Summer 2009

High Energy Particle Physics at the University of Tennessee

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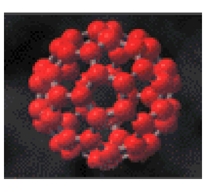
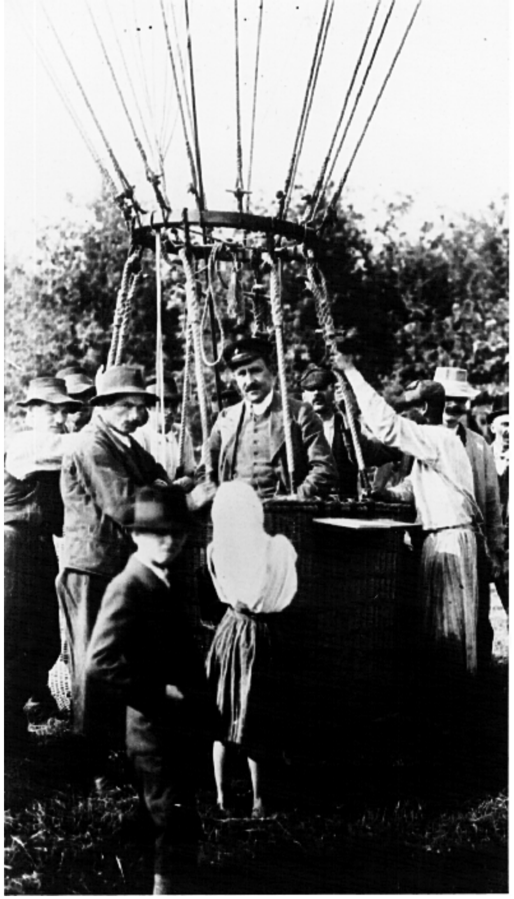



The University of Tennessee
Department of
Physics & Astronomy

• Cosmic Rays - Particle Physics: The Beginnings



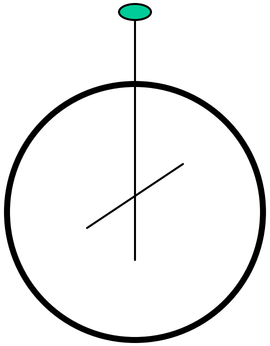
•1785 - Coulomb notices that a charged body left in air gradually loses its charge.

•1905 - Rutherford concludes radioactivity in the earth is responsible.

•1912 - Victor Hess reaches 5350 m altitude in a hydrogen filled balloon and shows conclusively that the rate of discharge increases significantly with height. He concludes that there is an extraterrestrial source of radiation.

(receives Nobel prize 1936)

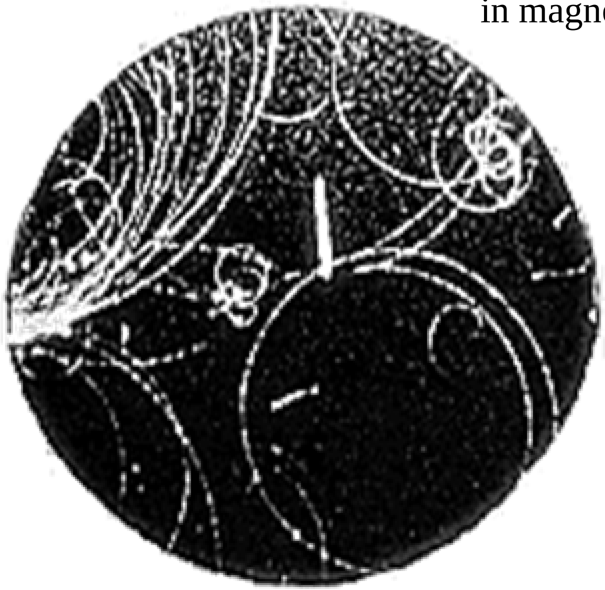
Electrometer:



• Cloud Chamber as Particle Detectors

Chamber filled with supersaturated vapor (water)

in magnetic field

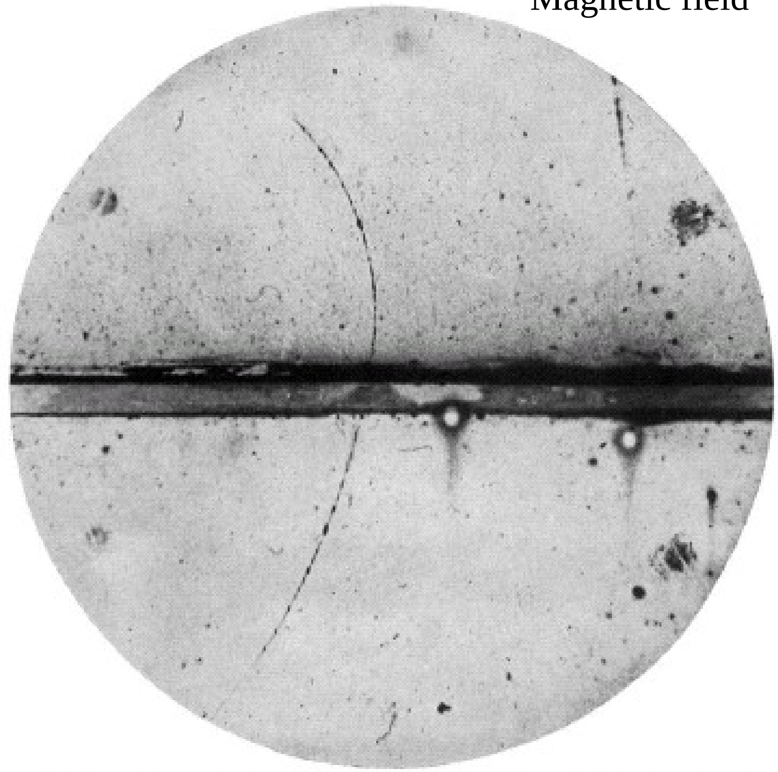


Expand and illuminate to take photograph

• The positive electron - First Discovery of Anti-Particles

Magnetic field

1932 C.D.Anderson (Caltech)



} *6 mm of lead*

FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

Fits into theory: P.A.M Dirac

relativistic wave equation for electrons predicts the existence of particles with charge opposite to electrons but same mass.

➔ Equation is invariant under C-parity transformation (fundamental symmetry)

$$C\, e^- = e^+$$

➔ Other important symmetry is parity P: $P\,\vec{r} = -\vec{r}$

How does it get produced ?

• Particle detection

Detection of elementary particles is based on their interaction with matter.

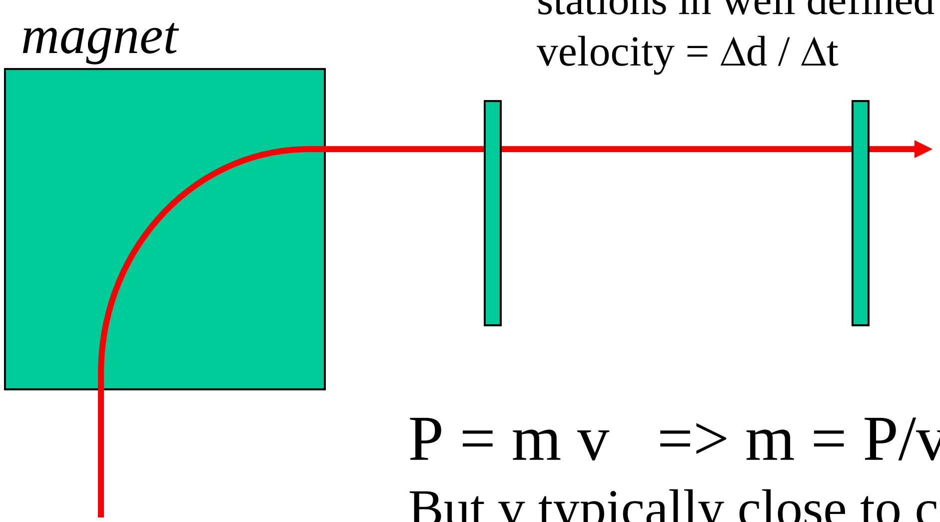
1937 Neddermeyer, Anderson find a heavy particle, but not as heavy as the proton in cosmic rays → the muon

➔ check the energy loss of the particle in a metal plate and its momentum (curvature) in magnetic field

Another idea of resolving a particles mass:

Curvature ~ momentum P

Measure time of flight, Δt, through two stations in well defined distance Δd
velocity = Δd / Δt



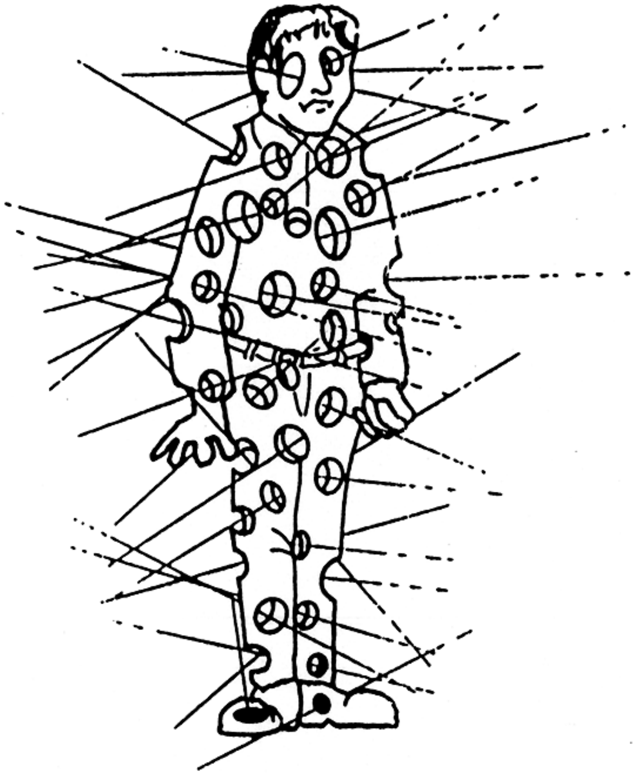
P = m v => m = P/v

But v typically close to c, speed of light

therefore $m = m_0 \gamma$, m_0= rest mass

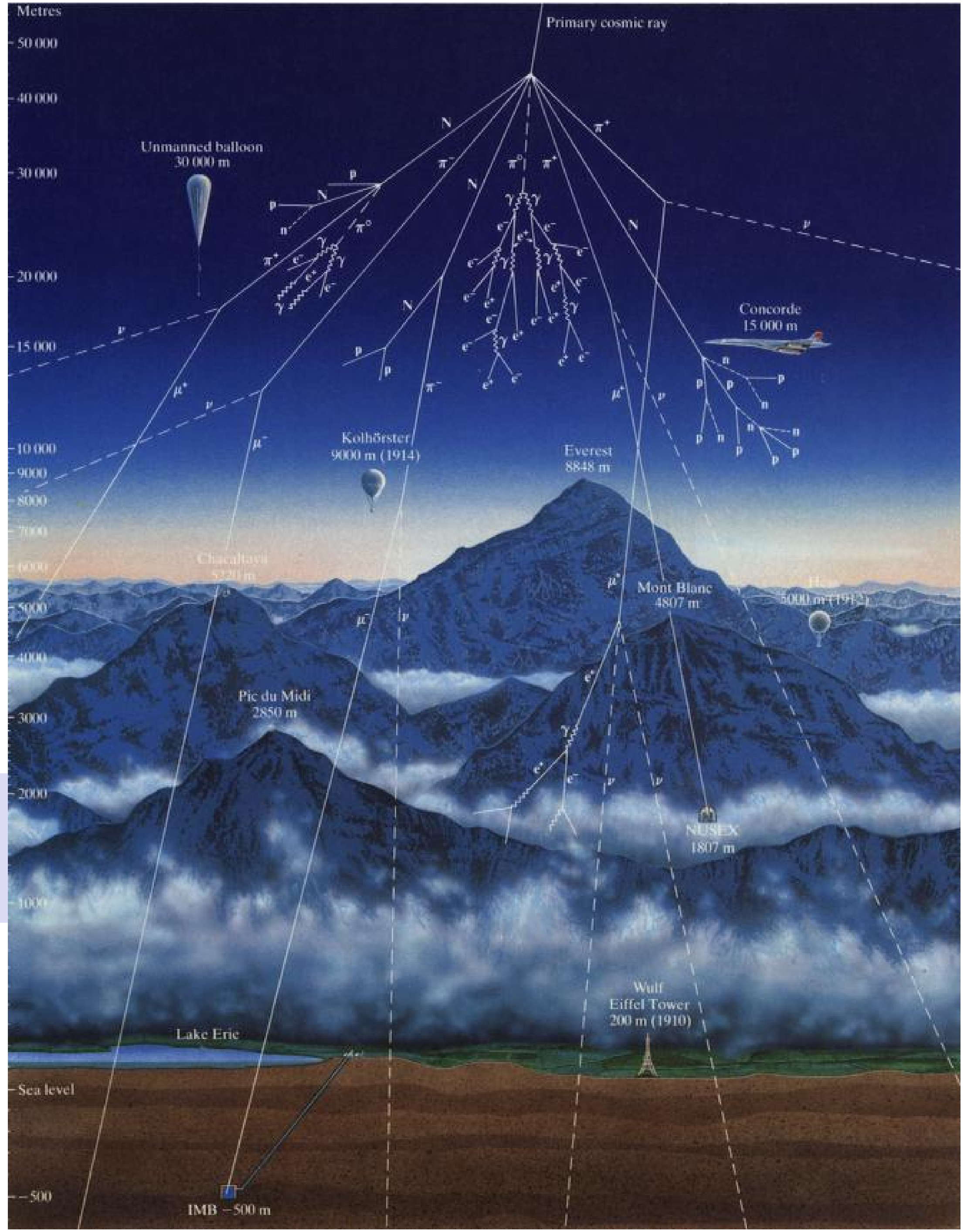
and for limited momentum range

• Cosmic ray laboratory



Cosmic Rays continually bombard the Earth. In fact, a large amount of cosmic rays will pass through a person every hour!

Cosmic rays are very energetic, but not sufficiently reliable and their rates are low !



• Why reliable energy ?   Resolution of smaller Dimensions

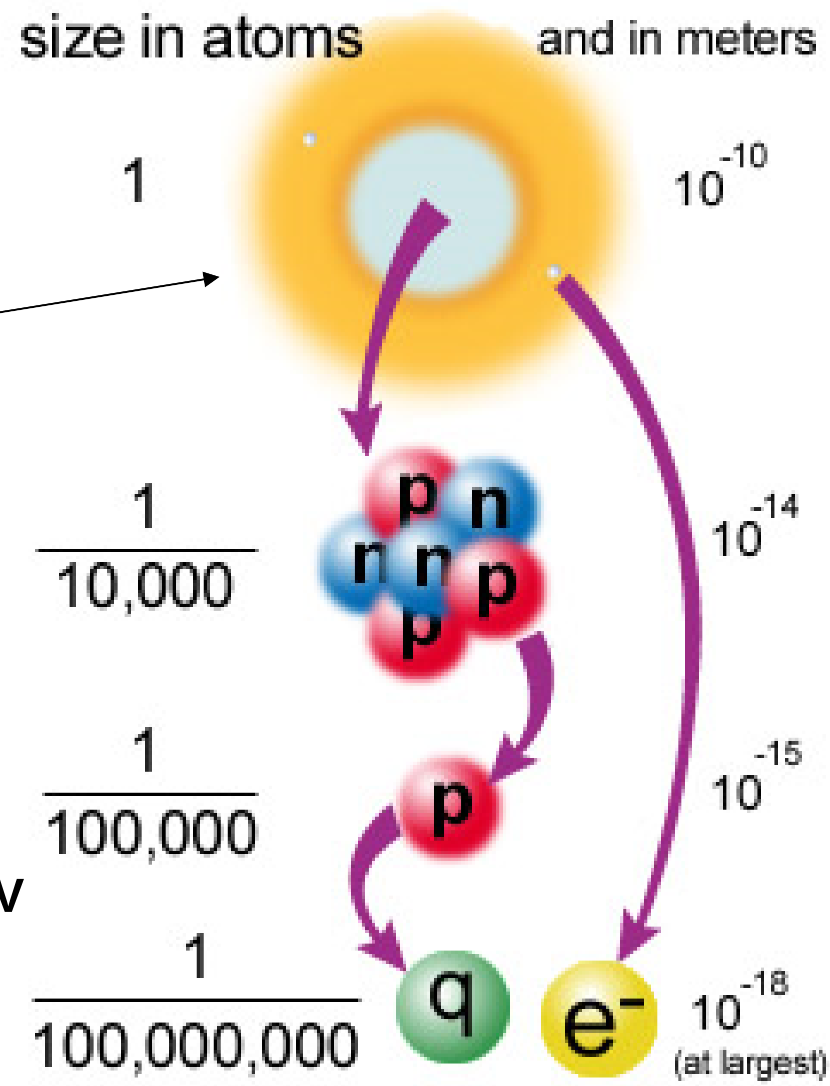
Wavelength $\approx$ dimension to be resolved

Wavelength $\propto$ 1/Energy

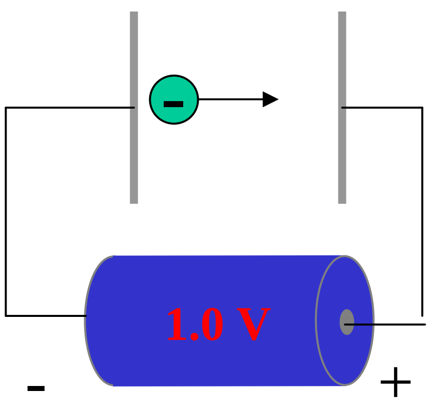
→ The smaller dimension the higher the energy of the light (particle)

Energy $\approx$ 10 kilo electron Volt (eV)

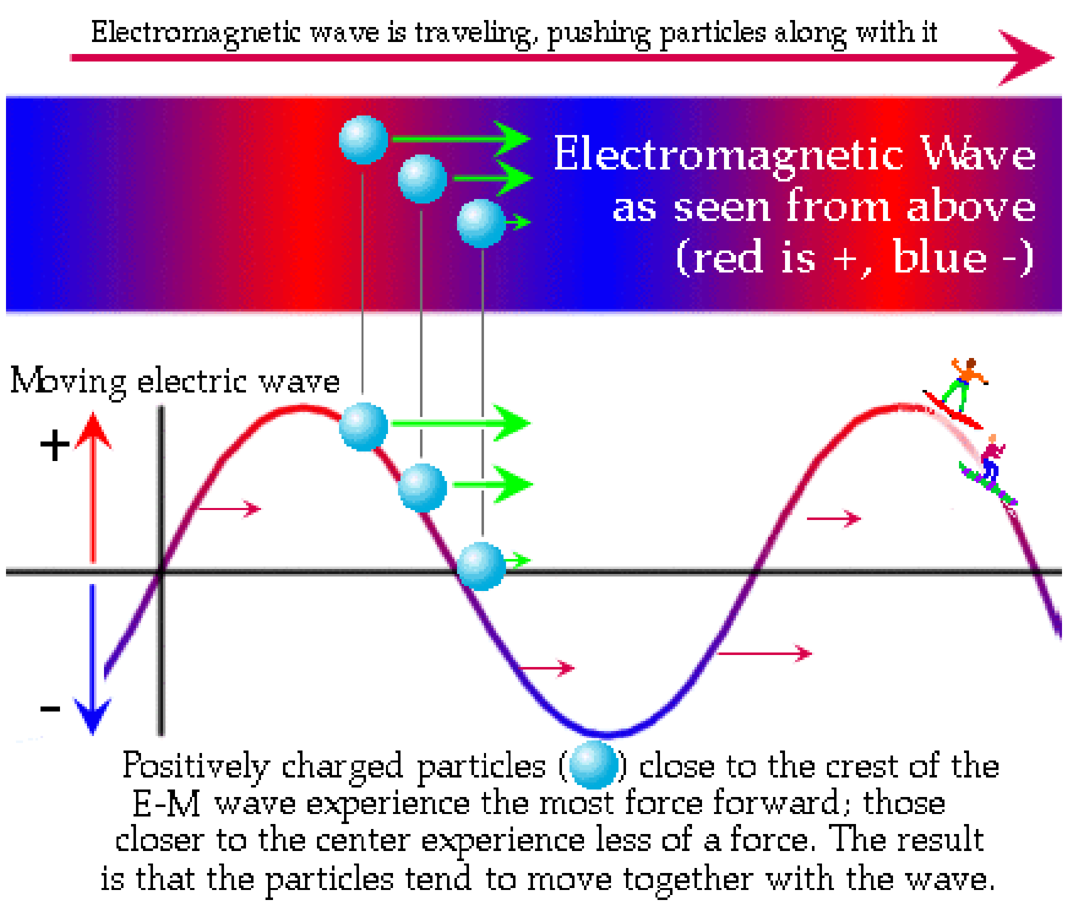
1eV = kinetic energy an electron gains in a electric field of 1 Volt



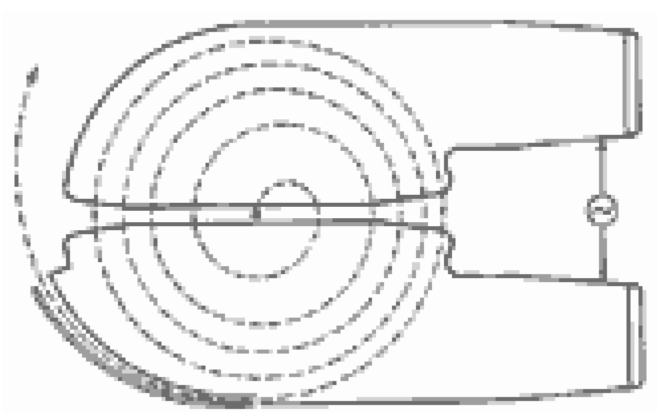
> 100 MeV



• Accelerators

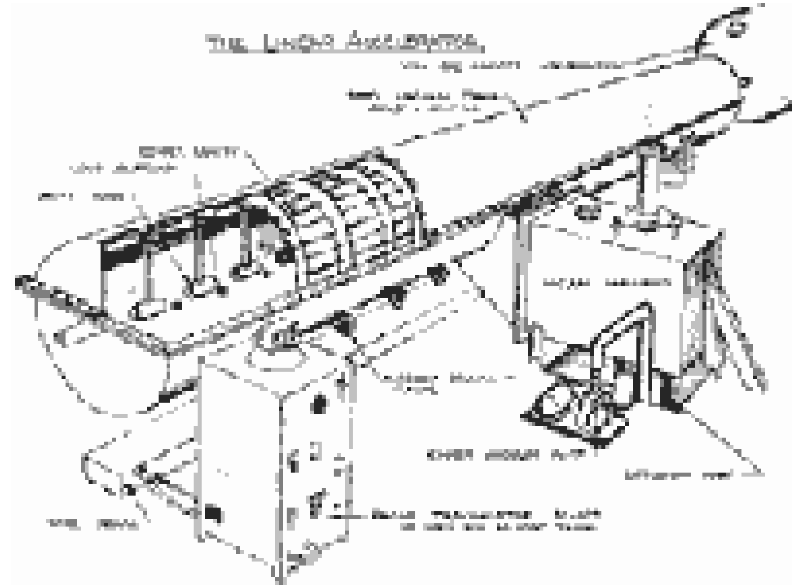


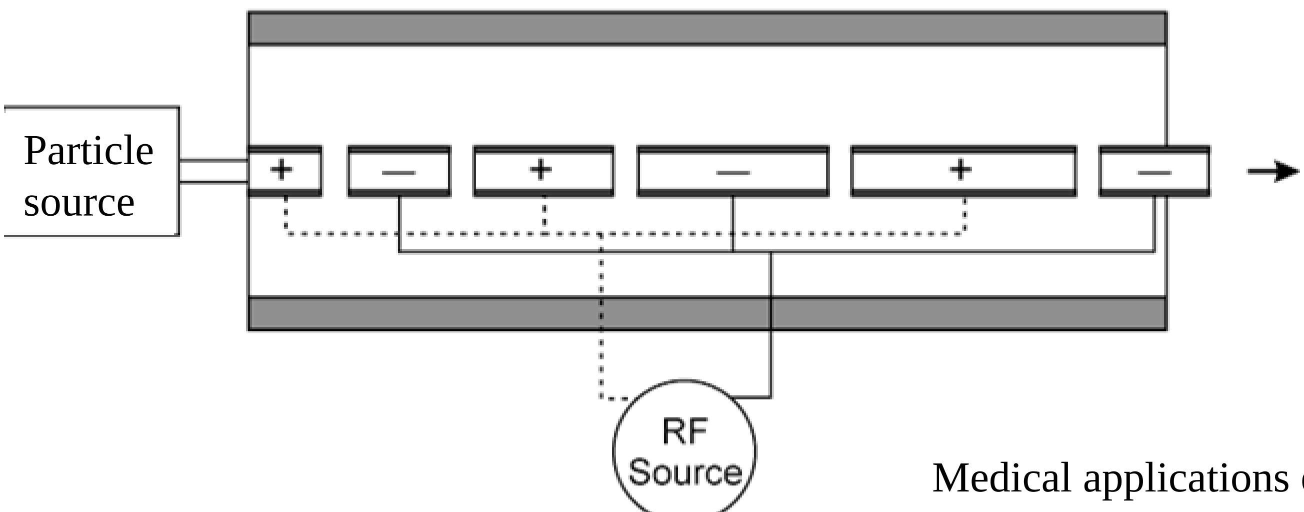
Synchrocyclotron: let particles run in a circle within a magnetic field and give them kicks with the electrical field at the same place in the right moment



But: Synchrotron Radiation ➔ Beam Energy Loss $\propto$ E^4

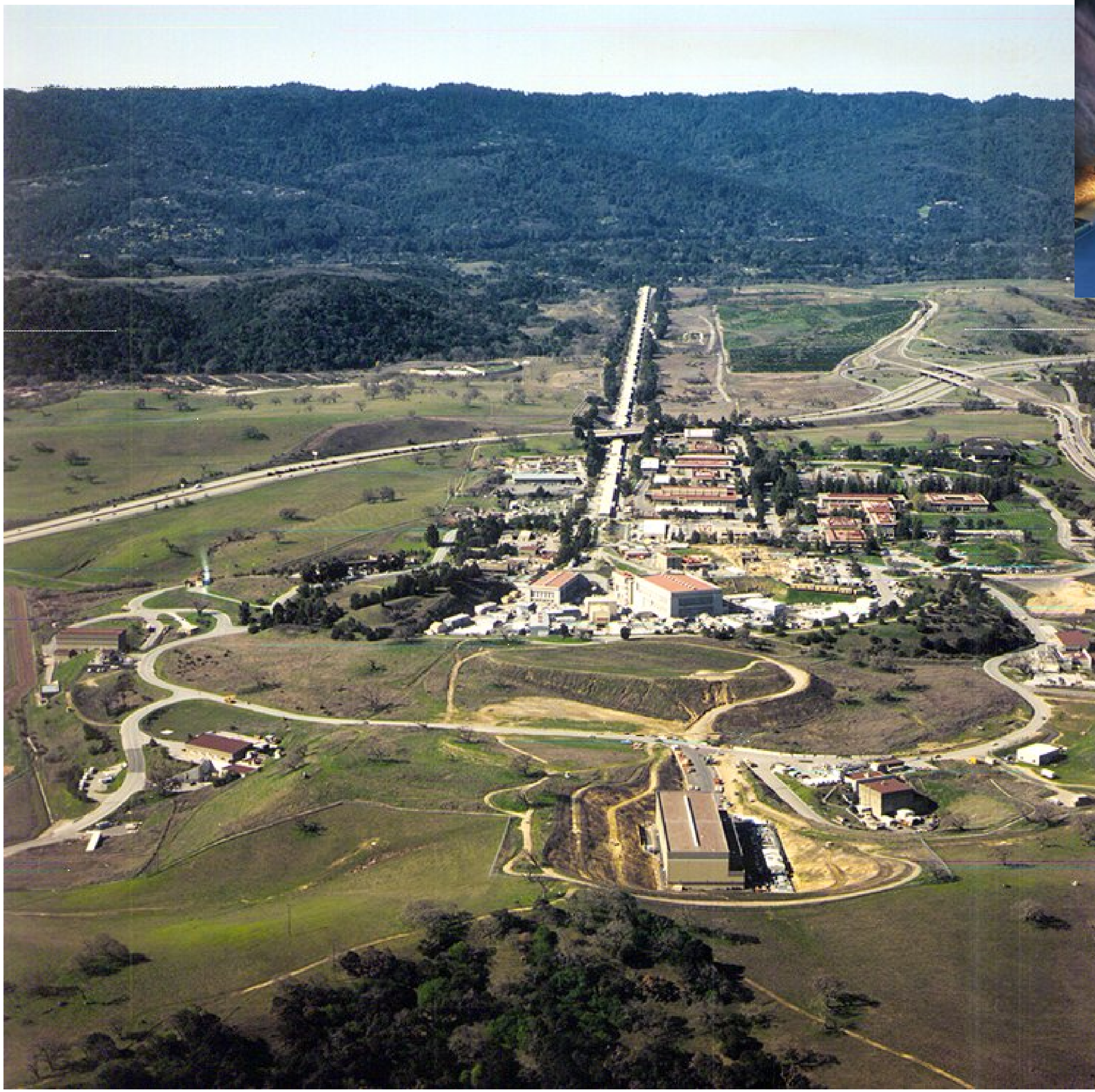
• Linear Accelerators





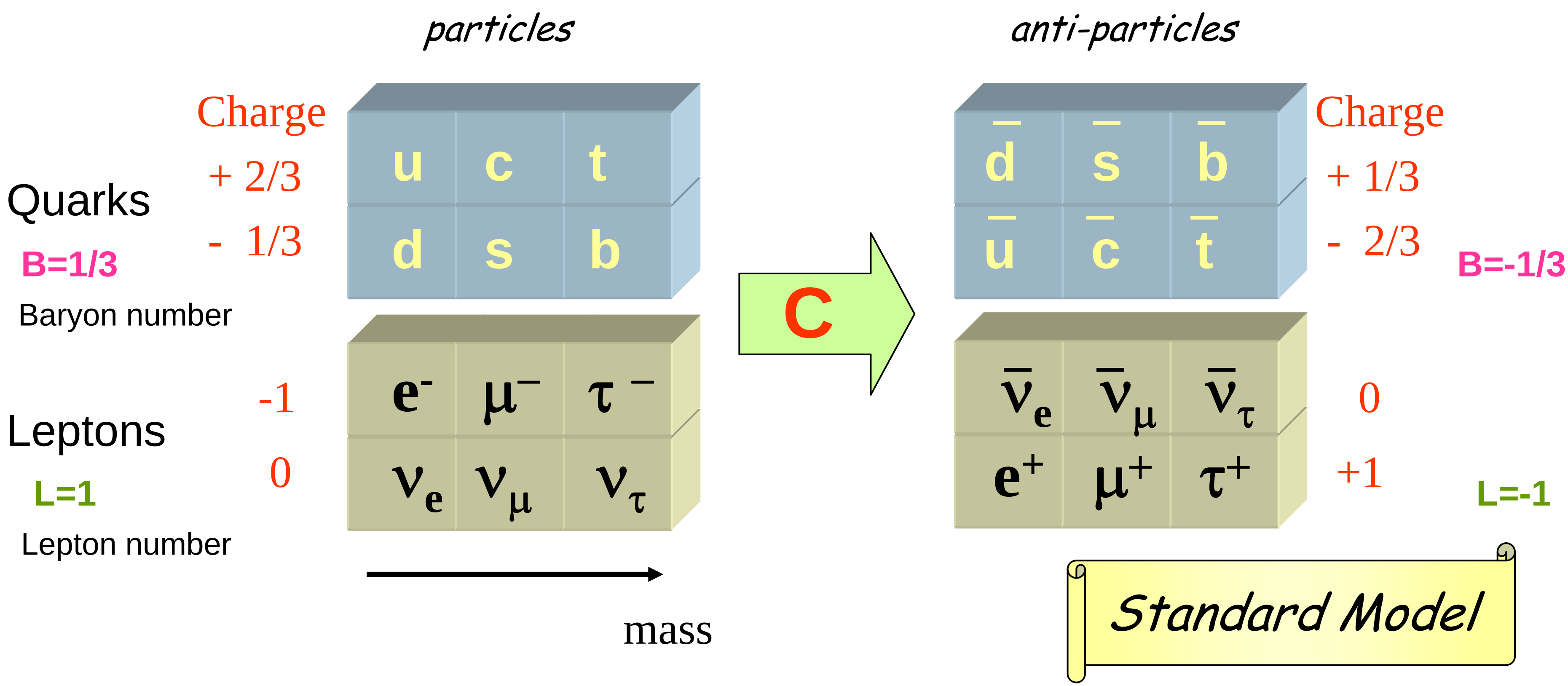
Medical applications e.g. tumor treatment.

• Stanford Linear Accelerator Center



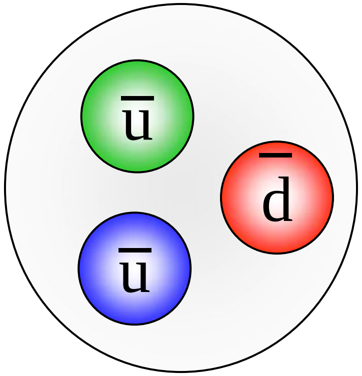
- **2 mile long accelerator (can be seen from moon)**
- **Final energy of 45 GeV for electrons/positrons**
- **Used to fill PeP II B-factory to measure CP violation**

• What have we learned → Standard Model fundamental ?



C: Charge conjugation symmetry

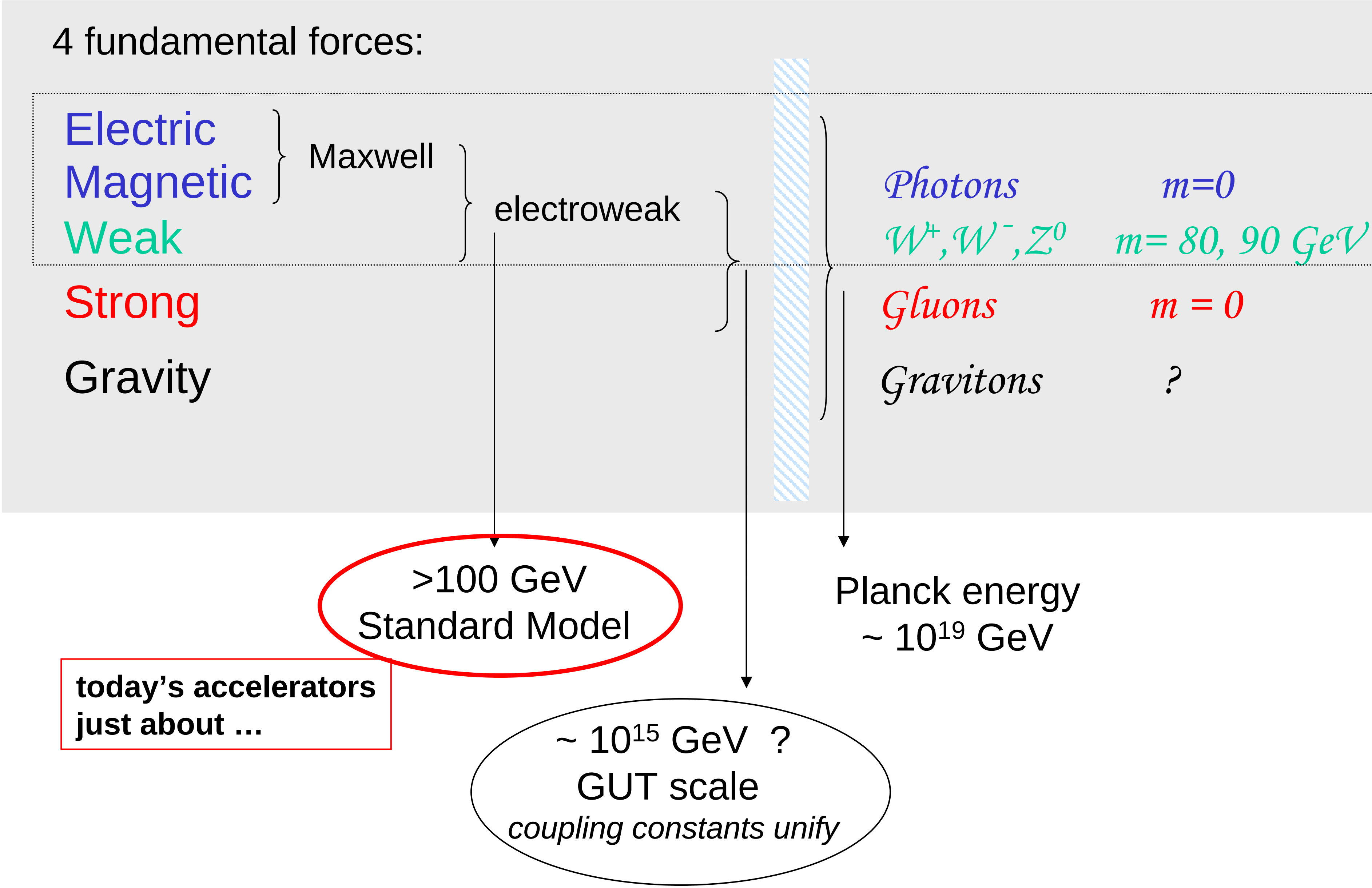
anti-proton $\bar{p}$:



$C\,\bar{p} = p$

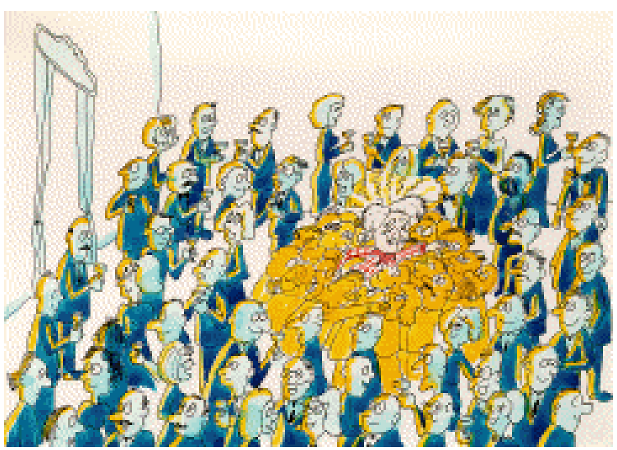
In accelerators (cosmic rays) particles and anti-particles are created and annihilate in pairs !

• What have we learned → Standard Model

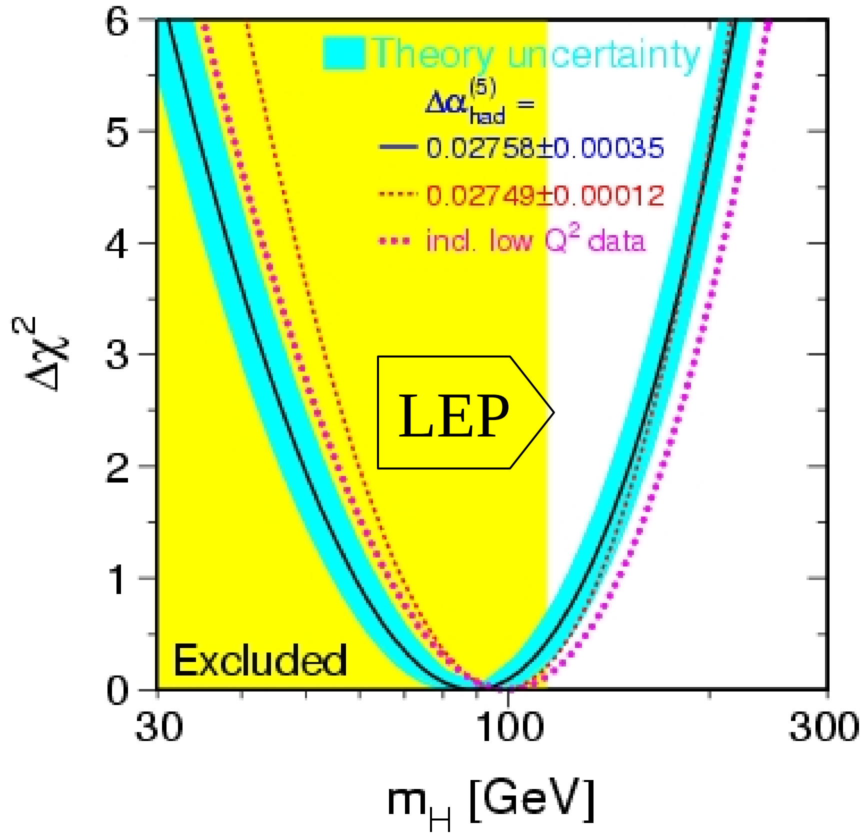


The particle masses …

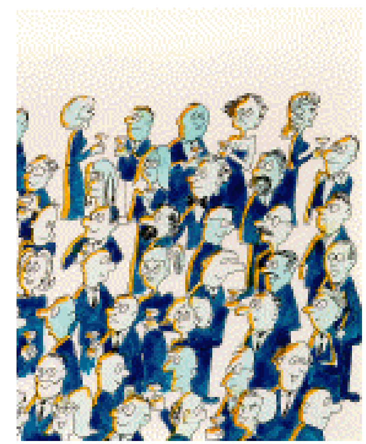
• Standard Model Symmetry Breaking ?



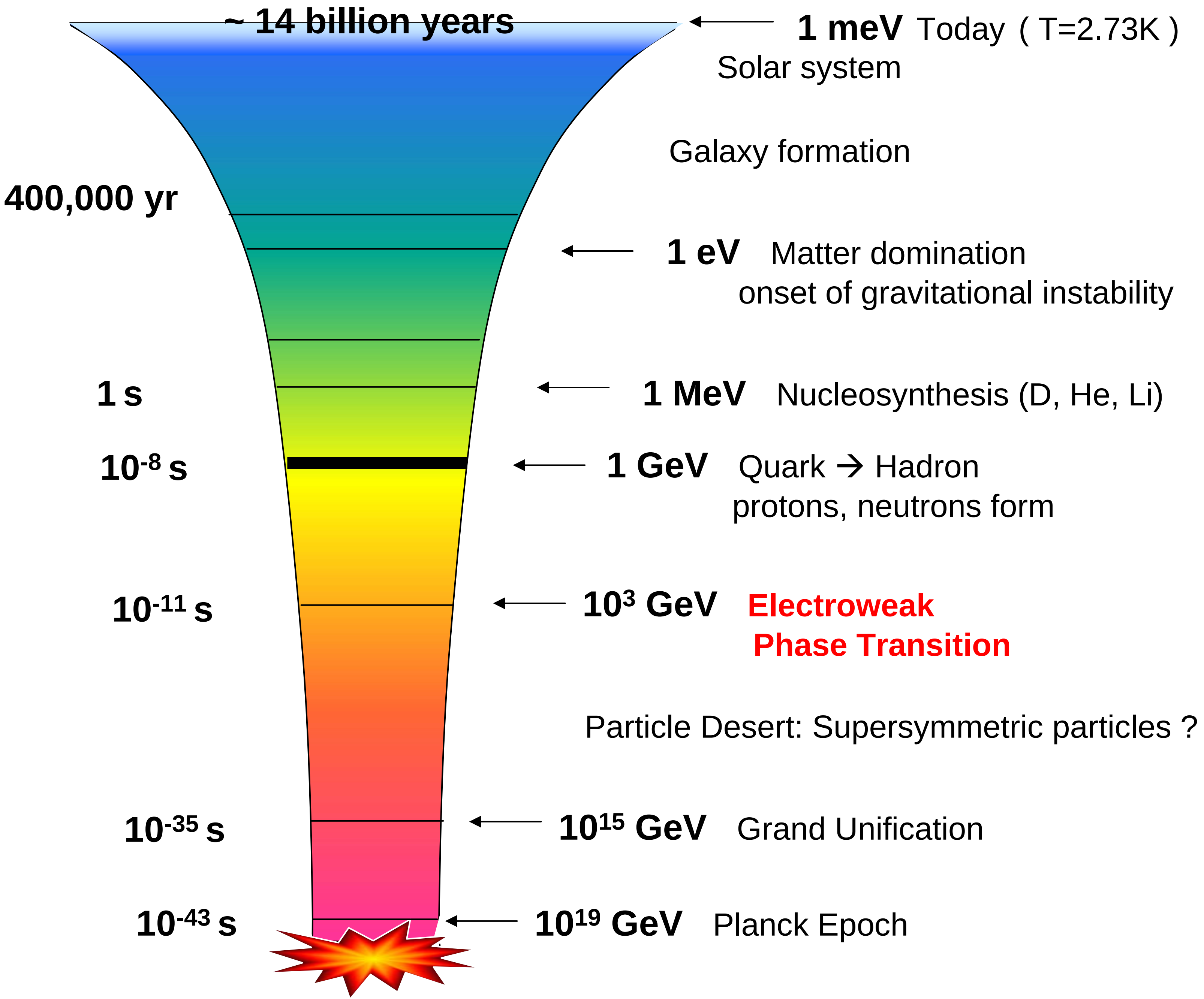
Higgs Mass = 100 .. 300 GeV ?



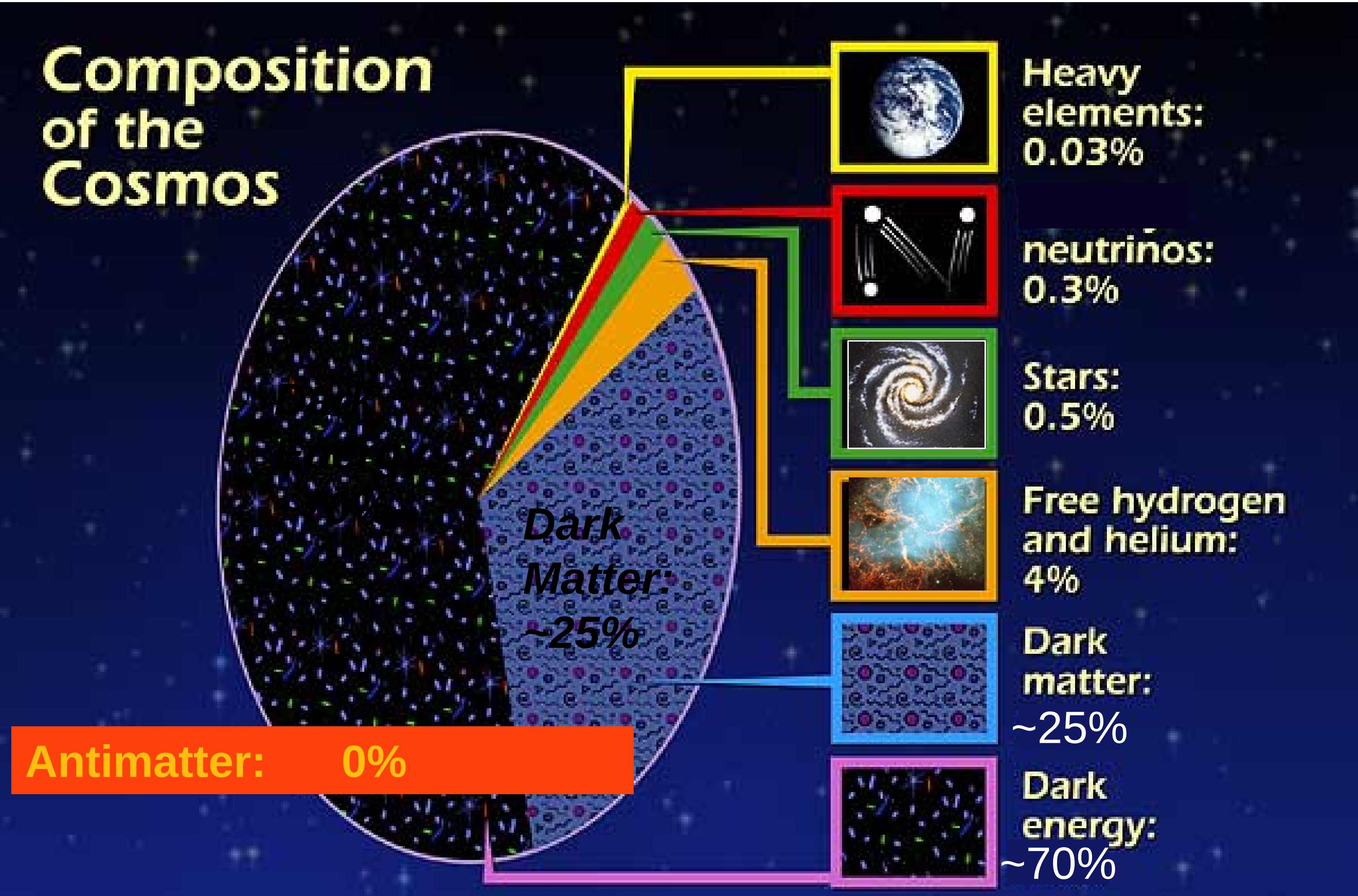
rticle generation



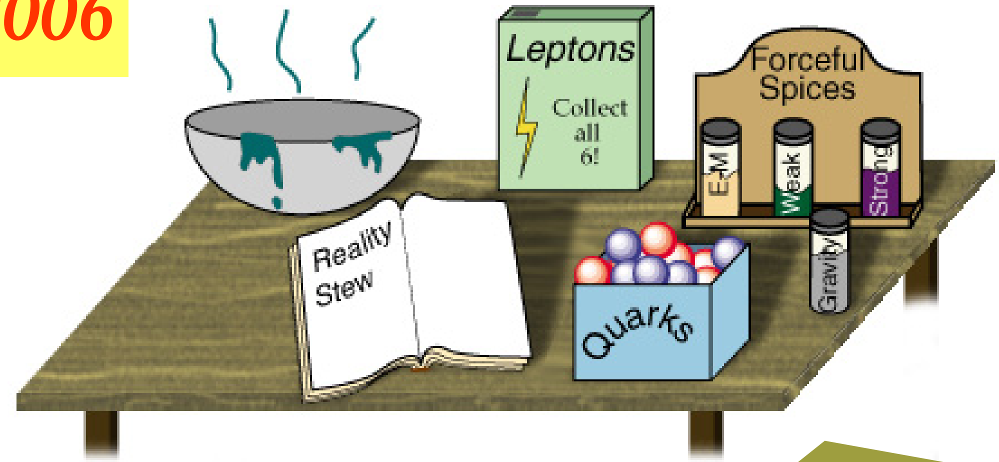
• Evolution of the Universe ?



- Energy Budget of the Universe



The Standard Model in 2006



The *Standard Model* is not complete; there are still many unanswered questions, such as:

- **Why can't the Standard Model predict a particle's mass ?**

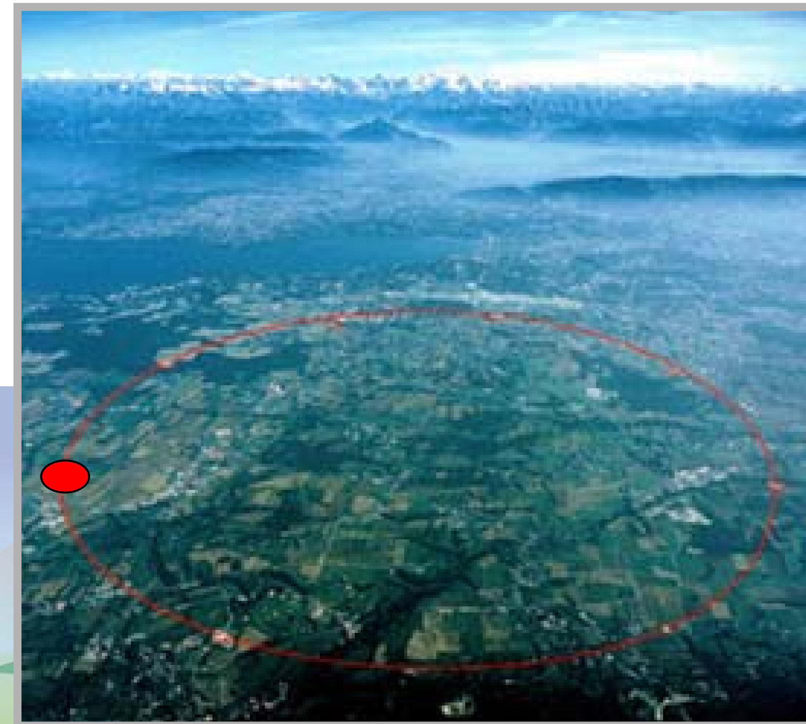
- **Are quarks and leptons actually fundamental ?**
- **Why are there exactly three generations of quarks and leptons?**
- **Why do we observe matter and almost no anti-matter in the Universe ?**
- **What is this "dark matter“ ?**
- **How does gravity fit into all of this?**

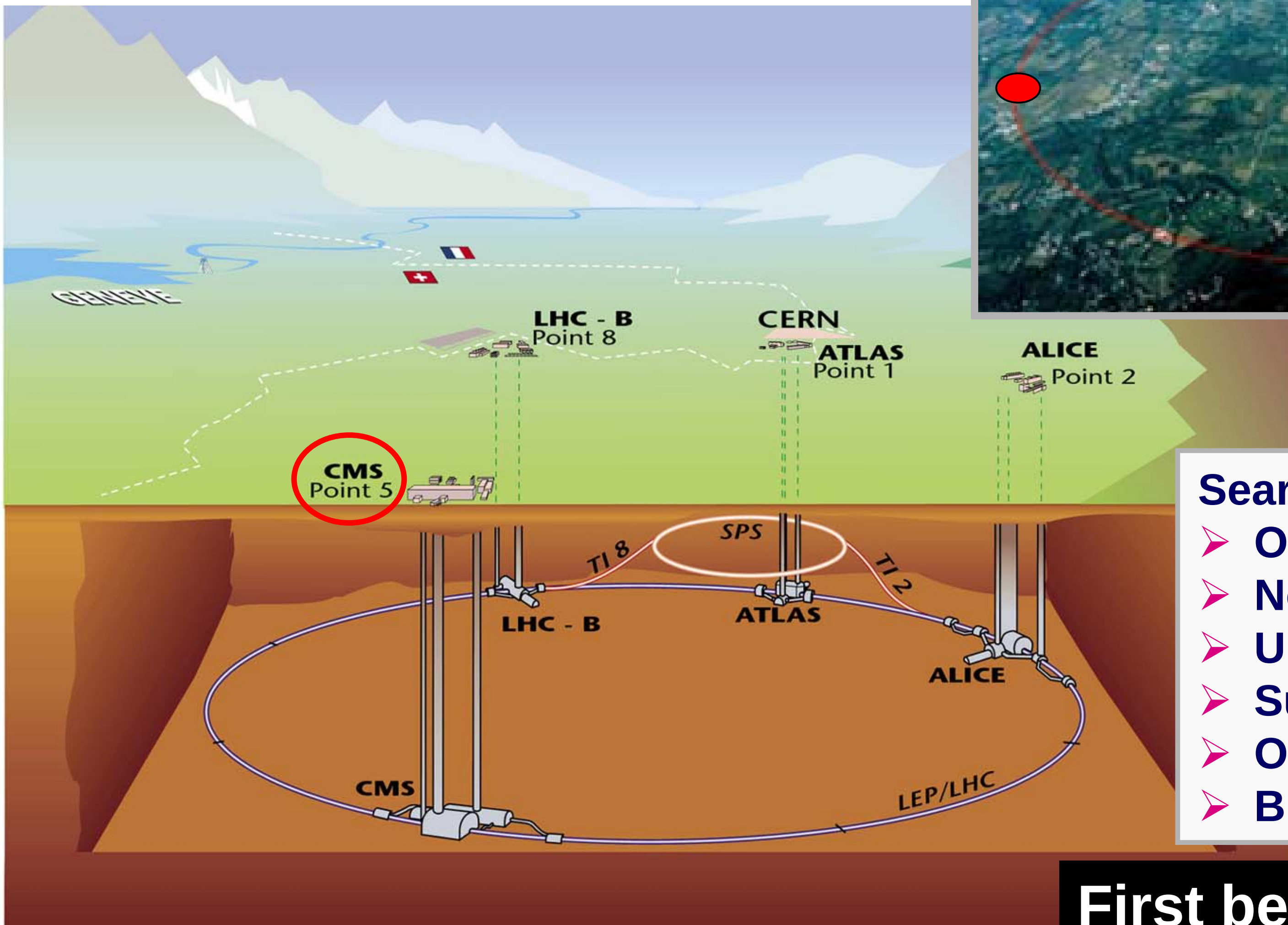
....

LHC *is the tool for a fundamental breakthrough*

• The LHC Project

- Proton-proton collider (14 TeV energy)
- 27 km in circumference, 50-175m deep
- between Jura mountains (France) and
  Lake Geneva (Switzerland)





Search for

- ➢ **Origin of Mass**
- ➢ **New forces**
- ➢ **Universe origin**
- ➢ **Supersymmetry**
- ➢ **Other new particles**
- ➢ **Black Holes**

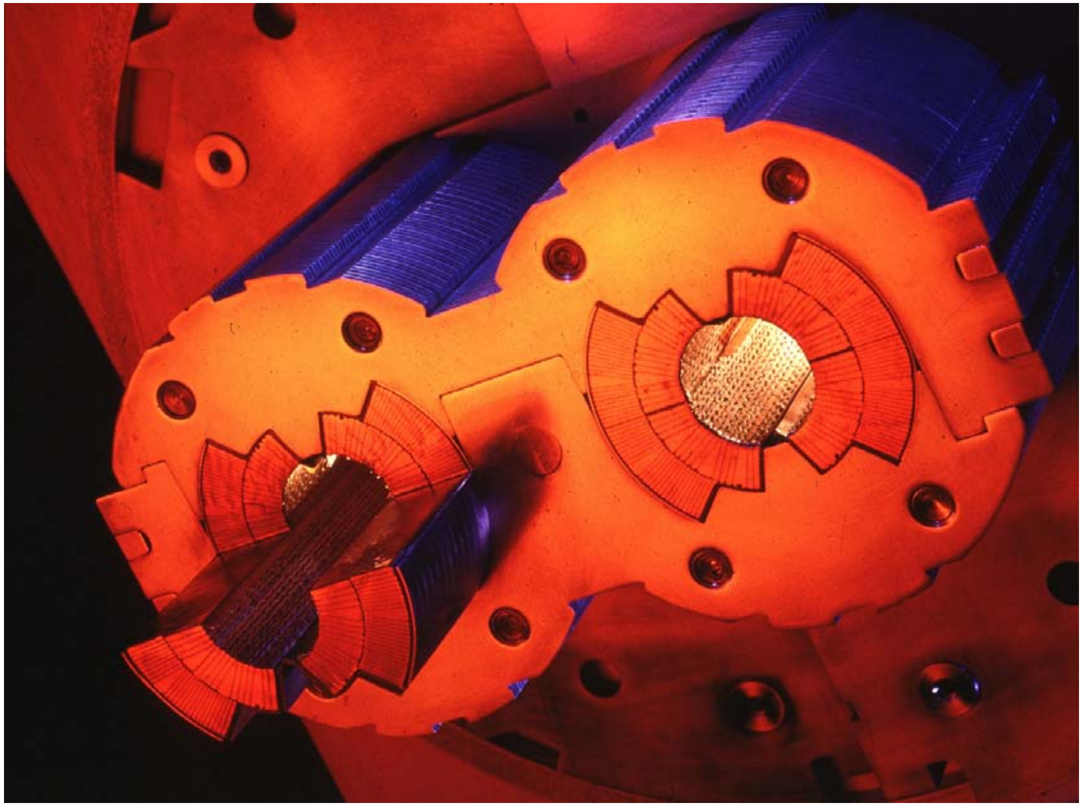
First beams fall 2007 !

- **The LHC**

> 2808 proton bunches/ring
> ~10^{11} protons/bunch
> Beam current: 584 mA

> Collision every 25 ns
> Beam stays for 10 hours after fill (30min energy ramp)

Accelerator tunnel



Energy stored/beam: 360 MJ

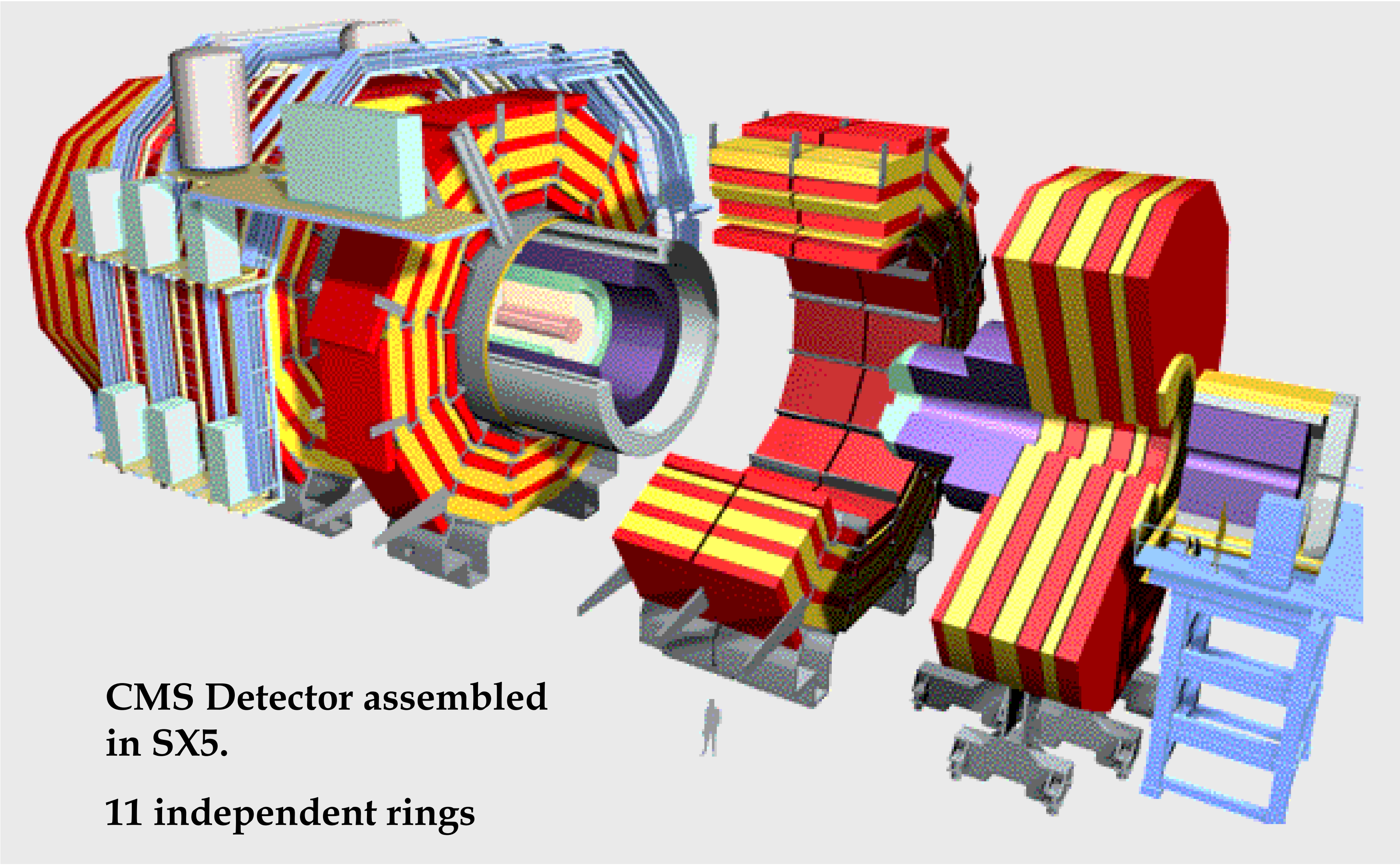
Superconducting magnets:
1232 dipole magnets (bending)
~500 quadrupole magnets (focus)

Energy stored in magnets: 700GJ

→ **Particle losses fatal !**

superconducting dipole magnet

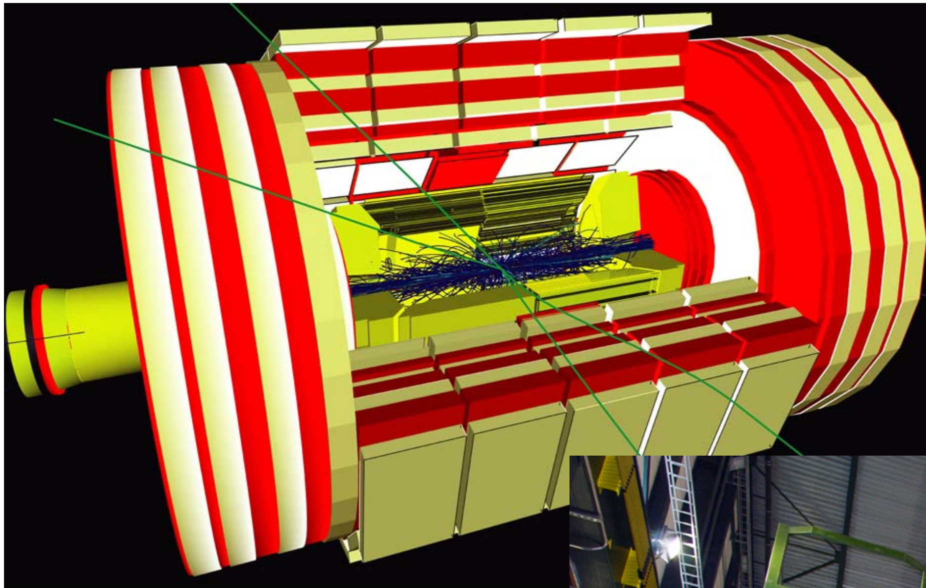
- **The Compact Muon Solenoid (CMS) Detector**



CMS Detector assembled in SX5.

11 independent rings

- **The Compact Muon Solenoid (CMS) Detector**



4 Tesla magnetic field

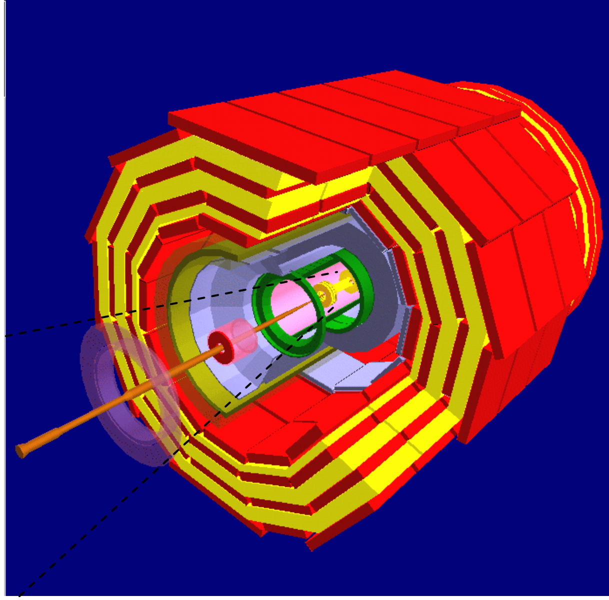
Higgs → 4 muons

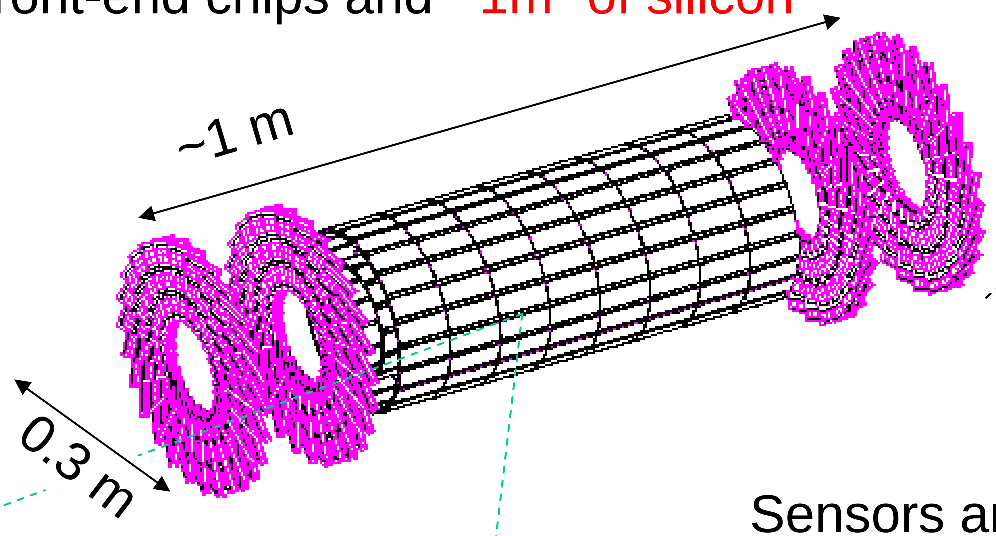
Solenoid Magnet Assembly

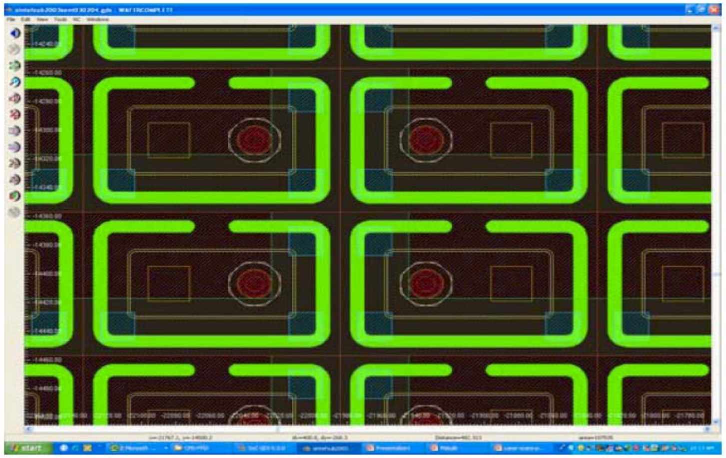
USCMS
THE COMPACT MUON SOLENOID

• The CMS Pixel Detector

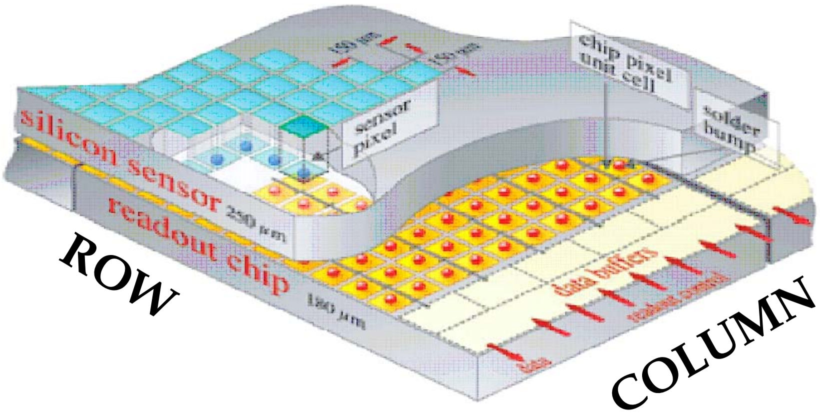
- 3-d tracking with about 66 million channels
- Barrel layers at radii = 4.3cm, 7.2cm and 11.0cm
- Pixel cell size = 100 µm x 150 µm
- ~15k front-end chips and ~1m^2 of silicon



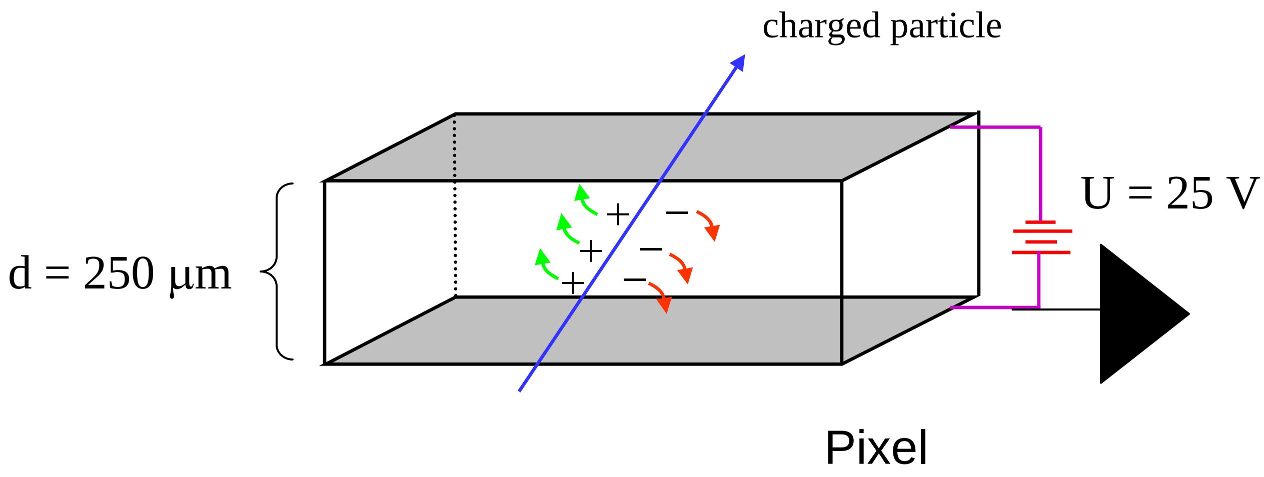




Sensors are bump-bonded to the readout chips



• Silicon Detector

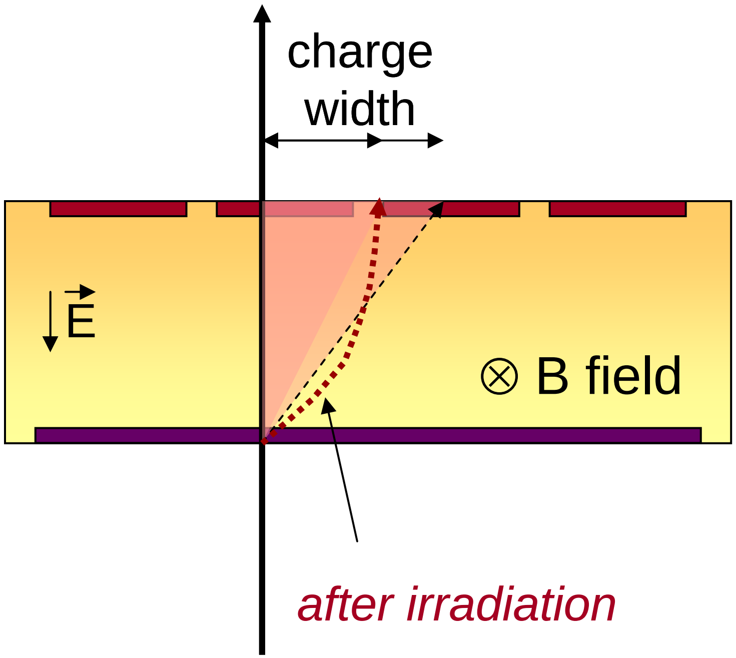


- Charged particle creates free electrons and holes in silicon while passing (deposits small fraction of its energy)
  → For minimum-ionizing particle ~ 20,000 electrons

- Silicon pixel (strip) detector works like a *semi-conductor diode* in reverse bias with large depletion zone (no free charges)
  → very large electric field E ~ 10^5 V/m pulls charges
  → very short collection time (few ns)

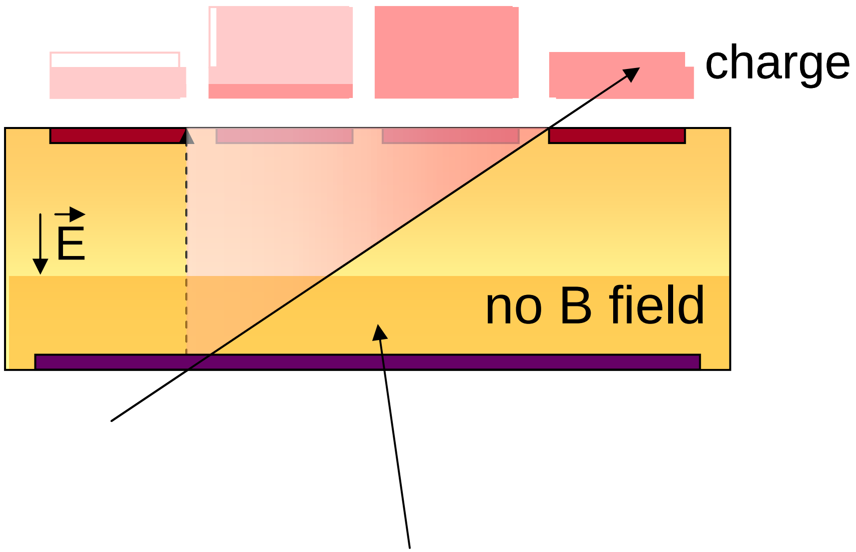
• The CMS Pixel Detector - Radiation Effects

r-ϕ plane



Irradiation modifies
the electric field profile:
varying Lorentz deflection

r-z plane



Irradiation causes
charge carrier trapping

• **The LHC Computing**

- **1 billion proton-proton collision events per second in detector**
- **100 events of interest/second recorded permanently (trigger/filter)**

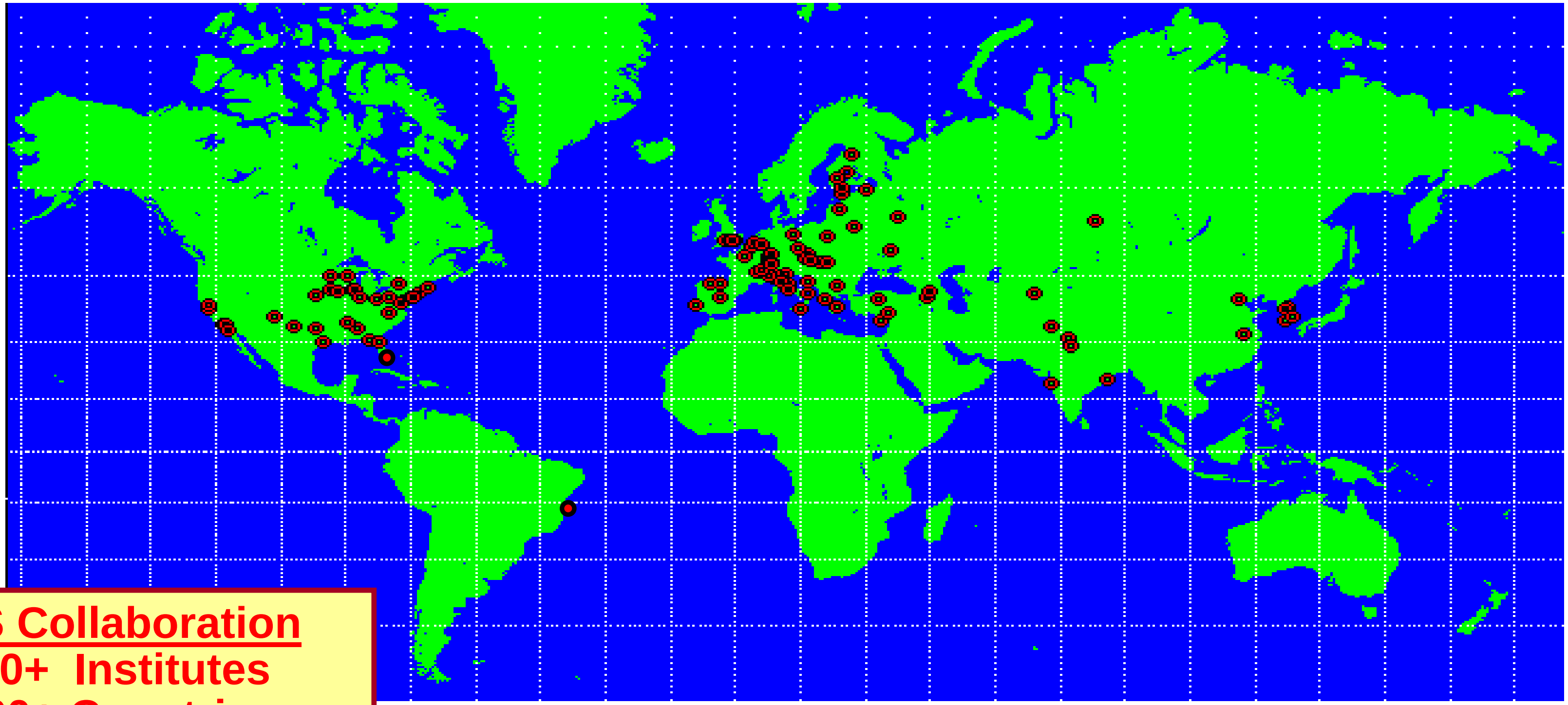
➔ **1 GByte/second**

+ Raw data, processed data, simulated events

➔ **15 PetaBytes/ year (= 15 M GBytes/year = 20 M CDs)**

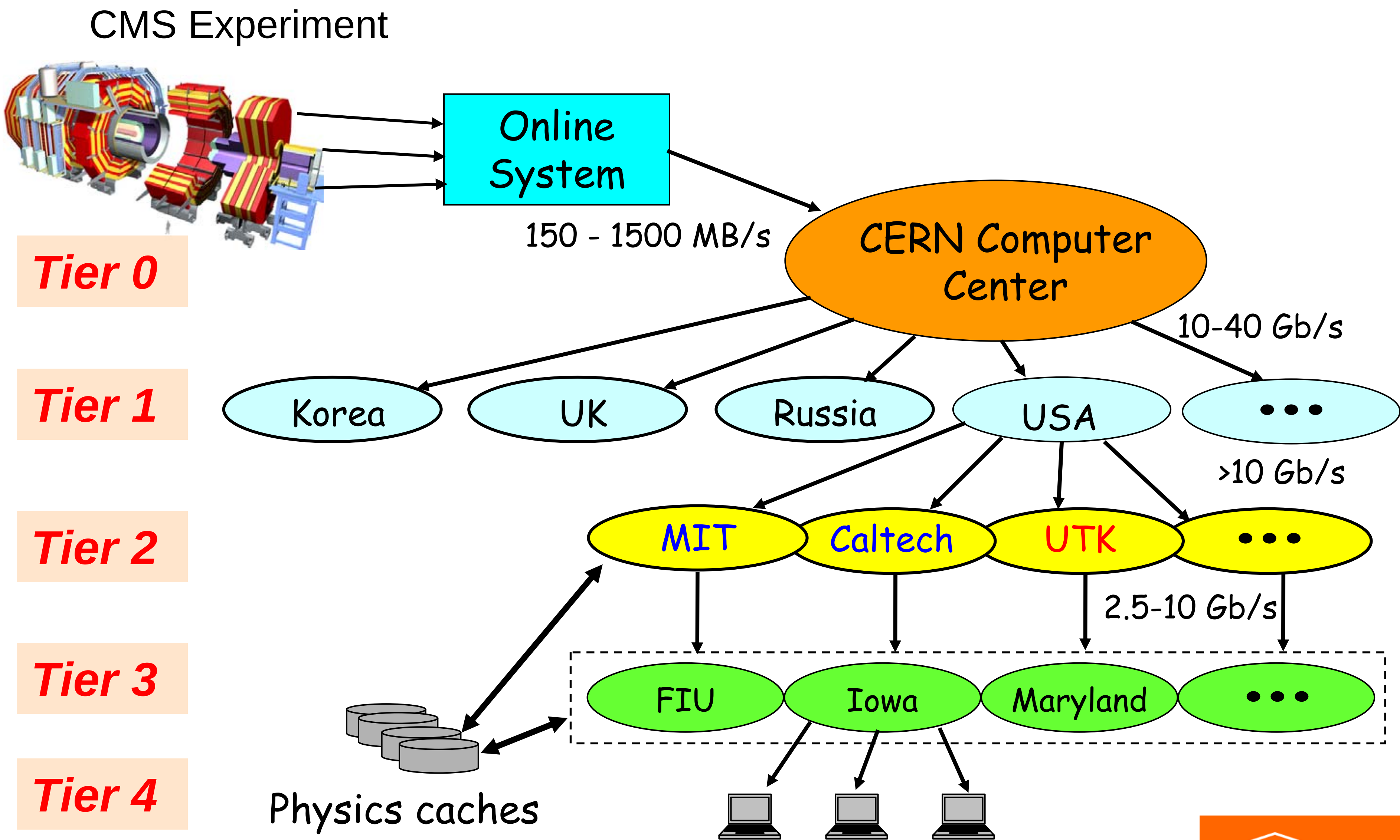
➔ **computing power equivalent: ~ 100,000 standard PC processors.**

• … needs **global** distribution of people & resources



CMS Collaboration
250+ Institutes
60+ Countries

• The LHC Global Data GRID (2007+)



…within the framework of the OpenScienceGrid (OSG)

Open Science Grid

• *Conclusion*

- High Energy Particle Physics (HEP) has answered many fundamental questions.
- In the energy regime below 100 GeV the picture appears complete
- but beyond this energy HEP opened many new questions

- LHC is the machine for a fundamental breakthroughs
- HEP is a challenging environment with many new technology developments to prepare for discoveries

We are involved in

- CP violation & Search for New Physics at BaBar, SLAC
- Readout and commissioning of pixel detector for CMS/LHC
- Beam radiation protection for the pixel detector at CMS
- Future radiation hard pixel detector development with PSI Switzerland
- GRID computing center at UT; R&D with UT's Computer Science Dpt.
- Search for new particles and interactions *beyond the Standard Model*