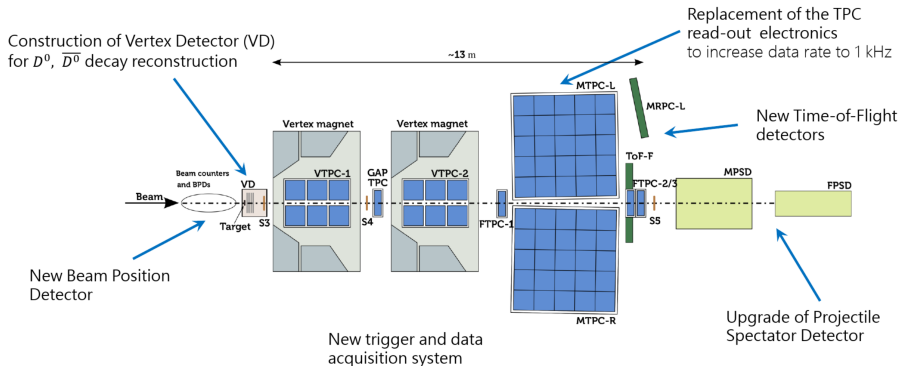


Do we see isospin symmetry breaking  
in kaon production  
in  $p+p$  and/or  $A+A$  collisions?

NA61/SHINE group in DBP-**BP3**:  
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December 13<sup>th</sup> 2023

# NA61/SHINE experiment at SPS - detector



- Large acceptance, full forward hemisphere,
- PID:  $dE/dx$  (TPC) and  $m^2$  (ToF),
- Ion (Be, Ar, Xe, Pb) and hadron ( $p$ ,  $\pi^\pm$ ,  $K^\pm$ ) beams, targets such as liquid  $H_2$ , Be, C, Sc, La, Pb,
- $p_{beam}$  : 13A  $\rightarrow$  158A GeV/c ( $\sqrt{s_{NN}}$  : 5.1  $\rightarrow$  17.3 GeV).

# Data taking after LS2

- Neutrino-related - secondary hadrons (summer 2023):
  - $K^+ + C$  @ 60A GeV/c, p+Ti and p+C @ 120A GeV/c  $\sim 4 \cdot 10^8$  events collected ( $\times 20$  largest neutrino data before LS2),
  - Magnet-off data (issues with cryogenic system)  $\rightarrow$  p+Ti,  $\pi^+ + Ti$ ,  $K^+ + Ti$  @ 60A GeV/c and p+C @ 90A GeV/c.
- Heavy ions (autumn 2023):
  - Pb+Pb @ 150A GeV/c (3 mm target),
  - Upgrades of the detector, combined with optimization of the SPS slow extraction, resulted in about a  $30\times$  increase of the data-taking efficiency with respect to 2018 data-taking.

# Publications - list

- 1 Two-pion femtoscopic correlations in  $Be + Be$  collisions at  $\sqrt{s_{NN}} = 16.84$  GeV measured by the NA61/SHINE at CERN.  
*Eur.Phys.J.C 83 (2023) 10, 919,*
  - 2 Search for the critical point of strongly-interacting matter in  $^{40}Ar + ^{45}Sc$  collisions at 150A GeV/c using scaled factorial moments of protons.  
*Eur.Phys.J.C 83 (2023) 9, 881,*
  - 3 Measurements of  $K_S^0$ ,  $\Lambda$ , and  $\bar{\Lambda}$  production in 120 GeV/c  $p + C$  interactions.  
*Phys.Rev.D 107 (2023) 7, 072004,*
  - 4 Measurement of hadron production in  $\pi^- - C$  interactions at 158 and 350 GeV/c with NA61/SHINE at the CERN SPS.  
*Phys.Rev.D 107 (2023) 6, 062004,*
  - 5 Measurements of  $\pi^+$ ,  $\pi^-$ ,  $p$ ,  $\bar{p}$ ,  $K^+$  and  $K^-$  production in 120 GeV/c  $p + C$  interactions.  
*Phys.Rev.D 108 (2023) 072013.*
- **On the relation between  $K_S^0$  and charged kaon yields in proton-proton collisions.**  
***Eur.Phys.J.C 83 (2023) 10, 928, (J. Stepaniak, D. Pszczel),***

# Other activities of the group

- We participated in the detector upgrade and shifts during data taking.
- Dr Maksiak is responsible for many technical activities in the experiment. He is the main reconstruction expert, calibration database maintainer, data and IT resources manager. Since this year is a co-expert of DAQ.
- In 2023, he was awarded the **NA61/SHINE Software and Hardware Award** for the activities mentioned above.

# Relation between neutral and charged kaon production

- Isospin symmetry: equivalence of QCD w.r. to  $u$  and  $d$  quarks,
- $K^+ \equiv u\bar{s}$ ,  $K^0 \equiv d\bar{s}$ ,  $\bar{K}^0 \equiv s\bar{d}$ ,  $K^- \equiv s\bar{u}$ ,
- $\langle K^+ \rangle = \langle K^0 \rangle$  and  $\langle K^- \rangle = \langle \bar{K}^0 \rangle$ ,
- $\langle K_S^0 \rangle = \langle K_L^0 \rangle = \frac{1}{2}\langle K^0 \rangle + \frac{1}{2}\langle \bar{K}^0 \rangle$ ,
  
- Therefore one expects  $\langle K_S^0 \rangle = \frac{1}{2}\langle K^+ \rangle + \frac{1}{2}\langle K^- \rangle$ ,
- $\implies R_K \equiv \frac{\langle K^+ \rangle + \langle K^- \rangle}{2\langle K_S^0 \rangle} \sim 1$
  
- *Initial state?*

On the relation between  $K_S^0$  and charged kaon yields in proton–proton collisions. *J. Stepaniak, D. Pszczel (Eur.Phys.J.C 83 (2023) 10, 928)*

- A compilation of p+p data  $\rightarrow$  discrepancy between  $K_S^0$  yield and the average number of charged kaons.
- “Naive” isospin symmetry:  
$$K_S^0 = \frac{K^+ + K^-}{2} \text{ (Eq. 1),}$$
- p+p: 4u and 2d valence quarks,
- $K^+(u\bar{s})$ ,  $K^-(s\bar{u}) \Rightarrow \neq$  production.

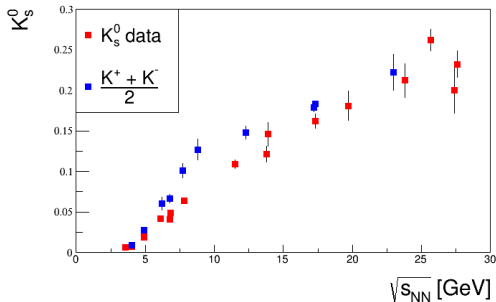
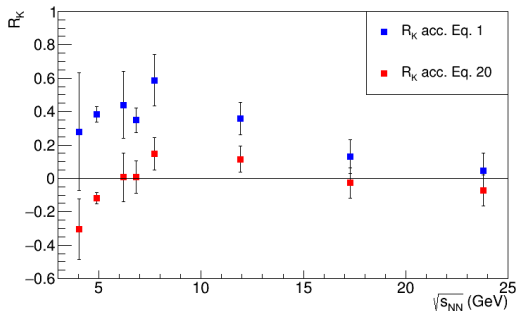


Figure: Multiplicity per event of neutral kaons  $K_S^0$  and charged kaons  $\frac{K^+ + K^-}{2}$  in inelastic  $p + p$  interactions as a function of collision energy in the center of mass reference frame.

On the relation between  $K_S^0$  and charged kaon yields in proton–proton collisions. *J. Stepaniak, D. Pszczel (Eur.Phys.J.C 83 (2023) 10, 928)*

- $K^+ = u_v \bar{s}_s, K^- = \bar{u}_s s_s, K_S^0 = (d_v \bar{s}_s + d_s \bar{s}_s + \bar{d}_s s_s),$
- In case of p+p:  $K_S^0 = \frac{K^+ + 3K^-}{4}$  (Eq. 20)



**Figure:** Difference, normalized by  $K_S^0$ , between a relation based on multiplicities of charged kaons given by the two models (Eq. 1 and Eq. 20) and  $K_S^0$  yields as a function of  $\sqrt{s}$ .

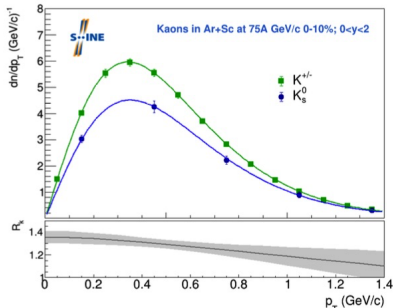
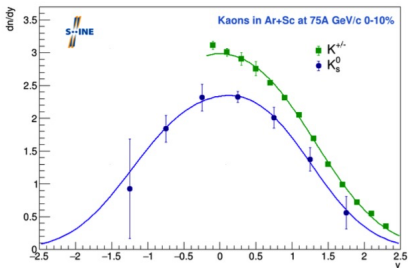


# $K_S^0$ vs $K^\pm$ in Ar+Sc @ 75A GeV/c

- NA61/SHINE observes a difference between charged and neutral kaon production also in Ar+Sc @ 75A GeV/c interaction.
- This result was shown by W. Bryliński, “Large isospin symmetry violation in kaon production?”, in 30th International Conference on Ultra-relativistic Nucleus-Nucleus Collisions (Quark Matter 2023).

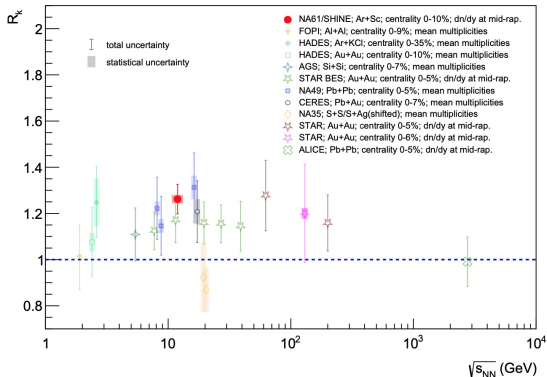
$$K^{+/-} = \frac{K^+ + K^-}{2}$$

$$R_k = \frac{K^{+/-}}{K_S^0}$$



# $K_S^0$ vs $K^\pm$ in Ar+Sc @ 75A GeV/c

$$R_k = \frac{K^{+/-}}{K_S^0}$$



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<https://cds.cern.ch/record/1497739>  
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- Scientific project of NA61/SHINE Consortium - GRIEG - nr 2019/34/H/ST2/00585 - "Study of charm production in heavy ion collisions".
- Scientific project nr 2021/WK/10. Ministry of Science and Education. NA61/SHINE experiment at CERN

# Summary

- The NCBJ DBP/BP3 group is taking part in multiple NA61/SHINE activities, from hardware (detector upgrade) to low and high level software-type works (DRS, data taking, calibration).
- We are also performing physical analyses using the collected data (e.g. strangeness production, dileptons and rare meson and baryon decays, two particle correlations, etc).
- Unexpected effect -  $R_k$  ratio in Ar+Sc and nucleus-nucleus central collisions is about 20% larger than expected.