Simulating the double differential density distribution for Pb+Pb reaction at $\sqrt{s_{NN}}$ = 8.8 GeV and 17.3 GeV

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Outline:

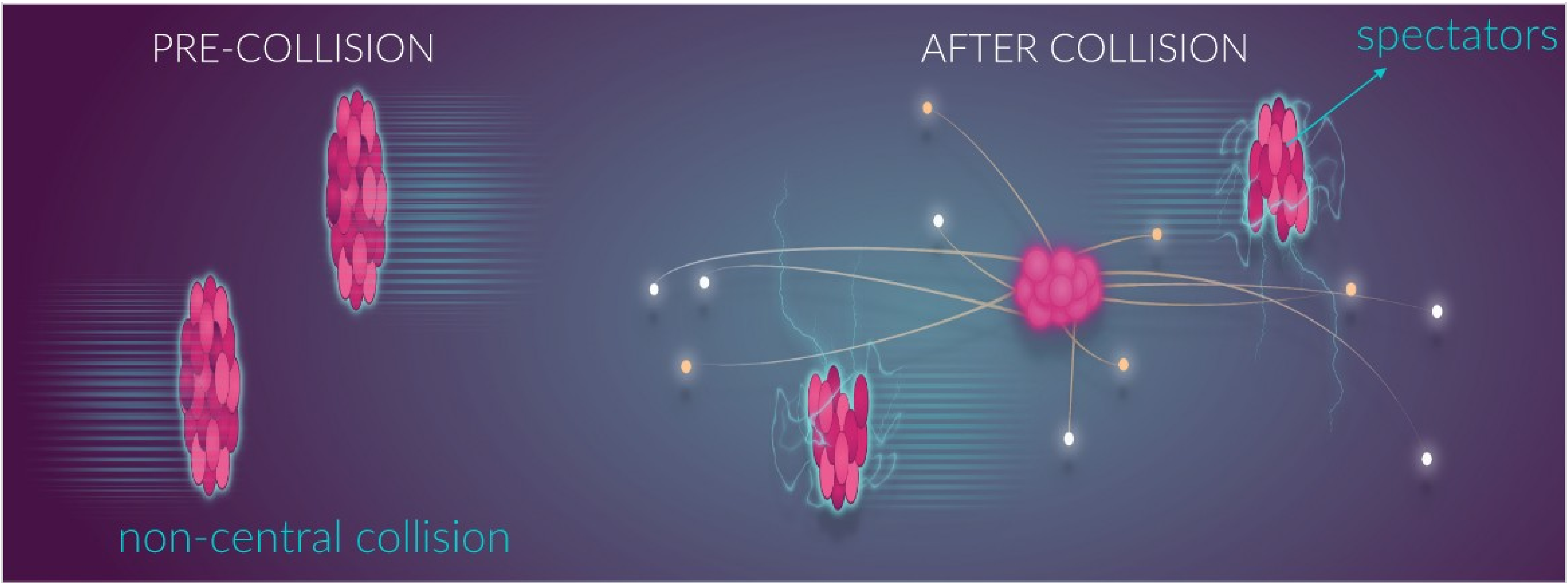
The aim of this talk is to obtain information on **double differential density distribution of charged π mesons** in A+A collisions at $\sqrt{s_{NN}}$ = 8.8 GeV.

This distribution is absolutely necessary to study the spectator induced electromagnetic effect, for instance also in Ar+Sc collisions.

1. Motivation;
2. Simulation methodology;
3. Results;
4. Summary;

Motivation: Why the double differential π mesons density distribution in A+A reaction at SPS energies?

1. The IFJ/SHINE group → studies on **spectator induced EM effects:**



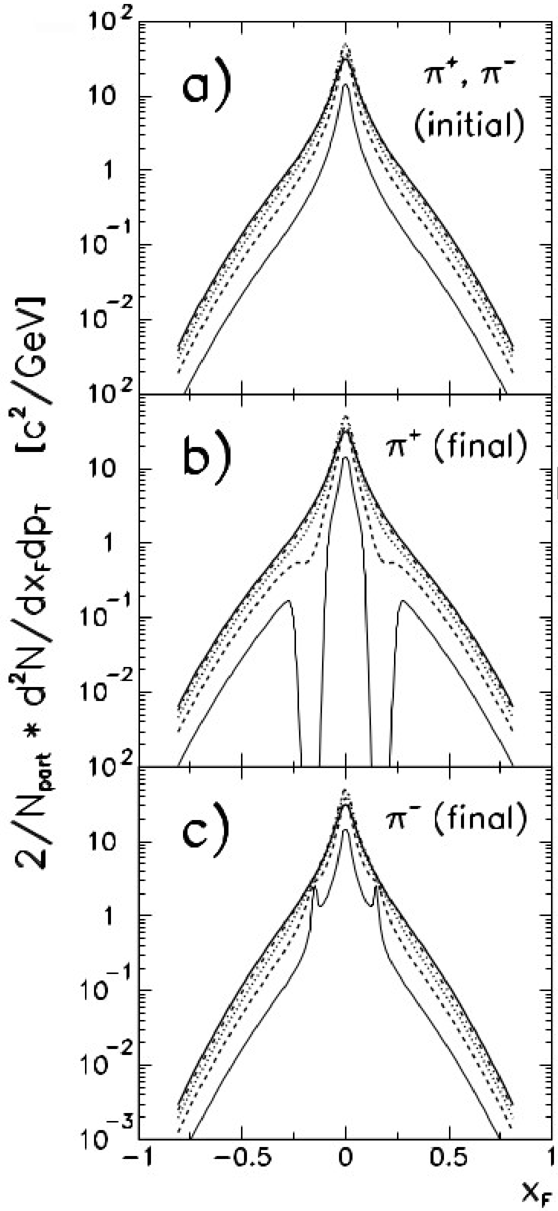
graphic by Iwona Sputowska

2. What We need is a double differential distribution of initially emitted pions in order to study this EM effect.

A. Rybicki, A. Szczurek Phys. Rev. C 75, 054903 (2007)

V. Ozvenchuk, A. Rybicki et al. Phys.Rev.C102.014901 (2020)

Motivation: Why the double differential π mesons density distribution in A+A reaction at SPS energies?



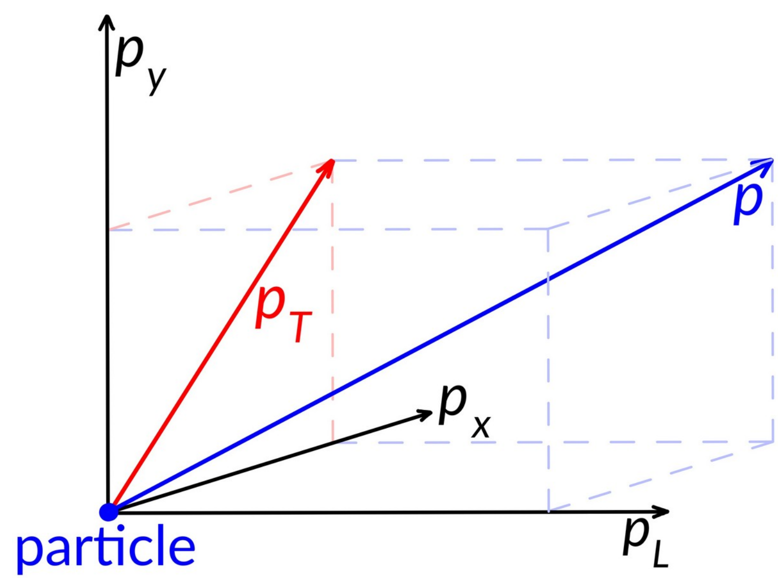
p_T = 325
175
125
75
25
[MeV/c]

A. Rybicki and A. Szczurek
Phys. Rev. C 75, 054903 (2007)

The electromagnetic distortions of double differential distributions of $\pi^{\pm}$ mesons in A+A collisions:

$$\left(\frac{d^2 n_\pi}{dx_F\, dp_T}\right)_{A+A\to\pi^{\pm}}$$

are sensitive to the space–time evolution of the system.



$$x_F = \frac{2 p_L}{\sqrt{s_{NN}}}$$

$$p_T = \sqrt{p_x^2 + p_y^2}$$

p_L → momentum component along beam direction

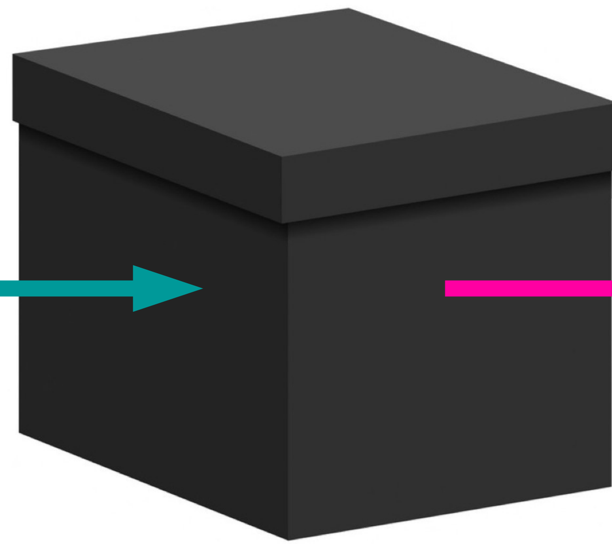
Simulation methodology

General idea → obtain the **double differential density distribution of charged π mesons** in A+A collisions at $\sqrt{s_{NN}}$ = 8.8 GeV and 17.3 GeV based on the triple differential cross section distribution from p+p reaction

INPUT

Triple differential cross section distributions

$$\left(E\frac{d^3\sigma}{dp^3}\right)_{p+p\rightarrow\pi^-\ \text{and}\ p+p\rightarrow\pi^+}$$



OUTPUT

Double differential pion density distribution

$$\left(\frac{d^2n}{dx_F\,dp_T}\right)_{A+A\rightarrow\pi^-\ \text{or}\ A+A\rightarrow\pi^+}$$

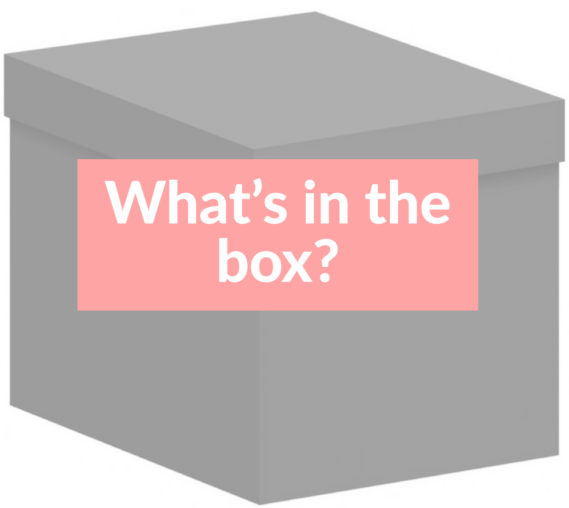
Lack of experimental $Ed^3\sigma/dp^3$ data for $\sqrt{s_{NN}}$ = 8.8 GeV, I had to "create" that distribution

Simulation methodology

INPUT

Triple differential cross section distributions

$$\left(E\frac{d^3\sigma}{dp^3}\right)_{p+p\rightarrow\pi^-}^{} \text{ and } \left(E\frac{d^3\sigma}{dp^3}\right)_{p+p\rightarrow\pi^+}$$



THREE STEPS APPROACH:

triple differential cross section → double differential π meson density

1. From $\left(E\frac{d^3\sigma}{dp^3}\right)_{p+p\rightarrow\pi^\pm}^{\sqrt{s}=17.3\,GeV}$ to $\left(\frac{d^2 n_\pi}{dx_F\,dp_T}\right)_{p+p\rightarrow\pi^\pm}^{\sqrt{s}=17.3\,GeV}$
2. Estimation of double differential charged π meson density in p+p collisions **@ √s= 8.8 GeV**.
3. Determination of double differential charged π meson density in **A+A** collisions (eg. Pb+Pb)

OUTPUT

Double differential pion density distribution

$$\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{A+A\rightarrow\pi^-} \text{ or } \left(\frac{d^2 n}{dx_F\,dp_T}\right)_{A+A\rightarrow\pi^+}$$

Simulation methodology

STEP ONE: From triple differential cross section to double differential distribution

1. Find formula relating double differential π meson density with triple differential cross section:

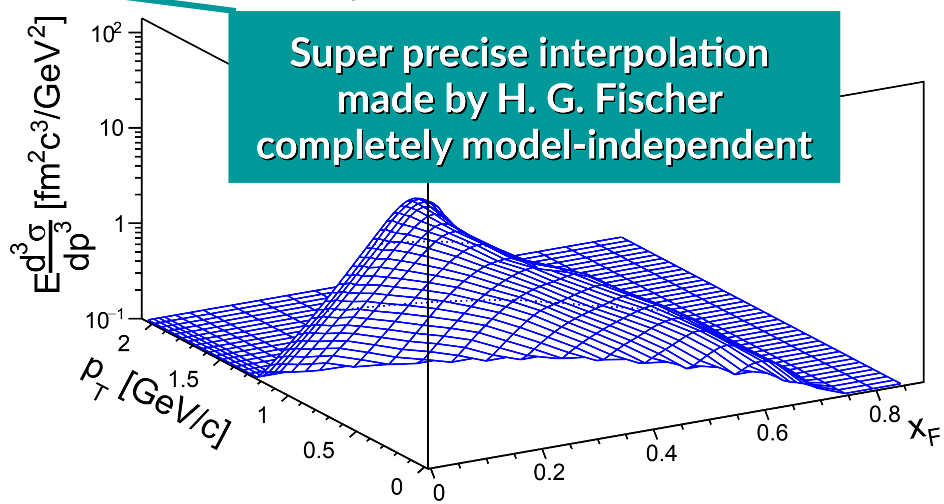
$$\frac{d^2 n_\pi}{dx_F\, dp_T} = \pi\sqrt{s_{NN}}\,\frac{p_T}{E}\left(E\frac{d^3\sigma}{dp^3}\right)\cdot\frac{1}{\sigma_{inel}}$$

2. Take **triple differential cross section** histogram for **p+p→π± @ √s=17.3 GeV**

3. Get $\left(E\frac{d^3\sigma}{dp^3}\right)$ values from histogram for uniformly given x_F and p_T

4. Create **double differential π± density distribution** for p+p @ √s=17.3 GeV.

The NA49 Collaboration
Eur. Phys. J. C 45, 343–381 (2006)

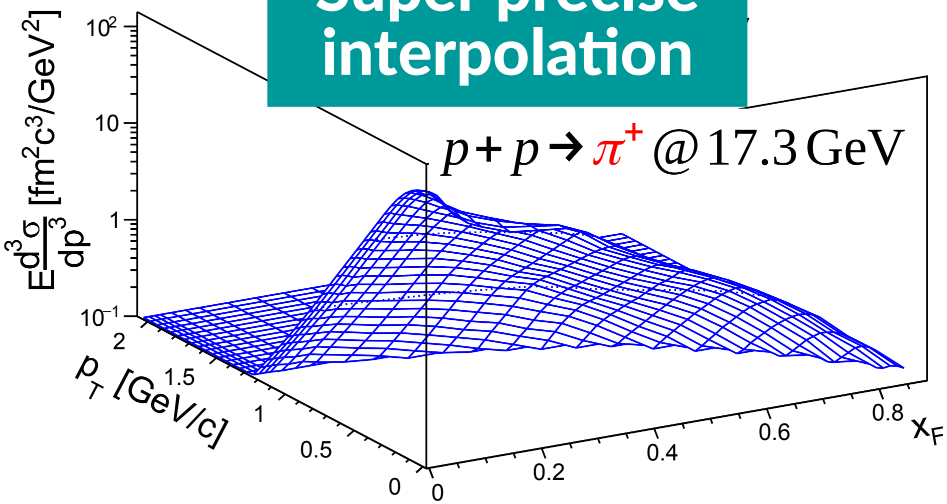


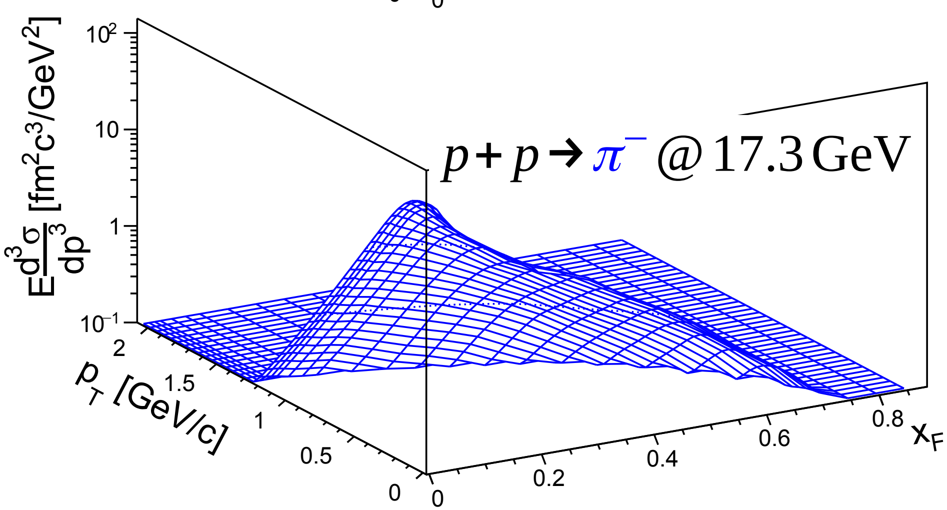
Simulation methodology

STEP ONE: From triple differential cross section to double differential distribution

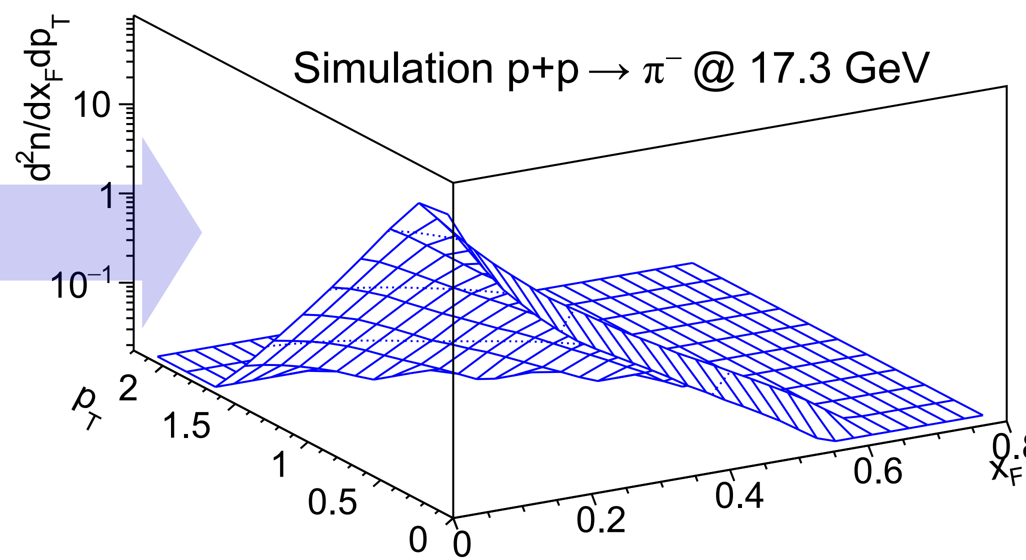
The NA49 Collaboration
Eur. Phys. J. C 45, 343–381 (2006)

Super precise interpolation



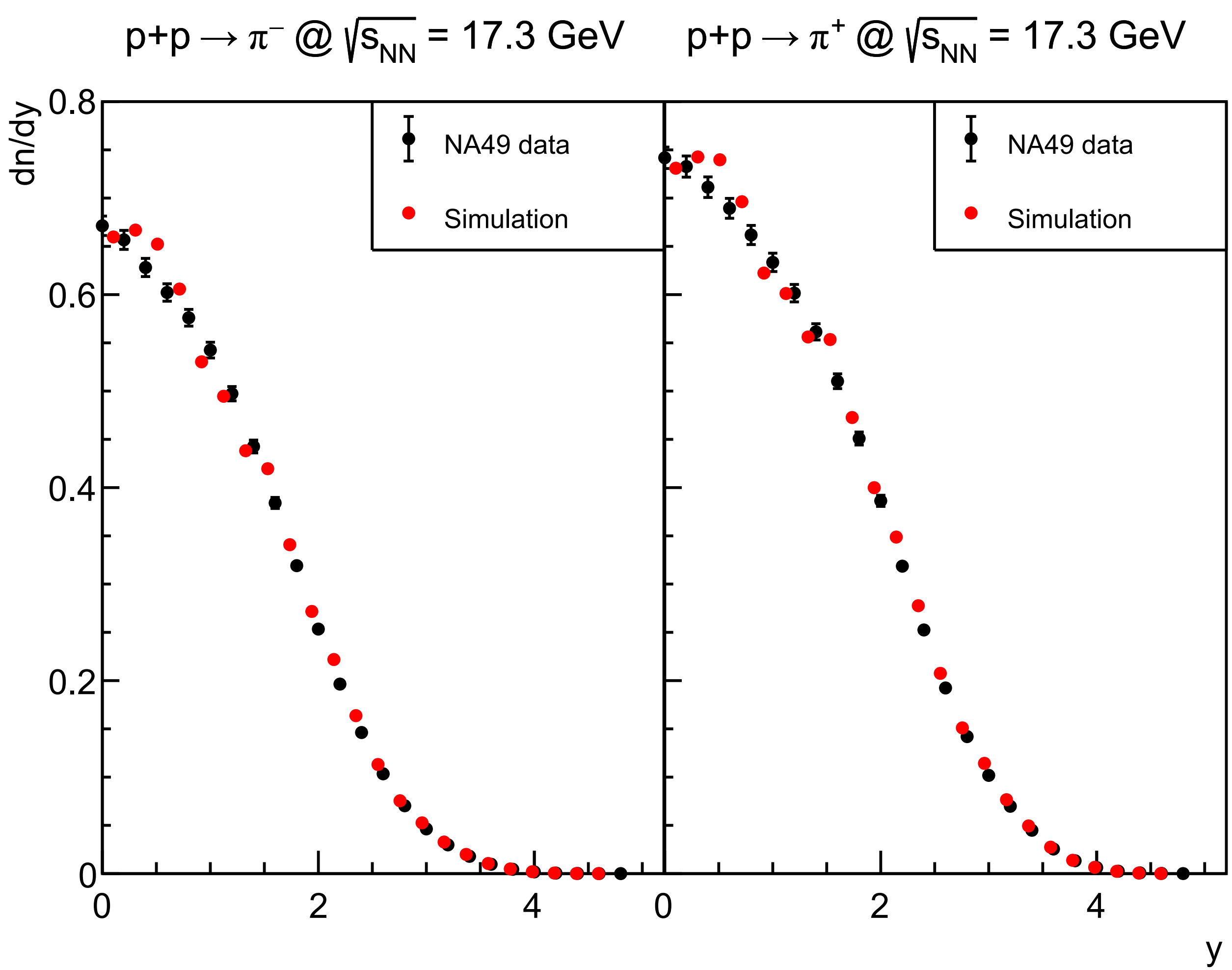


$\left(\frac{d^2 n}{dx_F\, dp_T}\right)$ Simulation for p+p→ π^- @ $\sqrt{s_{NN}}$ = 17.3 GeV



Simulation methodology

STEP ONE: From triple differential cross section to double differential distribution



Switch:

(to reproduced given available data)

$$\left(\frac{d^2 n}{dx_F\, dp_T}\right) \rightarrow \left(\frac{d^2 n}{dy dp_T}\right)$$

Our simulation is with good agreement with experimental data integrated over the p_T

NOTE: The fluctuations at low y are due to the flat generation in x_F, p_T

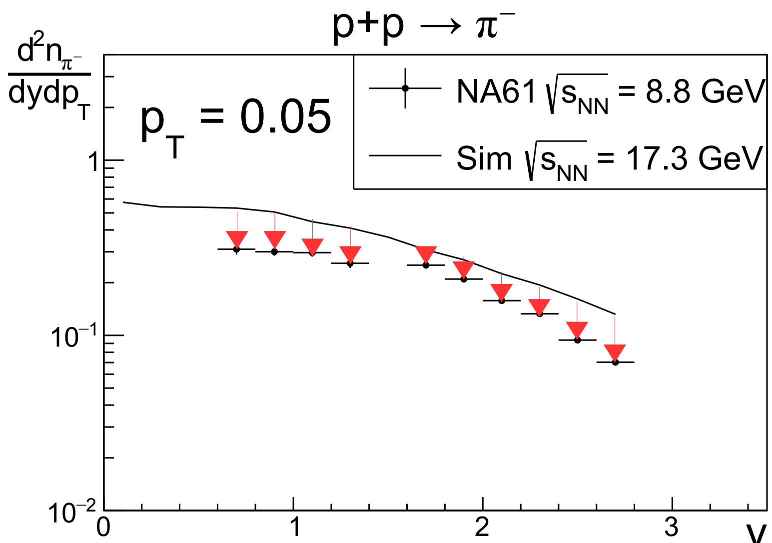
Data points from: The NA49 collaboration Eur.Phys.J C45 (2005) 343-381

Simulation methodology

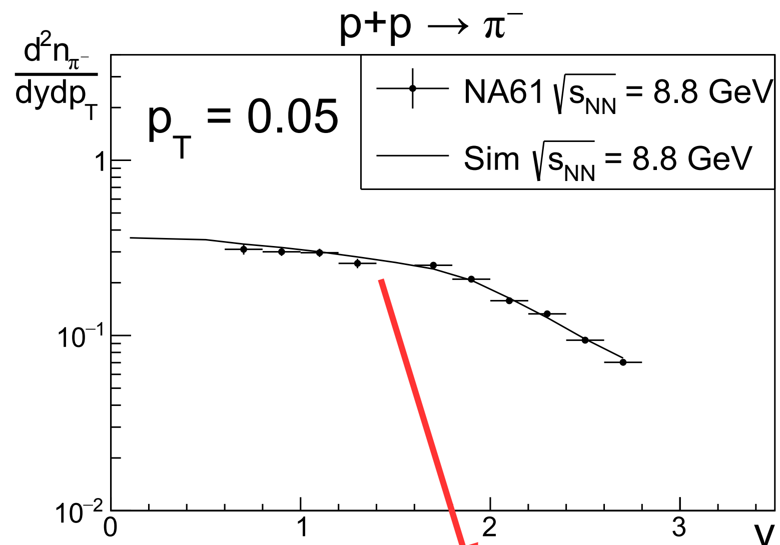
STEP TWO: Estimation of double differential $\pi^{\pm}$ meson density in p+p collisions @ $\sqrt{s}$= 8.8 GeV.

Data points from: The NA61/SHINE collaboration Eur.Phys.J.C 77 (2017) 671

$\sqrt{s}$=8.8 GeV (exp. data) vs $\sqrt{s}$=17.3 GeV (simulation)



$\sqrt{s}$=8.8 GeV (exp. data) vs $\sqrt{s}$=8.8 GeV (simulation)



→ First we need to correct the triple differential cross section distribution for $\sqrt{s}$=17.3 GeV to match the simulation to the p+p collision at $\sqrt{s}$=8.8 GeV data.

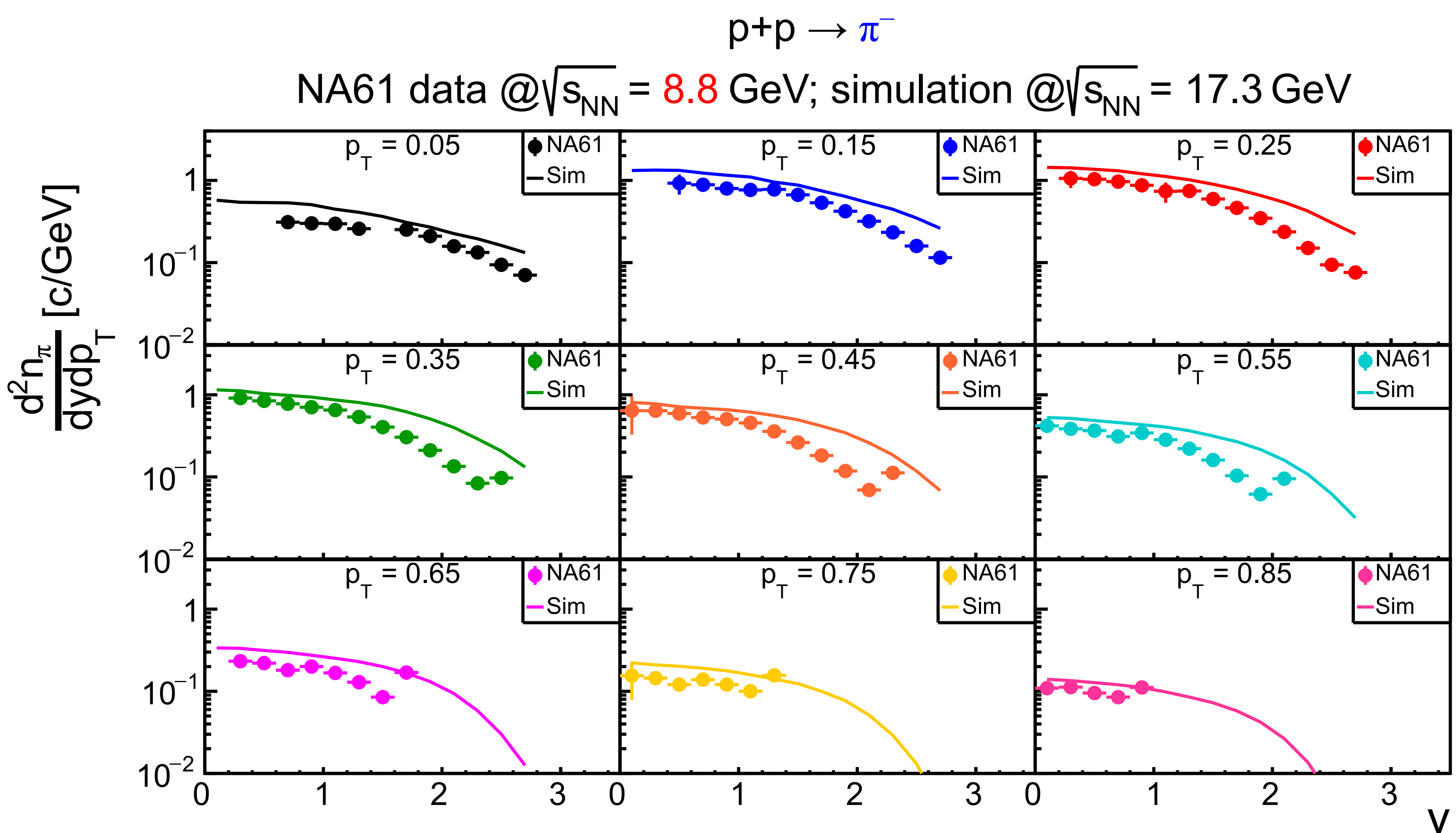
Simulation describes the experimental data very well

→ Then we perform a parametrization of the double differential density with a function:

$$f(x_F, p_T) = \frac{a_0}{a_1 + a_2 \cdot \exp\left(-a_3 x_F + a_4 p_T + a_5 x_F^2 + a_6 p_T^2 + a_7 x_F p_T + a_8 (x_F p_T)^2\right)}$$

Simulation methodology

STEP TWO: Estimation of double differential $\pi^{\pm}$ meson density in p+p collisions @ $\sqrt{s}$= 8.8 GeV.

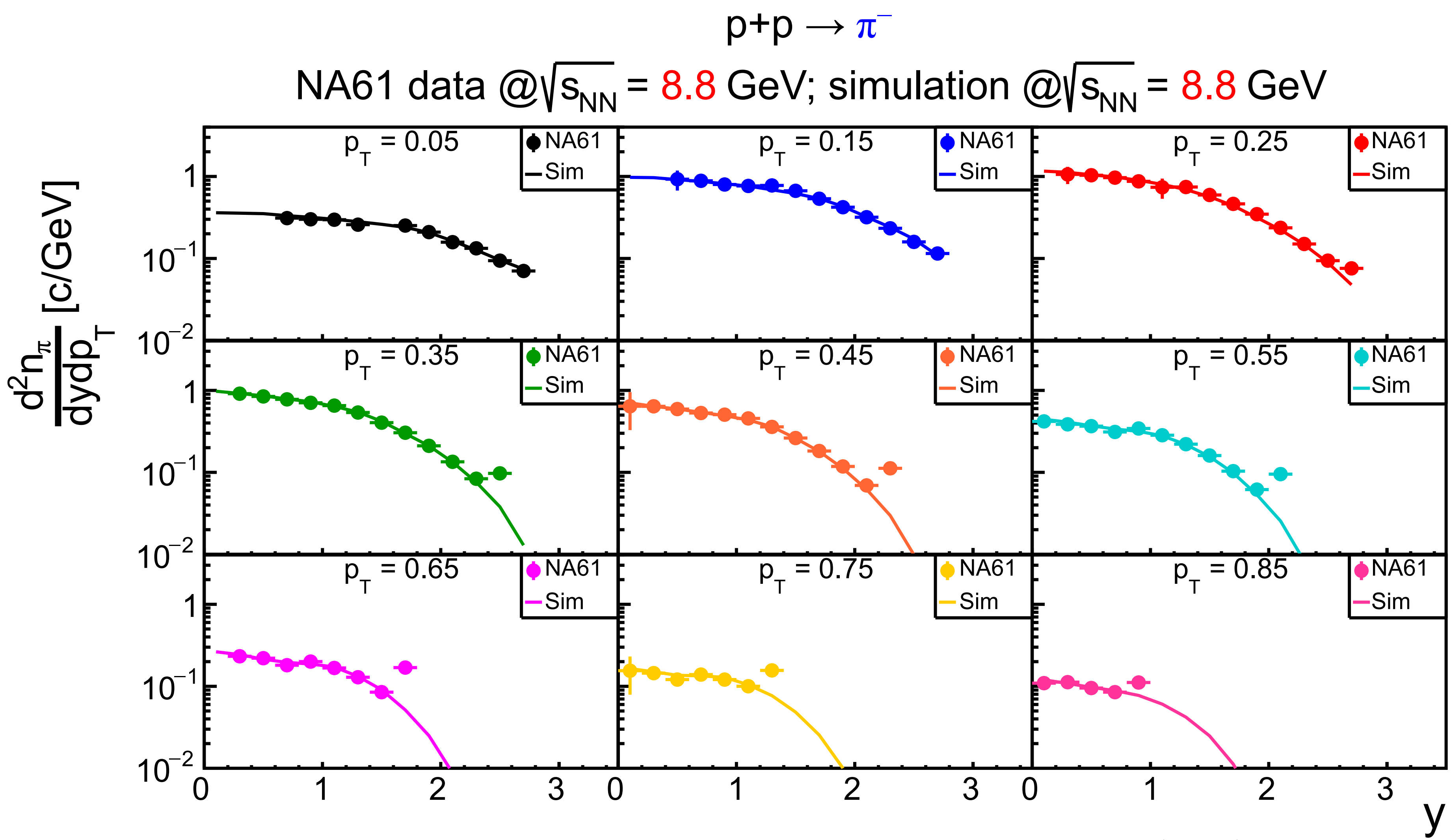


Data points from: The NA61/SHINE collaboration Eur.Phys.J.C 77 (2017) 671

Simulation methodology

STEP TWO:

Estimation of double differential $\pi^{\pm}$ meson density in p+p collisions @ $\sqrt{s}$= 8.8 GeV.

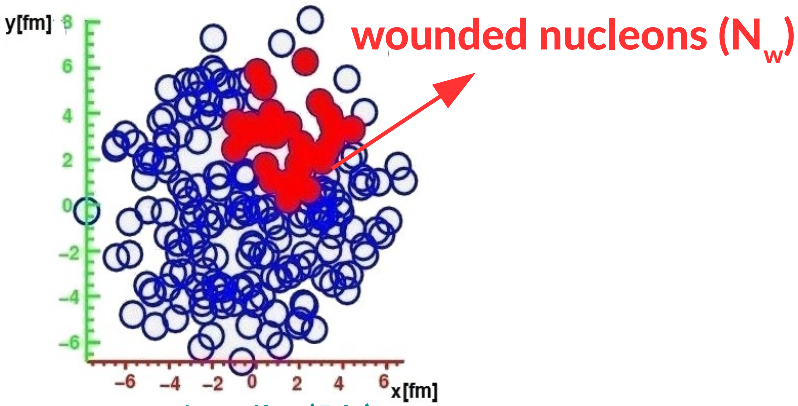


Data points from: The NA61/SHINE collaboration Eur.Phys.J.C 77 (2017) 671

Simulation methodology

STEP THREE: Determination of double differential $\pi^{\pm}$ meson density in A+A collisions.

XY- plane geometry



projectile (Pb)

Pb+Pb ≈ $N_w/2$ * N+N for $\left(\frac{d^2 n_\pi}{dx_F dp_T}\right)$ (approximation for)

Pb+Pb = N+N for $\left(\frac{\pi^+}{\pi^-}\right)$ (very good for)

See e.g.:
Rybicki, Acta Phys. Pol. B, 35 (2004) 145
POS EPS-HEP (2009) 031

1. Form p+p to A+A collisions...

$$\left(\frac{d^2 n_\pi}{dx_F dp_T}\right)_{p+p\to\pi^{\pm}} \xrightarrow{?} \left(\frac{d^2 n_\pi}{dx_F dp_T}\right)_{A+A\to\pi^{\pm}}$$

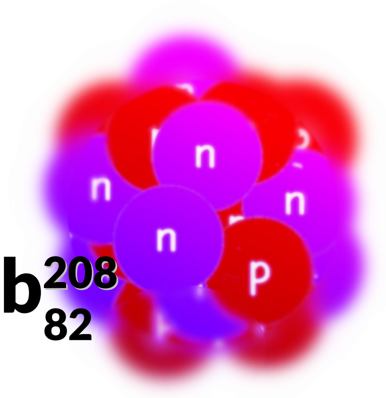
SUPERPOSITION APPROACH:

Particle production in A+A collisions:
→ superposition of independent contributions from the wounded nucleons (wounded protons and wounded neutrons!!!).

2. Neutron fragmentation is obtained from p+p taking into account isospin symmetry.

Simulation methodology

STEP THREE: Determination of double differential $\pi^{\pm}$ meson density in A+A collisions.

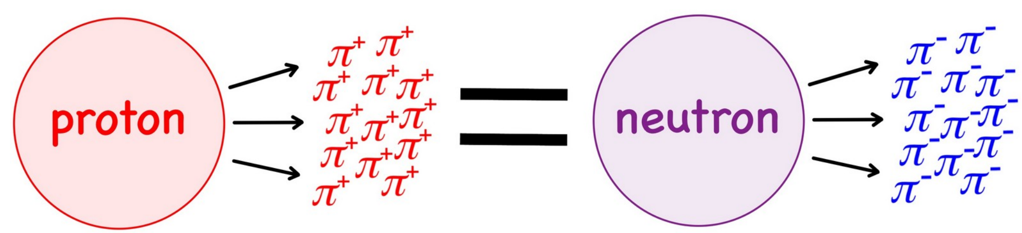


"**N+N**": 40% protons, 60% neutrons

ISOSPIN SYMMETRY:

$n \to \pi^{+} = p \to \pi^{-}$

$n \to \pi^{-} = p \to \pi^{+}$



Superposition of nucleon+nucleon (**N+N**) collisions:

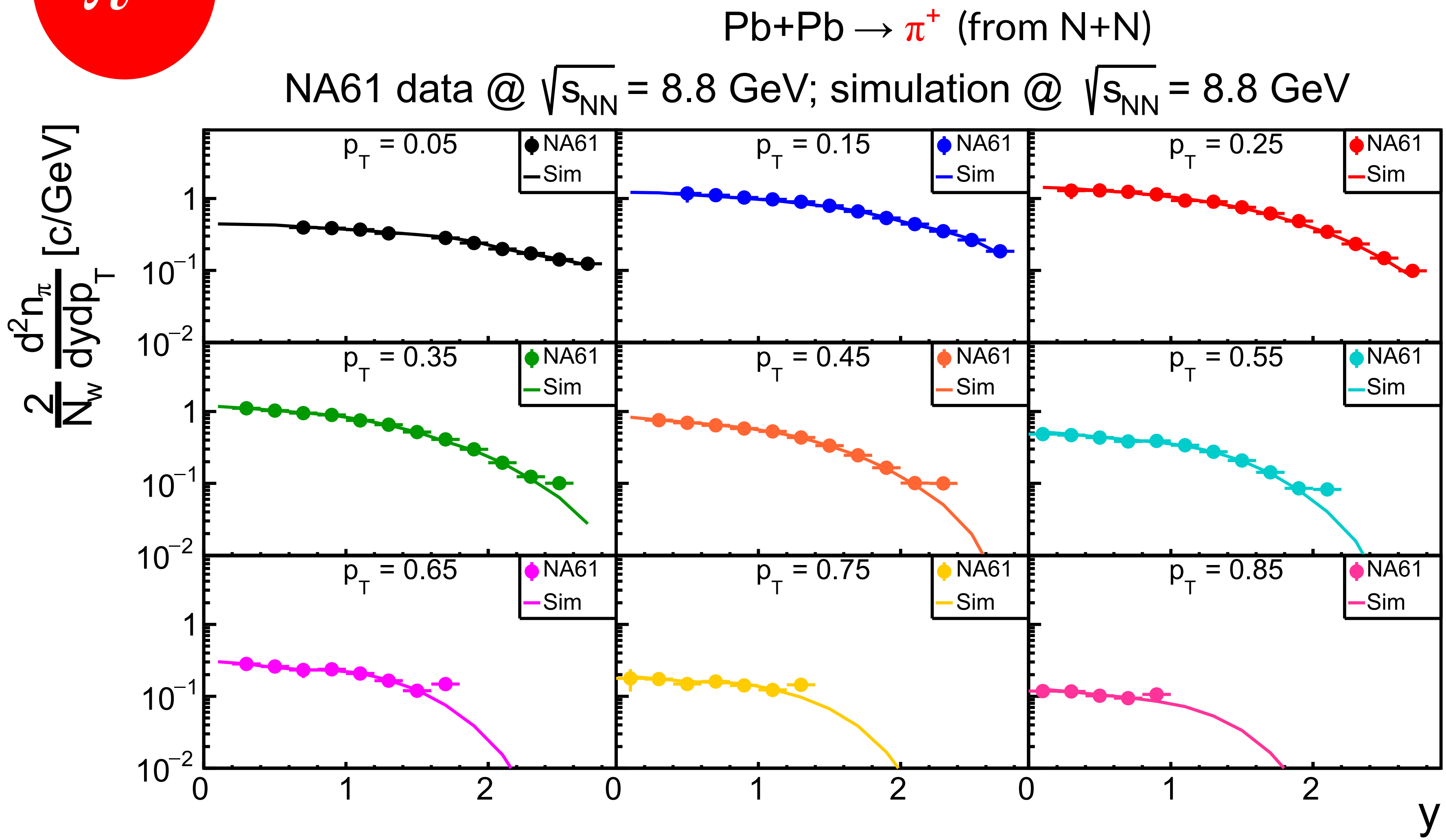
$$\frac{2}{N_w}\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{Pb+Pb\to\pi^-} = \frac{n_p}{n_N}\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{p+p\to\pi^-} + \frac{n_N - n_p}{n_N}\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{p+p\to\pi^+}$$

$$\frac{2}{N_w}\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{Pb+Pb\to\pi^+} = \frac{n_p}{n_N}\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{p+p\to\pi^+} + \frac{n_N - n_p}{n_N}\left(\frac{d^2 n}{dx_F\,dp_T}\right)_{p+p\to\pi^-}$$

Results: double differential π meson density distribution

π^{+}

Data points from: The NA61/SHINE collaboration Eur.Phys.J.C 77 (2017) 671

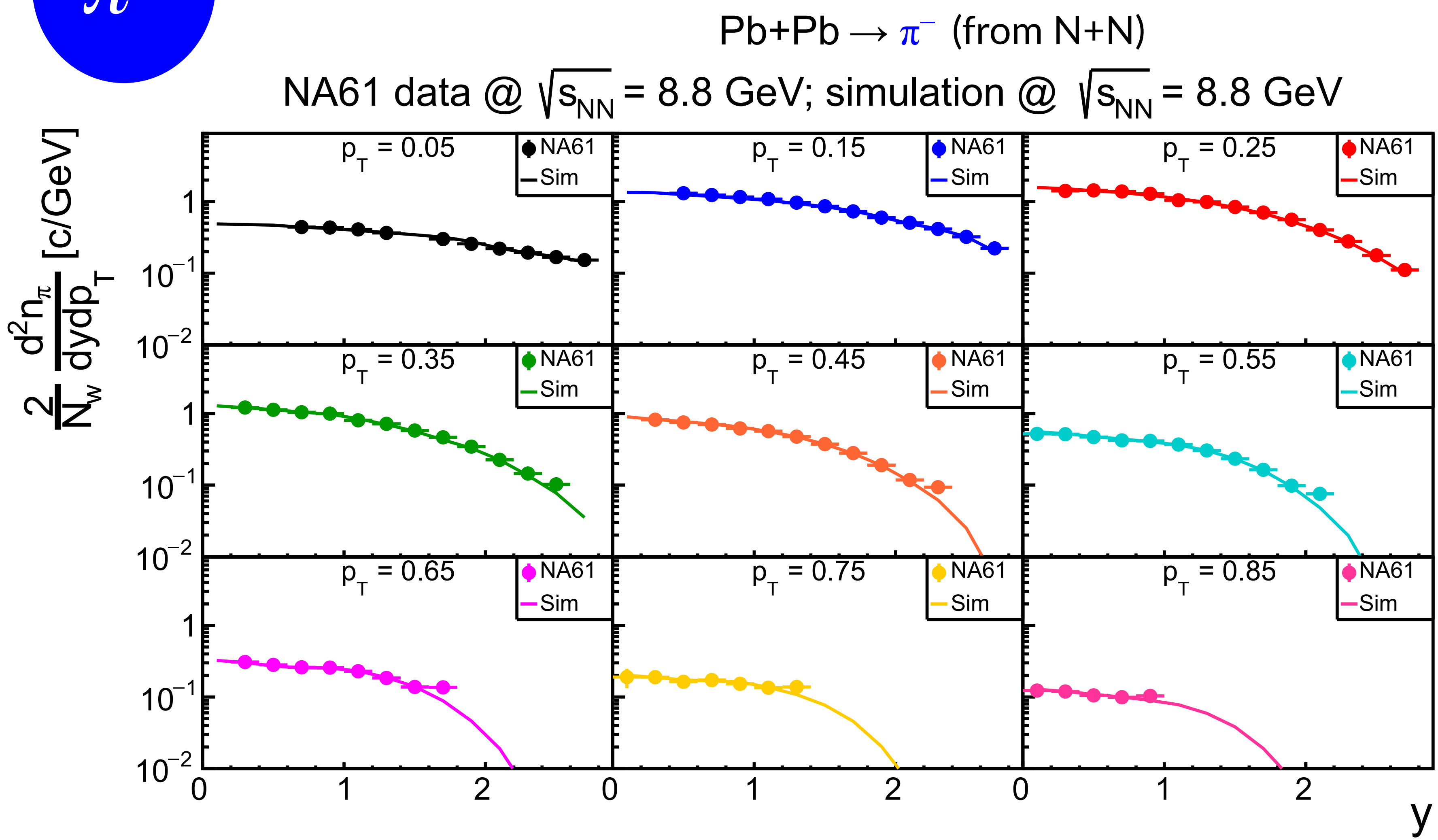


Conclusion There is good agreement between data and simulation @ 8.8 GeV.

Results: double differential π meson density distribution

π^-

Data points from: The NA61/SHINE collaboration Eur.Phys.J.C 77 (2017) 671



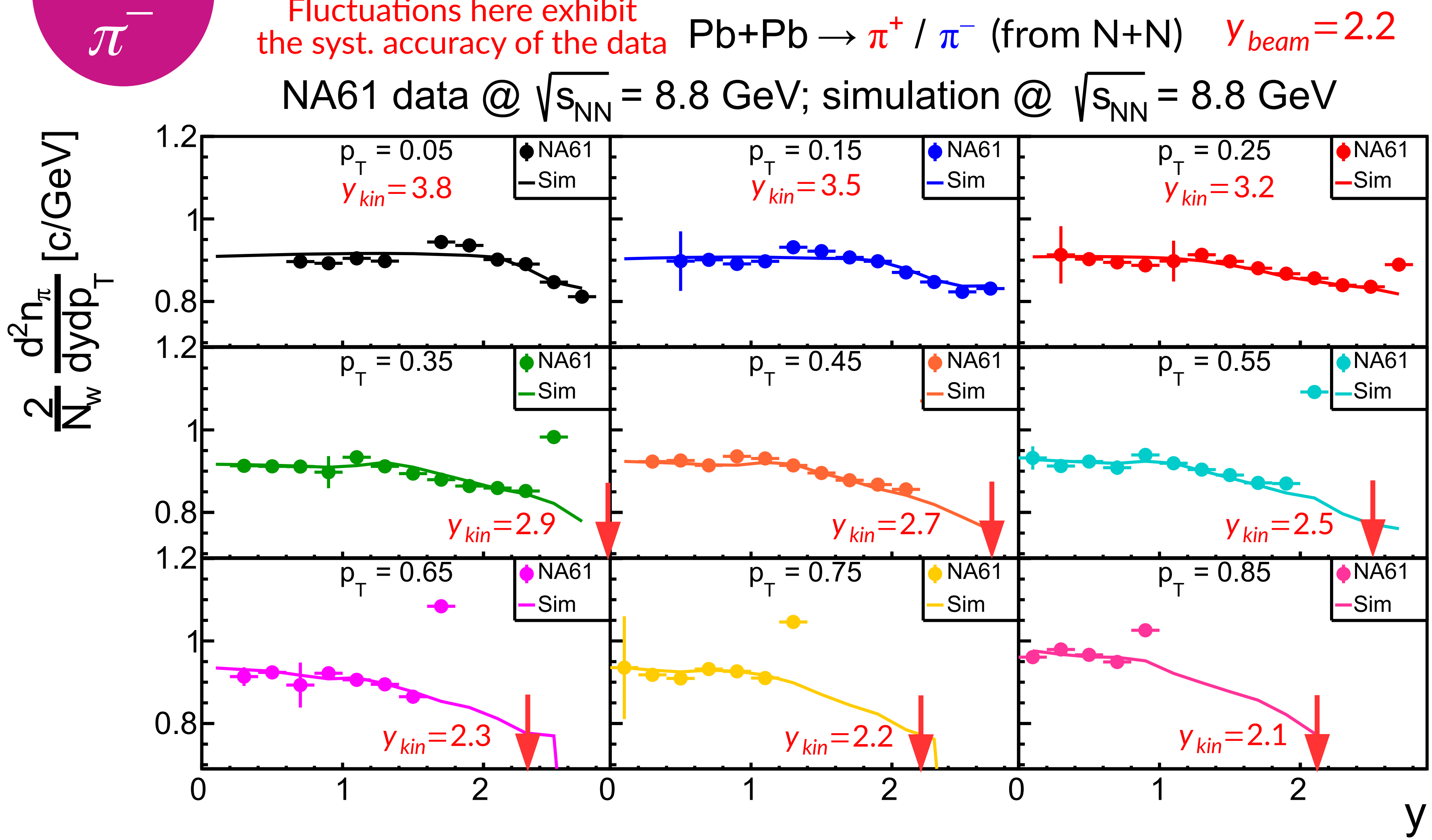
Conclusion There is good agreement between data and simulation @ 8.8 GeV.

Results: double differential π meson density distribution

$\frac{\pi^+}{\pi^-}$

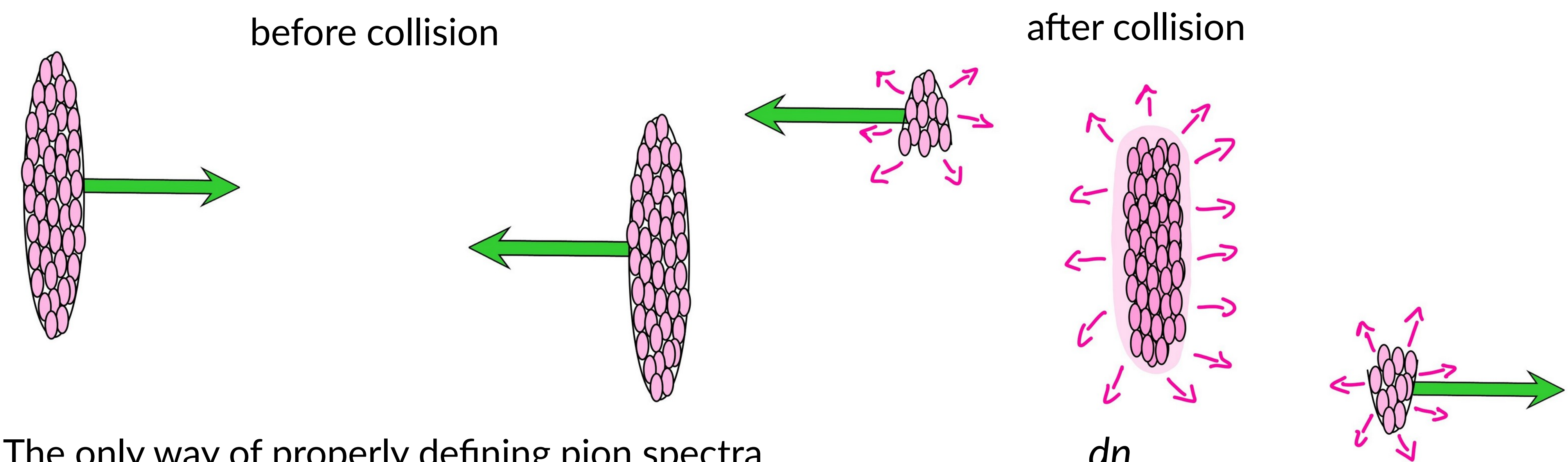
Data points from: The NA61/SHINE collaboration Eur.Phys.J.C 77 (2017) 671

Fluctuations here exhibit
the syst. accuracy of the data



Conclusion There is good agreement between data and simulation @ 8.8 GeV.

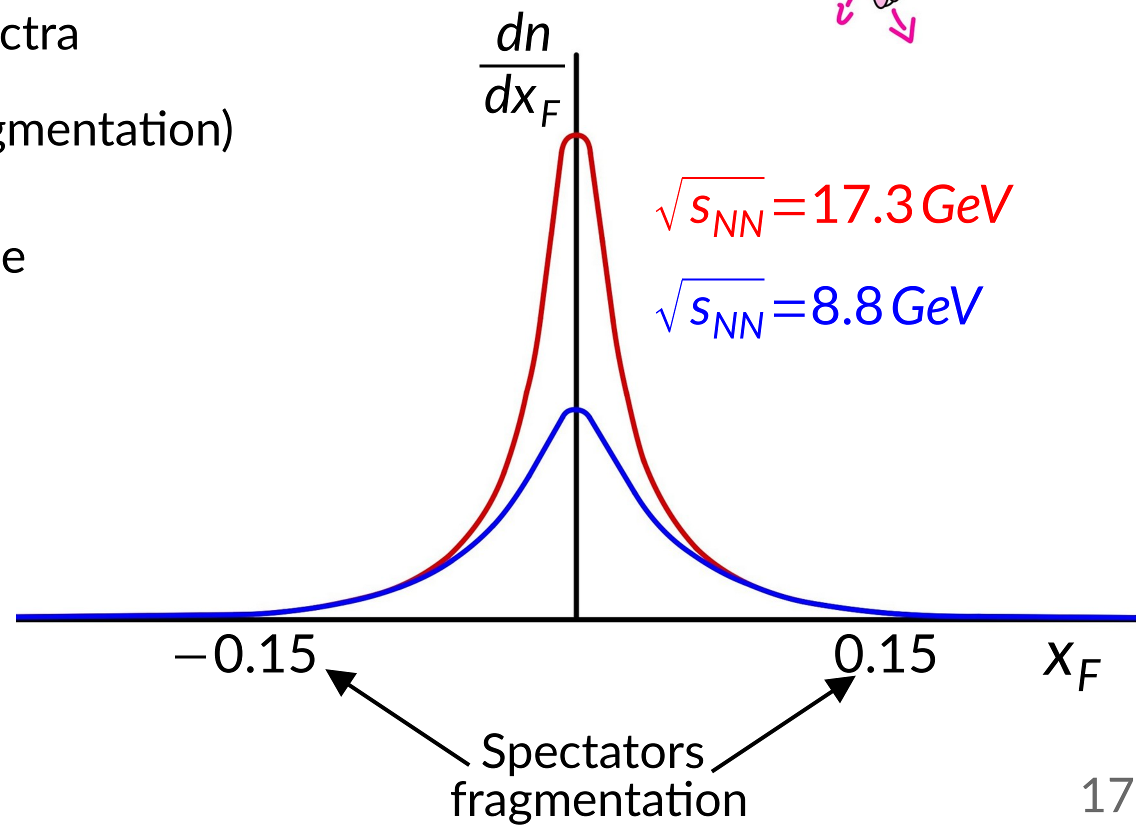
Feynman scaling



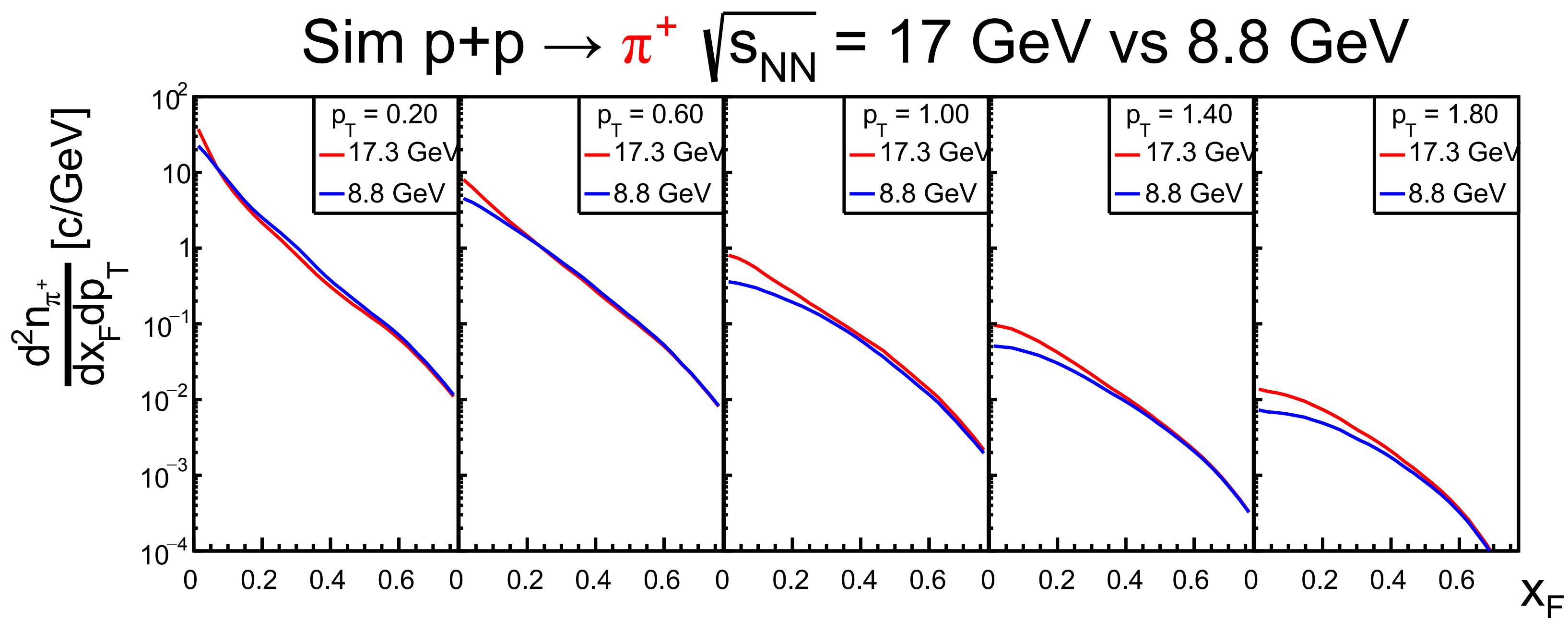
The only way of properly defining pion spectra at high x_F (where there is no NA61 data) is through Feynman scaling (or limiting fragmentation)

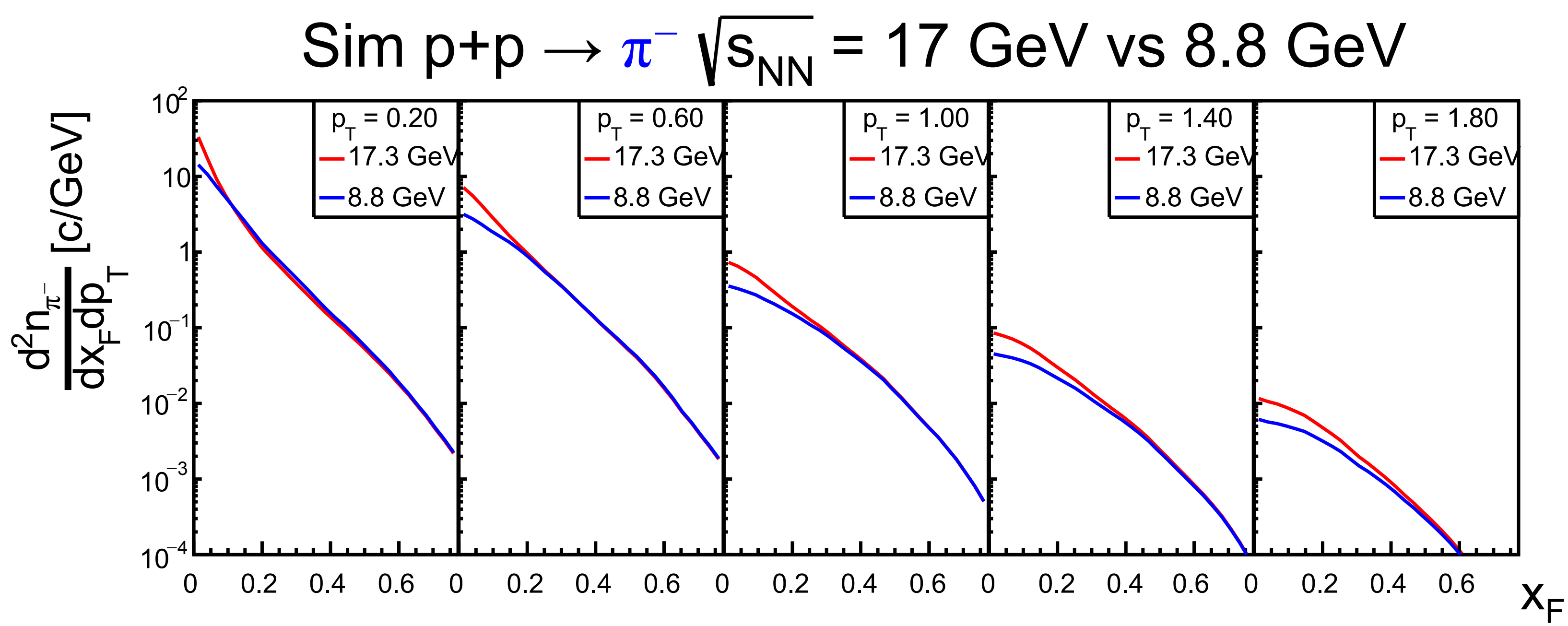
In p+p collisions Feynman scaling meas the invariance of the dn/dxF distribution with collision energy at high x_F

In A+A collisions this means:
Production of particles is independent of collision energy in the spectator fragmentation area



Results: Compare simulation between the two energies





Summary:

1. We have (painfully) created a simulation producing double differential (x_F, p_T) distribution for Pb + Pb→π at $\sqrt{s_{NN}}$ = 17.3 GeV and 8.8 GeV;
2. Consequently, this simulation can be used for any mixture of colliding protons and neutrons, in particular also Ar+Sc @ $\sqrt{s_{NN}}$ = 8.8 GeV;
3. This simulation will be used in the electromagnetic effect research;
4. In the situation of the lack of experimental $Ed^3\sigma/dp^3$ data for $\sqrt{s_{NN}}$ = 8.8 GeV,

   I had to “create” that distribution, what permitted this was:

   →NA61/SHINE p+p data

   →Isospin symmetry

   →Feynman scaling

Thank you for your attention :)