

# News from the NA61/SHINE

Marjan Ćirković

NA61/SHINE Collaboration

Faculty of Physics, University of Belgrade

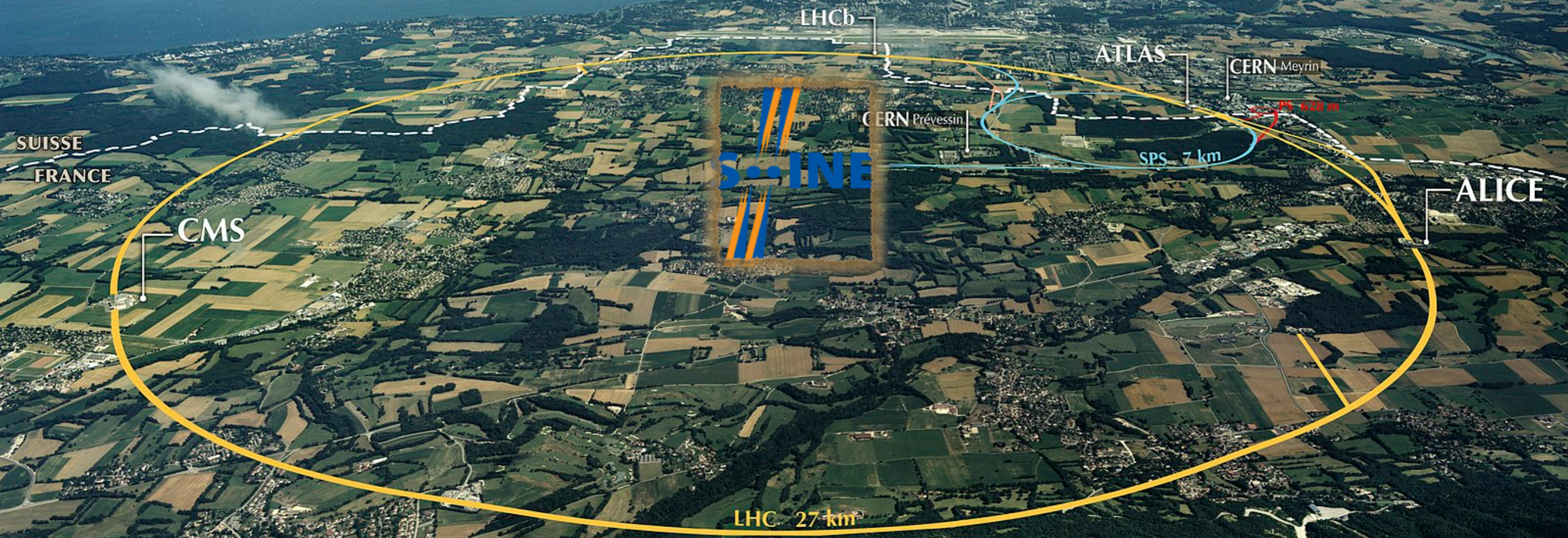
XII Collaboration Meeting of the MPD Experiment at  
the NICA Facility



October 6, 2023

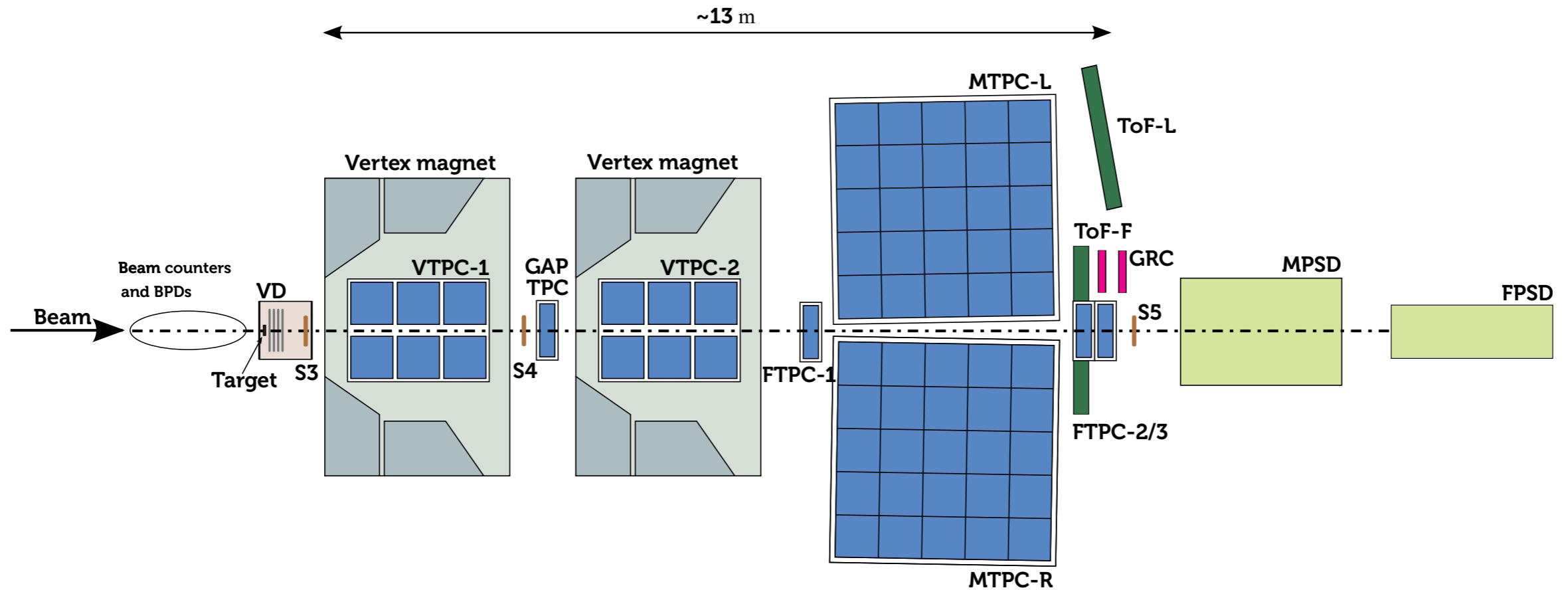


# NA61/SHINE - UNIQUE MULTIPURPOSE FACILITY: Hadron production in hadron+nucleus and nucleus+nucleus collisions at the high energy.



# Upgraded NA61/SHINE detector

coverage of the full forward hemisphere, down to  $p_T = 0$



- ion beams (Pb and others)  
 $p_{beam} = 13A - 150A \text{ GeV}/c$

- hadron beams ( $p, \pi, K$ )  
 $p_{beam} = 13 - 400 \text{ GeV}/c$

$$\sqrt{s_{NN}} = 5.1 - 16.8(27.4) \text{ GeV}$$

- Readout rate increased to 1kHz (more than factor 10 increased)
- New Vertex Detector
- New ToF system (MRPC-L)
- New DAQ and trigger system
- Upgraded PSD

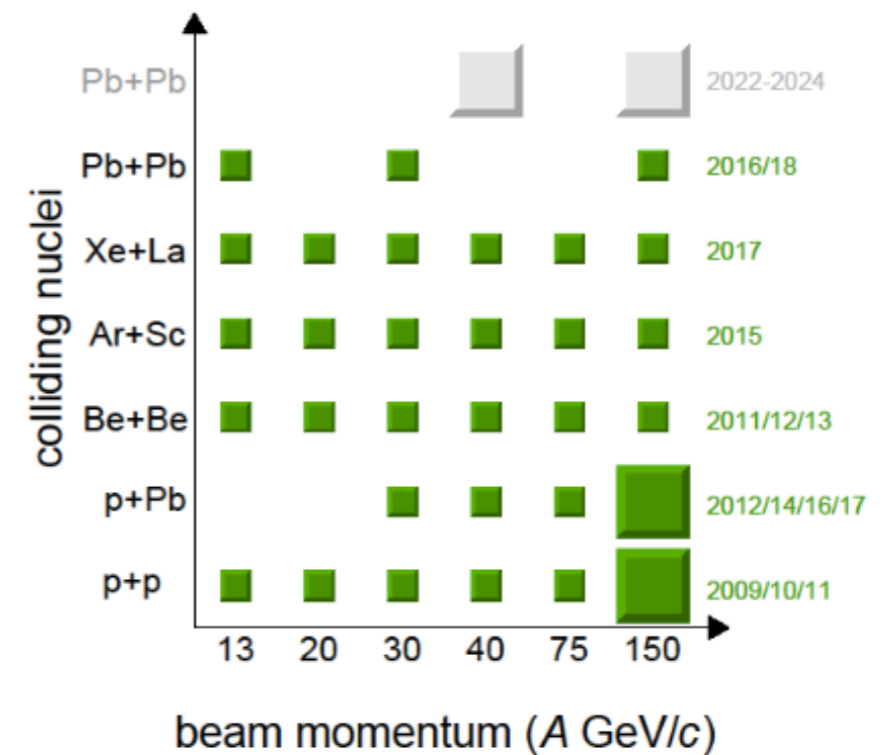
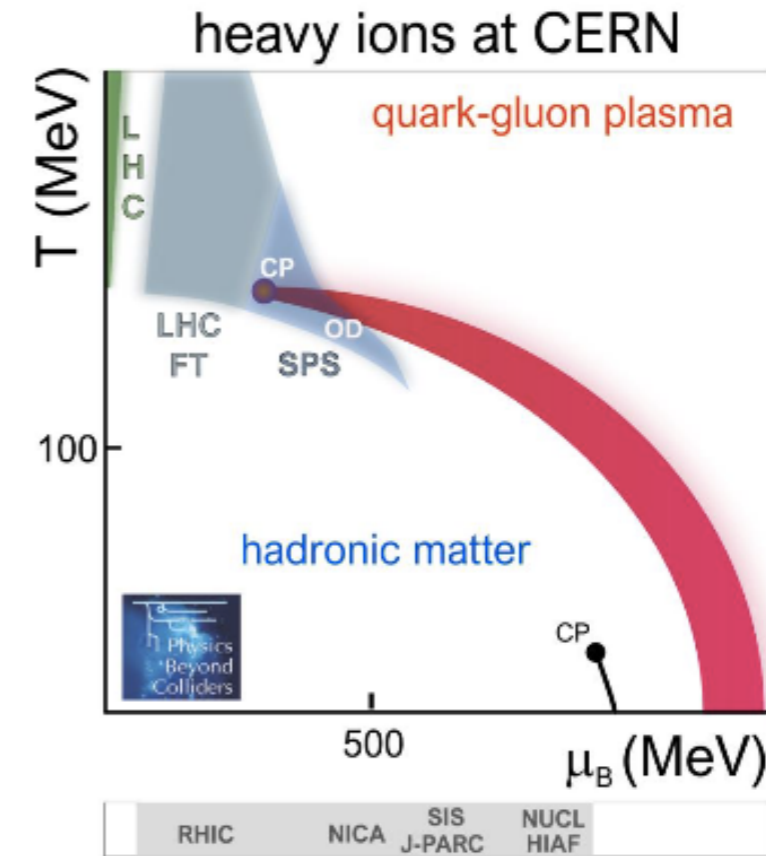
# NA61/SHINE physics program

## Strong interactions physics:

- Study of the properties of the **onset of deconfinement**.
- Search for the **critical point** of strongly interacting matter.
- Heavy quarks: direct measurement of **open charm at SPS energies**.

## Neutrino and cosmic ray physics:

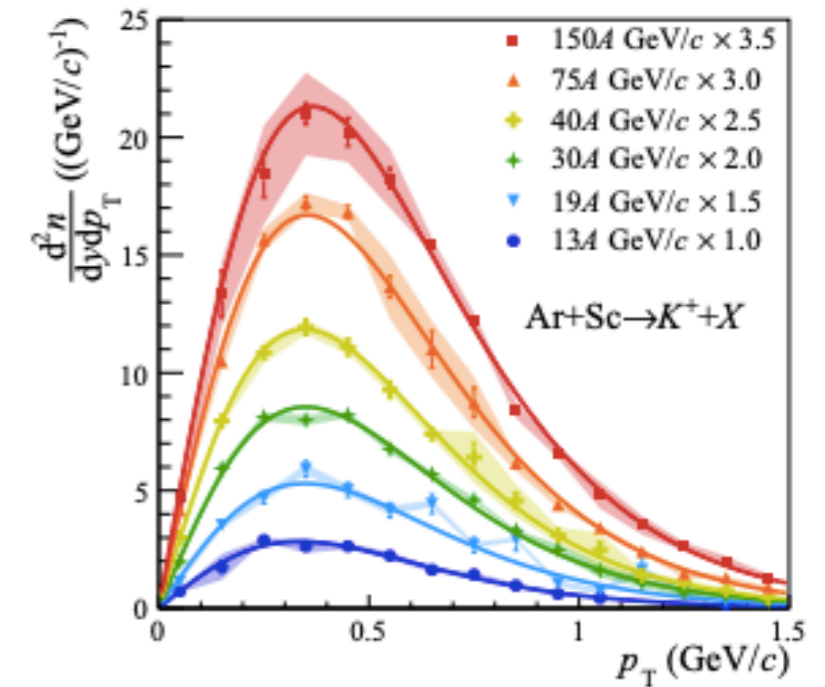
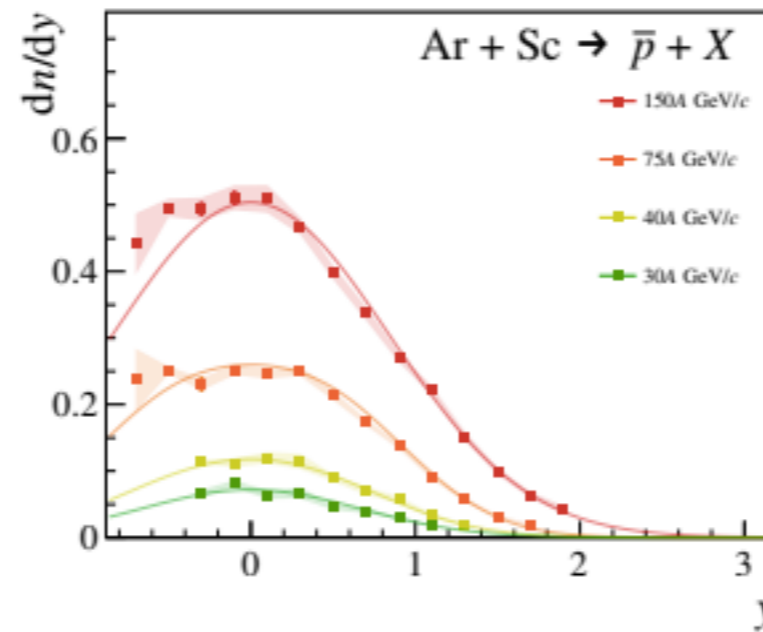
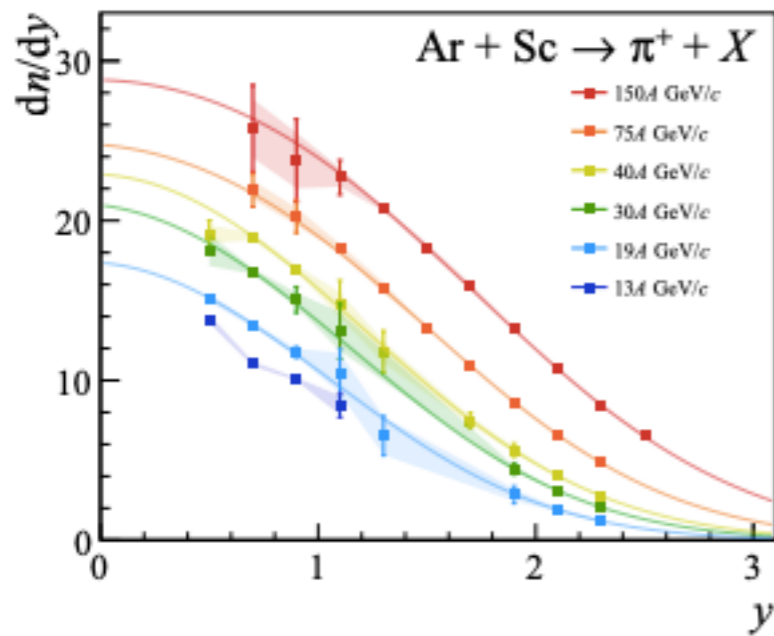
- Measurement for neutrino programs at J-PARC and FERMILAB.
- Measurements of nuclear fragmentation cross section for cosmic ray physics.



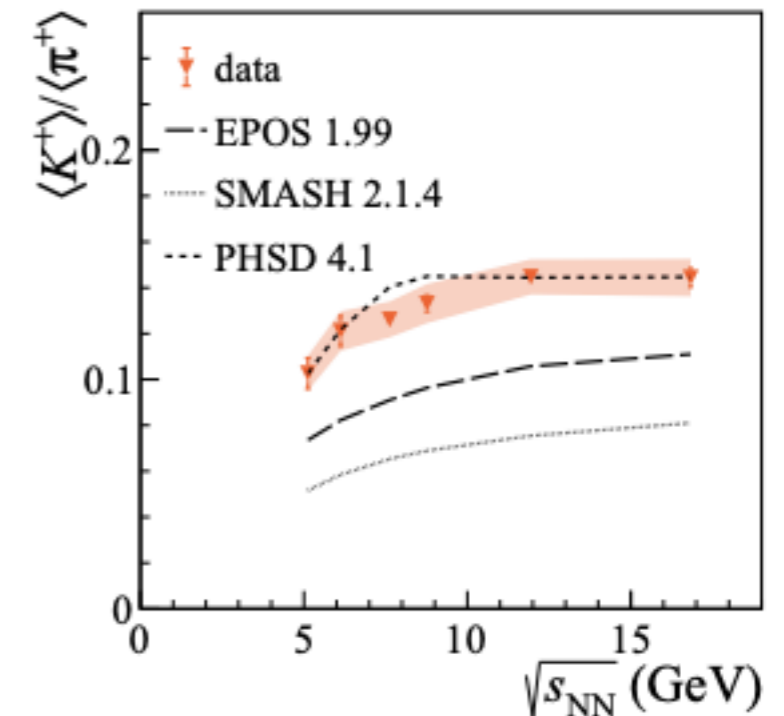


# Onset of deconfinement

# Spectra of charged particles in Ar+Sc

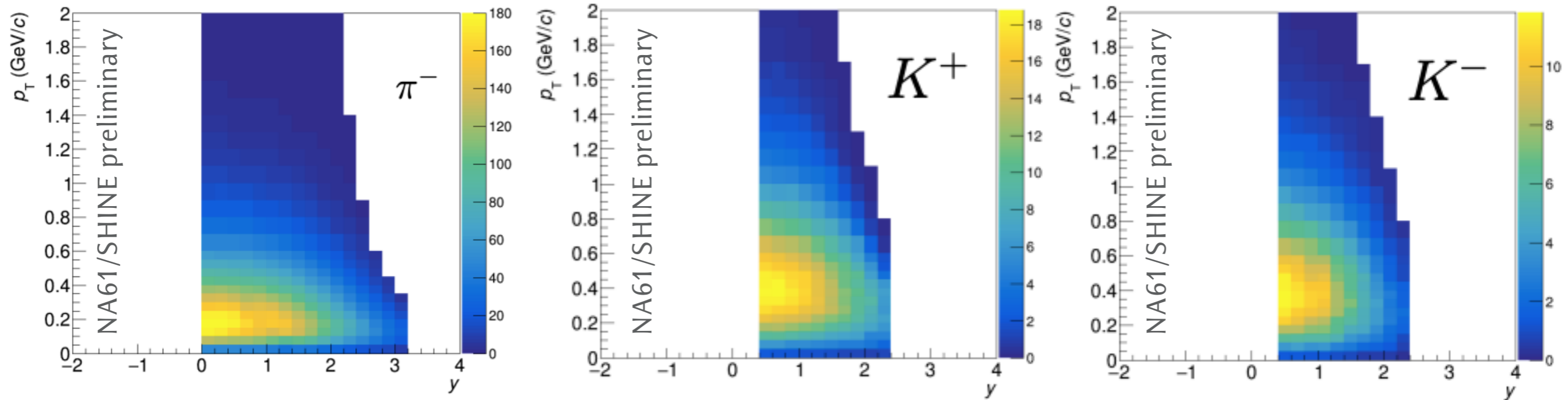


- New final results on  $K^\pm$ ,  $\pi^\pm$ ,  $p$  and  $\bar{p}$  in **Ar+Sc**.
- 0-10% of the most central collisions.
- Data available at six beam energies in range  $\sqrt{s_{NN}} = 5.1 - 16.8$  GeV.



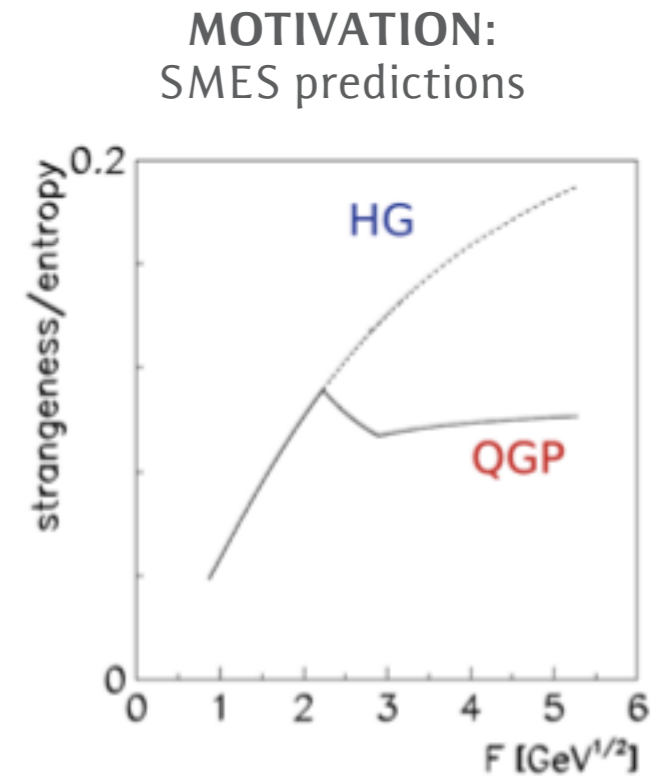
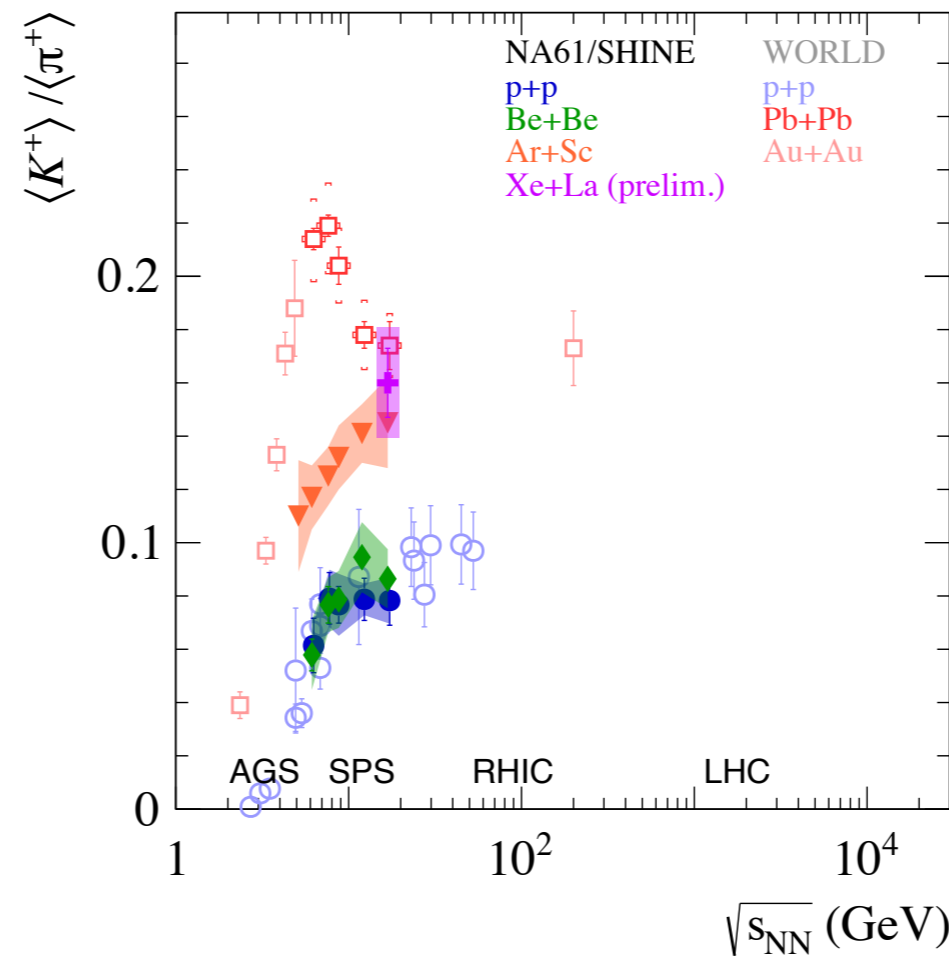
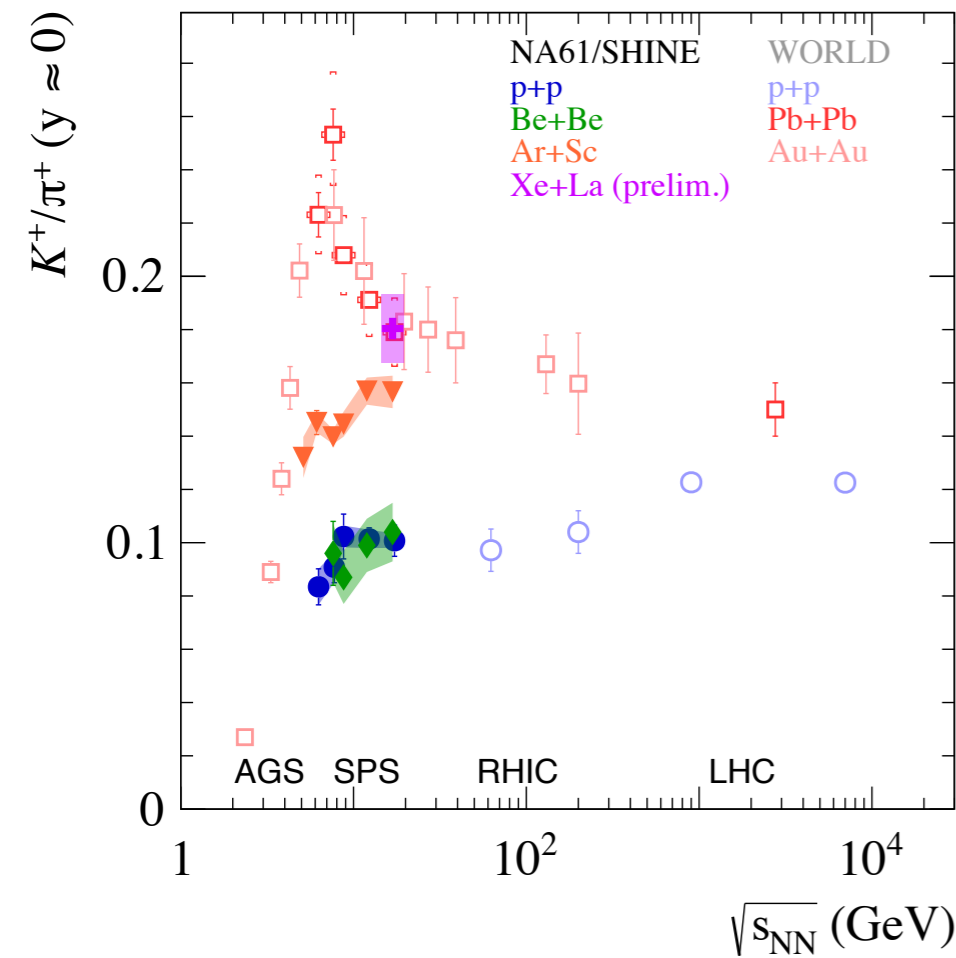
[arxiv.org/pdf/2308.16683.pdf](https://arxiv.org/pdf/2308.16683.pdf)

# Spectra of charged particles in Xe+La



- New preliminary results on  $K^\pm$  and  $\pi^-$  spectra in **Xe+La**.
- 0-20% of the most central collisions.
- Data available at  $\sqrt{s_{NN}} = 16.8$  GeV.

# $K^+/\pi^+$ (strangeness/entropy) ratio



Acta Phys. Polon. B  
46 (2015) 10, 1991

- SMES predictions: Rapid change in the energy dependence of  $K^+/\pi^+$  ratio in **Pb+Pb** collisions indicated the onset of deconfinement in the SPS energy range.
- Ar+Sc** systematically higher, **Xe+La** close to **Pb+Pb** at  $\sqrt{s_{NN}} = 16.8$  GeV.

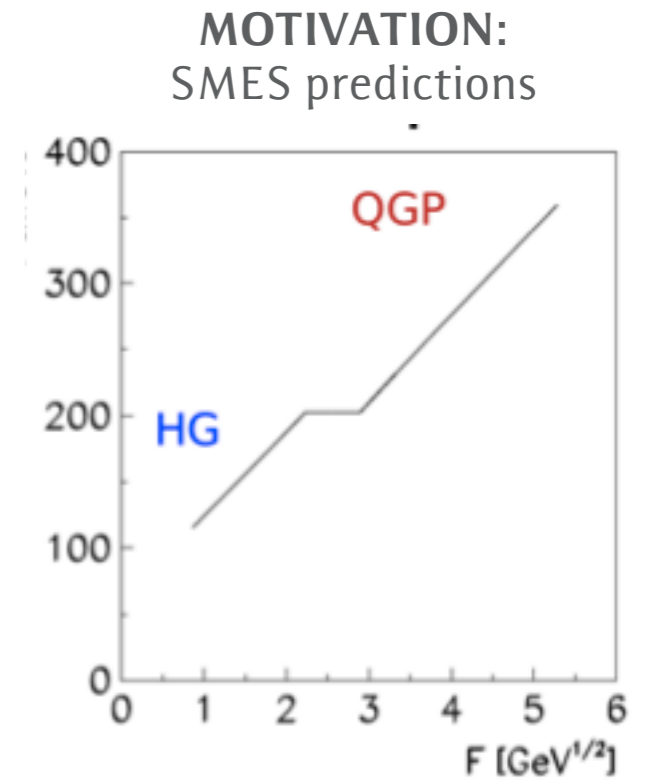
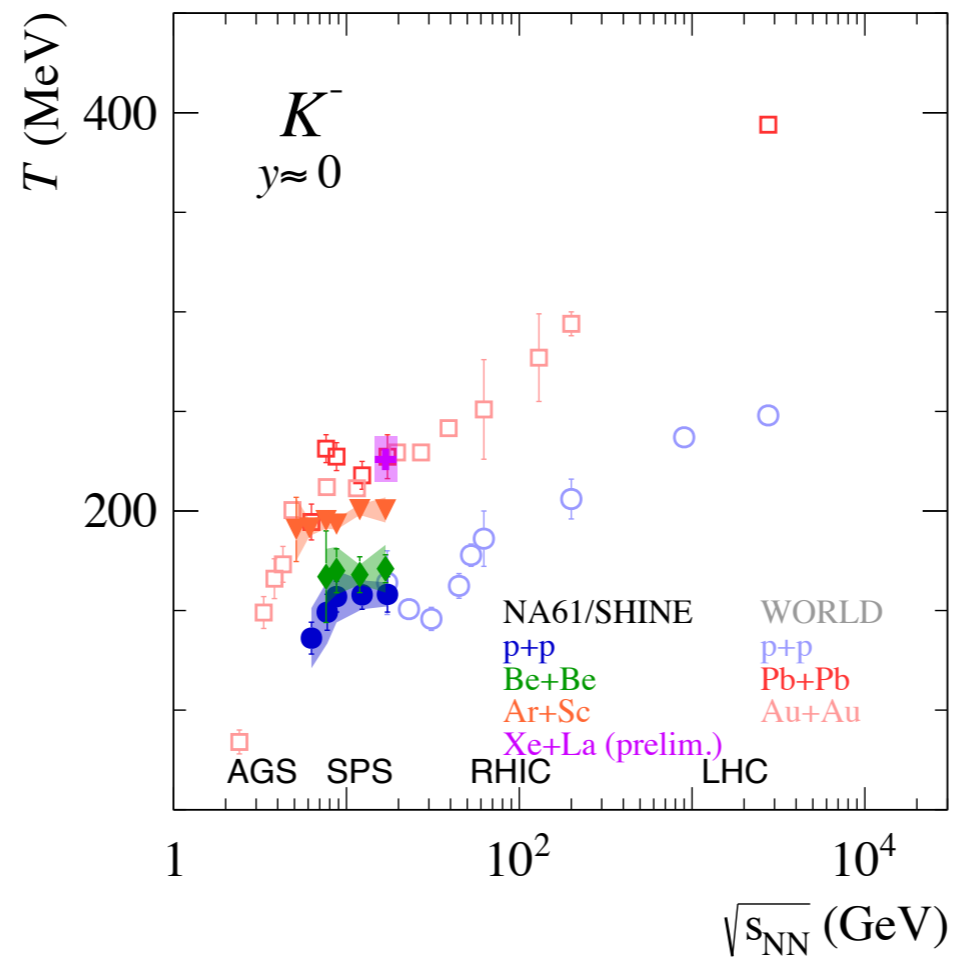
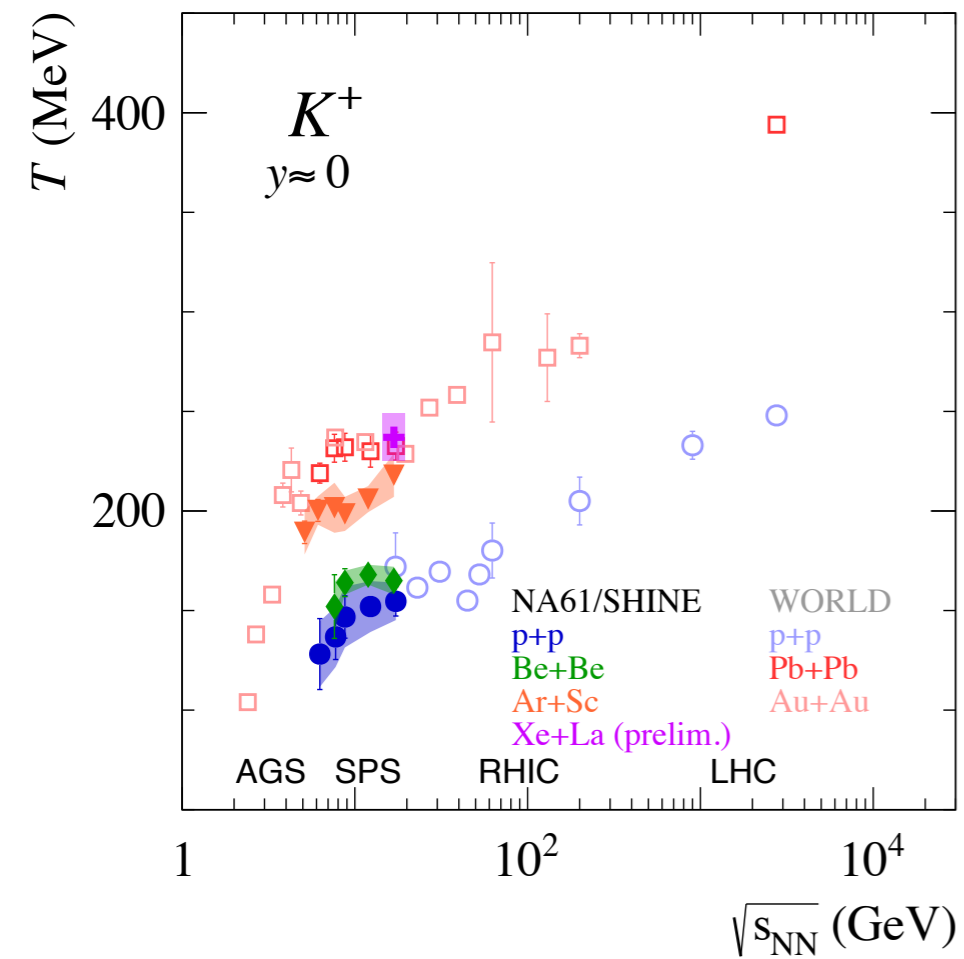
**p+p**: Eur.Phys.J. C77 (2017) 10, 671  
**Be+Be**: Eur.Phys.J. C81 (2021) 1, 73

**Ar+Sc**: [arxiv.org/pdf/2308.16683.pdf](https://arxiv.org/pdf/2308.16683.pdf)  
**Xe+La**: NA61/SHINE preliminary

**Pb+Pb**: Phys. Rev. C66 (2002) 054902



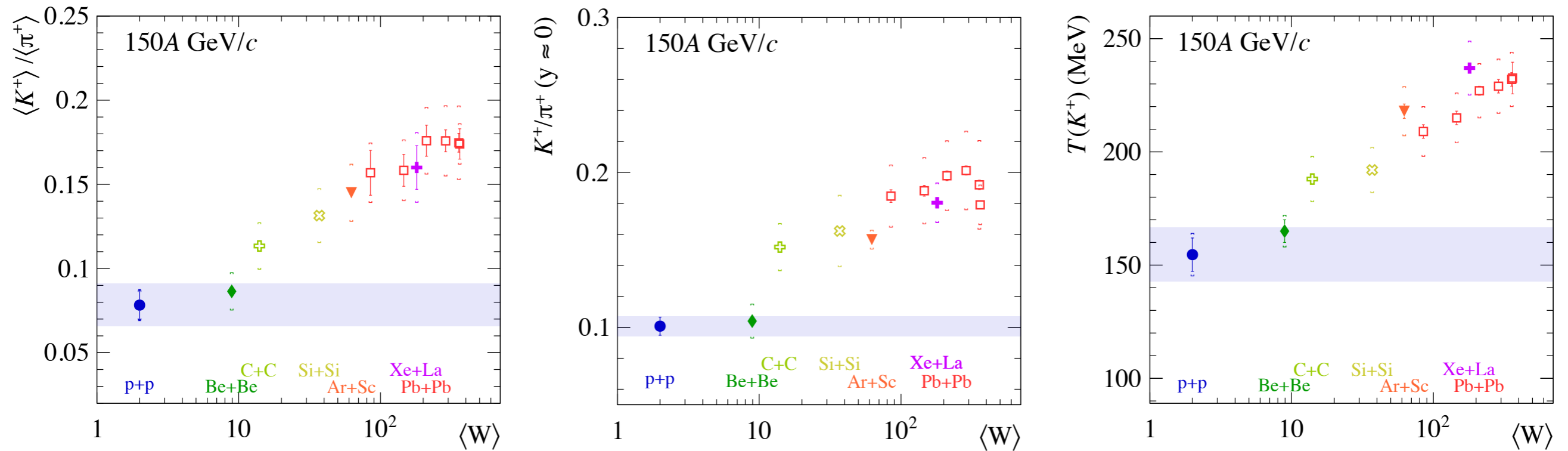
# Inverse slope parameter at midrapidity



Acta Phys. Polon. B  
46 (2015) 10, 1991

- Qualitatively similar energy dependence in  $p+p$ ,  $Be+Be$ ,  $Ar+Sc$  and  $Pb+Pb$ .
- Plateau-like structure visible in light systems ( $p+p$  and  $Be+Be$ ).
- Magnitude of  $T$  increases with the system size.

# Onset of fireball



- Rapid change of hadron production properties starts when moving from **Be+Be** to **Ar+Sc** collisions hints at some non-trivial threshold mechanism.
- Results of **Ar+Sc** collisions are closer to Pb+Pb collisions than to **p+p** and **Be+Be** measurements, hence the onset of fireball may be identified at the system size close to the measured **Ar+Sc** reactions and may depend on collision energy.

**p+p**: Eur.Phys.J. C77 (2017) 10, 671

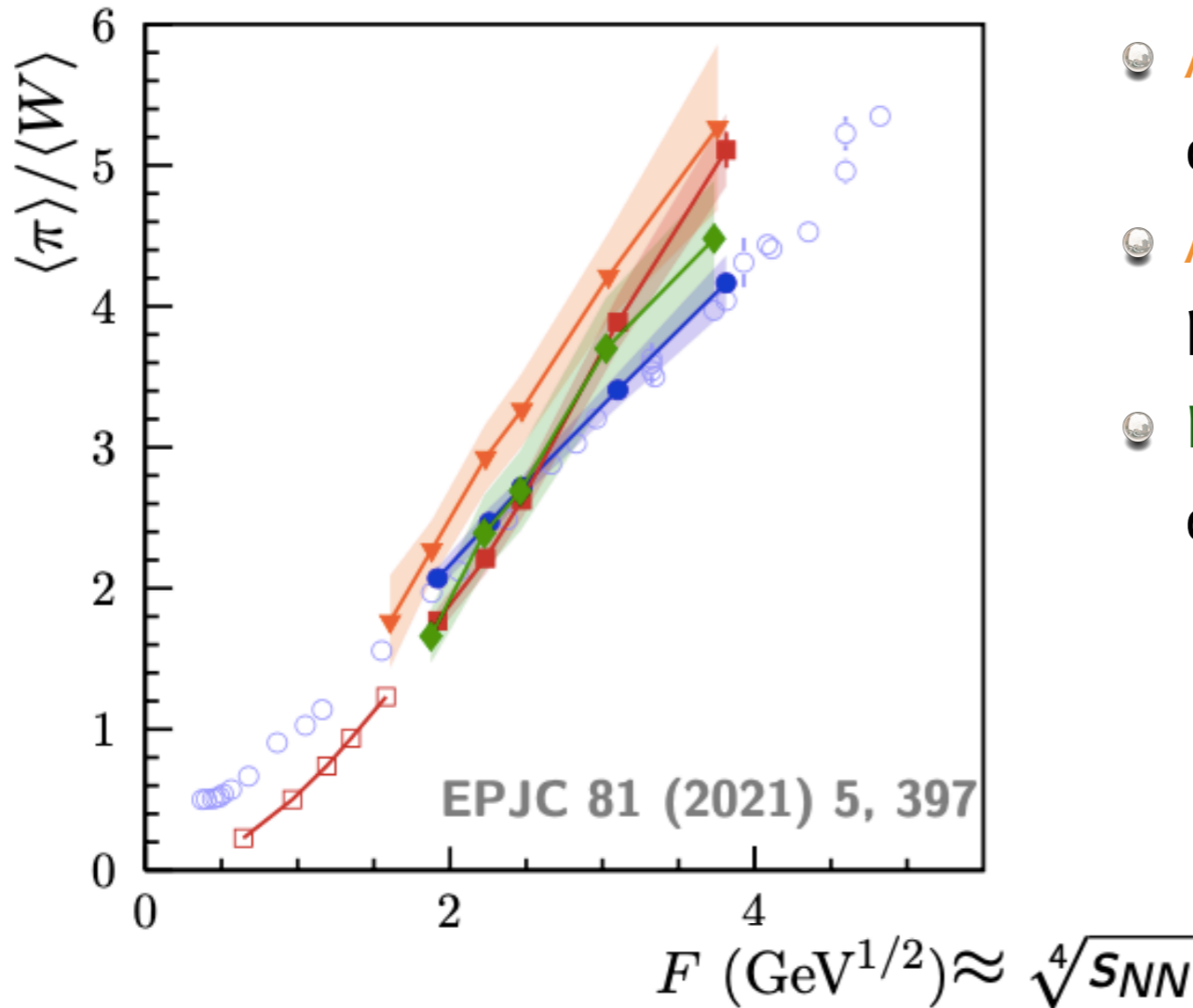
**Be+Be**: Eur.Phys.J. C81 (2021) 1, 73

**Ar+Sc**: [arxiv.org/pdf/2308.16683.pdf](https://arxiv.org/pdf/2308.16683.pdf)

**Xe+La**: NA61/SHINE preliminary

**Pb+Pb**: Phys. Rev. C66 (2002) 054902

# Pion multiplicity per number of wounded nucleons



NA61/SHINE

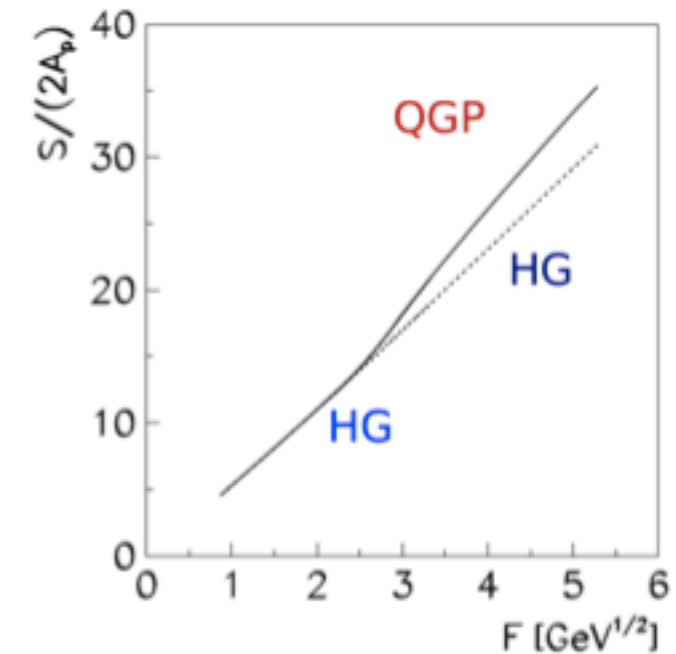
- ▼ Ar+Sc
- ◆ Be+Be
- N+N

World

- Pb+Pb (NA49)
- Au+Au (AGS)
- N+N

- Ar+Sc results higher than the results for all other systems, including Pb+Pb.
- Ar+Sc results close to Pb+Pb results at the highest energies.
- Be+Be results close to Pb+Pb at lower energies.

MOTIVATION:  
SMES predictions

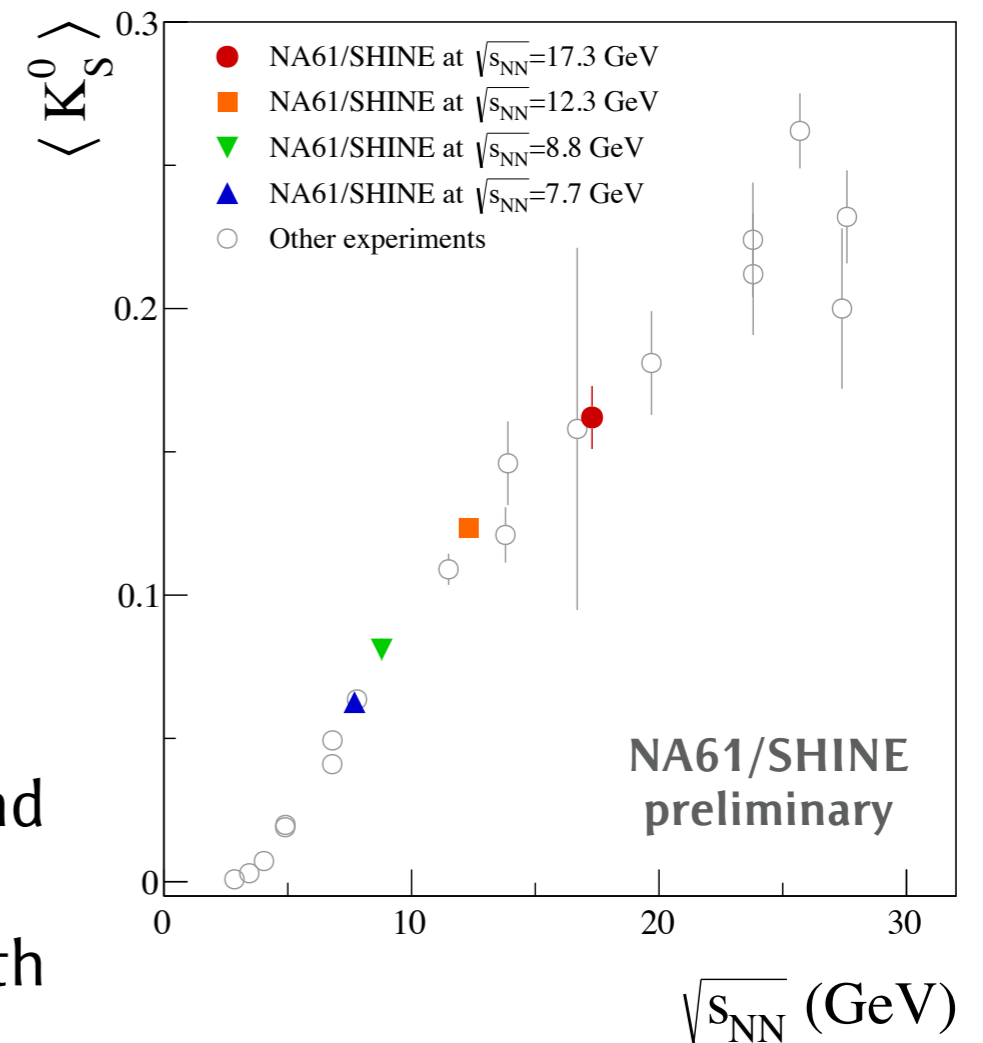
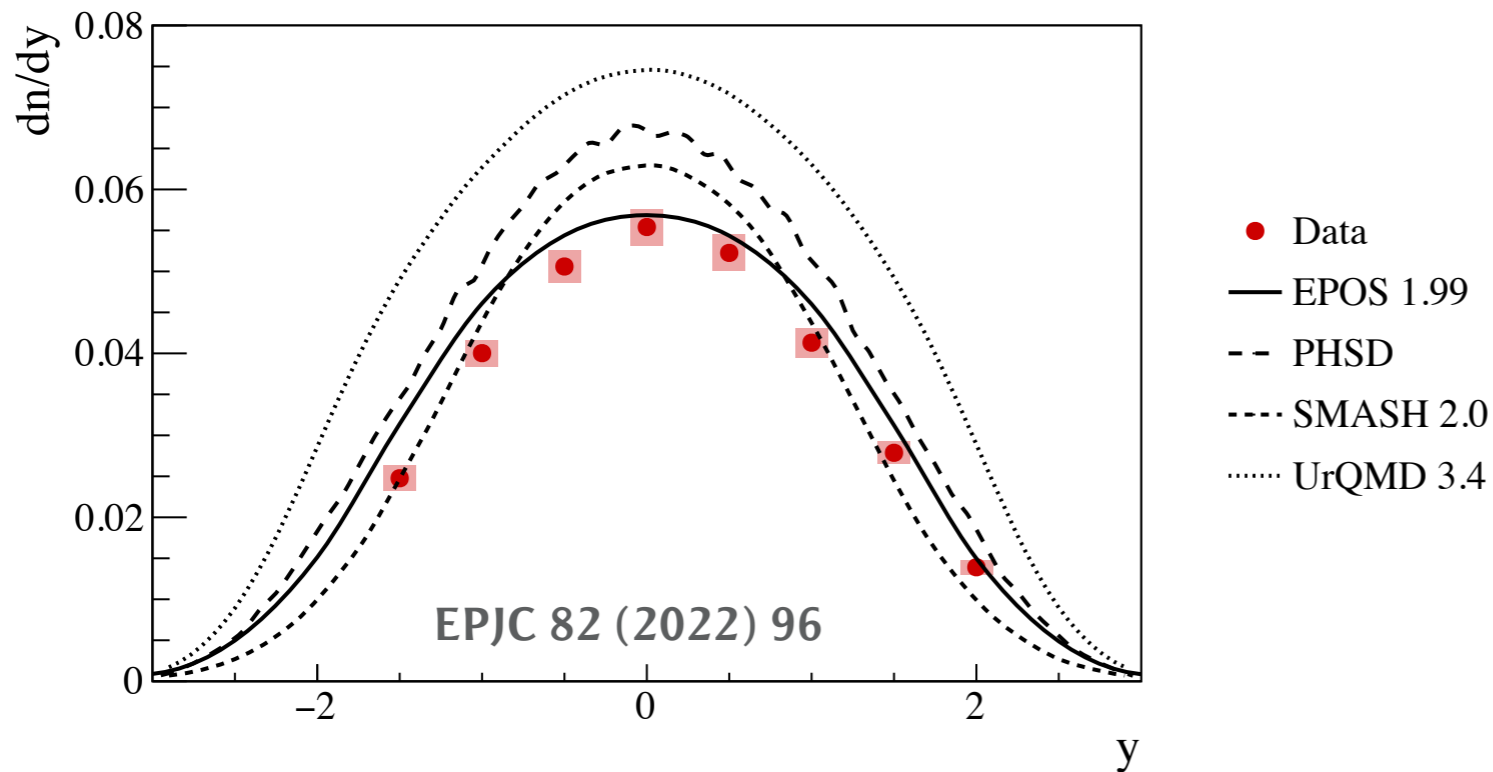
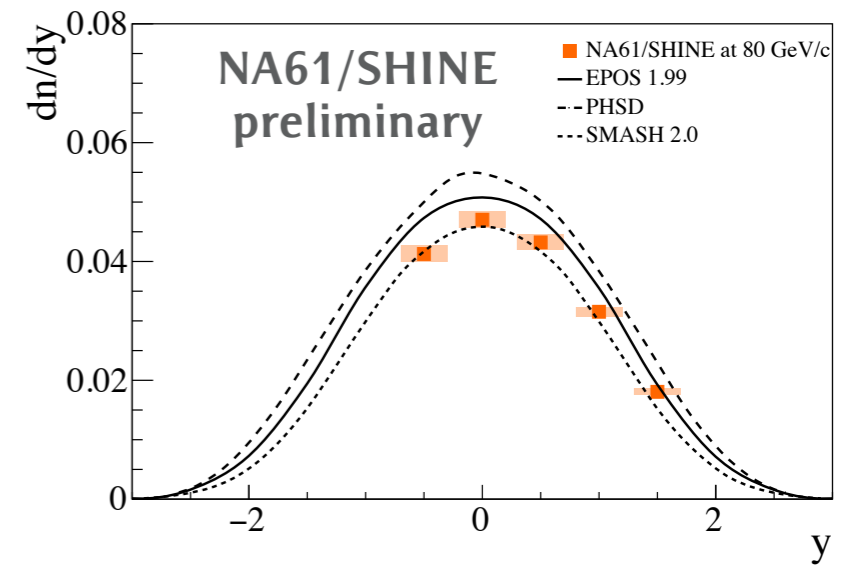
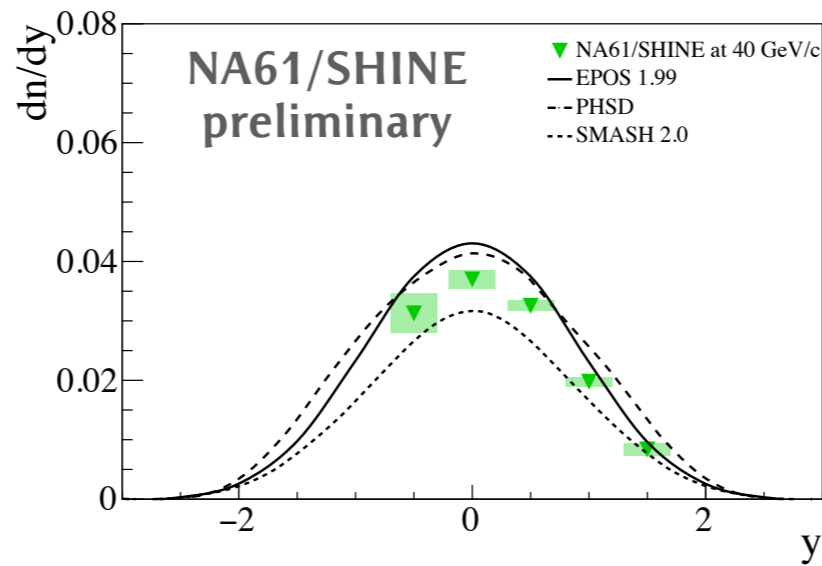
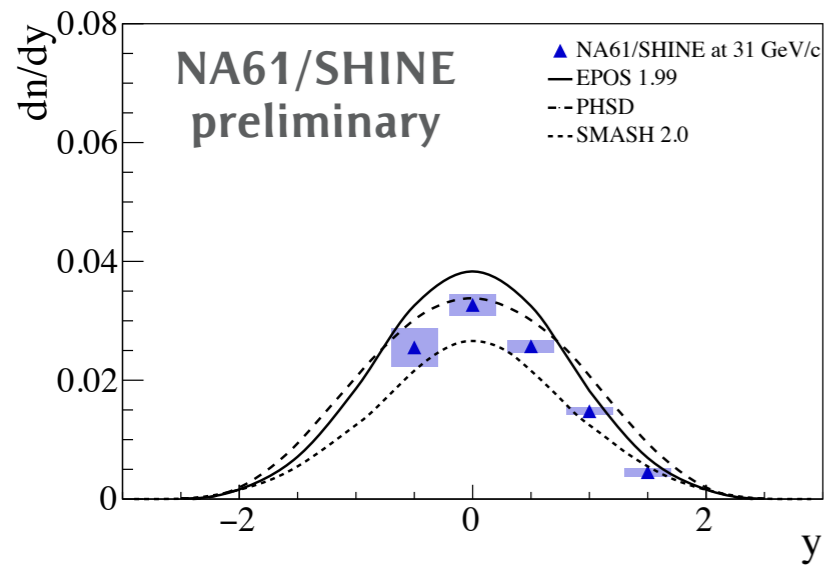


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46 (2015) 10, 1991



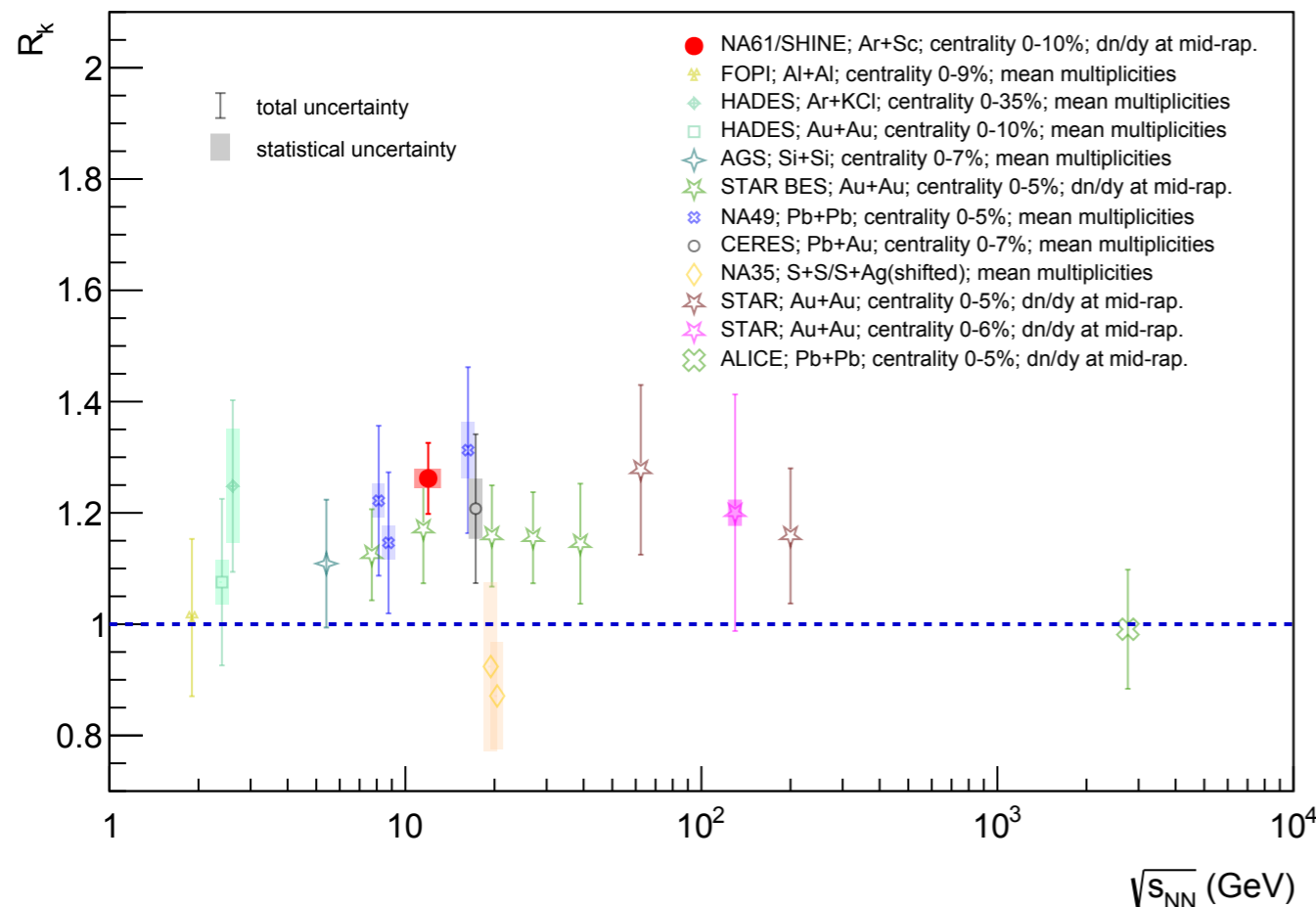
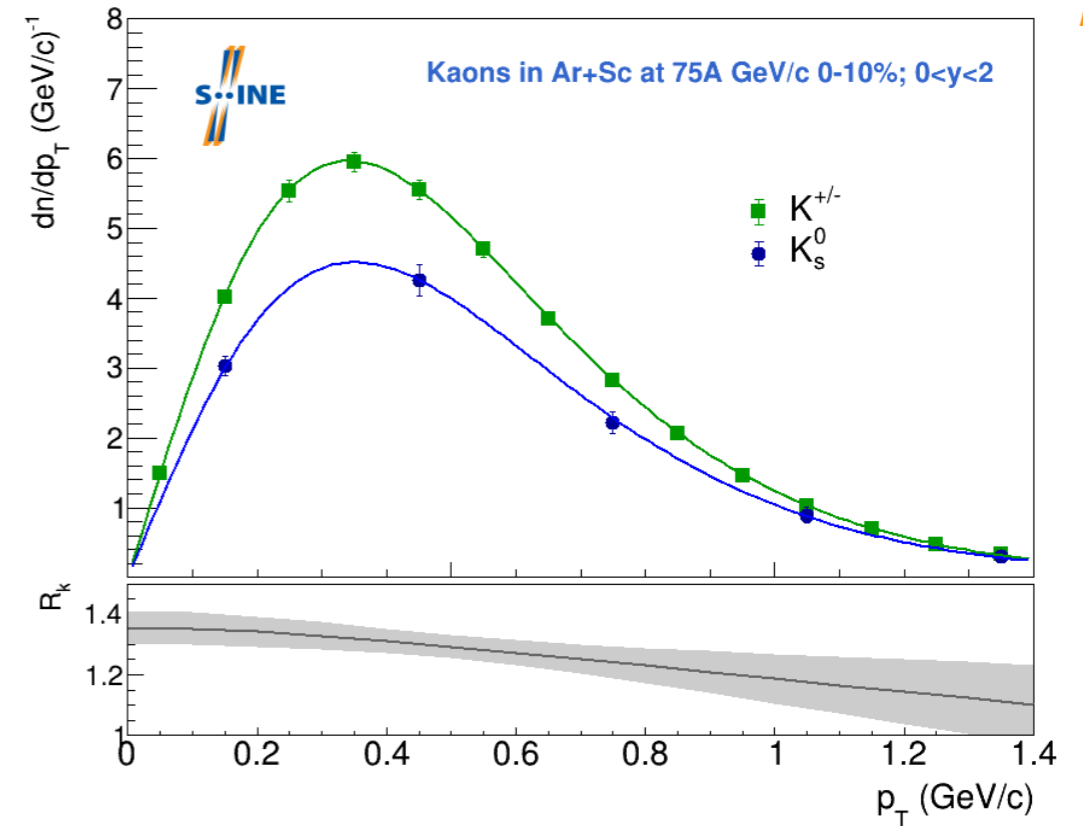
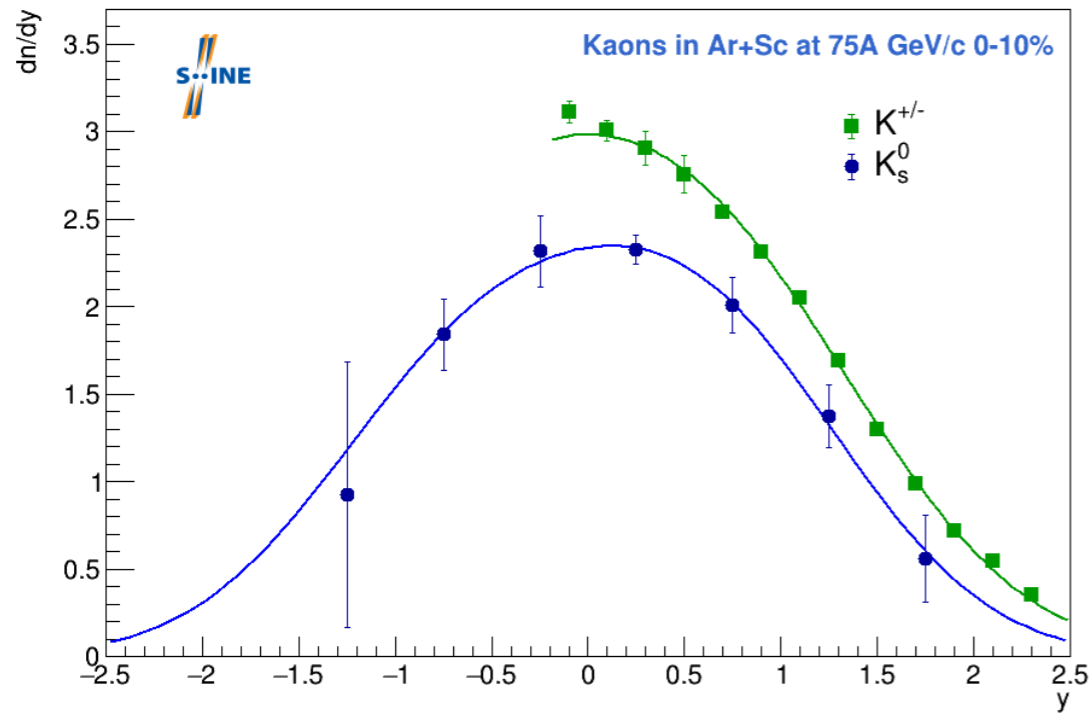
# Strangeness production

# $K_S^0$ meson production in $p+p$ at 31-158 GeV/c



- Very good agreement between measured data and theoretical models.
- The measured values are seen to rise linearly with collision energy.

# $K_S^0$ meson production in Ar+Sc at 75A GeV/c



$$R_K = \frac{K^+ + K^-}{2 \cdot K_S^0}$$

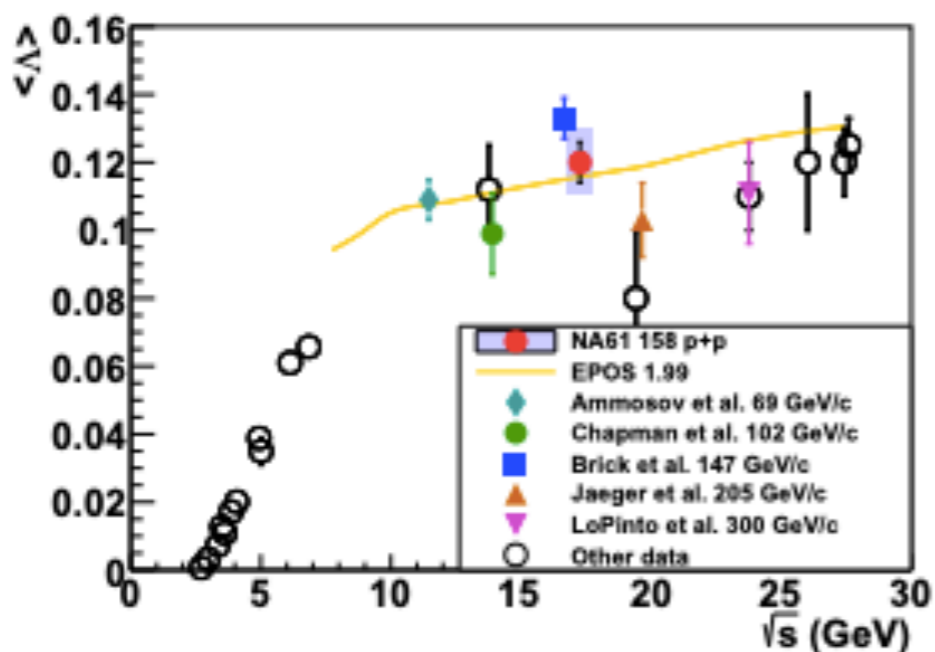
● Mean multiplicity:

$$\langle K_S^0 \rangle = 6.25 \pm 0.09(stat) \pm 0.73(sys)$$

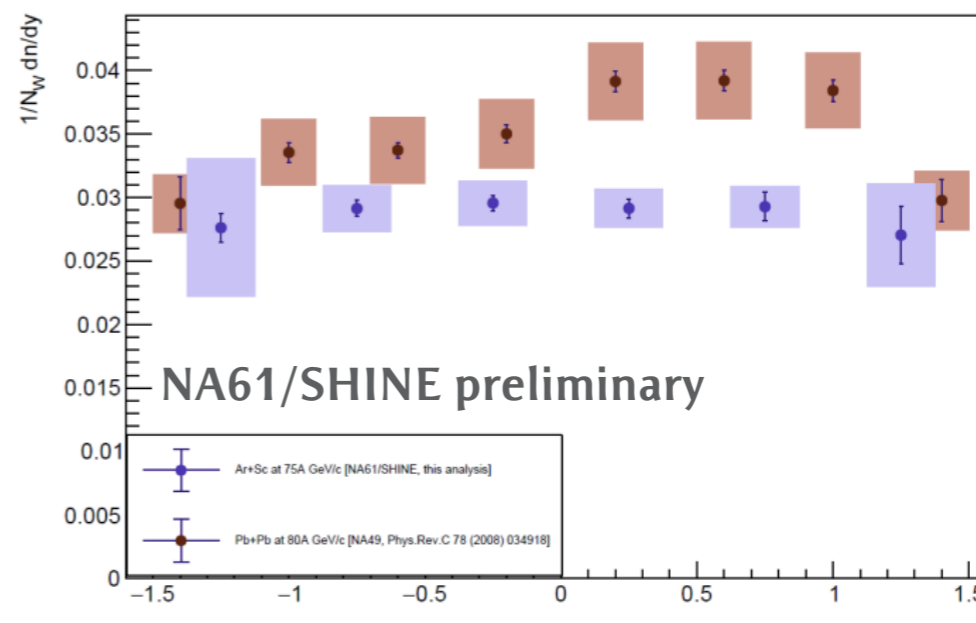
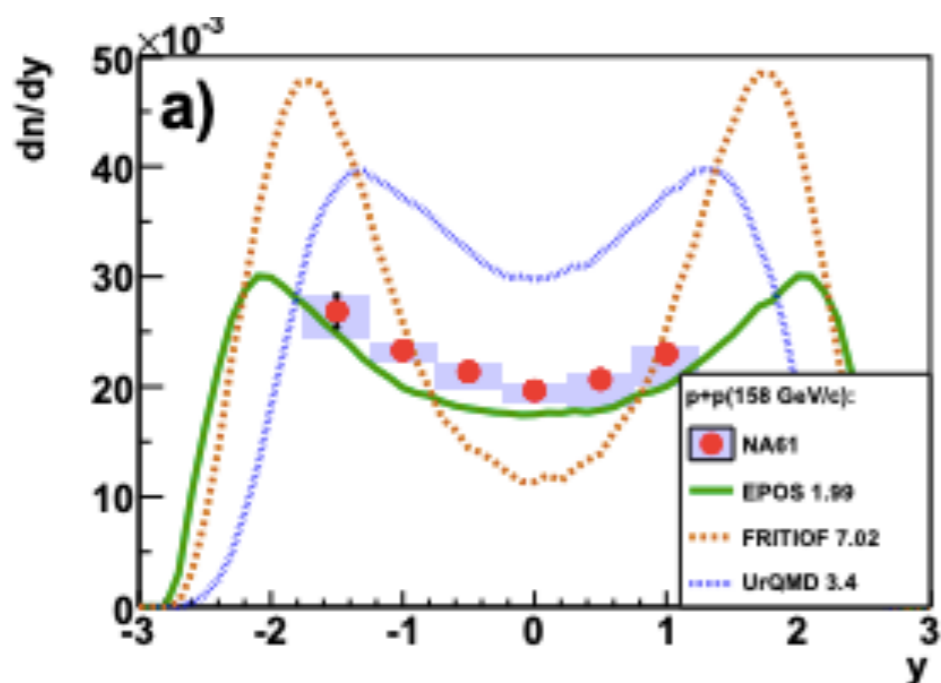
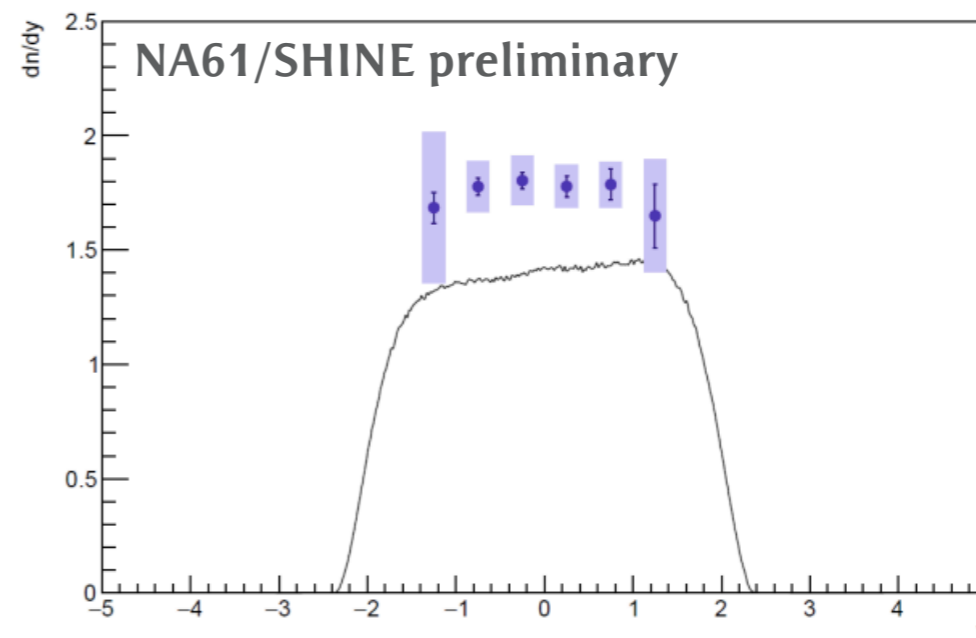
● Around 20-25% difference in the whole rapidity and transverse momentum range.

# $\Lambda$ production

$p+p$  at 158 GeV/c



Ar+Sc at 75A GeV/c



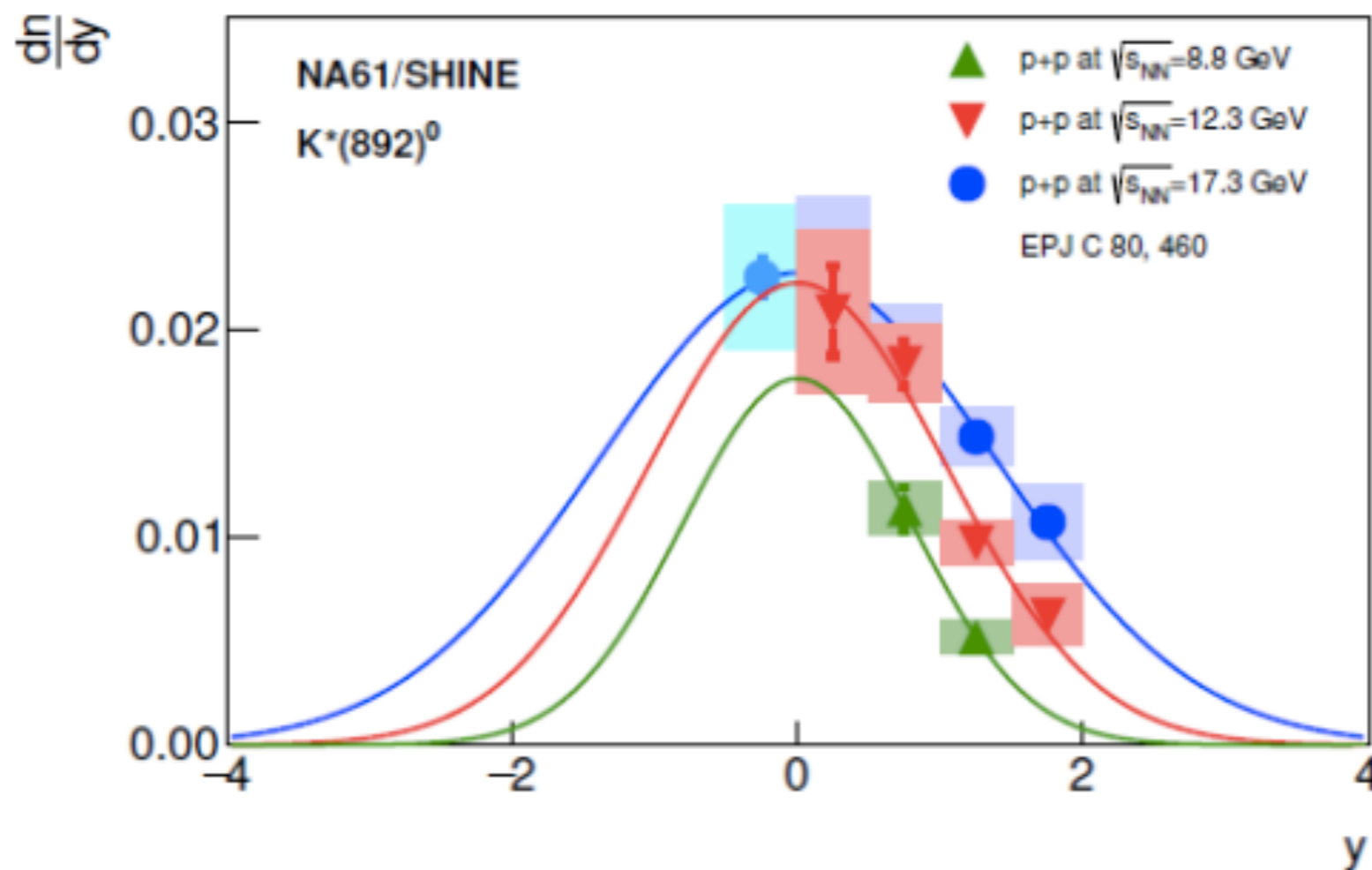
$$\langle \Lambda \rangle = 0.120 \pm 0.006(stat) \pm 0.010(sys)$$

$$\langle \Lambda \rangle = 6.44 \pm 0.24(stat) \pm 1.10(sys)$$

EPJC 76 (2016) 4, 198

NA61/SHINE preliminary

# $K^*(892)^0$ production in $p+p$ at 40-158 GeV/c

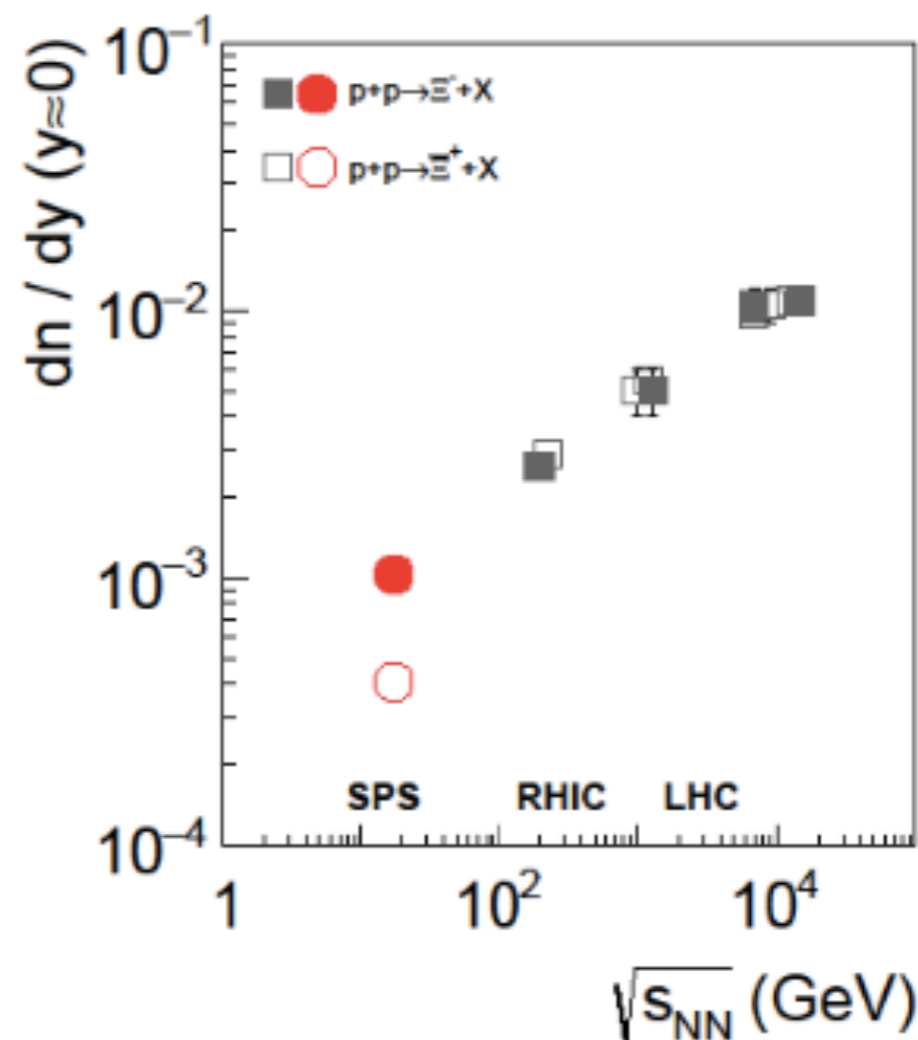
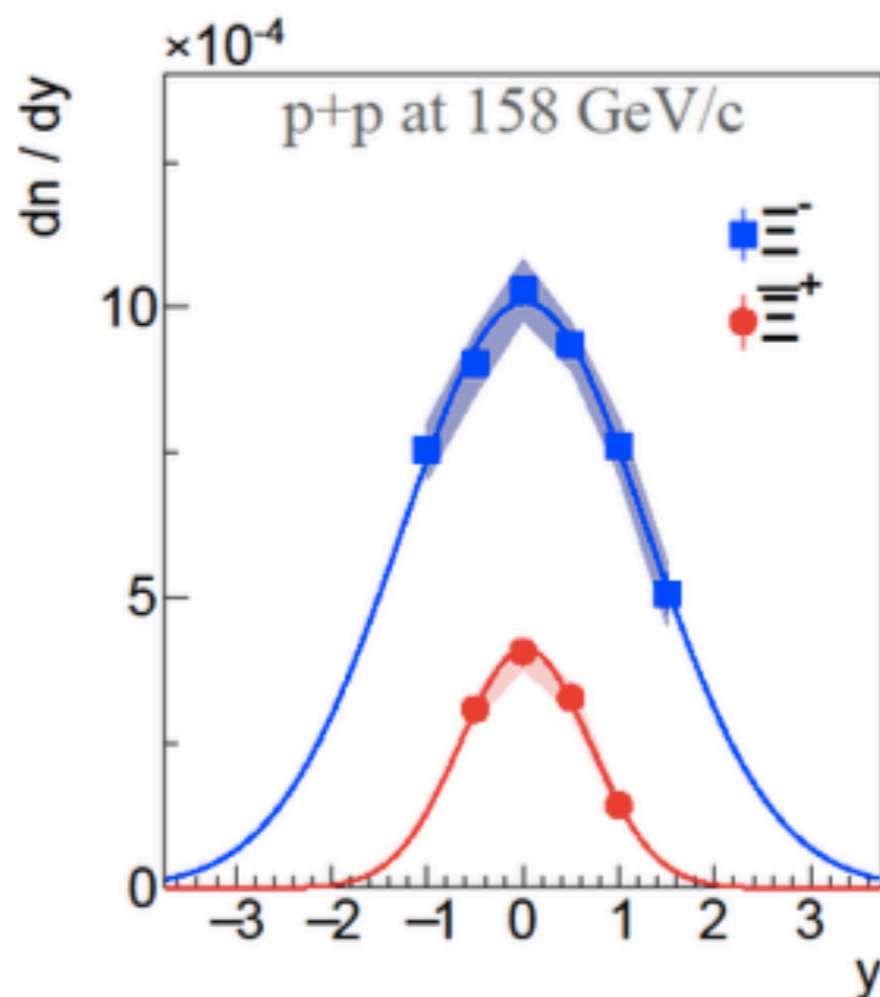


Mean multiplicity of  $K^*(892)^0$

	$\sqrt{s_{NN}}$	NA61	NA49 (PR C84, 064909, 2011)
EPJC 82 (2022) 4, 322	8.8	$(35.1 \pm 1.3 \pm 3.6) \cdot 10^{-3}$	-
	12.3	$(58.3 \pm 1.9 \pm 4.9) \cdot 10^{-3}$	-
EPJC 80 (2020) 5, 460	17.3	$(78.44 \pm 0.38 \pm 6.0) \cdot 10^{-3}$	$(74.1 \pm 1.5 \pm 6.7) \cdot 10^{-3}$



# $\Xi$ production in $p+p$ collisions at 158 GeV/c

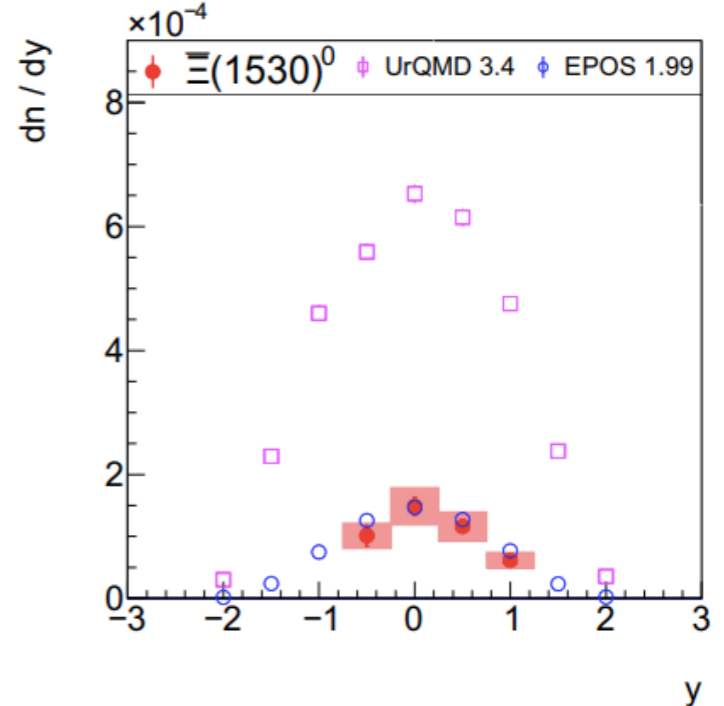
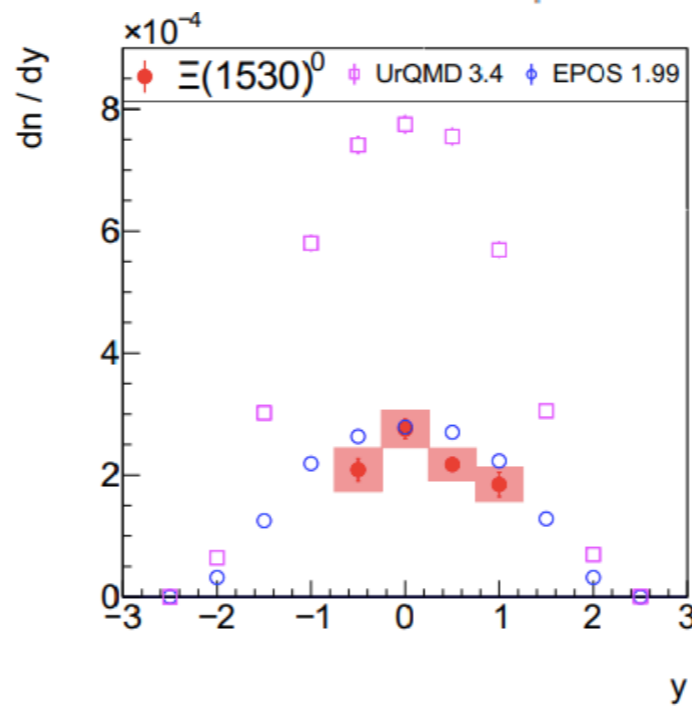
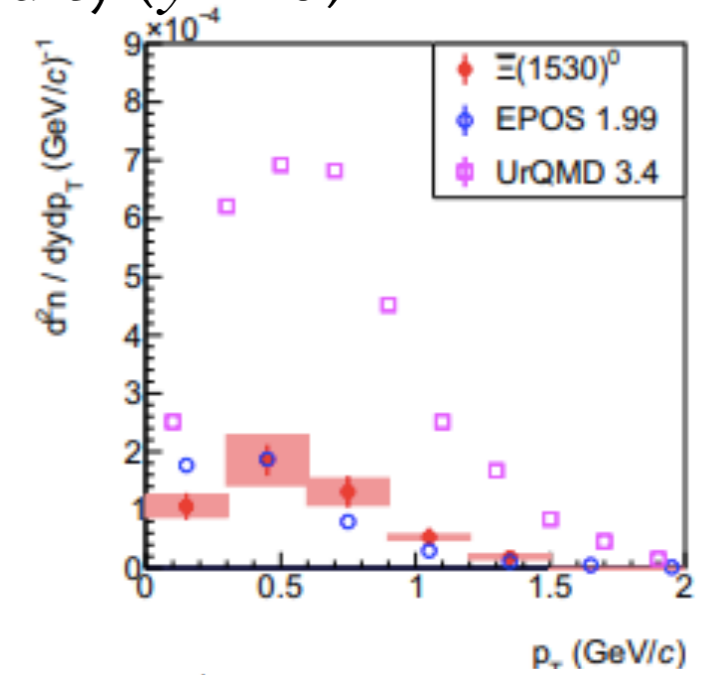
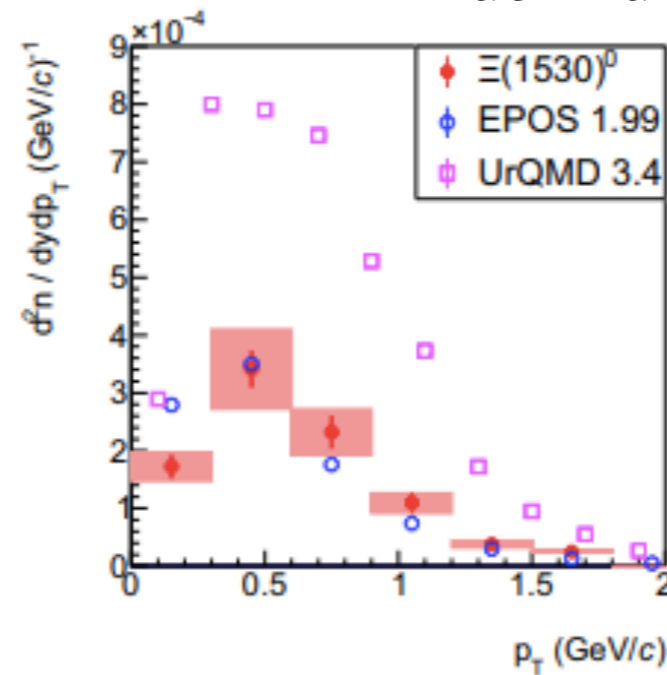
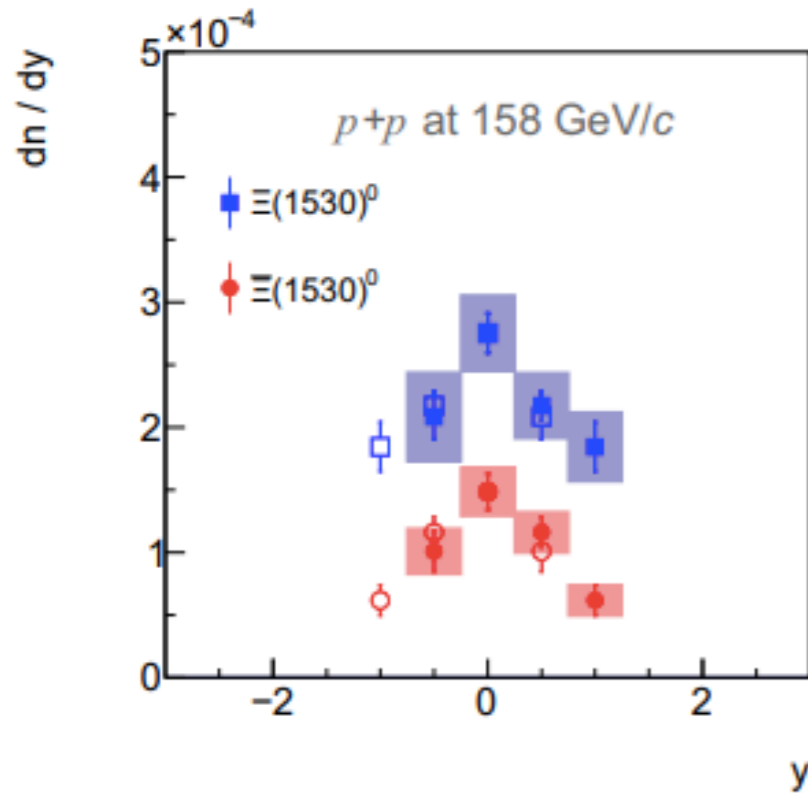


- The unique results on  $\Xi^-$  and  $\Xi^+$  production in  $p+p$  at SPS energy.
- Suppression of  $\Xi^+$  production:  $\langle \Xi^+ \rangle / \langle \Xi^- \rangle = 0.24 \pm 0.01(stat) \pm 0.05(sys)$ .

# $\Xi(1530)^0$ production in $p+p$ collisions at 158 GeV/c

at midrapidity ( $y \approx 0$ )

EPJC 81 (2021) 10, 911



- The unique results on  $\Xi(1530)^0$  production in  $p+p$  at SPS energy.
- Suppression of  $\bar{\Xi}(1530)^0$  production:  $\langle \bar{\Xi}(1530)^0 \rangle / \langle \Xi(1530)^0 \rangle = 0.40 \pm 0.03(stat) \pm 0.05(sys)$ .
- EPOS describes well transverse momentum and rapidity distributions, while UrQMD significantly overestimates all spectra.



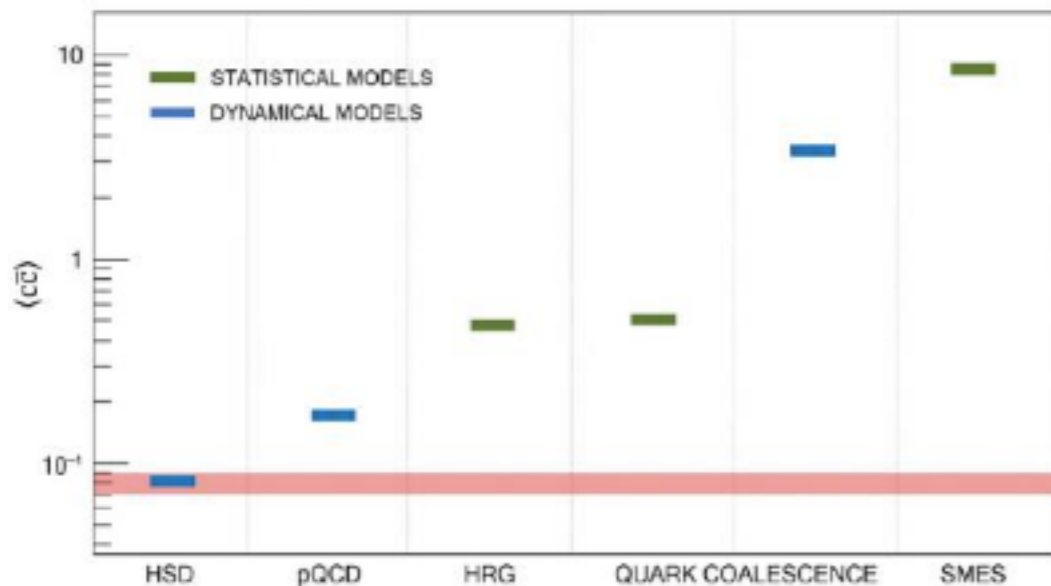
# NA61/SHINE program for 2022-2024

# Plans for the future

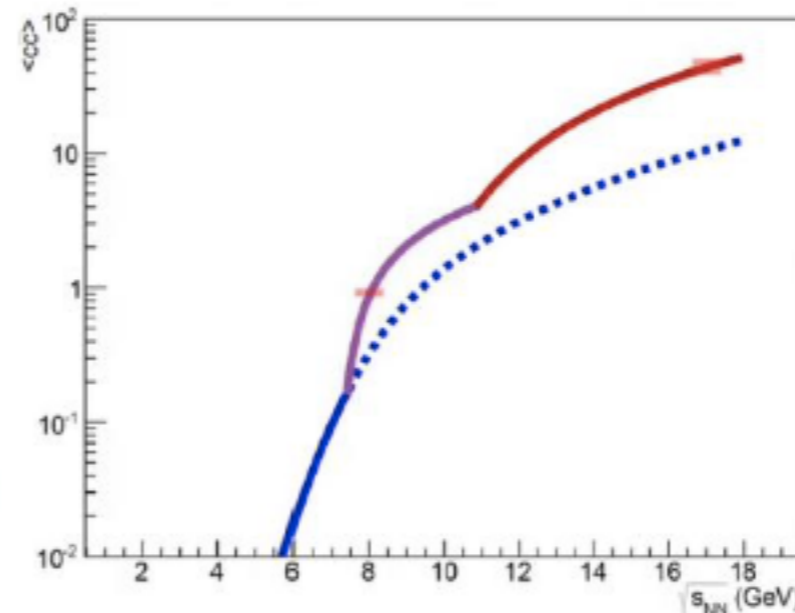
- A. What is the mechanism of open charm production?
- B. How does the onset of deconfinement impact open charm production?
- C. How does the formation of quark gluon plasma impact  $J/\Psi$  production?

These questions could be answered if we know the mean number of charm quark pairs produced in A+A collisions. Up to now the corresponding experimental data does not exist and NA61/SHINE will perform this measurement in the near future.

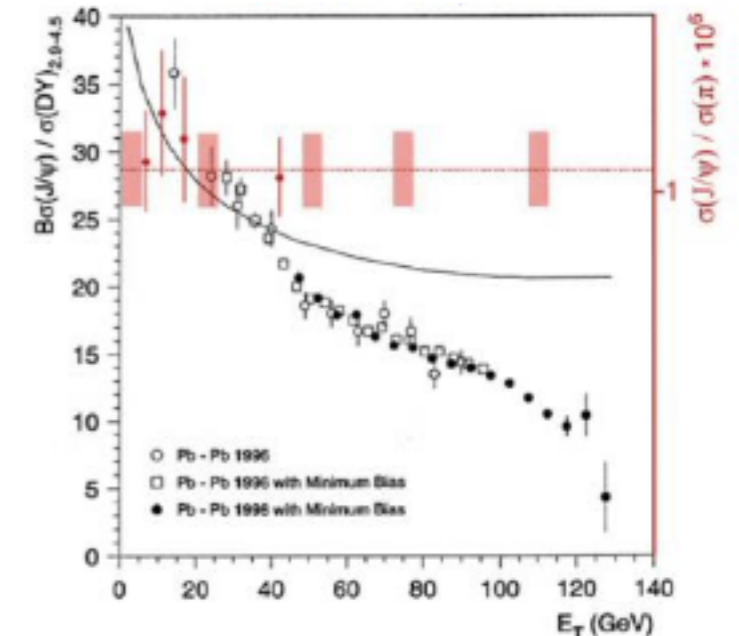
### $\langle c\bar{c} \rangle$ and models



### $\langle c\bar{c} \rangle$ and onset of deconfinement



### $\langle c\bar{c} \rangle$ , $\langle J/\Psi \rangle$ and QGP



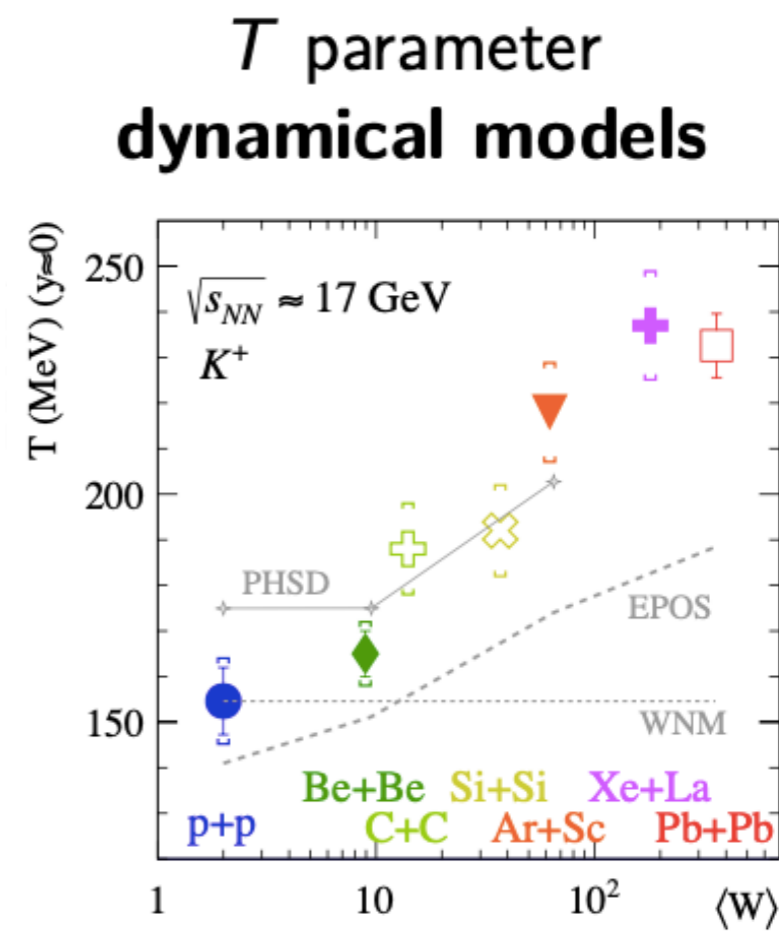
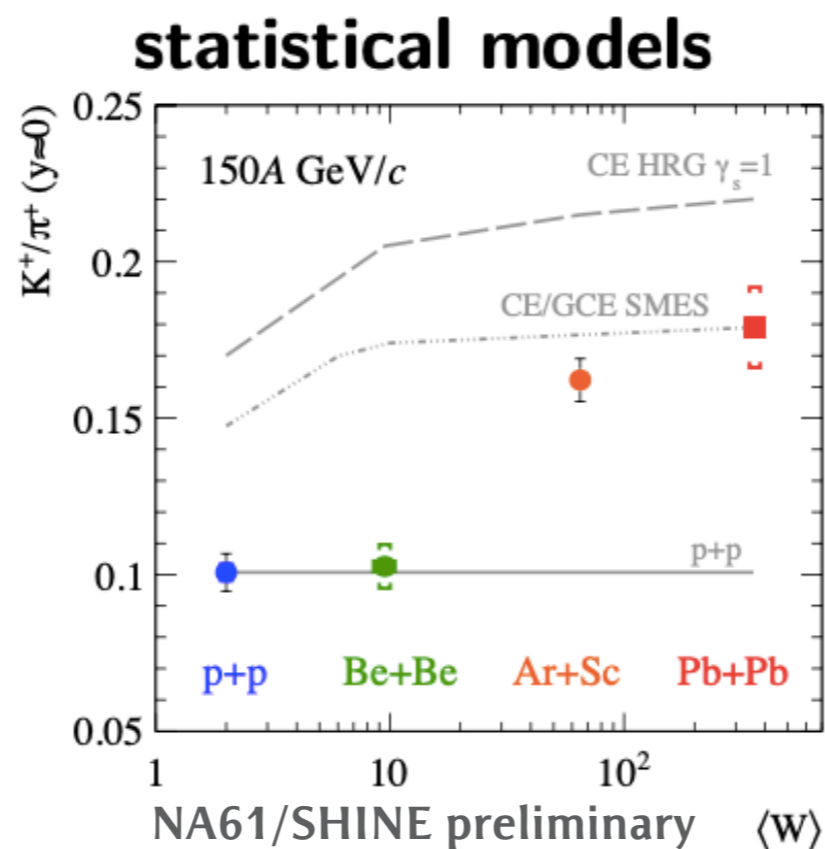
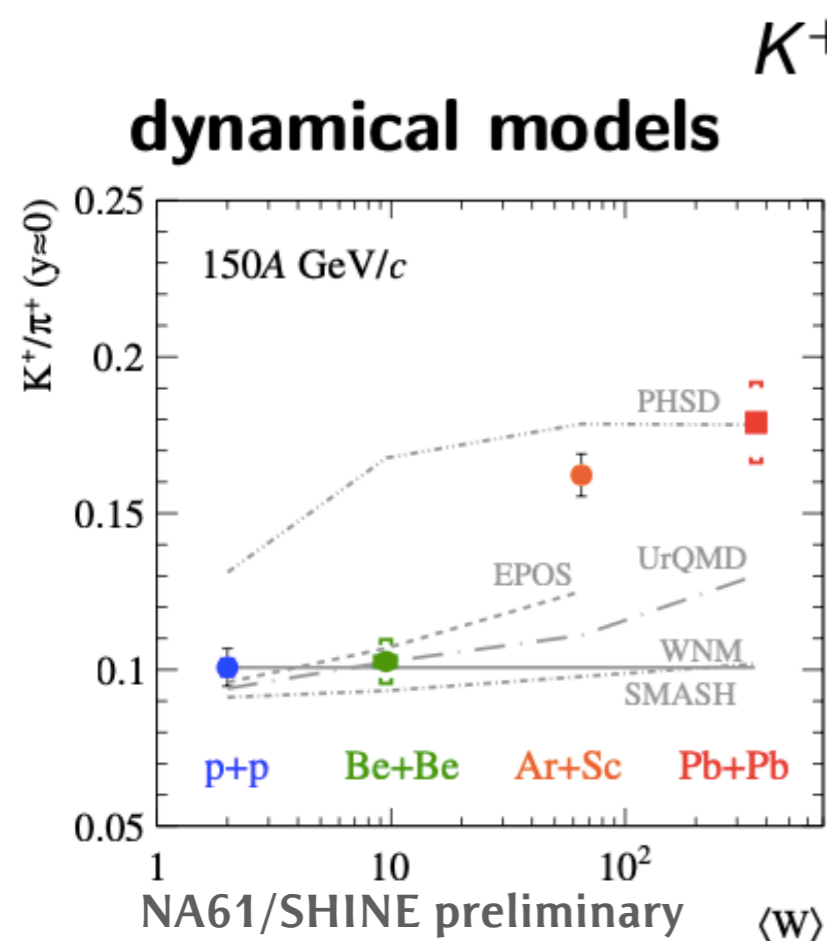
- Unique 2D scan in system size and collision energy was completed in 2017. Analysis ongoing for  $p+p$ ,  $\text{Be+Be}$ ,  $\text{Ar+Sc}$ ,  $\text{Xe+La}$  and  $\text{Pb+Pb}$  data. Results, specially from  $p+p$  data, could be used as a reference for MPD AA physics.
- NA61/SHINE data provided rich information related to onset of deconfinement.
- Unexpected system size dependence:  $(p+p \approx \text{Be+Be}) \neq (\text{Ar+Sc} \neq \text{Pb+Pb} \approx \text{Xe+La})$ .
- Unique results on strange baryon productions in  $p+p$  interactions.
- $\frac{K^+ + K^-}{2 \cdot K_S^0}$  ratio significantly higher than 1 in  $\text{Ar+Sc}$  at 75A GeV/c.
- NA61/SHINE program with measurement of open charm production in 2022-2024.



Thank you



**Backup slides**



- None of the models reproduce  $K^+/\pi^+$  ratio or  $T$  for whole  $\langle W \rangle$  range.

**p+p**: Eur.Phys.J. C77 (2017) 10, 671

**Be+Be**: Eur.Phys.J. C81 (2021) 1, 73

**Ar+Sc**: NA61/SHINE preliminary

**Xe+La**: NA61/SHINE preliminary

**Pb+Pb**: Phys. Rev. C66 (2002) 054902

**PHSD**: Eur.Phys.J. A56 (2020) 9, 223

**SMASH**: J. Phys. G 47 (2020) 6, 065101

**UrQMD and HRG**: Phys. Rev. C99 (2019) 3, 034909

**SMES**: Acta Phys. Polon. B46 (2015) 10, 1991