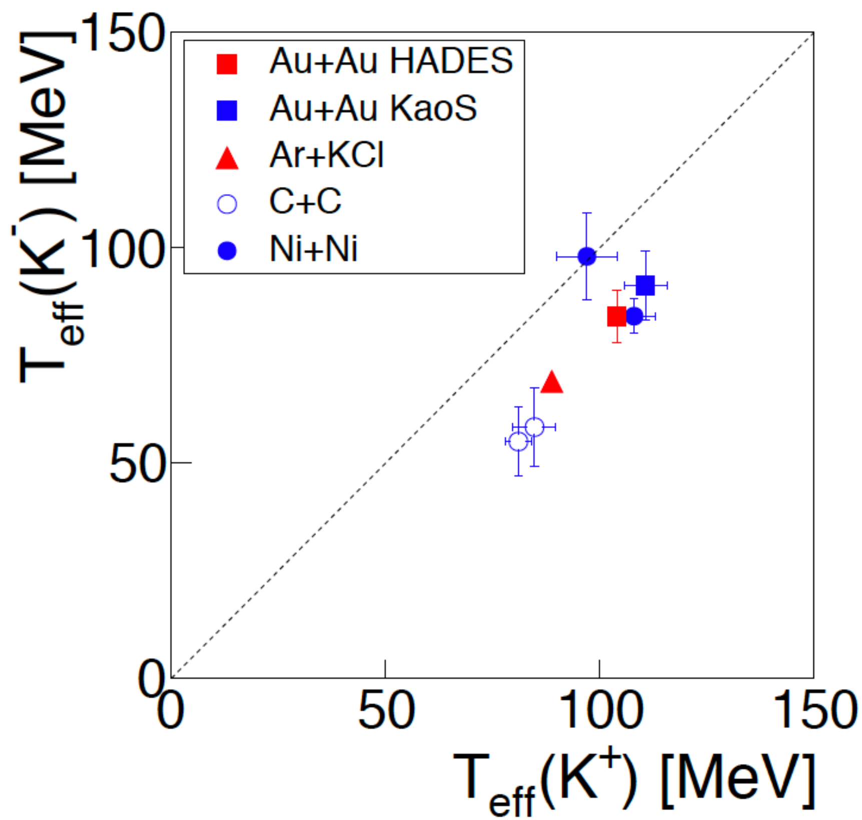




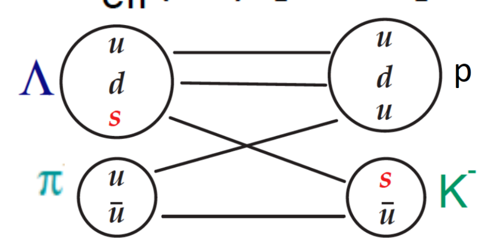
- No strong centrality dependence of K^- / K^+ ratio
- Data fits well into the extrapolation from higher energies

K^-/K^+ Production : Comparison to KaoS

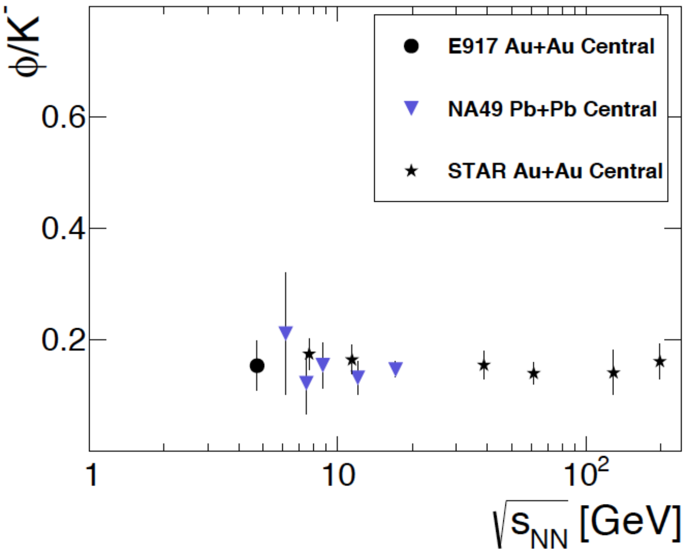




- No strong centrality dependence of K^- / K^+ ratio
- Effective temperature of K^- systematically below K^+
- ✓ *Interpretation: Production coupled via strangeness exchange reaction + later freeze-out of K^-*

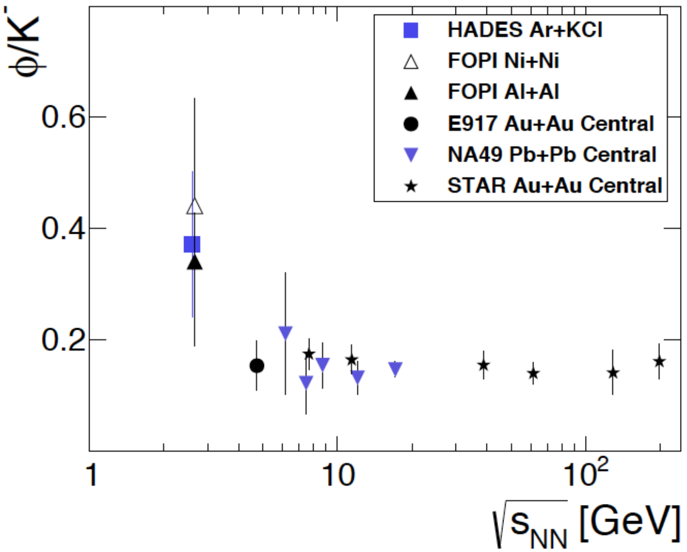


Deep Sub-threshold ϕ Production



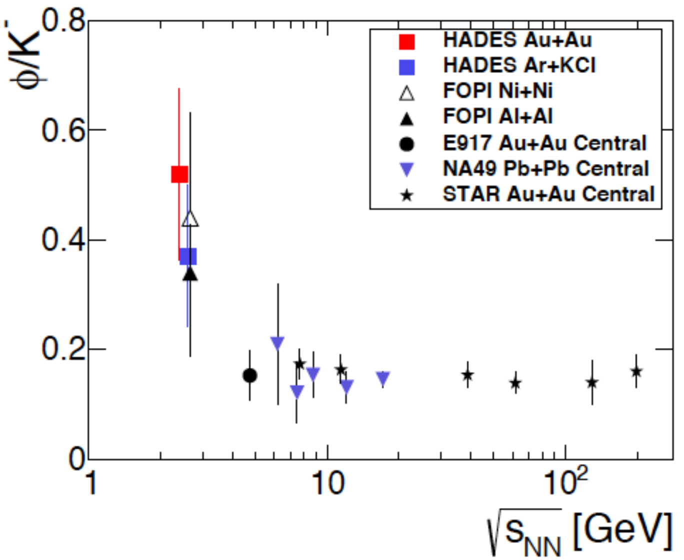
- ϕ/K^- ratio constant at high energy

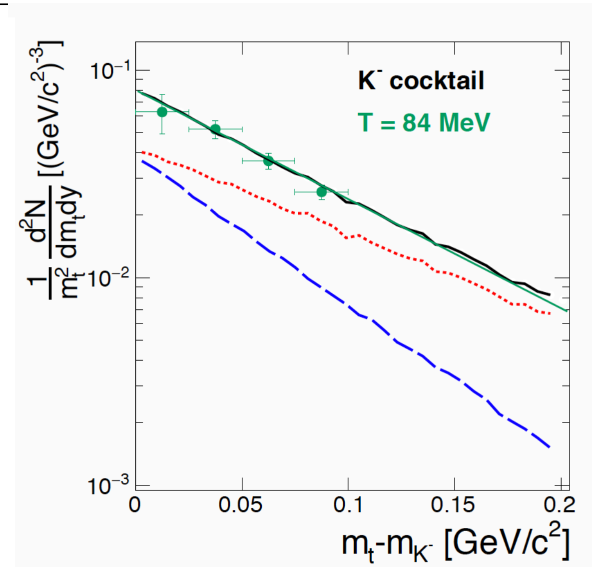
Deep Sub-threshold ϕ Production

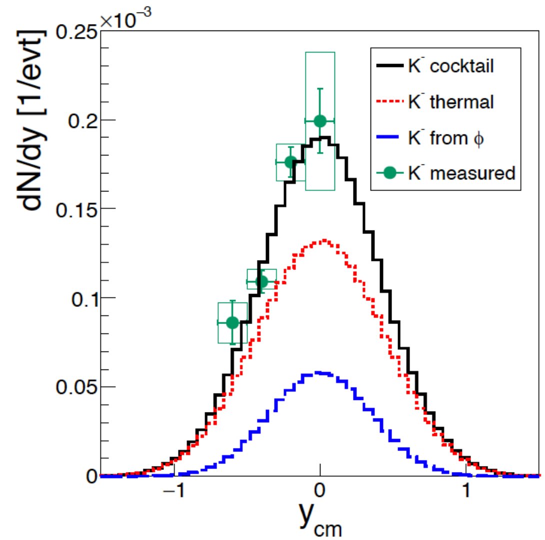


- ϕ/K^- ratio constant at high energy
- Sizeable increase of ϕ/K^- ratio around production threshold

Deep Sub-threshold ϕ Production







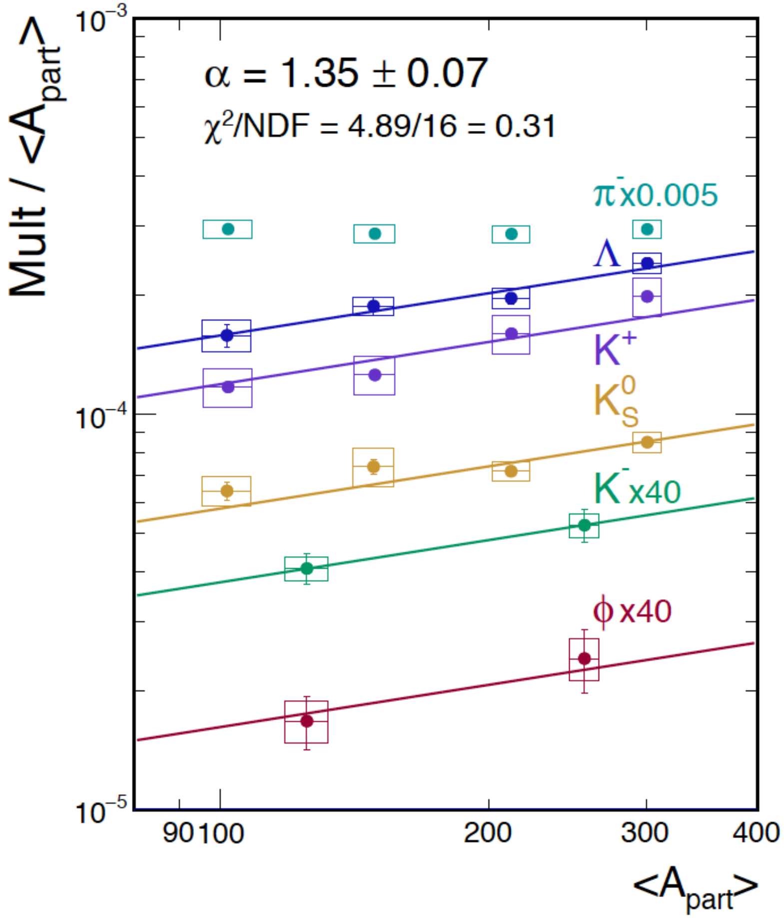
- ϕ/K^- ratio constant at high energy
- Sizeable increase of ϕ/K^- ratio around production threshold → even higher for Au+Au
- ϕ important source for K^- production below NN threshold

  → 25% of all measured K^- from ϕ feed-down
- Unique freeze-out criteria when ϕ decay kinetics taken into account

  → sequential freeze-out of K^+,K^- not necessary to describe the data

  → support for statistical model

Strange Particle Production: The Complete Picture



$\langle A_{part} \rangle$ dependent multiplicity

- First comprehensive set of strange particles
- Strangeness production far below NN threshold
  → Strong constraints on production mechanism
- Universal scaling of yield with participants
  → Mult ≈ A^{α}_{part}, with $\alpha > 1$
- Production yields reflect matter properties

Strange Particle Production: The Complete Picture

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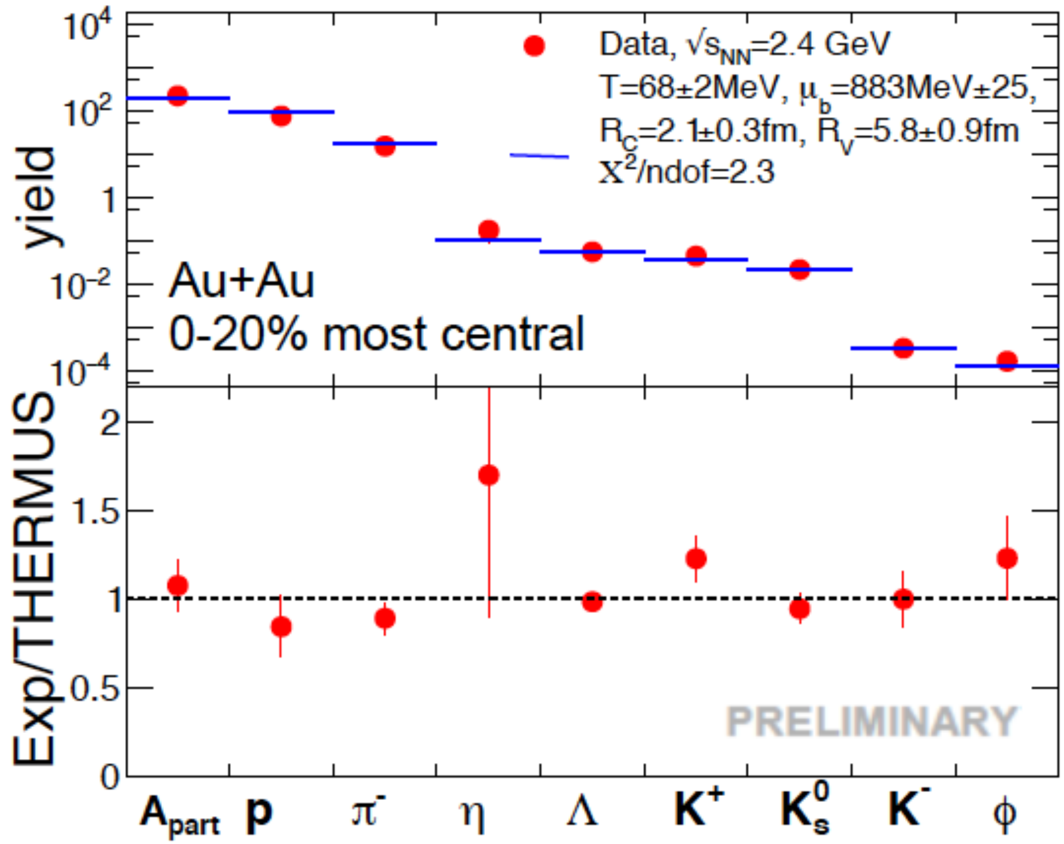
Chemical freeze-out

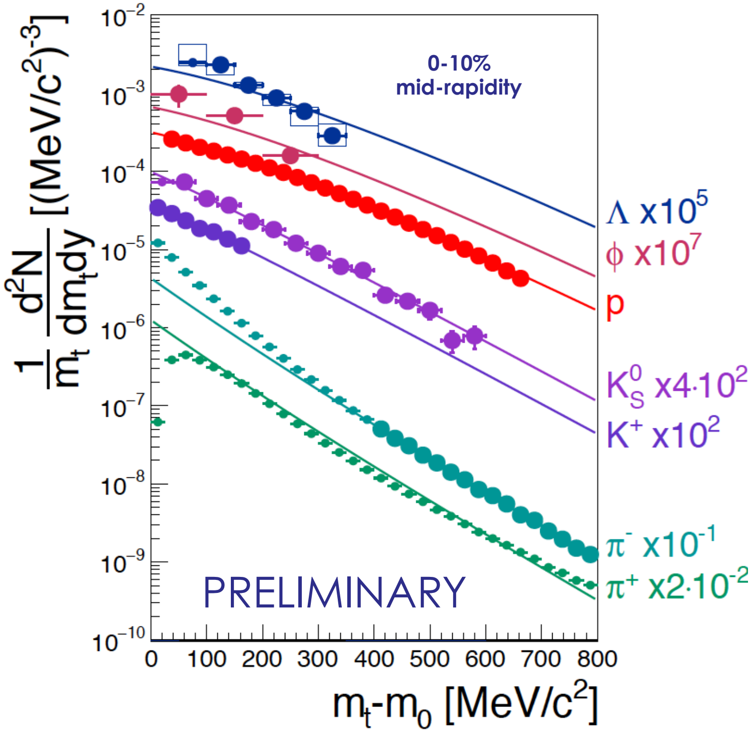
- Particle production from a homogeneous source
- Grand canonical ensemble Parameters : T, m_B, R_C
- Strangeness canonically suppressed → ϕ/K^- ratio Additional parameter needed ($R_C < R_V$)
- Hadron yields described by 4 parameters



Strangeness production consistent with the assumption of reaching a thermal equilibrium at SIS18 energies in baryonic matter

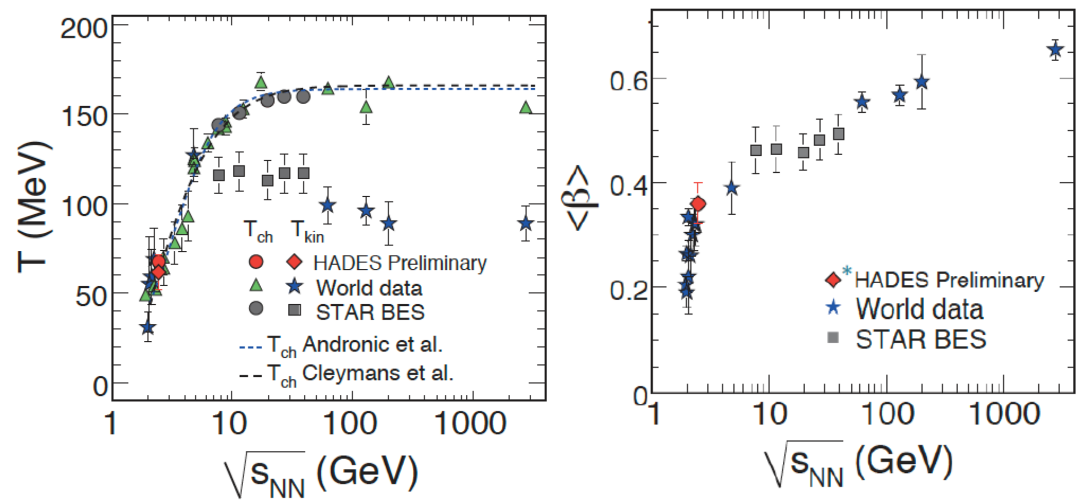
THERMUS v2.3
S. Wheaton, J. Cleymans
Comput.Phys.Commun()2009 180

Extraction of freeze-out temperature



Radial Flow

STAR arXiv:1701.07065, 2016



- Kinetic freeze-out parameters from blast wave fit to hadron spectra
- **T_{kin} = 62 ± 10 MeV, <β> = 0.36 ± 0.04**
- Λ and φ spectra steeper
- Global freeze-out parameters agrees well with the world data trend
- **$T_{kin} \leq T_{chem}$** also at low energies (high μ_B)

Summary

Microscopic description:

- Kaon spectra best described by IQMD with potential, however it does not describe Λ spectra
- ➢ No consistent picture when looking at different observables

Deep sub-threshold strangeness production:

- ϕ sizeable source for K^- production
- Feed-down can explain lower effective temperature and rapidity spectrum of K^-
- ➢ No indication for sequential freeze-out of K^+/K^-

The global picture:

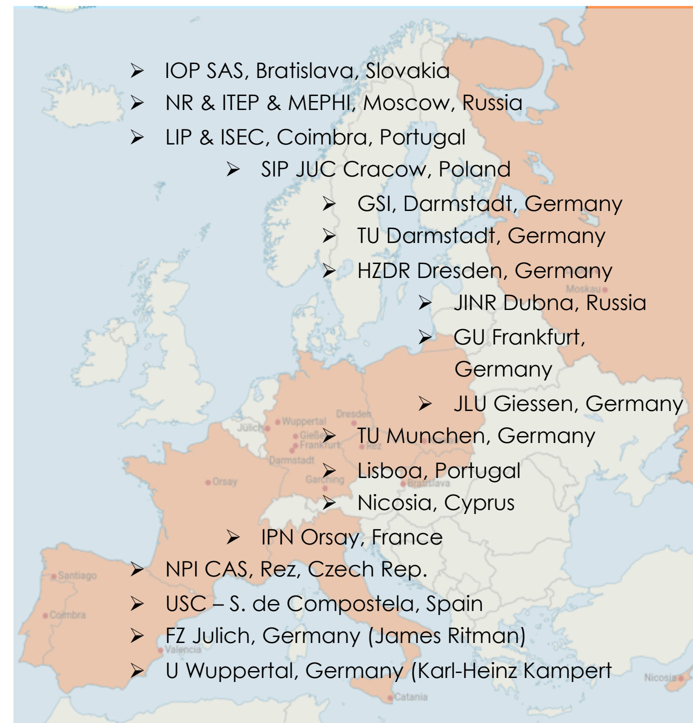
- Universal centrality dependence of strangeness production
- SHM describes particle yields
- ➢ Strangeness production suggests creation of thermalized strongly-interacting medium

Outlook

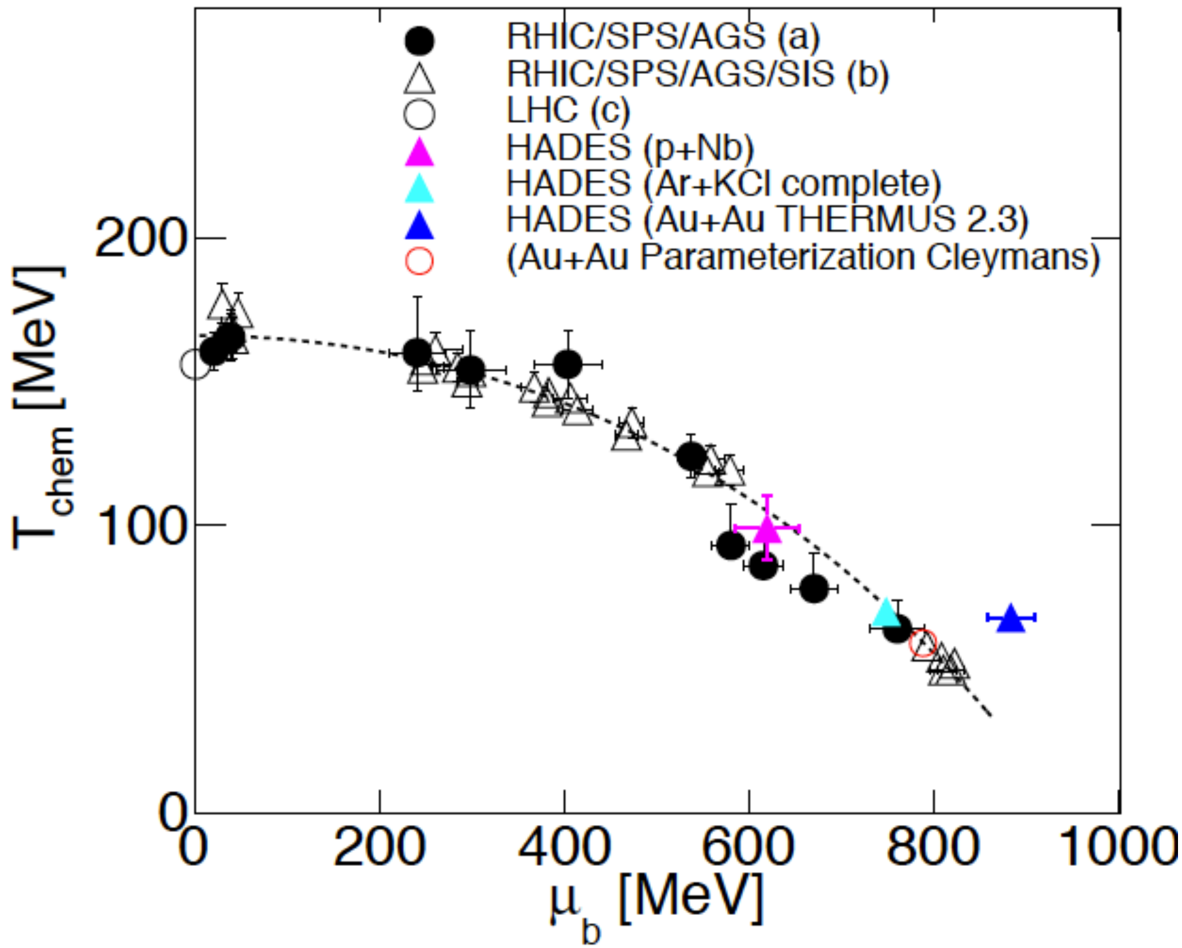
- Strong scientific program for **FAIR Phase-0**
  - Further exploration of the phase diagram and reference measurements
    - ✓ **π+p/A $\sqrt{s}$ = 1.7 – 1.9 GeV :**
      EM structure of baryonic resonances
    - ✓ **Ag+Ag at 1.65A GeV :**
      multi-strange hadrons & intermediate-mass dileptons

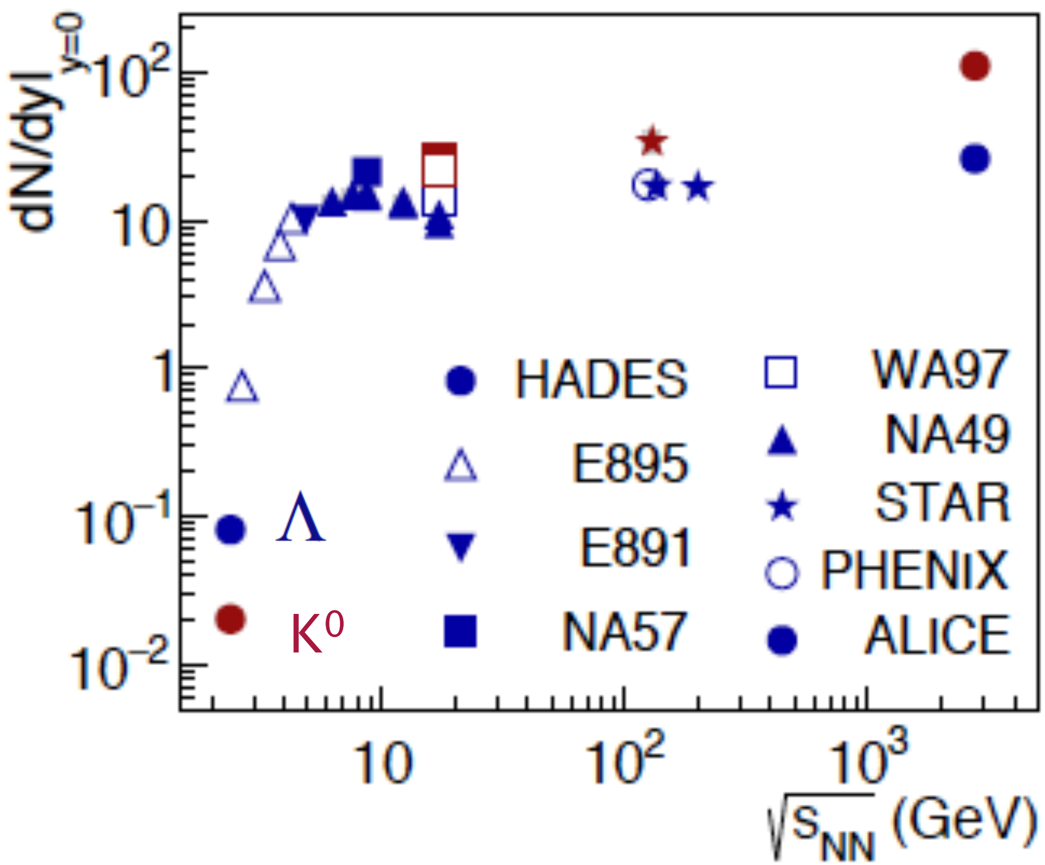
- Continue physics program at higher energies at **SIS 100**

Thank you for your attention !!!



- IOP SAS, Bratislava, Slovakia
- NR & ITEP & MEPHI, Moscow, Russia
- LIP & ISEC, Coimbra, Portugal
- SIP JUC Cracow, Poland
- GSI, Darmstadt, Germany
- TU Darmstadt, Germany
- HZDR Dresden, Germany
- JINR Dubna, Russia
- GU Frankfurt, Germany
- JLU Giessen, Germany
- TU Munchen, Germany
- Lisboa, Portugal
- Nicosia, Cyprus
- IPN Orsay, France
- NPI CAS, Rez, Czech Rep.
- USC – S. de Compostela, Spain
- FZ Julich, Germany (James Ritman)
- U Wuppertal, Germany (Karl-Heinz Kampert


RHIC/SPS/AGS (a)
RHIC/SPS/AGS/SIS (b)
LHC (c)
HADES (p+Nb)
HADES (Ar+KCl complete)
HADES (Au+Au THERMUS 2.3)
(Au+Au Parameterization Cleymans)
T_{chem} [MeV]
200
100
0
0
200
400
600
800
1000
μ_b [MeV]



dN/dy|y=0
10²
10
1
10⁻¹
10⁻²
10
10²
10³
√sNN (GeV)
HADES
E895
E891
NA57
WA97
NA49
STAR
PHENIX
ALICE
Λ
K⁰

ϕ/K- ration : comparison to models

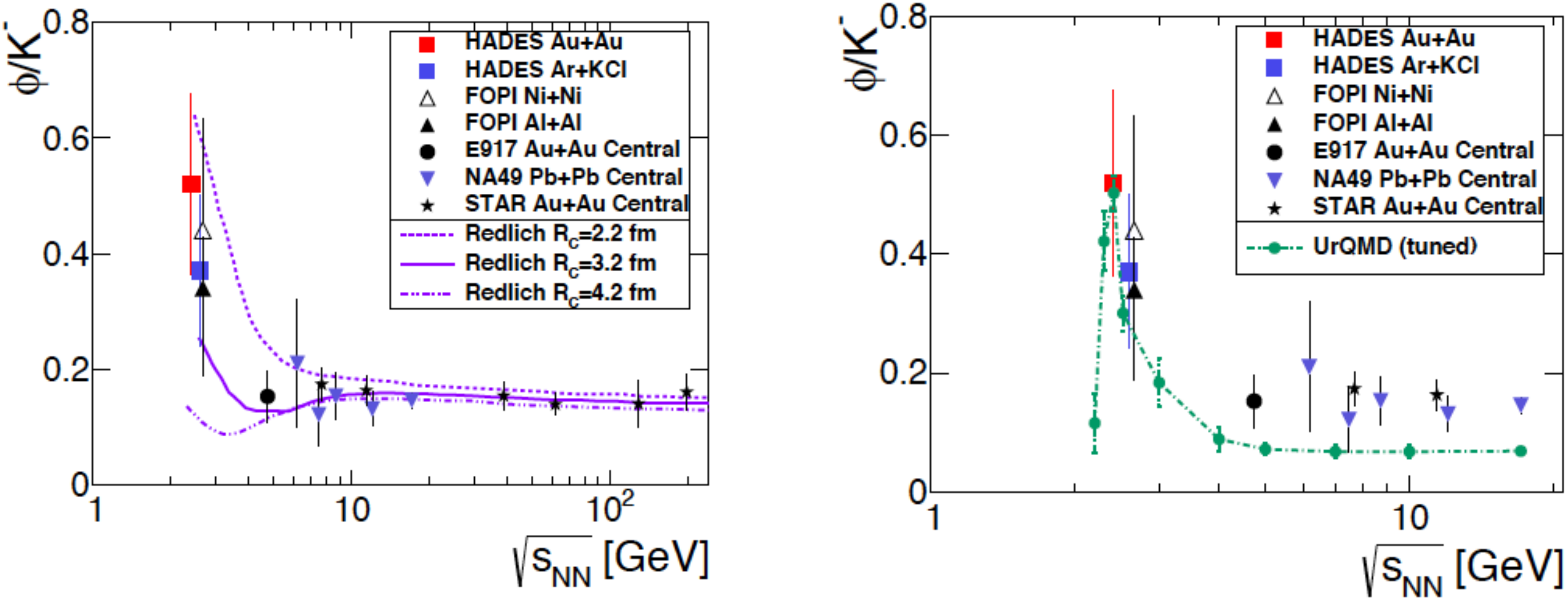
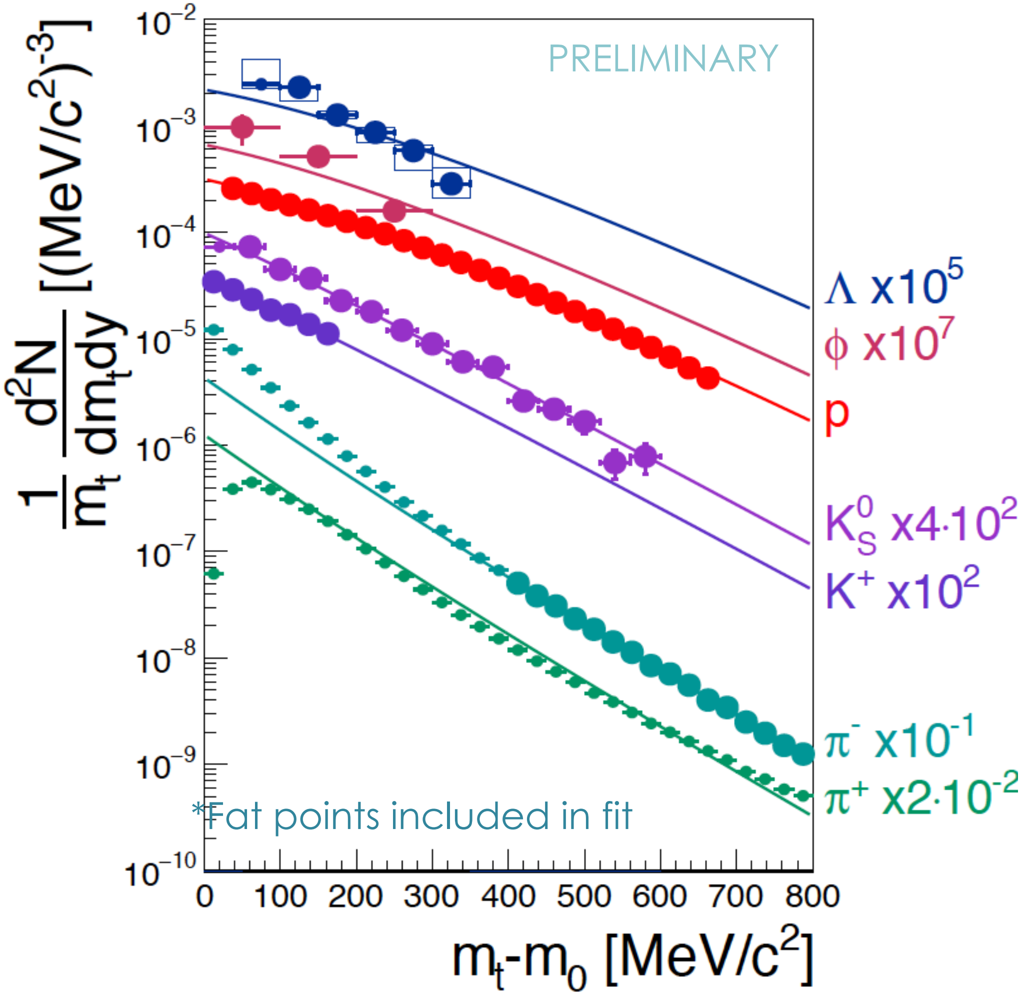


Figure 6.9: Excitation function of the measured ϕ/K^- ratio for various systems and energies (see legend) [2, 121, 3, 158, 159, 160]. While the ratio stays flat for energies above a few AGeV, it substantially increases towards lower energies around the elementary ϕ production threshold. Lines correspond to calculations from a statistical hadronization model for different values of the canonical suppression radius R_C (see legend).

Strangeness Production: The Global Picture



Phys.Rev. C 48, 2462

- Blast wave model:

$$\frac{dN}{p_T\,dp_T} \propto \int_0^R r\,dr\,m_T I_0\left(\frac{p_T \sinh\rho(r)}{T_{\rm kin}}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T_{\rm kin}}\right)$$

Linear flow velocity profile:

$$\beta = \beta_S (r/R)^n$$
$$n = 1$$

- Proton, Kaon and Pion spectra well described by simultaneous blast wave fit with global parameters:

$$T_{kin} = 62 \pm 10 \text{ MeV}$$
$$\langle \beta_r \rangle = 0.36 \pm 0.04$$

- $T_{kin} < T_{chem} = 68 \pm 2$ MeV