Introduction to Particle Physics

(for non physics students)

2. PARTICLES

(from atoms to quarks and leptons)

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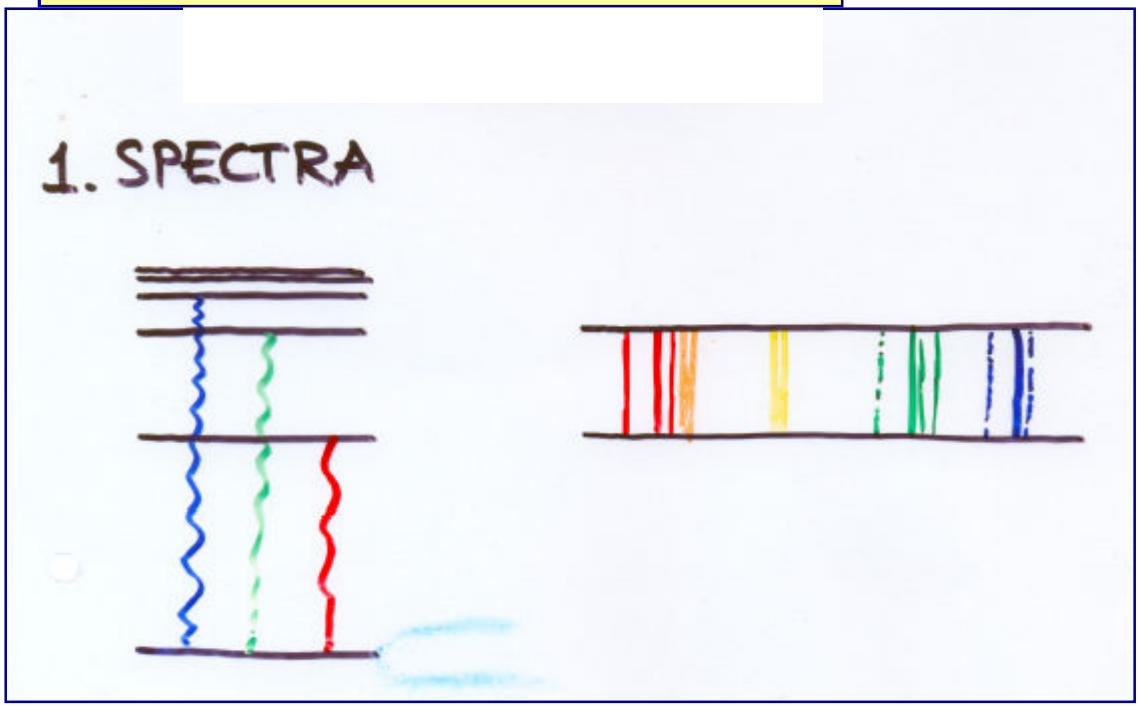
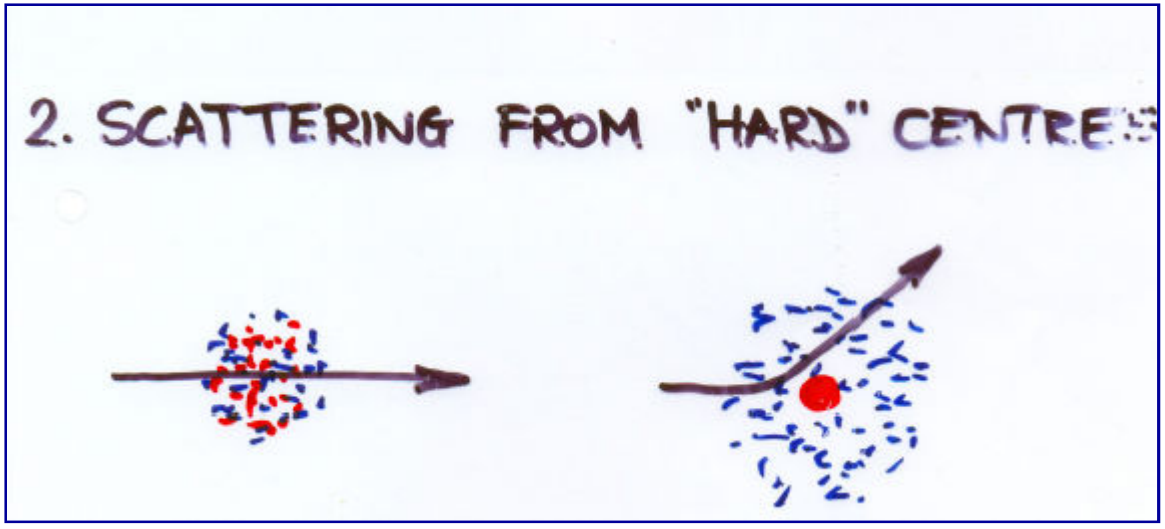
Structure of Matter

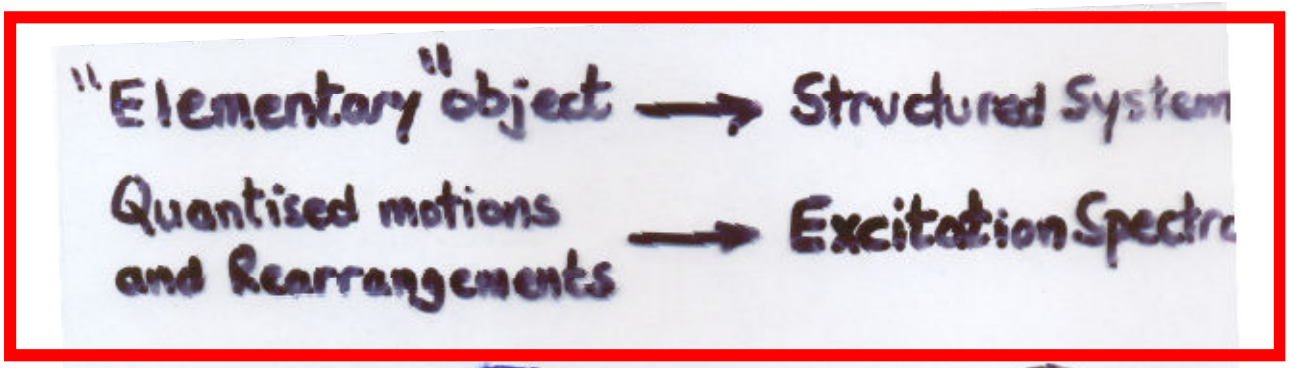
Two ways that structure is revealed:

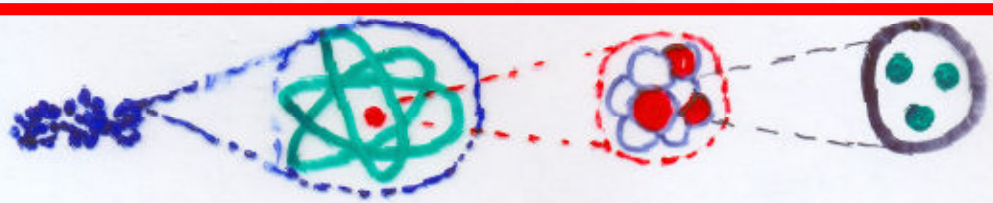


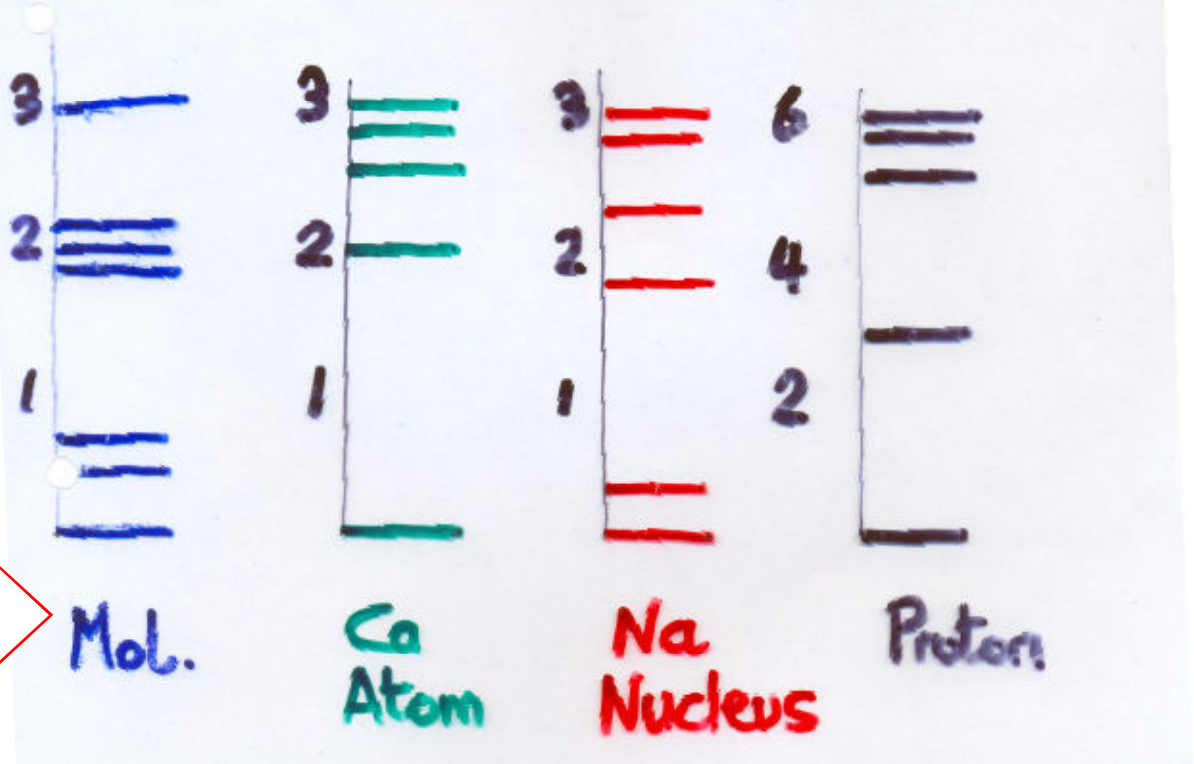


True from atoms to particles…..

Spectra

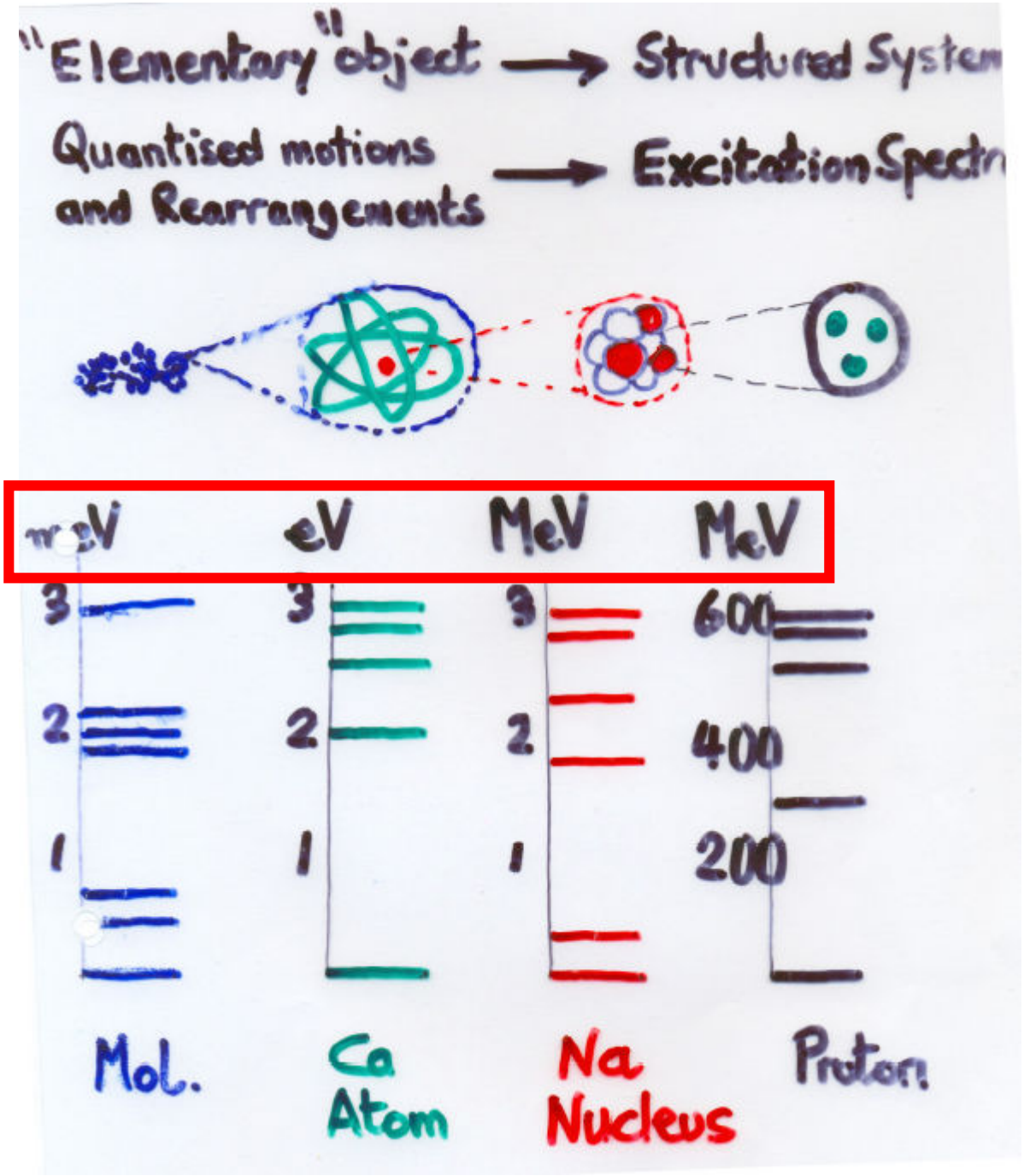






Qualitatively similar

Spectra



Quantitatively different

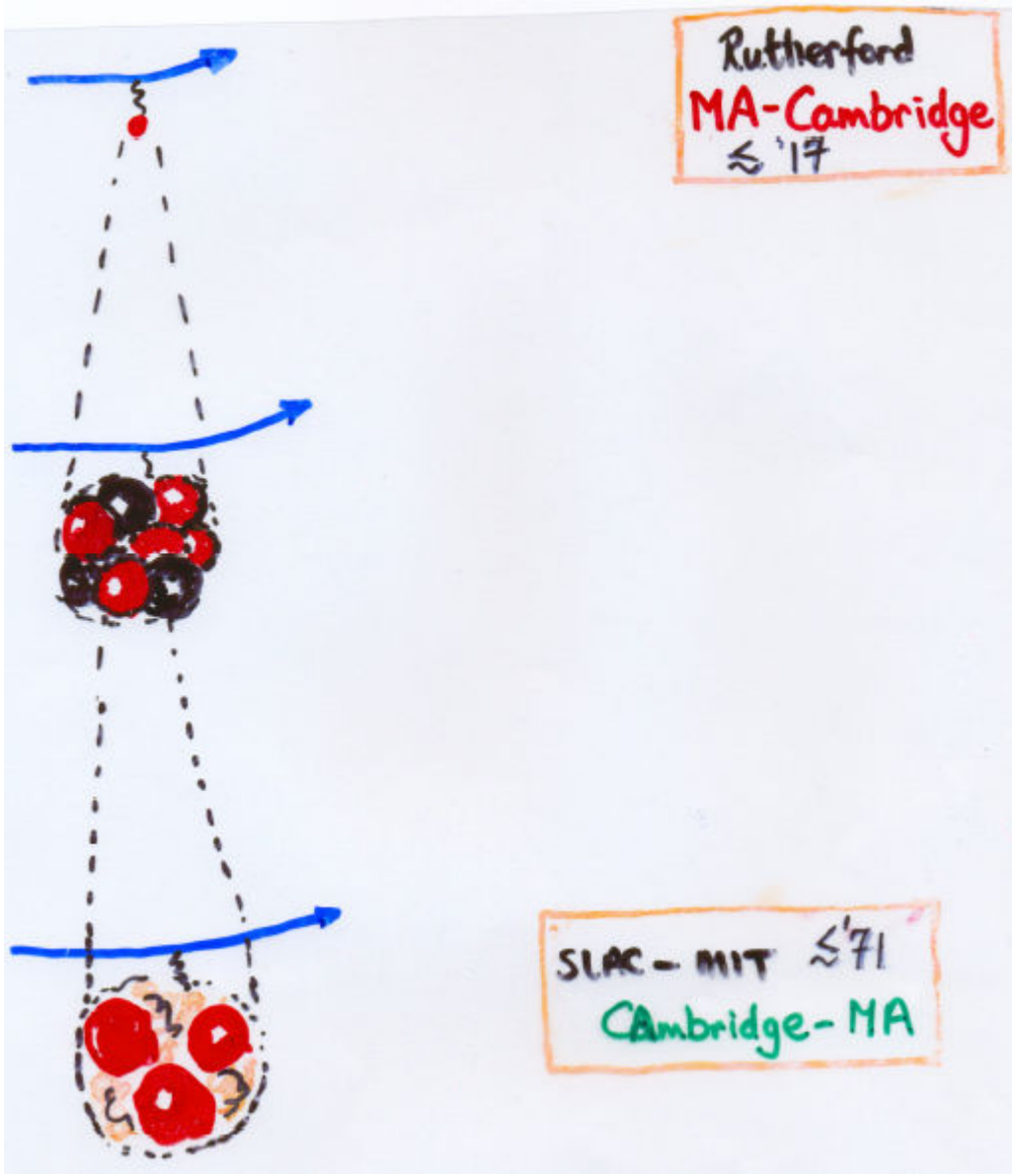
Scattering

Nuclear atom

Proton/neutron

Quarks

Qualitatively similar



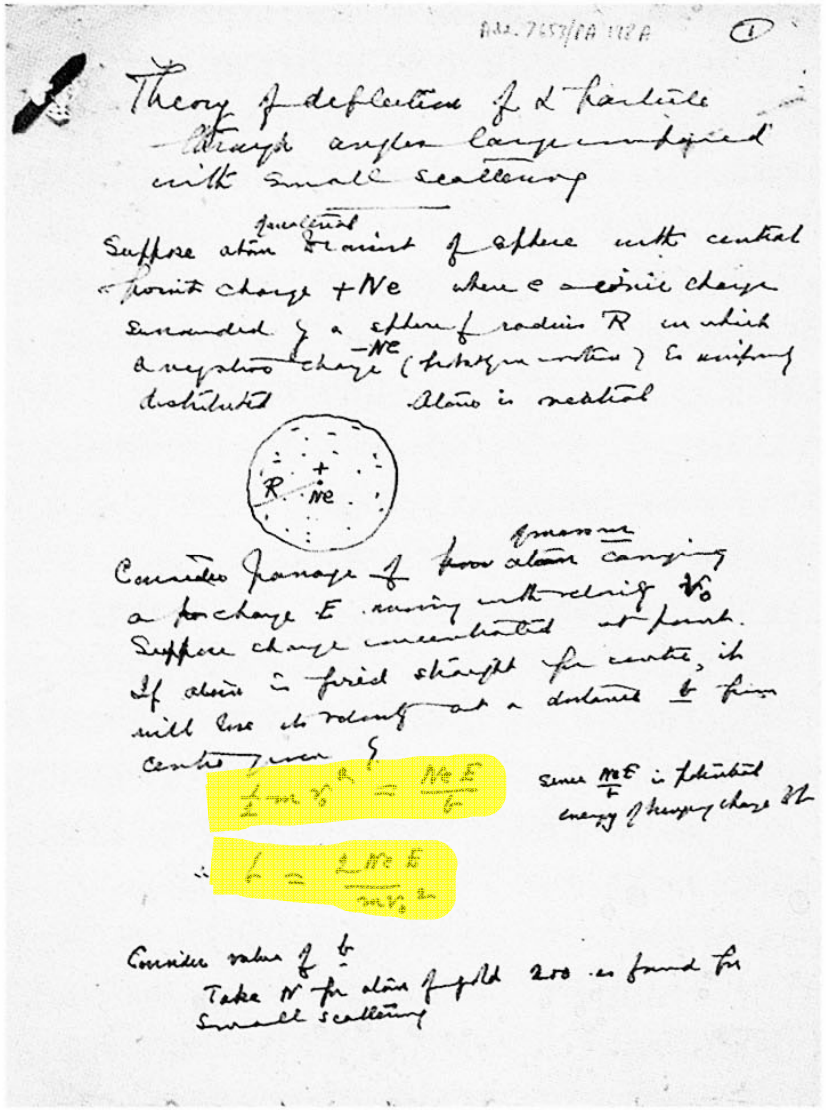
Rutherford: Nuclear Atom

Alpha particles from natural radioactivity

Gold leaf

Small scintillation screen

Rutherford used energy conservation…



Theory of deflection of α particle through angles large compared with small scattering

Suppose atom consist of sphere with central (functional) point charge +Ne where e = atomic charge surrounded by a sphere of radius R in which a negative charge −Ne (distributed in rotating orbits) is uniformly distributed. Atom is neutral

Consider passage of fast α particle (mass m) from atom carrying a positive charge E (mass M) moving with velocity V_0. Suppose charge concentrated at point. If atom is fixed straight for centre, it will rise to velocity V_0 at a distance b from centre. Then

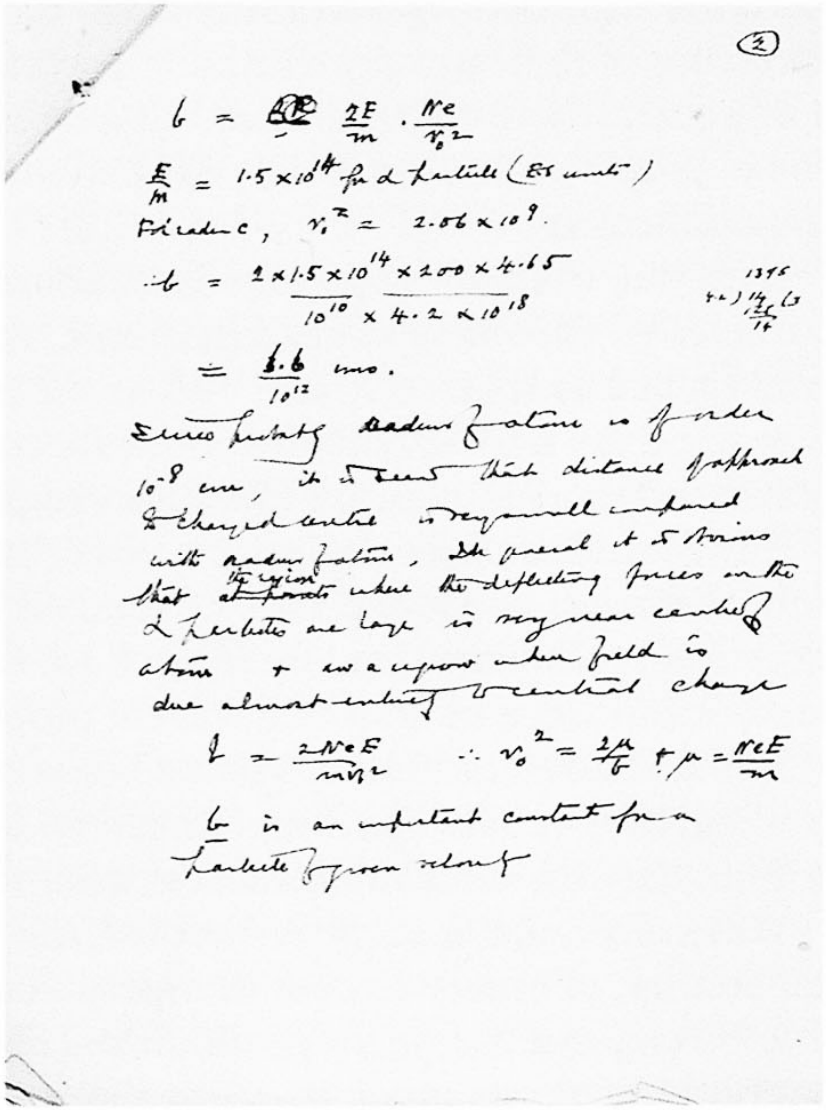
$$\frac{1}{2} m V_0^2 = \frac{NeE}{b}$$

since $\frac{NeE}{b}$ is potential energy of moving charge at b

$$\therefore b = \frac{2NeE}{m V_0^2}$$

Consider value of b

Take N for atom of gold 200 as found for small scattering



$$b = \frac{2E}{m} \cdot \frac{Ne}{V_0^2}$$

$\frac{E}{m} = 1.5 \times 10^{14}$ for α particle (E.S. units)

For radon, $V_0^2 = 2.06 \times 10^9$.

$$\therefore b = \frac{2 \times 1.5 \times 10^{14} \times 200 \times 4.65}{10^{10} \times 4.2 \times 10^{18}}$$

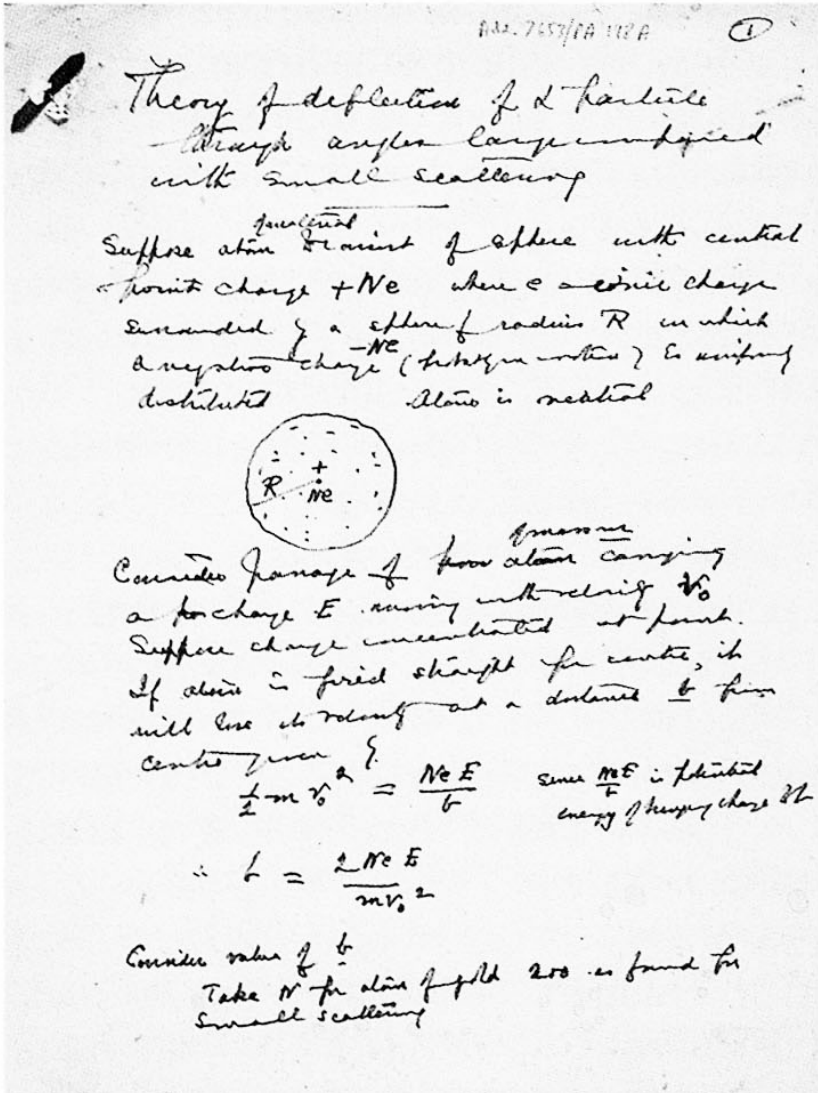
$$= \frac{3.6}{10^{12}} \text{ cms.}$$

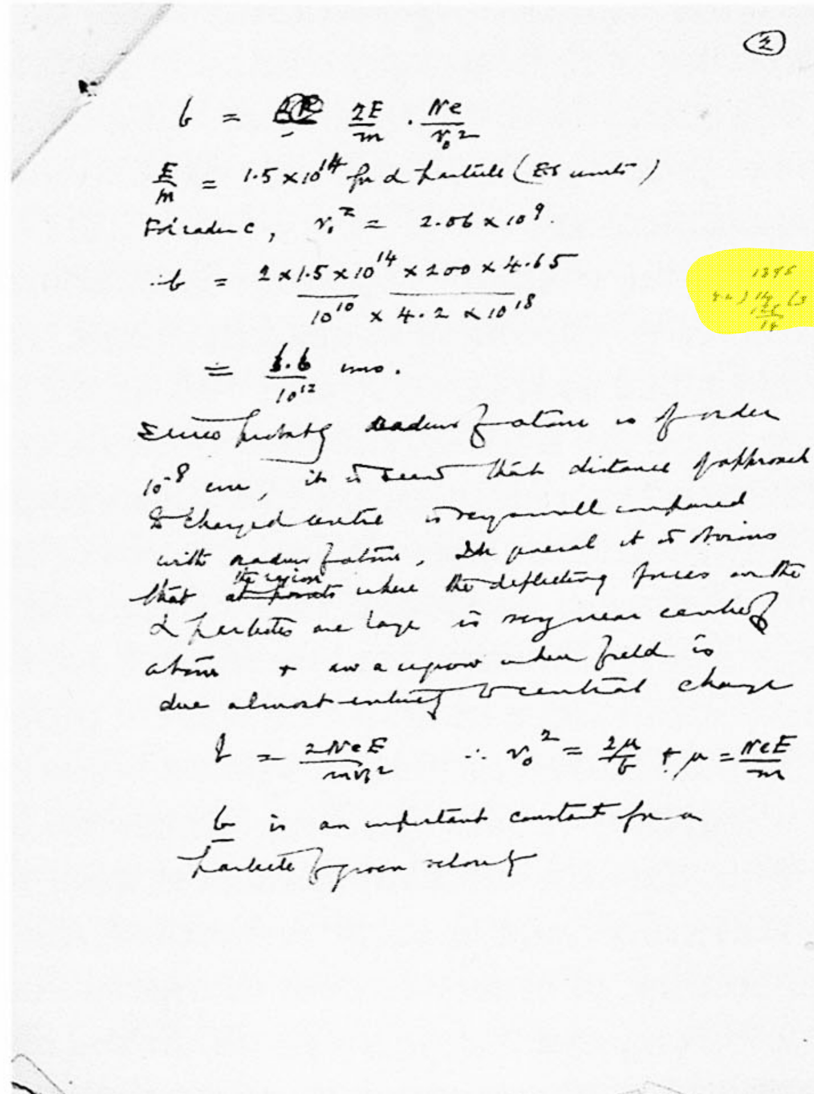
Since probably radius of atom is of order 10^{-8} cm, it follows that distance of approach of charged centre is very small compared with radius of atom, so that at points where the deflecting forces on the α particles are large in very near centre of atom + as a rule when field is due almost entirely to central charge

$$b = \frac{2NeE}{m V_0^2} \quad \therefore V_0^2 = \frac{2\mu}{b} \text{ if } \mu = \frac{NeE}{m}$$

b is an important constant for a particle of given velocity

…and long division





$$\therefore b = \frac{2 \times 1.5 \times 10^{?} \times 200 \times 4.65}{10^{10} \times 4.2 \times 10^{18}}$$

1396

4.2) 14 (3
126
14

$$\doteq \frac{3.6}{10^{12}} \text{ cms.}$$

Since probably radius of atom is of order 10^{-8} cm it is seen that distance of closest approach of charged centre is very small compared with radius of atom. In general it is obvious that the region where the deflecting forces on the α particles are large is very near centre of atom & in a region where field is due almost entirely to central charge

$$b = \frac{2NeE}{m v_0^2} \quad \therefore v_0^2 = \frac{2\mu}{b} \ \& \ \mu = \frac{NeE}{m}$$

Quarks in the proton

Qualitatively: Same idea

Quantitatively:
Different scale

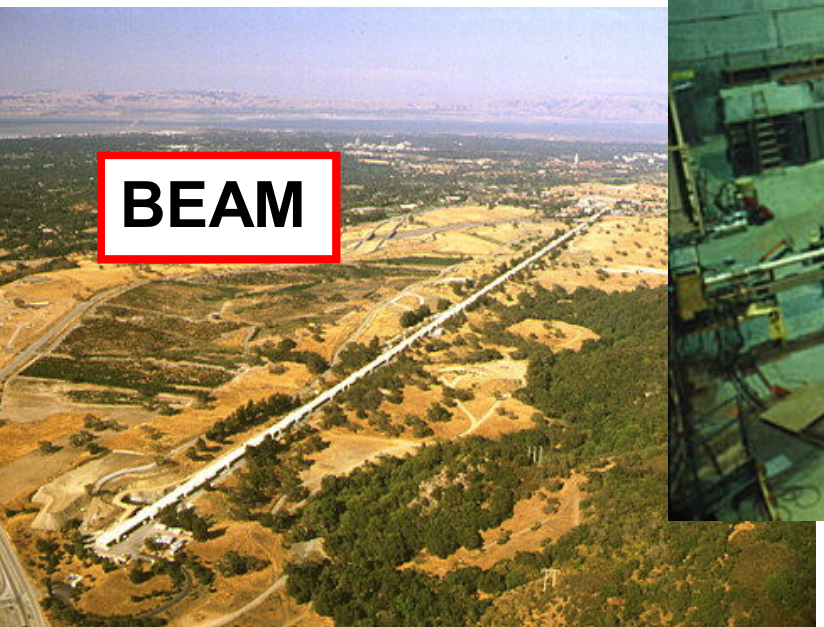
SLAC 3km electron accelerator

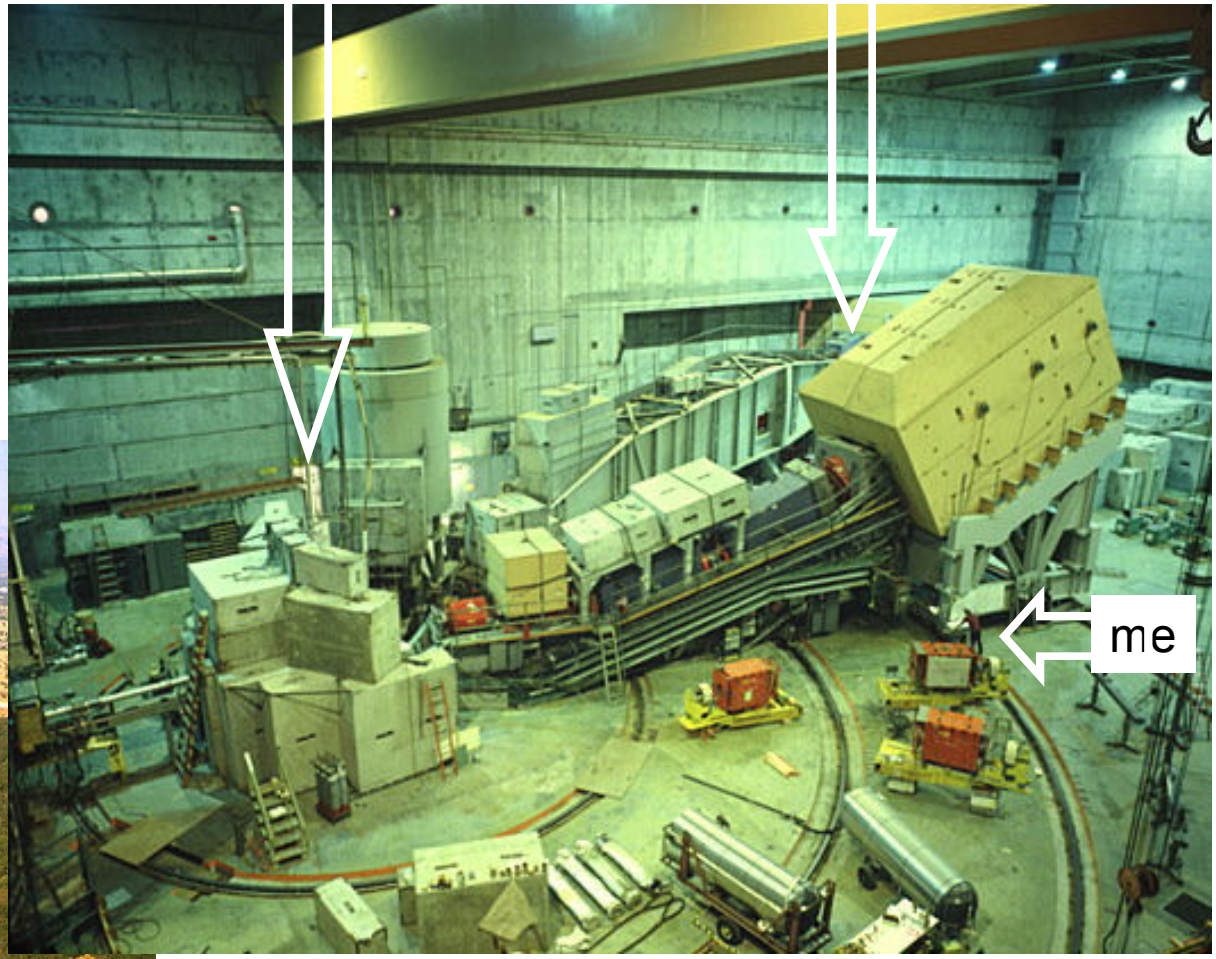
Quarks in the proton

Electron beam = 3 km

Proton target (hydrogen)

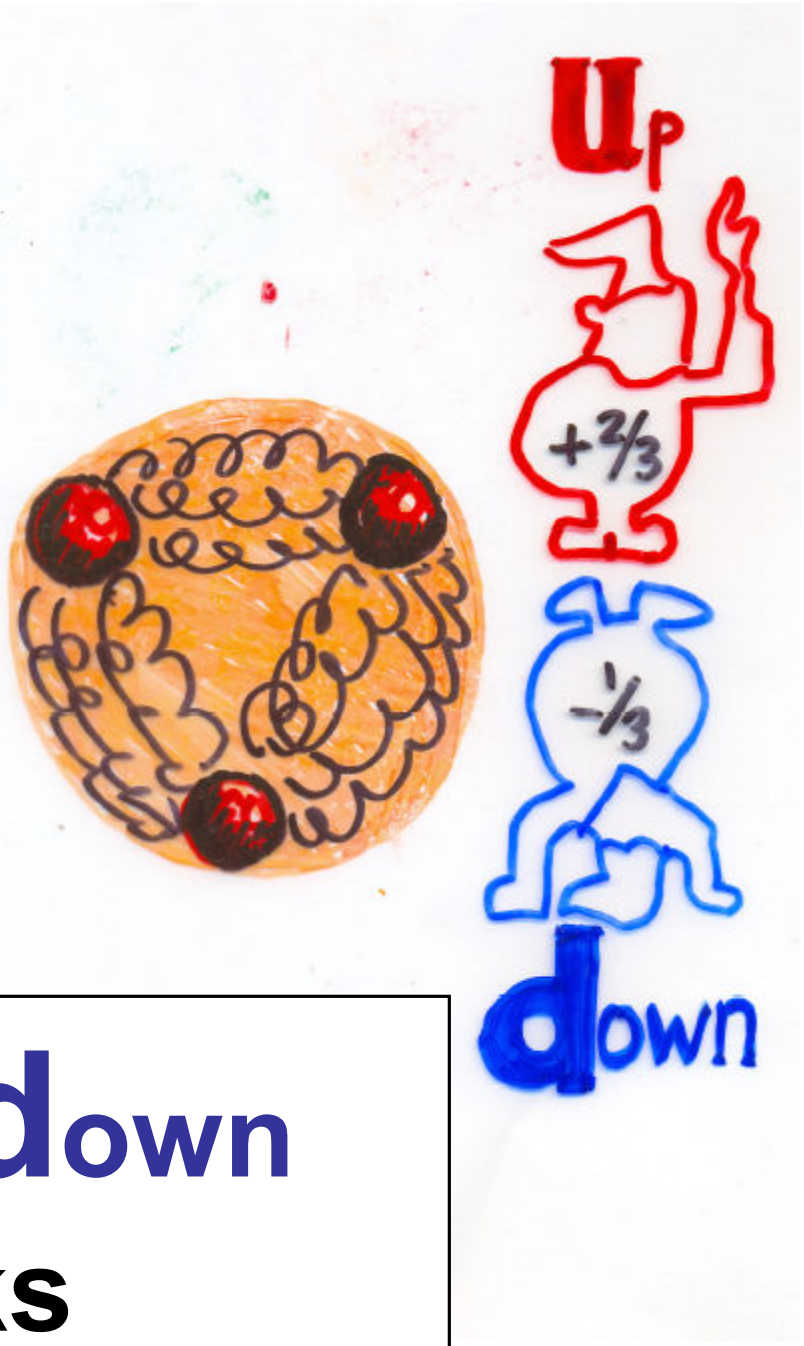
Big electronic detector


BEAM

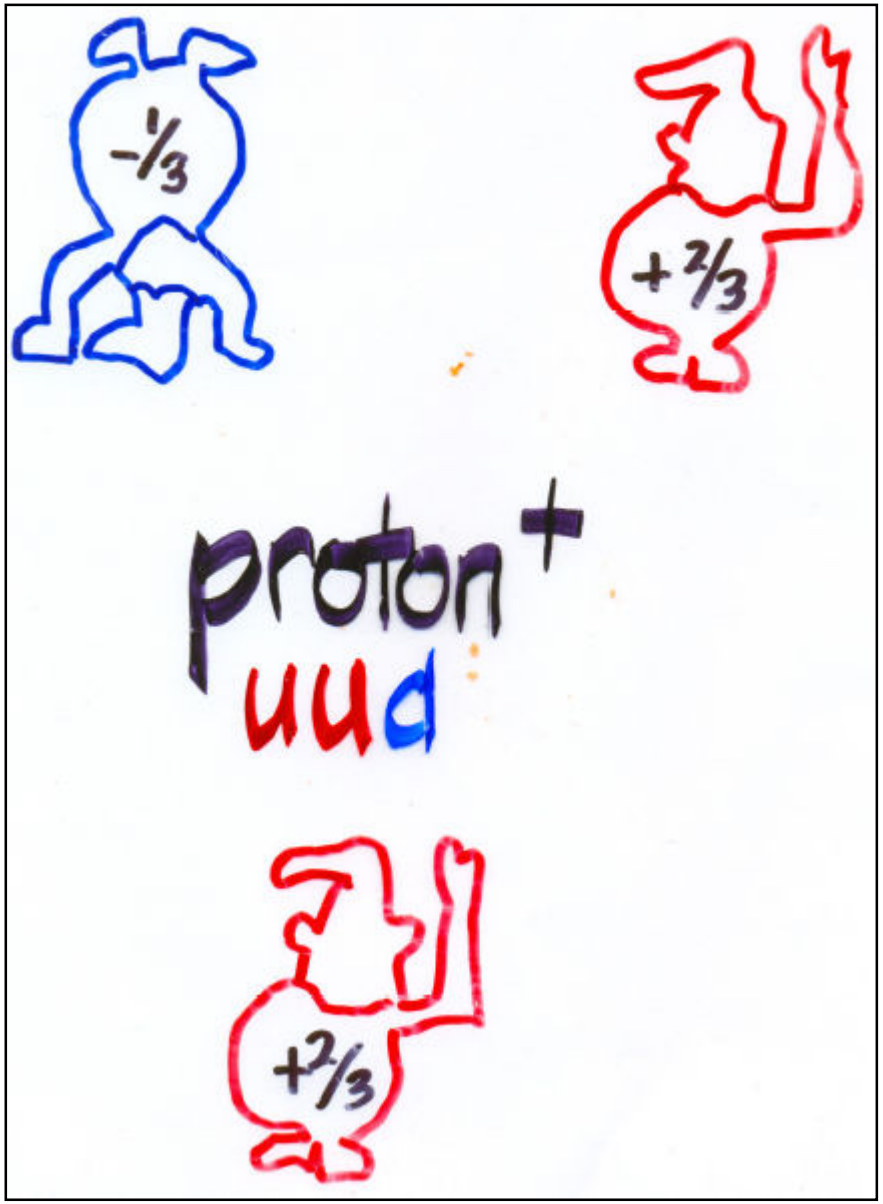

TARGET
DETECTOR
me

Proton made of 3 quarks, gripped by gluons

To make
proton
and
neutron
requires two
“flavours”
of
Quarks



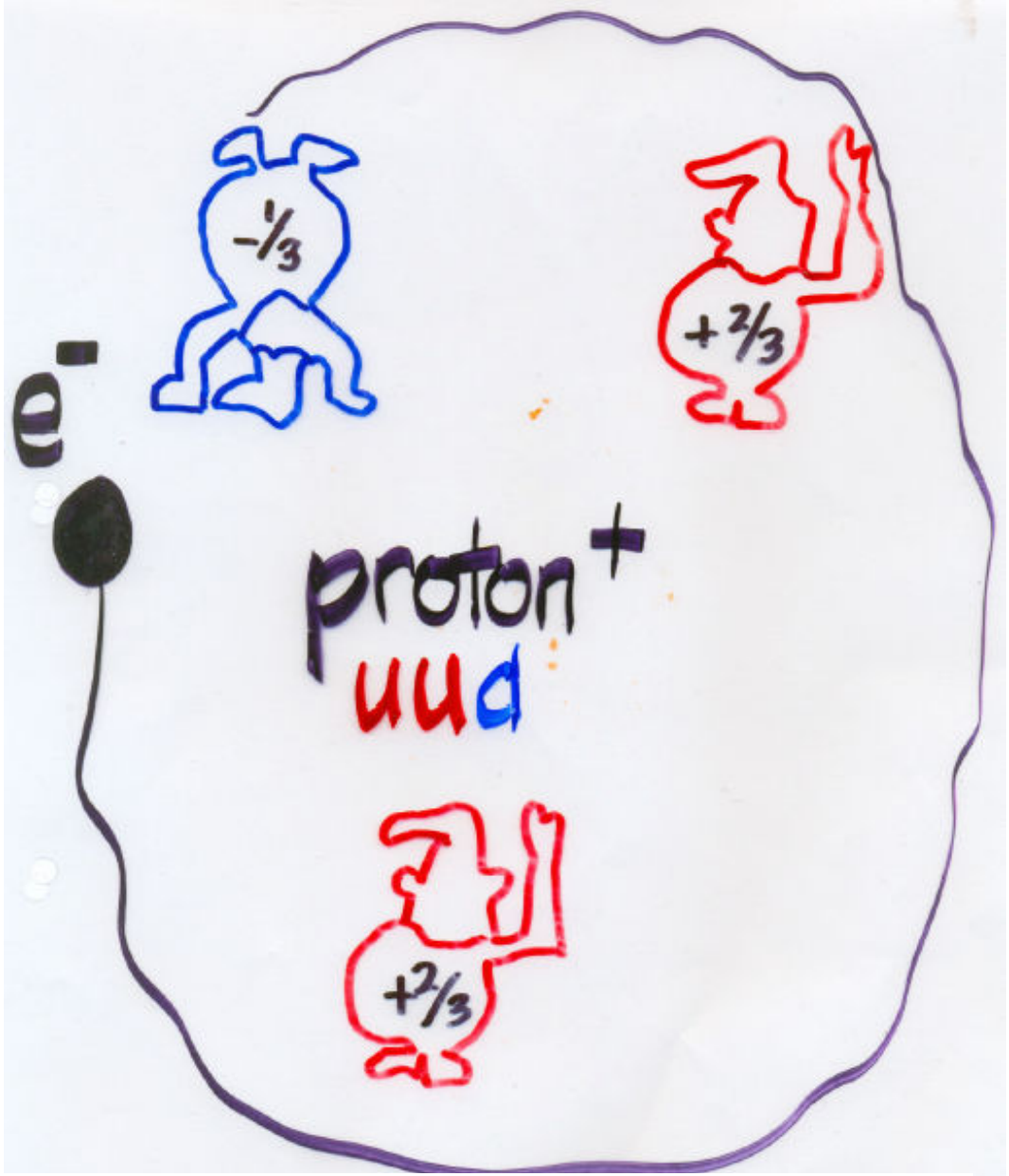
Up and down Quarks



and

neutron

ddu



H atom

(not to scale!)

a miracle of neutrality

electron

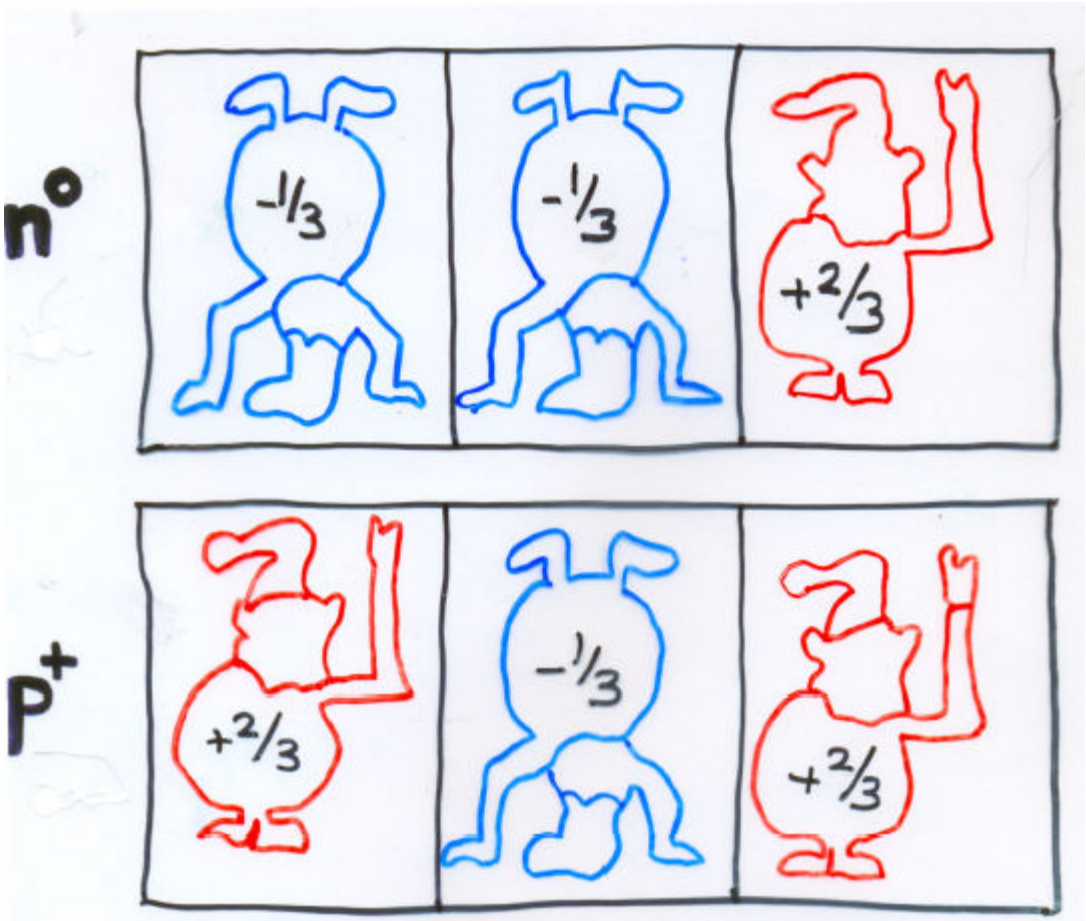
balances

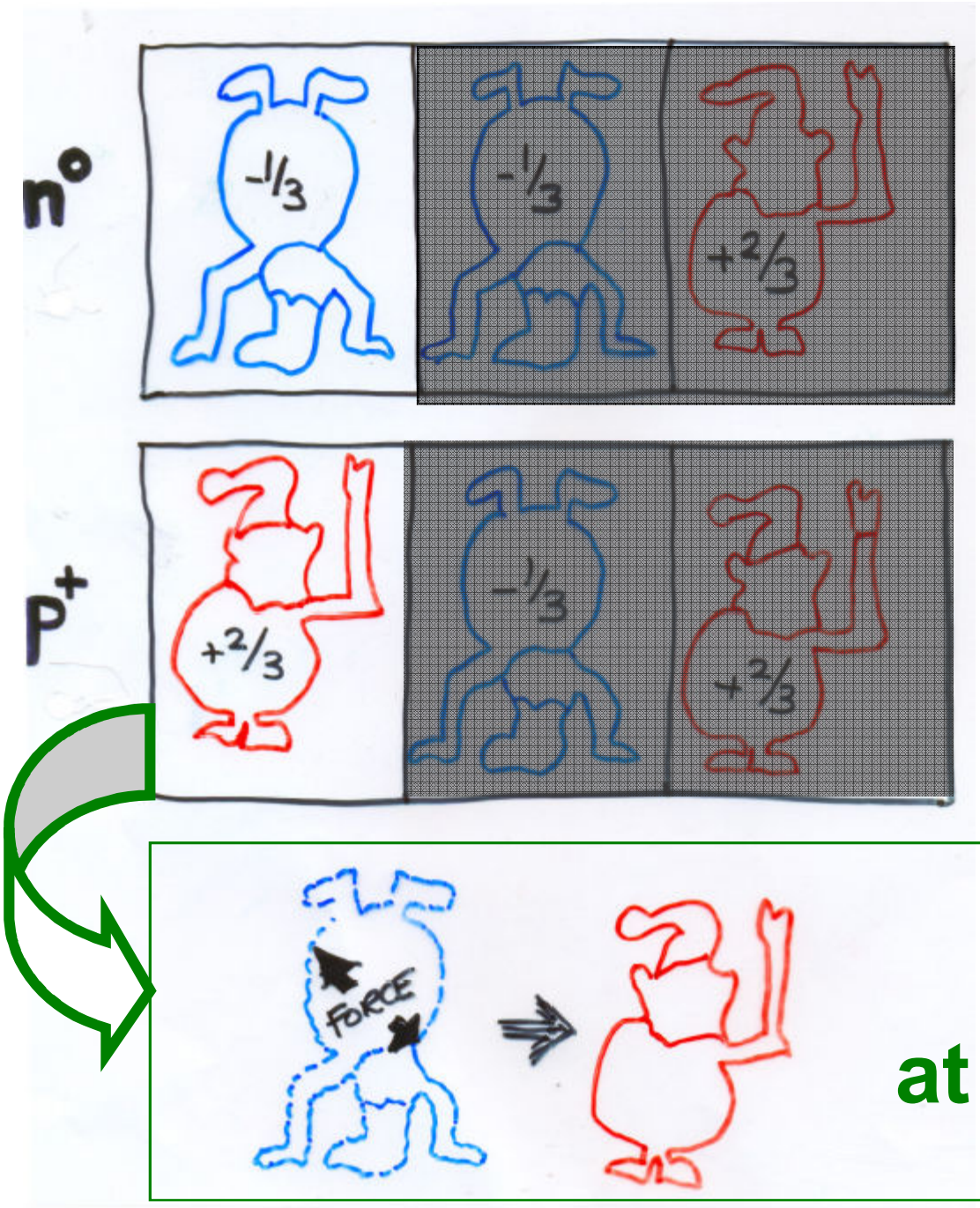
uud

hint of unification

The scale of things in the micro and macro cosmos

		factor
earth	10^7 m	
		100
sun	10^9 m	
		100
earth orbit	10^{11} m	
electron/quark	10^{-18} m	
		10000
nucleus	10^{-14} m	
		10000
electron orbit	10^{-10} m	


n°
-1/3
-1/3
+2/3
P+
+2/3
-1/3
+2/3



beta decay at quark level

Life, much of the Universe, but not everything

Stable (ordinary) matter

- up-quark (charge +2/3)
- down-quark (charge -1/3)
- electron (charge -1)
- neutrino (no charge and ≈ zero mass)

proton

neutron

what is the neutrino needed for ??

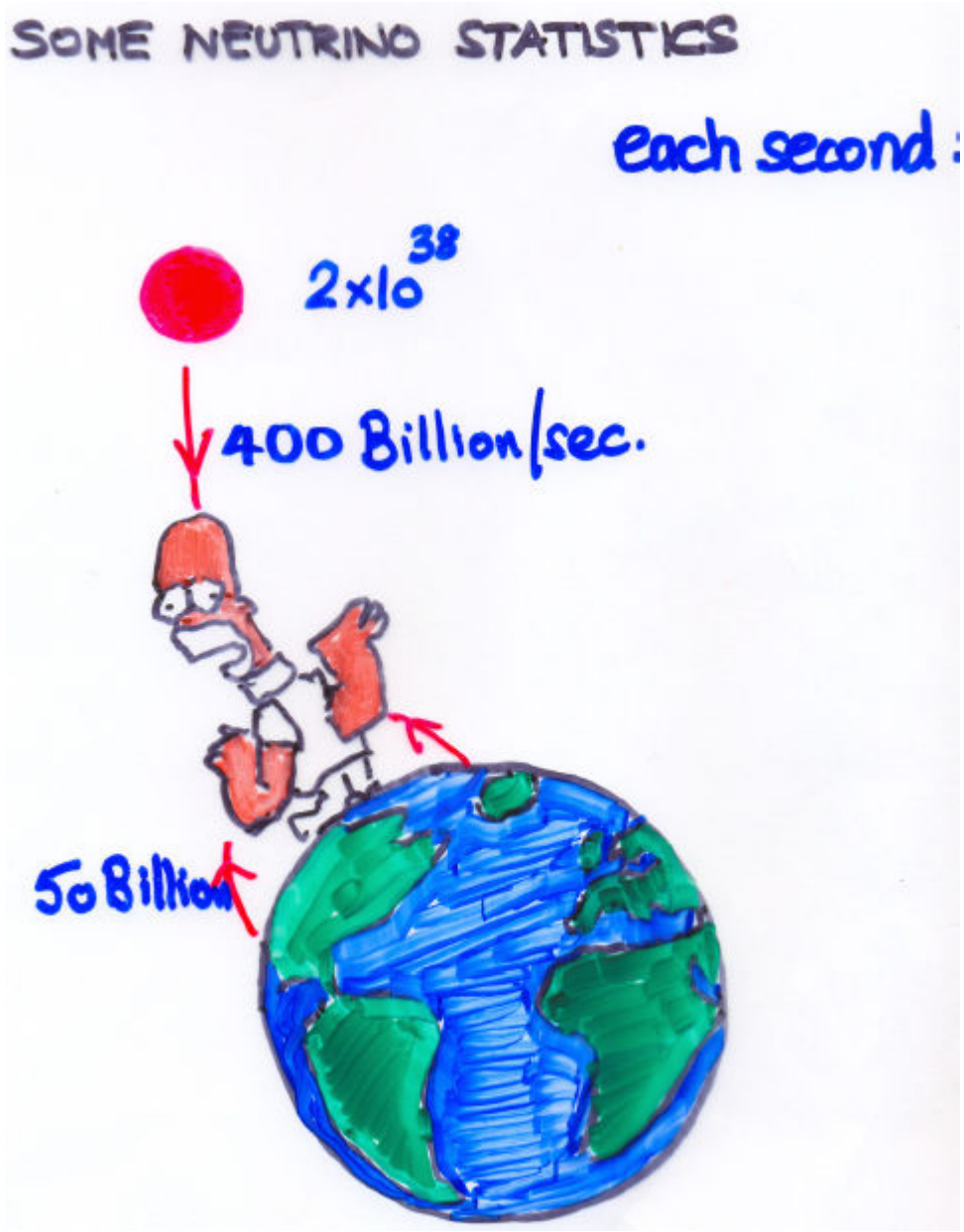
The Ghostly Neutrino

- goes through almost everything
- "impossible" to stop/detect
- the "smallest" of the particles

- the first fossil in the Universe
- Messenger from the earliest processes in the Universe
- determines the Expansion Rate of the Universe: Abundance of the first (light) Elements

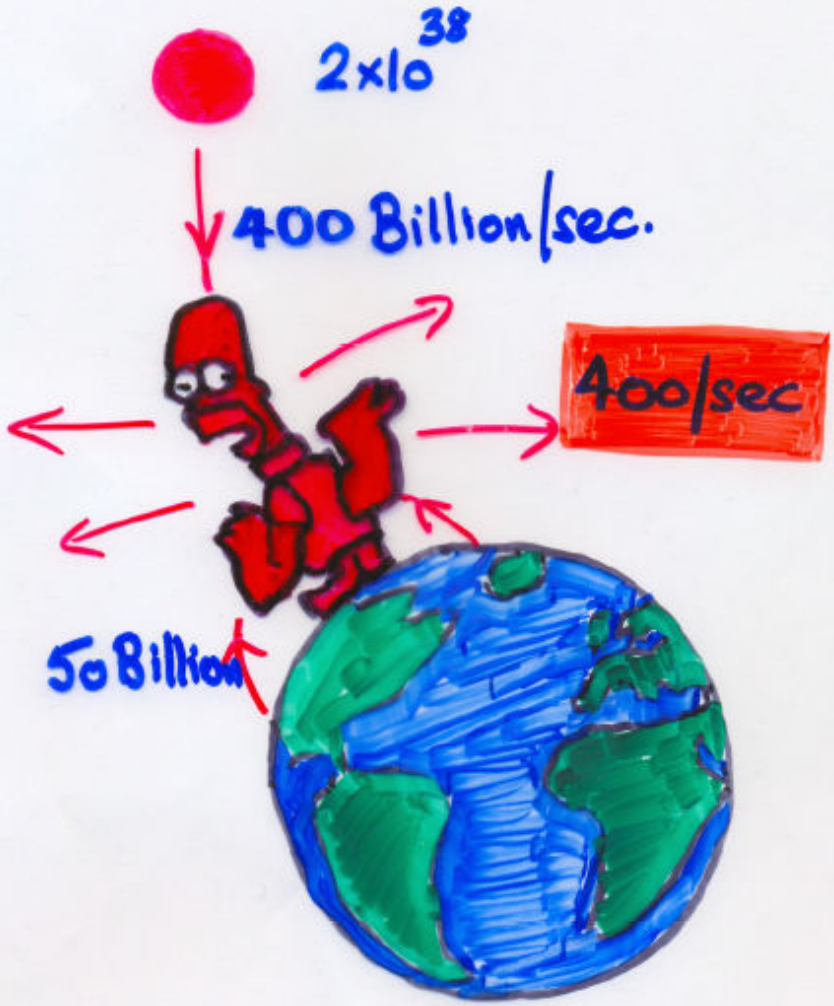
- essential in cooking the Heavy Elements needed for Life
- Neutrino astronomy looks "inside" the Sun and Supernovae

SOME NEUTRINO STATISTICS

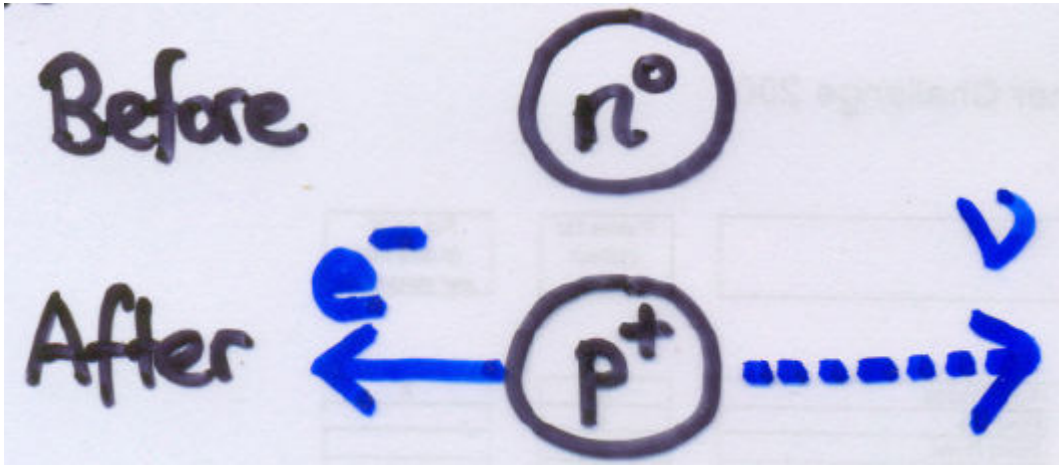


SOME NEUTRINO STATISTICS

each second :

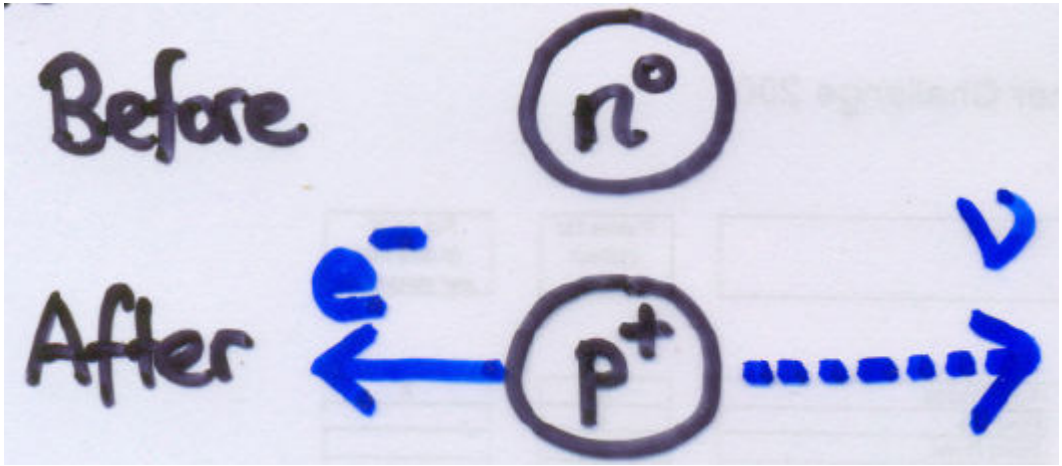


1 hr. x this audience ⇒ 100 million neutrinos



How do we know the neutrino is produced?

It hits a nucleus upstream and turns into charged lepton which is detected.



Three charged leptons

electron

muon

tau

And three neutral:

e-**neutrino**

mu-**neutrino**

tau-**neutrino**

MATTER

fundamental **LEPTONS** (like electron and ν

Composite HADRONS (made of **QUARKS**

QUARK MASSES (approximate)

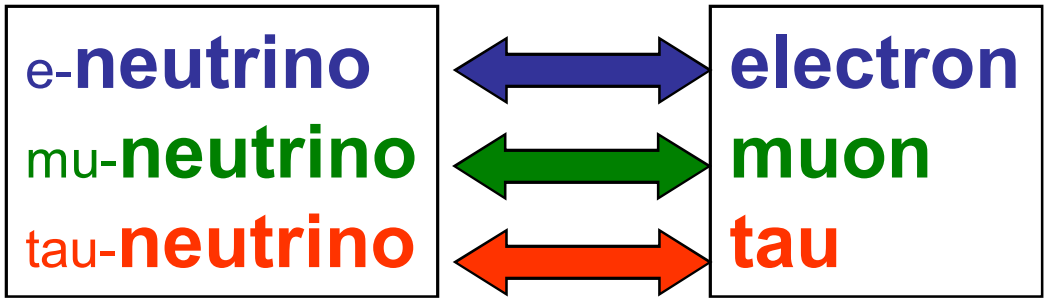
u (3 MeV)	d (5 MeV)
c (1.2 GeV)	s (100 MeV)
t (170 GeV)	b (4.5 GeV)

LEPTON MASSES

e (0.5 MeV)	ν_e
μ (106 MeV)	ν_μ
τ (1.8 GeV)	ν_τ

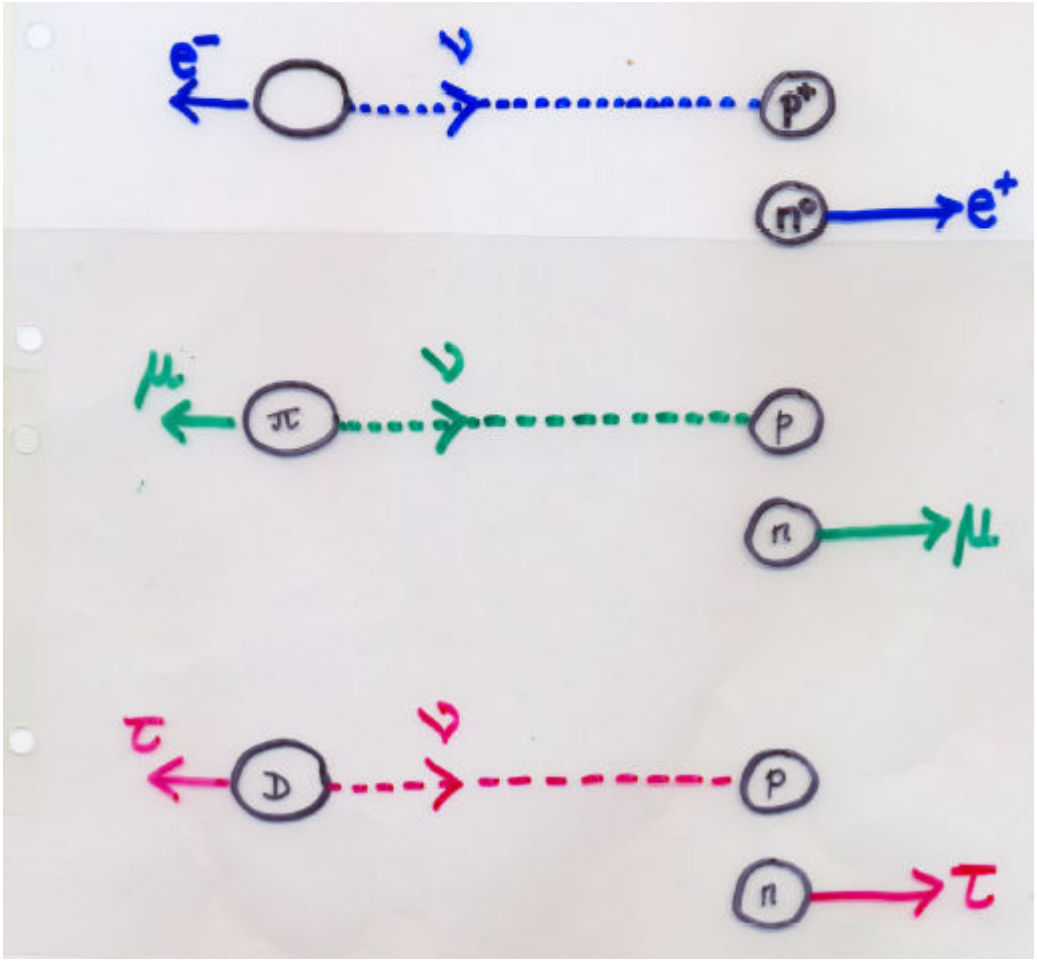
three neutrinos each with **ZERO** charge also have $\simeq$ **ZERO** Masses

Neutrinos and their charged partner are always linked

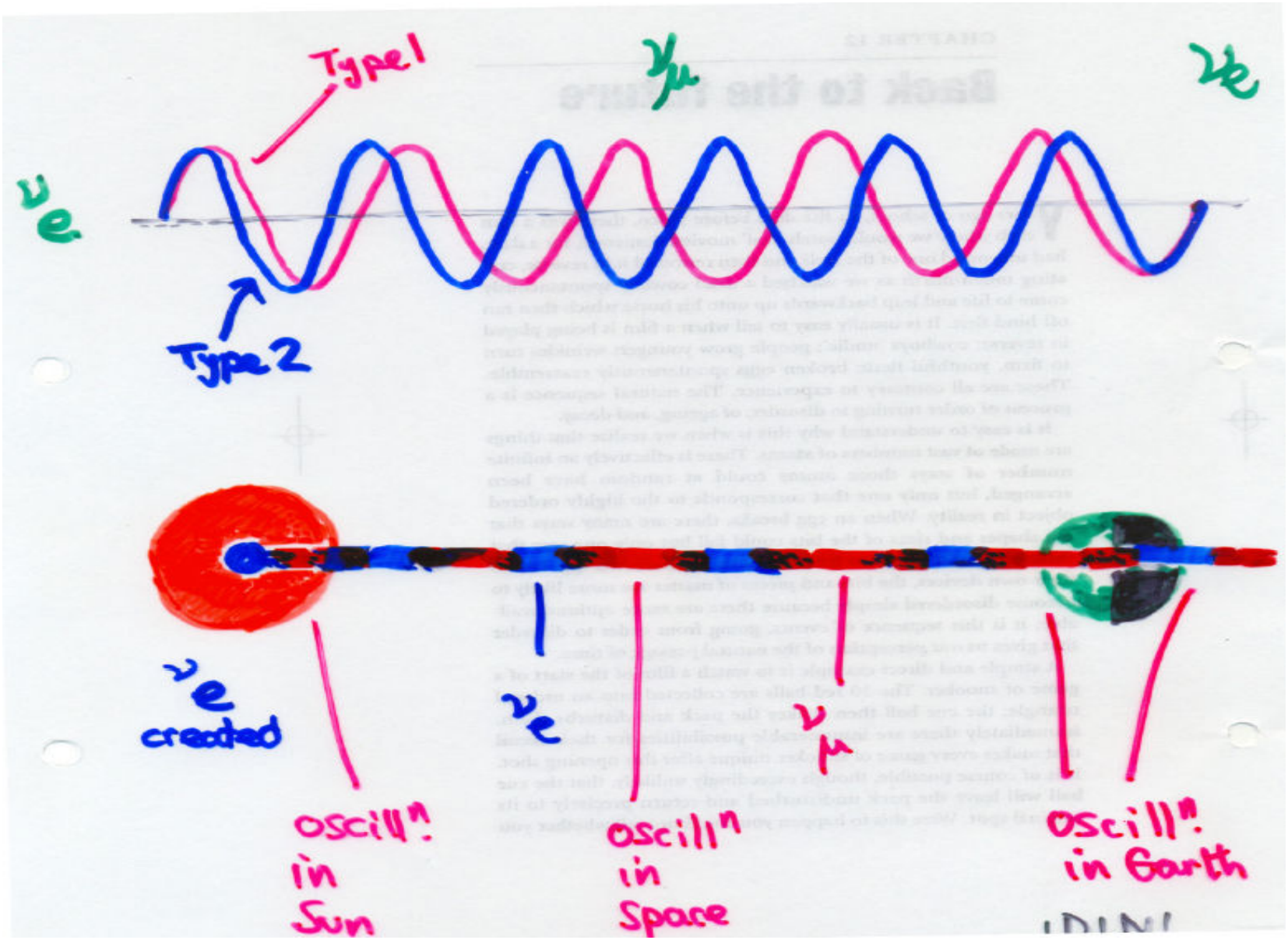


if

neutrinos are massless



BUT if neutrinos have mass, they can oscillate back and forth



BUT! if ν have mass

$\nu_e \leftrightsquigarrow \nu_\mu$ can oscillate back+forth

"wavelength" $L \sim \dfrac{\text{Energy of } \nu}{m_1^2 - m_2^2} \equiv \dfrac{E}{\Delta m^2}$

Probability $a \to b$

$$\sim \sin^2\left(1.27 \frac{\Delta m^2\,(eV)^2\; L\,(km)}{E\,(GeV)}\right)$$

Probability $a \to a = 1 - c\sin^2(\cdots)$

a disappears b appears

$\Delta m^2 \lesssim 10^{-N}$

$\therefore$ Need large L at high E

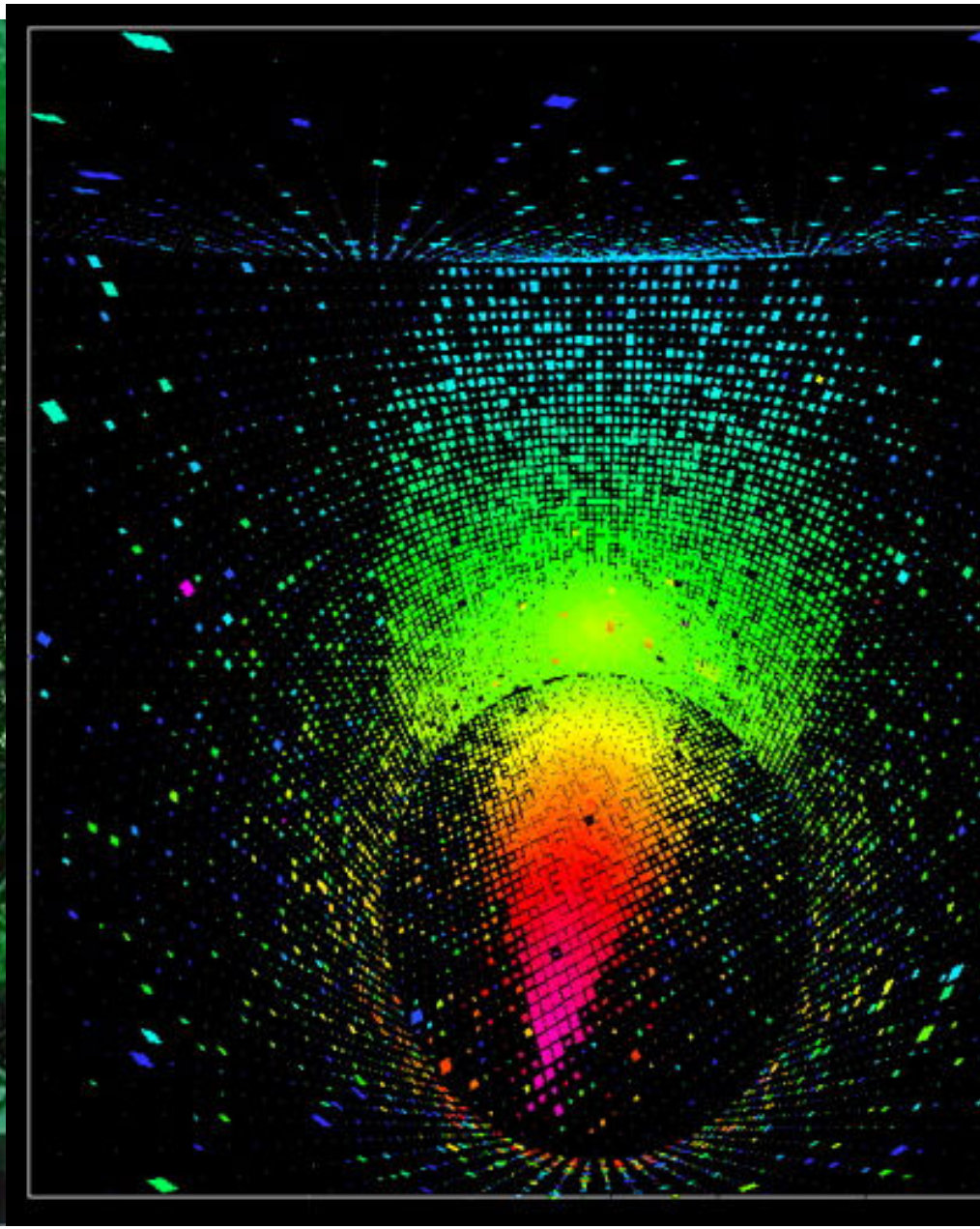
e.g. CERN to Gran Sasso Italy

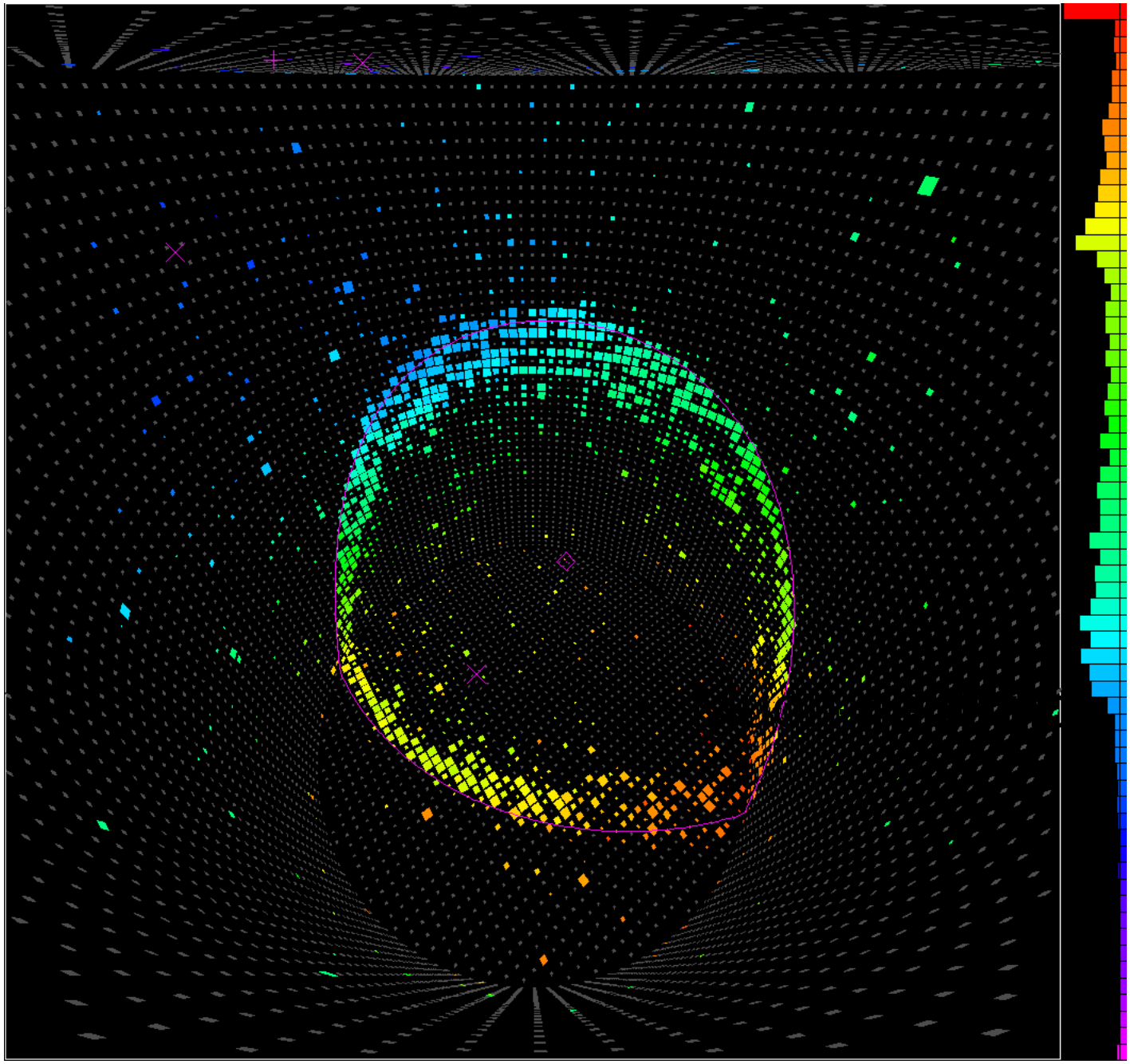
Neutrino Oscillations

- Nu beams from lab (CERN,Fermilab,KEK)
- Measure intensity nearby
- Measure 100s km away

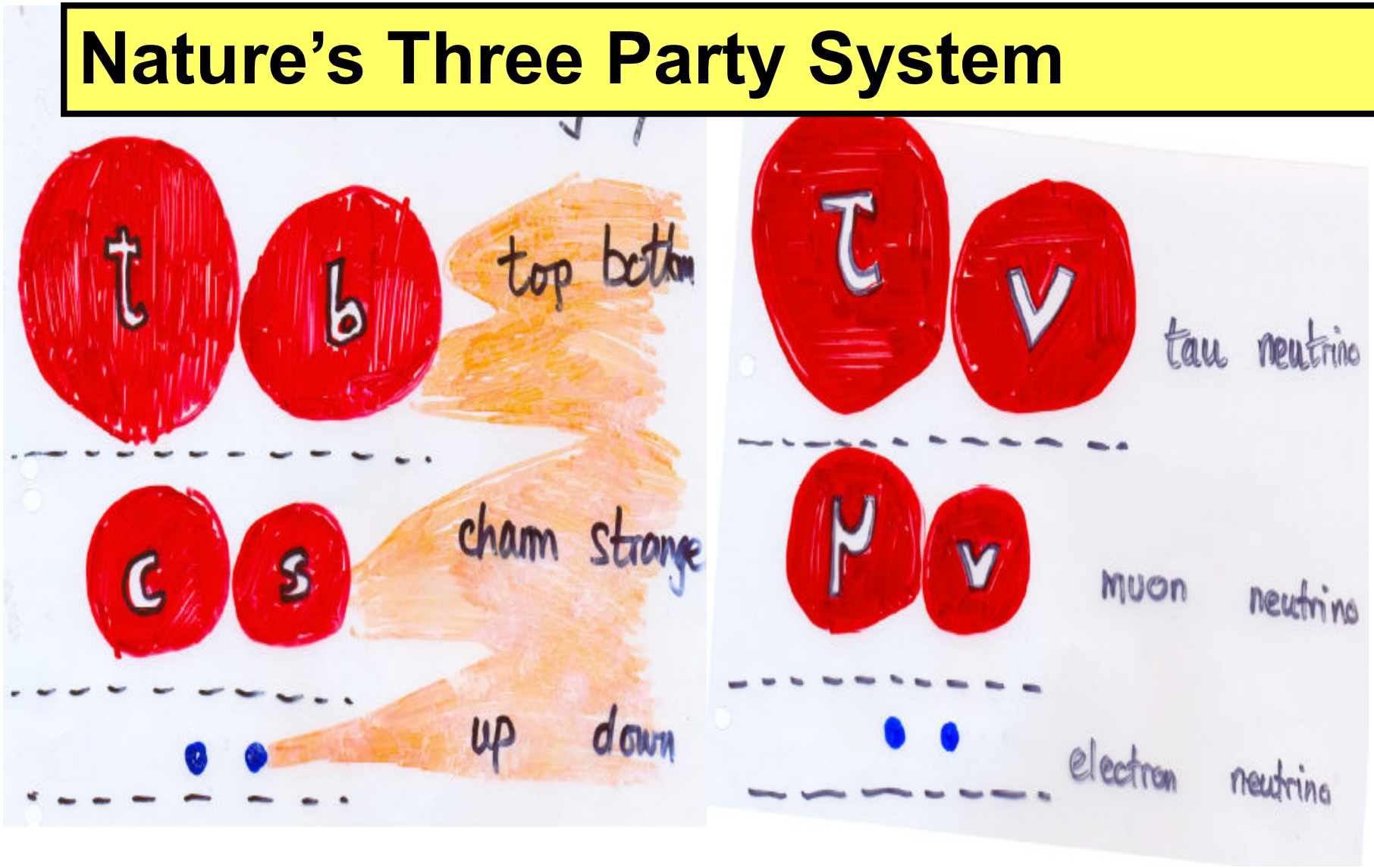
- Major research programme to understand neutrinos- masses, mixing, key to pattern of the three generations?

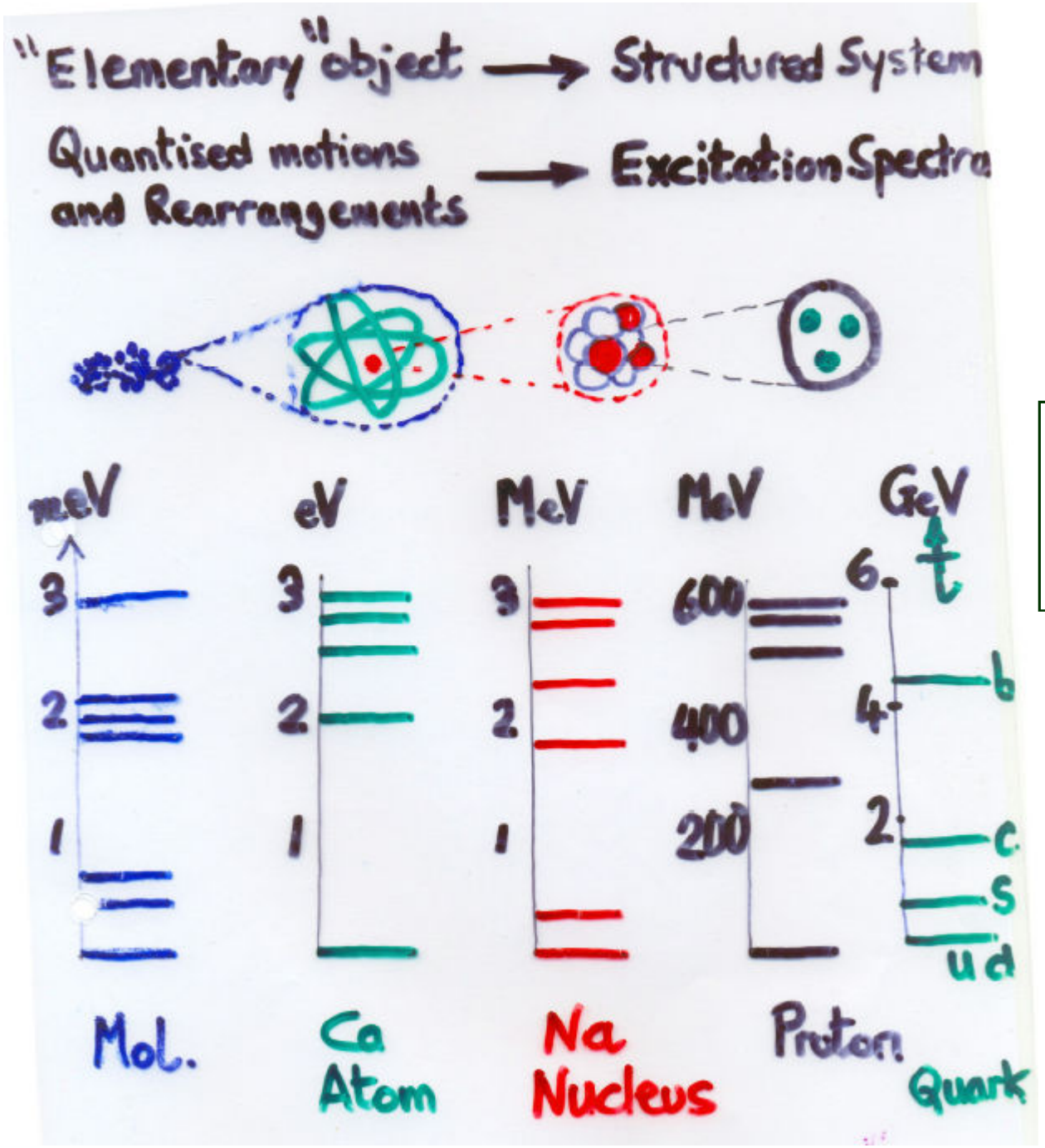
+ Neutrino astronomy – new science





Nature's Three Party System





Spectra

So are quarks (and leptons) also composites?

MATTER

quarks

electron
neutrino
leptons

ANTIMATTER

antiquarks
positron
antineutrino
antileptons

MATTER qqq proton

ANTIMATTER qqq antiproton

MATTER

qqq proton
BARYONS

MESONS

q
q

ANTIMATTER

qqq antiproton
ANTIBARYONS

ANTIMATTER

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