Neutrino Physics

Big Picture for Next few Lectures

- Start w/ Background of the Physics of ν's
- History of how we got to today (Brief)
- Will talk about what used to be called the "Neutrino Puzzles"
  - ↳ Neutrinos have mass (2nd major topic)

  this is ultimately the reason ν's more interesting than we once thought
- Neutrino Oscillations (Associated Physics)
- Where we are and where we want to go.
- Neutrino masses as physics beyond the SM.

Lots that I won't be covering
- ν's in astrophysics / cosmology / ect.

This is the plan, Questions?

Teasers

$10^9:1$ ratio of ν's to other known particles (e, p, n)

$\sim 400/cm^3$ density of "Relic ν's" from Big Bang

99% fraction of E carried away by ν in Super nova

10^{38}: ν's/s produced by Sun $\Rightarrow 10^{11} \frac{\nu\text{'s}}{cm^2\, s}$ @ Earth

10^6: ν's / day " " Banana from radioactive Potassium

Start w/ talking a little bit about how we got here

Brief History

- Pre-History (Will not be comprehensive) (cherry picked)
  Bad w/ names & dates

- 1896 Henri Becquerel
  (Studying phosphorescence in Uranium Salts.
  Expose sample & see how it behaves afterwards
  Long spell of bad ~~weath~~ weather + saw they exposed photographic plate)
  Even when not exposed to light.

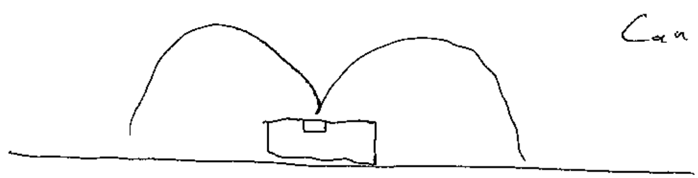
Very Suprising. Some materials that emit stuff.
Opened up huge industry of understanding radio activity

α-radiation $\Rightarrow$ + Easy to stop
β- " $\Rightarrow$ − Harder " "
γ - " $\Rightarrow$ 0 Very hard to stop

Classified these types in terms of various properties.
(Need to think about what was happening back then : Before QM.

Place in magnetic field, see what happens

Try to shield it ... and that's basically it



Can also tell mass this way

<u>1897</u> e was discovered (Important time in field)

But we are concerned w/ radiation...

Once you get good @ experiments can ask what is the E ~~of~~ that the radiation comes out with.

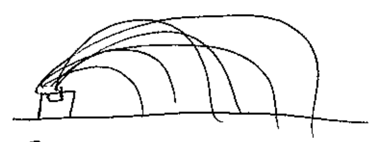
This is all weird <u>stuff</u>: Material that just spits out energy w/out being excited

If you look @ α-radiation most of the time well defined γ - Energy that comes out

We will be concerned mainly w/ β-radiation.
⟶ long (exciting) history long story

Real challenge w/ Spectrum of β-rad.

Discrete or Continuous ?



for different energies the curvature will be different.

The question is whether you will find d

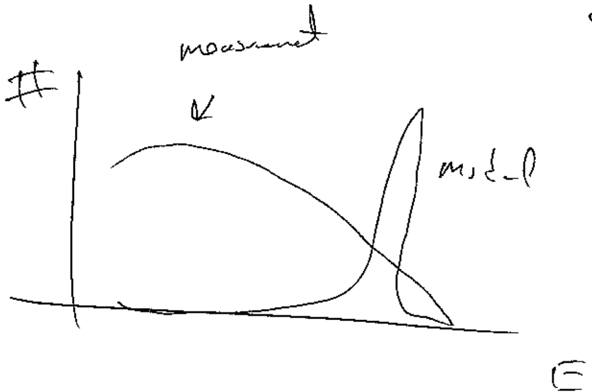
Naive expectation is that you would get a bunch of discrete lines.

Why? - "This is what spectra look like"
That's what they do.

Experimentally not sure if D or C. for about 15 y.

Took until 1914 (Chadwick) did a series of experiments that convinced everybody that β-decay was continuous

People were unhappy... (Worried if this was what was going on or artifact of measurement)



What happened?

Obvious answer you have losses some where.

↳ Clever experimentalist convinced everybody this was not case.

- Thin targets
- Measure if target "heats up"

$\Rightarrow$ fundamental Spectrum is <u>continuous</u>

<u>In the mean-time</u>. People hard @ work figuring out radiation

α - $N \to N' + N_{he}$

β $N \to N' + e$ ← model looks similar to α/γ
very good model

↳ Makes a prediction, ~~Given~~ 2-body decay. Given masses of 2 nuclie the electrons energy well-defined.

So clearly something fundamentally wrong w/ our model.

Situation in 1920's,

At same time people trying to figure out what nuclei are

Knew ~~atoms~~ nuclei had substructure, easy to see why can do complicated stuff like rad

Nuclear Physics in 20's (again still understanding what QM was)

$N \rightarrow n_p P + n_e e^-$

0th order model

Some unknown interactions that keep this together.

Every once in a while some subset can leave N

N can spit out e's so these must be there as well.

Very good model

$^4He = 4p + 2e^-$ ← Very good

$^{14}N = 14p + 7e^-$ ← disturbing

As we understand it Boson ($7n + 7p$ even fermions)

⟶ this collection odd # fermions

⇒ fermion

Have a model that makes prediction, wrong

Big Problem, Another was magnetic moments

$\mu \propto \frac{e}{m}$ $\quad \mu_e \gg \mu_p$ B/c mass so much smaller

Predict that Nuclei magnetic moments dominated by e's

$\mu_N \sim \mu_p \ll \mu_e$ Doesn't work w/ ^{14}N

Exciting times in Particle Physics

One hypothesis that got to be popular was

e^- in nuclei are weird
- violate statistics
- " magnetic moments
- β spectrum mean E & conservation when talk about e's in nucleus

Solutions to all these problems was the neutrino.

Early Days of ν's

- 1930 Pauli invents the neutrino (Make model little more complicated)

$$N = \underbrace{p + e^-}_{\text{charge worked well before}} + \nu$$

mass worked well before

neutral light

Spin ½ to make Spin/stats work

(doesn't explain μ problem ...)

Explains β-radiation as well. $N \to N' + e + \nu$

energy of e doesn't have what you thought should B/c sharing w/ ν

"Desperate way out"

Pauli feels bad, new particle that he doesn't think can be detected.

Fantastic Idea, turns out to be correct...

- 1932 Chadwick discovers the neutron (changed the way we understand nuclei in major qualitative way)

- 1934 Fermi theory of weak interactions
We already talked about how much of a big deal this was. Bold. Things we hadn't done before.