

hi

Day 26, 17.04.2018

Particle Physics 1

housekeeping

The end game: next slide

Particle Physics:

Readings: Oerter and Hobson

Hobson_PP.pdf is chapter 17 out of Hobson

Homework #12 is all from MasteringPhysics - normal due date

Feynman Diagram rules

3 movies in the lecture slide directory - you'll need them for homework and the final

they are: primitiveDiagrams_X. mp4

where $X = 0,1,2$



last 2 weeks & final

Homework #13 will be assigned 4/21 and due 4/28 - normal rotation

On-line final exam will be assigned Sunday, 4/29 and due Tuesday night, May 1

will cover material since midterm plus the last week of class

There is 1 more 10 point quiz (stay tuned)...

only the shadow knows when

Remember when I was sick?

been trying to catch up, but not going to make it. Hence:

Final Exam day:

1. You'll arrive at 0745 on May 4, here. I know.
2. I'll provide bagels. You supply liquids.
3. We'll have a quiz.
4. I'll finish with about a 1 hour grand finale, lalapalooza, mind-bending lecture
5. You'll do your Feynman Diagram Project
6. There will be no poster project this year



SORRY!®

The game of sweet revenge

PARKER BROTHERS

Plan a Family Game Night

Family AGE 6+ EDAD

I'm sorry.



honors project began

https://qstbb.pa.msu.edu/storage/Homework_Projects/honors_project_2018/

contains:

the first instructions: the plan & tutorial

the second instructions – v2 uploaded, added a missing student

the data, assigned by name in the second instructions - see next

dates:

complete first part, March 16

analyze data by April 24 and hand in complete writeup at the final exam

the data

should have been in zipped format

rather, somehow they were unzipped in some process

fixed: now

https://qstbb.pa.msu.edu/storage/Homework_Projects/honors_project_2018/

Index of /storage/Homework_Projects/honors_project_2018

Name	Last modified	Size	Description
 Parent Directory		-	
 ISP220_inspirationaltalk.pdf	2018-03-01 07:10	4.3M	Portable Document Format file
 MinervaInstructions1_2018.pdf	2018-03-01 07:10	2.3M	Portable Document Format file
 MinervaInstructions2_2018_2.pdf	2018-04-09 22:11	112K	Portable Document Format file
 Zpathintro.mp4	2018-03-01 07:16	274M	
 groupA-2.zip	2018-04-12 12:25	30M	ZIP archive
 groupA.zip	2018-04-12 12:25	28M	ZIP archive
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 groupT-2.zip	2018-04-12 12:28	31M	ZIP archive
 groupT.zip	2018-04-12 12:28	29M	ZIP archive

I need a Section 2

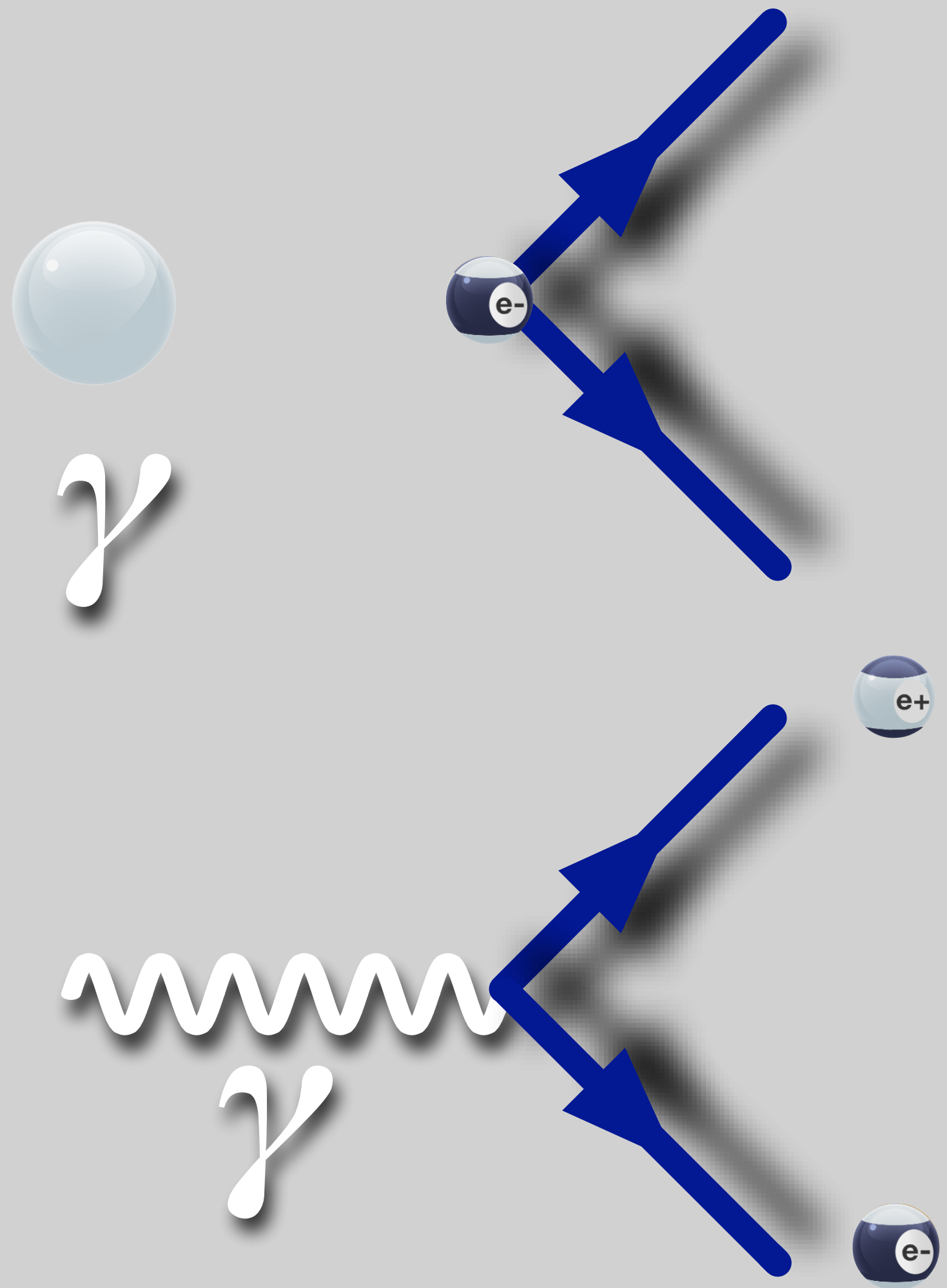
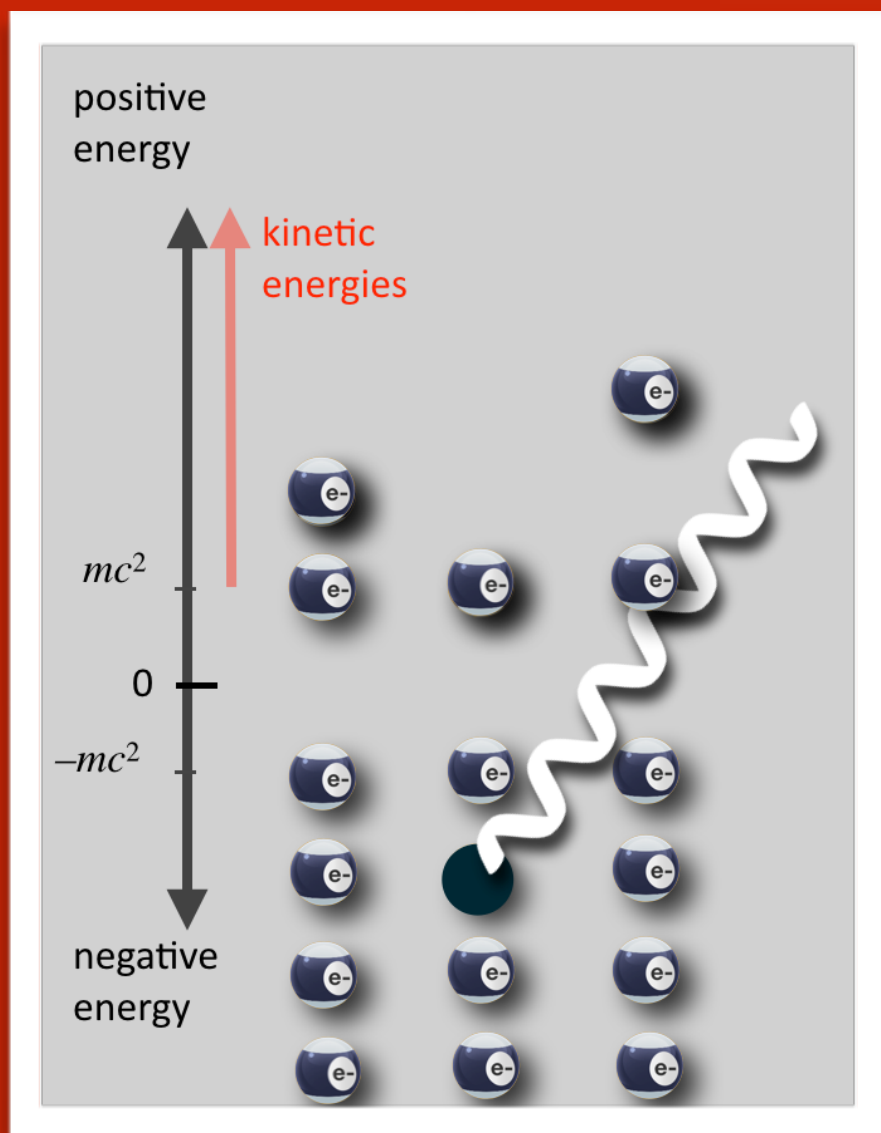


to test the Z-path uploading machinery and instructions

modern
interpretat

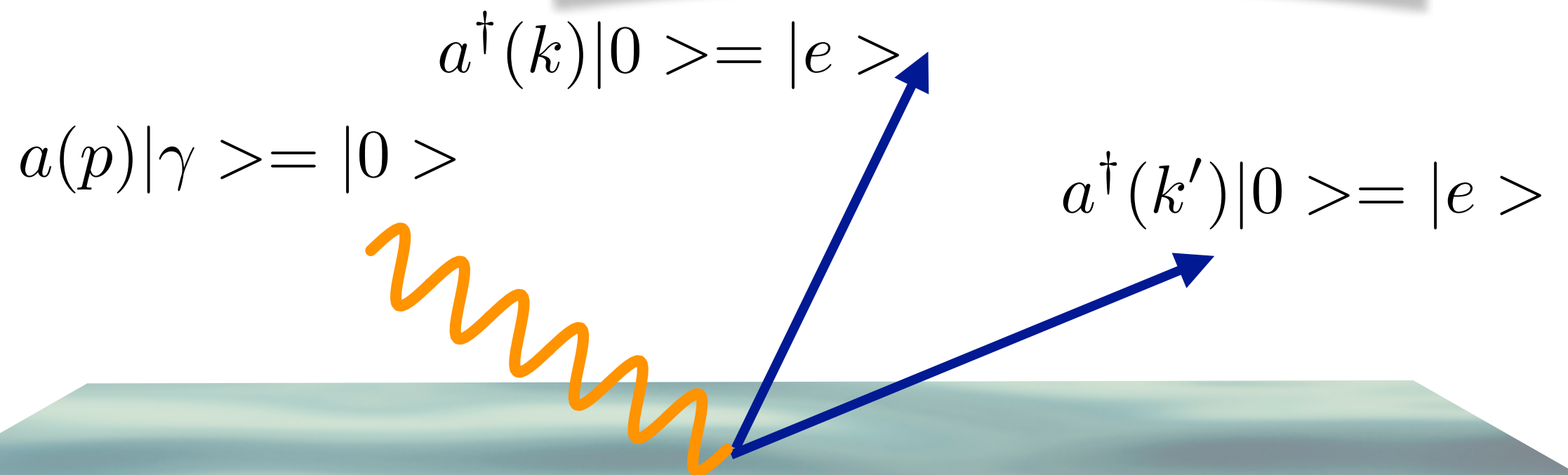
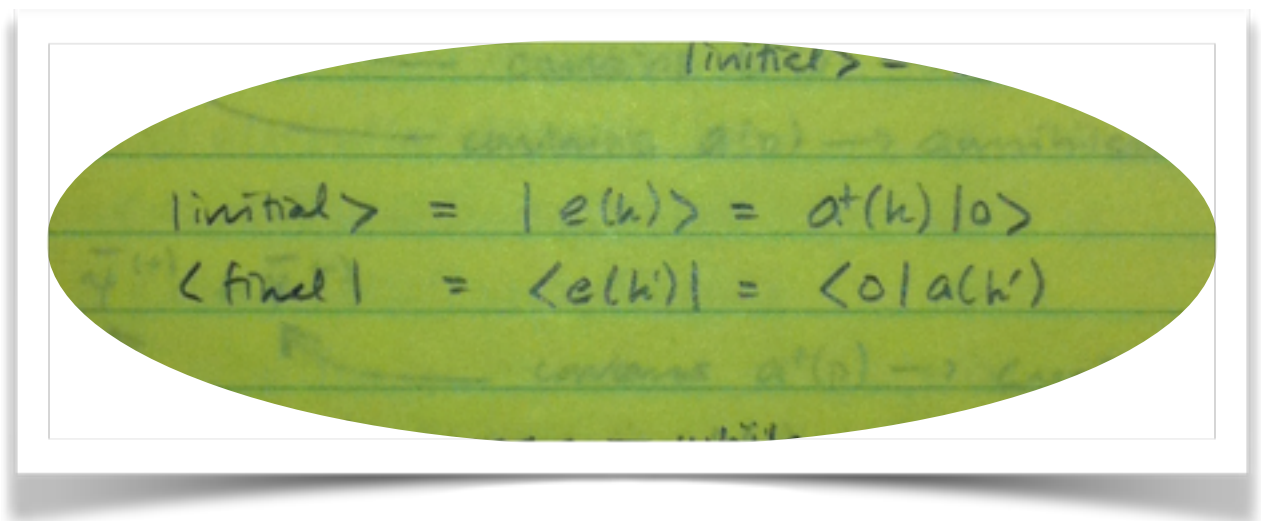


a photon
poof-disappears



a little
more
specific

what the
mathematics tells
us



it's not like the photon is now "in" the electron

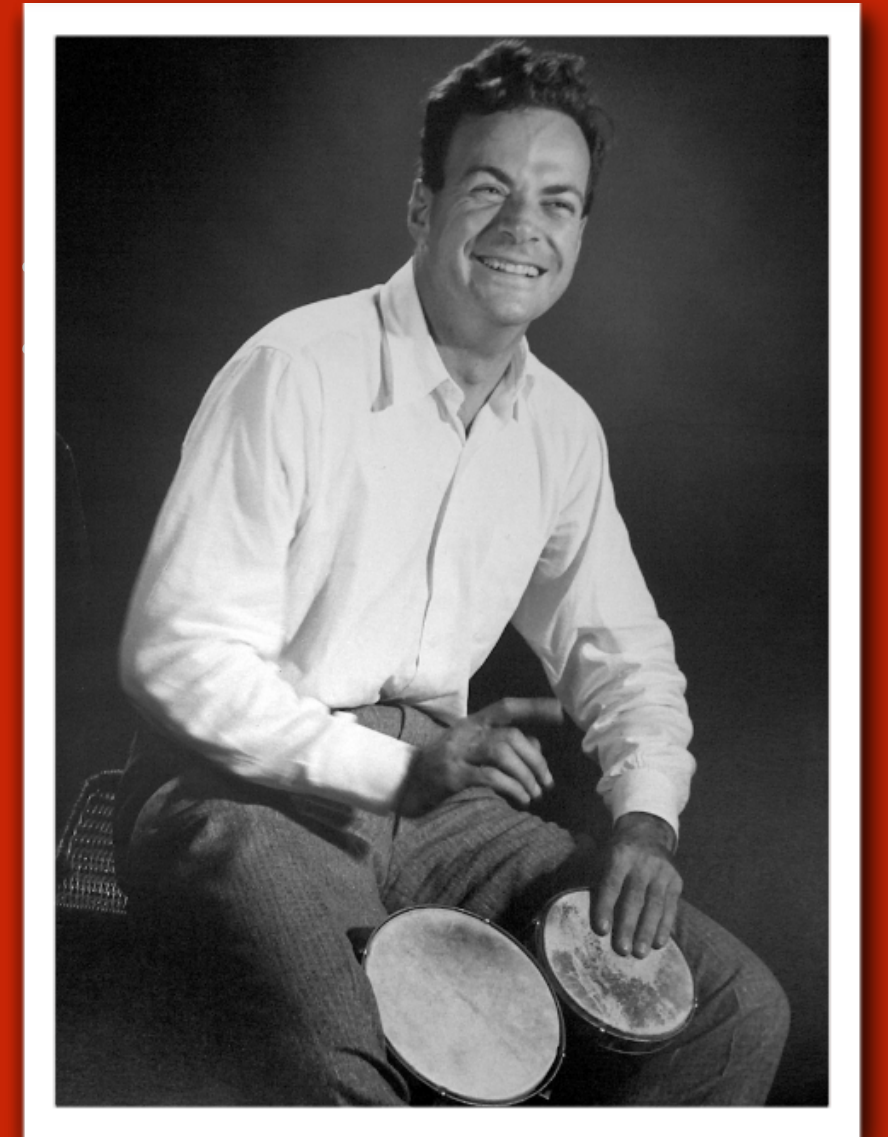
the photon pops the electron- positron pair out of the Ur
electron field

and itself disappears back into the Ur photon field.

Feynman Diagrams

now for real.

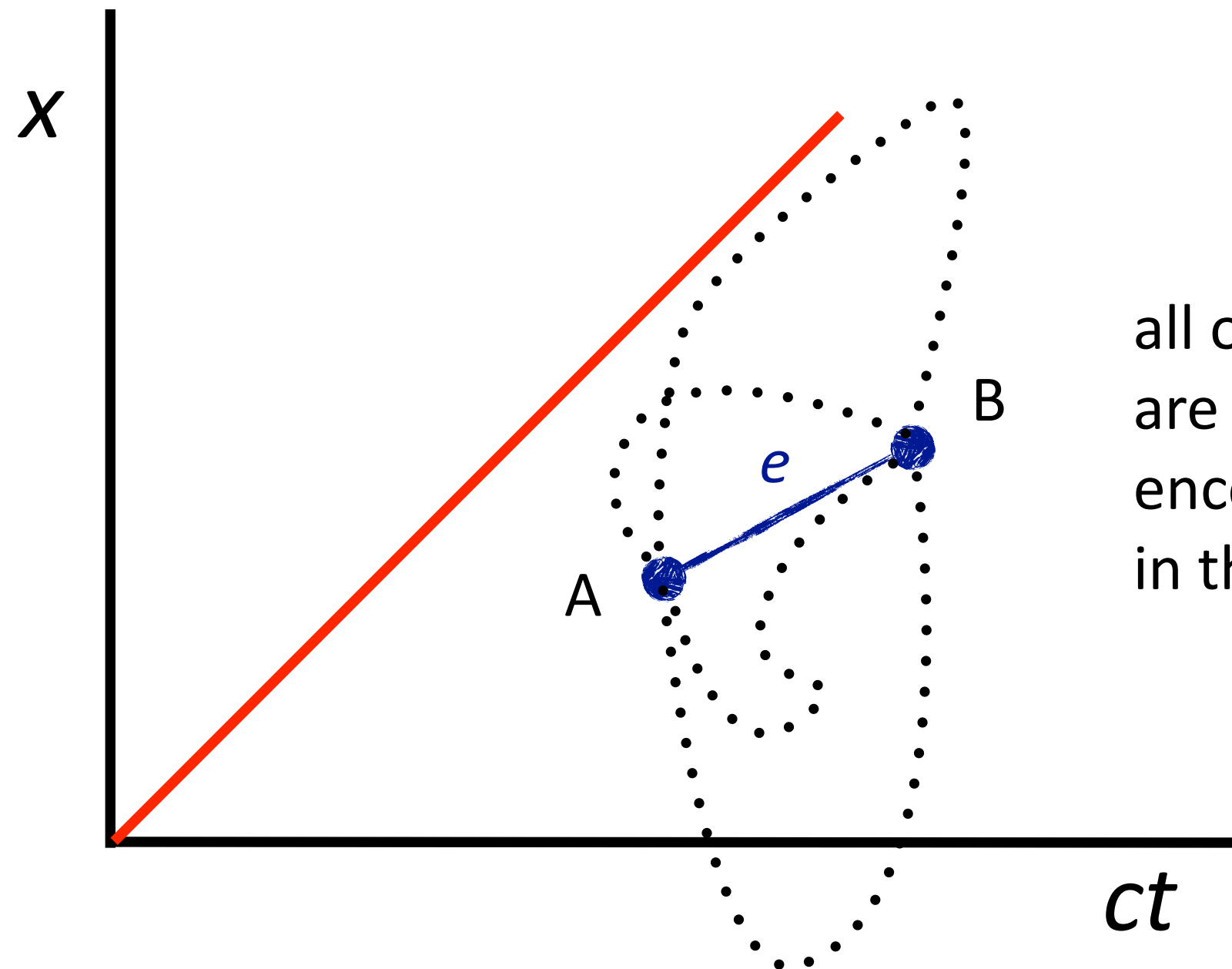
creation and annihilation of
can be embodied in Feynman Diagrams



the symbols of Feynman Diagrams

each line represents an entire "history" of trajectories

to go from A to B, represent all histories with a single line.



Feynman's lines include rules on how to calculate the possibilities in a relativistically consistent way.

Feynman's approach is really sneaky and really cute

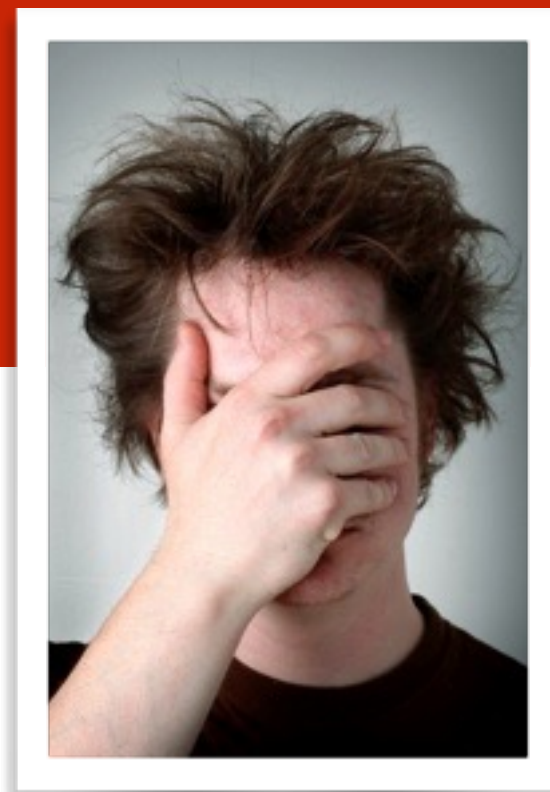
energy and time appear together in the equations:

In essence, this:

either energy solution: $(\pm E)(t)$

just the -E solution: $(-E)(t)$

move the - sign: $(E)(-t)$



Get a whole new interpretation of antimatter

antiparticles

can be interpreted as particles moving backwards in time.

that's it.

and visa versa

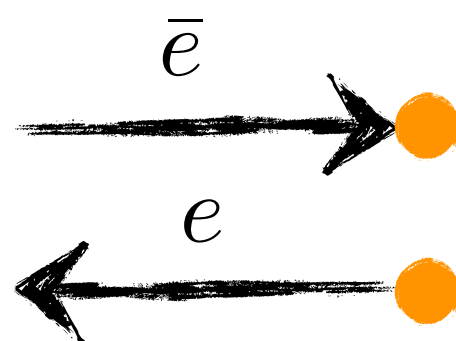
we'll do
this in

two steps

1. I'll show you how spacetime can be manipulated to predict new physical processes out of old ones

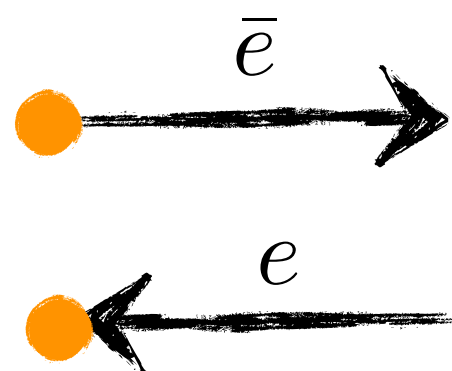
making use of the Feynman idea that antiparticles moving forward in time are the same as particles moving backwards in time

An anti-electron...coming **forwards into** an **initial** state:



is the same thing as
An electron coming
backwards out of an **initial** state

An anti-electron...coming **forwards out** of a **final** state:



is the same thing as
An electron coming
backwards into a **final** state

2. But *the vast majority of our use* will be to develop the handful (11) of “Primitive Diagrams” that we’ll put together like a puzzle

to predict all possible physical processes in the “Standard Model” of particle physics

jargon alert:

fermion

refers to:

any particle with half-integer spin

entomology:

from Fermi's theoretical work on the behavior of large numbers of Fermions

example:

electron, proton, neutron

jargon alert:

bosons

refers to:

any quantum object with integer spin

etymology:

from Satyendra Nath Bose, who worked on the effects of multiple boson aggregates

example:

photon, pion, Higgs Boson

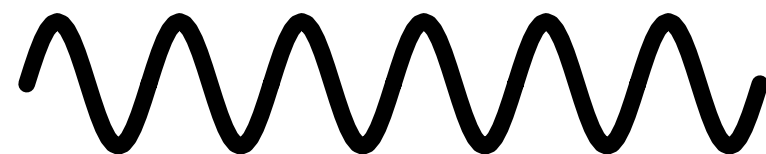
the key

the different kinds
of lines

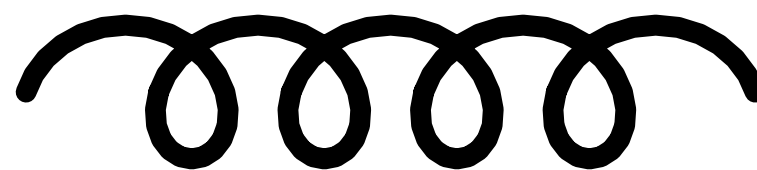
look at your Primitive
Diagram Sheet



fermion, spin $1/2$, e.g., electron



Vector Boson, spin 1, e.g., photon



gluon, spin 1



scalar Boson, spin 0, e.g., Higgs Boson

the first theory of Feynman's

"Quantum Electrodynamics" or "QED"

the full theory of the physics of photons and electrons

strap in

with pencil in hand

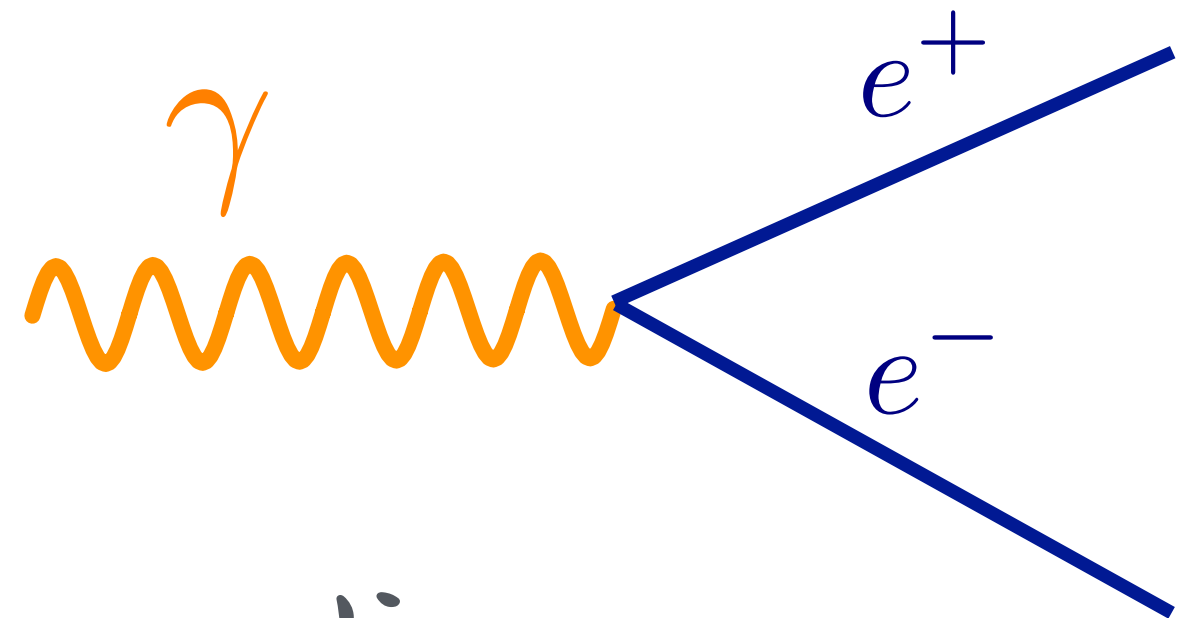
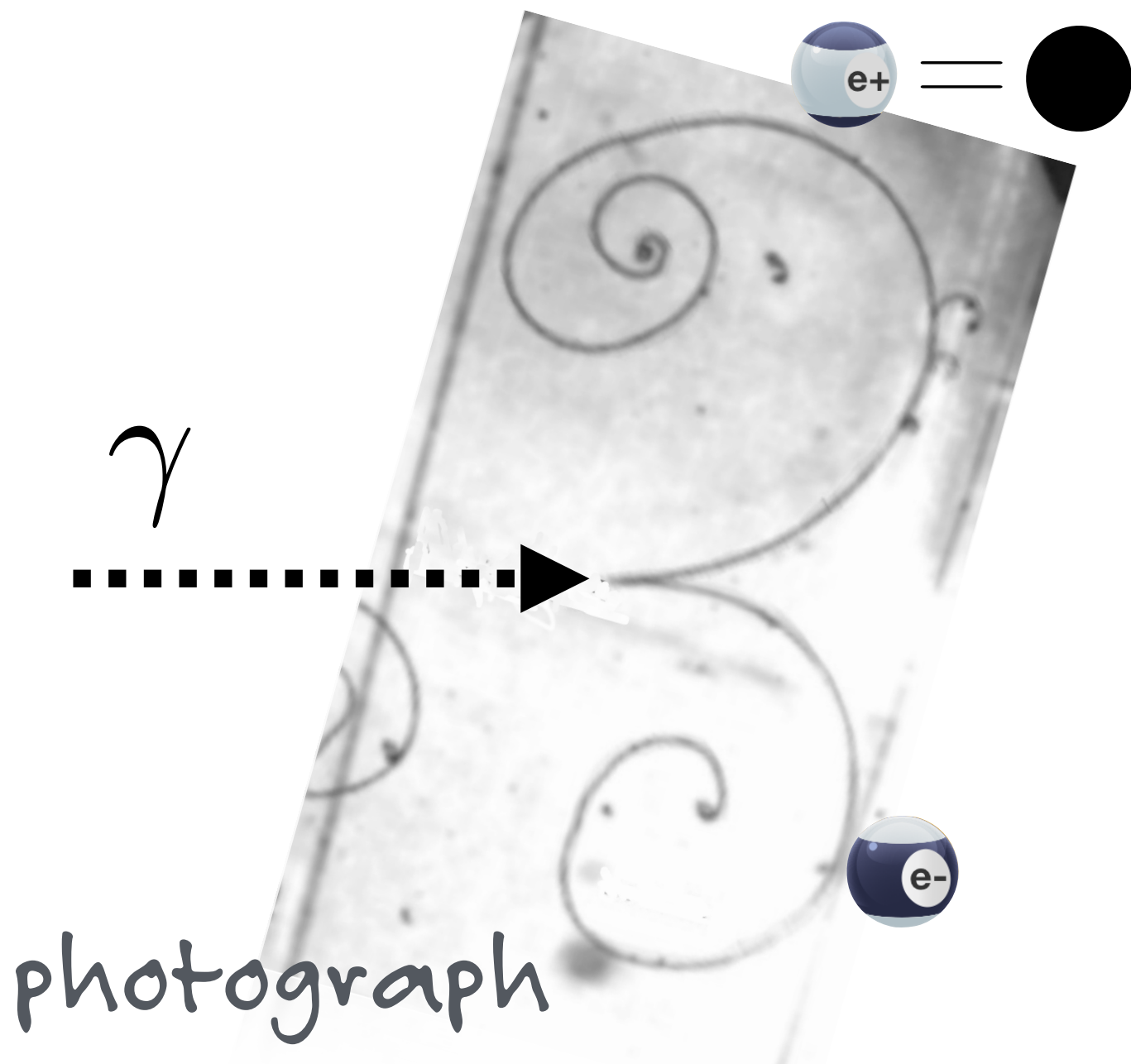
first idea

one can take a single Feynman Diagram that describes a process

and by rearranging it in spacetime, "predict" additional physical processes

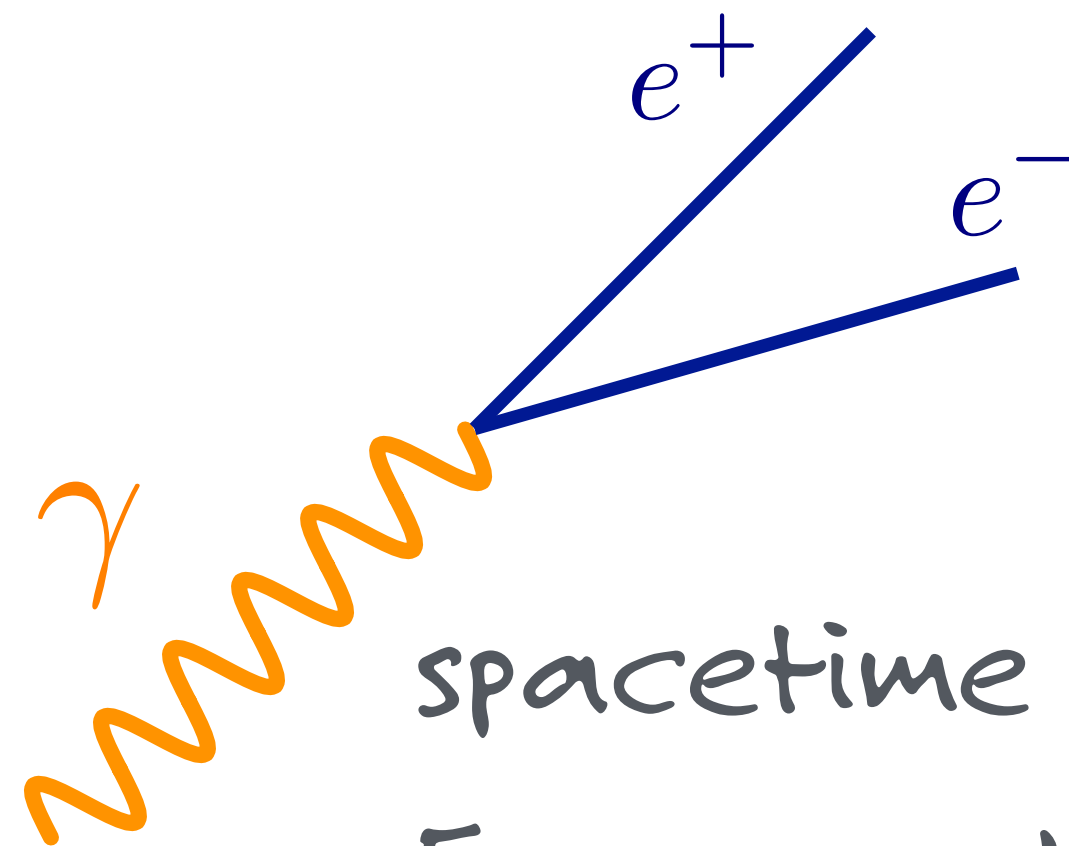
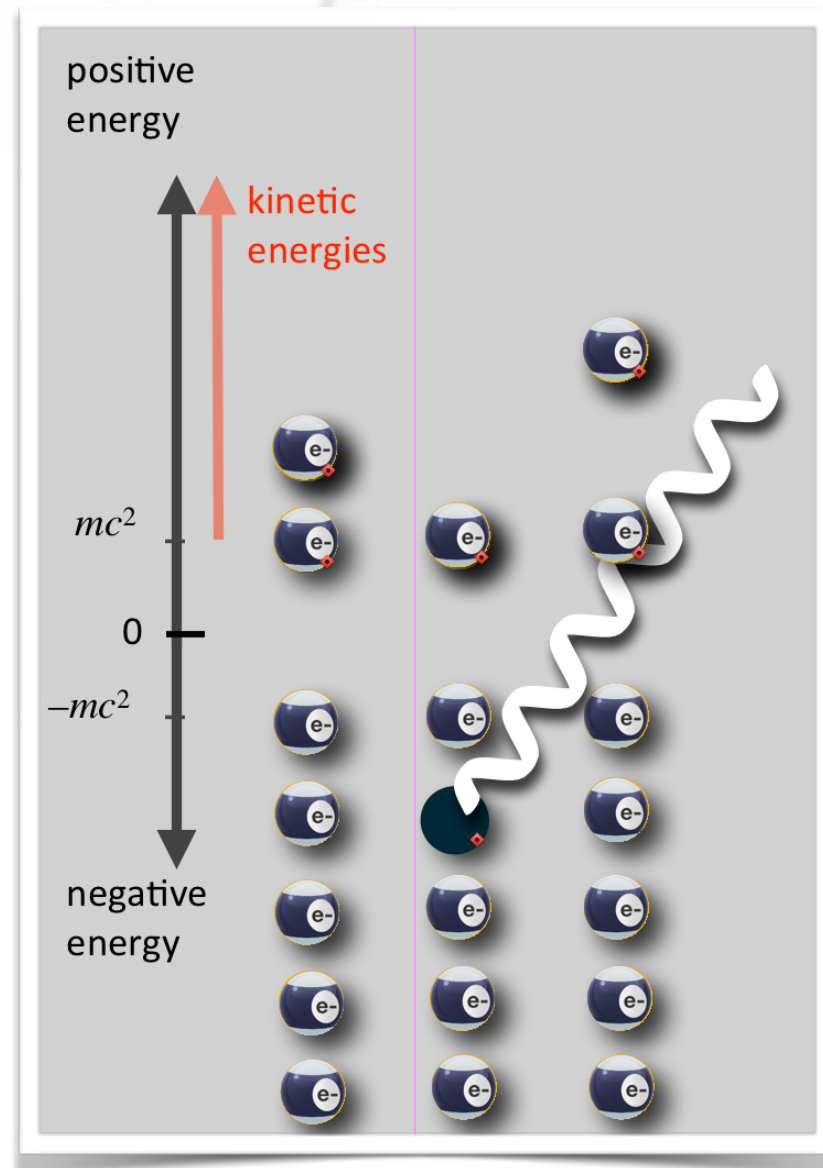
Dirac's story

& Feynman's picture



space diagram

cartoon

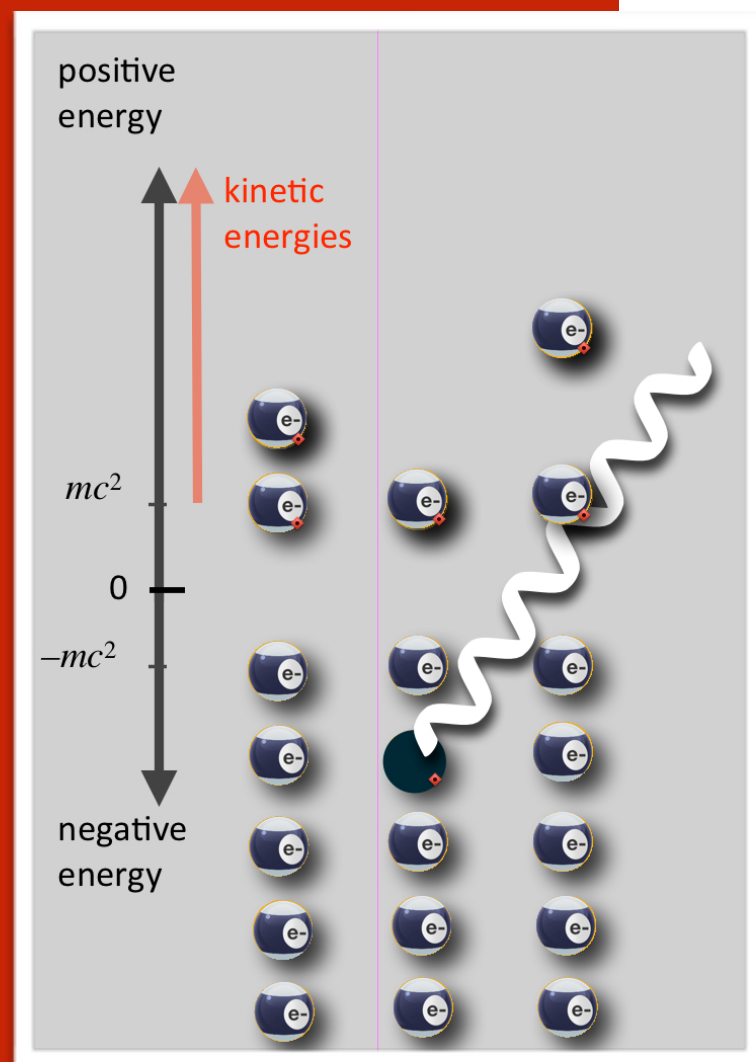


spacetime diagram
Feynman diagram

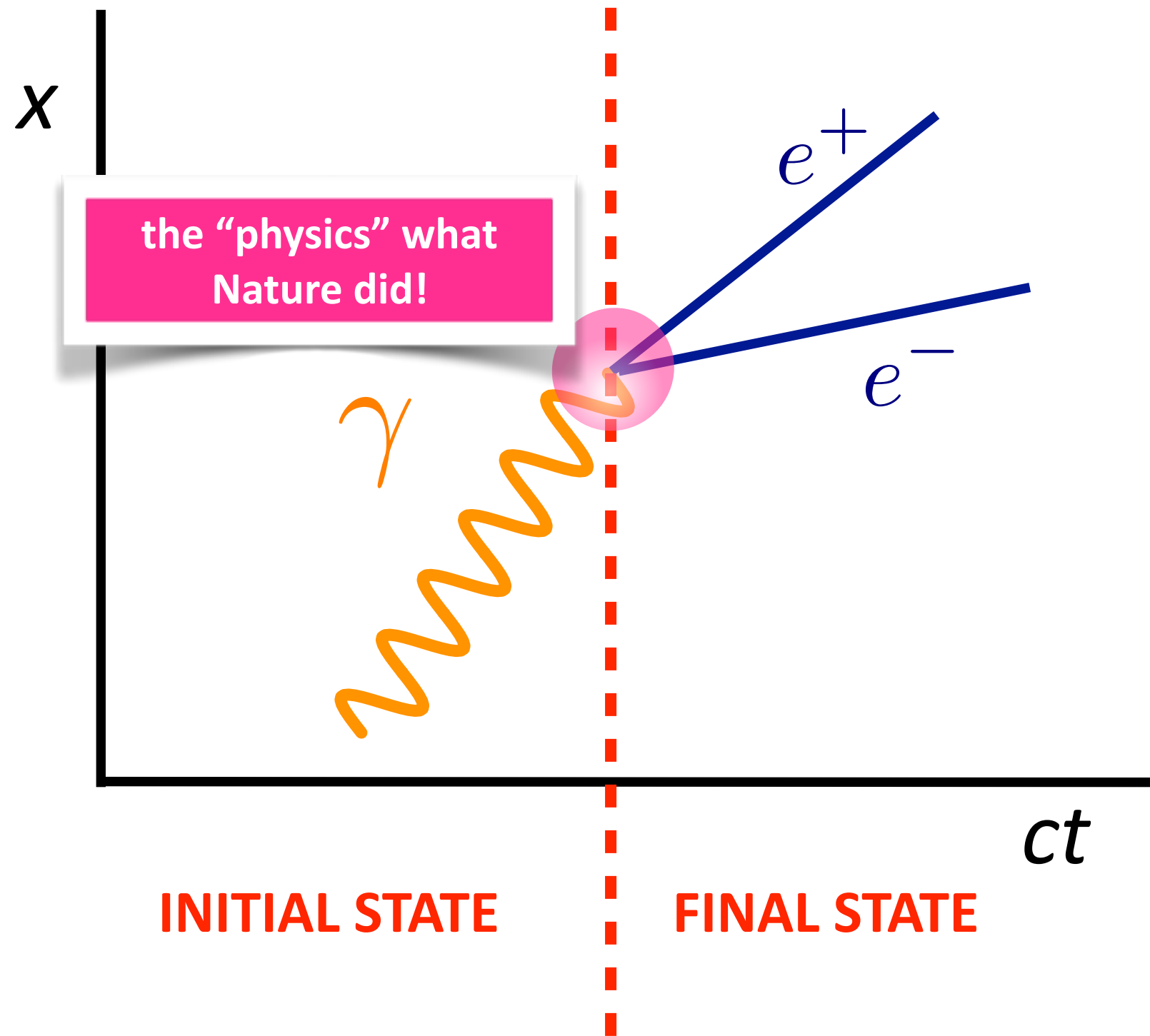
Dirac had photons creating an electron

Feynman's calculus allows that

and more



The Dirac hypothesis is called "Pair Production": photon in, electron & positron out



Now, remember that we treat ct and x identically...

The physics does not care which orientation is which.

note:

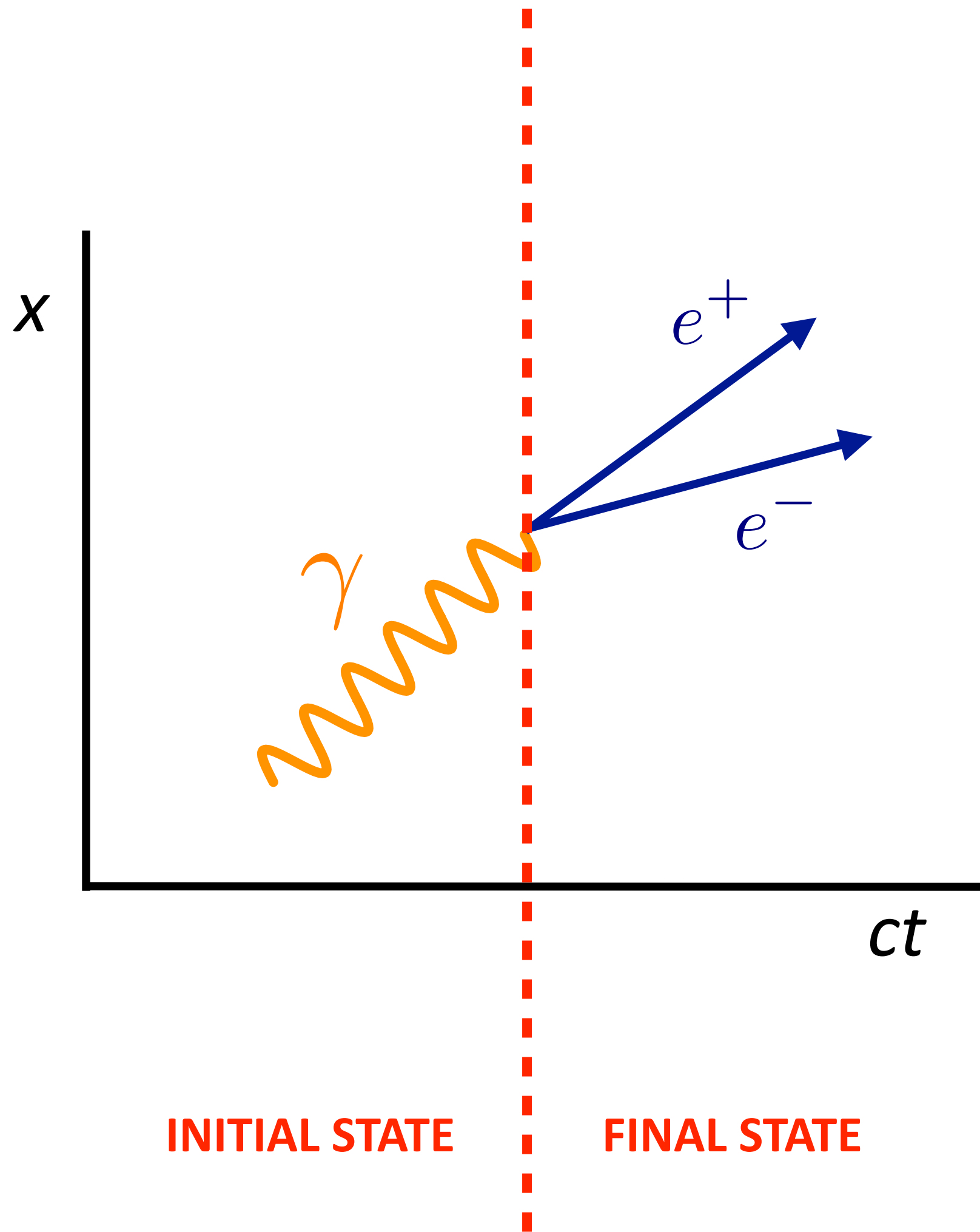
I've been banging on you to keep the slopes right

you know, photons have slope associated with c

We'll relax that now.

can always
rotate any
Feynman
Graph

and get a new one



BUT

We don't deal with particles moving backwards in time
when it happens...we fix it!

Feynman's trick

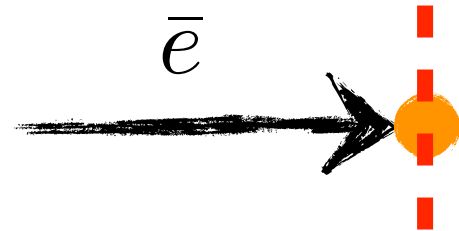
depends on the in and out states.

if some manipulation leaves you with particles going the "wrong" direction?

fix it.

particles in time

An anti-electron...coming **into** an **initial** state to a node:



is the same thing as

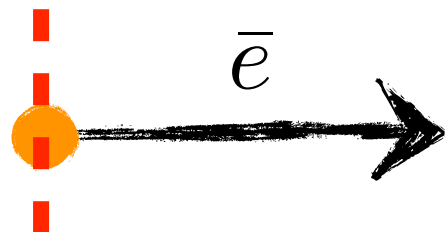
An electron coming **out** of an **initial** state (?)



Yes, this makes sense

Nope, this makes no sense...time-backwards

An anti-electron...coming **out** of a **final** state:



is the same thing as

An electron coming **into** a **final** state (?)

Yes, this makes sense

Nope, this makes no sense...time-backwards

Feynman had rules

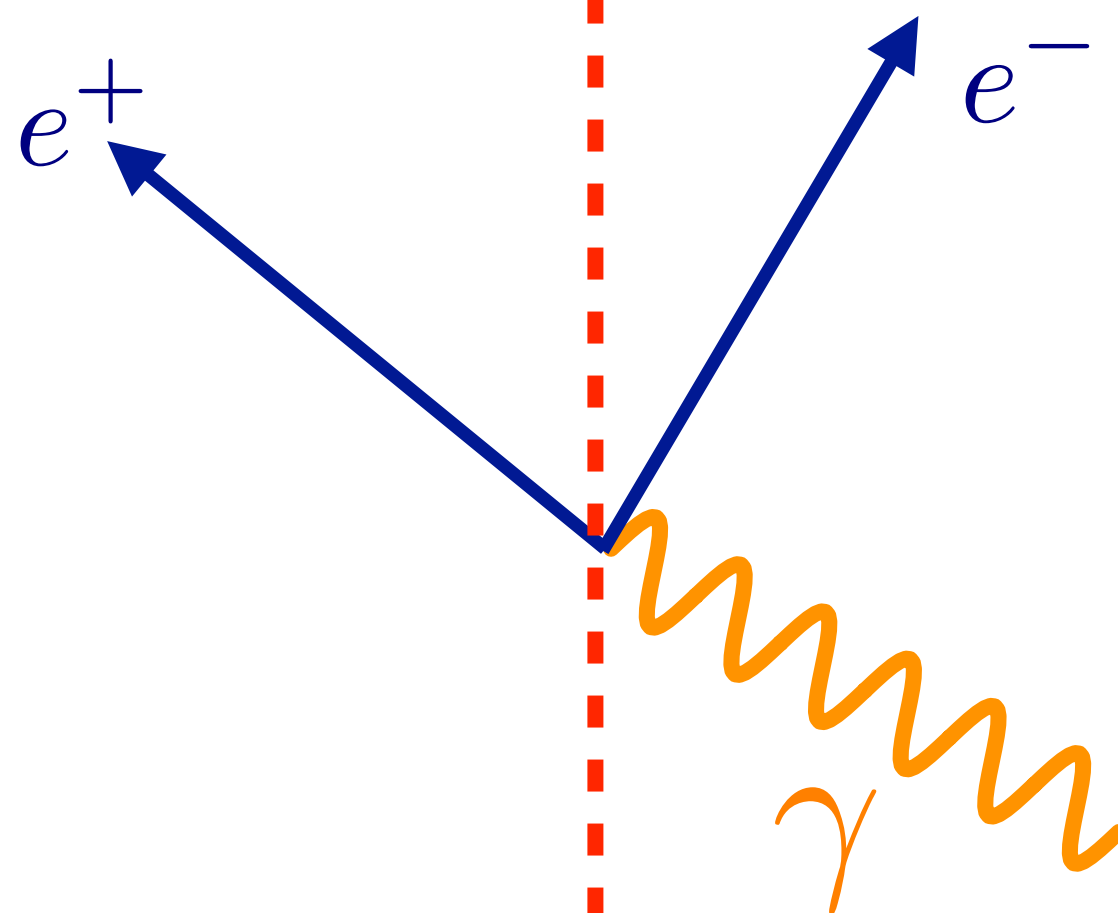
We'll have slightly different rules

but similar in spirit

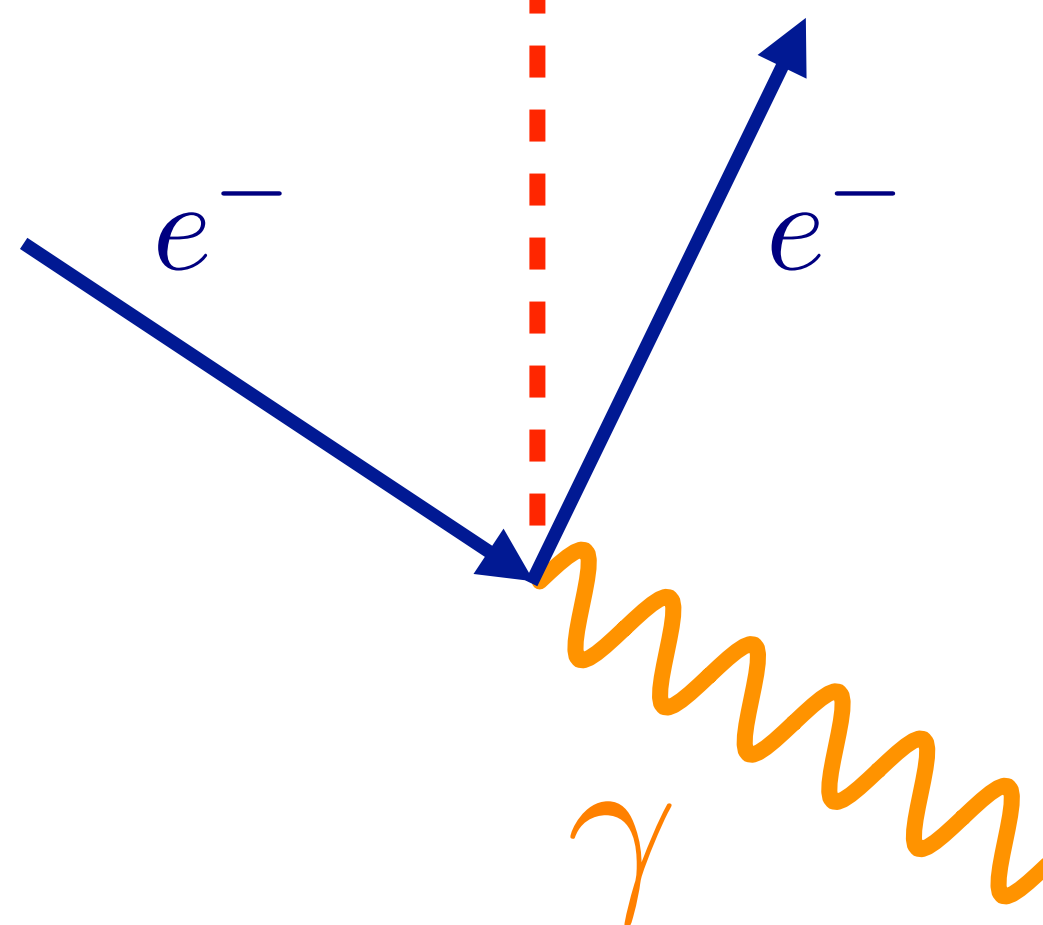
Rule 1.

If you flip a line's arrow forward or backward in time, you change the particle to antiparticle or antiparticle to particle

my rotated diagram...
spread out:



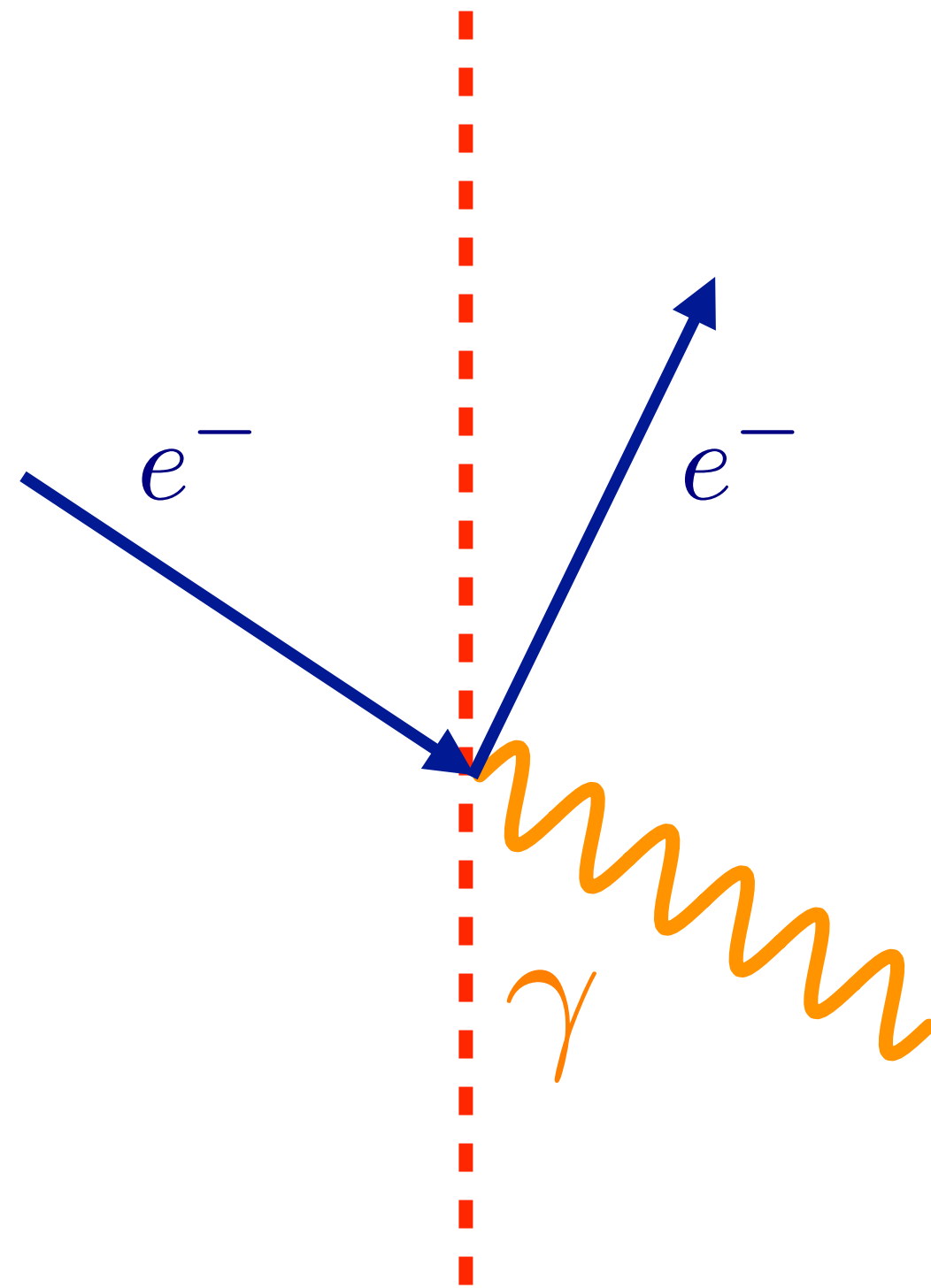
this is the same thing as:



look at
this

you know this.

familiar:



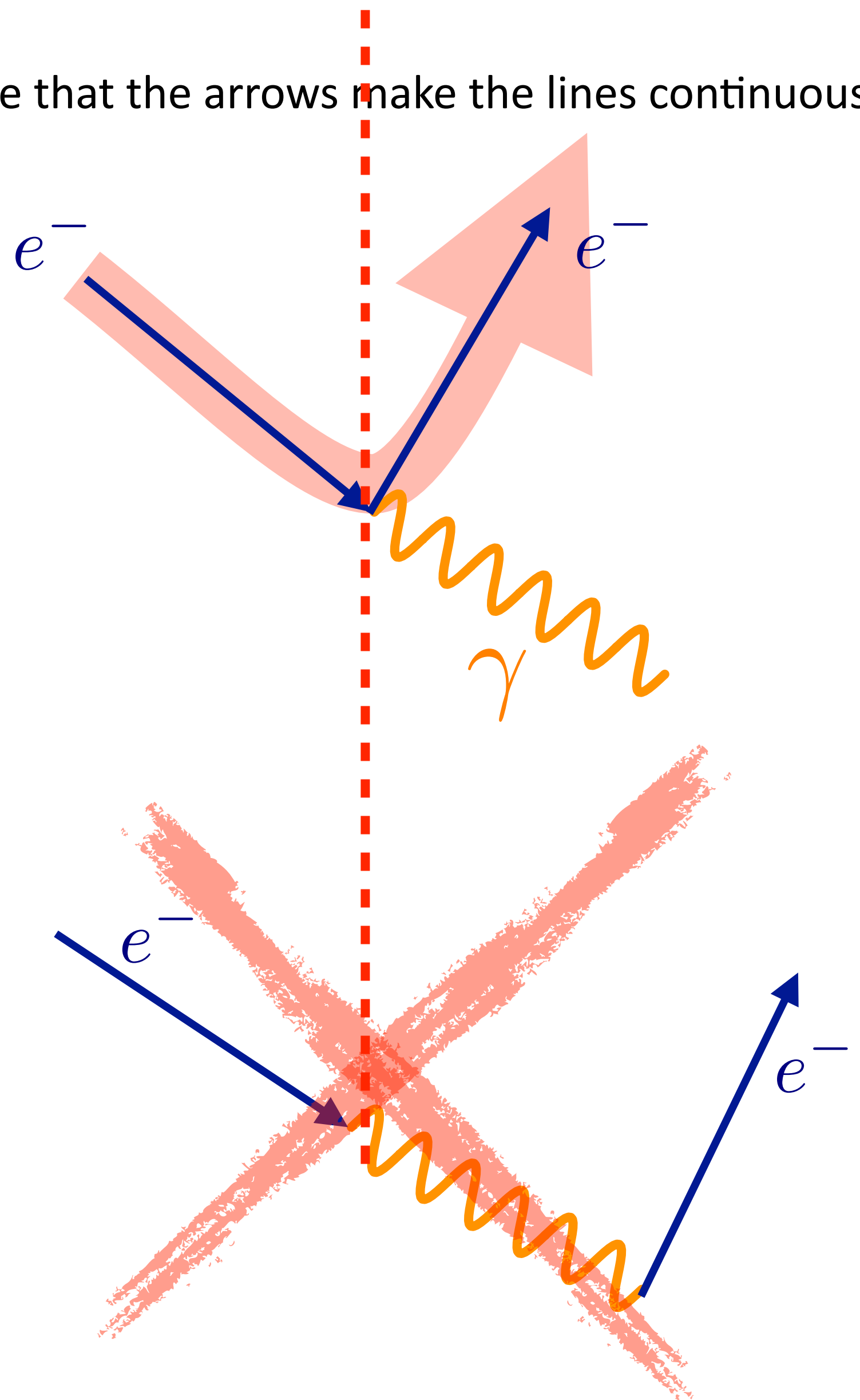
electron comes along and spits out a photon, recoils
and goes on its way

regular old radiation

Rule 2.

fermion lines
must be
continuous

notice that the arrows make the lines continuous



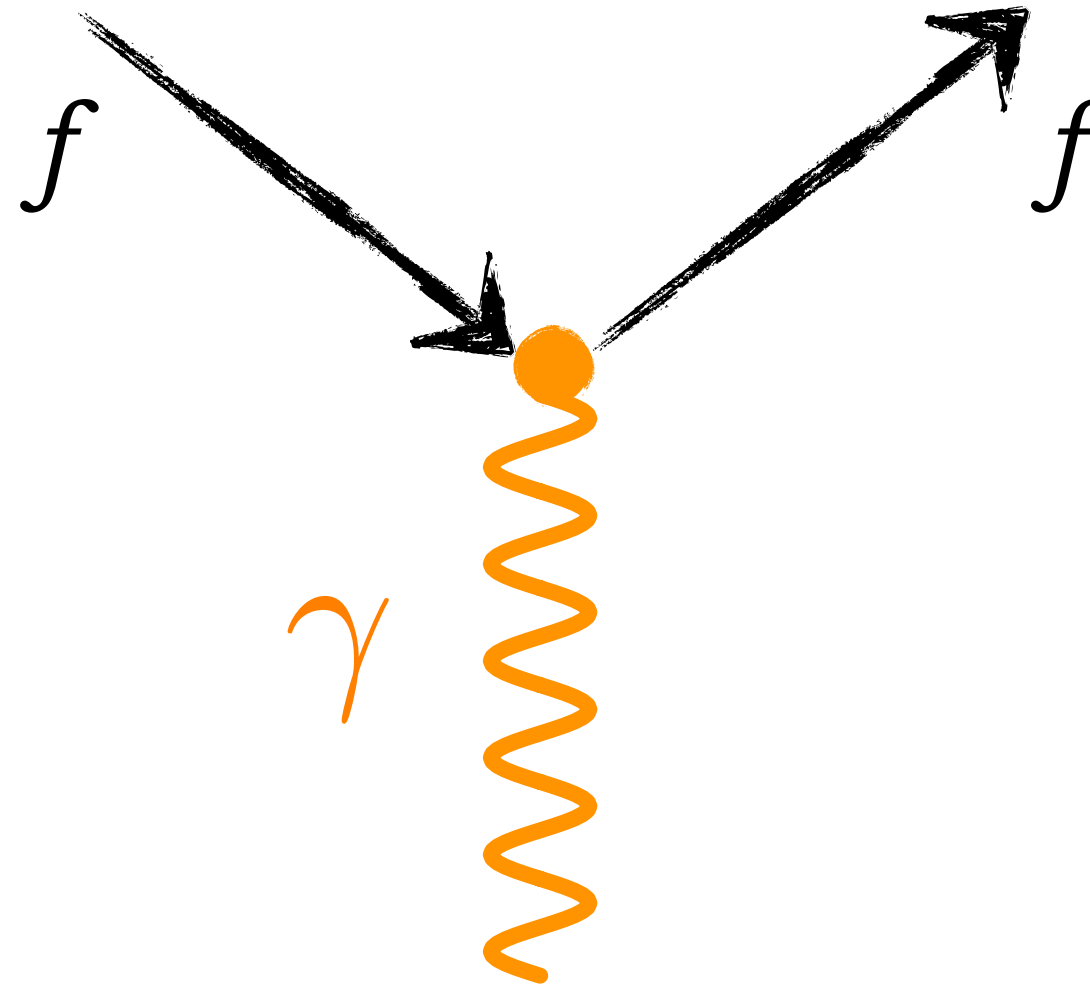


This and more is in those 3 movies

primitive diagrams

are general

but this is completely general...for any charged fermion:




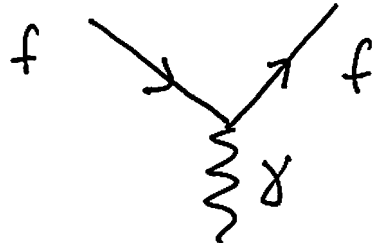
f could be electron, positron, proton, antiproton...and more – any electrically charged **f**ermion.

Their diagrams are identical.





Primitive Diagram Scorecard

your first entry

Primitive Diagrams TIME always: 

1			QED
2		3	Weak Interactions
6		7	
4		5	Strong Interactions
8		9	Higgs Interactions
10		11	

fermion, spin 1/2, e.g., electron Vector Boson, spin 1, e.g., photon gluon, spin 1 scalar Boson, spin 0, e.g., Higgs Boson

particle physics

particle:

neutron

symbol:

n

charge:

0

mass:

1.6749×10^{-27} kg, 939.6 MeV/c²

spin:

1/2

category:

fermion, baryon, $I = -1/2$, $B = 1$

particle:

proton

symbol:

p

charge:

$+1e$

mass:

$1.6726 \times 10^{-27} \text{ kg}, 938.2 \text{ MeV}/c^2$

spin:

$1/2$

category:

fermion, baryon, $I = 1/2, B = 1$

important realizations

nuclear force

exchange force

weak force: neutrinos

beta decay

the "weak force"

beta decay

something seriously wrong

remember: #neutrons doesn't affect the
Chemistry

can add neutrons

as long as the nucleus is
energetically stable

"isotopes"



^{13}C : 1.1% & stable

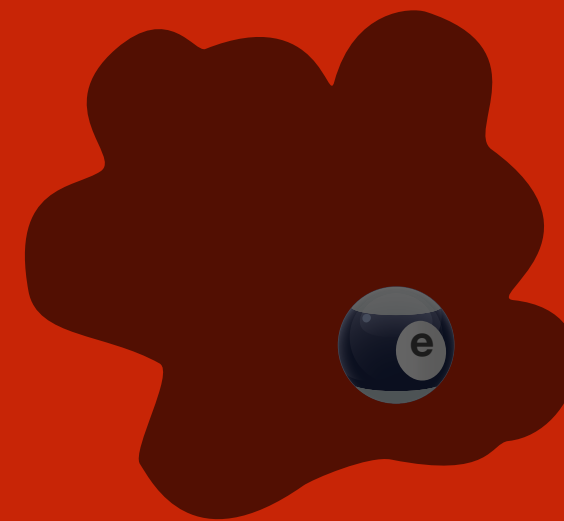
^{14}C : trace & unstable

some isotopes are unstable

they beta-decay

^{14}C : trace amounts & unstable

But there was a problem with beta decay

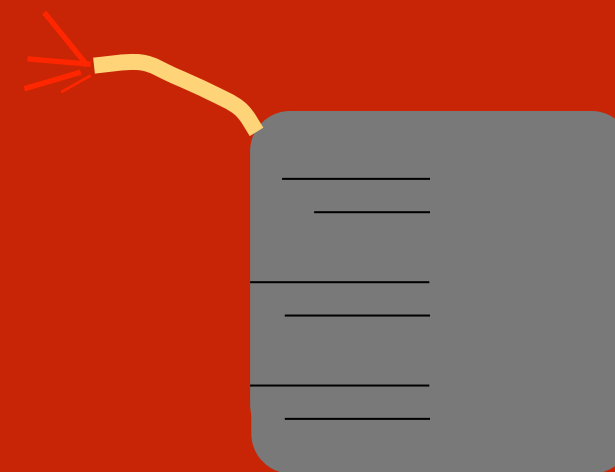


notice the funny
recoil?

Suppose we have a firecracker exploding
into two pieces:

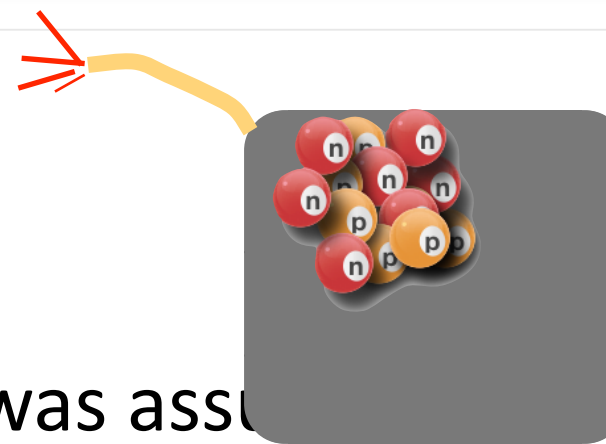
beta decay seemed like this

when you expect this



energies
in a “two
body
decay”

are single-valued



Beta decay was assumed to be a 2-body decay:
Nucleus \rightarrow e and Nucleus'

Do 100 decays and
measure the energy of
either object...

Should get a
particular speed
for the electron

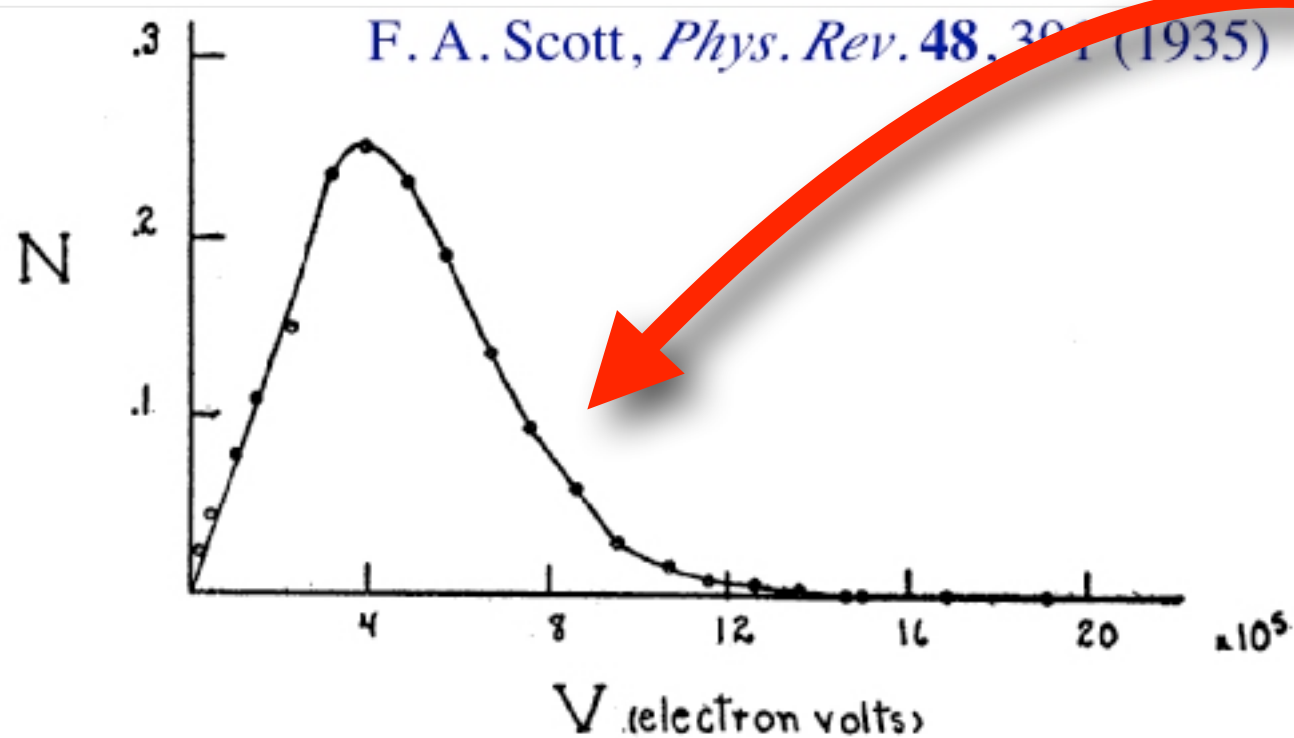
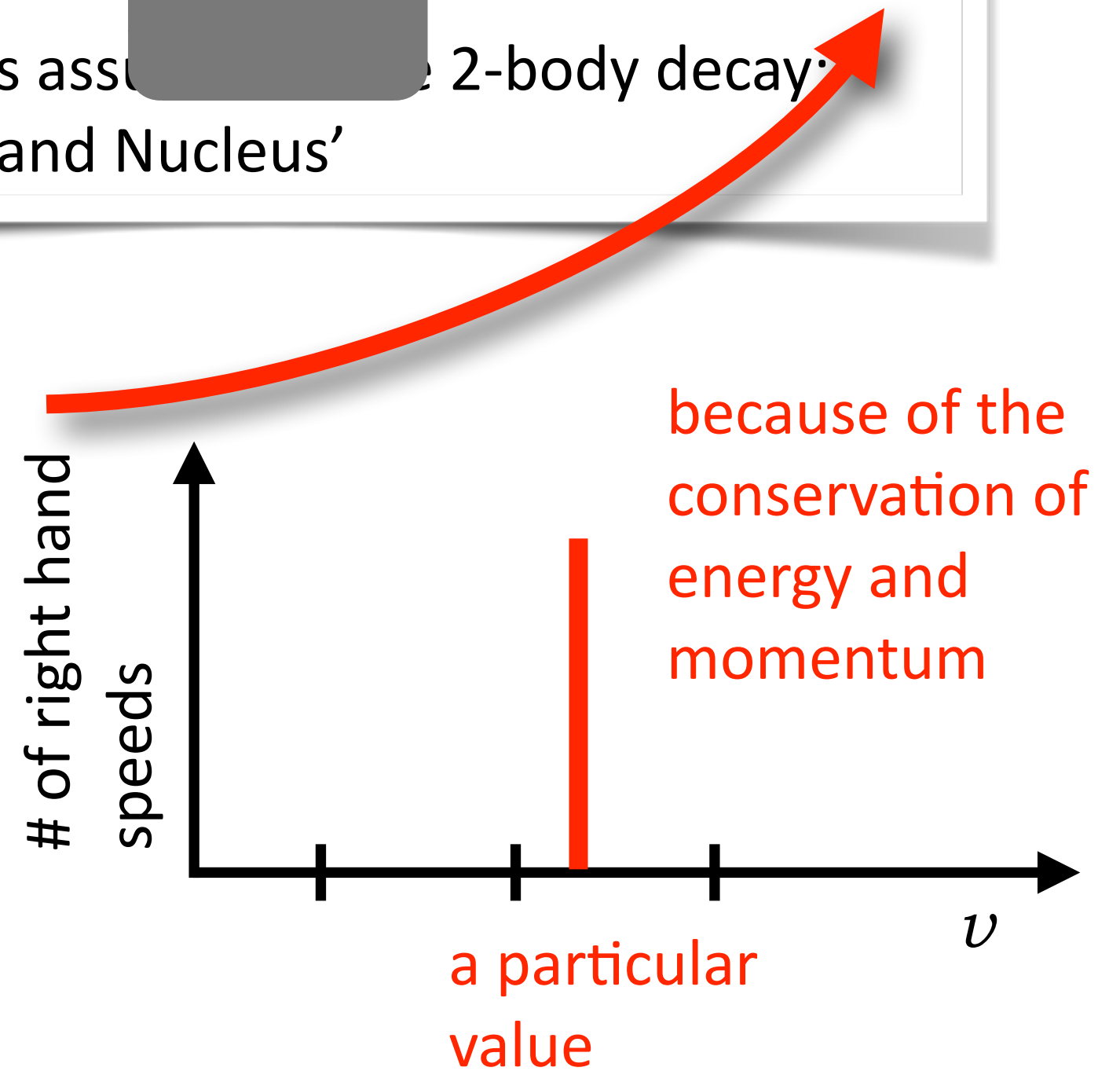
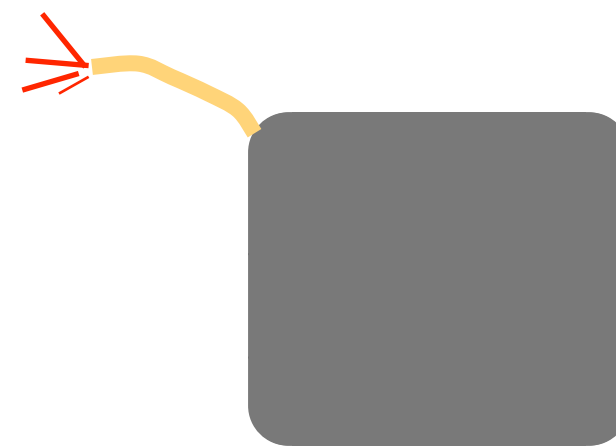


FIG. 5. Energy distribution curve of the beta-rays.

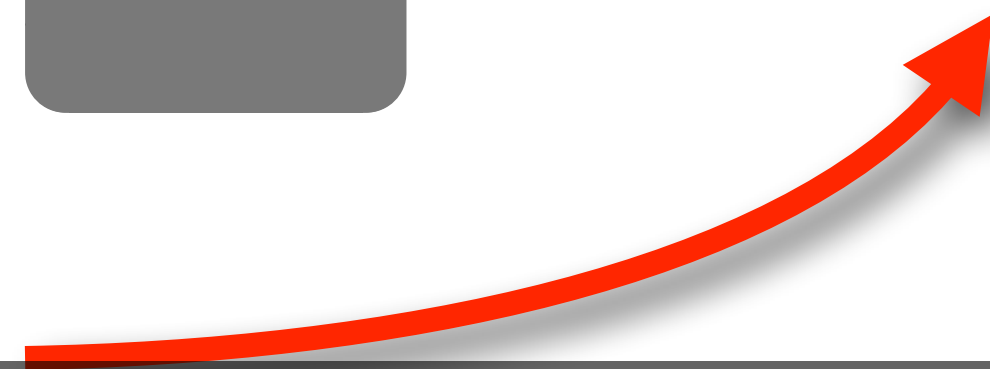
But this is what happened in beta
decay. **spread-out values for speed (energy)!**

suppose
you have
a "two
body

a single object
decays into
two objects



Do 100 explosions and
measure the energy of
either object...



an apparent crisis for energy conservation

because of the
conservation of
energy and
momentum

of right hand
speeds

a particular
value

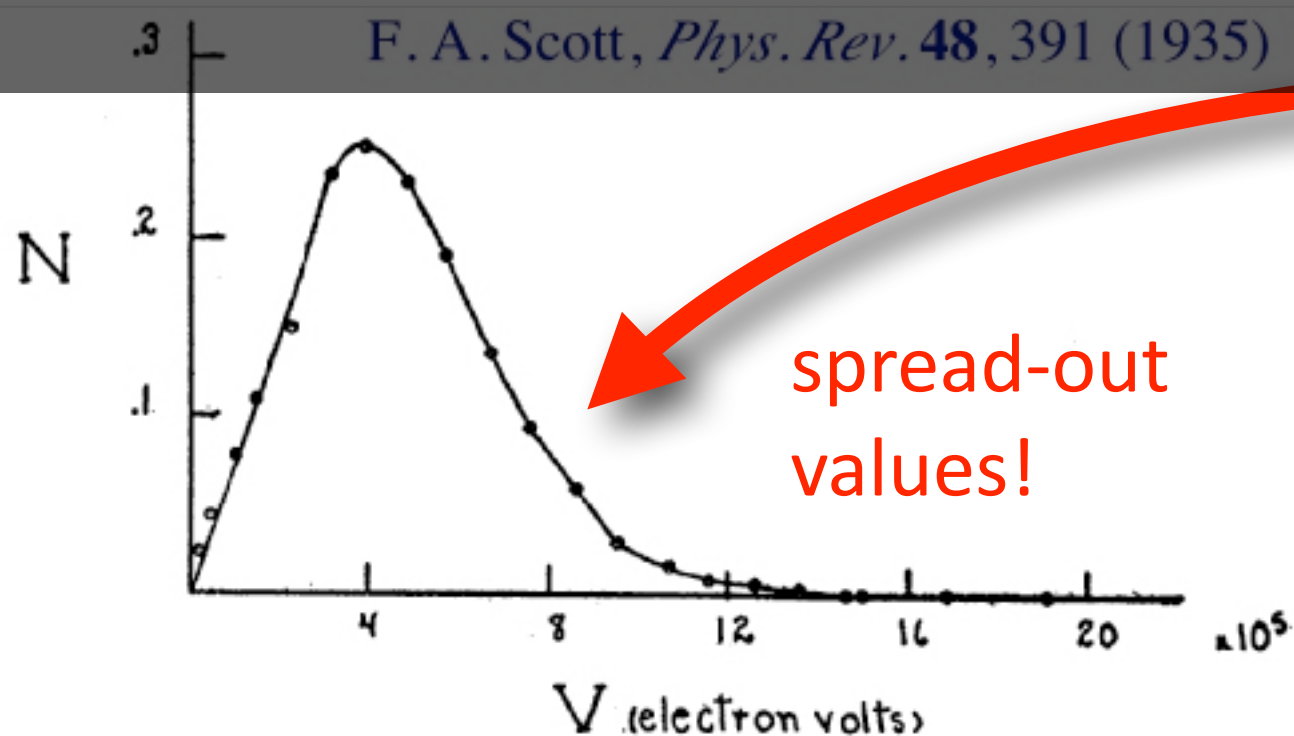


FIG. 5. Energy distribution curve of the beta-rays.

But this is what happened in beta decay.
Assumed to be 2 bodies:
Nucleus ---> e and Nucleus'



Wolfgang Pauli, distressed at the crisis and unwilling to part with energy conservation – like Bohr suggested – 1930 made a bold proposal, in an off-hand way:

“I have come upon a desperate way out. To wit, the possibility that there could exist in the nucleus electrically **neutral particles** which I shall call **neutrons**...the mass...should not be larger than 0.01 times the proton...the ... beta [energy] would then be understandable from the assumption that...a [neutron] is emitted along with the electron...I admit that my way out may not seem very probable...But only he who dares wins

...unfortunately I cannot appear personally in Tübingen since a ball which takes place in Zurich makes my presence here indispensable.”

Oops: James Chadwick called his new particle the “neutron”

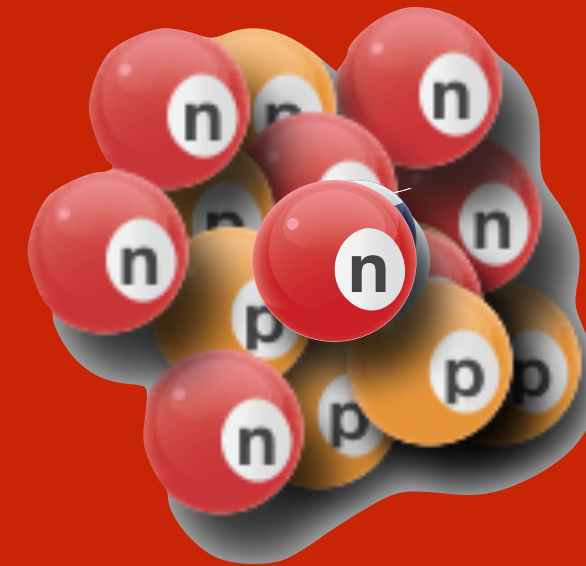
Enrico Fermi called Pauli’s the *neutrino*...little neutron

“



The prediction of the **Neutrino**
...thought to be **undiscoverable!**
and **massless!**

the idea hung around



the discovery of the neutron in 1932 gave Enrico Fermi an idea

beta decay 1933

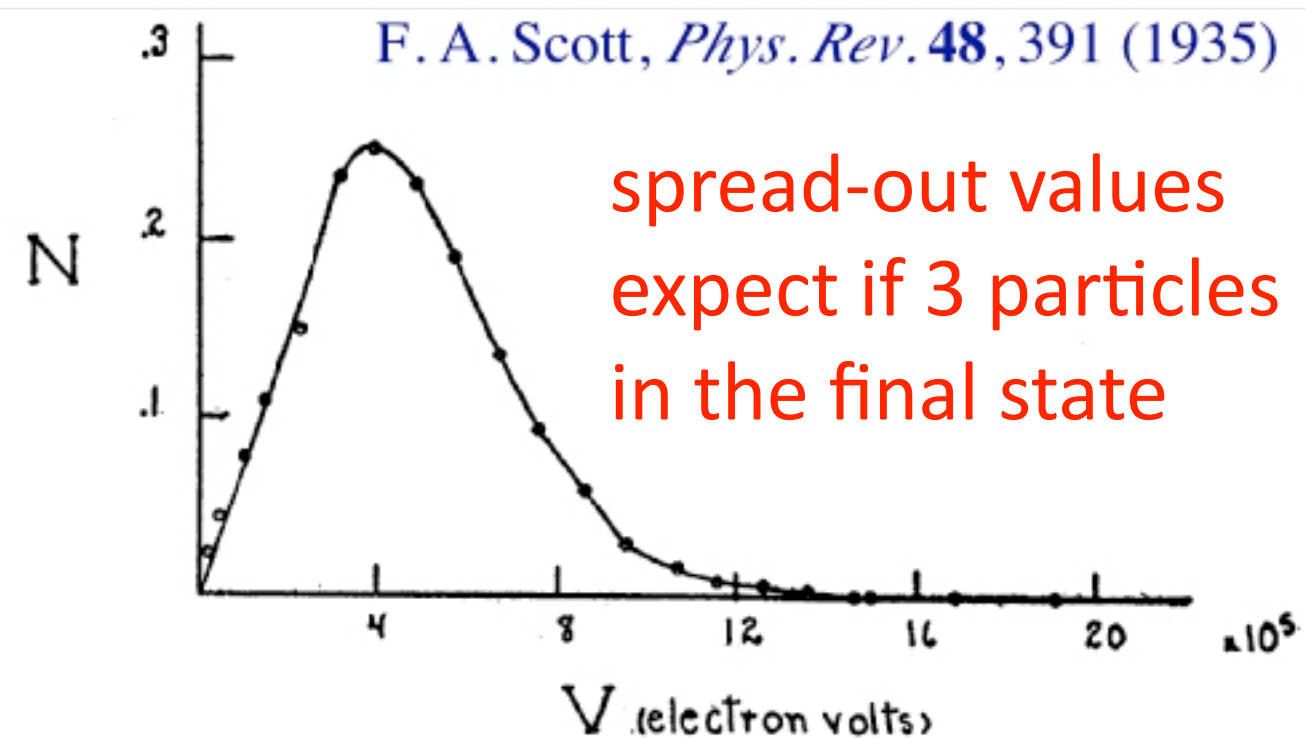
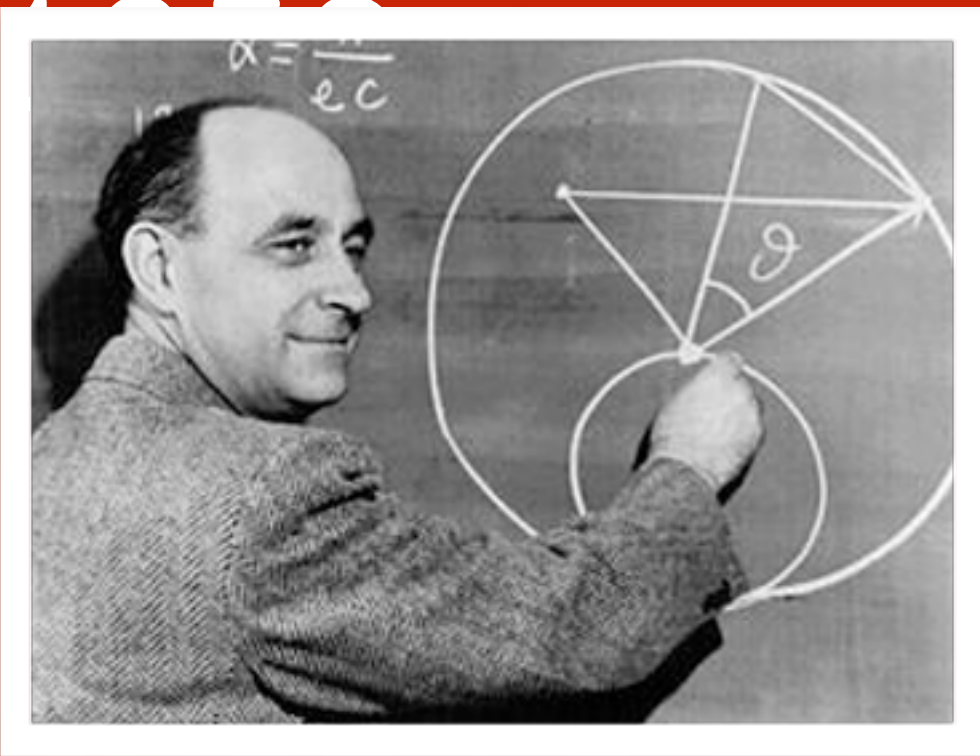


FIG. 5. Energy distribution curve of the beta-rays.

He suggested that a neutron turns into a proton during beta decay



Enrico Fermi

1901-1954

experimental &

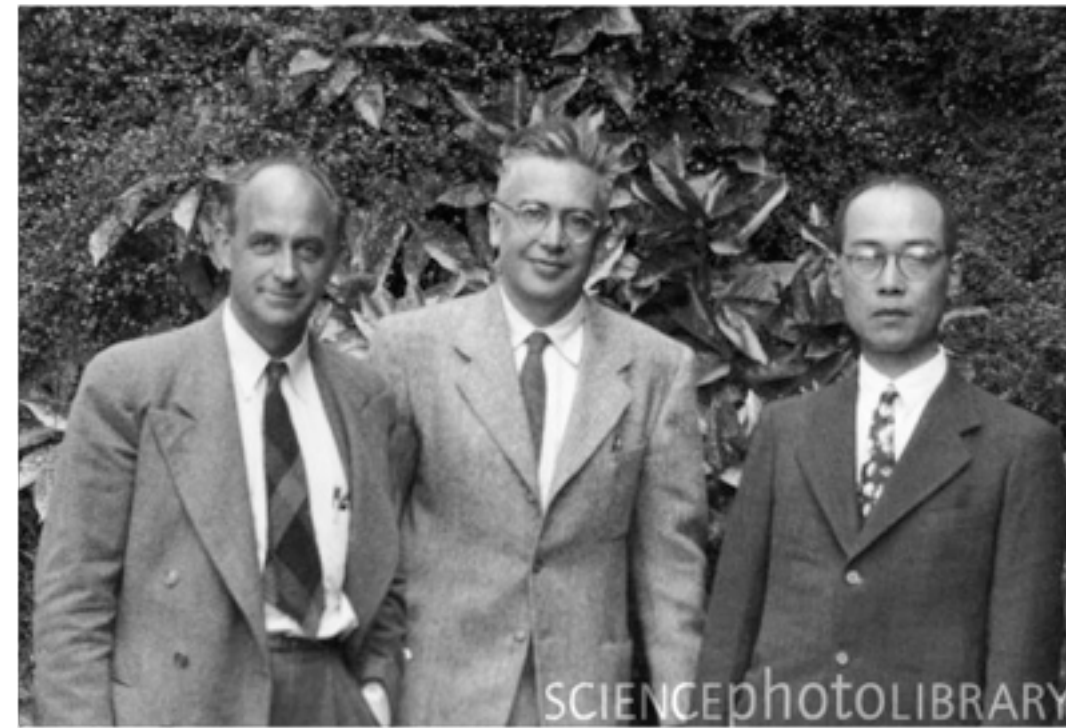
theoretical physicist!

Nobel Laureate 1938

Probably 2, maybe 3 Nobel prize-worthy experiments.

Probably 2, maybe 3 Nobel prize-worthy theoretical products.

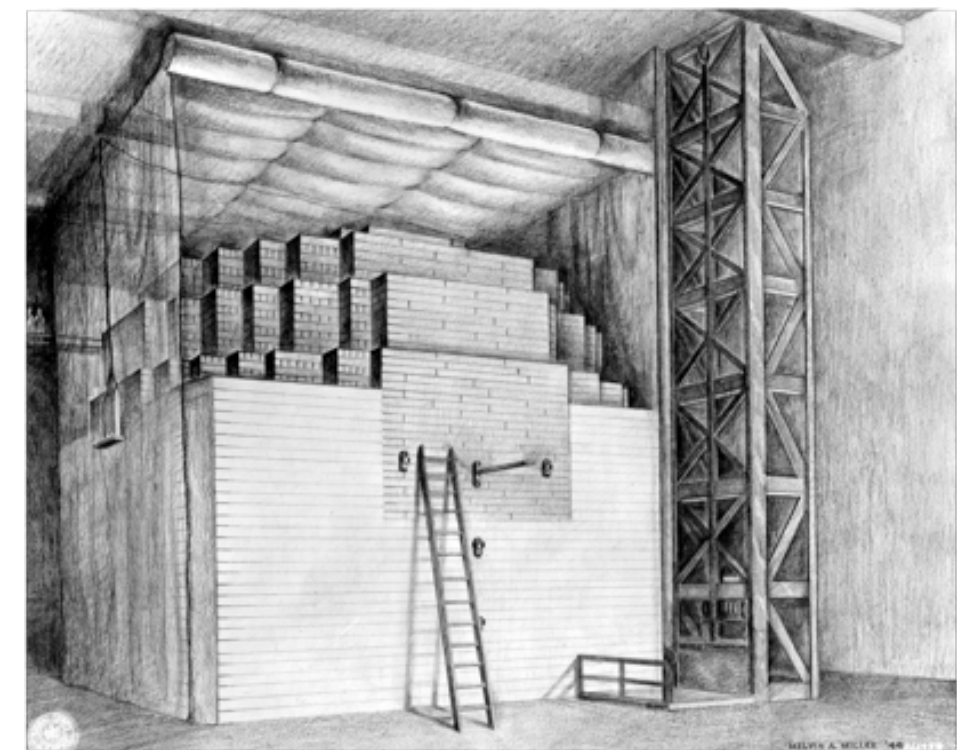
There will never be anyone like Enrico Fermi again.



Enrico Fermi

1901-1954

(actually in a cafeteria in Ann Arbor, 1935)




Enrico Fermi

Nobel 1938

not for beta decay

for bombarding nuclei
with neutrons and
causing fission



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The Official Web Site of the Nobel Prize

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Home / Nobel Prizes / Nobel Prize in Physics / The Nobel Prize in Physics 1938

About the Nobel Prizes

Facts and Lists

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- Nobel Prize in Chemistry
- Nobel Prize in Physiology or Medicine
- Nobel Prize in Literature
- Nobel Peace Prize
- Prize in Economic Sciences
- Nobel Laureates Have Their Say
- Nobel Prize Ceremonies

1901 2012 1938

Sort and list Nobel Prizes and Nobel Laur Prize category: Physics


The Nobel Prize in Physics 1938

Enrico Fermi

The Nobel Prize in Physics 1938

Nobel Prize Award Ceremony

Enrico Fermi



Enrico Fermi

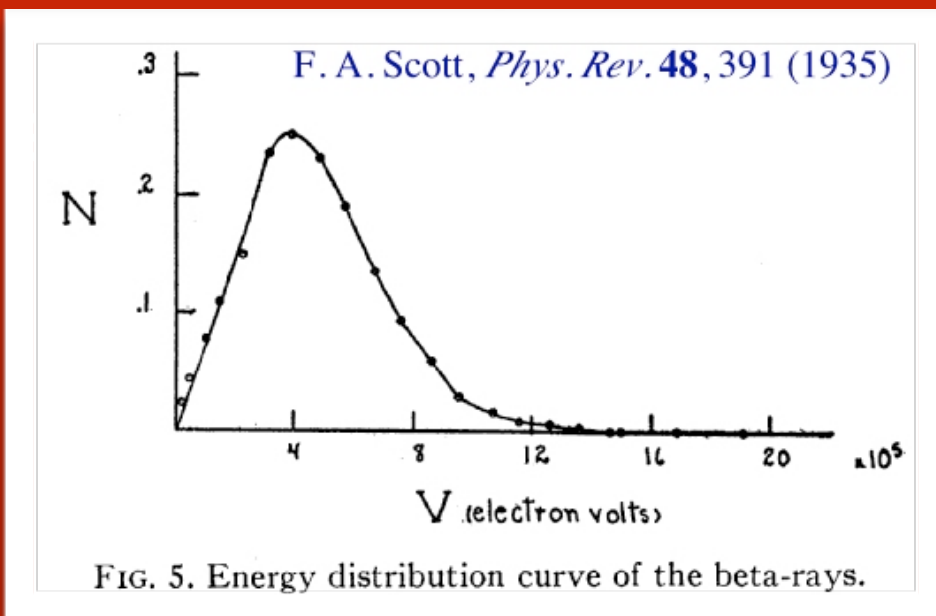
The Nobel Prize in Physics 1938 was awarded to Enrico Fermi "for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons".

Photos: Copyright © The Nobel Foundation

Fermi Theory of Beta Decay

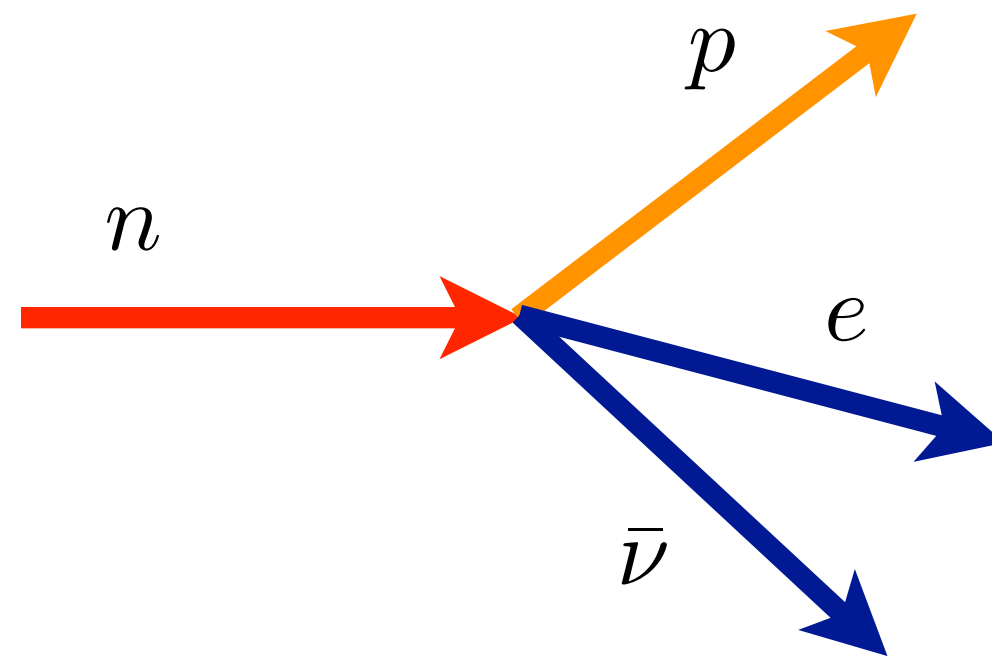
uses the Dirac
ideas of quantum
electrodynamics

particle creation and
annihilation



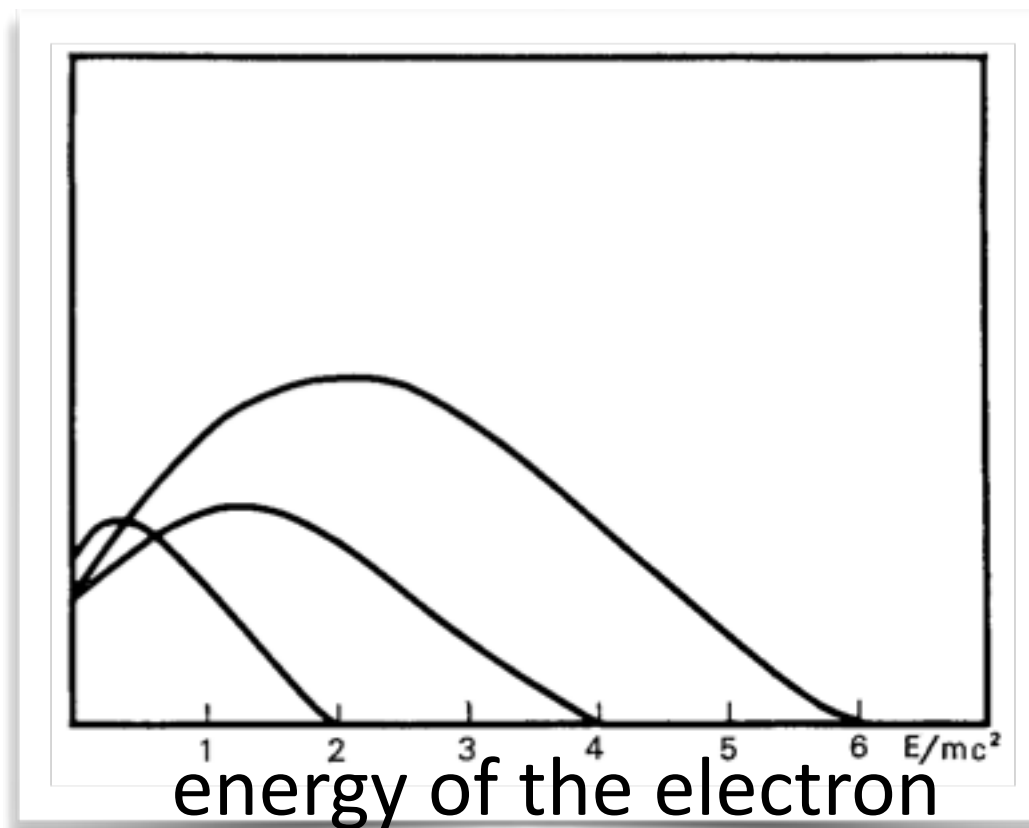
$$m_{\text{neutron}} > m_{\text{proton}}$$

a smidgen.



a free neutron has a lifetime of about 11 minutes.
He sent the paper to *Nature*, but it was rejected:

“it contained speculations which were too remote from reality”



from his original paper for different
nuclear species parameters

discovery of the neutrino

took 25 years

experimental tour de-force

Neutrinos very weakly interact in matter
lightyears of lead to stop one!

exchange force

the modern view:

if there's a force...there's a field

if there's a field...there's a particle

in 1932 Heisenberg had good idea:

the notion of an "Exchange Force"

the simplest, but most important modeling suggestion ever

Heisenberg: ‘‘Hmm. Electrons spontaneously appear out of nuclei...’’

maybe they’re in the nucleus all the time?

maybe they’re even holding it together?

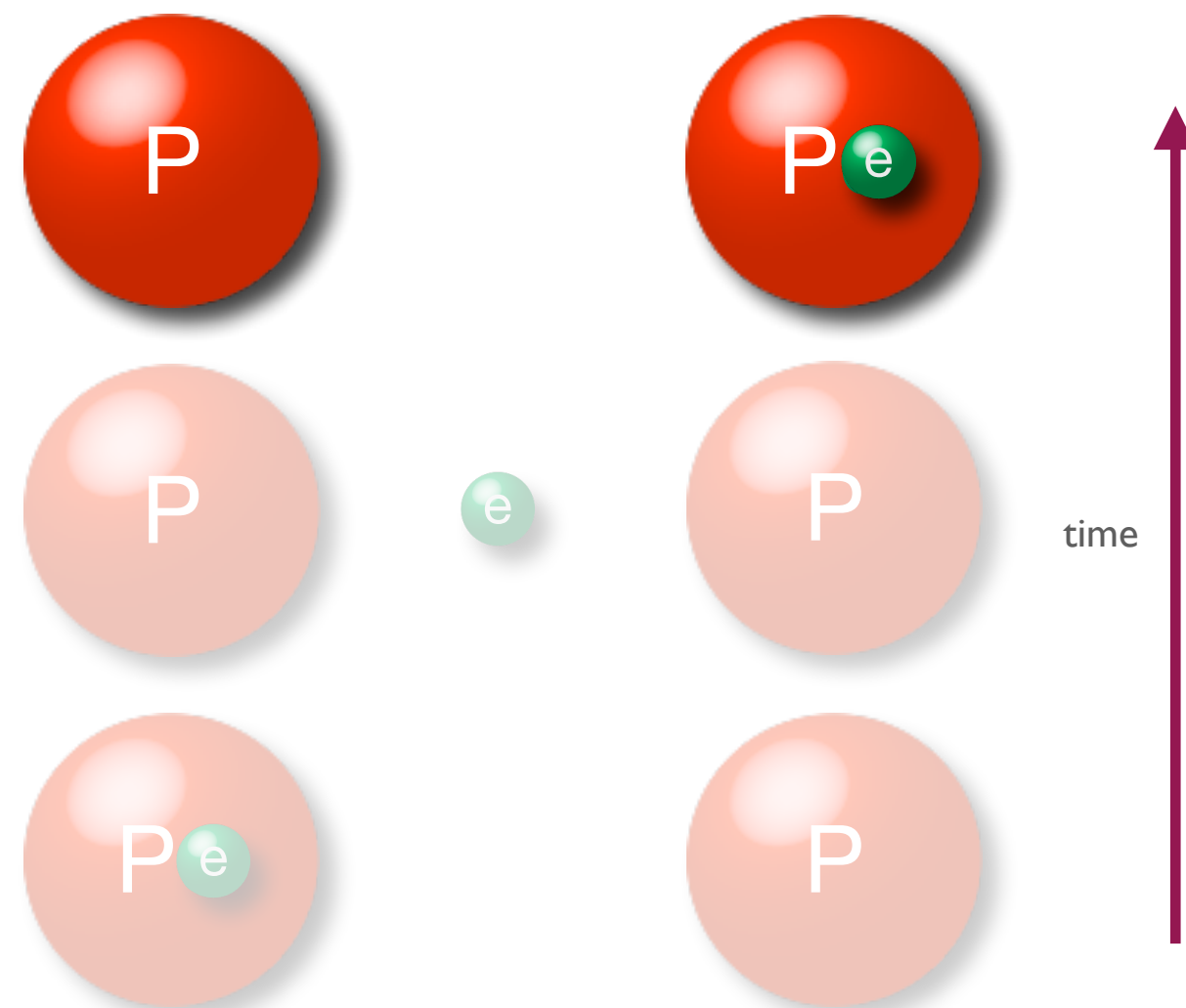
Exchange Force

The proton is
playing catch with
itself

with all he knew
about: electrons and
protons

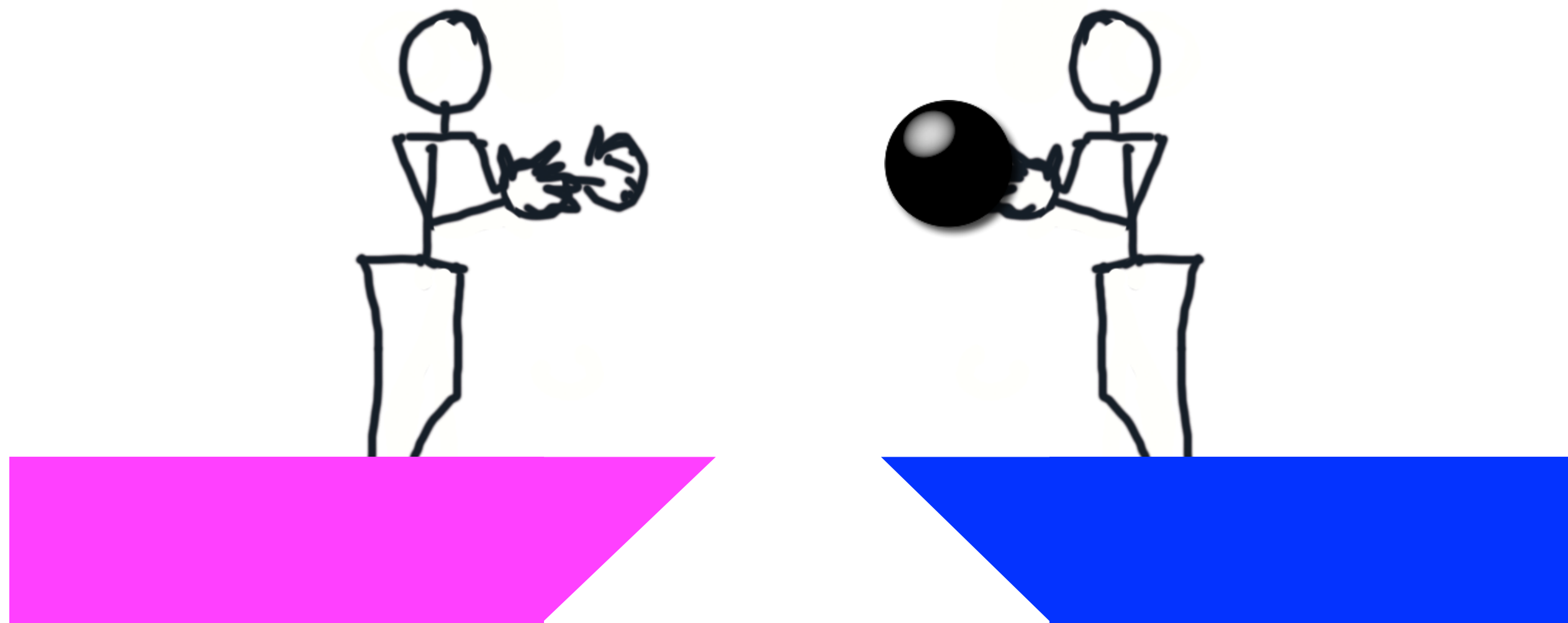
maybe beta decay?

He knew that sometimes nuclei just spit out an electron.
Rutherford's beta decay



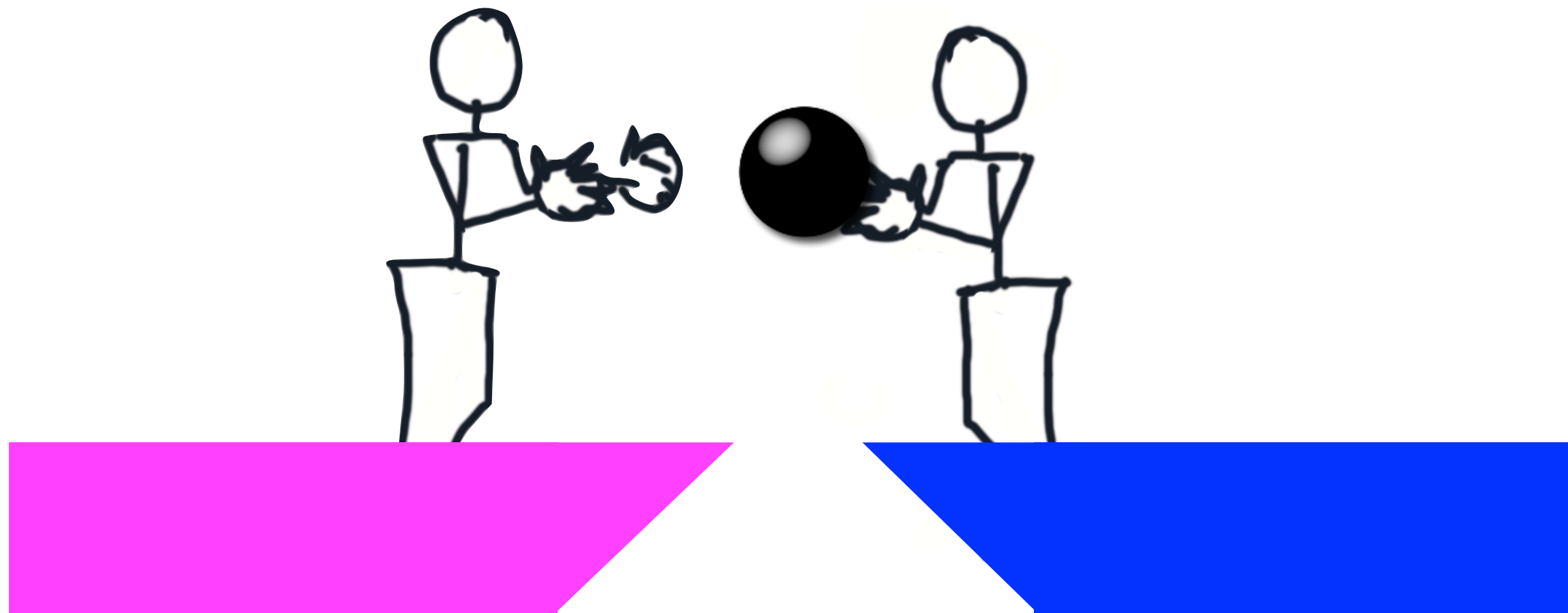
analogy: a repulsive exchange force

a repulsive exchange force



analogy: an attractive exchange force

an attractive exchange force



jargon alert:

exchange force

refers to:

the idea that the forces of nature are propagated by quanta

entomology:

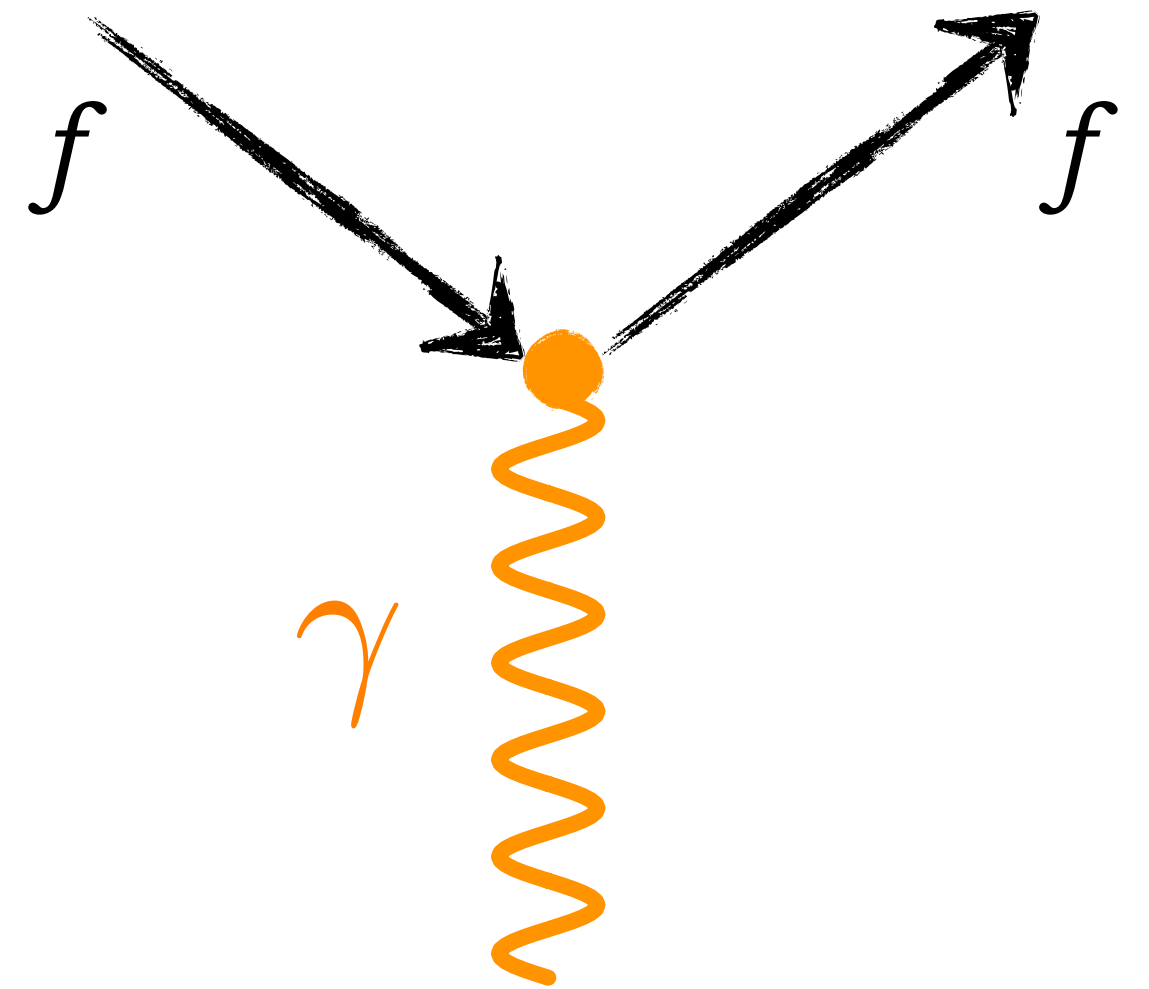
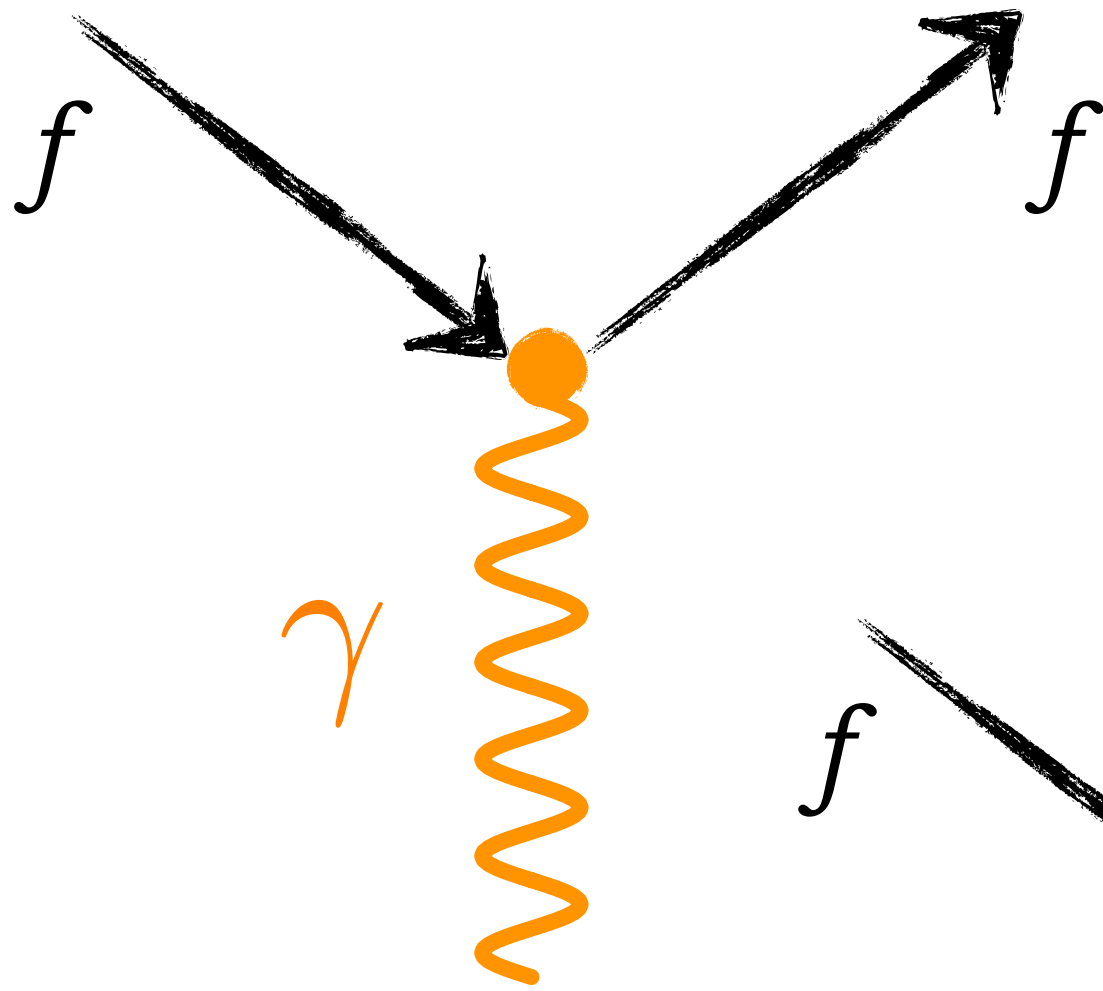
Heisenberg's picture of exchanging them

example:

the photon!

piece the
primitives
together

sharing a leg



we know
one force

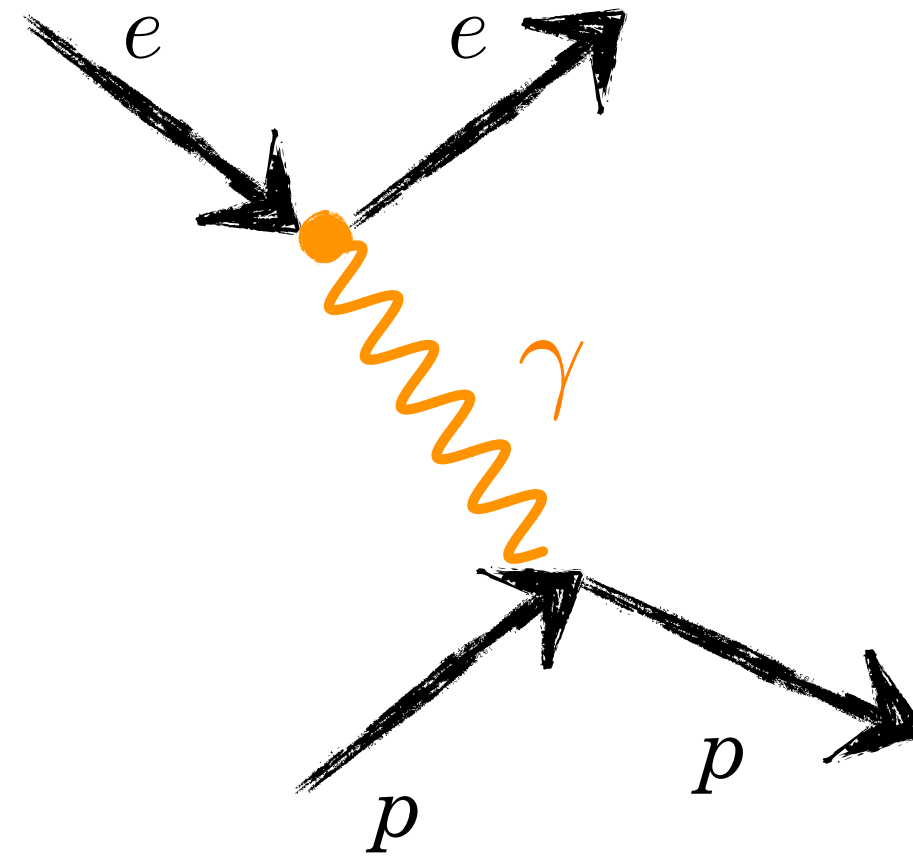
electromagnetism

electricity

magnetism

united by Relativity

remember?



The modern idea:

The force of electromagnetism is “propagated” by the photon.

Multiple names: “propogator”
“Intermediate Vector Boson”

I’ll call the photon:
the “**Messenger Field**
for Electromagnetism”

There's something funny about the nucleus
that it is.

charge independence

Heisenberg's original idea was before the neutron

his protons playing catch with electrons?

nope.

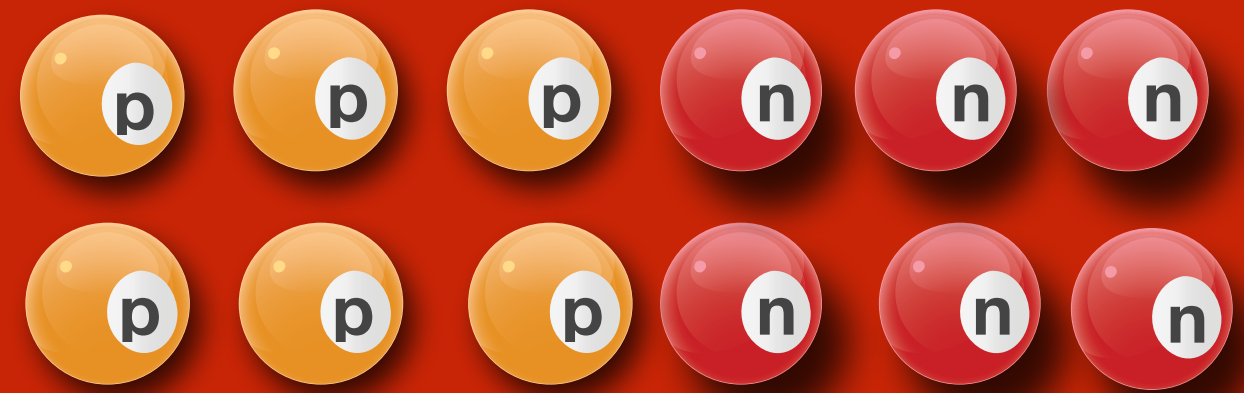
remember:

chemistry from # protons = #electrons

to "assemble" ^{12}C

they have to attract one another

NOT electromagnetism



remember:

chemistry from # protons = #electrons

to "assemble" ^{12}C

they have to attract one another



But *how* does it hold together?

why does any nucleus beyond Hydrogen hang together?

those protons want to get away from one another

the electrostatic force of repulsion

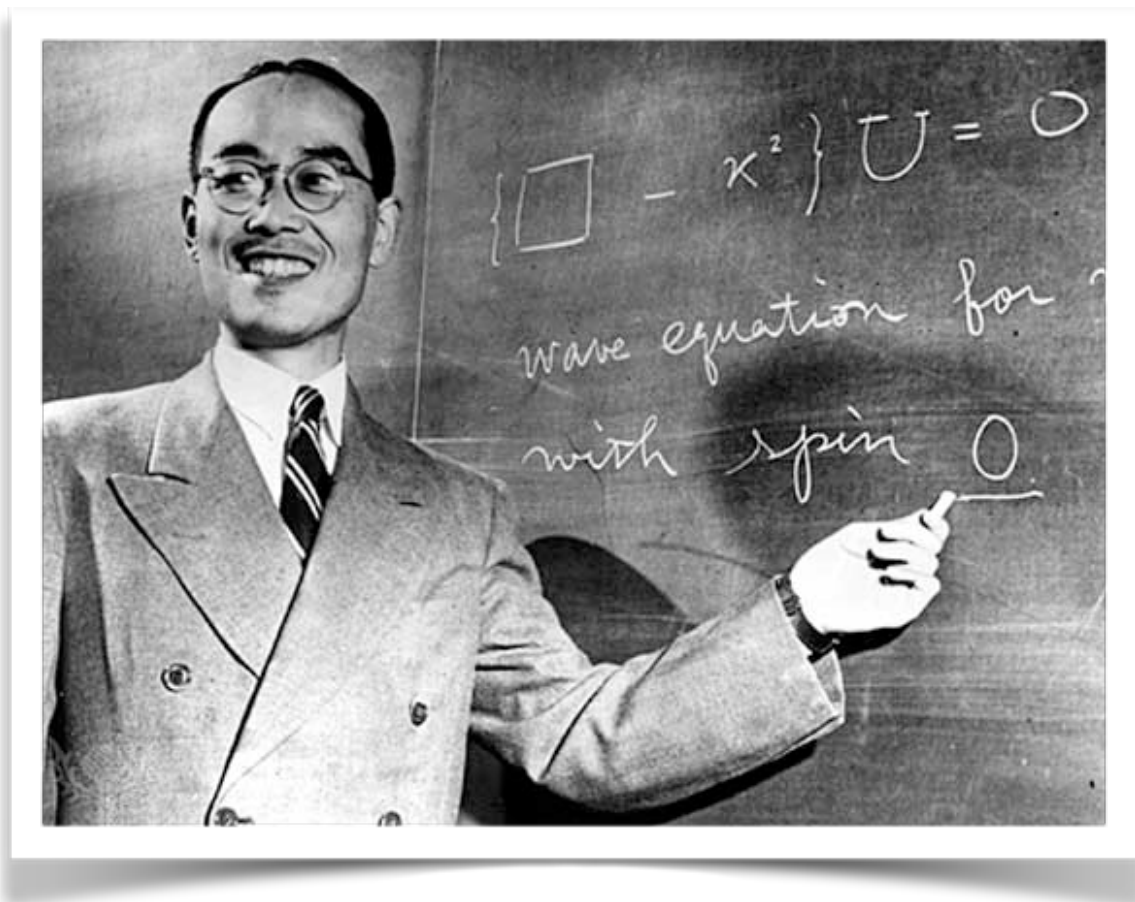
Is countered...by an even stronger force



Strong Force

1934

Hideki Yukawa



electromagnetic force -
infinite in extent

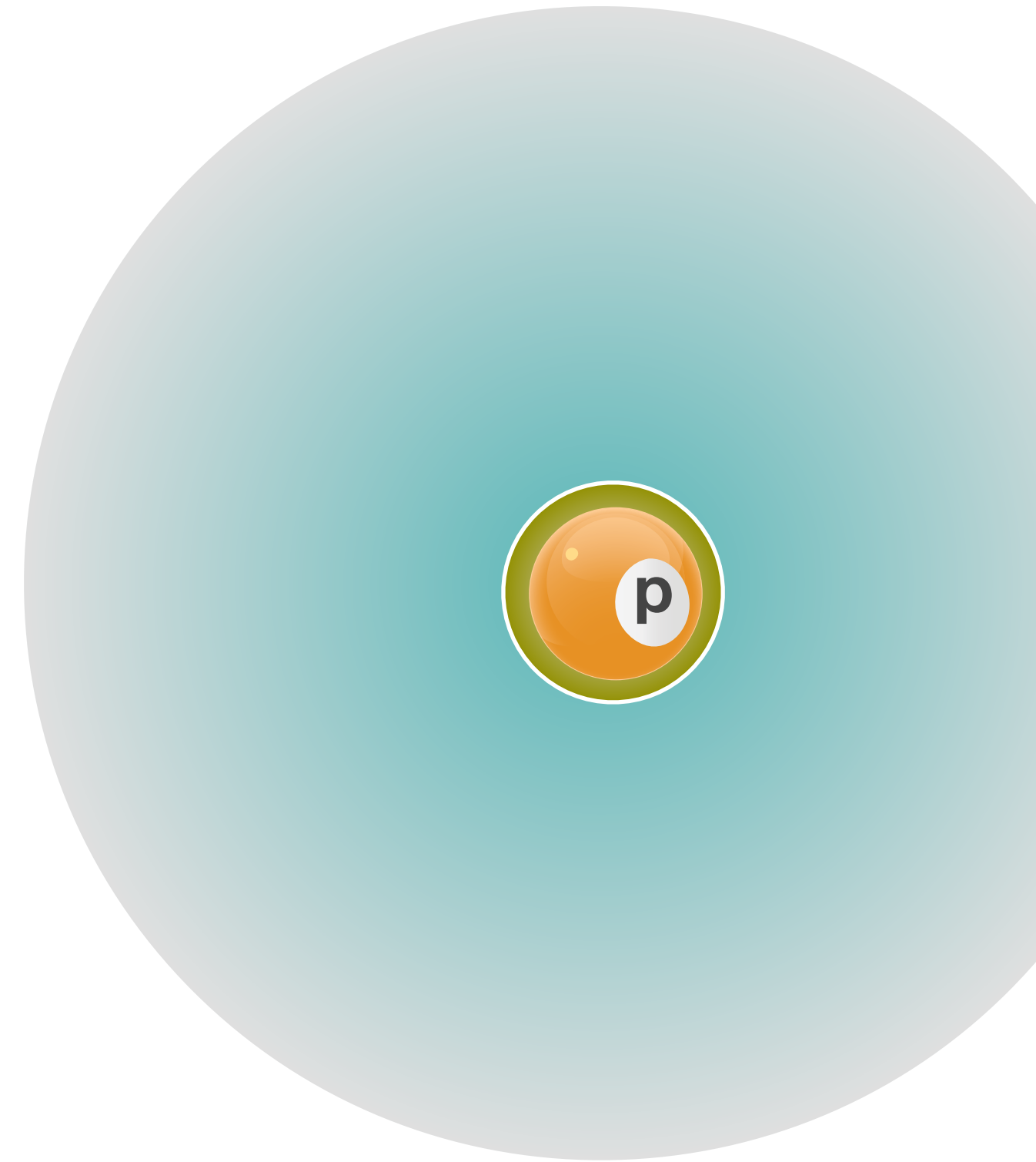
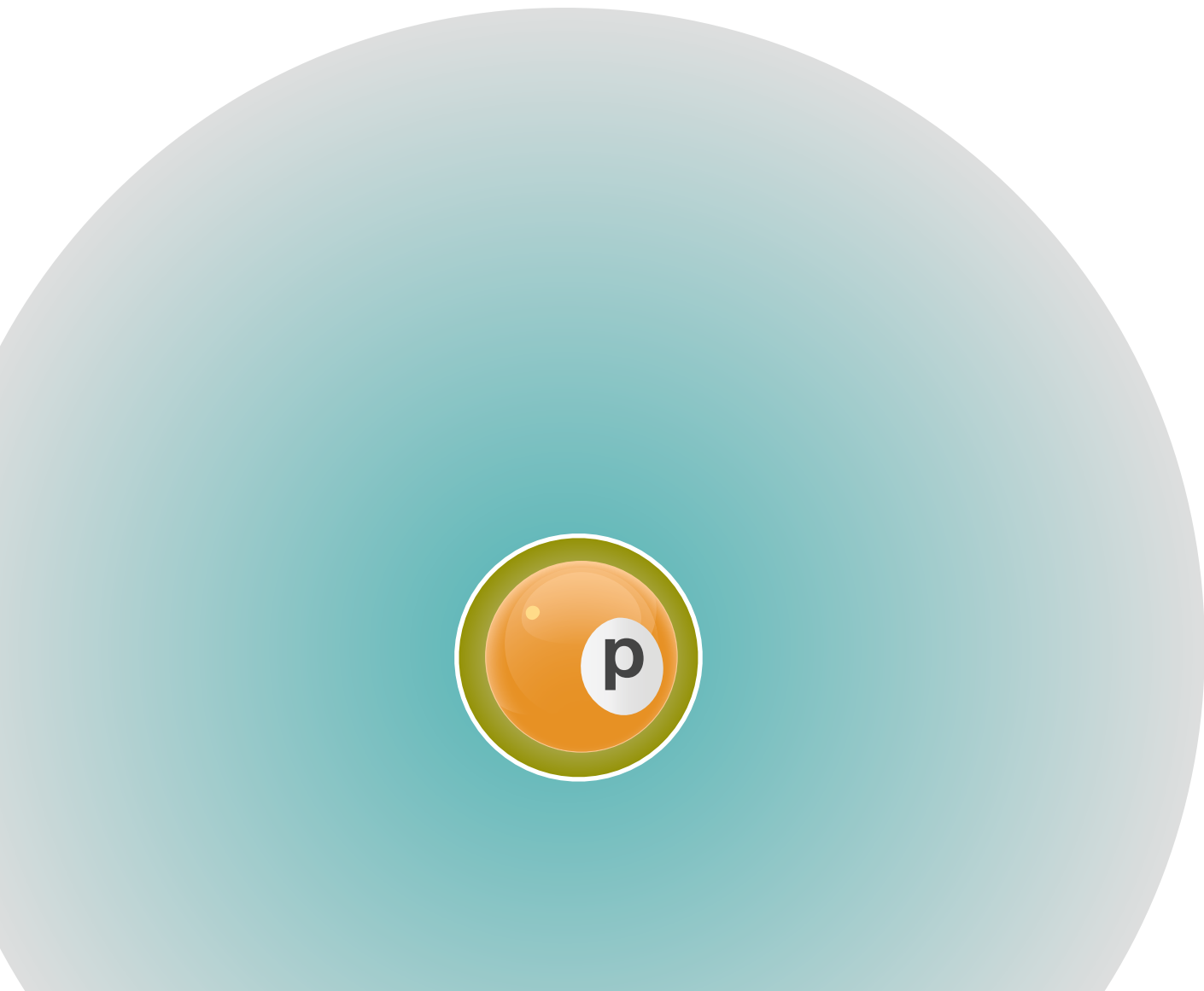
Yukawa's force -
finite in extent



The Strong Force is a stronger
than...anything in the universe.

two competing forces:

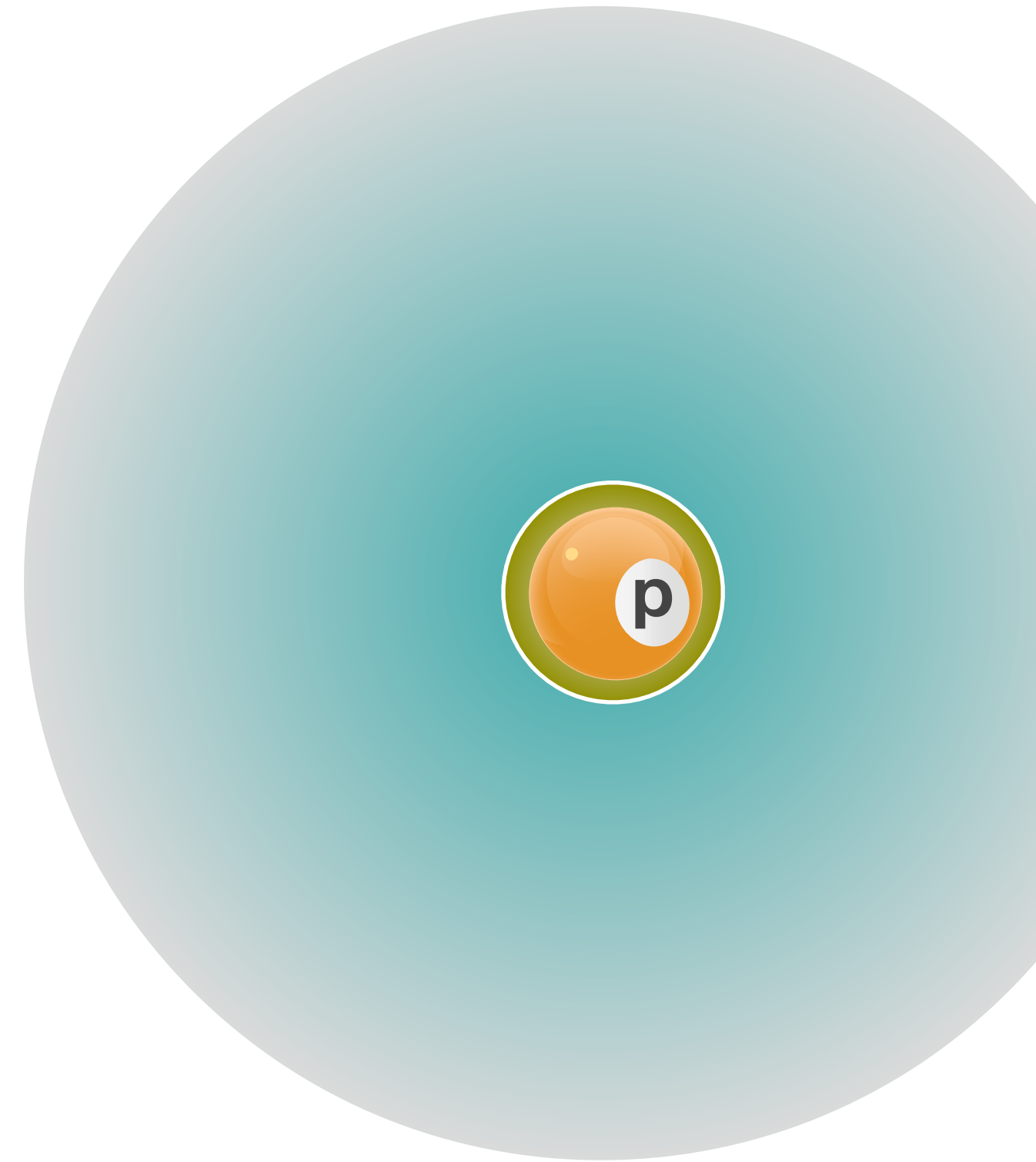
Electromagnetic Force



Strong is stronger than...anything.

two competing forces:

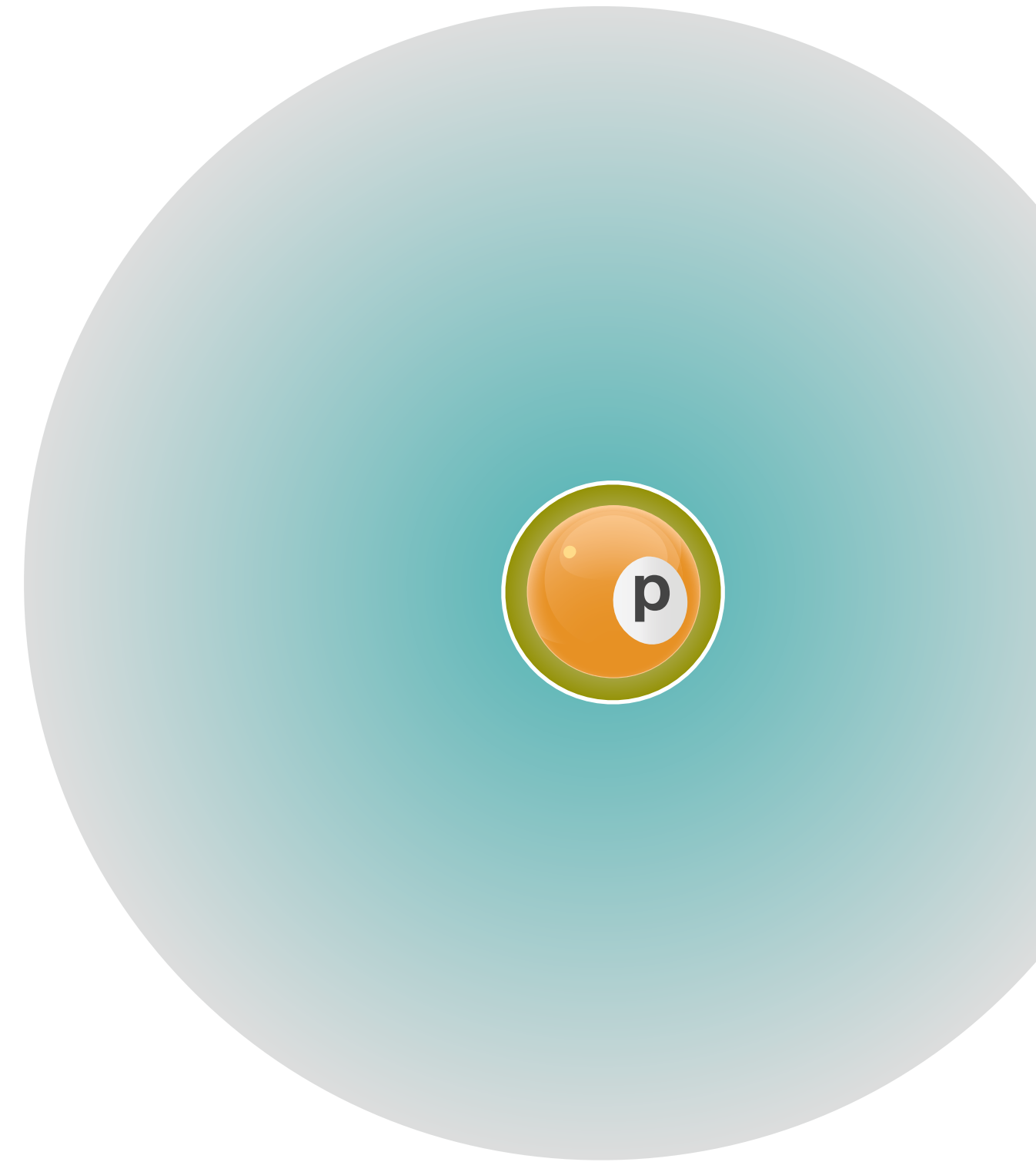
Electromagnetic Force



Strong is stronger than...anything.

two competing forces:

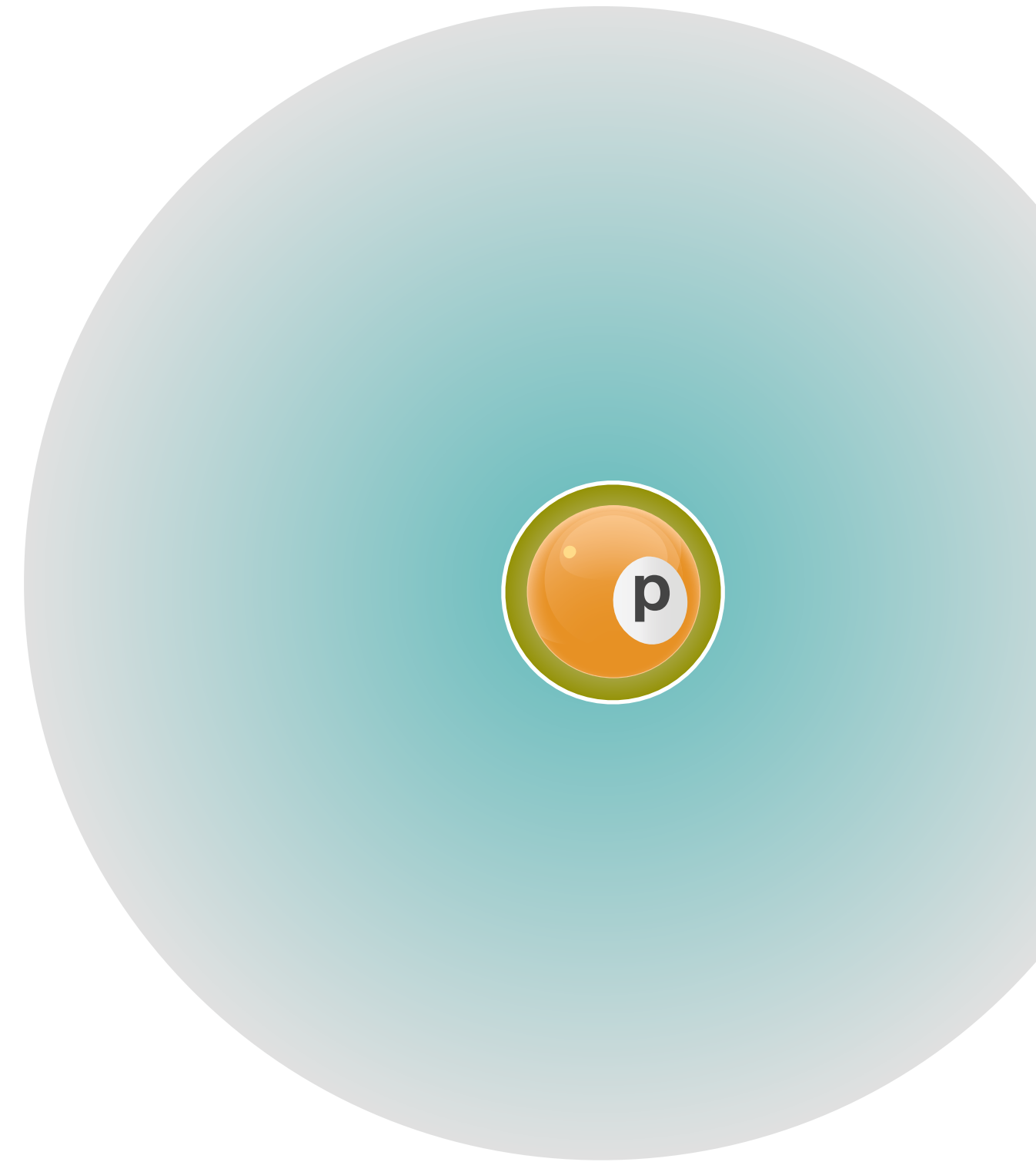
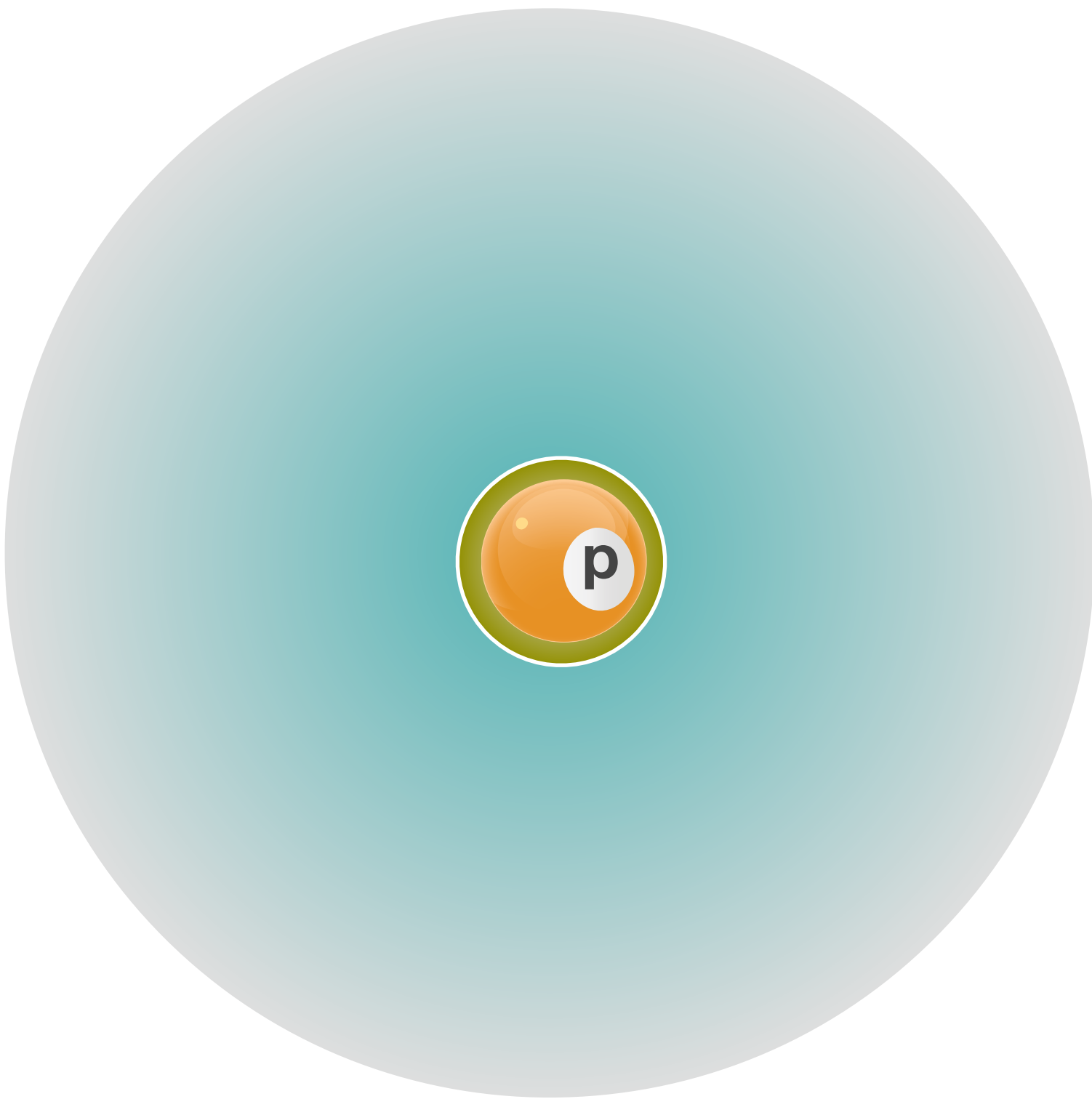
Strong Force



Strong is stronger than...anything.

two competing forces:

Strong Force



but only over a very short range...

the **STRONG** force

overwhelms the electromagnetic force



but only over a very short range...

the **STRONG** force

overwhelms the electromagnetic force

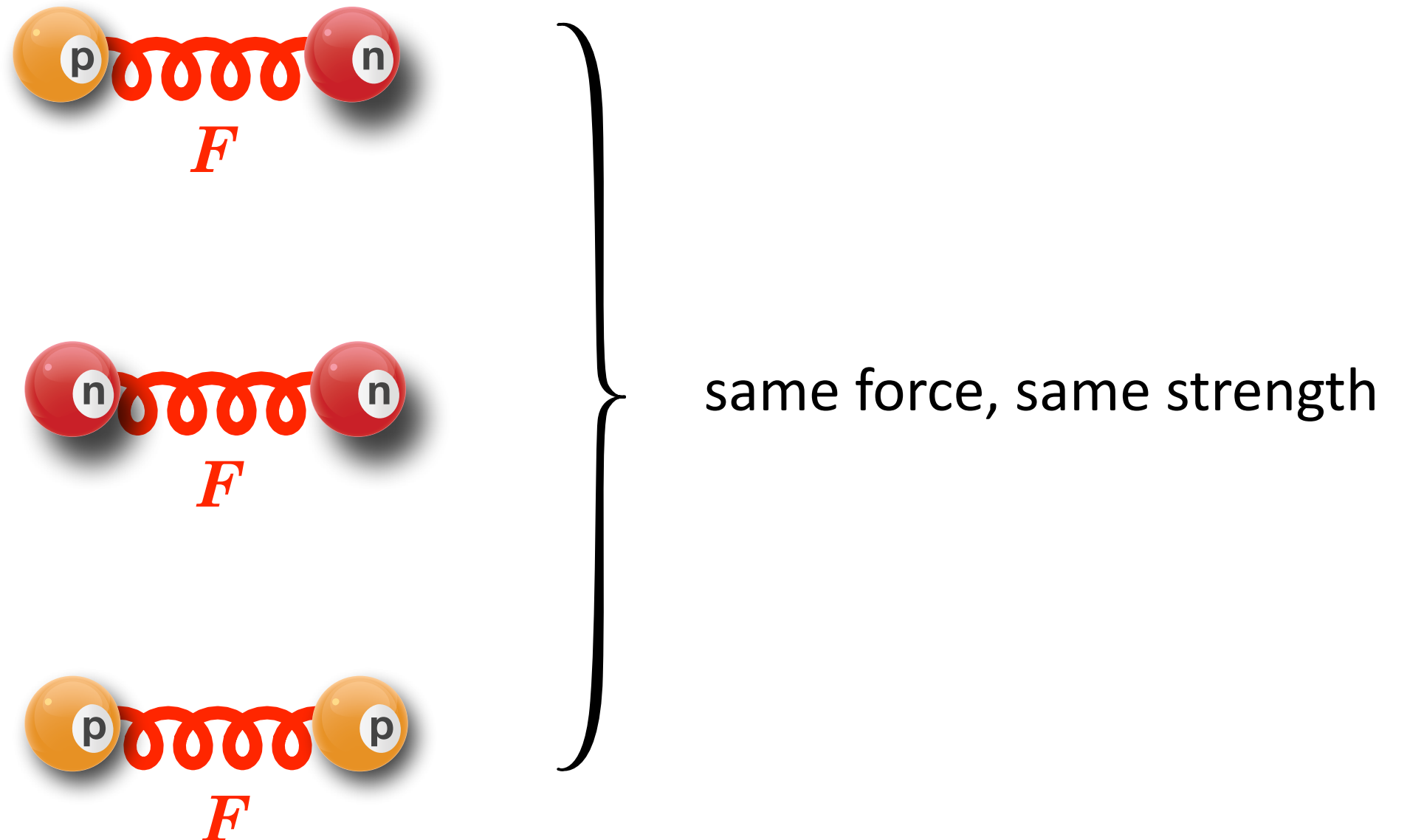


neutrons and protons

in the nucleus, the
proton and
neutron

are two
manifestations of the
same particle

whatever it is that holds the nucleus together:
it's symmetric between the proton and the neutron



For all practical purposes – in holding the nucleus together – the neutron and proton are the same particle – the “**Nucleon.**”

If we ignore electromagnetism...the proton & the neutron are very much alike - we can treat them as being the same particle

neutrons
and
protons

act like they are identical particles
the electric charge?
as a force...Yukawa's force is 100 times the electromagnetic

For nuclear forces: treat p and n as identical and differing only by a "quantum number" called "Isospin"

$$N = \begin{pmatrix} \text{p} \\ \text{n} \end{pmatrix} \quad \begin{matrix} I \\ + 1/2 \\ - 1/2 \end{matrix}$$

"nucleon"

A neutron... is a "nucleon" with "isospin down"
A proton... is a "nucleon" with "isospin up"

They go together...within the strong, nuclear force.

How?

jargon alert:

nucleon

refers to:

either a proton or a neutron

etymology:

from “nucleus”...the “-on” tends to be a particle name

example:

“nucleon force”

jargon alert:

hadron

refers to:

any particle that interacts via the Strong Force

etymology:

$\alpha\delta\rho\acute{o}\sigma$ "hadros" "large", "massive"

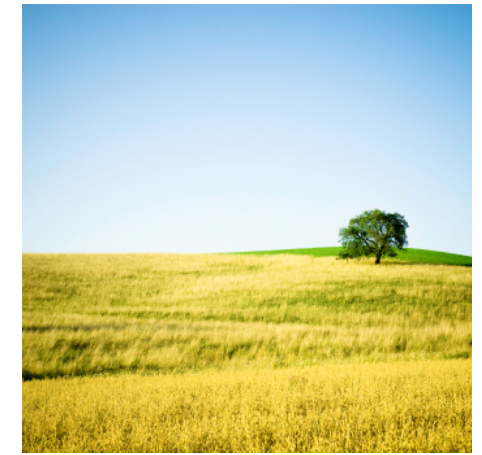
example:

proton and neutron

not electron, not photon

remember

If there is a force...there's a field

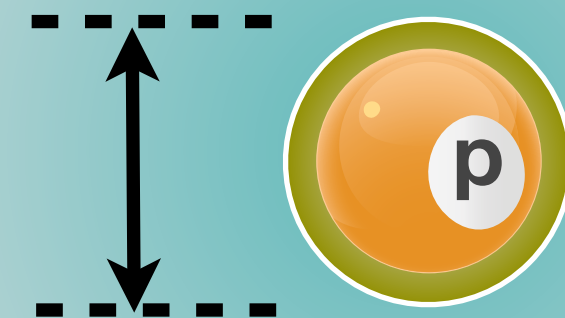


Nature is
clumpy

If there's a field,
there's a quantum to go with it.

The nuclear force is "active" over a short distance

$\sim 10^{-15}$ m



Yukawa knew that.

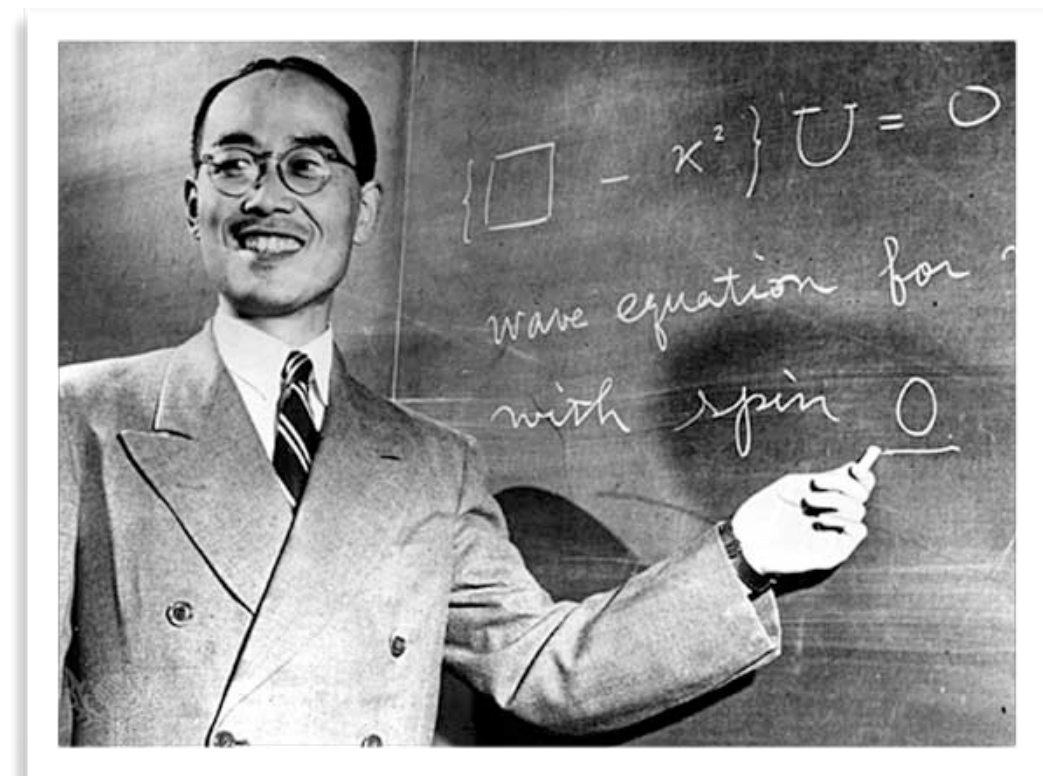
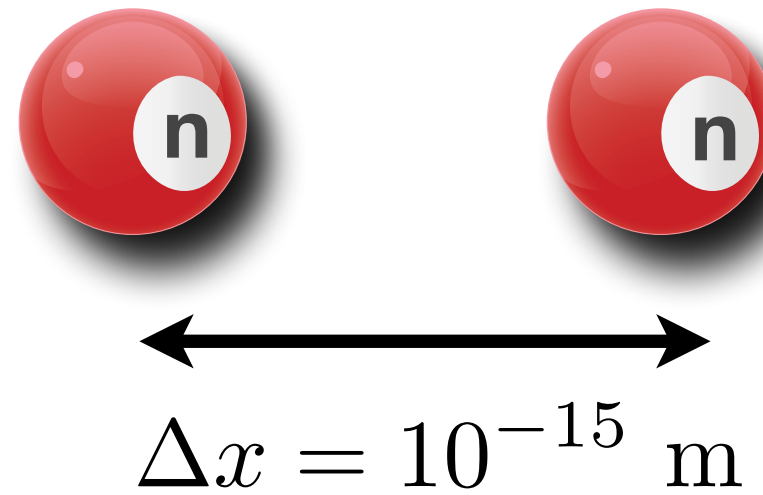
uncertainty
certainly
to the
rescue

brilliant
observation by
Yukawa

maybe there's a
quantum that is
active only over the
size of a nucleus: "U"

another exchange
force/particle?

So: $p \rightarrow n + U$?



Suppose U travels at c within a nucleus... $\Delta t = \Delta x / c$

Then Uncertainty could estimate U's mass... $\Delta E \Delta t = h / 4\pi$

$$m_U = \Delta E / c^2$$

?

$$m_U \approx 100 \times 10^6 eV = 100 MeV$$

the most important thing in particle physics?

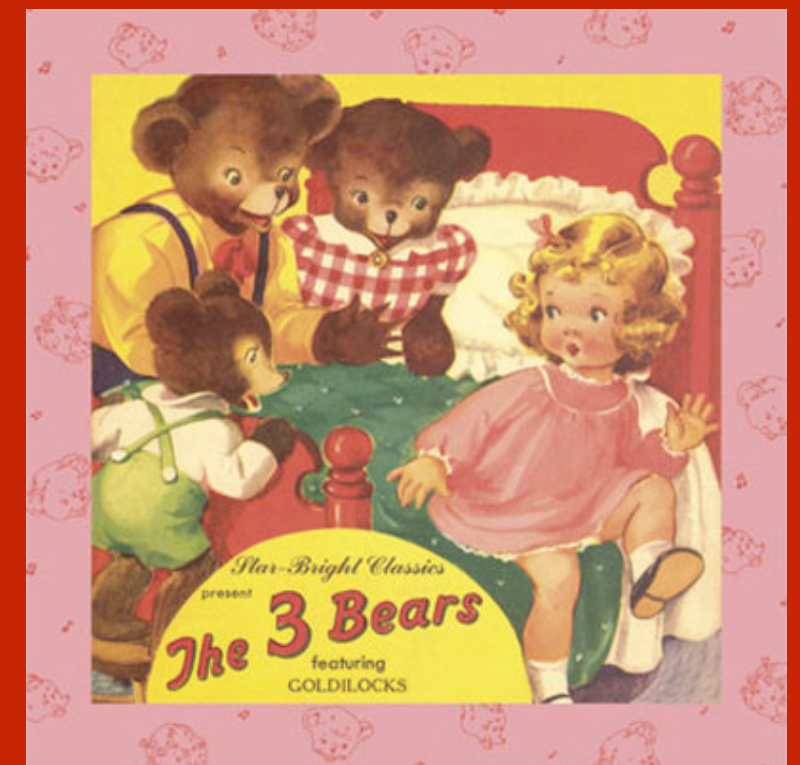
getting the name right.

the "U-kon"? thankfully, no.

the "meson"? Why yes, I think I like it.

medium mass...

not too big (proton) not too small (electron): just right.



the hunt was on

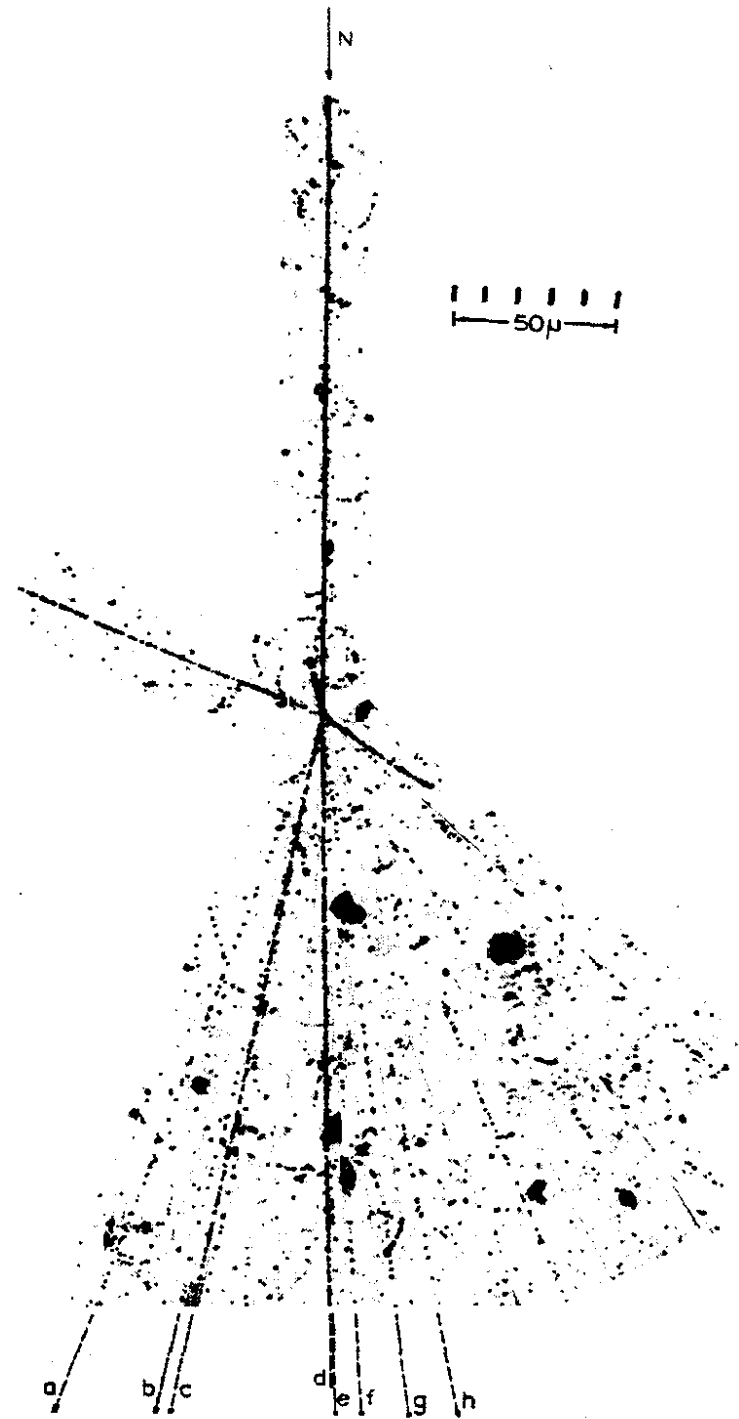
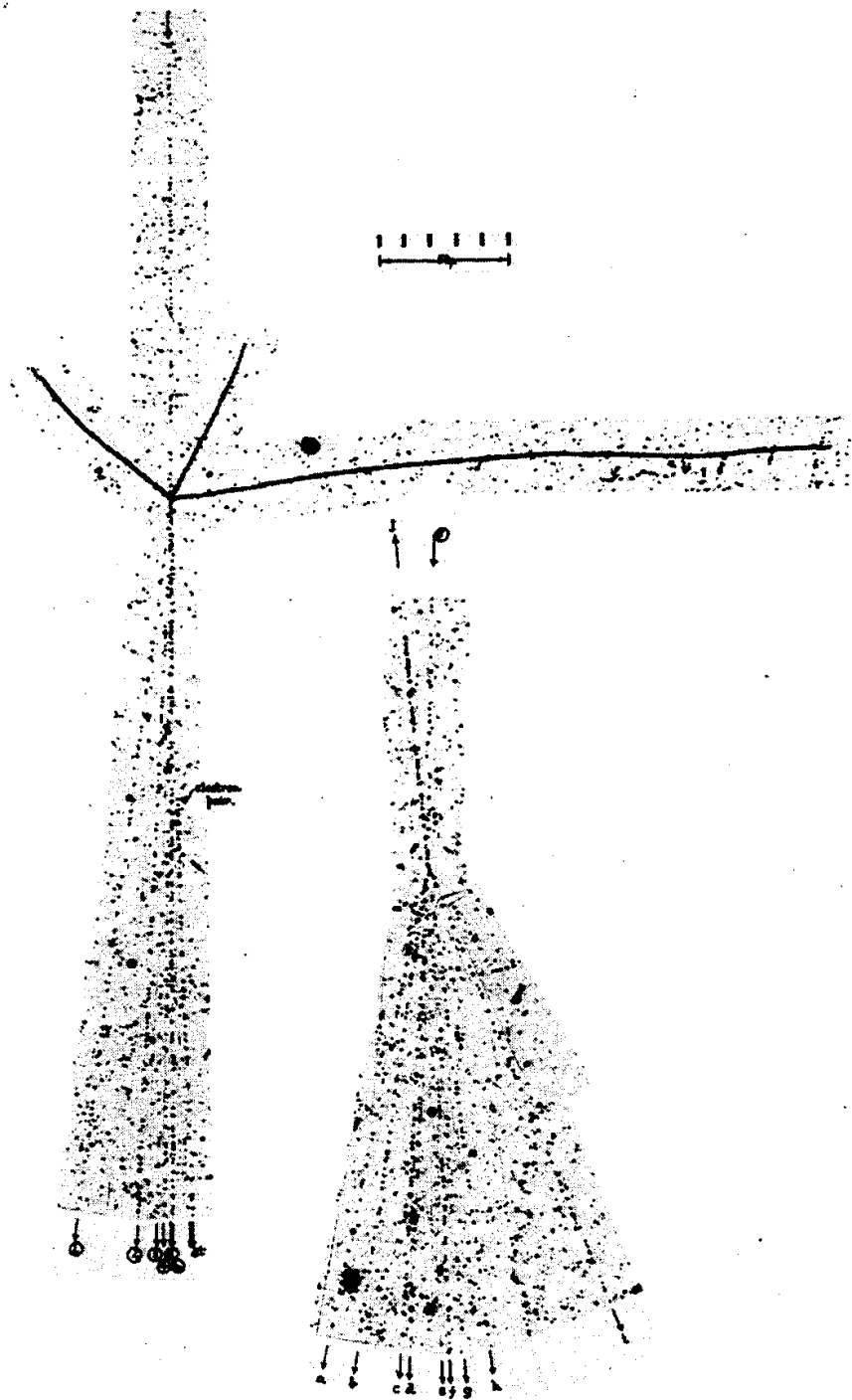
to find the Yukawa Particle

but WWII got in the way

Post-war emulsion exposures were startling

proton in cosmic rays

Nitrogen nucleus in cosmic rays



huh?



Mt. Pic Du Midi, 10000 ft



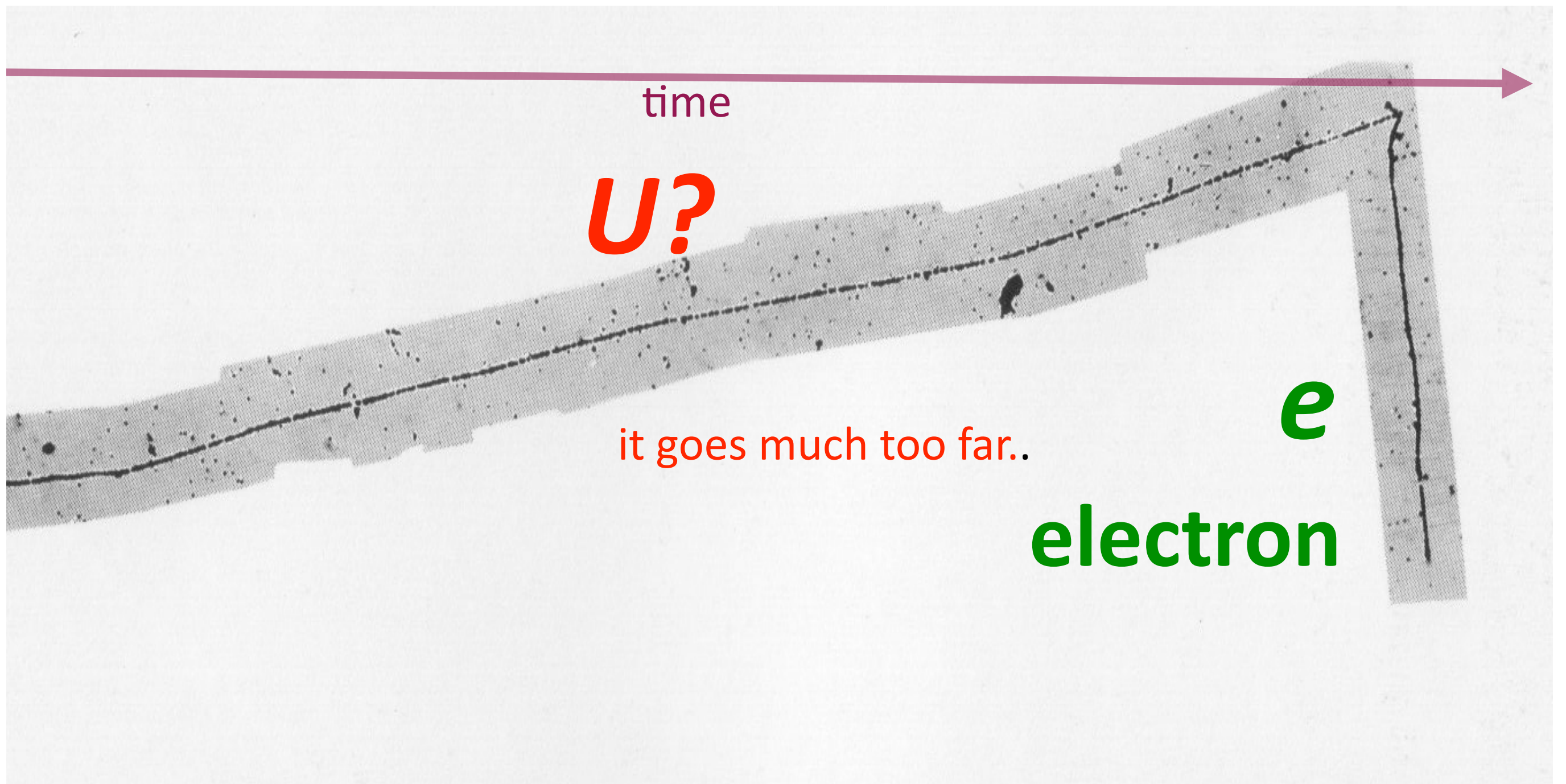
from Cecil Powell's Nobel lecture... a former student of?

...you guessed it.

many of these sort:

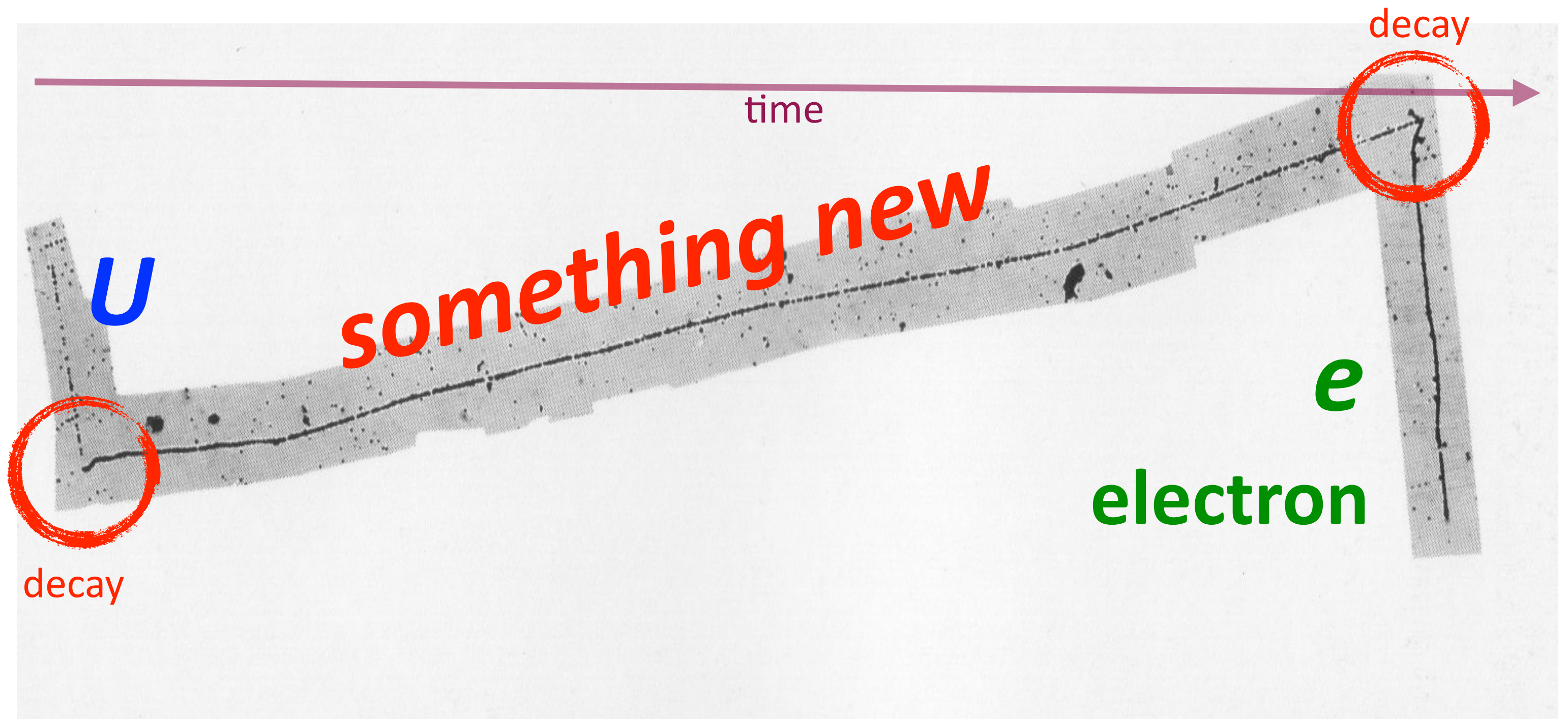
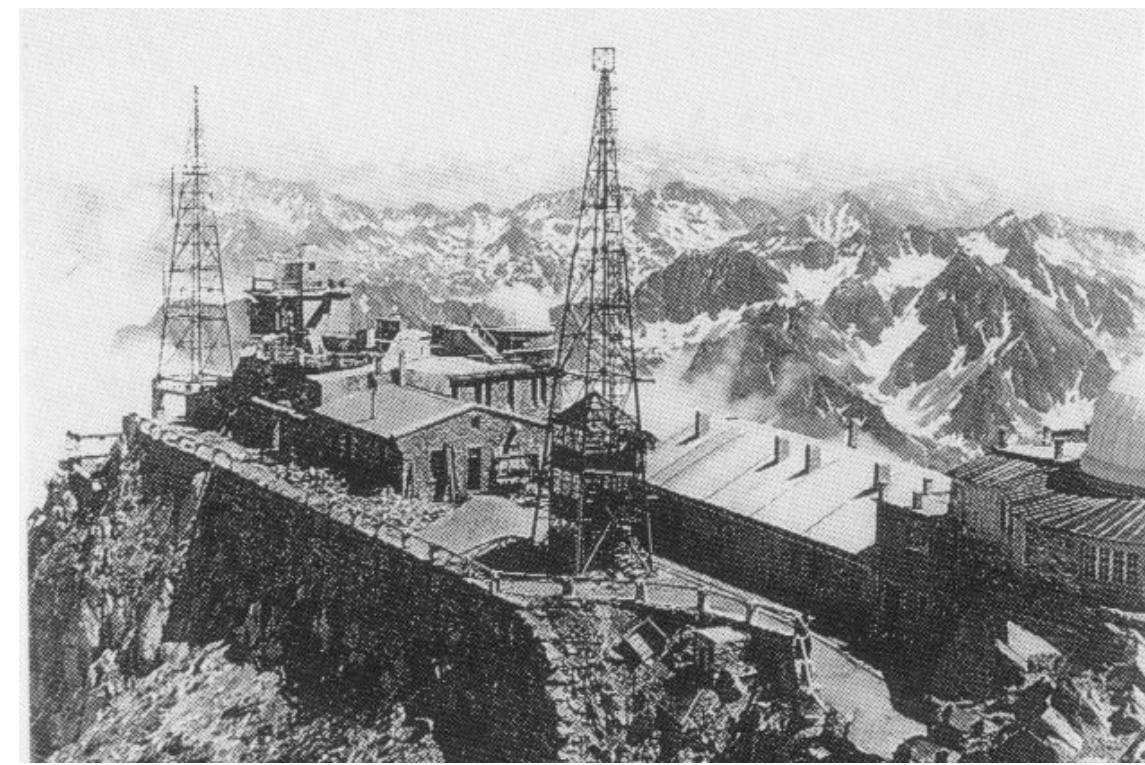
something unknown...

20,000 stereo photos --> 1600 usable tracks in 3 cm² plate



strange things in cosmic rays

thick photographic substrates



two discoveries

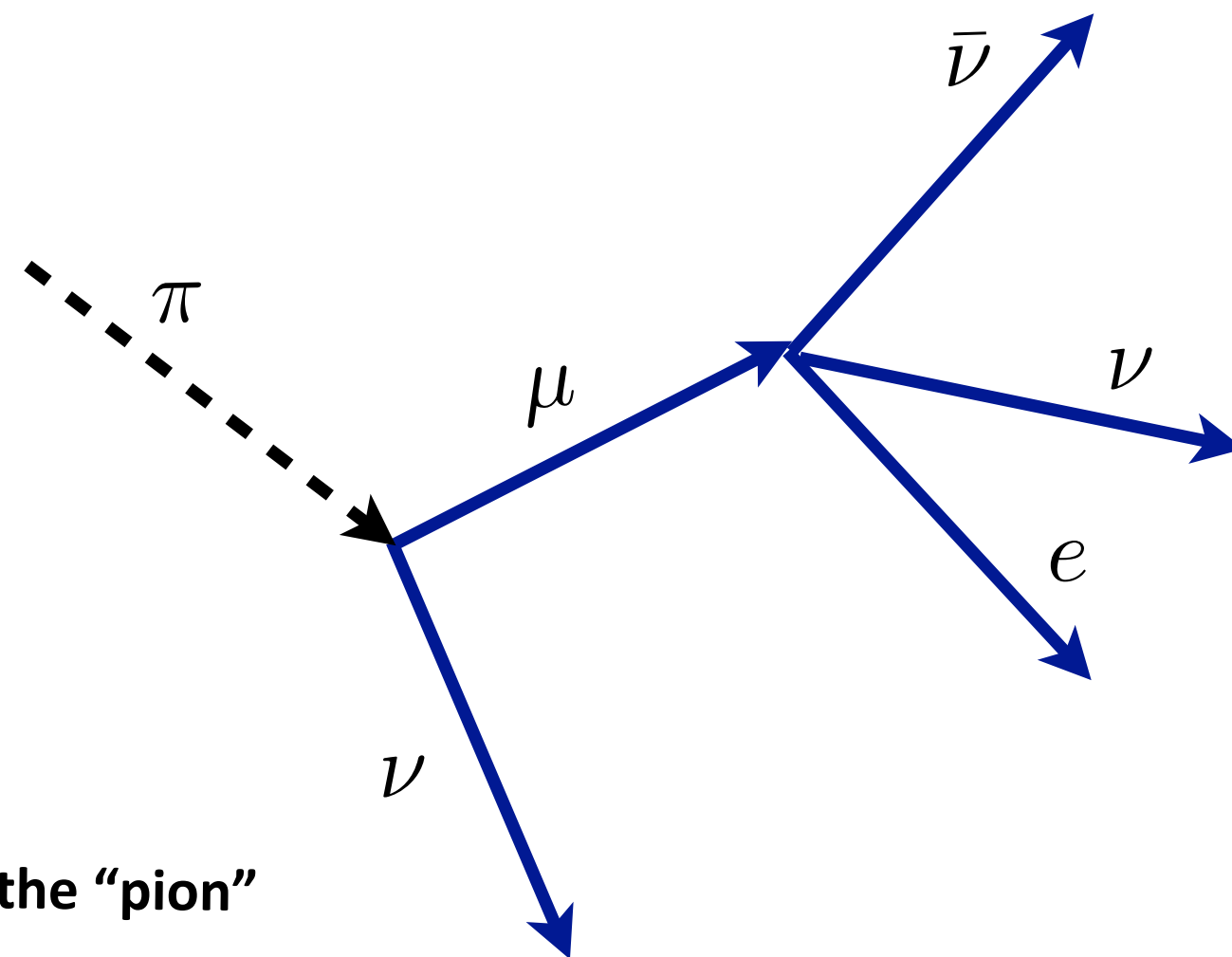
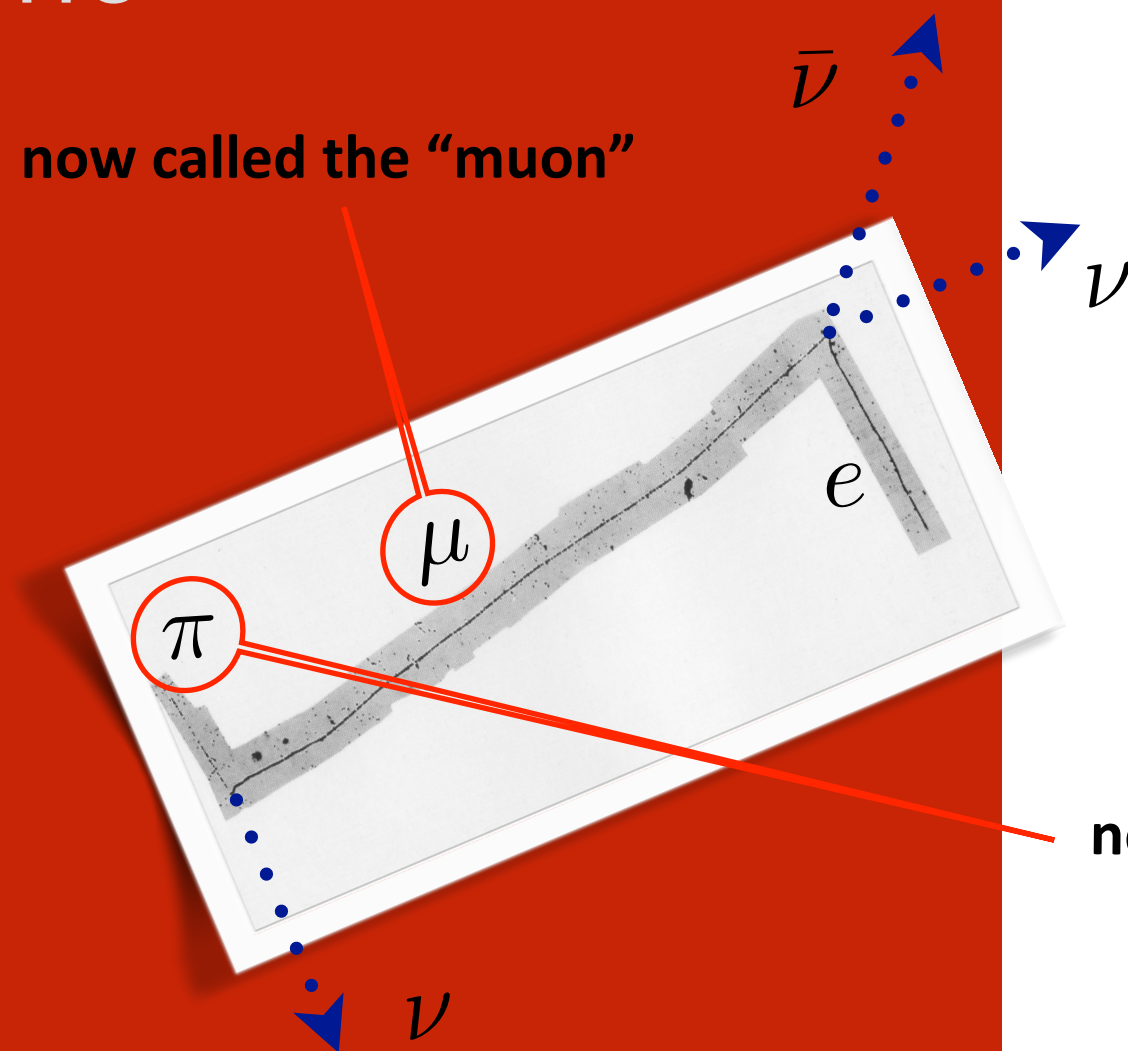
for the price of
one

This took some unraveling.

The “meson” appeared in and initiated nuclear collisions

The unknown particle seemed to live about a 6 μsec
too long to be a meson

The winning proposal:



now called the “pion”

particle:

pion

symbol:

π

charge:

$+, -, 0$

mass:

$139 \text{ MeV}/c^2,$

spin:

0

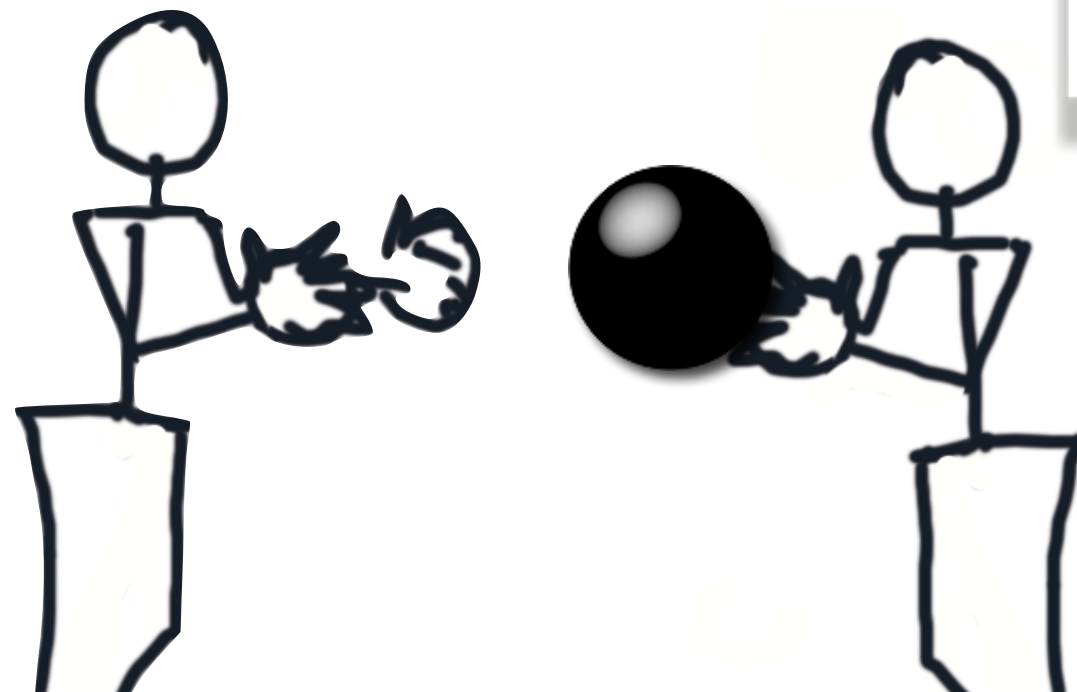
category:

Boson, hadron, meson

analogy:

an attractive exchange force

π
“pion”



proton or neutron

proton or neutron

remember: chemistry from
the # protons = #electrons
to “assemble” ^{12}C

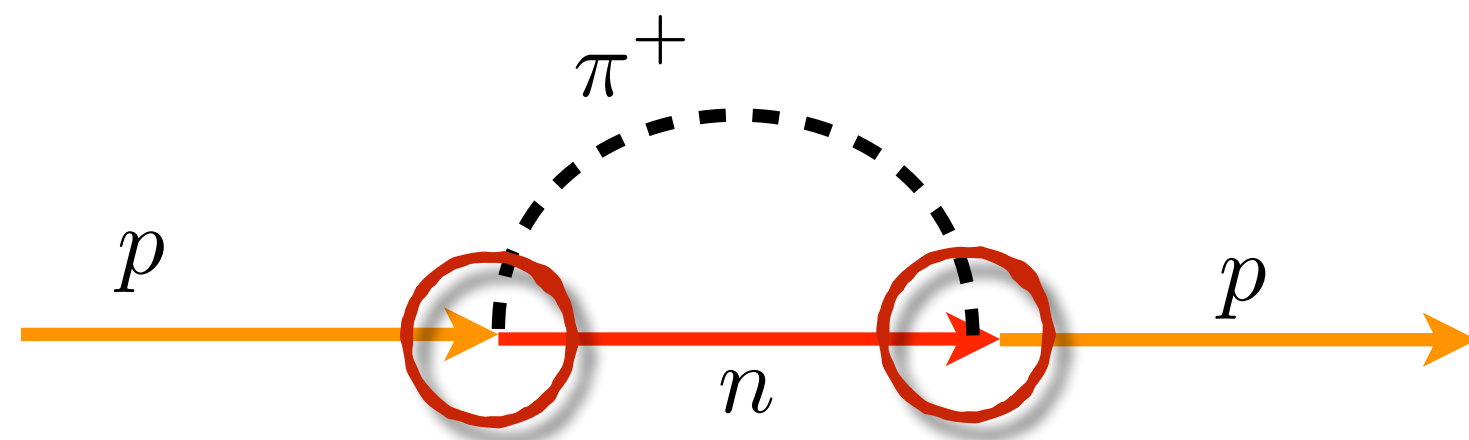
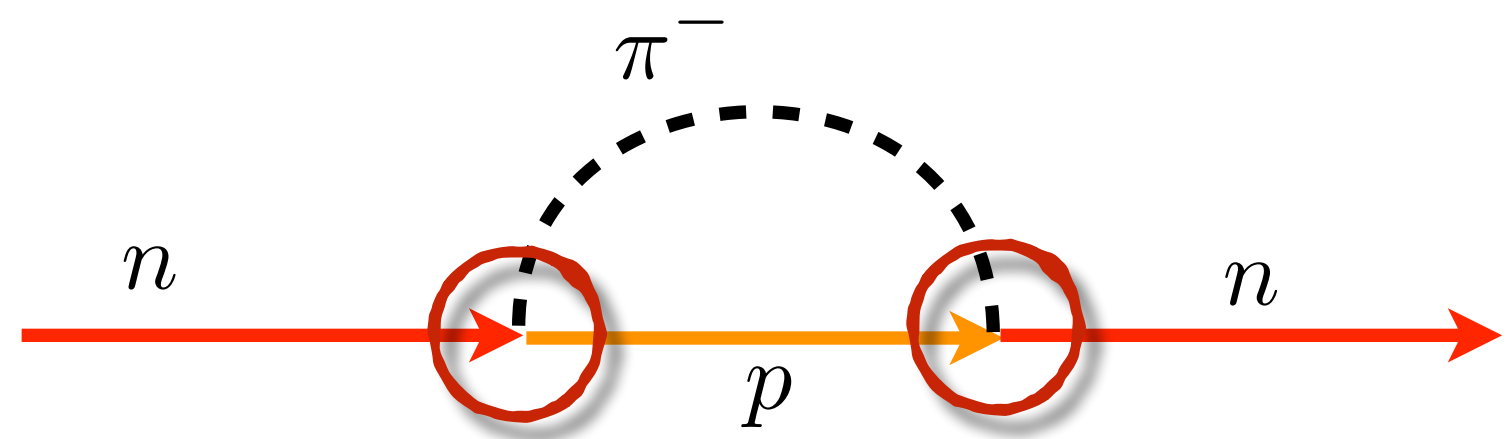
*they have to attract one another
that should bother you!*

stay tuned



the Yukawa particle

is the pion

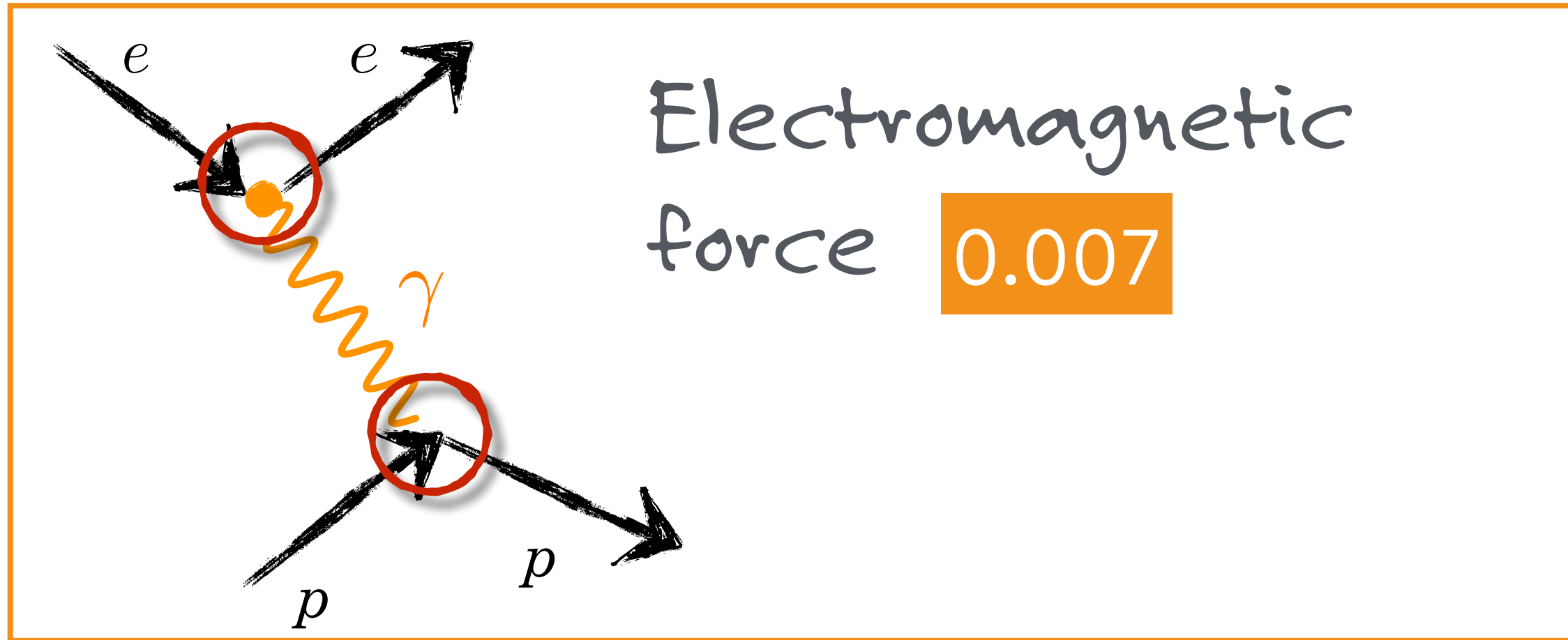


These coupling strengths are large - strong.

In technical terms we call this...the strong interaction.

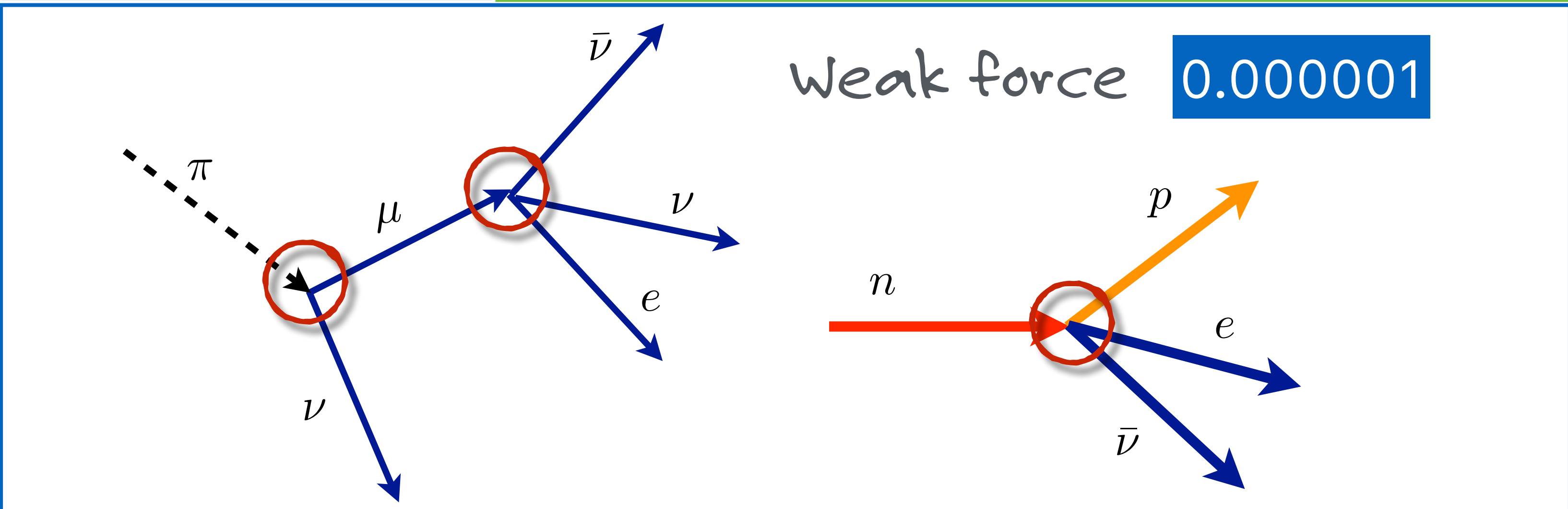
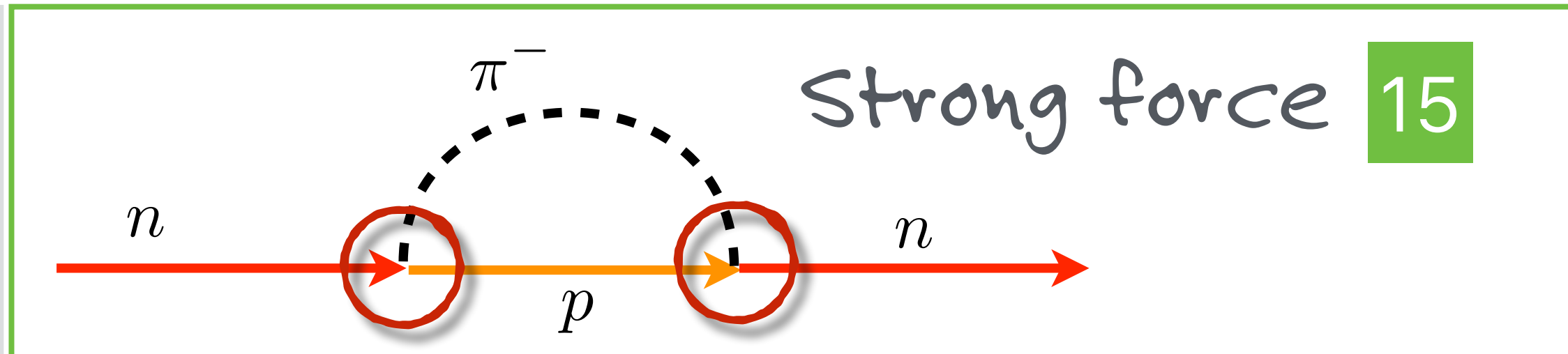
three forces now

of vastly different strengths



Gravitational force?

0.000000000000000000
000000000000000001



particle:

muon

symbol:

μ

charge:

$+, -$

mass:

$105.7 \text{ MeV}/c^2$

spin:

$1/2$

category:

Fermion, lepton

particle:

muon

symbol:

charge:

mass:

spin:

category:

Fermion, lepton

The Muon
an Electron

is like
a neutrino.



particle: tau
symbol: τ
charge: $+, -$
mass: $1776.82 \pm 0.16 \text{ MeV}/c^2$
spin: $1/2$
category: Fermion, lepton

The Tau is exactly like an
Electron just more
um...heavier.

BTW

there are as many neutrinos
as there are "electrons"

we got the original electron, we got an electron-neutrino

the muon, a muon neutrino

aaaand. another one: the tau and its neutrino

particle:

muon-neutrino

symbol:

ν_{μ}

charge:

0

mass:

0 or 0.4-ish to 1-ish eV/c²

spin:

1/2

category:

Fermion, lepton

particle:

tau-neutrino

symbol:

ν_{τ}

charge:

0

mass:

0 or 0.4-ish to 1-ish eV/c²

spin:

1/2

category:

Fermion, lepton

FAMILIES

Nature prefers

like-particles



Lepton Families

electrons and a neutrino

muons and a neutrino

taus and a neutrino

These sorts of patterns are a huge deal.

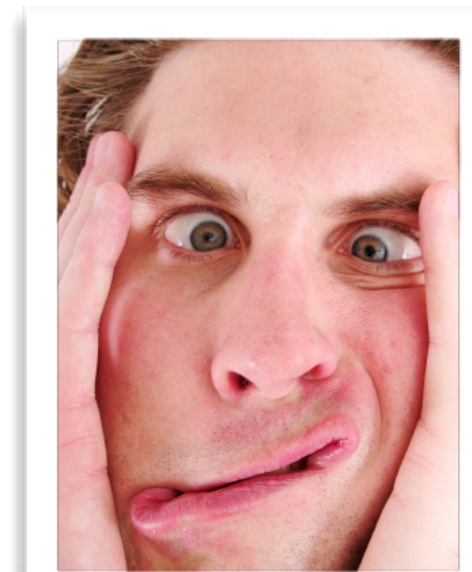
$$\begin{array}{c} Q \\ 0 \\ -1 \end{array} \quad \begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

Identical in every way...except mass

$$m_e \sim \frac{1}{1835} \times m_p$$

$$m_\mu \sim 10\% \times m_p$$

$$m_\tau \sim 1.8 \times m_p !!$$



jargon alert:

lepton

refers to:

originally, an electron, muon,
neutrino

etymology:

"λεπτός" (leptos), "fine, small, thin"

example:

electron, muon, neutrino, tau!

back to the 1940s

cosmic
rays
continue
to
surprise

1946

Cloud chamber...with Pb sheet

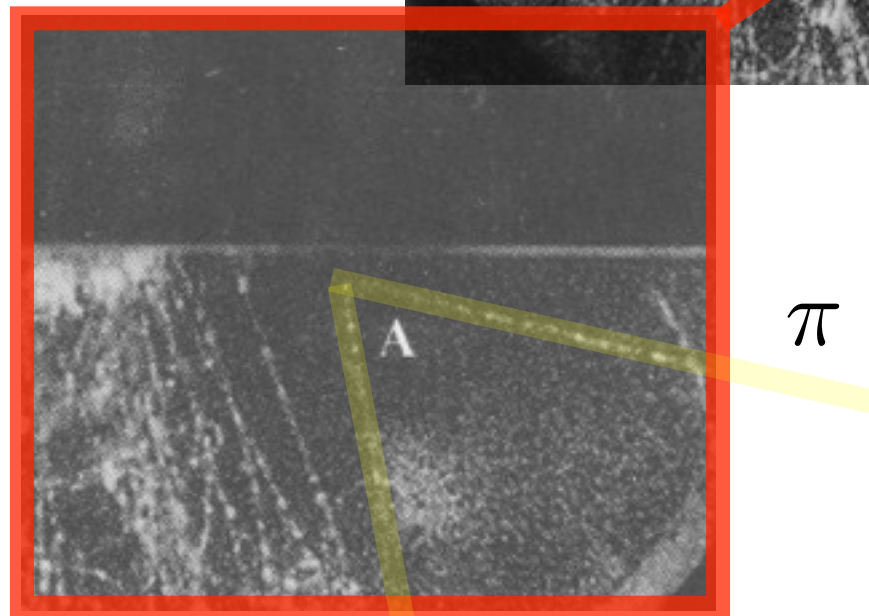
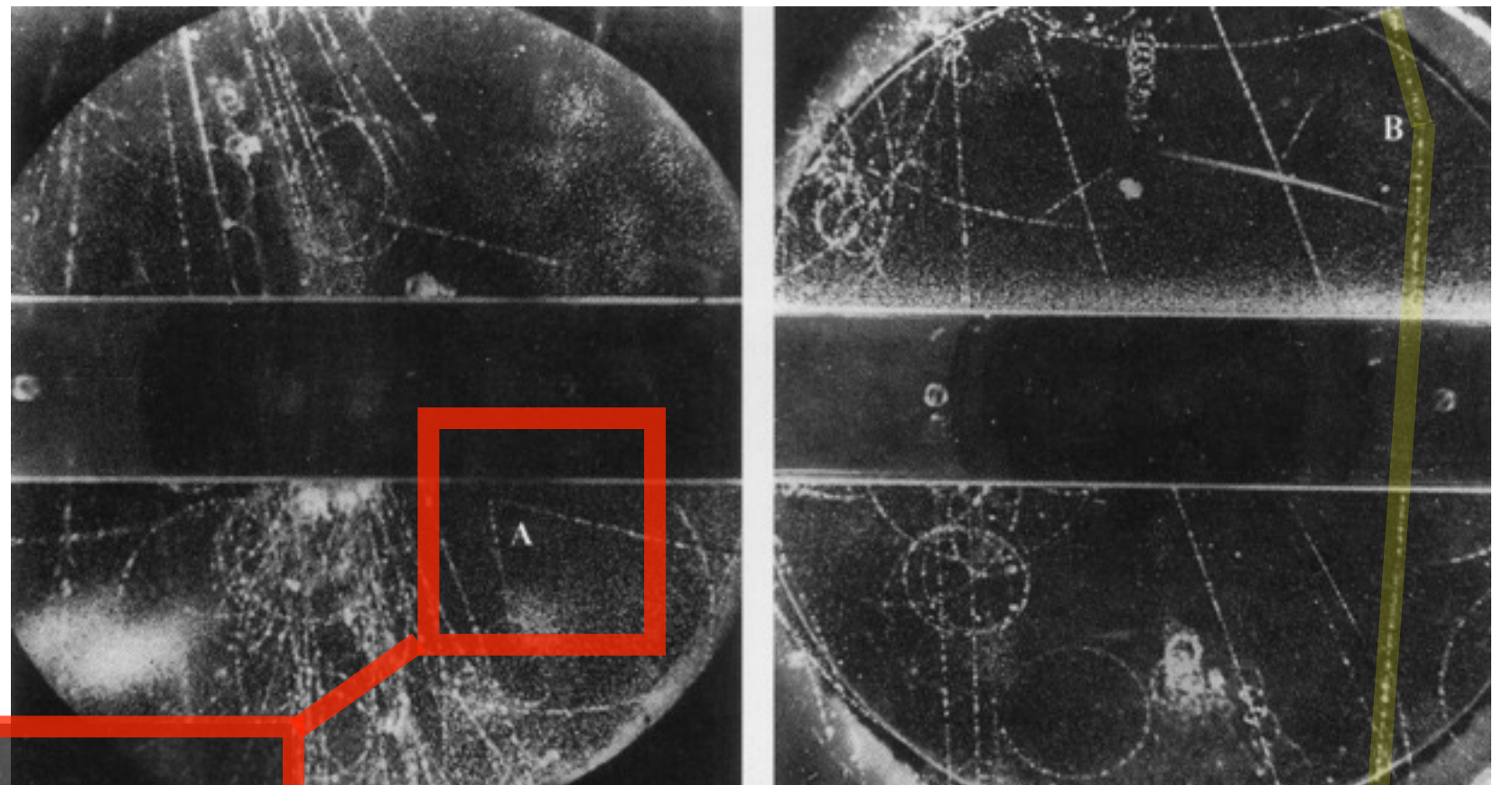
Manchester University

academic home for many years of...? who else.

Mysterious "Vees" began to crop up...

"Vee" $\rightarrow \pi^+ + \pi^-$

"Vee" $\rightarrow \mu + \nu?$



$K^\pm \rightarrow \mu^\pm + \nu$

dubbed "Kaons"...they were

"strange"

$K^0 \rightarrow \pi^+ + \pi^-$

particle:

Kaon

symbol:

K

charge:

$\pm 1, 0$

mass:

493.677 (charged state) MeV/c²

spin:

0

category:

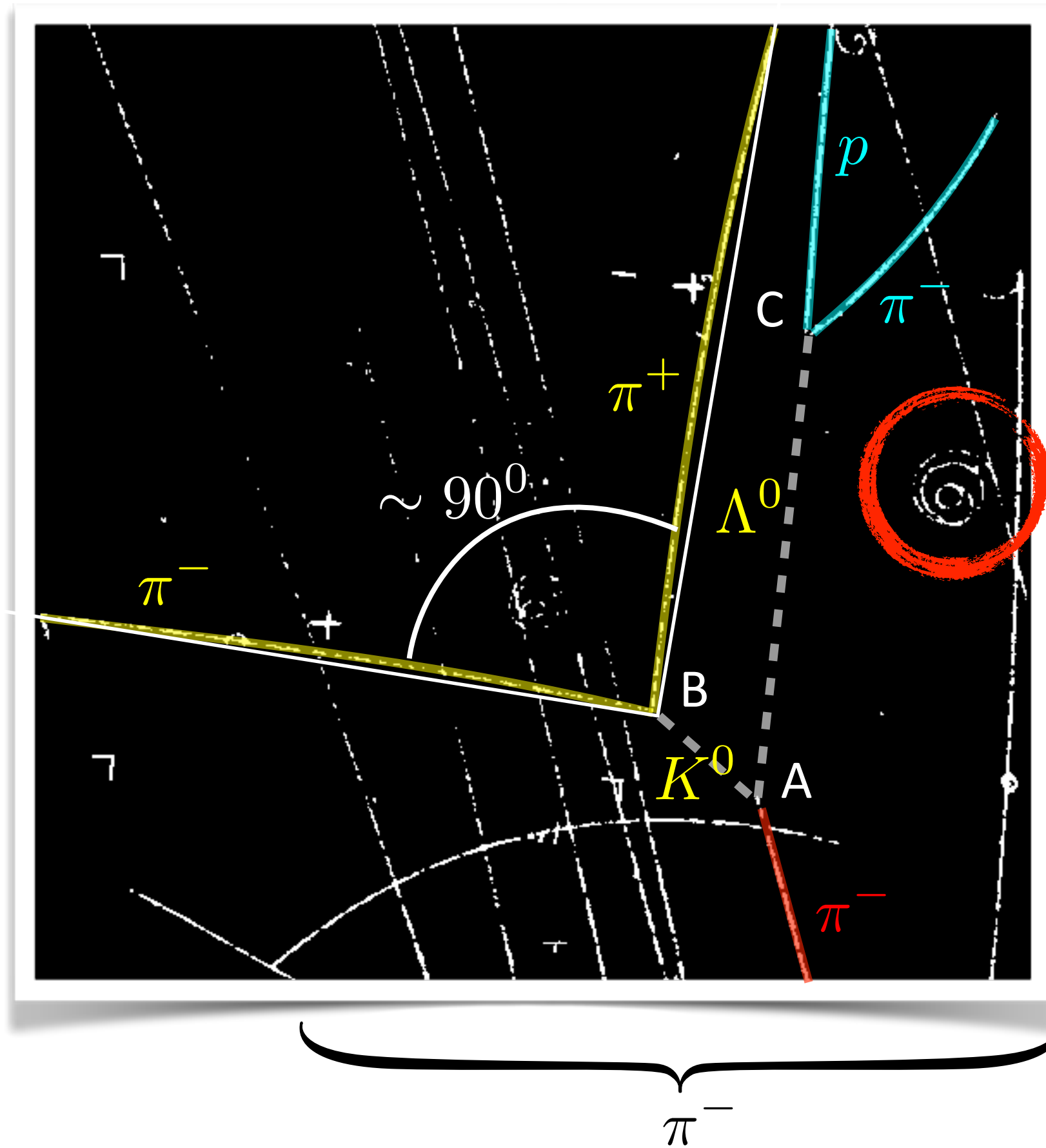
Fermion, baryon, $I = \pm 1/2$, $B=1$, $S=-3$

at the Bevatron

"cosmic ray"
events could be
manufactured on
earth

at will.

Without knowing details, we can decipher a lot:



a little
atomic
electron
kicked out of
liquid - tells
us the
magnetic
field
direction

a beam of negative pions at the Bevatron

1. the direction of the field is such that negatives curve left
2. there are two neutral particles produced at A...which decay at B and C
3. @B: the almost 90 degree opening angle - decay products are the same mass
3. @A: the positive track is a proton (bubble density at end), other a pion

yes, more strange particles

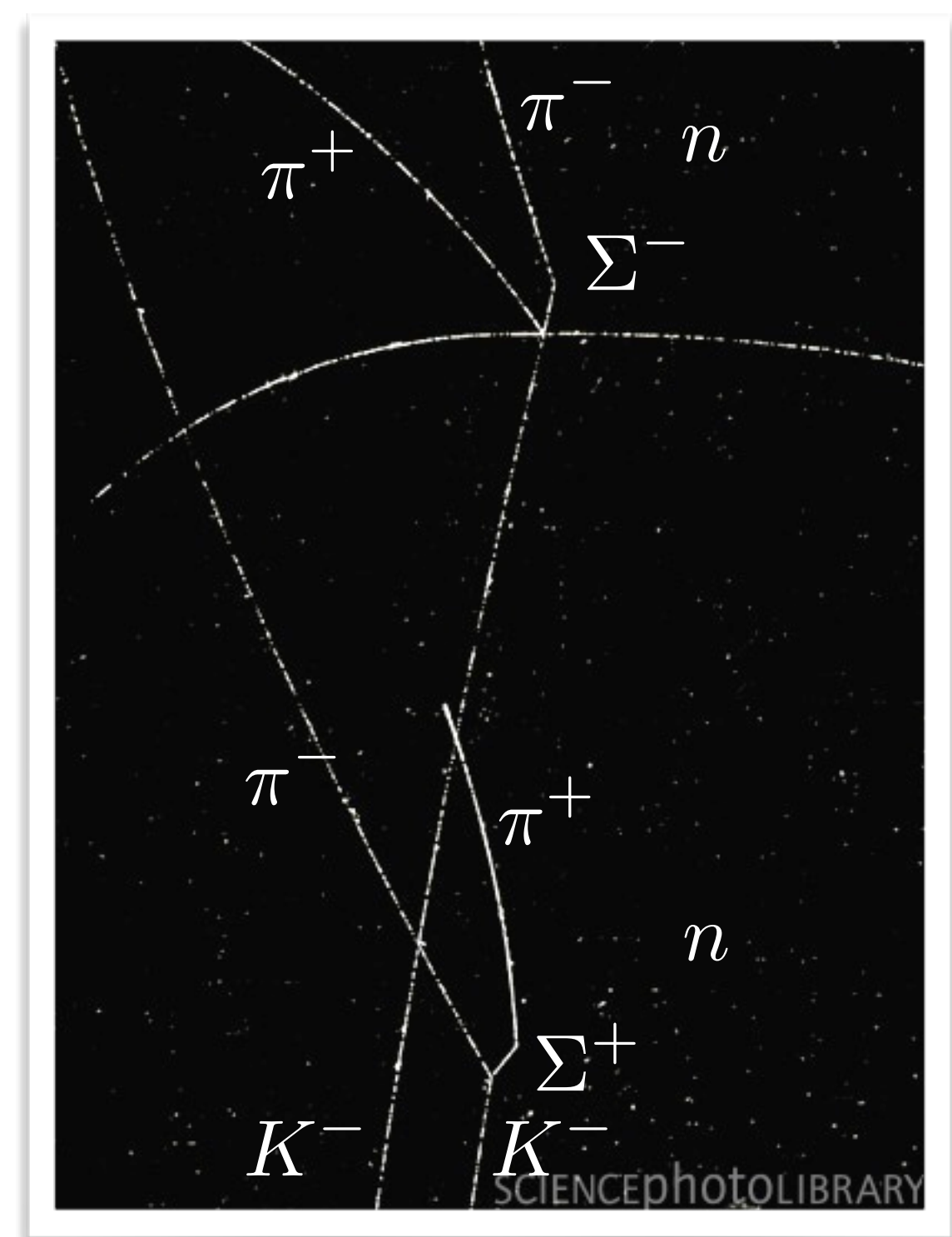
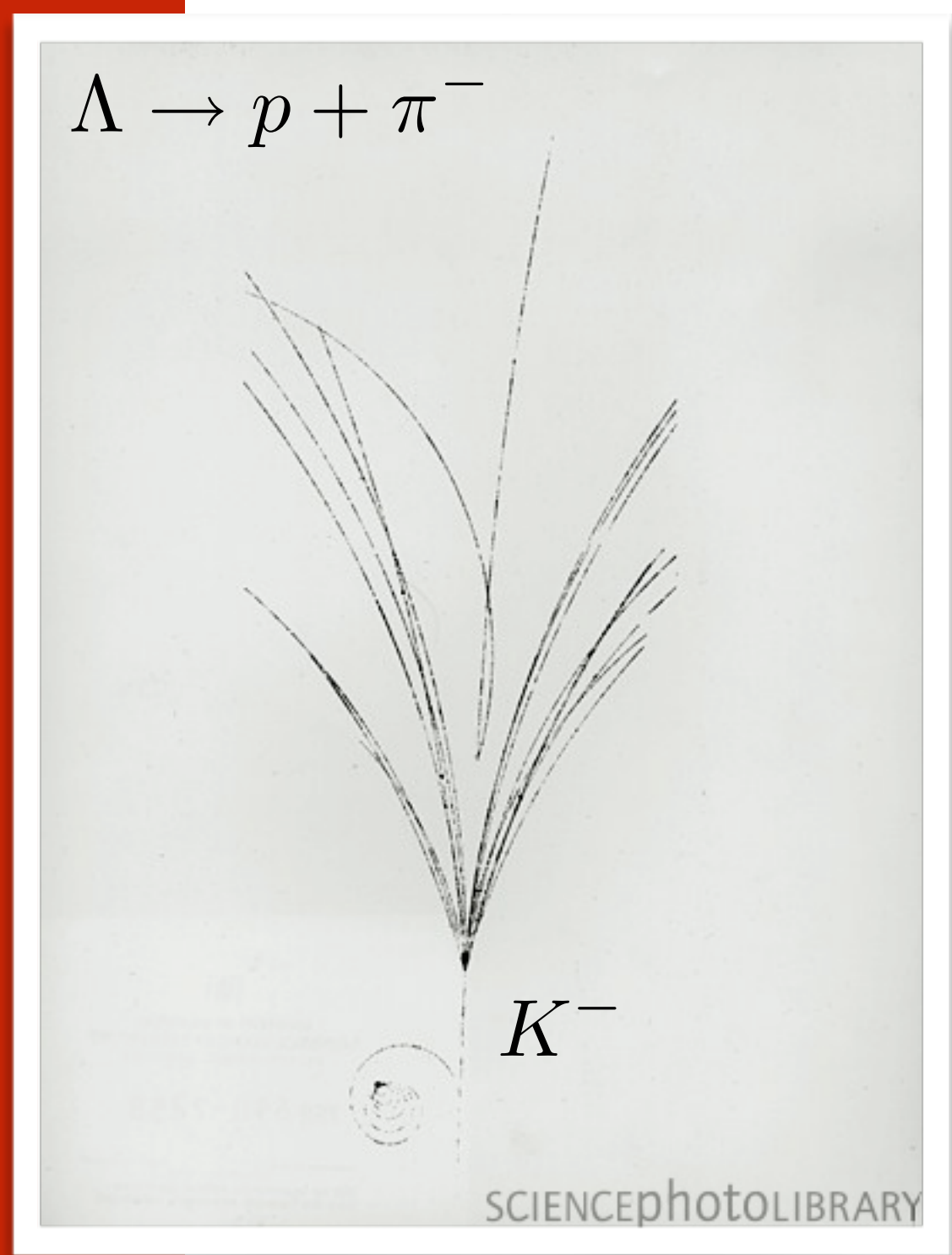
"Lambdas"
"Sigmas"
"Cascades"
"K-stars"

$$\Lambda \rightarrow p + \pi^- \quad 64\%$$

$$\Lambda \rightarrow n + \pi^0 \quad 36\%$$

$$\Sigma^+ \rightarrow n + \pi^+ \quad 51.6\%$$

$$\Sigma^+ \rightarrow p + \pi^0 \quad 48.4\%$$



particle:

Lambda

symbol:

Λ

charge:

0

mass:

1,115.683 MeV/c²

spin:

1/2

category:

Fermion, baryon, I = 0, B=1, S=-1

Particle Data Group Summary									
LIGHT UNFLAVORED ($S=C+B=0$)		STRANGE ($S=\pm 1, C=B=0$)		BOTTOM ($B=\pm 1$)		LIGHT UNFLAVORED ($S=C+B=0$)		STRANGE ($S=\pm 1, C=B=0$)	
J^P	J^P	J^P	J^P	J^P	J^P	J^P	J^P	J^P	J^P
π^\pm	$1^-(0^-)$	$\pi_2(1670)$	$1^-(2^-)$	K^\pm	$1/2(0^-)$	B^\pm	$1/2(0^-)$	π^\pm	$1^-(0^-)$
π^0	$1^-(0^+)$	$\phi(1680)$	$0^-(1^-)$	K^0	$1/2(0^-)$	B^0	$1/2(0^-)$	π^0	$1^-(0^+)$
η	$0^+(0^+)$	$\rho_3(1690)$	$1^+(3^-)$	K_S^0	$1/2(0^-)$	B_S^0	$1/2(0^-)$	η	$0^+(0^+)$
$\eta(600)$	$0^+(0^+)$	$\rho(1700)$	$1^+(1^-)$	K_L^0	$1/2(0^-)$	B_L^0	$1/2(0^-)$	$\eta(600)$	$0^+(0^+)$
$\rho(770)$	$1^+(1^-)$	$\omega(1700)$	$1^-(2^+)$	$K_2^*(800)$	$1/2(0^+)$	$B_2^*(800)$	$1/2(0^+)$	$\rho(770)$	$1^+(1^-)$
$\omega(782)$	$0^-(1^-)$	$\phi(1710)$	$0^+(0^+)$	$K_1^*(1270)$	$1/2(1^-)$	$B_1^*(1270)$	$1/2(1^-)$	$\omega(782)$	$0^-(1^-)$
$\eta(958)$	$0^+(0^+)$	$\eta(1760)$	$0^+(0^+)$	$K_1^*(1400)$	$1/2(1^+)$	$B_1^*(1400)$	$1/2(1^+)$	$\eta(958)$	$0^+(0^+)$
$\eta(980)$	$0^+(0^+)$	$\pi(1800)$	$1^-(0^-)$	$K^*(1410)$	$1/2(1^-)$	$B^*(1410)$	$1/2(1^-)$	$\eta(980)$	$0^+(0^+)$
$\omega(980)$	$1^-(0^+)$	$\phi_3(1810)$	$0^+(2^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\omega(980)$	$1^-(0^+)$
$\phi(1020)$	$0^-(1^-)$	$X(1835)$	$?^?(2^-)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\phi(1020)$	$0^-(1^-)$
$h_1(1170)$	$0^+(1^+)$	$\phi_3(1850)$	$0^-(3^-)$	$K_1^*(1410)$	$1/2(1^-)$	$B_1^*(1410)$	$1/2(1^-)$	$h_1(1170)$	$0^+(1^+)$
$h_1(1235)$	$1^+(1^+)$	$\eta_2(1870)$	$0^+(2^-)$	$K_1^*(1410)$	$1/2(1^-)$	$B_1^*(1410)$	$1/2(1^-)$	$h_1(1235)$	$1^+(1^+)$
$a_1(1260)$	$1^+(1^+)$	$\eta(1900)$	$1^+(1^-)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$a_1(1260)$	$1^+(1^+)$
$\omega(1270)$	$0^+(2^+)$	$\rho(1900)$	$1^+(1^-)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\omega(1270)$	$0^+(2^+)$
$f_1(1285)$	$0^+(1^+)$	$f_2(1910)$	$0^+(2^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_1(1285)$	$0^+(1^+)$
$\eta(1295)$	$0^+(0^+)$	$f_2(1910)$	$0^+(2^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\eta(1295)$	$0^+(0^+)$
$\pi(1300)$	$1^-(0^+)$	$\rho_3(1990)$	$1^+(3^-)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\pi(1300)$	$1^-(0^+)$
$\omega_2(1320)$	$1^-(2^+)$	$f_2(2010)$	$0^+(2^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\omega_2(1320)$	$1^-(2^+)$
$f_0(1370)$	$0^+(0^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_0(1370)$	$0^+(0^+)$
$h_1(1380)$	$?^-(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$h_1(1380)$	$?^-(1^+)$
$\pi_1(1400)$	$1^-(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\pi_1(1400)$	$1^-(1^+)$
$\eta(1405)$	$0^+(0^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\eta(1405)$	$0^+(0^+)$
$f_1(1420)$	$0^+(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_1(1420)$	$0^+(1^+)$
$\omega(1420)$	$0^-(1^-)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\omega(1420)$	$0^-(1^-)$
$f_2(1430)$	$0^+(2^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_2(1430)$	$0^+(2^+)$
$a_0(1450)$	$1^-(0^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$a_0(1450)$	$1^-(0^+)$
$\rho(1450)$	$1^+(1^-)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\rho(1450)$	$1^+(1^-)$
$\eta(1475)$	$0^+(0^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\eta(1475)$	$0^+(0^+)$
$f_0(1500)$	$0^+(0^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_0(1500)$	$0^+(0^+)$
$f_1(1510)$	$0^+(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_1(1510)$	$0^+(1^+)$
$f_2^*(1525)$	$0^+(2^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_2^*(1525)$	$0^+(2^+)$
$f_2(1565)$	$0^+(2^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_2(1565)$	$0^+(2^+)$
$h_1(1595)$	$0^-(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$h_1(1595)$	$0^-(1^+)$
$\pi_1(1600)$	$1^-(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\pi_1(1600)$	$1^-(1^+)$
$a_1(1640)$	$1^-(1^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$a_1(1640)$	$1^-(1^+)$
$f_2(1640)$	$0^+(2^+)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$f_2(1640)$	$0^+(2^+)$
$\omega(1650)$	$0^-(1^-)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\omega(1650)$	$0^-(1^-)$
$\omega_3(1670)$	$0^-(3^-)$	$f_6(2040)$	$1^-(4^+)$	$K_2^*(1430)$	$1/2(0^+)$	$B_2^*(1430)$	$1/2(0^+)$	$\omega_3(1670)$	$0^-(3^-)$

Young man, if I could remember the names of these particles, I would have been a botanist.

Enrico Fermi

By the mid-1950's

things are officially out of control.

by 1955

N(1535)	D ₁₃	Δ(1700)	D ₃₃	A(1600)	P ₀₁	Δ(1700)	D ₃₃	A(1600)	P ₀₁	Δ(1700)	D ₃₃	A(1600)	P ₀₁
N(1675)	D ₁₅	Δ(1905)	F ₃₅	A(1800)	S ₀₁	Δ(1905)	F ₃₅	A(1800)	S ₀₁	Δ(1905)	F ₃₅	A(1800)	S ₀₁
N(1680)	F ₁₅	Δ(1910)	P ₃₁	A(1810)	P ₀₁	Δ(1910)	P ₃₁	A(1810)	P ₀₁	Δ(1910)	P ₃₁	A(1810)	P ₀₁
N(1700)	D ₁₃	Δ(1920)	P ₃₃	A(1820)	F ₀₅	Δ(1920)	P ₃₃	A(1820)	F ₀₅	Δ(1920)	P ₃₃	A(1820)	F ₀₅
N(1710)	D ₁₁	Δ(1930)	D ₃₅	A(1830)	D ₀₅	Δ(1930)	D ₃₅	A(1830)	D ₀₅	Δ(1930)	D ₃₅	A(1830)	D ₀₅
N(1720)	D ₁₃	Δ(1940)	D ₃₃	A(1890)	P ₀₃	Δ(1940)	D ₃₃	A(1890)	P ₀₃	Δ(1940)	D ₃₃	A(1890)	P ₀₃
N(1900)	D ₁₃	Δ(1950)	F ₃₇	A(2000)	*	Δ(1950)	F ₃₇	A(2000)	*	Δ(1950)	F ₃₇	A(2000)	*
N(1990)	F ₁₇	Δ(2000)	F ₃₅	A(2020)	F ₀₇	Δ(2000)	F ₃₅	A(2020)	F ₀₇	Δ(2000)	F ₃₅	A(2020)	F ₀₇
N(2000)	F ₁₅	Δ(2150)	S ₃₁	A(2100)	G ₀₇	Δ(2150)	S ₃₁	A(2100)	G ₀₇	Δ(2150)	S ₃₁	A(2100)	G ₀₇
N(2080)	D ₁₃	Δ(2200)	G ₃₇	A(2110)	F ₀₅	Δ(2200)	G ₃₇	A(2110)	F ₀₅	Δ(2200)	G ₃₇	A(2110)	F ₀₅
N(2090)	S ₁₁	Δ(2300)	*	A(2325)	D ₀₃	Δ(2300)	*	A(2325)	D ₀₃	Δ(2300)	*	A(2325)	D ₀₃
N(2100)	P ₁₁	Δ(2350)	*	A(2350)	H ₀₉	Δ(2350)	*	A(2350)	H ₀₉	Δ(2350)	*	A(2350)	H ₀₉
N(2190)	G ₁₇	Δ(2390)	*	A(2585)	*	Δ(2390)	*	A(2585)	*	Δ(2390)	*	A(2585)	*
N(2200)	D ₁₅	Δ(2400)	*	Θ(1540) ⁺	*	Δ(2400)	*	Θ(1540) ⁺	*	Δ(2400)	*	Θ(1540) ⁺	*
N(2220)	H ₁₉	Δ(2420)	*			Δ(2420)	*			Δ(2420)	*		
N(2250)	G ₁₉	Δ(2750)	*			Δ(2750)	*			Δ(2750)	*		
N(2600)	h _{1,11}	Δ(2950)	*			Δ(2950)	*			Δ(2950)	*		

100's of them

Light Unflavored (S=C+B=0)	Strange (S=±1, C=B=0)	Bottom (B=±1, S=C=0)	Bottom Strange (B=±1, S=±1, C=0)	Charmed (C=±1)	Charmed Strange (C=S=±1)
π [±] 1 ⁻ (0 ⁻)	π [±] (1670) 1 ⁻ (2 ⁻ +)	K [±] 1/2(0 ⁻)	K [±] 1/2(0 ⁻)	D [±] 1/2(0 ⁻)	D [±] 1/2(0 ⁻)
π ⁰ 1 ⁻ (0 ⁻ +)	π ⁰ (1680) 0 ⁻ (1 ⁻ -)	K ⁰ 1/2(0 ⁻)	K ⁰ 1/2(0 ⁻)	D ⁰ 1/2(0 ⁻)	D ⁰ 1/2(0 ⁻)
η 0 ⁺ (0 ⁻ +)	η(1690) 1 ⁺ (3 ⁻ -)	K ⁰ _s 1/2(0 ⁻)	K ⁰ _s 1/2(0 ⁻)	D ⁰ _s 1/2(0 ⁻)	D ⁰ _s 1/2(0 ⁻)
ρ(600) 0 ⁺ (0 ⁻ +)	ρ(1700) 1 ⁺ (1 ⁻ -)	K ⁰ _l 1/2(0 ⁻)	K ⁰ _l 1/2(0 ⁻)	D ⁰ _l 1/2(0 ⁻)	D ⁰ _l 1/2(0 ⁻)
ρ(770) 1 ⁺ (1 ⁻ -)	ρ(1700) 1 ⁺ (2 ⁻ +)	K ⁰ _s (800) 1/2(0 ⁻)	K ⁰ _s (800) 1/2(0 ⁻)	D ⁰ _s (2007) ⁰ 1/2(1 ⁻)	D ⁰ _s (2007) ⁰ 1/2(1 ⁻)
ω(782) 0 ⁺ (0 ⁻ +)	ω(1710) 0 ⁺ (0 ⁻ +)	K ⁰ (892) 1/2(1 ⁻)	K ⁰ (892) 1/2(1 ⁻)	D ⁰ _s (2010) [±] 1/2(1 ⁻)	D ⁰ _s (2010) [±] 1/2(1 ⁻)
η(958) 0 ⁺ (0 ⁻ +)	η(1760) 0 ⁺ (0 ⁻ +)	K ₁ (1270) 1/2(1 ⁺)	K ₁ (1270) 1/2(1 ⁺)	D ⁰ _s (2400) [±] 1/2(0 ⁺)	D ⁰ _s (2400) [±] 1/2(0 ⁺)
φ(980) 0 ⁺ (0 ⁻ +)	φ(1800) 1 ⁻ (0 ⁻ +)	K ₁ (1400) 1/2(1 ⁺)	K ₁ (1400) 1/2(1 ⁺)	D ⁰ _s (2420) [±] 1/2(1 ⁺)	D ⁰ _s (2420) [±] 1/2(1 ⁺)
ω(980) 1 ⁻ (0 ⁻ +)	ω(1810) 0 ⁺ (2 ⁻ +)	K [*] (1410) 1/2(1 ⁻)	K [*] (1410) 1/2(1 ⁻)	D ⁰ _s (2430) [±] 1/2(1 ⁺)	D ⁰ _s (2430) [±] 1/2(1 ⁺)
φ(1020) 0 ⁻ (1 ⁻ -)	X(1835) 7 ² (7 ⁺ +)	K [*] _s (1430) 1/2(0 ⁻)	K [*] _s (1430) 1/2(0 ⁻)	D ⁰ _s (2460) [±] 1/2(2 ⁺)	D ⁰ _s (2460) [±] 1/2(2 ⁺)
h ₁ (1170) 0 ⁺ (1 ⁻ +)	φ ₃ (1850) 0 ⁻ (3 ⁻ -)	K ₂ [*] (1430) 1/2(2 ⁺)	K ₂ [*] (1430) 1/2(2 ⁺)	D ⁰ _s (2640) [±] 1/2(2 ⁺)	D ⁰ _s (2640) [±] 1/2(2 ⁺)
h ₁ (1235) 1 ⁺ (1 ⁻ +)	η ₂ (1870) 0 ⁺ (2 ⁻ +)	K(1460) 1/2(0 ⁻)	K(1460) 1/2(0 ⁻)		
a ₁ (1260) 1 ⁻ (1 ⁻ +)	ρ(1900) 1 ⁺ (1 ⁻ -)	K ₂ (1580) 1/2(2 ⁻)	K ₂ (1580) 1/2(2 ⁻)		
f ₂ (1270) 0 ⁺ (2 ⁻ +)	f ₂ (1910) 0 ⁺ (2 ⁻ +)	K(1630) 1/2(2 [?])	K(1630) 1/2(2 [?])		
f ₁ (1285) 0 ⁺ (1 ⁻ +)	f ₂ (1950) 0 ⁺ (2 ⁻ +)	K ₁ (1650) 1/2(1 ⁺)	K ₁ (1650) 1/2(1 ⁺)		
η(1295) 0 ⁺ (0 ⁻ +)	ρ ₃ (1990) 1 ⁺ (3 ⁻ -)	K [*] (1680) 1/2(1 ⁻)	K [*] (1680) 1/2(1 ⁻)		
π(1300) 1 ⁻ (0 ⁻ +)	f ₂ (2010) 0 ⁺ (2 ⁻ +)	K ₂ (1770) 1/2(2 ⁻)	K ₂ (1770) 1/2(2 ⁻)		
a ₂ (1320) 1 ⁻ (2 ⁻ +)	ρ ₃ (2020) 0 ⁺ (0 ⁻ +)	K ₂ (1780) 1/2(3 ⁻)	K ₂ (1780) 1/2(3 ⁻)		
h ₁ (1370) 0 ⁺ (0 ⁻ +)	a ₄ (2040) 1 ⁻ (4 ⁻ +)	K ₂ (1820) 1/2(2 ⁻)	K ₂ (1820) 1/2(2 ⁻)		
h ₁ (1380) 7 ⁻ (1 ⁻ +)	f ₄ (2050) 0 ⁺ (4 ⁻ +)	K(1830) 1/2(0 ⁻)	K(1830) 1/2(0 ⁻)		
π ₁ (1400) 1 ⁻ (1 ⁻ +)	π ₂ (2100) 1 ⁻ (2 ⁻ +)	K ₂ [*] (1950) 1/2(0 ⁺)	K ₂ [*] (1950) 1/2(0 ⁺)		
η(1405) 0 ⁺ (0 ⁻ +)	φ(2100) 0 ⁺ (0 ⁻ +)	K ₂ [*] (1980) 1/2(2 ⁺)	K ₂ [*] (1980) 1/2(2 ⁺)		
f ₁ (1420) 0 ⁺ (1 ⁻ +)	f ₂ (2150) 0 ⁺ (2 ⁻ +)	K ₂ [*] (2045) 1/2(4 ⁺)	K ₂ [*] (2045) 1/2(4 ⁺)		
ω(1420) 0 ⁻ (1 ⁻ -)	ρ(2150) 1 ⁺ (1 ⁻ -)	K ₂ (2250) 1/2(2 ⁻)	K ₂ (2250) 1/2(2 ⁻)		
f ₁ (1430) 0 ⁺ (2 ⁻ +)	φ(2200) 0 ⁺ (0 ⁻ +)	K ₂ (2320) 1/2(3 ⁺)	K ₂ (2320) 1/2(3 ⁺)		
a ₀ (1450) 1 ⁻ (0 ⁻ +)	f ₂ (2220) 0 ⁺ (2 ⁻ +)	K ₂ (2380) 1/2(5 ⁻)	K ₂ (2380) 1/2(5 ⁻)		
ρ(1450) 1 ⁺ (1 ⁻ -)	η(2225) 0 ⁺ (0 ⁻ +)	K ₄ (2500) 1/2(4 ⁻)	K(3100) 7 ² (7 ⁺ +)		
η(1475) 0 ⁺ (0 ⁻ +)	f ₂ (2300) 1 ⁺ (3 ⁻ -)				
φ(1500) 0 ⁺ (0 ⁻ +)	f ₄ (2300) 0 ⁺ (4 ⁻ +)				
f ₁ (1510) 0 ⁺ (1 ⁻ +)	f ₂ (2340) 0 ⁺ (2 ⁻ +)				
f ₂ (1525) 0 ⁺ (2 ⁻ +)	f ₂ (2350) 1 ⁺ (5 ⁻ -)				
f ₁ (1565) 0 ⁺ (2 ⁻ +)	h ₁ (1595) 0 ⁻ (1 ⁻ +)				
h ₁ (1595) 0 ⁻ (1 ⁻ +)	a ₀ (2450) 1 ⁻ (6 ⁻ +)				
π ₁ (1600) 1 ⁻ (1 ⁻ +)	φ(2510) 0 ⁺ (6 ⁻ +)				
a ₁ (1640) 1 ⁻ (1 ⁻ +)					
f ₂ (1645) 0 ⁺ (2 ⁻ +)					
ω(1650) 0 ⁻ (1 ⁻ -)					
ω ₃ (1670) 0 ⁻ (3 ⁻ -)					

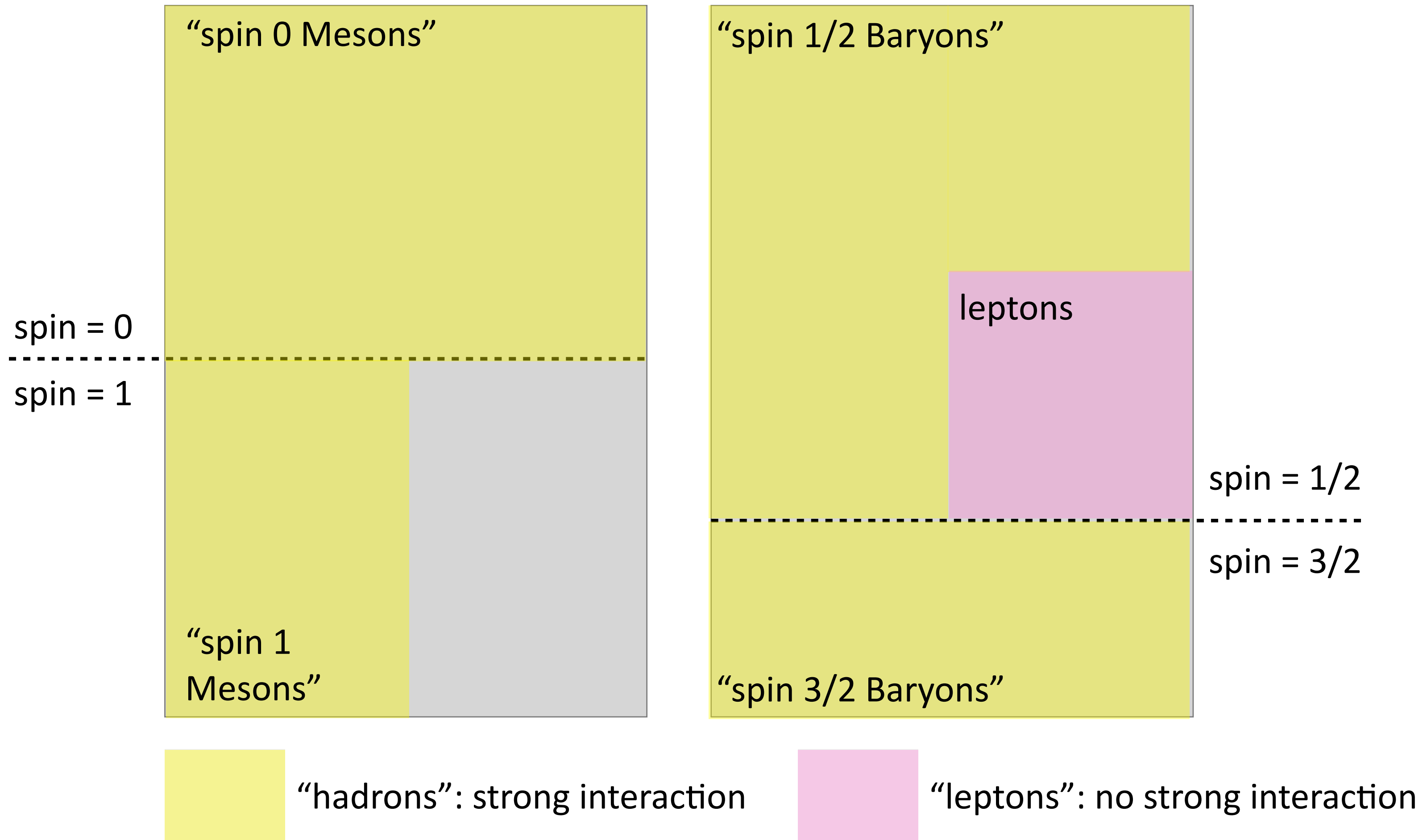
things were messy

what's so "elementary" about that?

The Particle Zoo?

Bosons

Fermions



there
were
clues

patterns and
organizing
features

began to emerge in
the pile of data

Hundreds of experiments, thousands of physicists
measuring lifetimes, probabilities, final state
multiplicities...and doing it over and over.



organizing

with many
different patterns
at a time

Strictly Empirical:

From a 20 year-long accumulation of thousands of different results on production, decay, mass, spin properties of 100's of particles...whole careers. *No clue why the patterns.*



Various “Quantum Numbers” – all reflecting an underlying “internal symmetry”

Electric Charge
Lepton Numbers
Baryon Number
Strangeness

jargon alert:

particle quantum numbers

refers to:

quantities that are inherently a part of particles, which are conserved in interactions or decays

etymology:

historical to Bohr and Schroedinger

example:

electric charge, baryon number, lepton number, isospin

this is empirical - it's what Nature seems to do

we have some ideas about how/why

but understanding quantum number rules is work in progress!

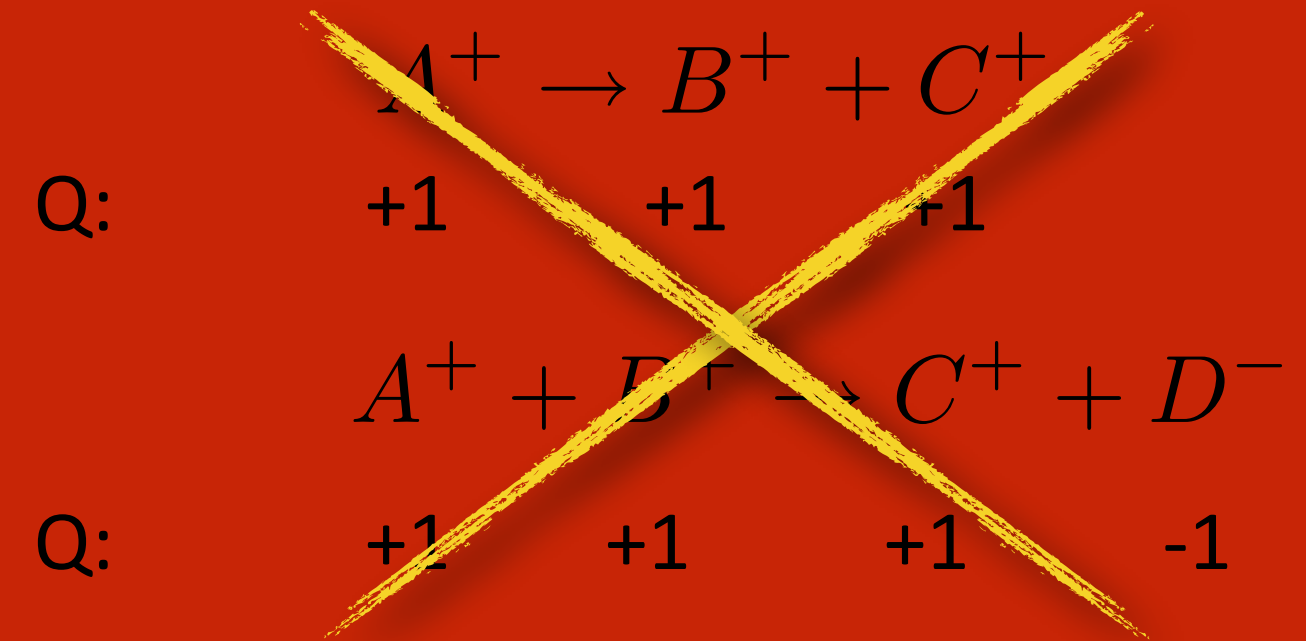
Quantum Number:

Electric Charge

so, you'll always see:

total electric charge at the beginning equals total charges at the end

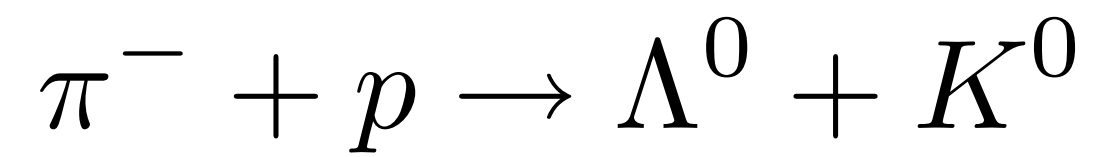
something like these will never happen:



Quantum Number:

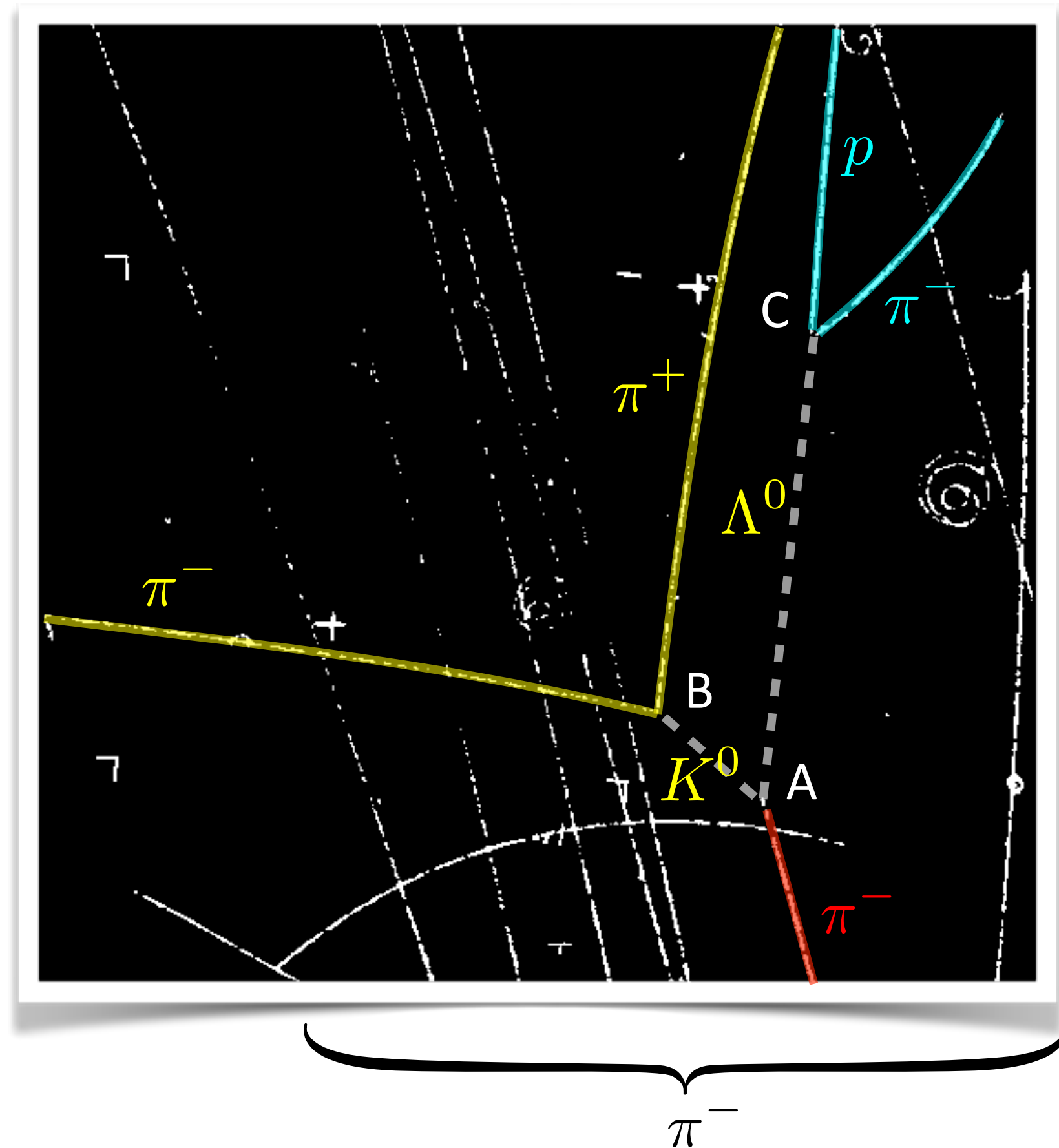
Strangeness

a clue



some particles are easily produced...but **only in pairs**
and they, in turn, are reluctant to decay

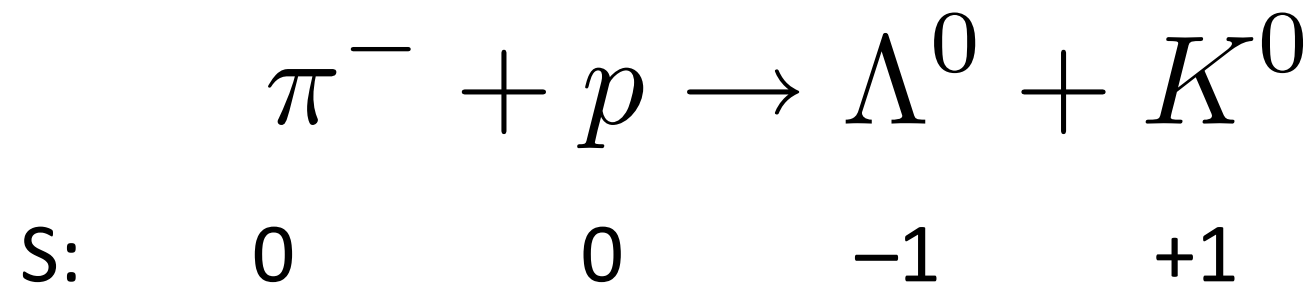
of another kind of
"number"



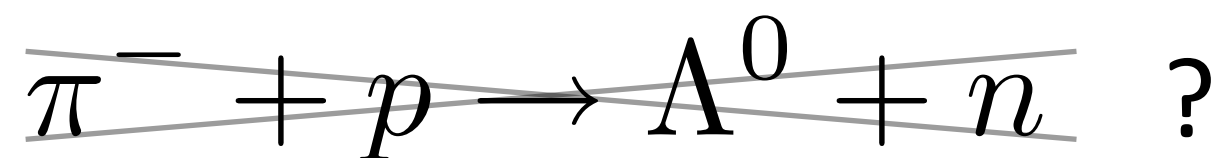
Strangeness, S

strangeness
seems to come in
pairs

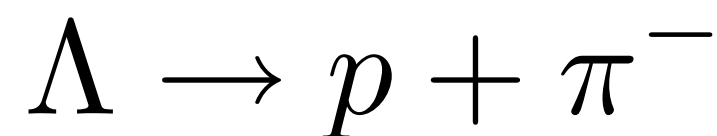
assign "strangeness"
empirically.



Strong
interaction



and yet you *do* see:



Weak
interaction

Production of a subset of all baryons seems to require them to come in pairs.

Strong interactions conserve Strangeness

Decay of those same baryons...notsomuch

Weak interactions change Strangeness by 1 unit

the dominant Baryons

Particle	Symbol	Rest Mass MeV/c ²	spin	Q	B	S	Lifetime	dominant decay modes
proton	p	938.3	1/2	+1	+1	0	$> 10^{31} \text{ y}$	
neutron	n	939.6	1/2	0	+1	0	920	$p e^{-} \bar{\nu}_e$
Lambda	Λ^0	1115.6	1/2	0	+1	-1	2.6×10^{-10}	$p\pi^{-}, n\pi^0$
Sigma	Σ^{+}	1189.4	1/2	+1	+1	-1	0.8×10^{-10}	$p\pi^0, n\pi^{+}$
Sigma	Σ^0	1192.5	1/2	0	+1	-1	6×10^{-20}	$\Lambda^0 \gamma$
Sigma	Σ^{-}	1197.3	1/2	-1	+1	-1	1.5×10^{-10}	$n\pi^{-}$
Delta	Δ^{++}	1232	3/2	+2	+1	0	0.6×10^{-23}	$p\pi^{+}$
Delta	Δ^{+}	1232	3/2	+1	+1	0	0.6×10^{-23}	$n\pi^{+}, p\pi^0$
Delta	Δ^0	1232	3/2	0	+1	0	0.6×10^{-23}	$n\pi^0$
Delta	Δ^{-}	1232	3/2	-1	+1	0	0.6×10^{-23}	$n\pi^{-}$
Xi	Ξ^0	1315	1/2	0	+1	-2	2.9×10^{-10}	$\Lambda^0 \pi^0$
Xi	Ξ^{-}	1321	1/2	-1	+1	-2	1.64×10^{-10}	$\Lambda^0 \pi^{-}$
Omega	Ω^{-}	1672	3/2	-1	+1	-3	0.82×10^{-10}	$\Xi^0 \pi^{-}, \Lambda^0 K^{-}$

the dominant Mesons

Particle	Symbol	anti-particle	Rest Mass MeV/c ²	spin	Q	B	S	Lifetime	dominant decay modes
Pion	π^+	π^-	139.6	0	+1	0	0	2.6×10^{-8}	$\mu^+ \nu_\mu$
Pi-zero	π^0	π^0	135	0	0	0	0	920	2γ
Kaon	K^+	K^-	493.7	0	+1	0	+1	1.24×10^{-8}	$\mu^+ \nu_\mu, \pi^+ \pi^0$
K-short	K_S^0	K_S^0	497.7	0	0	0	+1	0.89×10^{-10}	$\pi^+ \pi^-, 2\pi^0$
K-long	K_L^0	K_L^0	497.7	0	0	0	+1	5.2×10^{-8}	$\pi^\pm \ell^\mp \nu_\ell$
Eta	η^0	η^0	548.8	0	0	0	0	$< 10^{-18}$	$2\gamma, \pi^+ \pi^- \pi^0$
Eta-prime	$\eta^{0'}$	$\eta^{0'}$	958	1	0	0	0	...	$\pi^+ \pi^- \eta$
Rho	ρ^+	ρ^-	770	1	+1	0	0	0.4×10^{-23}	$\pi^+ \pi^-, 2\pi^0$
Rho-naught	ρ^0	ρ^0	770	1	0	0	0	0.4×10^{-23}	$\pi^+ \pi^-$
Omega	ω^0	ω^0	782	1	0	0	0	0.8×10^{-22}	$\pi^+ \pi^- \pi^0$
Phi	ϕ	ϕ	1020	1	0	0	0	20×10^{-23}	$K^+ K^-, K^0 \bar{K}^0$

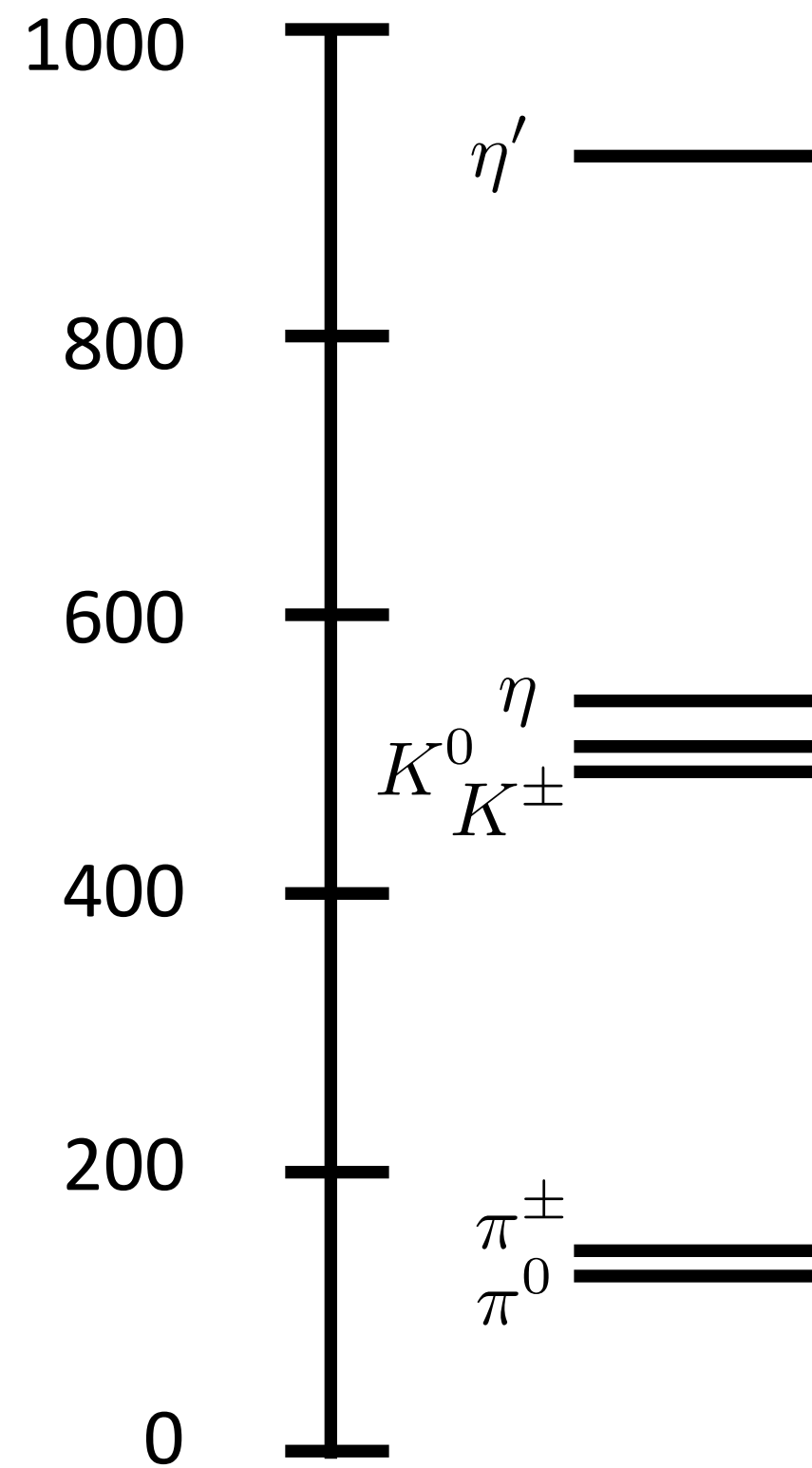
anyhow...back to the Zoo problem

all those particles.

There were some hints:

masses
seem to
clump

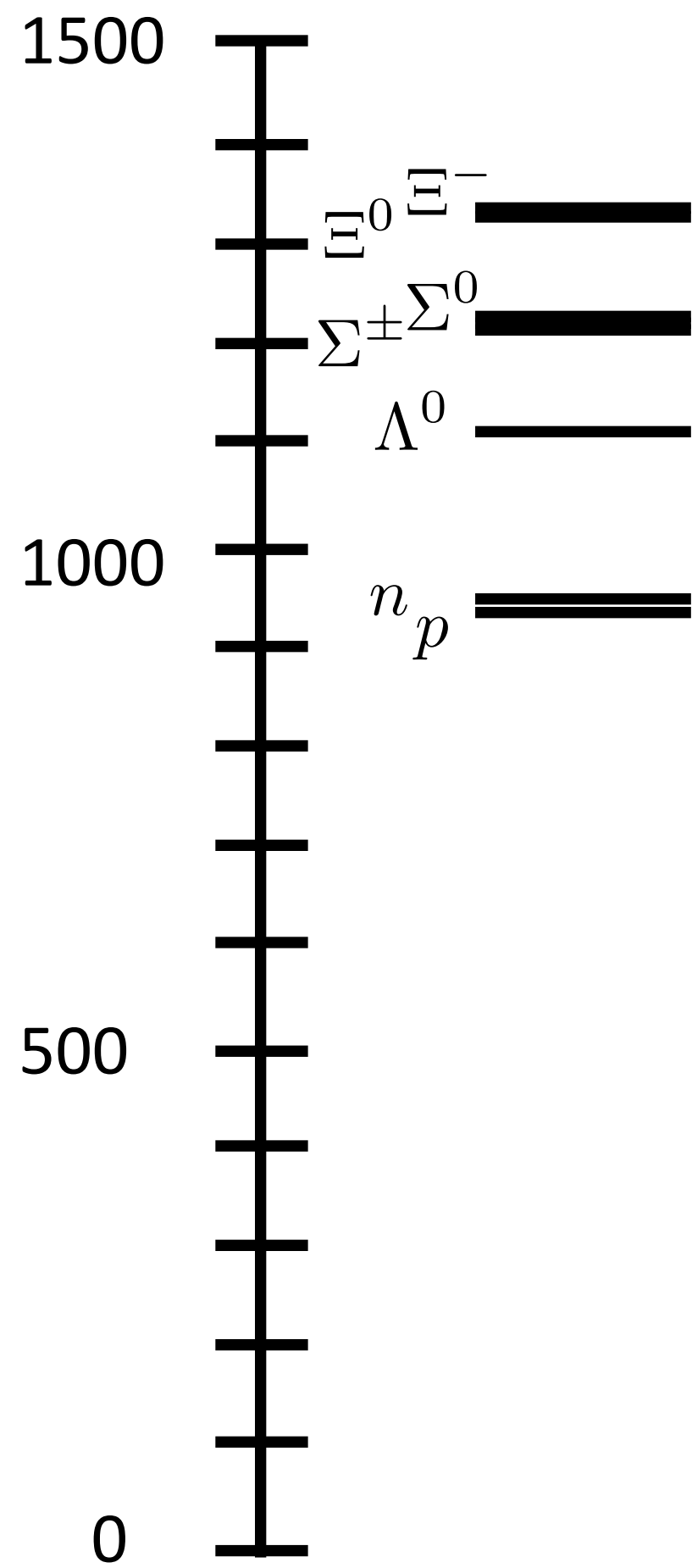
look at a set of the
mesons



as in
Nature

masses
seem to
clump

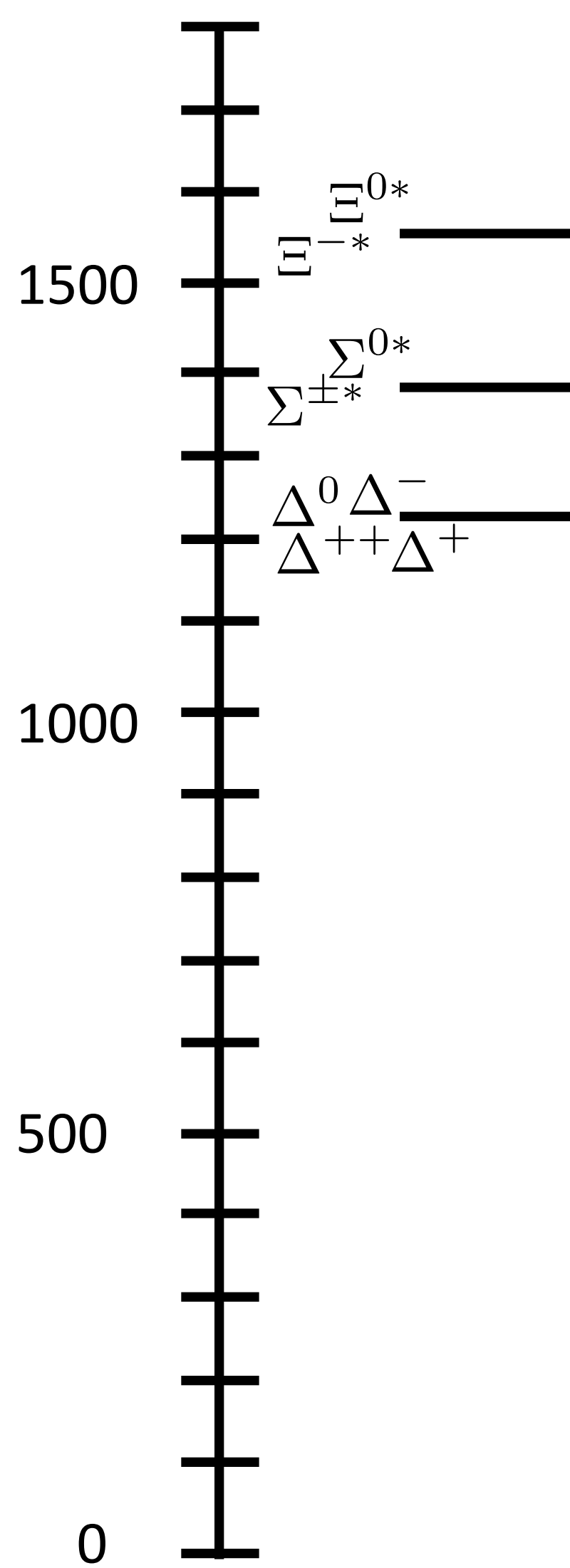
look at the
baryons



as in
Nature

masses
seem to
clump

look at a different
set of the baryons



as in
Nature