Recent results from NA61/SHINE

from the strong interaction programme

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SPbSU, Laboratory of Ultra-High Energy Physics

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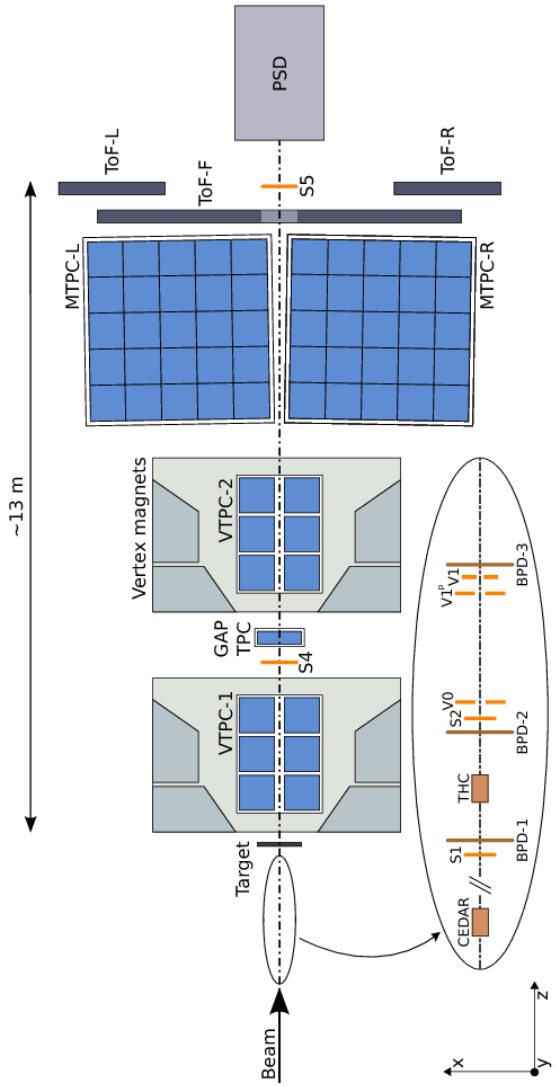
NA61/SHINE experiment

- Large acceptance hadron spectrometer located at the CERN SPS
- High momentum resolution:
  $\frac{\sigma(p)}{p^2} \approx 10^{-4}$ (GeV/c)$^{-1}$
  (at full $B = 9$ T m)
- ToF walls resolution: σ(tof)$\approx$ 60 ps
- Good particle identification:
  $\frac{\sigma(dE/dx)}{dE/dx} \approx 0.04$, $\sigma(m_{inv}) \approx 5$ MeV

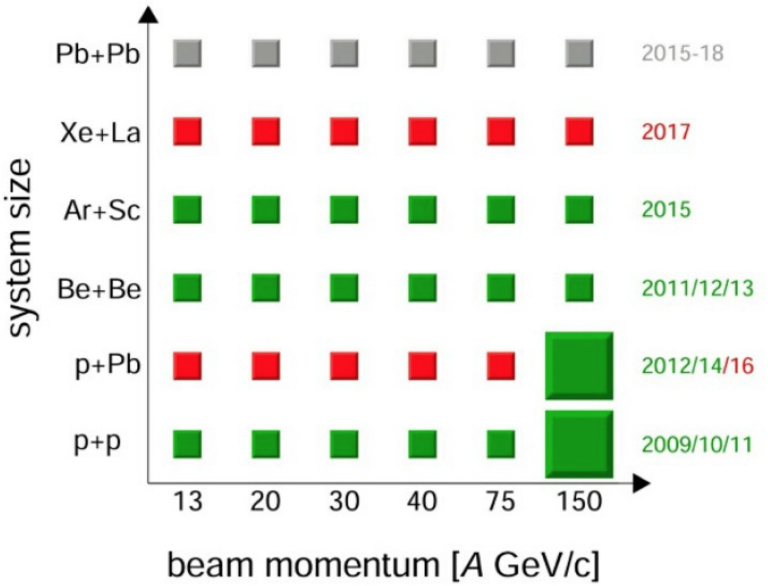


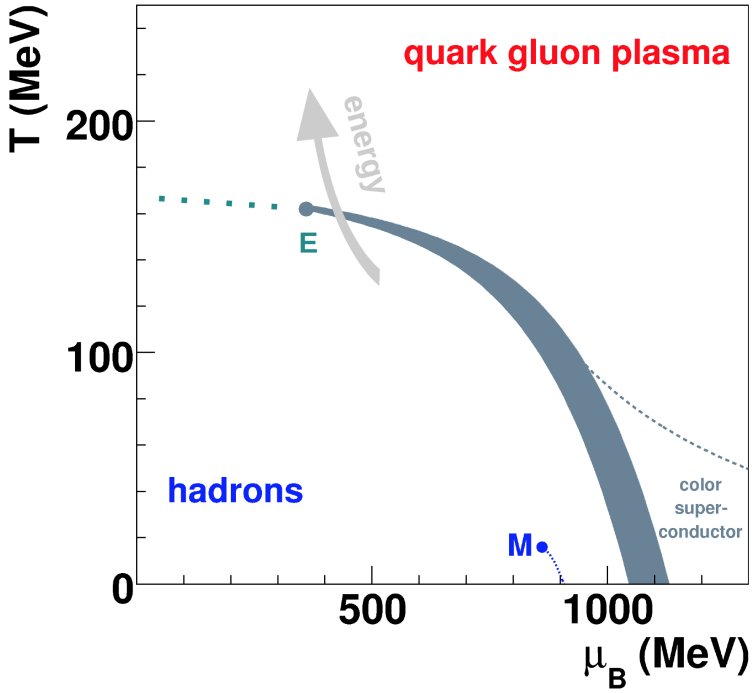
Proposal: CERN-SPSC-2006-034, SPSC-P-330 (November 3, 2006)

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

Motivation of the NA61/SHINE strong interaction programme

- Study of the onset of deconfinement
- Search for the critical point of strongly interacting matter

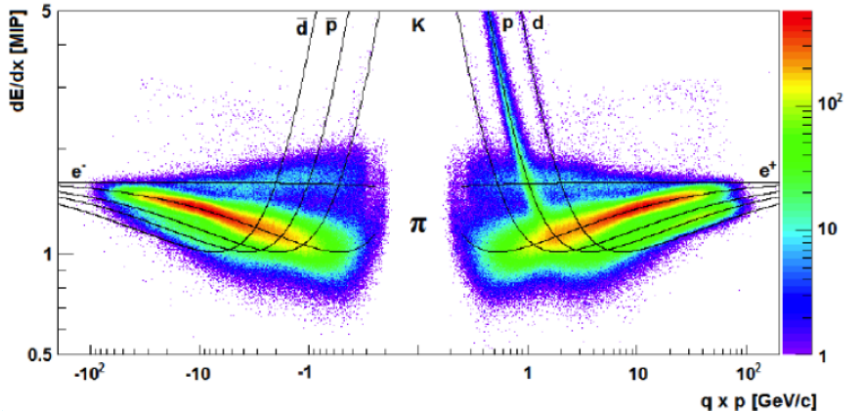




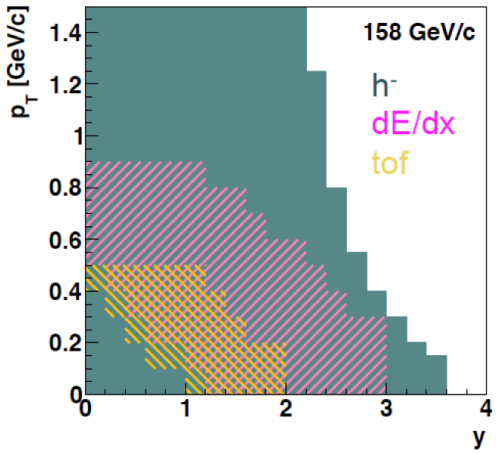
p+p and ^{7}Be+^{9}Be results to be shown in this presentation

Analysis

- Analyzed data:
  - inelastic p+p at $\sqrt{s} = 6.3, 7.7, 8.7, 12.3, 17.3$ GeV
  - centrality selected ^{7}Be+^{9}Be at $\sqrt{s_{NN}} = 5.11, 6.12, 7.74, 8.76, 11.94, 16.83$ GeV
- The results on kinematic spectra obtained via h^- analysis, dE/dx, $tof - dE/dx$ and V^0 identifications to be presented
- The results are corrected for particles from weak decays (feed-down), secondary interactions and detector effects using Monte-Carlo models
- The results are corrected for events with out of target interactions using events recorded with target removed



p+p 80 GeV/c



π^- acceptances from different methods

p+p results

p_T vs. rapidity spectra examples: energy dependence

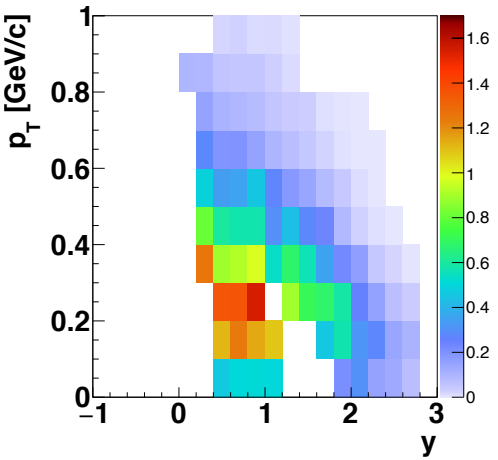
p+p

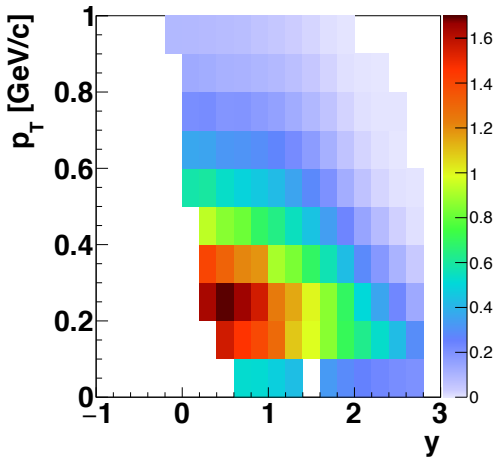
20 GeV/c

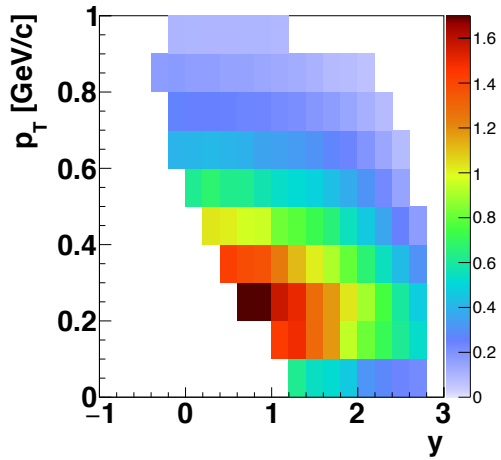
40 GeV/c

158 GeV/c

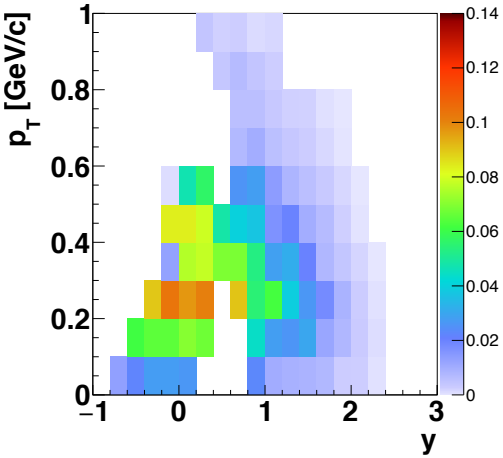
π^+

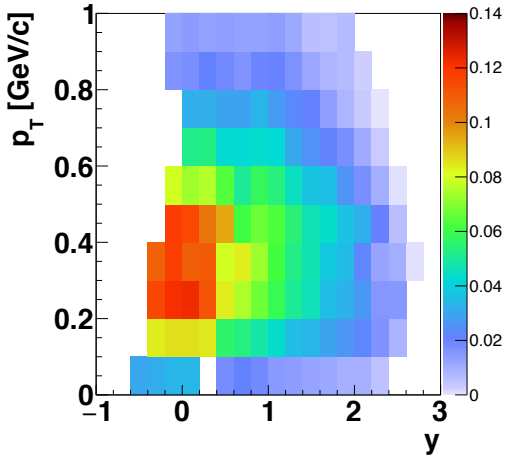


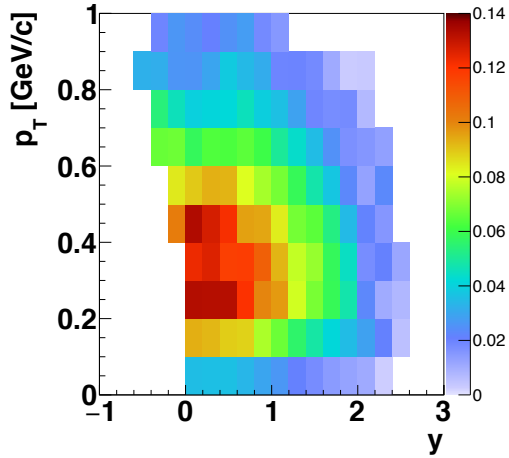




K^+

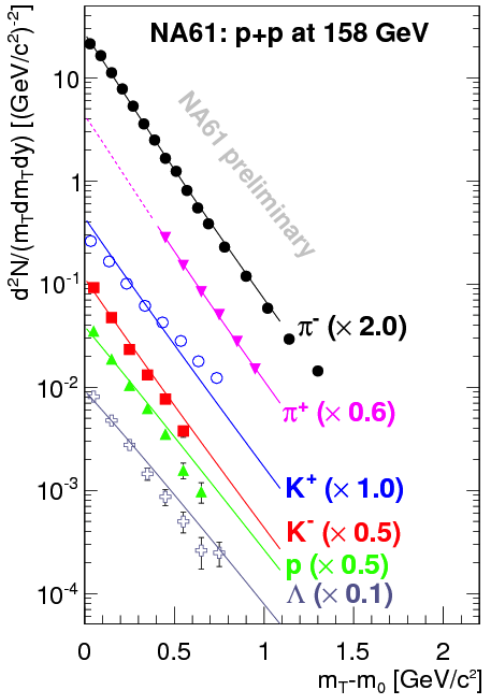


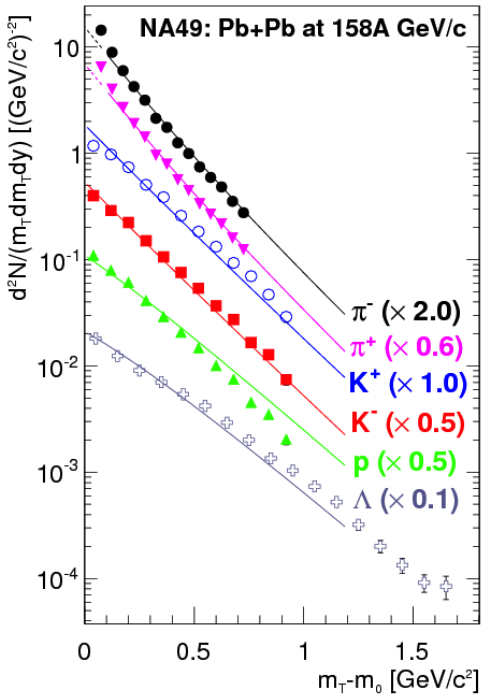




m_T spectra at mid-rapidity

p+p *vs.* $0-5\%$ central Pb+Pb at 158A GeV/c





In p+p $\frac{dN}{m_T dm_T} \sim e^{-m_T/T}$ with inverse slope parameter $\sim$ 150 MeV as expected from the Hagedorn statistical bootstrap model

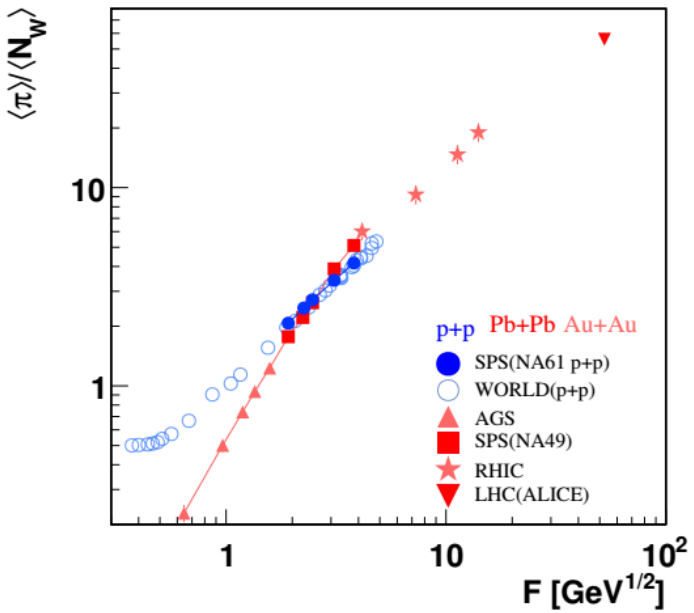
In central Pb+Pb the exponential dependence is modified (possibly due to collective transverse flow)

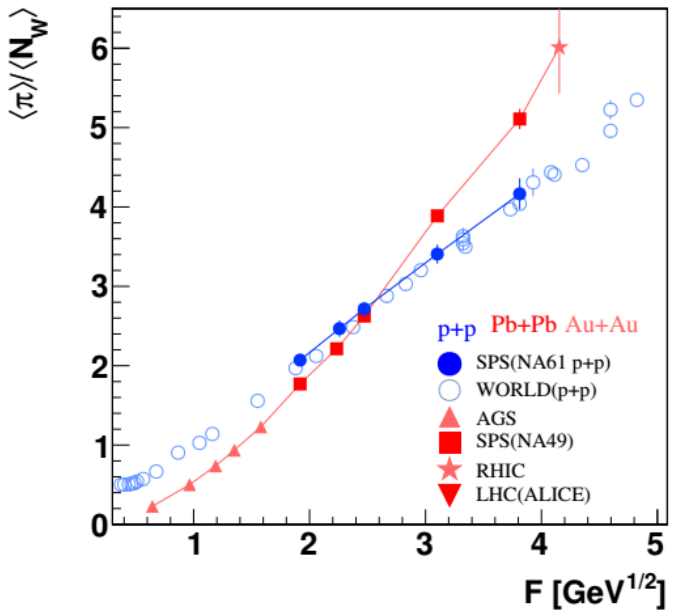
S. Pulawski [NA61/SHINE Collaboration], PoS(CPOD2013)056

π multiplicity - kink

p+p vs. Au+Au vs. Pb+Pb

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





Wounded Nucleon Model (Bialas et al, NPB 111, 461 (1976)): $\frac{\langle\pi\rangle}{\langle N_W\rangle}\,(AA) = \frac{\langle\pi\rangle}{2}\,(pp)$

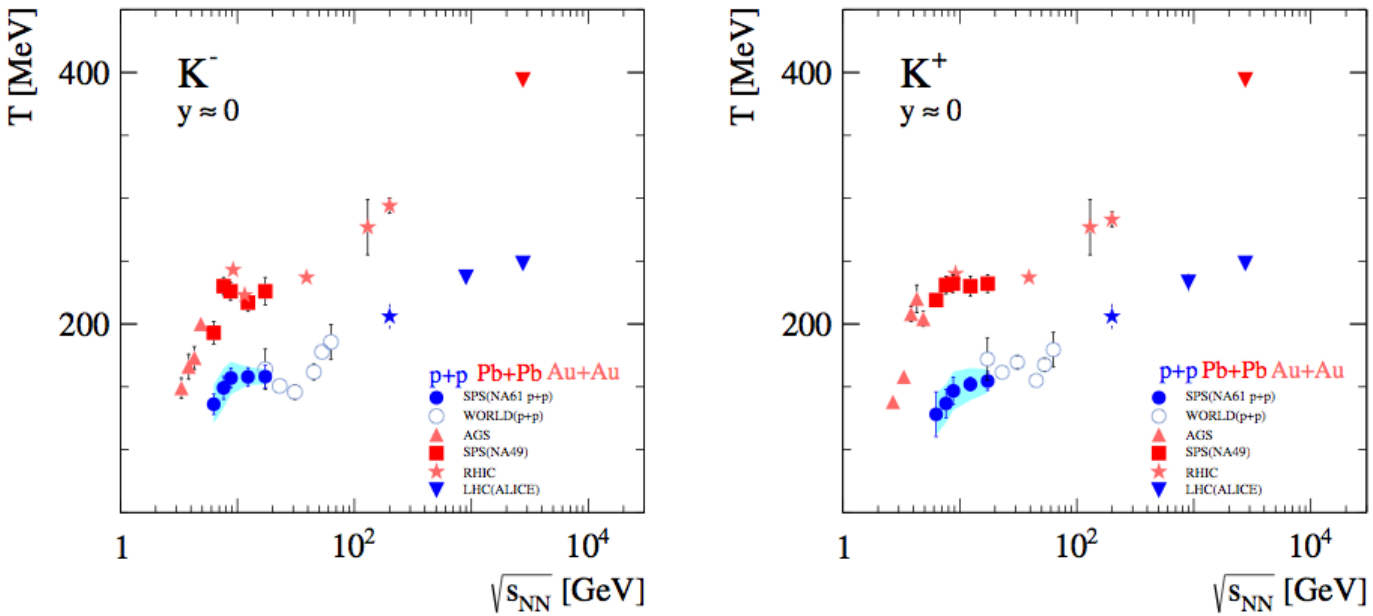
Data: $\frac{\langle\pi\rangle}{\langle N_W\rangle}\,(AA) > \frac{\langle\pi\rangle}{2}\,(pp)$ at $F > 2.5$ GeV$^{1/2}$

Data: $\frac{\langle\pi\rangle}{\langle N_W\rangle}\,(AA) < \frac{\langle\pi\rangle}{2}\,(pp)$ at $F < 2.5$ GeV$^{1/2}$

EPJC74:2794; PLB 726, 610 (2013); PRL 109, 252301 (2012)

K inverse slope parameter T - step

p+p vs. Au+Au vs. Pb+Pb



The NA61/SHINE results from inelastic p+p collisions exhibit rapid changes like observed in central Pb+Pb interactions

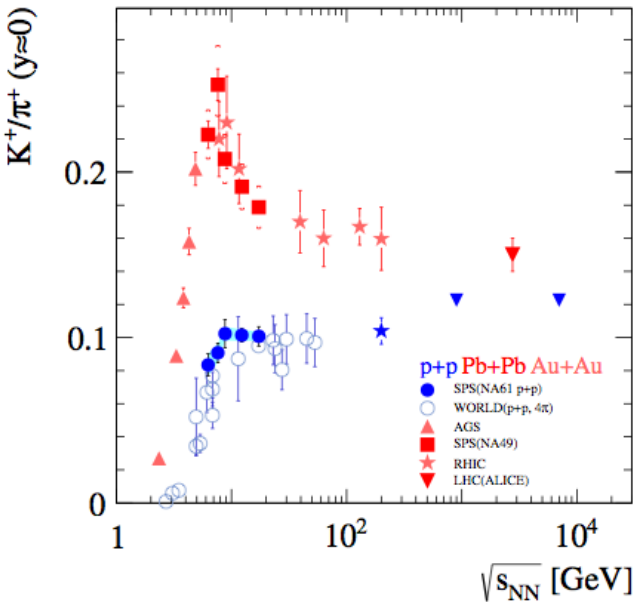
Do we see onset of deconfinement in p+p?

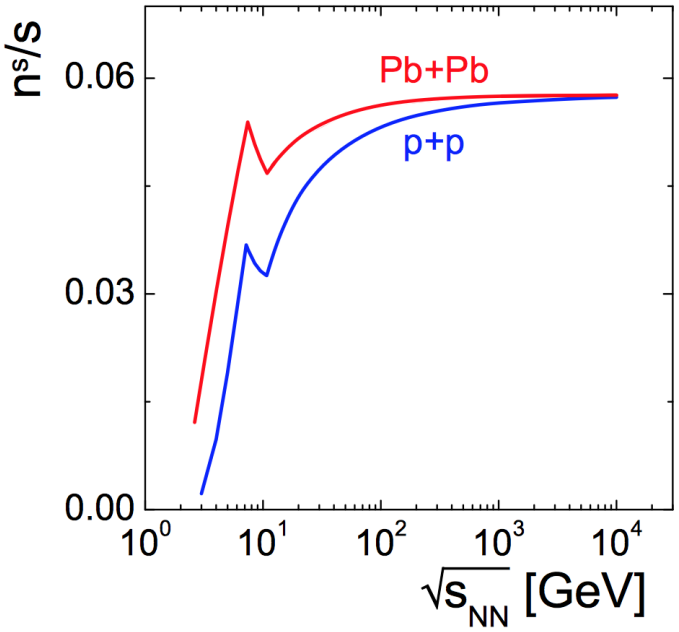
New p+p data for 350 GeV/c (25.66 GeV) to be obtained this autumn!

NA61/SHINE: CERN-SPSC-2014-031 ; SPSC-SR-145
PRC 69, 044903 (2004); PRC 79, 034909 (2009); PLB 736, 196 (2014); EPJC 71, 1655 (2011)

K/π - horn

p+p vs. Au+Au vs. Pb+Pb





arXiv:1502.05650

The NA61/SHINE results from inelastic p+p collisions exhibit rapid changes like observed in central Pb+Pb interactions

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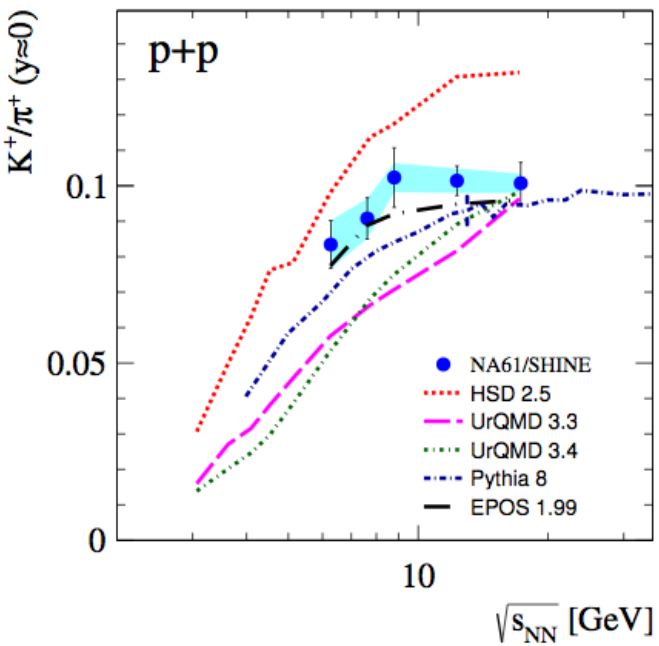
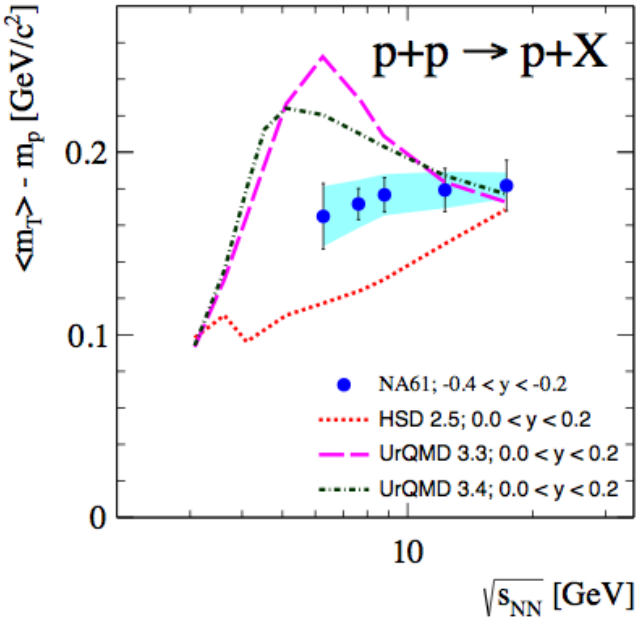
NA61/SHINE: 2014 CERN-SPSC-2014-031 ; SPSC-SR-145
ZP C65, 215 (1995); ZP C71, 55 (1996); PRC 72,014908 (2005); EPJC 71, 1655 (2011), PRL 109, 252301 (2012)

Comparison with models: K^+/π^+ and $\langle m_T \rangle - m_p$ for protons

p+p





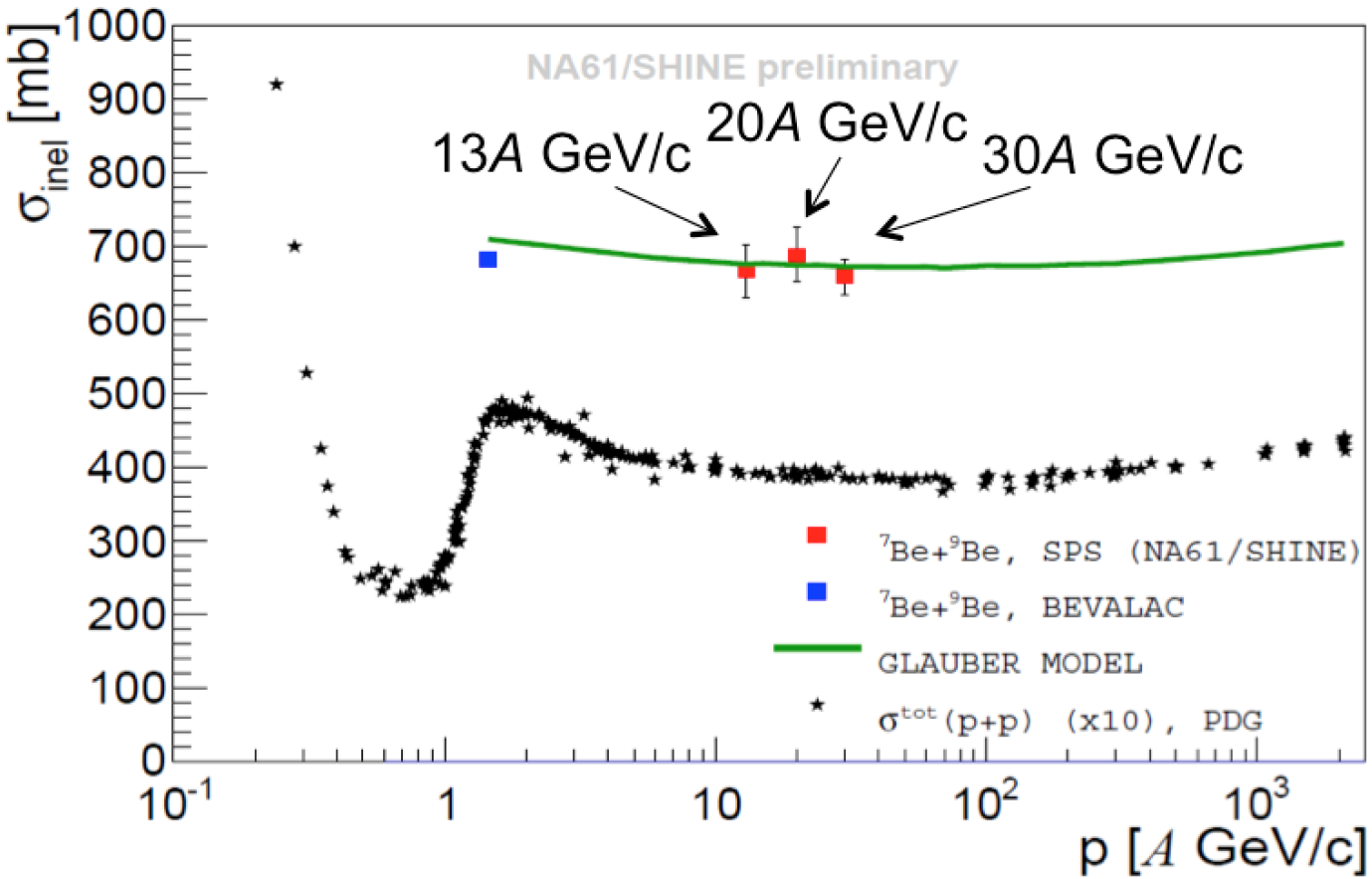
High precision NA61/SHINE data challenge Monte-Carlo models

NA61/SHINE: 2014 CERN-SPSC-2014-031 ; SPSC-SR-145
Vovchenko et al., PRC 90, 024916 (2014), and private communication; Gavin Salam private communication; Prog. Part. Nucl. Phys. 41 (1998), J. Phys. G: Nucl. Part. Phys. 25 (1999); NPA 602, 449 (1996), NPA 644, 107 (1998), Phys. Rept. 308, 65 (1999); Nucl.Phys.Proc.Suppl.196,2009; arXiv:1410.3012

^{7}Be+^{9}Be results

Inelastic cross section

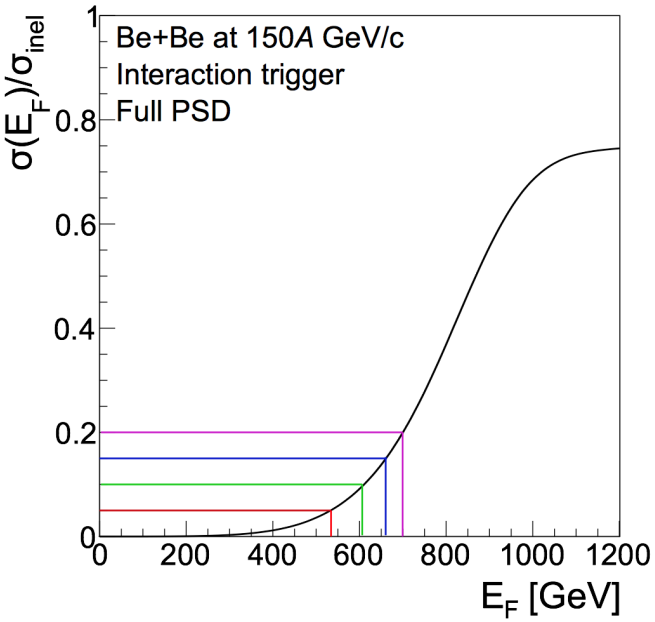
^{7}Be+^{9}Be

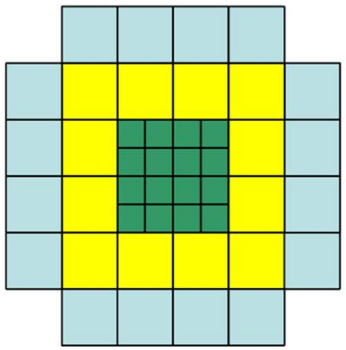


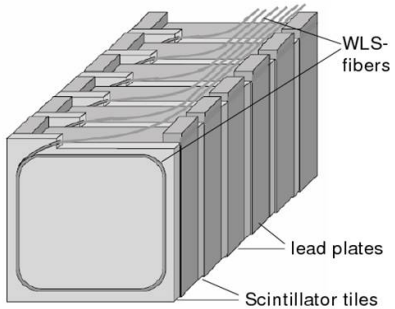
NA61 measurements together with 1A GeV/c Bevalac data established energy dependence of the inelastic cross section

PSD detector. Centrality determination.

PSD (Projectile Spectator Detector) is located on the beam axis and measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus



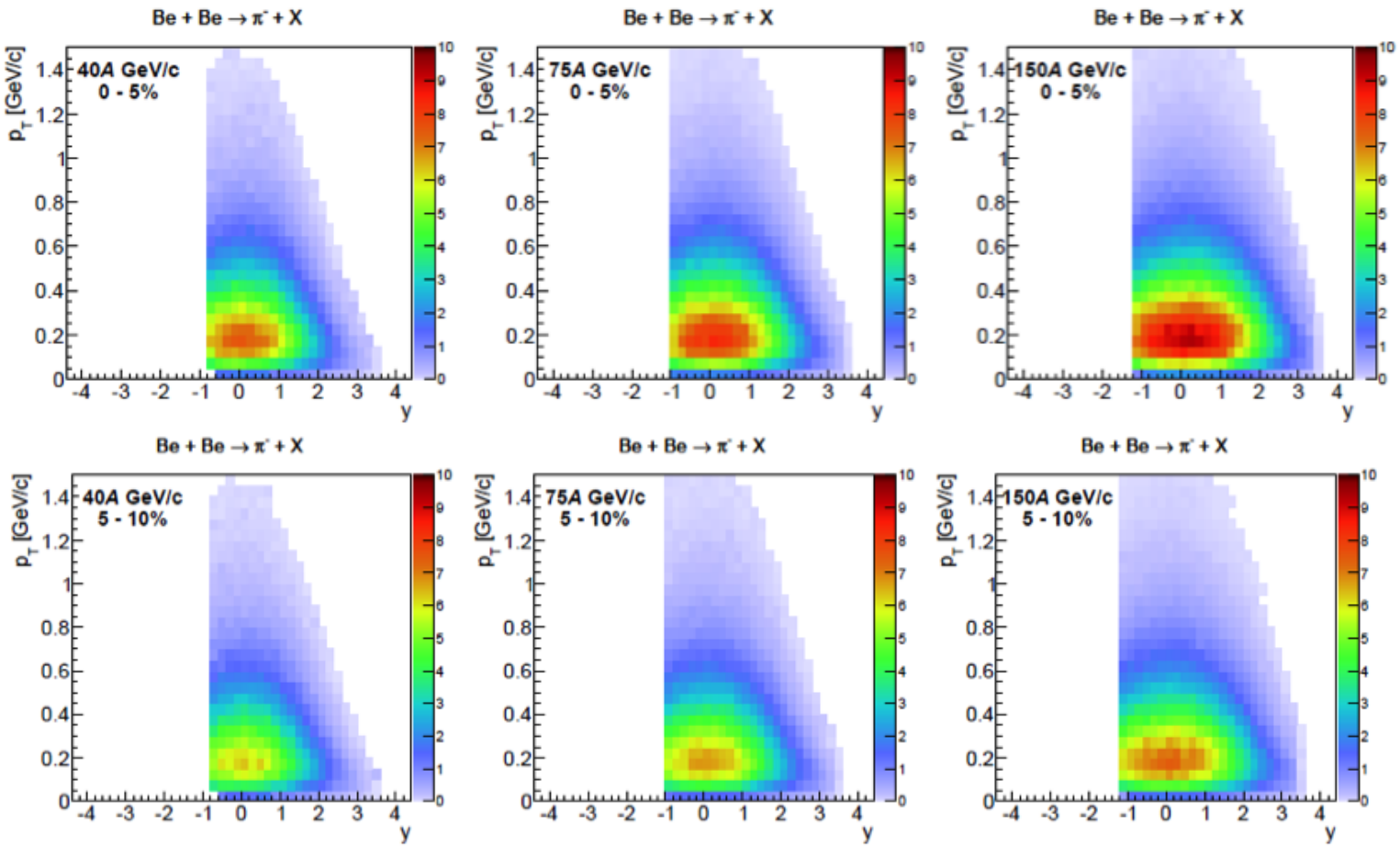




Cuts on E_F allows to select different centrality classes

Examples of $y - p_T$ spectra of π^-: energy and centrality dependence

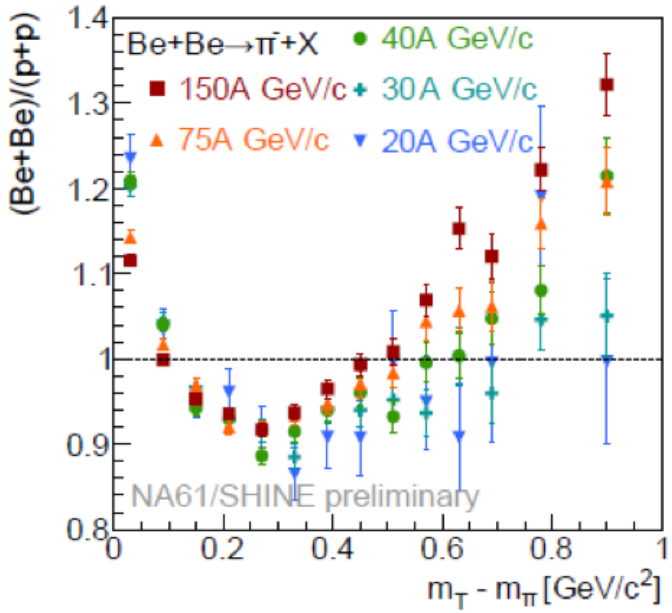
^{7}Be+^{9}Be

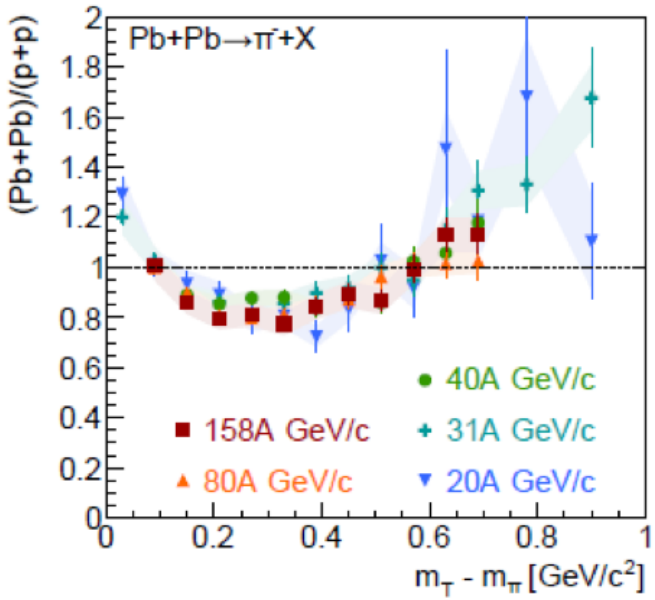


π^- transverse mass spectra comparison

^{7}Be+^{9}Be vs. p+p vs. Pb+Pb

$0 < y < 0.2$





The beam momentum dependence of the ratio observed in ^{7}Be+^{9}Be is not visible in Pb+Pb interactions

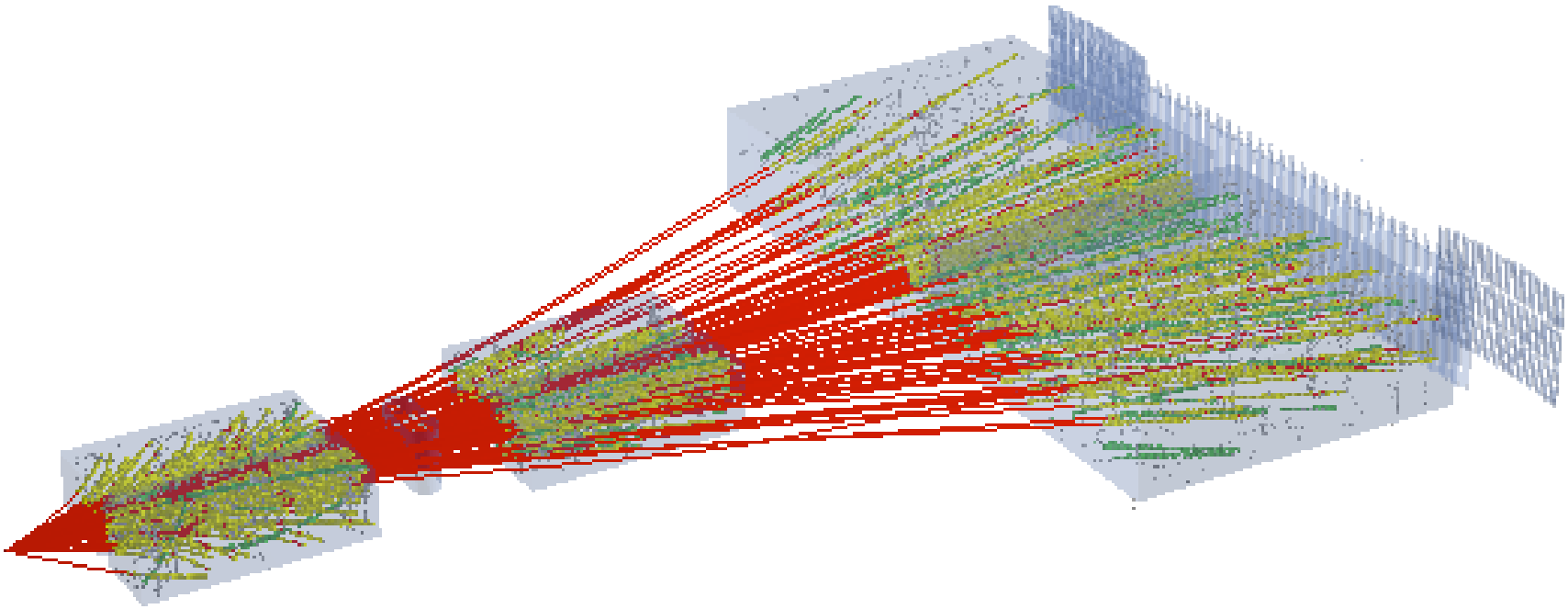
Pb+Pb data for 5% (150A GeV/c) and 7.5% (other momenta) most central interactions
^{7}Be+^{9}Be data for 15% most central interactions

Summary

- Data taking for the system size − energy scan is well advanced: data for p+p, ^{7}Be+^{9}Be and ^{40}Ar+^{45}Sc collisions have already been recorded
- Observation of rapid changes in p+p interactions at SPS
- Do we see onset of deconfinement in p+p interactions?
- String-hadronic model do not describe p+p spectra well
- Measured σ_{inel} in ^{7}Be+^{9}Be interactions shows a weak dependence on the collision energy
- The beam momentum dependence of the m_T spectra ratio was observed in ^{7}Be+^{9}Be interactions

First argon beam in CERN accelerator complex

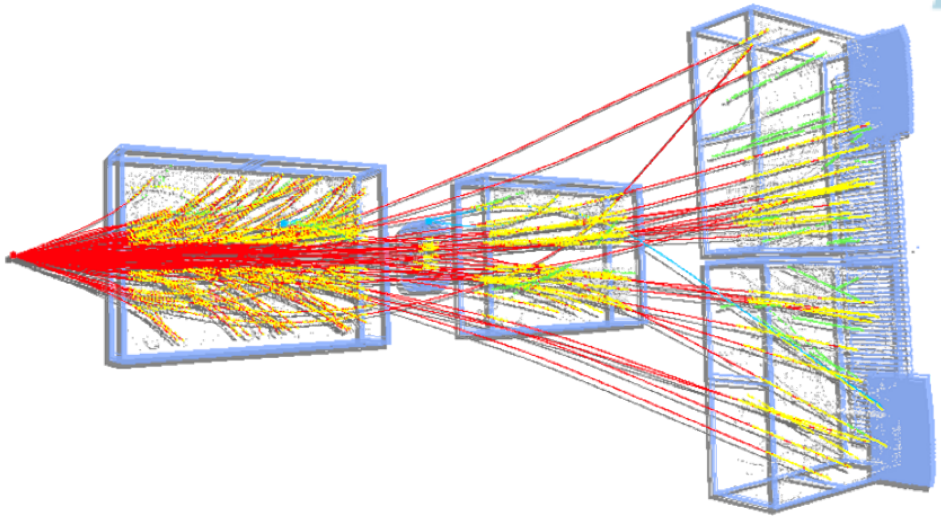
Soon results from Ar+Sc energy scan completed in February-April 2015!!



Example of Ar+Sc 150A GeV/c event

evgeny.andronov@cern.ch

Thank You!



Back-up

NA61/SHINE detector

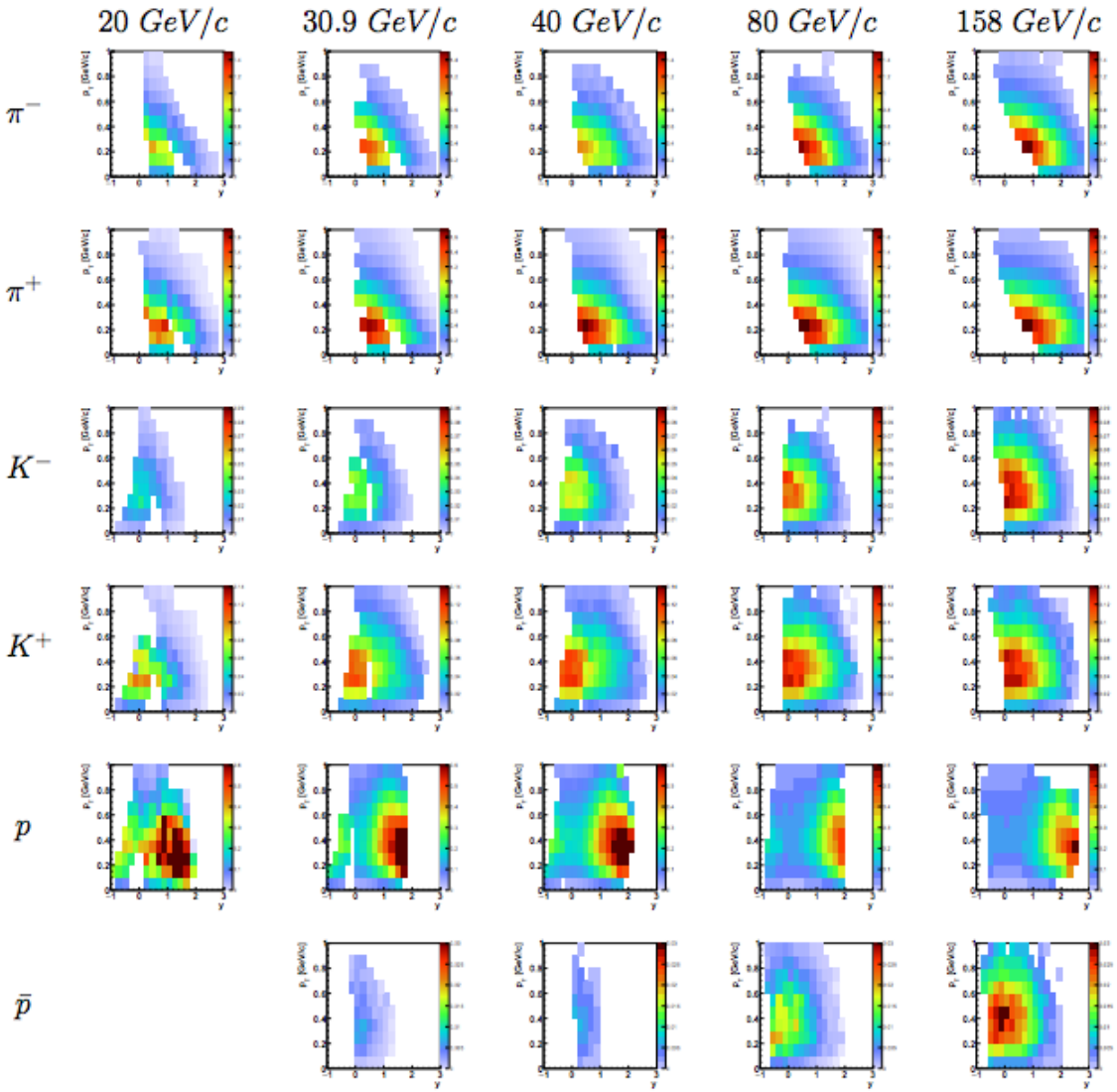
- Large acceptance: 50%
- High momentum resolution: $\frac{\sigma(p)}{p^2} \approx 10^{-4}(GeV/c)^{-1}$ (at full $B = 9Tm$)
- ToF walls resolution: $\sigma(t) \approx 60ps$
- Good particle identification: $\frac{\sigma(dE/dx)}{dE/dx} \approx 0.04$, $\sigma(m_{inv}) \approx 5MeV$
- High detector efficiency: 95%
- Event recording rate: 70 events/sec

Analysis methods

- h^- analysis based on the fact that the majority of negatively charged particles are π^- mesons. Contribution of the other particles is subtracted using Monte-Carlo models
- dE/dx analysis uses TPC energy loss information to identify particles

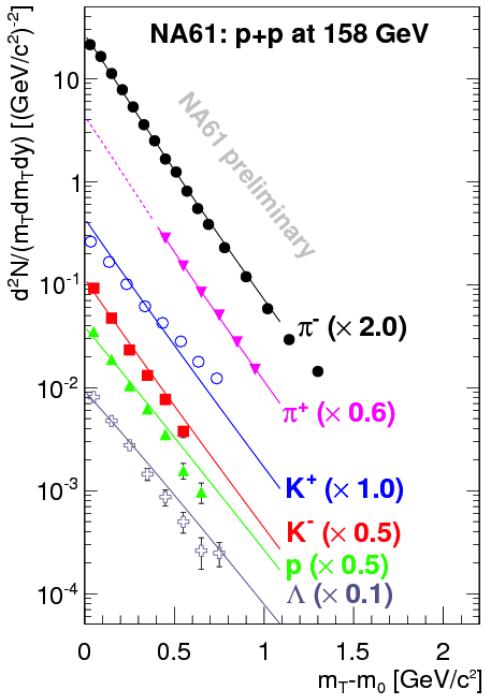
p_T vs. rapidity

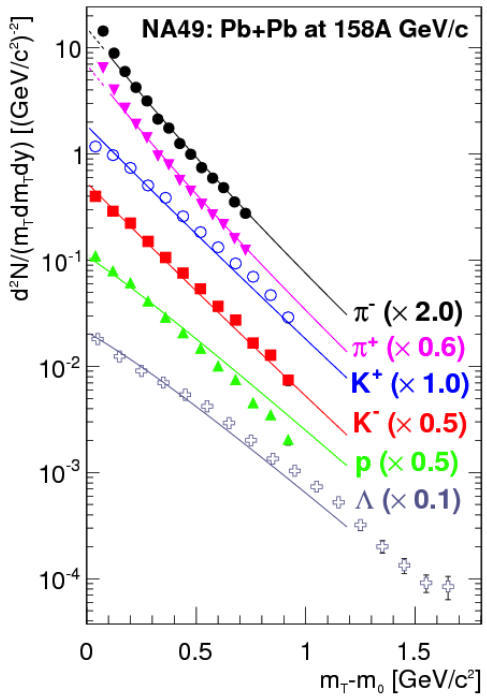
p+p



m_T spectra at mid-rapidity

p+p *vs.* $0-5\%$ central Pb+Pb at 158A GeV/c





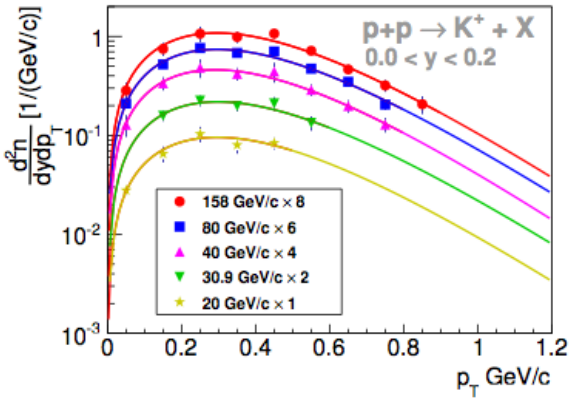
Fit by Blast Wave model: $\frac{dN_i}{m_T dm_T dy} = A_i m_T K_1\left(\frac{m_T \cosh\rho}{T}\right) I_0\left(\frac{m_T \sinh\rho}{T}\right);\ \rho = tanh^{-1}\beta_T$

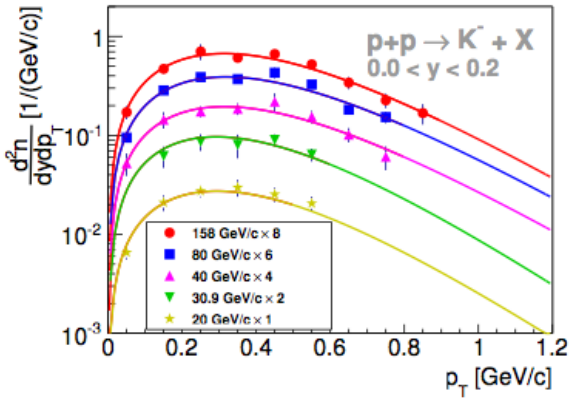
In central Pb+Pb the exponential dependence is modified (possibly due to collective transverse flow)

S. Pulawski et al. [NA61/SHINE Collaboration], CPOD 2013, March 11-15, 2013, Napa, California, US

Fit of K p_T spectra

p+p

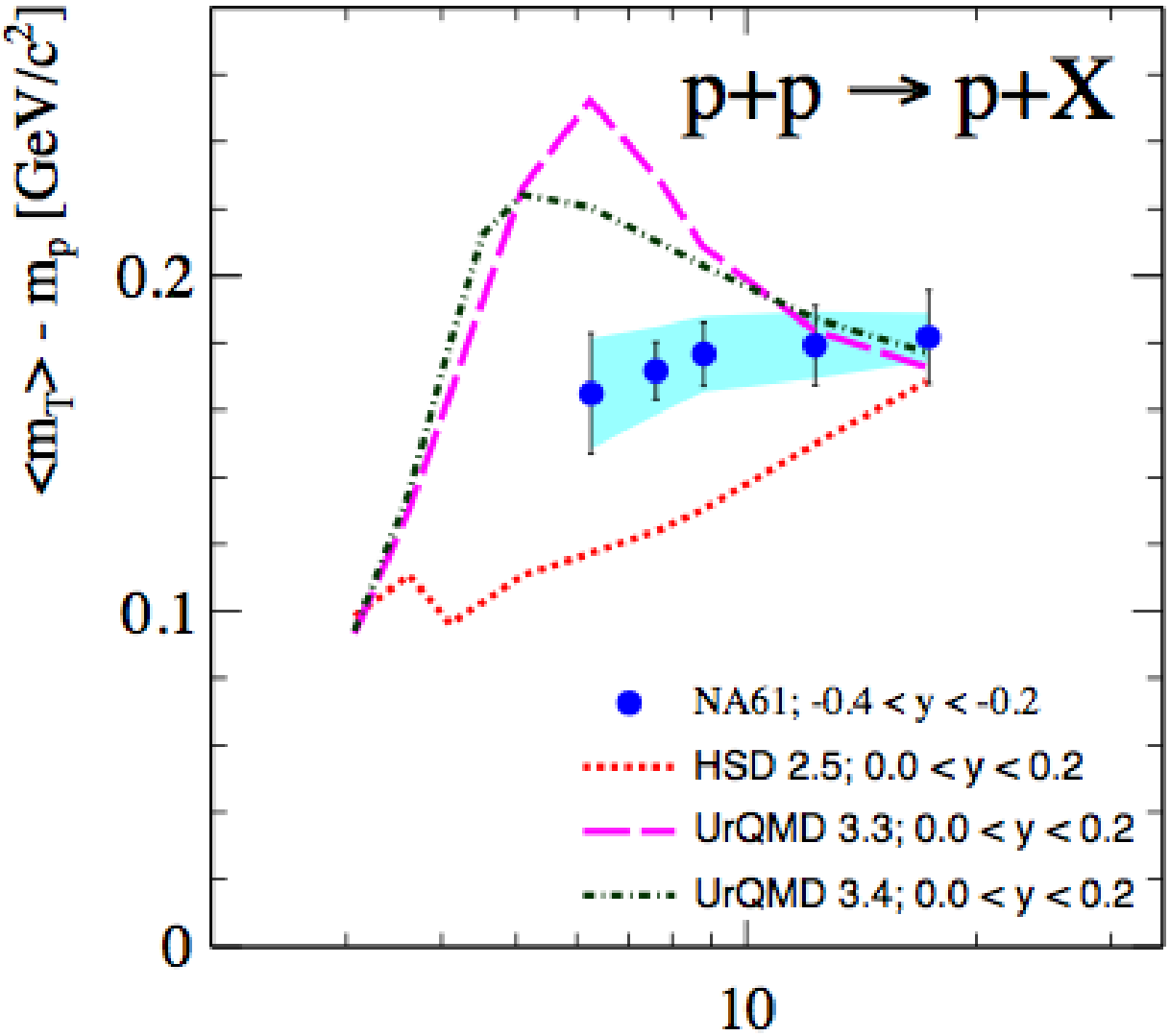




$$\frac{d^2N}{dp_T dy} = \frac{Sp_T}{T^2 + m_K T} exp\left(-\frac{\sqrt{{p_T}^2 + {m_K}^2} - m_K}{T}\right)$$

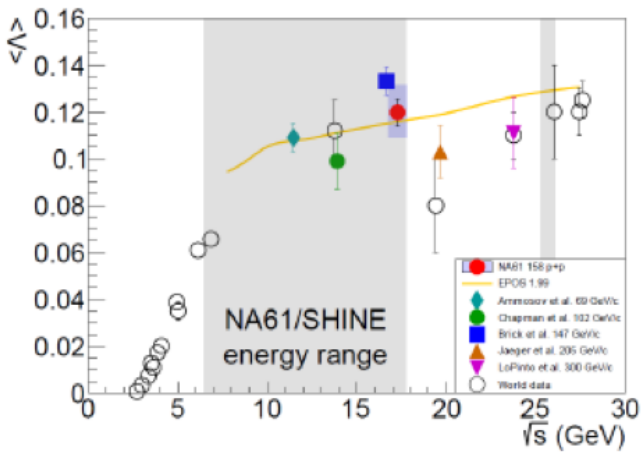
Fit of p p_T spectra

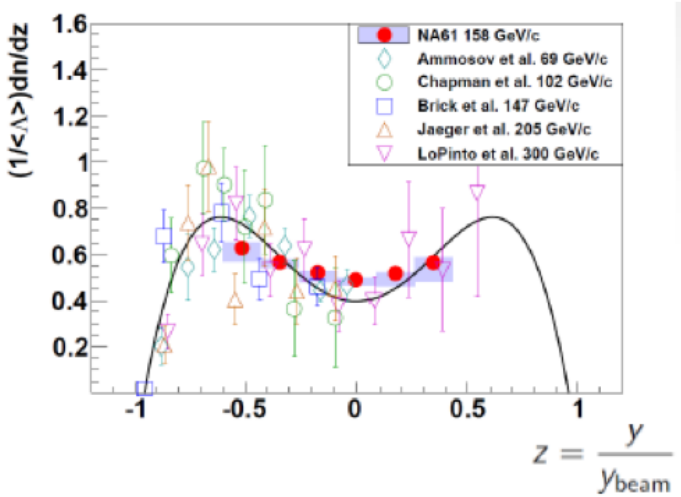
p+p



Λ spectra

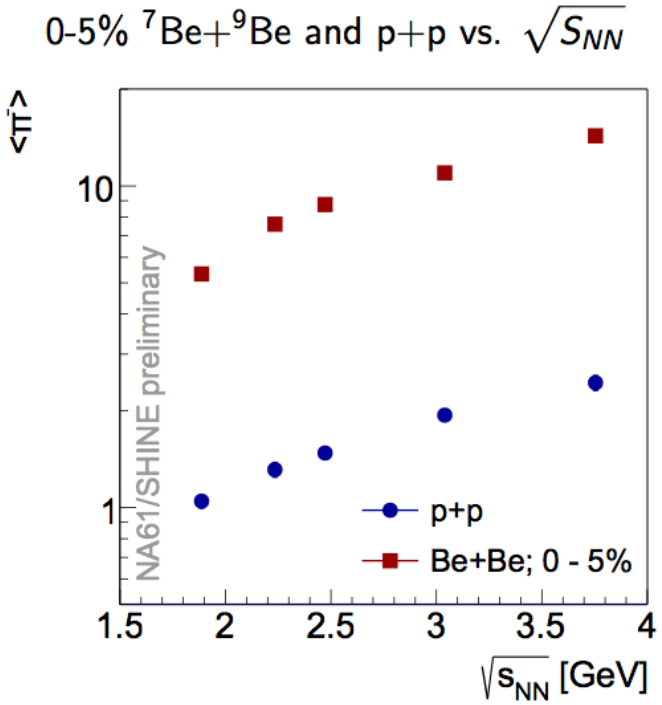
p+p at $\sqrt{s} = 17.3$ GeV

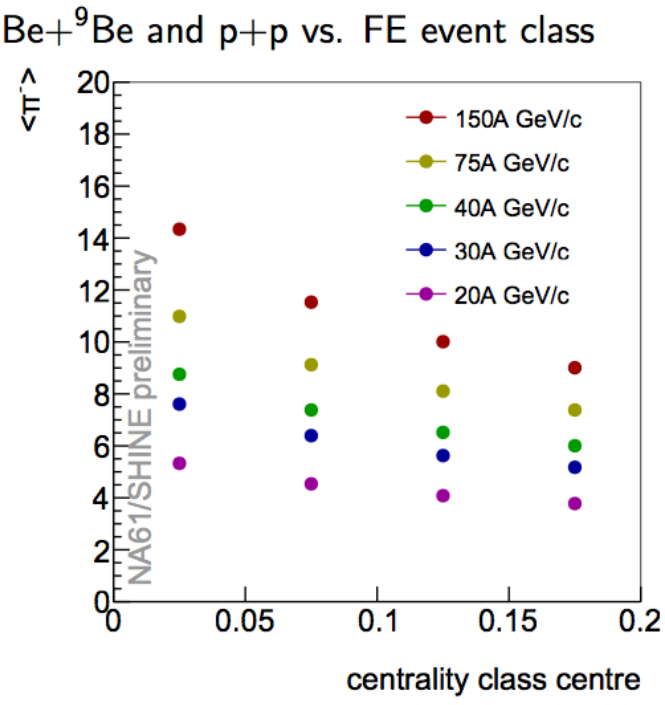




$\langle \pi^- \rangle$ for different centrality classes

^{7}Be+^{9}Be vs. p+p

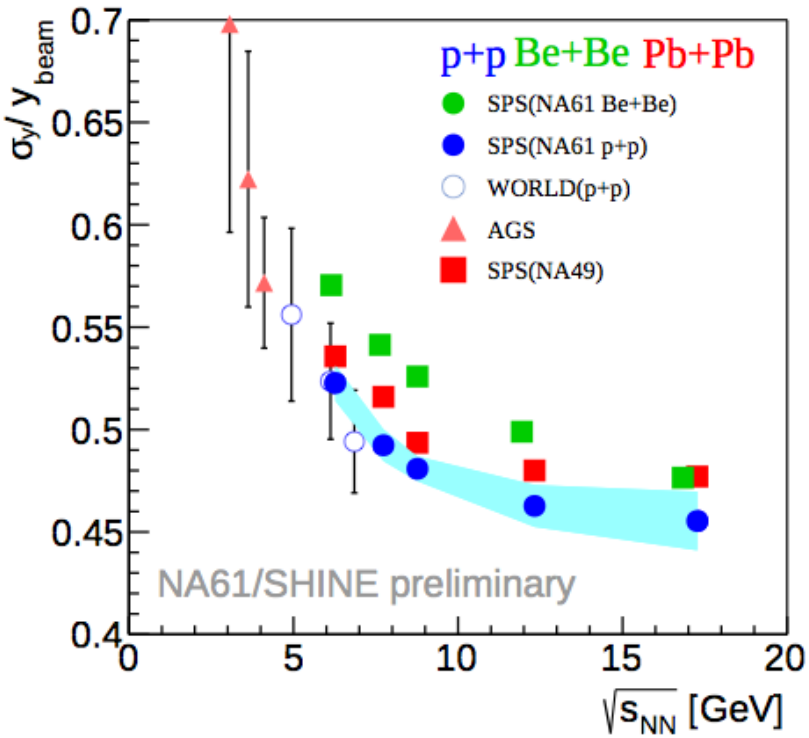




To compare results in system size scan a precise centrality determination is needed. Particle Spectator Detector (PSD) allows for a precise centrality selection by Forward Energy (FE) event selection.

π^- rapidity distribution width

^{7}Be+^{9}Be vs. p+p vs. Pb+Pb

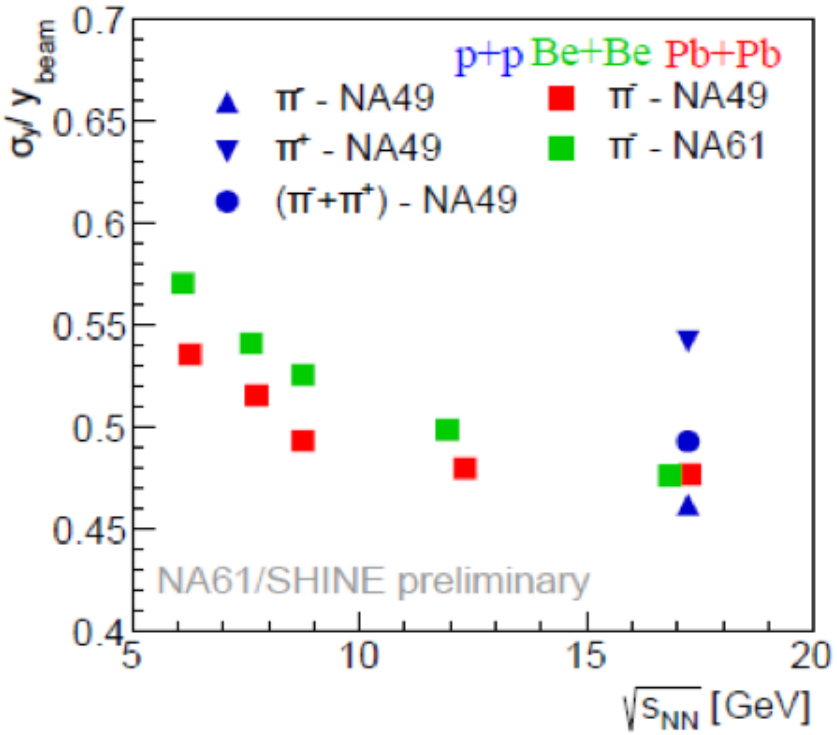


- σ_y calculated from fit of two symmetrically displaced Gaussians
- σ_y related to speed of sound c_S^2 (dale)
- Smooth, monotonic behaviour with energy
- Non-monotonic behaviour with system size

Pb+Pb data for 5% (150A GeV/c) and 7.5% (other momenta) most central interactions
^{7}Be+^{9}Be data for 5% most central interactions

π^- rapidity distribution width

^{7}Be+^{9}Be vs. p+p vs. Pb+Pb



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

Pb+Pb data for 5% (150A GeV/c) and 7.5% (other momenta) most central interactions
^{7}Be+^{9}Be data for 5% most central interactions