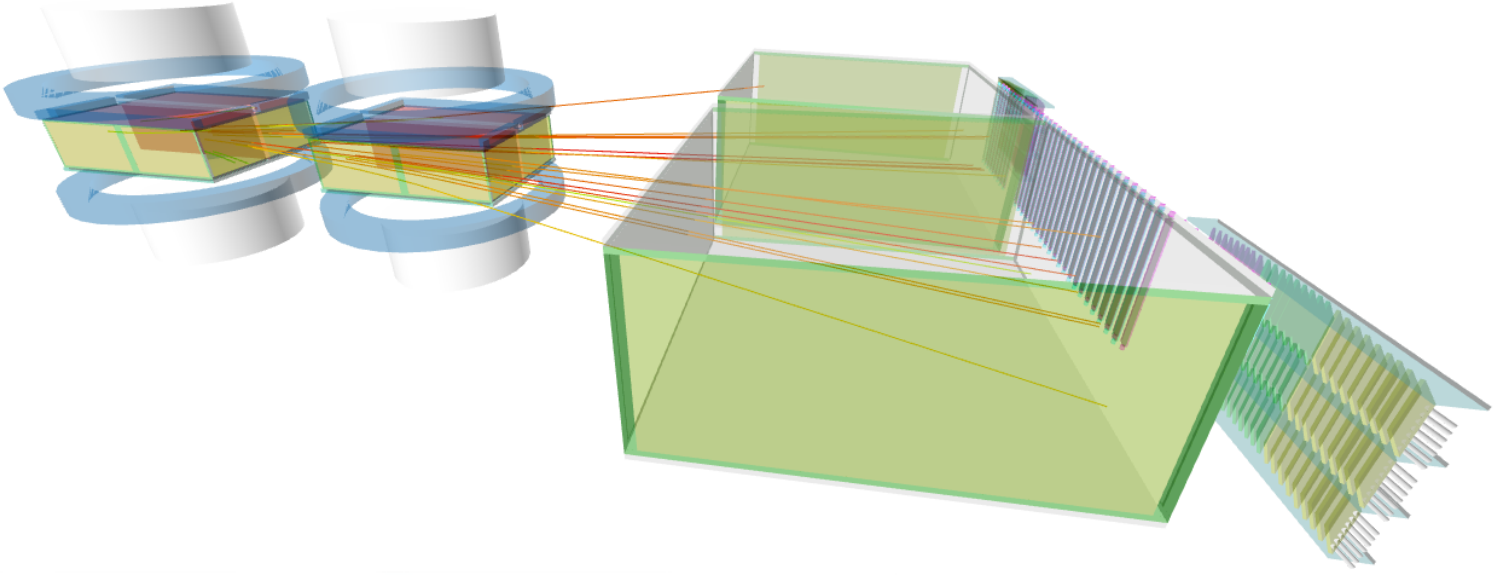


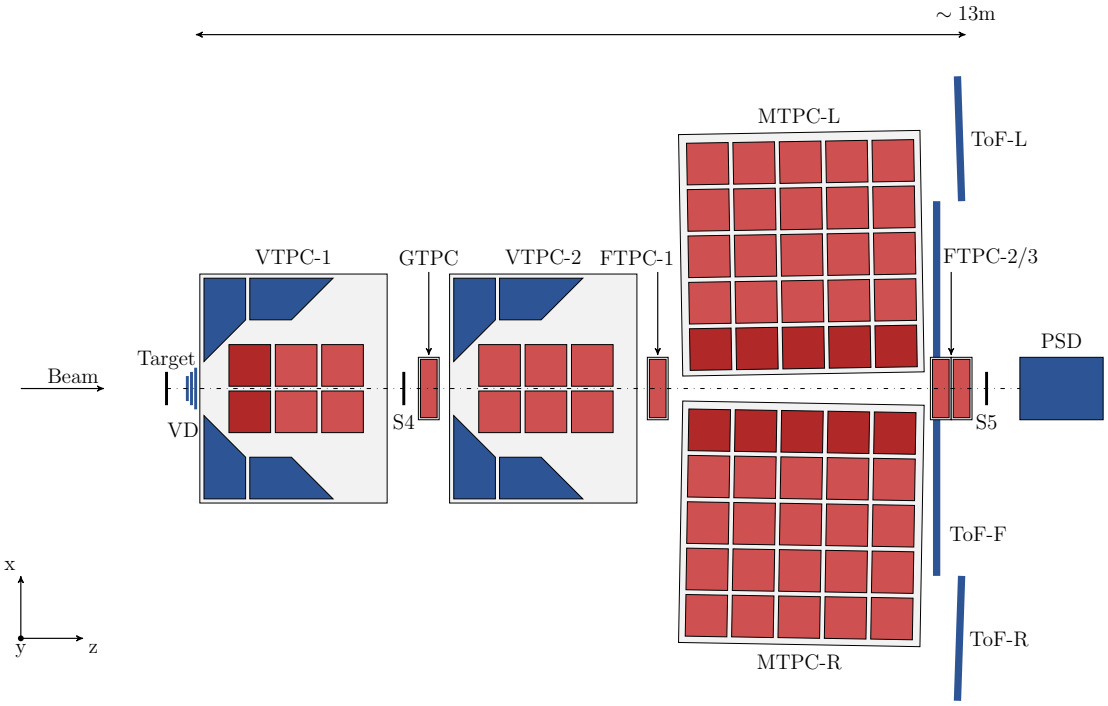
# Pion spectra in Ar+Sc collisions in the NA61/SHINE Collaboration

Michał Naskręt

WFiA UWr,
for the NA61/SHINE collaboration

December 6, 2017

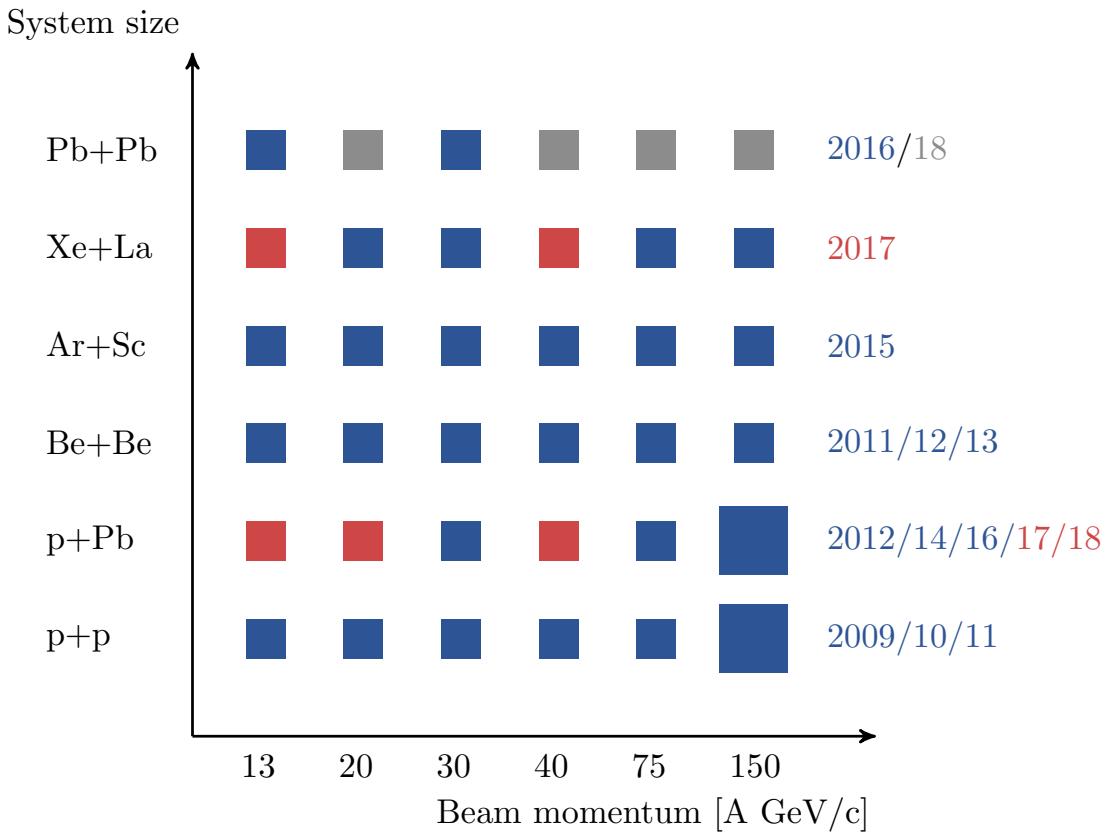
# The NA61/SHINE detector




- **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 $4\pi$ $\pi^-$ spectra and mean multiplicity in 5% most violent $^{40}$Ar+$^{45}$Sc collisions at 13*A*, 19*A*, 30*A*, 40*A*, 75*A* and 150*A* GeV/c beam momentum will be presented.

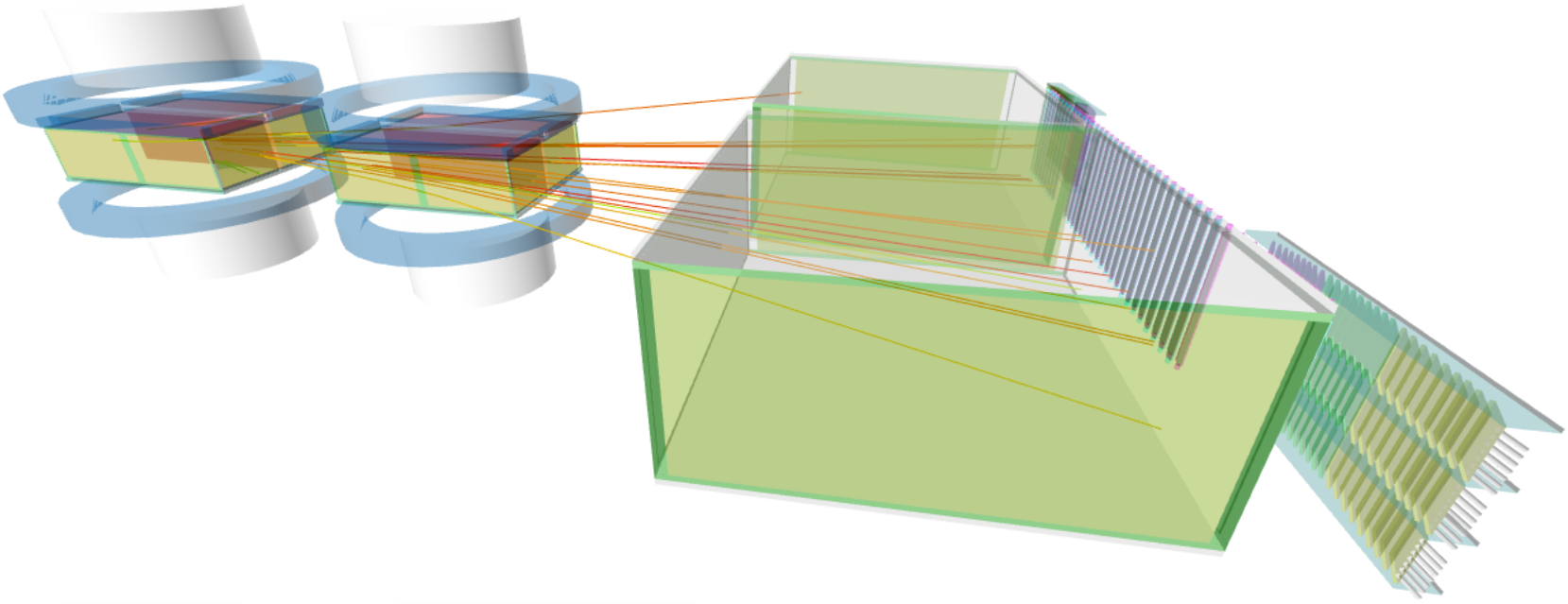
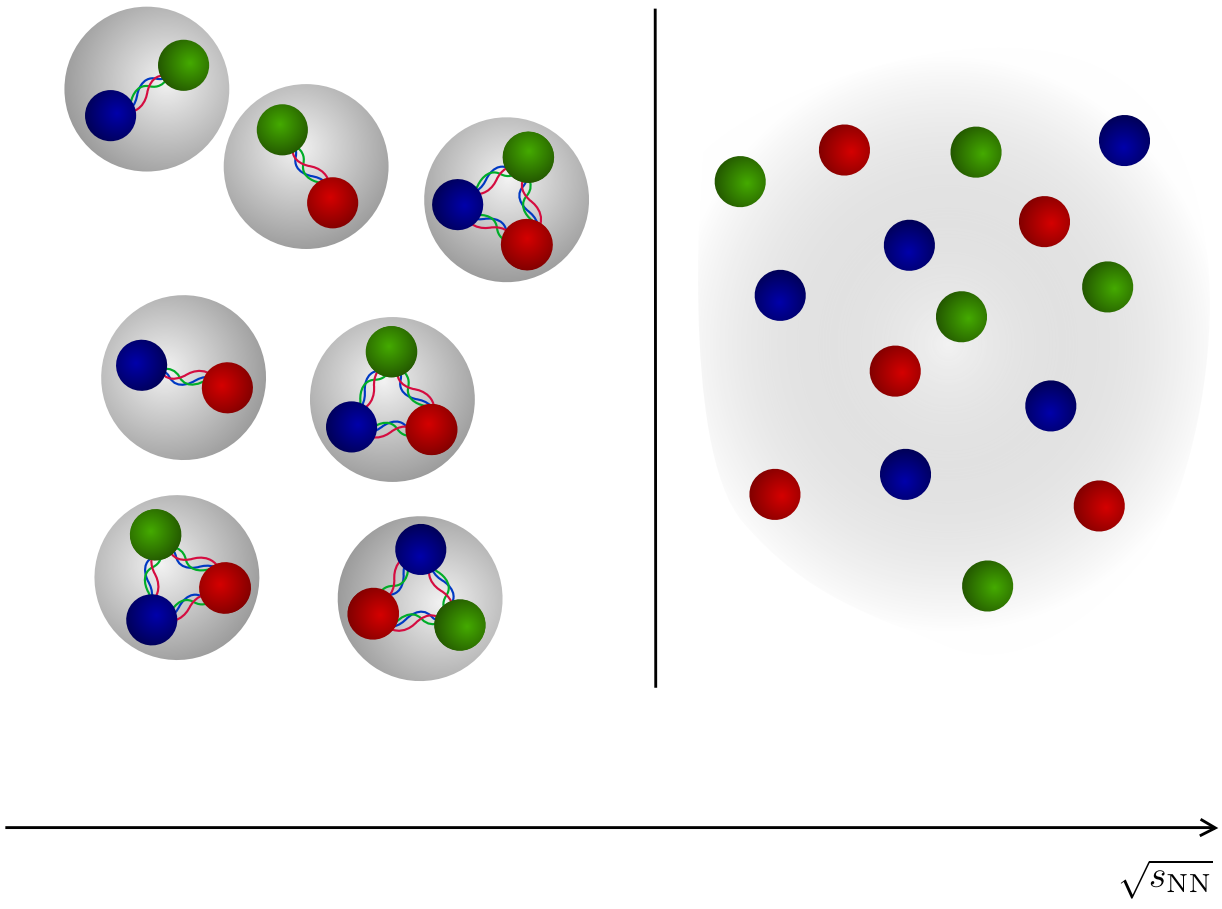
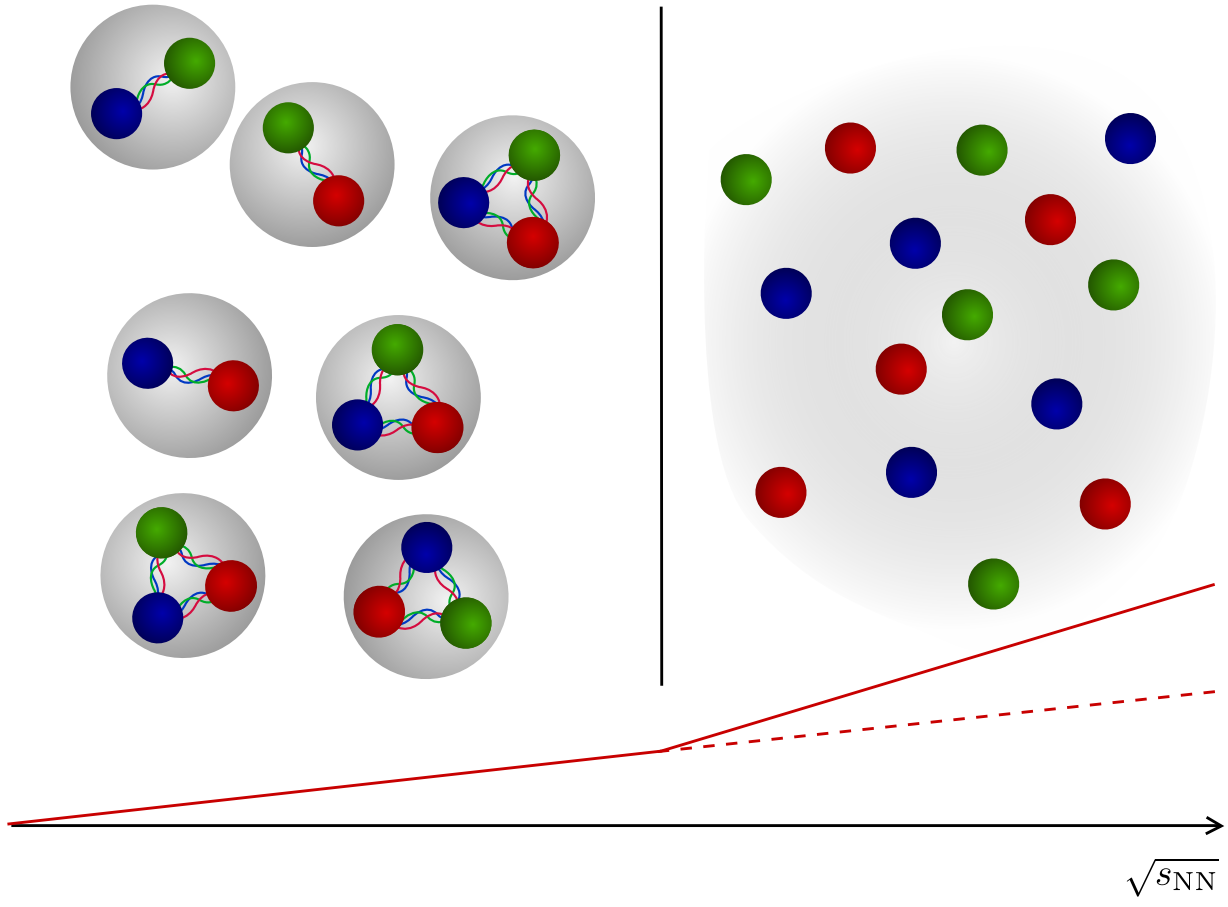


Figure: shine3d.web.cern.ch/shine3d/

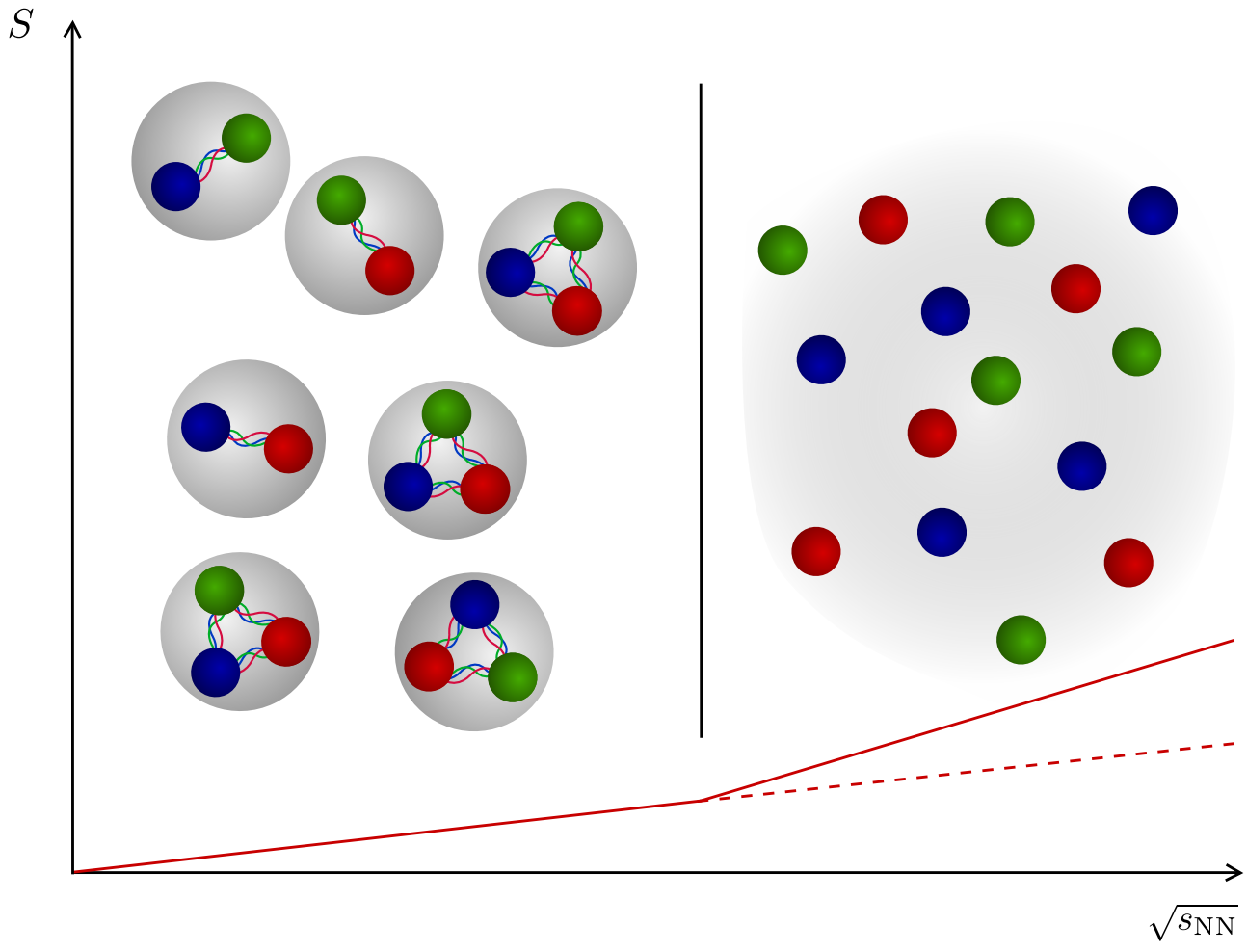
# Why?



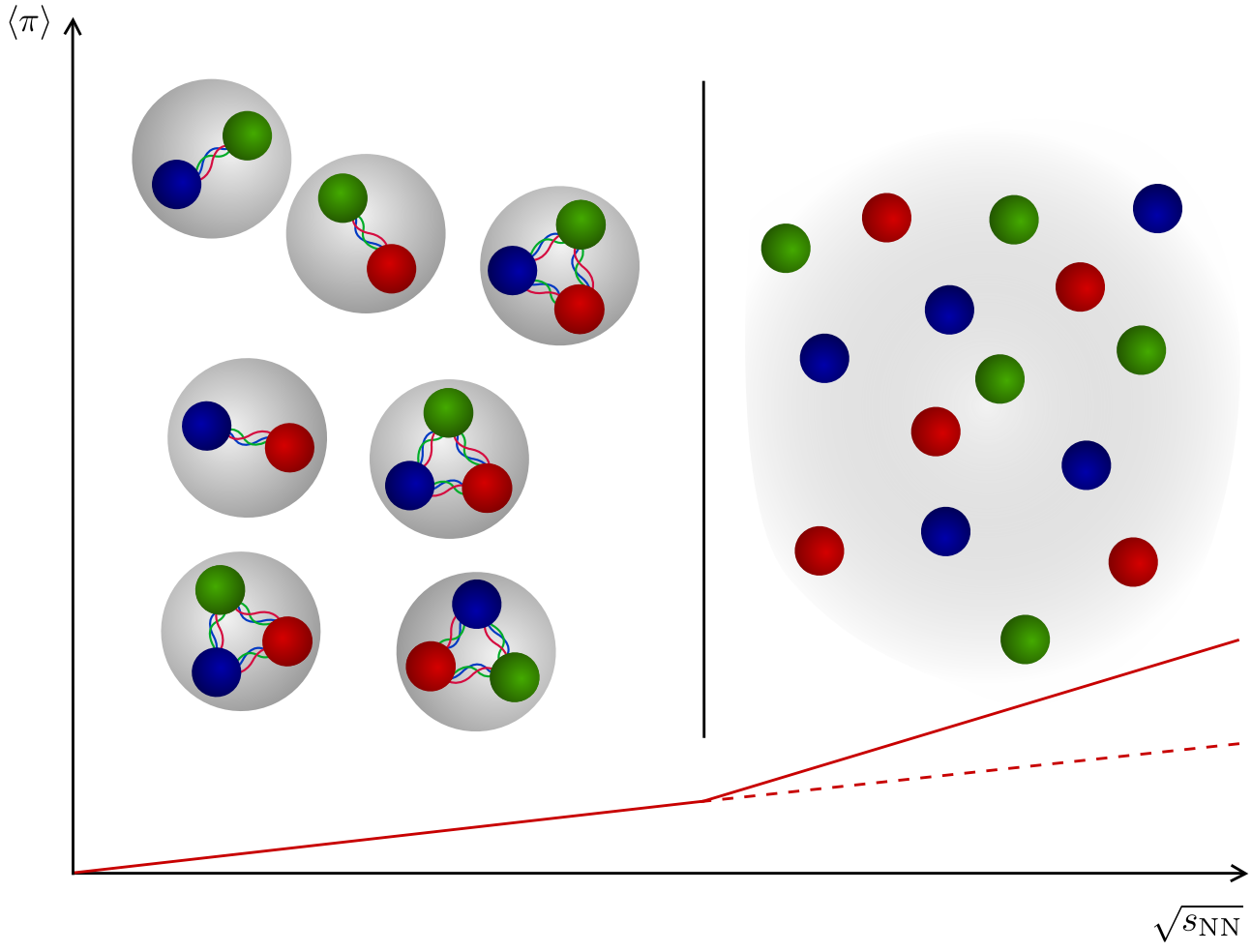
# Why?



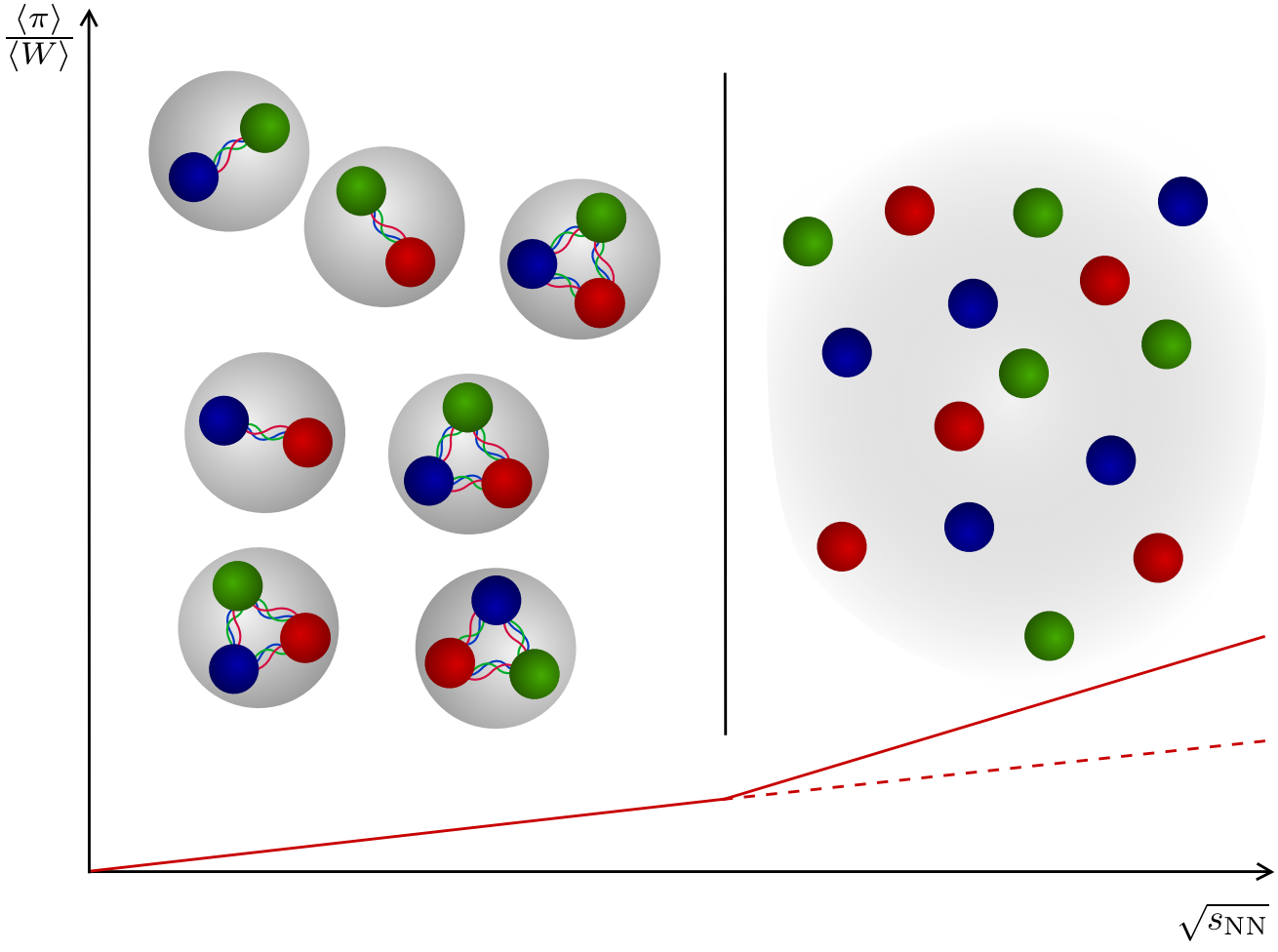
# Why?



# Why?

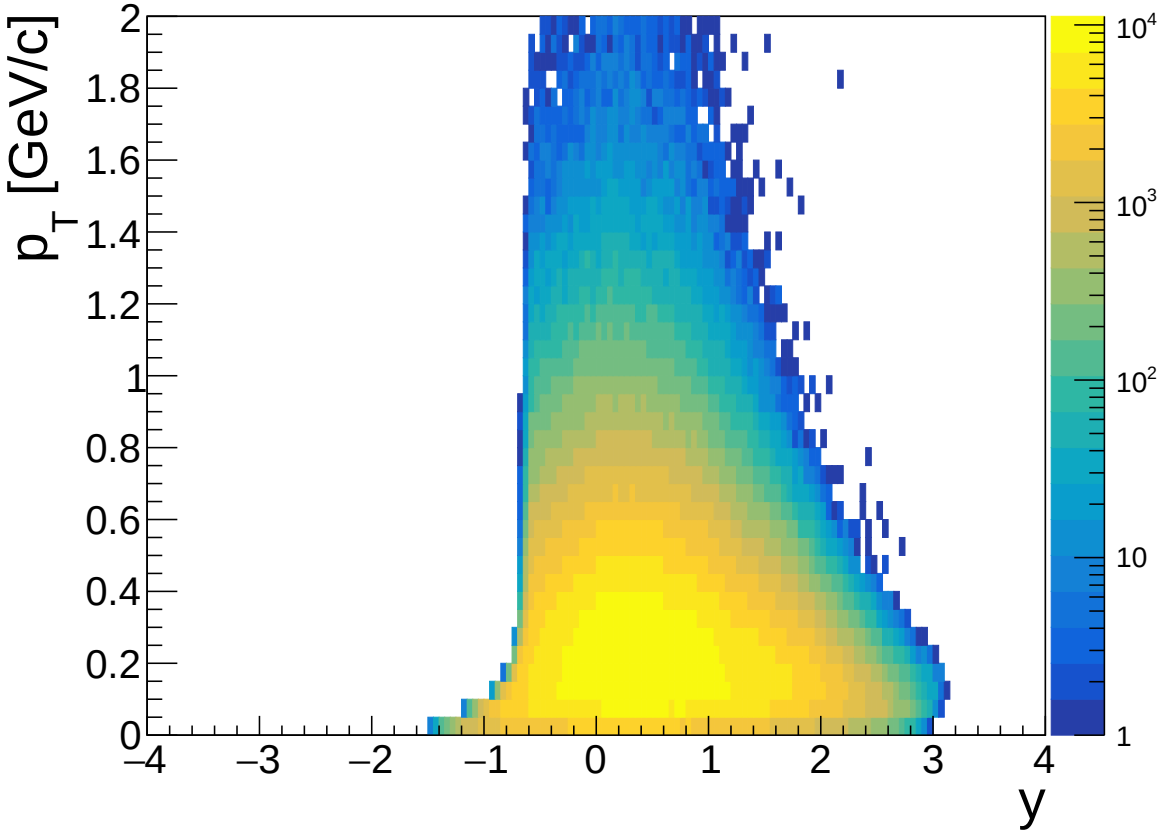


# Why?



# The $h^-$ method

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




**The $h^-$ method is used to extract $\pi^-$ 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

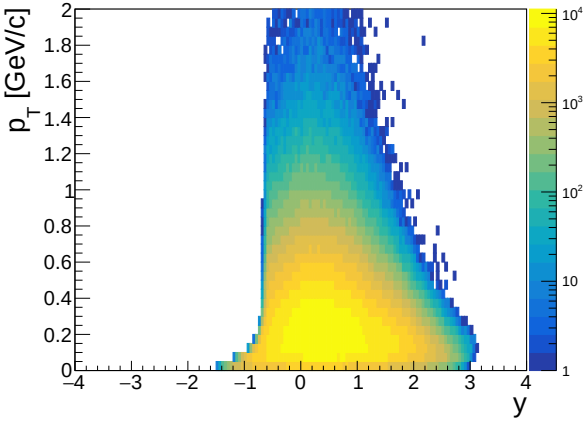
- The experimental data undergoes series of **quality cuts**.
- Spectra of negatively charged particles are detrmined using the selected events and tracks.
- The spectra are **corrected for acceptance, reconstruction efficiency and contamination of particles other than** primary $\pi^-$ mesons by EPOS 1.99 Monte Carlo model[1].
- Mean $\pi^-$ multiplicity in $4\pi$ is estimated by summing up the measured spectra and correcting it for missing acceptance by extrapolation.

[1] Liu et al. *PRC* 74.

# The $h^-$ method

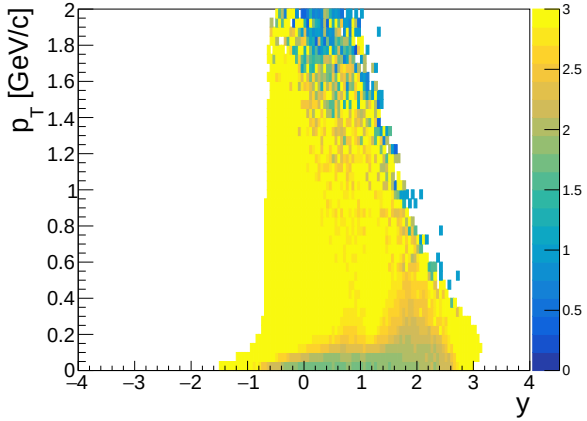
Example for $^{40}Ar+^{45}Sc$ at 19$A$ GeV/c

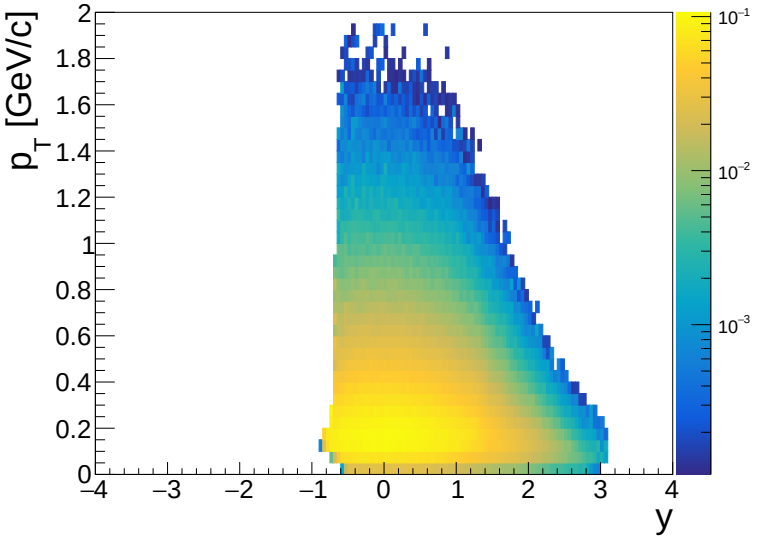
Raw data




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

MC corrections



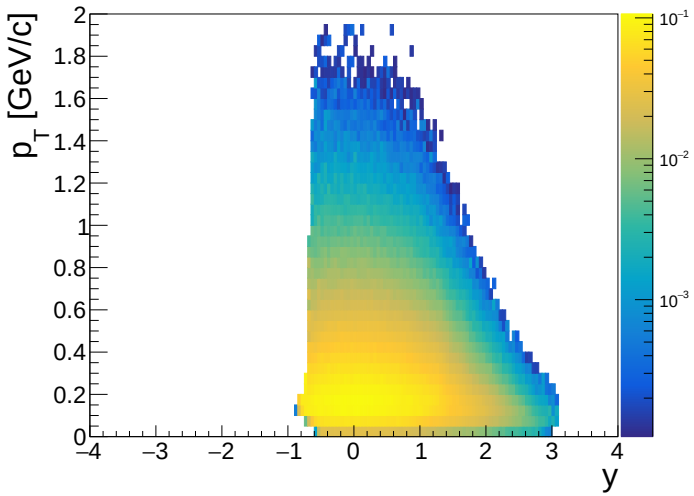



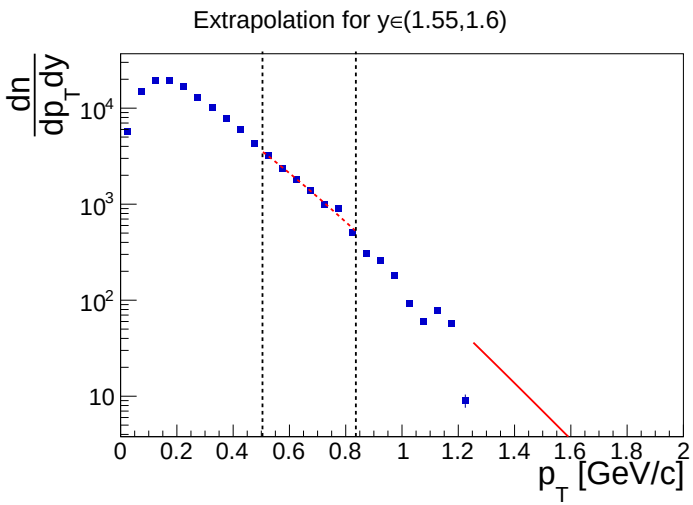

Corrected $\pi^-$ spectrum

# Extrapolation to $4\pi$ acceptance

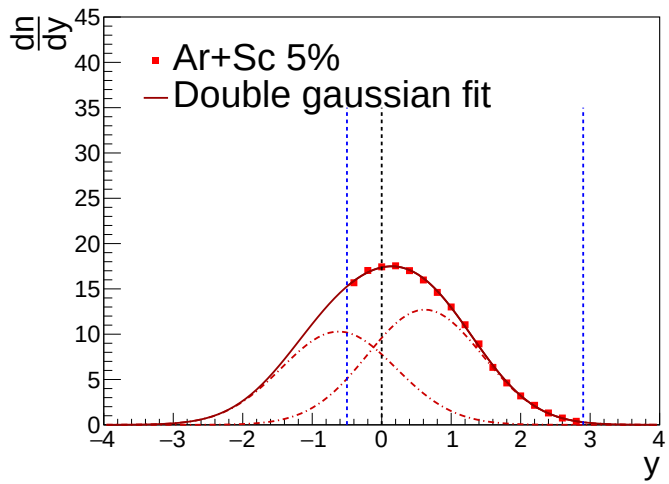
Example for $^{40}Ar+^{45}Sc$ at 19$A$ GeV/c

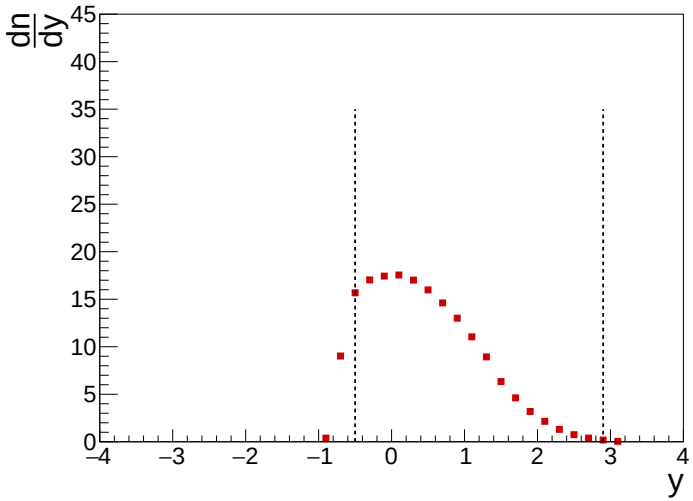
Extrapolation in $p_T$



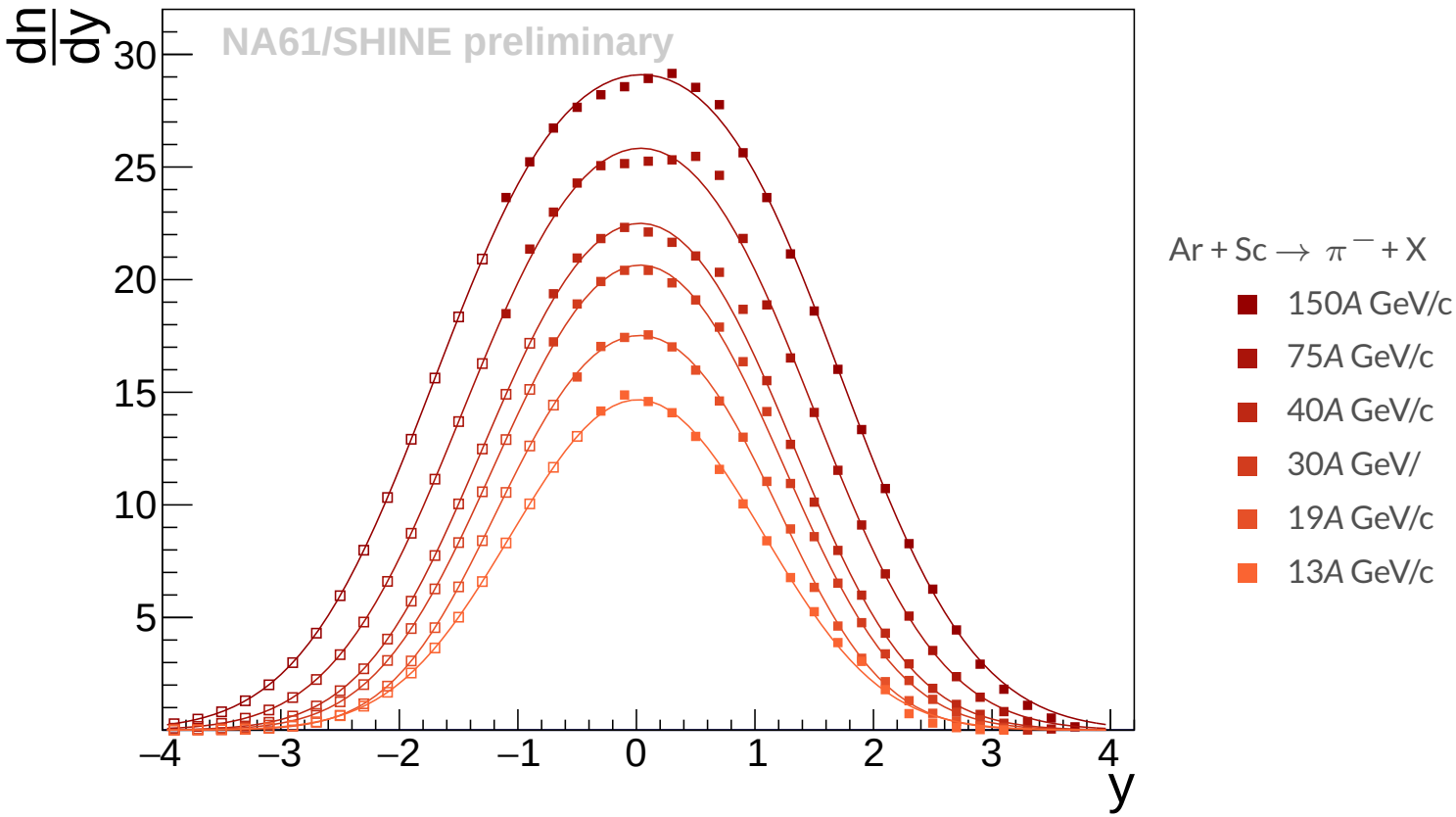

Sum




Fitting Gaussians

# Results: $\pi^-$ rapidity spectra




- $\pi^-$ 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.

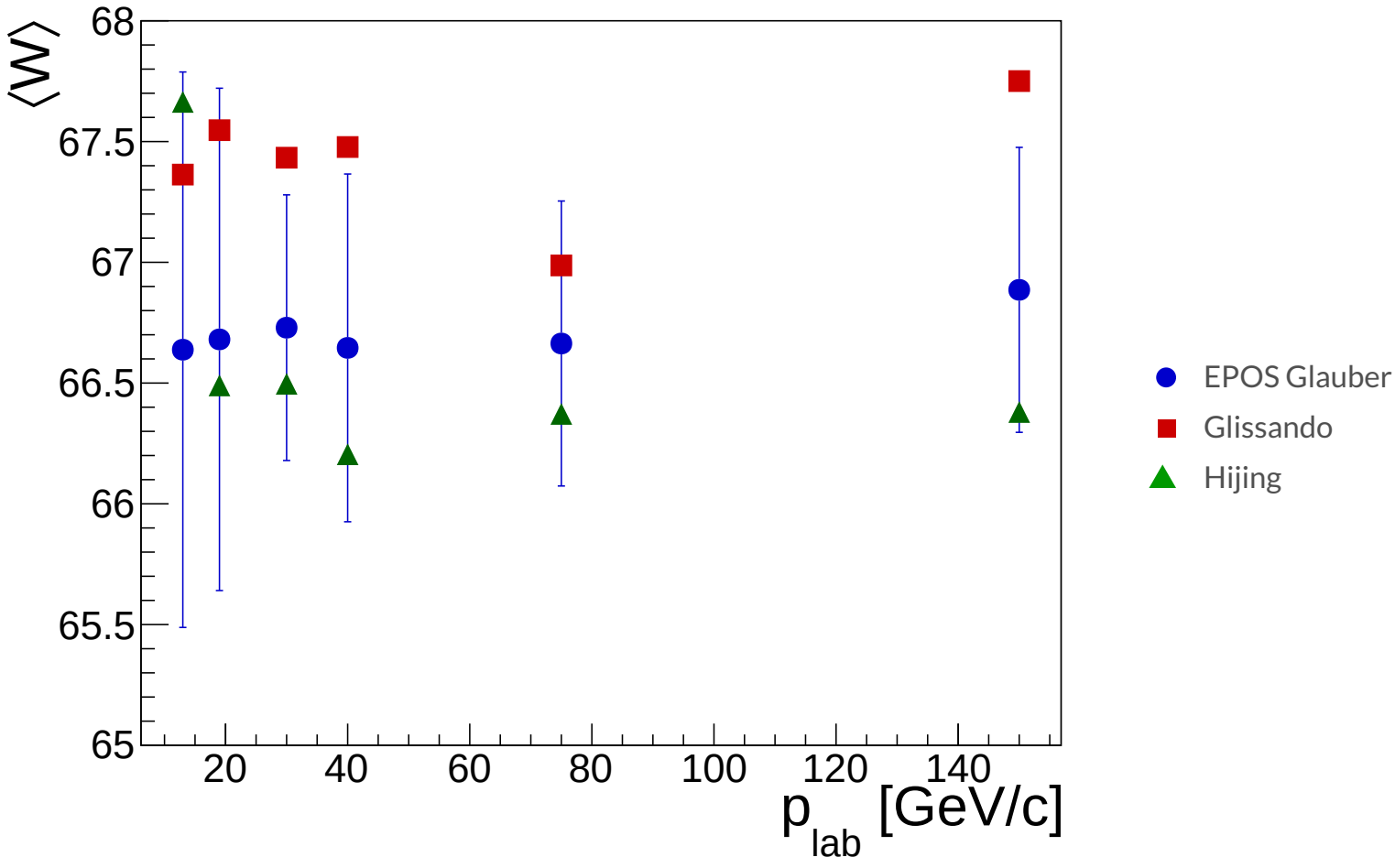
# Mean number of wounded nucleons $\langle W \rangle$

- 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 $< 1\%$ smaller than that from Glissando[3],
- 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.

[2] Liu et al. *PRC* 74.

[3] Rybczyński 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 $4\pi$, 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 analysis[4].

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

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

# The "Kink" plot

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

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

An increase of the slope of $\langle\pi\rangle/\langle W\rangle$ – **KINK** – at the onset of deconfinement is predicted by the SMES[5] due to the larger number of effective degrees of freedom in comparison to HRG.

[5] Gazdzicki 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:

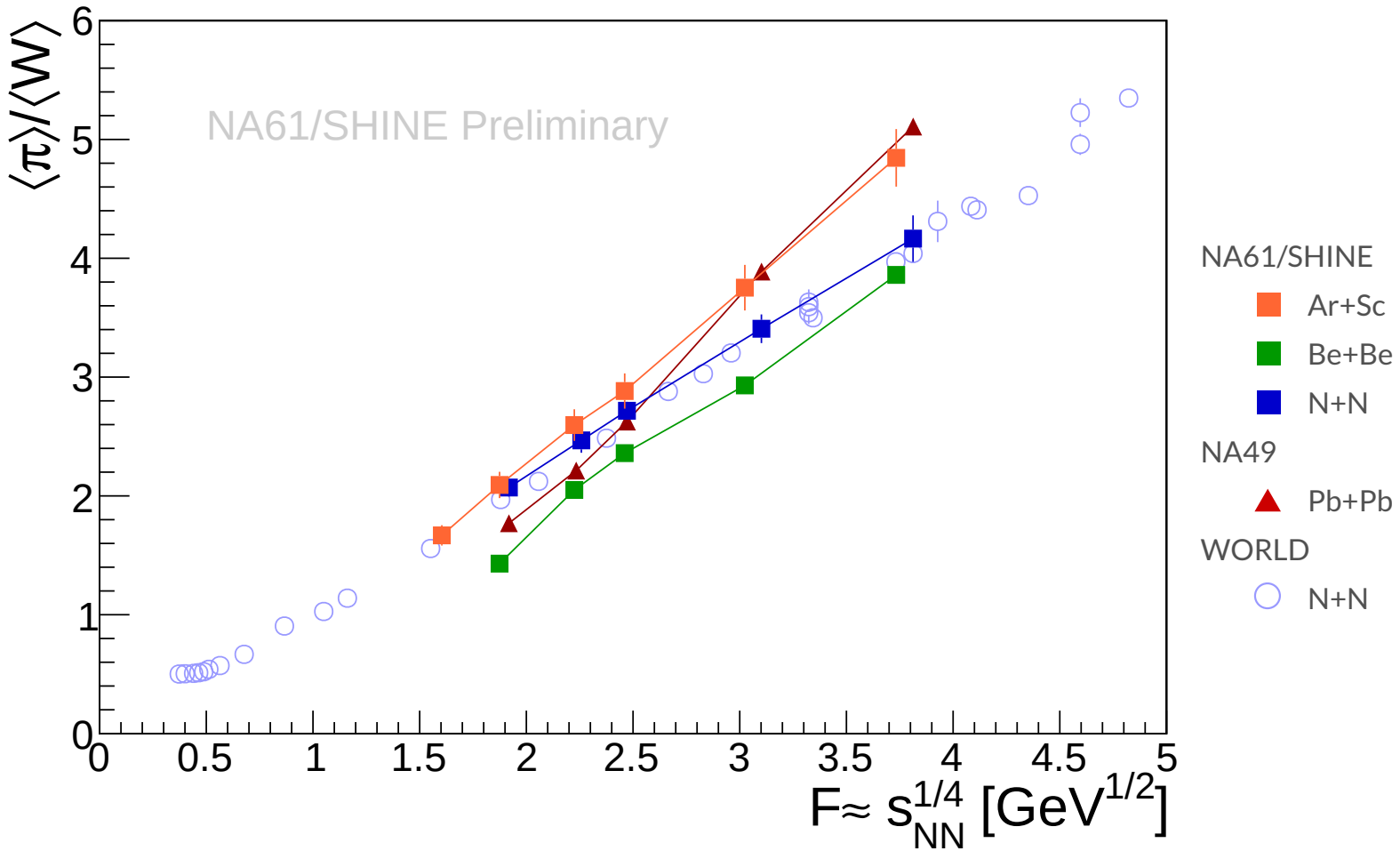
$$\langle \pi \rangle_{\text{N+N}} = 3 \langle \pi^- \rangle_{\text{N+N}}$$

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

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

This approach is motivated by the fact that the **NA61/SHINE acceptance is the largest for** $\pi^-$.

# 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

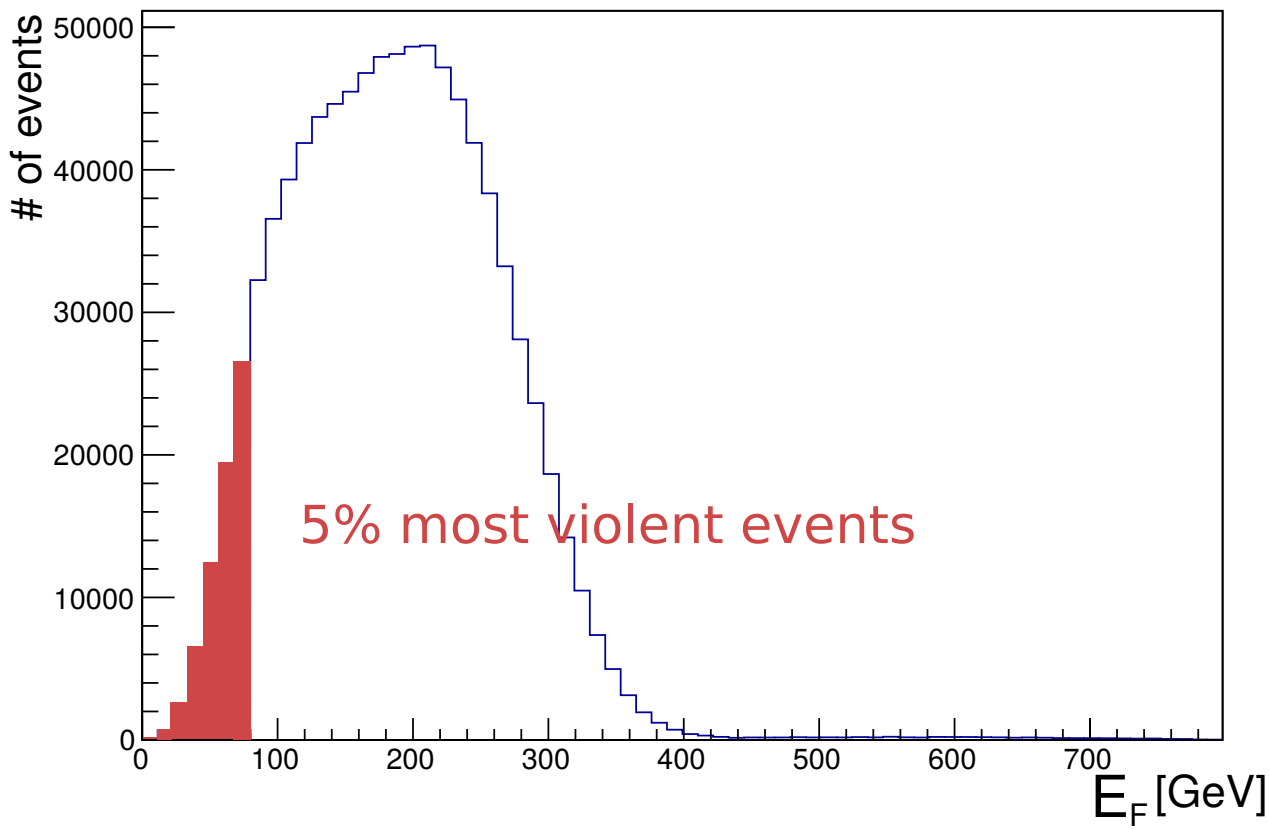
- Preliminary results on $\pi^-$ multiplicites in 5% most violent collisions of Ar+Sc at $p_{\mathrm{lab}} = 13A, 19A, 30A, 40A, 75A, 150A$ GeV/c are presented.
- At **high SPS energies Ar+Sc follows Pb+Pb**.
- At **low SPS energies no simple systematic is observed**.
- **Full simulation of fragmentation process and PSD response is urgently needed.**

Thank you for your attention.

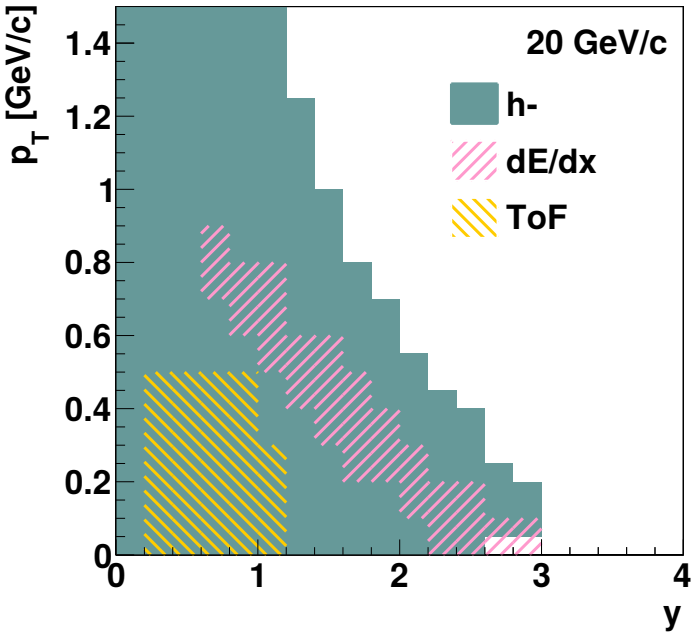
# Event classes

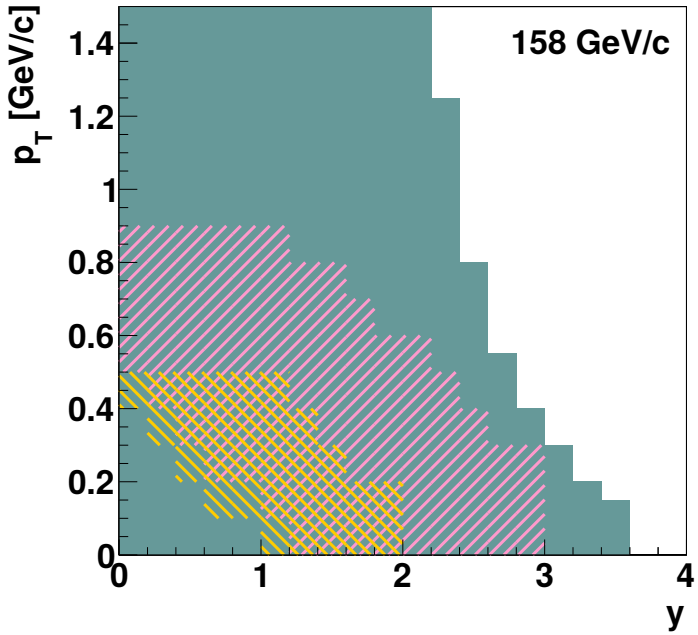
Event (centrality) classes are **chosen using the forward energy**, $E_F \approx$ energy of projectile spectators. $E_F$ is measured by the PSD zero-degree calorimeter. This is an important feature of NA61/SHINE.

Example for Ar+Sc at 13*A* GeV/c



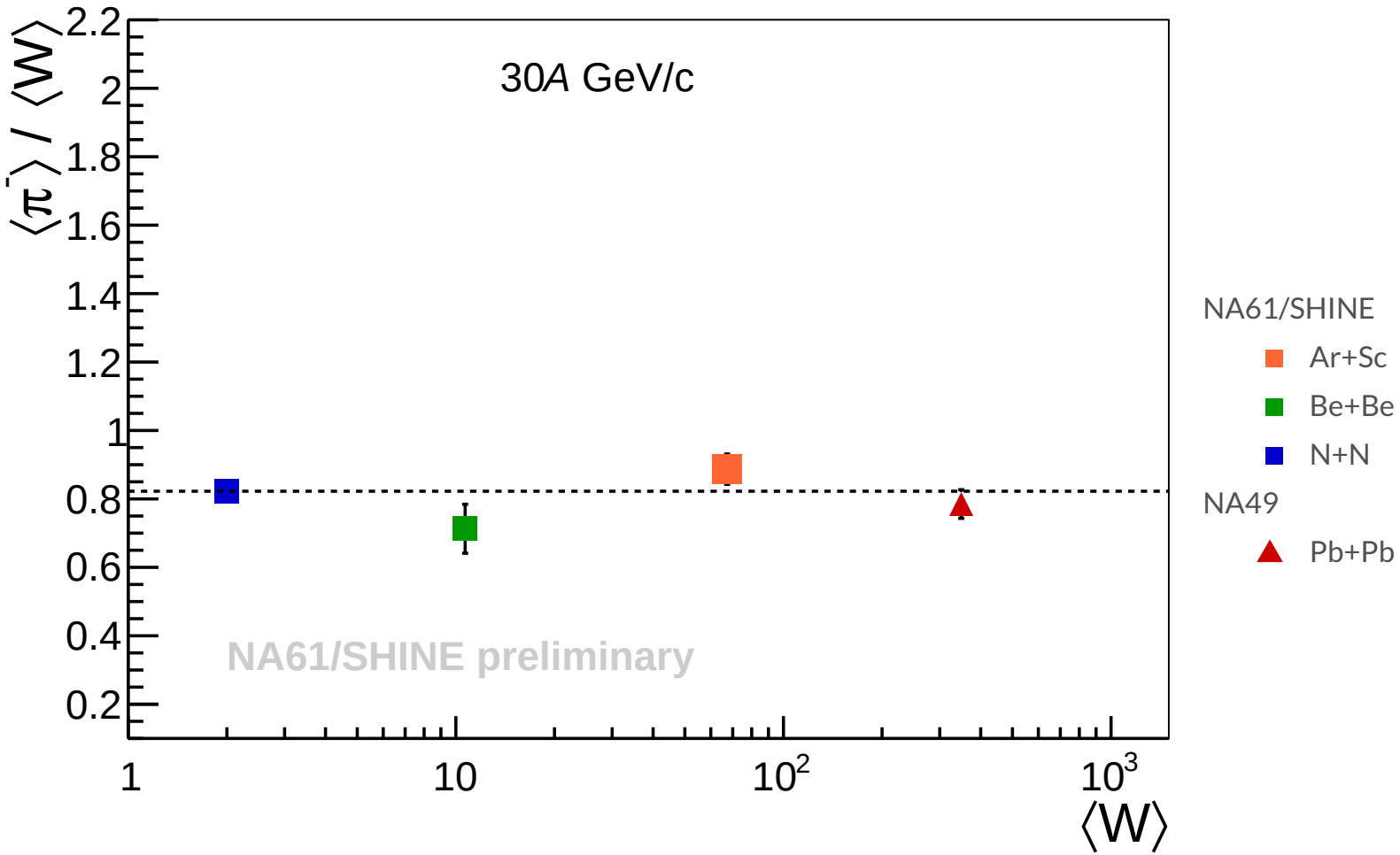
# PID methods in NA61/SHINE



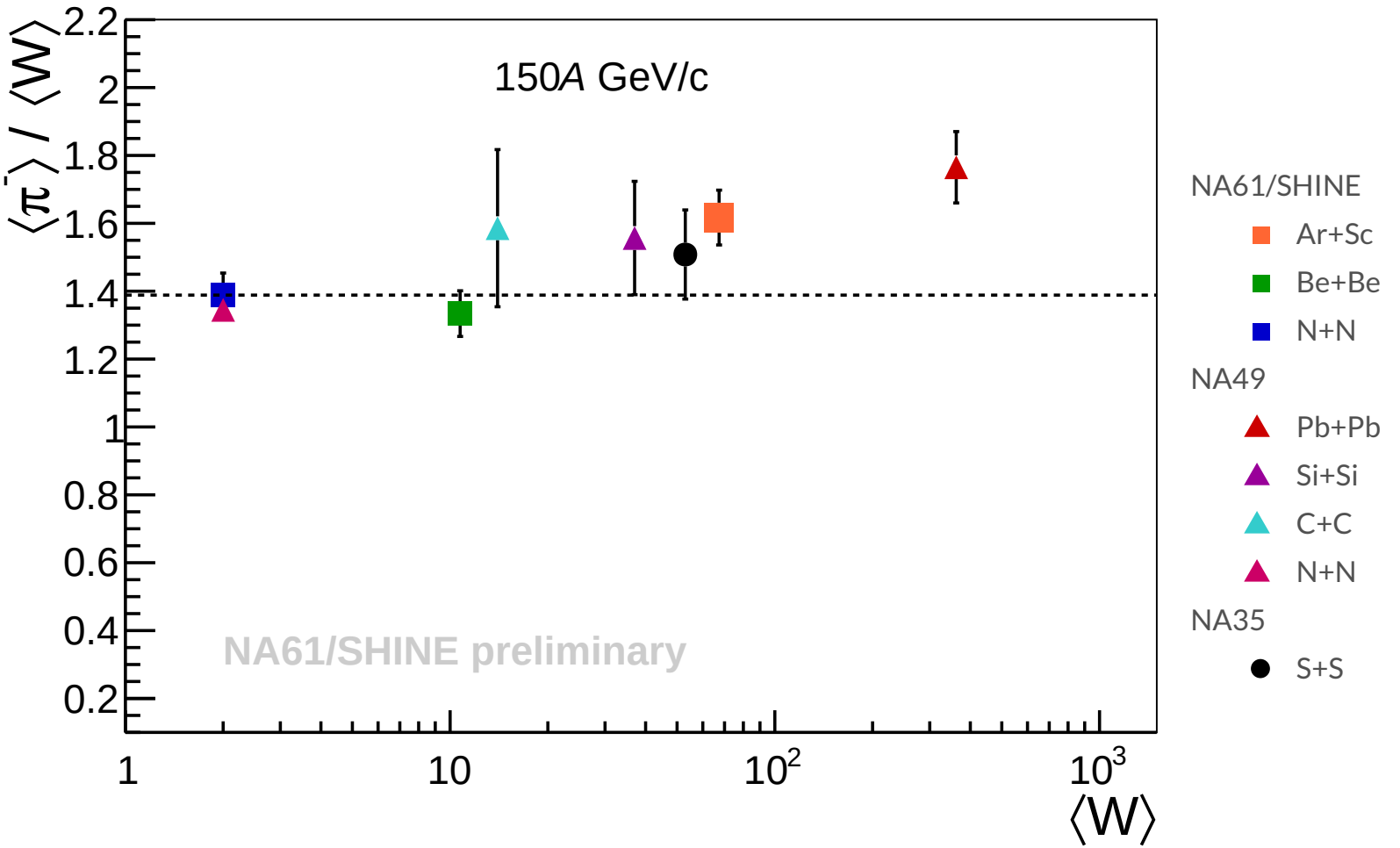

- $dE/dx$ method estimates multiplicities of $\pi^{\pm}$, $K^{\pm}$, $p$ and $\bar{p}$ using **energy loss measurements** in TPCs,
- *tof-*$dE/dx$ method estimates multiplicities of $\pi^{\pm}$, $K^{\pm}$, $p$ and $\bar{p}$ using **energy loss and particle time of flight measurements** in ToFs,
- $h^-$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

# 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 150*A* GeV/c. **Ar+Sc and Be+Be measurements in line**.
- Systematic and statistical uncertainties plotted.

# 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

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

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

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[6] and the model presented therein.

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

[6] Golokhvastov. *Physics of Atomic Nuclei* 64.1, p. 84.