LHCb experiment @ CERN

Masterclass 2022

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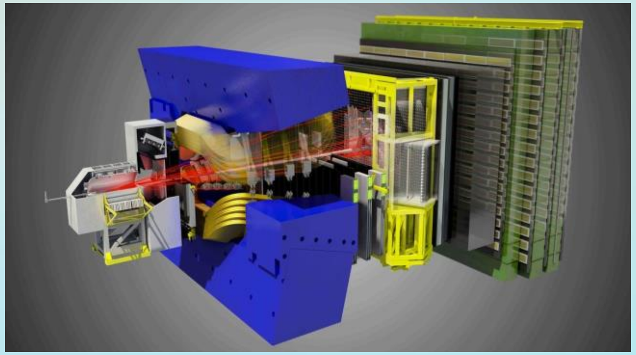


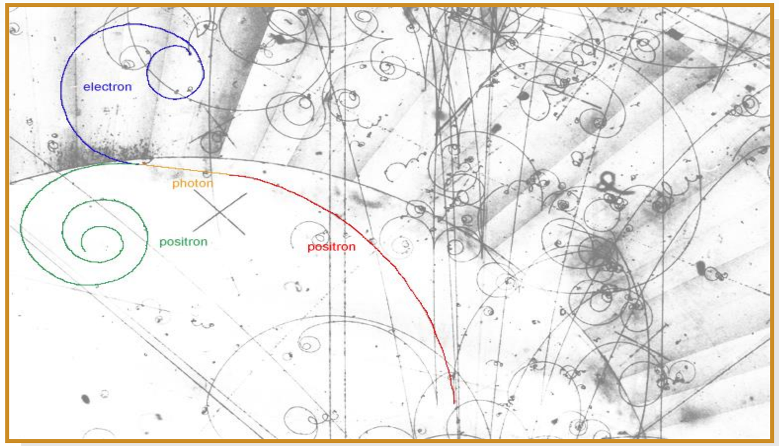
Outline

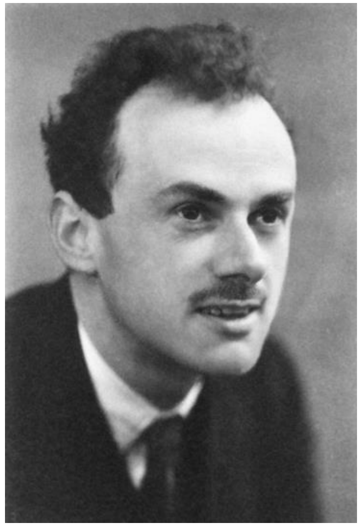
- Matter and antimatter
- Accelerators at CERN
- LHCb experiment
- Your measurement

Matter and antimatter

Antimatter discovery:
Anderson, 1932

- Matter consists of particles (MP)
- Antimatter consists of antimatter particles (AP)
- Antimatter particles: same mass, opposite electric charge
- MP and AP always produced in pairs
- MP + AP = annihilation

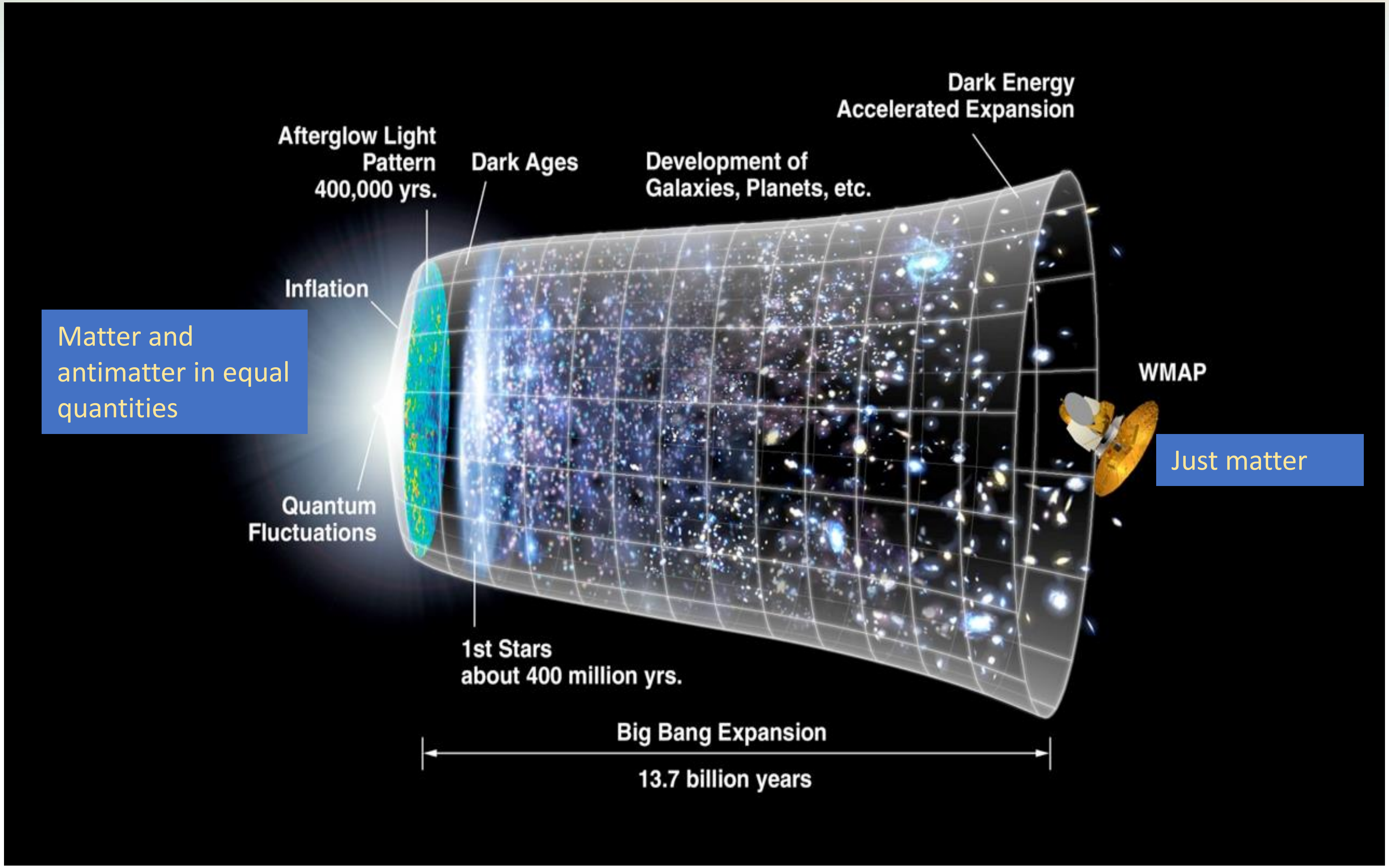




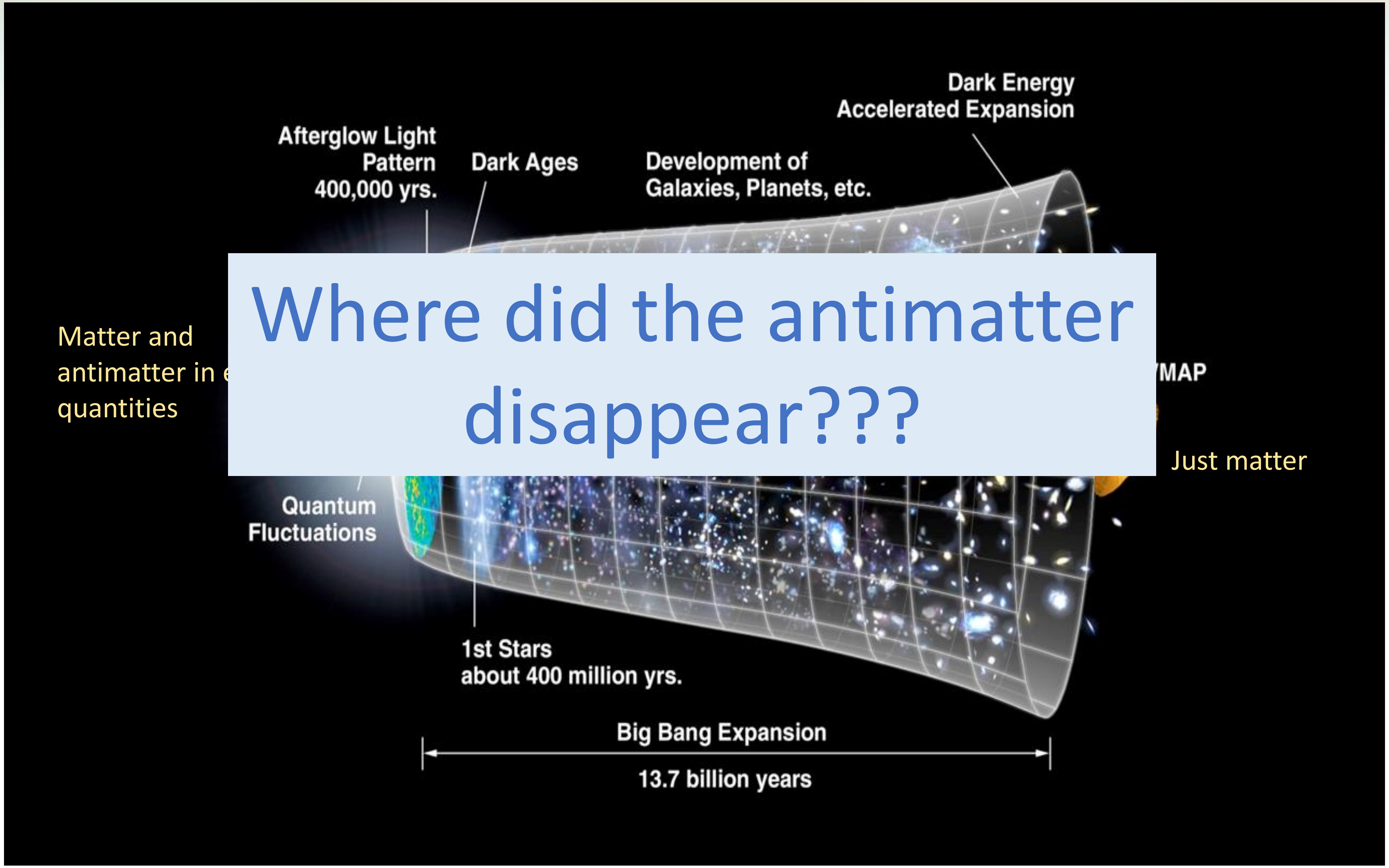
Antimatter prediction

- Dirac (1928): equation of relativistic motion of an electron
- Two solutions (like $x^2=4$): particle and antiparticle

Evolution of the Universe



Evolution of the Universe



Matter and
antimatter in e
quantities

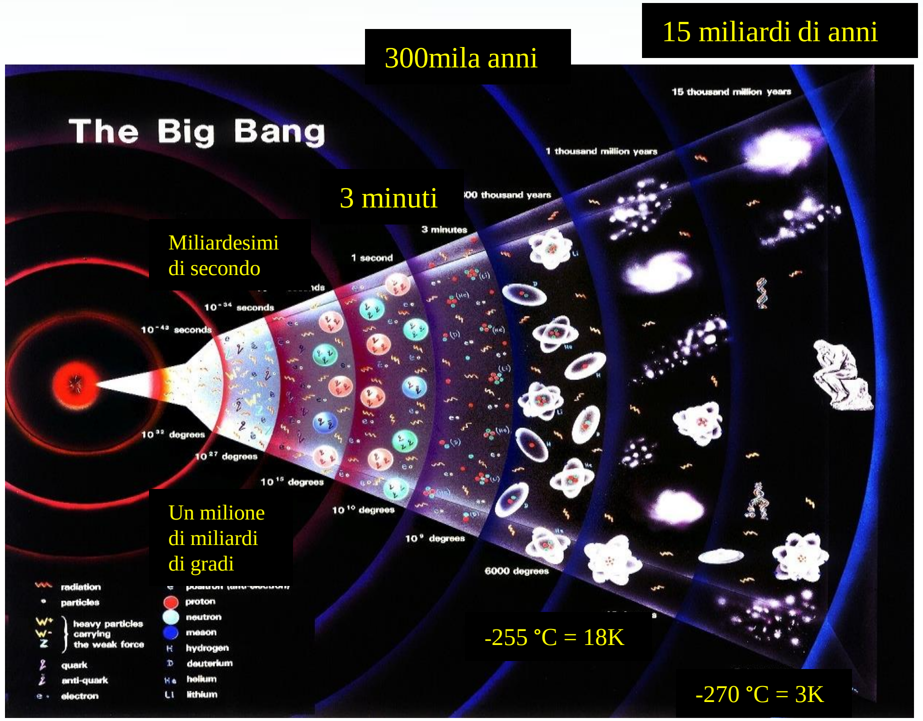
Where did the antimatter disappear???

Just matter

Big bang theory and accelerators

Big bang theory describes evolution of the Universe

- First 3 minutes after BB ($14*10^9$ years ago): very hot and dense
- Fast expansion
- Primordial soup: Universe was made of fundamental particles at high energies



If we want to understand what happened to antimatter, we must recreate conditions of the early Universe

Experiments with particles at accelerators with particles at high energies

Accelerators

Time machine

- Higher energies ⇒ earlier times of the Universe
- At LHC the conditions of first 3 minutes after the Big Bang are reproduced

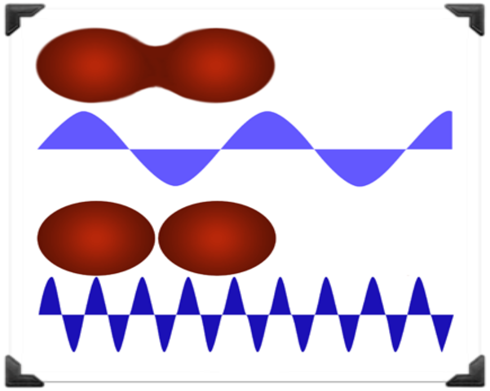
Smallest scales can be studied

Higher E ⇒ Higher ν ⇒ Smaller λ

$$E = h\nu$$

$$\nu = v/\lambda$$

Planck constant
$h = 6*10^{-34}$ J*s



Energy unit in particle physics

- 1 eV = $1.6*10^{-19}$ J
- 1 TeV = 10^{12} eV

LHC at CERN

- 14 TeV total energy
- $\lambda \sim 10^{-19}$ m

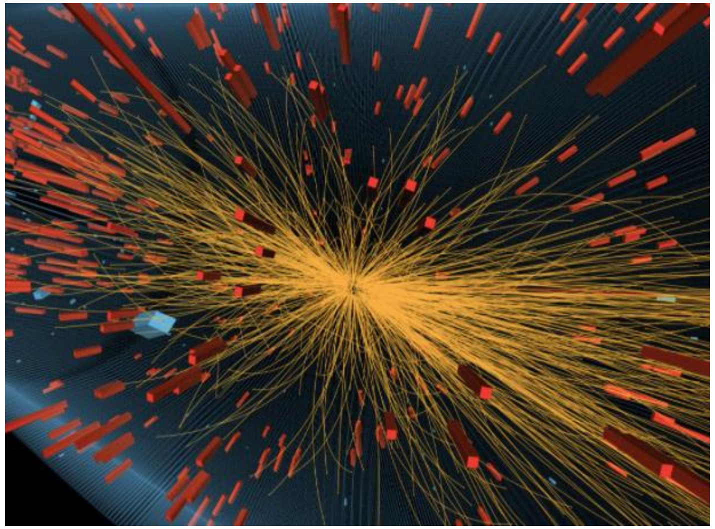
Colliders

- Accelerate two groups (beams) of particles
- Collide beams
- Particle energy can be used for the production of new particles

Key formula:

$E = mc^2$

Trajectories of particles produced in a collision



Experiments in high energy physics

Key ingredients

Accelerator
- Accelerate particles to high energies and collide them

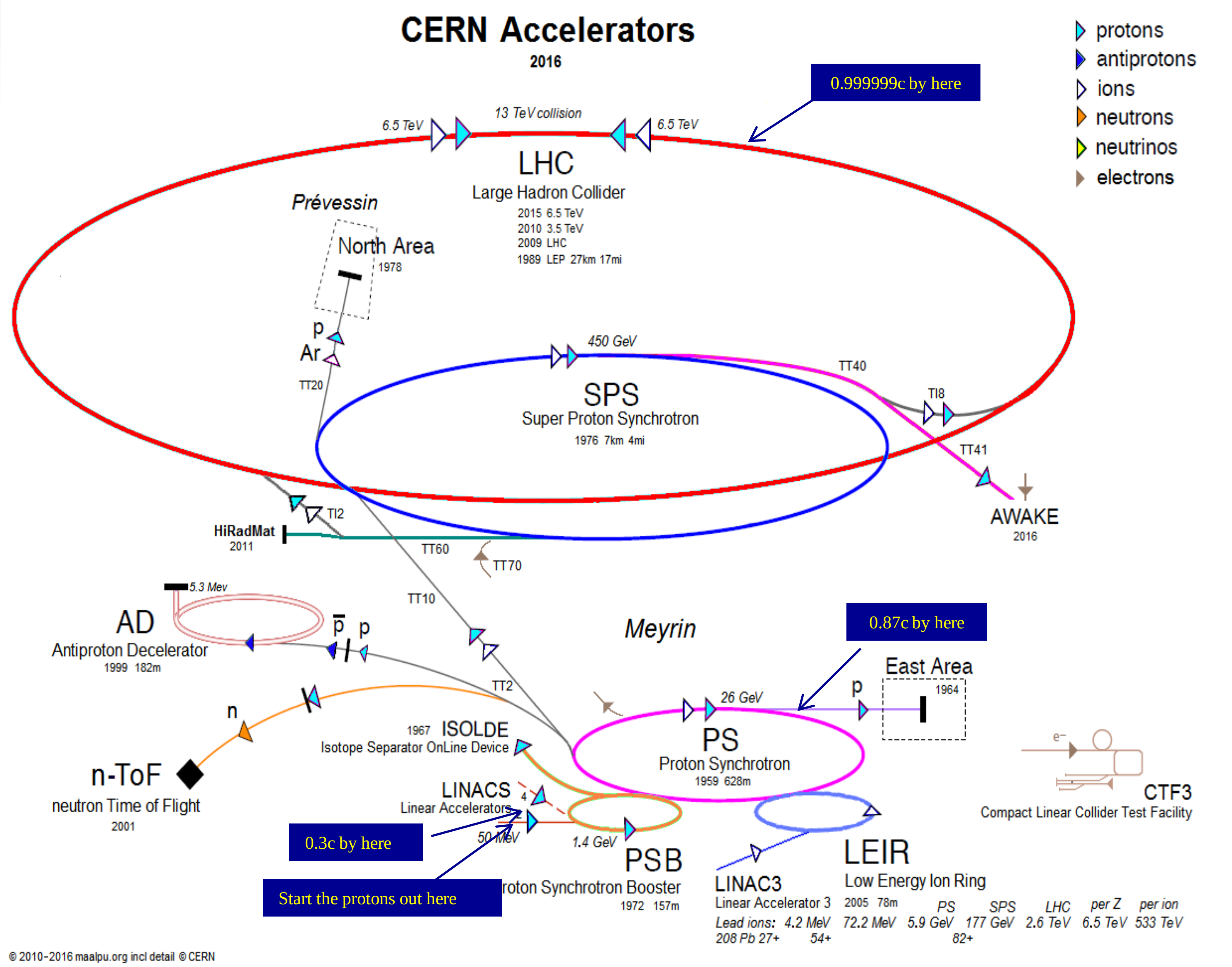
Experimental setup
- Detectors to measure particles produced in collisions

Computers
- Store collected data

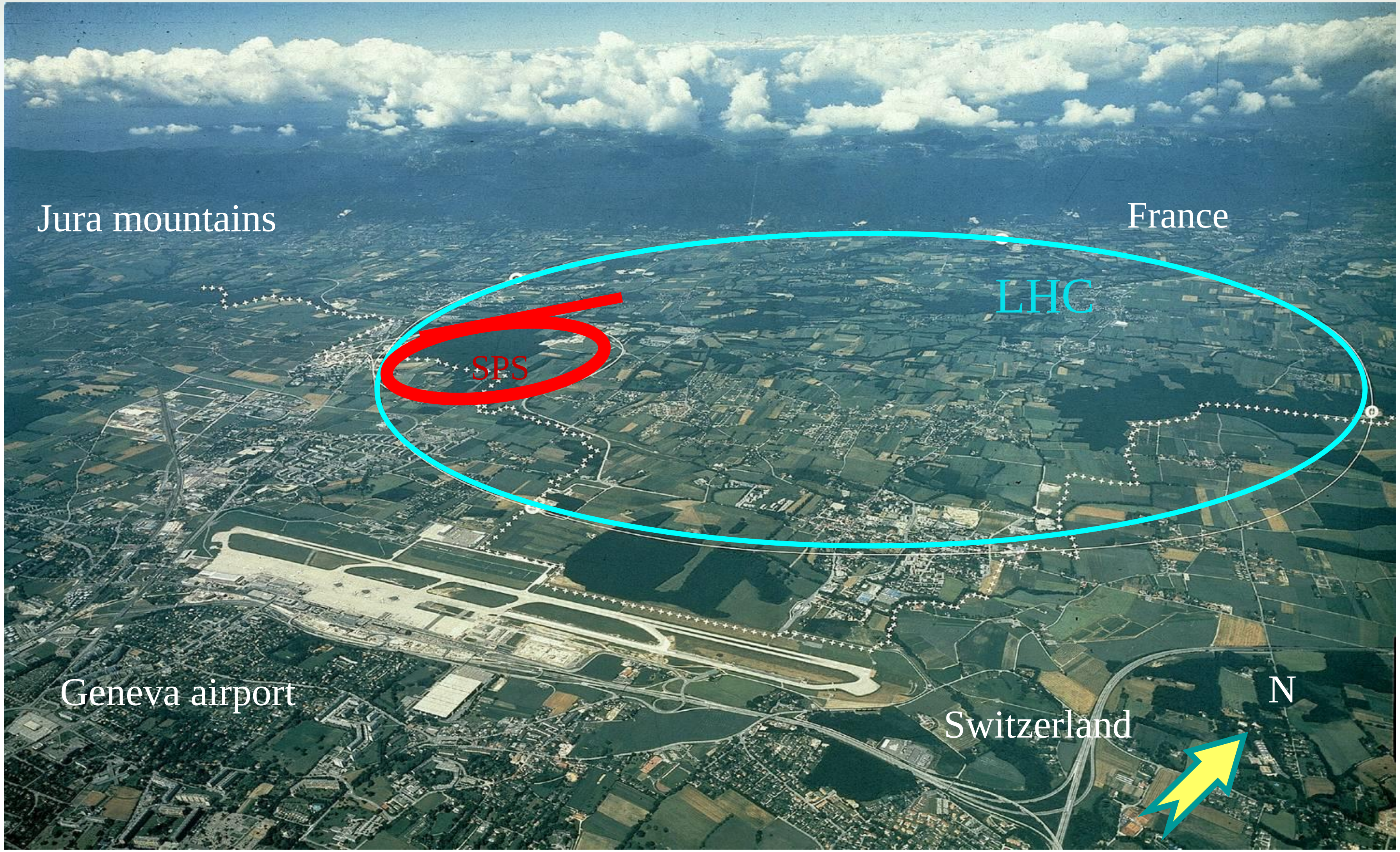
Manpower
- Physicists, engineers, technicians
- Project, create and maintain

Accelerator complex at CERN

- Protons are accelerated in several steps almost to the speed of light
- LHC is the last step
- Beam collision: 7 TeV + 7 TeV
- 4 main collision points (and 4 main experiments)

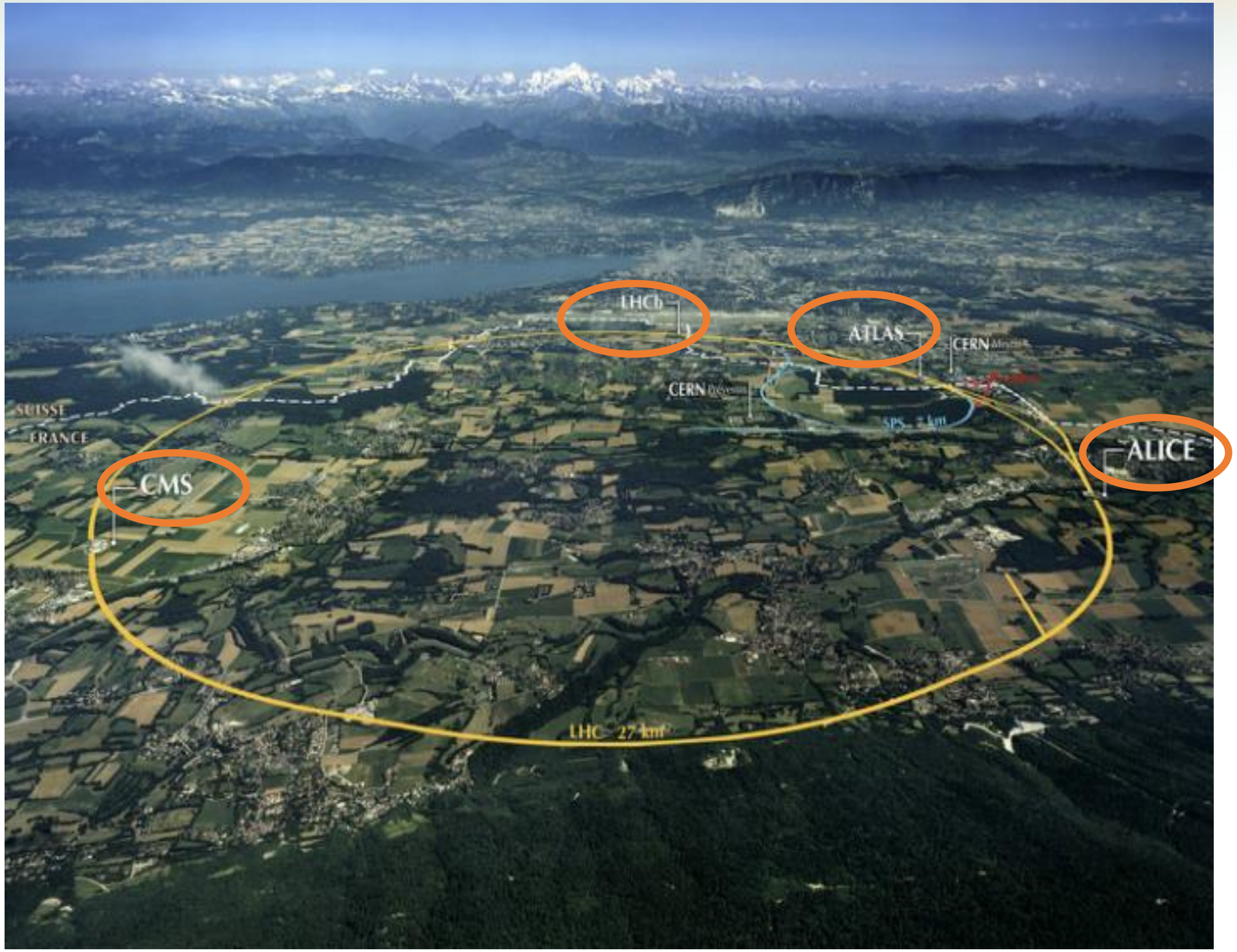


LHC at CERN



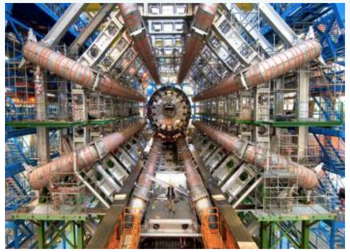
- 27 km long
- 100m under ground
- Both in France and Switzerland
- Proton energy: 7+7 = 14 TeV
- Proton beams collide 40 million times per second
- ~10^9 collisions per second

Experiments at LHC



CMS

ATLAS



LHCb

ALICE

Experiments at LHC

CMS, ATLAS

- Discovery of the Higgs boson
- Study of Higgs properties
- Search for new particles and interactions beyond the Standard Model

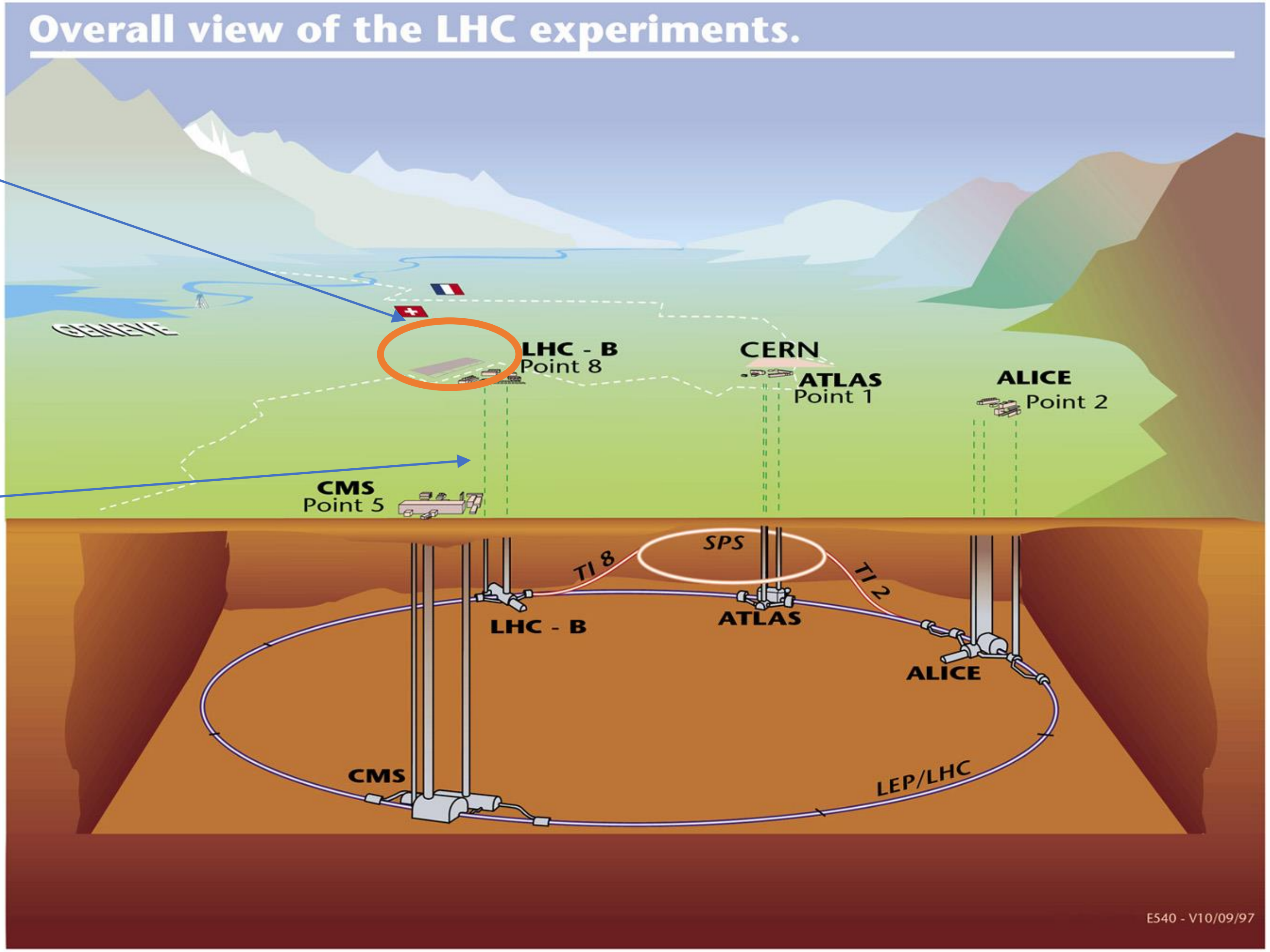
LHCb

- Matter-antimatter asymmetry
- Study of rare decays
- Search for new particles and interactions beyond the Standard Model

ALICE

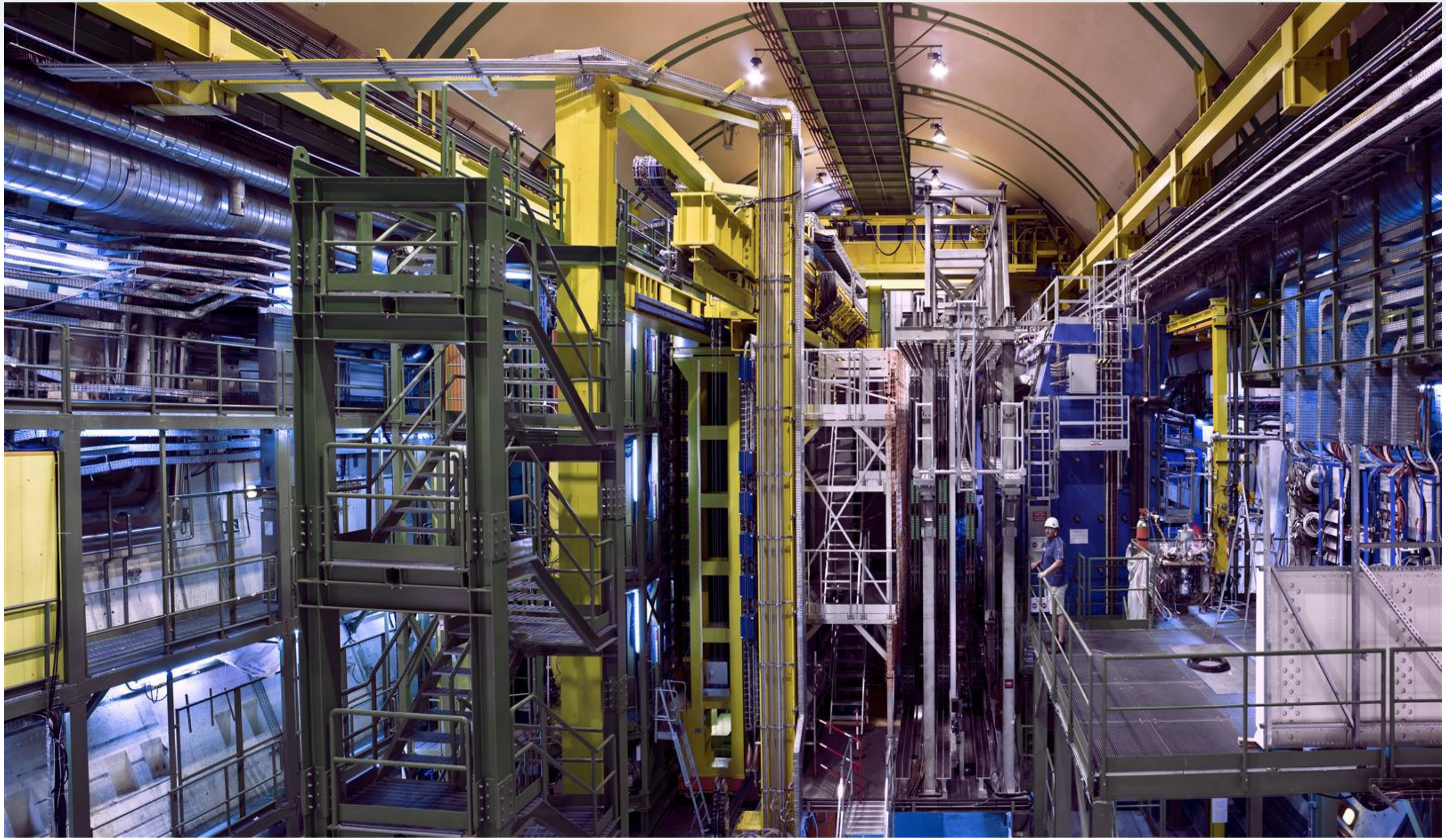
- Study of heavy ion collisions
- Quark-gluon plasma

Let’s go to LHCb!



LHCb setup

- weight: 57 tonnes
- Length: 20 m
- Width: 13 m
- Height: 10 m

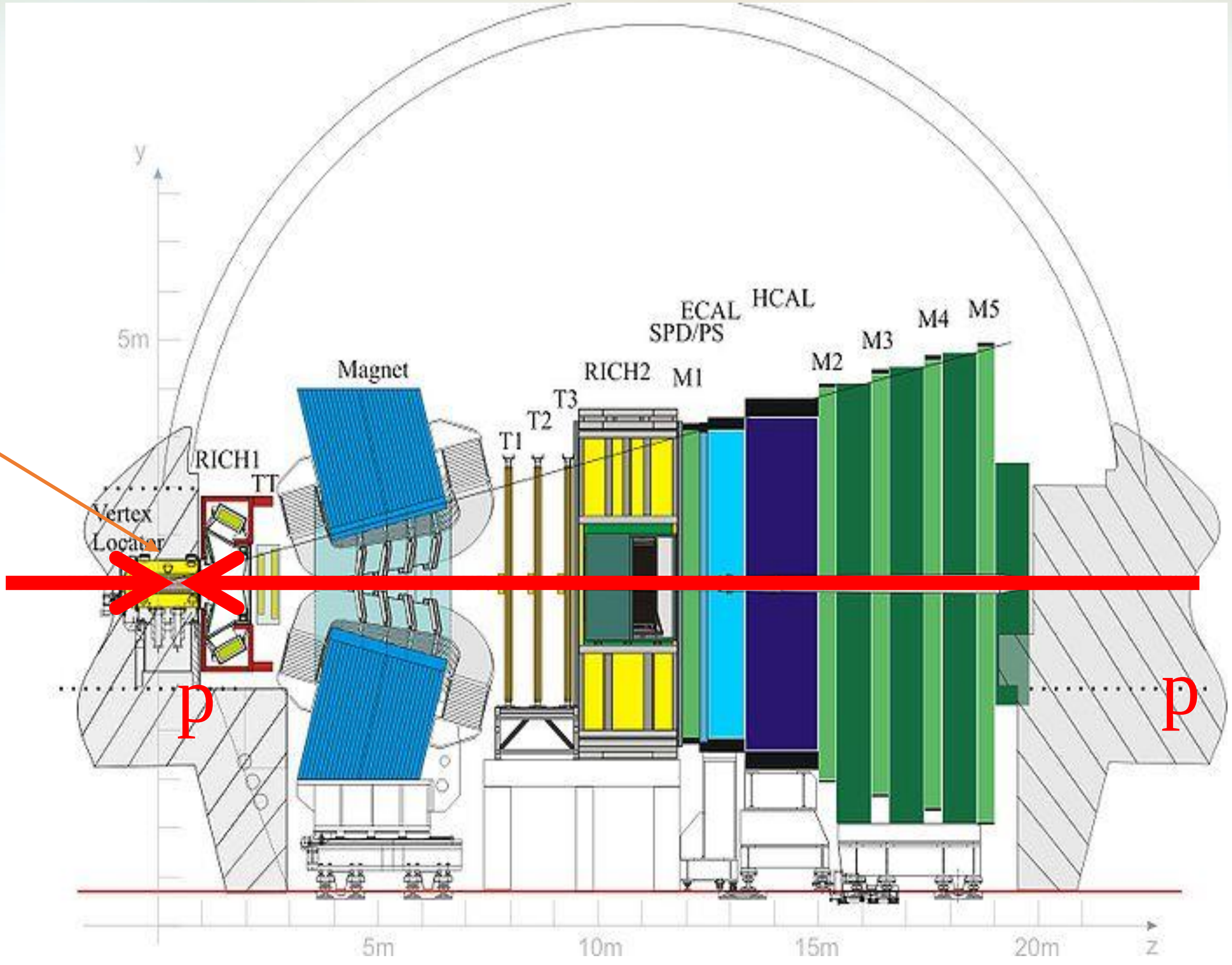


Collaboration

- 1400 members
- 18 countries

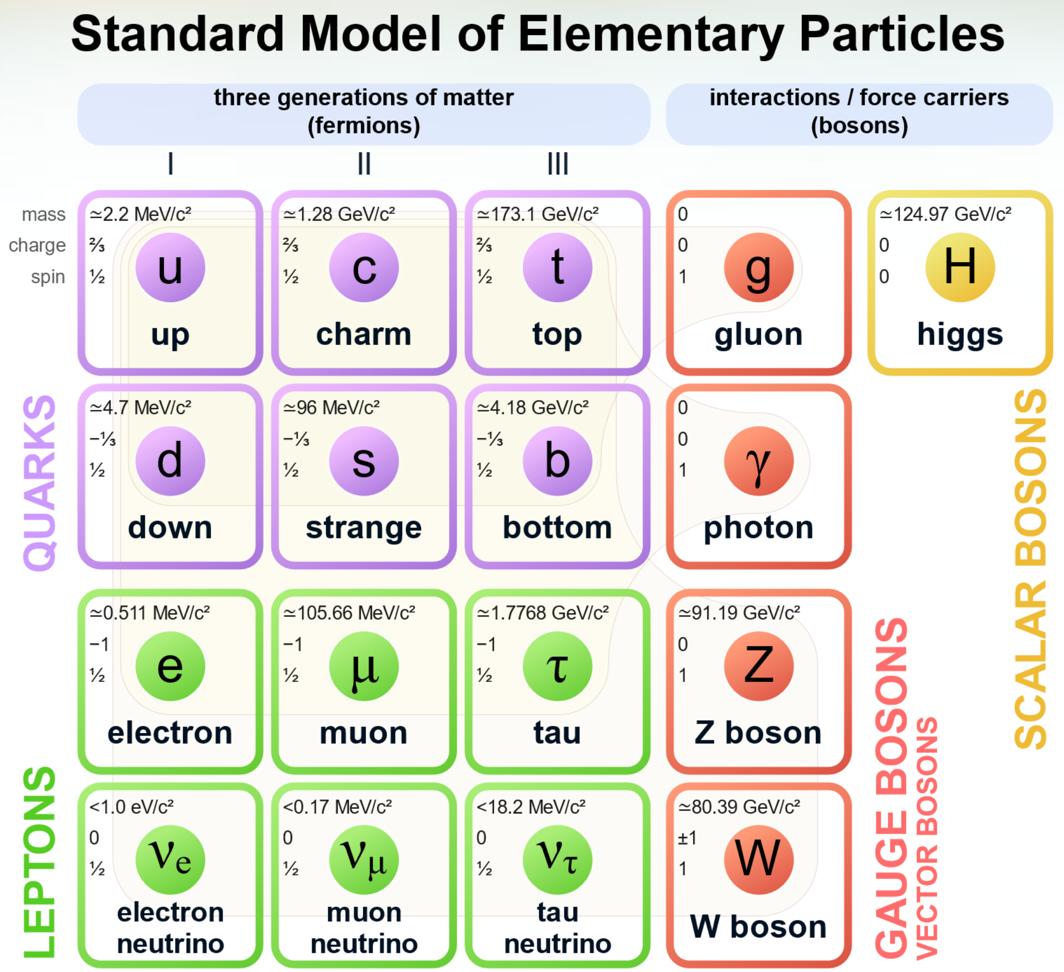
LHCb detectors

Proton collision point



LHCb physics

- In a proton collision a lot of particles produced
- Most of them are unstable and decay into other particles



Which processes we want to study at LHCb

- Decays of B mesons (with b-quark)
- Decays of D mesons (with c-quark)
- Decays of K mesons and hyperons (with s-quark)
- …

How we can identify different decays

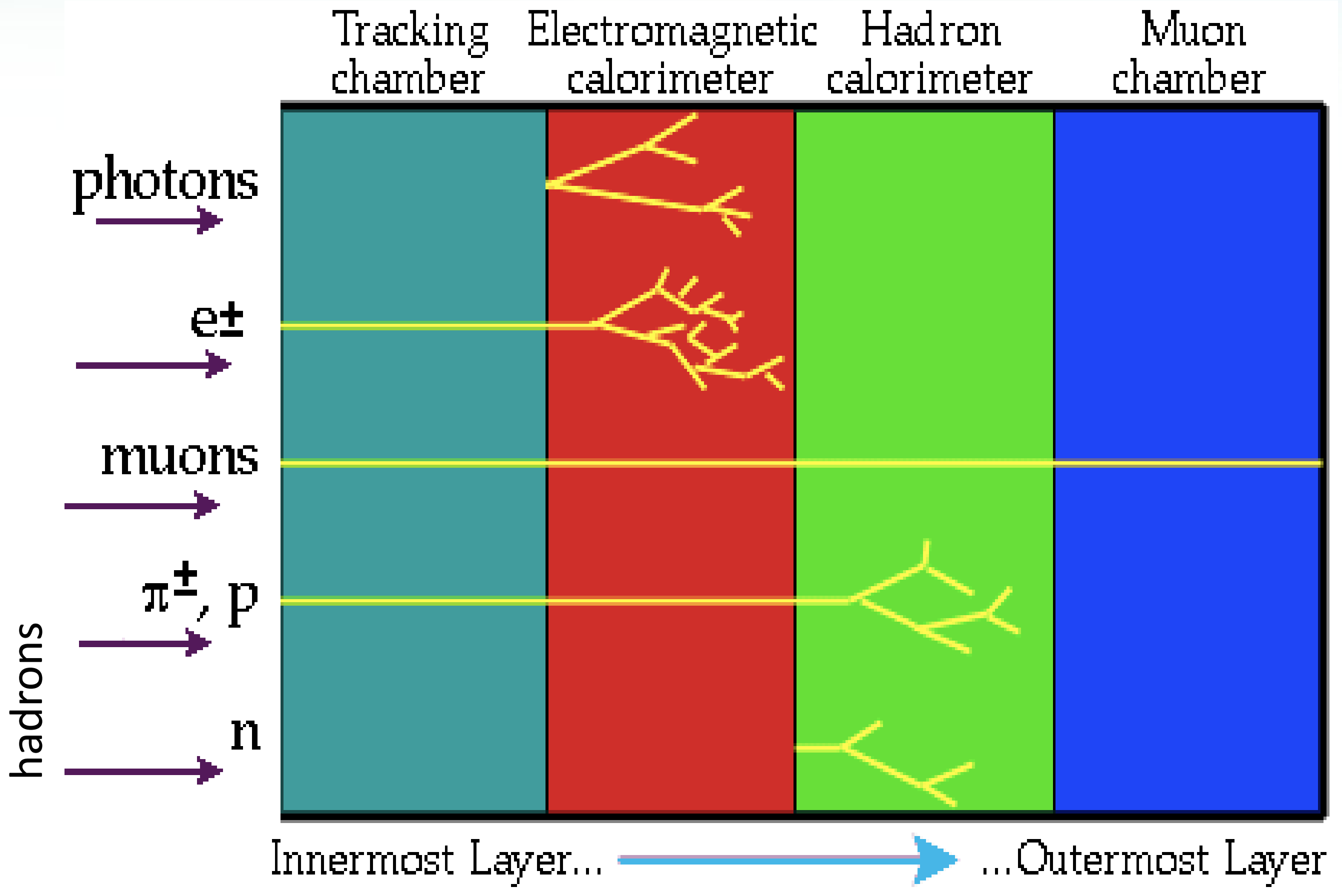
- Detect particles produced in meson decays
- Reconstruct the decay vertex
- calculate the total energy in the center-of-mass system (**cms**) to identify the parent particle

- Example: $B_s \rightarrow \mu^+\mu^-$
- Measure muons
- Calculate the total energy of two muons in cms, should be equal to the B_s mass

Particle detection

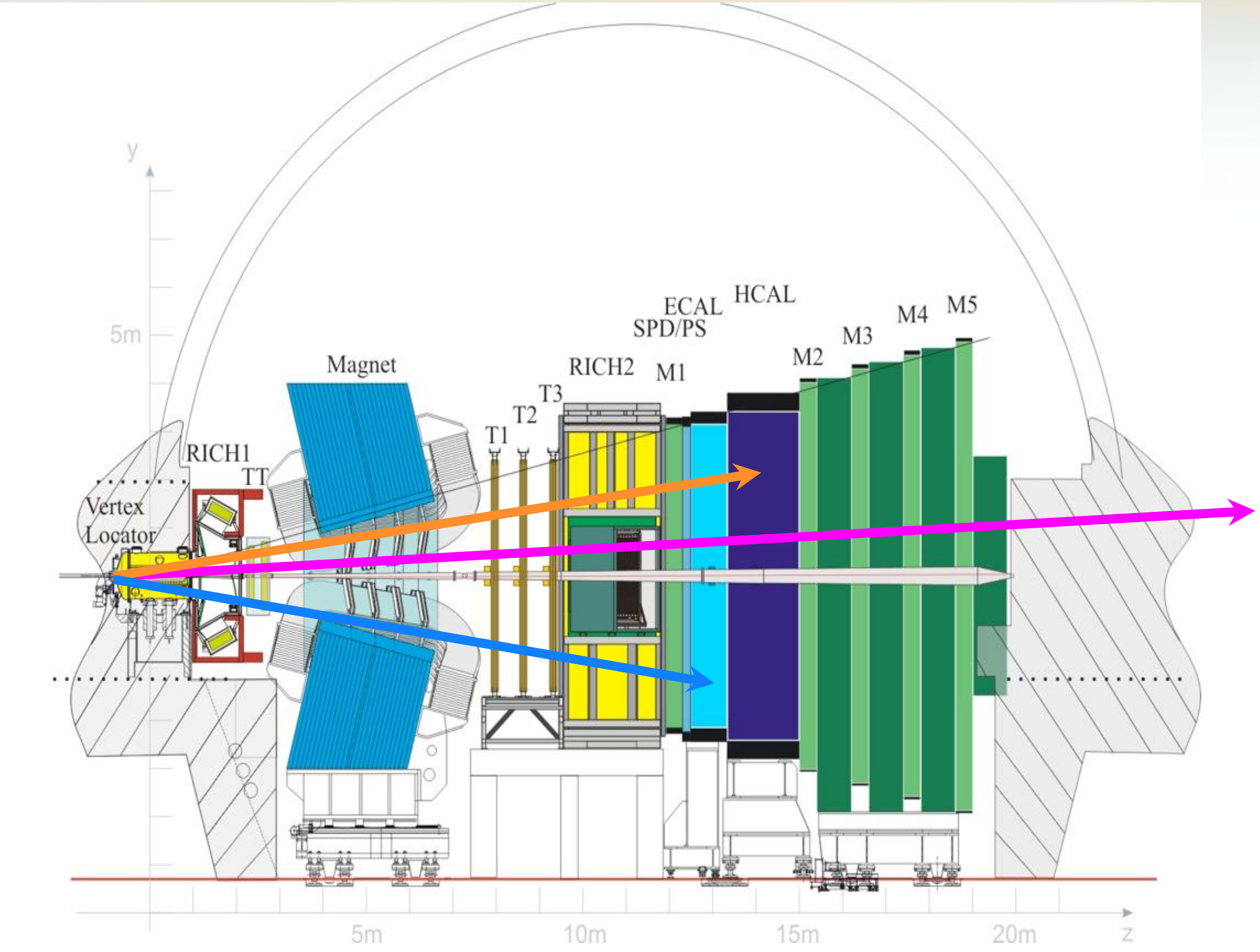
What we really measure
- Time
- Coordinates
- Energy released when passing through a detector

What we can calculate
- Particle track
- Momentum
- mass

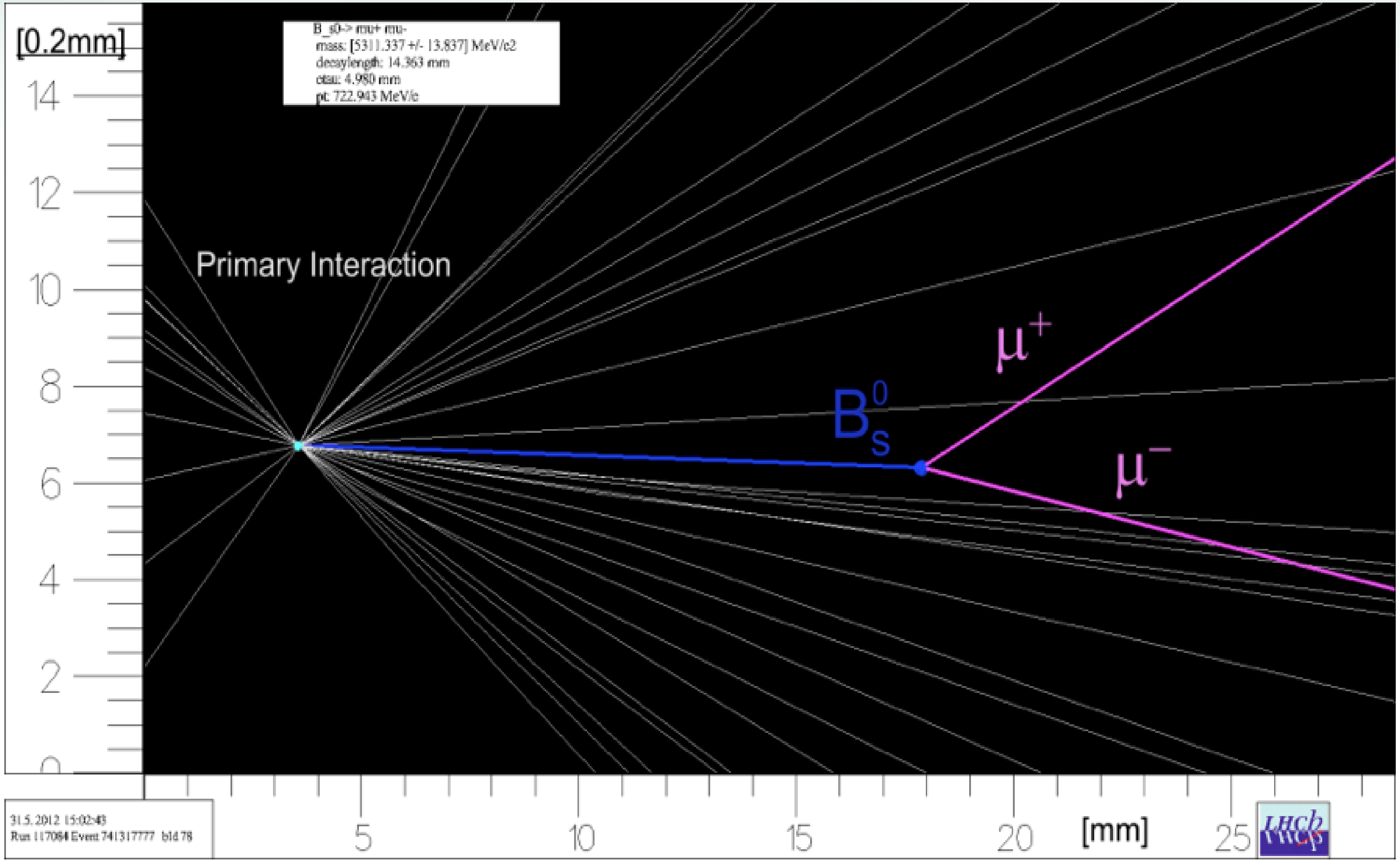


Particle detection at LHCb

→ ELETTRONI
→ FOTONI
→ ADRONI
→ MUONI



Event and decay reconstruction



Perugia @ LHCb

Perugia activities

- Detector part: Light leak detector (LLD) for the RICH
- Data analysis: search for new particles in decays of B mesons and hyperons

RICH detector

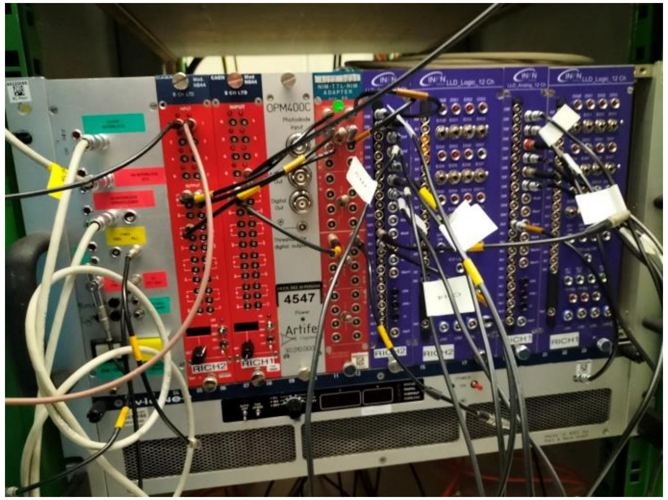
- Cherenkov light is produced when particles pass through the detector
- Light sensors are sensitive to single photons
- Light sensors should be isolated form the environmental light

Light leak detector (light sensors to control the darkness)

R&D tests in Perugia

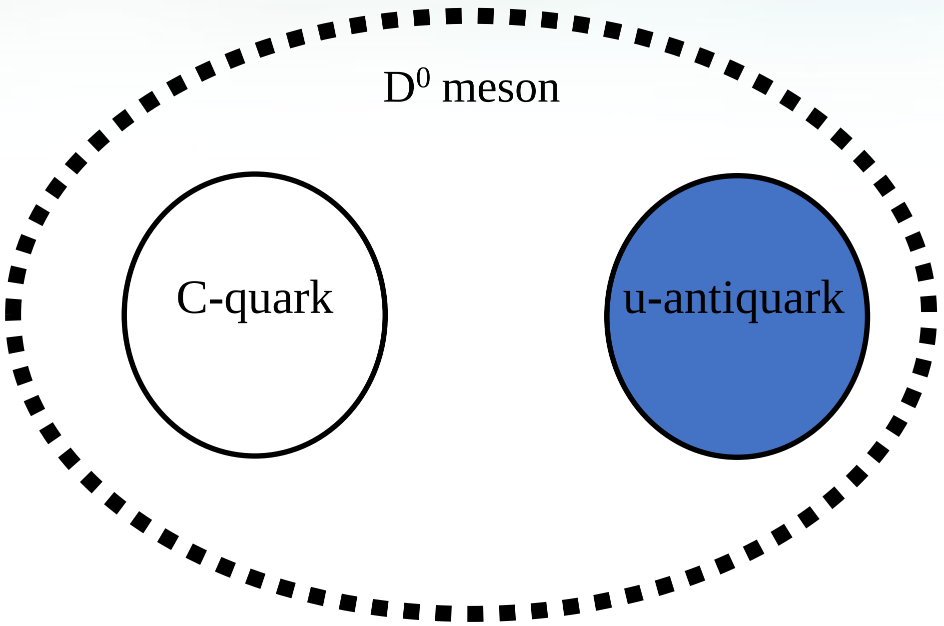
LLD installation at CERN

Electronics to read signals from the LLD



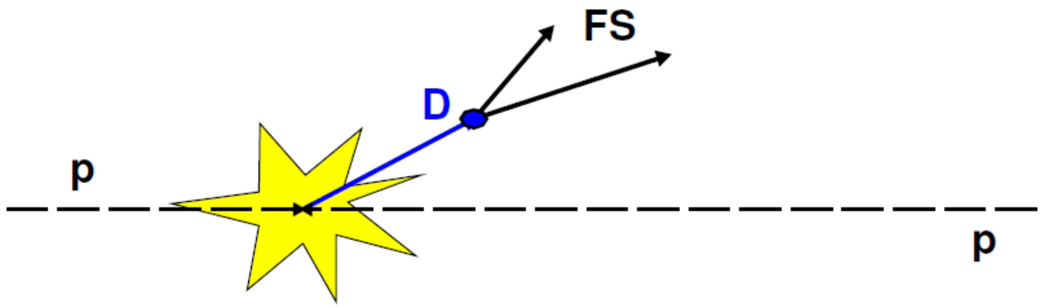
Your measurement

What you will measure
- Mean lifetime of D^0 meson
- Mass of D^0 meson



Why it is important
- D^0 and anti-D^0 could have slightly different properties
- This could lead to matter-antimatter asymmetry

How we measure
- D^0 could decay to $K^- \pi^+$
- Measure K^- and π^+
- Reconstruct the decay vertex
- Calculate the cms energy and D^0 mass



Your measurement

Decay law: $N(t) = N(t=0)*\exp(-t/\tau)$
τ is the mean lifetime: $N(t=0)/N(\tau) = 2.7$

D^0 lifetime: $0.4*10^{-12}$ s

How to measure τ?
- Measure distance: $c*\tau$ = 0.3 mm for slow (non-relativistic) D^0

Relativistic D^0 (e.g. @LHCb)
- Lifetime in the laboratory frame: $t_{lab} = t_{cms} / \sqrt{(1-v^2/c^2)}$
- Mean lifetime of D^0 @LHCb in the laboratory frame ~1 cm

Conclusions

- LHCb is one of four major experiments @ LHC
- LHCb primary goal is to study matter-antimatter asymmetry
- LHCb deals with decays of unstable particles produced in proton-proton collisions
- Decay products are measured by detectors
- You will measure the D^0 mass and lifetime

Details in the next talk by Mauro Piccini

Spare