

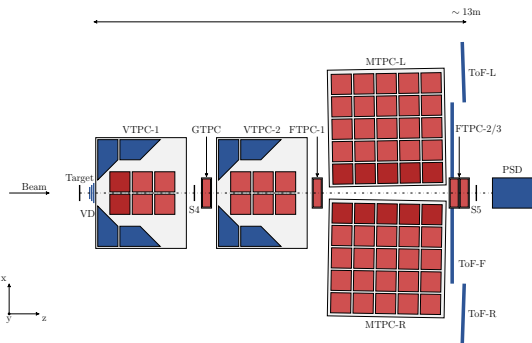
Pion spectra in Ar+Sc collisions in the NA61/SHINE collaboration

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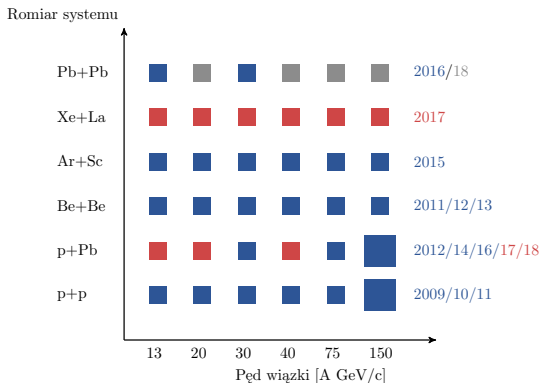
The NA61/SHINE detector



- **Fixed target** experiment,
- Located at the **SPS** accelerator,
- **Large acceptance** spectrometer – coverage of the full forward hemisphere, down to $p_T = 0$,
- Selection of **events based on forward energy** (projectile spectators) measured in PSD.

Strong interactions programme at NA61/SHINE

The NA61/SHINE performs a 2D scan over system size and collision energy to study the phase diagram of strongly interacting matter in temperature and baryon density.



■ Data taken,
■ Large statistics data taken,

■ Data taking scheduled,
■ Data taking planned,

Strong interactions programme at NA61/SHINE

In this talk news on 4π mean π^- multiplicity in $^{40}\text{Ar}+^{45}\text{Sc}$ collision in 5% most violent collisions will be presented.

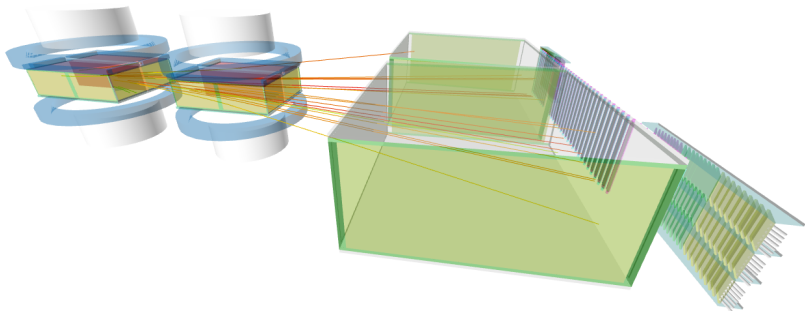
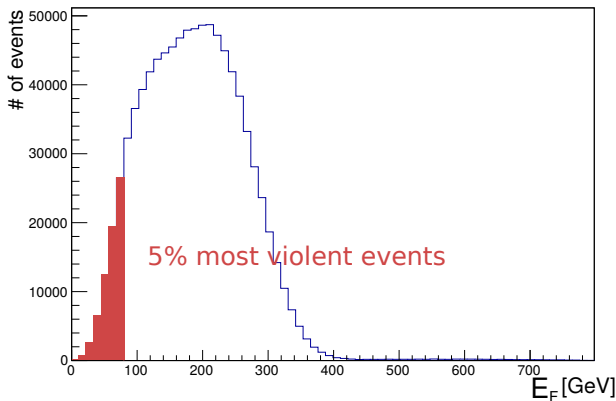


Figure: shine3d.web.cern.ch/shine3d/

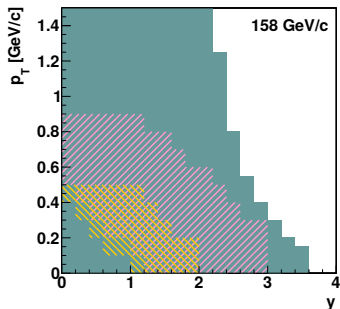
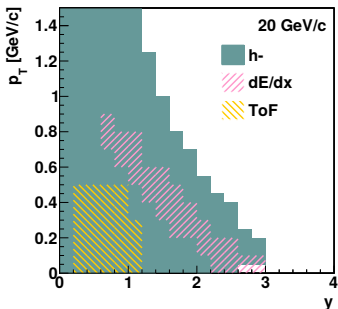
Event classes

Event (centrality) classes are **chosen using the forward energy**, $E_F \approx$ energy of projectile spectators. E_F is measured by the PSD zero-degree calorimeter. This is an important feature of NA61/SHINE.

Example for Ar+Sc at 13A GeV/c



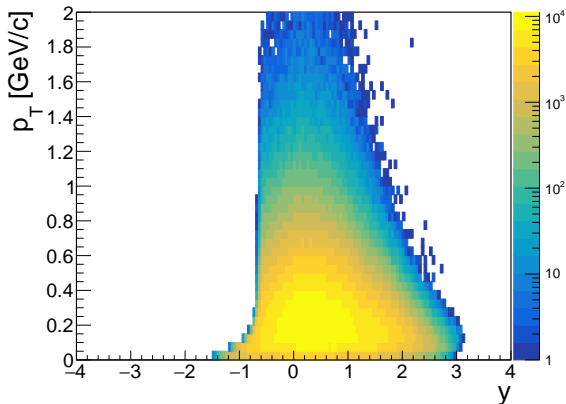
PID methods in NA61/SHINE



- dE/dx method estimates multiplicities of π^\pm , K^\pm , p and \bar{p} using energy loss measurements in TPCs,
- $tof-dE/dx$ method estimates multiplicities of π^\pm , K^\pm , p and \bar{p} using energy loss and particle time of flight measurements in ToFs,
- h^- method estimates multiplicities of π^- based on the fact that the majority of negatively charged hadrons produced in p+p and A+A collisions are π^- .

The h^- method

Example for $^{40}\text{Ar} + ^{45}\text{Sc}$ at 19A GeV/c



The h^- method is used to extract π^- spectra in Ar+Sc interactions at different beam momenta. Results refer to pions produced by strong interaction processes and in electromagnetic decays of produced hadrons.

The h^- method

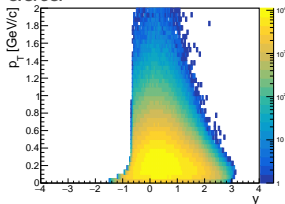
- The experimental data undergoes series of **quality cuts**.
- Spectra of negatively charged particles are determined using the selected events and tracks,
- The spectra are **corrected for acceptance, reconstruction efficiency and contamination of particles other than primary π^- mesons** by EPOS 1.99 Monte Carlo model¹.
- Mean π^- multiplicity in 4π is estimated by summing up the measured spectra and correcting it for missing acceptance by extrapolation.

¹Liu et al. *PRC* 74.

The h^- method

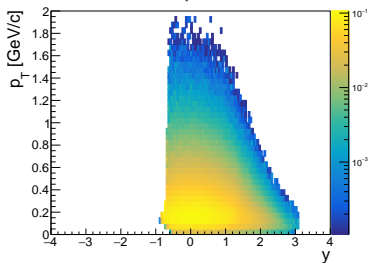
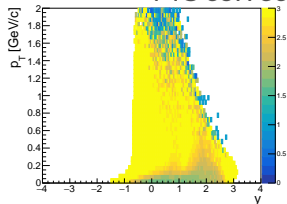
Example for $^{40}\text{Ar} + ^{45}\text{Sc}$ at 19A GeV/c

Raw data



$$\times \frac{1}{N_{\text{event}}} \times$$

MC corrections

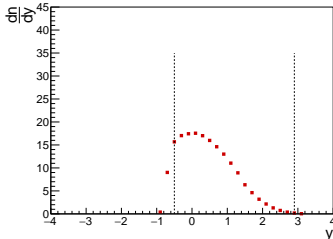
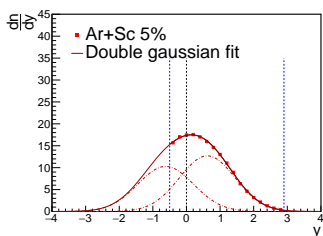
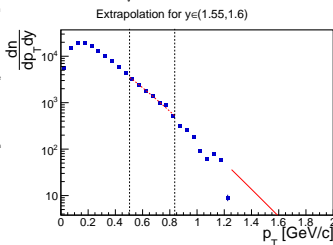
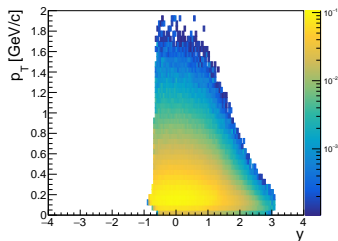


Corrected π^- spectrum

Extrapolation to 4π acceptance

Example for $^{40}\text{Ar} + ^{45}\text{Sc}$ at 19A GeV/c

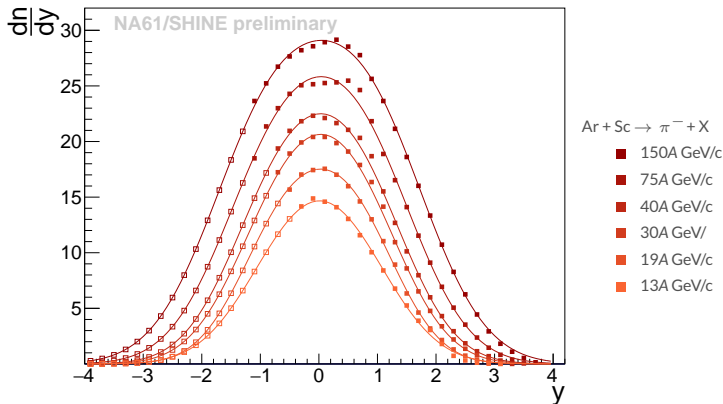
Extrapolation in p_T



Sum

Fitting Gaussians

Results: π^- rapidity spectra



- π^- spectra measured in large acceptance: p_T down to 0, in full forward hemisphere.
- Rapidity spectra are approximately gaussian, independently of the collision energy,
- Only statistical uncertainties plotted.

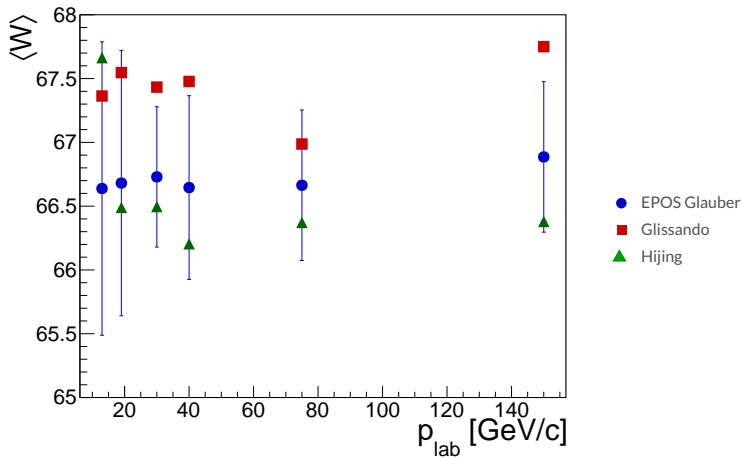
Mean number of wounded nucleons $\langle W \rangle$

- Mean number of wounded nucleons (nucleons interacting inelastically calculated within the Glauber model) $\langle W \rangle$ obtained using **EPOS 1.99**² Monte Carlo,
- Systematic and statistical uncertainties plotted. Systematic uncertainties are based on the uncertainty of p+p inelastic collision cross section and the difference between EPOS and Hijing values.
- $\langle W \rangle$ calculated from EPOS is $< 1\%$ larger than that from Glissando³,
- 5% most violent events chosen based on the number of projectile spectators. **Event selection based on the full simulation of the PSD response is under way.** Uncertainty coming from the selection is not shown here.

²Liu et al. *PRC* 74.

³Rybczyński et al. *Comp. Phys. Comm.* 185.6.

Mean number of wounded nucleons $\langle W \rangle$



Example of 5% most violent Ar+Sc collisions

Results: $\langle\pi^{-}\rangle$ and $\langle W\rangle$

Preliminary results for 4π , 5% event class $\langle\pi^{-}\rangle$ and $\langle W\rangle$ for Ar+Sc at different SPS momenta.

- Systematic uncertainty of $\langle\pi^{-}\rangle$ is estimated to be 5% based on previous NA61/SHINE analysis⁴.

	p_{lab} [A GeV/c]	$\langle\pi^{-}\rangle$	$\langle W\rangle$
Ar+Sc	13	38.46 ± 1.92	66.63 ± 0.50
	19	48.03 ± 2.40	66.68 ± 1.02
	30	59.72 ± 2.98	66.72 ± 0.50
	40	66.28 ± 3.31	66.64 ± 0.57
	75	86.12 ± 4.30	66.66 ± 0.52
	150	108.92 ± 5.44	66.88 ± 0.50

⁴N. Abgrall et al. *EPJ C* 74.3, p. 1.

Isospin correction

In order to compare results obtained for different systems, the **isospin correction** should be taken into account. To this end phenomenological formulas are used

$$\langle \pi^- \rangle_{N+N} = \langle \pi^- \rangle_{p+p} + \frac{1}{3}$$

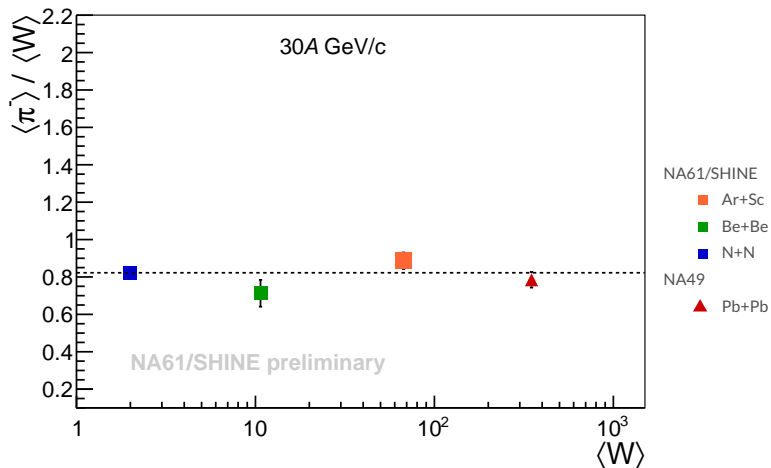
$$\langle \pi^- \rangle_{Au+Au}^I = (\langle \pi^- \rangle_{Au+Au} + \langle \pi^+ \rangle_{Au+Au})/2$$

The correction is only applied to measurements where its effect is the strongest. This assumption is based on the compilation of the world data presented in⁵ and the model presented therein.

Where needed, the data is corrected for slight differences in beam momentum.

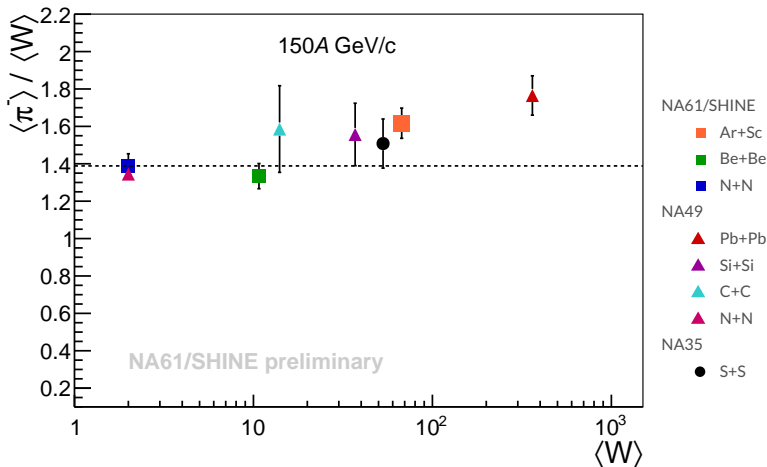
⁵Golokhvastov. *Physics of Atomic Nuclei* 64.1, p. 84.

Results: $\langle \pi^- \rangle / \langle W \rangle$ ratio



- No increase with system size,
- Systematic and statistical uncertainties plotted.

Results: $\langle \pi^- \rangle / \langle W \rangle$ ratio



- Data suggests monotonic increase with system size at 150A GeV/c. **Ar+Sc and Be+Be measurements in line.**
- Systematic and statistical uncertainties plotted.

The "Kink" plot

The Fermi statistical model predicts linear increase of $\langle\pi\rangle/\langle W\rangle$ with the Fermi energy measure

$$F = \left[\frac{(\sqrt{s_{NN}} - 2m_N)^3}{\sqrt{s_{NN}}} \right]^{1/4}$$

An increase of the slope of $\langle\pi\rangle/\langle W\rangle$ - **KINK** - at the onset of deconfinement is predicted by the SMES⁶ due to the larger number of effective degrees of freedom in comparison to HRG.

⁶Gazdzicki and Gorenstein. *APP B30*.

Estimation of $\langle\pi\rangle$ from $\langle\pi^{-}\rangle$

As for the NA61 Ar+Sc, Be+Be and p+p data we only have the $\langle\pi^{-}\rangle$ value, the multiplicities of $\langle\pi^{+}\rangle$ and $\langle\pi^{0}\rangle$ are as:

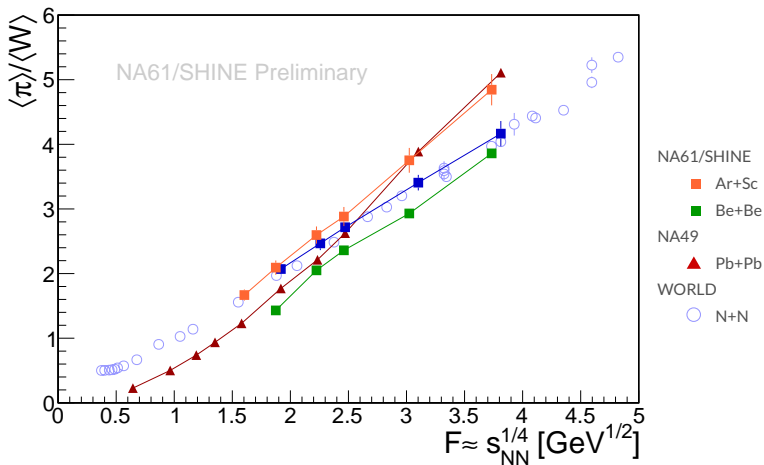
$$\langle\pi\rangle_{\text{N+N}} = 3\langle\pi^{-}\rangle_{\text{N+N}}$$

$$\langle\pi\rangle_{\text{Ar+Sc}} = 3\langle\pi^{-}\rangle_{\text{Ar+Sc}}$$

$$\langle\pi\rangle_{\text{Be+Be}} = 3\langle\pi^{-}\rangle_{\text{Be+Be}}$$

This approach is motivated by the fact that the **NA61/SHINE acceptance is the largest for π^{-}** .

The "Kink" plot



- At high SPS energies Be+Be approximately follows p+p, whereas Ar+Sc follows Pb+Pb.
- At low SPS energies no simple systematic is observed. The reason might be physical or due to systematic bias in $\langle W \rangle$ estimate. Full simulation of fragmentation process and PSD response is needed.

Summary

- Preliminary results on π^- multiplicities in 5% most violent collisions of Ar+Sc at $p_{\text{lab}} = 13A, 19A, 30A, 40A, 75A, 150A$ GeV/c are presented.
- The $\langle\pi^-\rangle/\langle W\rangle$ system size dependence is compared with other systems.
- The system size and energy dependence of the $\langle\pi^-\rangle/\langle W\rangle$ ratio was discussed in the context of previous measurements on other collision systems.
- **At high SPS energies Ar+Sc follows Pb+Pb.**
- **At low SPS energies no simple systematic is observed.**
- **Full simulation of fragmentation process and PSD response is urgently needed.**

Thank you for your attention.