Antibaryon production in pp interactions at $s^{1/2}$≈10 GeV: statistical hadronization and p+p-bar scaling?

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Antibaryon vs Baryon production

$$p + p \rightarrow \bar{B} + X$$
$$p + p \rightarrow B + X$$

$$p + p \rightarrow \bar{B} + B + p + p$$
$$p + p \rightarrow B + N + M$$

- Significant difference in threshold energy
- Negligible at SPS energies (5-20 GeV)???
- Imprint on fluctuations?

$$p + p \rightarrow \overline{\Lambda} + \Lambda + p + p$$
$$p + p \rightarrow \Lambda + p + K^+$$
$$\Delta(\sqrt{s}) = m_\Lambda + m_p - m_K = 1.6 GeV$$

- State-of-the-art calculations of pp->X multiplicities in PHSD and PYTHIA (2020)

Eur. Phys. J. A (2020) 56:223
https://doi.org/10.1140/epja/s10050-020-00232-7

THE EUROPEAN PHYSICAL JOURNAL A

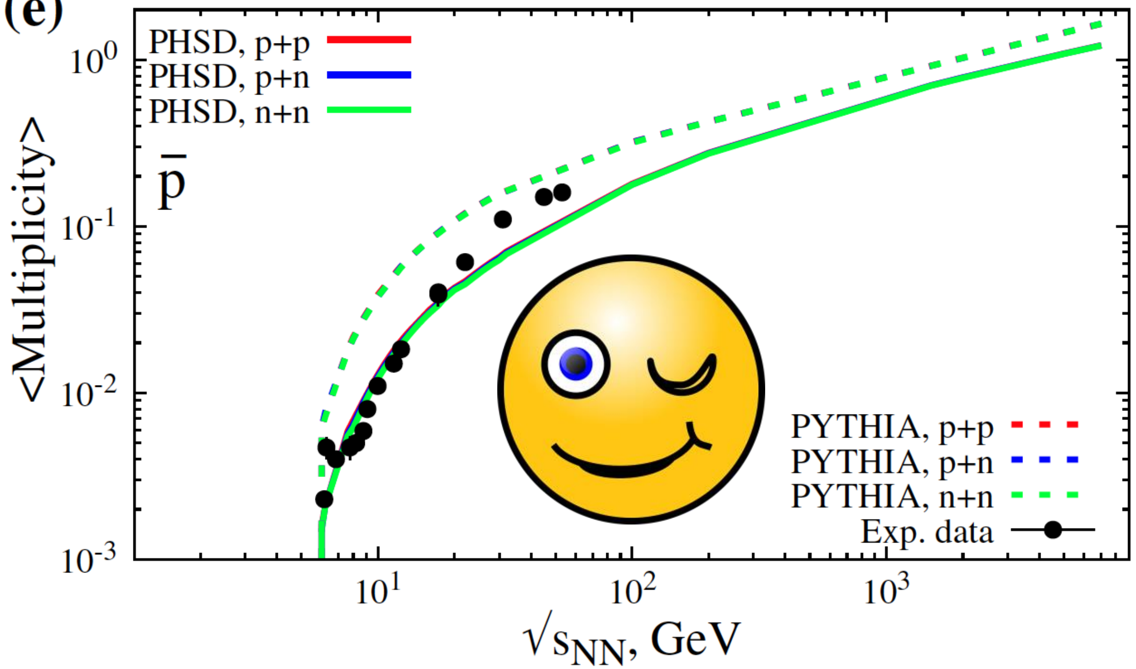
Review

Hadron production in elementary nucleon–nucleon reactions from low to ultra-relativistic energies

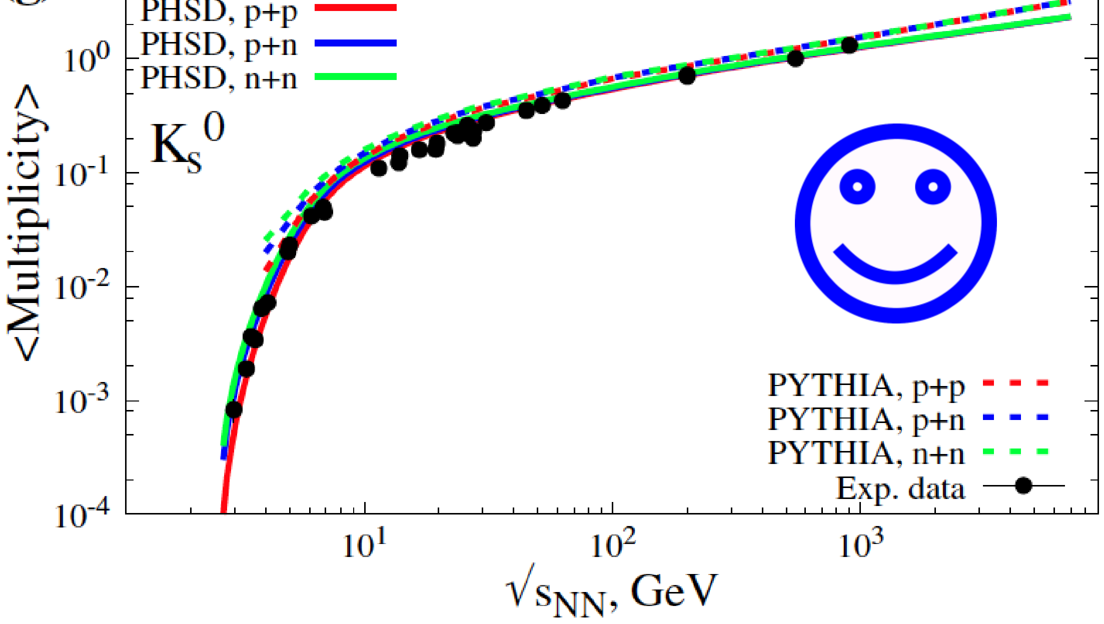
V. Kireyeu[1], I. Grishmanovskii[2], V. Kolesnikov[1], V. Voronyuk[1], E. Bratkovskaya[2,3,a]

Applicability of PHSD extended from $\sqrt{s_{BB}}$=10 GeV down to $\sqrt{s_{BB}}$=2.65 GeV („PHSD tune")

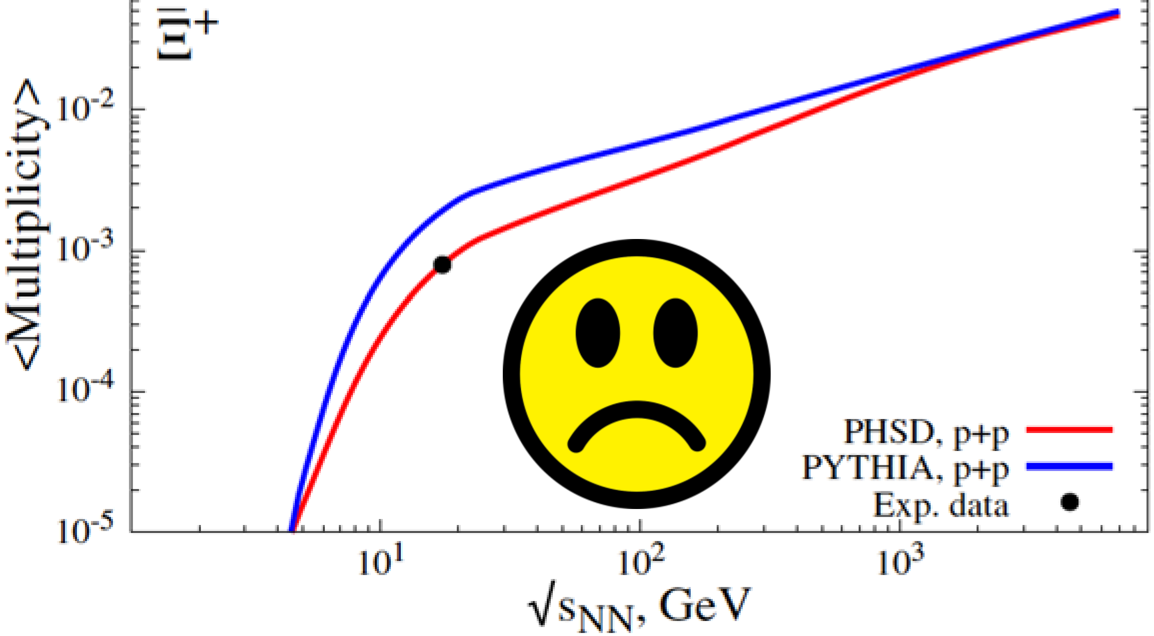
(e)



(g)



(d)

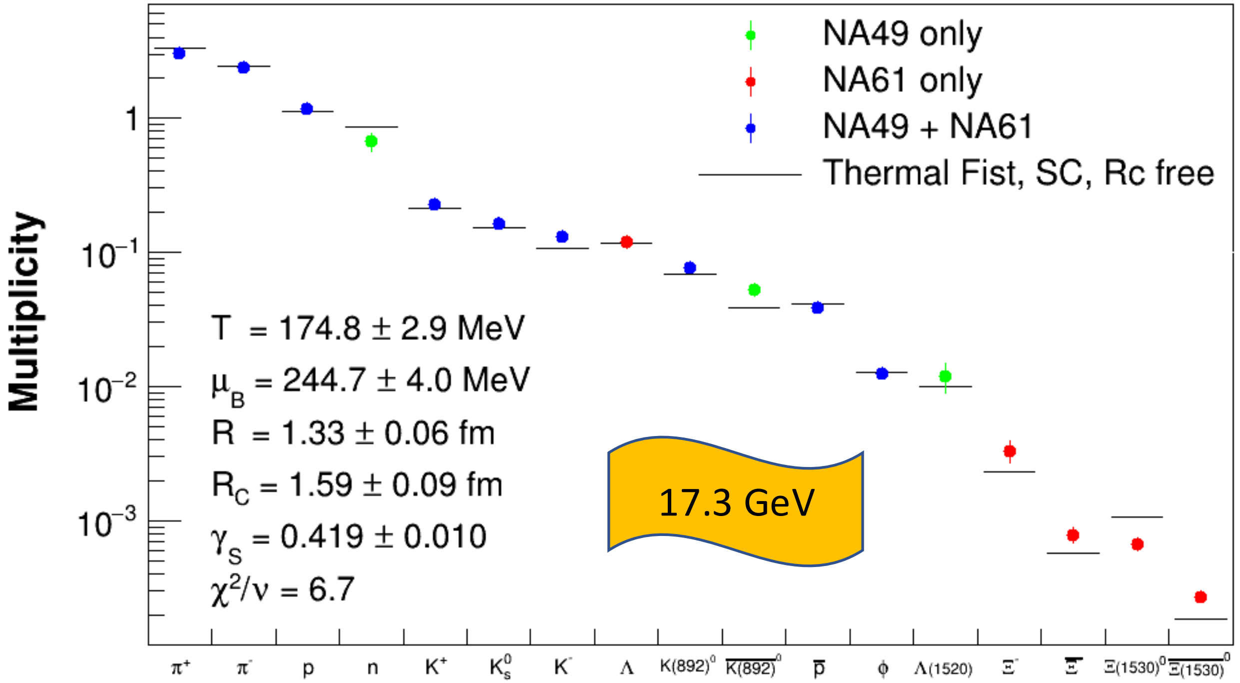


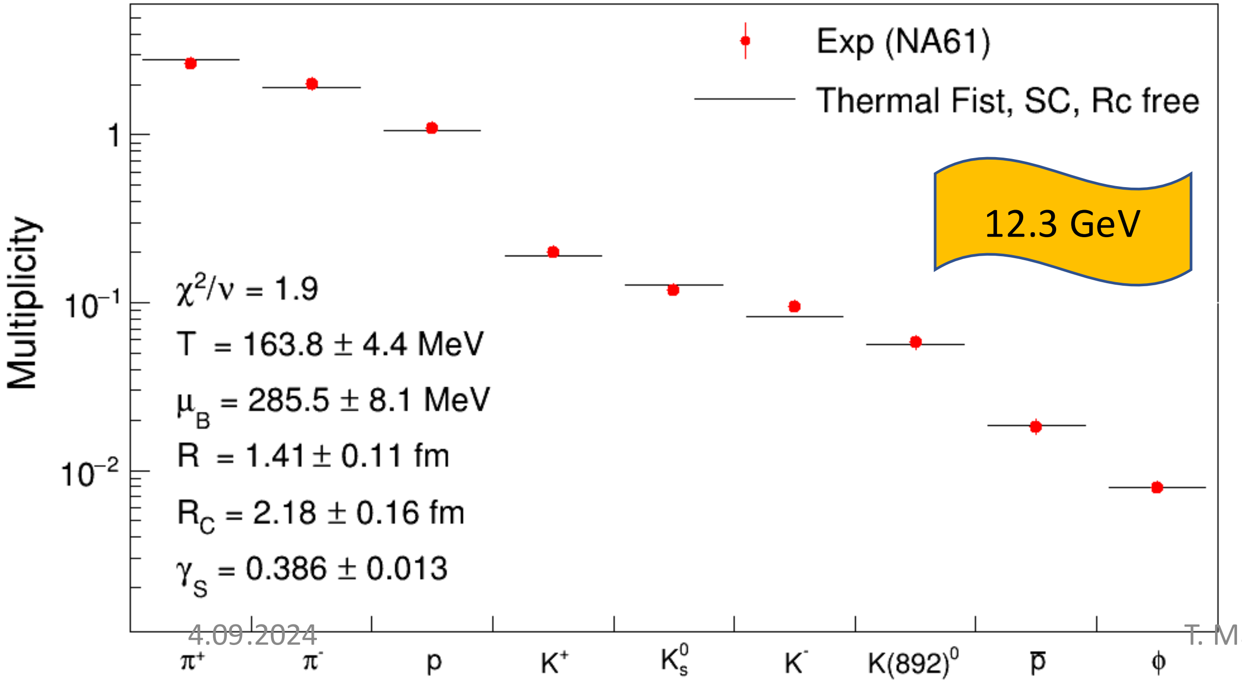
Description of particle yields within GCE+SC free volume for strangeness

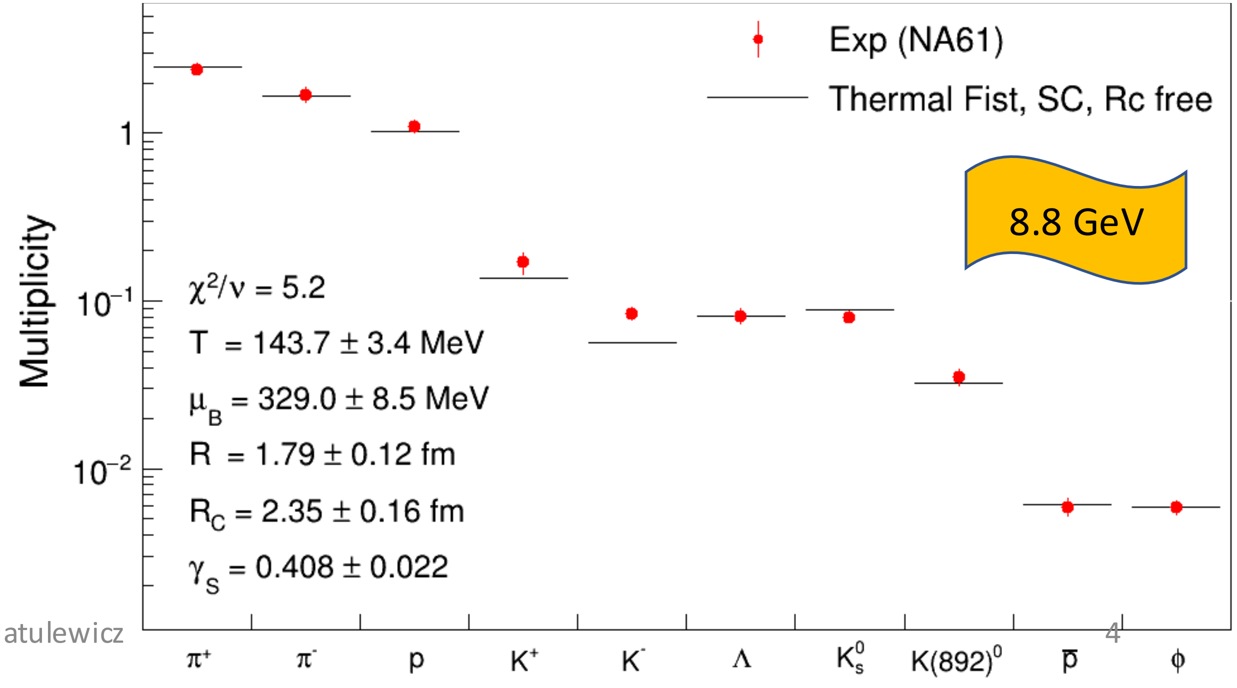
published:

J.Phys. G 48, 085006 (2021) first attempt

Acta Phys. Pol. B54, 12-A1 (2023) extension to 3 energies (December 2023)







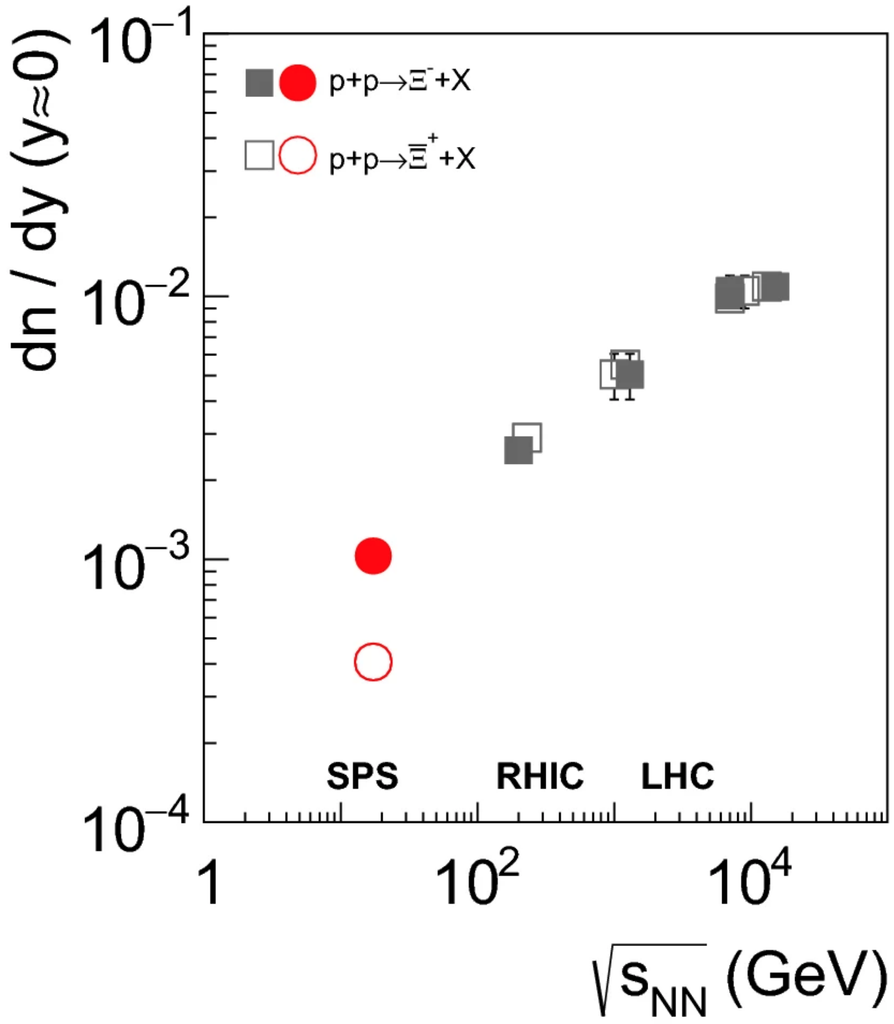
Relative accuracy of pp HRG ~20%

- Relative difference between experimental yields Y_{exp} and the results of hadronic thermalization Y_{stat} (36 multiplicities, 3 energies)

$$\left\langle \frac{Y_{\mathrm{stat}} - Y_{\mathrm{exp}}}{Y_{\mathrm{exp}}} \right\rangle = (-4 \pm 17)\%$$

- Precision of statistical HRG description of experimental yields ~20%. Working tool with limited prediction power only?? Some physics??
- Expected yields for many particles published (10.5506/APhysPolB.54.12-A1)
- Accuracy of predictions 20% ???

Antibaryon/baryon ratio

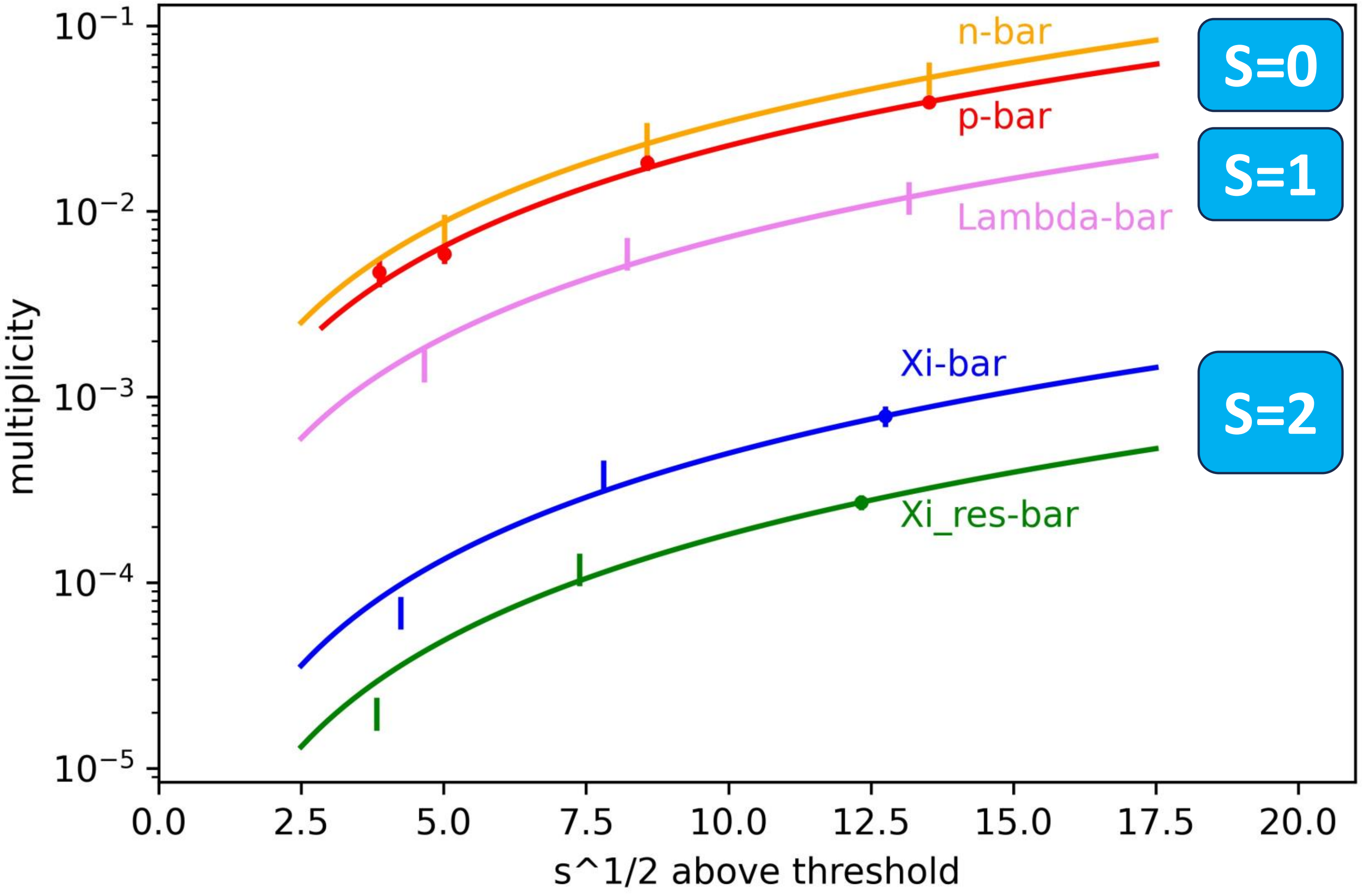


NA61/SHINE, Eur. Phys. J. C (2020) 80:833

p_T and $y = 0$ in rapidity. The small value of the ratio of mean multiplicities $\langle\overline{\Xi}^+\rangle / \langle\Xi^-\rangle = 0.24 \pm 0.01 \pm 0.05$ emphasizes the strong suppression of $\overline{\Xi}^+$ production.

0.25 (HRG)

p+p-bar scaling applied to other antibaryons



- experimental results (NA61/SHINE)

| HRG statistical model predictions (20% precision assumed)

Red curve - fit to antiproton production

Energy scale accounts for different threshold energy.

$$\sqrt{s_{free}} = \sqrt{s} - 2m_p - 2m_B$$

$$M_{\bar{B}} \sim \left(\sqrt{s_{free}}\right)^{\alpha}$$

α=1.81±0.09

Backup slides

Antiproton multiplicities (no errors!) from M.Antinucci et al., Lett. Nuovo Cim. 6, 121 (1973)

S (GeV^2)	$S^{1/2}$ (GeV)	Antiproton multiplicity
37.8	6.1	0.0023
46.8	6.8	0.0040
67.2	8.2	0.005
81	9.0	0.008
100	10	0.011
133	11.5	0.015
485	22	0.061
960	31	0.11
2025	45	0.15
2810	53	0.16

	NA61@SPS				NA49@SPS NA61@SPS	STAR@RHIC
	Energy $s^{1/2}$ (GeV)					
Particle	6.3	7.7	8.8	12.3	17.3	200
π^0						● (blue)
π^+	● (green)	● (green)	● (green)	● (green)	● (orange)	● (light blue)
π^-	● (green)	● (green)	● (green)	● (green)	● (orange)	● (light blue)
p	● (green)	● (green)	● (green)	● (green)	● (orange)	● (light blue)
p-bar	● (green)	● (green)	● (green)	● (green)	● (orange)	● (light blue)
n					● (purple)	
ϕ			● (green)	● (green)	● (orange)	● (light blue)
K^+	● (green)	● (green)	● (green)	● (green)	● (orange)	● (light blue)
K^-	● (green)	● (green)	● (green)	● (green)	● (orange)	● (light blue)
K^0_S		● (red)	● (red)	● (red)	● (green)	● (light blue)
$K(892)^0$			● (green)	● (green)	● (orange)	
$K(892)^0$-bar					● (purple)	
Λ			● (green)		● (green)	● (light blue)
Λ-bar						● (light blue)
$\Lambda(1520)$					● (purple)	
Ξ^-					● (green)	● (light blue)
Ξ^+					● (green)	● (light blue)
$\Xi(1530)^0$					● (green)	
$\Xi(1530)^0$-bar					● (green)	
Ω						● (light blue)
Ω-bar						● (light blue)

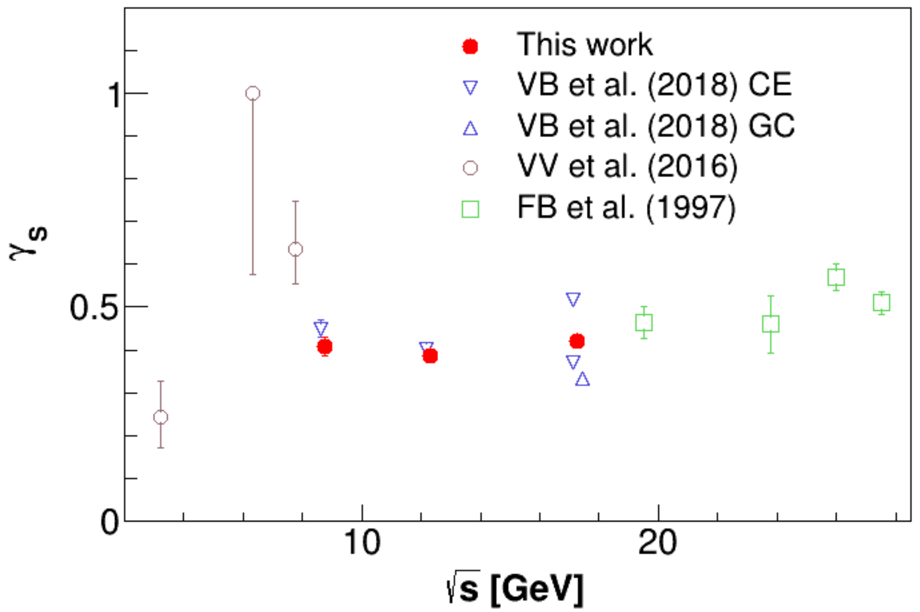
proton+proton

- NA61/SHINE — Eur. Phys. J. C (2017) 77:671 etc
  - new — K^0_S @80GeV/c, 40GeV/c, 31GeV/c *Eur. Phys. J. C* **84**, 820 (2024)
- NA49
- merged NA49&NA61/SHINE
  (M. Schmelling, Phys. Scr.51,676 (1995))
  J. Phys. G 48 (2021) 085004
- PHENIX — Phys.Rev.Lett.91:241803,2003
- STAR — Phys. Rev. C 75, 064901 (2007)
  Phys. Lett. 612B, 181 (2005)

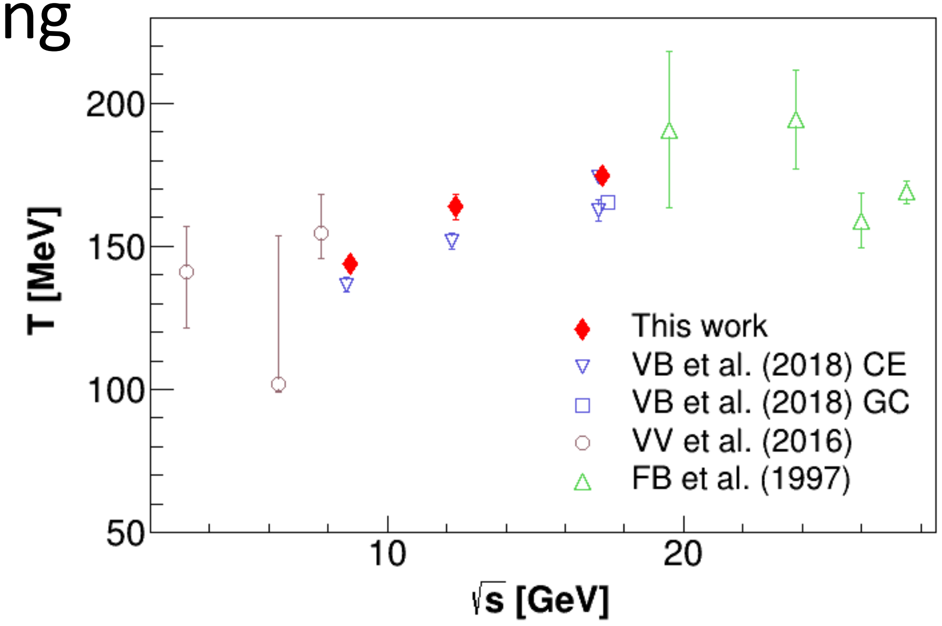
Results at $s^{1/2}$=17.3 GeV are complete

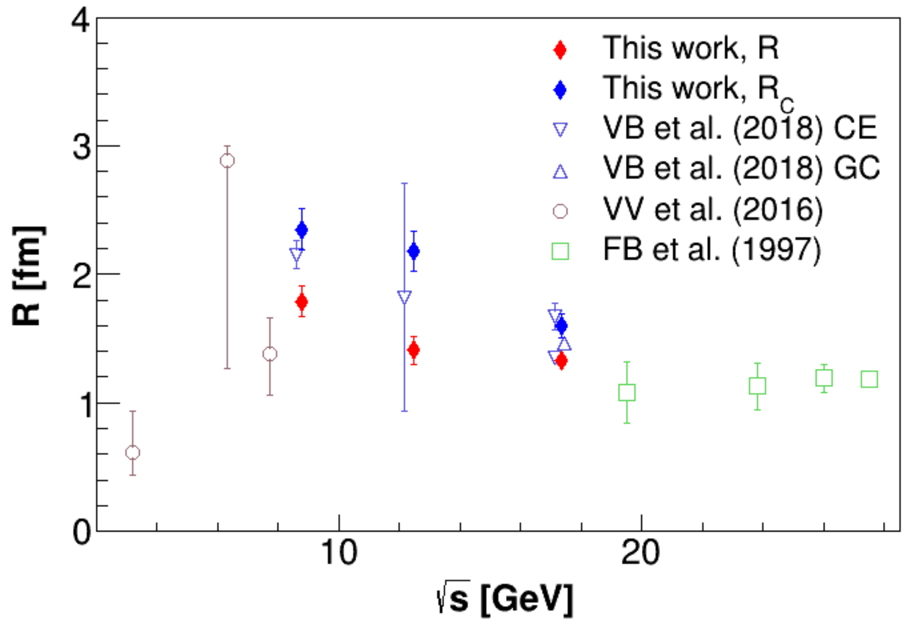
	Initial	Reconstructed
Charge	2	1.86 ± 0.22
Baryon number	2	1.92 ± 0.11
Strangeness	0	-0.014 ± 0.023

The effects of adding K_0^S yields



V.Begun et al,
PRC98 (2018)
V.Vovchenko et al.,
PRC93 (2016)
F.Beccatini&U.Heinz,
ZPhys C76 (1997)





- The χ^2 values in „acceptable" range for analyses with ϕ
- Strangeness undersaturation factor $\gamma_S \cong 0.4$
- Temperature (&baryochemical potential) similar to previous analyses
- Decrease of canonical volume with increasing energy

- R_C above R !

- *Acta Phys. Pol. B54, 12-A1 (2023)*
- *Both strangeness suppression factor <u>and</u> radius have to be used*

Could $R_C > R$? Hints not only from femtoscopy

pp collisions @ √s = 27.4 GeV

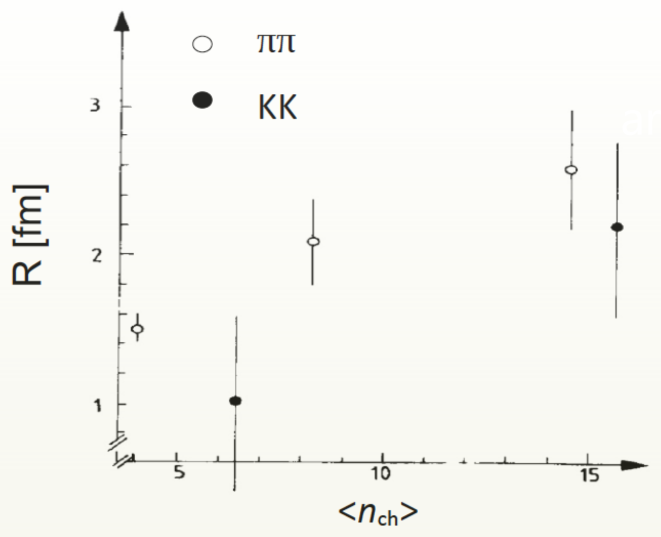
M. Aguilar-Benitez et al. (NA27 Collaboration), Z. Phys. C54, 21 (1992)

For $\pi^{\pm}\pi^{\pm}$ pairs, $R = 1.71 \pm 0.04$ fm

For $K^{\pm}K^{\pm}$ pairs, $R = 1.87 \pm 0.33$ fm

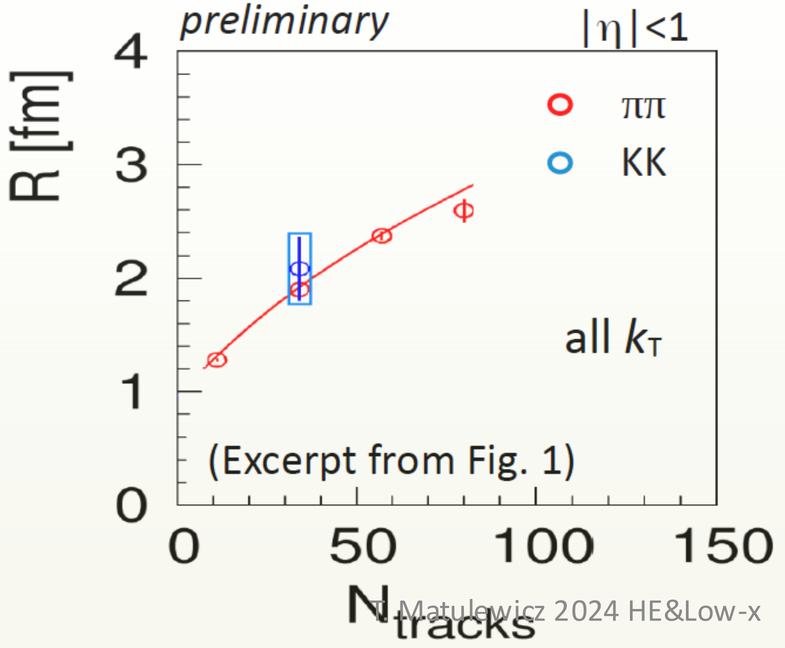
pp collisions @ √s = 63 GeV

T. Åkesson et al. (AFS Collaboration), PL 155B, 128 (1985)



pp collisions @ √s = 900 GeV

S.M. Dogra (CMS Collaboration), NP A931, 1061 (2014)



(Excerpt from Fig. 1)

PHYSICAL REVIEW C **103**, 014904 (2021)

J. Cleymans, P.M. Lo, K. Redlich, N. Sharma

The resulting yields (the SCE model fit to ALICE data) exhibit much better agreement with data by decreasing strangeness suppression at lower multiplicities due to ***larger value of V_C than V_A.***

Femtoscopic results inconclusive

→ more precise determination of the HBT radius of kaon pairs from pp interactions welcome!