The Discovery of the b Quark

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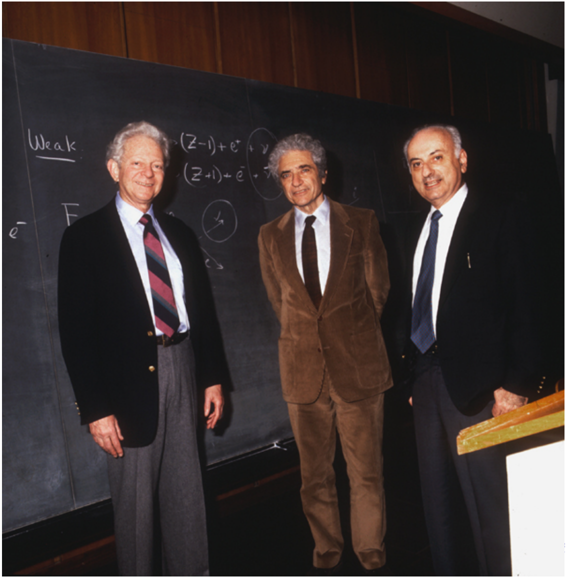
Background

- In 1962, Leon Lederman, Melvin Schwartz, and Jack Steinberger discovered the muon-neutrino at the AGS at Brookhaven.
- Afterwards, Lederman and his collaborators started several experiments looking for physics in the single muon and dimuon channels.
- Lederman wanted to find the W and Z. At that time, it was believed that they could have masses as low as a few GeV, making them accessible at BNL (proton beam energy 28 GeV).


Weak
(Z−1)+e⁺+ν
(Z+1)+e⁻+ν̄
e⁻
F

The 1968 BNL Dimuon Experiment

This experiment was based on *ranging*.

- An intense proton beam was steered into a Uranium beam dump, where all hadrons, electrons, and photons were absorbed.
- Only muons would survive. By measuring the range and direction of each muon, one could reconstruct the dimuon mass (with poor mass resolution).
- Decay muons contribued over 90% to the dimuon spectrum, but this background could be subtracted using measurements of accidentals.

A Strange Feature

The experimenters observed a broad bump at 3 GeV (note: J/ψ mass $= 3.1$ GeV). Lederman and his collaborators had several ideas for what this bump could be:

- Another ρ' resonance? (since their mass resolution was bad, they couldn't tell how wide the peak was)
- Light-cone theorists claimed they could explain the bump without resonance
- Some collaborators were opposed to making a big deal over the resonance interpretation

To pursue this further, Lederman took a two-pronged approach: the Fermilab search (high luminosity high-energy accelerator) and the CERN ISR search (highest collision energy with dielectron non-magnetic spectrometer).

Fermilab Study

Lederman and the E70/E288 collaborations at Fermilab wanted to do a survey of all leptons produced using the high-intensity Fermilab proton beam. The experimental setup consisted of:

- a target box
- A sweeping magnet to remove low-momentum particles and bend interesting electrons into
- detectors (outside the neutral-beam envelope). The detector was made of scintillator-hodoscope arrays (to measure e^- position and bend angle), backed up by a lead-glass array (to measure e^- energy and differentiate e^-'s and hadrons)

The group focused on the direct electron production.

Neutral Current Observed!

- Up until 1973, all observed weak interactions were consistent with a charged boson.
- In 1973, the Gargamelle collaboration at CERN announced the first observation of a neutral current interation:

$$\nu_\mu + \text{nucleus} \rightarrow \nu_\mu + \text{p} + \pi^- + \pi^0$$

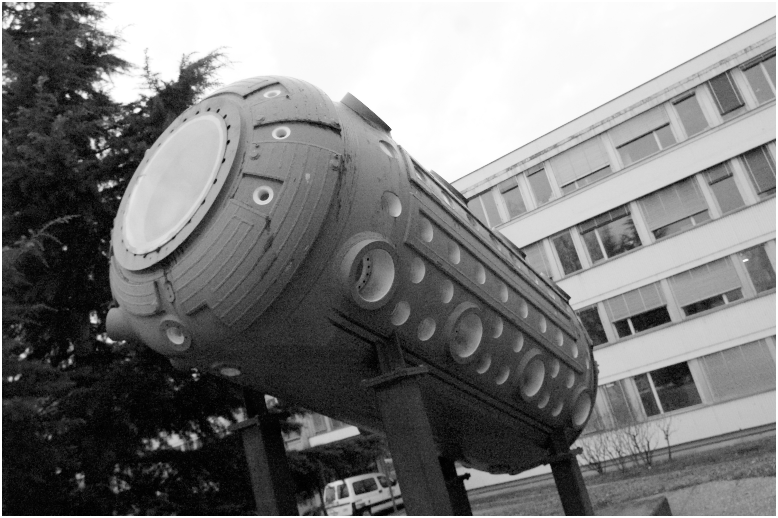
- It suddenly became very urgent to find the $W^\pm, Z^0$ bosons!

The November Revolution

While Lederman's group worked on direct-electrons, Sam Ting discovered the J particle while redoing Lederman's BNL dimuon experiment with dielectrons (along with the additon of multiwire proportional chambers).

At the same time, the Ψ particle was found at the SLAC Mark I experiment using an electron-positron storage ring.

It turns out that the J and the Ψ were the same particle, and the charm quark had officially been discovered.

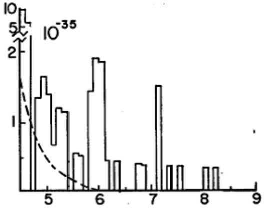


E288/CFS at Fermilab

After the November Revolution, it was clear that Lederman's collaboration had missed a big discovery. As a part of Proposal 288, they began working on some new searches:

- First, E288 worked on the virtual photon spectrum of e^+e^- pairs using MWPCs and a two-arm spectrometer.
- Next, Stony Brook joined the group, working on a dihadron spectrum (with a new number, E494). They also built gas Cherenkov counters to differentiae among π's, K's, and p's.
- By the middle of 1976, the dielectron data showed a clustering of events near 6 GeV. The probability of such a clustering occuring anywhere in the plot was estimated to be about 1 in 50.

Upsilon, or Oops-Leon?



It appeared that a discovery might be on the way. They decided upon the letter Υ for talks suggesting a new resonance (and "Oops-Leon" if it was fake!)

In the spring of 1976, the collaboration took data in the dimuon channel, which provided a factor of 5 increase in sensitivity. The clustering dissapeared, and the 6 GeV "bump" was shown to be an Oops-Leon after all!

Revenge of the Upsilon

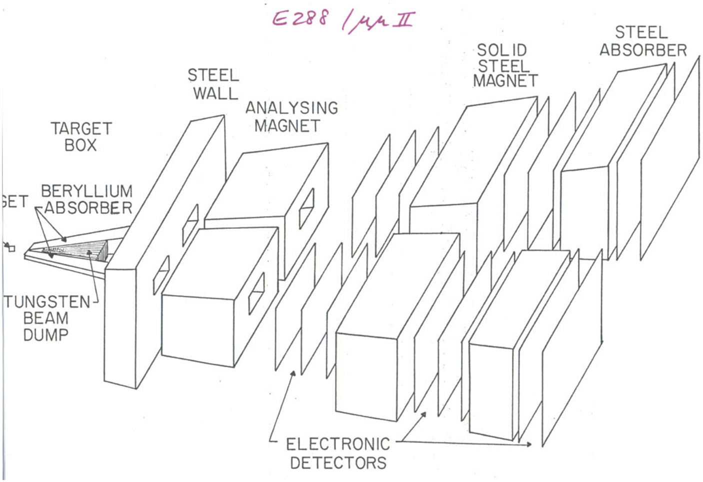
After the Oops-Leon bump was erased, another clustering in the dielectron spectrum began to appear around 9.5 GeV. 10 events (!) had been found within 300 MeV around 9.5 GeV. Despite a 1 in 200 probability of a fake clustering, the collaboration decided to be more careful this time.
John Moh, the experiment coordinator, set aside a bottle of champagne with "Υ9.5" written on it. 1976 ended on a hopeful note, and in spring of 1977, the second dimuon search would begin.

$\mu\mu$ II Phase

To prepare their detector for the dimuon search in hadronic interactions (which had high sensitive), absorbers were put in place to absorb hadronic debris.

- The absorbers ended up being troublesome and resulted in multiple scattering.
- To fix this, they placed the densest absorber near the interaction point, and low-Z absorbers afterwards.
- This lead to smearing of the production-angle measurement, but not a large error in momentum measurement.

Additionally, the target box was upgraded to be a Be absorber with interchangeable Be, Cu, and W absorbers downstream of the target.


E288 / μμ II
STEEL ABSORBER
SOLID STEEL MAGNET
STEEL WALL
ANALYSING MAGNET
TARGET BOX
ET
BERYLLIUM ABSORBER
TUNGSTEN BEAM DUMP
ELECTRONIC DETECTORS

One Last Crisis

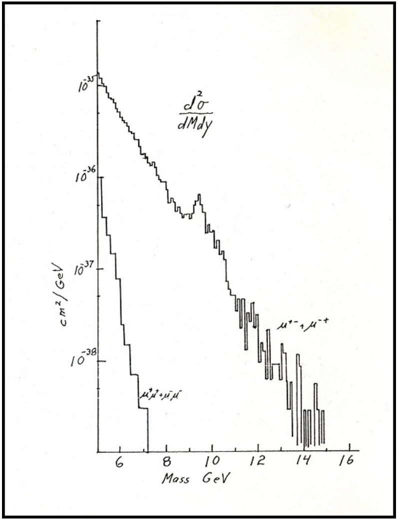
On May 13th, 1977, the $\mu\mu$ II Phase of data-taking began. Of course, there had to be one final disaster: On May 20th at 11 PM, a magnet shunt failed and started a dangerous fire. Smoke, laden with chlorine and fluorine, filled the experiment pit, coating the electronics in residue.

Luckily, Lederman knew a Dutch fire-salvage expert who fixed a similar problem at CERN. Unfortunately, he was having problems getting his visa. Lederman was able to convince a high official at the local embassy to help them (the official was a Columbia alumnus). The electronics were cleaned, and the experiment was saved.

Discovery and Impact

Within a week, the 9.5 GeV resonance had been confirmed with more that 8σ. The discovery of the new-and-improved Υ was announced on June 30th, 1977.

This discovery was actually much more unexpected than J/Ψ. At the time, the third-generation hypothesis was only supported by weak evidence from Mark I for the τ, although Kobayashi-Maskawa had speculated the existence of six quarks. The discovery of the Υ was the first strong evidence for three generations of particles.


$\frac{d^2\sigma}{dMdy}$
10^{-35}
10^{-36}
10^{-37}
10^{-38}
cm^2/GeV
$\mu^{+-}+\mu^{-+}$
$\mu^+\mu^+ + \mu^-\mu^-$
6
8
10
12
14
16
Mass GeV