Introduction to Particle Physics

(for non physics students)

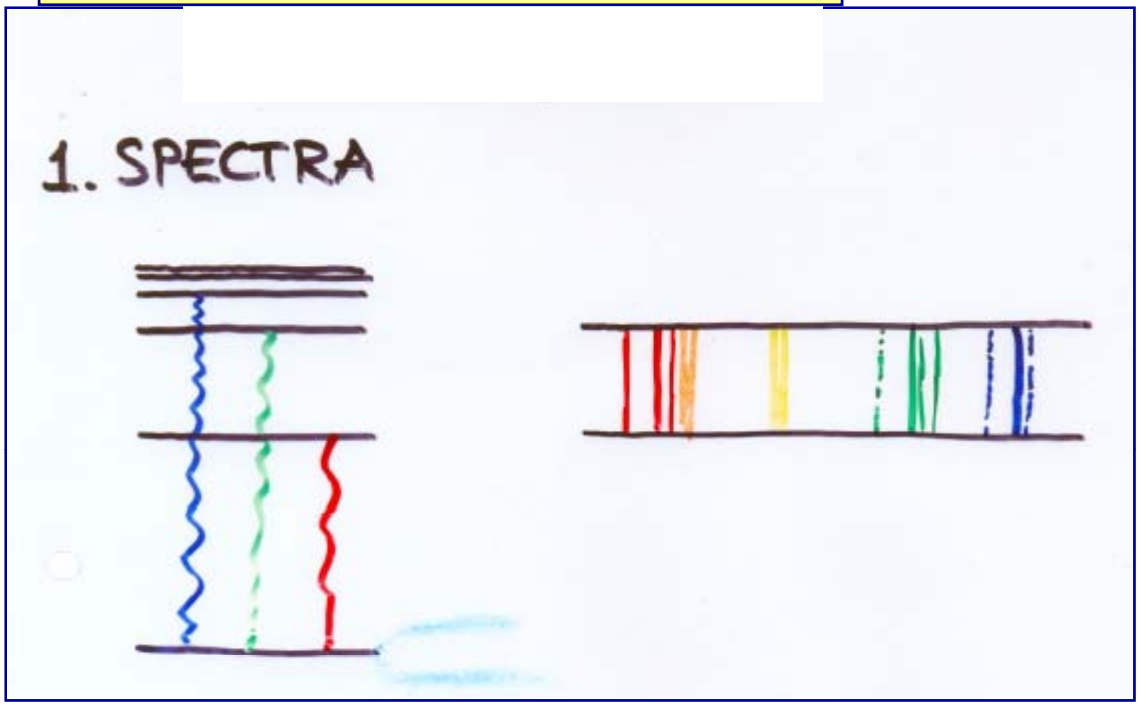
2. PARTICLES

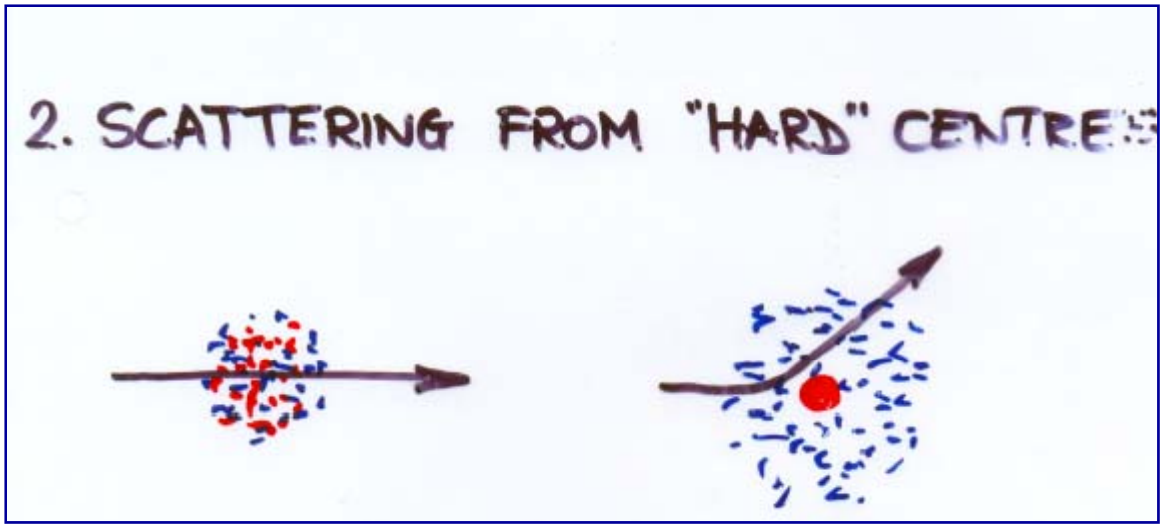
(from atoms to quarks and leptons)

PROFESSOR FRANK CLOSE
EXETER COLLEGE
UNIVERSITY OF OXFORD

Structure of Matter

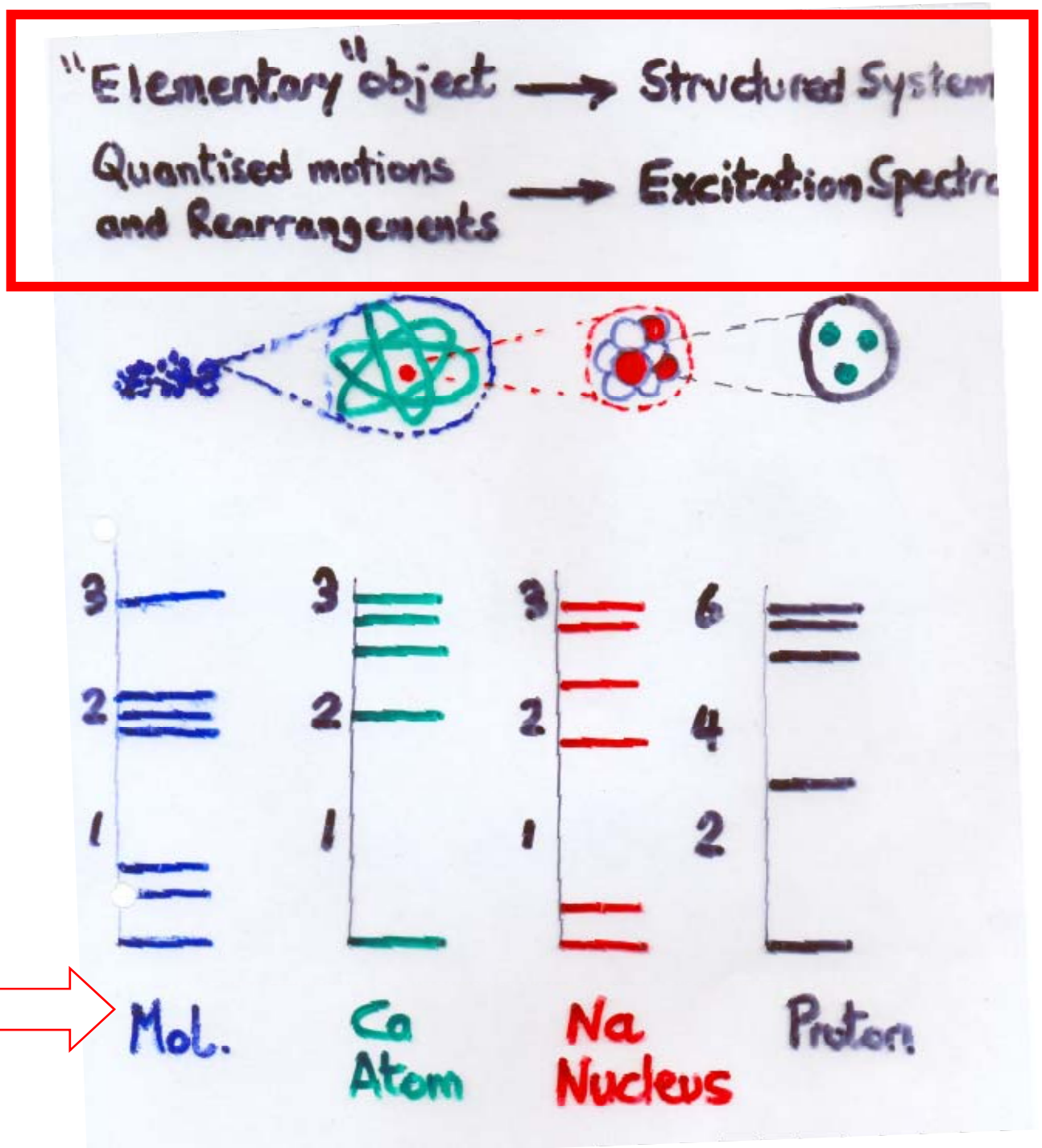
Two ways that structure is revealed:





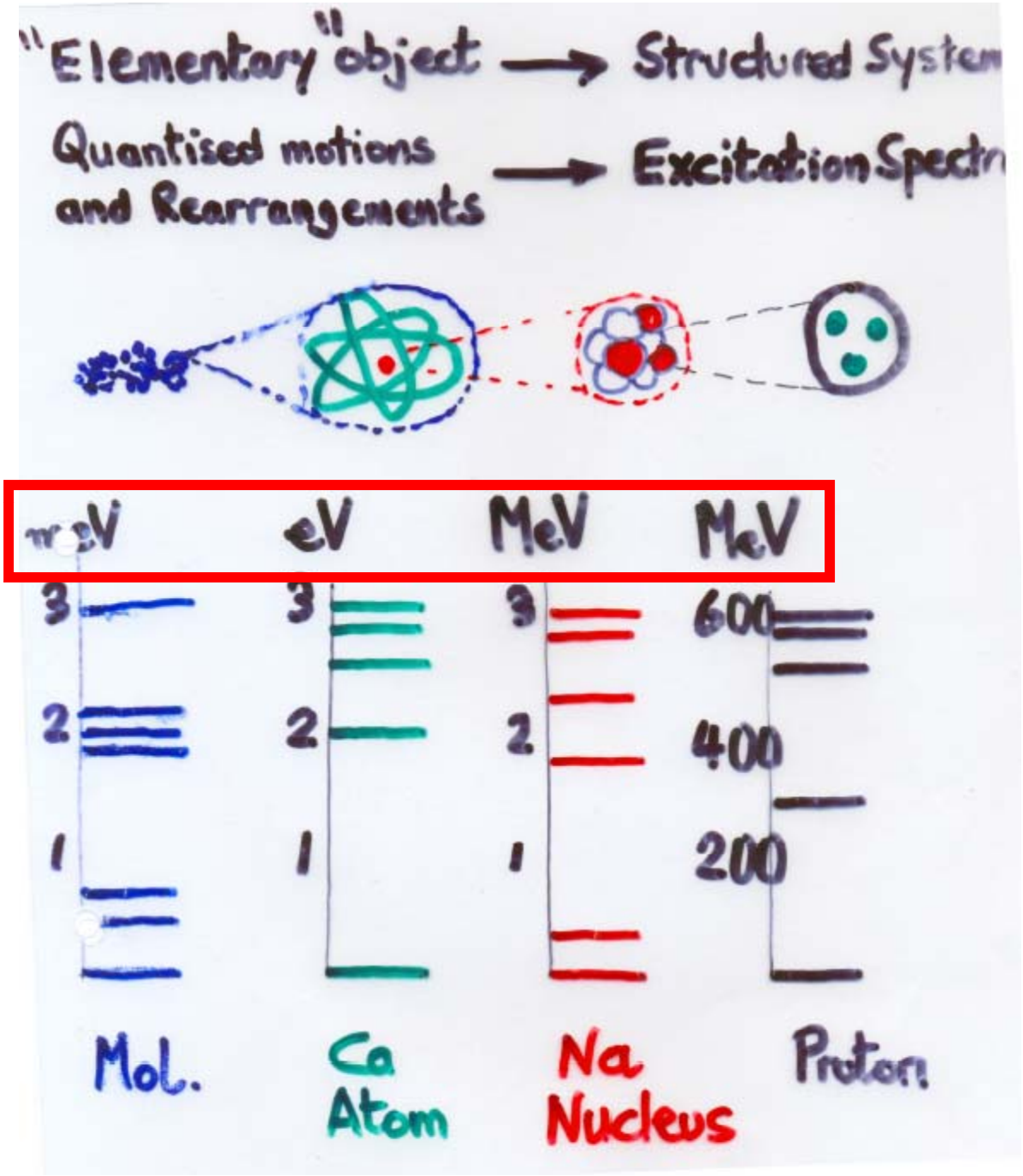
True from atoms to particles…..

Spectra



Qualitatively similar

Spectra



Quantitatively different

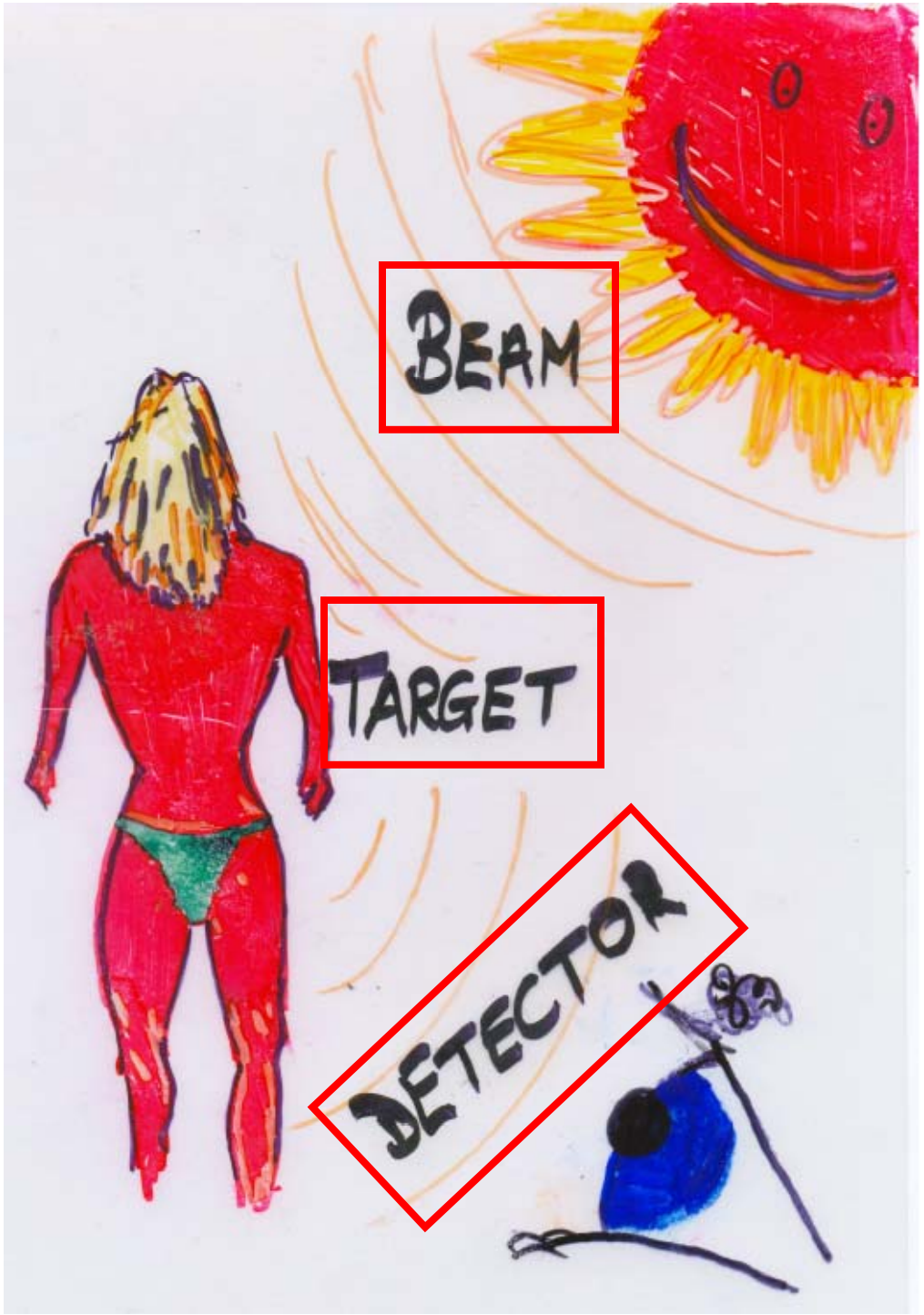
Scattering

Nuclear atom

Proton/neutron

Quarks

Qualitatively similar



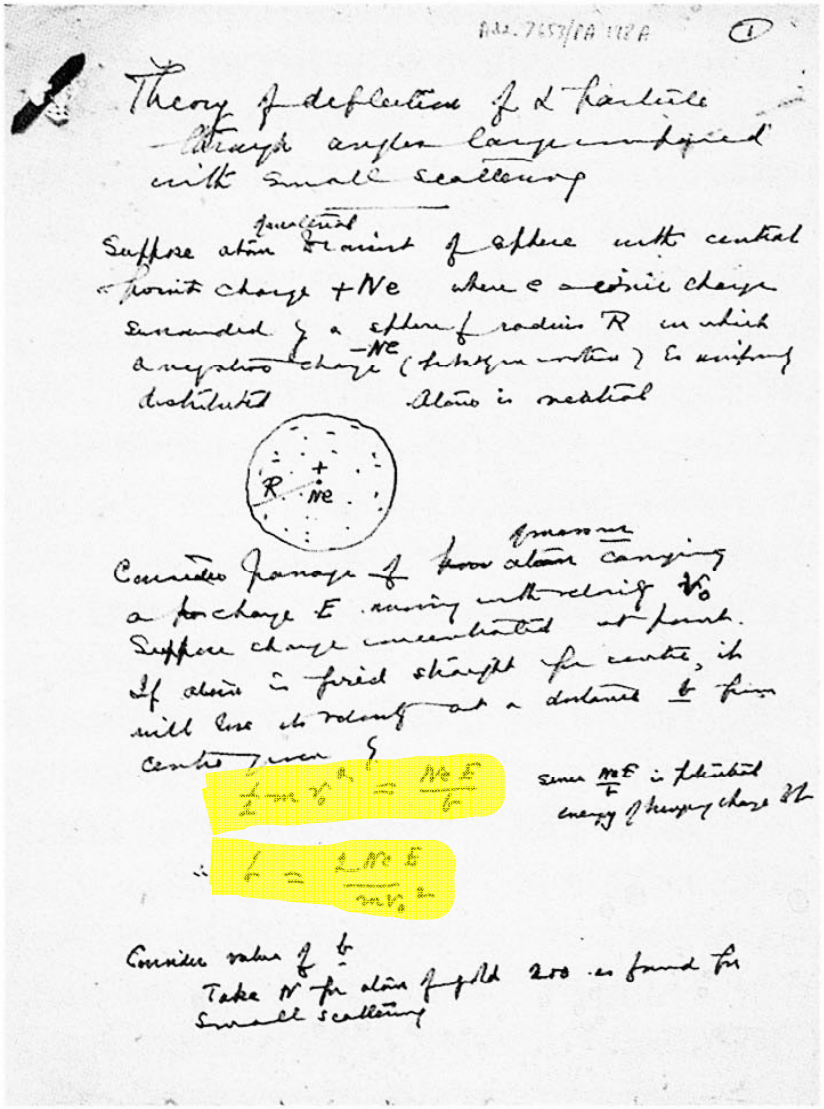
Rutherford: Nuclear Atom

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 point charge +Ne where e = ionic charge surrounded by a sphere of radius R in which a negative charge −Ne (distributed in unitary volume) is uniformly distributed. Atom is neutral

Consider passage of fast moving α atom carrying charge E moving with velocity v_0 Suppose charge concentrated at point. If atom is fired straight for centre, it will rebound along same line

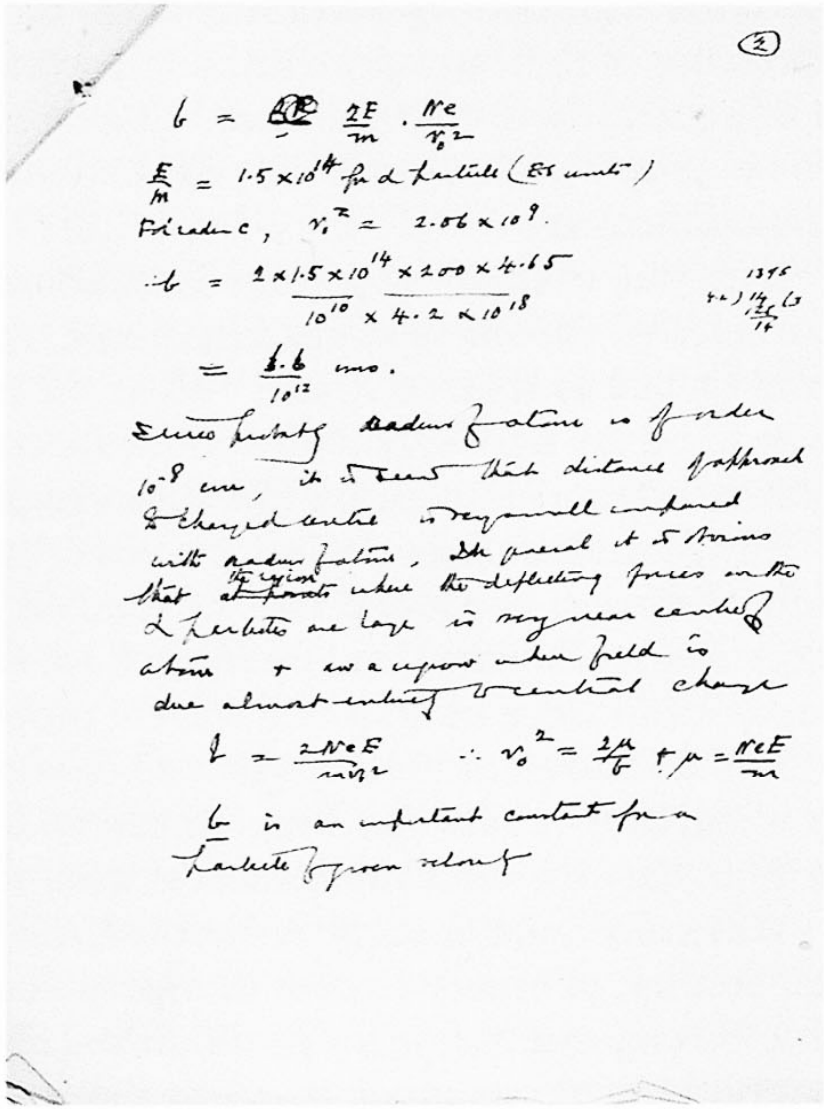
$$\frac{1}{2} m v_0^2 = \frac{NeE}{b}$$

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

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

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 radium, $v_1^2 = 2.06 \times 10^9$.

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

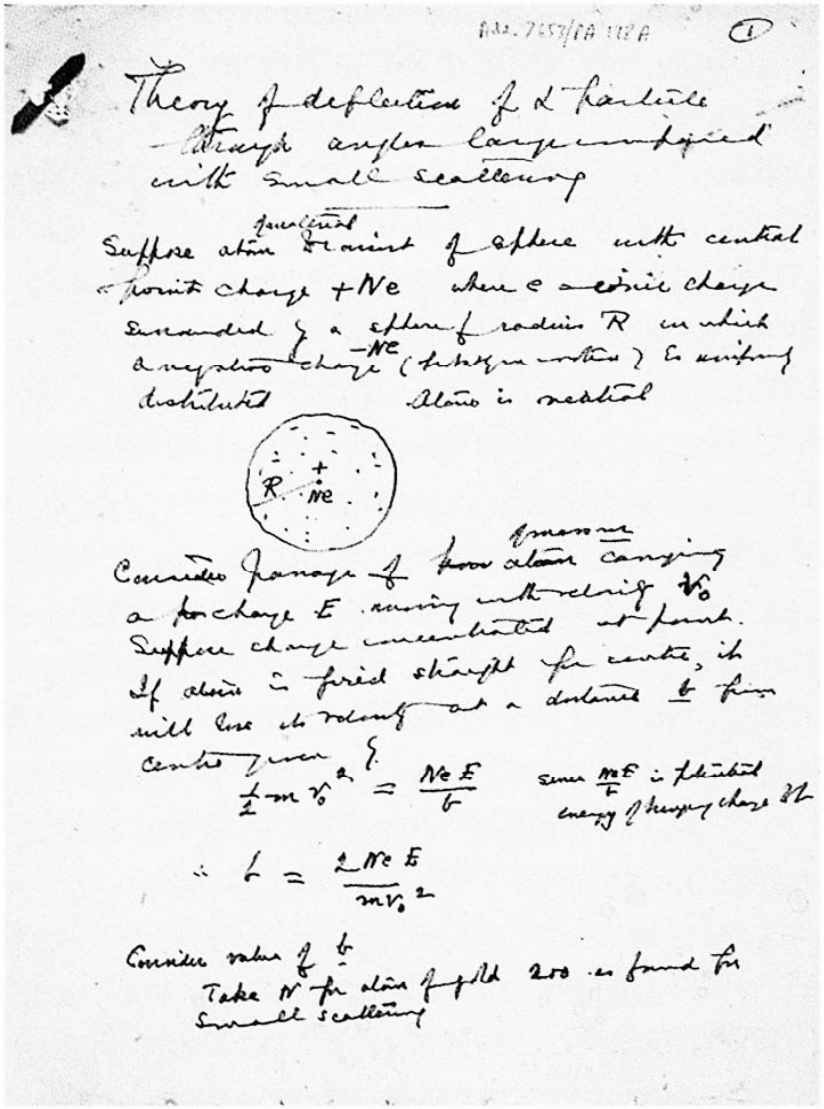
$$= \frac{1.6}{10^{12}} \text{ cms.}$$

Since probably radius of atom is of order 10^{-8} cm, it is seen that distance of approach of charged centre is beyond all comparison with radius of atom, so that at point where the deflecting forces on the α particle are large is very near centre of atom + as a uniform unless field is due almost entirely to central charge

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

b is an important constant for a particle of given velocity

…and long division



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

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

Consider passage of fast atom carrying a charge E moving with velocity v_0. Suppose charge concentrated at point. If atom is fired 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 $\frac{NE}{b}$ is potential energy of charge at

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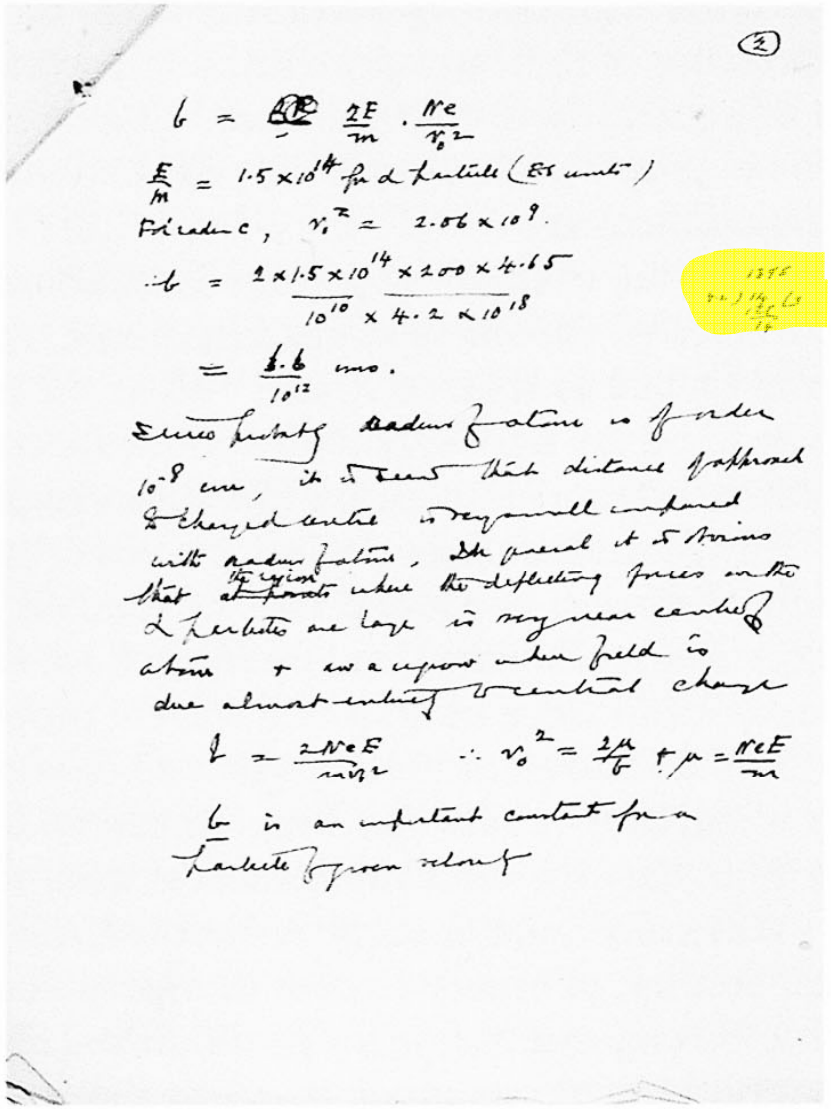

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$$\therefore b = \frac{2 \times 1.5 \times 10^{14} \times 200 \times 4.65}{10^{10} \times 4.2 \times 10^{18}}$$

$$= \frac{4.6}{10^{12}} \text{ cms.}$$

Since probably radius of atom is of order 10^{-8} cm, it is seen 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 any mean centre of atom + we are in region where field is due almost entirely to central charge

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

b is an important constant for a particle of given velocity

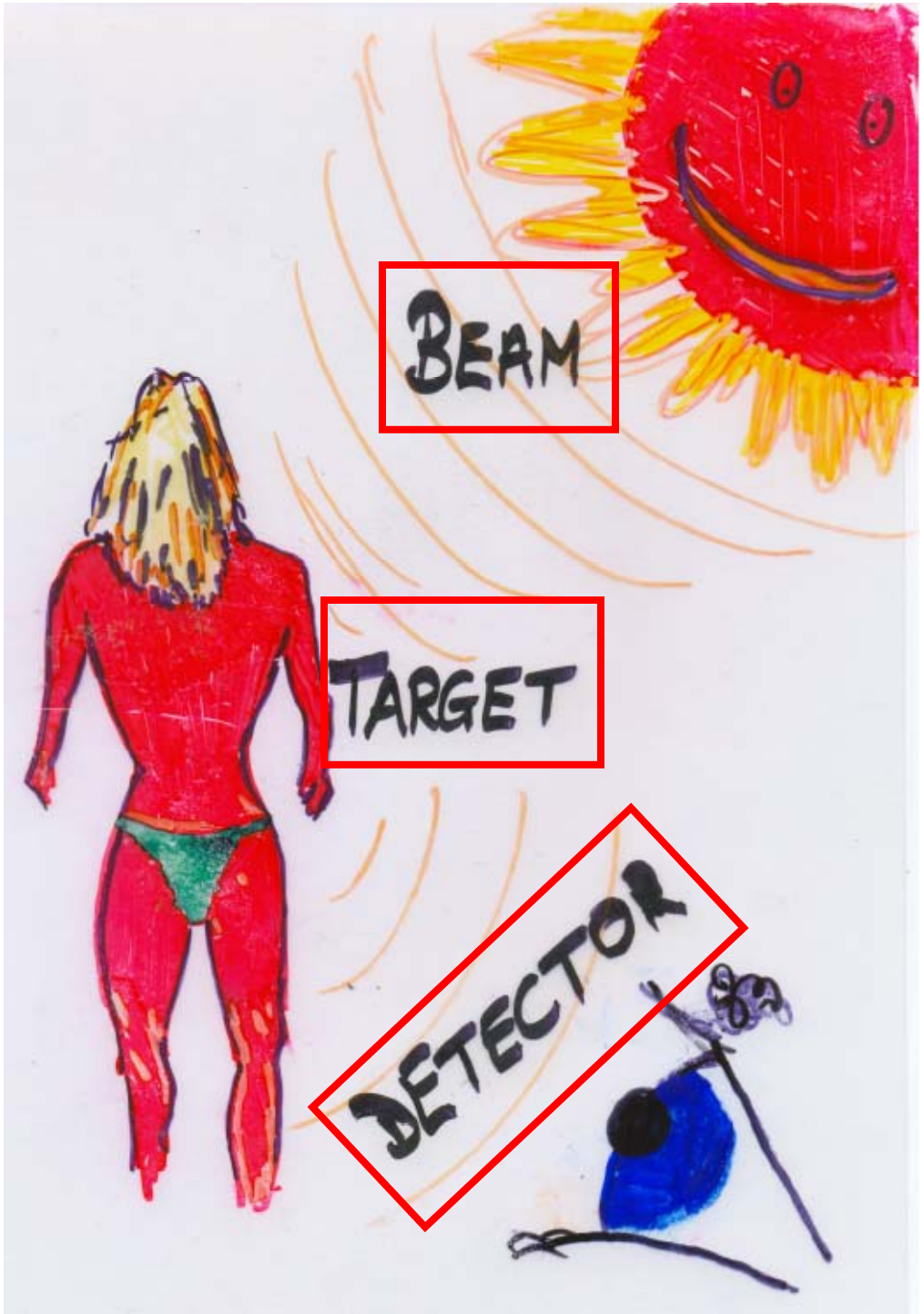
$$\therefore b = \frac{2 \times 1.5 \times 10^{?} \times 200 \times 4.6}{10^{10} \times 4.2 \times 10^{18}}$$ 1346

4.2) 14 (3
12.6
14

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

Since probably radius of atom is of order 10^{-8} cm & is 5 times this distance of approach of charged centre is very small compared with radius of atom. In general it is obvious that in 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

$$b = \frac{2NeE}{mv_0^2} \qquad \therefore v_0^2 = \frac{2\mu}{b} \quad \text{if } \mu = \frac{NeE}{m}$$

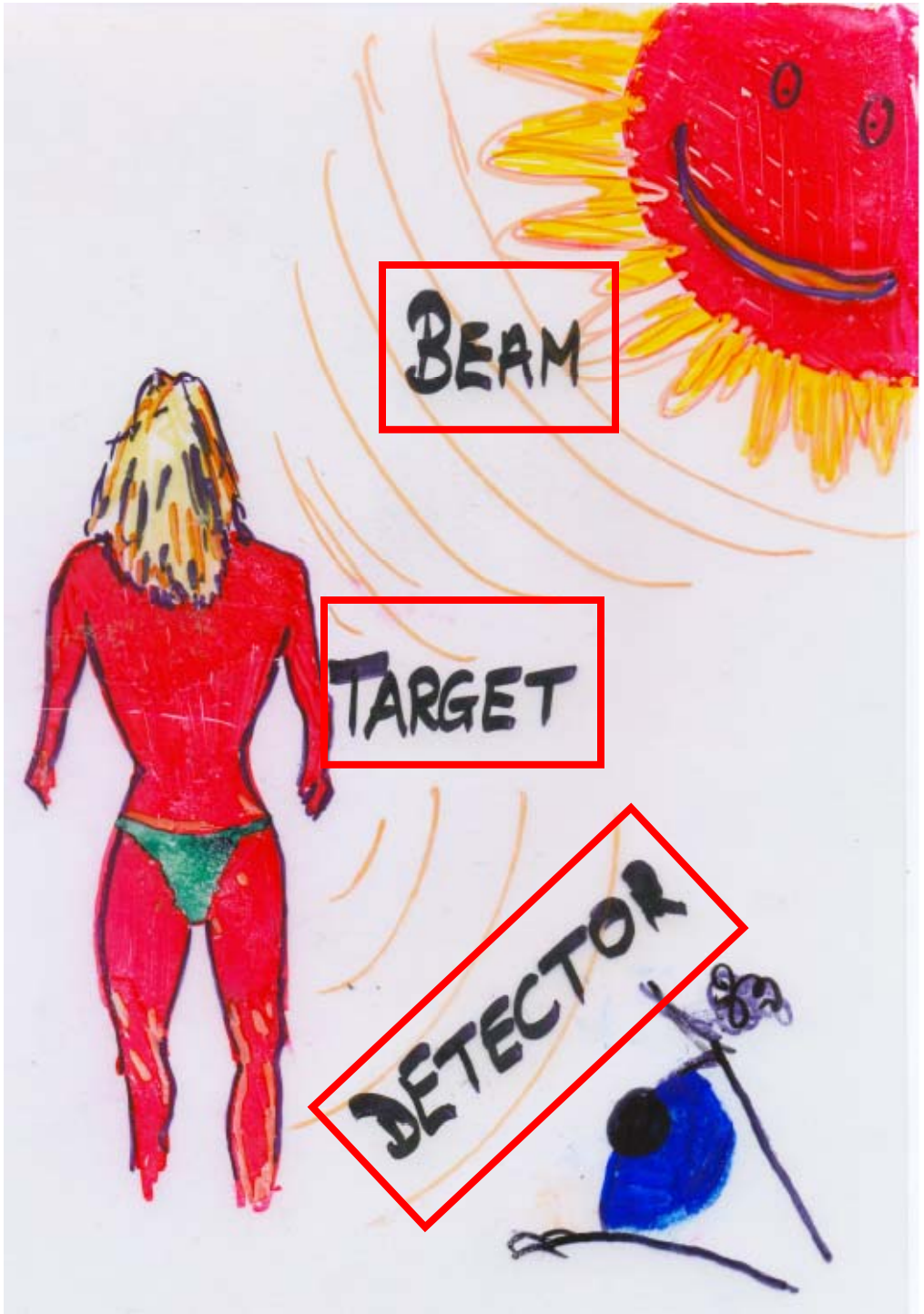


Quarks in the proton

Qualitatively: Same idea

Quantitatively:
Different scale

SLAC 3km electron accelerator

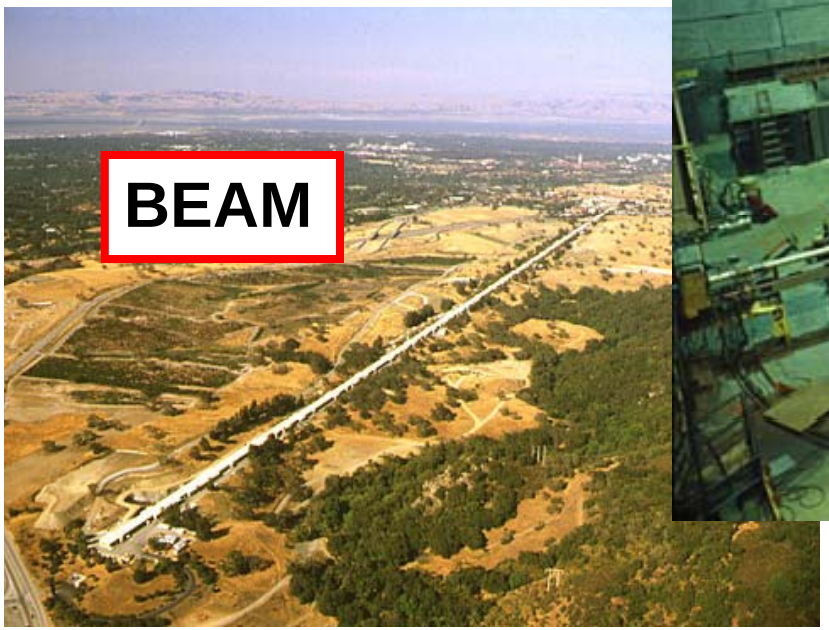


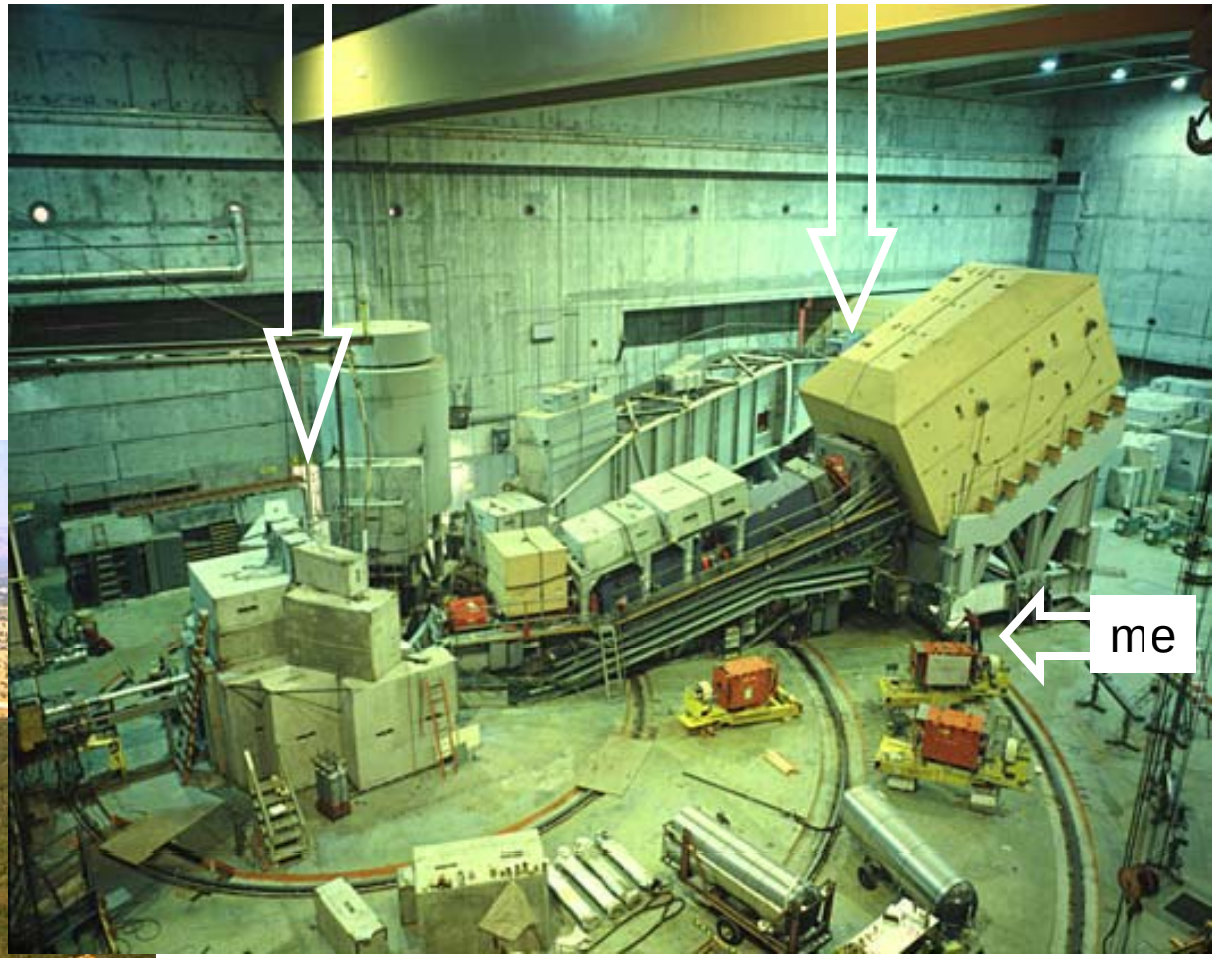
Quarks in the proton

Electron beam = 3 km

Proton target (hydrogen)

Big electronic detector

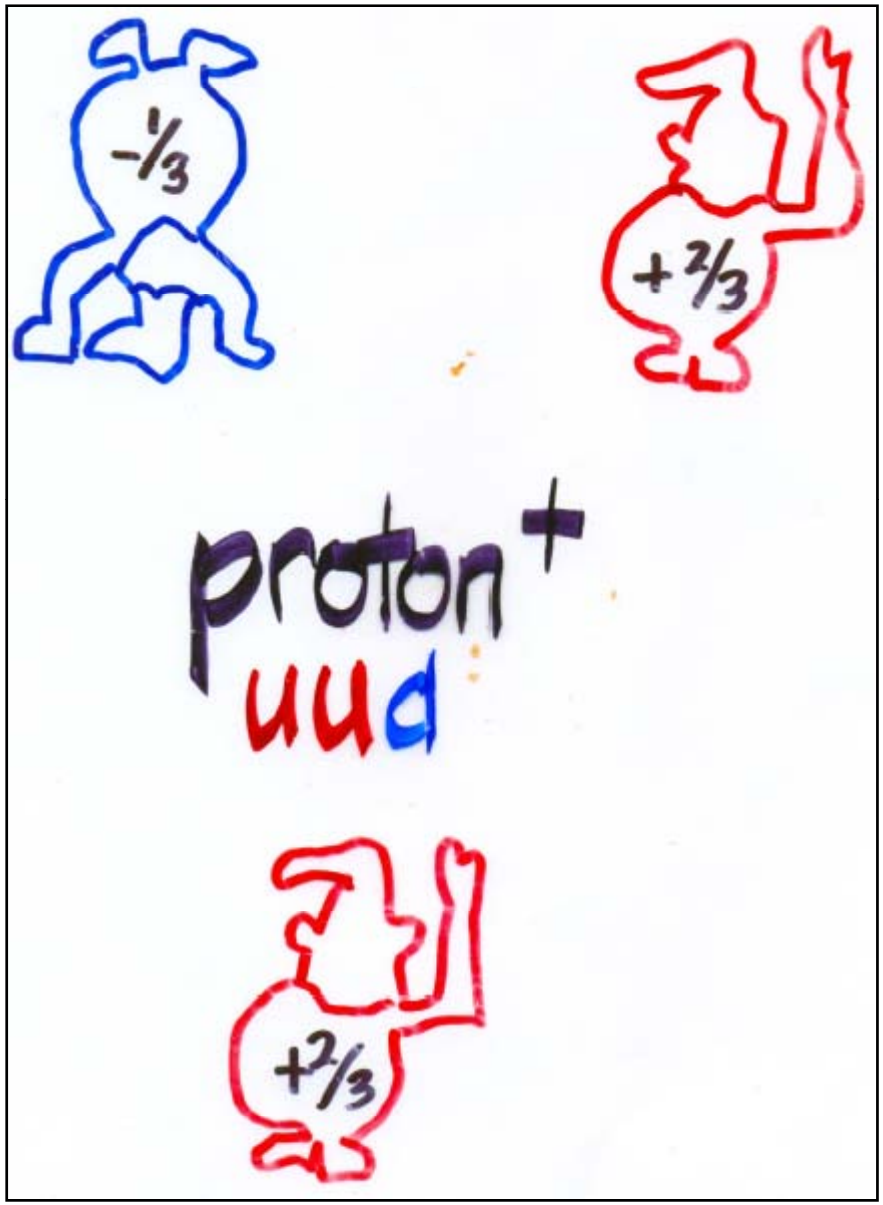

BEAM


TARGET
DETECTOR
me

Proton made of 3 quarks, gripped by gluons

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

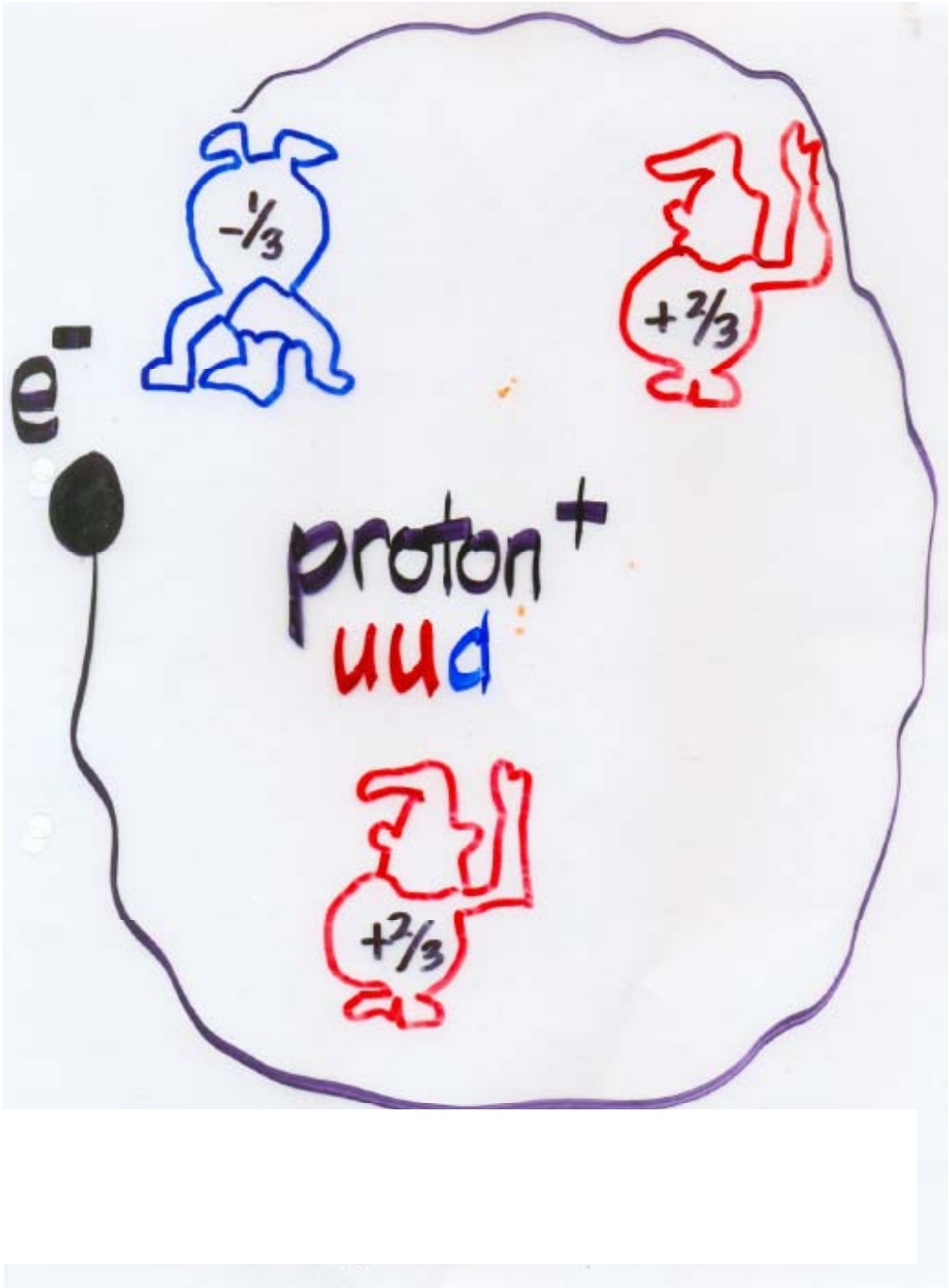
Up and down Quarks



and

neutron

ddu



H atom

(not to scale!)

a miracle of neutrality

electron

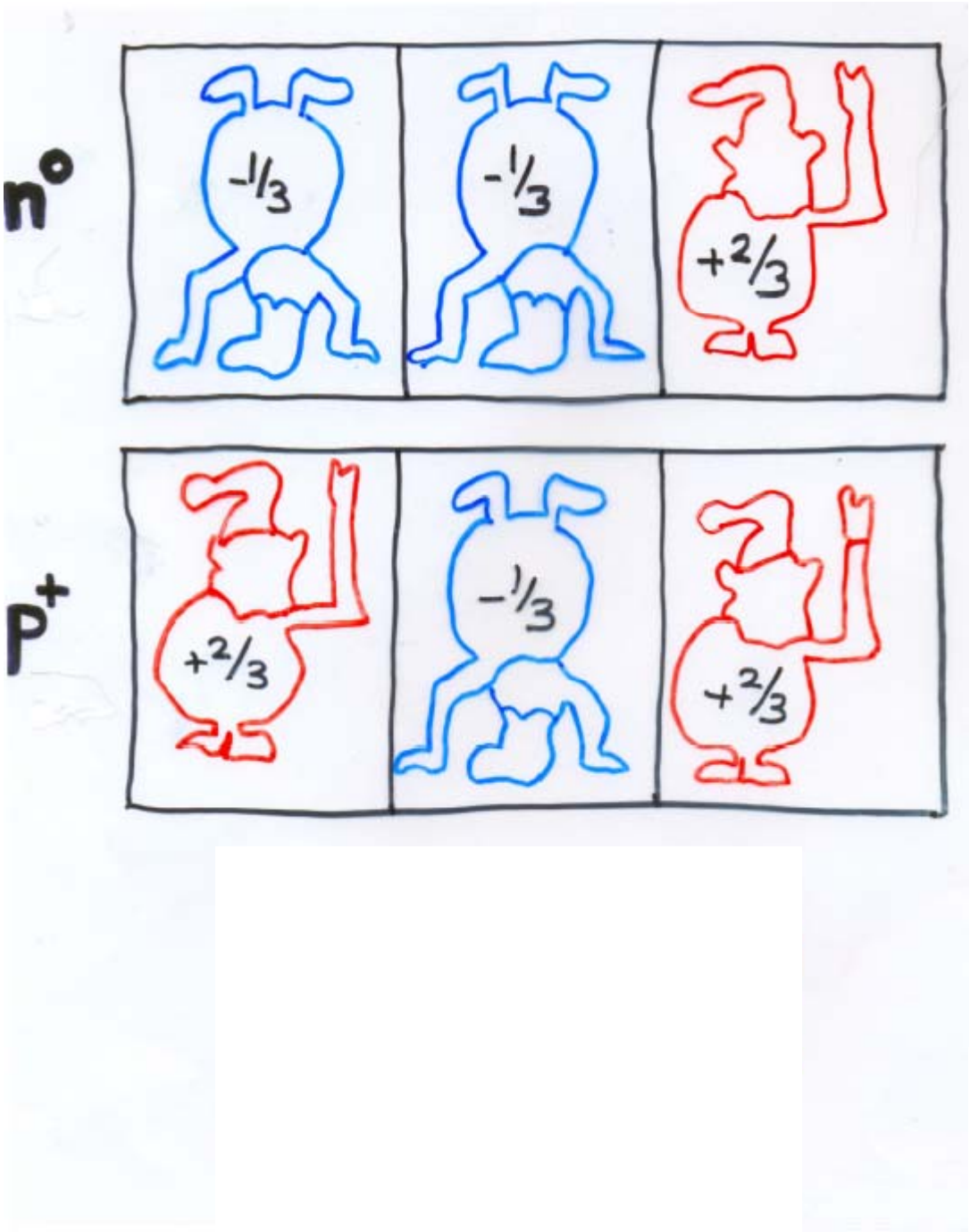
balances

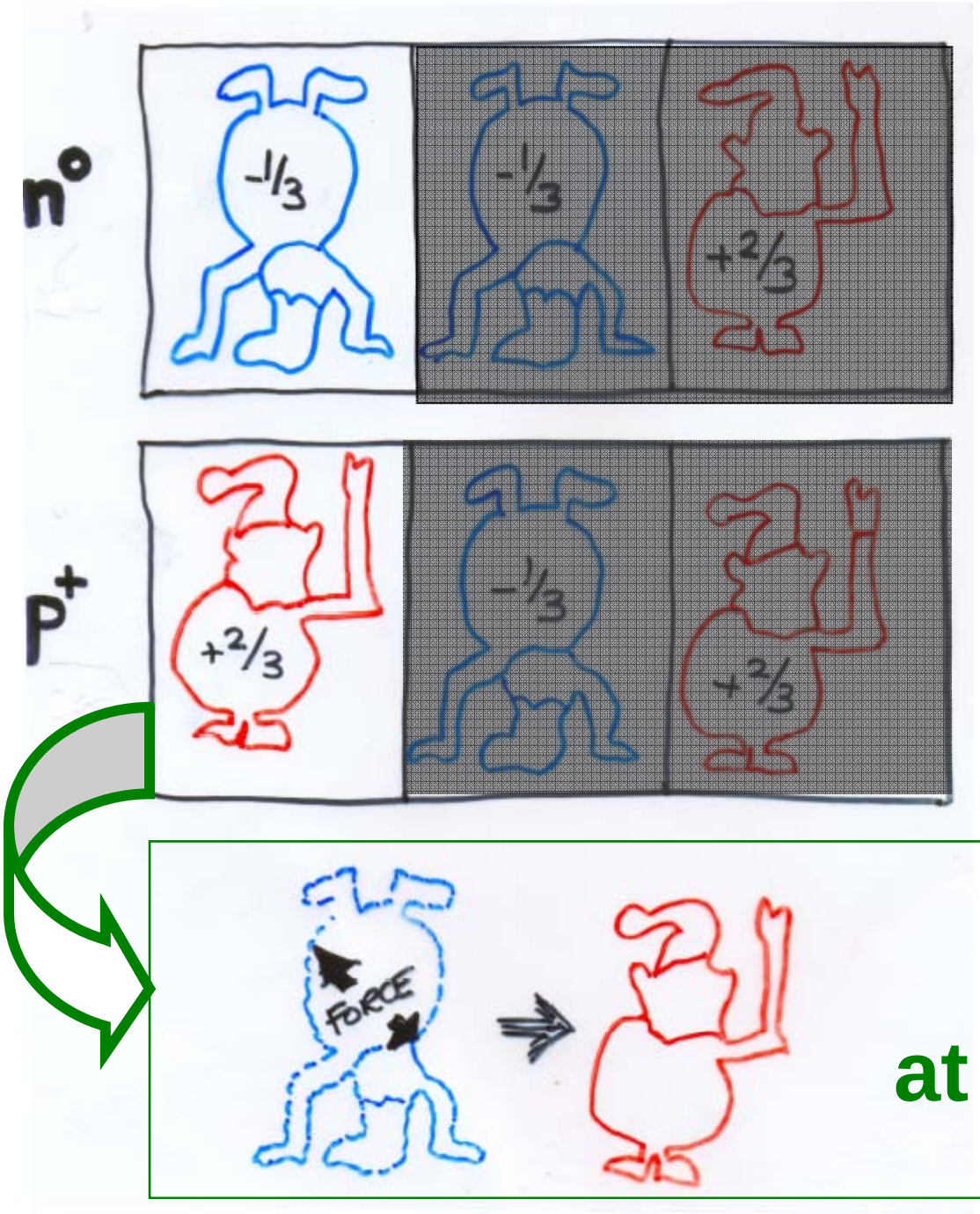
uud

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

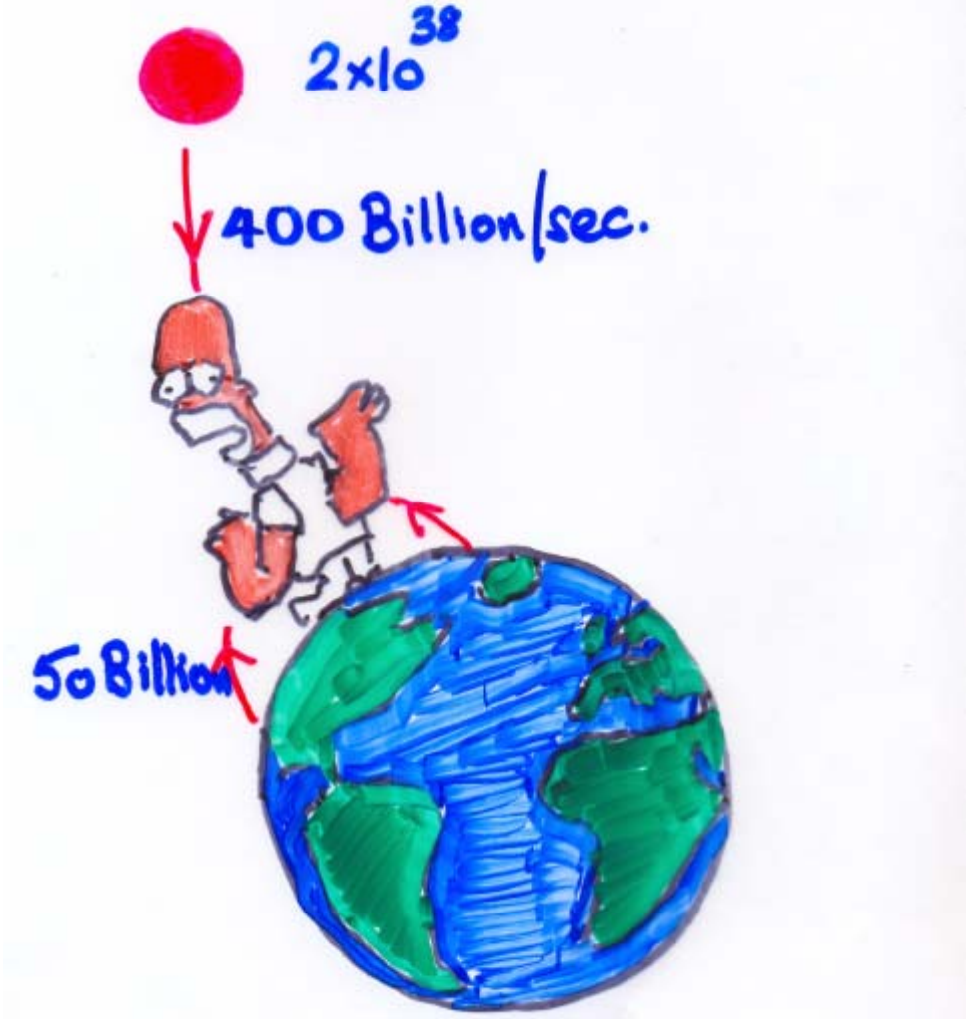
- goes through almost everything
- "impossible" to stop/detect
- the "smallest" of the particles

- 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

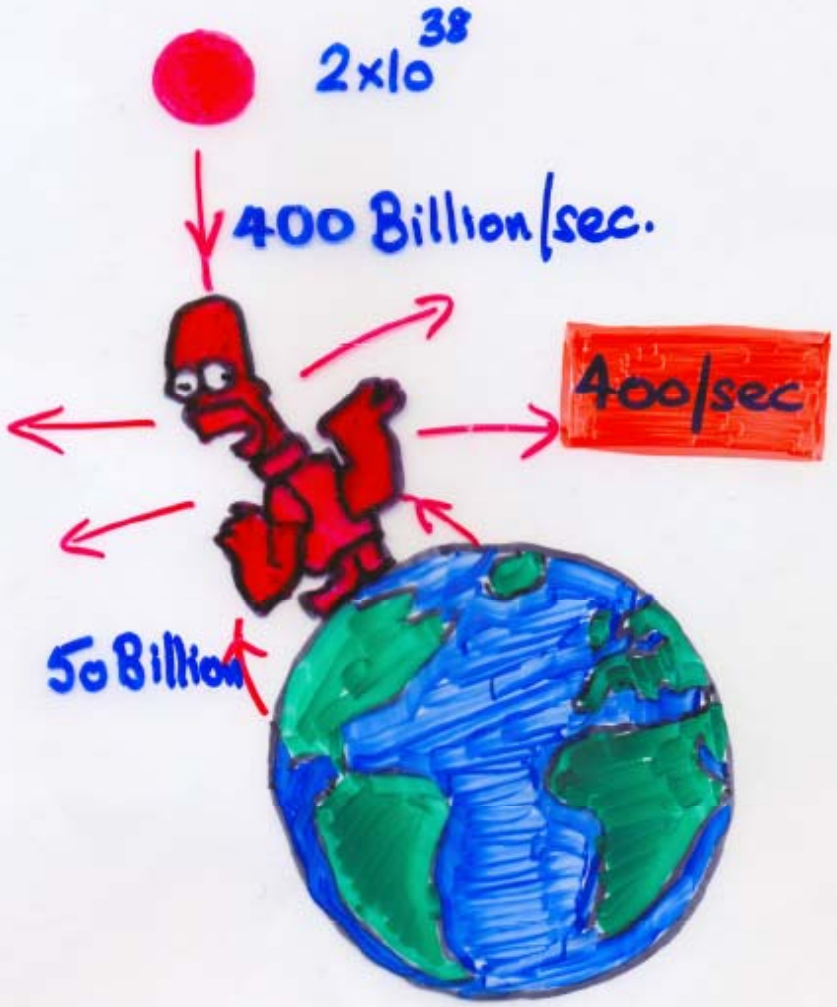
SOME NEUTRINO STATISTICS

Each second :



SOME NEUTRINO STATISTICS

each second :

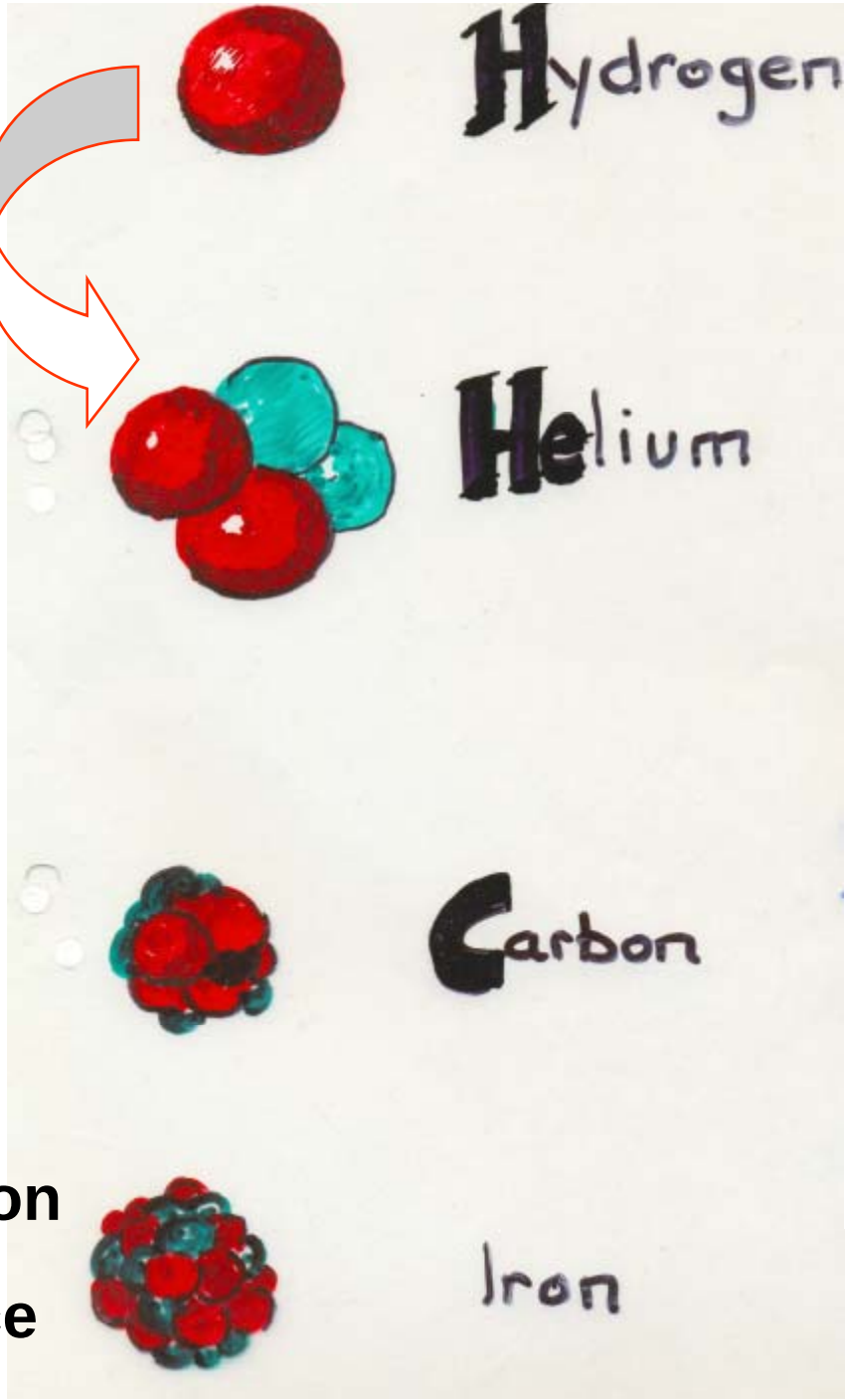


1 hr. x this audience ⇒ 100 million neutrinos


8 minutes
ν
Light
8minutes
H H
100 thousand yr.

Stars cook the elements

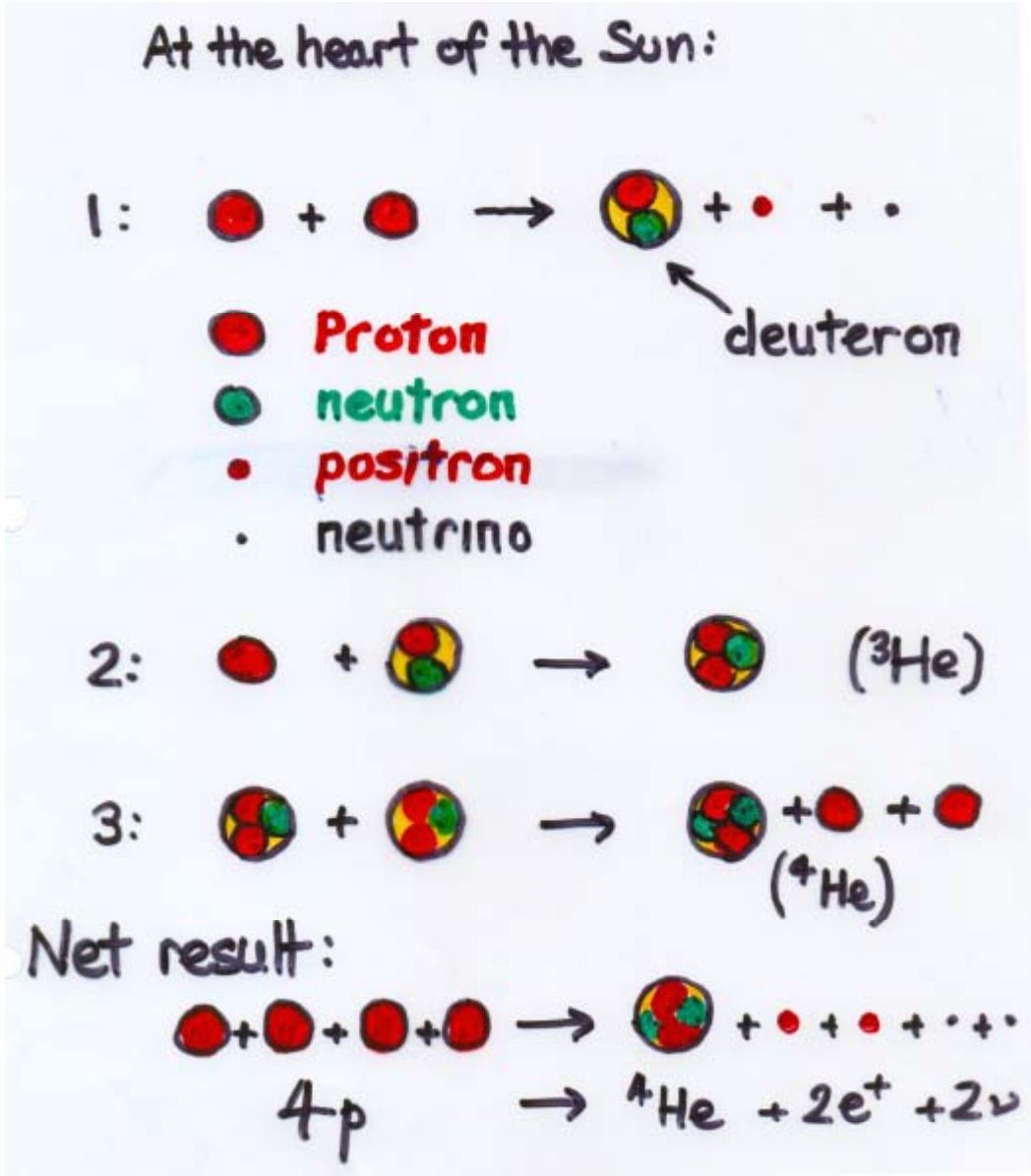
Sun is dominantly this first step

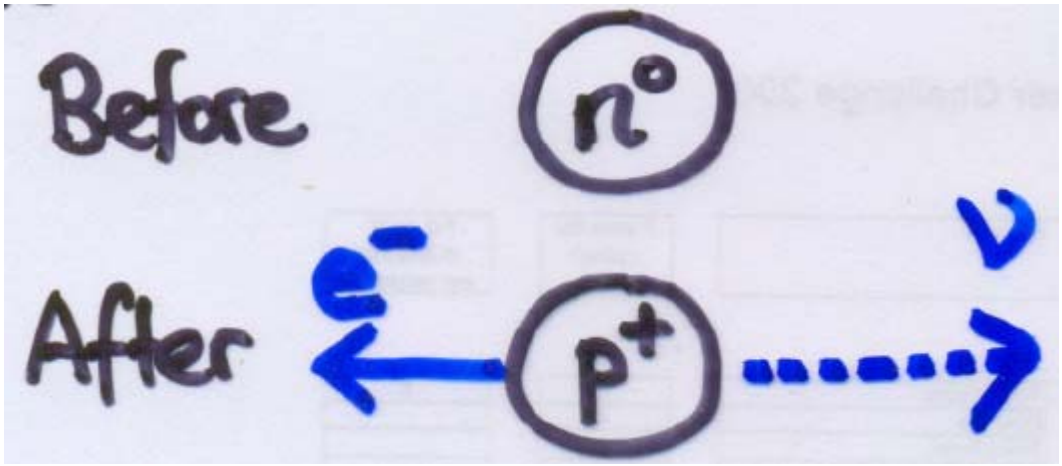


Heavy elements cooked in stars and ejected into cosmos in supernova explosion

Many protons; electrical disruption

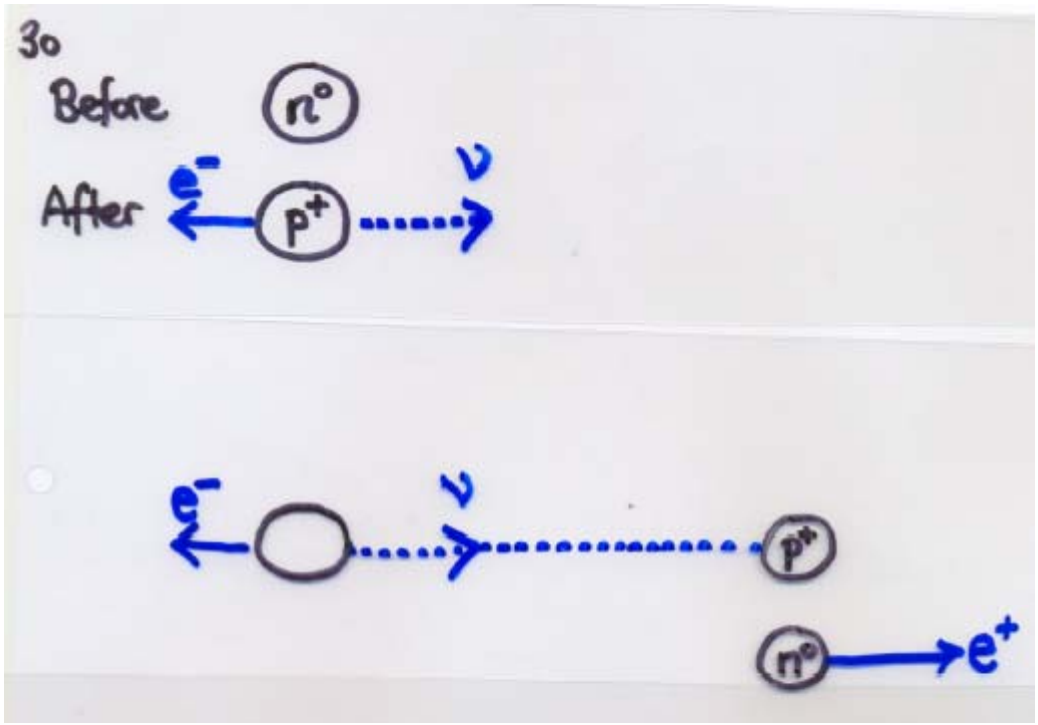
Stabilised by STRONG force

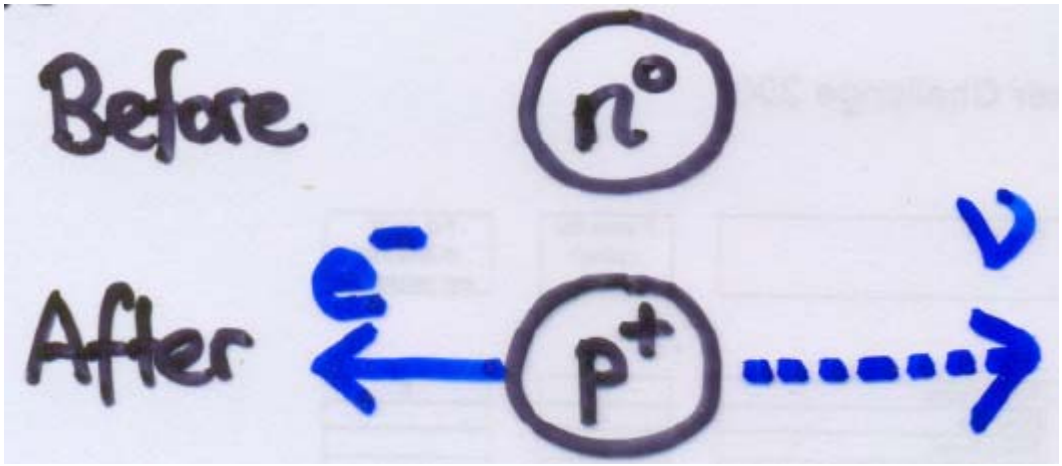

At the heart of the Sun:
1:
deuteron
Proton
neutron
positron
neutrino
2:
(3He)
3:
(4He)
Net result:
4p → 4He + 2e+ + 2ν



How do we know the neutrino is produced?

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


30
Before
n°
After
e⁻
p⁺
ν
e⁻
ν
p⁺
n°
e⁺



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)

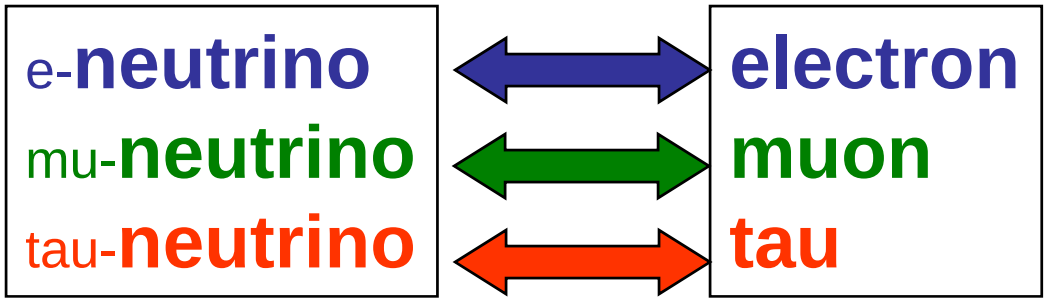
u (3 MeV)	d (5 MeV)
c (1.2 GeV)	s (100 MeV)
t (170 GeV)	b (4.5 GeV)

LEPTON MASSES

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

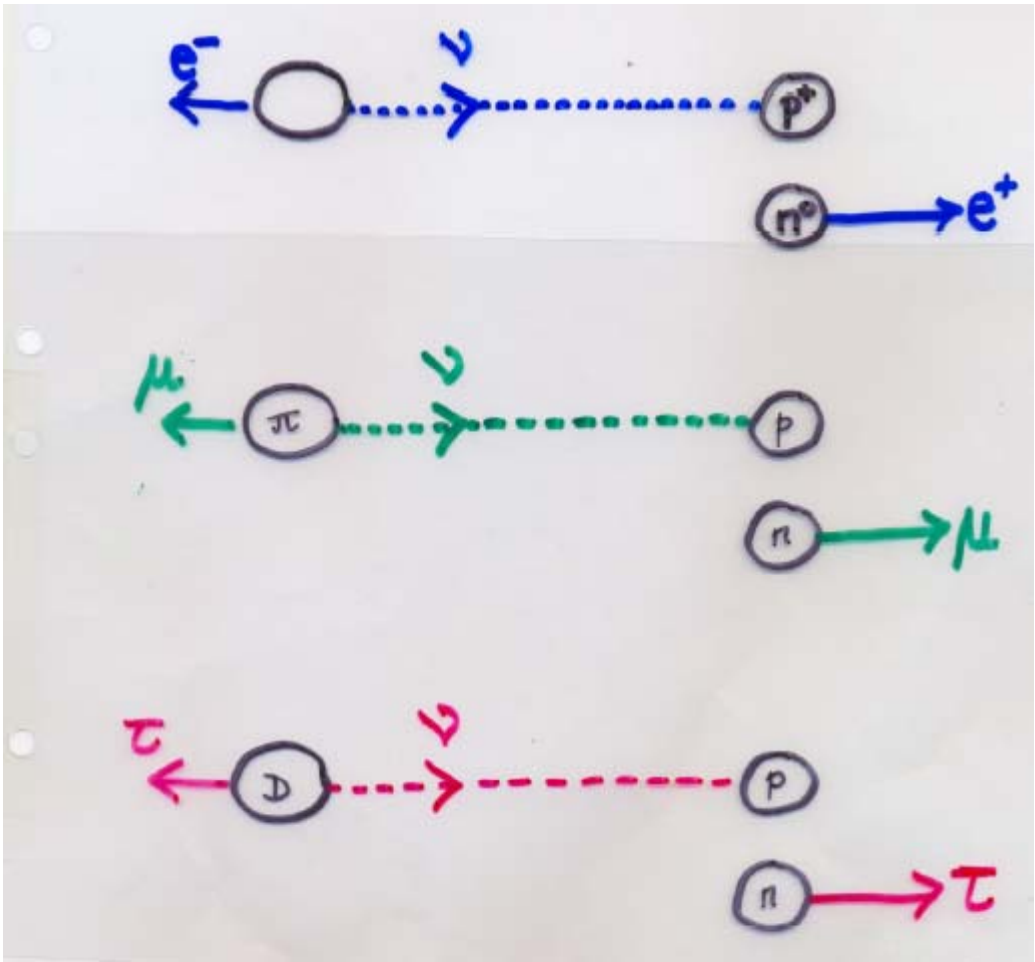
three neutrinos each with **ZERO** charge also have $\simeq$ **ZERO** masses

Neutrinos and their charged partner are always linked

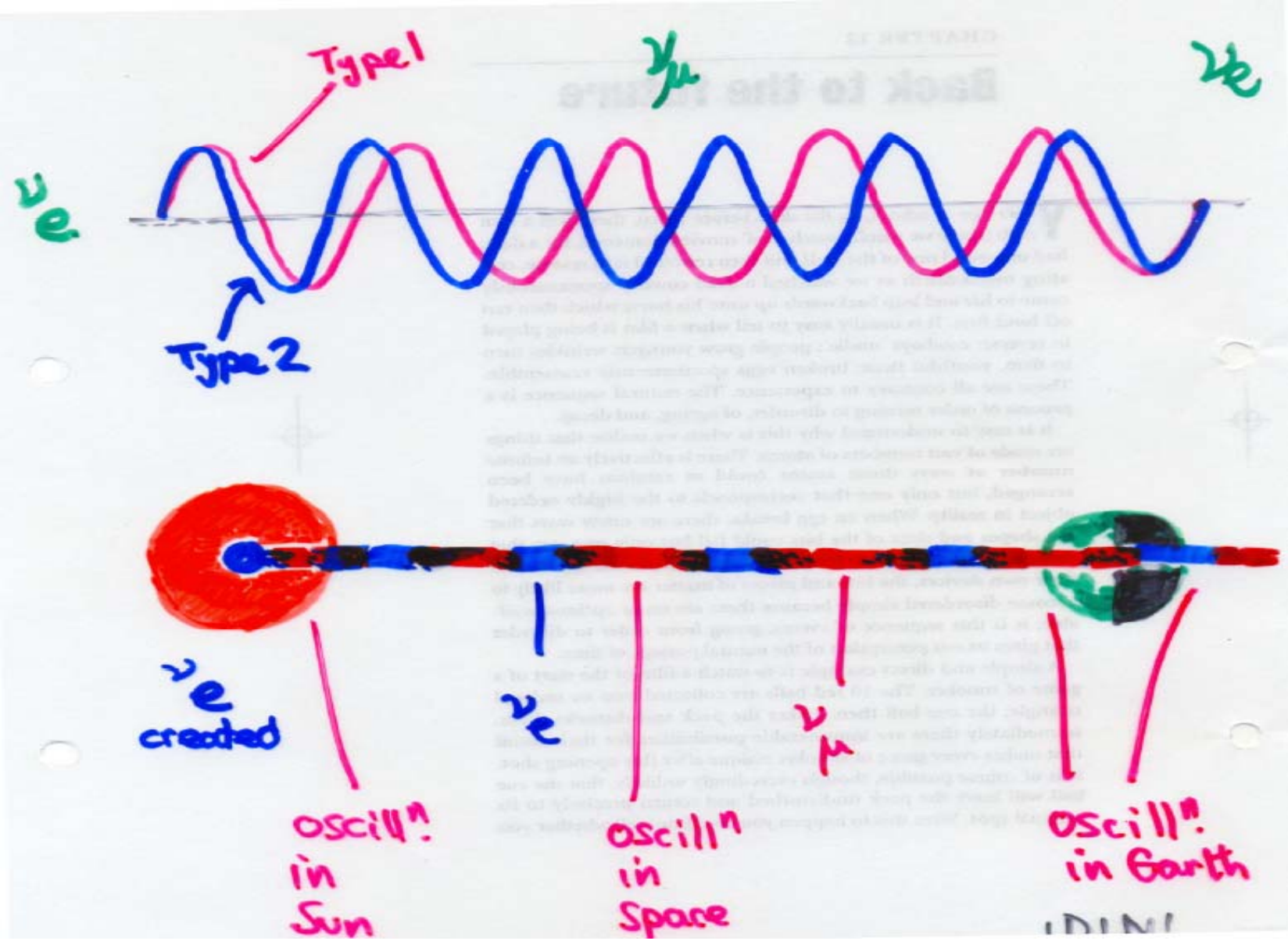


if

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

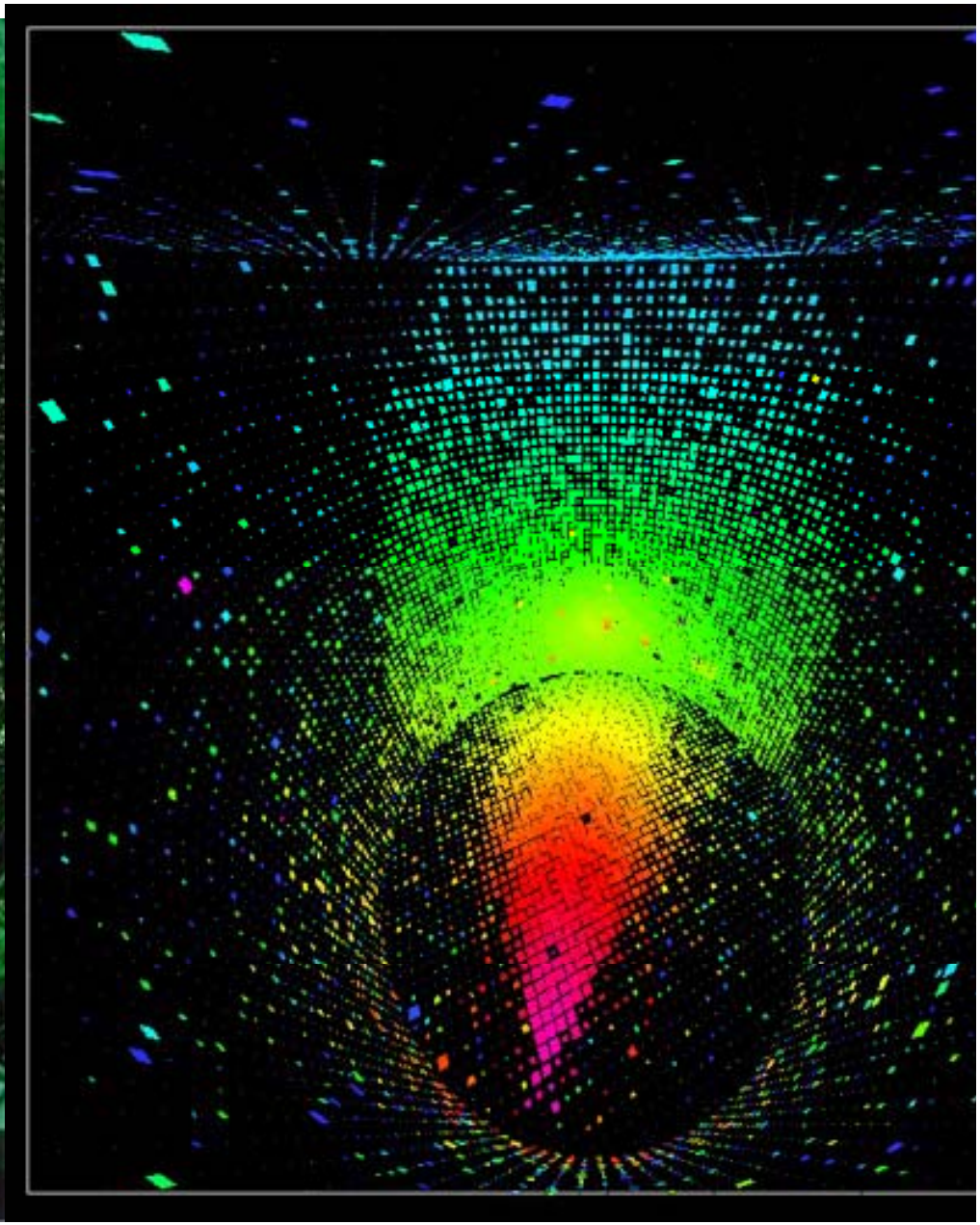
e.g. CERN to Gran Sasso Italy

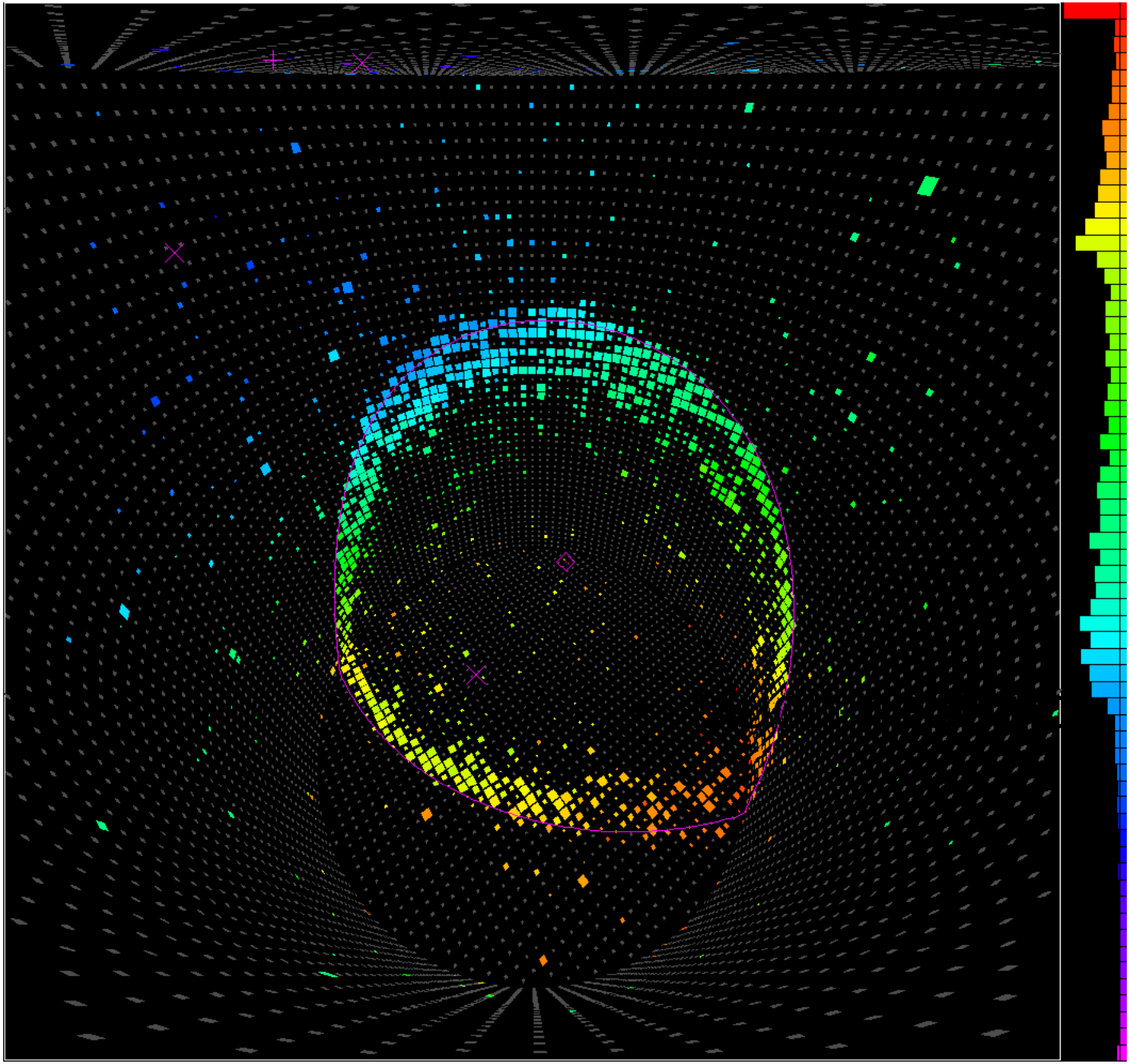
Neutrino Oscillations

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

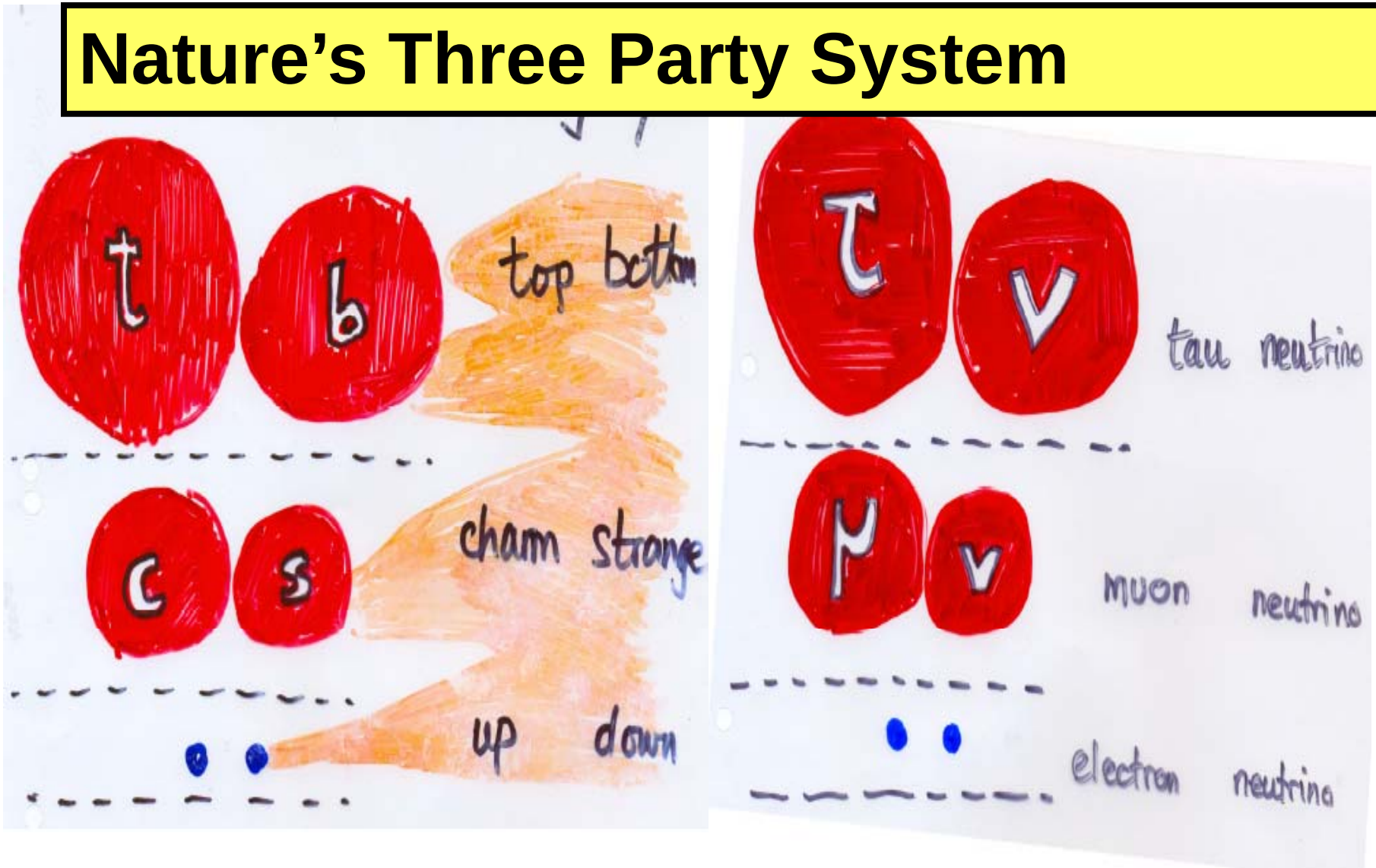
- Evidence that nu are disappearing
- Direct evidence for oscillation not yet

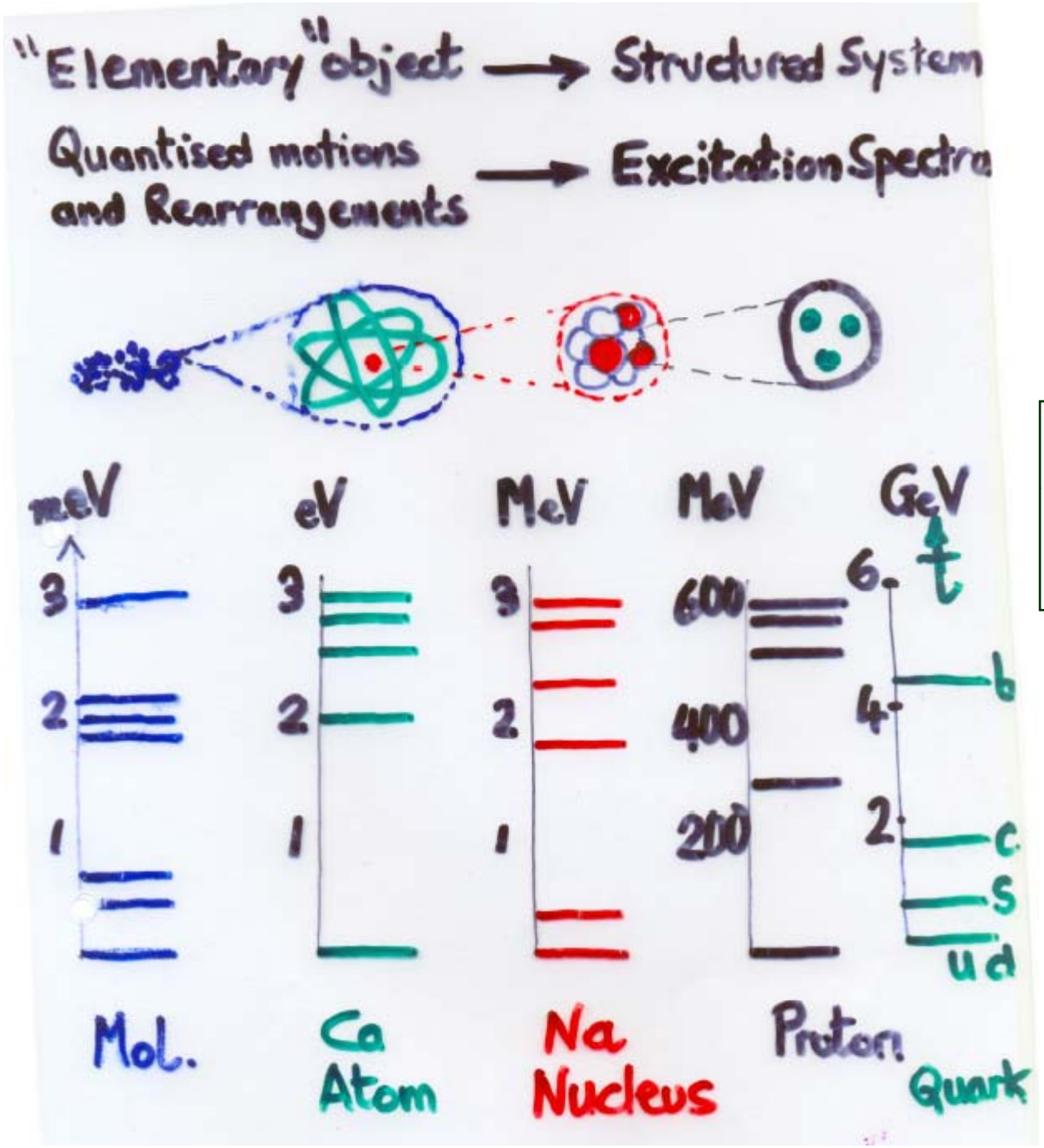
- Major research programme to understand neutrinos- masses, mixing, key to pattern of the three generations?





Nature's Three Party System





Spectra

So are quarks (and leptons) also composites?

MATTER

quarks

electron
neutrino
leptons

ANTIMATTER

antiquarks
positron
antineutrino
antileptons

MATTER **qqq proton**

ANTIMATTER **qqq antiproton**

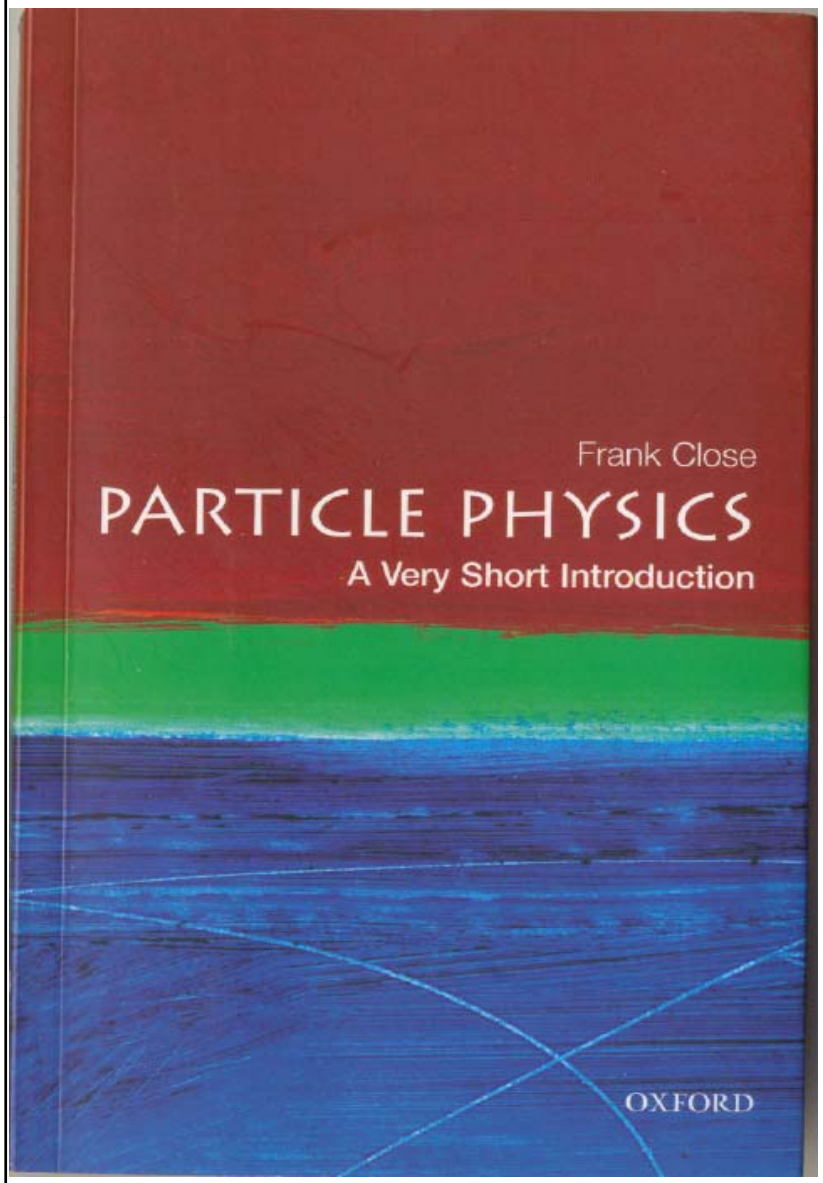
MATTER

qqq proton
BARYONS

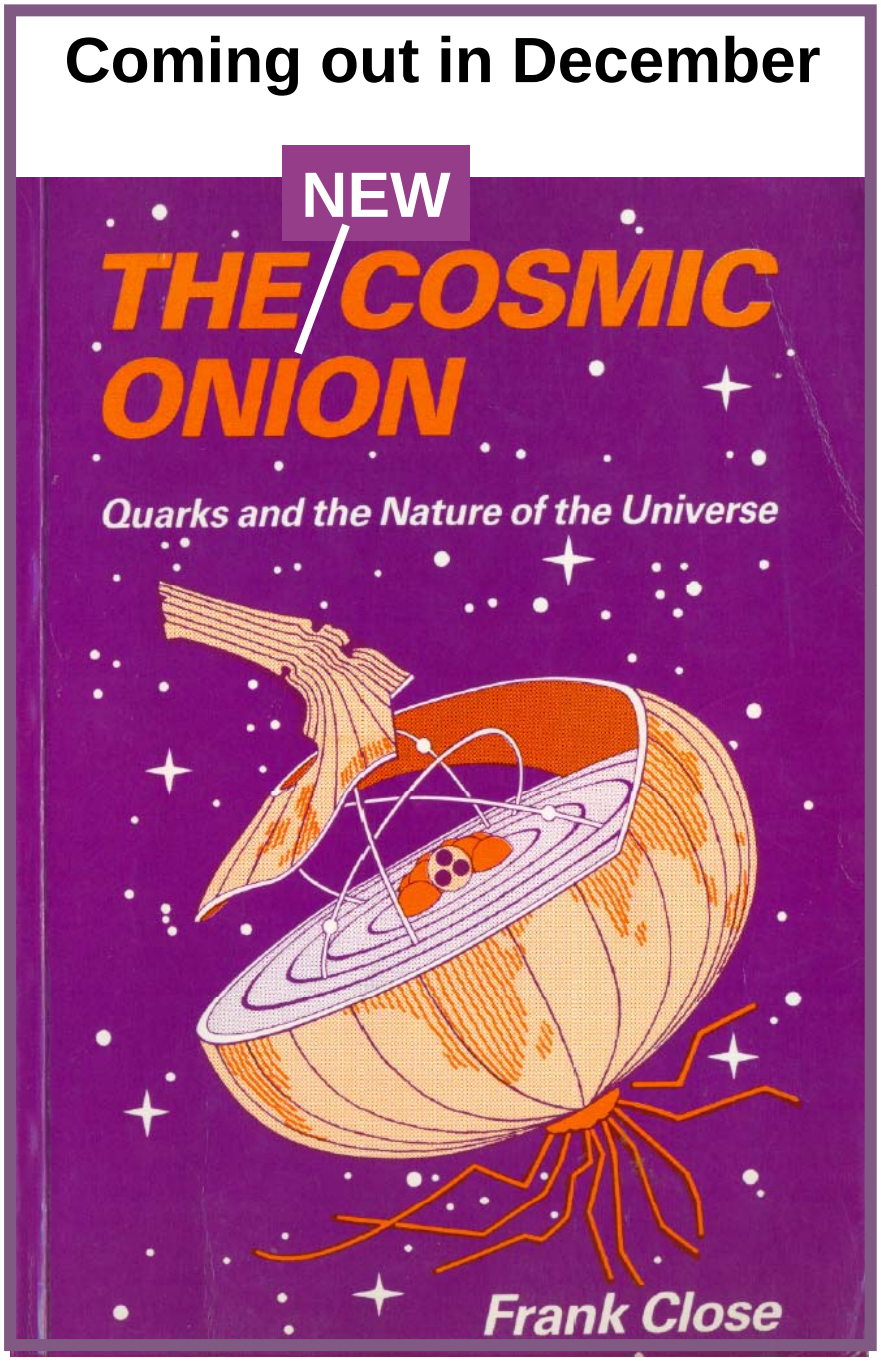
ANTIMATTER

qqq antiproton
ANTIBARYONS

A Very Short Introduction

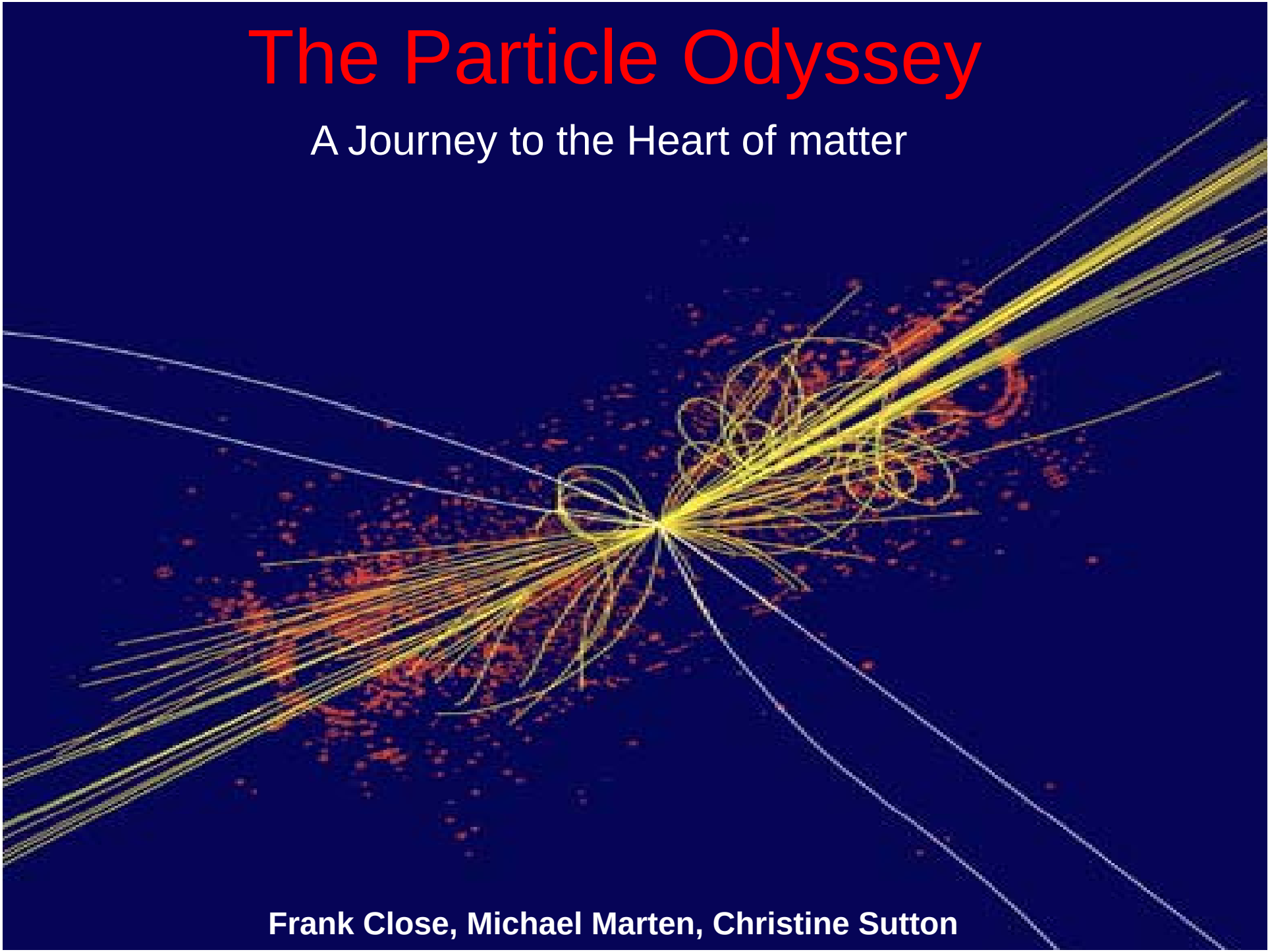


Coming out in December



The Particle Odyssey

A Journey to the Heart of matter



Frank Close, Michael Marten, Christine Sutton