

# Recent measurements of identified hadron spectra and multiplicities in Be+Be and Ar+Sc collisions at SPS energies

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Preliminary results on  $\pi^+$ ,  $\pi^-$ ,  $K^+$ ,  $K^-$  and  $p$  on:

- Transverse momentum distributions.
- Rapidity distributions.
- Mean multiplicities.

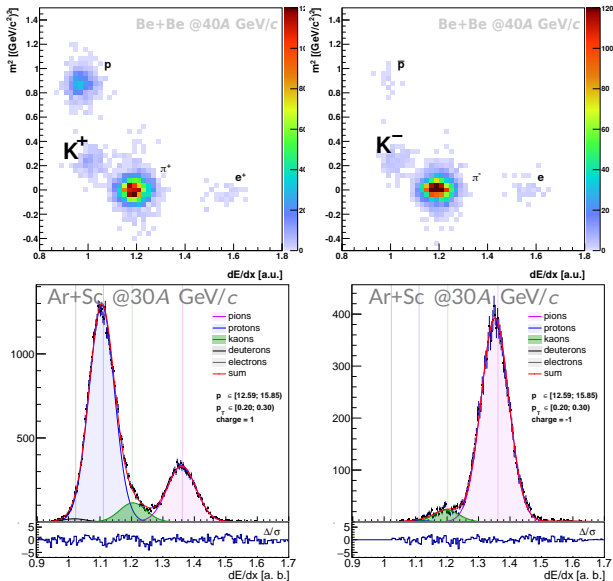
Produced in strong and electromagnetic processes in primary interactions:

- **Be+Be** – 20% most central collisions (NA61/SHINE preliminary).
- **Ar+Sc** – 5% most central collisions (NA61/SHINE preliminary).

Will be compared to available World data on **p+p**, **Au+Au** and **Pb+Pb**:

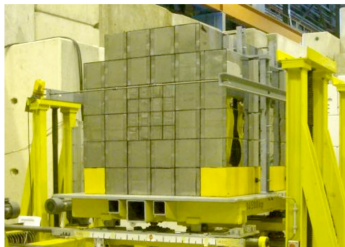
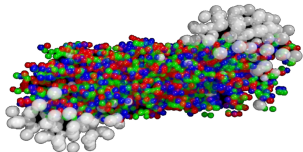
- NA61/SHINE: [Eur. Phys. J. C77 (2017) 671], [Eur. Phys. J. C74 (2014) 2794]
- NA49: [Phys. Rev. C77 (2008) 024903], [Phys. Rev. C66 (2002) 054902], [Phys. Rev. C86 (2012) 054903], [Eur. Phys. J. C68 (2010) 1; Eur. Phys. J. C45 (2006) 343]
- ALICE: [Phys. Lett. B736 (2014) 196], [Eur. Phys. J. C71 (2011) 1655], [Phys. Rev. Lett. (2012) 109]
- STAR: [Phys. Rev. C79 (2009) 034909], [Phys. Rev. C96 (2017) 044904]
- BRAHMS: [Phys. Rev. C72 (2005) 014908]
- p+p world data: [Z. Phys. C65 (1995) 215], [Phys. Rev. C69 (2004) 044903]

# Particle identification — *tof* and $dE/dx$



# Event selection – Centrality classes

Projectile Spectator Detector



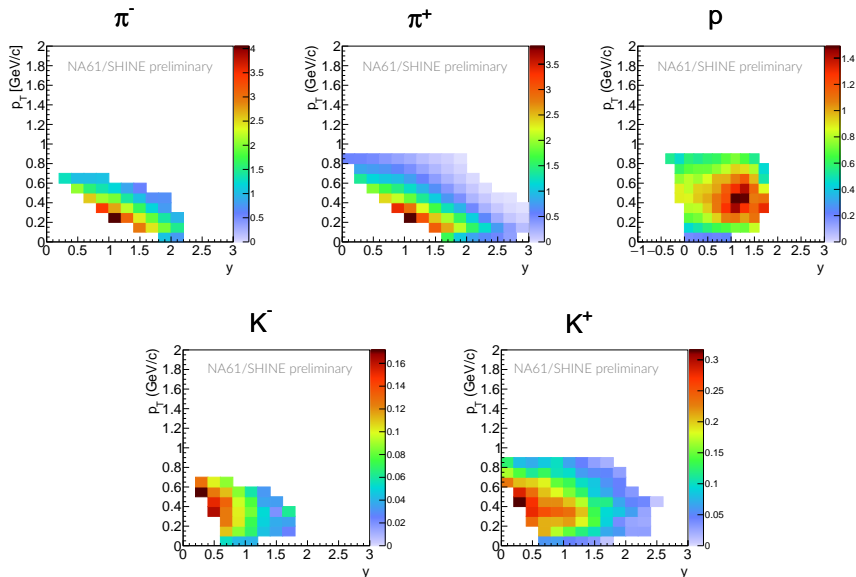
- The PSD is located most downstream on the beam line and measures the projectile spectator energy  $E_F$  of the non-interacting nucleons of the beam nucleus.
- The energy measured by the PSD is used to select events classes corresponding to the collision centrality.

# Section 1

## Identified hadrons spectra

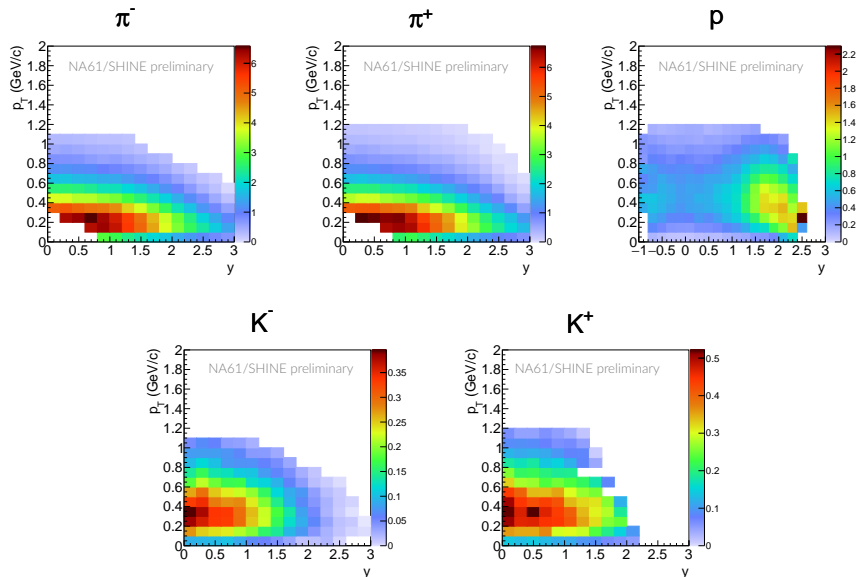
# Spectra in $y$ and $p_T$ – Be+Be @ 30A GeV/c

Preliminary results from "dEdx" analysis for 0-20% centrality



# Spectra in $y$ and $p_T$ – Be+Be @ 150A GeV/c

Preliminary results from "dEdx" analysis for 0-20% centrality

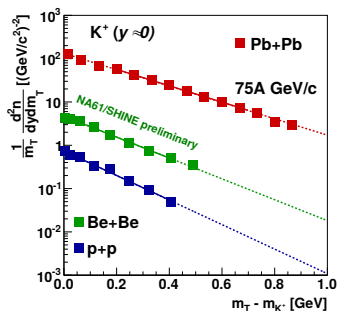
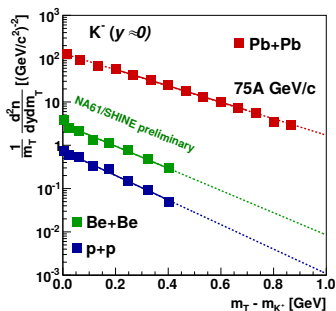


## Section 2

### Inverse slope parameter



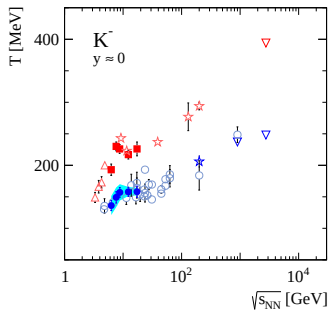
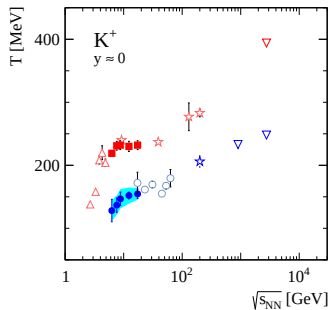
# $m_T$ distributions



Kaon spectra measured in mid-rapidity ( $0 < y < 0.2$ ) are fitted with exponential function in order to extract the inverse slope parameter  $T$ .

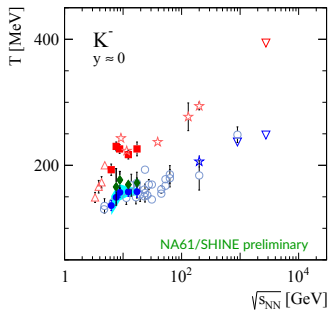
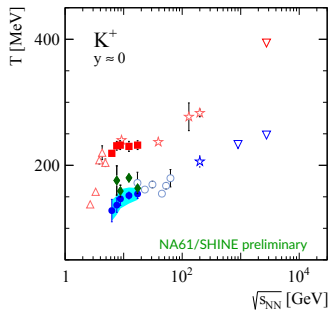
No systematic deviation from the exponent is observed in measured  $m_T$  region at all collision energies.

# Inverse slope parameter $T$



- p+p NA61 (prelim.)
- ◆ Be+Be NA61 (prelim.)
- ☆ p+p RHIC
- ▽ p+p LHC
- p+p world ( $4\pi$ )
- △ Au+Au AGS
- ☆ Au+Au RHIC
- Pb+Pb SPS
- ▽ Pb+Pb LHC

# Inverse slope parameter $T$

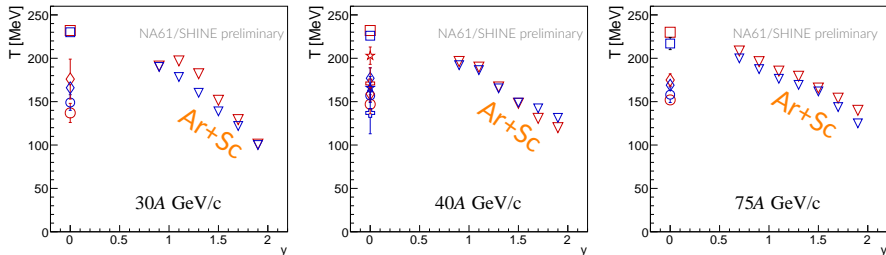


- p+p NA61 (prelim.)
- ◆ Be+Be NA61 (prelim.)
- ☆ p+p RHIC
- ▽ p+p LHC
- p+p world ( $4\pi$ )
- △ Au+Au AGS
- ☆ Au+Au RHIC
- Pb+Pb SPS
- ▽ Pb+Pb LHC

Inverse slope parameter  $T$  in **Be+Be** collisions is close to **p+p** measurements.

# Inverse slope parameter $T$

Extrapolation of Ar+Sc points to  $T(y \approx 0)$  falls close to Pb+Pb, while smaller systems are placed significantly lower.



NA61/SHINE

Ar+Sc

▽ K<sup>+</sup>

▽ K<sup>-</sup>

Be+Be

◇ K<sup>+</sup>

◇ K<sup>-</sup>

p+p

○ K<sup>+</sup>

○ K<sup>-</sup>

NA49

Pb+Pb

□ K<sup>+</sup>

□ K<sup>-</sup>

C+C

⊕ K<sup>+</sup>

⊕ K<sup>-</sup>

Si+Si

★ K<sup>+</sup>

★ K<sup>-</sup>

Preliminary

## Section 3

# Rapidity distributions

# Extrapolation in $p_T$

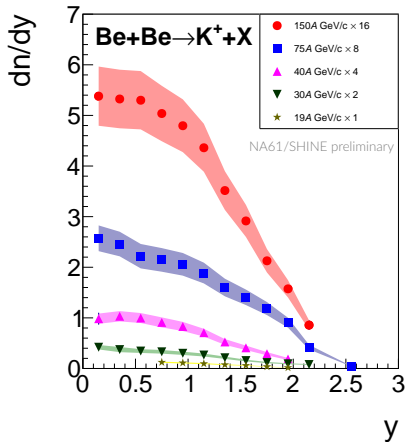
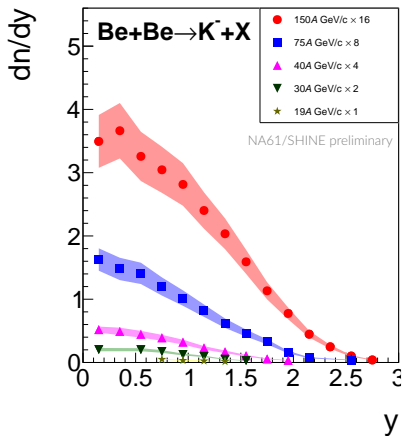
- In order to obtain  $dn/dy$  yields, the data is extrapolated in  $p_T$  to account for unmeasured regions.
- Exponential dependence in  $p_T$  is assumed:

$$\frac{1}{p_T} \frac{dn^2}{dp_T dy} = \frac{dn/dy}{T \cdot (m_K + T)} \cdot e^{-(m_T - m_K)/T}$$

- The function integral outside the acceptance region is added to the measured data points (typically of the order of 1%).

# Rapidity distributions of kaons from Be+Be collisions

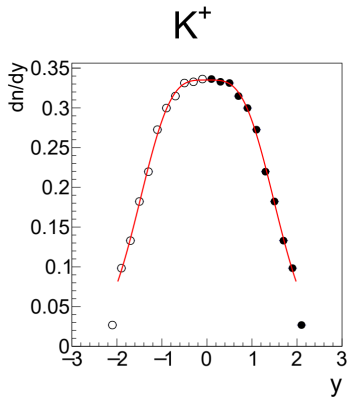
0-20% centrality, tof-dEdx and dEdx methods combined



## Obtaining "4 $\pi$ " acceptance: extrapolation in $y$

Two symmetrically placed gaussians are used to construct the fitting function:

$$f_{fit}(y) = A \times \left( \frac{1}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{(y - y_0)^2}{2\sigma_0^2}\right) + \frac{1}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{(y + y_0)^2}{2\sigma_0^2}\right) \right)$$



← Be+Be @150A GeV/c

Symmetry with respect to  $y=0$  is assumed at all beam energies.



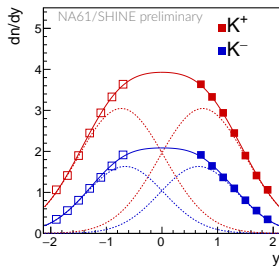
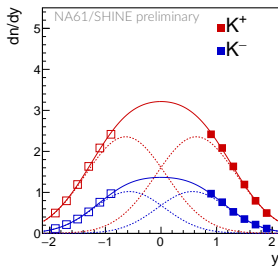
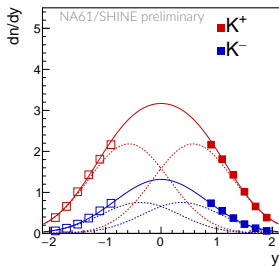
# Kaon rapidity distributions from Ar+Sc collisions

0-5% centrality, dEdx analysis method only

30A GeV/c

40A GeV/c

75A GeV/c

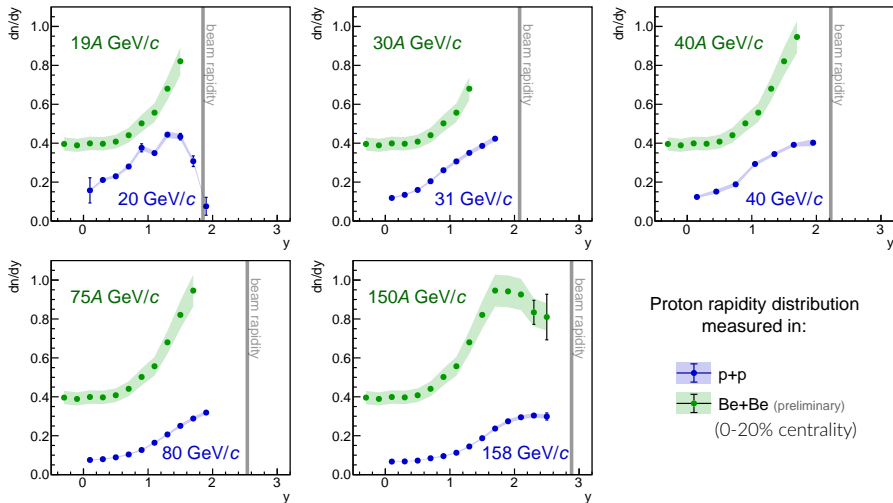


Shape parameters:  $y_0$  and  $\sigma$  are fixed to values obtained in NA49's **Pb+Pb**.

Measurements of  $tof$  will add data in  $y \approx 0$  region in the near future.

# Proton rapidity distribution

Comparison with Pb+Pb



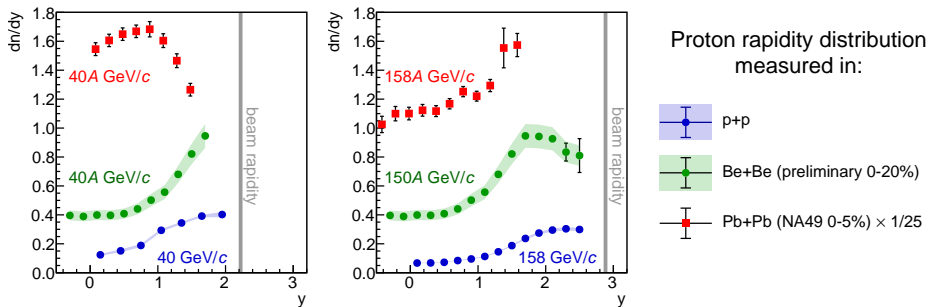
Proton rapidity distribution measured in:

- p+p
- Be+Be (preliminary)  
(0-20% centrality)

Qualitative similarity of proton  $y$  spectra in Be+Be and p+p.

# Proton rapidity distribution

Comparison of Be+Be and p+p collisions

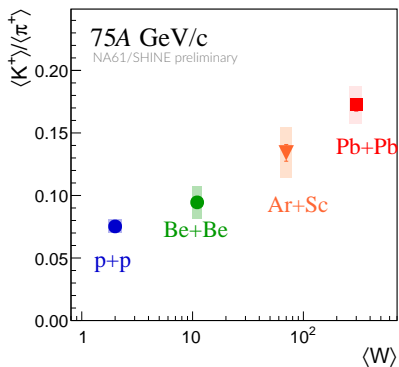
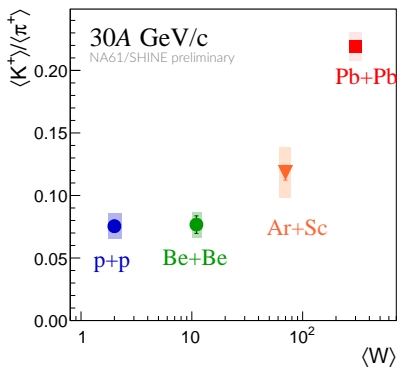


Pronounced qualitative difference of proton rapidity spectrum between light systems (p+p, Be+Be) and Pb+Pb in 40A GeV/c.

## Section 4

# Mean multiplicities with comparison to other systems

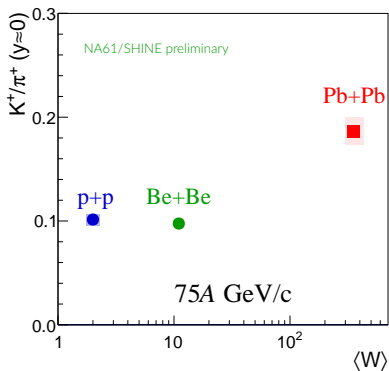
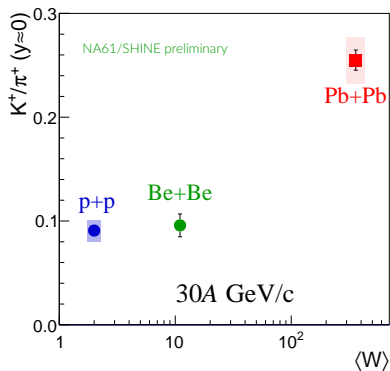
$$\langle K^+ \rangle / \langle \pi^+ \rangle$$



$\langle K^+ \rangle / \langle \pi^+ \rangle$  for Be+Be close to p+p.

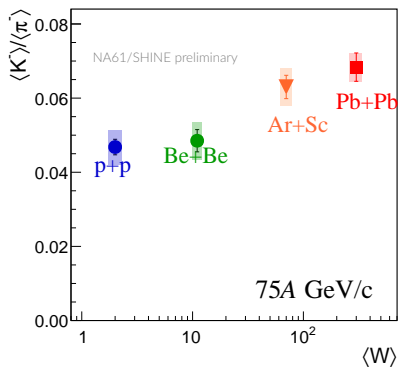
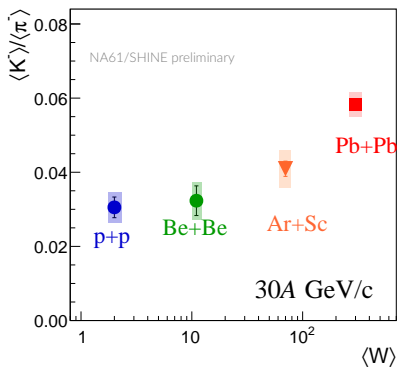
Ar+Sc placed in between p+p and Pb+Pb.

# $K^+/\pi^+$ at $y \approx 0$



$K^+/\pi^+$  at  $y \approx 0$  is similar for Be+Be and p+p and largely different for Pb+Pb.

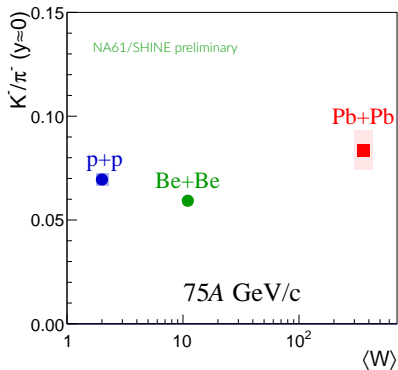
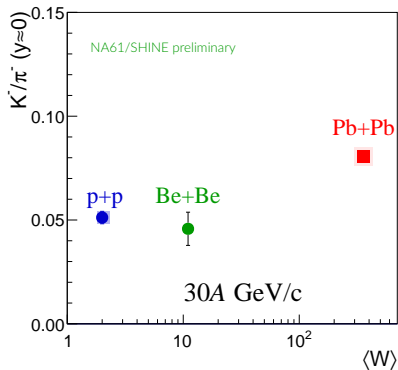
$$\langle K^- \rangle / \langle \pi^- \rangle$$



$\langle K^- \rangle / \langle \pi^- \rangle$  for Be+Be close to p+p.

Ar+Sc placed in between p+p and Pb+Pb.

# $K^-/\pi^-$ at $y \approx 0$

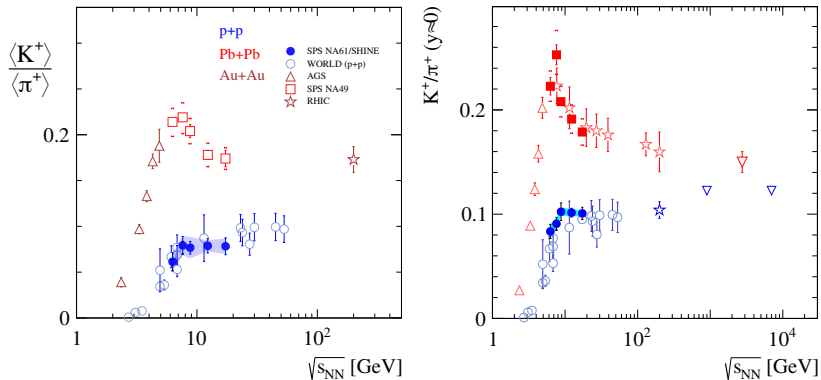


$K^+/\pi^+$  at  $y \approx 0$  for **Be+Be** is lower than results for **p+p** collisions.



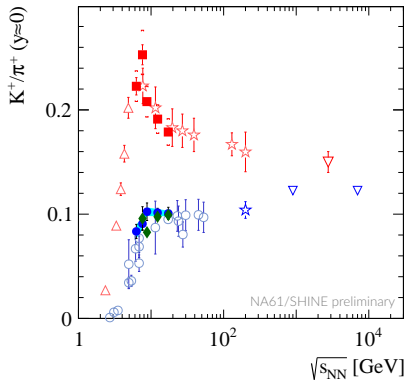
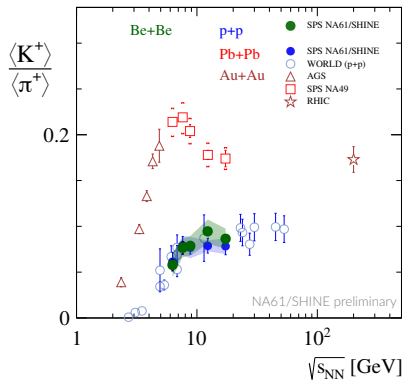
# Energy dependence of $K^+/\pi^+$

"the horn" plot



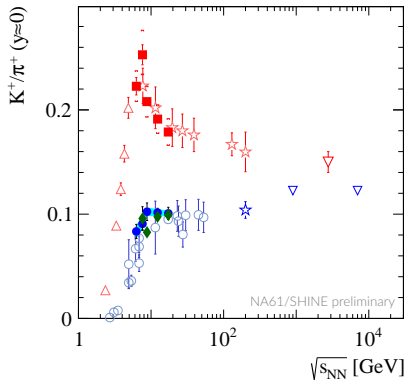
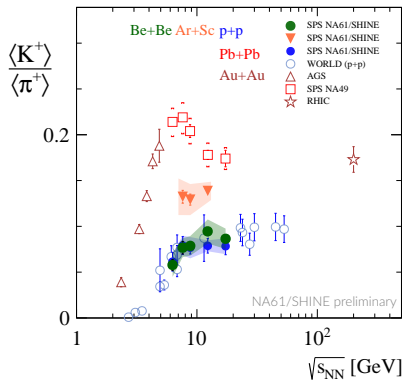
# Energy dependence of $K^+/\pi^+$

"the horn" plot



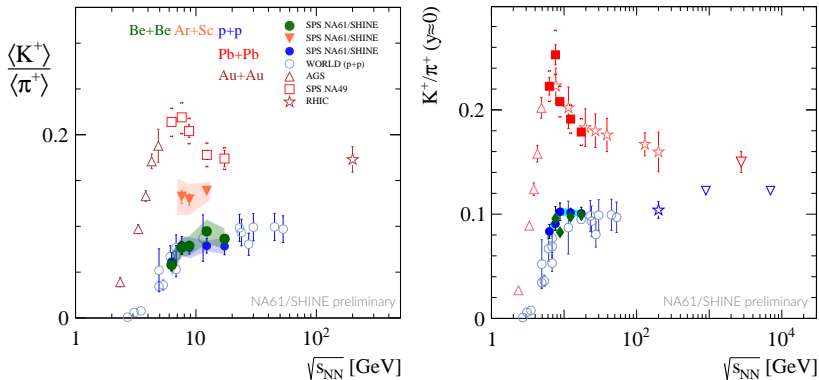
# Energy dependence of $K^+/\pi^+$

"the horn" plot



# Energy dependence of $K^+/\pi^+$

"the horn" plot



No "horn"-like structures visible in intermediate size systems: **Be+Be** and **Ar+Sc**.

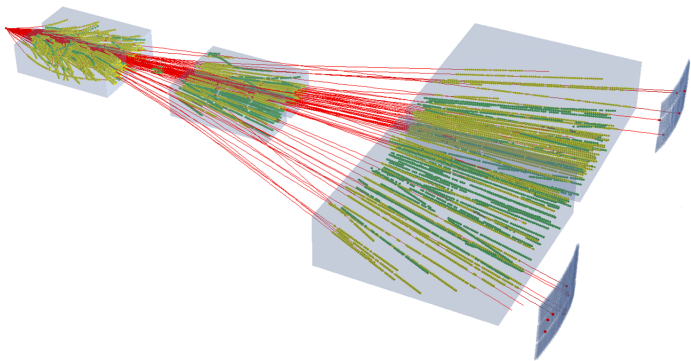
# Conclusions

Preliminary results on: – 20% most central **Be+Be** collisions were presented.  
– 5% most central **Ar+Sc**

- Spectra in  $y$  and  $p_T$  of  $\pi^+$ ,  $\pi^-$ ,  $K^+$ ,  $K^-$  and  $p$  were discussed.
- Inverse slope parameter  $T$  measured in **Be+Be** collisions is close to **p+p**, while  $T$  obtained for **Ar+Sc** closer resembles results from **Pb+Pb**.
- The measurements of  $K^+/\pi^+$  and  $K^-/\pi^-$  ratios show similar trend in system size dependence – data on **Be+Be** is usually closer to **p+p**, while results on **Ar+Sc** are placed in between **p+p** and **Pb+Pb**.
- No "horn"-like structures seen in energy dependence of  $K^+/\pi^+$  ratios measured in intermediate size systems: **Be+Be** and **Ar+Sc**.

More results on the subject will follow in the near future!

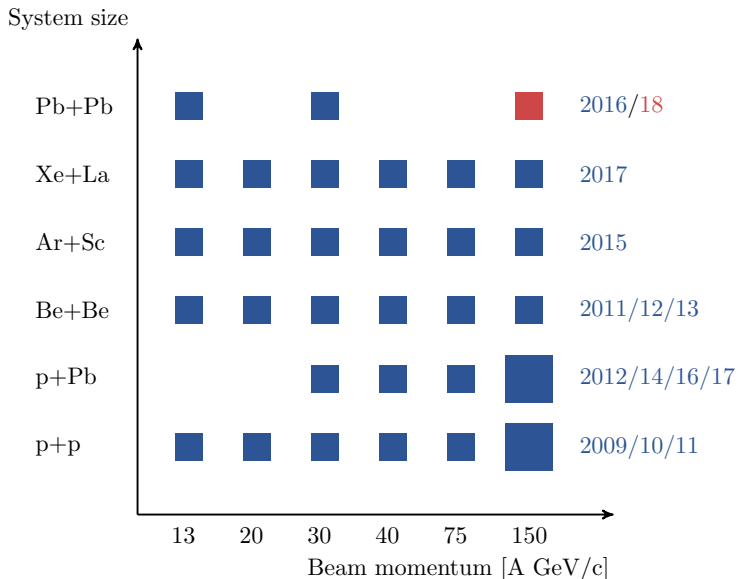
Thank you for your attention!



*Event of Ar+Sc collision  
recorded by NA61/SHINE*

Backup slides

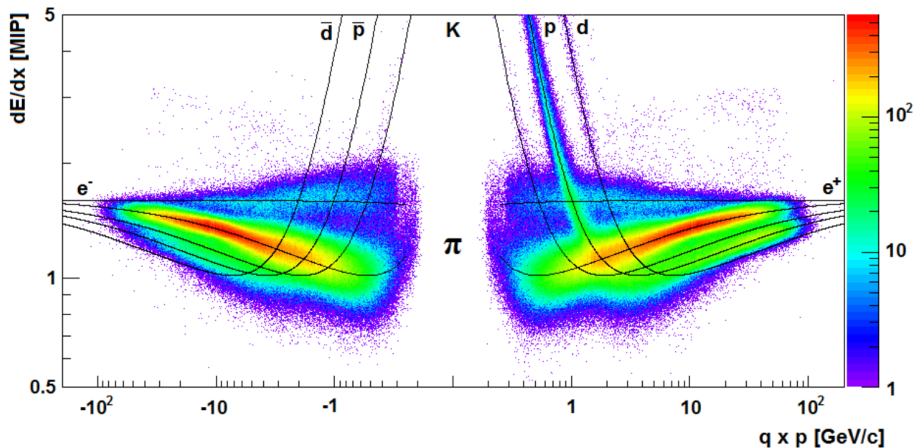
# NA61/SHINE Schedule



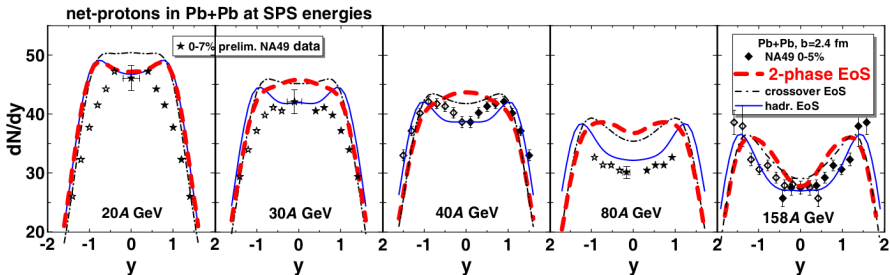
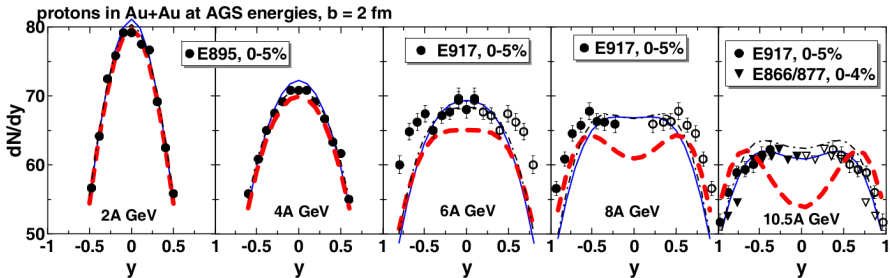


# $dE/dx$ distribution

p+p data



# Baryon stopping



# K/ $\pi$ @ 40A GeV/c

