Overview of the results from the NA61/SHINE strong interaction program

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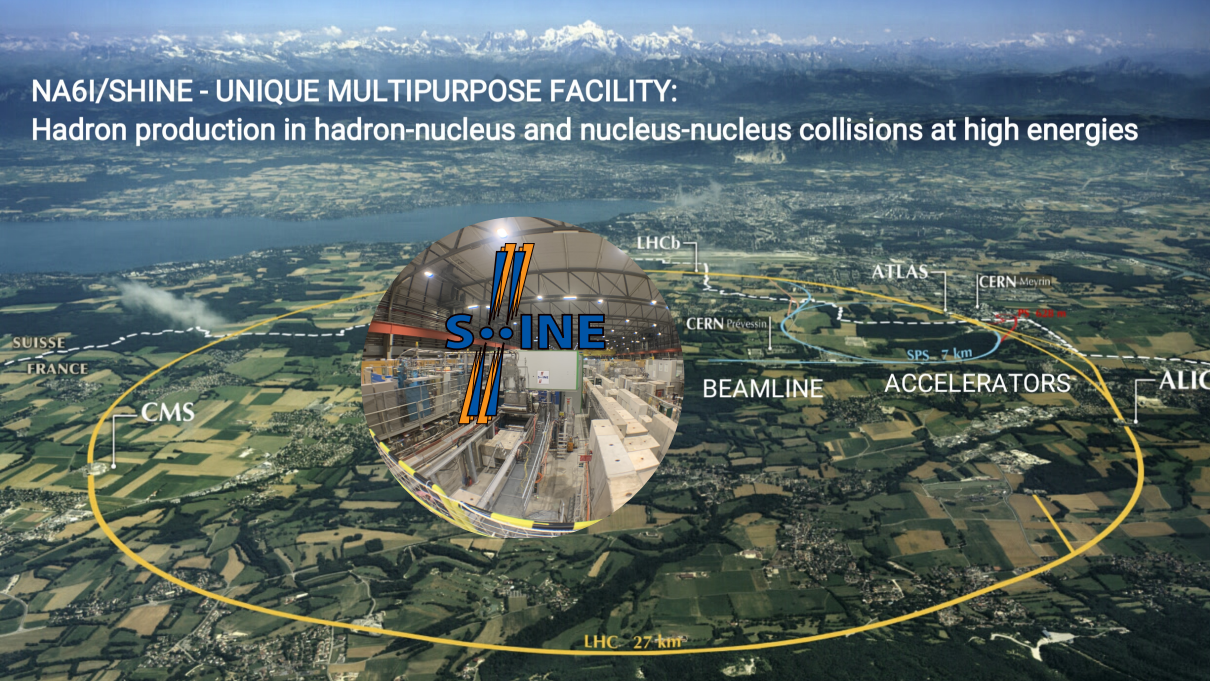
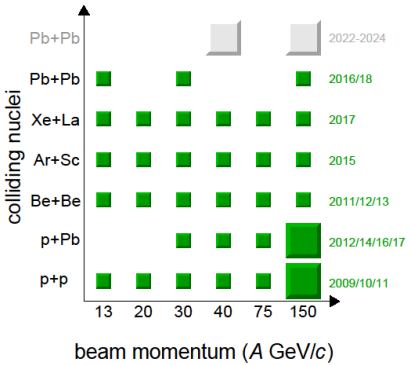
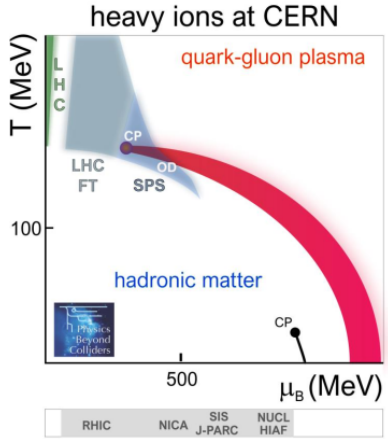
NA6I/SHINE - UNIQUE MULTIPURPOSE FACILITY:
Hadron production in hadron-nucleus and nucleus-nucleus collisions at high energies



NA61/SIHNE two-dimensional scan

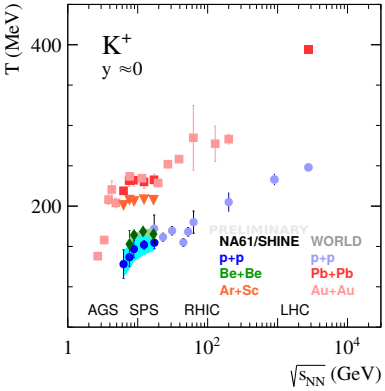
In 2017 NA61/SHINE finished a two-dimensional scan in **collision energy** and **size of the colliding system**. Results of the measurements are used to study the **phase diagram of strongly interacting matter**.

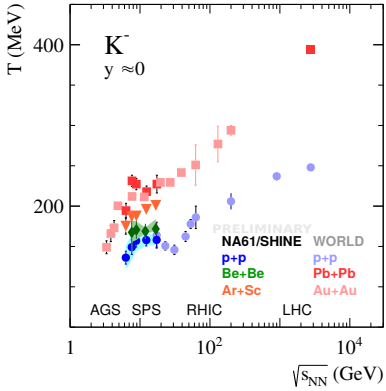




Study of the onset of deconfinement

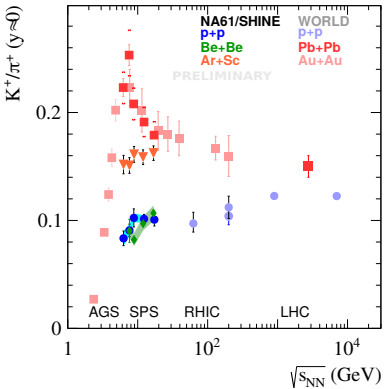
Onset of deconfinement: step

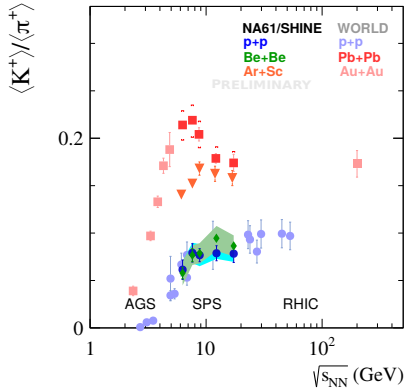




- Plateau in the inverse slope parameter T of m_T spectra of $K^{\pm}$ spectra in Pb+Pb was predicted within SMES due to mixed phase of hadron gas and QGP *Acta Phys. Polon.* **B30**, 2705 (1999)
- Similar structures are visible in other systems
- Magnitude of the T parameter increases with the colliding system size

Onset of deconfinement: horn

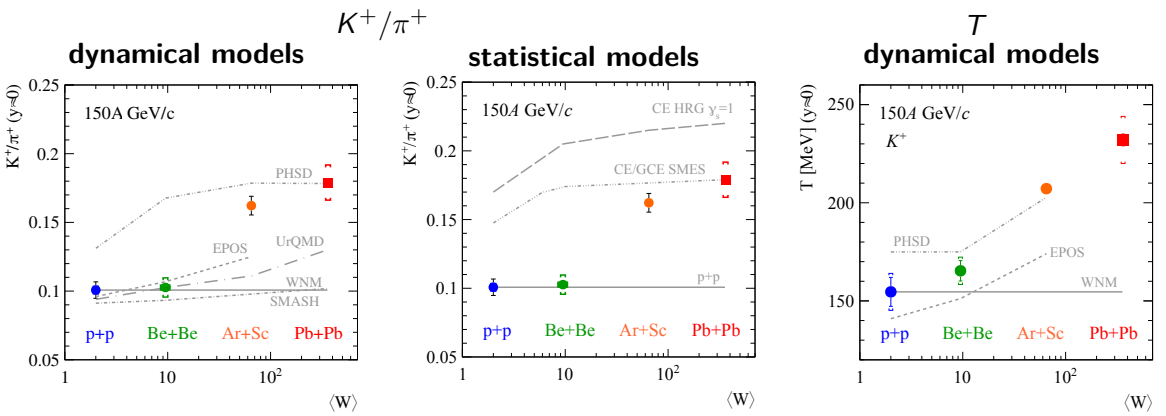




- Rapid change in the energy dependence of K^+/π^+ ratio in Pb+Pb collisions indicated the onset of deconfinement in the SPS energy range, as predicted within SMES
- Plateau like structure visible in small systems (p+p and Be+Be)
- Ar+Sc systematically higher, shows dependence on collision energy qualitatively similar to p+p and Be+Be (no horn structure)

Study of the onset of fireball

System size dependence of K^+/π^+ and T at 150A GeV/c



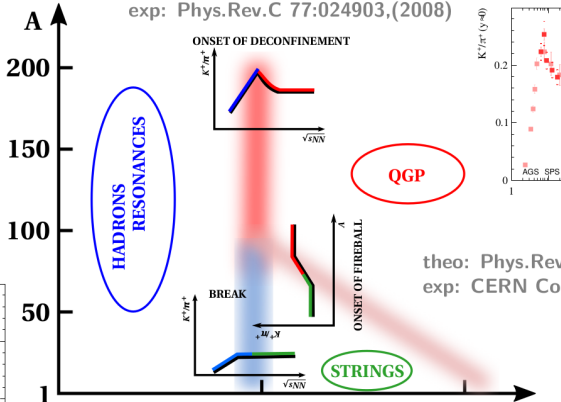
- None of the models reproduce K^+/π^+ ratio or T in the whole $\langle W \rangle$ range

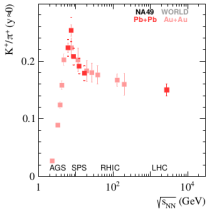
PHSD: Eur.Phys.J.A 56 (2020) 9, 223, arXiv:1908.00451 and private communication;
SMASH: J.Phys.G 47 (2020) 6, 065101 and private communication;
UrQMD and HRG: Phys. Rev. C99 (2019) 3, 034909;
SMES: Acta Phys. Polon. B46 (2015) 10, 1991 - recalculated

p+p: Eur. Phys. J. C77 (2017) 10, 671
Be+Be: Eur. Phys. J. C81 (2021) 1, 73
Ar+Sc: NA61/SHINE preliminary
Pb+Pb: Phys. Rev. C66, 054902 (2002)

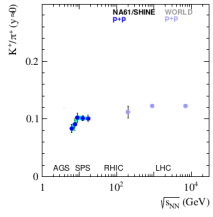
Unique NA61/SHINE results on heavy ion collisions

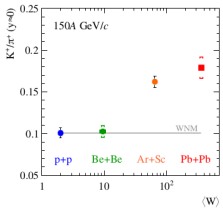
theo: Acta Phys.Polon.B 46 (2015) 10, 1991
exp: Phys.Rev.C 77:024903,(2008)





theo: Phys.Rev.D 90 025031 (2014)
exp: CERN Courier, Sep 23rd, 2019





theo: Phys.Part.Nucl. 51 (2020) 3, 337-339
exp: Phys.Rev.C 102 (2020) 1, 011901

Search for Critical Point

Second factorial moment - proton intermittency

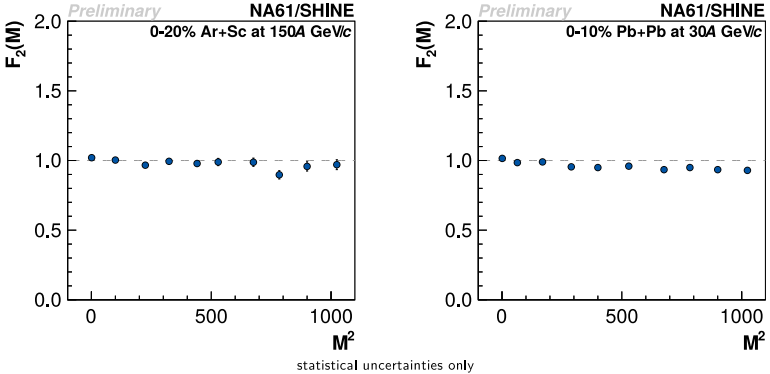
using statistically independent points and cumulative variables:

$$F_2(M) = \frac{\langle \frac{1}{M} \sum_{i=1}^{M} n_i(n_i - 1) \rangle}{\langle \sum_{i=1}^{M} n_i \rangle^2}$$

M - number of p_T subdivision intervals
n_i - number of particles in i-th p_T bin

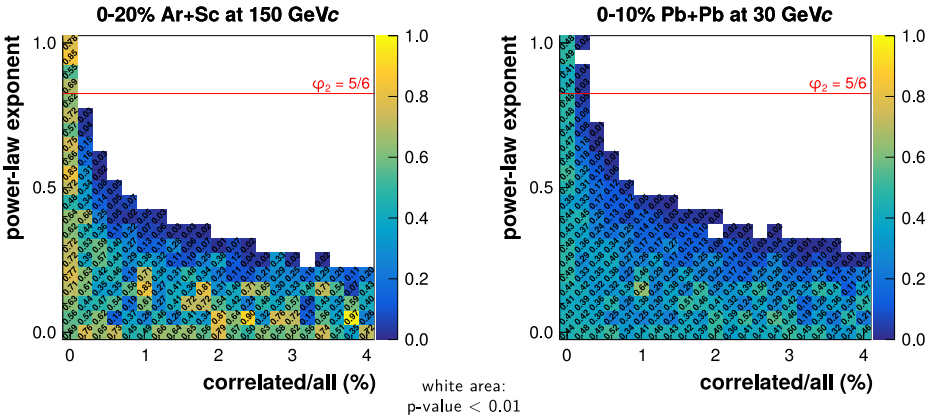
At the second order phase transition $F_2(M)$ exhibits a power-law dependence on M:

$$F_2(M) \sim (M^2)^{\phi_2}$$



- $F_2(M)$ of protons for Ar+Sc at 150A GeV/c and Pb+Pb at 30A GeV/c show no indication of power-law increase with number of bins

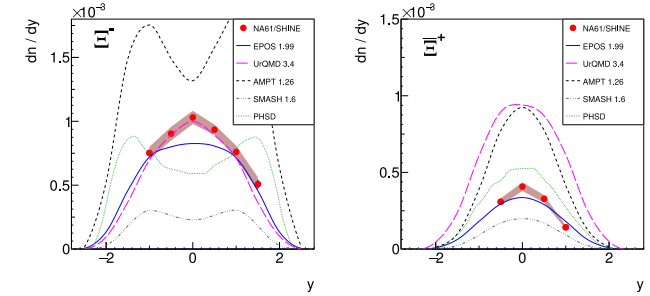
Exclusion plots for parameters of simple power-law model



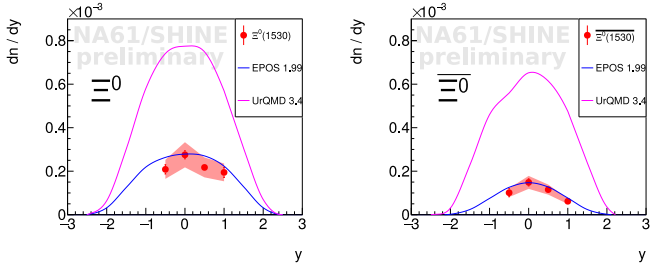
- The intermittency index ϕ_2 for a system freezing out at the QCD critical endpoint is expected to be $\phi_2 = 5/6$ assuming that the latter belongs to the 3-D Ising universality class.

Strangeness production in $p+p$ at 158 GeV/c

Strangeness production in p+p at 158 GeV/c



Eur.Phys.J.C 80 (2020) 9, 833



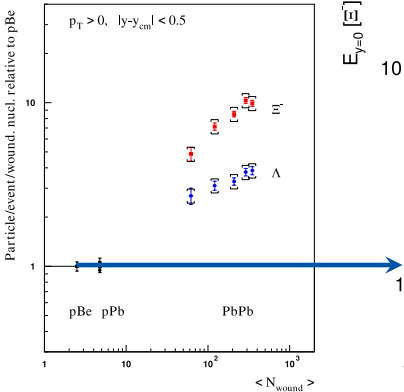
arXiv:2105.09144

- First measurements of $\Xi^{\pm}$ and $\Xi^0(1530)$ in p+p interactions at CERN SPS energies

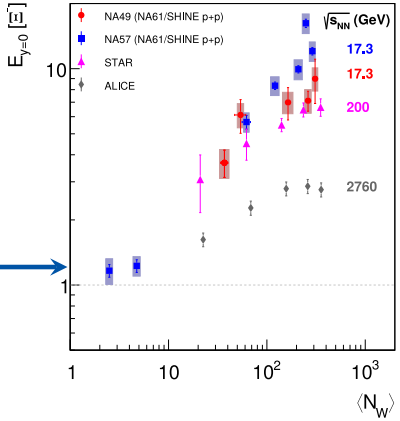
Present theoretical models do not describe the NA61/SHINE results on strange particles production in p+p interactions

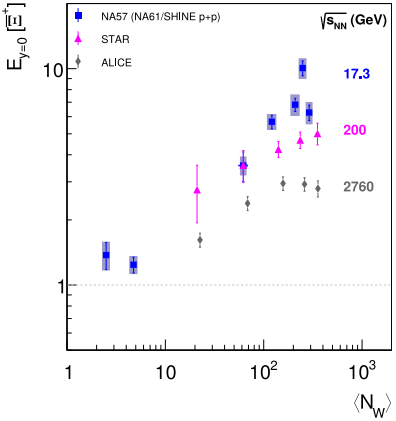
Strangeness enhancement factors

J. Phys. G 32 (2006) 427–442



Eur.Phys.J.C 80 (2020) 9, 833





$$E_{\Xi_s} = \frac{2}{\langle W \rangle} \frac{dn/dy(A+A)}{dn/dy(p+p)}$$

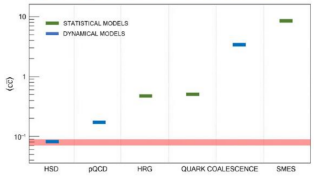
NA61/SHINE results give new base-line for strangeness enhancement study in SPS energy range

NA61/SHINE in 2022-2024

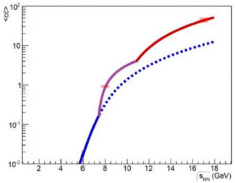
- What is the mechanism of open charm production?
- How does the onset of deconfinement impact open charm production?
- How does the formation of quark-gluon plasma impact J/ψ production?

To answer these questions a **mean number of charm quark pairs**, $\langle c\bar{c}\rangle$, produced in A+A collisions has to be known. Up to now corresponding **experimental data does not exist** and **only NA61/SHINE can perform this measurement in the near future**.

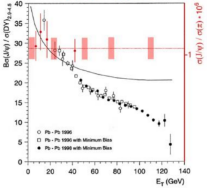
$\langle c\bar{c}\rangle$ and models



$\langle c\bar{c}\rangle$ and onset of deconfinement



$\langle c\bar{c}\rangle$, $\langle J/\psi\rangle$ and QGP



Foreseen NA61/SHINE resolution is sufficient to answer addressed questions

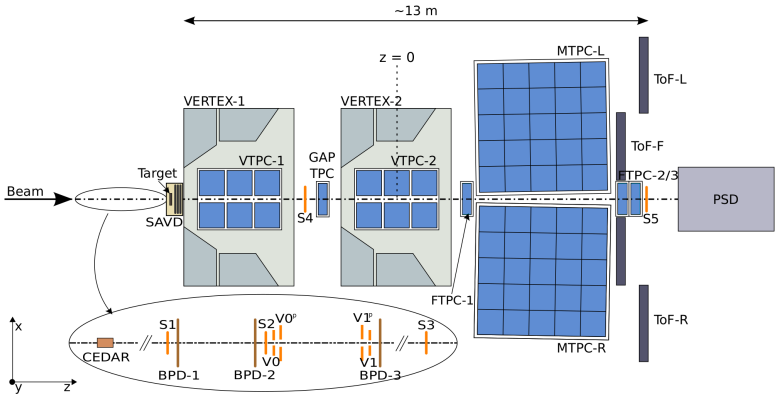
Summary

- Unique 2D scan in system size and the collision energy is completed
- So-called step structure visible in p+p, Be+Be, and Ar+Sc
- So-called horn structure does not appear in p+p, Be+Be, and Ar+Sc
- Unexpected system-size dependence: (p+$p \approx$ Be+Be) $\neq$ (Ar+Sc $\leqslant$ Pb+Pb)
- So far no convincing indication of the Critical Point
- Unique results on multi-strange baryons production in p+p interactions in SPS
- NA61/SHINE will measure open charm production in 2022-2024

Thank you

Backup

Fixed target experiment located at the CERN SPS accelerator:

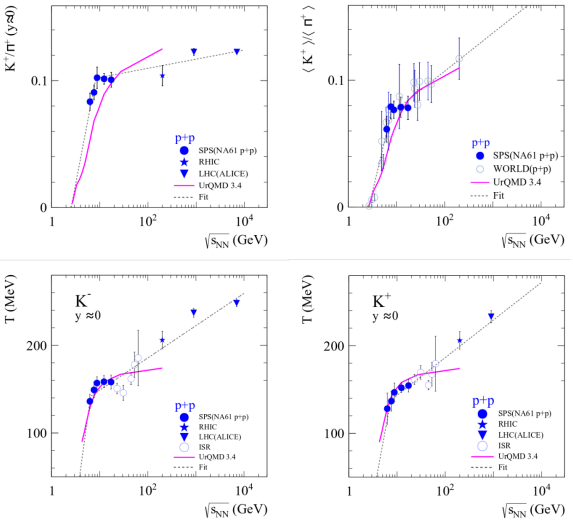


Beams:

- hadrons (π, K, p) p_{beam}=13-400 GeV/c
- ions (Be, Ar, Xe, Pb) p_{beam}=13-150A GeV/c
- $\sqrt{s_{NN}}$=5.1-16.8(27.4) GeV

Large acceptance hadron spectrometer covers the full forward hemisphere, down to $p_T = 0$

Transition from resonances to strings



- Rates of increase of K^+/π^+ and T change sharply in $p+p$ collisions at SPS energies
- The fitted change energy is ≈7 GeV - close to the energy of the onset of deconfinement ≈8 GeV
- Models assuming change from resonances to string production mechanism show similar trend

Proton intermittency - simple power-law model

Lots of model data sets generated:

- correlated-to-all ratio: vary from 0.0 to 4.0% (with 0.2 step)
- power-law exponent: vary from 0.00 to 1.00 (with 0.05 step)

and compared with the experimental data

For the construction of exclusion plots, statistical uncertainties were calculated using model with statistics corresponding to the data.