NA61/SHINE: energy dependence of hadron spectra and yields in p+p and Be+Be collisions

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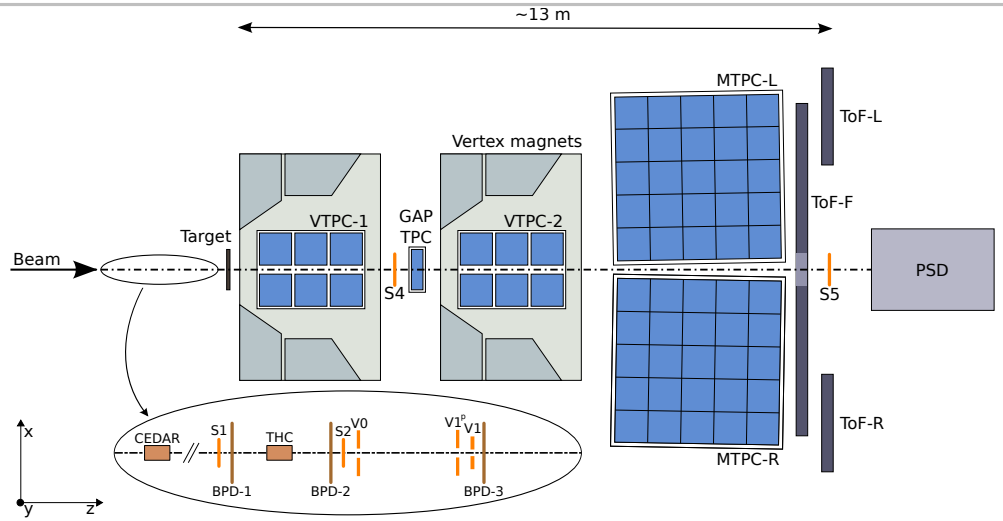
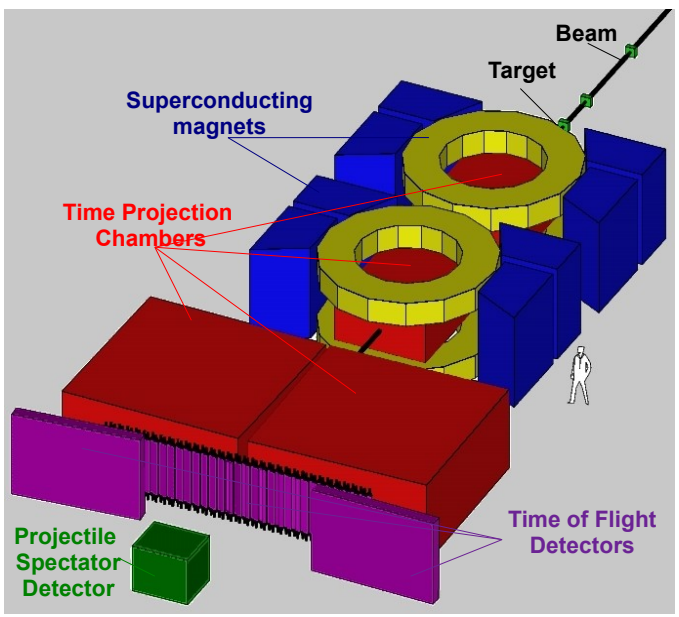
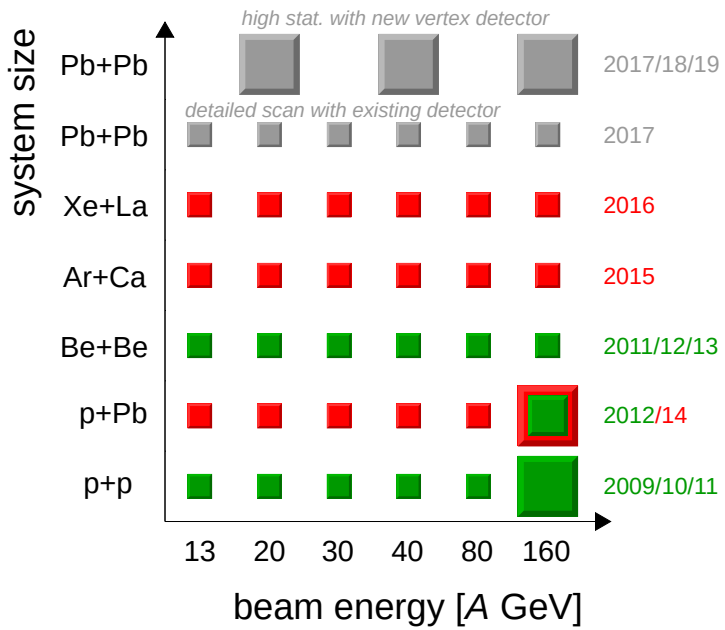
for the NA61/SHINE Collaboration

SQM at JINR/Dubna
2015-07-06

NA61/SHINE experiment set-up







Multi-purpose, fixed-target experiment at the CERN SPS

NA61/SHINE facility paper: JINST 9 (2014) P06005

Outline

- p+p
  - pion, kaon, proton: transverse mass, dn/dy, yields
- Be+Be
  - cross section, event selection
  - pions: transverse mass, rapidity, isospin

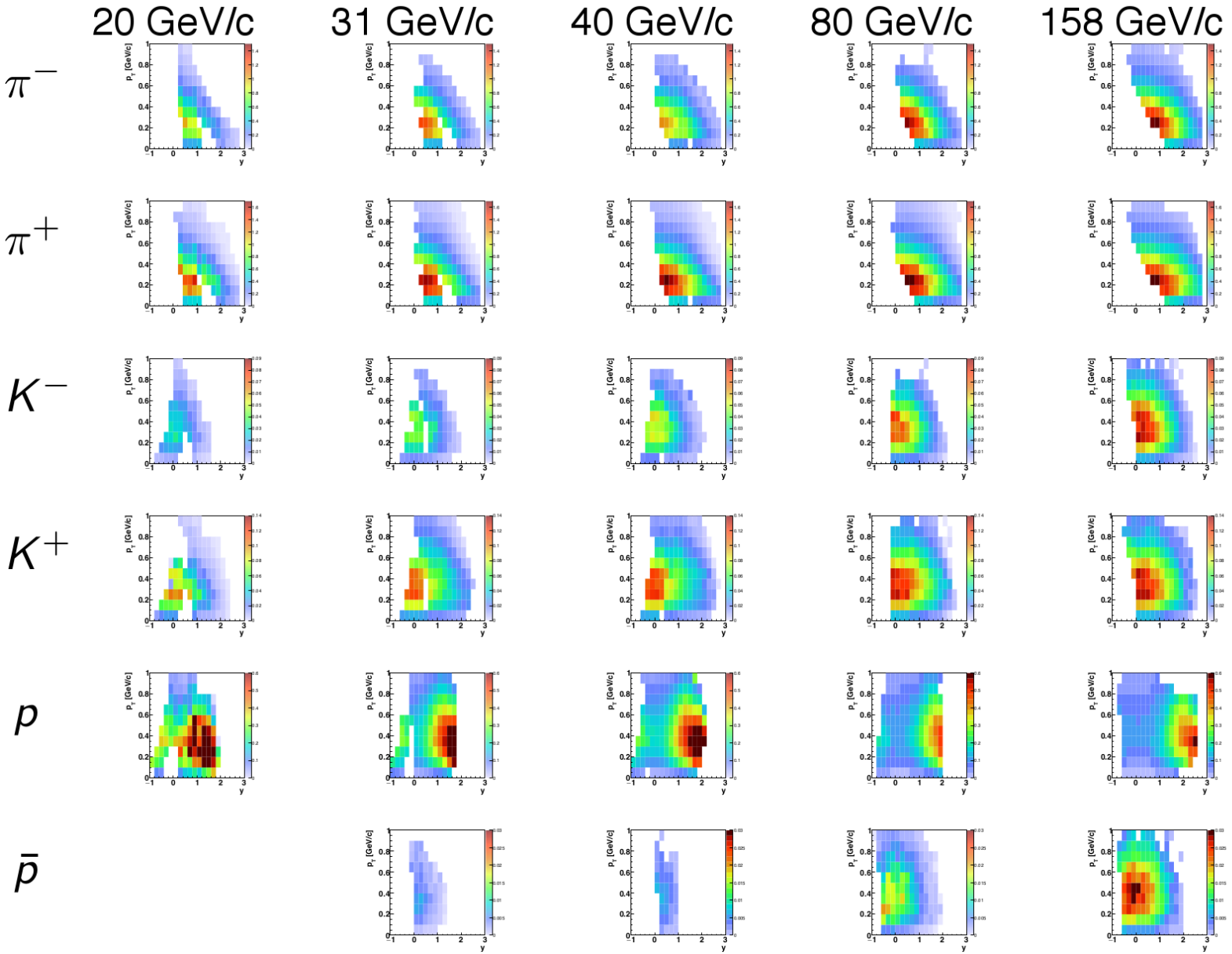
Other NA61/SHINE talks at SQM

- Energy dependence of fluctuations in p+p and Be+Be collisions from NA61/SHINE — Evgeny Andronov
- Energy dependence of correlations — Andrey Seryakov
- Vertex detector for open charm measurements for NA61/SHINE — Grigori Feofilov
- Search for the critical point of SIM (NA49, NA61, STAR, PHENIX) — Peter Seyboth

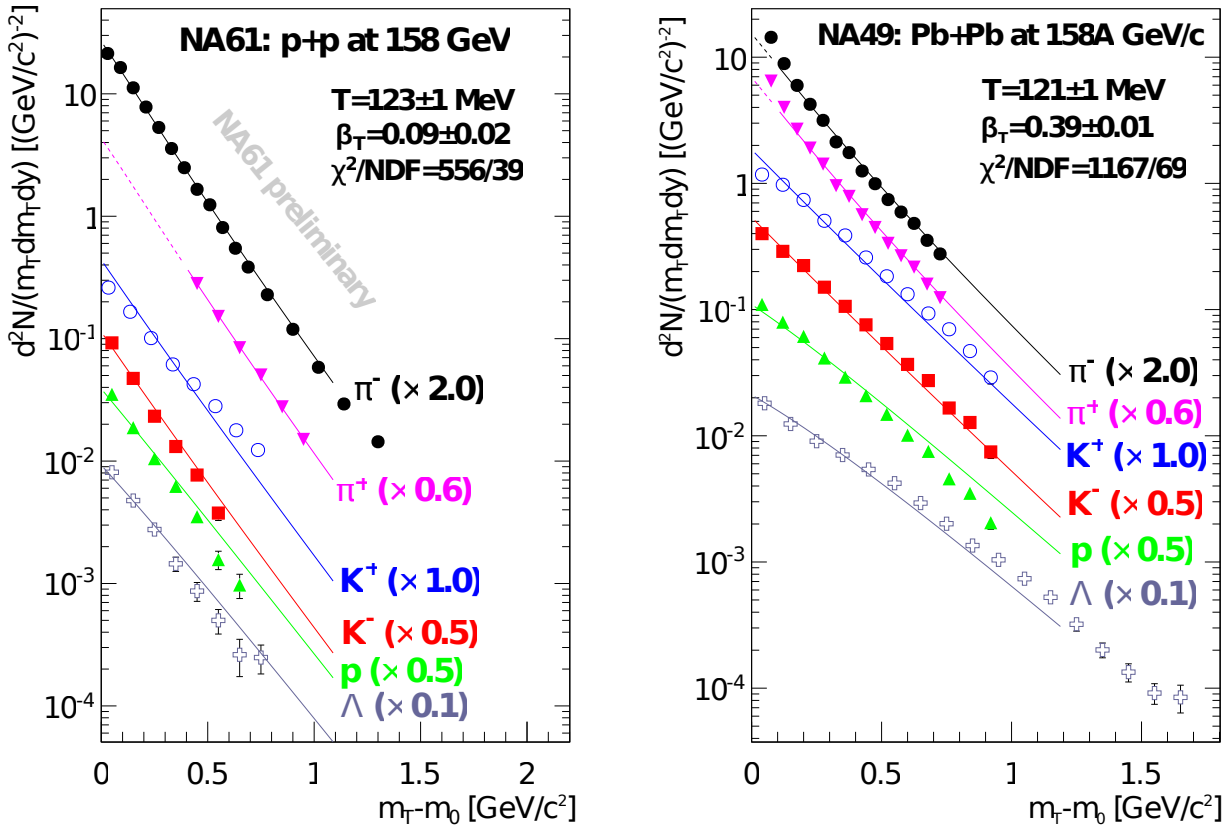
Notes

- Particle spectra
  - h^- analysis, dE/dx, tof-dE/dx and V_0 identifications
  - The results are corrected for particles from weak decays (feed-down) and secondary interactions and detector effects using Monte-Carlo models
  - Out of target interactions are subtracted using events recorded with target removed
- p+p
  - Data taken: 2009/10/11
  - Data taken at 20, 31, 40, 80, 158 GeV/c
  - Results: Eur.Phys.J. C74 (2014) 3, 2794; CPOD 2014 arXiv:1502.07916; CERN-SPSC-2014-031
  - Hadrons produced in inelastic p+p collisions
- Be+Be
  - Data taken: 2011/12/13
  - Data taken at: 13, 19, 31, 40, 75, 150 A GeV/c
  - Results: CERN-SPSC-2014-031; E. Kaptur, CPOD (2014)
  - Hadrons produced in centrality selected

p+p: 2D spectra p_T vs. rapidity

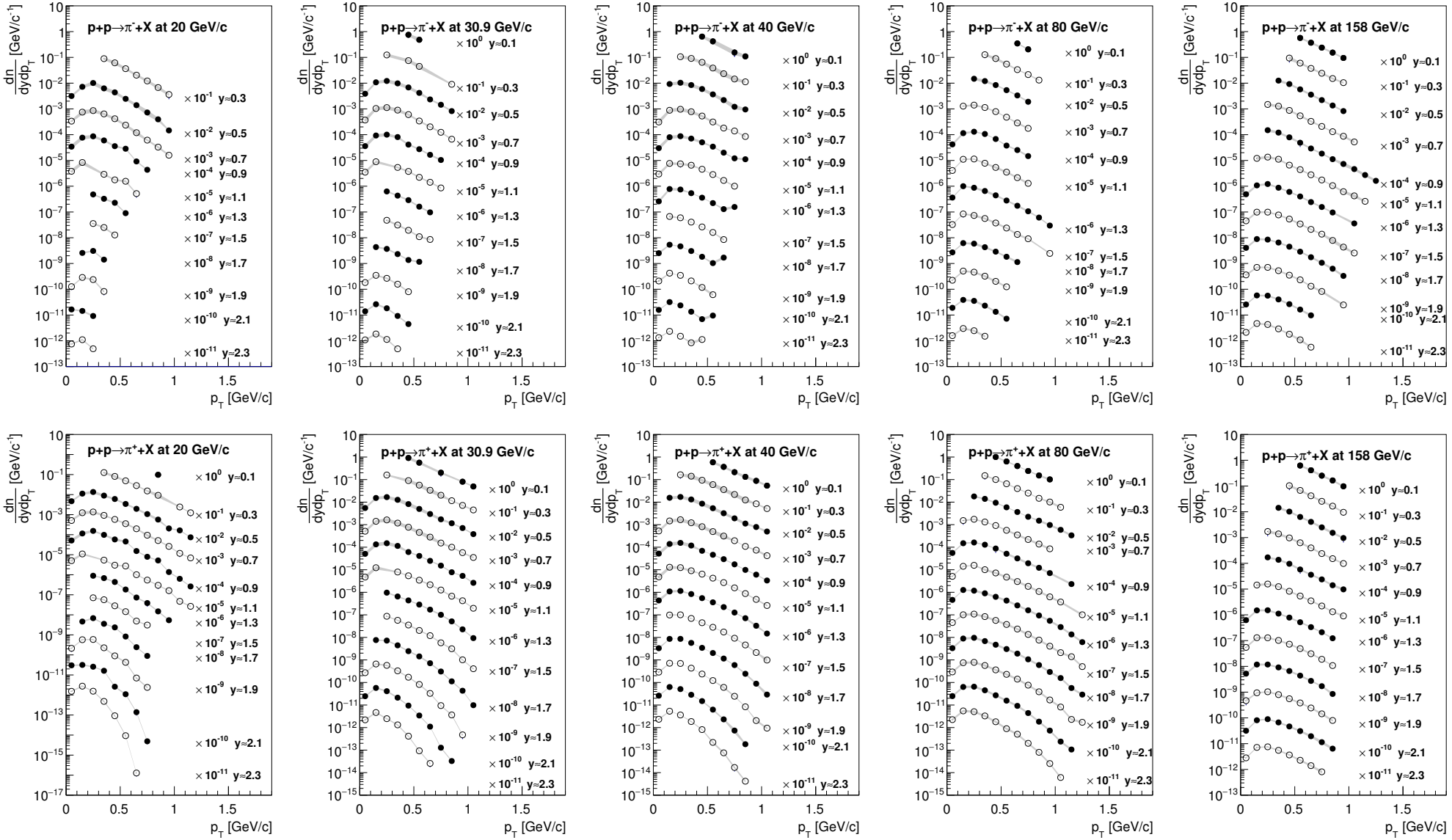


p+p: transverse mass spectra at mid-rapidity

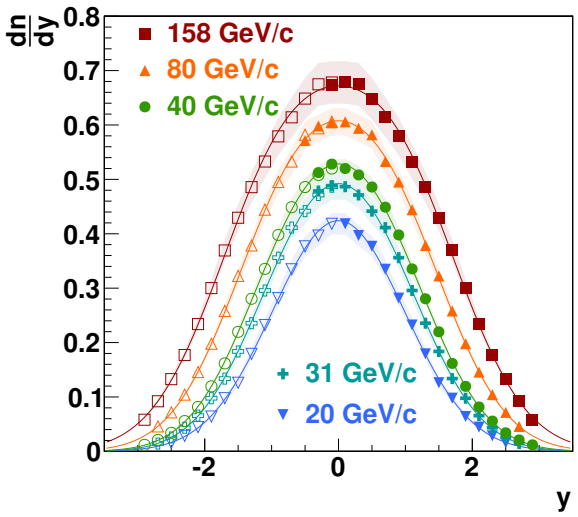


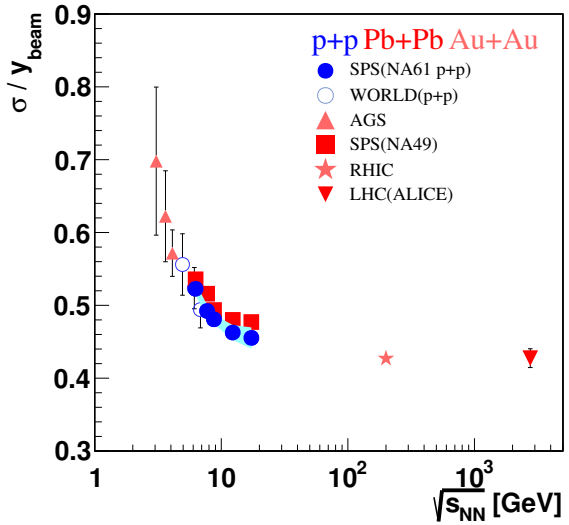
- Transverse mass spectra are approximately exponential in p+p interactions
- In central Pb+Pb collisions the exponential dependence is modified by the transverse flow

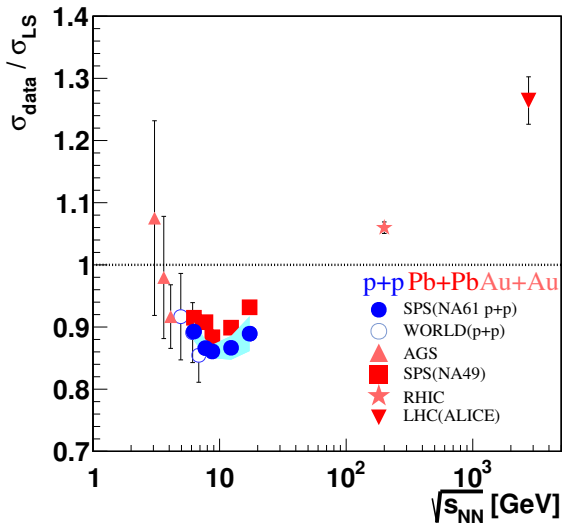
p+p: π transverse momentum spectra vs. y



p+p: π^- rapidity width – dale



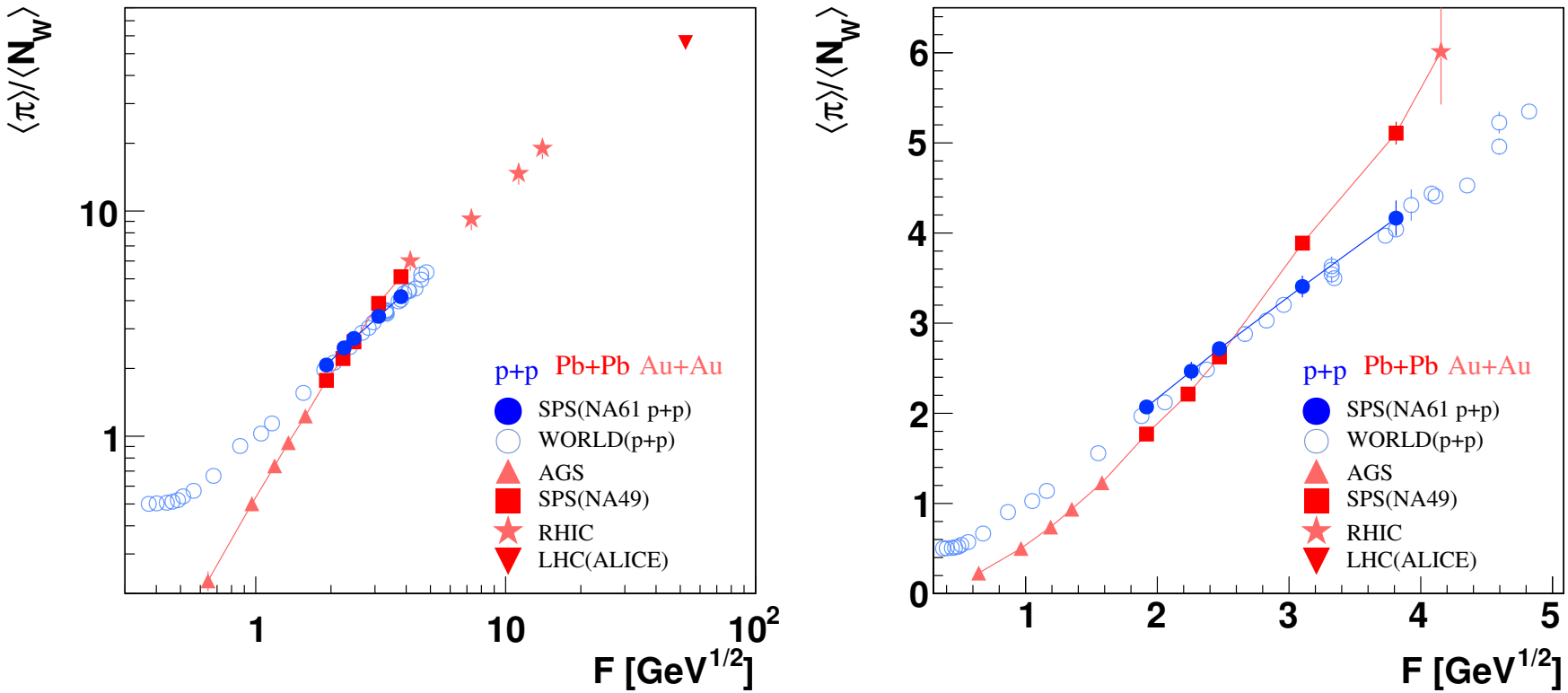




- dn/dy distribution is approximately Gaussian, best fit by sum of two Gauss distributions
- The width of the rapidity distribution divided by beam rapidity increases with energy
- $\sigma_{data}/\sigma^*_{LS}$ and σ_{data}/y_{beam} is smaller in p+p than in Pb+Pb interactions
- No significant difference of energy dependence of π^- rapidity width in p+p and Pb+Pb observed
- Result not corrected for isospin effect

Hydrodynamics model: Landau, Izv. Akad. Nauk Ser. Fiz. 17, 51 (1953). Shuryak, Yad.Fiz. 16, 395 (1972);
E895: Phys.Rev.C68:054905,2003, PHENIX: Phys.Rev.C69:034909,2004; ALICE: Phys.Lett.B726, (2013) 610-622

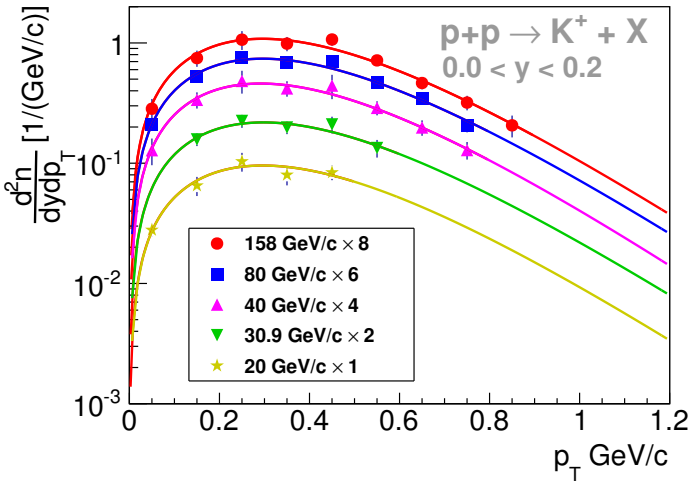
p+p: π multiplicity – kink

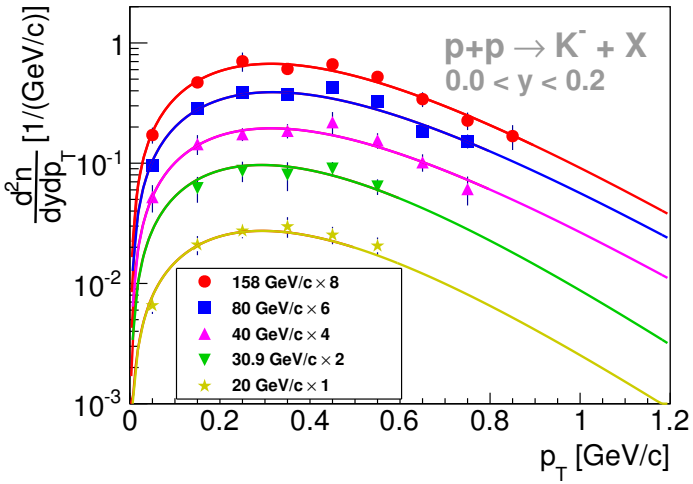


- π multiplicity at the SPS energies increases faster in central Pb+Pb than in p+p (kink)
- The two dependencies cross each other at about 40A GeV/c

Results published: EPJC74:2794 (NA61/SHINE p+p) ALICE: Phys. Lett. B 726 (2013), PRL 109, 252301 (2012)

p+p: K at mid-rapidity



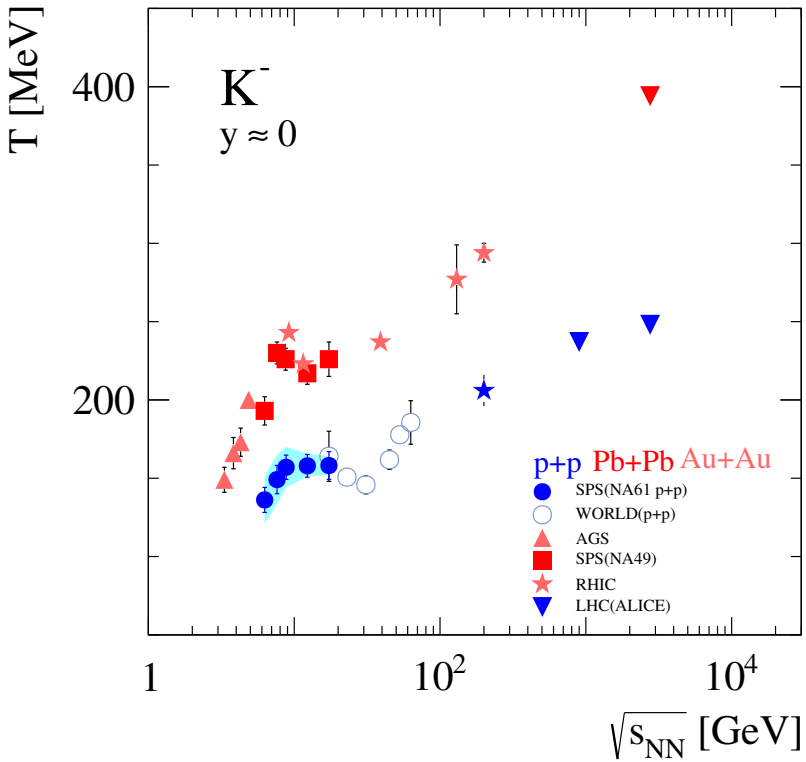


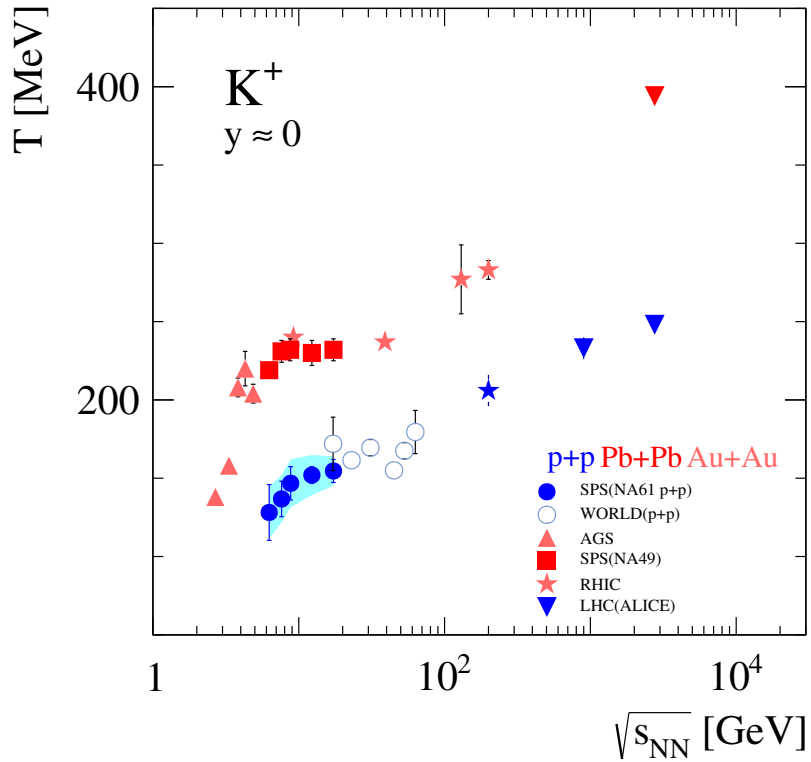
- Spectra fitted by:

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

- Fit allows to estimate
  - The inverse slope parameter T
  - K multiplicity for p_T range not accessible by data

p+p: K inverse slope parameter T – step

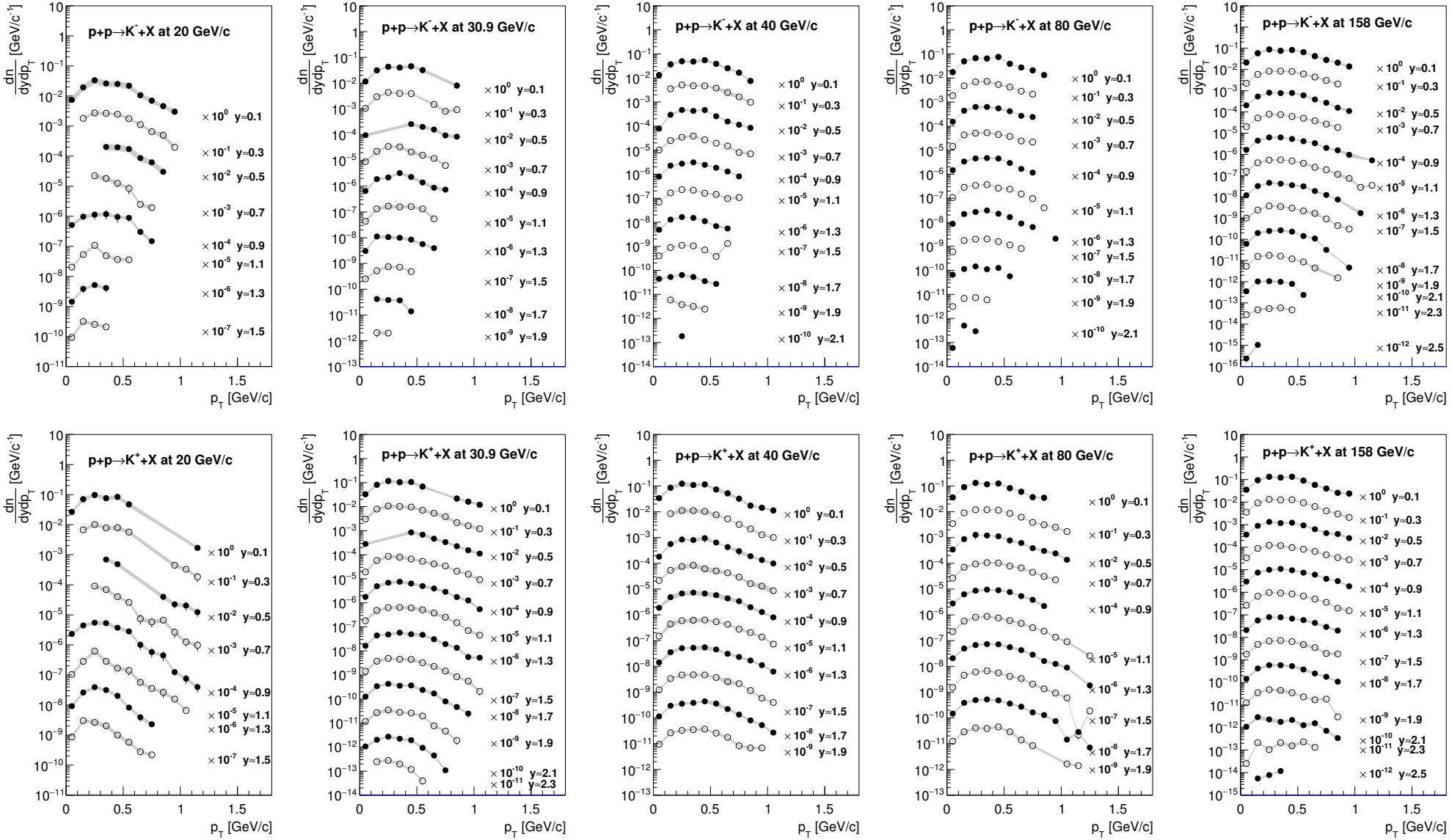




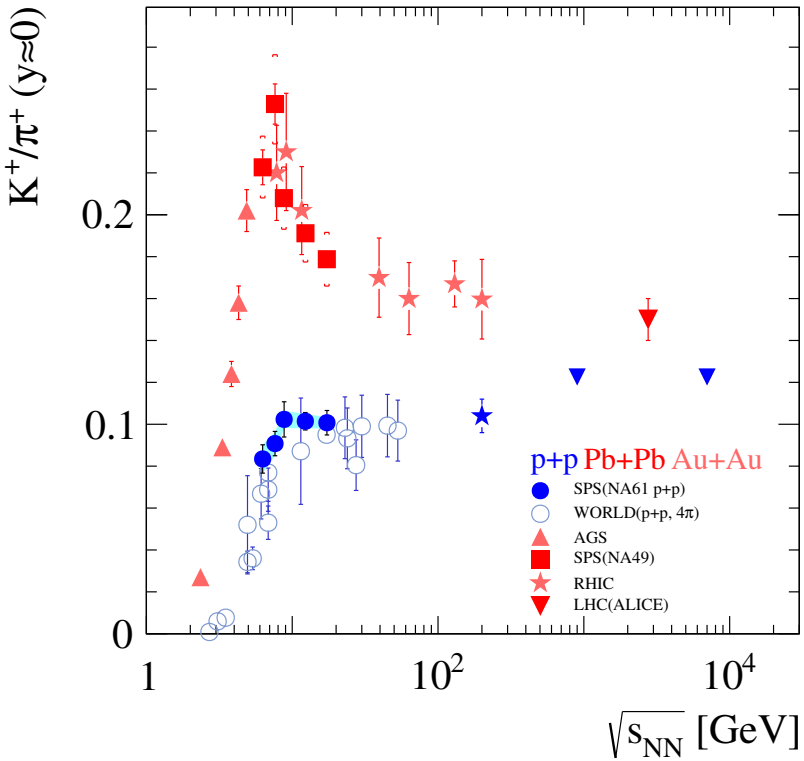
- In p+p collisions energy dependence of K inverse slope parameter T exhibits rapid changes like in Pb+Pb interactions

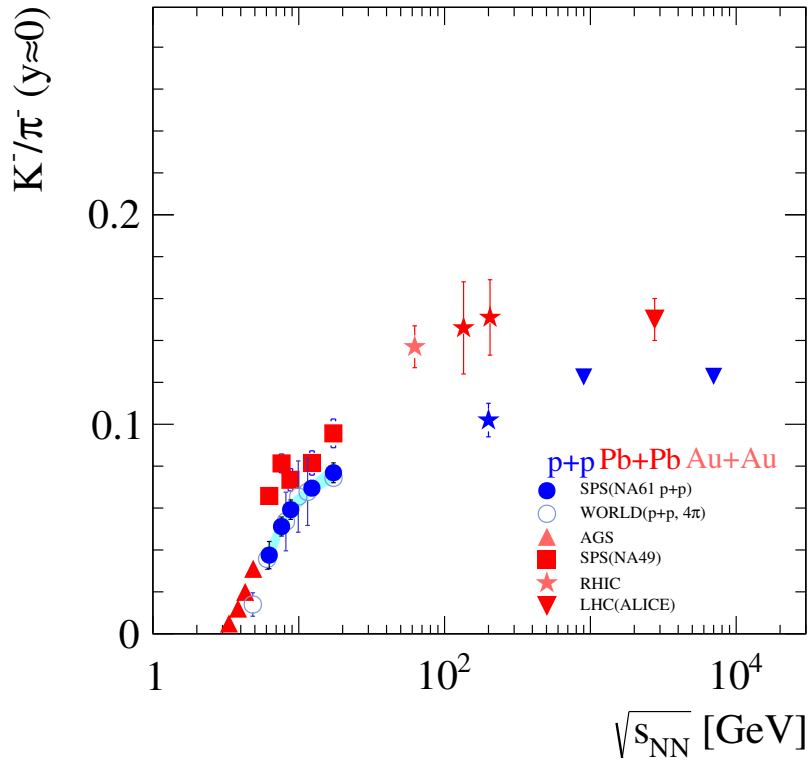
Phys.Rev. C69 (2004) 044903, STAR: Phys.Rev.C79:034909,2009;
ALICE: PLB 736 (2014) 196-207, Eur. Phys. J , C (2011) 71:1655

p+p: K transverse momentum spectra vs. y



p+p: K/π – horn

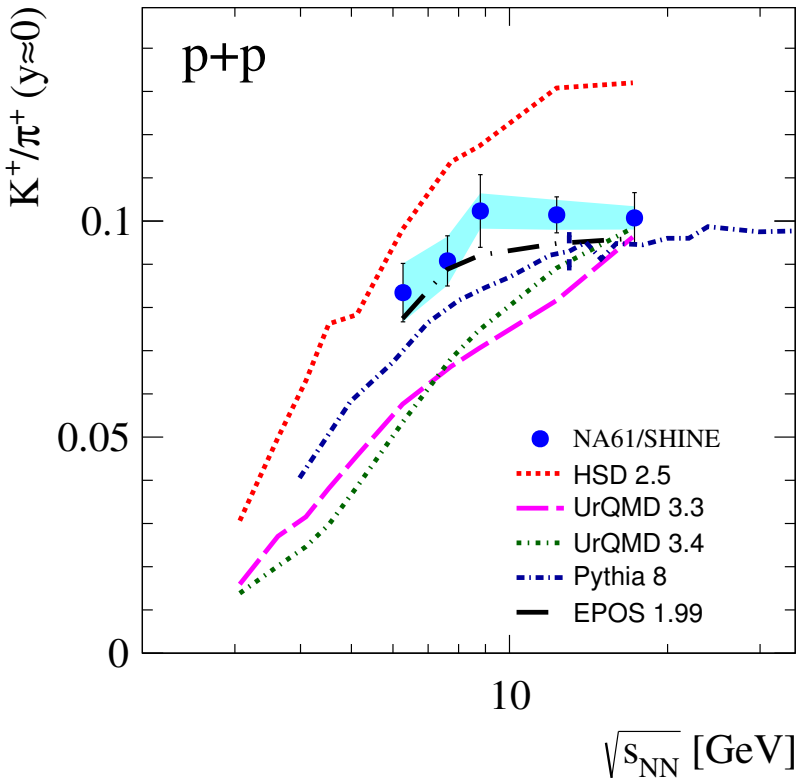


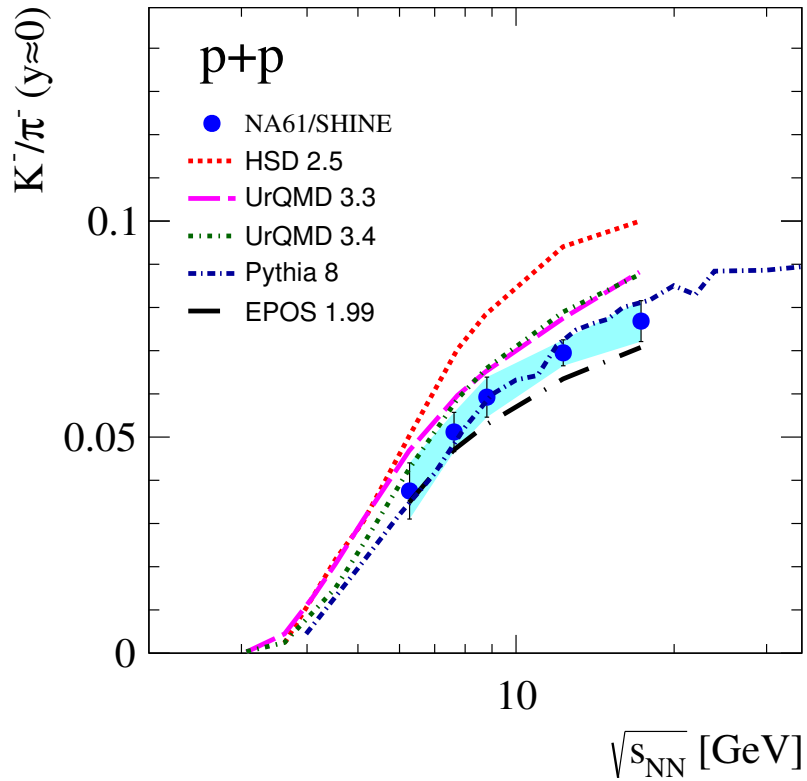


- A shadow of the Pb+Pb horn structure is visible in p+p but significantly reduced

NA61/SHINE: 2014 status report http://cds.cern.ch/record/1955138
Z.Phys. C65 (1995) 215-223 (), 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.

p+p: K/π – model comparison

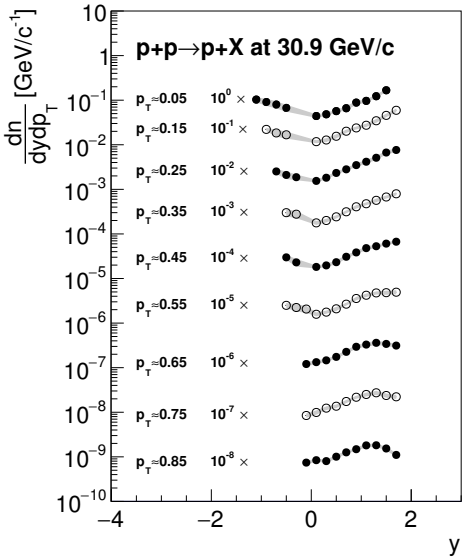


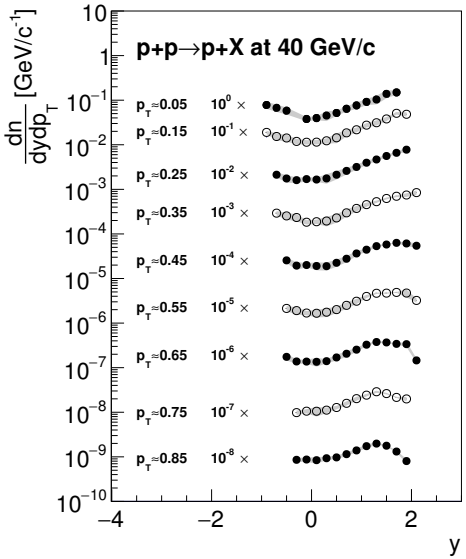


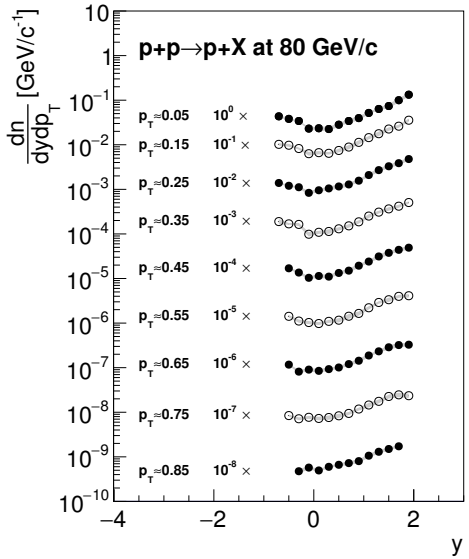
- Models do not describe well NA61/SHINE data on p+p interactions
- High precision NA61/SHINE data allow for their significant improvement

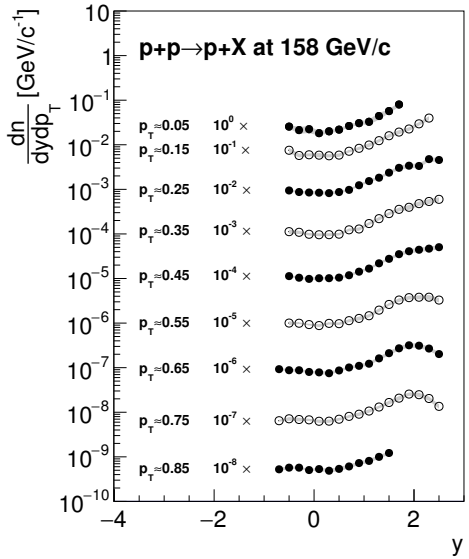
Vovchenko et al., PRC 90, 024916 (2014), and private communication. Gavin Salam private communication; UrQMD: Prog. Part. Nucl. Phys. 41 (1998), J. Phys. G: Nucl. Part. Phys. 25 (1999); HSD: Nucl. Phys. A 602, 449 (1996), Nucl. Phys. A 644, 107 (1998), Phys. Rept. 308, 65 (1999); EPOS: Nucl.Phys.Proc.Suppl.196,2009,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

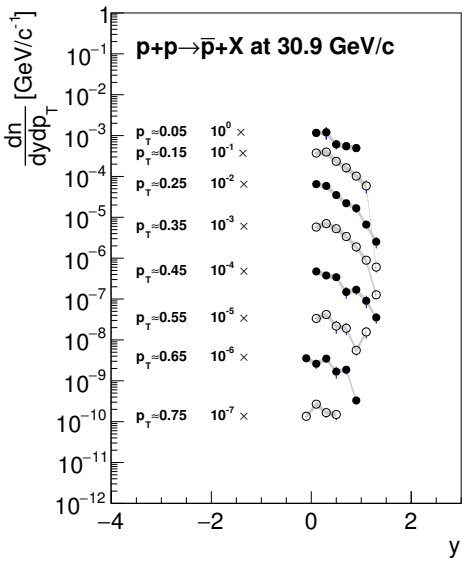
p+p: p rapidity spectra vs. p_T

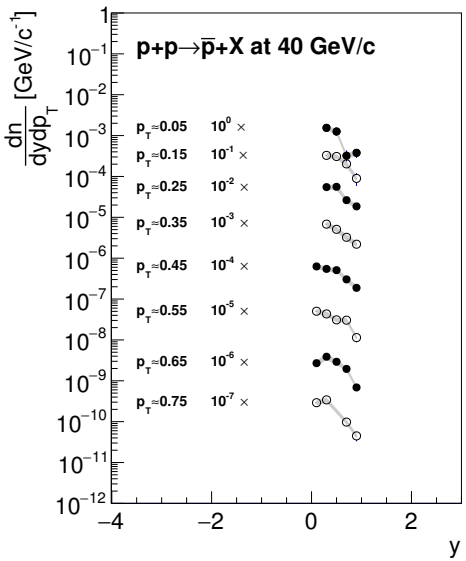


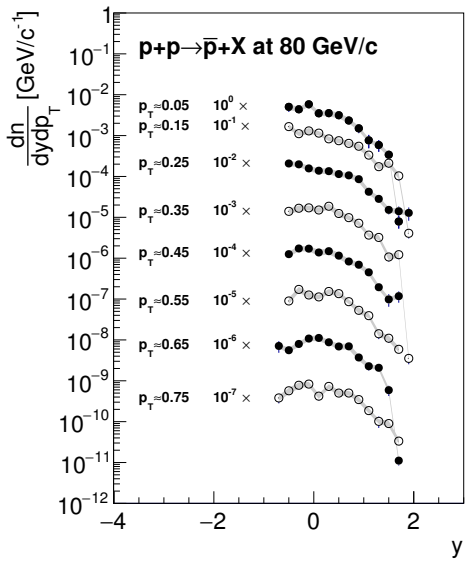


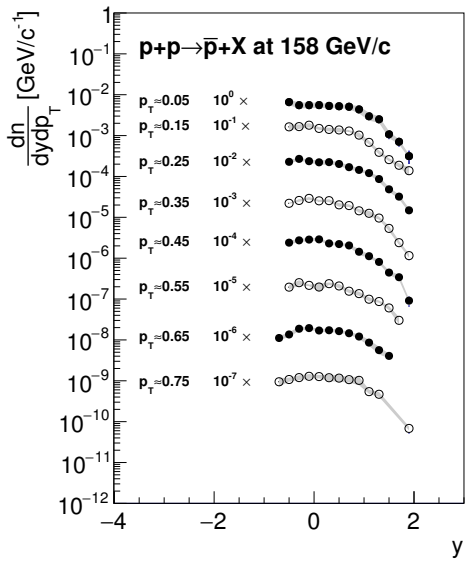






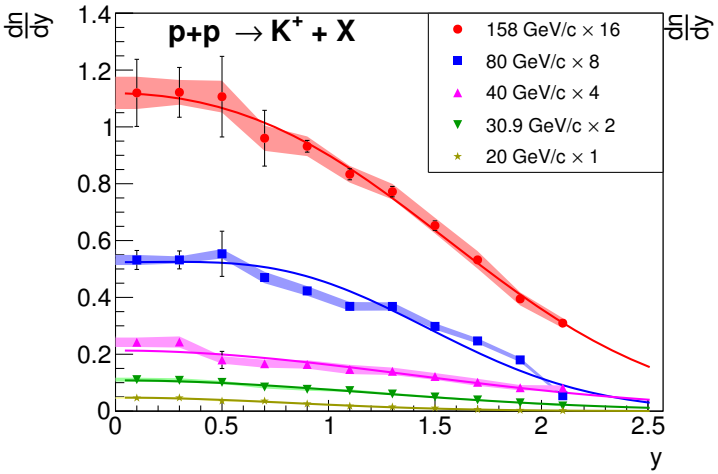


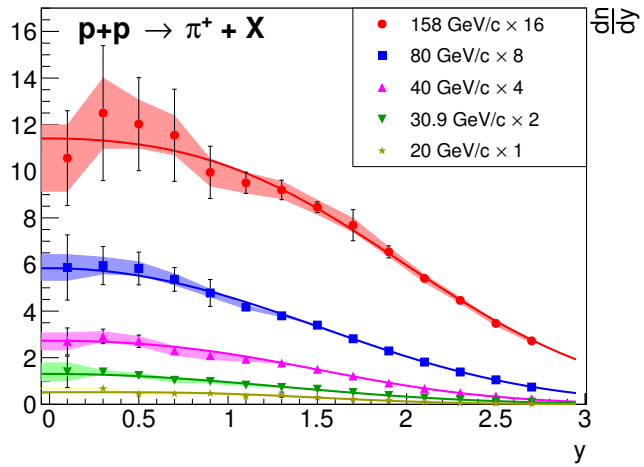


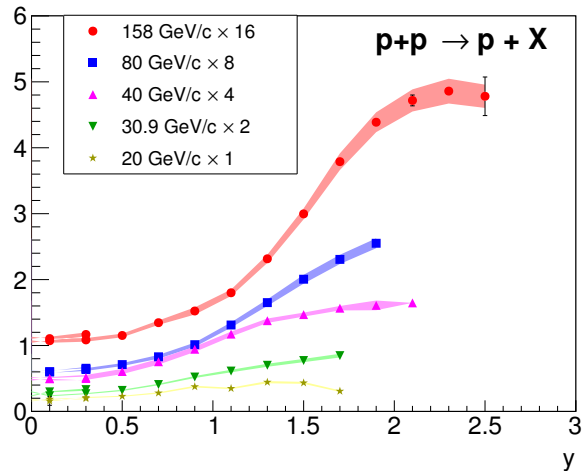


p+p: dn/dy

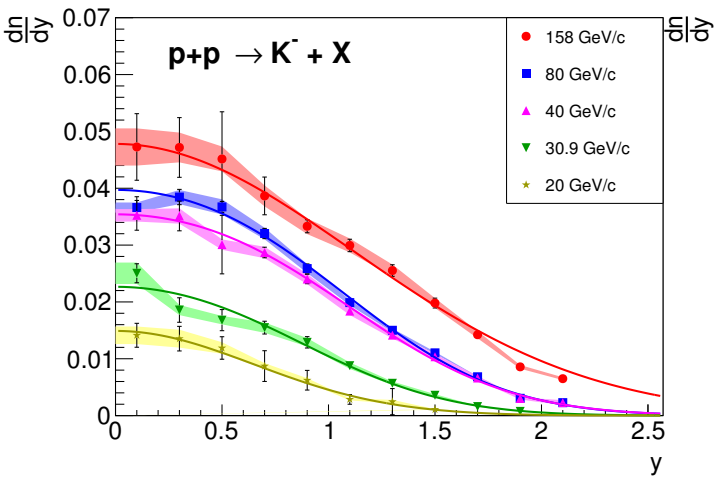
K, π, p: positive

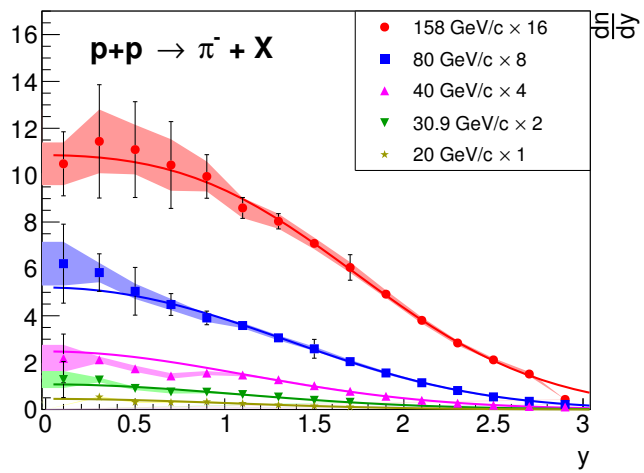


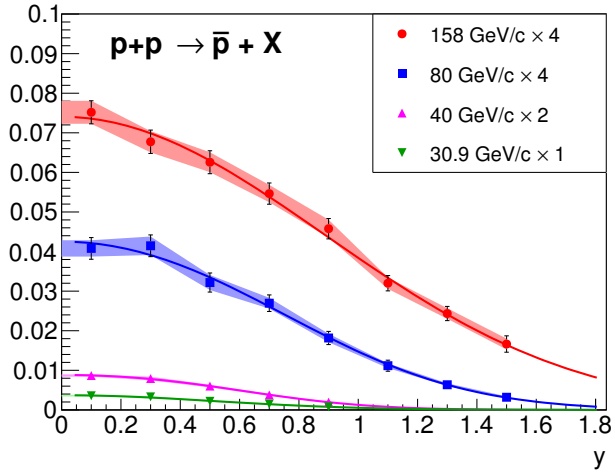




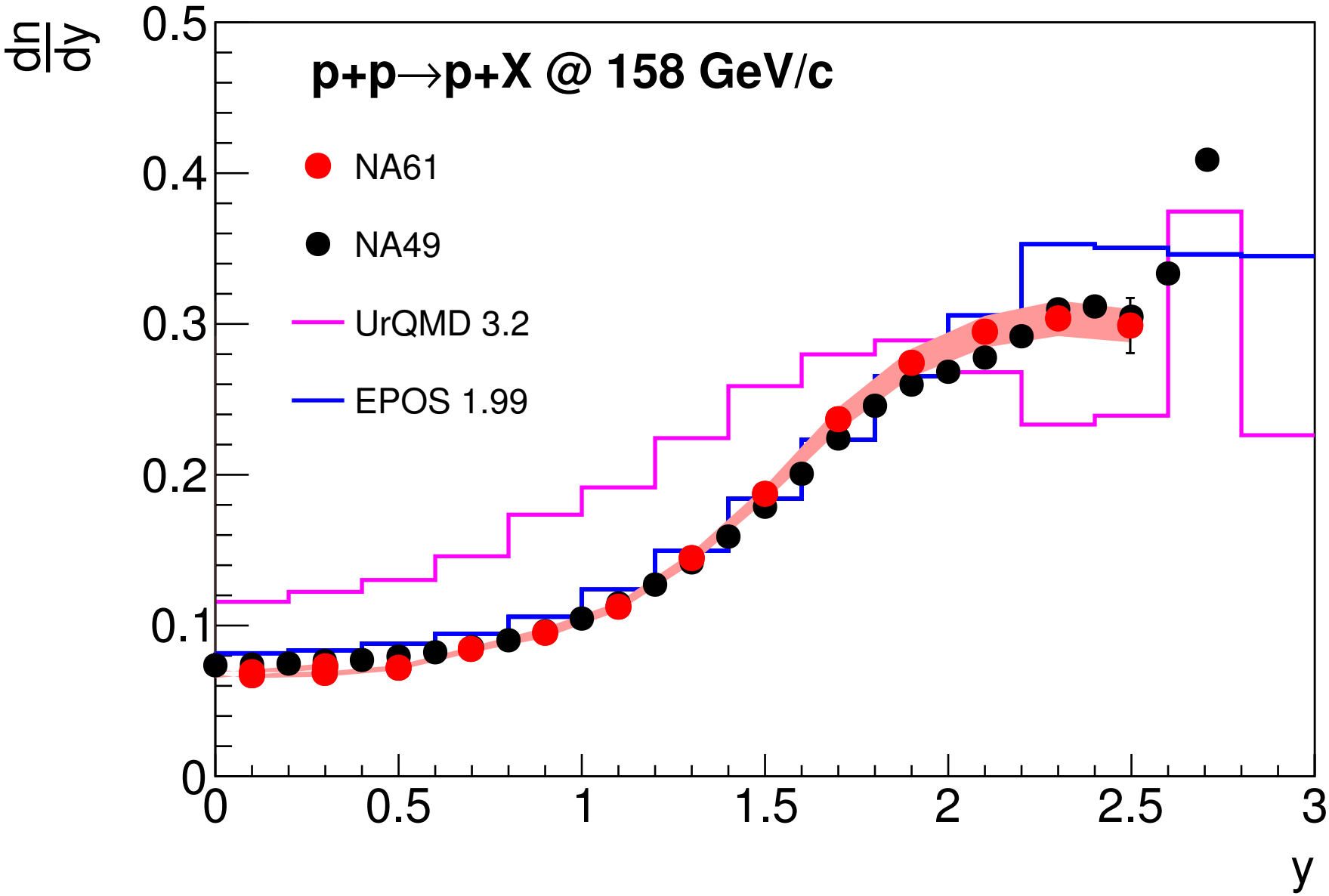
K, π, p: negative



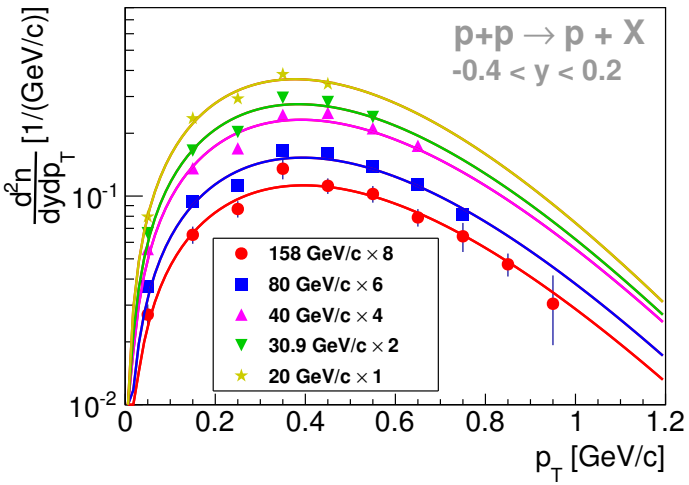


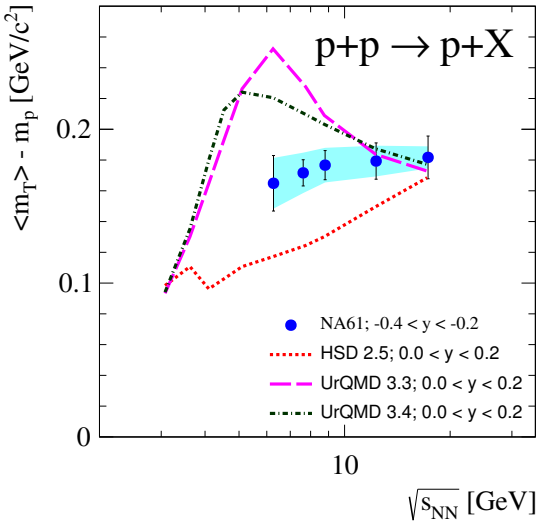


p+p: p dn/dy – data vs. models



p+p: p mean transverse mass





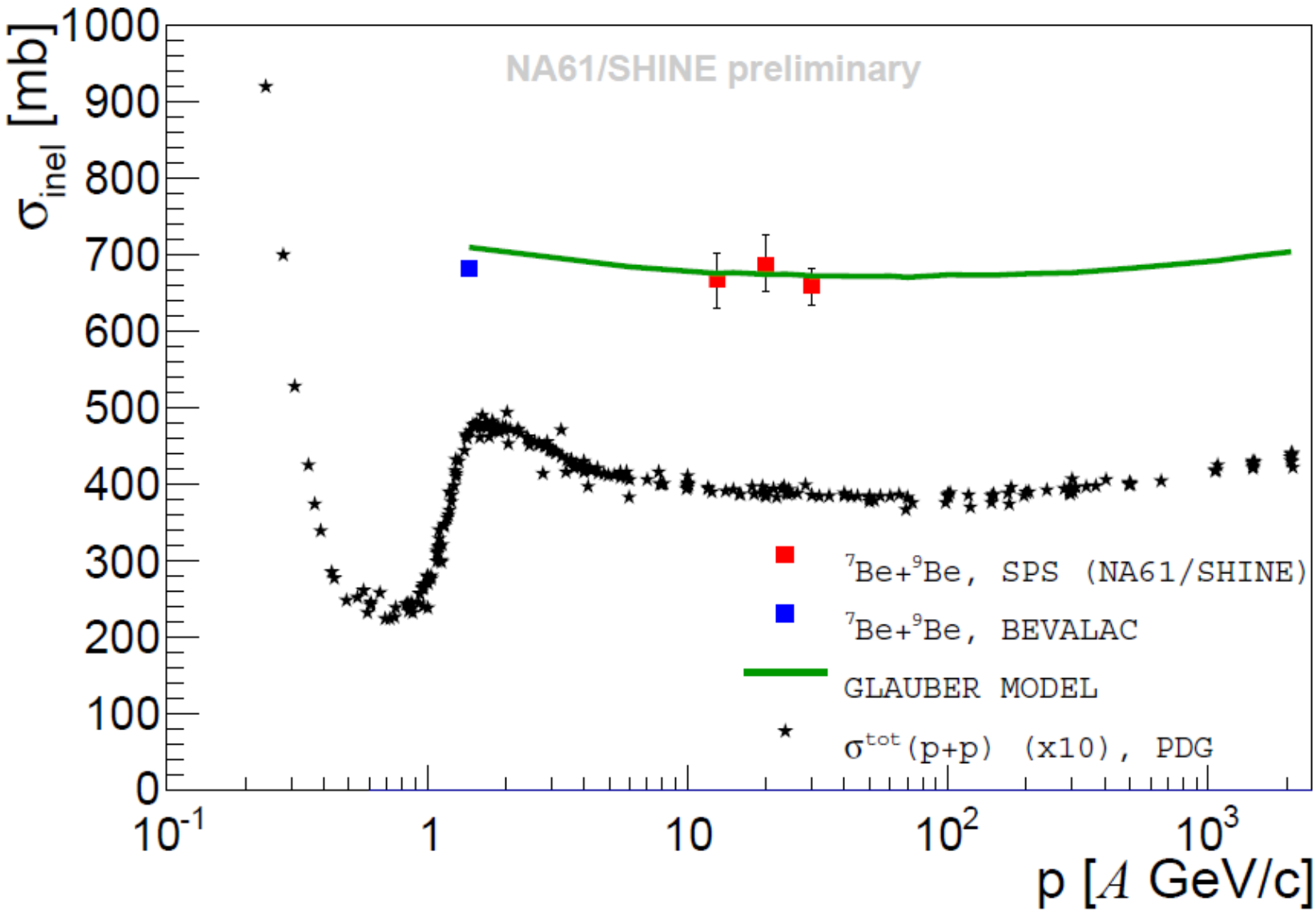
- $\langle m_T \rangle$ was calculated using fitted function:

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

- $\langle m_T \rangle$ of p produced in p+p interactions around mid-rapidity increase slowly with collision energy
- Neither UrQMD nor HSD describe this behaviour

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);

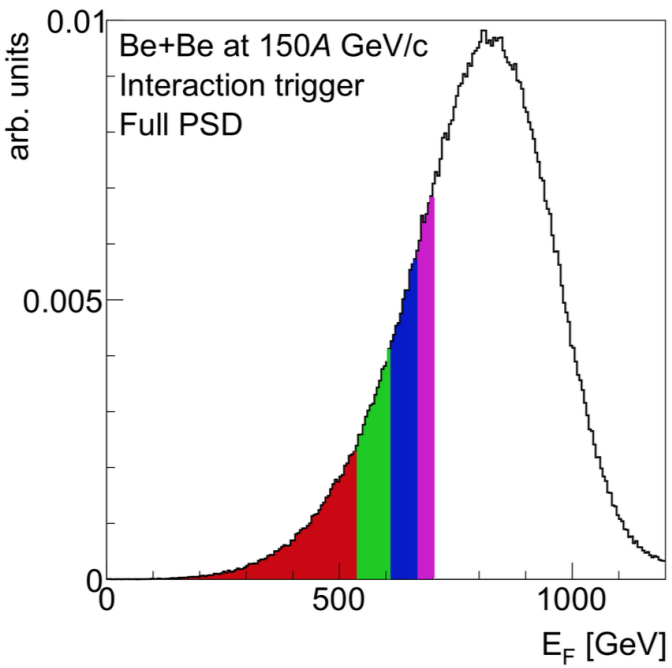
Be+Be: inelastic cross-section

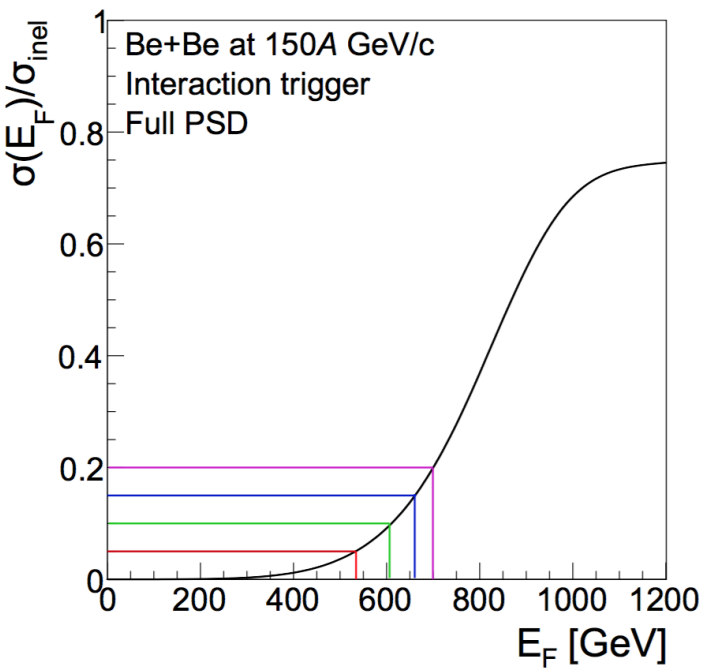


Bevalac point, Phys. Rev. Lett. 55 (1985) 2676. Glauber (GLISSANDO) Model, Comput.Phys.Commun. 180 (2009) 69.

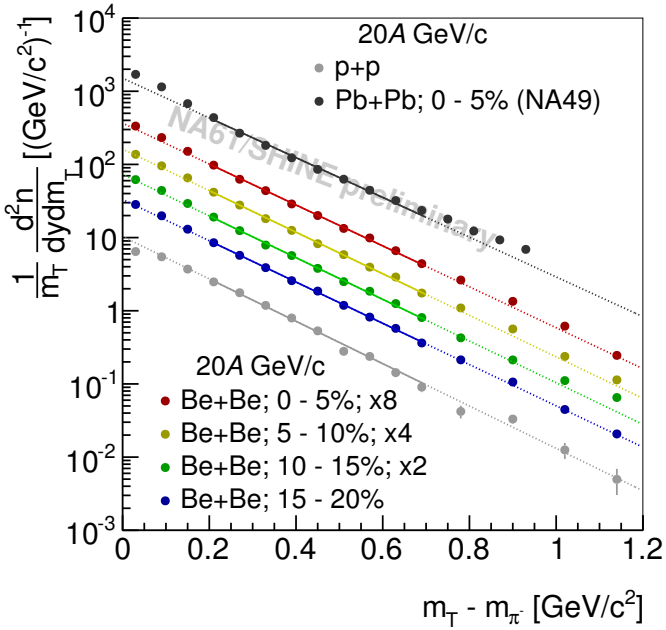
Be+Be: event selection based on forward energy

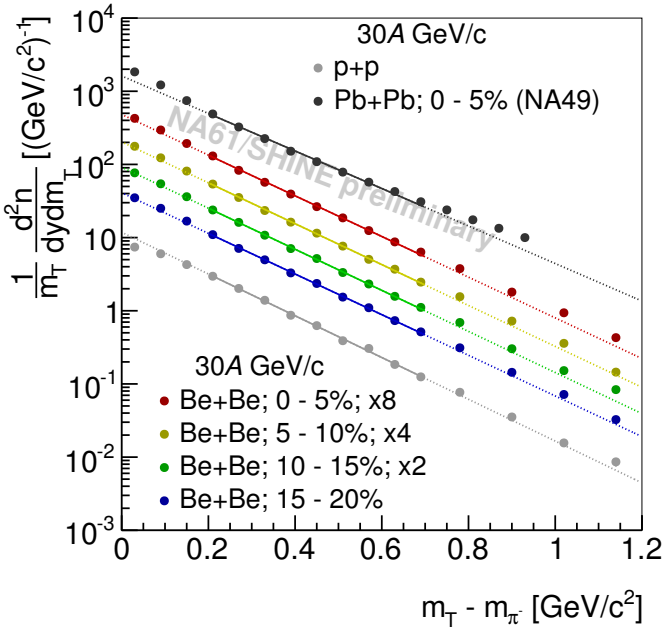
- Forward energy measured by PSD (mostly spectator energy) is used to group events in FE event classes

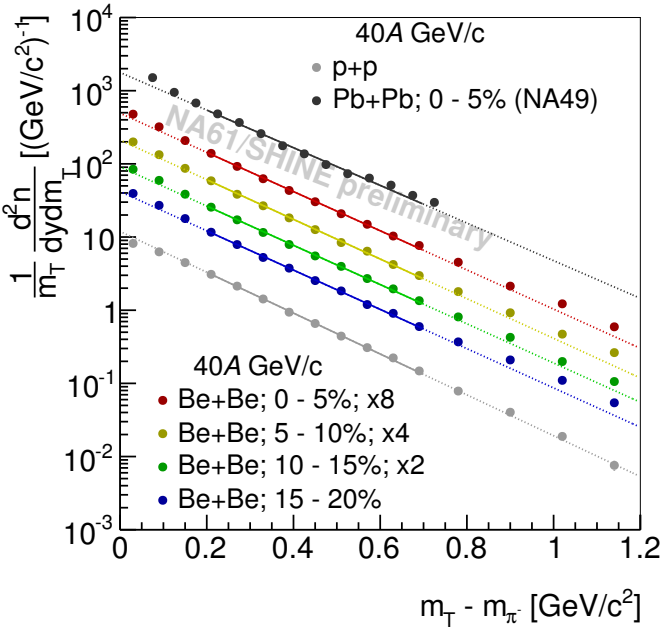


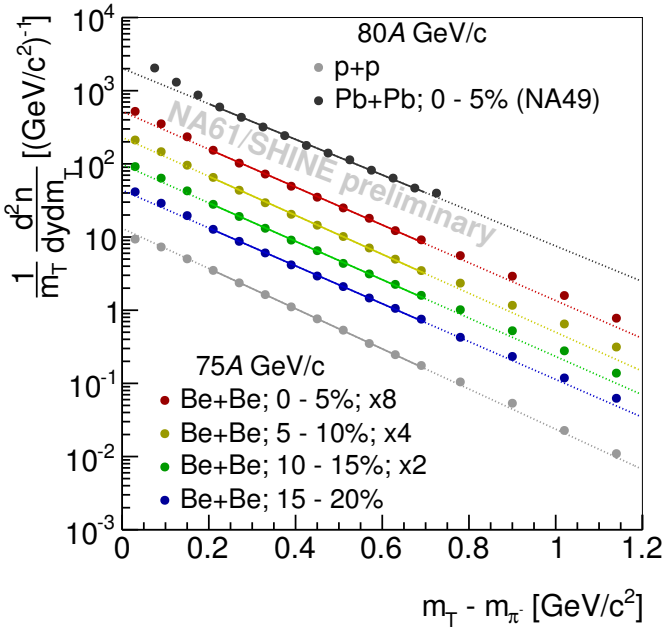


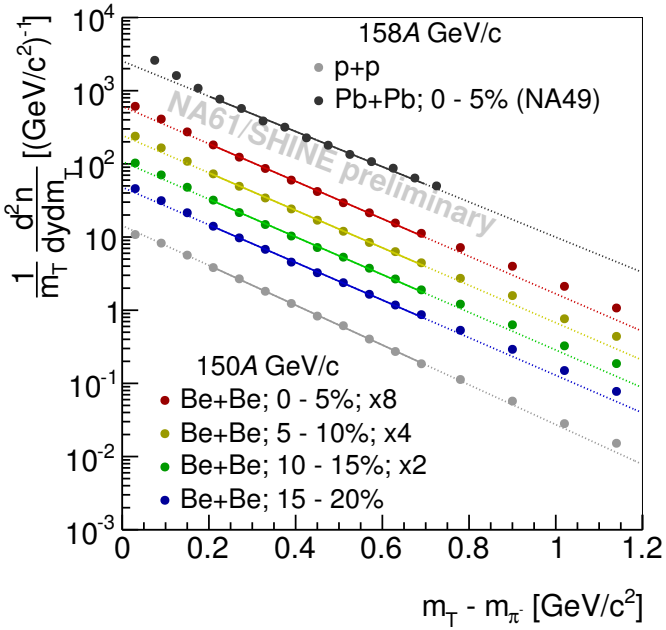
Be+Be: π^- transverse mass spectra



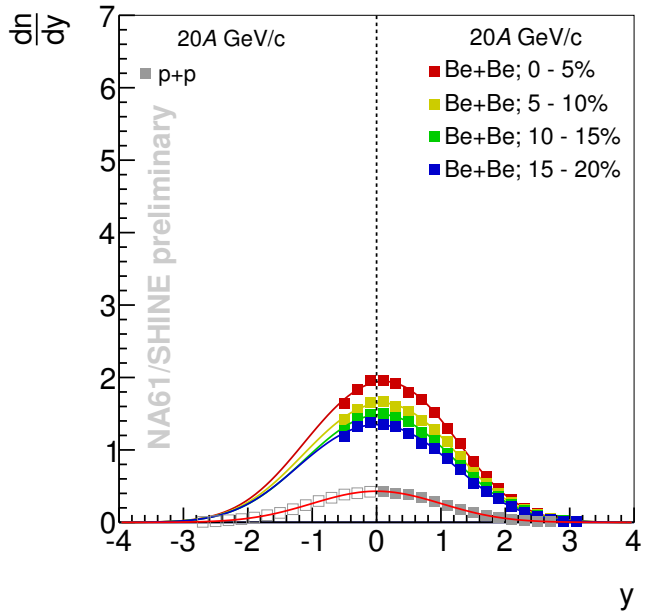


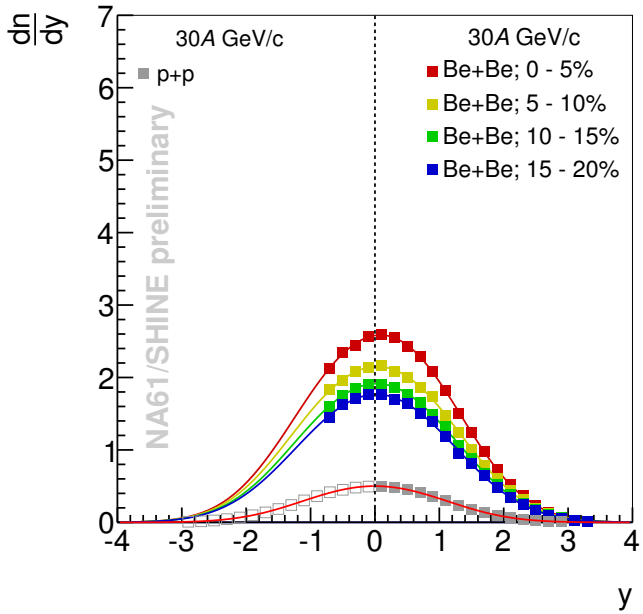


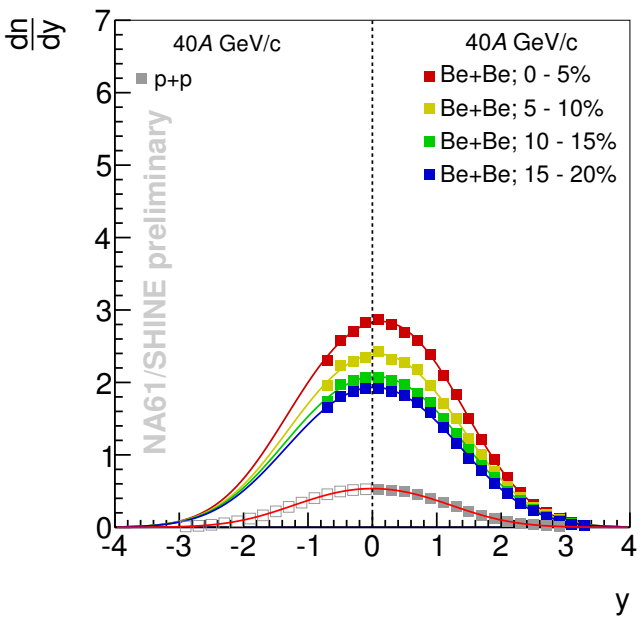


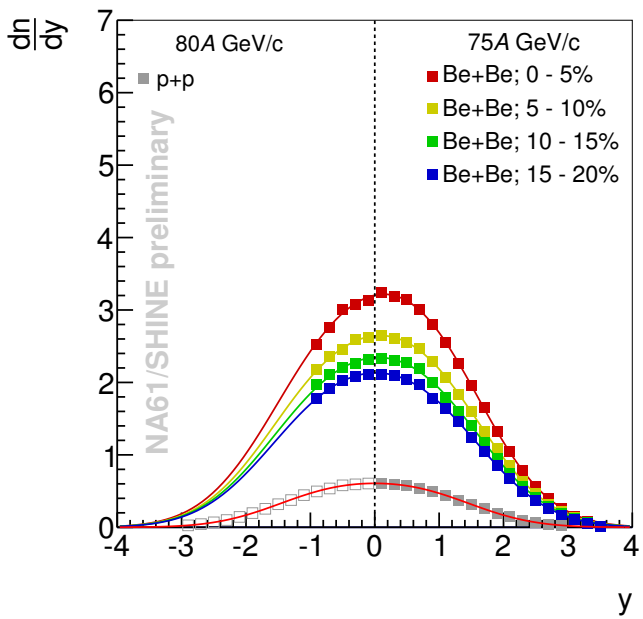


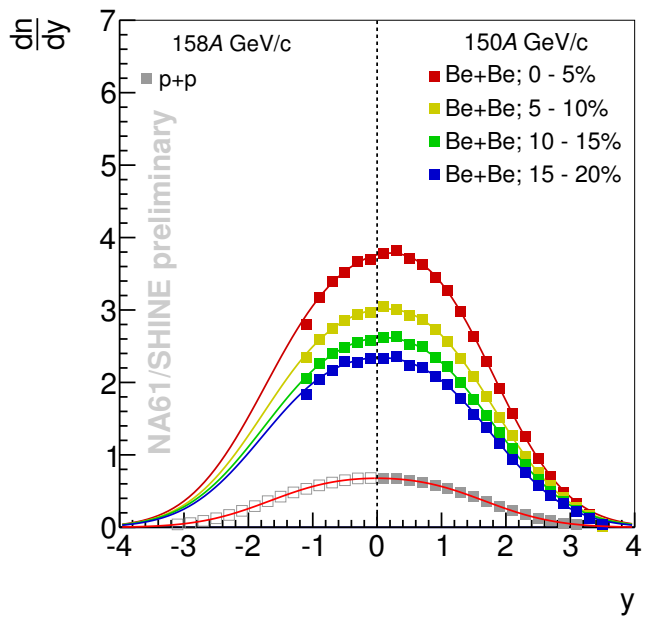
Be+Be: 5 energies, 4 event classes π^- dn/dy



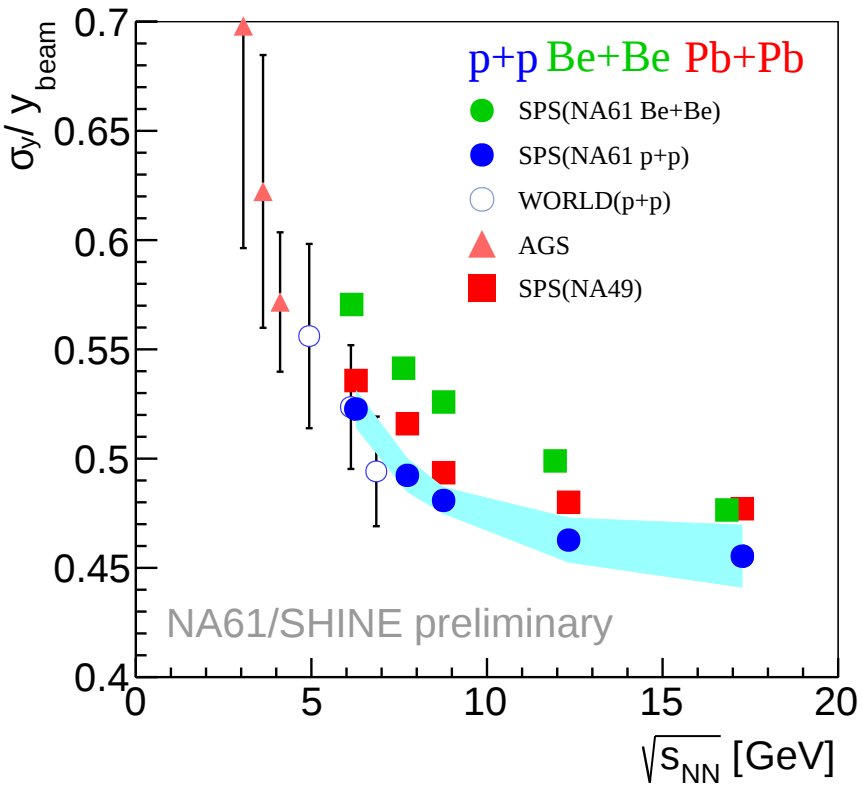








Be+Be: π^- rapidity distribution width



- σ_y calculated from fitted function (two symmetrically displaced Gaussians)
- Smooth, monotonic behaviour with energy
- Non-monotonic behaviour with the system size: $\frac{\sigma_y(p+p)}{y_{beam}} < \frac{\sigma_y(Pb+Pb)}{y_{beam}} < \frac{\sigma_y(Be+Be)}{y_{beam}}$

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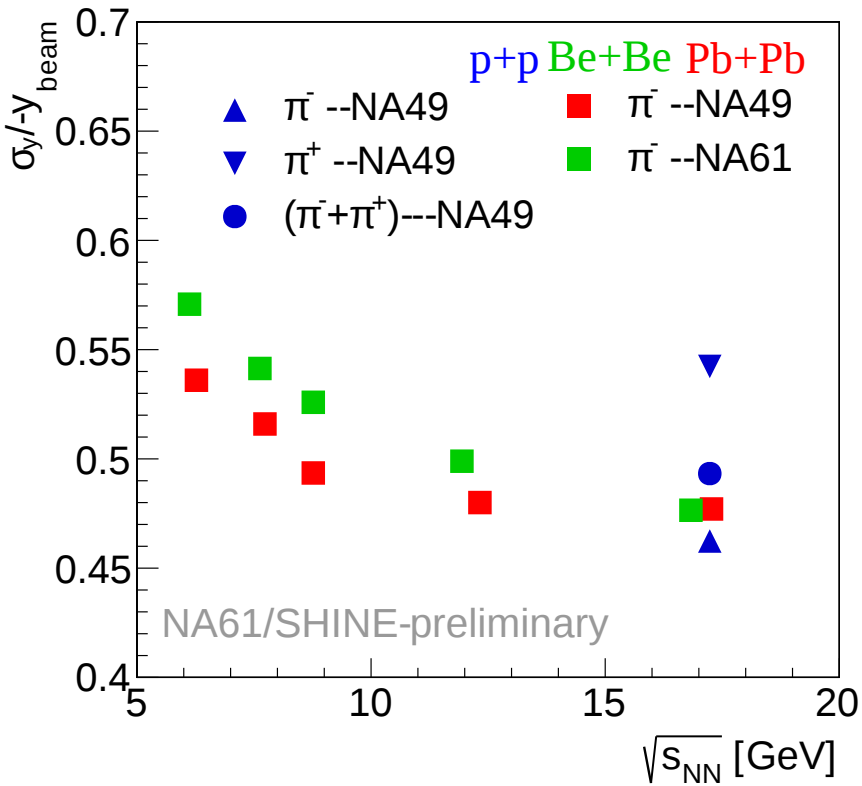
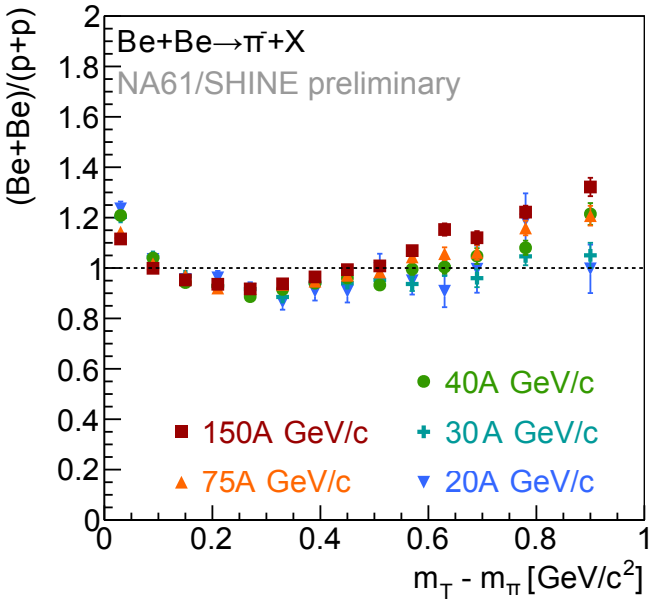
Be+Be: isospin asymmetry effect on π σ_y/y_{beam}

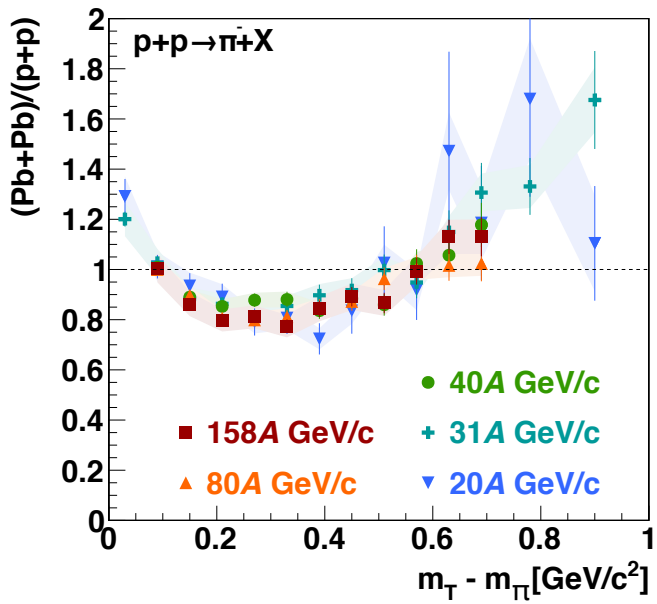
- The isospin asymmetry affects width of the π^- rapidity distribution in p+p and Pb+Pb
- ^{7}Be+^{9}Be is almost isospin symmetric
- In p+p collisions rapidity width of π^+ is larger than width of π^- distribution
- The width of the sum of π^+ and π^- distributions is in between



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

Be+Be: π^- transverse mass spectra comparison





^{7}Be+^{9}Be data for 0-15% FE event class. Pb+Pb data for 5% or 7.5% most central interactions

- From $m_T - m_{\pi^-} > 0.3 GeV/c^2$ the ratio increases with p_{beam}
- Up to $m_T - m_{\pi^-} < 0.3 GeV/c^2$ the ratio decreases with p_{beam}
- The beam momentum dependence of the ratio observed in ^{7}Be+^{9}Be is not visible in Pb+Pb collisions
- 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

p+p: summary

- p+p data is unexpectedly interesting
- Even in p+p the energy dependence of K^+/π^+ and in 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 present a challenge for models and should allow for their improvement

Be+Be: summary

- The π^- spectra from ^{7}Be+^{9}Be interactions at five beam momenta were shown
- Low momentum NA61/SHINE data together with the Bevalac measurements indicate a weak energy dependence of inelastic ^{7}Be+^{9}Be cross-section. The results agree with Glauber model
- Large acceptance of NA61/SHINE allows to study the asymmetry of rapidity distribution
- $\langle \pi^- \rangle$ was calculated for five beam momenta and four FE event classes
- The isospin effects play a large role in p+p data, the effects will be studied in detail to compare p+p with Be+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 seems to increase with collision energy

Collaboration list

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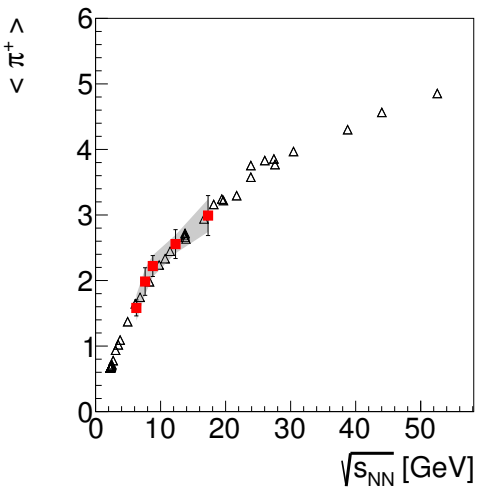
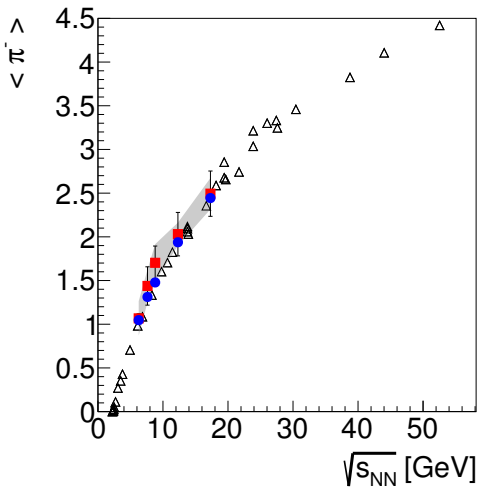
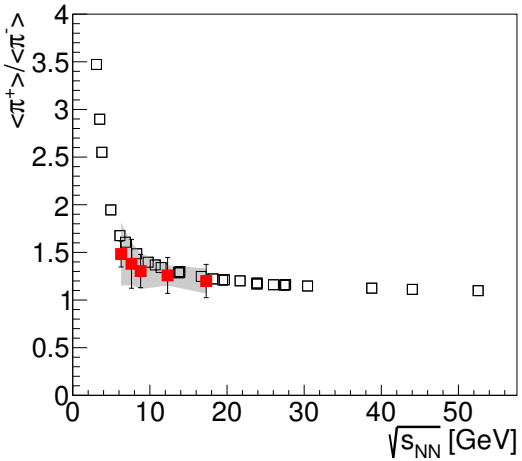
Karlsruhe Institute of Technology, Germany
Fachhochschule Frankfurt, Germany
Institut für Kernphysik, Goethe-Universität, Germany
Nuclear and Particle Physics Division, University of Athens, Greece
Wigner RCP, Hungary
Institute for Particle and Nuclear Studies (KEK), Japan
University of Bergen, Norway
Institute of Physics, Jan Kochanowski University, Poland
National Center for Nuclear Research, Poland
Institute of Physics, Jagiellonian University, Poland
Institute of Physics, University of Silesia, Poland
Faculty of Physics, University of Warsaw, Poland
Department of Physics and Astronomy, University of Wroclaw, Poland
Faculty of Physics, Warsaw University of Technology, Poland
Institute for Nuclear Research, Russia
Joint Institute for Nuclear Research, Russia
St. Petersburg State University, Russia
National Research Nuclear University, Russia
University of Belgrade, Serbia
ETH Zürich, Switzerland
University of Bern, Switzerland
University of Geneva, Switzerland
University of Colorado Boulder, USA
Los Alamos National Laboratory, USA
Department of Physics and Astronomy, University of Pittsburgh, USA
Fermilab, Neutrino Division, USA

Backup

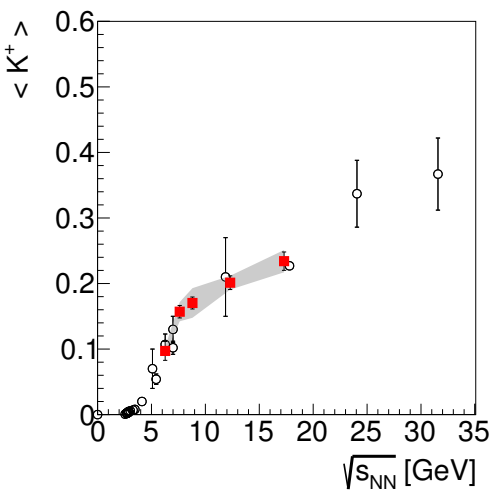
p+p: π event multiplicity & 4π ratio

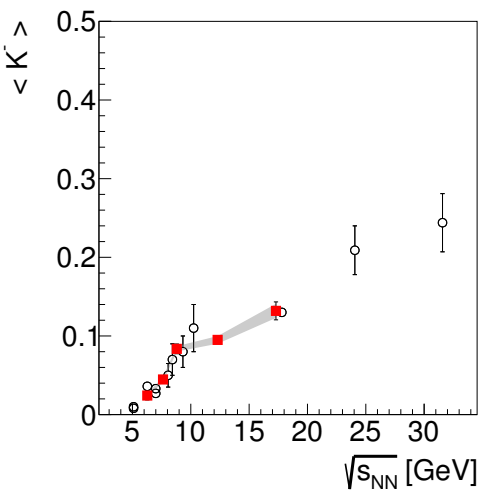


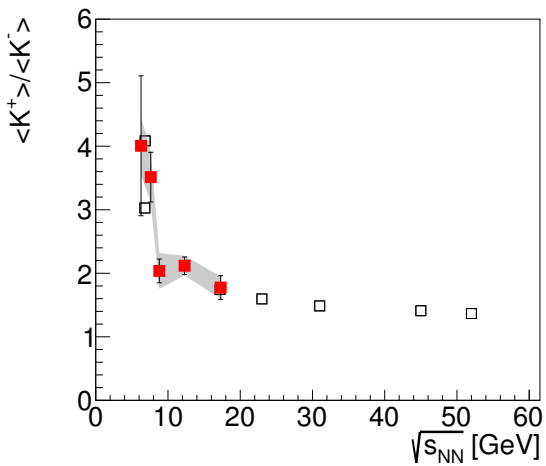




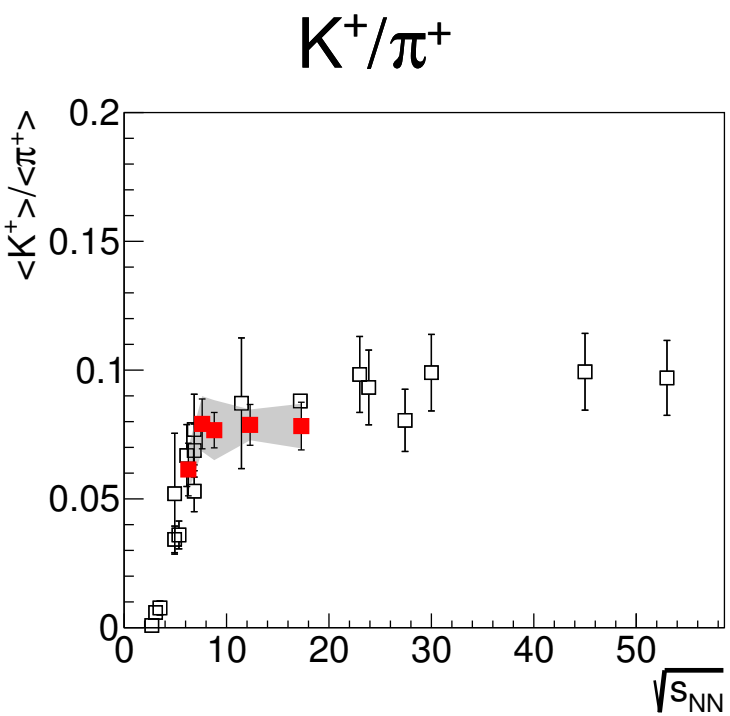
p+p: K event multiplicity & 4π ratio

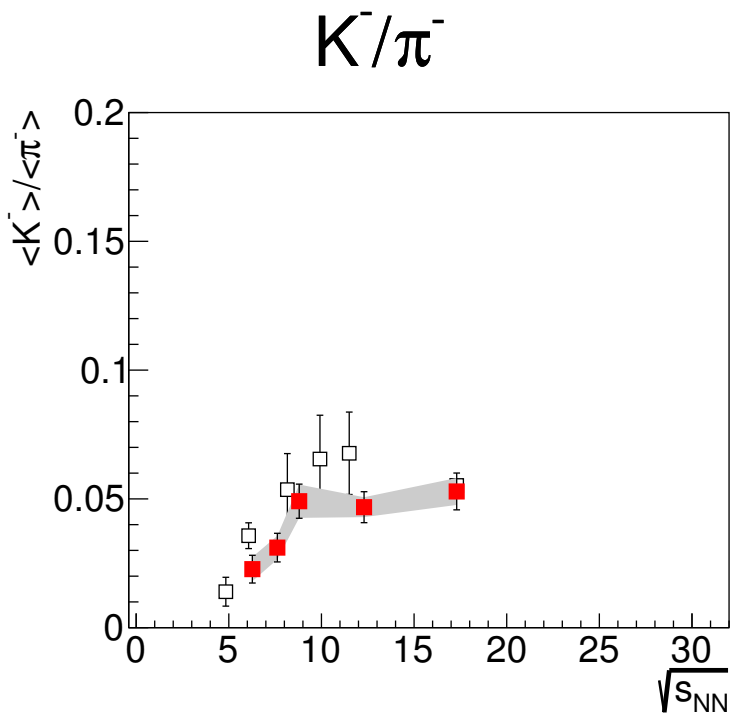




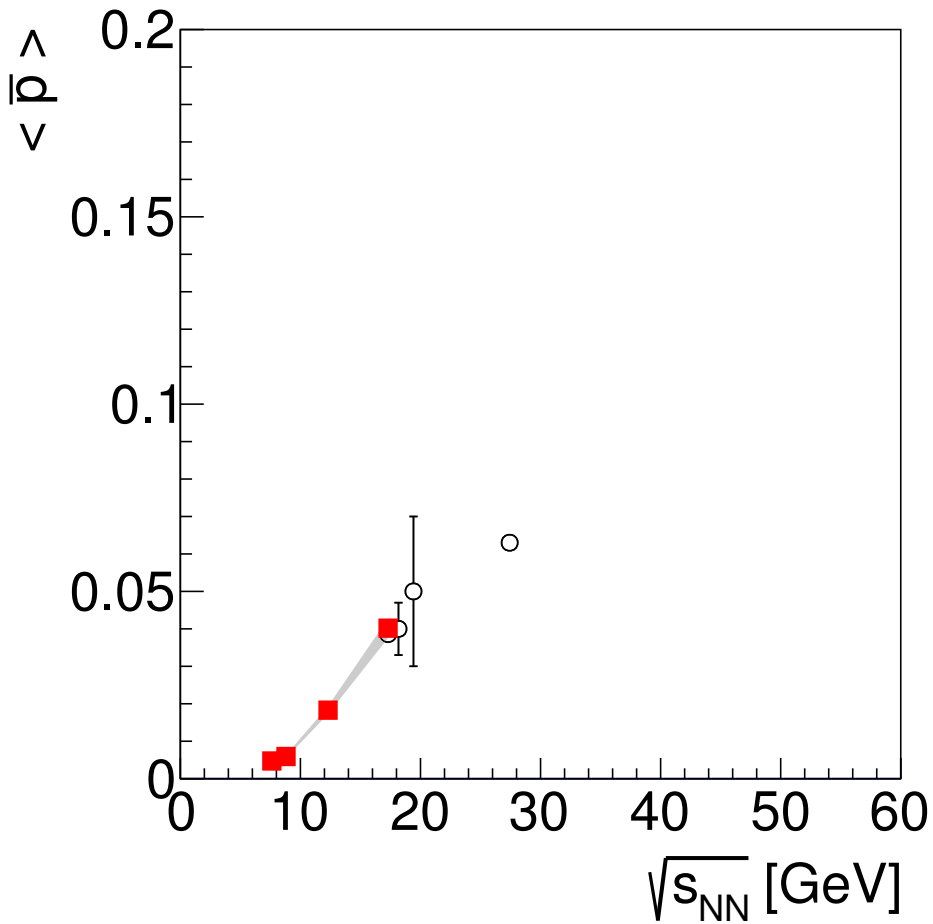


p+p: K/π 4π ratio

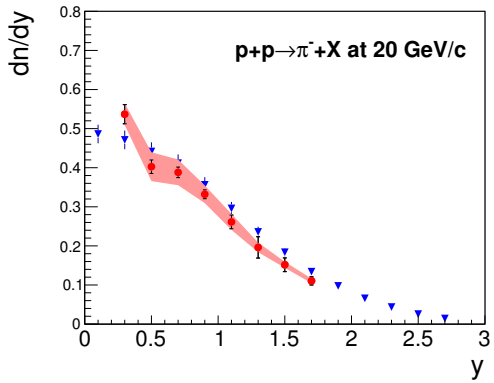


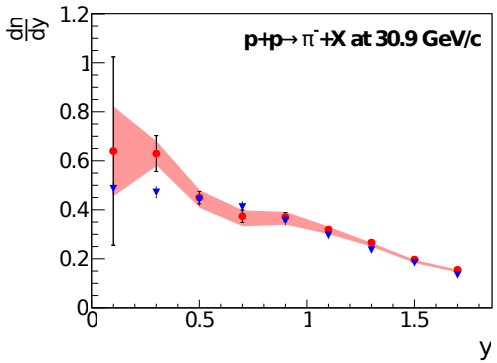


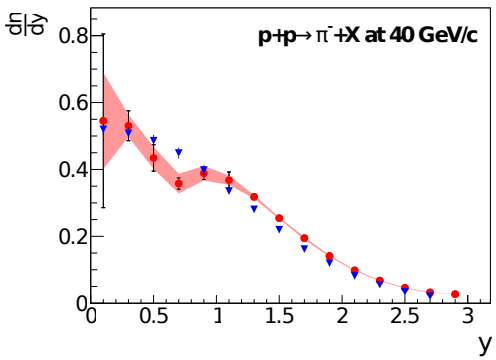
p+p: $\bar{p}$ event multiplicity

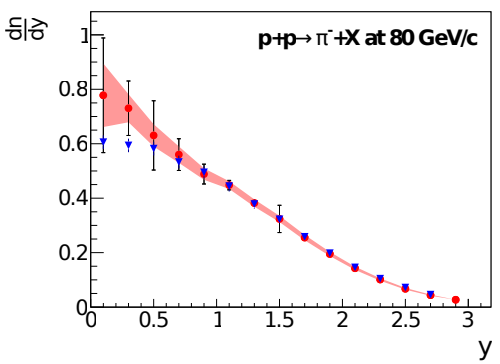


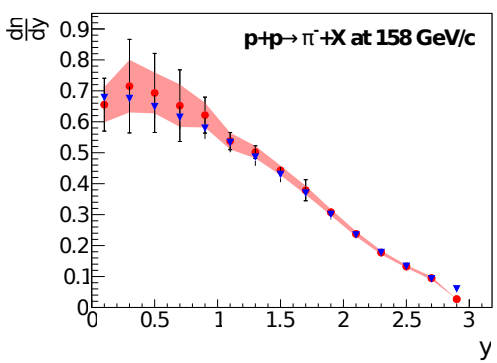
p+p: dn/dy – comparison with h^-









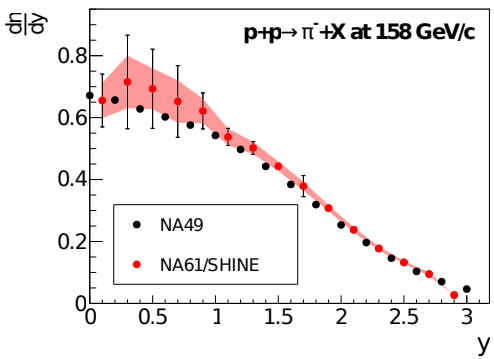


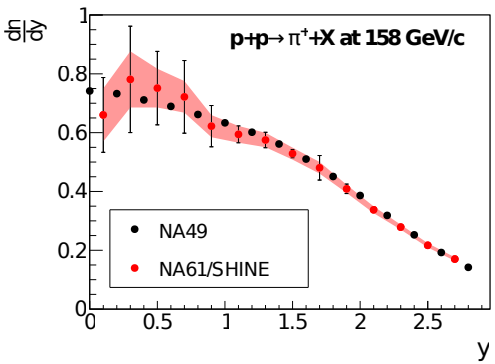
NA61/SHINE:

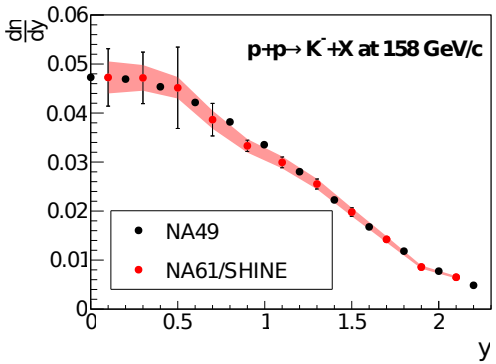
h^- method

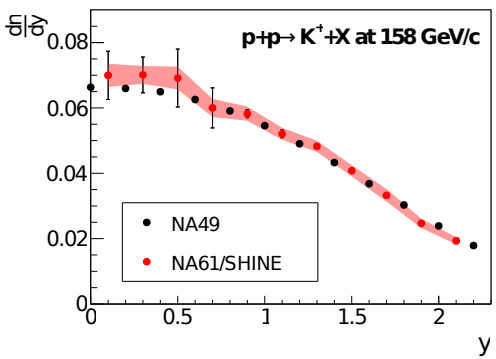
dE/dx and tof-dE/dx methods

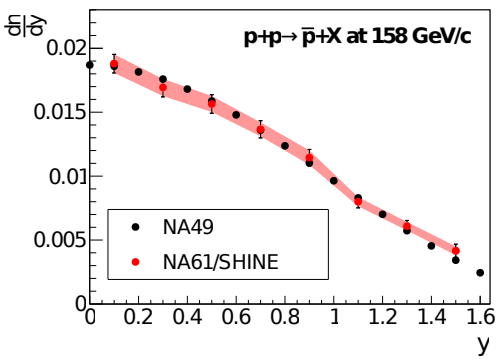
p+p: dn/dy – comparison to NA49 p+p at 158 GeV

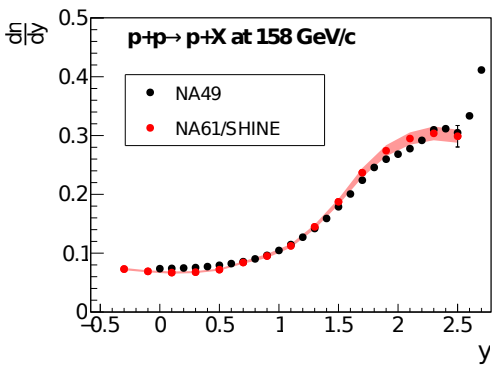




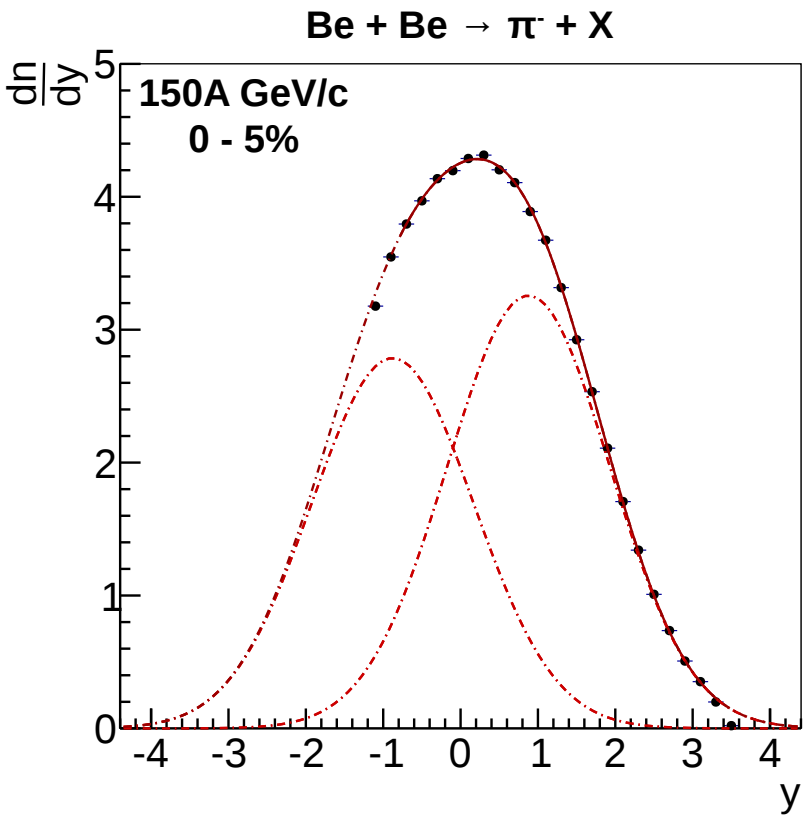


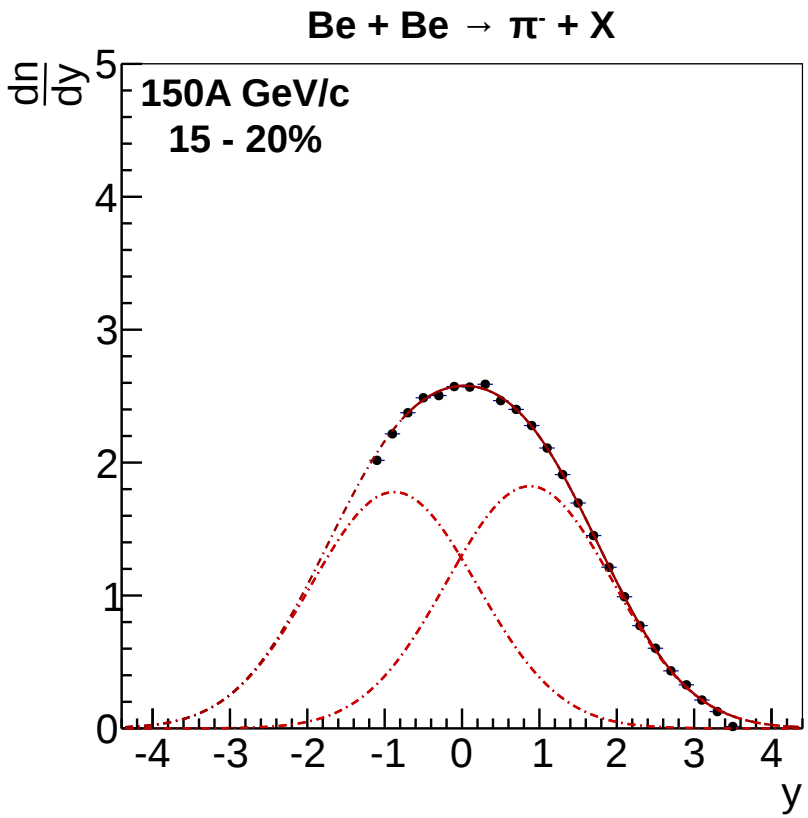






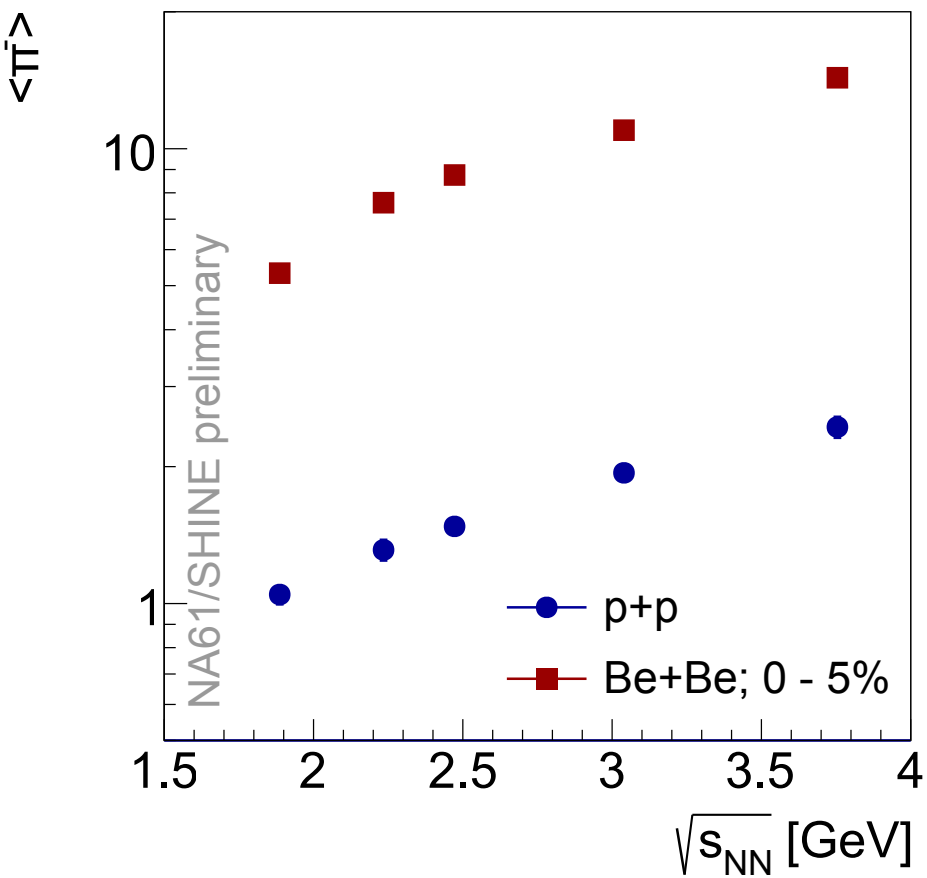
Be+Be: asymmetry in rapidity spectra



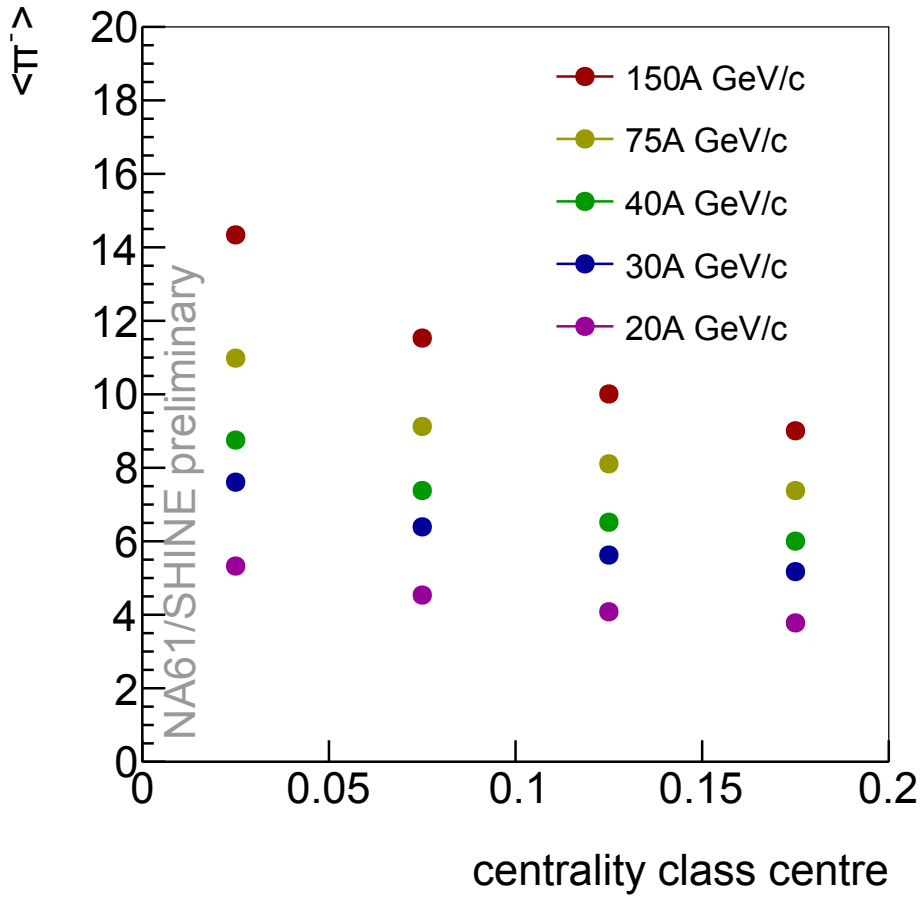


Be+Be: mean π^- multiplicity

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



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



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