The November \( (J/\Psi) \) Revolution : Twenty-Five Years Later

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Abstract
Exactly twenty five years ago the world of high energy physics was set on fire by the discovery of a new particle with an unusually narrow width at 3095 MeV, known popularly as the \( J/\Psi \) revolution. This discovery was very decisive in our understanding as well as formulating the current picture regarding the basic constituents of nature. I look back at the discovery, pointing out how unexpected, dramatic and significant it was.
Exactly twenty five year ago, on November 10, 1974 two groups (one, a MIT group doing experiment on the east coast at Brookhaven National Laboratory, U.S.A. and the other a SLAC- Berkeley group doing experiment on the west coast at Stanford Linear accelerator centre, U.S.A) simultaneously announced the discovery of a new particle at 3095 MeV whose lifetime was about 1000 times longer than that of other particles of comparable mass. This announcement set on fire the world of high energy physics and is now known in the physics community as the November revolution. Like many revolutions, its meaning was not clear at first. To appreciate the surprise, imagine if one suddenly discovers a new pyramid, twice as heavy as the largest one known so far and yet a thousand times narrower and thus higher! The unprecedented large life time (or narrowness of the peak) led to a host of theoretical speculations and vigorous experimental activity. During the next one year, more than seven hundred papers were written related to this discovery which was a record in physics (if not in entire science) at that time. Subsequently, this record was broken after the discovery of high $T_c$ super-conductivity.

The $J/\Psi$ discovery electrified the community for many reasons including its simultaneous discovery in two different laboratories and on two entirely different type of machines. Its impact on the development of high energy physics was tremendous and within two years of its discovery, in 1976, the two men Samuel Ting and Burton Richter who led those two group were awarded the Nobel prize in physics. Apart from Raman effect and parity violation, there are not many other discoveries which were recognized that soon by the Nobel committee. The simultaneity has often led to speculation about how independent were the two discoveries. Is it true that the work about the peak some how spread from Brookhaven to SLAC and played a role in the decision by Richter and his group to set back the machine energy?

The plan of the article is the following. I shall first briefly review the situation as prevalent in high energy physics at the time of the discovery. Then I shall discuss in some detail the events leading to the discovery. Finally, I shall discuss in brief the future developments as well as the current status of the field.

Status of HEP in 1974

The question of the basic constituents of nature has attracted human mind since time memorial. *Atomos* the Greek word of “atom” means indi-
visible, and it was thought for a long time that atoms were the ultimate, indivisible constituents of matter. The discovery of electron at the end of the last century marks the end of the speculation era of about twenty five hundred years and beginning of the realization that the atom is not indivisible or elementary. In 1911, Rutherford showed that the atom consists of a small dense nucleus surrounded by a cloud of electrons. Subsequently, it was revealed that the nucleus consists of neutrons and protons. During the fifties and the sixties, a large number of such particles were detected. It was then suggested that perhaps all these particles are also composite being made out of still smaller constituents called quarks. Three kinds of quarks (u,d,s) and their anti-particles were sufficient to describe all known hadrons at that time. In 1969, the deep inelastic scattering experiments at SLAC (which were analogous to the Rutherford experiments of 1911) conclusively proved that proton, neutron and other particles are indeed composite being made out of quarks.

The particles made out of quarks are called hadrons. These are the particles which interact through strong force. It is this strong force which binds protons and neutrons together in a nucleus. This force is also responsible for the rapid decay of many of the hadrons.

In nature, there exist another kind of particles called leptons. By 1974, four such leptons were known i.e. electron, electron neutrino, muon and muon neutrino (and of course their anti-particles). The leptons (unlike hadrons) do not experience strong force. Of course electron and muon being electrically charged feel the electromagnetic force (which is roughly hundred times weaker than the strong force). The neutrinos have however no electric charge and hence they neither feel the strong nor the electromagnetic force, but interact through weak interaction (it is weaker by several orders of magnitude compared to the electromagnetic interaction). It is worth pointing out these three together with gravitation were the four basic interactions in nature at that time. Some people had however already started wondering about the idea of unification of these forces. In particular, inspired by the unification of terrestrial and celestial gravity by Newton and electricity and magnetism by Maxwell, people were wondering if electromagnetic and weak interactions could be unified into a single force. Such a unified model for leptons was written down by Weinberg in 1967 but it did not receive much attention in the physics community till the work of 't Hooft who showed the renormalizability of the model. The discovery of (weak) neutral current in
1973-74 was a big boost to these ideas but initially several people including 
the experimental groups themselves were not sure of their results so that it 
was jokingly termed as the discovery of “alternating neutral current ” and 
hence physics community had not grasped its full significance in 1974. I may 
add here that no Nobel prize has been awarded to the discovery of neutral 
current.

Thus in 1974 the common belief was that the basic constituents of nature 
were three quarks and four leptons (and their anti-particles) and they all 
seemed point-like objects. Among these, whereas the four leptons had been 
experimentally seen in the laboratory as isolated particles, the quarks always 
resided inside hadrons and no one was able to isolate a single quark. This 
was one of the most puzzling aspect at that time.

Towards The Discovery

I might point out that the situation in high energy physics was even more 
confusing in 1970 when Ting wrote his proposal. Since 1965 Ting had been 
working on the tests of quantum electrodynamic at high momentum transfer. 
It may be noted that at small momentum transfer, there is agreement be-
tween quantum electrodynamics and experiment about the anomalous mag-
netic moment of electron to seven decimal places. I know of no other theory 
in physics (may be even in science?) in which there is such an unprecedented 
agreement between theory and experiment. From 1965 to 1969 Ting and his 
group observed the production of heavy photons (vector mesons) \( \rho, \omega \) and \( \phi \) 
(whose masses were around 1 GeV) and their subsequent decay to electron 
positron pair \( (e^+e^-) \). One obvious question was : how many heavy pho-
tons exist and what are their masses and other properties ? Ting wanted 
to study this question but his proposal was rejected by both Fermilab and 
CERN. Finally he submitted a proposal to Brookhaven on January 11, 1972. 
He wanted to look for heavy photons (vector mesons) through fixed target 
production experiments in which high energy protons will slam into a target
\[
p + p \rightarrow V^0 + X, \ X.... \ anything
\]
and they will try to look for the heavy vector meson \( V^0 \) through its decay to 
\( e^+e^- \) pair. The interesting part of his proposal was his assertion “contrary to 
popular belief, the \( e^+e^- \) storage ring is not the best place to look for vector 
mesons. In the \( e^+e^- \) storage ring the energy is well defined. A systematic 
search for heavier mesons requires a continuous variation and monitoring of
the energy of the two colliding beams, a difficult task requiring almost infinite time. Storage ring is best suited to perform detailed studies of vector meson parameters once they have been found”. The subsequent events have confirmed this assessment and that is why hadron machine is popularly termed as a “discovery machine” while $e^+e^-$ machine is meant for precision studies.

Richter, on the other hand, was involved with $e^+e^-$ storage ring. He was interested in understanding about the production of hadrons in $e^+e^-$ collisions. In 1965, SLAC submitted a proposal to the US atomic energy for such a machine with an energy of 3 GeV for each beam. Funds were made available for this collider (SPEAR) only in 1970 and the machine was built by April 72. The SPEAR group was primarily examining the ratio $R$ which roughly speaking is the number of hadrons divided by the number of muons produced in $e^+e^-$ collisions. More precisely

$$R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

where $\sigma$ denotes the cross-section. They wanted to study the variation in the value of this ratio as the total energy is changed from 2.4 GeV in steps of 200 MeV. From their preliminary study they found that this ratio $R$ was rising from 2 to 6 as the total energy was increased from 2 to 5 GeV. Richter gave a talk about these results at the biannual Rochester conference held in London in the summer of 1974. John Ellis also gave a talk at the same conference reviewing the production of hadrons in $e^+e^-$ collisions from different models. He showed that depending on the model, this ratio could be anything from $0.36$ to $\infty$ (i.e. $0.36, 2/3, 2, 10/3, 4,...,\infty$). The most widely accepted three quark model (with color) predicted $R$ to be 2. Thus the situation appeared totally confusing as late as the summer of 1974.

The Discovery

Ting’s proposal to Brookhaven got approved in May 1972 and was awarded a thousand hours of beam time. It took the group almost 18 months to built the detector which was enormous in every way: in size, intricacy, sensitivity, and cost. The actual experiment started in April 1974. They first looked at $\phi(1020)$ meson, the idea being, if one plots the number of $e^+e^-$ pairs produced in this experiment as a function of total energy then one should see a broad peak whose maximum height is at 1020 MeV. One remarkable thing of his detector was that he could measure the energy of the $e^+e^-$ pair with great
accuracy. Of course this made the detector very costly and he got lot of criticism for making the detector needlessly accurate since no one at that time thought that there could be a heavy vector meson with very narrow width.

On August 22, the team turned the detector to energies between 2000 and 4000 MeV and took data for two weeks. Within couple of days of the data taking, two analysis teams independently started to analyze the data (normally only one team analyzes the results but Ting being a very careful man always had two) and both independently realized that when they analyzed the number of events from 2875 to 3225 MeV in gradation of 25 MeV, nearly all events were piled up at 3100 MeV i.e. instead of a hill, they actually had a needle! And that was the big surprise as till then no subatomic particle was known which had such a narrow width (i.e. such a large lifetime). It seemed to be 1000 times narrower than expected! This is where the personality of Ting came into the picture.

Several members of his group urged him to publish the results immediately but he decided to doubly check the results. But this was highly risky proposition since Ting knew that SPEAR could discover the peak in a day if only they knew where the peak was! On the other hand, Ting could observe it in fixed target experiment only because of his obsessive insistence on fine-tuning the detector. During this period the MIT group members were making discrete enquiries about the energy at which SPEAR was running and when they heard that it was running between 4.5 GeV and 6 GeV, the group breathed freely!

Ting’s frustrations increased when the machine restarted on October 2 but developed problems immediately. He then thought about announcing the results during October 17-18 MIT festival to honour the retirement of Victor Weisskopf. However, he backed out at the last moment. On October 22, Ting got back the machine to further recheck the data and one of his group member, Ulrich Becker gave a previously scheduled seminar at MIT where he disguised his very narrow peak by presenting the number of events over a sufficiently wide energy range. However, it did not fool Martin Deutsch who took Becker aside after the seminar and asked him to publish the results immediately. On the same day, Mel Schwartz of Stanford stopped at Brookhaven to assess the progress of his experiment. His assistant Jayashree Toraskar then told him about the rumour out the bump at 3.1 GeV in Ting’s experiment. Schwartz met Ting to get a confirmation about the rumour. The conversion that followed had far reaching consequences. It is therefore
worth reproducing the conversation (as per Schwartz's recollection).

Schwartz: Sam, I hear you got a bump at 3.1.

Ting: No, absolutely not. Not only do I not have a bump, it's absolutely flat.

Schwartz: I will make you a bet. Ten dollars you get a bump.

Ting: Absolutely. I will bet.

Clearly, at least after this conversation, Ting should have announced the discovery as he knew very well that Schwartz was going back to Stanford (where SLAC is situated) and once SPEAR hears the rumor about 3.1, they will just get it in a day. By denying the rumor so flatly he in fact weakened his case and eventually he had to share the Nobel prize with Richter. There is no doubt in my mind that if only he had been honest with Schwartz he would have got the full credit.

On October 25, Deutsch again pressed the MIT group to publish the results soon as otherwise SPEAR would get to it but still nothing happened. Apparently, Ting now felt that there could be more than one bump and he wanted to get credit for it too.

On the west coast, on Saturday, November 9 the SLAC group decided to stop their run between 4.5 and 6 GeV and instead go back to 3.1 GeV. Apparently, one member of the group, Roy Schwitters felt that the SPEAR group needed to write a paper on their experiment and hence he started to look at the data carefully. While doing so, he noticed that there was something inconsistent in the data around 3.1 GeV. He talked with other group members including Gerson Goldhaber and Richter and they agreed that indeed there was something odd and that one should go back to 3.1 GeV. It may be noted that it is not easy to change energy just like that. One has also to retune the beam and reset all the magnets. The official reason for going back is hardly convincing to say the least and it appears that the conversation of Schwartz with Ting two weeks ago as well as other rumors floating around played some part in this decision. As expected, within a day (i.e. on Sunday, November 10) they had confirmed the existence of an unusually narrow hadron at 3095 MeV.

As the luck would have been, on the same day, Sunday November 10, Ting arrived at SLAC to attend a previously scheduled meeting of the SLAC Programme Advisory Committee. At the hotel, Ting got a frantic message from Deutsch who had heard that SPEAR had found something at 3.1 GeV. Ting was obviously horrified and immediately telephoned Brookhaven and
asked them to announce the discovery right away and informed them that he will announce the discovery at SLAC the next day. Ting also telephoned to the $e^+e^-$ machine at Frascati about the discovery and within two days they too confirmed the existence of the particle. The three papers were published back to back in the December 2 (1974) issue of Physical Review Letters.

Why did Ting not publish his data earlier when so many of his group members were urging him to do so? Was he ultra cautious or was he not very confident of the results? Or was he greedy? Was he so naive to believe that his conversation with Schwartz will not reach SLAC just because he had denied the rumour?

While it is true that perhaps Ting should have got full credit for the discovery of $J/\psi$, the SPEAR group took over from that moment onwards, doing all the precision studies related to the production and decay properties of $J/\psi$. Further, within ten days, the group discovered another vector meson $\psi'(3695)$ MeV.

Soon after the announcement of the $J/\psi$ discovery, there followed a host of theoretical speculations about what it is. The big question was, why is $J/\psi$ so narrow and hence long lived? Some of the suggestions were: it is an intermediate vector boson, Higgs boson, lightest colored particle, lightest particle with a new quantum number called paracharge, charm-anticharm ($c\bar{c}$) quark bound state (i.e. charmonium bound state). There followed a vigorous theoretical activity trying to figure out the correct answer. In between, the SPEAR group also discovered three more states through radiative transitions whose masses were between those of $\psi'$ and $J/\psi$. Within about one year after the discovery it was clear that $J/\psi$ was $c\bar{c}$ bound state so that the basic constituents of nature were four quarks and four leptons. The other states discovered at SPEAR were also easily understood as the various states of the charmonium ($c\bar{c}$). Remarkably, it was shown that the $c\bar{c}$ spectrum can be well understood within the framework of non-relativistic quantum mechanics plus spin dependent corrections. One last obstacle in this picture was the existence of "Charmed mesons". However even these were discovered by the middle of 1976 and it convinced even the most die-hard skeptics about the validity of the charm hypothesis.

Around this time followed two more rather unexpected discoveries, namely those of $\tau$ lepton at 1786 MeV and $b\bar{b}$ bound states where $b$ is the fifth quark. I would say that these two were the last two surprises and in the last twenty years we have not had any more surprises in High Energy Physics.
It was clear by then that there are twelve basic constituents of nature i.e. six leptons (τ-neutrino being the sixth lepton) and six quarks. Even though only five quarks were known till then, the community was confident that there must exist the sixth quark and such a quark (t-quark) was indeed discovered at Fermilab in 1994.

**The Present Picture**

As of today, the basic constituents of nature are six quarks and six leptons. The strong interaction between quarks is due to their colour degree of freedom and the corresponding gauge quanta are called gluons and this theory is known as quantum chromodynamics. On the other hand, the electromagnetic and weak interaction between quarks and leptons is given by a unified electroweak theory $SU(2)_L \otimes U(1)_Y$. By now all its predictions have been experimentally verified except for the prediction of a neutral Higgs boson. A Large Hadron Collider (LHC) machine is being built at CERN specifically to look for this particle and it is expected that this issue will be resolved by the year 2007.

It must be made clear that there are several basic questions that have not been answered by the above (so called) “Standard Model”. For example, the standard model has several arbitrary parameters. Besides, the origin of fermion masses is unclear. Further, there is only a partial unification of the basic forces. In recent years a truly unified theory called the superstring theory has been proposed which unifies all the four interactions. One remarkable break from the past is that here the basic constituents of nature are not particles at all! Rather the basic object is a string of length $10^{-33}$ cm. The quarks, leptons and the gauge bosons are merely the different modes of vibration of the string. The unification ideas have brought closer the seemingly contrasting worlds of the smallest and the largest. In particular, these ideas hold the promise to explain how the universe evolved a very short time after the big bang. Another possibility is that the quarks and leptons are themselves composed of more elementary objects. It must be made very clear here that unfortunately, so far we have no experimental evidence for any of the ideas beyond the standard model.

**Suggested Reading**

1. R.P. Crease and C.C. Mann, *The Second Creation*, (Macmillan Publishing Company, U.S.A., 1986).
2. Nobel Lectures by S. Ting and B. Richter (1976).