Energy and precision frontiers at LHC

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INFN and INAF activities in Bologna

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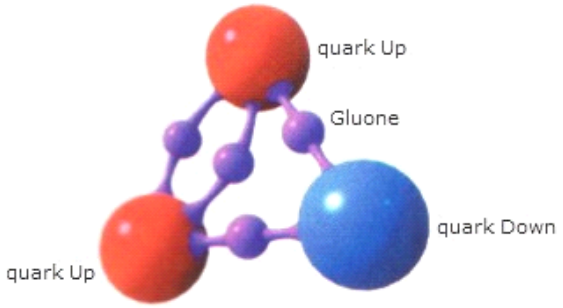
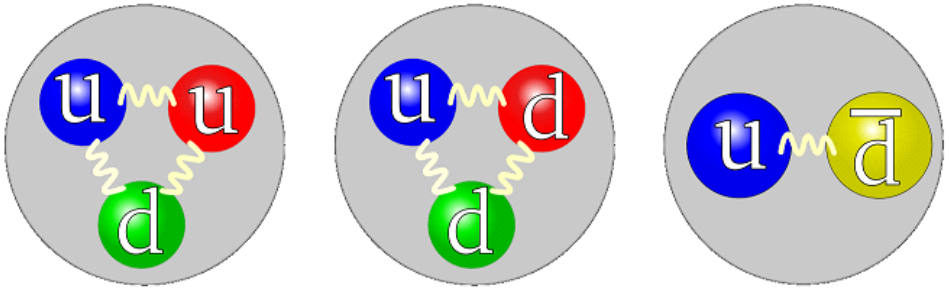
INFN Istituto Nazionale di Fisica Nucleare

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

What do we study with particle accelerators

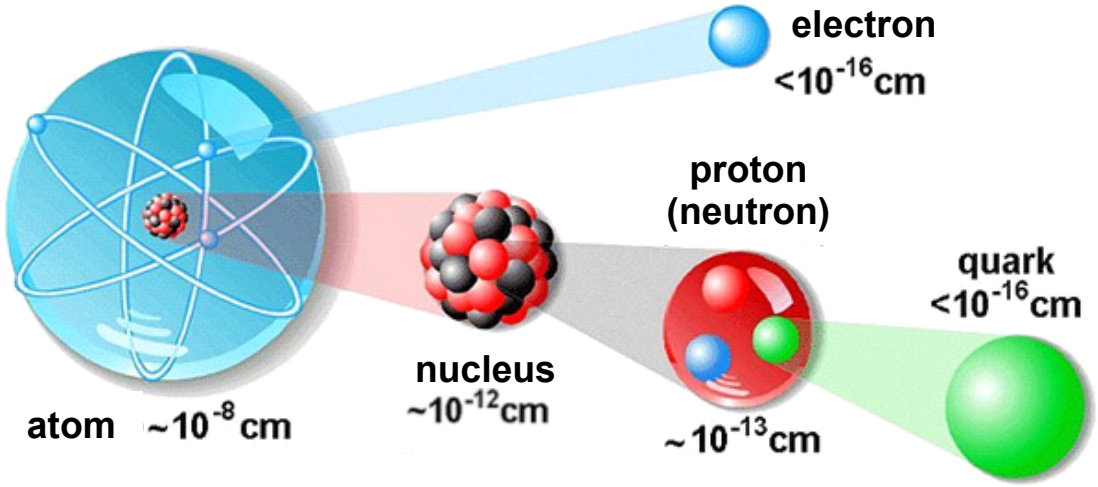
- Today we know hundreds of particles
- But we also know that all of them are generated by binding a small number of elementary particles
  - 6 quarks (+ 6 anti-quark)
  - 6 leptons (+ 6 anti-leptons)
  - 4 force carriers
  - Higgs boson

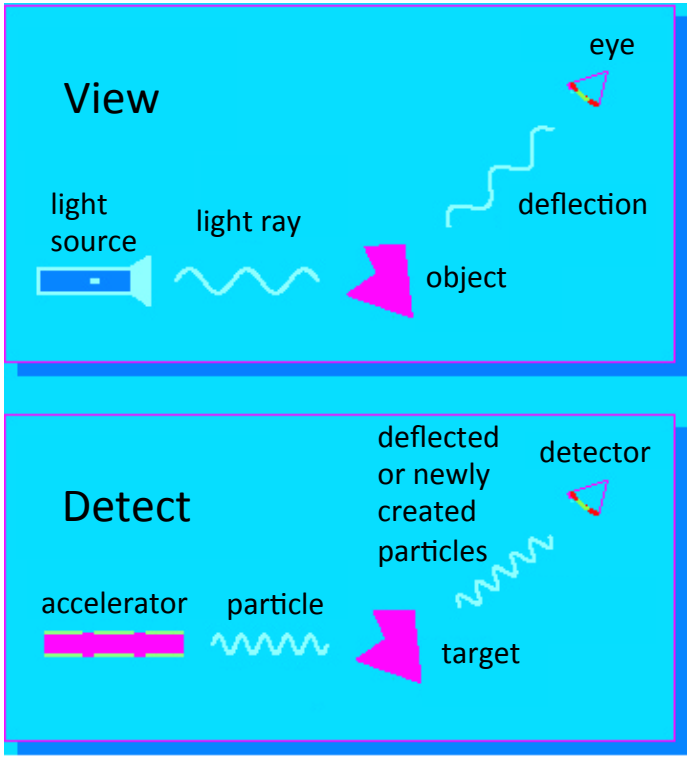




H^0_2

How big is a particle?

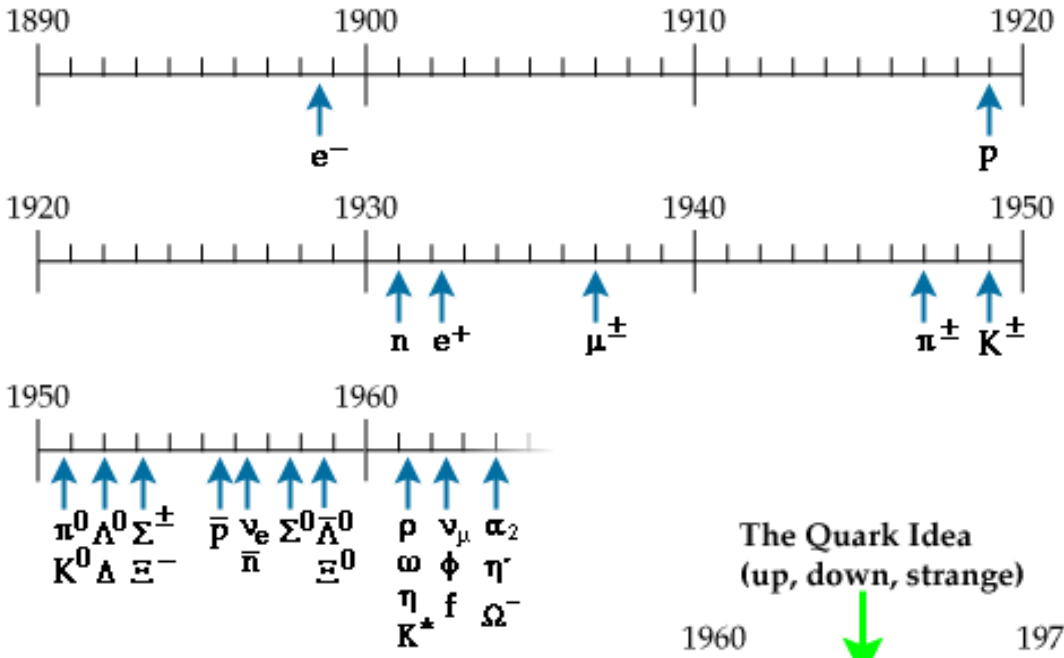




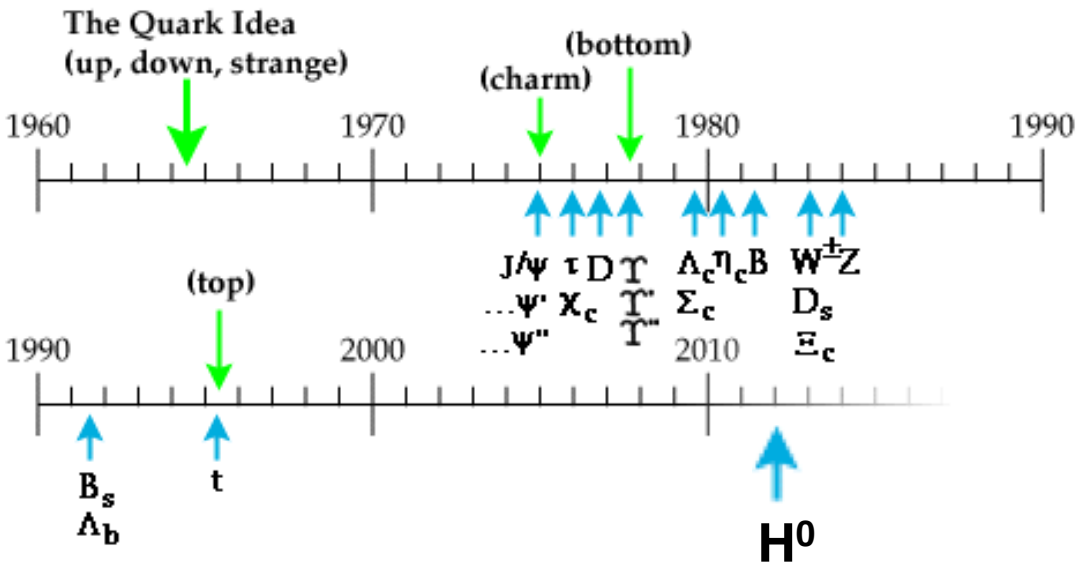
We need highly energetic radiation (small wave lengths):

Particle Accelerators!

Let's step back

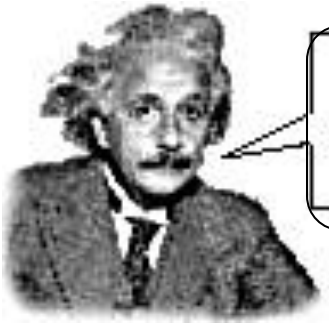


From the sporadic discovery of a few particles... a zoo shows up in the 1950's



And already in the 1970's we were able to realize the picture behind the zoo: the Standard Model of particle physics

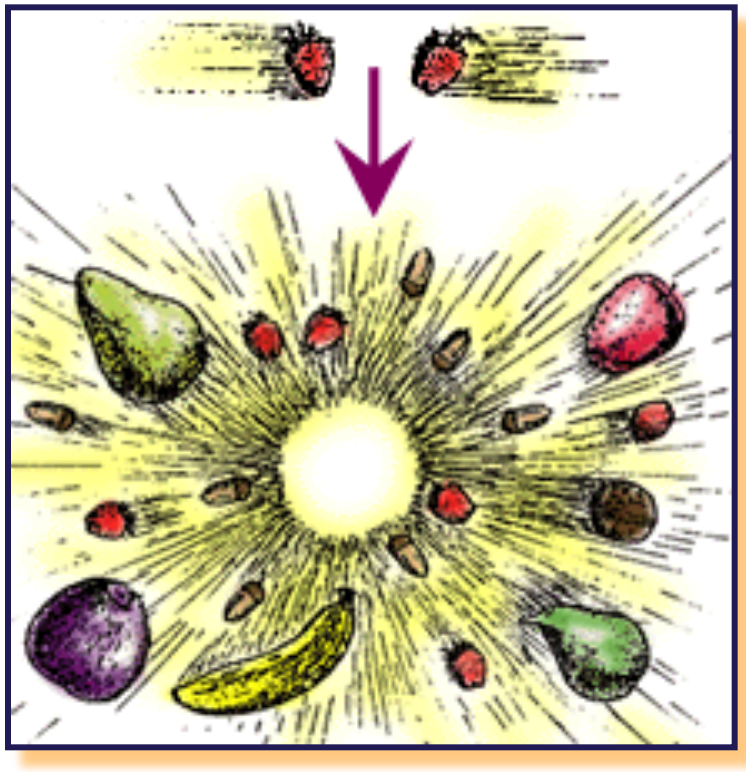
How do we produce new particles?



Mass is a form of energy...

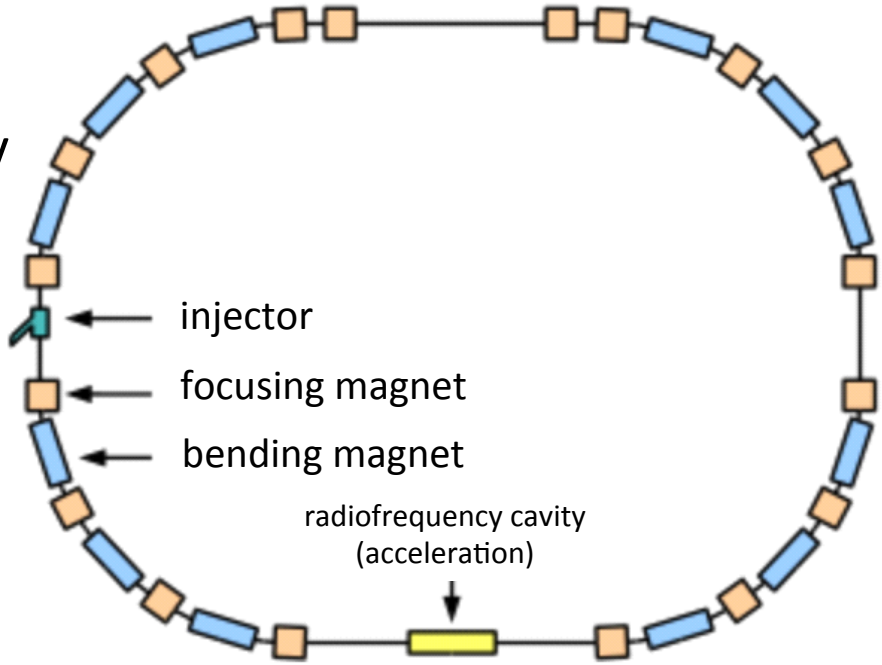
$E=mc^2$

- To study particles with large mass and highly unstable, we use ordinary particles with small mass (e.g. electrons and protons) but with very high kinetic energy pumped by an accelerator



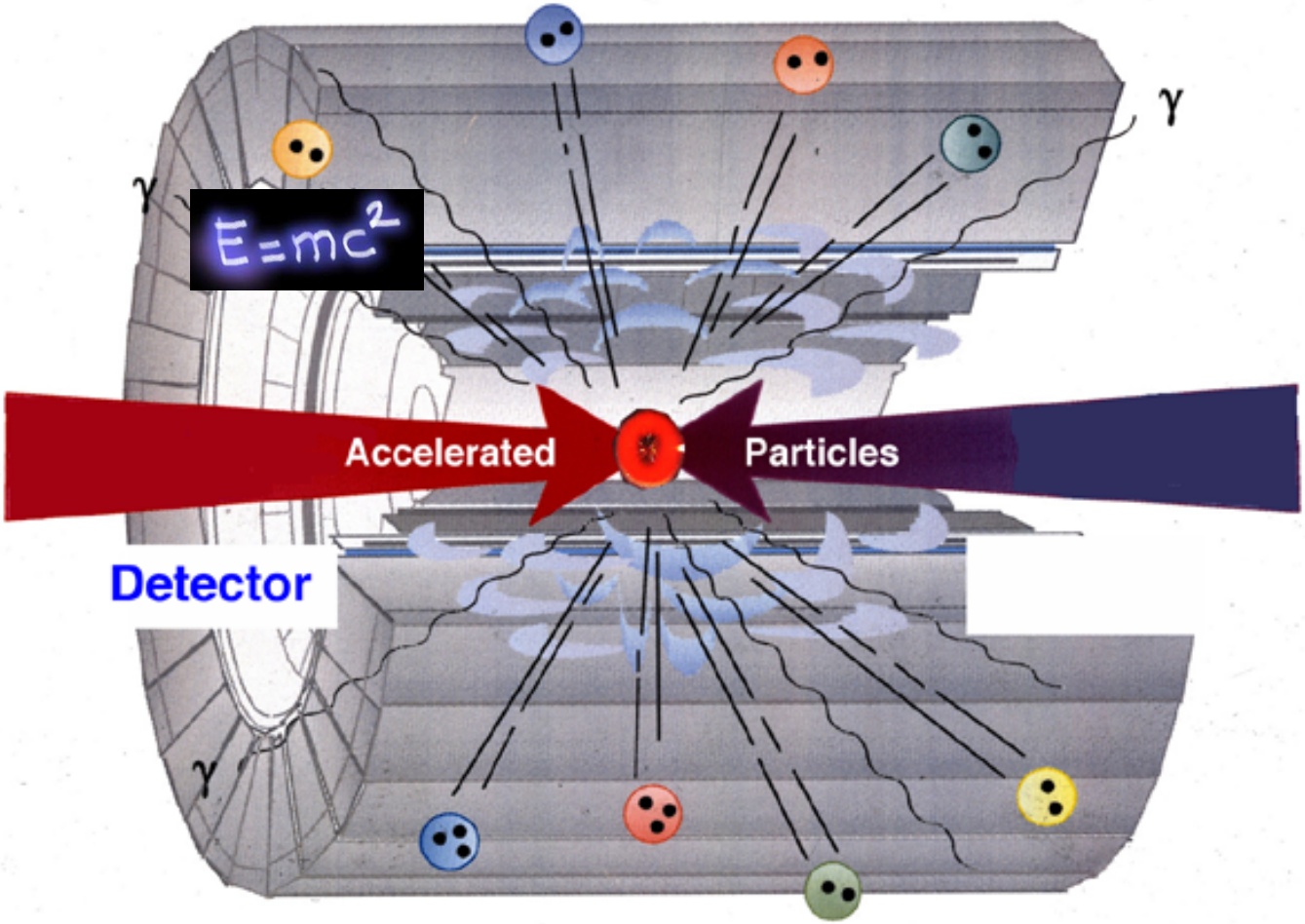
Basic acceleration principle

- The synchrotron is an accelerator where charged particles are accelerated along a circular trajectory
- Magnetic fields on the circuit guide the charged particles acting by the Lorentz force
- At every round, particles receive a "kick" by a radio frequency so that they increase their energy in small steps until they reach the maximum energy that the machine can tolerate



- At every round, the increase in energy must be compensated by a synchronous increase of the magnetic fields needed to keep the beam at a constant curvature

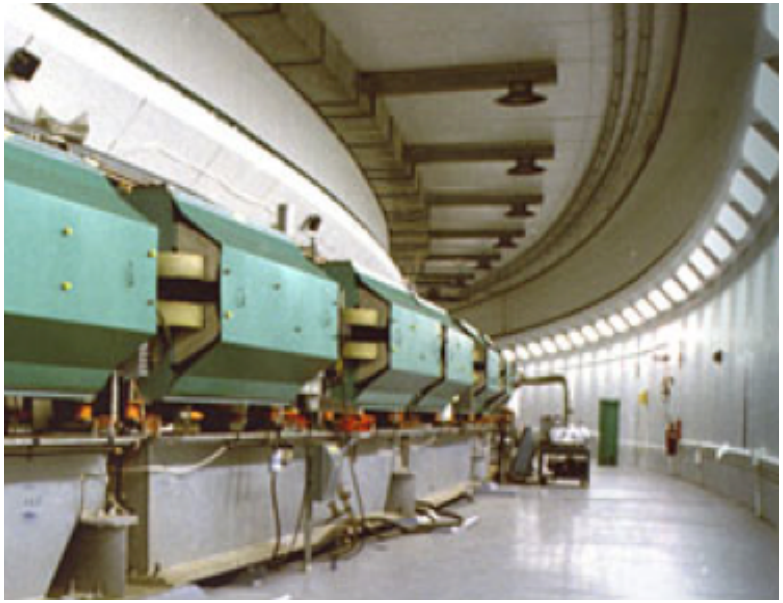
And how do we detect the particles?



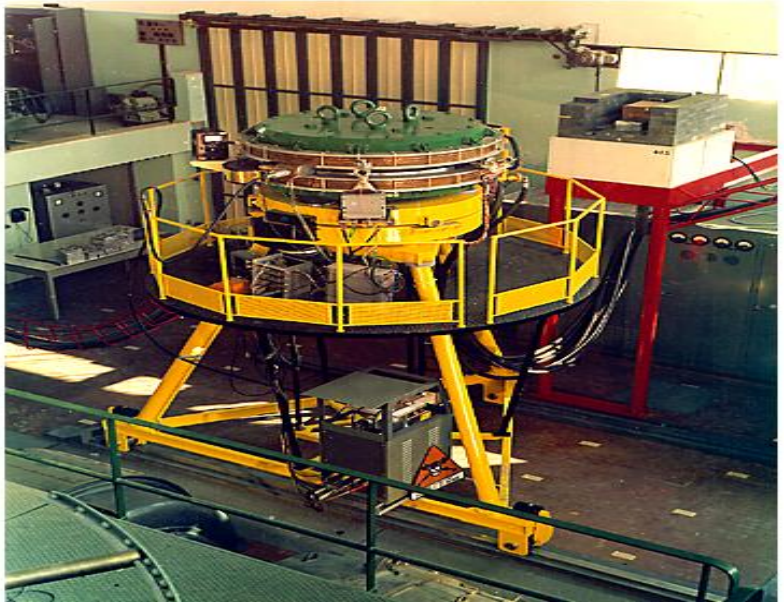
Bevatron (Berkeley) 1954

PS (CERN) 1959

AGS (Brookhaven) 1960

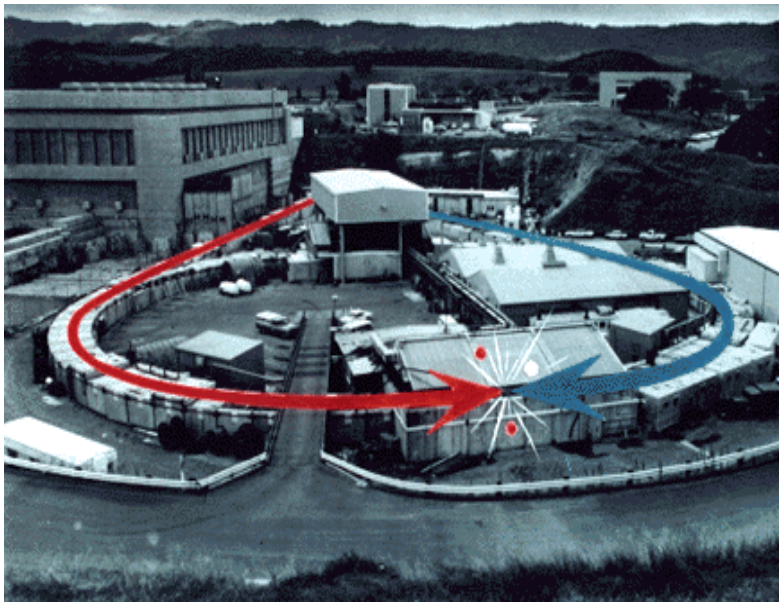


AdA (Frascati) 1961



ISR (CERN) 1971

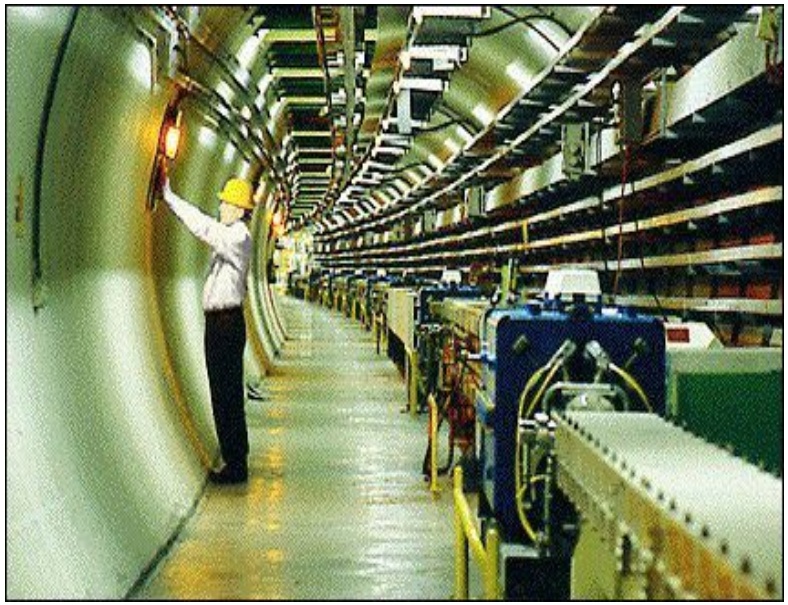
SPEAR (SLAC) 1972



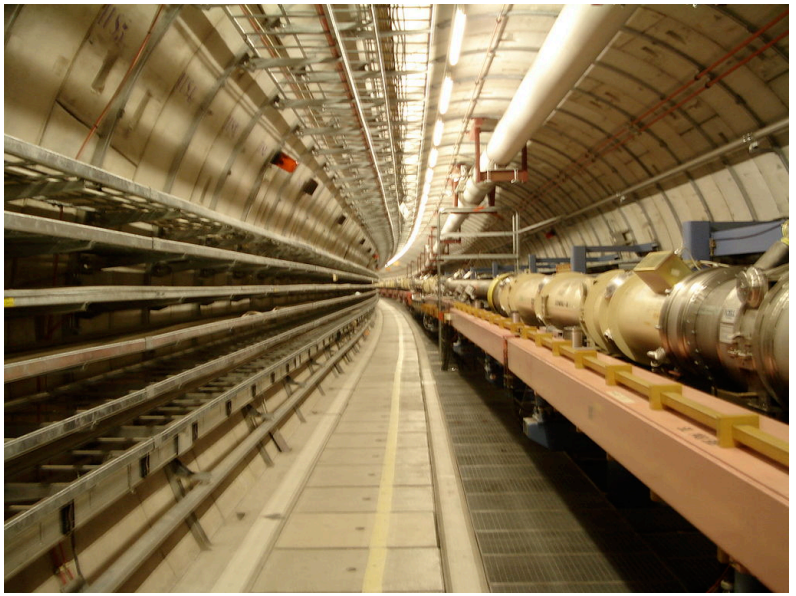
SPS (CERN) 1976

Tevatron (FNAL) 1983

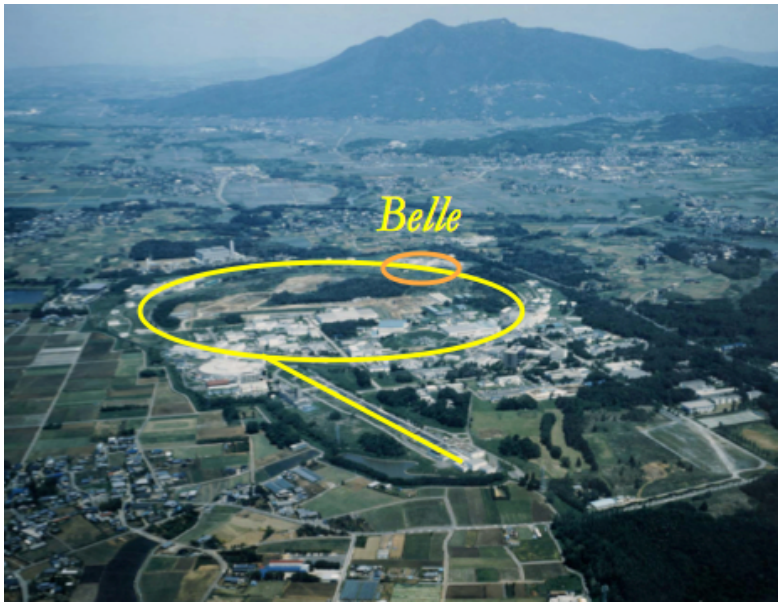
LEP (CERN) 1989



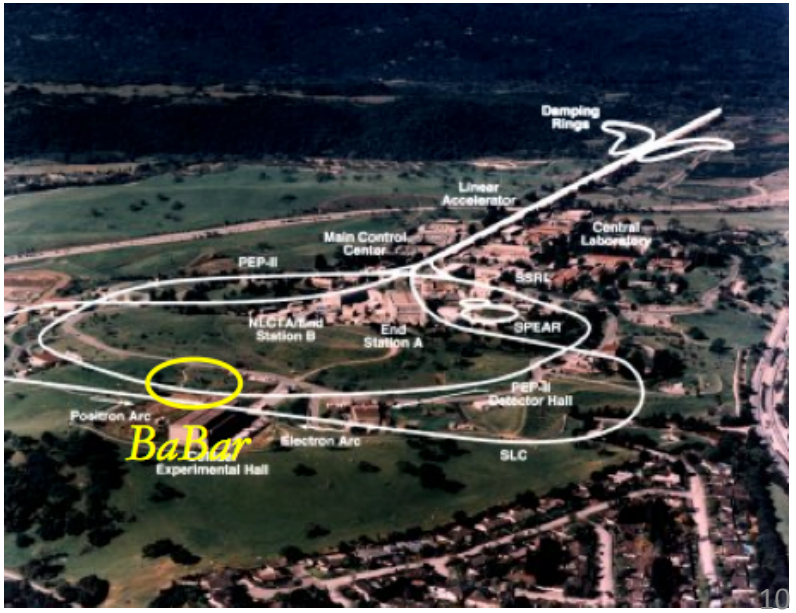
HERA (DESY) 1992



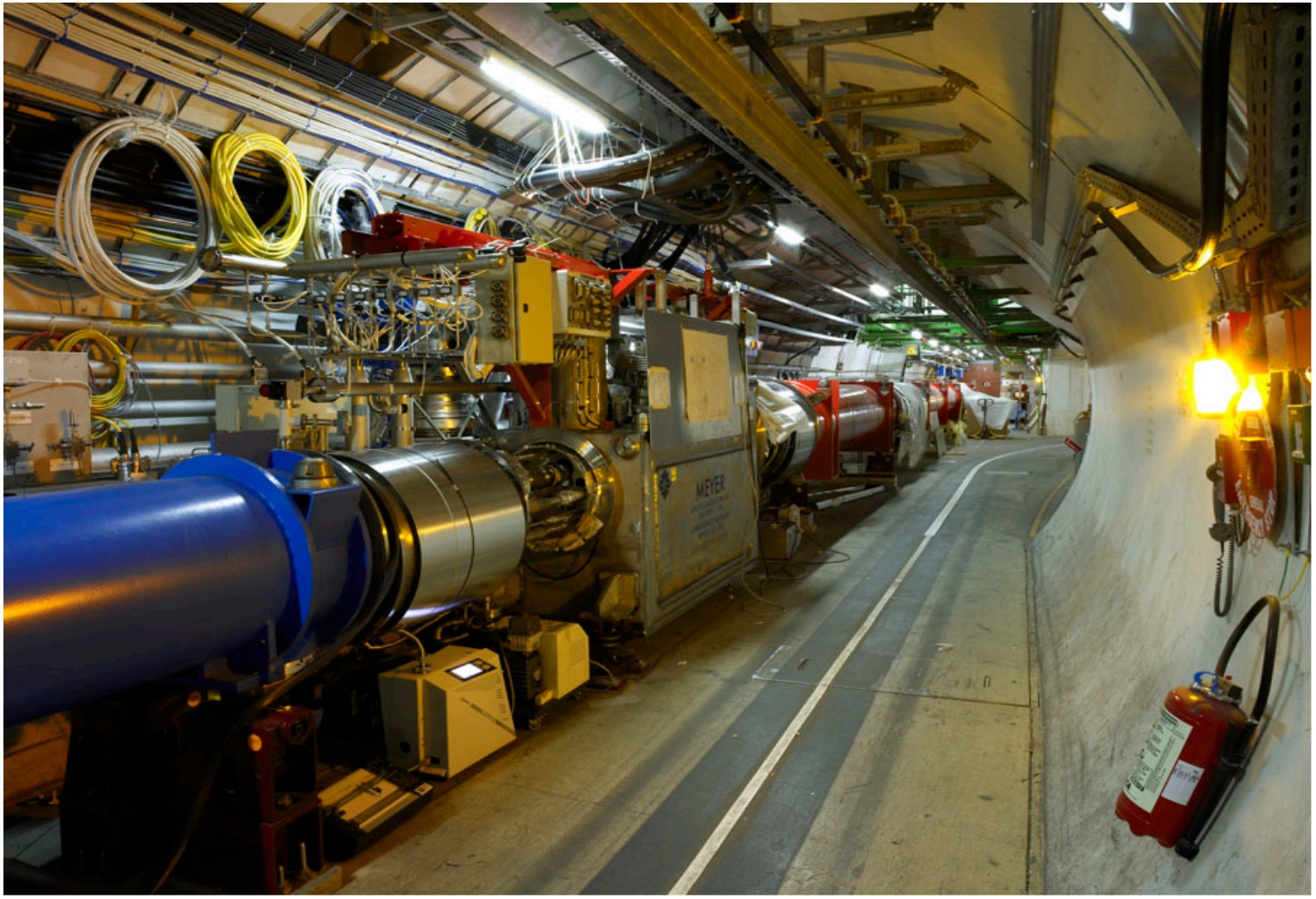
KEKB (KEK) 1999



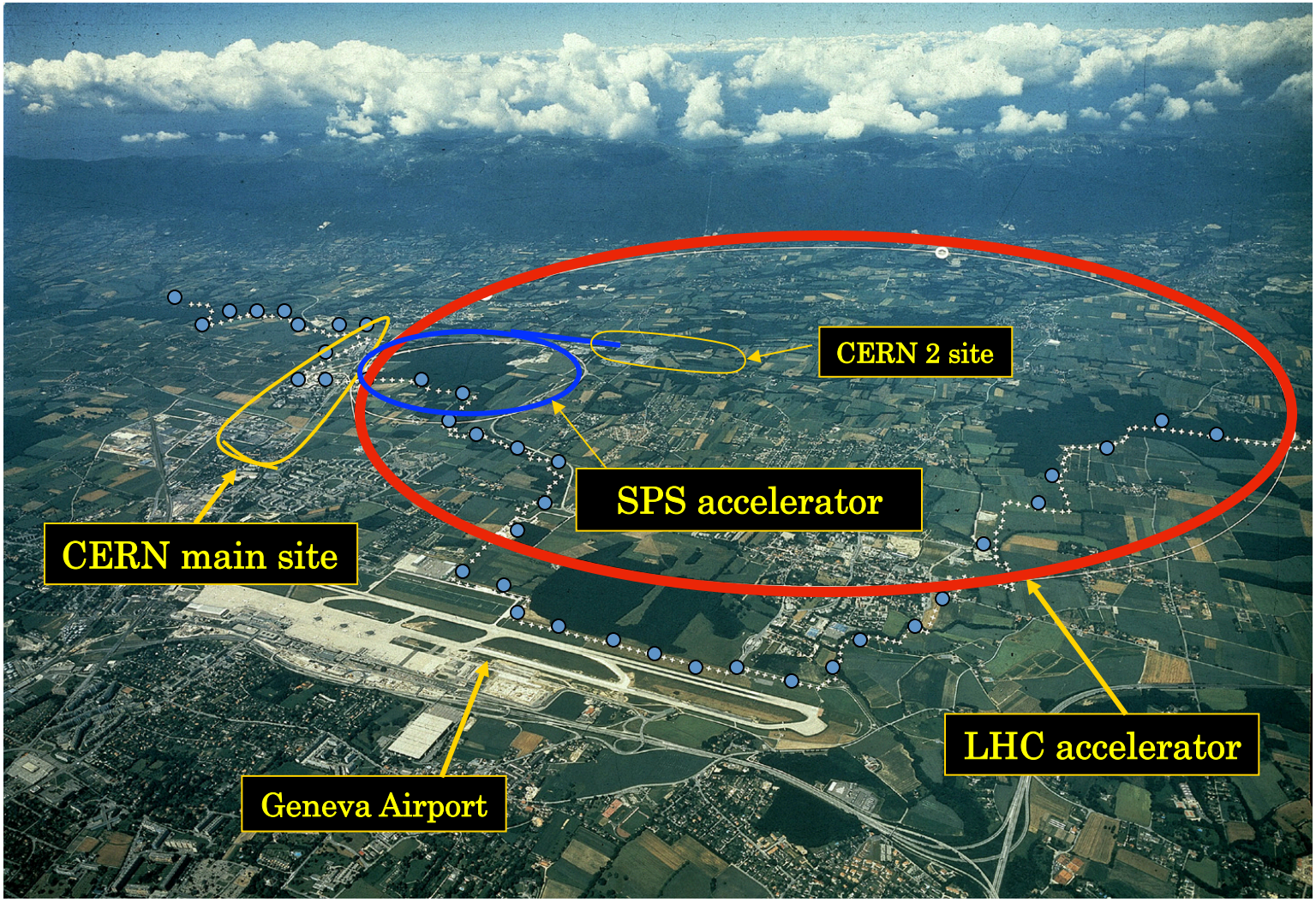
PEP-II (SLAC) 1999



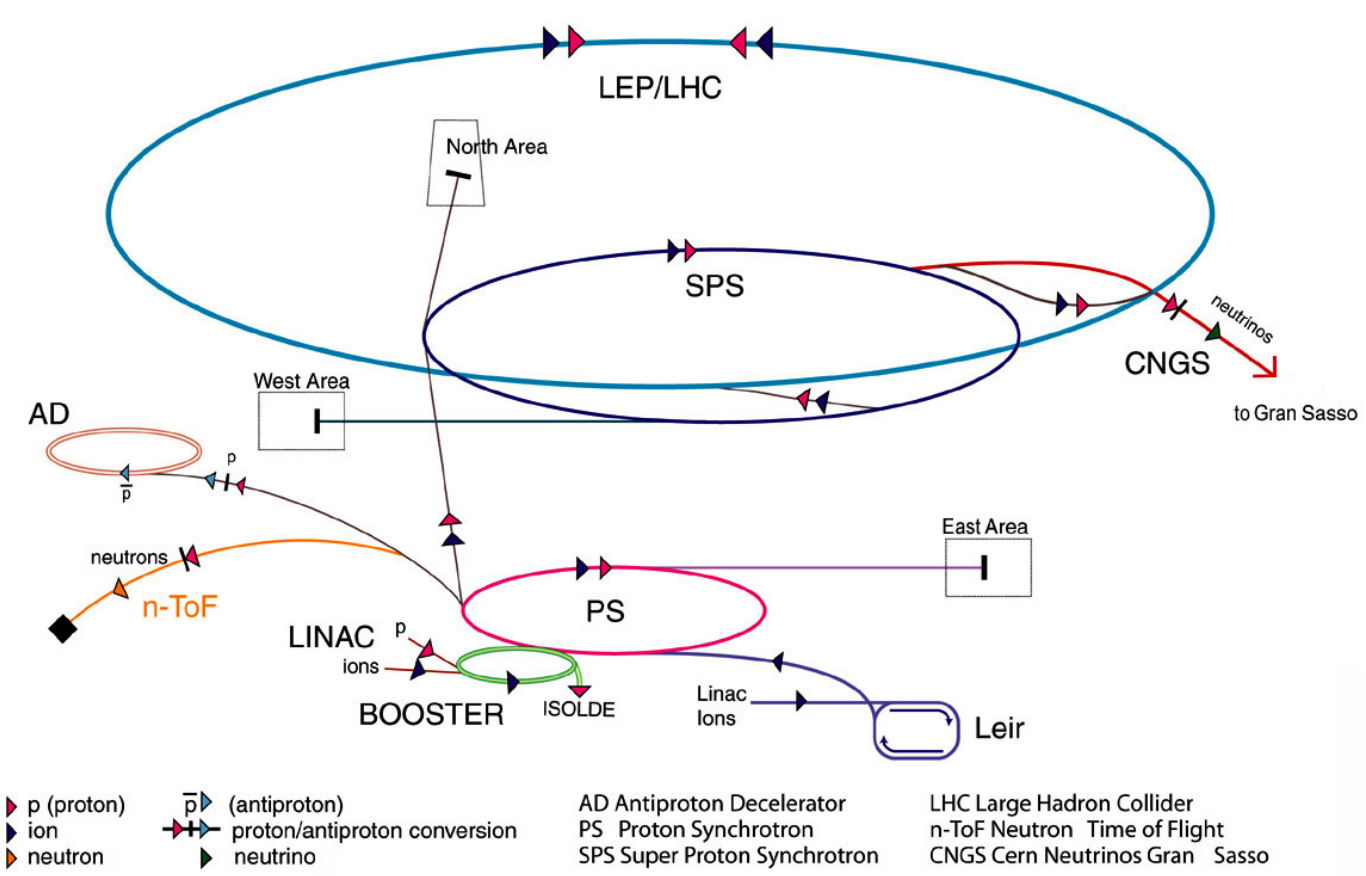
LHC (CERN) 2008



LHC (CERN) 2008



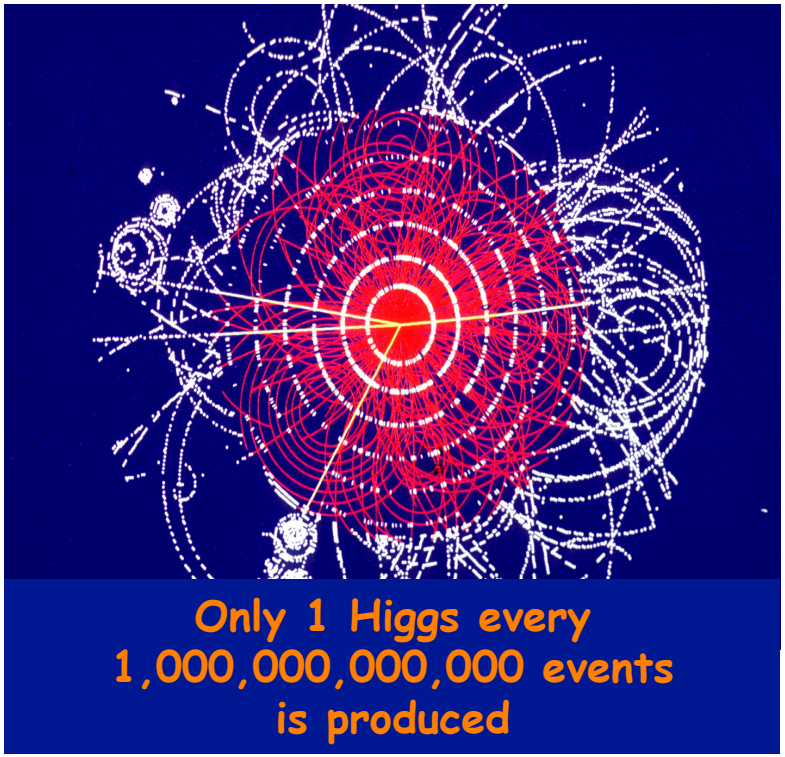
CERN accelerator complex



- The accelerator chain at CERN has evolved with time
- We reuse accelerators, detectors, infrastructure, knowledge and experience

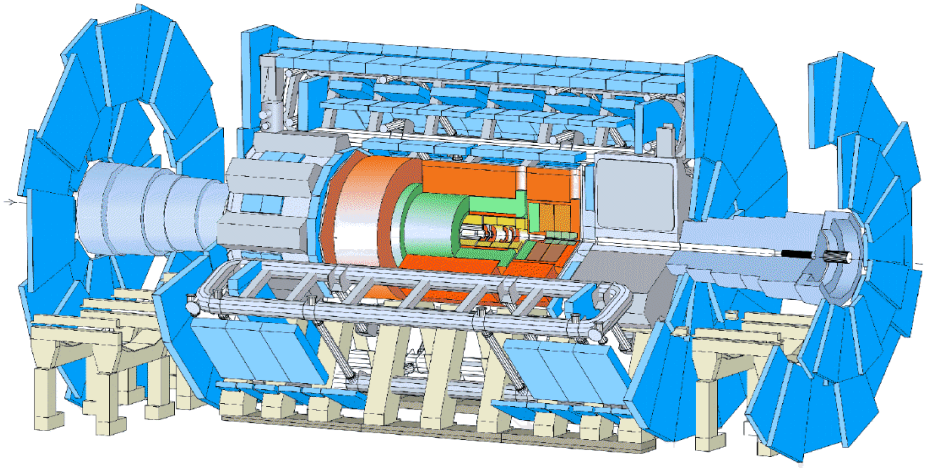
LHC energy

- The LHC accelerates two counter-rotating beams of protons to the energy of 7 TeV each (starting from 2015, so far reached 4 TeV per beam)
  - The protons in the beams collide at the beam crossing points 800 million times per second
- The energy of a proton is equivalent to about 100 million times the energy of electrons in the cathode ray tube of an old television
- The whole energy circulating in the machine is equivalent to a mass of 1 kg at a speed of 100000 km/h

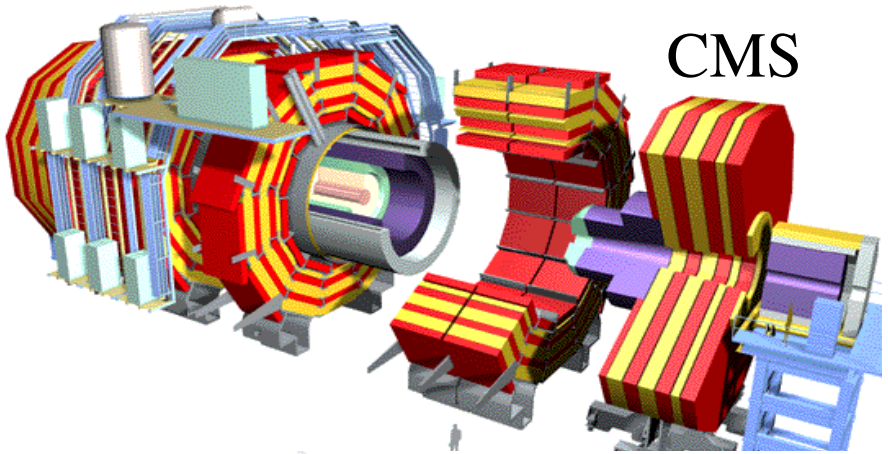


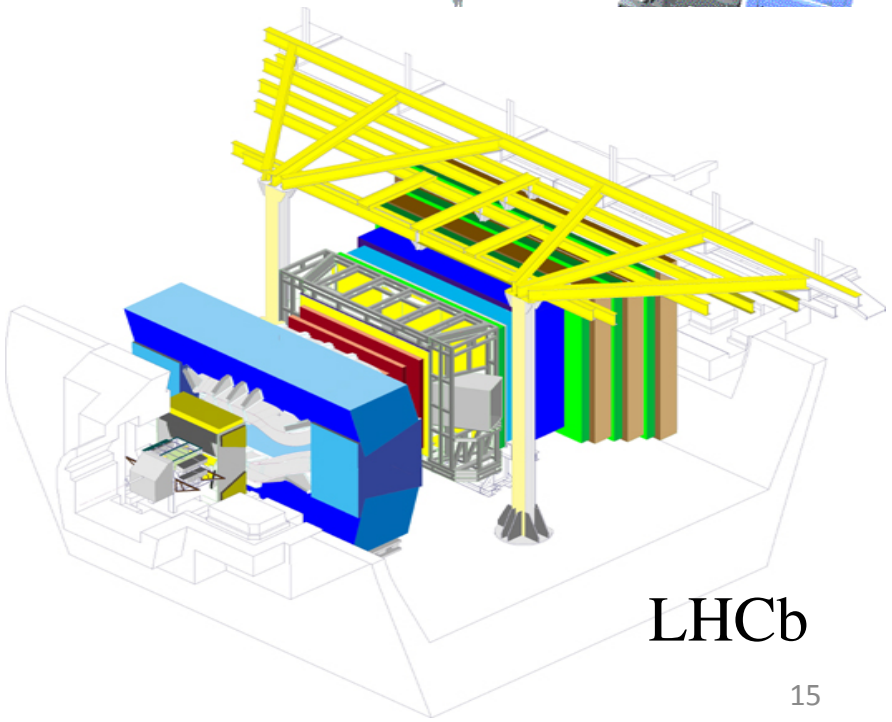
ATLAS, CMS and LHCb experiments

ATLAS



CMS

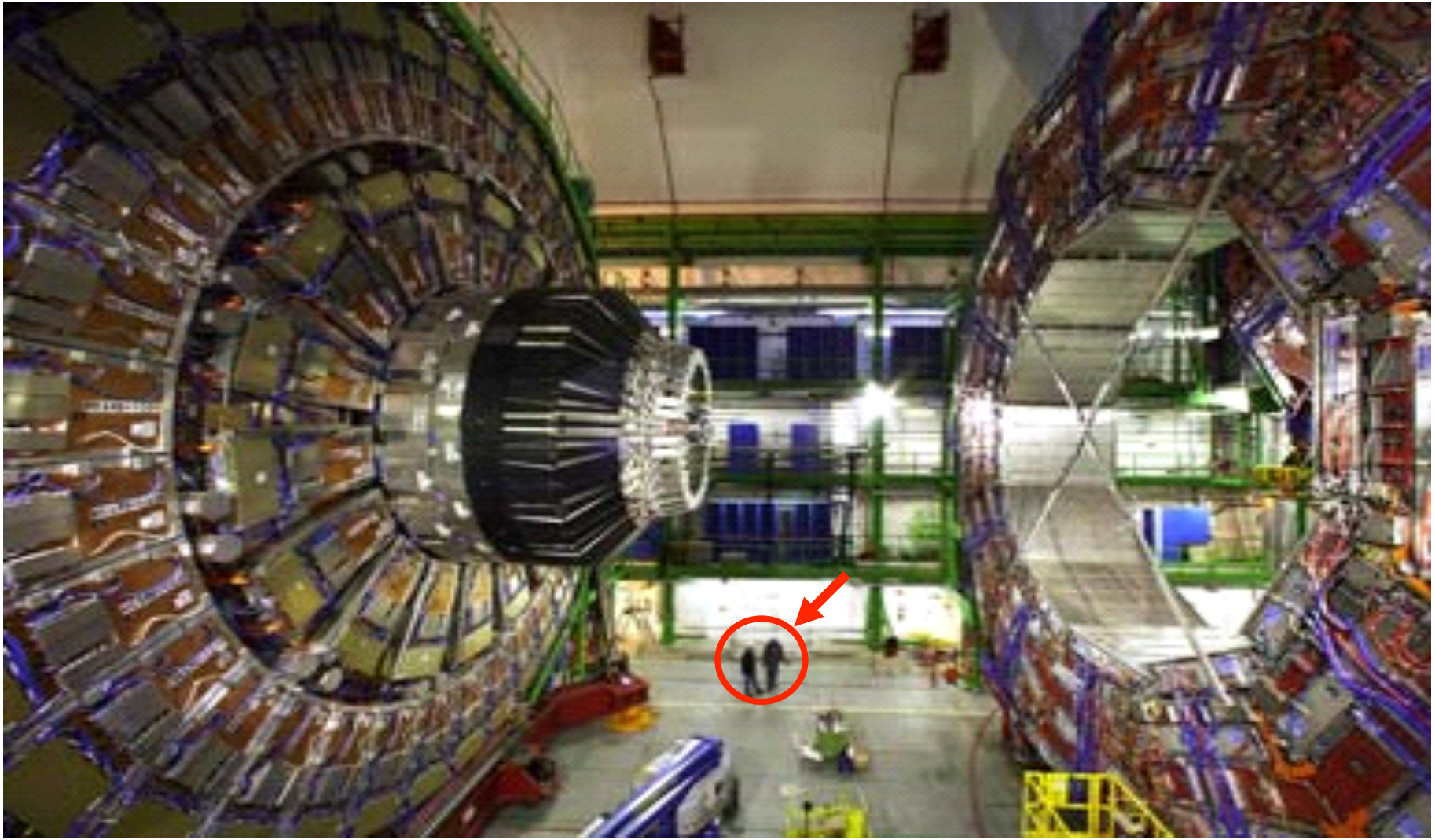




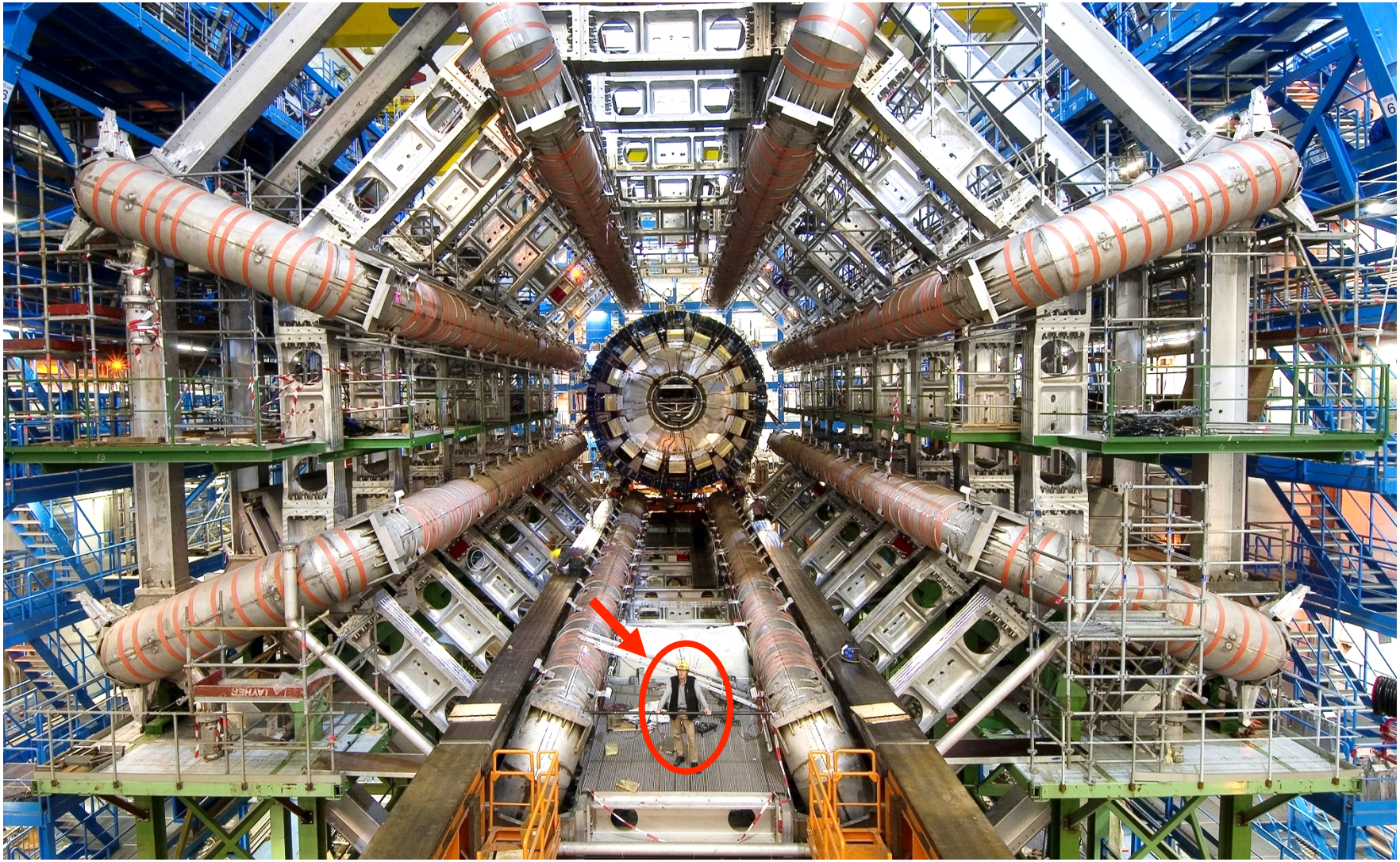
LHCb

- The high energy physics activities in INFN Bologna focus today on these three experiments

The CMS detector during construction



The ATLAS detector during construction



ATLAS and CMS

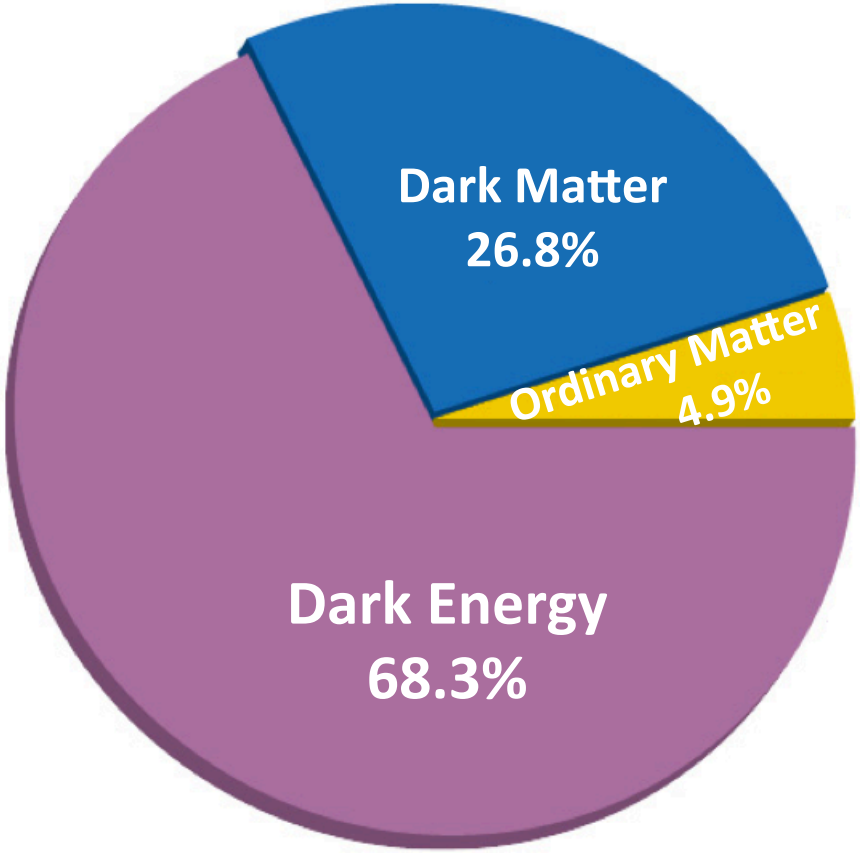
- Their main feature is to be very efficient in detecting particles with very high momentum in the direction transverse to the LHC beams
  - in the HEP jargon, this is said to be high p_T region
- The ATLAS and CMS researchers in these first years of LHC data taking have achieved the triumph of the Higgs boson discovery
- The new frontier now is the search for new particles of high mass, not yet observed
  - but why should they exist?
- The LHC is now in shutdown, and will restart next year at twice the energy that it reached so far
  - the new energy range could give rise to the creation of such new particles, this is the hope
  - This research needs the highest possible energy, and possibly high intensity if the events are rare enough

LHCb

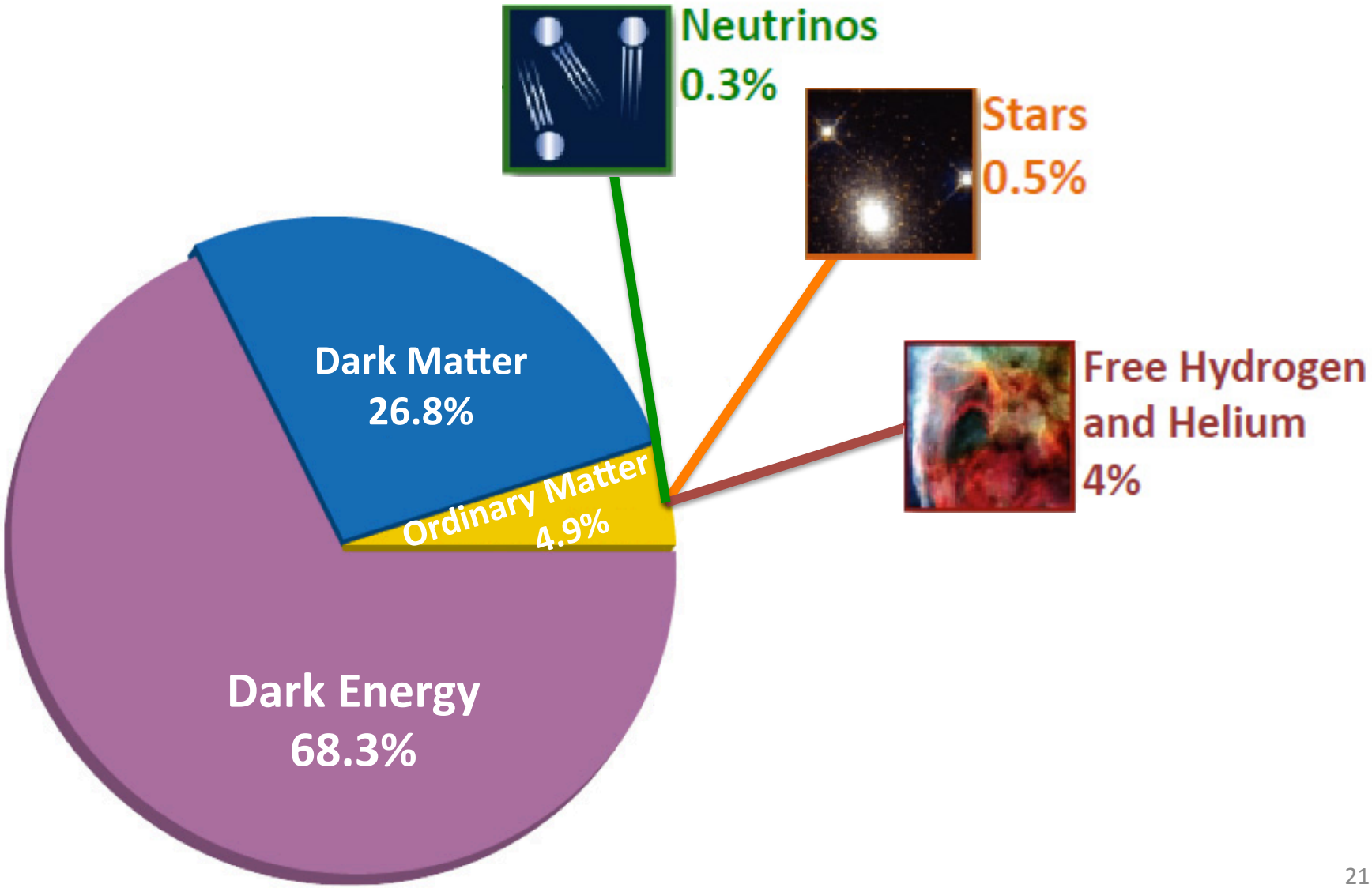
- It is designed to study with high precision the asymmetry in the behaviour of matter and antimatter particles, in order to answer one of the fundamental questions of modern physics
  - why the Universe that we observe seems to be made of matter, whereas antimatter completely disappeared?
- The detector has the feature of being very efficient in the detection of particles containing beauty and charm quarks, that are produced prevalently along the axis of the proton beams
  - the decays of such particles are sensitive to quantum virtual effects, and new particles might show up in the Feynman diagrams of the decays → indirect search of new physics, needs high intensity

Relative abundance of "ordinary" matter, Dark Matter and Dark Energy from CMB data

- Ordinary matter is just the tip of the iceberg: ~5% of the total budget of the Universe



Relative abundance of "ordinary" matter, Dark Matter and Dark Energy from CMB data

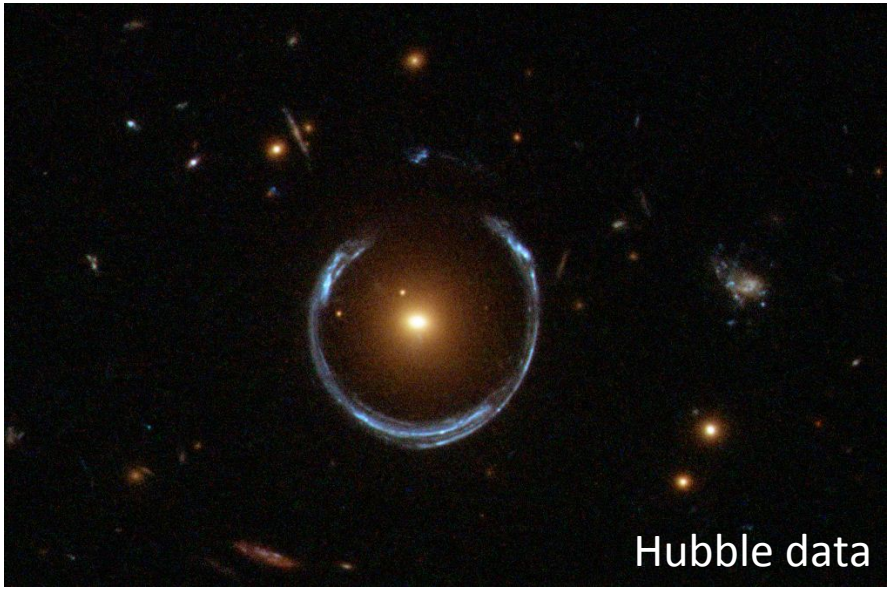


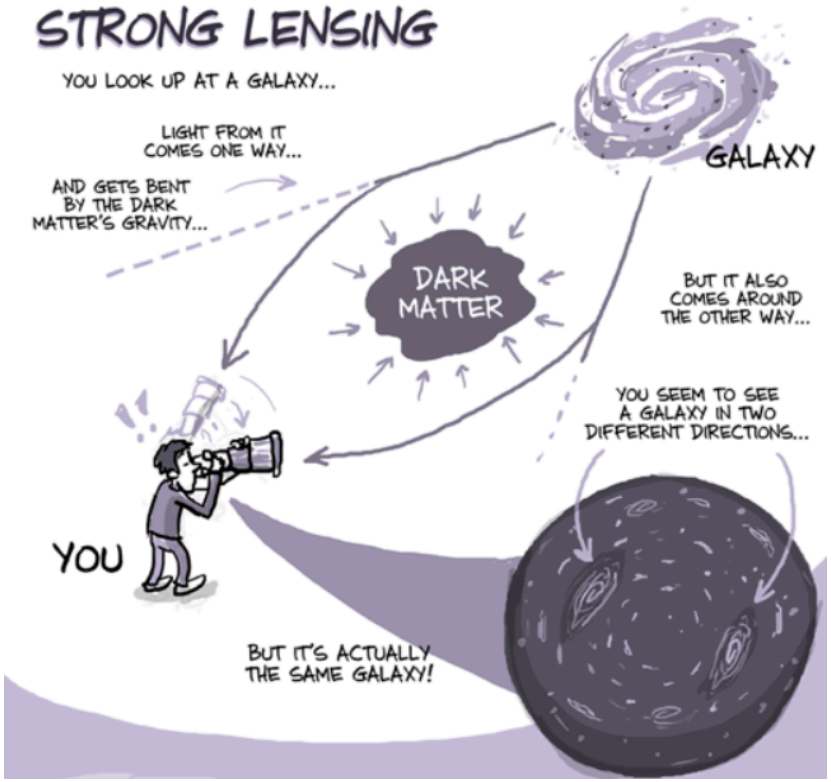
Relative abundance of "ordinary" matter, Dark Matter and Dark Energy from CMB data

If you ever had any doubt… we are peanuts!

Astronomical evidences of Dark Matter

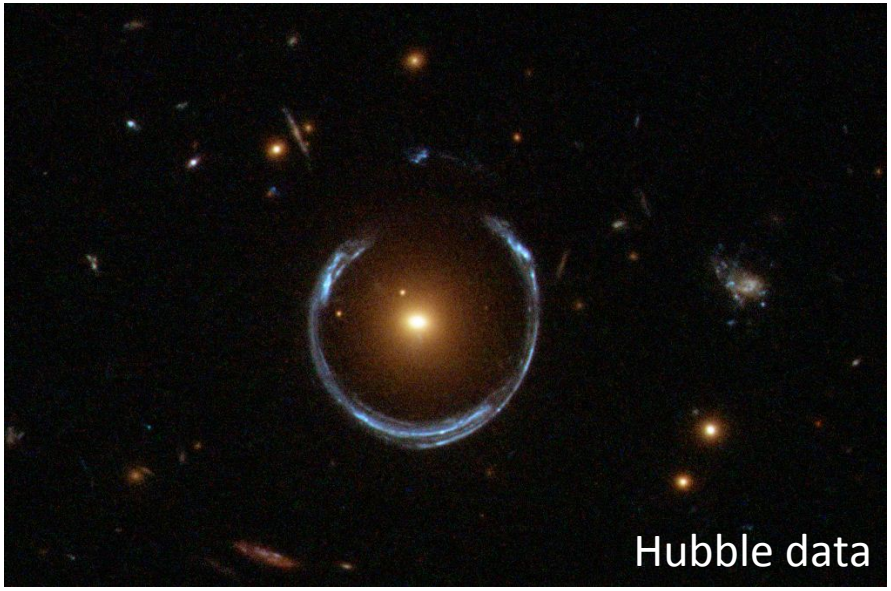
Gravitational lensing



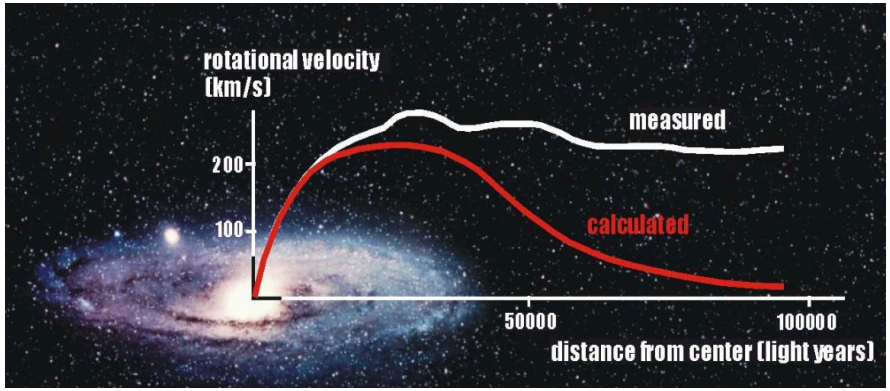


Astronomical evidences of Dark Matter

Gravitational lensing

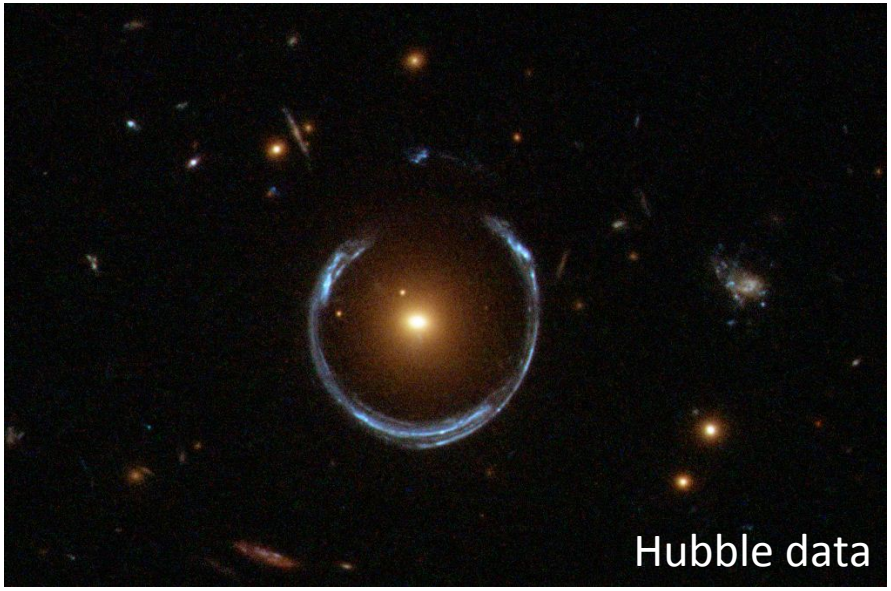


Galaxy rotation curves



Astronomical evidences of Dark Matter

Gravitational lensing



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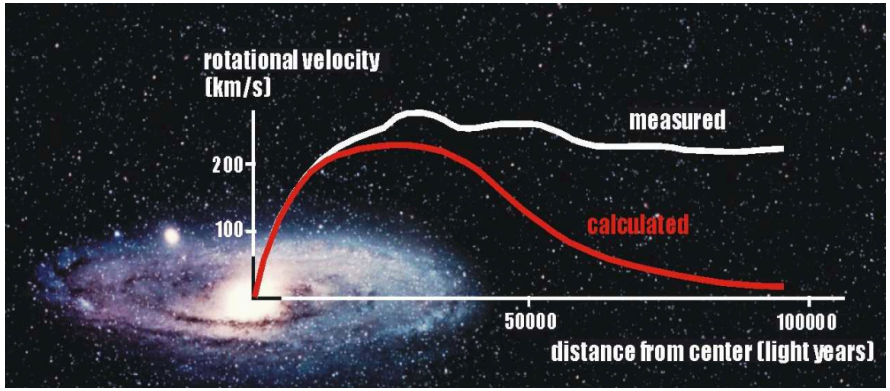
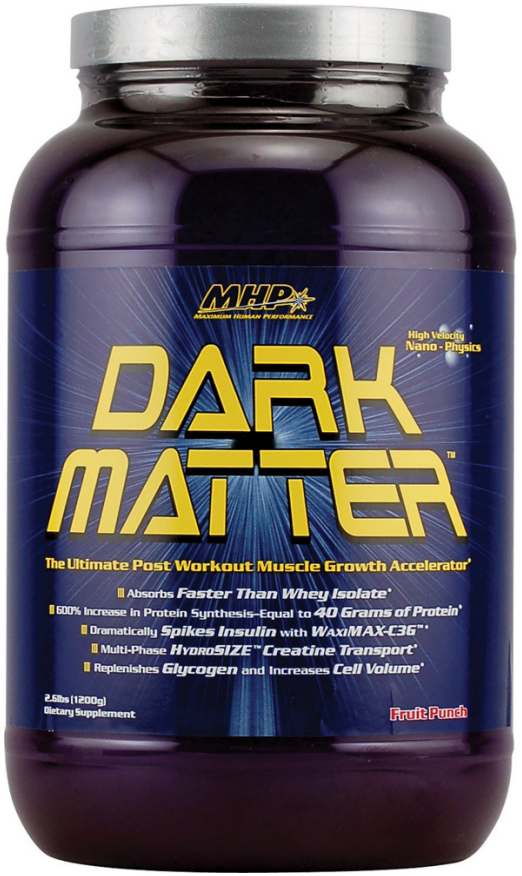


- Several independent observations
  - in particular recent ones with CMB data, not shown here
- Note that the existence of invisible matter in the Universe was already conjectured in the 1930's by measuring the relative velocities of galaxies inside the Coma cluster, to estimate the mass of the cluster itself
  - The mass resulted to be much larger than that inferred from visible stars
- **Dark Matter is nowadays a solid experimental matter of fact**

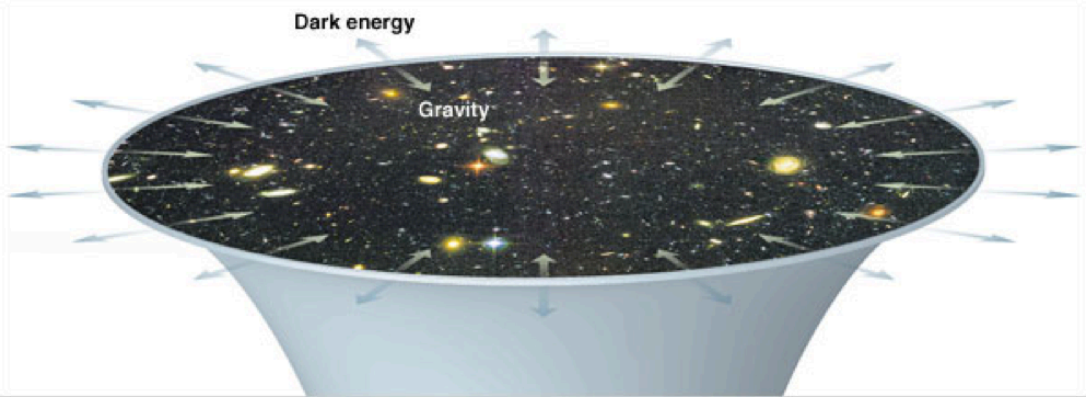
What is Dark Matter made of?

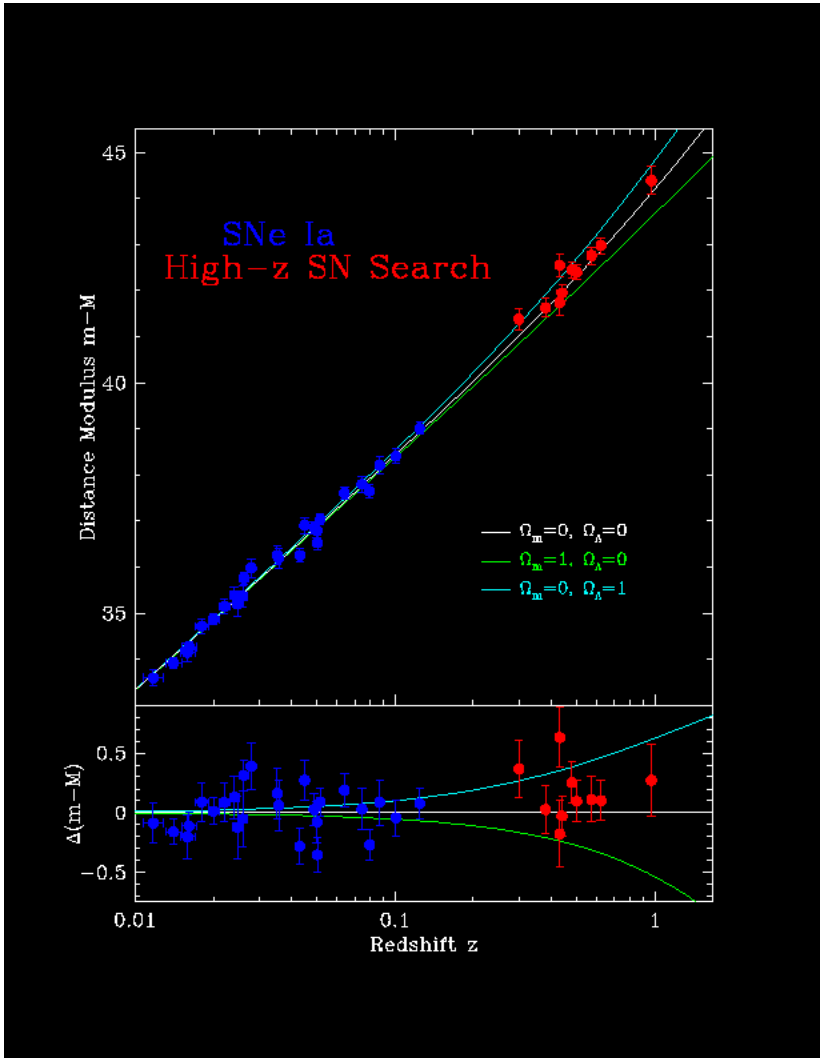
- The attempts to explain the totality of Dark Matter with astronomical objects that do not emit light have failed
- Dark Matter must be made by fundamental new particles, whose properties are starting to be quite well-constrained
  - **Gravitationally interacting**
  - **Stable (on cosmological time scales)**
  - **Cold (slow-moving)**
  - **Not made of baryons and (very) weakly interacting**



What is Dark Energy made of?

- We know that it is not matter and that it acts as a repulsive gravitational force
- It is thought to be what drives the acceleration of the expansion of the Universe over the last 5 billion years



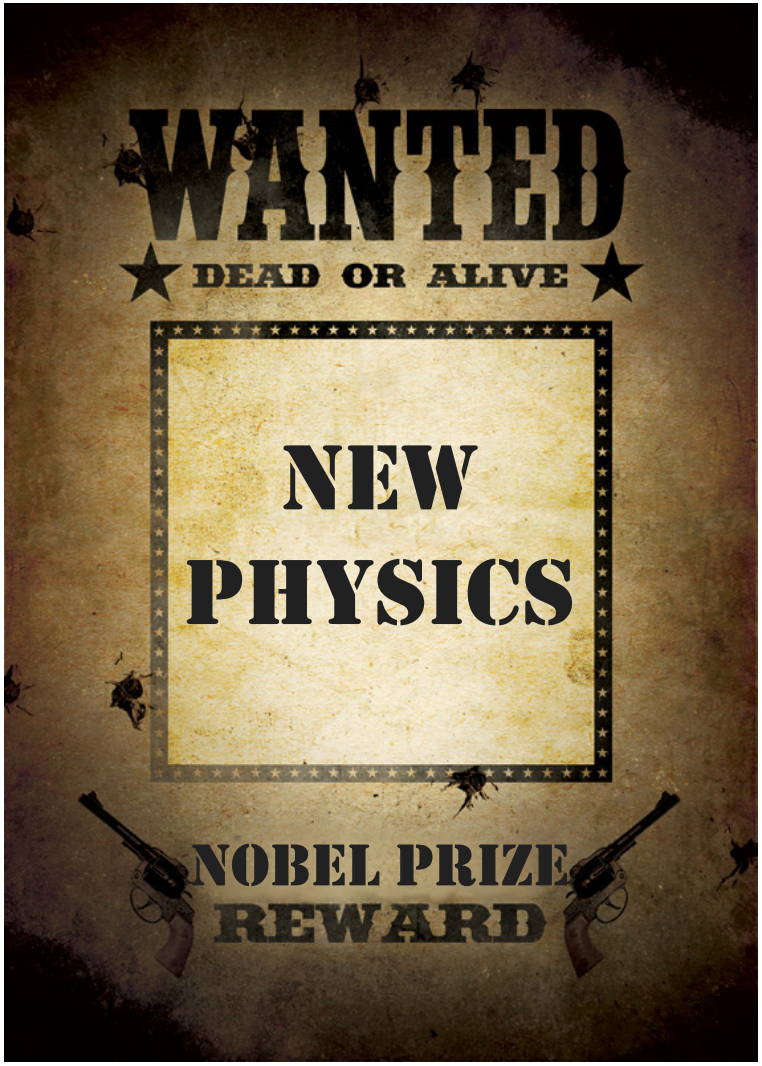


Some open questions to Particle Physics

- Antimatter and matter were present in equal amount right after the Big Bang, why only matter is left?
- What is Dark Matter made of?
- And what about Dark Energy?

The Standard Model of Particle Physics is incomplete

- (At least) it cannot explain
  - **what Dark Matter and Dark Energy are made of**
  - **the matter-antimatter asymmetry of the Universe**
- **New Physics must be out there!**



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