Thermal model interpretation of particle production in pp interactions around $s^{1/2}$≈10 GeV

Tomasz Matulewicz and Krzysztof Piasecki

Faculty of Physics, University of Warsaw

HE&Low-x Sfantu Gheorge, Romania
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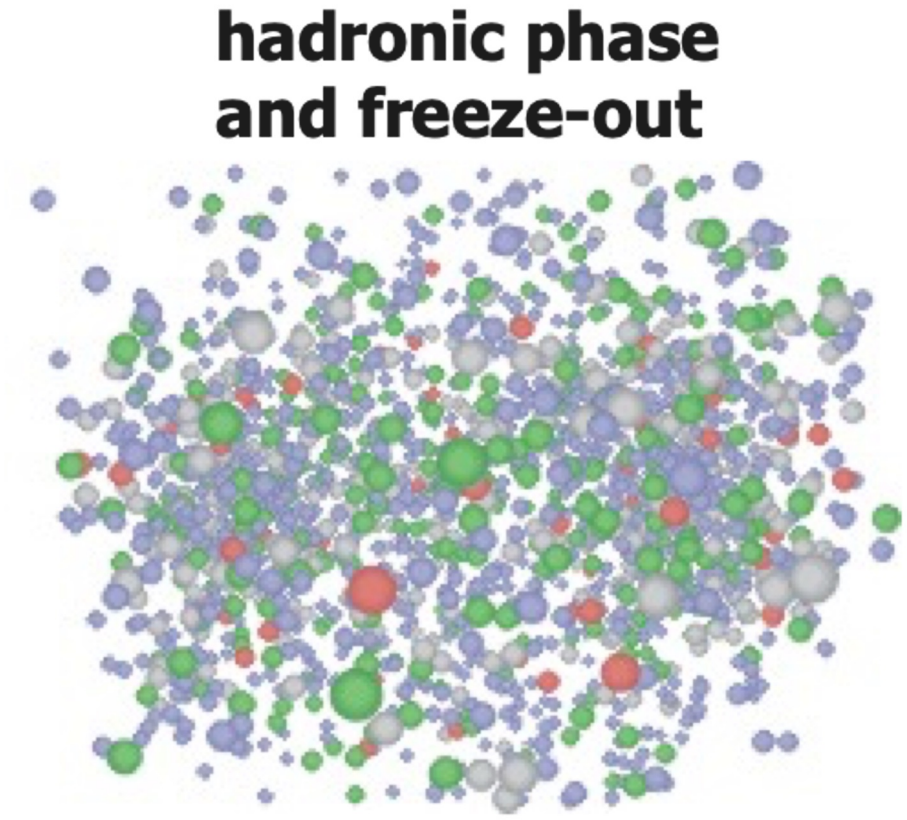
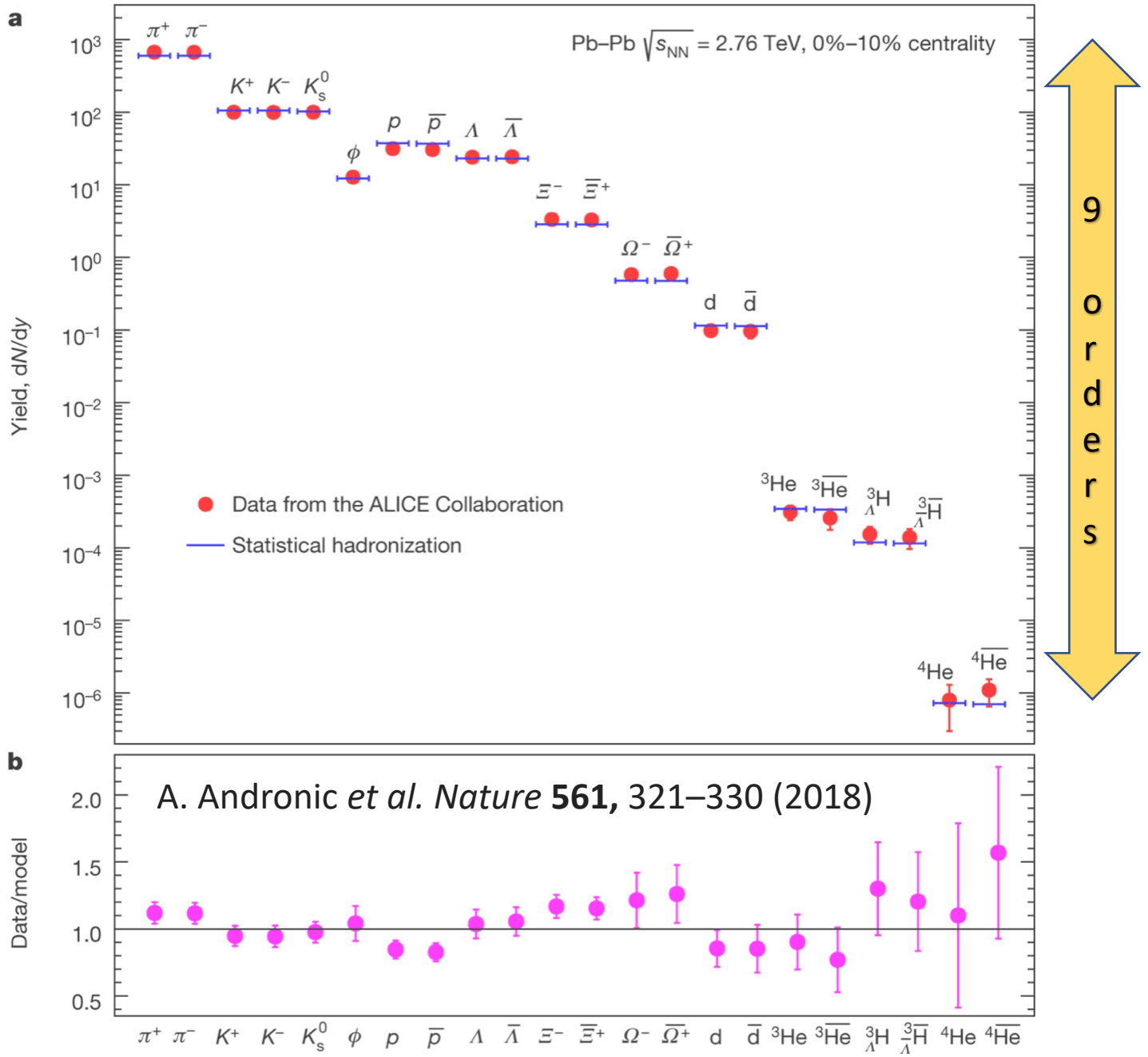
Thermal model in AA

$$\frac{N_{\bar{X}}}{N_X} \cong exp\left(-\frac{2\mu}{T}\right)$$





	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						●
π^+	●	●	●	●	●	●
π^-	●	●	●	●	●	●
p	●	●	●	●	●	●
p-bar	●	●	●	●	●	●
n					●	
ϕ			●	●	●	●
K^+	●	●	●	●	●	●
K^-	●	●	●	●	●	●
K^0_S		●	●	●	●	●
$K(892)^0$			●	●	●	
$K(892)^0$-bar					●	
Λ			●		●	●
Λ-bar						●
$\Lambda(1520)$					●	
Ξ^-					●	●
Ξ^+					●	●
$\Xi(1530)^0$					●	
$\Xi(1530)^0$-bar					●	
Ω						●
Ω-bar						●

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 case of the ϕ-meson

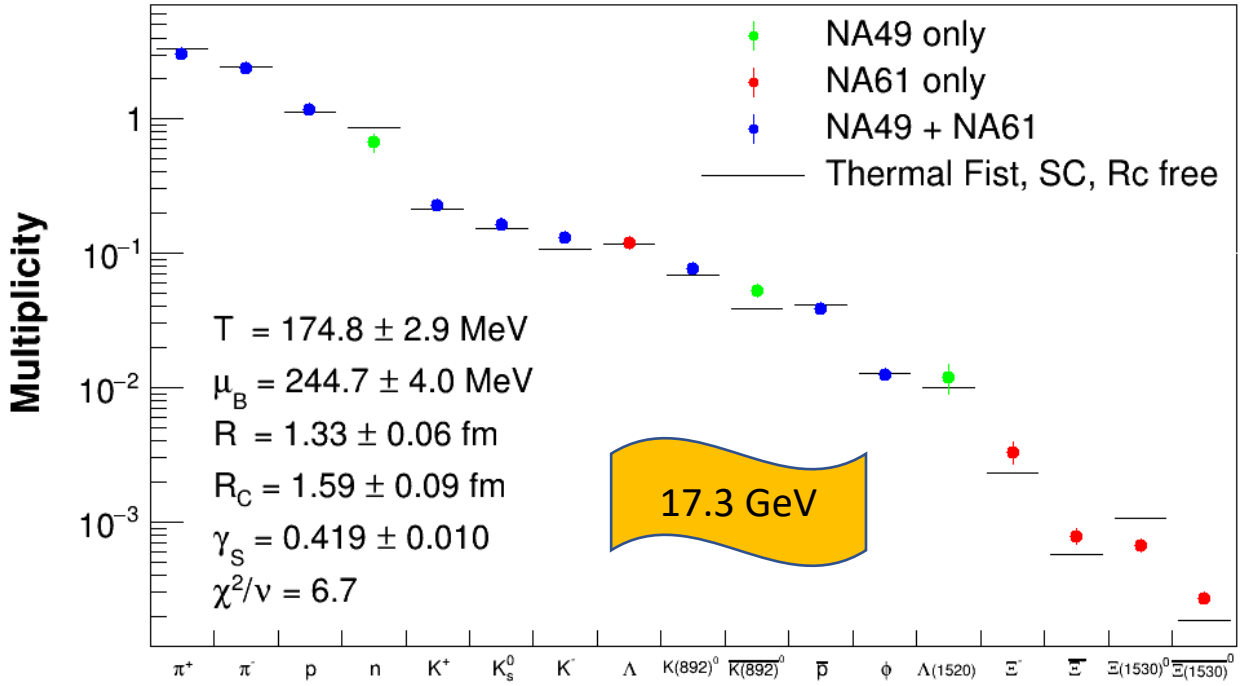
- **Excluding the ϕ-meson improves the fit quality (the same is observed), but why a well measured particle should be excluded?**
- **In all following analyses <u>the yield of the ϕ-meson is always included</u>**
- **Extended Breit-Wigner (eBW) shape for broad resonances**
- **High χ^2 values 😕 → free volume for strange particles 😀**

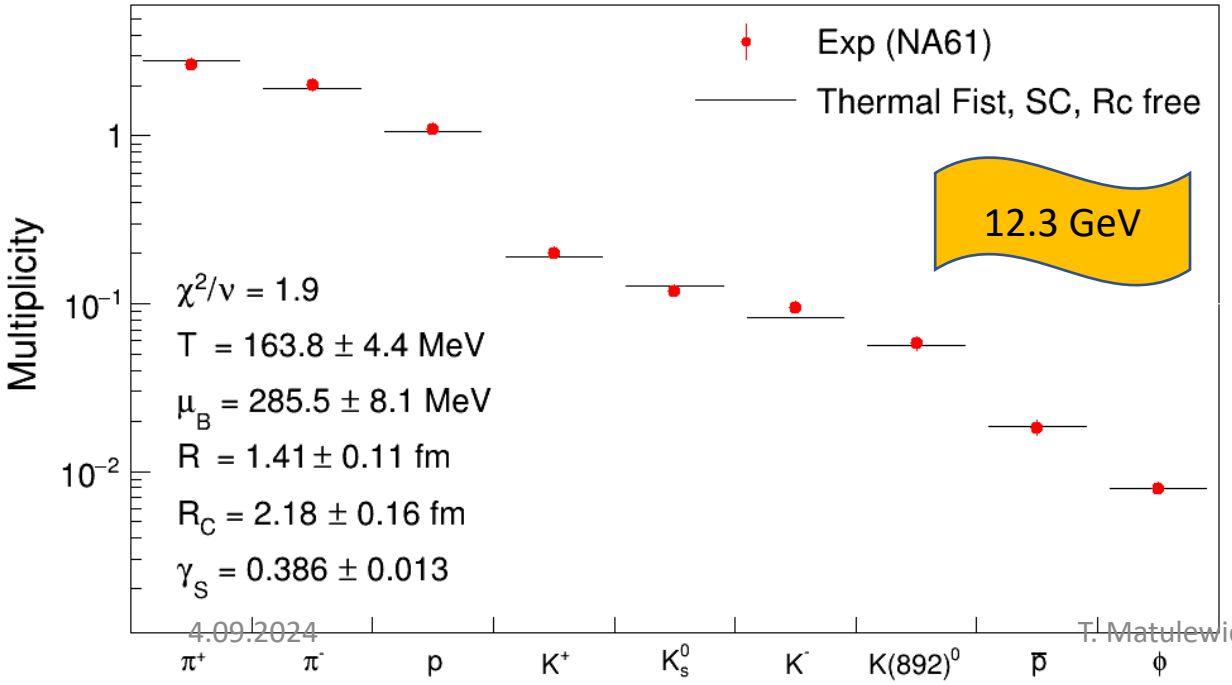
Description of particle yields within GCE+SC free volume for strangeness

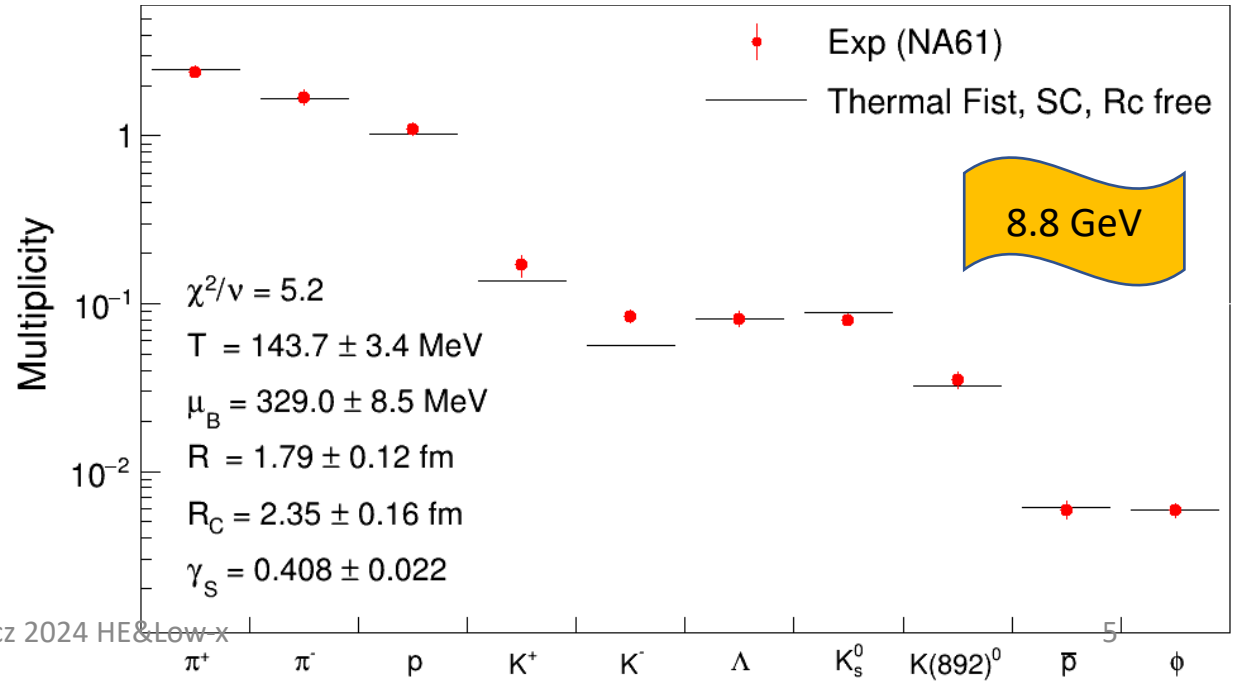
published:

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

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







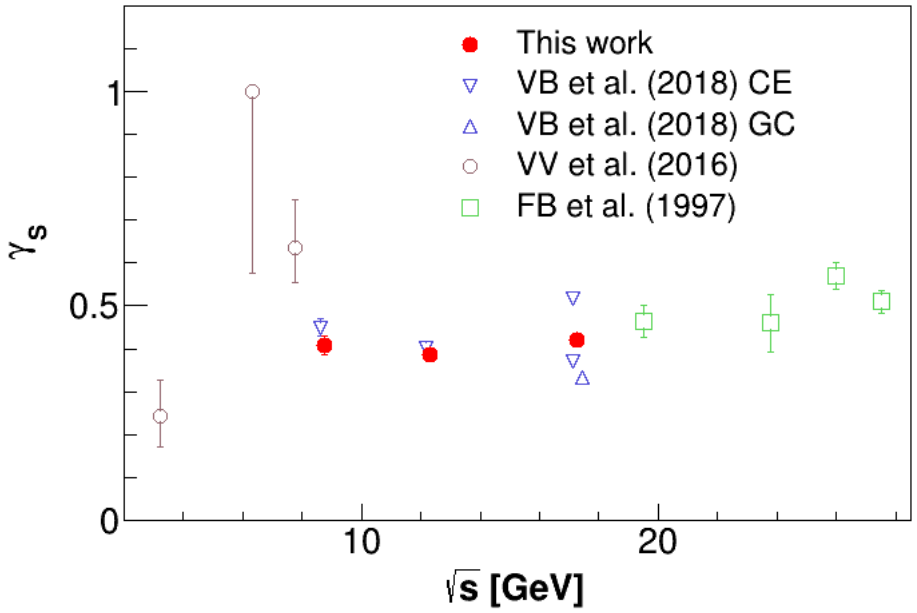
Relative accuracy of pp HRG ~20%

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

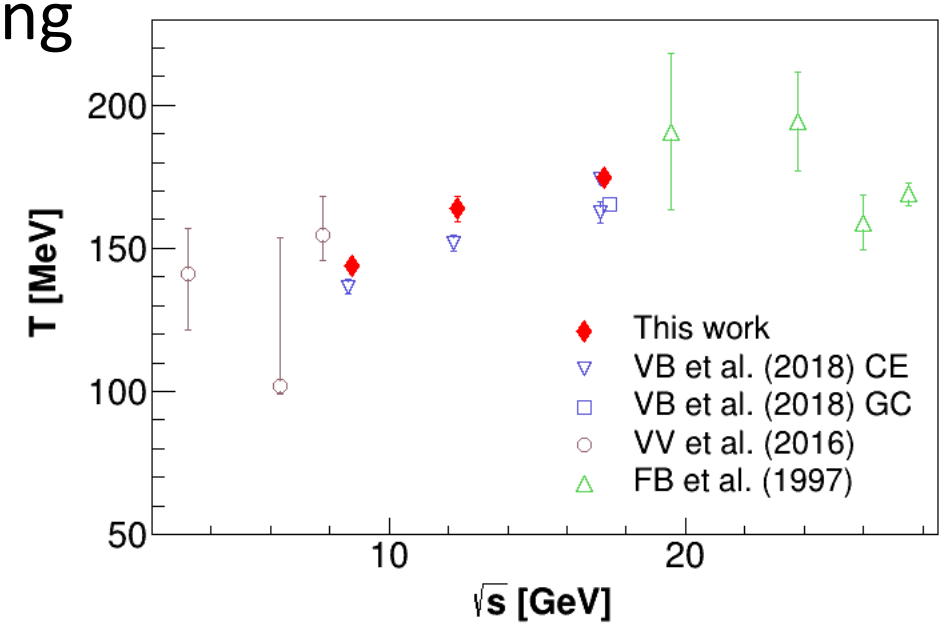
$$\left\langle \frac{Y_{\mathrm{stat}} - Y_{\mathrm{exp}}}{Y_{\mathrm{exp}}} \right\rangle = (-4 \pm 17)\%$$

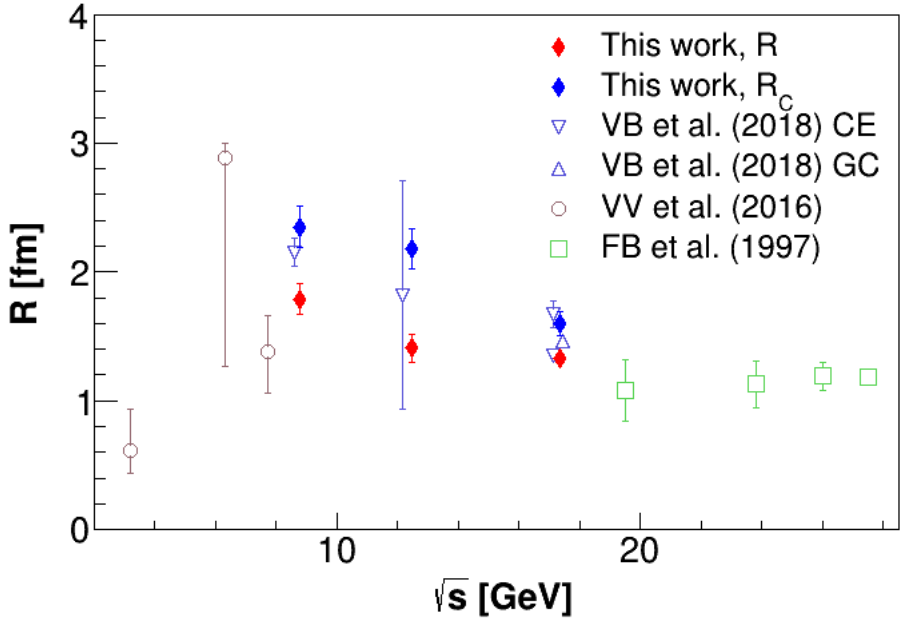
- Precision of HRG description ~20%
- Expected yields from pp published (December 2023)
- Working tool with limited prediction power only?? Some physics??

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 and radius have to be used*

Could R_C > R? Hints not only from femtoscopy

pp collisions @ **$\sqrt{s}$ = 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

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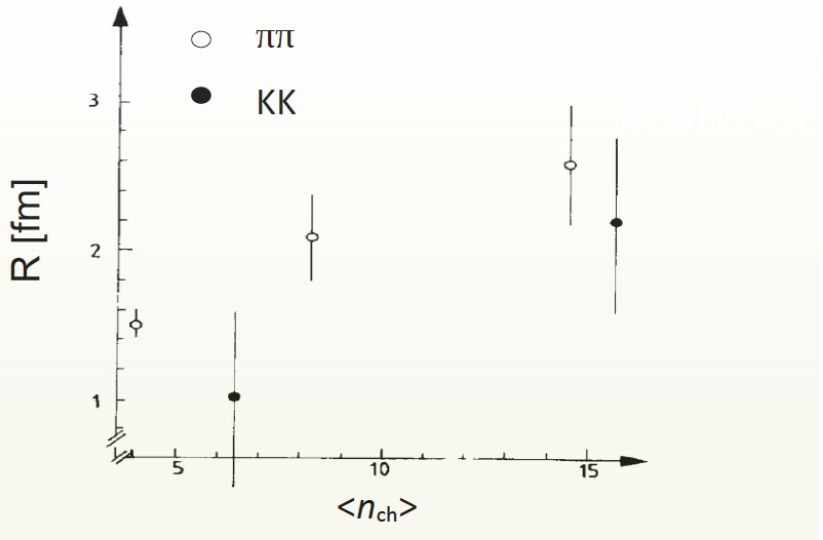
T. Åkesson et al. (AFS Collaboration), PL 155B, 128 (1985)



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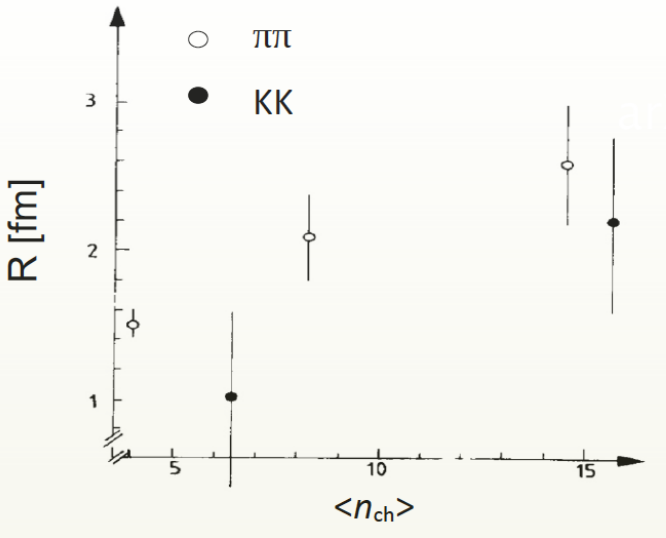
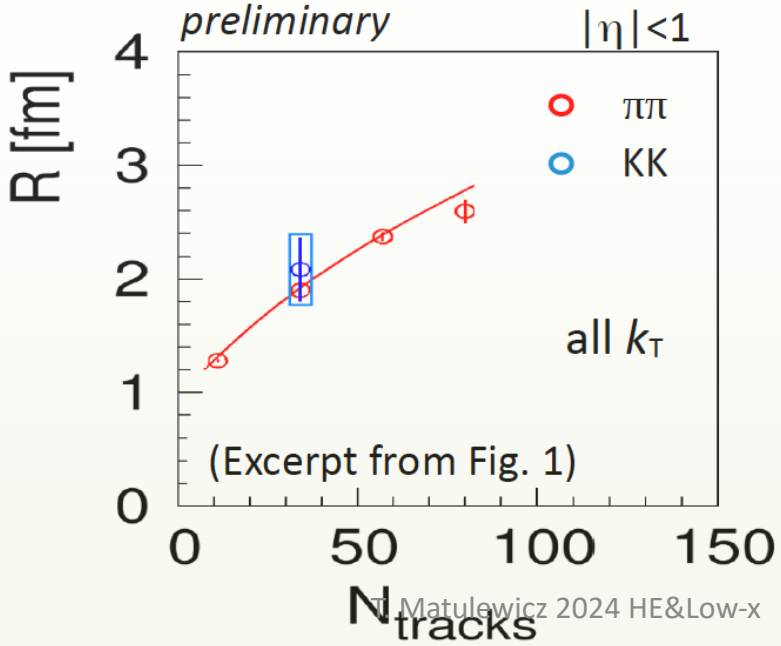


pp collisions @ $\sqrt{s}$ = 900 GeV

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



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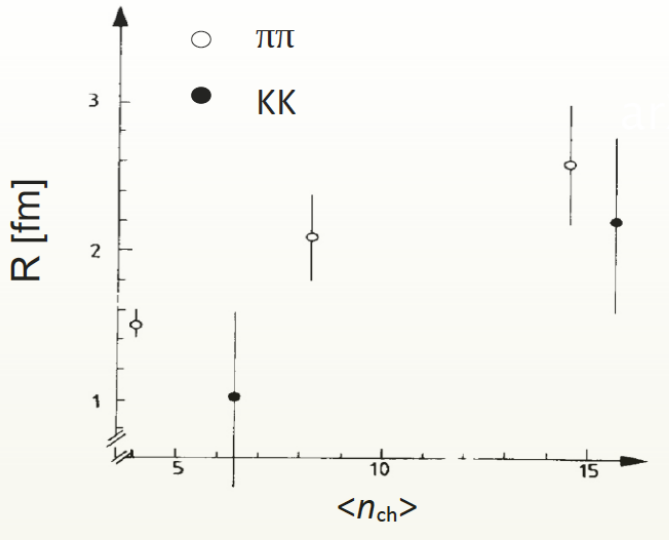

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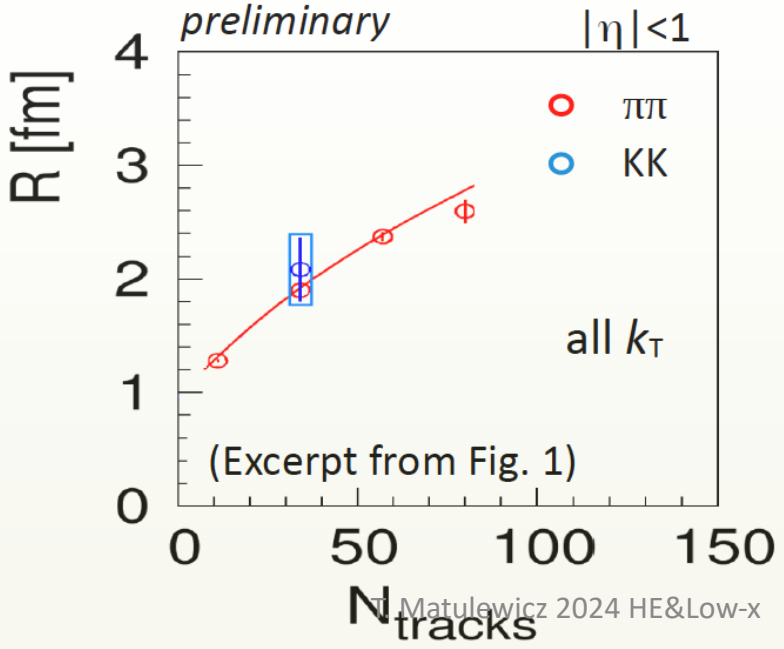

PHYSICAL REVIEW C **103**, 014904 (2021)
J. Cleymans, P.M. Lo, K. Redlich, N. Sharma

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!

Conclusions

- Reasonable description of particle yields from pp interactions at $s^{1/2}$=8.8, 12.3 and 17.3 GeV within thermal hadron gas model in Grand Canonical+Strangeness Canonical scenario (ThermalFist)
- The well-measured yield of the ϕ-meson is always included
- The new results on K_0^S production well described
- The strangeness canonical volume parameter R_C larger than the fireball R
- Analysis at $s^{1/2}$=7.7 GeV – not conclusive, as the yields of ϕ-meson and Λ baryon not yet determined from experiments
- *Femtoscopy analysis of kaon pairs not precise enough*

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

Future?

- HADES Collaboration at SIS18 Darmstadt measured pp at E_p=4.5 GeV ($s^{1/2}$=3.46 GeV)
- Production of π^+ π^- π^0 K^+ K^- K^0_S η Λ $\Lambda(1405)$ $\Sigma(1385)$ ω ϕ observed

- NA61/SHINE Collaboration plans pp at p=400GeV/c ($s^{1/2}$=3,46 GeV)

Stay tuned…


strangeness