Mean pion multiplicities in Ar+Sc collisions

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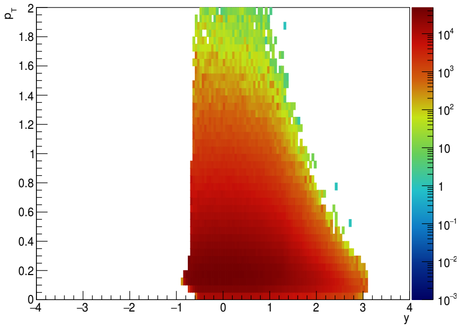
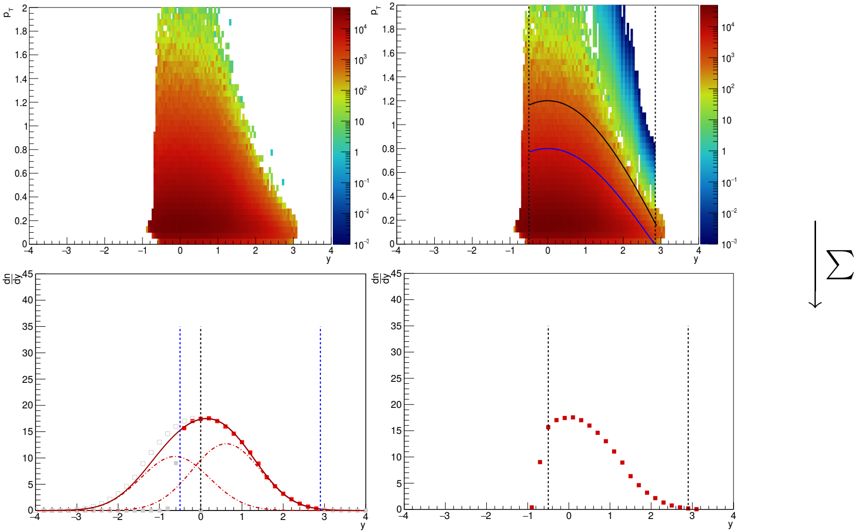
Pion spectra from h^- analysis

The data extracted using the h^- method is used for the calculation of mean pion multiplicities. In order to obtain 4π acceptance the $\frac{dn}{dy dp_T}$ is extrapolated in p_T and y.



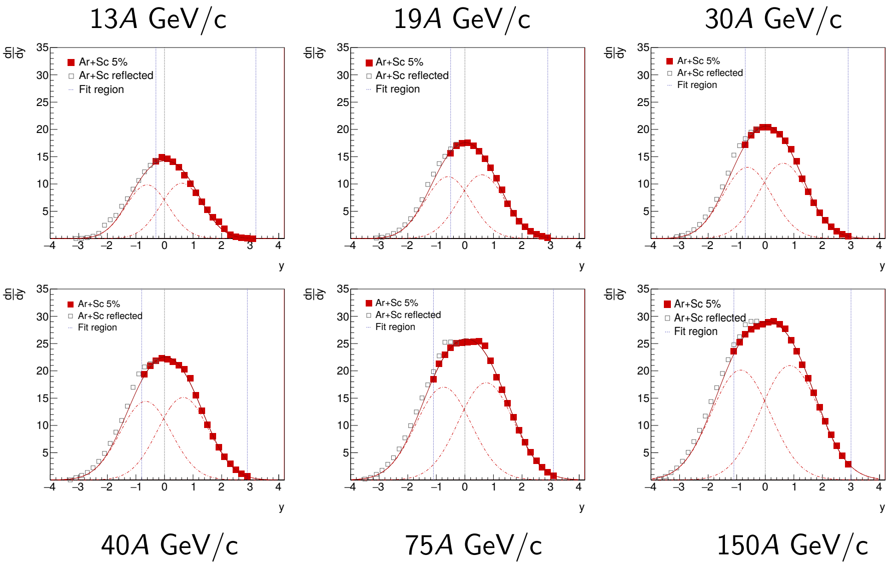
The details of the extrapolation process are described in separate presentation by Maciej Lewicki.

Extrapolation in p_T



Fitting Gaussians

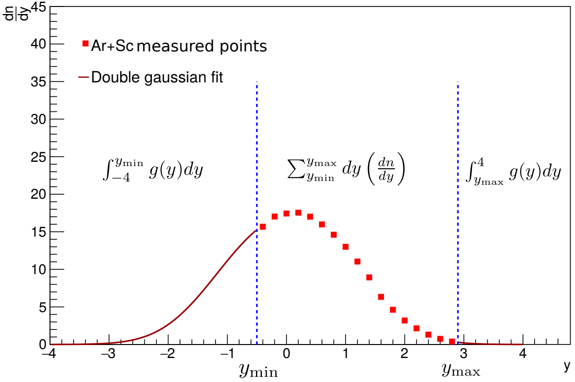
Resulting y spectra with fitted Gaussians



Calculating mean pion multiplicity

The total mean π^- multiplicity is calculated as:

$$\langle \pi^- \rangle = \int_{-4}^{y_{\text{min}}} g(y)dy + \sum_{y_{\text{min}}}^{y_{\text{max}}} dy \left(\frac{dn}{dy} \right)_{\text{extrapolated in} p_T} + \int_{y_{\text{max}}}^{4} g(y)dy$$



Statistical and systematic uncertainties for $\langle \pi^- \rangle$

Statistical uncertainties $\sigma_{\text{stat}}(\langle \pi^- \rangle)$ are propagated from the statistical uncertainties of $\frac{dn}{dydp_{\text{T}}}$ spectra.

Systematic uncertainties $\sigma_{\text{sys}}(\langle \pi^- \rangle)$ are assumed to be 5% based on previous NA61 analysis (from p+p collisions).

Preliminary results

The procedure leads to the following results:

Momentum [A GeV/c]	13	19	30	40	75	150
$\langle\pi^-\rangle$	38.46	48.03	59.72	66.28	86.12	108.92
$\sigma_{\text{stat}}(\langle\pi^-\rangle)$	$\pm$0.021	$\pm$0.021	$\pm$0.024	$\pm$0.018	$\pm$0.0079	$\pm$0.0088
$\sigma_{\text{sys}}(\langle\pi^-\rangle)$	$\pm$1.92	$\pm$2.40	$\pm$2.98	$\pm$3.31	$\pm$4.30	$\pm$5.44

Statistical uncertainty is negligible comparing to the systematic one. The former is smaller than the bin size, therefore the total error calculated as $\sqrt{\sigma_{\text{sys}}^2 + \sigma_{\text{stat}}^2}$ is plotted.

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

$$\langle W \rangle = \langle N_W \rangle$$

The analysis of the mean number of wounded nucleons was performed using two Monte Carlo models:

- **Glissando 2.73**, *Computer Physics Communications, 185(6):1759 – 1772, 2014*[1]
- **EPOS 1.99** (version CRMC 1.5.3), *Phys. Rev. C, 74:044902, Oct 2006.* [2]

Uncertainties of $\langle W \rangle$ will not be presented.

Obtaining $\langle W \rangle$

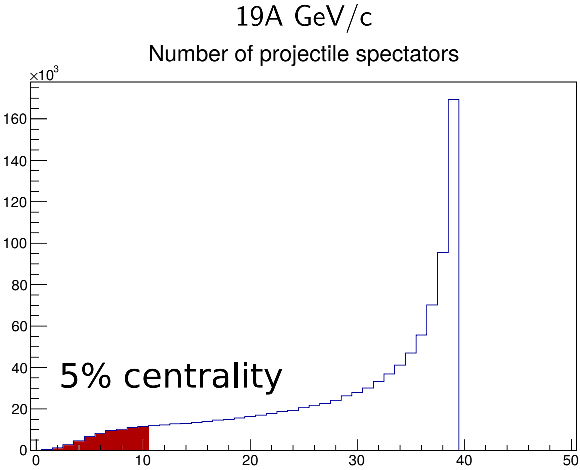
Glissando MC is based on Glauber model, whereas EPOS utilizes parton ladder model.

"...in our case the inelastic Nucleon-Nucleon cross-section in a nucleus is smaller than the corresponding pp cross-section leading to **less binary collisions than in standard Glauber**"

– Tanguy Pierog, core EPOS developer

Obtaining $\langle W \rangle$

In both models events are selected in the same way. **The selection is based on the number of projectile spectators.**



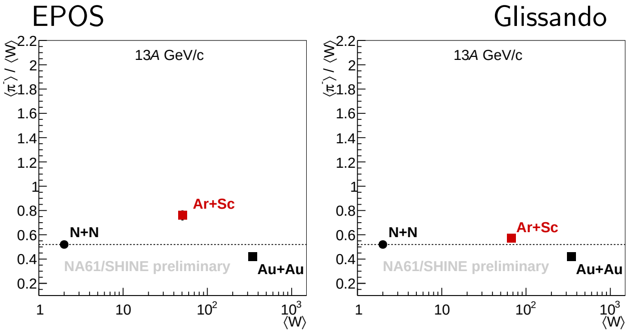
Obtaining $\langle W \rangle$

The differences between resulting $\langle W \rangle$ are significant. For lower momenta EPOS gives much smaller values than Glissando. In both cases the resulting $\langle W \rangle$ is calculated for 5% centrality.

Momentum [A GeV/c]	13	19	30	40	75	150
$\langle W \rangle_{\text{EPOS}}$	50.63	54.68	58.44	59.01	61.12	63.04
$\langle W \rangle_{\text{Glissando}}$	67.44	68.85	68.98	69.01	68.87	69.18

Obtaining $\langle W \rangle$

Changes in the value have a great impact on the $\langle \pi^- \rangle / \langle W \rangle$ ratio.
To visualize this fact, plots of the $\langle \pi^- \rangle / \langle W \rangle$ with $\langle W \rangle$ from different models is presented (only for Ar+Sc data).



- ■ $\langle \pi^- \rangle$ AGS Au+Au central collisions at 11.6*A* GeV [3],
- ● $\langle h^- \rangle$ Bonn-Hamburg-München p+p collisions at 12*A* GeV/c [4].

Ar+Sc preliminary data

In order to stay consistent with previously calculated ratios, **the value calculated using Glauber model $\langle W \rangle_{\text{Glissando}}$ is chosen.**

Momentum [A GeV/c]	$\langle \pi^- \rangle$	$\langle W \rangle_{\text{Glissando}}$	$\langle \pi^- \rangle / \langle W \rangle$
13	38.46	67.44	0.57 ± 0.028
19	48.03	68.85	0.69 ± 0.034
30	59.72	68.98	0.86 ± 0.043
40	66.28	69.01	0.96 ± 0.047
75	86.12	68.87	1.25 ± 0.062
150	108.92	69.18	1.57 ± 0.078

Be+Be preliminary data

Preliminary results for $\langle\pi^-\rangle/\langle W\rangle$ **in Be+Be collisions are presented** for the very first time.

Momentum [A GeV/c]	$\langle\pi^-\rangle$	$\langle W_{\text{Glissando}}\rangle$	$\langle\pi^-\rangle/\langle W\rangle$
19	5.32	10.615	0.50 ± 0.051
30	7.60	10.674	0.71 ± 0.071
40	8.75	10.676	0.81 ± 0.041
75	10.98	10.635	1.03 ± 0.052
150	14.32	10.737	1.33 ± 0.067

The systematic uncertainty $\sigma_{\text{sys}}(\langle\pi^-\rangle)$ for low momenta (i.e. 19 and 30A GeV/c) was approximated to 10% due to PSD module selection sensitivity. For higher momenta the error is assumed to be 5%.

$\langle \pi^- \rangle / \langle W \rangle$ comparison with other measurements

NA61/SHINE $\langle \pi^- \rangle$ results:

- ■ Ar+Sc 5% most central collisions at: 13, 19, 30, 40, 75 and 150A GeV/c,
- ▲ Be+Be 5% most central collisions at: 19, 30, 40, 75 and 150A GeV/c [5],
- ● p+p inelastic collisions at: 20, 31, 40, 80 and 158A GeV/c [6].

$\langle\pi^-\rangle/\langle W\rangle$ comparison with other measurements

NA49 $\langle\pi^-\rangle$ results:

- Pb+Pb 7% most central collisions at: 20, 30A GeV [7] and 40, 80A GeV [8],
- Pb+Pb 5% most central collisions at: 158A GeV [8],
- Si+Si 29.2% most central collisions at 80A GeV [9],
- Si+Si 12.2% most central collisions at 158A GeV [10],
- C+C 65.7% most central collisions at 80A GeV [9],
- C+C 15.3% most central collisions at 158A GeV [10],
- p+p inelastic collisions at 158A GeV [11].

$\langle\pi^-\rangle/\langle W\rangle$ comparison with other measurements

Other experiments' results:

- ■ $\langle\pi^-\rangle$ AGS Au+Au central collisions at 11.6A GeV [3],
- ▲ $\langle h^-\rangle$ NA35 S+S central collisions at 200A GeV [12],
- ● $\langle h^-\rangle$ Bonn-Hamburg-München p+p collisions at 12A GeV/c [4].

Isospin correction

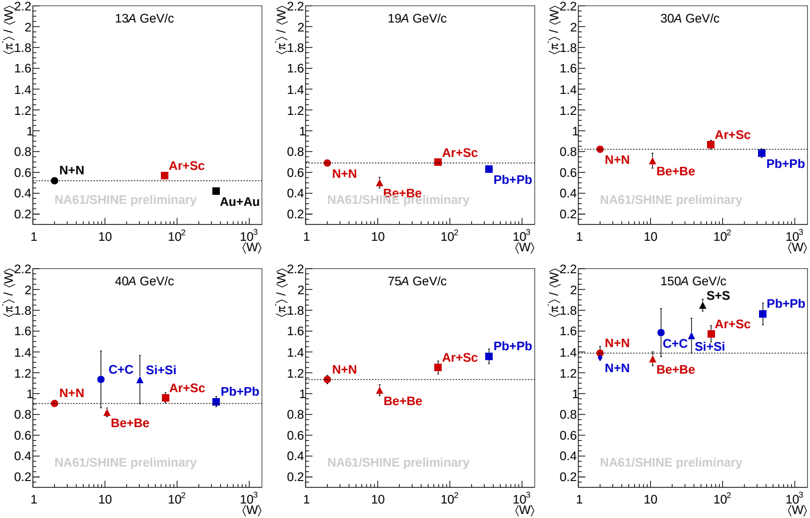
In order to compare results obtained for different systems, the **isospin correction** should be taken into account. To this end a phenomenological formulas are used

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

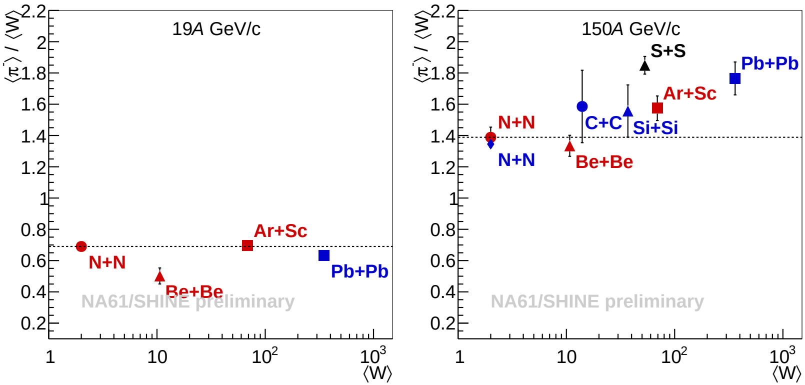
$$\langle \pi^- \rangle^{\mathrm{I}}_{\mathrm{Au+Au}} = (\langle \pi^- \rangle_{\mathrm{Au+Au}} + \langle \pi^+ \rangle_{\mathrm{Au+Au}})/2$$

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 in [13] and the model presented therein.

$\langle \pi^- \rangle / \langle W \rangle$



First glimpse at the preliminary Ar+Sc $\langle\pi^-\rangle/\langle W\rangle$



- Data shows monotonic behavior for 150*A* GeV/c momentum. **Ar+Sc measurement is in line with the trend**.
- **No monotonic behavior for 19*A* GeV/c** momentum caused by larger uncertainty of $\langle W\rangle$ than in 150*A* GeV/c.

The kink

The $\langle\pi\rangle/\langle W\rangle$ values can also be plotted against the Fermi energy measure

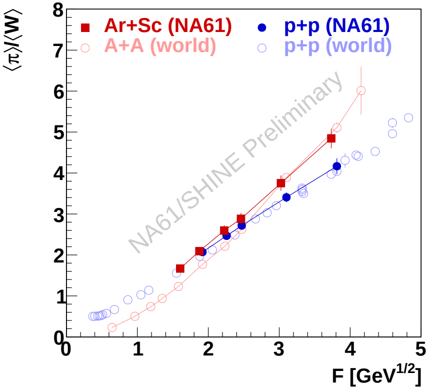
$$F = \left[\frac{(\sqrt{s_{\mathrm{NN}}} - 2m_{\mathrm{N}})^3}{\sqrt{s_{\mathrm{NN}}}}\right]^{1/4}$$

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 approximated in the following way

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

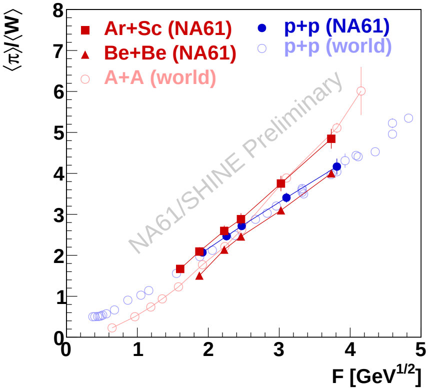
$$\langle\pi\rangle_{\mathrm{Ar+Sc}} = 3\langle\pi^-\rangle_{\mathrm{Ar+Sc}}$$

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



- For **high SPS energies Ar+Sc follows the Pb+Pb** trend,
- For **low SPS energies Ar+Sc follows the p+p** tendency.

First glimpse at the kink + preliminary BeBe data



- For **high SPS energies Be+Be follows the p+p** trend,
- For **low SPS energies Be+Be follows the Pb+Pb** tendency,
- Results suffer from **high model dependence of $\langle W \rangle$**.

Summary

- For $p_{\text{lab}} = 13A, 19A, 30A, 40A, 75A$ and $150A$ GeV/c the **preliminary results of $\langle\pi^-\rangle$ in Ar+Sc** at 5% centrality are obtained,
- Number of wounded nucleons $\langle W \rangle$ **is determined from the Glissando** model,
- Preliminary results of $\langle\pi^-\rangle/\langle W\rangle$ **ratios are calculated**,
- Comparison with other systems, i.e. N+N, Be+Be, Pb+Pb, C+C, Si+Si, S+S, Au+Au is presented,
- The enhancement of $\langle\pi\rangle/\langle W\rangle$ produced in p+p collision compared to A+A collisions is confirmed,
- Be+Be measurements of $\langle\pi^-\rangle/\langle W\rangle$ do not follow the trend, because of the **high model dependence of $\langle W \rangle$**, particularly for low SPS energies.

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