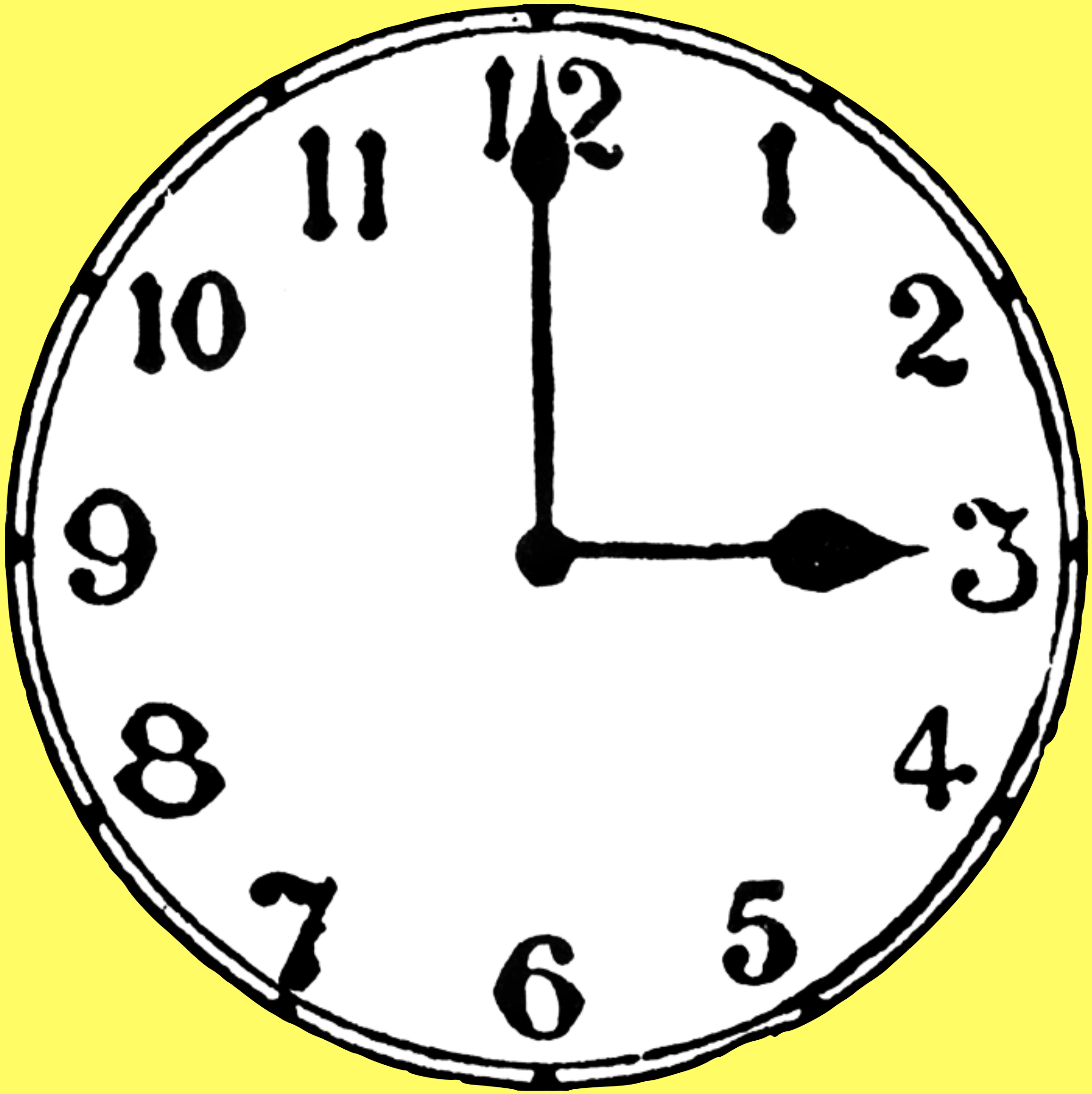

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14. Particle Physics, 2

lecture last, December 8, 2017

pitchers and catchers report in 70 days

housekeeping

Exam 3: average 35, incl. extra

Chapter 14, Particle Physics

mostly entertainment, some serious moments

read the chapter!

Final: Monday, December 11, 3:00-5:00 pm, 101 Biochemistry Building

two 5″x8″ index cards

I predict problems and questions could come from Chapters:

- 2. **Relativity**
- 3. Experimental Basis for Quantum Theory
- **4. Structure of the Atom**
- 5. Wave Properties of Matter
- **6. Quantum Mechanics**
- **7. Hydrogen Atom**
- 12. Atomic Nucleus
- 13. Nuclear Reactions
- 14. Particle Physics, but qualitative
- **Thermodynamics**

I might ask you to summarize some famous experiments and the accomplishments of possibly some of these people:

Lorentz, Einstein, Michelson and Morley, Joule, Carnot, Boltzmann, Roentgen, JJ Thompson, Millikan, Planck, Compton, Rutherford, Bohr, Moseley, Bragg, De Broglie, Heisenberg, Schrodinger, Zeeman, Chadwick, Marie Curie, Yukawa, Fermi, Pauli

Name:

Student #

PHY215, fall 2017
Modern Physics and Thermodynamics

Final Exam. Monday, December 11, 2017: 80 points
3:00pm - 5:00pm in 101 Biochemistry

Please show all of your work. If you need more space, use the back and indicate clearly what problem is being continued. If you still need more space...ask for another sheet and clearly include your name and what problem is begin continued.

Constants

1 calorie = 4.186 J
1 atmosphere = 1.01×10^5 Pa
Gas Constant: $R = 8.3145$ J/mol·K
Bolzmann's Constant: $k = 1.38 \times 10^{-23}$ J/K $= 8.617 \times 10^{-5}$ eV/K
Sefan-Boltzmann's constant: $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4
Avagadro's Number: $N_A = 6.023 \times 10^{23}$ mol^{-1}
Speed of Light: $c = 3 \times 10^8$ m/s
Charge of the electron: $-e = -1.6 \times 10^{-19}$ C
1 atomic mass unit: $u = 1.66054 \times 10^{-27}$ kg $= 931.494043$ MeV/c^2
Mass of the electron: $m_e = 9.1094 \times 10^{-31}$ kg = 511 keV/c^2
Mass of the proton: $m_p = 1.6726 \times 10^{-27}$ kg = 938.3 MeV/c^2
Mass of the proton: $m_p = 1.007277\ u$
Mass of the neutron: $m_n = 1.6749 \times 10^{-27}$ kg = 939.6 keV/c^2
Mass of the neutron: $m_n = 1.008665\ u$
Mass of the alpha particle: $m_\alpha = 3727.4$ MeV/c^2
Mass of the alpha particle: $m_\alpha = 4.00151\ u$
Planck's Constant: $h = 6.63 \times 10^{-34}$J-s $= 4.14 \times 10^{-15}$ eV-s
...times c: $hc = 1.9864 \times 10^{-25}$J-m = 1239.8 eV-nm
Reduced h: $h/2\pi = \hbar = 1.0546 \times 10^{-34}$J-s $= 6.5821 \times 10^{-16}$ ev-s
...times c: $\hbar c = 3.162 \times 10^{-28}$J-m = 197.33 eV-nm
Electrostatic constant: $\frac{1}{4\pi\epsilon_0} = 8.9876 \times 10^9$ N-m^2-C^{-2}
...times e^2: $\frac{e^2}{4\pi\epsilon_0} = 2.3071 \times 10^{-28}$ J-m $= 1.4400 \times 10^{-9}$eV-m
Bohr radius: $a_0 = \frac{\hbar}{m_e c\alpha} = 0.5292 \times 10^{-10}$ m
Fine structure constant: $\alpha = \frac{e^2}{4\pi\epsilon_0 \hbar c} = 1/137.036$
Radioactive activity: 1 Curie = 1 Ci $= 3.7 \times 10^{10}$ decays/s
Radioactive activity: 1 Bq = 1 decay/s

Formulae and Integrals

$$
\begin{aligned}
\text{reduced mass: } \mu &= \frac{mM}{m+M} \\
\text{mean velocity for an ideal gas: } <v> &= \frac{4}{\sqrt{2\pi}}\sqrt{\frac{kT}{m}} \\
\int \sin x dx &= -\cos x \\
\int \cos x dx &= \sin x \\
\int \sin^2 x dx &= \frac{1}{2}x - \frac{1}{2}\sin 2x \\
\int x \sin^2 x dx &= \frac{x^2}{4} - \frac{x\sin 2x}{4} - \frac{\cos 2x}{8} \\
\int x^2 \sin^2 x dx &= \frac{x^3}{6} - \left(\frac{x^2}{4} - \frac{1}{8}\right)\sin 2x - \frac{x\cos 2x}{4} \\
\int e^{-ax} dx &= -\frac{1}{a}e^{-ax} \\
\Delta Q &= mc\Delta T \\
\Delta Q &= \Delta W + \Delta U \\
\text{Ideal Gas Law: } PV &= nRT \\
\text{Work done: } \Delta W &= \int PdV \\
\text{Molar Specific Heats: } C_V &= \Delta U/n\Delta T \\
C_P &= \Delta Q/n\Delta T \\
C_P &= C_V + R \\
\gamma &= C_P/C_V \\
\text{For adiabatic transformations: } \Delta Q &= 0;\ \text{and } PV^\gamma = \text{constant} \\
\text{Thermodynamic efficiency: } \epsilon &= \frac{W}{Q_{in}} \\
\text{Wave motion: } v &= f\lambda \\
\text{Relativistic ``beta'': } \beta &= v/c \\
\gamma &= \frac{1}{\sqrt{1-\beta^2}} \\
\text{Length contraction: } L' &= L/\gamma \\
\text{Time Dilation: } T' &= \gamma T \\
\text{Relativistic addition of velocities: } v' &= \frac{v+u}{1+vu/c^2} \\
E^2 &= p^2c^2 + m^2c^4 \\
E &= \gamma mc^2 \\
p &= \gamma mv \\
K &= E - mc^2
\end{aligned}
$$

$$
\begin{aligned}
\text{Planck energy relation: } E &= hf \\
\text{Einstein's photoelectric relation: } hf &= K + \phi \\
\text{Compton formula: } \Delta\lambda &= \lambda' - \lambda = (1-\cos\theta)h/m_e c \\
\text{Bohr's quantization condition: } L &= mvr = n\hbar \\
\text{Bohr Atom Energy: } E_n &= -\frac{e^2}{8\pi\epsilon r_n} = -\frac{E_0}{n^2} \\
\text{Bohr Atom Radius: } r_n &= \frac{4\pi\epsilon_0\hbar^2}{me^2}n^2 \\
\text{For H: } E_0 &= 13.6\ \text{eV} \\
a_0 &= 5.29 \times 10^{-11}\ \text{m} \\
\text{Reduced mass: } \mu &= \frac{mM}{m+M} \\
\text{Rutherford Scattering: } N(\theta) &= \frac{N_i nte^4 Z_1^2 Z_2^2}{16(4\pi\epsilon)^2 r^2 K^2 \sin^4(\theta/2)} \\
\text{De Broglie wavelength: } \lambda &= h/p \\
\text{Uncertainty relations: } \Delta p_x \Delta x &\geq \hbar/2;\ \Delta E\Delta t \geq \hbar/2 \\
\text{Probability density: } &= \psi^\star\psi \\
\text{Normalization condition: } \int \psi^\star\psi dx &= 1 \\
\text{Infinite Square Well in 1 dimension: } \psi &= \sqrt{\frac{2}{L}}\sin\frac{n\pi x}{L} \\
\text{Infinite Square Well in 1 dimension: } E_n &= \frac{n^2\pi^2\hbar^2}{2mL^2} \\
\text{Infinite Square Well in 3 dimensions: } E_n &= \frac{\pi^2\hbar^2}{2m}\left(\frac{n_1^2}{L_1^2} + \frac{n_2^2}{L_2^2} + \frac{n_3^2}{L_3^2}\right) \\
\text{Simple Harmonic Oscillator: } V &= 1/2kx^2;\ \ \omega^2 = k/m;\ \ E_n = (n+1/2)\hbar\omega \\
\text{Radioactive Decay: } N &= N_0 e^{-\lambda t} \\
\text{Activity: } R &= R_0 e^{-\lambda t} \\
\text{Half-life: } T_{1/2} &= \ln(2)/\lambda,\ \ \ln(2) = 0.693 \\
\text{Activity: } R &= \lambda N \\
\text{For } x + X \to y + Y\text{: } Q &= (M_x + M_X - M_y - M_Y)c^2
\end{aligned}
$$

plus

review me

today

particle physics

PARTICLE PHYSICS

aka High Energy Physics

nuclear physics ~1950's
→ higher energies → probing smaller distances & creating new quanta.
→ more complexity → rare isotopes
complicated higher states
high densities of nuclear matter

Both fields depend on accelerators and storage rings.

But – the early, defining discoveries were in cosmic rays

We left off with the following cast:

~1933

electrons
photons
protons } each a discovery, then a probe
neutrons

neutrinos 1931
pions (actually 1935) } predicted
positron 1928

electromagnetic force: e, p, γ, e^+

strong force: p, n, π

weak force: p, n, e, ν

Then, it got strange... following Dirac in 1928.

Paul Dirac

- showed Schrodinger's & Heisenberg's QM were the same
- developed relativistic QM.
- invented quantum field theory.

Dirac Equation

remember QM operators $\quad p_x \longrightarrow -i\hbar \frac{\partial}{\partial x}$

$$E \longrightarrow i\hbar \frac{\partial}{\partial t}$$

So,

$$E = \frac{p^2}{2m} + V \longrightarrow i\hbar \frac{\partial}{\partial t}\psi = -\frac{\hbar^2}{2m}\frac{\partial^2 \psi}{\partial x^2} + V\psi$$

But relativity: $\quad E^2 = p^2c^2 + m^2c^4$

$$E = \sqrt{p^2c^2 + m^2c^4} \longrightarrow \text{huh?}$$

negative E

negative $\psi^*\psi$

S.E. is 2-valued & 2nd order in space terms.

following Pauli, we write $\psi = \begin{pmatrix} \psi_\uparrow \\ \psi_\downarrow \end{pmatrix}$ a matrix in "spin space"

a general solution might involve a V with operators only in spin space ... like a magnetic field

$$S\psi \xrightarrow{\text{might}} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}\psi = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} \psi_\uparrow \\ \psi_\downarrow \end{pmatrix} = \begin{pmatrix} \psi_\uparrow \\ 0 \end{pmatrix}$$

all built into S.E. ... a cludge ... very ad hoc.

1928

Dirac found he could get around the negative probability problem

with a 1^{st}-order differential equation $\frac{\partial}{\partial t}$ & $\frac{\partial}{\partial x}$ $\frac{\partial}{\partial y}$ $\frac{\partial}{\partial z}$ only

at a price:

$$\psi = \begin{pmatrix} \psi^+_\uparrow \\ \psi^+_\downarrow \\ \psi^-_\uparrow \\ \psi^-_\downarrow \end{pmatrix}$$

} + energy electrons ↑ & ↓

} − energy X ↑ & ↓

a 4-component "spinor"

a bigger Dirac-space which contains spin-space inside

what was X ?

He guessed "proton" Oppenheimer showed $m_X = m_e$, not proton

an anti-electron

Dirac's idea of how e's interacts w/ γ's changed

changed our ideas about the vacuum & particle interactions

Ⓐ more →

A

here’s a number:

0

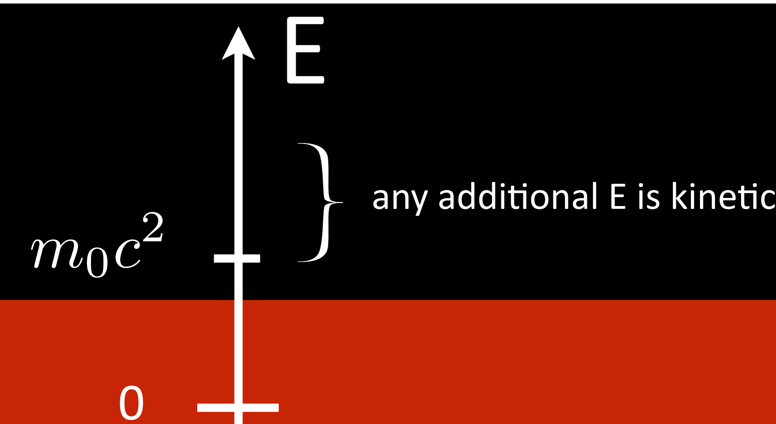
0

zero

the # of successfully combined models of

Quantum Mechanics and Relativity

prior to 1928



negative energies for unbound systems

a disaster

negative energies for unbound systems

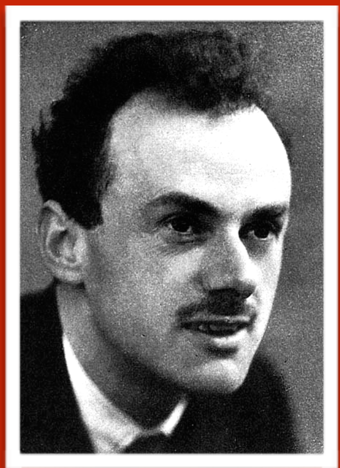
a disaster

negative energies for unbound systems

a disaster

there’s no bottom!

1928



Paul Dirac

1902 – 1984

“

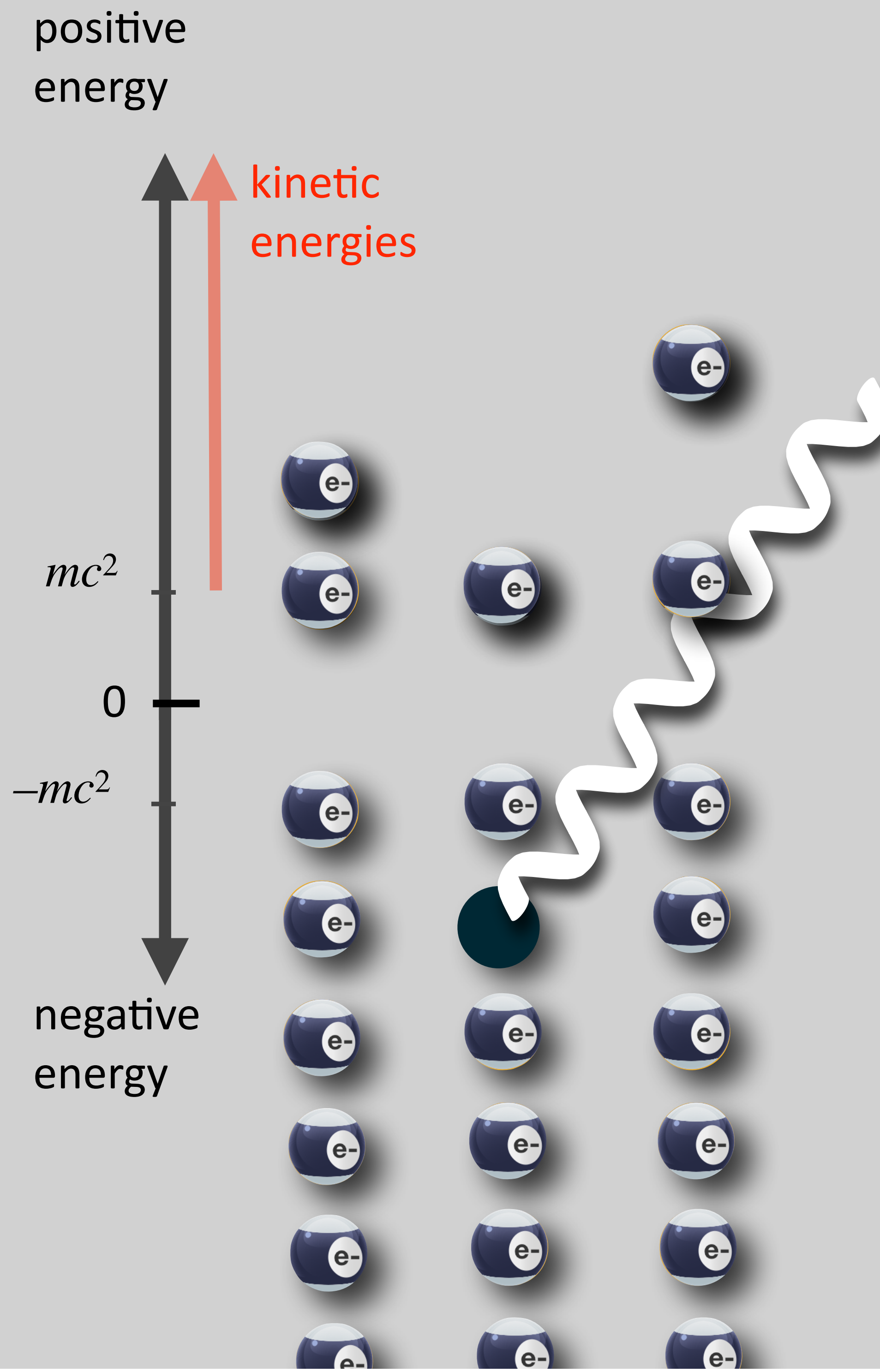
At the question period after a Dirac lecture at the University of Toronto, somebody in the audience remarked: "Professor Dirac, I do not understand how you derived the formula on the top left side of the blackboard."
"This is not a question," snapped Dirac, "it is a statement."

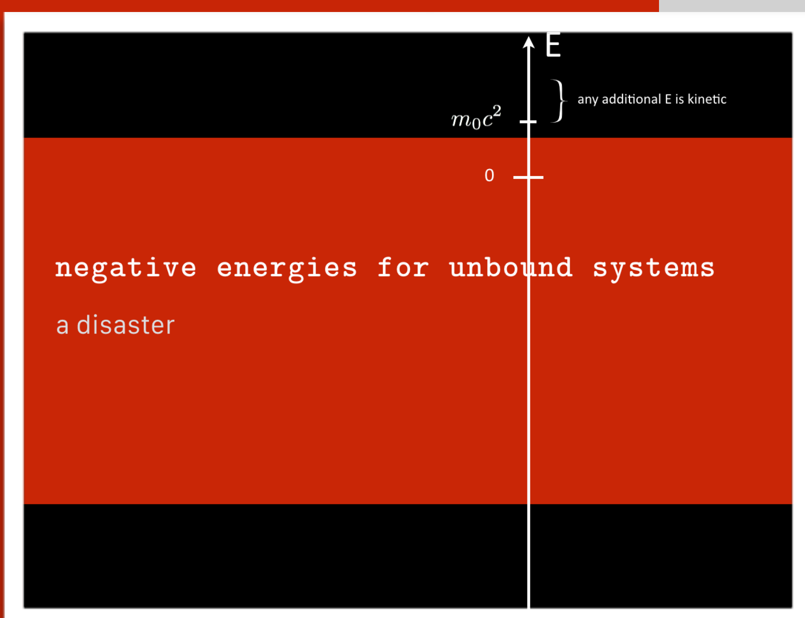
hilarious interview with the Wisconsin State Journal from 1929 on the blog.

still negative energies?

"solved" it with Pauli's Exclusion Principle

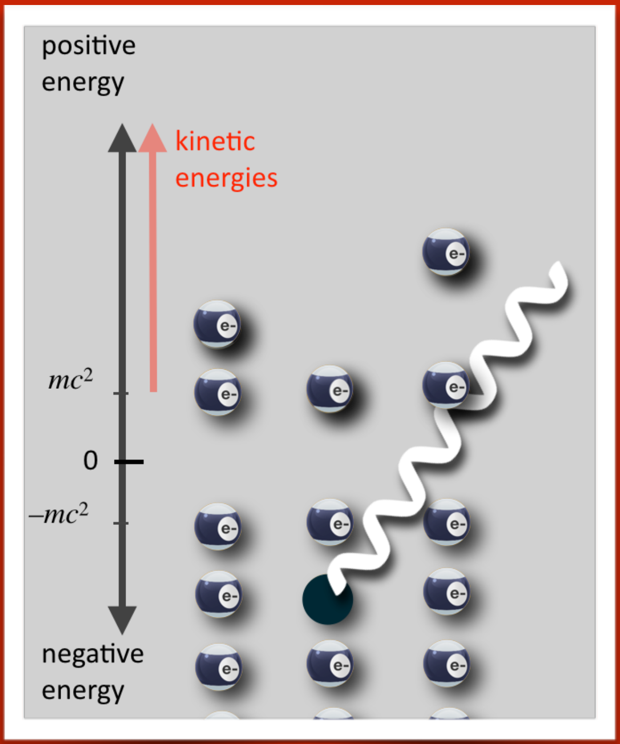
His vacuum is full of negative energy electrons





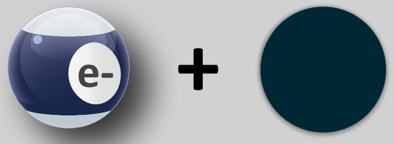
start with nothing

$$E_\gamma > 2\, m_e\, c^2$$



NOTHING

+ Energy



Let's talk about Nothing.

Dirac began this discussion

which continues today

in particle physics

and in cosmology

what is this?

$\psi(-E)$ **a positively charged object with negative energy?**

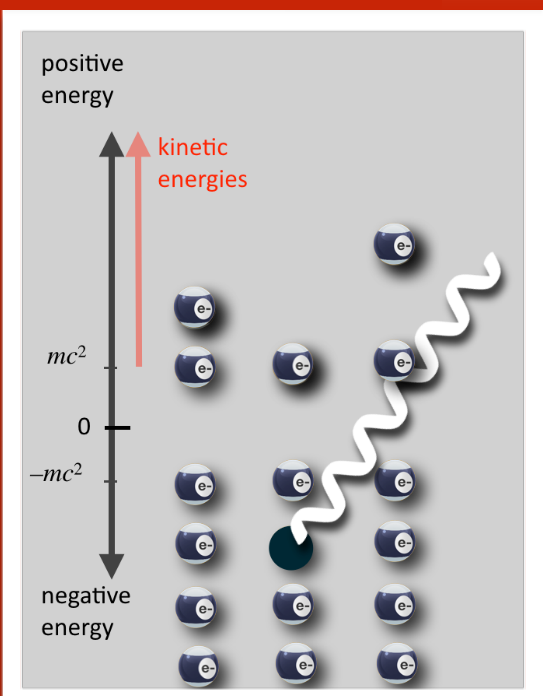
At first, he thought: “proton”

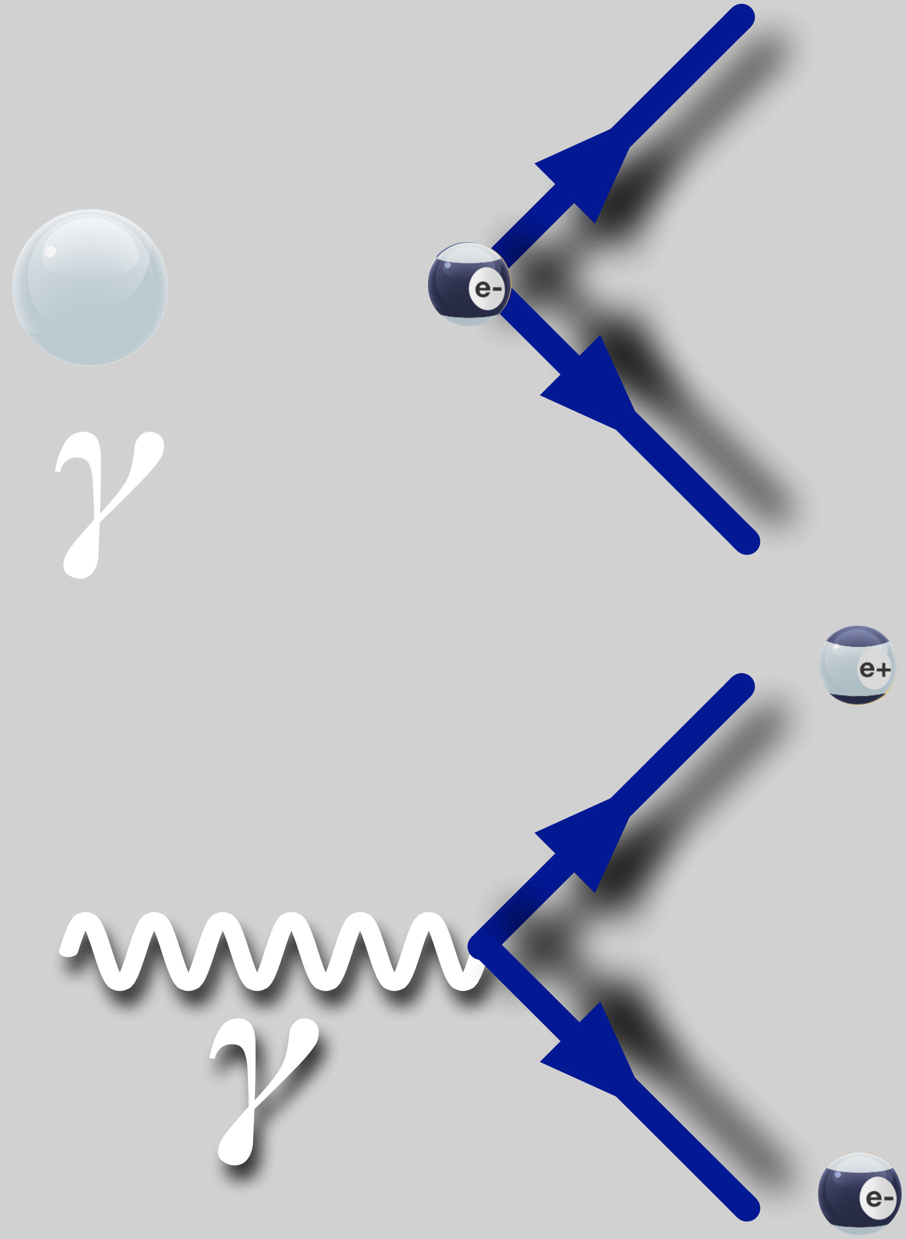
nah. A bolder idea: an anti-electron. The Positron.


Yes...antimatter.
ANGELS&DEMONS
WWW.ENTERTAINMENTWALLPAPER.COM

modern intepretat

a photon poof-disappears





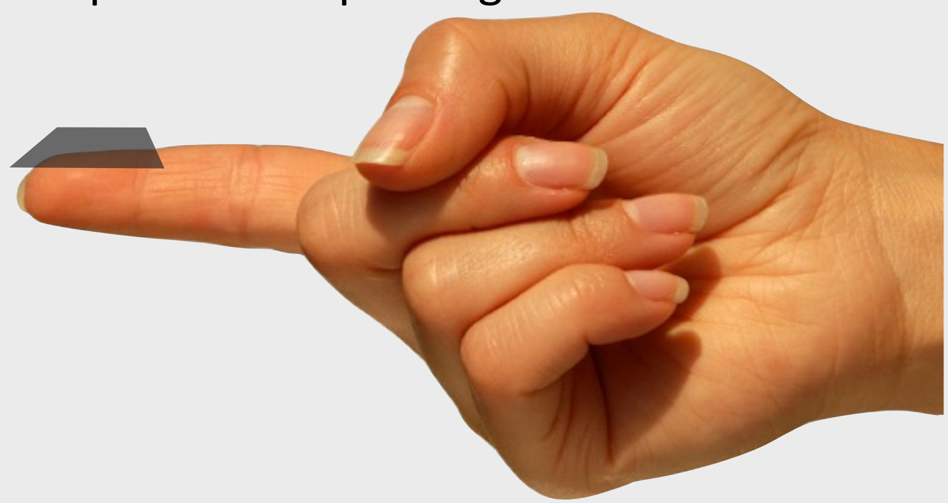
The antimatter story has a happy ending:

1932

Cosmic Rays

very high energy protons from space

~2 per minute per fingernail

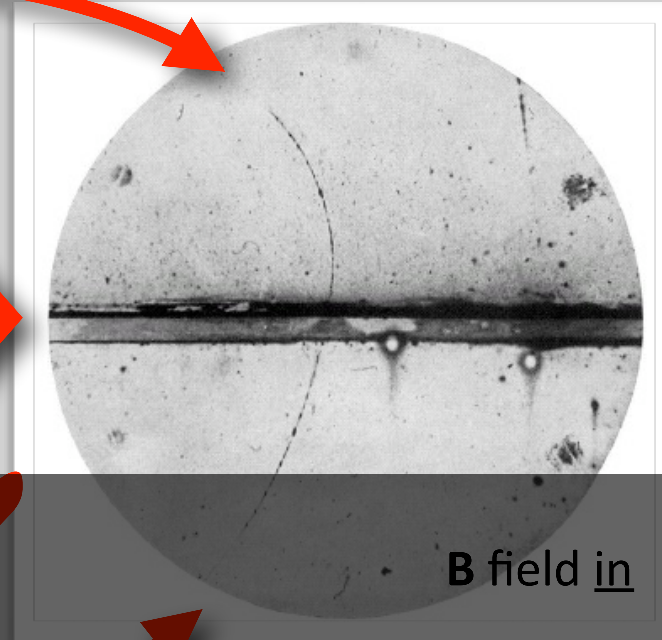


Carl Anderson

look at this track...

sharper curvature at top

clever...put in a lead plate to cause particles to lose energy



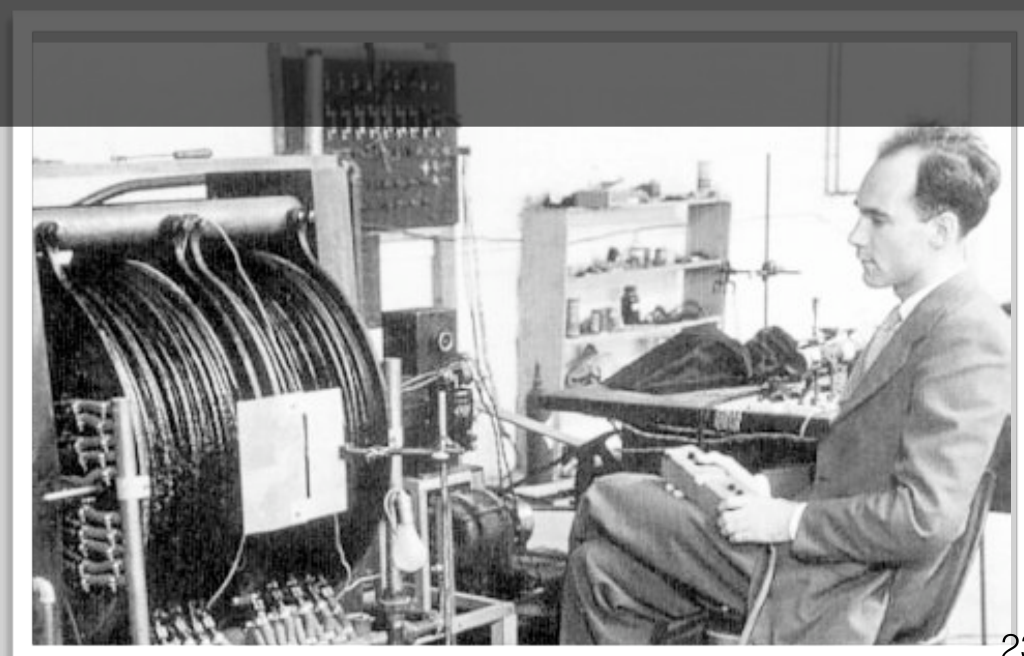
DOWN and negative?

UP and positive? ✔

Right on schedule: 1932

Yes...antimatter.

B field in



the bar over the top will mean "antiparticle"

anti-electron, aka "positron"

symbol:	$\overline{e}$ or e^+
charge:	$+1e$
mass:	$m_e = 9.0 \times 10^{-31}$ kg ~ 0.0005 p
spin:	*1/2*
category:	anti-fermion, anti-lepton

antimatter

is a fact of life

every particle has it’s anti-particle partner

same mass, different electrical charge

Dirac
Nobel

at the age of 31

Carl Anderson and Victor Hess

Anderson was 31

this is where it gets interesting

we need to establish a language for Dirac-like reactions

“Relativistic Quantum Field Theory”
essentially invented by Paul Dirac

notice a couple of things about what appears in Dirac's equation

1. it's about more than one thing: two electrons and a photon

   "regular" Quantum Mechanics is about single objects only

2. stuff appears and stuff disappears

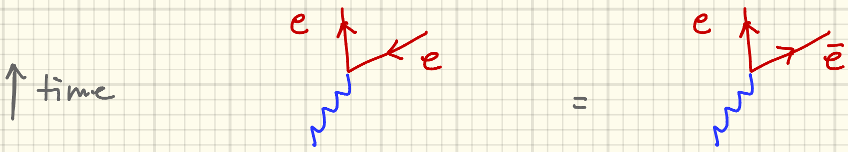
B

(B)

$$\psi^+ \sim e^{-iEt} \qquad \text{moving forward in time}$$

$$\psi^- \propto e^{-i(-E)t} \xrightarrow{\text{sorta}} \propto e^{-i(E)(-t)}$$

Feynman's Interpretation



but how?

(C) ⟶

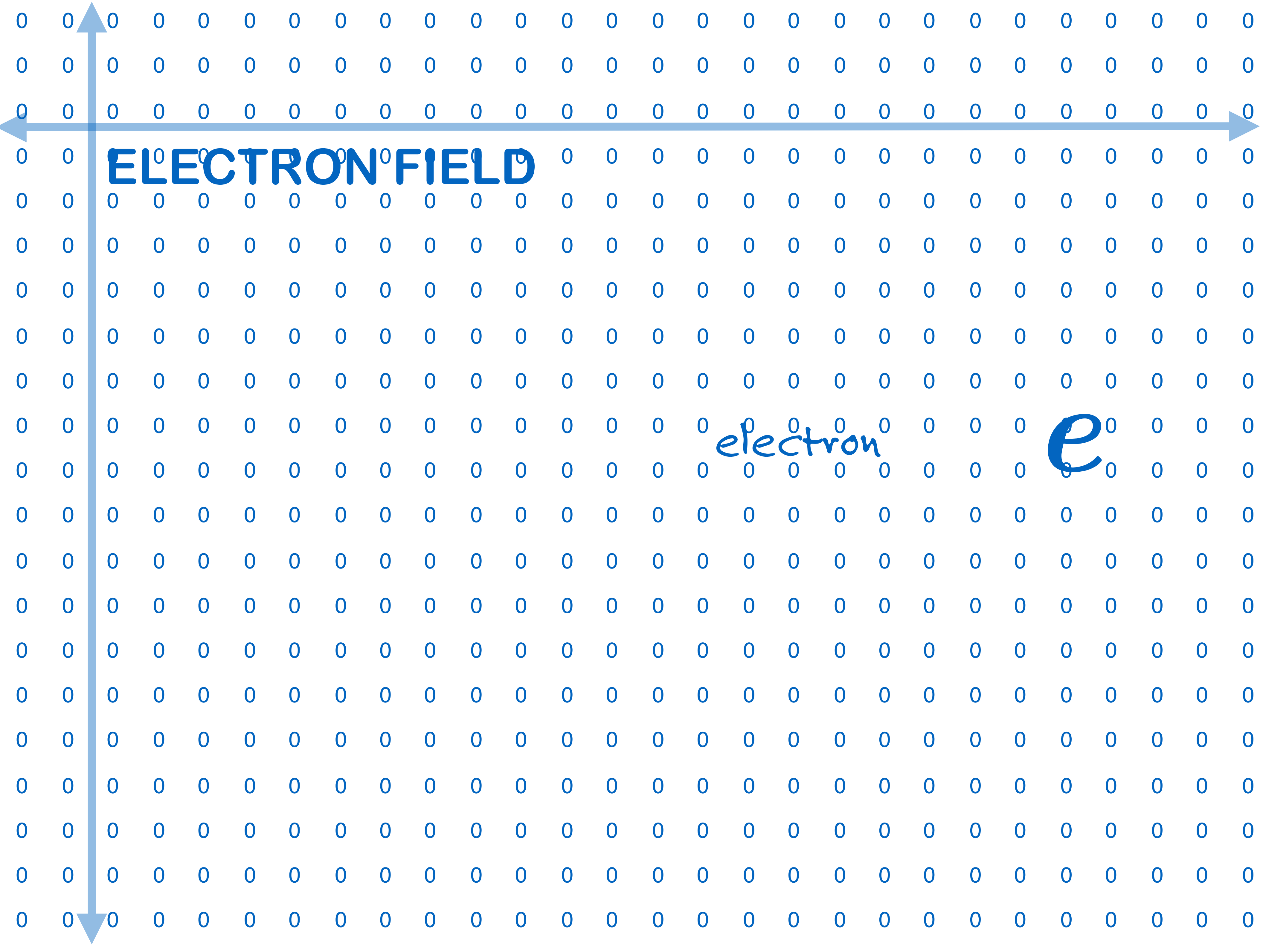
relativistic quantum field theory

no charge

here's how

stuff happens

in this particle field theory model


ELECTRON FIELD
electron
e

2	1	0	-1	-1	-2	2	-1	0	-1	1	2	1	-1	1	0	1	-1	-1	-2	-2	-1	0	-1	1	-2	-1	1
2	-1	1	-2	-2	-1	1	2	2	-1	-1	-1	0	2	-1	1	2	1	-2	0	0	-2	0	1	2	2	2	0
0	-1	2	2	-1	1	-1	-1	-1	-2	0	-1	-2	-2	-1	2	-2	1	1	0	2	-1	1	1	2	0	-1	-1
1	-2	2	1	1	1	0	1	-1	-1	2	0	0	-2	2	0	2	2	-1	1	-2	2	2	0	2	2	-1	0
0	-2	1	-2	-2	0	1	0	0	0	-1	-1	0	2	-2	0	-2	-1	-2	0	2	2	0	0	1	-1	2	-2
0	1	1	-2	-2	-2	0	-2	0	1	-2	0	1	2	-1	2	-2	2	0	2	1	2	-2	1	-1	-1	1	0
-2	-2	-2	1	1	1	-1	-1	1	2	-1	1	1	-2	-1	-2	1	0	1	2	-1	0	-2	2	2	1	0	2
0	-2	-2	2	-1	2	0	1	-1	0	0	-2	-2	0	0	0	-2	-2	-1	1	0	1	-2	-2	1	-2	-1	0
-1	1	-1	1	0	-2	2	-2	2	-2	0	1	0	2	-2	-2	2	-2	-1	-1	-1	0	2	0	-1	0	0	1
1	2	-1	-1	-2	-1	-1	-2	0	-2	1	1	2	1	-2	-1	-1	1	-2	-2	-2	0	-2	2	-2	-1	2	0
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0	0	-1	-2	2	2	-2	0	1	2	-2	-1	-1	0	-2	1	0	0	1	2	1	-2	-1	2	-2	2	-1	-1
0	1	0	0	2	-2	0	-1	-1	2	2	0	0	-1	1	-2	-2	0	0	0	1	-2	-2	-1	1	1	1	1
-1	2	0	2	-2	1	1	1	2	1	-1	2	1	2	-2	2	2	1	1	2	-1	0	-2	-2	2	0	-2	-2
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0	-1	-2	-2	0	2	2	0	-1	1	-2	-2	1	-1	0	2	-1	-2	1	2	-2	2	0	0	2	0	0	0
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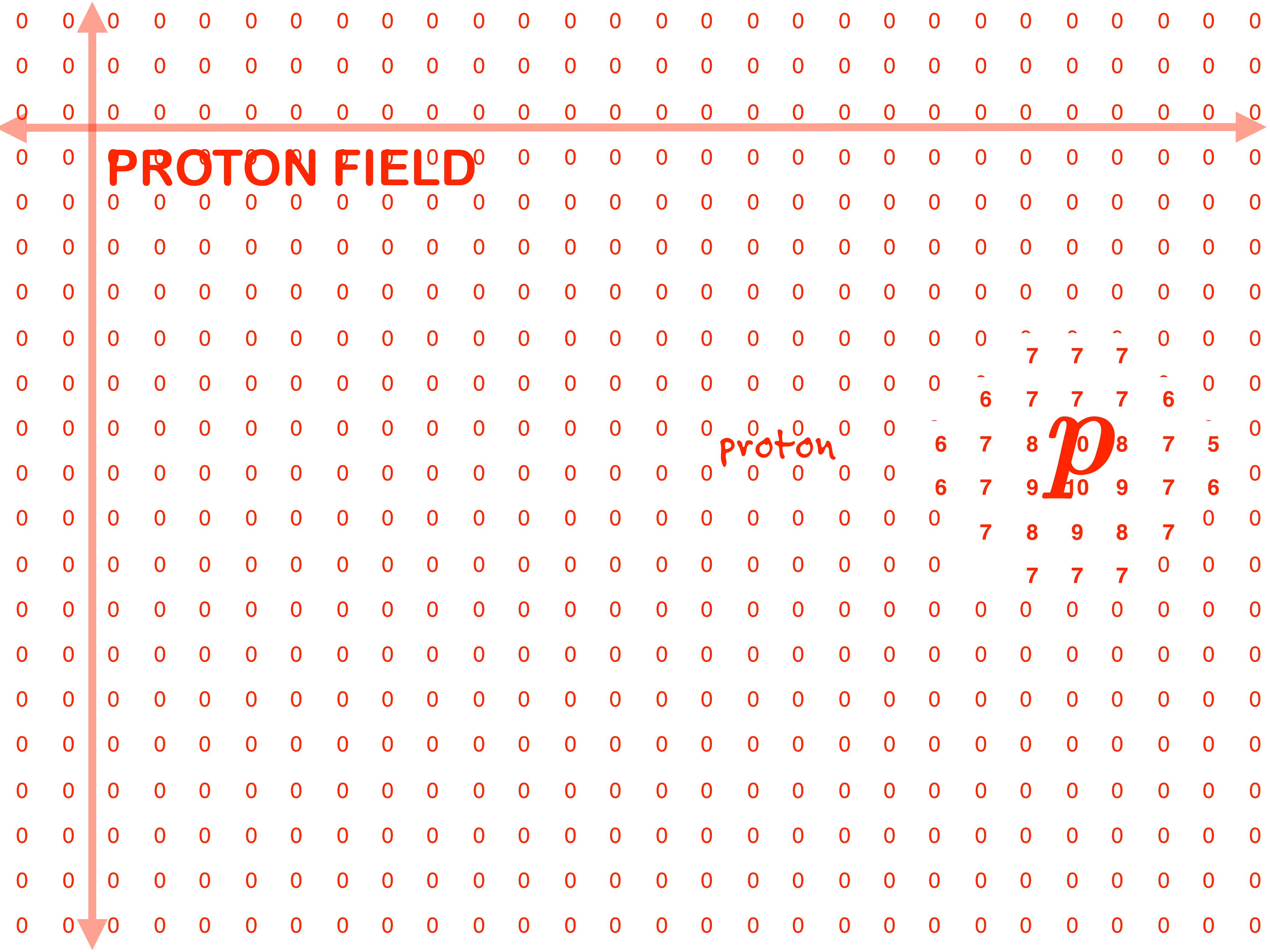
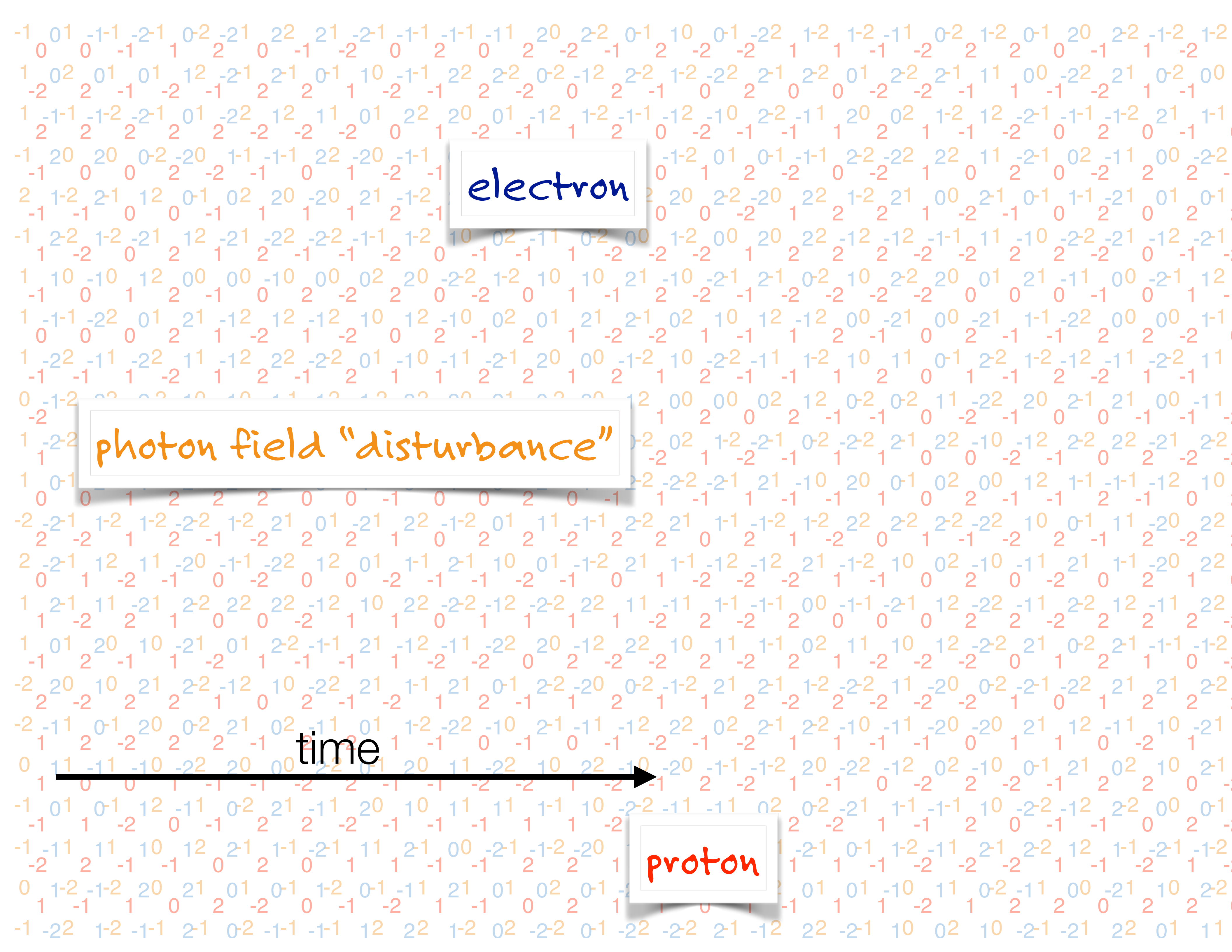
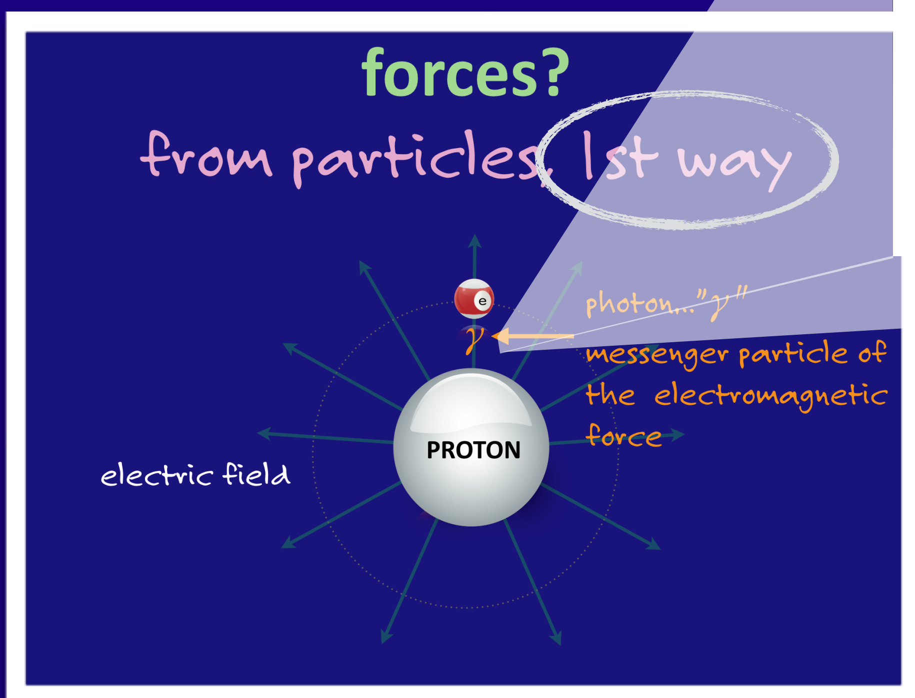
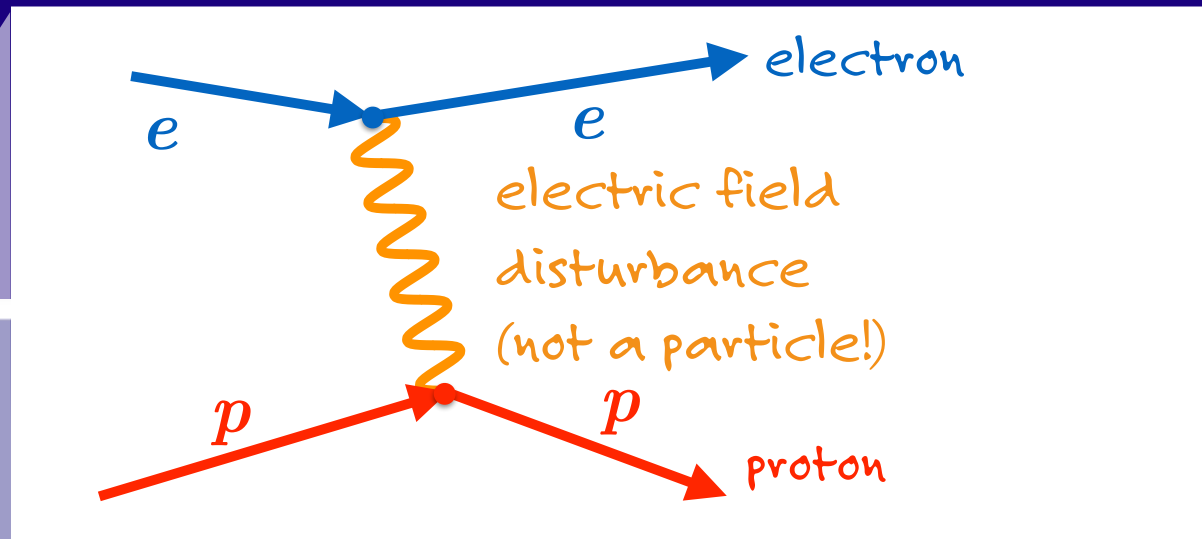
-1	1	-1	1	-1	2	1	1	1	-2	1	0	2	1	-2	-2	0	1	-1	-2	-2	2	1	1	-1	-2	-1	1


PROTON FIELD
proton
p


electron
photon field "disturbance"
time
proton

our atom


forces?
from particles, 1st way
photon..."γ"
γ
e
messenger particle of the electromagnetic force
PROTON
electric field


e
e
electron
electric field disturbance (not a particle!)
p
p
proton

particle field theory*

the best theory in history

never an incorrect prediction

outrageously precise agreement, prediction and measurement

*Quantum Electrodynamics

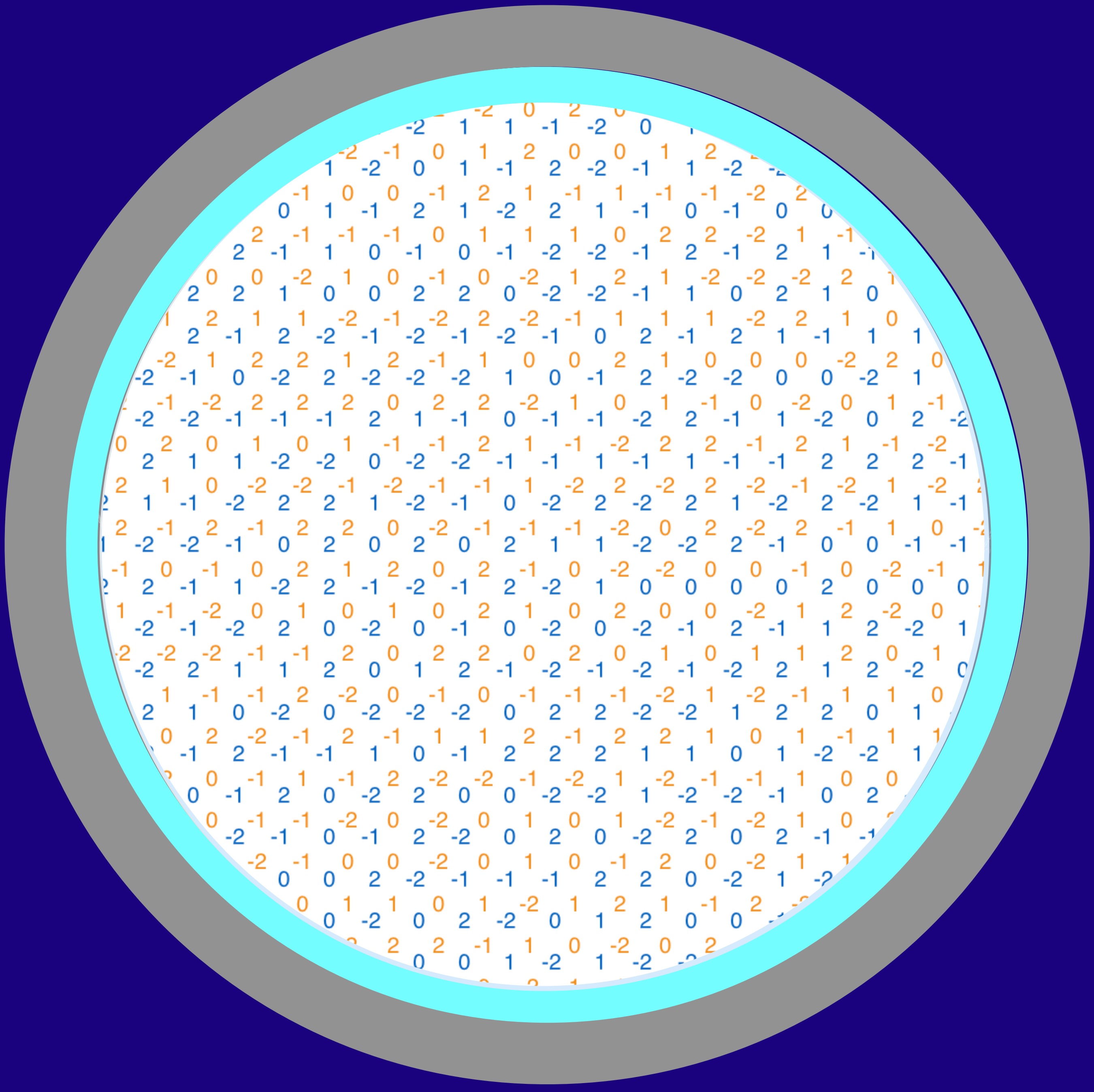
what's more fundamental?

a winner

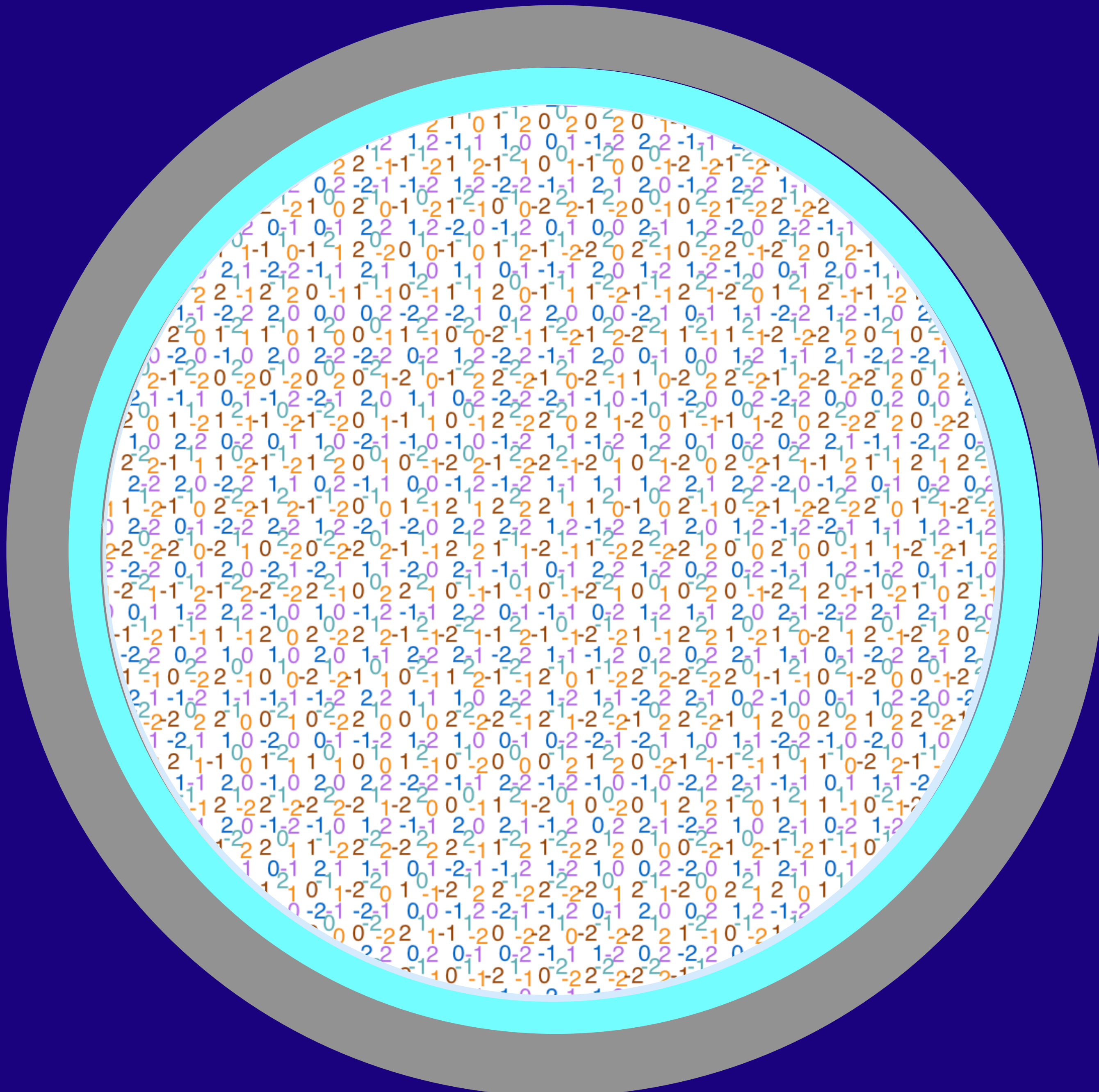
particles

fields

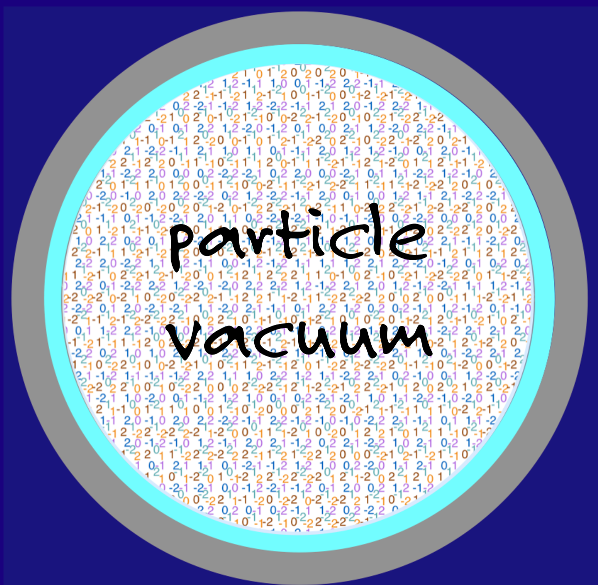
the particle vacuum full of fields:



the particle vacuum full of fields for every "particles"



two predictions for "space"



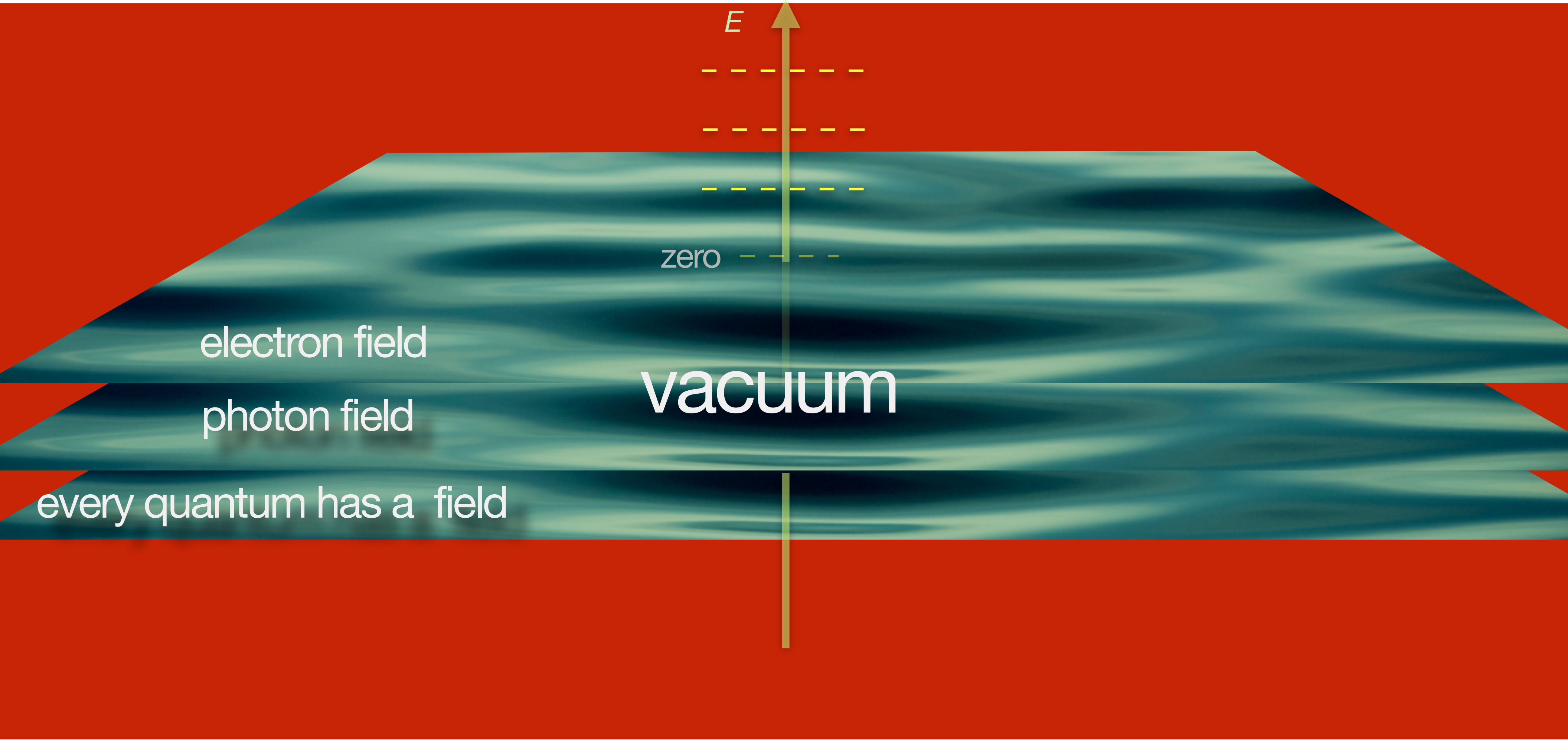
energy in the particle vacuum is

30,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,0
00,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000

times the energy in the dark energy vacuum

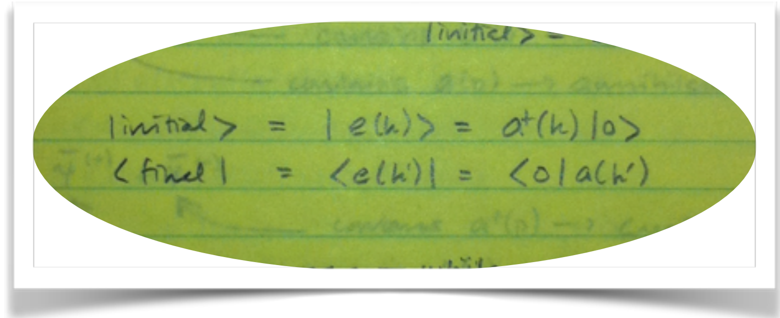
this has a name

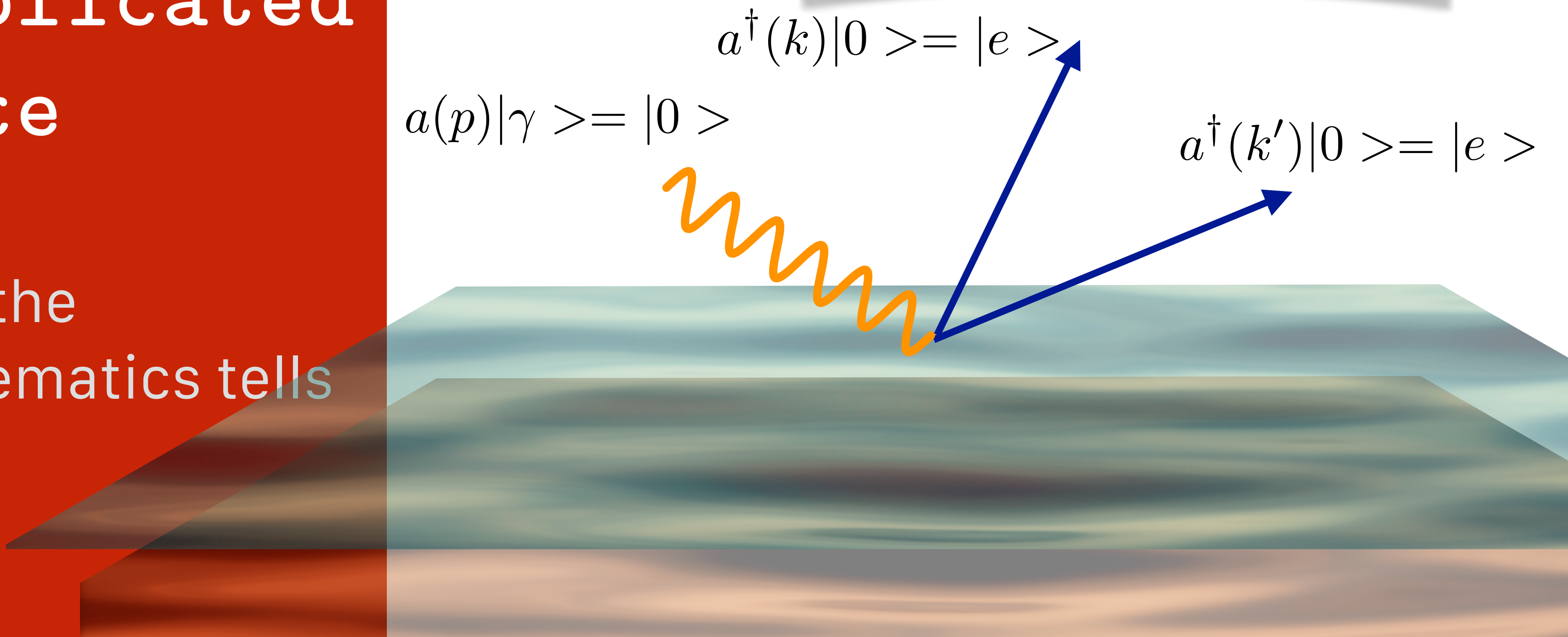
"the worst prediction in the history of physics"


E
zero
electron field
vacuum
photon field
every quantum has a field

the vacuum is a complicated place

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.

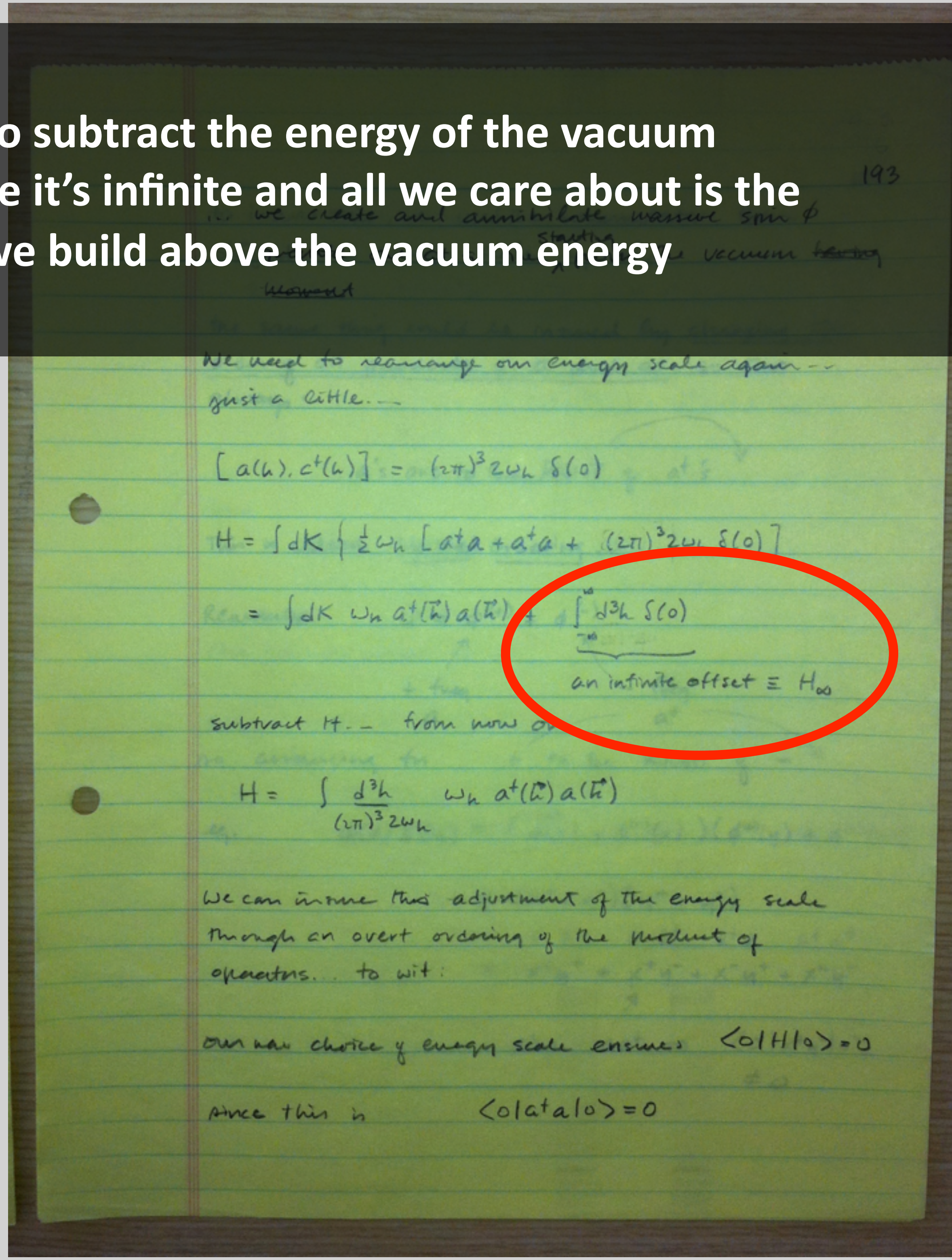
but what does that mean?

we have to subtract the energy of the vacuum away...because it's infinite and all we care about is the states we build above the vacuum energy

it means that the vacuum is full of energy

like a reservoir

particles are created out of the vacuum



Uncertainty...

$$\Delta x \, \Delta p \sim h$$

↑ interpret this as an energy.

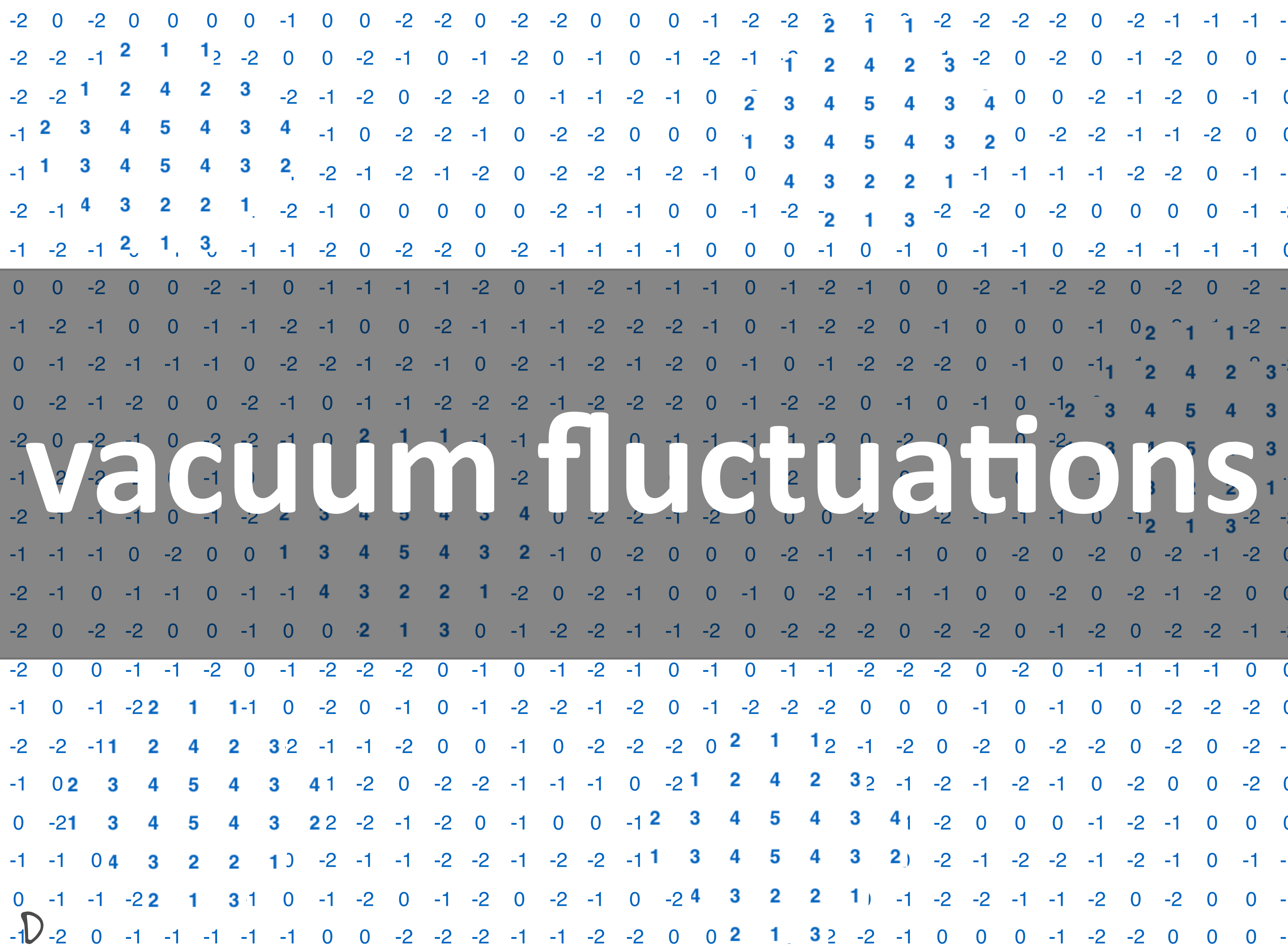
$$\Delta x \, \Delta p c \sim hc$$

↑ interpret this as rest energy $\quad \Delta pc \sim \text{"}m_e\text{"} c^2$

$$\Delta x \sim \frac{hc}{\text{"}m_e\text{"} c^2}$$

↖ the uncertainty in energy? interpret as a "mass"

but not actually THE m_e


vacuum fluctuations

Now, compton scattering -- remember?

$$\gamma + e \longrightarrow \gamma' + e'$$

the most important thing in particle physics?

getting the name right.

the “Yukon”? thankfully, no.

the “meson?” Why yes, I think I like it.

medium mass…

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

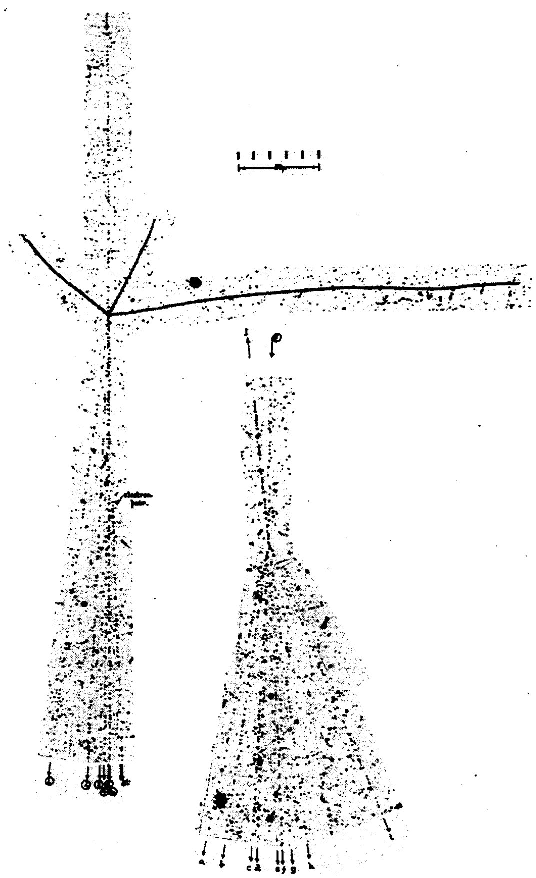
the hunt was on

to find the Yukawa Particle

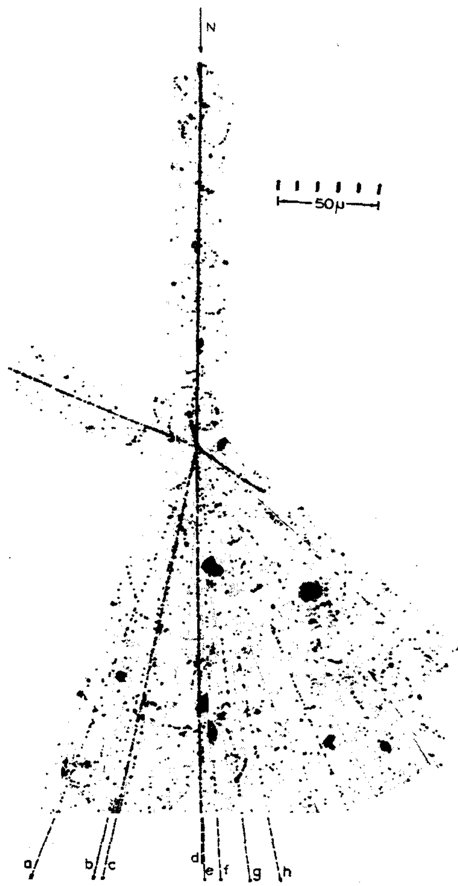
but WWII got in the way

Post-war emulsion exposures were startling

proton in cosmic rays



Nitrogen nucleus in cosmic rays



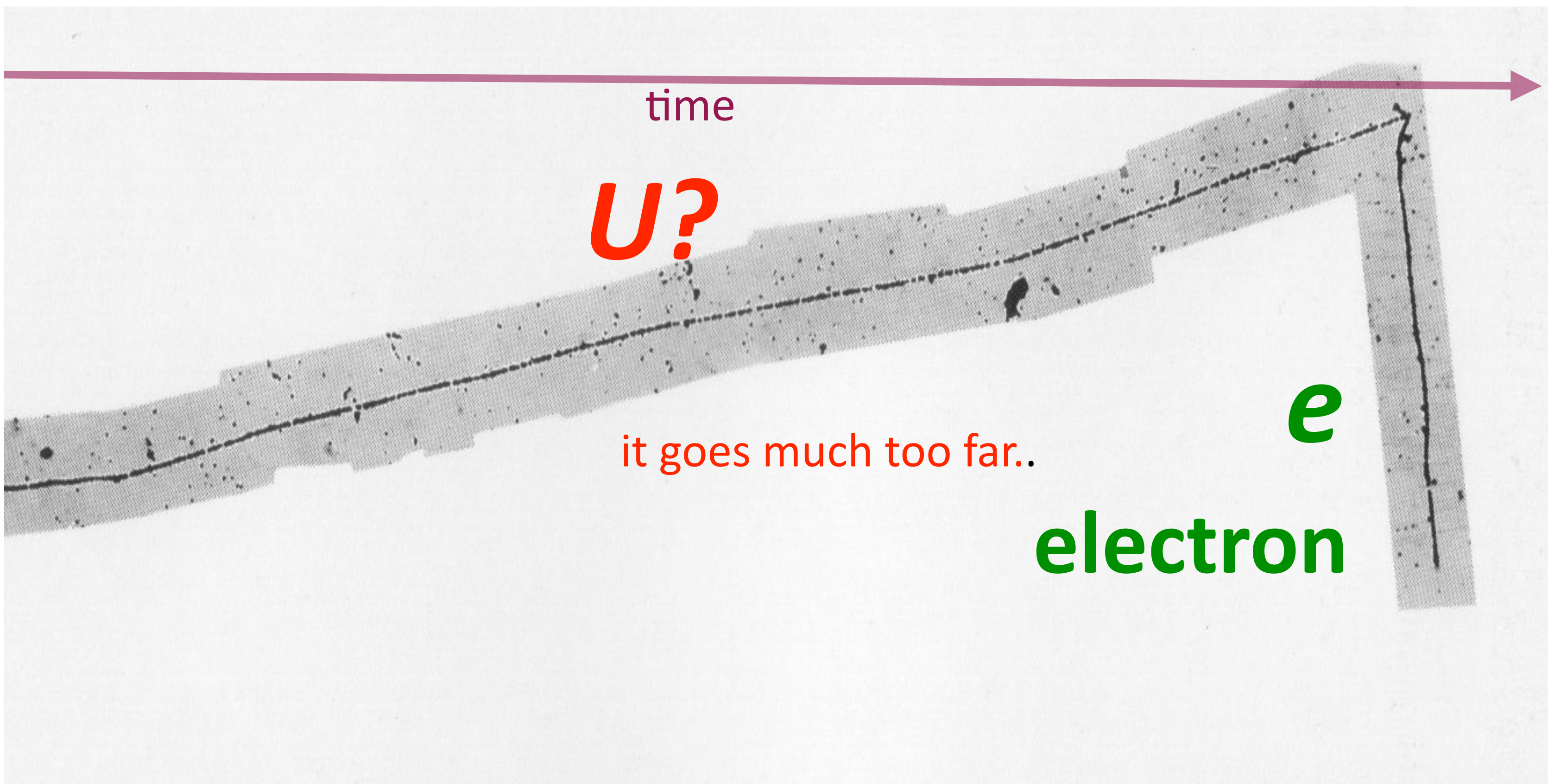
huh?

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

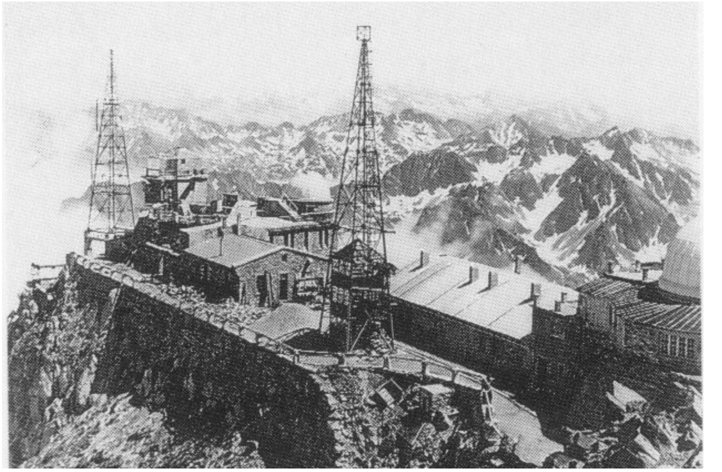
many of these sort:

something unknown...

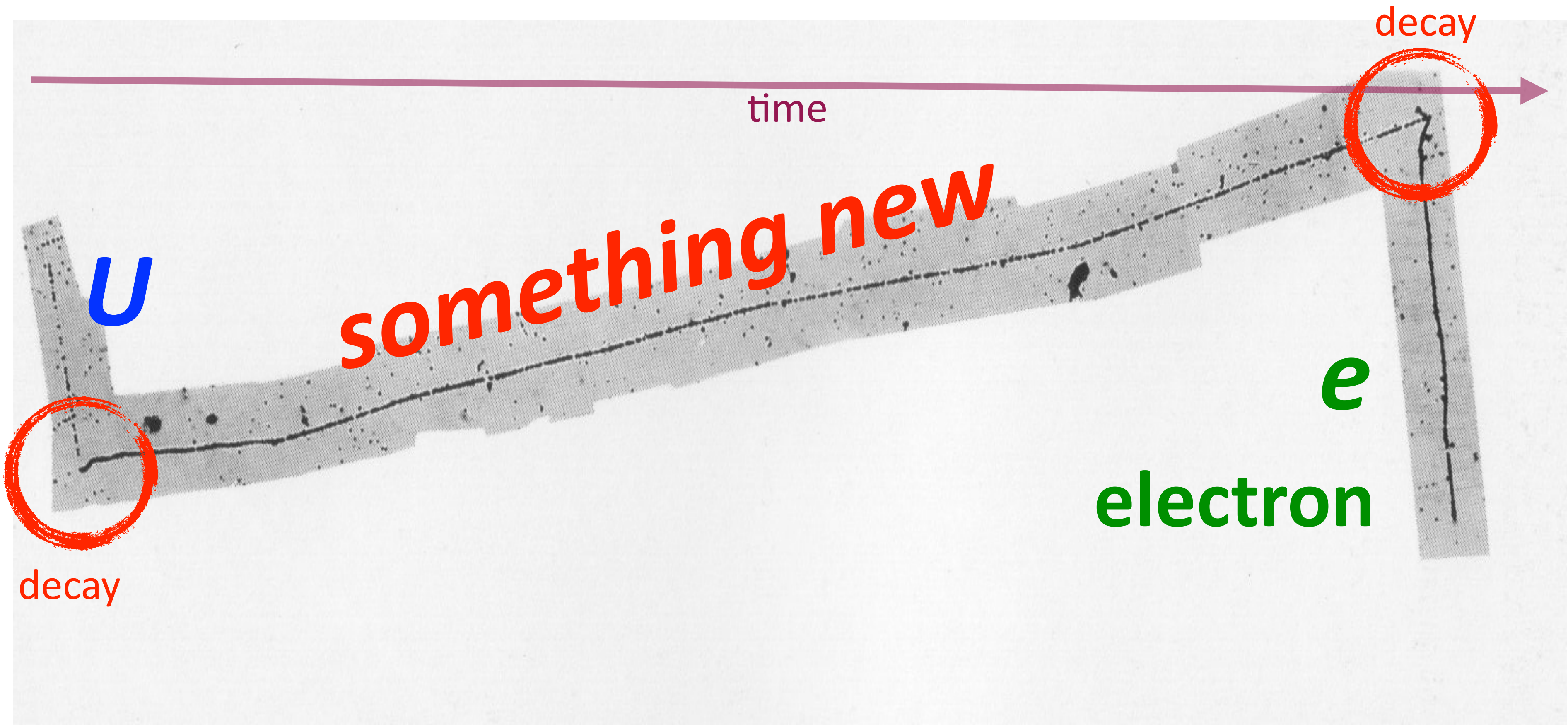
20,000 stereo photos --> 1600 usable tracks in 3 cm^2 plate



strange things in cosmic rays

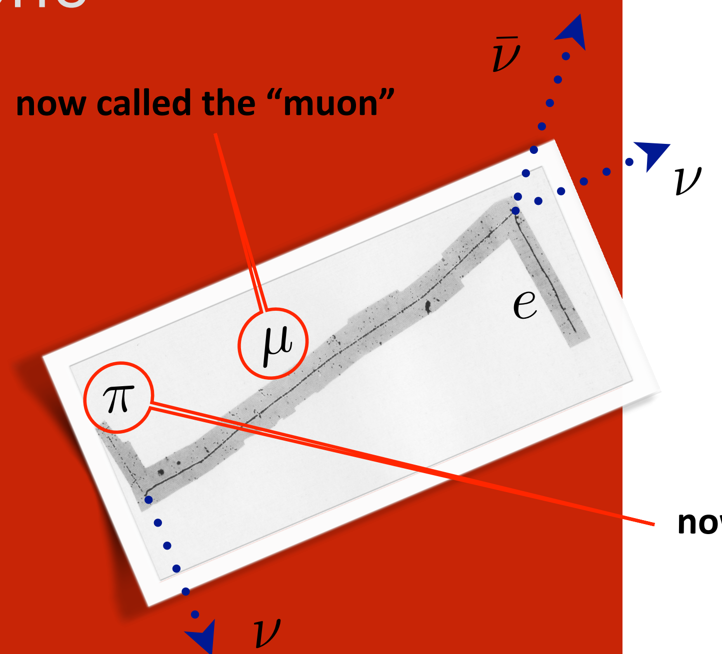


thick photographic substrates



two discoveries

for the price of one



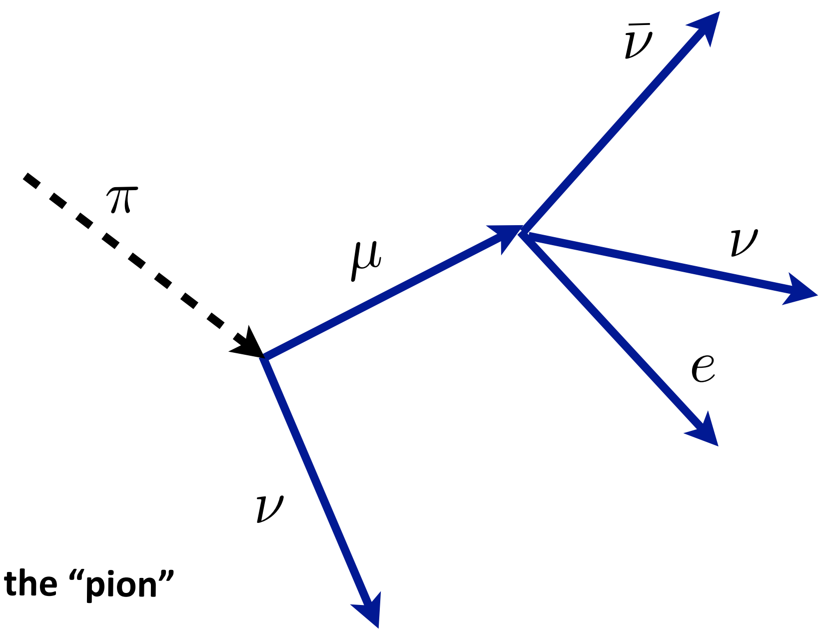
This took some unraveling.

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:

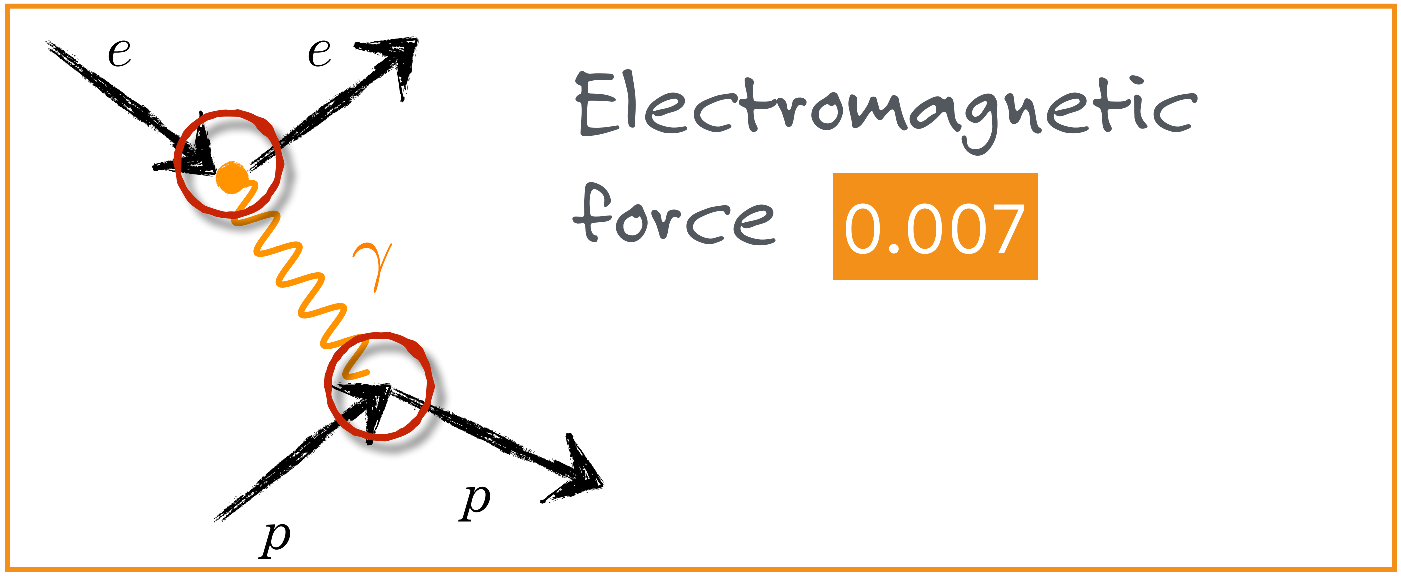


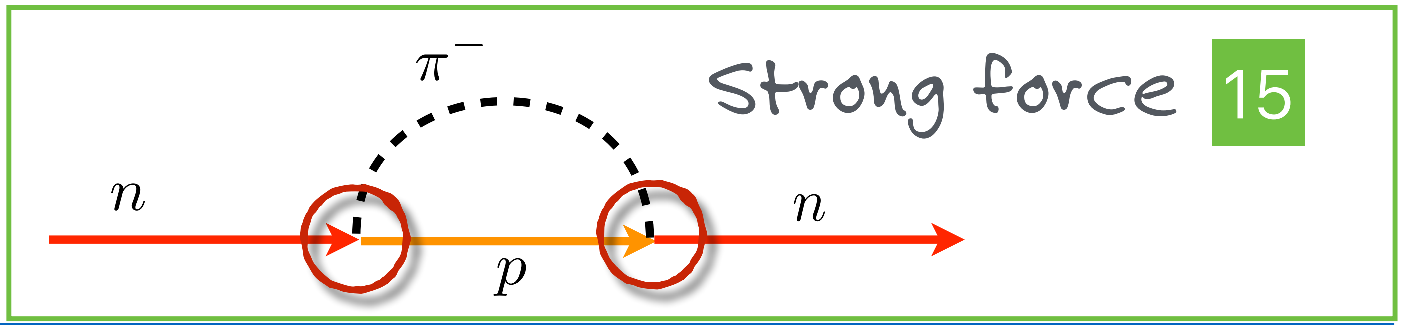
particle: **pion**

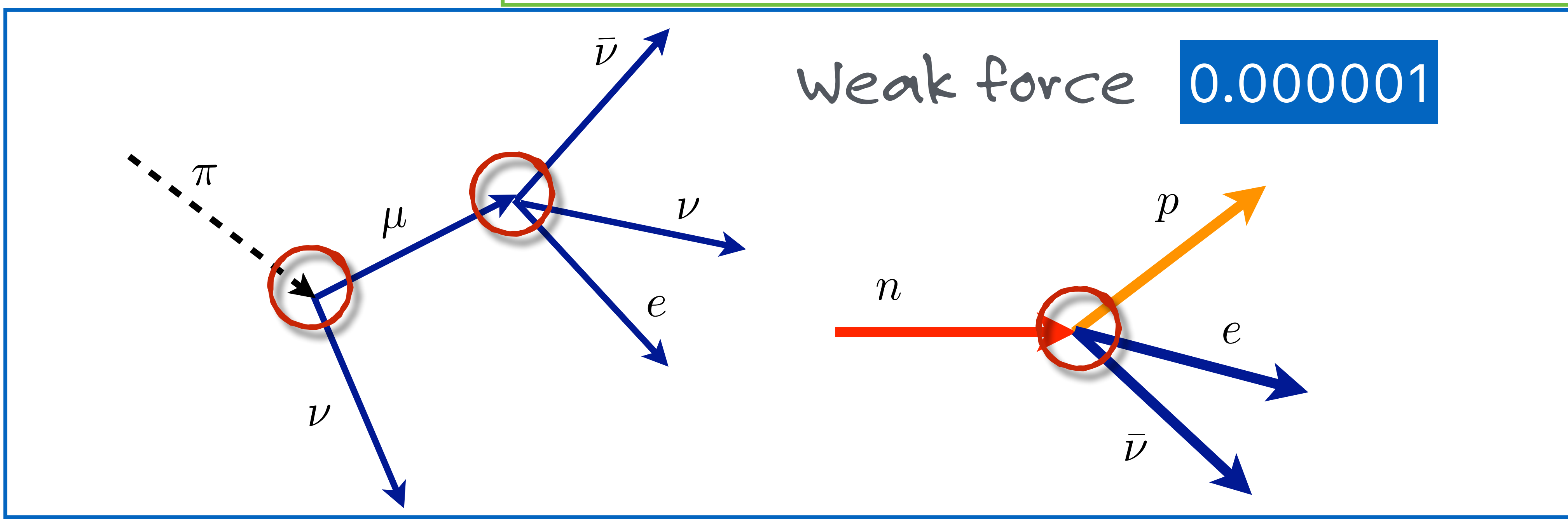
symbol:	π
charge:	+, –, 0
mass:	139 MeV/c^2,
spin:	0
category:	Boson, hadron, meson

three forces now

of vastly different strengths







particle: **muon**

symbol:	μ
charge:	+, –
mass:	105.7 MeV/c^2
spin:	1/2
category:	Fermion, lepton

particle: **muon**

symbol:

charge:

mass:

spin:

category: Fermion, lepton

The Mu… like
an Ele… vier.

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

particle:	**tau**
symbol:	τ
charge:	+, –
mass:	1776.82 ± 0.16 MeV/c^2
spin:	1/2
category:	Fermion, lepton

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/c^2
spin:	1/2
category:	Fermion, lepton

particle: **tau-neutrino**

symbol:	ν_τ
charge:	0
mass:	0 or 0.4-ish to 1-ish eV/c^2
spin:	1/2
category:	Fermion, lepton

the players

in our universe, circa June, 2012

	generation	1st	2nd	3rd	messenger particles
leptons	$q=0\,e$	ν_e neutrino	ν_μ neutrino	ν_τ neutrino	γ photon
	$q=-1\,e$	e electron	μ muon	τ tau	W *W* boson
quarks	$q=+2/3\,e$	u electron	c electron	t electron	Z *Z* boson
	$q=-1/3\,e$	d electron	s electron	b electron	g gluon

E

E

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \text{Gauss's law}$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \text{Ampere's law}$$

$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{j} + \frac{\partial \vec{E}}{\partial t} \qquad \text{Faraday's law,}$$

$$\vec{B} = \vec{\nabla} \times \vec{A} \quad \text{and} \quad \vec{E} = -\vec{\nabla}\phi - \frac{\partial \vec{A}}{\partial t}.$$

"Vector potential"

→ age-old way to add electromagnetism to classical Newtonian mechanics and N.R.Q.M. & R.Q.M.

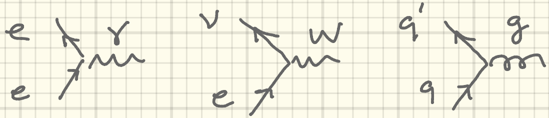
"minimum coupling rule"

p^2 like in $\frac{p^2}{2m} \longrightarrow (p - ie\vec{A})^2$

a rule

so in 1 d $\quad (p_x - ieA_x)^2$

Gauge Principle



all spin 1 fields... all "are messengers" of a fundamental force of nature

all have a reason...

Symmetries are king of the universe and the queen was Emmy Noether

Symmetry in the FORM of a mathematical model

⇓

Physical conservation laws.

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x) + V\psi(x) = E\,\psi(x)$$

How about: $\psi(x) \longrightarrow \psi'(x) = e^{i\alpha(x)}\psi(x)$

"LOCAL"

derivatives complicate this.

$$\frac{\partial\psi'}{\partial x} = i\frac{\partial\alpha}{\partial x}e^{i\alpha}\psi + e^{i\alpha}\frac{\partial\psi}{\partial x}$$

$$\frac{\partial^2\psi'}{\partial x} = i\frac{\partial^2\alpha}{\partial x^2}e^{i\alpha}\psi + 2i\frac{\partial\alpha}{\partial x}\frac{\partial\psi}{\partial x}e^{i\alpha} - \left(\frac{\partial\alpha}{\partial x}\right)^2\psi e^{i\alpha} + e^{i\alpha}\frac{\partial^2\psi}{\partial x^2}$$

substitute

$$E\,\psi(x) = -\frac{\hbar^2}{2m}\left[\frac{\partial}{\partial x} + i\frac{\partial\alpha(x)}{\partial x}\right]^2\psi(x) + V(x)\,\psi(x,t)$$

nope -- no longer the Schroedinger equation.

BUT. DEMAND THIS SYMMETRY & ACCEPT CONSEQUENCES

$$\left[\frac{\partial}{\partial x} + i\frac{\partial\alpha(x)}{\partial x}\right]^2 \quad ?$$

that's minimum coupling to E&M

$$\downarrow$$

$$\left[\frac{\partial}{\partial x} - ieA_x(x)\right]^2$$

If the universe prioritizes this local symmetry?

then it had to invent the photon & its coupling to e's

SYMMETRIES seem to be prior. ⟶ all vector fields come from this premise