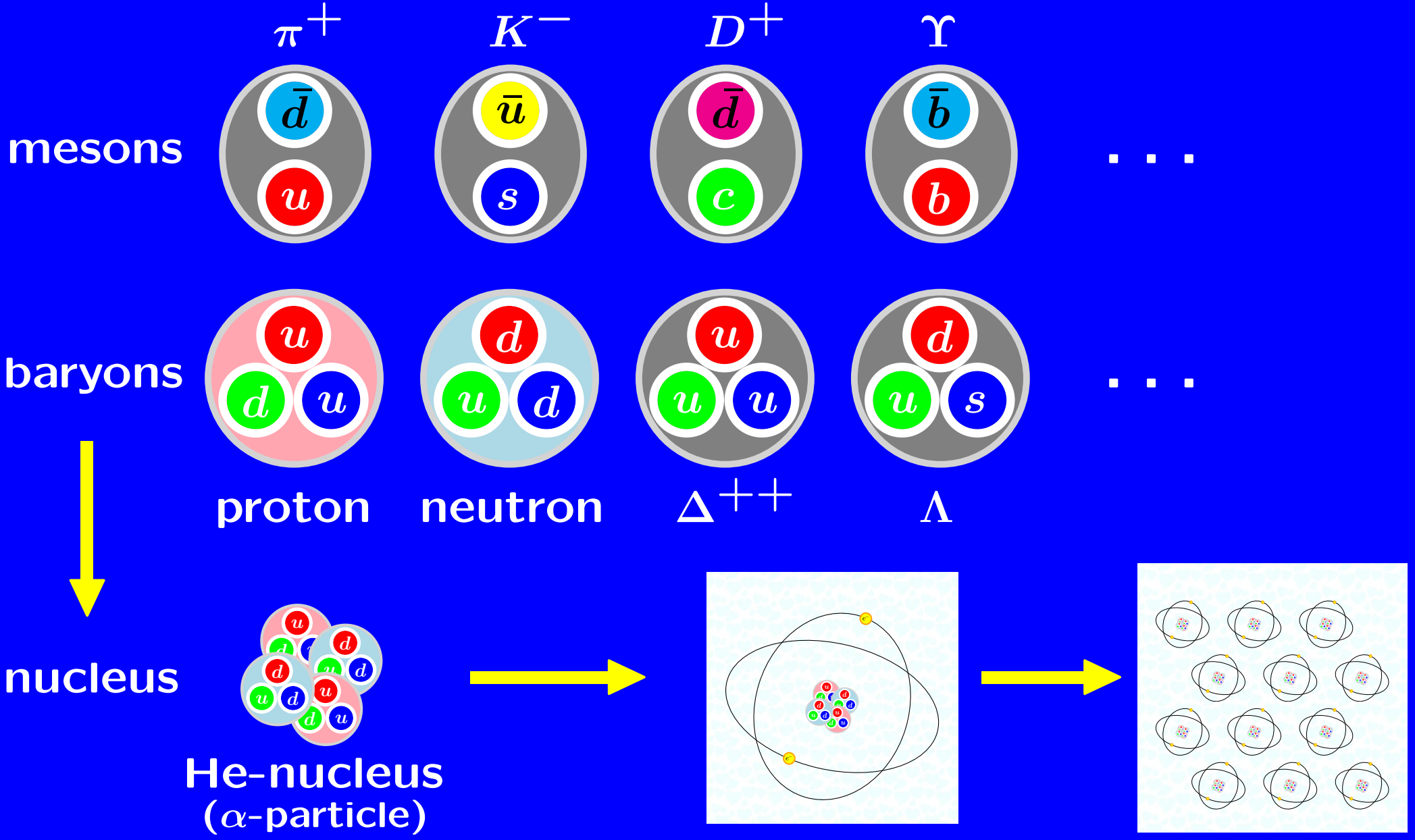
Taxonomie of Particles



angular momentum

Bosons

Spin 0,1,2, ...

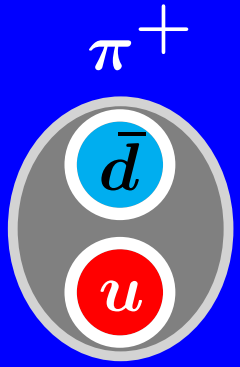
Bose-Einstein statistic

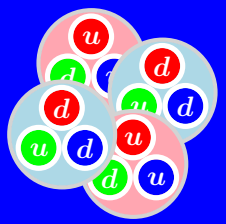
Fermions

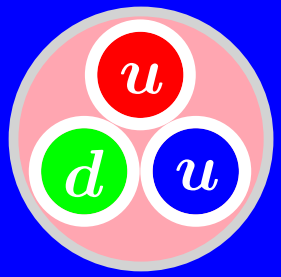
Spin $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, ...

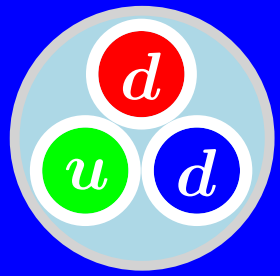
Fermi-Dirac statistic

Pauli exclusion principle





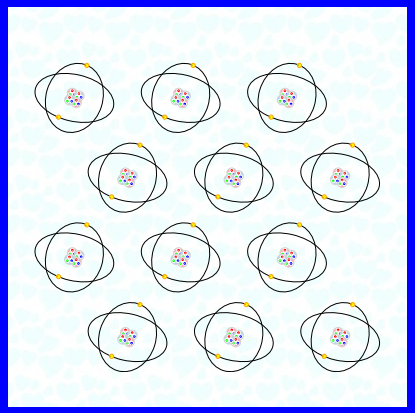




divisible into smaller parts

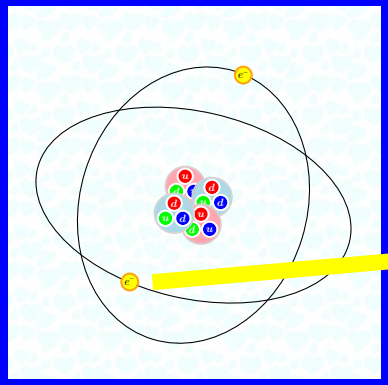
composite

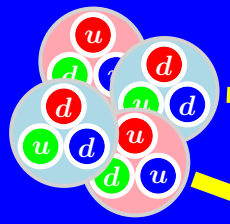
elementary



matter

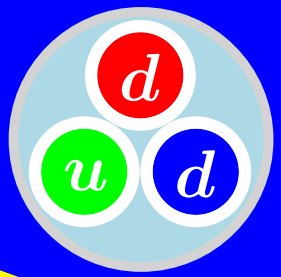
atom



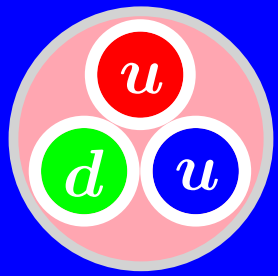


He-nucleus
(α-particle)

neutron



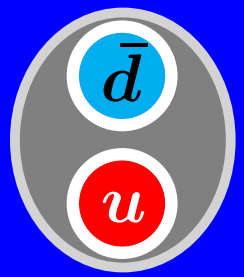
photon



proton

electron

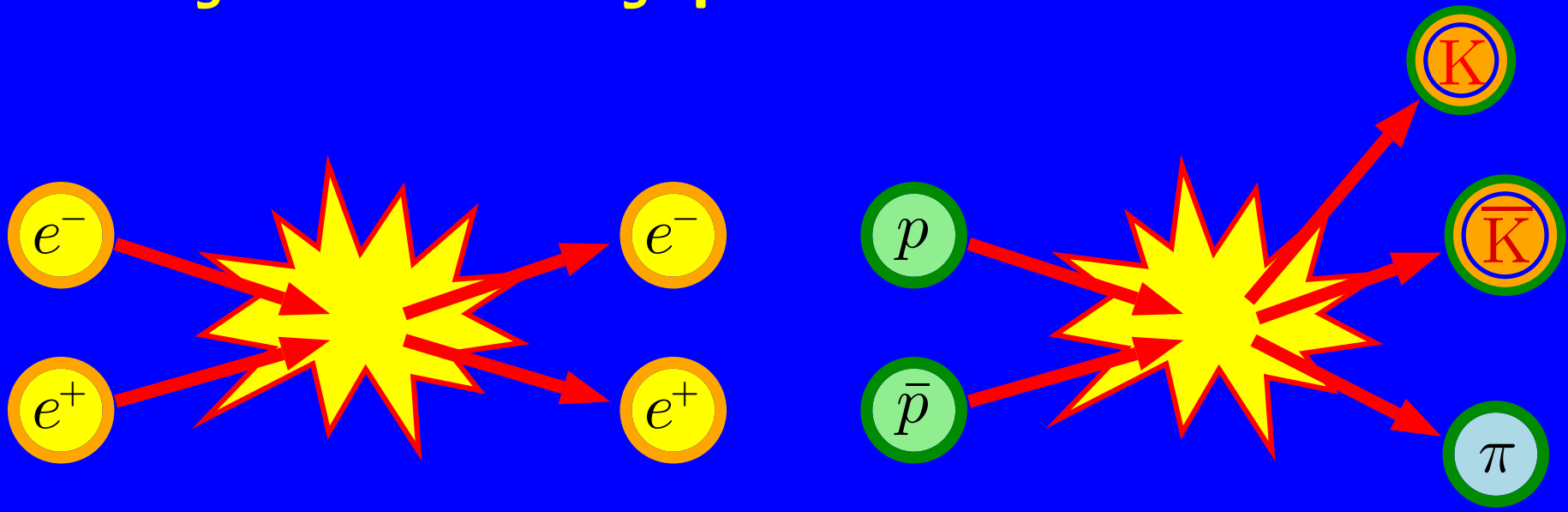
π^+



elementary

if one collides elementary particles,

only elementary particles come out

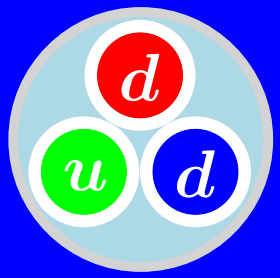


it is impossible to "split" elementary particles!

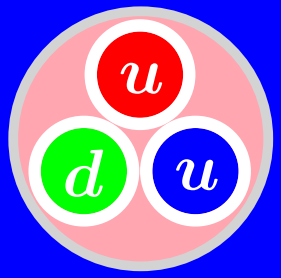
(i.e.: to separate and isolate the parts of an elementary particle)

but elementary particles can have a (sub)structure

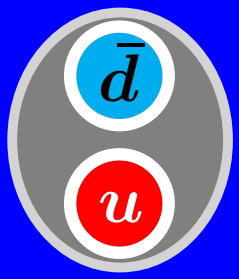
extended Hadrons

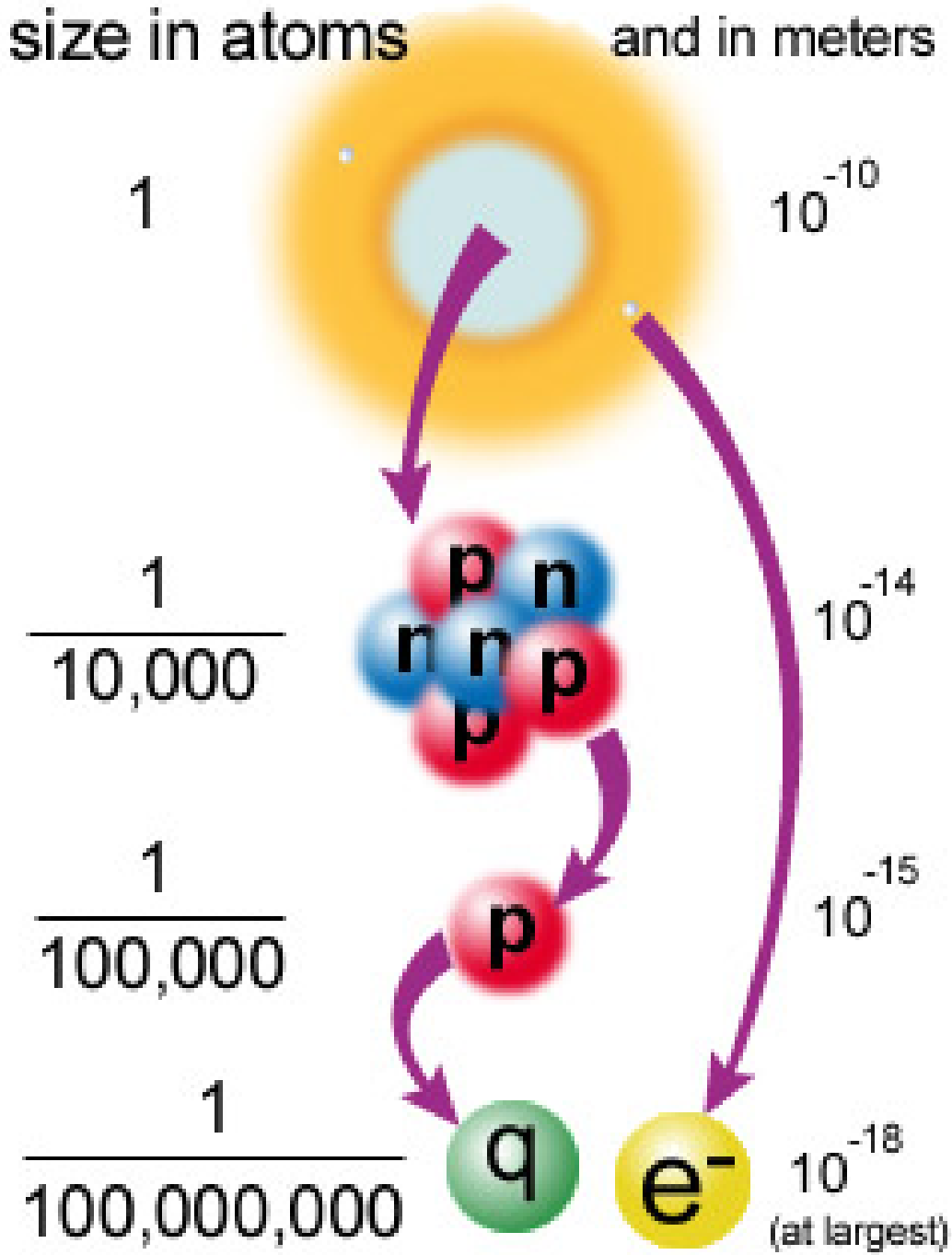


neutron



proton

π^+ 



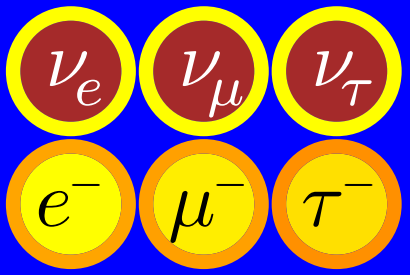
fundamental ~ pointlike

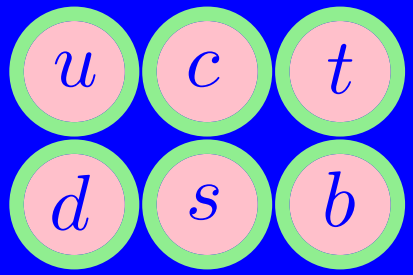
in fundamental particles, scientists could not find any substructure.

They appear point-like even to our best microscopes

(which are particle accelerators)

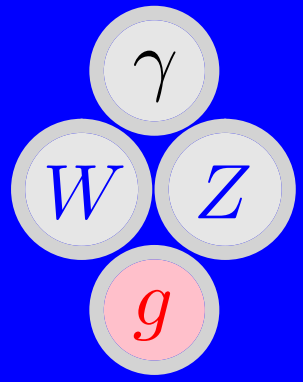
leptons





quarks

gauge bosons



Higgs boson

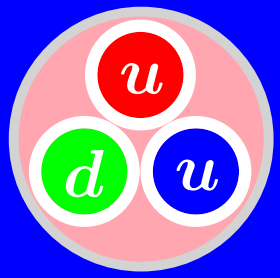
Hadrons

Baryons

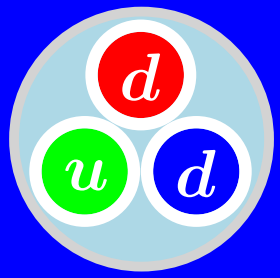
- are fermions
  - Spin $\frac{1}{2}$ and $1\frac{1}{2}$
- made of 3 quarks (or antiquarks)

Mesons

- are bosons
  - Spin 0 (pseudoscalar)
  - Spin 1 (vector)
- quark and antiquark

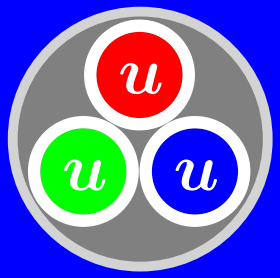


proton



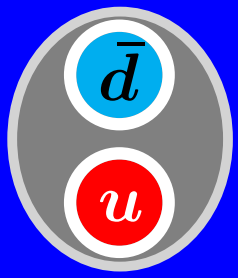
neutron

Spin $\frac{1}{2}$



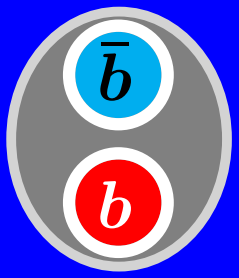
Δ^{++}

Spin $1\frac{1}{2}$



π^+

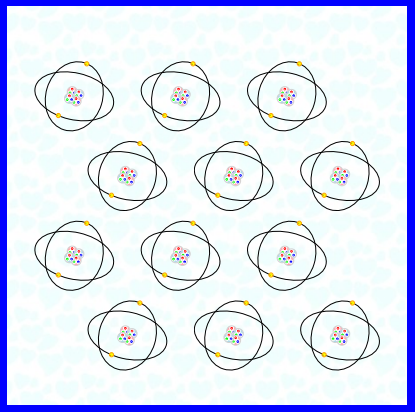
Spin 0



$\Upsilon(1s)$

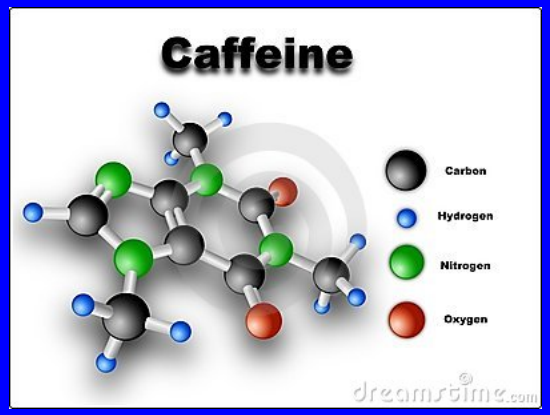
Spin 1

Taxonomie of Particles



macroscopic matter

- follows the laws of classical physics: the quantum mechanical description brings understanding of the properties of the material, but is not suited to classify the macroscopic object.
- There is no Bose-Einstein or Fermi-Dirac statistics, only Maxwell-Boltzman

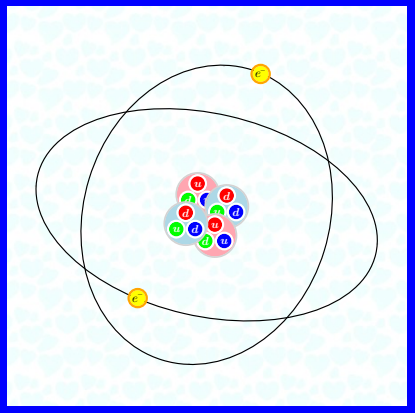


molecule

- is a borderline case:
  - large molecules behave more or less like classical objects
  - small molecules, like H_2 can form quantum mechanical coherent states:
    - ▶ H_2 is a boson
    - ▶ HD is a fermion

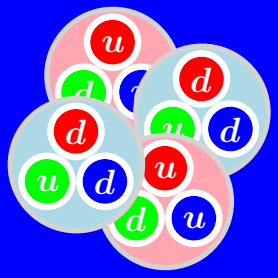
they are neither point-like nor elementary!

Taxonomie of Particles



atom

- the atom is a quantum mechanical object
- it has definite spin and parity
  → it can be a boson or a fermion
- it is extended
- it can be split into electrons and nucleus:
  ▶ plasma (only a few eV are needed)



He-nucleus
(α-particle)

- the nucleus is a quantum mechanical object
- it has definite spin and parity
  → it can be a boson or a fermion
- it is extended
- it can be split into nucleons:
  ▶ protons and neutrons
  (a few MeV are needed)

they are neither point-like nor elementary!

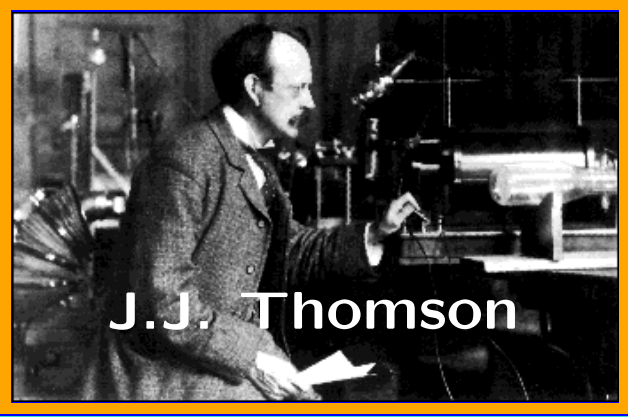
the electron

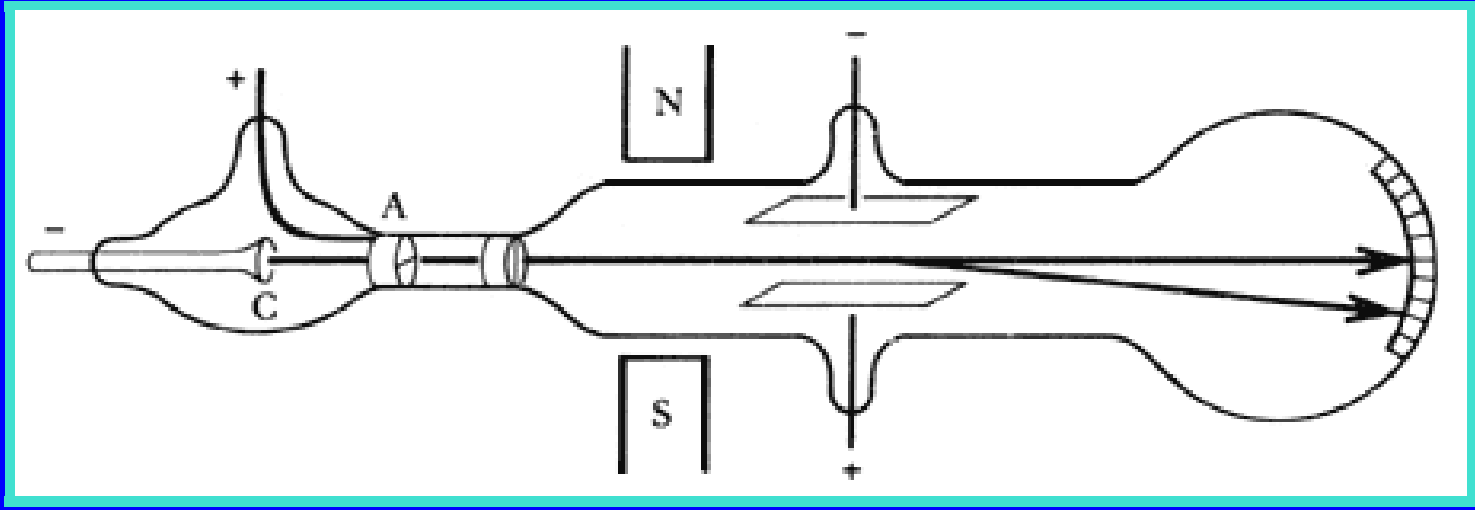
Spin $\frac{1}{2}$ ➡ Fermion

Mass: 511 keV

Charge: -1

stable





the electron is point-like and elementary!

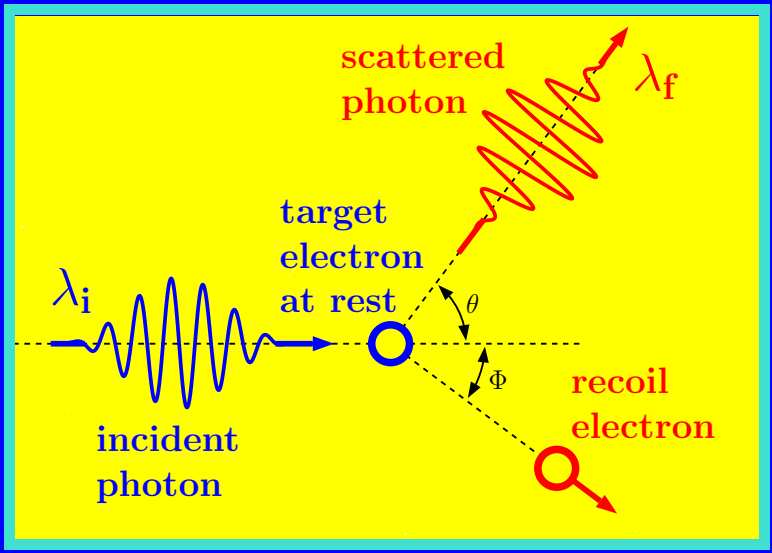
γ the photon

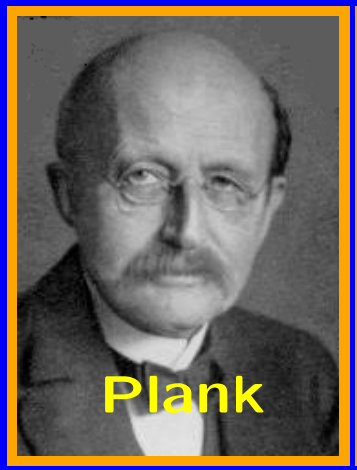
Spin 1 → Boson

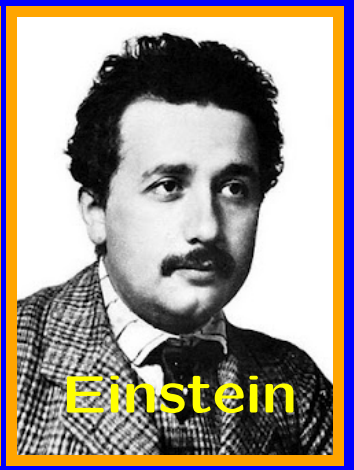
Mass: 0

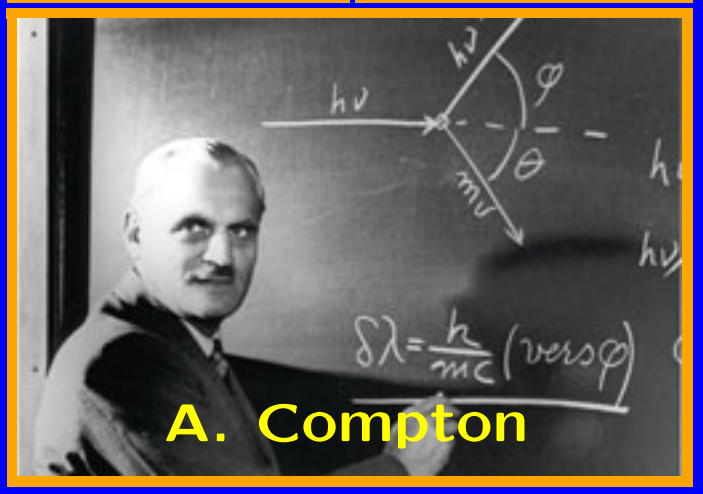
Charge: 0

stable









e^-

the photon is point-like and elementary!

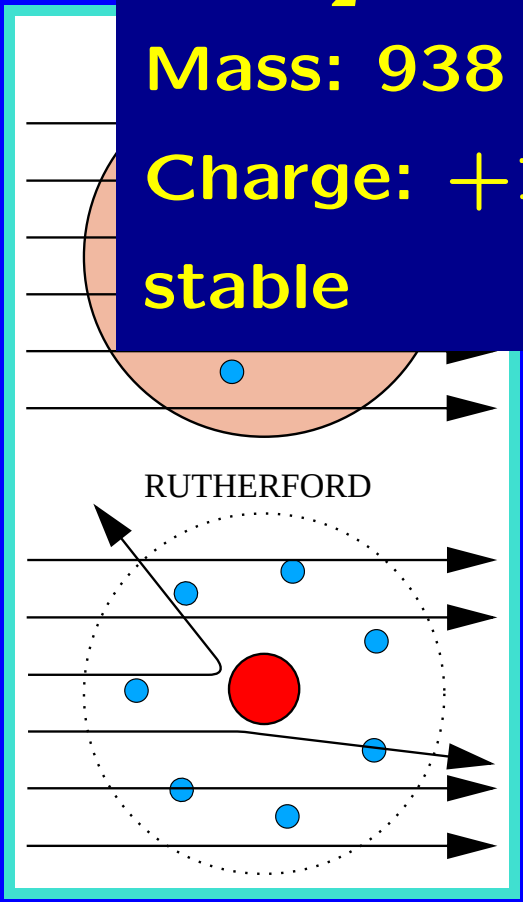
p the proton – the atomic nucleus

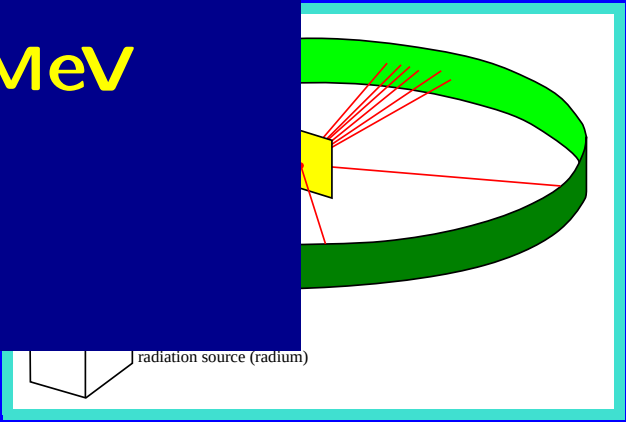
Spin $\frac{1}{2}$ ➡ Fermion

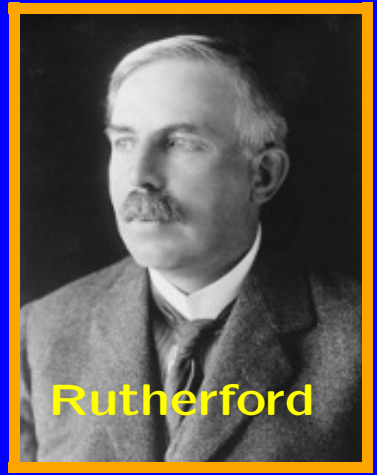
Mass: 938 MeV

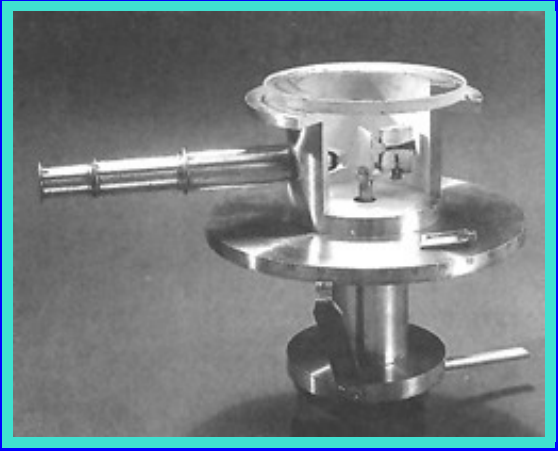
Charge: +1

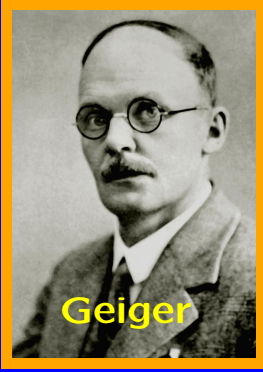
stable

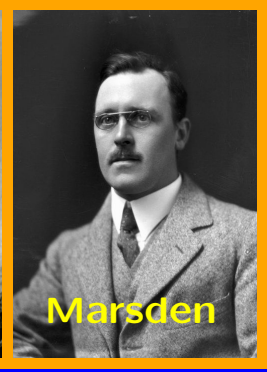












e^-

γ

the proton is not point-like but elementary!

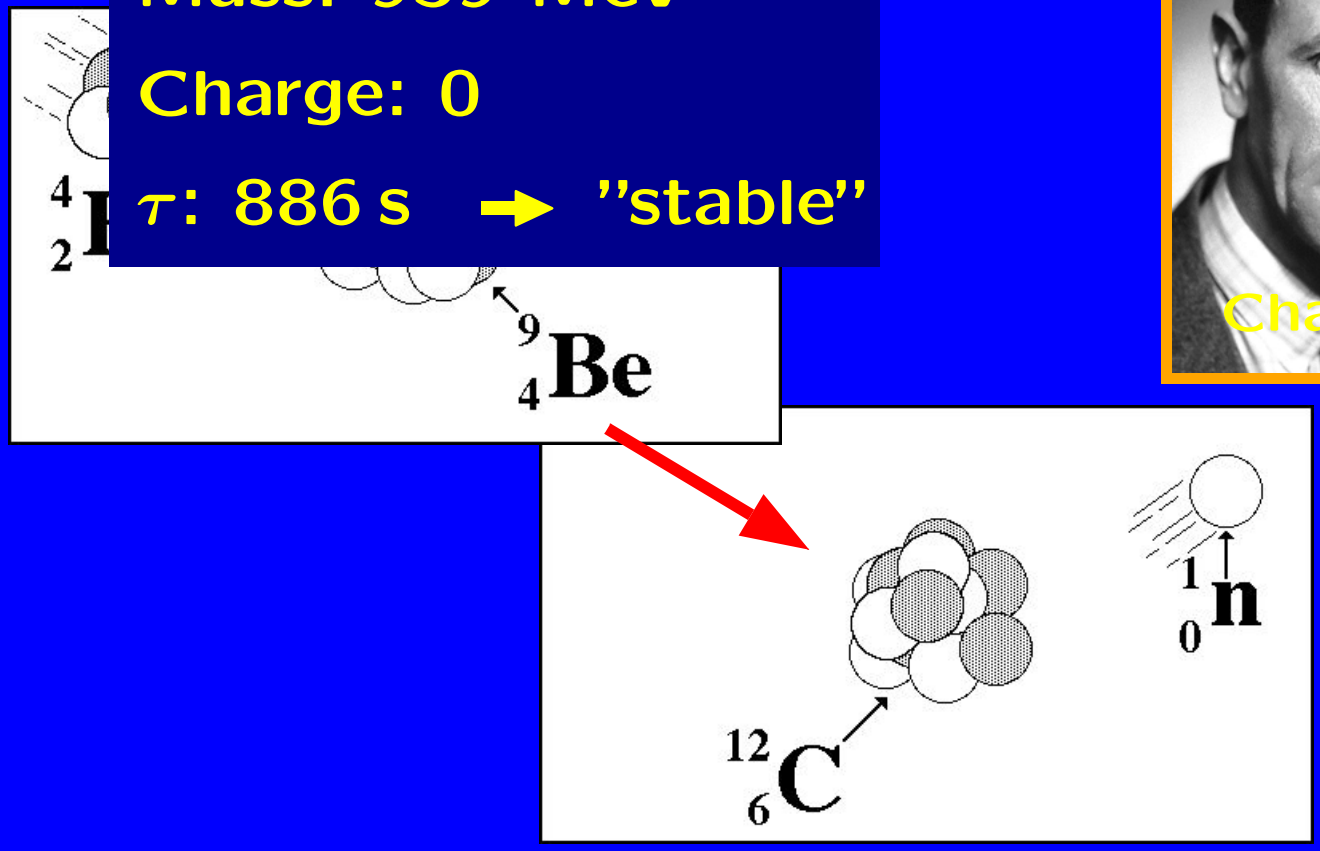
n the neutron

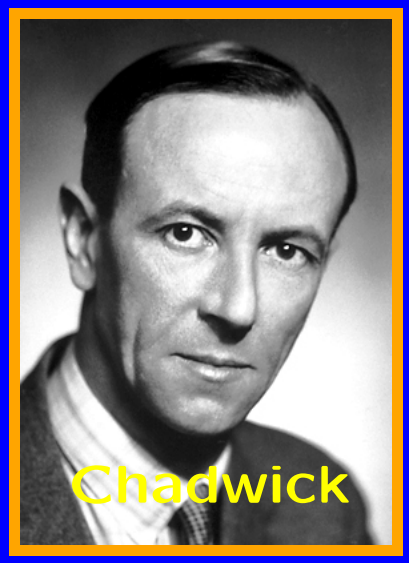
Spin $\frac{1}{2}$ ➡ Fermion

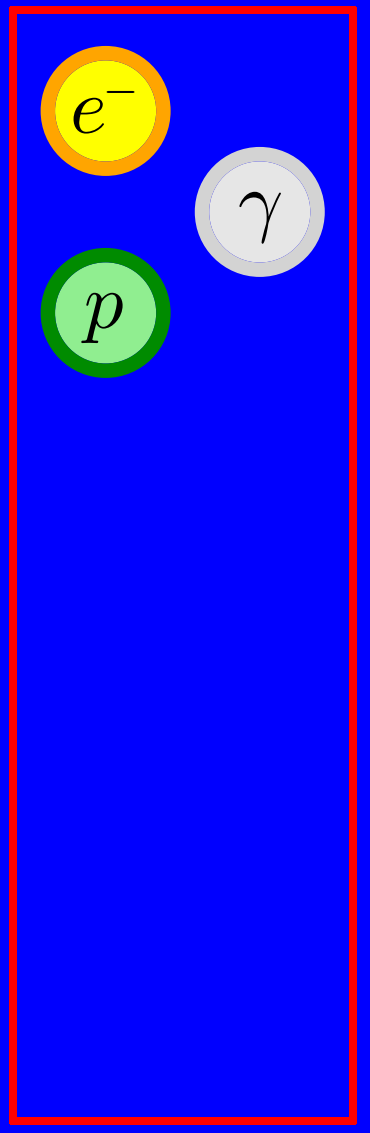
Mass: 939 MeV

Charge: 0

τ: 886 s ➡ "stable"







the neutron is not point-like but elementary!

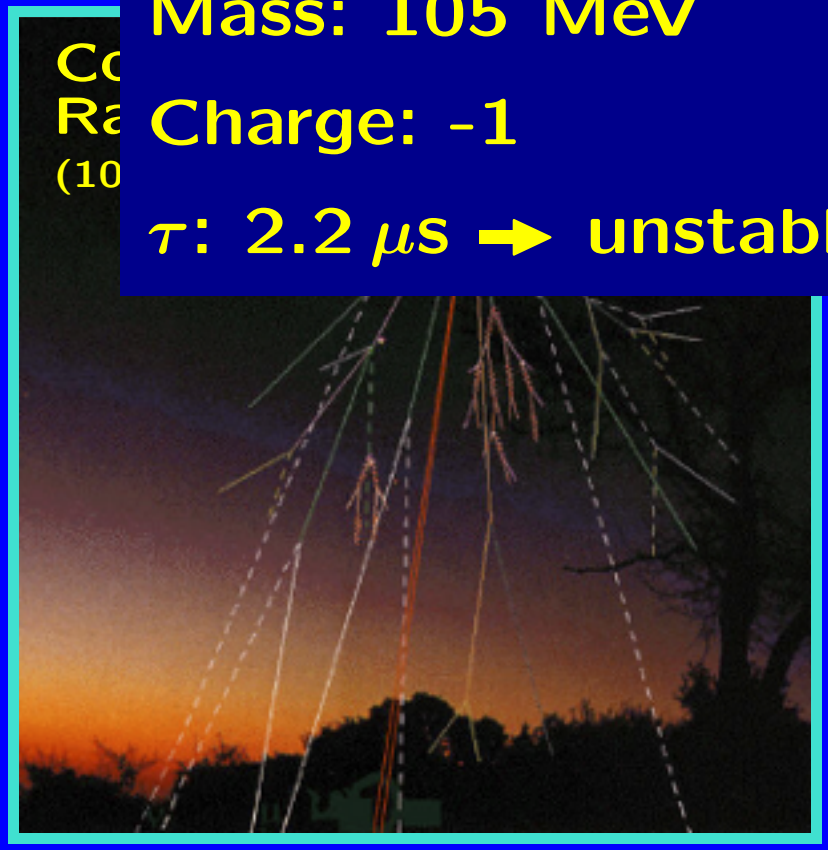
μ^- the muon

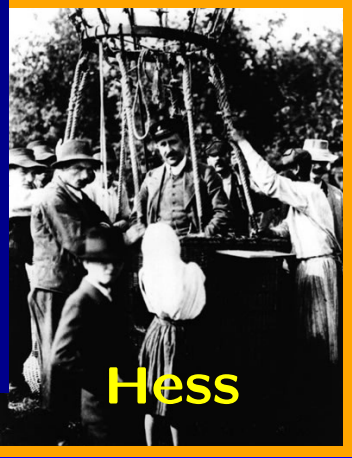
Spin $\frac{1}{2}$ ➡ Fermion

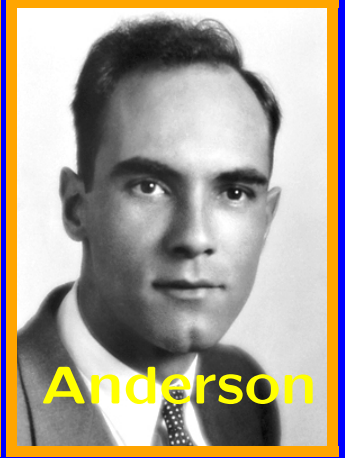
Mass: 105 MeV

Charge: -1

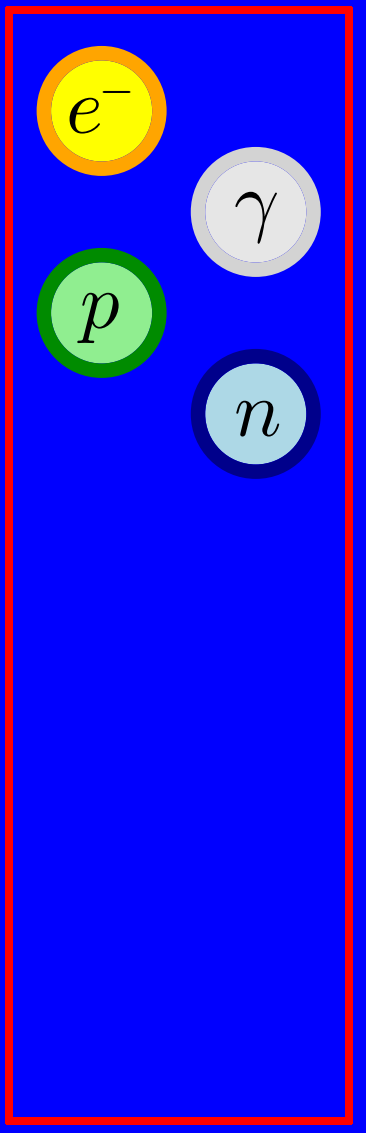
τ: 2.2 μs ➡ unstable




Hess


Anderson


Spark Chamber



the muon is point-like and elementary!

π the pion

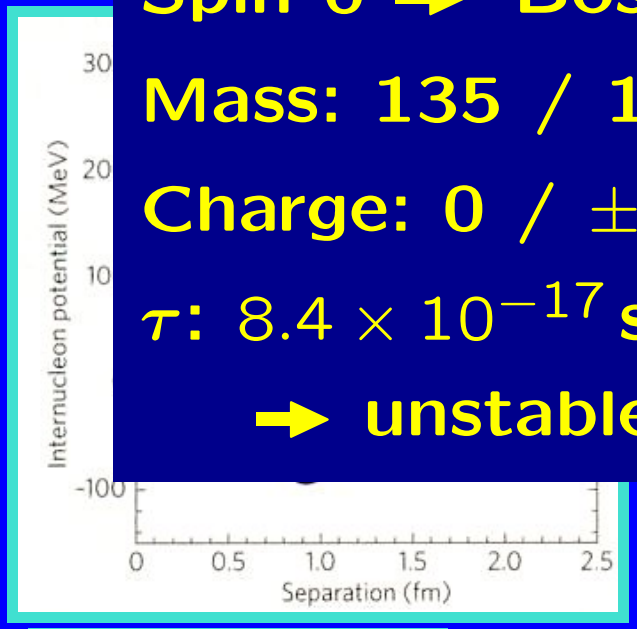
Spin 0 → Boson

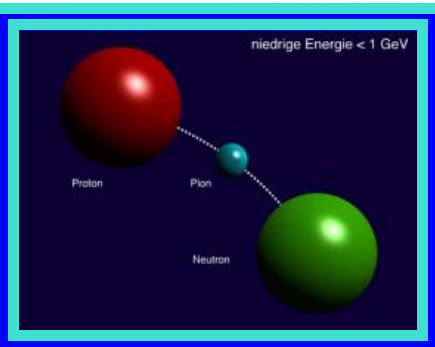
Mass: 135 / 140 MeV

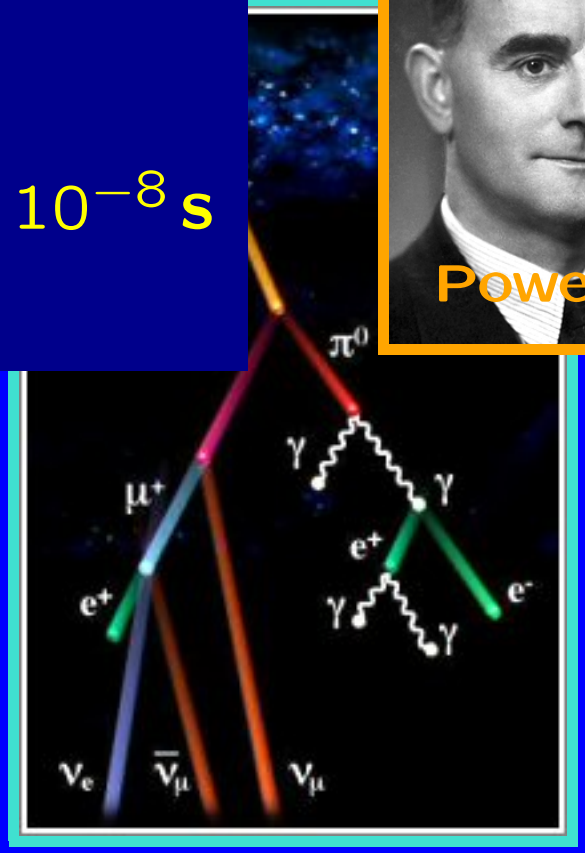
Charge: 0 / ±1

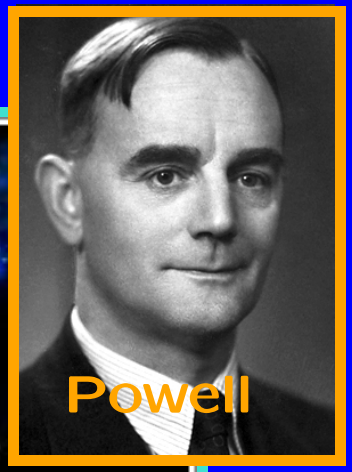
τ: 8.4×10^{-17} s / 2.6×10^{-8} s

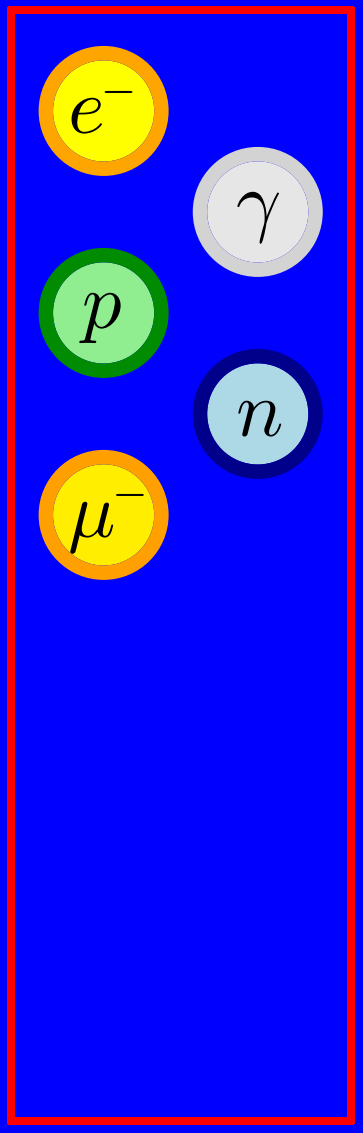
→ unstable











the pion is not point-like but elementary!

e^+ the positron

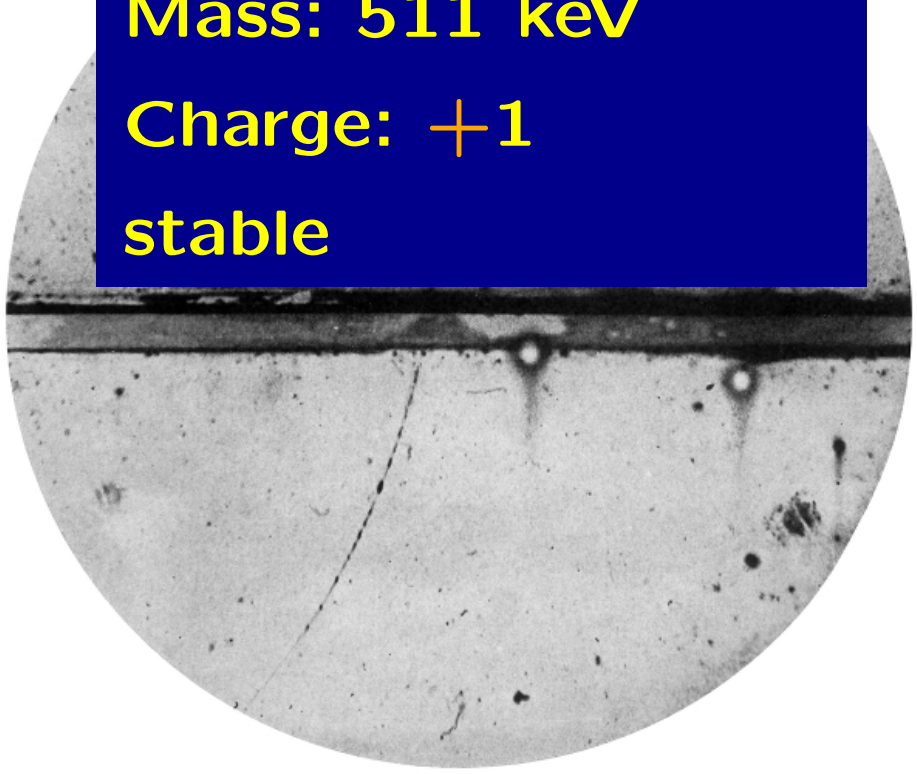
exactly like the electron!

Spin $\frac{1}{2}$ ➡ Fermion

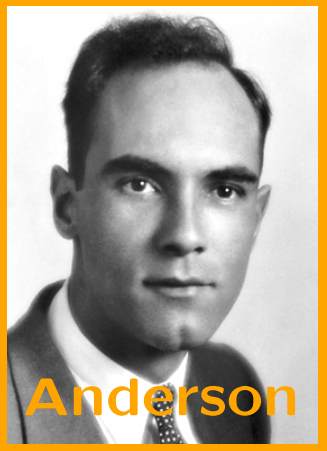
Mass: 511 keV

Charge: $+1$

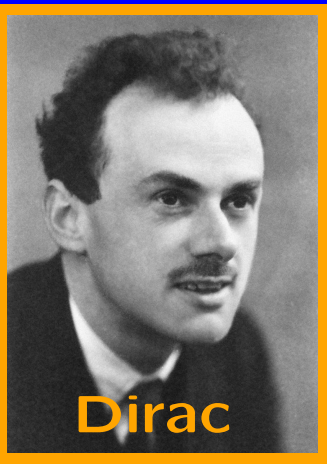
stable



Discovery



Prediction



e^- γ p n μ^- π

the positron is point-like and elementary!

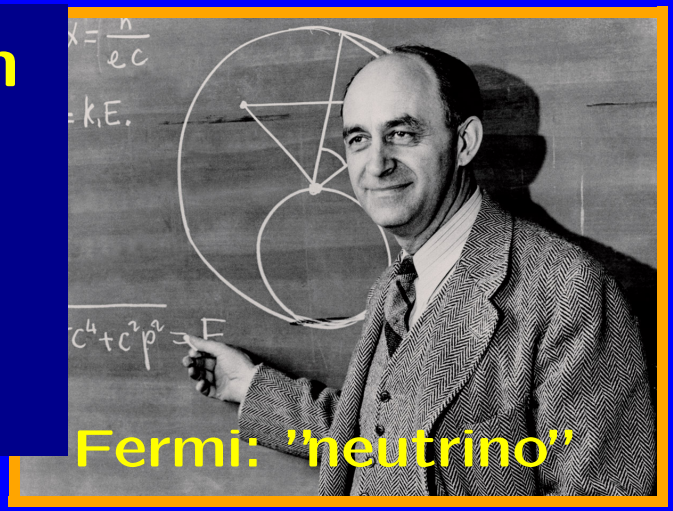
ν the neutrino – theory prediction

Spin $\frac{1}{2}$ ➡ Fermion

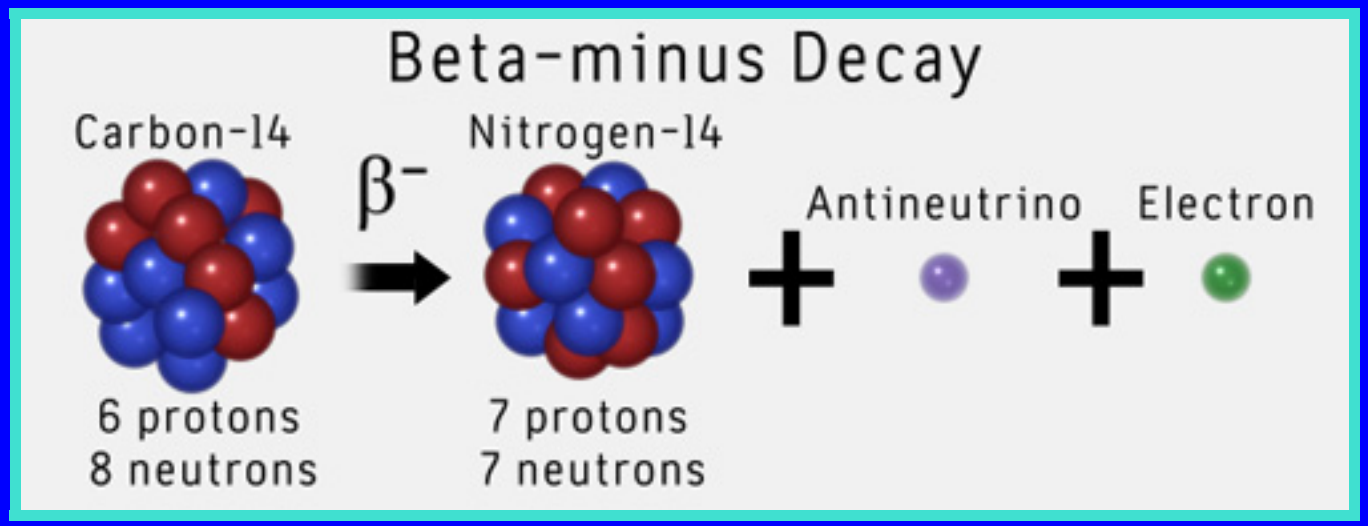
Mass $<$ 2.2 eV

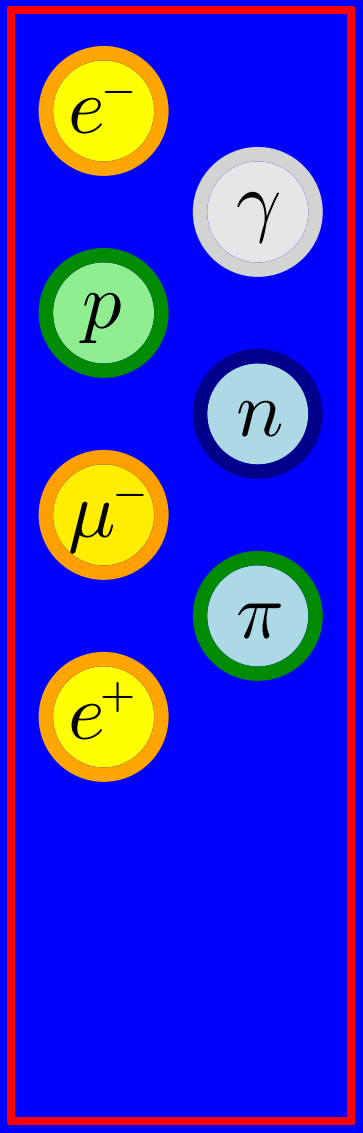
Charge: 0

stable



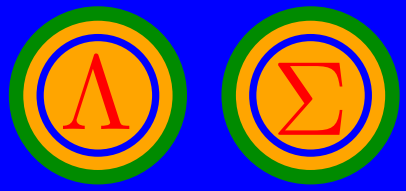
Fermi: "neutrino"





the neutrino is point-like and elementary!

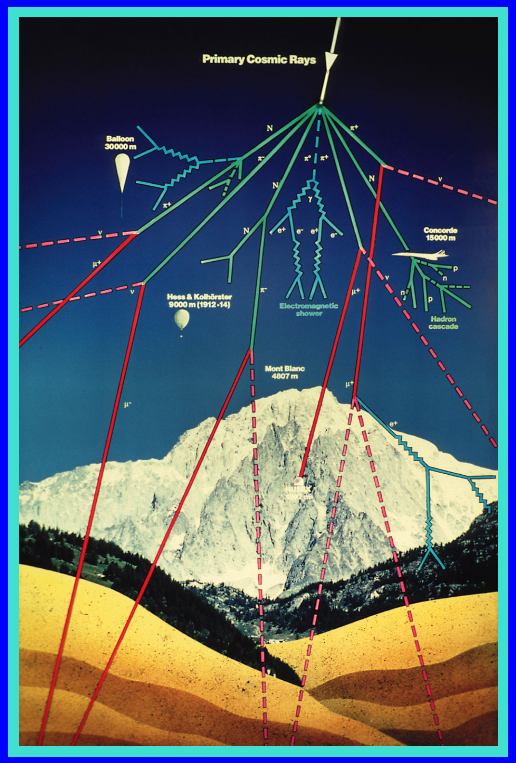
strange particles



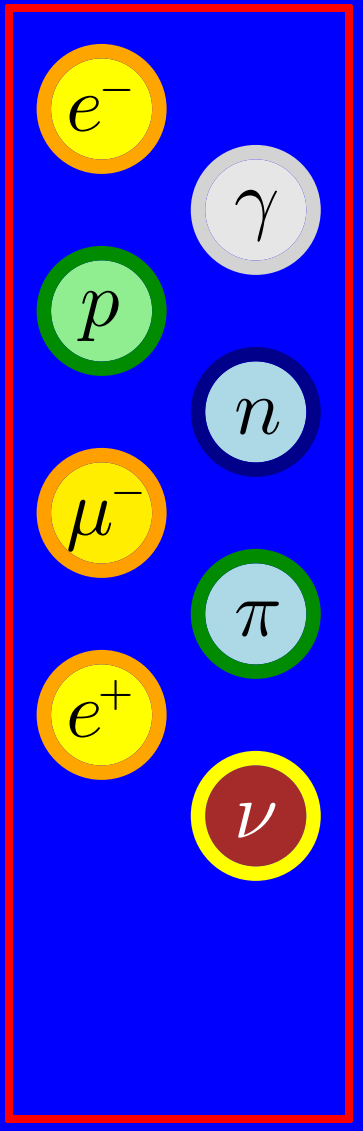
- are Hadrons
- are unstable

K: **Rochester** and **Butler** (Univ. of Manchester)

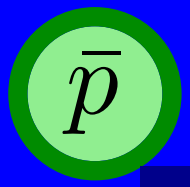
Λ: **Hopper** and **Biswas** (Univ. of Melbourne)



particles in a cloud chamber



strange particles are not point-like but elementary!



antiproton

exactly like the proton!

Spin $\frac{1}{2}$ ➡ Fermion

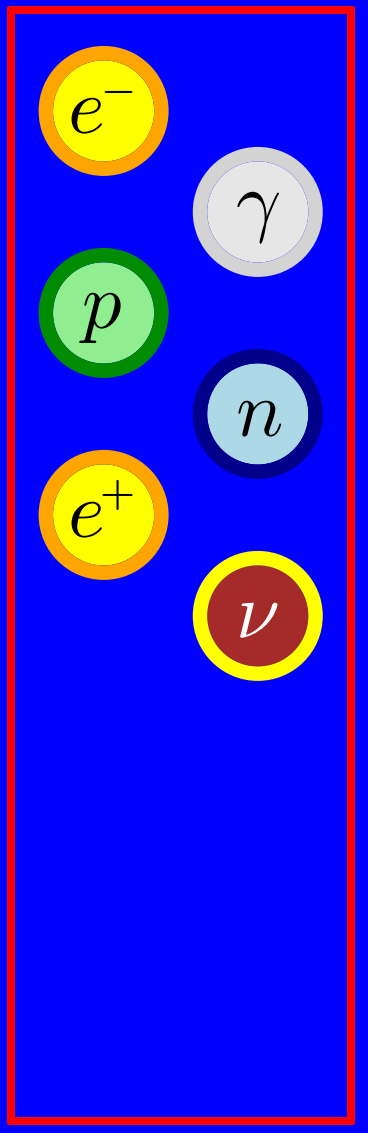
Mass: 938 MeV

Charge: -1

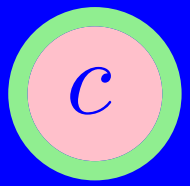
stable

Edwin McMillan and Edward Lofgren on the shielding of the **Bevatron**.

Antiprotons are also found in cosmic rays



the antiproton is not point-like but elementary!



charm quark: J/ψ

Spin $\frac{1}{2}$ ➡ Fermion

Mass: 1.29 GeV

Charge: $+\frac{2}{3}$

unstable

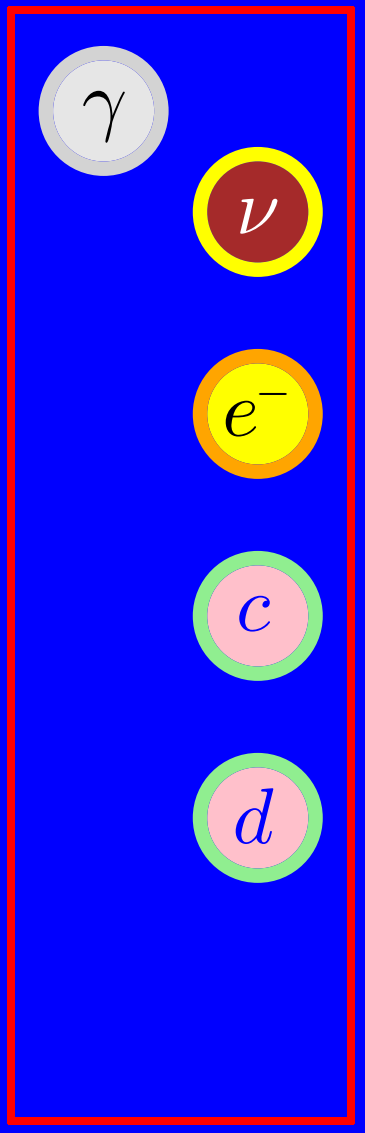
SLA… side

BNL: NSLS-II under construction

Burt Richter (SLAC)

Samuel Ting (BNL)

1974



all quarks are point-like but not asymptotic states!

τ lepton

Spin $\frac{1}{2}$ ➡ Fermion

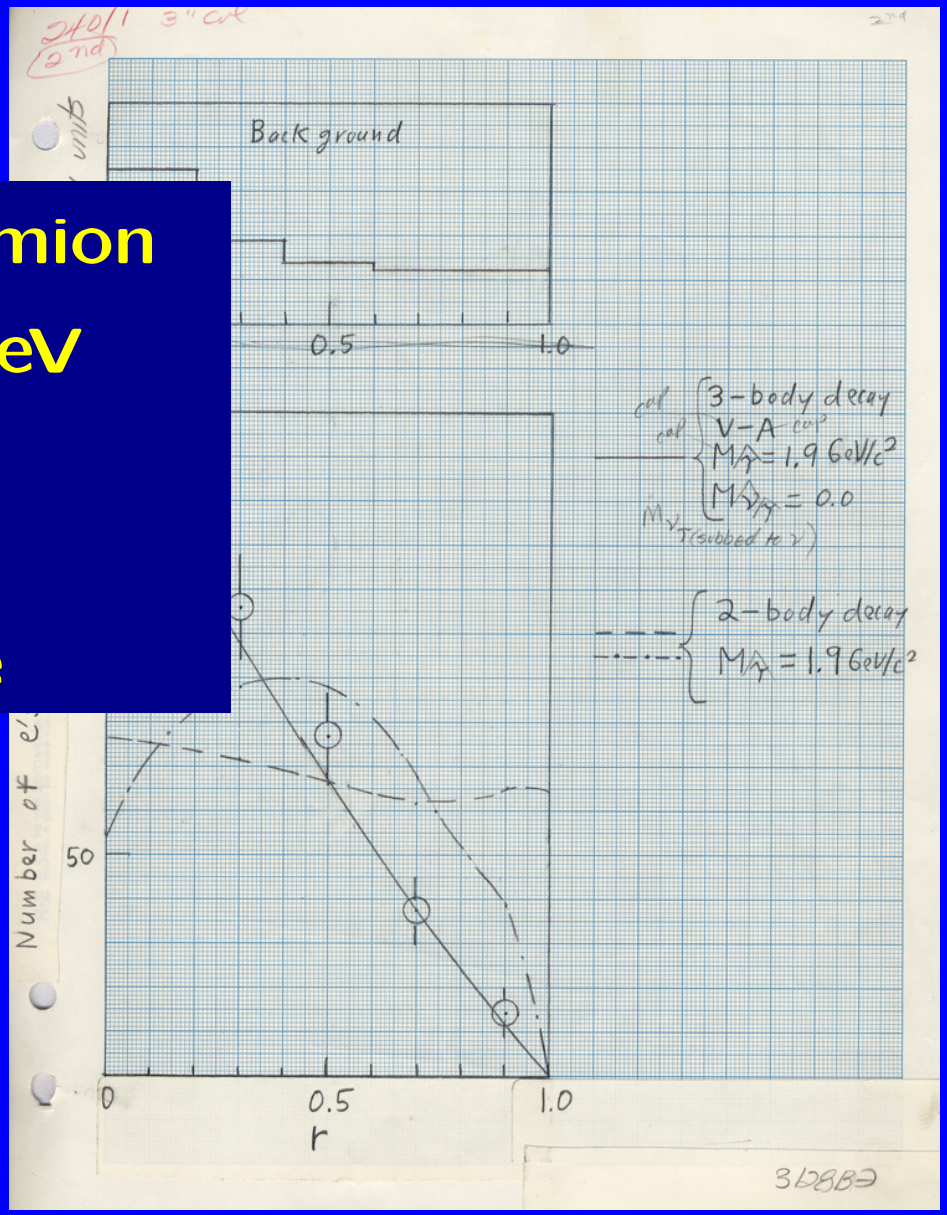
Mass: 1777 MeV

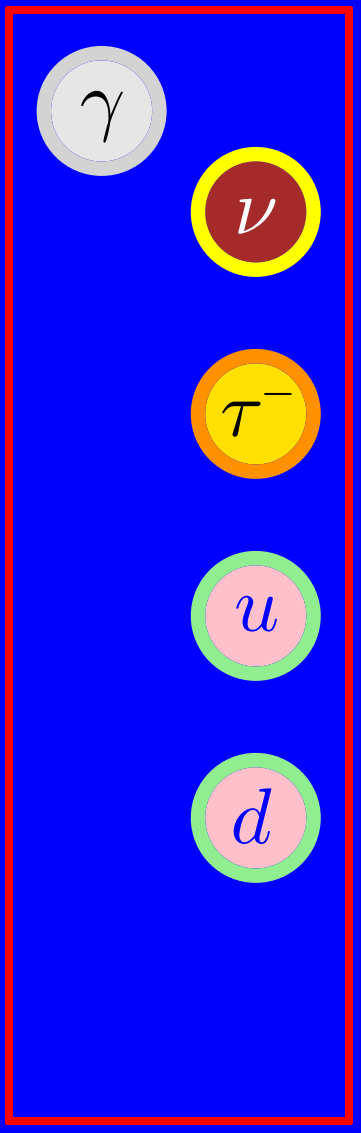
Charge: -1

τ: 2.9×10^{-13} s

➡ unstable

Ma
(SLA
197
- usin
(SLAC
  - first 4π-detector
- comparing **signal** to **background**





all leptons are point-like and elementary!

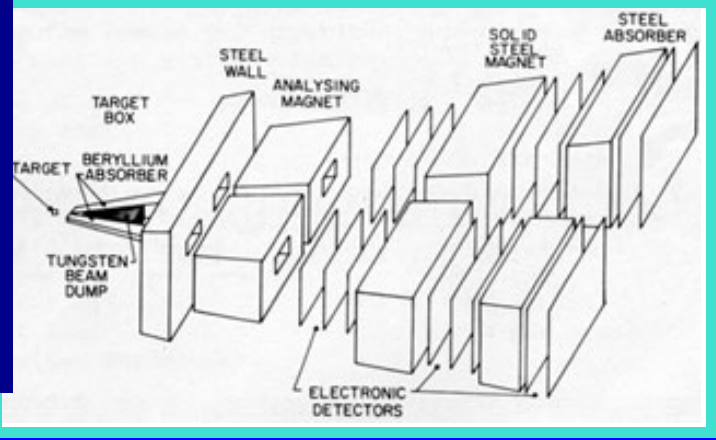
b bottom quark: Υ

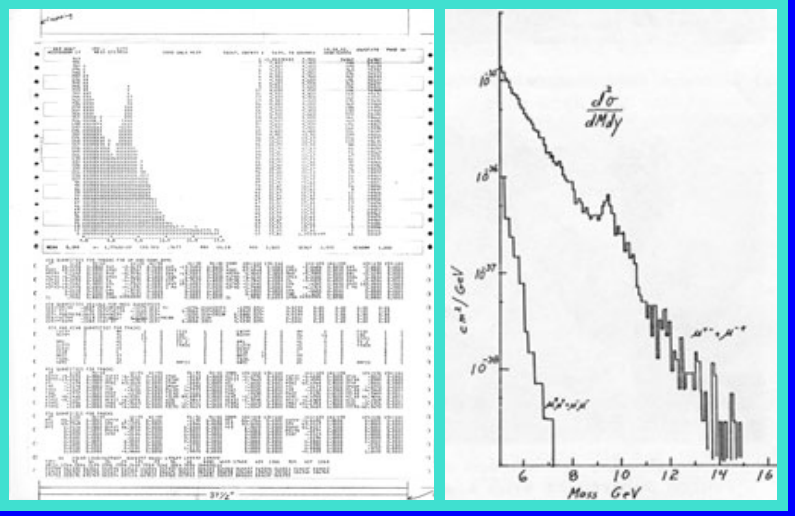
Spin $\frac{1}{2}$ ➡ Fermion

Mass: 4.18 GeV

Charge: $-\frac{1}{3}$

unstable



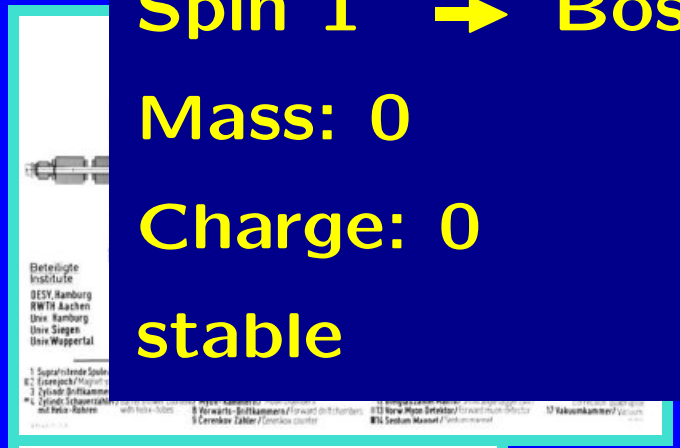


background suppression and computer aided statistical analysis lets the **Fermilab E288** experiment discover the Upsilon meson **1974**

γ ν e^- u b

all quarks are point-like but not asymptotic states!

g gluon

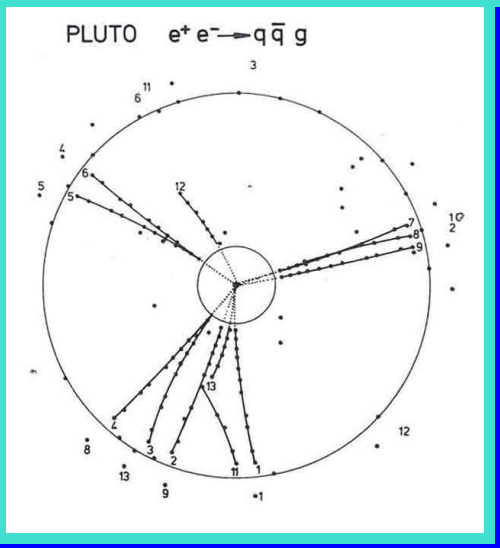


Spin 1 ➡ Boson

Mass: 0

Charge: 0

stable

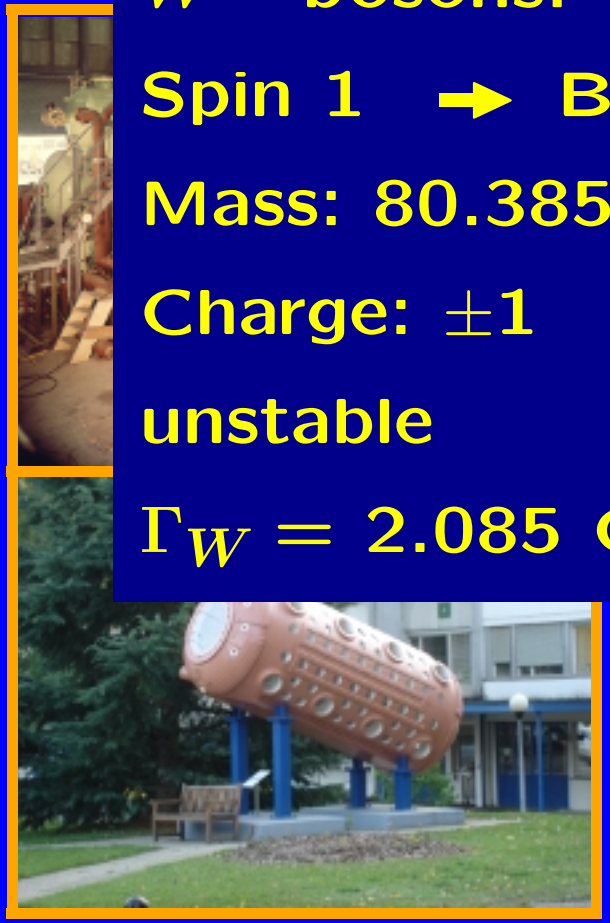


the consistent interpretation of **3-jet events** as **gluon bremsstrahlung** in the framework of QCD, done in PLUTO, TASSO, MARK-J, and JADE (experiments at PETRA, DESY), marks the discovery of the gluon **1979**

γ ν e^- u g d

the gluon is point-like but not an asymptotic state!

W Z hints for $W^{\pm}$- and Z-boson



$W^{\pm}$-bosons:

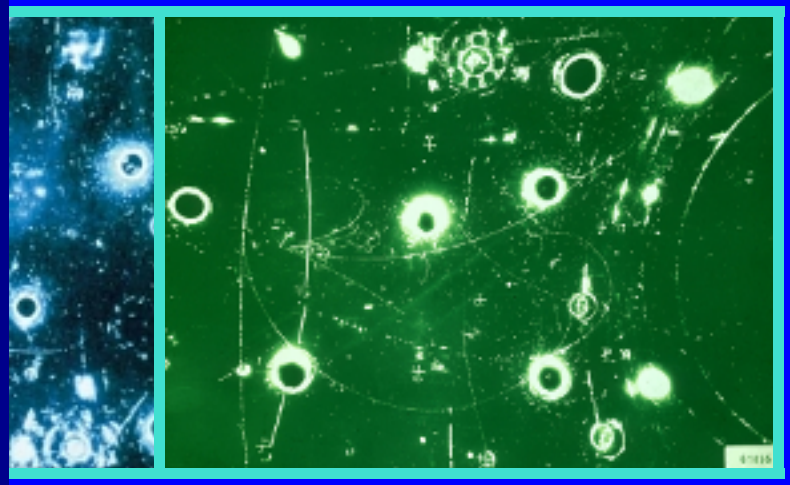
Spin 1 ➡ Boson

Mass: 80.385 GeV

Charge: ± 1

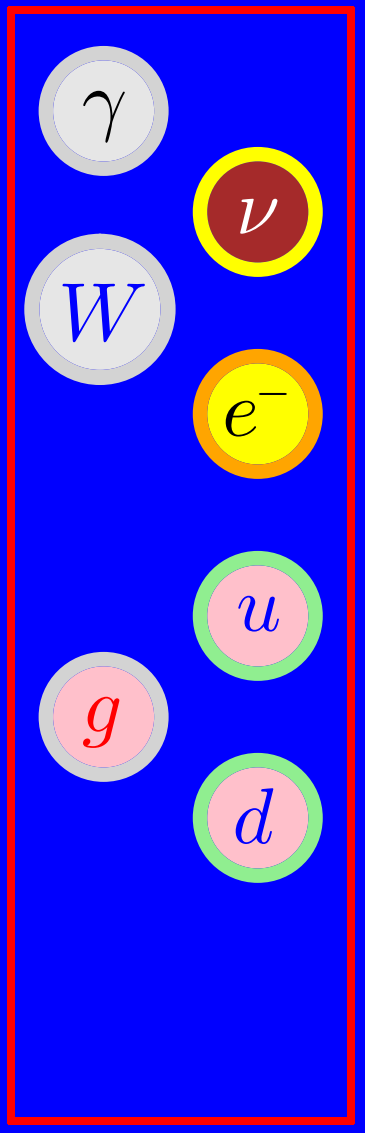
unstable

$\Gamma_W = 2.085$ GeV



arged currents were known from detection.

CERN announced the experimental observation of **weak neutral currents**, shortly after they were predicted by the electroweak theory of Abdus Salam, Sheldon Glashow and Steven Weinberg.

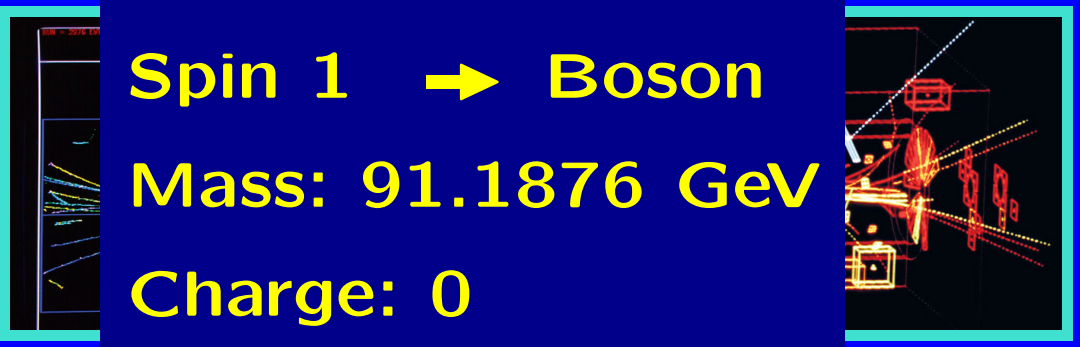


the $W^{\pm}$-bosons are point-like and elementary!

W Z $W^{\pm}$- and Z-boson

even

UA1



Z^0-boson:

Spin 1 ➡ Boson

Mass: 91.1876 GeV

Charge: 0

unstable

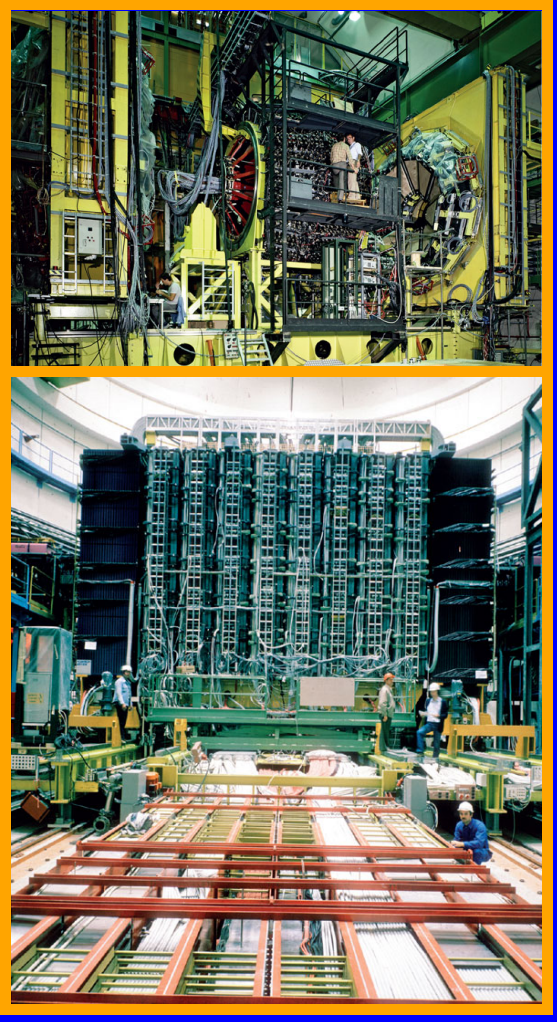
$\Gamma_W = 2.4952$ GeV

Ja

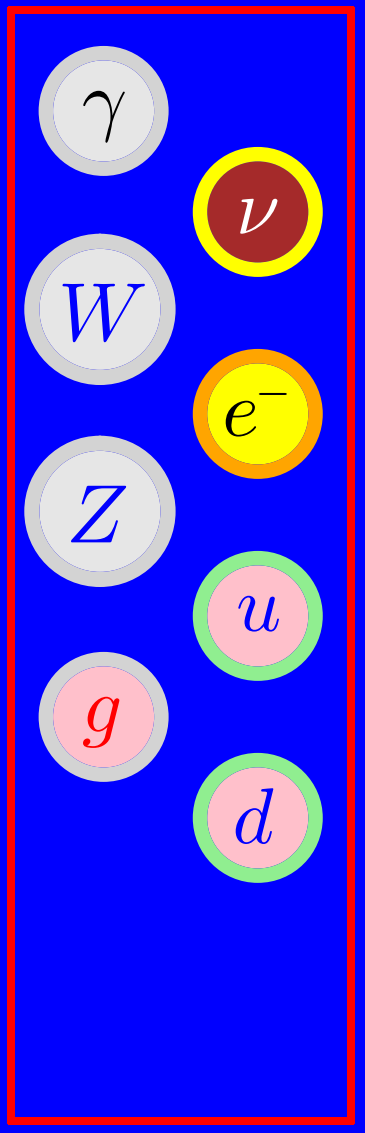
Ru they feel like Ws, they smell like Ws, they must be Ws''.

4 Z-events by end of June 1983

UA2 detector



UA1 detector (parking)



the Z^0-boson is point-like and elementary!

t top quark

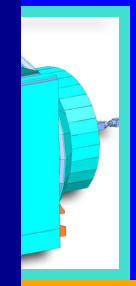
Spin $\frac{1}{2}$ ➡ Fermion

Mass: 173 GeV

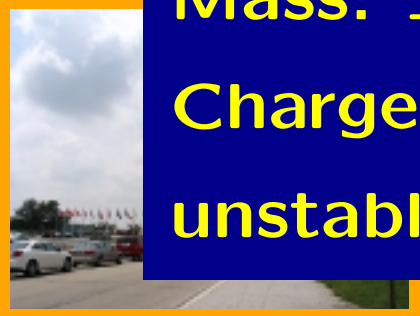
Charge: $+\frac{2}{3}$

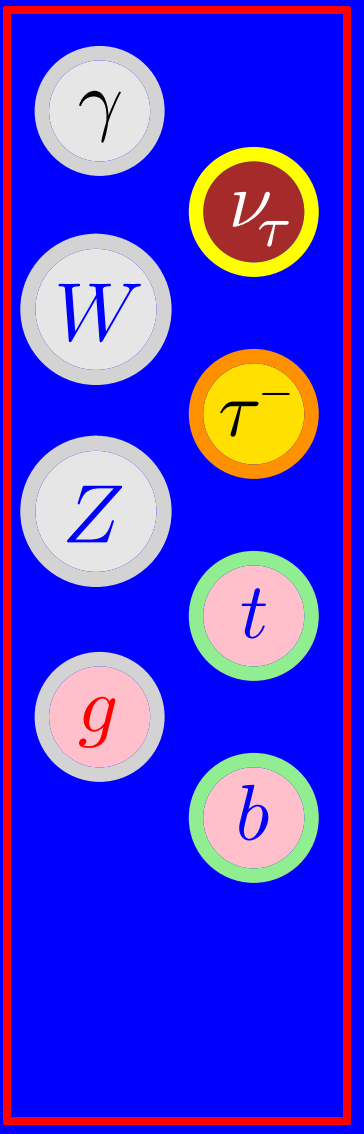
unstable

CDF



DØ





all quarks are point-like but not asymptotic states!

H Higgs boson

Pred

Spin 0 ➡ Boson

Mass: 125.09 GeV

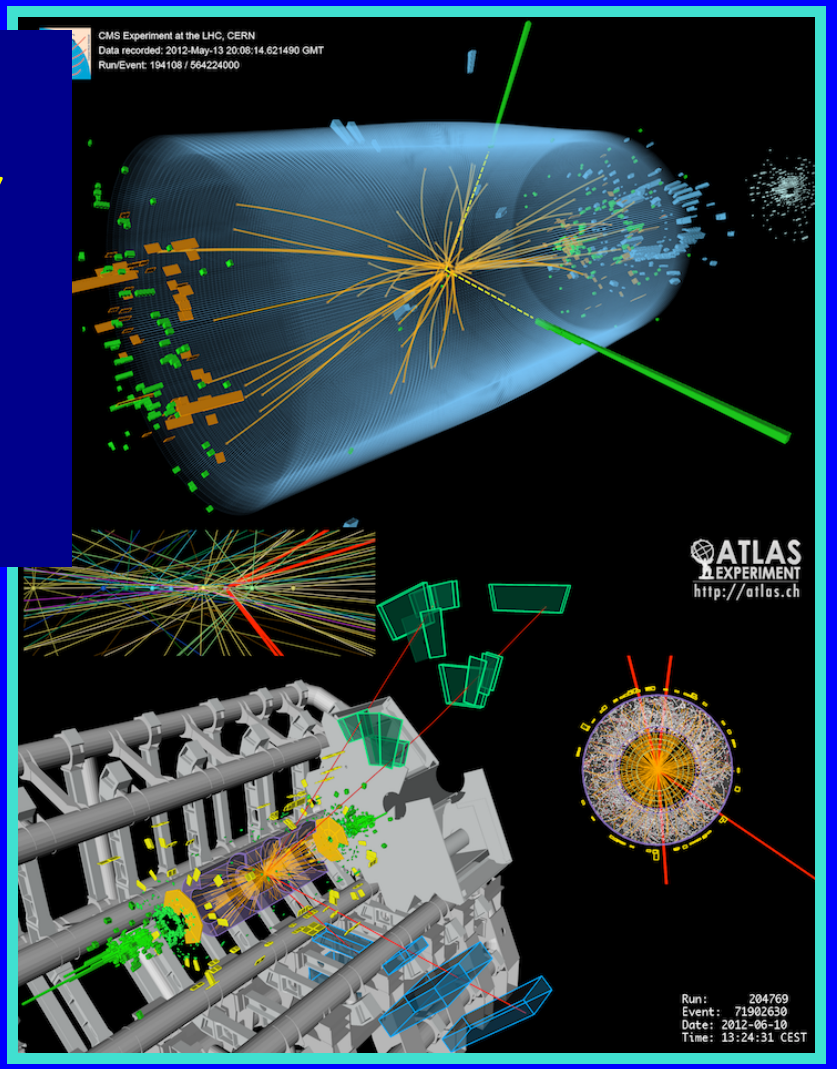
Charge: 0

unstable

predicted τ: 1.5×10^{-22} s

Nobel prize 2013

2012 CMS & ATLAS (CERN)



γ ν W e^- Z u g d H

the Higgs boson is point-like and elementary!