# A Student's View of Fermi

Jerome I. Friedman, February 14, 2010

It is a great pleasure to be here today to participate in this special session of the American Physical Society to remember and honor Enrico Fermi. As Fermi's last student, I was asked to give my reminiscences of this great man, which cover the period from 1951 to 1954. However, I do so with some hesitancy because time has no doubt clouded and colored my memory. Nevertheless, I will try to give you some of my recollections from my student days of Fermi and the environment he created.

In 1950, I entered the Physics Department of the University of Chicago after completing my work in the highly innovative and intellectually stimulating College established by Robert Maynard Hutchins, who was then President of the University.

The Physics Department was a whole new world, one that was equally stimulating and demanding. The unquestioned intellectual leader of that world was Enrico Fermi. It is difficult to convey the sense of excitement that pervaded the Department at that time.

A number of factors combined to create this especially lively atmosphere. Among these were

Fermi's brilliance and leadership, and the absolutely outstanding physics faculty that had been assembled at Chicago. The many notable physicists who came to visit Fermi also contributed to the excitement in the department. In addition, the pioneering investigations of pion- proton scattering at the newly constructed synchrocyclotron gave Chicago a leadership position in experimental particle research. These all made the Department a very special place at a special time in the development of particle physics.

When Fermi was attracted to the University of Chicago, he came with a vision to establish an Institute for Nuclear Studies, to study nuclear and sub-nuclear physics with the most powerful tools that could be made available.

Slide # 2

Fermi placing cornerstone of his vision at the U of C

Slide # 3

Ribbon cutting for Institute for Nuclear Studies 1950

Slide # 4

Shows Institutes: Initially, 2 Institutes: 1) Institute for Nuclear Studies, 2) Institute for the Study of Metals

A 100 MeV betatron was completed at the Institute in 1950, and in 1951 a 450 MeV synchrocyclotron came into operation. For a few years this cyclotron was the highest energy accelerator in the world and attracted a good deal of attention, like the LHC does today.

Slide # 5

The U of C Betatron

Slide # 6

Construction of U of C Synchrocyclotron

Slide # 7

Life magazine cover showing construction of UC cyclotron

In 1973 the magnet of cyclotron was installed at Fermilab to be employed as an analyzing magnet in Experiment NA 98, a muon – nucleon scattering measurement. This is also shown in this slide, showing the continuing change of scale in high energy physics.

His vision for advancing high energy physics was sadly cut short by his untimely death in 1954, but in a short time he led the effort that discovered the (3/2, 3/2) resonance and confirmed the conservation of

isotopic spin in the strong interactions. This is in addition to the theoretical work he did in astrophysics and high energy particle production. The discovery of the (3/2,3/2) resonance is now seen as the first evidence of an excited state of the nucleon and the first indication of the sub-structure of the nucleon.

He was a very careful experimentalist who delved into all technical aspects of an experiment, often making suggestions that were critical to the success of the experiment. He developed his own statistical methods for analyzing data, which he taught his students and others, and he admonished his students to be generous in estimating their systematic errors. Also, he was not one to jump to conclusions. It took some time before he accepted the validity of the (3/2,3/2) resonance, and in his talks he always left the door open for the possibility that it was not a resonance because in one of the partial wave analyses, the relevant scattering phase shift did not go through 90 degrees. The discovery of this resonance was not confirmed by other experiments until after his death when higher energy measurements were carried out.

Slides # 8, # 9, # 10

First results for pi+ - p scattering and later results.

Slide # 11

Fermi talking to Herb Anderson and John Marshall in the Cyclotron Pit

My first recollection of Fermi is of a talk he gave to incoming students. I vividly remember his advice to us to become experimentalists because the time was especially ripe for great progress in experimental physics, and field theory had come to a dead end. Many of us had wanted to be theorists; but we changed our minds as a result of this advice from some one whom we so greatly respected and admired. The ratio of theoretical to experimental students in our class was very small.

My next contact with Fermi occurred when I was a student in his famous courses in thermodynamics and statistical mechanics that were given in the Autumn of 1951 and the Spring of 1952. These were extraordinary courses, covering in addition to classical physics many aspects of atomic physics, nuclear physics, condensed matter physics, and astrophysics. It was clear to us that Fermi had enormous breadth, as well as depth, in his knowledge of physics. He encompassed all of physics.

In the winter and spring of 1953, he gave courses in nuclear and particle physics and covered virtually all

that was known in these two areas, which were closely related at that time. His presentations were the ultimate in clarity and his legendary physical approach to demystifying problems often gave students the impression that the results were obvious. But they were not so obvious when we tried to reproduce them on our own because we didn't have Fermi's powerful physical insight and his ability to simplify complex problems. Nevertheless, we all tried to emulate Fermi's approach to solving problems.

Fermi did more than his share of teaching at the University of Chicago. He surpassed the required teaching load, essentially covering the entire physics curriculum, including three freshman courses.

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Fermi lecturing

Slide # 13

Fermi's teaching record.

When I passed the Ph. D. examination - called the Basic Exam - I summoned up the courage to ask Fermi if I could do my doctoral research under his supervision. To my great surprise, he said yes; and I was overjoyed to be given this wonderful

opportunity. The emulsion lab that Fermi had established became the center of my activities. The lab's day-to-day operations were looked after by Art Rosenfeld; and some of the other people who were working in the lab at the time were Jay Orear, Gaurang Yodh, Elliot Silverstein, Bob Swanson and Horace Taft.

Fermi was highly solicitous with regard to having his students understand physics. With patience and good humor he was invariably willing to explain any aspect of physics that had escaped their understanding. He had obvious pleasure in explaining his insights to his students. And he was readily available. As I recall, when his office door was open, which was often, one could always go in to see him. Only when it was closed, was he unavailable.

On a few occasions he invited me to social gatherings at his home. He and his elegant wife, Laura, could not have been more hospitable and gracious. He personally took me, a very junior graduate student, around the room to meet his guests. This was another measure of his regard for his students. His students were his extended family. Often at his social gatherings, there were parlor games. And Fermi was very competitive in these and clearly liked to win.

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Fermi playing a game

I noticed that at about 10:30 in the evening all of the guests almost simultaneously left. I was told that Fermi went to bed early and all of his guests were aware of this. He was meticulous about time. Speakers at seminars were told that they would have to finish by 6 pm if they wanted Fermi to be present for their entire presentation. He always promptly left at that time and arrived at work before 8 o'clock in the morning.

Fermi was a cheerful man with a good sense of humor. He appeared to greatly enjoy our annual Christmas parties at which the students and young faculty put on skits that poked fun at members of the senior faculty. Valentine Telegdi, who was a junior faculty member at the time, had an uncanny ability to imitate some of the stellar figures in physics. His ability to imitate Fermi was remarkable. At one Christmas party, Val was enclosed in a huge box with flashing lights that represented a computer and was labeled with the name, the ENRIAC or FERMIAC - I don't remember which. Fermi's voice emanated from the box in a very slow and authoritative manner. This computing machine was supposed to be able to

answer any order of magnitude question in physics, and it was put to some hilarious tests to Fermi's great amusement. He clearly found this very funny. Often in lectures, he would insert quips that displayed his humor and his sense of irony. He was also a modest man. Whenever the subject of Fermi statistics came up in his lectures, he would use the phrase "statistics that obey the Pauli Principle".

Not only had I been a cyclotron operator during some of his pion-proton measurements, I was later an occasional helper on his cyclotron runs. During one run there was something that had to be made in the machine shop, and I offered to do it for him. But it was clear that he wanted to do it himself. This man of genius did not consider working in the machine shop beneath him, and he actually seemed to enjoy it. He had his own private machine shop next to his office in the Institute that he shared with his students. When the plans for the Institute were being developed, he apparently made sure that he would have his own shop. It was my impression that he took a special pleasure in the mechanical devices he designed and made. One of these was the internal target mover that he designed and made for the synchrocyclotron, often referred to as Fermi's trolley. And another was a mechanical analogue of strong focusing that he gleefully demonstrated at a

colloquium that he gave. Fermi was clearly a hands-on experimentalist.

Slide # 15

This shows Fermi's Trolley. Its position in two dimensions could be controlled and measured, and it also measured the beam's energy dissipation in the target. Fermi was an egalitarian man. He participated in every aspect of an experiment, even the dirty parts.

Slide # 16

Fermi enjoyed working in the lab.

Slide # 17

Fermi checking the meter readings in synchrocyclotron's control room

Fermi's presence at Chicago not only attracted an outstanding faculty, but he also drew some of the most renowned physicists in the world as visitors to Chicago. I clearly remember Pauli's and Heisenberg's visits and the excitement their presence caused among the students.

Up and coming young physicists were also attracted. He hired Gell-Mann just out of graduate school. And Feynman visited a few times to give Fermi

private lectures about his latest calculations, and the people working in Fermi's lab were invited. I can recall Fermi listening with a smile on his face as Feynman, speaking with a somewhat exaggerated Brooklyn accent and great animation, reported his latest results on liquid helium.

We had many illustrious speakers at our seminars and colloquia. Fermi inevitably would have penetrating comments and questions. His questions were gentle but sometimes devastating to the speaker, and they usually started off with the phrase 'There is something that I do not understand". After seminars and colloquia, Fermi and Teller often had fascinating exchanges, which sometimes were very much like sparring matches. I often felt that I was observing the discourse of titans who spoke in a language that I did not yet fully understand.

SLIDE # 18

Fermi and Teller conversing in the U of C Quadrangle

For my thesis research, Fermi suggested that I carry out a nuclear emulsion investigation of proton polarization produced by nuclear scattering, an effect that had been observed at cyclotron energies. The objective of this study was to determine whether the

polarization resulted from elastic or inelastic scattering. I did not know at the time that Fermi had already theoretically shown that elastic nuclear scattering could produce large polarizations. This calculation was in his famous notebook of problems that he had investigated and solved. The calculation was, as usual, based on a simple model, utilizing a real and an imaginary nuclear potential and a spin-orbit coupling term. This is the same term that he had suggested to Maria Mayer as possibly playing a role in the structure of the nucleus and which was crucial to her development of the Shell Model.

When I had only partially completed scanning my emulsion plates, Segre visited Fermi and told him that he had observed large polarizations in nuclear elastic scattering in a counter experiment at the Berkeley cyclotron. According to Segre, on the morning of his visit, Fermi calculated the polarization produced in elastic scattering and his results matched Segre's measurements beautifully.

I had been scooped and was quite dejected. However, Fermi was very understanding and suggested that I continue my measurements. First, it would be valuable to confirm Segre's results with another technique; and secondly, I could also determine to

what extent inelastic scattering produced polarization.

During this period I also sat in on Fermi's wonderful courses in quantum mechanics, which were given in the Winter and Spring of 1954. These were the last courses he gave at Chicago. That summer he went to Italy where he became ill. When he returned to Chicago in September, I saw him in a corridor at the Institute. We were some distance apart and we waved to one another. I was struck by how gaunt he looked. The next day he underwent exploratory surgery at Billings hospital and was found to have inoperable cancer. I never saw him again.

Chandrasekhar told me that when he and Herb Anderson first went to visit him at the hospital, they were initially at a loss for words. Fermi sensed this and put them at ease by asking, "Tell me Chandra, when I die will I come back as an elephant?" After that remark, the conversation proceeded smoothly. Fermi was truly a remarkable man in all respects.

Fermi died on November 28, 1954. It was a terrible loss not only for our department but also for the world of physics. In 1955, I completed the project that Fermi had assigned to me, verifying Segre's results with different nuclei and showing that

at cyclotron energies highly inelastic scattering had no measurable polarization, but that quasi –elastic scattering had a small polarization. John Marshall kindly signed my thesis.

After Fermi's death, I was asked to gather up his books and journals for the University of Chicago. I don't remember finding any journals, but I found about four books. I no longer remember the titles or authors of the books, except for one, which was probably there for sentimental reasons. It was written by his boyhood friend, Enrico Persico. It was clear that Fermi didn't need books. He worked out everything himself.

I was indeed fortunate to have been taught and supervised by this giant of physics and to have seen the practice of physics carried out at its very best, at such an early stage in my development. Over half a century later, I still look back in awe at this great physicist and remarkable human being.