The LHC experiments

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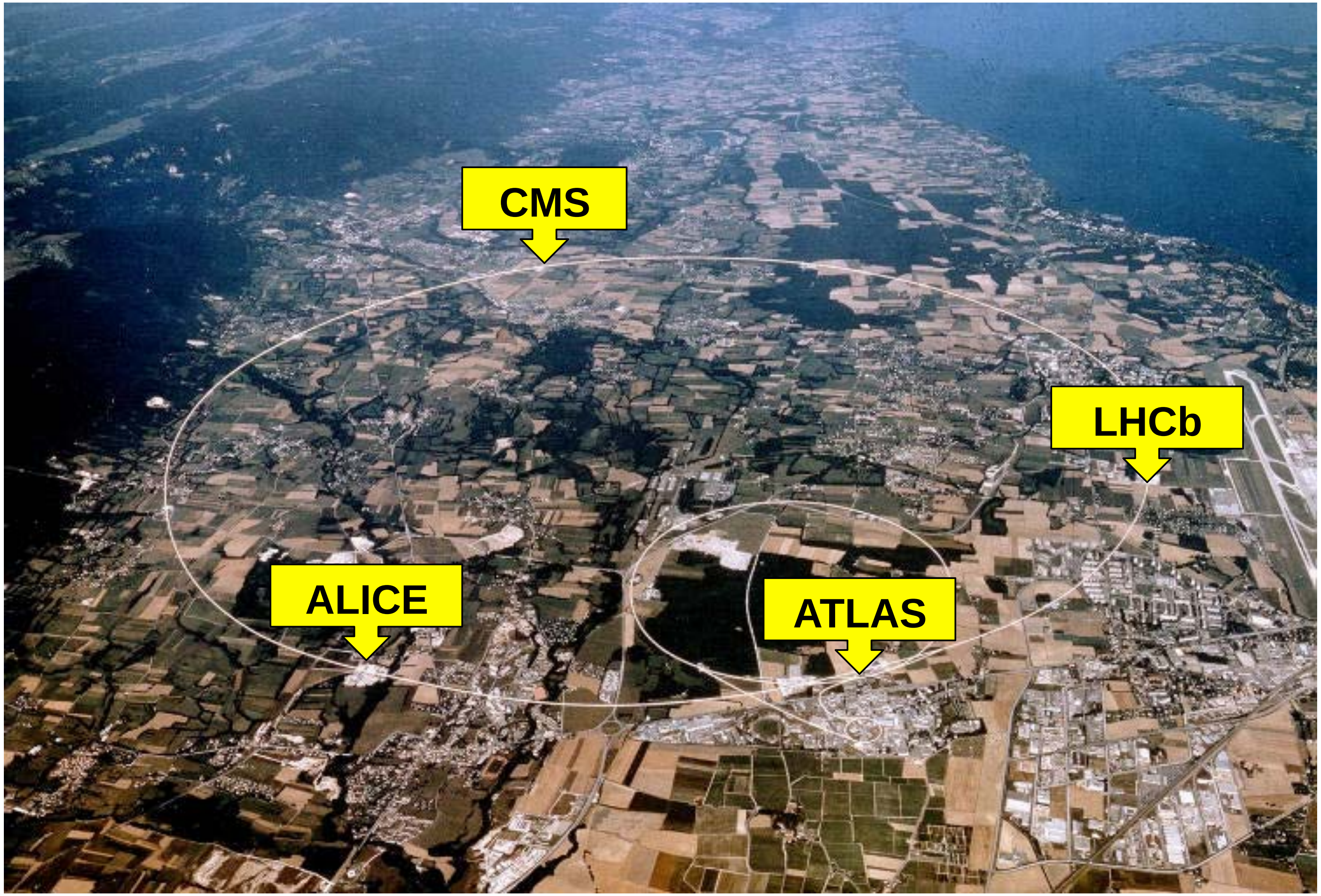
CSCS, April 29th, 2010

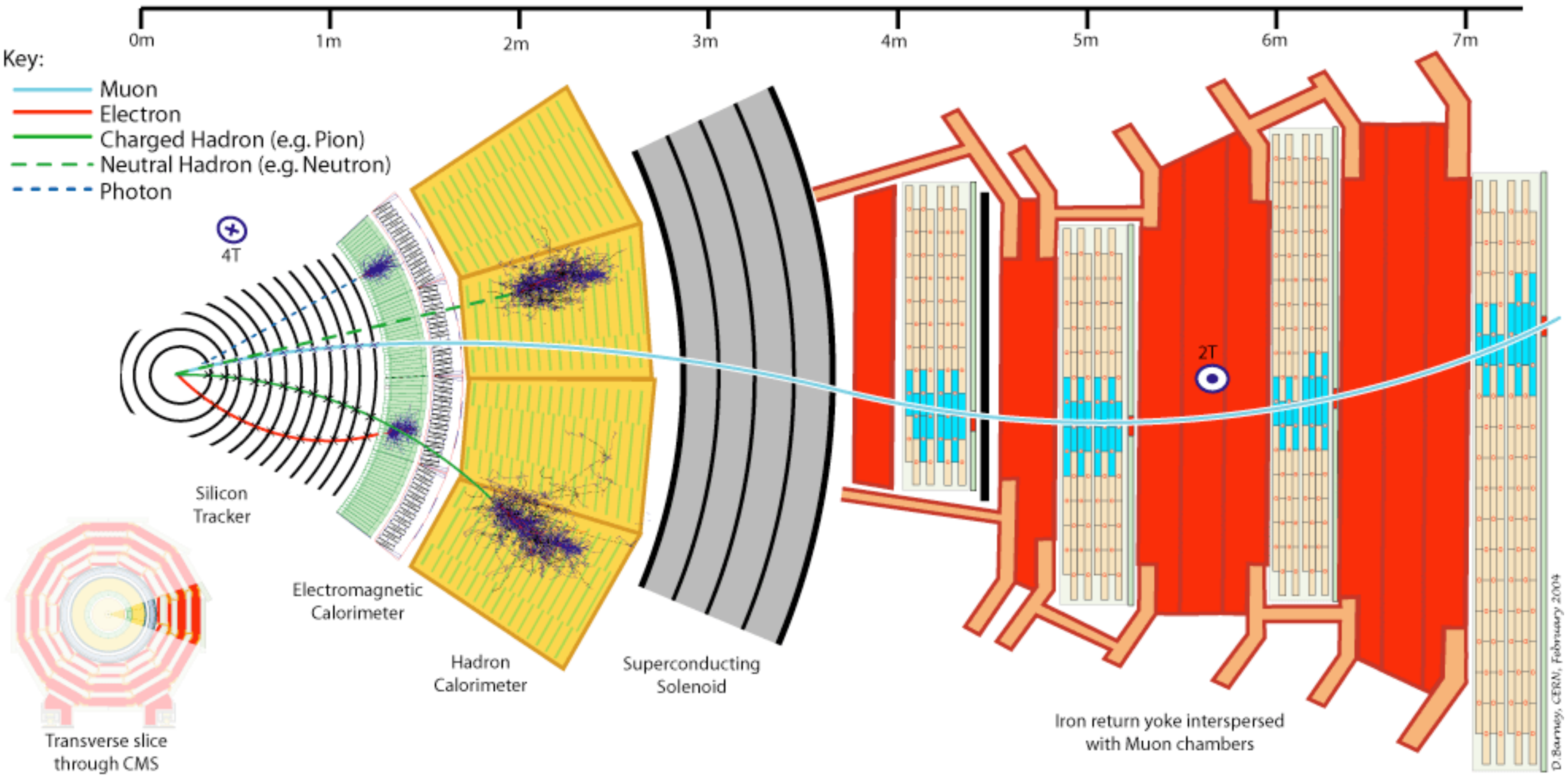
- general features of collider experiments
- the four experiments at the LHC
- status and news of the experiments

The LHC ring and the detectors



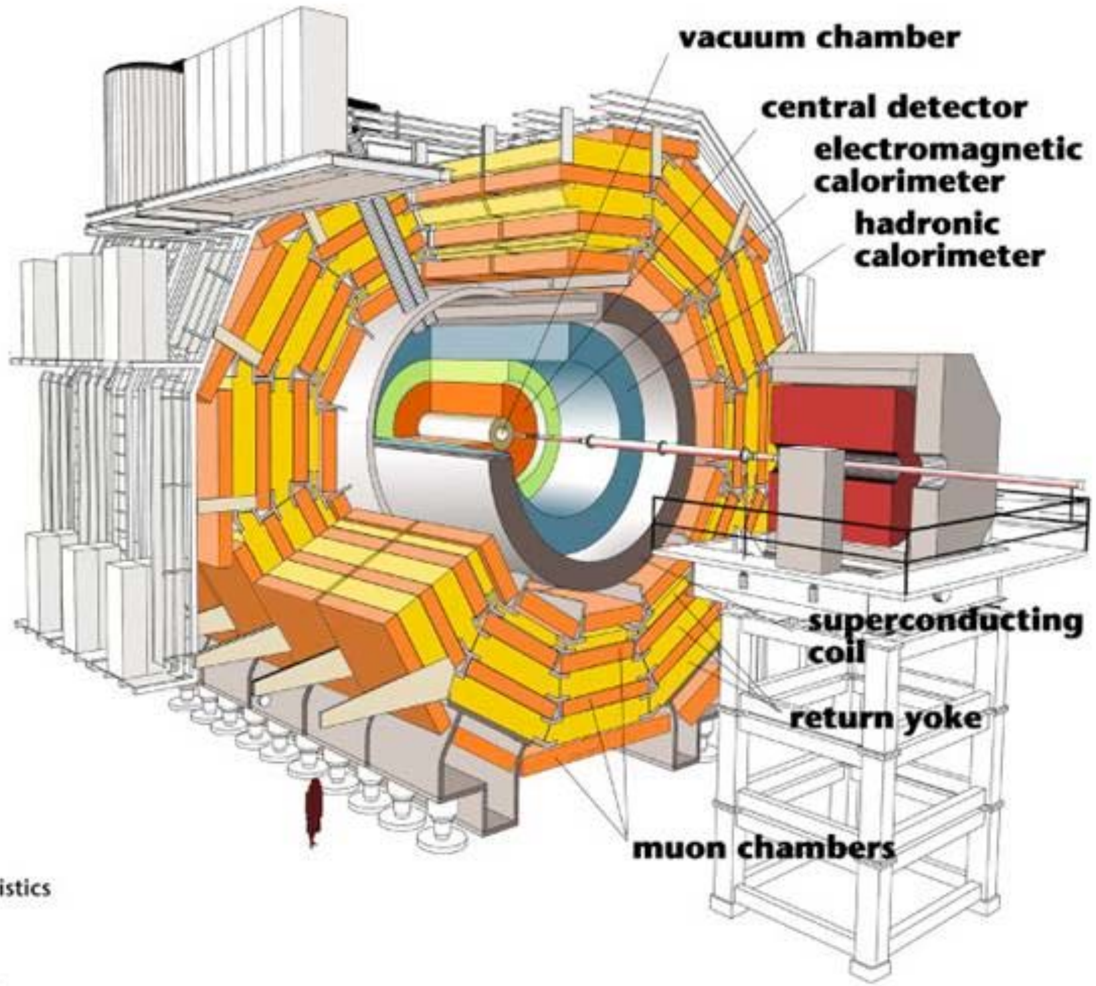
Layers of a detector

Identify particles, measure properties.



The CMS detector

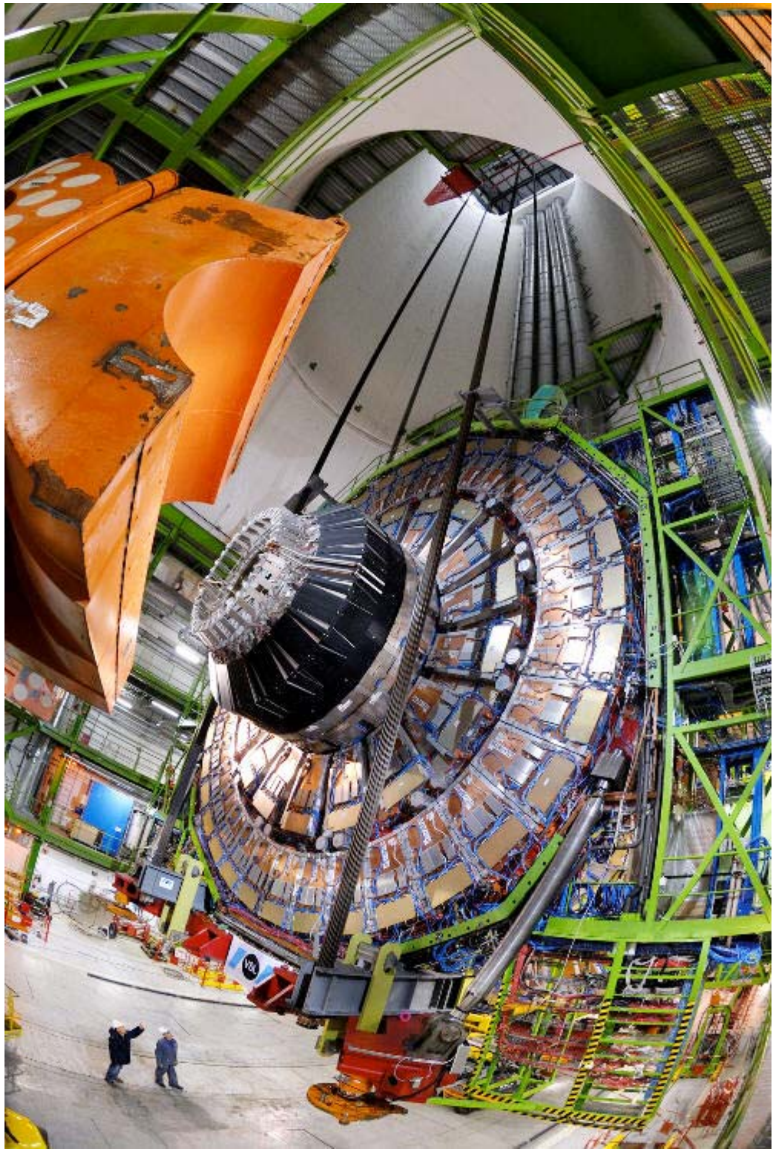
Surrounding the interaction point to:
- **see all visible particles**
- **see others from energy balance**



Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

Photo of CMS assembly



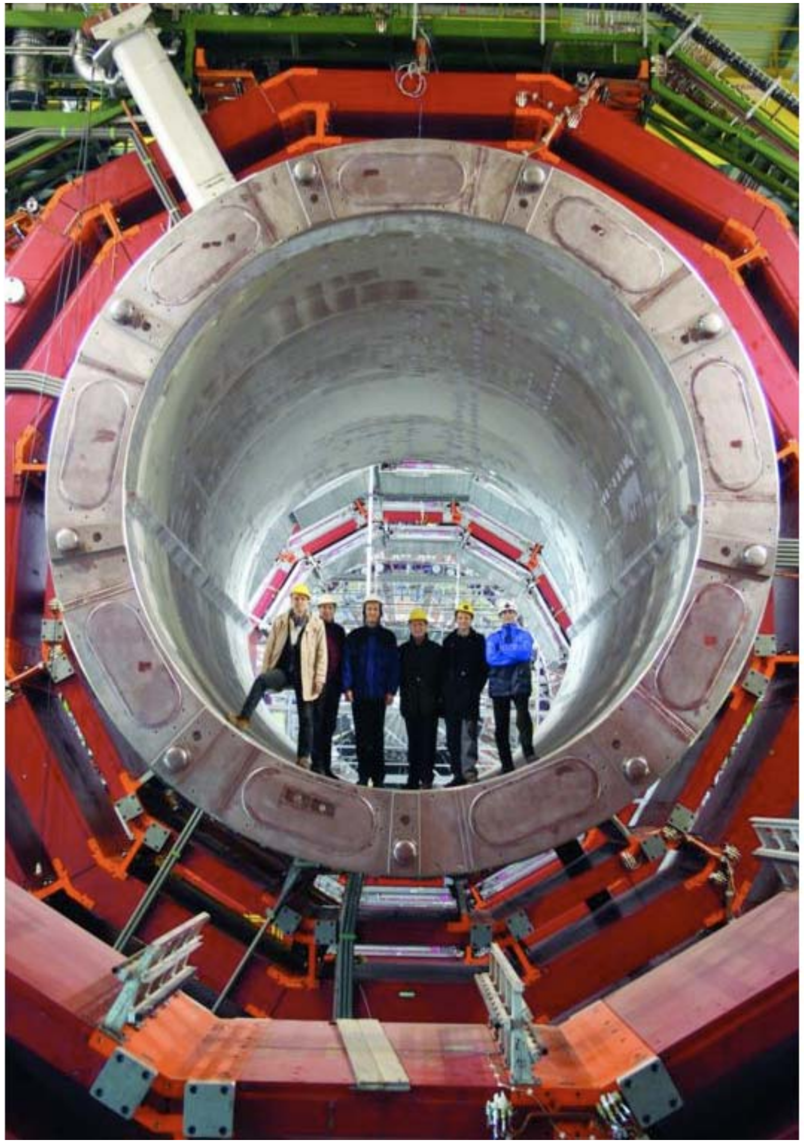
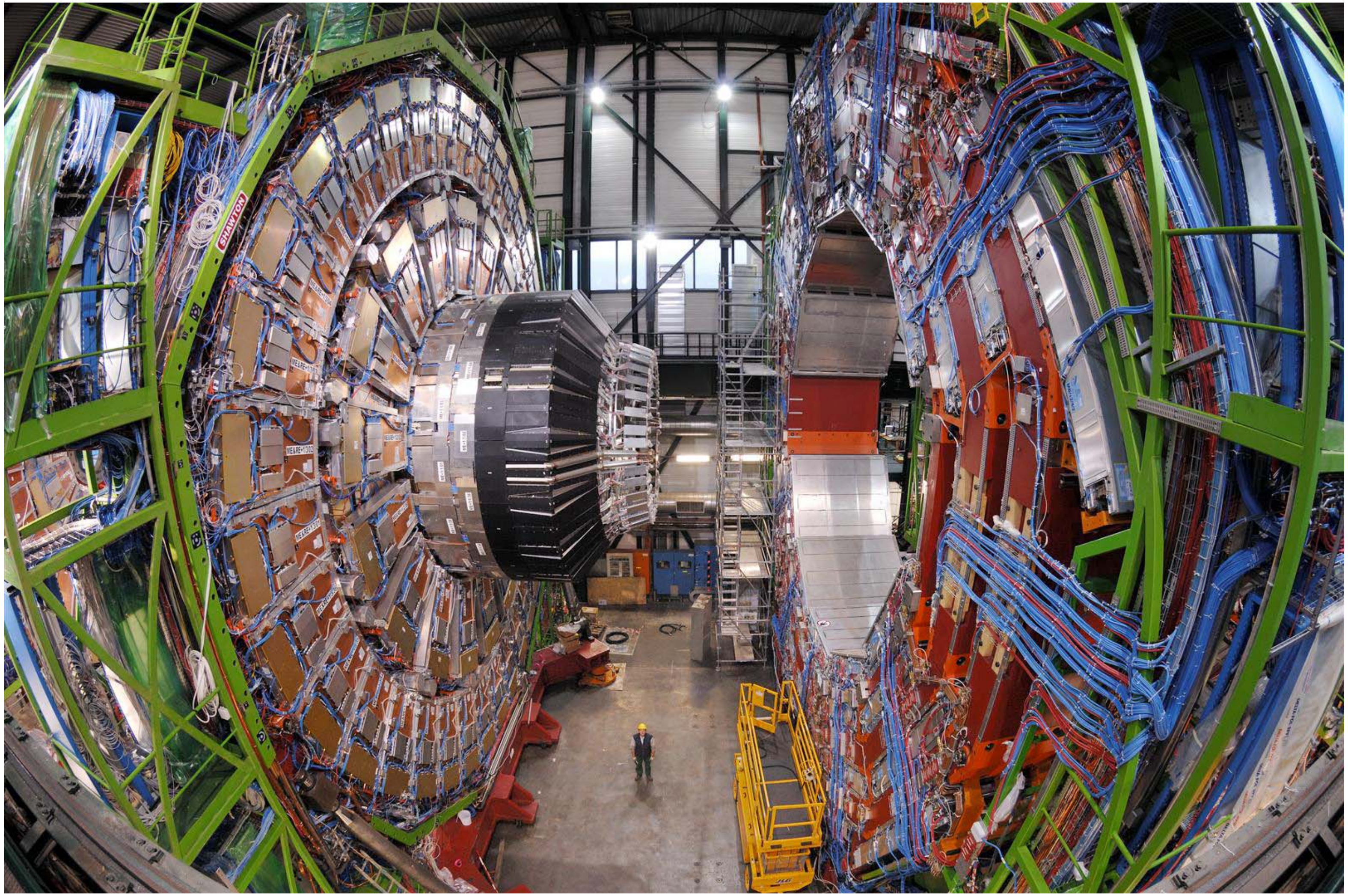
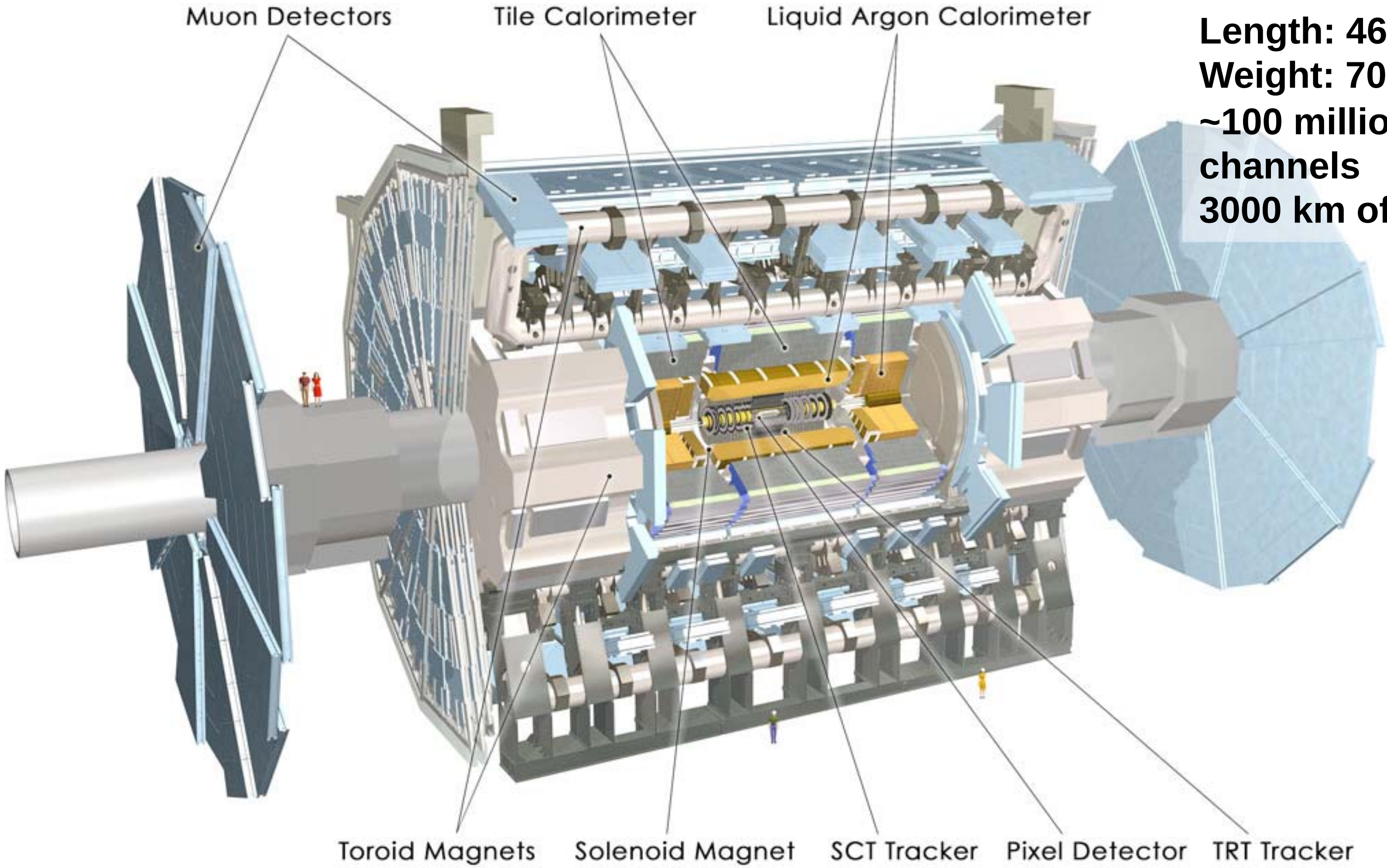


Photo of CMS assembly



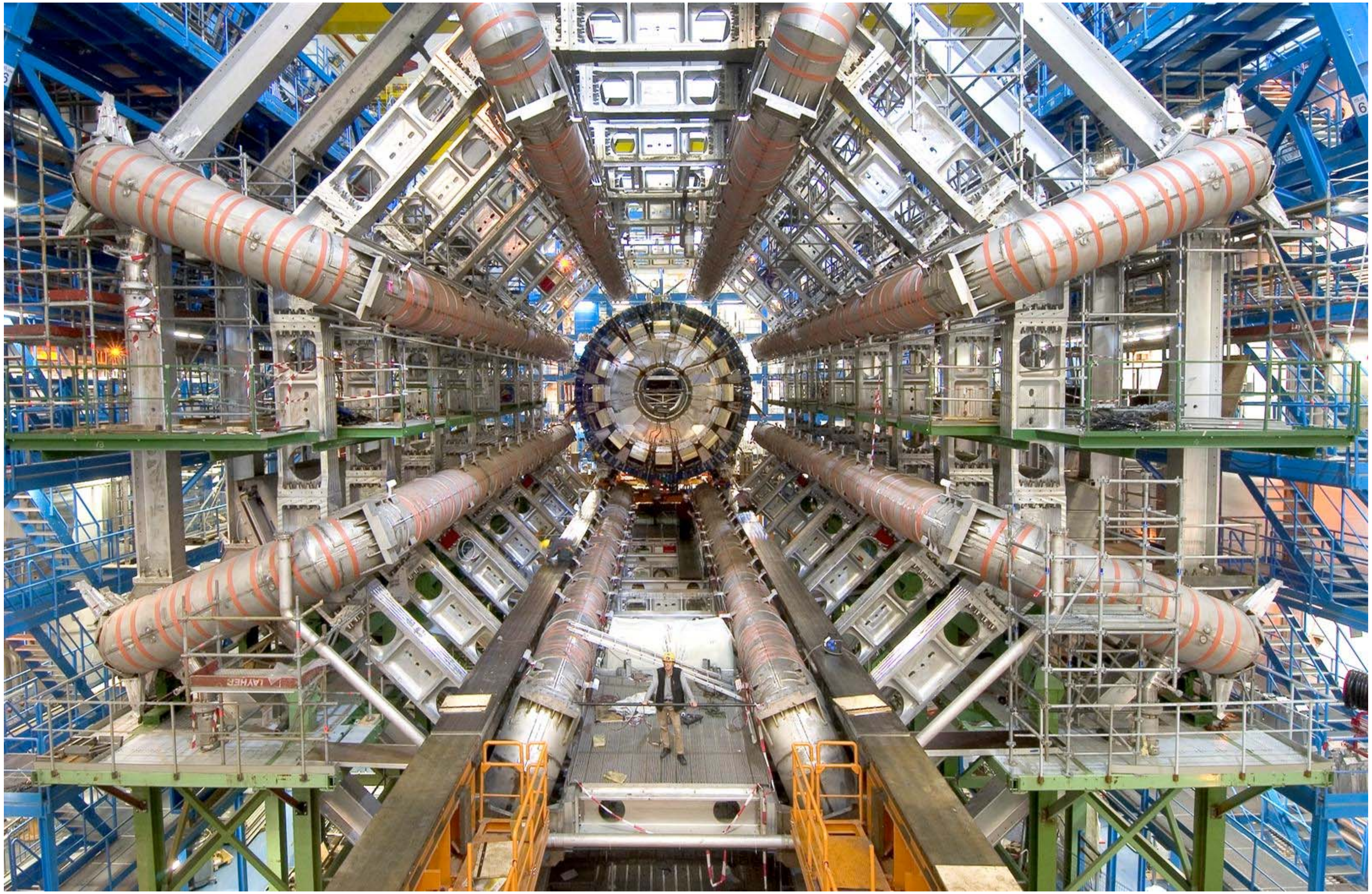
The ATLAS detector



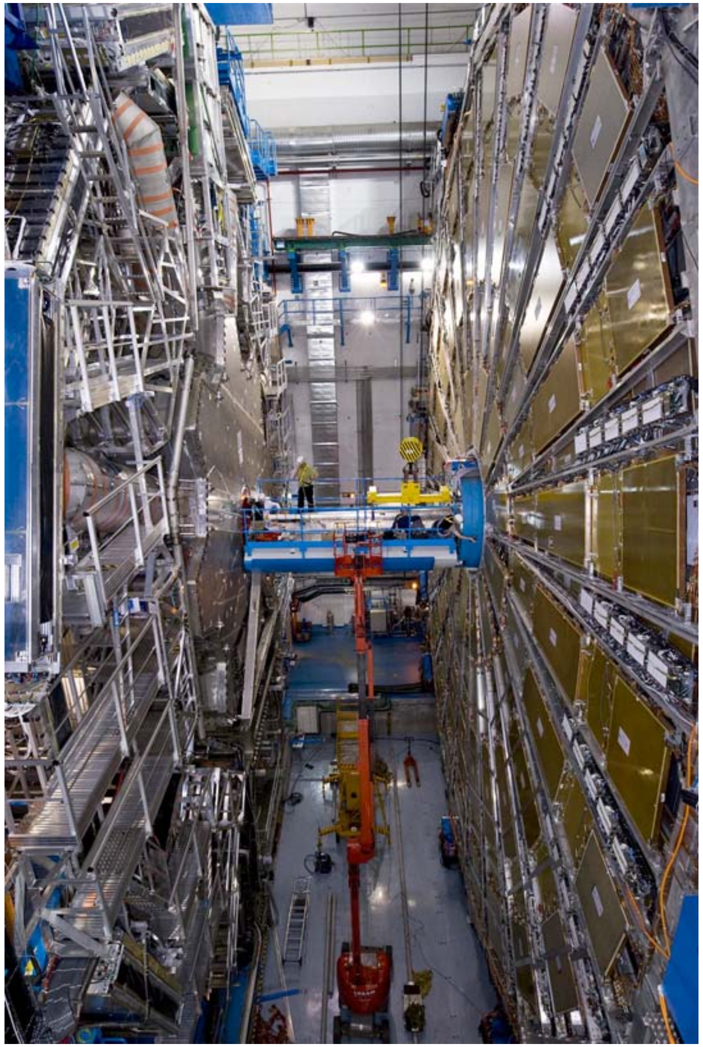
Diameter: 25m
Length: 46m
Weight: 7000 tonnes
~100 million electronic channels
3000 km of cables

ATLAS assembly

ATLAS Toroid assembled underground



Why *two* giant detectors?



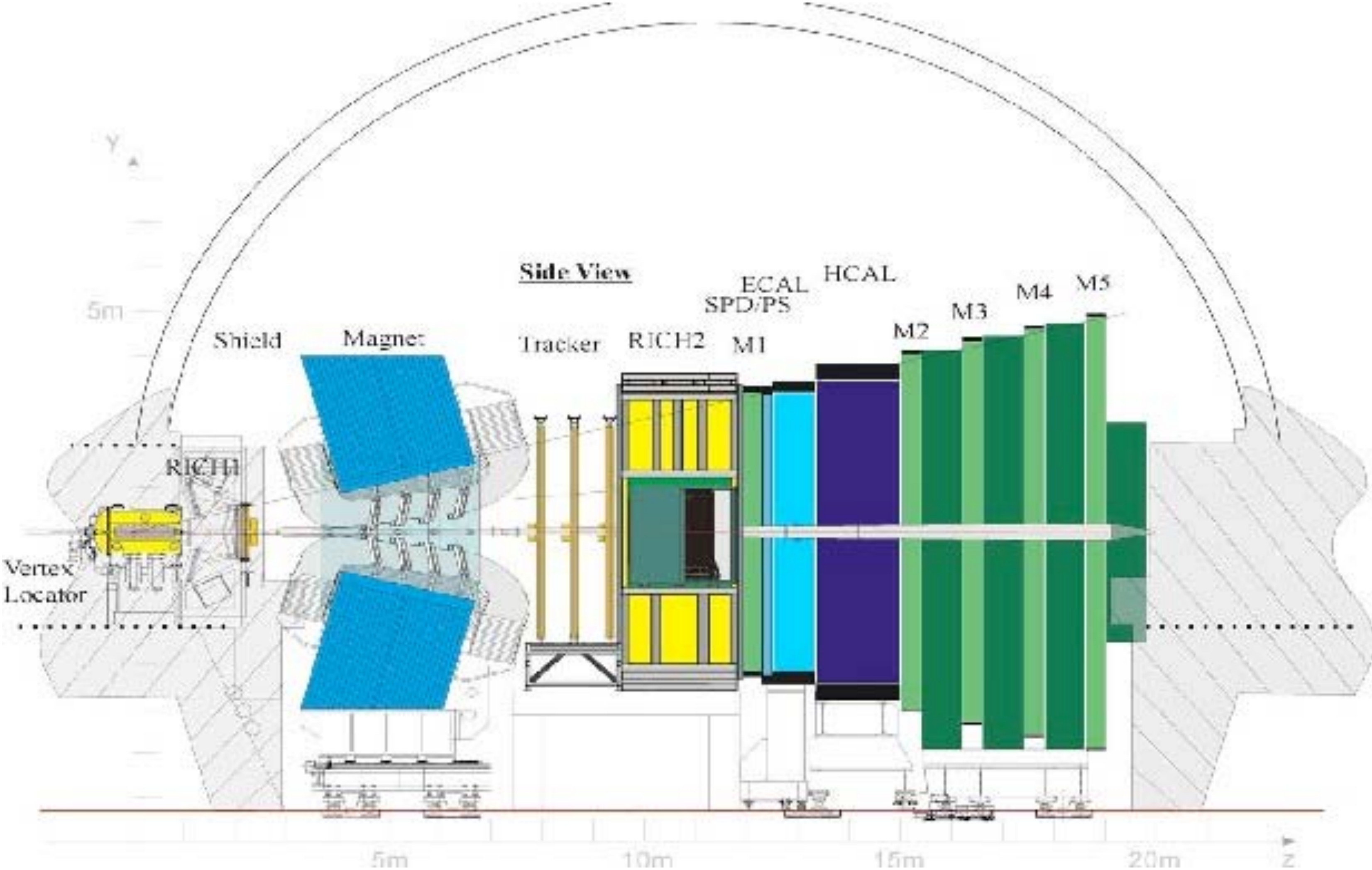
Why so big?

- heavy unknown particles
- their “daughters” will have high energy
- material needed to absorb the energy
- distance (and strong magnetic field) needed to measure momentum

Why two, ATLAS *and* CMS?

- different technology choices
- cross-check results

The different detector of the LHCb



The LHCb experiment

Why the LHCb is so different

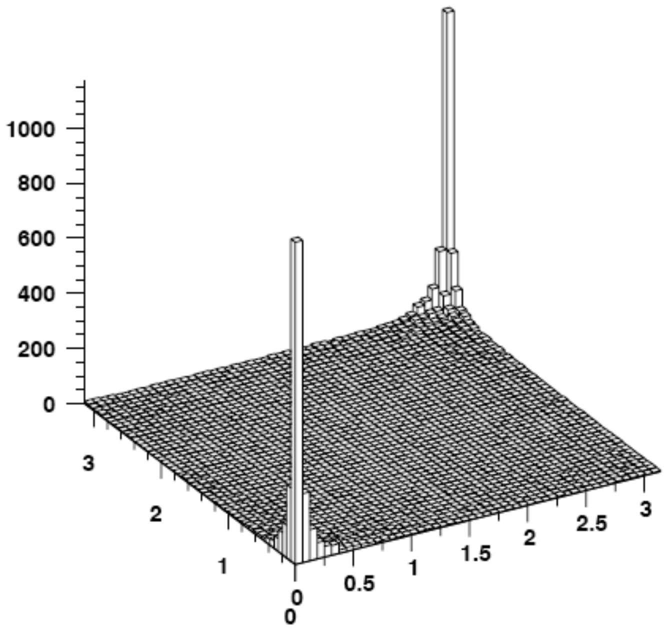
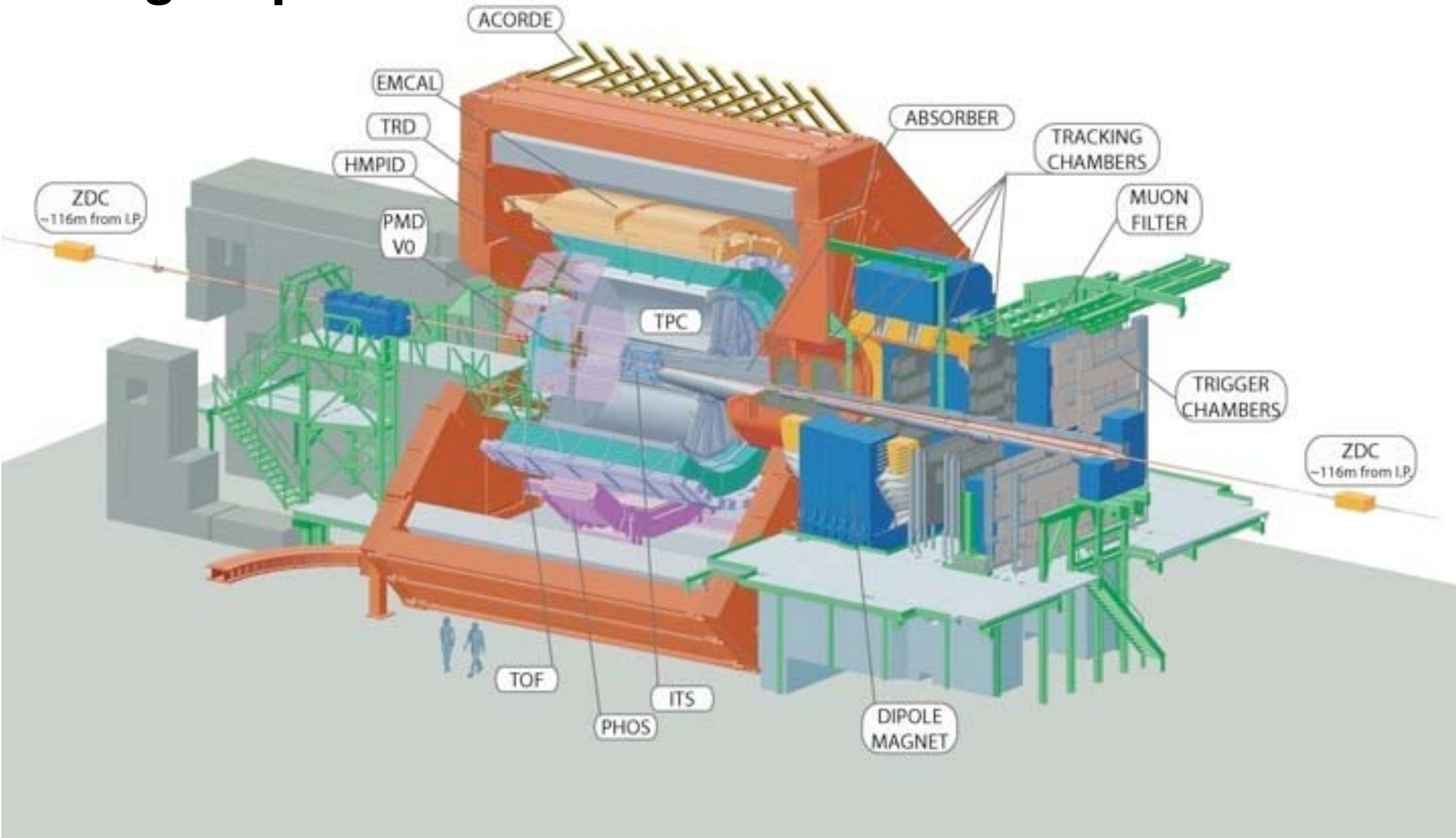


Figure 1.1: Production angle of B vs. angle of $\overline{\mathrm{B}}$ in the laboratory (in units of rad.), calculated using PYTHIA. The peaks in the forward directions shows the correlation between their respective production directions.

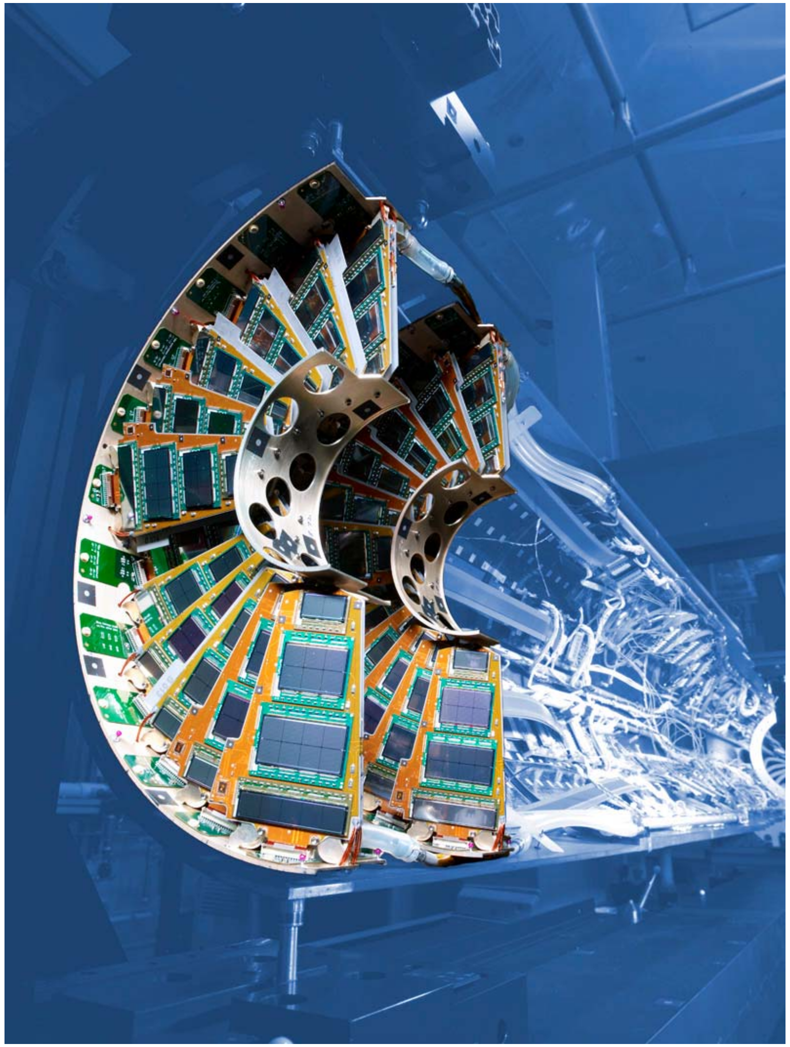
- **Particles containing b quark are wanted, as many as possible!**
- **There is no need to reconstruct the events fully!**
- **The detector covering a smaller angle is simpler, less expensive.**
- **Higher momentum of particles in the forward direction – they are easier to measure.**

There is one more…

ALICE is optimized for heavy ion collisions.
No Swiss group.



Pixel detector of CMS



- closest to the interaction point
- precision and fine segmentation
- $100 \times 150\ \mu m^2$
- 6700 pixels per cm^2
- 66 M channels

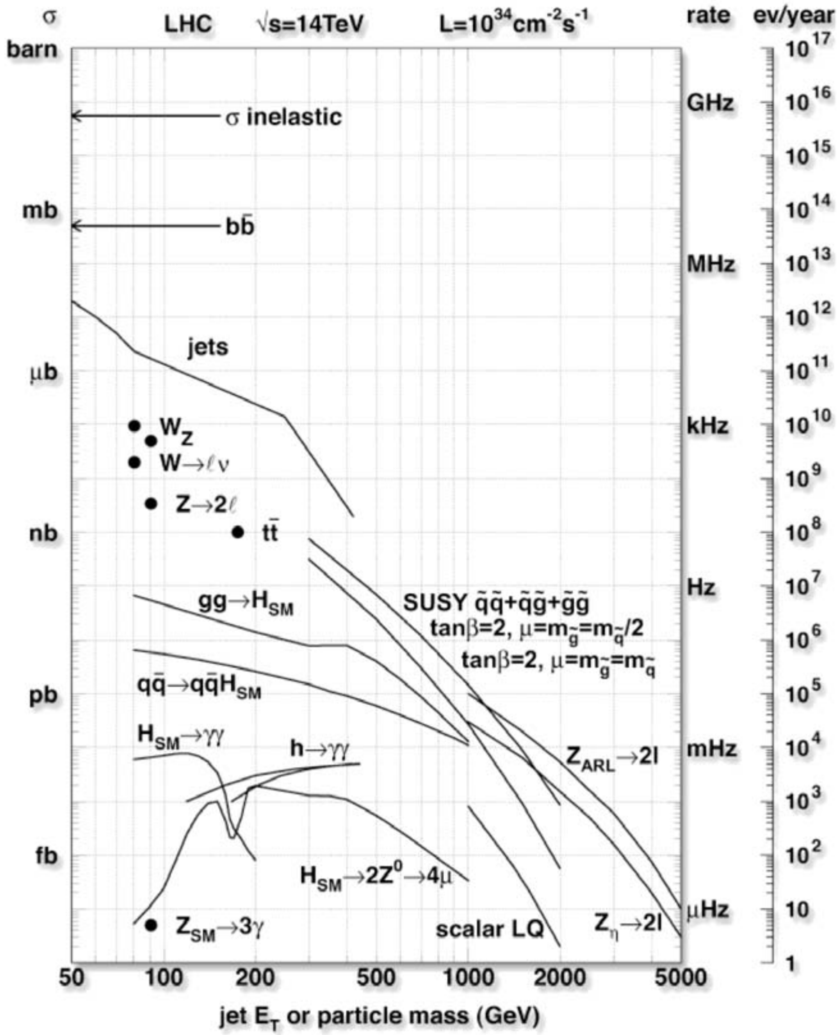
Silicon Tracker of ATLAS

Silicon tracker of ATLAS

80 µm strip pitch (125 per mm) 6 M channels

Two pieces of the LHCb

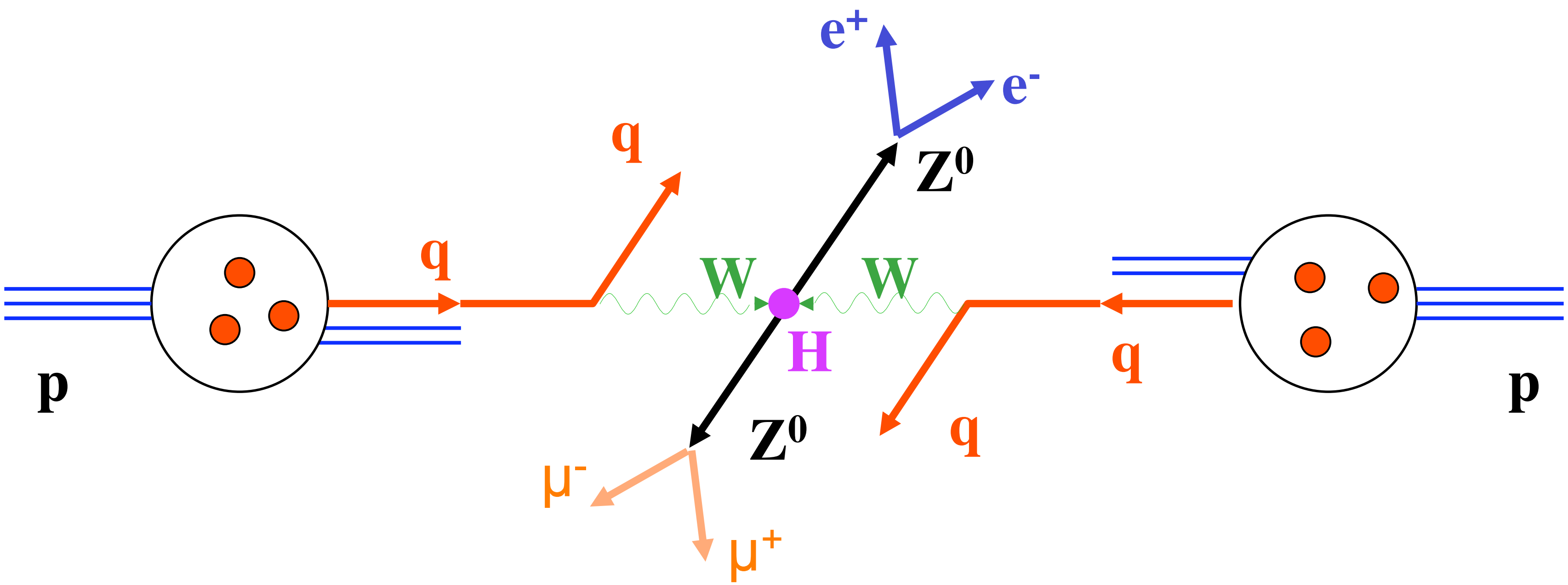
The challenge of the LHC



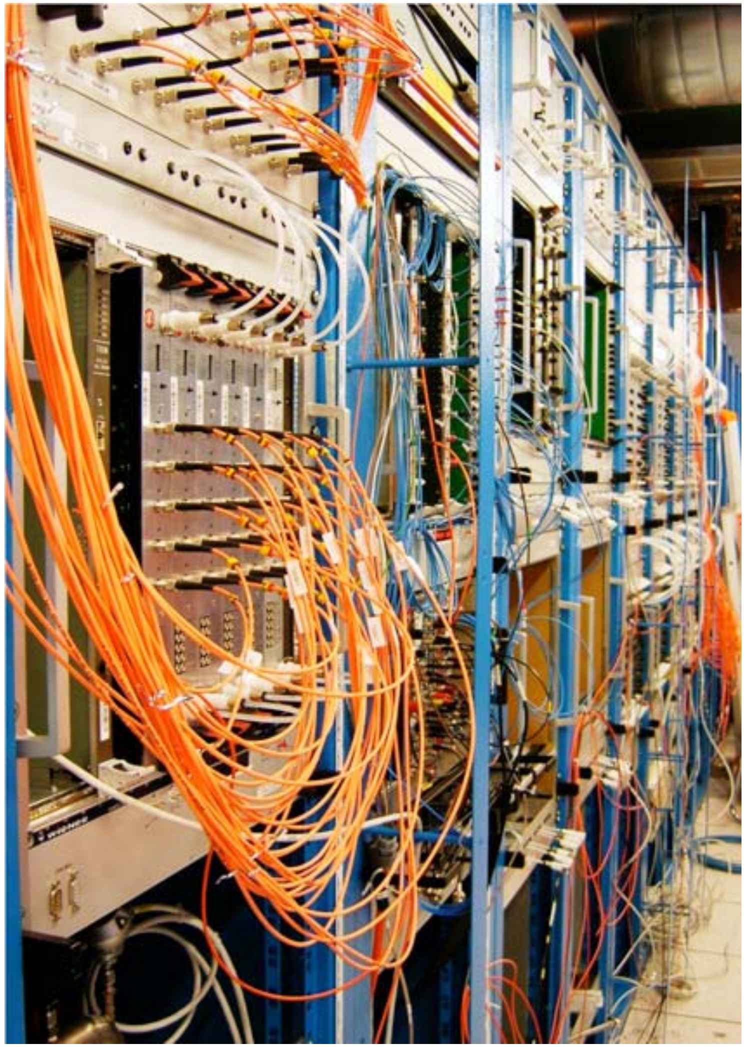
- **signatures of "new physics" may be *very* rare**
- **16 orders of magnitude to go in probability**
- **this expectation drove rates of collisions**

Production of a hypothetical particle (Higgs)

Protons are not elementary particles. What matters is the energy of the components of the protons. Both quarks (or gluons) need to carry a large fraction on the momentum. This is rare!



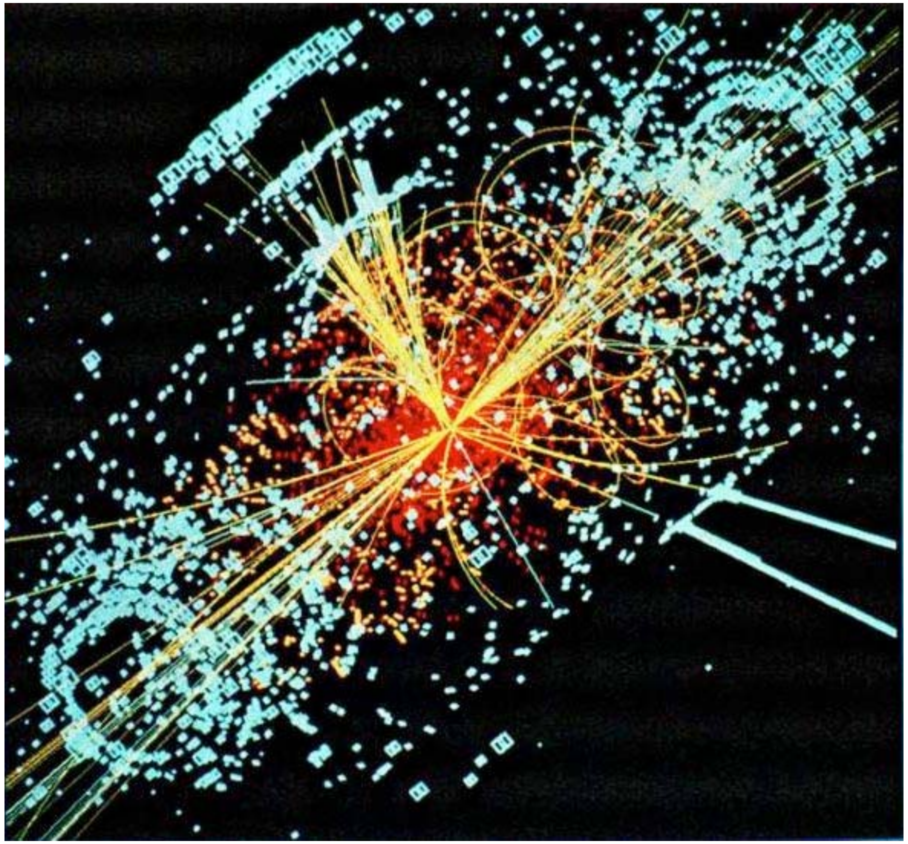
Online selection of data



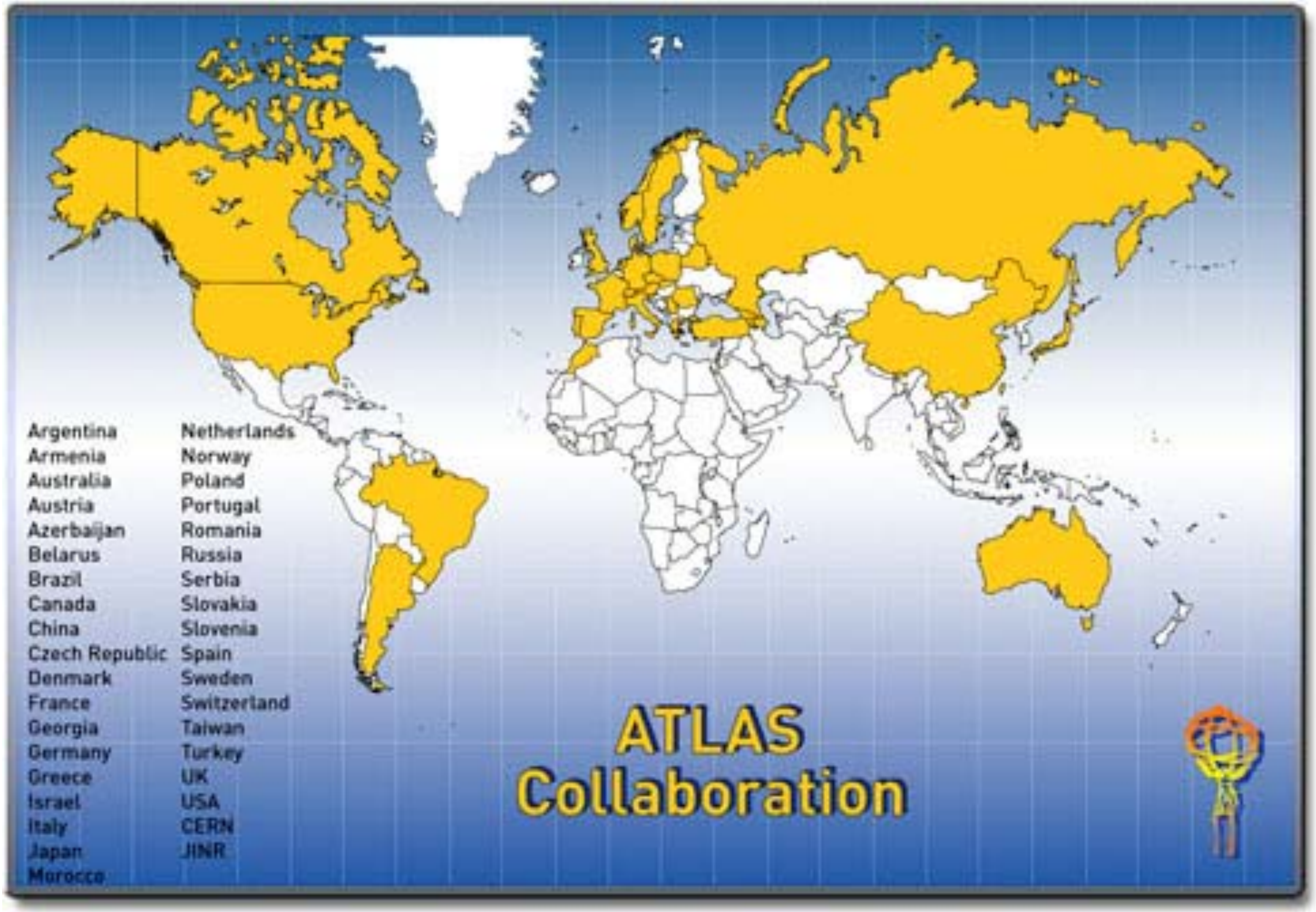
recording collisions at 200 Hz (1 in ~200'000)

Recorded data

- **3 PB per year of raw data from one experiment**
- **up to 15 PB per year for the four experiments, (counting derived formats)**
- **~25 pp collisions per "event"**



Global collaboration to analyze the data

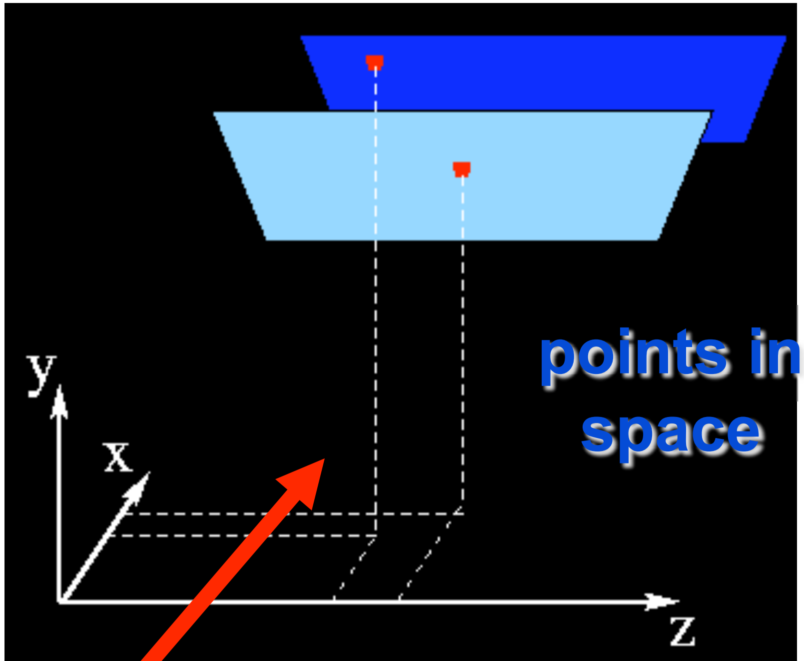


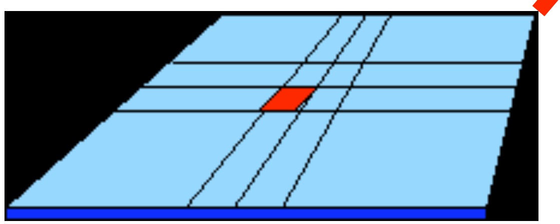
Data analysis – first steps

first steps

```
0155200 00000001 0100000d 00000002
0155220 00000cc6 dd1234dd 000001d6
0155240 02040000 00012100 00000000
0155260 00000000 00000000 00000001
0155300 00000004 0000001d 00000cc6
0155320 00000000 ee1234ee 00000009
0155340 00002200 00000000 0000001d
0155360 00000000 00000000 27004000
0160000 d2b1d2b1 d2b9d2b1 d5c1d5f9
0160720 c844d6c0 da044000 00000096
0160740 00000002 000001b8 00000001
0160760 00000004 0000001f 00000760
```

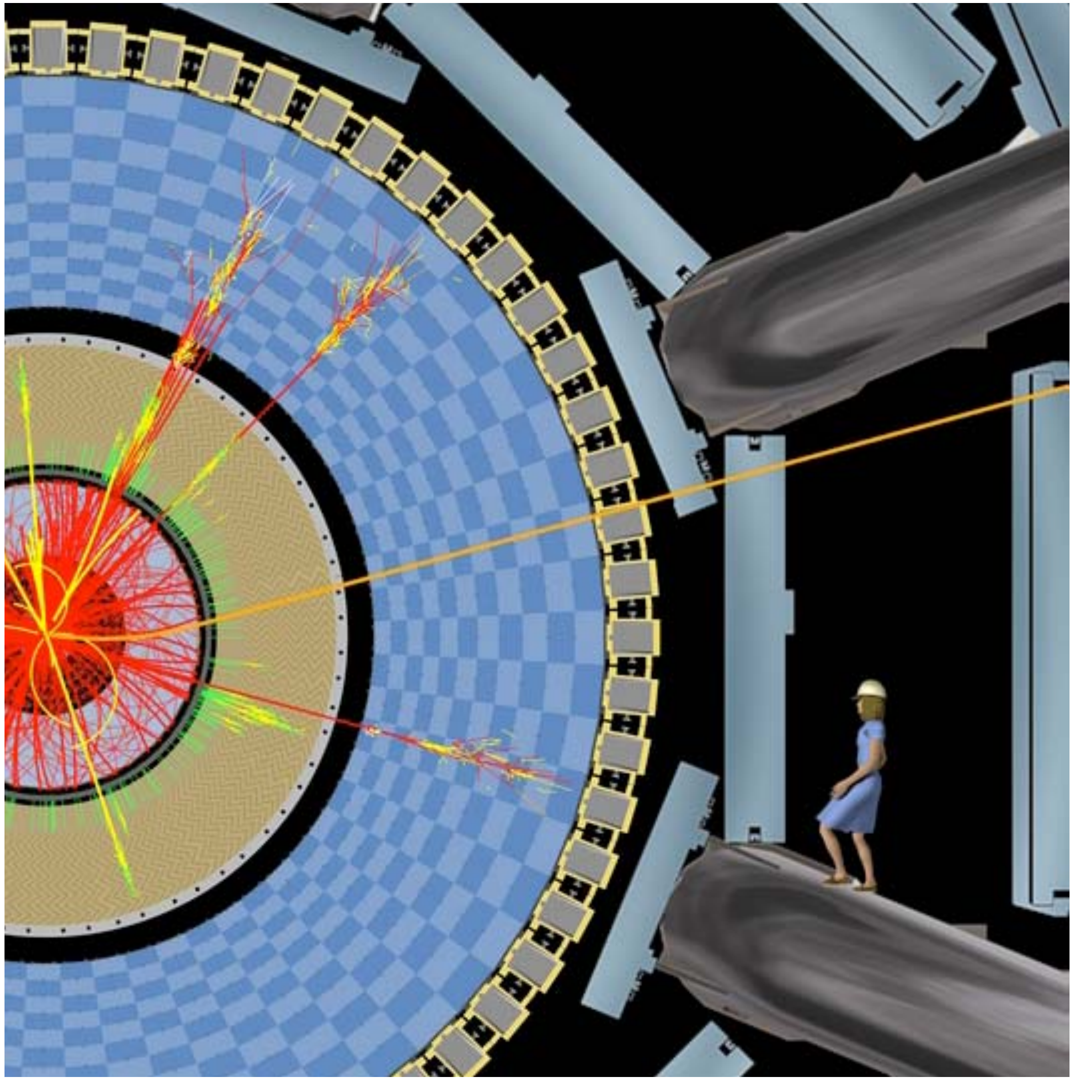
- "raw" data from the electronics





- points local to a detector

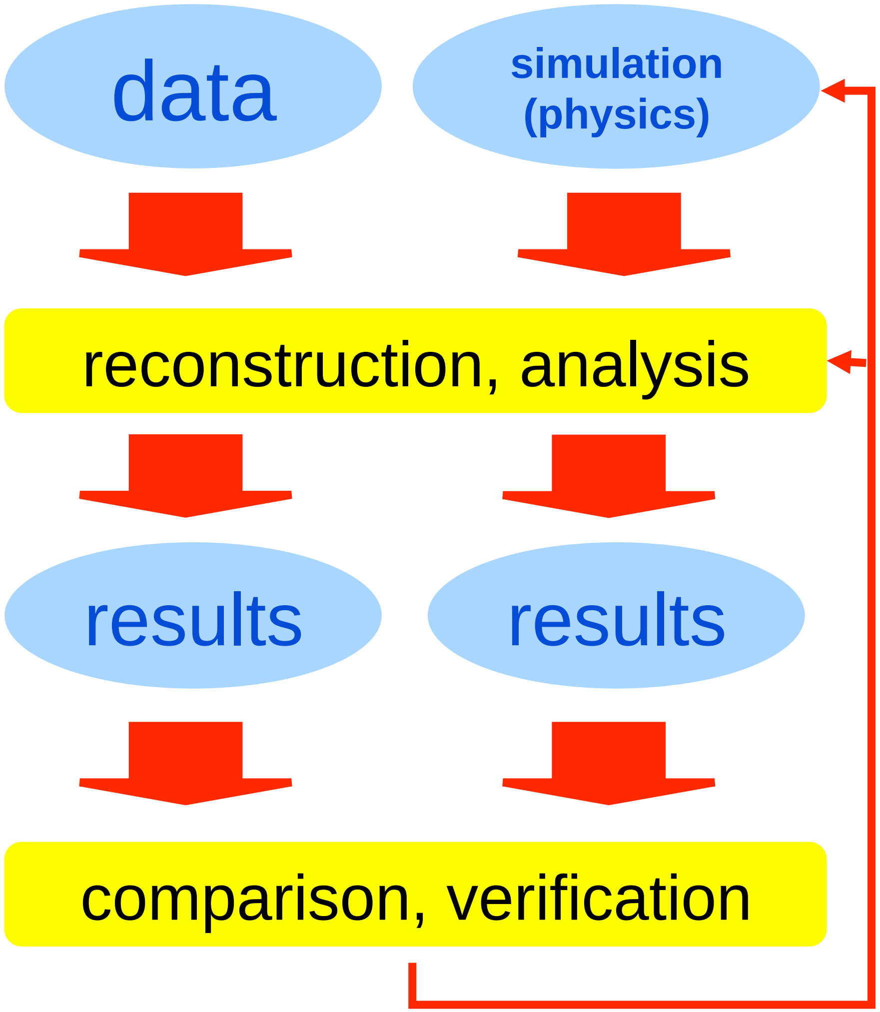
Data analysis – next steps



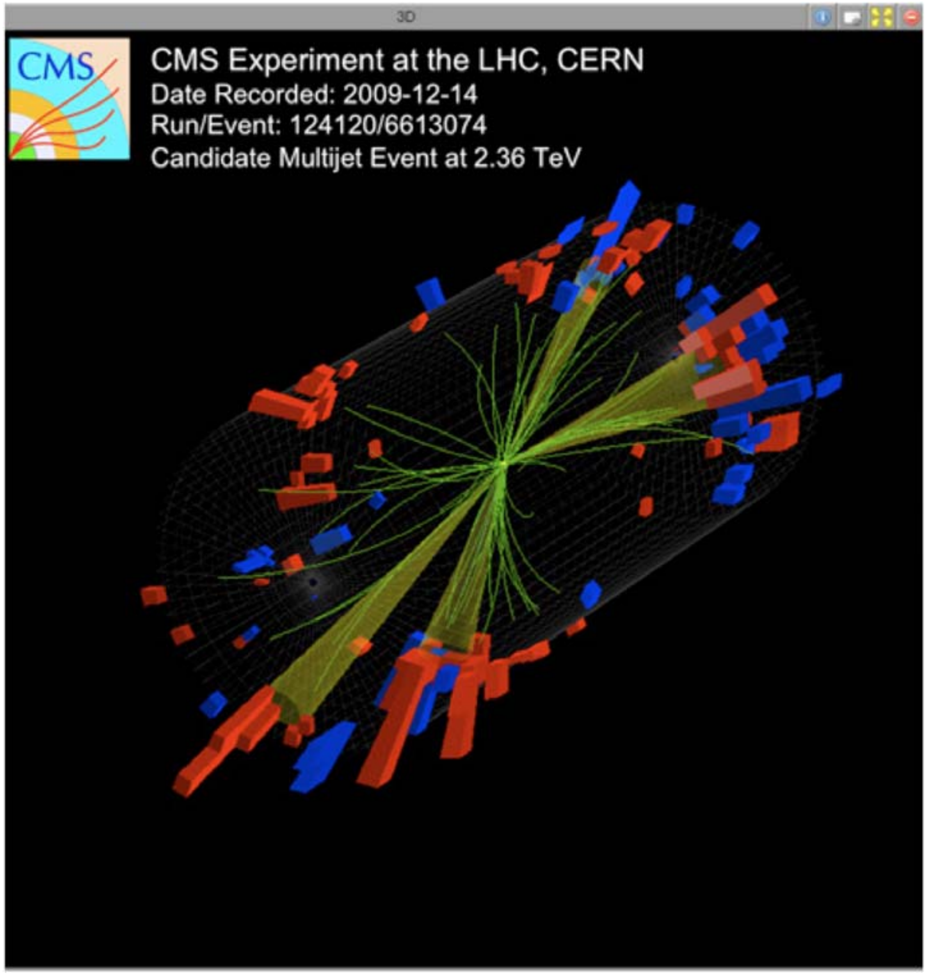
- reconstruction of tracks and energy deposits
- identification of particles, their parameters
- properties of "parent" particles, (possibly unknown)

Analysis and simulation

- an iterative process
- understanding of detector and physics improves
- comparison of simulation and data is repeated until agreement

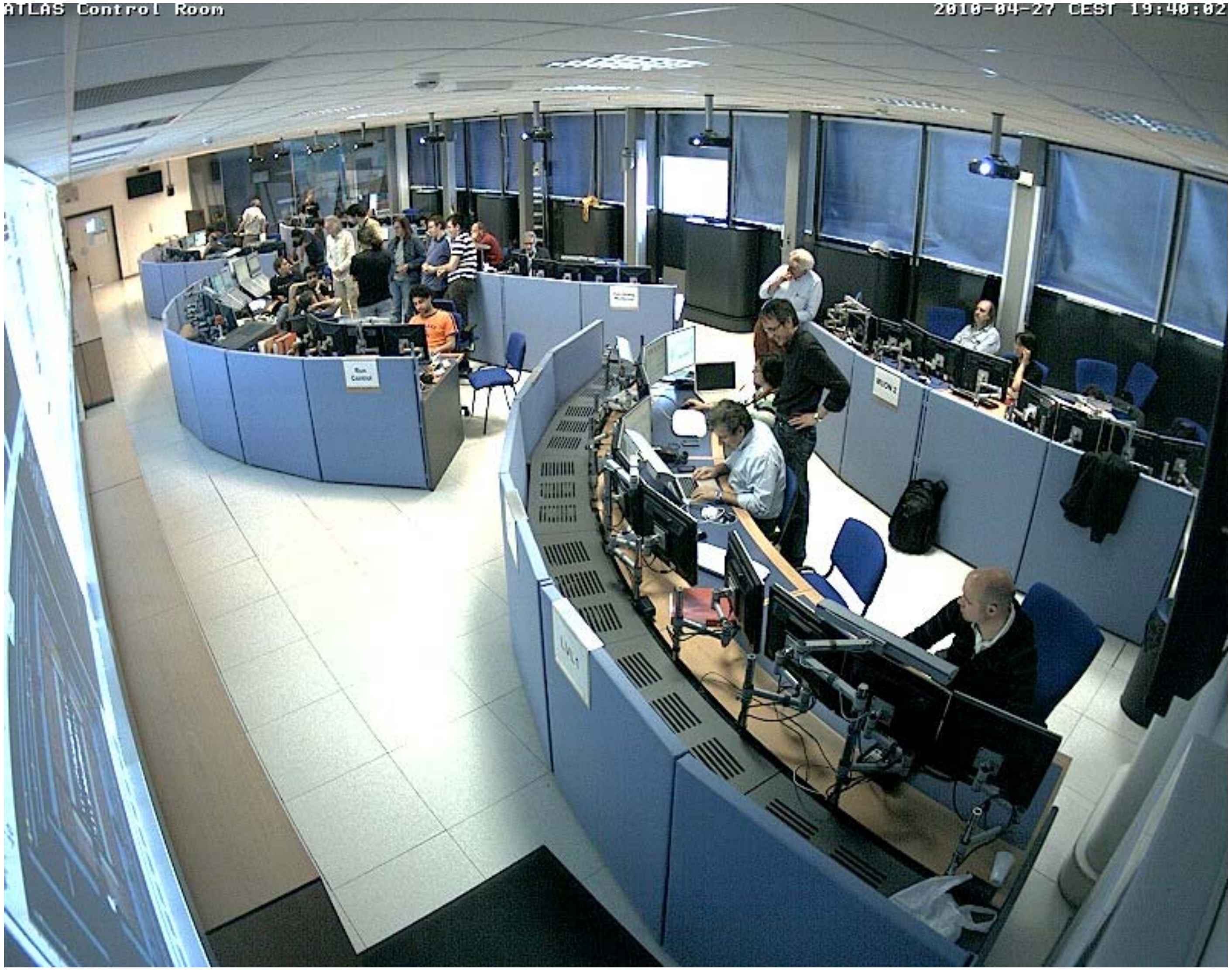


Finally taking data!



- 0.9 TeV
  - ⇐ First collisions: 23 Nov 2009
  - First stable beams: 6 Dec 2009
  - More than 300 k events collected
- 2.36 TeV
  - First collisions: 14 Dec 2009
  - About 20 k events collected
- 7 TeV
  - First collisions: 30 Mar 2010
  - Several million events so far
  - Very many ongoing analyses

Doing shifts!



The detectors are in good shape

Operational fraction of ATLAS sub-detectors

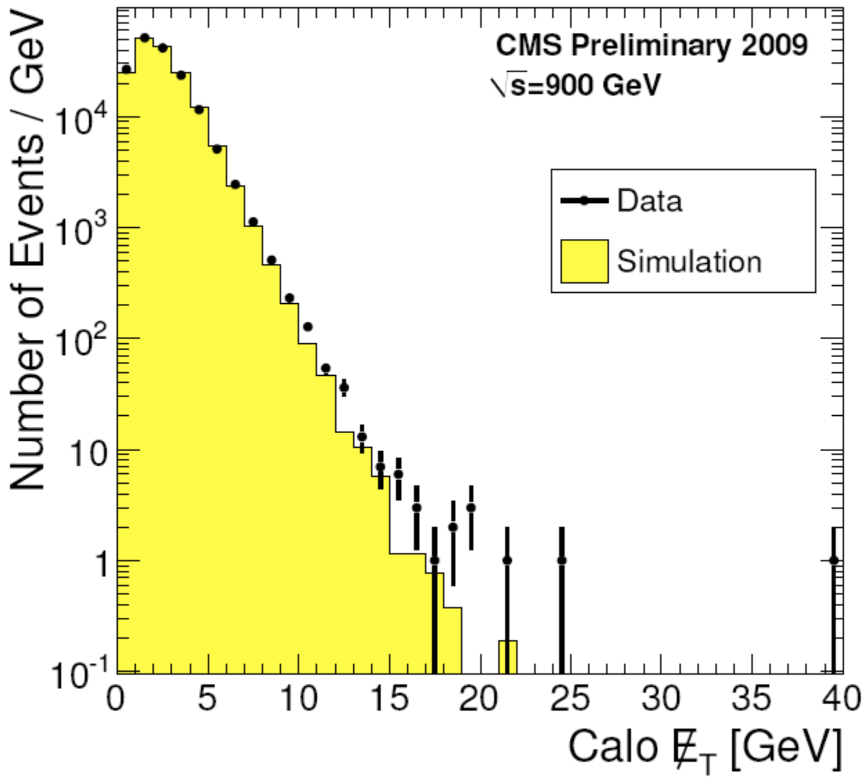
Status: Feb. 2010

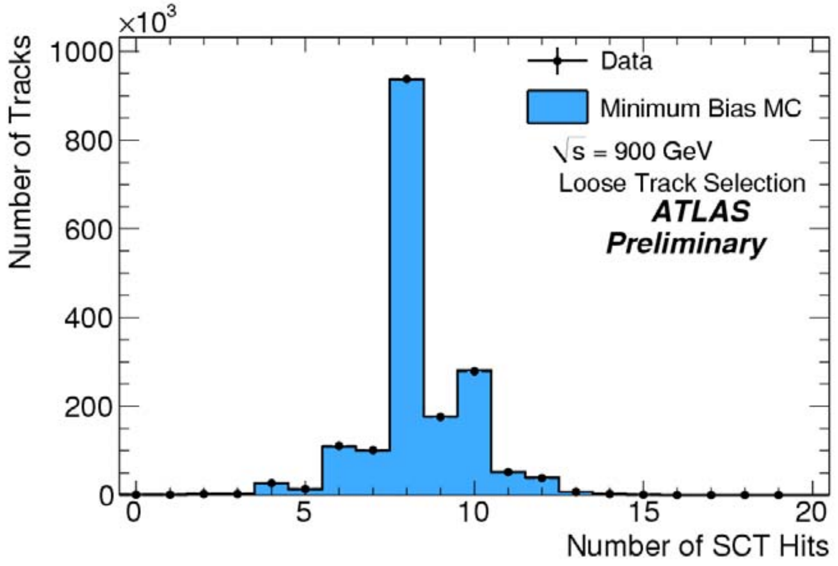
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.5%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	98.6%
Tile calorimeter	9800	98.0%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.5%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Trigger	370 k	99.5%
TGC Endcap Muon Trigger	320 k	100%

The detector is in excellent condition!

Simulation agrees with early data

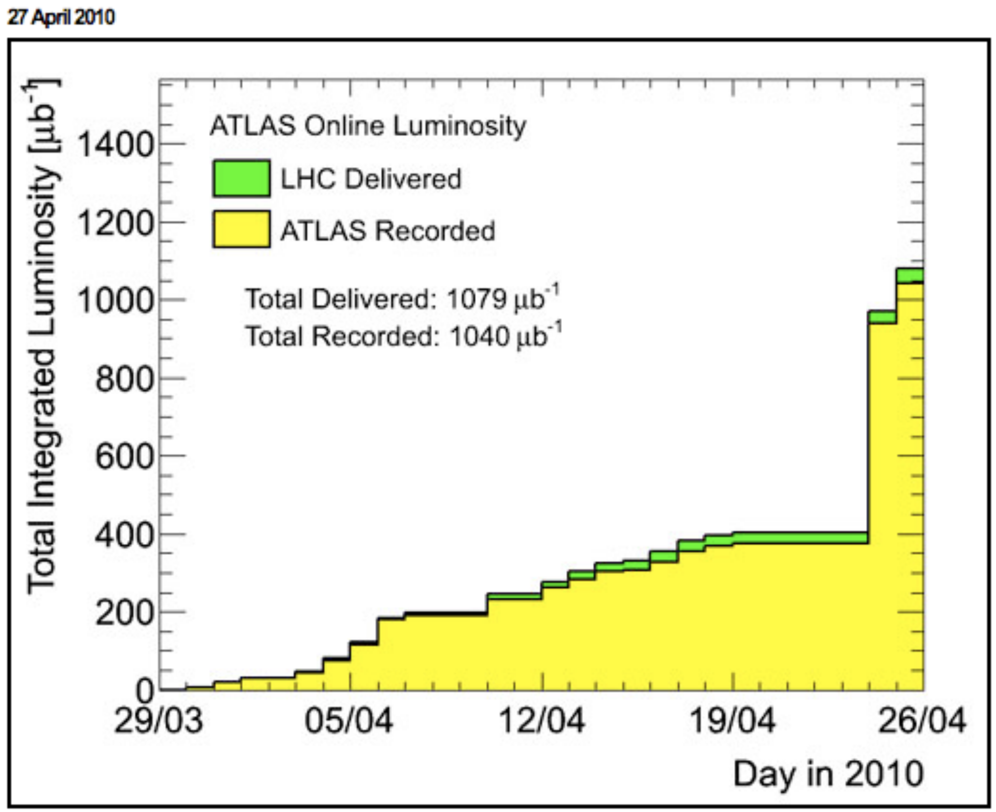
Calorimeter



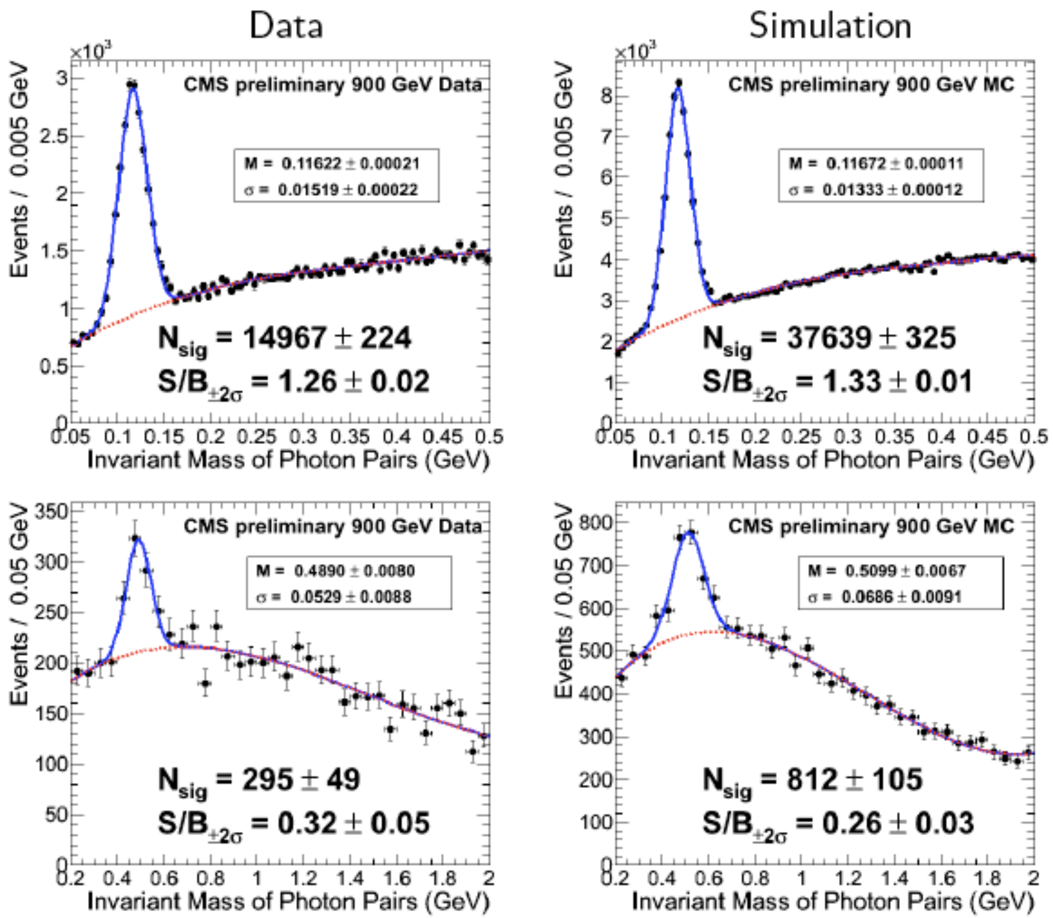


The accelerator is ramping up

- **energy 7 TeV**
  - **(1/2 of design value)**
- **collision rate factor 10^6 below design value**
- **the rate can improve rapidly**



Re-discovering known particles

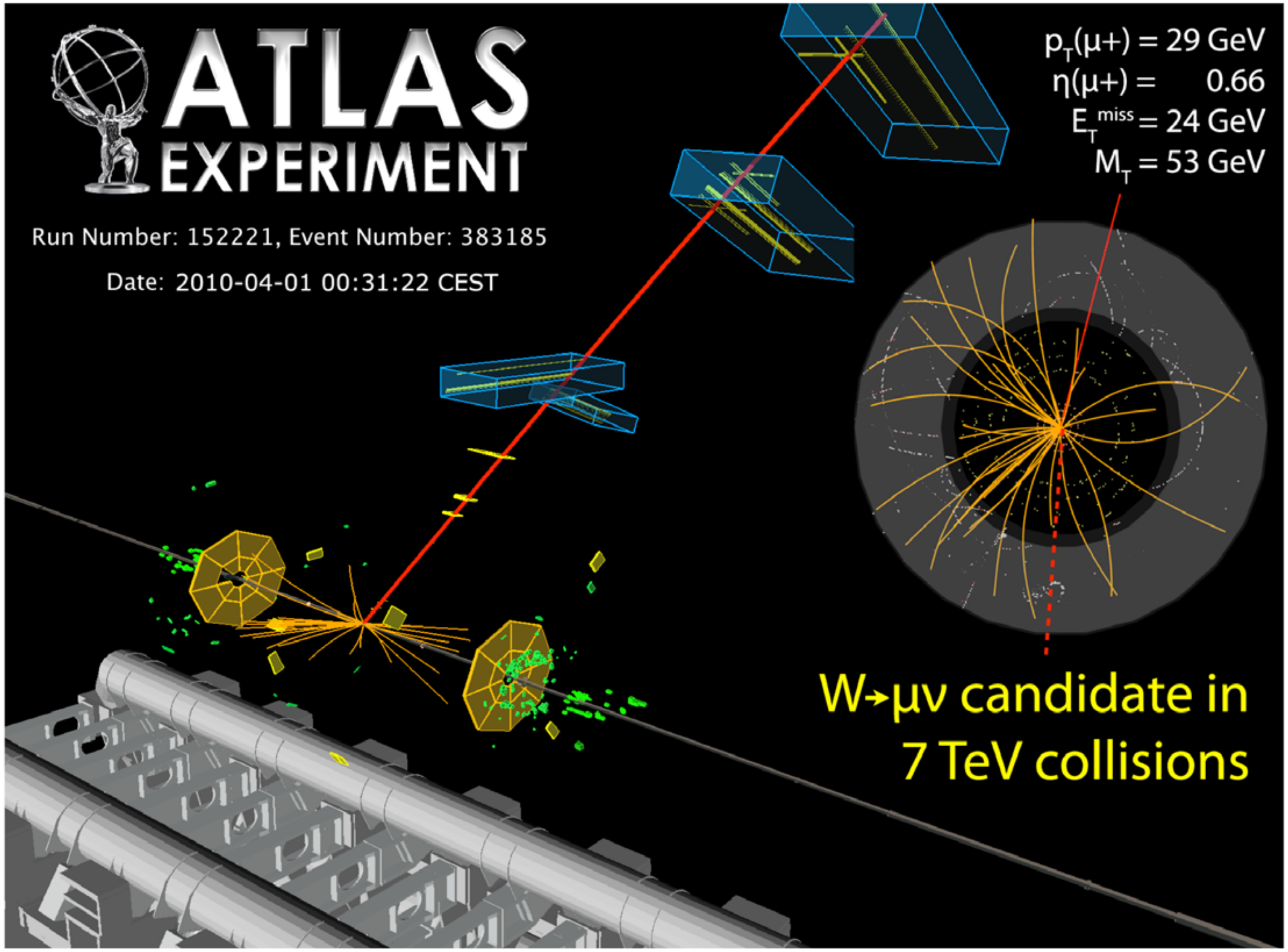


$\pi^0 \rightarrow \gamma\gamma$
No corrections
(for shower containment, thresholds, energy loss)

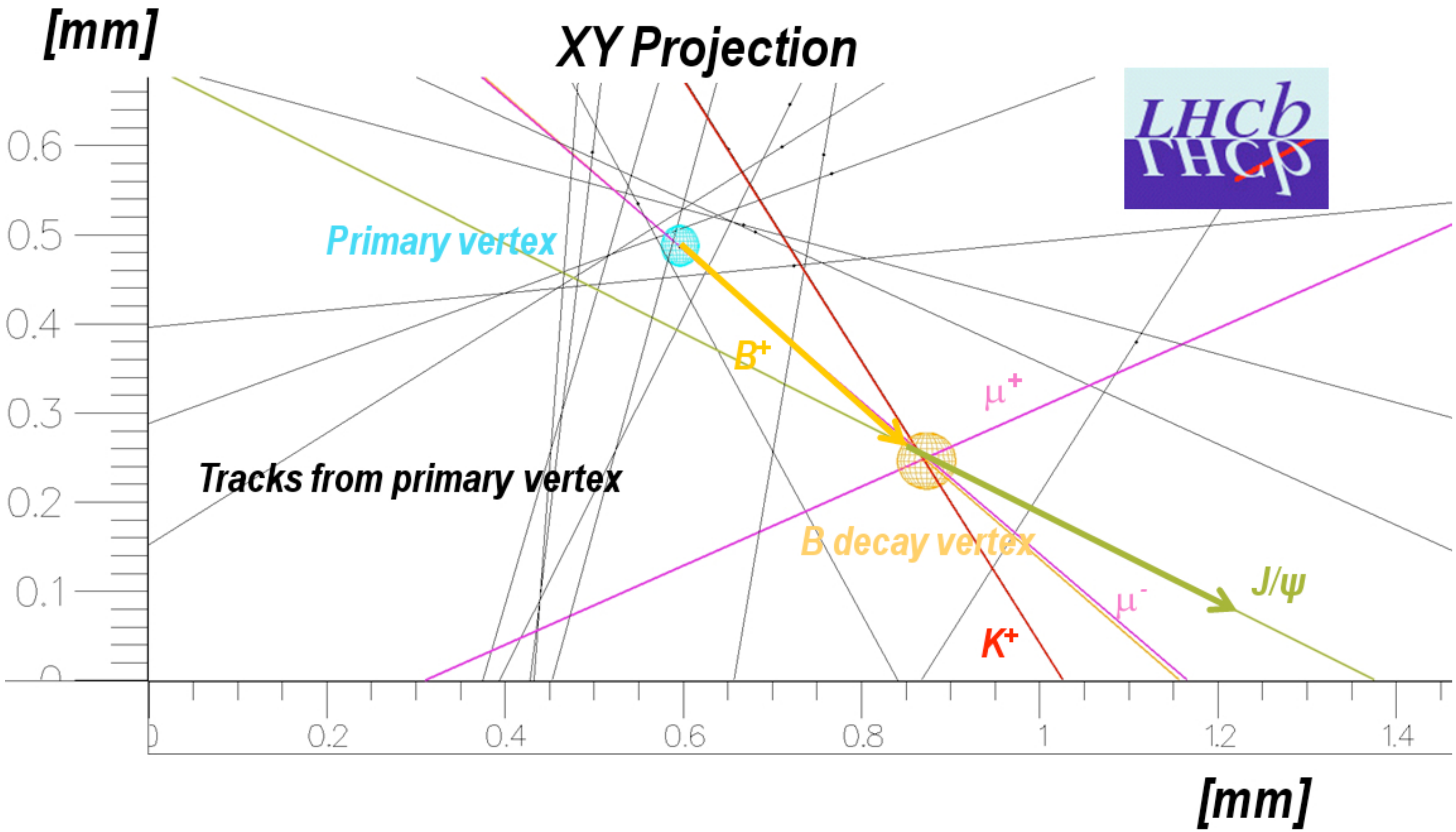
$\eta \rightarrow \gamma\gamma$
Corrected,
good agreement:
peak position and S/B

ECAL photons: energy scales now in data and MC agree within 2%

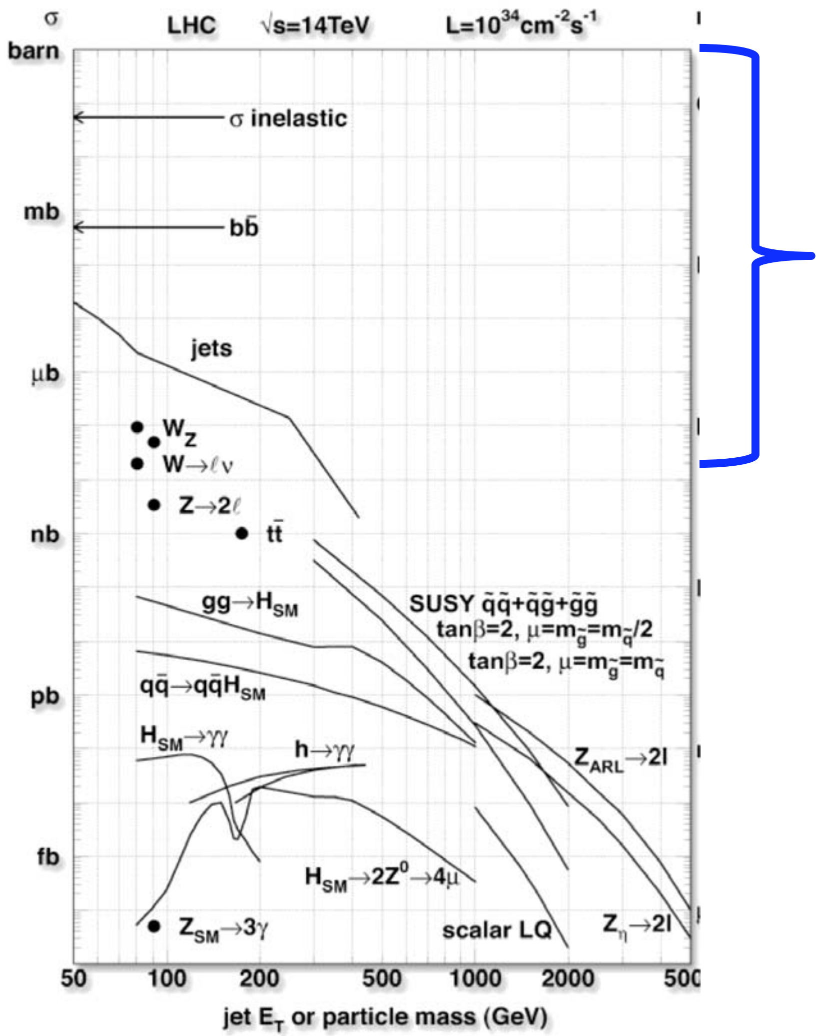
Gradually moving to heavier objects



LHCb has fully-reconstructed B decays



This is where we are now…

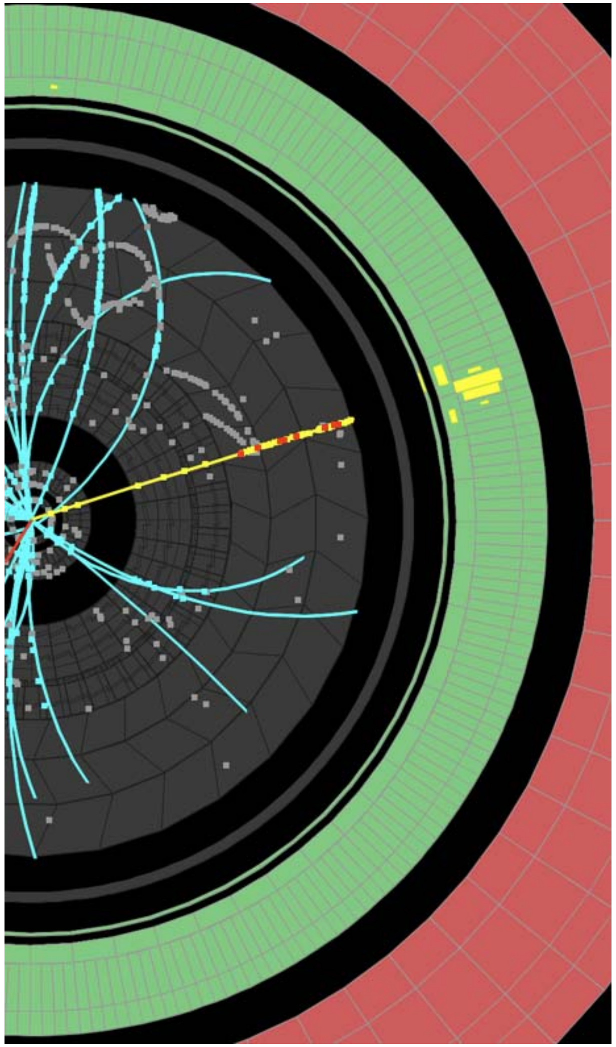


- when we have thousands of top quark events, the “known ground” will be covered
- surprises are not excluded before

The analysis process

- **iterative**
- **unpredictable**
- **only after looking at the data you know what to do next**
- **may need to go back, reprocess the data, look in more detail at some problem**
- **may need to redo a lot of simulation**
- **we need *flexible* computing systems**
- **“computing models” of experiments will evolve**

Summary



- The LHC is finally providing the collisions.
- The experiments are ready and in excellent shape, recording the data.
- Excellent agreement of simulations with data so far.
- We are in a frantic early analysis phase.

backup slides

Computing in Particle Physics

- parallelism is trivial
  - data for different collisions (“events”) treated independently
- unprecedented data volumes will be produced by LHC experiments
  - 3 PB of raw data per year will be produced by ATLAS
  - 10 to 15 PB/y for the four experiments, counting derived data
- global collaborations for data analysis
- reconstruction, selections, analysis of data done in steps
- iterative analysis process, difficult to predict, we learn from data
- so far Monte Carlo simulations and “cosmic” data
- applications frameworks exist and are ported to the Grid
  - mixture of C++ and Python
  - physicists write almost all the code
- batch processing dominant
- manpower limited everywhere, CERN cuts all corners