Introduction to the CMS Detector

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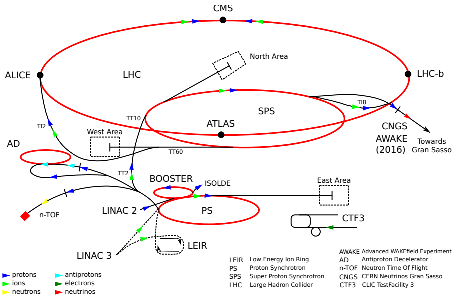
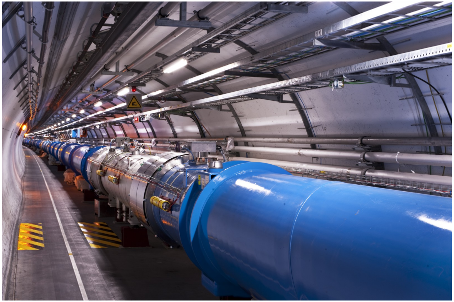
Introduction

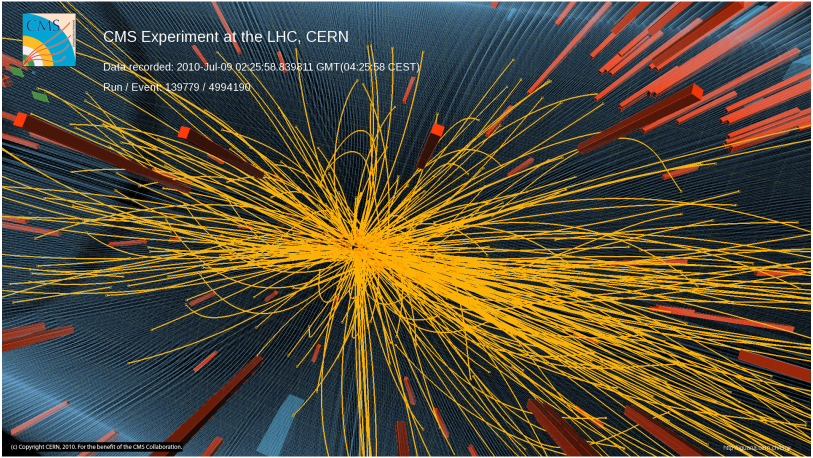
Accelerators at CERN



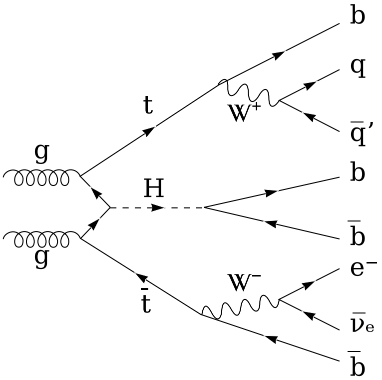


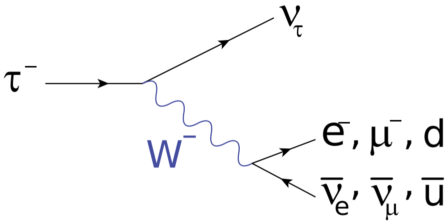
All is needed to achieve ...

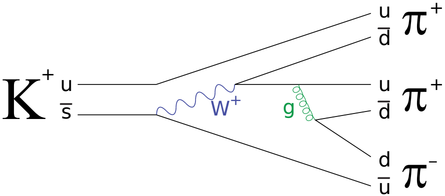
High-Energy Collisions (1)

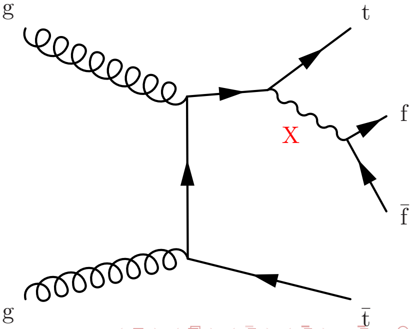


High-Energy Collisions (2)









Detectors

Types of Detectors (1)

Classified by

- Type
  - Tracking
  - Calorimetry (uniform, sampling)
- Technology
  - Gaseous
  - Crystal
  - Semiconductor
  - Metallic
  - Scintillating/optical fibers
  - Exotic

Types of Detectors (2)

Classified by

- Physical objects/fragments
  - Electromagnetic
  - Hadronic
  - Muonic
  - Charge tracker
- Location
  - Inner
  - Outer
  - Barrel
  - Endcap

All the combinations are possible

Complex Detectors ("Experiments")

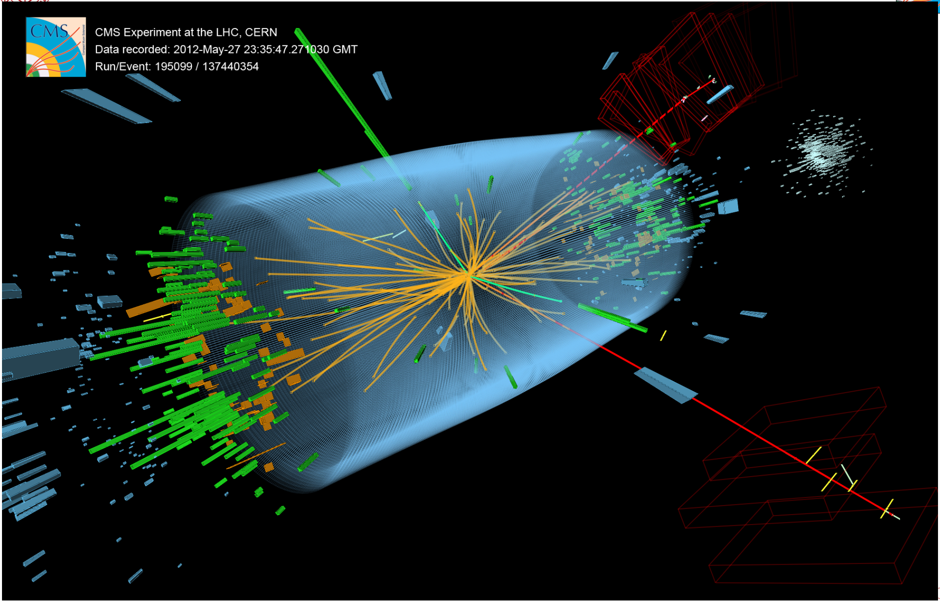
Classified by

- **Physics goal**
  - General purpose
  - Heavy ions
  - Precision studies
  - Specialized

Depending on the context:
parts are named: subdetectors, systems, subsystems.

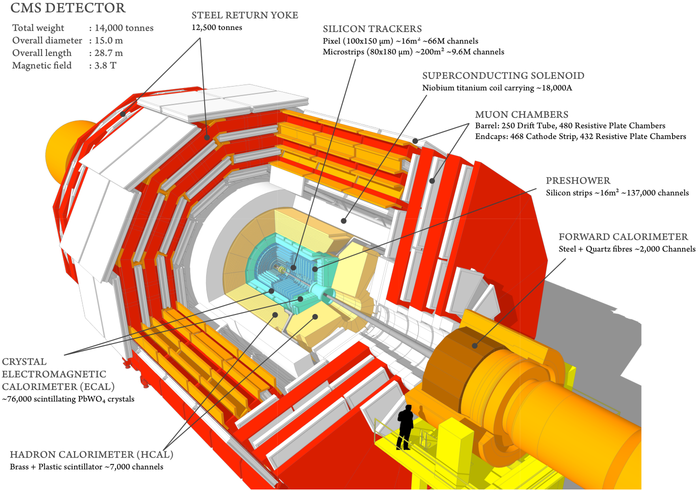
Complex detectors try to catch everything.

Recorded Collision



Compact Muon Solenoid (CMS)

Sliced CMS detector



20–40 MHz

×

$\sim$30 p–p collisions

×

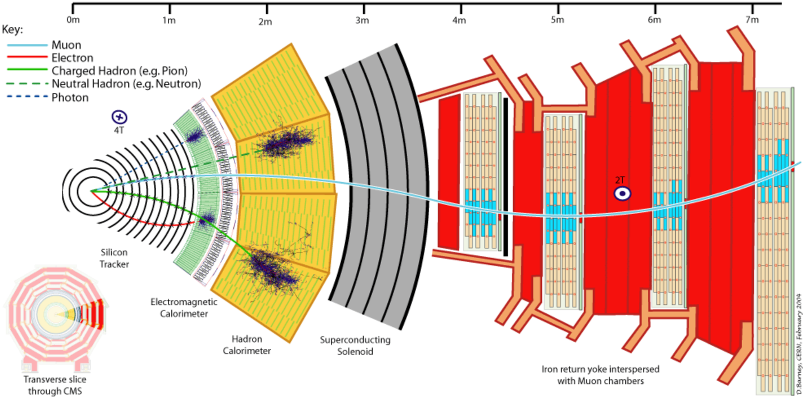
p–p = $\sim$400 fragments

=

$\sim$50 Tb/s

Final particle	Resolution
γ	1.5–5% @ 60 GeV
e	2–4% @ 10 GeV
μ	1–1.5% @ 10 GeV
j	o(10)%

Particle Identification



The CMS Anatomy

(its Subdetectors)

Simplified Data Acquisition (DAQ)

Module

Active material
Passing particles leave traces

↓

On-module electronics
Servicing/control on-module electronics

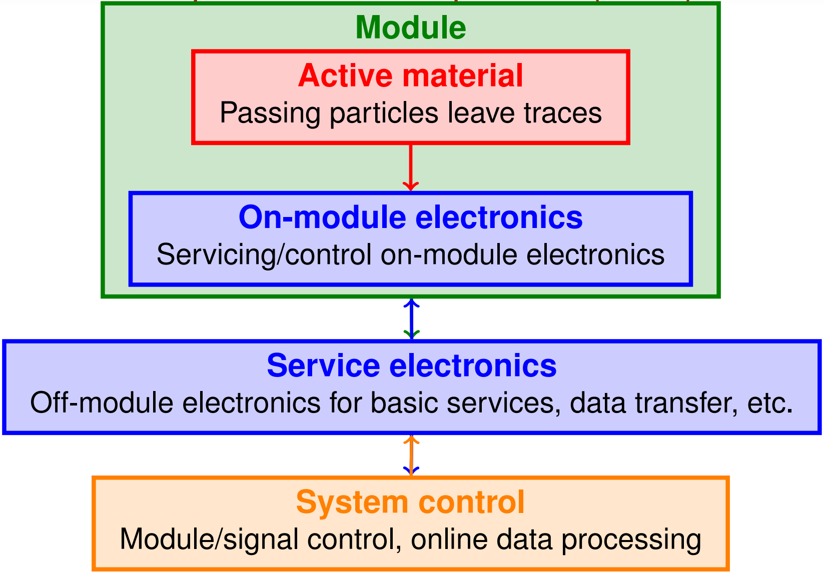
↓

Service electronics
Off-module electronics for basic services, data transfer, etc.

↓

System control
Module/signal control, online data processing

Simplified Data Acquisition (DAQ)

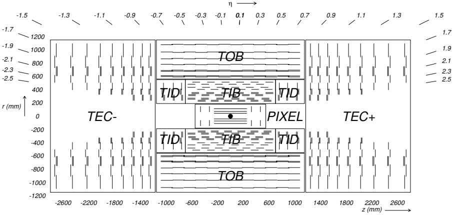


CMS Magnet

Highlights:

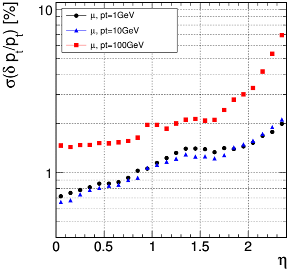
- Superconducting solenoid, $B = 4$ T
- Current: 20 kA
- Superconductor: NbTi ($\sim$4 K)
- Dimensions: 13 $\times$ 4 m — tracker and calorimeters inside
- Cost $\sim$80 MCHF

Semiconductor Tracker



Highlights:

- Silicon sensors (strips, pixels).
- Sensitive to charged particles: $e^{\pm}$, $\mu^{\pm}$,...
- Momentum measurement.

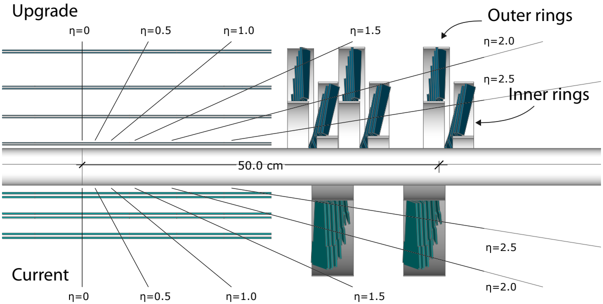


- Built for identification of collision points.
- Resolution $\sim$1%.

The Ongoing Phase-1 Pixel Upgrade

Main goals of upgrade:

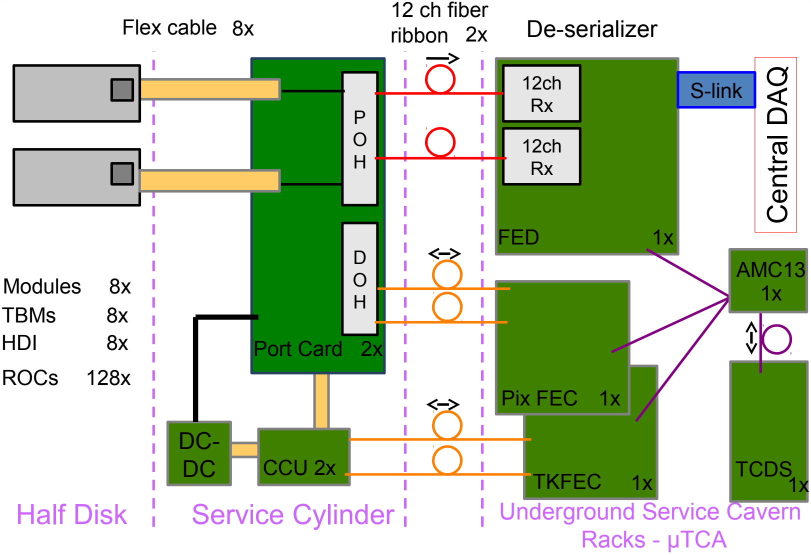
- Keep performance levels of current detector at higher
  - Instantaneous luminosity (up to $2 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$);
  - Pileup (up to 50 p–p interactions, hopefully not 100).
- Reduce detector mass.
- Survive radiation damage through 500 fb^{-1}.



Install during extended year-end technical stop: **Now!**

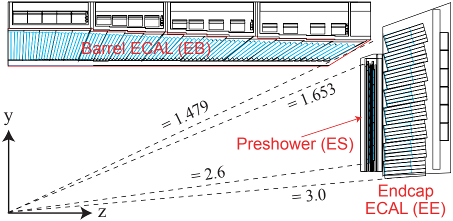
$3 \rightarrow 4$	barrel layers
$2 \rightarrow 3$	forward disks
$66 \rightarrow 124$	M pixels

Phase-1 Pixel-Tracker DAQ Scheme



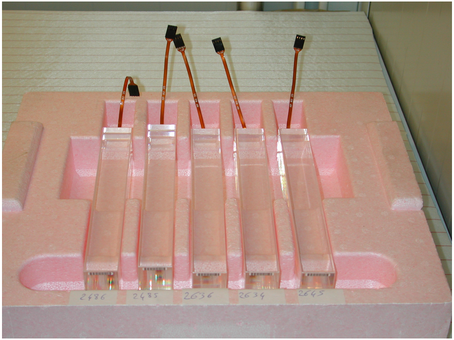
Single chain only

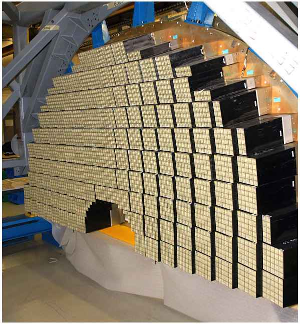
Electromagnetic Calorimeter (ECAL)



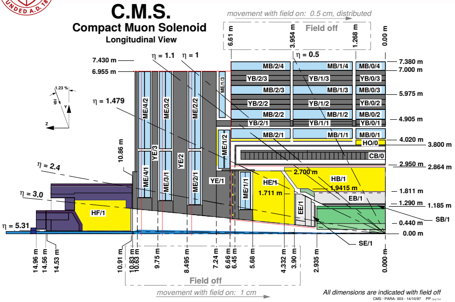
Highlights:

- Lead tugstate crystals ($PbWO_4$).
- Measures energy: $e^{\pm}$, γ (radiation length: $25X_0$).



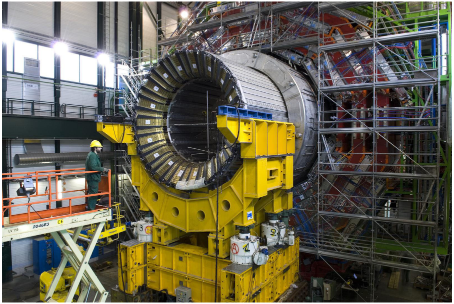


Hadron Calorimeter (HCAL)

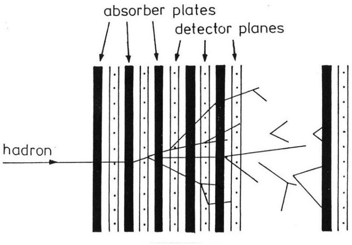


Highlights:

- Brass absorber w/ plastic scintillating layers.
- Measures (hadron) energy: p^{+}, n^{0}, $\pi^{\pm}$, K mesons.



Sampling Calorimeter



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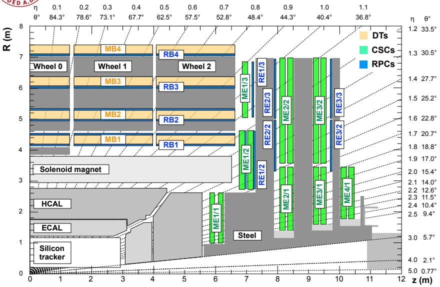
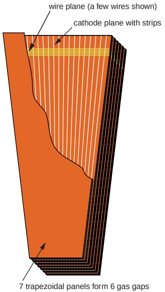
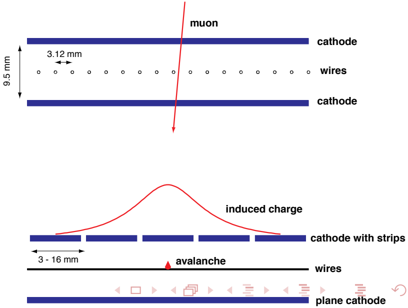
Muon Detector



Highlights:

- Gaseous detectors.
- Important for μ identification.
- Used in L1 filter.



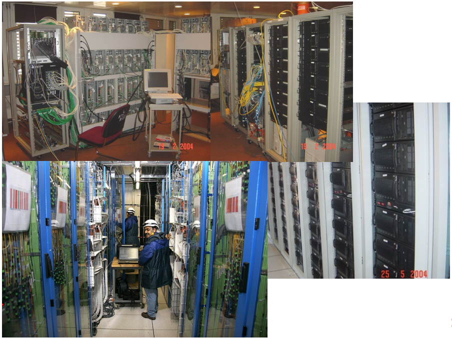


Trigger (Filter)

One collision $\sim O(1)$ Mb of data.

- Collisions at 40 MHz.
- Level 1 (L1) trigger (online): 100 kHz.
  Subsystems: CSCs+DTs, ECAL, HCAL.
- High level filter (HLT) is more sophisticated (offline): 300 Hz.
  All subsystems are used. Approx. ”full” reconstruction.

Now and then:



Trigger Schematics

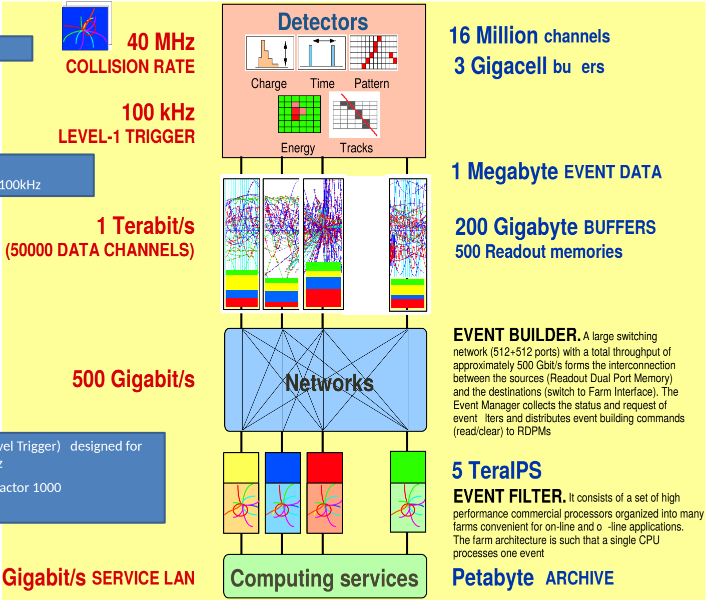
All 25 ns

DAQ accepts
Level-1 rate of 100kHz

HLT (High Level Trigger) designed for about 100Hz

- Reduction factor 1000

~2000 CPUs



Conclusions

Conclusions

- Detectors are very complex systems.
- Capabilities depend on goals and available technologies.
- Data acquisition and analysis are multistep processes.
- All the possible help is needed.

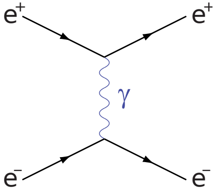
Thank you for your attention!

BACKUP

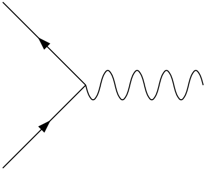
Detector Interactions

Possible Elementary Interactions

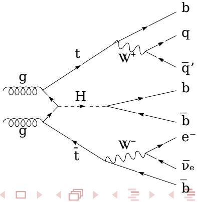
- Scattering



- Annihilation



- Particle (pair) production



Macrointeractions (1)

Photons:

- Compton scattering
- Photoelectric effect
- Pair production

Charged particles:

- Scattering — highly undesired
- Ionization (kicks off an electron off an atom)
- Excitation (excites electrons to higher energy orbitals)
- Photon radation:
  - Bremsstrahlung (accelerated movement of a charge)
  - Transition radiation
  - Cherenkov radiation (excees the speed of light in mat.)

Macrointeractions (2)

Hadronic interactions:

- Strong interactions due to inelastic scattering with nuclei: charged fragments are detected.

Neutrinos:

- Do no interact.
- Missing transverse energy/momentum.

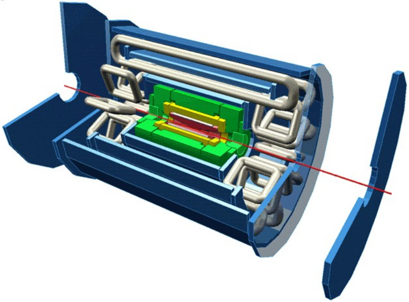
How to build a detector?

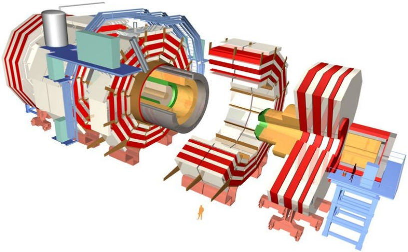
One needs to know:

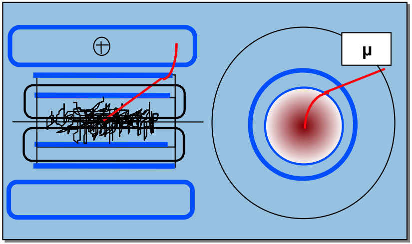
- Physics goal
- Physical objects/fragments
- Technology
- DAQ specifics
- Load
- Experimental conditions
- Goals of your colleagues
- Budget

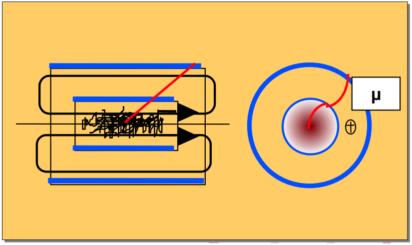
Magnet — The Special Component

A Toroidal LHC Apparatus (ATLAS) | Compact Muon Solenoid (CMS)



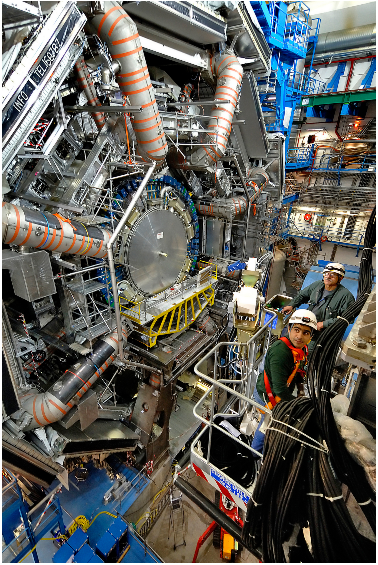




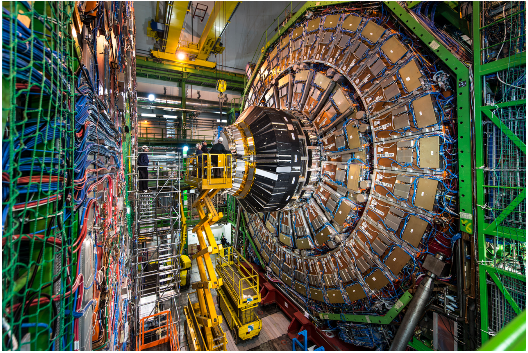


General Purpose Detectors

ATLAS

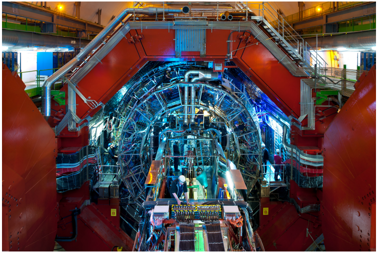


CMS



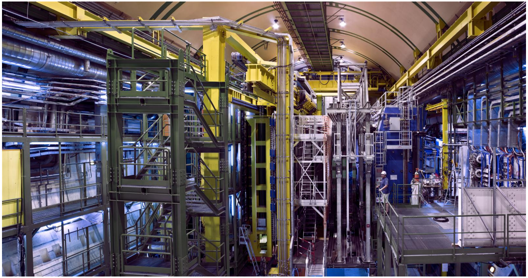
Specialized Detectors

ALICE



- Heavy-ion research

LHCb



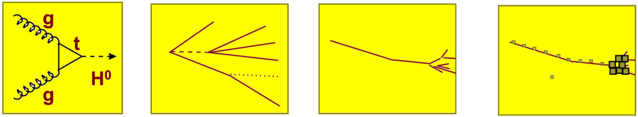
- High resolution

Miscellaneous Comments

DIY

- LHC ”equipment” is (almost) all DIY:
  - Hardware, firmware, software.
- Many systems are prototypes (calibrations are needed).
- It is hard to take into account (predict) everything.
- Experimental conditions (data taking) is a running target: 8, 13 TeV, ...

From Physics to Raw Data



2037 2446 1733 1699
4003 3611 952 1328
2132 1870 2093 3271
4732 1102 2491 3216
2421 1211 2319 2133
3451 1942 1121 3429
3742 1288 2343 7142

Basic physics

Fragmentation, Decay

Interaction with detector material
Multiple scattering, interactions

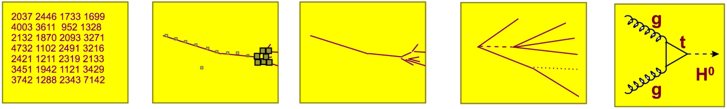
Detector response
Noise, pile-up, cross-talk, inefficiency, ambiguity, resolution, response function, alignment

Raw data

Read-out addresses, ADC, TDC values, Bit patterns

- Really recorded raw data for ATLAS/CMS ~400 MB/s
  - mainly electronics numbers
    - e.g. number of detector element where ADC (Analog-to-Digital converter) saw signal with x counts…

From Physics to Raw Data



Raw data

Convert to physics quantities

Detector response

apply calibration, alignment

Interaction with detector material

Pattern, recognition, Particle identification

Fragmentation Decay

Physics analysis

Basic physics

Results

Reconstruction

Analysis

Simulation (Monte-Carlo)

- We need to go from raw data back to physics
  - reconstruction + analysis of the event(s)