ALICE experiment at the LHC – Little “Big Bang”

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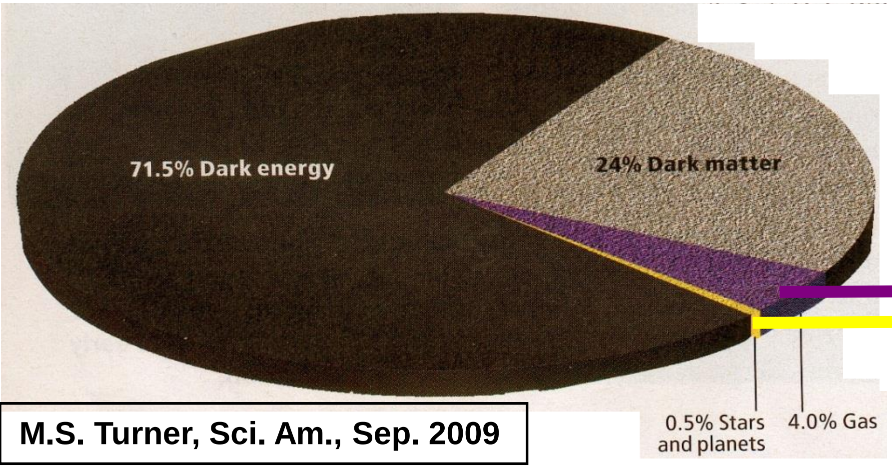
UiB, Norway

- What is matter?
- The quark-gluon plasma
- The Large Hadron Collider at CERN
- The ALICE experiment at the LHC

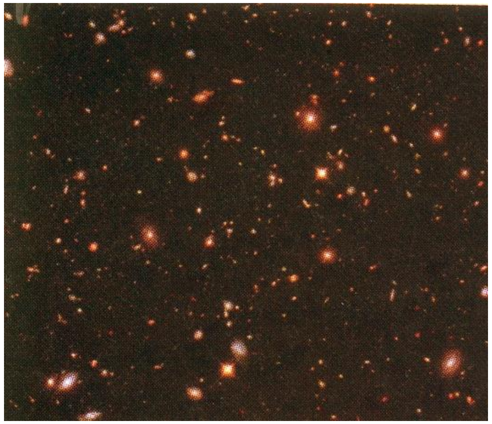
What is matter?

Constituents of the universe



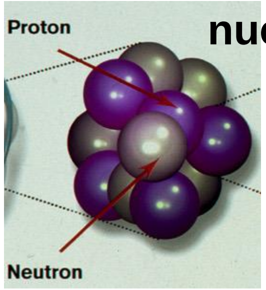
M.S. Turner, Sci. Am., Sep. 2009

visible universe

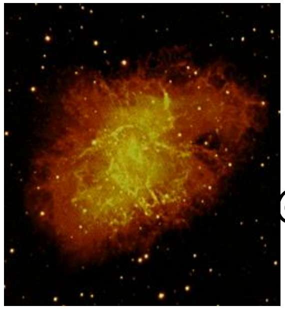


”QCD-matter”

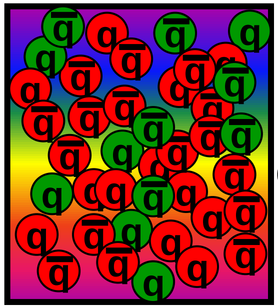
made up of quarks and gluons - macroscopic manifestion of the strong interaction



nuclear matter
@ nuclei



neutron/
quark matter
@ neutron stars?

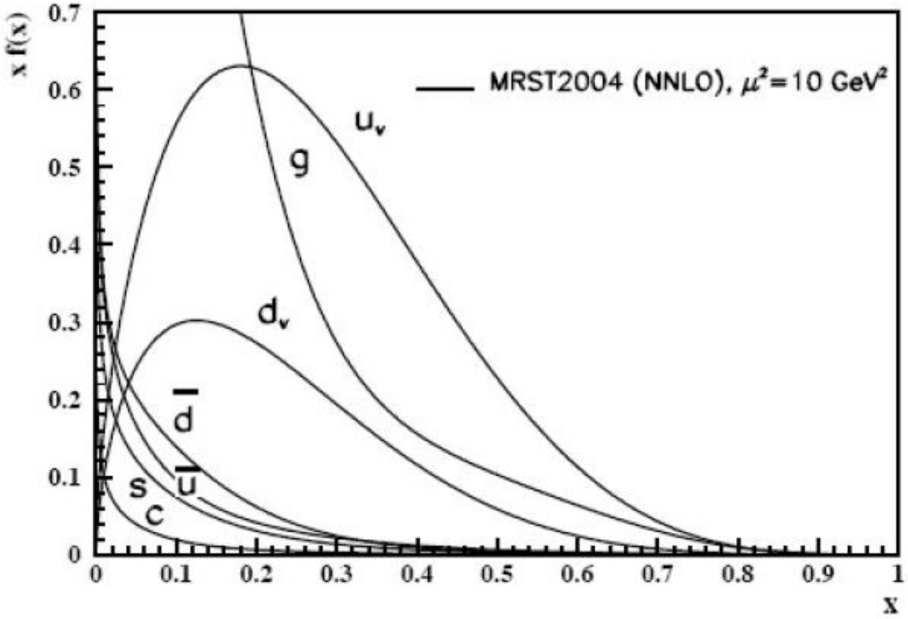


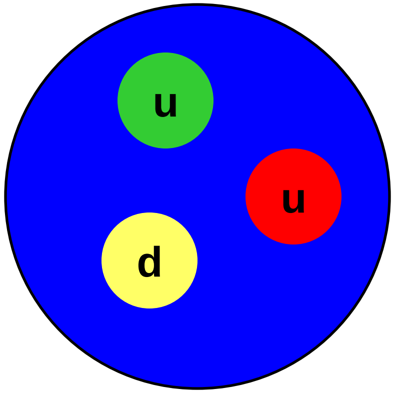
quark-gluon
matter
@ LHC

QCD = Quantum ChromoDynamics

What is a proton?

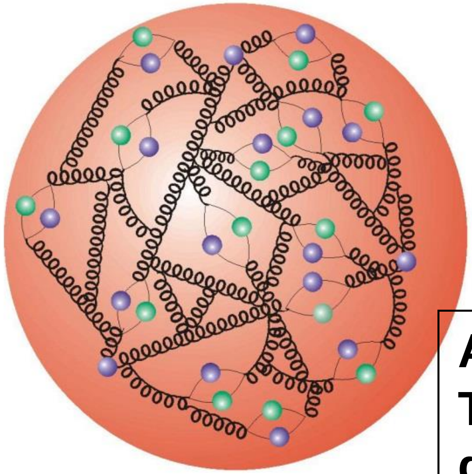
- **Looking into a proton:**





low resolution

x: momentum fraction of the proton carried by the parton



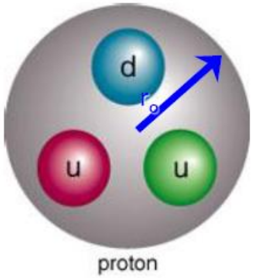
high resolution

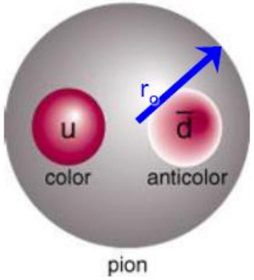
A proton is not, in fact, simply made up of three quarks (uud). There are actually 3 "valence" quarks (uud) + a "sea" of gluons and short-lived quark-antiquark pairs.

Questions

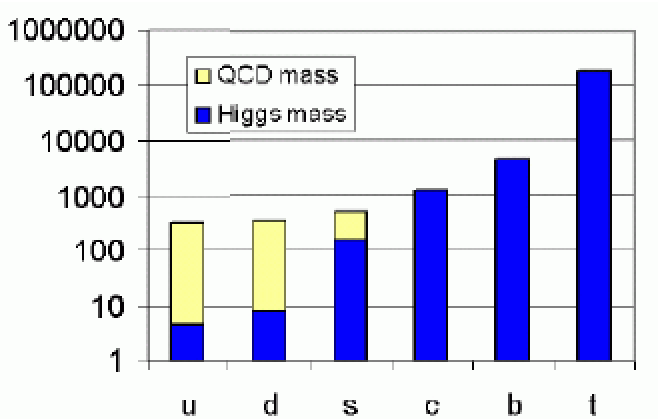
- **Confinement**

  - **Quarks and gluons are confined bags of radius r_0**
  - **All hadrons (baryons and mesons) have the same radius**
    - **Characteristic length scale: r_0 = 1 fm**
    - **Characteristic energy scale: $\hbar c/ r_0$= 200 MeV**



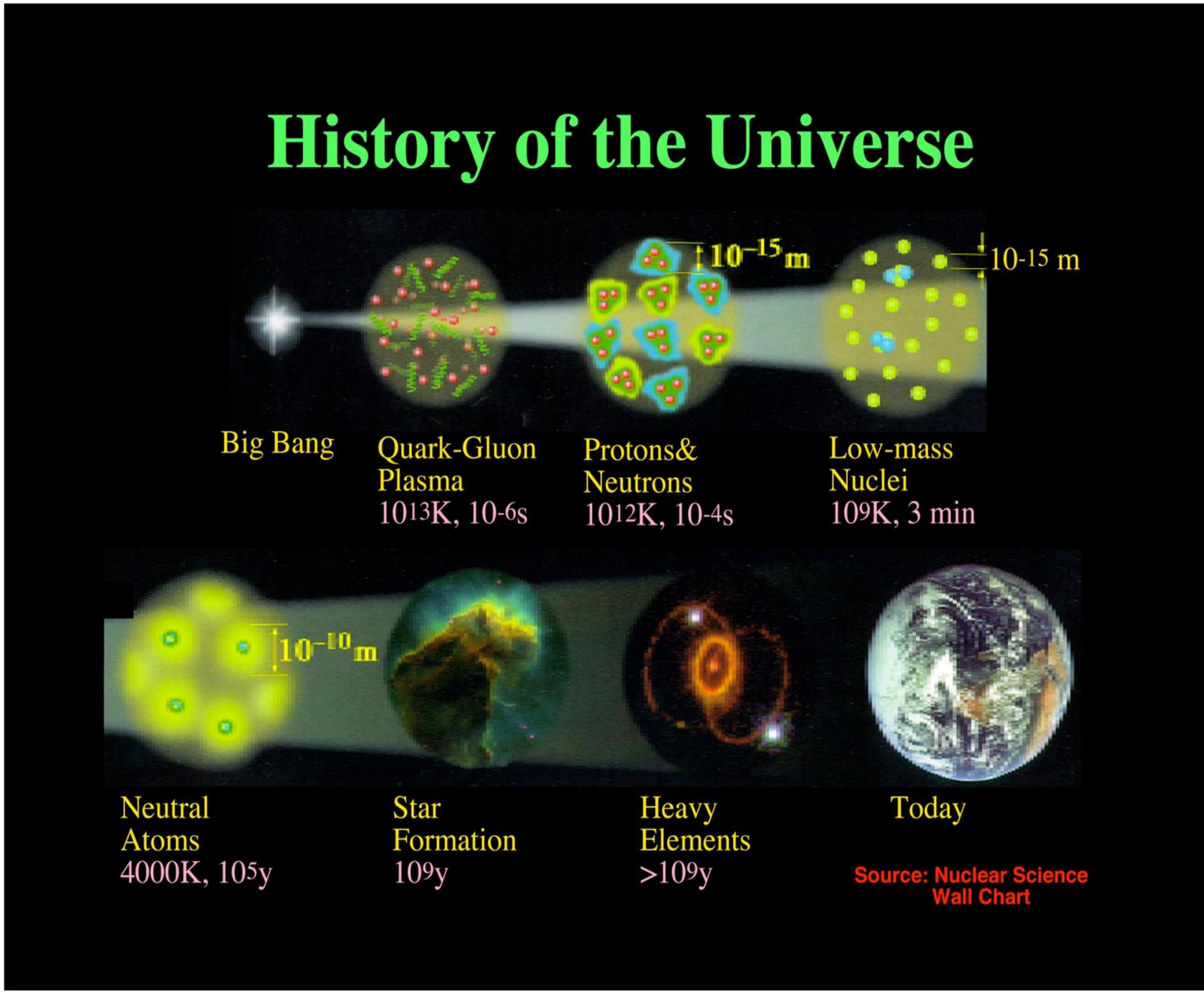


- **Generation of mass**
  - **$m_{up} \approx m_{down} \approx$ few MeV/c²**
  - **Nucleon mass ≈ 940 MeV/c²**
  - **Dynamic generation of mass!**



More questions

- **History of the universe**
  - **first 10 μsec: energy density $\approx$ 1 GeV/fm^3 temperature $\approx$ 160 MeV**
  - **hot soup of quarks, leptons and force carriers,…**
  - **properties of new states of matter at high temperatures and densities**



Why do we need particle accelerators?

To accelerate particles to high energies!

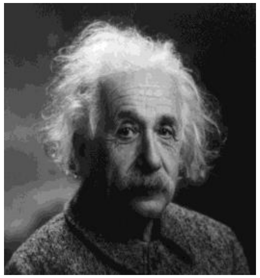
The higher energies allow us

i) to look deeper into matter
($E \alpha$ 1/size), ("powerful microscopes")

ii) to discover new, heavier particles
($E = mc^2$)

iii) to probe matter at extreme conditions;
to probe conditions of the early universe
($E = kT$)

de Broglie

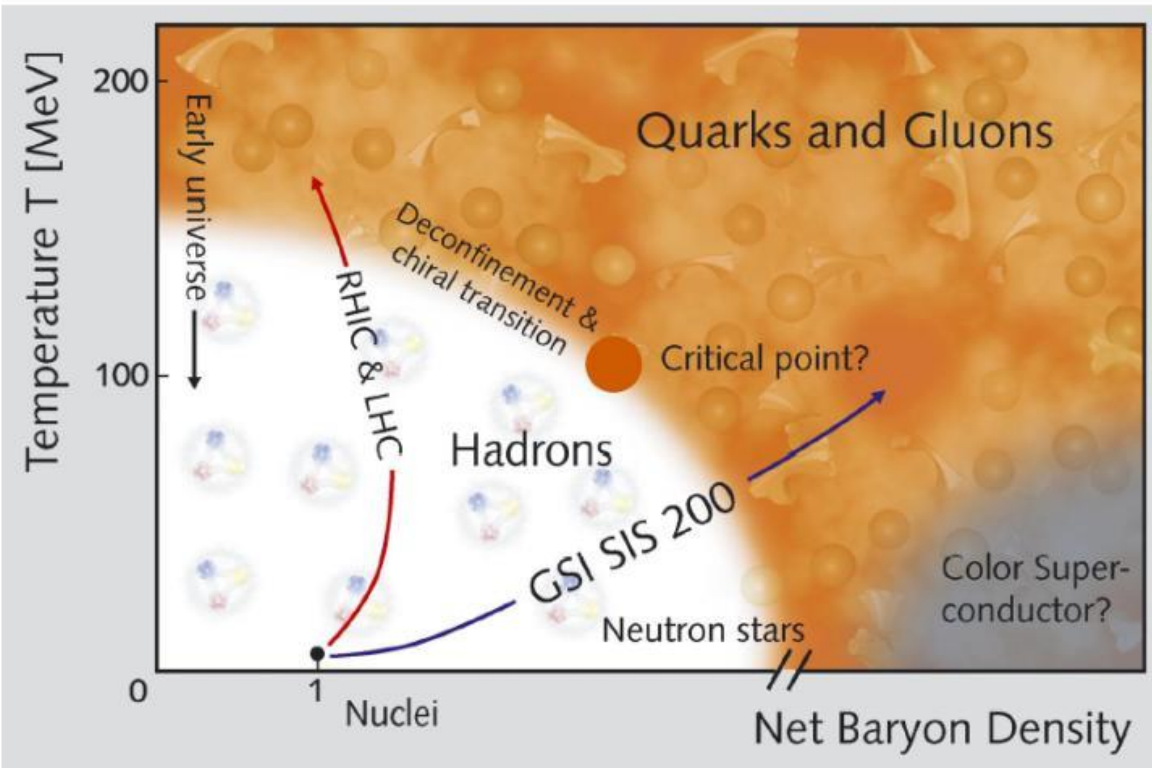


Einstein

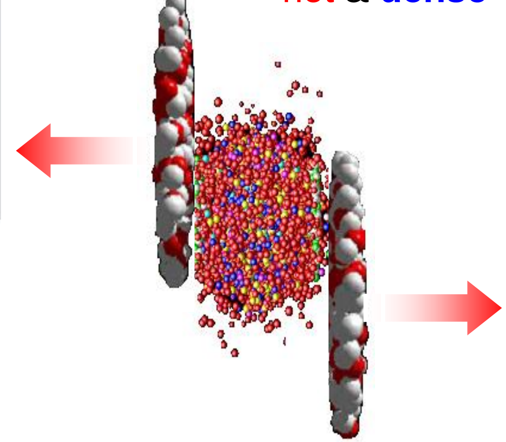
Boltzmann

The QCD phase diagram

- **Goal: exploring phases and structures of the QCD phase diagram**

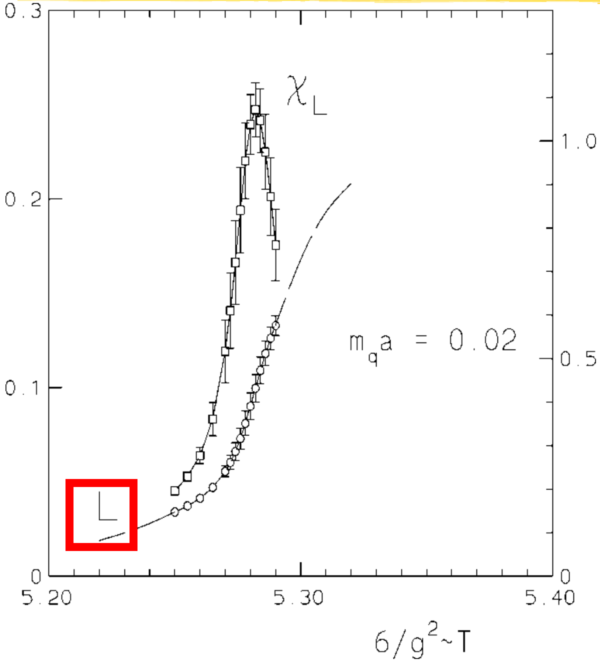


hot & **dense**



- **Tool: (Ultra-)relativistic heavy ion collisions**

The phase transition – lattice calculations



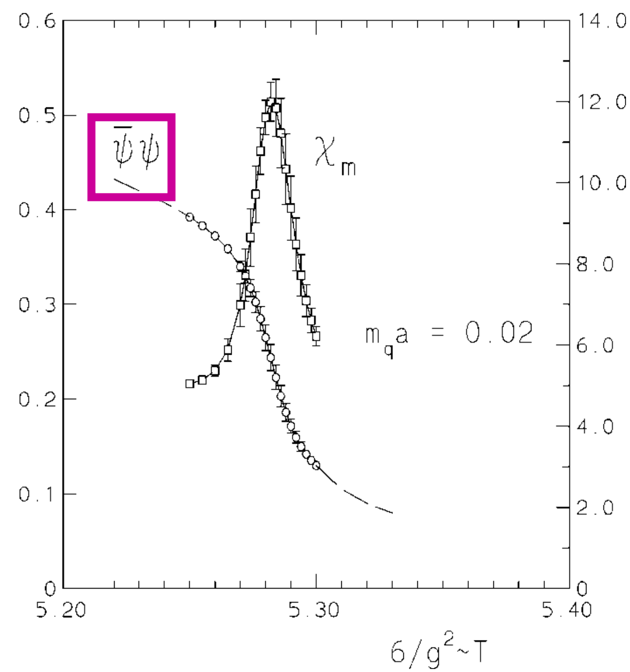
$L \sim \exp(F/T)$

F: free energy, T: temperature

color mobility

deconfinement

color confinement



$\psi\bar{\psi}$: effective quark mass scale

massive "constituent" quarks

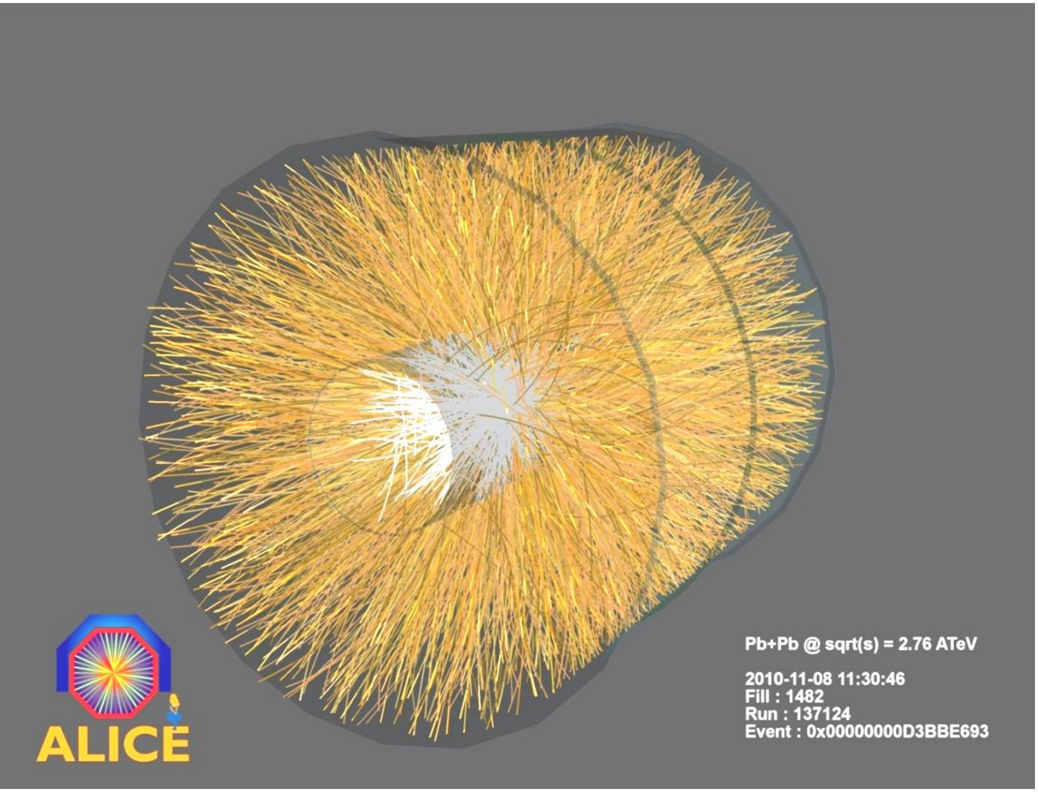
chiral symmetry restoration

massless "current" quarks

F. Karsch, Lect. Notes Phys. 583, 209 (2002)

Heavy Ion Collisions at the LHC

On Sunday November 7th, 2010, the ALICE experiment recorded the very first Pb-Pb collision



- **Collision of two lead nuclei at 5.5 TeV per nucleon pair = 1100 TeV**
- **macroscopic energy**
  1100 TeV = 0.2 mJ
  ≈ collision of two mosquitos

BUT

energy is squeezed into a microscopic volume

➡ **fireball – a billion times hotter than the sun**

First results from the LHC

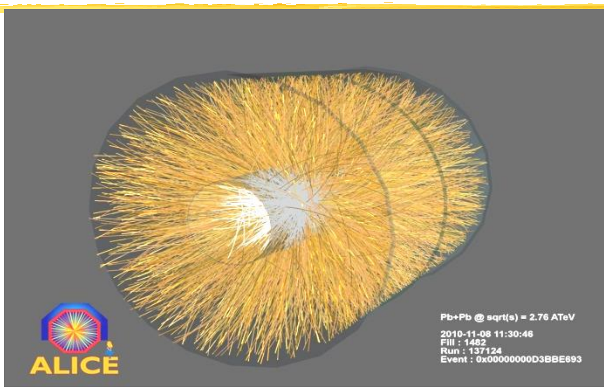
- **Can we talk about matter?**
  - **Does the matter show collective behaviour (hydrodynamic flow)?**

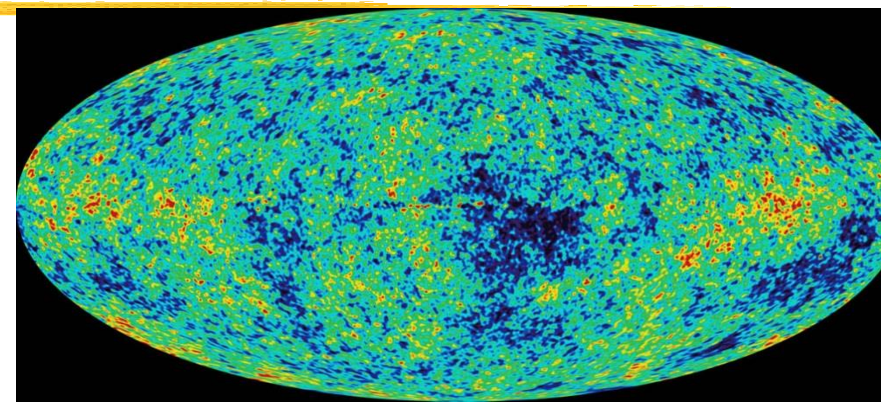
    -> yes

- **Is the matter deconfined?**
  - **Does the matter consist of quarks and gluons?**
  - **Is the matter opaque to partons (quarks and gluons) traversing it?**

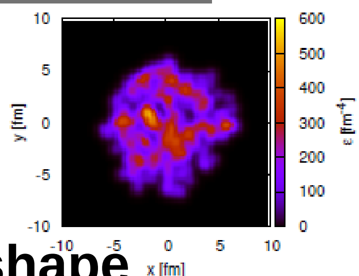
    -> yes

Little Bangs vs Big Bang

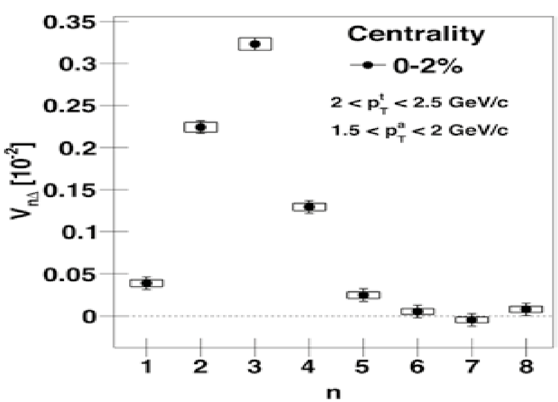




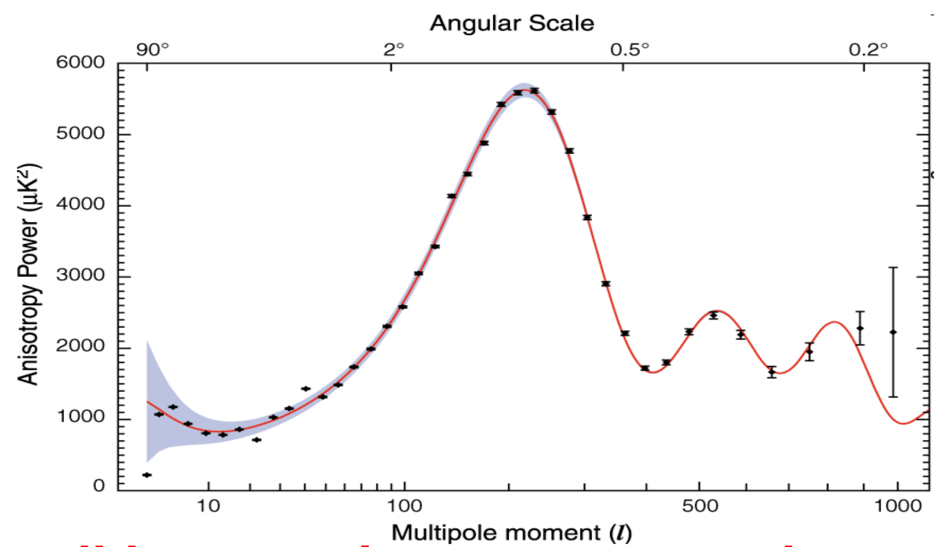
- Many small events
- Strong initial fluctuations →



- Asymmetric event shape

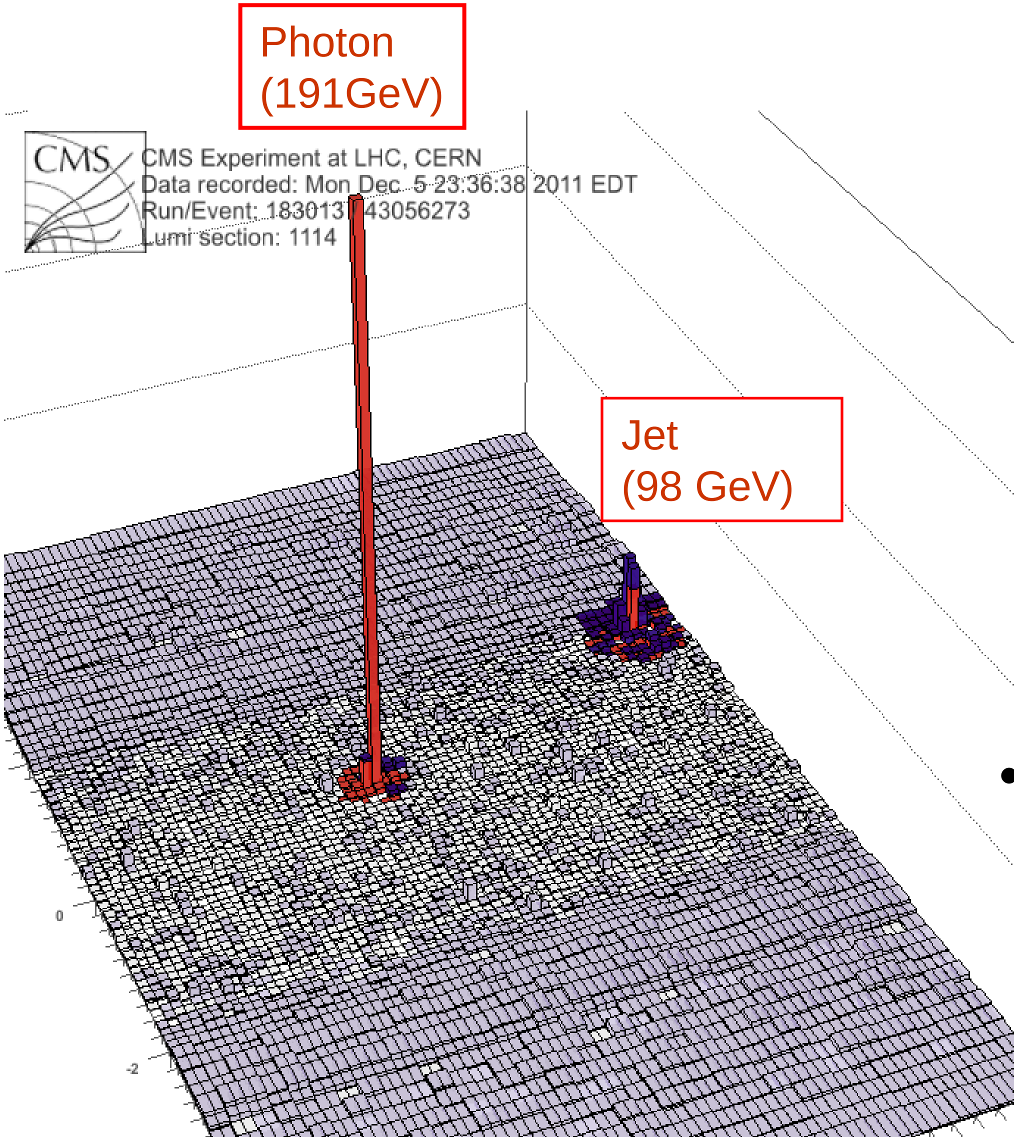


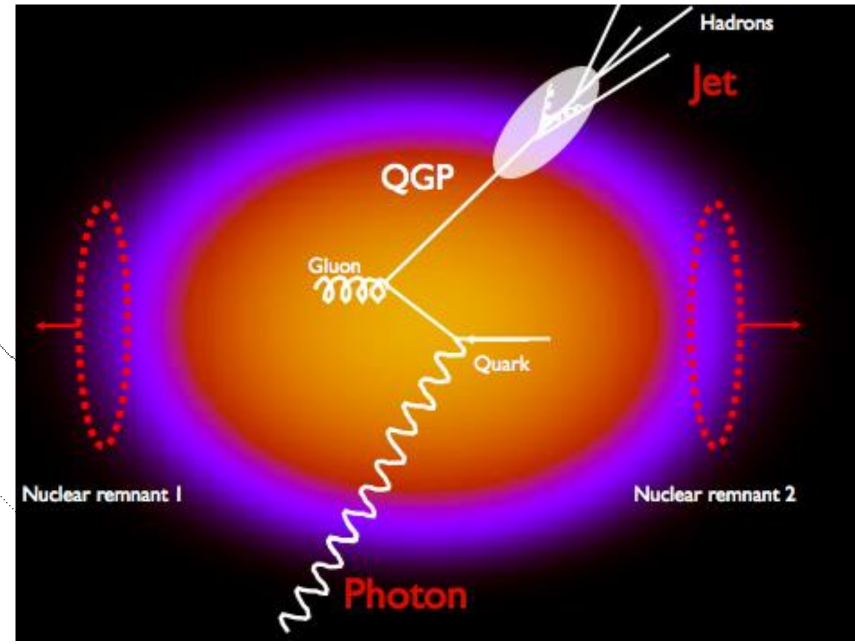
- One large event
- very homogenous



Evolution of the fluctuating initial condition reveals matter properties

Measuring the energy loss of a parton traversing the QGP





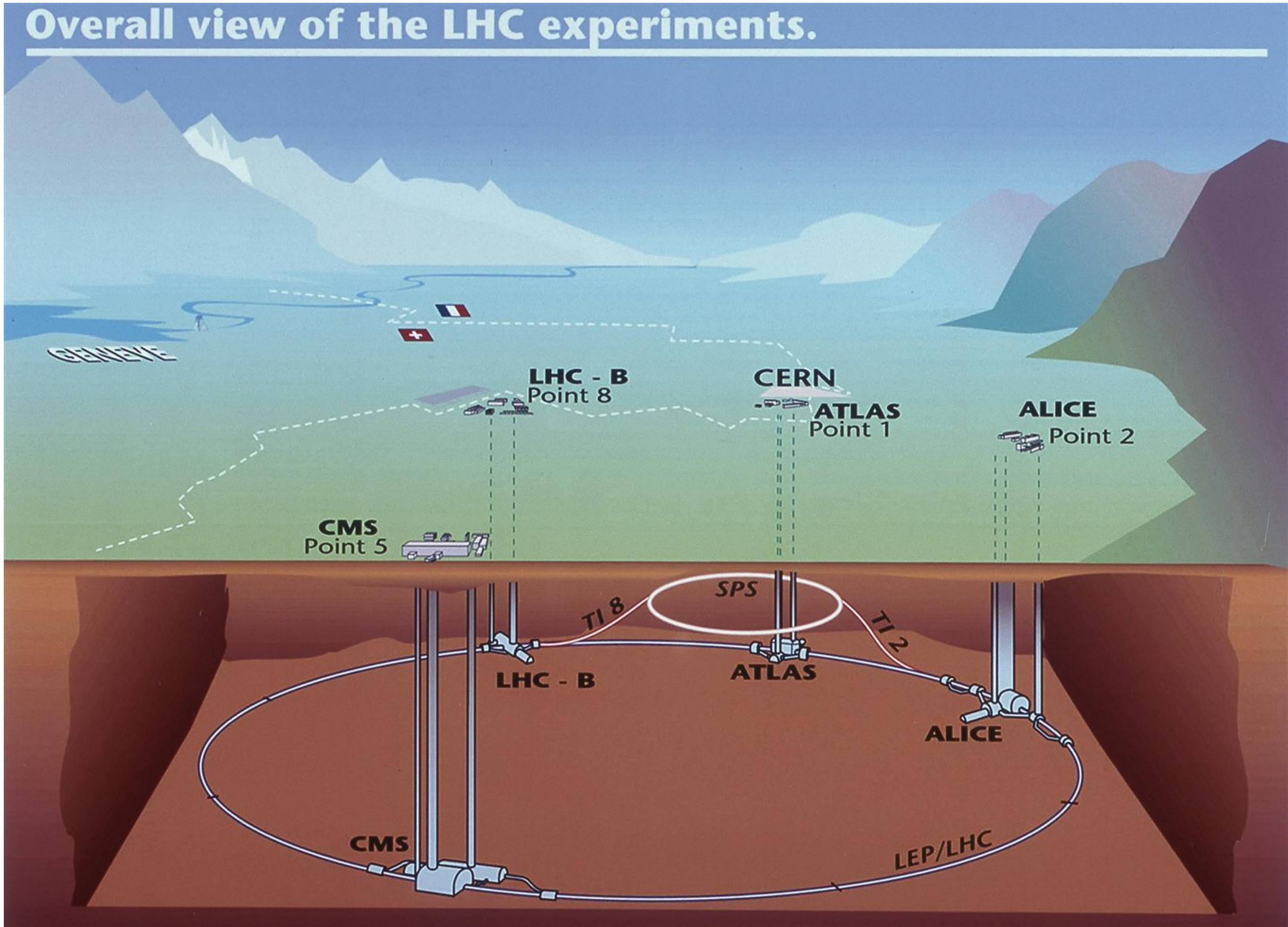
- **fast quarks and gluons loose energy in the medium**

-> Quark-Gluon Plasma

Large Hadron Collider @ CERN

LHC–project: accelerator + experiments

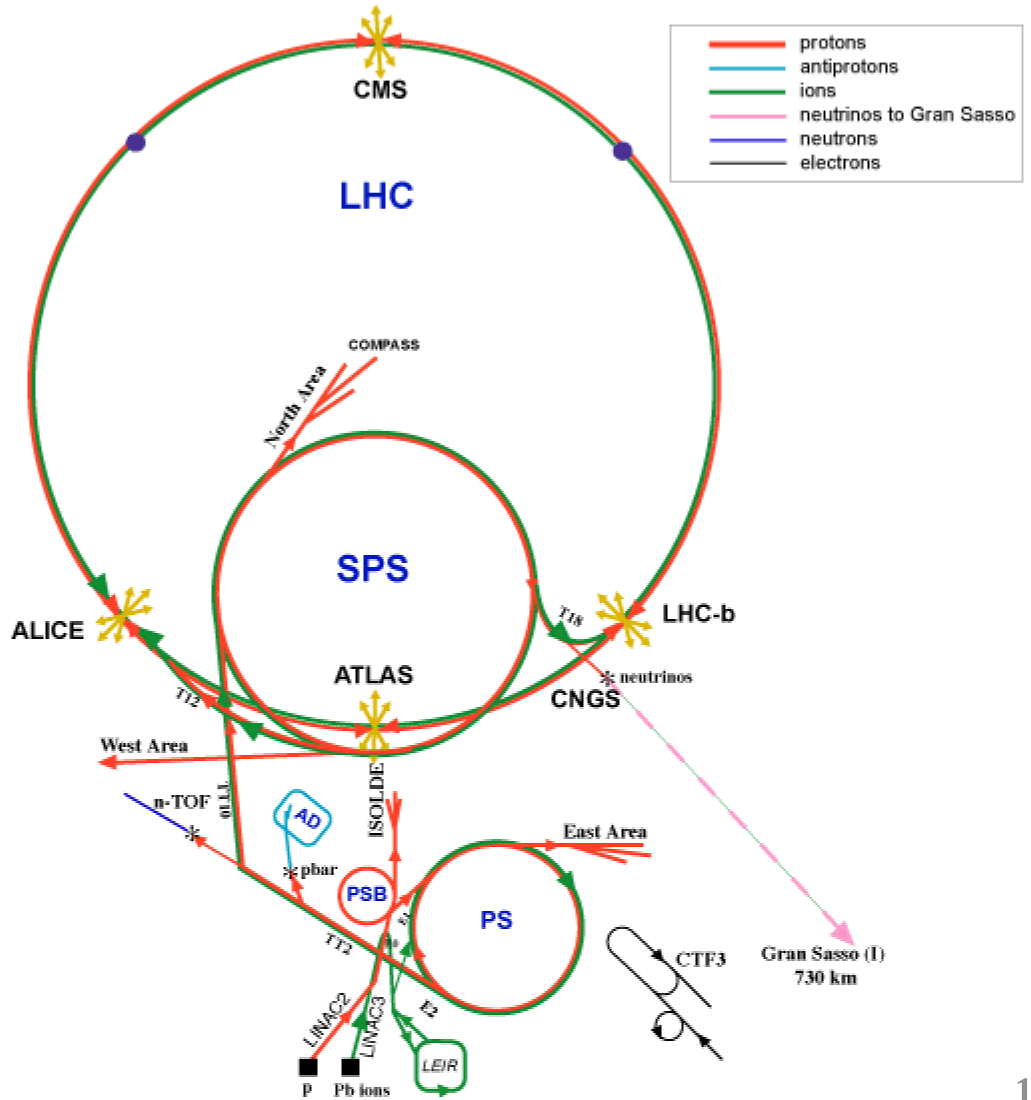
- **LHC circumference: 27 km**
- **about 100 m underground**
- **Protons and heavy ions circulate at 99.999999% of the speed of light**
- **Four large caverns for experiments**



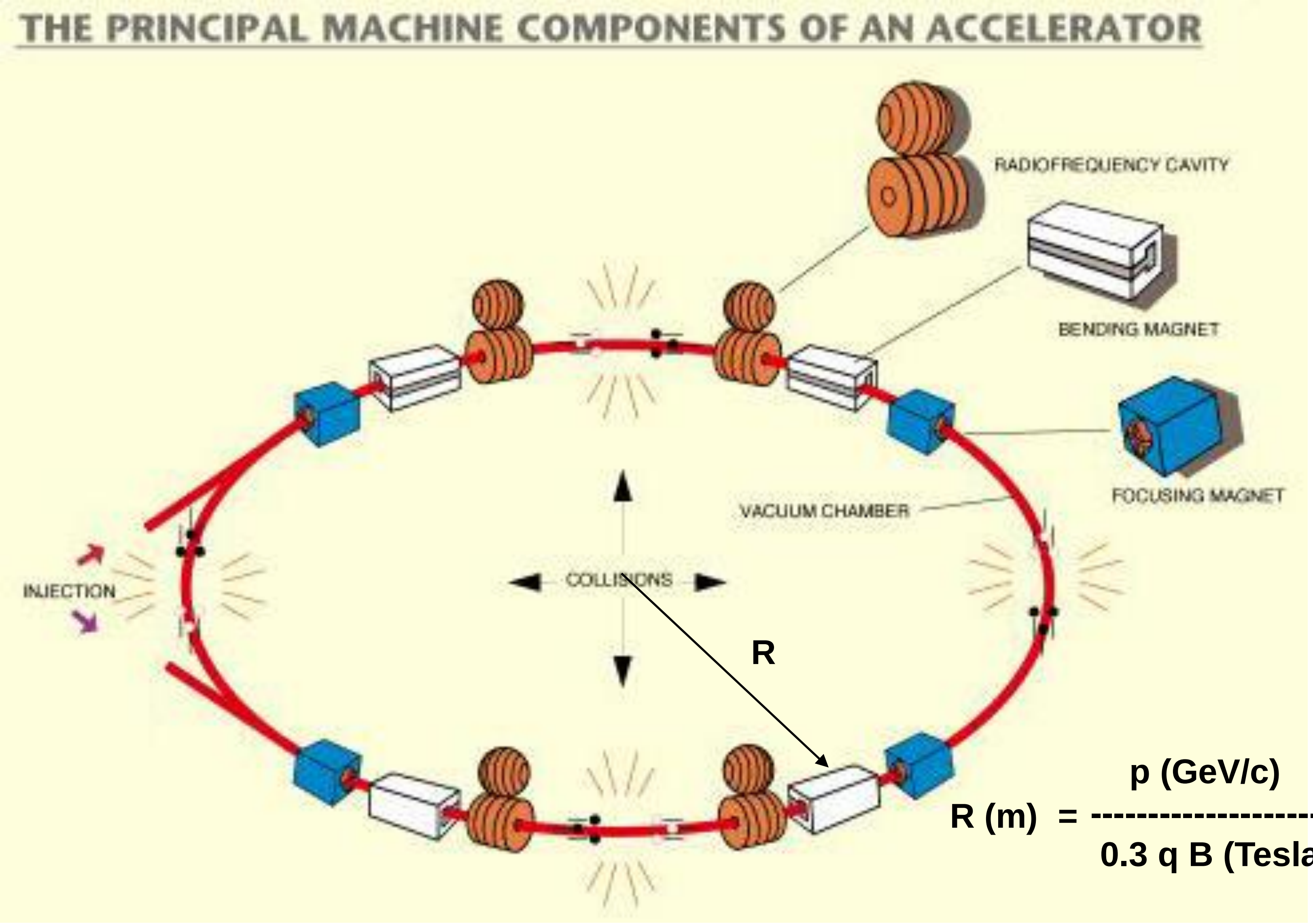
LHC – accelerator complex

The counter rotating proton and heavy ion beams are brought into collision at four experimental collision points around the LHC:

At CMS
LHCb
ATLAS
ALICE



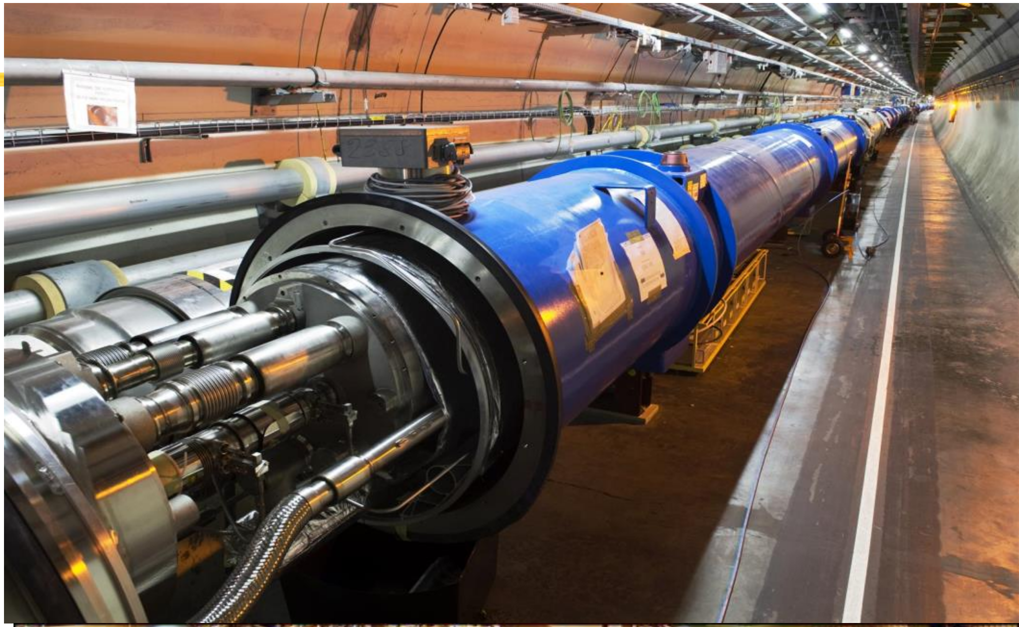
LHC – machine components



$$R\,(m) = \frac{p\,(GeV/c)}{0.3\,q\,B\,(Tesla)}$$

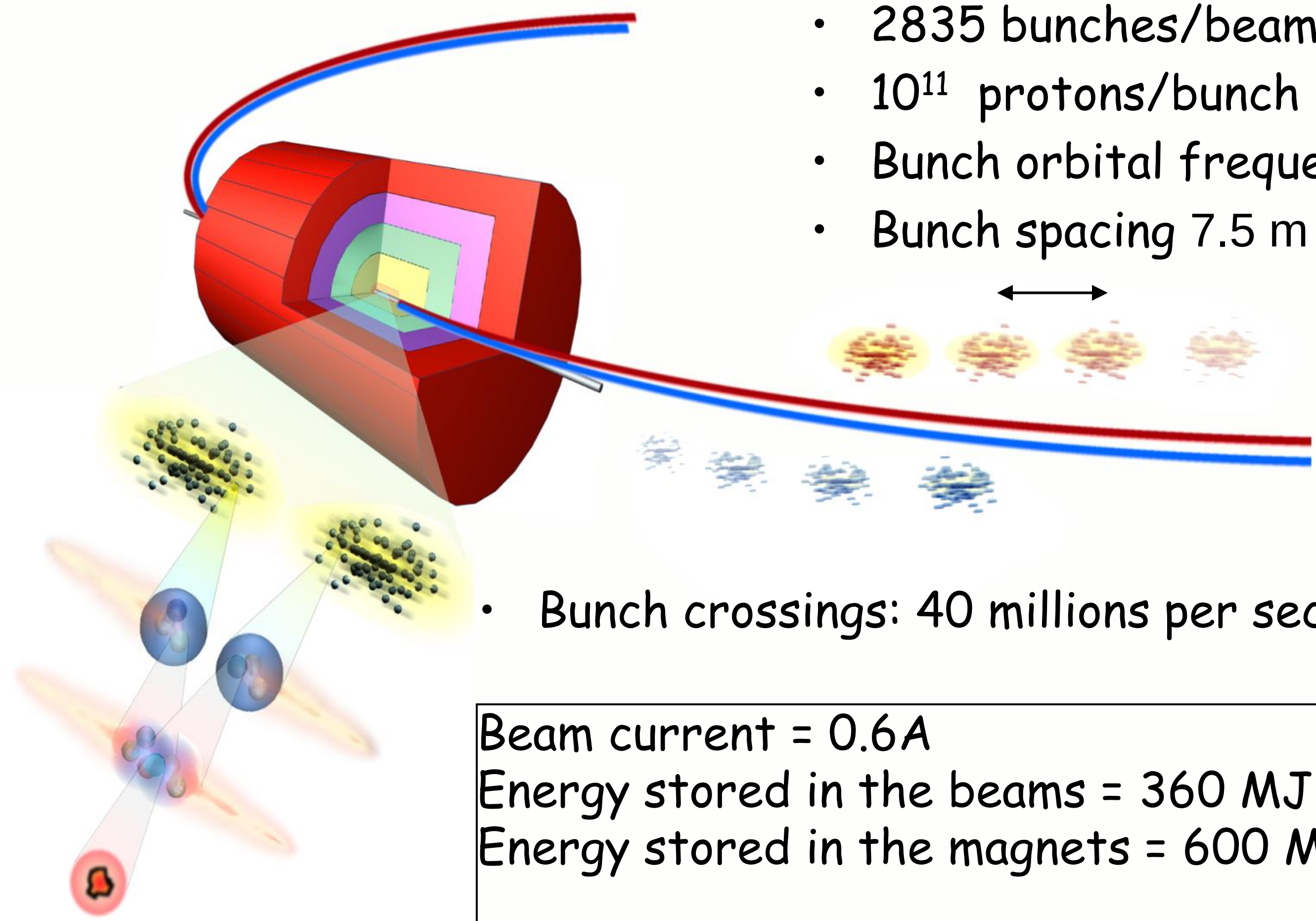
LHC - components

- **1232 superconducting dipole magnets bend the beams**



- **Radiofrequency cavities accelerate the ion bunches**

LHC – collisions



- 2835 bunches/beam
- 10^{11} protons/bunch
- Bunch orbital frequency 11 kHz
- Bunch spacing 7.5 m (25 ns)

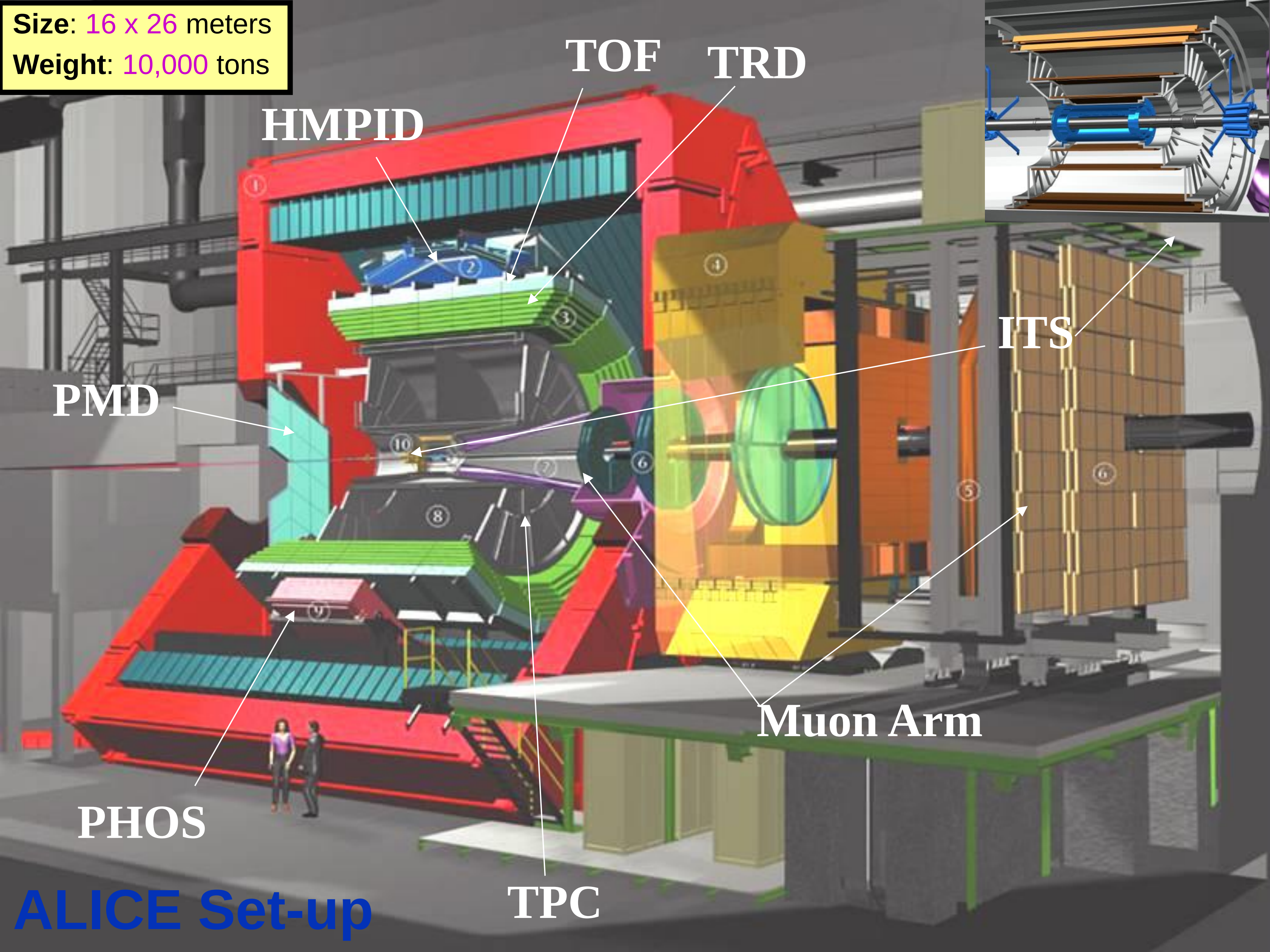
- Bunch crossings: 40 millions per second

Beam current = 0.6A
Energy stored in the beams = 360 MJ
Energy stored in the magnets = 600 MJ

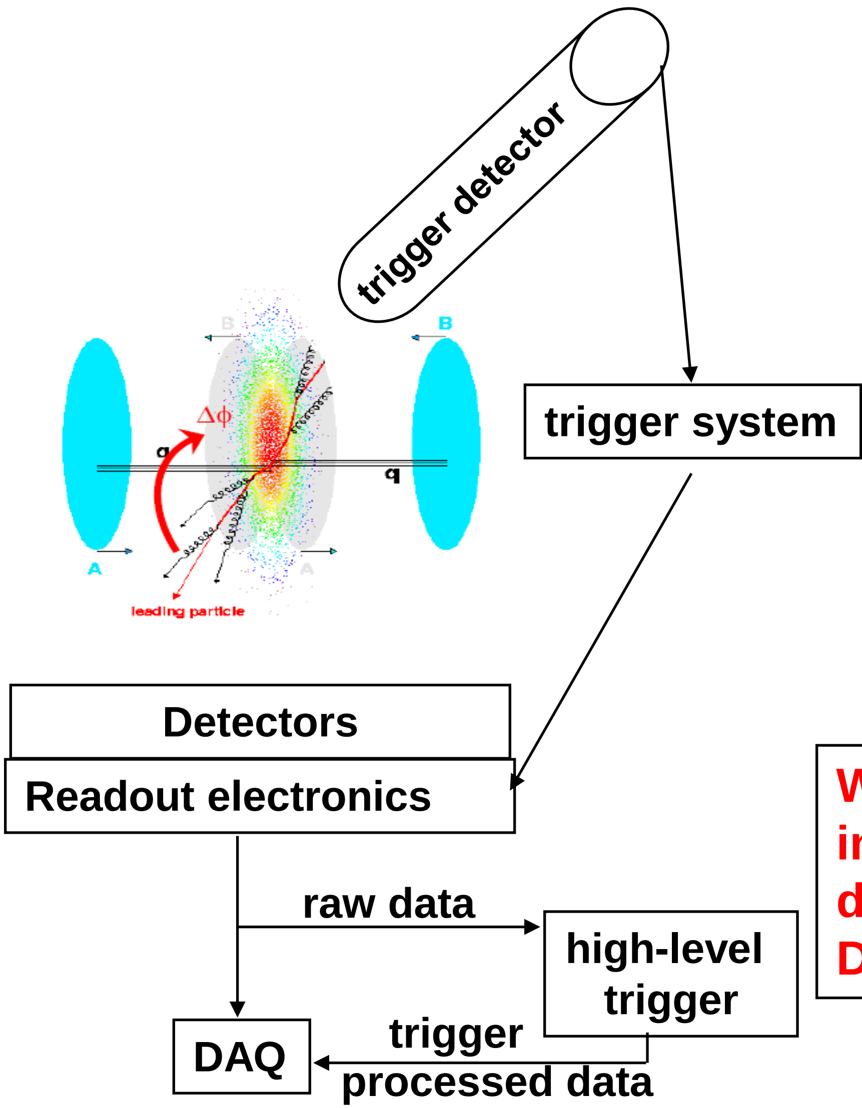
- Beam energy equivalent to 80 kg of TNT
- Beam energy equivalent to a 400 ton train traveling at 150 km/h

ALICE Set-up

Size: 16 x 26 meters
Weight: 10,000 tons



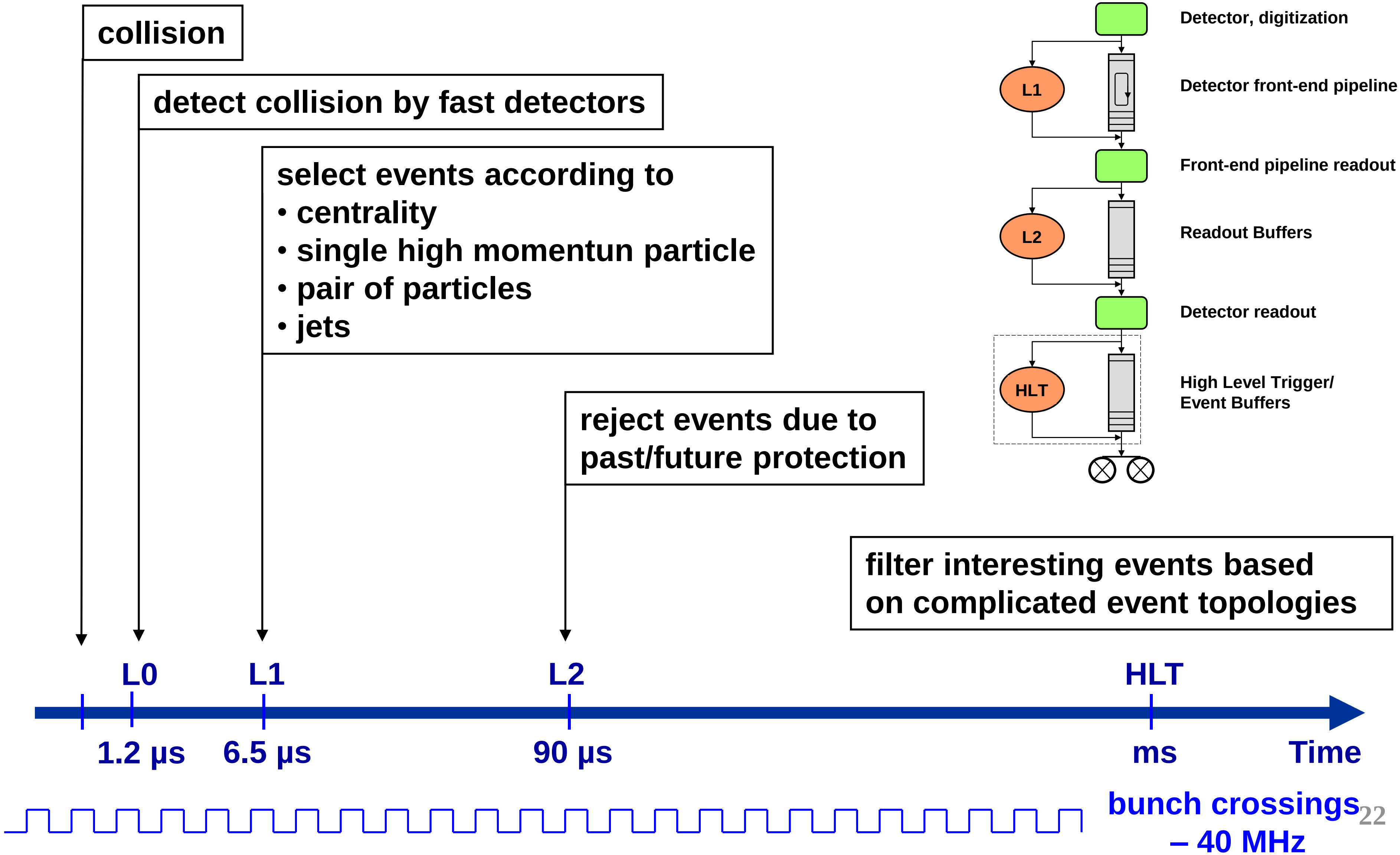
Trigger system



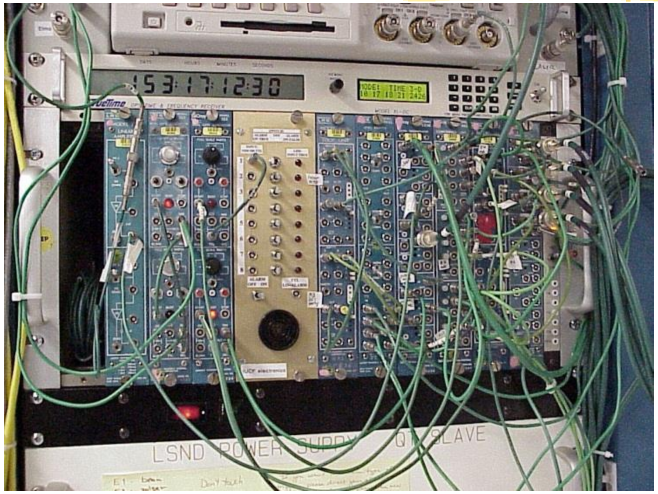
- **Minimal requirements**
  - **Detect collisions**
  - **Initialise readout of detectors**
  - **Initialise data transfer to data acquisition (DAQ)**
  - **Protection against pile-up**
- **High level requirements**
  - **Select interesting events**
  - **Needs real-time processing of raw data and extraction of physics observables**

Why?
interaction rate (e.g. 8 kHz for Pb+Pb) >
detector readout rate (e.g. 1 kHz for TPC) >
DAQ archiving rate (50 - 100 Hz)

Trigger hierachy



Trigger implementation



fixed latency – hard real-time

pipelined – soft real-time

(micro-)electronics **FPGAs** **DSPs** **PC farms – 2000 cores**

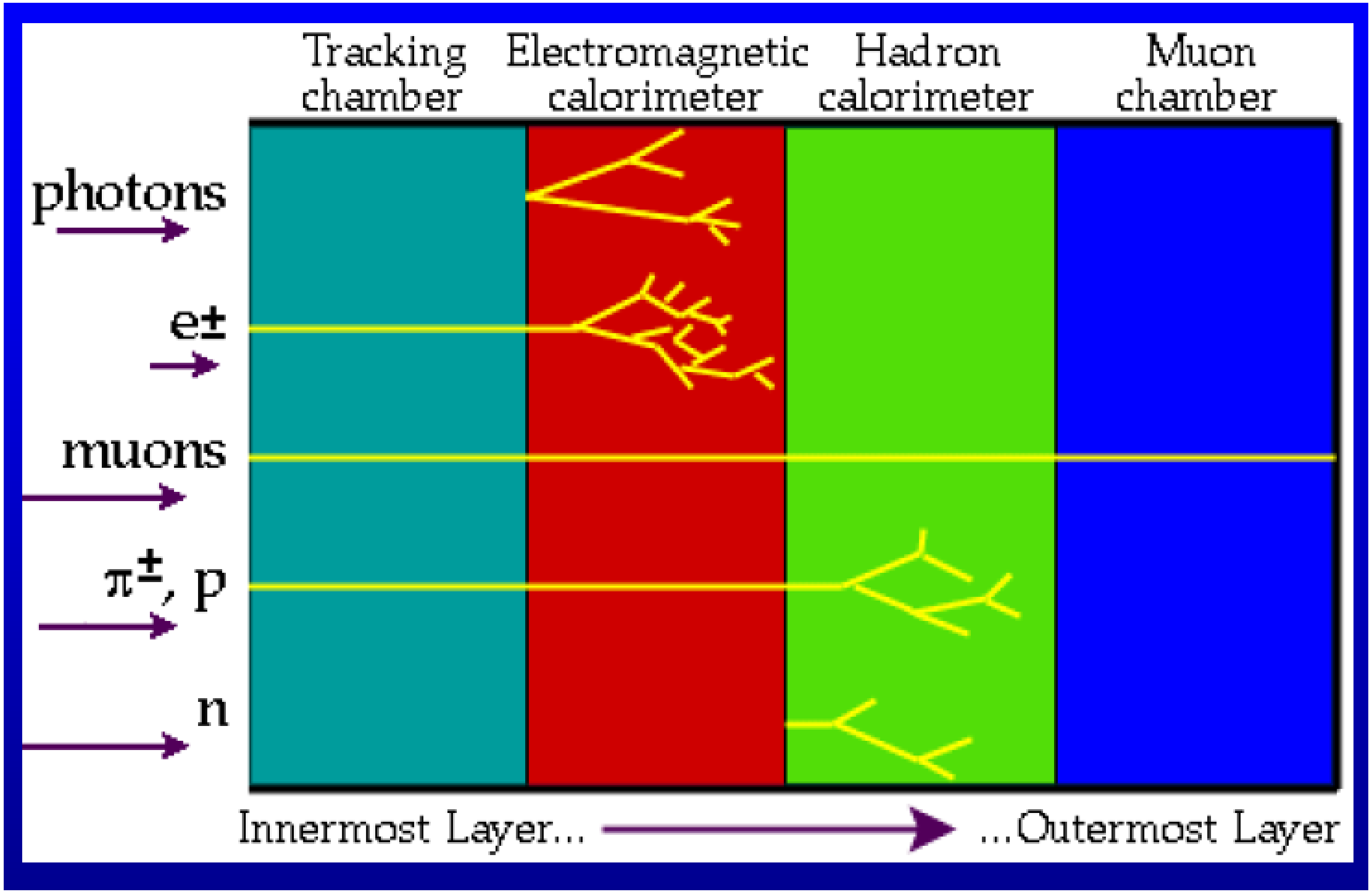
L0 **L1** **L2** **HLT**

1.2 μs **6.5 μs** **90 μs** **ms** **Time**

bunch crossings – 40 MHz

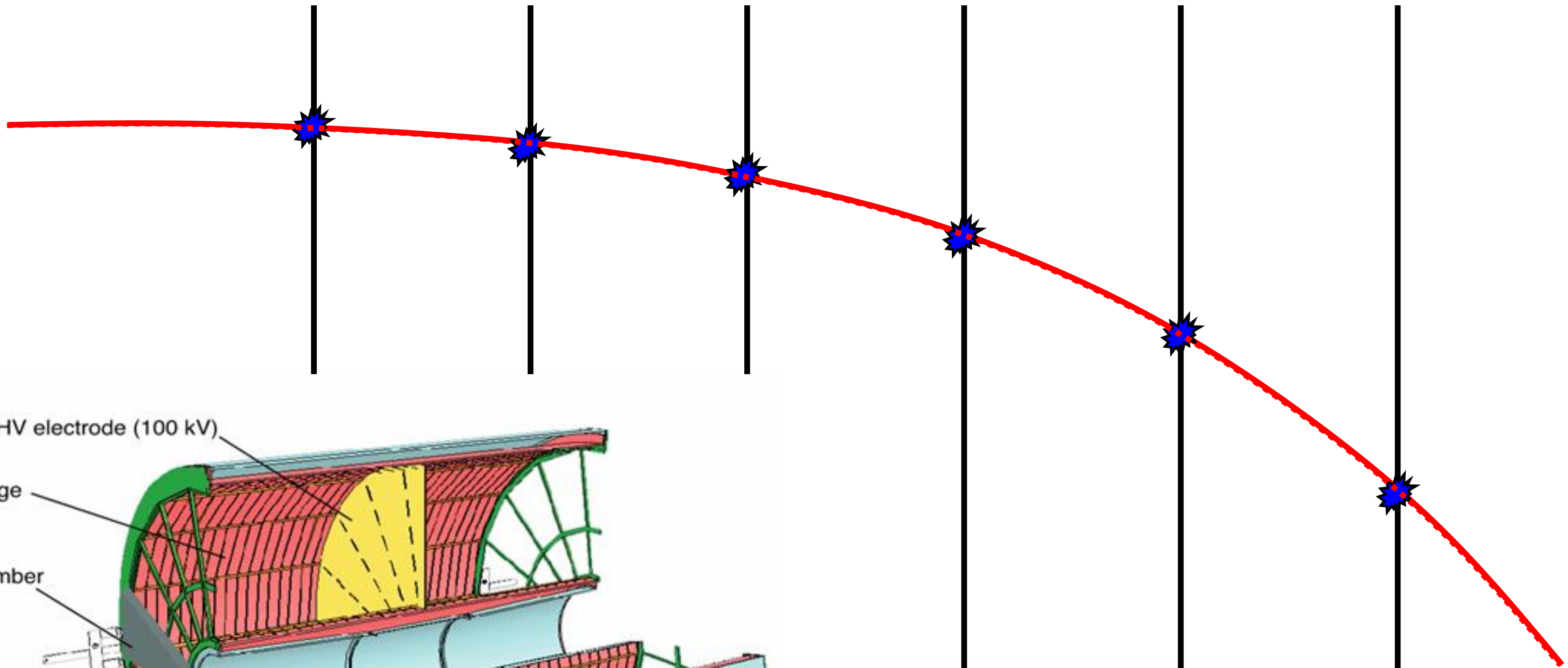
Detectors

- **Detection concepts**

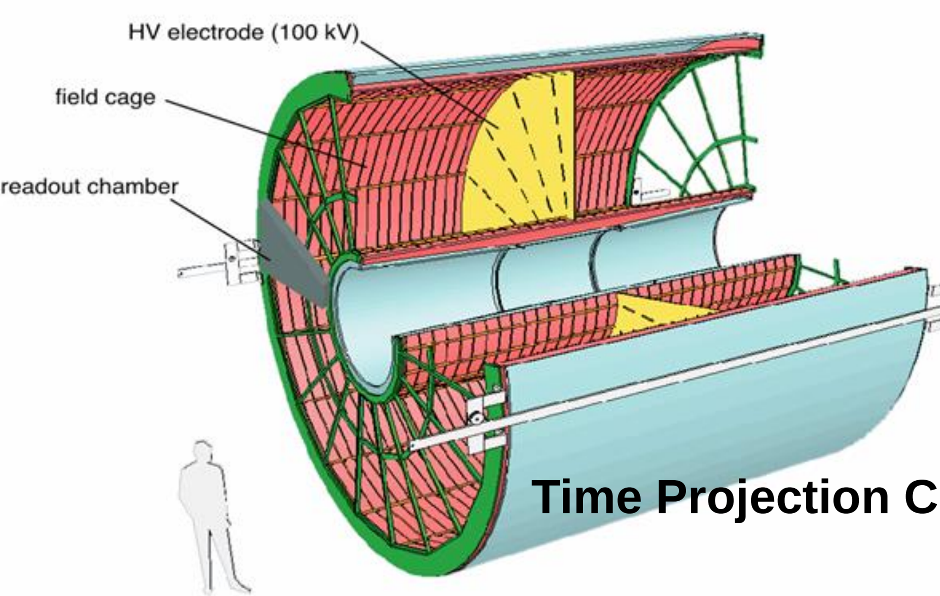


Detectors

- **Tracking detectors: silicon and/or gas detectors**



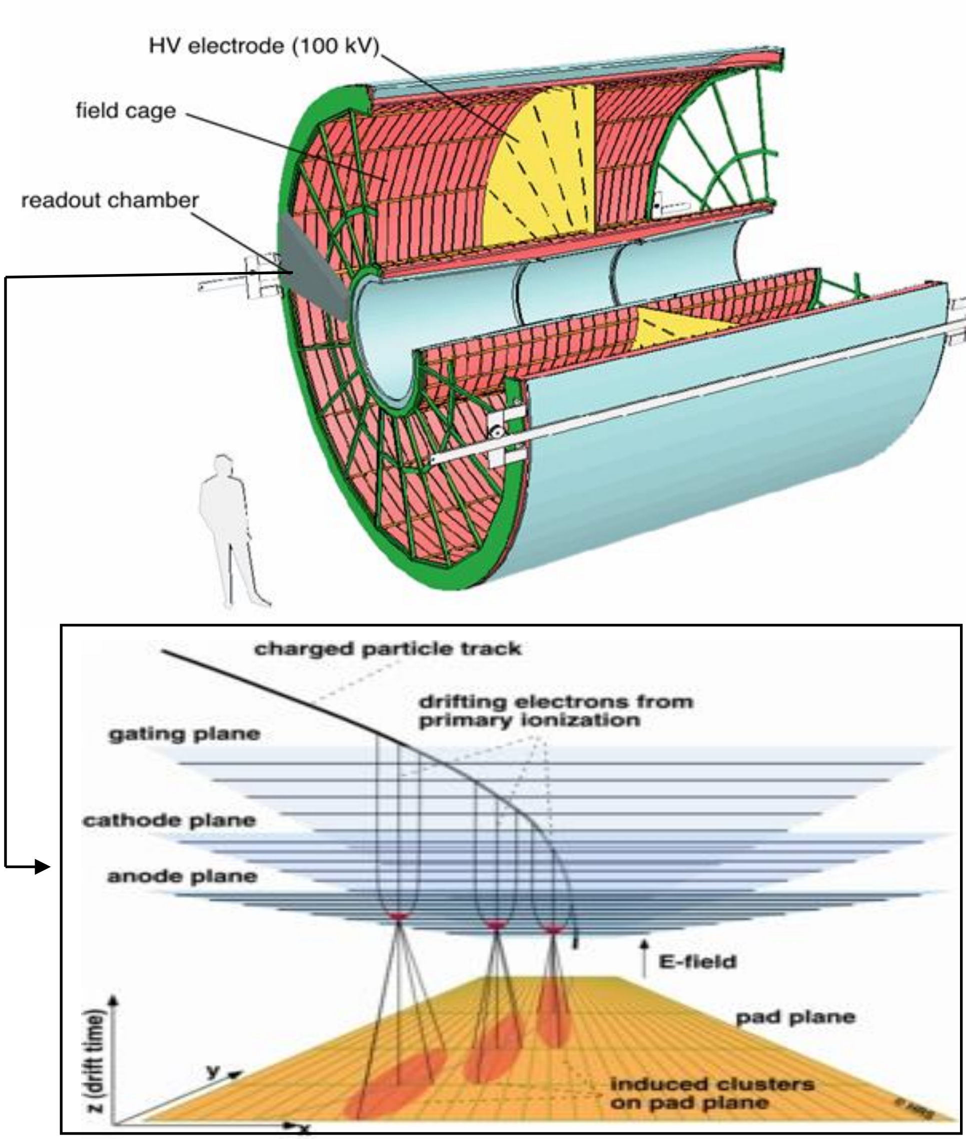
Multiple thin layers of, for example, silicon sensors or gas volumes



Time Projection Chamber TPC

ALICE TPC

- Large volume gas detector
- Drift volume and MPWC at the end caps
- 3-dim. “continuous” tracking device for charged particles
  - x,y of pad
  - z derived from drift time
- Designed to record up to 20000 tracks
- Event rate: about 1 kHz
- Typical event size for a central Pb+Pb collision:
  about 75 MByte

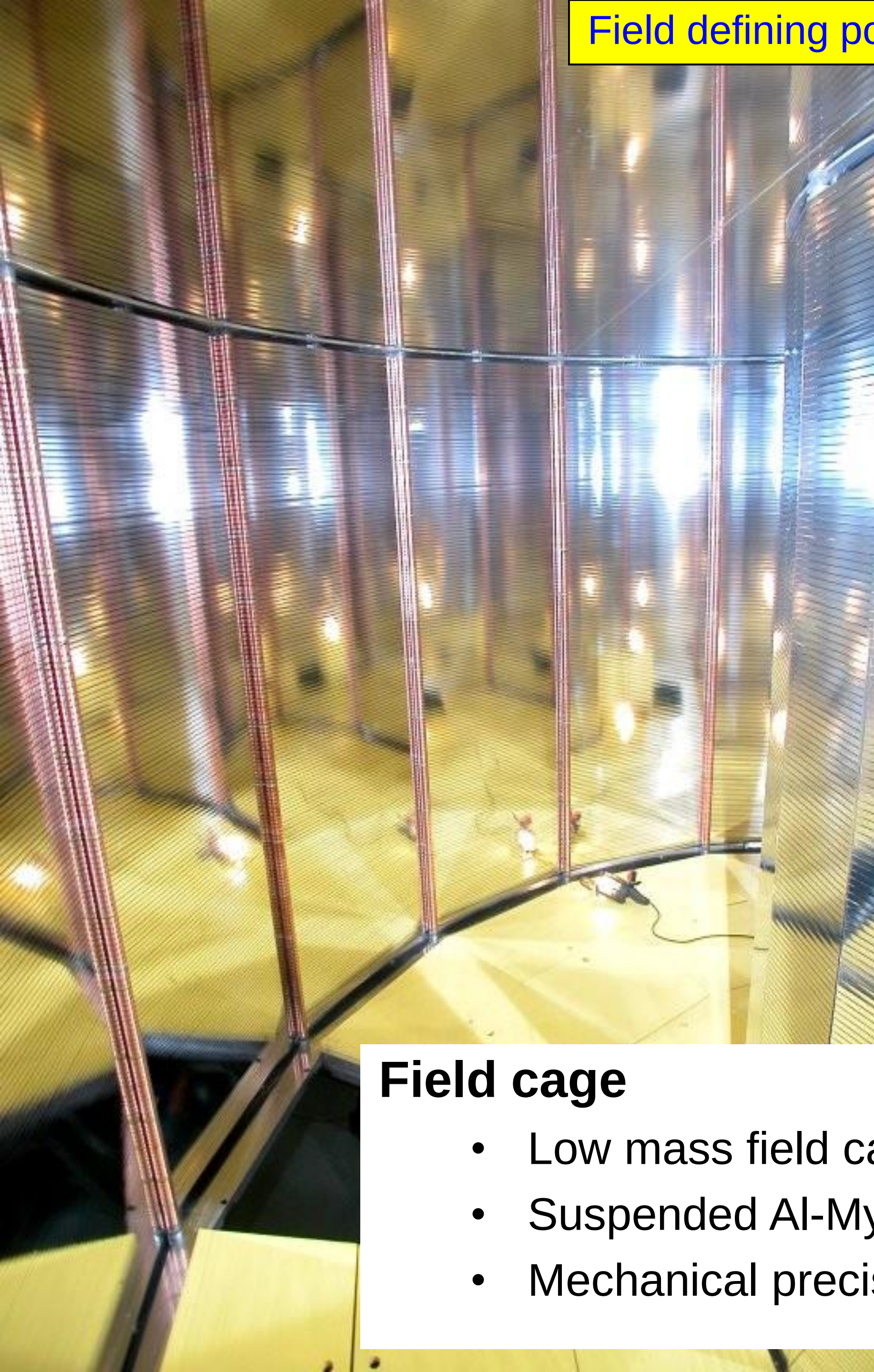


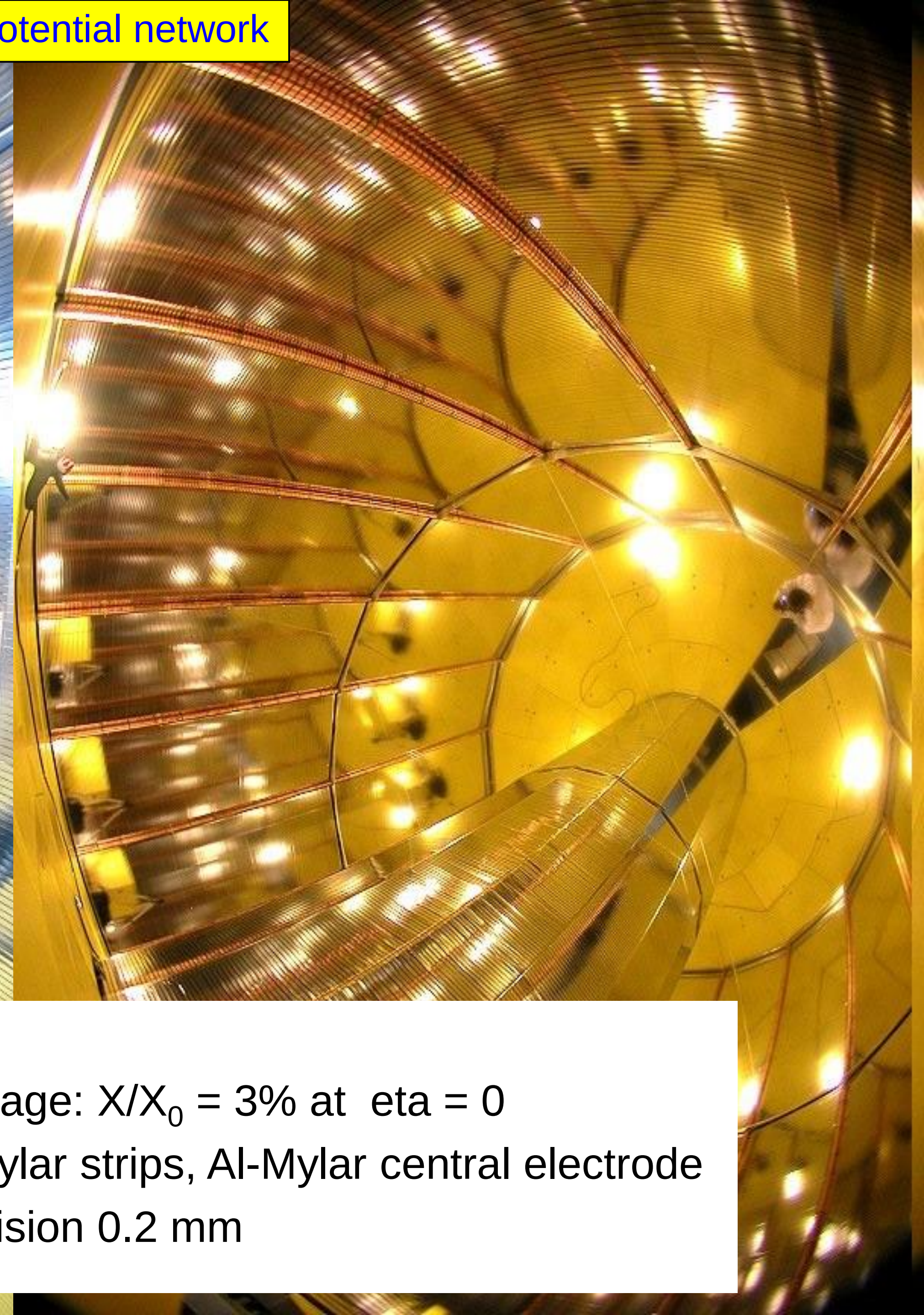
ALICE TPC: 5 years of construction

TPC Field Cage


Inserting central membrane
100 μm alumised Mylar

Field defining potential network





Field cage

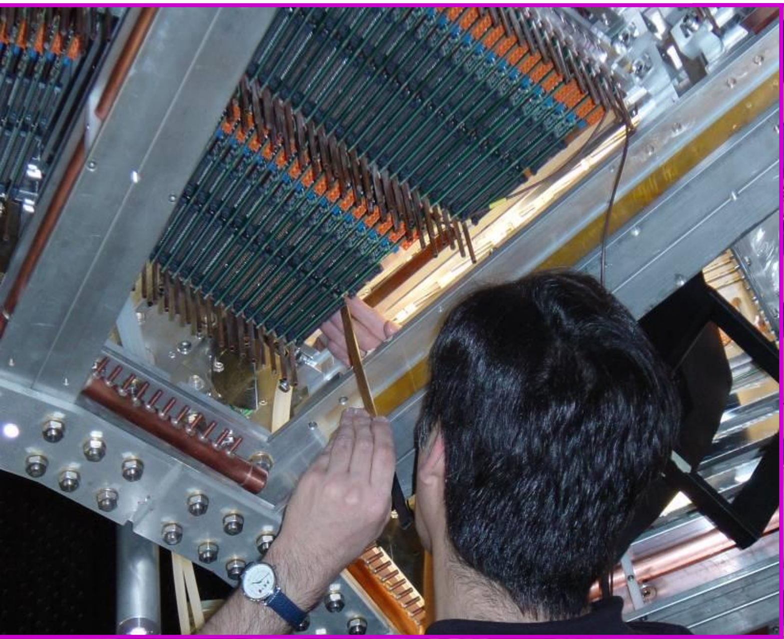
- Low mass field cage: X/X_0 = 3% at eta = 0
- Suspended Al-Mylar strips, Al-Mylar central electrode
- Mechanical precision 0.2 mm

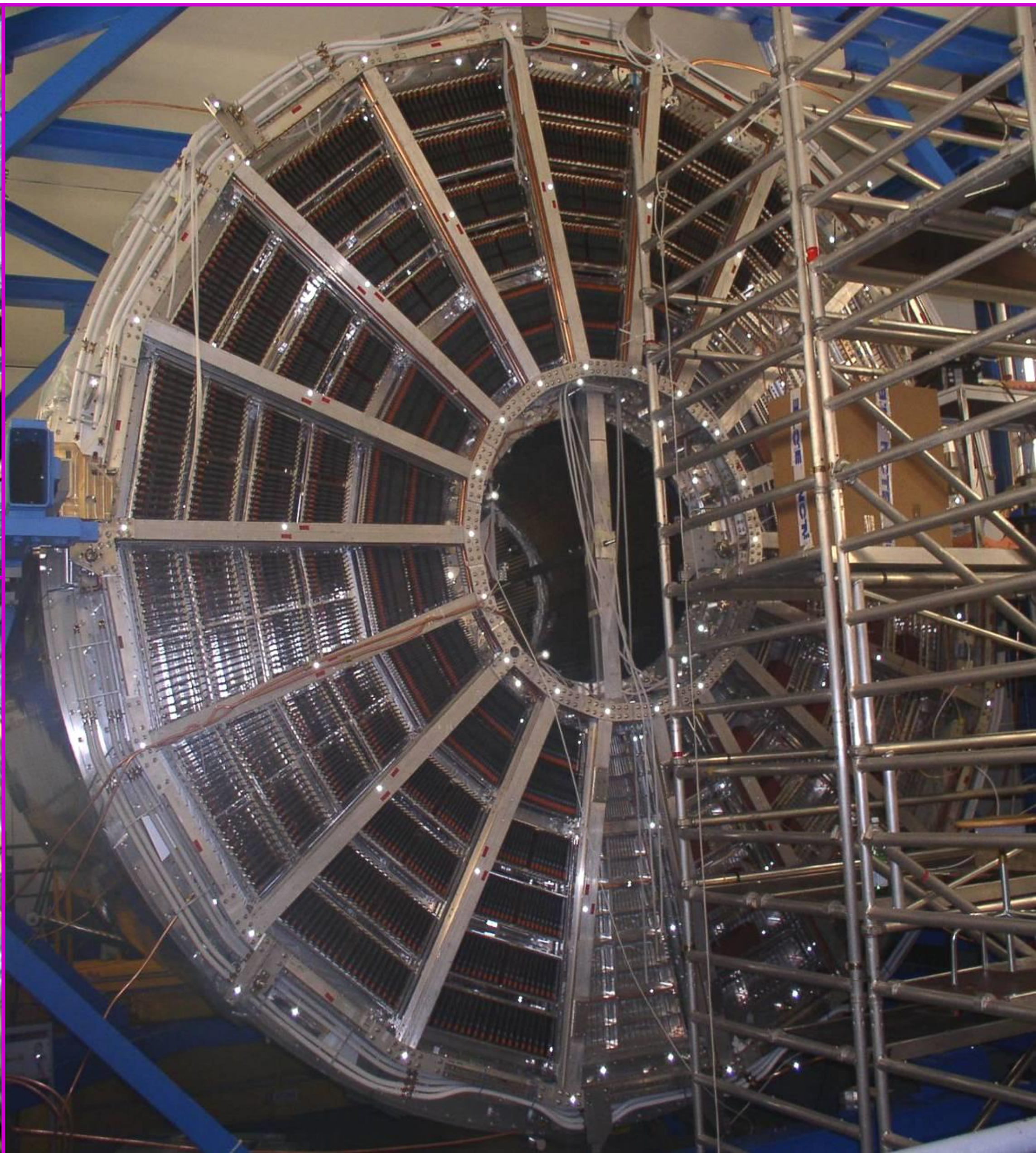
Readout Chambers

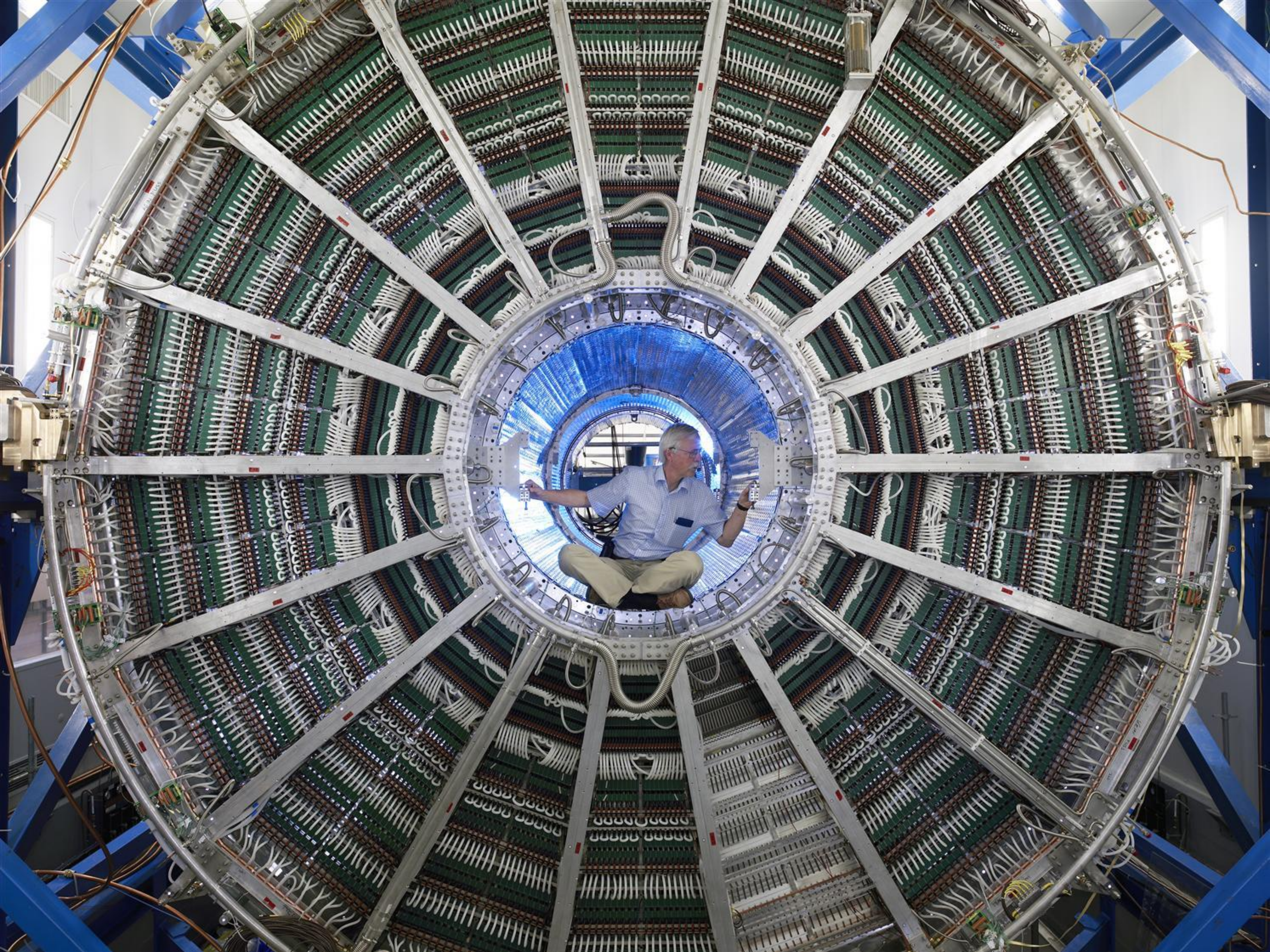
- Inner Readout Chambers (IROC)
  - Padsize 4 x 7.5 mm^2
  - Anode-cathode distance 2 mm
- Outer Readout Chambers (OROC)
  - Padsizes 6 x 10 and 6 x 15 mm^2
  - Anode-cathode distance 3 mm
- Gas gain up to $\approx 2 \times 10^4$
- Gating wire grid
  - High suppression of ion feedback ($\approx 10^{-5}$)

TPC Chambers

Front-end electronics installation

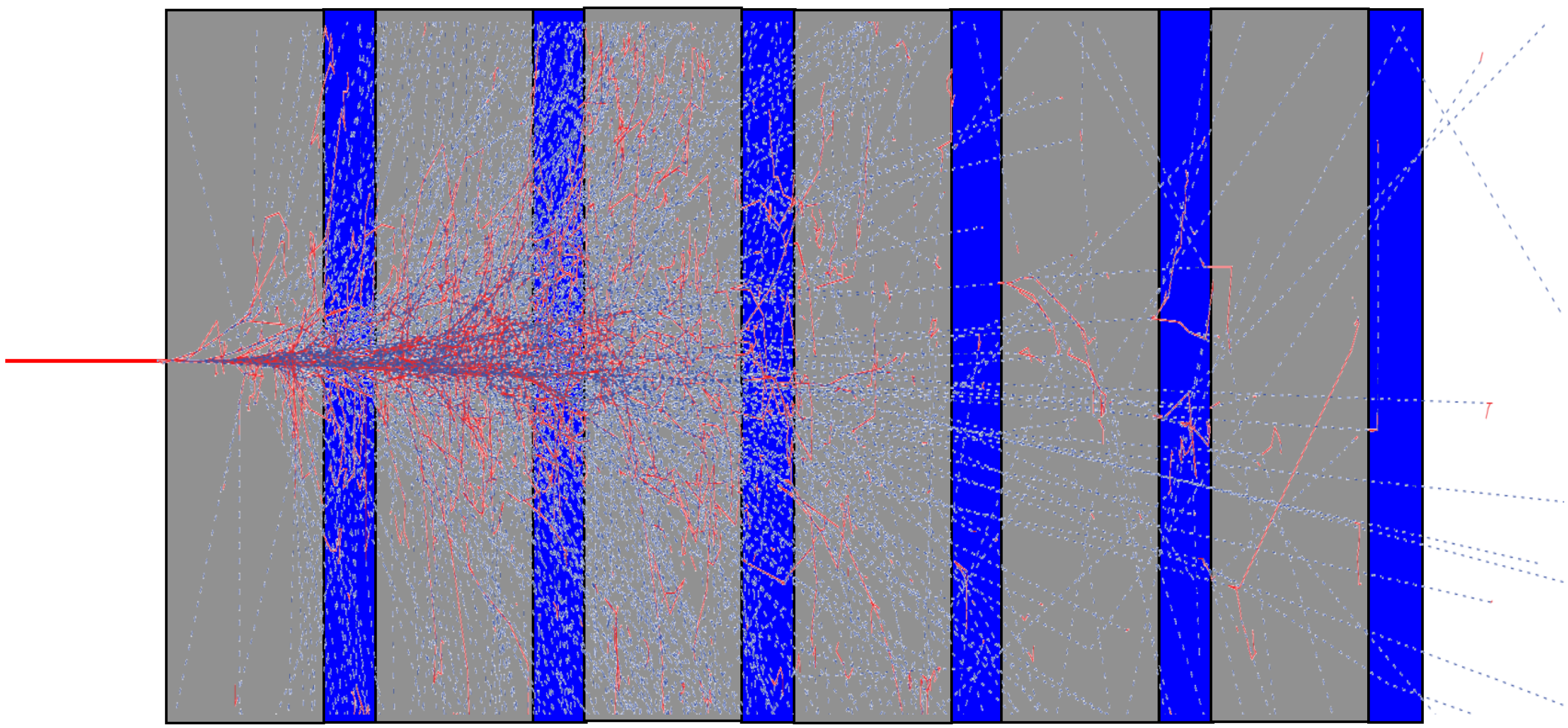






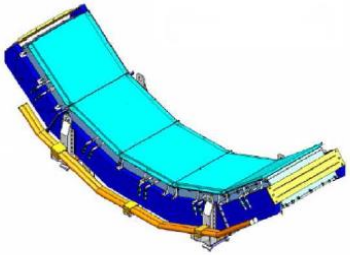
Detectors

- **Calorimeter**



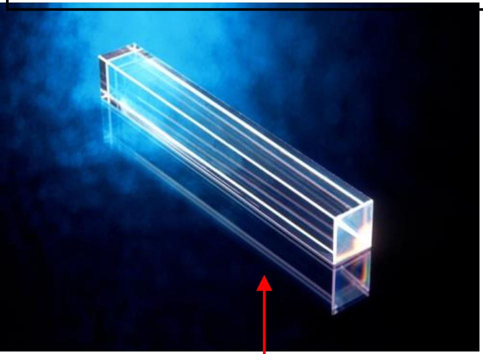
Total number of particles is proportional to energy of incoming particle

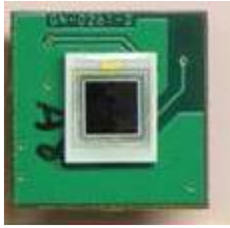
PHOton Spectrometer – readout and trigger

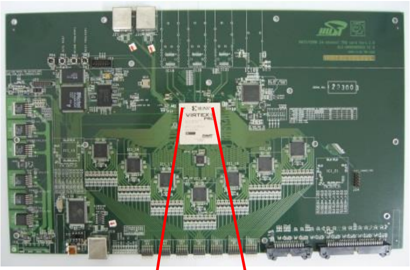


PbO_4W- crystal calorimeter for photons, neutral mesons, 1 to > 100 GeV

Array of crystals + APD + preamp + trigger logic + readout



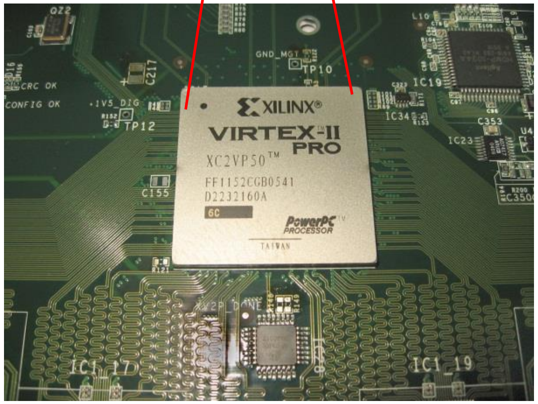




DAQ →

L0 trigger

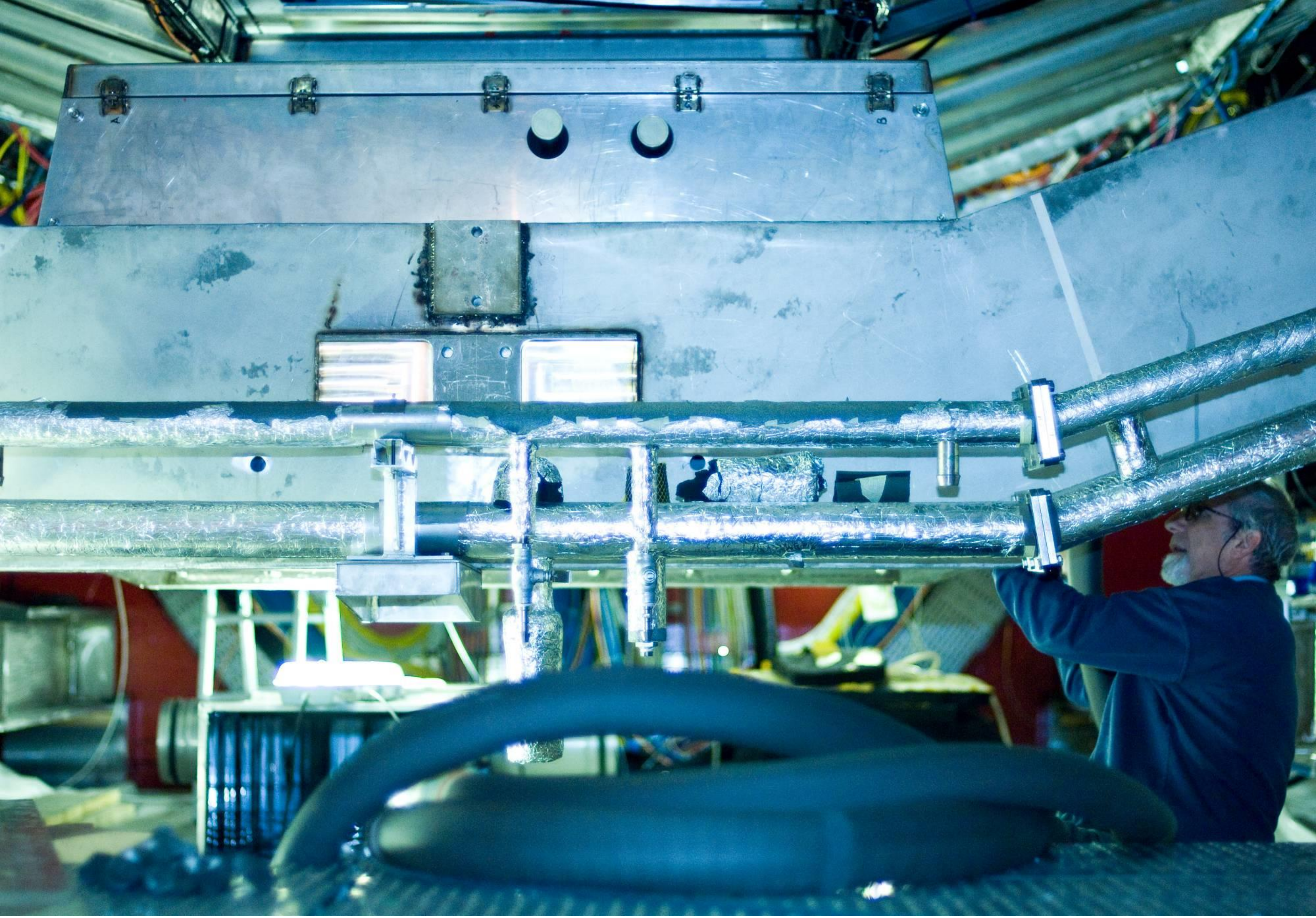
- **tasks**
  - **shower finder**
  - **energy sum**
- **implementation**
  - **FPGA**
  - **VHDL firmware**



L0/L1 trigger →

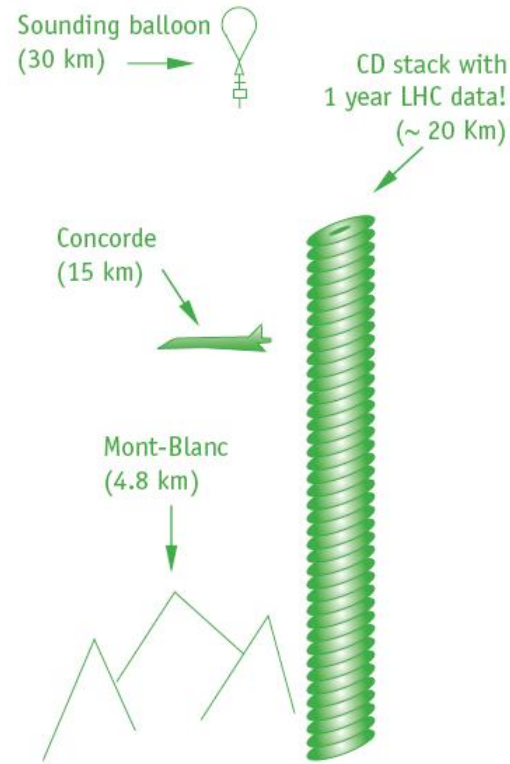
 36

Installation 1st PHOS module



Installation 1st PHOS module

and a lot of computers...



That is 15,000,000 GB (15 PB) per year

20 km stack of average CDs per year.

Conclusion

- The first run period (RUN 1) of the LHC project has successfully finished
- At the moment upgrade of detectors
- Next run period will start in 2015
- Next upgrade in 2018
- …

The end