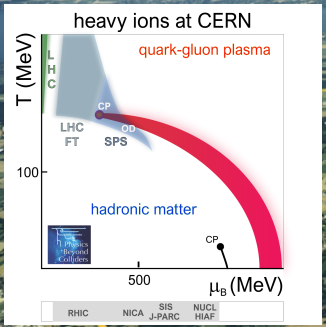
Ion beams in the North Area: **NA61/SHINE**

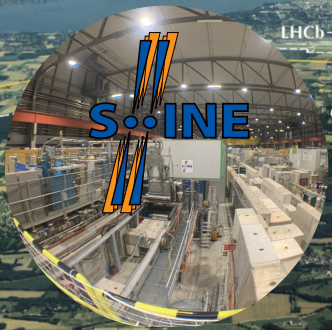
Maja Maćkowiak-Pawłowska
for the NA61/SHINE Collaboration

Warsaw University of Technology

NA61/SHINE - UNIQUE MULTIPURPOSE FACILITY:

Hadron production in hadron-nucleus and nucleus-nucleus collisions at high ene[illegible]es





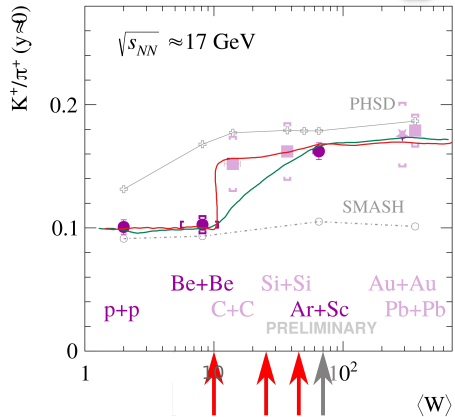
NA61/SHINE program post-LS3

SPS **H**eavy **I**on and **N**eutrino **E**xperiment

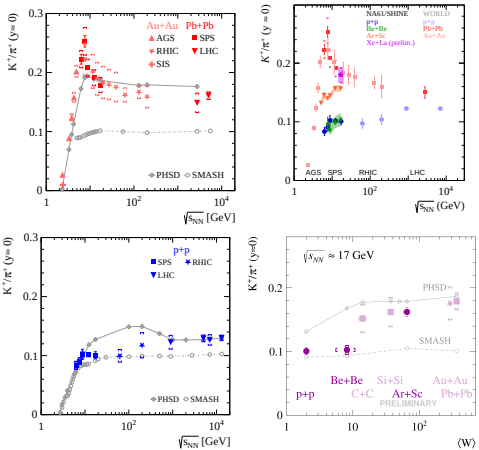
- **Energy scan with light and medium mass ions to study the phase diagram of strongly interacting matter**
- Measurements of heavy hadron resonances in large statistics p+p interactions
- Measurements with antiproton beams
- Measurements of hadron emission from the LBNF and HYPER-K replica targets
- Data for flux predictions in neutrino experiments using very low energy beams

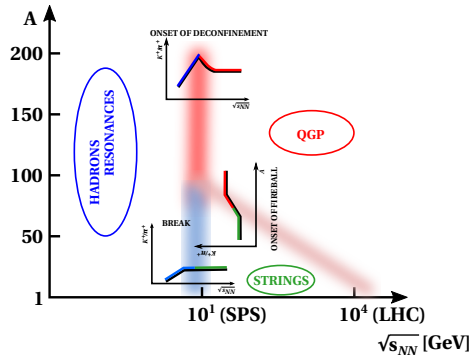
News

- **Long-term plans** for the strongly interacting matter program of the NA61/SHINE prepared
- **Addendum with light-ion scan post-LS3** submitted to SPSC (SPSC-P-330-ADD-14)
- All **ions** are **selected** in close collaboration with CERN BE
- All initial target configurations selected



Indications of the onset of fireball





E. Andronov *et al.*, Universe 9 (2023) 2, 106

Onset of fireball studies are part of post-LS3 program

Production of kaons

- Strong interactions preserve isospin symmetry, which, among others, corresponds to equivalence in production of new pairs of u-$\bar{u}$ and d-$\bar{d}$ quarks

P. B. Pal, An introductory course of particle physics, CRC Press, Taylor & Francis Group (2015) Dokl. Akad. Nauk SSSR 103 (1965), 235; Am. J. Phys. 50 (1982), 748–753; Phys. Rev. 140 (1965), B1045–B1053

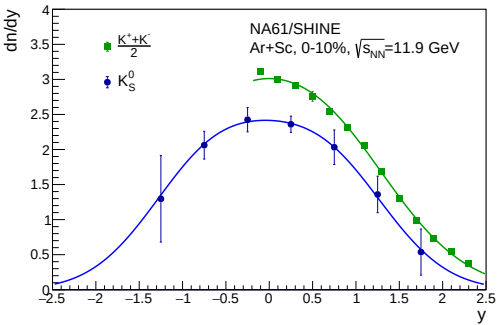
- The isospin symmetry leads to the equation:

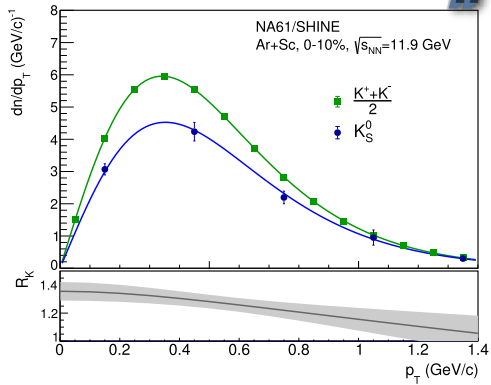
$$K^+ + K^- = K^0 + \overline{K^0}$$

- K^0 and $\overline{K^0}$ mesons are not directly measured in detectors, since the physical neutral states are the K^0_S and K^0_L; the production of K^0_S is given by (neglecting CP violation):

$$K^0_S = \frac{K^0 + \overline{K^0}}{2} = \frac{K^+ + K^-}{2}$$

Kaons in Ar+Sc at 75A GeV/c



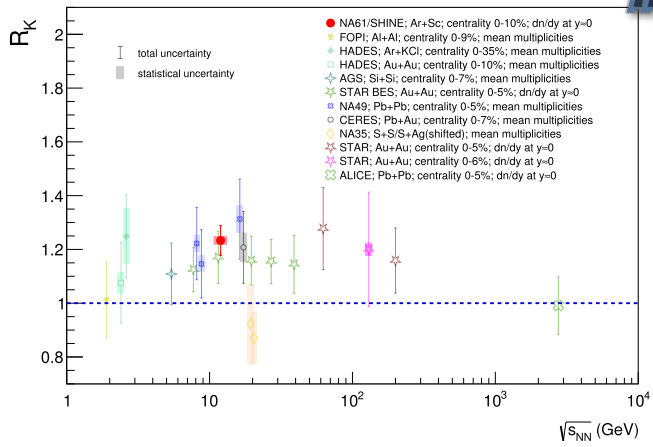


NA61/SHINE Coll., CERN-EP-2023-283

Ratio of charged to neutral kaons

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

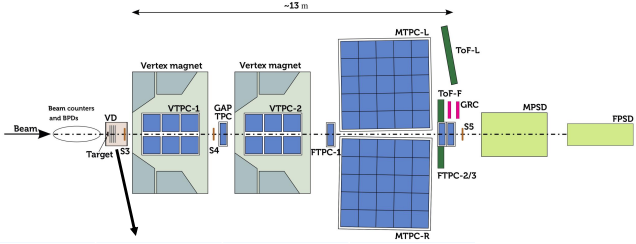
NA61/SHINE Coll.,
CERN-EP-2023-283



Unexpected excess of charged over neutral kaon yield in A+A collisions

Detector

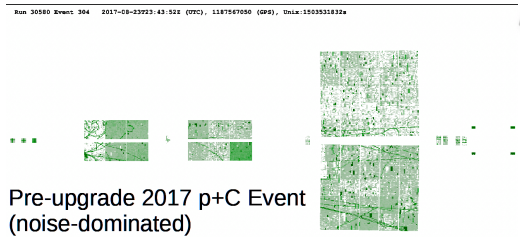
Significantly upgraded during LS2, the detector was successfully used in 2022 & 2023 data taking. No additional upgrades are needed for light-ion measurements



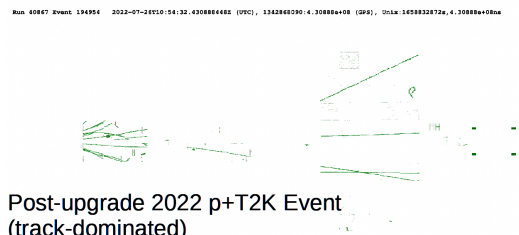
Cluster distribution in four planes of the new Vertex Detector

First data-taking after LS2

- Significant increase in the TPC raw data quality (new electronics):
  - **Noise reduction**
  - **Cluster shape improvement**
- New DAQ performed better than expected - **up to 1.6 kHz** event rate for p+C interactions



Pre-upgrade 2017 p+C Event
(noise-dominated)



Post-upgrade 2022 p+T2K Event
(track-dominated)

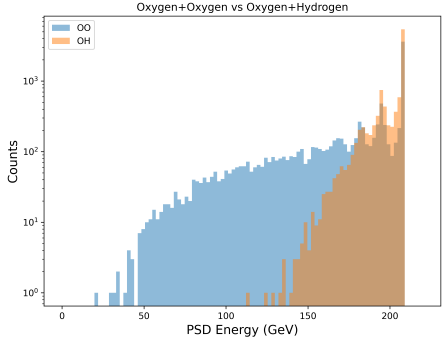
Request for light ions

p_{beam} (AGeV/c)	$\sqrt{s_{NN}}$ (GeV)	^{10}B # days (# events)	^{16}O # days (# events)	^{24}Mg # days (# events)
13	5.1	7 (100M)	7 (100M)	7 (100M)
30	7.6	7 (100M)	7 (100M)	7 (100M)
150	16.8	7 (100M)	7 (100M)	7 (100M)

Assuming the nominal data-taking, optimal SPS supercycle with an extraction duty-cycle of 36% $\longrightarrow$ 40M events/day.
The requested time includes setup time and one more day for possible stops in the beam delivery, longer supercycle, etc.

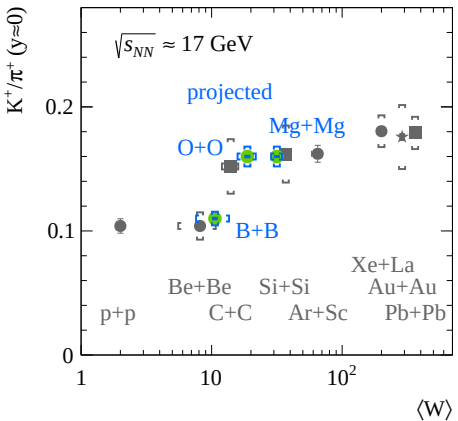
Targets

- Study of the onset of fireball and isospin symmetry in light systems **requires symmteric reactions** with preferable N = Z
- All **considered systems allow** for a **short target** $\longrightarrow$ allows for data-taking with Vertex Detector



Physics performance

- **System size dependence and the onset of fireball - OF**



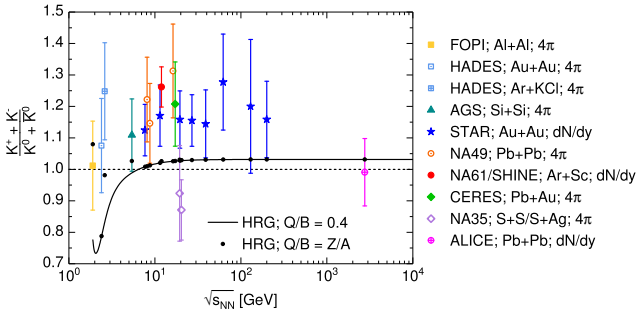
Considerable difference between light and heavy systems $\Longrightarrow$ **onset of fireball**

SPSC-P-330-ADD-14 was submitted as proposals to extend the ion program by **light ion beams after LS3**

The two main requested ion species are ^{16}O and ^{24}Mg

Physics performance

- **hypothesis of large isospin violation**



W. Brylinski, *et al.* arXiv: 2312.07176

The two main requested ion species are ^{16}O and ^{24}Mg

Assuming collisions of N = Z nuclei and the exact isospin symmetry one gets $R_K = 1$. The proposed runs with O+O and Mg+Mg collisions post-LS3 may allow us to verify the hypothesis of a large isospin symmetry violation in kaon production.

Summary

Physcics program post-LS3 with light ion beams:

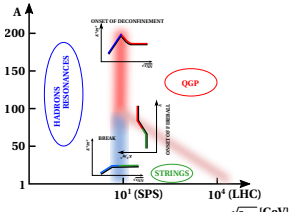
- The upgraded detector indicates a significant **increase of data quality** sufficient for post-LS3 measurements
- All targets allow for **optimal detector configuration** - including configuration with vertex detector
- The **beam conditions** are well understood

  $\longrightarrow$ waiting for the **formal decision** from the CERN injector complex
- **New and exciting physics post-LS3**:
  - search for **the onset of fireball** of strongly interacting matter
  - verification of the hypothesis of **large isospin violation** with **N=Z** nuclei (the simplest case).

Thank you

NA61/SHINE would like to thank the CERN EP, BE, HSE and EN Departments for support

Possible explanations - references



Onset of strings:

- PHSD: PRC, 78, 034919, 200; and NPA, 831, 215–242, 2009
- SMASH: PRC, 94, 5, 054905, 2016 and J. Phys. G, 47, 6, 065101, 202
- UrQMD: Prog. Part. Nucl. Phys.,41,255–369, 1998 and NPA, 936,1–5, 2015

Onset of deconfinement:

- SMES: Acta Phys.Polon. B30 (1999) 2705; PHSD: PRC, 78, 034919, 200; and NPA, 831, 215–242, 2009

Onset of QGP fireball:

- colour ropes: NPB, 245, 449–468, 1984.
- string fusion: NPB, 390, 542–558, 1993; PLB, 287, 154–158, 1992; EPJA, 51, 4, 44, 2015; Phys. Rep., 599, 1–50, 2015; and PRD, 103, 9, 094029, 2021.
- core fragmentation: PRL., vol. 98, p. 152301, 2007.
- string melting: PRC, 72, 064901, 2005.
- percolation: EPJC, 32, 547–553, 2004; and PLB, 640, 96–100, 2006.
- **AdS/CFT duality:** PRC, 90, 1, 014901, 2014; PRD, 90, 2, 025031, 2014; PRC, 92, 1, 014011, 2015