



Introduction to the CMS Detector

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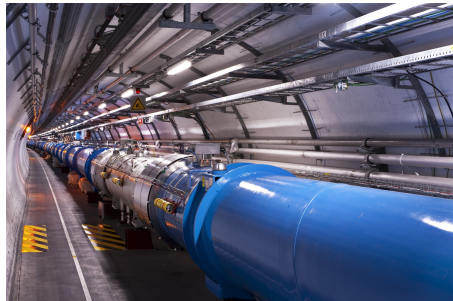
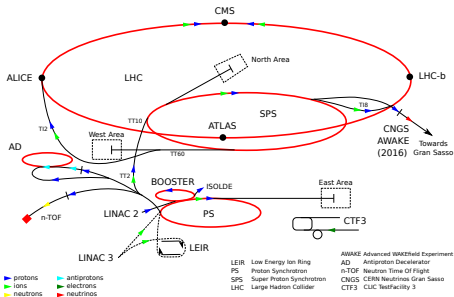
Conclusions



Introduction



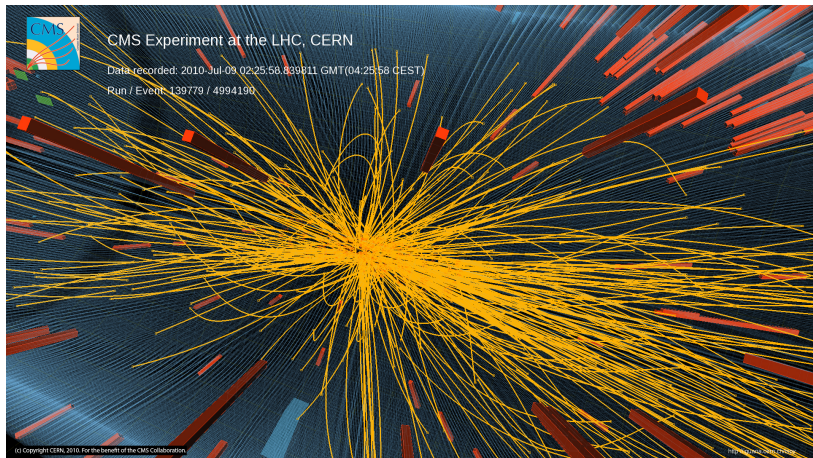
Accelerators at CERN



All is needed to achieve ...

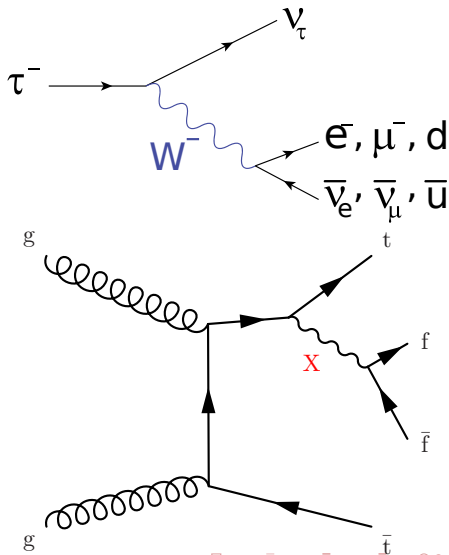
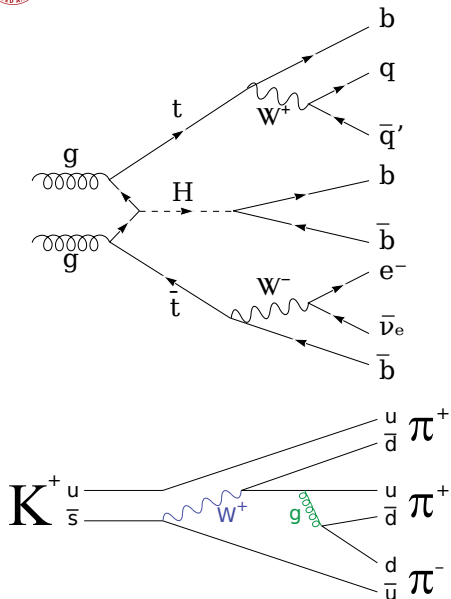


High-Energy Collisions (1)





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:

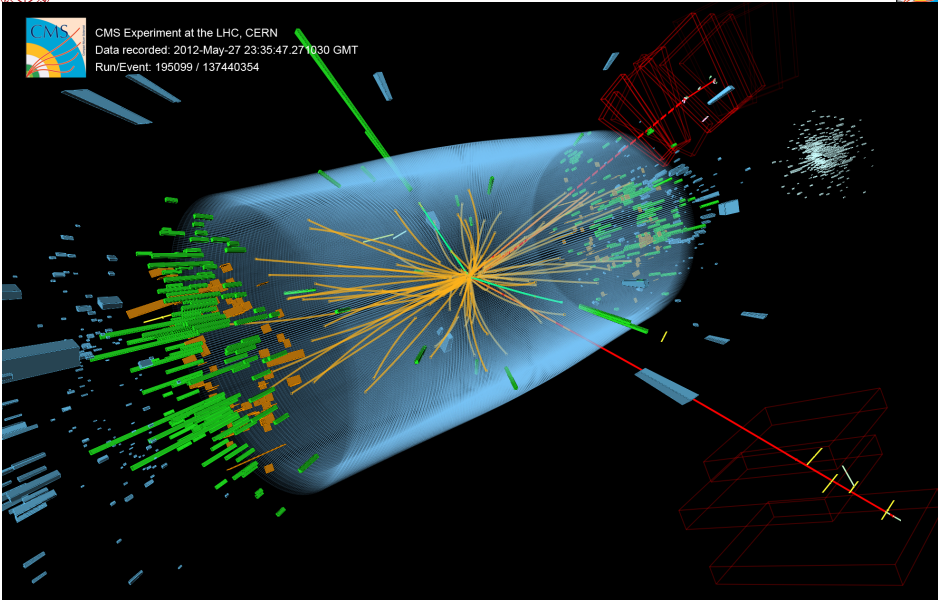
parts are named: subdetectors, systems, subsystems.

Complex detectors try to catch **everything**.

Recorded Collision



CMS Experiment at the LHC, CERN
Data recorded: 2012-May-27 23:35:47.271030 GMT
Run/Event: 195099 / 137440354





Compact Muon Solenoid (CMS)



Sliced CMS detector

20–40 MHz

CMS DETECTOR

Total weight : 14,000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

STEEL RETURN YOKE
 12,500 tonnes

SILICON TRACKERS

Pixel (100x150 μm) ~16m² ~66M channels
 Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying ~18,000A

MUON CHAMBERS

Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
 Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER

Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER

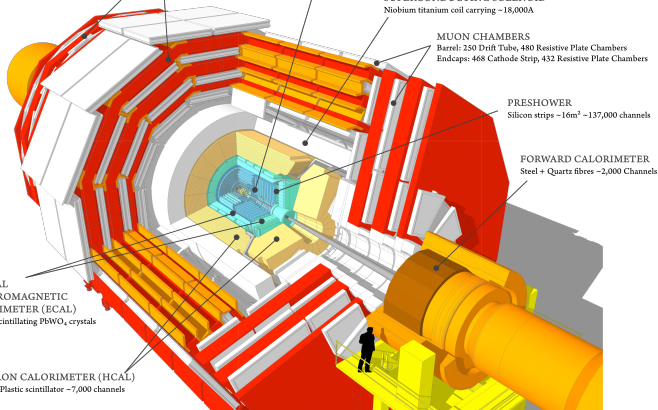
Steel + Quartz fibres ~2,000 Channels

CRYSTAL
 ELECTROMAGNETIC
 CALORIMETER (ECAL)

~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)

Brass + Plastic scintillator ~7,000 channels



×

~30 p–p
 collisions

×

p–p = ~400
 fragments

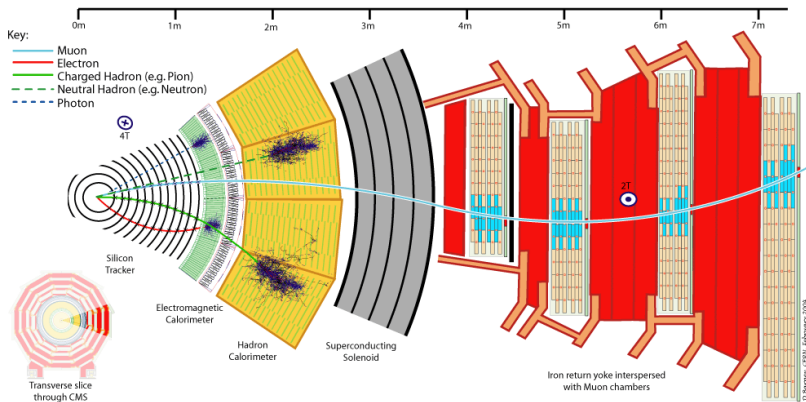
=

~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

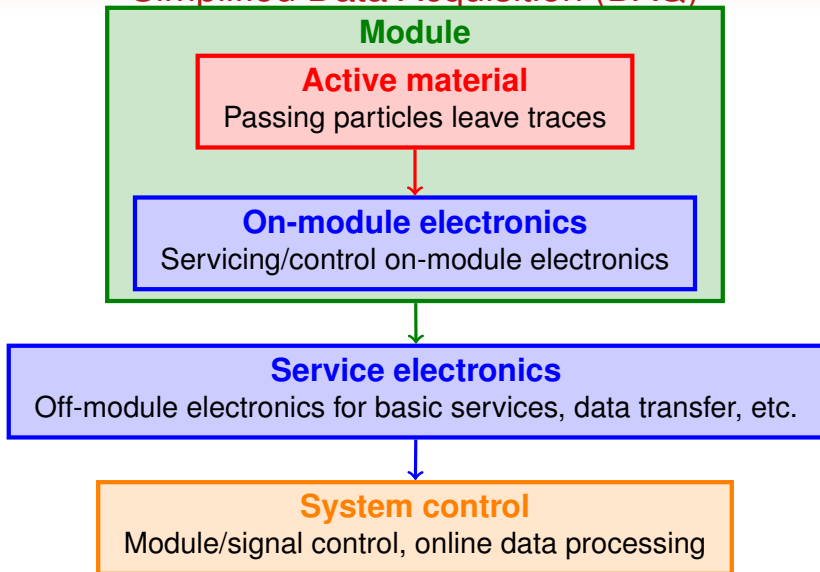




The CMS Anatomy (its Subdetectors)

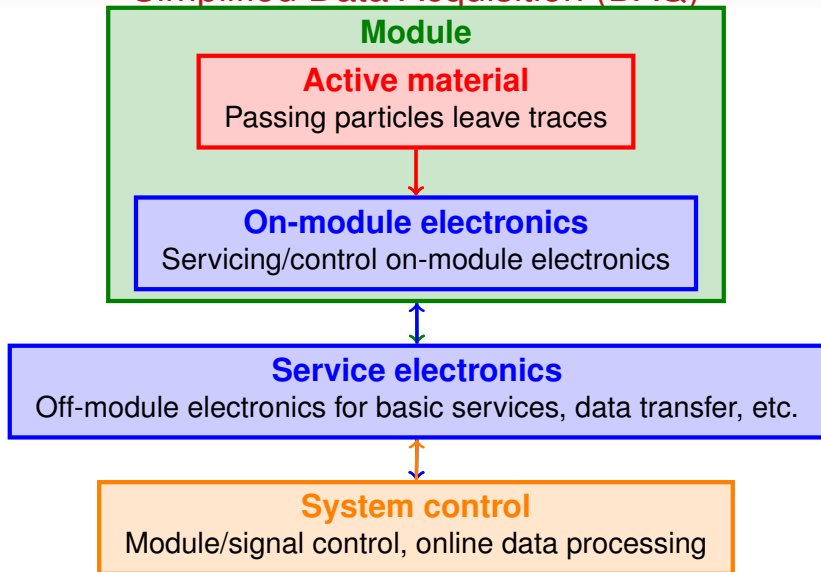


Simplified Data Acquisition (DAQ)





Simplified Data Acquisition (DAQ)





CMS Magnet

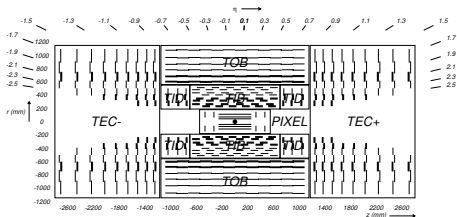


Highlights:

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

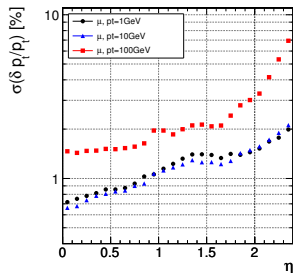


Semiconductor Tracker



Highlights:

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



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

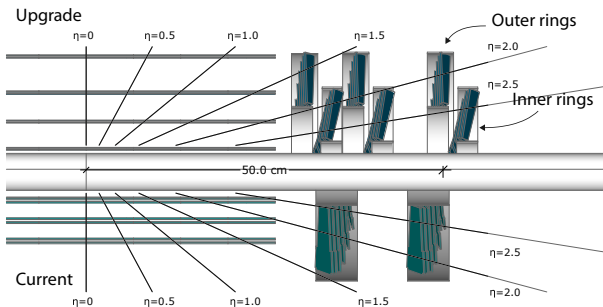


The Ongoing Phase-1 Pixel Upgrade



Main goals of upgrade:

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

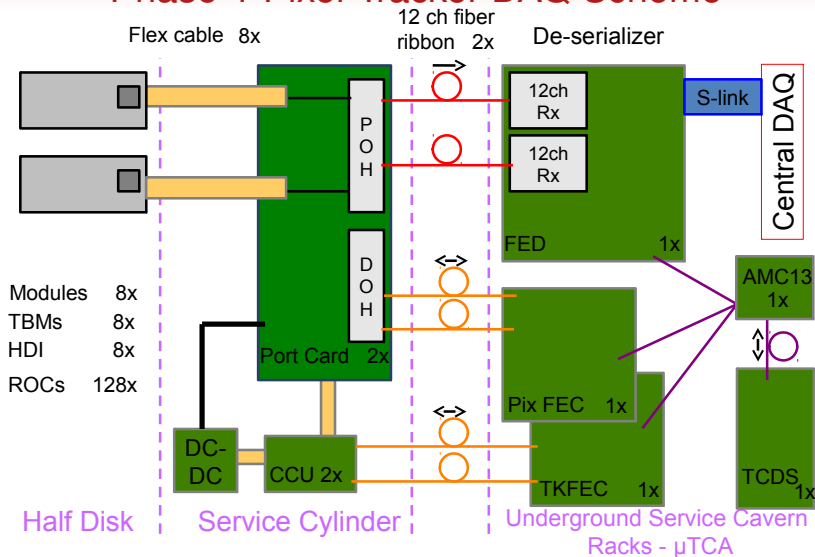


Install during extended
year-end technical stop:
Now!

{	3 → 4	barrel layers
	2 → 3	forward disks
	66 → 124	M pixels



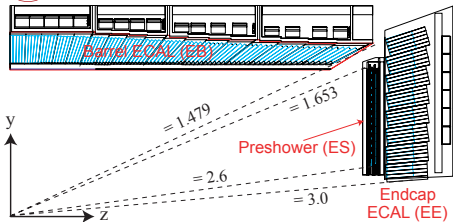
Phase-1 Pixel-Tracker DAQ Scheme



Single chain only

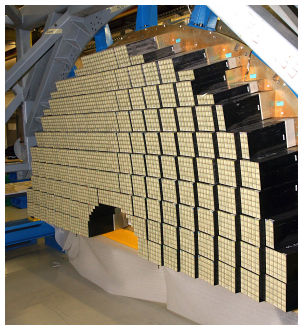
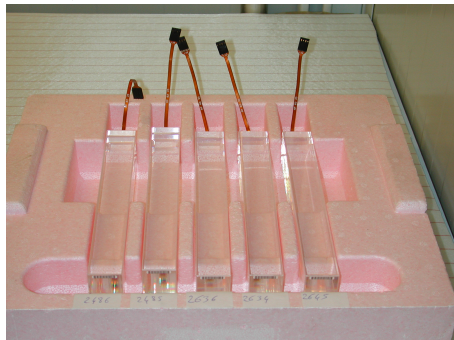


Electromagnetic Calorimeter (ECAL)



Highlights:

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

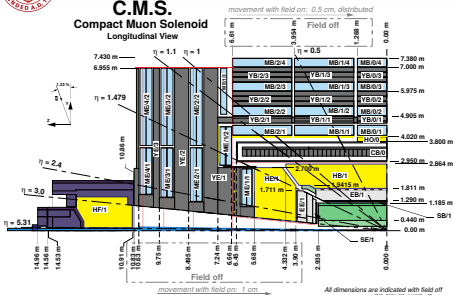




Hadron Calorimeter (HCAL)

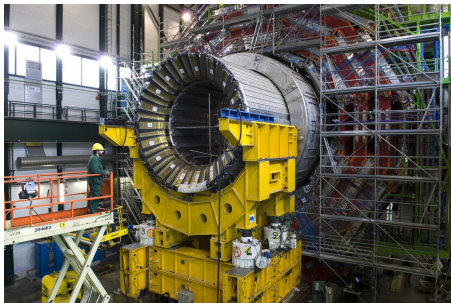


C.M.S. Compact Muon Solenoid Longitudinal View

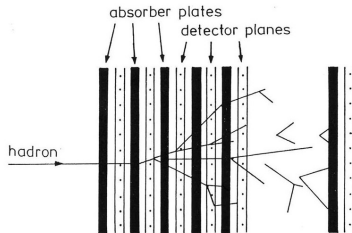


Highlights:

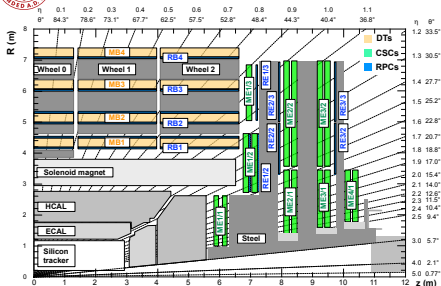
- Brass absorber w/ plastic scintillating layers.
- Measures (hadron) energy: p^+ , n^0 , π^\pm , K mesons.



Sampling Calorimeter

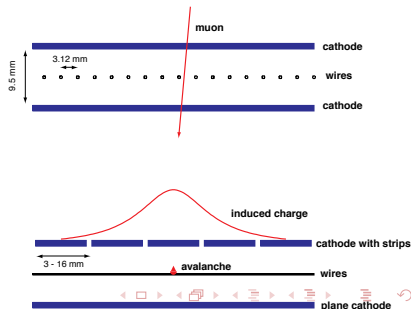
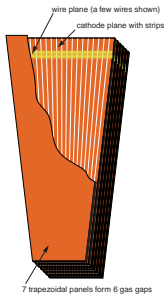


Muon Detector



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



40 MHz
COLLISION RATE

100 kHz
LEVEL-1 TRIGGER

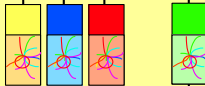
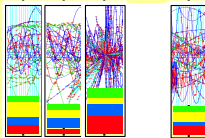
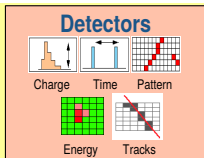
DAQ accepts
Level-1 rate of 100kHz

1 Terabit/s
(50000 DATA CHANNELS)

500 Gigabit/s

HLT (High Level Trigger) designed for
about 100Hz
- Reduction factor 1000
~2000 CPUs

Gigabit/s SERVICE LAN



Computing services

16 Million channels
3 Gigacell buffers

1 Megabyte EVENT DATA

200 Gigabyte BUFFERS
500 Readout memories

EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs

5 TeraIPS

EVENT FILTER. It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event

Petabyte ARCHIVE



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



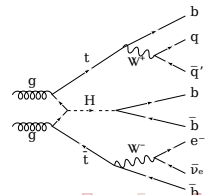
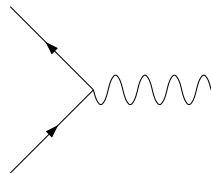
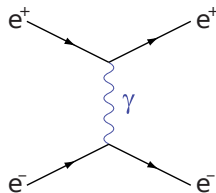
Detector Interactions



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 radiation:
 - Bremsstrahlung (accelerated movement of a charge)
 - Transition radiation
 - Cherenkov radiation (exceeds the speed of light in mat.)



Macrointeractions (2)



Hadronic interactions:

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

Neutrinos:

- Do not interact.
- Missing transverse energy/momentum.



How to build a detector?



One needs to know:

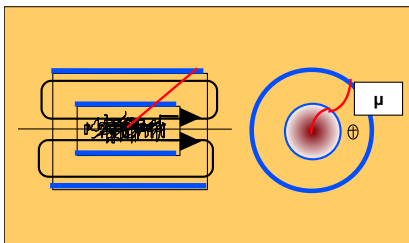
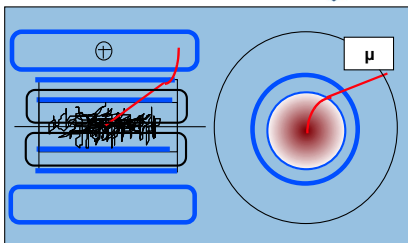
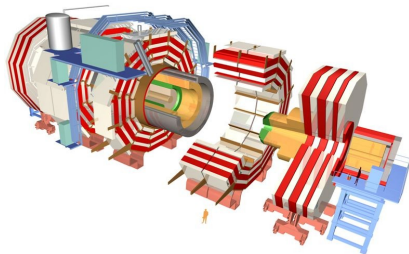
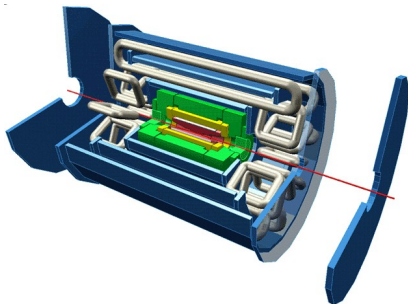
- Physics goal
- Physical objects/fragments
- Technology
- DAQ specifics
- Load
- Experimental conditions
- Goals of your colleagues
- Budget



Magnet — The Special Component



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



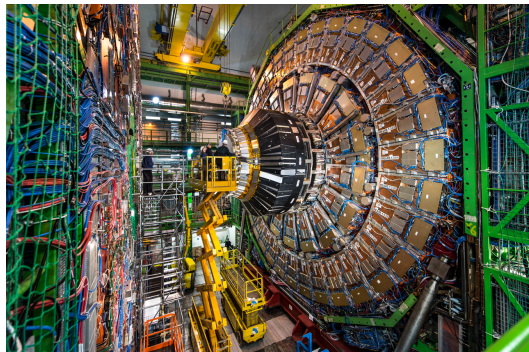
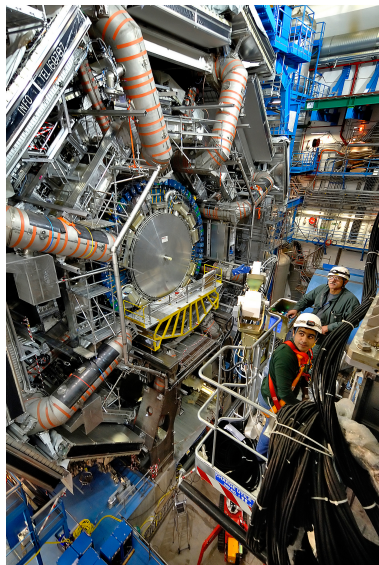


General Purpose Detectors



ATLAS

CMS

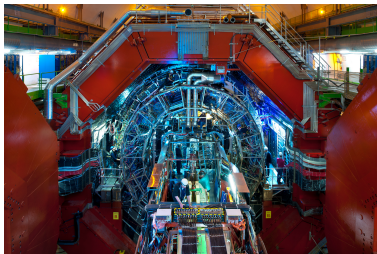




Specialized Detectors

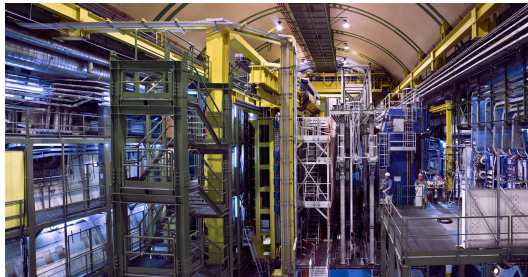


ALICE



- Heavy-ion research

LHCb



- High resolution



Miscellaneous Comments



DIY

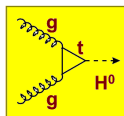


- LHC "equipment" is (almost) all DIY:
 - Hardware, firmware, software.
- Many systems are prototypes (calibrations are needed).
- It is hard to take into account (predict) everything.
- Experimental conditions (data taking) is a running target: 8, 13 TeV, ...

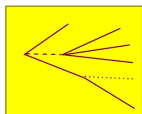




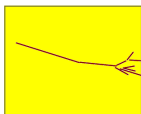
From Physics to Raw Data



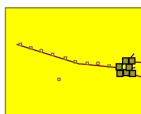
Basic physics



**Fragmentation,
Decay**



**Interaction with
detector material**
Multiple scattering,
interactions



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

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

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...

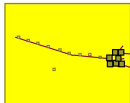


From Physics to Raw Data

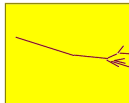
```
2037 2446 1733 1699
4003 3611 952 1328
2132 1870 2093 3271
4732 1102 2491 3216
2421 1211 2319 2133
3451 1942 1121 3429
3742 1288 2343 7142
```

Raw data

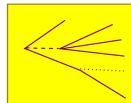
Convert to
physics
quantities



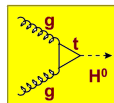
**Detector
response**
apply
calibration,
alignment



**Interaction with
detector material**
Pattern,
recognition,
Particle
identification



**Fragmentation
Decay**
Physics
analysis



Basic physics

Results



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