Recent results from the NA61/SHINE experiment

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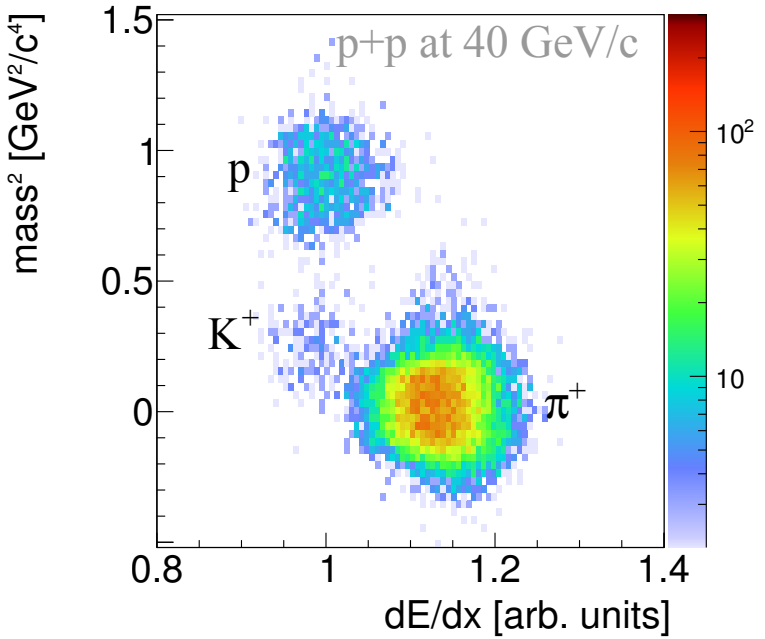
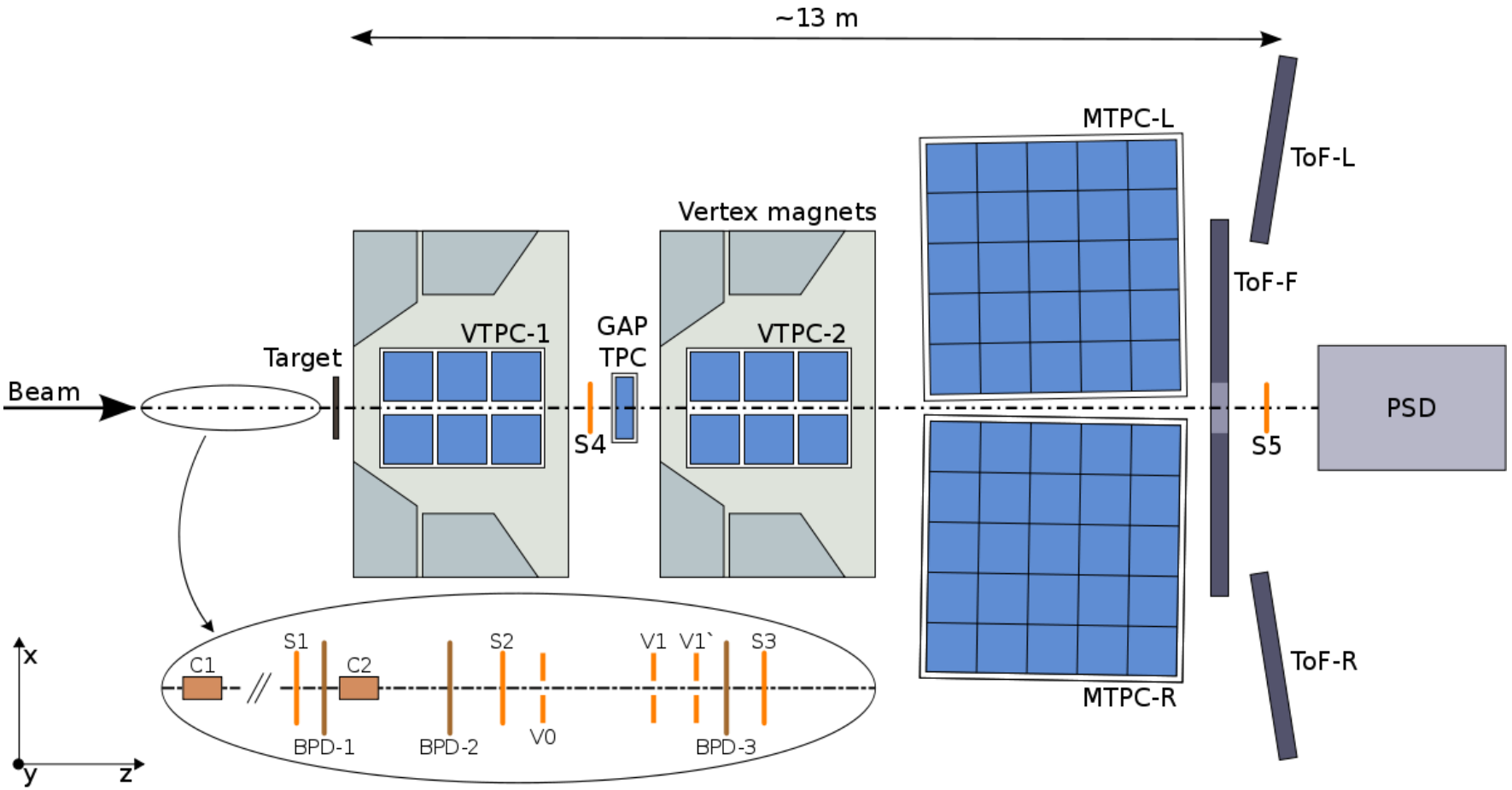
Outline

- NA61/SHINE experiment
- 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

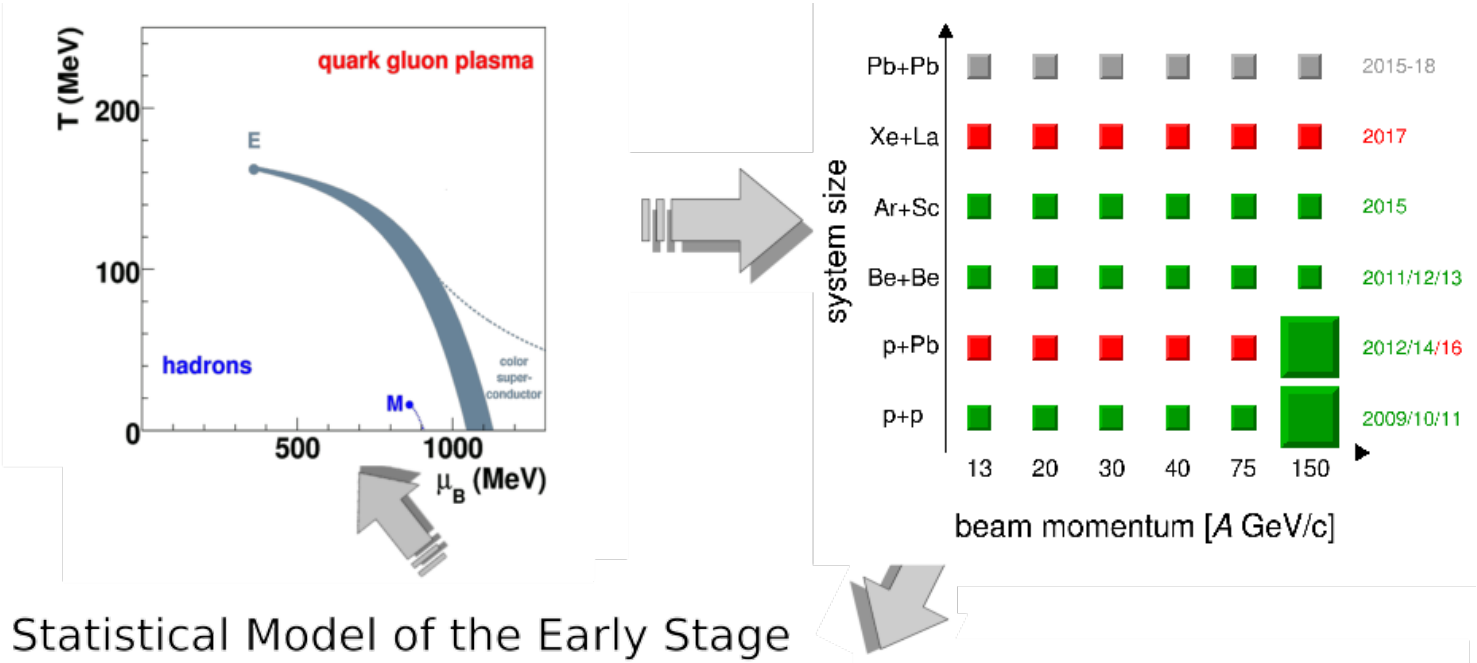


NA61/SHINE detector system

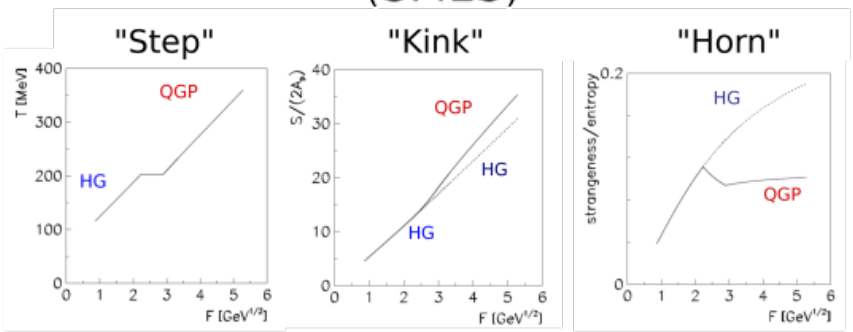


JINST 9 (2014) P06005

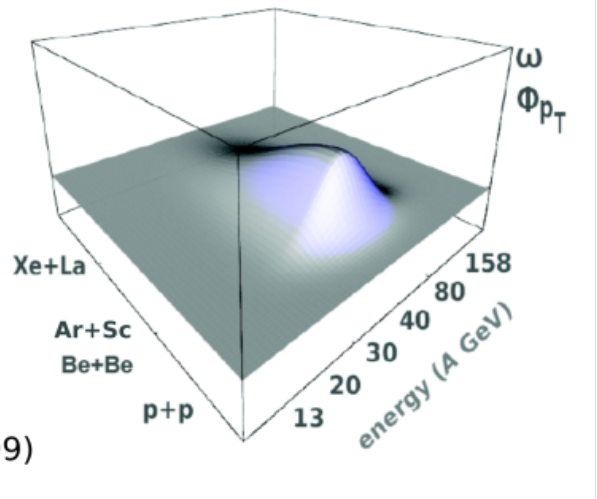
NA61/SHINE 2D scan goals



Statistical Model of the Early Stage (SMES)



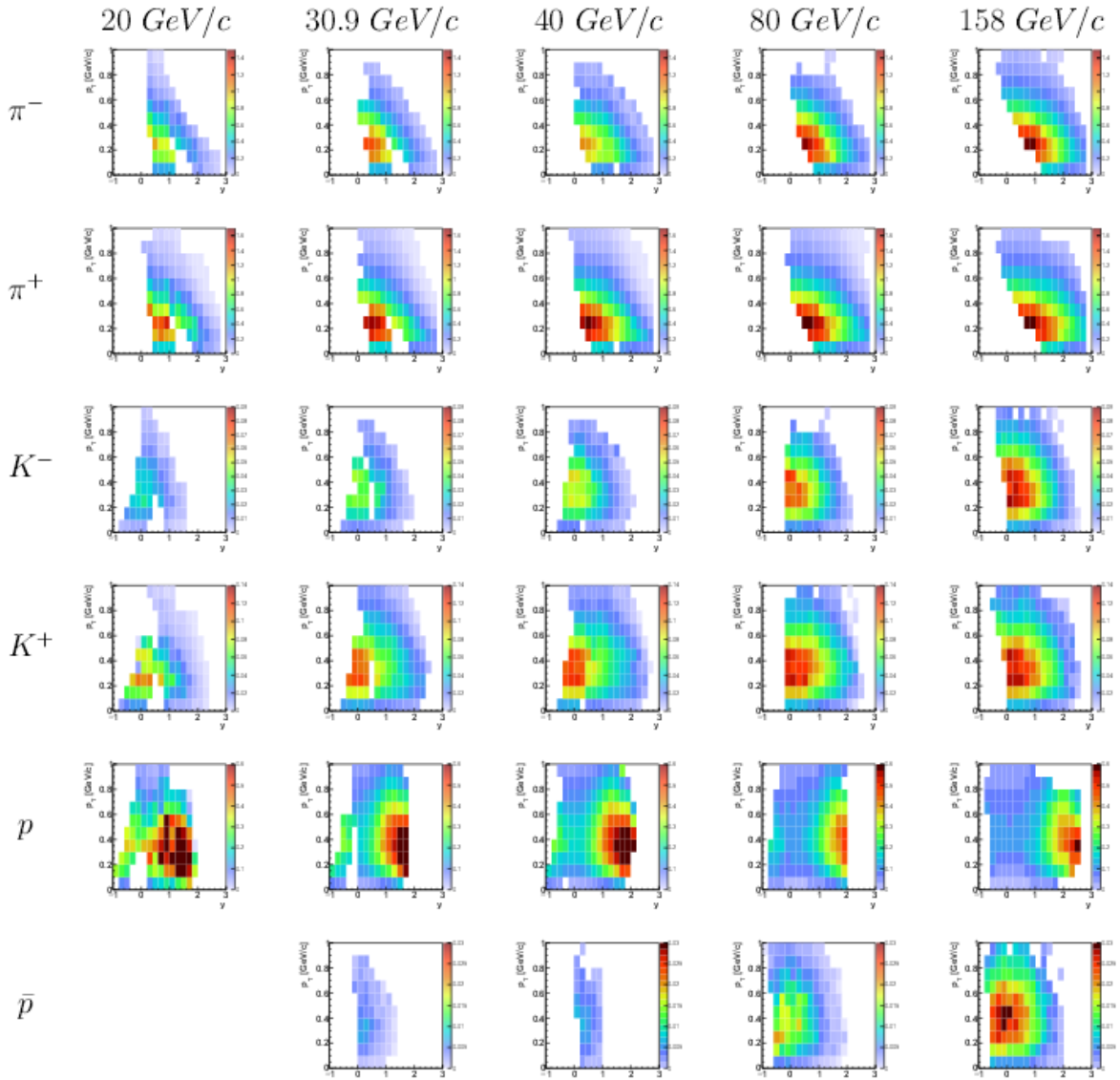
$F \approx \sqrt[4]{s_{NN}}$



Gaździcki, Gorenstein, Acta Phys. Polon. B30, 2705 (1999)

p+p

$y - p_T$ identified particle spectra in p+p



- Large acceptance for all particle types
- $p_T < 1$ GeV/c
- $y_{\text{Beam}}(158\ \text{GeV/c}) = 2.8$
- $y_\pi \lesssim 3$
- $y_K \lesssim 2$
- $y_p \lesssim y_{\text{Beam}}$
- lack of mid–rapidity pions, but they are possible

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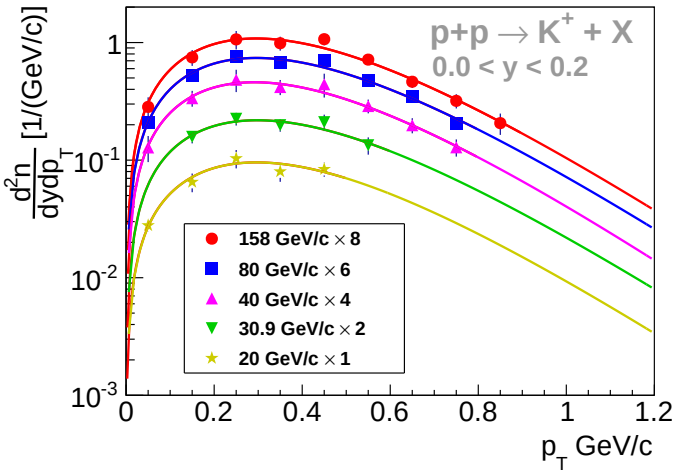
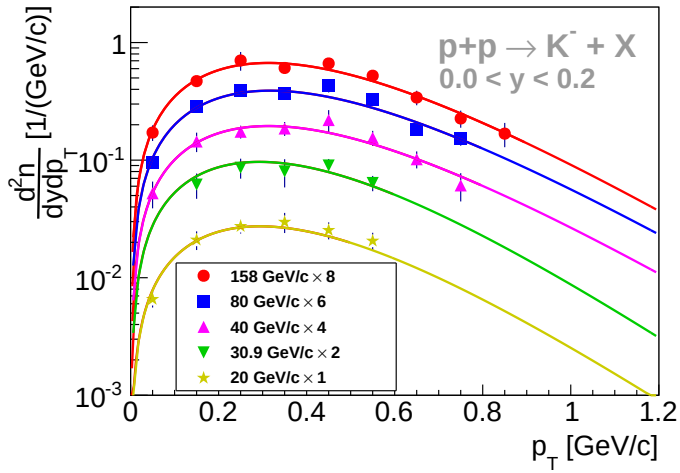
Mid–rapidity spectra of Kaons





- 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

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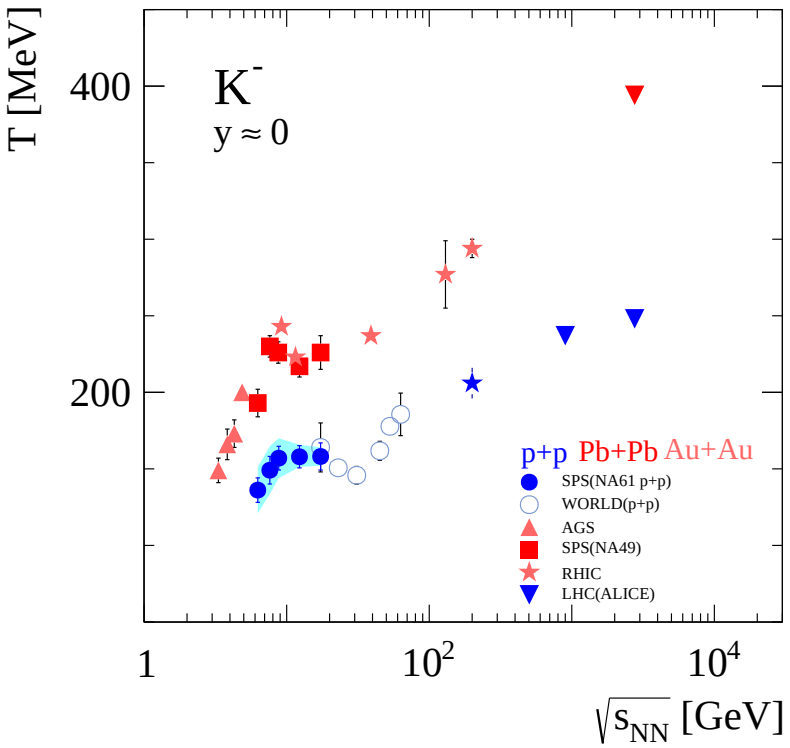
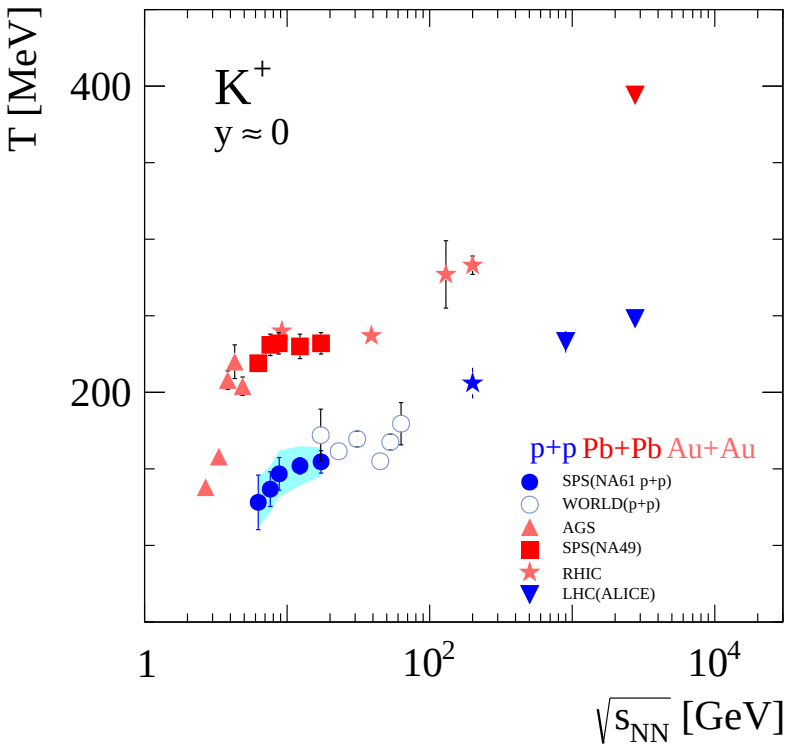
Inverse slope parameter T — "Step"

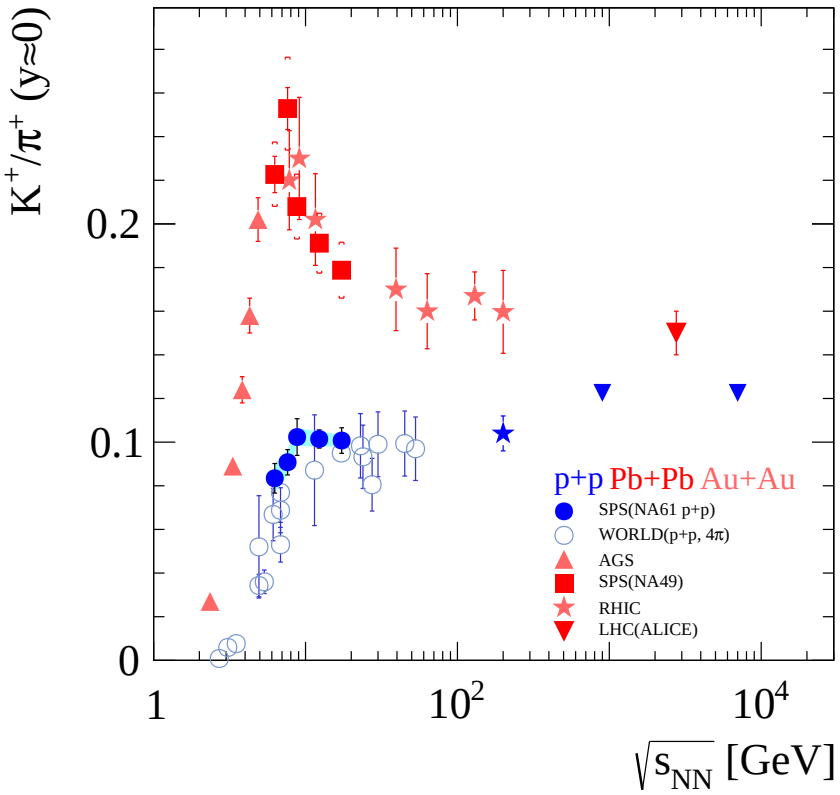


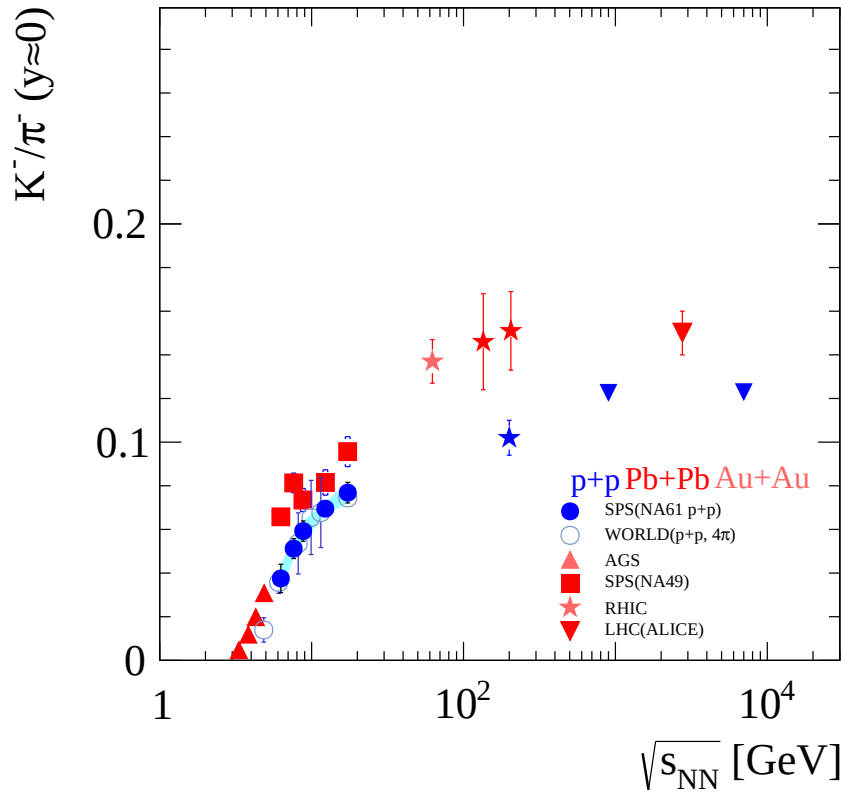


- Energy dependence of the inverse slope parameter T of kaon spectra exhibits rapid changes in both p+p and Pb+Pb interactions.

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

$\frac{K}{\pi}$ ratio — "Horn"

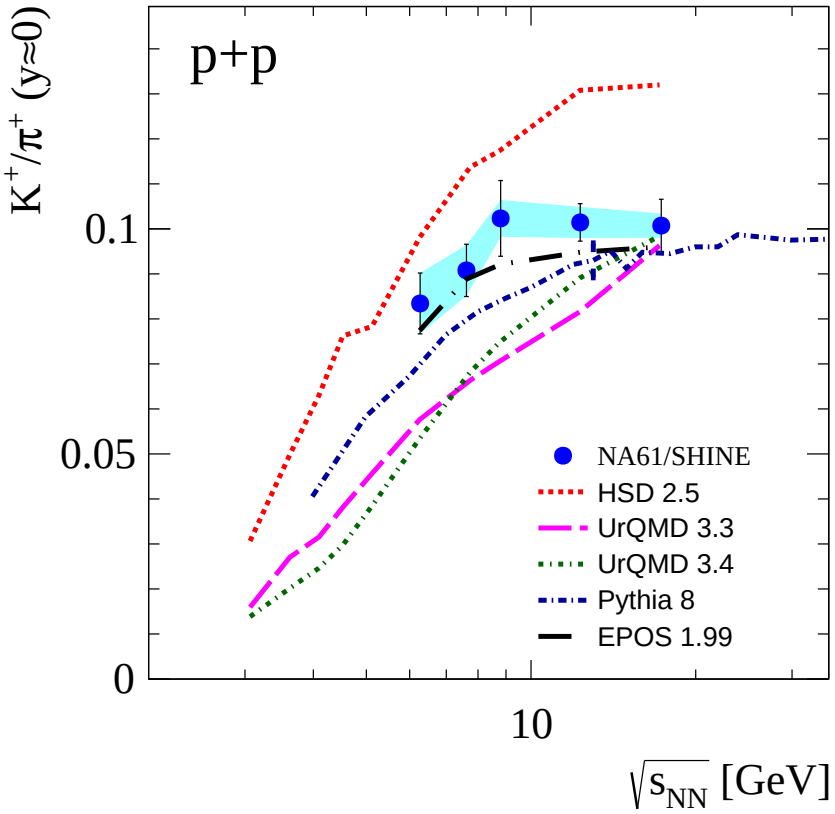


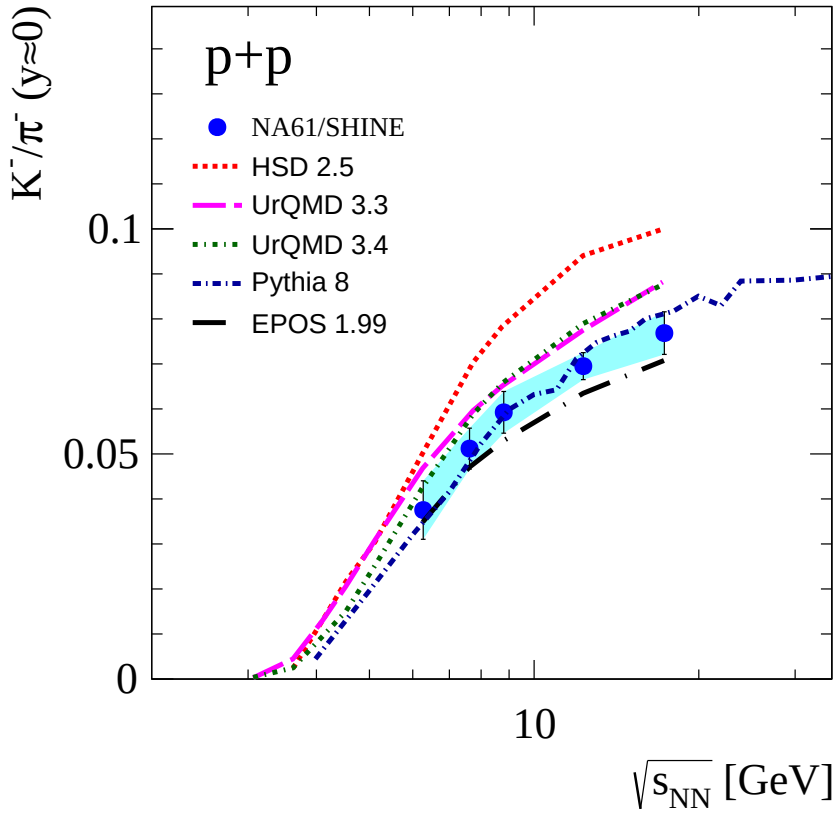


- The energy dependence of K^+/π^+ ratio in p+p changes at the energy where horn structure is visible in Pb+Pb

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.;
PhD thesis of S. Pulawski

$\frac{K}{\pi}$ 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;
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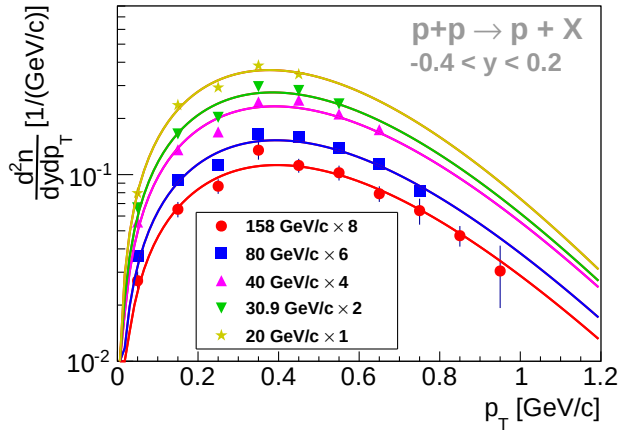
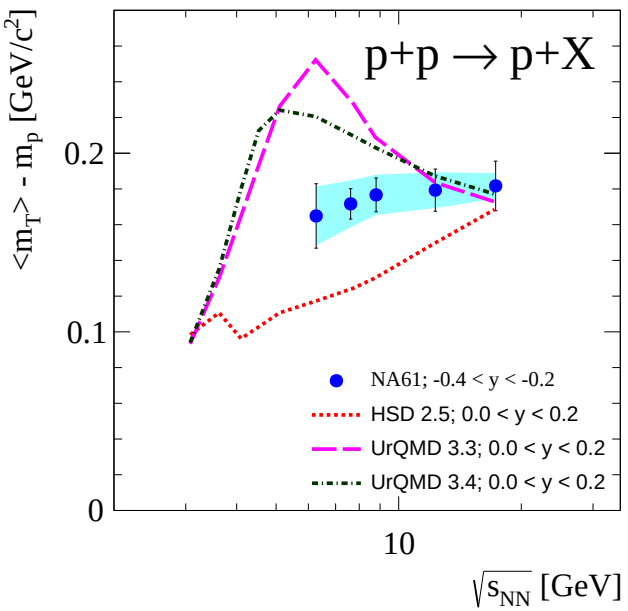
Proton mean transverse mass





- $\langle m_T \rangle$ 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);
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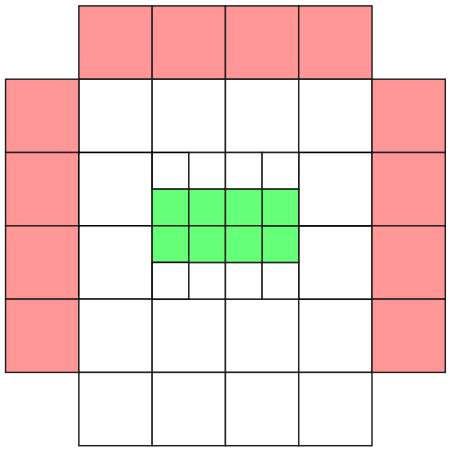
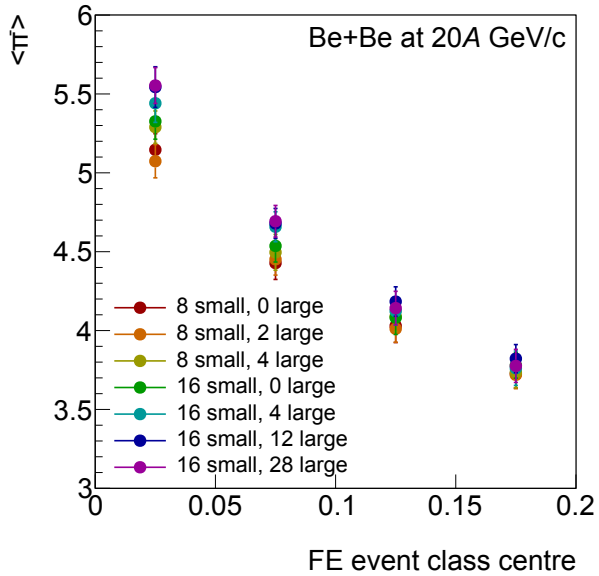
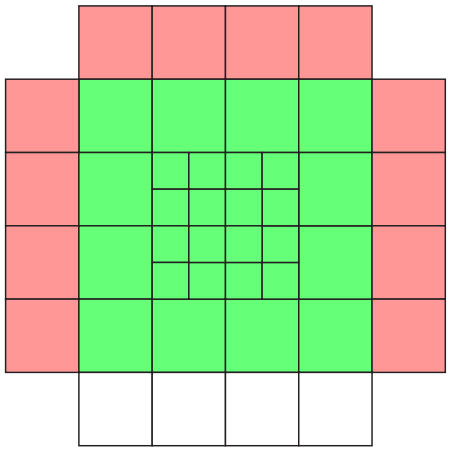
$^{7}\mathrm{Be}+^{9}\mathrm{Be}$

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

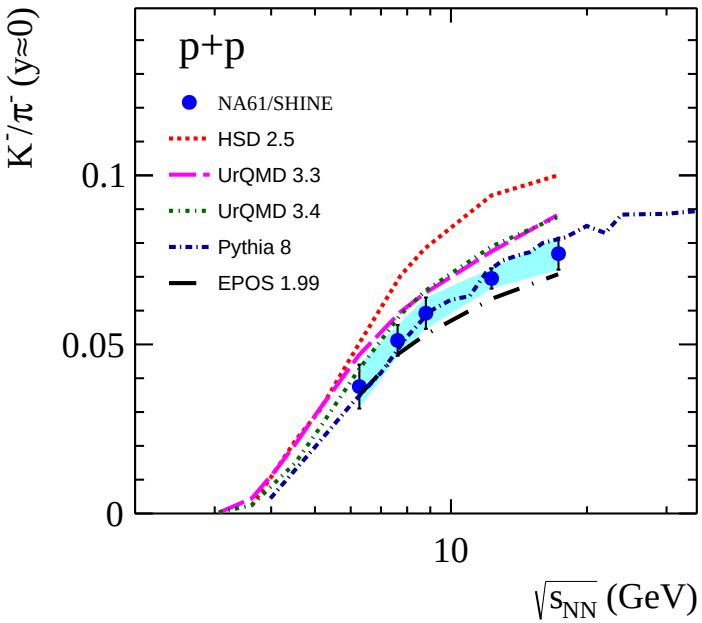


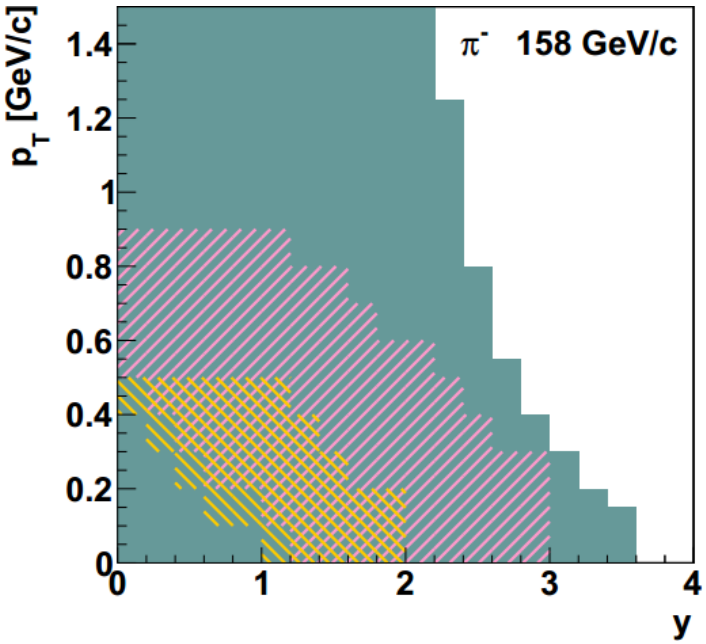




The "h^-" analysis method

- $\approx 90\%$ of the negatively charged hadrons produced in ^{7}Be+^{9}Be interactions are π^-
- In the h^- method a small contribution of other particles (K^-, $\bar{p}$, and decays from Λ and K^0_S) is subtracted based on EPOS model predictions
- In p+p interactions the $\mathrm{d}E/\mathrm{d}x$ and tof identification methods cover much narrower region of the phase–space than the h^- method



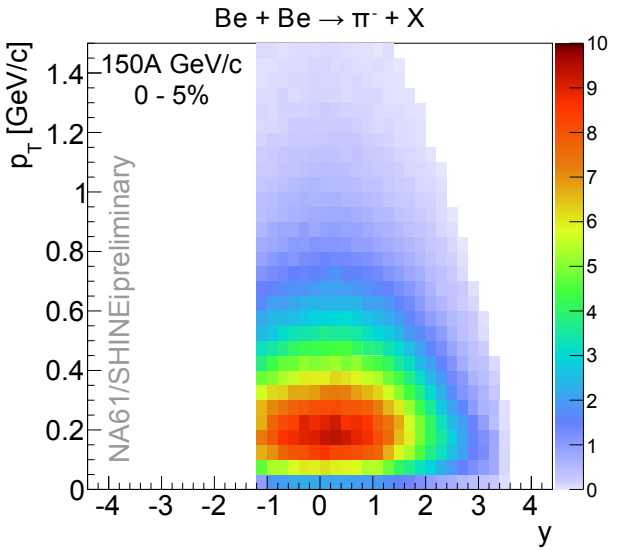


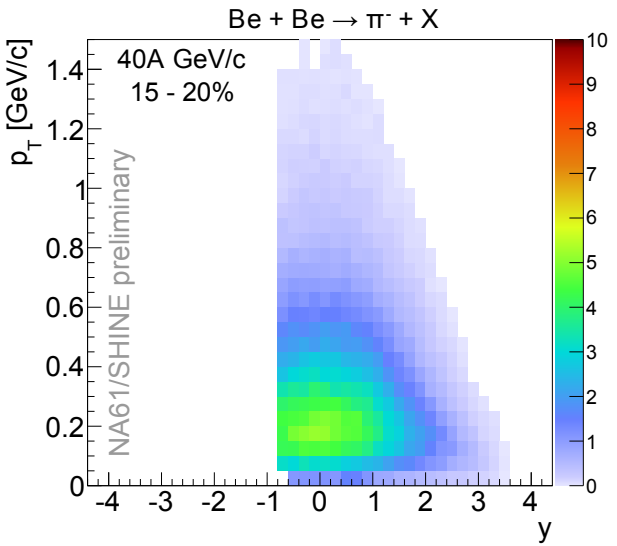
Double differential spectra of π^-

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

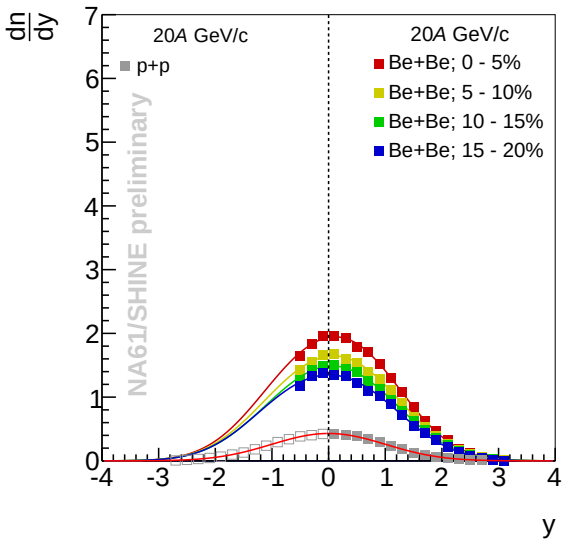
$$\frac{d^2n}{dydp_T} \text{ or } \frac{d^2n}{dydm_T}$$

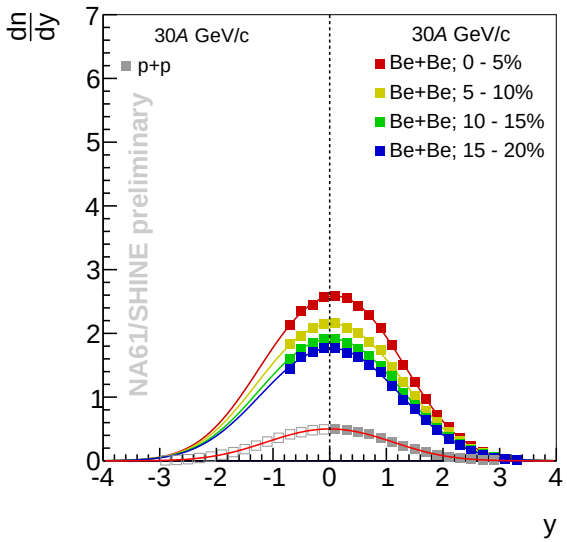
corrected for detector effects
and feed–down from weak decays

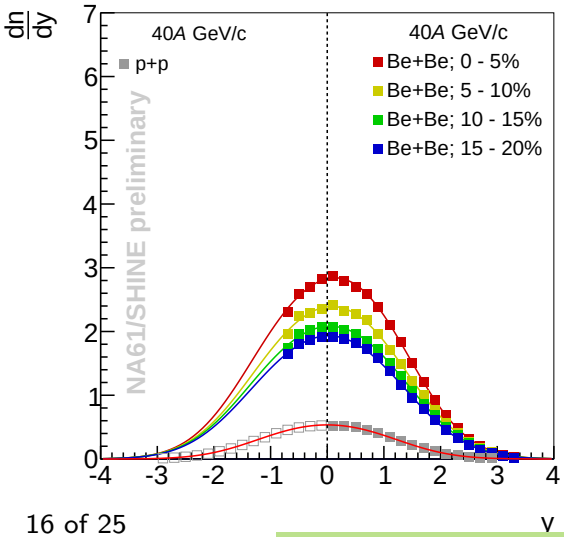


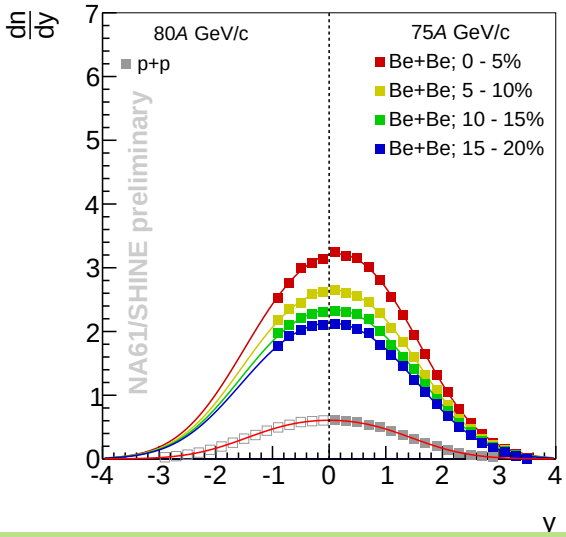


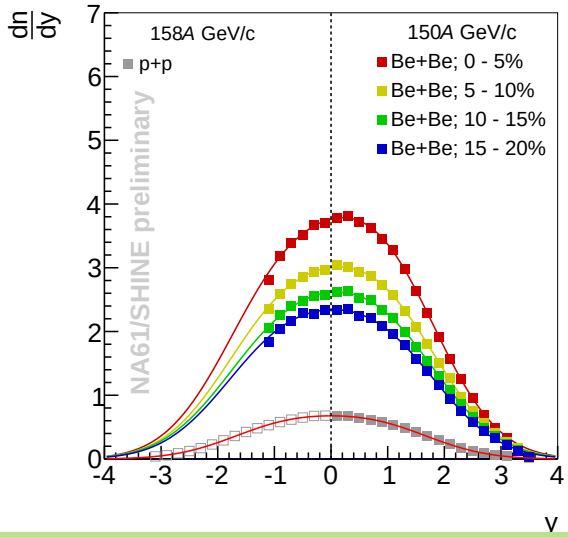
Rapidity spectra (^{7}Be+^{9}Be, p+p)
5 energies, 4 FE event classes



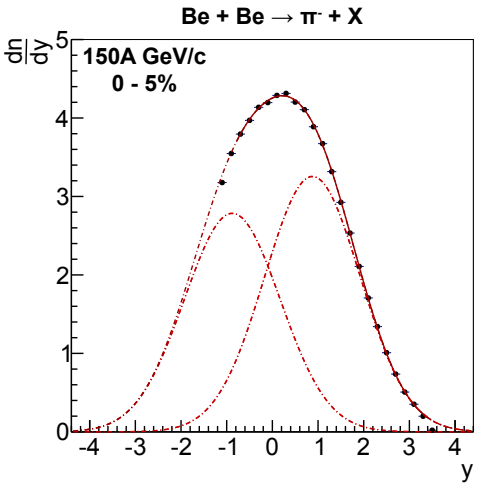


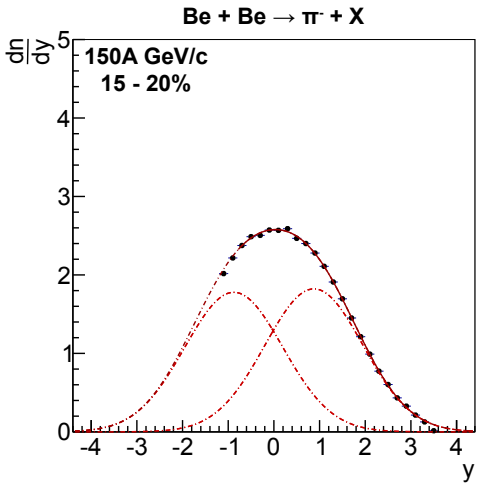


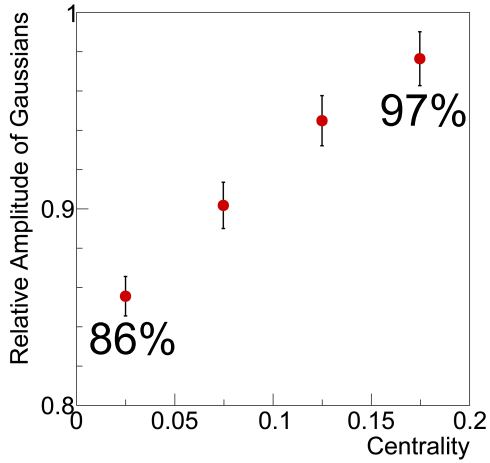




Asymmetry in rapidity spectra







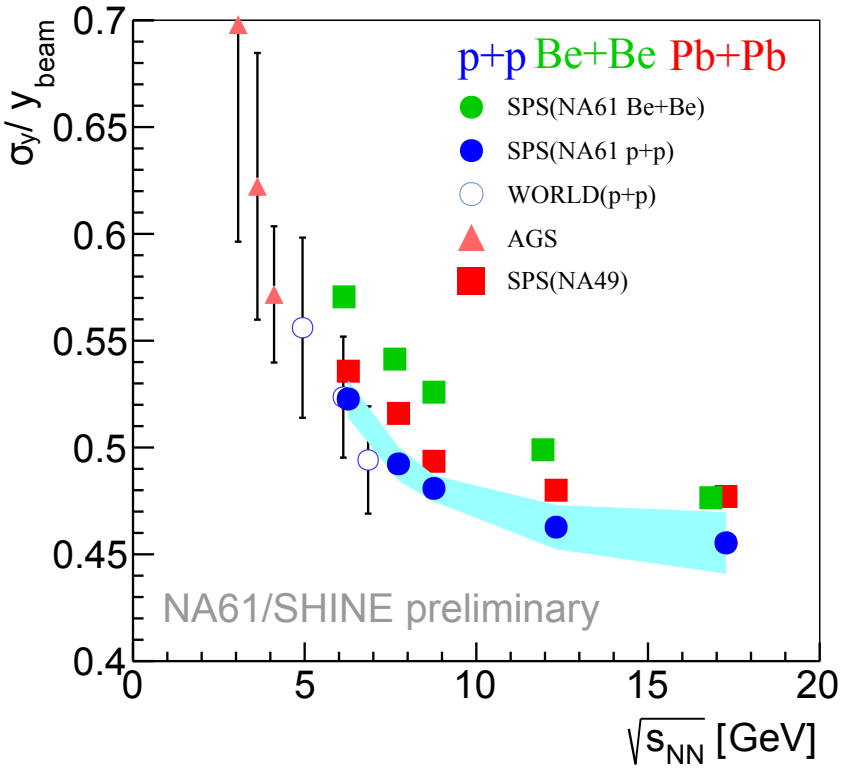
Two opposite effects influence asymmetry of the spectra:

- 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 ($N_S^{\text{targ}} \approx \text{Gaussian}(x_0 = 3.7; \sigma = 1.4)$).

Width of the rapidity distribution

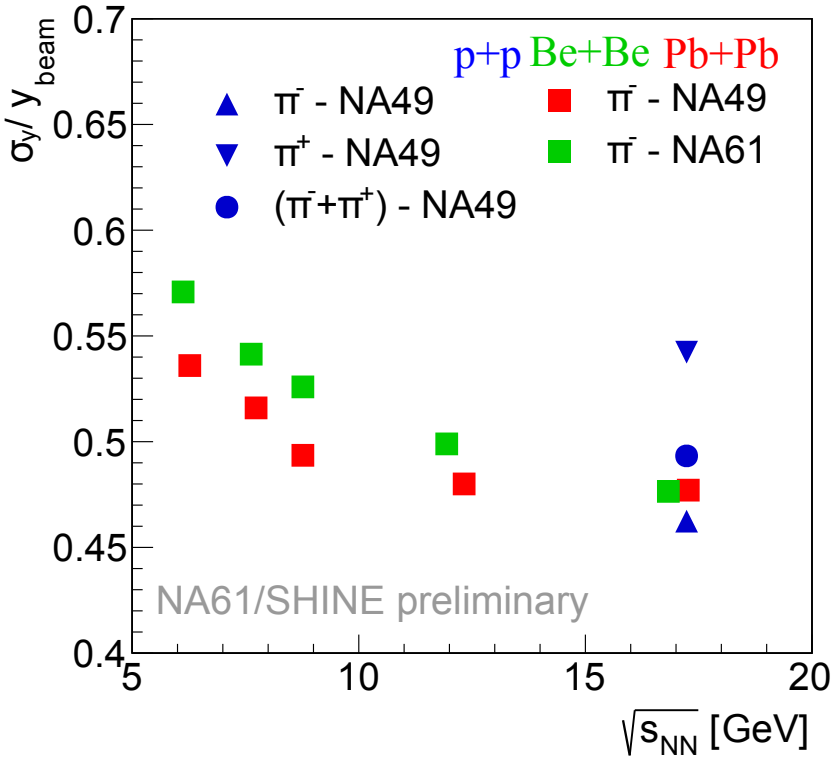


- σ_y calculated from fitted function (two symmetrically displaced Gaussians)
- σ_y related to speed of sound c_s^2 — "Dale"
- Smooth, monotonic behaviour with energy
- *Non-monotonic* behaviour with the system size:

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

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

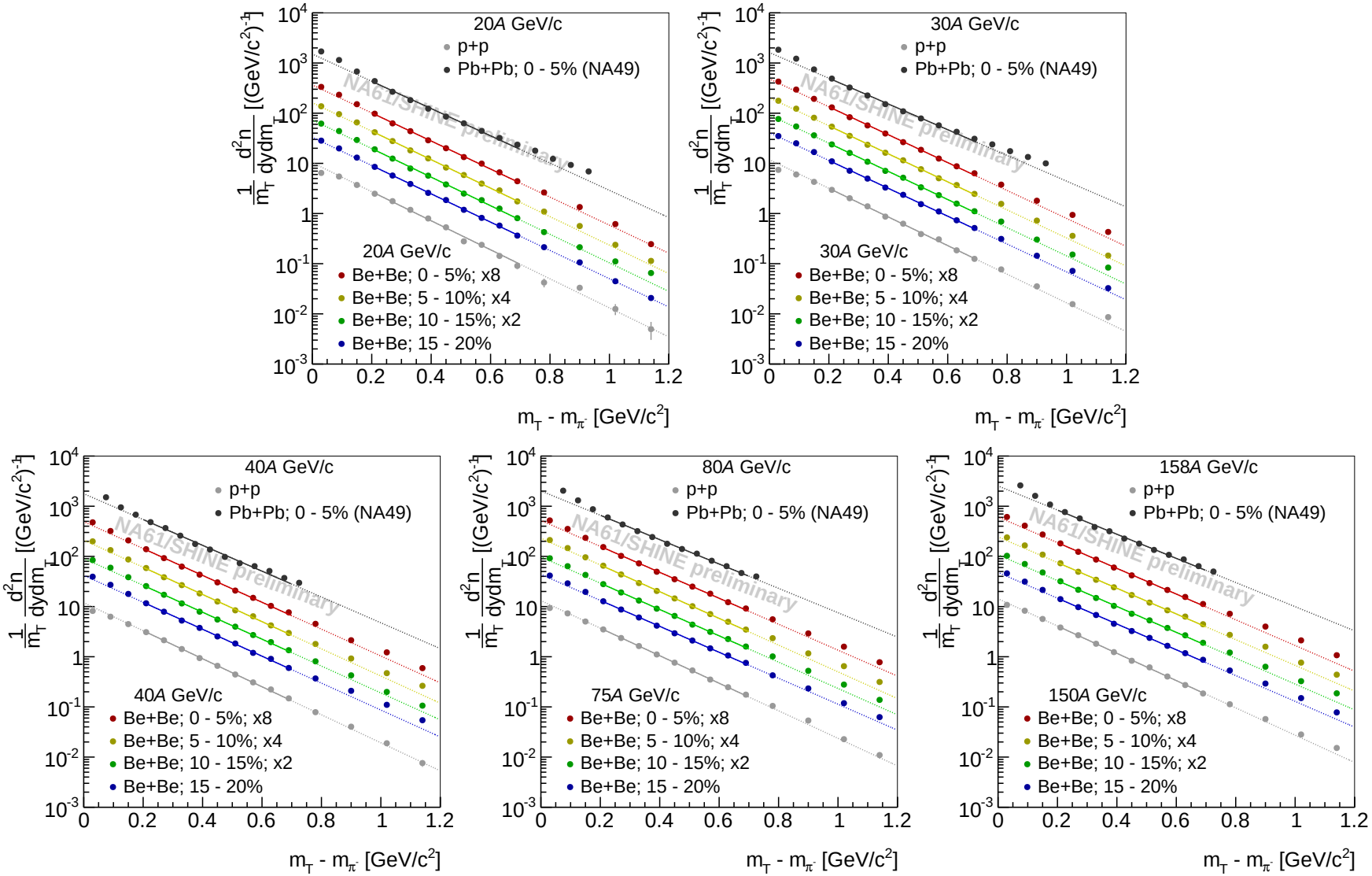
Effect of isospin asymmetry on σ_y / y_{beam}



- 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

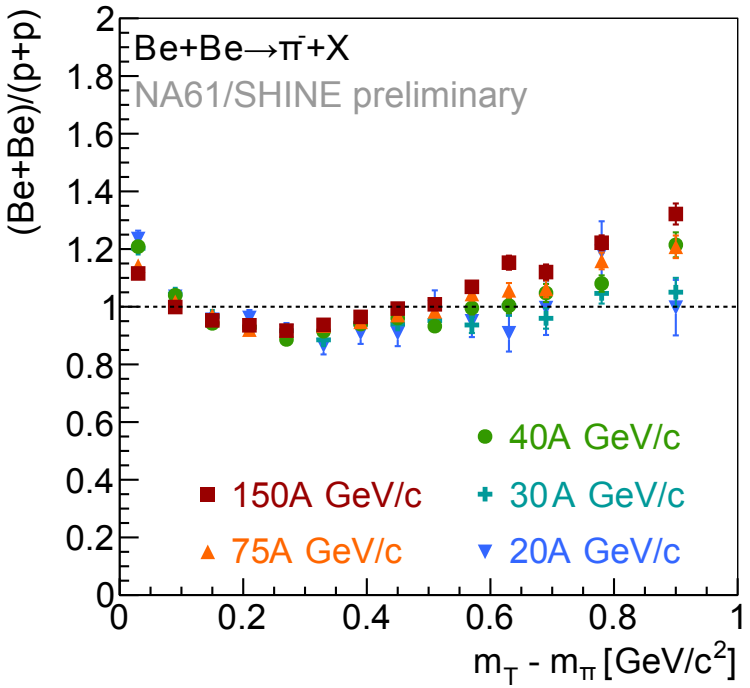
NA49 π^- and π^+ rapidity distributions in p+p collisions from: Eur. Phys. J. C45 (2006) 343-381

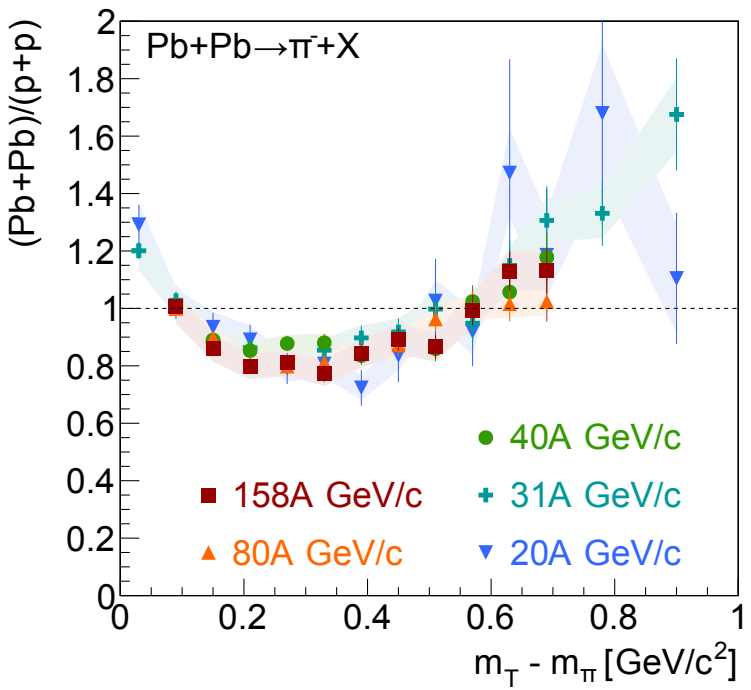
Transverse mass spectra (p+p, ^{7}Be+^{9}Be, Pb+Pb)



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

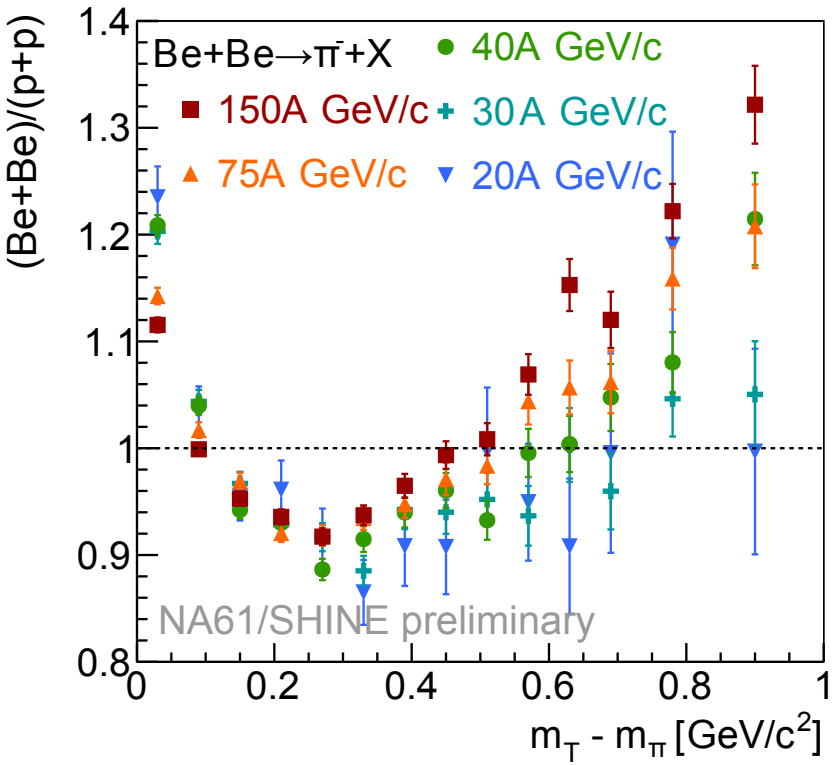




^{7}Be+^{9}Be data for 0-15% FE event class

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

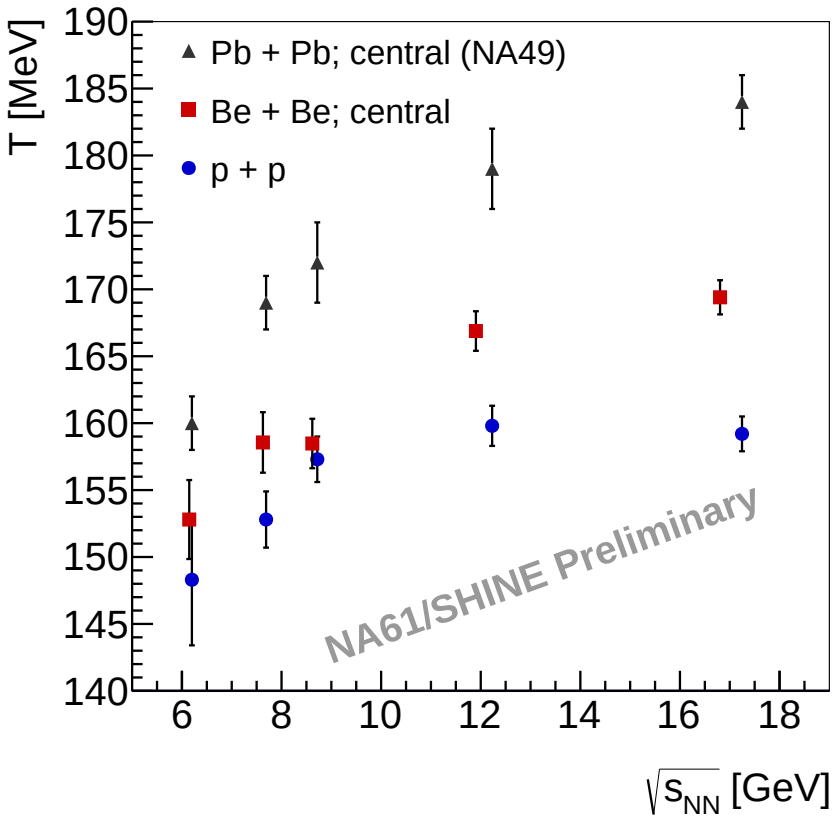
Summary

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.
- 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.