

hi

Lecture 26, 04.13.2017

Particle Physics 1

housekeeping



Question about anything?

I'll make a movie for you:

Poster selection:

April 13, outline due April 20...read the instructions.

Homework:

For month of April, I've shifted due dates to Saturdays.

Readings:

*There is a manuscript chapter on antimatter and Dirac...Antimatter,
Paul Dirac's Second Big Score*

Honors Project

Data due April 22. Paper due on May 4 (final day).

the dropbox instructions? Forget them. We'll be uploading files to a site in Norway. I'll let you know.

Read the Second of two sets of instructions:

`MinervaInstructions2_2017.pdf` in

www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/



SORRY!®

The game of sweet revenge

PARKER BROTHERS

Plan a Family Game Night

Family AGE 6+ EDAD

I'm sorry.



the data


should have been in zipped format

rather, somehow they were unzipped in some process

fixed: now

[http://www.pa.msu.edu/~brock/
file_sharing/QSandBB/
2017homework/
honors_project_2017/
data_zipped/](http://www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/honors_project_2017/data_zipped/)

Index of /~brock/file_sharing/QSandBB/2017homework/honors_project_2017/data_zipped

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 Parent Directory	-	-	-
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 groupT.zip	12-Apr-2017 17:04	29M	

Apache/2.2.3 (Red Hat) Server at www.pa.msu.edu Port 80

it dawned on me

at the Science Festival, I tried to interpret some of this for
the public...

a reprise of a few slides...

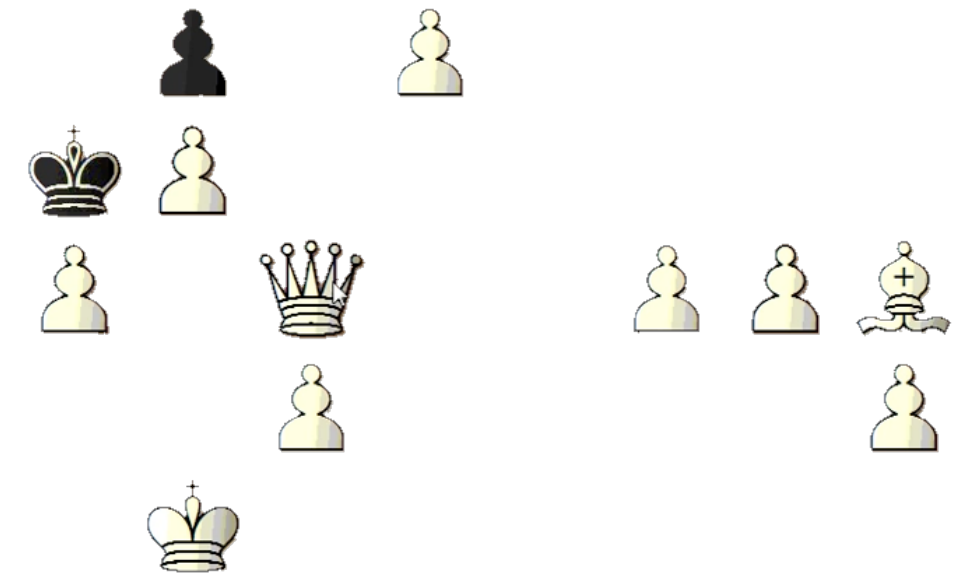
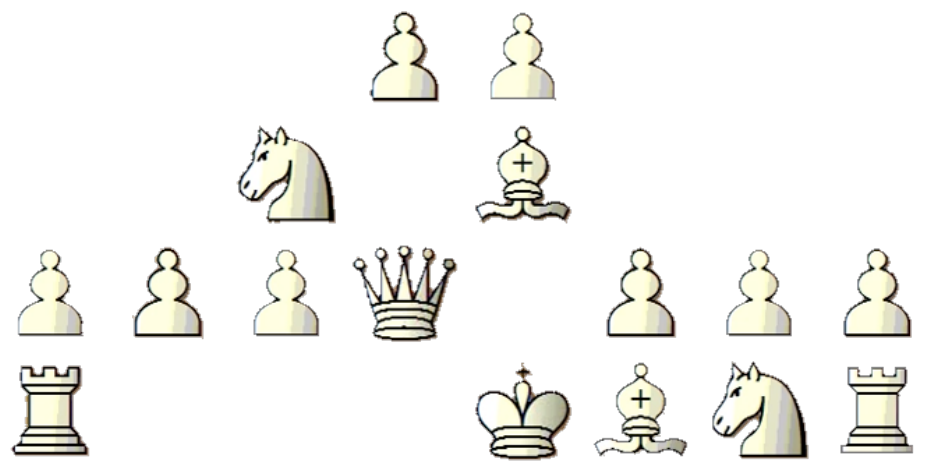
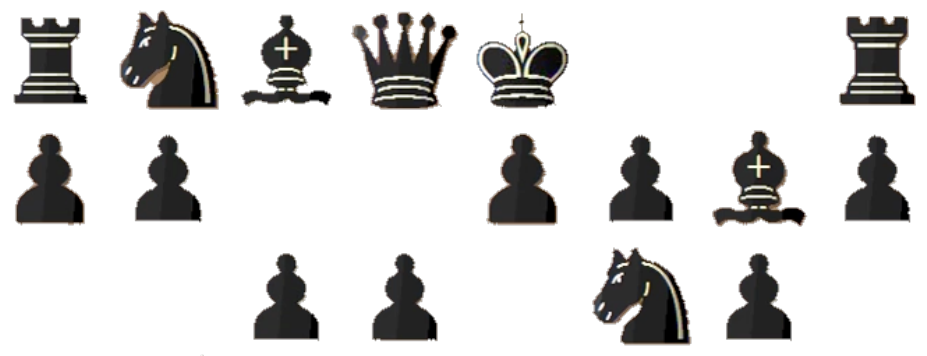
no charge

a word about theories

let's play chess...

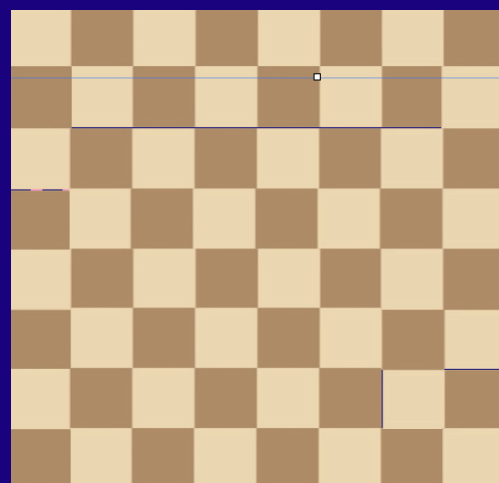
my model of chess

watch tons of matches



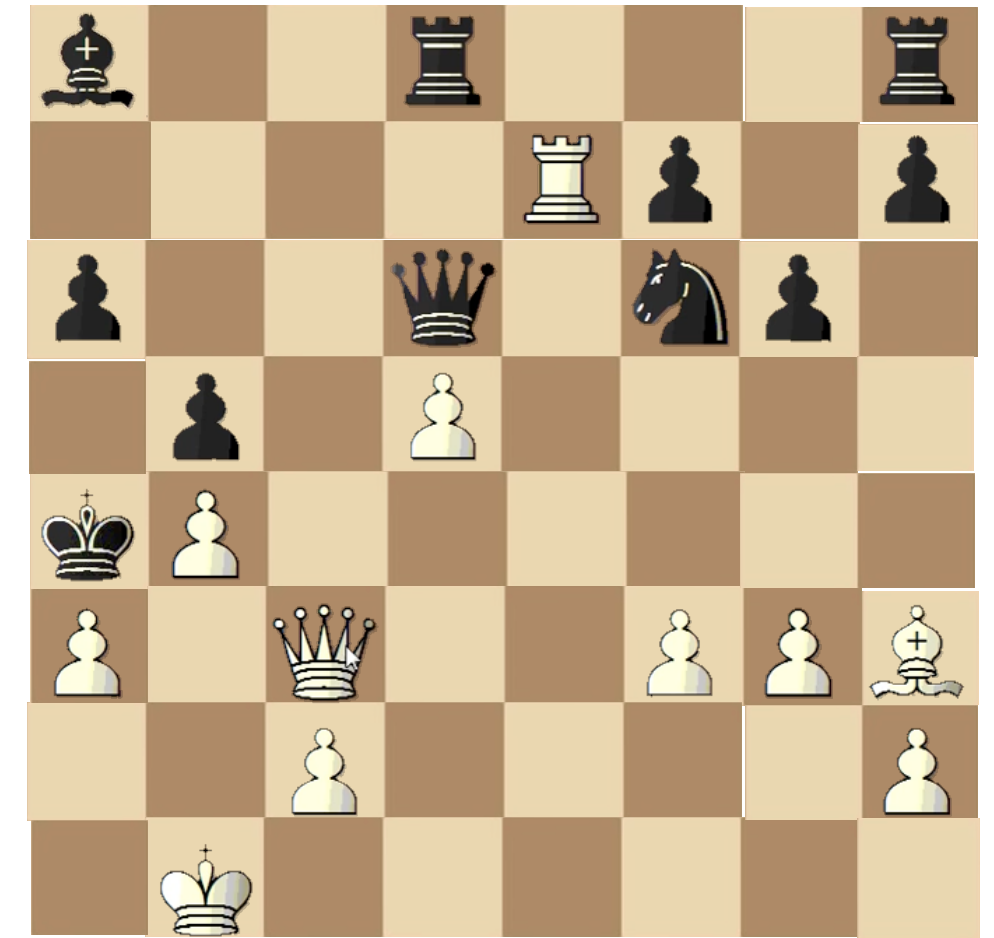
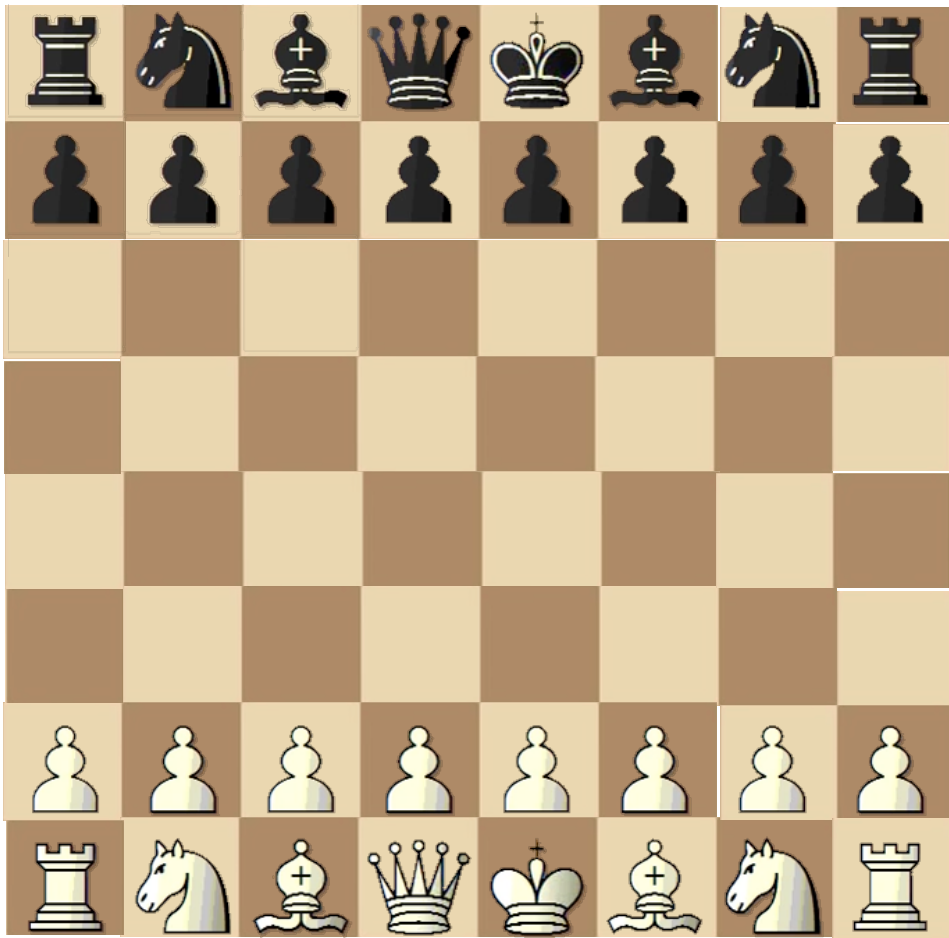
my model requires

the existence of a new entity



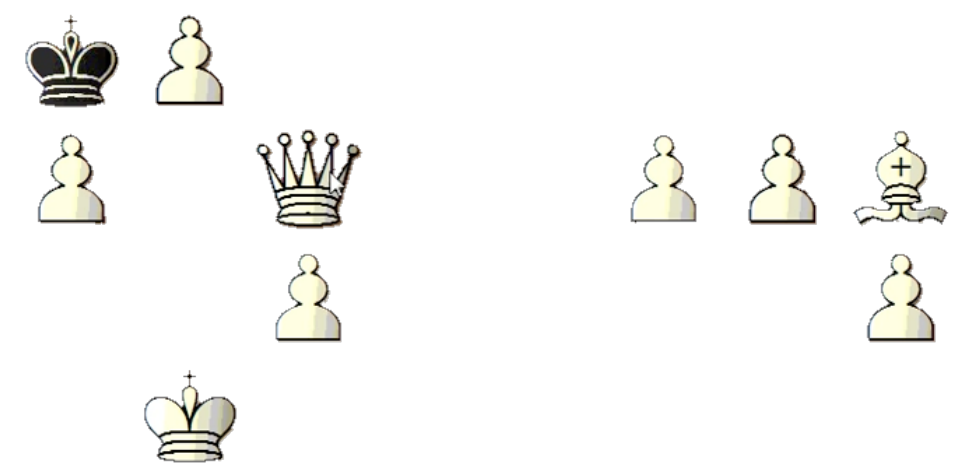
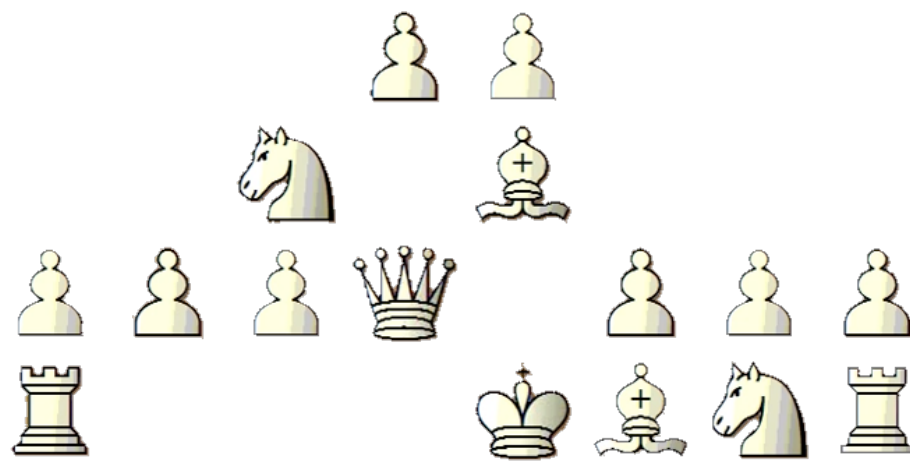
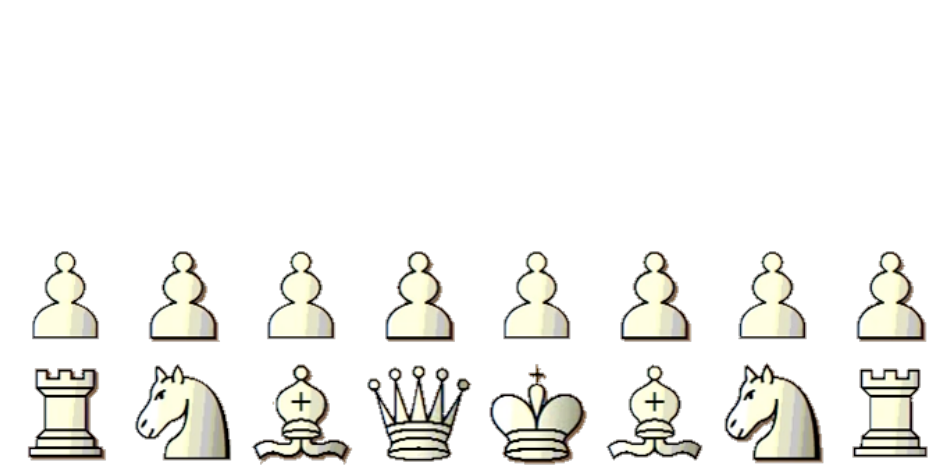
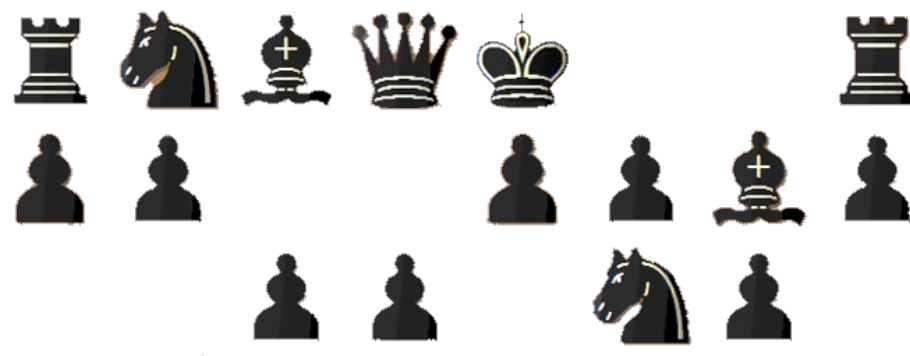
my model of chess

only with the board do the rules make sense



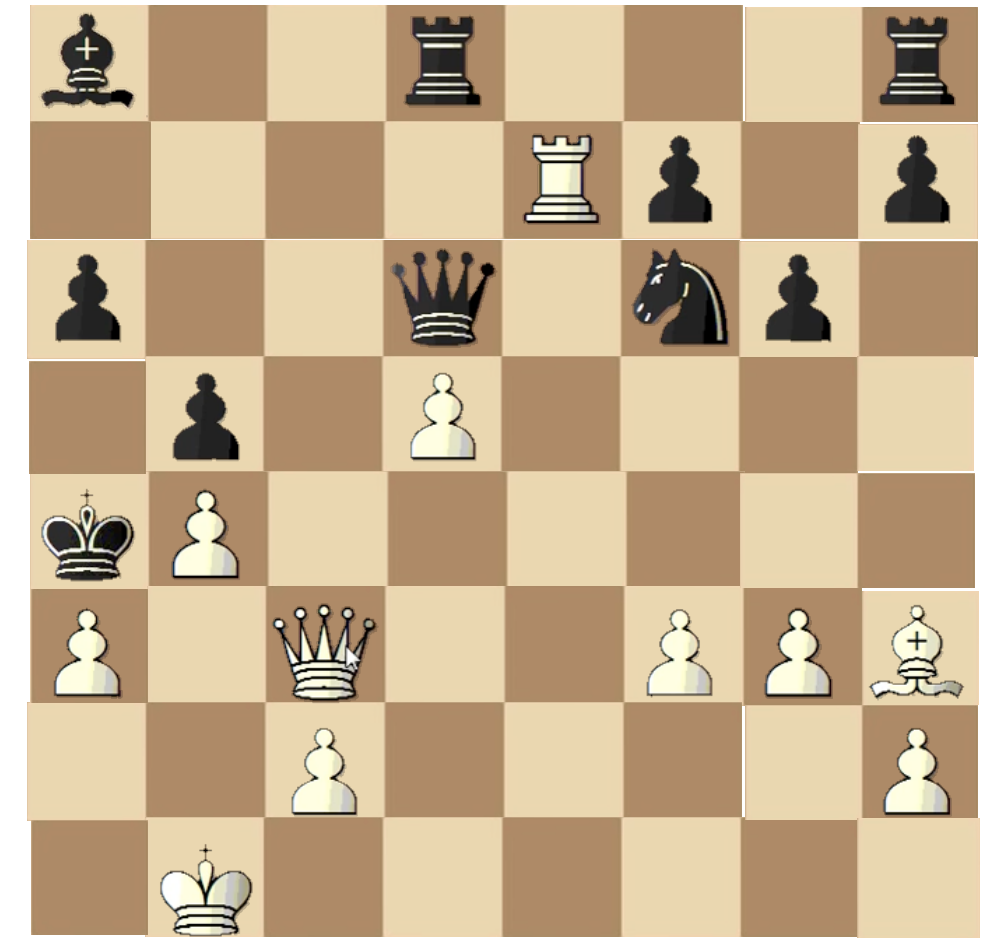
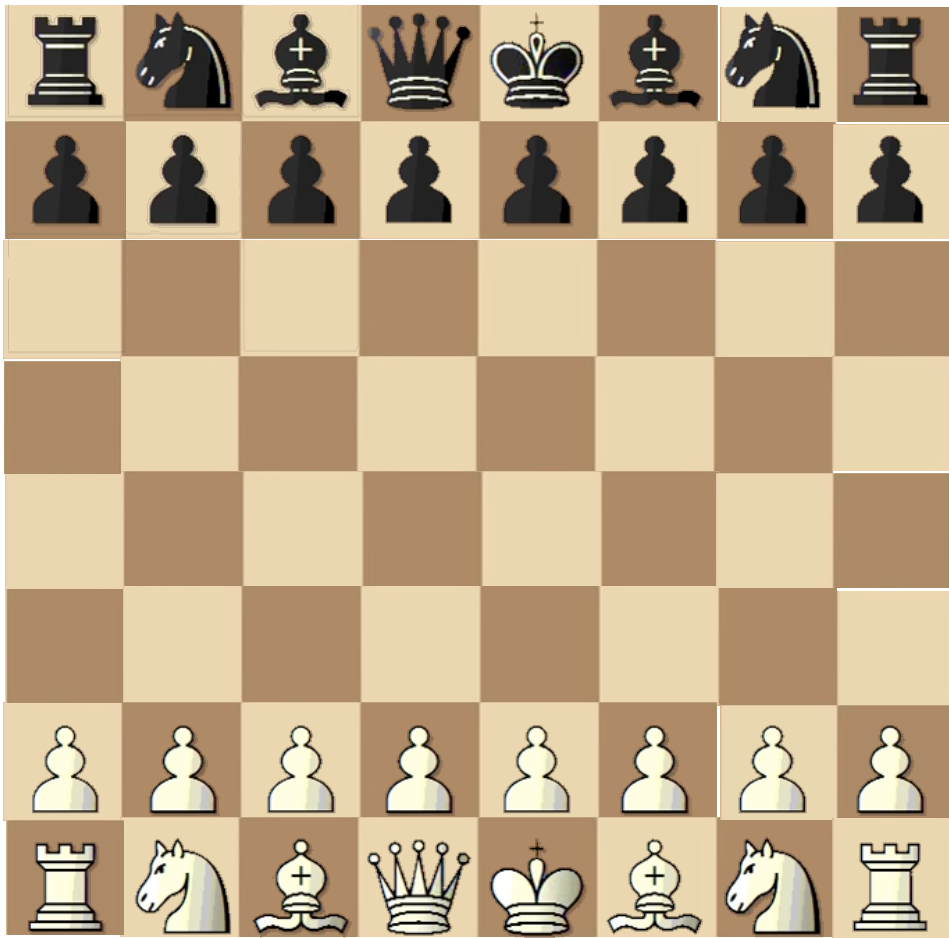
remember

what I see are the pieces



remember

what I need to be the case...is the board



The technical description:

"if it walks like a  and it quacks like a , then it must be a 

"



"

a successful physics model that requires an additional commitment!



PHYSICS
OFFICE

COMMON
SENSE!

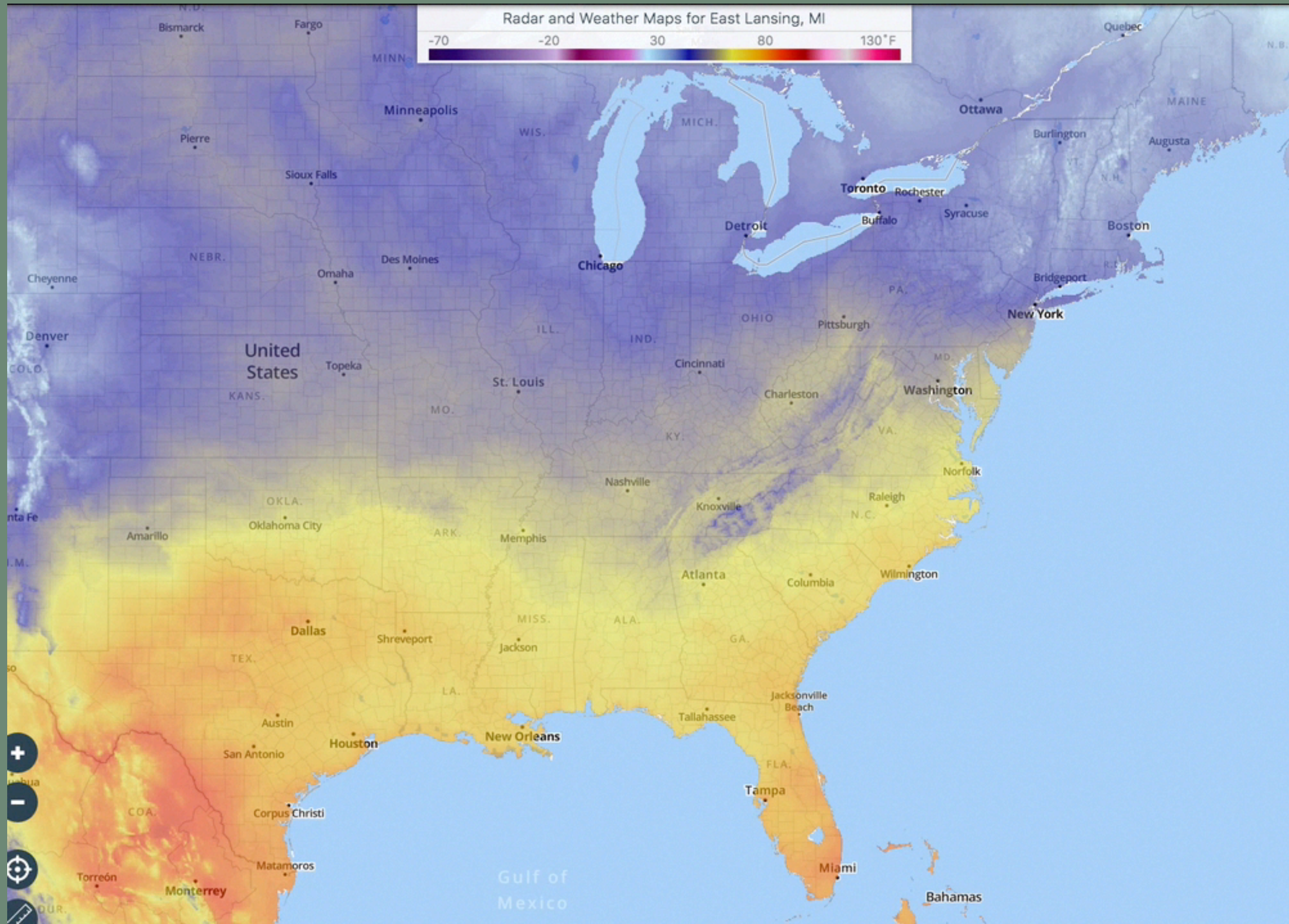
what about

fields?

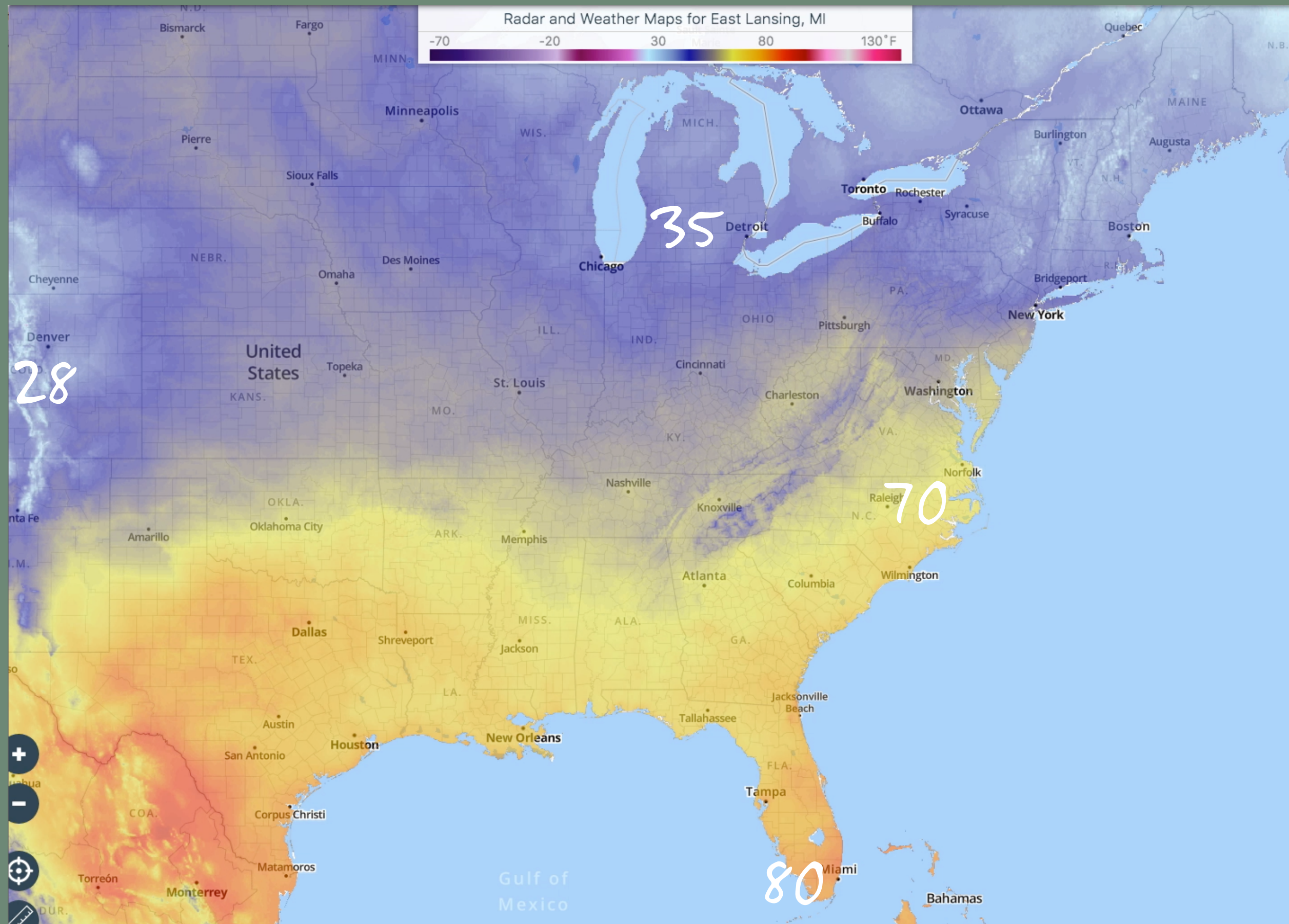
fields

a number in space

you know one
everywhere...a number



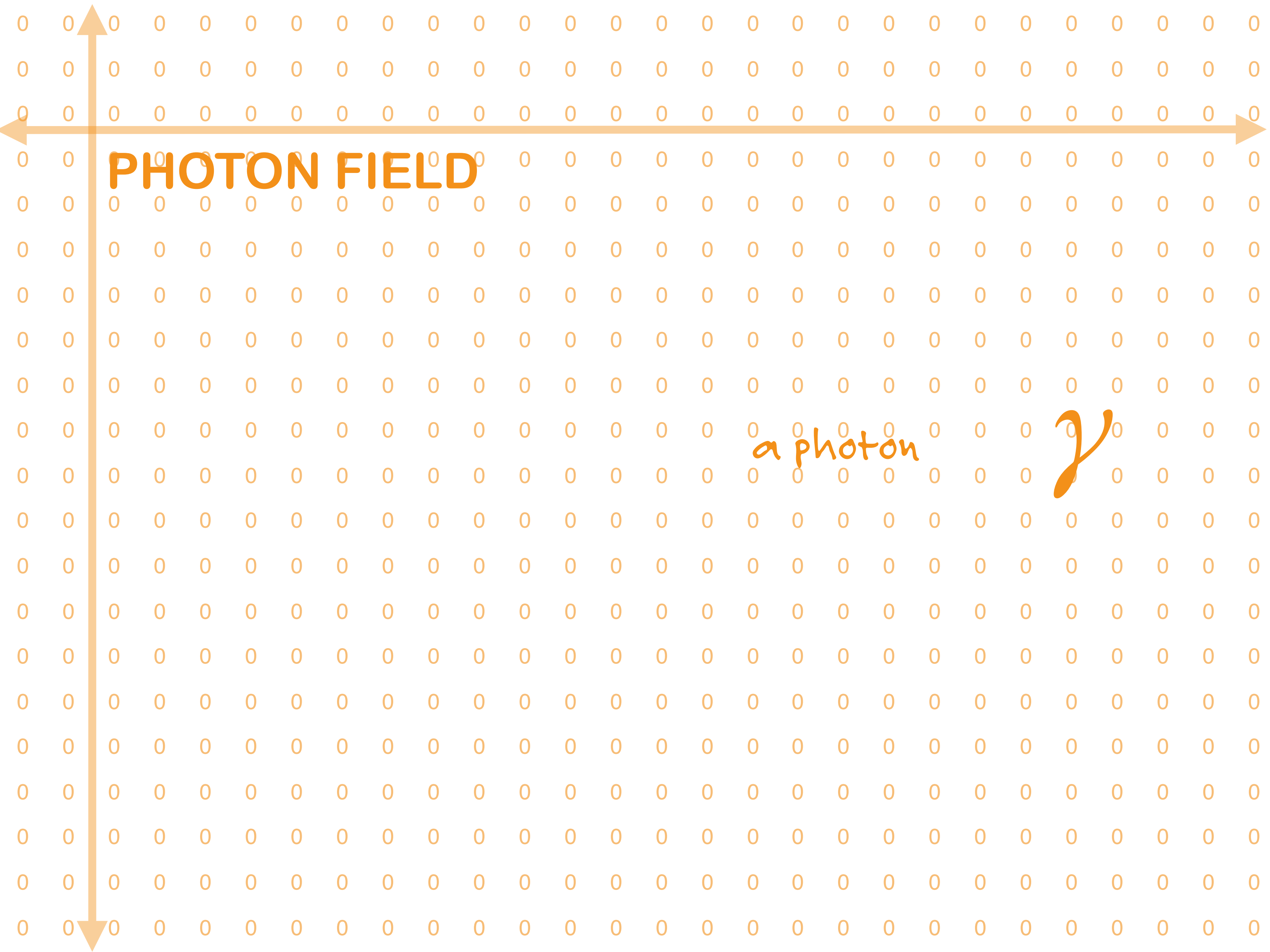
you know one
everywhere...a number



what's a particle?

it's localized wave in a field



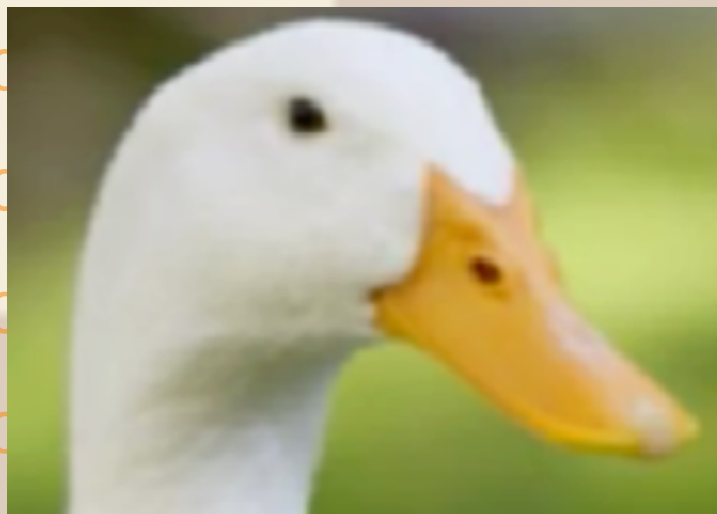


PHOTON FIELD

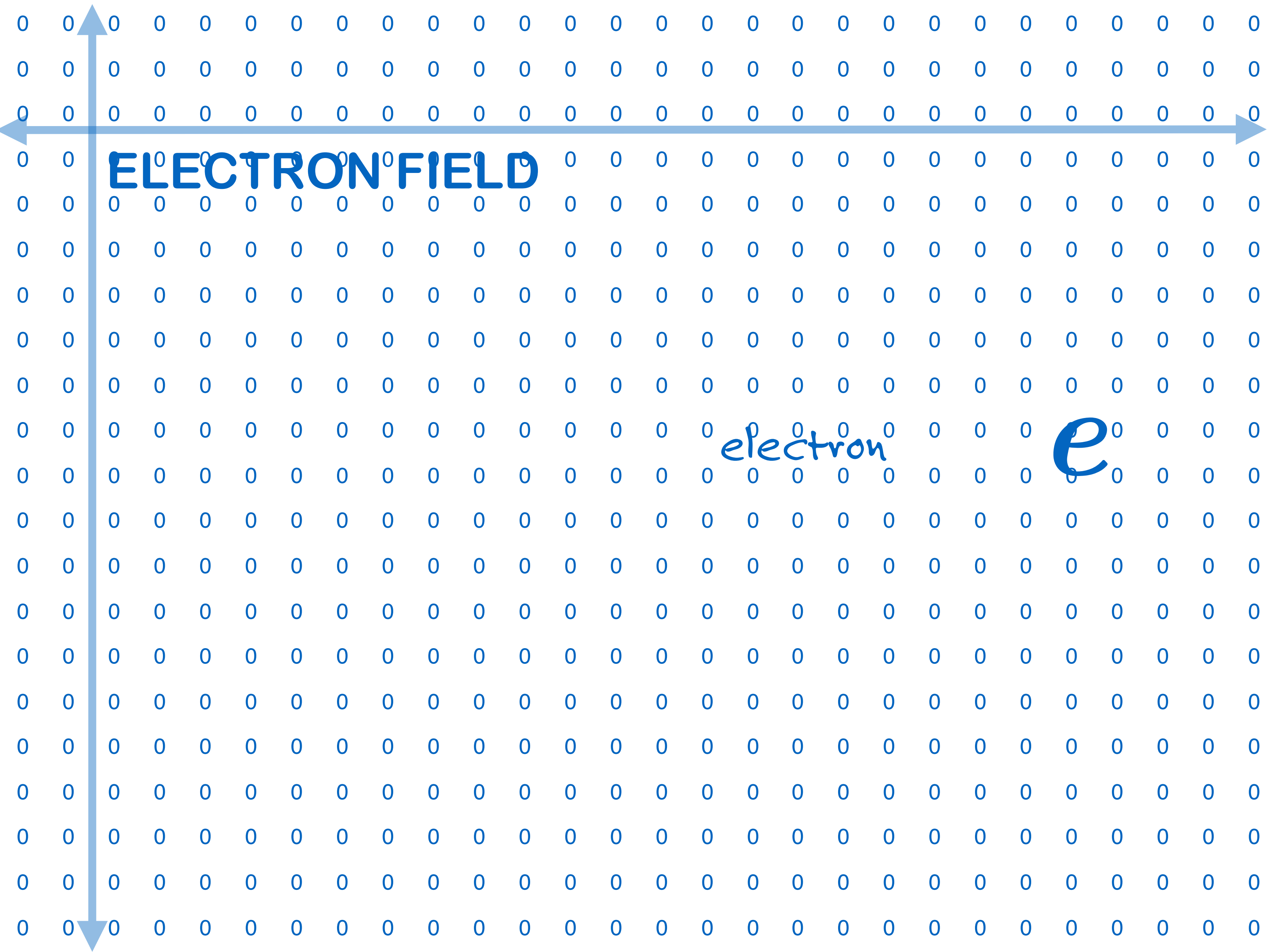
a photon

γ

PHOTON FIELD



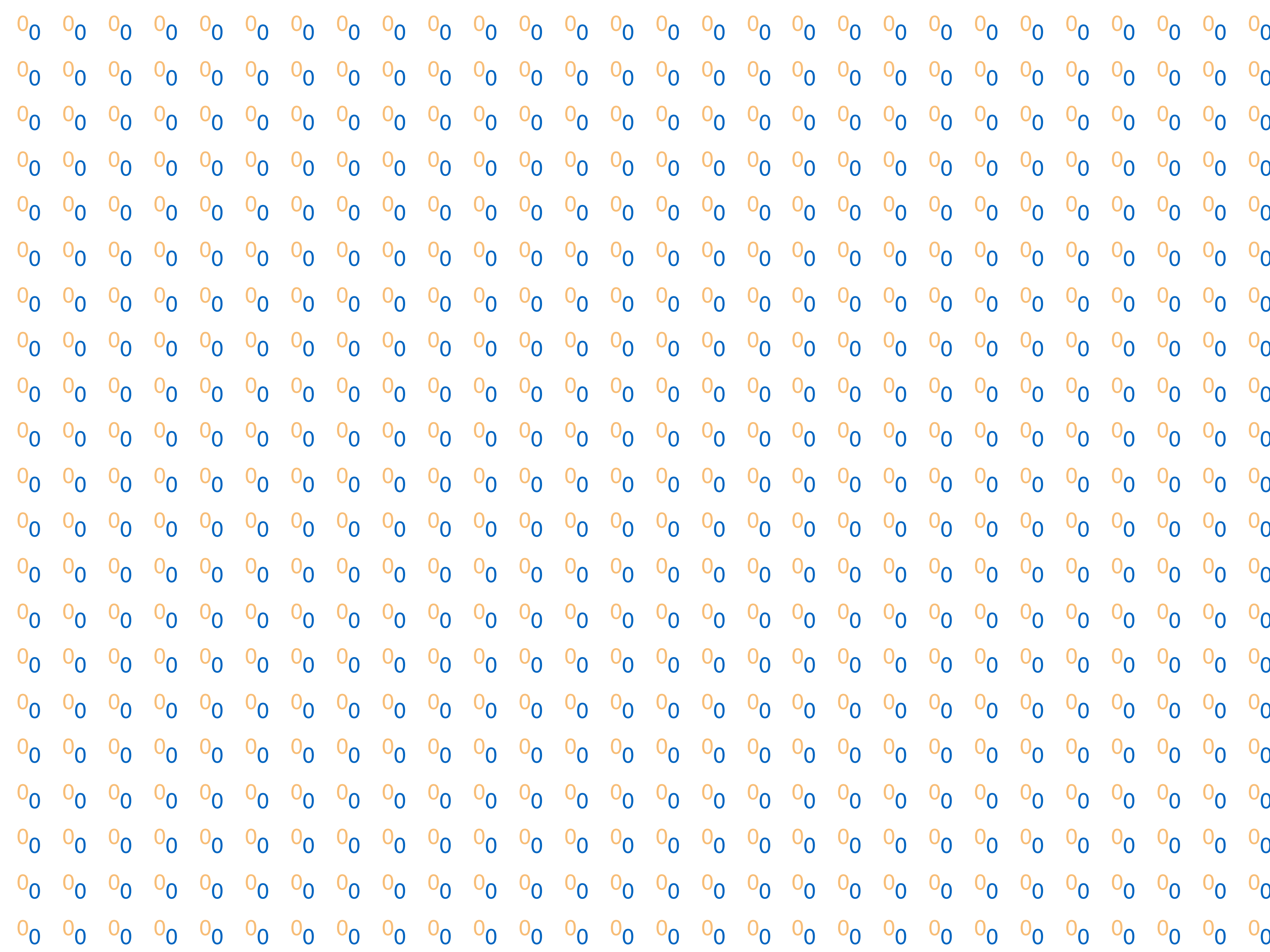
a photon γ



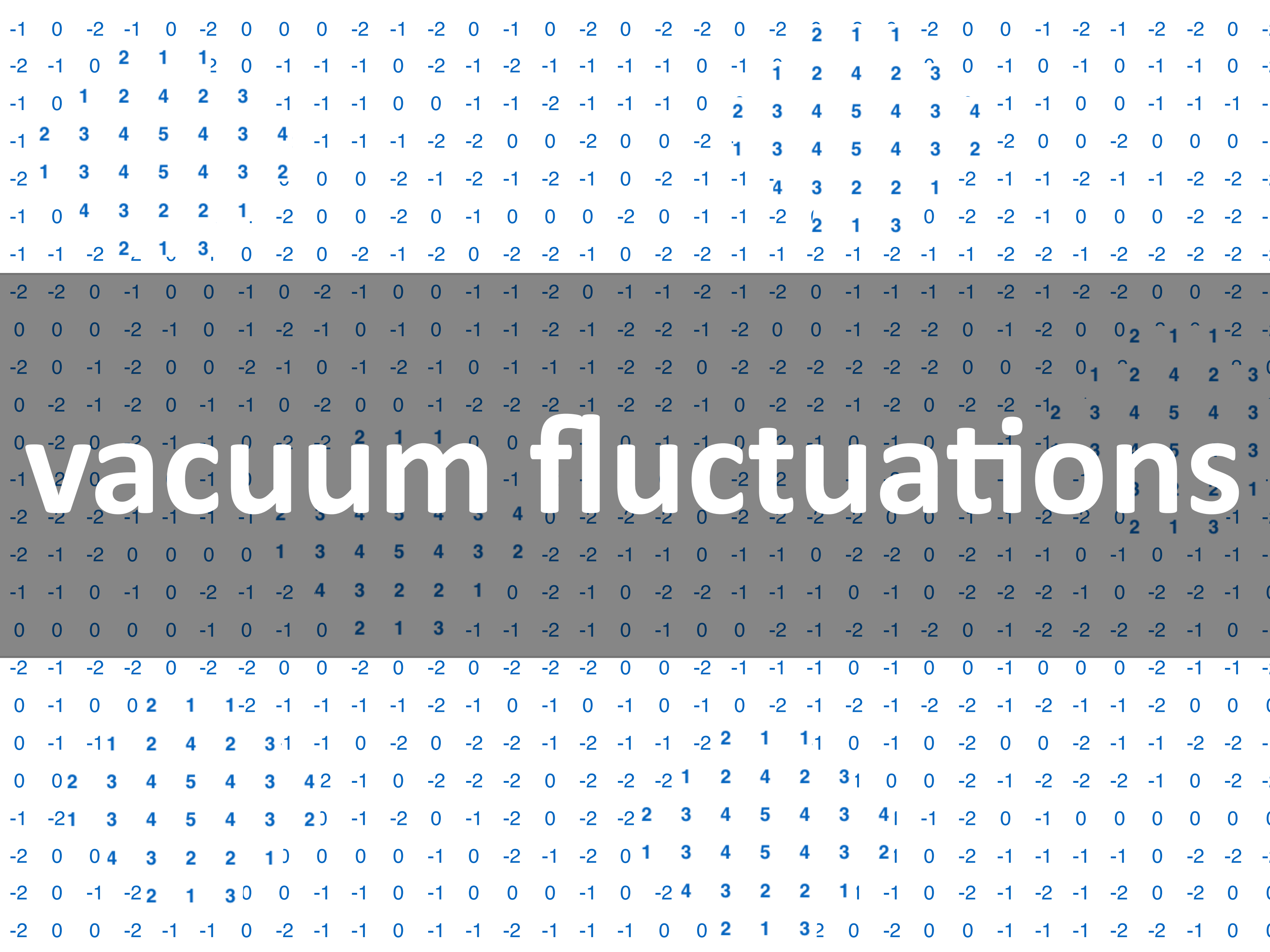
ELECTRON FIELD

electron

e



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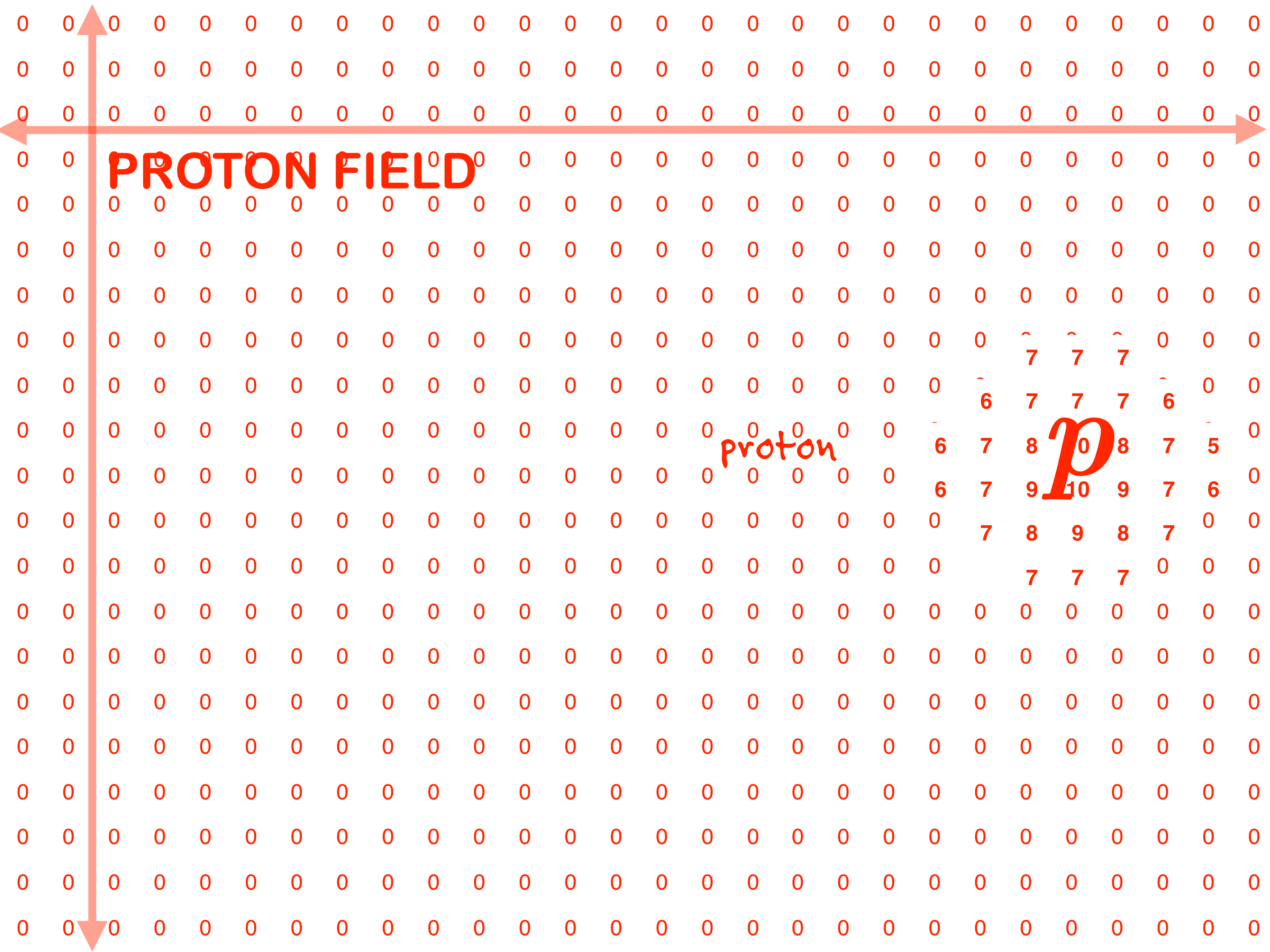


vacuum fluctuations

here's how

stuff happens

in this particle field theory model



PROTON FIELD

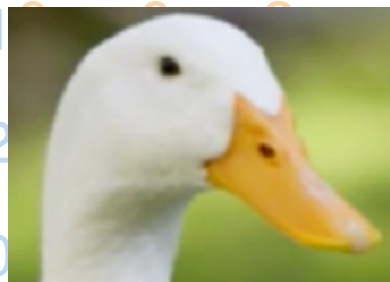
proton

P^{10}

~7 ~7 ~7
6 7 7 7 6
6 7 8 9 7 6
7 8 9 8 7
7 7 7

electron

photon field "disturbance"



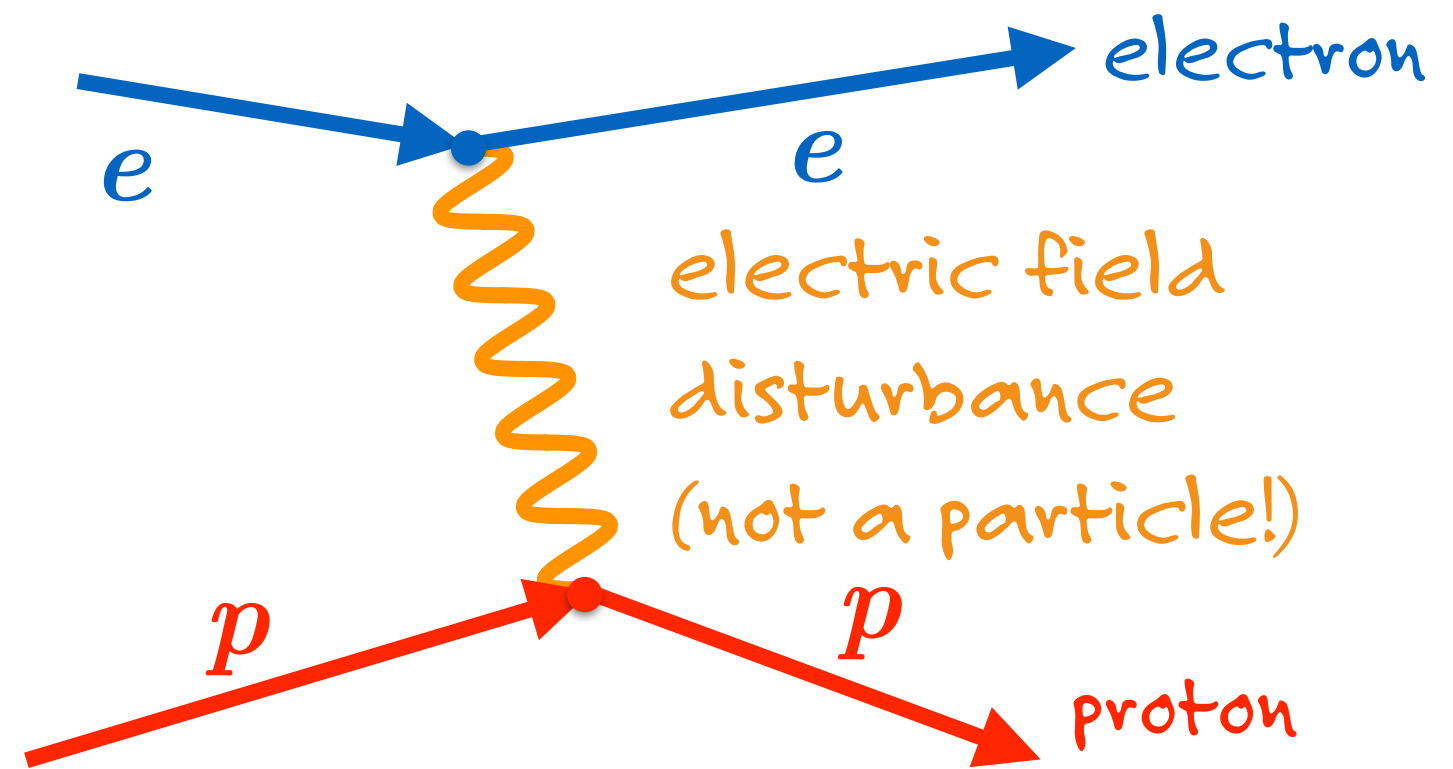
time

proton

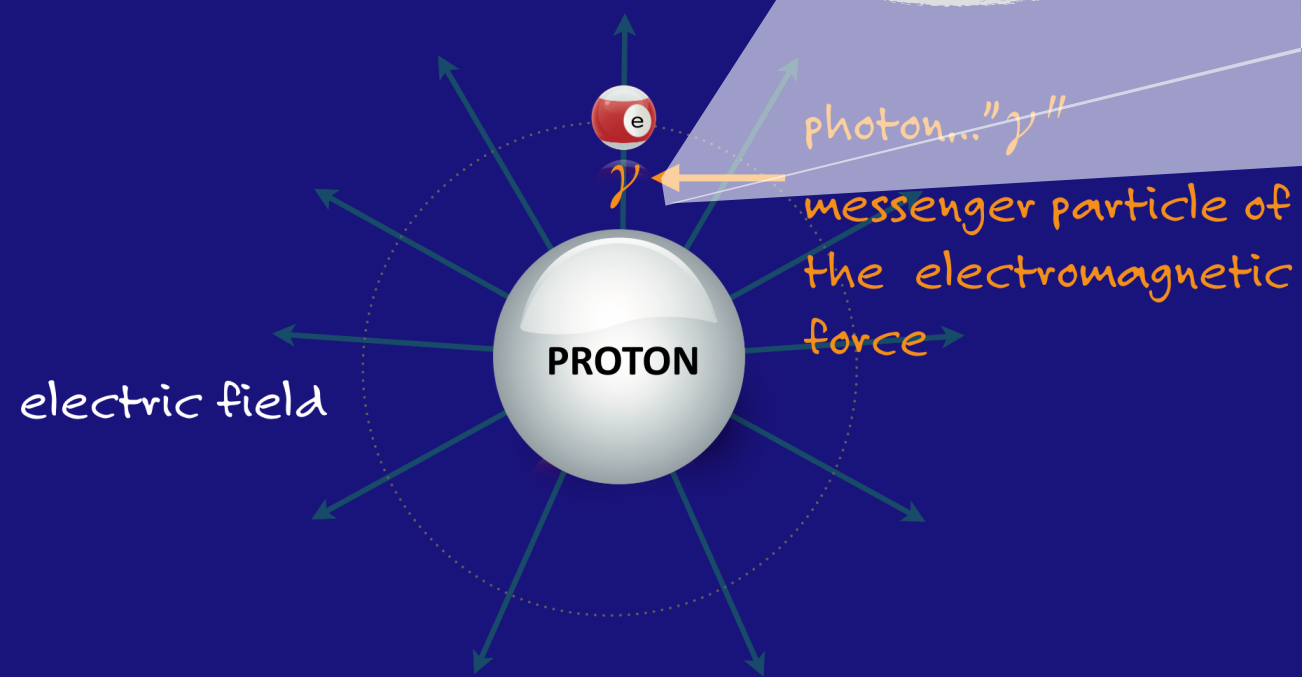


our atom

2nd way



forces?
from particles, 1st way



particle field theory*

the best theory in history

never an
incorrect
prediction



outrageously
precise
agreement,
prediction and
measurement

*Quantum Electrodynamics

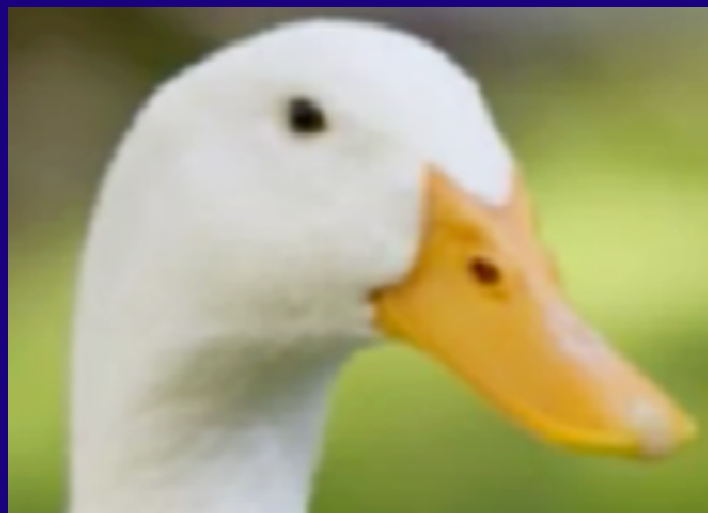
what's more fundamental?

a winner

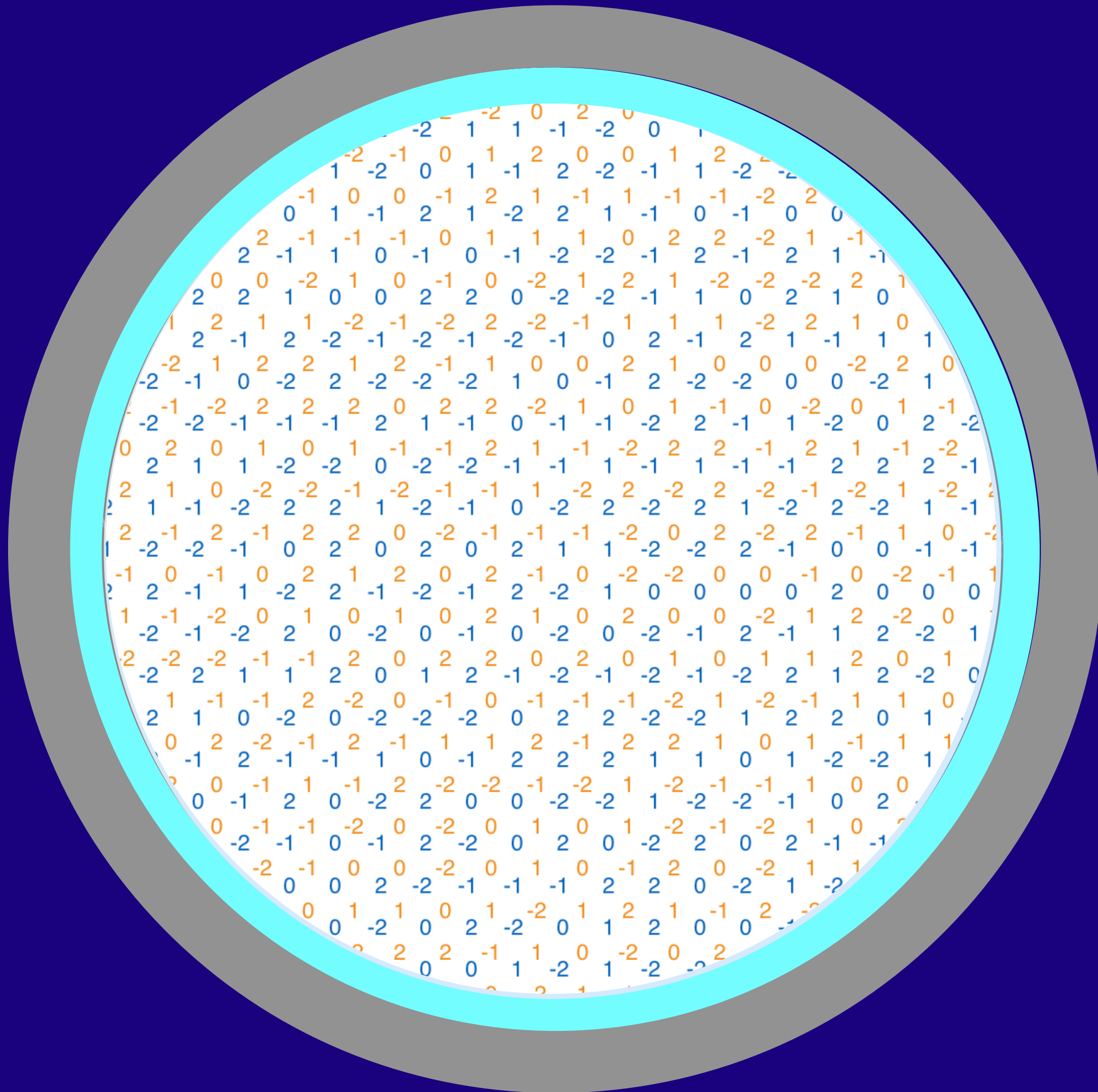


particles

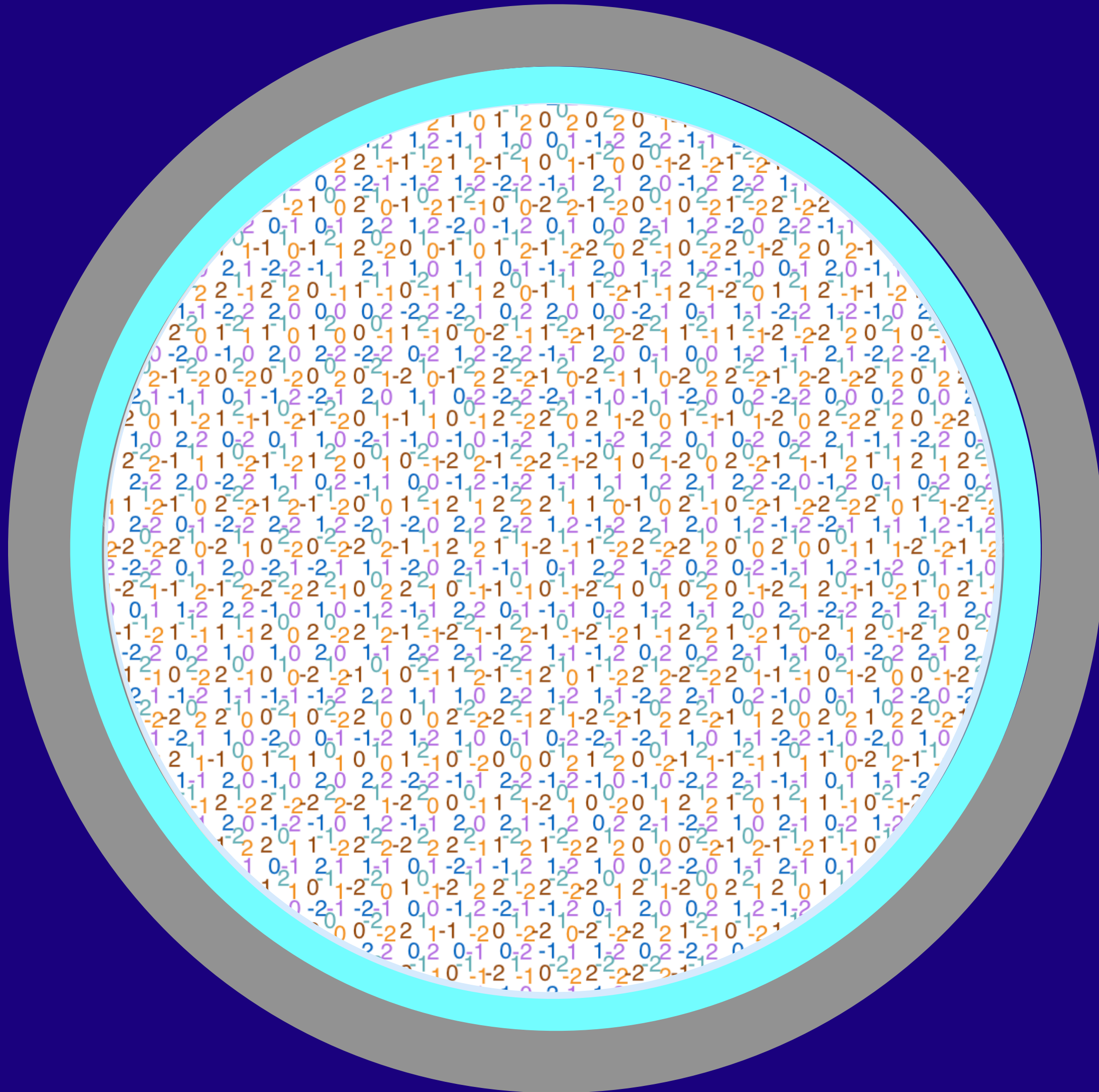
fields



the particle vacuum full of fields:



the particle vacuum full of fields for every "particles"



this has a name



"the worst prediction in the history of physics"



remember

trying to trap an electron?

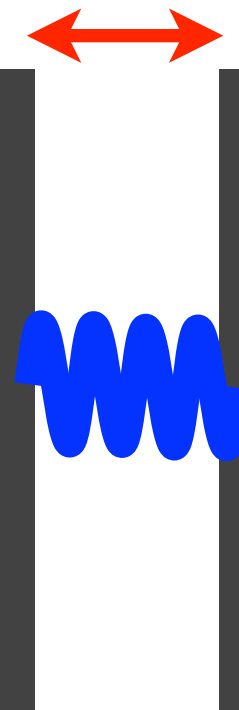
do nothing tighter



What's in Nothing?



or nothing, somewhere here:



make the trap smaller to this value:

$$\Delta x \sim \frac{h}{m_e c}$$

$$\sim 2.2 \times 10^{-12} \text{ m}$$

The size of a Hydrogen atom... $5 \times 10^{-11} \text{ m}$

The size of a proton... $\sim 10^{-15} \text{ m}$

a very
important
“length”

Compton
Wavelength

we consider this to be
“the size of a
particle”

$$\Delta x \sim \frac{h}{m_e c} = \lambda_{\text{Compton}} = \lambda_C$$

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

$$\frac{h}{m_e c} \Delta p \sim h$$

$$\frac{1}{m_e c^2} \Delta p c \sim 1$$

$$\Delta p c \sim m_e c^2$$

Remember: $E_T^2 = (m c^2)^2 + (p c)^2$

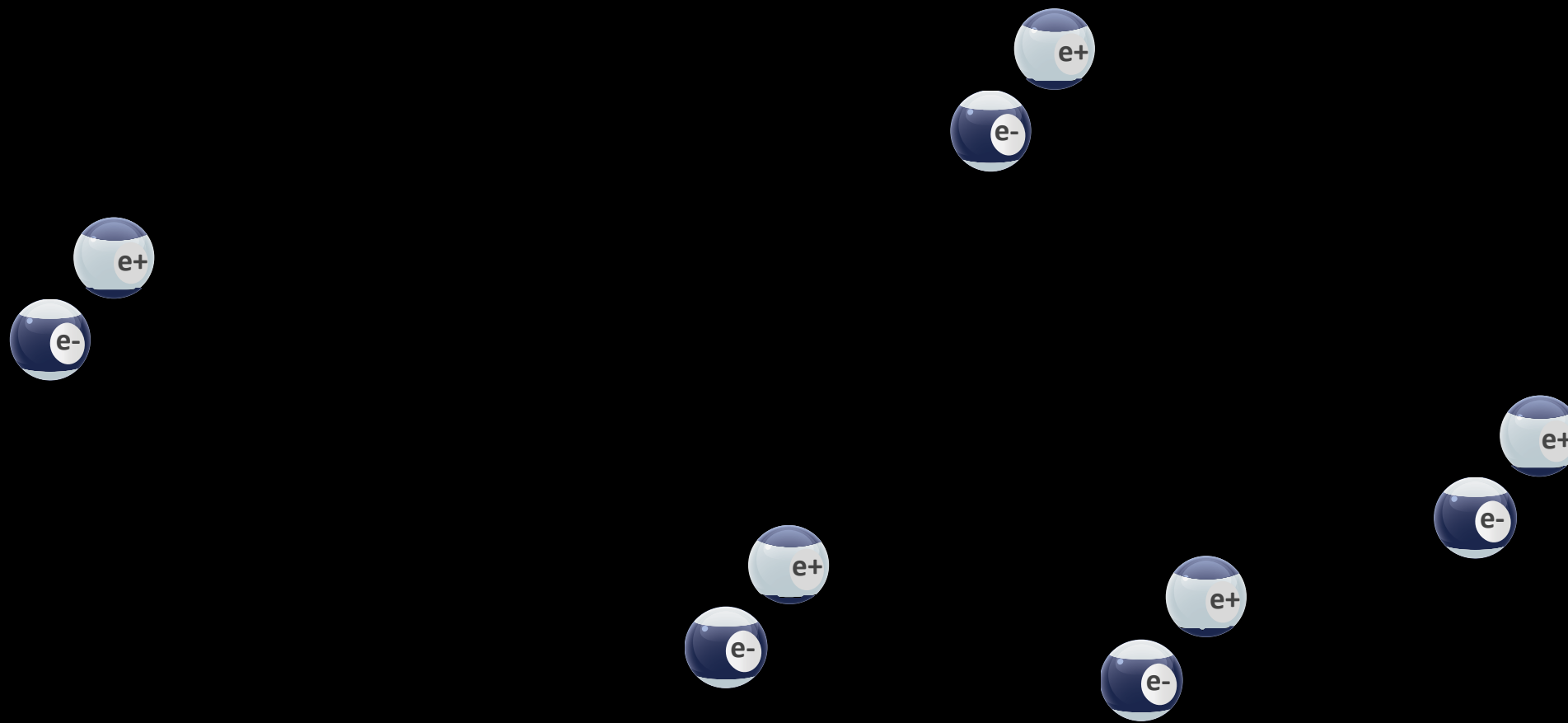
An energy equivalent to the mass energy...all by looking
closely at nothing.

pop

the Uncertainty Principle requires

that particle-antiparticle pairs pop into and out of existence

all the time



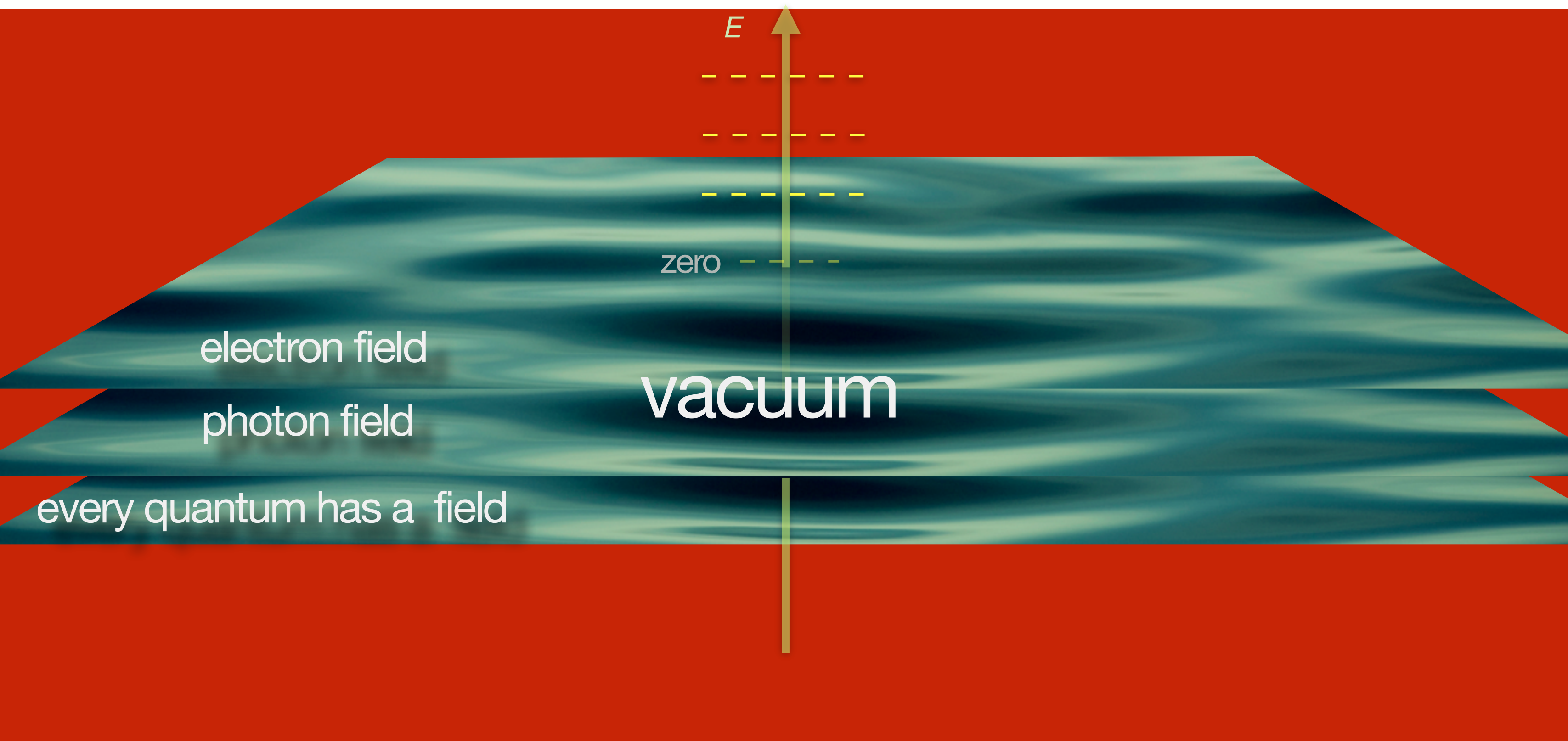
uncertainty principle

+ the particular length of:

$$\lambda_C = \frac{h}{mc}$$

makes the vacuum very active.





electron field

photon field

vacuum

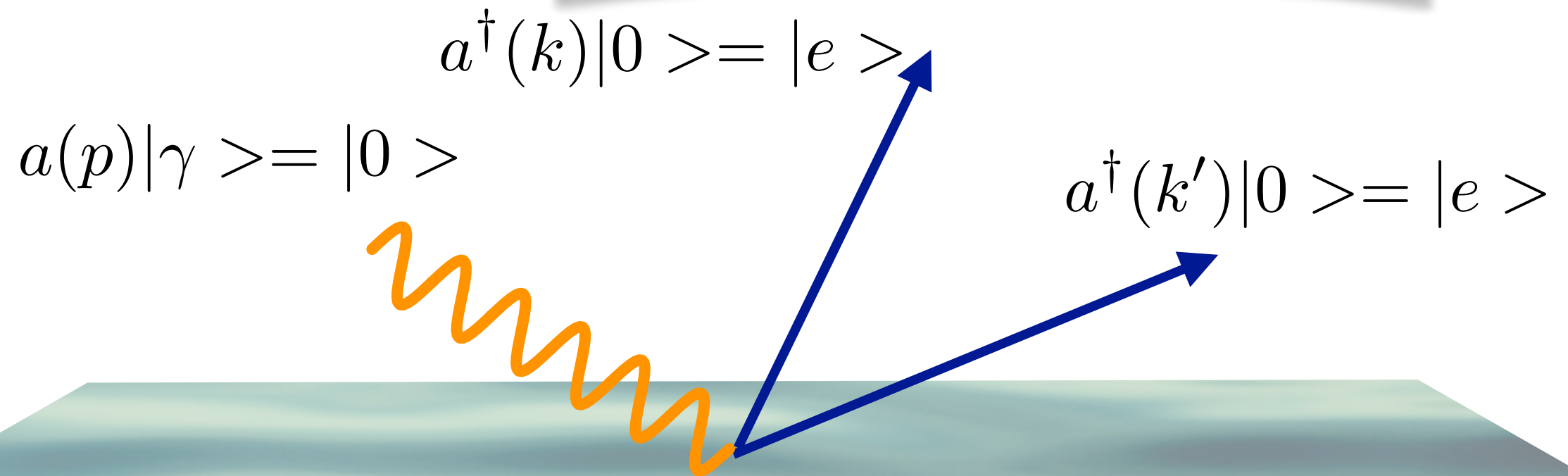
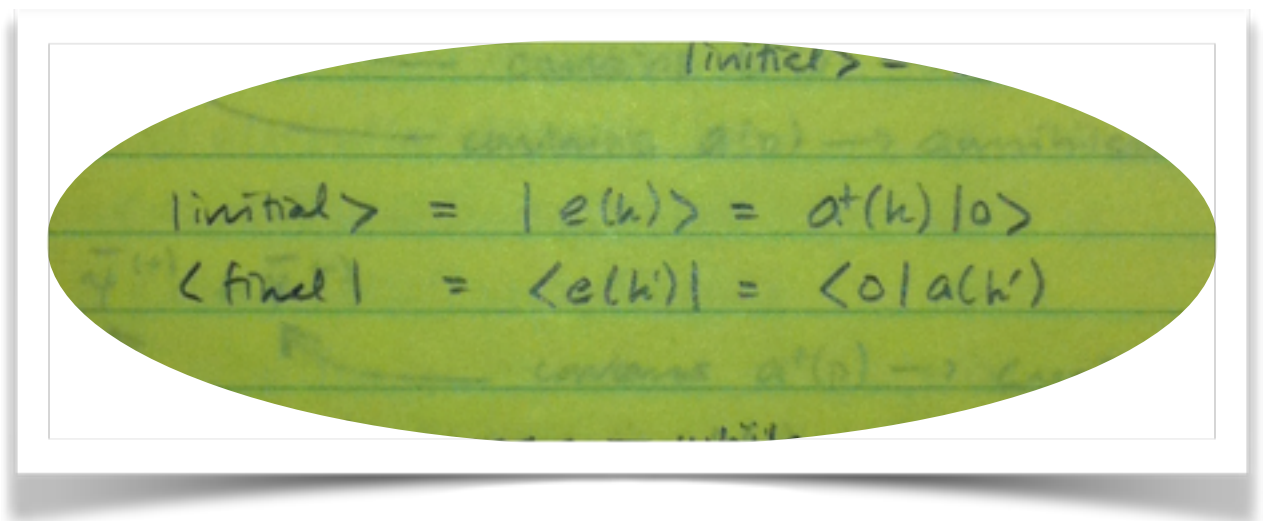
E

zero

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.

Feynman Diagrams

now for real.

antiparticles

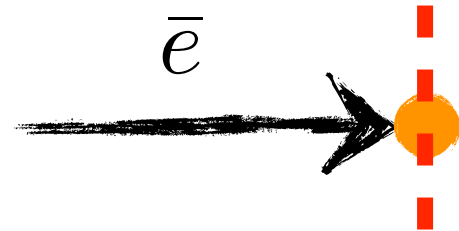
can be interpreted as particles moving backwards in time.

that's it.

and visa versa

particles in time

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



is the same thing as

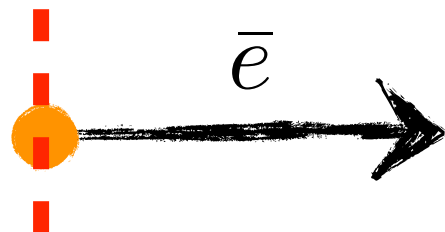
An electron coming **out** of an **initial** state (?)



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

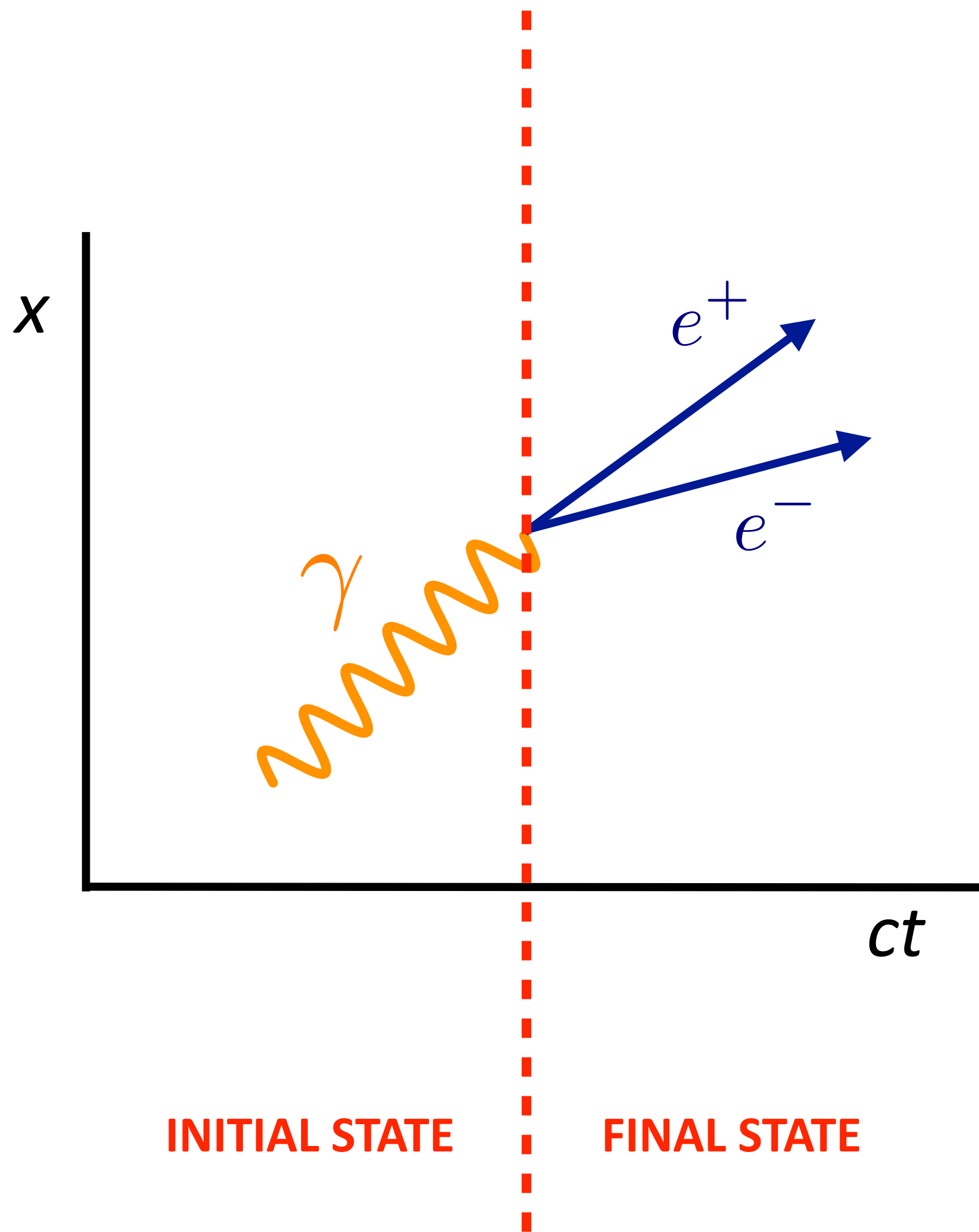
An electron coming **into** a **final** state (?)

Yes, this makes sense

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

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.

Feynman had rules

We'll have slightly different rules

but similar in spirit

1 Feynman Diagrammatic Gymnastics

Diagrams are “artistically”¹ drawn in spacetime coordinates. Every line (“leg”) from one spacetime point to another represents a particle’s propagation. The form of the line indicates its identity as shown in Fig. 1. Two or more lines intersect at a vertex, which represents an “interaction.”

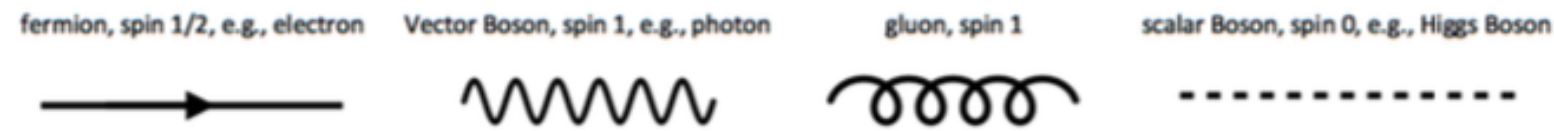


Figure 1: Feynman Diagram symbol for all particles.

Arrows on fermion lines indicate the time direction and the causal nature of the line.

Feynman Diagrams are legal if:

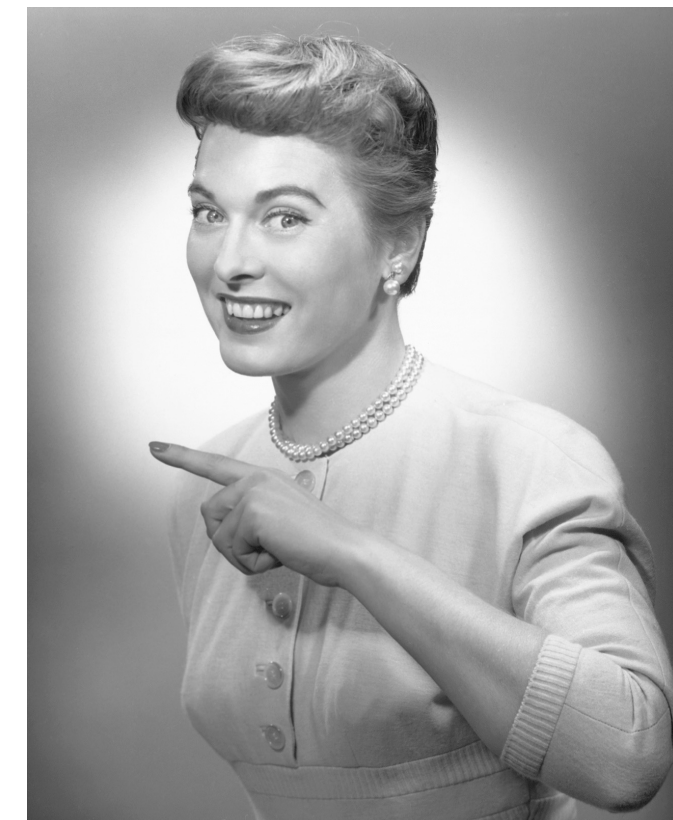
- A. real particles and antiparticles move forward in time
- B. orientation doesn't matter, as long as particles don't change from initial \longleftrightarrow final states. *connecting initial to final states*
- C. fermion lines are always continuous at vertices: what comes in, must go out and at a vertex, arrows are continuous
- D. electric charge must be conserved at every vertex

One can change one process into another process with these manipulations:

1. one can rotate a whole diagram by 90 degrees CW or CCW
2. one can change all particles \rightarrow antiparticles and antiparticles \rightarrow particles if done all at once to every leg

Interactions happen according to one of the four elementary forces of nature. They can be constructed by combining Primitive Diagram pieces by:

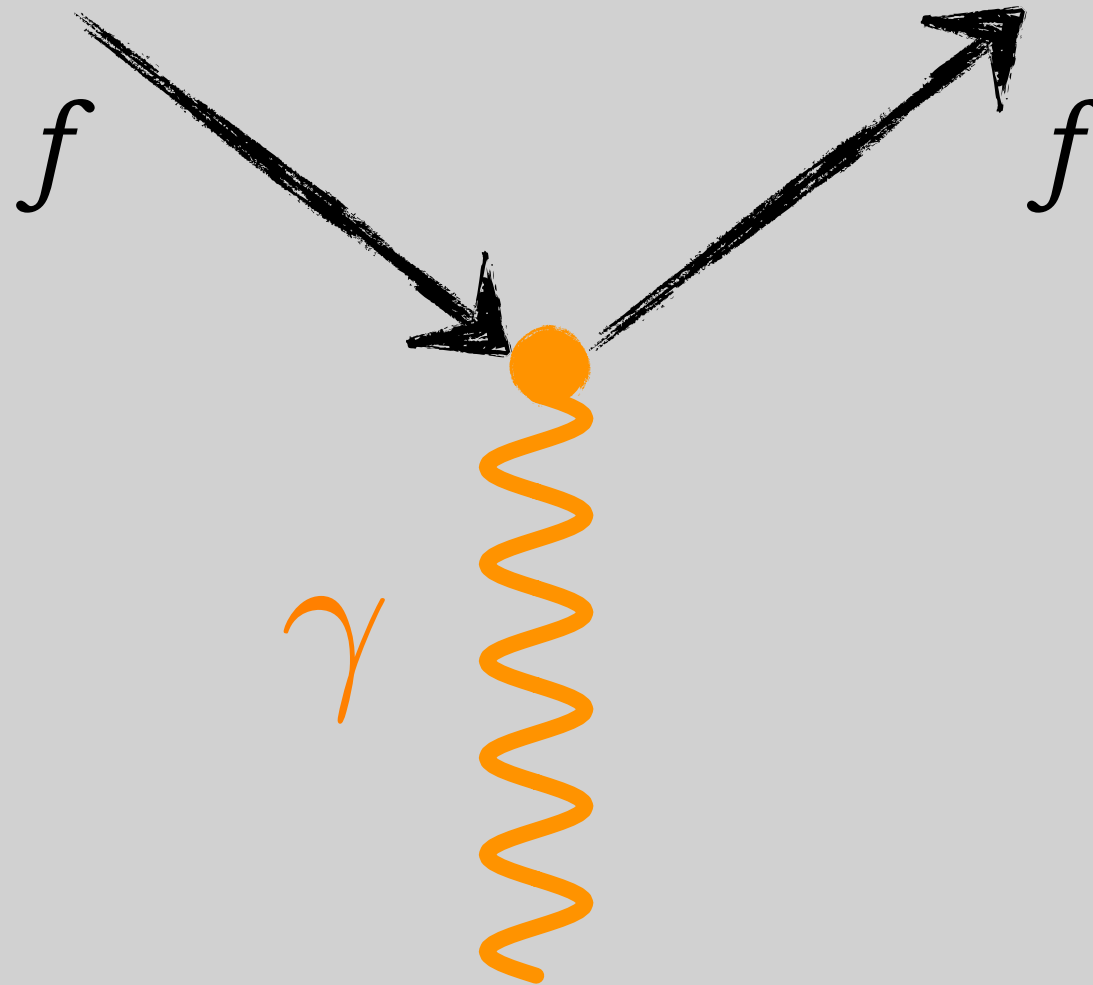
- attaching a boson line to a boson line or
- a fermion line to a fermion line



primitive diagrams

are general

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




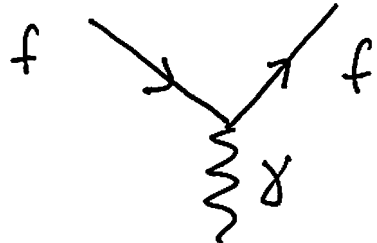
f could be electron, positron, proton, antiproton...and more – any electrically charged **f**ermion.

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	

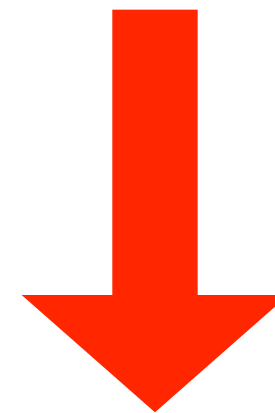
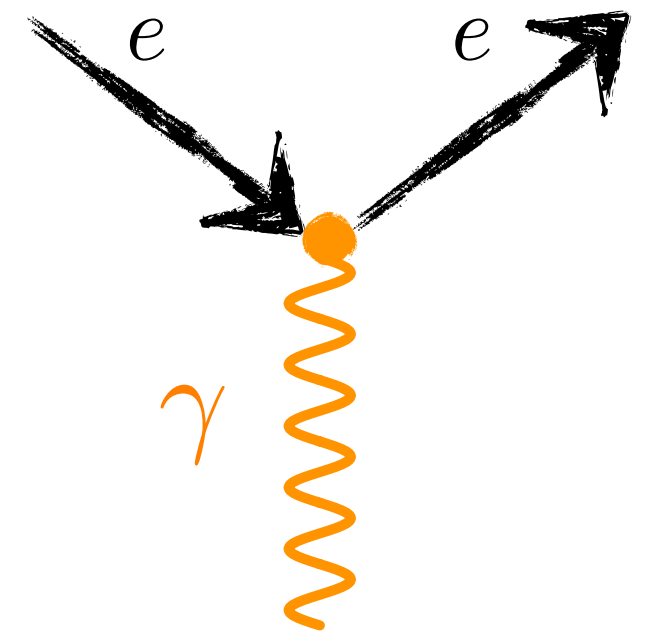
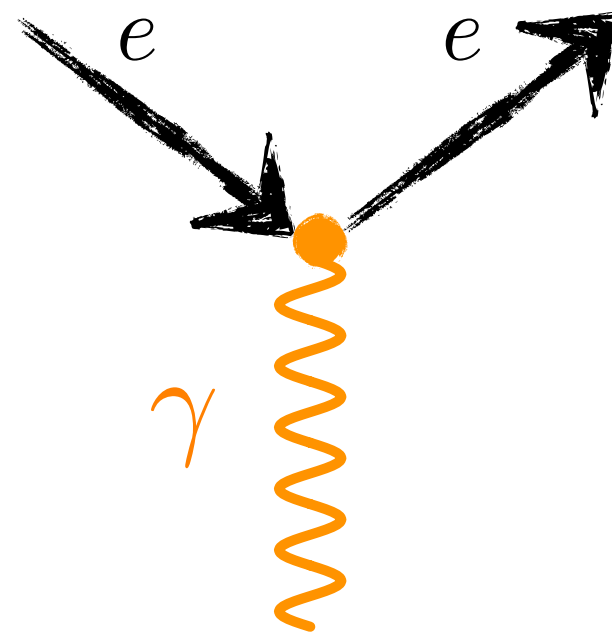
fermion, spin 1/2, e.g., electron Vector Boson, spin 1, e.g., photon gluon, spin 1 scalar Boson, spin 0, e.g., Higgs Boson

for
example

from my primitive,
I can make two
standard
processes

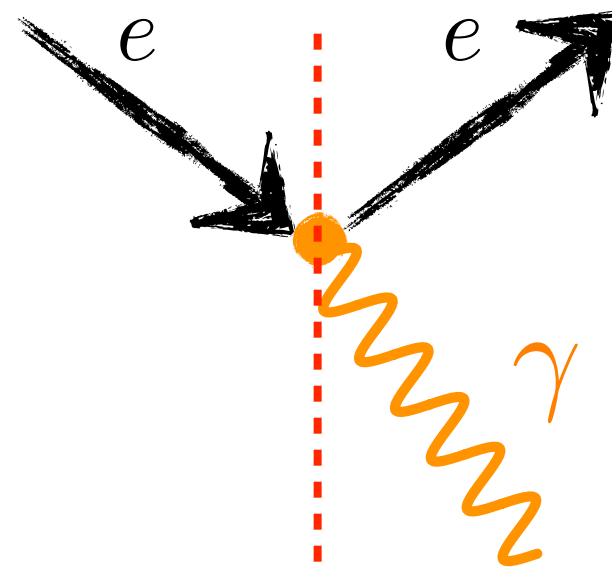
the photon is its own
antiparticle



twist the
photon one
way

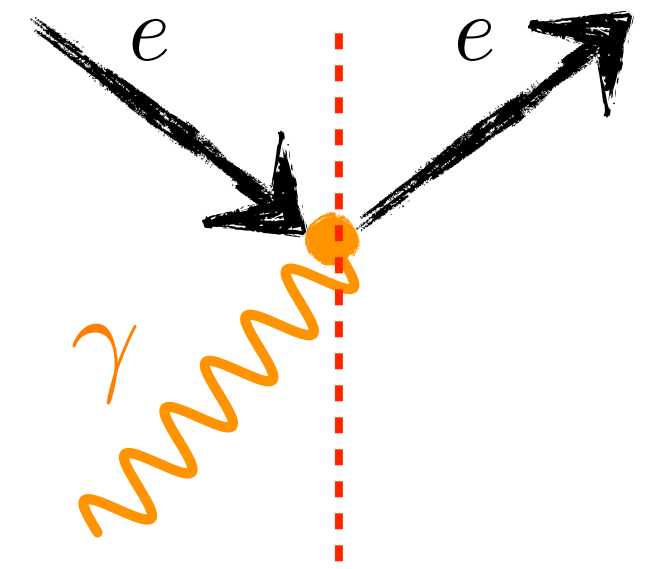


twist the
photon the
other way



INITIAL STATE FINAL STATE

electron radiating,
as I noted



INITIAL STATE FINAL STATE

electron reacting to a
electric Coulomb force
or a magnetic Lorentz force

a couple of more

games with Feynman Diagrams

(second)

build some particles