Conversations with Genya about Saturation*

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Abstract

Genya Levin has made seminal contributions to the theory of high energy scattering and the properties of very high energy density gluon matter. This paper contains anecdotes about Genya Levin's work in this area.

1 Early Work in St. Petersburg

Genya Levin's classic work was done with Leonya Gribov (the son of Volodya Gribov) and Misha Ryskin[1]. This is the classic paper "Semi-Hard Processes in QCD"[1]. I learned about this work during my first visit to Russia in 1984. I met both the teams of Gribov, Levin and Ryskin, and of Frankfurt and Strikman. Both were interested in the high energy limit of parton densities, and the high gluon density environment important for the high energy limit.

Genya had deeply thought through issues related to saturation. Fig. 1 of Ref. [1] is the first place where appears the now famous conception of parton saturation in the $ln(Q^2) - ln(1/x)$ plane. Genya was the co-inventor of this paradigm. I am told by Al Mueller that all

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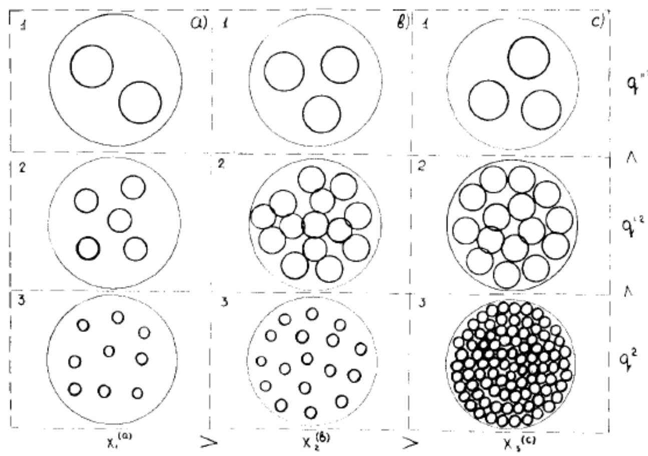

Figure 1: Genya's cartoon about saturation.

of the figures for this paper were hand drawn by Genya's daughter. Apparently they were drawn and redrawn many times prior to publication since there was little possibility for copying figures at that time in Russia, and it took a very long time for an article to be cleared for publication abroad.

Genya understood at that time that there was a saturation momentum characterizing the momentum scale at which the gluons become very densely packed in a hadron, and the implication of this for scattering: The saturation momentum cuts off infrared singularities in particle production cross sections. Correctly understanding saturation would allow for finite computations of particle production. Shown in Fig. 2 is Genya's conception of how saturation affects particle production.

Genya also understood the importance of fan diagrams in describing the interaction of an elementary probes with a saturated target, as shown in Fig. 3. This is of course fundamental to later developments for describing the saturated gluon density in terms of classical fields.

Leonya Gribov patiently explained all of this during my visit. I am afraid I was not ready to appreciate its importance. Only ten years later did I turn to this problem, after sitting through several lectures at the Crakow School of Physics in Zakopane, where I heard results presented from HERA on growing gluon distributions, as well as early

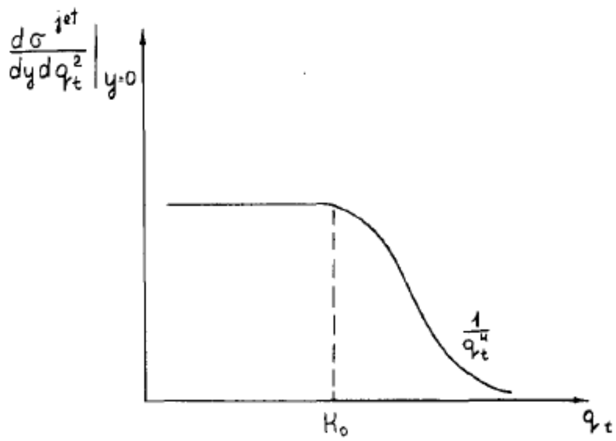

Fig. 1.13. Inclusive cross section of a large q_t jet production; the plateau at $q_t < k_0$ is due to parton–parton interactions.

Figure 2: Particle production and the saturation momentum.

results from the CERN Heavy Ion experiments concerning particle multiplicities. In some sense, my conversations with colleagues in St. Petersburg at that time were a lot like attempts to communicate between people speaking different languages from very different cultural background. Soviet science at that time had been very isolated from the west, and the problems emphasized and the methods used were described differently than in the US and Western Europe. I missed many opportunities provided me by Russian scientists because I could neither not communicate my ideas, nor adequately understand theirs. Perhaps I did not listen carefully enough, or perhaps I simply could not understand the significance of the ideas presented. This is illustrated in Fig. 4.

Of course, not everything Genya told me turned out to be important or true. At a scientific meeting a few years later, Genya pulled me aside and tried to convince me that parton saturation was the Quark Gluon Plasma. I should also mention that my colleague Al Mueller understood far better the significance of Genya's work. A few years after his first visit to Russia in 1983, Al and Jian Wei Qiu wrote their famous seminal contribution to the concept of parton saturation[2].

The contribution that Raju Venugopalan and I made to the theory

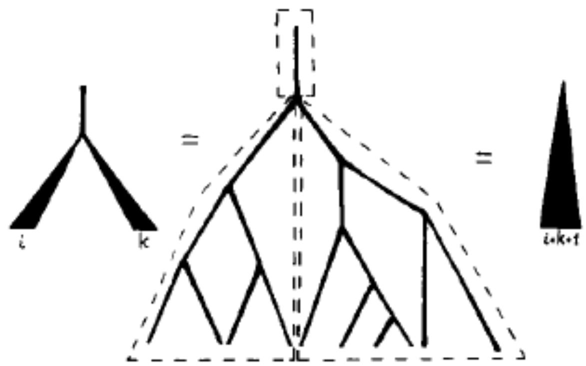

Fig. 2.9. A typical "fan" diagram.

Figure 3: The Fan diagrams as in Genya's paper.

of gluon saturation was to understand that the high gluon densities implied that one could treat the gluons as classical fields[3]-[4]. This led to the idea of the Color Glass Condensate as a form of matter made by these high energy density gluons. Much of our contribution was to make the ideas concerning the saturation of gluon densities intuitively plausible, and of course, to begin drawing figures in color. An example of a color rendition of the original figure of Genya and colleagues is shown in Fig. 5. After my paper with Raju Venugopalan, I began to listen carefully to what Genya had to say, and we became very good friends.

2 Genya's style

All of us who know Genya understand is not a gentle little mountain flower crushed by the tread of human feet. His arguments involve much waving of hands, and assertiveness as represented in the pictures below, Fig. 6. To have a real discussion with Genya is sometimes difficult. Genya like all of us, wants to win his arguments. On the other, unlike most of us, Genya works extraordinarily hard to do this, and is reasonably successful.

I used this joke stolen and paraphrased from Will Rogers at the birthday celebration of Eduard Shuryak, and will repeat it here:

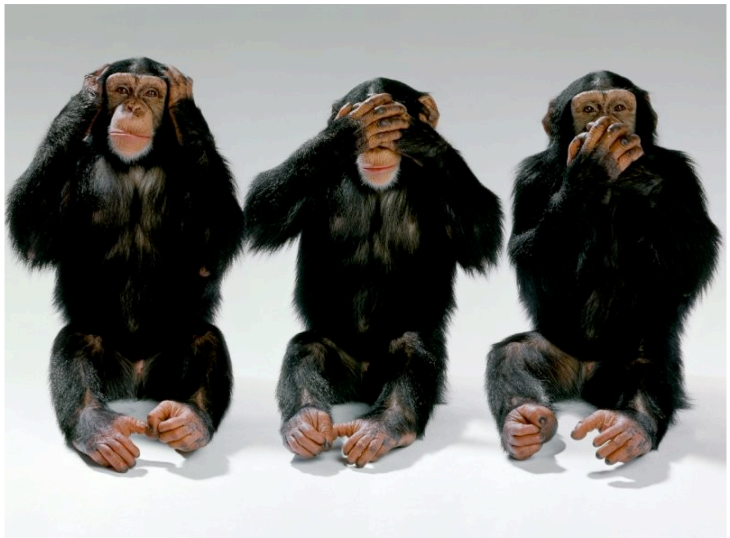

Figure 4: To paraphrase Paul Newman in the famous movie Cool Hand Luke: "What we had there was a failure to communicate."

There are two theories about winning an argument with Genya.
Both of them are wrong.

I actually have three theories:

1. Try to convince Genya that what you are saying is in one of Genya's papers.

   Unfortunately:

   Genya is not so stupid as to believe his own papers.

2. Begin your argument in the manner of Misha Voloshin by saying "As every elementary school student from Moscow knows.."

   Unfortunately:

   Genya never attended elementary school in Moscow.

3. Try to grab the chalk away from Genya when he is writing on the board. When he is trying to keep hold of the chalk, make your argument.

   Unfortunately:

   Grabbing the chalk works for only one argument. After that Genya is more careful how he holds the chalk.

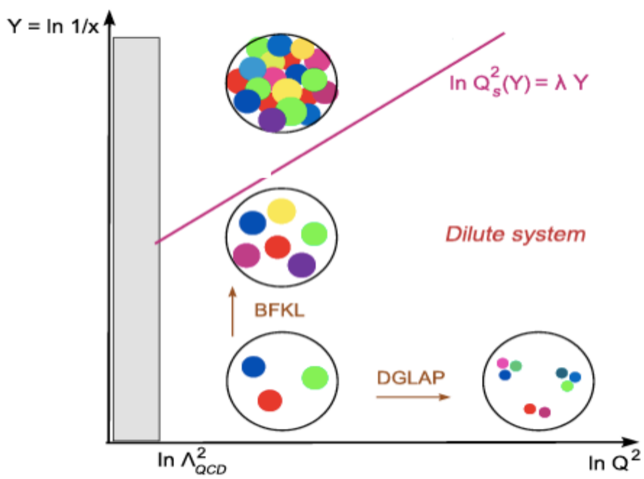

Figure 5: One of the early color figures that represent gluon saturation

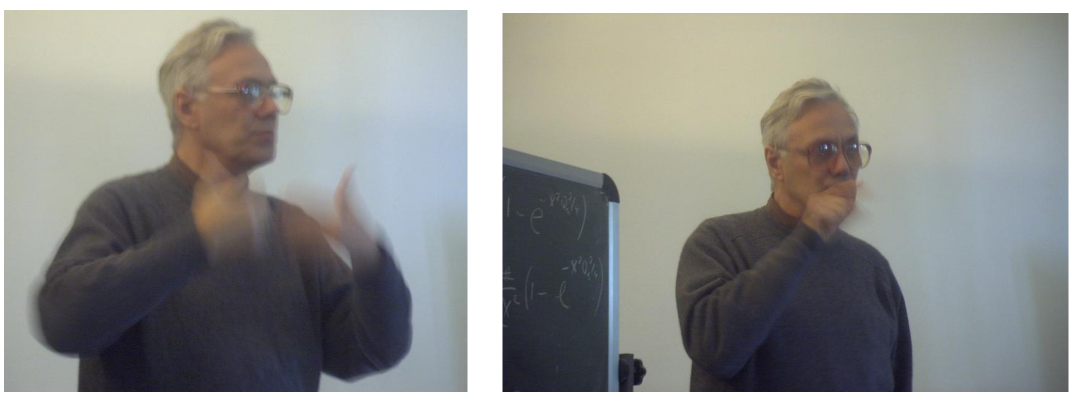

Figure 6: (a) Genya making a hand waving argument. (b) Genya asserting that such argument is true.

3 Genya's work on the HERA Data

In the 1990's, Genya was very active trying to explain the HERA data that showed an increase in the gluon density at small x[5]-[7]. I think all of us here agree that this work was on the correct track, and that ultimately gluon saturation and the Color Glass Condensate provide a good description of the HERA data for $x \leq 10^{-2}$, and that it is quite probably the correct description. As we also would agree, no consensus developed among the HERA experimental community that the ideas of saturation or the CGC were needed to explain the data.

It is a remarkable situation where a theory based on first principles from QCD simply describes all of the HERA data at small x, and yet these ideas are largely ignored by the experimenters in the field. Part of this no doubt stems from the frustration of the large majority of the HERA community that they were unable to discover new particles such as lepto-quarks. Part of the failure is also due to honest scientific skepticism based on a variety of different models to fit various aspects of the data, and the great success of the DGLAP analysis of the high Q^2 data for F_2. I visualize the situation in the figure below, modified from a satirical motivation calendar made by the company Despair Inc., Fig. 7. (My wife Alice buys me such calendars, and I strongly recommend them for a nice take on human behaviour.) No matter how it is visualized, those of us who have tried to generate interest in these ideas within the HERA community have not found an inspiring response.

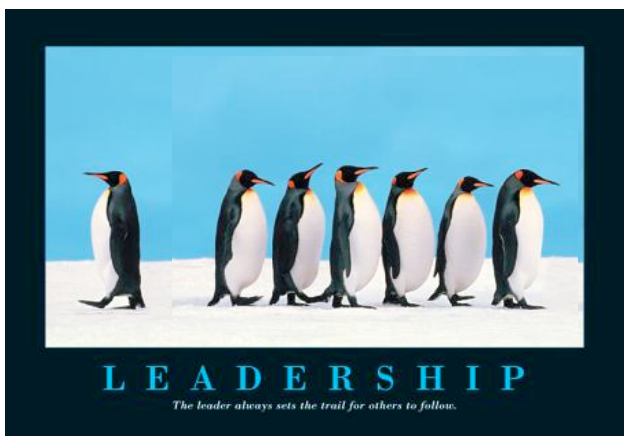

Figure 7: Genya to the left. HERA experimenters to the right.

4 Genya in the New Millenium and RHIC Physics

At the end of the Millenium, Genya turned to the problem of heavy ion collisions. The matter in nuclei that is at the same x as that of a proton, and is surely more dense than that in a proton. Nuclei may provide a tool to understand gluon saturation at lower energy than is possible in proton-proton collisions. This is because the gluon density roughly scales as

$$\frac{1}{\pi R^2}\frac{dN}{dy} \sim \frac{1}{\alpha_S} Q_{sat}^2 \sim ln(A)\ A^{1/3}/x^{\delta} \tag{1}$$

The parameter δ is known from the HERA data to be in the range of $\delta \sim 0.2 - 0.3$. Much excitement was generated by the paper of Kharzeev and Nardi, who argued that saturation explained the dependence on centrality of multiplicities of particle produced in heavy ion collisions[8]. Genya wrote a number of papers that showed how to estimate the rapidity depedence of produced particles and how to compute two particle correlations.[9]-[12]

Two particle correlation angular correlations in deuteron-gold collisions turns out to be a good signature of the Color Glass Condensate when looking in the small x region (forward rapidity for the deuteron) of the gold nucleus. In this region one would expect no diminishing of the backward going signal in ordinary perturbative QCD computations. At central rapidity, there is no decrease in the backward going correlation nor is there in peripheral d-Au collisions at small nuclear x. However, as the x of the nucleus decreases and the centrality of the collision increases there is a strong decrease in the backward peak. This is shown in Fig. 8. This is because the backward going particle shares its momentum with the gluons of the Color Glass Condensate. It is well described by computations incorporating the effects of saturation. [13]-[14]

5 The LHC Frontier

Recently proton-proton scattering data has been released from the LHC. Heavy ion data is not far away. In the closing few minutes of this talk I want to make some provocative and qualitative statements about the LHC pp data. I want to argue that the early data appears

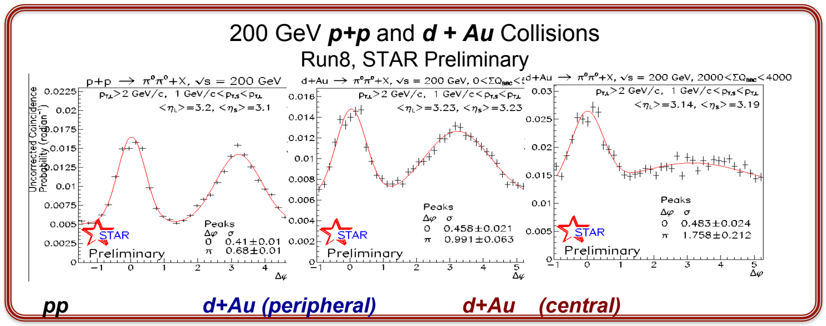

Figure 8: The forward backward angular correlation at forward rapidity for dA collisions.

to be consistent with the expectations for saturation.[15] The arguments I give are based on very simple considerations and surely will be improved by more detailed computation.

We expect that up to logarithmic corrections, the gluon multiplicity $dN/dy \sim Q_{sat}^2 \sim 1/x^\delta$ where $\delta \sim 0.2 - 0.3$ in the LHC range. The average $p_T \sim A + BQ_{sat}$ where A is constant different for pp and $p\overline{p}$ collisions. We also expect that in the transverse momentum distributions there is an approximate geometrical scaling.

$$\frac{dN}{dyd^2p_T} = F\left(\frac{p_T}{Q_{sat}(p_T/\sqrt{s})}\right) \tag{2}$$

In Fig. 9 we see that the central rapidity density and transverse momenta are both well fit by such forms for $\delta \sim .23 - .27$. The accuracy of the geometrical scaling fit is truly remarkable, as shown in Fig. 10

6 No One is Too Old to Learn Something New

I want to finish with one last Genya story: Several years ago Genya, I and Yuri Kovchegov were attending a seminar at Brookhaven Laboratory. Genya did not like what the speaker was saying and asked a question. The speaker did not really answer Genya's question, and answered by a clever and funny joke. Genya politely waited for a few minutes before asking essentially the same question again. The

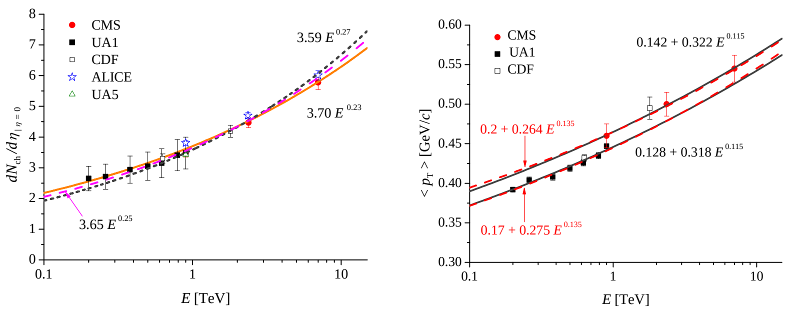

Figure 9: Multiplicity and p_T fit by CGC considerations.

speaker responded with an even funnier joke, and Genya was becoming angry. The implication of the joke was of course that Genya was a fool to have asked the question. Genya was not happy. About 15 minutes later Genya tried again, with the same result, and then for the first time in my life, I saw Genya be quiet for the 1/2 hour remaining in the seminar. After the talk was over and the speaker had left the room, Genya came over to me and was very angry. "He never answered my questions. He only told clever jokes. His work is all garbage." Genya said. Yuri Kovchegov then came up and looked at Genya innocently, in a way that only Yri can, and said "Genya, remember there is an old Russian saying: You don't shake your fist after the fight is over."

I hope Genya keeps shaking his fist.

7 Acknowledgements

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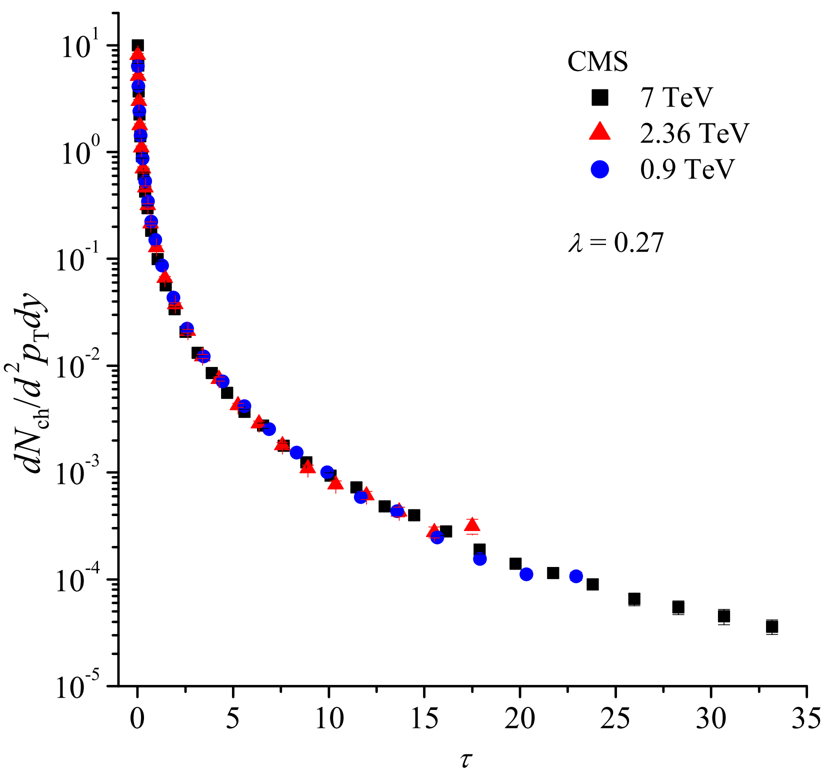

Figure 10: Geometrical scaling of the transverse momentum distribution for the data of CMS.[16] -[18]

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