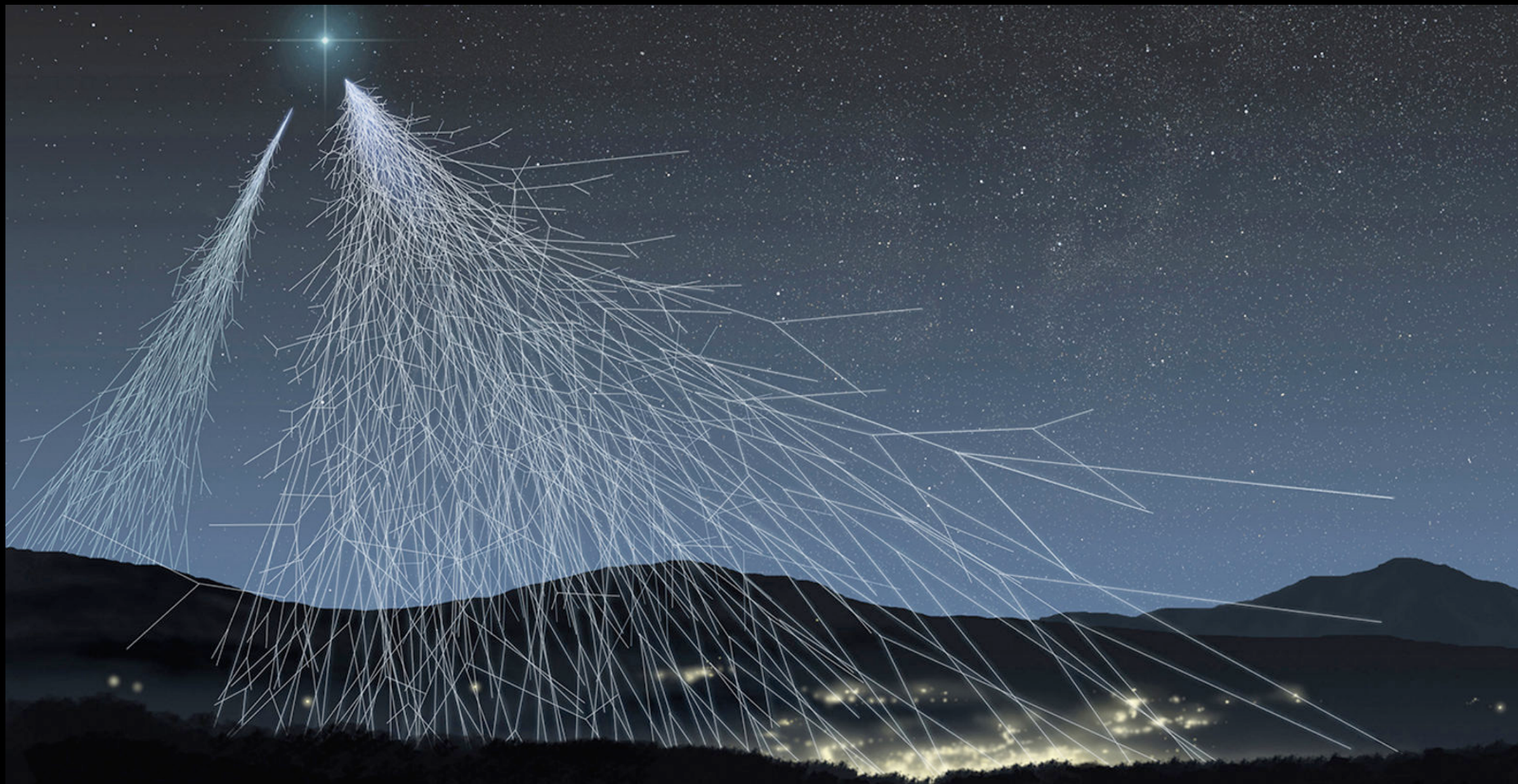
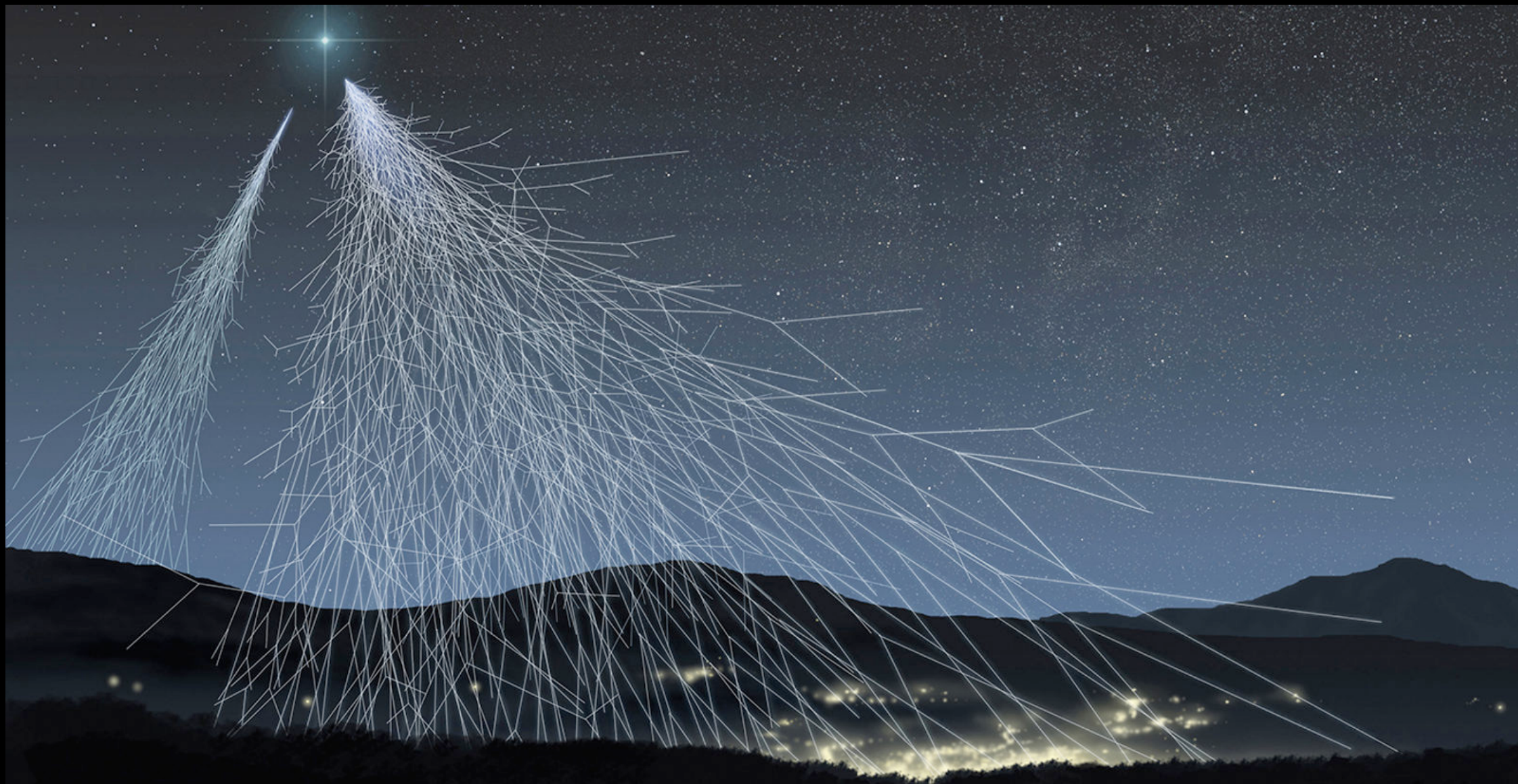
Muons and pions

Freshman seminar

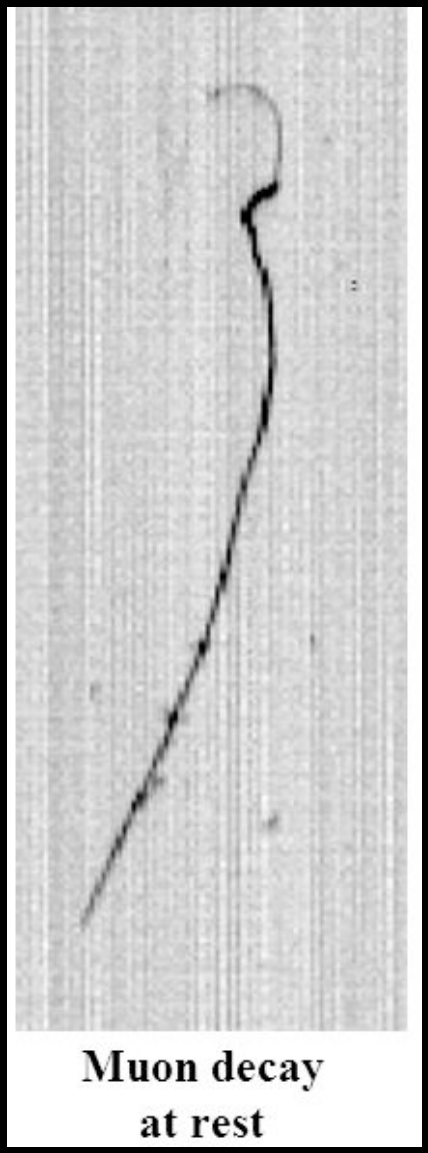
David Stuart, UC Santa Barbara



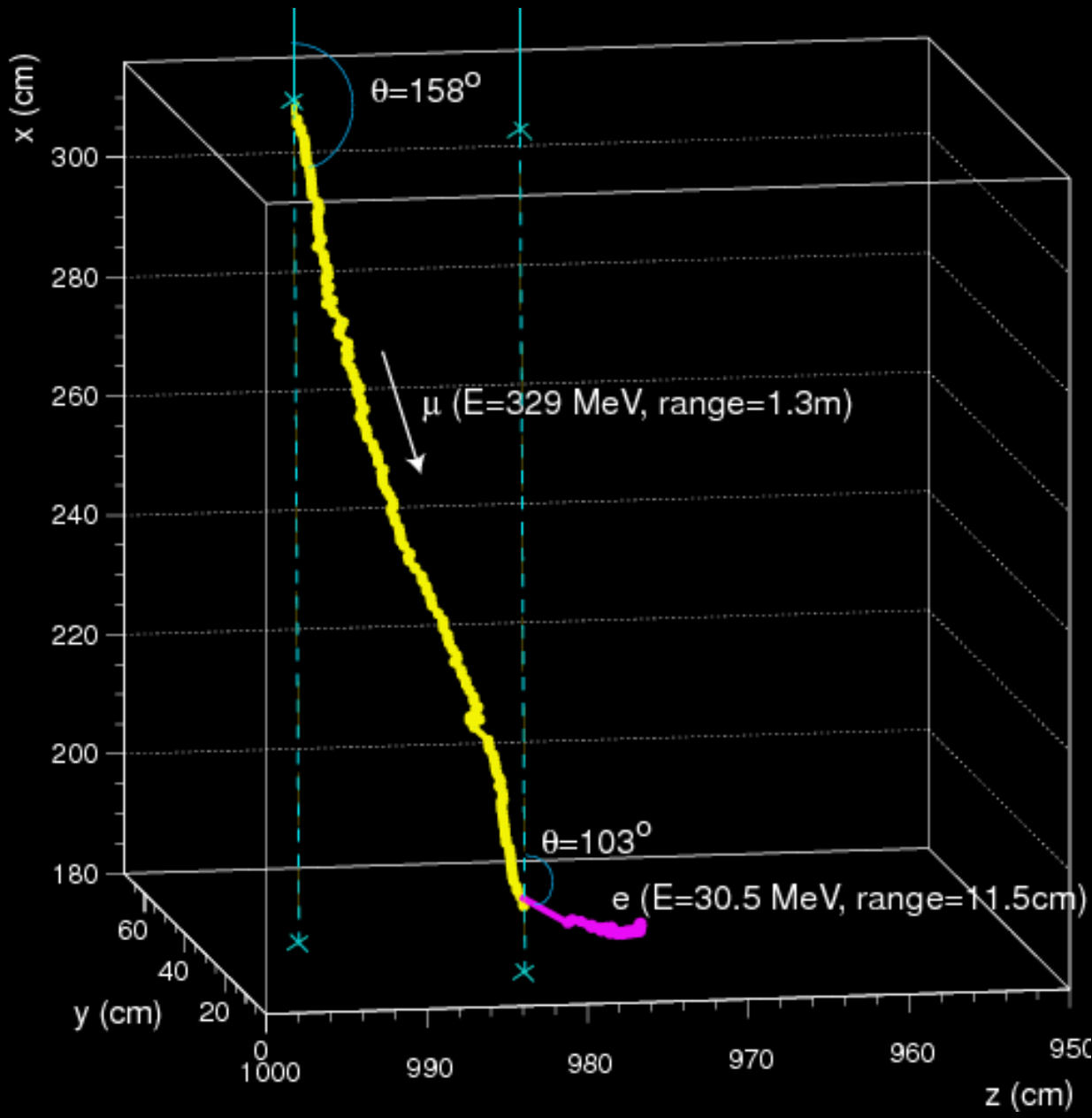
Recall that last time we discussed the discovery of cosmic rays, which involve a new particle called the muon.



Muons decay to electrons with ~2 microsecond lifetime. $\mu \rightarrow e\,\nu\,\nu$
And it behaves like a heavier version of an electron.



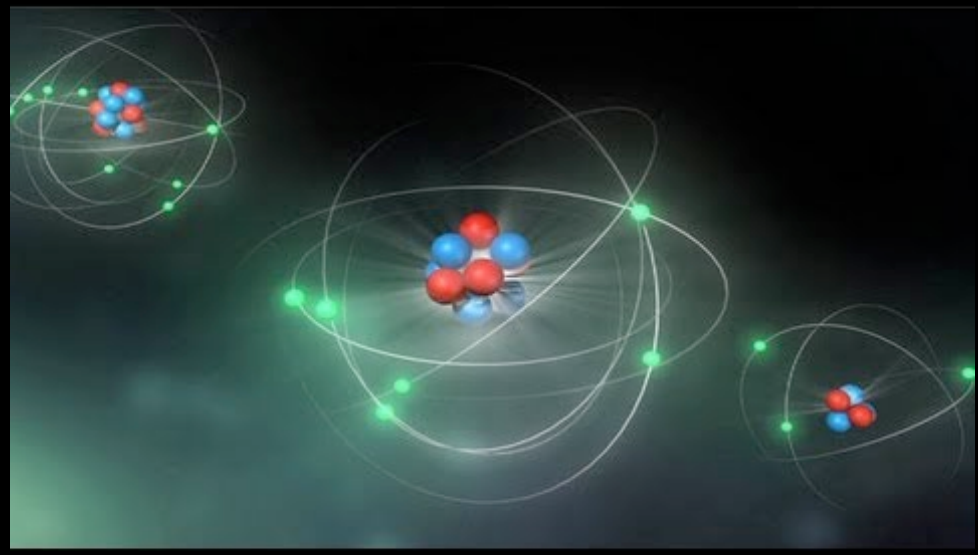
Muon decay at rest



Icarus, Eur. Phys. J. C33 (2004) 233-241

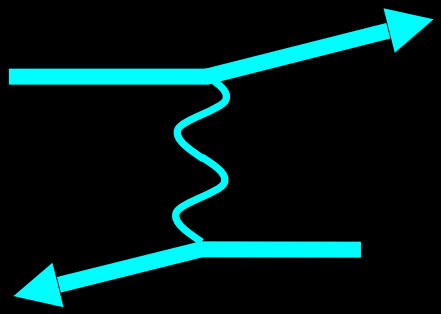
How does this new particle fit into understanding the fundamental constituents of matter?

Initially, it was thought to be the solution to another puzzle.



What holds the nucleus together?

The nuclear force is much stronger than electrostatic repulsion of the protons; called the strong force.



Photon exchange for EM force.
Meson exchange for Strong force.

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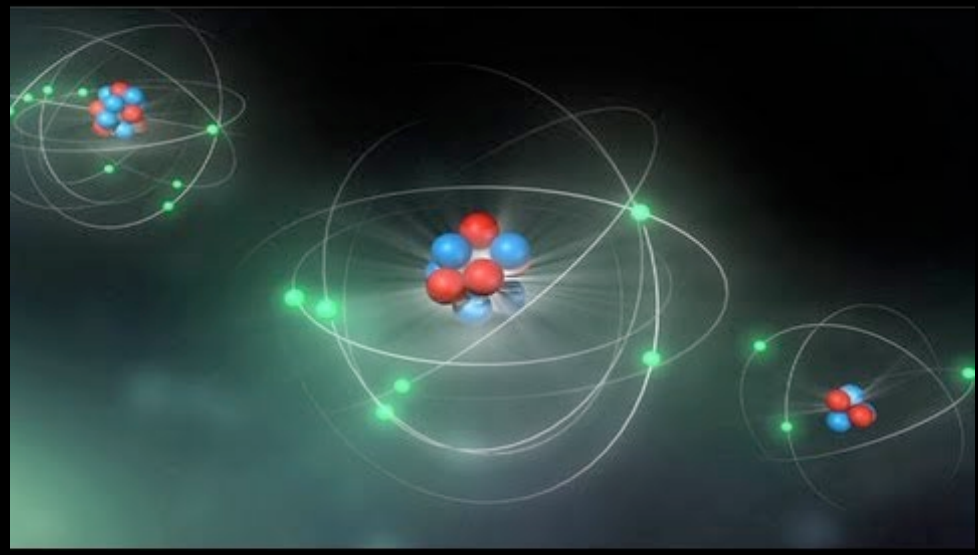

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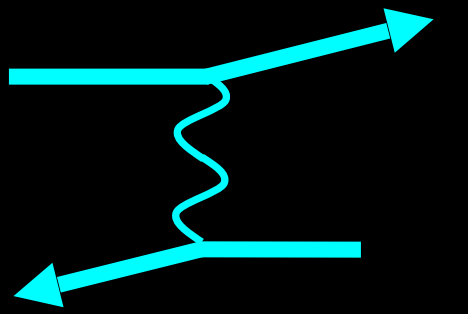

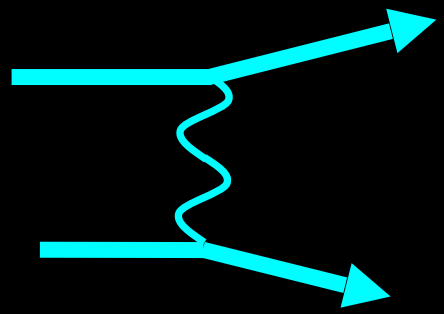

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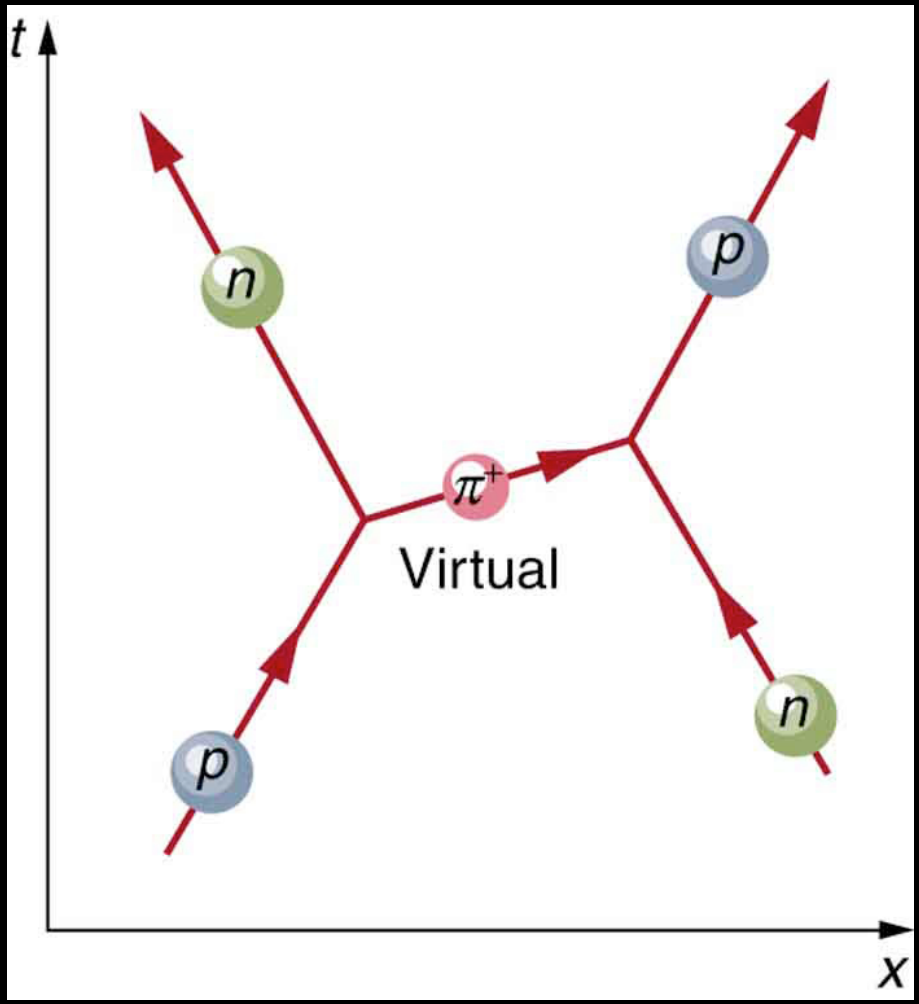

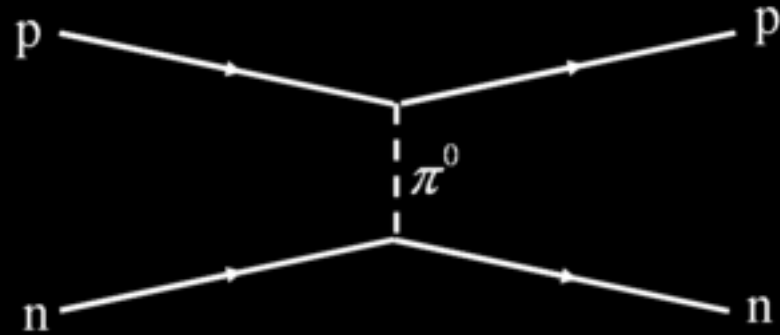

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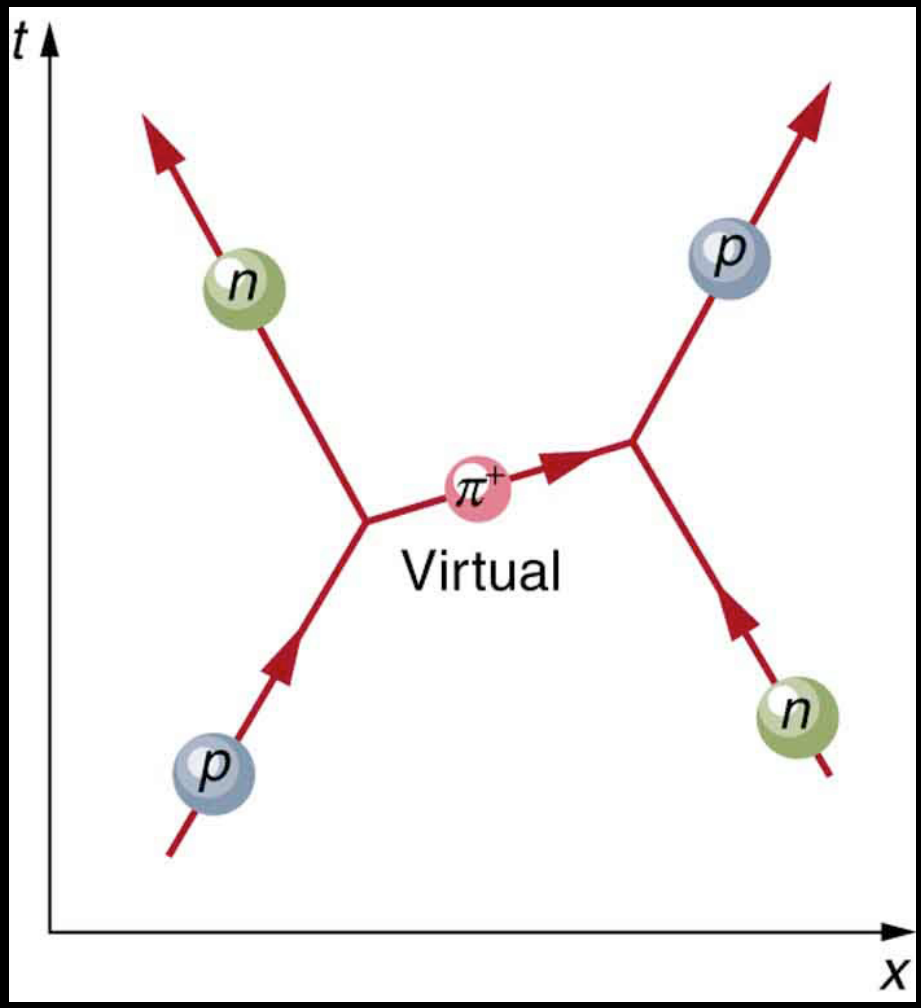

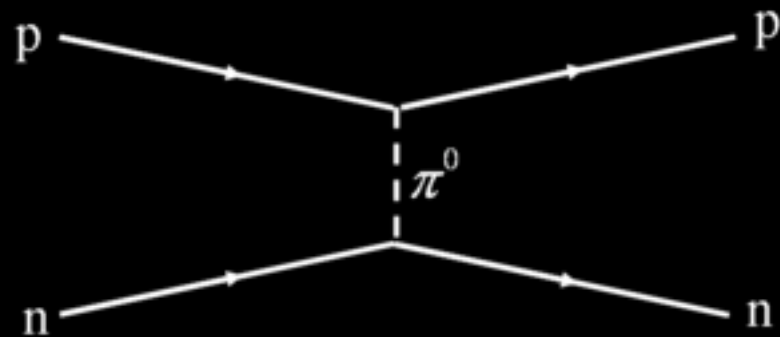

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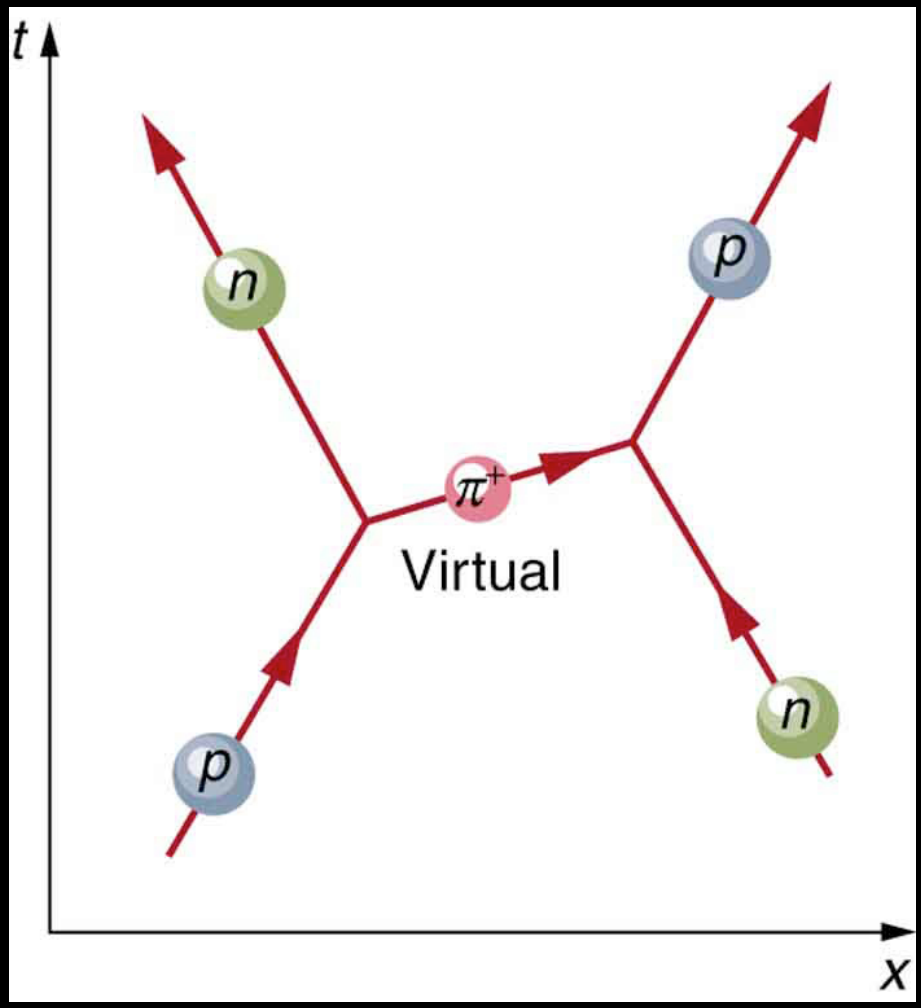
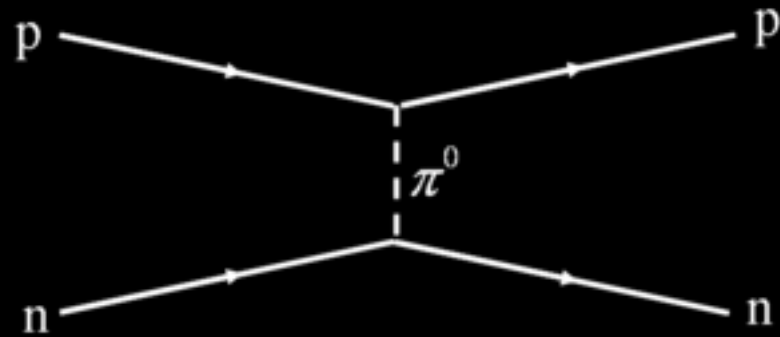
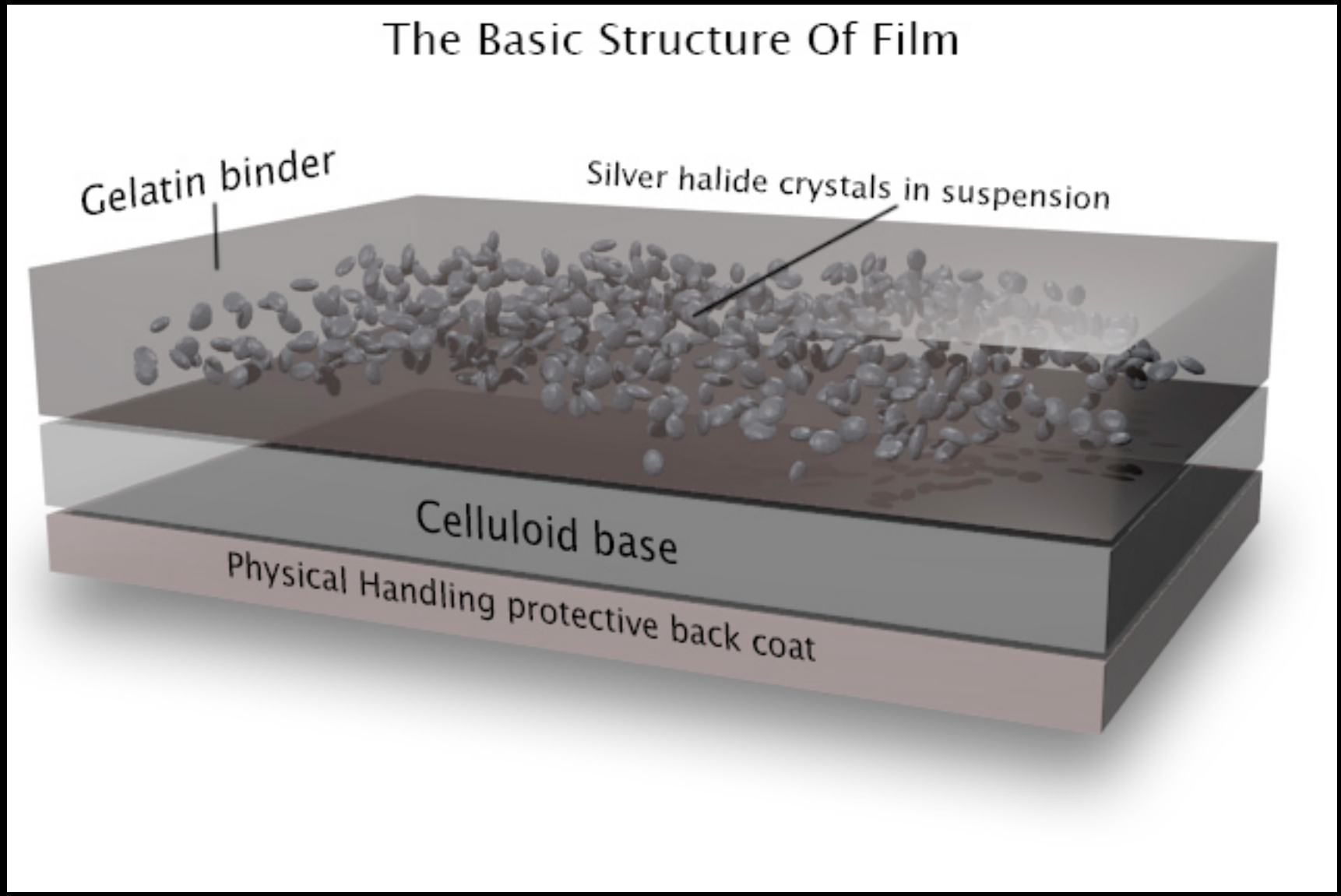
So what should be done next?





Measure the properties of the muon carefully.

Nuclear Emulsions were developed from photographic film



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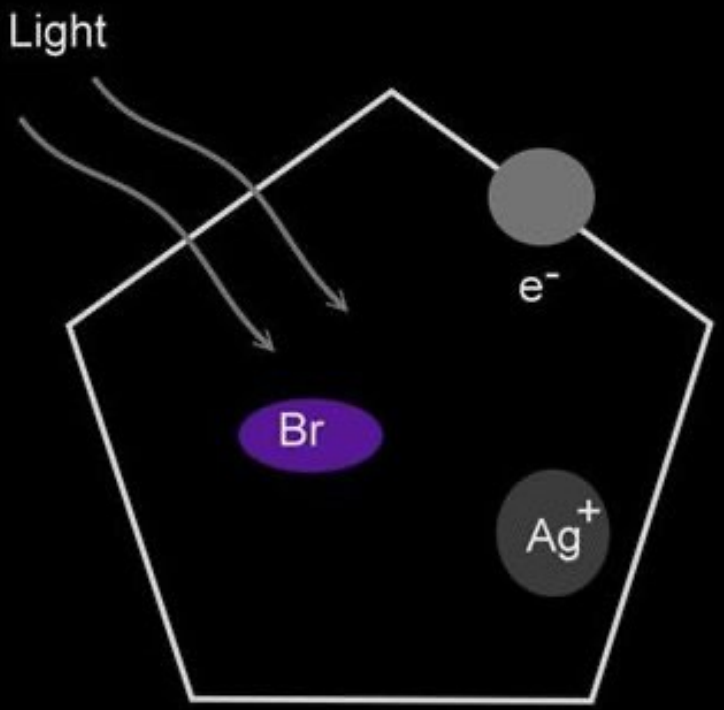

Light or ionization produces
free electrons in a Ag+Br- crystal
The electrons move to a charge trap
(impurity in the crystal).

That attracts the Ag+ ions toward it.

Chemical processing later uses that
Ag+ build up to generate a
metallic silver cluster that blocks light.

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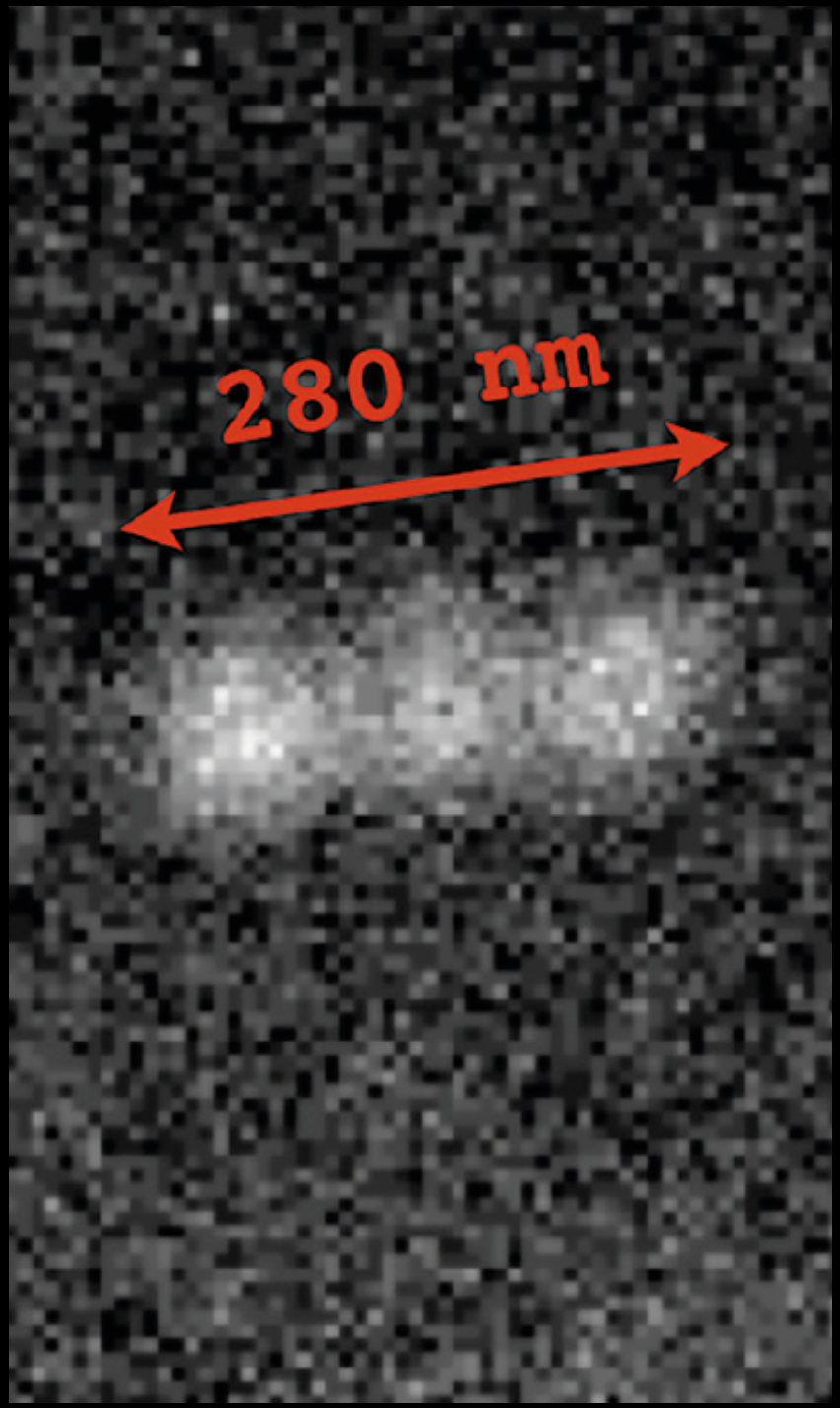

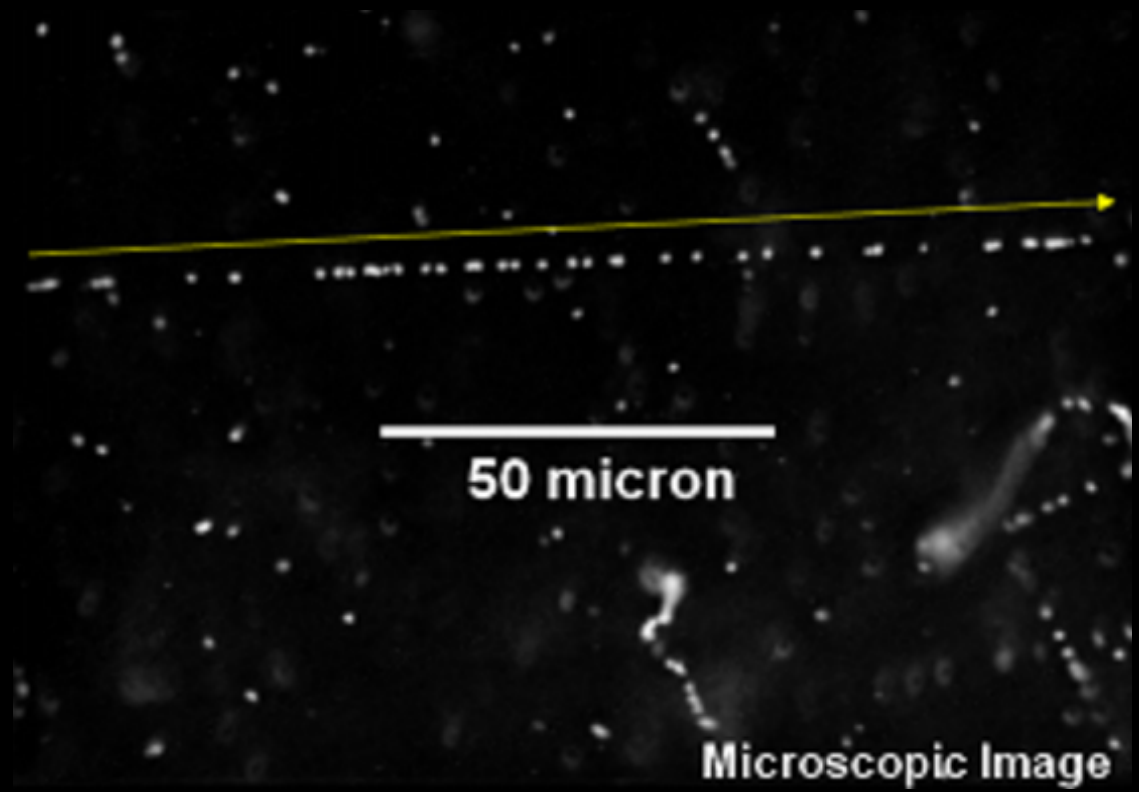

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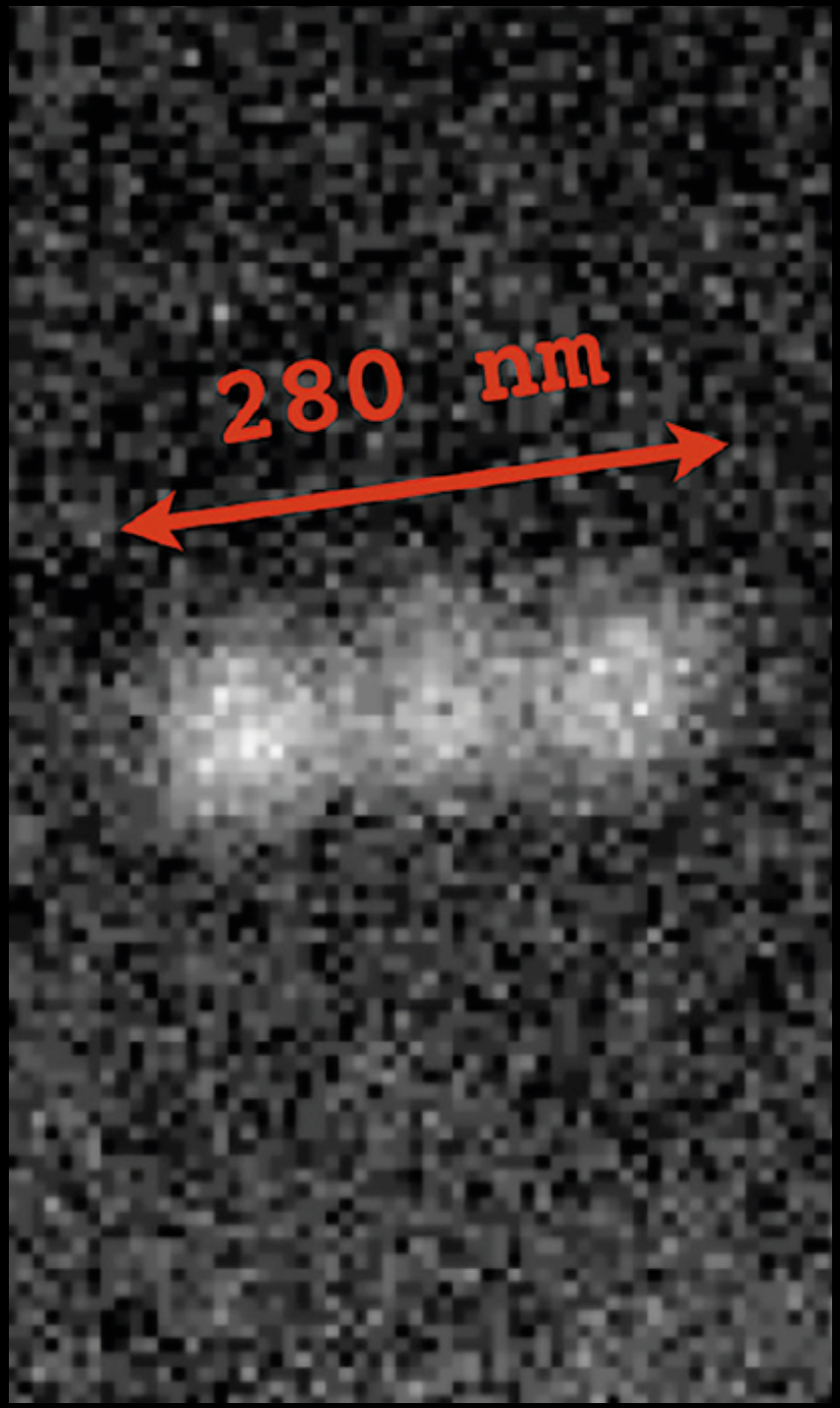
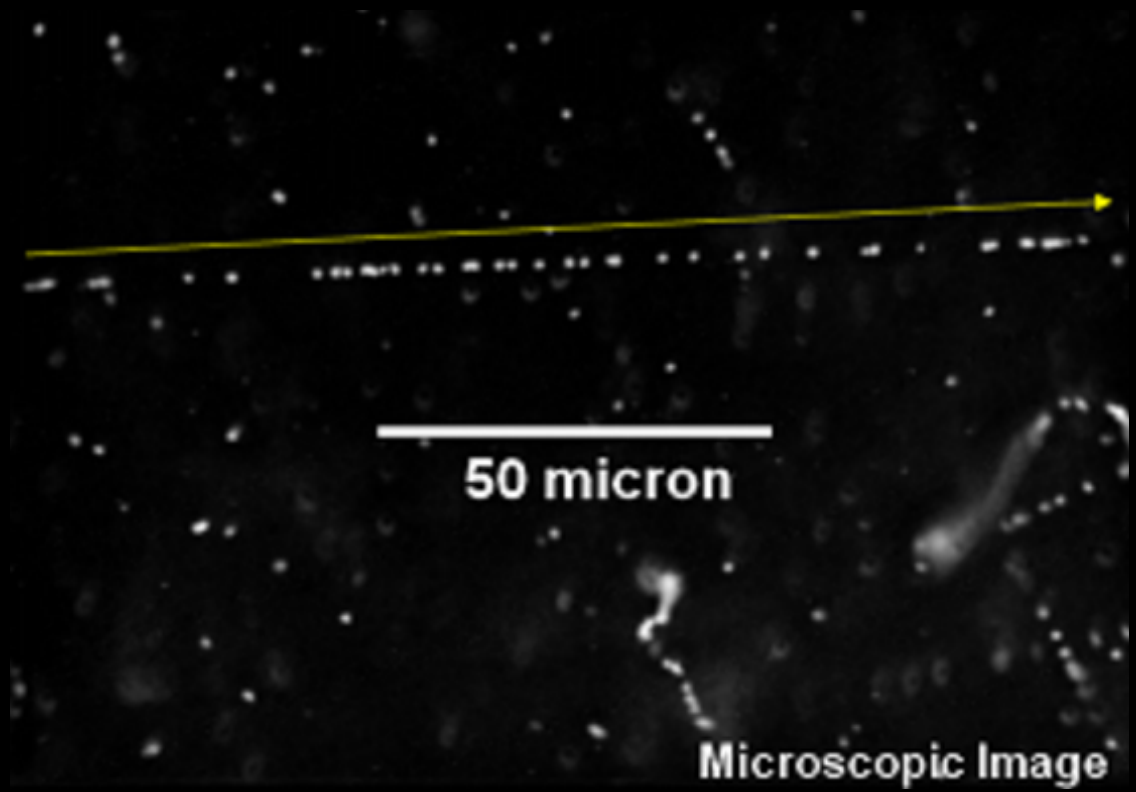
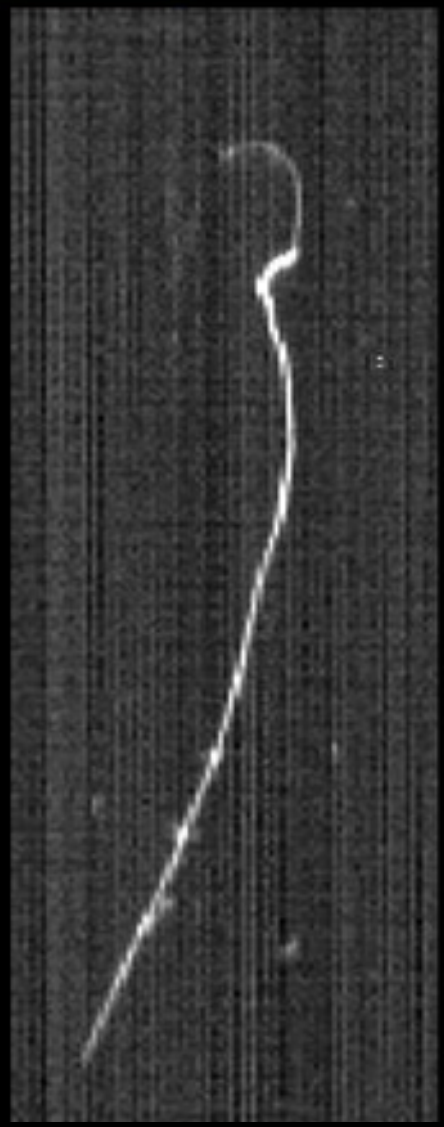




What are all of these things?

Some example events in nuclear emulsions. What are they?



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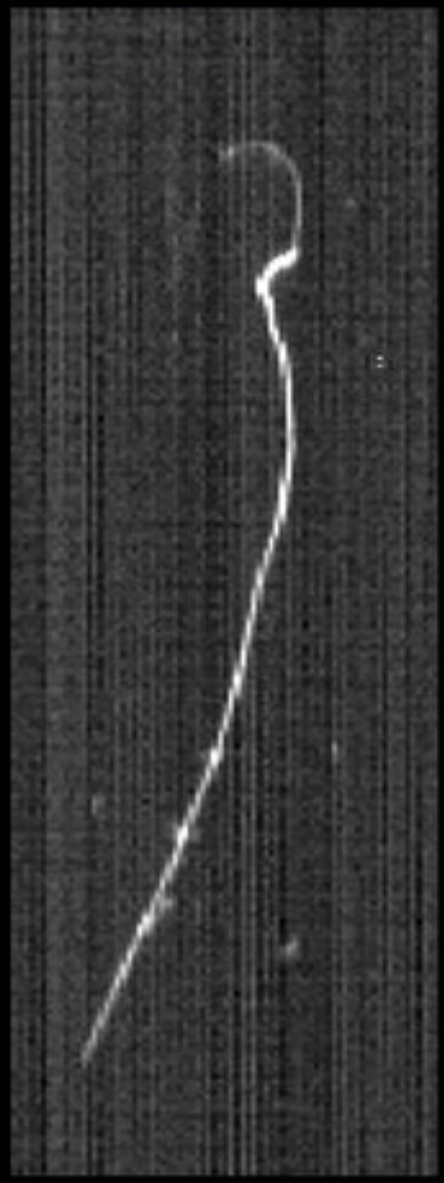

Muon decay at rest

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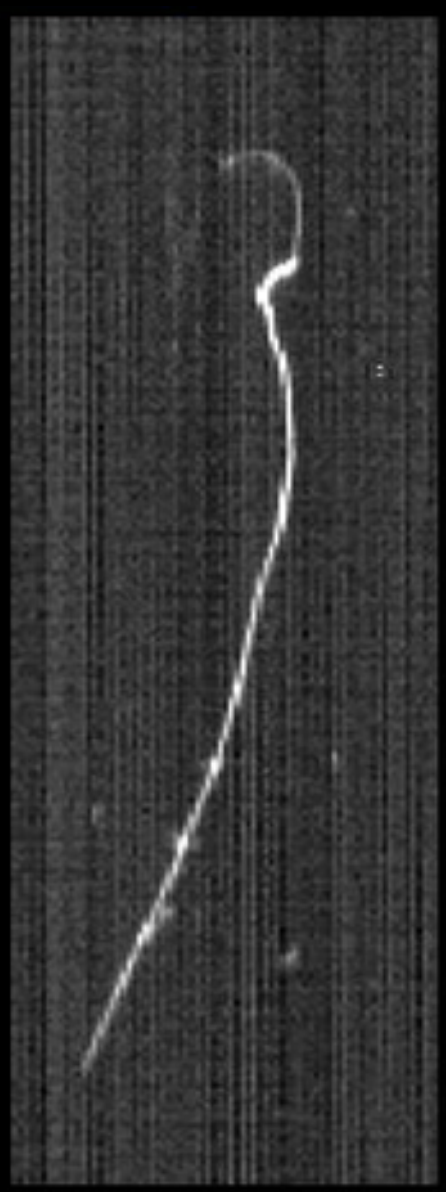

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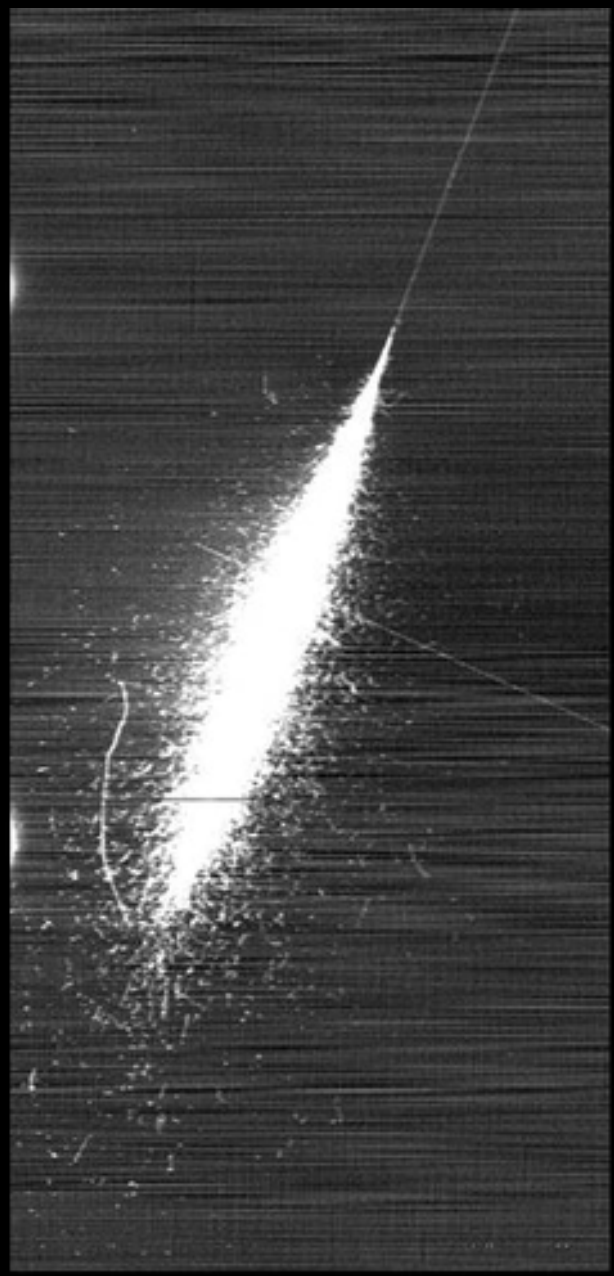

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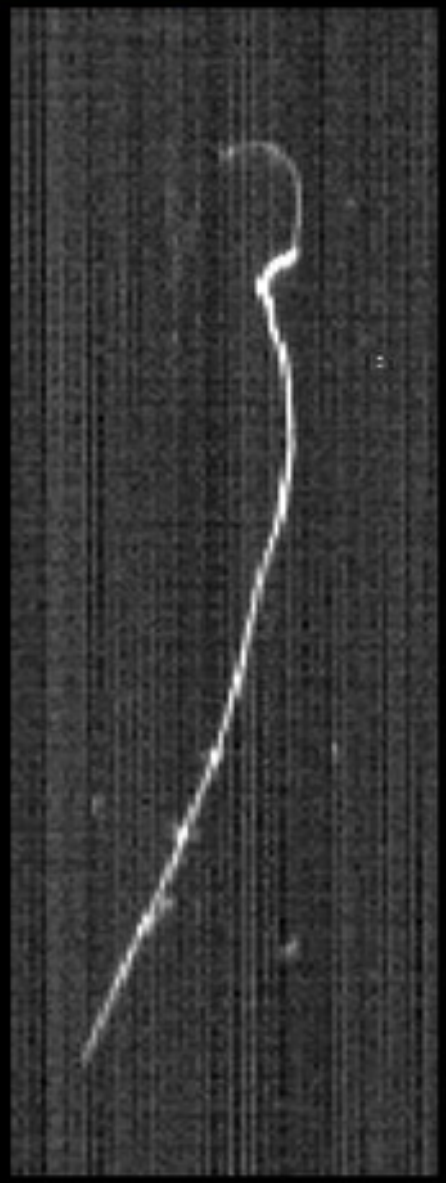

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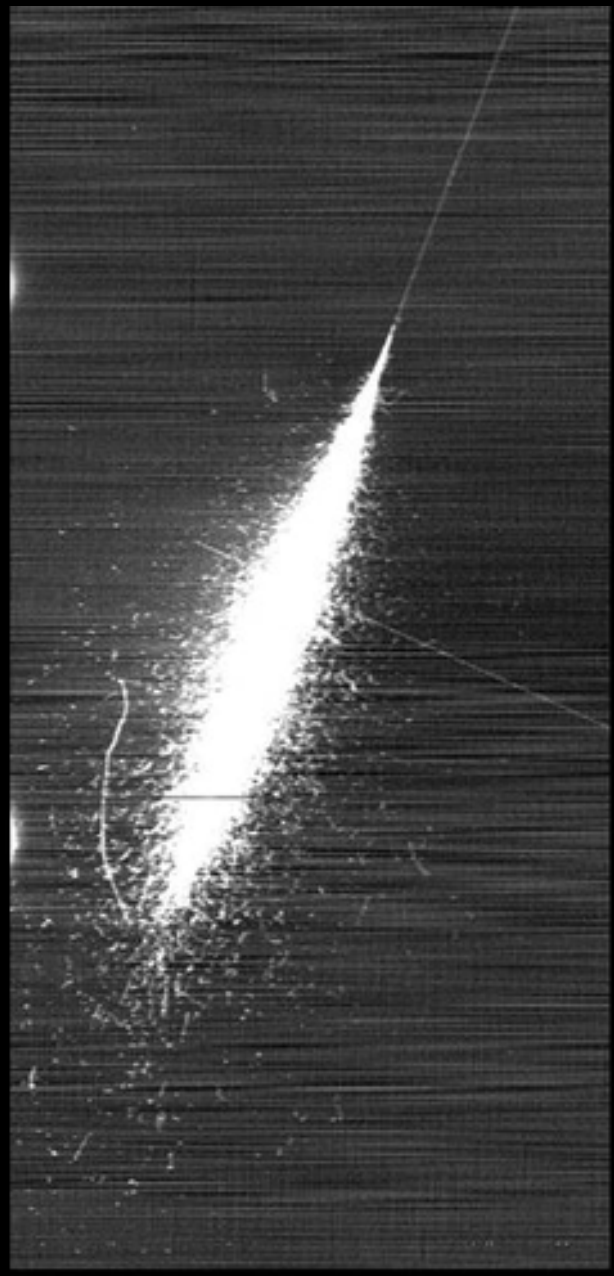

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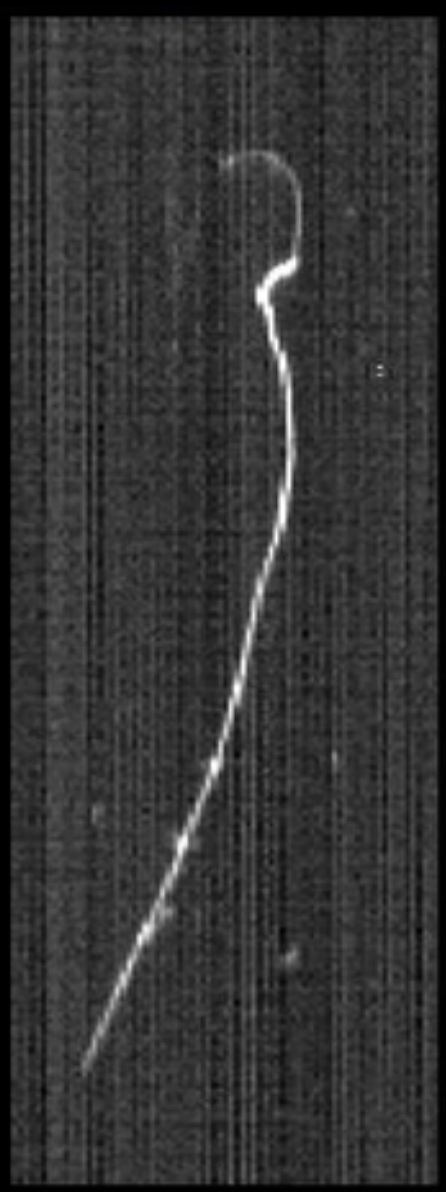

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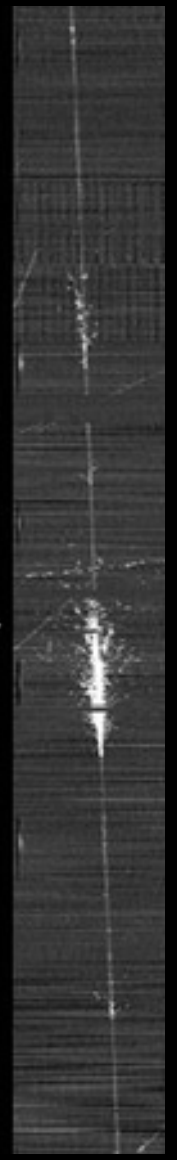

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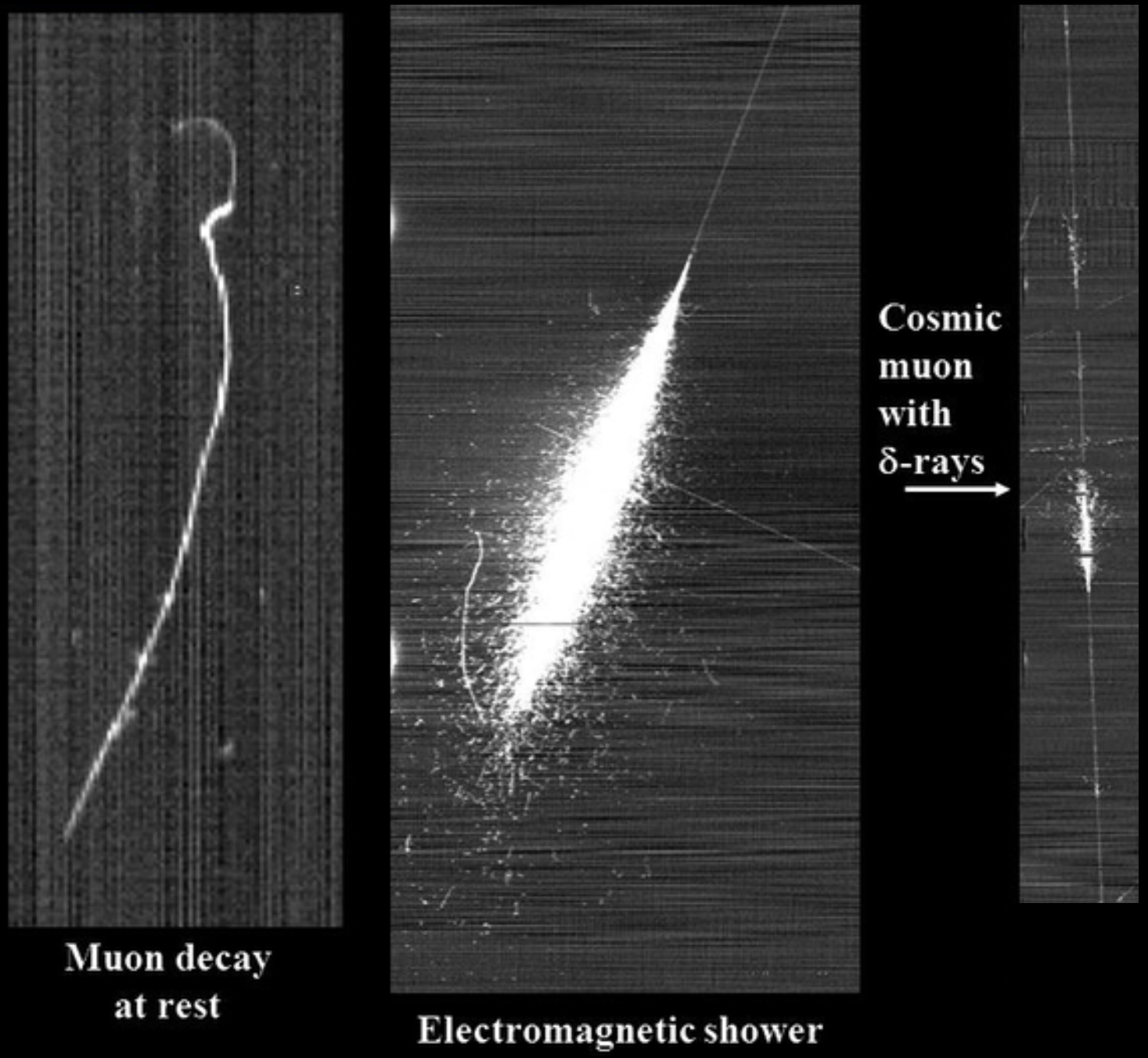

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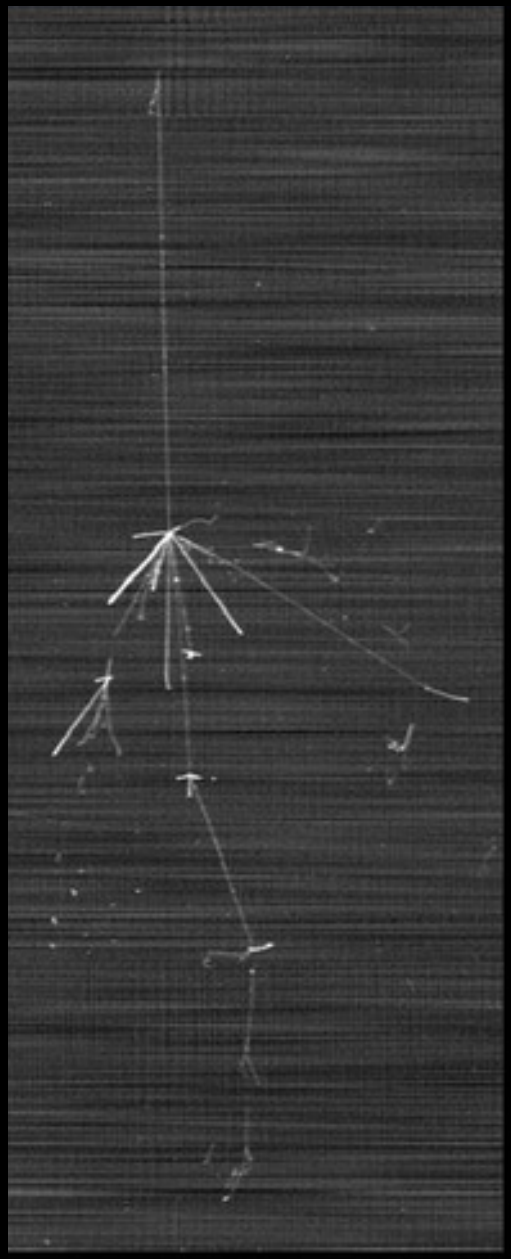

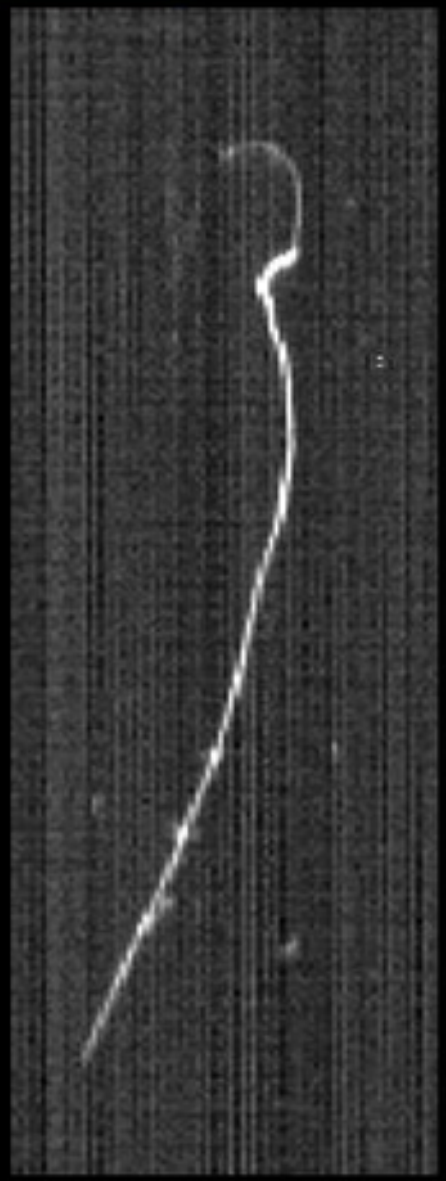

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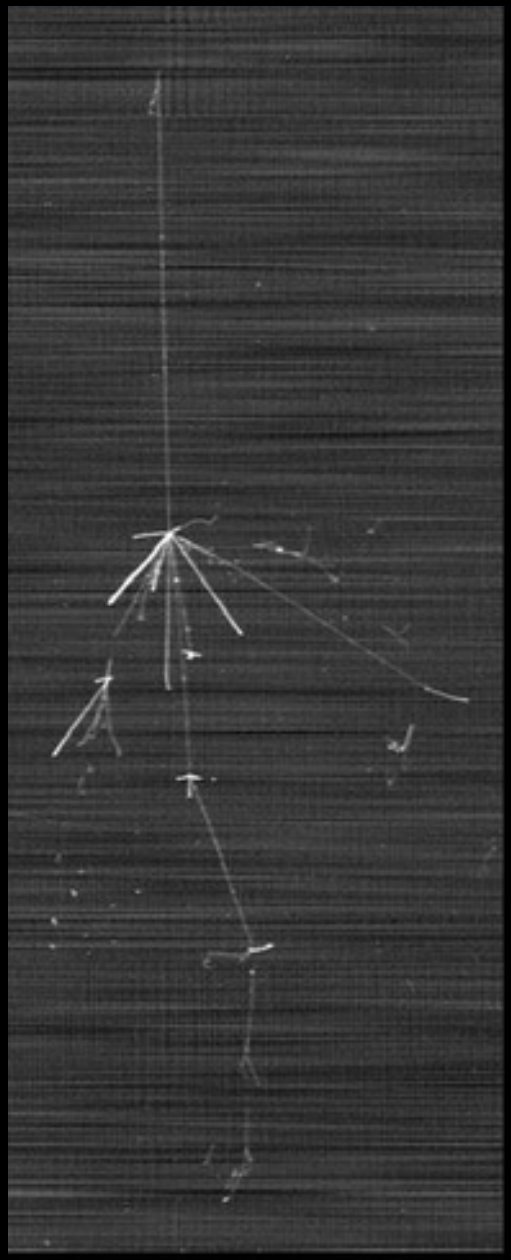
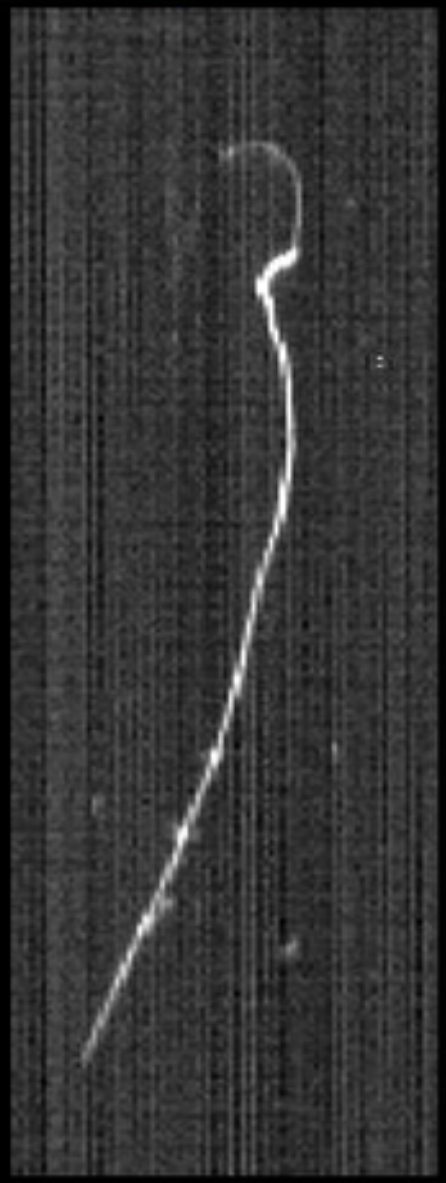


Hadron interaction



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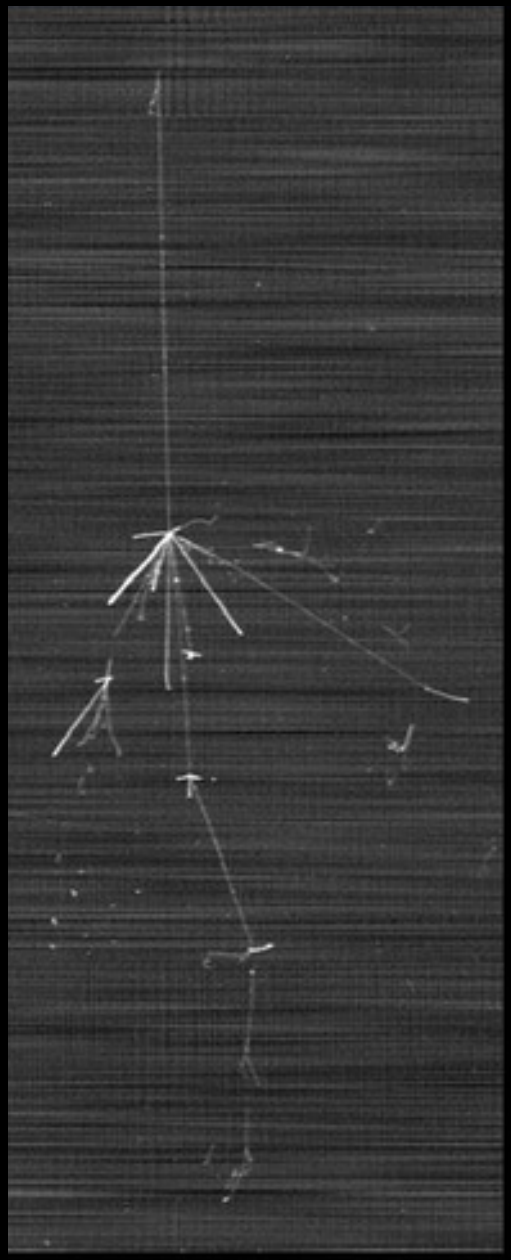

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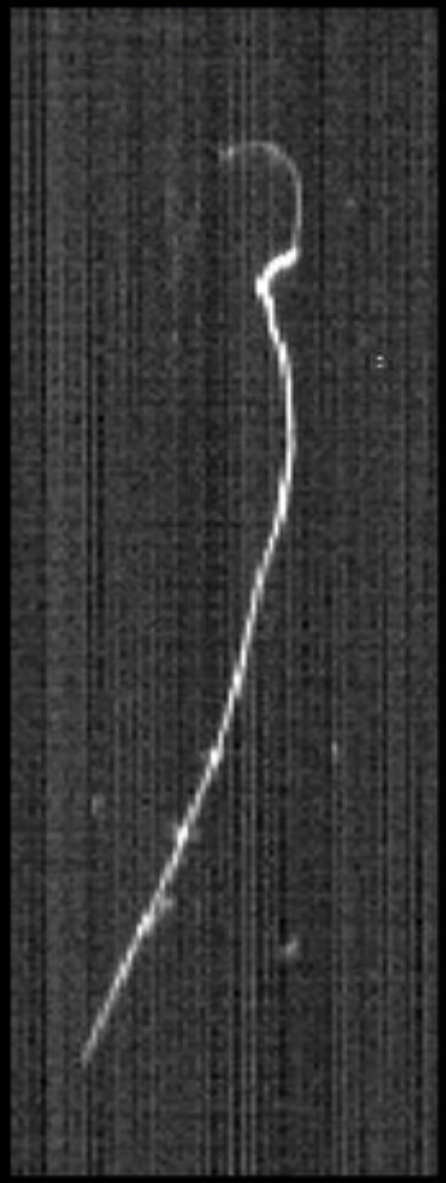

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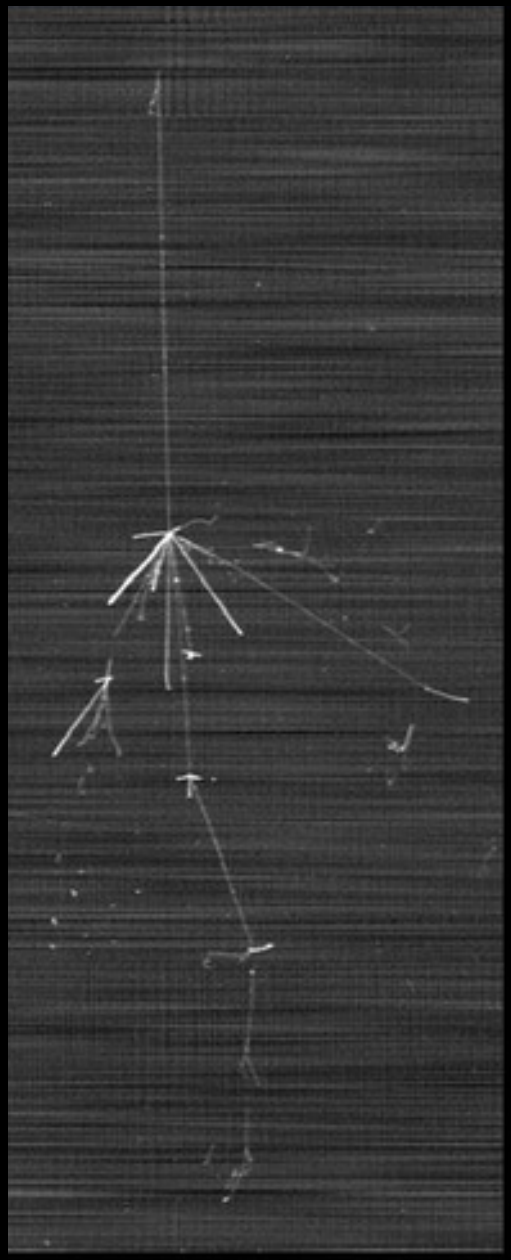

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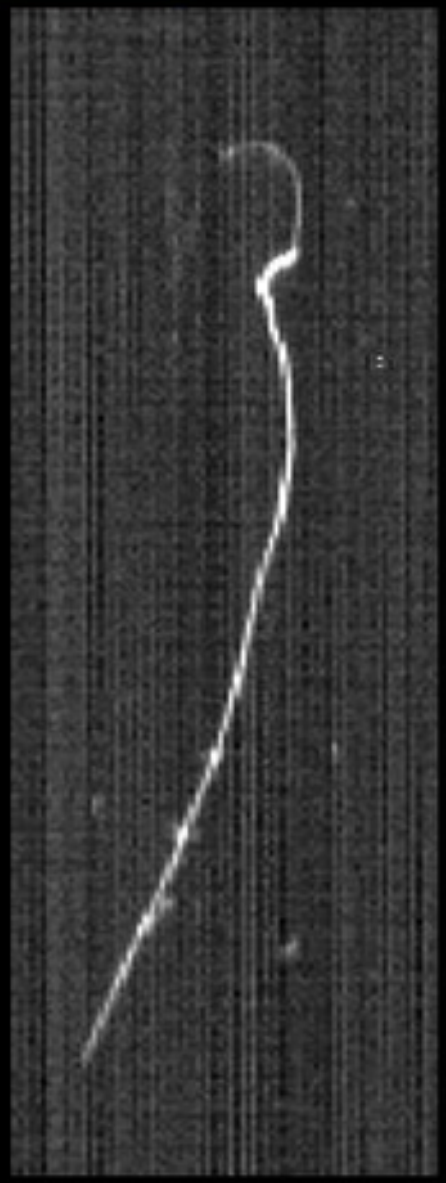

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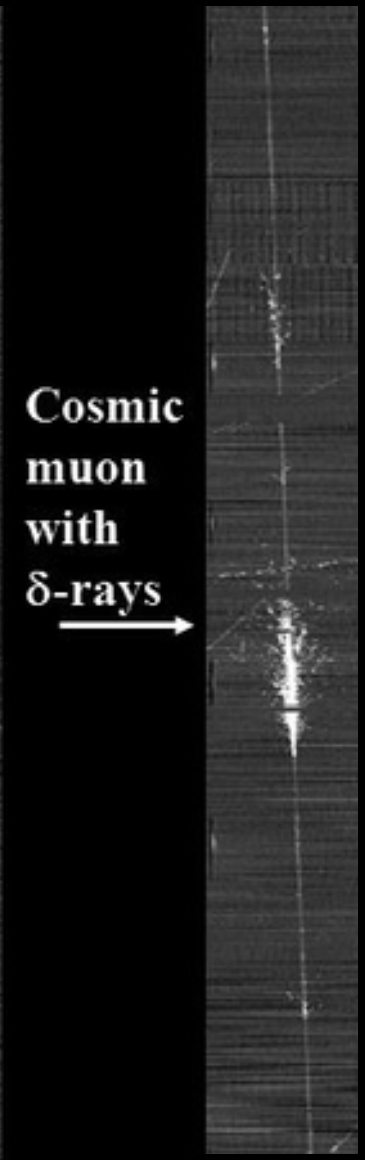

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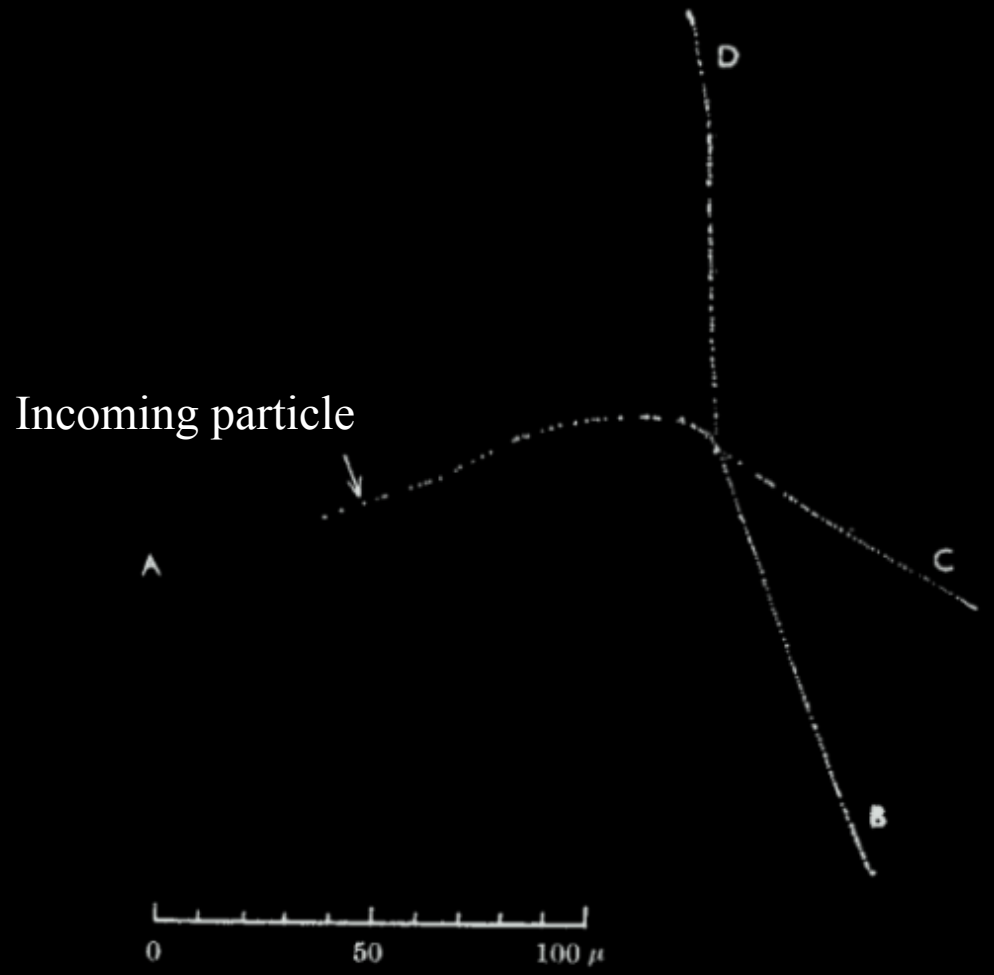

Fig. 1 *b*. TRACE OF COMPLETE STAR ON SCREEN OF PROJECTION MICROSCOPE, SHOWING PROJECTION OF THE TRACKS IN THE PLANE OF THE EMULSION. TRACK *A* CANNOT BE TRACED WITH CERTAINTY BEYOND THE ARROW

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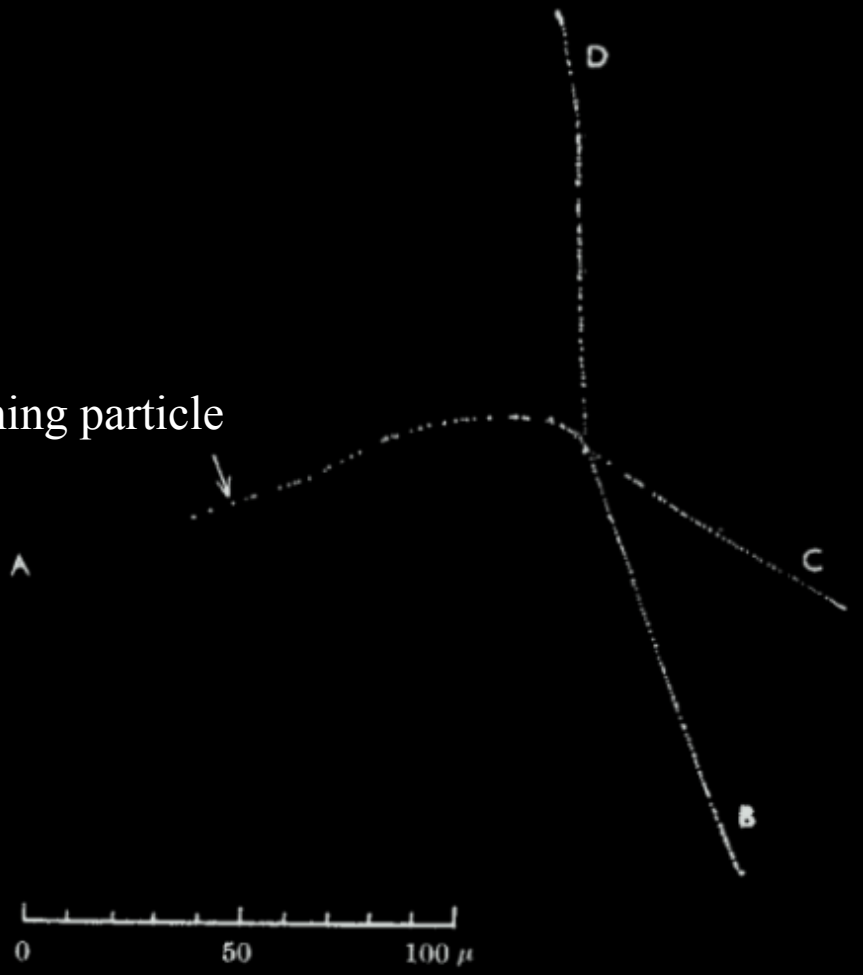
Did not see these in emulsions
exposed to cosmic rays, at least at first.

High altitude exposures
did find them.



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Eventually understood to be two particles.

Originally proposed by Yasutaka Tanikawa, Shoichi Sakata and Takeshi Inoue in 1942

Separately developed by Robert Marshak in 1947.

Heavier one interacts strongly, lighter one doesn’t.
Heavy one decays to the lighter one.

Eventually understood to be two particles; pion decays to muon.

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Why were the strongly interacting pions only seen in high altitude exposures, and muons seen at low altitude?

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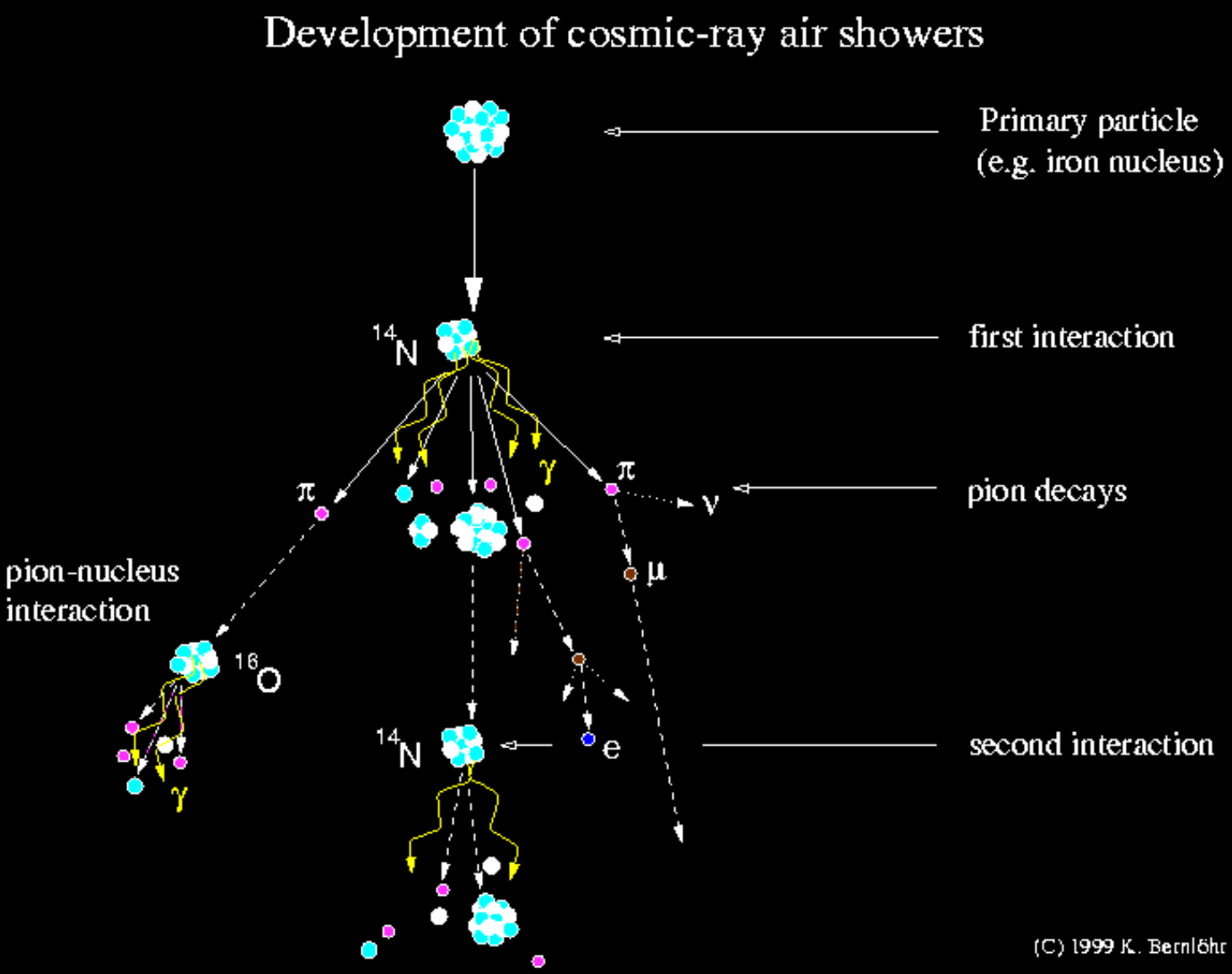

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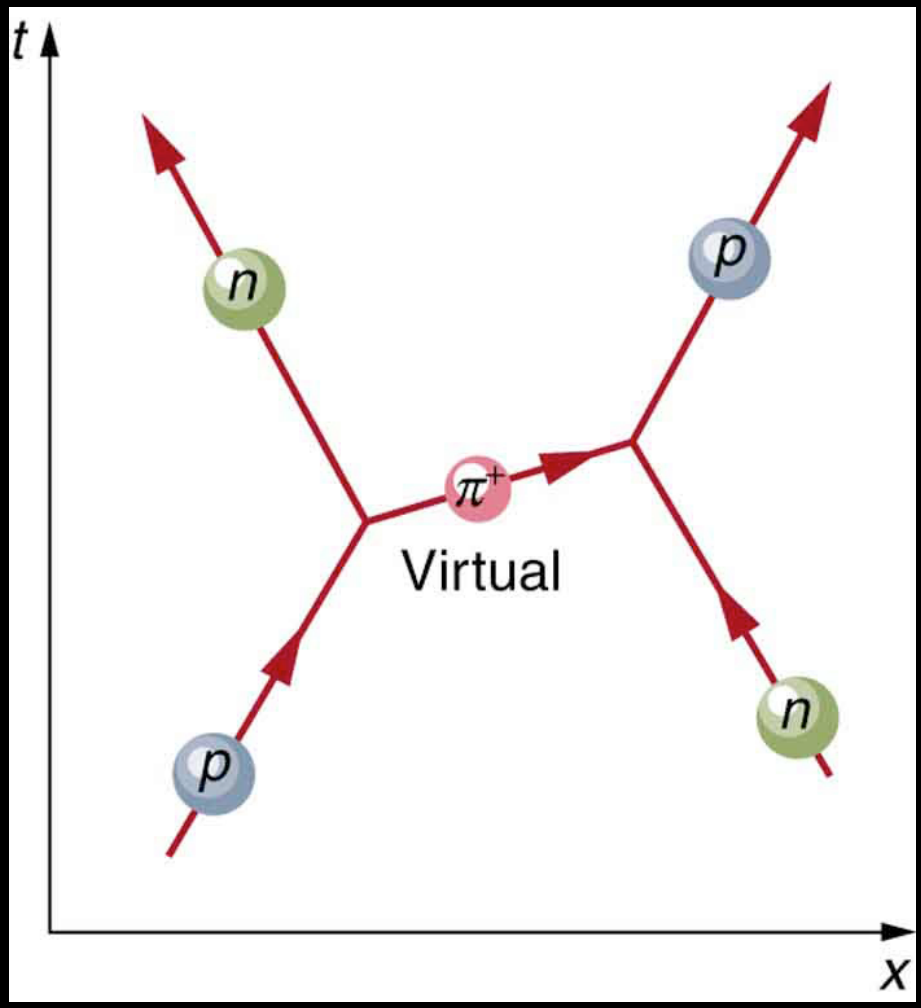
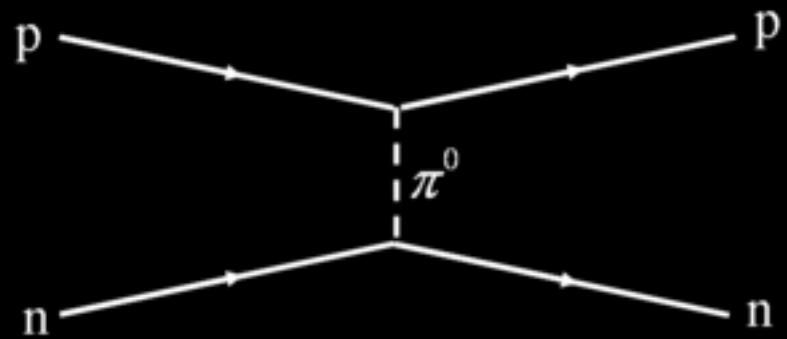
Pi+ and Pi0, what else?





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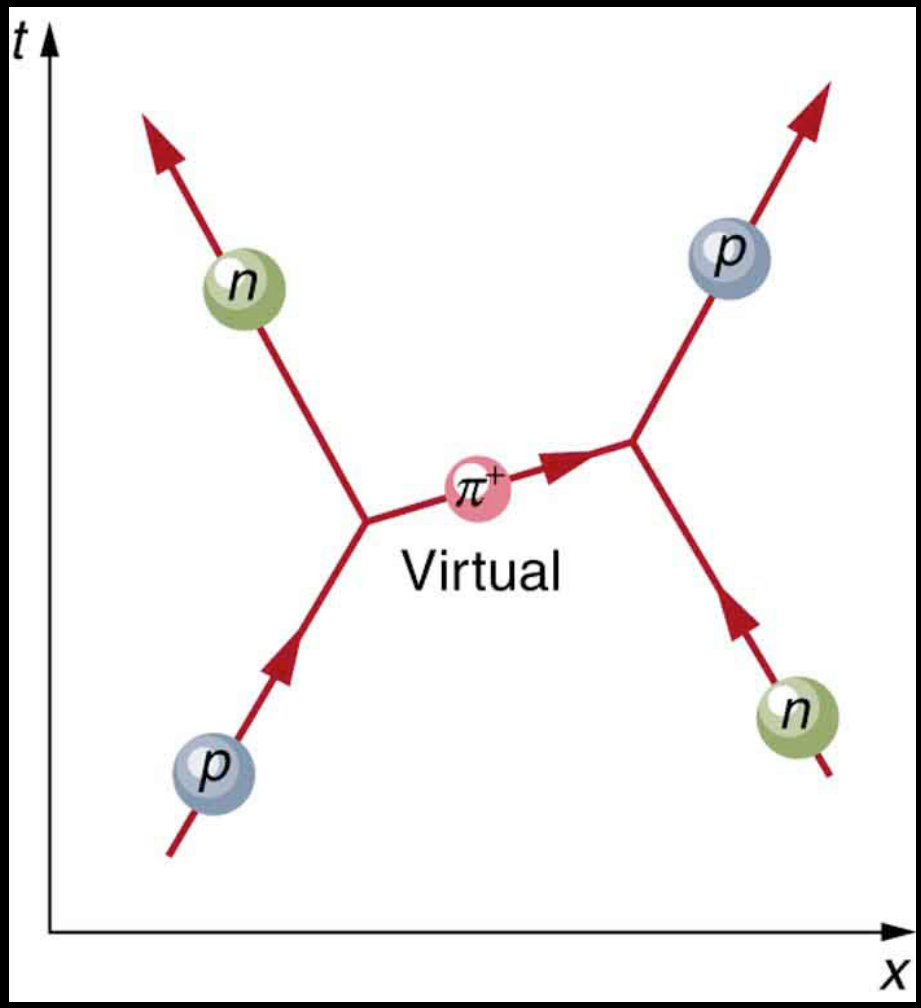
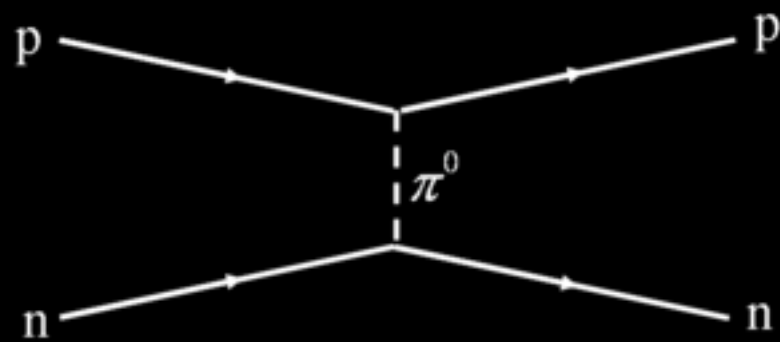
The neutral pion decays to ɣ ɣ
so it is harder to see.

New technology discussed next time



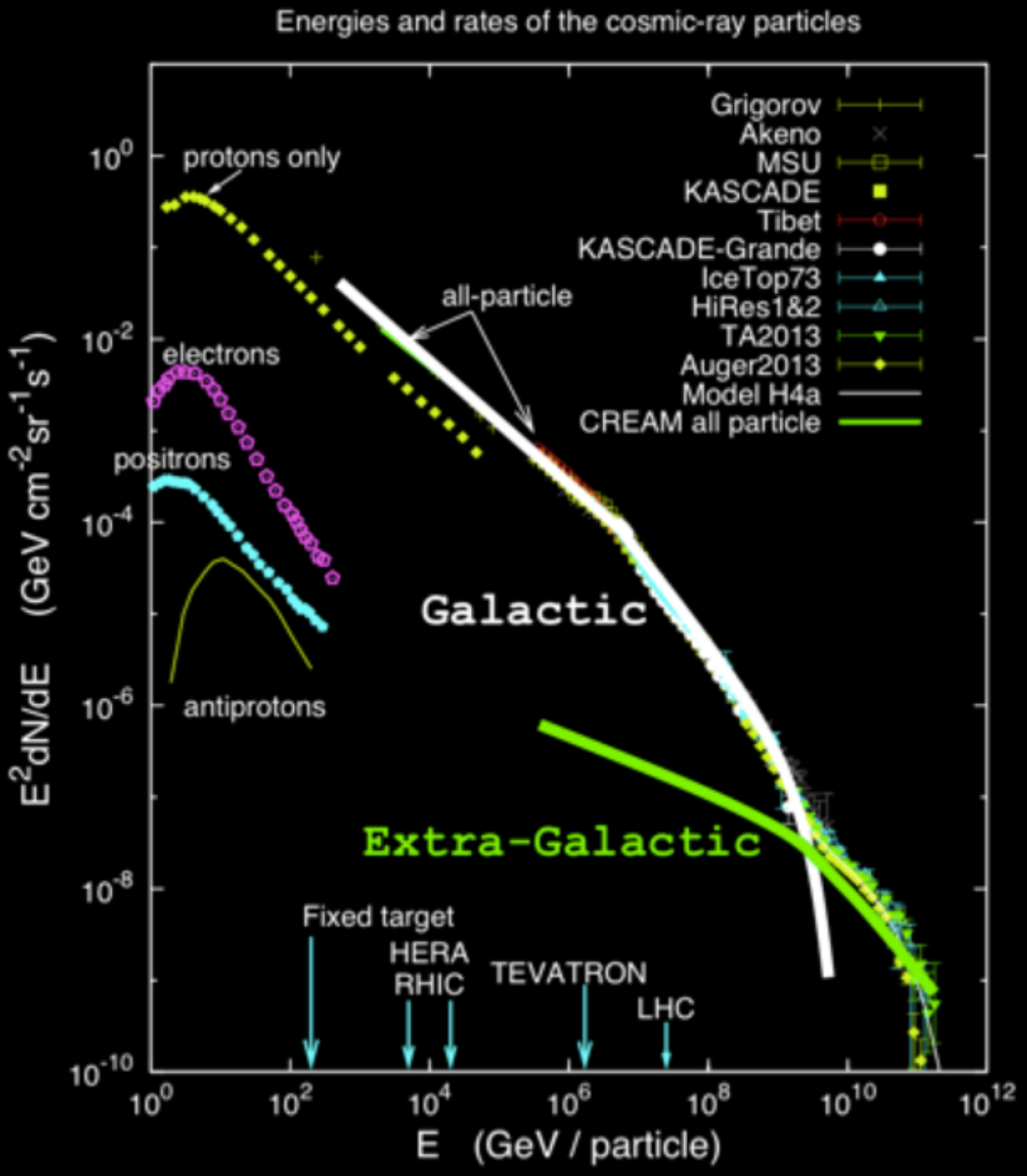


Back to a connection to the cosmic rays energy distribution

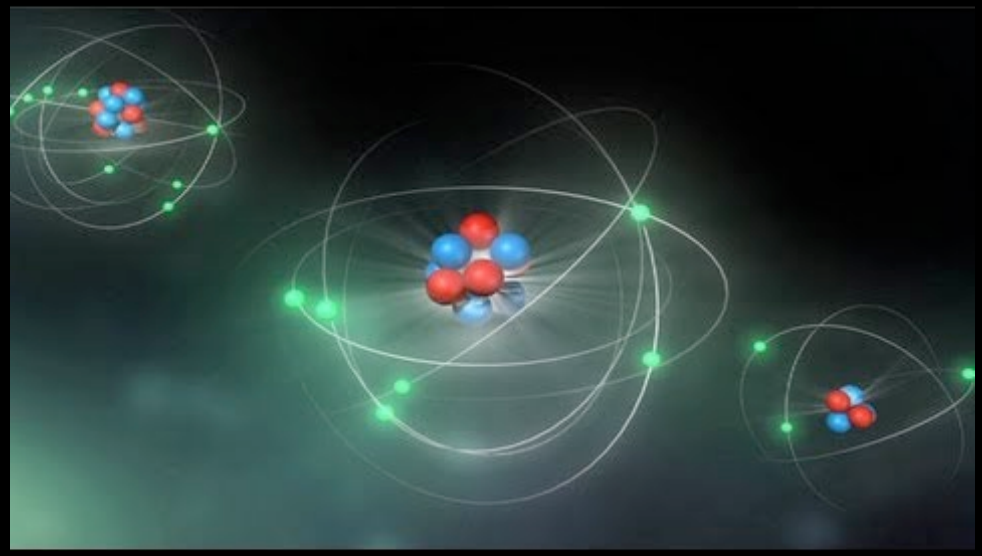
Now their energy distribution and astronomical sources are being studied with large detectors.

There seems to be a cutoff at the maximum energy

This is where p + CMB ɣ has enough energy to create a pion.

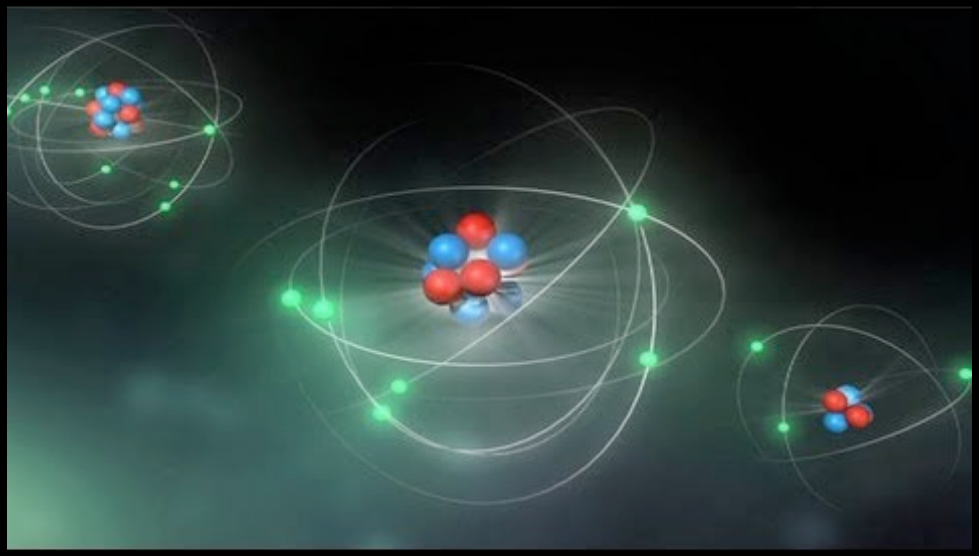


Can you form “muonic atoms” with a proton and a muon?



$$r = \frac{h^2 n^2}{4\pi^2 m e^2 Z}$$

The smaller radius of “muonic atoms” allows two atoms to get closer.



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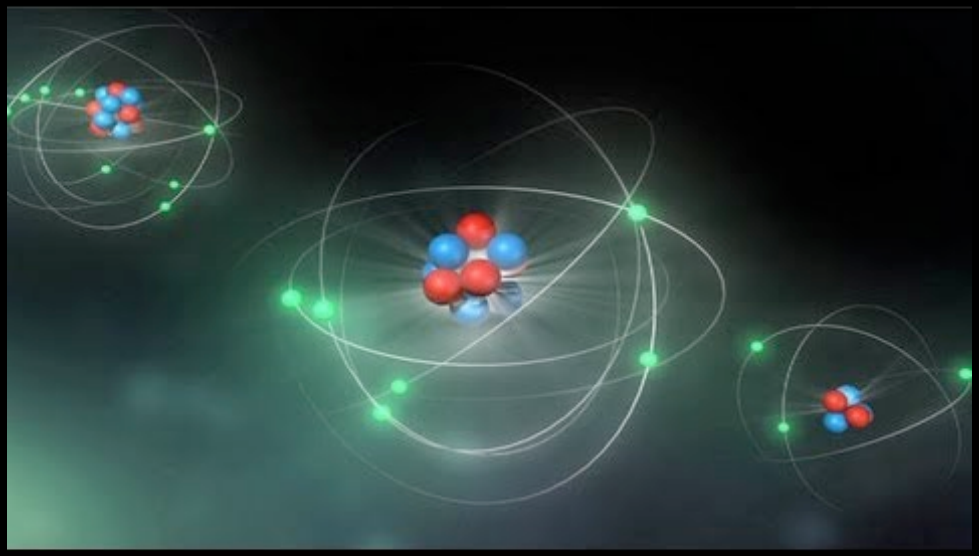
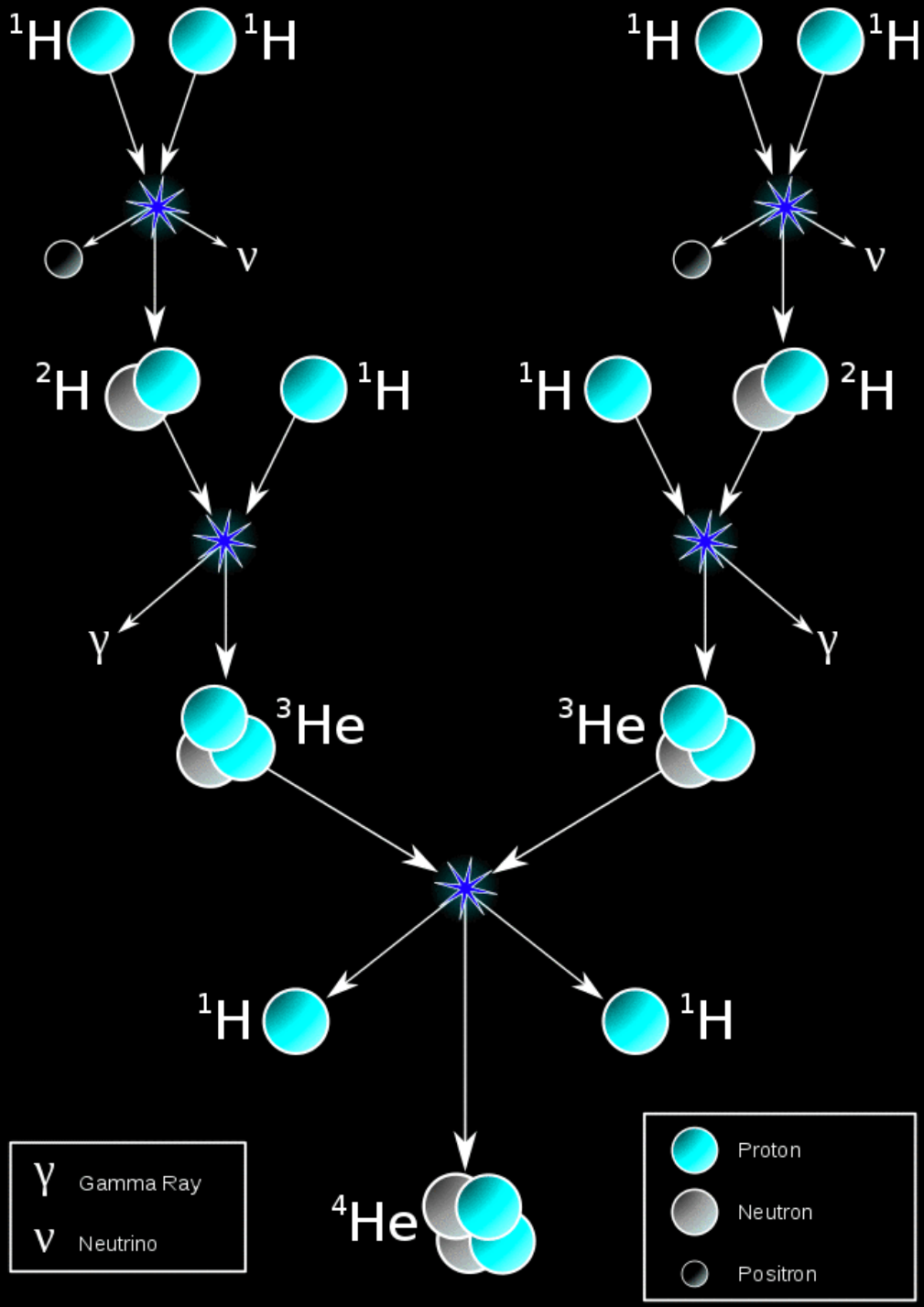
Muon catalyzed fusion.



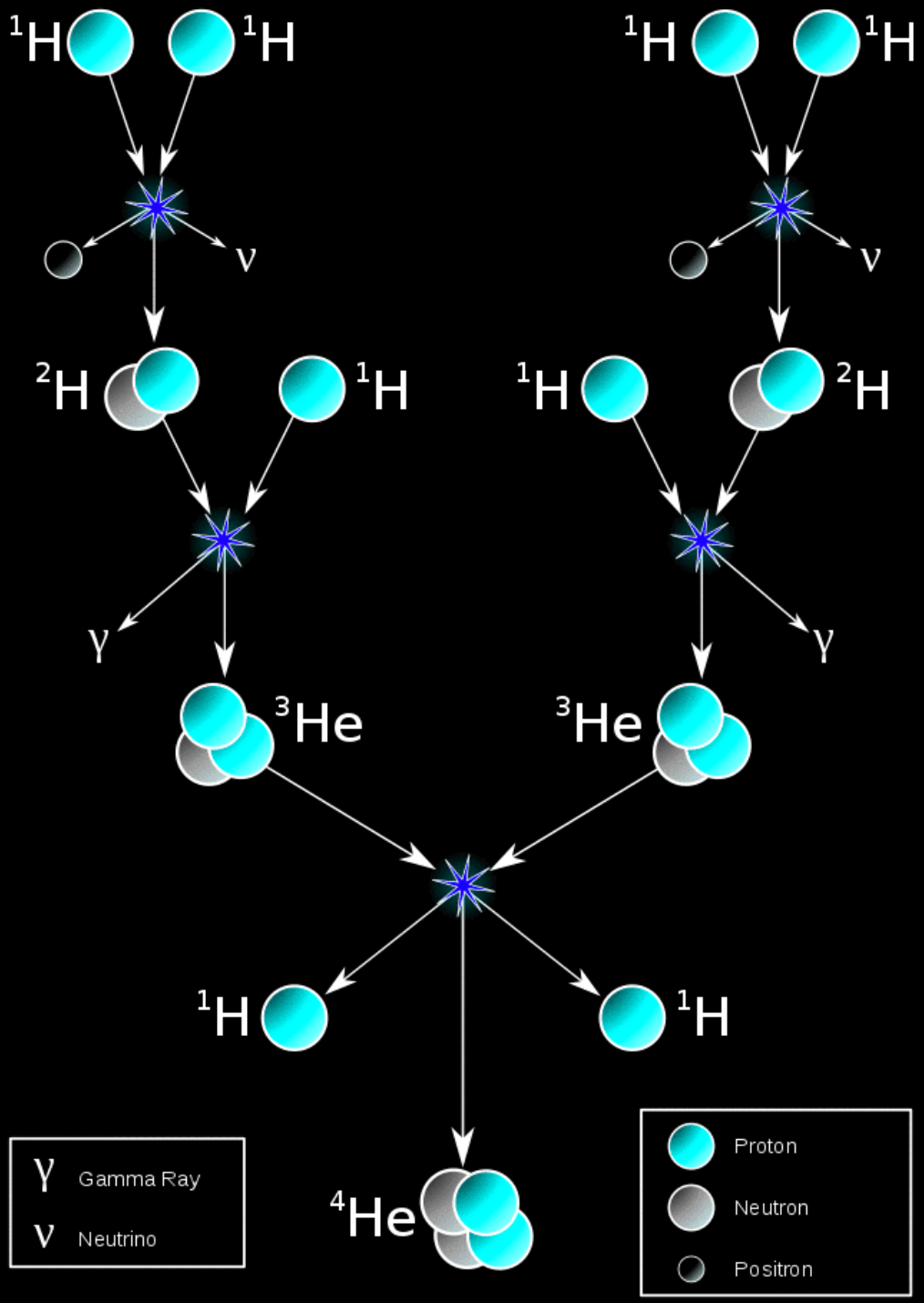
$$r = \frac{h^2 n^2}{4\pi^2 m e^2 Z}$$



The smaller radius of “muonic atoms” allows two atoms to get closer.
Muon catalyzed fusion.

This process was observed
by Luis Alvarez
(produced tritium and proposed
muon tomography)

Original source of term “cold fusion”.



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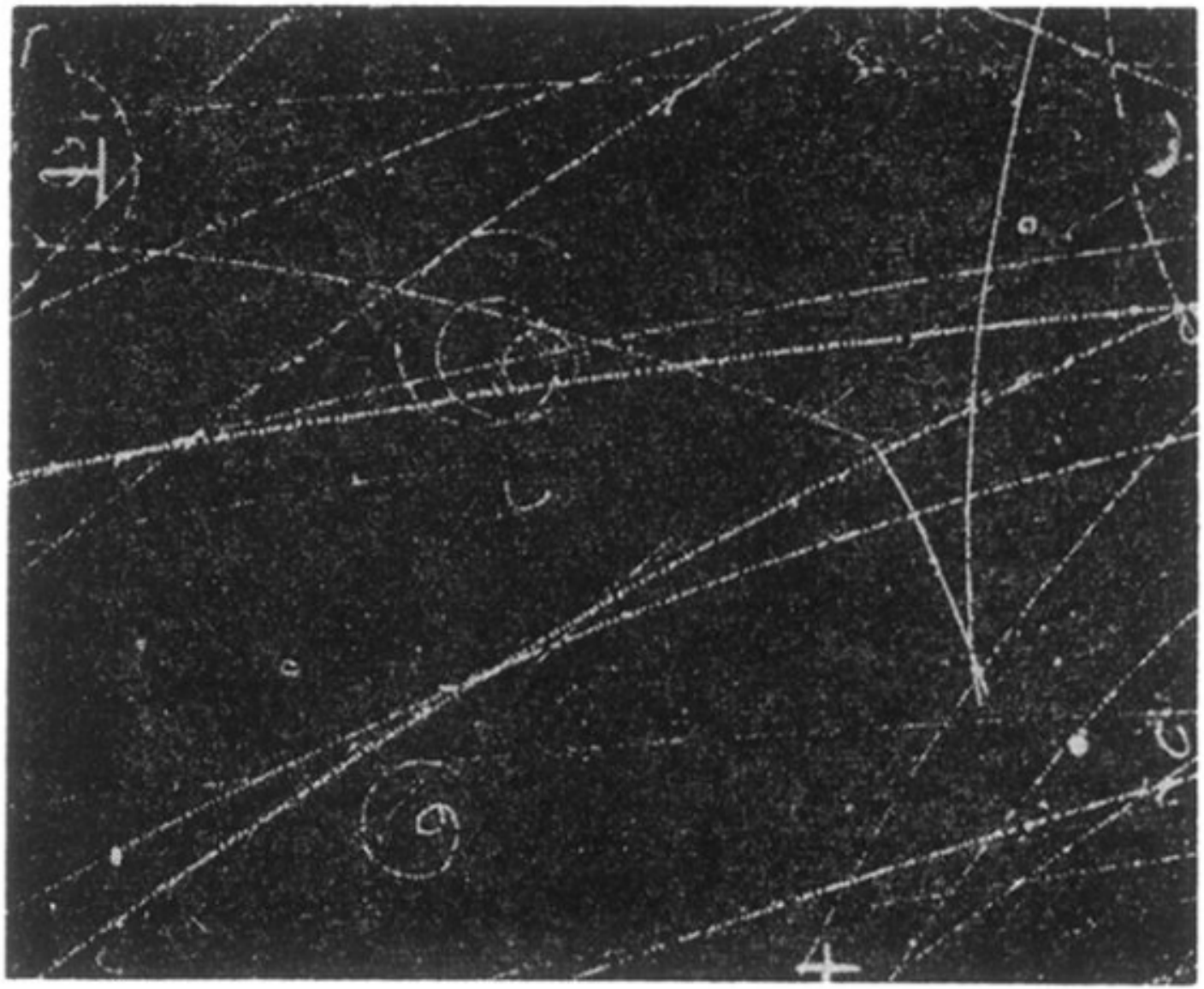

FIG. 1. Example of H-D reaction catalyzed by μ^- meson. The incident meson comes to rest, drifts as a neutral mesonic atom, is ejected with 5.4 Mev by the H-D reaction, comes to rest again after 1.7 cm, and decays.

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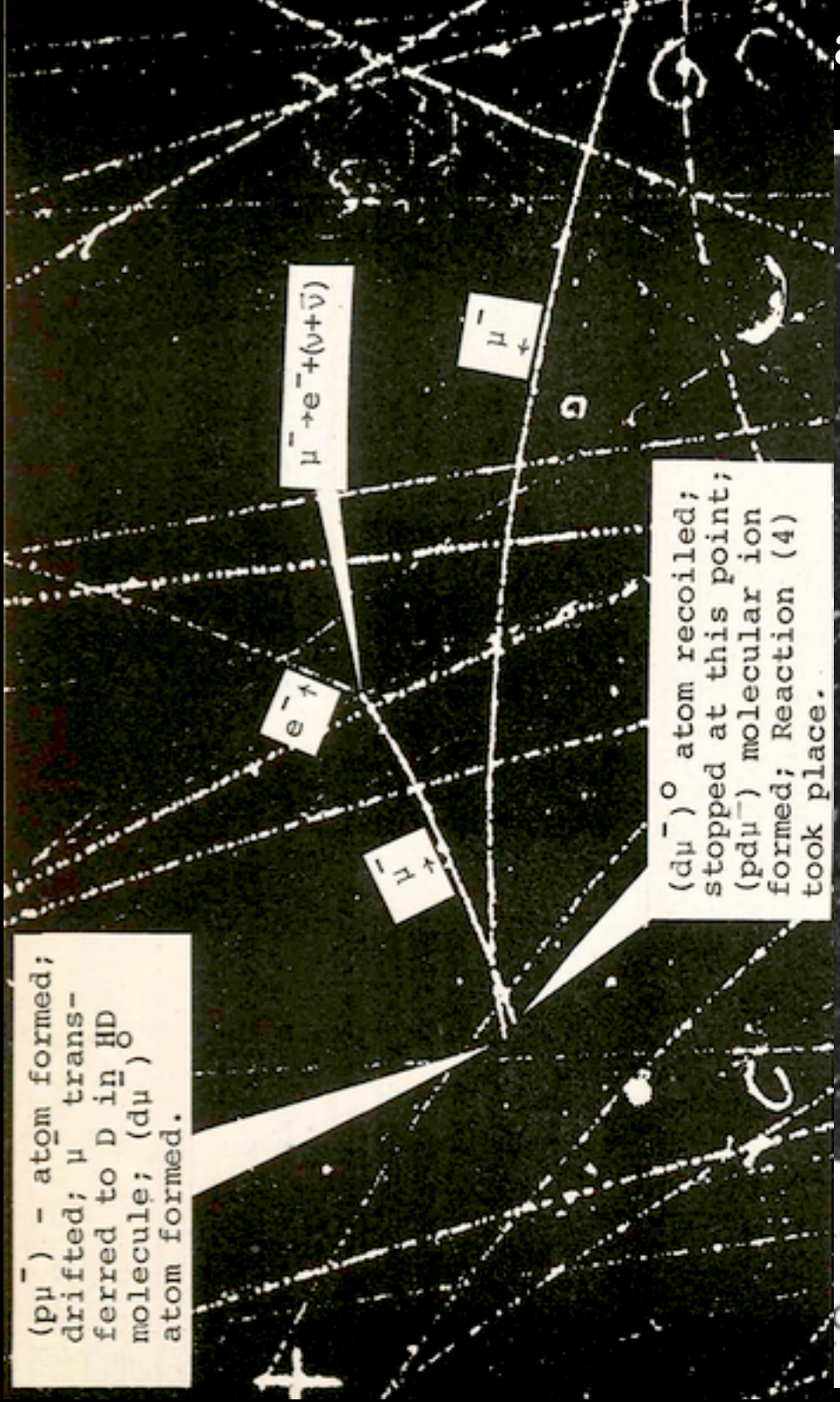

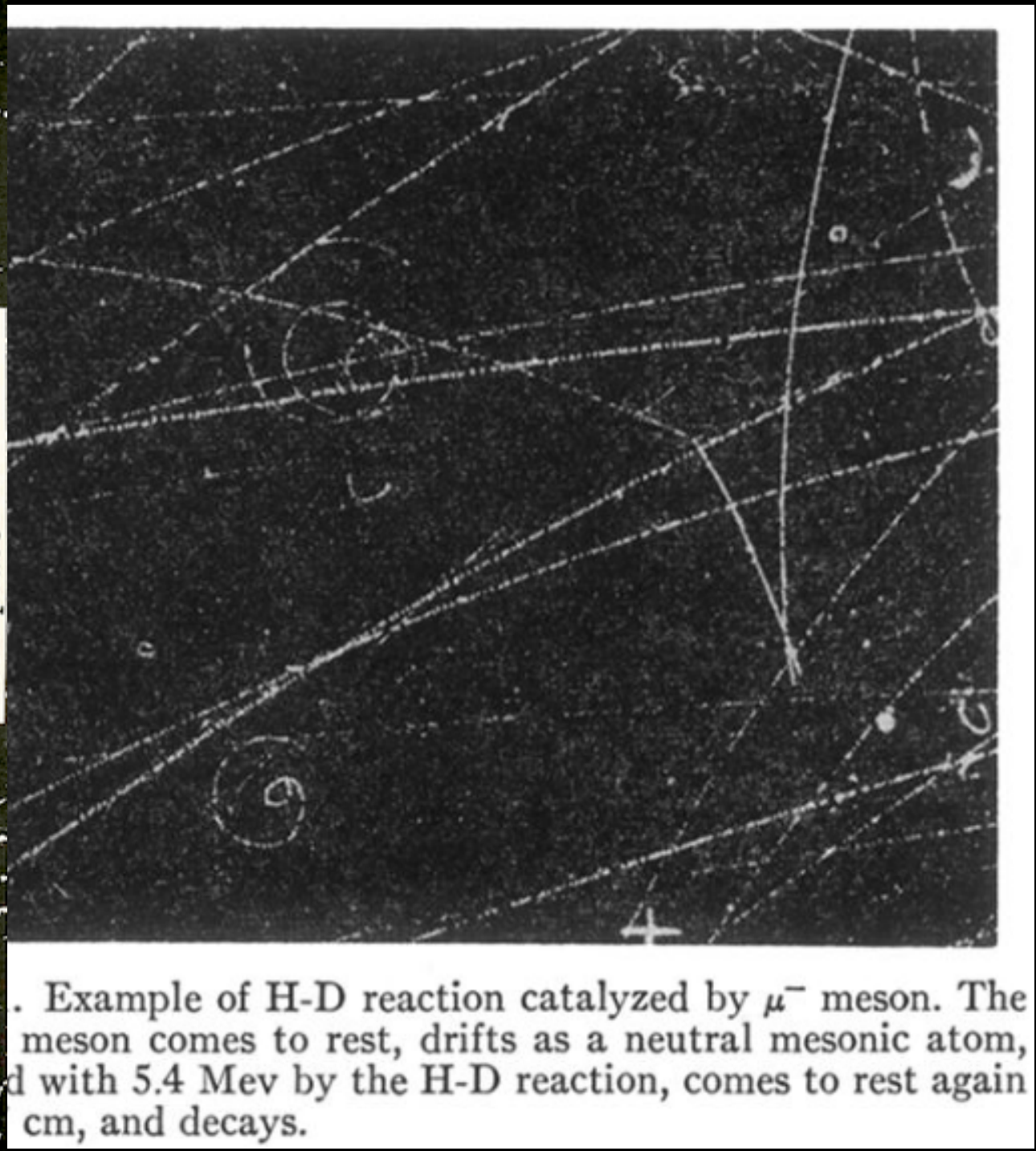

. Example of H-D reaction catalyzed by μ^- meson. The meson comes to rest, drifts as a neutral mesonic atom, d with 5.4 Mev by the H-D reaction, comes to rest again cm, and decays.

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Muon catalyzed fusion.

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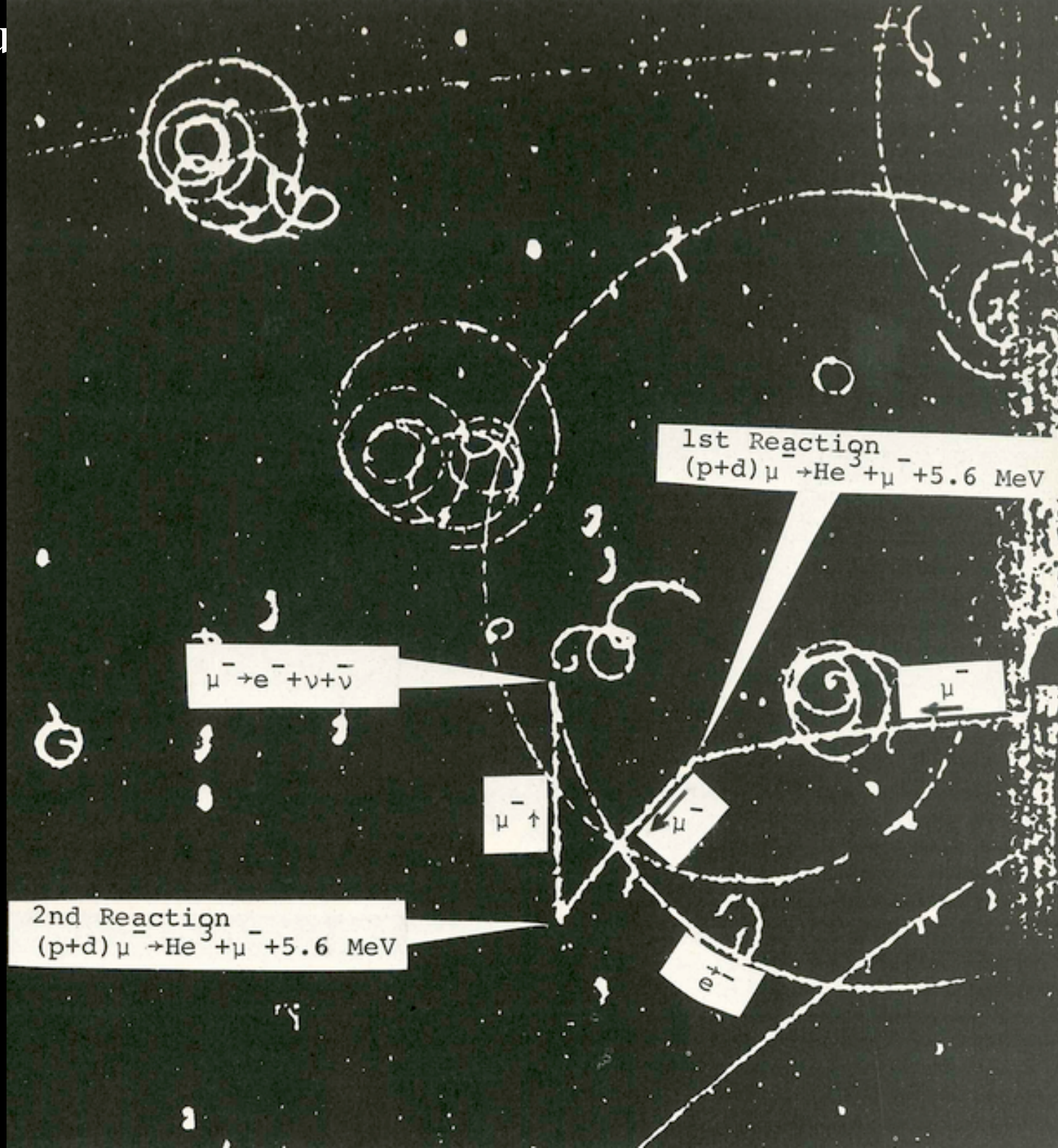
"We had a short but
exhilarating experience
when we thought we
had solved all of the fuel
problems of mankind for
the rest of time. A few hasty
calculations indicated that in
liquid HD a single negative
muon would catalyze enough
fusion reactions before it
decayed to supply the
energy to operate an
accelerator…"



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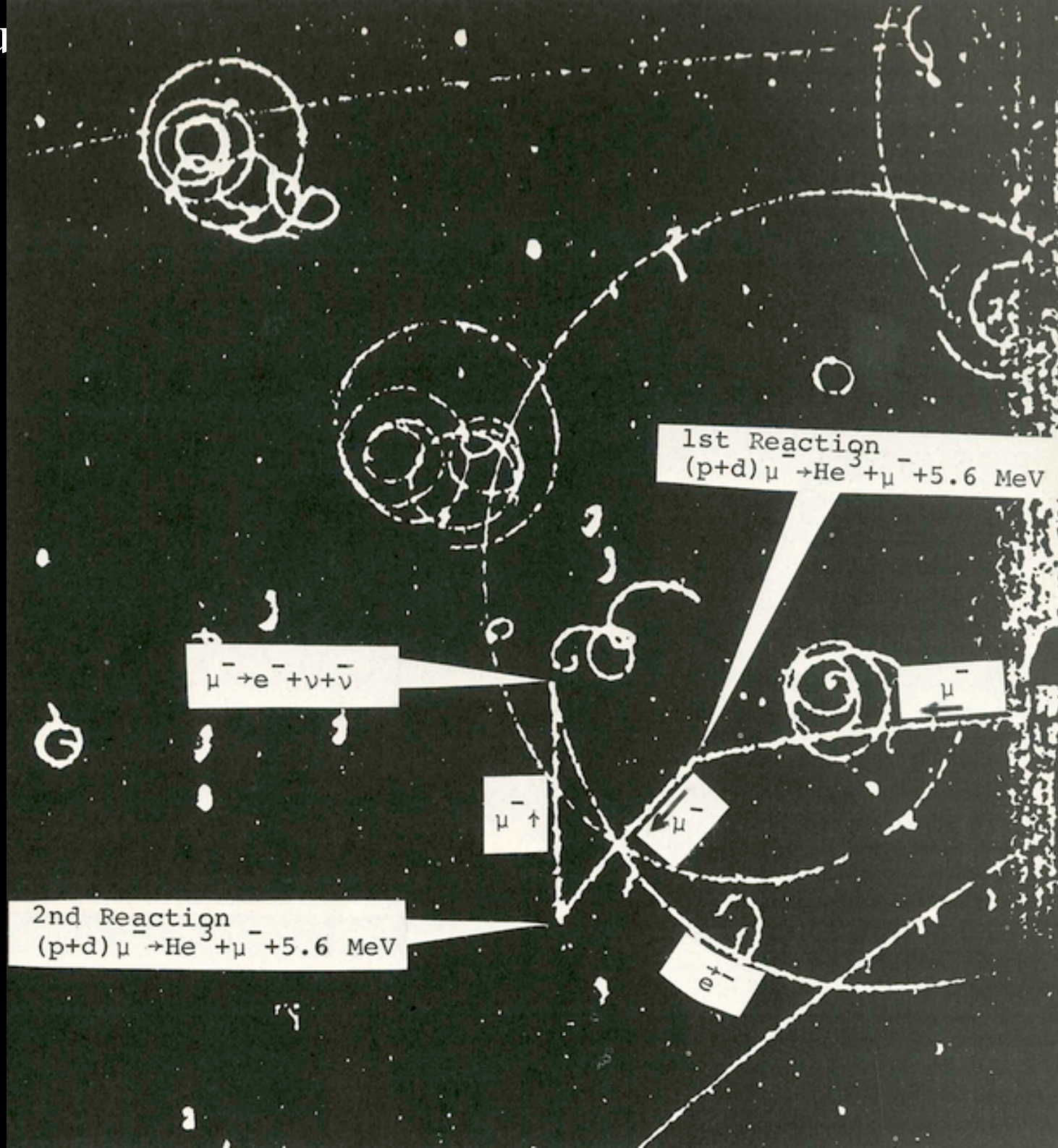
There are a few challenges:



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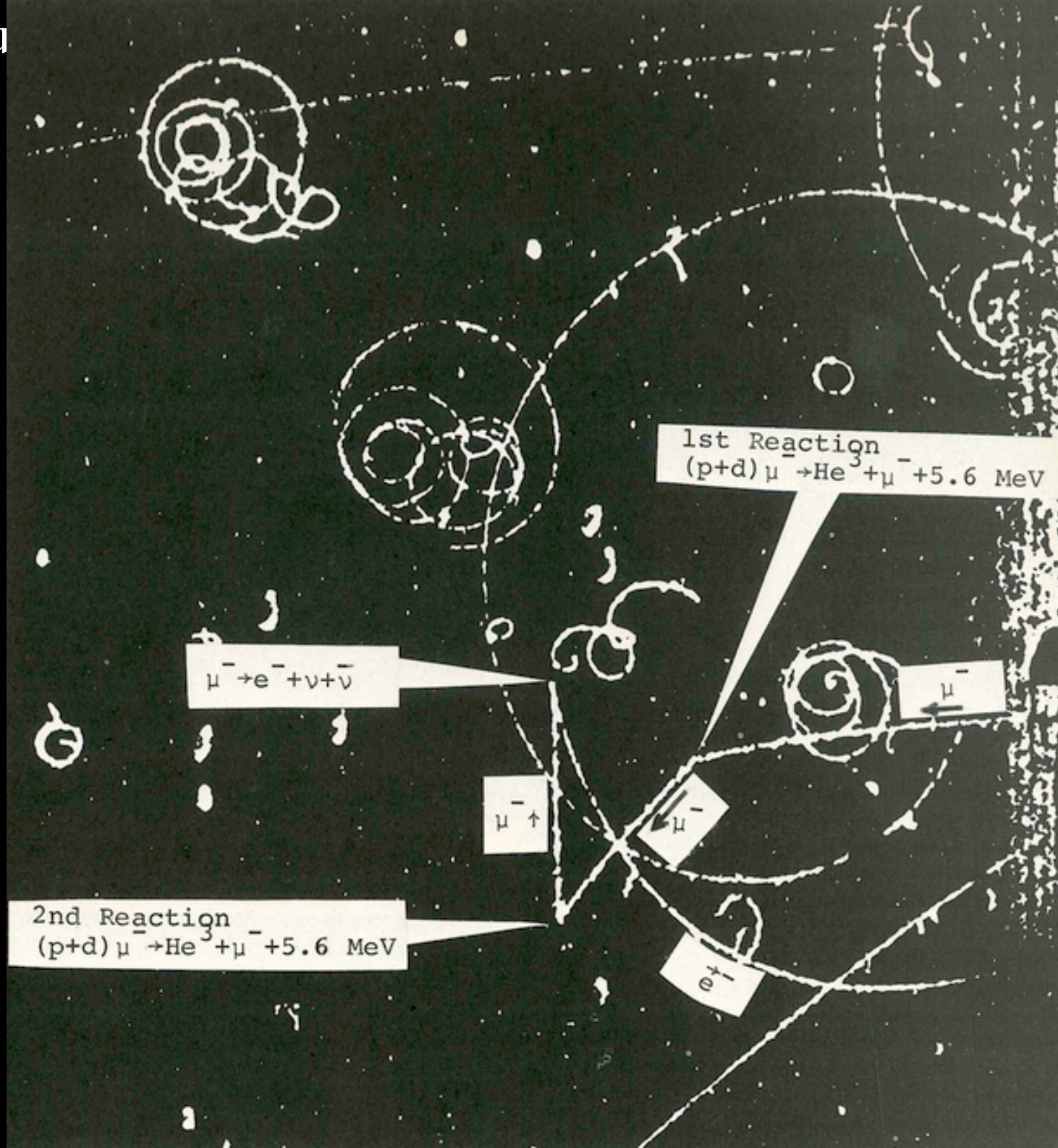
There are a few challenges:
- Muon lifetime is short (≈2μs)
- Energy to create muon
- Muons get captured on He^3



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Get maybe 200 fusions per muon

200x5MeV is close but not enough