Summer Students

+ Teachers

Lectures 2000

Introduction to Particle Physics

(for non Physics Students)

Frank Close

CERN & Rutherford Appleton Lab. UK

20:00 Creation BigBang

(dinner, wine, sleep)

6:00 SUN → EARTH 7:00

(breakfast, coffee, first talk, more coffee. 2nd talk)

10:30 Oldest Fossils

10:59.30 First Humanoids

11:00 -  Millenium

11:00 NOW

How did it survive

72 dpi

JPEG

until [redacted]:00.0000000000.........1 ?

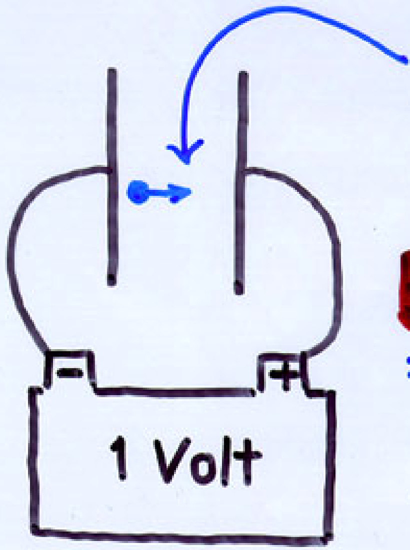
640 x ...
width

72 dpi

JPEG

	m
Human	10^{0}
Earth	10^{7}
Sun	10^{9}
Earth Orbit	10^{11}
Light Year	10^{16}
Milky Way	10^{21}
Clusters of Galaxies	10^{23}
Super Clusters	10^{24}
"Visible" Universe	10^{26}

Practical Units



electron (energy E)

E = 1 eV

= 1.6×10^{-19} J

1 keV = 10^3 eV

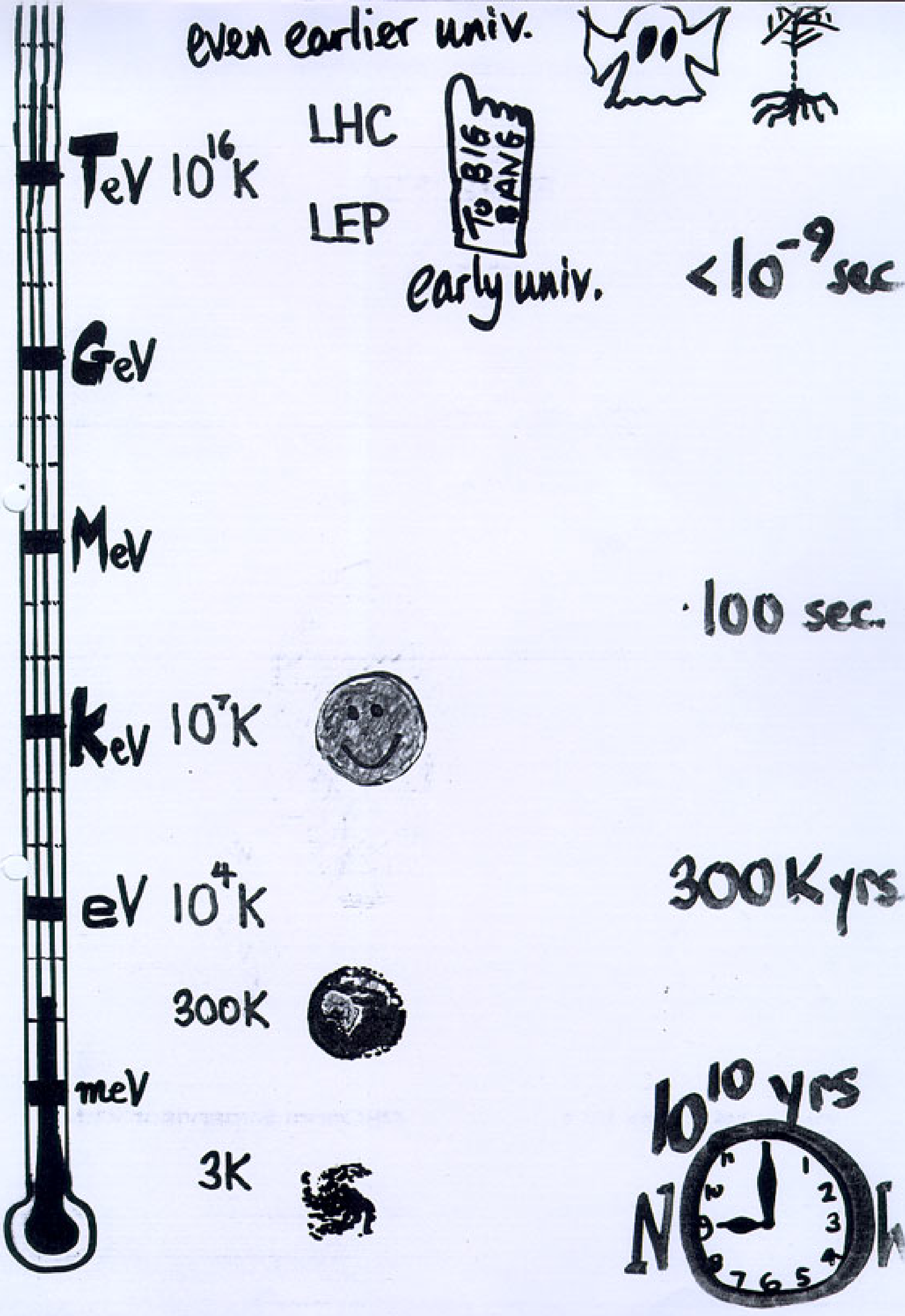
1 MeV = 10^6 eV

1 GeV = 10^9 eV

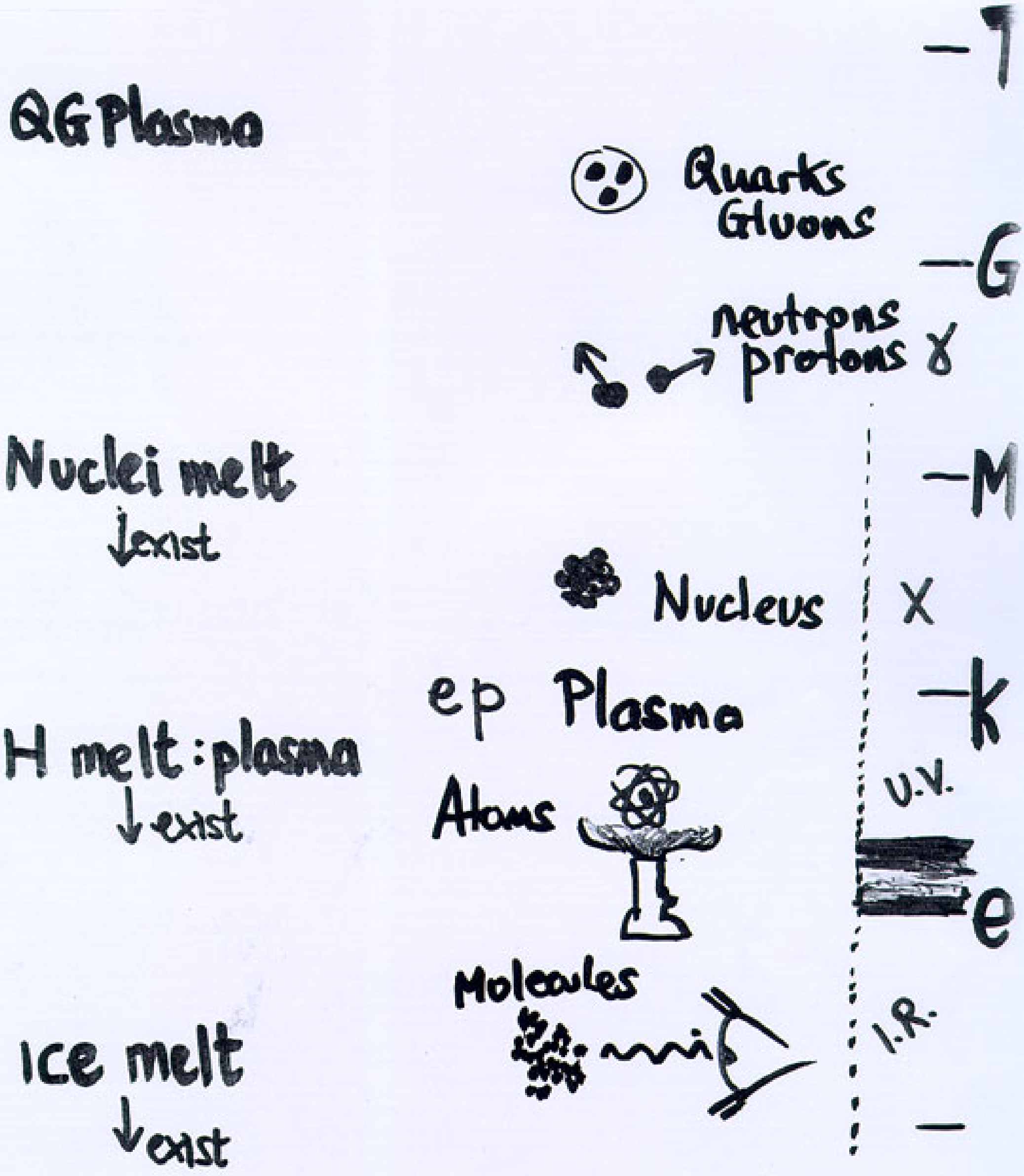
1 TeV = 10^{12} eV

LEP = 200 GeV

LHC = 14 TeV



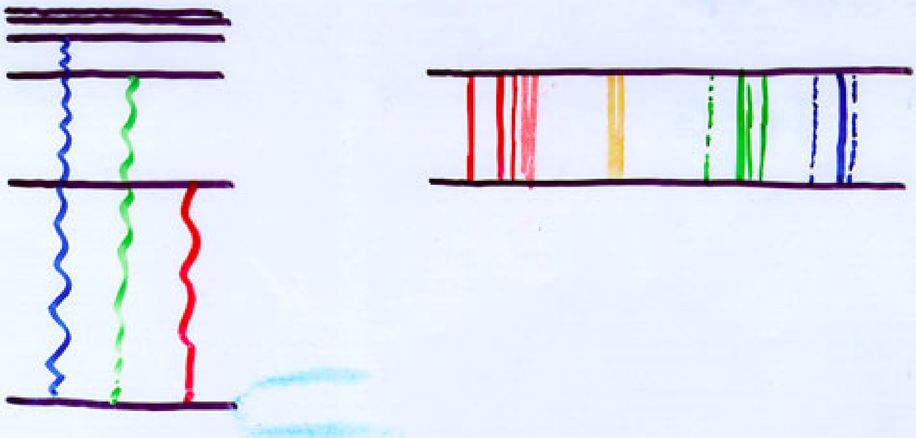
even earlier univ.
LHC
LEP
To BIG BANG
early univ.
TeV 10^{16} K
< 10^{-9} sec
GeV
MeV
100 sec.
KeV 10^{7} K
eV 10^{4} K
300 K yrs
300K
meV
3K
10^{10} yrs



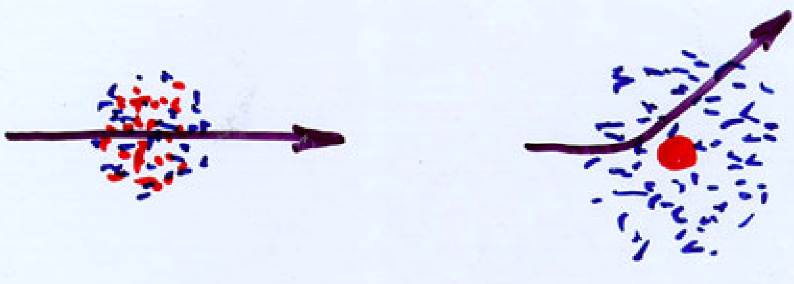
T
QG Plasma
Quarks
Gluons
G
neutrons
protons
γ
Nuclei melt
↓exist
M
Nucleus
X
ep Plasma
k
H melt : plasma
↓exist
Atoms
U.V.
e
Molecules
I.R.
Ice melt
↓exist

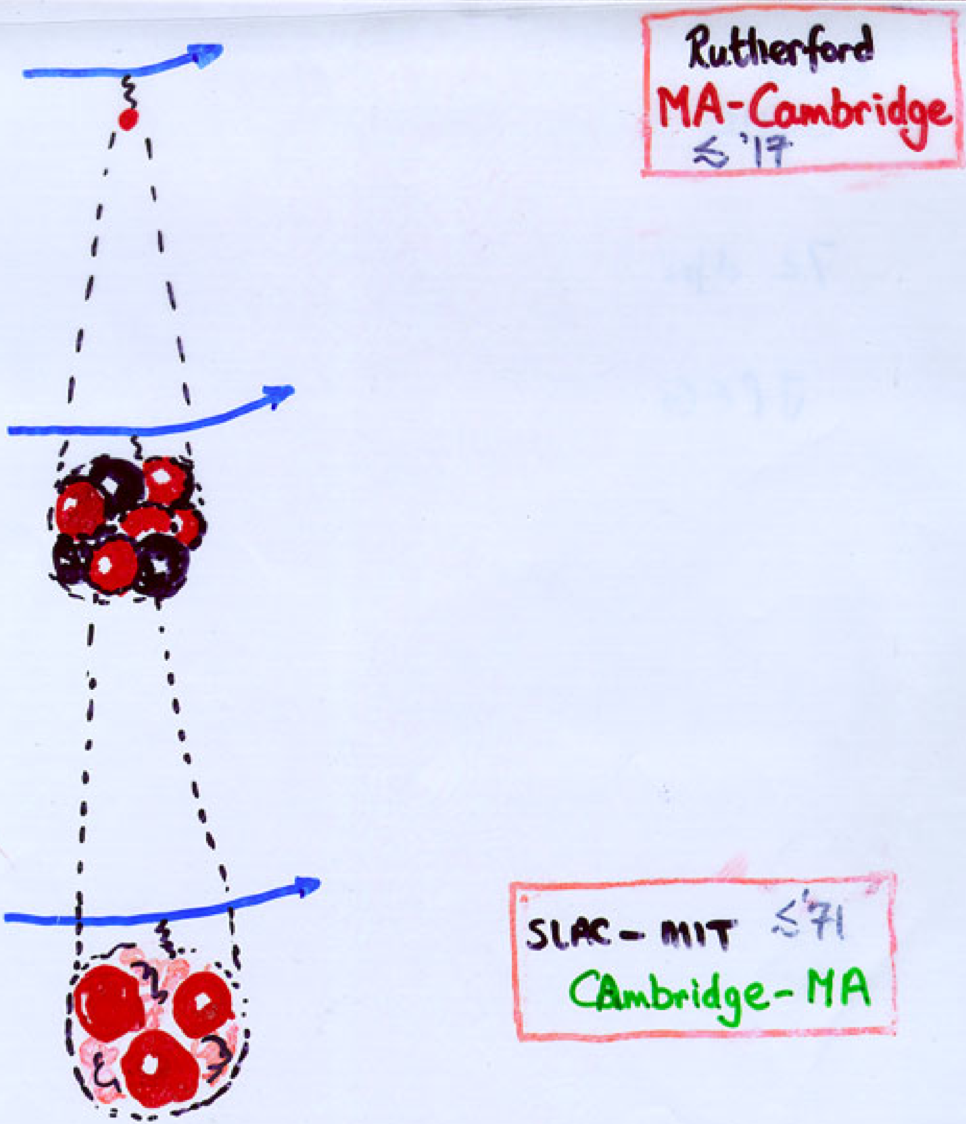
Structure of matter

1. SPECTRA



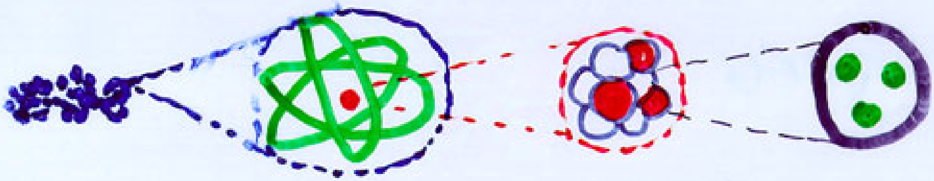
2. SCATTERING FROM "HARD" CENTRES

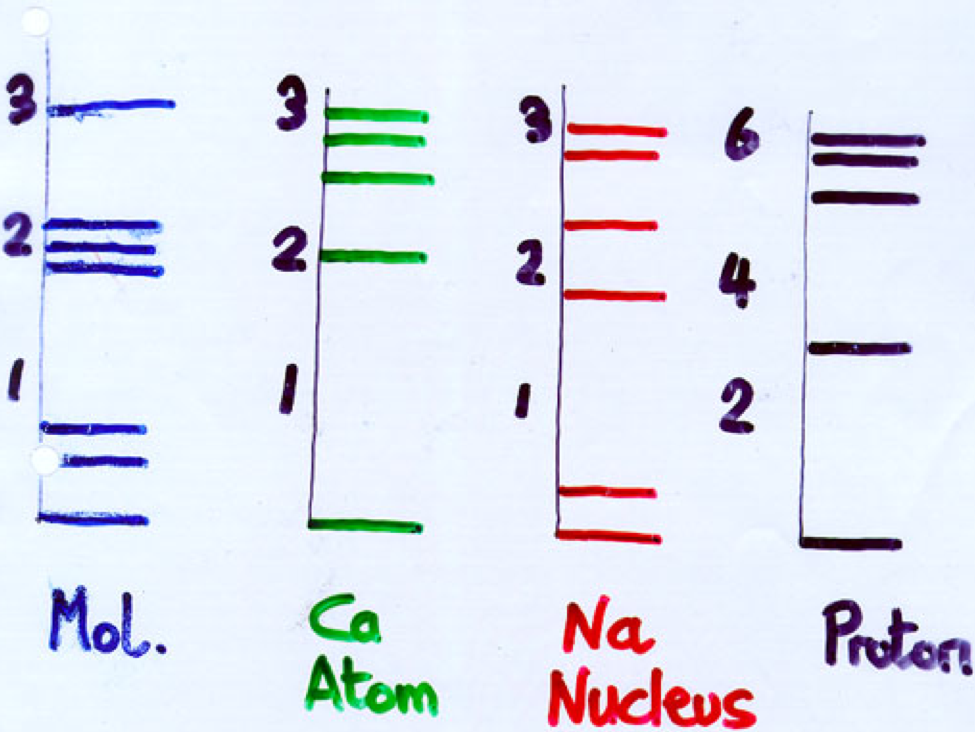



Rutherford
MA-Cambridge
≲ '17
SLAC - MIT ≲ '71
Cambridge-MA

"Elementary" object → Structured System

Quantised motions and Rearrangements → Excitation Spectra



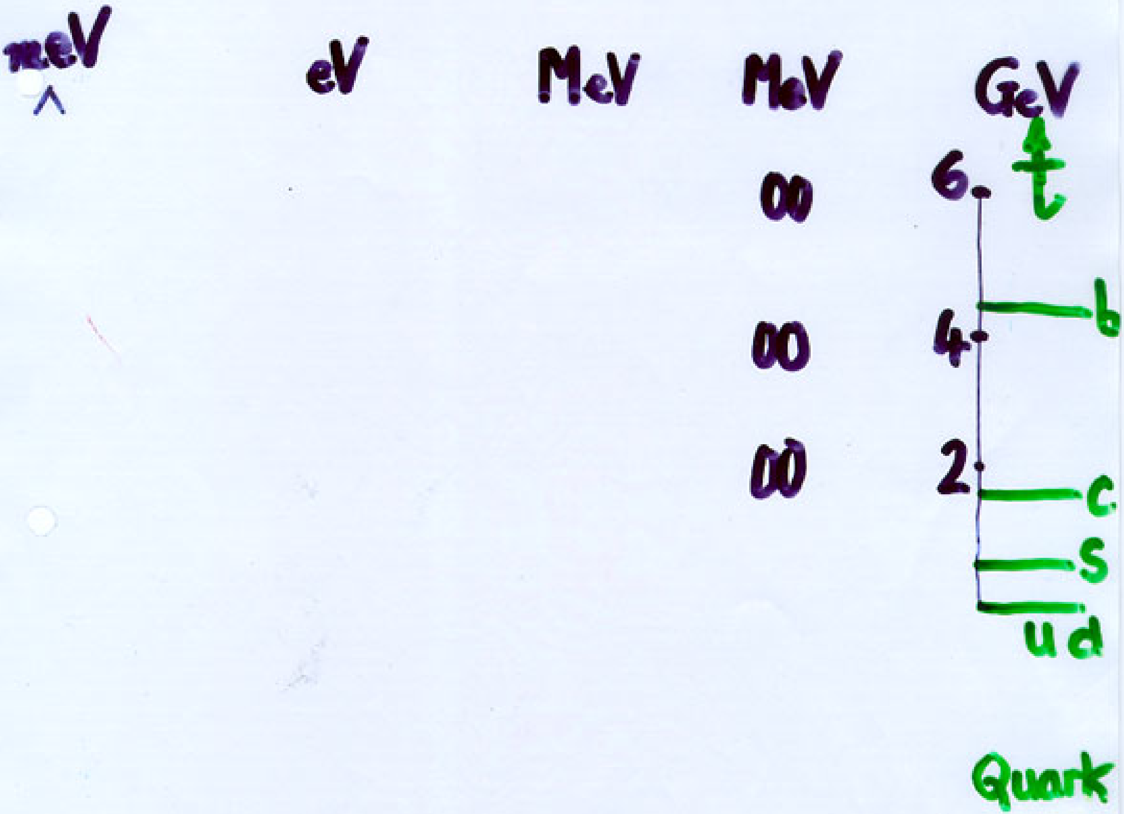


meV eV MeV MeV

00

00

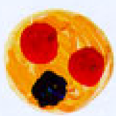
00


meV
eV
MeV
MeV
GeV
00
00
00
6
4
2
t
b
c
s
u d
Quark

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
- may determine the Destiny of the Universe

- essential in cooking the Heavy Elements needed for Life

- Neutrino astronomy looks "inside" the Sun and Supernovae

SOME NEUTRINO STATISTICS

each second:

1 hr. x this audience ⇒ 100 million neutrinos

→ into universe – for ever !

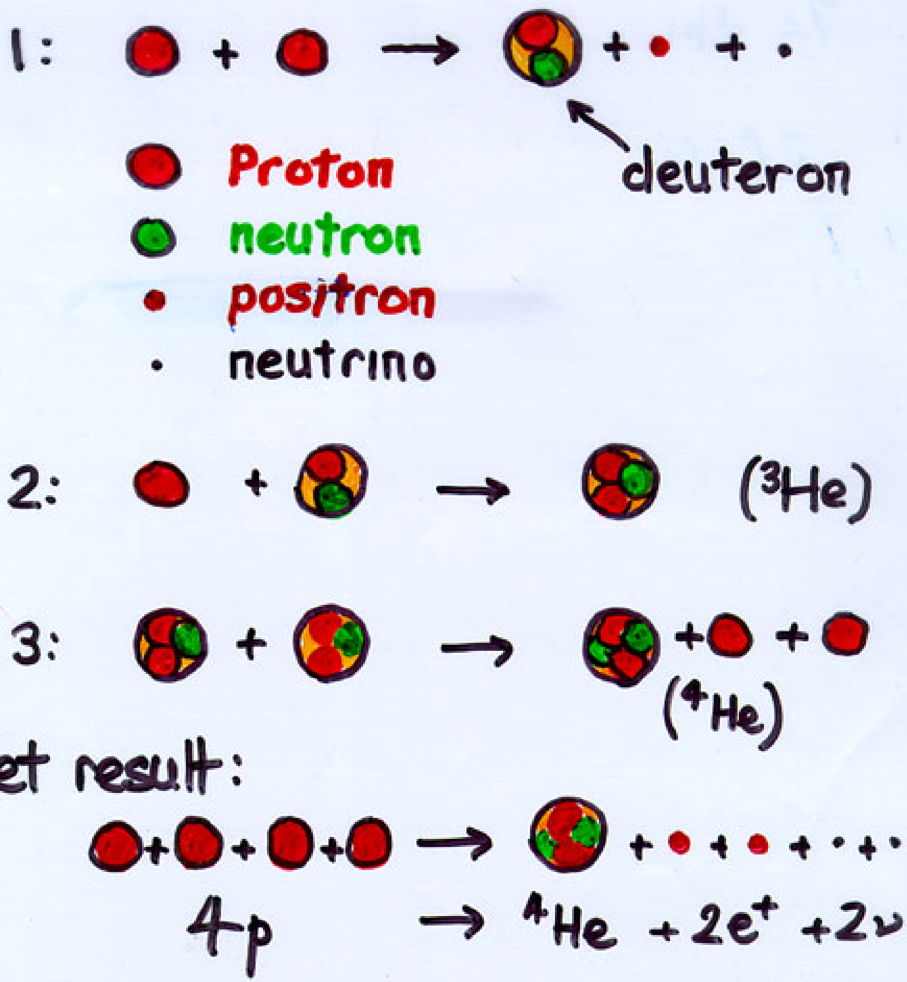
SOME NEUTRINO STATISTICS

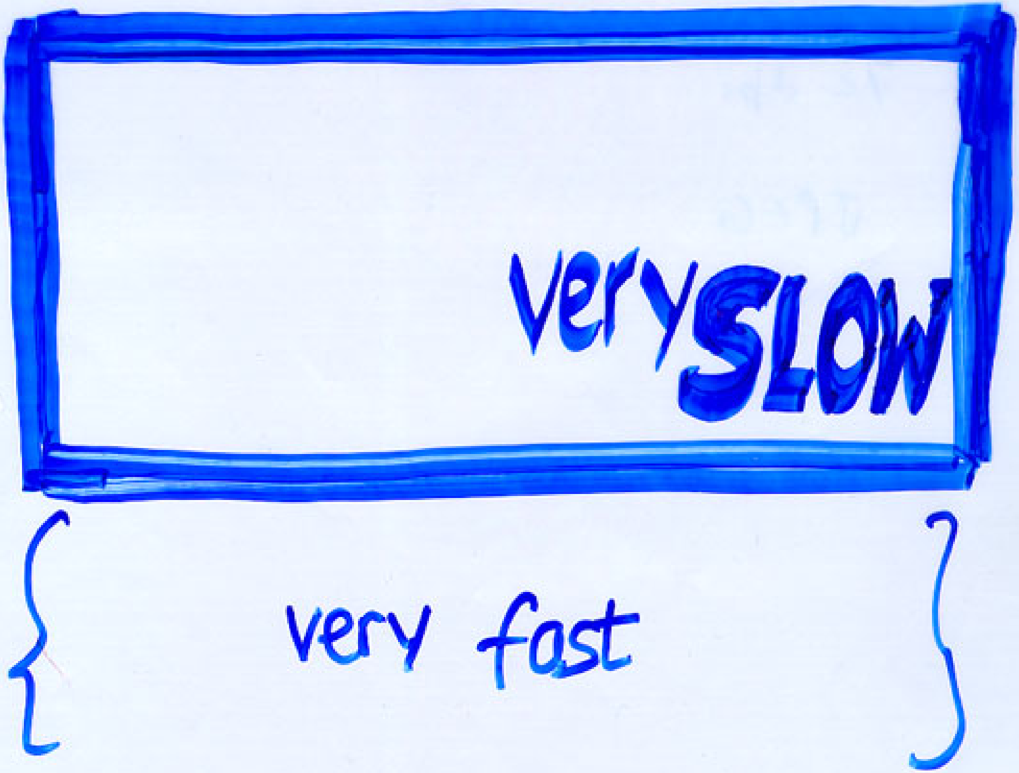
each second:

1 hr. x this audience ⇒ 100 million neutrinos

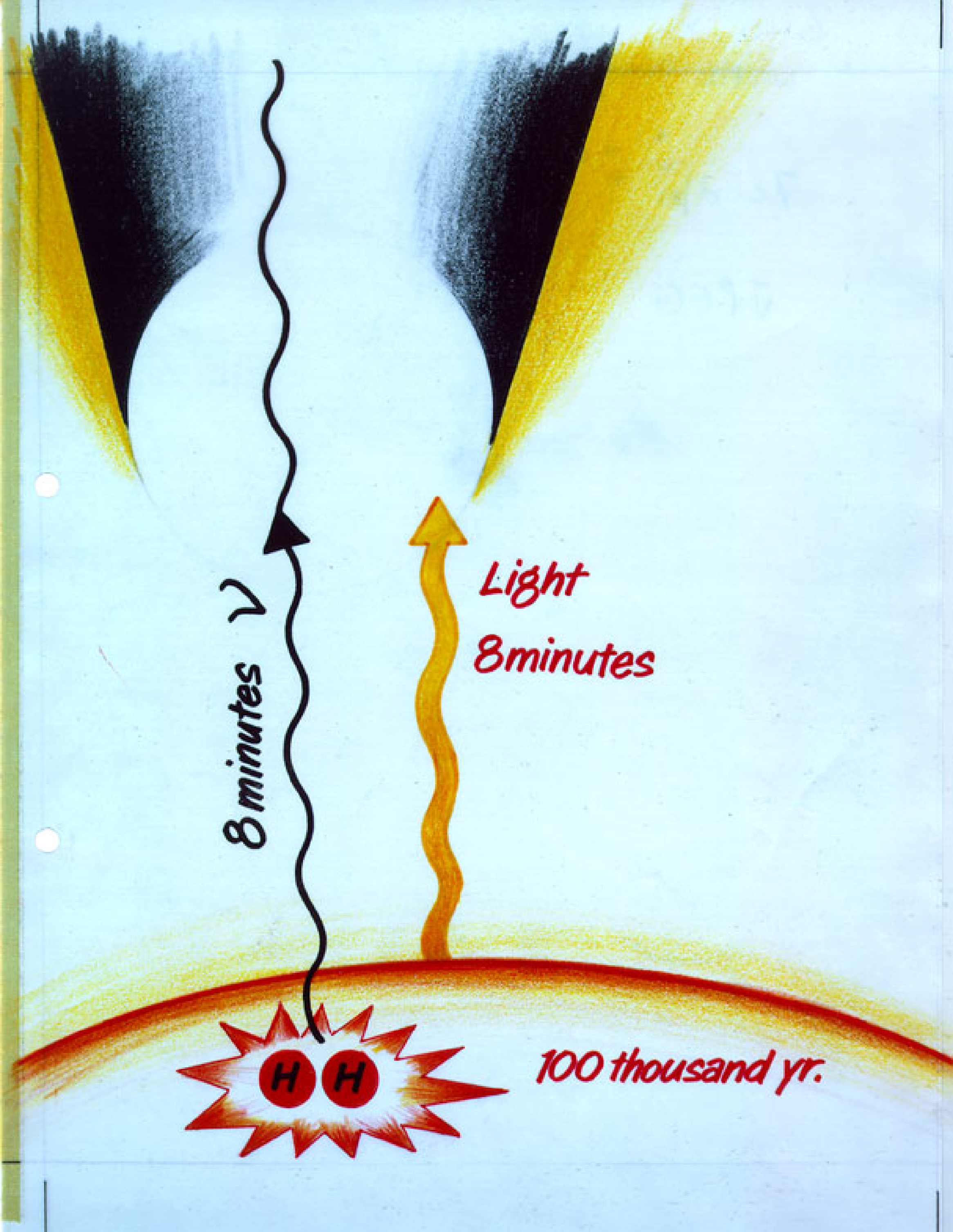
→ into universe – for ever!

At the heart of the Sun:

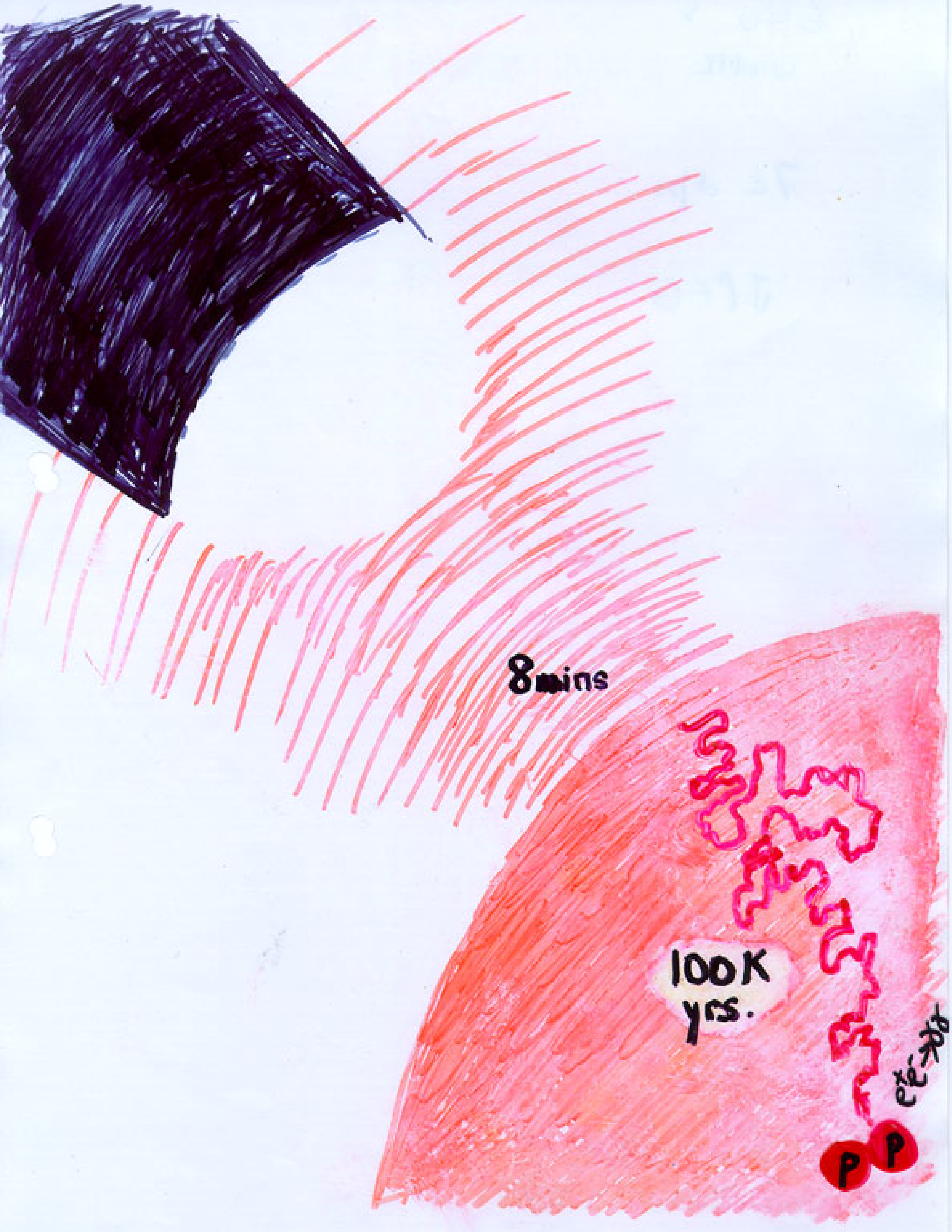


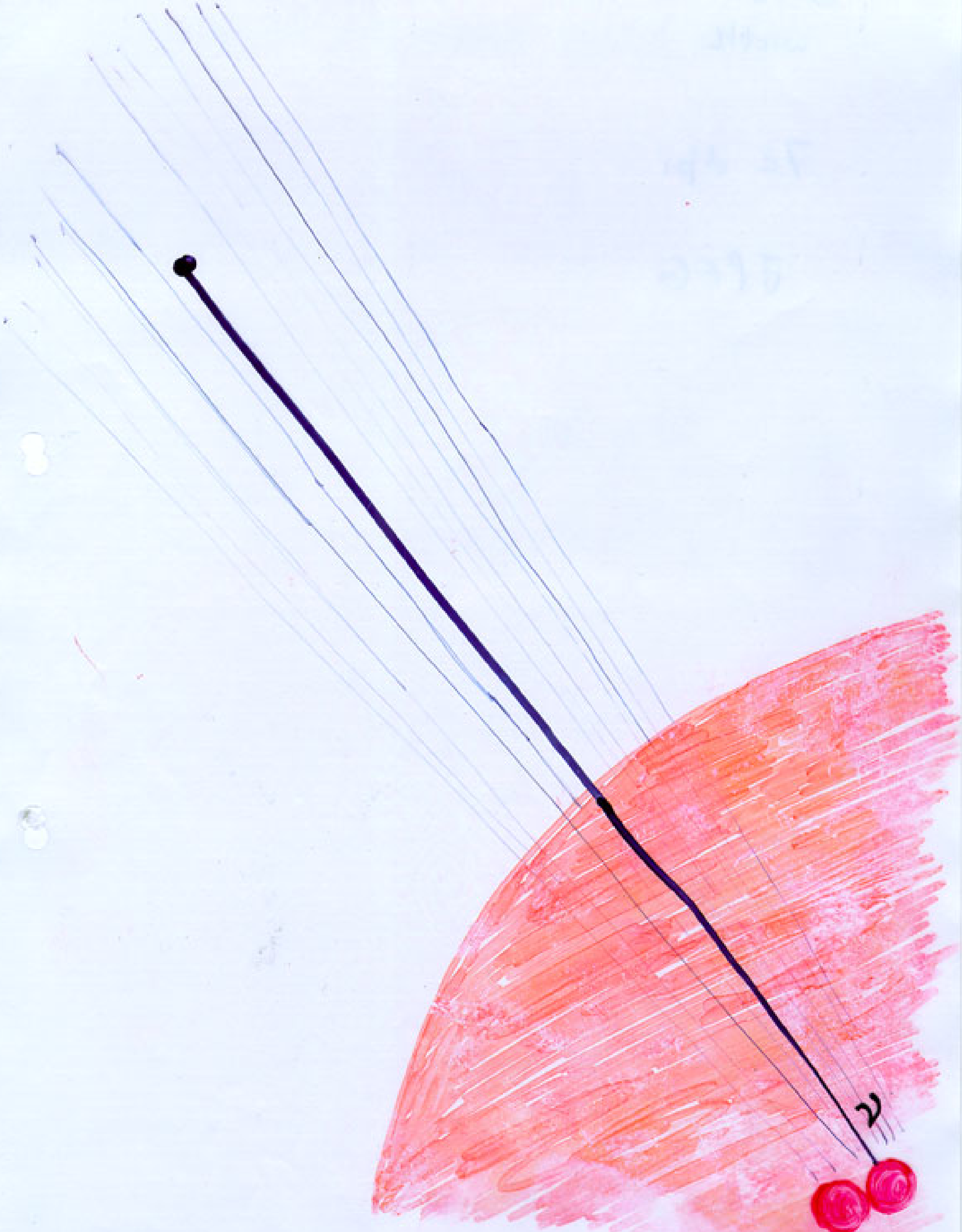


$\Delta E = \Delta M c^2$: $-{}^{4}He + 4p \simeq 28\,MeV$


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


200 thousand years
LMC


8mins
100K yrs.
P
P



Underground Detectors Capture a few.
$\simeq \frac{1}{2}$ expected

most pass through

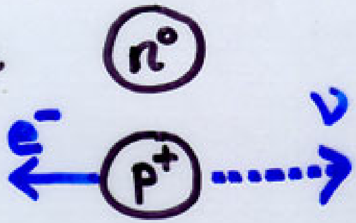
THEORY
ν flux: $6 \times 10^{10}/cm^2/sec$

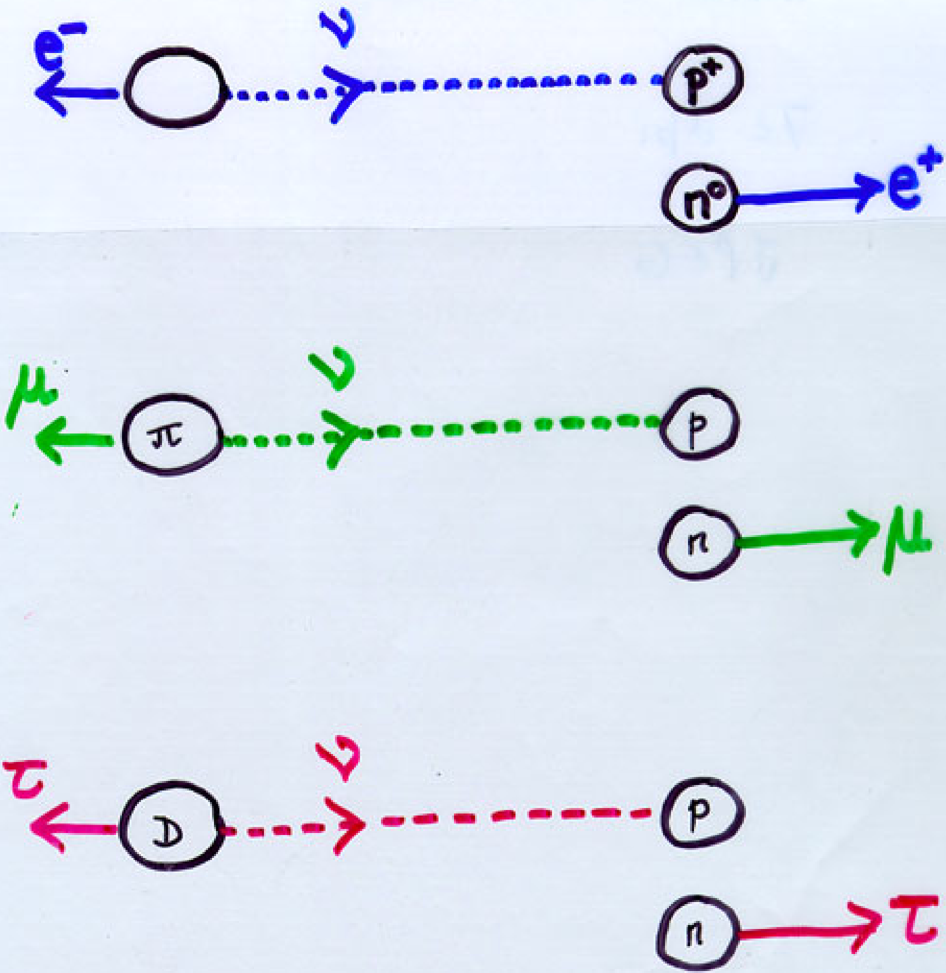
"SOLAR ν PROBLEM"

30

Before

After





e⁻
ν
p⁺
n°
e⁺
μ
ν
π
p
n
μ
τ
ν
D
p
n
τ

MATTER

ANTIMATTER

Anti particles → anti matter

e^- electron

e^+ positron

Quark

Anti$\bar{Q}$uark

proton

"Baryon"

↓

Collapse to lightest (p, n) = Stable

Antiproton

"Anti Baryon"

↓

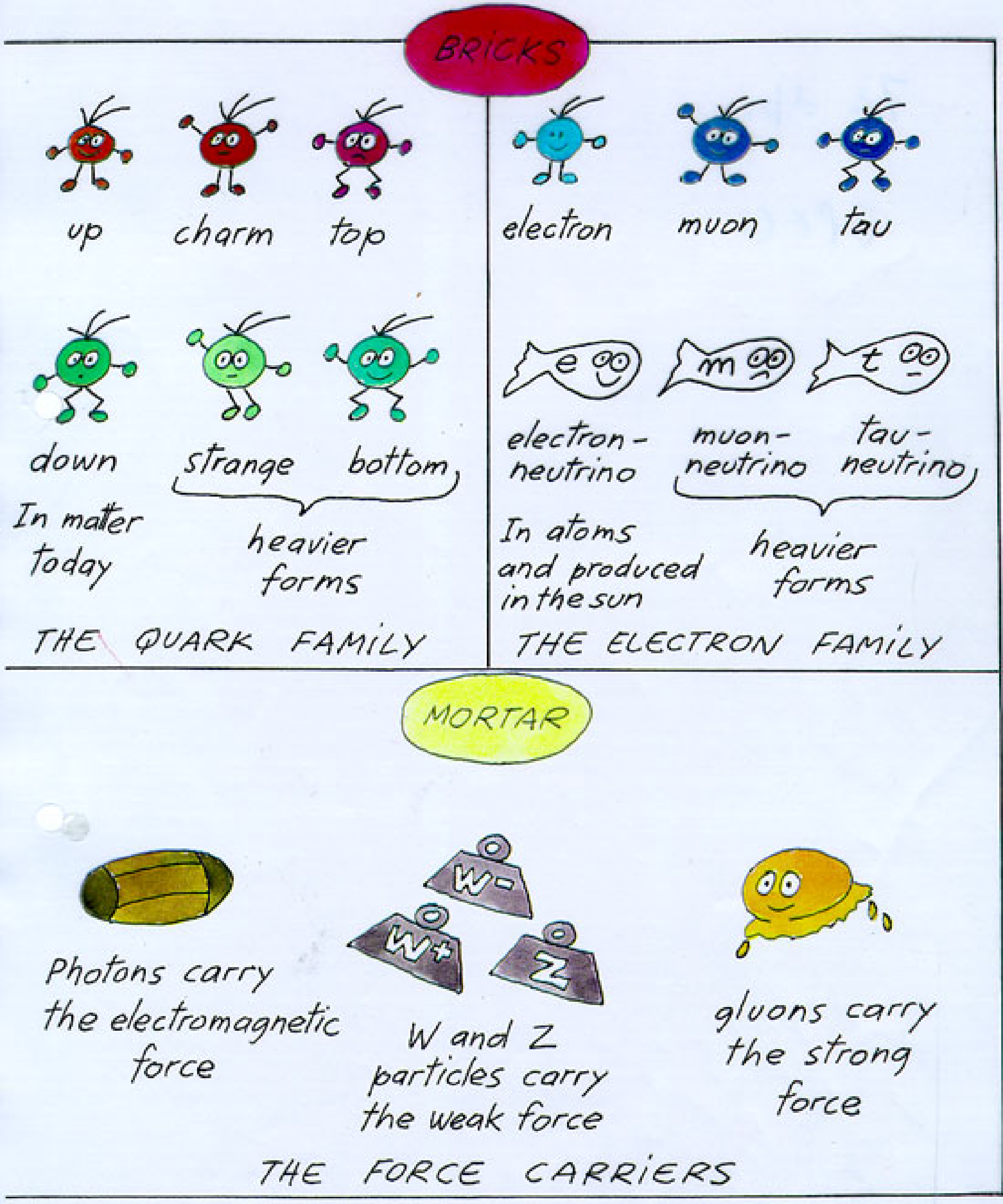
rare in univ.

Meson

e.g. Pion

↓

Survive only $< 10^{-N}$ secs.


BRICKS
up
charm
top
electron
muon
tau
down
strange
bottom
electron-neutrino
muon-neutrino
tau-neutrino
In matter today
heavier forms
In atoms and produced in the sun
heavier forms
THE QUARK FAMILY
THE ELECTRON FAMILY
MORTAR
W-
W+
Z
Photons carry the electromagnetic force
W and Z particles carry the weak force
gluons carry the strong force
THE FORCE CARRIERS

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)

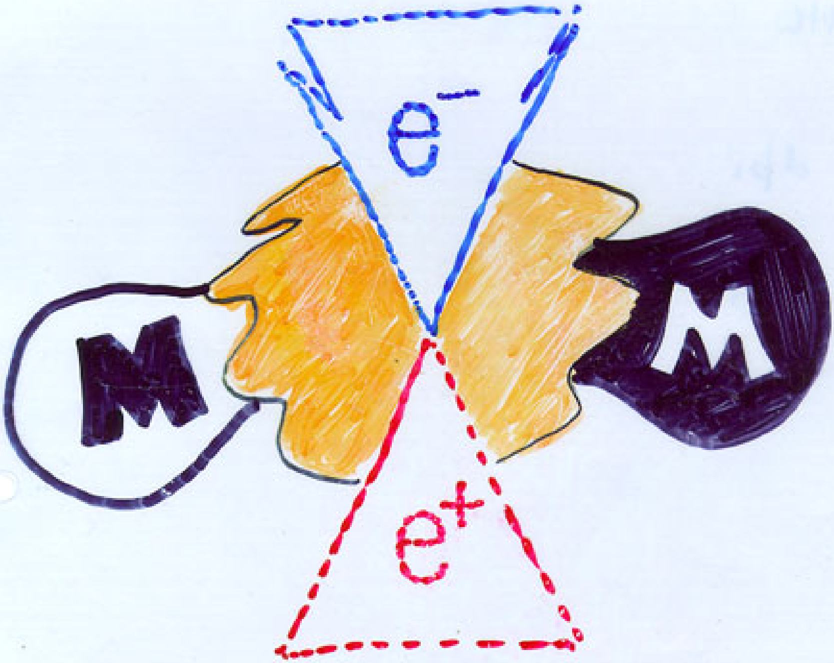
μ (106 MeV)

τ (1.8 GeV)

ν_e, ν_μ, ν_τ } three neutrinos each with ZERO charge also have $\simeq$ ZERO masses

perfect balance

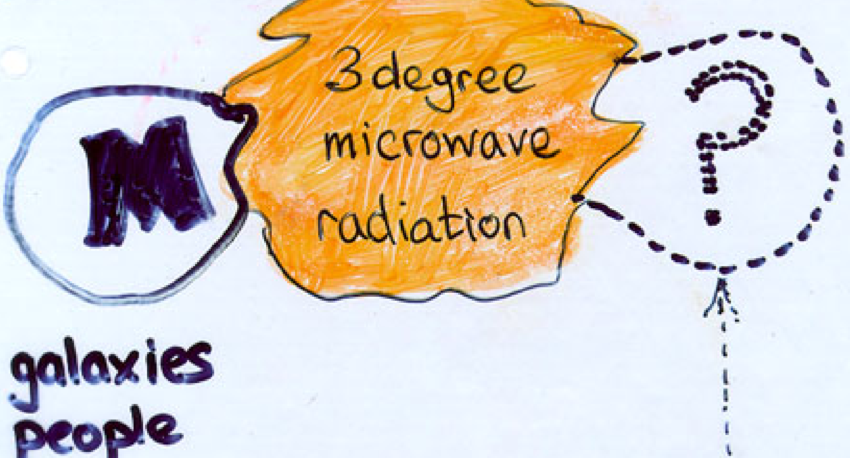
LEP or very early univ.



---

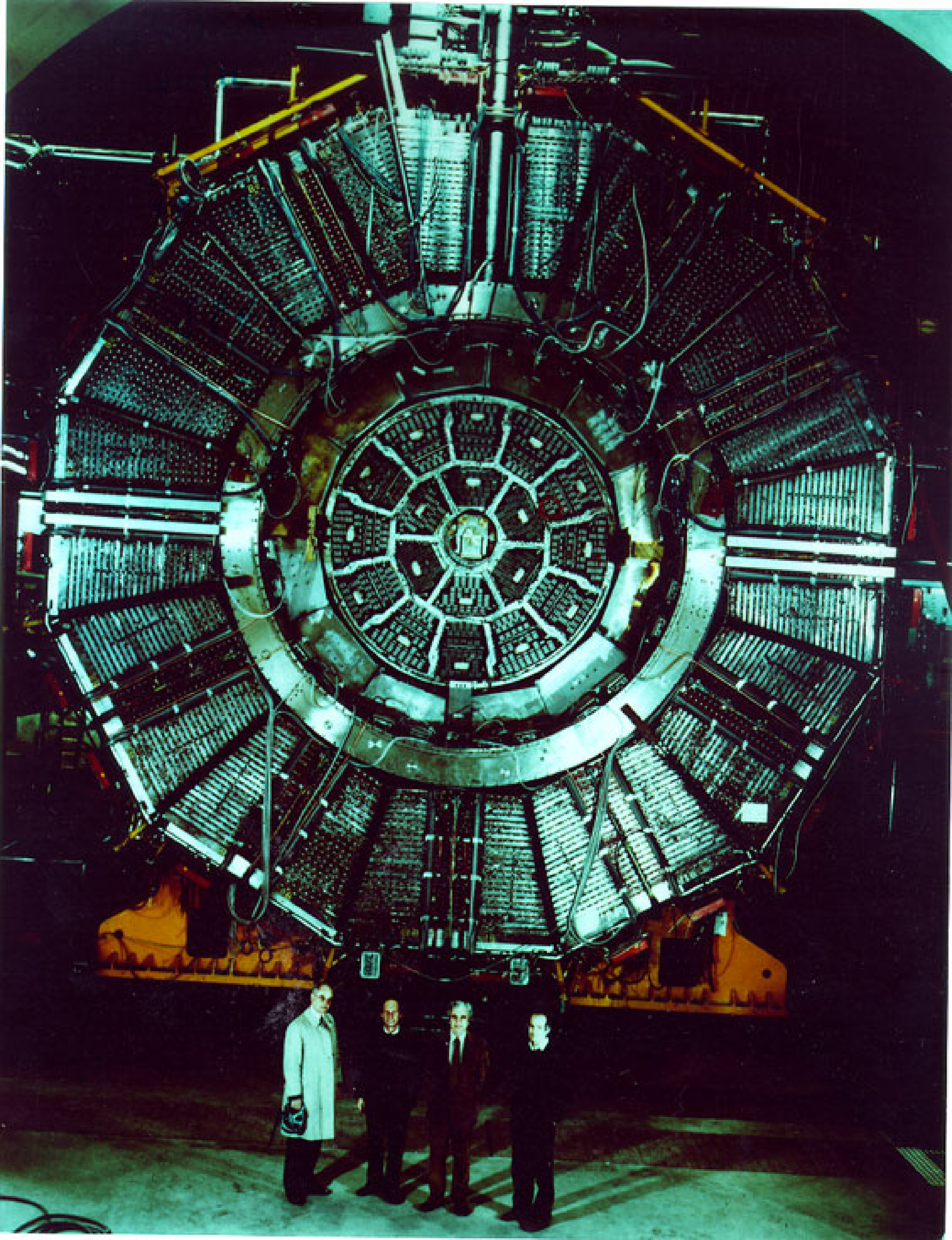
lopsided universe

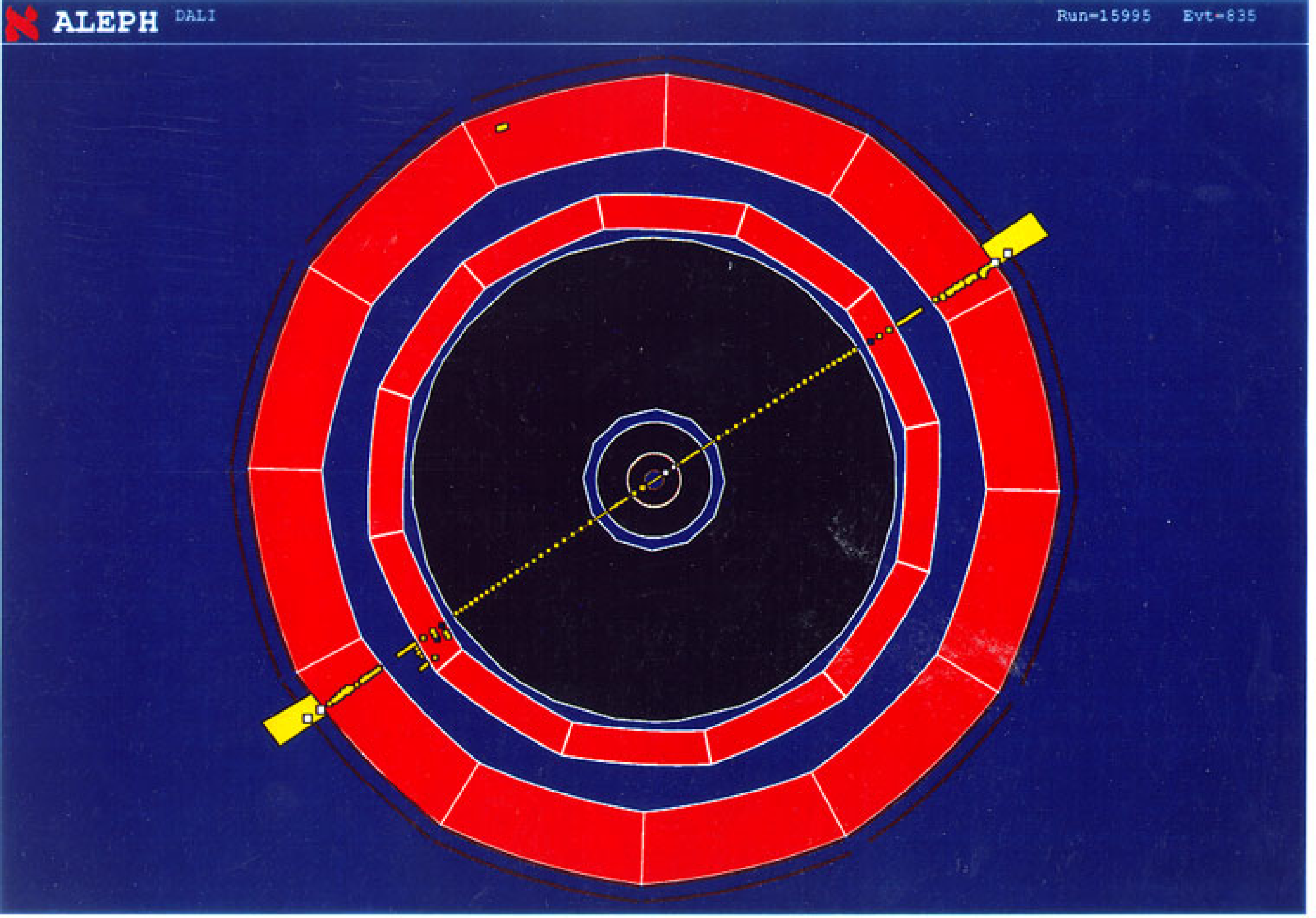
univ now

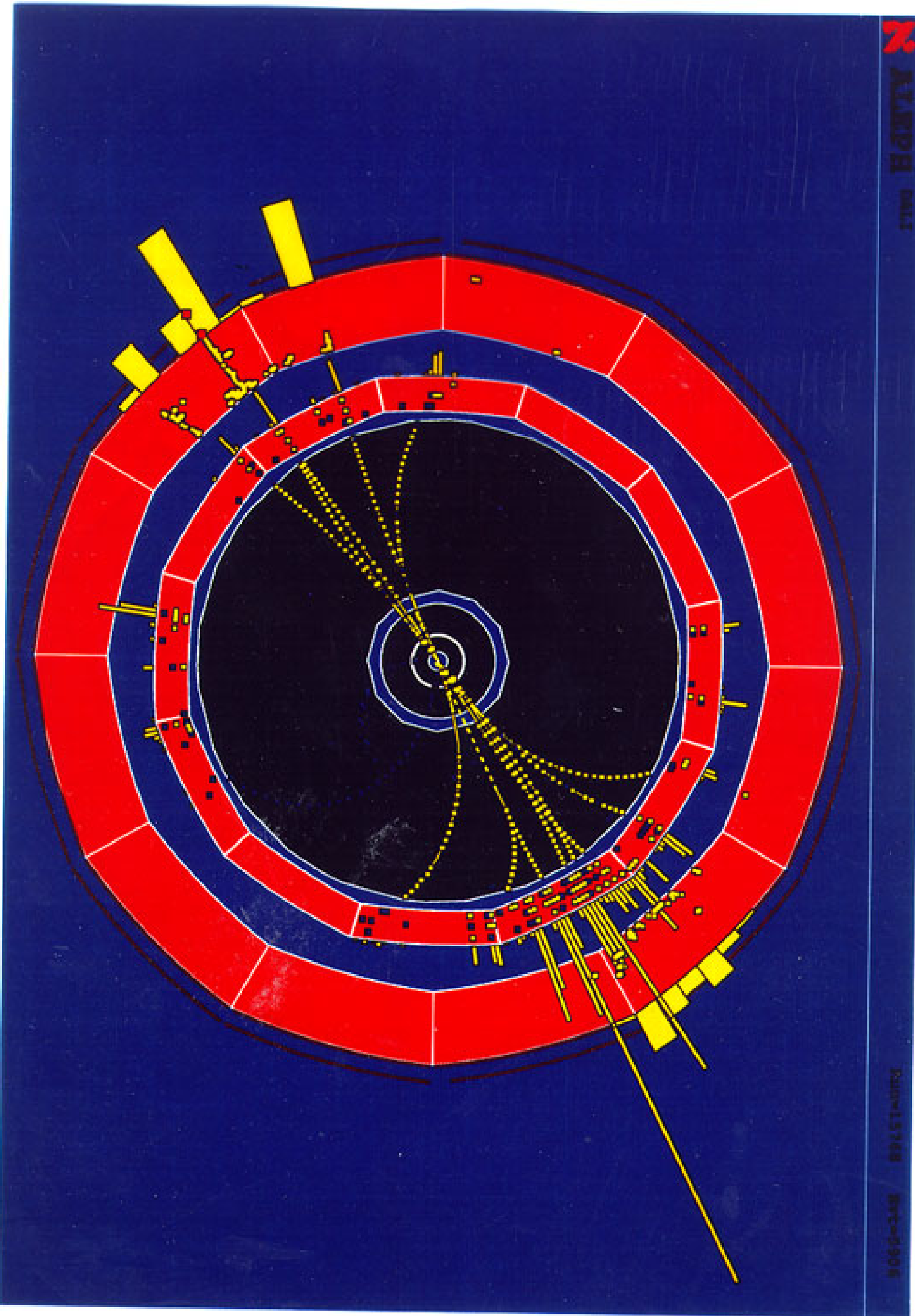


galaxies
people
atoms
particles

antihydrogen (9 only)
antiparticles — LEP
— PET




ALEPH
DALI
Run=15995 Evt=835


ALEPH
DALI

How did a Perfect Creation

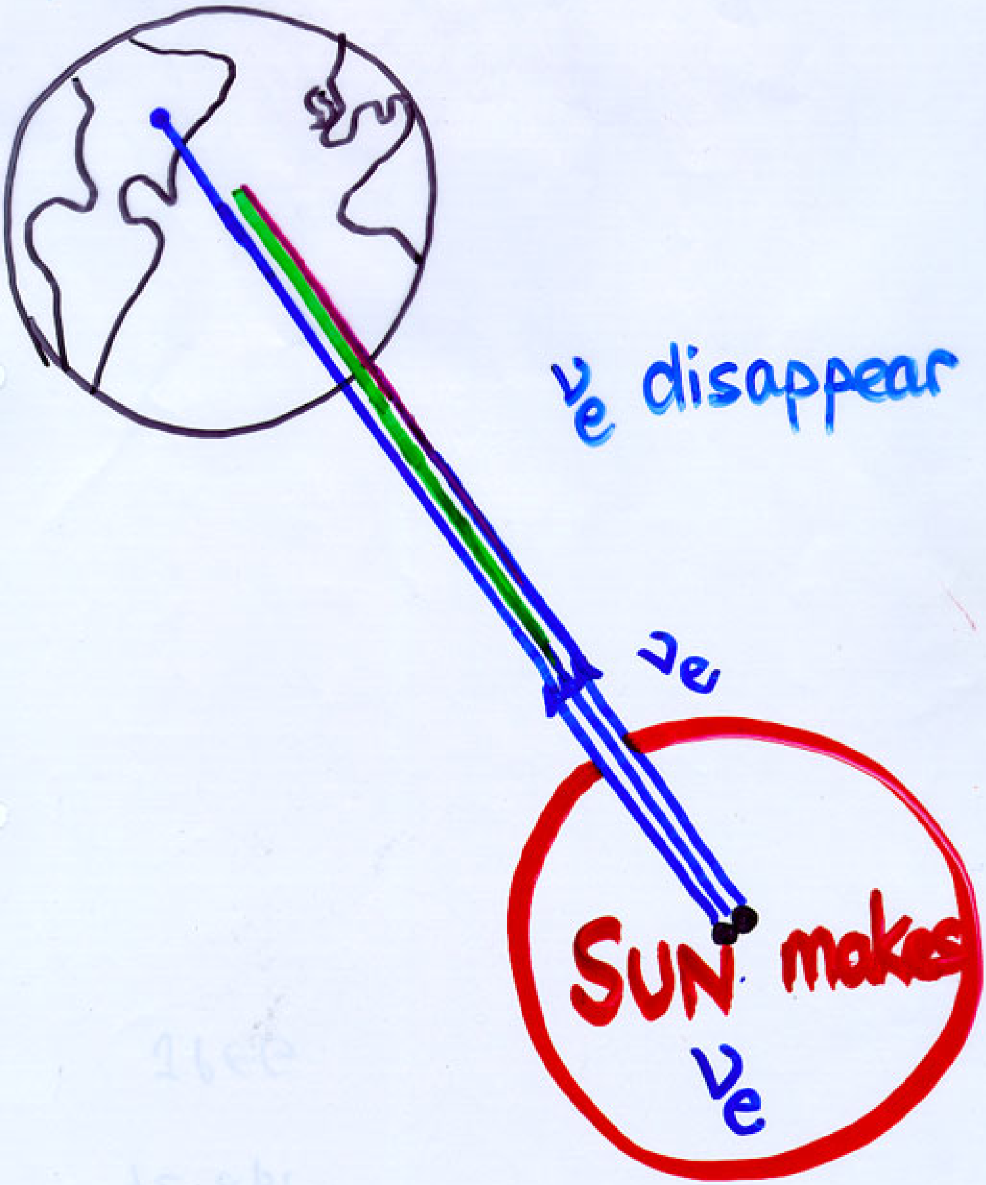
lopsided universe?

Second party: "Strange" → subtle clue

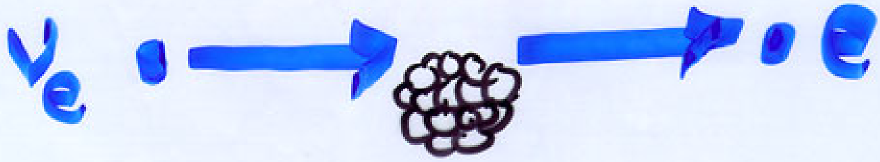
Third party: Bottom → Big clue

→ **LHC** = factory for massive Bottom and Top

Experiment detects $\nu_e \simeq \frac{1}{3}$ expectation



HOW DO WE KNOW THE ν ARE DIFFERENT?



BUT NEVER !!

electron-neutrino hits nucleus emits electron

mu-neutrino hits nucleus emits muon

mu-neutrino with too low energy just disappears

BUT! if ν have mass

$\nu_e \leftrightarrow \nu_{\mu,\tau}$ oscillate back & forth

$(m^2_{e\nu} - m^2_{\mu\nu})$ L/E

Large E → Large L (10^3 km)

BUT! If ν have mass

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

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

Probability $a \rightarrow b$

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

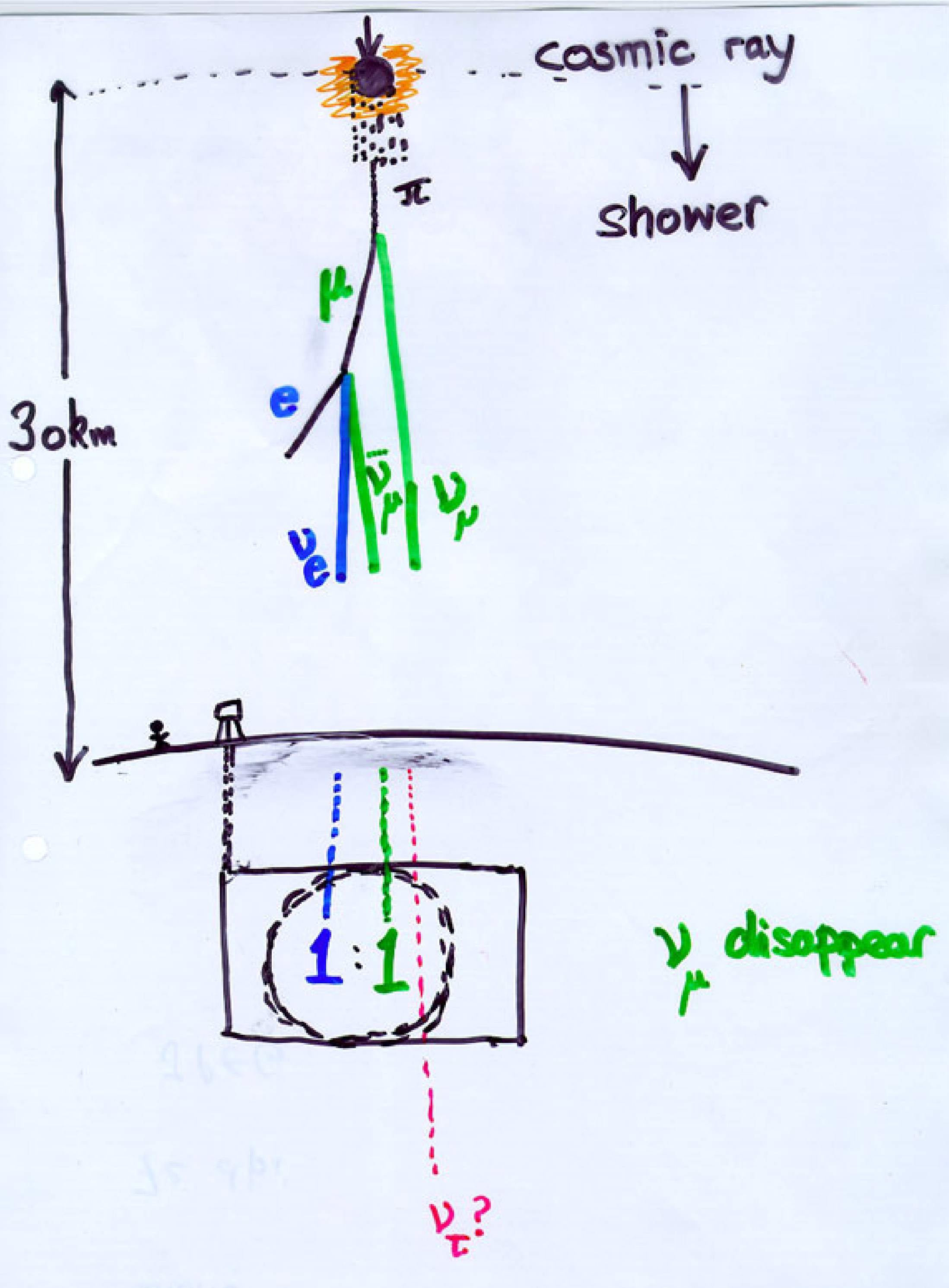
Probability $a \rightarrow a = 1 - c \sin^2(\cdots)$

a disappears   b appears

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

$\therefore$ Need large L at high E

e.g. CERN to Gran Sasso Italy

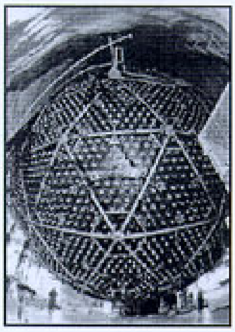

cosmic ray
shower
π
μ
e
30km
$\bar{\nu}_\mu$
ν_μ
ν_e
1 : 1
ν_μ disappear
ν_τ?

ppUK HOME Picture Database

Classic images from the world of particle physics featuring discoveries, people, experiments, or images that are simply good to look at. A simple explanation accompanies them. There is also an archive!

---

29 April 1998



A new neutrino telescope

Today sees the official opening of the Sudbury Neutrino Observatory (SNO), located in the Creighton mine in Sudbury, Ontario. SNO has been designed to catch neutrinos from the Sun - in particular, it will use 1000 tonnes of heavy water in an attempt to solve the puzzle as to why previous experiments seem to detect too few neutrinos. This image shows the 12-m diameter acrylic vessel built to hold the heavy water. It bristles with the 10,000 light-sensitive phototubes which will detect light flashes (Cherenkov radiation) emitted when neutrinos interact in the water.

Credit: Ernest Orlando Lawrence Berkeley National Laboratory

Please contact person or institution named for information about permission for public or commercial use.

Previous pictures, Picture index, Alphabetical Index, Picture of the Week

---

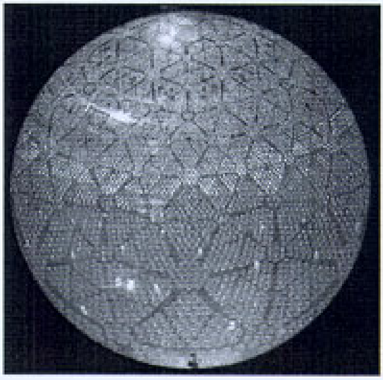
Open Directory Cool Site **This website is supported through a grant from the Particle Physics and Astronomy Research Council (PPARC)**

Picture Database

Classic images from the world of particle physics featuring discoveries, people, experiments, or images that are simply good to look at. A simple explanation accompanies them. There is also an archive!

---

16 June 1999



A neutrino's eye-view inside SNO

A view inside the Sudbury Neutrino Observatory (SNO) shows the geometric arrangement of the phototubes that detect light flashes emitted when the elusive particles called neutrinos interact in the detector. SNO, located in the Creighton mine in Sudbury, Ontario, has been designed to catch neutrinos from the Sun. In particular, it uses 1000 tonnes of heavy water in an attempt to solve the puzzle as to why previous experiments seem to detect too few neutrinos. This wide-angle image shows the view *inside* the 12-m diameter acrylic vessel built to hold the heavy water. Altogether,10,000 phototubes surround the vessel, to detect the flashes of light (Cherenkov radiation) emitted by electrically charged produced when neutrinos interact in the water. (The phototubes, and their light-concentrating "collars" can be seen more clearly in a closer image) .

Credit: Ernest Orlando Lawrence Berkeley National Laboratory

Previous pictures, Picture index, Alphabetical Index, Picture of the Week

---

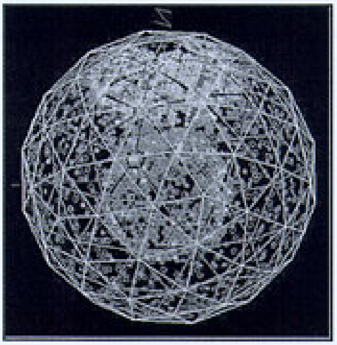
This website is supported through a grant from the Particle Physics and Astronomy Research Council (PPARC)

Picture Database

Classic images from the world of particle physics featuring discoveries, people, experiments, or images that are simply good to look at. A simple explanation accompanies them. There is also an archive!

---

9 June 1999



SNO's first images

Within days of commencing full operation the Sudbury Neutrino Observatory (SNO) observed this striking event, shown here in an image in which the detector is seen from side. The white lines indicate geodesic support structure for the 10,000 photomultiplier tubes (PMTs) that detect light (Cherenkov radiation) emitted by charged particles produced in the interactions of neutrinos in the 1000 tonnes of heavy water within the detector. This light is emitted in a cone around the particle's path, and so forms a circular pattern when it strikes walls of the detector.

The coloured hexagons reveal the PMTs that have registered photon hits (light) in this event. The area of hits with the pink centre appears to have been caused by a muon exiting the detector. (The black area within this pattern is the hole in the PMT sphere for the chimney at the top of the acrylic heavy-water container.) This shows that the muon was headed almost straight up. The neutrino that reacted within the detector to create this muon would have to have been produced in a cosmic-ray interaction within the atmosphere on the other side of the Earth. The second ring of hits with a hollow centre is probably from a particle (a pi-meson) produced when a quark struck by the neutrino was ejected all the way from its parent proton or neutron in a nucleus in the heavy water.

Credit: SNO collaboration

For the full event display see here; and further images of this event can be accessed here (.jpg and .tiff format).

See also pictures from inside the acrylic vessel; a phototube and light concentrators; SNO under construction; and see here for a further selection of images

Please contacted credited institutions if you require higher resolution images

Please contact person or institution named for information about permission for public or commercial use.

Previous pictures, Picture index, Alphabetical Index, Picture of the Week

---

This website is supported through a grant from the Particle Physics and Astronomy Research Council (PPARC)

Search for m_ν : ν oscillations

appearance experiments
disappearance experiments

Disappearance:
Start with an intense beam of ν_e (say) and count them far away to see if a fraction has disappeared.

e.g. ν_e produced by sun. 50% disappeared by time reach Earth

Appearance:
Start with intense and pure beam of ν of one type and see if some change into another type

e.g. CERN (Chorus + Nomad)

start with pure beam of ν_μ

check if they are producing ν_τ

by ν_τ + Nucl. $\rightarrow \tau$

e.g. cosmic rays $\rightarrow \pi, \mu \rightarrow \nu_{\mu,e}$

FORCES

Gravity

Electromagnetic. Weak. Strong

ep in H atom

$$\frac{\text{Gravity P.E.}}{\text{Electromag}} \simeq 10^{-40}$$

c.f. size of proton $\simeq 10^{-15}$ m.

size of univ. $\lesssim 10^{10}$ yr. * 10^{16} m yr^{-1}

$\lesssim 10^{26}$ m.

$$10^{-40} \simeq \frac{\text{Radius of proton}}{\text{Radius of Universe}}$$

→ Ignore Gravity for individual particles at present energies

(10^{-35} m length or 10^{19} GeV grav. strong ....)

WEAK

1 in 10^{32} collisions*

STRONG

10^{22} collisions / p / year $\Rightarrow$ 10^{10} years

Today: 50:50 chance per p

FORCES Summary

(remember that waves ⟷ particles)

NAME	action	CARRIER
Gravity	keeps us on ground	graviton ?
Electromagnetic	electrons in atoms solids stops us falling to centre of Earth	photon (γ)
Weak	β- radioactivity $p \rightarrow He$ in Sun	W^+ W^- Z^0
Strong	quarks glued inside p, n... p, n in nuclei	gluons (g) 8 different

Only the weak force carriers have MASSes

$M_W \sim 80\ GeV/c^2$

$M_Z \sim 91\ GeV/c^2$

1864

Maxwell unifies electricity and magnetism

→ electromagnetism

100 years later

Glashow Salam Weinberg propose unification of Electromagnetic and weak

electro-weak

They use Higgs mechanism

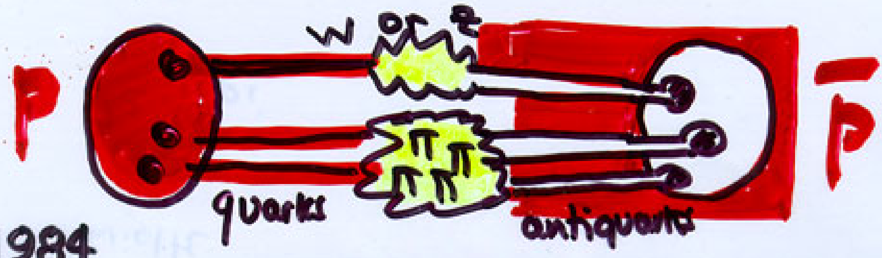
→ predict force carriers

W^+ W^- Z^0

→ masses predicted. ($m_\gamma = 0$)!

1983-84

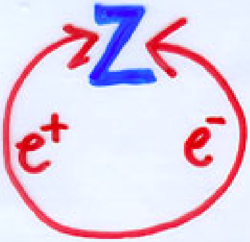
W and Z particles found by CERN experiments UA1 + UA2



1984

Rubbia + van der Meer → Nobel Prize

1989-95



Tune $E_+ + E_- = M_Z c^2 \approx 91\,\text{GeV}$

LEP 4 experiments
20 million Z^0

Z unstable. Decays "democratically" to

$q\bar{q}$ e^+e^- $\mu^+\mu^-$ $\tau^+\tau^-$

$\nu_e\bar{\nu}_e$ $\nu_\mu\bar{\nu}_\mu$ $\nu_\tau\bar{\nu}_\tau$ .....

$\frac{1}{\text{Life}}$ ~ # of holes

⇒ # of decay paths

Perfect match if $\#\nu = 3$

Since 1996 LEP $e^+(100\,\text{GeV}) + e^-(100\,\text{GeV}) \rightarrow W^+W^-$

+ look for Higgs ....

Z Lifetime

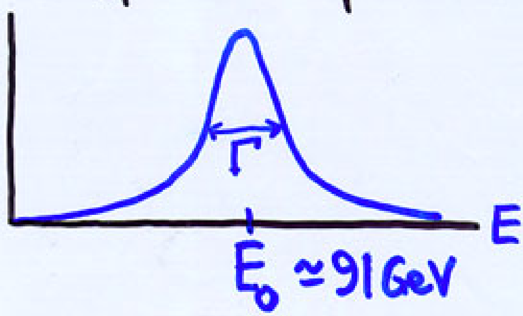
Heisenberg Uncertainty Principle

$$\Delta E\,\Delta t \simeq \hbar \simeq 6\times10^{-25}\ \text{GeV sec}$$

example Δt = lifetime of unstable particle

$$\Rightarrow \Delta E = \Delta M c^2 = \frac{6\times10^{-25}\ \text{GeV}}{\Delta t\ (\text{sec})}$$

$e^+e^- \to Z$ (production probability)



$\Gamma = \Delta E = 2.5$ GeV

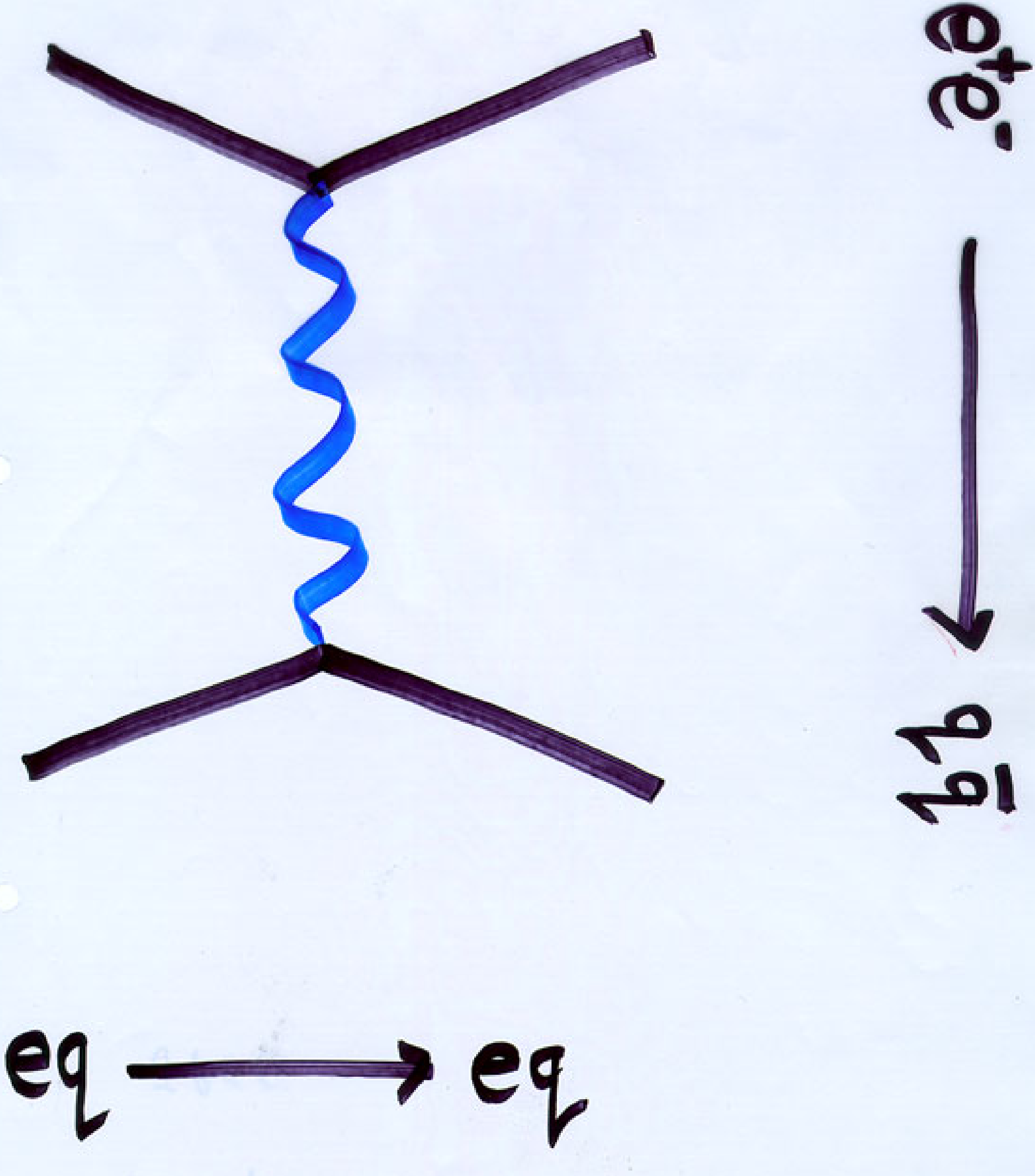
$\Rightarrow$ Lifetime $\simeq 10^{-25}$ sec photon $\propto 1/E^2$

$\sigma \sim L^2$

$\sim E^{-2}$

$Z^0 \propto 1/(E^2 + M_Z^2)$

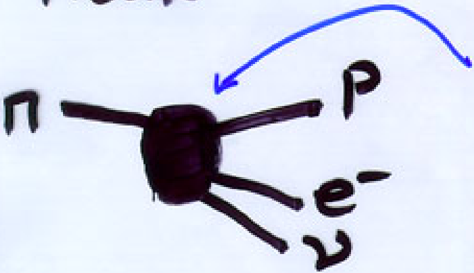
$E \gtrsim M_Z$ to "unfreeze"



$e^+e^- \rightarrow q\bar{q}$
$eq \rightarrow eq$

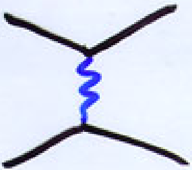

GOVERNMENT
HEALTH
WARNING

"Weak"

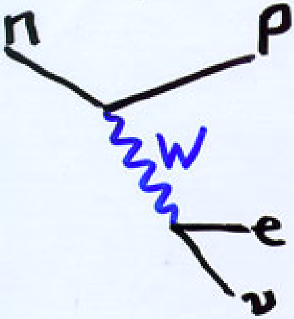


$G_F \approx 10^{-5}\ \text{GeV}^{-2}$

E.m.



$\alpha = 1/137$



γ

$$\alpha_{eff} \simeq G_F M_W^2$$

$\alpha_{eff} \to \frac{1}{137}$, $M_W^2 \to O(30\,GeV)$

$SU_2 \times U_1$ GSW angles

$\sqrt{2}$ etc

$M_W = O(80)\,GeV$

W is "virtual"

$\Delta E \simeq 80\,GeV$

$\Delta x \lesssim c\Delta t \simeq 10^8\,m/s\; 10^{-26}\,s = 10^{-18}\,m$

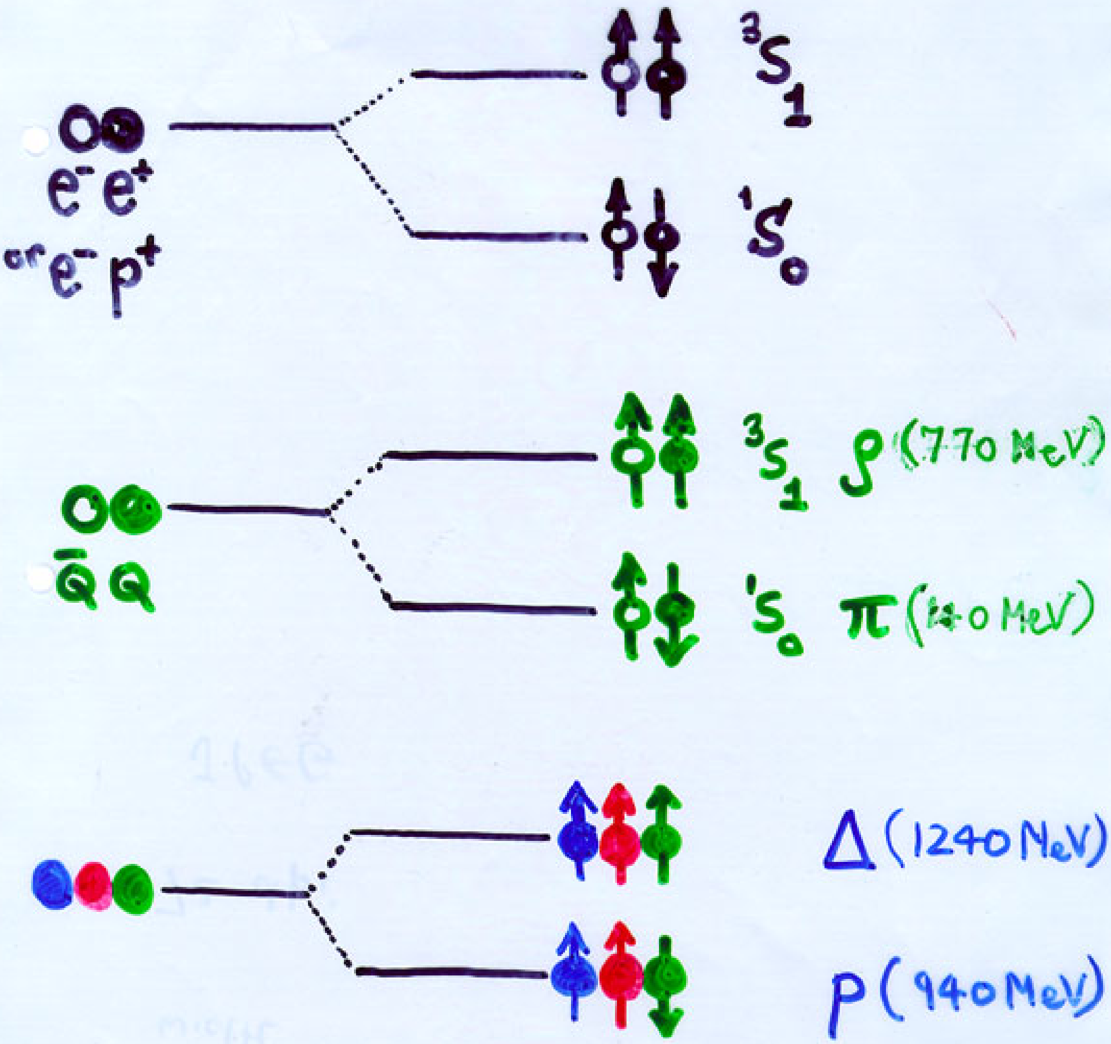


Electro STATICS binds Atoms

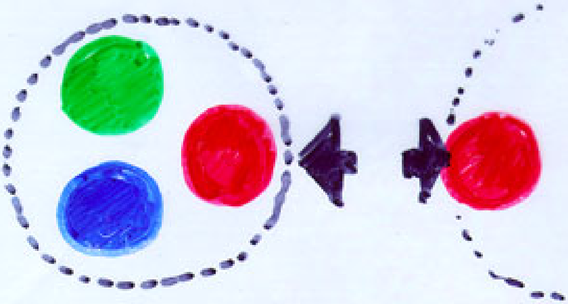
Chromo STATICS binds Hadrons

ChromoMAGNETIC perturbation

e.g. 1S energy

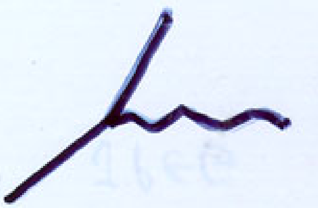


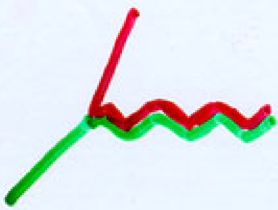
Electro + Chromo [redacted] Rely. QFT



QED e^- — atoms — molecule

QCD quark — p,n — nuclei



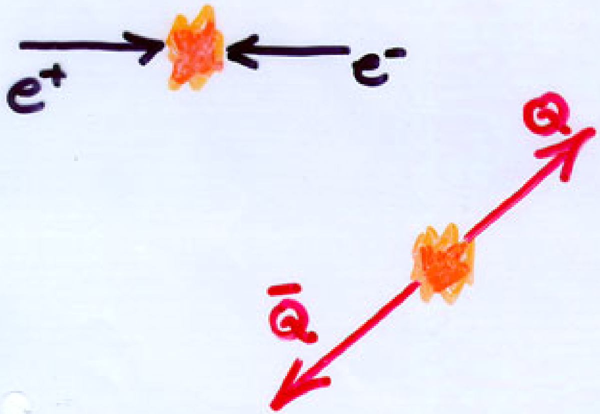


At source QED QCD syblings

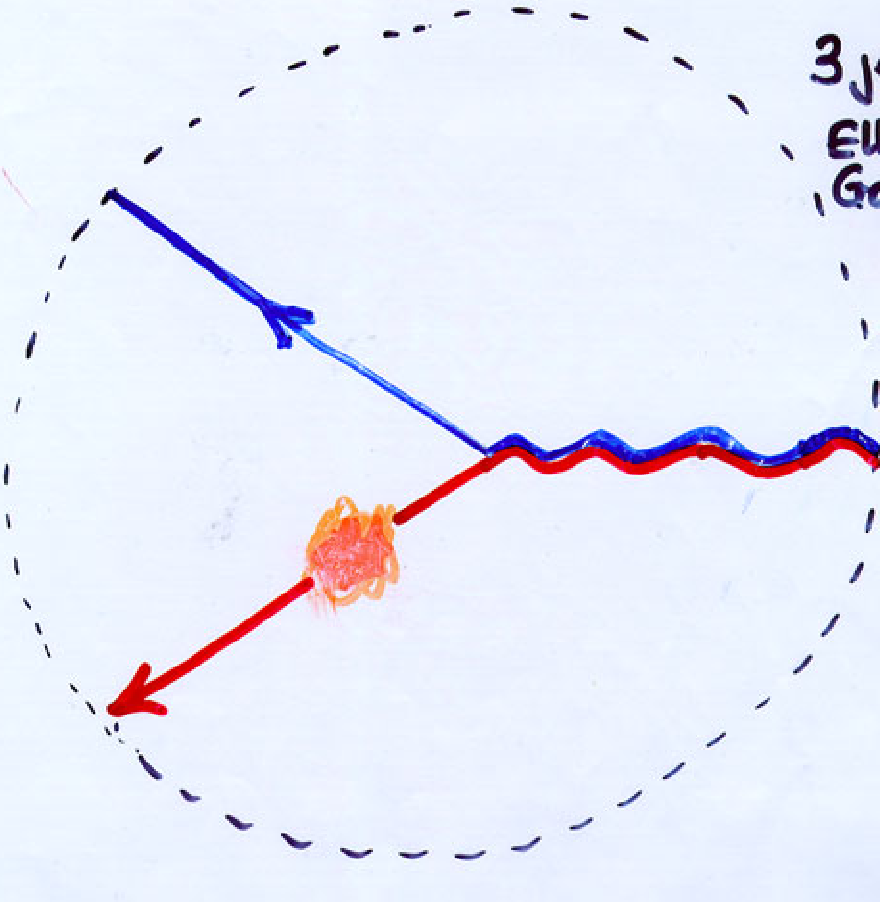
⇓

precision calc^n for quarks

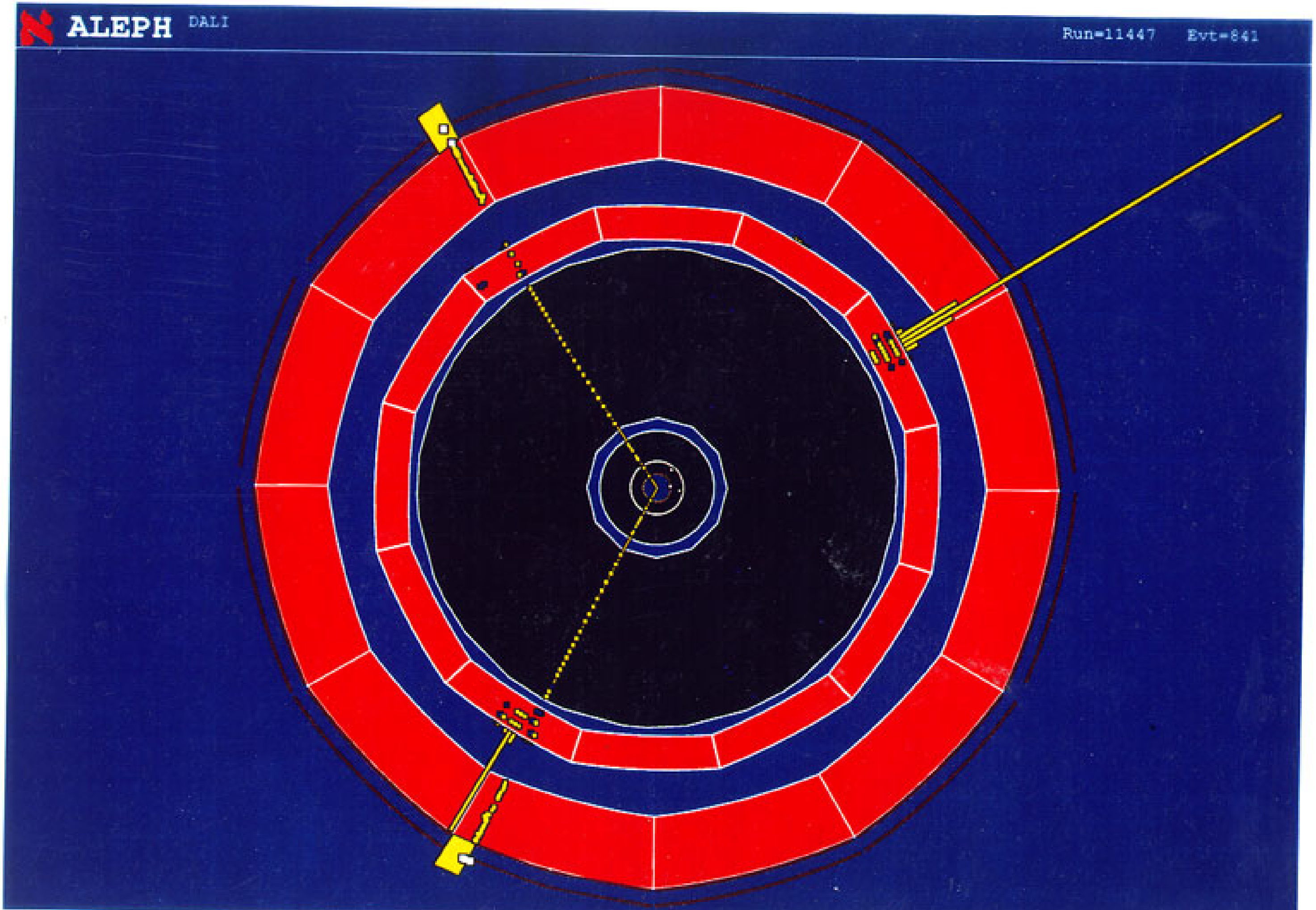
Gluon footprints in jets 1978

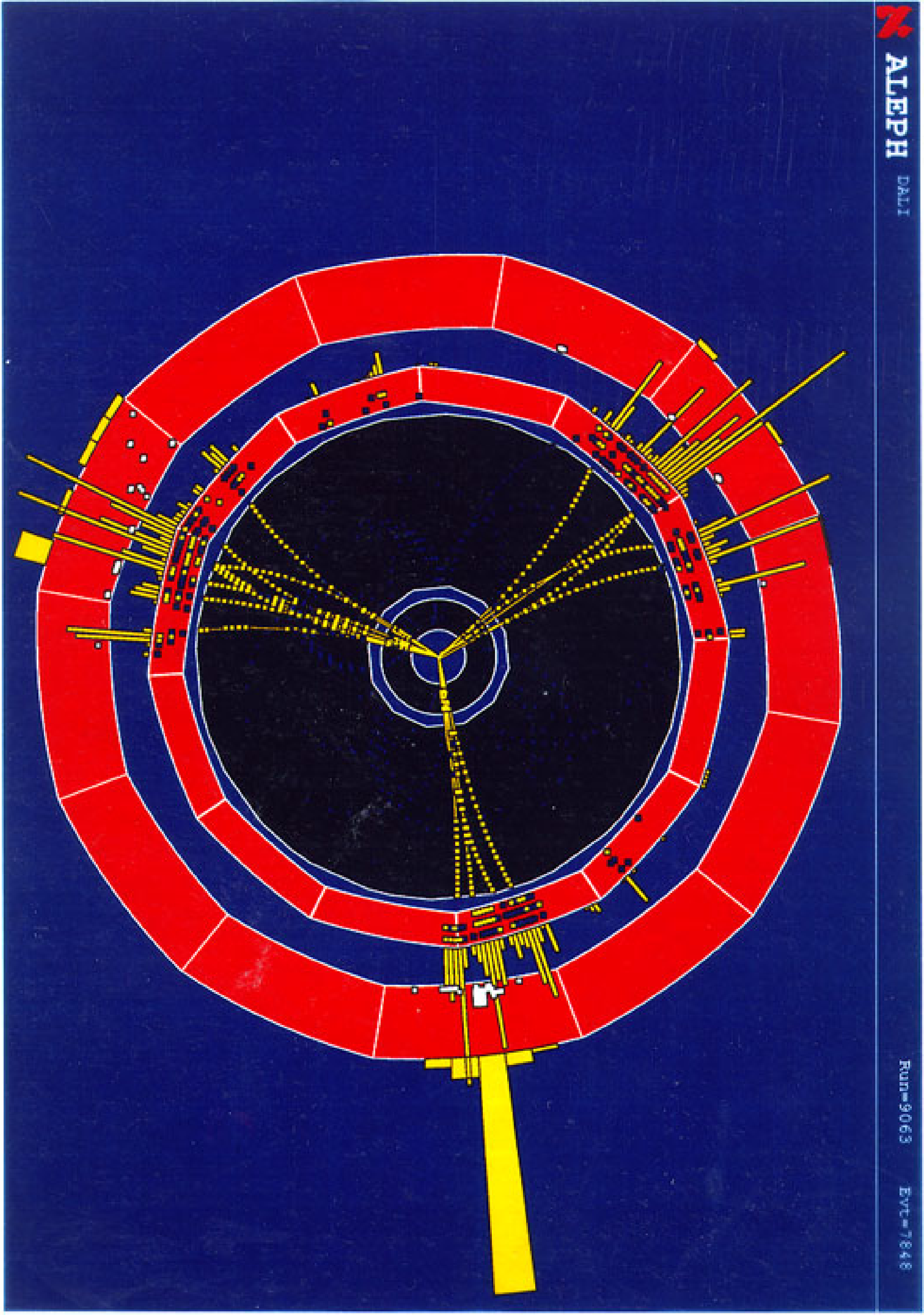


back to back jets

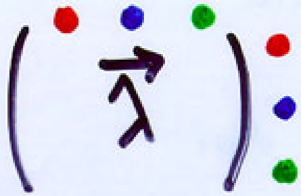


3 jets
Ellis
Gaillard
Ross

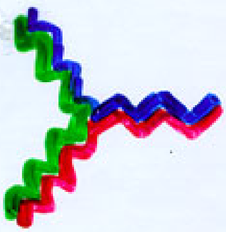

ALEPH
DALI
Run=11447 Evt=841


ALEPH
DALI
Run=9063
Evt=7848

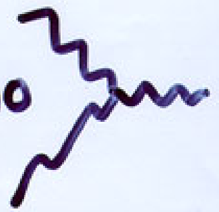
QCD = bj drell + $\vec{\lambda}$?



No! ∵ extra feature



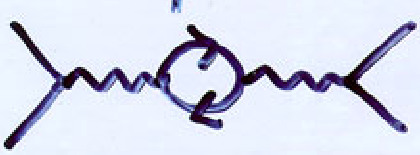
in QCD but no



in QED

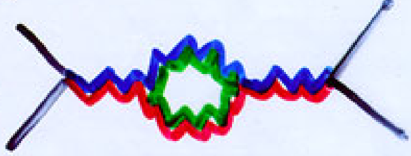
⇒ different long range $V(r)$

⇒ new quantum effects



QED

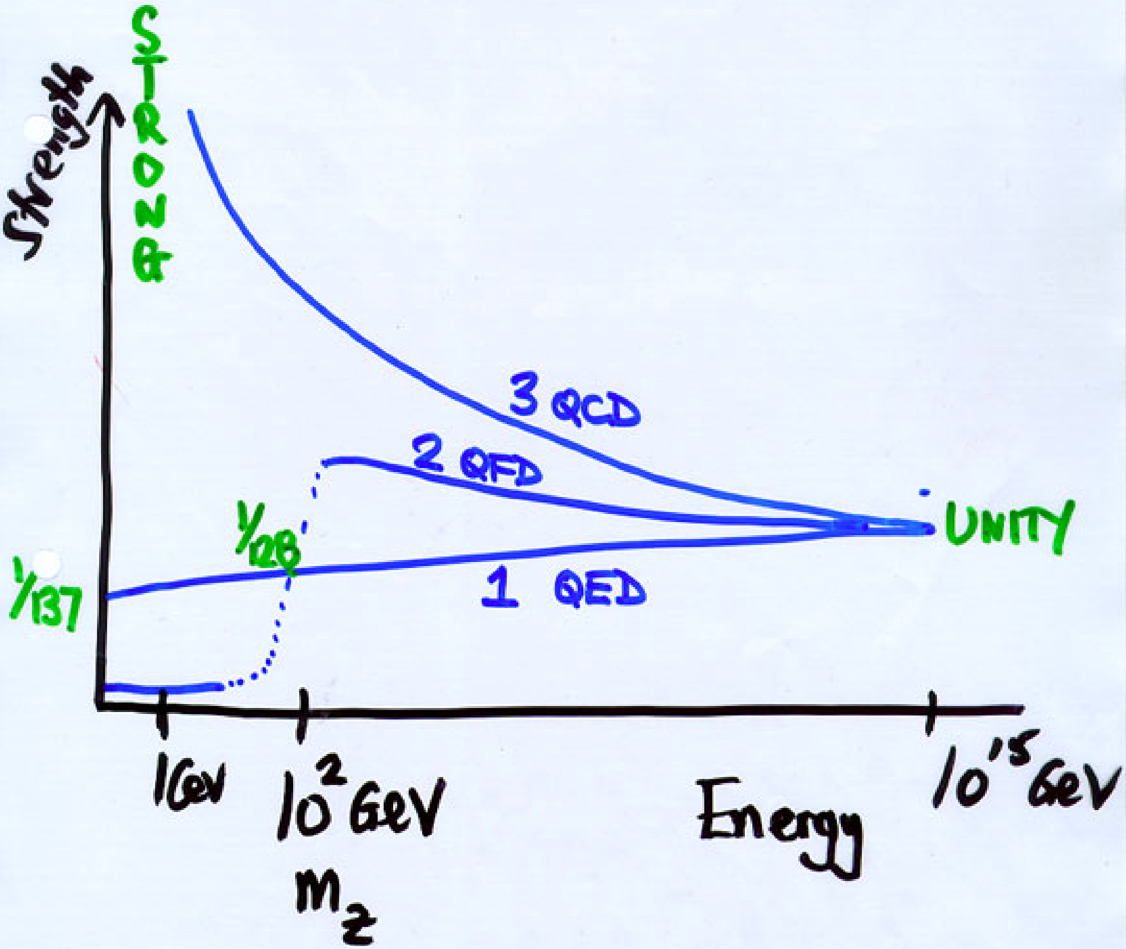
+



QCD

⇒ GLUEBALLS

Forces: Effective Strengths "evolve" with Energy



Big Bang ⇒ e + p

Thermal Equilibrium:

$$e + p \longleftrightarrow n + \nu$$

Temperature (energy) drops ⇒
After 1 μsec ⇒ one way only:

$$n \longrightarrow p + e + \bar{\nu}$$

But at the same time:

$$n + p \longrightarrow (d)$$

then like processes 2 and 3 in the Sun* until all the **neutrons** have gone

*MAKING **Helium**

or

particles so far apart in the expanding universe that they no longer interact

T = 1 μsec after BIG BANG

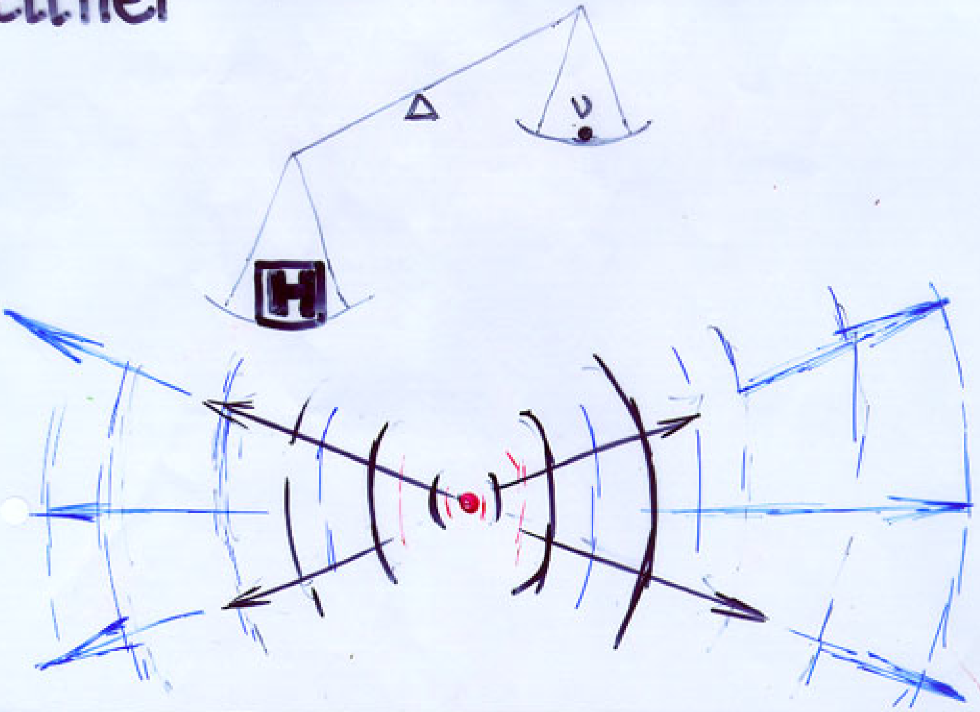
neutrinos are free
("the first fossils in the Universe)

move at high speed
and if they have mass they
start clustering together
→ contribute to formation of galaxies

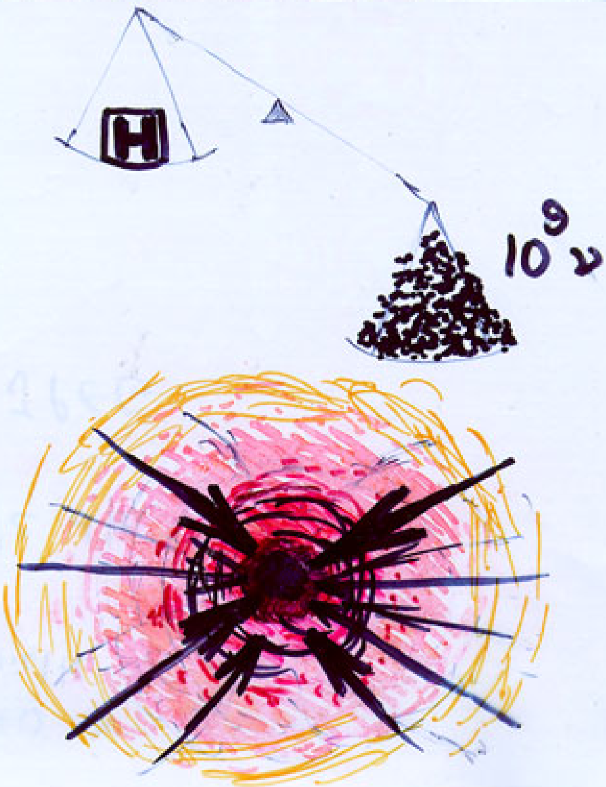
Billion ν per atom
⇒ if $m(\nu) > m(\text{proton})/10^9 \simeq 1\,\text{eV}$
they will dominate mass
density of the Universe

⇒ m_ν big question
for future of universe
and its formation

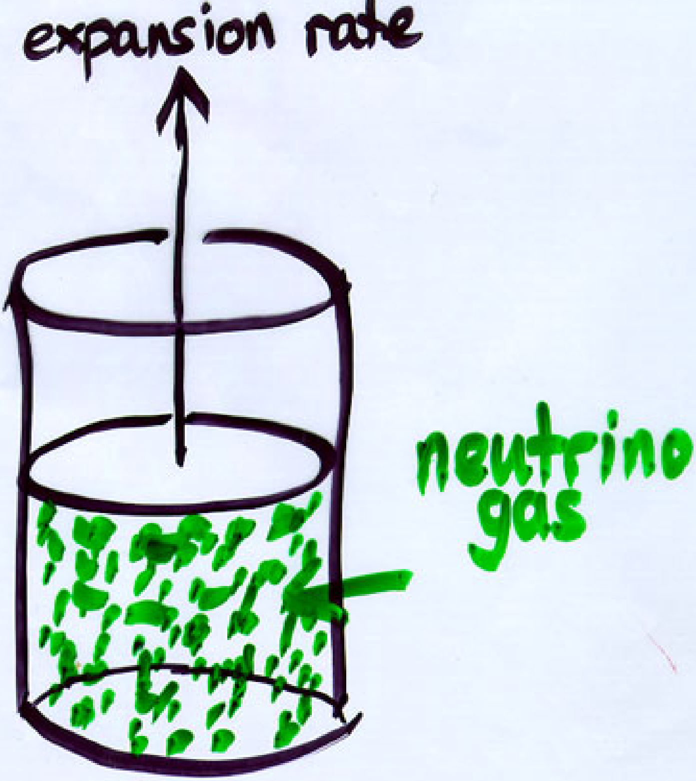
either



or



Universe expands - and cools



Rate depends on pressure
which depends on the
temperature in the gas and
the number of neutrinos inside
the gas volume (density)
and this # depends on
number of neutrino species

T = 3 minutes after BIG BANG

75% protons
24% Helium Nuclei
+ small amount of deuterons
+ free electrons.

✓ if 3 ν species

Helium abundance*: + traces of other light elements

depends on expansion rate of the Universe which depends on number of neutrino species

✓ **Deuterium abundance**

depends on density of "ordinary matter" in the Universe.

IF density of ordinary matter $\ll$ total in universe

→ part of DARK MATTER puzzle

Time Passes. Temp drops

300,000 years later $E < 10\,eV$
$T < 10^4 K$

electrons combine with nuclei
and make neutral atoms

electromagnetic radiation was set free

Universe becomes transparent

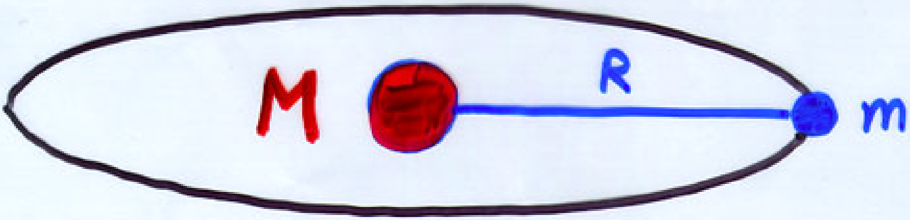
10^{10} years later

Emag λ stretched : Microwave Bgnd.
Black body background 3K

(small fluctuations in Mwave rad
= hints of proto structures, galaxies
in early universe)

DARK MATTER

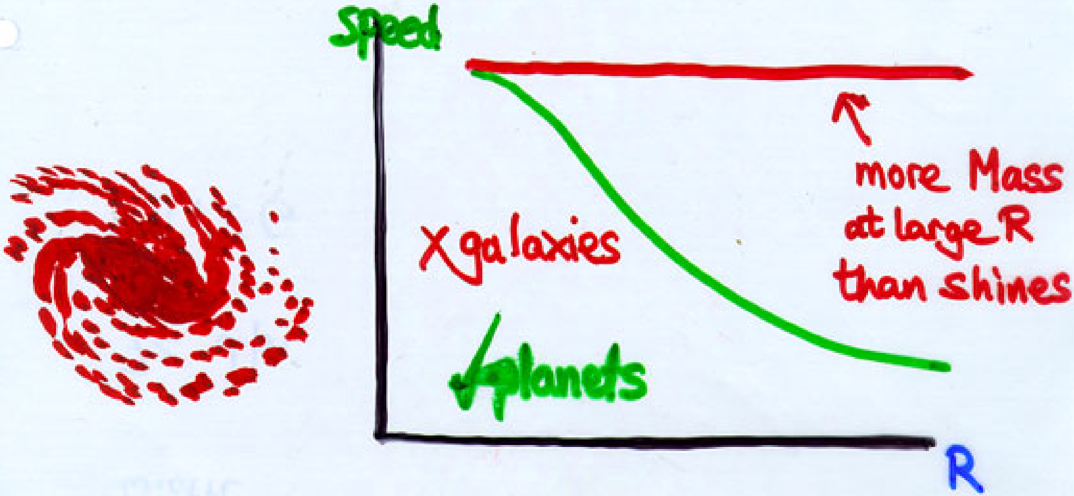
Rotation speed via gravity around a central mass



Newton: $F = G\frac{Mm}{R^2} = \frac{mv^2}{R}$

$\Rightarrow v^2 = \frac{GM}{R}$

speed goes down as $\sqrt{R}$

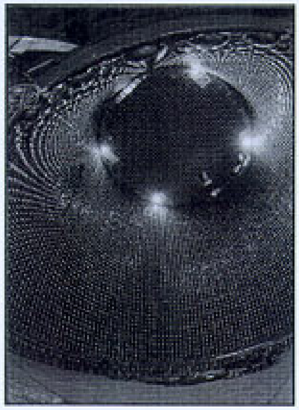


Picture Database

Classic images from the world of particle physics featuring discoveries, people, experiments, or images that are simply good to look at. A simple explanation accompanies them. There is also an archive!

---

10 June 1998



Super-Kamiokande - 9000 neutrino eyes

One thousand metres underground in a mine in Kamioka in Japan, a huge tank of water, 42 m high and 39 m in diameter, watches for the interactions of the elusive particles called neutrinos. The walls, ceiling and floor of the tank - which is the major part of a detector called Super-Kamiokande - are covered at regular intervals by 11,146 light-sensitive phototubes, each about 50 cm in diameter. These pick up light (Cherenkov radiation) emitted as the energetic charged particles produced in the neutrino interactions travel through the water. This picture shows about 9000 of the tubes - the small bright spots - on the walls and ceiling of the tank, before it was filled with water. Super-Kamiokande detects neutrinos emitted in nuclear interactions in the Sun, and also in the interactions of cosmic-ray particles in the atmosphere. Measurements of these "atmospheric neutrinos" suggest that neutrinos may "oscillate" - change from one type to another - which they can do only if they have some mass, although this mass must be very, very small.

Credit: Super-Kamiokande

Previous pictures, Picture index, Alphabetical Index, Picture of the Week

---

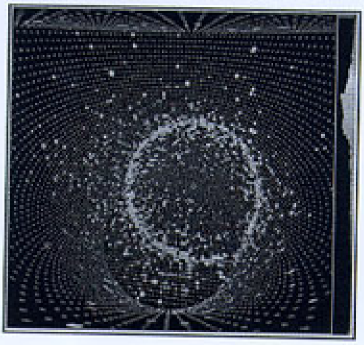
Open Directory Cool Site **This website is supported through a grant from the Particle Physics and Astronomy Research Council (PPARC)**

Picture Database

Classic images from the world of particle physics featuring discoveries, people, experiments, or images that are simply good to look at. A simple explanation accompanies them. There is also an archive!

---

6 December 2000



Neutrinos - 70 years on

On 4 December 1930, theorist Wolfgang Pauli wrote a famous letter in which he dared to hypothesise the existence of new particle - the particle now known as the neutrino. Pauli proposed the new particle to explain why energy seemed to go missing in the form of radioactivity known as beta-decay. The neutrino would took away energy but without being detected, as it has no electric charge and a very small mass. It was to be another 26 years before Fred Reines and Clyde Cowan claimed the first detection of Pauli's "undetectable" particle.

Nowadays, neutrinos are detected in many experiments throughout the world. In this image an electron-neutrino - the kind of neutrino that steals the energy in beta-decay - has been detected in the vast tank of water that forms the Super-Kamiokande experiment in Japan. Imagine looking down into the cylindrical tank, 42 m deep. The dots are phototubes on the curved walls, and the coloured blocks show where light has struck a tube. The ring of light has been produced by an electron moving through the water faster than light does, to produce Cherenkov radiation. You can find out more about this image, and a comparison with a muon-neutrino here.

Credit: Super-Kamiokande/Tomasz Barszczak

Please contact person or institution named for information about permission for public or commercial use.

Previous pictures, Picture index, Alphabetical Index, Picture of the Week

---

Open Directory Cool Site **This website is supported through a grant from the Particle Physics and Astronomy Research Council (PPARC)**

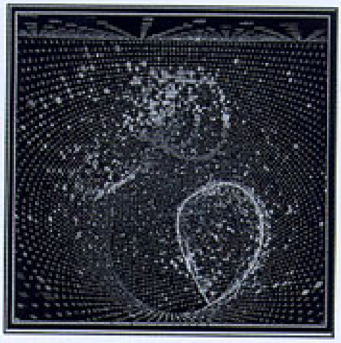
ppUK HOME Picture Database

Classic images from the world of particle physics featuring discoveries, people, experiments, or images that are simply good to look at. A simple explanation accompanies them. There is also an archive!

---

20 December 2000

Seasons greetings and best wishes for a prosperous New Year to all !



Three (or more ?) Cherenkov light rings

"On the third day of Christmas, my physicist sent to me ....". Multiple rings of Cherenkov light brighten up this display of an event found in the Super-Kamiokande neutrino detector in Japan. The pattern of rings - produced when electrically charged particles travel faster through the water in the detector than light does - is similar to the result if a proton had decayed into a positron and a neutral pion. The pion would decay immediately to two gamma-ray photons that would produce fuzzy rings, while the positron would shoot off in the opposite direction to produce a clearer ring. Such kinds of decay have been predicted by "grand unified theories" that link three of nature's fundamental forces - the strong, weak and electromagnetic forces. However, there is so far no evidence for such decays; this event, for example, did not stand up to closer scrutiny.

Credit: Super-Kamiokande/Tomasz Barszczak

Previous pictures, Picture index, Alphabetical Index, Picture of the Week

---

Open Directory Cool Site **This website is supported through a grant from the Particle Physics and Astronomy Research Council (PPARC)**

Official Super-Kamiokande Press Release from Japan

MEDIA ADVISORY for afternoon June 5, 1998, Takayama, Japan

EVIDENCE FOR MASSIVE NEUTRINOS

We announce today at "**Neutrino '98**", the international physics conference underway in Takayama, Japan, that the Super-Kamiokande Experiment has found evidence for non-zero neutrino mass. Neutrinos are tiny, electrically neutral, sub-atomic particles. Papers related to the results were submitted to the scientific journals "Physical Review Letters" and "Physics Letters." The experiment yields results that are outside the standard theory of particle physics, which describes the fundamental constituents of matter and their interactions. Until now, there has been no firm evidence that neutrinos possess mass.

The new evidence is based upon studies of neutrinos which are created when cosmic rays, fast-moving particles from space, bombard the earth's upper atmosphere producing cascades of secondary particles which rain down upon the earth. Most of these neutrinos pass through the entire earth un-scathed. The Super-Kamiokande group uses a large, 50,000 ton tank of highly purified water, located about 1000 meters underground in the Kamioka Mining and Smelting Company Mozumi Mine. Faint flashes of light given off by the neutrino interactions in the tank are detected by more than 13,000 photomultiplier tubes that were manufactured for the experiment by Hamamatsu Corporation.

By classifying the neutrino interactions according to the type of neutrino involved (electron-neutrino or muon-neutrino) and counting their relative numbers as a function of the distance from their creation point, we conclude that the muon-neutrinos are "oscillating". Oscillation is the changing back and forth of a neutrino's type as it travels through space or matter. This can occur only if the neutrino possesses mass. The Super-Kamiokande result indicates that muon-neutrinos are disappearing into undetected tau-neutrinos or perhaps some other type of neutrino (e.g., sterile-neutrino). The experiment does not determine directly the masses of the neutrinos leading to this effect, but the rate of disappearance suggests that the difference in masses between the oscillating types is very small. The primary result that we are reporting has a statistical significance of more than 5 standard deviations. An independent measurement based on upward-going muons in the detector confirms the result at the level of more than 3 standard deviations.

The Super-Kamiokande Collaboration includes scientists from 23 institutions in Japan and the United States. Principle funding for the experiment is provided by the Japanese Ministry of Education, Science, Sports, and Culture (Mombusho) while funding for the detector's outer most region is provided by the United States Department of Energy. In addition to advancing our understanding of basic science, the collaboration has established a strong international partnership between the Japanese and American teams.

Since the beginning of its operation in April, 1996, the Super-Kamiokande experiment has been the most sensitive in the world for monitoring neutrinos from various sources. In our studies, we have found interesting results in the measurements of electron-neutrinos coming from the sun. The number detected is about 35% of the number predicted by the well established theoretical model of the sun's neutrino producing processes. In addition, we obtained an indication that the observed energy spectrum of those neutrinos is deformed from the the predicted one. Super-Kamiokande's observation of too few electron-neutrinos coming from the direction of the sun also may be interpreted as due to oscillations. We are continuing to study this exciting possibility.

Reflecting on the significance of the new finding, we note that massive neutrinos must now be incorporated into the theoretical models of the structure of matter and that astrophysicists concerned with finding the 'missing or dark matter' in the universe, must now consider the neutrino as a serious candidate.

MEDIA ADVISORY for afternoon JUNE 5, 1998, Takayama, Japan

SUPER-KAMIOKANDE OPERATION JEOPARDIZED BY BUDGET CUT

The Super-Kamiokande experiment, using a gigantic water filled detector, began operation over 2 years ago in April, 1996. Today, we announced that evidence has been found for non-zero neutrino mass (See attached, **EVIDENCE FOR MASSIVE NEUTRINOS**). This important physics result follows from our precise measurement of the composition of atmospheric neutrinos. We will continue our observations and will study the details which may clarify the role of the mysterious neutrinos in elementary particle physics and in the universe.

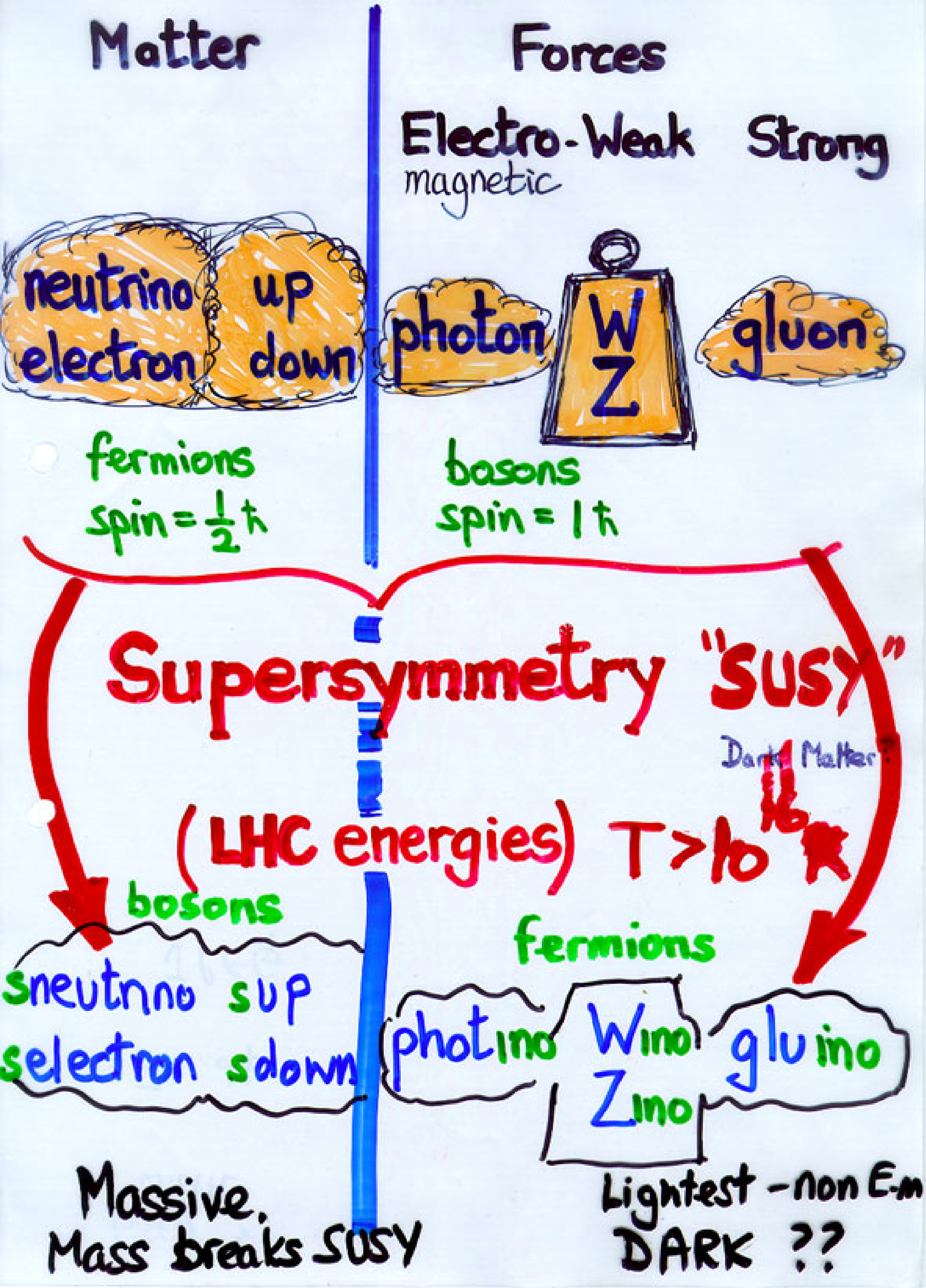
In addition, we will continue to study the characteristics of electron-neutrinos from the sun; we will maintain a vigilant watch for neutrino bursts arising from supernovae explosions within our galaxy; and we will search for proton decay to the longest lifetimes ever probed experimentally. We expect results from these studies to be as significant as the present finding of finite neutrino mass through our study of atmospheric neutrinos.

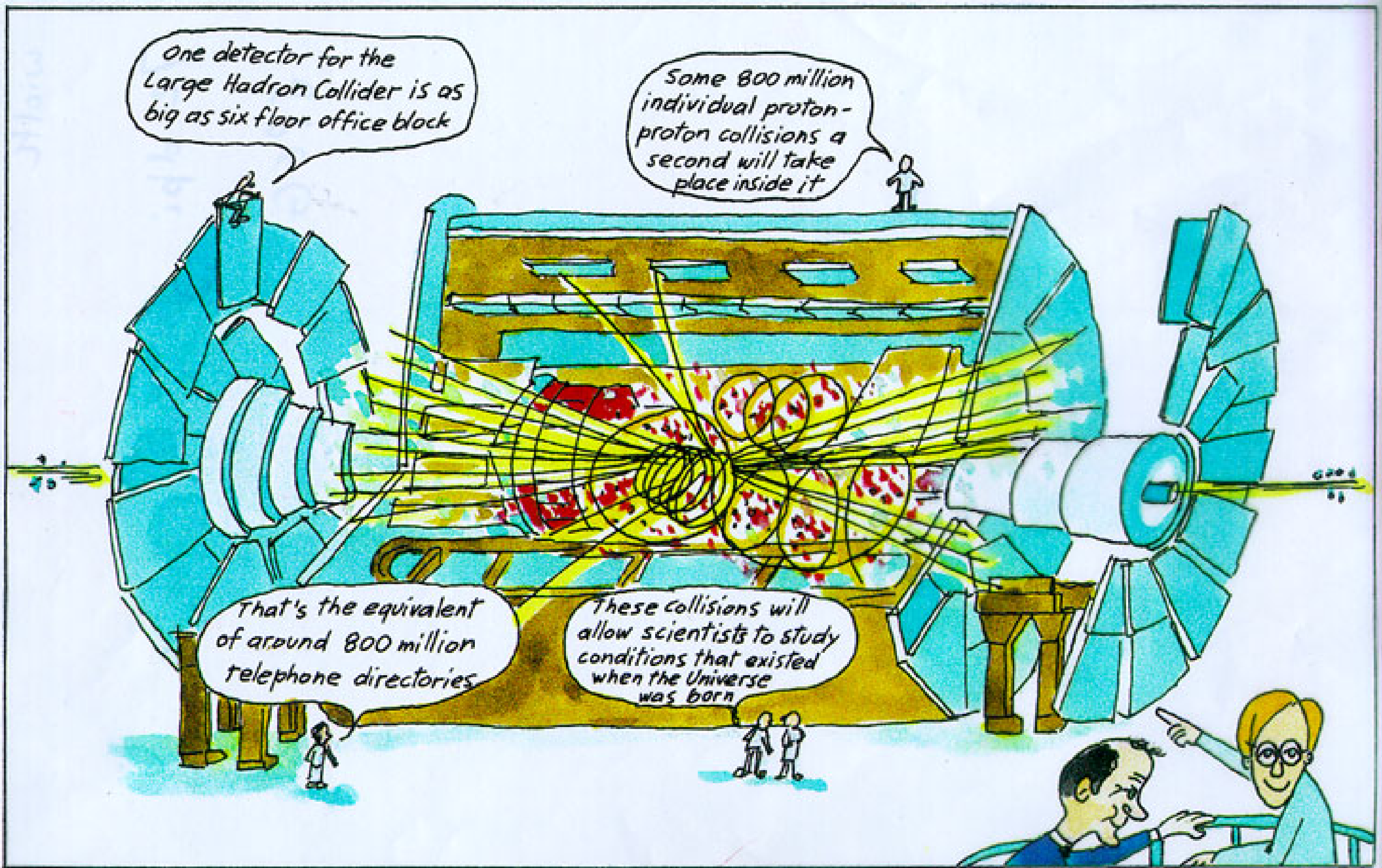
The sensitive measurements being made by Super-Kamiokande require continuous operation of the detector facility to obtain maximum efficiency for acquiring data. This is essential if important new physics results are to be achieved. Unfortunately, due to the financial difficulty of the Japanese government, the operating funds for Super-Kamiokande have been reduced by 15% for the present fiscal year. This is a serious budget cut for the experiment and may require us to cease operation for up to 2 months this year.

An additional 15% cut back is expected in the next fiscal year, resulting in a 30% reduction compared to the JFY97 budget. Under these circumstances, we will have no option but to stop the operation of the experiment and make no observations for a certain time, perhaps as long as 4 months. We regret that these cuts in government funds are being applied equally, across-the-board, to all institutions, without consideration of the relative scientific importance of the projects or the devastating impact that such cuts may have.

Super-Kamiokande has begun to produce physics results which will require changes in our standard pictures of particle physics and the universe. More results are expected with continued operation of the experiment. Budget cuts which stop the detector operation, jeopardize the strength of the international collaboration and could result in the loss of important observations, such as a rare supernova event. The U.S. collaborators are requesting that ICRR, The University of Tokyo, make every effort not to interrupt the experiment. We ask everyone to understand the importance of this international collaboration for obtaining new observations in basic physics research. We appeal for continuous operation support for Super-Kamiokande.

The Super-Kamiokande Collaboration.


Matter
Forces
Electro-Weak
magnetic
Strong
neutrino
electron
up
down
photon
W
Z
gluon
fermions
spin = ½ ħ
bosons
spin = 1 ħ
Supersymmetry "SUSY"
Dark Matter?
(LHC energies) T > 10^16 K
bosons
sneutrino
selectron
sup
sdown
fermions
photino
Wino
Zino
gluino
Massive.
Mass breaks SUSY
Lightest - non E-m
DARK ??


One detector for the Large Hadron Collider is as big as six floor office block
Some 800 million individual proton-proton collisions a second will take place inside it
That's the equivalent of around 800 million telephone directories
These collisions will allow scientists to study conditions that existed when the Universe was born

Particle Physics @ CERN.

Standard Model of Ptles + Forces.

- Quarks + Leptons. — Spin ½ fermions
- γ $W^{\pm}Z$ gluons — Spin 1 gauge bosons
- Higgs — Spin 0 boson

High Energy ⟷ Early Universe

Origins of matter.

[Structures + patterns at $E \lesssim 1$ TeV
Symmetry revealed at $E \gtrsim O$(TeV)]

Forces (and particles) unified – SUSY.

Some current big puzzles.

- Dark Matter, Solar ν, massive ν?
  (all the same?)
- Why 3 generations
  What is difference between M and $\bar{M}$? } the same?
- ? ⟶ The Fifth Dimension

Lucifers Legacy

– the meaning of asymmetry

(Oxford Univ Press)

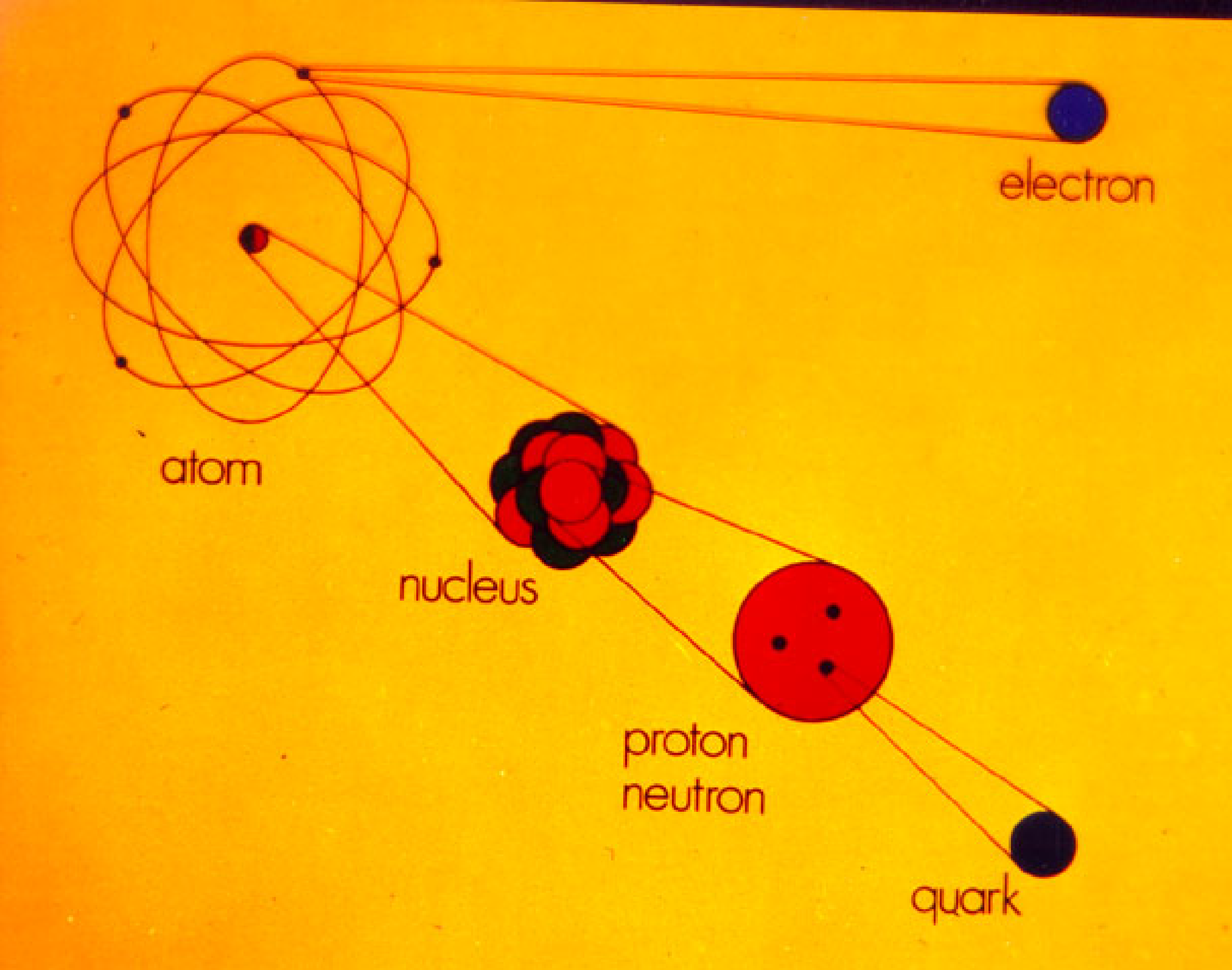
Amazon.co.uk

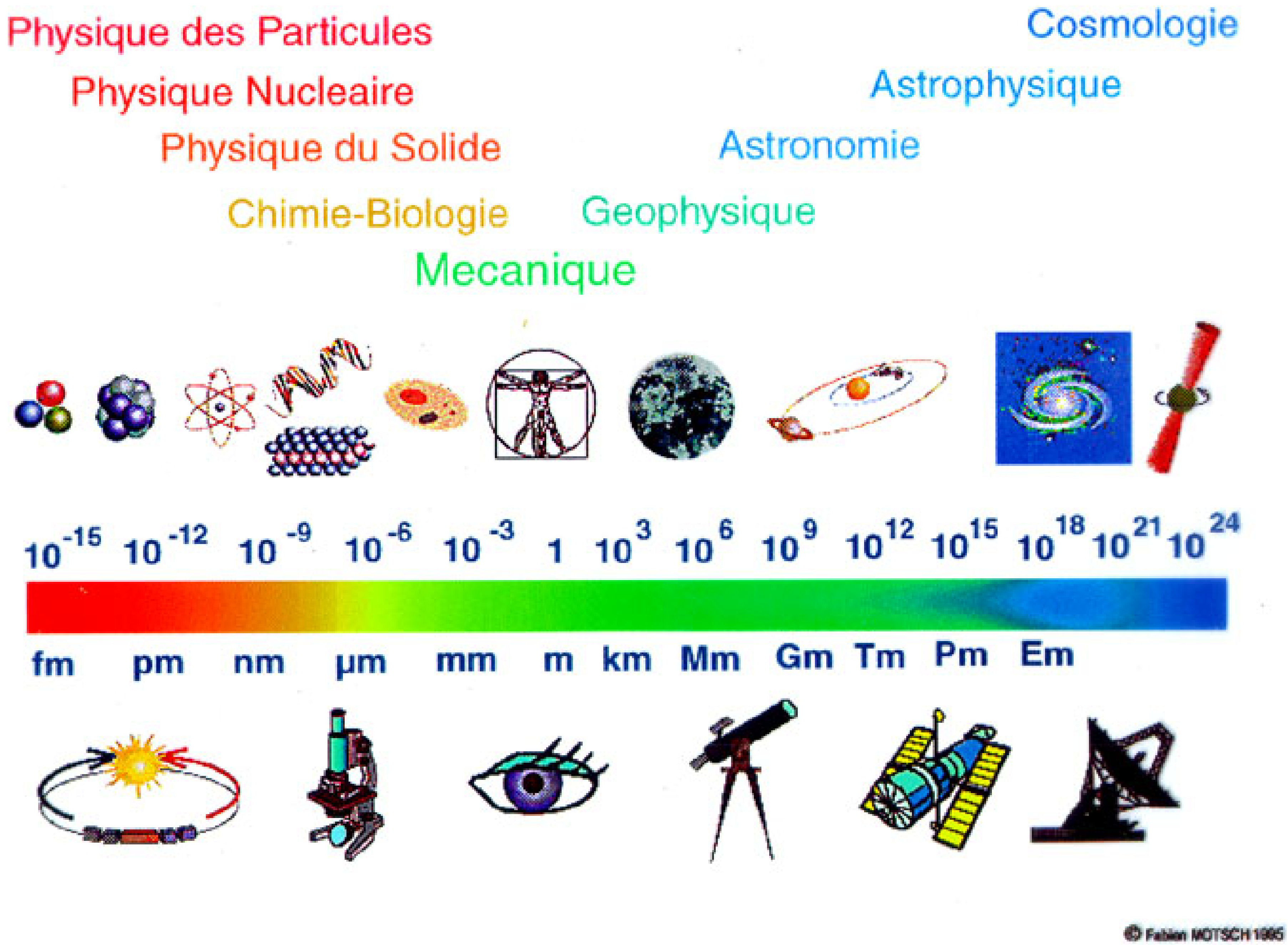
No equations
All the way to the
LHC

The Cosmic Onion

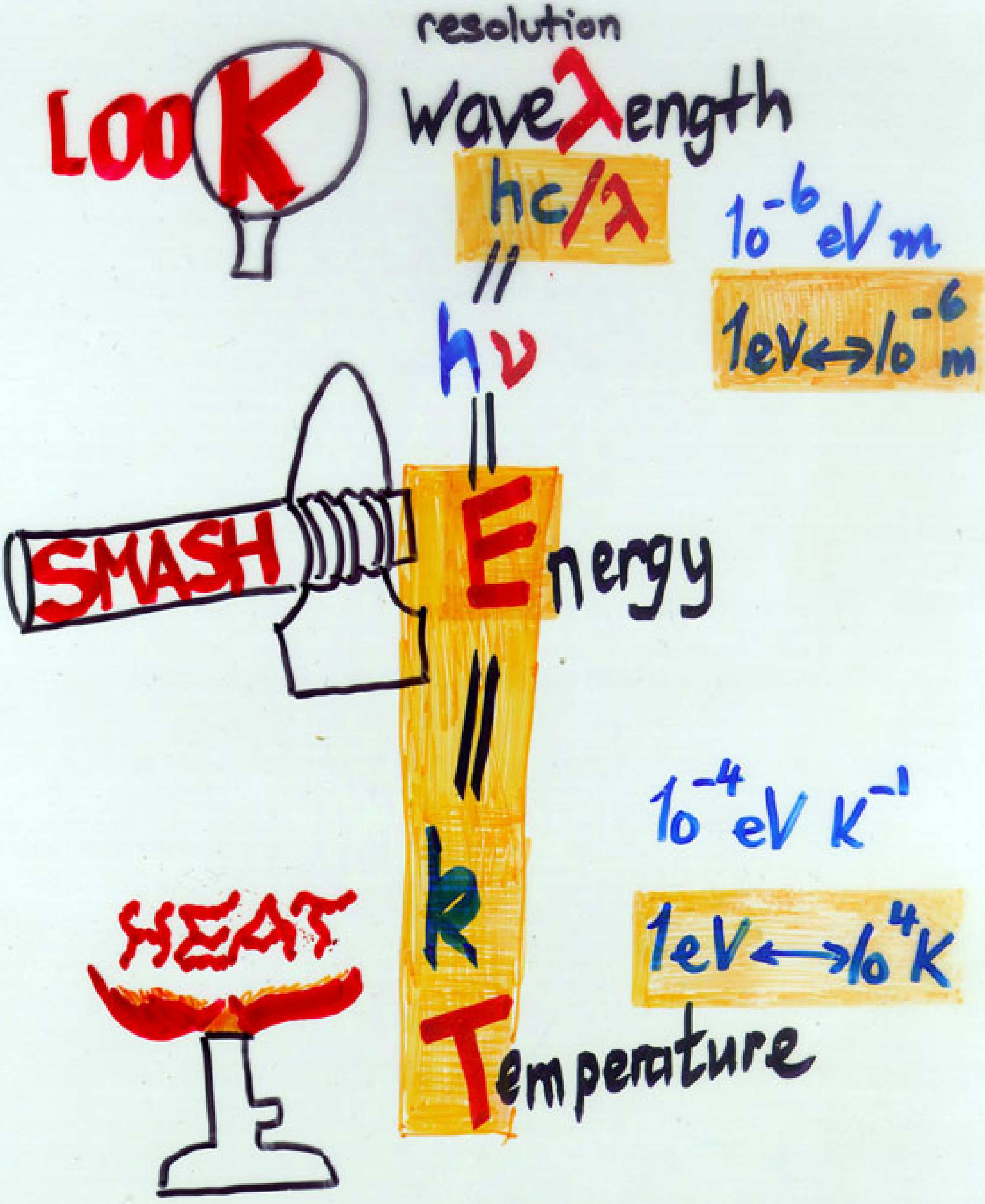
(Heinemann)

C20 atomic
nuclear
particles
for highschools
+ undergraduates


electron
atom
nucleus
proton
neutron
quark

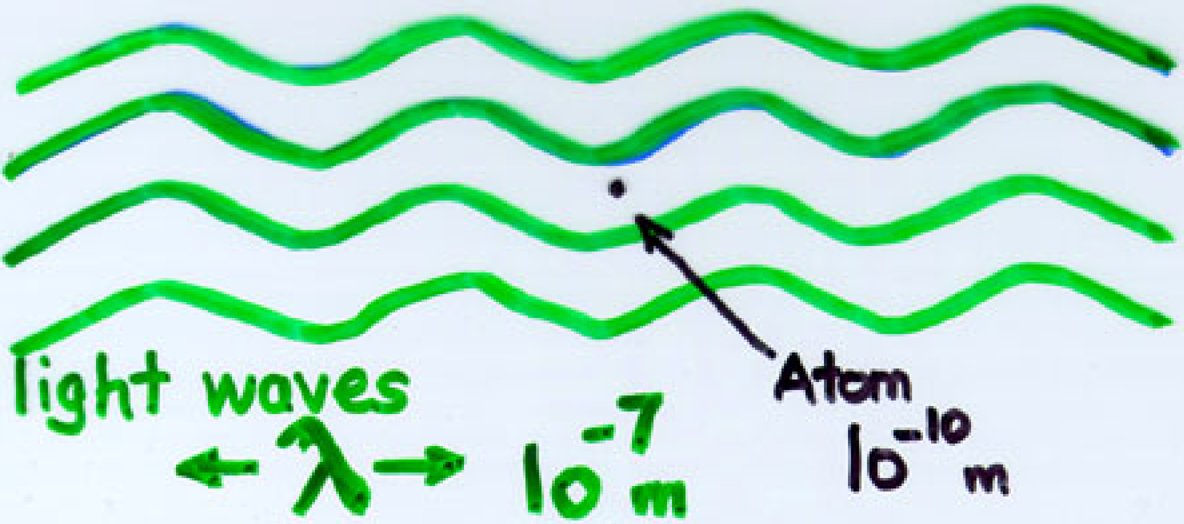

Physique des Particules
Physique Nucleaire
Physique du Solide
Chimie-Biologie
Mecanique
Geophysique
Astronomie
Astrophysique
Cosmologie
10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 1 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18} 10^{21} 10^{24}
fm pm nm µm mm m km Mm Gm Tm Pm Em
© Fabien MOTSCH 1995

How to learn what things are made of

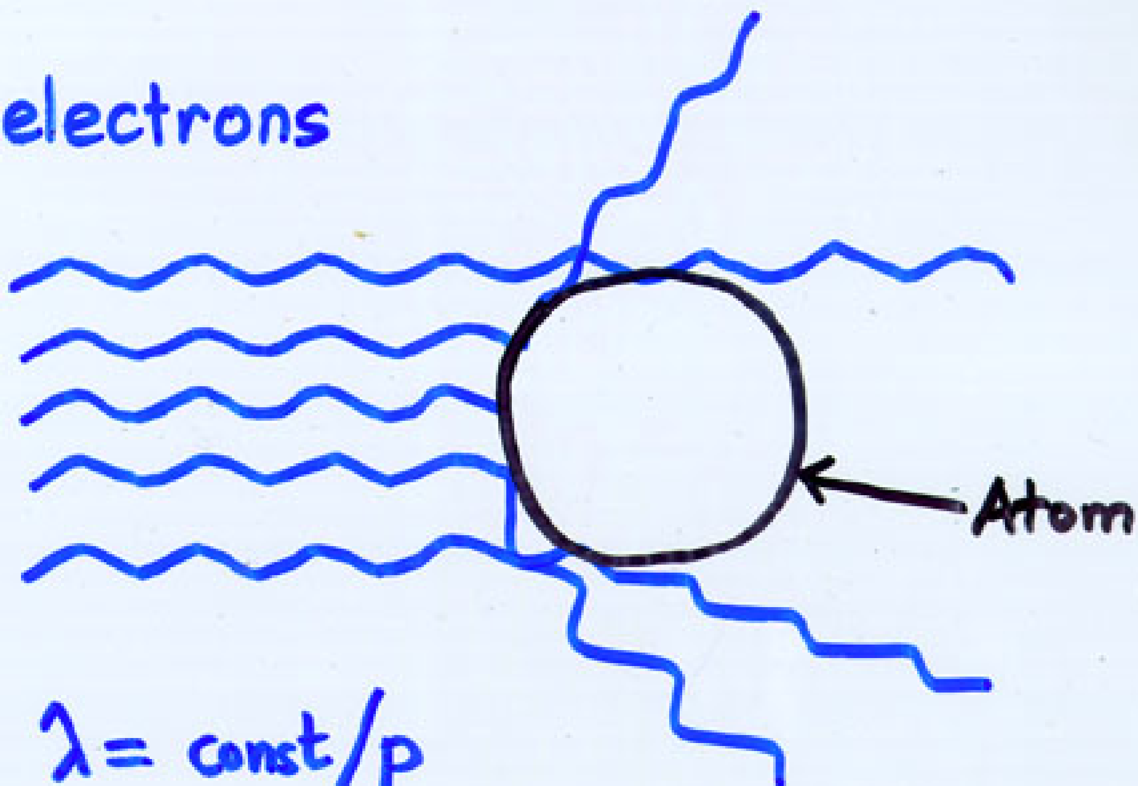



BEAM
TARGET
DETECTOR

How to see small things



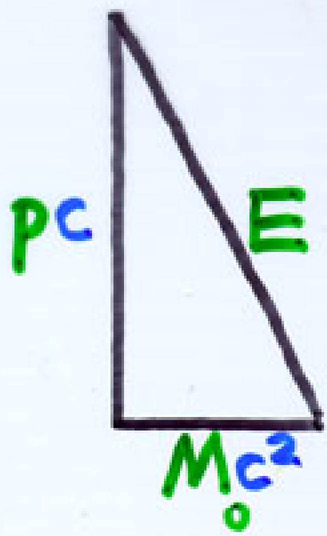
Electron microscope



$\lambda = \text{const}/p$

Einstein: $E = Mc^2$

Special Relativity



$$E^2 = (pc)^2 + (M_0c^2)^2$$

use units such that $c = 1$

E (GeV or MeV)
p (GeV/c or MeV/c)
M (GeV/c^2 or MeV/c^2)

$M_{electron} = 0.5$ MeV/c^2

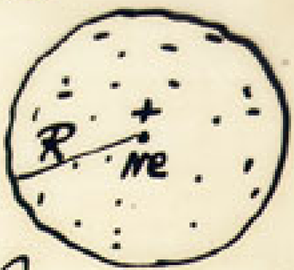
$M_{proton} = 938$ MeV/c^2 $\simeq 1$ GeV/c^2

$M_{top} = 170$ GeV/c^2

proton diameter = length scale:
10^{-15} m = 1 fermi (femtometer)

Theory of deflexion of α particle through a large angle compared with small scattering

Suppose atom [qualitatively] consists of sphere with central point charge +Ne where e = ionic charge surrounded by a sphere of radius R in which a negative charge −Ne (total quantity) is uniformly distributed. Atom is neutral.



Consider passage of [a mass m] through atom carrying a pos. 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 $\frac{NeE}{b}$ is potential energy of charge at

$$\therefore b = \frac{2NeE}{mv_0^2}$$

Consider value of b.

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

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

$\frac{E}{M} = 1.5\times10^{14}$ for α particle (E.S. units)

For radium C, $v_1^2 = 2.06\times10^{9}$.

$$\therefore b = \frac{2\times1.5\times10^{14}\times100\times4.65}{10^{10}\times4.2\times10^{18}}$$

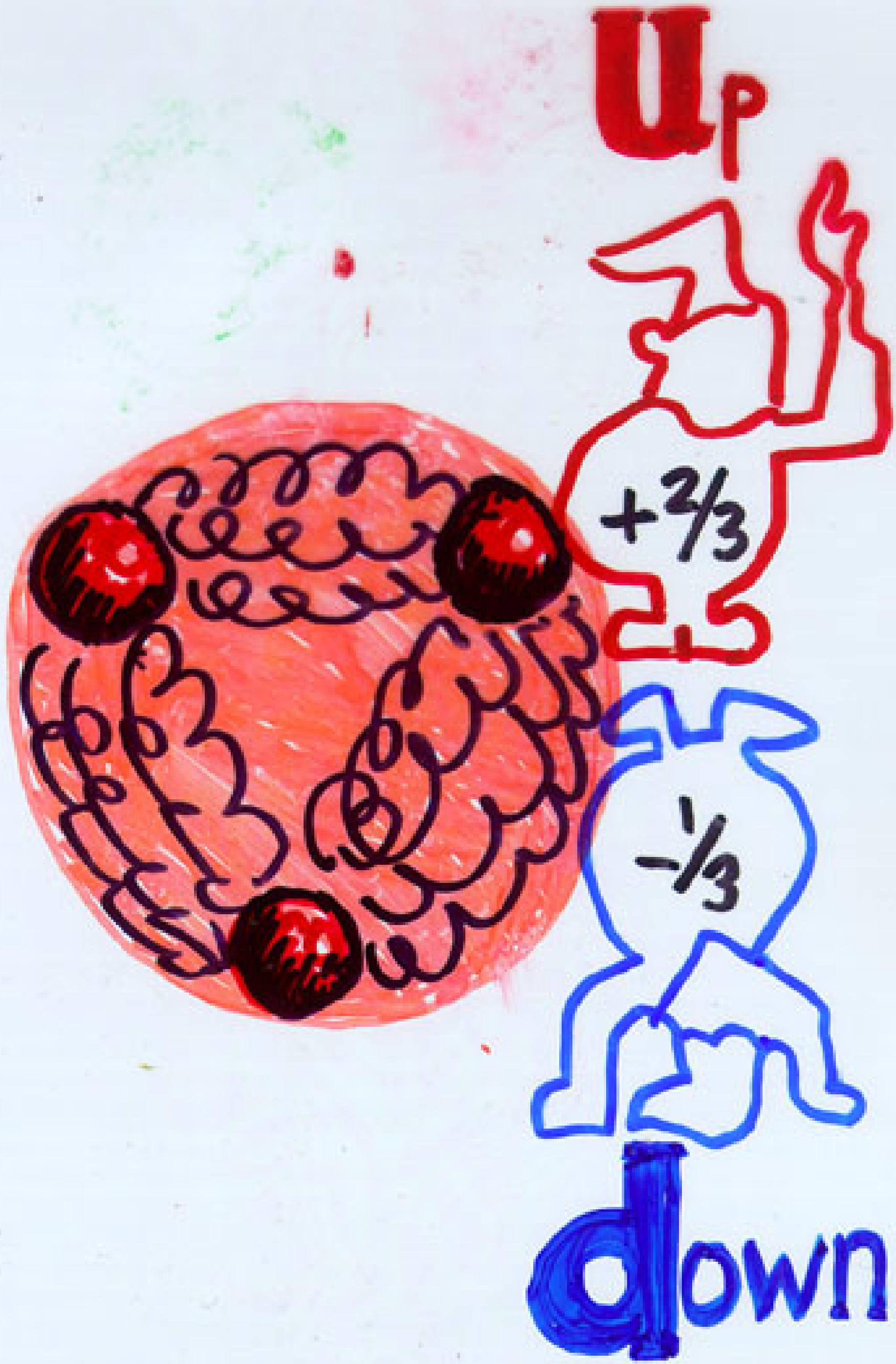
1395 / 4.2) 14 (3 / 12.6 / 14

$$\doteq \frac{3.3}{10^{12}} \text{ cms.}$$

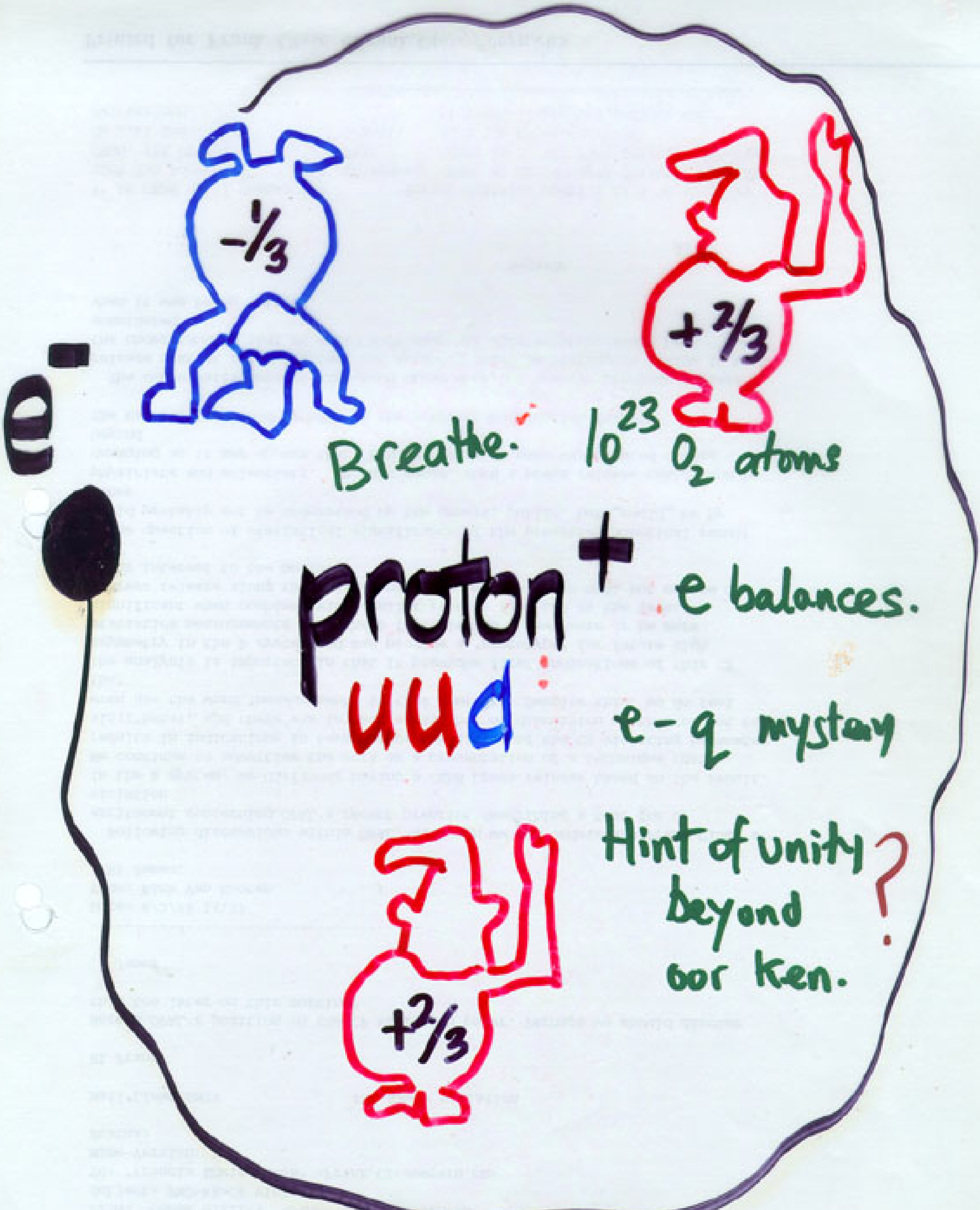
Since probably radius of atom is of order 10^{-8} cm, it is seen that distance of approach of charged centre is very small compared with radius of atom. In general it is obvious that the region where the deflecting forces on the α particles are large is very near centre of atom + in a region where field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

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

b is an important constant for a particle of given velocity

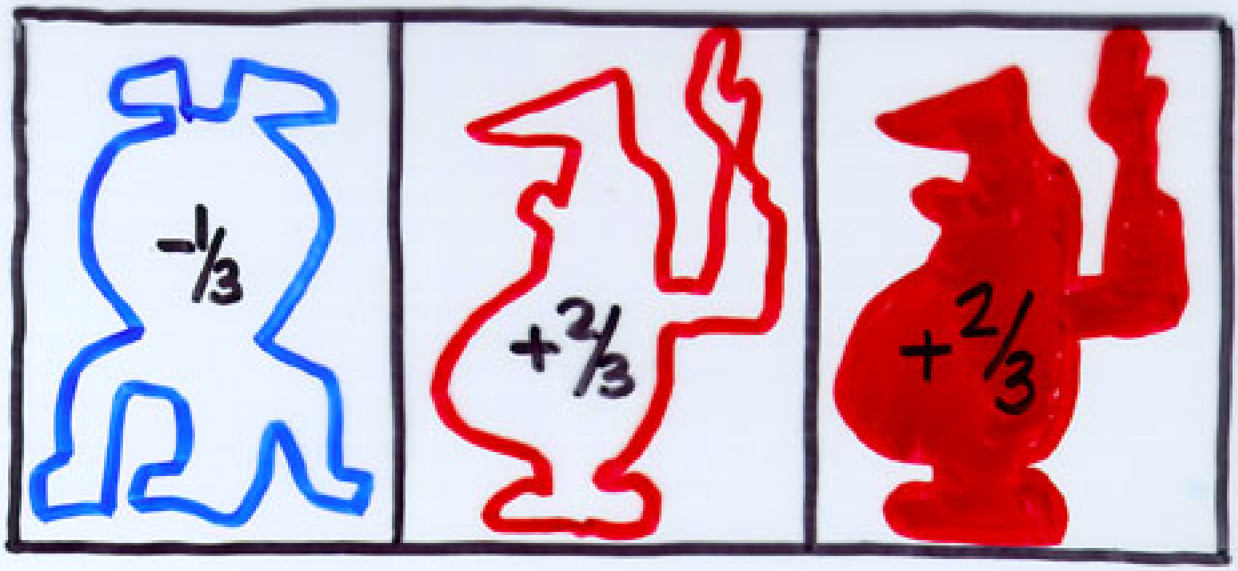


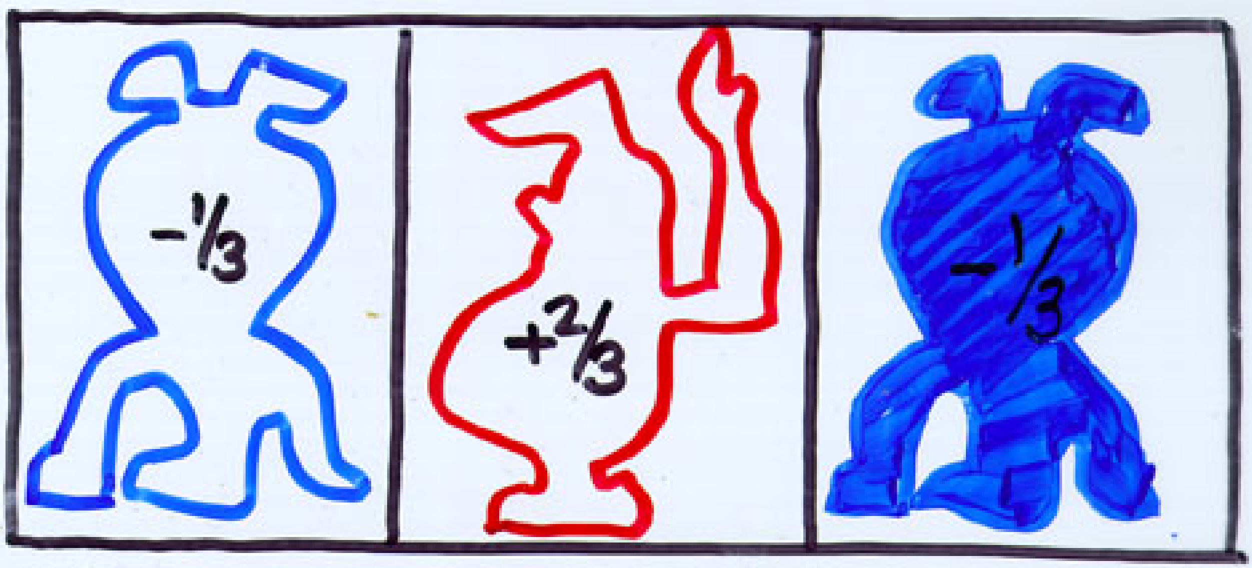
Quarks



H atom (not to scale)

p^+ Proton





n^0 Neutron

β radioactivity

$$n \longrightarrow p\, e^-\, \bar{\nu}$$

$$d \longrightarrow u\, e^-\, \bar{\nu}$$

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 ??

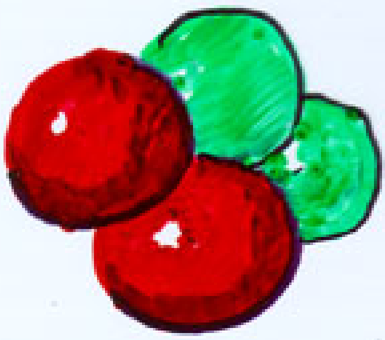
SOME NEUTRINO STATISTICS

each second :

1 hr. x this audience ⇒ 100 million neutrinos

→ into universe – for ever !

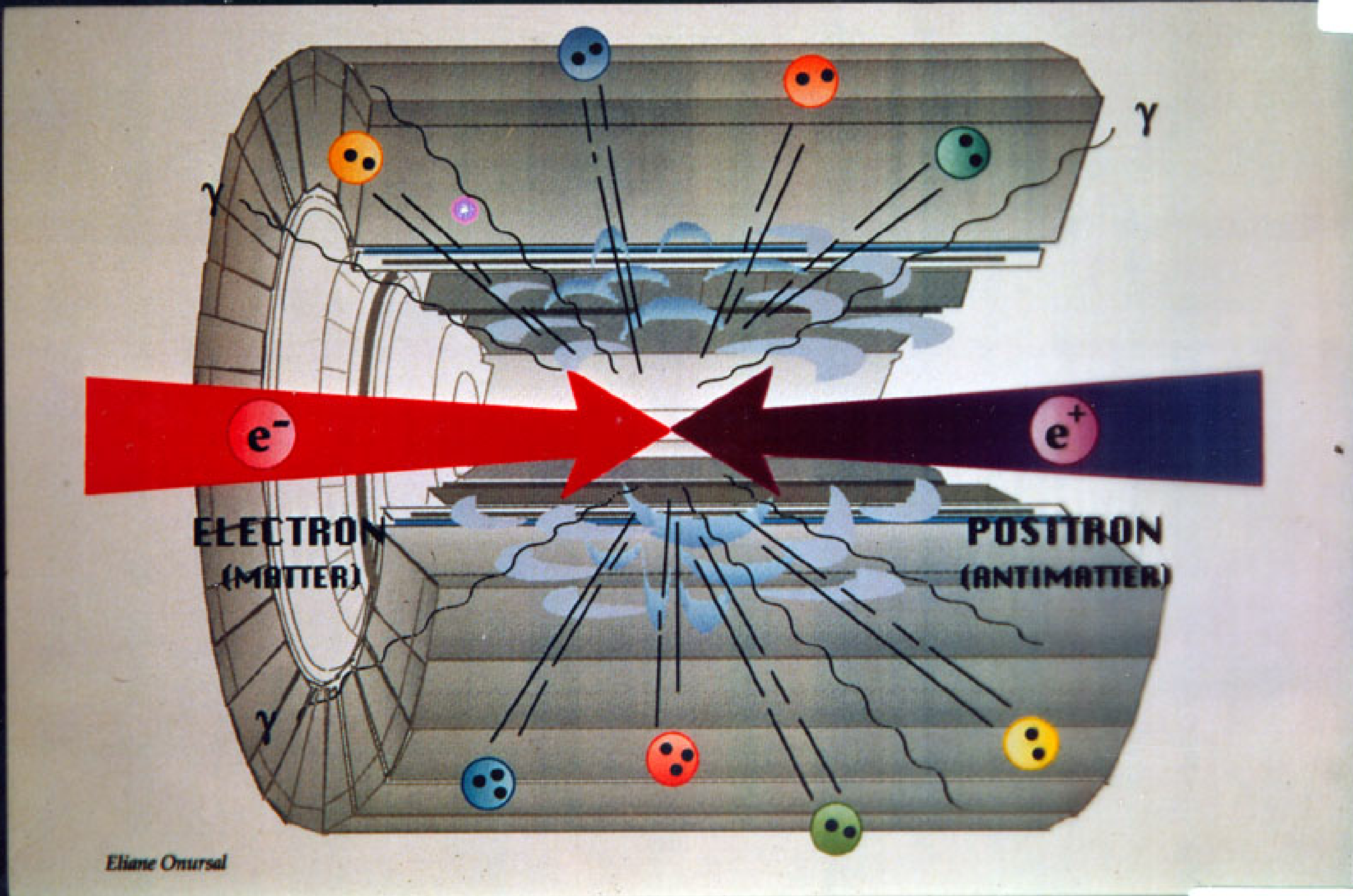
Hydrogen



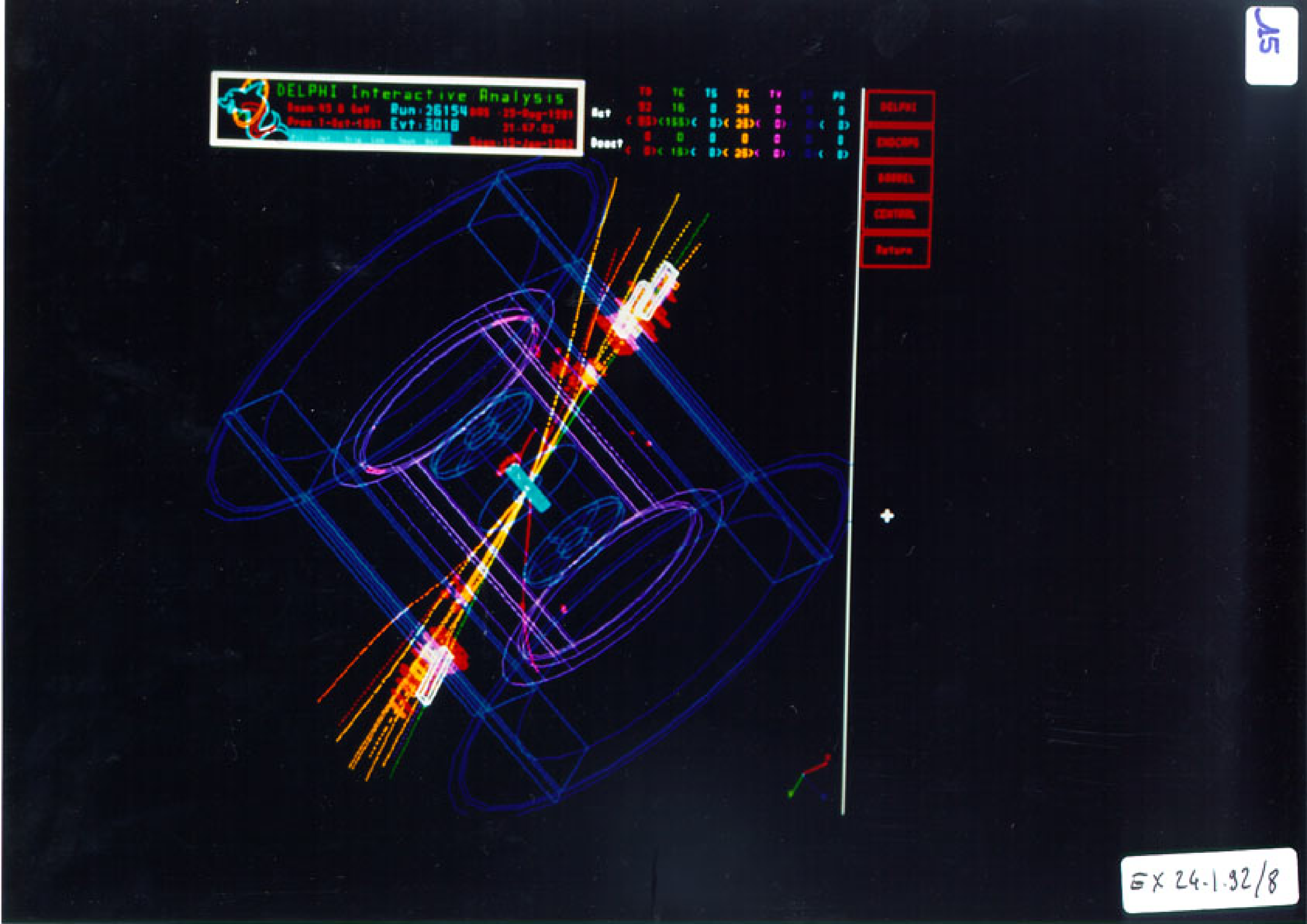
Helium

Carbon

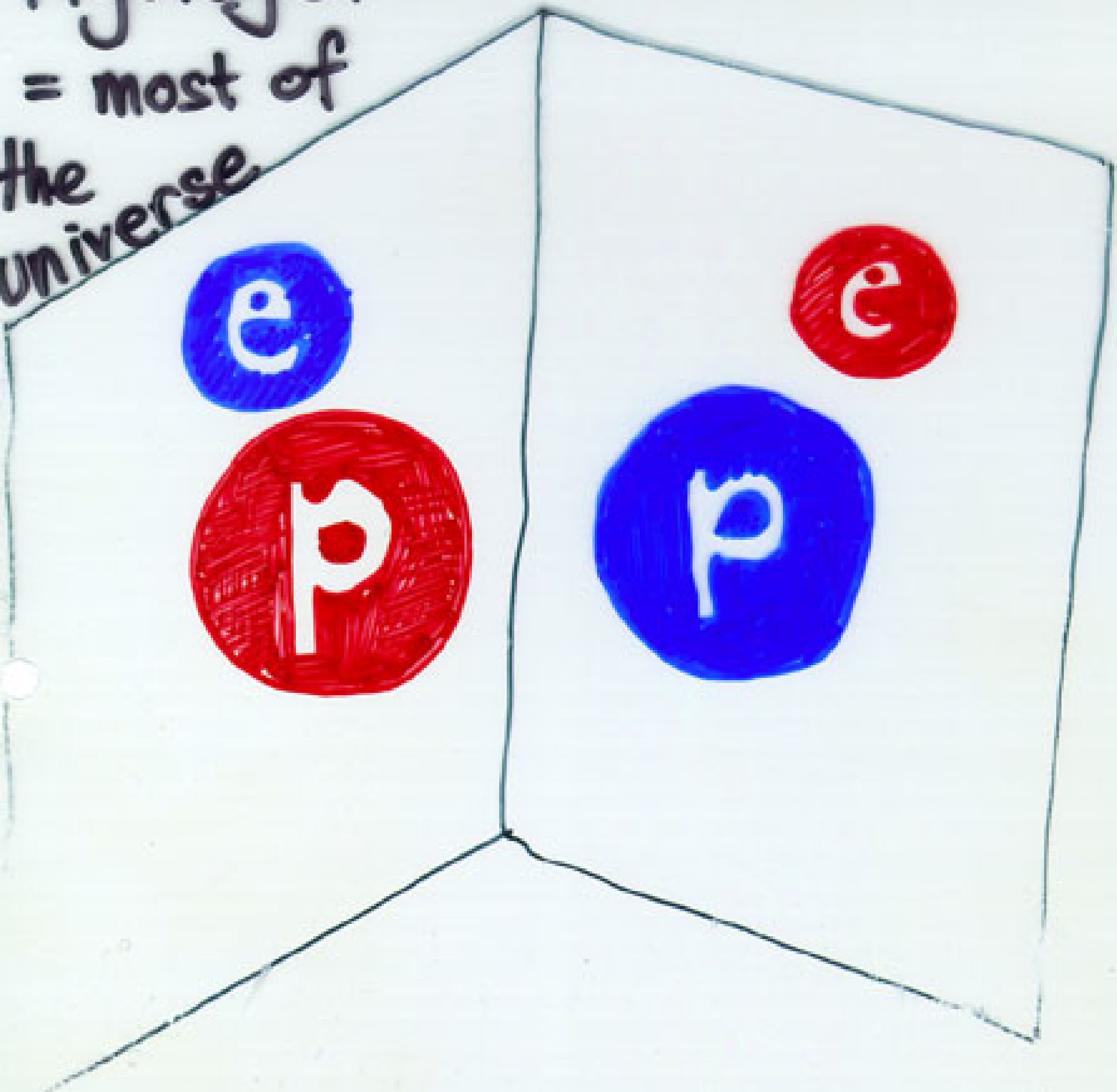
Iron


γ
γ
γ
e⁻
e⁺
ELECTRON
(MATTER)
POSITRON
(ANTIMATTER)
Eliane Onursal

$$Mc^2 \leftarrow E \rightarrow Mc^2$$


DELPHI Interactive Analysis
Run: 26154
Evt: 5018
EX 24-1-92/8

Hydrogen
= most of the universe



10^{13} degrees to make $\bar{p}$
= hotter than any star

<1 degree to trap in antihydrogen
= colder than outer space

$$E = mc^2$$

E ↑ energy

m ↑ mass

c^2 ↑ exchange rate = velocity of light = HUGE!

25×10^9 kWhr = 1 kg of anything

1 gr → Bham / Manch for 1 day

1 gm anti-ice = 10^{23} anti atoms

CERN 2000/hour

If 2000/second

= 10^{11}/year

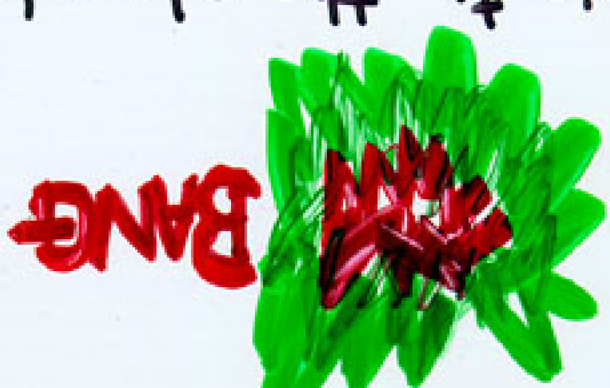
= 10 billion years

= as long as universe

You only need 1 gm of anti-ice

+ water

=



⇒ spaceship to the planets

You only need

1 gm of anti-ice

+ water

=

⇒ spaceship to the planets

---

1 gm anti-ice = 10^{23} anti atoms

CERN 2000/hour

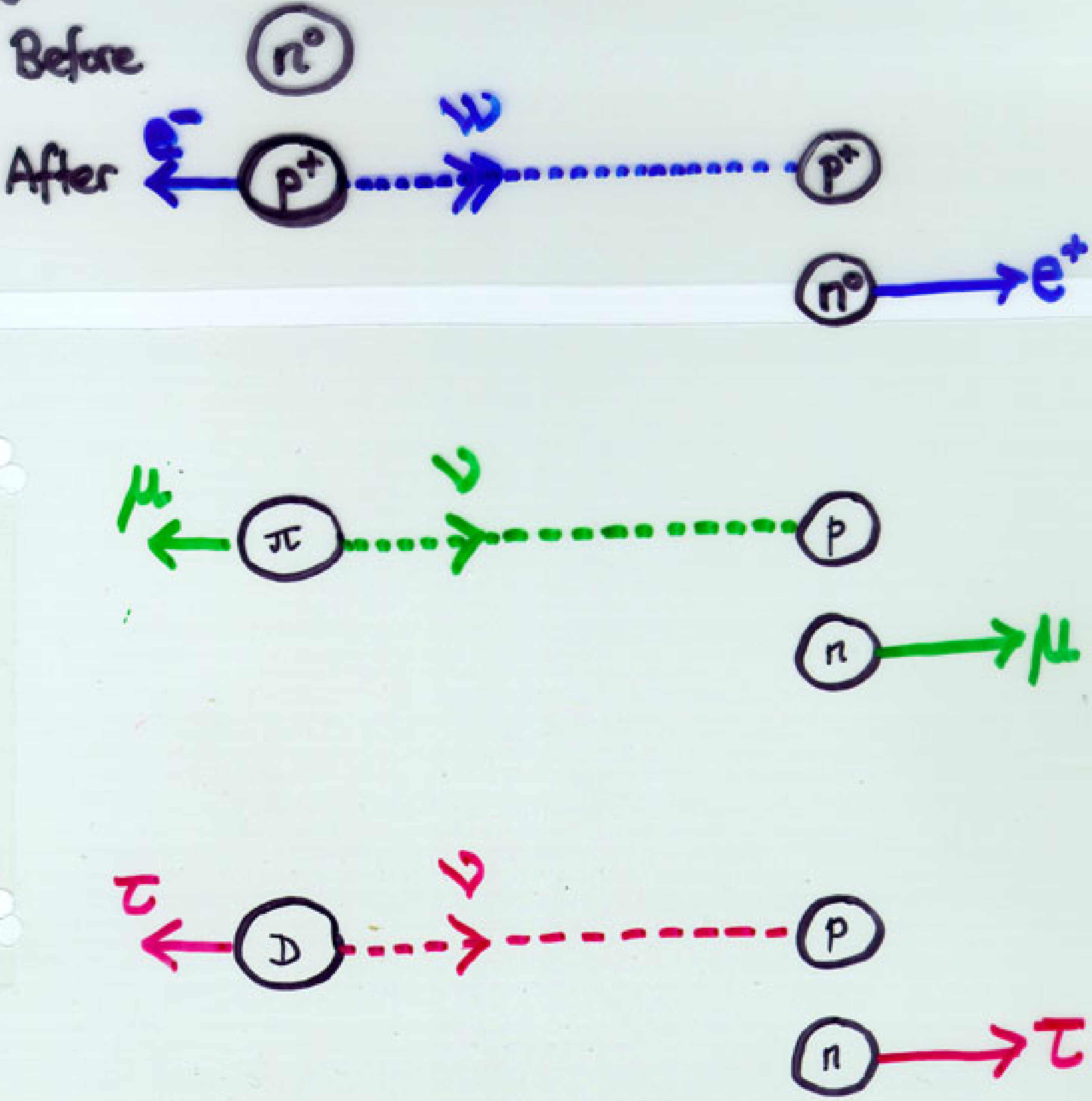
If 2000/second

= 10^{11}/year

= 10 billion years

= as long as universe

30



BUT! If ν have mass

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

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

Probability $a \rightarrow b$

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

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

a disappears b appears

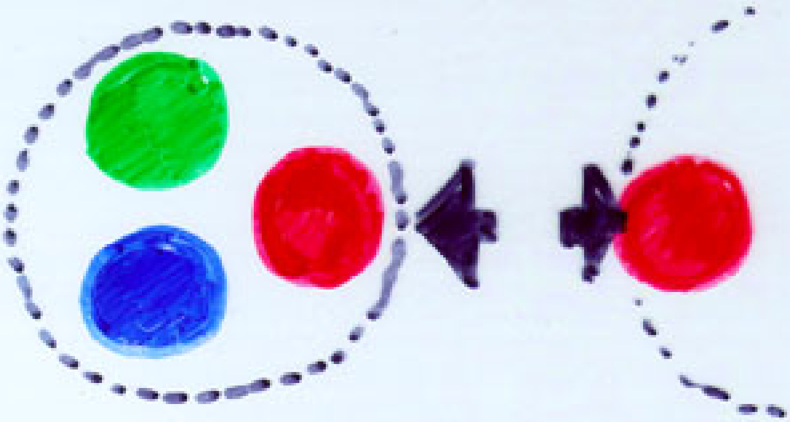
$\Delta m^2 \lesssim 10^{-N}$

$\therefore$ Need large L at high E

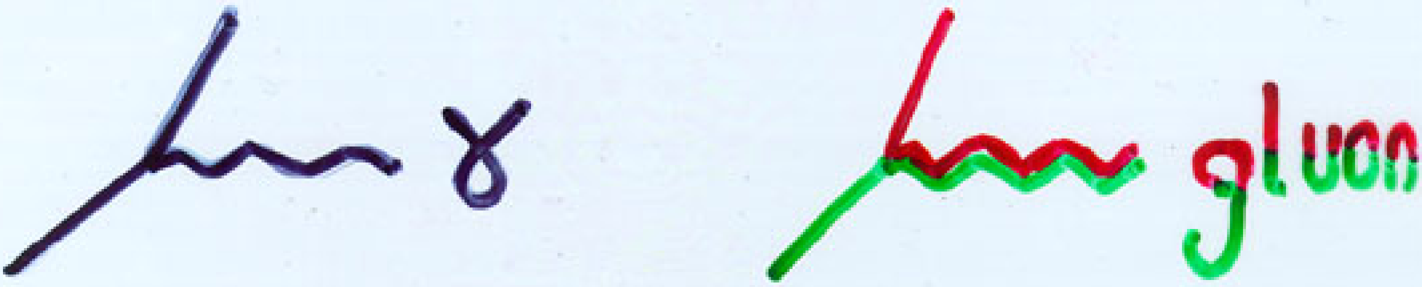
e.g. CERN to Gran Sasso Italy



Electro + Chromo[redacted] Rely. QFT



QED	e^- —	atoms —	molecule
QCD	quark —	p, n —	nuclei



At. source QED QCD syblings

⇓

precision calc.^{n} for quarks

T = 3 minutes after BIG BANG

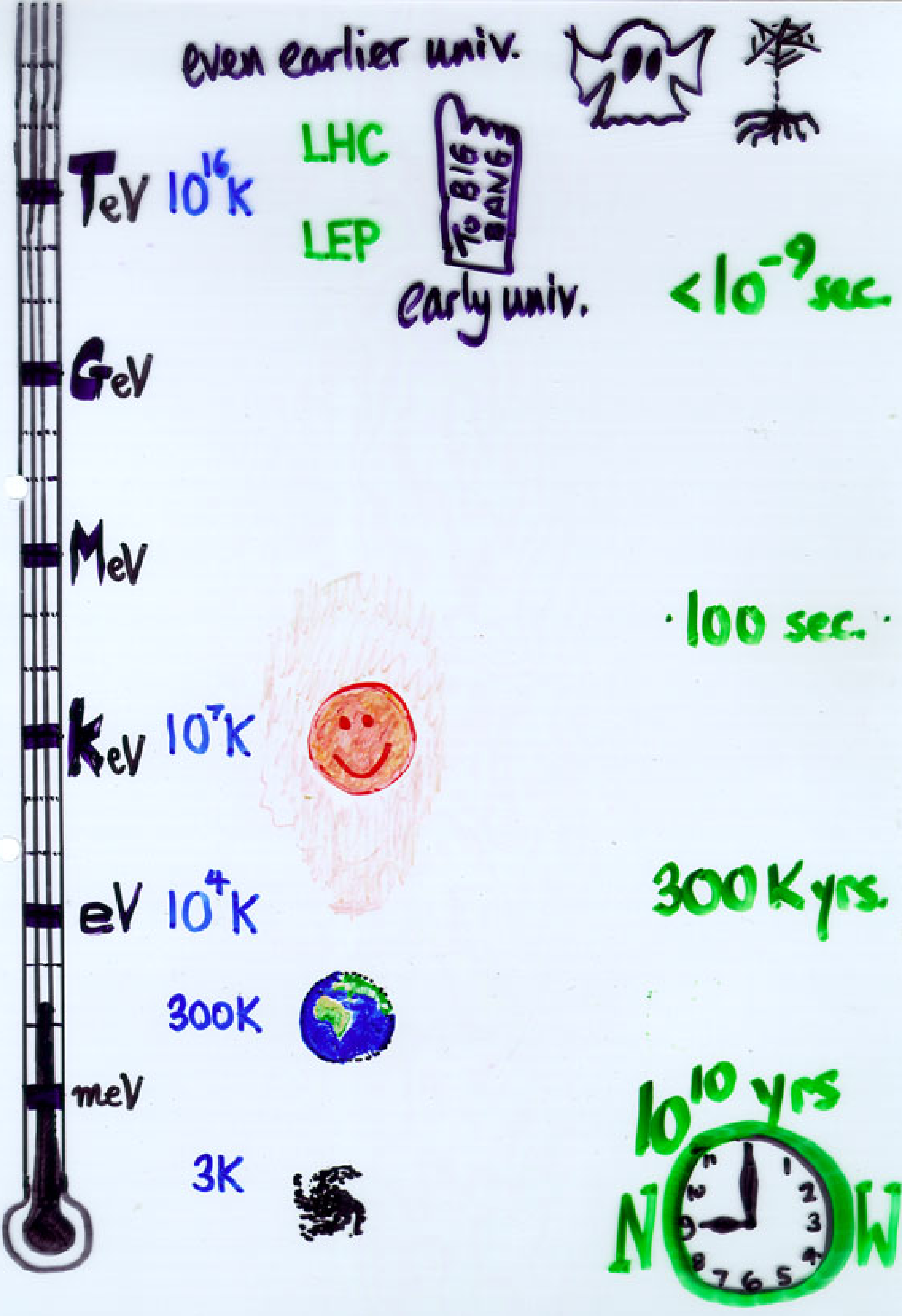
75% protons
24% Helium Nuclei
+ small amount of deuterons
+ free electrons.

✓ if 3 ν species
Helium abundance*: *+ traces of other light elements
depends on expansion rate of the Universe which depends on number of neutrino species

✓ Deuterium abundance
depends on density of "ordinary matter" in the Universe.

IF density of ordinary matter << total in universe

⇒ part of DARK MATTER puzzle


even earlier univ.
LHC
LEP
TO BIG BANG
early univ.
TeV
10^{16}K
$<10^{-9}$sec.
GeV
MeV
100 sec.
KeV
10^{7}K
eV
10^{4}K
300 K yrs.
300K
meV
10^{10} yrs
3K
NOW

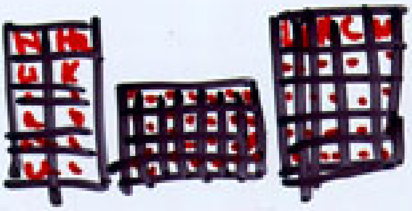
No mass. Unified Theory

Standard Model MASS

t	b	τ	ν	W
c	s	μ	ν	Z
u	d	e	ν	γg

Nuclear Isotopes

Mendeleev



Snowflake pattern