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CONCLUSIONS AND PERSPECTIVES

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Abstract

The Sixth *Rencontres de Blois* featured many approaches to the question, "What is a proton?" I remark particularly on the proton's structure as expressed through parton distributions and on the top quark's influence upon the proton mass.

Closing remarks at the Sixth *Rencontres de Blois, «Au Cœur de la Matière»*, June 20–25, 1994.

1 Local Color

One of the guiding principles of our friend Trân Thanh Vân, the *animateur* of the *Rencontres de Blois,* is that scientific discussions at the highest level should be mixed with culture in an atmosphere that makes us aware of our heritage in the broadest sense. This splendid chateau, the art and history of this region, and the exuberant *Fête de la Musique* have all enriched our experience in Blois. Imagine my delight when I discovered in the traveler's cultural reference, the *Guide Michelin,*[1] that two of the most celebrated historical figures *d'origine Blésoise* had connections with physics!

Perhaps you have noticed under construction at the far end of the esplanade a new National Center of Magic and Illusions. Although you might imagine that it is being built as a permanent home for the *Rencontres de Blois*, it is intended as a monument to the life and work of Jean-Eugène Robert-Houdin (1805–1871), the most famous magician in all of France and the father of modern conjuring. Robert-Houdin, whose name was taken by Houdini, was the first magician to appear in formal wear, and the first to use electricity in his act. Part of his legacy is a posthumous work[2] devoted to magic and "amusing physics." I hope that, once the new center is complete, demonstrations of amusing physics in the style of Robert-Houdin will become a regular feature of the cultural program of future *Rencontres.*[3]

The second famous son of the city of Blois is Denis Papin (1647–1714), the master of steam power who worked in London with Robert Boyle. There, in 1679, he invented the pressure cooker, or *marmite de Papin*,[4] a kind of pot in which you can cook arbitrarily tough meat and render it soft. The consequences for English cuisine are well known. The sad truth is that British cooking was actually improved by this invention![5]

2 Hommage à Louis XII

The most famous *Blésois* of them all, Louis XII, has not—until today—had a connection with physics. In the spirit of the *Rencontres de Blois*, I will repair that historical omission.

This meeting has been devoted to the strong interactions. The ideas we have heard and the data we have seen make it plain that the strong interactions comprise a richer field than we can describe in terms of perturbative QCD. Interesting strong-interaction phenomena are not merely reactions involving a few jets. The rest of strong interactions, however, isn't confined to common processes with large cross sections like the whole of the total cross section, elastic scattering, or diffraction. It may well be that interesting, unusual occurrences happen outside the framework of perturbative QCD—happen in some collective way. Before coming to Blois, I was looking for an illustration of this sort of phenomenon—something unusual that might happen in the strong interactions—so I appealed to a colleague to watch the event display at CDF and pick out a few *atypical* events for me.

The most interesting of these is shown in Figure 1. Now, at the entrance to the Château de Blois, you can see the heraldic device of Louis XII, the porcupine or hedgehog launching its quills. I present this hedgehog to you as the Louis XII event. It comes from a $\sum E_T$ trigger in CDF, without any topological requirement.[6] The LEGO plot shows many bursts of energy: More than a hundred active towers pass the threshold of 0.5 GeV. The total transverse energy in the event is 321 GeV, but it is not concentrated in a few sprays, it is everywhere. The central tracking chamber records about sixty charged particles.

This event is authentic; it is not merely noise in the counters. My colleague tells me that Louis XII events are about as common on the online display as Z^0 production and decay into lepton pairs: about one in ten thousand triggers. I show this striking picture as a reminder that when we think about the strong interactions outside the realm of a single hard scattering, we should think not only about large cross sections, but also about rare phenomena.[7]

Figure 1: A *porc-à-pic* captured in the CDF detector at Fermilab.

3 Perturbative QCD

Over the past decade, there has been enormous progress in the application of perturbative QCD to a wide range of processes. Reactions involving many partons in the final state that could be calculated only with great difficulty as recently as ten years ago are now within theorists' power to calculate. I have in mind final states like $W+$ two jets, or three, or four. Essentially any process can now be calculated to leading order, thanks to a series of very interesting and creative technical developments that have made it possible to rearrange and simplify the calculations.[8, 9] There has also been considerable progress in going beyond leading order to calculate the first-order corrections and next-to-leading-order corrections for a subset of those processes.[10]

That is extraordinarily important for the comparison of the theory with experiment, and there has been a rich and fruitful interchange between the two. Some of these theoretical calculations began in anticipation of supercollider physics and the complicated processes that can occur at very high energies. They have been nourished by the data coming from the S$p\bar{p}$S collider, the Tevatron, LEP, and now HERA. There has been a renaissance of interest and accomplishment in perturbative QCD. Thanks to heroic efforts by many people, we can make quantitative comparisons of theory and experiment.

4 What Is a Proton?

If the strong interactions are the topic of this conference, then the question that frames the work we celebrate and the work we carry on is, "What is a proton?" Pursuit of that question has led us to a great many insights, including the development two decades ago of QCD. It has shown that insights into the structure and properties of the proton can come from unexpected quarters.

4.1 Asymptotic Properties of the Proton

When we talk about hadron structure, it is important to distinguish several different regimes. The asymptotic properties of hadrons can be calculated without knowing very much at all about hadron structure. They are consequences simply of perturbative QCD applied to the notion that the hadron viewed at large Q^2 can be considered a collection of basically independent partons.

For example, as long as we know the complete spectrum of colored particles, it is easy to calculate at infinite Q^2 what fraction of the hadron's momentum is carried by each quark flavor, and what fraction is carried by the gluons. As $Q^2 \to \infty$, the momentum fraction carried by valence quarks tends to zero. If there are n_f quark flavors, each quark or antiquark species in the sea carries a fraction

$$\frac{1}{2n_f}\Sigma_2^\infty = \frac{3}{32+6n_f} \quad , \tag{4.1}$$

while the gluons carry a fraction

$$G_2^\infty = \frac{16}{16+3n_f} \quad . \tag{4.2}$$

These limits do not depend on any details of hadron structure, only on the QCD Lagrangian.[11] They don't require us to know the configuration of the valence quarks. They arise simply as consequences of the eventual evolution of the parton distributions.

These are universal results, in the sense that the asymptotic momentum fractions are the same for all hadrons. Of course, the way the asymptotic momentum fractions are approached depends on the hadron species. For a glueball, it is to be expected that the momentum fraction carried by quarks is very small at small values of Q^2 and increases toward the asymptotic limit. For a proton or other state whose static properties are dominated by quarks, the momentum fraction carried by all the quarks starts near unity and decreases to the limiting value.

4.2 Static Properties of the Proton

At the other extreme stand the static properties of hadrons, for which the valence quarks are all-important. Examples of these static properties are the mass, magnetic moment, charge radius, and axial charge. The crucial feature here is the coherence, or correlation, among the quarks. We have devised various systematic theoretical schemes to analyze them: the $1/N$ approximation and the quenched approximation on the lattice, to name two. In addition, many models are useful in different settings. Perturbative QCD affords only partial insight into static properties.

4.3 Quasistatic Properties: A Closer Look at the Proton

A whole range of information about the properties of hadrons and their interactions lies in between these two extremes. The properties I would like to call quasistatic are determined by low-energy, nonperturbative phenomena, but probed by hard interactions. I now want to talk briefly about some of these, because this line of thought represents a tiny but important step beyond the normal notions of perturbative QCD. For the structure of the proton as expressed through the study of structure functions, it raises the next set of issues we will have to face. I begin by stating the answer, and then I will tell you why I believe it is true.

- I believe, on theoretical grounds, that the number of down antiquarks in the proton is larger than the number of up antiquarks,

$$\int_0^1 dx \left[\bar{d}_s(x) - \bar{u}_s(x)\right] > 0 \quad . \tag{4.3}$$

  This implies that the Gottfried integral,

$$\int_0^1 dx \frac{F_2^{\mu p}(x) - F_2^{\mu n}(x)}{x} < \frac{1}{3} \quad , \tag{4.4}$$

  as observed.[12)]

- I furthermore believe that the sea quark and antiquark distributions need not be identical, $q_s(x) \neq \bar{q}_s(x)$, though of course the number of quarks and antiquarks in the sea are the same: $\int_0^1 dx\, [q_s(x) - \bar{q}_s(x)] = 0$. (The vanishing of the difference integral is implied by the definition of the sea.)

- In a polarized proton, the sea quarks are polarized. In particular, for a proton with spin up, it is natural for the strange quarks have net spin down: $s_\uparrow - s_\downarrow < 0$. This means that the special assumptions needed to derive the Gourdin–Ellis-Jaffe sum rules[13)] will not be satisfied, so the sum rules cannot be exact.

- Finally, polarization in the sea quarks does not imply polarization in the sea antiquarks.

These statements—that simplifying, increasingly tacit, assumptions we have made out of convenience need not be true, and might have to be relaxed—have implications for the goals of experiments, for the way we analyze data, for the way we report the results of experiments, and, finally, for the determination of parton distributions in global fits. In other words, they have implications for refining our picture of the proton's structure. It is time to ask how the simplifying assumptions break down.

4.3.1 The Important Degrees of Freedom

It is plain that the properties I have named are fixed at low values of Q^2. For example, if there is a flavor asymmetry in the sea of the proton, that difference is not going to be changed by fluctuations of gluons into quark-antiquark pairs in the evolution to large Q^2. The gluon is flavor neutral, so a flavor asymmetry, once built up, will remain forever. It seems to me productive to think of the origin of these small differences—or these details of the properties of the proton—at modest values of Q^2. There, as everywhere, it is crucial to identify the important degrees of freedom for that setting and calculate their effects with controlled approximations. At the values of Q^2 that are important for setting these refined properties of the proton, the right degrees of freedom are constituent quarks, with masses on the order of 350 MeV given by confinement or chiral-symmetry breaking, an octet of Nambu-Goldstone bosons—the π, K, and η—which are the collective modes of the chiral condensate, and, in the background, gluons.

4.3.2 Implications of a Chiral Quark Model

As a refinement of the quark model, we have developed effective field theories with well-defined limits of validity that allow us to isolate and deal with the chiral properties of the quarks and the correlations embodied in the existence of light pseudoscalar mesons.[14] Although a quantitative calculation has been made, a toy model will suffice to indicate how the properties I have claimed will arise.[15)]

Think at first of the proton as three valence *constituent* quarks, uud. When we scatter a probe inelastically from that object, at values of Q^2 large enough that the incoherence of the parton model makes sense, a constituent quark may be resolved sometimes into a current quark and a Goldstone boson. In the example sketched in Figure 2, I consider fluctuations of the constituent quark into a current quark and a pion. Pions are special because they are light. The reason it may be useful to think in this way is that the Goldstone bosons represent a correlation of flavor or isospin or spin that comes ultimately from QCD, but is not manifest in perturbative QCD. That is why we have to build the Goldstone bosons into our effective field theory.

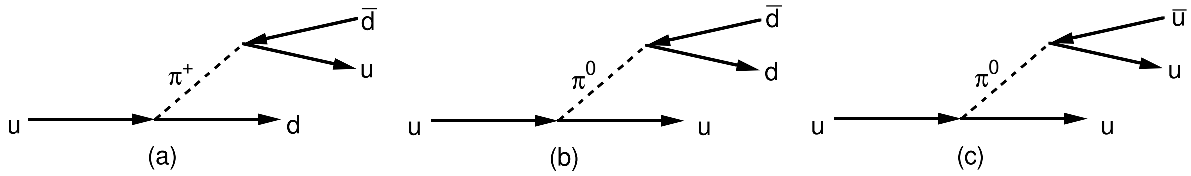

Figure 2: Fluctuations of a valence up quark in chiral field theory.

If a constituent up quark has probability a to fluctuate into a down quark and a π^+, which then resolves itself into $u\bar{d}$, then it is easy to calculate the probability $(a/4)$ for the up quark to fluctuate into an up quark and a π^0 resolved into $u\bar{u}$, or the probability $(a/4)$ for the up quark to fluctuate into an up quark and a π^0 resolved into $d\bar{d}$. The probability to emit a pion is $3a/2$, so the probability for no fluctuation is $(1 - 3a/2)$.

After one fluctuation, the constituent up quark becomes

$$\begin{aligned} u &\rightarrow a\pi^+ + ad + \frac{a}{2}\pi^0 + (1-a)u \\ &= \left(1 + \frac{a}{4}u\right) + \frac{5a}{4}d + \frac{a}{4}\bar{u} + \frac{5a}{4}\bar{d} \ . \end{aligned} \tag{4.5}$$

A similar calculation for the fluctuation of a constituent down quark follows from isospin symmetry. After one fluctuation, the constituent down quark becomes

$$\begin{aligned} d &\rightarrow a\pi^- + au + \frac{a}{2}\pi^0 + (1-a)d \\ &= \frac{5a}{4}u + \left(1 + \frac{a}{4}\right)d + \frac{5a}{4}\bar{u} + \frac{a}{4}\bar{d} \ . \end{aligned} \tag{4.6}$$

The proton therefore becomes

$$p = (2 + \frac{7a}{4})u + (1 + \frac{11a}{4})d + (\frac{7a}{4})\bar{u} + (\frac{11a}{4})\bar{d} \ . \tag{4.7}$$

Notice that the number of valence up quarks $(u - \bar{u}) = 2$ and the number of valence down quarks $(d - \bar{d}) = 1$ are preserved. But you see that the number of up quarks in the sea is different from the number of down quarks in the sea: $(\bar{d} - \bar{u}) = a$, the probability for a fluctuation. That asymmetry in the sea quarks—or sea antiquarks—has been generated not because isospin is violated in the interaction, but precisely because the proton is not isoscalar. It starts as two ups and a down, and the two ups fluctuate more often into down than one down fluctuates into up. This is an isospin-respecting mechanism for generating an asymmetry between the quark-antiquark flavors.

The parton distributions for the neutron are obtained by isospin symmetry. We then find a defect for the Gottfried integral that is

$$\Delta I_G = \frac{2}{3}(\bar{u} - \bar{d}) = -\frac{2a}{3} < 0 \ . \tag{4.8}$$

If you want to describe the NMC results for the Gottfried integral defect, the probability of fluctuation must be about $a \approx 0.14$. That is a small number, for which it is reasonable to consider a single fluctuation a good approximation.

This component of the sea also generates different momentum spectra for the quarks and antiquarks. Clearly, there is no reason for the spectrum of the left-behind quarks to be the same as the (identical) spectra of the quarks and antiquarks that come out of the structure of the pions. The chiral quark model is a counterexample to the simplifying assumption that the quarks in the sea must have the same spectrum as the antiquarks in the sea.

The other implication of this picture has to do with the distribution of spin in a polarized proton. A quark with spin up that emits a Goldstone boson in an axial-vector transition will leave behind a quark with spin down. The spins of the quarks in the spinless Goldstone boson are paired. This is a mechanism for naturally shedding the spin carried by the valence quarks.

An interesting special case—because it gives a counterexample to the assumption of Gourdin and Ellis & Jaffe—is the fluctuation of a valence quark with spin up into a strange quark with spin down plus a kaon. The strange quarks produced in this way will be polarized, with

$$\Delta s \equiv s_{\uparrow} - s_{\downarrow} = a_K < 0 \quad . \tag{4.9}$$

That invalidates the assumption needed to derive the spin sum rules for proton and neutron separately. By tying an estimate of this probability to the Gottfried defect, one can estimate $a_K \approx 0.08$, so that $\Delta s \approx -0.08$ is completely natural in this picture.

In the physical picture I have outlined, the flavor asymmetry comes about because the mass of the η' is much larger than the mass of the octet of Goldstone bosons. If the η' were degenerate with the pseudoscalar octet, fluctuations of $q \to q + \eta'$ would wash out the flavor asymmetry. That means that the flavor asymmetry between $\bar{u}$ and $\bar{d}$ in the proton is a consequence of the anomaly. Ball and Forte[16)] have made explicit the link between the anomaly and the flavor asymmetry in the sea.

5 The Top Quark and the Proton

Seventeen years after the discovery of the b-quark, the CDF Collaboration has presented the first tantalizing evidence for its weak-isospin partner. Giorgio Bellettini has summarized for us the searches at the Tevatron Collider.[17] CDF has observed a number of events that match the description of $t\bar{t}$ production and decay in their (i) isolated $\mu+$ isolated $e+$ 2 jets and (ii) isolated lepton + jets + b-tag samples.[18] Interpreting these events as top, they estimate

$$m_t \approx 174 \pm 15 \text{ GeV}/c^2 \tag{5.1}$$

with a production cross section $\sigma \approx 13.9^{+6.1}_{-4.8}$ pb, somewhat larger than the theoretical prediction, $\sigma_{\text{th}} = 5.1^{+0.8}_{-0.4}$ pb. For its part, the DØ Collaboration gives a 95% confidence level upper limit of 13 pb on the cross section for the production of top.[19]

CDF's value for the top-quark mass is in good agreement with the estimate

$$m_t = 177^{+11+18}_{-11-19} \text{ GeV}/c^2 \tag{5.2}$$

that follows from a combined fit to all available LEP data, within the standard electroweak theory.[20] (The second error in Equation (5.2) reflects the uncertainty in the Higgs-boson mass.)

The definitive discovery of top and refinement of the properties of top will make possible more acute tests of the electroweak theory. It should be possible to measure m_t with an uncertainty of $\sim$ 5 GeV/c^2 at the Tevatron and M_W with an uncertainty of $\sim$ 100 MeV/c^2 or better at the Tevatron and LEP200. It may then be possible to begin to constrain the mass of the standard-model Higgs boson H.

As the heaviest quark by far, top offers a new window on flavor physics. The dimensionless $Ht\bar{t}$ Yukawa coupling G_t that generates the top mass through

$$m_t = G_t \langle v \rangle / \sqrt{2} \ , \tag{5.3}$$

where $\langle v \rangle = (G_F\sqrt{2})^{-1/2} \approx$ 246 GeV is the vacuum-expectation value of the Higgs field, is not only much larger than any other Yukawa coupling we know, it is of order unity. The $t\bar{t}$ invariant mass distribution would be sensitive to many kinds of new structures that might provide insight into the interactions of top, the meaning of flavor, and the nature of electroweak symmetry breaking.

5.1 Move over, Copernicus!

A striking aspect of Nature's richness is that we find new and interesting phenomena whenever we explore an unfamiliar regime of distance, or time, or energy. Experience on one scale is not enough to anticipate everything that will occur on other scales. Ours is not a universe of Russian dolls! When we study matter under unusual conditions, surprises are everywhere—from the superconductivity exhibited by many materials at very low temperatures to the new forms of matter created in particle accelerators at very high energies.

Copernicus showed us that there is no preferred position in the universe. The renormalization group and effective field theories[21)] teach us that there is no preferred scale. (In an era when experimental collaborations involve hundreds of persons, it is perhaps fitting that we owe this new cosmic insight to a group, rather than an individual.) The idea that insights may come on different scales, that different degrees of freedom may be required to understand different phenomena, or to understand phenomena at different levels, is a manifestation of the insight that underlies particle physics: To understand the everyday world, we may be obliged to leave it.

It is popular to say that top quarks were created in great numbers in the early moments after the big bang some fifteen thousand million years ago, disintegrated in a fraction of a second, and vanished from the scene until my colleagues learned to create them in the Tevatron at Fermilab. That would be reason enough to be interested in top: to learn how it helped sow the seeds for the primordial universe that has evolved into the world of diversity and change we live in. But it is not the whole story; it invests the top quark with a remoteness that hides its real importance—and overlooks the immediacy of particle physics. The real wonder is that here and now, every minute of every day, top affects the world around us.

5.2 *A Fantasy*

The essence of building a physical model is to isolate a set of phenomena and describe them without having to understand everything in the universe. We can often divide the parameter space of the world into different regions, each with a different appropriate description of the important physics, each with a different "effective theory." The most familiar nontrivial example of an effective field theory in particle physics is the chiral Lagrangian approach reviewed here by Leutwyler.[22)]

In the extreme version of the effective-field-theory language, we associate each particle mass with a boundary between two effective theories. For momenta less than the particle mass, the corresponding field is omitted from the effective theory. For larger momenta, the field is included. We must relate the parameters in the effective theories on either side of the boundary so that the description of physics just below the boundary (where no heavy particles are produced) is the same in the two effective theories. In lowest order, the appropriate smoothness is ensured by the condition that the coupling constants for the interactions involving the light fields are continuous across the boundary.

Consider a simple unified theory of the strong, weak, and electromagnetic interactions—say three-generation $SU(5)$—in which all coupling constants take on a common value, α_U, at some high energy, M_U. If we take the point of view that the value of the coupling constant is fixed at the unification scale, then the value of the QCD scale parameter Λ_{QCD} depends on the mass of the top quark.[23)] If we evolve the $SU(3)_c$ coupling, α_s, down from the unification scale in the spirit of Georgi, Quinn, and Weinberg,[24)] then the leading-logarithmic behavior is given by

$$1/\alpha_s(E) = 1/\alpha_U + \frac{21}{6\pi}\ln(E/M_U) \ , \tag{5.4}$$

for $M_U > E > m_t$. In the interval between m_t and m_b, the slope $(33-2n_f)/6\pi$ (where n_f is the number of active quark flavors) steepens to $23/6\pi$, and increases by another $2/6\pi$ at every quark threshold. At the boundary $E = E_n$ between effective field theories with $n-1$ and n active flavors, the coupling constants $\alpha_s^{(n-1)}(E_n)$ and $\alpha_s^{(n)}(E_n)$ must match. This behavior is shown by the solid line in Figure 3.

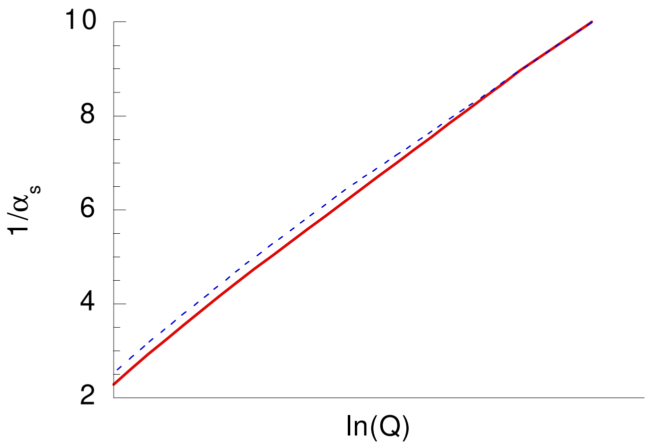

Figure 3: Two evolutions of the strong coupling constant.

To discover the dependence of Λ_{QCD} upon the top-quark mass, we use the one-loop evolution equation to calculate $\alpha_s(m_t)$ starting from low energies and from the unification scale, and match:

$$1/\alpha_U + \frac{21}{6\pi}\ln(m_t/M_U) = 1/\alpha_s(m_c) - \frac{25}{6\pi}\ln(m_c/m_b) - \frac{23}{6\pi}\ln(m_b/m_t) \ . \tag{5.5}$$

Identifying

$$1/\alpha_s(m_c) \equiv \frac{27}{6\pi}\ln(m_c/\Lambda_{\mathrm{QCD}}) \ , \tag{5.6}$$

we find that

$$\Lambda_{\text{QCD}} = e^{-6\pi/27\alpha_U} \left(\frac{M_U}{1\text{ GeV}}\right)^{21/27} \left(\frac{m_t}{m_b}\right)^{2/27} \text{GeV} \ . \tag{5.7}$$

Since the scale parameter Λ_{QCD} is the only dimensionful parameter in QCD, it determines the scale of the confinement energy that is the dominant contribution to the proton mass. We conclude that, in a simple unified theory,

$$M_{\text{proton}} \propto m_t^{2/27} \ . \tag{5.8}$$

The dotted line in Figure 3 shows how the evolution of $1/\alpha_s$ changes if the top-quark mass is reduced by an order of magnitude. We see from Equations (5.7) and (5.8) that a factor-of-ten decrease in the top-quark mass would result in a 20% decrease in the proton mass. The microworld does determine the behavior of the quotidian! While we await definitive news of the top quark, let us savor the realization that, in this speculative but entirely plausible example of a fundamental theory, we can understand the origin of one of the most important parameters in the everyday world—the mass of the proton—only by knowing the properties of the top quark. Top matters!

6 The Gargoyle's Smile

If the development of scientific understanding is like the construction of a cathedral, then we need the details, the ornamentation, to give meaning to the overall structure. A theory of everything that deals with no specifics would in the end be a hollow—or partial—achievement. A minimalist cathedral would not long hold our interest. It would be as tedious as a life accompanied by a Philip Glass score. We need the attention to details, we need the specifics that address this world, just as a cathedral needs its gargoyles.

My fear for particle physics is that without a commitment to exploration at the highest energies we may all find ourselves sculpting the smiles of gargoyles, not lifting the arches and spanning the vaults. The ideas exposed at the Sixth *Rencontres de Blois* represent first-rate, imaginative research. But exploring the richness of the strong interactions is not everything. If the finest artisans produced a whole warehouse full of fine gargoyles, would they hold our attention? Would they change our thinking? Would they lift our eyes? While perfecting the smiles on our gargoyles, we need to be raising the structure on which the gargoyles fit.

For particle physics today, building the cathedral of understanding means accepting the challenge of the 1-TeV scale and bending our energies to the problem of electroweak symmetry breaking. Little more than a year ago, we could look forward to two splendid vessels of discovery to carry us to the new world. Today, there is only the Large Hadron Collider at CERN, and its future is not yet secure. We must not be lulled into a too-comfortable complacency by today's interesting research. We need to prepare the particle physics of tomorrow. Securing the LHC and using it imaginatively is the key to our future.

Acknowledgements

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Footnotes and References

1. *Châteaux de la Loire* (Michelin et Cie., Clermont-Ferrand, 1977).

2. Jean Eugène Robert-Houdin, *Magie et Physique Amusante* (Calmann Lévy, éditeur, Ancienne Maison Michel Lévy Frères, Paris, 1877).

3. Robert-Houdin is also immortalized by a small street in the eleventh *arrondissement* in Paris, near *Métro Belleville.*

4. Denis Papin, *A new digester, or engine for softening bones: containing the description of its make and use in these particulars: cookery, voyages at sea, confectionary, making of drinks, chymistry, and drying: with an account of the price a good big engine will cost and of the profit it will accord* (H. Bonwicke, London, 1681).

5. The *Rue Papin* leads from the *Conservatoire des Arts et Métiers* to the *Boulevard de Sébastopol* in the third *arrondissement.*

6. I am grateful to Drasko Jovanovič for finding the Louis XII event in the CDF online event display.

7. One example is the speculations of I. I. Balitskii and V. M. Braun, *Phys. Lett.* **B314**, 237 (1993), about instanton-induced contributions to particle production.

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23. I owe these insights to discussions with Bob Cahn.

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