G minus TWO plus EMILIO

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Abstract

This verbatim transcription of a talk given on the occasion of Emilio Picasso's retirement from CERN in 1992 describes how he came to the organization following an improbable encounter with the author in a Bristol pub and his contribution to the first muon storage ring. It traces the series of false arguments leading to the discovery of the 'magic energy' used in the second muon storage ring, reviews his leadership style, and includes some physics results.

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G minus TWO plus EMILIO

Emilio, Ladies and Gentlemen: I feel like the elderly gentleman who one afternoon accosted Cocconi outside the library. The man said to him, "I feel terribly tired; is there anywhere I could lie down for a few moments and get some sleep?" And Cocconi said, "Not really. But you could always come to the seminar — we always sleep in the seminar!" The man replied, "The only trouble is …. I am giving the seminar!"

I've known Emilio for nearly 30 years, and you've asked me to give my impressions in 30 minutes. That is a compression ratio of 500,000 to one … two parts per million is one way of looking at it. I'll do my best, but I think you'll find that Emilio is incompressible.

Let me first track back to 1963. We met by accident. This leads me to underline the role of chance in human affairs. Let's start at the beginning. For every one of us in this room — well, most of us — the beginning, I suspect, our conception, was probably an accident. You may have chosen your parents but certainly the particular combination of genes, which makes you what you are, was a question of probability. And if you want to know what might have happened, just look at your brothers and sisters — it's rather a sobering thought. And then at the end, our death will be the result of another accident; a meeting with a microbe, a virus, a chance mutation, not to speak of the rare violent event. So we go from one accident to another, and we make the best of it.

One of the accidents that happened to me was meeting Emilio. So let me go back to that. In 1963, we'd done the first g–2 experiment on the cyclotron and the group had dispersed, I was the only one left thinking about this problem, and I came up with the idea of a new experiment on the PS, with 1.2 GeV muons, time-dilated to get more g–2 cycles, and I put this forward. In this I was helped by our two Nobel prizewinners. One of them came along and said, "Call it the muon storage ring". That was a very good political approach, and this man is now Director-General. Shortly after this, another Nobel prizewinner came along, in the shape of Simon van der Meer, and said, "Would you like me to build the magnet?" Of course I said "Yes" and the project was beginning to take shape, but there were still no physicists on it.

In 1963, I was visiting the University of Bristol to give some lectures — please don't laugh — on the Dirac equation and quantum electrodynamics — to the final-year students. I arrived there on a Monday, I think it was. Emilio had been in Bristol for one year on some kind of sabbatical year with Mariella, and I met him at coffee. I remember very vividly what happened because he immediately bent my ear about a paper he'd seen in the American Journal of Physics describing a new approach to electromagnetic theory based on the postulate that there really were magnetic poles.

The theory in this paper [1] was that you could approach Maxwell's equations in a much more symmetric way. The idea is to introduce a free magnetic pole density ρ_m so that this equation which you all know div $E = \rho_e$ is partnered by div $B = \rho_m$ with $\rho_m \neq 0$. Then you introduce the current of magnetic poles in curl $E = -(dB/dt + j_m)$ in analogy with the usual curl $B = -(dE/dt + j_e)$.

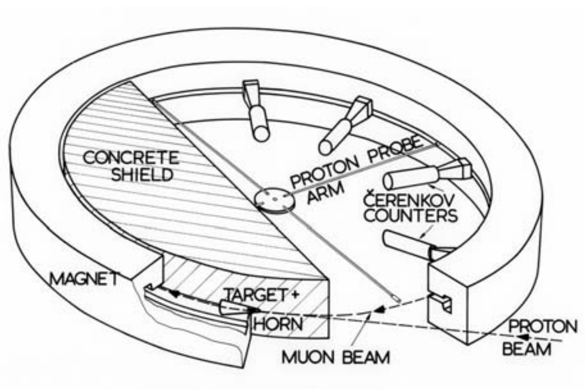
You see a symmetry already apparent. There were simple conversion rules to get from one equation to its partner; the normal Lorentz force on a charge is $F = q_e\,(E + v \times B)$, and the force on a magnetic pole became $F = q_m\,(H + v \times D)$.

This was the sort of thing he was talking to me about on that first day. I mention it because it is typical of Emilio to be interested in the fundamental questions of physics. But after coffee I didn't see him again; he was leaving the next day, and as far as I was concerned that was that. Now in the evening, I was by myself in the Hawthorne Hotel. The Hawthorne Hotel had eight bars. I asked them about this: "Why do you have eight bars?" They said, "Every time we open a new bar, we make more money." I don't know how many they have now. So I was by myself, and I was not thirsty. But I thought, perhaps in one of these bars is some tender flower longing for human company. So I went into one of the bars, chosen at random. Emilio's apartment was nearby. Mariella had already gone back to Genoa, this was his last night in Bristol, and apparently he felt thirsty. The probability of my going into the same bar was small. But in the one I chose, there he was. I'd found my tender flower *[much laughter]*.

Naturally we talked, we drank, and eventually I explained to him what I was doing in CERN. Emilio is interested in fundamental physics — there and then he offered to join the experiment, I accepted with pleasure, and shortly he started visiting CERN from Genoa, and from the very beginning he insisted on understanding everything in depth. He wrote Fortran programs, checked the calculations that I had done, and he found some mistakes. Luckily they were not lethal. Later on I visited Genoa, and I remember meeting Mariella in the very elegant apartment they had overlooking the harbour; later on, they moved to Geneva. Now we had a good physicist on the experiment, as well as a marvellous engineer, and the thing was rolling.

It wasn't trivial to get this experiment off the ground. I remember discussing with Léon van Hove, who was head of Theory at the time, and he said, "The muon obeys QED. g–2 is correct to half a per cent. In my opinion, it will be right to any accuracy. So it's not worth doing the experiment." I said to him, "Would you like to predict the result?" He didn't want to predict the result. And we went ahead and did the experiment.

I have some pictures of this. When you look back on it, it was incredibly simple. Here (in figure 1) is a proton beam coming into the ring. There was a target in the ring where pions were produced. They went round and decayed to muons. In fact, van der Meer introduced a magnetic horn around the target to increase the flux of pions and therefore muons; it also increased the background by a huge factor, and we eventually ran without it. When the muon decayed, the electron came out on the inside of the ring and went into one of these counters and we got the data. (I'm not explaining the experiment in detail; I have too many other things to talk about.)



MUON STORAGE RING

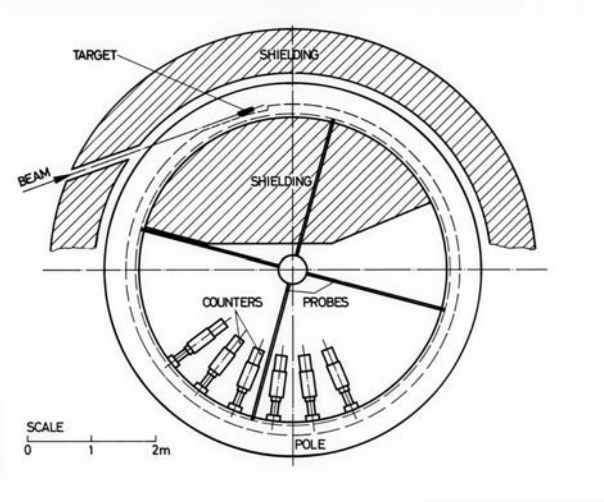


Figure 2 is a plan view; some of you have seen this before. Picking up some old slides, I found an engineering drawing of this magnet. What struck me — it was all incredibly simple, compared with what we try to do now! It's a miracle.

Figure 3 is an old photograph of people in the counting room. (Left to right: Hans Jöstlein, Simon van der Meer, me, Emilio, Robin Brown, Manfred Giesh, and John Bailey.) Emilio is usually explaining something.

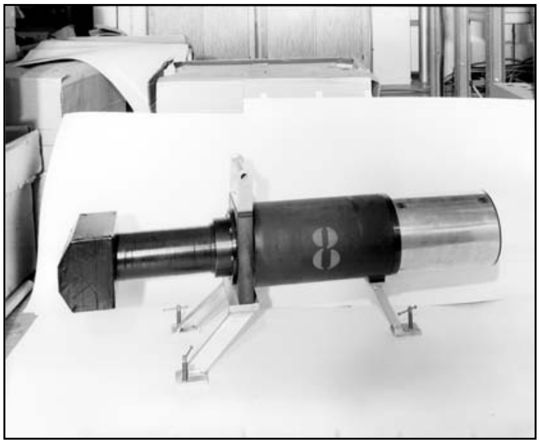


Figure 4 is what we used to call a dog, because it looked like a dog, a little calorimeter which we used for measuring the electron energy. I remember we took these down to Frascati to calibrate with an electron beam. For some reason there were no electron beams in CERN of order 1 GeV. It was the first time Emilio and I were actually running together and I remember very vividly his enthusiasm writing down the results — "Oh, boy!" he'd say, "Look at that!" Then he'd say, "What next?" He'd write a number — 52. "What next?"

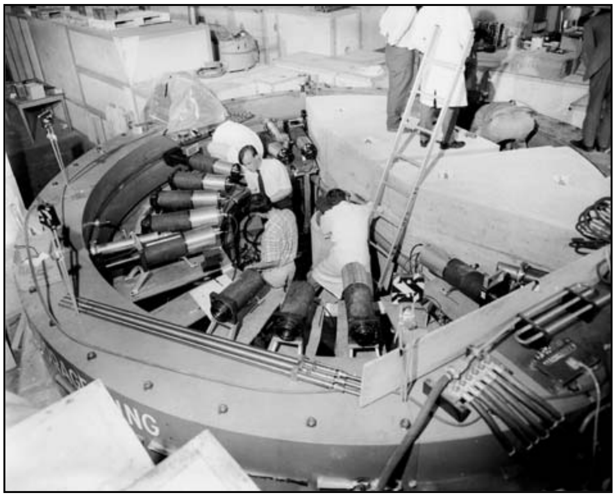


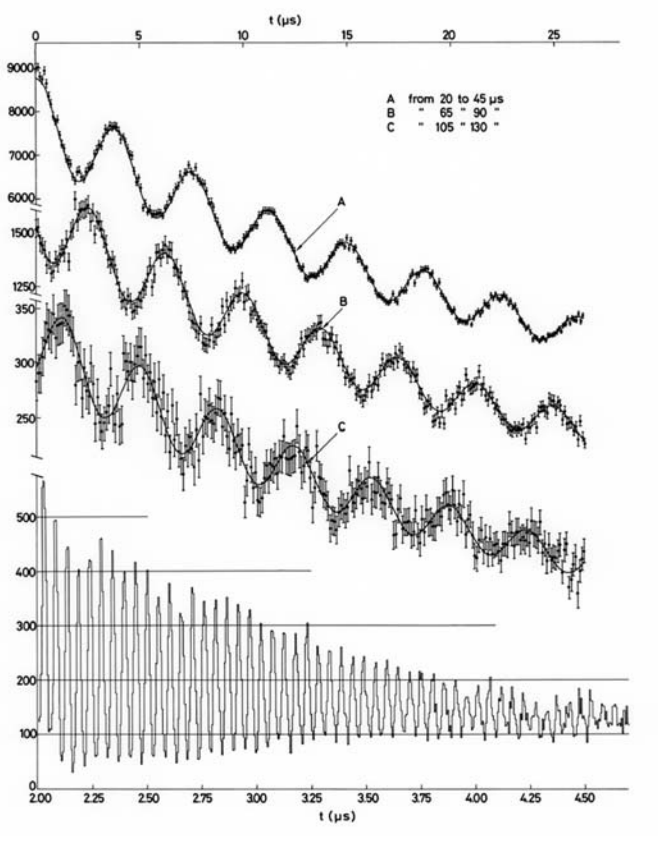
Figure 5 is another view of the apparatus. See the ring, the counters in position. And people often ask me (pointing to crouching man on top right), “What is this man doing?” Well, I have to explain that to make your experiment work you must placate the gods of the laboratory. And so we used to carry out little ceremonies to make sure that the gods were on our side.

During this time a rather talented Italian film producer came to CERN and made some film. A short bit of this film shows the g–2 group and if we are ready we will show it now.

(Part of film by Guido Franco is shown.)

It was a good film for capturing the atmosphere of CERN. But it didn’t say much about the experiment. I’ll tell you a bit more about the experiment. After we’d done all that, we had quite a bit of trouble making it work. Eventually it looks easy.

Figure 6 (lower curve) shows the muons turning in the ring with storage time 2–4.5 microseconds and we can read off the orbit frequency. We had a weak focusing magnet with a gradient field, and to calculate the mean field seen by the muons you needed to know the radius. You get the radius from the orbit frequency and we reckoned we could do that to three millimetres, which corresponded to 160 parts per million in the field. Above on a slower time scale you see the g–2 precession with the three curves following one after the other, the bottom one going out to 130 microseconds. Here you can still see the precession. Clearly you get a good fit to the frequency from that. And as the muon normally only lives for 2 microseconds, seeing it for 130 microseconds we thought was rather good.



Luckily, van Hove didn't predict a number because he'd have been wrong. Our result disagreed with theory by 1.7 standard deviations. The theorists later found they'd made a mistake, they corrected it, and then they agreed with us.

It was a good thing to have this discrepancy because it was obvious that we needed to do a better experiment. We had no trouble with the management this time in eventually proposing a new experiment. Towards the end of the one we've just discussed, I left CERN and took a job in England, and Emilio became the group leader. So the situation was now reversed; he was the group leader, and I was visiting CERN. And under Emilio's leadership, we grappled with the problem of how to do a better experiment. And I thought I'd explain the steps in this rather carefully, because it's interesting to see how scientific ideas develop often from a number of false steps. But I'm going to try to do this without saying who said what, because I believe very strongly that when a group is working well together, creative ideas can come out of it — and afterwards, people go away and they tend to say, "It was my idea!" But it wasn't in fact; it came out of the group. The group is greater than the sum of the parts. So I'll try and avoid saying who said what. But this was the flow of thought.

The first problem in doing a more accurate experiment was how to get rid of the 50 ppm per millimetre field gradient essential for focusing. We were aiming at 20 parts per million accuracy and we would not know the radius of the muons to better than about a millimetre. So the thought was, "Can we cancel the variation of g–2 frequency with radius, and still keep the vertical focusing?"

It was already known that a radial electric field changes the precession frequency — a possible souce of error in the electron g–2. My friend here, Telegdi, with Bargmann and Michel, had worked out the formula. So you look at the formula, and you see that a radial electric field can indeed change the frequency, and by how much.

$$\Delta f/f = (\beta - 1/\alpha\beta\gamma^2)\,(E/B)$$

For example, with gamma equal to ten, you can do a quick calculation, you find that you need 1.2 kilovolts per centimetre only at the edge of the aperture to cancel the effect of the magnetic gradient. So the idea is to have an electric field that varies with radius, that is, an electric quadrupole field. The electric field is, say, radially outwards at one side of the aperture and radially inwards at the other. But of course the electric field must be known, and you must match the gradient of the magnet exactly.

Can we go to higher gamma, to get even more time dilation of the lifetime? One notices from this formula that, as you increase gamma, the effect gets less, because there's gamma squared in the denominator. And, my goodness, you had better not go to 3.1 GeV, because then the electric field does nothing — the two terms in the first bracket just cancel out.

So at this stage of the thinking, we wanted to keep away from 3.1 GeV. We use the radial component of the electric field, but the vertical component does nothing. But now comes the counter argument, which says, “Ah ha! Intuitively, for relativistic particles, electric and magnetic fields are indistinguishable. If you cancel out the variation of f with radius, you’ll almost certainly cancel out the vertical focusing.”

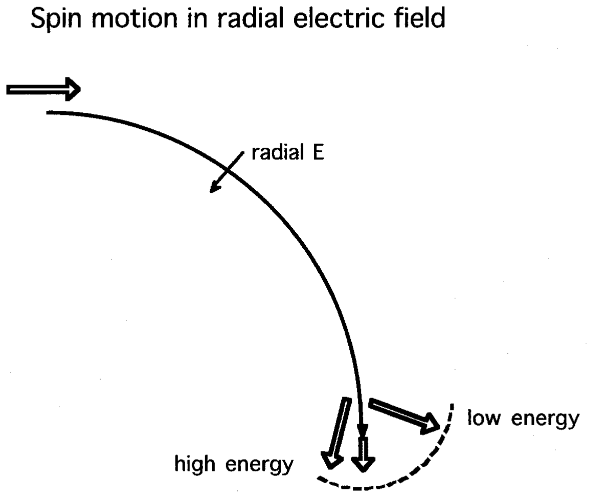
“Rubbish! This is a GeV muon! One kilovolt per centimetre — that’s a factor of 10 to the minus six, it won’t affect the orbit at all!”

So, OK, it’s not too difficult to work out the focusing effect for an elecric quadrupole of half-aperture a with voltage V applied. At the edge, the electric force is $2eV/a$, while the magnetic force for field index n would be $nBe\beta\ (a/\rho)$, so the effective field index due to the electric quadrupole comes to $n_{\text{eff}} = 2V/B\beta\rho\ (a/\rho)^2$. You put in numbers, say for a 7 metre radius, 15 kV applied, 7 centimetre aperture — to make the arithmetic easy — and 1.5 tesla, you find that n_{eff} is 0.1. Lo and behold, an electric quadrupole, in spite of this order of magnitude remark, does have, could have, a very nice focusing effect.

So now you say, “Oh, perhaps we don’t need a magnetic gradient at all.” We can use an electric quadrupole instead, *with a uniform magnetic field*. So now instead of running away from 3.1 GeV you sit on it, and the radial electric field has no effect on the spin!! We use the vertical component of the electric field, and the horizontal component does nothing; and E does not have to be known exactly.

Now, of course, that would be true only at the centre of the aperture where you have the so-called magic gamma. At greater radius, the momentum is too high; you are one side of magic, and the electric field is outward, say, and that reduces the spin frequency. And on the other side, the electric field is reversed, but you are the other side of magic, so the effect is reversed twice, and you get two linear effects giving a parabolic result, and in the middle you are just at the maximum of the g–2 frequency. Maxima tend to be flat, so the total variation is only a few ppm over the aperture while the muons are concentrated in the centre. It turned out, suddenly we had an experiment in which the systematic errors were of the order parts per million. And also 3.1 GeV was a very convenient energy to go up to from 1.2. We were lucky; it was a miracle that the magic energy was easily accessible with the accelerators here.

Another way of understanding this — this is a rather useful general remark — if you look in the rest frame, the forces that bend the muon and focus the muon look in the rest frame like an electric field E^*. And because the muon is at rest in the rest frame, the magnetic field B^* does nothing to the position of the particle. On the other hand, the spin is affected by B^* and not by E^*. These can be varied independently. So in principle, by using the right value of B and E in the lab, you can get any combination you like of E^* and B^* in the rest frame. So that is another way of seeing why this works.



Another way again is shown in figure 7. Here a particle is being bent by a radial electric field. The spin starts off longitudinal. At very low energies the electric field does not affect the spin, and the spin will end up pointing more or less in the same direction while the orbit is turning. So you get an apparent outward precession. But at super-high energies, using the principle that electric and magnetic fields are indistinguishable, we get a g–2 precession, and the spin will end up slightly inwards. Using the principle of continuity, there must be some intermediate energy for which the spin will remain pointing forwards; in other words, the electric field will not precess the spin relative to the momentum. So that is a hand-waving way of seeing why at the magic energy the electric field does not affect the g–2 precession.

Just a few view foils on this, but first I must say the following. Emilio was now the group leader, and he masterminded the whole of this experiment. He used his charm, skill, and sheer hard work to make it a success. And this is where his talents as a leader really came out. And there are so many things one can say about this. I've talked to quite a few members of the group on the phone, and they all emphasize the same things, not in any logical order:

"His enthusiasm for physics always comes through, and his enthusiasm for people."

"He is always radiating Mediterranean warmth; he creates a happy atmosphere."

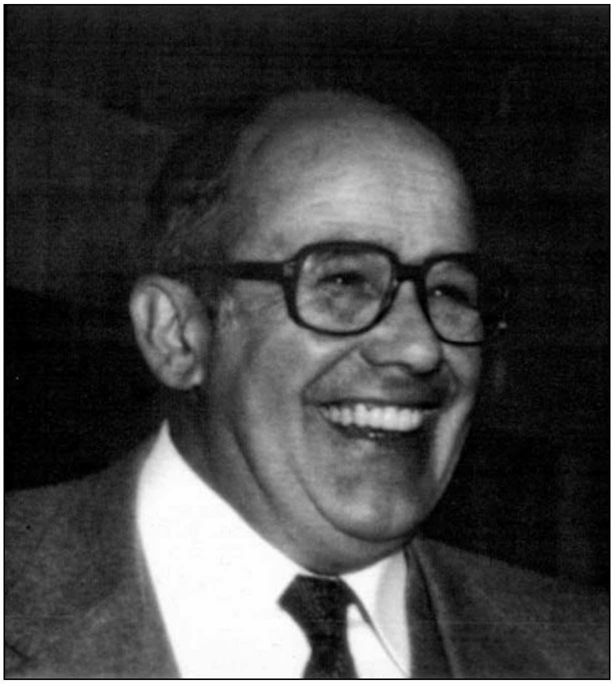
"He's always positive, bringing out the best in each person, seeing where each person can best contribute and giving credit and appreciation when they've done something."

If you have an idea, so many people will tell you, "No, no, that's no good!" But if you go with an idea to Emilio, he'll say, "Oh, boy! Good idea! Let's try it!" And if it doesn't work out, he's genuinely sorry. If it does work out, he'll give you the credit.

There were many occasions when members of the group were invited around to Thoiry, maybe at the weekend, to work out with him details of the experiment and many of them have spoken to me of these occasions, with Mariella in the background providing food, hospitality and support. And it's also been emphasized that there was something that was very unusual in this group — even extraordinary — there was not a single crisis. No one was discouraged, no one was demoralized, no one walked out; there were no wars, no clashes. In a word, Emilio has no enemies.

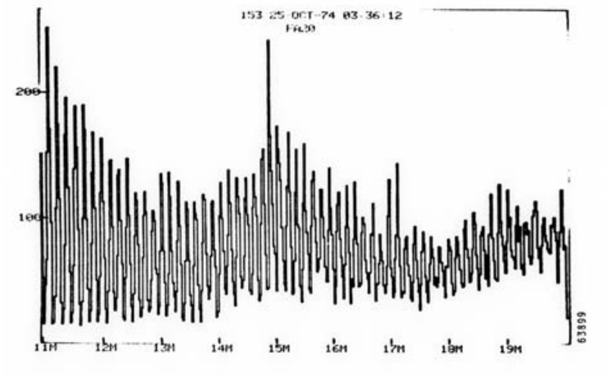
I have a few personal memories of how Emilio operates. He used to come to me and say, "I've just been talking to so-and-so. I've switched him on — he is going to help us with this!" And that's what he can do — he can switch people on. And of course, he knows everybody. Once we were having coffee in the cafeteria, and some stranger came in and was standing around. Emilio jumps up, goes across, shakes him by the hand, pats him on the back, they talk away, goodbye, warm and so on, see you again, comes back. I say to him, “Well, who was that?” “I don’t know his name, but I’ve met him somewhere!”

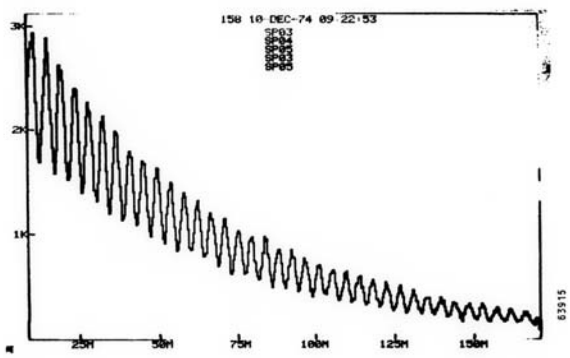
Figure 8 is a view of this much bigger ring magnet, and there again you can see *[laughter]* how we carried out these ceremonies to placate the gods of the laboratory. Let me say straightaway, that is not Emilio.



THIS is Emilio (figure 9).

And now the rotation patterns of the muons looked like this (figure 10). It goes on much longer, going out to about 20 microseconds, and at this energy you can see the g–2 of the muon combined with the rotation frequency. And figure 11 is the sort of results that we got in two days running — a precession curve going out now to 175 microseconds with a nice big amplitude.

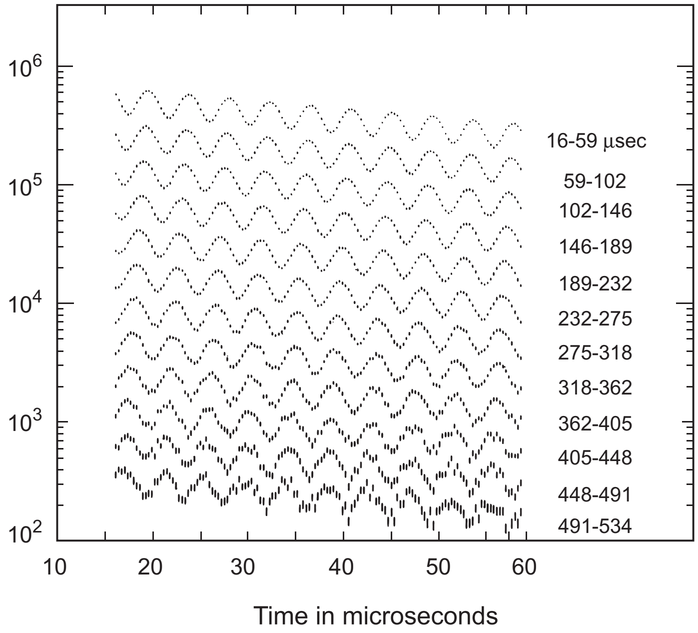




This is Emilio again with the whole group (figure 12). He seems to be happy about the results.

Left to right, back to front, Petrucci, Lebée, Bailey, Lange, Mühlemann, Krienen,
Farley, Field, Fremont, von Rüden, Drumm, Picasso, Flegel

And this (figure 13) is a combined graph going out to 534 microseconds. And so we got a result, and this time it agreed with theory. The theorists had made some progress.



A few more remarks that I've gleaned from different people about Emilio. Here he is again (figure 14). I talked to one of the secretaries. "You always know he's there; he's always warm and happy; he fills all space". Peter Hattersley told me the following: "Kurt Borer, and I went over the road from CERN to the Tastevin restaurant to book a dinner. The proprietor asked what name to book it in. "Picasso." "Ah, is that THE Picasso?" "No, no, not the painter, it isn't him." "I don't mean the painter, THE Picasso, the one across the road, in CERN." "Oh, yes, that's the one." "Magnifique — come in and have a drink!"

So this is my two parts per million of Picasso — I kept the best photo to the end (figure 15).

I'm delighted to be here today and to contribute to this meeting. From all the g–2 people I say, "Thank you, Emilio, it has been an enormous pleasure to work with you, a truly memorable experience. And to you and to Mariella, our warmest wishes for the future."

Good luck, and keep in touch!

Acknowledgements

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Reference

[1] Robert Katz, American Journal of Physics 29, 41 (1961).