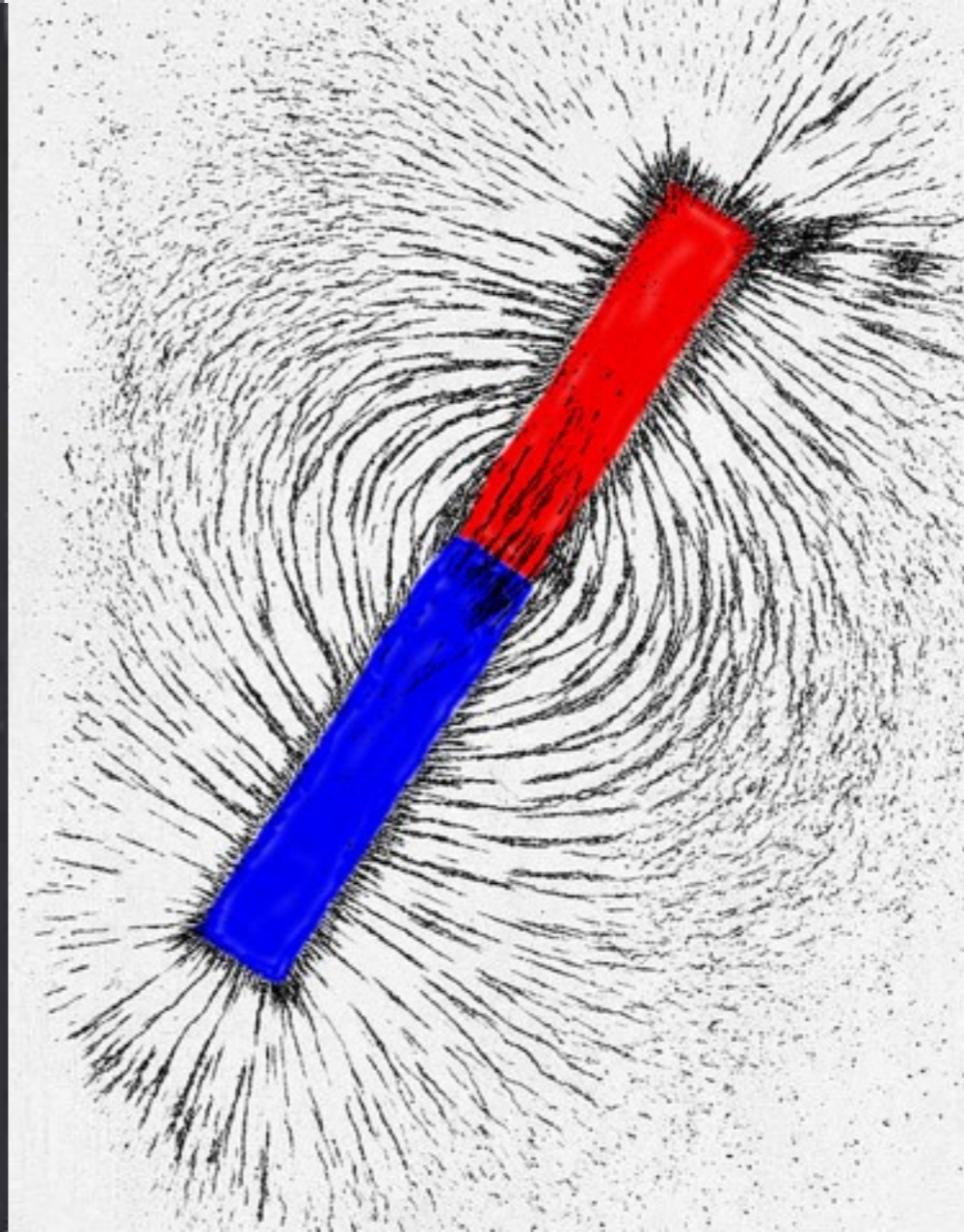
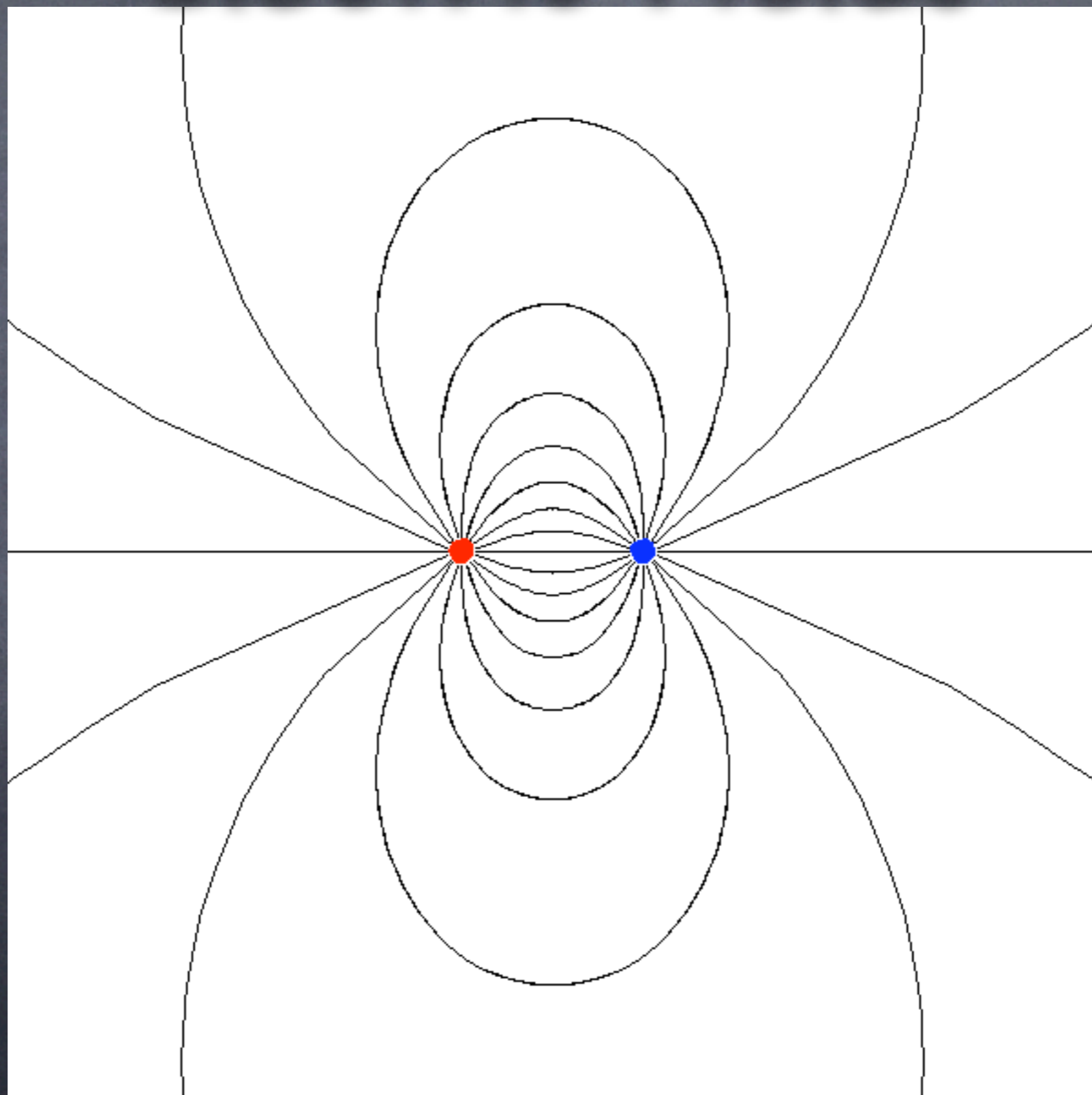


# Chapter 7: The Standard Model

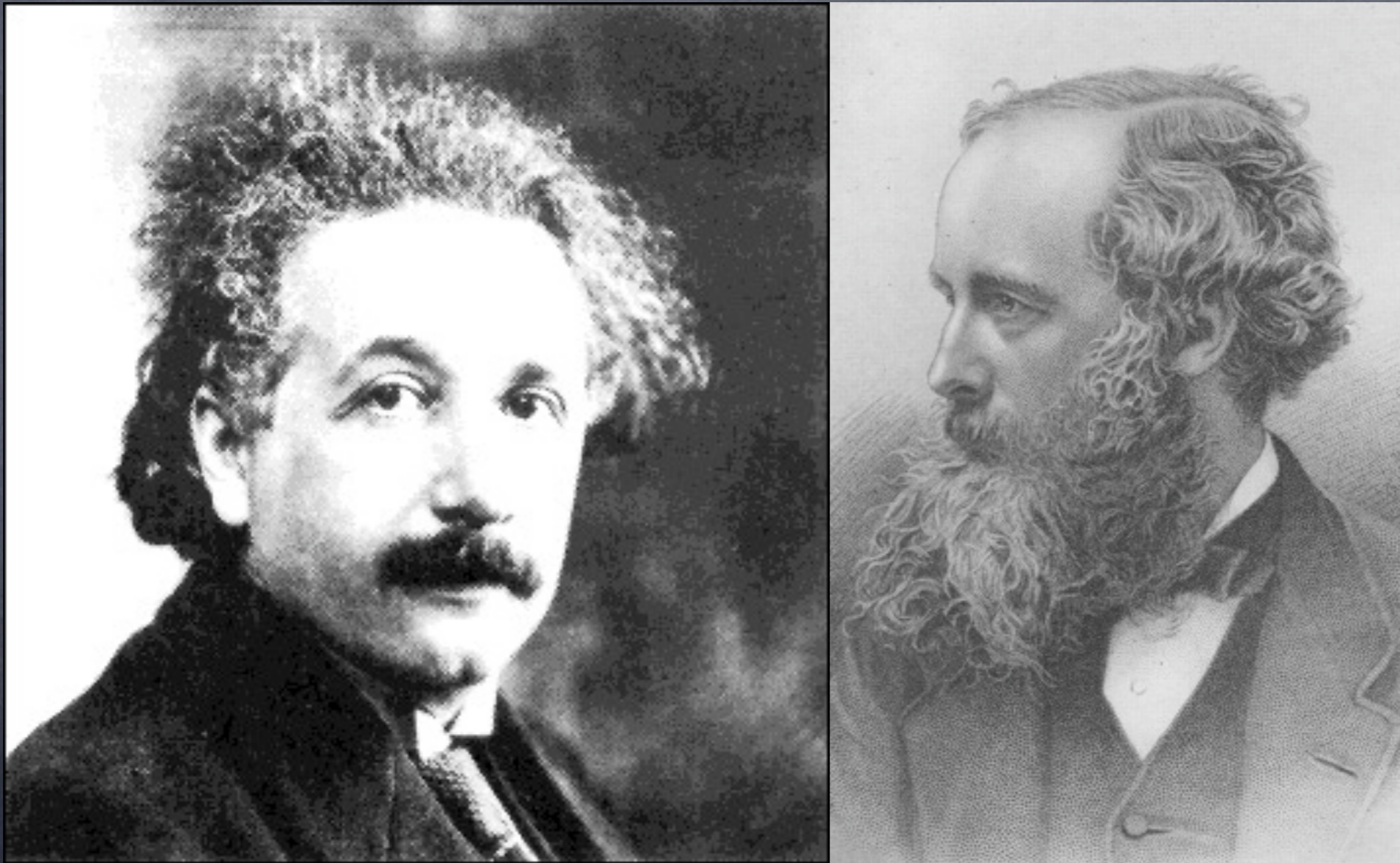
# Electro-Magnetic Fields



# Electric Fields



# Einstein and Maxwell

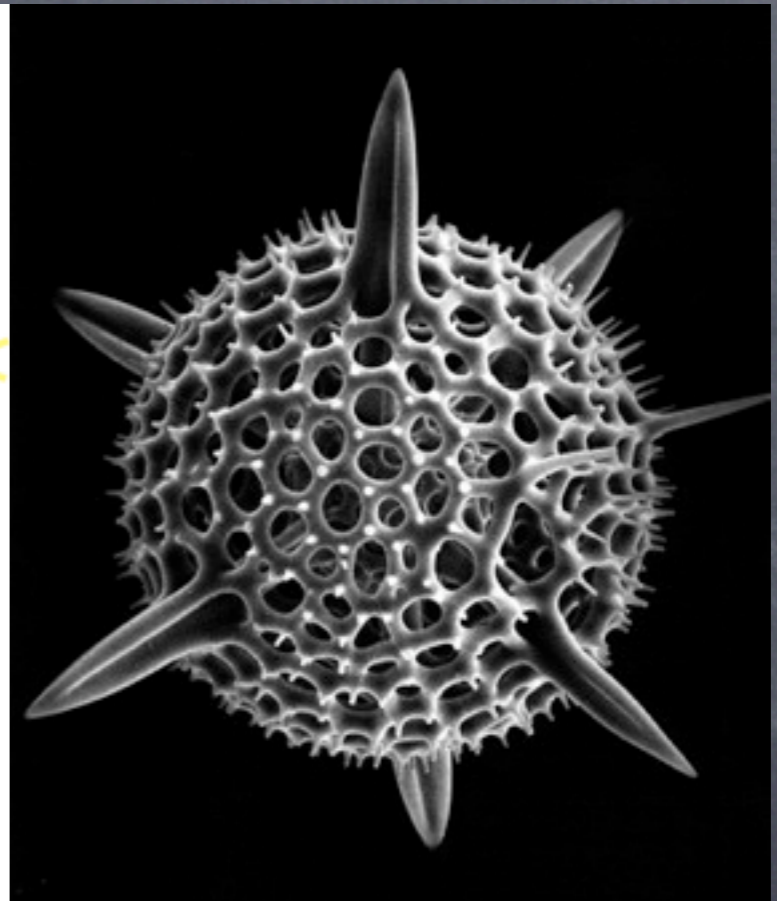
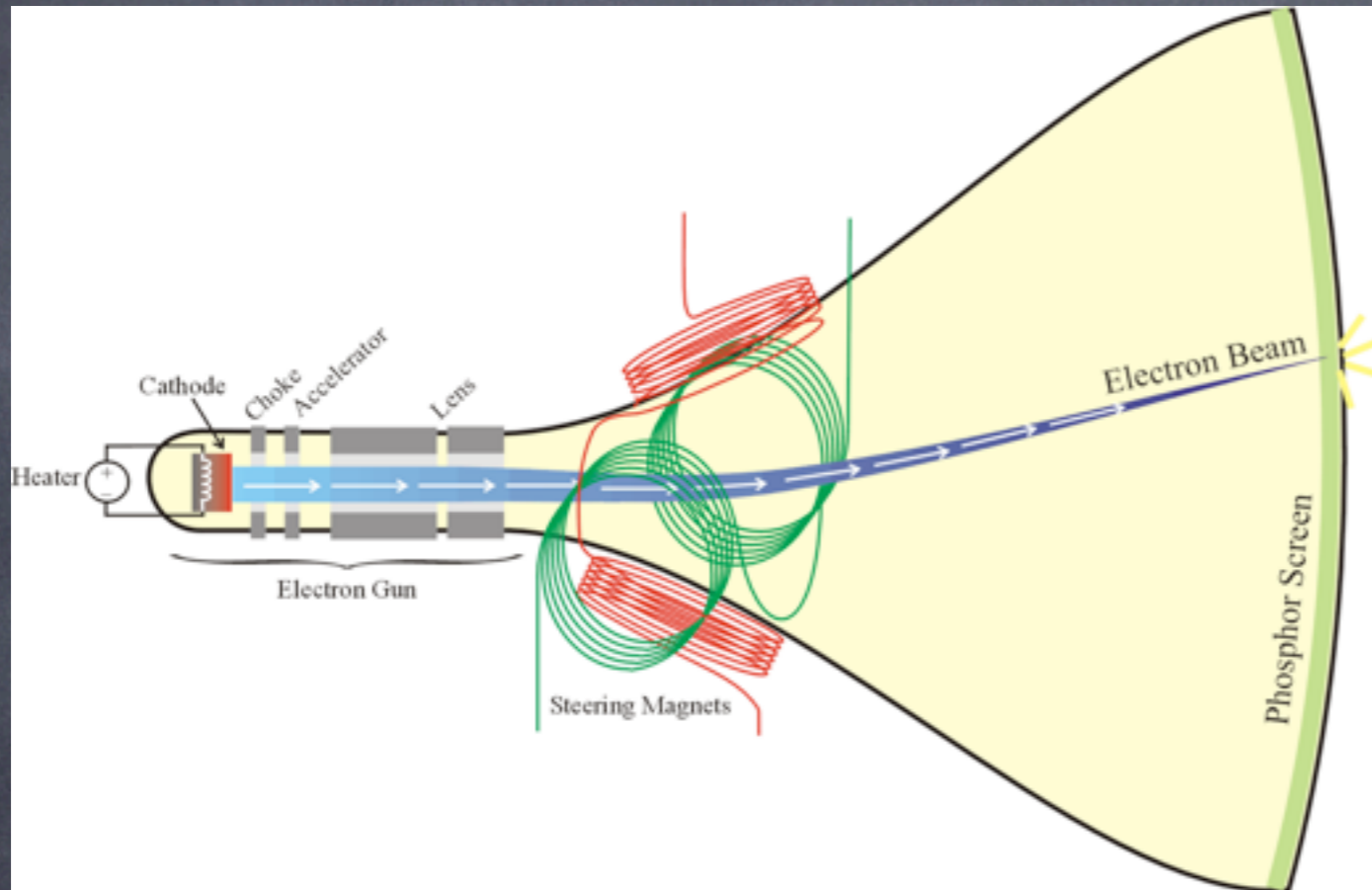


Photon is a particle of light

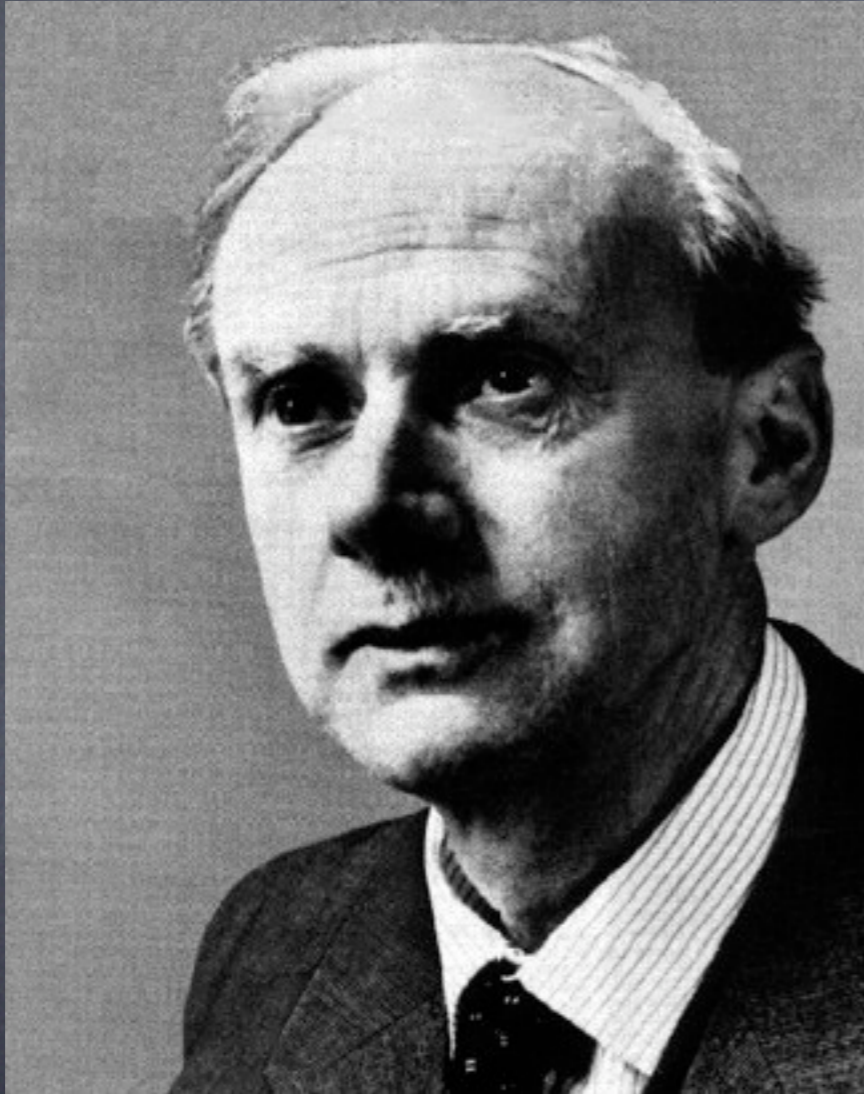
# Modern Physics Since Einstein

- discovery of many new particles
- discovery of substructure of proton and others
- detailed understanding of three forces
  - Quantum ElectroDynamics (QED)
  - Weak Interactions
  - Strong Interactions

# Electrons



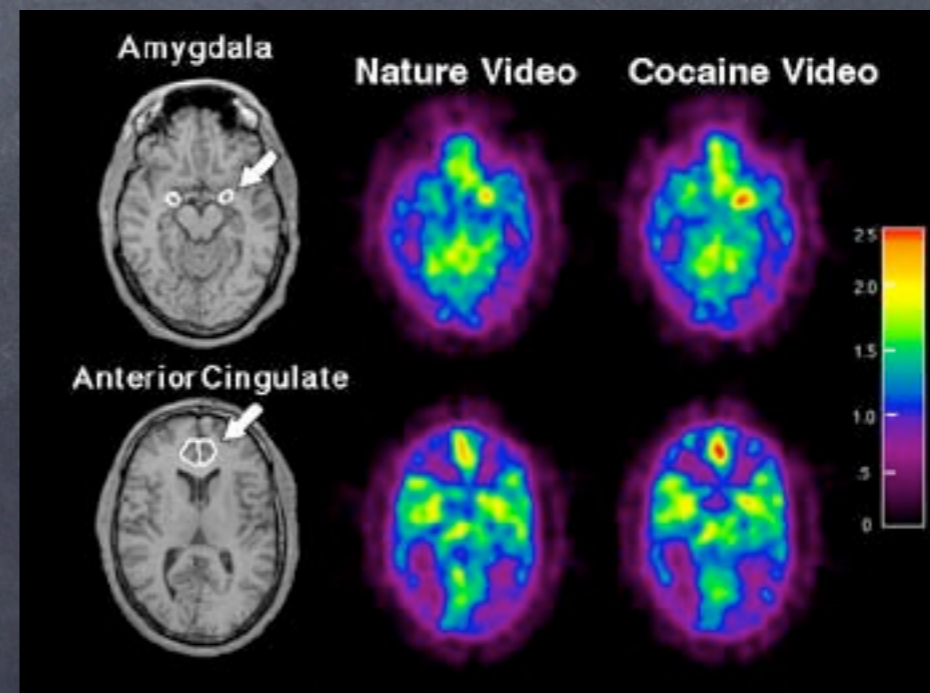
# Dirac



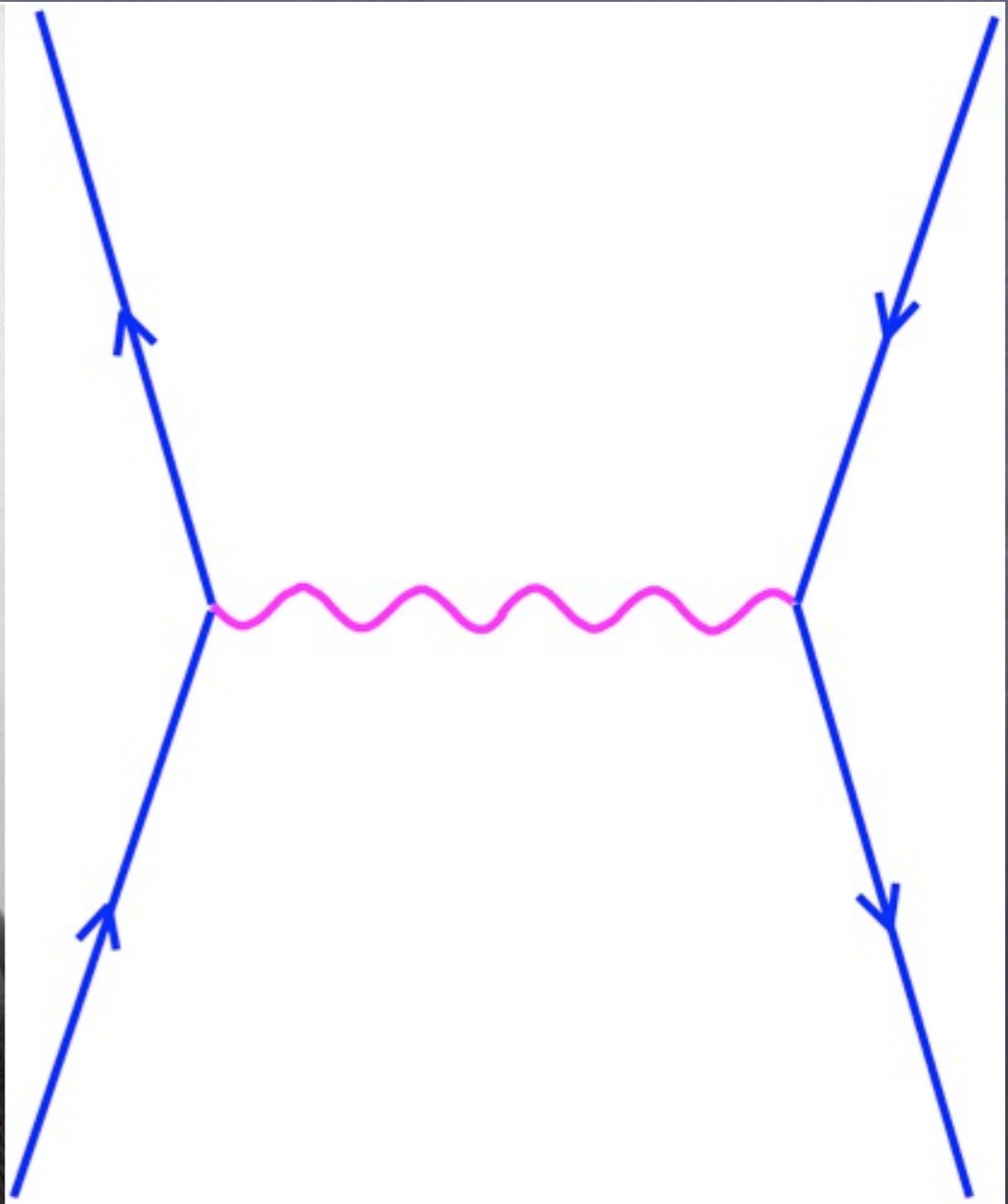
relativity  
+  
quantum physics



antimatter

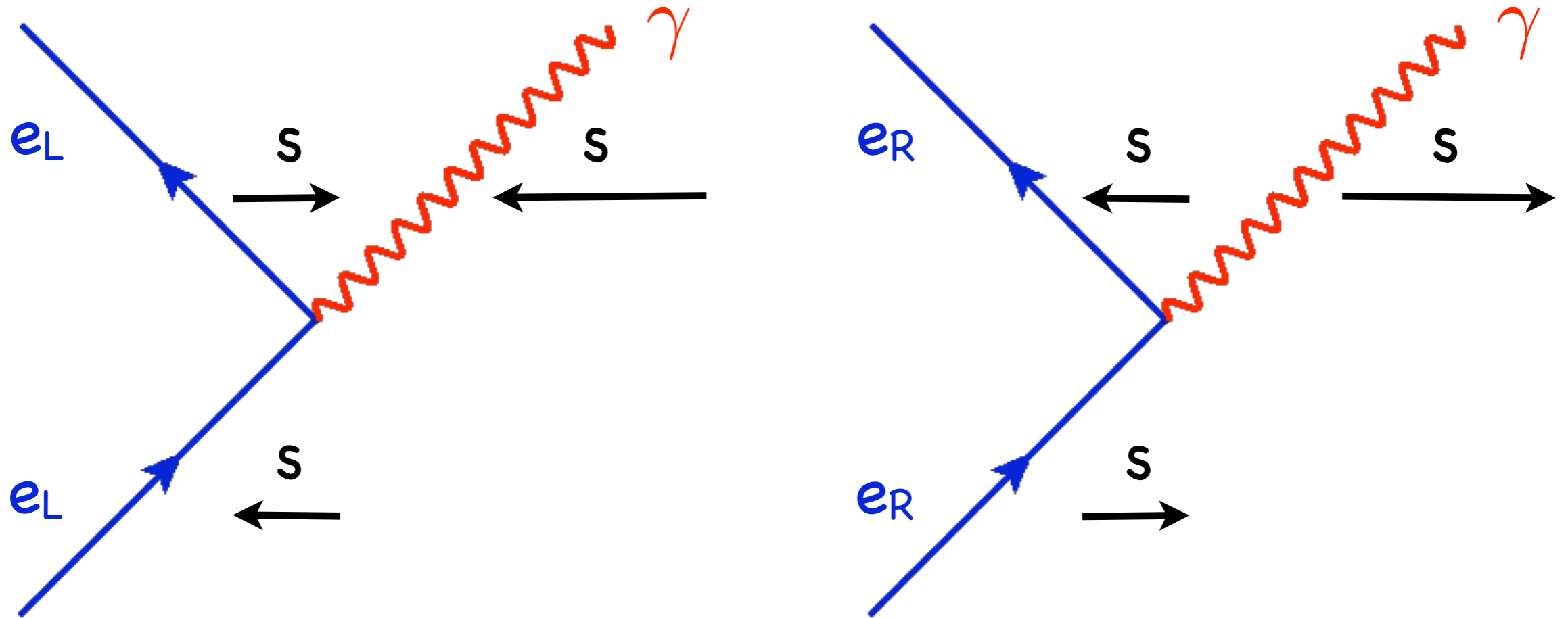


# Feynman Diagrams



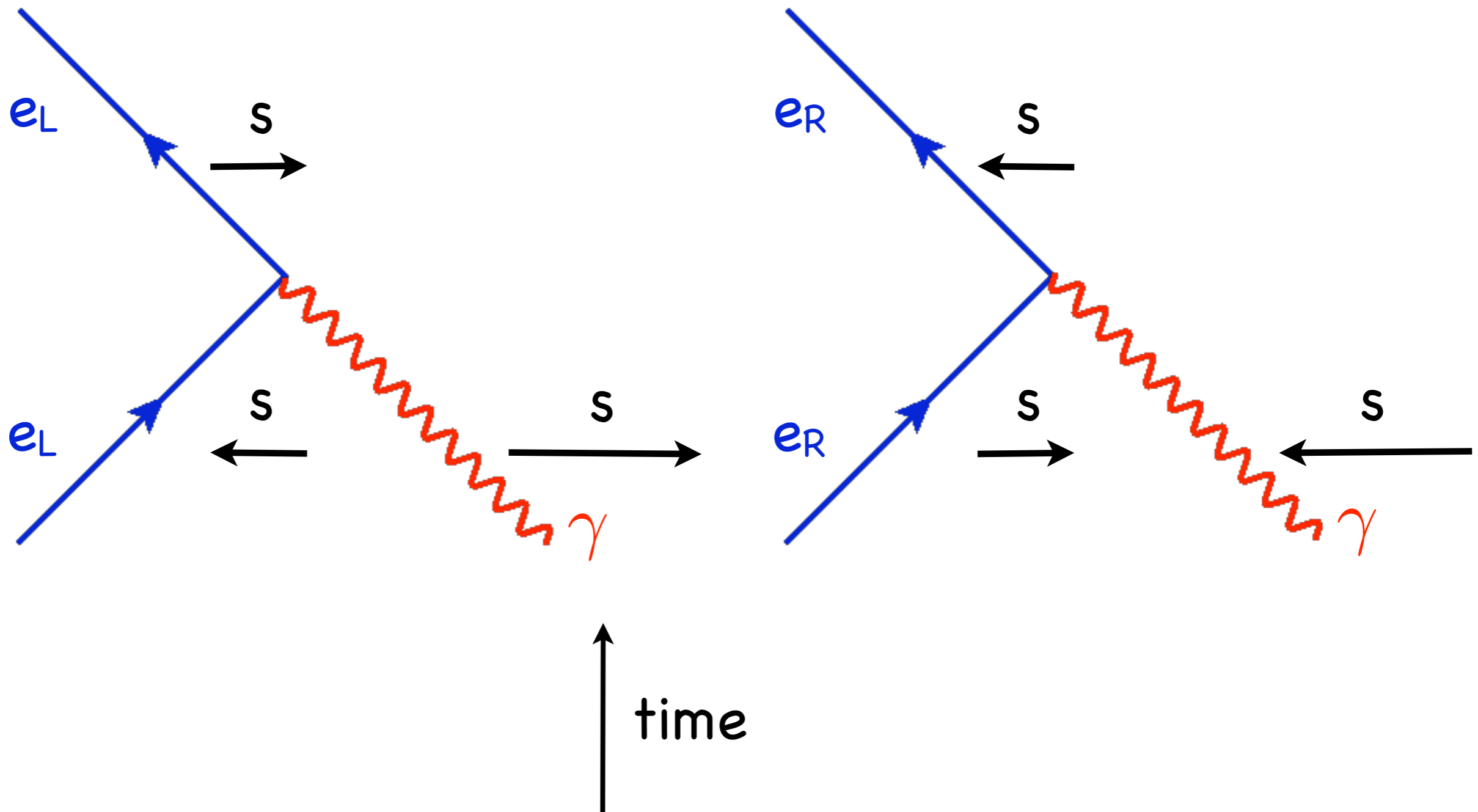


# Emission

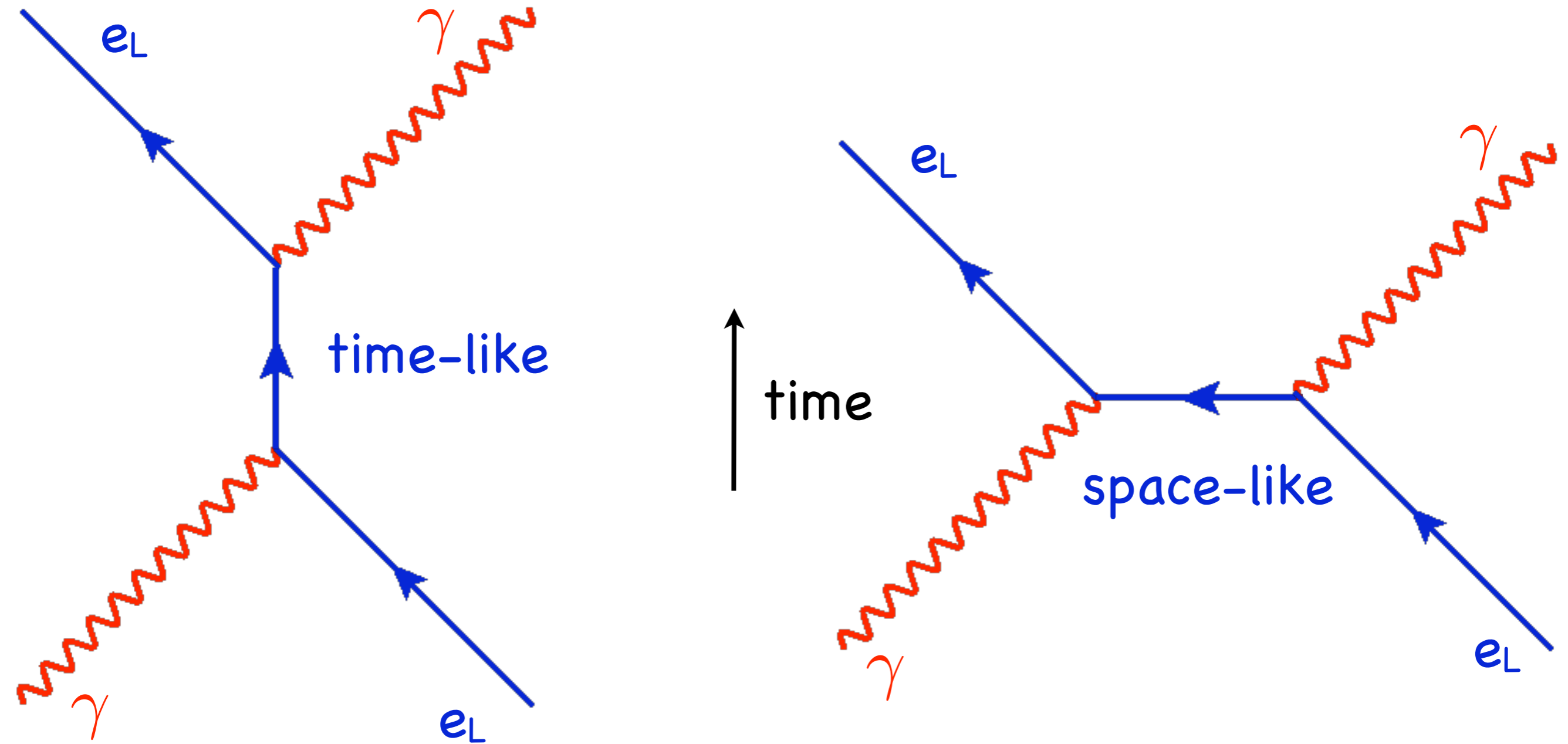


↑  
time

# Absorbtion

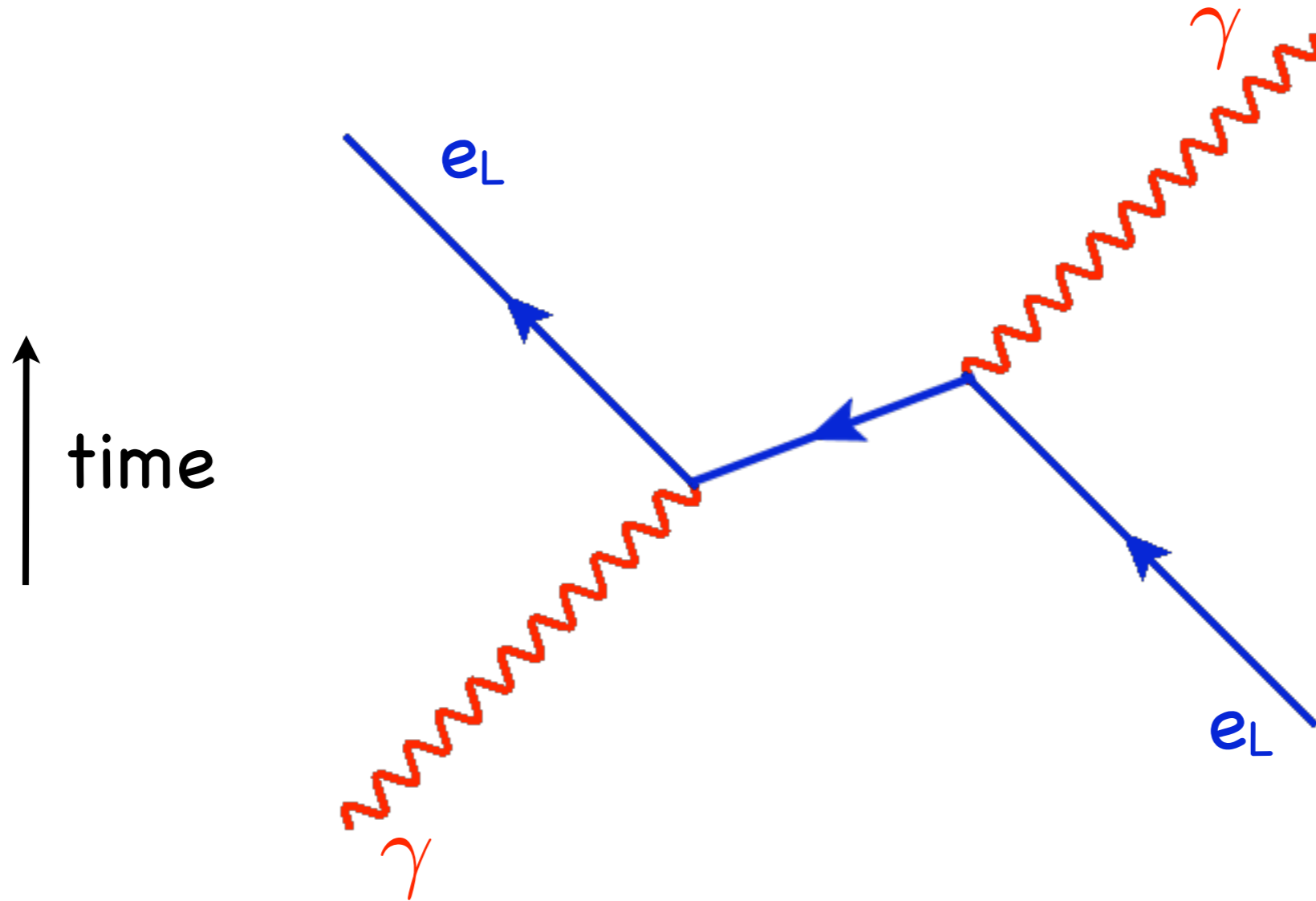


# Scattering

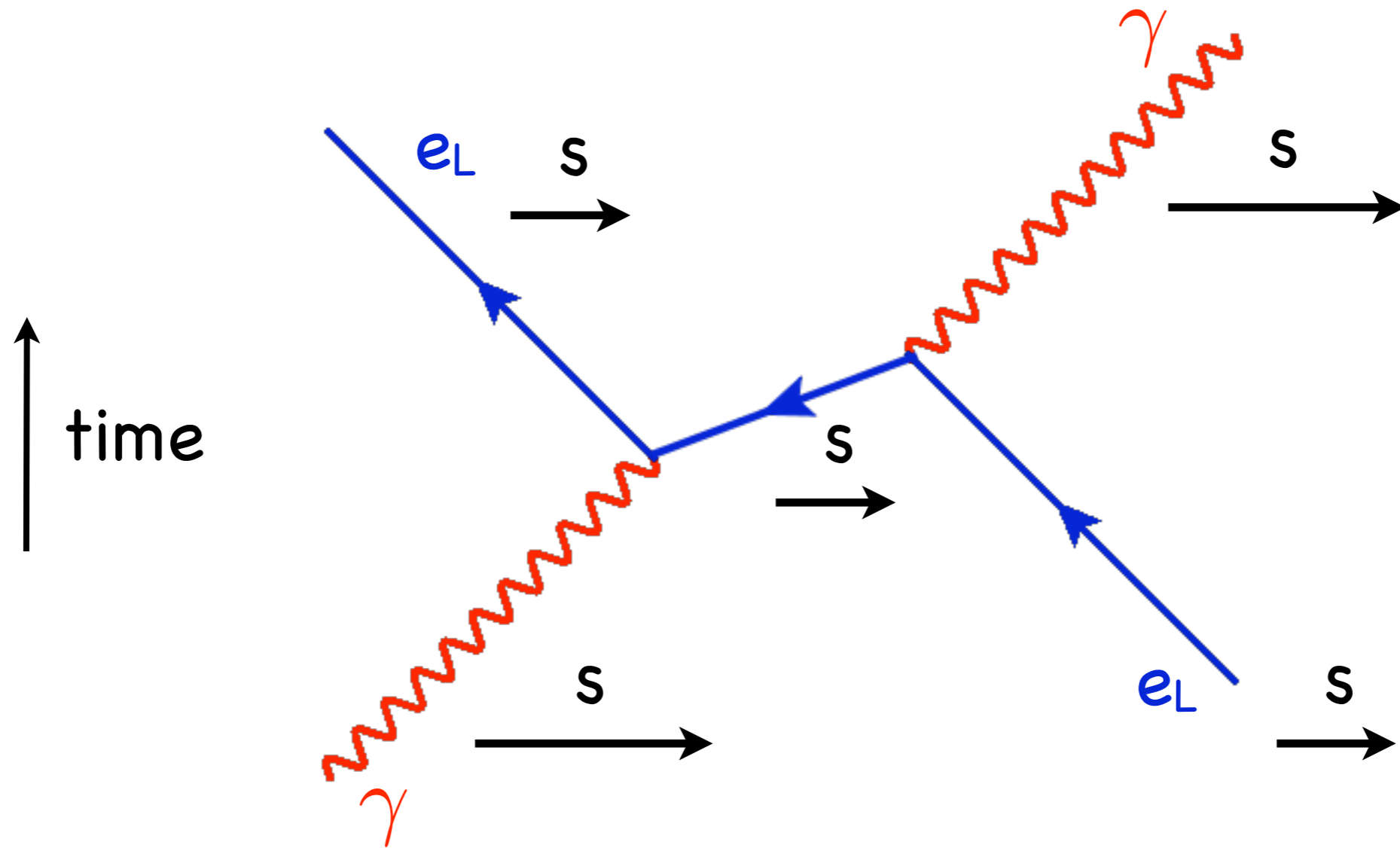


boost changes space or time ordering

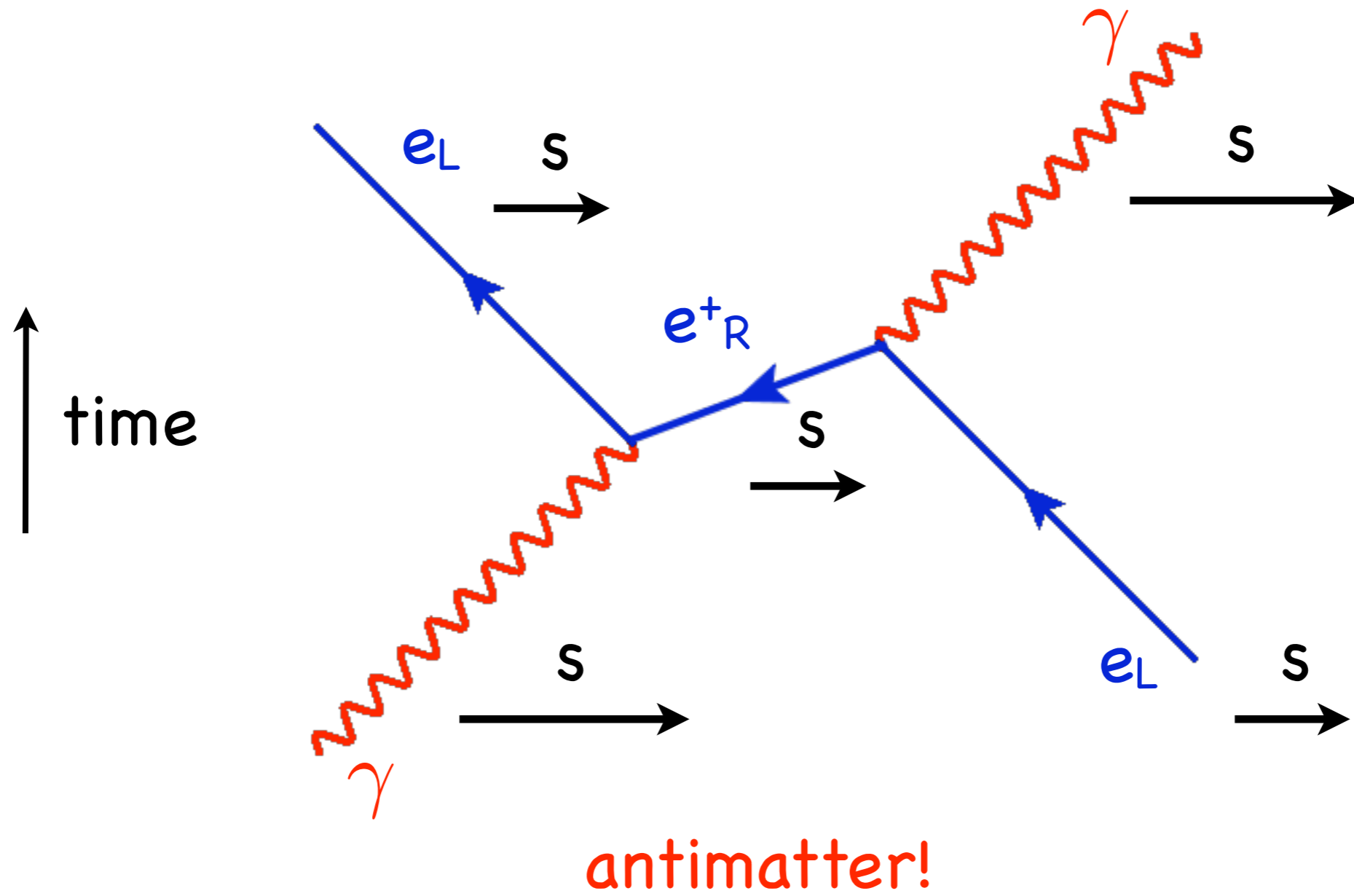
# Scattering



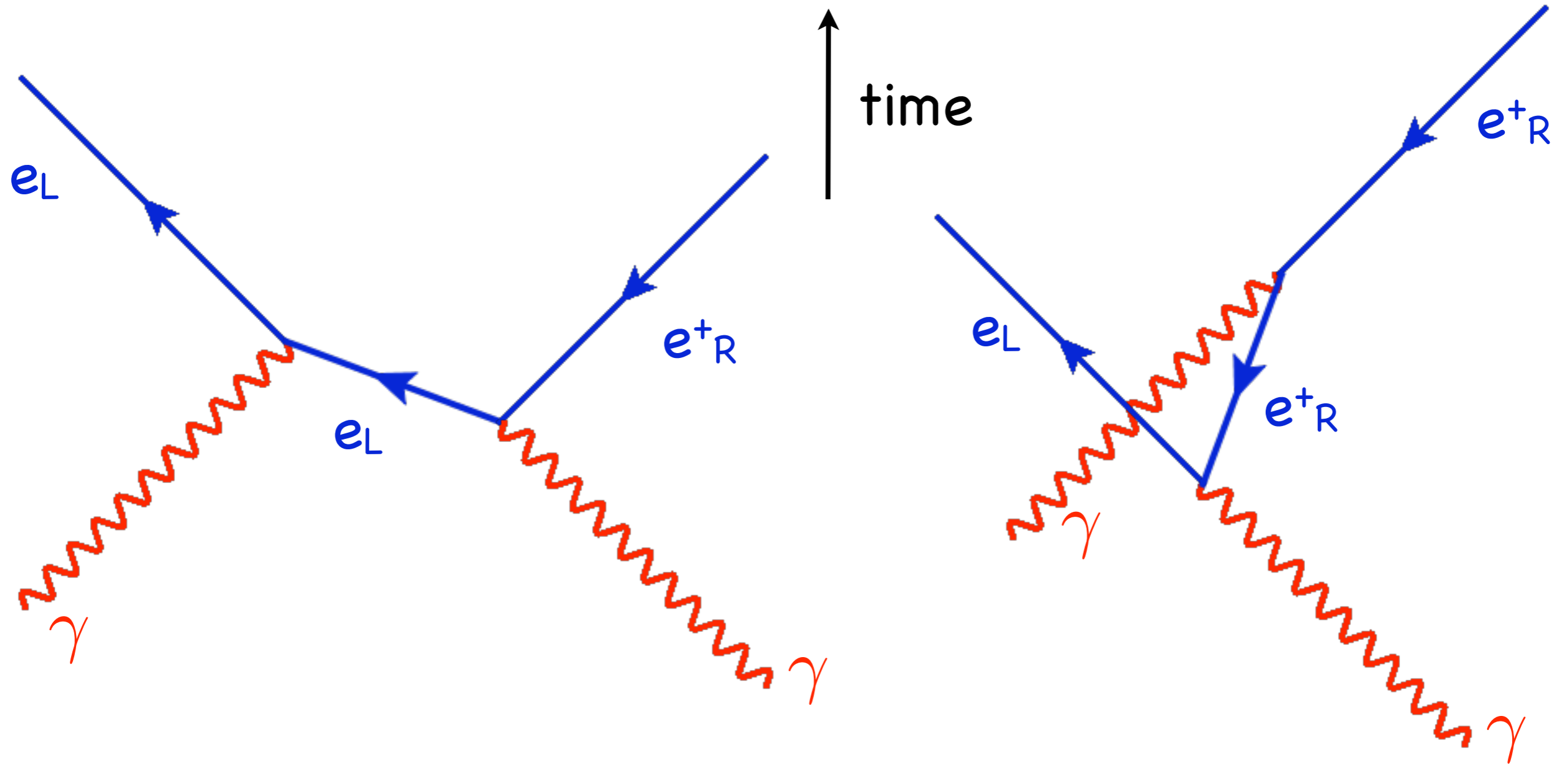
# Scattering



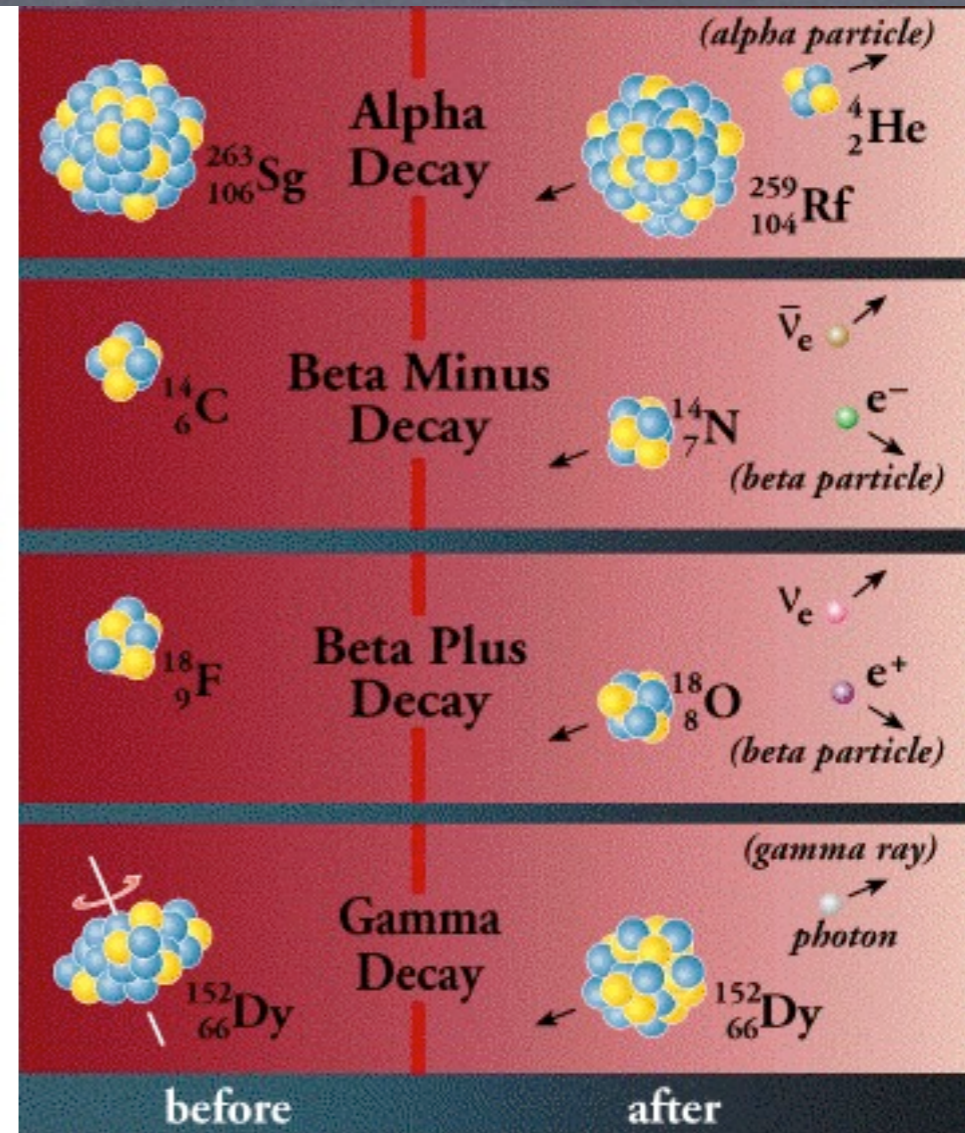
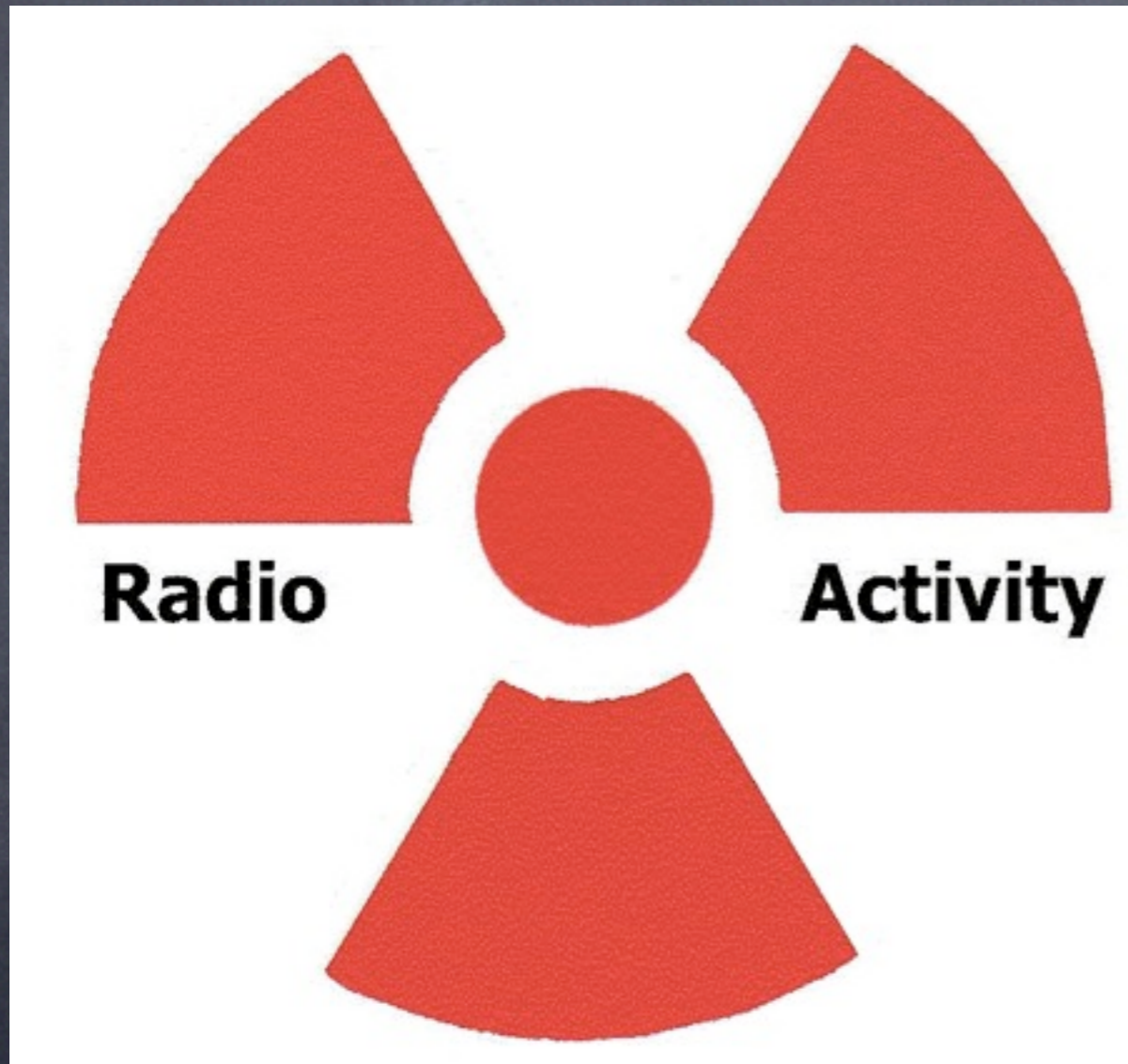
# Scattering



# Pair Creation

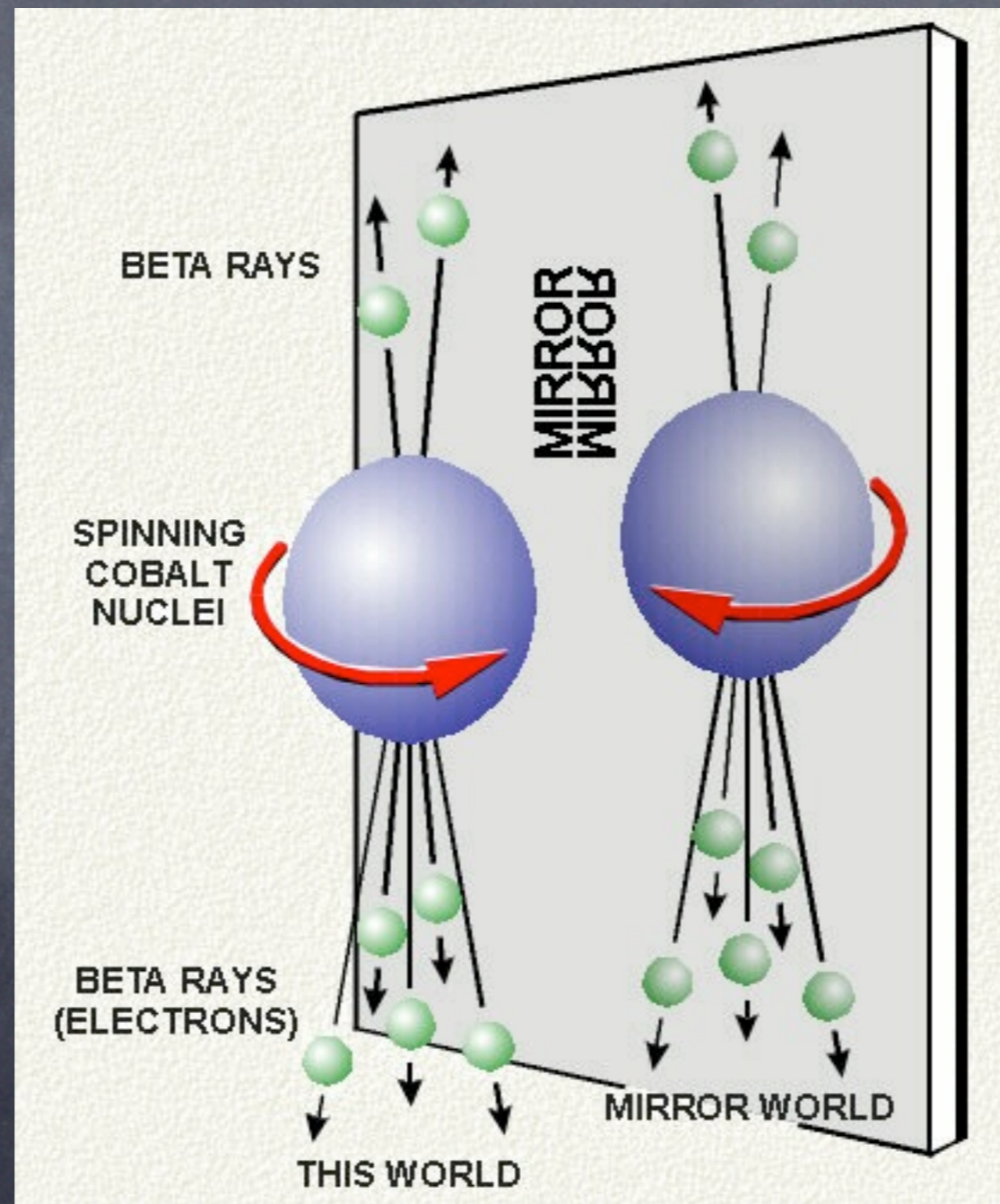


# Radioactivity

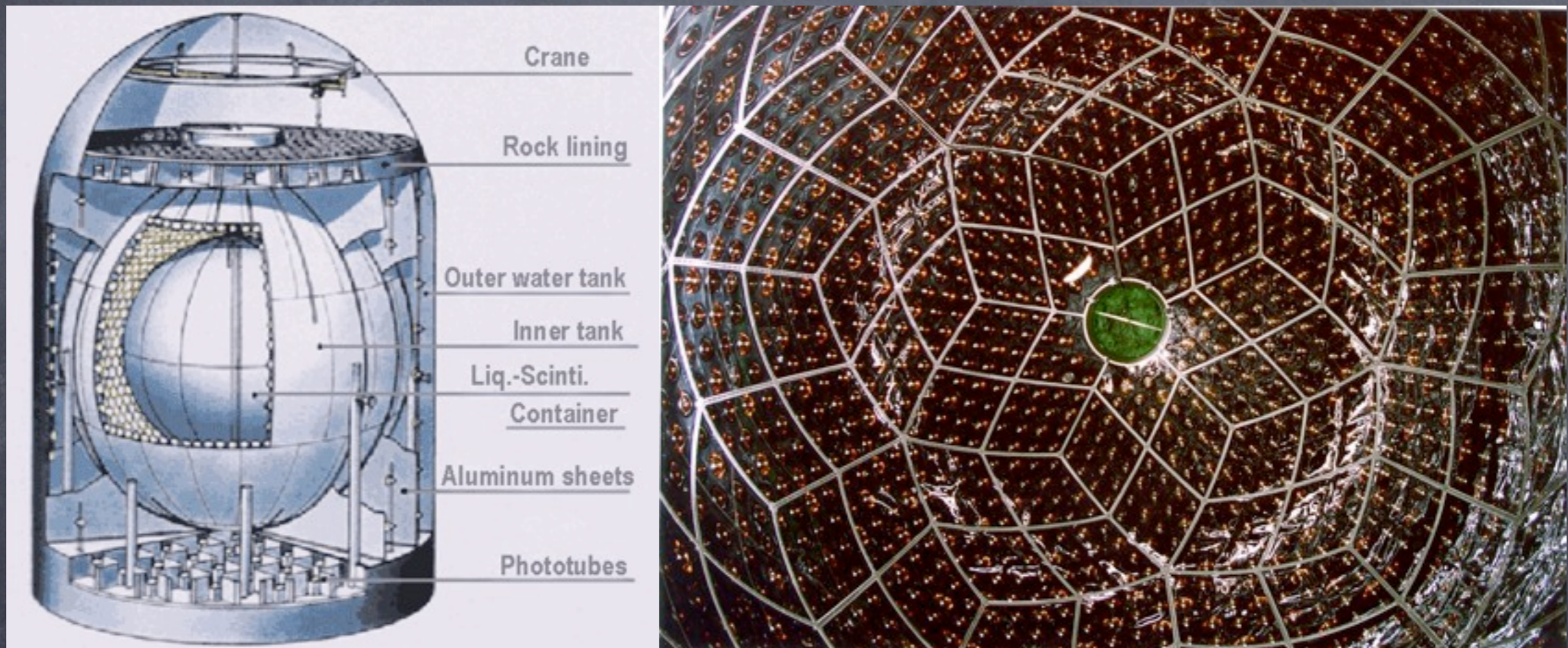




# Weak Interactions

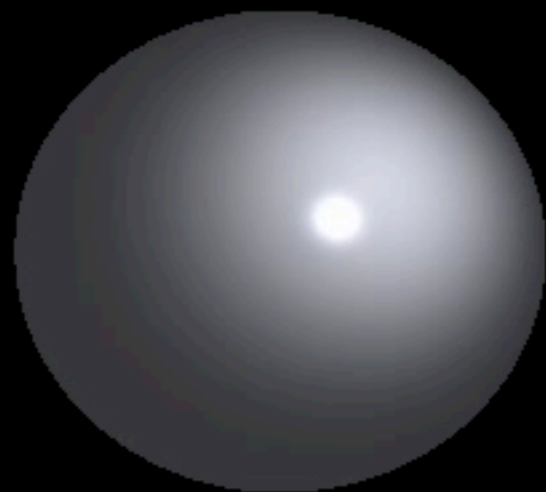


# Radioactivity Heats Earth



16.2 million antineutrinos/square centimetre/second  
streaming out from Earth

# Weak Decays

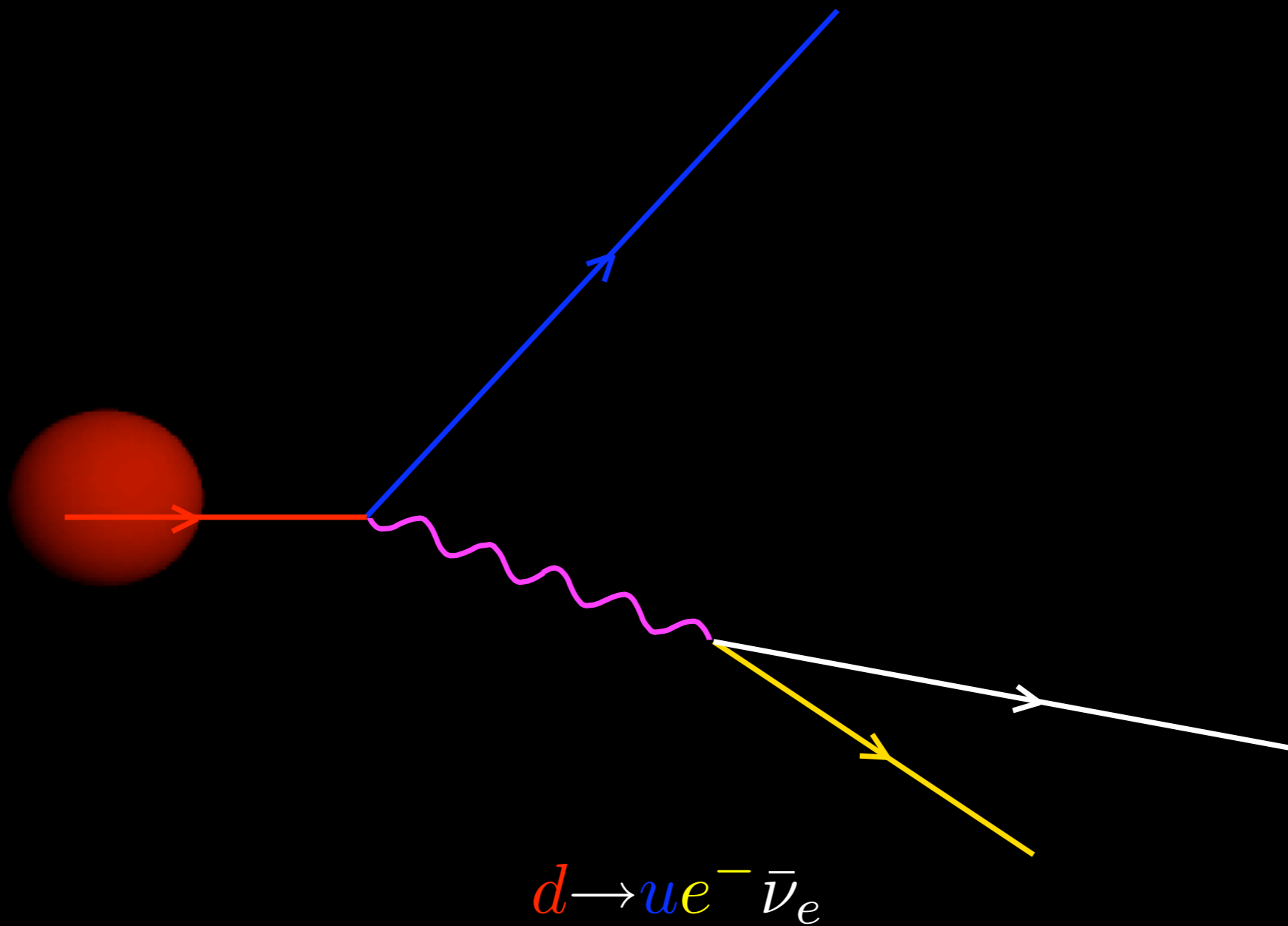


# Weak Decays

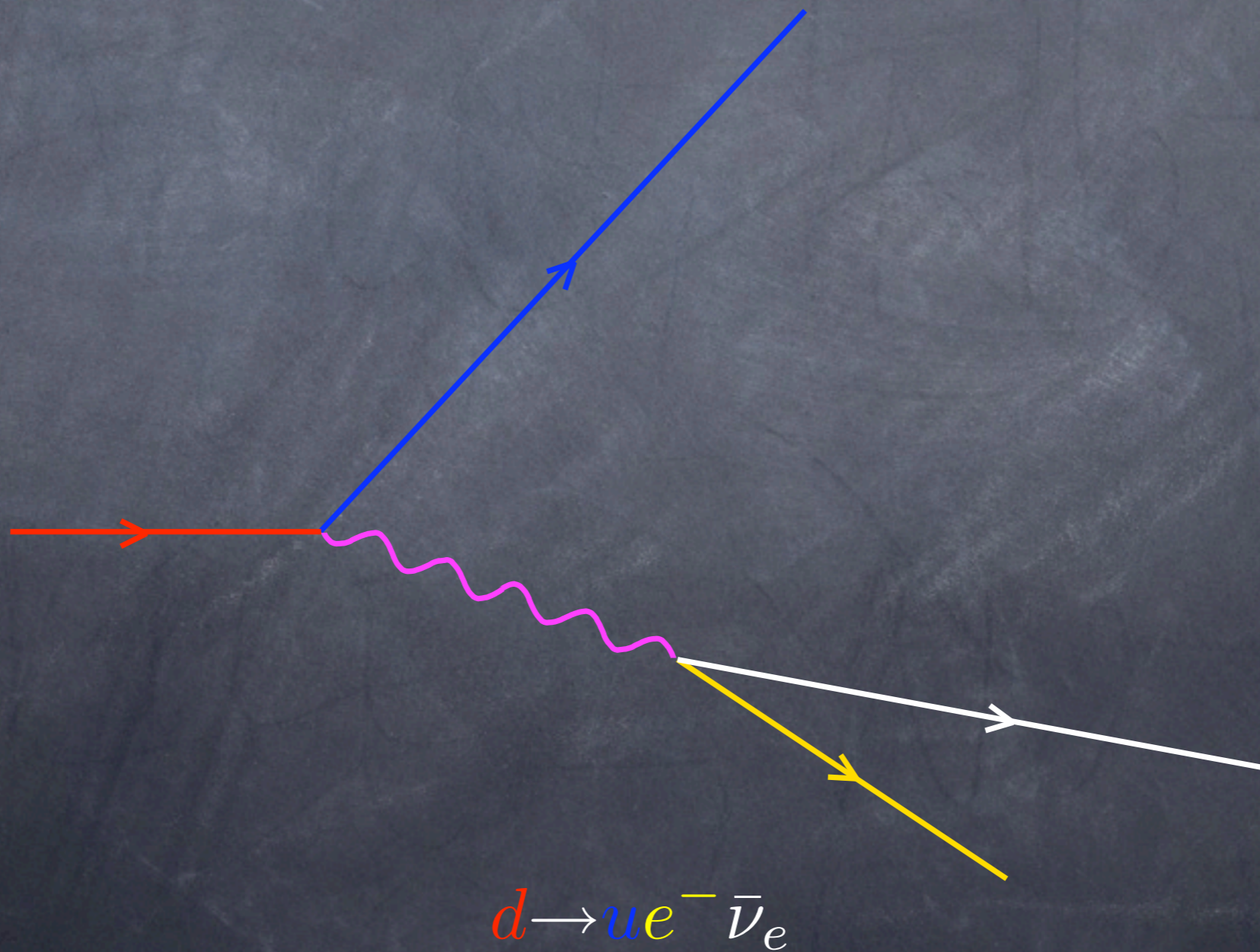


$$d \rightarrow u e^- \bar{\nu}_e$$

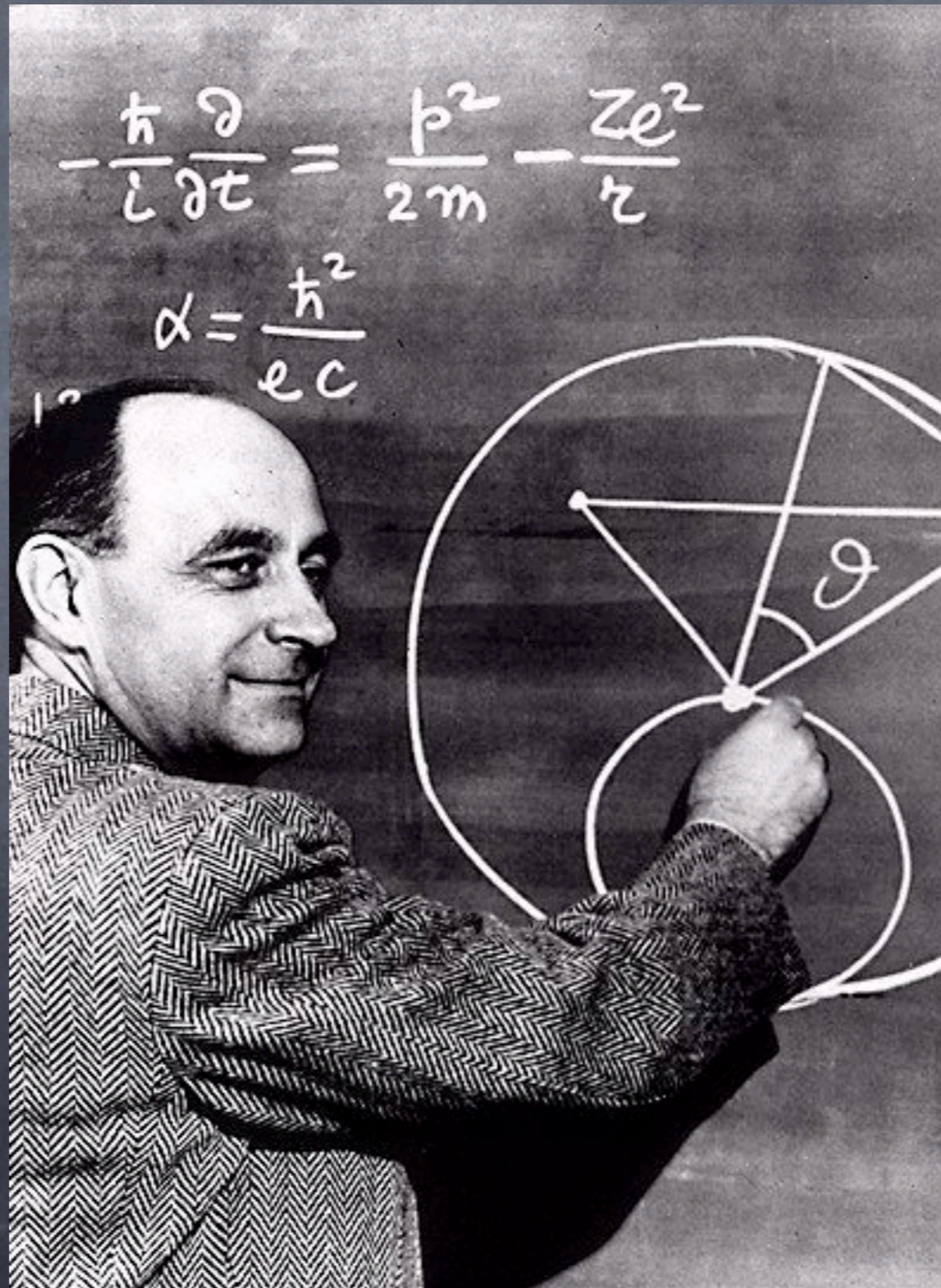
# Weak Decays



# Weak Decays

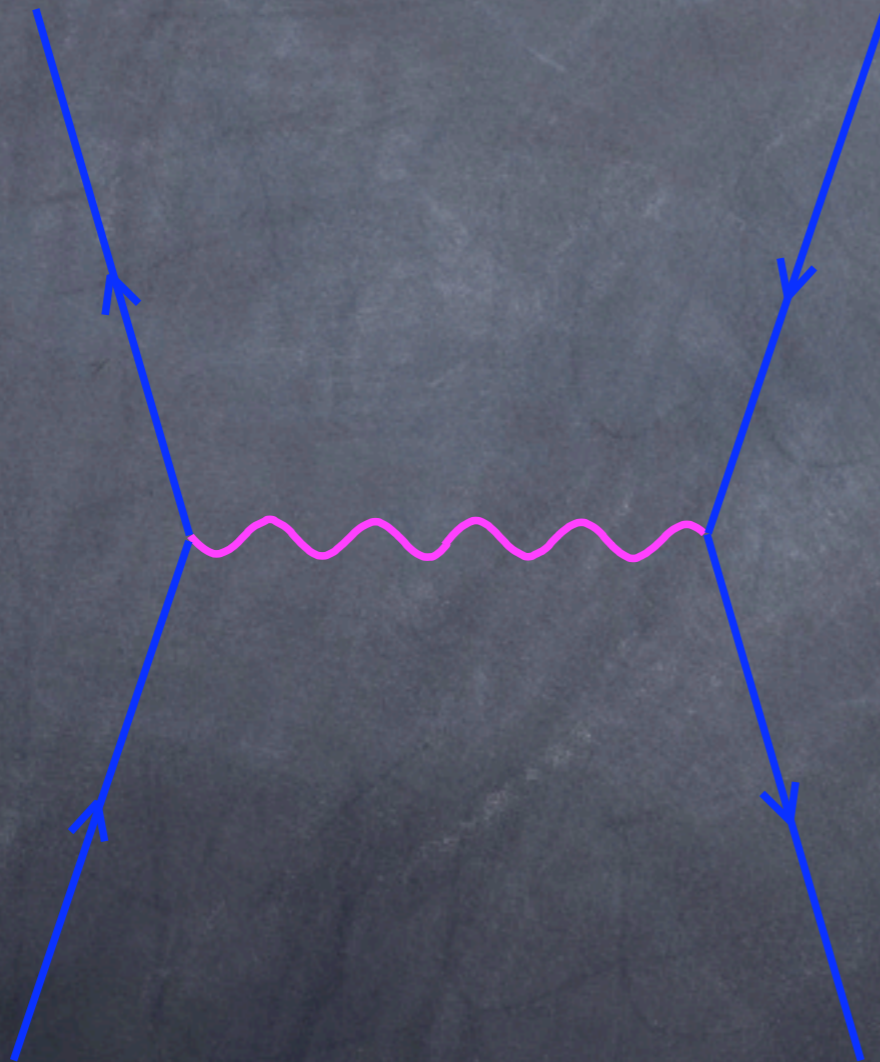


# Fermi's Theory



# Fermi's Theory

QED:



Weak:

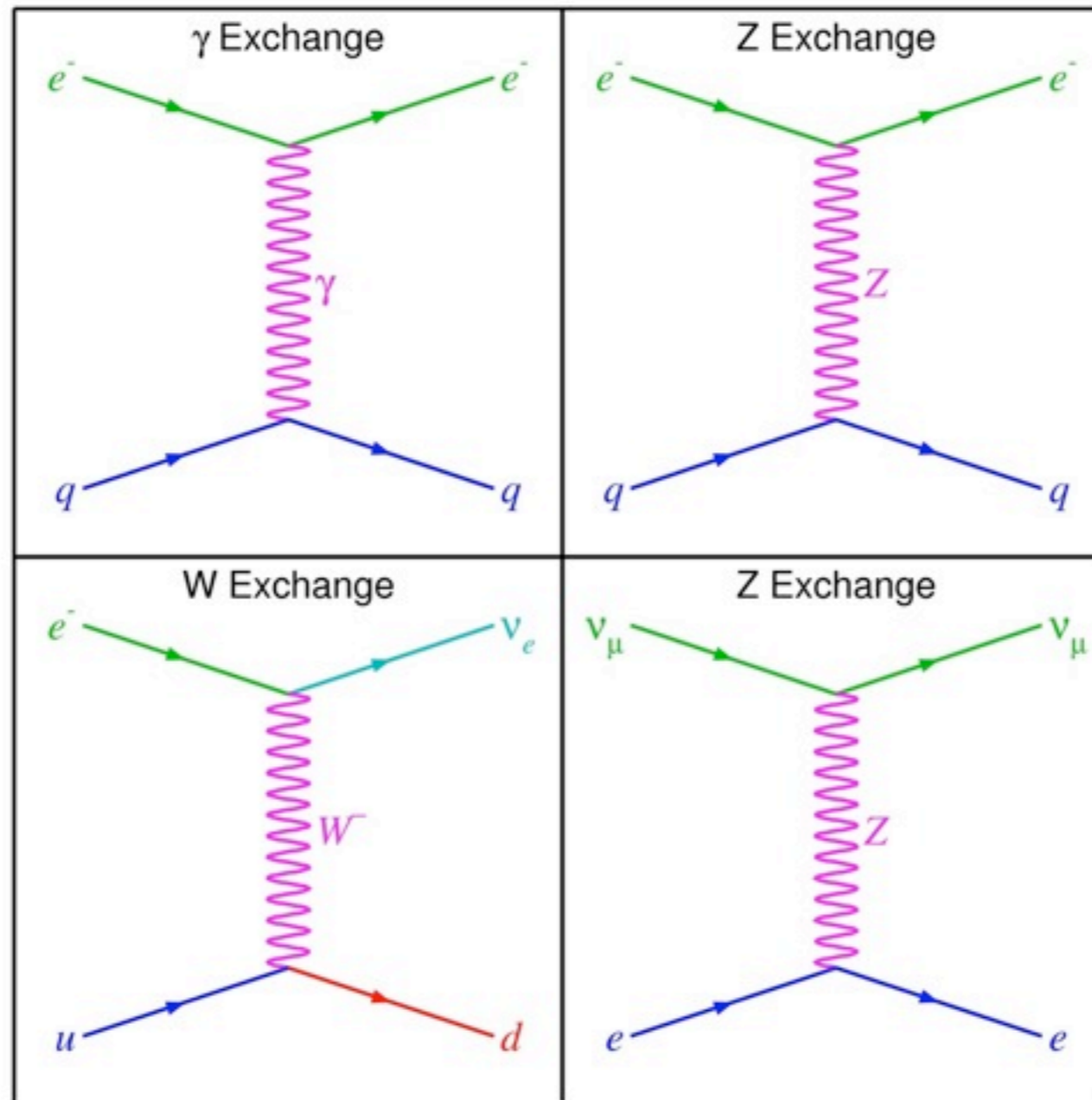




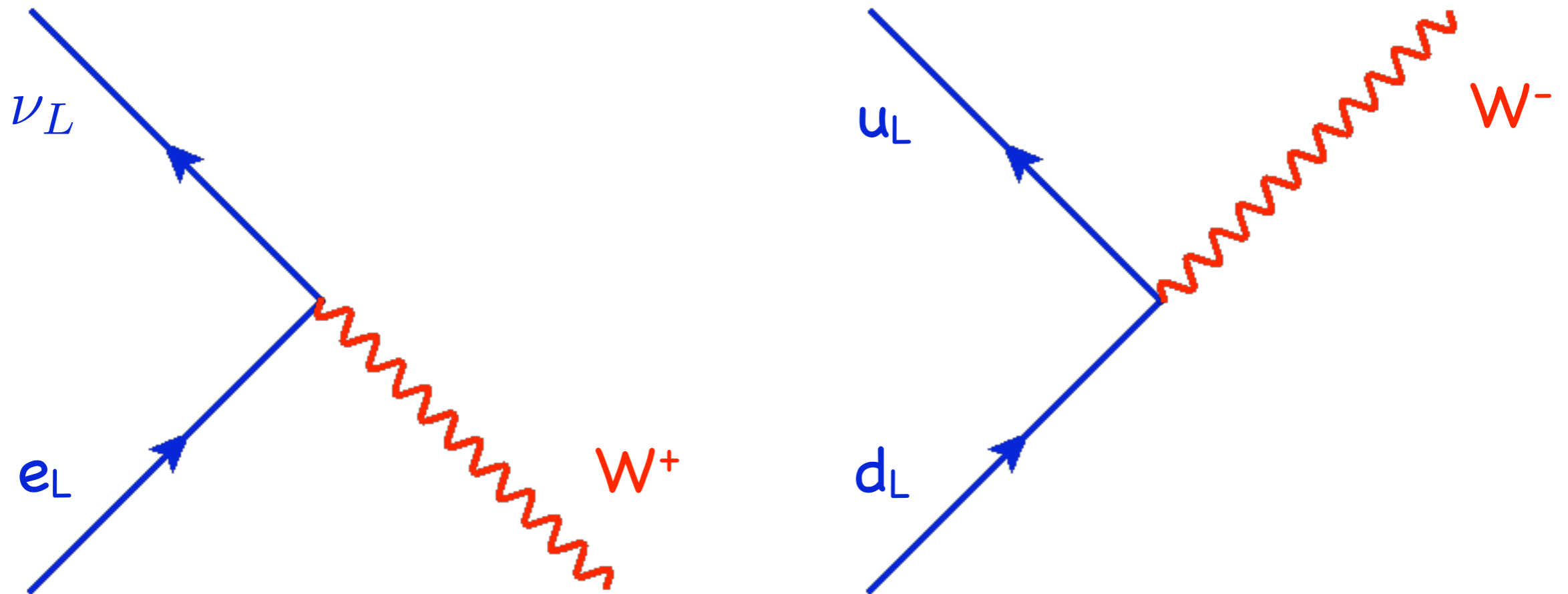
# Glashow, Salam, Weinberg



# Weak Interactions

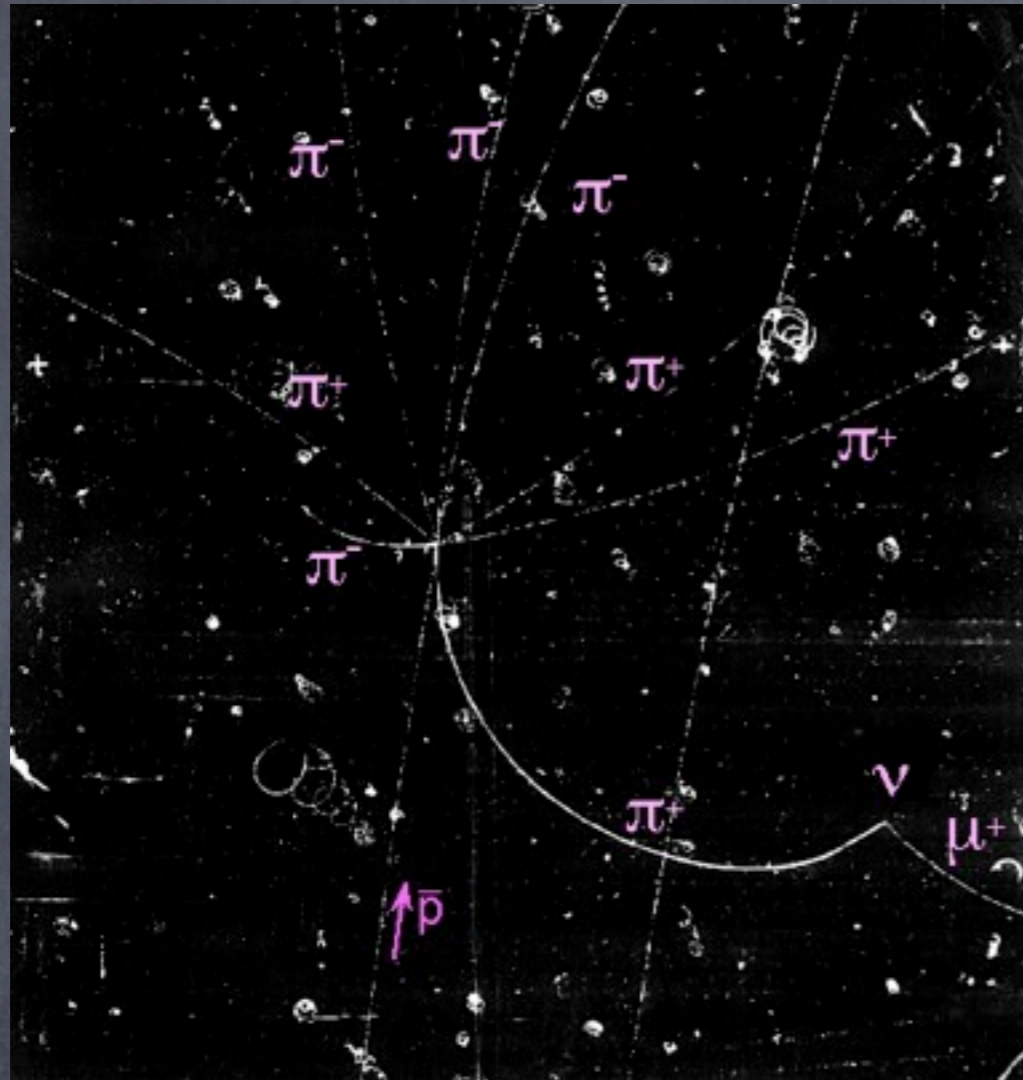


# Weak Charged Interactions

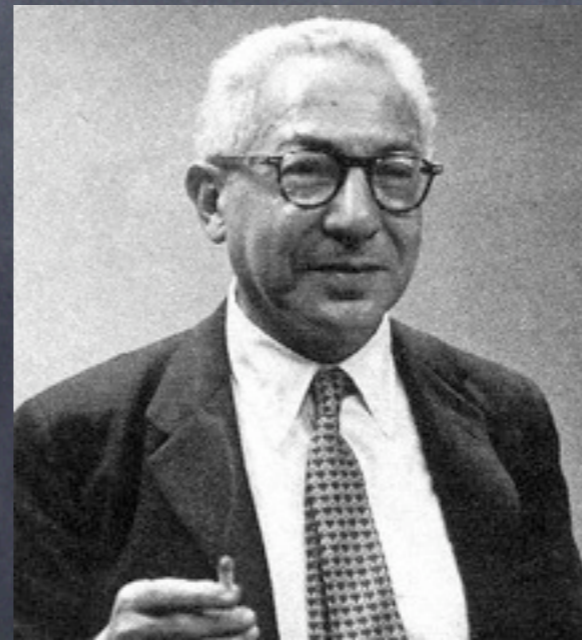


Violates Parity!

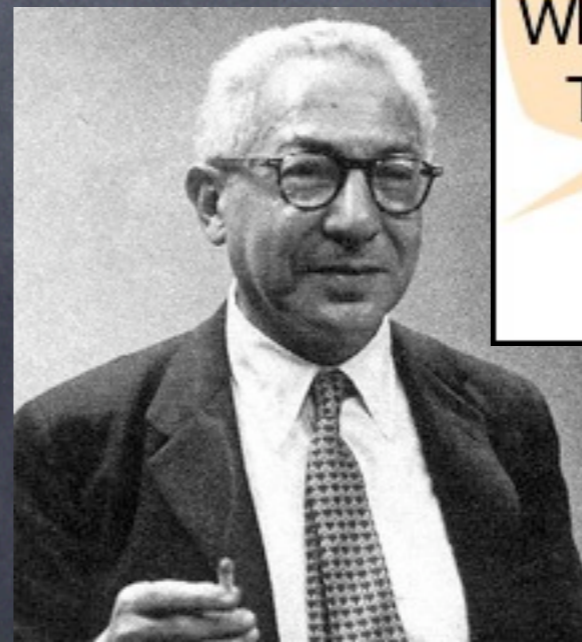
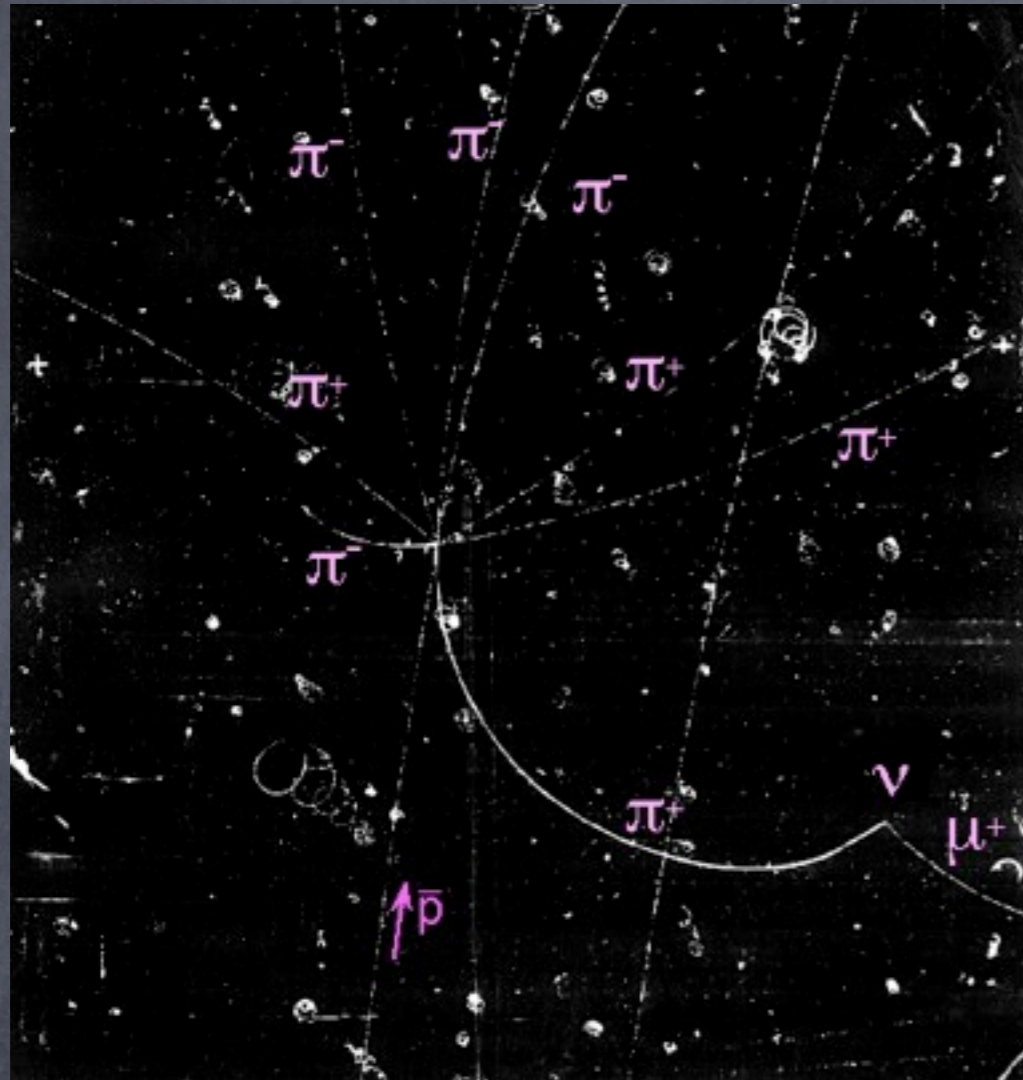
# Pions and Muons



Isidor Isaac Rabi

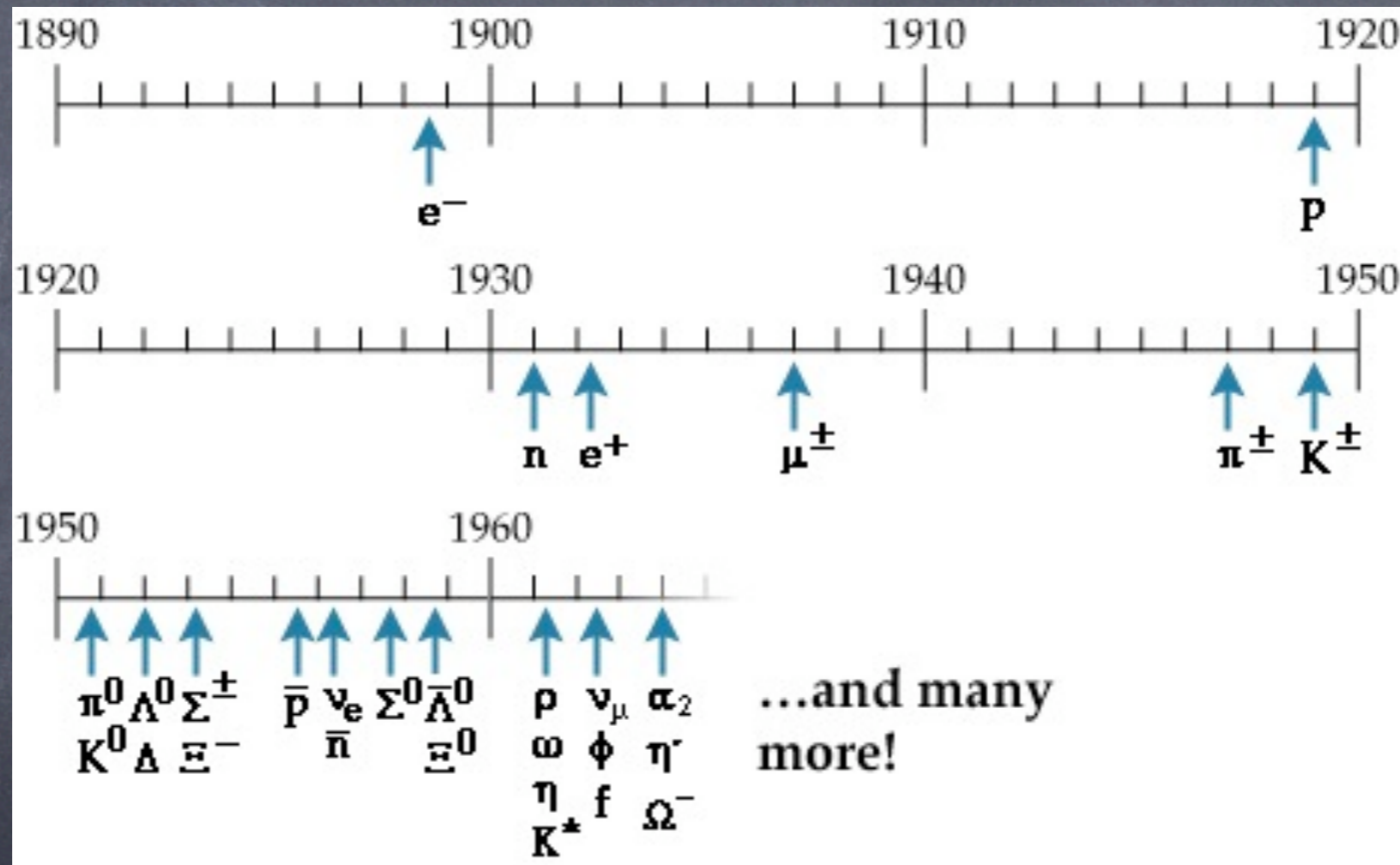


# Pions and Muons

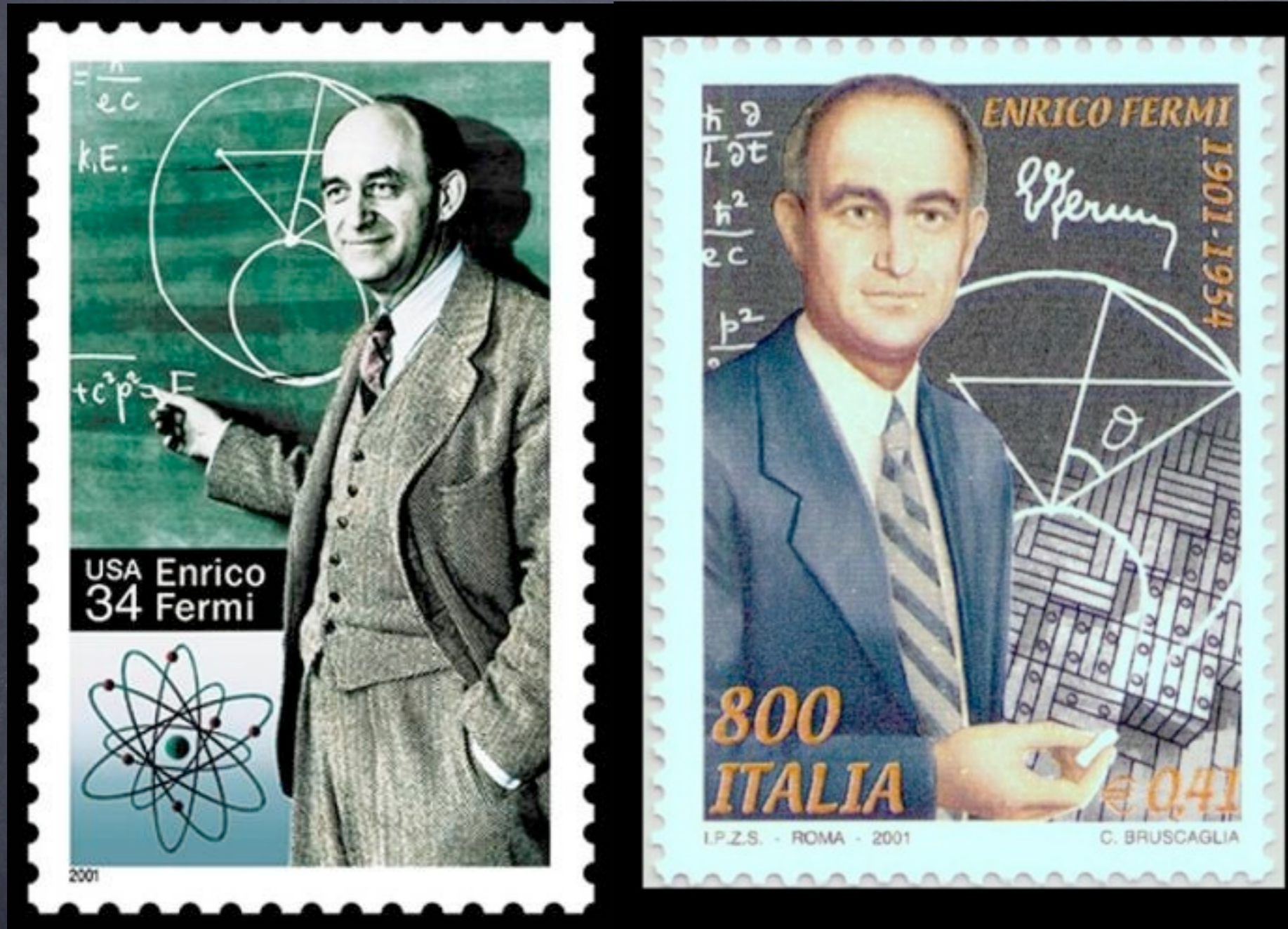


Isidor Isaac Rabi

# Too Many Particles

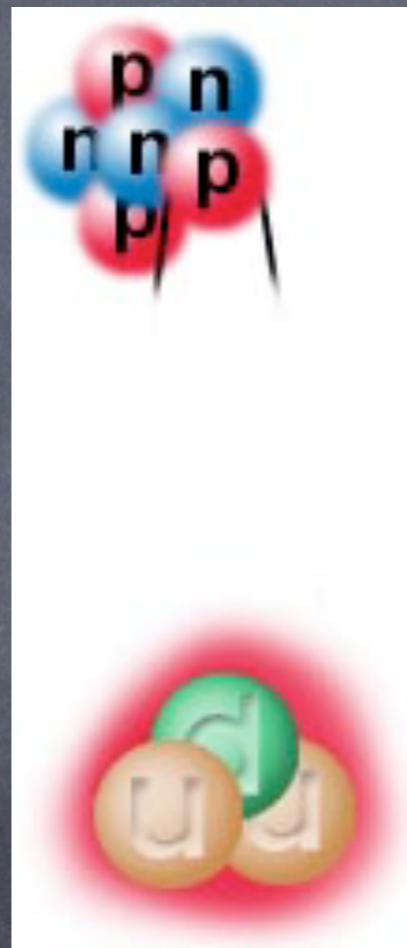


# Too Many Particles



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

# Inside the Proton



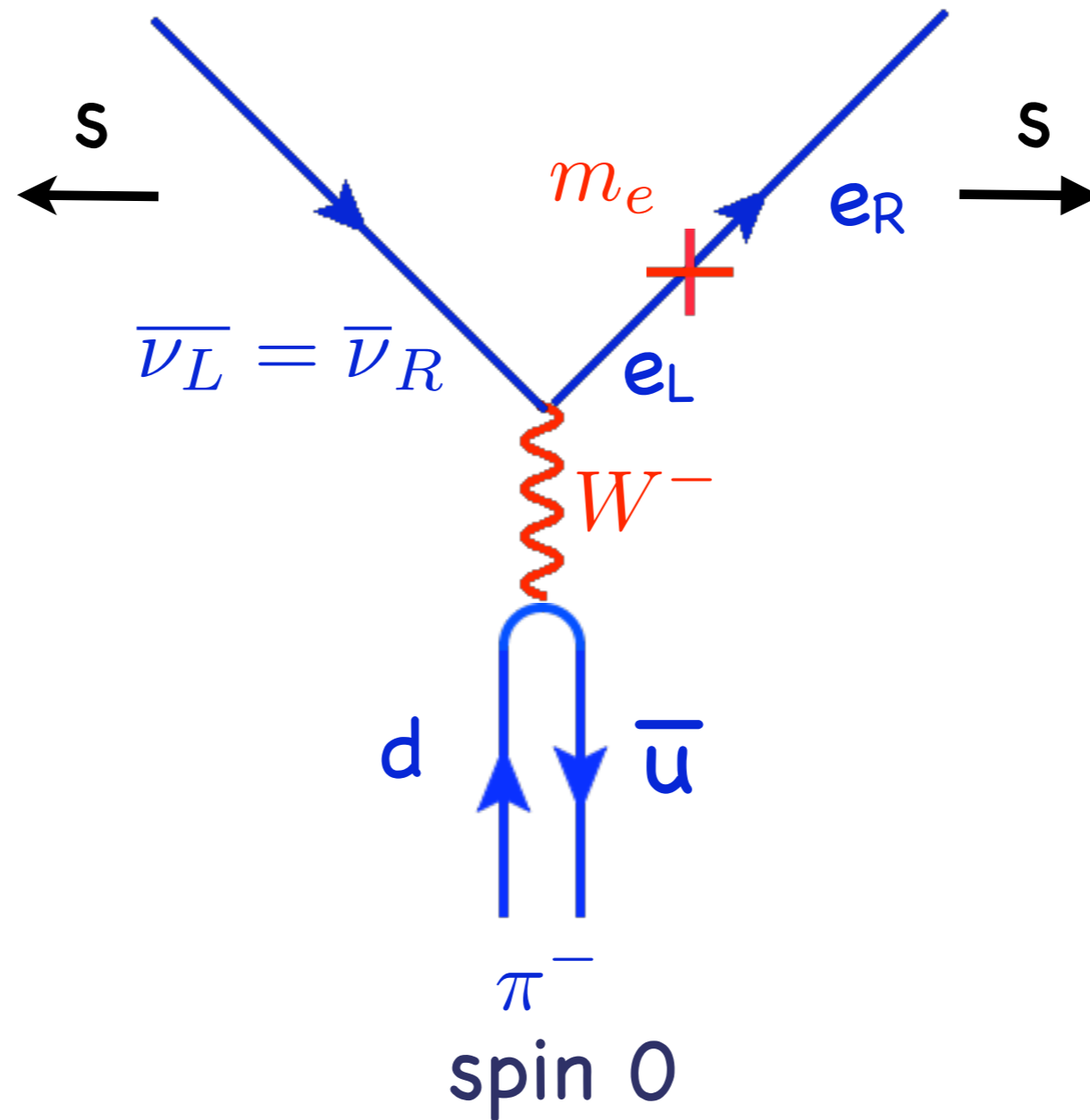


# Quarks



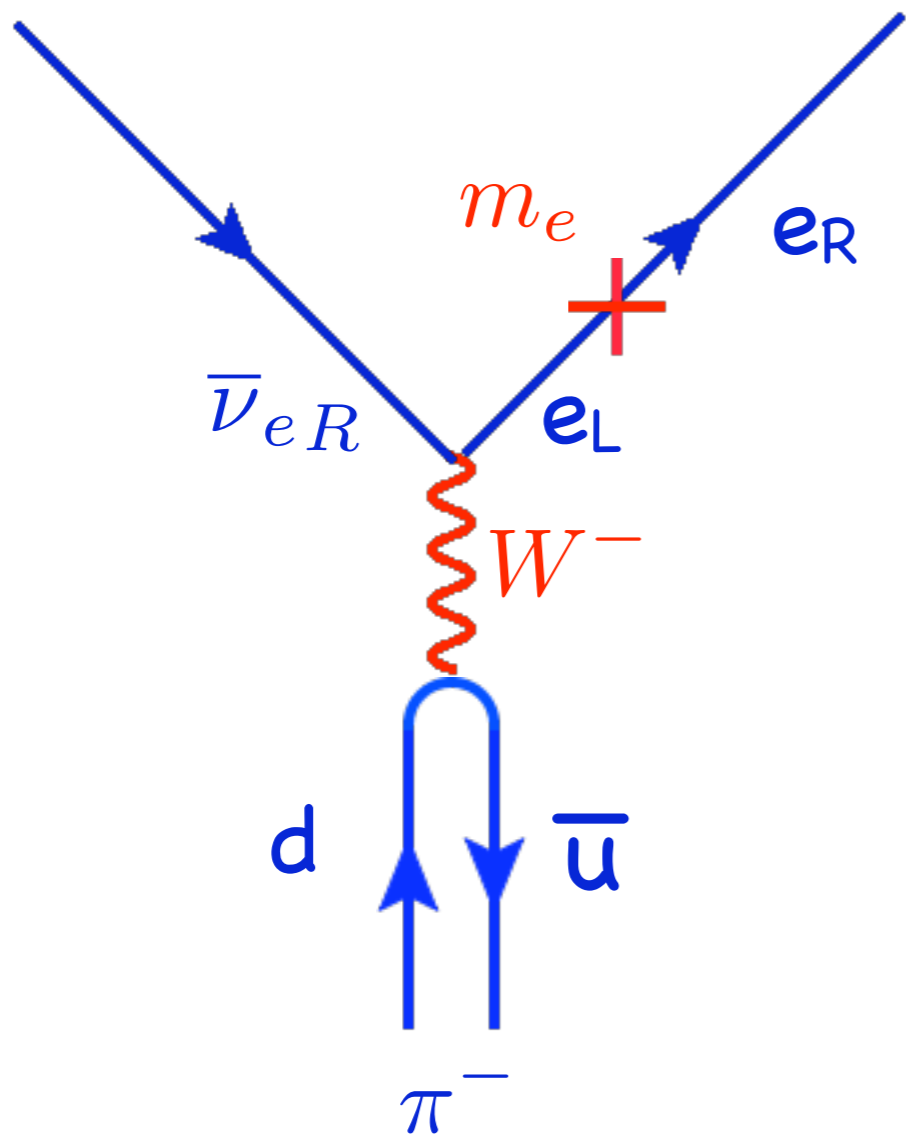
**"Three quarks for Muster Mark!"**

# Charged Pion Decay

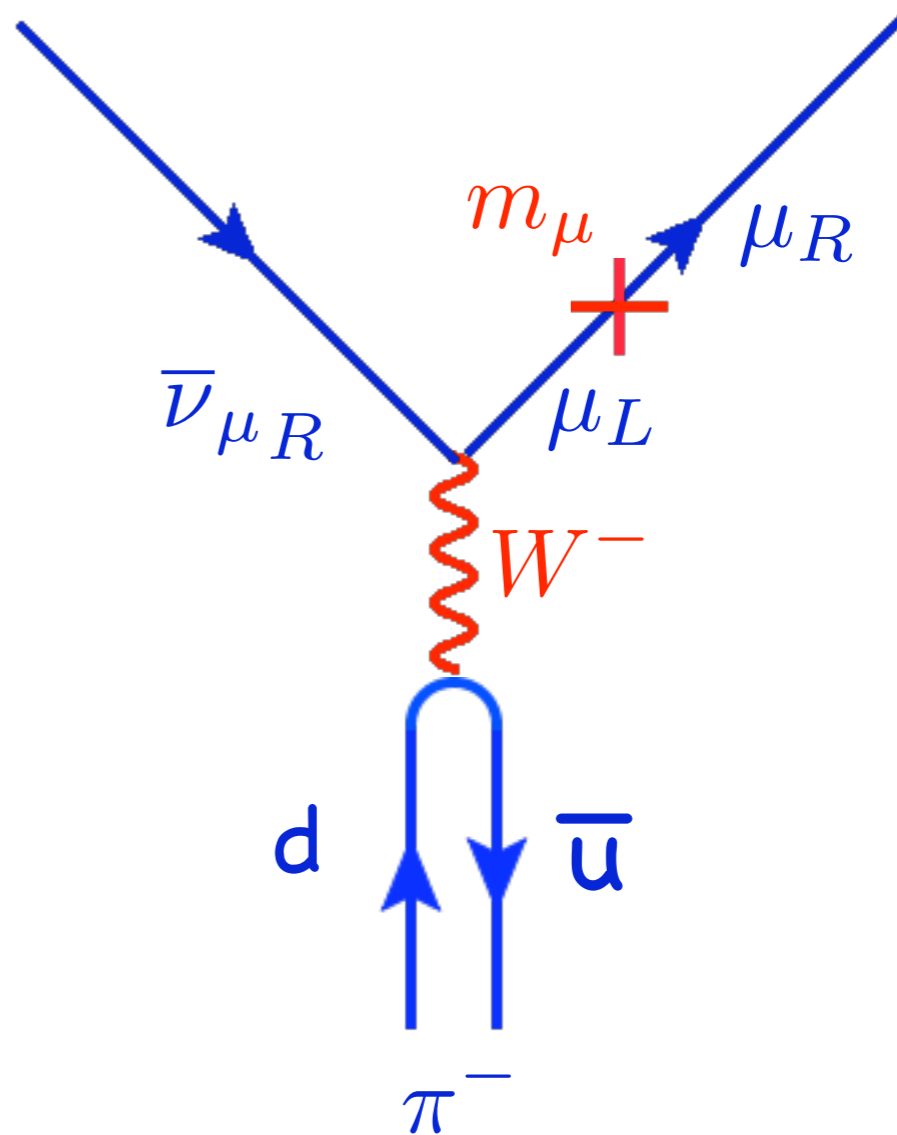


Prob. amplitude proportional to electron mass

# Charged Pion Decay

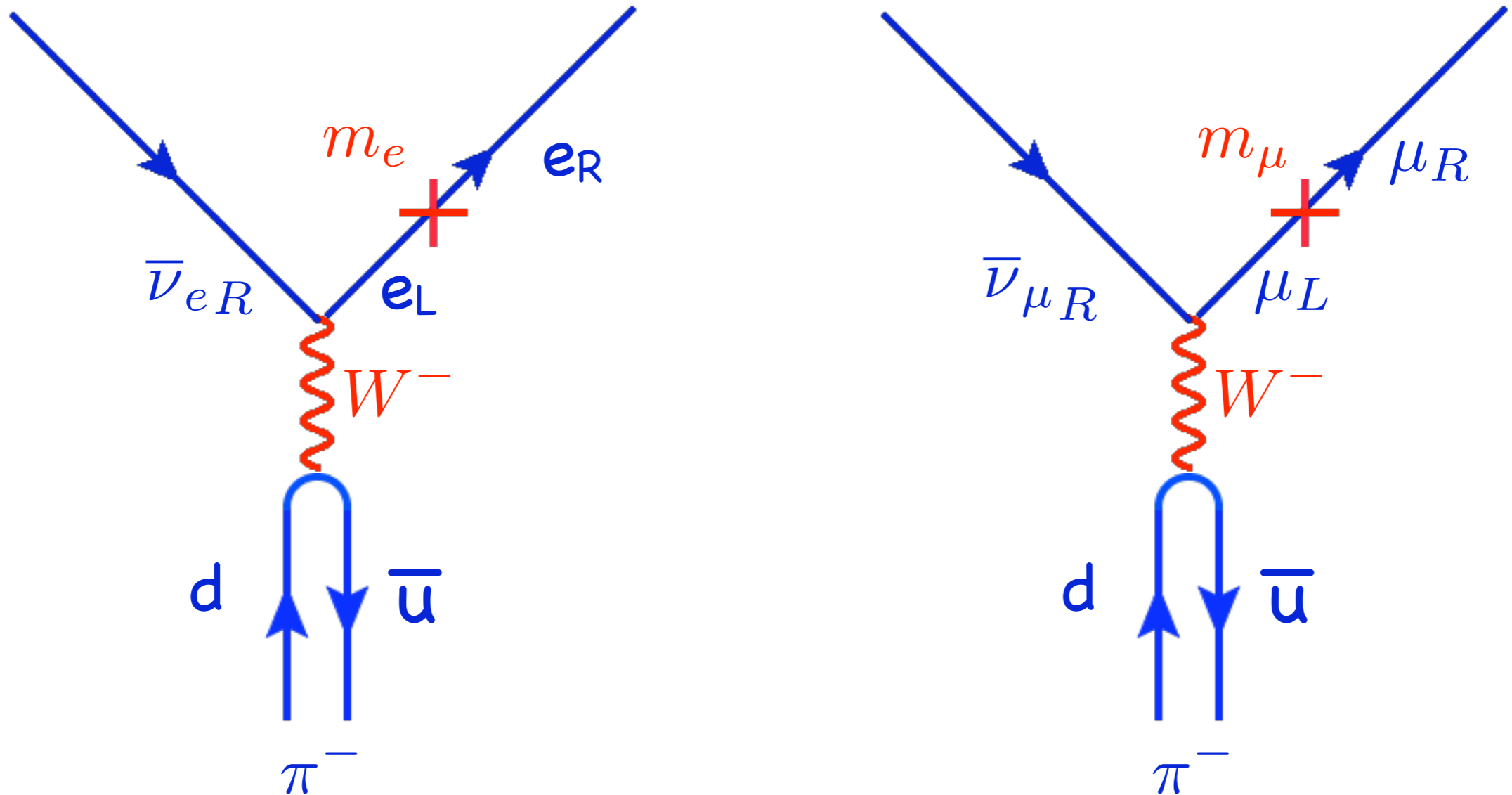


Probability:  $\propto m_e^2$



$\propto m_\mu^2$

# Charged Pion Decay

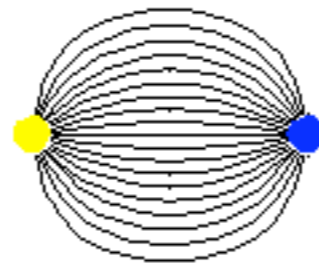


Probability:  $\propto m_e^2$

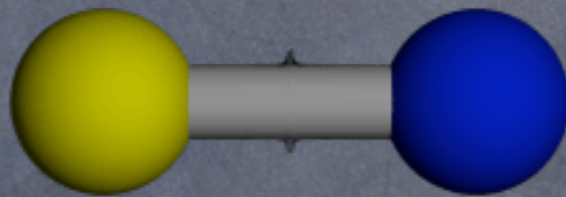
$\propto m_\mu^2$

Experimentally ratio is  $10^{-4}$

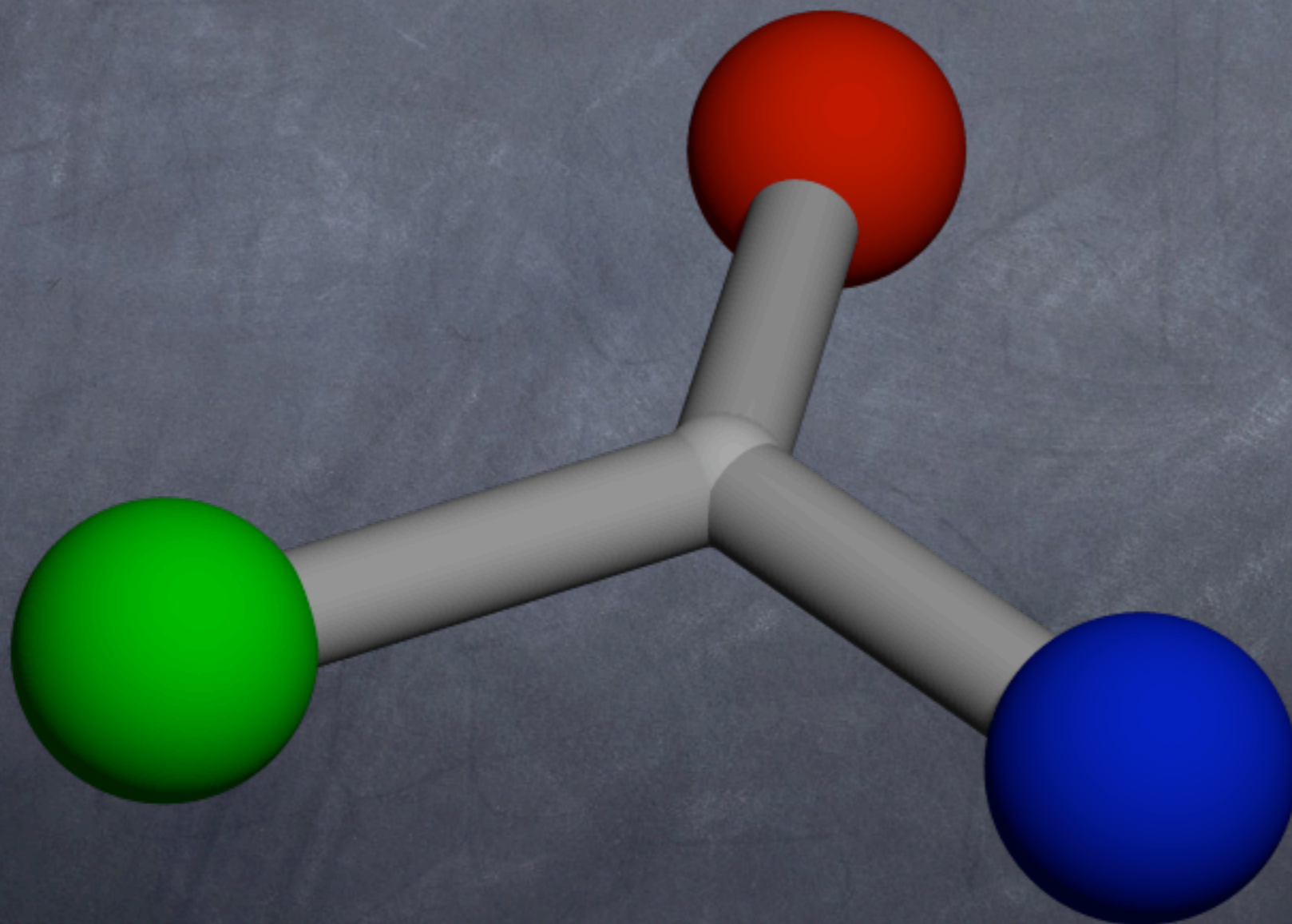
# Color Fields



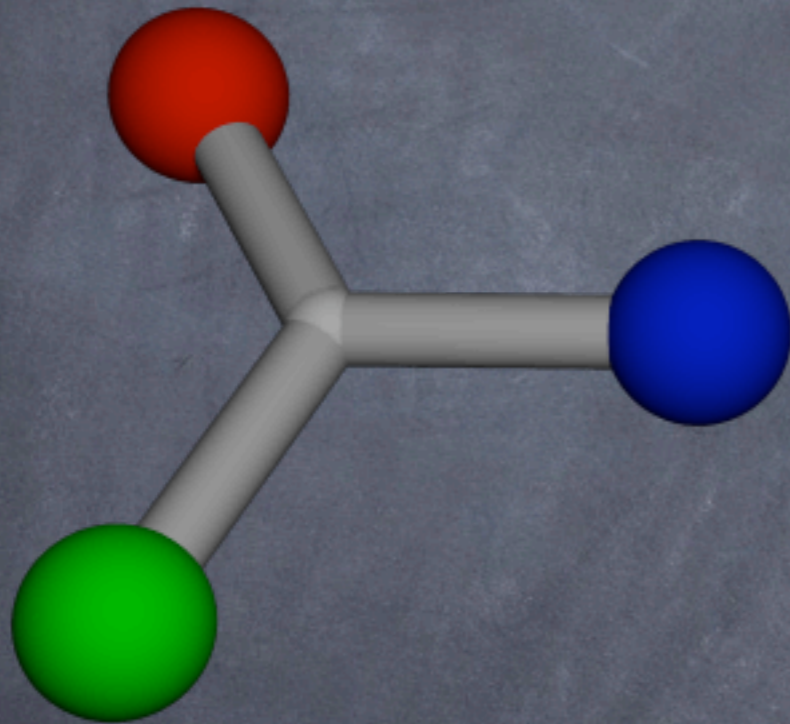
# Flux Tube or String



# Proton

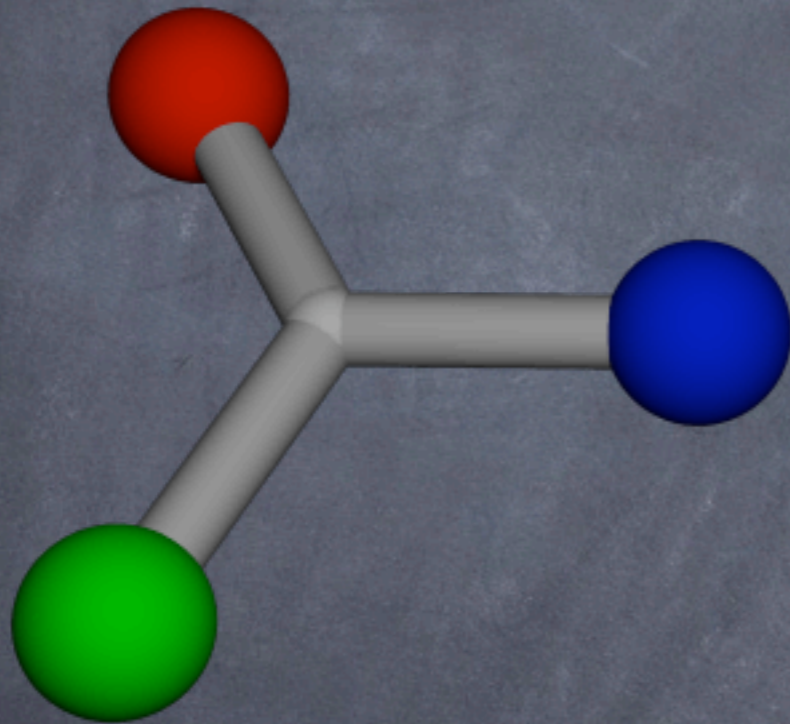


# Flux Tube Breaking





# Flux Tube Breaking



If quarks and gluons are confined,  
how do we know they exist?

# Generations

Quarks	$u$ up	$c$ charm	$t$ top
	$d$ down	$s$ strange	$b$ bottom
Leptons	$\nu_e$ e- Neutrino	$\nu_\mu$ $\mu$ - Neutrino	$\nu_\tau$ $\tau$ - Neutrino
	$e$ electron	$\mu$ muon	$\tau$ tau
	I	II	III

The Generations of Matter

# Quark Bound States

## Baryons $qqq$ and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.  
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass $\text{GeV}/c^2$	Spin
$p$	proton	$uud$	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
$n$	neutron	$udd$	0	0.940	1/2
$\Lambda$	lambda	$uds$	0	1.116	1/2
$\Omega^-$	omega	$sss$	-1	1.672	3/2

## Mesons $q\bar{q}$

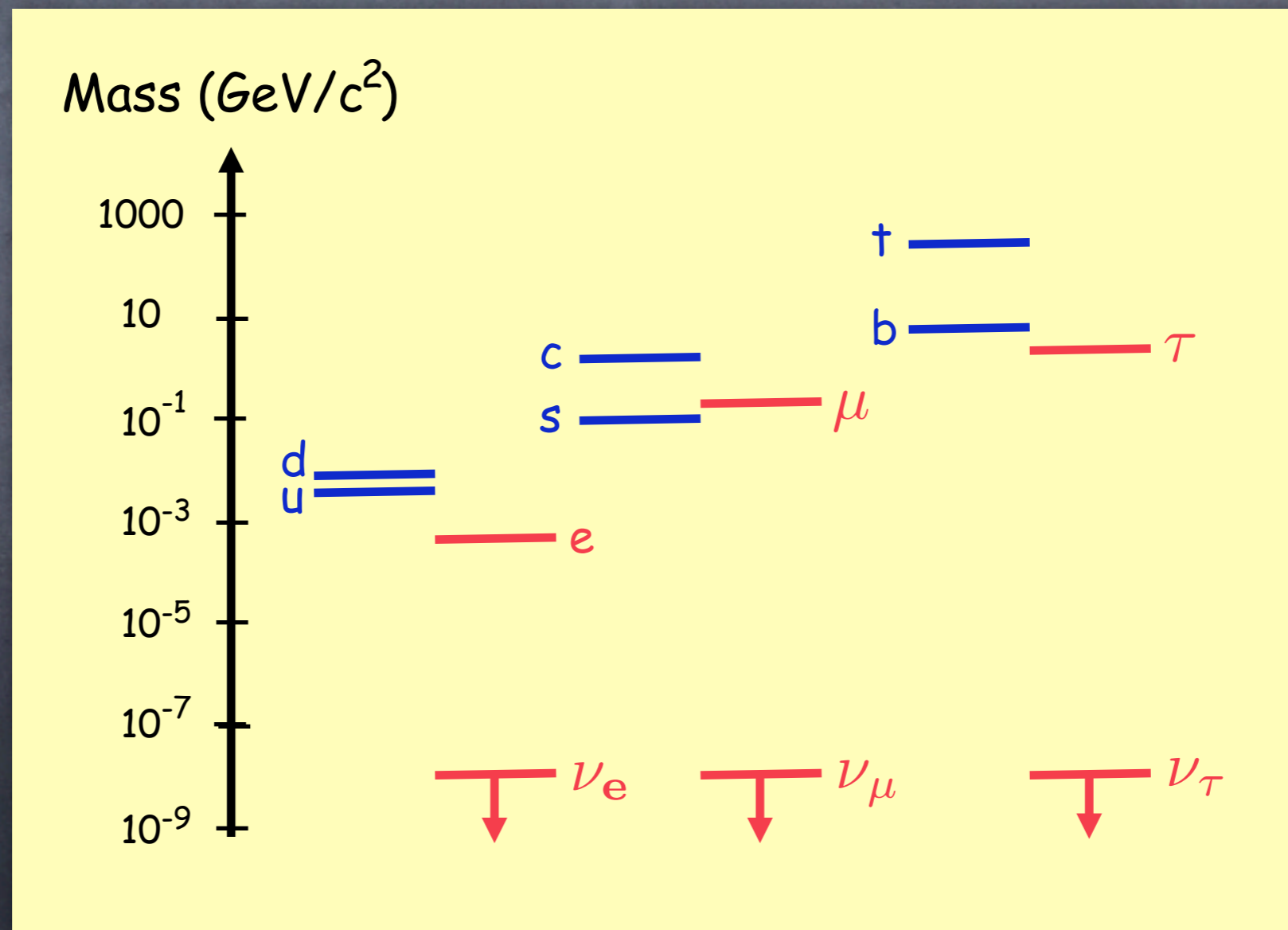
Mesons are bosonic hadrons.  
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass $\text{GeV}/c^2$	Spin
$\pi^+$	pion	$u\bar{d}$	+1	0.140	0
$K^-$	kaon	$s\bar{u}$	-1	0.494	0
$\rho^+$	rho	$u\bar{d}$	+1	0.770	1
$B^0$	B-zero	$d\bar{b}$	0	5.279	0
$\eta_c$	eta-c	$c\bar{c}$	0	2.980	0

# The Standard Model of Particle Physics

- All known forces except gravity
  - QED
  - Weak Interactions
  - Strong Interactions
- gauge theory of quarks and leptons
  - 1 photon, 3 weak gauge bosons, 8 gluons
  - $\gamma$        $W^+$ ,  $W^-$ ,  $Z^0$        $G^a$

# The Standard Model of Particle Physics



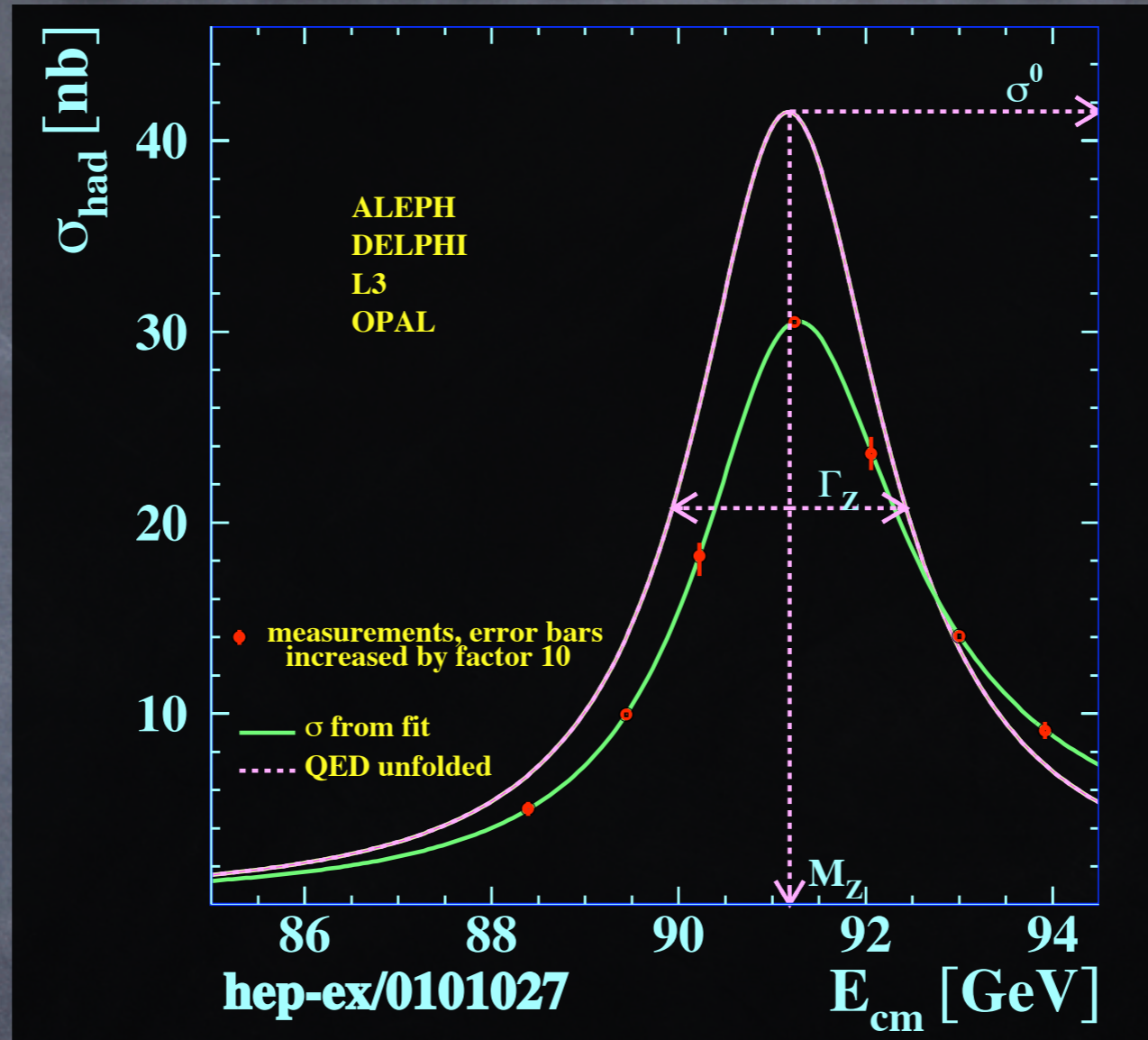
# The Standard Model of Particle Physics

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# The Standard Model

- consistent with all precision data
- fine-tuned to 1 part in  $10^{30}$
- must be wrong

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