Single particle spectra from the energy scan of p+p and ^{7}Be+^{9}Be interactions in the SPS energy range

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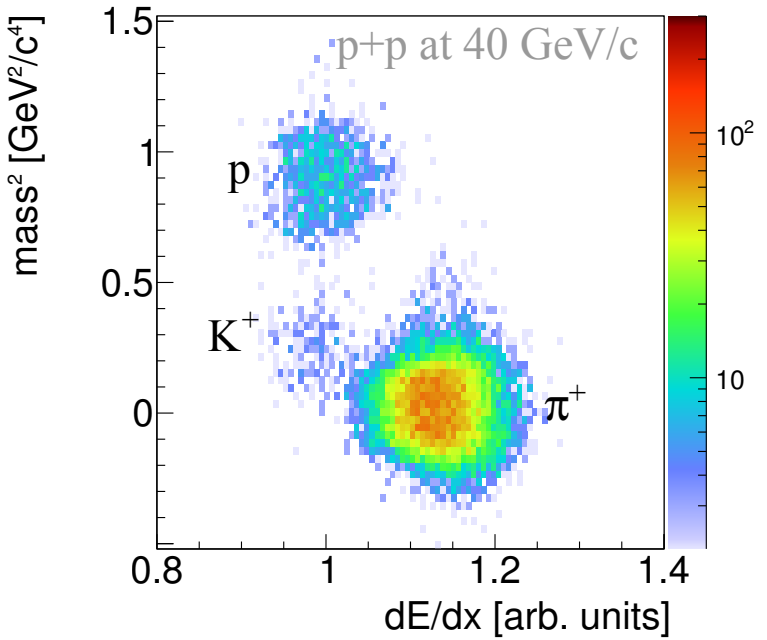
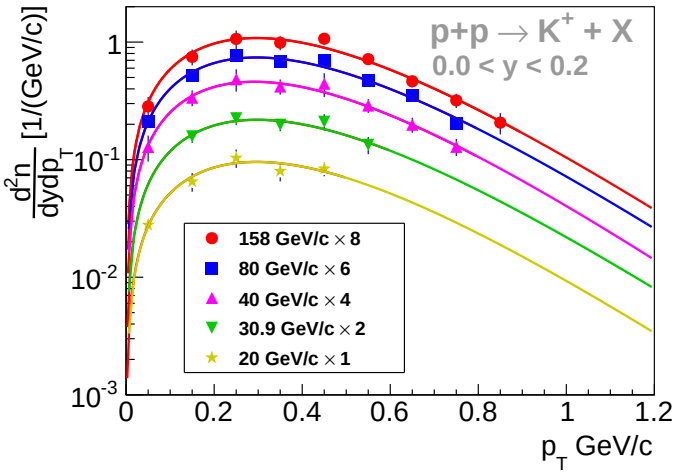
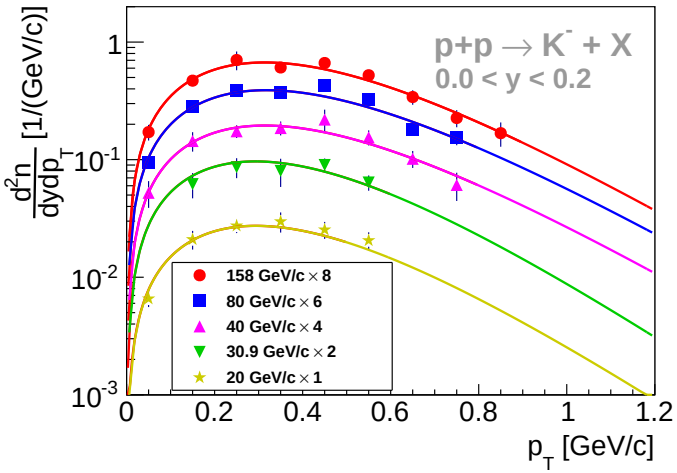
Outline

- Selected results from p+p energy scan (20, 31, 40, 80, 158 GeV/c):
  - Inverse slope parameter T — "Step"
  - π^+ mid–rapidity multiplicity calculation
  - K/π ratio — "Horn"
  - Comparison with Monte–Carlo models
- Selected results from ^{7}Be+^{9}Be energy scan (20A, 30A, 40A, 75A, 150A GeV/c):
  - Forward Energy (FE, E_F) event selection (centrality)
  - Width of the π^- rapidity distribution — "Dale"
  - Collectivity in ^{7}Be+^{9}Be



Mid–rapidity spectra of Kaons



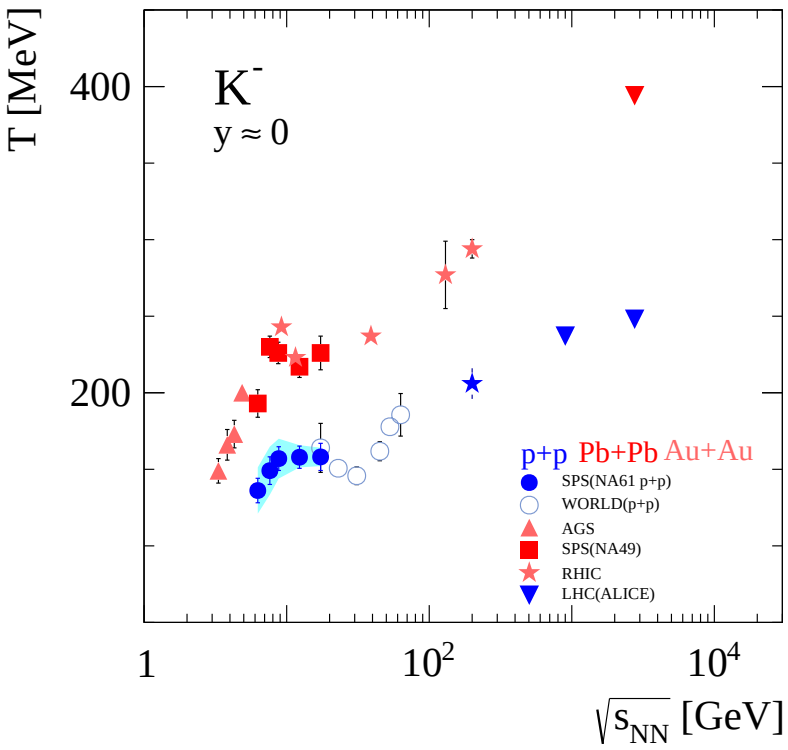


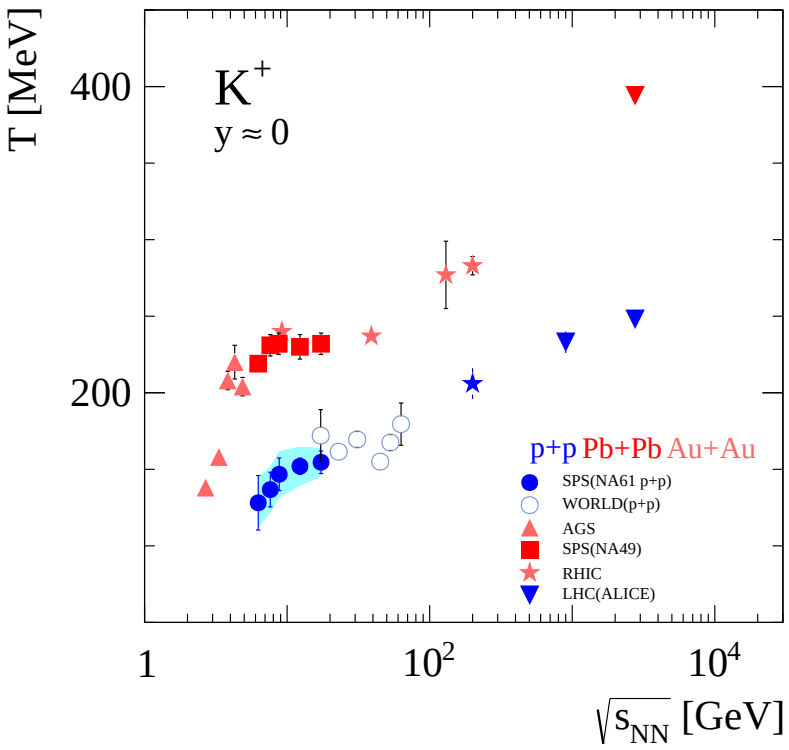
- Spectra fitted by:

$$\frac{d^2n}{dp_T dy} = \frac{S\ p_T}{T^2 + m_K T} \exp\left(-\frac{\sqrt{p_T^2 + m_K^2} - m_K}{T}\right)$$

- Fit allows to calculate:
  - The inverse slope parameter T
  - Kaon multiplicity in p_T range not accessible by data

Inverse slope parameter T — "Step"

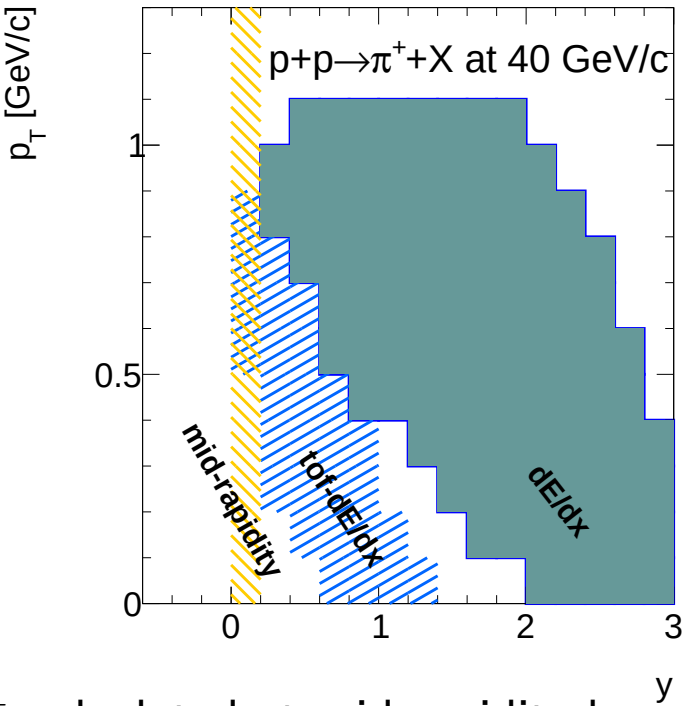


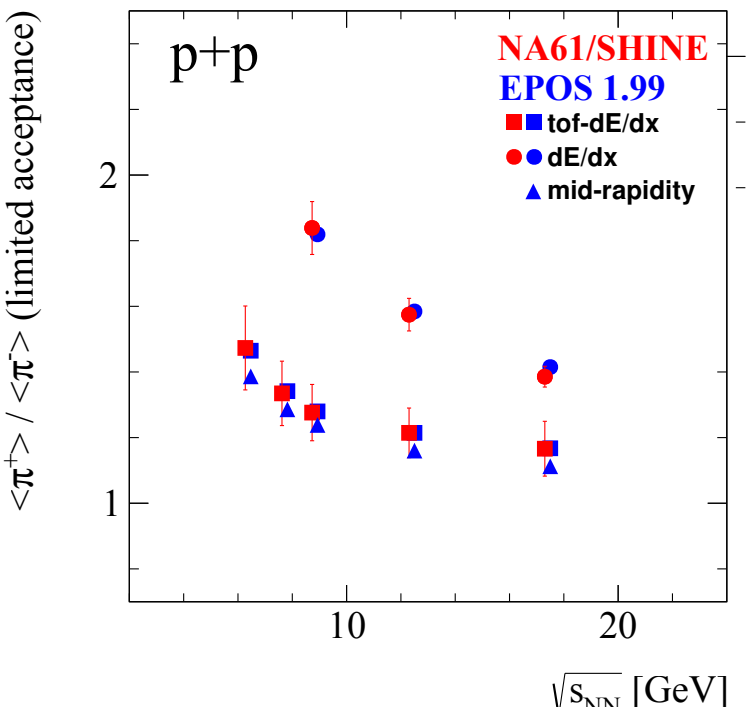


- Energy dependence of the inverse slope parameter T of kaon spectra exhibits rapid changes in both p+p and Pb+Pb interactions.

Phys.Rev. C69 (2004) 044903, STAR: Phys.Rev.C79:034909,2009;
ALICE: PLB 736 (2014) 196-207, Eur. Phys. J , C (2011) 71:1655

π^+ multiplicity

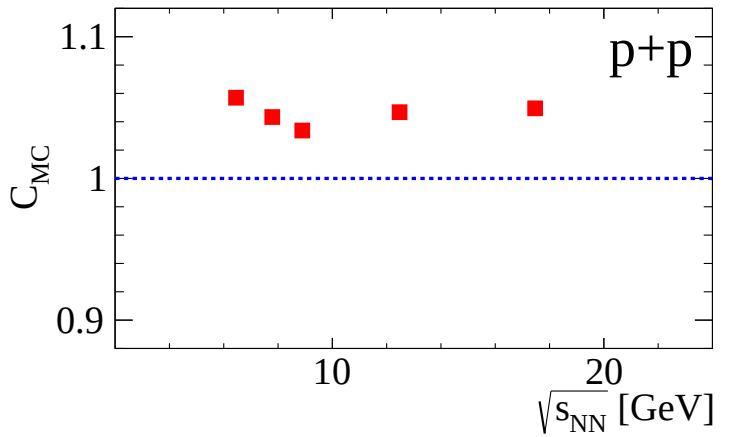




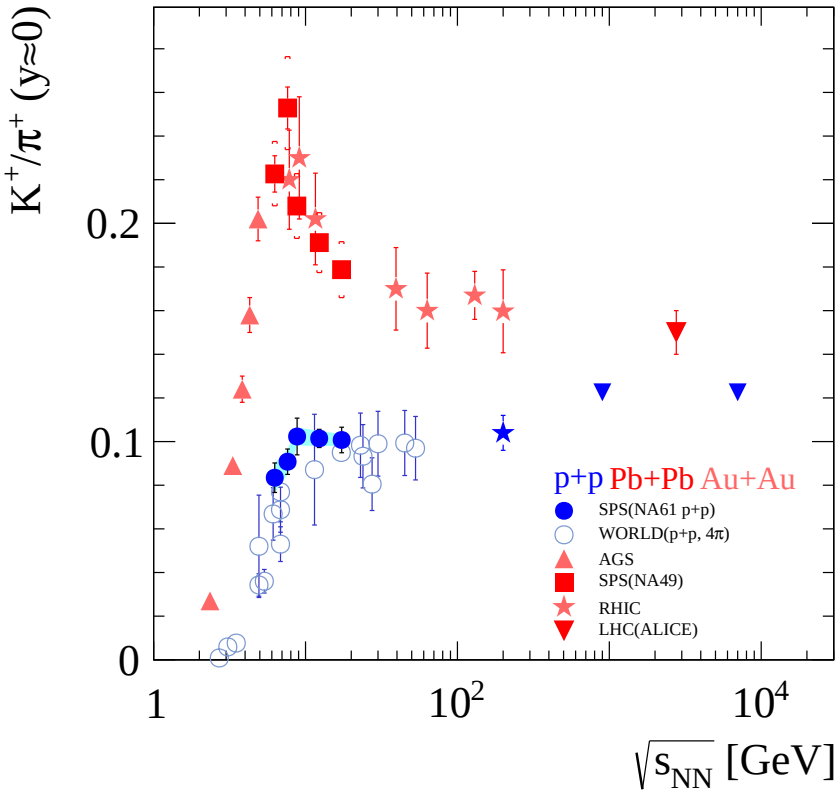
π^+ calculated at mid-rapidity based on data and MC correction:

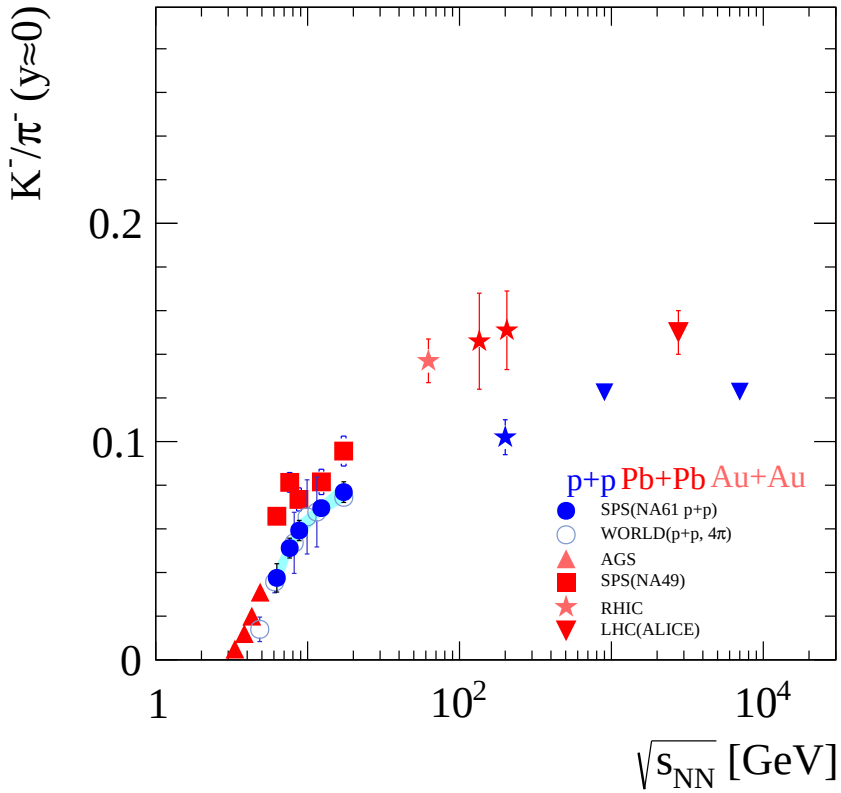
$$\pi^+(y=0) = \pi^-(y=0)\,\frac{\pi^+}{\pi^-}(tof)\,C_{MC}$$

$$C_{MC} = \left[\frac{\pi^+}{\pi^-}(y=0)/\frac{\pi^+}{\pi^-}(tof)\right]_{MC} \approx 5\%$$



$\frac{K}{\pi}$ ratio — "Horn"

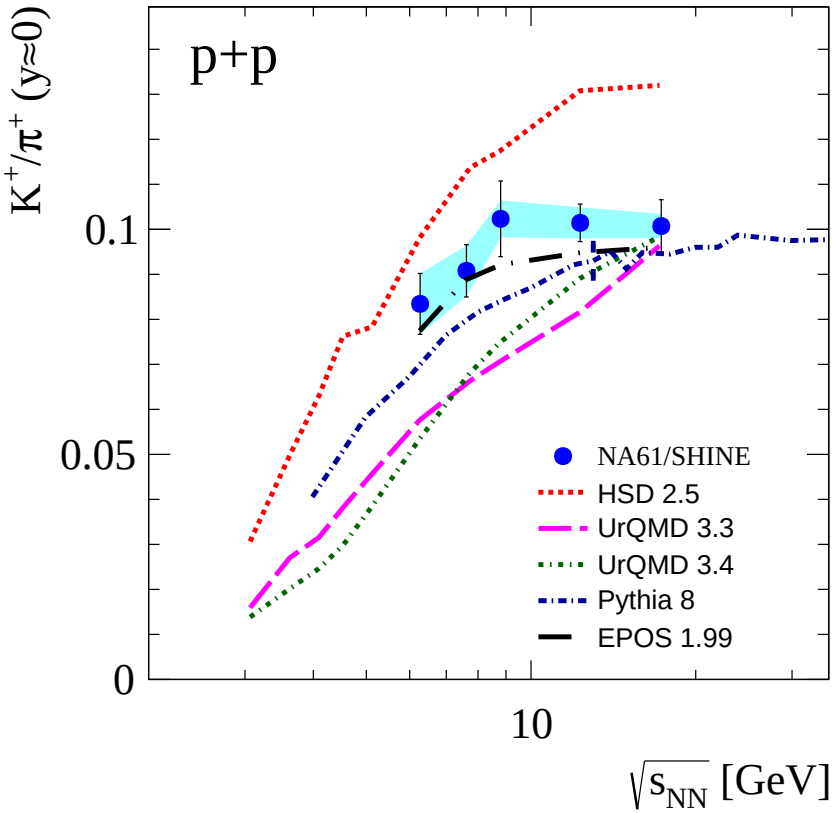


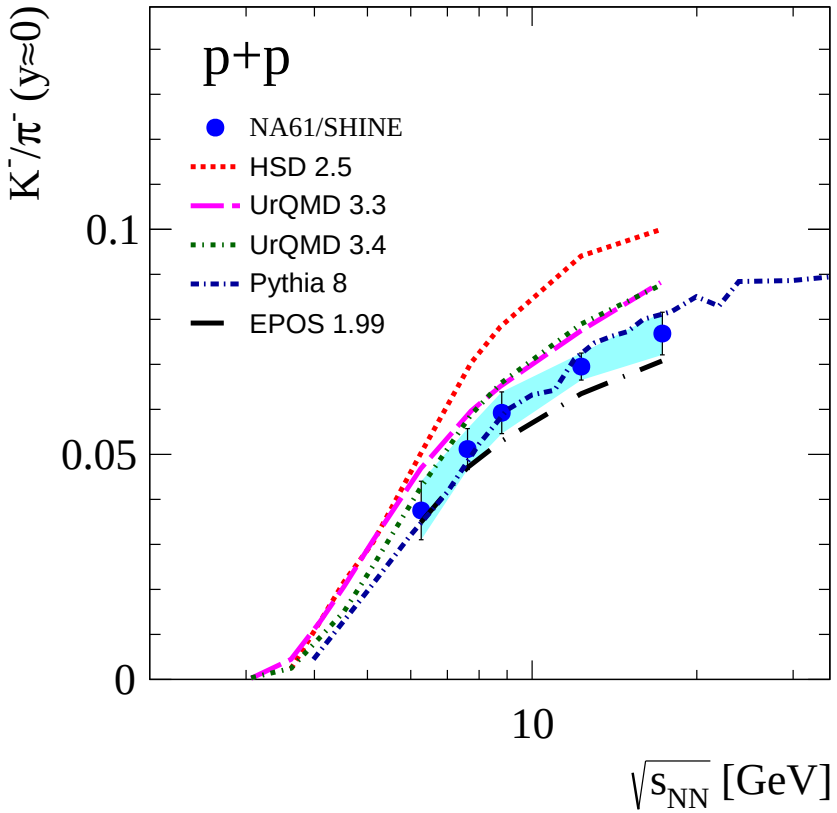


- The energy dependence of K^+/π^+ ratio in p+p changes at the energy where horn structure is visible in Pb+Pb

Z.Phys. C65 (1995) 215-223 (π), Z.Phys. C71 (1996) 55-64 (K); BRAHMS: Phys.Rev.C72:014908,2005;
ALICE: Eur. Phys. J , C (2011) 71:1655, PRL 109, 252301 (2012), PhD thesis of Chojnacki, M.

$\frac{K}{\pi}$ ratio in p+p interactions — comparison to models

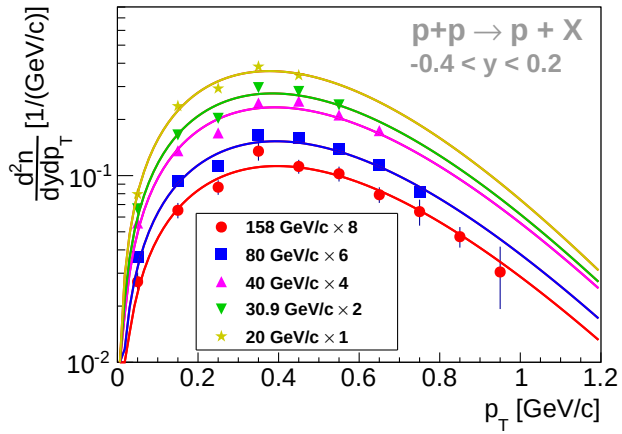


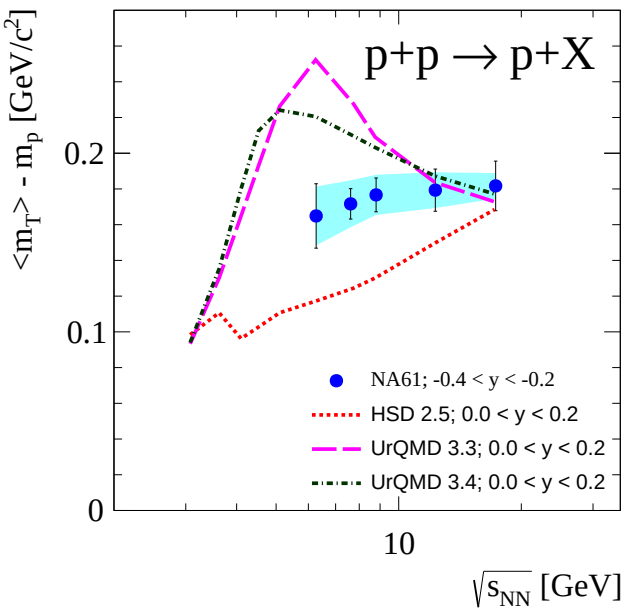


- High precision NA61/SHINE data allows to impose rigorous constraints for Monte-Carlo models.

Vovchenko et al., PRC 90, 024916 (2014), and private communication. Gavin Salam private communication
UrQMD: Prog. Part. Nucl. Phys. 41 (1998), J. Phys. G: Nucl. Part. Phys. 25 (1999); HSD: Nucl. Phys. A 602, 449 (1996), Nucl. Phys. A 644, 107 (1998), Phys. Rept. 308, 65 (1999); EPOS: Nucl.Phys.Proc.Suppl.196,2009, PYTHIA: arXiv:1410.3012

Proton mean transverse mass





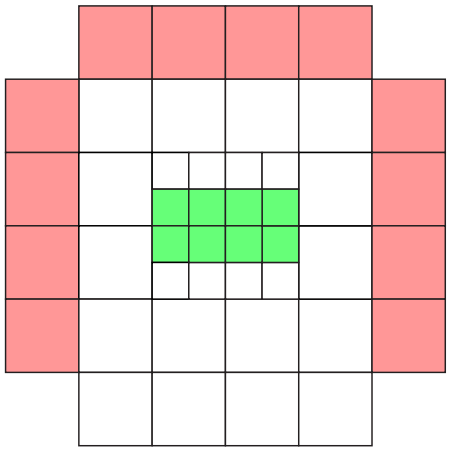
- $\langle m_T \rangle$ was calculated using fitted function:
  $\frac{d^2n}{dp_T dy} = \frac{S\ p_T}{T^2 + m_p T} \exp\left(-\frac{\sqrt{p_T^2 + m_p^2} - m_p}{T}\right)$.
- $\langle m_T \rangle$ of protons produced in p+p interactions around mid-rapidity increase slowly with collision energy.
- Neither UrQMD nor HSD describe this behavior.

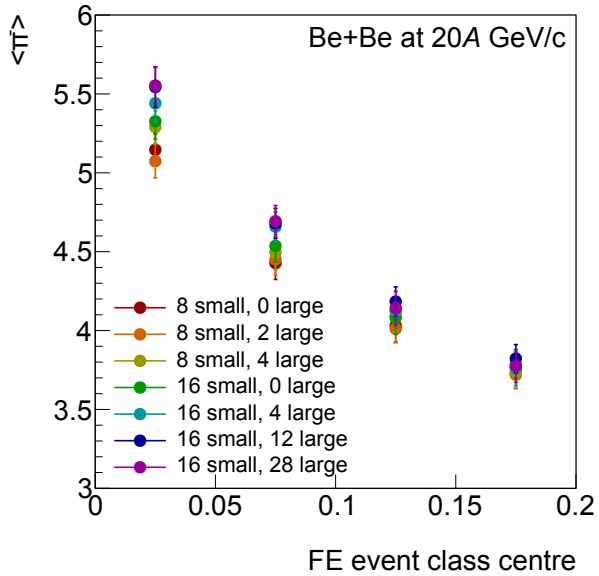
Vovchenko et al., PRC 90, 024916 (2014), arXiv:1408:5493, and private communication;
UrQMD: Prog. Part. Nucl. Phys. 41 (1998), J. Phys. G: Nucl. Part. Phys. 25 (1999); HSD: Nucl. Phys. A 602, 449 (1996), Nucl. Phys. A 644, 107 (1998), Phys. Rept. 308, 65 (1999);

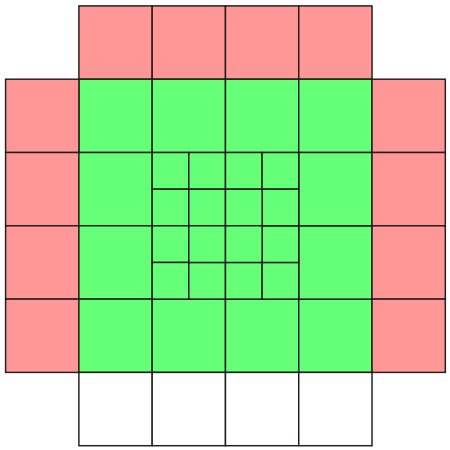
$^{7}\mathrm{Be}+^{9}\mathrm{Be}$

Results sensitivity to Forward Energy (FE) definition

- The results depend ($< 5\%$) on the definition of forward energy
- By calculating E_F in a larger PSD acceptance,
  we include more spectators but also more produced particles







Note on errors

All data points are drawn with statistical errors only.

Preliminary estimation of systematic errors for mean multiplicity show additional uncorrelated contributions:

- 5% from definition of forward energy (event selection)
- 2% from uncertainty of correction based on MC models
- 5% from other sources

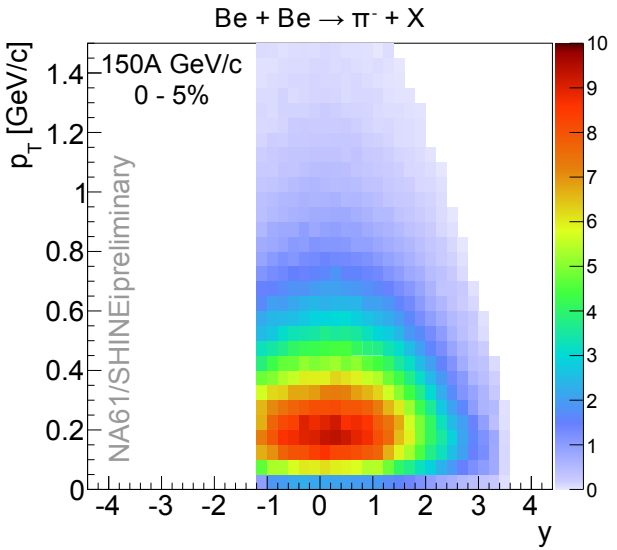
For all other measured quantities systematic errors are smaller.

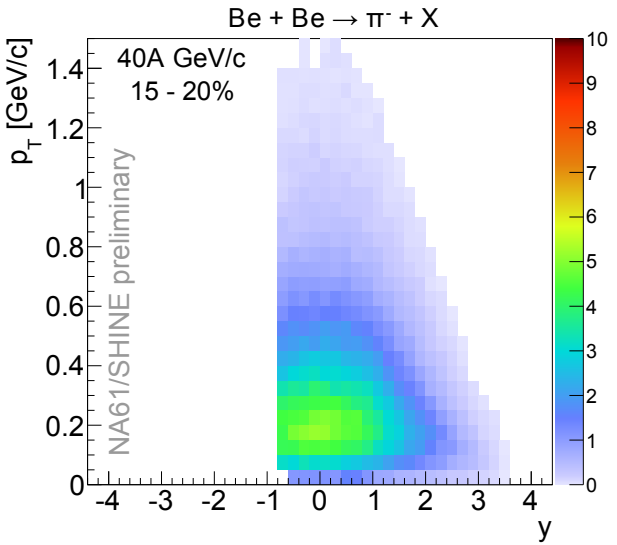
Double differential spectra of π^-

- Analysis done in four FE event classes: 0–5%, 5–10%, 10–15%, 15–20%
- All quantities were derived from double differential spectra

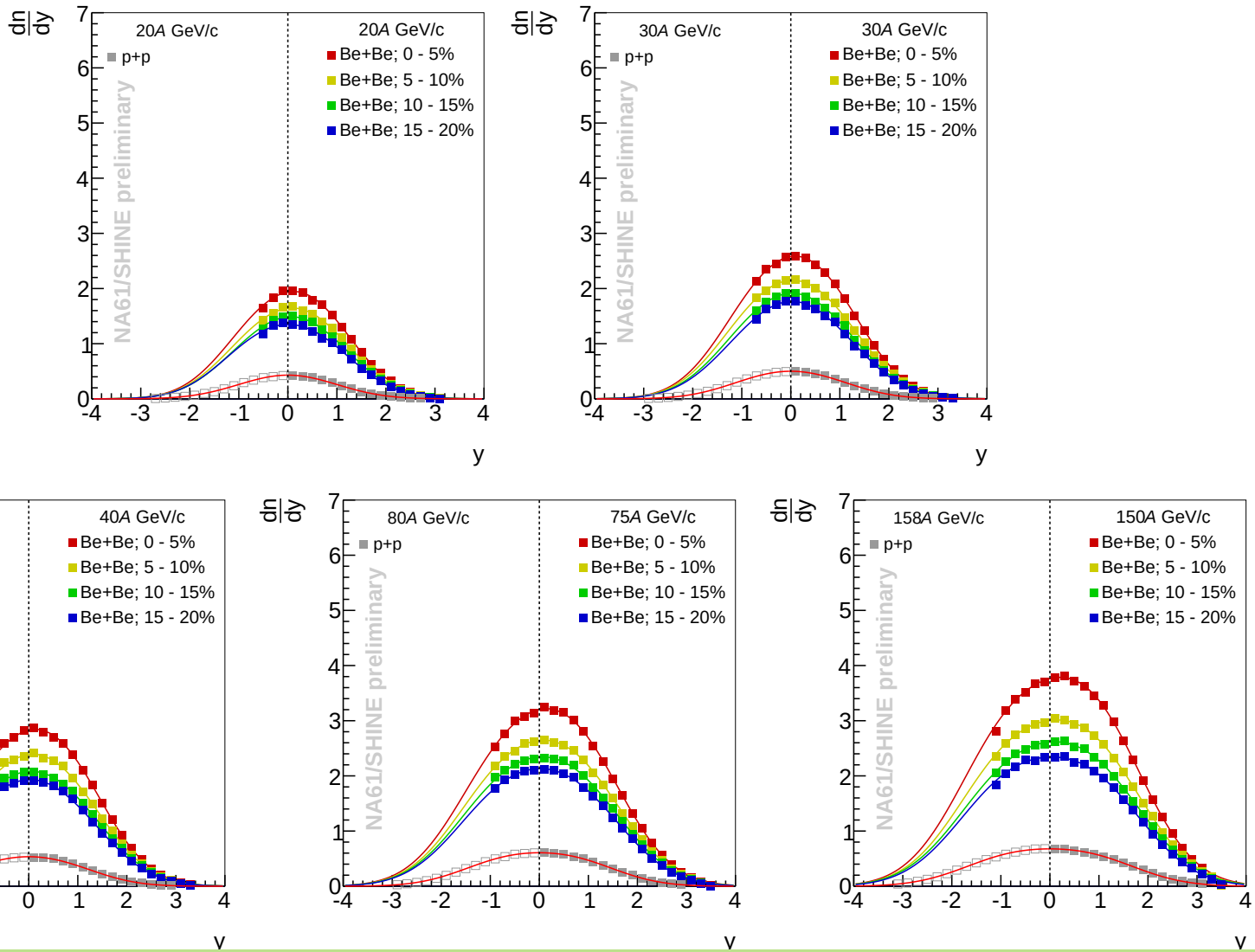
$$\frac{d^2n}{dydp_T} \text{ or } \frac{d^2n}{dydm_T}$$

corrected for detector effects
and feed–down from weak decays

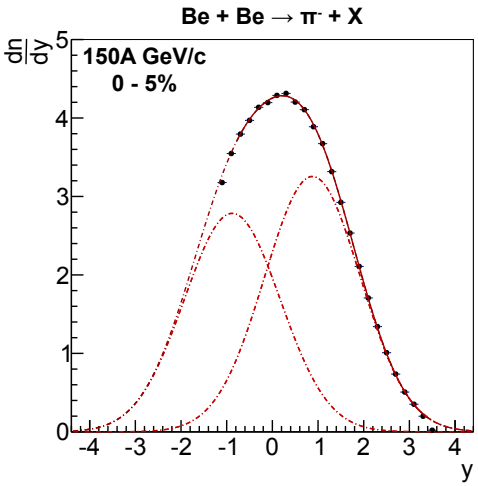


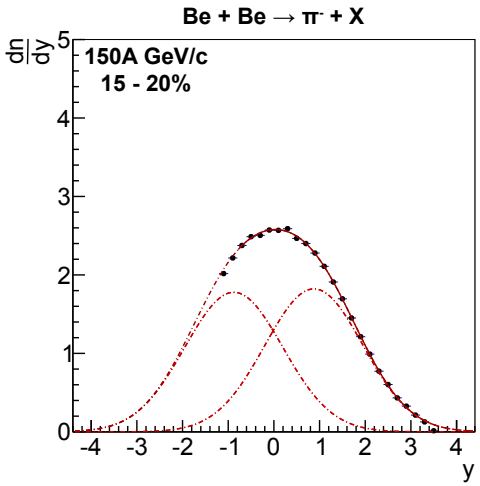


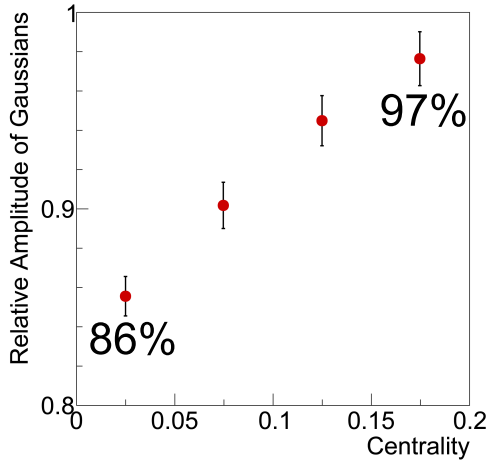
Rapidity spectra (^{7}Be+^{9}Be, p+p)
5 energies, 4 FE event classes



Asymmetry in rapidity spectra







Two opposite effects influence asymmetry of the spectra:

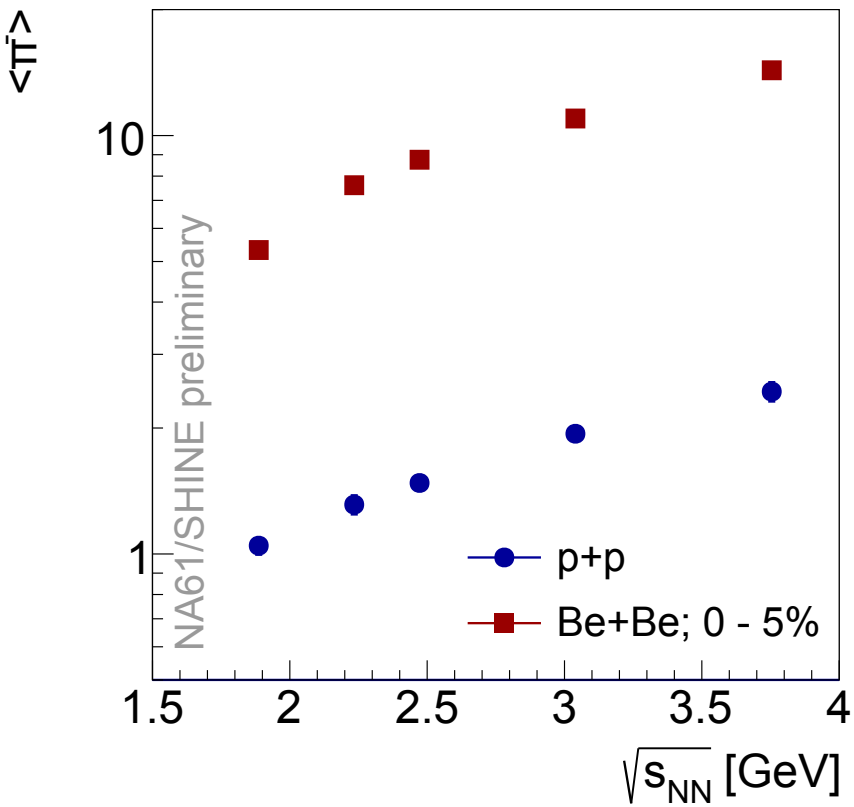
- asymmetric system — ^{7}Be projectile on ^{9}Be target (small effect),
- centrality selection based on projectile spectators (large effect).

Selection of 5% of most central collisions:

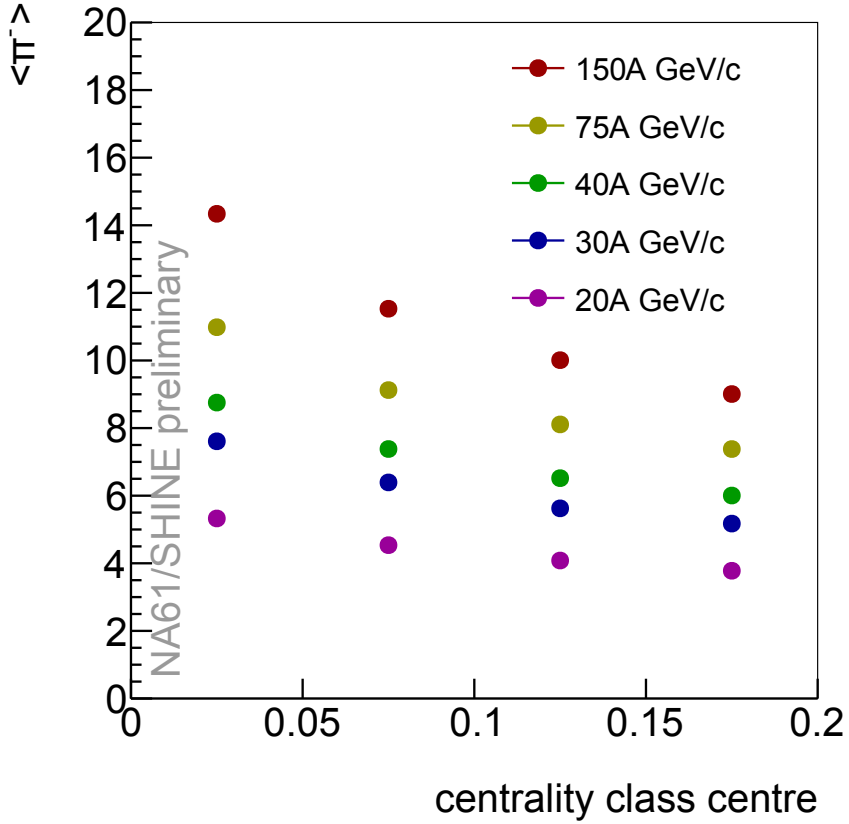
- introduce sharp cut on projectile spectators ($N_S^{\text{proj}} \leq 2$),
- fluctuations of target spectators are not explicitly restricted ($N_S^{\text{targ}} \approx \text{Gaussian}(x_0 = 3.7; \sigma = 1.4)$).

Mean multiplicities of π^- in ^{7}Be+^{9}Be collisions

0-5% ^{7}Be+^{9}Be and p+p vs. $\sqrt{s_{NN}}$

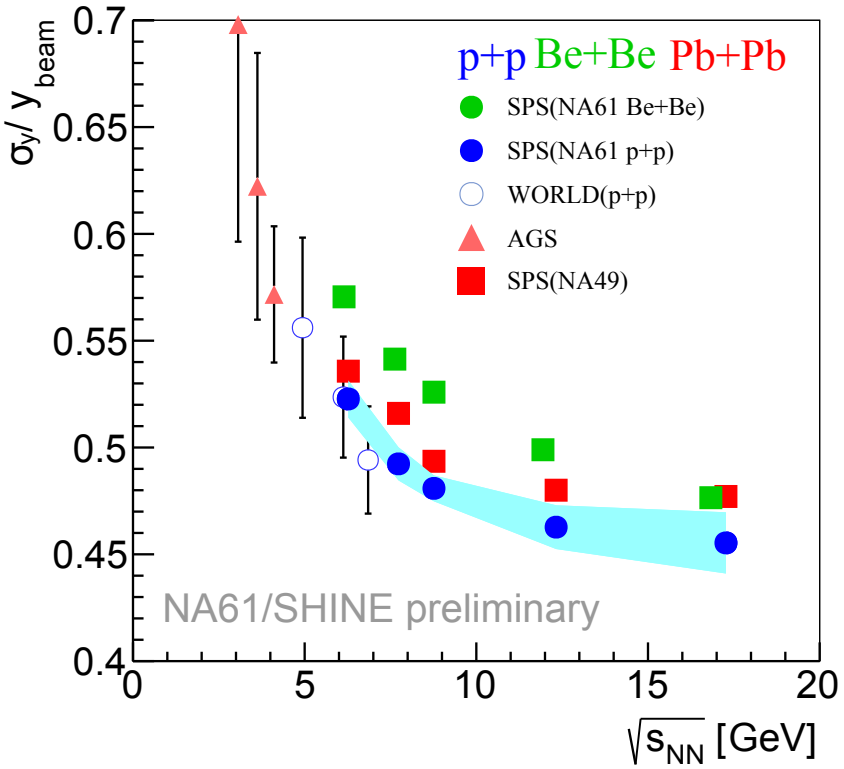


^{7}Be+^{9}Be vs. FE event class



NA61/SHINE p+p results published in Eur.Phys.J. C74 (2014) 2794

Width of the rapidity distribution

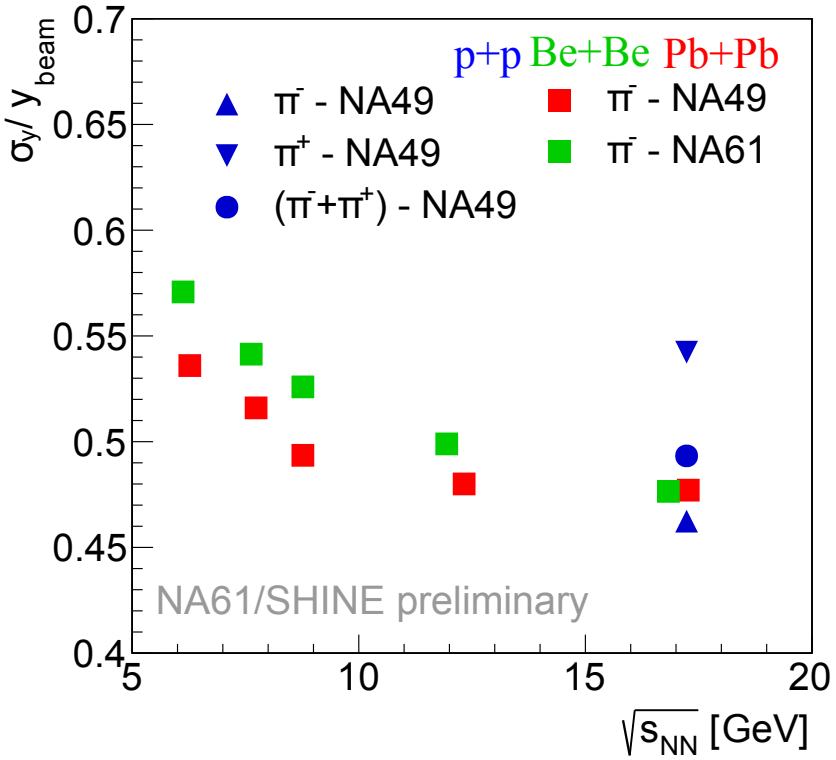


- σ_y calculated from fitted function (two symmetrically displaced Gaussians)
- σ_y related to speed of sound c_s^2 — "Dale"
- Smooth, monotonic behaviour with energy
- *Non-monotonic* behaviour with the system size:

$$\frac{\sigma_y(\mathrm{p+p})}{y_{\mathrm{beam}}} < \frac{\sigma_y(\mathrm{Pb+Pb})}{y_{\mathrm{beam}}} < \frac{\sigma_y(^7\mathrm{Be}+^9\mathrm{Be})}{y_{\mathrm{beam}}}$$

NA61/SHINE p+p results published in Eur.Phys.J. C74 (2014) 2794

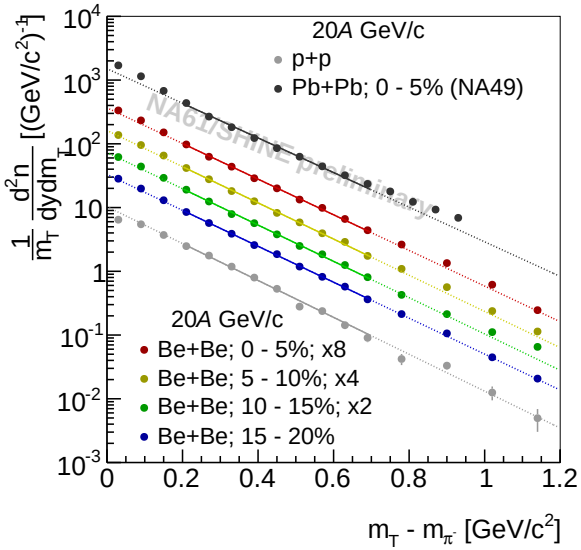
Effect of isospin asymmetry on σ_y / y_{beam}

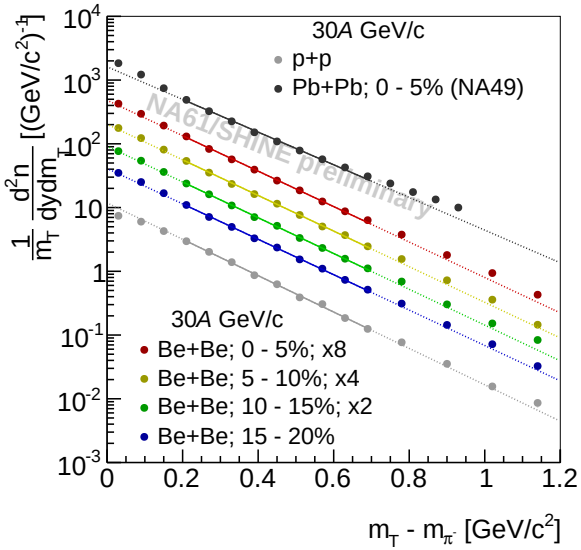


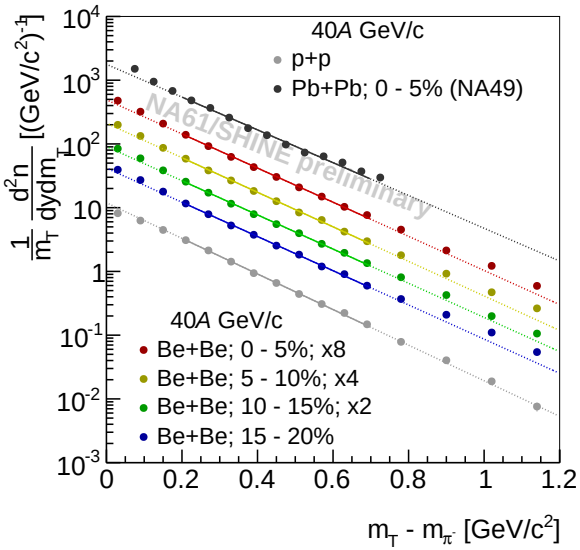
- The isospin asymmetry affects width of the π^- rapidity distribution in p+p and Pb+Pb
- ^{7}Be+^{9}Be is almost isospin symmetric
- In p+p collisions rapidity width of π^+ is larger than width of π^- distribution
- The width of the sum of π^+ and π^- distributions is in between

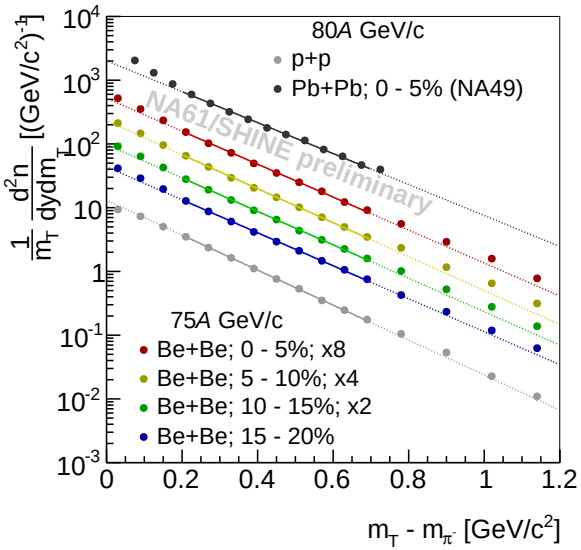
NA49 π^- and π^+ rapidity distributions in p+p collisions from: Eur. Phys. J. C45 (2006) 343-381

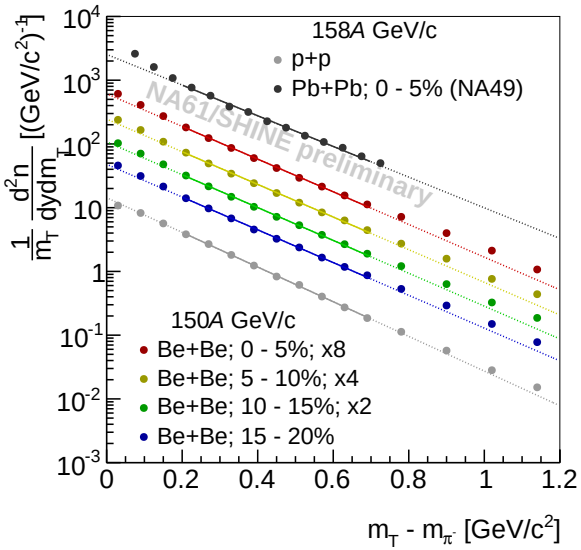
Transverse mass spectra (p+p, ^{7}Be+^{9}Be, Pb+Pb)





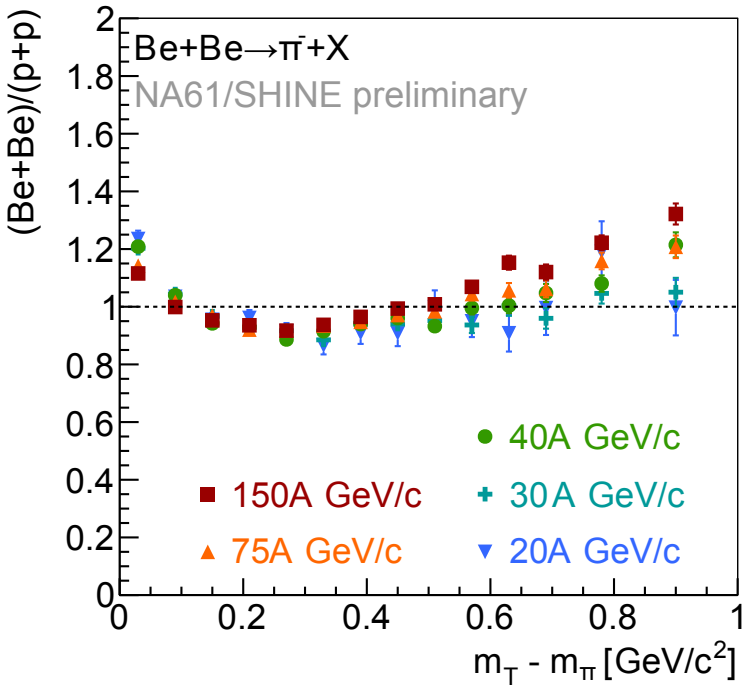


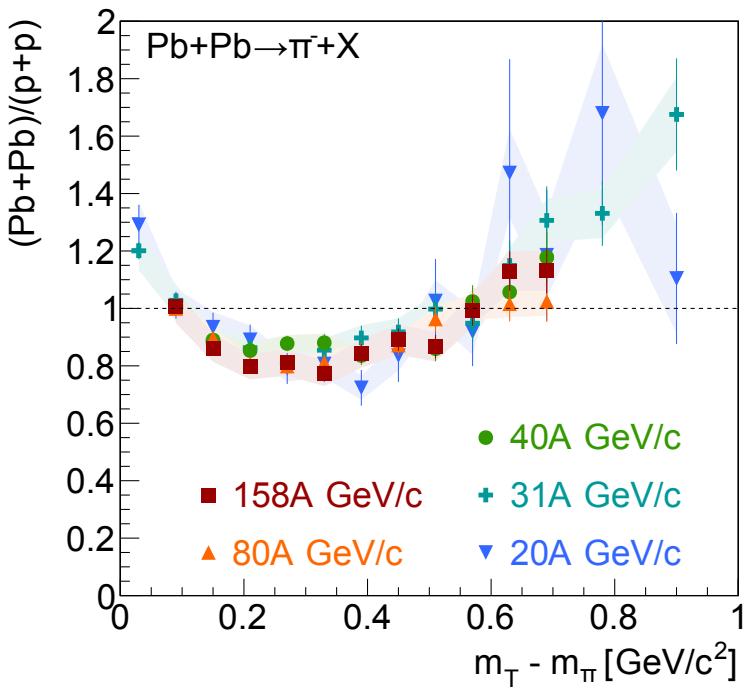




Comparison of transverse mass spectra (energy and system size)

Ratio of normalized m_T spectra at different energies
allows to compare shape of the spectra

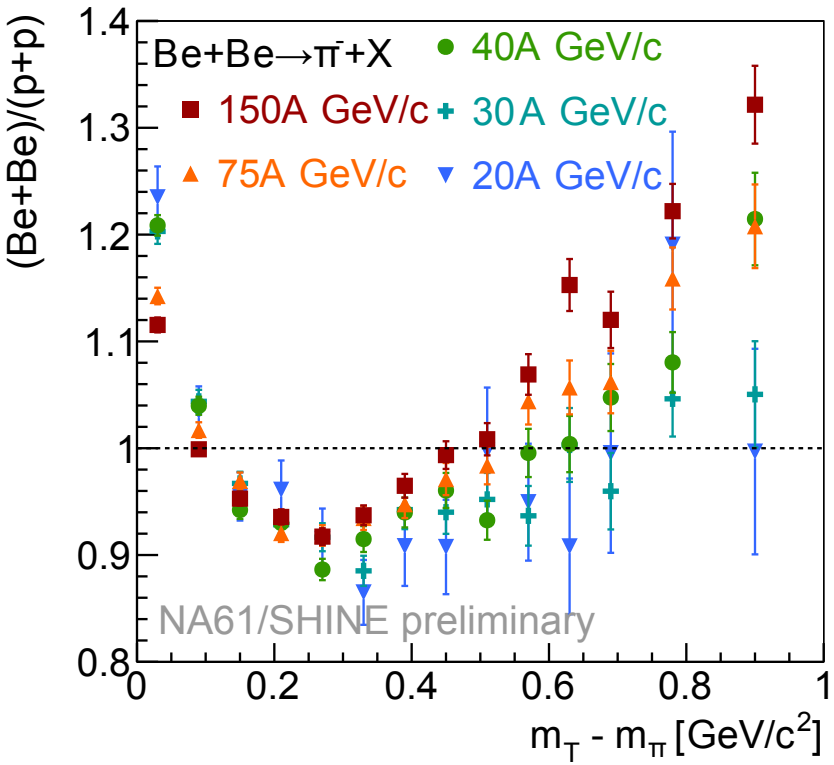




^{7}Be+^{9}Be data for 0-15% FE event class

Pb+Pb data for 5% or 7.5% most central interactions

Comparison of transverse mass spectra



- From $m_T - m_{\pi^-} > 0.3$ GeV/c^2 the ratio increases with beam momentum
- Up to $m_T - m_{\pi^-} < 0.3$ GeV/c^2 the ratio decreases with beam momentum
- The beam momentum dependence of the ratio observed in ^{7}Be+^{9}Be is not visible in Pb+Pb collisions (previous slide)
- The shape of the ratio indicates the presence of radial collective flow in ^{7}Be+^{9}Be
- The energy dependence of the ratio suggests that the radial flow increases with the collision energy

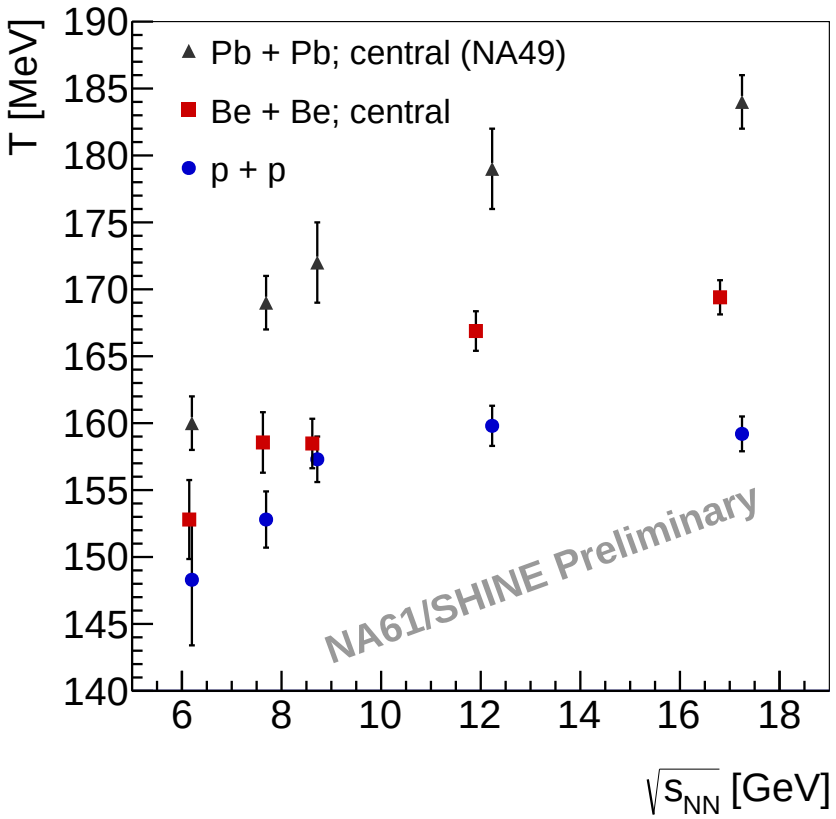
Summary

The data on pion, kaon and proton production properties in p+p was presented, as well as negative pion spectra from ^{7}Be+^{9}Be at five beam momenta (20A, 30A, 40A, 75A, 150A GeV/c).

- p+p data is unexpectedly interesting.
- Even in p+p the energy dependence of K^+/π^+ and inverse slope parameter T exhibits rapid changes in the SPS energy range.
- High precision NA61/SHINE data present a challenge for models and should allow their improvement.
- $\langle\pi^-\rangle$ was calculated for five beam momenta and four FE event classes for ^{7}Be+^{9}Be collisions.
- The isospin effects play a large role in p+p data, the effects will be studied in detail to compare p+p with ^{7}Be+^{9}Be data.
- The shape of transverse mass spectra shows energy dependence that is different in ^{7}Be+^{9}Be and p+p.
- The radial flow in ^{7}Be+^{9}Be might increase with collision energy.

Additional Slides

Inverse slope parameter system size and energy dependence



- Pb+Pb much higher than p+p
  Effect of radial flow
- ^{7}Be+^{9}Be points in between Pb+Pb and p+p
- Note: Inverse slope parameter in A+A collisions is very sensitive to fit range and size of the rapidity bin.