4. LHC experiments

Summary from yesterday:

- Hadron colliders play an important role in particle physics discory but also precision measurements

- LHC will open up TeV energy range
  new particles with 3-5 TeV mass could be produced and hopefully detected

- typical sigantures include high pT objects, leptons and photons and often missing (transverse) energy

- challenges at LHC

huge interaction rates and large QCD background
pile up

requires detectors and electronics
fast, high granularity, radiation hard
... lets have a look at them!

Detector requirements

The signatures we look for ...

- Leptons and photons at high p_T
- missing Energy --> $E_t$miss
- b quarks, tau leptons
- Jets

with high backgrounds and low pT pile up

Detector requirements ...

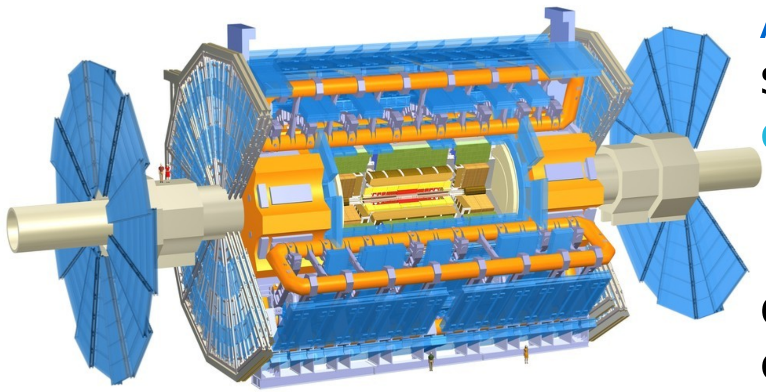
- radiation hardness
- timing 25 ns

- identify and measure leptons, photons at high pT
  lepton ID over huge background e/jet ~ 10^{-5}
- good measurement of missing transverse Energy
  energy measurement in forward region ($|\eta|<5$)
- b and τ tag (silicon detectors)

- highly selective and fast trigger
  signal xs ~ 10^{-14} of total xs

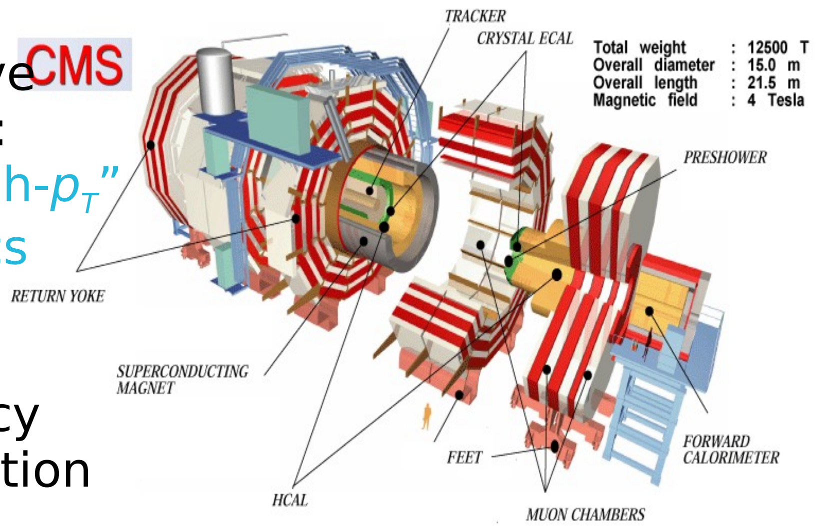
LHC experiments

ATLAS



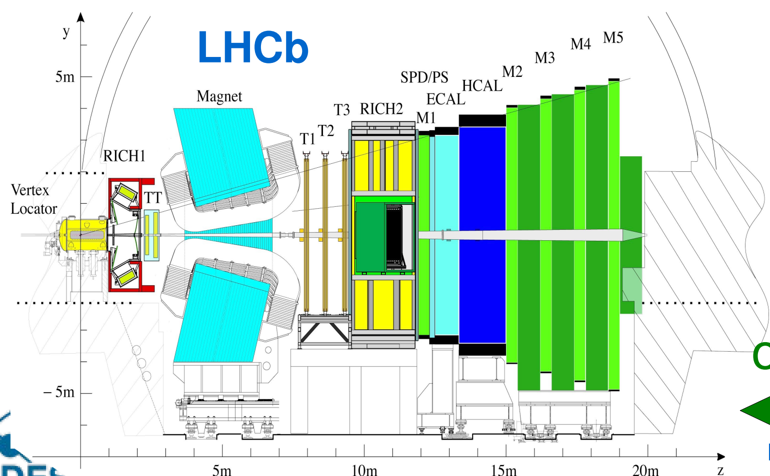
ALTAS and CMS have same physics goals:
concentrate on “high-p_T” discovery physics

different detector concepts redundancy and fruitful competition



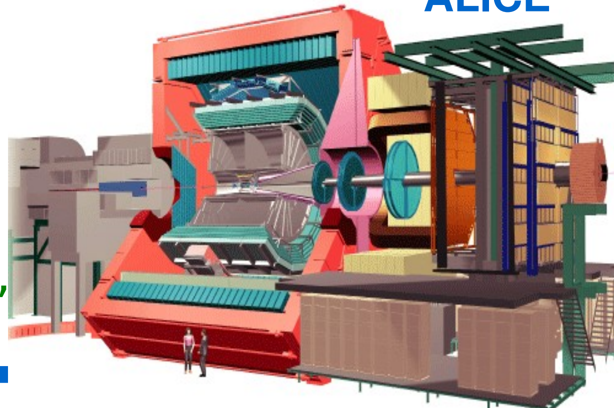
LHCb looks like a fixed-target experiment (though it is not!), but only forward region covered...
concentrates on low-p_T B physics in pp collisions

ALICE will exploit high-energetic nucleus-nucleus (“heavy-ion”) collisions

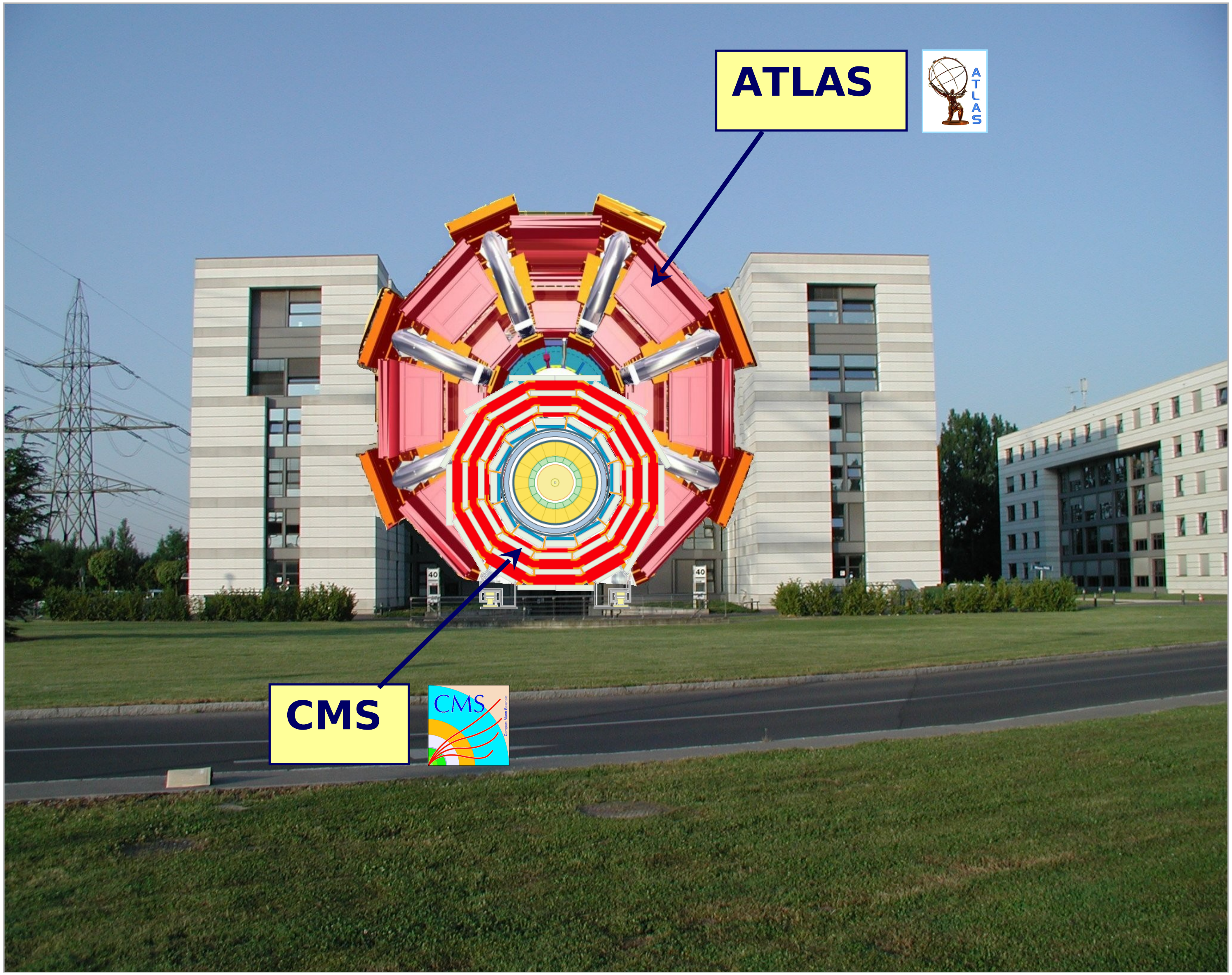


This lecture concentrates on high-p_T pp physics, only covers CMS and ATLAS,
sorry !

ALICE

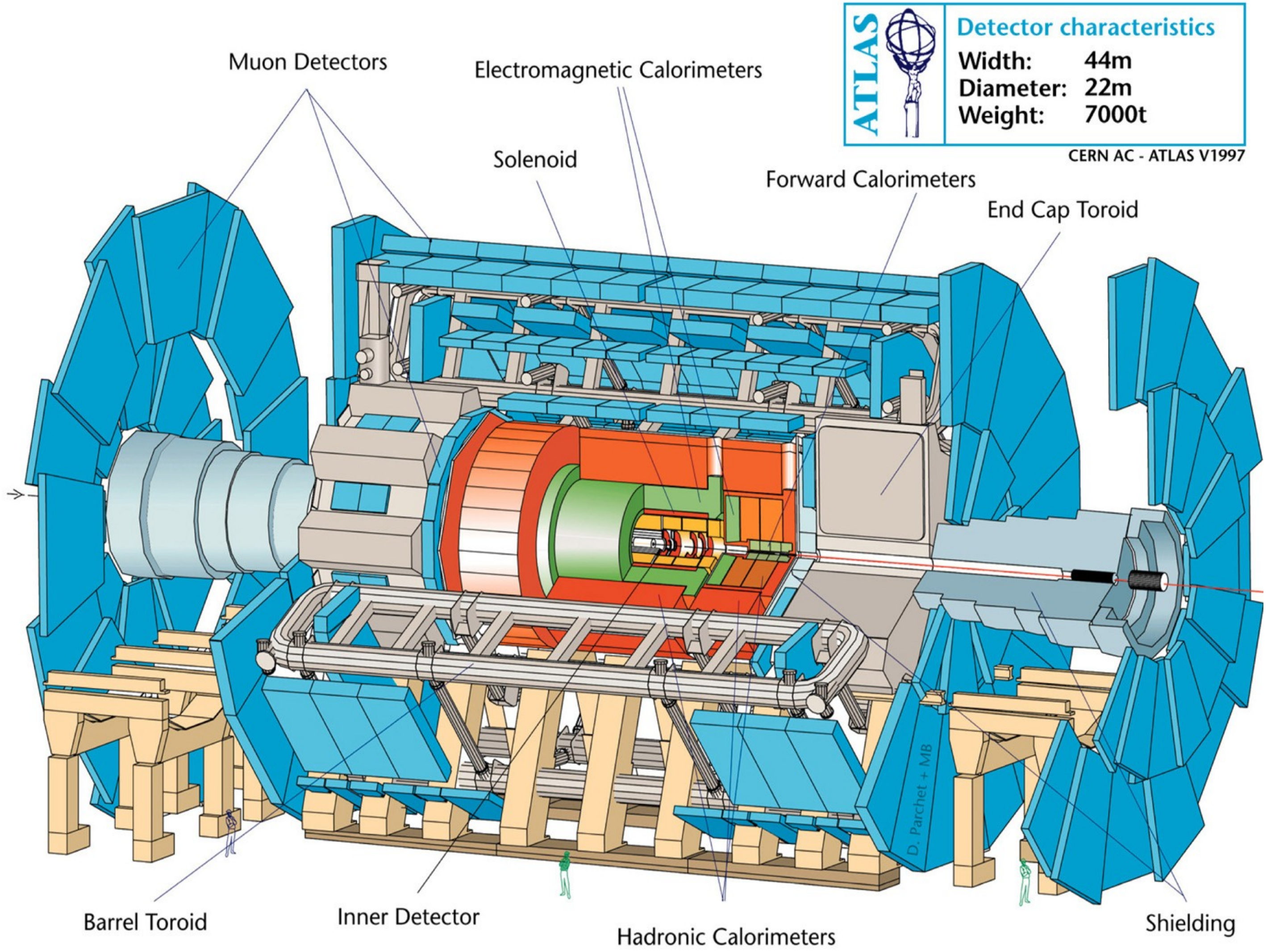


ATLAS and CMS in their office building



ATLAS

A Toroidal LHC ApparatuS



SemiConducterTracker
Pixel Detector

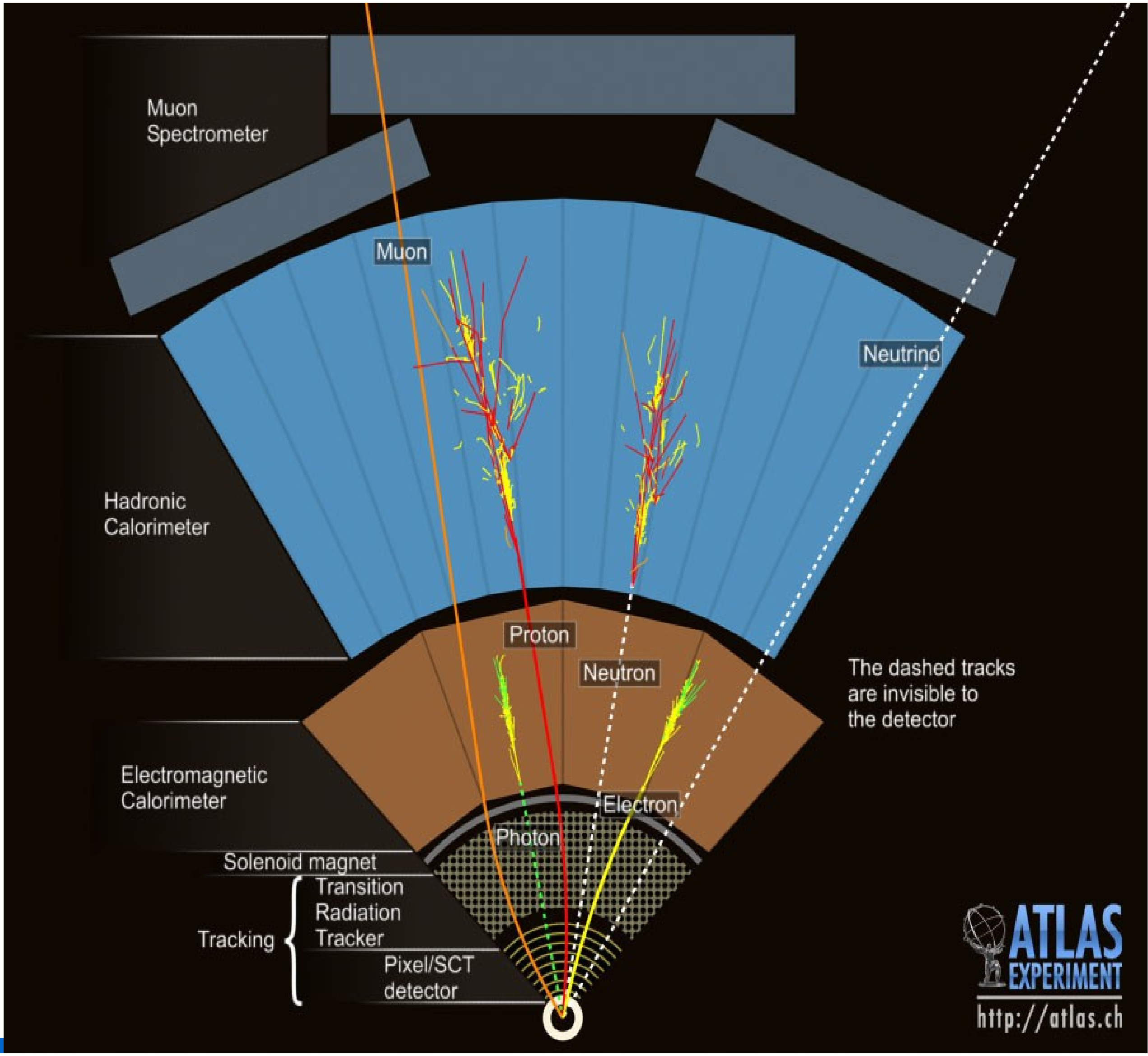
6 Mio channels:
80 μm x 12 cm
100 Mio channels:
50 μm x 400 μm
space resolution ~15 μm

solenoid
2T field
momentum measurement

el. magn. and
hadr. calorimeters

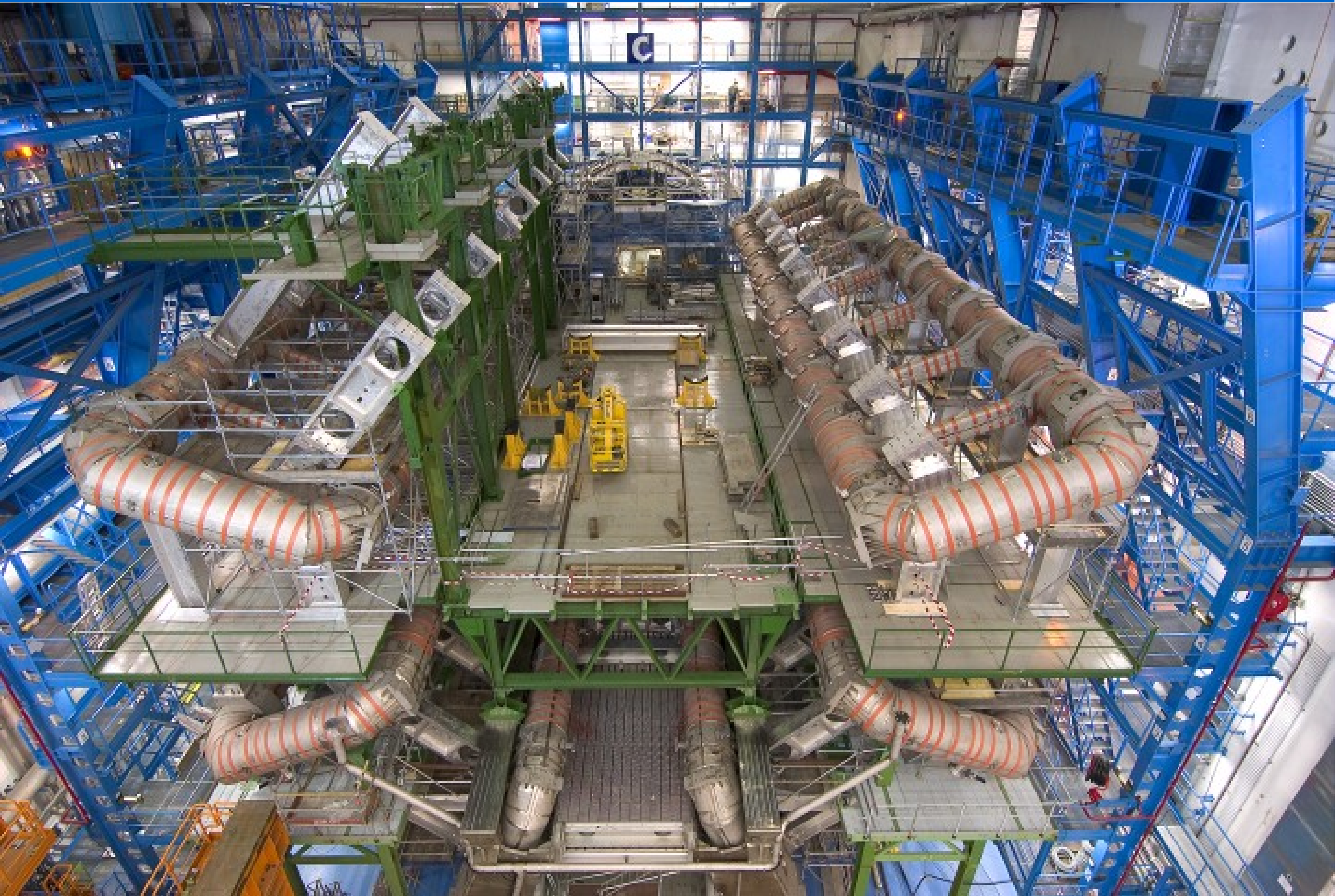
muon spectrometer
(streamer tubes)
8 superconducting
toroid magnets

Particle measurement in ATLAS

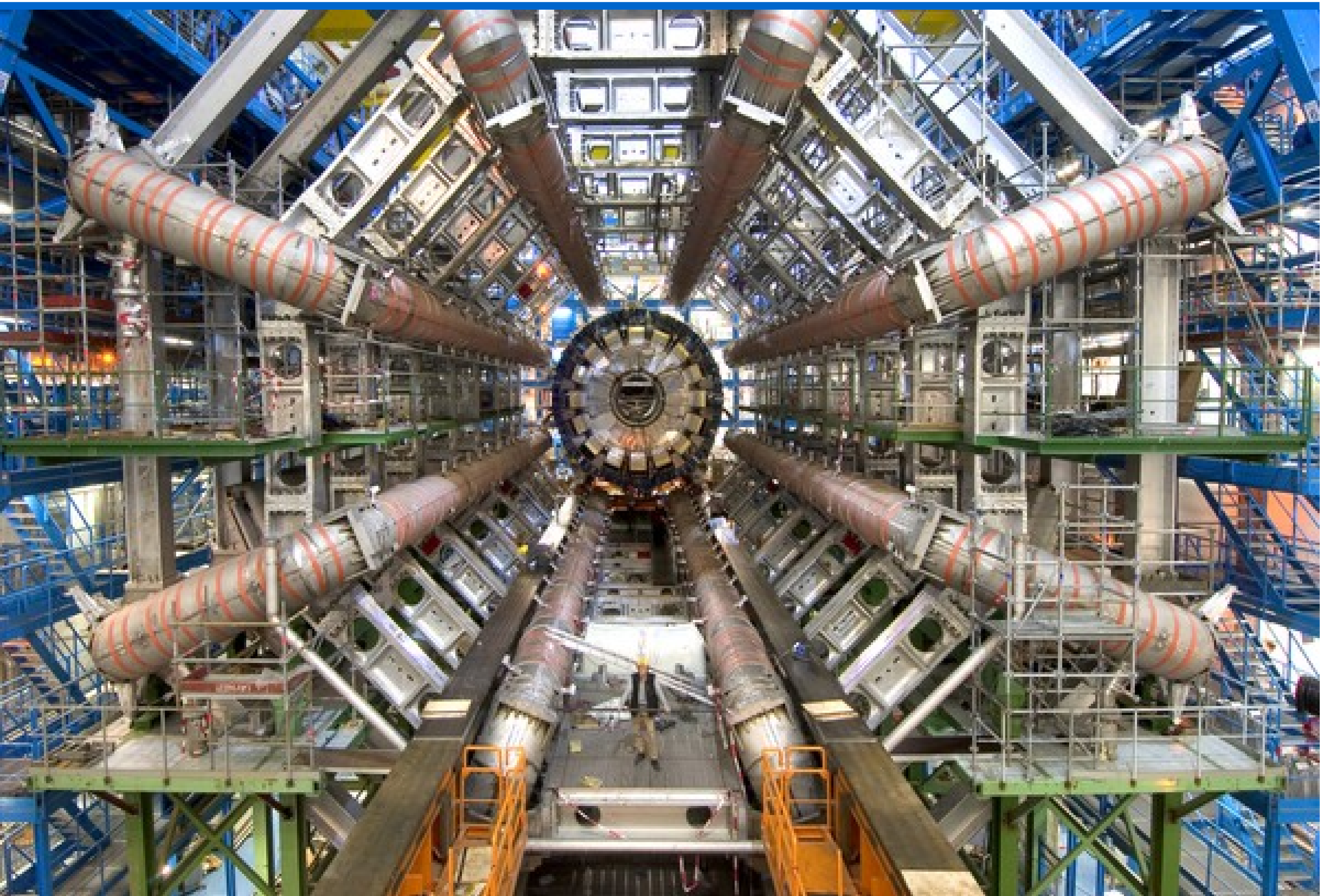


- **Tracking :**
  - **high resolution HLT**
  - **TRT (e/π separation)**
- **Energy measurement:**
  - **EM : Pb-LAr**
  - **HAD: Fe/Szint. (cent), Cu/W-LAr (fwd)**
- **Muon spectrometer: Toroid with streamer tubes**

ATLAS

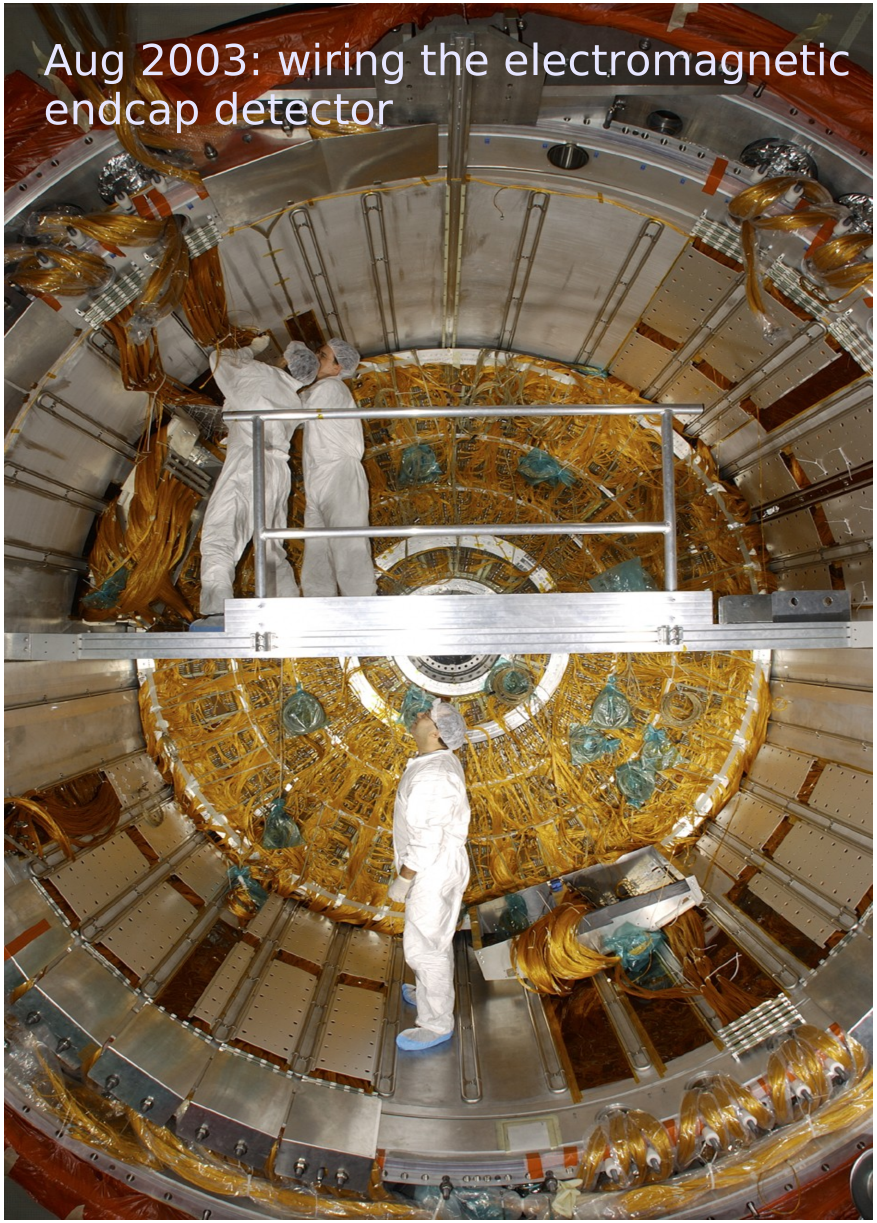


ATLAS



ATLAS

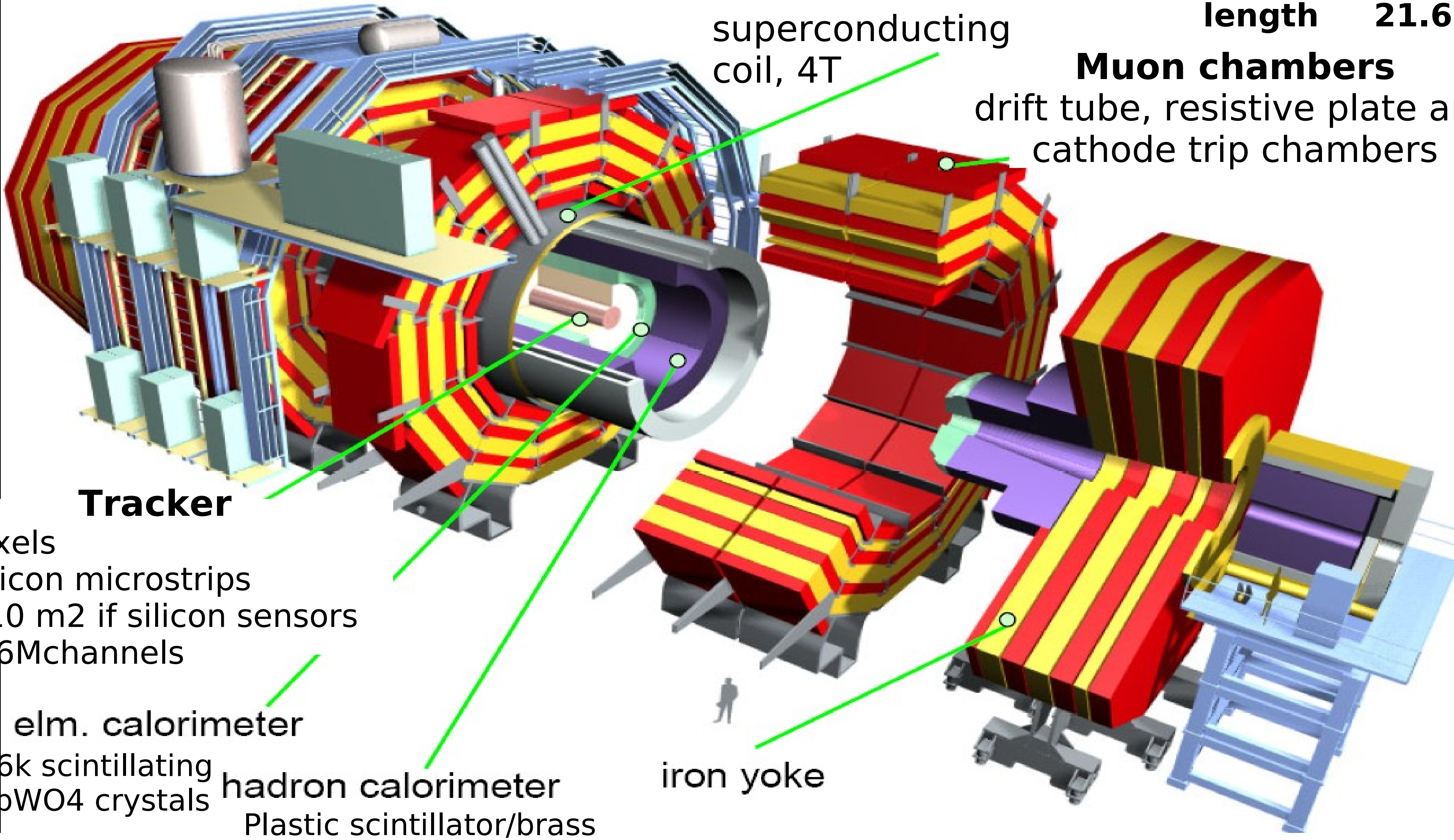

Oct 2004: lowering the first of eight barrel toroid coils into the cavern


Aug 2003: wiring the electromagnetic endcap detector

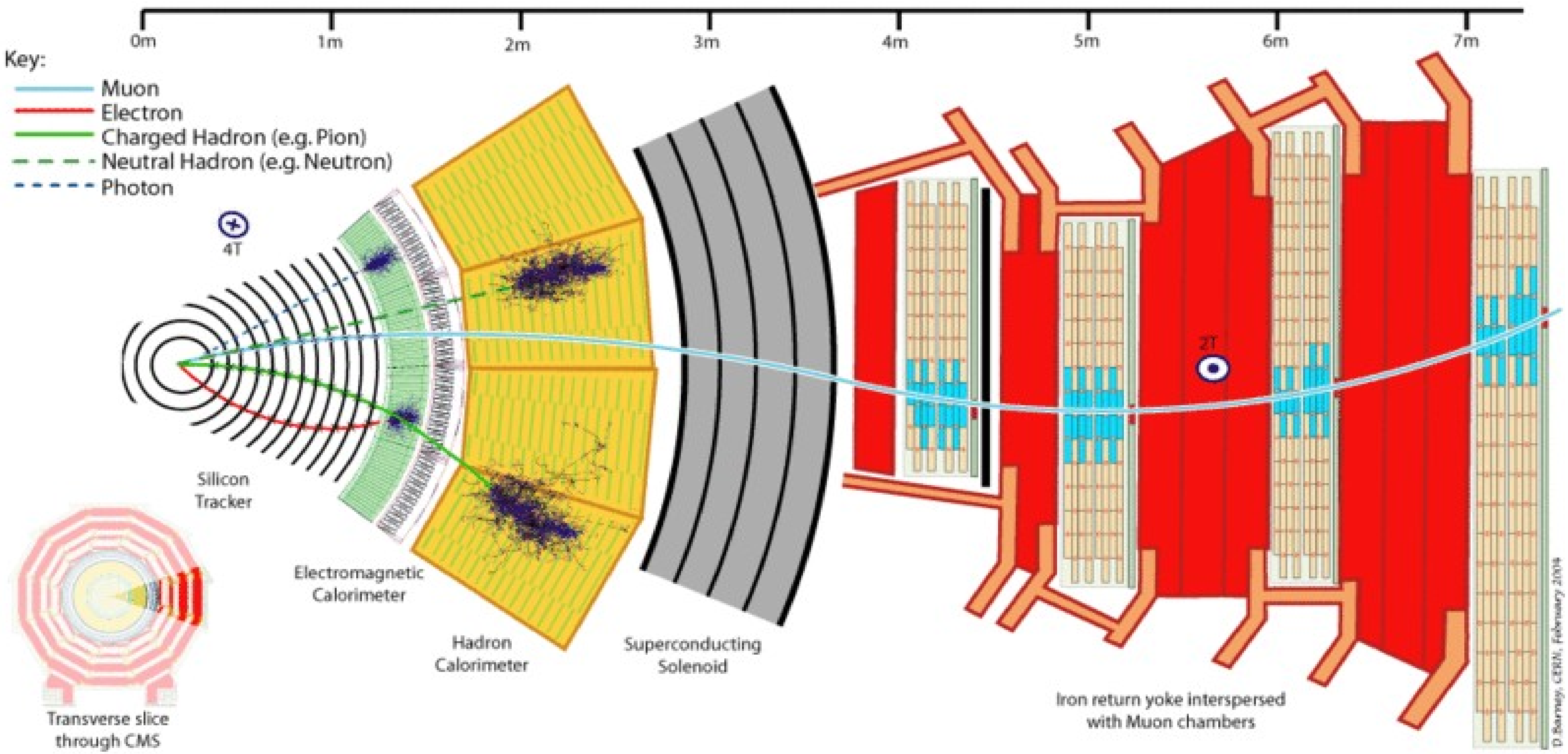
CMS

Compact Muon Solenoid

weight 12500 t
diameter 15 m
length 21.6 m

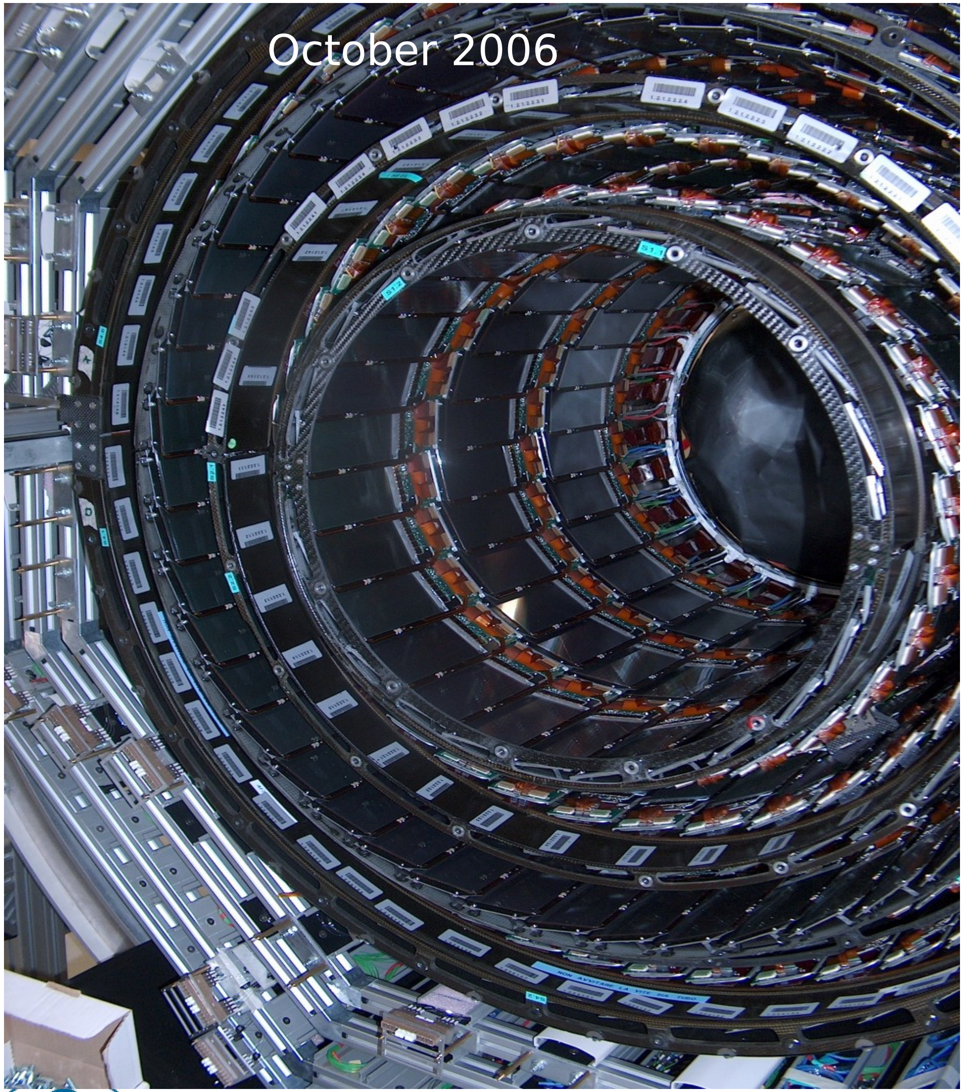


Particle measurement in CMS ...

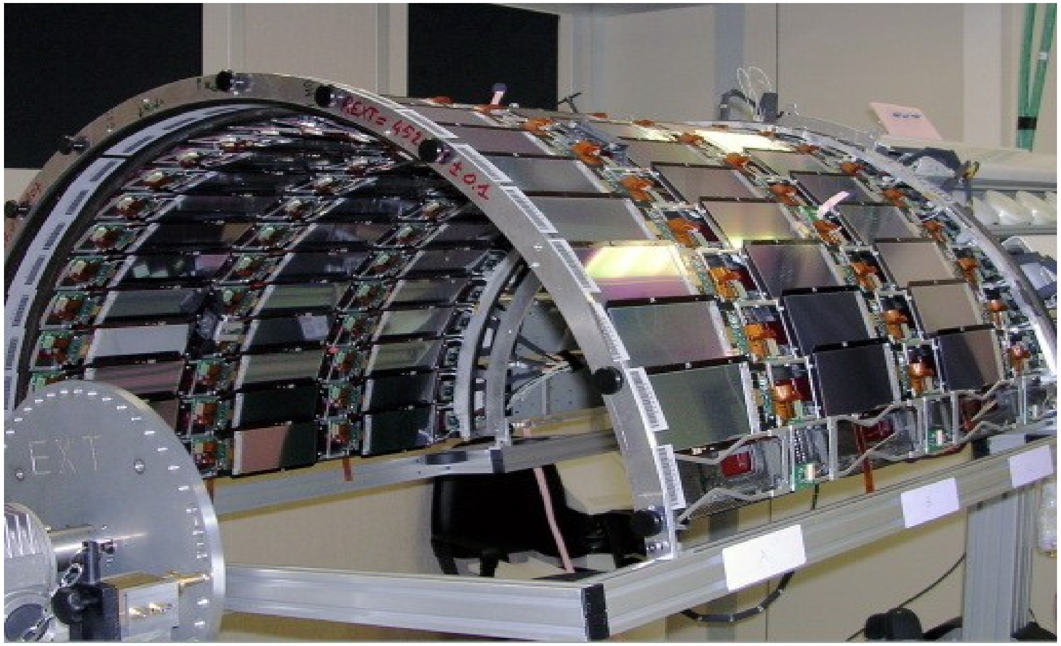


CMS

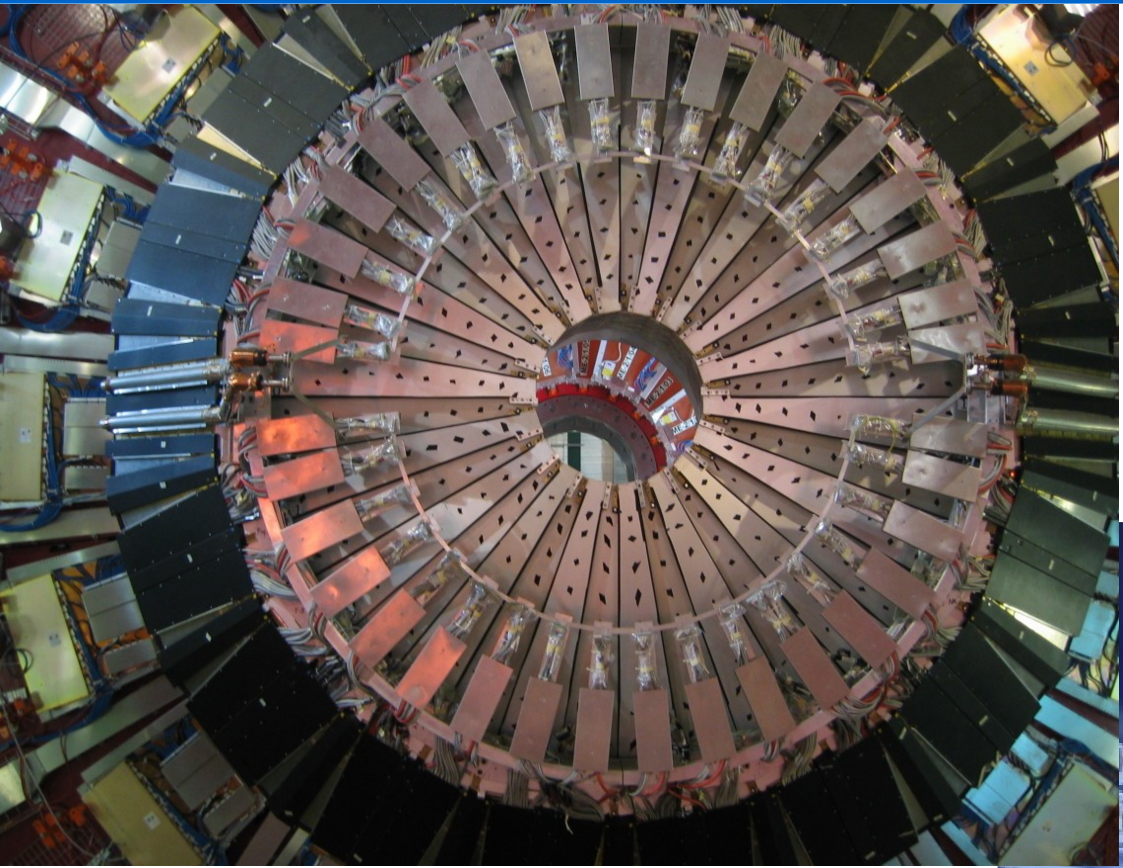
Second half of the Inner Tracker (TIB +TID) ready for assembling in Pisa before transportation to CERN



Tracker Inner Barrel integration activities performed in Florence and Pisa in May 2005



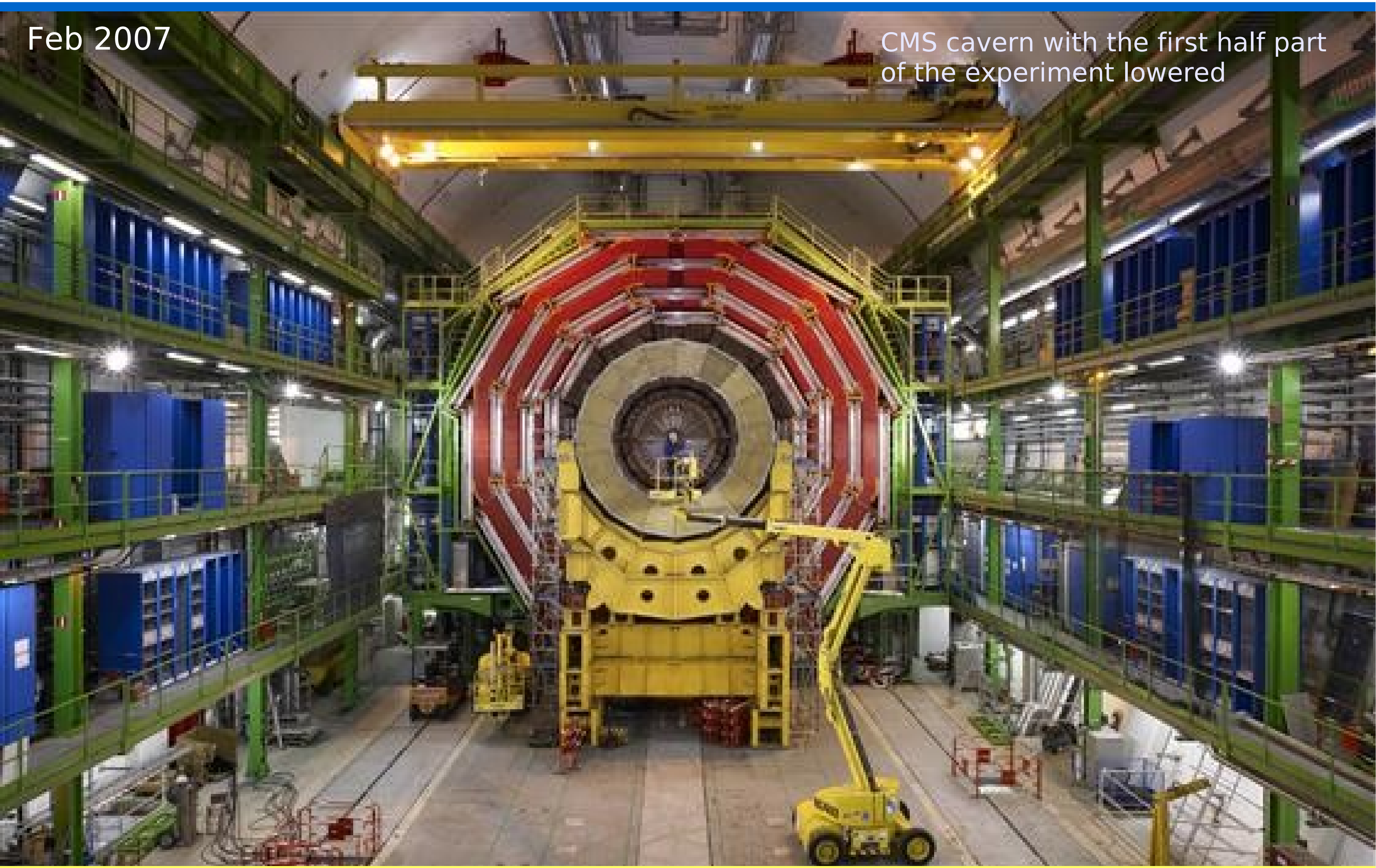
CMS



view of CMS HCAL endcap
some Cathode Strip Chambers (CSC) can be seen through the central hole

APD (Avalanche PhotoDiodes) photodetectors are being glued onto the rear face of PWO (lead tungstate, $PbWO_4$) crystals ready for assembly

CMS



CMS was assembled on the surface and then lowered down!

Movies of the lowering of the barrels: http://cmsinfo.cern.ch/outreach/CMSmedia/CMSmovies.html

CMS and ATLAS

	ATLAS	CMS
weight	7000 t	12500 t(iron yoke)
length	46m	22m
diameter	22m	15m
solenoid field	2T	4T

CMS vs. ATLAS
main difference in design:magnets

- **CMS single solenoid 4T**
  muon system: instrumented iron yoke
  saturated, 2T

☺ higher B field – momentum resolution!
☹ limited space for calos (inside coil)
limited performance of μ system

- **ATLAS smaller solenoid field 2T**
  + huge toroid magnet system to
  bend muons

☺ acceptance for μ at large polar angles
☹ expensive

Huge experiments

- size of detectors
- 200 m2 of silicon (CMS)
- V=20000 m3 (ATLAS)

- time scale > 25 yrs
  first LHC studies ~1987
  ATLAS, CMS approved 1995
  data taking 2008 + 10 yrs

- collaboration size ~2000
- # ppt presentations, meetings

Triggering at LHC

Reminder of some numbers ...

in 25 ns particles at the speed of light travel only 7m
next bc while particles still traverse the detector!

- LHC bunch crossing interval 25 ns
  event rate of 40 Mhz

for triggering BC rate of 40 MHz is of interest

- each bunch crossing ~23 piled up events leading to an interaction rate of 1 GHz

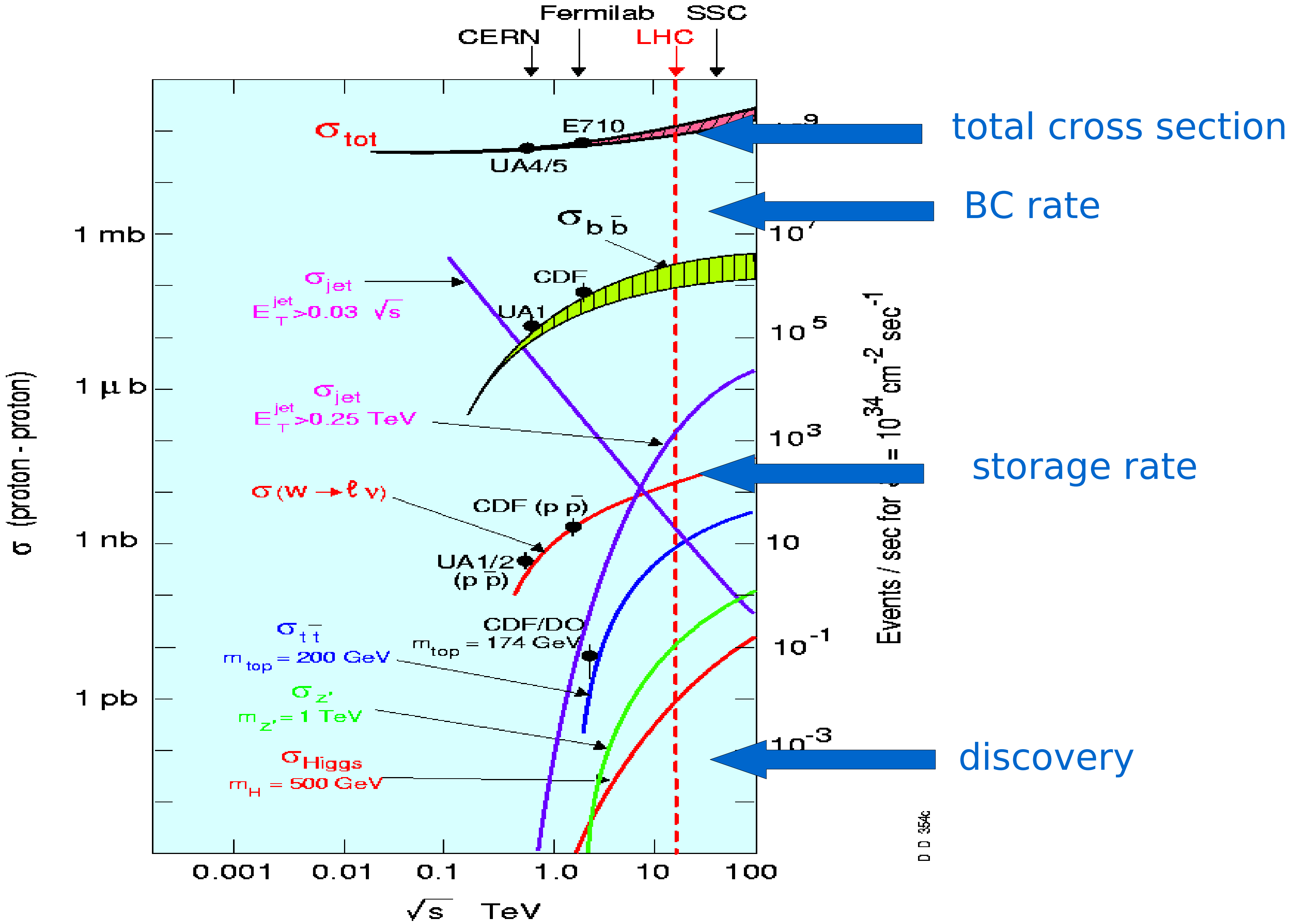
ATLAS has in total 140 mio channels

- size of events e.g. ATLAS : 1-1.5 MB
- affordable mass storage: ~300 MB/s or event rate of 200 Hz

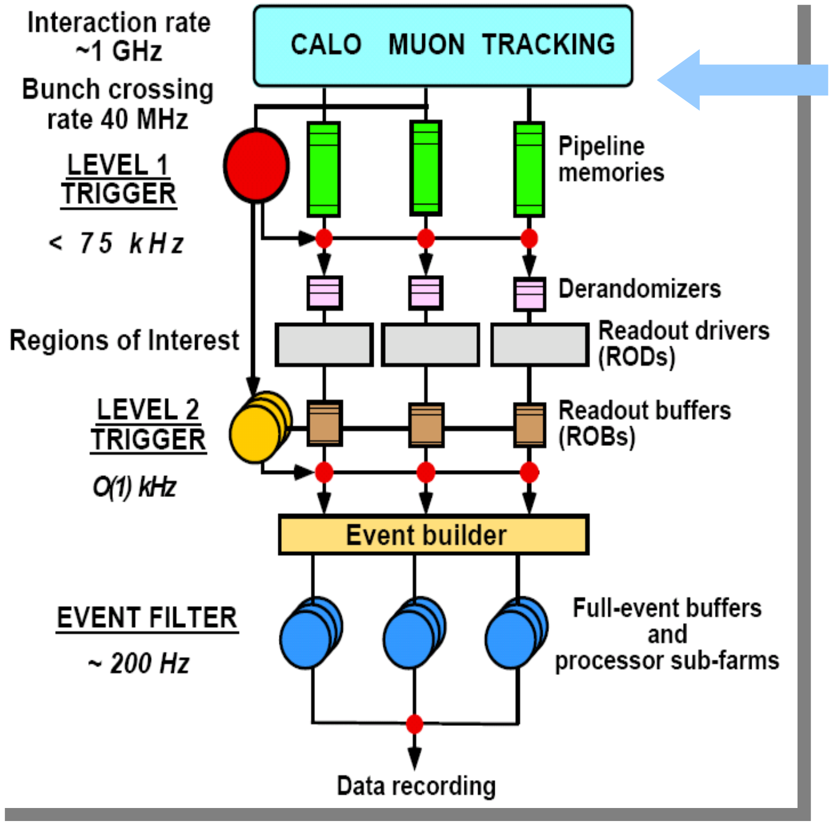
reduction needed 40 MHz down to 200 Hz reject 99.9995 %

interesting rare physics cross section ~10^{-9} and lower w.r.t. Total cross section
but have to identify these events fast!

Triggering at LHC



ATLAS Trigger

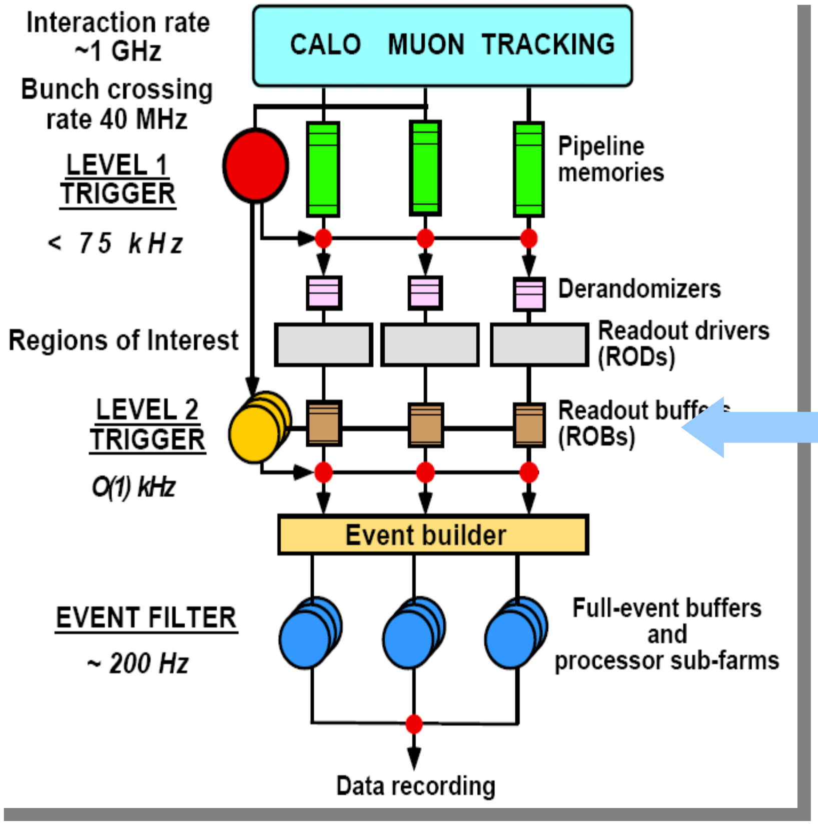


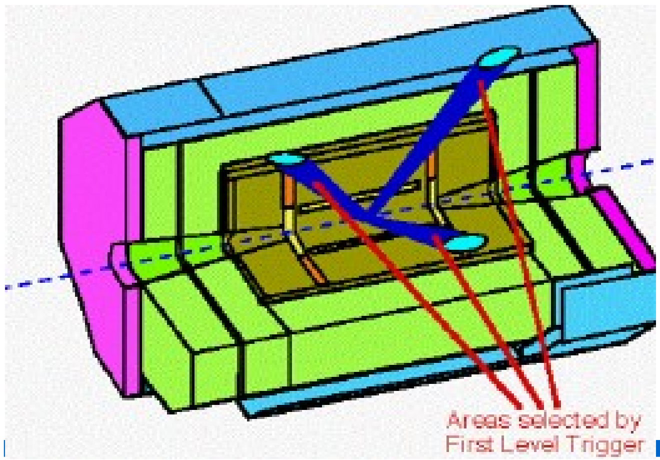
three trigger levels:
LVL1 – fast hardware (electronics) trigger
LVL2 – software triggers
Event Filter

LVL1

hardware trigger
- using information from
e.m. and hadr. Calorimeters, μ system
- triggers on high pT objects
- synchronous with LHC clock (25ns)
- decision time 2.5 μs
100 BCs must be kept in pipelines

reduces rate from 40 MHz to <75 kHz





three trigger levels:
LVL1 – fast hardware (electronics) trigger
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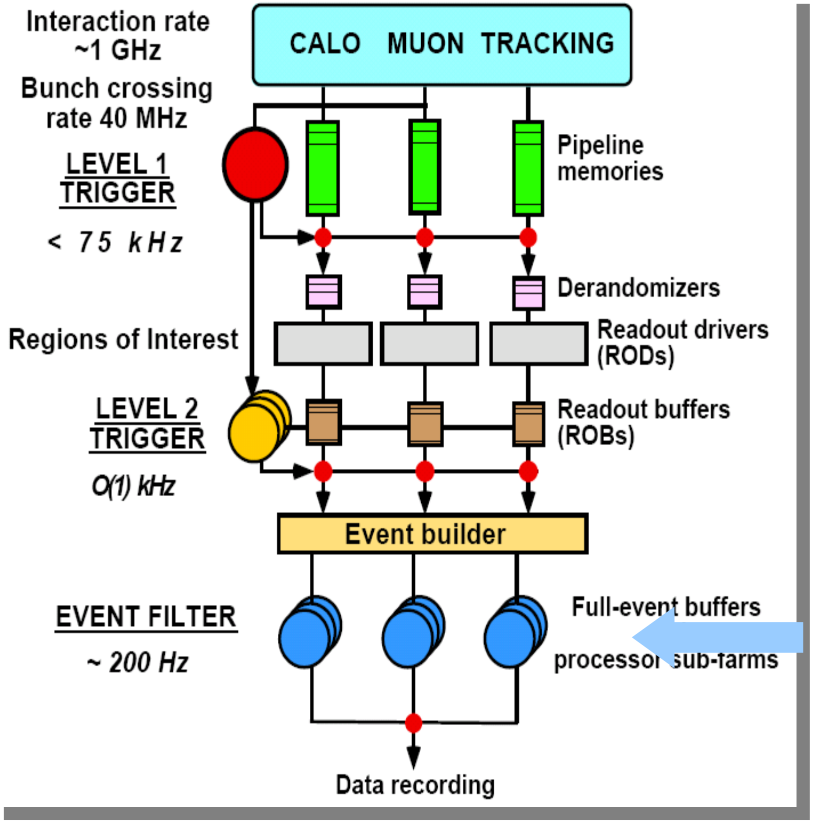
Event Filter

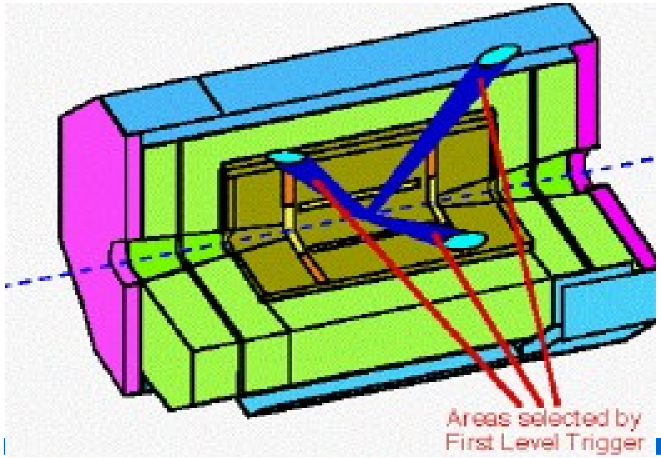
LVL2

software trigger
- uses only data from Regions of Interest
  ~2% of full event
  data still on detector near hardware
- data from all detectors, full granularity
- decision time ~ 10 ms

reduces rate from 75 kHz to ~ 1kHz

ATLAS Trigger





three trigger levels:
LVL1 – fast hardware (electronics) trigger
LVL2 – software triggers
Event Filter

Event Filter

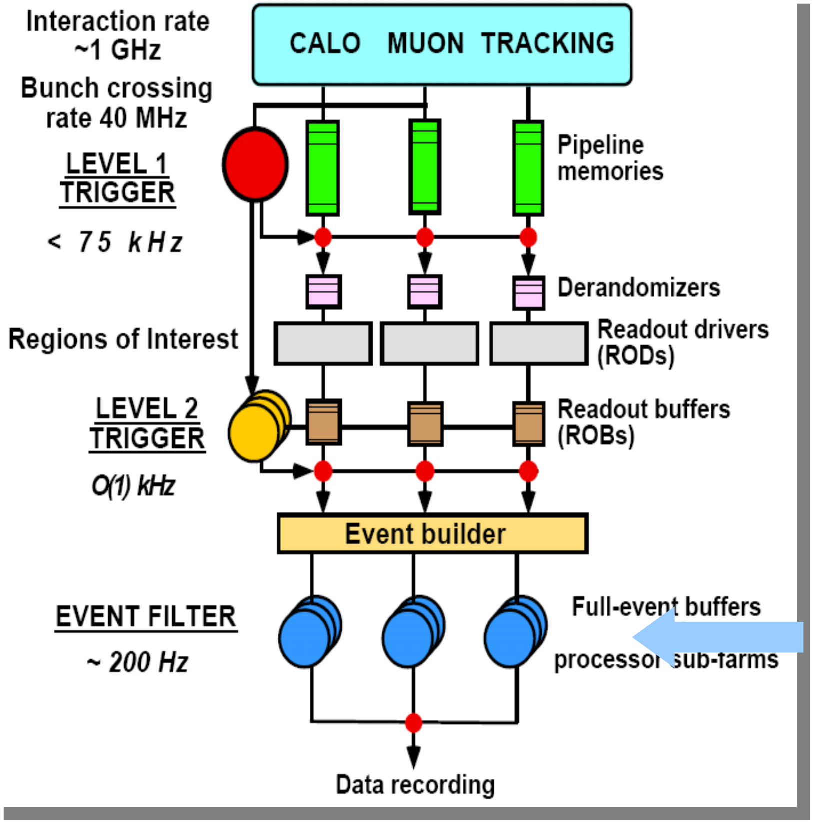
after LVL2 accept, detectors readout and full event built

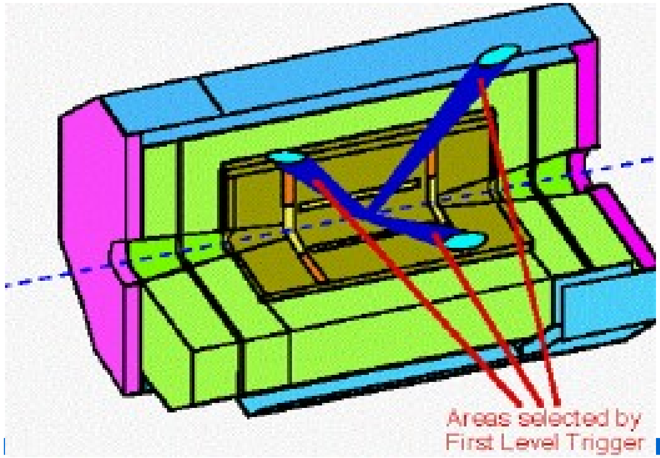
- full event data
- algorithms also explot RoI concept
- decision time ~ sec.

reduces rate from 1 kHz to ~ 200 Hz written to tape

LVL2 and EF: run on PC farm on surface exploit RoI concept and stepwise decision

ATLAS Trigger





three trigger levels:
LVL1 – fast hardware (electronics) trigger
LVL2 – software triggers
Event Filter

LVL2 and EF:
- run on PC farm on surface
- exploit RoI concept …

dont start looking at full event,
but with interesting part
RoI = seed for trigger algorithm

- …and stepwise decision

refine event reconstruction step wise
early reject possible
run time consuming algorithms late

Summary

- Hadron colliders play an important role in particle physics discory but also precision measurements

- LHC will open up TeV energy range
  new particles with 3-5 TeV mass could be produced and hopefully detected

- typical signatures include high pT objects, leptons and photons and often missing (transverse) energy

- challenges at LHC
  huge interaction rates and large QCD background
  pile up

- requires detectors and electronics
  fast, high granularity, radiation hard
  fast and highly selective triggers