Traipsing – Herumspazieren – Through Some Fifty Five Years of Experimental Particle Physics

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INTRODUCTION

Particle physics as we know it today,
with its connotation of large accelerators
and huge experimental groups working
with huge complex detectors,
was not always so,

In fact quite the opposite!

For those of us who worked in it for about half a century,

we are proud of our composite achievements in ferreting out the existence of short lived quarks, intermediate bosons and leptons.

We also admire the ingenious theoretical construct, the Standard Model – SM –,

which describes with such accuracy the properties and interactions amongst the particle-world denizens known today.

Nevertheless, we know that we are standing at a peculiar fork on the road of the future development of our field.

We can not think that bigger and better machines, collaborations alone are sufficient to go further.

New insights, both theoretical and technical, are needed as well. It is time to take a look backwards at how we arrived to where we are.

How did we accumulate the present particle table and why did we aim our efforts in the particular directions we did.

Specifically as experimentalists, we ask ourselves:

What drove us to measure the properties of known particles better and better?

Just because they're there?

What drove us to search for hypothesized particles?

Just because theorists said they ought to be there?

What fuels the relentless drive for better (and eventually bigger) instruments?

Who made the specifications (specs in technical jargon.)?

In this series of lectures Paolo and I will attempt to answer the above questions, mostly for ourselves.

Clearly he and I have different views, if not opposite, very often orthogonal. We come from dissimilar background, when young I knew only of the Asian literary world, was a "tabula rasa" as far as Western scientific thought is concerned. Paolo instead, was steeped in its Apollonian tradition, with both parents being physicists.

What we have in common however, is that we are experimentalists foremost, phenomenonlogists second. We are both constrained by the reality of the instruments at hand and what we can build, and the results which come out from our experiments.

This is why you will see alternate lectures given by he and I. For example I get the first shot on the historical introduction, and he in the second lecture will tell you HOW we formulated these understandings.

You will see that for me that Particle Physics began with the question WHY was there leakage of charge from the nicely shielded ionization detectors on earth? And when they were proven to be radiation from outer space, WHAT are these creatures?

Of course, in his and my narratives, WHO did what, and WHERE (which lab?) did it first? come in, but remember we're not historians and don't claim neither complete knowledge, nor impartiality.

If we are to go back to, say to 1933,

there were essentially five established elementary particles:

electron (1897, J.J. Thomson), proton (1919, Rutherford, He+N$\rightarrow p+X$),

photon (1923, its particle property established via Compton scattering),

neutron (1932, Chadwick, $np \rightarrow np$) and positron (1932).

Note that all elements necessary to construct matter, atoms and molecules, were present, except...

What holds a proton and a neutron together?

Sure, there were hints that more particles ought to exist,

(1) a massless spin 1/2 particle, the neutrino

for explaining that the β spectrum from radioactive decay is continuous.

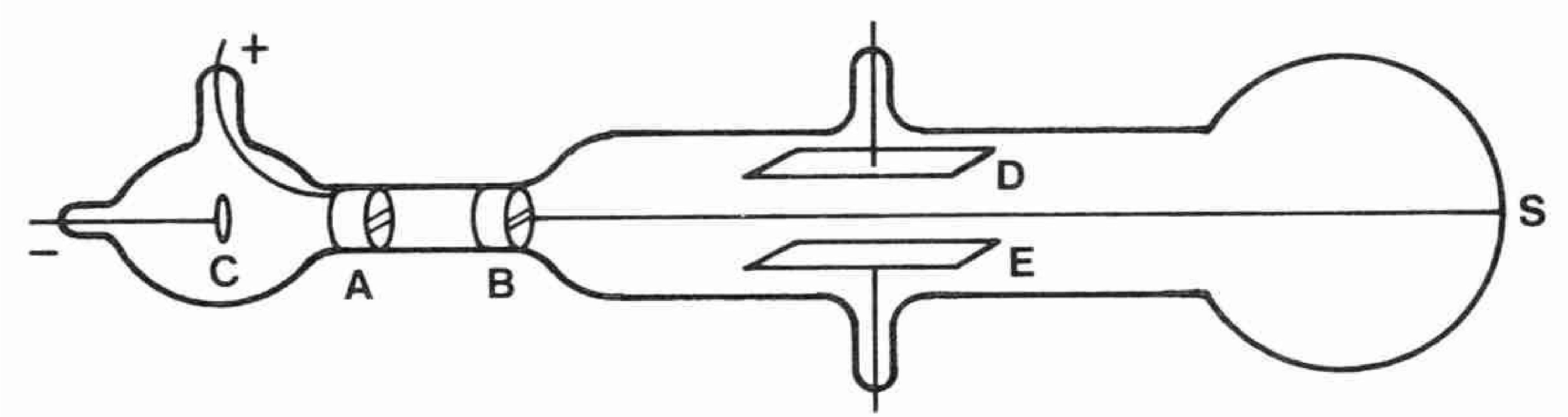
(2) where is the antiparticle of the proton,

since the proton is not the anti-electron, as first thought by Dirac, and the newly discovered positron is clearly the anti-electron

(*albeit* we did not need it to construct matter, nor the e^+)?

The establishment of the first four particles which began in the late nineteenth century, had been a real saga of: studies of X-rays and radioactive sources in the laboratory by measuring scattering angles, ionization loss and energy absorption in matter, using cathode ray tubes (CRT), photosensitive plates and ionization counters.

All through particle history experimentalists have capitalized on the fact that as charged particles pass through matter they knock off some electrons (also produce secondary particles)... resulting in tiny charges which can be collected and measured by various devices (neutral particles manage somehow to make charged ones).


+
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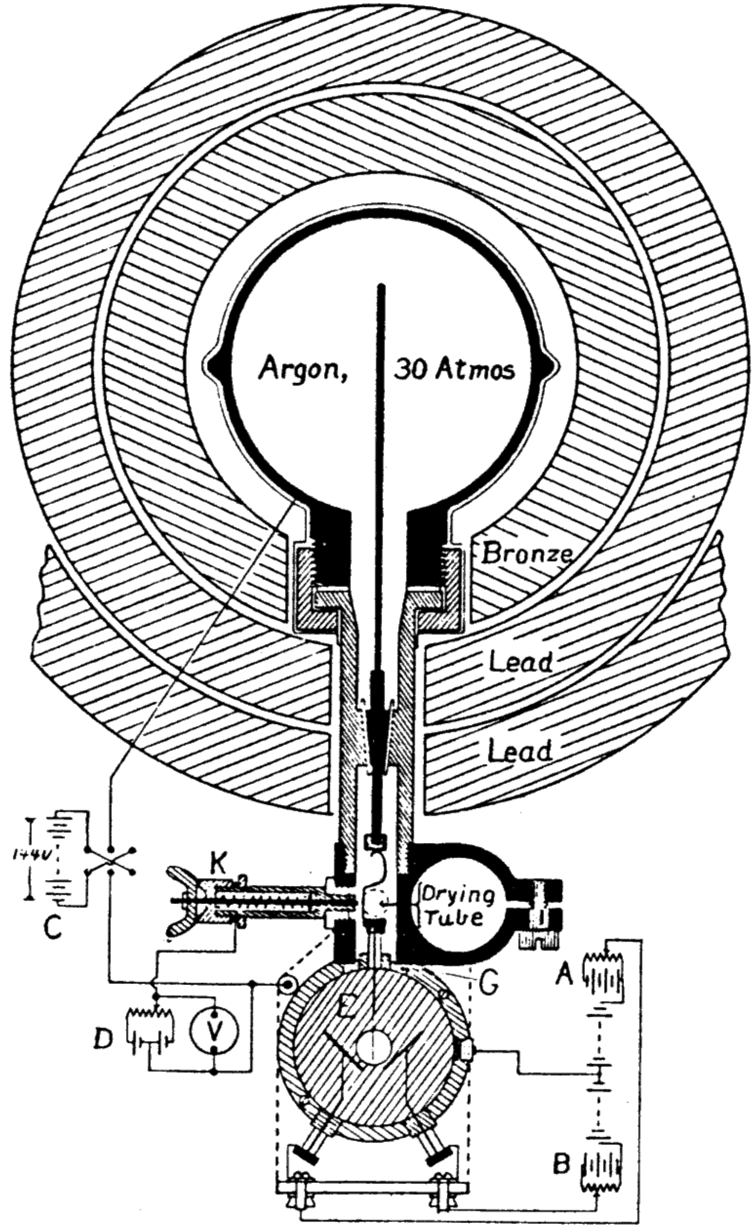
Ionization of a charged particle depends on its charge, Z, squared and inversely on its speed, $1/\beta^2$, squared (a slow particle spends more time around the atoms in the detecting medium thus losing more energy).

The distance it takes for a charged particle travelling in a medium to lose all its energy, i.e. stop, is called its range R. The range depends on the amount of kinetic energy the particle had initially, hence on both its mass and speed.

Note that one needs independent measurements to determine an unknown particle's charge and mass.

There are ∼two classes of detectors. Some give us limited information, maybe only that a particle is there. Some can follow a sequence of events.


Argon, 30 Atmos
Bronze
Lead
Lead
K
144V
C
Drying Tube
G
A
E
D
V
B

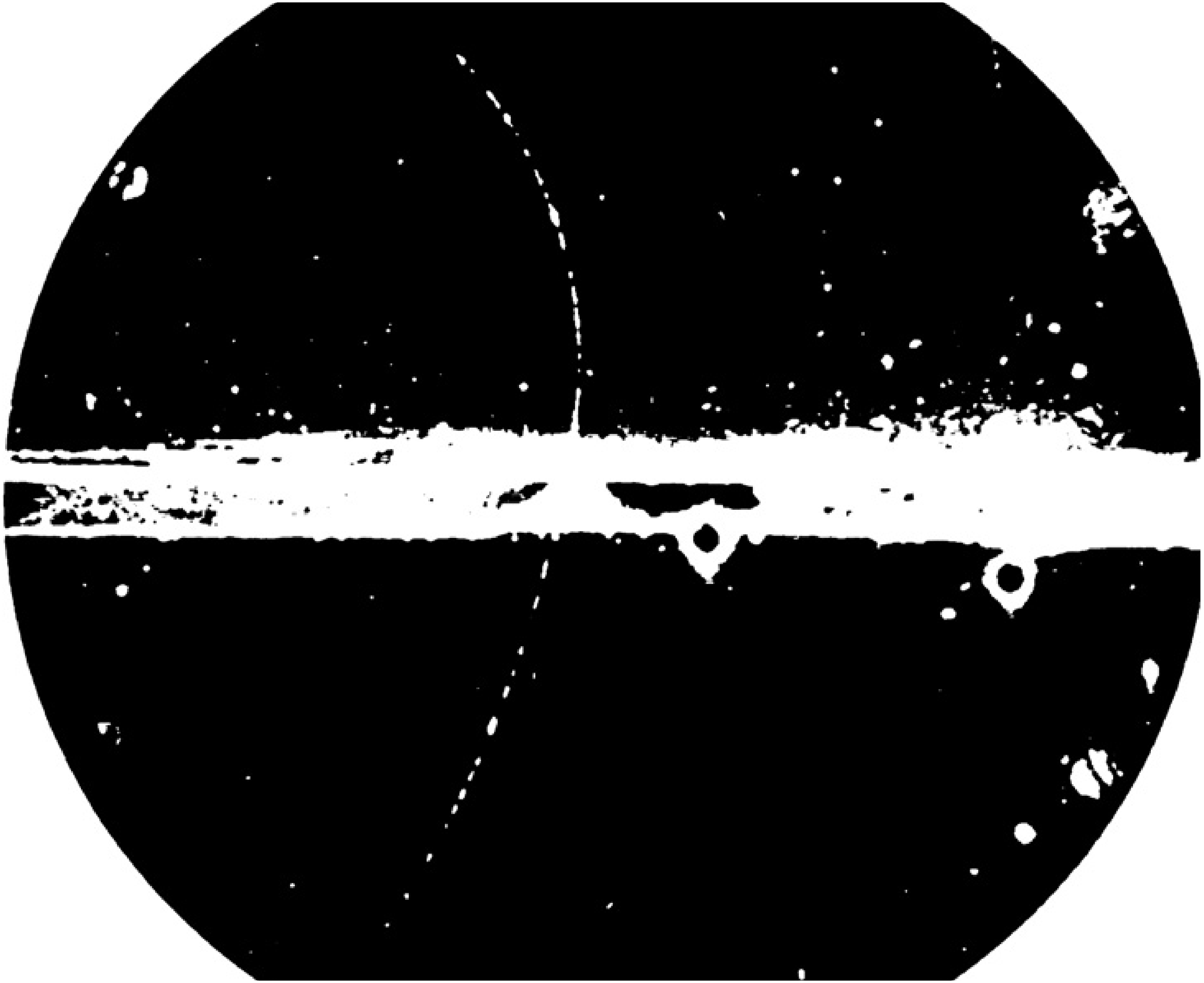
The positron's discovery by Anderson, resulted from studying curved particle tracks in a Wilson cloud chamber which was surrounded by a magnet, exposed to cosmic rays.

We see here the first significant entry of momentum measurements in a magnetic field in high energy particle studies (recall that the CRT's always had magnetic and electrostatic deflections of the particle rays).

The cloud chamber was the foremost visual instrument for cosmic rays physics.

Its one limitation was that its live time is only a tiny fraction of the exposure time, $\sim$1/1000. This was largely removed by outfitting it with trigger counters, Blackett and Occhialini, 1932.

21 MeV



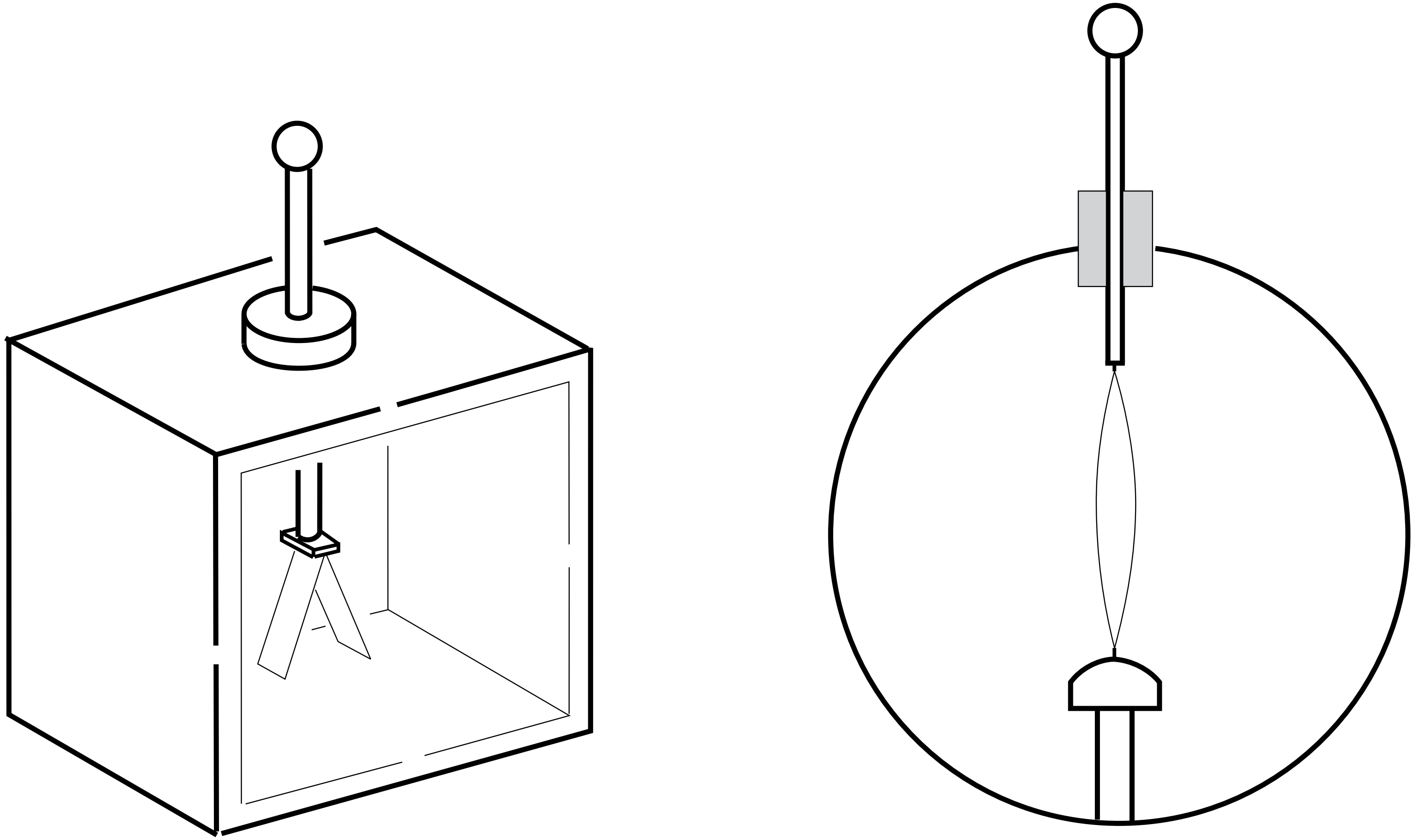
LEAD

63 MeV

Amusingly, Anderson shared his Nobel prize, NP, (1936) for this discovery with Victor Hess,

who in 1912 during a balloon flight, over Europe, noted that his electroscope's gold leaves were bombarded by more and more radiation as his balloon gained more and more altitude (from 5,000 to 17,500 feet).
He was thus belatedly recognized as the discoverer of cosmic rays whose name was given by Millikan, another story.

(reminiscent of Van de Meer's winning the NP for providing the $\bar{p}$ source together with Rubbia's wining the prize for the W's produced).



Father Wulf's electroscope
went up the Tour Eiffel in 1910

Incidentally, the Wilson chamber itself had been invented in 1912, but Wilson's Nobel prize was awarded only in 1927,

"for his method of making the paths of electrically charged particles visible by condensation of vapor".

He shared his prize with A.H. Compton
"for his discovery of the effect named after him" using a spectrometer.

Odd pairing, isn't it?

Also, during this period when measurement and analysis techniques had obviously been evolving at a great rate, machines for creating and manipulating particle sources were being invented.

In 1931, E. O. Lawrence proposed the cyclotron and tested a first model (NP 1939).
In 1932, first evidence of nuclear reactions with accelerated protons were seen by J. D. Cockcroft and E. T. S. Walton (NP 1951).
In 1933, Van de Graff invented the electrostatic accelerator (NP none).
Incidentally, the NP was first awarded to Röntgen in 1902, for the discovery of X-rays, only 100 years ago.

If we were to step to 1947, we'd notice that the particle list has been augmented by at least three more species

(1) The "mesotrons" seen in cosmic rays in the previous decade have been shown to be two distinct particles:
(a) pion, specifically π^+.
The pions' existence had been postulated by Yukawa in 1935 (unknown to most people), as the mediator between neutrons and protons to bind the nucleus. They should come both charged and neutral.The predicted neutral pion was not discovered until 1950 since it decays into two photons within 10^{-16} sec.

(b) muon, specifically μ^+

Particles with masses around 200 MeV actually had been seen first in 1936 by Anderson and Neddemeyer in their cloud chamber, announced informally during his NP award ceremony for the e^+ .

They deduced the mass by looking at tracks which had penetrated a one cm platinum plate placed in the middle of their chamber, their change in curvature before and after, coupled with energy loss in the plate. Two other groups had also seen the "mesotrons", and knew their average speed were greater than 0.3 c.

One property of the Yukawa particle is that it should be radioactive, namely decay.
The first such decay was detected by Williams and Roberts, they saw in their chamber a "fast" electron emerging from a slow "mesotron" of the same charge.

They inferred the speed of the particles because the incoming particle track was becoming increasingly **darker**, and the emergent same charged particle track consisted of sparsely spaced dots.

The first attempts to measure the “mesotron” lifetimes were by Bruno Rossi, who measured the number of “penetrating” cosmic rays as a function of the thickness of absorbers placed above and in between layers of Geiger counters, and of altitude, to separate the effects between decay and collision.

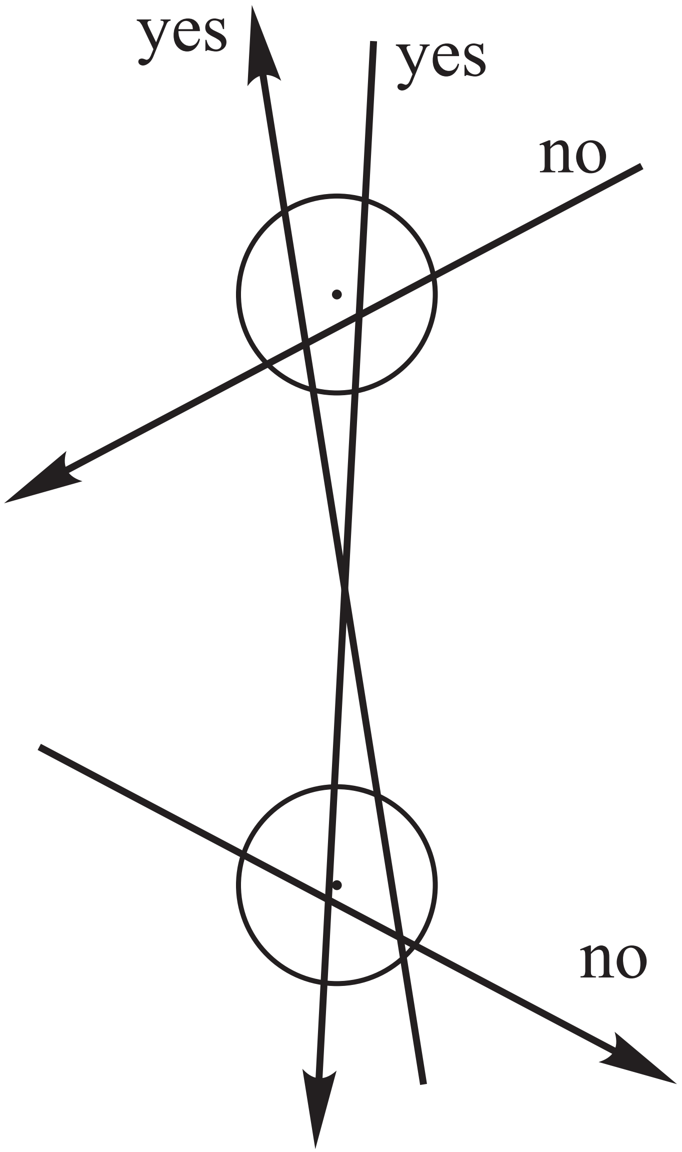
Amazingly, he was able to deduce the “mesotron” mean life this way, to be about 2 microseconds.

Incidentally, the Geiger-Muller counter, an ionization chamber which operates in an avalanche mode, was invented in 1929.

It became so well known that it featured in Schrödinger's "cat in the box" *gedanken* (I hope) experiment.

Put a cat in a closed box, along with a vial of poison gas, a piece of uranium, and a Geiger counter hooked up to a hammer suspended above the gas vial. During the course of the experiment, the radioactive uranium may or may not emit a particle. If the particle is released, the Geiger counter will detect it and send a signal to a mechanism controlling the hammer, which will strike the vial and release the gas, killing the cat. If the particle is not released, the cat will live. Schrödinger asked what could be known about the cat before opening the box?

Bothe first (1929. NP, 1954) used coincidence between two G-M counters. Rossi designed an electronic coincidence circuit of far greater accuracy. He could thus observe coincidences between the delayed signal from "mesotron"'s coming to rest in the absorber surrounded by his counter array, and a later electron's emergence. He measured a lifetime of 2.15 μs, close to the value he'd obtained in 1938.



The test as to whether these “mesotrons” were the nuclear glue, pions, postulated by Yukawa was done by Conversi, Pancini and Picioni, under most trying conditions between 1943-1947.

This experiment is based on the fact that positive pions should decay and negative pions should interact with nuclear matter, that is, be absorbed before they could decay to electrons. To make a long story short, they found the negative “mesotron” were absorbed in iron, but not in carbon, as published in Phys. Rev. in 1947. So their negative “mesotrons” did not always interact with nuclear matter strongly, so failed the test.

The final disentangling of the two “mesotrons” was aided by the arrival of a new technique now called: nuclear emulsions, sheets of photographic emulsions which consist of a not-so-thin layer of gelatin containing crystals of silver bromide, placed one upon one another to form a stack for exposure to particles, before removal for development.

By the way, immense delicacy during preparations, intricacy in analysis, as well as visual beauty, is often found in nuclear emulsion studies. It merits its own lecture, later.

Powell and Occhialini had been working with Ilford to improve photographic emulsions. The first new batch they left at various high altitude cosmic rays stations.

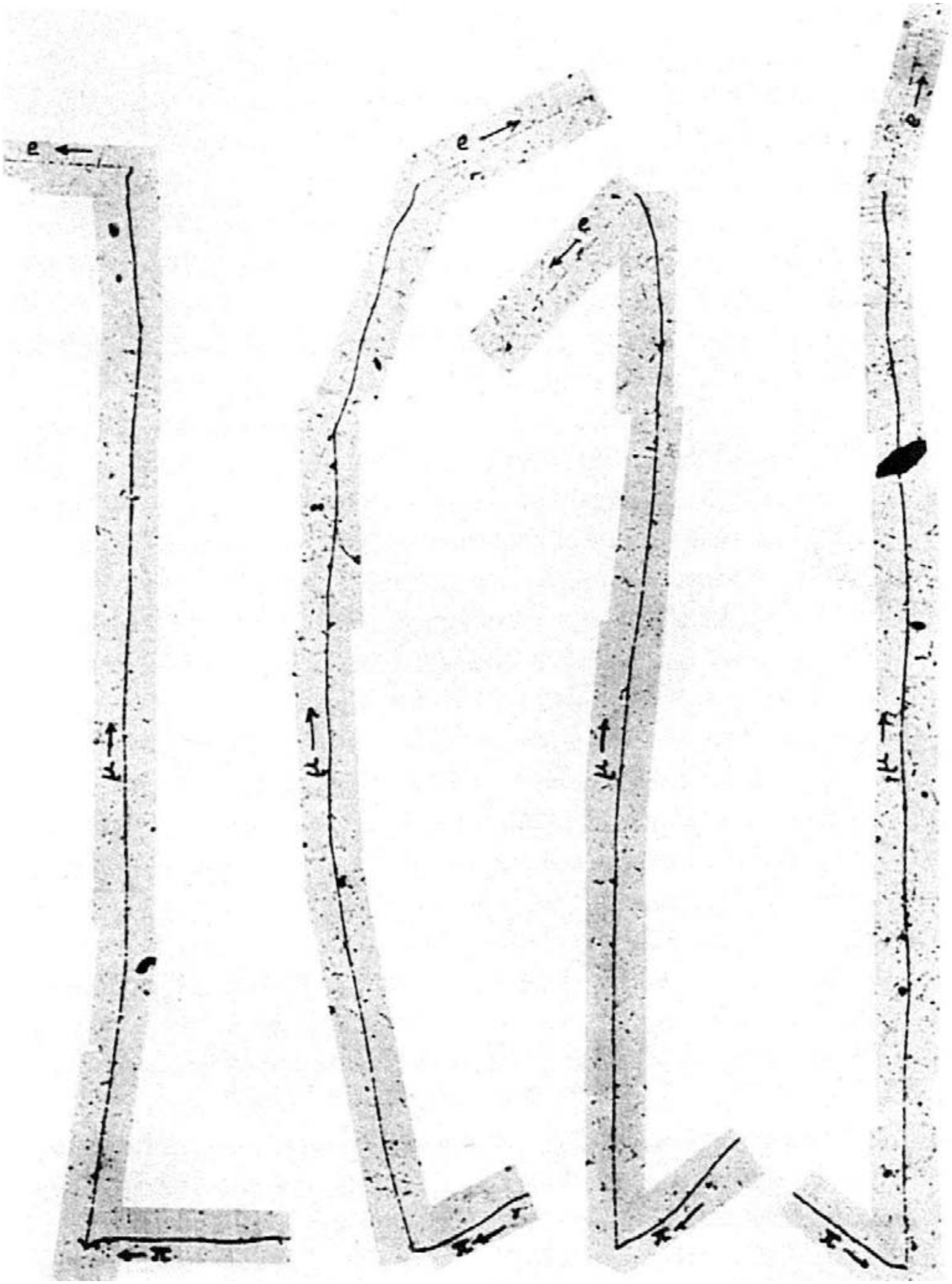
After exposures of weeks, they found a group of tracks which showed an increase of grains and scatterings, signalling a stopping particle, followed by another track which slowed and stopped. The primary particle was dubbed a pion, had a mass of about 350 electron masses, m_e.

The daughter, dubbed the muon, had a mass of about 200-300 m_e. All the secondaries had identical path length, circa 600 microns, hence had the same kinetic energy, signifying a two body decay, the other secondary particle was invisible (neutral).

Meanwhile, little “stars” were also observed in nuclear emulsions at other labs, signifying nuclear interacting “mesotron”’s existed as well.

Thus two kinds of negative “mesotrons” coexist: the negative pion interacts strongly with matter, the negative muon decays.

In short, the Yukawa particle was found.


e
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e
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μ
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μ
μ
π
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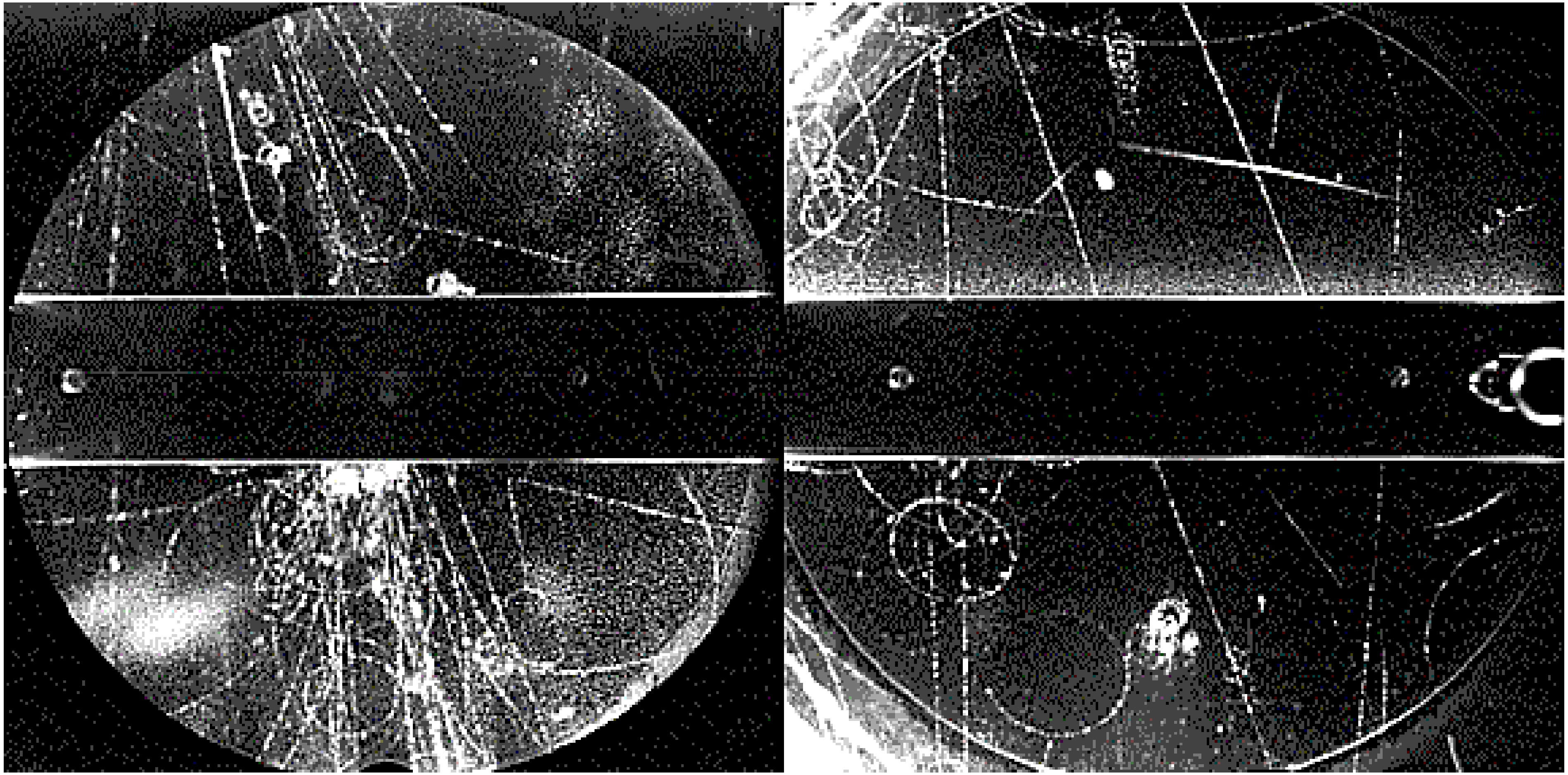
π

(2) The first sighting of Strange particles , in the form of two “V-events” in cloud chamber exposures was in 1946, published 1947. Their appellation was simply topological convenience, they’d not been foreseen, hence “strange”, a la Gell-Mann.

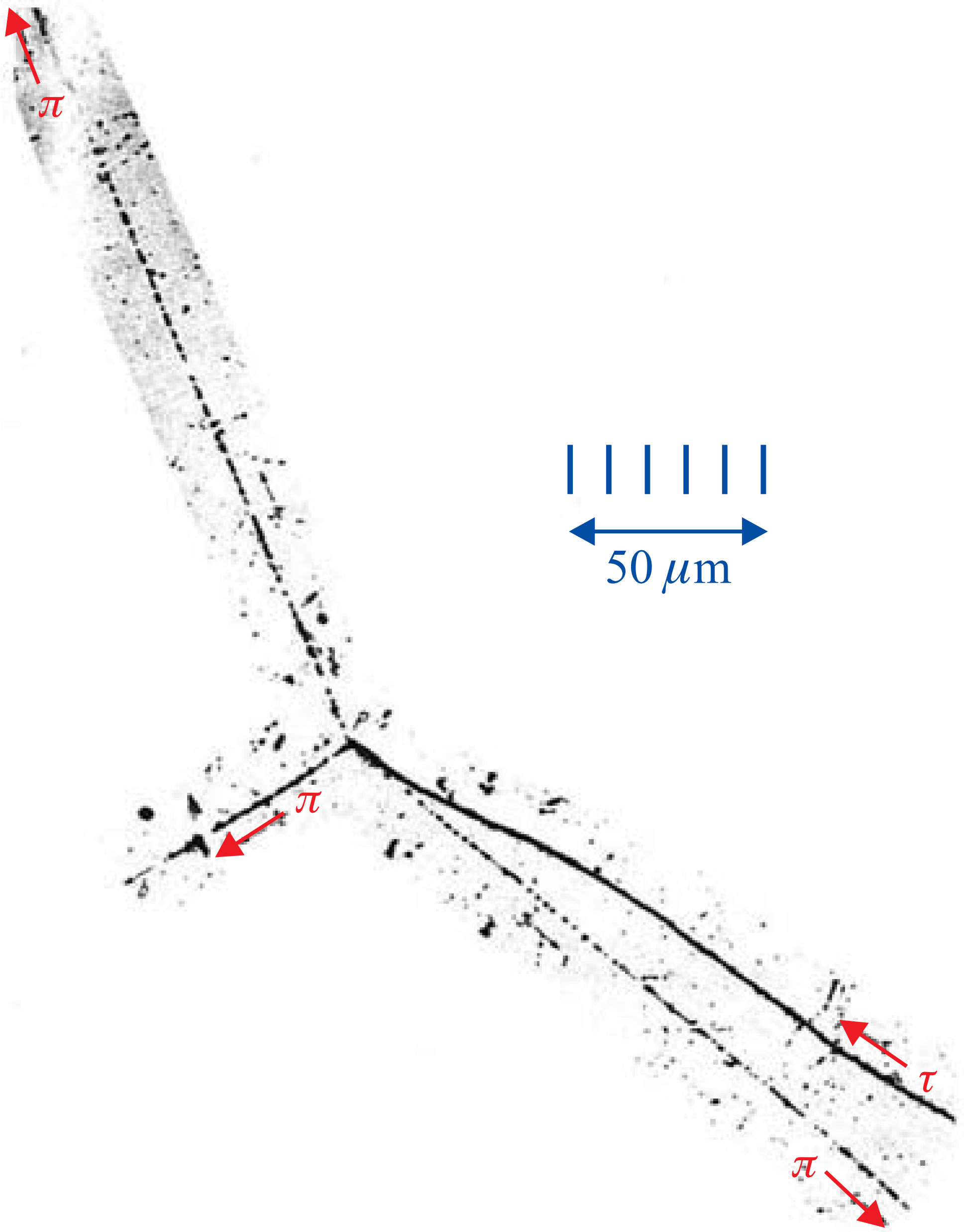
The first “V” had a secondary which traversed across the lead plate in the chamber, the second “V” suddenly appears a little distance from the lead plate. The first “V” was estimated to have a mass about 770 m_e, and the second “V” is patently the decay product of a neutral particle whose mass is about 1000 m_e.



During the late 1940's and early 1950's, research groups multiplied as fast as did new event types. There was keen competition between cloud chamber and nuclear emulsion groups, for ex. a 960 m_e particle was seen to decay clearly into three pions in nuclear emulsions in 1951

To clarify the nature of these new objects, it became imperative to have man-made sources for them, which meant high energy machines,

In fact the first production of π^0's was observed at LBL in 1950, strange particles were first produced at the Cosmotron in 1953.


π
π
τ
π
50 μm

Paolo and I entered the field around 1954, as you see, a very exciting and also chaotic time.

We were flooded by the experimental questions of HOW MANY of these particles are there? HOW do they interact? And, HOW do we improve and invent Instrumental Techniques to answer these questions?

Remember, we don't propose to go into a real discourse of particle physics history (in fact the whole business of credit attribution WHO? WHERE? is just as contentious here as in any other field.)

What this series of lectures are intended to convey is the impressions from the voyage of a couple of experimental physicists during their journey through this half a century of the so-called

Golden Age of particle physics

LECTURES

1. From the Nucleus to the Muon
2. Cloud Chambers, Cosmic Rays
3. Nuclear emulsions, μ, π, K, ν
4. Fast scintillators and electronics. Muon helicity, $\mu \not\to e\gamma$
5. Spark chambers. Michel parameter
6. Bubble chambers. Flavor, $\not{R}$, WI
7. Solid state detectors, pp resonances
8. Crystal calorimeters, Υ spectroscopy
9. Hadron calorimeters, D0
10. General purpose detector: KLOE