The task in front of me...

Trying to put the very different ideas, on the very different topics, ultimately related to a non-perturbative theory whose exact dynamics is not known

I will do a lousy job. A good job will qualify me for a Nobel prize.

Important disclaimer : If I did not include your talk, it is not because I did not think it is important. It is because I only have 10 minutes and have to try to present talks with a unified theme. There is also an important acceptance bias (my expertise is heavy ion physics, and I found out I am giving this 2 days after the start of the lecture)

What can we agree on?

- We are interested in many particles, $N(\vec{p})$
- The system is quantum, ie probabilistic and correlated
  Not just $N(\vec{p})$, but the full $\langle N(\vec{p})\rangle$, $\langle N^2\rangle - \langle N\rangle^2$, $\langle N_1(\vec{p_1})N_2(\vec{p_2})\rangle$ has to be considered.
- Even $N = 0$ (the vacuum) is not understood, through we might have heard a step in this direction (V.Kuvshinovs talk)!

If we do not understand something, we try to find a limit where we can Taylor-expand! The different sessions here can be reduced to different ways to do that

$Q^2 \gg \Lambda_{QCD}$ this is the jet session

$M \gg Q^2$ this is the heavy quark session

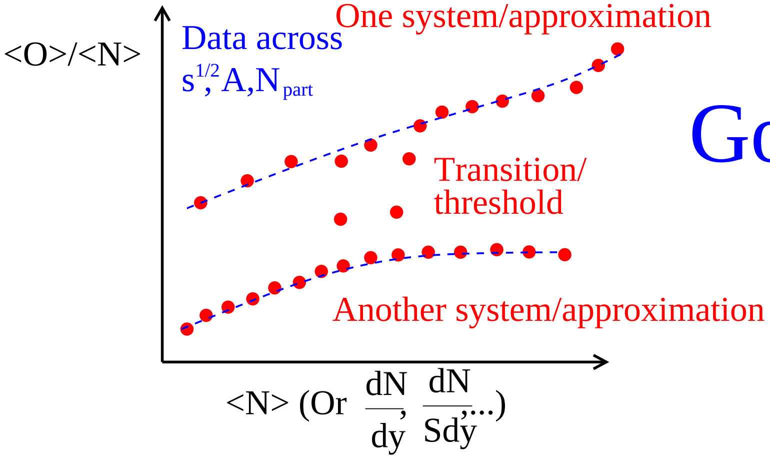
$R_{system} \gg l_{microscopic}$ these are the sessions connected to heavy ions

Of course the approximations still leave us with a richness of parameters!

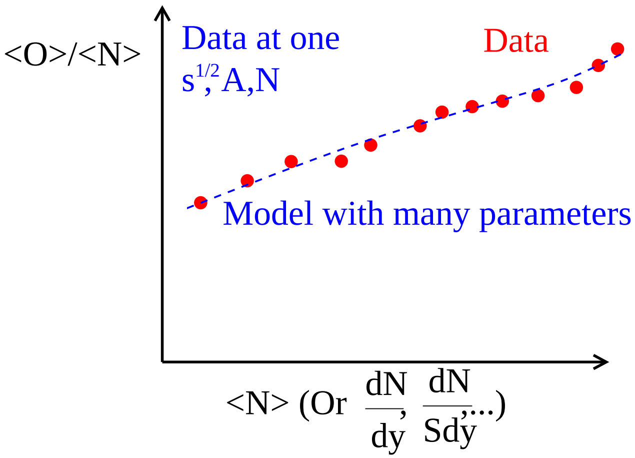
There is also a richness of experimental data to fit.
We can vary $\sqrt{s}, A$,impact parameter,y, p_T,particle species,$\phi - \phi_R$

This can go both ways: On the one hand, there is a danger that with enough parameters you will be able to fit a dog wagging its tail On the other hand, the range of energies and system sizes provide us with the opportunity to study the scaling of different observables. Multi-particle events give you the ideal opportunity for scaling studies, because events of different system size, centrality,$\sqrt{s}$ could well have the same number of particles

But we have to go beyond considering each $\sqrt{s}$ in isolation



Good!



Not so good!

At the moment many models, including mine, are not so good

But were on the way to make them good

What the transition could be

$$\underbrace{Quarks}_{interact} \Leftrightarrow \underbrace{Hadrons}_{seen}$$

This happens

- At 0 temperature (splitting functions, fragmentation)
- At finite temperature (QGP)

How inevitable is this transition? How "classical" is QCD?
(Y. Dokshitzer)

Quantum field theory,nearly always, aquires a scale due to quantum corrections (running of the coupling constant). Only exception known is $\mathcal{N}_{supersymmetries} = 4$ SU(N) gauge theory. Might (or not!) be similar to QCD, and has the big privilege of being calculable even at stong coupling (AdS/CFT) and well-behaved (integrable).

Dynamics could well be effectively "classical", through gluon dynamics as non-trivial as in QCD (anomalous dimension). Investigation on-going.

Bottom line: We still do not know how similar is $\mathcal{N}_{supersymmetries} = 4, N_f = 0, SU(\infty)$ to $\mathcal{N}_{supersymmetries} = 0, N_f = 3, SU(3)$ Attempt to answer this question phenomenologically still far away, but we started the journey (see my talk).

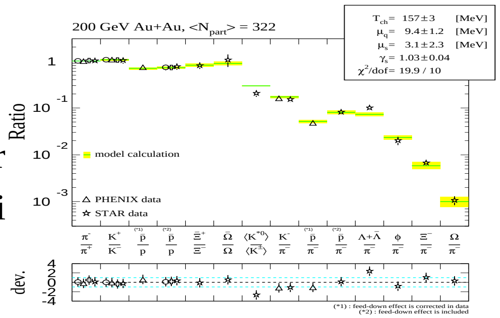
A talk we should have heard (Becattini)!

How big does the system need to be to be "statistical"?

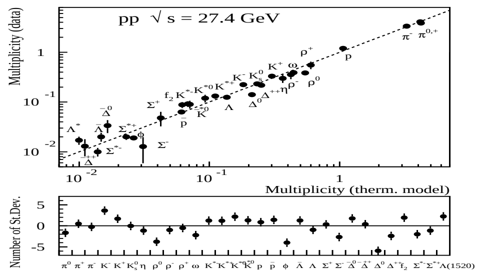
The chemical analysis of A-A collisions is often shown. many particles, including rare, weakly interacting ones (ϕ, Ω) described by same T, μ_B.

A−A fit

(Kaneta,Xu) Also
P.Braun−Muntziger
J.Stachel J.Rafelski
G. Torrieri ...



p−p fit
F.
Becattini



but, up to strangeness chemical (non)-equilibrium (parametrized by γ_s , p-p and even e^+e^- data also look statistical! Is nature telling us something deep (particles born in equilibrium,black holes)? Or trivial? (phase space, not the same but looks statistical) Or does the lower statistical significance of elementary fit invalidate it? Question lively and controversial.

How jets can shade light (or rather, shadow) on the medium

A dense medium can stop jets. Hence, we can use the lack of jets to diagnose the initial density of the system. This procedure, tomography, is very well known in cancer research. Implementation of this procedure was presented by L. Bravina,I. Lokhtin in pQCD, and by me non-perturbatively. Encouragingly, the perturbative models, when embedded in ideal hydrodynamics, aim successfully to capture both hard and soft physics!

BUT1 Until now, most of these studies have concentrated on fitting one energy (RHIC). I very much hope the next steps include an energy scan. Jet scaling with system size is very different between SPS and RHIC, and it would be very interesting to see how suppression "turns on" .

BUT2 ...

But what exactly is a jet in general?

We do not observe a fast parton directly, but only after it hadronizes into a collimated cluster of hard particles we call a "jet". Of course, these are qualitative statements. Distinguishing a "jet" from a "background" random cluster of softer particles is not easy. And it is crucial if we want to understand the effect of the medium on the jet, ie to disentangle in-medium from hadronization.

Is the jet suppressed,broadened, thermalized,or all of the above?

We have heard a possible approach (sapeta), and some very exciting new results (Kapitan). It is fair to say that we are far from a consensus, but watch this topic in future ISMDs.

More on jets(?) and medium: The ridge

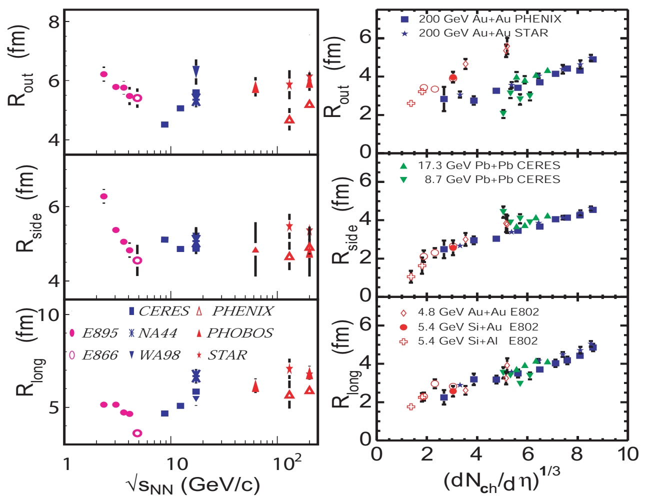
Intriguing, not as yet understood phenomenon. We heard an interesting explanation (C.K.Wong), which would suggest large ($\Delta\eta \sim \eta_{lim}$) quantum coherence). A somewhat different mechanism was suggested by Y.Hama : in their model, the ridge is hydrodynamical in origin, and hence independent of a "hard trigger". Who is right? The (still unresolved experimentally) "soft ridge" question might tell us!

More generally,scaling issue not clear to me: experimentally the ridge arises at a critical centrality. Why? Experimentally , energy dependence of ridge would be very interesting (I understand difficoulties due to statistics)

HBT: on the way to solution?

Historically, system seemed smaller, and breaking up considerably faster, than hydrodynamics suggested.
Y.Sinyukov has shown us one of the first calculations that seem to fit RHIC data. "Winning" formula is a combination of (all reasonable) effects contributing: Initial flow, a harder EoS, and (some) final viscosity . But conspiracy of different effects might have a problem with scaling,from Au-Au RHIC to AGS and all the way to p-p

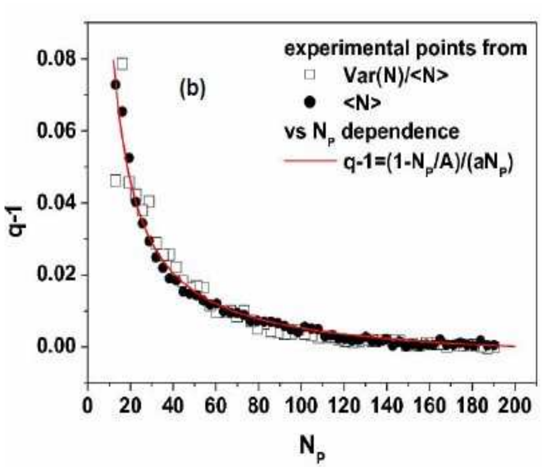
Mike Lisa
ISMD2005

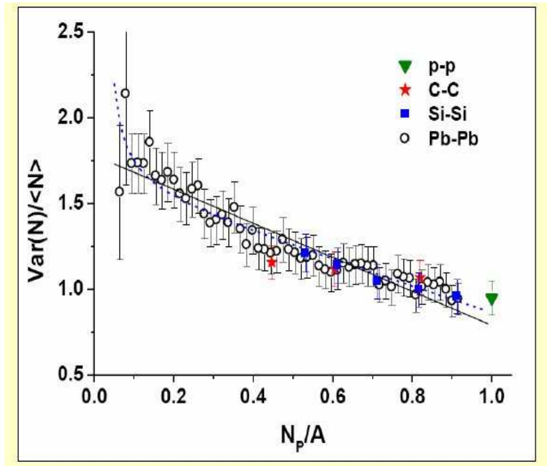


Fluctuations

Speaking of scaling from p-p to Au-Au, G.Wilkhas shown us an impressive and successful compilation of multiplicity fluctuations, from p-p to A-A, fitted with the same statistical model generalized with a q-parameter

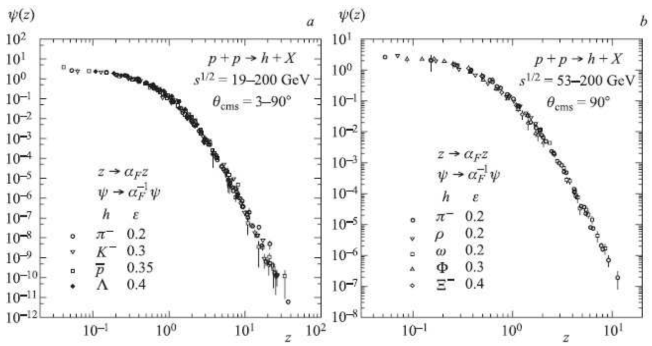
G.Wilk



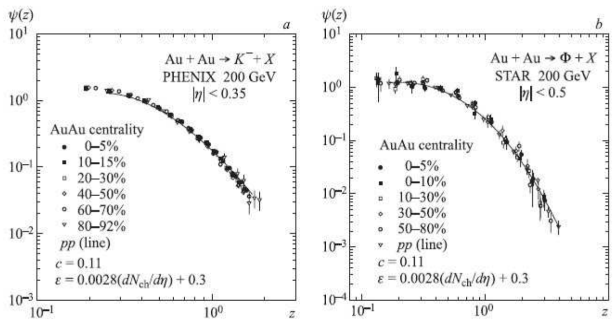


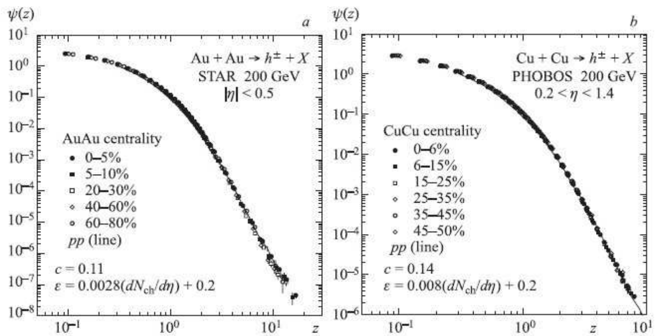
But what does this mean? I am worried about geometric fluctuations, but perhaps nature is trying to tell us something.Observables less sensitive to geometry exist (ratios).

A non-standard statistical scaling was also found by Tokarevto work for averages for a surprising range of p_T, A and species. It might be useful to investigate weather a similar scaling arises in pQCD, and hence use the empirical scaling as a probe to constrain the domain of validity of perturbative and non-perturbative physics



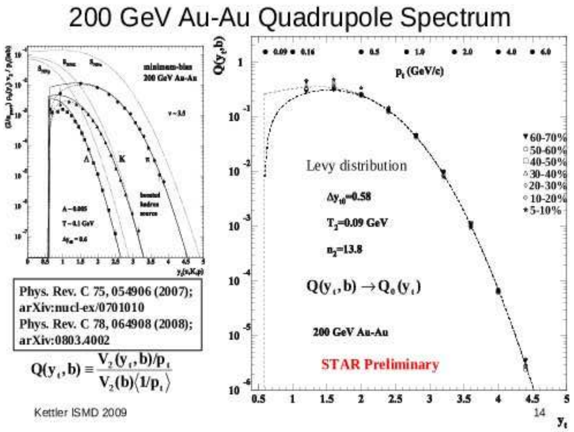
M.Tokarev





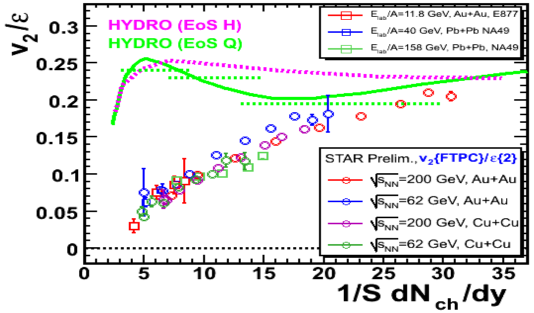
More to scaling:T.Trainor and D.Kettler

"Traditional measurements" of elliptic flow, jet suppression susceptible to systematic errors. Different analysis suggests event more pQCD-like than hydro-like at high (SPS,RHIC energies). Current consensus upside down



vs

approach to ideal hydro limit at RHIC



I urge the people involved to look at scaling...from the theory side, no <u>direct</u> (ie,beyond "this model fits") signal of local equilibration <u>so far</u>.

(Worth underlining in view of the ambiguity of interpreting the "jet observables" presented by J.Kapitan)

Many More interesting talks...

A.Kaidalov,M.Erofeeva,V.Abramovsky... What is the QCD dynamics responsible for particle creation in high energy hadronic interactions (Pomerons,string models...)
Would be interested in scaling by system size, as well as $\sqrt{s}$.

B.Boimska,G.Wolshin , on the other hand, provided some very nice quantitative studies of geometric scaling. Are we moving towards full $\sqrt{s} - A$ space understanding in all models? Scaling multiplicity studies could again be crucial in model falsification

... many more interesting talks than time to cover in these short minutes (no) conclusion:

- Space of theoretical ideas, and space of experimental data, large
- But interpolating between them to crack the code of QCD hard

Perhaps its the kind of N_p hard problem quantum computers will solve! DB Horoshkos talk and work at IP-NASB Minsk. Lacking that, plenty of things to think about for ISMD2010 (Next talk!)