SQM 2013 Theory Summary Review

Subjective remarks

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Fundamental Questions

- Gott würfelt nicht... (but oft enough it looks like that)
- Particles (mass points) or Fields (waves): both...
- Shall we ever know the Initial State?
Outline

1. Versus
2. Highlights
More... size, time, gradients

\[ \frac{dN_{\text{ch}}}{d\eta} \propto \ln \sqrt{s} \sim y_{\text{beam}} \]

\[ V \approx 730 \text{fm}^3 + 2.545 \frac{dN_{\text{ch}}}{d\eta}, \quad \mathcal{T} \approx 0.875 \left( \frac{dN_{\text{ch}}}{d\eta} \right)^{1/3} \]
1. thermalization: exponential vs power-law
2. hydrodynamics: initial vs eos-driven
3. hadronization: phase space vs QCD
4. QM eos: lattice vs dual gravity
5. nuclear medium: cross sections vs mean fields
6. simulation: particle vs field
Outline

1 Versus
   - Thermalization
   - Hydrodynamics
   - Hadronization
   - Lattice

2 Highlights
Thermal and Hydro: why and how?

Florkowski: Thermalization of massive partons in anisotropic medium
Rafelski: First 3 seconds
Stachel: Thermal model
Kolomeitsev: Strangeness balance in HIC
Cleymans: Systematic Properties of the Tsallis Distribution
Beitel: Thermalization through Hagedorn States
Grossi: Relativistic distribution function...
Essence of Hydro: LCNC

\[ \partial_\mu J^\mu_a = 0. \] (1)
Essence of Hydro: dominant LCNC-s

\[ \partial_\mu J_\mu^{B,S,Q}(B,S,Q) = 0 \]
\[ \partial_\mu T^{\mu \nu} = 0 \]
\[ \partial_\mu M^{\mu \nu \rho} = 0 \] (2)

NC-s are connected
Essence of Hydro: Connections

chemistry (types of charges, single or multi-fluid)

\[ J^{\mu a} = \sum_{i=+, -} q_i^a u^{\mu}_{(i)} \]  

(conductive (carried by the stream) + else)

\[ T^{\mu \nu} = P^{\mu} u^{\nu} + P^{\nu} u^{\mu} + \mathcal{S}^{\mu \nu} \]  

polarisation

\[ M^{\mu \nu \rho} = x^{\mu} T^{\nu \rho} - x^{\nu} T^{\mu \rho} + S^{\mu \nu \rho} \]
Hydro Hopes

citing Takeshi Kodama

Expectations and hopes:

- Determination of Properties of Matter (EoS, Transport coefficients)
- Comparison with Lattice QCD
- Determination of Initial State just after the Collision
- Key for the QCD dynamics···
Numeric Hydro

Joanis Bouras: BAMP Mach Cones

Ideal Solutions of Mach Cones

Viscous Solutions of Mach Cones

Mach Cone structure still visible for $\frac{\eta}{s} = 0.1 - 0.15$
Coarse Graining = UV open (anti/dissipative?) system

Finite Reservoir (fluctuating intensives) = IR open system
Equilibrium after dissipation:

\[ \partial_\mu S^\mu + \lambda_a \partial_\mu J^{\mu,a} \geq 0. \]  (6)

Gibbs potential

\[ S^\mu + \lambda_a J^{\mu,a} = \Phi^\mu \]  (7)

Gibbs-Duhem relation (in/out local equilibrium)

\[ \partial_\mu \Phi^\mu \geq J^{\mu,a} \partial_\mu \lambda_a \]  (8)

Linear transport (\( \eta_{ab} \) positive semi-definite)

\[ \partial^\mu \lambda_a = -\eta_{ab} J^{\mu,b}. \]  (9)
Pseudo-thermalization? Pseudo-Hydro?

\[ I(f) \propto \int e^{i\frac{1-v(t)}{1+v(t)}d\tau - ft} d\tau \]

Doppler faktor: \( z \)

\[ I(f) \propto \int_{0}^{\infty} e^{icoz/g} z^{-1} \pi cf/g - 1 \]

\[ \frac{1}{e^{2\pi cf/g} - 1} \]

Biró

SQM2013 Theory Review
(Semi)classical Photon Spectra

T. S. Biro, Z. Schram, Z. Szendi: work in progress...
Hydro: initial state or eos?

Takahashi: Effects of Jets in the Flow Observables
Kodama: Thermal Equilibrium and ... Initial Condition
Tamosiunas: Landau hydrodynamics...
Wiranata: Shear viscosity of hadrons...
Csornai: Turbulence, Vorticity and Lambda Polarization
Bozek: Hydrodynamic models of particle production
Song: QGP viscosity and the flow ...
Molnar: Event-by-event correlation...
Scradina: Elliptic Flow from CGC
Huovinen: Dynamical freeze-out in event-by-event hydro...
Hadronization: Phase Space or QCD dynamics?

- Werner: Monte Carlo
- Bratkovskaya: Strongly interacting parton-hadron matter...
- Gousset: Gluon radiation by heavy quarks
- Kitazawa: Diffusion of Non-Gaussianity ...
- Flores: Strangeness baryon to meson ratio
- Tiwari: ... Excluded-Volume Model
- Petran: Interpretation of strange hadron production at LHC
- Chatterjee: Chemical freezeout via HRG
Defactorizing the "Thermo" Part

1. Find Scaling Variable(s) which unifies different mass hadron $p_{\perp}$-spectra
2. Try Coalescence Hypothesis, if Baryon and Meson branches differ
3. Find out the Functional Form on the quark (parton) level
4. Test trends (with binary scaling, participant number, rapidity window)
5. Interpret Parameters (vs on/off-equilibrium, finite/infinite size, . . . )
Defactorizing the "Thermo" Part

1. Is it \( f(p_T, m) = f(E_v(p_t, m) - \mu(m)) = f(X) \) ?

2. Coalescence scaling? \( f_h(X) = f_q^n(X/n) \) for \( n = 2, 3 \)

3. (X-)Energy distribution? \( f(X) \sim (1 + a\beta X)^{-1/a} \rightarrow e^{-\beta X} \)

4. Test trends \( (N_{part}, N_{bin}, P(N), \sqrt{s}, \Delta \eta \ldots) \)

5. Interpret Parameters: \( \beta, v, a, \ldots \)
When old people make a new theory, they know all about assumptions, approximations, implied or explicit. But young people, who learn it from a textbook, believe that this were TRUTH.
Quarkonia and Energy Loss

Horowitz: Heavy Quark Energy Loss
Das: ... Boltzmann vs Langevin
Berrehrah: Towards... (QGP)
Uphoff: Heavy vs light flavor energy loss...
Renk: Jet quenching and Heavy Quarks
Lee: Free energy vs internal energy potential...
Katz: Quantum and semiclassical...
Djordjevic: ... finite magnetic mass...
Does AdS/CFT well?

From Thorsten Trenk’s review

- Does AdS get the scaling from RHIC to LHC?

⇒ Clear no for both heavy and light quarks! AdS techniques predict too much suppression at LHC when tuned to RHIC and extrapolated.

- No viable AdS/CFT model candidate for the more involved light quark observables ⇒ revise or abandon!

Lattice or other Models?

Torrieri: ... high-density quark matter
Chao: ... Sphalerons
Bluhm: Flavor Hierarchy...
Yamazaki: ... PNJL model
Marty: ... Nambu-Jona-Lasinio model for SU(3)f
Allton: First Principles Calculation...
Redlich: Role of fluctuations in detecting the QCD phase transition
Kumar: Holographic descriptions of dense quark matter
Herold: "chiral fluid dynamics"
Schmidt: "ab initio Lattice QCD calculations"
High-T = pQCD ???

Thermal distribution of $Q^2$

$$P(Q^2) = \frac{1}{64T^2} \left( \frac{Q^3}{T^3} K_1 \left( \frac{Q}{T} \right) + 2 \frac{Q^2}{T^2} K_2 \left( \frac{Q}{T} \right) \right)$$
Boltzmann-Gibbs $Q^2$ distribution
Order parameter of Non-Perturbativity

Thermal expectation of NP order parameter

\[ \langle \Theta(\Lambda^2 - Q^2) \rangle = \int_0^{\Lambda^2} P(Q^2) dQ^2 \]
Hadrons Survive until $T \approx 1$ GeV

Between $T_1 \approx 1/6$ GeV and $T_2 \approx 1$ GeV: both worlds!
Outline

1. Versus

2. Highlights
   - Other topics
Highlights

- New Theories
- New Aspects
- New Proposals
- New Calculations
- New Insights
(Towards) New Theory

EoS, transport, capacities \((q=1-1/C)\), fluctuations, ...

Expectations and hopes:

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- Key for the QCD dynamics...

What about the Birth of Hadrons?
Becattini, Csernai, Wang: Lambda Polarization .... (1304.4427)

\[ \Pi_\mu \sim \langle \varepsilon_{\mu \rho \sigma \tau} p^\tau \partial^\rho (\beta u^\sigma) \rangle \text{Cooper–Fry} \]  \hspace{1cm} (10)

analogy: Pauli-Lubanski vector
New Calculations: Strange Temperatures?

Markus Bleicher’s opening talk:

Is there a different transition temperature for strangeness?
Summary

- Traditional Monte Carlos have difficulties to describe strange particle production in pp. Hydrodynamical picture helps.

- pPb looks very much like a hydrodynamically expanding system (more clean than PbPb, where hydro and minijets heavily interact, as well as the final hadrons among themselves)
Proposal: Message via Fluctuations

Krzysztof Redlich


Energy dependence for different centralities
“pure” quarkyonic effect, it is due to sensitivity of quark wavefunctions to baryon location. **signature?**
Astro, Nuclear, ... new insight?

Quark matter in compact stars

**Conventional scenario**
- Neutron/hybrid star
  - Neutron star
  - Hybrid star

**Strange Matter Hypothesis**
- Strange star
  - SQM
  - Strangelet crust

Bodmer 1971; Witten 1984; Farhi, Jaffe 1984
Astro, Nuclear, ... new insight?

Alford, Han arXiv:1111.3937

Not all theories survive observation...

Recent measurement: $M = 1.97 \pm 0.04 M_\odot$

Apple = Theory

Ice = Experiment