Theory Summary Talk

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Foreword

It is my firm belief that a write-up of a theoretical summary makes even less sense than conference proceedings in general. A summary talk may be helpful on-line, to the participants of the conference who by the end of the meeting may feel overwhelmed by the information flow and might appreciate such a presentation as a mere filing tool:

- What did we learn?
- What was impressive enough to be remembered?
- Which issues should we try to understand and develop with Moriond–2002 in sight?

For a potential reader of the proceedings, such an introduction is hardly necessary and could have been traded for a table of contents: the conference contributions are carefully written by the authors and laid before the readers' eyes.

Bearing this in mind, I will share with you my personal biased impressions and feelings, organized in a manner of the above filing list, rather than review each and every theoretical presentation. In doing so, I will try to be provocative, and concentrate on open questions and defects of our understanding rather than on successes and achievements which are obviously there but shy away in view of the vast territories yet unexplored.

But first, the main resume of the QCD-Moriond–2001: we live in exciting times with Theory and Experiment being back together, in a Big Way. In spite of what our fashion-following colleagues may think and say, Field Theory as a tool for digging into the structure and interactions of (once) elementary particles, is not yet dead. Moreover, it is not yet explored and barely understood. Quantum Chromodynamics offers us a unique chance of understanding dynamics of physical systems plagued by *strong* interactions. This statement applies to a much wider context than that of the Particle Physics.

Indeed, to the best of my knowledge, the condensed matter physics is the only example where theoretical tools have been developed to address the issue of strong interactions. The progress in understanding phase transitions, however, was mostly due to *good guesses*: proper order parameters, the scaling ansatz resulting in calculability of critical indices, etc., rather than microscopic dynamics. At the same time, QCD, once understood, should provide us the physics of phase transitions, of compound objects, their structure and interactions, as derived from the *first dynamical principles.* Such a chance should not be missed.

1 Extra-D World

> ☞ The method employed I would gladly explain,
> while I have it so clear in my head,
> If I had but the time and you had but the **bra~~i~~n**^{e}
> — But much yet remains to be said.
> *Butcher to Beaver*, Fit the Fifth,
> “The Hunting of the Snark”. Lewis Carroll

Following a high-tech overview of the extra-dimensional world presented by Greg Landsberg, various aspects of this brave new world were discussed by Bob Oliver, Jacek Wosiek, Satoshi Matsuda, Ina Sarcevic and Ian Kogan.[a]

As far as I can see, this specific session was planned for educational purposes, to make stubbornly four-dimensional particle physicist, theorists and experimenters alike, aware of the todays fashion in theoretical theory. As such, the session was a success.

The starting point for the fantasies is perfectly sound. The hypothesis of a different (much stronger) gravitational force at small macroscopic (micron) distances, in place of the good old Newton’s law, is no doubt legitimate as long as it is verifiable (which it is). Moreover, it is also a *fascinating* hypothesis, since the application of the multi-dimensional Gauss law to drive the our-world gravity crazy, is a little marvel from an aesthetic point of view.

Whether or not the viability of the hypothesis of “hidden” extra dimensions is disproportionate to the amount of theoretical effort which is being put into it, is another matter. Let all the flowers blossom. For the time being.[b]

There is an ironic twist to the story. As you well know, a sufficiently light Higgs is welcome to rescue particle physicists from the *electro-weak* interaction going *strong* at the 1–2 TeV scale. The Extra-D advocates tell us: “*Wait, you had a trouble with the weak interaction turning strong? How about the* gravity *becoming a strong interaction at the few-TeV scale as well?*” (The proper French expression is, I gather: “*Il ne manquait plus que ça.*”) To be serious, however, it is this very fantasy of shifting the gravity unification scale down to the accessible TeV range that makes the new hypothesis really attractive. When/if the extra-D hypothesis is proved correct, we would learn that not only was the Creator not malicious but that He/She was also playful.

For now, a humble four-dimensional practitioner cannot but notice that the extra-D picture of the world, provided it has “conquered the masses”, would inevitably be warmly greeted by

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[a] For the brevity sake, in the summary talk these issues naturally went under the Ina–Ian logo.

[b] As long as responsible G-unmodified crops on the particle physics fields don’t suffer from the lack of manpower and resources. Do they not?

the proponents of "parallel worlds", teleportation and all sort of mystics. To add a positive touch to this sad observation, it will at the same time enrich our vocabulary, mainly on the part of exclamations, like "*Where on the 4-brane ...*" (in place of an obsolete "Where on Earth"), "*R U out of brane*?" and, the most precious of them all, "*Go to ... bulk*!"

2 pQCD expanding

Many talks dealt with advancing perturbative QCD (pQCD).

Firooz Arash discussed a good old valence quark picture, in connection with the parton evolution.

A noble quest of studying next-to-leading order effects in various QCD processes, and implementing them into corresponding Monte-Carlo (MC) generators, were presented by Gudrun Heinrich (the state-of-the-art NLO analysis of prompt photon production), Thomas Binoth (γ– and π–pairs at LHC), Bryan Cox (POMWIG — the MC generator for hard diffractive phenomena) and John Campbell (NLO effects in Higgs searches).

2.1 NNLO

Nigel Glover gave a comprehensive review of the progress in the next-to-next-to-leading order QCD calculations. Various aspects of the NNLO problematics were presented by Adriano Ghinculov (Bhabha scattering), Massimo Grazzini (Higgs) and Patrik Eden (multiplicities and multiplicity correlators).

Keeping the promise to be critical (though not intending to be nasty), here comes a critical remark.[c] Terry Sloan's taught us that for an experimenter "*One event makes a cross section, two events – angular distributions, and three – asymmetry*". Adjusting his teaching to the theoretical context, I would say that typically "*LO satisfies one's curiosity, NLO – needs, and NNLO – but ambitions.*"

I could not but agree with Nigel Glover that the progress in the past two years in handling integrals has been indeed enormous: all difficult integrals entering two-loop massless Feynman 2→2 amplitudes were cracked. At the same time, I don't think that getting hold of the NNLO pQCD calculations, in general, would mark a breakthrough in the subject. To that there are many reasons: an intrinsic deficiency of perturbative series as such, a relatively large numerical value and an elusive nature of the pQCD expansion parameter α_s being the first to name.[d]

Strictly speaking, the perturbative series in powers of the coupling constant makes no sense in the first place. They don't converge and, moreover, do not even represent an *asymptotic* expansion. This is a built-in defect common for "logarithmic" field theories with the dimensionless coupling we are dealing with (QCD, QED).

In practical terms, in the QED context this is an academic problem since the number of terms one can reliably calculate and keep to achieve a better approximation to the true answer, before the series starts to explode, $c_n \propto n!\alpha^n$, is astronomically large, $n < 1/\alpha \sim 10^2$. Not so in QCD.

More importantly, the very notion of the *perturbative* QCD coupling α_s cannot be uniquely defined beyond two loops. It is well known that starting from the three-loop level, the QCD β–function becomes scheme– and even gauge–dependent an object, imposing these unwelcome features upon the coupling itself. Physically this means that the way α_s depends on the momentum scale ("runs") ceases to depend only on what happens in the *ultra-violet* (UV) domain

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[c] If someone finds it nasty, it is my imperfect English to be blamed, not my perfectly friendly Russian intentions.

[d] Answering the visiting archbishop's complaints of not being greeted by the church bells toll upon entering a small town, the local priest apologized: "*Your eminence, there are twelve reasons for that. The first is, we've got no bells...*" [Reportedly, one of the favorite Pomeranchuk jokes.]

where the asymptotic freedom reigns. It becomes sensitive to the structure of the theory in the *infra-red* (IR) or, in other words, on non-perturbative physics. UV–driven Renormalization Group has limited command of the QCD coupling: two loops, and no free lunch beyond this point.

Why bother? — one may say; let us fix a definite perturbative renormalization scheme, and gauge (the $\overline{\mathrm{MS}}$ scheme being everyone's favorite), specify some renormalization scale μ and calculate, order by order in $\alpha_{\overline{\mathrm{MS}}}(\mu)$. This would mean a technically involved calculation in higher orders, but it is well formulated and straightforward a procedure. Such a formal solution, though perfectly legitimate, is likely to fail.[e]

Without putting special effort into the way the perturbative series is being *organized*, higher order corrections are likely to (bound to) turn out damagingly large. (Recall the recent NLO BFKL thriller [1].) The perturbative expansion only makes sense if the next correction is smaller than the previous one: NLO vs. LO, NNLO vs. NLO, etc. To have it this way, one has, however, to be smart and arrange the series in such a manner as to embody the *essential physics* into the *leading* term, as much as possible.

In particular, this implies a careful analysis of the *meaning* and of the precise argument of the α_s in the perturbative term(s) of the preceding order(s). This issue has never been addressed in the "NNLO vs. NLO" context. Moreover, such an optimization program was not systematically carried out in the "NLO vs. LO" problem either.

The only (limited) example I know of is given by a meticulous study of (the perturbative part of) the heavy quark fragmentation functions, where the *true* second loop contribution to the "anomalous dimension" was found to be uniformly small[f] and *negligible numerically.* To define the meaning of the word "true", however, one had to fish out various bits that *looked* as α_s^2 (NLO) but rightfully belonged to the LO physics: running of the coupling in the anomalous dimension and in the coefficient function, evolution kinematics effects confusing LO×LO with NLO, etc. (An interested reader may find the details buried in the appendices to [2].)

The most important element of such a sophisticated reshuffling is the *physical coupling* as it emerges from the two-loop analysis. This issue is worth displaying in more details, as it will lay a bridge to the next Moriond topic.

The "Hamiltonian" describing the evolution of the valence quark distributions at the two-loop level (NLO)[g] has the form

$$H^{(1+2)}(x) = \left[a_{\overline{\mathrm{MS}}} + \mathcal{K} a^2 \right] C_F P(x) \;+\; (a\, C_F)^2\, \mathcal{V}(x) \;+\; a^2 C_F\, \mathcal{R}(x) \tag{1}$$

where

$$a \equiv \frac{\alpha_s}{2\pi}, \qquad \text{and} \quad P(x) \equiv P_{qq} = \frac{1+x^2}{1-x} \tag{2}$$

is the well-known LO quark → quark splitting function. The combination in square brackets in (1) forms the *physical coupling* in terms of the formal $\overline{\mathrm{MS}}$ one,

$$a_{\mathrm{phys}} = a_{\overline{\mathrm{MS}}} + \mathcal{K} a^2 + \ldots\,, \qquad \mathcal{K} \,=\, \left(\frac{67}{18} - \frac{\pi^2}{6}\right) C_A - \frac{5}{9} n_f\,. \tag{3}$$

The famous coefficient $\mathcal{K}$ persistently appears in all the problems where soft gluon radiation matters, namely in quark and gluon Regge trajectories and double-logarithmic form factors which enter DIS SF at large x, Drell-Yan transverse momentum spectra, energy-energy correlations, various jet shape distributions, etc.

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[e] I would have said "is bound to", if I wanted to be nasty. Which I don't; see above.

[f] especially so, in the most important region of energetic (leading) quarks, $1-x \ll 1$, where soft gluon radiation dominates

[g] a scheme independent mixture of the anomalous dimension and the (derivative of the) coefficient function

The last two contributions to the NLO Hamiltonian are free from the n_f dependence (a postcard to BLM[3]). The second term in (1), though $\mathcal{O}\left(a^2\right)$, derives from the previous order as a specific convolution of the LO splitting functions P:

$$\mathcal{V}(x) \;=\; \int_0^1 dz \int_0^1 dy\, \delta(x-yz)\, \left\{P(y)\right\}_+ \, P(z) \ln z\,, \tag{2.4a}$$

$$\mathcal{V}_j \;\equiv\; \int_0^1 dx\, x^{j-1}\, \mathcal{V}(x) = P_j\, \frac{d}{dj} P_j\,, \qquad P_j \equiv \int_0^1 dx\, \left[x^{j-1}-1\right] \frac{1+x^2}{1-x}\,. \tag{2.4b}$$

It is this (purely Abelian) contribution that is responsible for the difference between the time-like and space-like anomalous dimensions (violation of the Gribov–Lipatov reciprocity[4] beyond the LO): it changes (acquires an opposite sign) when one compares time- and space-like evolution.[5]

The "true NLO" piece $\mathcal{R}$ in (1) turns out to be numerically small. Moreover, it *vanishes* $\propto (1-x)$ in the soft gluon limit, i.e. is down by $(1-x)^2$ as compared with the singular leading term $P(x) \propto (1-x)^{-1}$. *Two* powers of the soft gluon energy is a typical gap between the "classical" $(d\omega/\omega)$ and "quantum" $(\omega d\omega)$ gluon radiation. The former, according to the celebrated Low-Burnett-Kroll theorem[6], is simple as it is universal. Its simplicity rightfully puts it into the LO term in (1), supplied with the tuned physical coupling; its universality explains the universality of the latter (universal $\mathcal{K}$ renormalization constant). The soft gluon universality can be easily illustrated by the structure of the gluon radiation off a scalar (squark?), spin $\frac{1}{2}$ (quark) and vector partons (gluon):

$$\begin{aligned}
P_{ss}(x) &= \frac{2x}{1-x} &&= \frac{2x}{1-x} + (1-x)\times 0\,,\\
P_{qq}(x) &= \frac{1+x^2}{1-x} &&= \frac{2x}{1-x} + (1-x)\times 1\,,\\
P_{gg}(x) &= \frac{1+x^4+(1-x)^4}{x(1-x)} &&= \frac{2x}{1-x} + (1-x)\times 2\,\frac{1+x^2}{x}\,.
\end{aligned}$$

These are the LO splitting functions. But LBK is a powerful wisdom. It tells us that in higher orders in α_s (in *all* orders in perturbation theory, not just in the NLO, *sic*!) nothing can happen to the common first piece $2[(1-x)^{-1}-1]$ but building up the universal constant in front of it — the physical coupling. At the same time, non-trivial genuine higher order corrections are bound to be $\propto (1-x)$ and numerically small (hard "quantum" gluons have non-enhanced matrix elements and smallish phase space).

The "physical coupling" defined as the soft gluon radiation strength was first introduced by Catani, Marchesini and Webber in the context of the Herwig MC[7] and it is often referred to these days as the "bremsstrahlung scheme".

It is curious to notice that beyond the first loop the soft ("classical") and the hard ("quantum") parts of the splitting function in the anomalous dimension actually acquire different physical interaction strength:[8]

$$H^{(1)} = a\cdot\frac{1+x^2}{1-x} \implies H^{(1+2)} = a\cdot\frac{2x}{1-x} + \left[a-a'\right]\cdot(1-x)\,; \quad a'(k^2) \equiv \frac{d}{d\ln k^2}\, a(k^2).$$

This observation resulted from the dispersive analysis of α_s, because this is the way the running coupling emerges in the evolution of inclusive observables in the Minkowskian world, as was shown by Gribov & Lipatov three decades ago.[4]

The dispersive approach to defining and analyzing the coupling has recently penetrated the non-perturbative domain, with an ambitious intention to introduce, in a meaningful way, an effective QCD interaction strength down into the infra-red momentum region (see the review[9] for details).

> ☞ “We know this problem has no solution”— he frowned,
> “we just want to know how to solve it!”
> A. & B. Strugatsky, “Monday begins on Saturday”

In his talk Dimitry Shirkov described a specific scheme for introducing an infra-red finite QCD coupling that is free from the unphysical Landau pole and respects the perturbative renormgroup at the NLO level. To force the coupling to respect causality by eliminating the “Landau ghost” is not a bad idea, in spite of the fact that the couplings like this “obscure the relation to the operator product expansion” [10].

An *analytic perturbation theory*, of which an analytic (causal) coupling is an intrinsic element, is doing a good job for the quantities that are “translatable” from the Euclidean to Minkowskian worlds, such as the Adler D-function related, e.g., with hadronic τ-lepton decays [11]. However, a significant portion of α_s measurements which D.V. Shirkov suggested us to reconsider, belongs to intrinsically Minkowskian *jet shape* variables which have no Euclidean image. Dealing with such observables a certain care should be exercised prior to deciding to simply use a formal analytic continuation of the coupling $\alpha_s(-k^2)$ from negative to positive values of k^2 each time the properties of the final state (time-like) jets are being addressed.

2.2 B–puzzle: who keeps the ball?

A steady progress in the pQCD domain would leave us with too rosy and boring a picture if not for problems. Here is one: according to Zack Sullivan and Terry Sloan B-quarks misbehave both at Tevatron and HERA. I would not mind B-excess (reportedly, factor 2–3 above “the NLO QCD prediction”) leading to discovery of light SUSY particles. I am afraid, however, the ball is on the QCD side, so that this trouble is not going to be resolved in Stockholm. Before betting our shoes on SUSY we’d rather have a deep long look into what was called “the NLO QCD prediction” two sentences ago.

I wish I knew the answer (I would have been writing a paper, not proceedings, if I did). For the time being let me give you a hint or two at where the solution of the puzzle might be hidden. The first thing to put under scrutiny should be the scale of α_s used to describe the $B\bar{B}$ production. As far as I can tell, it is usually taken to be a mixture of the transverse momentum in the 2→2 parton subprocess and of the quark mass scale, say, $k_\perp^2 + M_Q^2$.

The problem is really touchy, with the answer depending on the precise observable, $B\bar{B}$ production channel, and even on experimental setup (cuts). Without much ado, suffice it to take into consideration that the popular belief that heavy quarks couple to gluons *weaker* than massless ones is a long-standing mistake. Don’t rush to protest. Just think over the following statement:

> *a potential dependence of the QCD interaction strength α_s on the quark mass would have destroyed gauge invariance (would contradict the Ward identities).*

3 *The* **Problem**

As has been already mentioned in the introduction, we are fighting to understand and build up QCD as a quantum field theory to understand strong interaction dynamics. The main problem in this quest remains to be the gap between the microscopic quark-gluon QCD Lagrangian and the hadronic physical spectrum of the World and, one keeps hoping, of the Theory. *Confinement* is the word. As any word, it is being overused, misused and abused.

In a comprehensive and honest review of the status and open problems of the lattice QCD we have heard Adriano do Giacomo stating that “*the only tool to understand confinement is lattice*”. I tend to unconditionally agree with each word of the statement but one: *confinement*. The problem is, there are many various confinements around. One can study confinement in “pure gluodynamics”, in QCD or in any other sister non-Abelian QFT; a different picture of physical spectrum will be in a QFT with heavy quarks. Yet another confinement one expects to operate in the real world that we happen to live in, the one which is plagued (from the lattice point of view) or rather blessed by existence of *very light* quarks. Such quarks, whose Compton wavelength is much larger than the distance scale where the basic interaction grows sufficiently strong, are capable of screening the catastrophic increase of the coupling and prevent the gluon fields in the vacuum from becoming really large.

This is the essence of the Gribov light-quark confinement scenario, and the theory.[12]

3.1 Quantifying NP phenomena in hard processes

We have been *testing* QCD for so many years trying, as much as possible, to stay clear of *confinement*, *hadronization*, *non-perturbative* effects. Time has come to start *understanding* them. To minimize our ignorance about confinement physics, a family of large-distance-insensitive observables (the so-called Collinear- and Infrared-safe observables[13]) was invented and stayed under the main focus of the studies of production of hadrons in hard processes. In recent years a theoretical framework has been developed which aims at *quantifying* genuine confinement effects in CIS observables. In particular, the pQCD-calculable jet shape characteristics were expected, and had been found, to exhibit large $1/Q$ suppressed NP corrections (see[14,15] for review). Recent findings, both theoretical and experimental, in this hot field were presented by Sofian Tafat, Stephan Kluth, Roman Pöschl and Gavin Nesom. They convinced us that the studies of different jet shape variables consistently point at the characteristic value of the QCD interaction strength in the infrared domain

$$\frac{\alpha_0}{\pi} \equiv \frac{1}{2\mathrm{GeV}} \int_0^{2\mathrm{GeV}} dk\, \frac{\alpha_s(k^2)}{\pi} \equiv \left\langle \frac{\alpha_s}{\pi} \right\rangle_{\mathrm{IR}} \simeq\; 0.15 \div 0.18\,.$$

3.2 Probing hadron structure

Importance of the understanding of the details of hadron structure from within the QCD was demonstrated in a comprehensive review of “strong” (QCD) effects in electro-weak phenomena given by Patricia Ball. A broad variety of “structural” issues was covered by Alexander Bakulev ($\gamma^*\gamma \to \pi^0$), Andrei Belitsky and John Hart (generalized = non-forward = off-diagonal parton distributions; DVCS = deeply virtual Compton scattering), by James Ely and Anton Jgoun.

The constructive discussion of the puzzle brought up by A. Jgoun — an asymmetry between transverse momenta of pions seen by HERMES, $\langle p_t \rangle_{\pi^+} > \langle p_t \rangle_{\pi^-}$ — constituted a perfect example of the Moriond meeting setup: the power of the on-line experiment–theory interface.

3.3 Non-linear dynamics

Perturbative QCD essentially deals with *linear* phenomena, if you take my meaning. The very classical picture of partons as small-scale constituents of hadron matter implies small (parton) densities, rare (hard) interactions and, therefore, a “linear evolution”. The situation changes (or, to be cautious, is expected to change) when the parton densities become large, in the small-x limit and/or in scattering on nuclei. Initially small hard cross sections (large Q^2) grow with energy ($s = Q^2/x$, $x \to 0$), and non-linearity comes onto the stage. It has to, for one thing. The *unitarity* condition which any dynamics should respect is non-linear in nature, as it relates the (imaginary part of the) scattering amplitude with the squared amplitude: $T - T^\dagger = i\,|T|^2$. Thus, from the unitarity angle, the first essential manifestation of non-linearity is an appearance of elastic (diffractive) processes as a *shadow* of inelastic interactions. The problematics of Diffraction ⇔ Unitarity was scrutinized in the talks by Vincenzo Monaco and Carlos Salgado.

3.4 Hard–Soft transition

As far as inclusive deep inelastic phenomena are concerned, however, the linear dynamics seems to work better than expected. According to Max Klein, “DGLAP works OK for $Q^2 > 1$GeV and $x > 5 \cdot 10^{-5}$, with charm production and σ_L going along.”

This is actually very confusing an observation. How about “higher twists” whose contribution has no reason to be small at such a small momentum transfer, where is “saturation”? It seems that the transition from the coherent scattering of a quasi-real photon on a nucleon to the naïve pQCD deep inelastic scattering regime is sharp and occurs rather early, at $Q^2 \sim m_\rho^2$.

3.5 In-medium probes

Here we deal with hadro-dynamics of complex systems. The hope is that a more complex environment can help to reveal more simple a physics, as it had happened once with (a complex) deep inelastic versus (a simple) elastic lepton-hadron scattering phenomena.

A broad spectrum of problems was addressed in this field by Dominique Schiff and François Gelis (basics of thermalization and photons from a plasma), by Sonya Kabana (physics of the medium frustrated by abundance of baryons), Krzysztof Redlich (strangeness issues) and John/Ian Rafelski (production of resonances as a specific probe of the dynamical properties of the medium).

Dolores Sousa and Alexei Kaidalov demonstrated the power of the “conventional” high energy hadron interaction wisdom in treating in-medium issues.

Looking retrospectively (and perspectively) into the recent history (future) of particle physics, we may say that the God has invented quantum mechanics on purpose, arguably as a partial redemption for the harsh treatment of the First experimenter. [16] Indeed, if not for quantum mechanics, particle detectors would have been buried under an avalanche of soft (small momentum) hadrons in high energy experiments. He is patient, and keeps sending the same message, repeatedly, to each generation of physicists:

back 30 years: Logarithmic hadron multiplicities $n \sim \ln s$ (“Feynman plateau”) in place of $n \sim s^\gamma$ envisaged by classical hydrodynamical pictures of hadroproduction. Source: coherent collapse of virtual multi-particle fluctuations of “untouched” partons in the Fock wave function of the projectile (quantum mechanics);

back 15 year: Finite number of slow hadrons in the final state of e^+e^- annihilation, whatever huge the annihilation energy. Source: QCD coherence (quantum mechanics);

last year: RHIC. A spectacular overestimate of hadron densities by “billiard-ball” cascade models. Source: Gribov-Glauber screening effects (quantum mechanics);

-5 years back: LHC: Central hadron density of 2000 instead of 8000 per unit rapidity,
$\ln$ [superfluous detector cost] $\simeq 18$. Source: Kaidalov’s talk (guess what).

4 So, where is QGP?

> ☞ It is all around you: in the tree, in the rock,...
> Feel the force flowing through you [elliptically]
> *Yoda, The Jedi Master*

Quark-Gluon Plasma is written on the banner. This state of matter is supposed to manifest itself in collisions of large enough ions at high enough energies. From this points of view, I see “bad news” for QGP advocates:

! The same “thermo” Hagedorn *abundances* are there in e^+e^- annihilation. This very fact speaks (actually, *cries*) against the interpretation of the exponential m_T fit to the hadron yields in thermodynamical terms. We don’t understand much about hadrons, nor about QCD. Let’s face it. At least one thing we know for sure, however: particles streaming from e^+e^- annihilation *do not* form any thermodynamical system. The reason is obvious: flying apart from the initial $q\bar{q}$ production point they simply cannot communicate with each other, to interact, not mentioning *equilibration* into an ensemble with a definite temperature. If anyone has a “temperature” in the e^+e^- annihilation process at all, it is the vacuum itself which, for the reason beyond our apprehension, chooses to throw out different hadrons according to the Hagedorn-like distribution.

!! Lifting-off *strangeness suppression* is not specific for AA collisions and therefore cannot be employed as a true QGP signal: it is there in pA and even in pp.

!!! “Stopping” — another potential QGP trigger — is actually *better* pronounced in pA than in AA.

In certain sense we have seen QGP showing up many times, and long ago too. The standard classical picture of a nucleus consisting of a given number of well separated billiard-ball nucleons is correct and operational only *in average*. To be more precise, it is perfectly adequate for addressing static properties and *typical* interaction patterns that are not biased for one or another reason. However, as soon as we start looking into the details of particle production by squeezing the system under study into a corner, the pattern changes: the omnipresent fluctuations (field theory, you know!) take over. In particular, by selecting AB heavy ion collision events with very large accompanying E_T which exceeds the average value typical for a “billiard-ball” interaction of $A+B$ “participants”, we start to be sensitive to specific (rare) initial configurations of incident nuclei that might be characterized as consisting of (semi)melted nucleons. Thus, we can very well have QGP in the *initial state*, rather than resulting from the post-collision dynamics.

This picture is neither mysterious nor heretic: even the proton-proton scattering cross section which we are accustomed to characterizing by a mere number (of so-and-so many millibarns), is actually not a number but is subject to fluctuations. It is (supposed to be well) known and is well documented.[17] For example, the *dispersion* of the corresponding cross section *distribution* is measurable and related to the amount of inelastic diffraction on nuclei.[18]

Looking at rare events, we may say to have seen QGP, markedly, in the so-called “cumulative effect” measurements (ITEP–Dubna), where production of hadrons with $x > 1$ on a nucleus called for a group of (up to four) nucleons sitting “on top of each other”, melted together. By the way, in the ITEP experiments[19] the maximal strangeness enhancement (complete lift-off of the strangeness suppression, $K^+/\pi^+ \sim 0.8 - 1$) had been observed.[h]

Speaking of *strangeness*, one can see the K/π ratios increasing each time when we step away from a “typical” (soft, unbiased) hadroproduction environment: in J/ψ decays, in the fragmentation region (with increase of x_F) in pp (UA1), DIS (EMC) and e^+e^- interactions, in pA and pp (with increase of the number of projectile collisions; NA49), etc. Definitely, something to think about.

Conclusions

> ☞ “I can’t believe *that*!” — said Alice.
> “Can’t you?” — the Queen said in a pitying tone.
> “Try again: draw a long breath, and shut your eyes.”
> ALICE, *First physics results* (200N)

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[h] I am indebted to Alexei Kaidalov who brought this to my attention.

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