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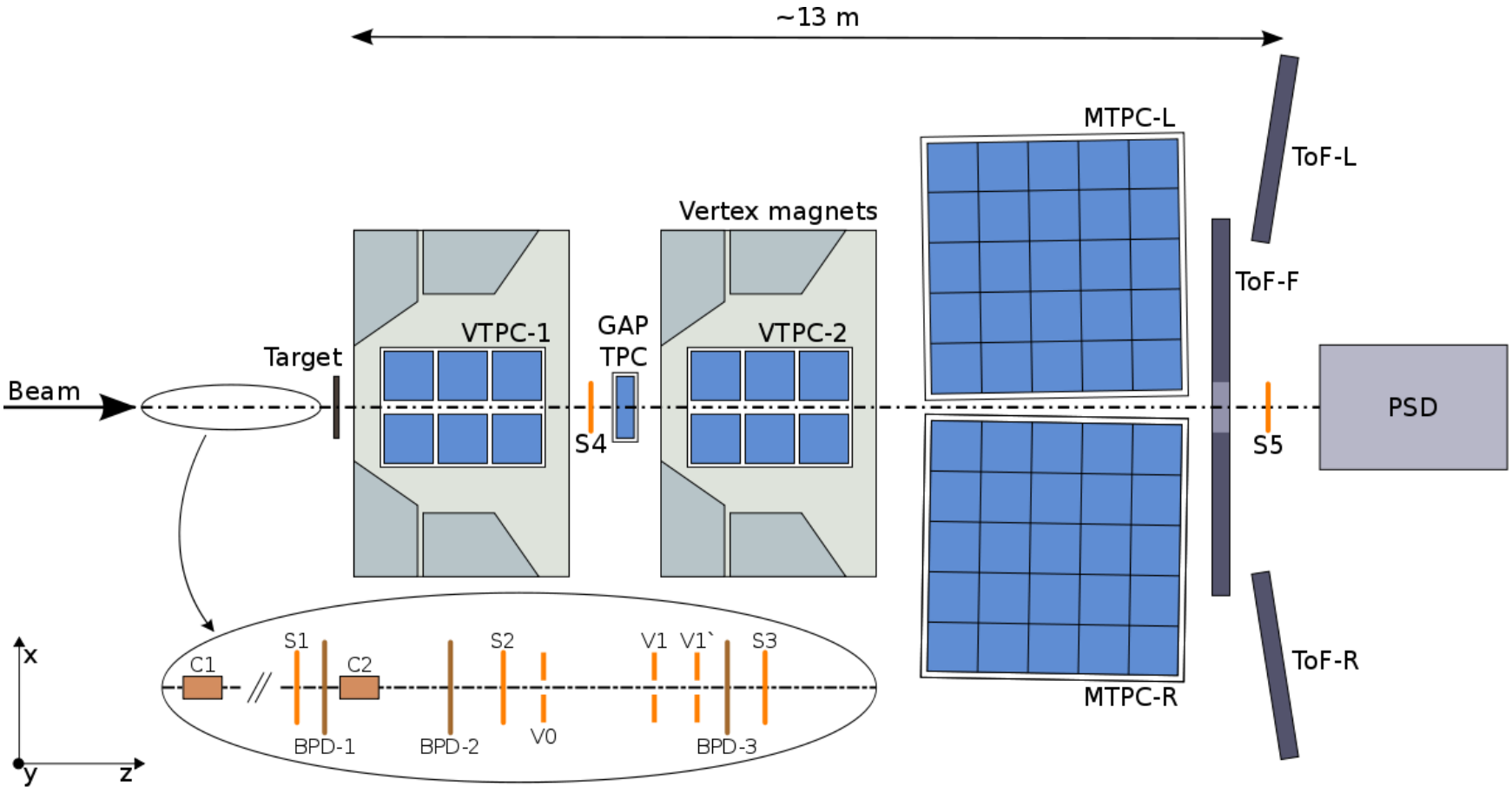
Strangness production in p+p interactions at 20, 31, 40, 80 and 158 GeV/c from NA61/SHINE at the CERN SPS

Szymon Puławski
for the NA61/SHINE Collaboration

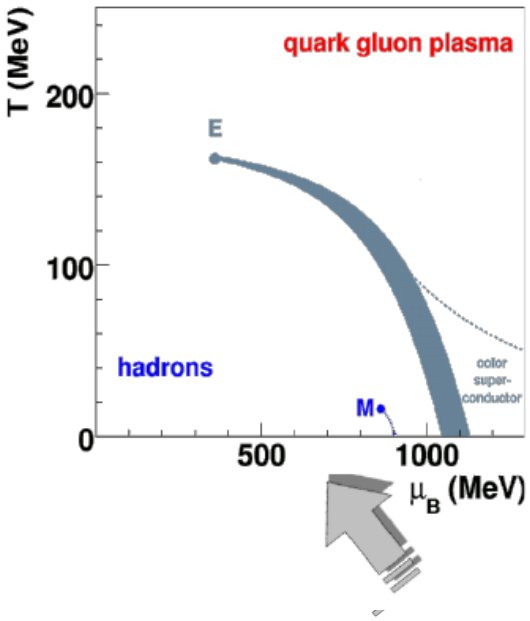
University of Silesia, Katowice

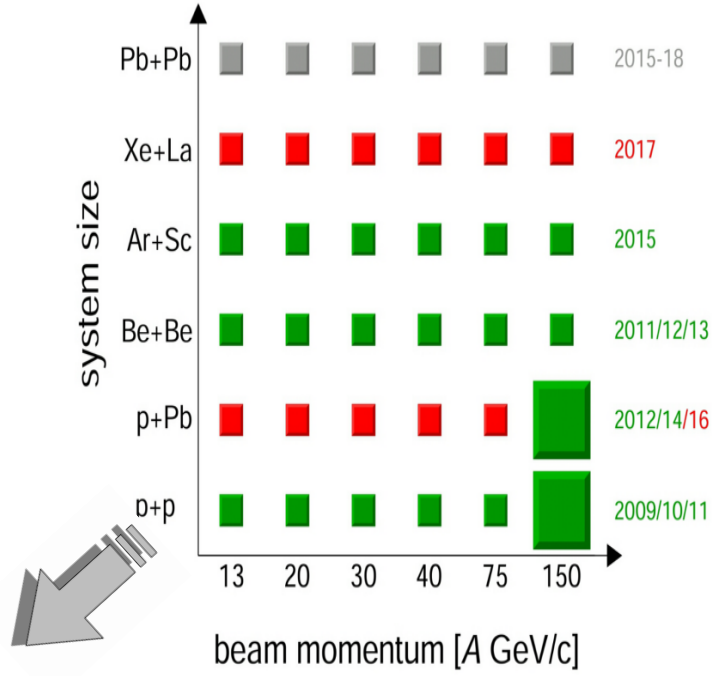
September 2015

NA61/SHINE detector system

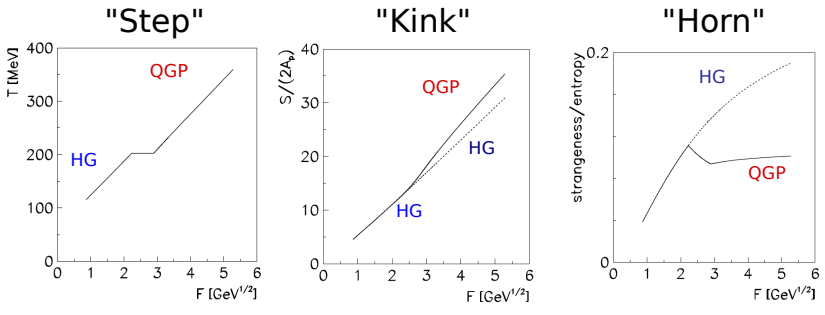


NA61/SHINE strong interactions program



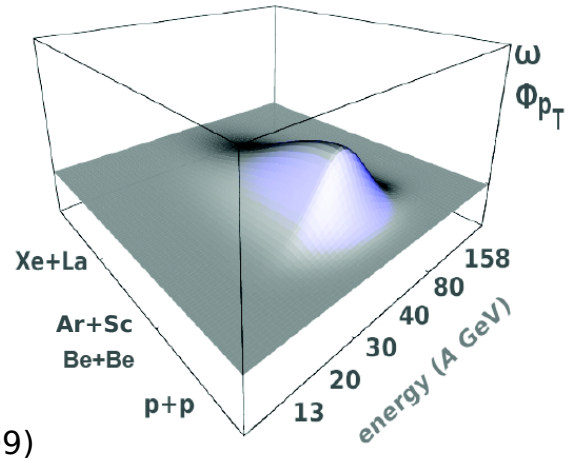


Statistical Model of the Early Stage (SMES)



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

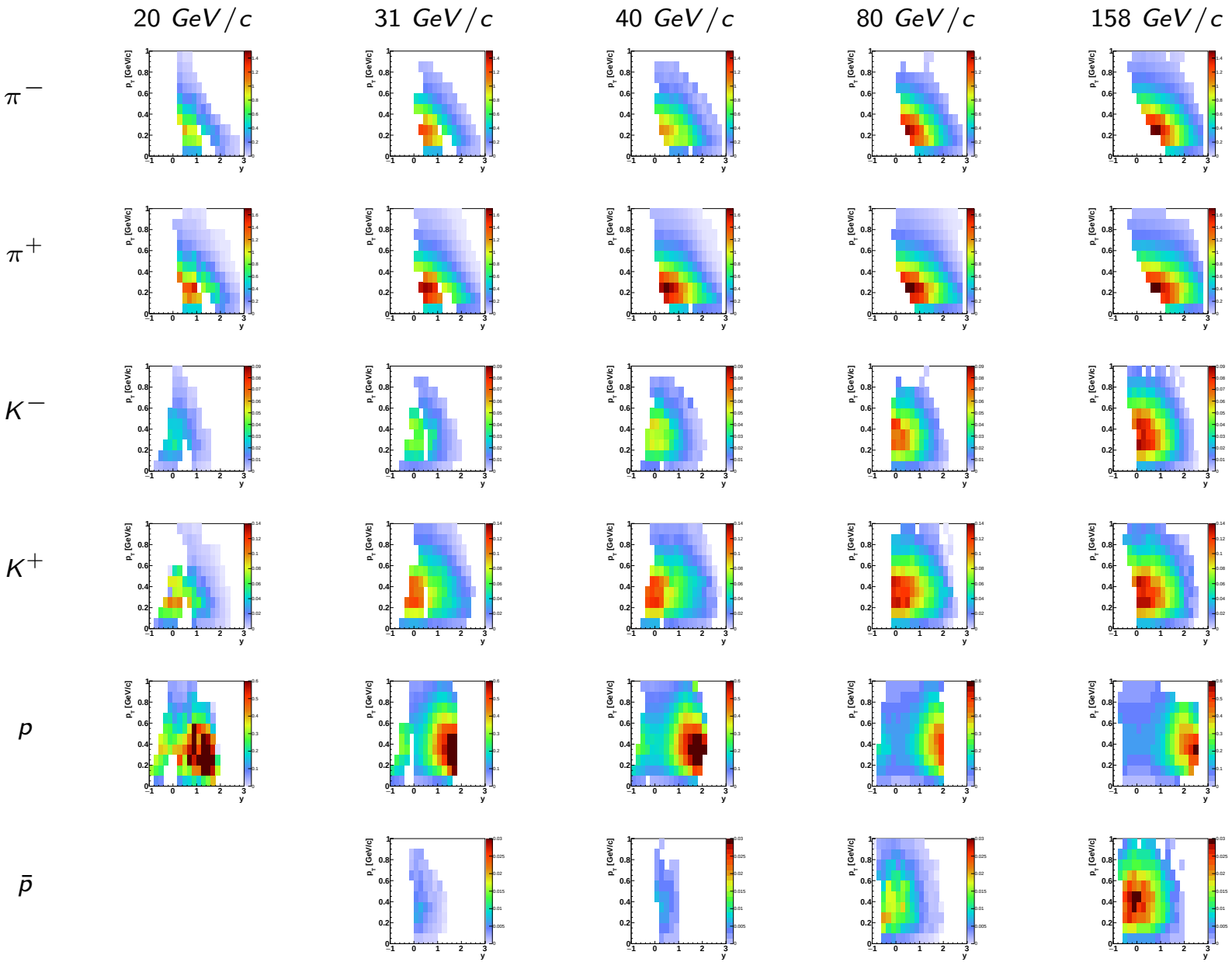
Gaździcki, Gorenstein, Acta Phys. Polon. B30, 2705 (1999)



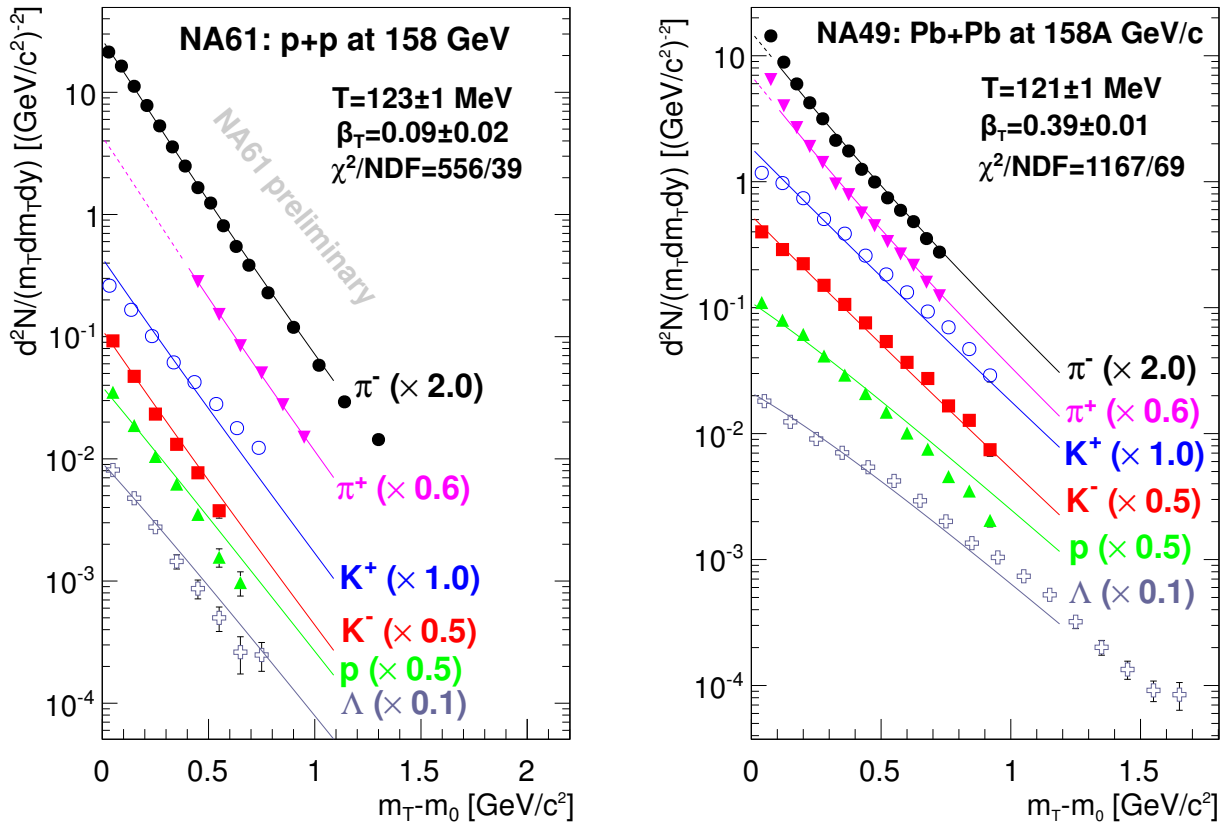
Results on p+p interactions

- Data analyzed:
  - p+p @ 20 GeV/c ($\sqrt{s} = 6.2$ GeV): $1.3 \cdot 10^6$ events
  - p+p @ 31 GeV/c ($\sqrt{s} = 7.7$ GeV): $3.1 \cdot 10^6$ events
  - p+p @ 40 GeV/c ($\sqrt{s} = 8.8$ GeV): $5.2 \cdot 10^6$ events
  - p+p @ 80 GeV/c ($\sqrt{s} = 12.3$ GeV): $4.3 \cdot 10^6$ events
  - p+p @ 158 GeV/c ($\sqrt{s} = 17.3$ GeV): $3.5 \cdot 10^6$ events
- Results presented for hadrons produced in inelastic p+p collisions.
- Particle spectra:
  - dE/dx, tof-dE/dx and V^0 identifications.
  - The results are corrected for particles from weak decays (feed-down) and detector effects using Monte-Carlo models.
  - Out of target interactions are subtracted using events recorded with empty target.

Particle spectra

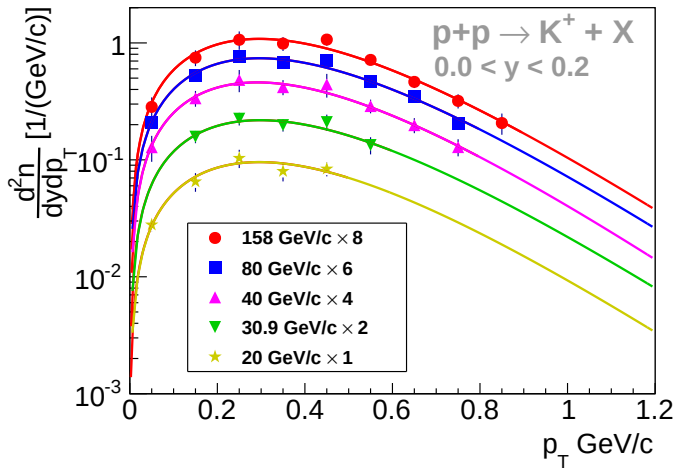


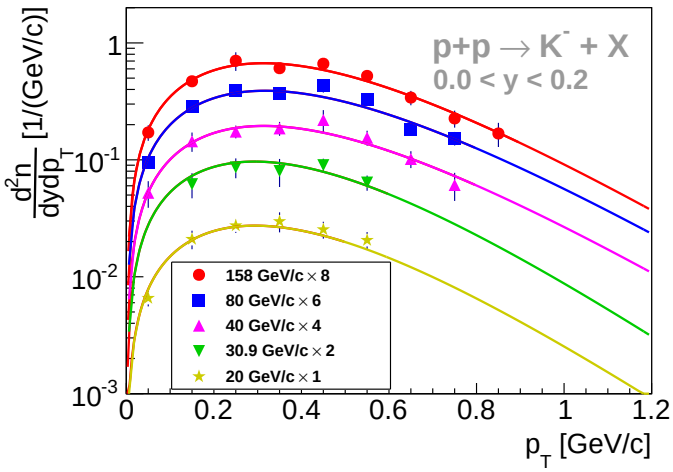
Transverse mass spectra at mid-rapidity



Transverse mass spectra are approximately exponential in p+p interactions. In central Pb+Pb collisions the exponential dependence is modified by the transverse flow.

Kaon at mid-rapidity



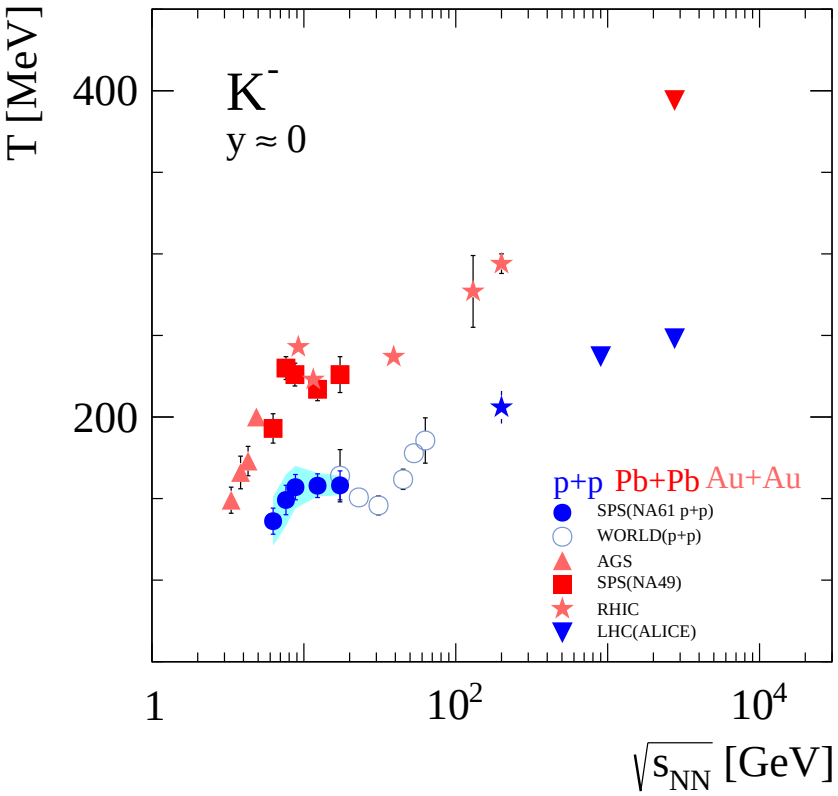


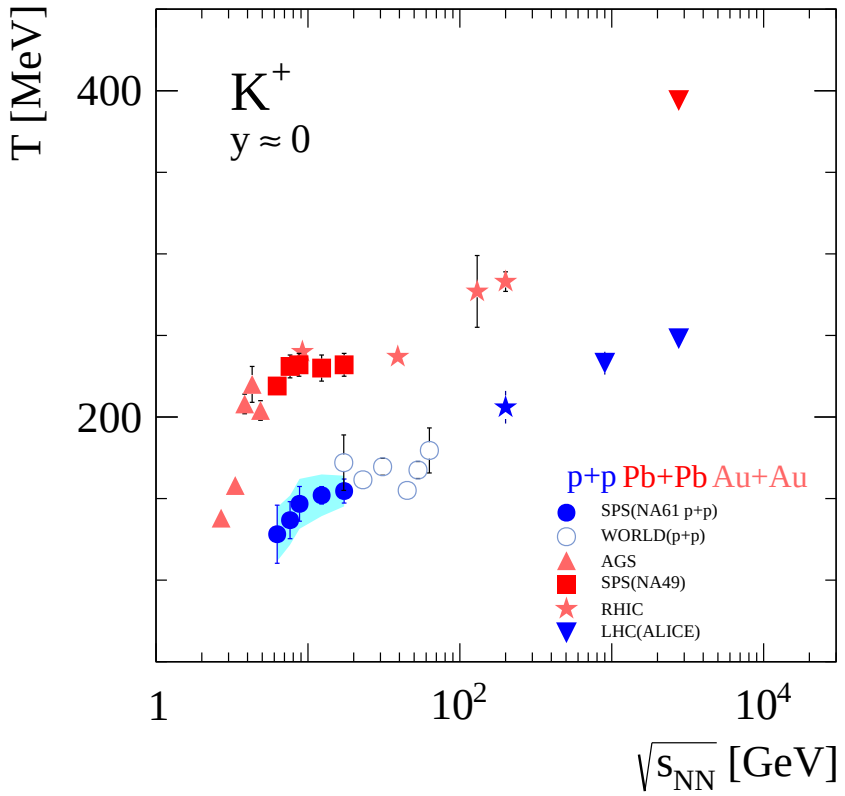
- Spectra fitted by:

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

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

Inverse slope parameter T - Step

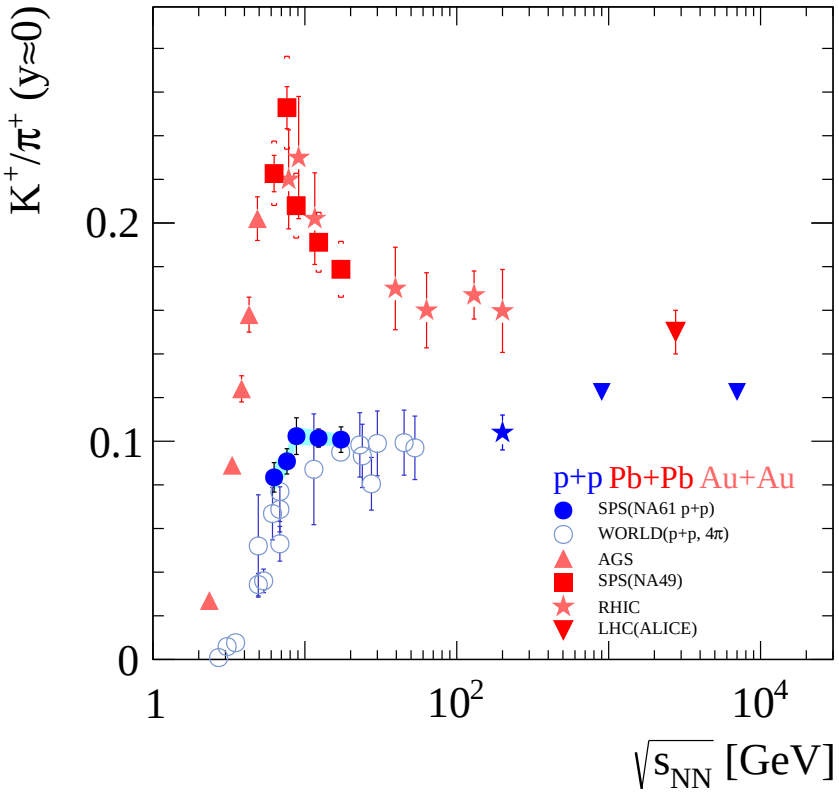


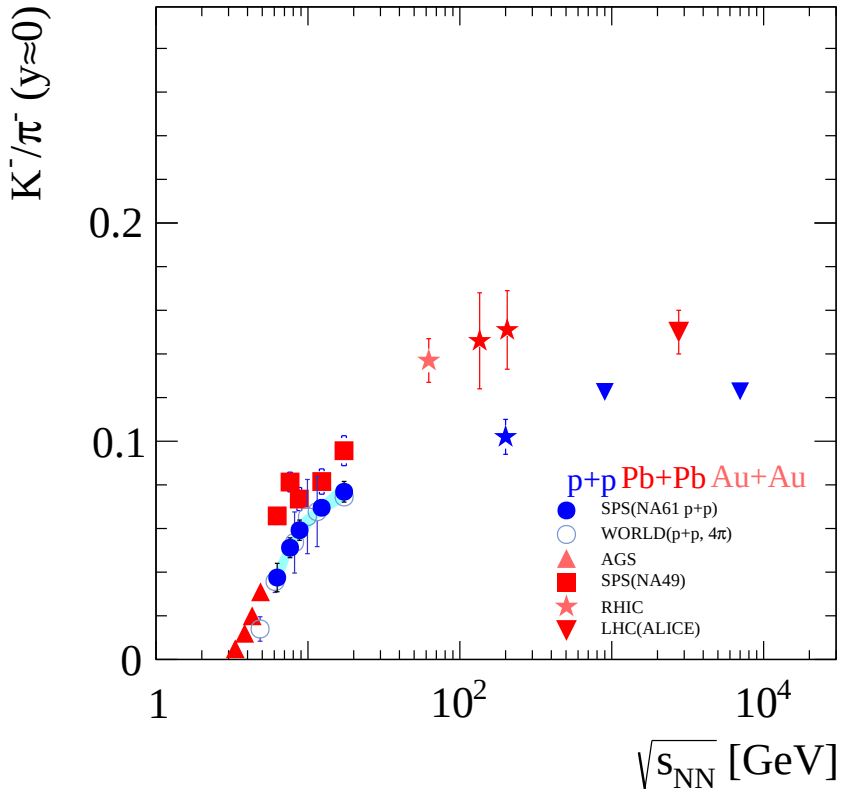


- In p+p collisions energy dependence of inverse slope parameter T of kaon exhibits rapid changes like in Pb+Pb interactions.

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

$\frac{K}{\pi}$ ratio - Horn

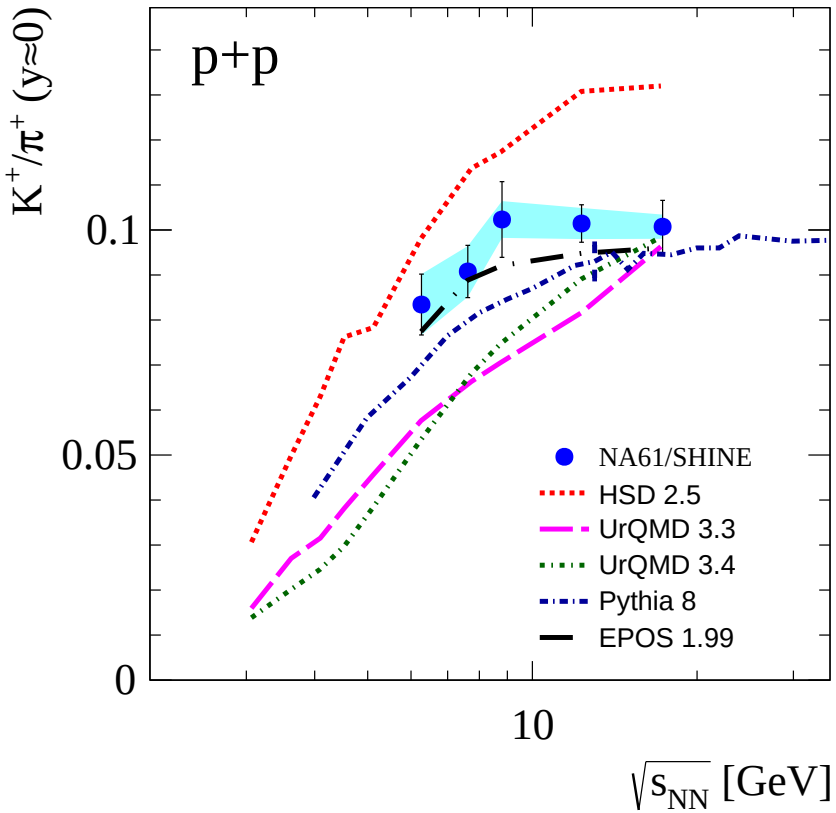


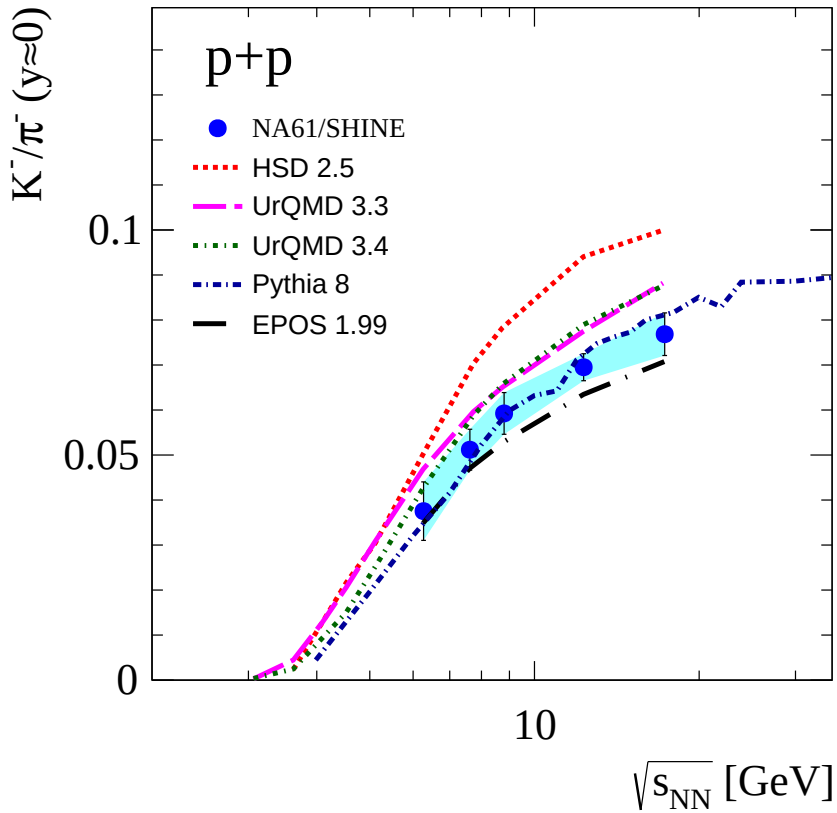


- A shadow of the horn structure is visible in p+p reactions but significantly reduced.

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)

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

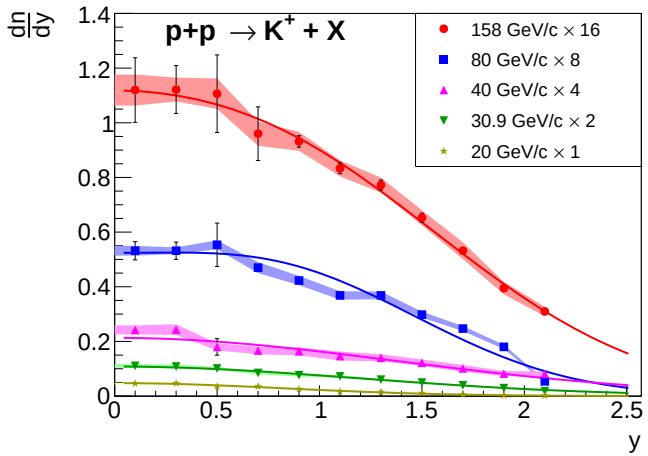


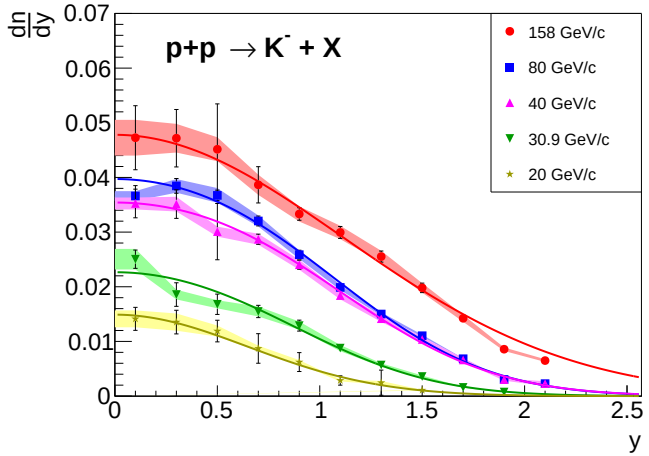


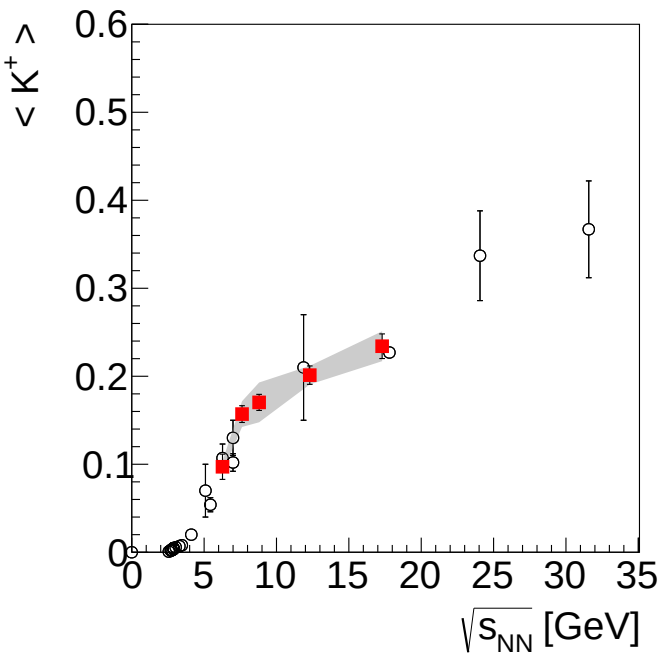
- Models do not describe well NA61/SHINE data on p+p interactions.
- High precision NA61/SHINE data allow for their significant improvement.

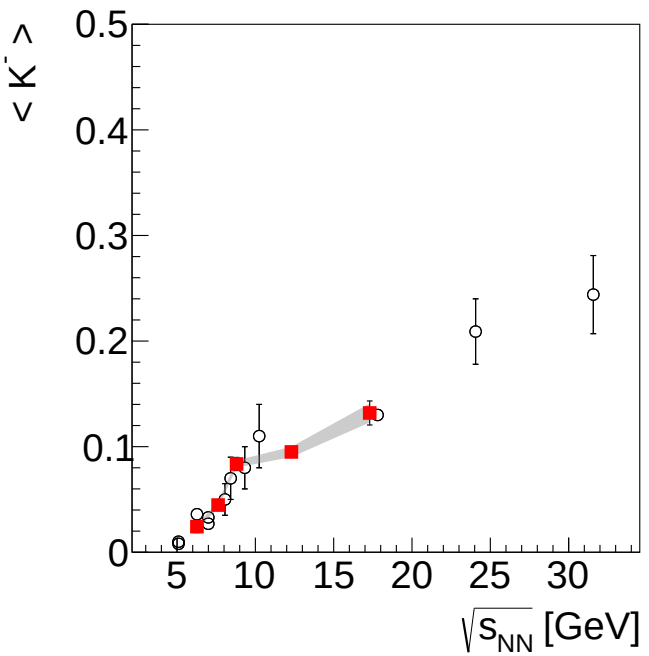
Vovchenko et al., PRC 90, 024916 (2014), and private communication. Gavin Salam private communication
UrQMD: Prog. Part. Nucl. Phys. 41 (1998), J. Phys. G: Nucl. Part. Phys. 25 (1999); HSD: Nucl. Phys. A 602, 449 (1996), Nucl. Phys. A 644, 107 (1998), Phys. Rept. 308, 65 (1999); EPOS: Nucl.Phys.Proc.Suppl.196,2009,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

Rapidity spectra and mean kaons multiplicities

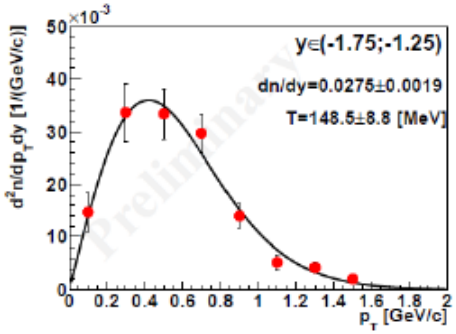


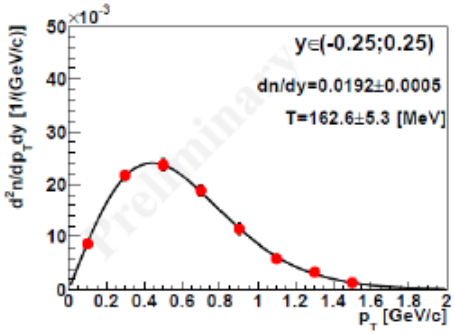




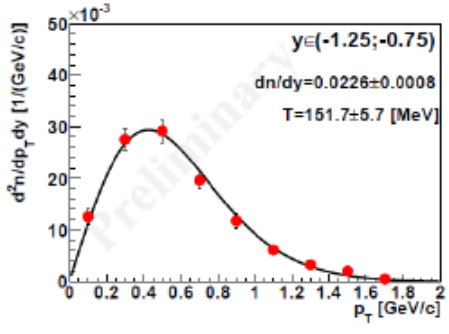


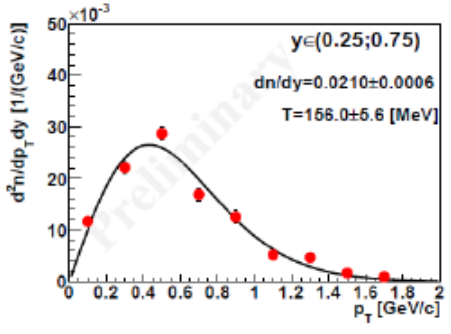
Λ spectra in p+p at 158 GeV/c

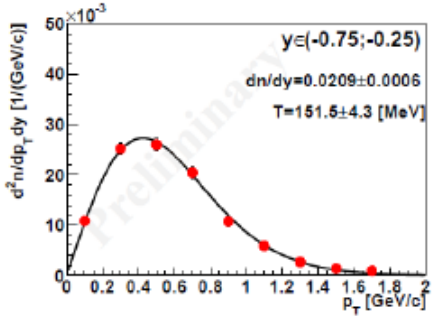


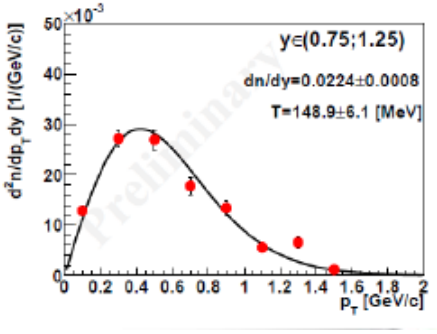


$$\frac{d^2n}{dp_T dy}(p_T)_y = A p_T e^{-\frac{\sqrt{p_T^2+m_\Lambda^2}}{T}}$$

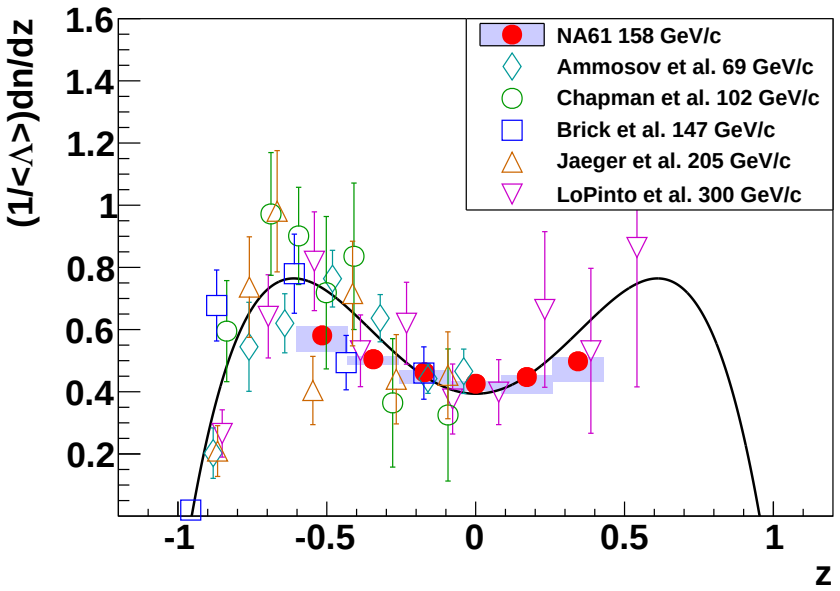


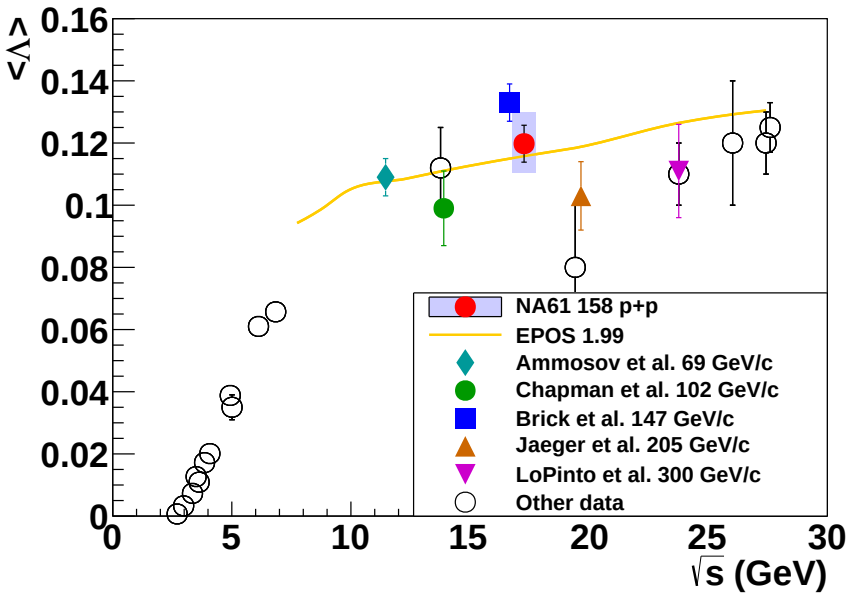






Λ spectra in p+p at 158 GeV/c





- $z = y/y_{beam}$
- Extrapolation to the full phase space by function:

$$\frac{1}{\langle n \rangle}\frac{dn}{dz} = 0.369 + 2.10z^2 - 2.69z^4$$

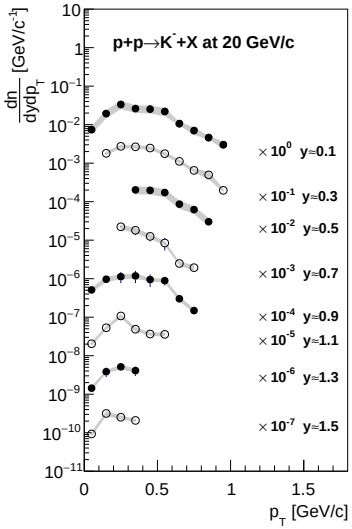
- NA61/SHINE results are consistent with world data
- Other NA61/SHINE energies – work in progress

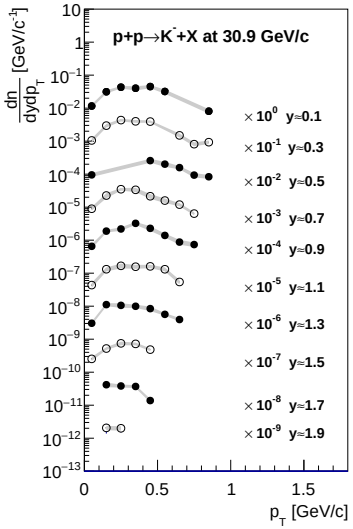
Summary

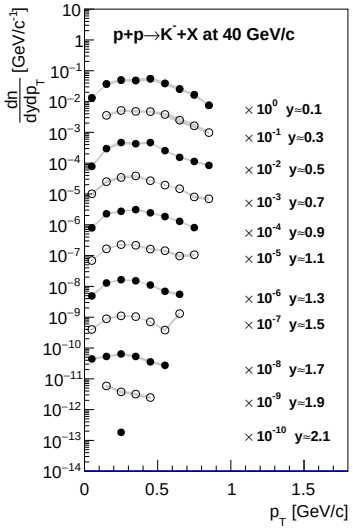
- p+p data is unexpectedly interesting.
- Even in p+p the energy dependence of K^+/π^+ and inverse slope parameter T exhibits rapid changes in the SPS energy range.
- Do we see onset of deconfinement in p+p interactions?
- High precision NA61/SHINE data presents a challenges for models and should allow their improvement.

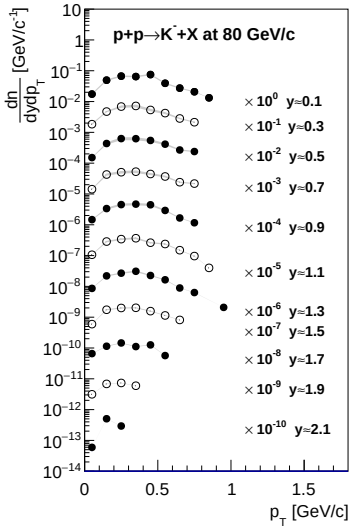
Backup

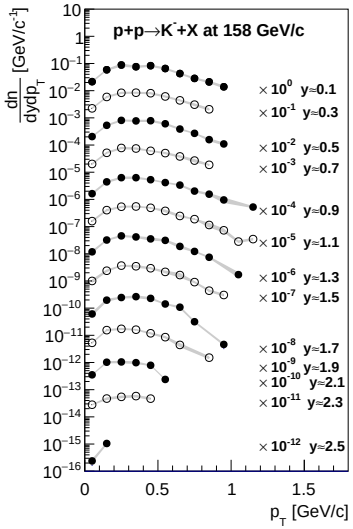
Kaons spectra

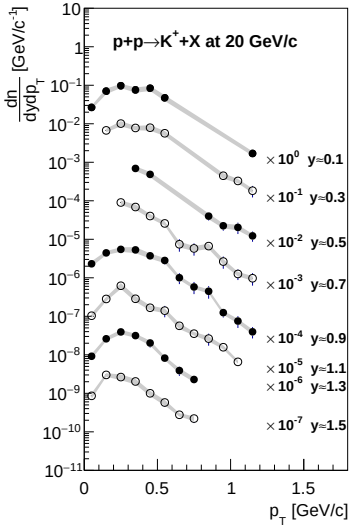


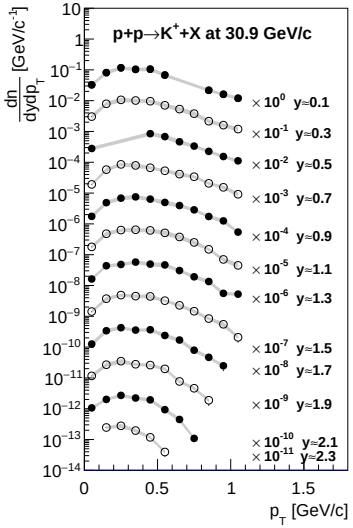


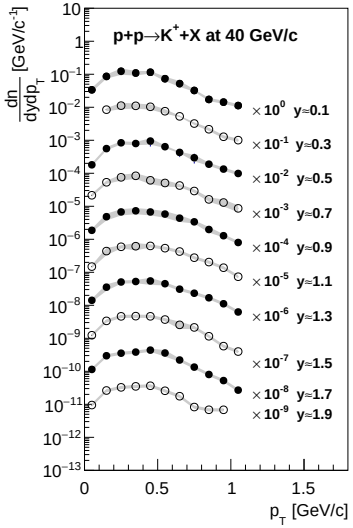


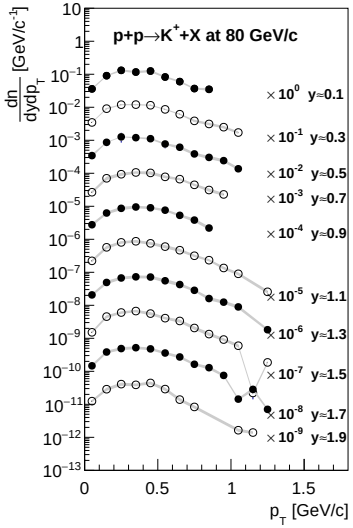


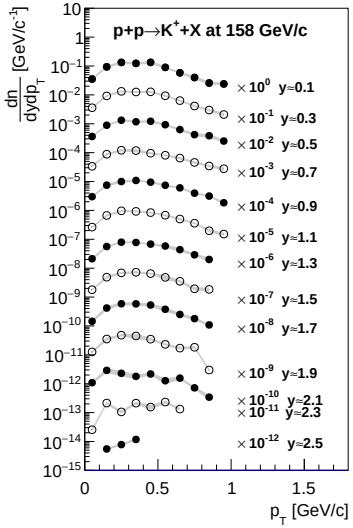




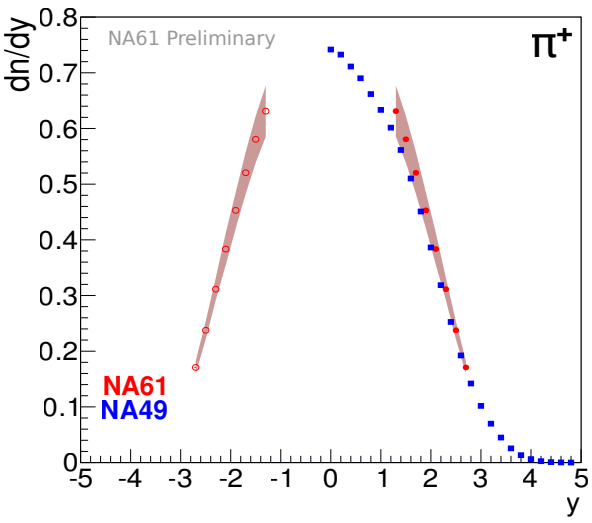


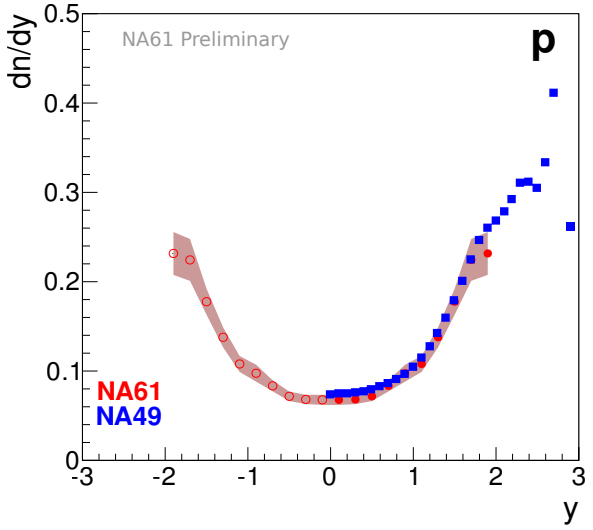


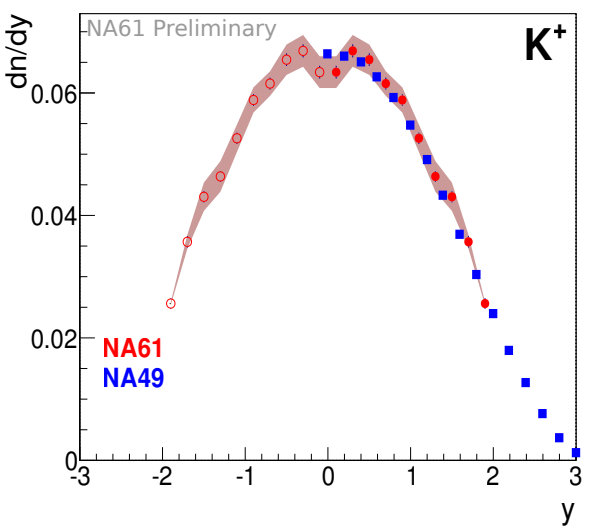


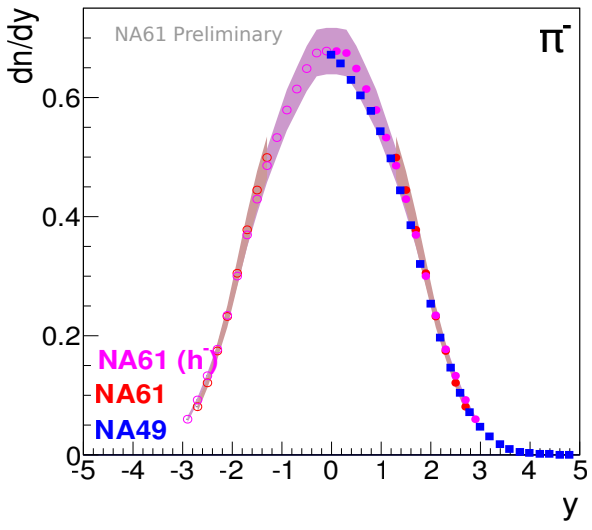


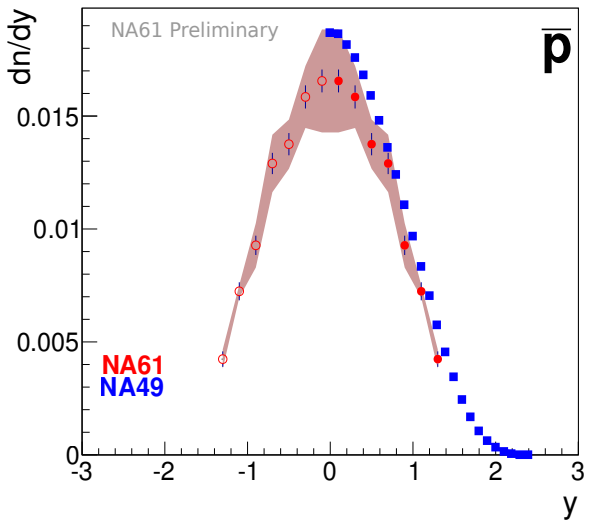
Comparison with NA49 p+p results

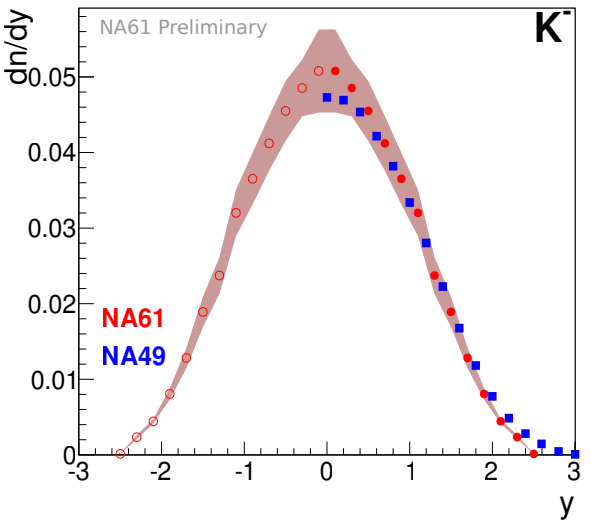




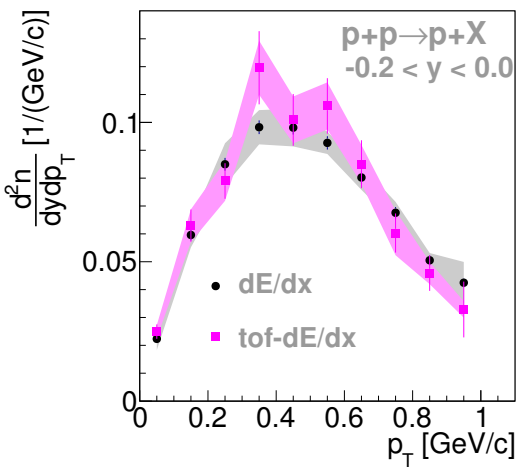


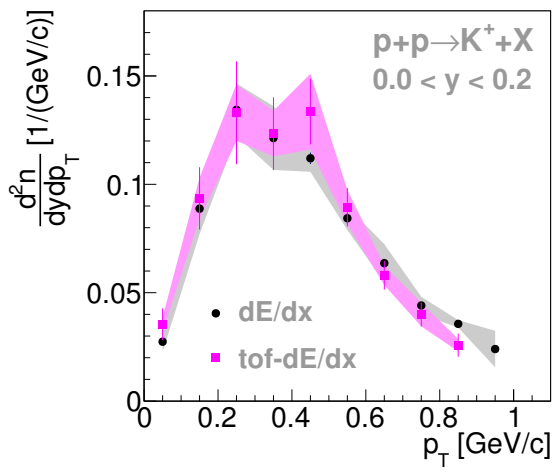


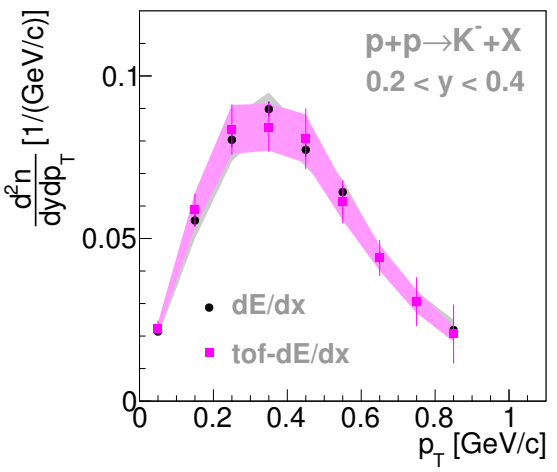




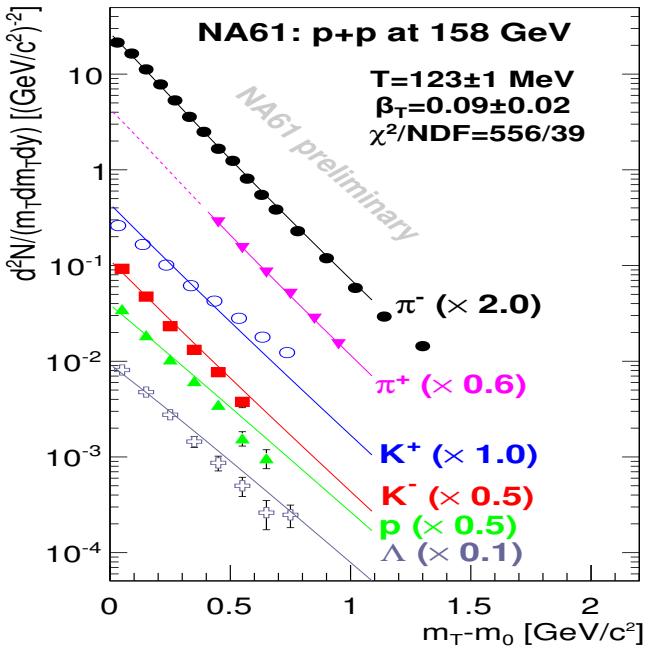
Analysis comparison

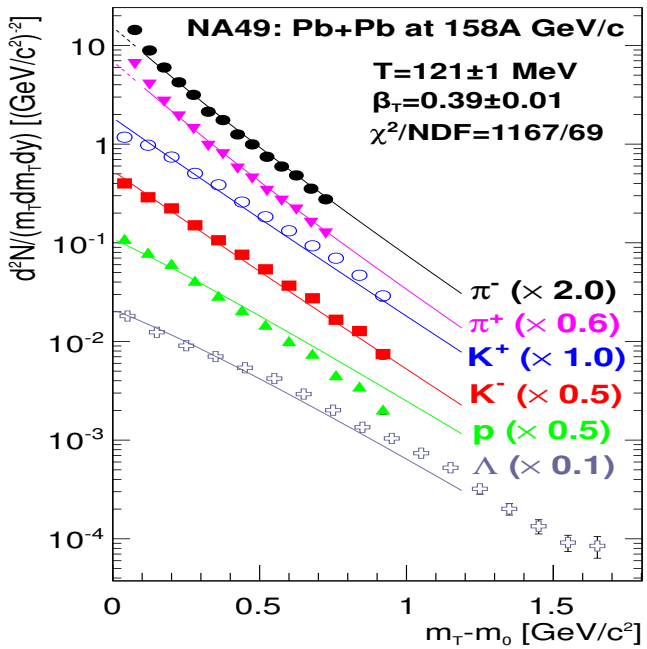






Transverse mass spectra at mid-rapidity





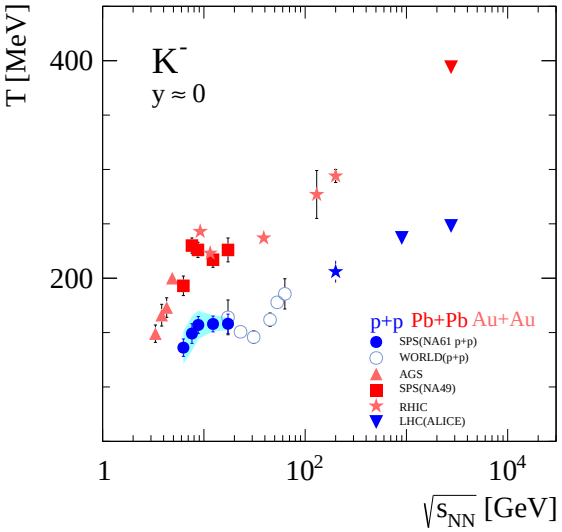
Transverse mass spectra are approximately exponential in p+p interactions. In central Pb+Pb collisions the exponential dependence is modified by the transverse flow.

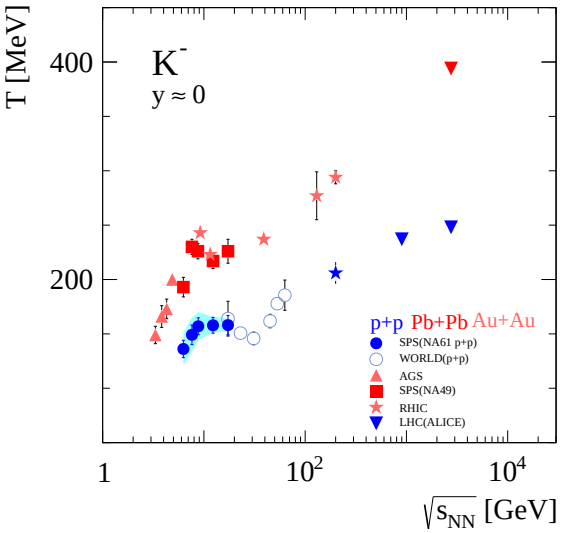
fitted by Blast Wave Model:

$$\frac{dN_i}{m_T dm_T dy} = A_i m_T K_1\left(\frac{m_T \cosh\rho}{T}\right) I_0\left(\frac{p_T \sinh\rho}{T}\right) \quad (1)$$

from Schnedermann, Sollfrank, Heinz, PRC 48, 2462 (1993)

Dip in ISR energies





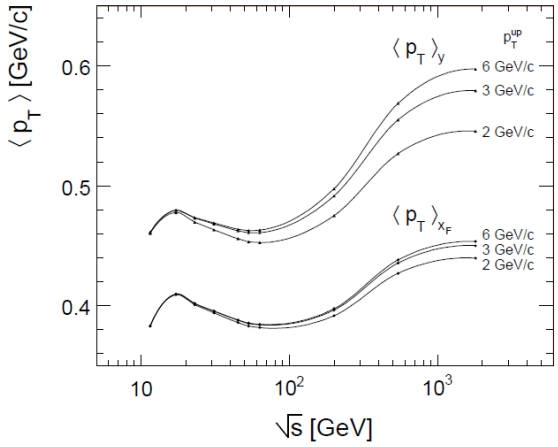


Figure 117: $\langle p_T \rangle_{x_F}$ at $x_F = 0$ and $\langle p_T \rangle_y$ at $y = 0$ as a function of $\sqrt{s}$ for different values of the upper integration limit from 2 to 6 GeV/c

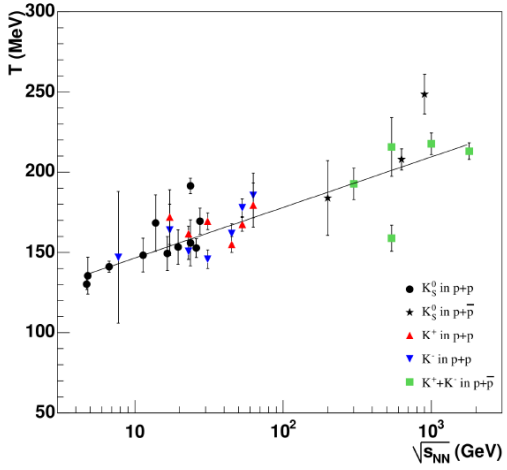
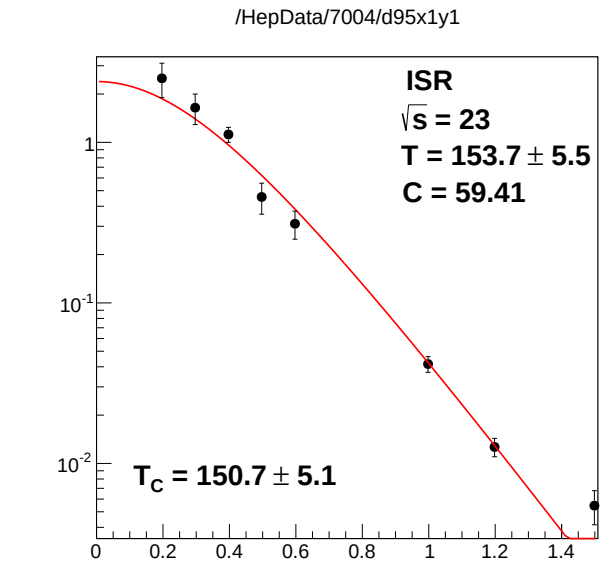
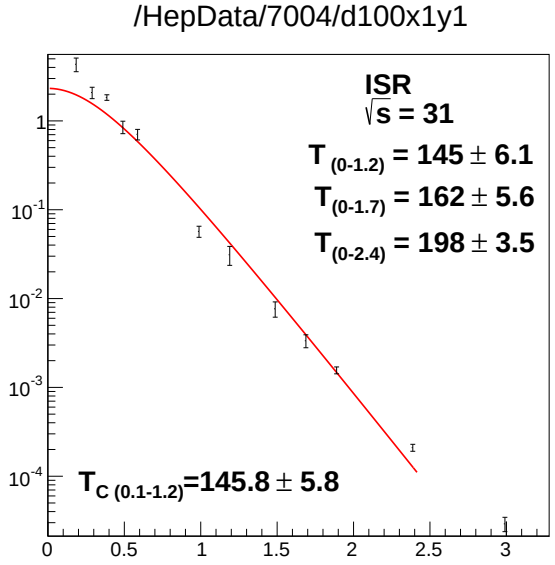
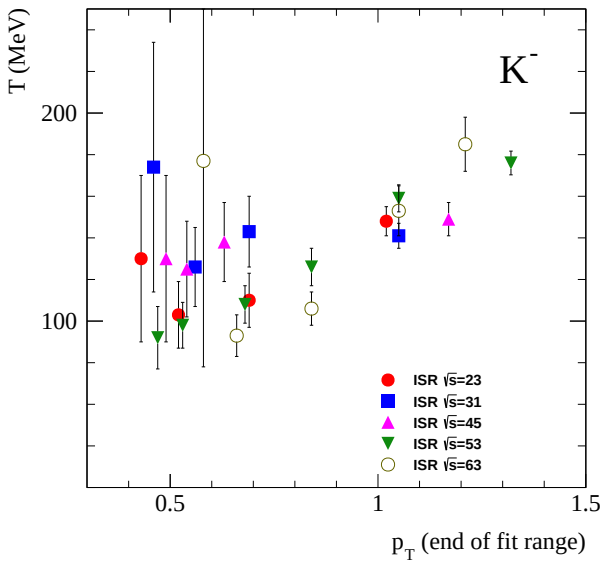


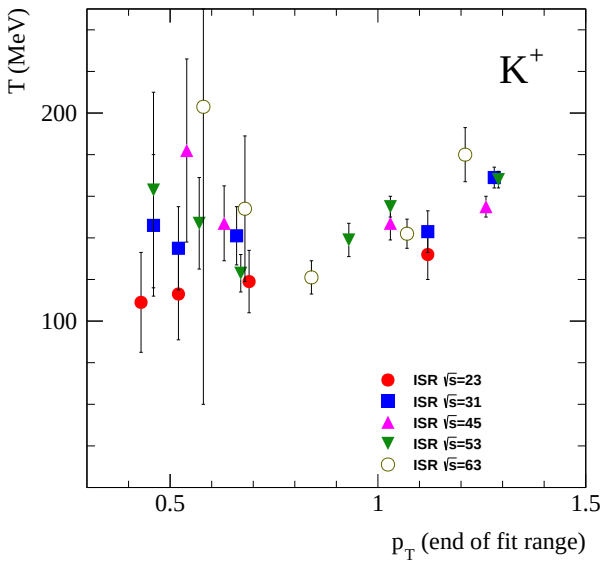
Figure 4: (Color online) Energy dependence of the inverse slope parameter T of transverse mass spectra of K^0_S, K^+ and K^- mesons produced in p+p and p+$\bar{p}$ interactions. The T parameter was determined by fitting the spectra (Eq. 1) in the whole analyzed m_T interval, $m_T - m_0 < 0.25$ GeV/c^2. The logarithmic parameterization is indicated by solid line.

ISR dependence of fit range





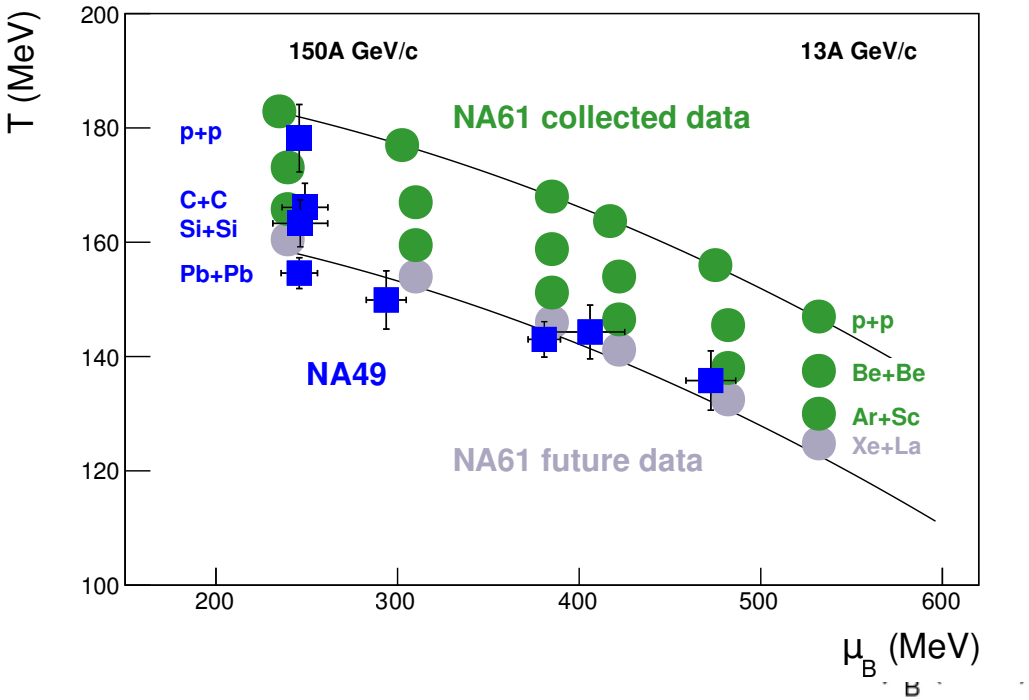




Strong interaction program

The most interesting region of the phase diagram is accessible at the SPS

- Onset of deconfinement at ≅ 30*A* GeV ($\sqrt{s_{NN}}$=7.6 GeV) PRC 77, 024903 (2008)
- Critical point? Example: (T^{CP}, $\mu_B{}^{CP}$) = (162±2, 360±40) MeV JHEP 0404, 050 (2004)



Estimated (NA49) and expected (NA61) chemical freeze-out points according to PRC 73, 044905 (2006)

Comprehensive scan in the whole SPS energy range (13A-158A GeV ⇔ $\sqrt{s_{NN}}$=5.1-17.3 GeV) with **light and intermediate mass nuclei**

- **Search for the critical point**
  Search for a maximum of CP signatures: fluctuations of N, average p_T, etc., intermittency, when system freezes out close to CP

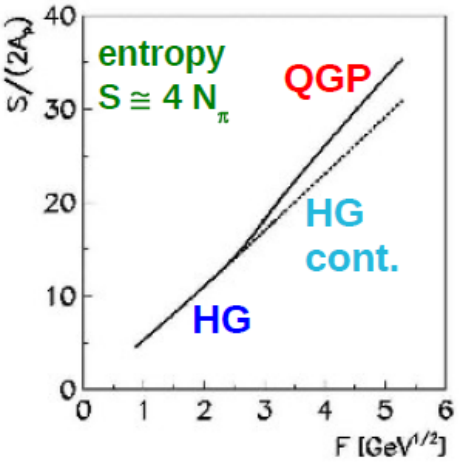
- **Study of the properties of the onset of deconfinement**
  Search for the onset of horn, kink, step, etc. in collisions of light nuclei

Statistical model of the early stage

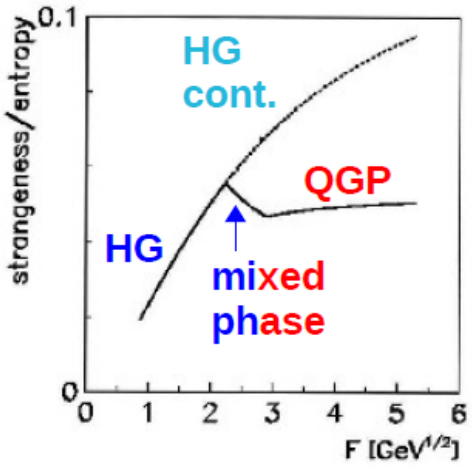
Motivation: **S**tatistical **M**odel of the **E**arly **S**tage (SMES)

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

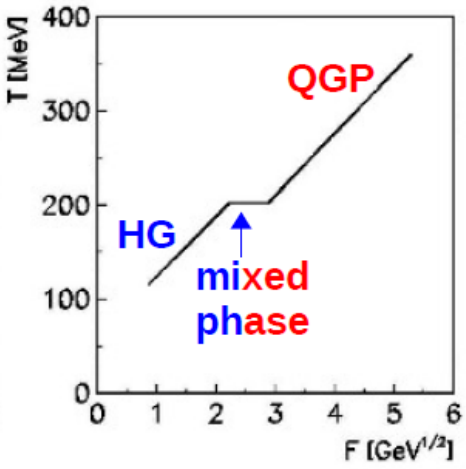
"kink"



"horn"



"step"



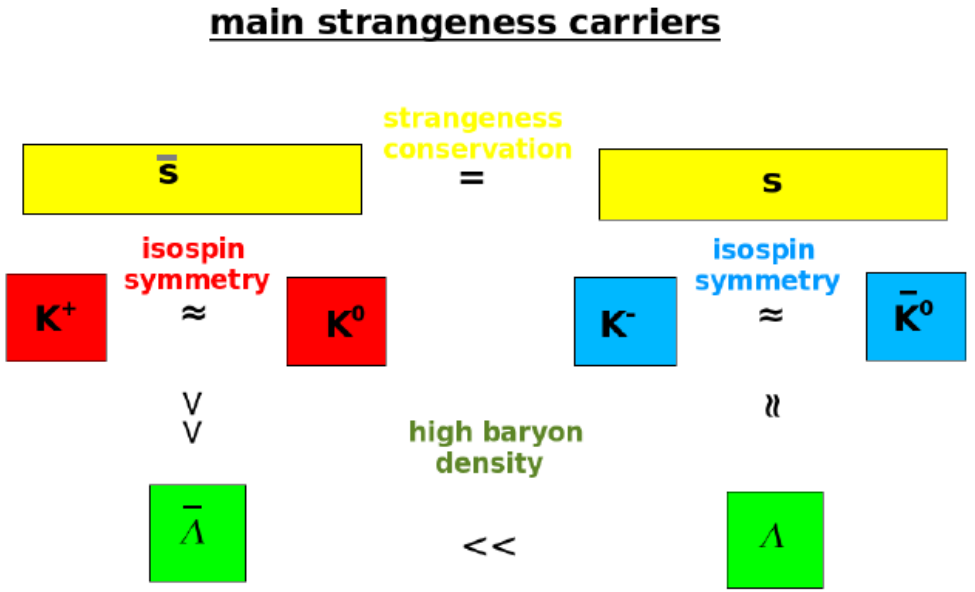
Fermi variable

$$F \equiv \left[\frac{\left(\sqrt{s_{NN}} - 2m_N\right)^3}{\sqrt{s_{NN}}}\right]^{1/4}$$

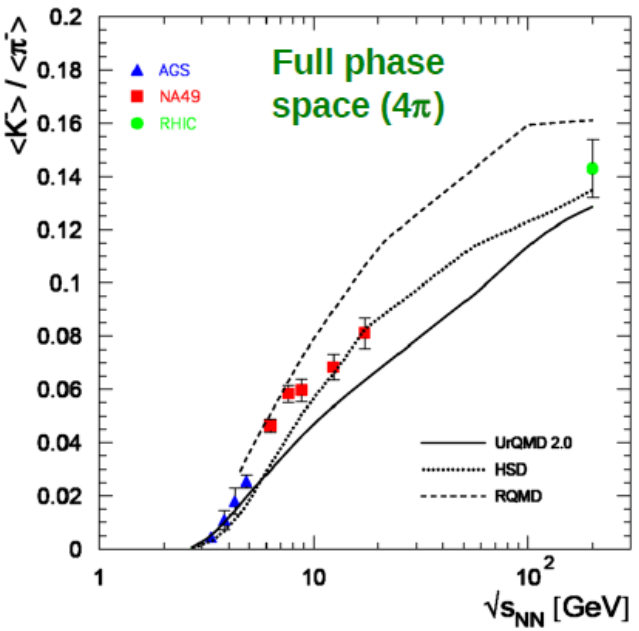
$$F \simeq \sqrt{\sqrt{s_{NN}}}$$

- 1st order phase transition to QGP between top AGS and top SPS energies $\sqrt{s}_{NN} \approx 7$ GeV
- number of internal degrees of freedom (*ndf*) increases HG → QGP (activation of partonic degrees of freedom)
- total entropy and total strangeness are the same before and after hadronization (cannot decrease QGP → HG)
- mass of strangeness carriers decreases HG → QGP ($m_{\Lambda, K, \ldots} > m_s$)
- constant temperature and pressure in mixed phase

Assumptions



Λ (uds)
K^+ (u **anty-s**)
K^- (anty-u **s**)
K^0 (d **anty-s**)
anty-K^0 (anty-d **s**)



sensitive to strangeness content only

sensitive to strangeness content and baryon density

Difference in ⟨K^+⟩ and ⟨K^-⟩ production due to different sensitivity to baryon density. At SPS energies lambdas have significant influence on total strangeness production (anti-lambdas not)

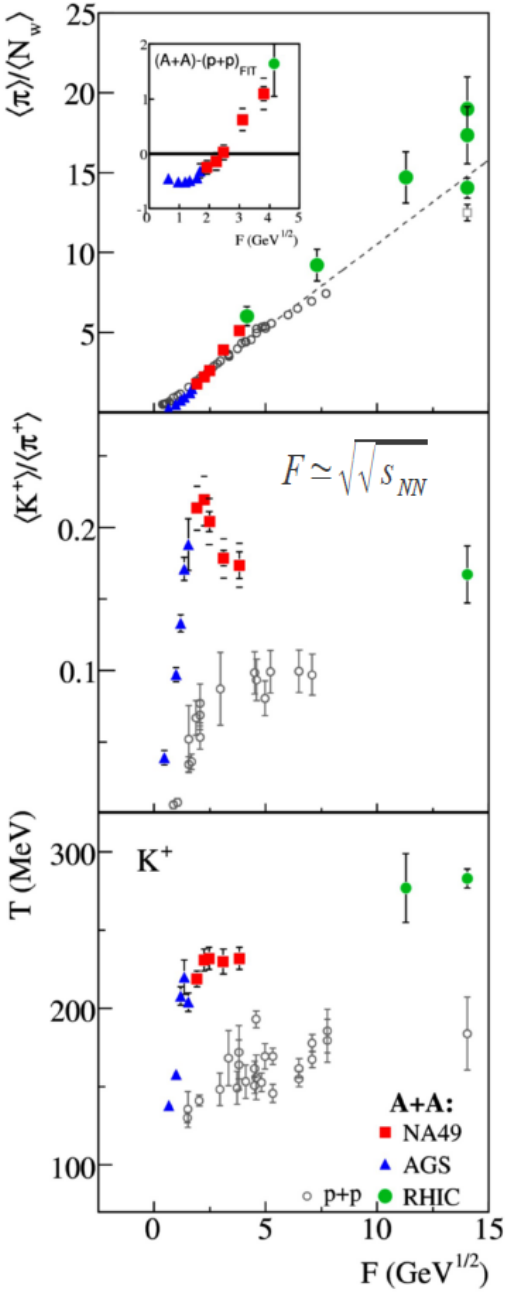
$\bar{s} \rightarrow K^+, K^0$

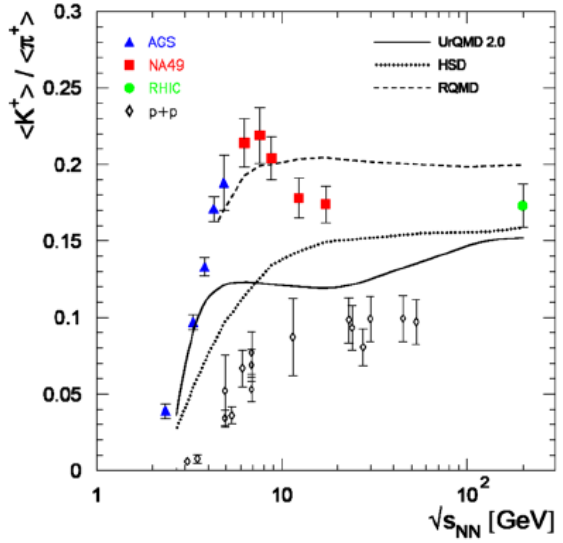
$s \rightarrow K^-, \bar{K}^0, \Lambda$

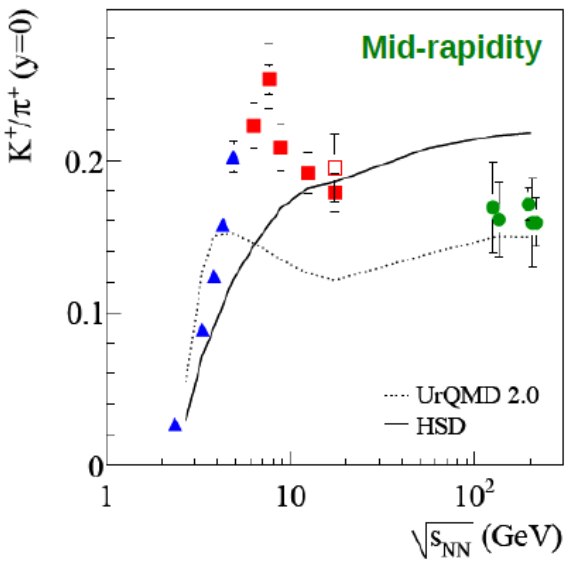
⟨K^+⟩/⟨π^+⟩ proportional to strangeness/entropy

⟨K^-⟩/⟨π^-⟩ additionally sensitive to baryon density

NA49 results

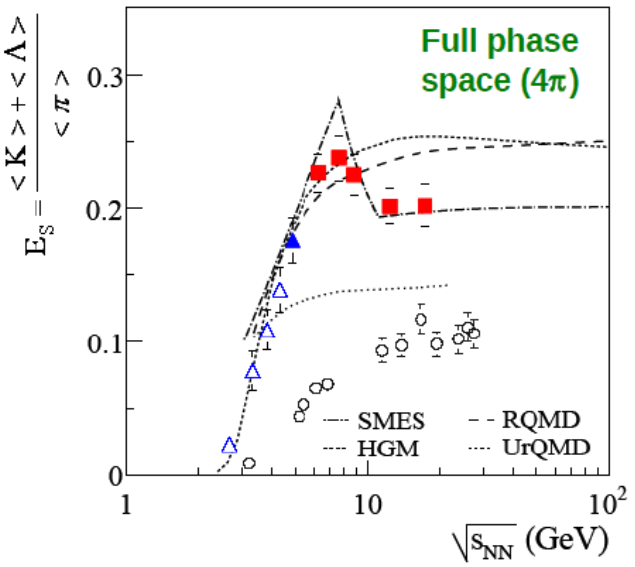






→ Effect on ⟨K⁺⟩/⟨π⁺⟩ even more pronounced at mid-rapidity

E_s - strangeness to entropy



E_S calculated from π, K and Λ yields in 4π. Proposed as a measure of strangeness to entropy ratio (SMES)

→ **E_s shows distinct peak at 30*A* GeV**

→ **Described (predicted) only by model assuming phase transition (SMES)**