Predictions for particle production in Ag+Ag collisions at E_{kin}=1.58A GeV from a hadronic transport approach

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Introduction

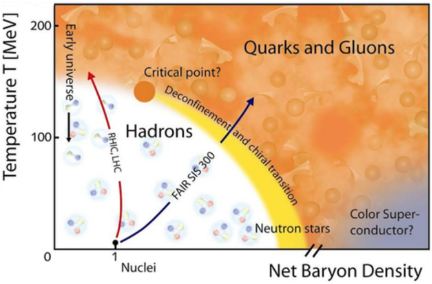
Heavy-ion collisions as a key to the phase diagram of QCD

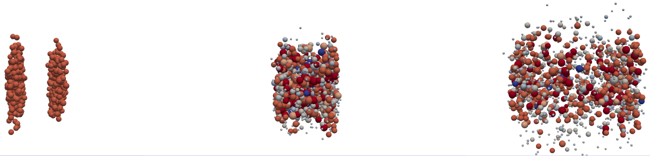
Why low energies?

- High net baryon density
- First order phase transition
- Search for critical endpoint

Why transport approaches?

- Microscopic non-equilibrium description
- Successful in reproducing particle spectra



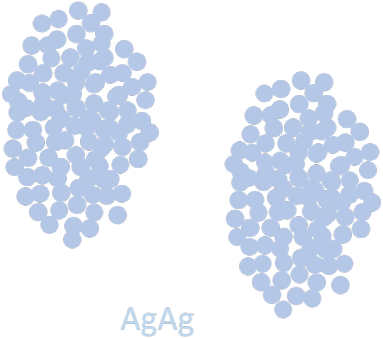


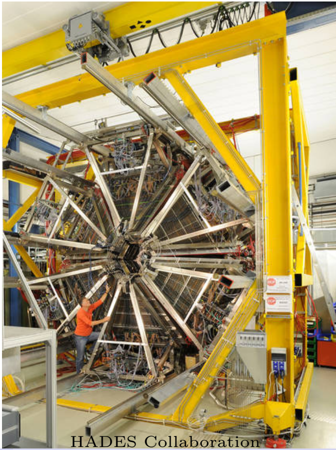
By J. Mohs

Motivation and Outline

Recent experiment at GSI perfomed by the HADES Collaboration

- Transport approaches
- Ξ^- production – high yields in AuAu collisions
- System size dependence
- Dilepton emission





HADES Collaboration

SMASH: A Hadronic Transport Approach

Simulating **M**any **A**ccelerated **S**trongly-interacting **H**adrons[1,2]

- Solves the relativistic Boltzmann equation effectively:

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

- Geometrical collision criterion:

$$d_{coll} < \sqrt{\frac{\sigma_{tot}}{\pi}}$$

- All particles in the PDG with masses up to ~ 2 GeV included

Find us on GitHub!

github.com/smash-transport/smash

[1] J. Weil *et al.* (2016): Phys. Rev. C**94**, 054905

[2] D. Oliinychenko *et al.* (2019): SMASH-1.6, 10.5281/zenodo.3485108

SMASH: Particle Production

Hadronic degrees of freedom

Mesons	Baryons
π, η, η'	N, N*
ρ, ω, ϕ	Δ, Δ^*
σ	Λ, Λ^*
f_0, a_0	Σ, Σ^*
K	Ξ, Ξ^*
Higher mesonic resonances	Ω

Processes for particle production

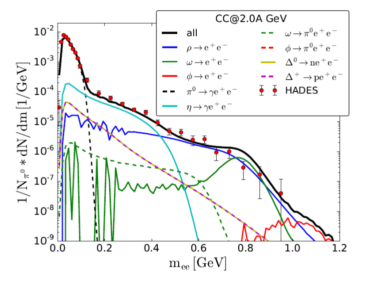
- $2 \rightarrow 1$ resonance production
- (In-)Elastic scattering
- Decay processes
- String fragmentation

For low energies dominated by excitation and decay of resonances

SMASH: Previous Results

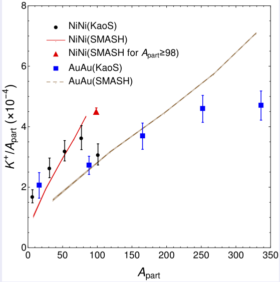
- SMASH has been applied to different collision systems
  - Dilepton emissions with all available HADES data from elementary collisions to heavy ions
  - Strangeness production

J. Staudenmaier *et al.* (2018)



Phys. Rev. C**98** (2018) no.5, 054908

V. Steinberg *et al.* (2019)



Phys. Rev. C**99** (2019) no.6, 064908

Ξ^- Implementation in SMASH

Goal: Study Ξ^- production in SMASH

$\rightarrow$ Follow ansatz introduced by J. Steinheimer and M. Bleicher in J.Phys. G43 (2016) no.1, 015104

UrQMD

Additional decay channels:

$$N^* \rightarrow \Xi K K \quad (10\%)$$

For high mass resonances:

N(1990), N(2080), N(2190), N(2220), N(2250)

SMASH

Pole mass shift:

- N(2220) $\rightsquigarrow$ N(2350)
- N(2250) $\rightsquigarrow$ N(2400)

Additional decay channels:

- N(2350) $\rightarrow \Xi$ K K (50%)
- N(2400) $\rightarrow \Xi$ K K (50%)

Ξ^- Yield Comparison

Agreement with experimental data?

p+Nb at 3.5A GeV (used to fit branching ratios):

	HADES[1]	UrQMD[2]	SMASH
Ξ^-	$(2.0 \pm 0.3 \pm 0.4) \times 10^{-4}$	$(1.44 \pm 0.05) \times 10^{-4}$	2.03×10^{-4}
Ξ^-/Λ	$(1.2 \pm 0.3 \pm 0.4) \times 10^{-2}$	$(0.71 \pm 0.03) \times 10^{-2}$	1.5×10^{-2}

Ar+KCl at 1.76A GeV:

	HADES[3,4]	SMASH
Ξ^-	$(2.3 \pm 0.9) \times 10^{-4}$	1.95×10^{-4}
Ξ^-/Λ	$(5.6 \pm 1.2 \pm^{1.8}_{1.7}) \times 10^{-3}$	4.5×10^{-3}

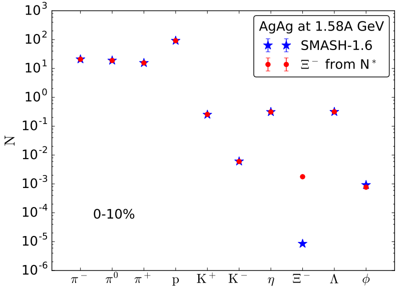
$\Rightarrow$ Agreement with both elementary and larger systems!

[1] G. Agakishiev *et al.* (2015): Phys. Rev. Lett. 114, 212301
[2] J. Steinheimer and M. Bleicher (2016): J.Phys. G43 no.1, 015104
[3] G. Agakishiev *et al.* (2009): Phys. Rev. Lett. 103, 132301
[4] G. Agakishiev *et al.* (2011): Eur. Phys. J. A (2011) **47**:2

Particle Production for AgAg at 1.58A GeV

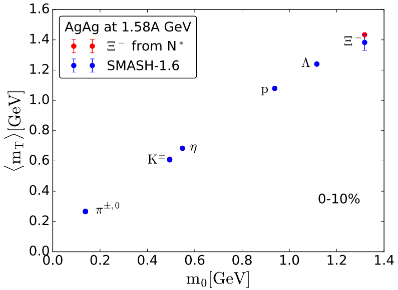
Multiplicities

- Mostly protons
- Strange particles rare
- Rough isospin symmetry in pion production

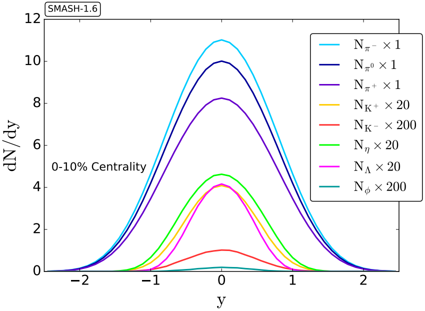


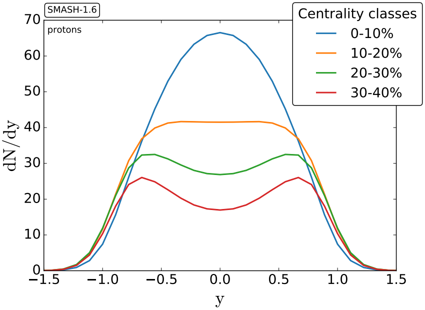
Mean transverse mass

- Higher pole mass ⇒ higher $\langle m_T \rangle$



Note: $N^* \to \Xi^-$ decays do not affect other yields, except ϕ slightly



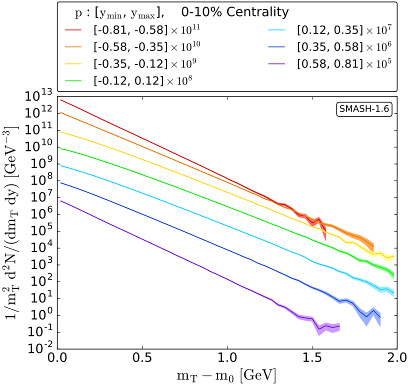


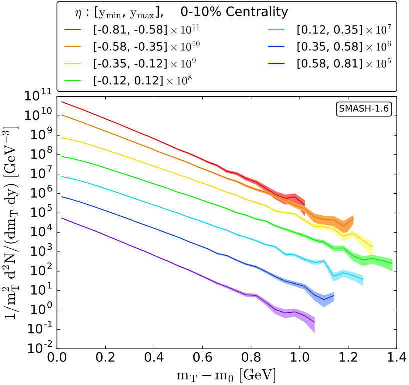
- Typical Gaussian behavior for 0-10% centrality
- Protons: expected behaviour as a function of centrality is observed

$\Rightarrow$ Longitudinal dynamics seem reasonable

Transverse Mass

Normalized m_T distributions





$\Rightarrow$ Noticeable difference in slopes of each rapidity bin

Inverse Slope Parameter

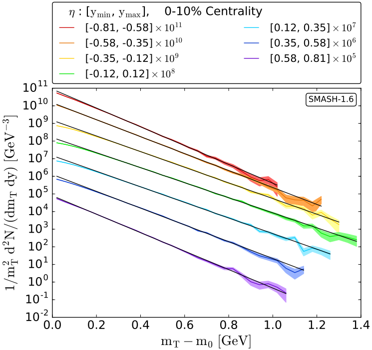
Applying the Boltzmann fit for each rapidity bin

$$\frac{1}{m_T^2}\frac{d^2N}{dm_T dy} = C(y)\exp\left(-\frac{(m_T - m_0)}{T_B(y)}\right)$$

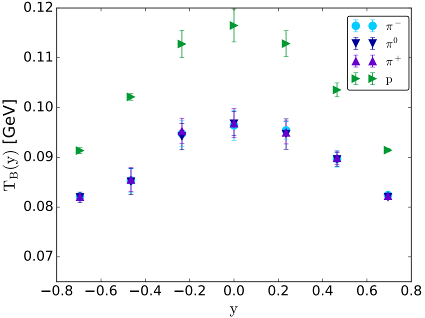
yields inverse slope parameter $\mathrm{T_B(y)}$:

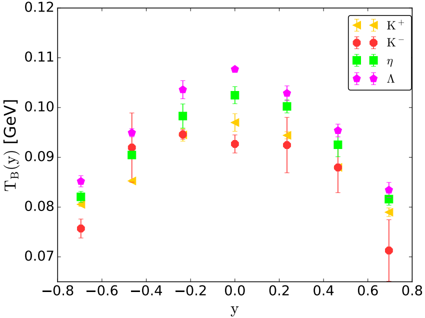
$$T_B(y) = \frac{T_{\mathrm{eff}}}{\cosh(y)}$$

which is connected to the effective temperature $\mathrm{T_{eff}(y)}$.



Inverse Slope Parameters:





Effective Temperatures:

	π^-	π^0	π^+	p	K^+	K^-	η	Λ
$T_{eff}(y)$ [MeV]	102.6	101.6	102.8	114.3	97.6	96.0	100.8	106.8

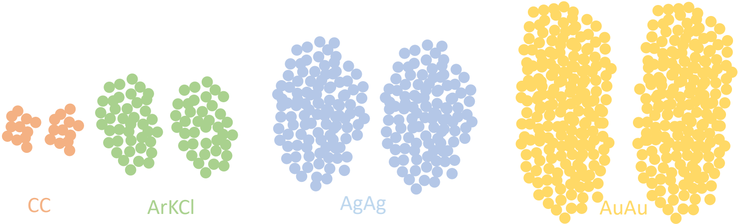
Analysis of additional collision systems of different sizes at **same energy**

	HADES [A GeV]	This Work [A GeV]
CC[1]	2.0	1.58
ArKCl[2]	1.76	1.58
AuAu[3]	1.23	1.58
AgAg	1.58	1.58

[1] HADES Collab. (2009): arXiv:0906.2309v1 [nucl-ex]

[2] G. Agakishiev *et al.* (2013): Eur. Phys. J. A 49, 34

[3] C. Franco (2017): JPS Conf. Proc. 13, 020003



N_{part} Scaling

AuAu collisions at 1.23A GeV:

$$\frac{N}{N_{part}} \sim (N_{\text{part}})^{\alpha}$$

⇒ Strange particles scale with same α exponent!

HADES Paper

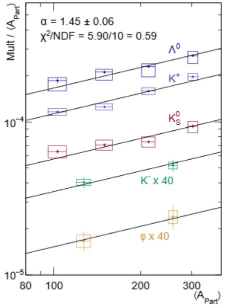
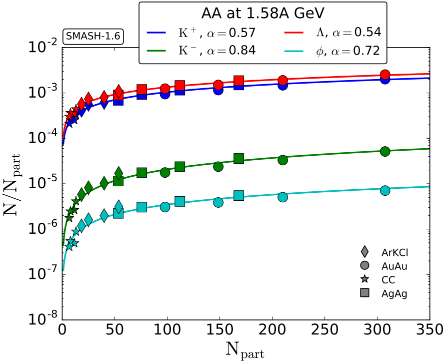


FIG. 5: Multiplicities per mean number of participants Mult/$\langle A_{part}\rangle$ as a function of $\langle A_{part}\rangle$. All hadron yields are fitted simultaneously with a function of the form Mult $\propto \langle A_{part}\rangle^{\alpha}$ with the result: $\alpha = 1.45 \pm 0.06$.

HADES Collab. (2019): Phys.Lett. B793, 457-463

N_{part} Scaling



Here: cross system behavior

⇒ different α's – why?

- Different energy
- Depend on definition of participants and centrality classes

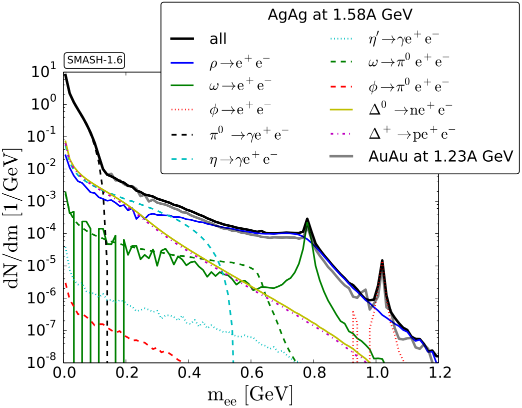
Number of participants N_{part} from MC Glauber

Centrality	CC	ArKCl	AgAg	AuAu
0-10%	13.1	53.8	168.1	307.4
10-20%	11.5	39.9	112	210
20-30%	7.8	25	75.8	148.6
30-40%	5.7	18.4	53.4	97.9

D. Miskowiec: http://web-docs.gsi.de/ misko/overlap/

Dilepton Emission

- Collisional broadening
- (Vacuum) Breit-Wigner distributions for all resonances
- Larger systems require additional medium modifications
- Similar to AuAu at 1.23A GeV



Summary and Outlook

Summary

- Predictions for Ξ^- yields with SMASH
- Determination of T_{eff} between 96 and 114.3 MeV, depending on particle species
- Analysis of cross system N_{part} scaling, found α's between 0.54 and 0.84
- Invariant mass spectra for dileptons similar to Au+Au collisions at 1.23 AGeV

Outlook

- Comparison to experimental data
- Further constraint particle production (ϕ, Ξ^-)
- Publication of results

Backup: Resonance Shift

Why is it necessary?

SMASH follows resonance treatment introduced by Manley and Saleski[1] to calculate the decay widths:

$$\Gamma_{R\to ab} = \Gamma^0_{R\to ab}\frac{\rho_{ab}(m)}{\rho_{ab}(M_0)}$$

⇒ Calculation of ρ does not work if sum of decay products is larger than resonance pole mass!

Why is it reasonable?

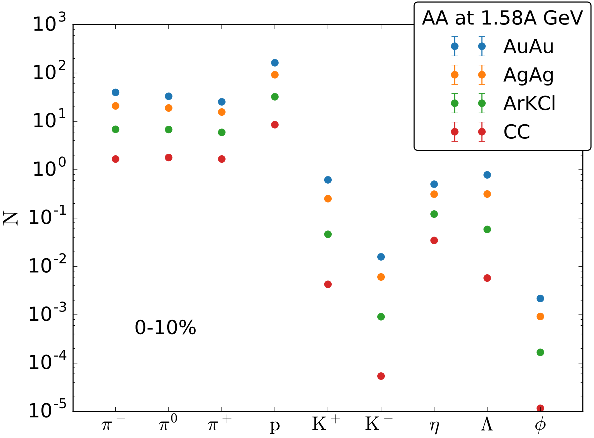
Resonances N(2220) and N(2250) are experimentally not well constrained and have a broad width[2]:

- Width of 300 MeV
- Errorbars of ∼100 MeV

[1] D. M. Manley and E. M. Saleski, Phys. Rev. D **45**, 4002 (1992)

[2] http://pdg.lbl.gov/2019/listings/contents_listings.html

Backup: System Size Dependence



Backup: Spectators