New results on hadron spectra in Be+Be collisions from NA61/SHINE at the CERN SPS

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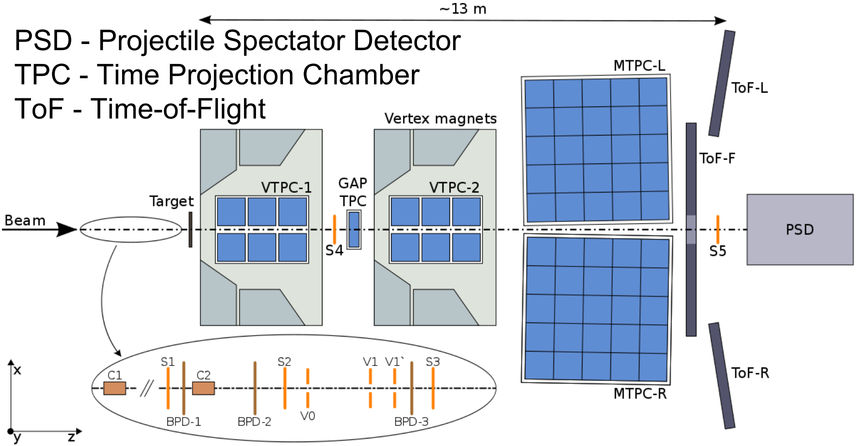
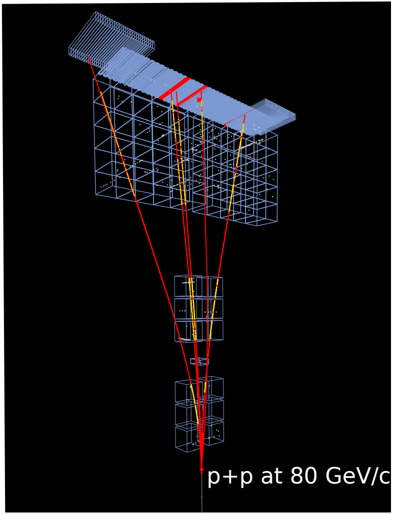
NA61/SHINE detector system

PSD - Projectile Spectator Detector
TPC - Time Projection Chamber
ToF - Time-of-Flight

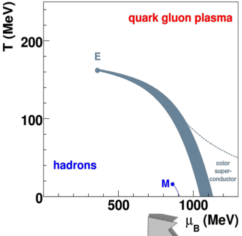


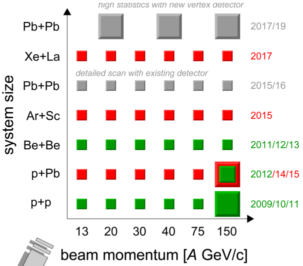
NA61/SHINE detector system



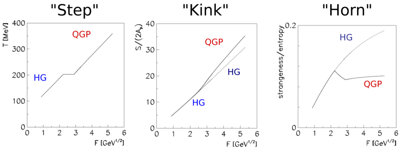
- Large acceptance: $\approx 50\%$
- High momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}\ (GeV/c)^{-1}$ (at full B=9 T m)
- ToF walls resolution: ToF-L/R: $\sigma(t) \approx 60ps$; $ToF - F : \sigma(t) \approx 120ps$
- Good particle identification: $\sigma(dE/dx)/ < dE/dx > \approx 0.04$; $\sigma(m_{inv}) \approx 5MeV$
- High detector efficiency: 95%
- Event rate: 70 events/sec

NA61/SHINE 2D scan goals



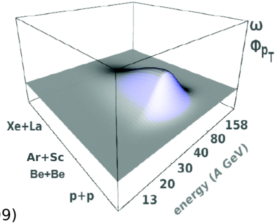


Statistical Model of the Early Stage (SMES)



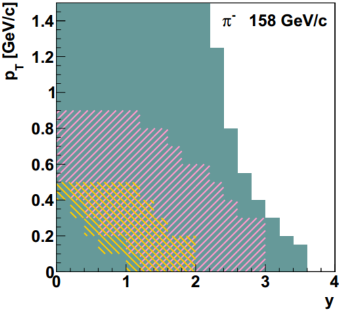
$F \approx \sqrt[4]{s_{NN}}$

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



Introduction to "h$^-$" analysis method

- $\approx$ 90% of the negatively charged hadrons produced in Be+Be interactions are π^-
- In the h$^-$ method the small contribution of other particles (K$^-$, $\bar{\text{p}}$, and decays from Λ and K^0_S) is subtracted based on the 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 h$^-$ method



- Analysis done in bins of rapidity

$$y = 0.5 \ln \frac{E + p_L}{E - p_L}$$

and transverse momentum or mass

Double differential spectra of π^-

- Analysis done in four centrality classes: 0–5%, 5–10%, 10–15%, 15–20%
- Centrality definition:

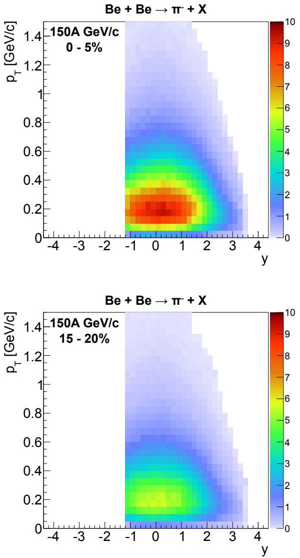
$$c(E_F) = \frac{\sigma(E_F)}{\sigma_{\text{inel}}},$$

where E_F is forward going energy (deposited in the PSD)

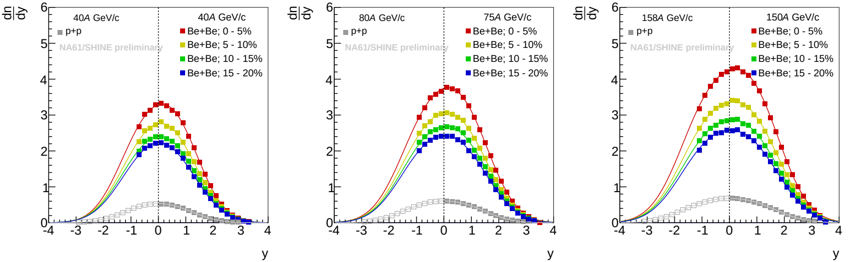
- All quantities were derived from double differential spectra

$$\frac{d^2 n}{dy dp_T} \text{ or } \frac{d^2 n}{dy dm_T}$$

corrected for detector effects and feed–down from weak decays



Rapidity spectra (Be+Be, p+p)
3 energies, 4 centrality classes



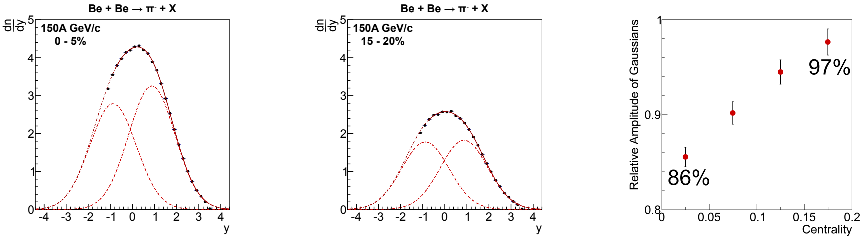
To extract mean multiplicity the spectra were fitted with:

$$\frac{\mathrm{d}n}{\mathrm{d}y}(y) = A_0 \cdot A_{rel} \cdot \exp\left(-\frac{(y-y_0)^2}{2\sigma_0}\right) + A_0 \cdot \exp\left(-\frac{(y+y_0)^2}{2\sigma_0}\right),$$

where $A_0 = \frac{\langle\pi^-\rangle_{\text{forward}}}{\sigma_0\sqrt{2\pi}}$, and $\int \frac{\mathrm{d}n}{\mathrm{d}y}(y)\,\mathrm{d}y = \langle\pi^-\rangle$.

Fit range is from -0.8 to beam rapidity.

Asymmetry in rapidity spectra



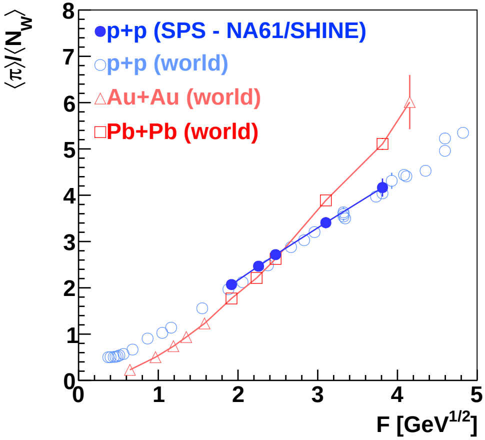
Two opposite effects influence asymmetry of the spectra:

- 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 ($N_S^{proj} \leq 2$),
- no selection for target allows for fluctuations ($N_S^{targ} \approx \text{Gaussian}(x_0 = 3.7; \sigma = 1.4)$).

"Kink" — $\langle\pi\rangle/\langle N_W\rangle$



In Statistical Model of Early Stage:

- $\langle\pi\rangle/\langle N_W\rangle$ is related to entropy
- $\langle\pi\rangle/\langle N_W\rangle$ increase faster with energy in Pb+Pb than in p+p due to QGP formation

Ongoing work for Be+Be points

Reliable calculation of $\langle\pi\rangle/\langle N_W\rangle$ in small system is not a trivial task

Transverse mass spectra — collectivity

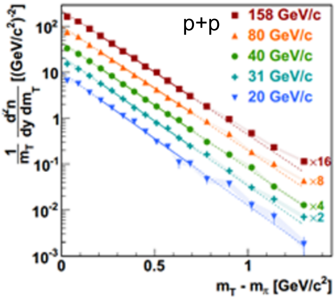
Static source

$T_{(slope)} = T_{freeze\text{-}out}$
(thermal freeze-out)

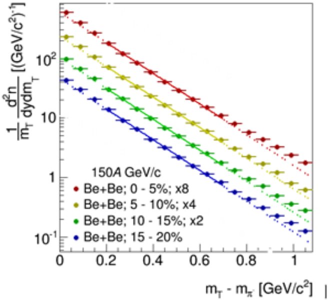
Expanding source

$T_{(slope)} = T_{freeze\text{-}out}$ + effect of radial flow

Exponential shape of transverse mass spectra

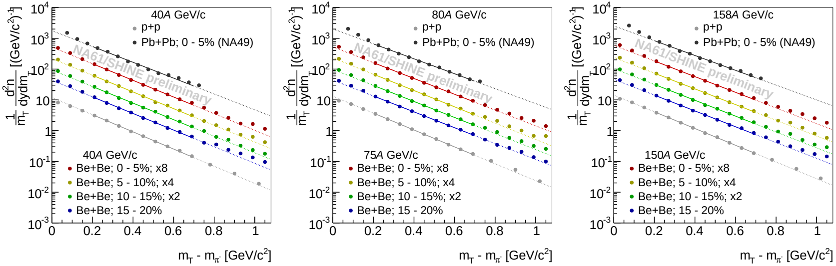


Enhancement at high transverse mass



Transverse mass spectra (p+p, Be+Be, Pb+Pb)

40*A* GeV/c 75*A* GeV/c 150*A* GeV/c



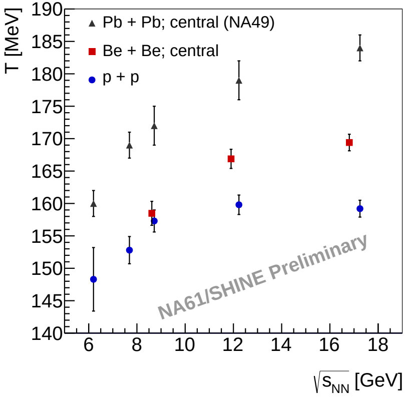
Fitted in range $0.18 \leq m_T - m_0 \leq 0.72$

p+p and Pb+Pb data for $0 < y < 0.2$

Be+Be data for $-0.2 < y < 0.2$

p+p data nearly exponential — Be+Be and Pb+Pb data show deviations

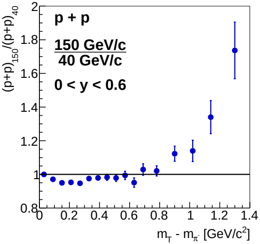
Inverse slope parameter system size and energy dependence



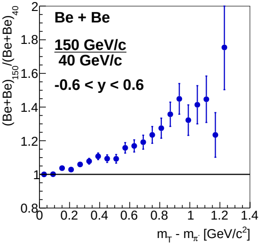
- Pb+Pb much higher than p+p
  Effect of radial flow
- Be+Be higher than p+p
  at 75*A* and 150*A* GeV/c
- At 40*A* GeV/c Be+Be overlap with p+p
- Onset of collective effects
  around 40*A* GeV/c?

Systematics of transverse mass spectra (energy and system size)

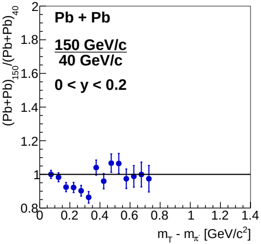
Normalized ratio of m_T spectra at different energies allows to compare shape



Enhancement at $m_T - m_{\pi^-} > 1$ GeV/c^2 due to energy conservation

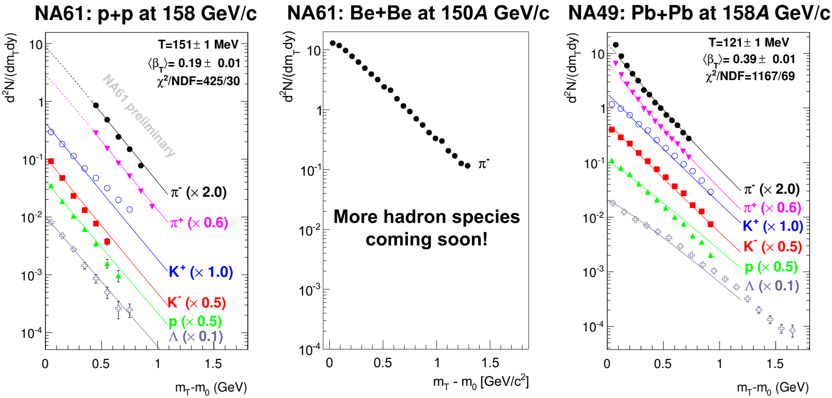


Enhancement in the whole range
Effect of radial flow at 150A GeV/c



Flat distribution
Radial flow present at both energies

Future possibilities



Data for Ar+Sc and Xe+La expected in 2015 and 2017

fitted function: $\frac{dN_i}{m_T dm_T dy} = A_i m_T K_1(\frac{m_T \cosh\rho}{T}) I_0(\frac{p_T \sinh\rho}{T})$ from Schnedermann, Sollfrank, Heinz, PRC 48, 2462 (1993)

$\rho = atanh \beta_T$

Summary

- Double differential π^- spectra in large region of phase–space (including backward rapidity!)
- Asymmetry in the rapidity distribution easily parametrized
- Detailed study of extracting $\langle\pi\rangle/\langle N_\mathrm{W}\rangle$ ratio from data underway
- Onset of collectivity observed around $40A$ GeV/c based on π^- transverse mass spectra