Diagram of high-energy nuclear collisions New results on Xe+La central collisions from NA61/SHINE at CERN SPS

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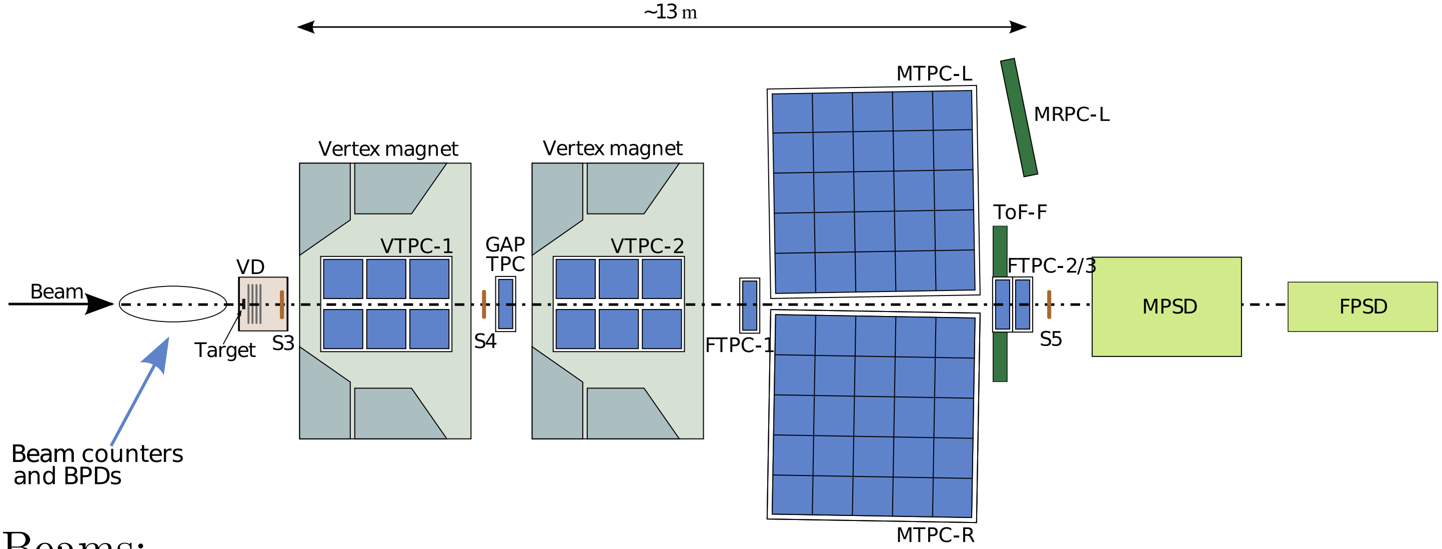
NA61/SHINE experiment

Fixed target experiment located at the CERN SPS.
Coverage of the full forward hemisphere, down to $p_T = 0$.



Beams:

- Ions (Be Ar, Xe, Pb):
  $p_{\text{beam}} = 13A - 150A$ GeV/c, $\sqrt{s_{NN}} = 5.1 - 16.8$ GeV.
- Hadrons (π, K, p):
  $p_{\text{beam}} = 13A - 400A$ GeV/c, $\sqrt{s_{NN}} = 5.1 - 27.4$ GeV.

NA61/SHINE physics program

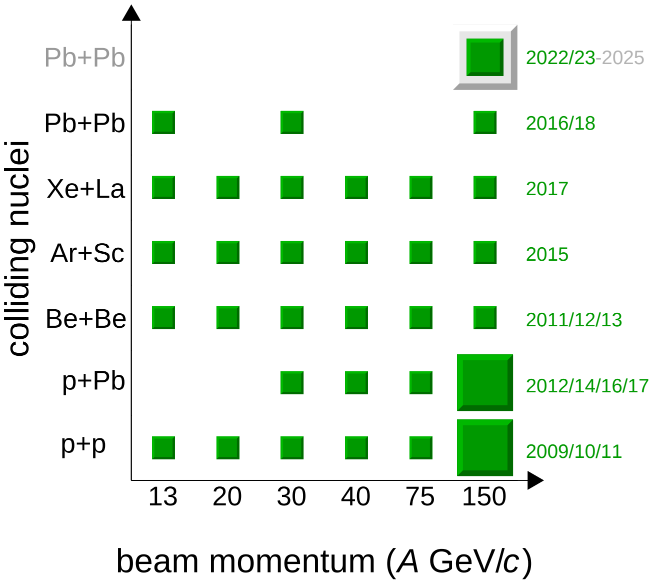
Strong interaction physics:

- study properties of the **onsets of deconfinement and fireball**,
- search for the **critical point** of strongly interacting matter,
- direct measurements of **open charm**.

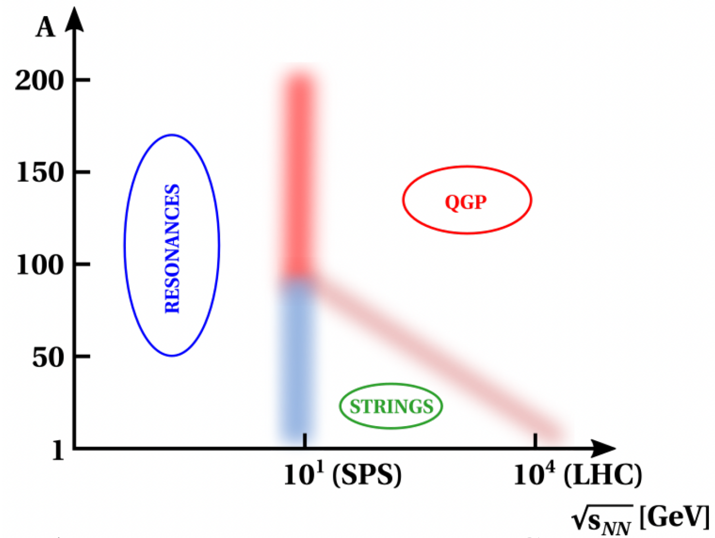
Neutrino and cosmic ray physics:

- measurements for neutrino programs at J-PARC and Fermilab,
- measurements of nuclear fragmentation cross section for cosmic ray physics.

NA61/SHINE 2D scan



CERN-SPSC-2006-034

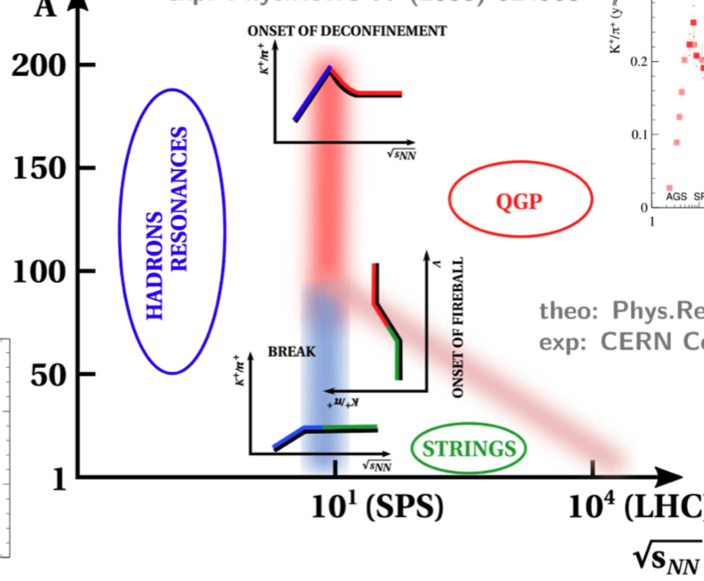


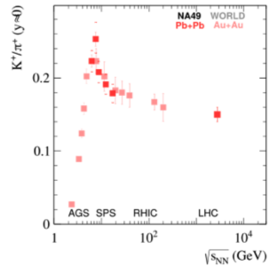
E. Andronov, M. Kuich, and M. Gazdzicki
Universe 9 no. 2, (2023) 106

Two-dimensional scan in collision energy and mass of colliding nuclei.

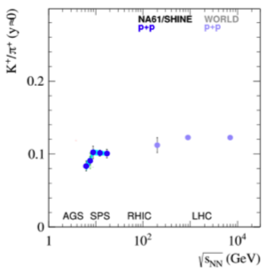
Diagram of high-energy nuclear collisions

theo: Acta Phys.Polon.B 46 (2015) 10, 1991
exp: Phys.Rev.C 77 (2008) 024903

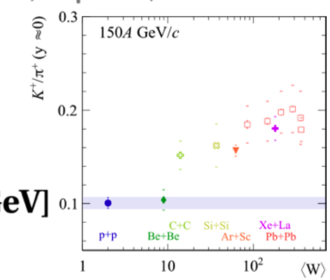




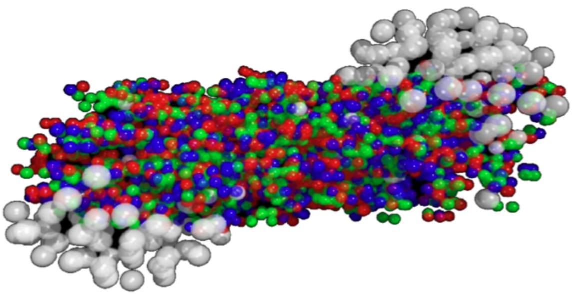
theo: Phys.Part.Nucl. 51 (2020) 3, 337-339
exp: Phys.Rev.C 102 (2020) 011901



theo: Phys.Rev.D 90 (2014) 025031
exp: CERN Courier, Sep 23rd, 2019



Centrality selection



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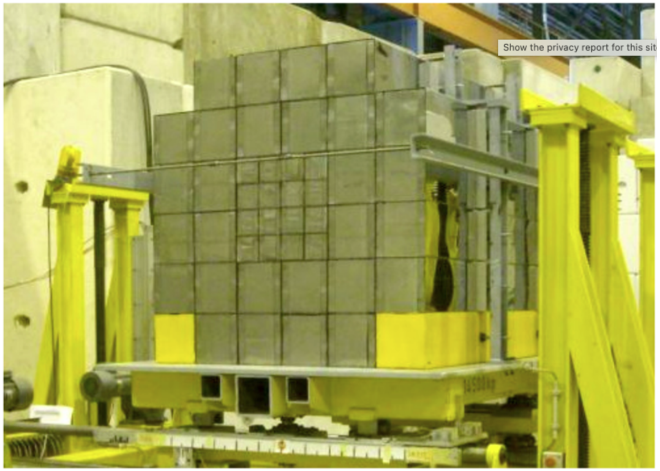
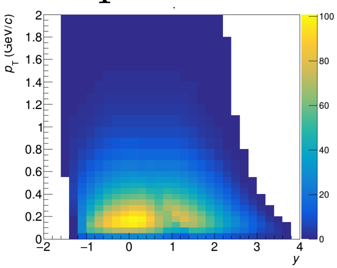


Centrality selection is based on the projectile spectator energy E_F measured by the Projectile Spectator Detector (PSD).
For Xe+La the 10% most central collisions are selected at 150A GeV/c and 10% at 30A – 75A GeV/c.

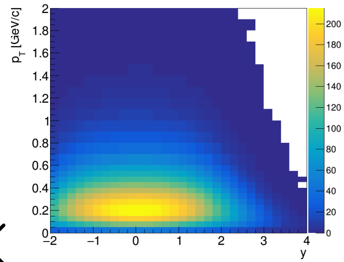
h^- – all negatively charged hadrons ($\approx 90\%\ \pi^- + K^- + \bar{p} + \ldots$)

h^- raw spectrum

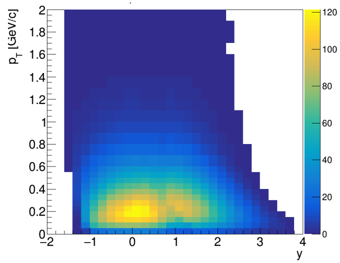


$\times$

π^- MC generated

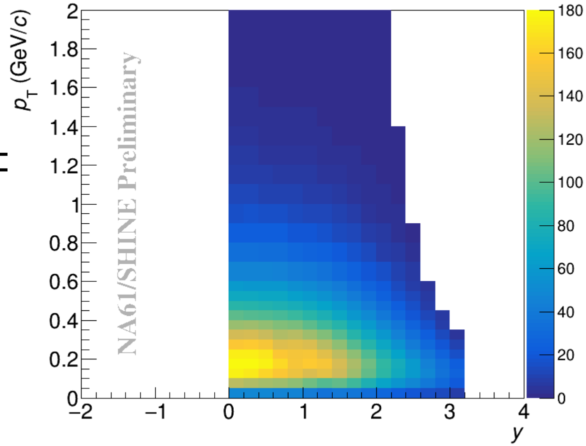


h^- MC selected



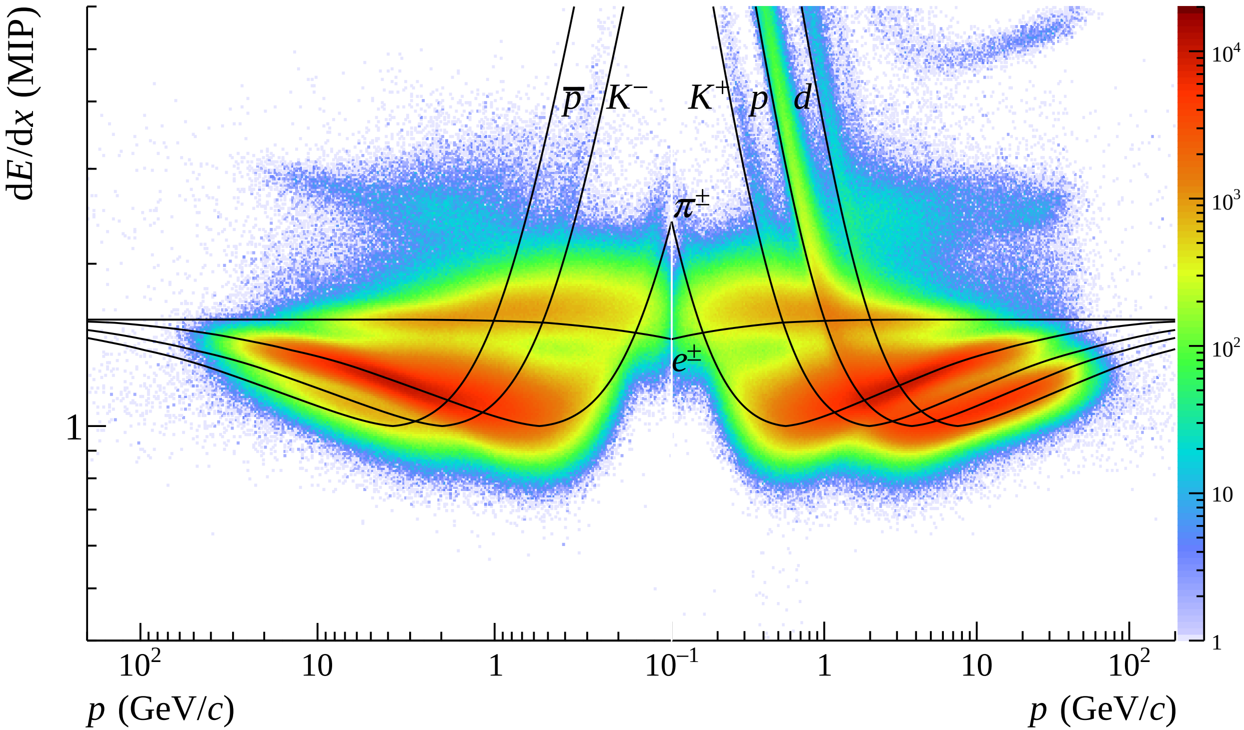
$=$

π^- corrected spectrum



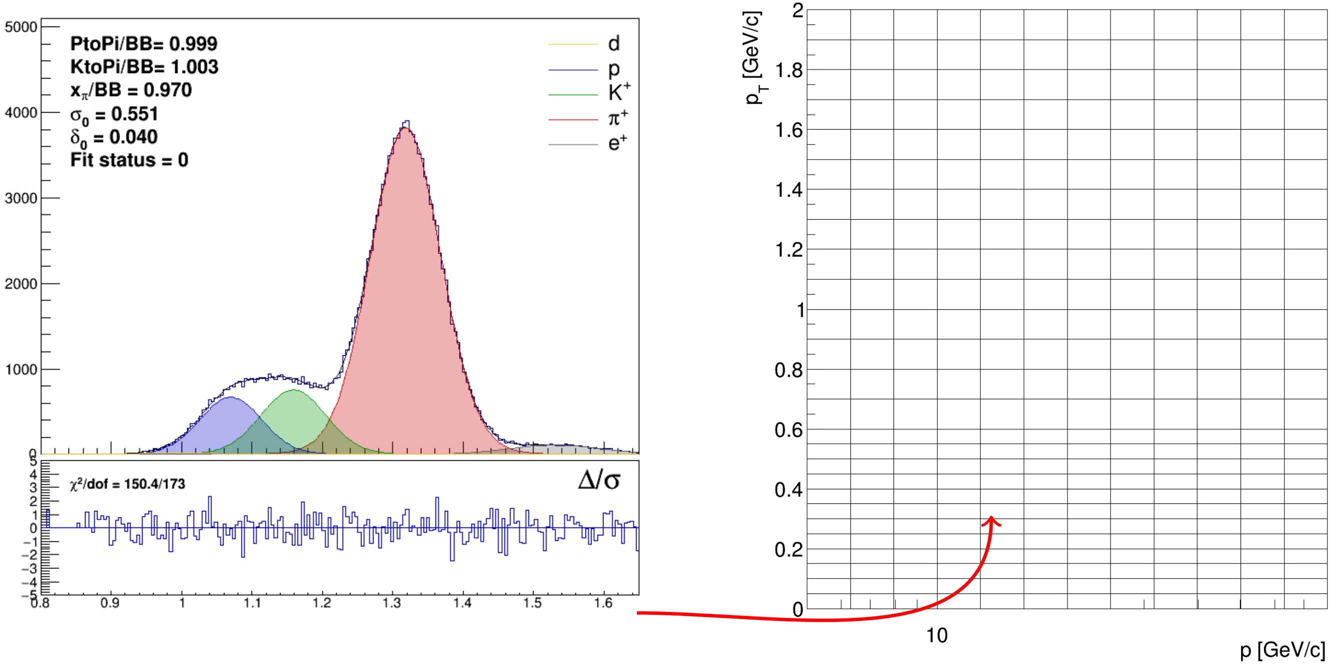
Raw h^- spectrum, MC generated π^- and selected h^- spectra, corrected spectrum of π^- using h^- method for Xe+La at 150A GeV/c.

dE/dx vs p after all cuts



Bethe: $$\left\langle -\frac{\mathrm{d}E}{\mathrm{d}x} \right\rangle = \frac{A}{\beta^2}\left[\ln B\beta^2\gamma^2 - 2\beta^2 - \delta(\beta\gamma)\right],\ (0.1 \leq \beta\gamma \leq 1000)$$

Fitting

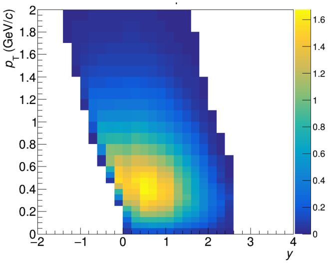


Fit with sum of asymmetric Gaussians for $p, \bar{p}, K^{\pm}, \pi^{\pm}, e^{\pm}, d$:

$$f(x) = \sum_{i=p,K,\pi,e,d} N_i \frac{1}{\sum_l n_l} \sum_l \frac{n_l}{\sqrt{2\pi}\sigma_{i,l}} \exp\left[-\frac{1}{2}\left(\frac{x - x_i'}{(1 \pm \delta)\sigma_{i,l}}\right)^2\right]$$

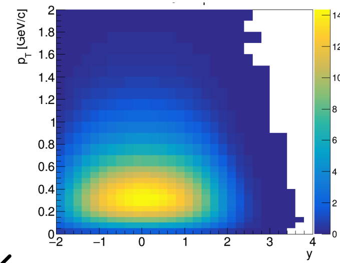
MC corrections for $\mathrm{d}E/\mathrm{d}x$ method (example for K^-)

K^- raw spectrum

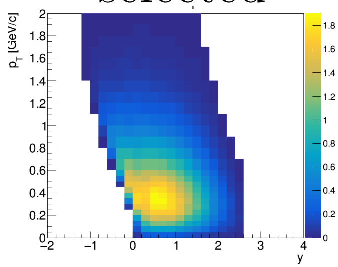


$\times$

K^- MC generated

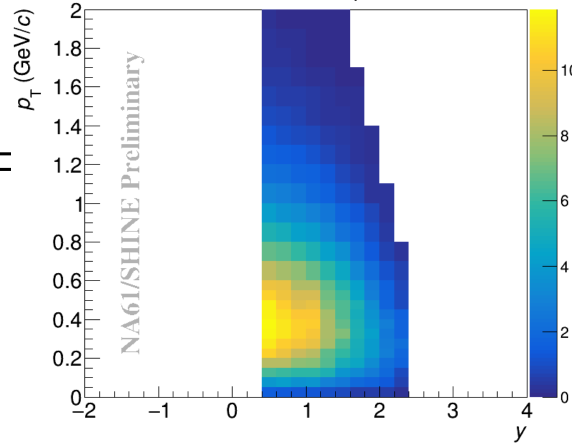


K^- MC selected



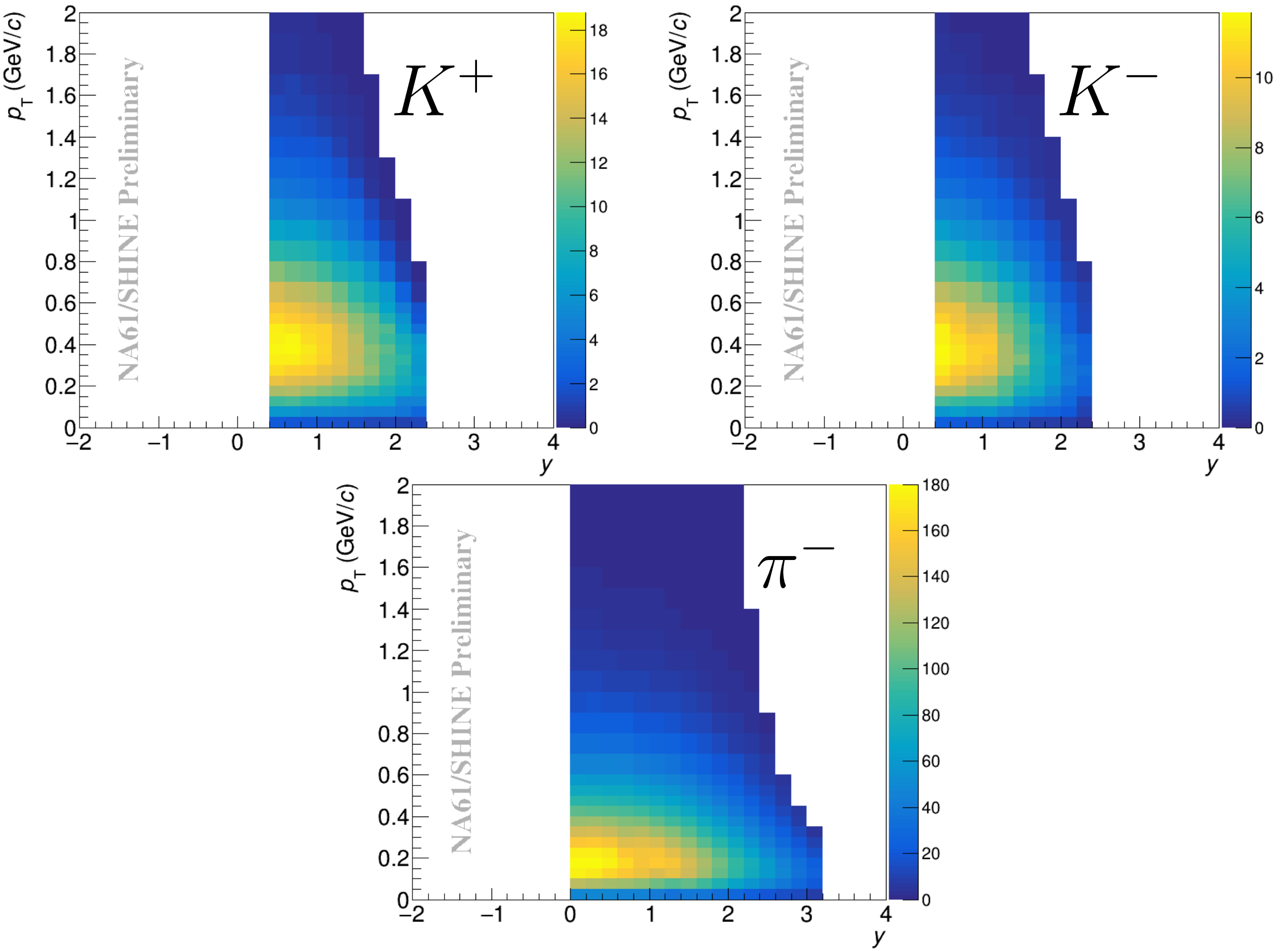
$=$

K^- corrected spectrum

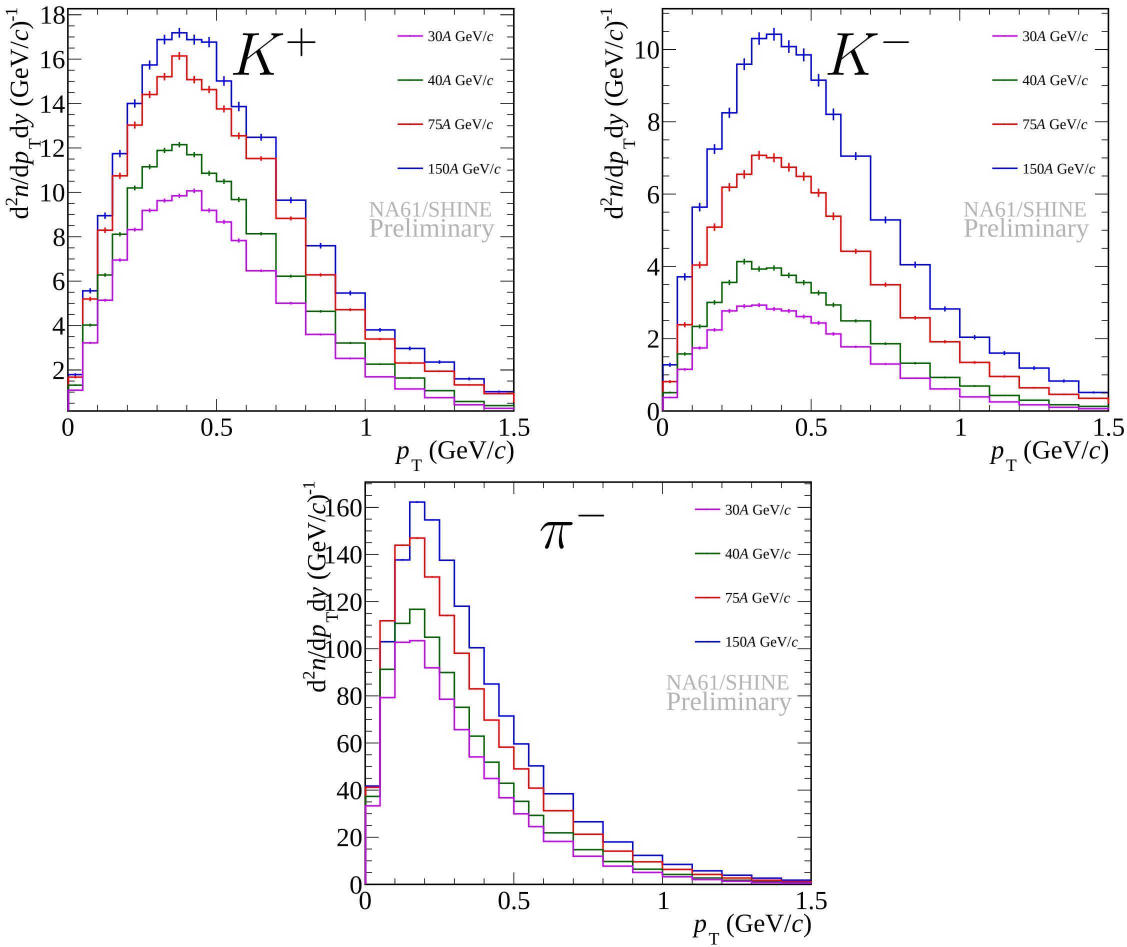


Raw K^- spectrum, MC generated and selected K^- spectra, corrected spectrum of K^- using $\mathrm{d}E/\mathrm{d}x$ method for Xe+La at 150A GeV/c.

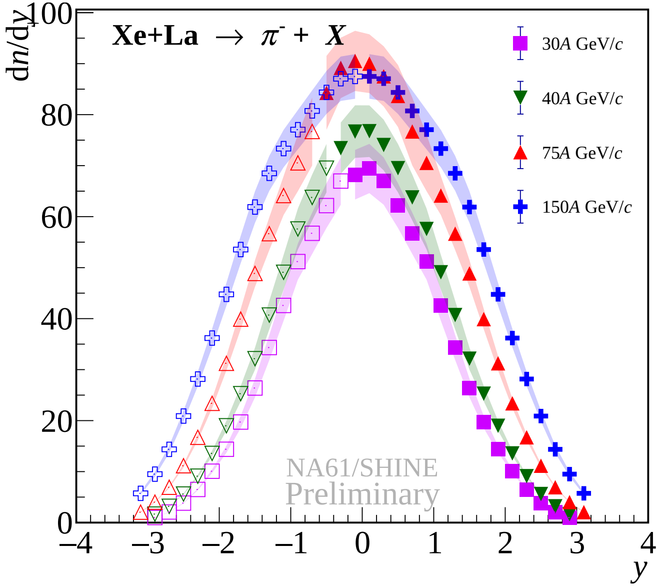
$\mathrm{d}^2n/\mathrm{d}y\mathrm{d}p_\mathrm{T}$ spectra of K^+, K^-, and π^- at $150A$ GeV/c

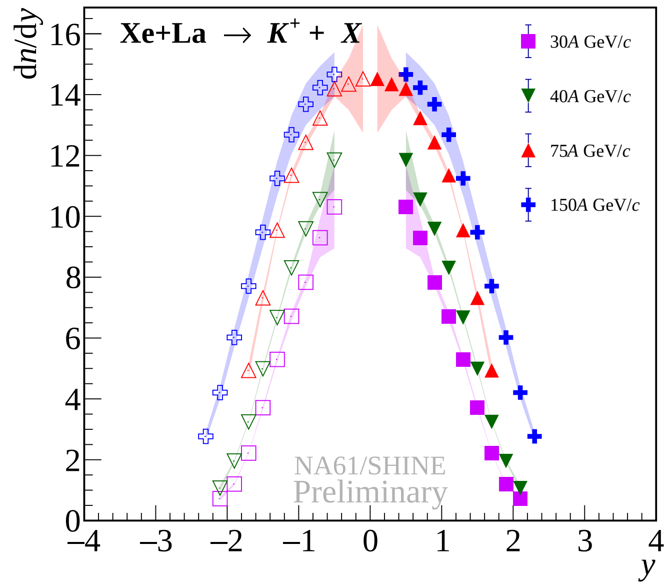


K^+, K^-, and π^- p_T spectra at $y = 1.0 - 1.2$



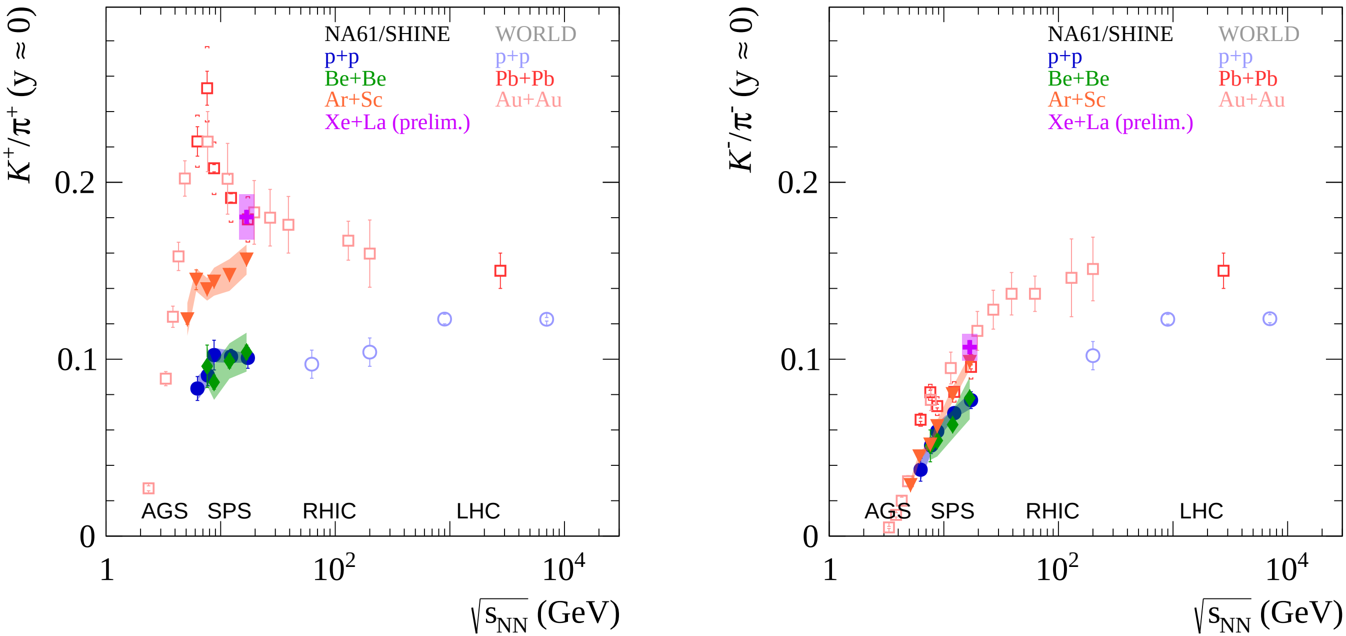
dn/dy spectra of π^- and K^+





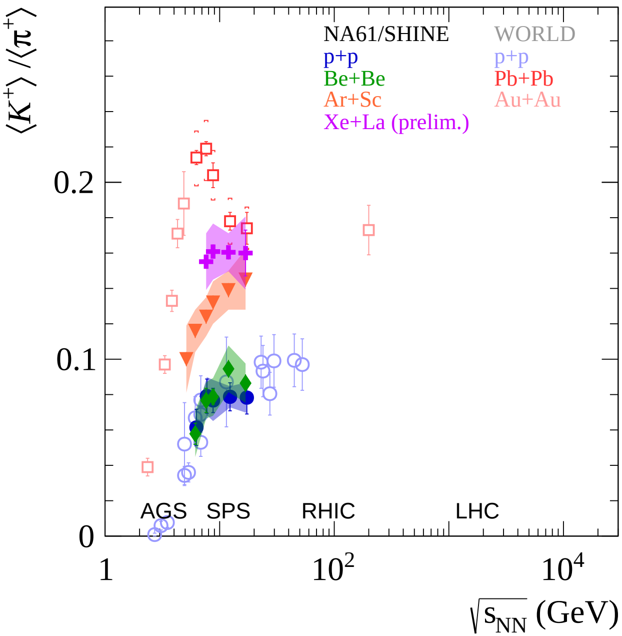
For all spectra open points are reflected measured data points.

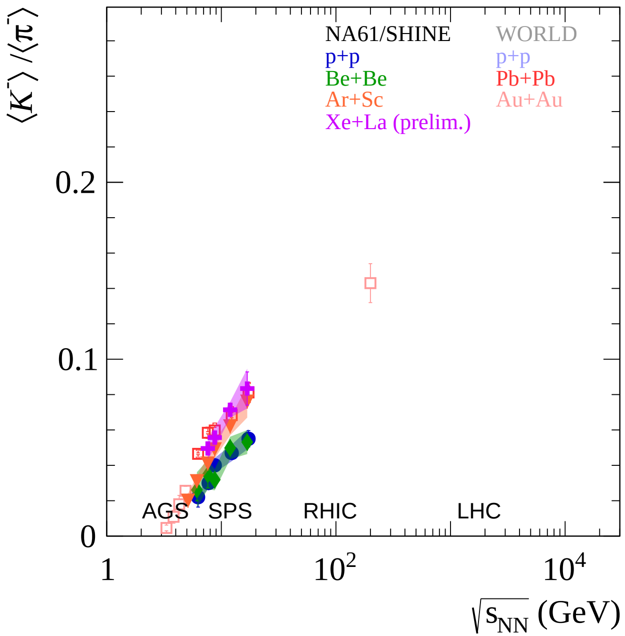
K^+/π^+ and K^-/π^- at $y \approx 0$



π^+ at $y \approx 0$ was estimated from π^- at $y \approx 0$ using isospin correction factor calculated from MC.

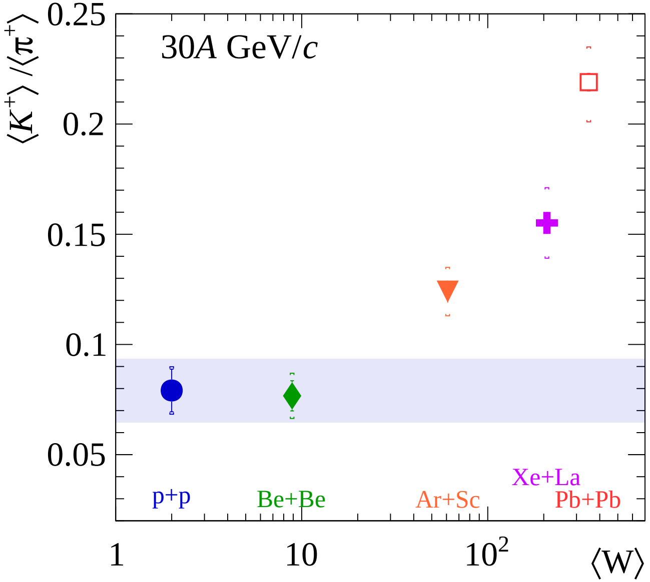
$\langle K^+\rangle/\langle\pi^+\rangle$ and $\langle K^-\rangle/\langle\pi^-\rangle$

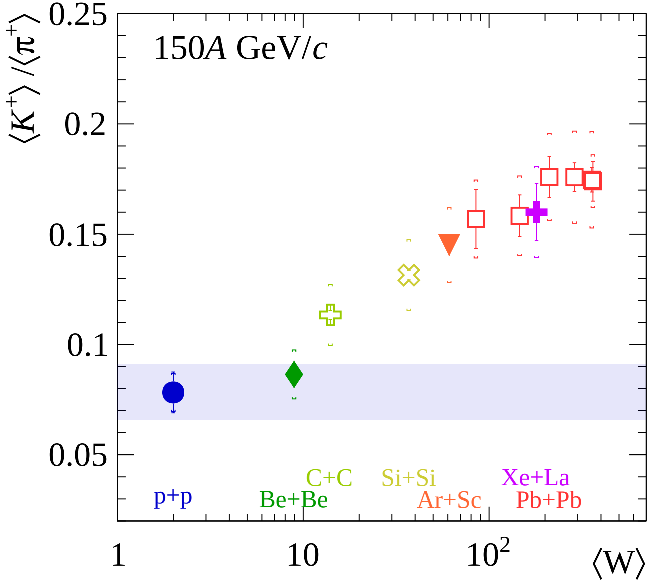




$\langle\pi^+\rangle$ was estimated from $\langle\pi^-\rangle$ using isospin correction factor calculated from MC.

System size dependence of the $\langle K^+ \rangle / \langle \pi^+ \rangle$





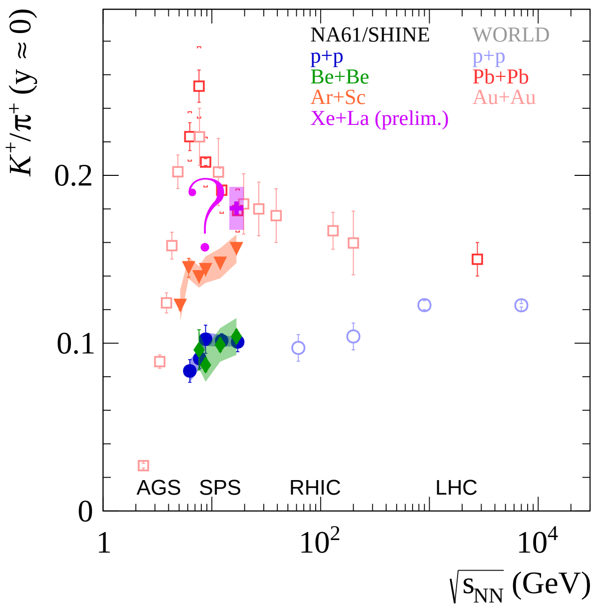
$\langle W \rangle$ – mean number of wounded nucleons.
Statistical uncertainties are shown as bars and systematic with square braces.

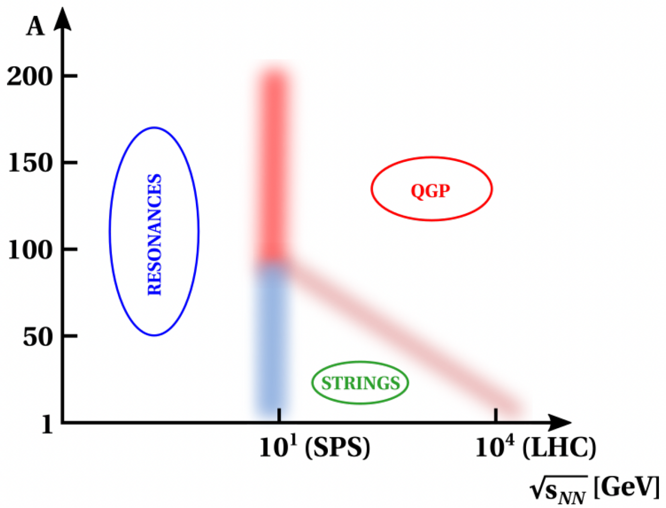
Summary

- Results on spectra and total yields of π^-, K^+ and K^- produced in central Xe+La collisions at beam momenta $30A - 150A$ GeV/c are presented.
- The 10% most central collisions were selected at $30A - 75A$ GeV/c and 20% at $150A$ GeV/c.
- K^+/π^+ and K^-/π^- ratios at $y \approx 0$ and $\langle K^+\rangle/\langle\pi^+\rangle$ and $\langle K^-\rangle/\langle\pi^-\rangle$ for Xe+La are between the corresponding ratios for Ar+Sc and Pb+Pb.

Summary

- New results at lower SPS beam momenta will be released soon and they will help to locate Xe+La at the diagram of high-energy nuclear collisions and answer the question whether horn is visible in Xe+La.





Backup Slides

Distribution of strangeness between hadrons

net strangeness conservation

$\bar{s}$ $=$ s

isospin symmetry: $K^+(u\bar{s}) \approx K^0(d\bar{s})$

isospin symmetry: $K^-(\bar{u}s) \approx \bar{K}^0(\bar{d}s)$

$K^+(u\bar{s}) \ggg \bar{\Lambda}(\bar{u}\bar{d}\bar{s})$

$\bar{K}^0(\bar{d}s) \approx \Lambda(uds)$

high baryon density

$\bar{\Lambda}(\bar{u}\bar{d}\bar{s}) \ll \Lambda(uds)$

(red) – sensitive to strangeness content only

(blue, green) – sensitive to strangeness content and baryon density

How to measure strangeness

$$2\langle N_{s\bar{s}}\rangle = \langle \Lambda + \bar{\Lambda}\rangle + \langle K^+ + K^- + K^0 + \bar{K}^0\rangle + ...$$

$$2\langle N_{s\bar{s}}\rangle \approx \langle \Lambda\rangle + \langle K^+ + K^- + K^0 + \bar{K}^0\rangle,$$

$$\langle N_{s\bar{s}}\rangle \approx \langle \Lambda\rangle + \langle K^- + \bar{K}^0\rangle \approx \langle K^+ + K^0\rangle \approx 2\langle K^+\rangle.$$

How to measure entropy

Entropy $\sim \langle \pi \rangle$

$$\langle \pi\rangle = \langle \pi^+ + \pi^0 + \pi^-\rangle \approx 3\langle \pi^+\rangle$$

Experimental measure of strangeness to entropy ratio

$$\frac{\text{strangeness}}{\text{entropy}} \sim \frac{\langle N_{s\bar{s}}\rangle}{\langle \pi\rangle} \approx \frac{2\langle K^+\rangle}{3\langle \pi^+\rangle}$$