



Introduction to Particle Physics

(for non physics students)

2. PARTICLES

(from atoms to quarks and leptons)

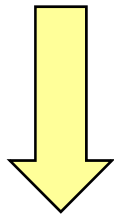
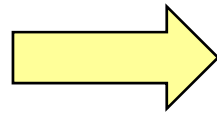


*PROFESSOR FRANK CLOSE
EXETER COLLEGE
UNIVERSITY OF OXFORD*

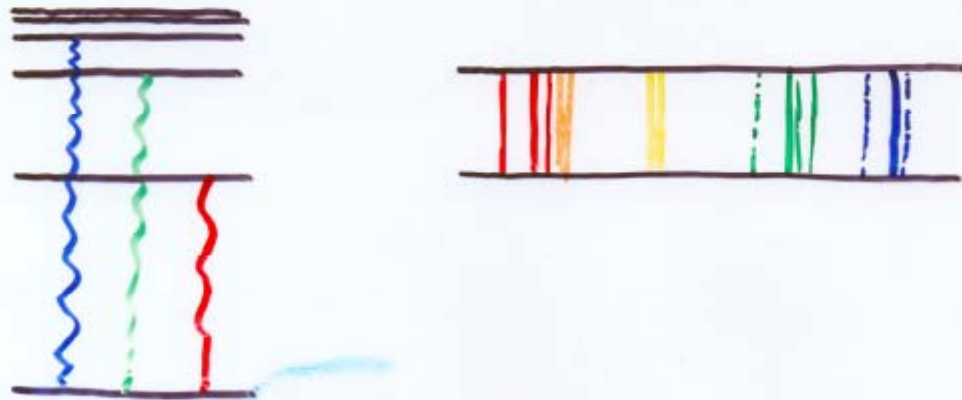


Structure of Matter

Two ways that structure is revealed:



1. SPECTRA



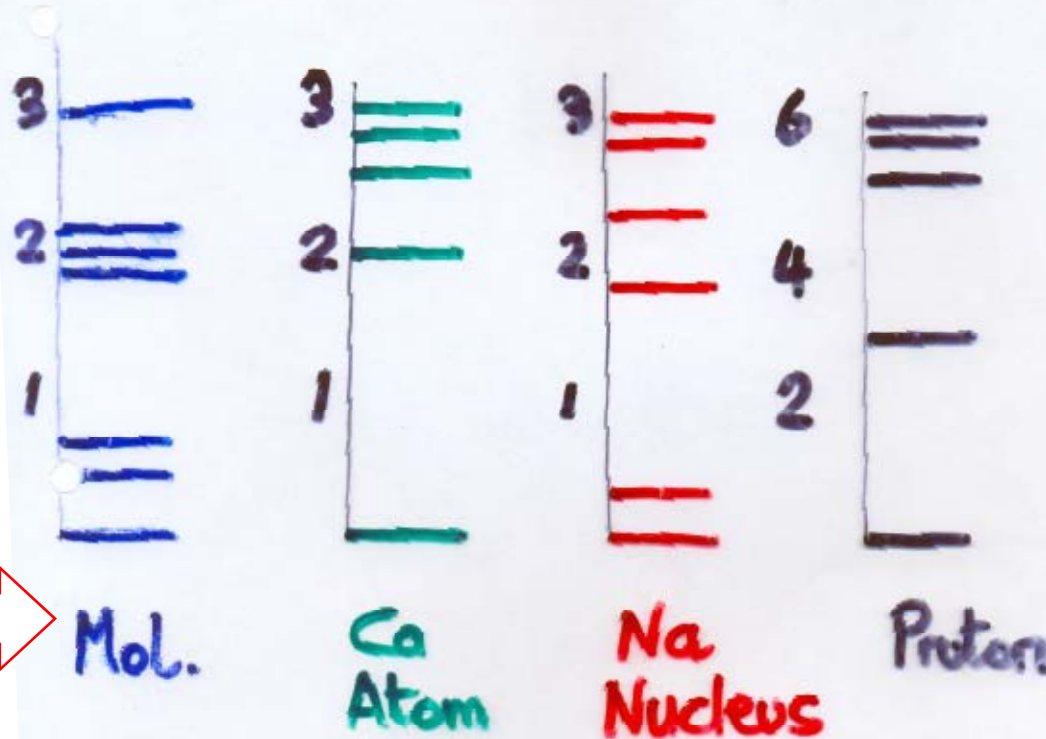
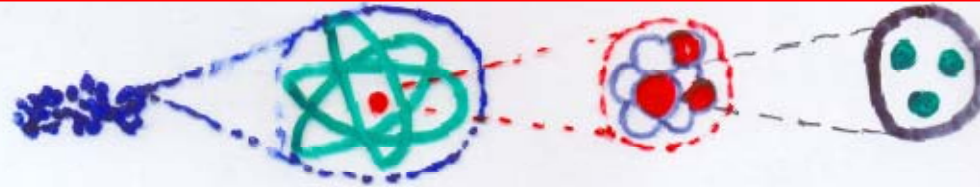
2. SCATTERING FROM "HARD" CENTRES



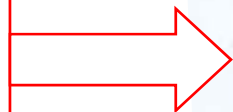
True from atoms to particles.....

Spectra

"Elementary" object \rightarrow Structured System
Quantised motions and Rearrangements \rightarrow Excitation Spectra

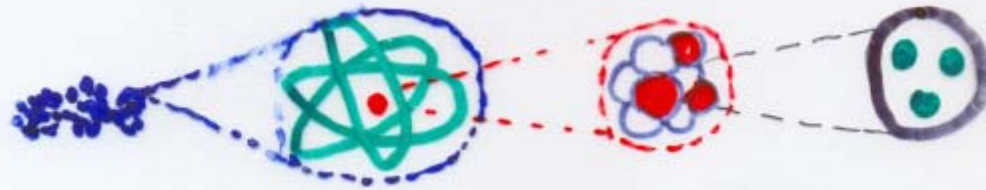


Qualitatively similar

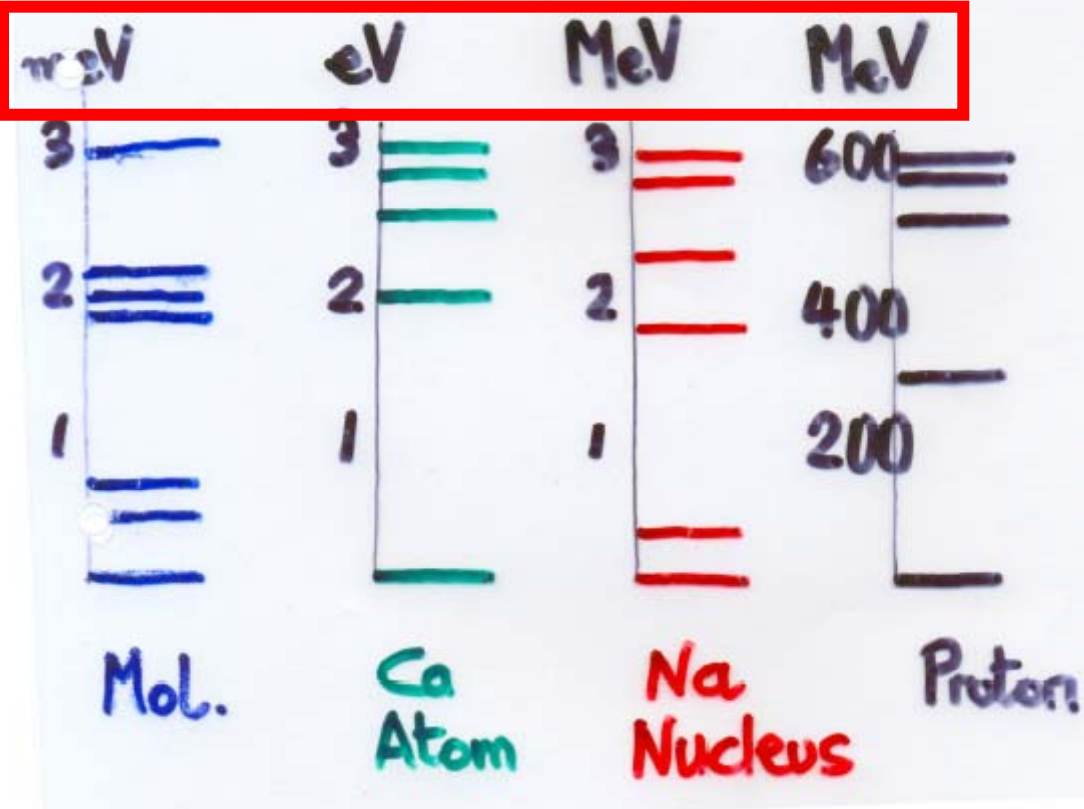


Spectra

"Elementary" object \rightarrow Structured System
Quantised motions and Rearrangements \rightarrow Excitation Spectra



Quantitatively different \rightarrow



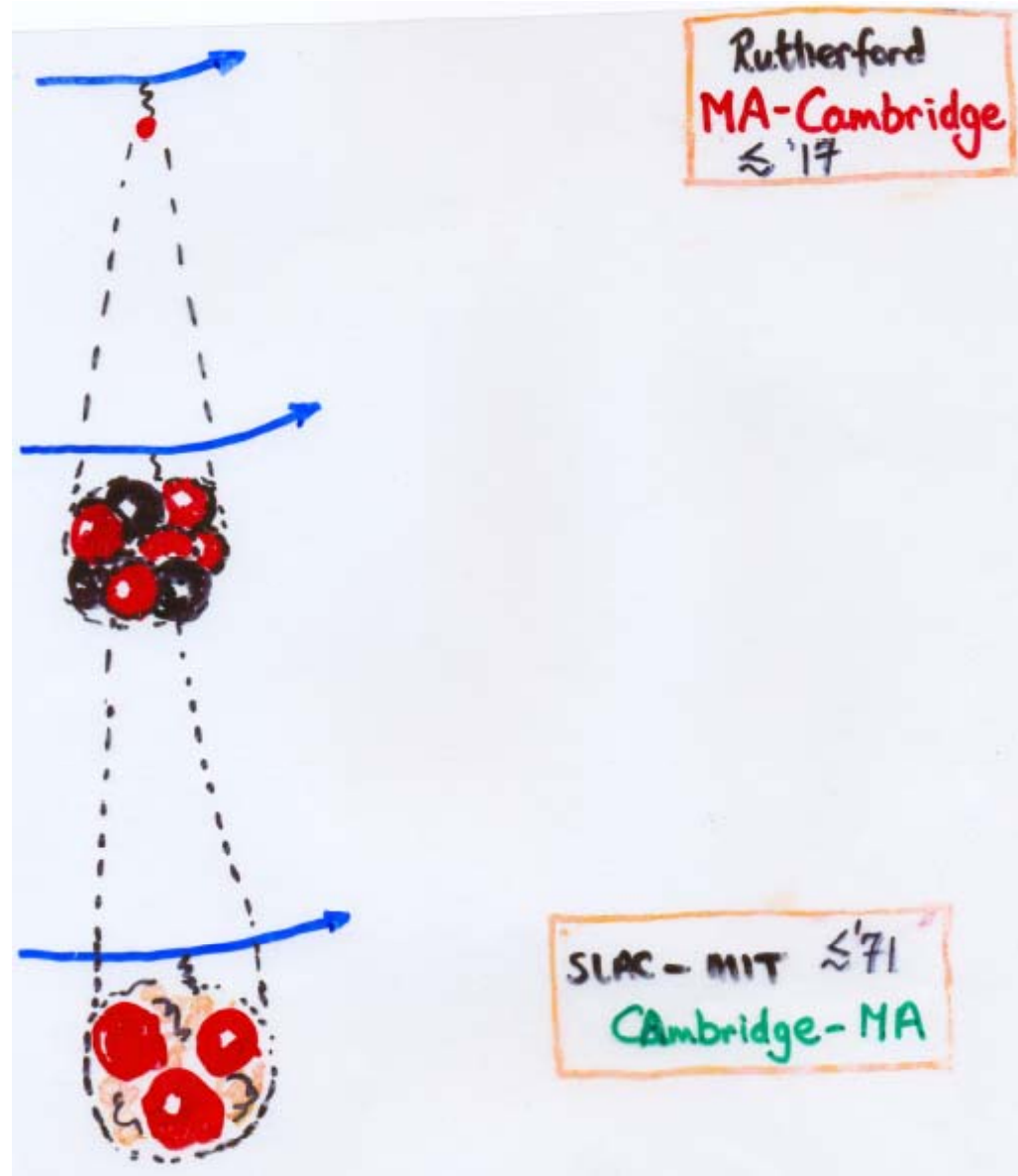
Scattering

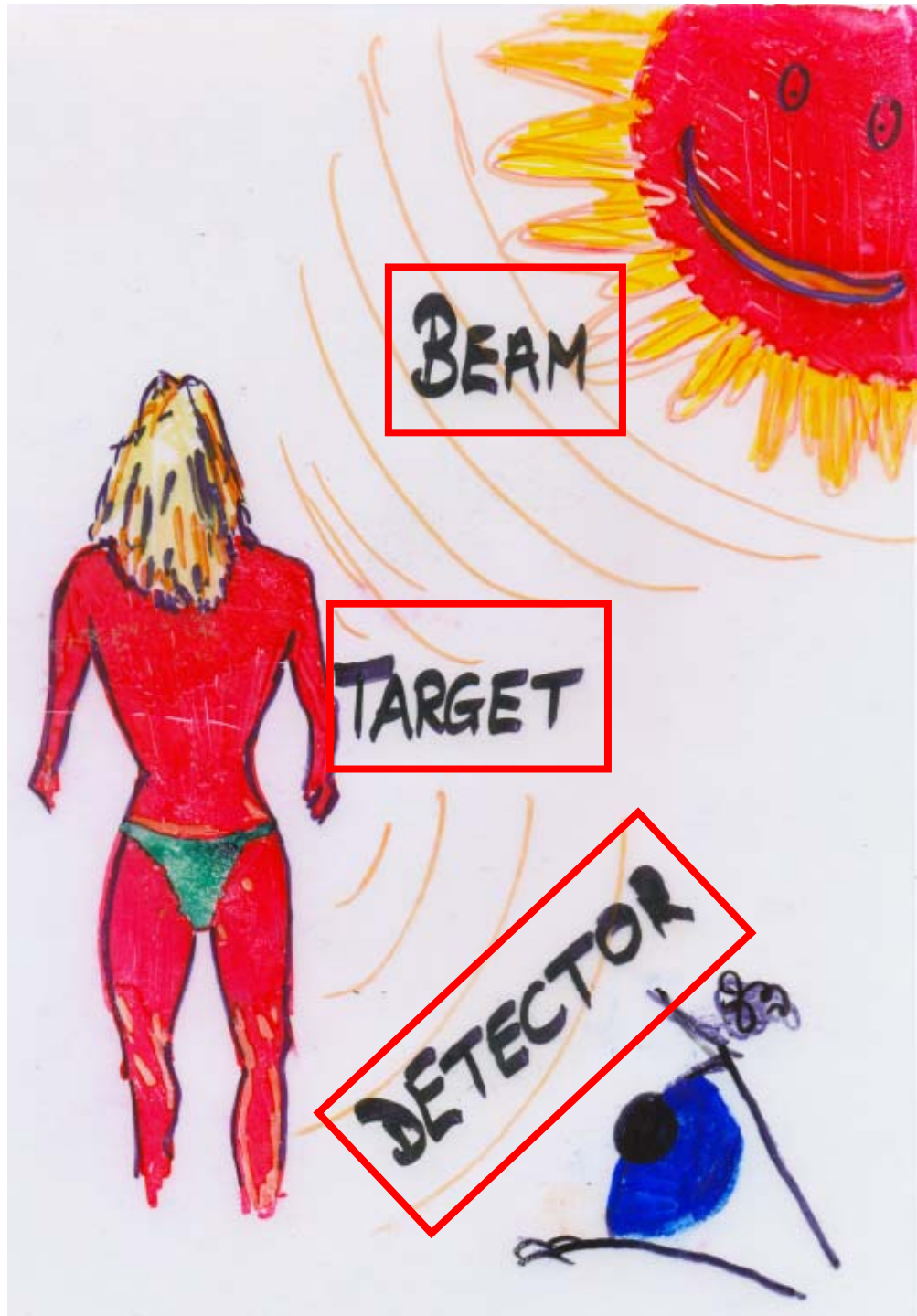
Nuclear atom

Proton/neutron

Quarks

Qualitatively similar





Rutherford: Nuclear Atom

Alpha particles from natural radioactivity

Gold leaf


Small scintillation screen

Rutherford used energy conservation...

(1)

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

Suppose atom consists of sphere with central positive charge $+Ne$ where e = electric charge surrounded by a sphere of radius R in which a negative charge $-Ne$ (distributed uniformly) is uniformly distributed. *Atom is neutral*



Consider passage of α particle carrying a positive charge E moving with velocity v_0 . Suppose charge concentrated at point. If atom is fixed straight for center, it will lose its velocity at a distance b from center.

$\frac{1}{2} m v_0^2 = \frac{NeE}{b}$

$L = \frac{2NeE}{mv_0^2}$

since $\frac{NeE}{b}$ is potential energy of heavy charge α

Consider value of b
Take N for atom of gold 200 as found for small scattering

(2)

$b = \frac{2E}{m} \cdot \frac{Ne}{v_0^2}$

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

Practical, $v_0^2 = 2.06 \times 10^9$

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

$\frac{1375}{14}$
 $\frac{1375}{14}$

$= \frac{1.6}{10^{12}}$ cm.

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

$L = \frac{2NeE}{mv_0^2} \quad \therefore v_0^2 = \frac{2Ne}{b} + \mu = \frac{NeE}{m}$

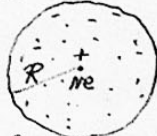
b is an important constant for α particles of given velocity

...and long division

(1)

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

Suppose atom consists of sphere with central positive charge $+Ne$ where e = electronic charge surrounded by a sphere of radius R in which a negative charge $-Ne$ (distributed uniformly) is uniformly distributed. *Atom is neutral*



Consider passage of α particle carrying a positive charge E moving with velocity v_0 . Suppose charge concentrated at point. If atom is fixed straight for centre, it will lose its velocity at a distance b from centre given by

$$\frac{1}{2} m v_0^2 = \frac{NeE}{b}$$

since $\frac{1}{2} m v_0^2$ is kinetic energy of moving charge α

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

Consider value of b . Take N for atom of gold 200 as found for small scattering

(2)

$$b = \frac{2E}{m} \cdot \frac{Ne}{v_0^2}$$

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

For gold, $v_0^2 = 2.06 \times 10^9$

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

1375
200
4.65
4.2

$$= \frac{2.79 \times 10^{17}}{4.2 \times 10^{28}} = \frac{6.6}{10^{12}} \text{ cm.}$$

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

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

b is an important constant for α particles of given velocity

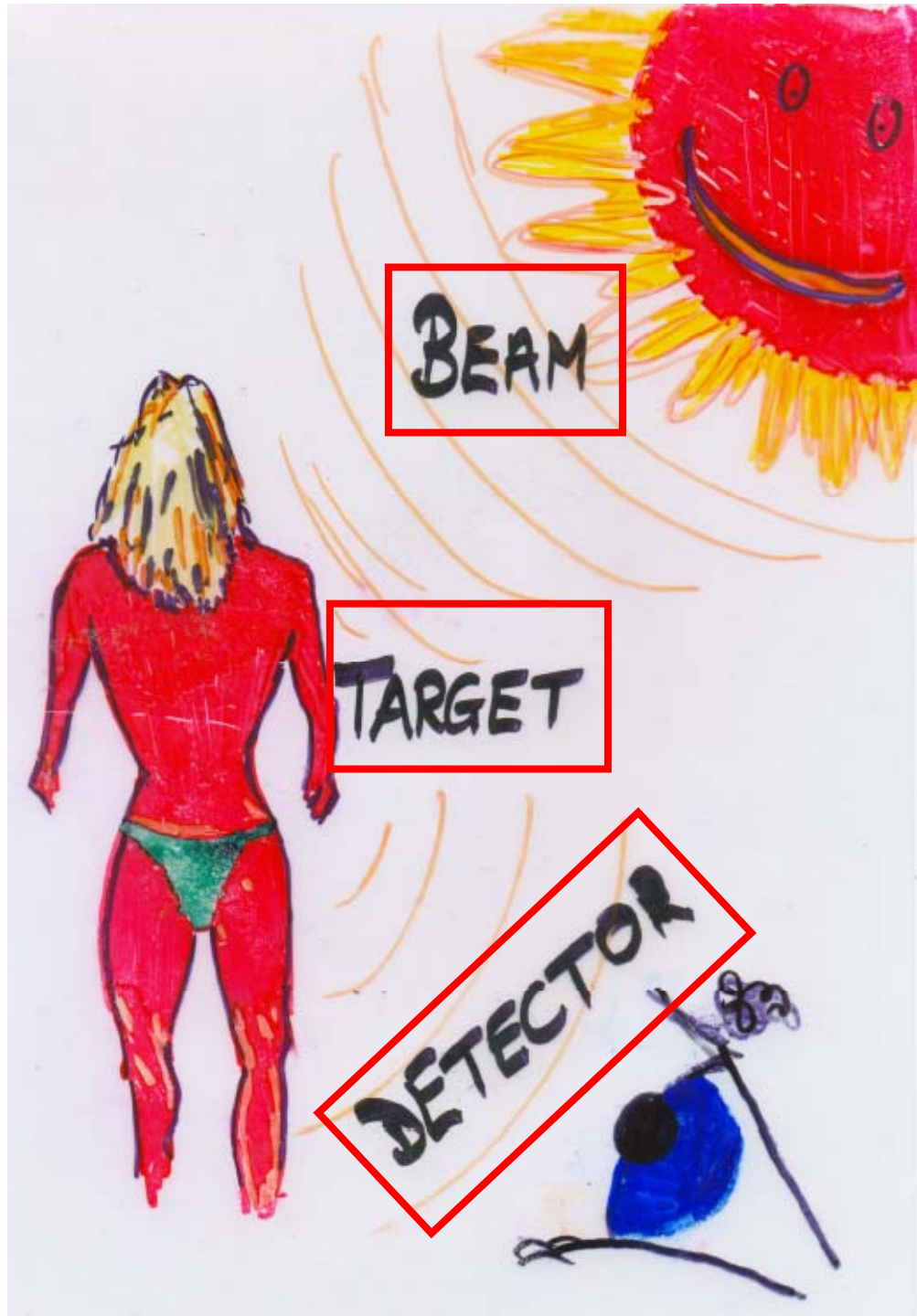
$$b = \frac{2 \times 1.5 \times 10^7 \times 200 \times 4 \times 10^0}{10^{10} \times 4.2 \times 10^{18}}$$

$$= \frac{1.6}{10^{12}} \text{ m.}$$

1395
 $42 \overline{) 14.13}$
 $\underline{12}$
 2.13
 $\underline{14}$
 0.13

Since typical radius of atom is of order 10^{-8} m. It is seen that distance of approach to charged centre is very small compared with radius of atom. In general it is Avinno that ^{to atom} at points where the deflecting forces on the α particles are large is very near centre of atom + as a result when field is due almost entirely to central charge

$$b = \frac{2NeE}{mv^2} \quad \therefore v_0^2 = \frac{2\mu}{b} + \mu = \frac{\pi e E}{m}$$



Quarks in the proton

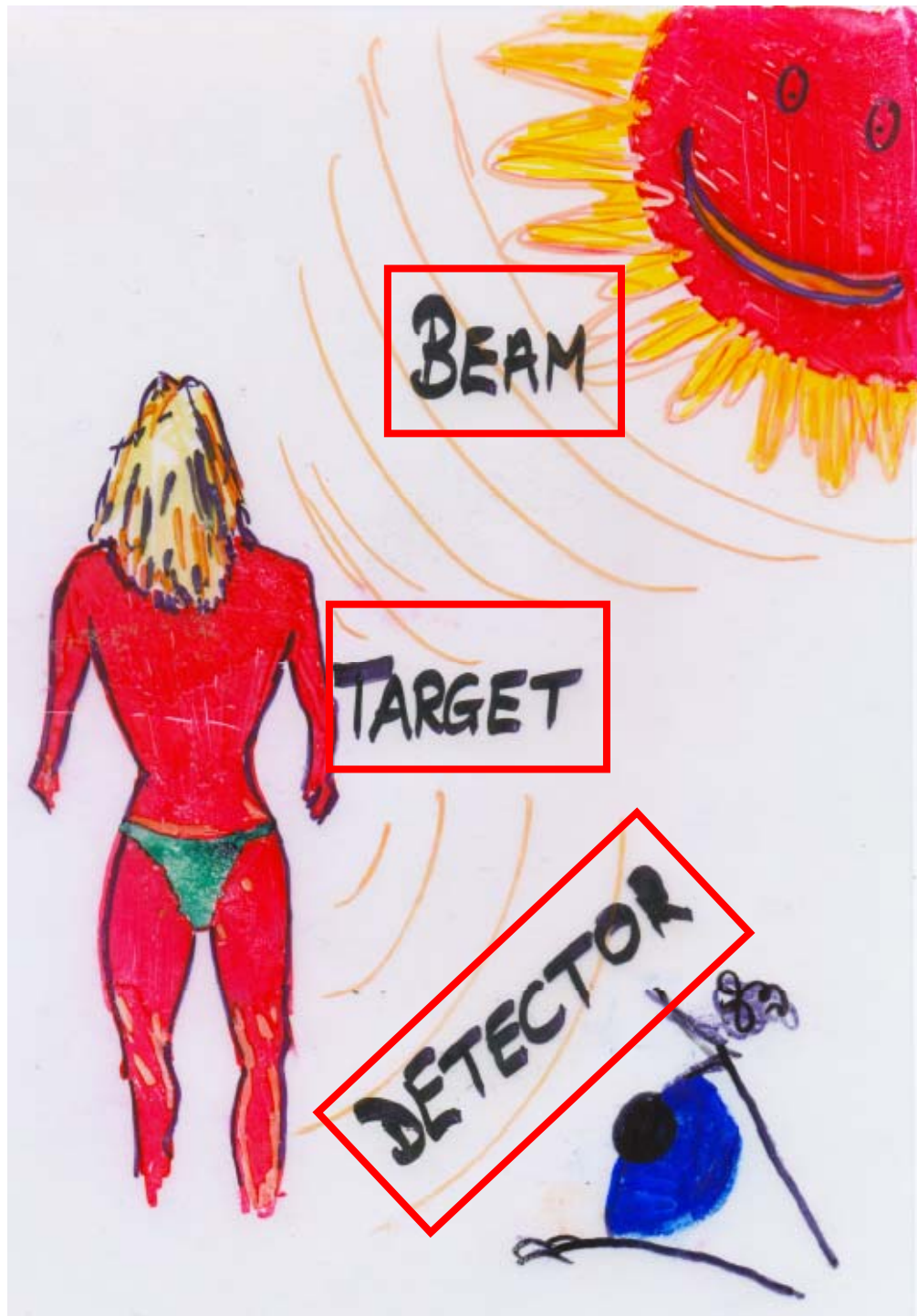
Qualitatively: Same idea

**Quantitatively:
Different scale**

SLAC 3km electron accelerator



The BEAM



Quarks in the proton

Electron beam = 3 km

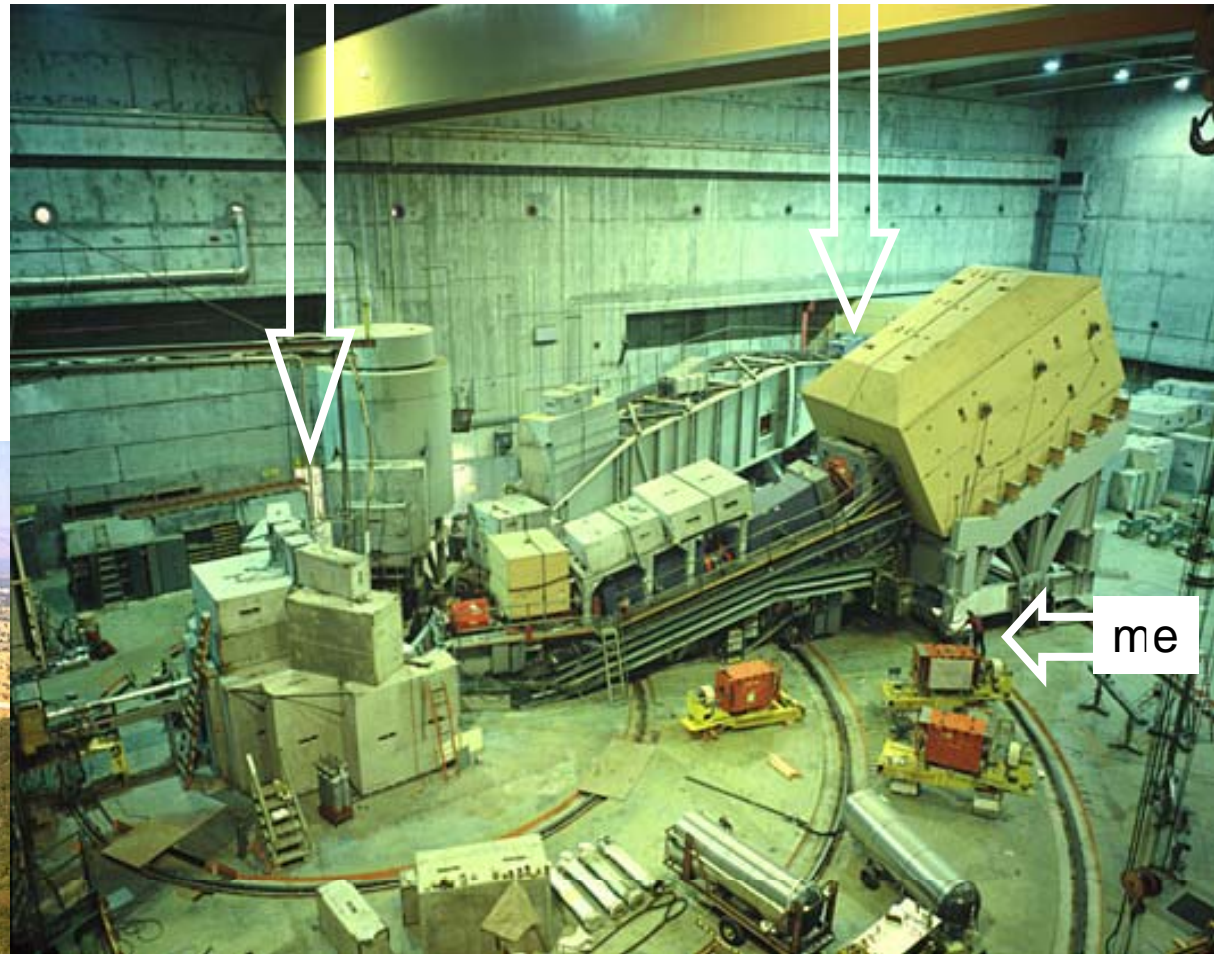
Proton target (hydrogen)

Big electronic detector

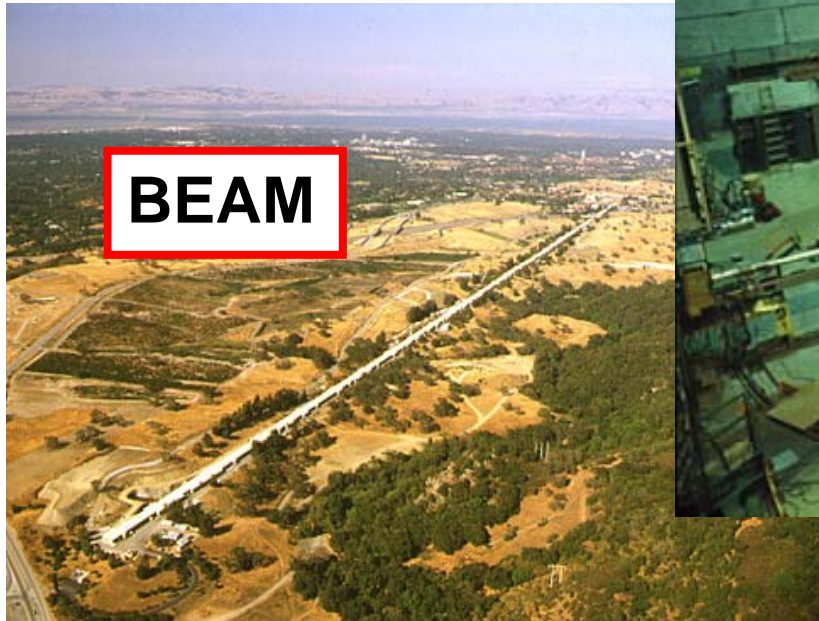
TARGET

DETECTOR

BEAM



me



Proton made of 3 quarks, gripped by gluons



To make

proton

and

neutron

requires two

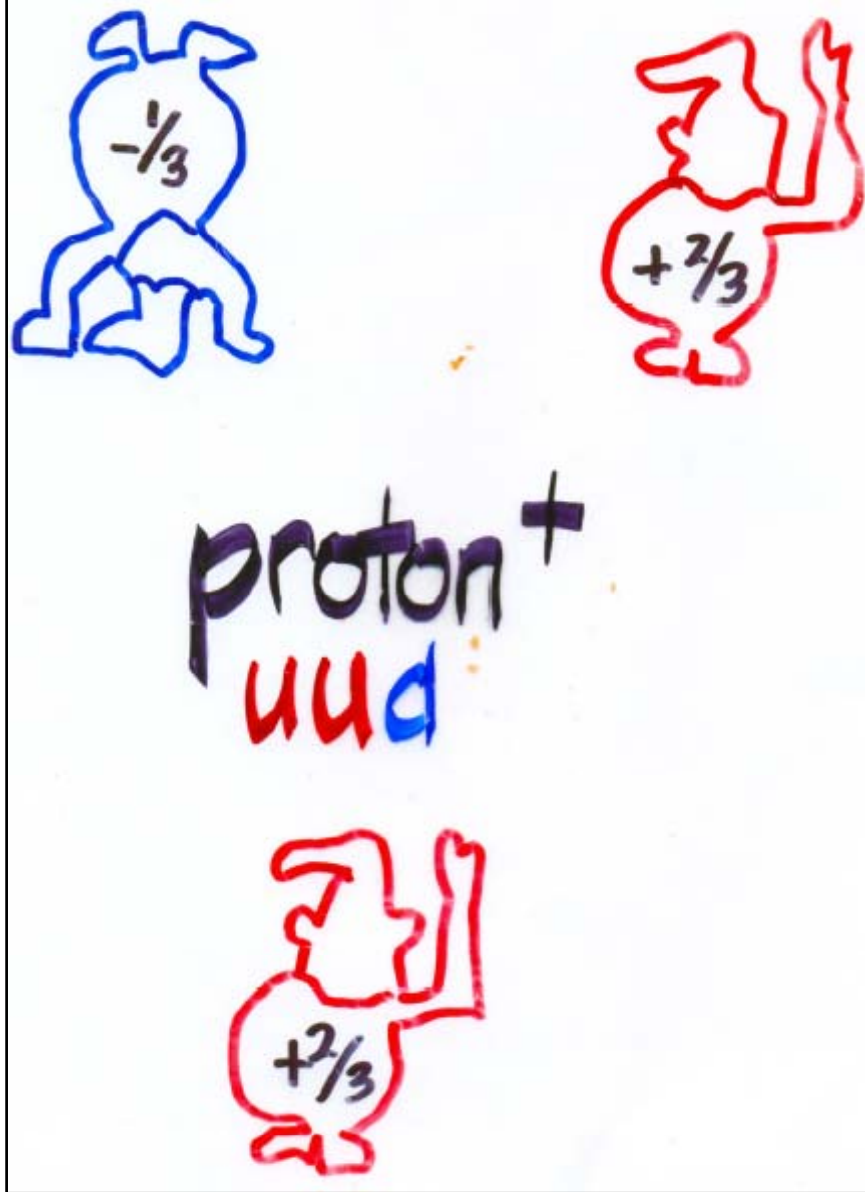
“**flavours**”

of

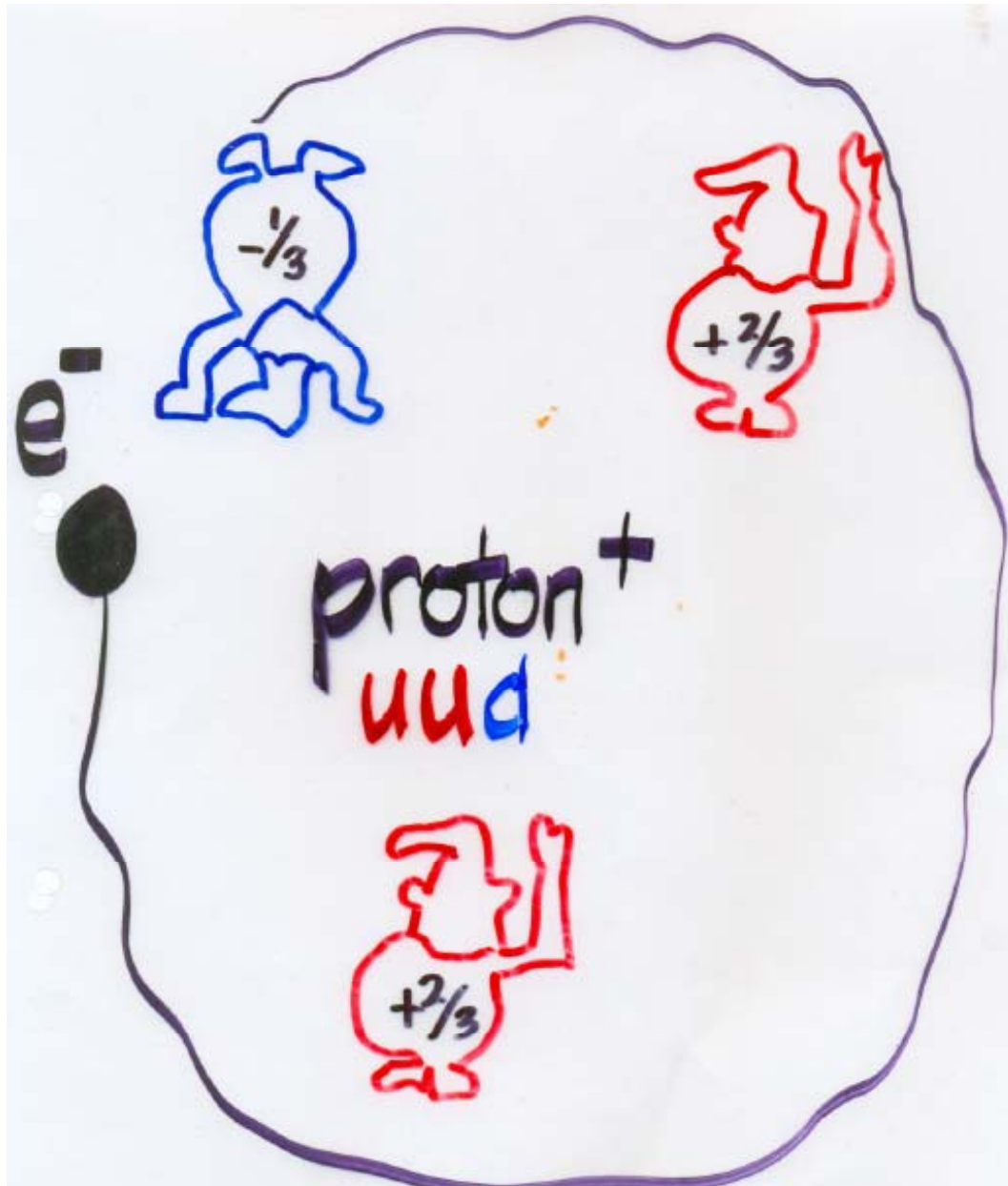
Quarks



Up and **down**
Quarks



and
neutron
ddu



H atom

(not to scale!)

**a miracle
of
neutrality**

electron

balances

uud

hint of unification

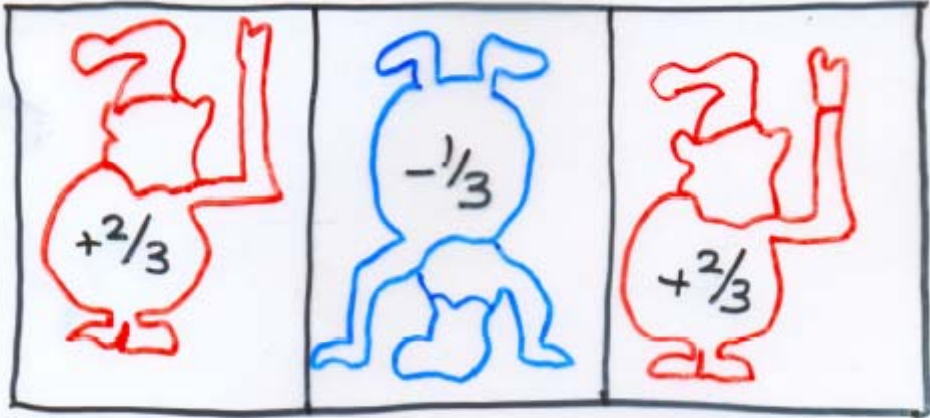
The scale of things in the
micro and macro cosmos

		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	

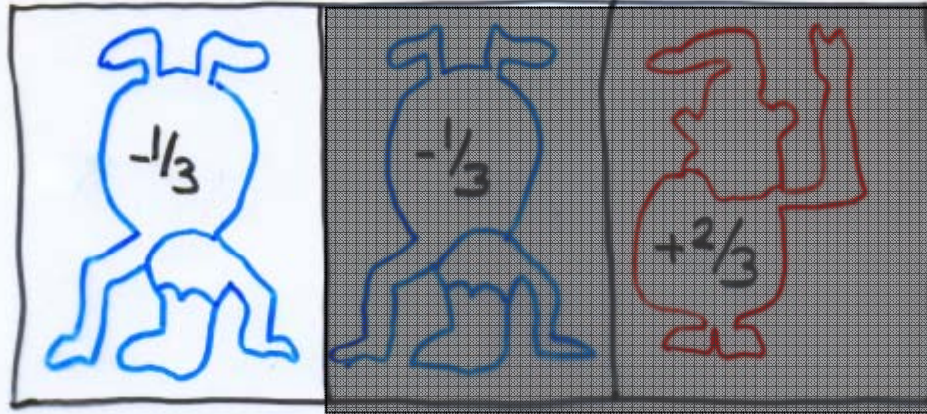
n^0



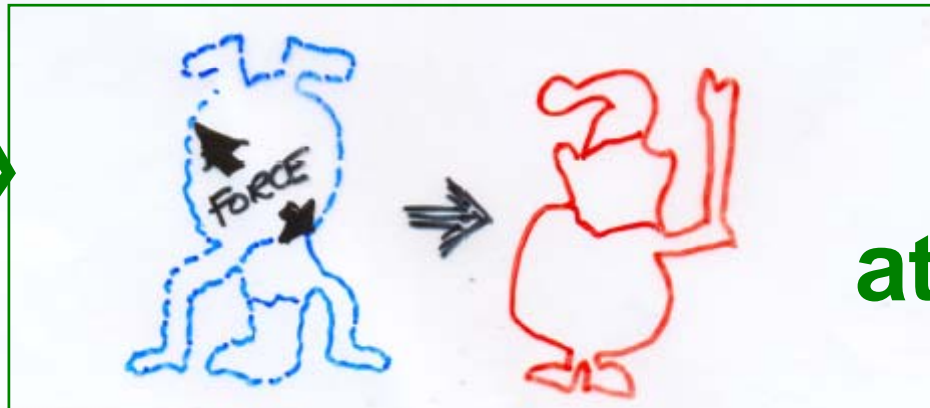
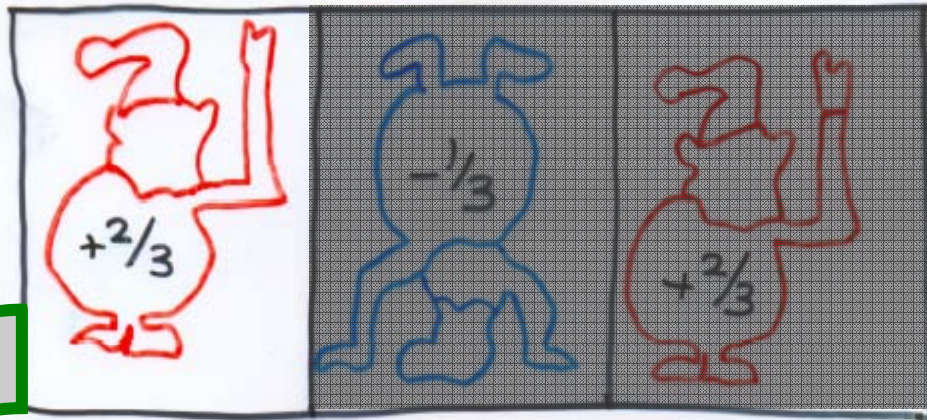
P^+



n^0



p^+



**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 \approx 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

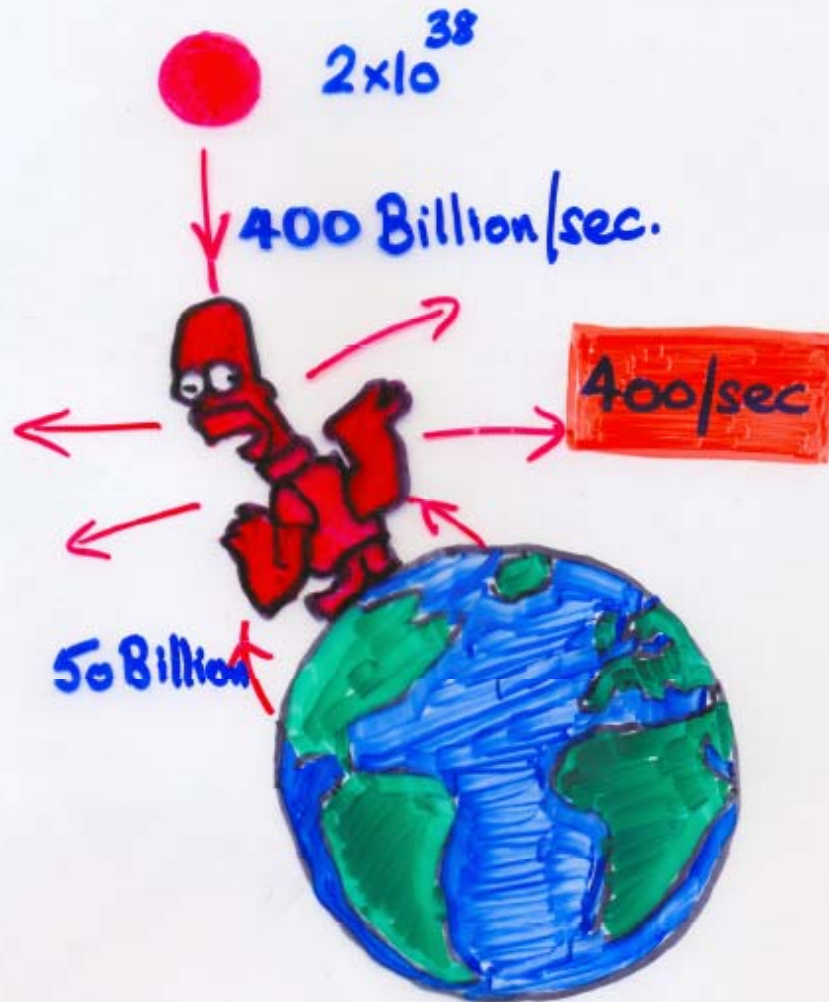
SOME NEUTRINO STATISTICS

each second :



SOME NEUTRINO STATISTICS

each second :



1 hr. x this audience \Rightarrow 100 million neutrinos



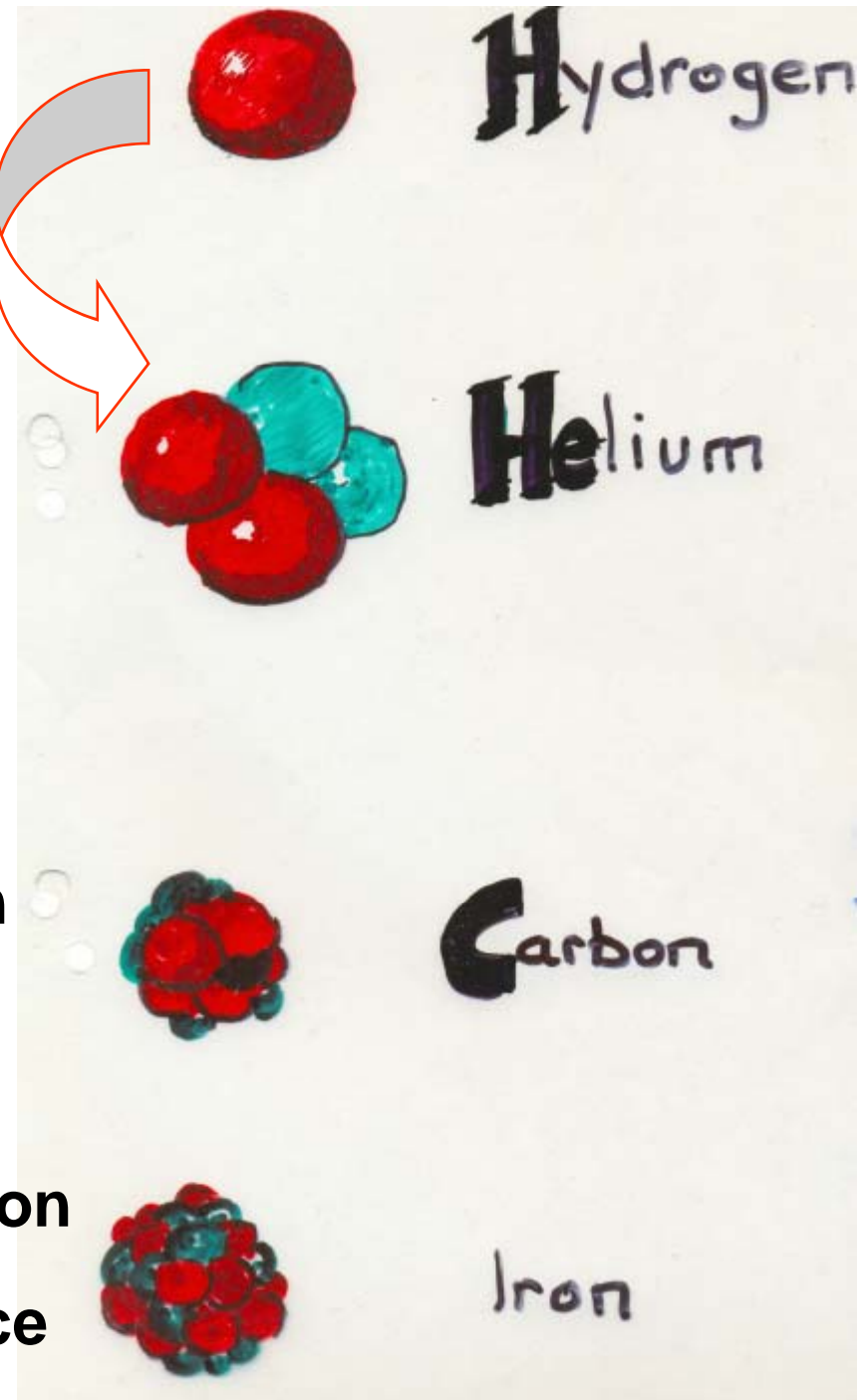
Stars cook the elements

Sun is dominantly this first step

Heavy elements cooked
in stars and ejected into
cosmos in supernova explosion

Many protons; electrical disruption

Stabilised by **STRONG** force



At the heart of the Sun:



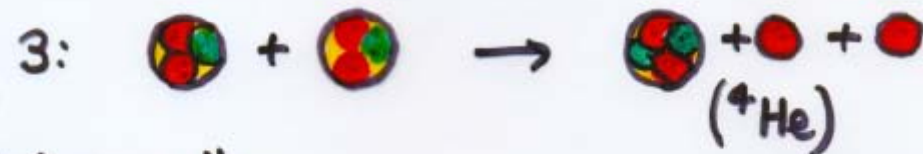
 **Proton**

 **neutron**

 **positron**

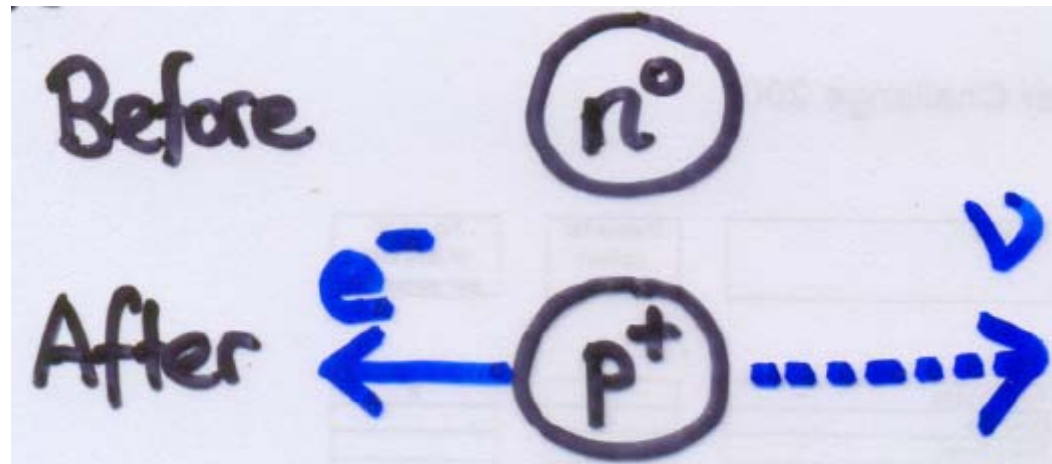
 **neutrino**

 deuteron



Net result:





**How do we know
the neutrino is produced?**

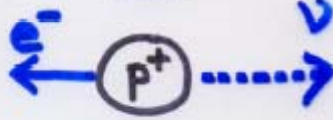
**It hits a nucleus upstream
and turns into charged
lepton which is detected.**

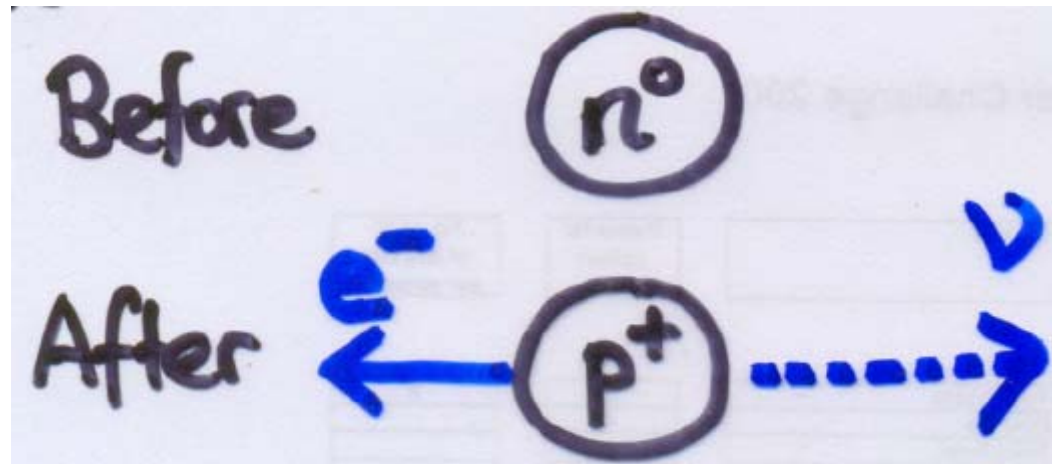
30

Before



After





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

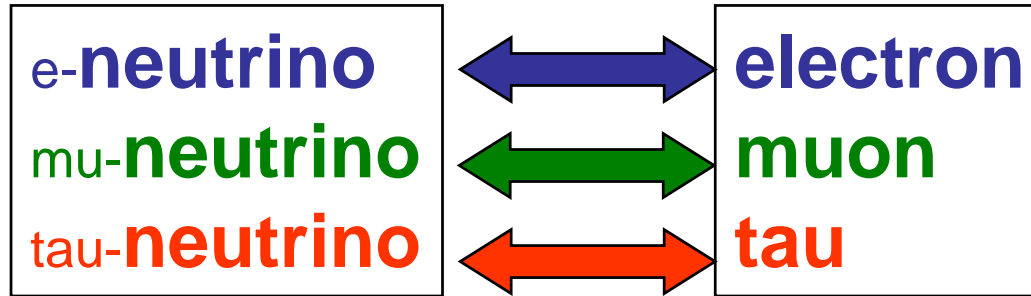
e (0.5 MeV)

μ (106 MeV)

τ (1.8 GeV)

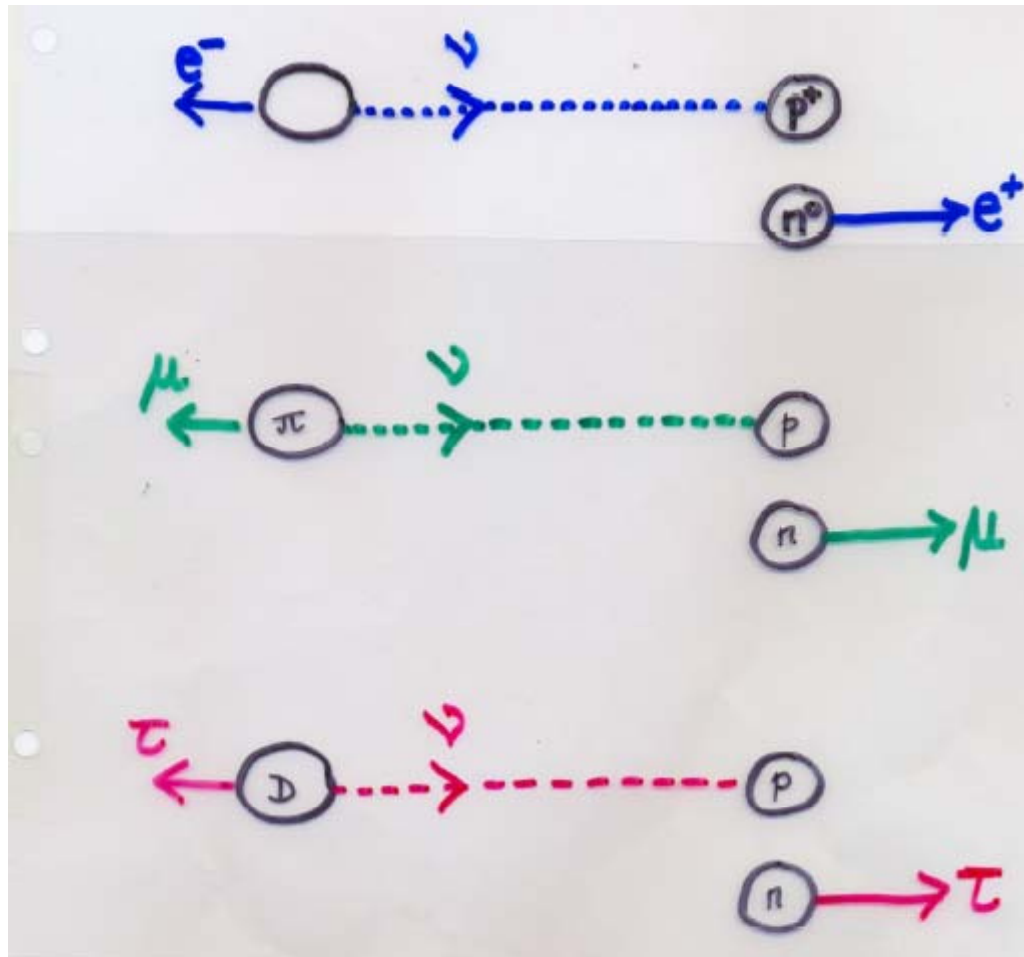
ν_e } three neutrinos
 ν_μ } each with
 ν_τ } **ZERO** charge
also have
 \approx **ZERO** masses

Neutrinos and their charged partner are always linked

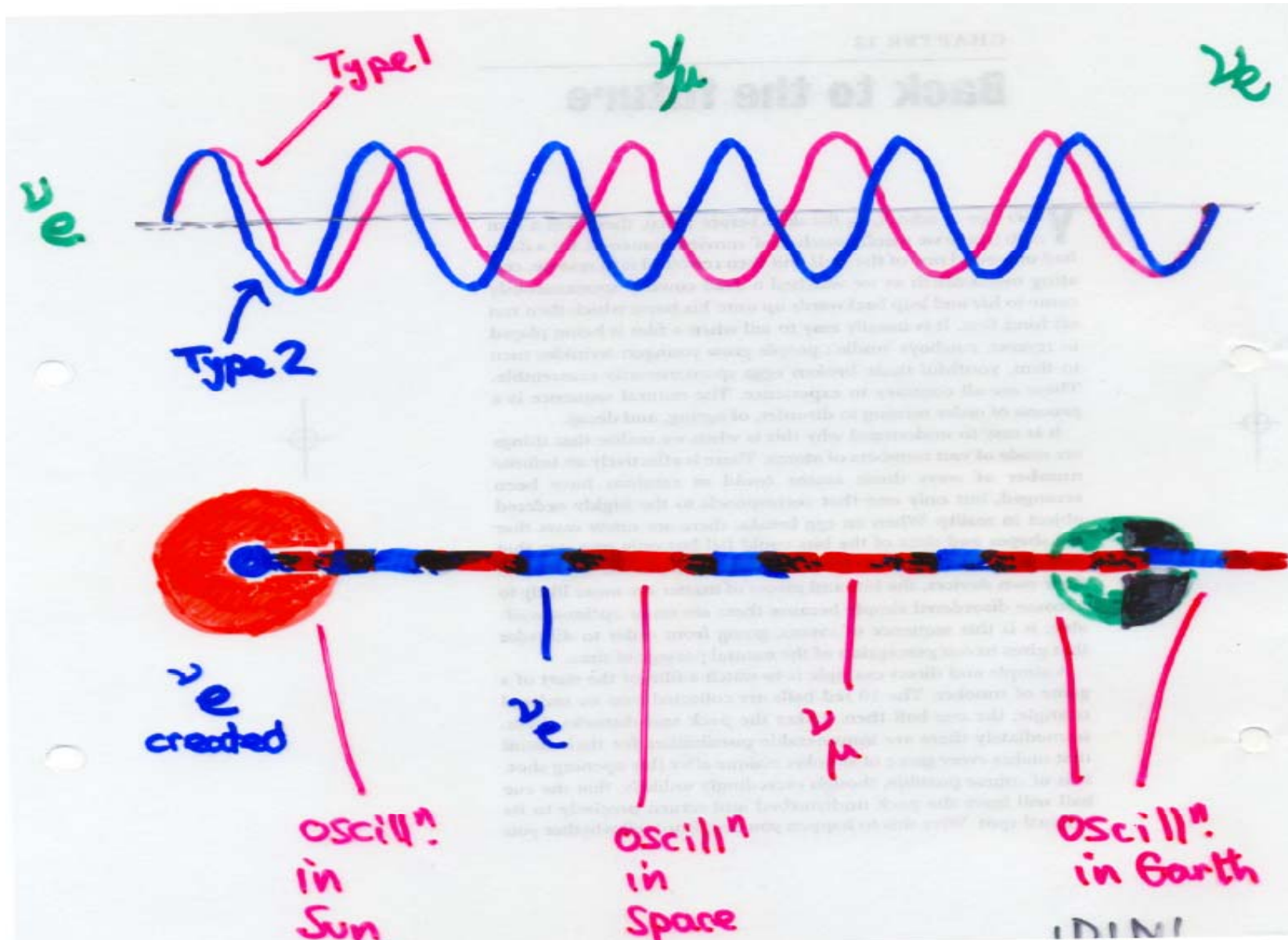


if

neutrinos are massless



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



BUT! if ν have mass

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

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

Probability $a \rightarrow b$

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

Probability $a \rightarrow a = 1 - \text{c} \sin^2(\dots)$

a disappears b appears

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

\therefore Need large L at high E

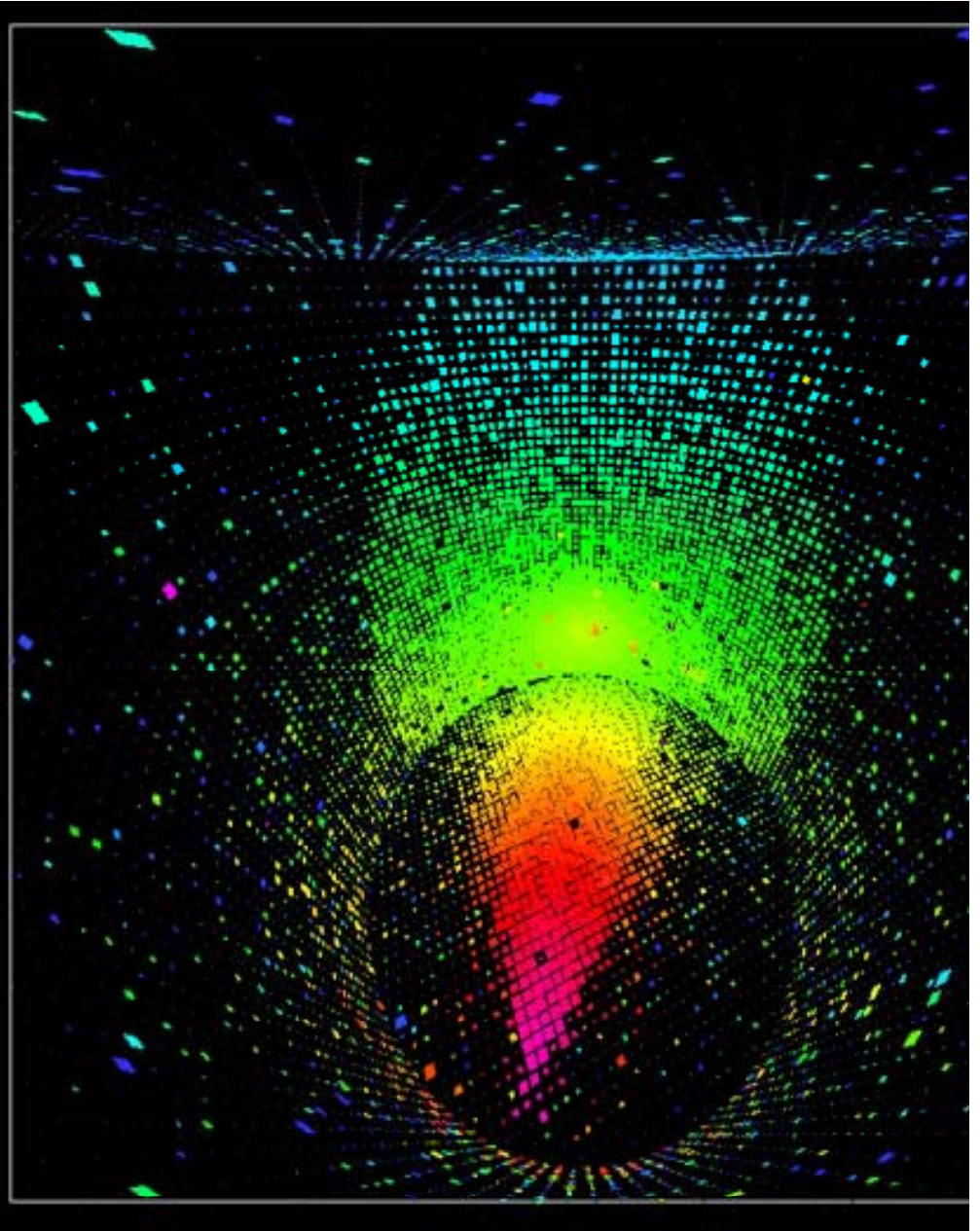
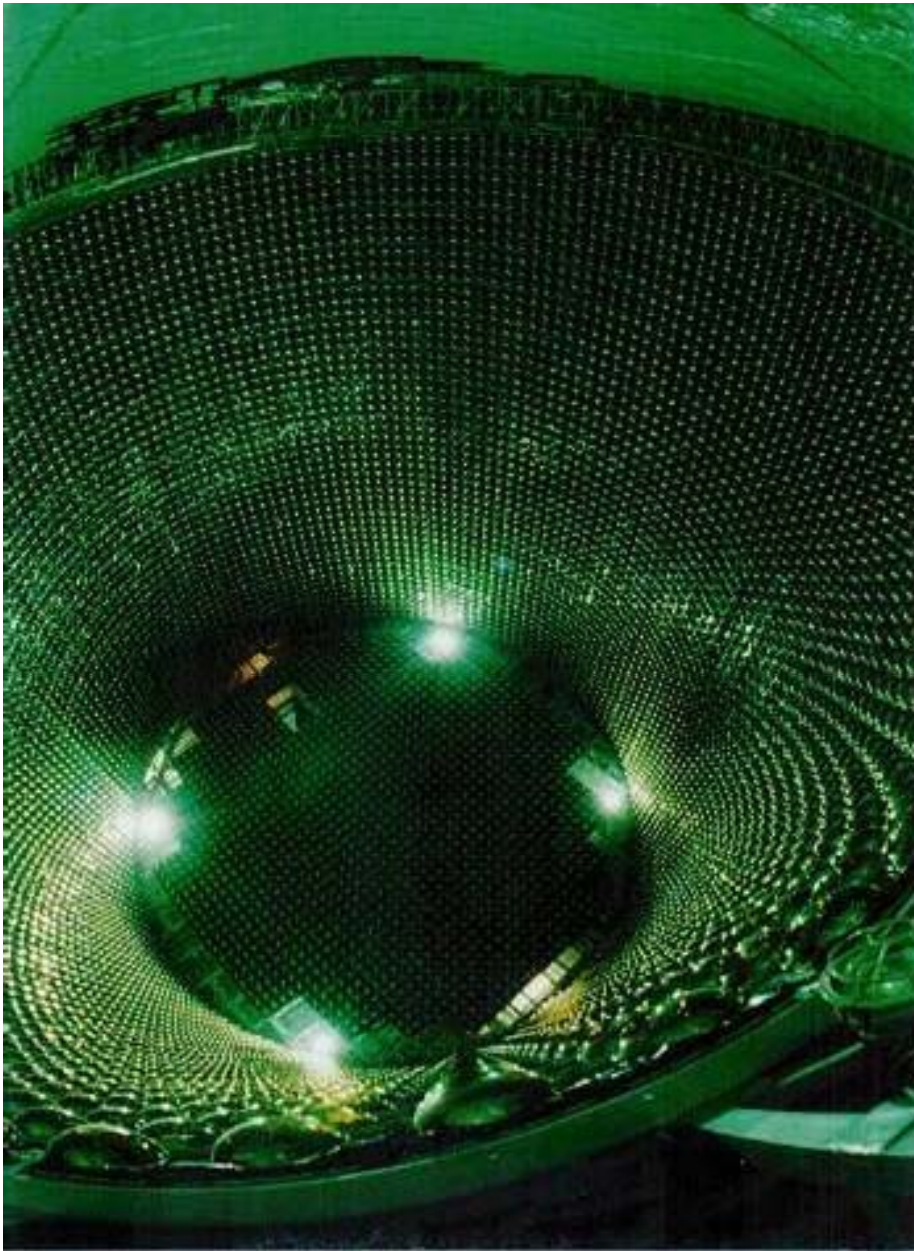
e.g. CERN to Gran Sasso Italy

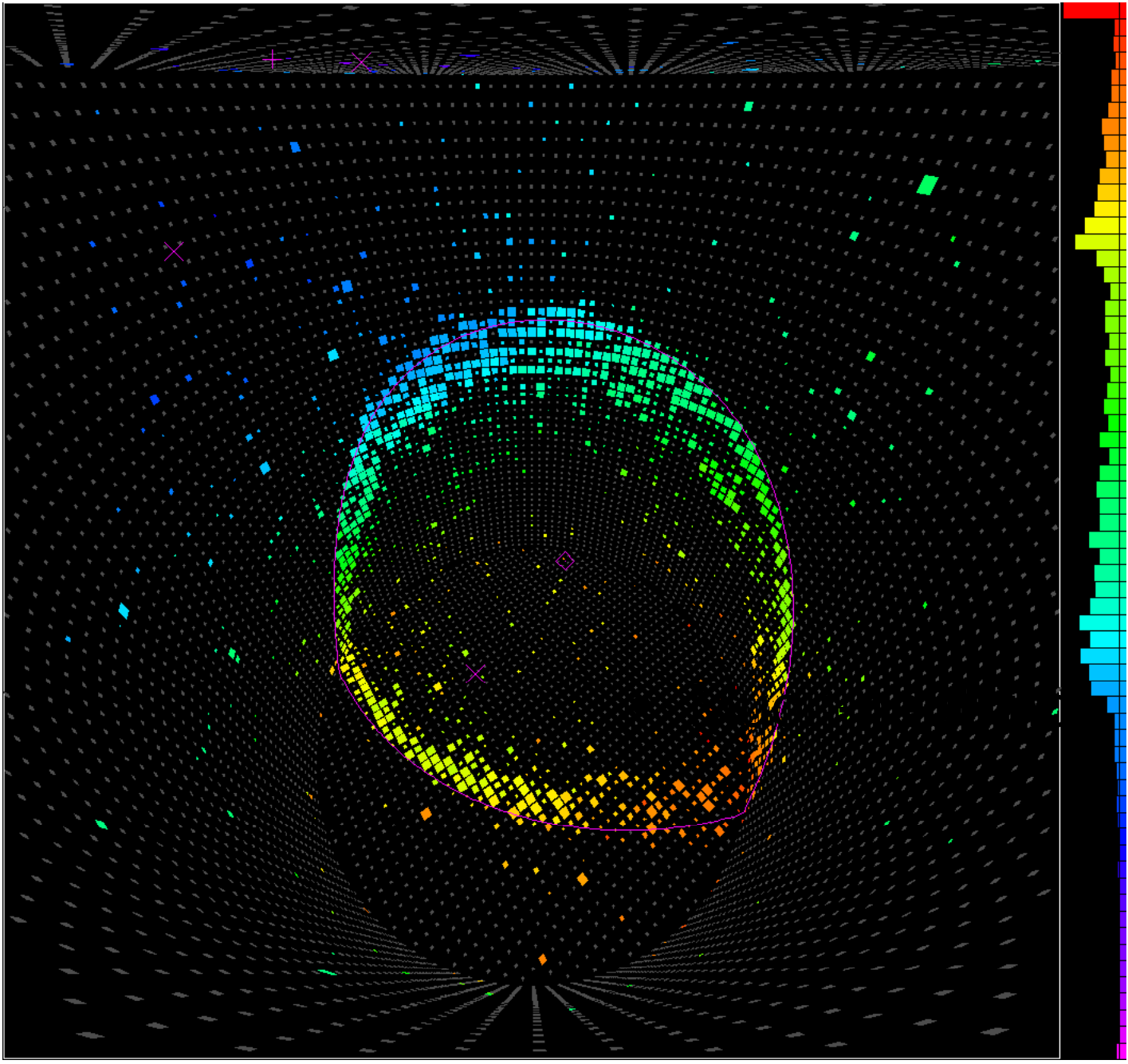
Neutrino Oscillations

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

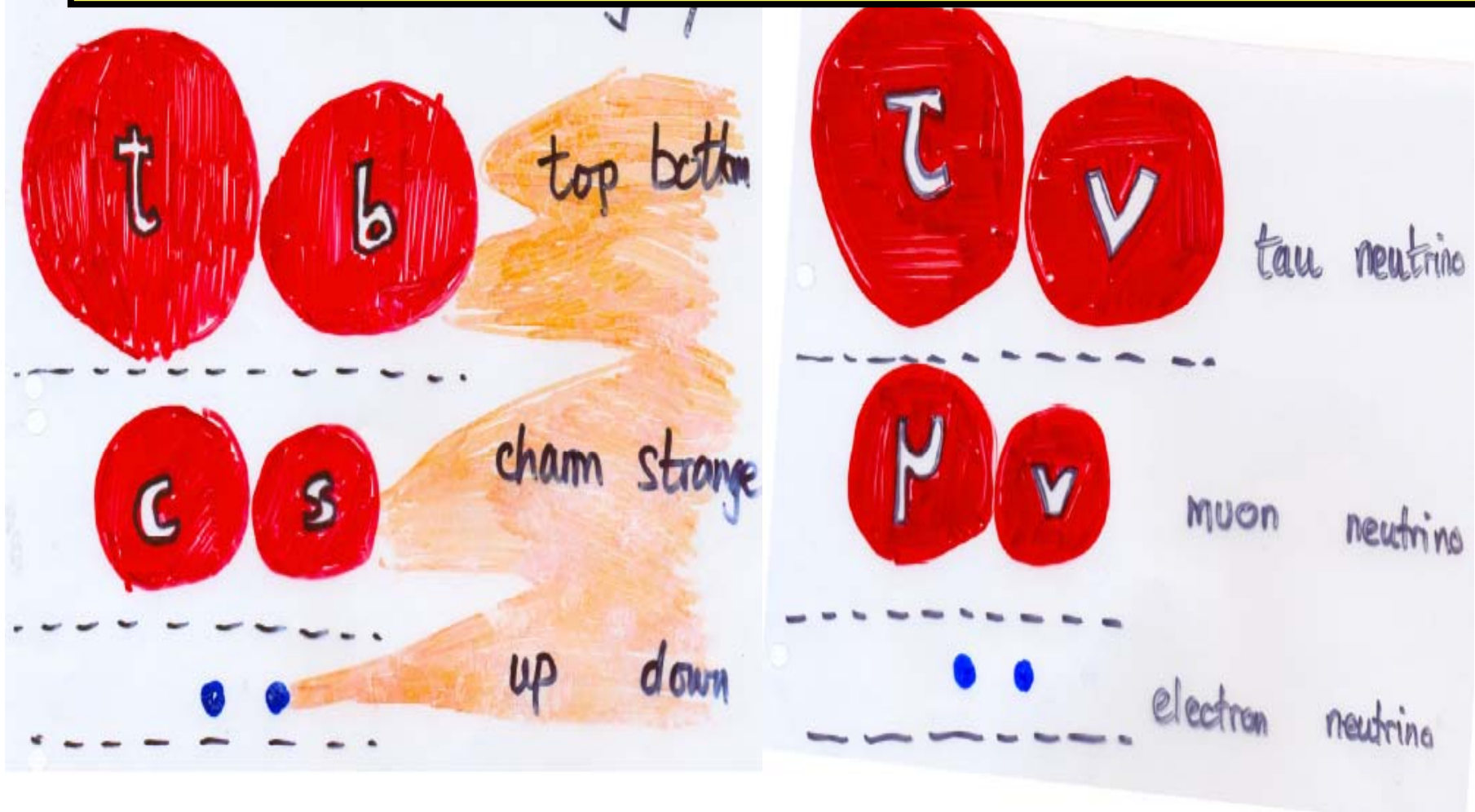
- Evidence that nu are disappearing
- Direct evidence for oscillation not yet

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



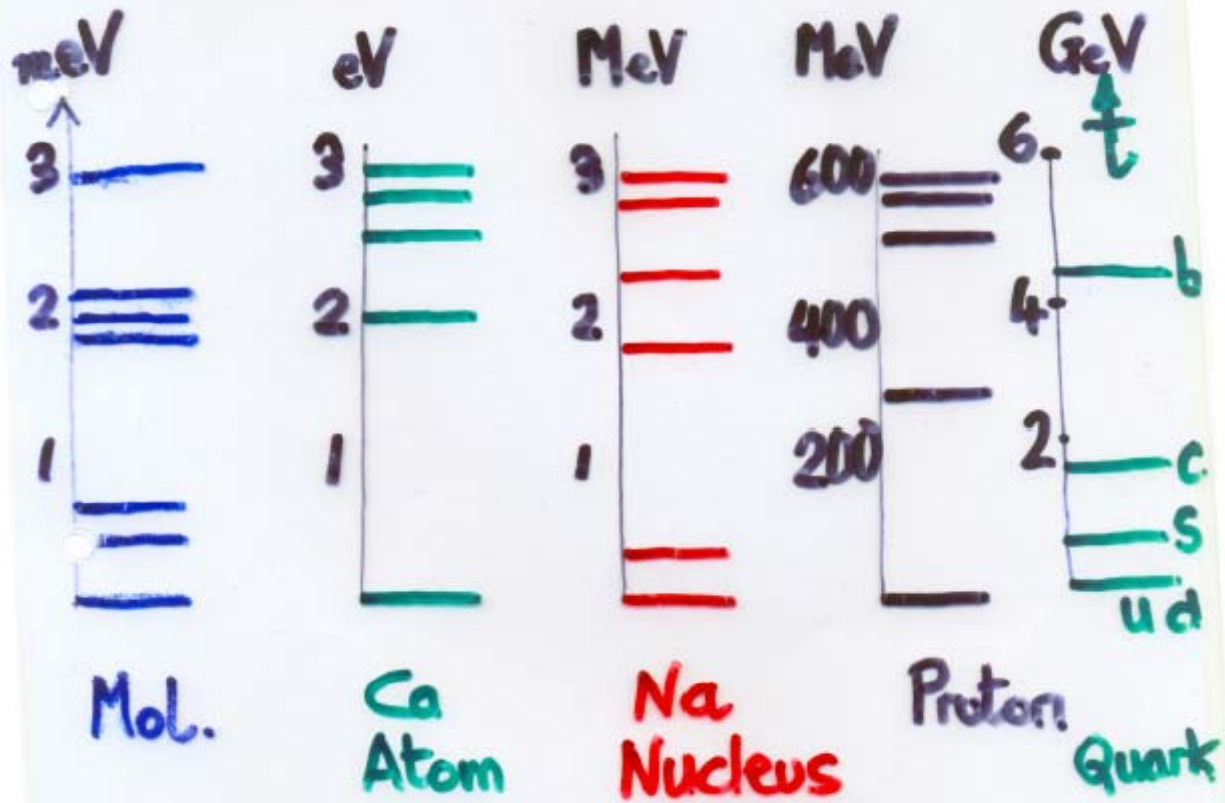


Nature's Three Party System

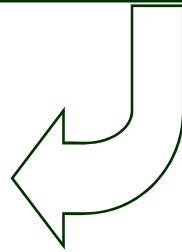


"Elementary" object \rightarrow Structured System
 Quantised motions and Rearrangements \rightarrow Excitation Spectra

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

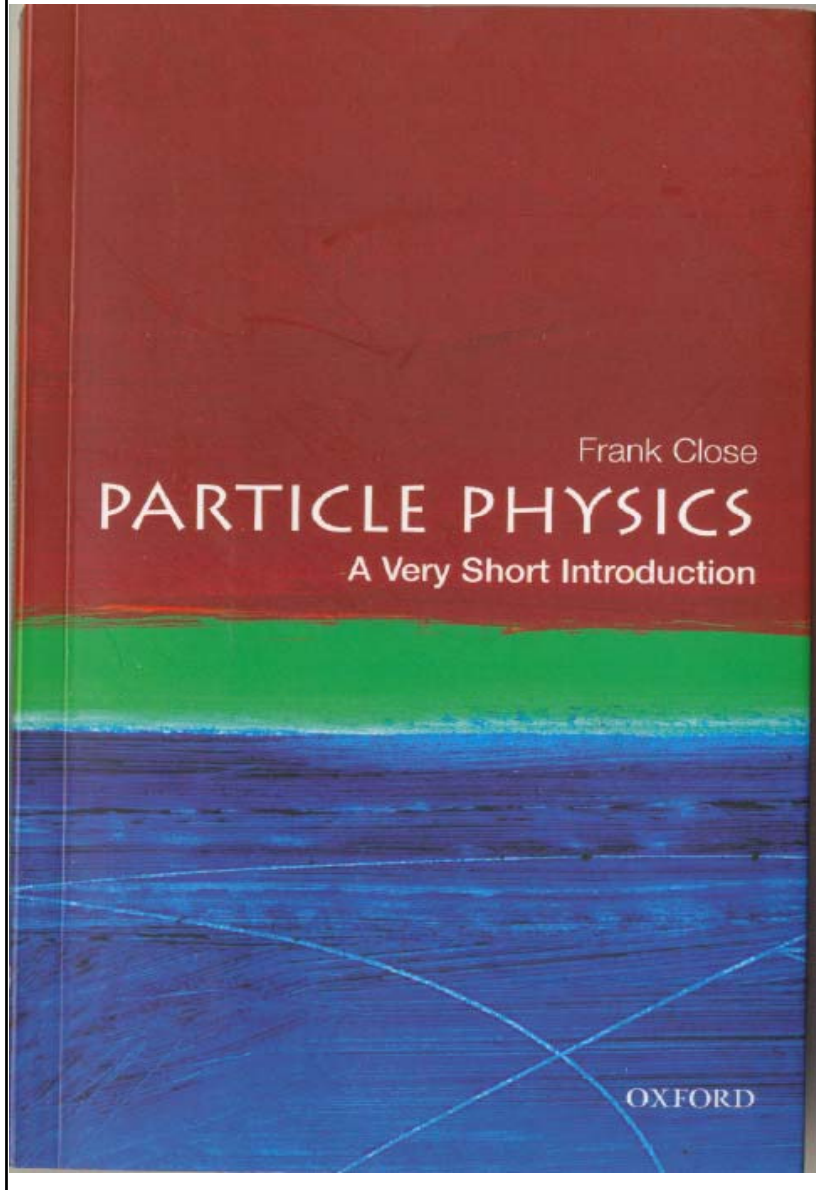
q

q

ANTIMATTER

**qqq antiproton
ANTIBARYONS**

A Very Short Introduction

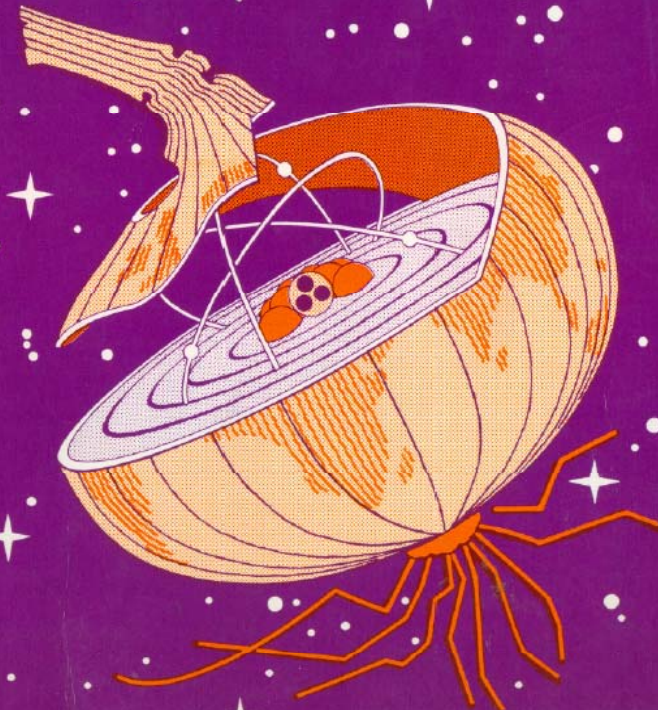


Coming out in December

NEW

THE COSMIC ONION

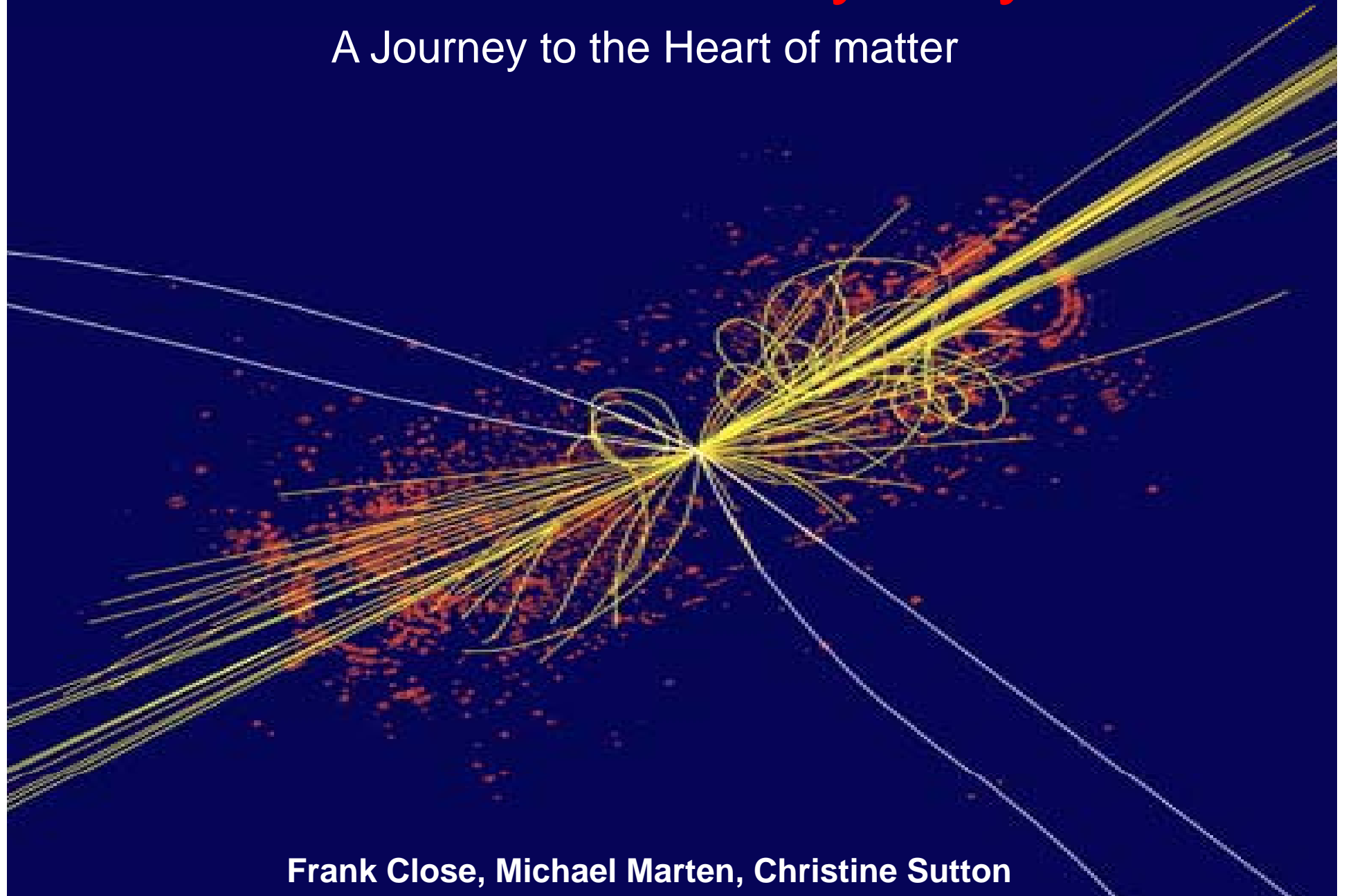
Quarks and the Nature of the Universe



Frank Close

The Particle Odyssey

A Journey to the Heart of matter



Frank Close, Michael Marten, Christine Sutton

