

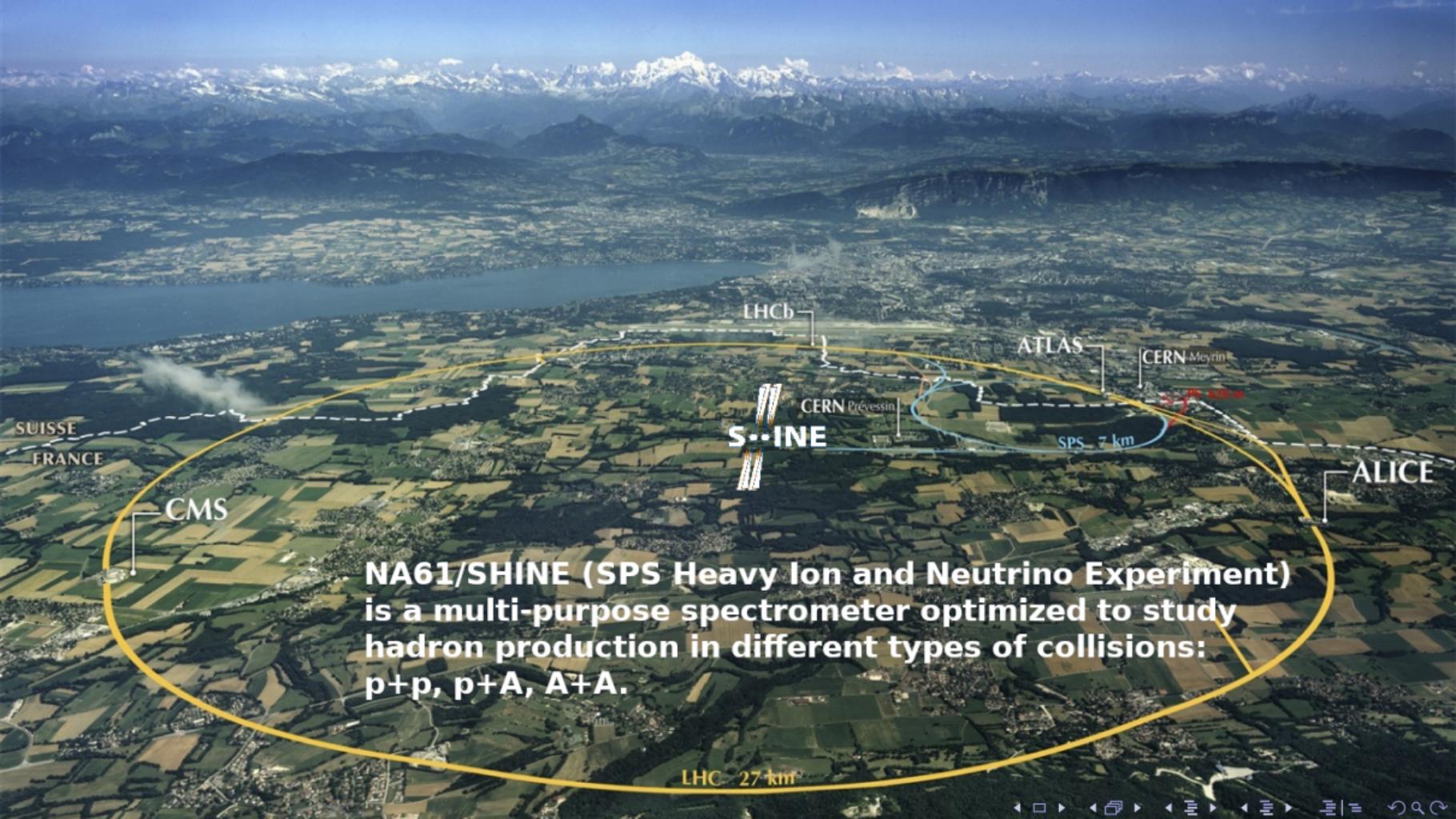


S.INE

Large isospin symmetry violation in kaon production?

Wojciech Bryliński

for the NA61/SHINE Collaboration
Warsaw University of Technology

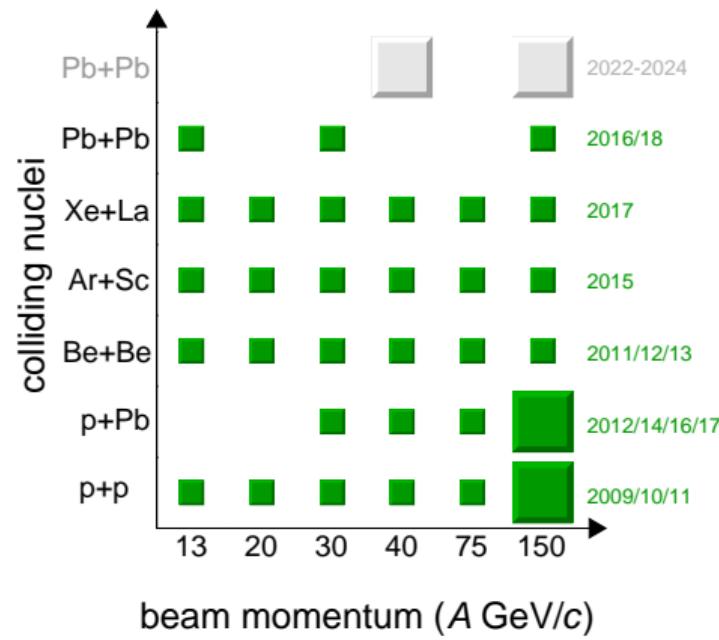
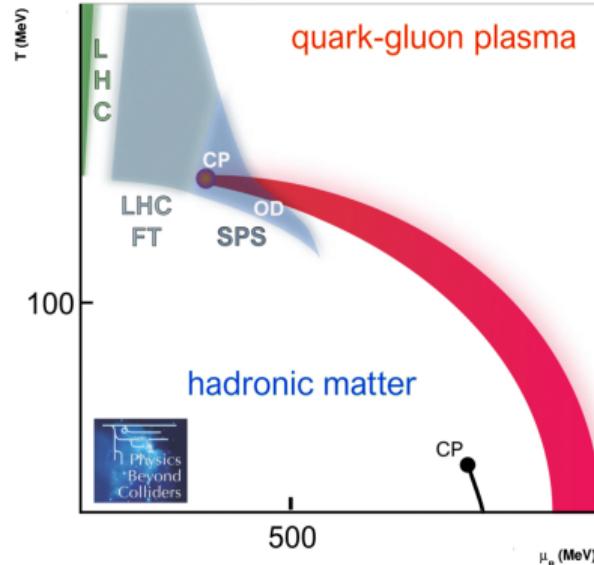


NA61/SHINE (SPS Heavy Ion and Neutrino Experiment)
is a multi-purpose spectrometer optimized to study
hadron production in different types of collisions:
 $p+p$, $p+A$, $A+A$.

LHC 27 km

NA61/SHINE strong interactions program

NA61/SHINE explores the phase diagram of strongly interacting matter by performing a 2D scan in collision energy and system size



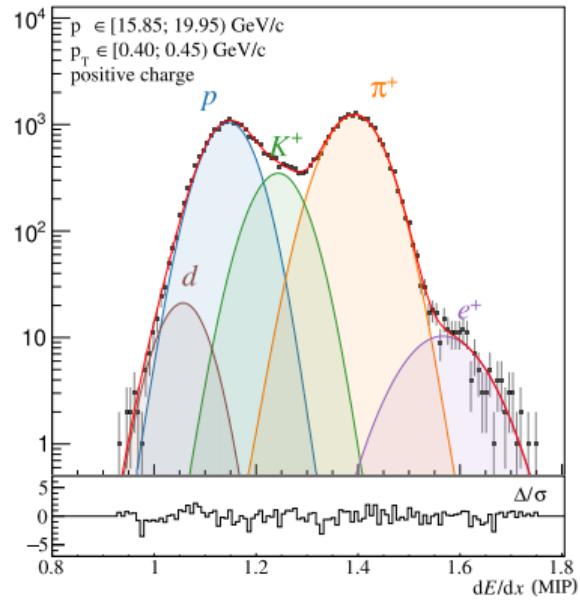
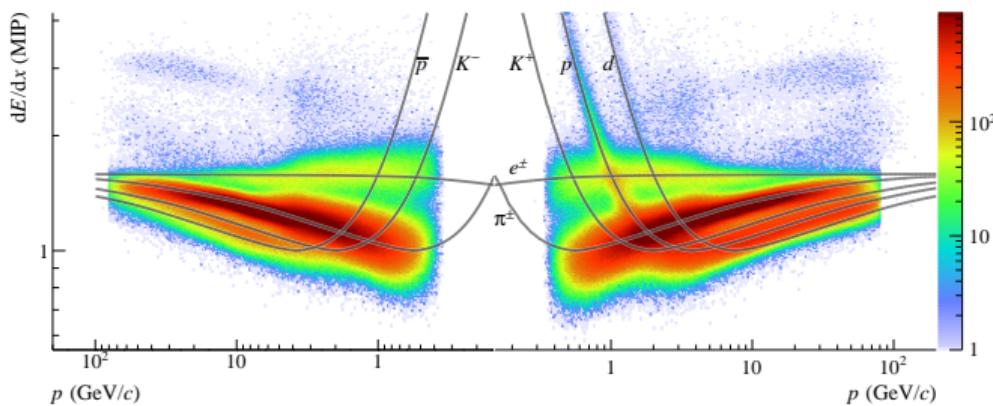


Kaon analysis
in 10% most central
Ar+Sc collisions

Ar: $Q = 18$, $B = 40$, $Q/B = 0.45$
Sc: $Q = 21$, $B = 45$, $Q/B \approx 0.47$

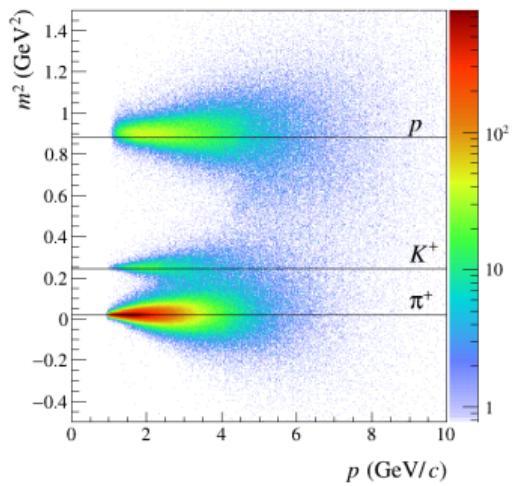
Charged kaon identification

- Combined analysis based on dE/dx and $tof - dE/dx$ identification
 - dE/dx – based on the measurement of energy loss of charged particles along the particle trajectory in Time Projection Chambers

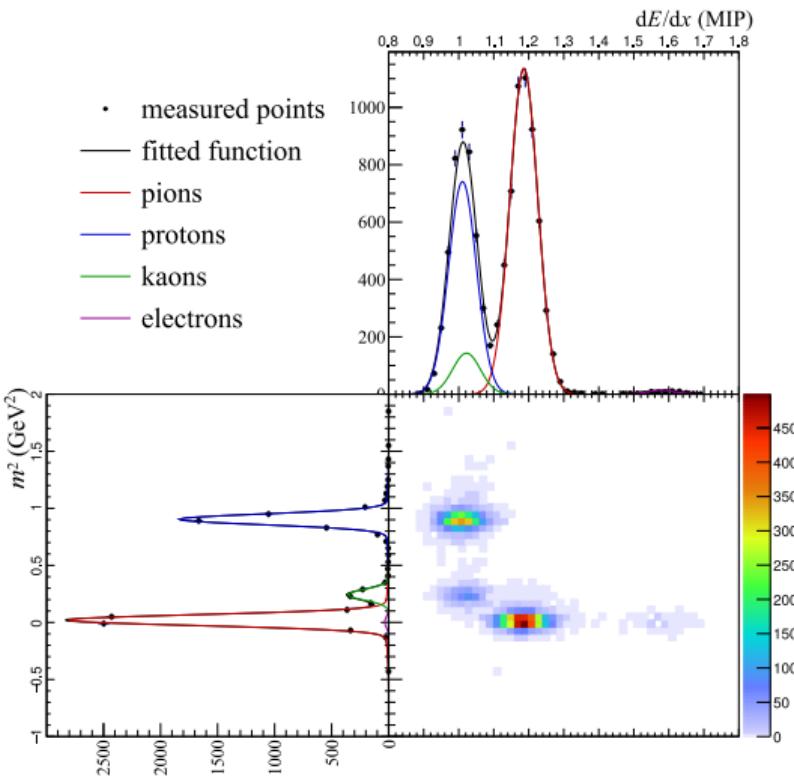


Charged kaon identification

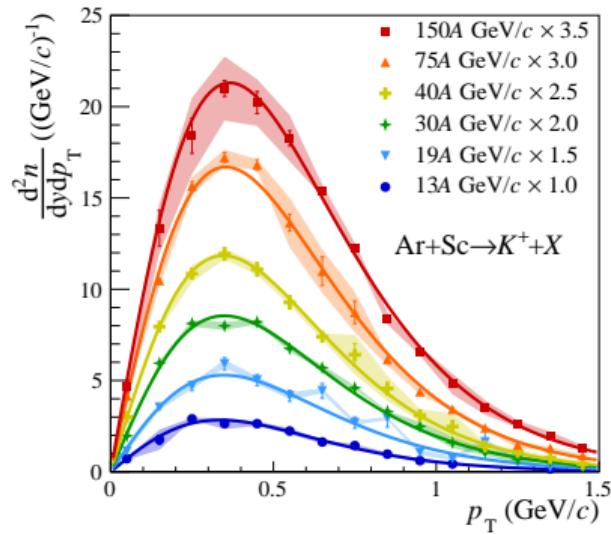
- $tof - dE/dx$ – based on the measurement of energy loss of charged particles combined with the measurement of time of flight



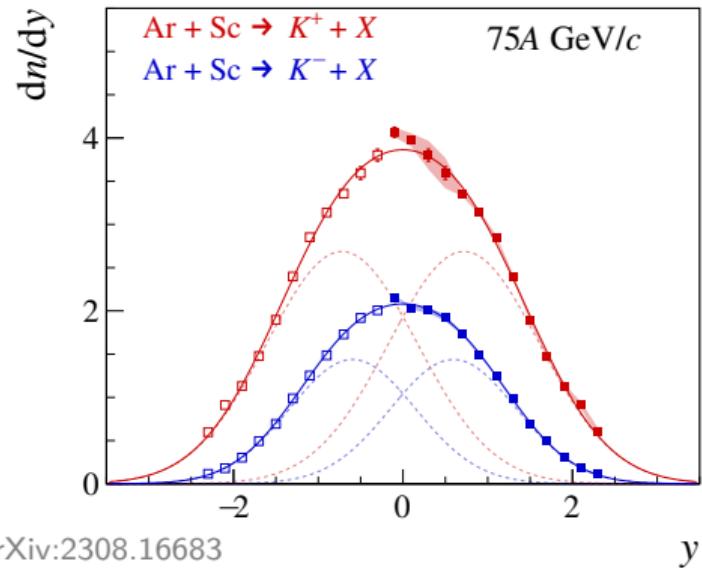
- measured points
- fitted function
- pions
- protons
- kaons
- electrons



Charged kaon production

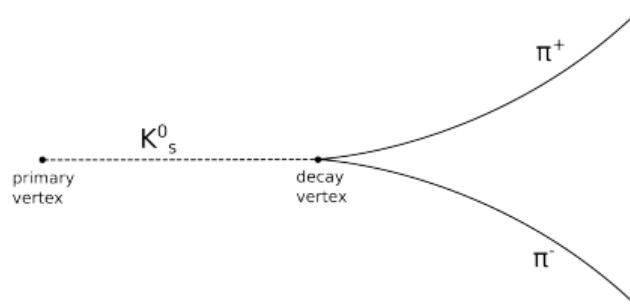


NA61/SHINE, arXiv:2308.16683

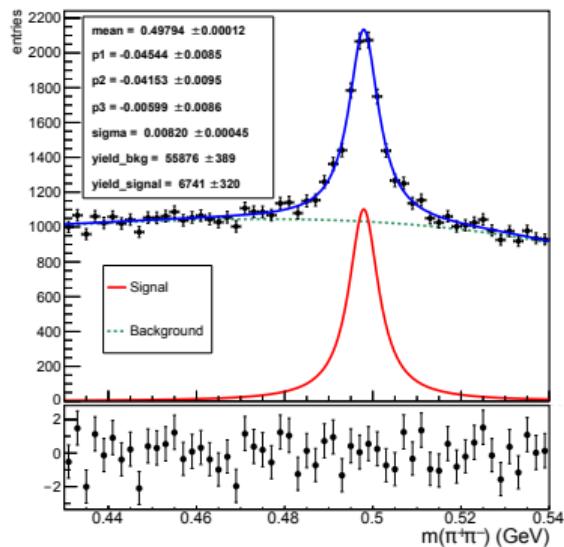


Mean multiplicities for Ar+Sc at 75A GeV/c : $\langle K^+ \rangle = 12.01 \pm 0.20(\text{stat}) \pm 0.42(\text{sys})$
 $\langle K^- \rangle = 5.35 \pm 0.04(\text{stat}) \pm 0.15(\text{sys})$

K_S^0 identification

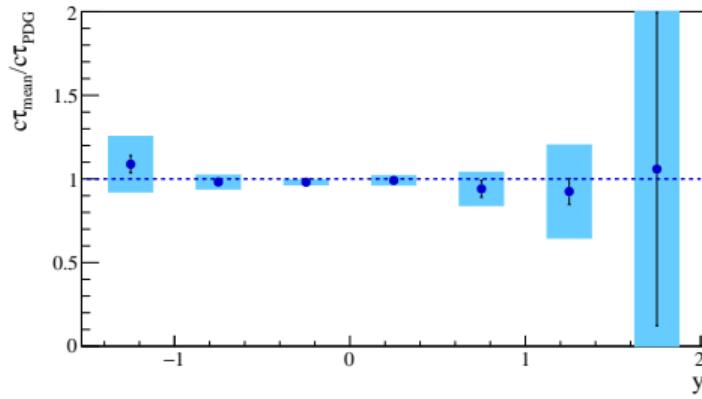
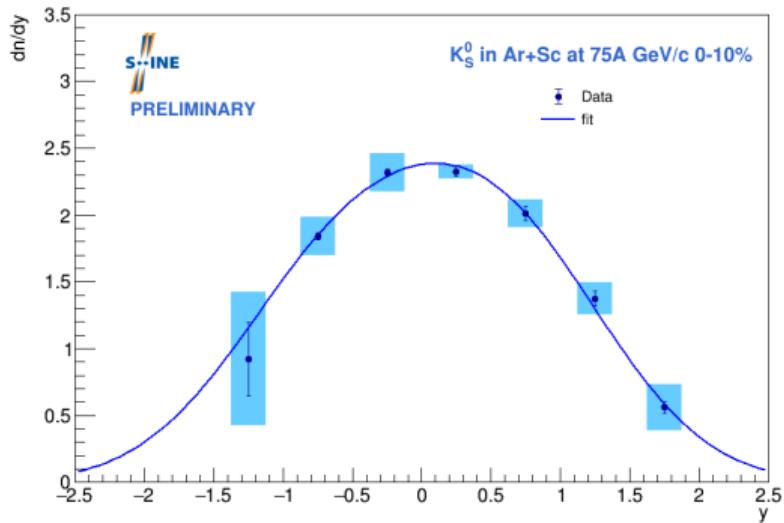


- Reconstruction based on decay topology
- K_S^0 decays into π^+ and π^- with $\text{BR} \approx 69.2\%$
- Breit-Wigner function is used to describe signal



$$y \in (0.5, 1.0), p_T \in (1.2, 1.5) \text{ GeV}/c$$

K_S^0 production



Mean multiplicity for Ar+Sc at 75A GeV/c: $\langle K_S^0 \rangle = 6.25 \pm 0.09(\text{stat}) \pm 0.73(\text{sys})$



Charged-to-neutral
kaon ratio

Production of kaons – expectations for Q/B = 0.5 and in the case of exact isospin symmetry

- 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)

- From Smushkevich rule: "For all particle involved in isospin-conserving relation all members of isospin multiplets are produced in equal numbers if and only if the initial population is uniform":

Dokl. Akad. Nauk SSSR 103 (1995), 235; Am. J. Phys. 50 (1982), 748–753; Phys. Rev. 140 (1965), B1045–B1053

- $K^+(u\bar{s}) = \overline{K^0}(d\bar{s})$
- $K^-(\bar{u}s) = \overline{K^0}(\bar{d}s)$

- By summing up the equations:

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

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

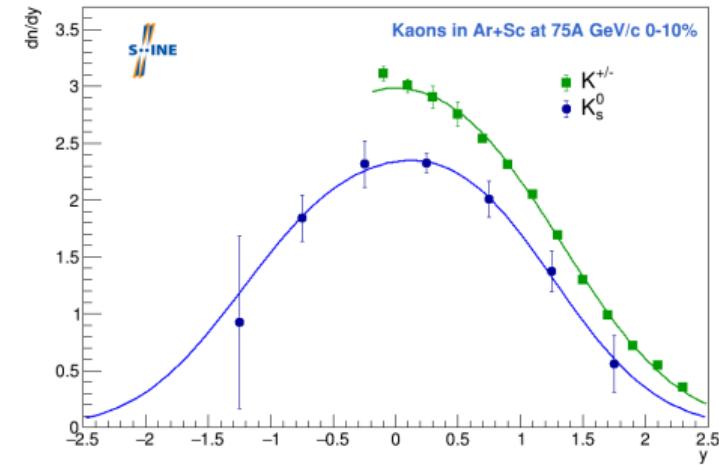
- $K_S^0 = \frac{K^0 + \overline{K^0}}{2}$

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

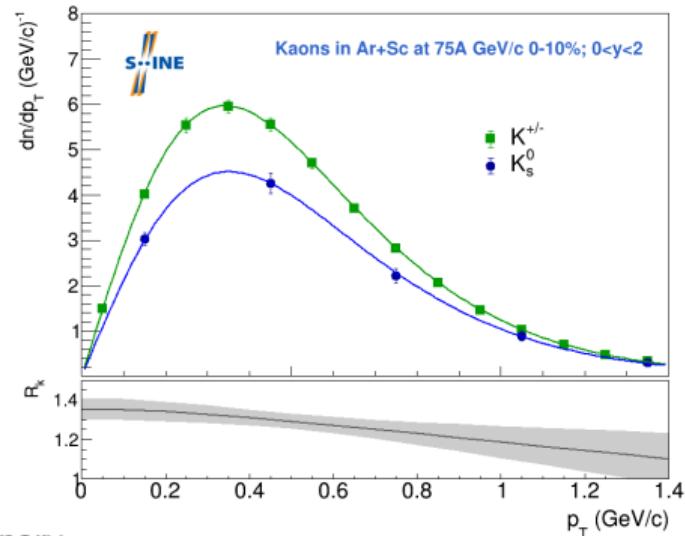
Comparison of charged and neutral kaons in central Ar+Sc collisions



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

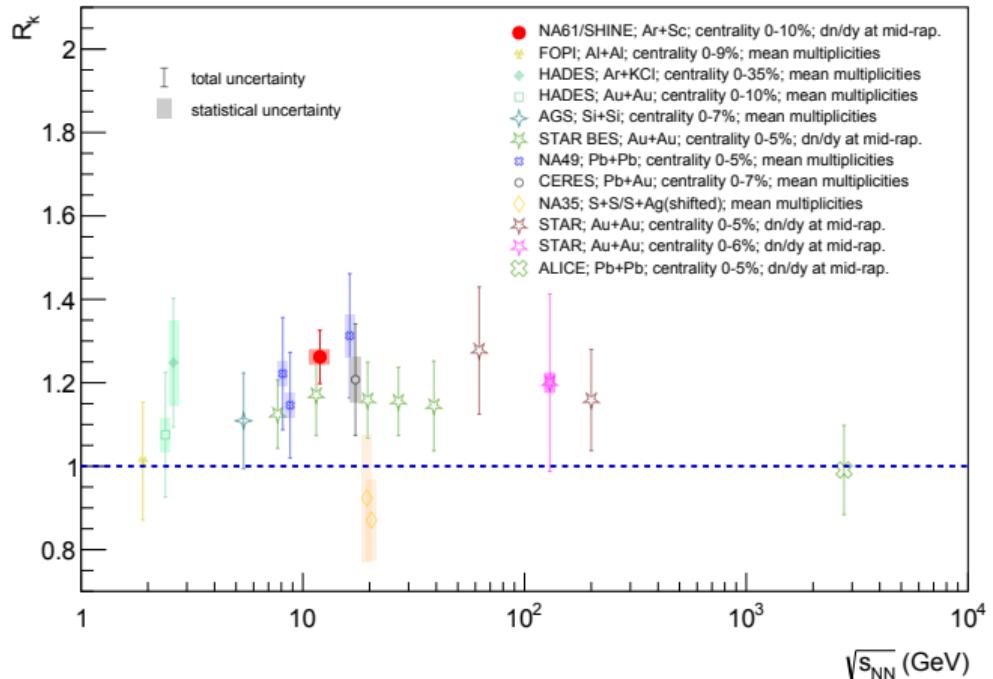


$$R_k = \frac{K^{+/-}}{K_s^0}$$



- $K^{+/-}$: NA61/SHINE, arXiv:2308.16683, K_s^0 : preliminary
- Total uncertainties plotted: $\sqrt{sys^2 + stat^2}$
- Around 15–30% difference in the whole rapidity and transverse momentum range

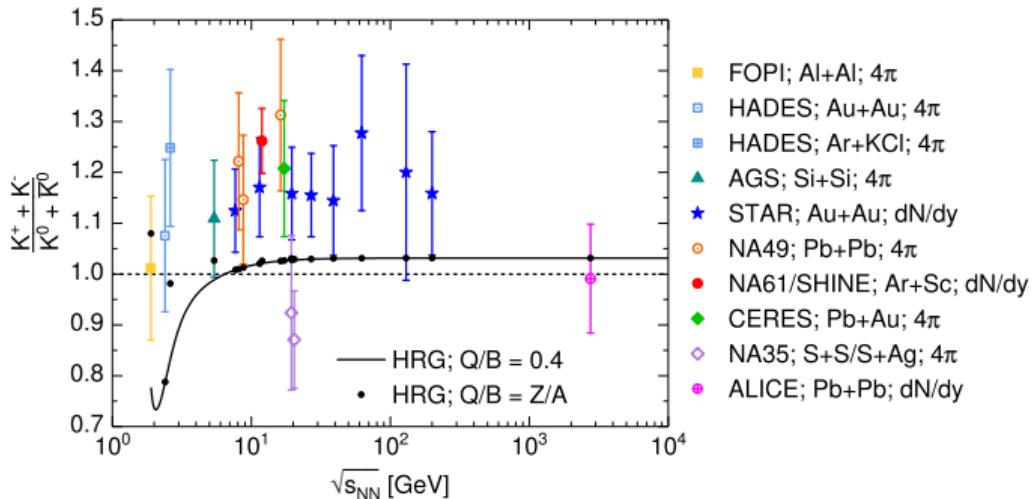
Comparison of charged and neutral kaons in world data



- NA61/SHINE: preliminary; arXiv:2308.16683
- CERES: M. Kalisky, PhD thesis 2007, <https://cds.cern.ch/record/1497739>
- STAR: Phys. Rev. C **102** (2020) no.3, 034909
- Phys. Rev. C **96** (2017) no.4, 044904
- Phys. Lett. B **595** (2004), 143-150
- Phys. Rev. C **83** (2011), 024901
- Phys. Rev. Lett. **108** (2012), 072301
- Phys. Rev. C **79** (2009), 034909
- ALICE: Phys. Rev. Lett. **111** (2013), 222301
- Phys. Rev. C **88** (2013), 044910
- AGS and NA35: Z. Phys. C **71** (1996), 55-64
- Z. Phys. C **64** (1994), 195-207
- Z. Phys. C **58** (1993), 367-374
- NA49: C. Strabel, PhD thesis 2006, <https://edms.cern.ch/document/2693436/1>
- HADES: H. Schuldes, PhD thesis 2016, <https://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/docId/42489>
- Phys. Lett. B **793** (2019), 457-463
- Phys. Rev. C **80** (2009) 025209
- Phys. Rev. C **82** (2010) 044907
- FOPI: Eur. Phys. J. A **52** (2016) 6, 177
- Phys. Rev. C **81** (2010) 061902

World data, having large uncertainties of individual points, support the NA61/SHINE finding

Charged-to-neutral kaon ratio – comparison with HRG model



- Black line shows the HRG baseline for electric-to-baryon charge $Q/B = 0.4$
V. Vovchenko, H. Stoecker,
Comput. Phys. Commun. 244 (2019), 295-310
- Black dots represent the HRG baseline for Q/B values specified accordingly to the given types of colliding nuclei

W. Brylinski, M. Gazdzicki, F. Giacosa, M. Gorenstein, R. Poberezhnyuk, S. Samanta, and H. Stroebele
– private communication, paper in preparation

- HRG model does not reproduce the experimental results on charged-to-neutral kaon ratio
- Is this an evidence for the *violation of the isospin symmetry* beyond the known effects?

Summary

- Observation of $R_k = \frac{K^{+/-}}{K_S^0}$ ratio to be 1.262 ± 0.064 in central Ar+Sc collisions at $75A \text{ GeV}/c$ ($\sqrt{s_{NN}} = 11.9 \text{ GeV}$)
- The HRG model **does not** explain the observed effect, predicting $R_k \approx 1.026$ (for Ar+Sc at $75A \text{ GeV}/c$)



Thank you!

wobrylin@cern.ch

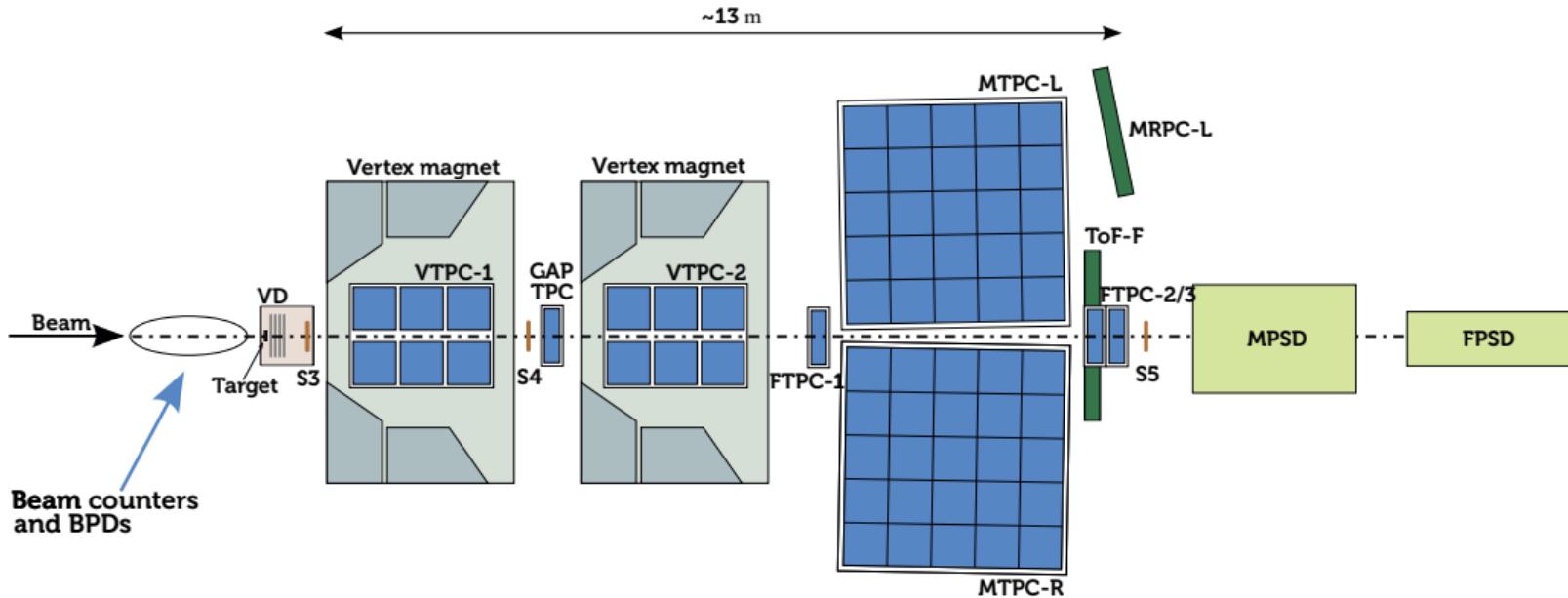
Have a SHINY day!

This work was supported by the Polish Ministry of Science and Higher Education (grant WUT ID-UB), the Norwegian Financial Mechanism 2014–2021 (grant 2019/34/H/ST2/00585), the Polish Minister of Education and Science (contract No. 2021/WK/10)



Backup

NA61/SHINE detector



- coverage of the full forward hemisphere, down to $p_T = 0 \text{ GeV}/c$
- ion (Be, Ar, Xe, Pb) and hadron (π , K, p) beams

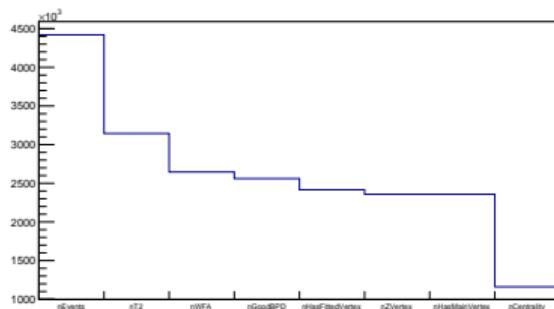
Ar+Sc@75 GeV/c – Events selection

ArScCutter class used (<https://twiki.cern.ch/twiki/bin/viewauth/NA61/Ar+ScEventCuts>)

Experimental data:

- nEvents: ~4.5M
- nT2: $S1 \times S2 \times \sqrt{V1} \times \sqrt{S5} \times PSD$
- nWFA: WFA 4ms, WFA T4: 25ms
- nGoodBPD: signal from BPD3 and fitted BPD track and BPD3x charge: [3800, 7200], BPD3y charge: [3600, 6800]
- nHasFittedVertex: primary vertex quality is ePerfect
- nZVertex: [-582, -578]
- nHasMainVertex: has main vertex
- nCentrality: 10% of most central events

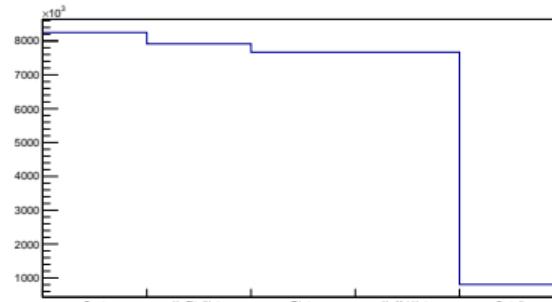
After cuts: ~1.2M



Monte Carlo data:

- nEvents: ~20M
- nHasFittedVertex: primary vertex quality is ePerfect
- nZVertex: [-582, -578]
- nHasMainVertex: has main vertex
- nCentrality: 10% of most central events

After cuts: ~2M



Tracks selection

- basic cuts:

- different charges of V0 daughter particles
- number of points in VTPCs for V0 daughter particles > 10
- minimum momenta of V0 daughter particles: $p > 0.4 \text{ GeV}/c$

- rapidity dependent cuts:

- directional angle cut (Cosine of the angle between the V0 mother momentum and the line joining the primary vertex and the decay vertex: for two body decay ≈ 1):

$$-1.5 \leq y < -1: \cos\alpha > 0.995$$

$$-1 \leq y < -0.5: \cos\alpha > 0.999$$

$$-0.5 \leq y < 0: \cos\alpha > 0.999$$

$$0 \leq y < 0.5: \cos\alpha > 0.999$$

$$0.5 \leq y < 1: \cos\alpha > 0.999$$

$$1 \leq y < 1.5: \cos\alpha > 0.9995$$

$$1.5 \leq y < 2: \cos\alpha > 0.9995$$

- ΔL cut distance between primary and secondary vertex:

$$-1.5 \leq y < -1: \Delta L > 5$$

$$-1 \leq y < -0.5: \Delta L > 5$$

$$-0.5 \leq y < 0: \Delta L > 7.5$$

$$0 \leq y < 0.5: \Delta L > 12.5$$

$$0.5 \leq y < 1: \Delta L > 12.5$$

$$1 \leq y < 1.5: \Delta L > 15$$

$$1.5 \leq y < 2: \Delta L > 12.5$$

Cuts optimization

- done on MC data (compared with experimental data)
- for given rapidity bin:
 - for given cut value:
 - plot mass invariant spectrum
- fit obtained mass invariant spectra (see next slide)
- calculate signal significance $S/\sqrt{S+B}$
- select optimal cut value for each rapidity bin

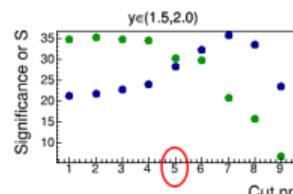
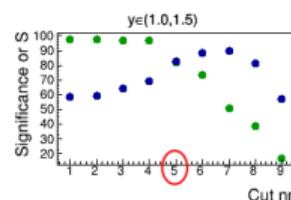
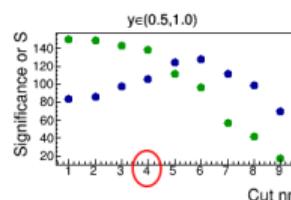
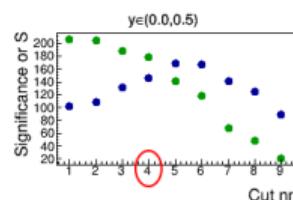
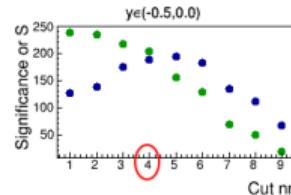
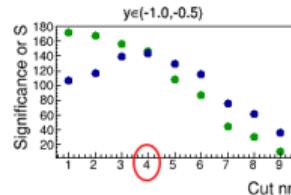
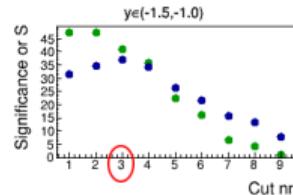
Checked cuts values:

- DirA: 0.99, 0.995, 0.999, 0.9995, 0.9999, 0.99995, 0.99999, 0.999995, 0.999999
- ΔL : 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5

Signal significance plots $S/\sqrt{S+B}$

Signal significance – blue, signal yield (scaled) – green: Checked cuts values:

- DirA: 0.99, 0.995, 0.999, 0.9995, 0.9999, 0.99995, 0.99999, 0.999995, 0.999999
- ybins: (-1.5,-1), (-1, -0.5), (-0.5, 0), (0, 0.5), (0.5, 1), (1, 1.5), (1.5, 2)

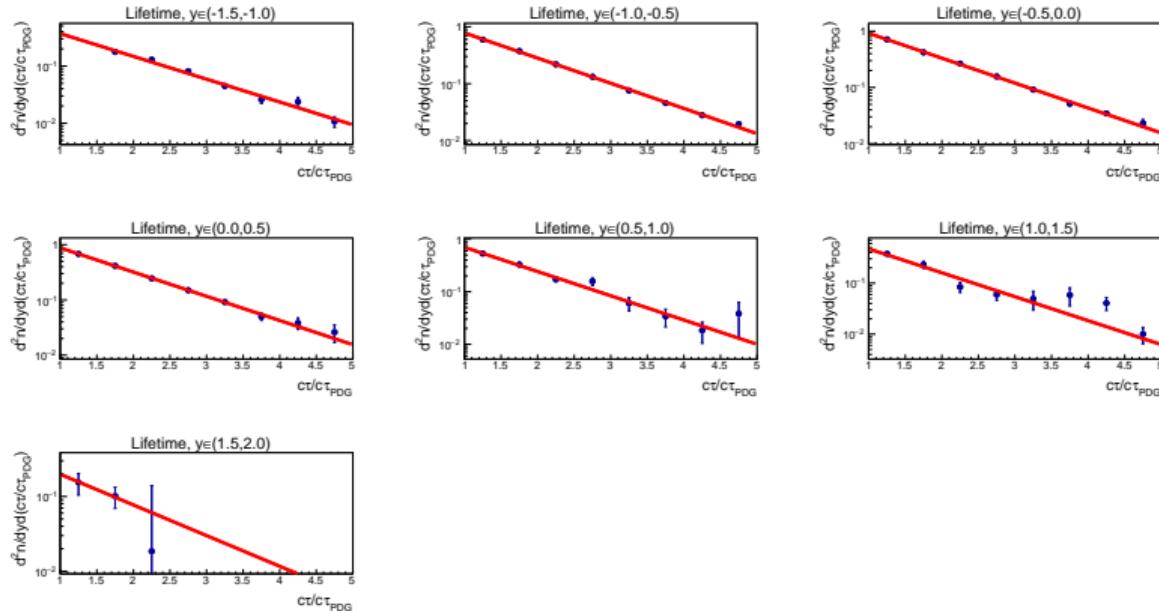


- Significance
- S (scaled)

K_s^0 lifetime analysis – $c\tau$ corrected distrib. for Ar+Sc at 75A GeV/c



For a given V0 candidate, the lifetime ($c\tau$) was calculated using the distance (ΔL) between the decay vertex and the primary vertex ($c\tau = \Delta L/(\gamma\beta)$, where γ, β are the Lorentz variables) and then divided by the tabulated PDG value $c\tau_{PDG} = 2.6844$ cm



From the fit one can extract the mean value and compare with PDG

Electron-positron collider data

This is what I found in the literature for electron-positron collider data on K⁺/K0s:

- Z. Phys. C20,1983,187 from PETRA/Desy

$\text{sqrt}(s) \quad 2\langle N_{K0s} \rangle$

12 GeV 1.14 ± 0.3

14 GeV 1.05 ± 0.1

22 GeV 1.27 ± 0.16

30 GeV 1.49 ± 0.22

36 GeV 1.45 ± 0.08

- Master thesis 1983 $\langle N_{K^+} \rangle$

14 GeV 1.2 ± 0.1

22 GeV 1.5 ± 0.2

34 GeV 1.8 ± 0.17

Not very conclusive but trend for more K⁺, than 2 K0s

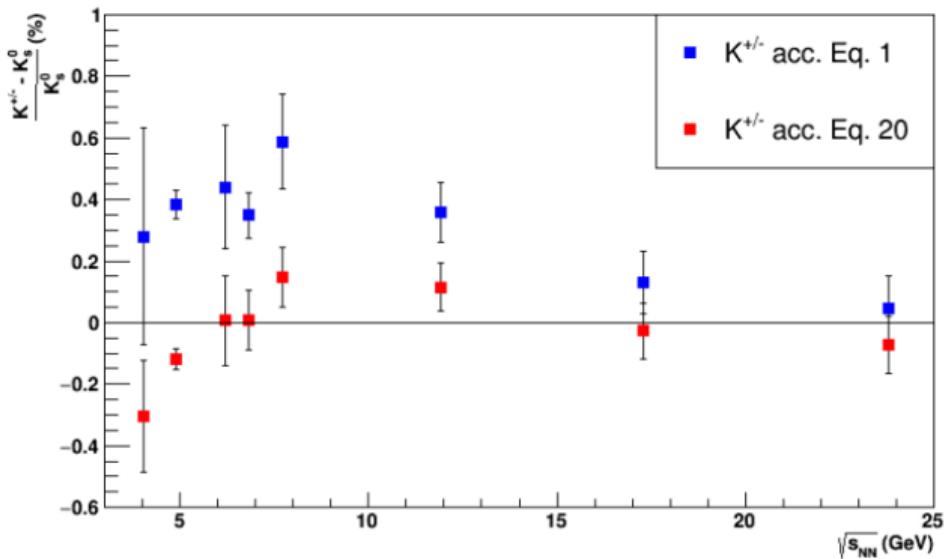
Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have investigated inclusive production of π^\pm , K^\pm , K_s^0 and \bar{p} in multihadron events at 9.98 GeV and in direct decays of the $\Upsilon(1S)$ meson, i.e. from quark and gluon fragmentation. The most pronounced difference is the rate of baryon production. The Lund Monte Carlo program gives a reasonable qualitative description, although it cannot reproduce our data in detail.

Multihadron final states in e^+e^- annihilation are produced via quark and antiquark fragmentation, those from direct $\Upsilon(1S)$ decays originate from the hadronization of three gluons. Data from these processes allow a test of our present ideas on quark and gluon fragmentation. One of the most striking differences observed so far [1,2,3] is the rate of baryon production. Many alternative explanations have been proposed [4], and more precise data are needed to improve our understanding of this phenomenon. In this paper, we present a study of inclusive production of protons as well as charged pions and charged and neutral kaons, which as final products of the fragmentation and decay chain give information on the global properties of the hadronization of quarks and gluons.

Table 9 π^\pm , K^\pm , K_s^0/\bar{K}^0 and $2 \cdot \bar{p}$ multiplicities obtained with the ARGUS detector, compared to the LUND Monte Carlo (version 6.2, [9]) and to results from other experiments. The continuum data are taken at 9.98 GeV (this experiment), in the range 9.4 to 10.1 GeV (DASP II) and at 10.49 GeV (CLEO), respectively. Contributions from K_s^0 and Λ to these multiplicities are determined from experimental data.

		$T(1S)_{dir}$	continuum
π^\pm	(not from K_s^0, Λ) this expt.	$6.691 \pm 0.029 \pm 0.123$	$5.694 \pm 0.034 \pm 0.103$
	(incl. K_s^0, Λ) this expt.	7.55 ± 0.14	6.38 ± 0.12
	(not from K_s^0, Λ) Lund	6.912 ± 0.003	5.676 ± 0.002
	DASP II [1]	6.1 ± 0.6	5.5 ± 0.6
	CLEO [2]	8.7 ± 0.4	8.3 ± 0.4
K_s^0/\bar{K}^0	this expt.	$1.033 \pm 0.036 \pm 0.037$	$0.910 \pm 0.050 \pm 0.034$
	LUND	0.809 ± 0.001	0.907 ± 0.001
	CLEO [2]	1.05 ± 0.13	0.92 ± 0.12
K^\pm	this expt.	$0.908 \pm 0.016 \pm 0.020$	$0.888 \pm 0.018 \pm 0.024$
	LUND	0.828 ± 0.001	0.948 ± 0.001
	DASP II [1]	1.22 ± 0.23	1.26 ± 0.29
	CLEO [2]	1.4 ± 0.2	1.3 ± 0.2
$2 \cdot \bar{p}$	(not from $\bar{\Lambda}$) this expt.	$0.361 \pm 0.011 \pm 0.023$	$0.212 \pm 0.012 \pm 0.012$
	(incl. $\bar{\Lambda}$) this expt.	0.507 ± 0.028	0.271 ± 0.018
	(not from $\bar{\Lambda}$) Lund	0.491 ± 0.001	0.254 ± 0.001
	DASP II [1]	0.64 ± 0.17	0.10 ± 0.04
	CLEO [2]	0.60 ± 0.09	0.40 ± 0.06



On the relation between K_s^0 and charged kaon yields in proton-proton collisions

Joanna Stepienak (NCBJ, Swierk), Damian Pszczel (NCBJ, Swierk)

May 5, 2023

6 pages

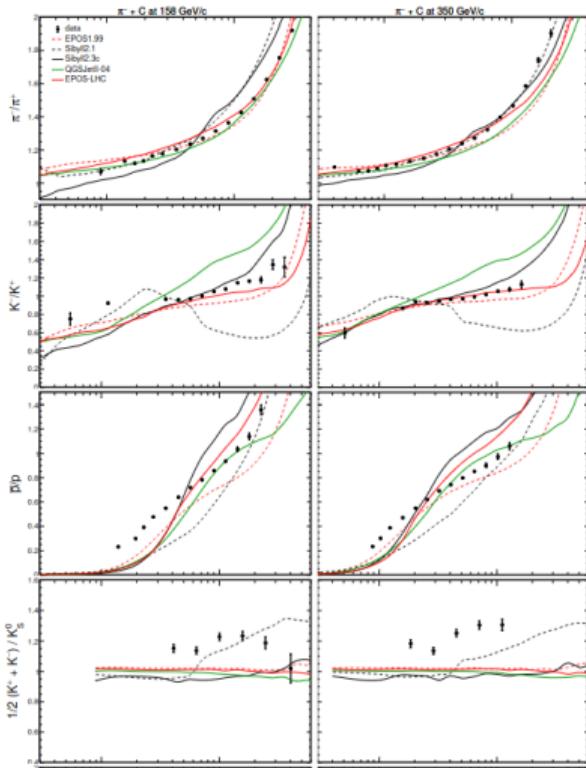
e-Print: 2305.03872 [hep-ph]

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$\pi^- C$ data



Measurement of hadron production in π^- -C interactions at 158 and 350 GeV / c with NA61/SHINE at the CERN SPS

NA61/SHINE Collaboration • H. Adhikary (Jan Kochanowski U., Kielce (main)) [Show All\(158\)](#)
Sep 21, 2022

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Published in: [Phys.Rev.D 107 \(2023\) 6, 062004](#)
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DOI: [10.1103/PhysRevD.107.062004](#) (publication)
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