Strangeness from SPS to FAIR

Searching for the Onset of Deconfinement

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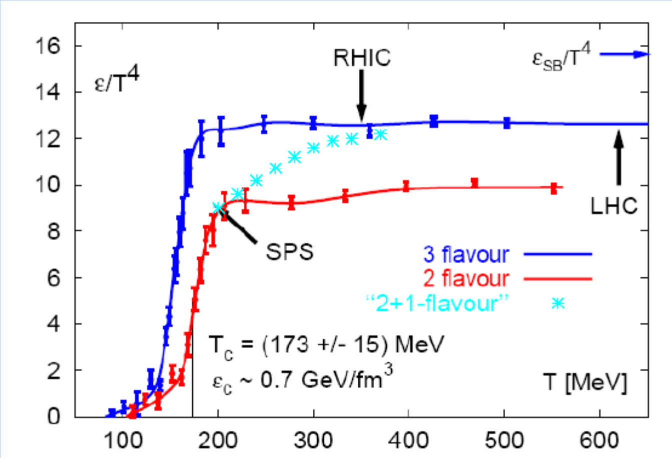
What is all about

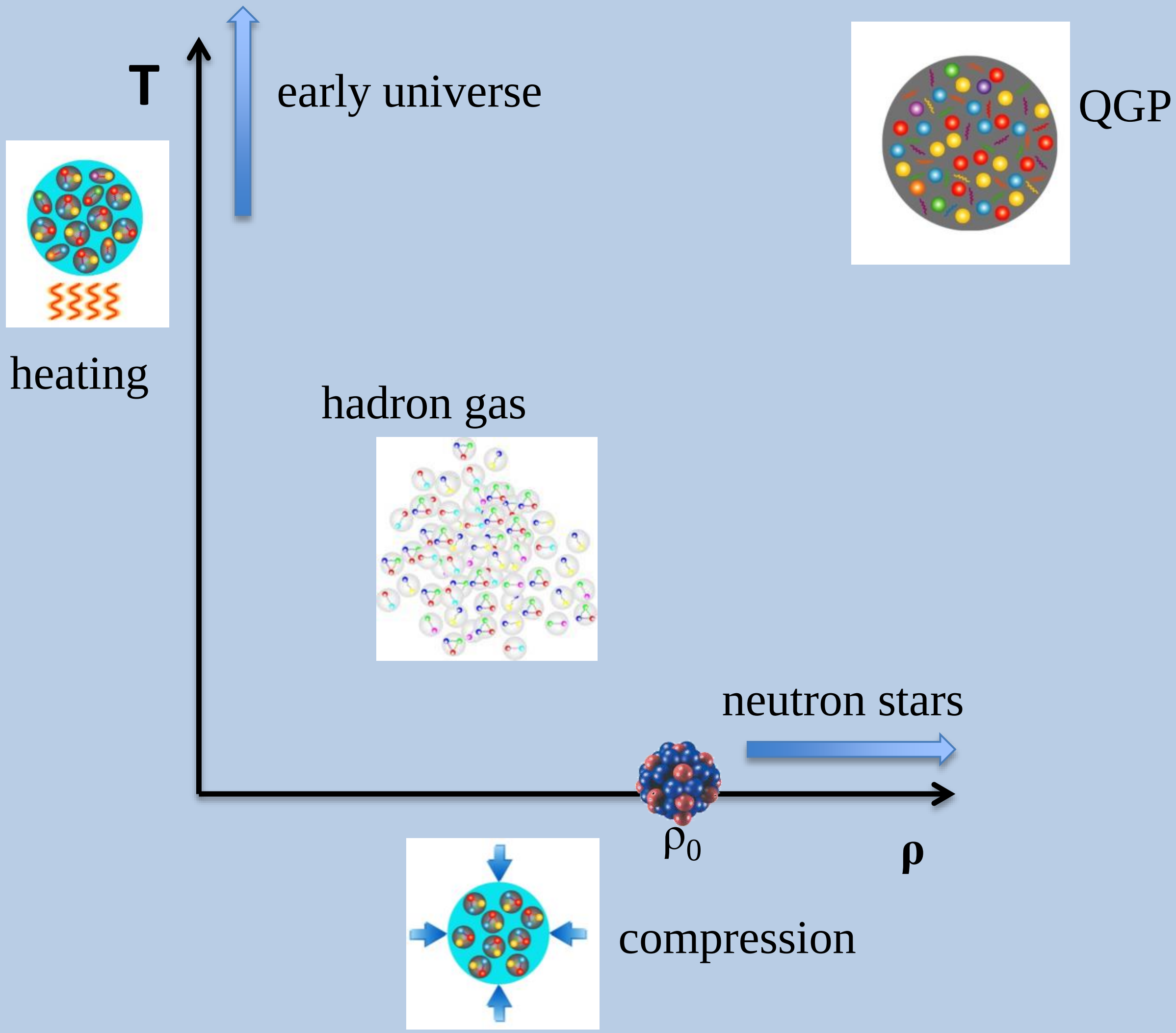
confined matter: hadrons → Heat, compression → deconfined matter: quarks and gluons

At high energy densities, hadrons "melt"; the degrees of freedoms are partonic: Quark-Gluon-Plasma

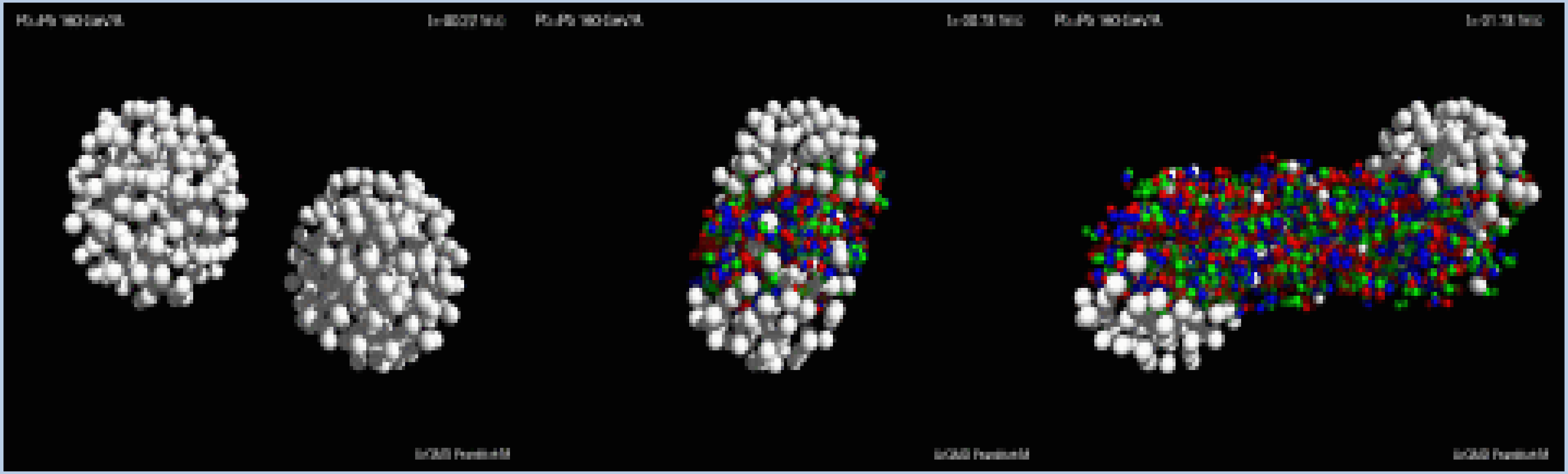


Lattice QCD: phase transition at critical energy density ε_c / critical temperature $T_c \cong 160 – 170$ MeV

Phases of QCD Matter



Extreme matter in the laboratory

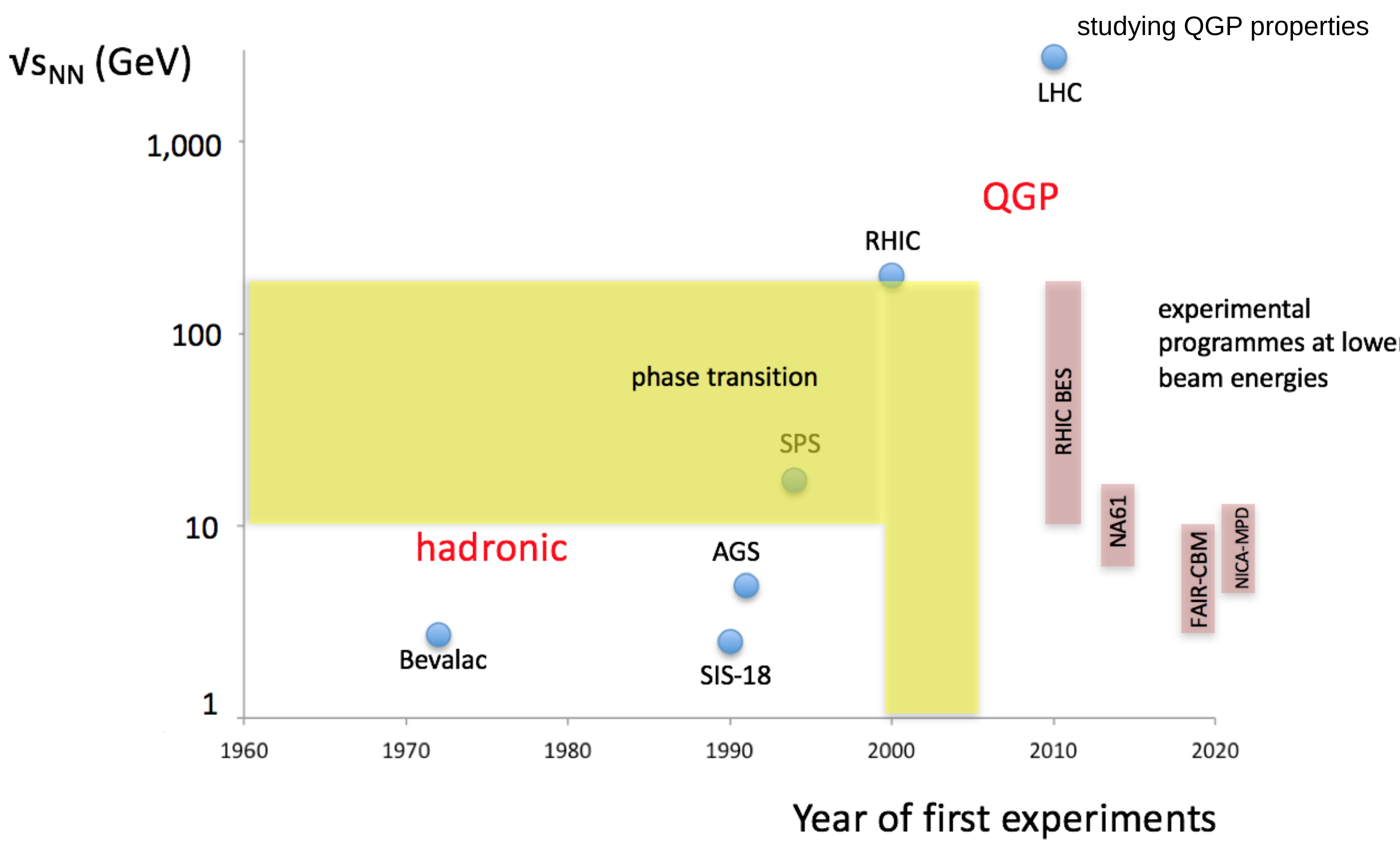


In high-energy collisions of heavy nuclei, matter at high energy densities (hot and dense) is created – for a very short time and in a very limited volume.

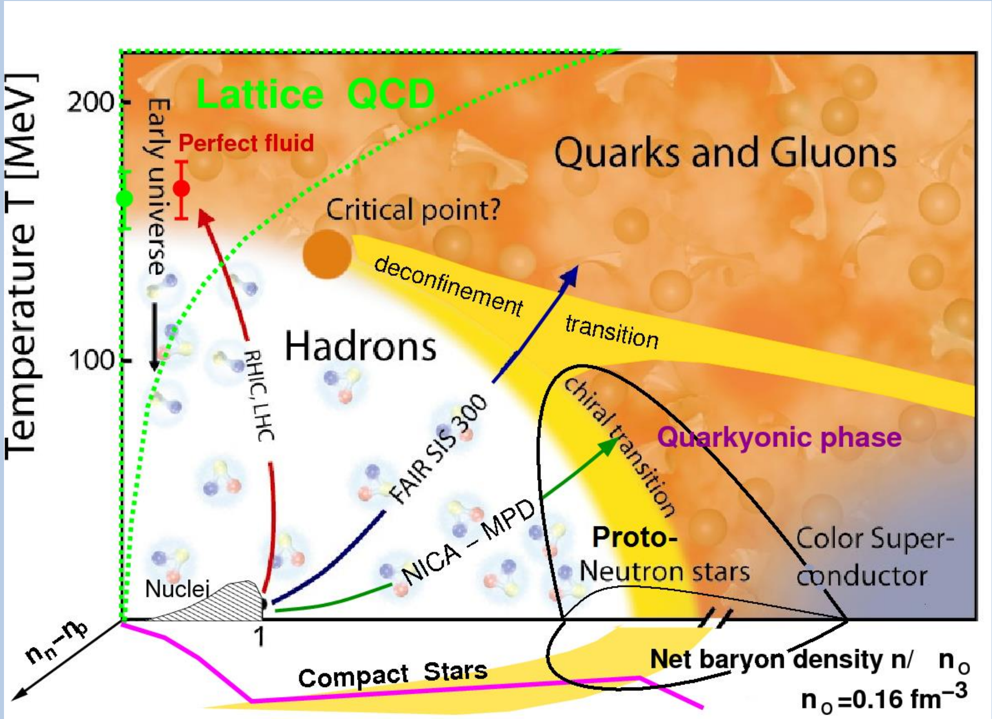
Control parameters:

- Collision energy
- System size (ion species / collision centrality)

A Brief History of Experimental Heavy-Ion Physics



Why Going Back to Lower Energies?

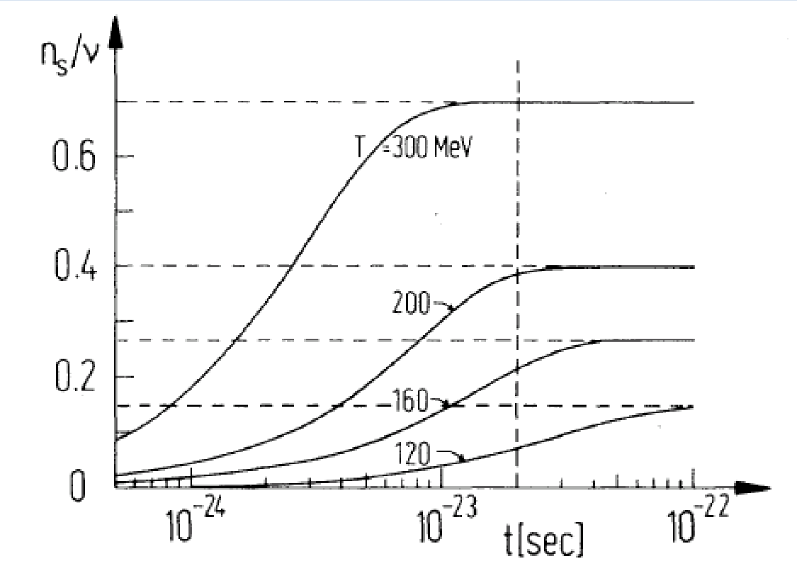


- The picture would not be complete without detecting the phase transition itself.
- Unlike RHIC and LHC, lower energies probe matter at finite net-baryon density.
- The QCD phase diagram might be more complex than originally thought.
- Earlier data from AGS and SPS left key questions open:

- Is there a critical point, and if yes, where?
- Where is deconfinement first reached?
- Is there a first-order phase transition?
- Is there a difference between chiral and deconfinement transition?

Why strangeness is interesting

- No strangeness in entrance channel (nucleons): strangeness is produced in the reaction
- Hadronic production (e. g. p+p -> KΛp): $m_K \approx 500$ MeV >> T_H
- Partonic production (e.g. g + g -> s sbar): $m_s \approx 100$ MeV <= T_H



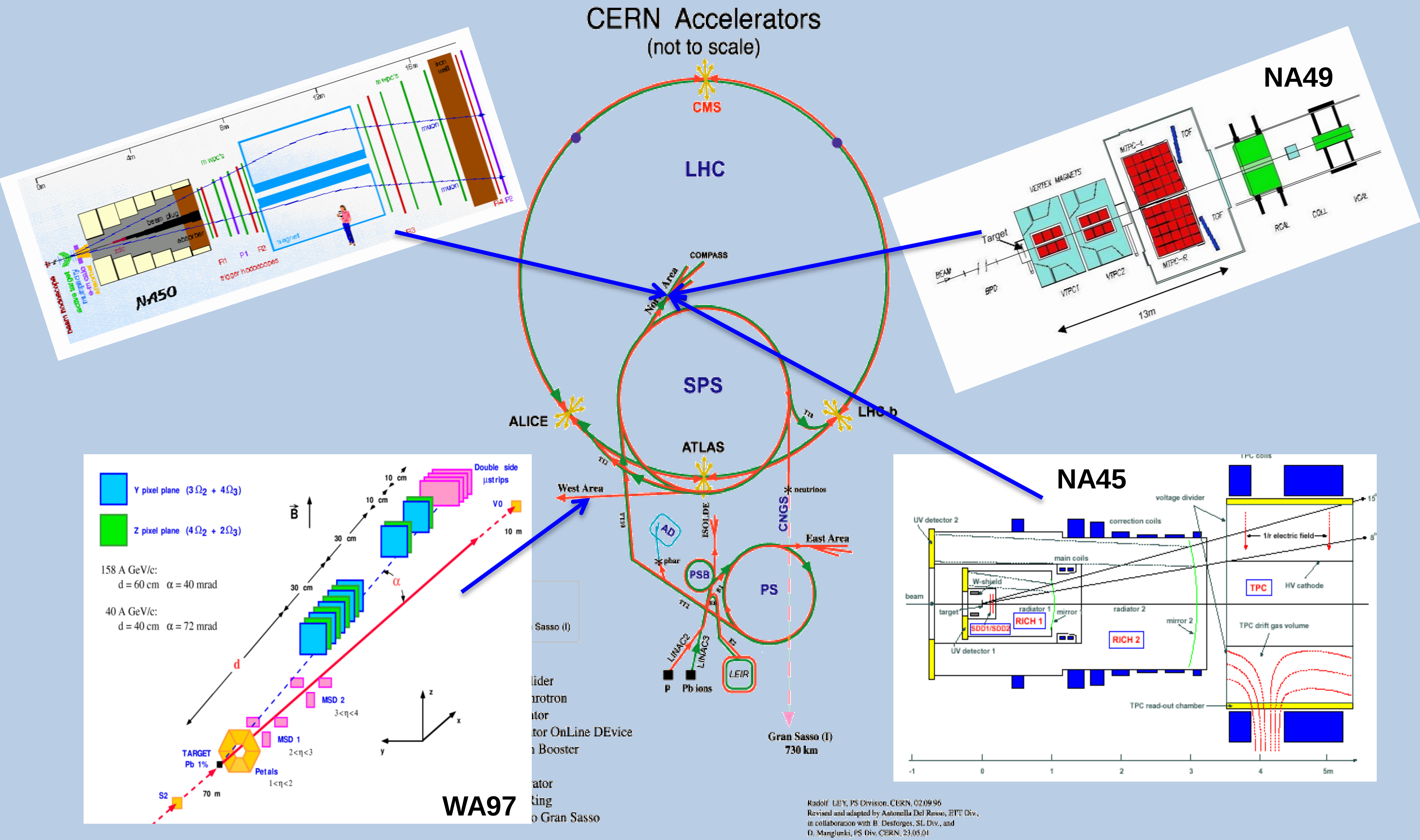
Koch, Müller, Rafelski, Phys. Rep. 142 (1986) 167

Relaxation of s-Quarks in a QGP within few fm/c ≈ lifetime of the fireball

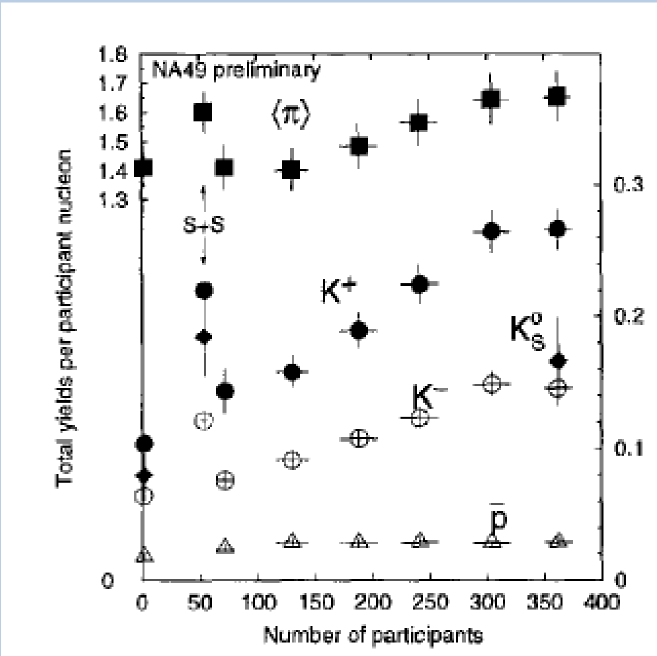
Expectation: More strangeness production in A+A relative to p+p, if QGP was formed

„Strangeness enhancement“

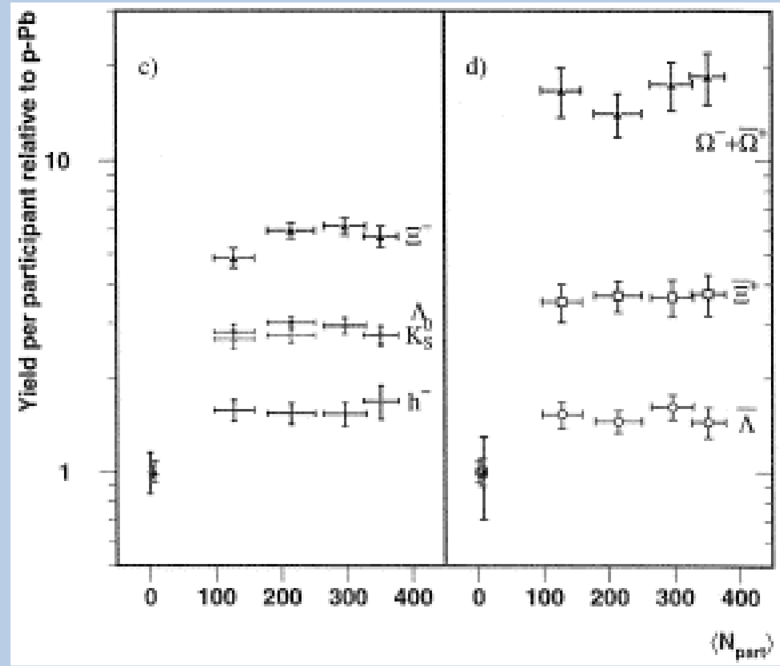
Experiments...(SPS)



...and results



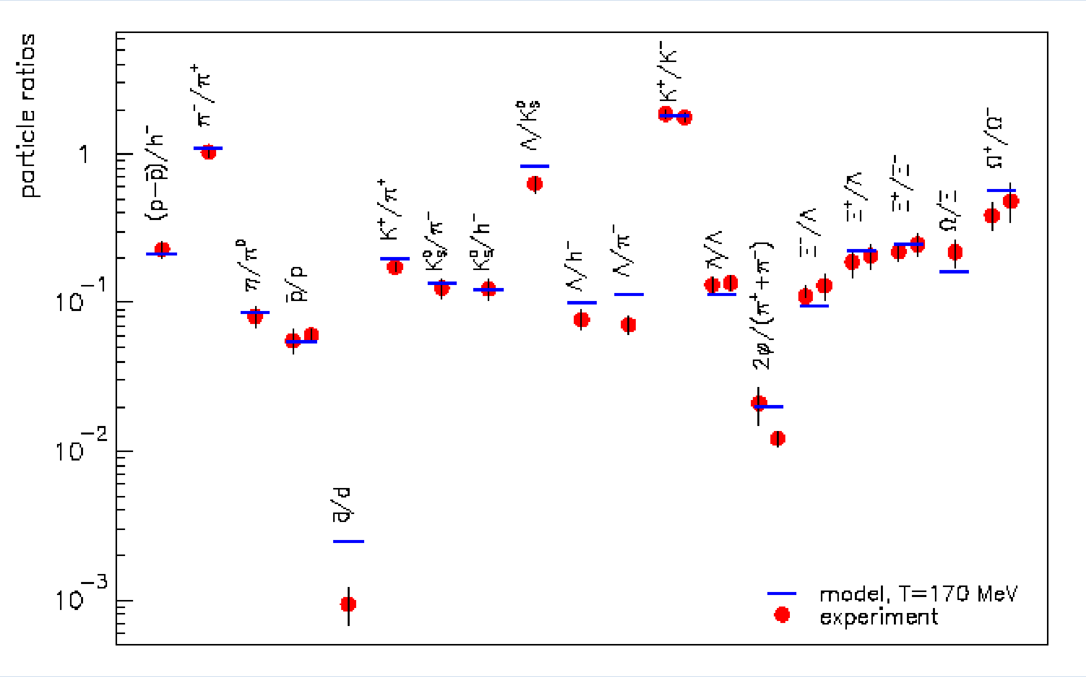
NA49, Nucl. Phys. A 661 (1999) 45



WA97, Phys. Lett. B 499 (1999) 401

- strangeness enhancement relative to p+p observed (factor 15 for Ω!)
- Hierarchy with number of strange valence quarks : E(K,Λ) < E(Ξ) < E(Ω)

But: the statistical model



J. Stachel, Nucl. Phys. A 654 (1999) 119 c

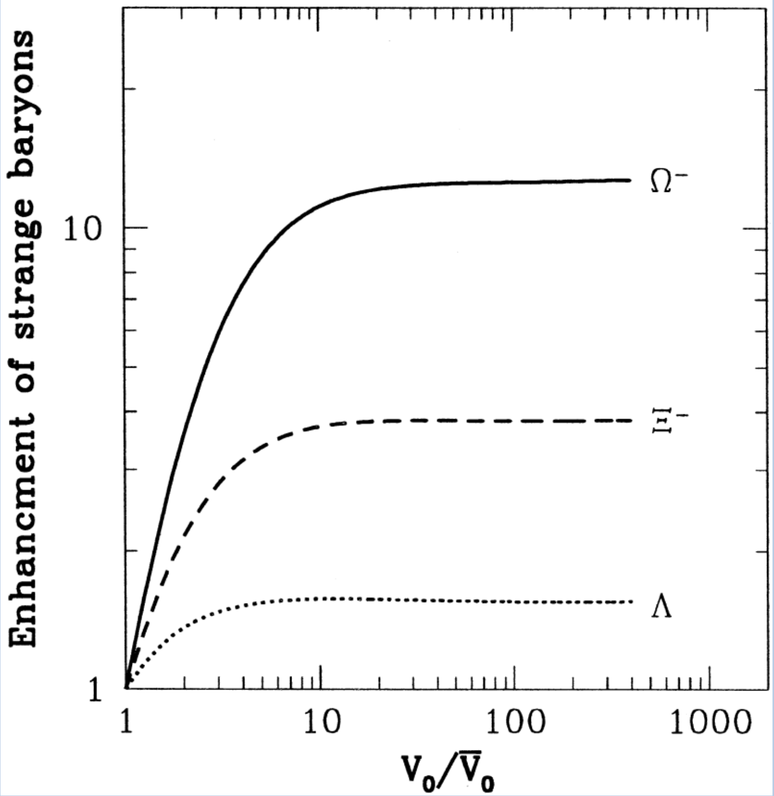
Particle multiplicities (multiplicity ratios) are well described by a hadron gas in chemical equilibrium.

Including strange particles: Ξ, Ω

Fit parameters: T_{chem}, μ_b, (V)

- Why equilibrium? Hadronic relaxation processes are not efficient enough..
- $T_{chem} \approx 170$ MeV $\approx T_c$: coincidence?
- What is the relation to strangeness enhancement?

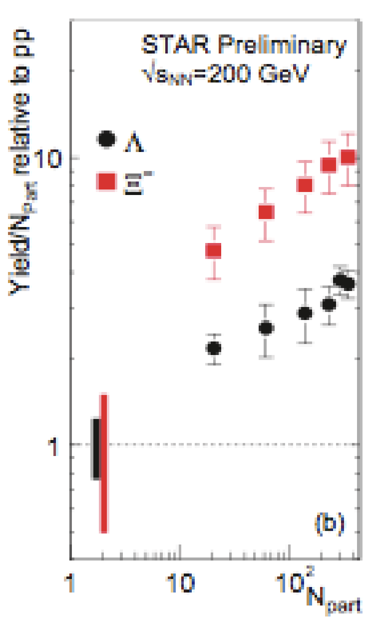
Strangeness enhancement and statistical model



S. Hamieh, K. Redlich und A. Tounsi, Phys. Lett. B 486 (2000) 61

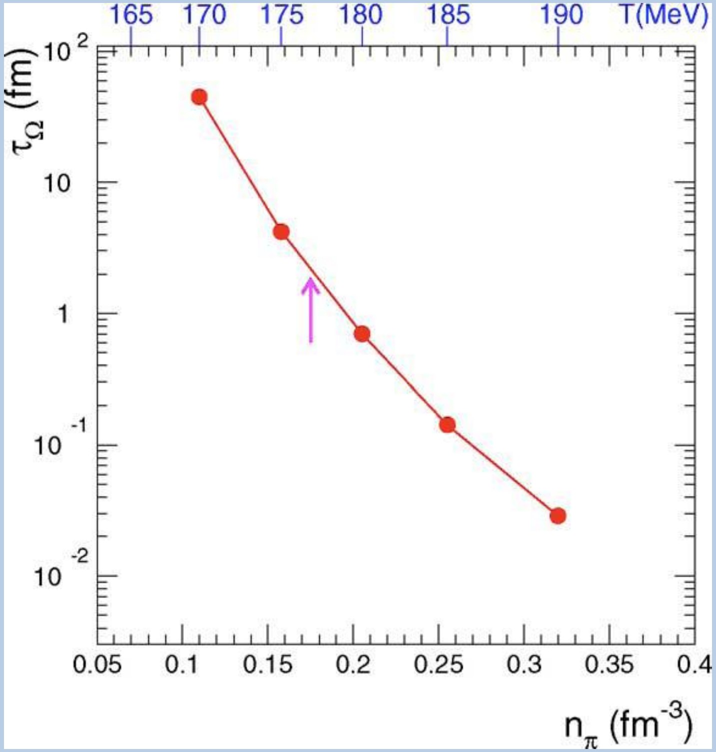
- Small systems: exact conservation of strangeness (needs canonical formulation)
- Large systems: approximation by conservation of strangeness on average: grand-canonical formulation
- Strangeness enhancement -> „canonical suppression“

Strangeness enhancement as a volume effect!



Why chemical equilibrium?

- Braun-Munzinger, Stachel, Wetterich 2004: Equlibration of strangeness through collisions with more than two particles in the entrance channel (strangeness exchange reactions, e. g. $2\pi + 3K \to \Omega$);
- Extreme dependence of rates from temperature and/or density: effective only at $T \approx T_c$
- Strangeness content is determined at phase boundary.
- Equilibration of strangeness (in particular of multi-strange baryons) is indirect proof of phase transition.



P. Braun-Munzinger, J. Stachel und C. Wetterich, Phys. Lett. B 596 (2004) 61

Searching for the onset of deconfinement

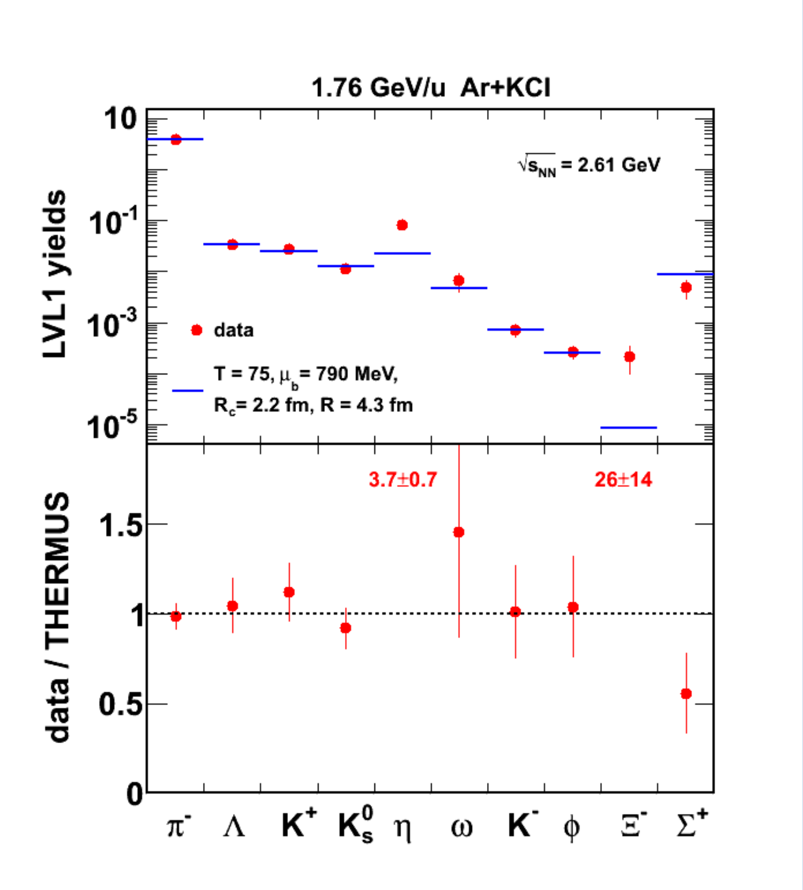
- Following the argumentation „equilibration of multi-strange baryons -> QGP“, one would search for the onset of deconfinement by measuring strange baryon abundances at lower energies.
  - Down to which collision energies does the hadron gas model hold?
- Model fits describe data at lower SPS and at AGS
  - But with a limited amount of particle species
  - Data on multi-strange baryons are scarce

Breakdown of strangeness thermalisation?

HADES result for Xi⁻ at SIS-18 (1.76A GeV): Xi⁻ yield is off by an order of magnitude from the statistical model.

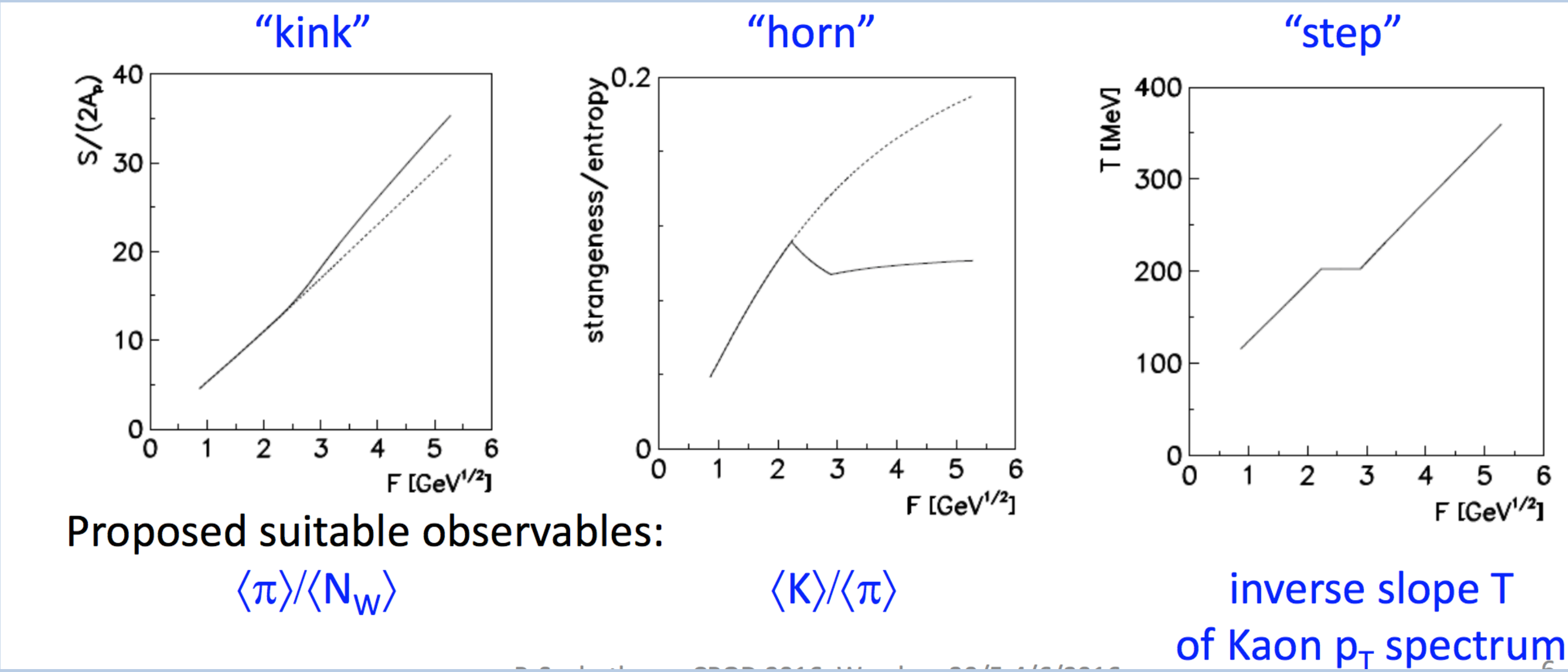
N.b.: This is deep sub-threshold. Production through multi-step processes

$$\Lambda K \rightarrow \Xi \pi \quad \Lambda\Lambda \rightarrow \Xi^- p \quad \Xi K \rightarrow \Omega \pi$$



R. Holzmann, CBM Physics Workshop, April 2010

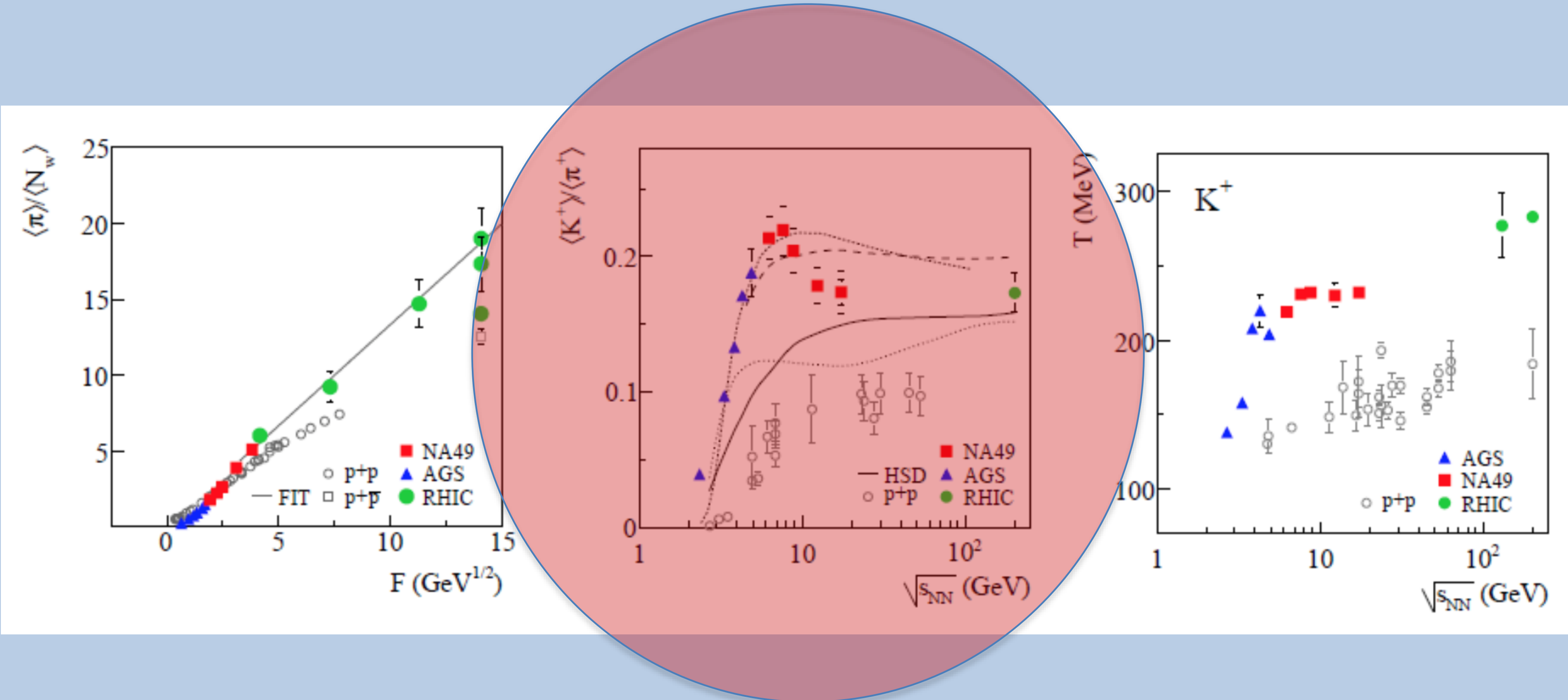
The search for the onset



"Statistical Model of the Early Stage":

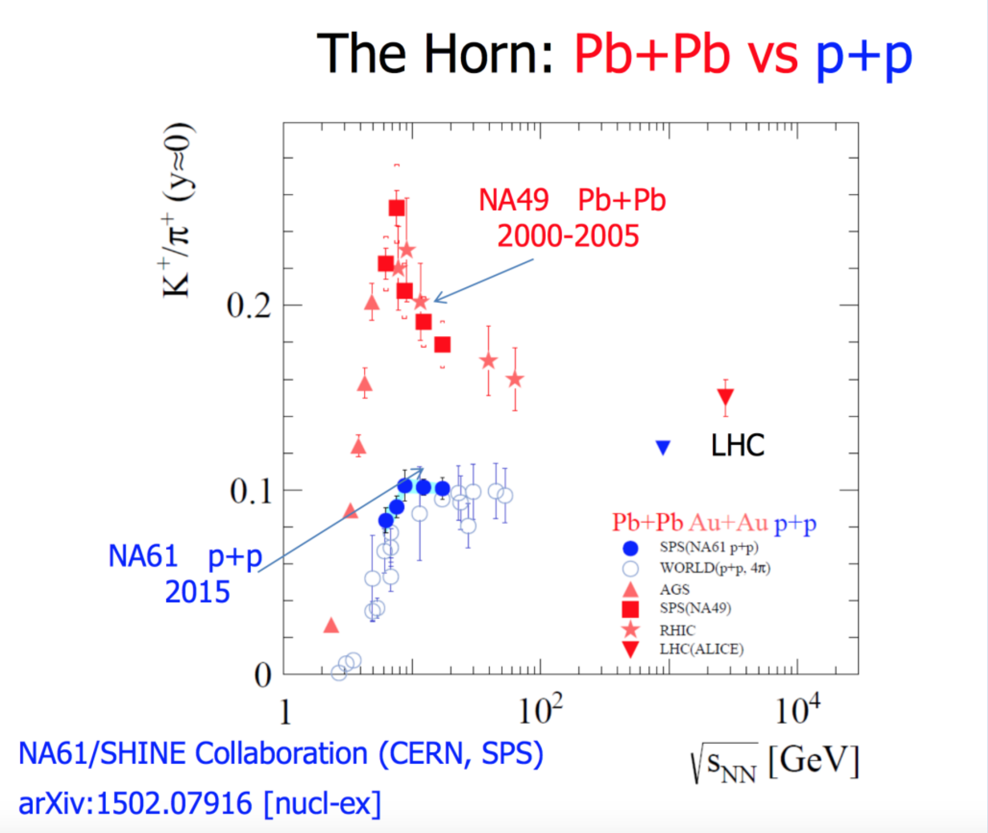
- "Early stage" (hadronic / partonic) im thermal equilibrium
- First-order phase transition at ε_c/T_c
- Mixed phase around ε_c

Results at SPS (NA49)



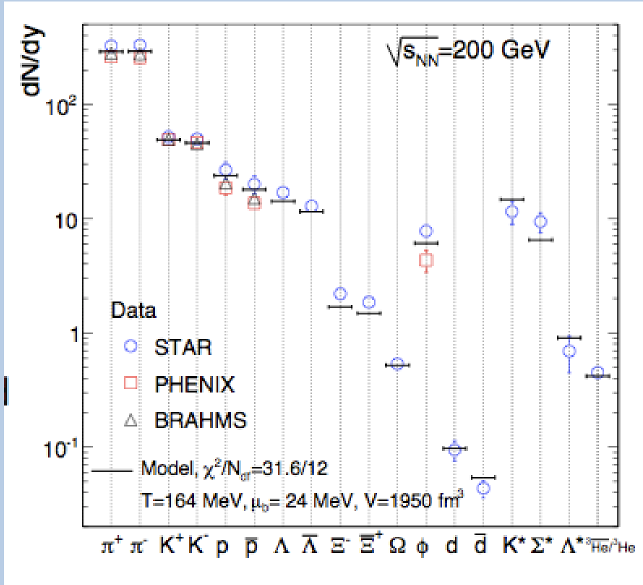
Evidence for the onset of deconfinement at 30A GeV ?

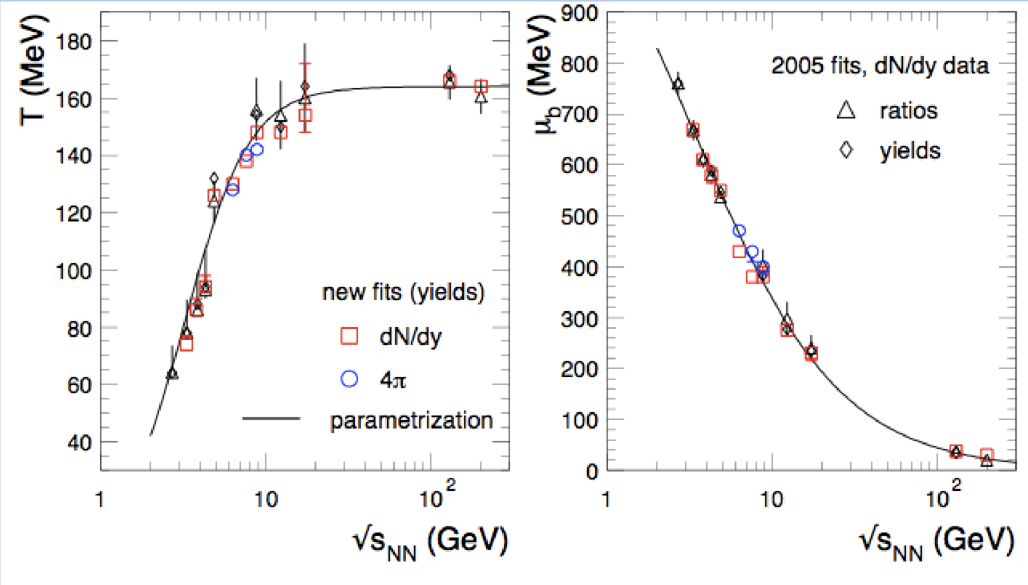
The Horn: A Closer Look



- NA49 data confirmed by STAR-BES measurements
- Precision data on p+p by NA61: no horn, but also change in energy dependence
- What happens at 30A GeV?

What about the statistical model?

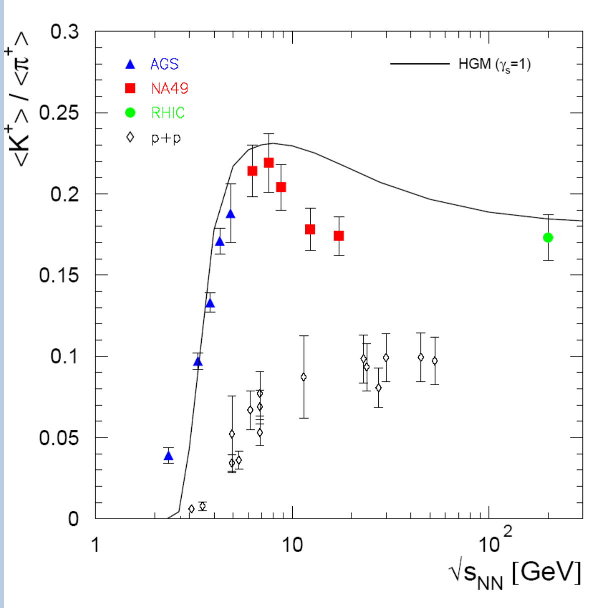




- Fits for many collision energies: SIS, AGS, SPS, RHIC
- T, μ_b monotonic functions of $\sqrt{s_{NN}}$
- T saturates at $\sqrt{s_{NN}} \approx$ 10 GeV; $T_{limit} \approx$ 160 MeV

The „horn“ in the statistical model

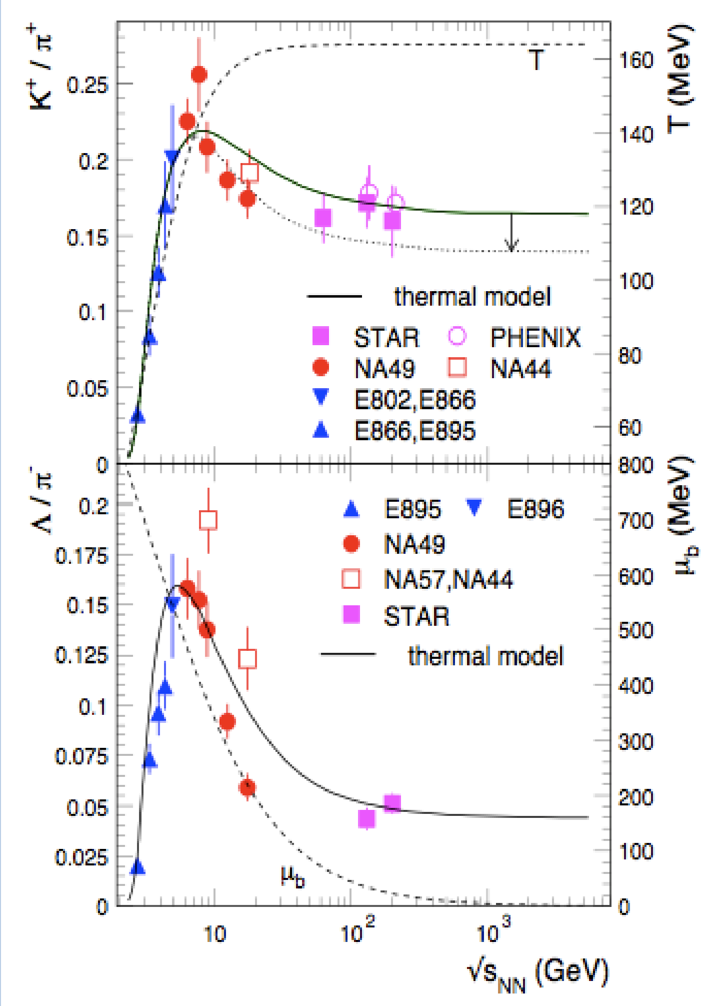
2006



A. Andronic, P. Braun-Munzinger und J. Stachel, Nucl. Phys. A 772 (2006) 167

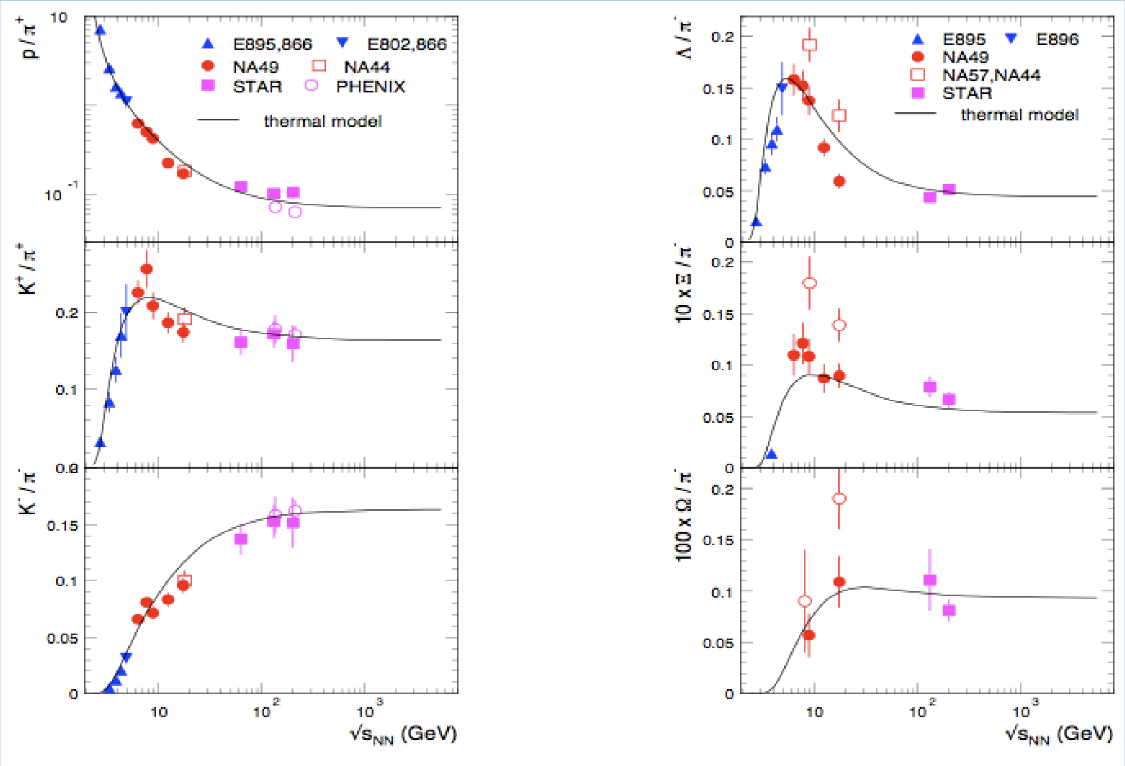
- Broad maximum at ≈ 30A GeV (interplay of T and μ_b)
- No satisfactory description of the K/pi energy dependence
- Improvement when including high-mass resonances

2009



A. Andronic, P. Braun-Munzinger und J. Stachel, Phys. Lett. B 673 (2009) 142

The need for data on multi-strange baryons

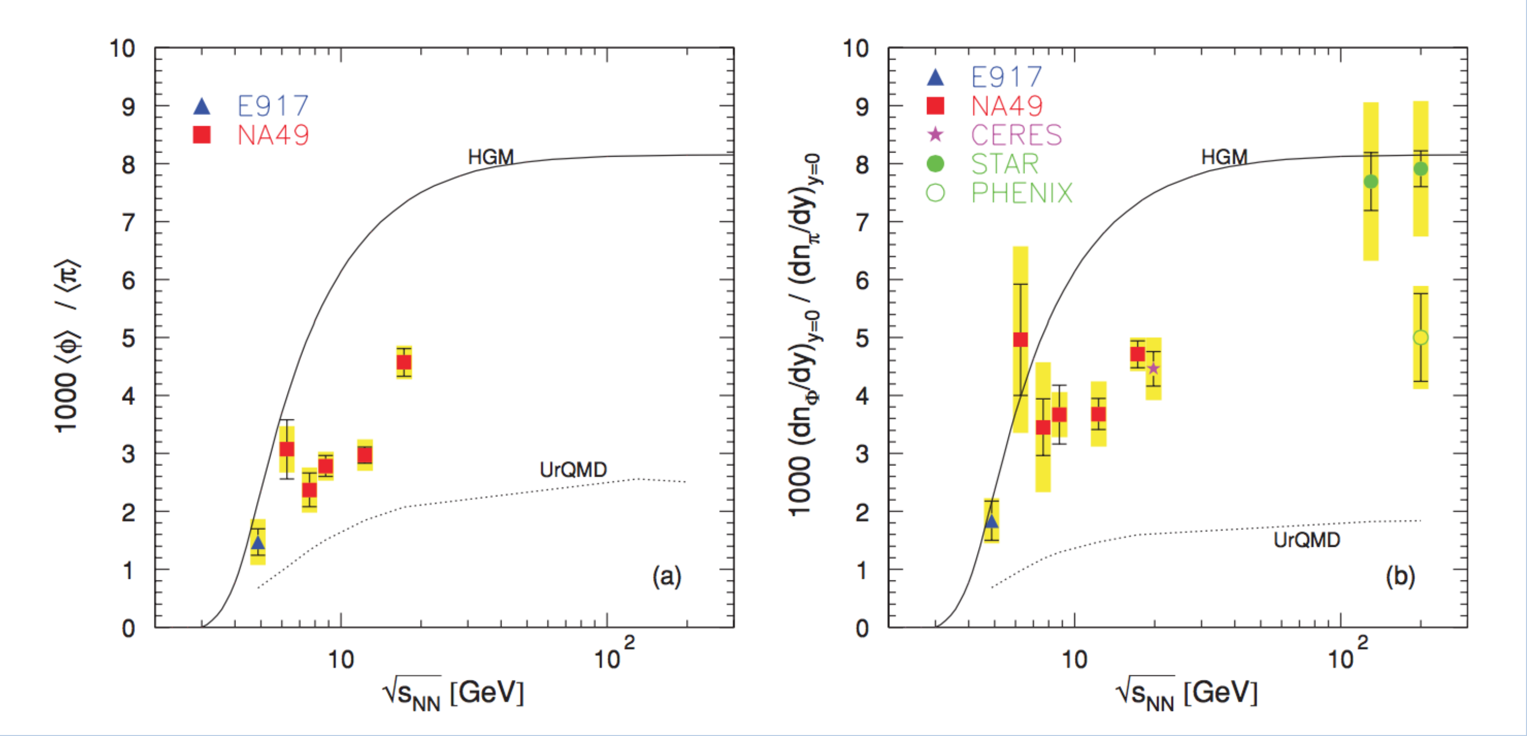


A long-lasting debate: pure hadronic description or signal of drastic change in matter properties?

Data on multi-strange baryons will be decisive!

- “Onset” scenario: effect is due to increase in strangeness; sharp maximum at same location as K/pi; size of peak increases with strangeness content
- Hadron Gas Model: effect is due to net-baryon density; broad maximum; size of maximum decreases with strangeness content; position of maximum shifts

Not to forget: the phi meson

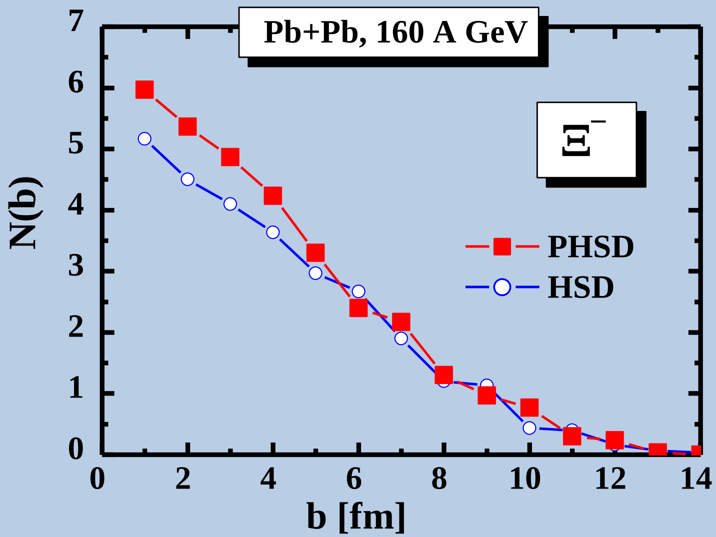


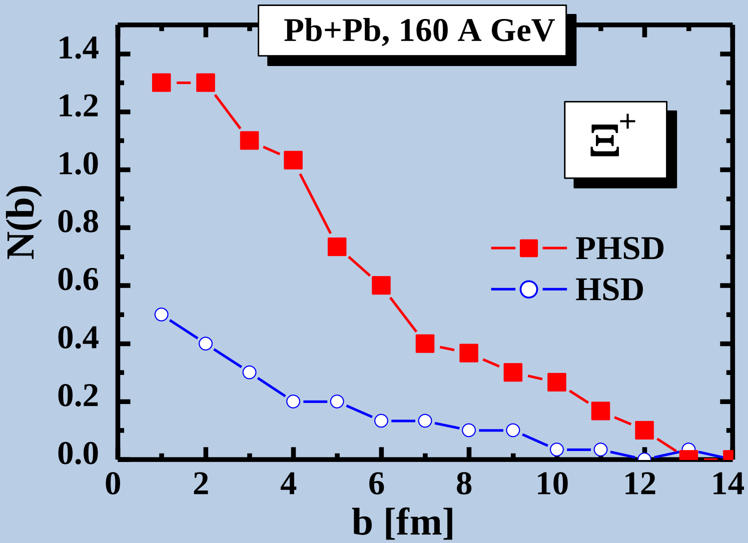
- s-sbar: strangeness-neutral in a hadronic picture; double-strange in a partonic view
- No satisfactory description of the excitation function neither by statistical model nor by microscopic transport
  - HADES (sub-threshold): good description by statistical model

What about strange anti-baryons?

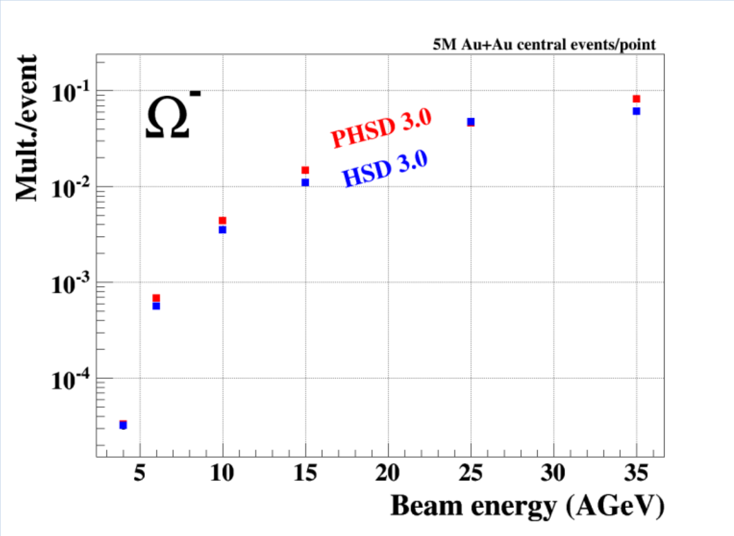
At large net-baryon density, the production of anti-baryons is heavily suppressed. This is not the case in a deconfined phase.

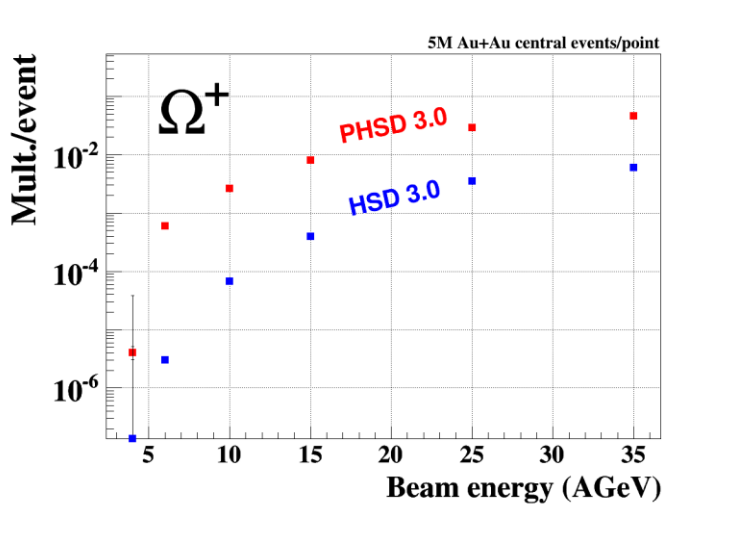
pHSD model: microscopic transport; assumes QGP in fireball regions where a critical energy is exceeded
For comparison: HSD (purely hadronic)
At top SPS energy: small effect on Xi, huge effect on anti-Xi.





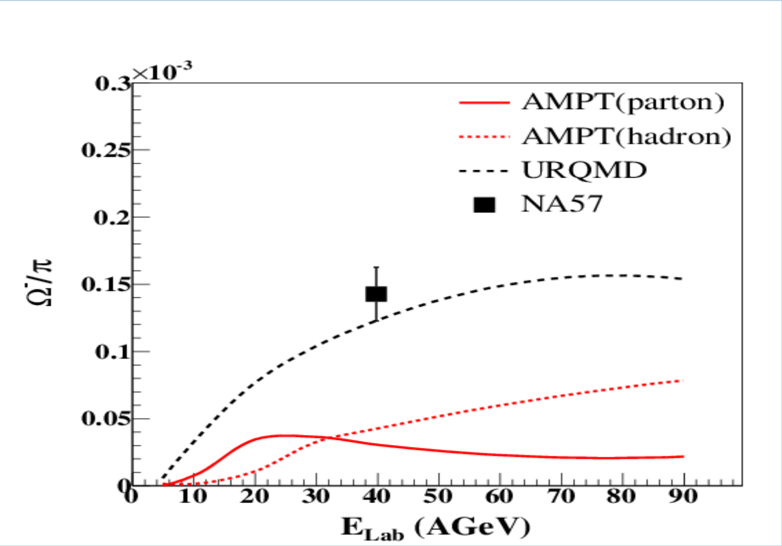
Strange anti-baryons at FAIR/NICA energies

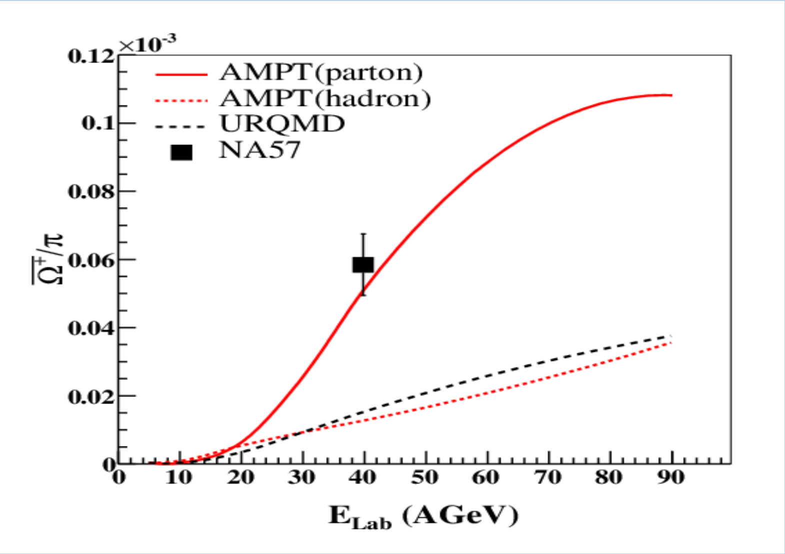




"Enhancement" of strange-anti-baryons is expected to be much stronger at lower energies!

Strange anti-baryons at FAIR/NICA energies





Similar results from AMPT (Multi-Phase Transport Model): Anti-Omega is strongly sensitive to partonic production; Omega much less.

Summary

- Strangeness below top-SPS energy is far from being understood.
- It is still one of the most promising probes to search for the first-order deconfinement phase transition.
- Many open questions:
  - Does thermalisation hold at lower energies?
  - Can the „horn" be fully understood in terms of the statistical model?
  - What happens at maximal net-baryon densities (30A GeV)?
  - What are the production mechanisms near or below threshold?
- A systematic measurement of multi-strange hadrons is most promising to answer those questions
  - CBM, BM@N, MPD, NA61, STAR
- Multi-strange anti-baryons are probably even more sensitive
  - Extremely rare probe; needs a high-rate experiment (CBM)