british science festival
BIRMINGHAM
14-19 SEPT 2010

Particle Physics and the mysteries of the early Universe

Science & Technology Facilities Council

THE ROYAL SOCIETY
CELEBRATING 350 YEARS

UNIVERSITY OF BIRMINGHAM

Cristina Lazzeroni
Royal Society University Fellow
University of Birmingham

Saudi Aramco

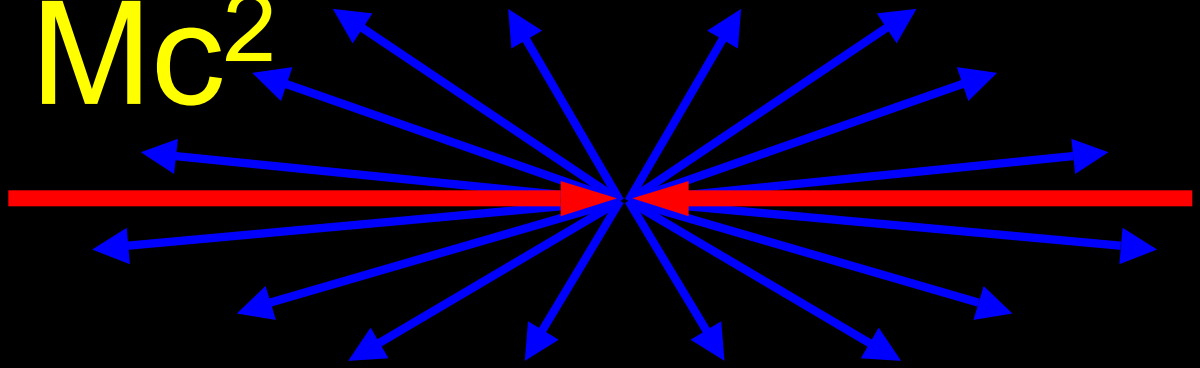
Birmingham City Council

Birmingham Science City
ideasforlife

Aston University
Birmingham

Particles accelerated to speed of light :

$E = Mc^2$



Protons smashing together can produce all sorts of particles, seen in the earliest moments of the universe

$E = h\nu$ h = Plank constant

Particle-wave equivalence

The 'Large Hadron Collider' accelerates 2800 bunches, 10^{11} protons per bunch, at 7 TeV

This corresponds to:

350 MJ stored energy per proton beam

= Kinetic energy of 1200 elephants running at 25 mph

= Kinetic energy of family car travelling at 1000 mph

= Kinetic energy of fully loaded Airbus A320 at landing speed

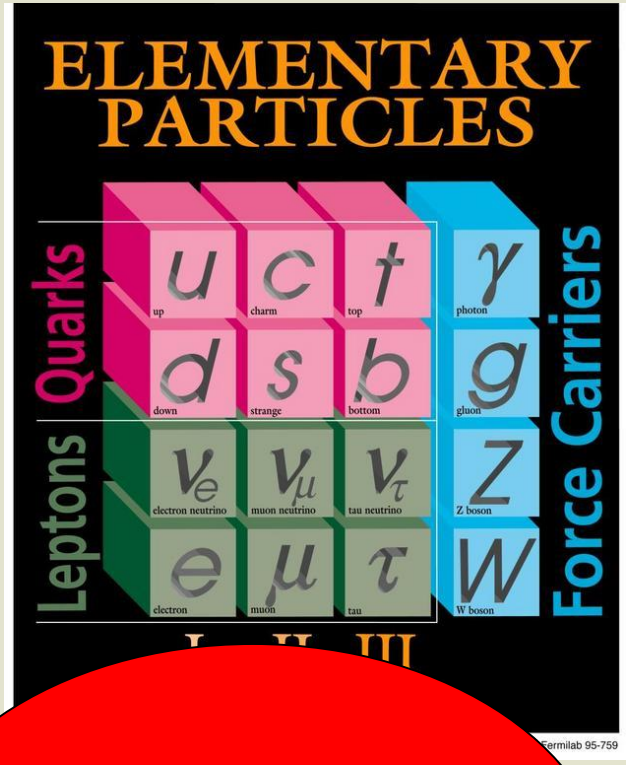
= Enough energy to melt 550 kg copper

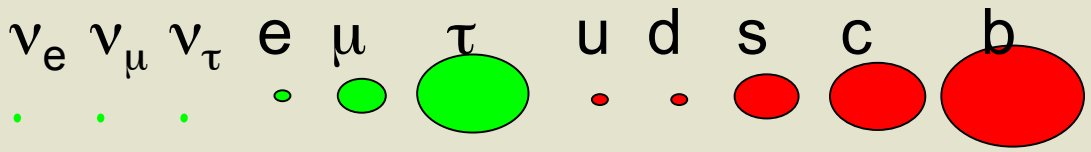
TOTAL ENERGY STORED in LHC superconducting magnets: 10 GJ = "An avalanche"

(10000 t of snow, sliding down 100 m)

cake tin, football,
ping pong balls

Overall there are
6 quarks, 6 leptons, 4 force carriers





top quark

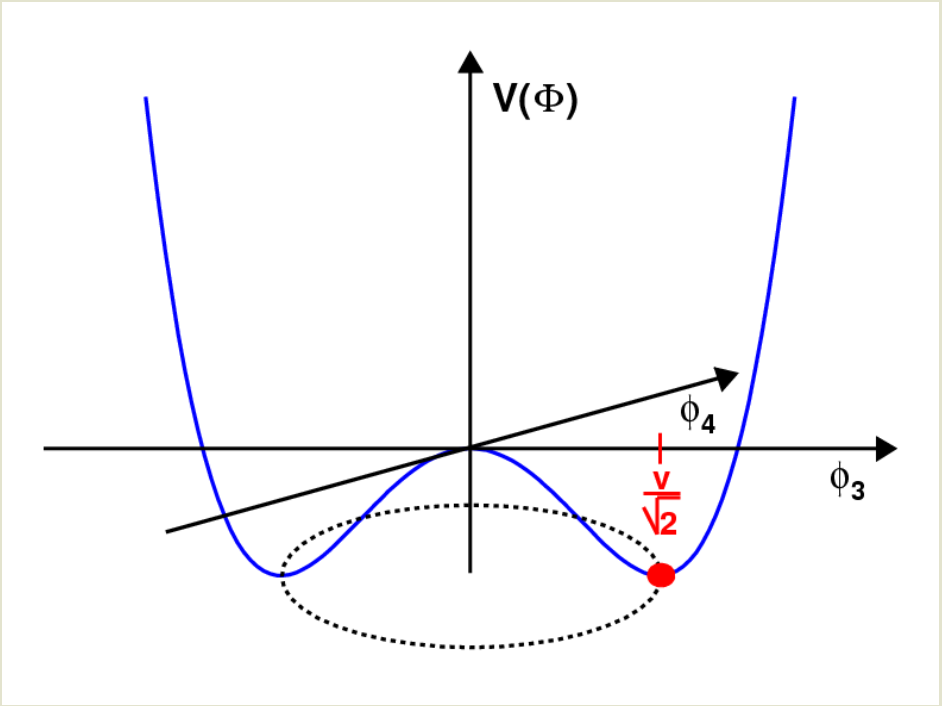
W

Z

All nice, simple, understood ?!

Higgs field -
magnetic field

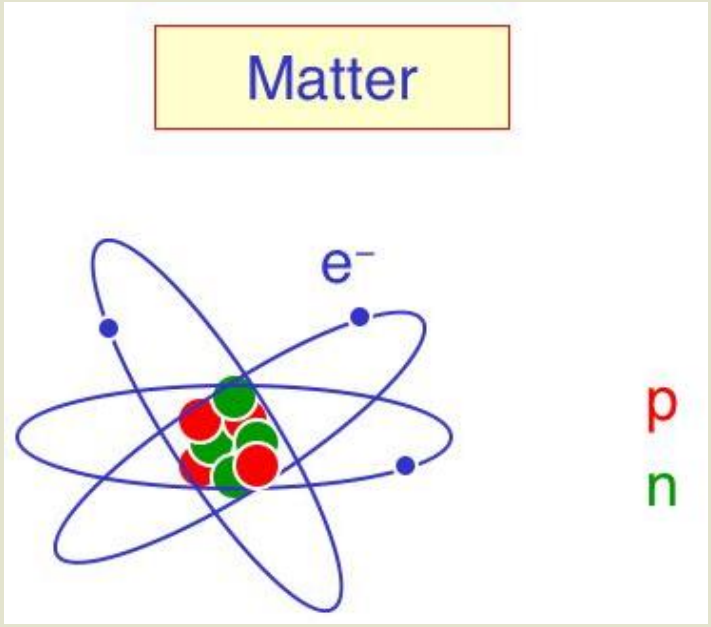
The “Mexican hat” : radial symmetry

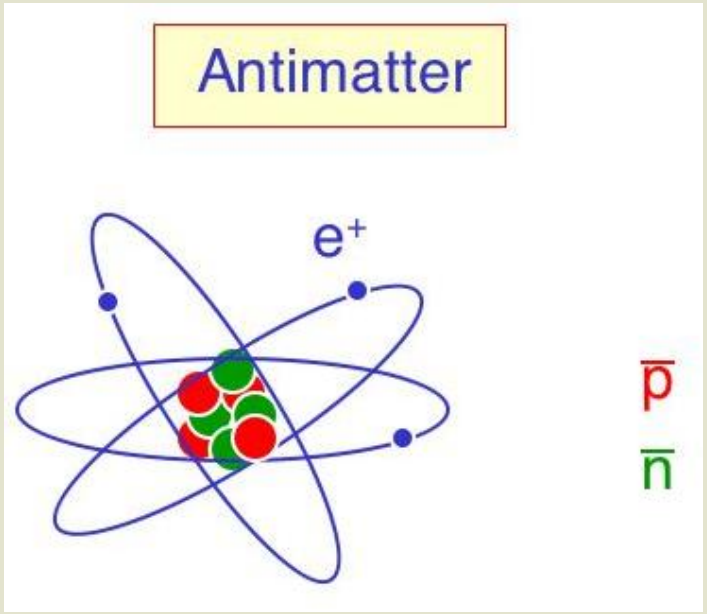


A ball at the top of the ‘hat’ can fall down in any direction, all equally probable. When it does fall, a particular direction is chosen and the symmetry is broken

Higgs events are rare

Matter and Anti-matter





Equal quantities of Matter and Anti-matter should have been produced in the Big Bang, then annihilated each other leaving just radiation

Antimatter in the story of

ANGELS & DEMONS

In the Angels and Demons story, the bad guys go to a laboratory called “CERN”.

They steal half a gram of antimatter in a canister, which they then take to Rome to use as a bomb.

A feather weigths about ½ gram.

How Long to Get Half a Gram?

All the antimatter produced in accelerators annihilates within a fraction of a second.

If LHC could somehow accumulate all the antimatter it produced,

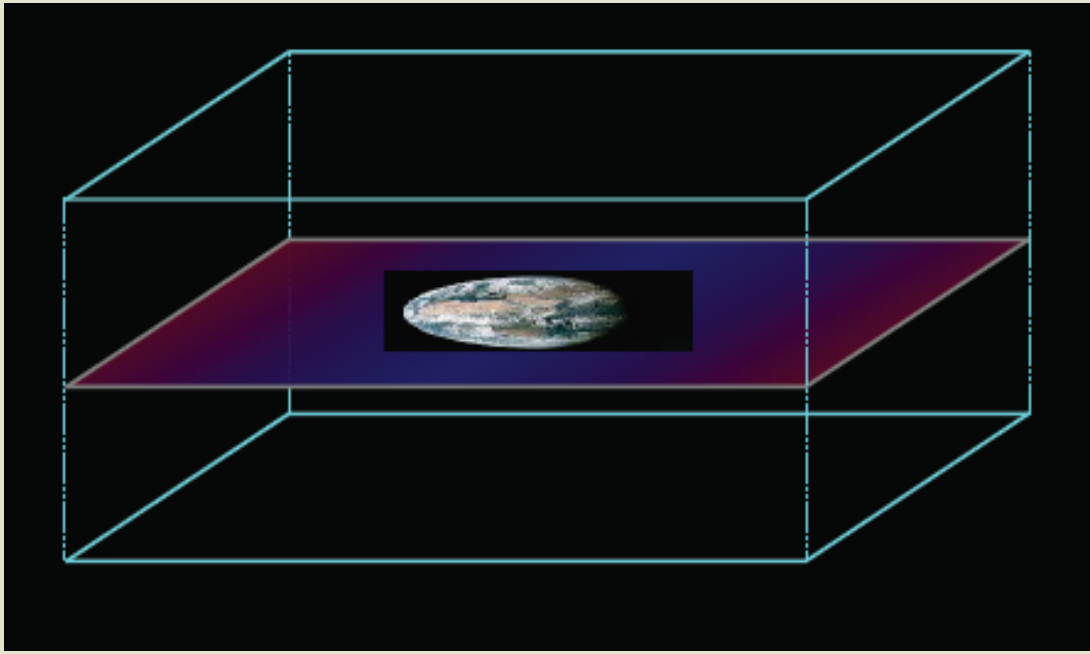
it would take 10 million years to get ½ a gram of antimatter

How many spacetime dimensions? No reasons why they should be 3 ... apart from observational reasons !

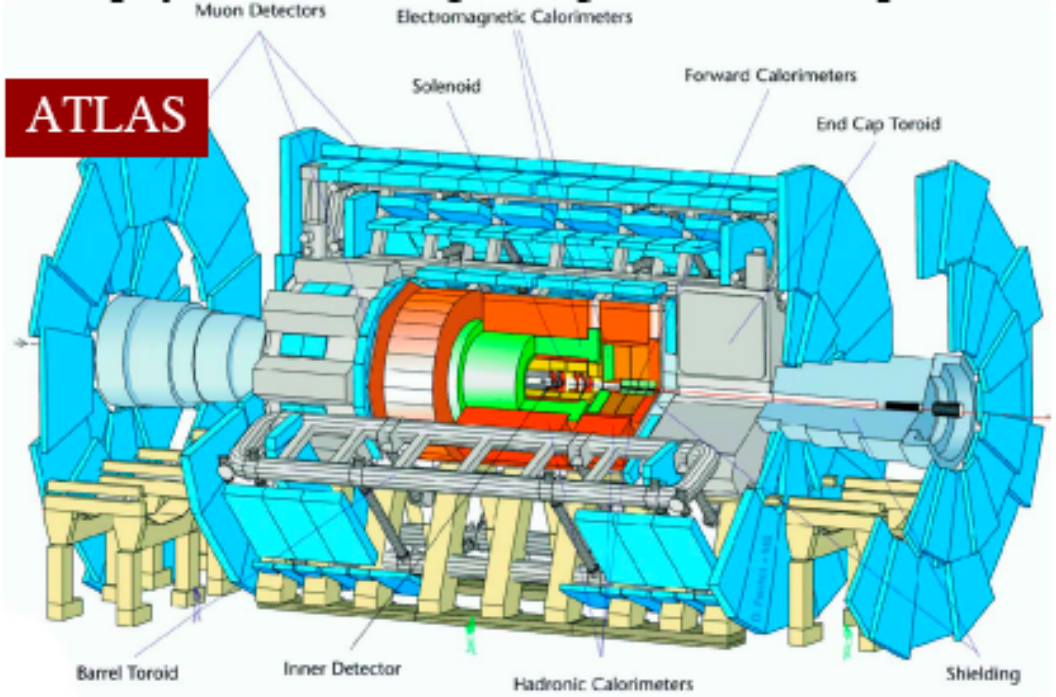
New dimensions can be small

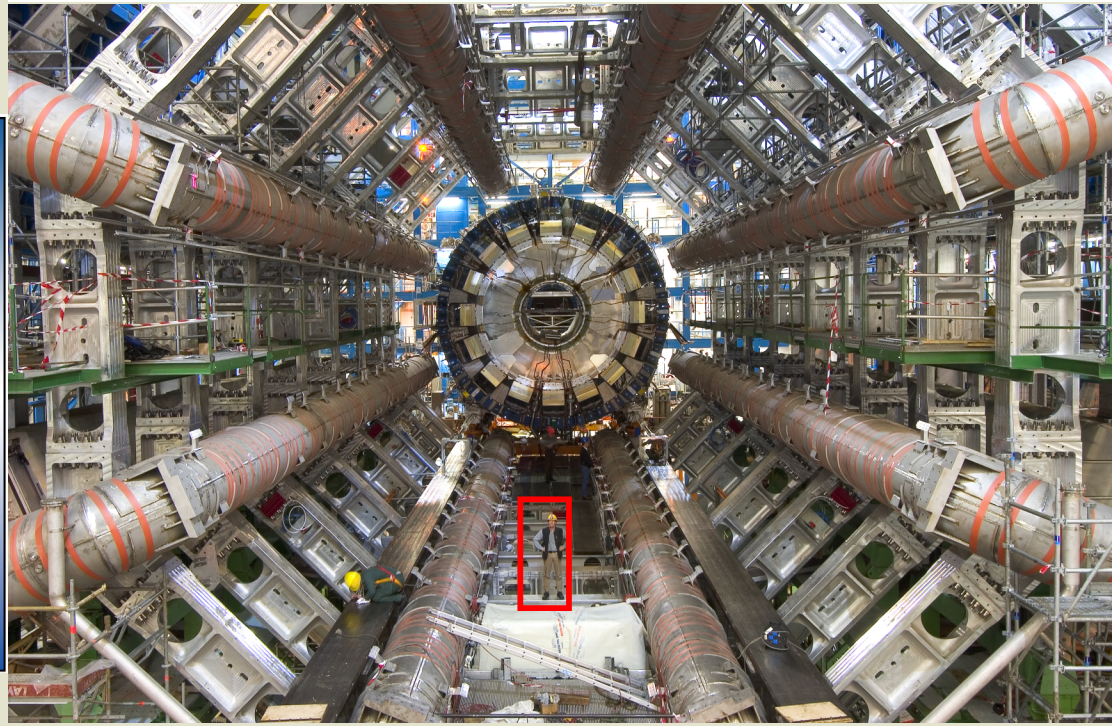
Or impossible to detect :

Particles would become extended objects

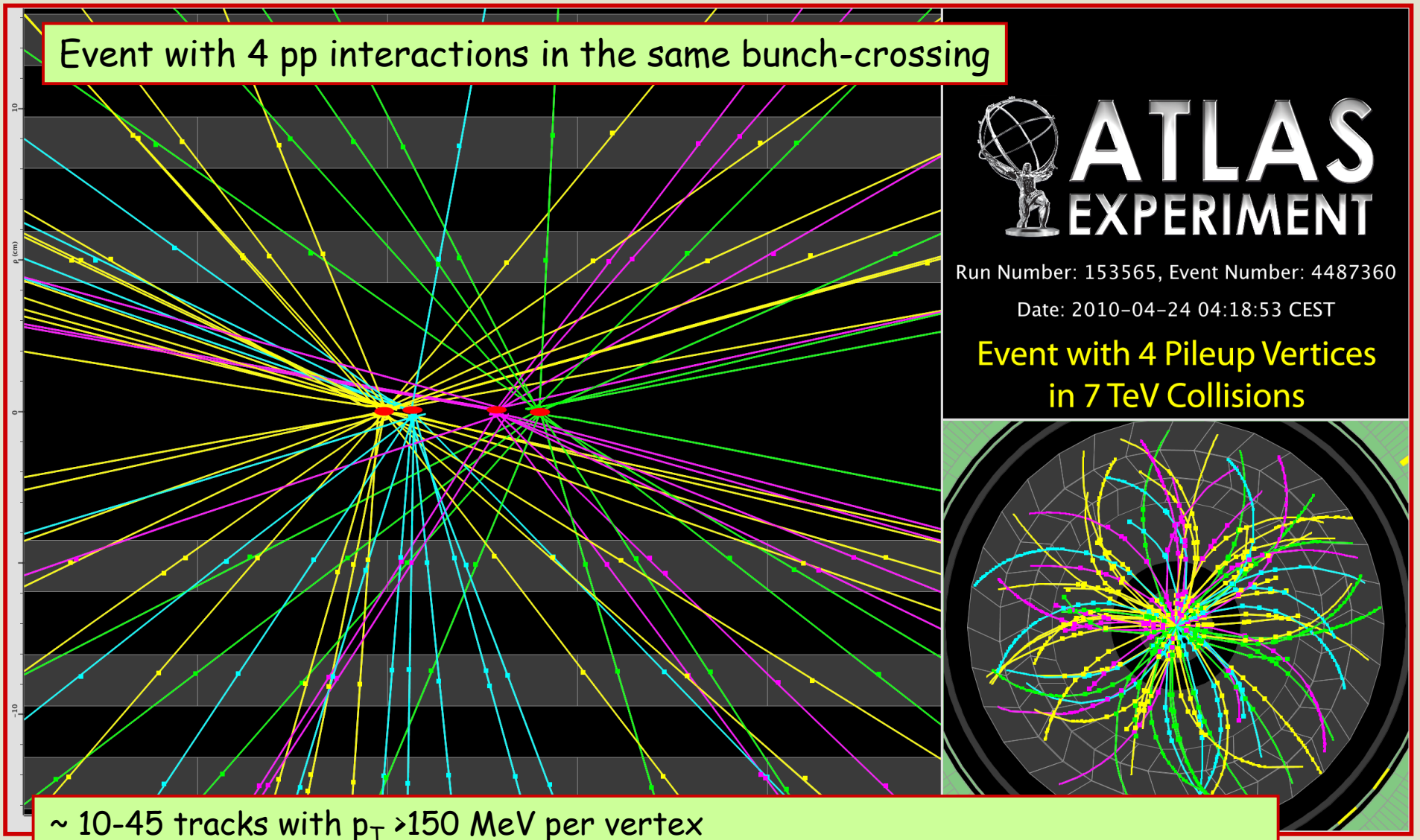


World's most massive "onion" structure to capture the particles



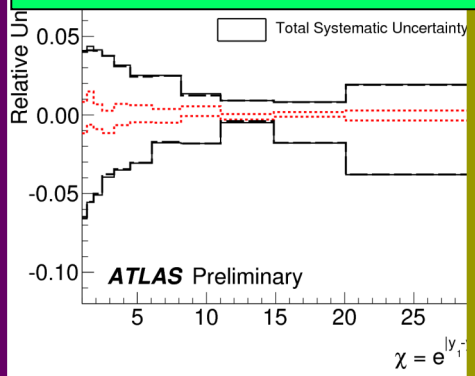


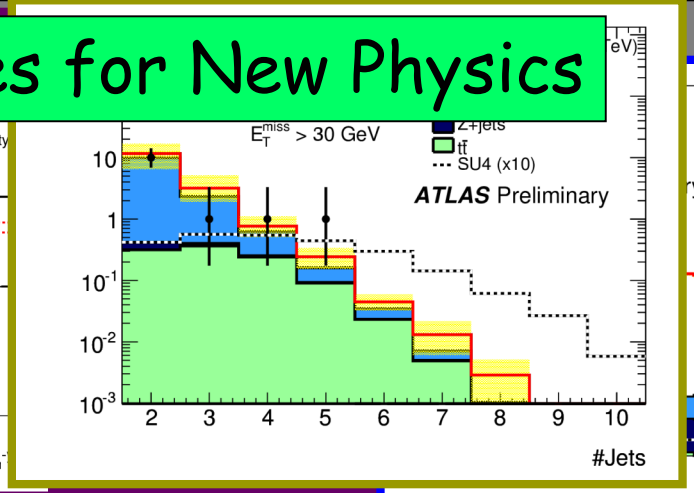
Max peak luminosity: $L \sim 1.6 \times 10^{30}\ cm^{-2}s^{-1}$
→ average number of pp interactions per bunch-crossing: up to 1.3
→ "pile-up" (~40% of the events have > 1 pp interaction per crossing)

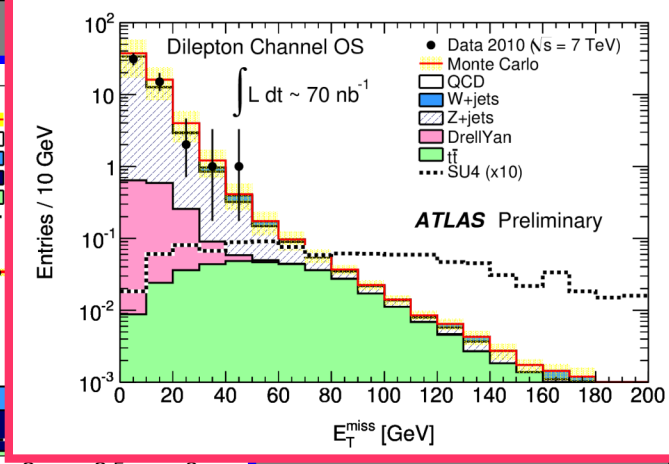


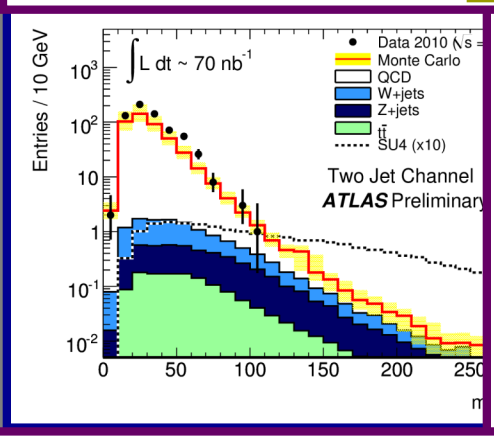
~ 10-45 tracks with p_T >150 MeV per vertex
Vertex z-positions : −3.2, −2.3, 0.5, 1.9 cm (vertex resolution better than ~200 μm)

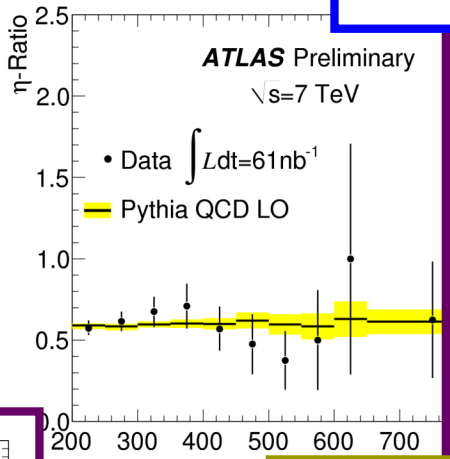
First searches for New Physics

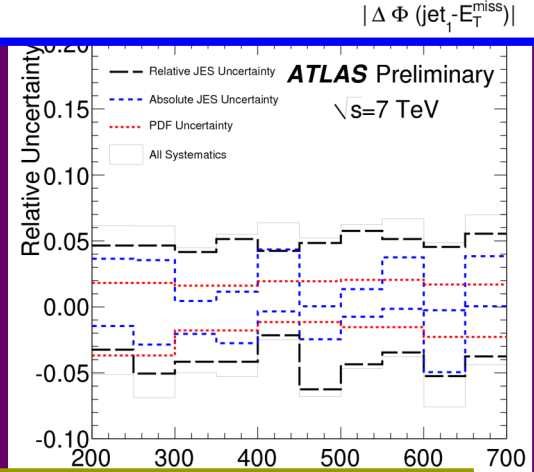


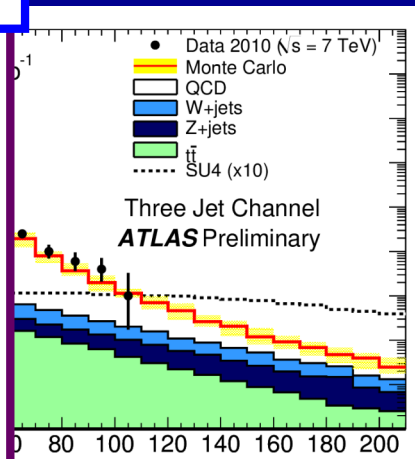


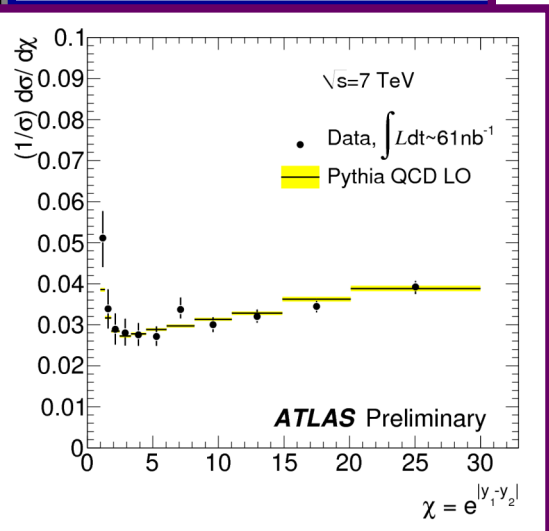


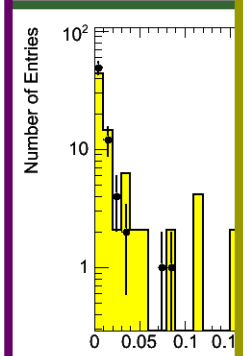


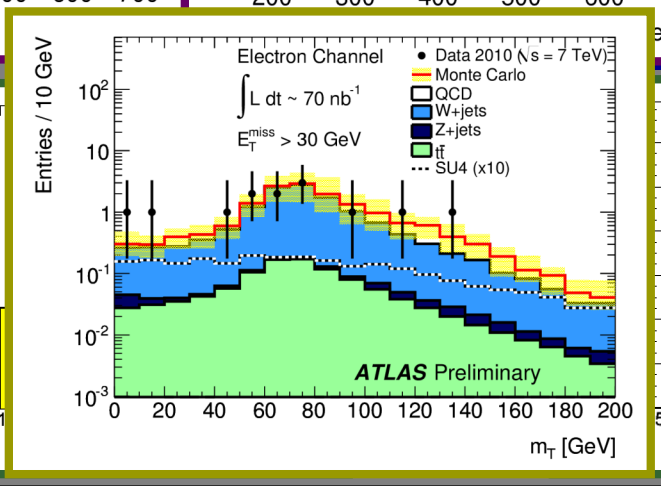


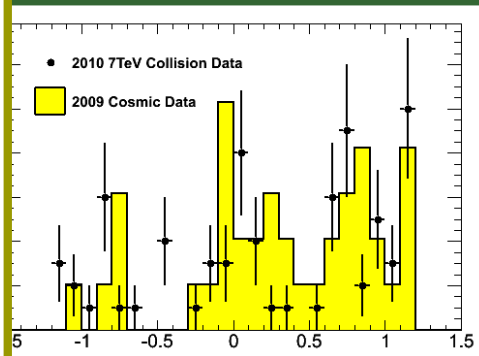










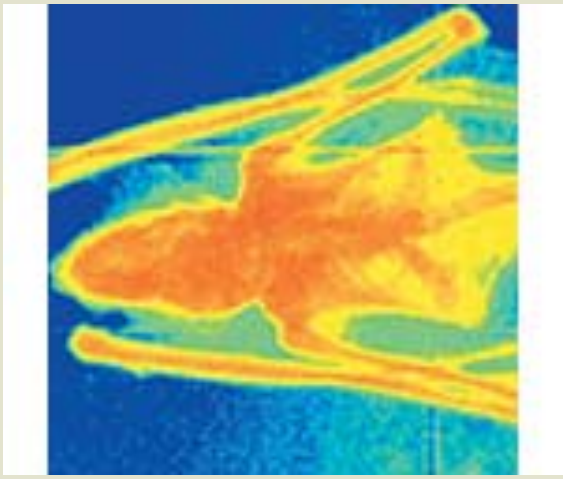


Spares

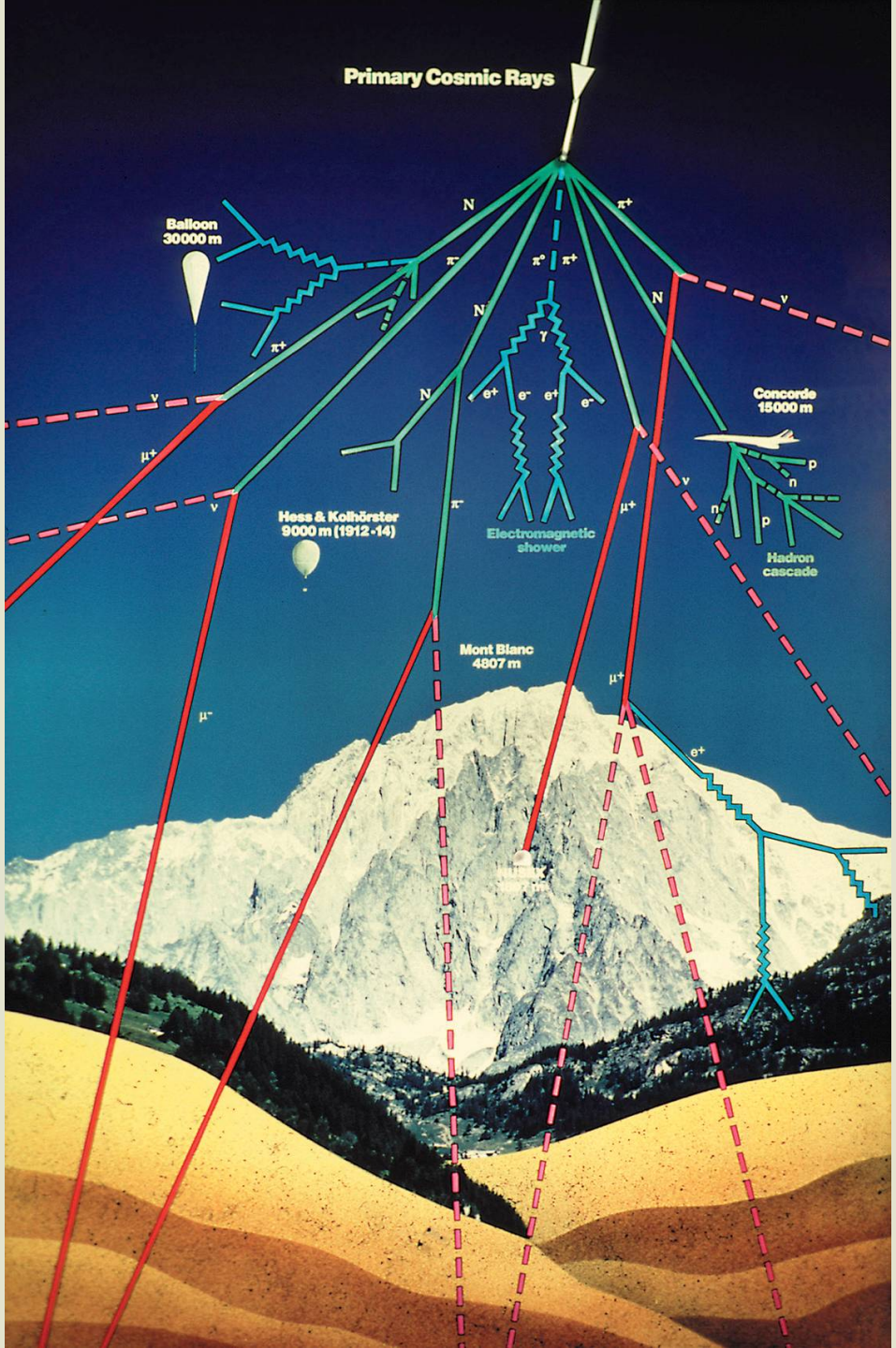
Benefits

First, the new knowledge.
Also, the technology is pushed to the limits
and produces many practical applications

Most of the 17000 particle accelerators are used in medicine for cancer treatment
Particle detectors are used in medical imaging



Then the computing :
the world wide web !
And soon the GRID



- Primary cosmic ray in upper atmosphere
- Collision with nucleus
- Initiates “cascade”
  - Secondary cosmic rays

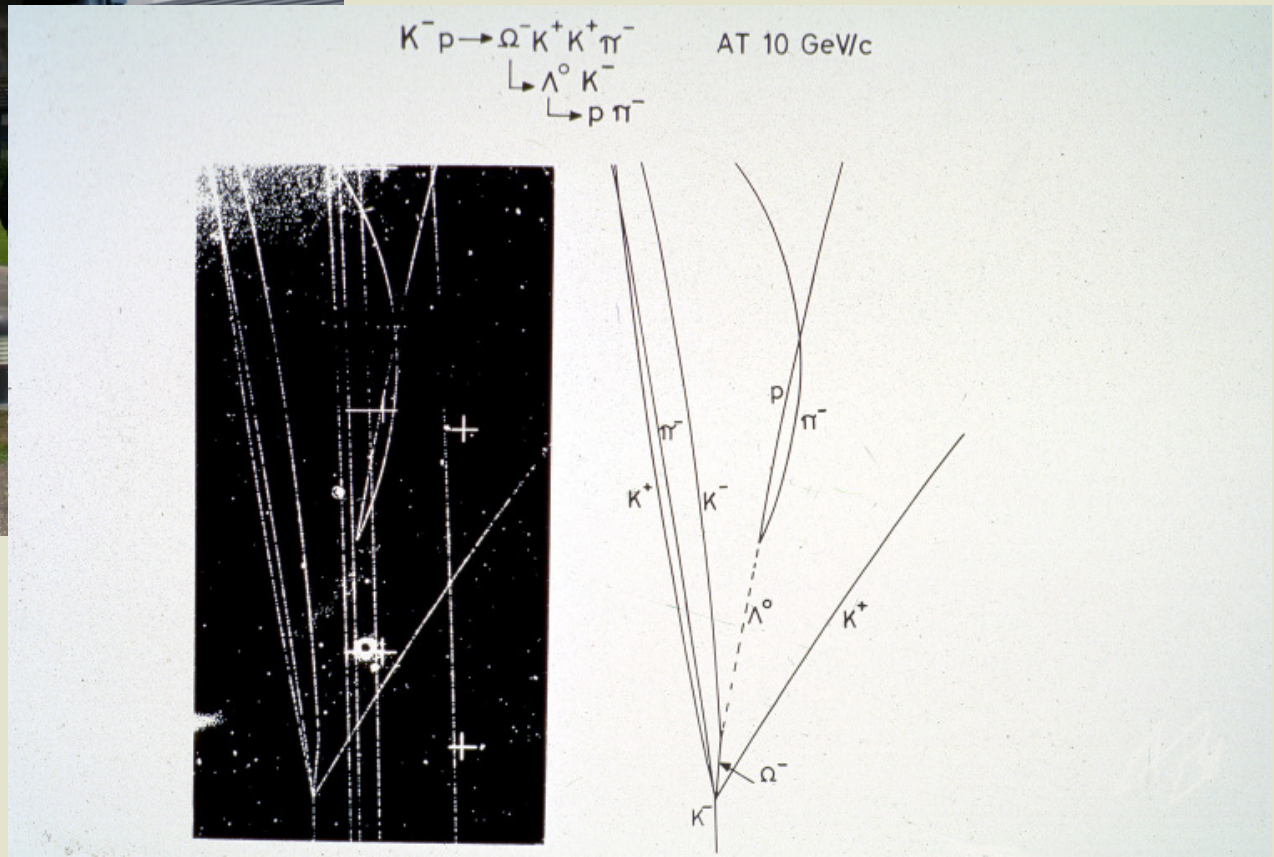
  (pions that decay into muons, electrons and neutrinos)
  - Higher energy primary
    - larger secondary shower
- Time dilation effects:

muons arrive at ground level

Detecting Particles

- **Only 1 event / second**
- **Photos scanned by hand**
- **No selection on events**

Used Bubble Chambers up to 1970s



the Universe was born with
equal amounts of matter and antimatter

$t = 0$

CP violation :

(and B violation and
phase transitions)

the Universe contains
slightly more matter than antimatter

$t \sim 1\mu\,\mathrm{sec}$

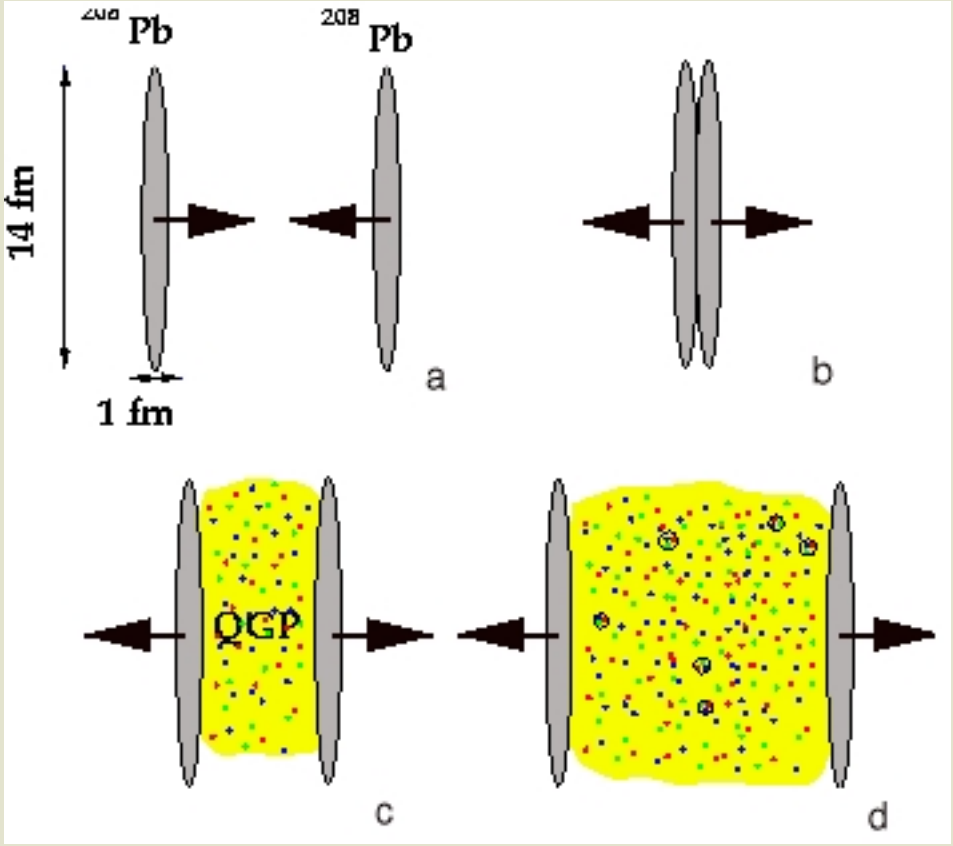
Particles and anti-particles annihilate :

the Universe contains only matter
(and lots of photons)

$t \sim 1\,\mathrm{sec}$

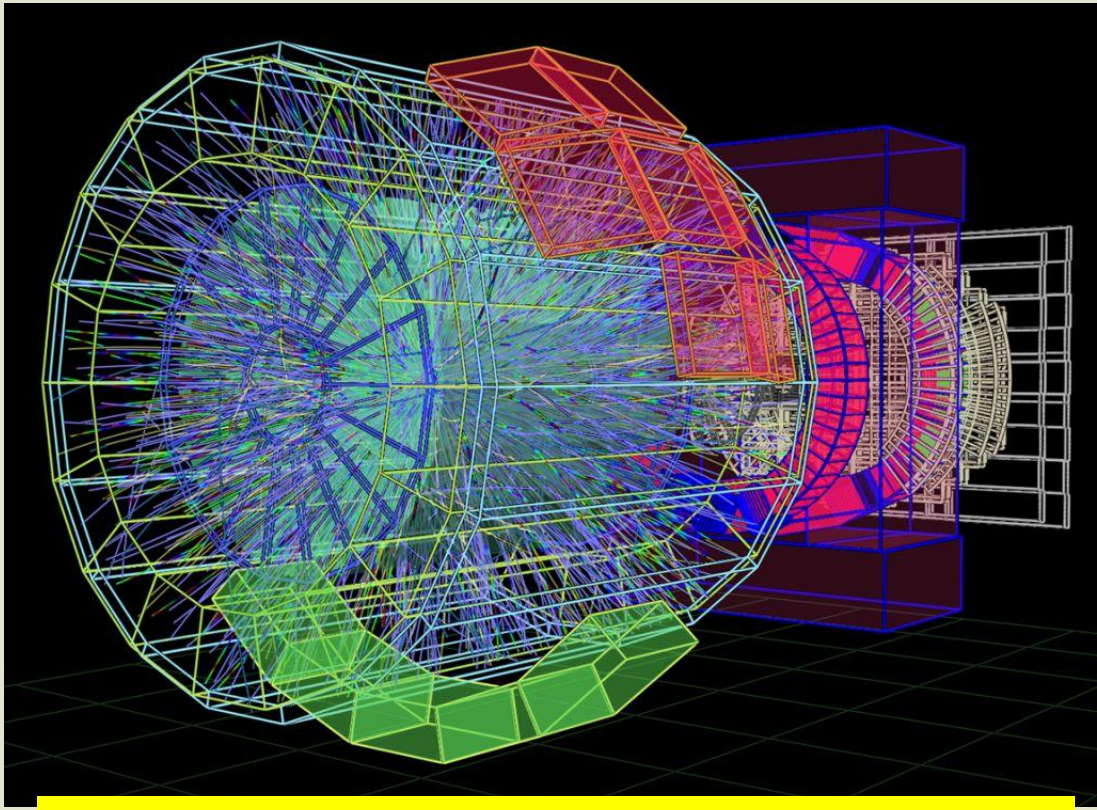
How to Make a QGP

- Need very high energy densities
- Create sub-atomic volumes of hot, dense matter similar to conditions 10^{-6}s after Big Bang
- Fireball must live long enough for phase transition to take place
- **Collide lead ions (lead nuclei) at highest energies**



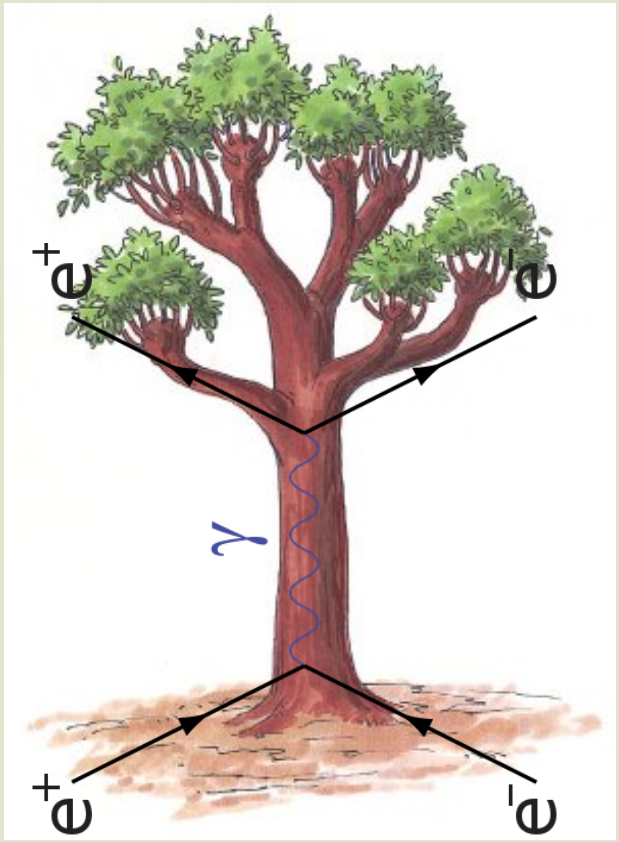
What Happens ?

- Energy is converted into many quarks, anti-quarks and gluons.
- QGP lasts for about 10^{-22} seconds
- Then thousands of particles are produced

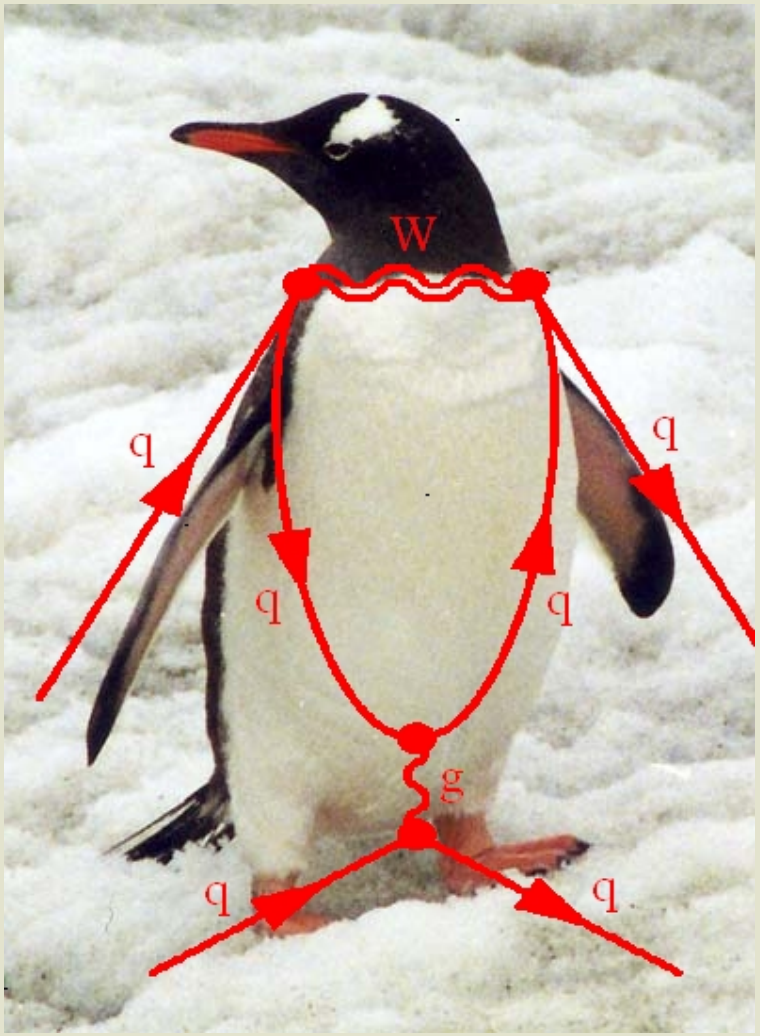


We have to study the QGP from this!

Feynman diagrams



Trees



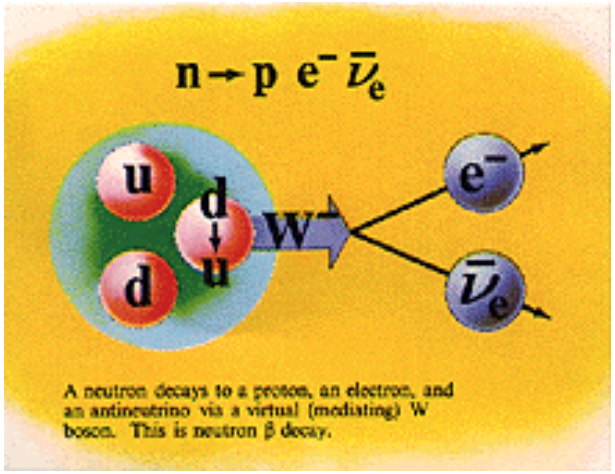
Penguins

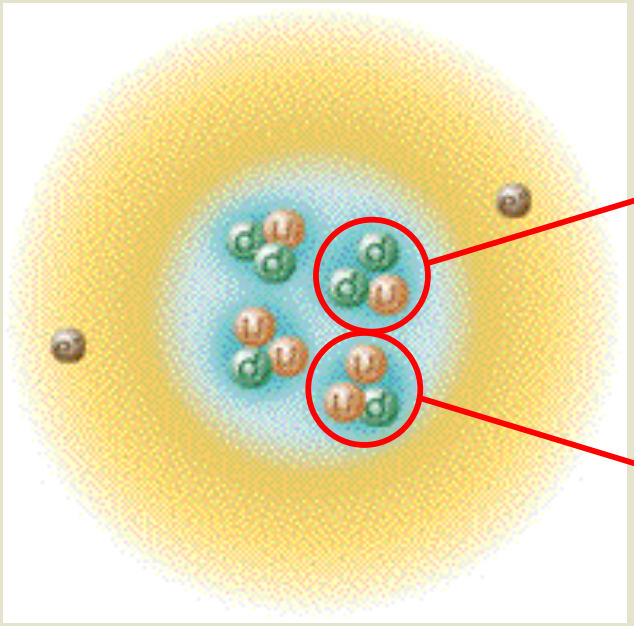
How stars generate energy

Weak Force

Enrico Fermi
(1901 - 1954)

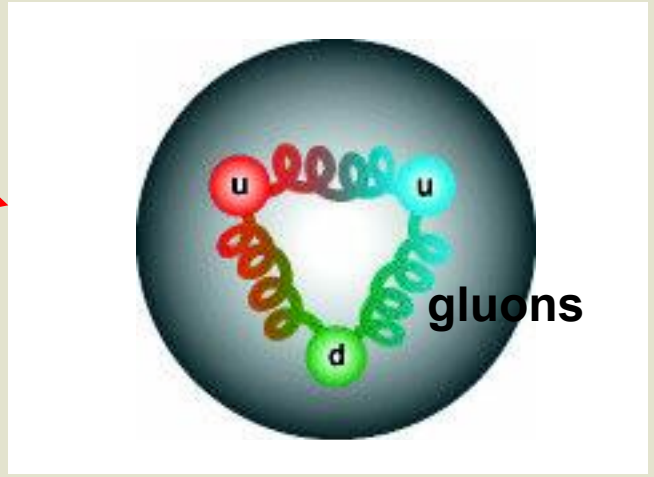
radioactive decays





neutron decay

holding proton, nucleus



Strong Force

Size of nuclei is set by strength of strong force