4E : The Quantum Universe

Lecture 31, May 26

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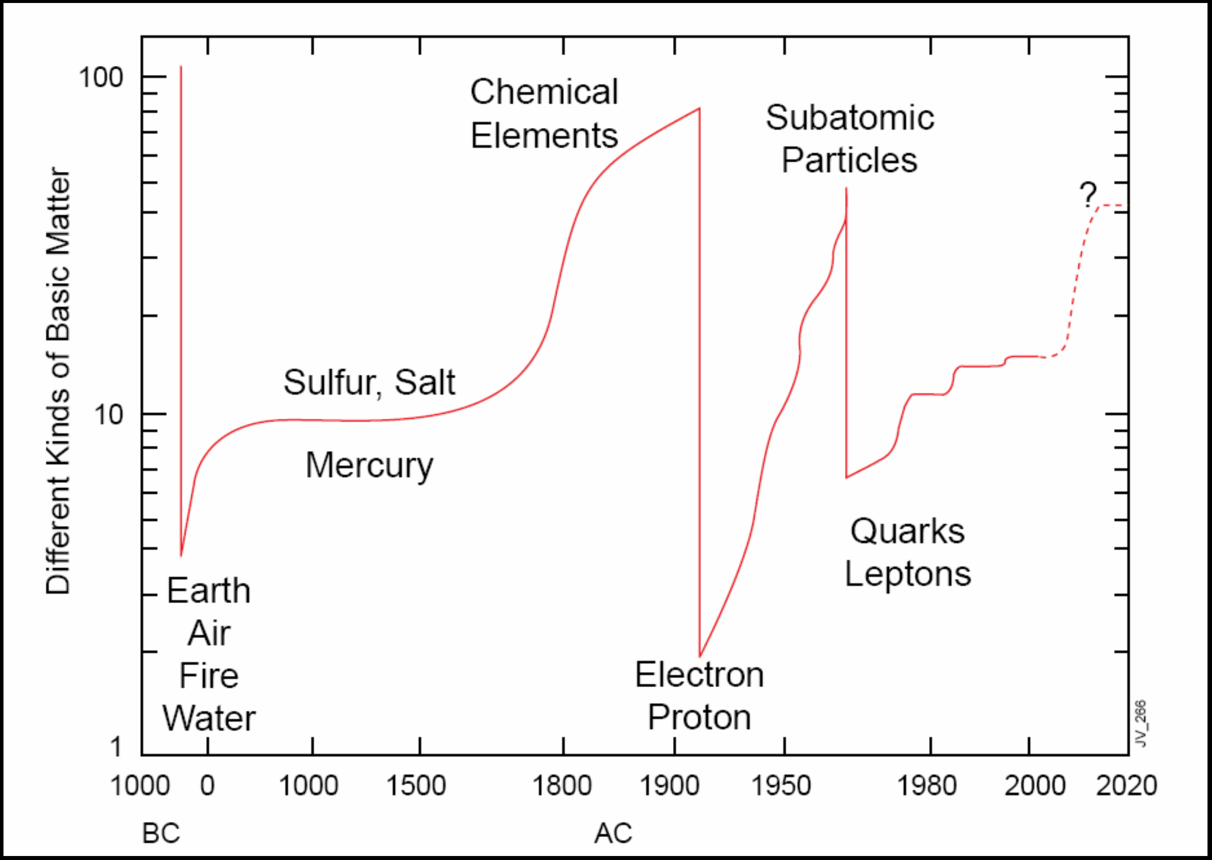
Topics In Particle Physics

- Cosmic Messengers!
  - Dirac, Anderson and the Positron !
    - antimatter
- Fundamental forces in nature
- How elementary particles are produced: Accelerators
- Classification of Particle and How we know this
  - Conservation laws
- Colored Quarks and Quantum Chromodynamics!
- Electroweak theory and Standard model
- The Higgs Particle and Large Hadron Collider
- Beyond the Standard model : Supersymmetry & Strings

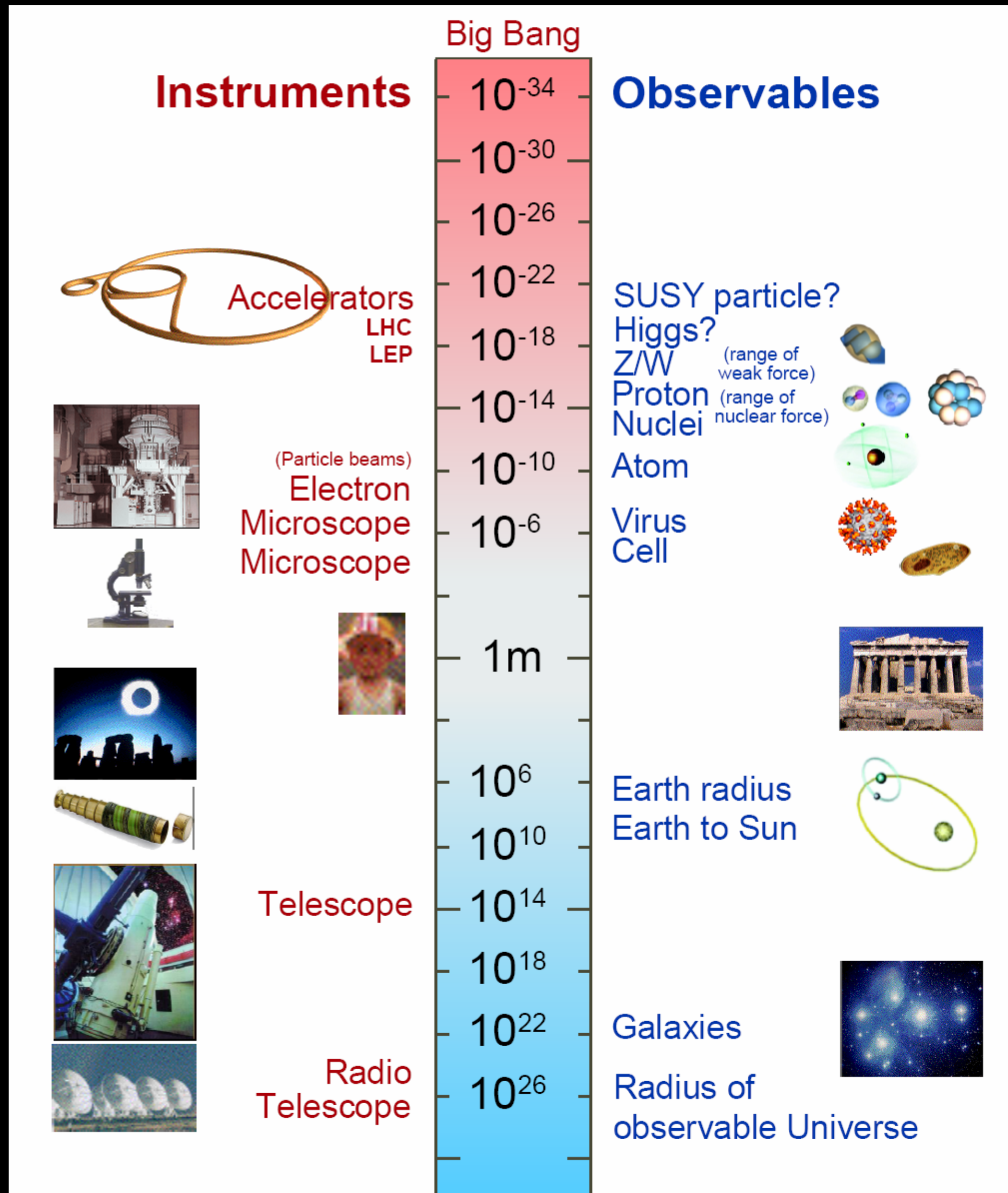
Fundamental Particle Physics

What are the elementary constituents of matter ?

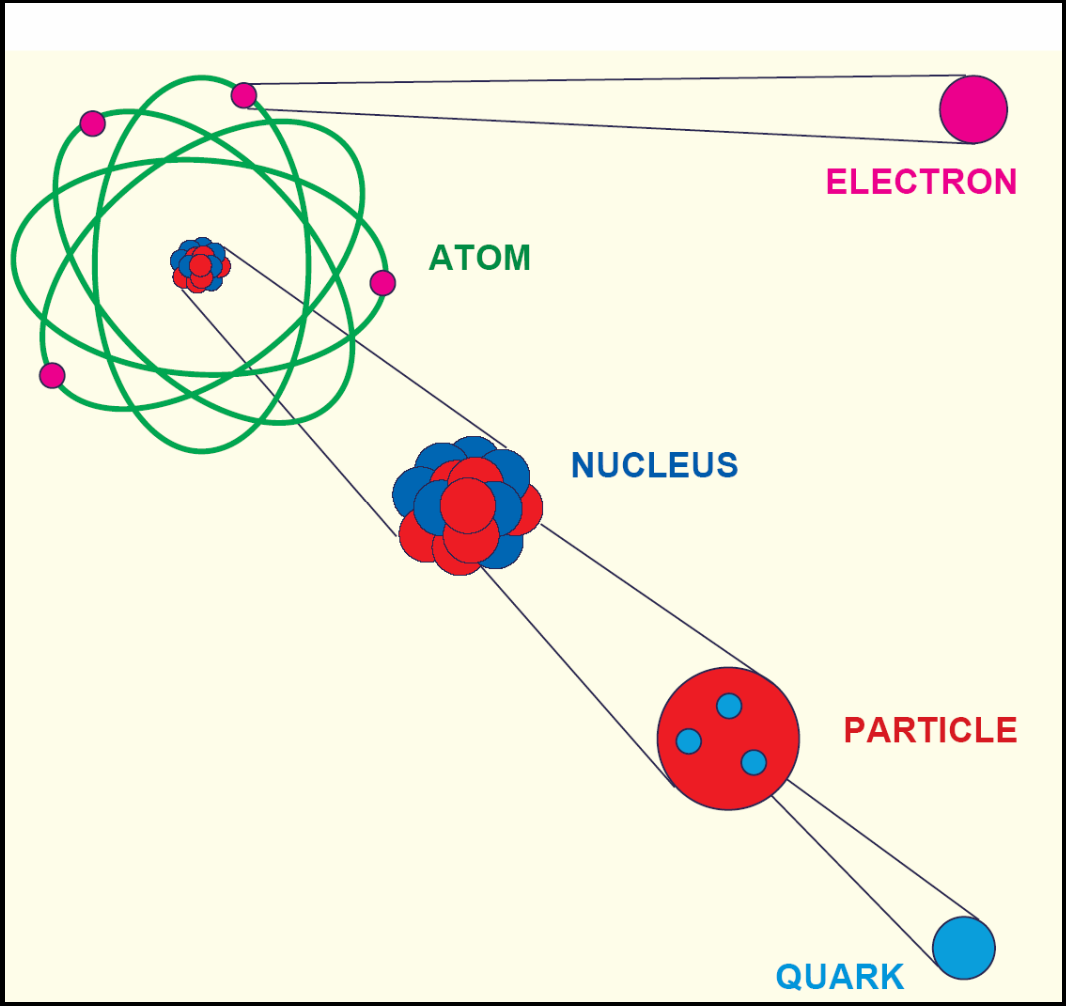
What are the forces that control their behaviour at the most basic level ?



Size of Things



Probing The Cosmic Onion: Experimentally



Rutherford (1909):	Nuclear atom (proton)
Chadwick (1932):	Discovers neutron
SLAC (1968):	Quarks in neutrons and protons

Power of Microscope

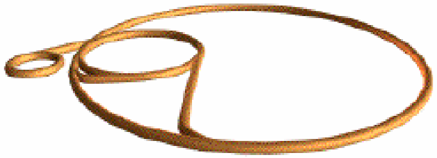
Wavelength of probe radiation should be smaller than the object to be resolved

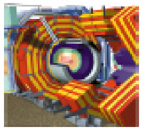
$$\lambda << \frac{h}{p} = \frac{hc}{E}$$

Object	Size	Energy of Radiation
Atom	10^{-10} m	0.00001 GeV (electrons)
Nucleus	10^{-14} m	0.01 GeV (alphas)
Nucleon	10^{-15}m	0.1 GeV (electrons)
Quarks	?	> 1 GeV (electrons)

Radioactive sources give energies in the range of MeV

Need accelerators for higher energies.

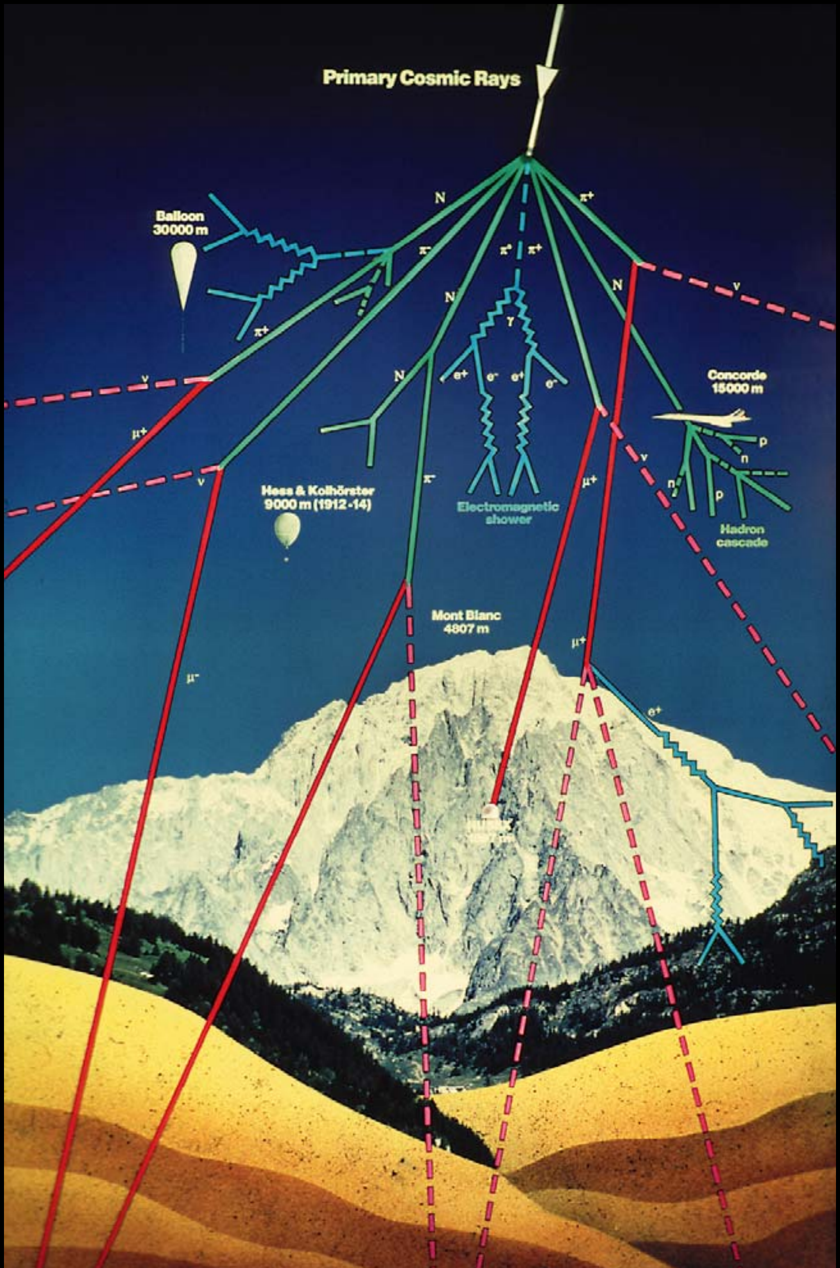




"electronic eyes"

Cosmic Messengers

High energy particles bombard the earth at large rate



Discovery of new subatomic particles: Muon and positron !

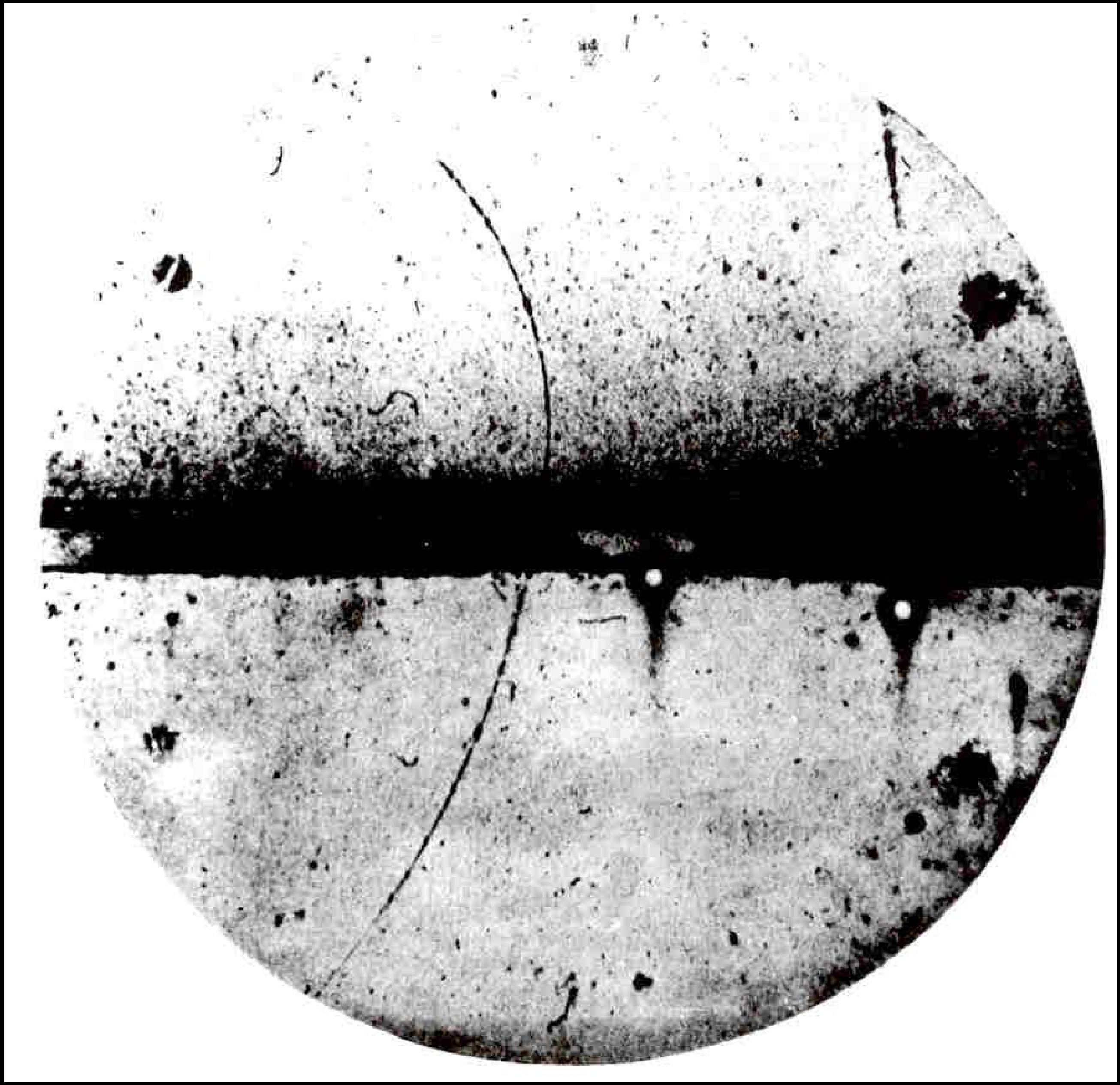
Relativity, Dirac and Anti-matter

$$E^2 = (pc)^2 + (mc^2)^2 \Rightarrow E = \pm\sqrt{(pc)^2 + (mc^2)^2}$$

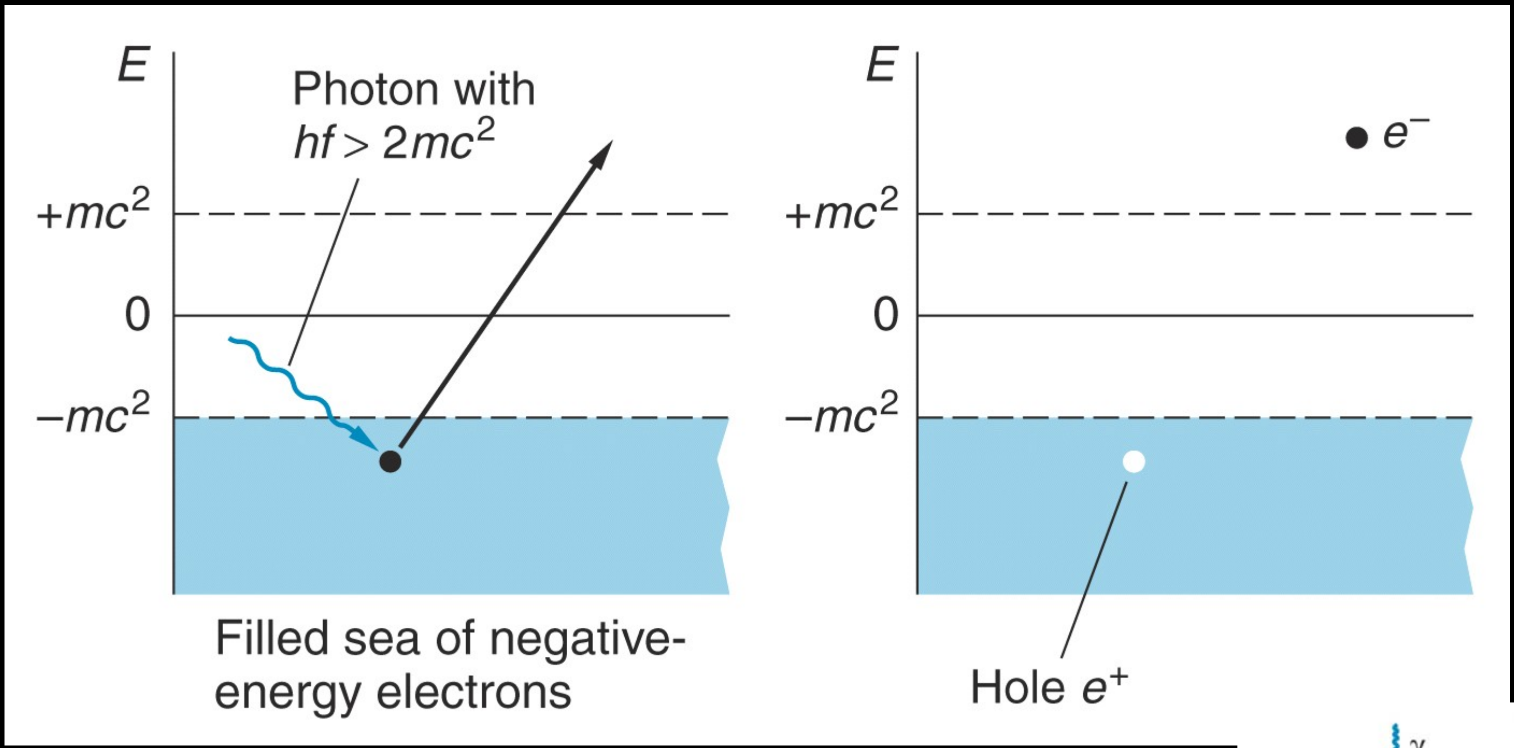
What does the negative energy solution imply ??!

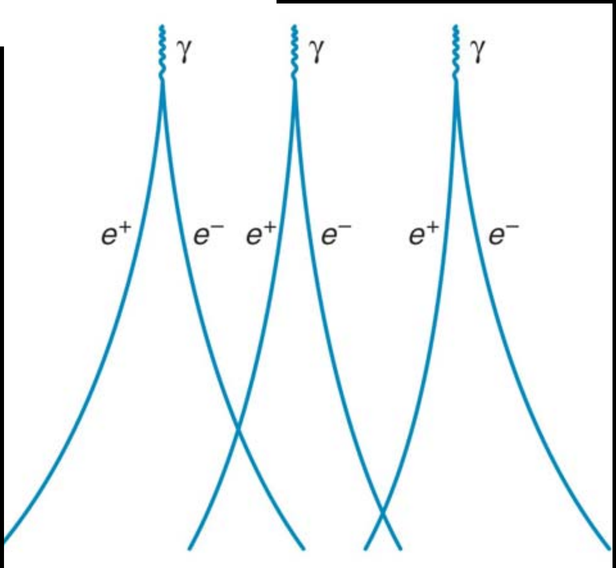
- Dirac postulated that all negative energy states were filled with electrons. They exert no net force on any thing and thus are unobservable
- Used Pauli Excl. principle to claim that only “holes” in this infinite sea of negative energy states observable
- Holes would act as positive charge with positive energy
  - Anderson’s discovery of positron !

Discovery of Positron From Cosmic Rays



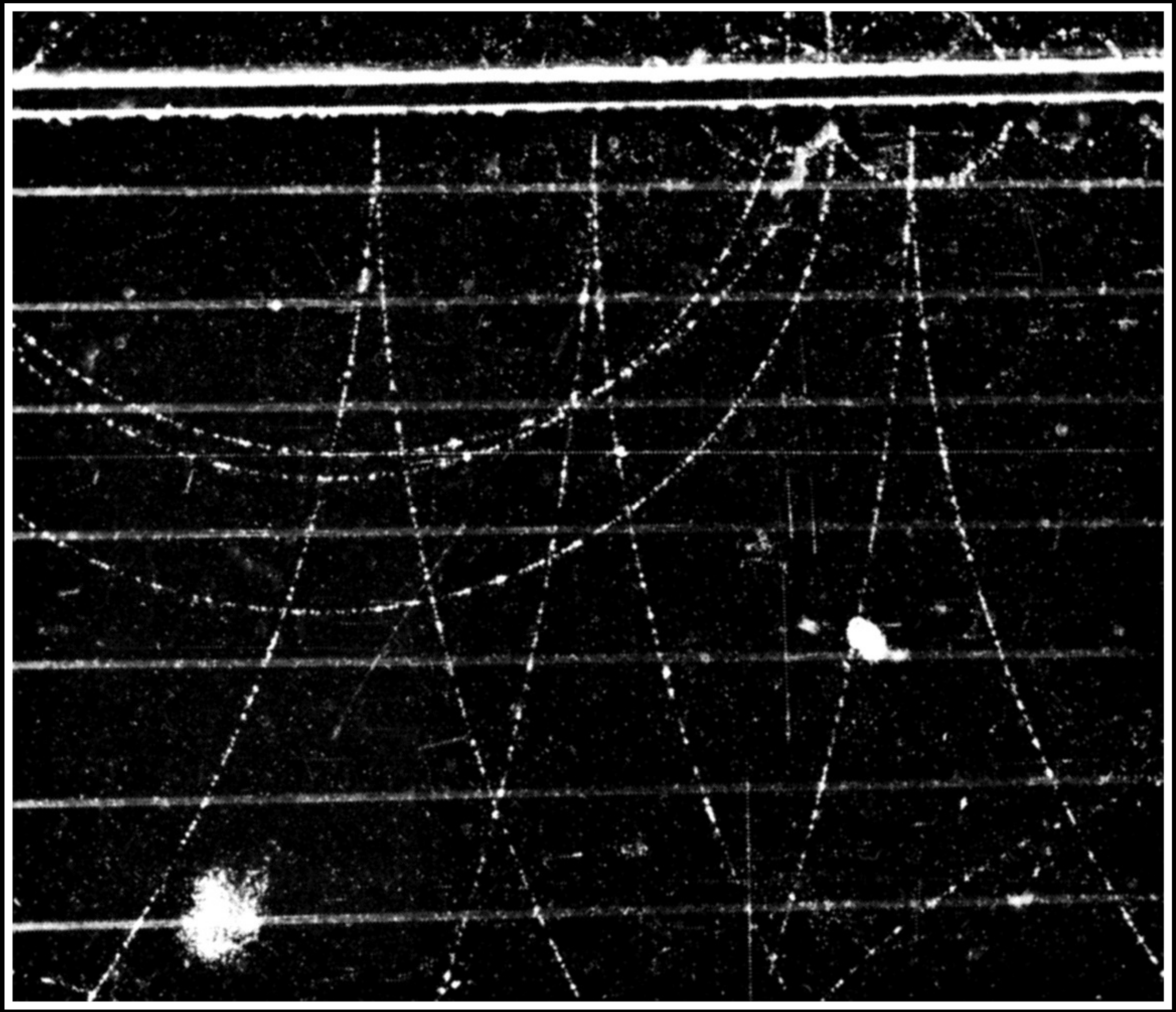
Pair Production: Photoelectric effect with a negative energy electron !



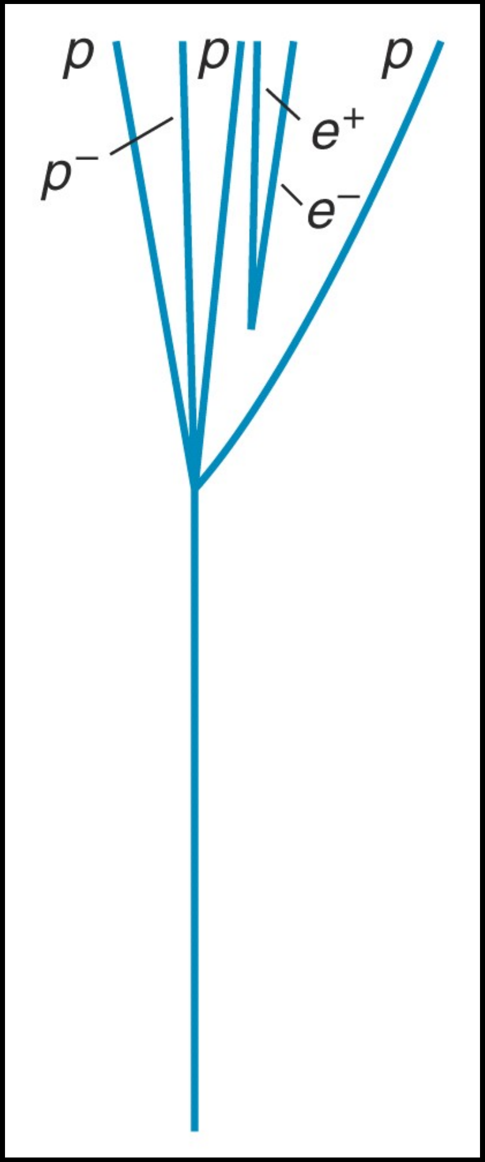


Photon collides with the negative energy Electron and excites it to positive energy state, leaving a "hole" that appears as positron

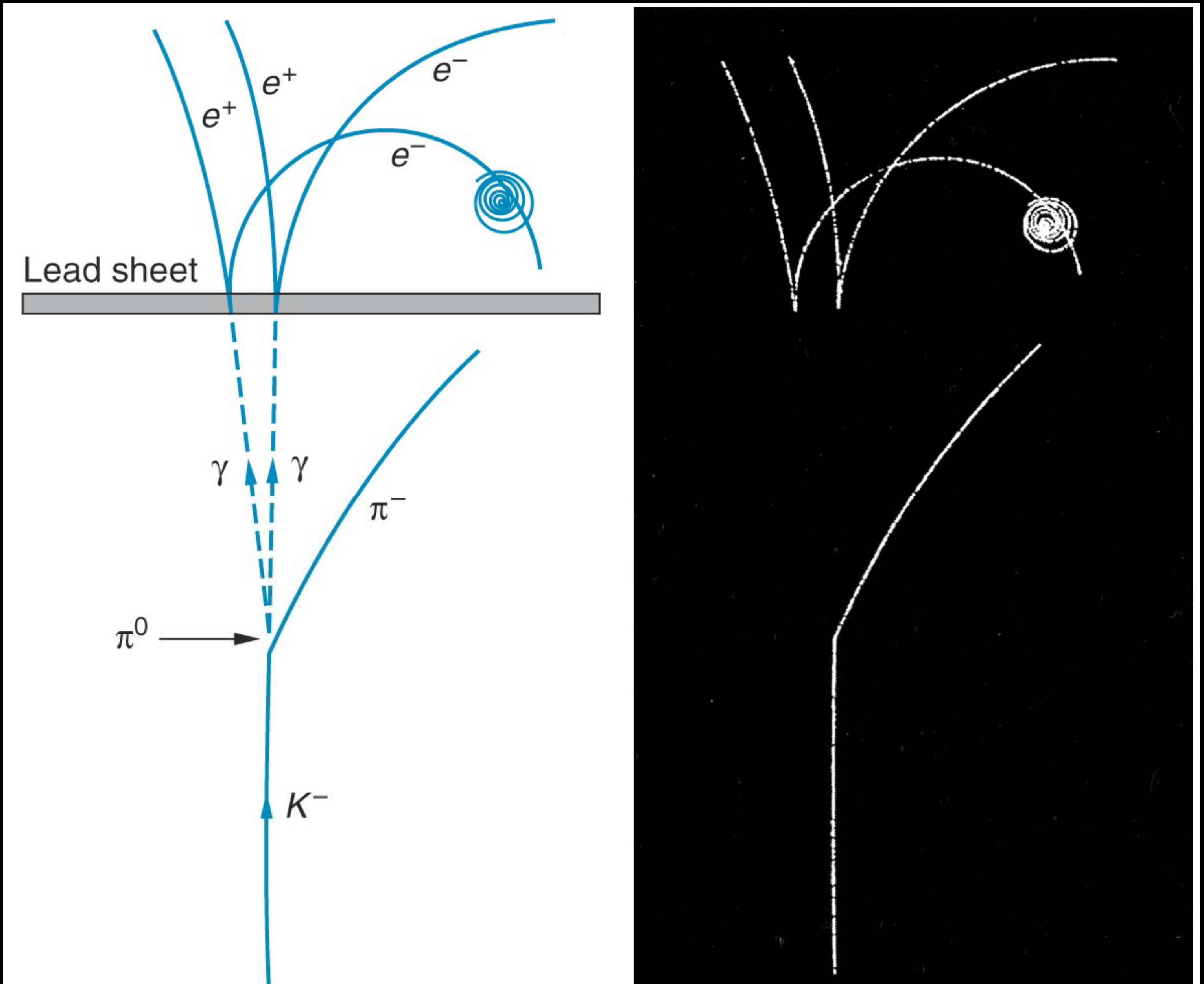
Pair Production Photographed in B field: Note Curvature



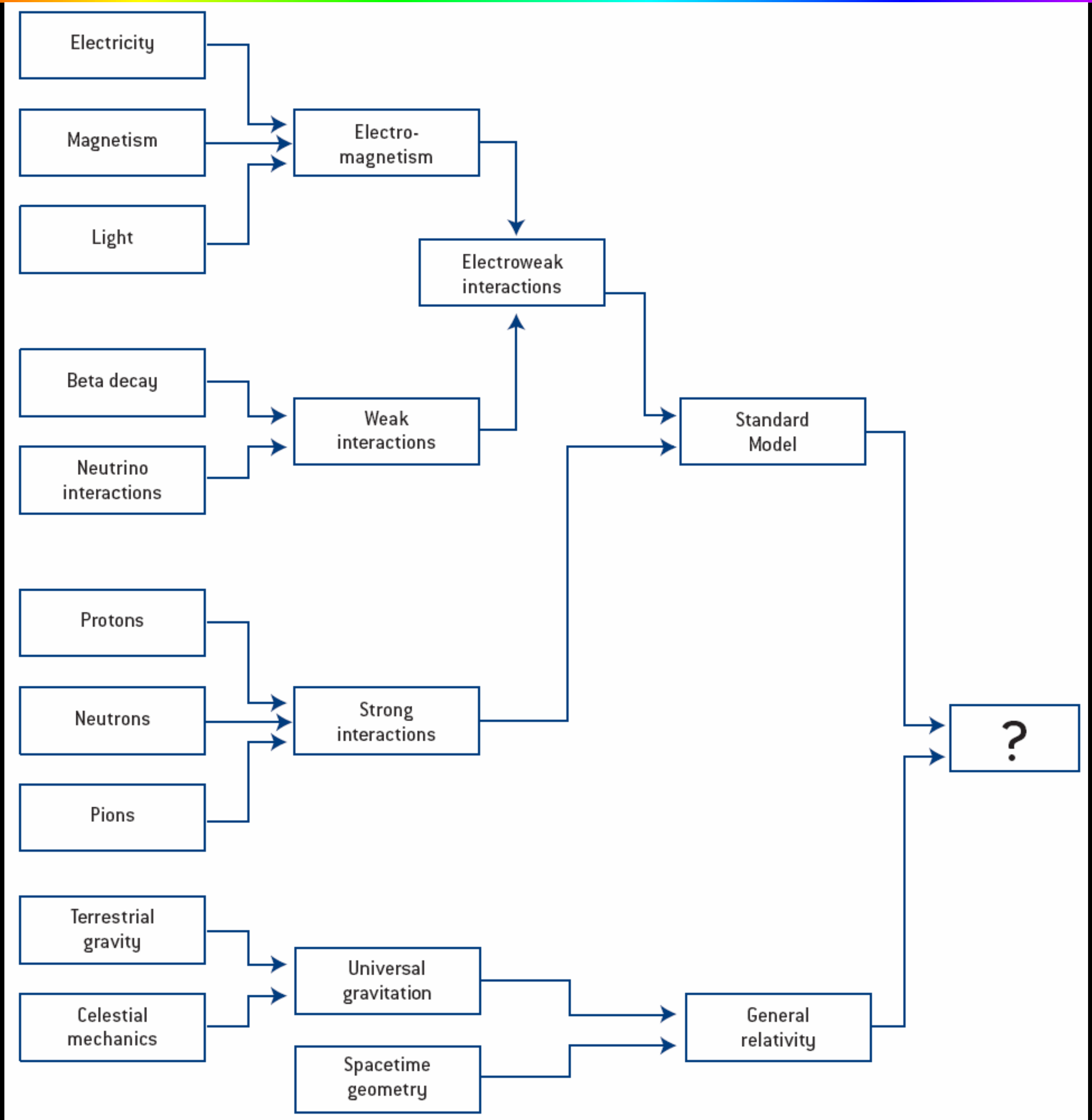
All particles have an anti-matter partner !



Look Ma : Antimatter !



Forces of Nature

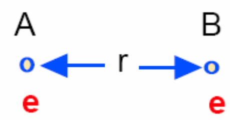


Quanta of Interaction

Interaction between two matter particles e.g. electrons

Action at a distance

$$F \propto \frac{e^2}{r^2} \hat{\underline{r}}$$



Newton
Force on A depends on where B is.
But how does A know where B is ?

Interaction through Fields

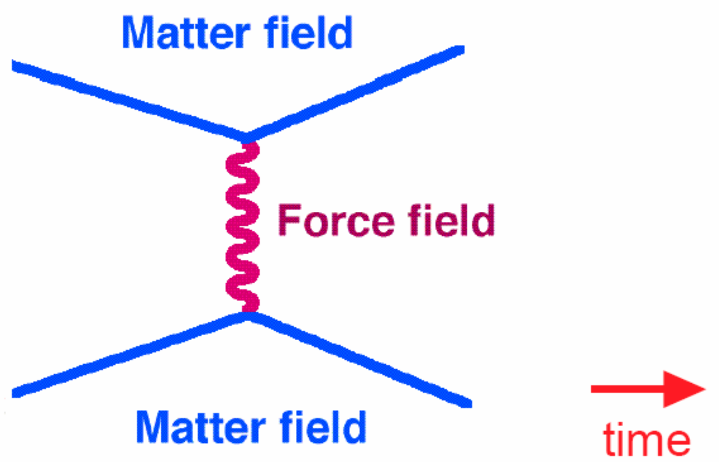
Maxwell
B produces a field, characterized by a number (e/r^2) at every point in space.
Force on A is towards the direction in which the number changes fastest
A determines its response by **'sniffing'** in its immediate neighbourhood

BUT - still no tangible connection between A and B

Forces are produced by exchange of force or 'messenger' particles

Feynman:
B continually emits carriers of the electromagnetic force - 'photons'
Electron A absorbs the photons and recoils - repulsive force between the electrons.
In Quantum Field Theory both signs of impulse are possible.

Force Field



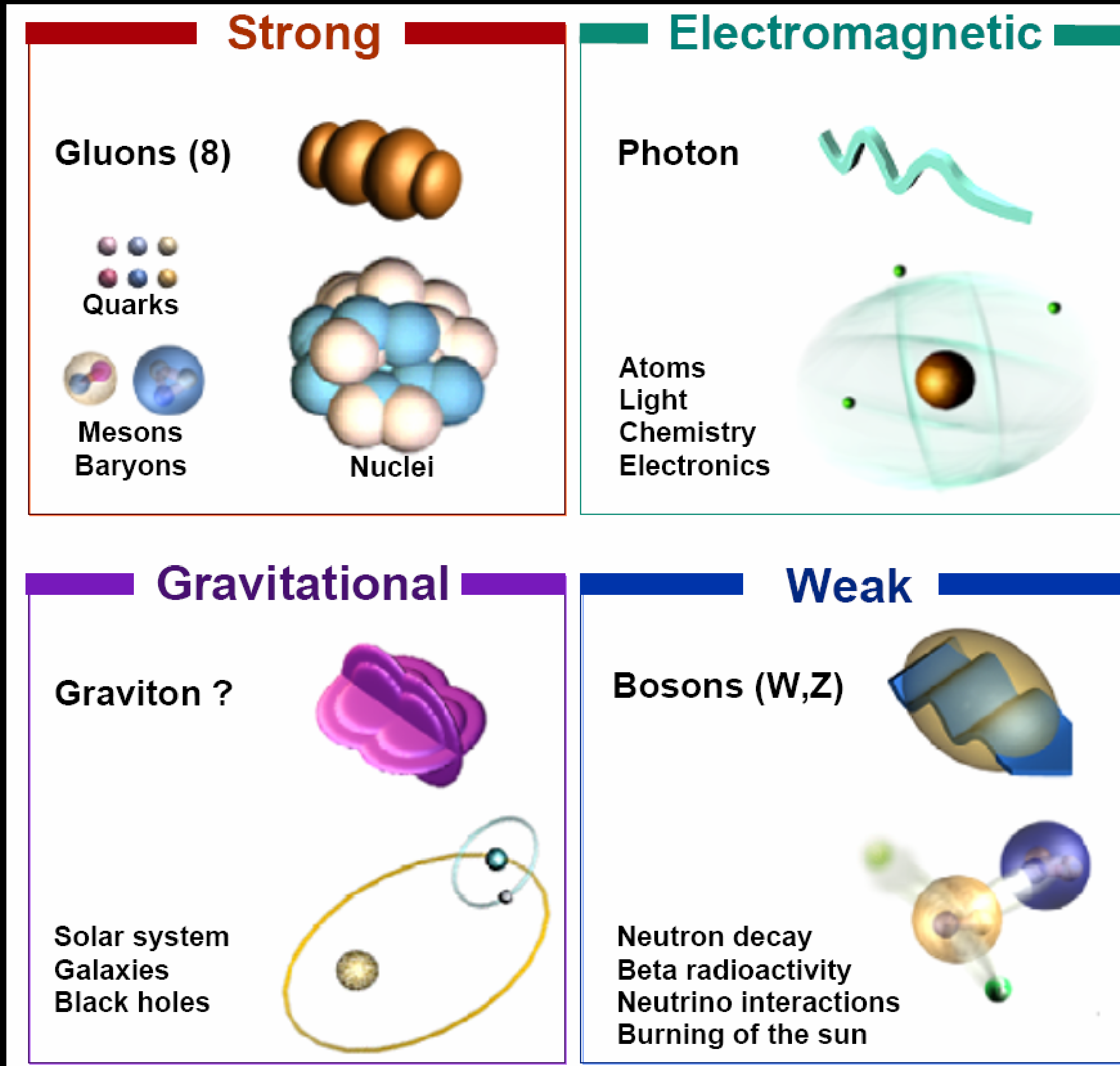
Forces are transmitted by the exchange of (force) particles between (matter) particles

Explains the differences between forces
To verify : look for force particles

$$\text{Range of a Force} \;\alpha\; \frac{1}{\text{mass of exchange particle}}$$

Observe 4 forces
There are 4 different types of force fields

The Four Fundamental Forces



Forces in Nature

Table 15.1 Particle Interactions

Interaction (Force)	Particles Acted on by Force	Relative Strength[a]	Typical Lifetimes for Decays via a Given Interaction	Range of Force	Force-Carrying Particle Exchanged
Strong	Quarks, hadrons	1	$\leq 10^{-20}$ s	Short ($\approx$1 fm)	Gluon
Electromagnetic	Charged particles	$\approx 10^{-2}$	$\approx 10^{-16}$ s	Long (∞)	Photon
Weak	Quarks, leptons	$\approx 10^{-6}$	$\geq 10^{-10}$ s	Short ($\approx 10^{-3}$ fm)	$W^{\pm}$, Z^0 bosons
Gravitational	All particles	$\approx 10^{-43}$	?	Long (∞)	Graviton[b]

[a]For two u quarks at 3×10^{-17} m.

[b]Not experimentally detected.