# Freeze-out parameters reachable in a rapidity scan in the AFTER@LHC project

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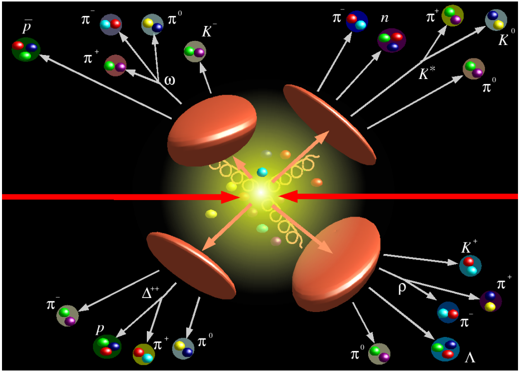
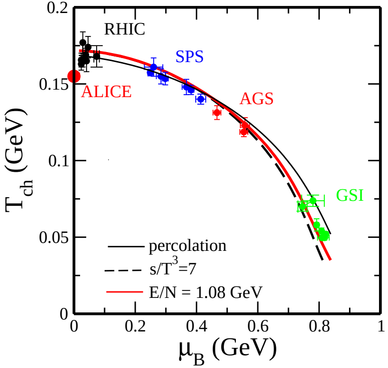
based on the paper by

**V.B.**, **Kikoła**, **Vovchenko**, **Wielanek**,

arXiv:1806.01303, PRC (2018)



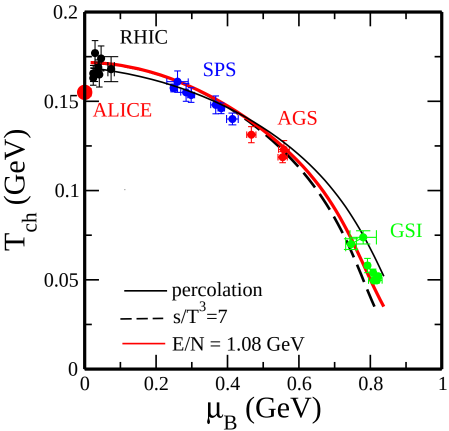
http://personalpages.to.infn.it/∼alberico/QGP2008/becattini/becattini1.pdf



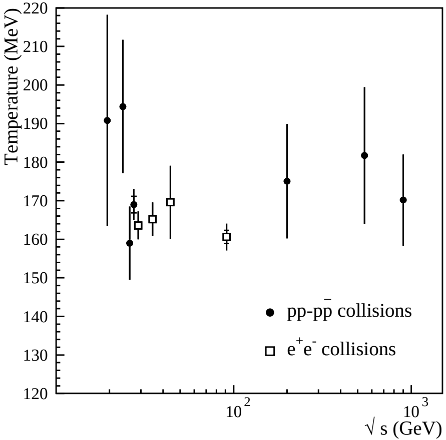

Cleymans, Oeschler, Redlich, Wheaton, PRC (2006); EPJ (2015)

- **Hadron-Resonance Gas** model allows to obtain **QCD phase diagram** $T(\mu_B)$.

# Temperature in A+A (GCE, sCE) and p+p (CE) collisions




Cleymans, Oeschler, Redlich, Wheaton, PRC (2006); EPJ (2015)

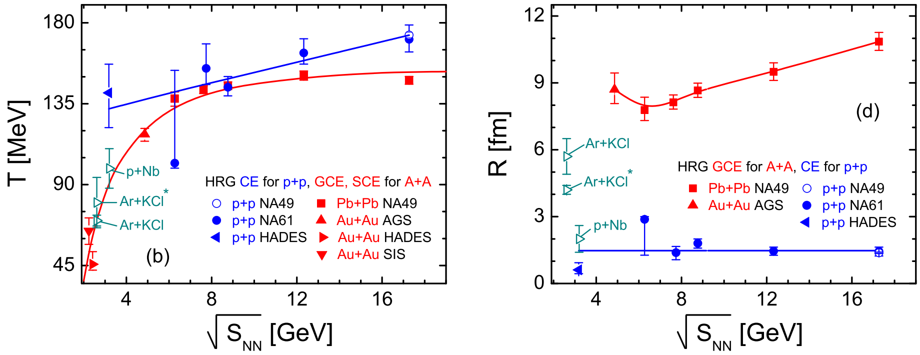



Becattini, Heinz ZPC (1997)

- The **temperature** in **A+A follows** the common **freeze-out line**, except for the LHC
- The **temperature** in **p+p** was found **high**, with **unclear** behavior **at** the **SPS** energies

# The surprise from the low energy p+p data

- The **temperatures** in **p+p** and **A+A** are **very close !**

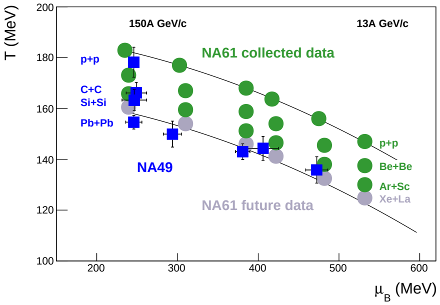



V.B., Vovchenko, Gorenstein, PRC (2016)

- Therefore a **system size scan** should give the **same temperature**, but **different radius**.

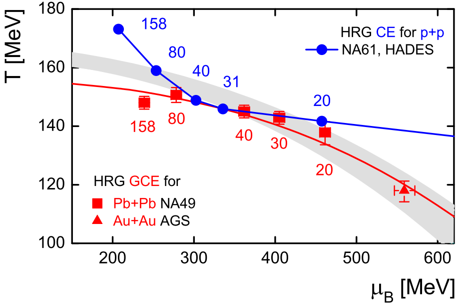
# The $T(\mu_B)$ in the system size scan by NA61 could look like below

## Early expectation



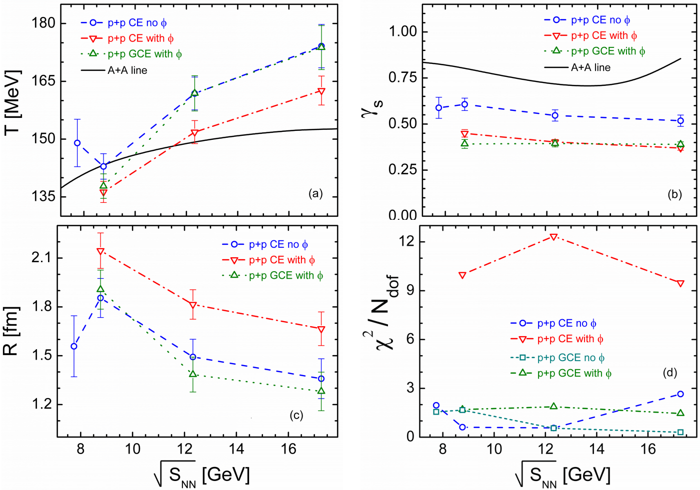

Gazdzicki, Seyboth, arXiv:1506.08141

## Our analysis of A+A and p+p data




V.B., Vovchenko, Gorenstein, PRC (2016), arXiv:1609.04827

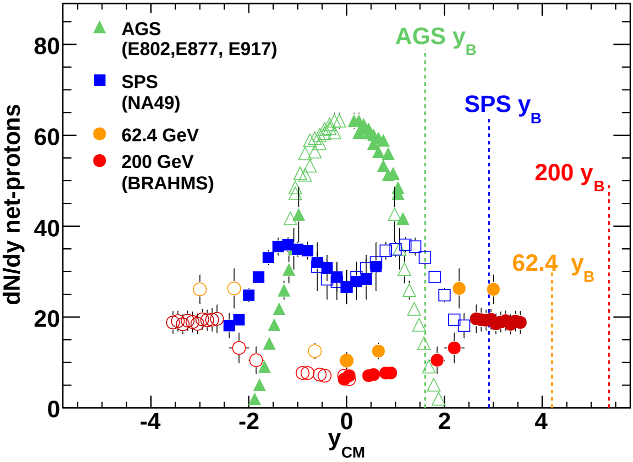
- The available **range of parameters** is **squeezed** and **shifted** compared to expectations.
- The **p+p** line **crosses** the **A+A** line in the **vicinity** of the **$K^+/\pi^+$ horn**.




V.B., Vovchenko, Gorenstein, Stoecker, arXiv:1805.01901

- **The need of ‘centrality’ selection for p+p** by NA61 ?

Net-proton distributions from AGS to top RHIC energies.

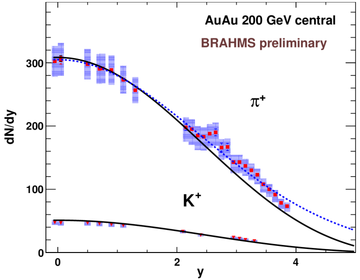


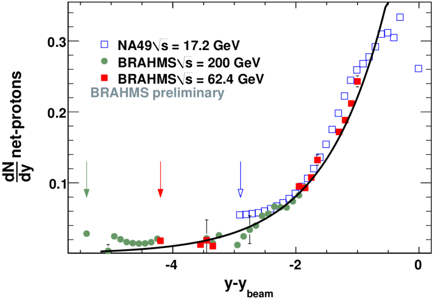

Videbaek (BRAHMS Collaboration), NPA (2009), arXiv:0907.4742 (nucl-ex).

The beam rapidity $y_B$ at each energy is indicated by the dashed lines.

(Left) Rapidity distributions for pions and kaons in central Au+Au collisions at 200 GeV.

(Right) Net-proton rapidity distributions in p+p scaled to the beam rapidity.

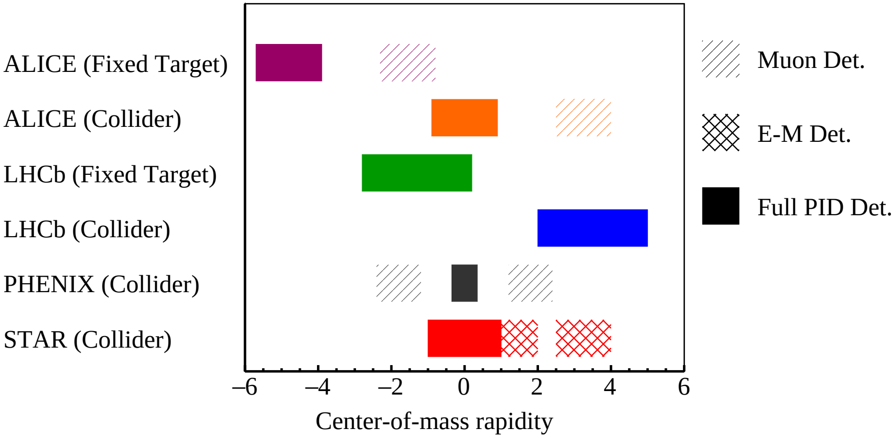



Videbaek (BRAHMS Collaboration), NPA (2009), arXiv:0907.4742 (nucl-ex).

The arrows indicate the position of mid-rapidity for 200, 62.4 and 17.2 GeV, (left to right).

- **Mesons are produced at mid-rapidity.**
- **Baryon charge is growing towards forward rapidity.**

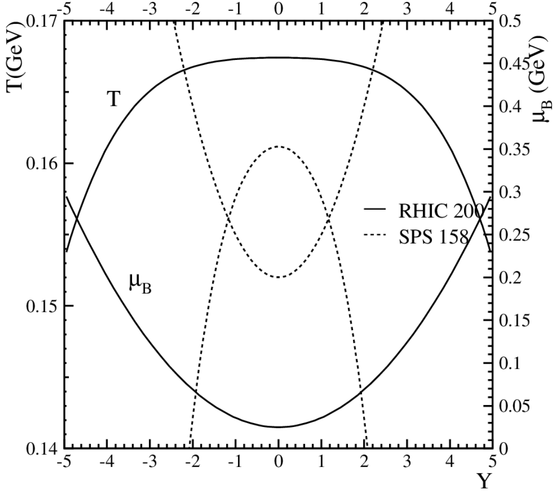



Hadjidakis, Kikoła, Lansberg *et al.* arXiv:1807.00603

- The ‘Full PID Det.’ label indicates detector with particle identification capabilities, ‘E-M Det.’ - an electromagnetic calorimeter, ‘Muon Det.’ - a muon detector.

# Can we change $T$ and $\mu_B$ by changing rapidity instead of energy?

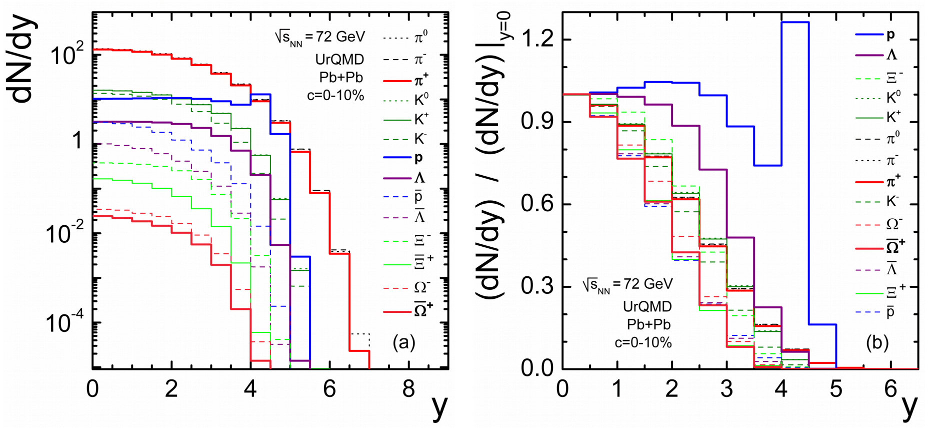
**Yes!**




Becattini, Cleymans, JPG (2007), arXiv:hep-ph/0701029.

# Particle multiplicities per event generated in the UrQMD model

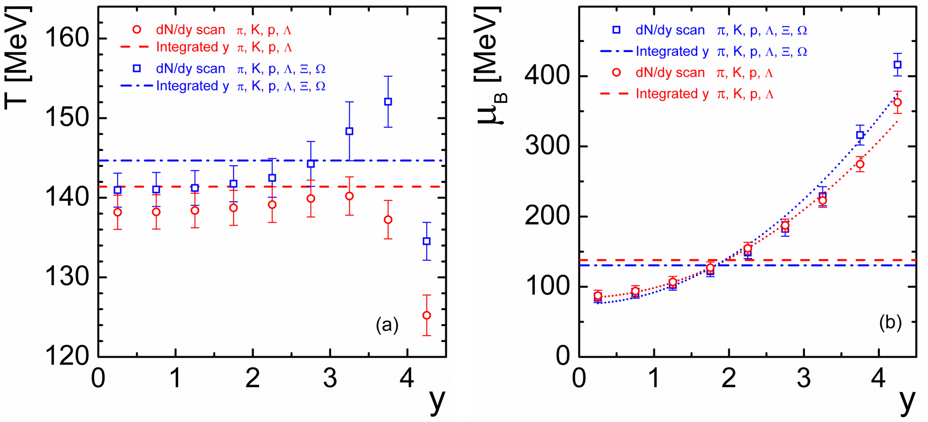
Particle labels are sorted according to their abundance at $y = 0$ (left), and at $2 < y < 2.5$.




V.B., Kikoła, Vovchenko, Wielanek, arXiv:1806.01303, Phys.Rev. C (2018)

- A **strong rapidity dependence** for all particles.
- **Proton** and **Λ** are relatively more abundant at **forward rapidity**.

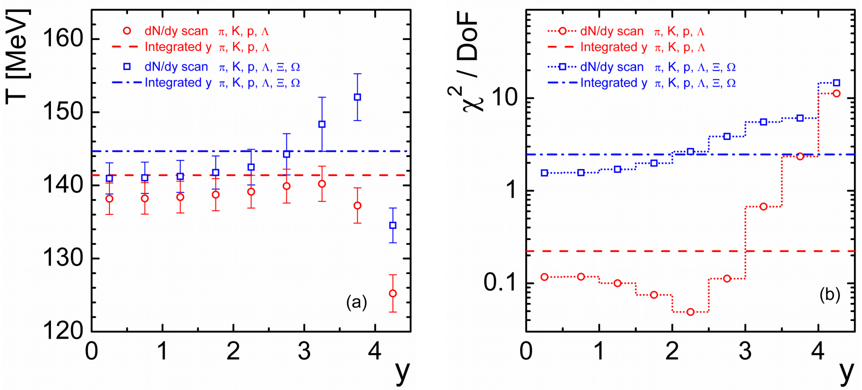
# $T$ and $\mu_B$ as a function of rapidity and of a particle set




V.B., Kikoła, Vovchenko, Wielanek, arXiv:1806.01303, Phys.Rev. C (2018)

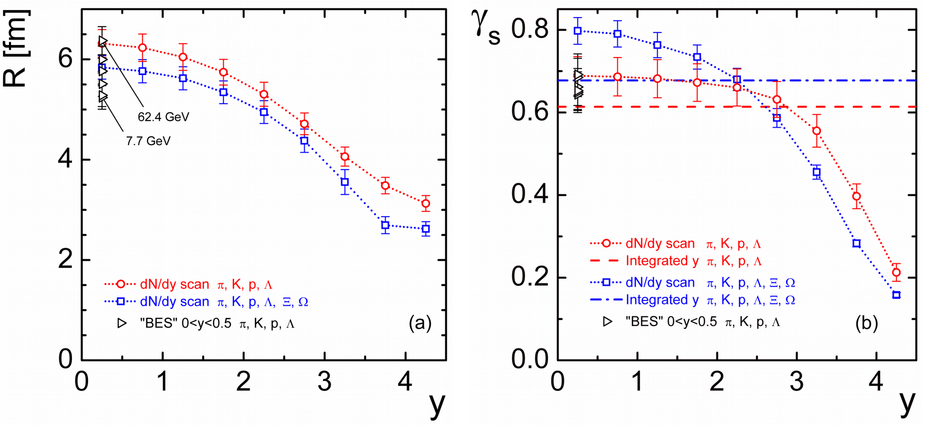
- Approximately **constant $T$, growing $\mu_B$** with y.
- Some uncertainty at large rapidity.

# $T$ and $\chi^2$/DoF as a function of rapidity and of a particle set




V.B., Kikoła, Vovchenko, Wielanek, arXiv:1806.01303, Phys.Rev. C (2018)

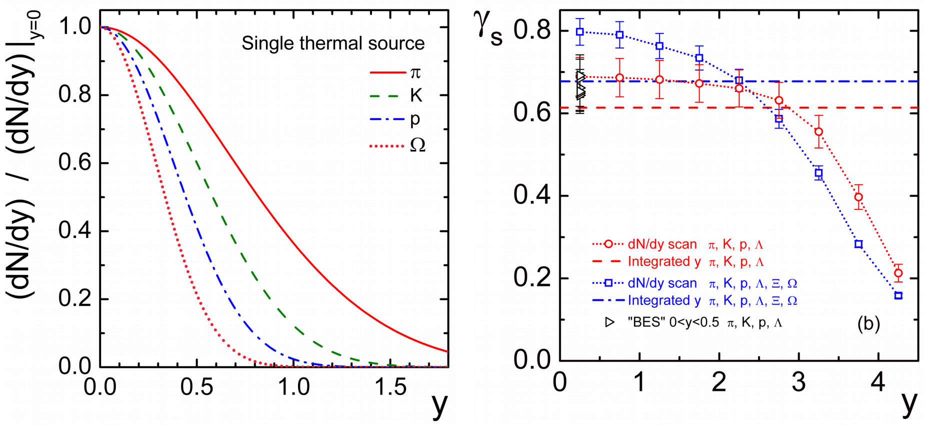
- The **temperature changes** correlate with a fast increase in $\chi^2$/DoF at $y > 3$.
- The **uncertainties of the HRG** parameters result from the **assumed 10% systematic uncertainties of the input** multiplicities from the UrQMD.




V.B., Kikoła, Vovchenko, Wielanek, arXiv:1806.01303, Phys.Rev. C (2018)

- The matter contains **less strangeness at forward rapidities** than at mid-rapidities.
- The radius (**volume**) for the most forward rapidity bin is still much **larger than in p+p**.

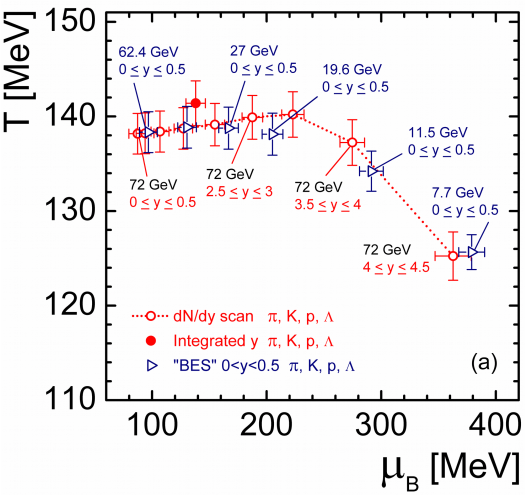
# A single thermal source at rest and a $\gamma_S$




Schnedermann, Sollfrank, Heinz, PRC (1993).

V.B., Kikoła, Vovchenko, Wielanek, Phys.Rev. C (2018)

- A fit of a single thermal source in different rapidity intervals gives different results.




V.B., Kikoła, Vovchenko, Wielanek, arXiv:1806.01303, Phys.Rev. C (2018)

- The rapidity scan covers almost the same $T(\mu_B)$ range as the energy scan at $y = 0$.

# Conclusions

- The **rapidity scan** with Pb+Pb collisions at $\sqrt{s_{NN}} = 72$ GeV can be used to study systems which have **similar temperatures**, but at least a factor **2.5 larger $\mu_B$** in forward rapidity compared to midrapidity.
- The rapidity scan at the **AFTER@LHC covers** the majority of the **$\mu_B$ range** accessible in the **RHIC Beam Energy Scan** program.
- Such a dN/dy study in the AFTER@LHC project will provide a **complementary approach** to the QCD phase diagram studies, with all the benefits of a **high-luminosity** fixed-target experiment at the LHC.