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PION SPECTRA IN AR+SC INTERACTIONS



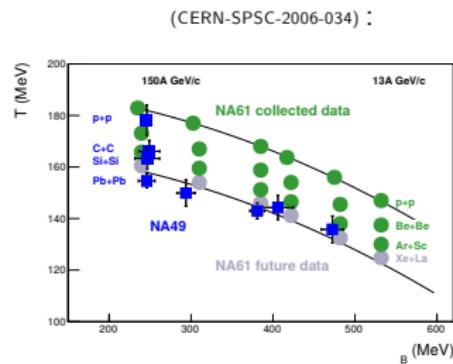
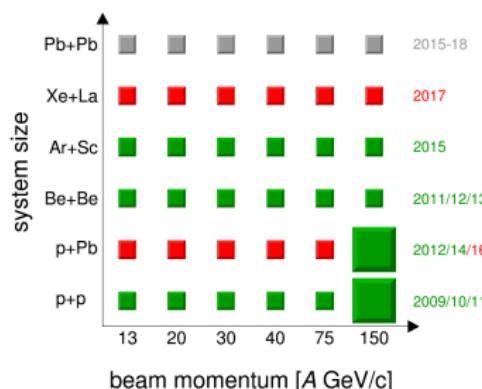
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Faculty of Physics and Astronomy
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October 3, 2016

- ▶ The search for the **critical point** of the phase transition
- ▶ The study of the **onset of deconfinement**.

Two-dimensional scan in collision energy and the system size probes the QCD phase diagram:



This presentation focuses on the preliminary results on **Ar+Sc** collisions.

$^{40}\text{Ar} + ^{45}\text{Sc}$ energy scan:

13A, 19A, 30A, 40A, 75A, 150A GeV/c:

- ▶ Preliminary results on π^- produced in strong and electromagnetic processes at the primary interactions.
Selected 0%-5% most central events.
 - Double differential spectra in **transverse momentum** ($p_T = \sqrt{p_x^2 + p_y^2}$) and **rapidity** (y).
 - Rapidity spectra.
 - **Asymmetry** of the rapidity distribution.
 - **Width** of the rapidity distribution.
 - Spectra of **transverse mass** $m_T = \sqrt{m_{\pi^-}^2 + p_T^2}$.
- ▶ **System size dependence** of π^- spectra –
 - a comparison with other systems (p+p, Be+Be, Pb+Pb).

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 π^- SPECTRASYSTEM SIZE
DEPENDENCE

SUMMARY

PRESENTED Ar+Sc DATA

- **Ar+Sc 5% most central collisions from NA61/SHINE**
at: $19A$, $30A$, $40A$, $75A$ and $150A$ GeV/c

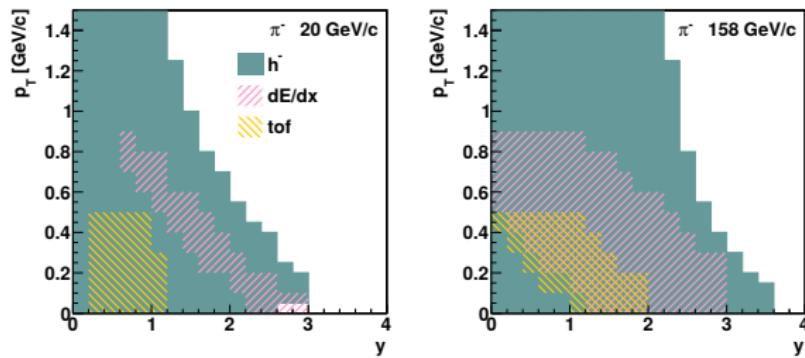
OTHER SYSTEMS

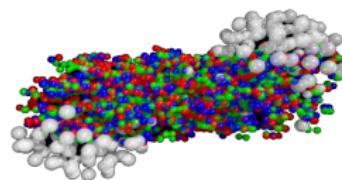
- **p+p inelastic collisions from NA61/SHINE**
at: 20 , 31 , 40 , 80 and 158 GeV/c
[Eur.Phys.J. C74 (2014) 2794]
- **Be+Be 5% most central collisions from NA61/SHINE**
at: $19A$, $30A$, $40A$, $75A$ and $150A$ GeV/c
Preliminary results: [PoS CP0D2014 (2015) 053]
- **Pb+Pb 5%-7% most central collisions from NA49**
at: $20A$, $31A$, $40A$, $80A$ and $158A$ GeV/c
[Phys.Rev.C (2002) 66:054902; Phys.Rev.C (2008) 77:024903]

Using spectra of negatively charged hadrons for pion analysis

- ▶ $\approx 90\%$ of produced negatively charged hadrons are π^- .
- ▶ A small contribution of other particles (K^- , \bar{p} , and decays from Λ and K_S^0) is subtracted based on EPOS model.
- ▶ The dE/dx and tof identification methods cover much narrower region of the phase-space.

Example of coverage for p+p interactions:





- ▶ 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.

For details please see Andrey Seryakov's presentation.



MODEL CORRECTIONS

- ▶ Monte Carlo used for corrections: EPOS1.99 model (version CRMC 1.5.3), GEANT3.2.
- ▶ The centrality classes selected by the number of forward spectators.

ERRORS

- ▶ All data points are drawn with statistical errors only. There are two sources:
 - Data uncertainties.
 - MC corrections uncertainties (insignificant).
- ▶ Based on a previous analysis for other systems (i.e. Be+Be, p+p) in NA61/SHINE, we estimate systematic errors on a level of 5%-10%.

DOUBLE DIFFERENTIAL π^- SPECTRA

p_T VS y IN AR+SC COLLISIONS – PRELIMINARY

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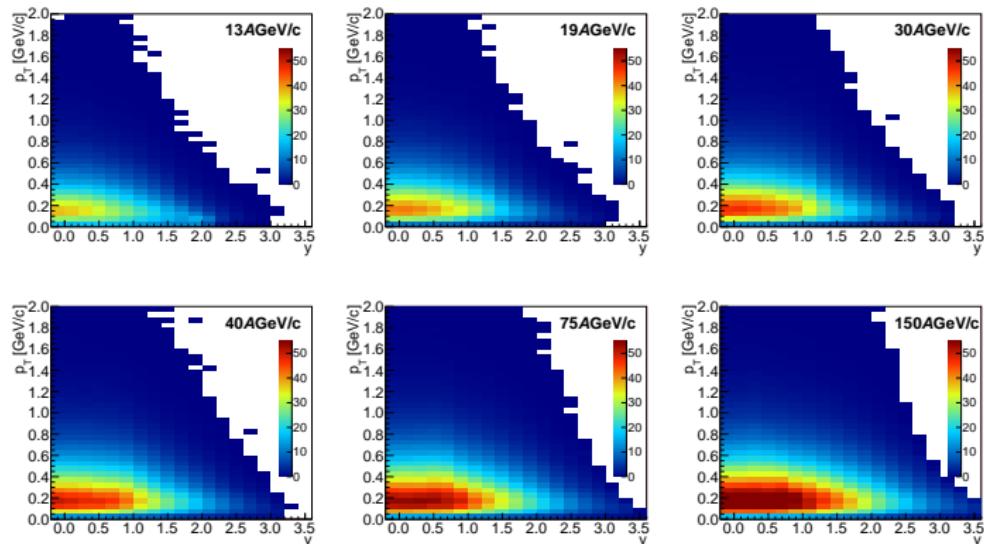
π^- SPECTRA

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Preliminary double differential spectra:

$$\frac{dn^2}{dy \ dp_T}$$

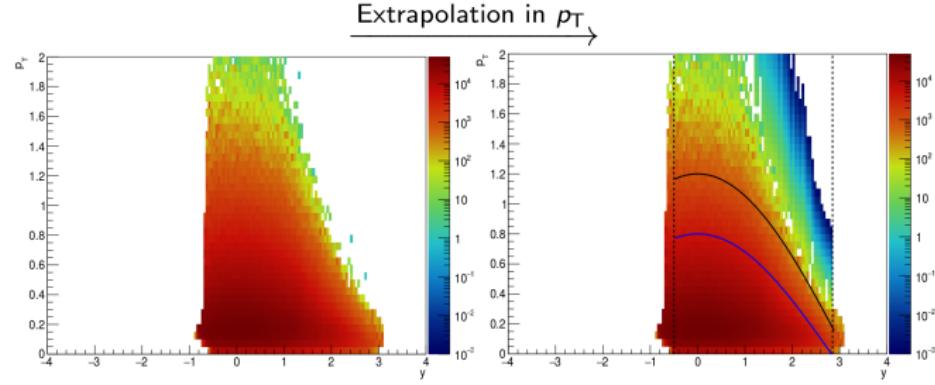


Measurements cover almost full acceptance in the forward rapidity.

EXTRAPOLATION IN p_T

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- ▶ In order to increase the accuracy, the data is extrapolated beyond the detector acceptance.
- ▶ Exponential dependence in p_T is assumed.
- ▶ The extrapolation functions are fitted in the region between the blue and the black curve.
- ▶ The function integral from acceptance edge to $p_T = 3.0$ is added to the rapidity bin.

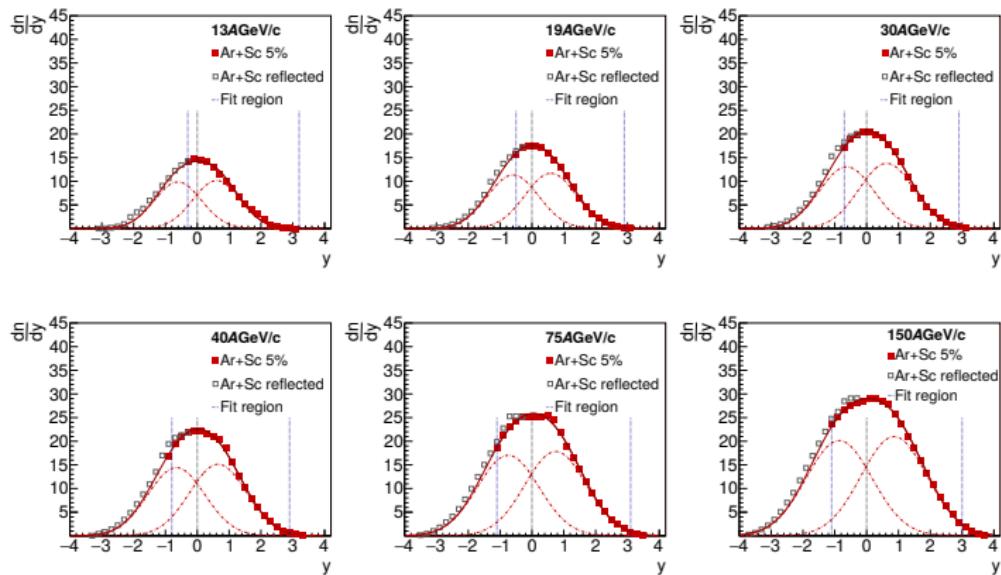


π^- RAPIDITY SPECTRA

PRELIMINARY RESULTS

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Spectra indicate an asymmetry with respect to c.o.m. rapidity.

Preliminary results



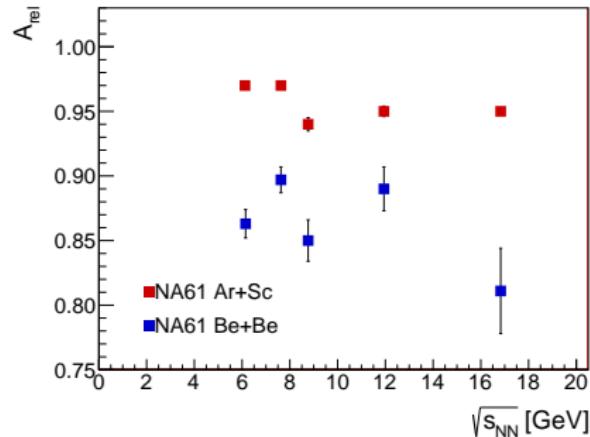
Two symmetricaly placed gaussians, with different amplitudes, are used to construct the fitting function:

$$f_1 = \frac{A_0 A_{rel}}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{(y - y_0)^2}{2\sigma_0^2}\right), \quad f_2 = \frac{A_0}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{(y + y_0)^2}{2\sigma_0^2}\right)$$

$$f_{fit} = f_1 + f_2$$

Energy	A_0	A_{rel}	σ_0	y_0	σ
13. A GeV/c	18.61 ± 0.019	0.97 ± 0.0002	0.60 ± 0.0014	0.72 ± 0.0010	0.94 ± 0.043
19. A GeV/c	23.59 ± 0.017	0.97 ± 0.0036	0.59 ± 0.0018	0.80 ± 0.0016	0.99 ± 0.049
30. A GeV/c	29.78 ± 0.049	0.94 ± 0.0051	0.62 ± 0.0026	0.86 ± 0.0018	1.06 ± 0.053
40. A GeV/c	33.88 ± 0.045	0.95 ± 0.0040	0.65 ± 0.0021	0.89 ± 0.0016	1.10 ± 0.048
75. A GeV/c	43.09 ± 0.034	0.95 ± 0.0021	0.74 ± 0.0013	0.96 ± 0.0012	1.21 ± 0.038
150. A GeV/c	54.39 ± 0.040	0.96 ± 0.0019	0.86 ± 0.0011	1.03 ± 0.0013	1.34 ± 0.036

Where $\sigma = \sqrt{\sigma_0^2 + y_0^2}$.



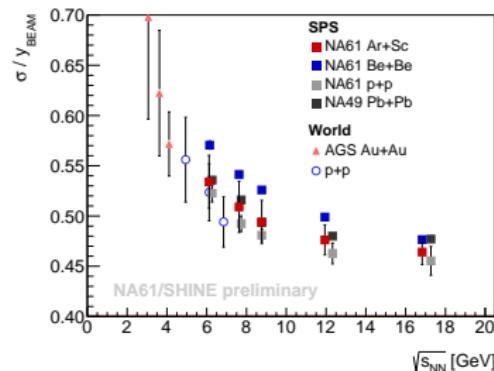
Two opposite effects influence the asymmetry of the spectra:

- ▶ Asymmetric system – ^{40}Ar projectile on ^{45}Sc target (small effect, > 1).
- ▶ Centrality selection based on projectile spectators (large effect, < 1).

RAPIDITY DISTRIBUTION WIDTH

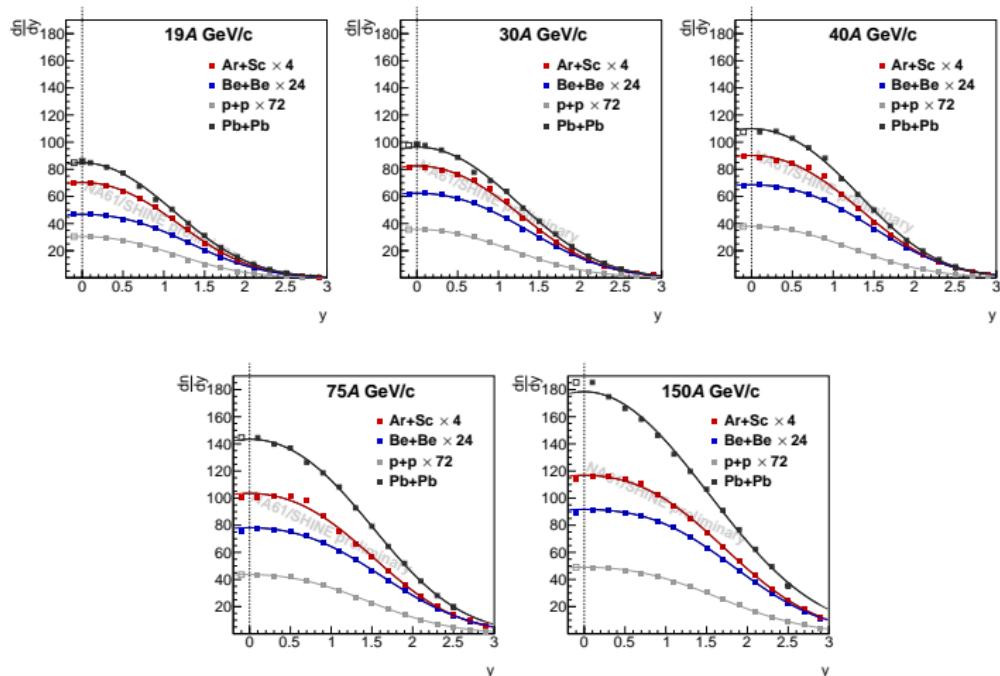
PRELIMINARY RESULTS

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- ▶ The width σ shows monotonic behavior with increasing energy.
- ▶ Non-monotonic behavior is observed in dependence on the system size:
$$\frac{\sigma_y(\text{p+p})}{y_{\text{beam}}} < \frac{\sigma_y(\text{Ar+Sc})}{y_{\text{beam}}} \approx \frac{\sigma_y(\text{Pb+Pb})}{y_{\text{beam}}} < \frac{\sigma_y(\text{Be+Be})}{y_{\text{beam}}}$$
- ▶ Shown p+p collisions are uncorrected for isospin effects.

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



Lines to guide the eye

Preliminary results

π^- RAPIDITY SPECTRA

RATIO TO $p + p$ COLLISIONS

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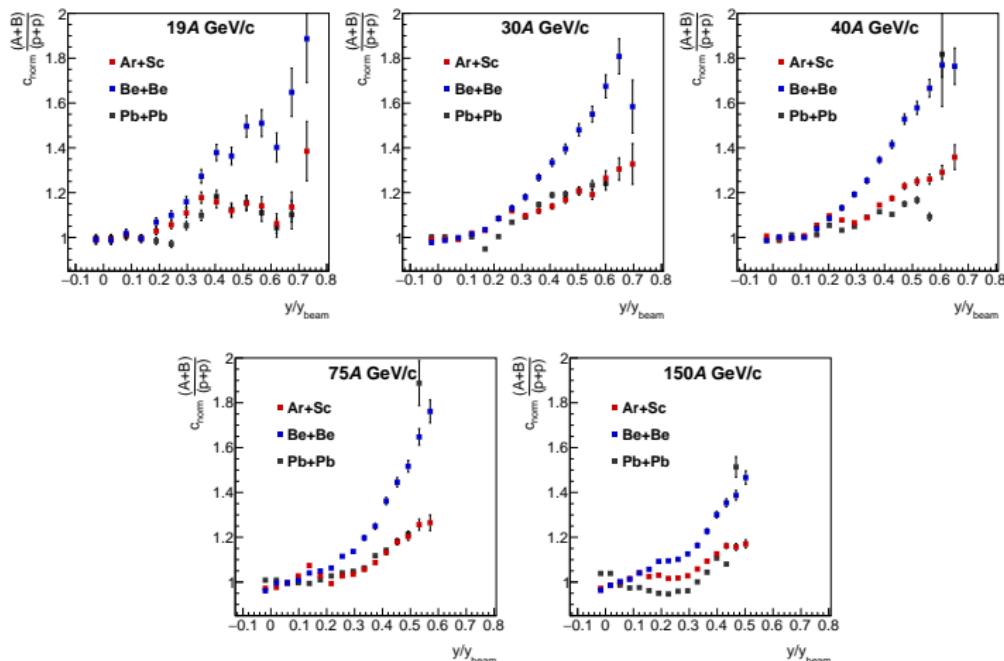
ERRORS

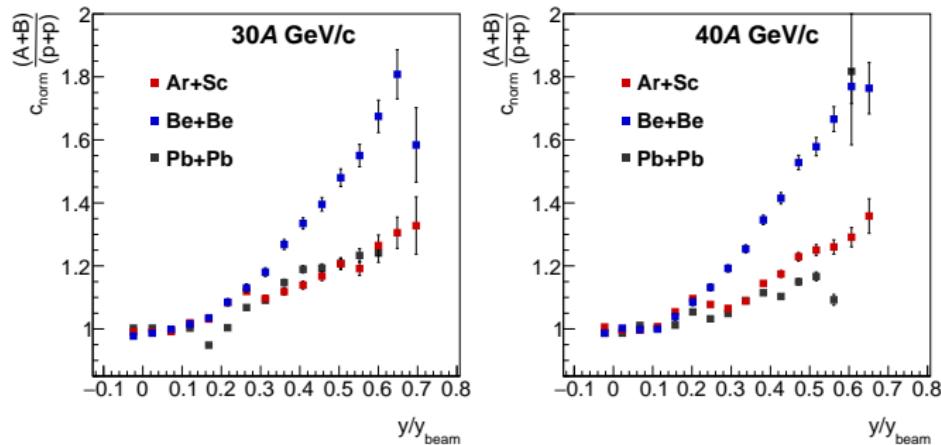
 π^- SPECTRASYSTEM SIZE
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SUMMARY

Normalized $\frac{dn}{dy}$ spectra divided by the normalized $\frac{dn}{dy}$ data on $p+p$ inelastic interactions.

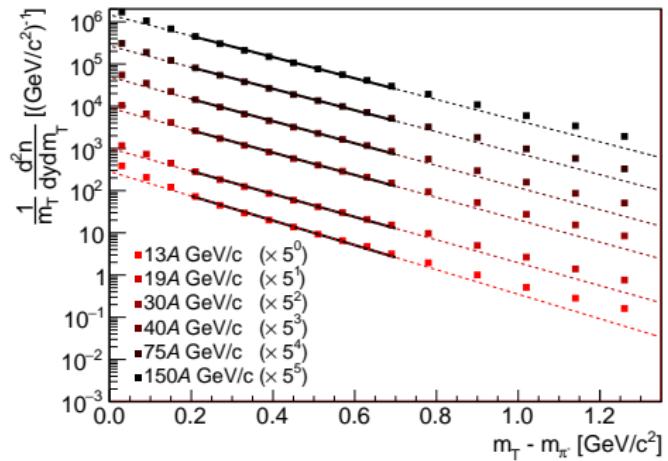
"Normalized" – divided by integral in $y \in (0.0, 0.5)$.





- ▶ The spectrum shape for **Ar+Sc** interactions is resembling very closely **Pb+Pb** spectrum.
- ▶ **Ar+Sc** spectra differ significantly from the ones for **Be+Be**.

Preliminary results



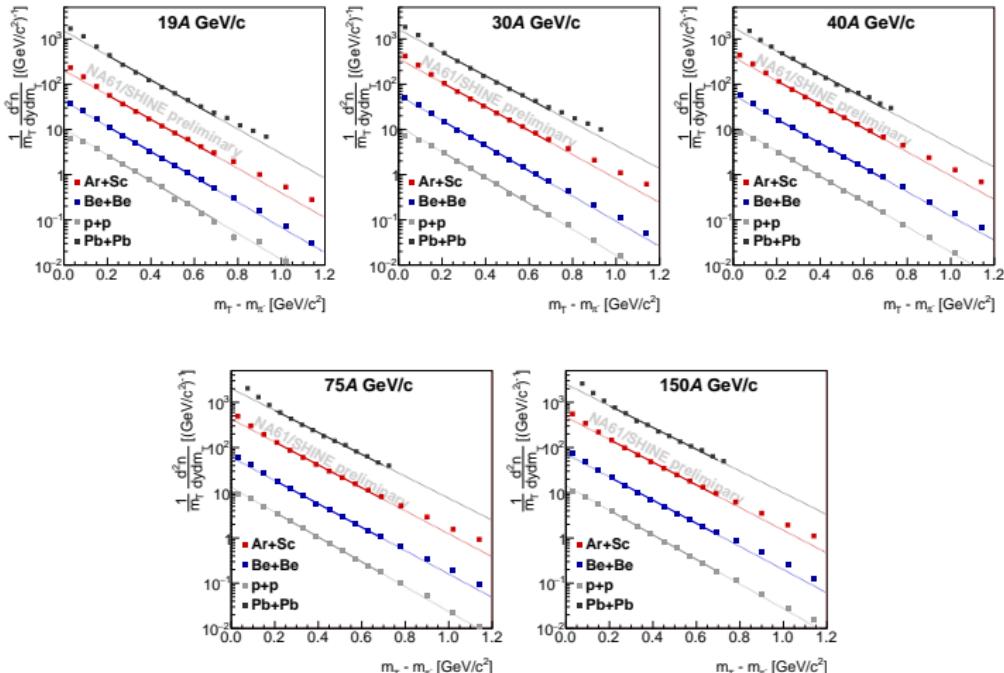
- ▶ The m_T spectra are scaled by an arbitrary constant for a better clarity of the plot.
- ▶ Indications of the radial flow in high m_T .

Preliminary results

m_T SPECTRA – SYSTEM SIZE DEPENDENCE

MIDRAPIDITY: ($y \in (-0.2; 0.2)$)

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m_T SPECTRA – RATIO TO $p + p$ COLLISIONS

MIDRAPIDITY: ($y \in (-0.2; 0.2)$)

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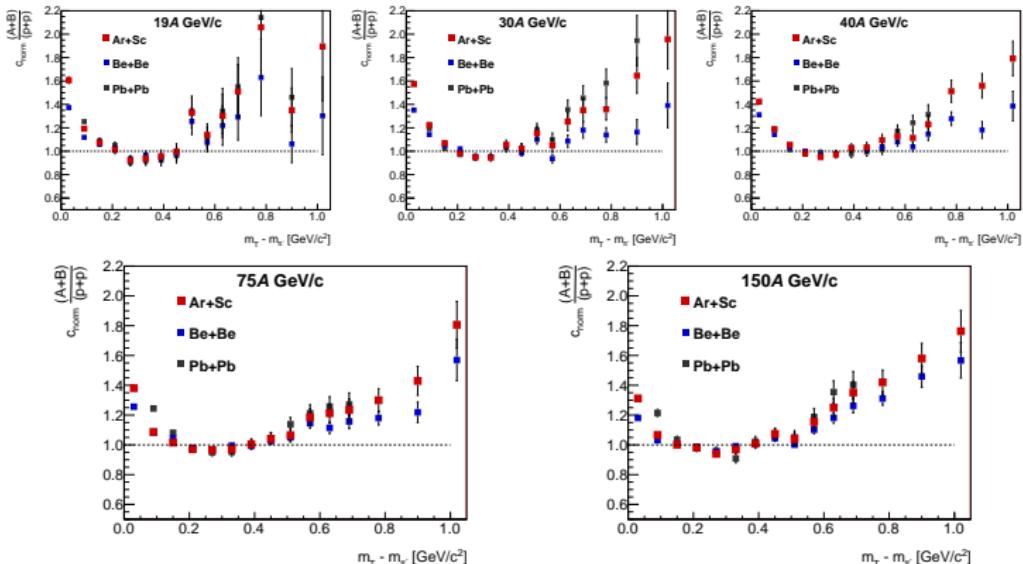
π^- SPECTRA

SYSTEM SIZE
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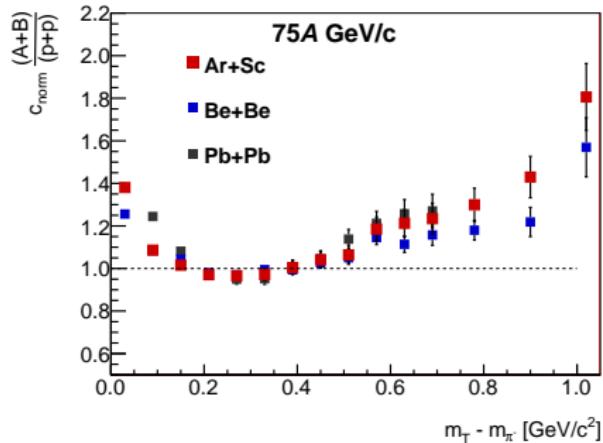
Normalized ion spectra divided by the normalized $p+p$ data.

"Normalized" – divided by integral in $(m_T - m_{\pi^-}) \in (0.2, 0.7)$.



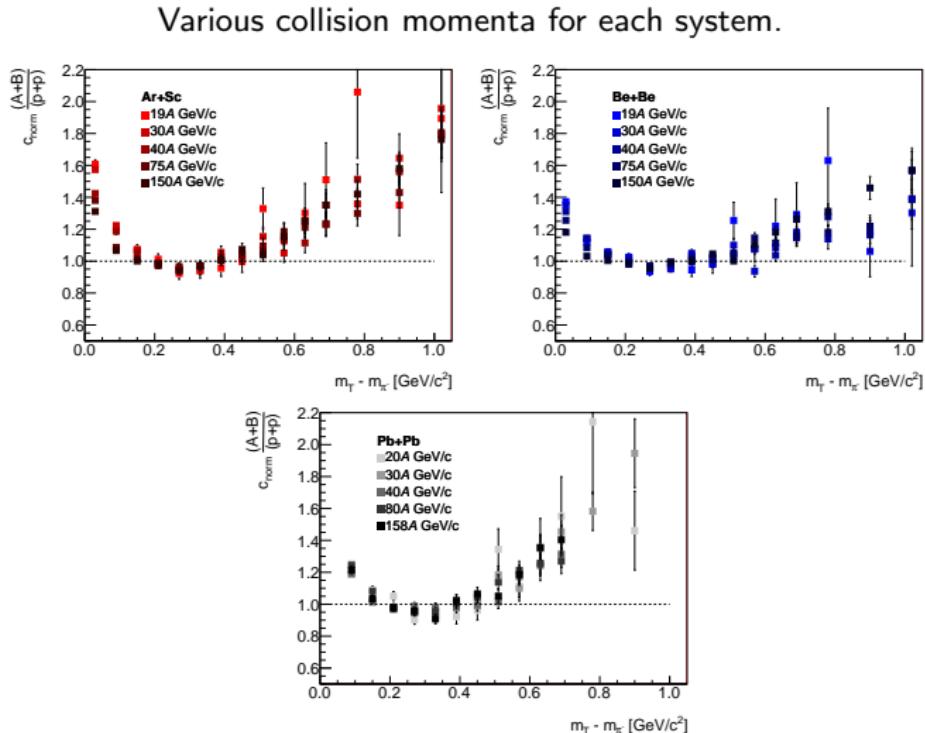
Various systems for each collision momentum.

Preliminary results



- ▶ The shape of the m_T spectra for all ions' interactions is similar.
- ▶ The deviation from the $p+p$ data in high m_T is higher for heavier ions.

Preliminary results



Preliminary results



The new preliminary results on negative pion production properties in **Ar+Sc** at six beam momenta (13A-150A GeV/c) were presented.

- ▶ Rapidity spectrum is almost symmetric for **Ar+Sc** interaction (**Be+Be** data shows far higher asymmetry).
- ▶ The rapidity distribution width decreases monotonically with collision energy and falls close to the values for **Pb+Pb**
- ▶ The rapidity spectrum shape resembles the one of **Pb+Pb** interactions.
- ▶ The m_T distribution for all compared ion systems is qualitatively similar. This suggests the presence of the radial flow.

More analysis on this subject will follow in a near future.



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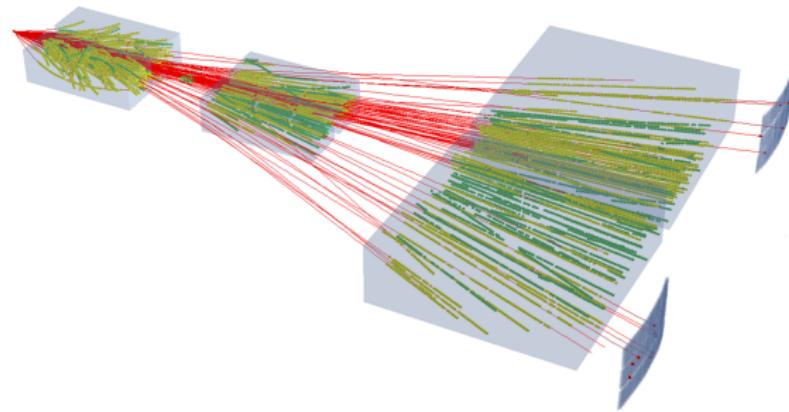
ERRORS

π^- SPECTRA

SYSTEM SIZE
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SUMMARY

Thank you for your attention!



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



BACKUP SLIDES



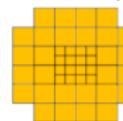
- ▶ Checked on **p+p** data:
 - The EPOS model reproduced the K^-/π^- ratio very well.
 - The EPOS model reproduced the Λ production well.
 - "h⁻" reproduced very well the results from dE/dx and dE/dx -tof analysis.
- ▶ ... and on **Be+Be** data
 - Preliminary results on dE/dx and dE/dx -tof analysis showed good agreement.

Due to the:

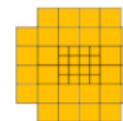
- ▶ Ratio of *Fermi motion* to the beam rapidity,
- ▶ Differences in magnetic field and
- ▶ PSD position for various energies,

different set of modules is chosen to calculate the E_F :

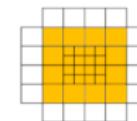
13 AGeV/c



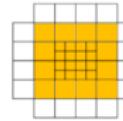
19 AGeV/c



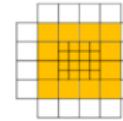
30 AGeV/c



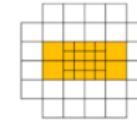
40 AGeV/c



75 AGeV/c



150 AGeV/c



The module sets are chosen on the basis of correlations between energy and multiplicity for each module.

The comparison of the slope T of the fitted exponents.
(The errors are fit uncertainties)

