

FOREWORD

My career in theoretical high energy physics began 25 years ago. I was lucky — its beginning coincided with a very exciting time in this field, when a major breakthrough in our understanding of nature took place. The Standard Model of fundamental interactions was born, and Quantum Chromodynamics (QCD) gradually emerged as *the* theory of hadronic matter. Unlike many other theories created later whose relevance to nature is still a big question mark, these two will definitely stay with us forever. And, fortunately, I happened to be in the right place at the right time so that I could appreciate these discoveries early. The infancy of any true theory creates great opportunities for young researchers who suddenly find themselves pioneers in *terra incognita*, with so many interesting, important and challenging problems around.

For about twenty years, I was a member of the ITEP theory group.¹ During those years I gave many lectures at different schools of physics. Some of these are presented below. As a matter of fact, a few of these lectures are recent, given after I left ITEP. Still, I consider them ITEP lectures since I acquired many of the ideas found in them from my formal and informal teachers at ITEP. I am especially grateful to B. Ioffe, A. Vainshtein and V. Zakharov.

Since the ITEP theory group of the seventies and the eighties was quite an endemic phenomenon, it seems worthwhile to introduce it to the reader before I proceed to the scientific issues.

Glimpses of ITEP

ITEP was more than an institute. It was our refuge where the insanity of the surrounding reality was, if not eliminated, reduced to a bearable level. Doing physics there was something which gave a meaning to our lives, making it interesting and even happy. Our theory group was like a large family. As in any big family, of course, this did not mean that everybody loved everybody else, but we knew that we had to stay together and to rely on each other, no matter what, in order to survive and to be able to continue doing physics. This was considered by our teachers to be the most important thing, and this message was always being conveyed, in more than one way, to young people joining the group. We had a wonderful feeling of stability in our small brotherhood. A feeling so rare in the western laboratories where a whirlpool of postdocs,

¹For those who do not know: ITEP is an abbreviation for Institute of Theoretical and Experimental Physics, in Moscow.

visitors, sabbatical years come and go, there are a lot of new faces, and a lot of people whom you do not care so much about.

The rules of survival were quite strict. First, seminars --- what is now known worldwide as the famous Russian-style seminars. The primary goal of the speaker was to *explain* to the audience his or her results, not merely to advertise them. And if the results were nontrivial, or questionable, or just unclear points would surface in the course of the seminar, the standard two hours were not enough to wind up. Then the seminar could last for three or even four hours, until either everything was clear or complete exhaustion, whichever came first. I remember one seminar in Leningrad in 1979, when Gribov was still there, which started at eleven in the morning. A lunch break was announced from two to three, and then it continued from three till seven in the evening.

In IATEP we had three, sometimes more, theoretical seminars a week. The most important were a formal seminar on Mondays, and an informal coffee seminar which at first took place every Friday at 5 o'clock, when the official work day was over, but later was shifted to Thursdays, at the same time. Usually, these were by far the most exciting events of the week. The leaders and the secretaries of the seminars were supposed to find exciting topics, either by recruiting IATEP or other "domestic" authors, or, quite often, by picking up a paper or a preprint from the outside world and asking somebody to learn and report the work to the general audience. This duty was considered to be a moral obligation. The tradition dated back to the time when Pomeranchuk was the head of the theory group, and its isolation had been even more severe than during my time. As a matter of fact, in those days there were no preprints, and getting fresh issues of *Physical Review* or *Nuclear Physics* was not taken for granted at all. When I, as a student, joined the group --- this was a few years after Pomeranchuk's death --- I was taken, with pride, to the Pomeranchuk memorial library, his former office where a collection of his books and journals was kept. Every paper, in every issue, was marked by Chuk's hand (that's how his students and colleagues would refer to him), either with a minus or a plus sign. If there was a plus, there would also be the name of one of his students who had been asked to "dig into" the paper and give a talk for everyone's benefit. This was not the end of the story, however. Before the scheduled day of the seminar, Pomeranchuk would summon the speaker-to-be to his office to give a pre-talk to him alone, so that he could judge whether the subject had been worked out with sufficient depth and that the speaker was "ripe enough" to face the general audience and their bloodthirsty questions. In my

time, the secretaries of the seminars were less inclined to sacrifice themselves to that extent, but, still, it was not uncommon that pre-talks were arranged for unknown, young or inexperienced speakers.

Scientific reports of the few chosen to travel abroad for a conference or just to collaborate for a while with western physicists, were an unquestionable element of the seminar routine. The attendance of an international conference by A or B by no means was considered as a personal matter of A and B alone. Rather, these rare lucky guys were believed to be our ambassadors, and were supposed to represent the whole group. In practical terms, this meant that once you had made your way to a conference, you could be asked to present important results of other members of the group. Moreover, you were supposed to attend as many talks as physically possible, including those which did not exactly belong to your field, make extensive notes and then, after returning home, deliver an exhaustive report of all new developments discussed, all interesting questions raised, rumors, etc.

The scientific rumors, as well as nonscientific impressions, were like an exotic dessert, usually served after nine. I remember that, after his first visit to the Netherlands, Simonov mentioned that he was very surprised to see a lot of people on the streets just smiling. He said he could not understand why they looked so relaxed. Then he added that he finally figured out why: "... because they were not concerned with building communism..." This remark almost immediately became known to "Big Brother" who was obviously watching us this evening, as usual, and it cost Simonov a few years of sudden "unexplainable allergy" to any western exposure. His "health condition", of course, would not allow him to accept any invitation to travel there. I cannot help mentioning another curious episode with Big Brother. Coffee, which we used to have during the coffee seminars, was prepared in turn, by all members of the group. Once, when it was Ioffe's turn, he brought a small bottle of cognac and added a droplet or two in every cup. I do not remember why, perhaps, it was his birthday or something like that. That was Friday evening. Very early on the next Monday morning, he was summoned to the corresponding ITEP branch office to give explanations concerning his "obviously subversive activities"!

The coffee seminars typically lasted until nine, sometimes much later, for instance, in the stormy days of the November revolution in 1974. The few months following the discovery of J/ψ were the star days of QCD and, probably, the highest emotional peak of the ITEP theory group. Never were the mysteries of physics taken so close to our hearts as then. There was a spontaneously arranged team of enthusiasts working practically nonstop. A limit

to our discussions was set only by the schedule of the Moscow metro — those who needed to catch the last train had to be leaving before 1 a.m.

The ITEP seminars were certainly one of the key elements in shaping the principles and ideals of our small community, but not the only one. The process of selecting students who could eventually grow up into particle theorists played a crucial role and was, probably, as elaborate as the process of becoming a knight of the British crown. Every year we had about 20 new students, at the level roughly corresponding to that of graduate students in American universities. They came mostly from the Moscow Institute for Physics and Technology, a small elite institution near the city, a counterpart of MIT in the States. Some students were from the Moscow Engineering and Physics Institute, and a few from the Moscow State University. They were offered (actually, obliged to take) such a spectrum of courses in special disciplines which I have never heard of anywhere else in the world: everything from radiophysics and accelerator physics; several levels of topics in quantum mechanics, including intricacies of theory of scattering; radiation theory and nuclear physics; mathematical physics (consisting of several separate parts); not less than three courses in particle phenomenology (weak, electromagnetic and strong interactions); quantum electrodynamics, numerous problem-solving sessions, etc. And yet, only those who successfully passed additional examinations, covering the famous course of theoretical physics by Landau and Lifshitz, were allowed, after showing broad erudition and ingenuity in solving all sorts of tricky problems, to join the theory group. Others were supposed to end up as experimentalists or engineers. Needless to say, the process of passing these examinations could take months, even years, and was notoriously exhausting, but there was never a lack of volunteers trying their luck. They were always seen around Ter-Martirosian and Okun who were sort of responsible for the program. It should be added that the set of values to be passed from the elders to the young generations included the idea that high energy physics is an experimental science that *must* be very closely related to phenomena taking place in nature. Only those theoretical ideas which, at the end of the day, could produce a number which could be confronted with phenomenology were cherished. Too abstract and speculative constructions, and theoretical phantoms, were not encouraged, to put it mildly. The atmosphere was strongly polarized against what is now sometimes called “theoretical theory”. Even extremely bright students, who were too mathematically oriented, like, say, Vadim Knizhnik, were having problems in passing these examinations. Vadim, by the way, never made it to the end, got upset and left ITEP. Well, nothing

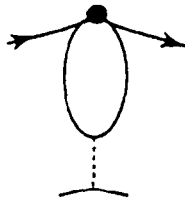
is perfect in this world, and I do not want to make an impression that the examination routine in the ITEP theory group was without flaws.

The ITEP theory group was large — about 50 theorists — and diverse. Moreover, it was a natural center of attraction for the whole Moscow particle physics community. Living in the capital of the last world empire had its advantages. There is no question, it was the evil empire, but what was good, as it usually happens with any empire, all intellectual forces tended to cluster in the capital. So, we had a very dynamic group where virtually every direction was represented by at least several theorists, experts in the given field. If you needed to learn something new, there was an easy way to do it, much faster and more efficient than through reading journals or textbooks. You just needed to talk to the right person. Educating others, sharing your knowledge and expertise with everybody who might be interested, was another rule of survival in our isolated community. In such an environment, different discussion groups and large collaborations were naturally emerging all the time, creating a strong and positive coherent effect. The brain-storming sessions used to produce, among other results, a lot of noise, so once you were inside the old mansion occupied by the theorists, it was very easy to figure out which task force was where — just step out in the corridor and listen. And, certainly, all these sessions were open to everybody.

Now I would like to mention one more aspect which concerns me at present, a very strong pressure existing in our community, to stay in the “mainstream”, to work only on fashionable directions and problems which, currently, are under investigation in dozens of other laboratories. This pressure is especially damaging for young people who have little alternative. Of course, a certain amount of cohesion is needed, but the scale of the phenomenon we are witnessing now is unhealthy, beyond any doubt. The isolation of the ITEP theory group had a positive side effect. Everybody, including the youngest members, could afford to work on problems not belonging to the fashion of the day, without publishing a single line for a year or two. Who cared about what we were doing there anyway? This was okay. On the other hand, it was considered indecent to publish results of dubious novelty, incomplete results (of the status report type) or just papers with too many words per given number of formulae. Producing dense papers was a norm. This style, which was probably perceived by the outside readers as a chain of riddles, is partly explained by tradition, presumably dating back to the Landau times. It was also due to specific Soviet conditions, where everything was regulated, including the maximal number of pages any given paper could have. Compressing derivations and arguments

to the level considered acceptable, was an art which had its grandmasters. Arkady Vainshtein was especially good at inventing all sorts of tricks which allowed him to squeeze in extra formulae with very few explanatory remarks. I remember that in 1976, when we were working on the large JETP paper on penguins in weak decays,² we had to make 30 pages out of the original 60-page preprint version, and he managed to do that without losing any equations and even inserting a few extra ones! This left a strong impression on me.

By the way, about penguins. From time to time students ask how this word could possibly penetrate high energy physics. This is a funny story indeed. The first paper where the graphs that are now called penguins were considered in the weak decays appeared³ in JETP Letters in 1975, and there they did not look like penguins at all. Later on they were made to look like penguins:



and called penguins by John Ellis. Here is his story as he recollects it himself.

“Mary K. [Gaillard], Dimitri [Nanopoulos] and I first got interested in what are now called penguin diagrams while we were studying CP violation in the Standard Model in 1976... The penguin name came in 1977, as follows.

In the spring of 1977, Mike Chanowitz, Mary K and I wrote a paper on GUTs predicting the b quark mass before it was found. When it was found a few weeks later, Mary K, Dimitri, Serge Rudaz and I immediately started working on its phenomenology. That summer, there was a student at CERN, Melissa Franklin who is now an experimentalist at Harvard. One evening, she, I and Serge went to a pub, and she and I started a game of darts. We made a bet that if I lost I had to put the word penguin into my next paper. She

²By “we” I mean Zakharov, Vainshtein and myself. Arkady Vainshtein had a permanent position at the Budker Institute of Nuclear Physics in Novosibirsk. He commuted between Moscow and Novosibirsk for many years, and was considered, essentially, as a member of the ITEP theory group.

³A. Vainshtein, V. Zakharov and M. Shifman, *Pis'ma ZhETF* **22** (1975) 123 [*JETP Lett.* **22** (1975) 55].

actually left the darts game before the end, and was replaced by Serge, who beat me. Nevertheless, I felt obligated to carry out the conditions of the bet.

For some time, it was not clear to me how to get the word into this *b* quark paper that we were writing at the time. Then, one evening, after working at CERN, I stopped on my way back to my apartment to visit some friends living in Meyrin where I smoked some illegal substance. Later, when I got back to my apartment and continued working on our paper, I had a sudden flash that the famous diagrams look like penguins. So we put the name into our paper, and the rest, as they say, is history.”

About These Lectures

Below the reader will find lectures devoted to different topics in theoretical high energy physics which occupied me during the last 15 years. The choice of topics might seem somewhat chaotic, at first sight. The selection criteria were simple: I tried to select only those topics which are of interest today. Besides, I was limited by the fact that not all the lecture notes are available; some have never been published and have disappeared with time.

These are *lectures*, not reviews; they were intended for beginners — mostly graduate students — who were just about to submerge into the subject and needed some initial impetus and general idea and guidance. Therefore, the pedagogical element was most important. I made no attempt at complete coverage, the lists of references are usually quite fragmentary and so on. These lectures can be used for the initial exposure. Those who would like to master the corresponding topics in full, will need to proceed to more detailed reviews and the original literature. At the end of each lecture I recommend a few sources for further studies.

The lectures written in the eighties were revised and updated specifically for this volume. I significantly expanded them. At the same time, I had to resist the temptation to completely rewrite them. This process would take too much time, and this volume would never appear had I not settled on a compromise.

October 29, 1995