Strangeness production in heavy-ion collisions at E_{kin} = 1-2 AGeV

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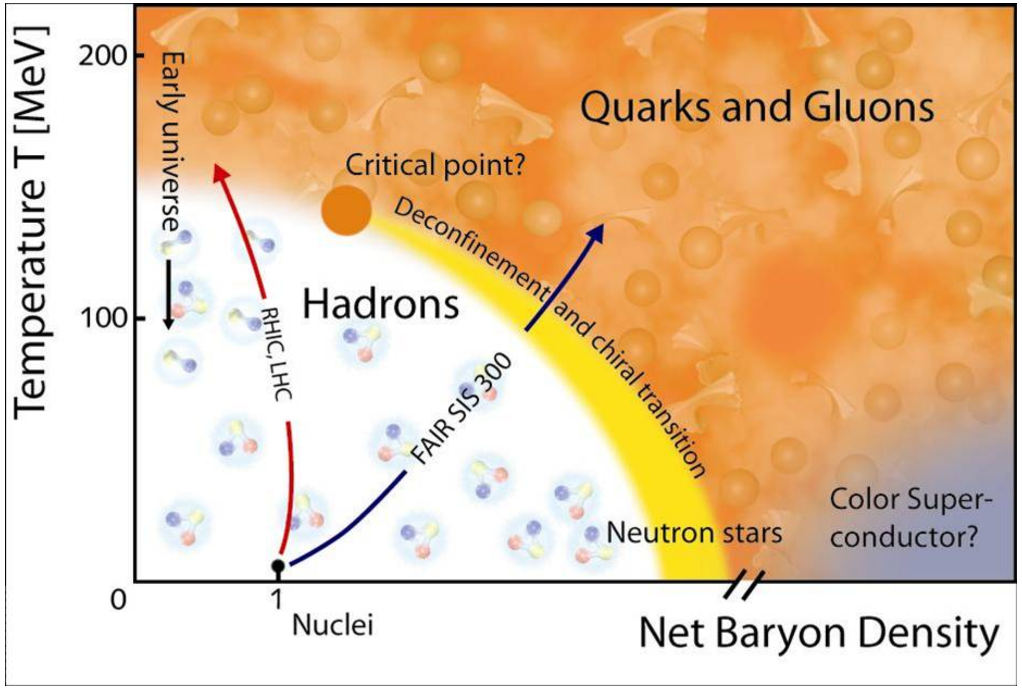
HELMHOLTZ GEMEINSCHAFT

FIAS Frankfurt Institute for Advanced Studies

Motivation

- Nuclear matter under extreme conditions
  - State of the universe microseconds after the Big Bang
  - Hot and dense matter
    → Quark-Gluon-Plasma (QGP)
  - Quarks and gluons are **deconfined**
  - At high temperatures and densities hadronic matter forms QGP



Goal: Understand phase transition

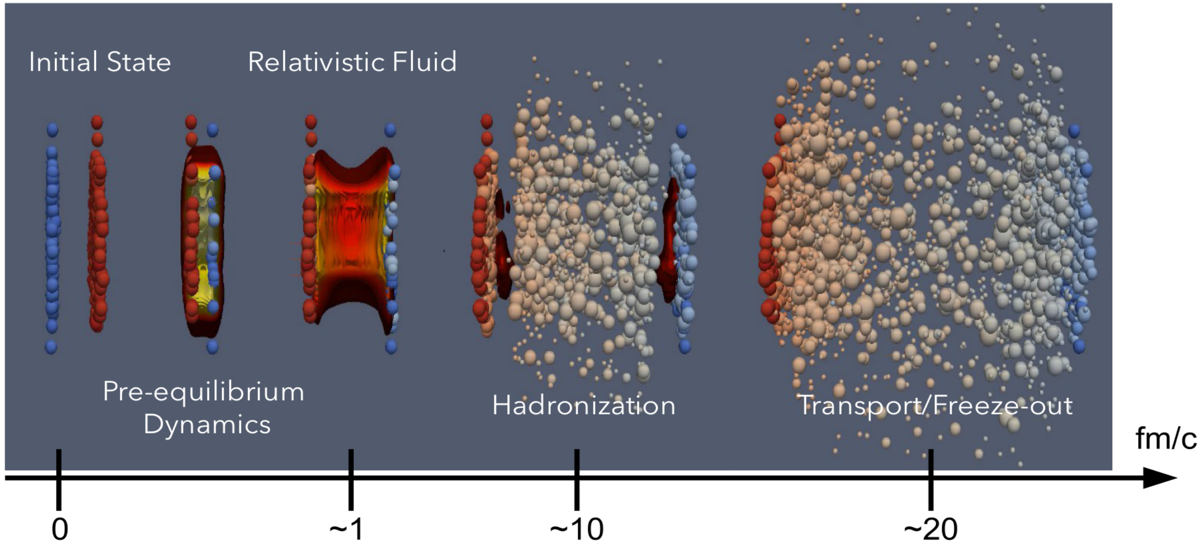
Source: teilchen.at

Motivation

- Heavy-ion collisions
  - At low energies, unique possibility to study nuclear matter at high densities
  - Created particles give information about conditions inside reaction zone
  - Sensitive probe → **strange particles**

- Specific production mechanism and long mean free path

  → ideal probes for exploring high density phase in heavy-ion reactions



Strangeness production

- Strange particles contain an s- or $\bar{s}$-quark
- Strange quarks have higher masses (95 MeV) than up and down quarks (2-5 MeV)
- Created by strong interaction and decay via weak interaction
  → long lifetime $1{,}238 \cdot 10^{-8}$ s
- Examples: $K^+(u\bar{s}), K^-\ (\bar{u}s), K^0\ (d\bar{s}), \bar{K}^0\ (\bar{d}s),\ \Lambda^0\ (uds), \Sigma\ (uus)$
- Production channels at low energies:

$$NN \rightarrow N\Lambda K^+$$
$$\pi Y \leftrightarrow K^- N \quad Y = \Lambda, \Sigma$$

- **Strangeness exchange** suggested as an important production channel in nucleus – nucleus collisions
  - Responsible for appearance and disappearance of K^-

Transport models

- Offer deeper understanding of the dynamics of heavy-ion collisions
- Simulate whole reaction
- Based on microscopic theory (transport theory)
- Whole information of particles is available in phase space
- Effectively solve relativistic Boltzmann equation:

$$p^{\mu}\partial_{\mu}f_i(x,p) + m_i F^{\alpha}\partial^{p}_{\alpha}f_i(x,p) = C^{i}_{coll}$$

SMASH

- **S**imulating **M**any **A**ccelerated **S**trongly-interacting **H**adrons
- C++ based hadronic transport code
- Simulation of nucleus-nucleus collisions at low energies
- Geometric collision criterion:

$$d_{trans} < d_{int} = \sqrt{\frac{\sigma_{tot}}{\pi}}$$

Strangeness production in SMASH

- Strange particles: K ,K* (11), Λ ,$\Lambda^*(13), \Sigma, \Sigma^*(9)$, $\Xi, \Xi^*(5), \Omega, \Omega^*(1)$
- Production via:

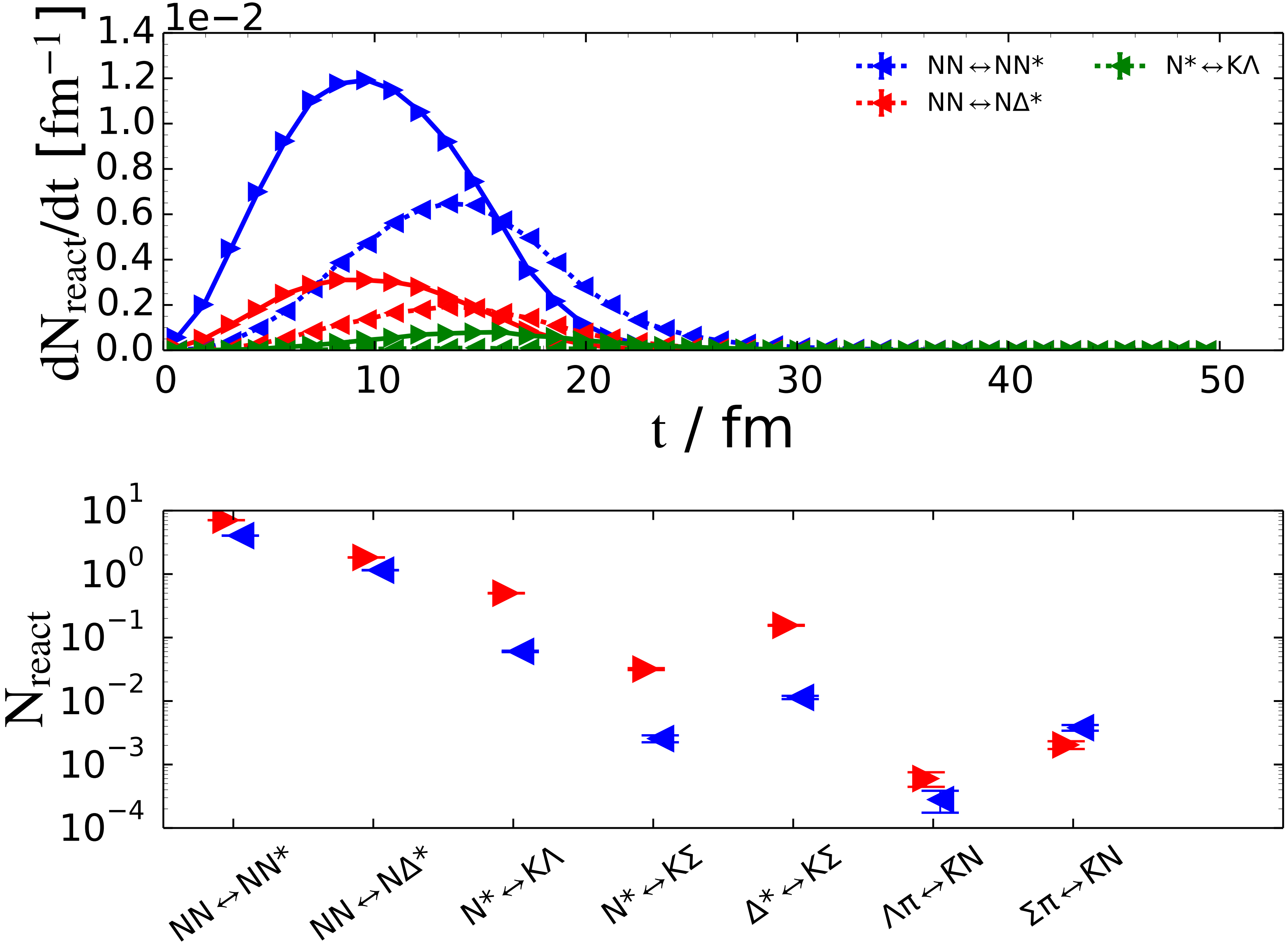
(1) $\mathrm{NN} \rightarrow \mathrm{NN}^*, \mathrm{N}\Delta^*$

(2) $\mathrm{N}^*, \Delta^* \rightarrow \mathrm{YK} \qquad \mathrm{Y} = \Lambda, \Sigma$

(3) $\pi\mathrm{Y} \leftrightarrow \mathrm{K}^-\mathrm{N}$

(Gräf, Steinheimer et al. Phys.Rev. C90 (2014) 064909)

→ Only produced in secondary processes via resonances



Au +Au at E_{kin} = 1.5 AGeV

Events = 25000

Calculation specifics

- With Fermi motion
- No potentials
- No Pauli-blocking

- No string fragmentation necessary because E_{kin} = 1-2 AGeV
- Results compared to measurements by
  KaoS (Kaon Spectrometer)
  HADES (High Acceptance Dielectron Spectrometer)

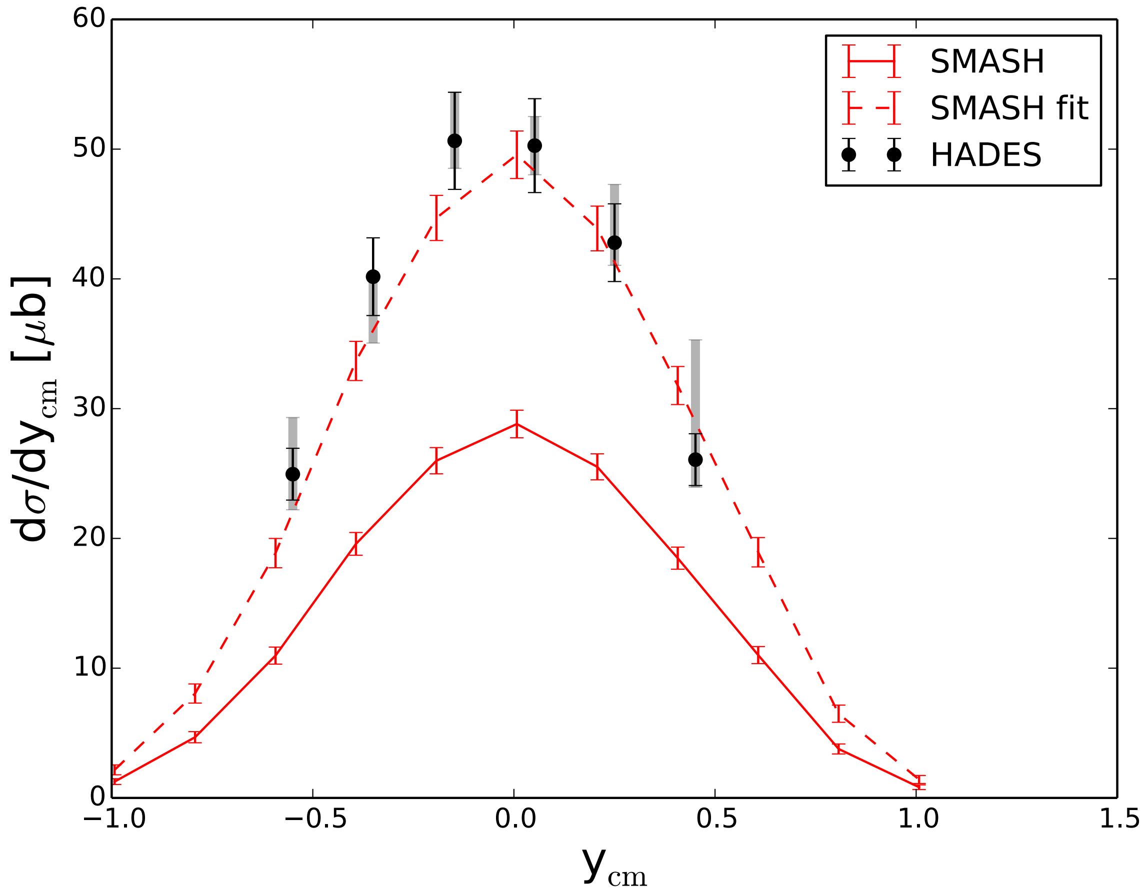
System	Observable
HADES: p+p at E_{kin} = 3.5 GeV	Rapidity spectra y Transverse momentum spectra p_T
SMASH: Au+Au, π^-+ C, π^-+ W at E_{kin} = 1.7 AGeV	Multiplicities N
KaoS: Au+Au, Ni+Ni at E_{kin} = 1.5 AGeV	Centrality dependence A_{part}
HADES: Ar+KCl at E_{kin} = 1.76 AGeV	Transverse mass spectra m_T
KaoS: Au+Au at E_{kin} = 1.5 AGeV	Effective temperature T_{eff}

p+p E_{kin} = 3.5 AGeV, K_S^0

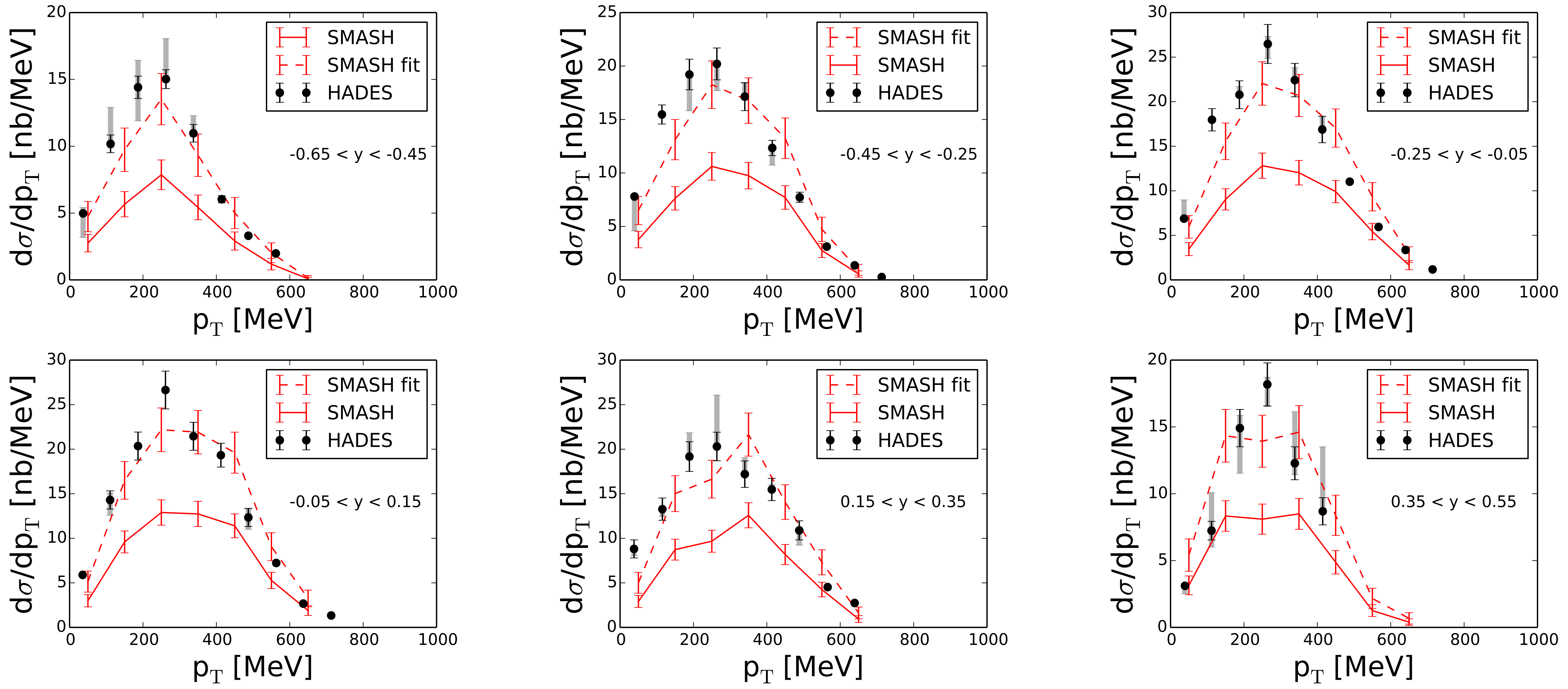
- K^0 and $\overline{K}^0$ form CP-eigenstates in K_S^0 and K_L^0
- Transverse momentum: $p_T = \sqrt{p_x^2 + p_y^2}$
- Rapidity: y = $0.5 \ * \ln(\frac{E+p_z}{E-p_z})$

p+p E_{kin} = 3.5 AGeV, rapidity spectra K_S^0

- Cross section calculated from properties of resonances
- $\sigma^{pp\rightarrow K^0 X}$= 60μb   (SMASH)
- $\sigma^{pp\rightarrow K^0 X}$= 103μb   (HADES)
  (Agakishiev et al. Phys.Rev. C90 (2014) 054906)
- Dashed lines scaled by $\sigma^{pp\rightarrow K^0 X}$ ratio

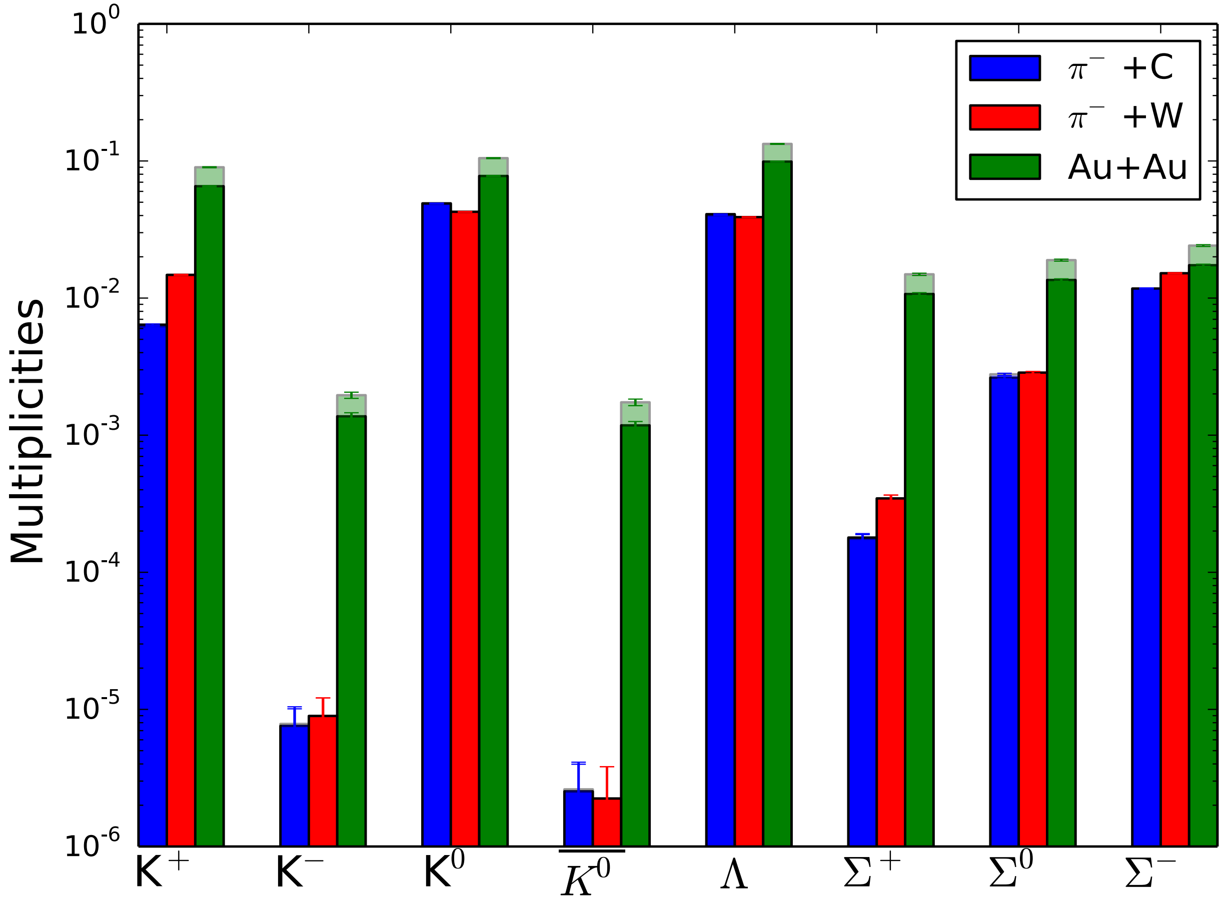


p+p E_{kin} = 3.5 AGeV , p_T – spectra K_S^0



SMASH E_{kin} = 1.7 AGeV, Multiplicities

- Filled bars:
  without Fermi motion
- Transparent bars:
  with Fermi motion

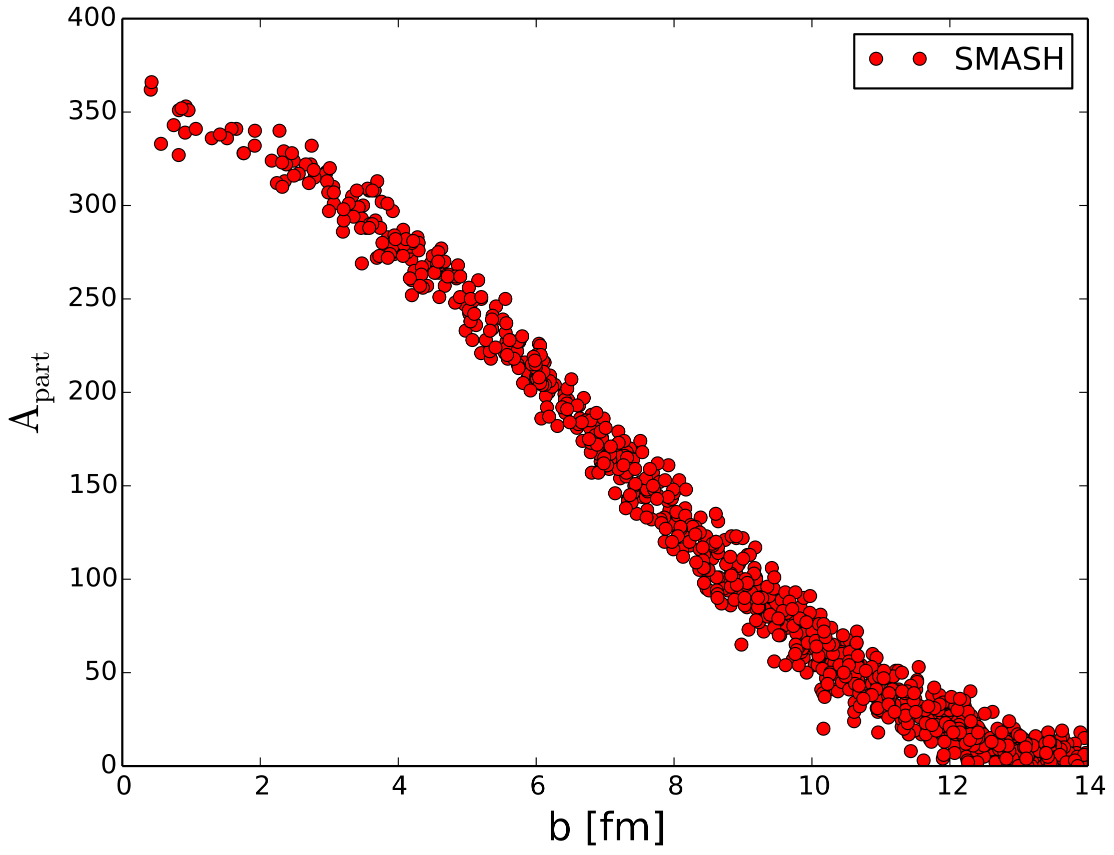


Heavy – ion reactions

Au+Au E_{kin} = 1.5 AGeV

- Number of participants depending on impact parameter

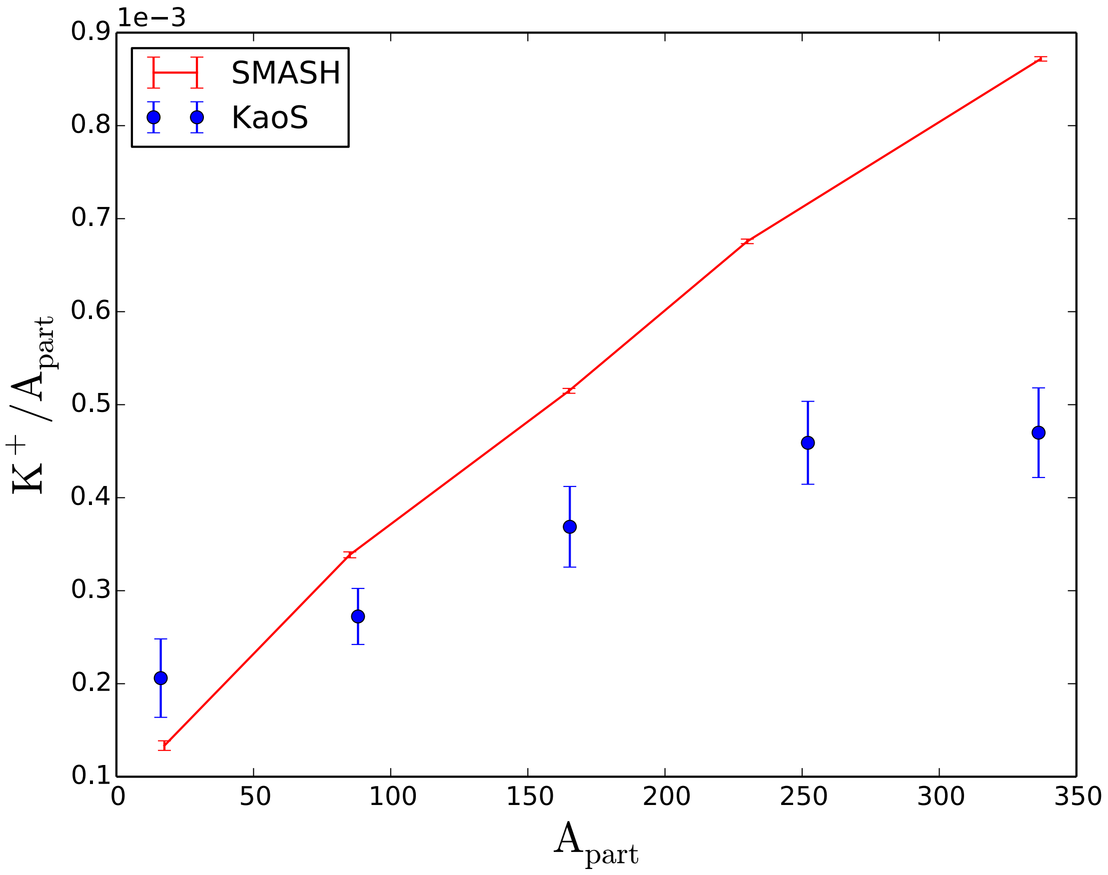
→ Number of participants decreases with higher impact parameter



Au+Au E_{kin} = 1.5 AGeV

- Number of K^+ and K^- rises with A_{part}
- In comparison to KaoS : at high participants SMASH overshoots

(A.Forster et al J.Phys. G31 (2005) no.6, S693-S700)



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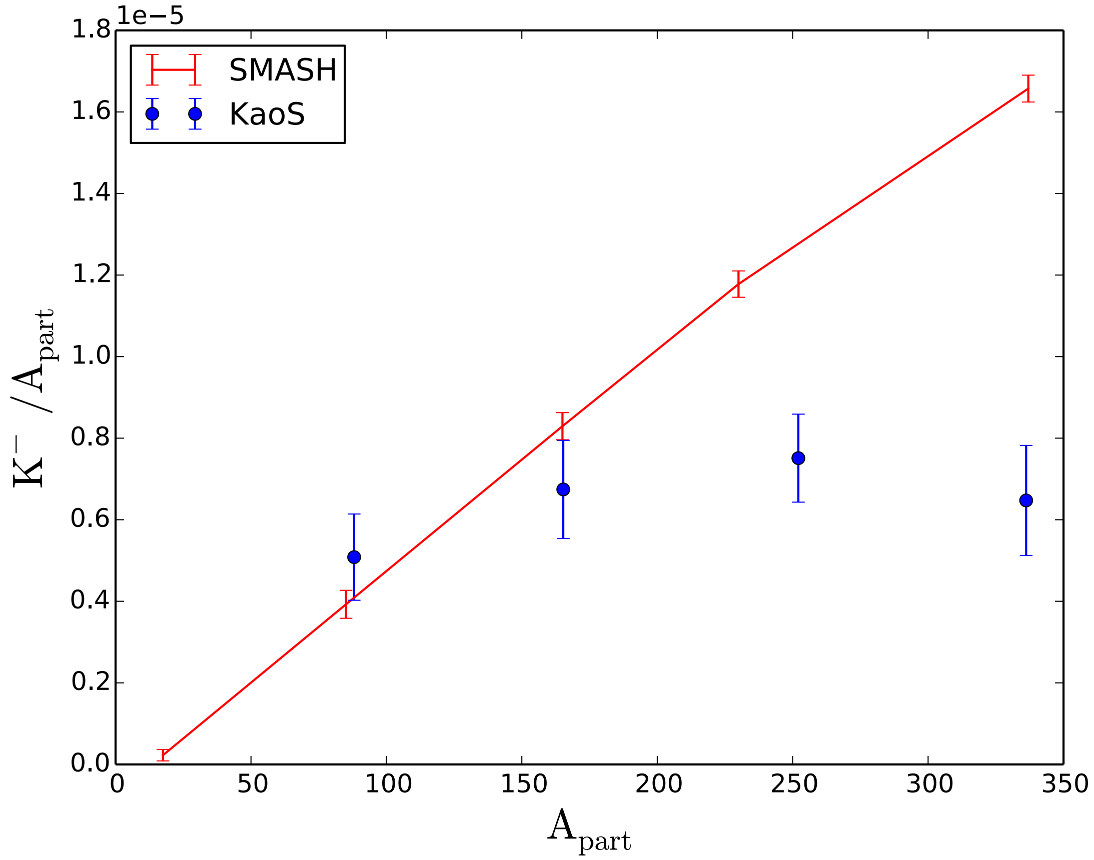
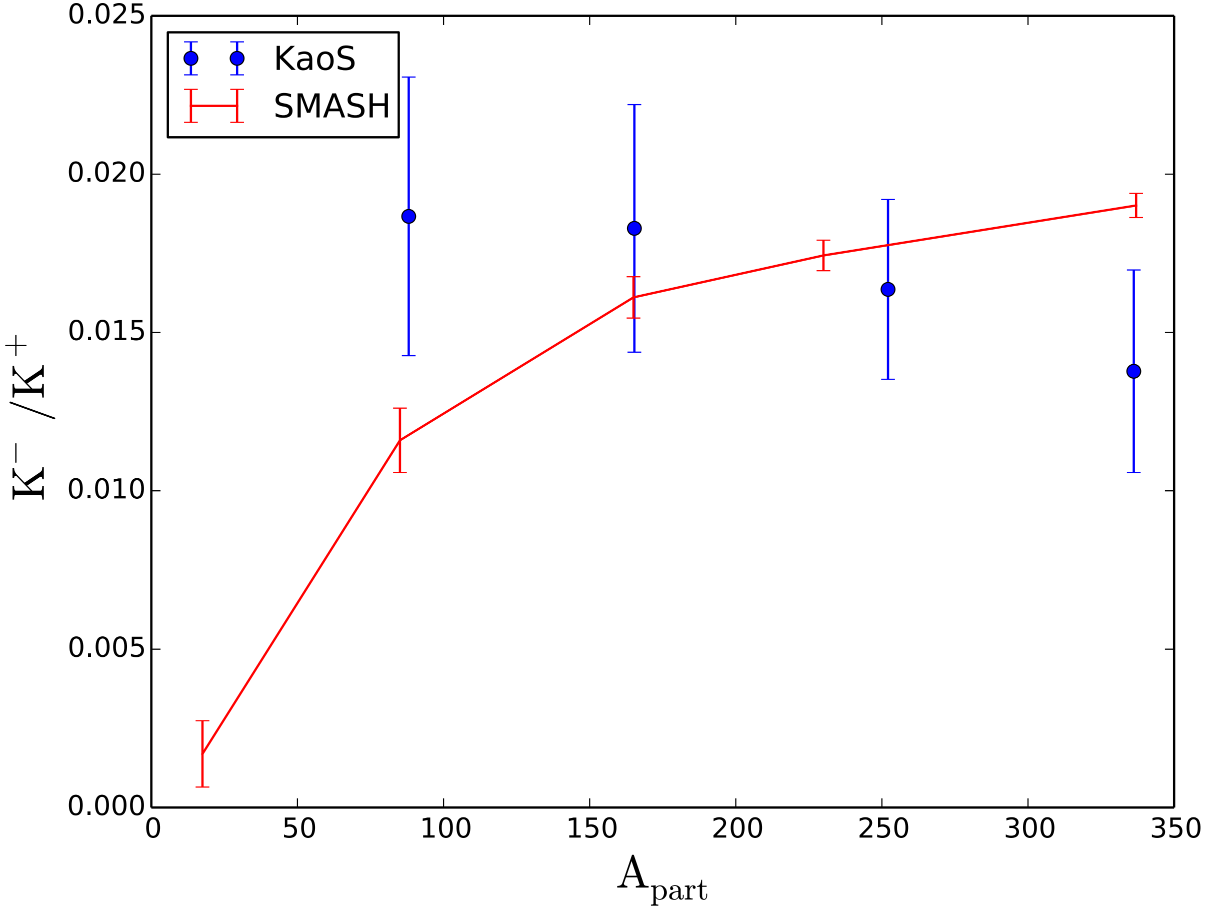


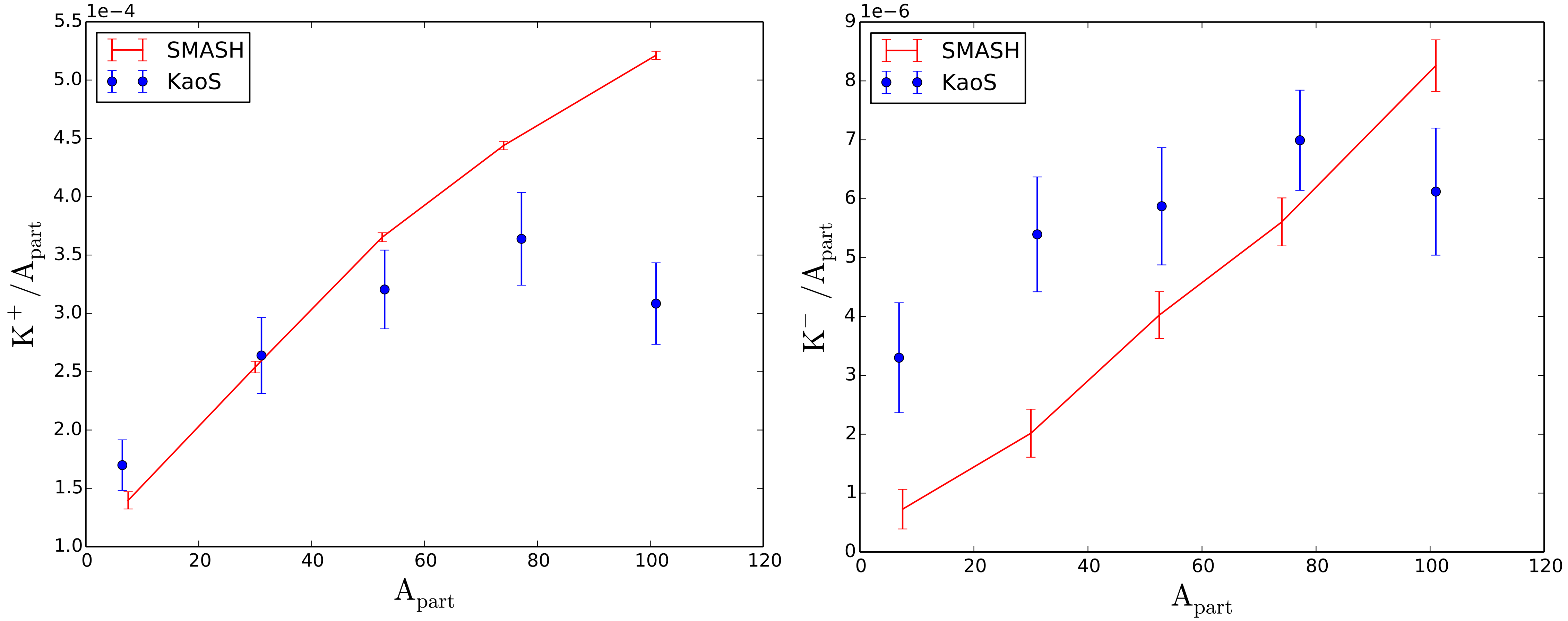
Au+Au E_{kin} = 1.5 AGeV

- KaoS
  - K^- to K^+ ratio is at 0.02

- SMASH
  - K^- to K^+ ratio increases with A_{part}



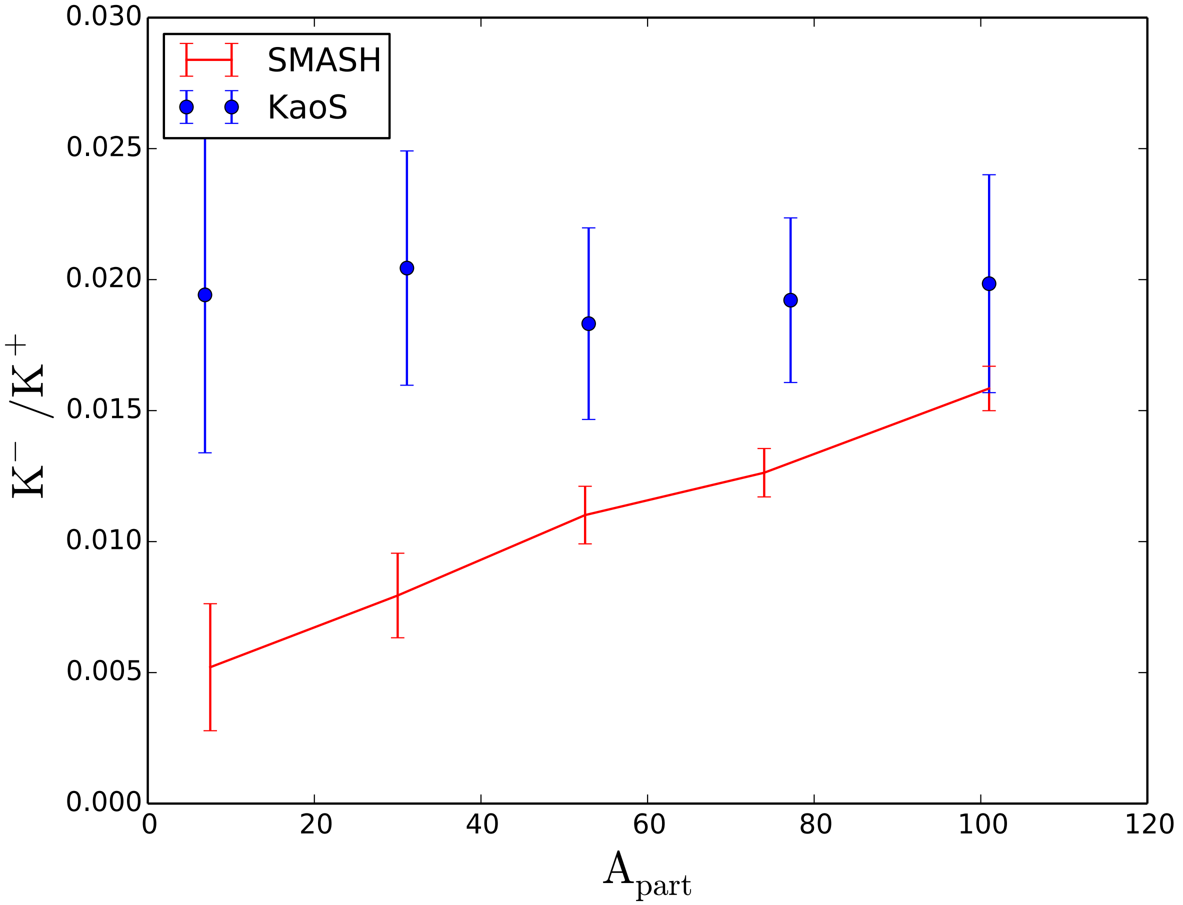
Ni+Ni E_{kin} = 1.5 AGeV



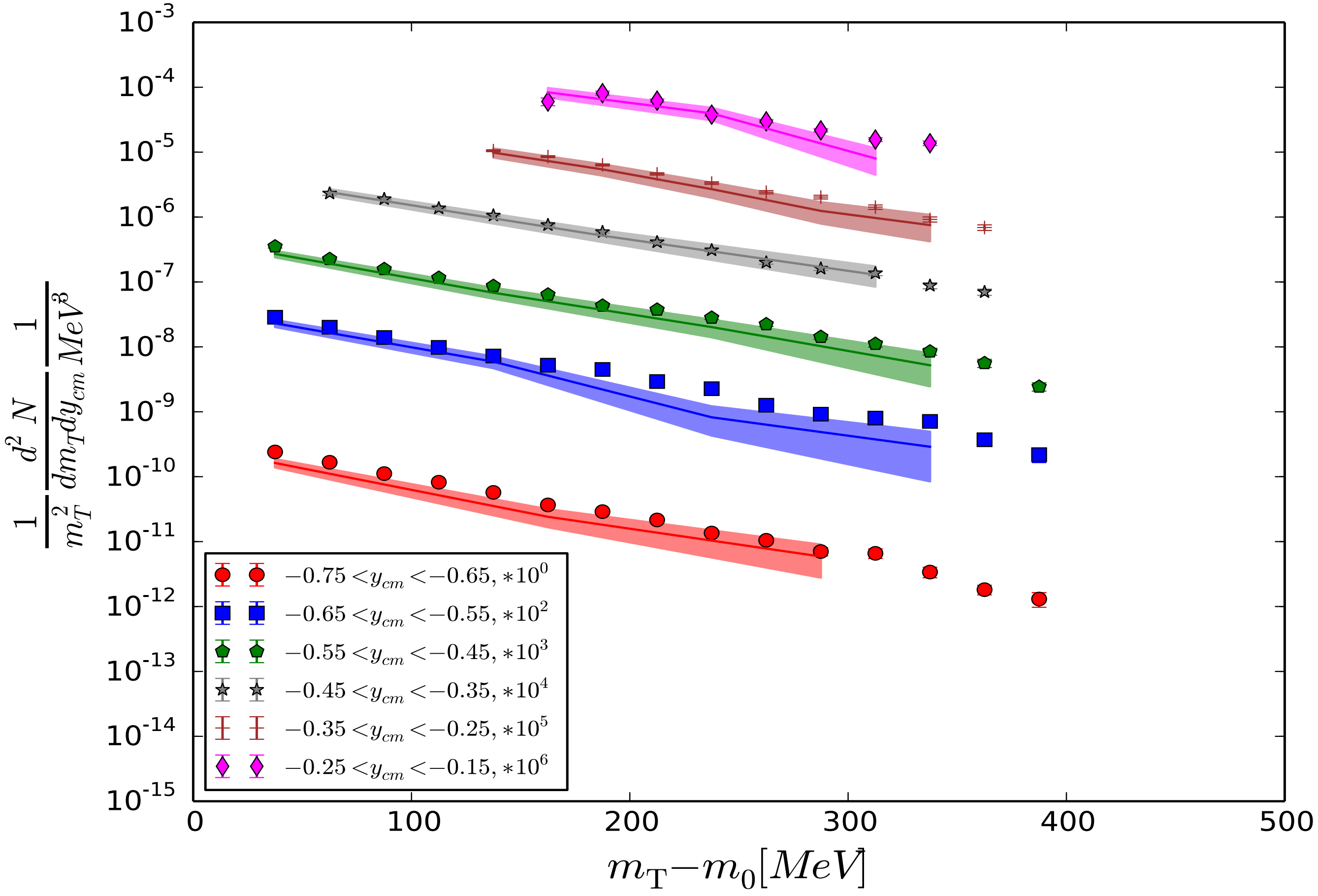
Ni+Ni E_{kin} = 1.5 AGeV

- Number of K^+ , K^- and the ratio rises with A_{part}

→ Same behaviour for smaller systems



Ar+KCl E_{kin} = 1.76 AGeV, m_T – spectra K^+



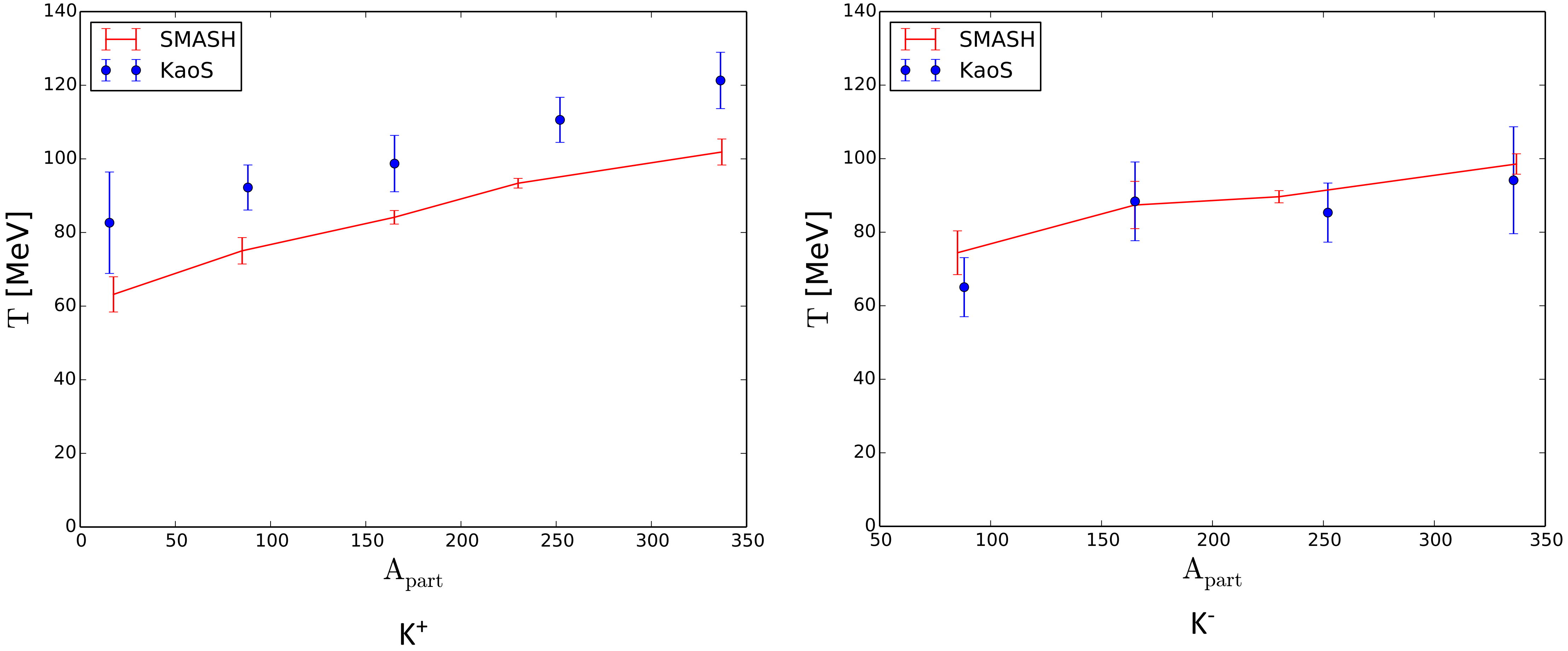
HADES = Ar + KCl

SMASH = Ca + Ca

Transverse mass distribution
has been determined in six rapidity bins,
ranging from:

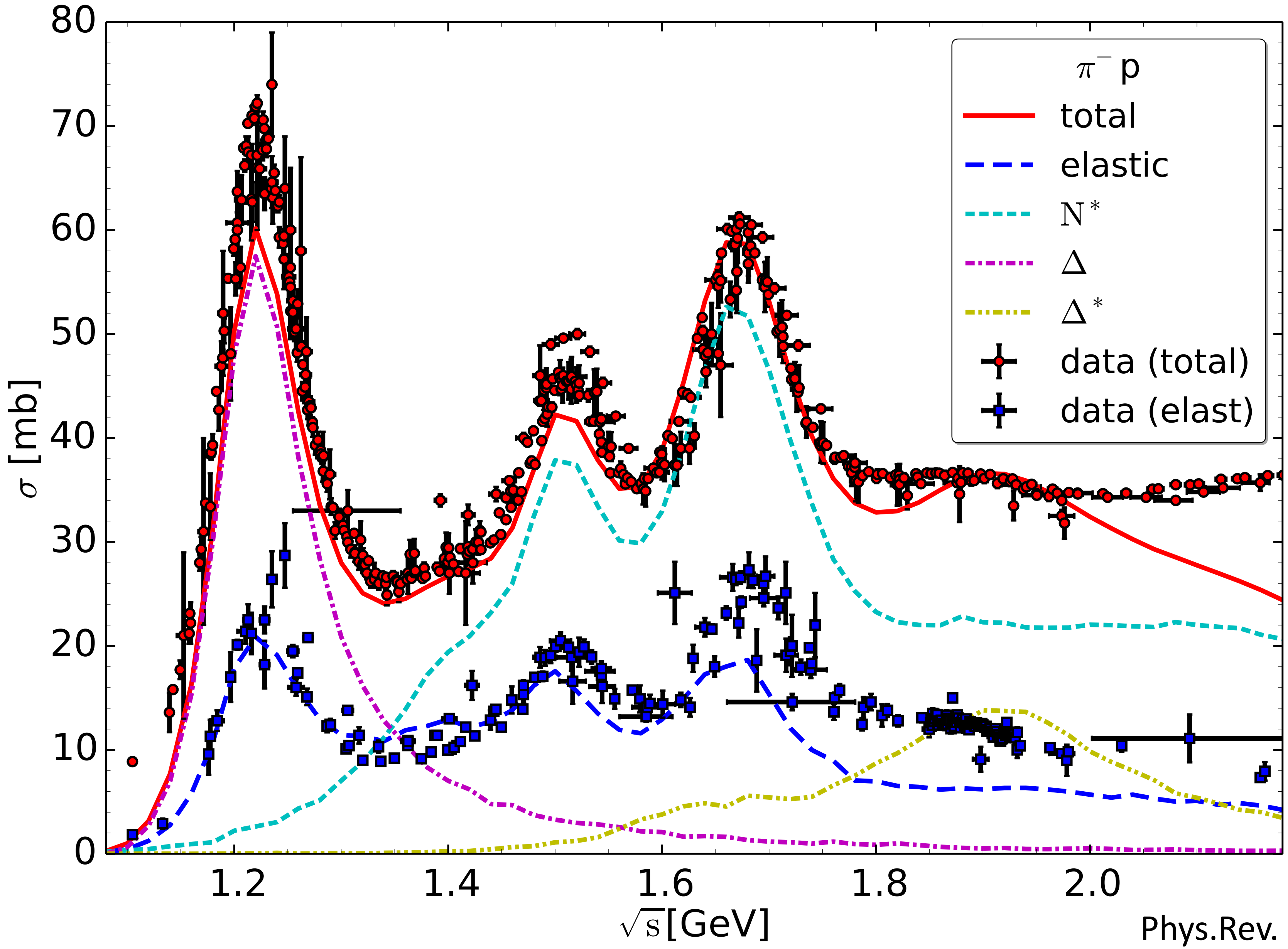
$-0.75 < y_{cm} < -0.15$

Au+Au E_{kin} = 1.5 AGeV, T_{eff}

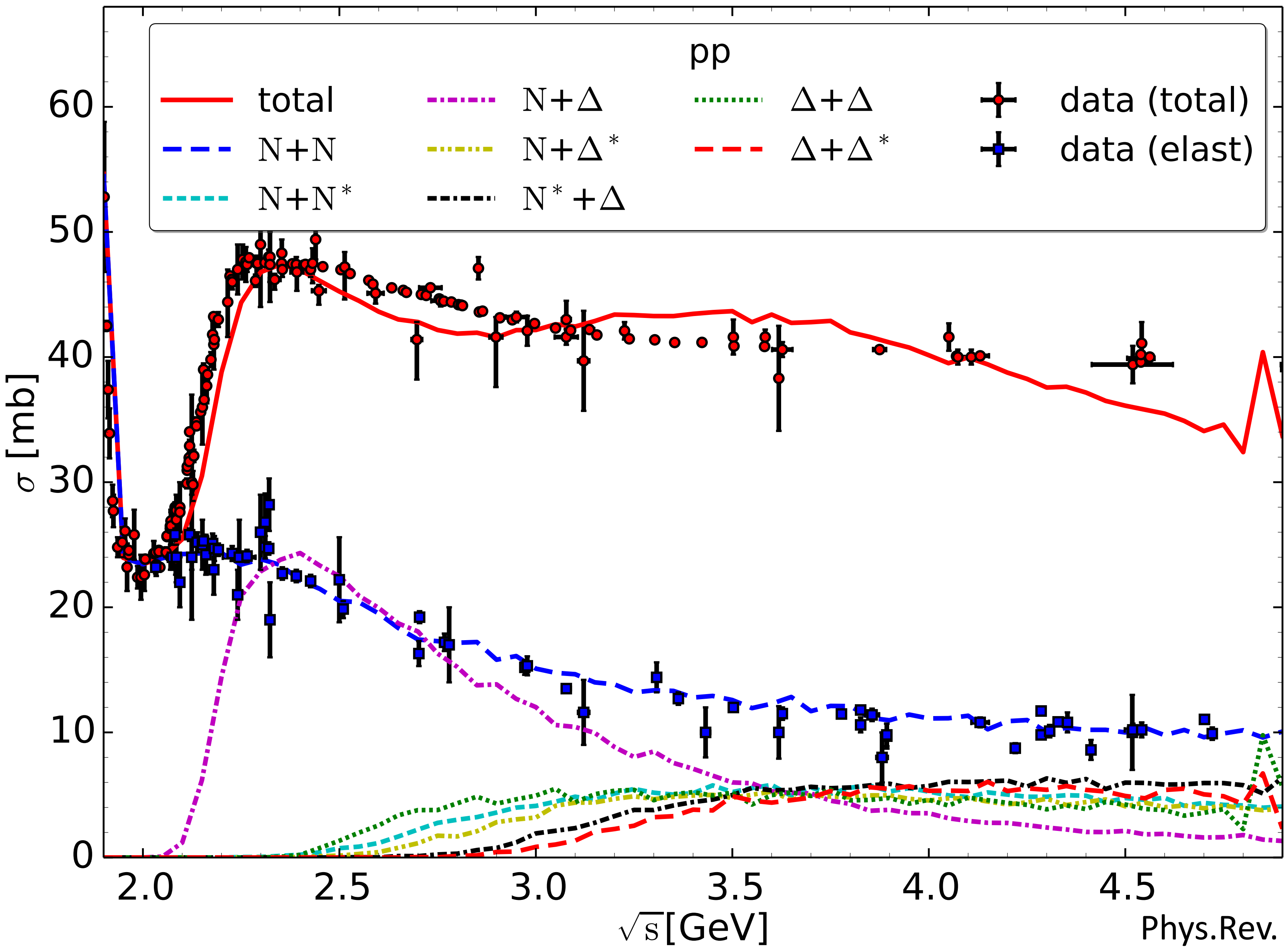


System	Observable	Results
HADES: p+p at E_{kin} = 3.5 GeV	$\frac{d\sigma}{dy}, \frac{d\sigma}{dp_T}$	K_s^0: Lower multiplicities, same shape
SMASH: Au+Au, π^-+ C, π^-+ W at E_{kin} = 1.7 AGeV	N	Waiting for HADES data
KaoS: Au+Au, Ni+Ni at E_{kin} = 1.5 AGeV	$\frac{K^+}{A_{part}}, \frac{K^-}{A_{part}}, \frac{K^-}{K^+}$	In central collisions: → Overshooting
HADES: Ar+KCl at E_{kin} = 1.76 AGeV	m_T	Good agreement
KaoS: Au+Au at E_{kin} = 1.5 AGeV	T_{eff}	K^+ : Lower K^- : Good agreement

Thank you for your attention!



Phys.Rev. C94 (2016) no.5, 054905



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