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QCD Hadronization

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The Veneziano-Webber Model

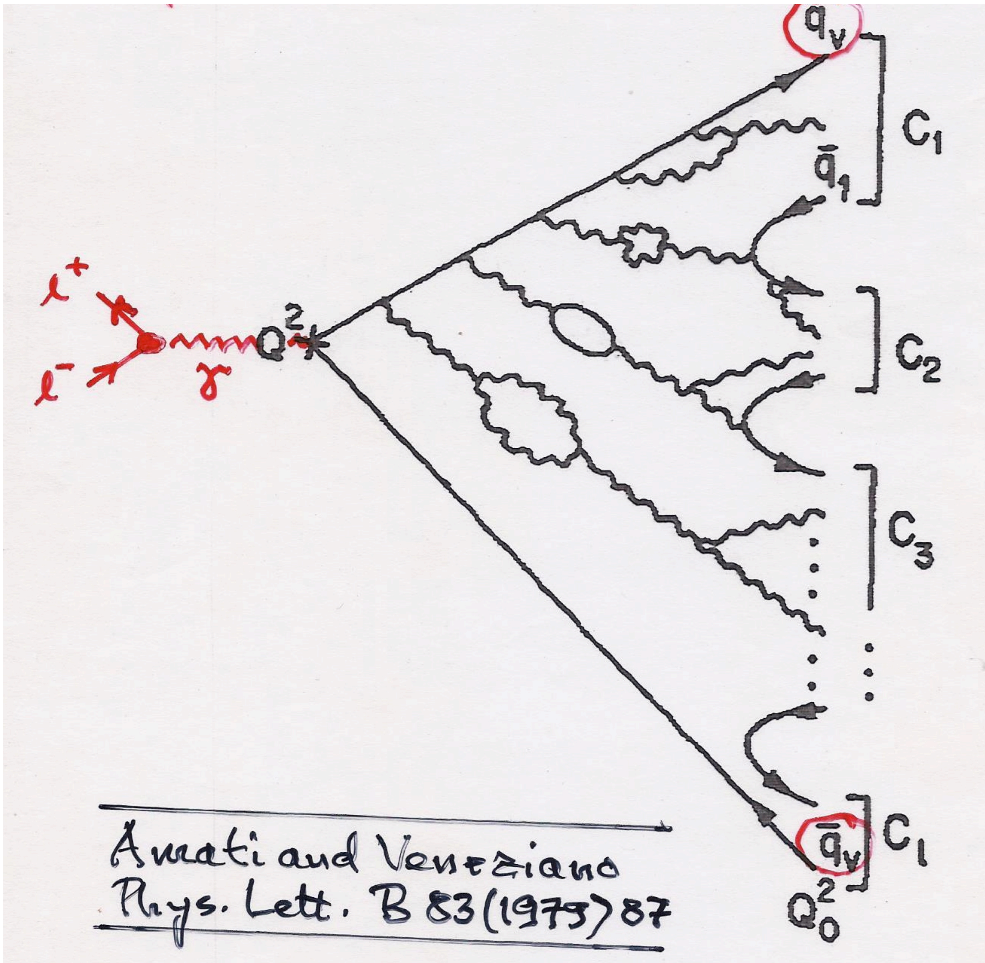
e^+e^- Annihilation to Hadrons: QCD DGLAP

Note: the photon is "virtual":
It has E_{CM} but no P_{CM}!
For "real" particles: $E^2 = p^2 + m^2$

Virtuality ≈ virtual mass!

End of pQCD phase: spatial order of color in "cluster" regions:

"Color pre-confinement!"



QCD Evolution in di-jet Hadronization: The Singlet Cluster Mass Spectrum

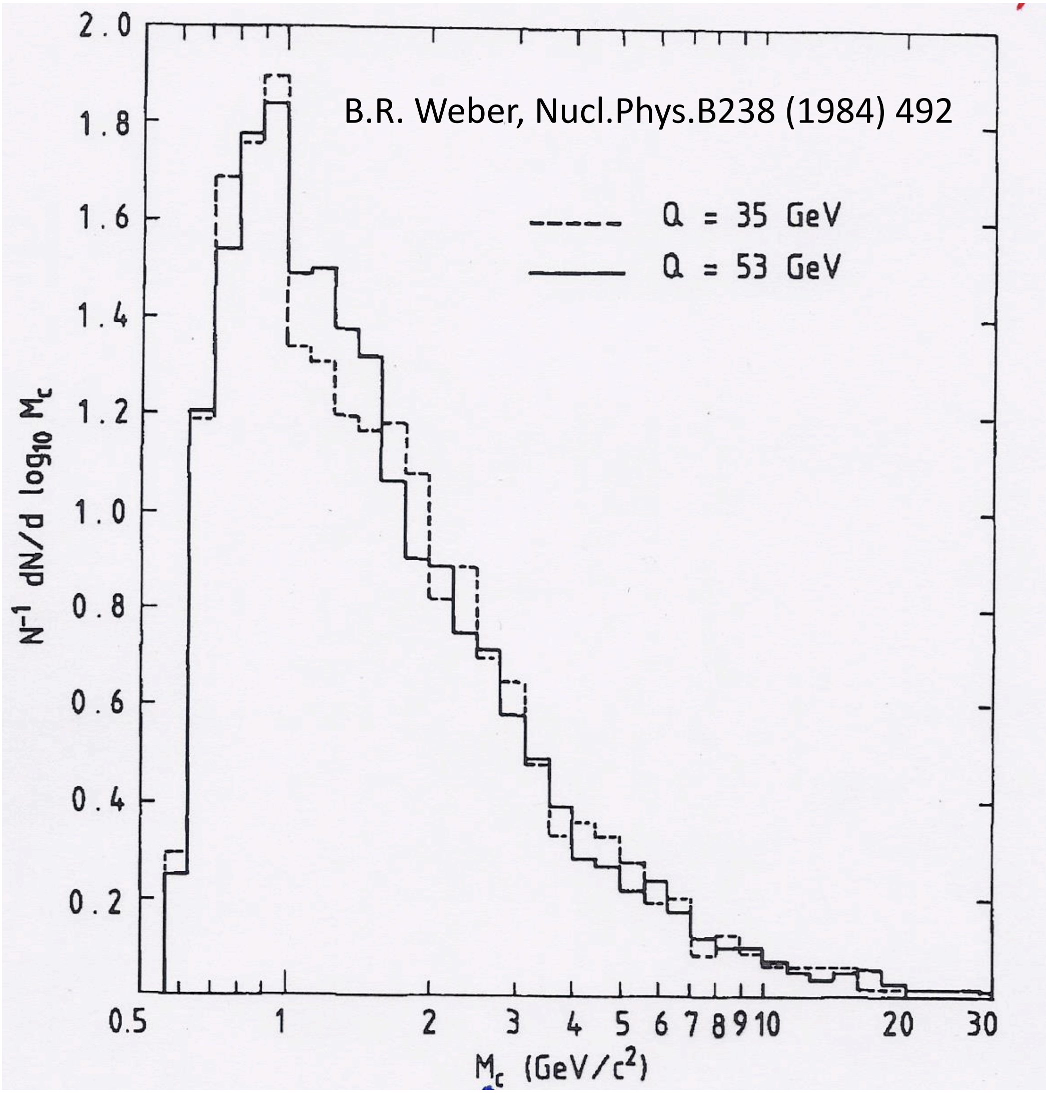
The Code "HERWIG"
pQCD invariant mass of clusters gets reinterpreted in non-pertubative language:

"Condensates, hadronic mass"

↓

Statistical decay into on-shell hadron spectrum

Phase space dominance



Clusters

Symbolic language! (strings, Hagedorn-Resonances, heavy resonances)

QCD aspects: 1. confinement -> color neutralization

2. chiral symm. -> cluster mass
breaking

3. Quantum Mechanics -> cluster decay

4. E and quantum number conservation
-> cluster net charges, T

Microscopic implementation

PHYSICAL REVIEW D VOLUME 52, NUMBER 3 1 AUGUST 1995

Real-time description of parton-hadron conversion and confinement dynamics

John Ellis* and Klaus Geiger†

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(Received 2 March 1995)

We propose a new and universal approach to the hadronization problem that incorporates both partonic and hadronic degrees of freedom in their respective domains of relevance, and that describes the conversion between them within a kinetic field theory formulation in real time and full seven-dimensional phase space. We construct a scale-dependent effective theory that reduces to perturbative QCD with its scale and chiral symmetry properties at short space-time distances, but at large distances ($r \gtrsim 1$ fm) yields symmetry-breaking gluon and quark condensates plus hadronic excitations. The approach is applied to the evolution of fragmenting $q\bar{q}$ and gg jet pairs as the system evolves from the initial two-jet configuration, via parton showering and cluster formation, to the final yield of hadrons. The phenomenological implications for $e^+e^- \to$ hadrons are investigated, such as the time scale of the transition, and its energy dependence, cluster size, and mass distributions. We compare our results for particle production and Bose-Einstein correlations with experimental data, and find an interesting possibility of extracting the basic parameters of the space-time evolution of the system from Bose enhancement measurements.

PACS number(s): 13.87.Fh, 12.38.Bx, 12.38.Lg, 13.65.+i

PHYSICAL REVIEW D VOLUME 54, NUMBER 3 1 AUGUST 1996

Space, time, and color in hadron production via $e^+e^- \to Z^0$ and $e^+e^- \to W^+W^-$

John Ellis* and Klaus Geiger†
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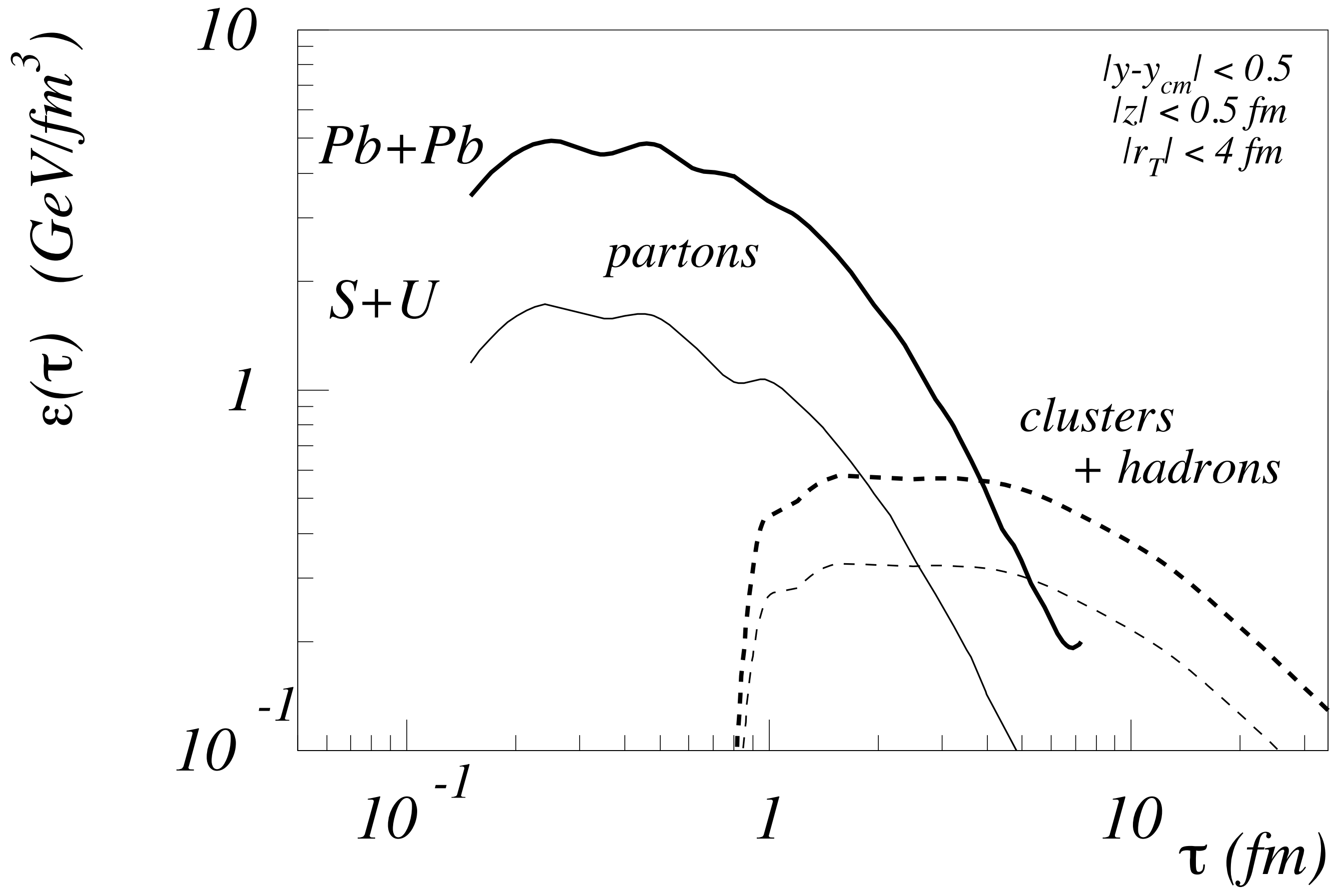
(Received 14 November 1995)

Second, it is evident that at a macroscopic level the overall space-time evolution is only marginally different for scenarios 1–3, implying that the gross features of the dynamical parton-hadron conversion are primarily determined by kinematics and the way in which the particles occupy phase space, and to a much lesser extent by the role of the internal color degrees of freedom.

Parton Cascade Description of Heavy-Ion Collisions at CERN (Klaus Geiger, 1998)



Evolution of mid-rapidity energy density (J.Ellis and K.Geiger Phys.Rev. D54 (1996) 1967)

Note: Hadron formation occurs at about 0.7 GeV/fm^3

Like in the statistical Hadronization Model

SHM observations I

The γ(s)-Factor: isolated clusters, dN/dy = 3 only!

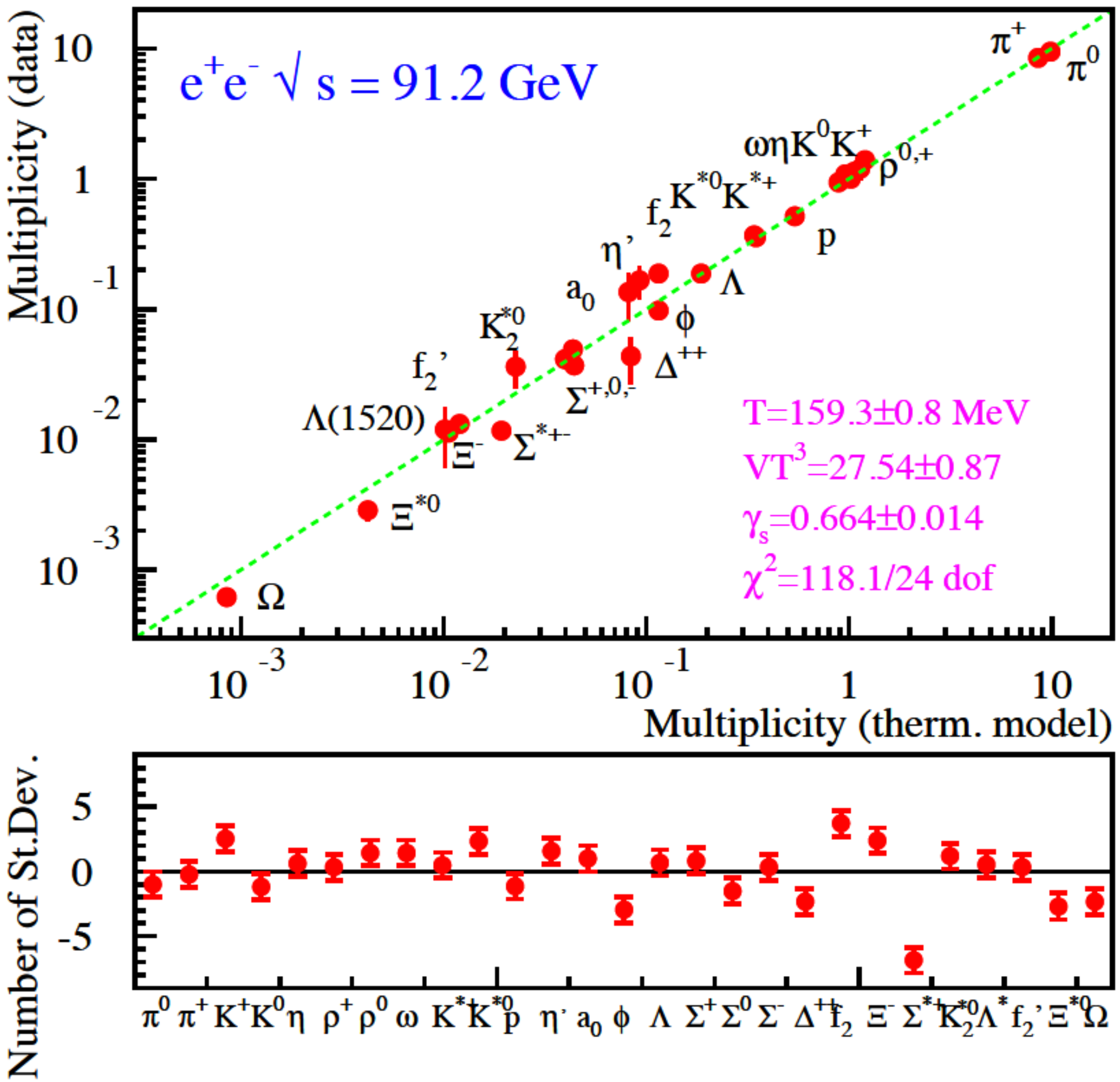
Francesco Becattini
Nucl.Phys. A702 (2002) 336

LEP data

Canonical statistical model analysis

T≈160 MeV
the hadronization temperature

Phase space weights plus quantum number conservation

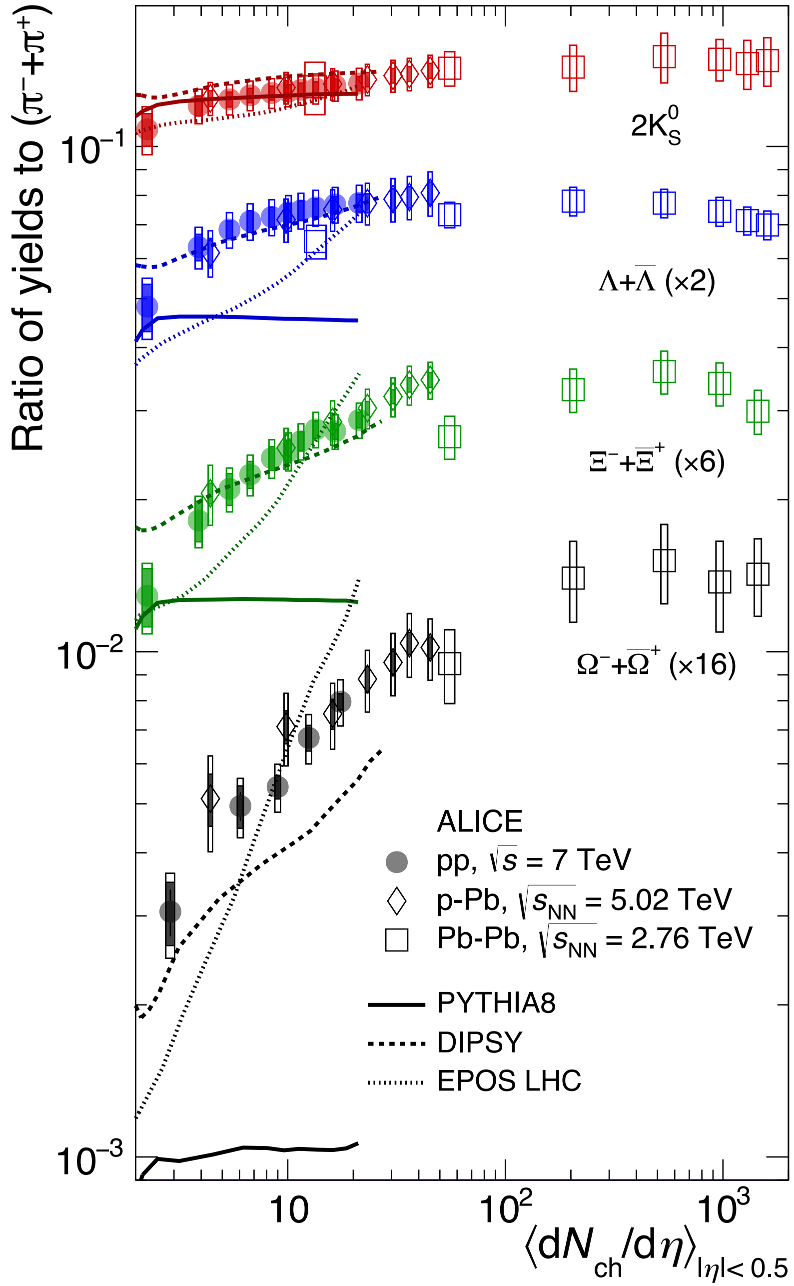


SHM observations II

LHC 7 TeV p+p
ALICE 1606.07424

dN/dη -> 30

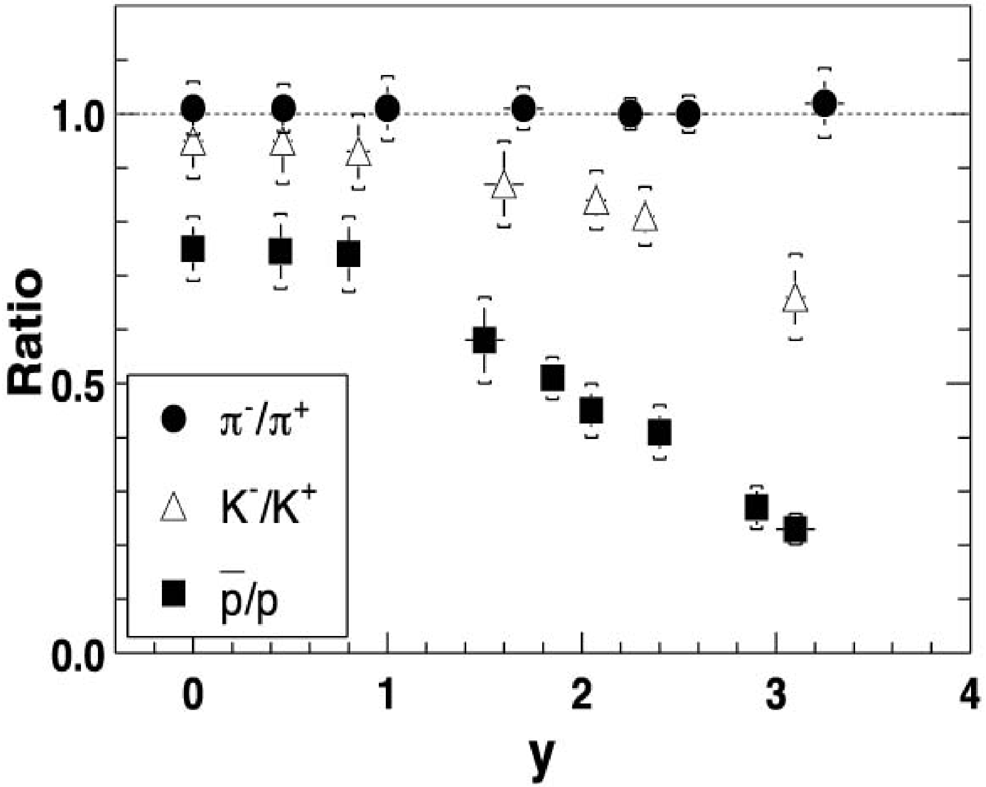
Toward the Grand Canonical Limit

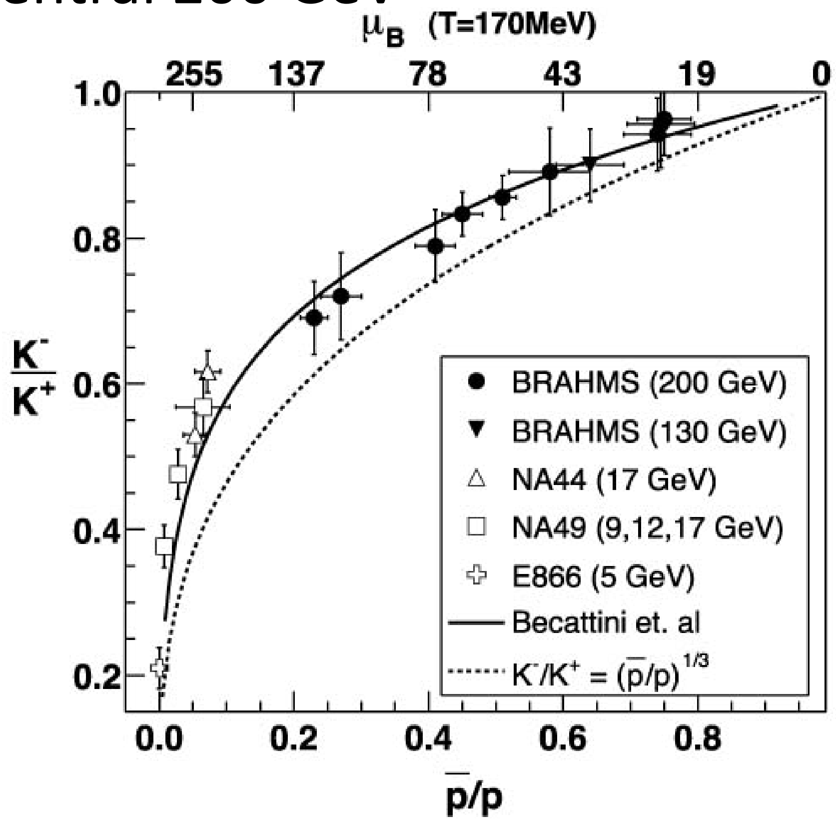


SHM observations III

Net Charge Conservation

BRAHMS Au+Au Central 200 GeV





- T, μ_B in successive unit rapidity windows
- No microscopic gamma(s)
- Connected cluster volumes -> Grand Canonical coherence

Conclusion

- A „minimal“ model
- Hadronization occurs after a formation time (Ellis and Geiger)
- Equilibrium explained as a QM effect
- Preserves memory of Energy and Net-Charge density, and cluster size
- Maximum Entropy State: no memory to primordial QCD mechanisim, other than conservation