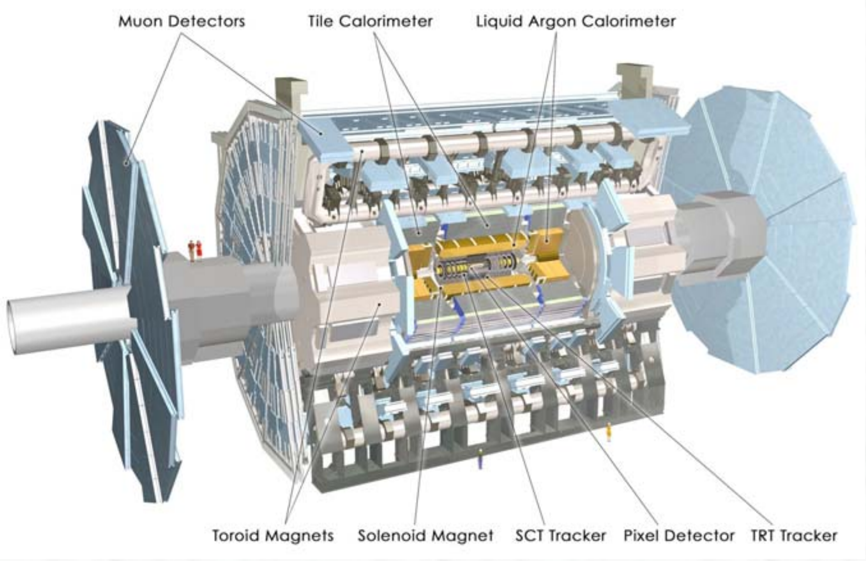
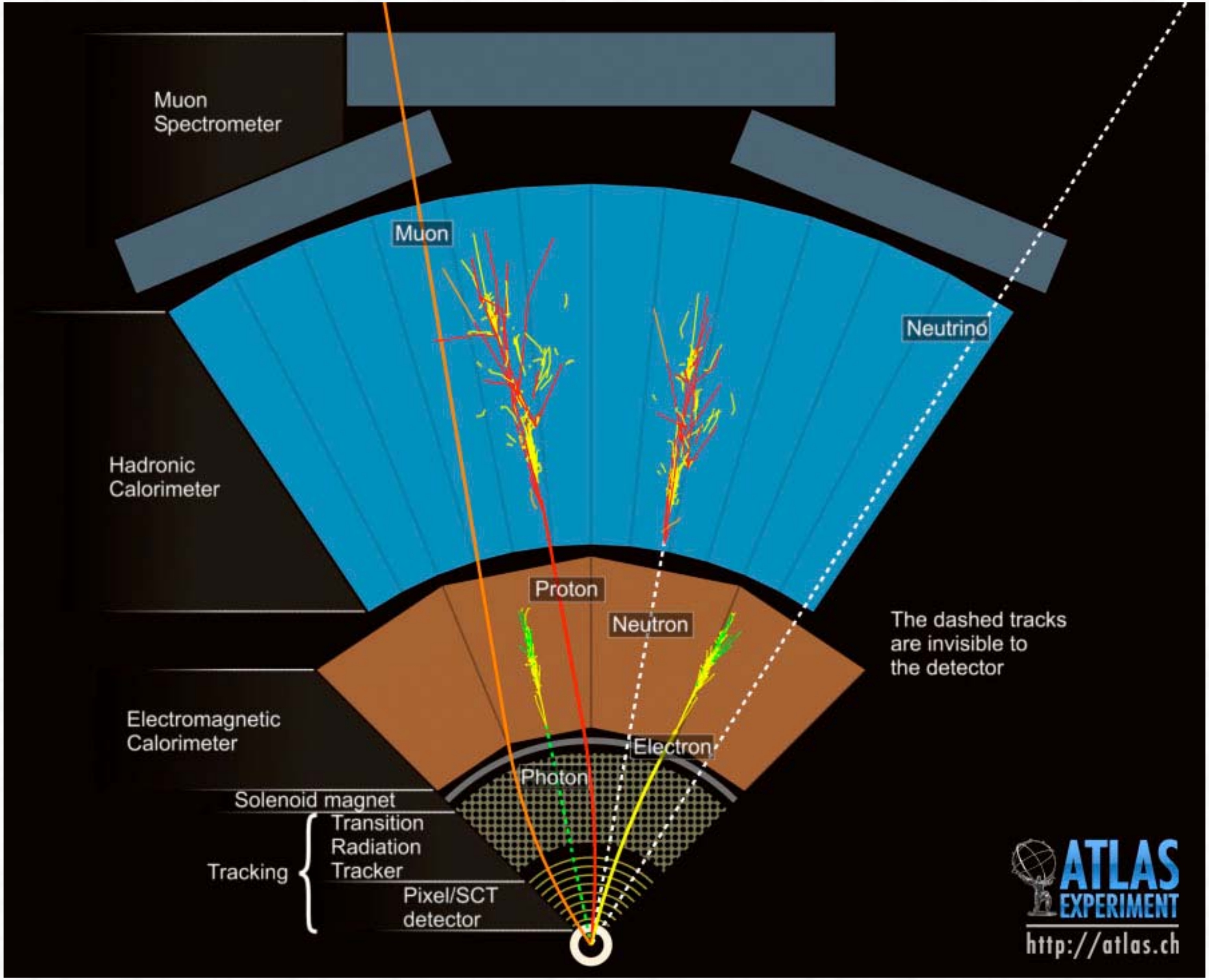
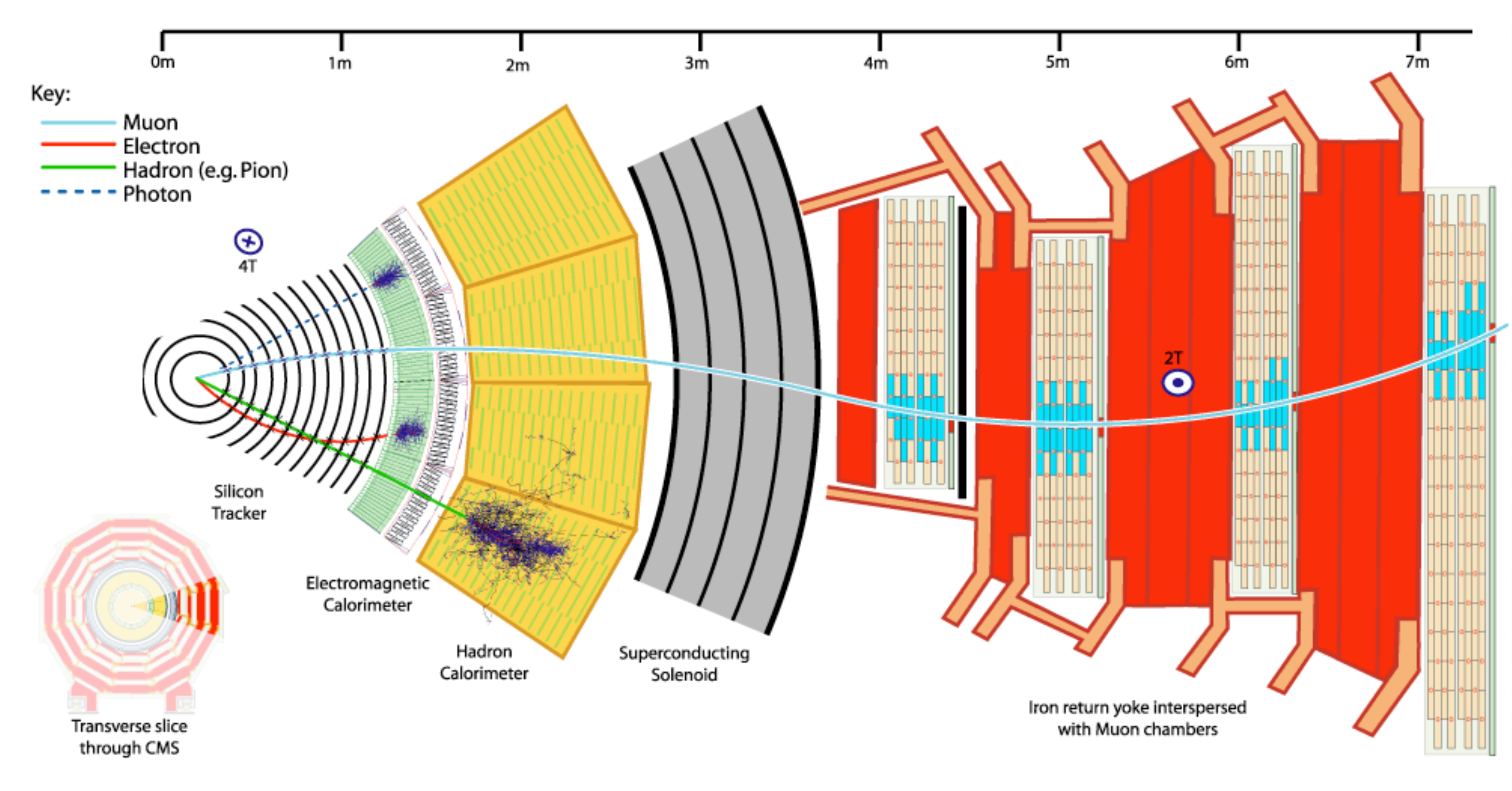
# 2.5 Important differences between the ATLAS and CMS detectors




# The ATLAS detector concept

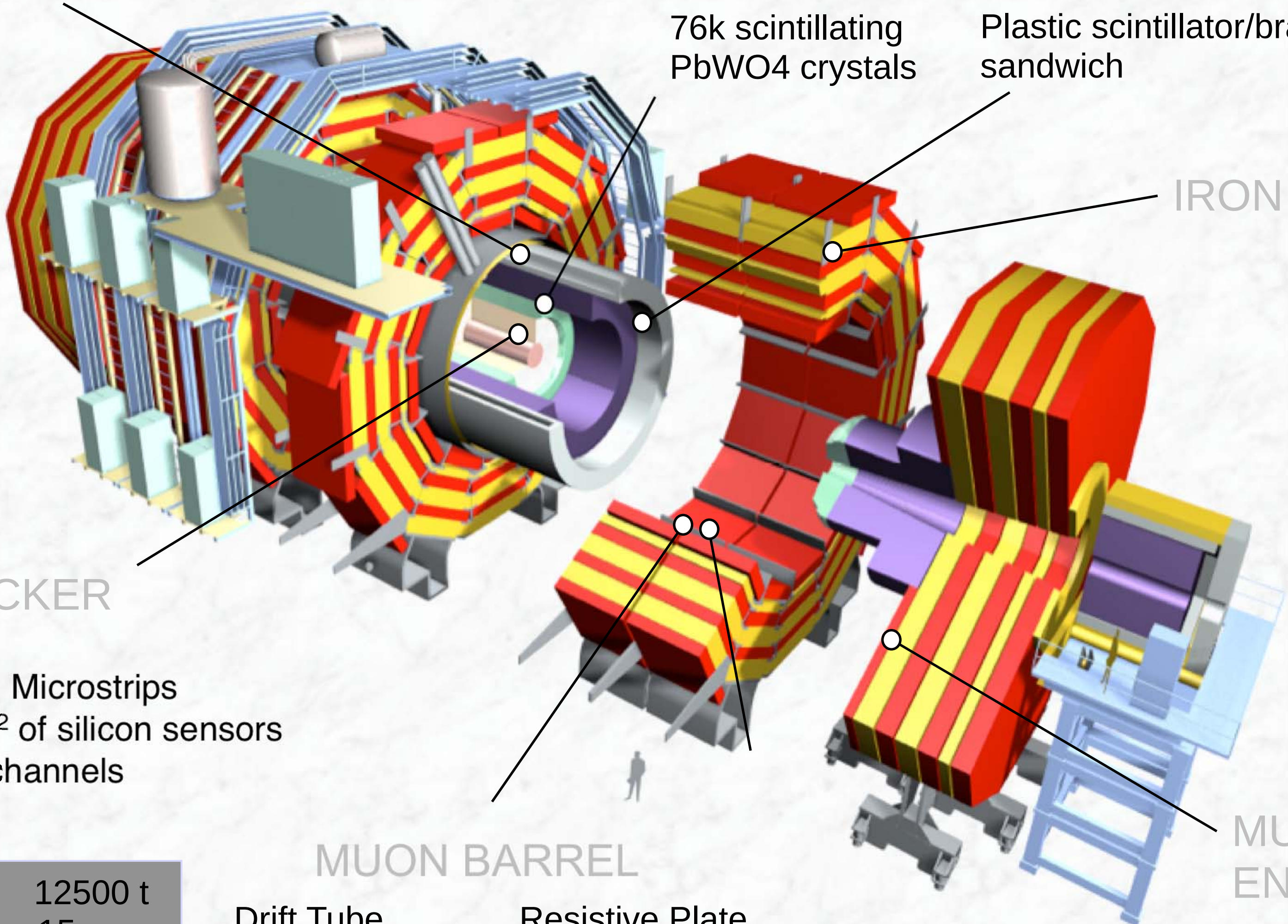


# CMS Detector Concept




Tracker | Calorimeter | Coil | Muon Detector and iron return yoke

# CMS




| | |
|---|---|
| Total weight | 12500 t |
| Overall diameter | 15 m |
| Overall length | 21.6 m |

# How huge are ATLAS and CMS?

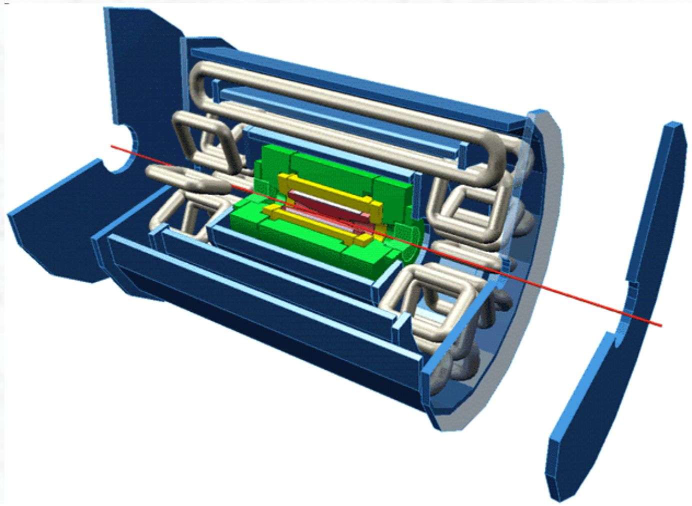
## Size of detectors:

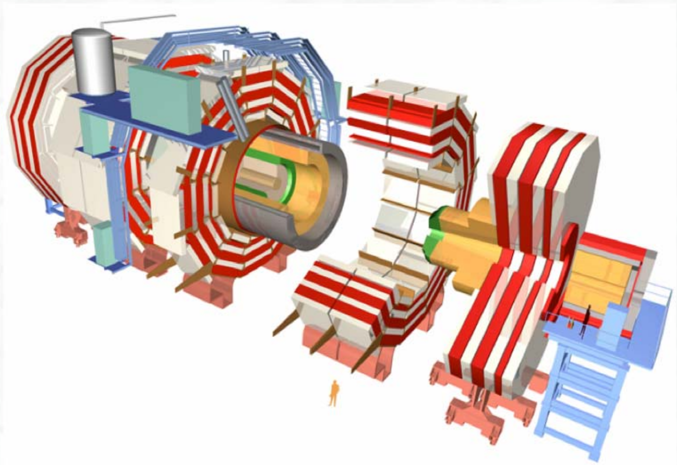
- Volume: 20 000 $m^3$ for ATLAS
- Weight: 12 500 tons for CMS
- 66 to 80 million pixel readout channels near vertex
- 200 $m^2$ of active silicon for CMS tracker
- 175 000 readout channels for ATLAS LAr EM calorimeter
- 1 million channels and 10 000 $m^2$ area of muon chambers
- Very selective trigger/DAQ system
- Large-scale offline software and worldwide computing (GRID)

## Time-scale:

More than 25 years from first conceptual studies (Lausanne 1984) to solid physics results in 2011 confirming that LHC has taken over the high-energy frontier from the Tevatron

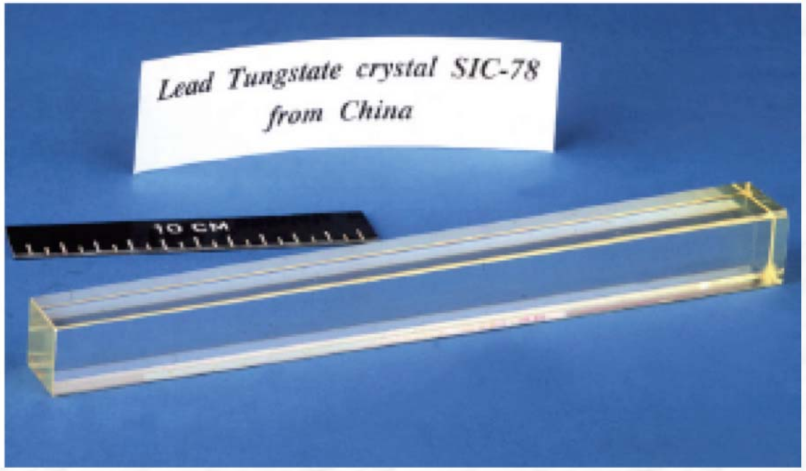
| | ATLAS | CMS |
|---|---|---|
| Magnetic field | 2 T solenoid<br>+ toroid: 0.5 T (barrel), 1 T (endcap) | 4 T solenoid + return yoke |
| Tracker | Silicon pixels and strips<br>+ transition radiation tracker<br>$\sigma/p_T \approx 5 \cdot 10^{-4} p_T + 0.01$ | Silicon pixels and strips<br>(full silicon tracker)<br>$\sigma/p_T \approx 1.5 \cdot 10^{-4} p_T + 0.005$ |
| EM calorimeter | Liquid argon + Pb absorbers<br>$\sigma/E \approx 10\%/\sqrt{E} + 0.007$ | $PbWO_4$ crystals<br>$\sigma/E \approx 3\%/\sqrt{E} + 0.003$ |
| Hadronic calorimeter | Fe + scintillator / Cu+LAr (10λ)<br>$\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV | Brass + scintillator (7 λ + catcher)<br>$\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV |
| Muon | $\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV<br>(Inner Tracker + muon system) | $\sigma/p_T \approx 1\%$ @ 50GeV to 10% @ 1TeV<br>(Inner Tracker + muon system) |
| Trigger | L1 + HLT (L2+EF) | L1 + HLT (L2 + L3) |





## Important differences I:

- In order to maximize the sensitivity for **$H \to \gamma\gamma$ decays**, the experiments need to have an excellent e/γ identification and resolution

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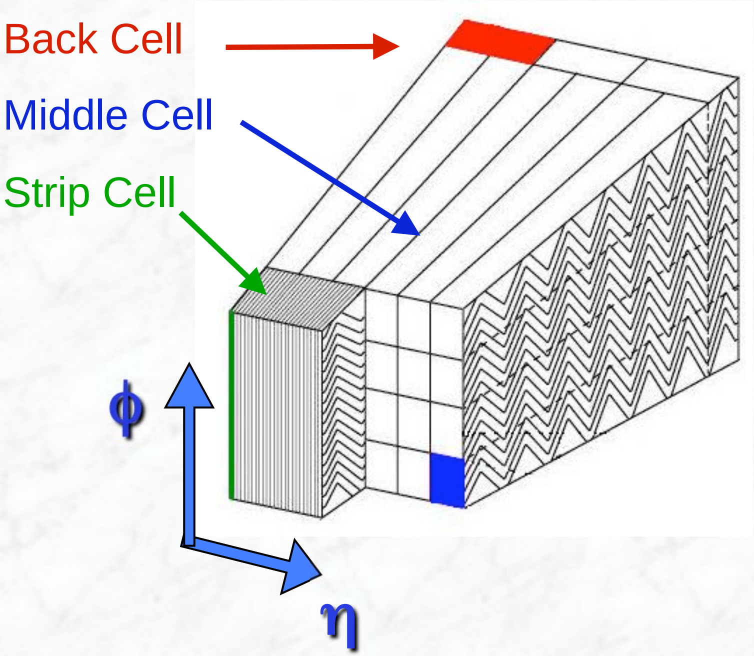
- CMS: has opted for a high resolution $PbWO_4$ crystal calorimeter
  - higher intrinsic resolution

- ATLAS: Liquid argon calorimeter
  - high granularity and longitudinally segmentation (better e/γ ID)
  - electrical signals, high stability in calibration & radiation resistant

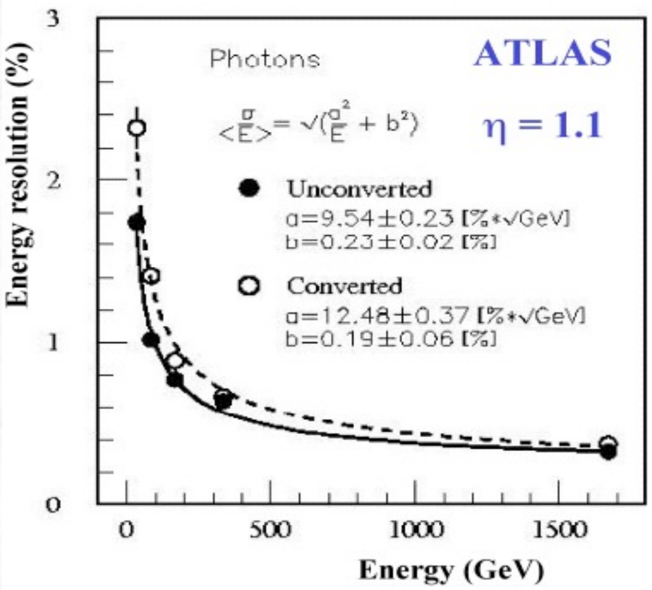


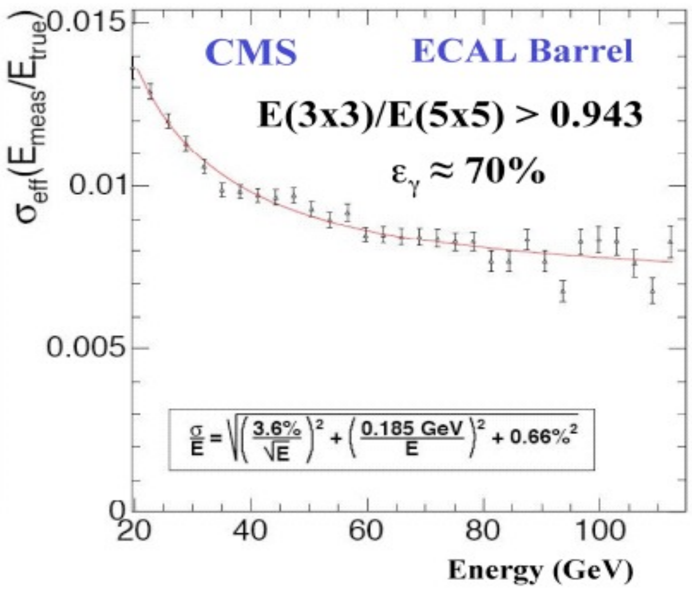
# ATLAS/CMS: e/γ resolutions

**Photons at 100 GeV**

ATLAS: 1-1.5% energy resol. (all γ)

CMS: 0.8% energy resol. ($\varepsilon_\gamma$ ~ 70%)

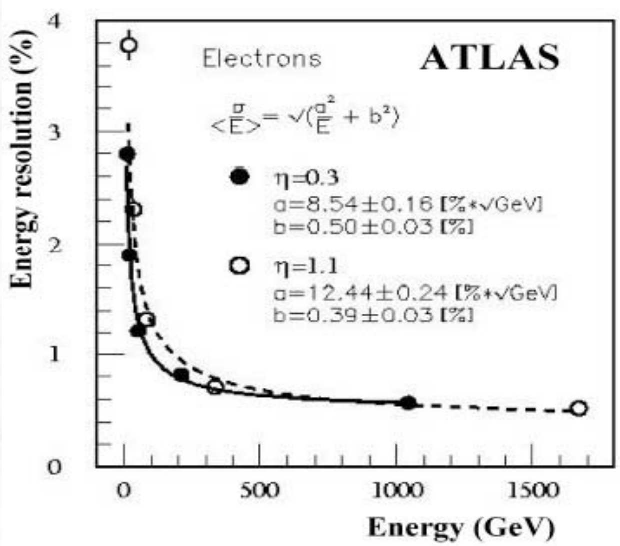


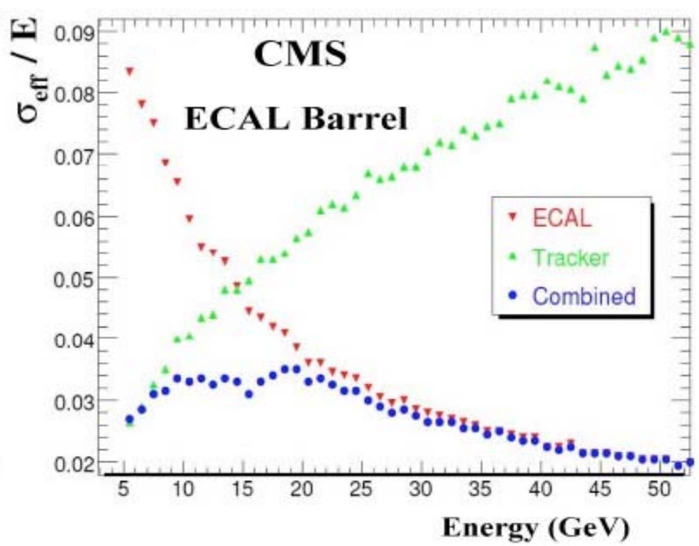




**Electrons at 50 GeV**

ATLAS: 1.3-2.3% energy resol.
(use EM calo only)

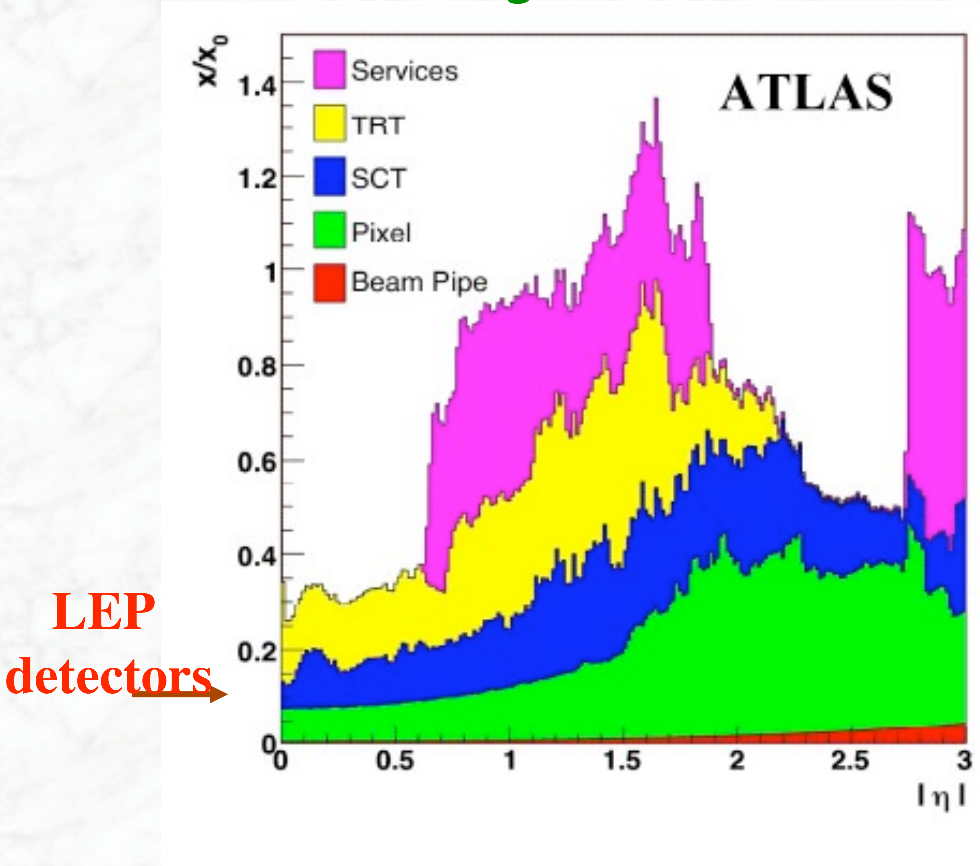
CMS: ~ 2.0% energy resol. (combine EM calo and tracker)



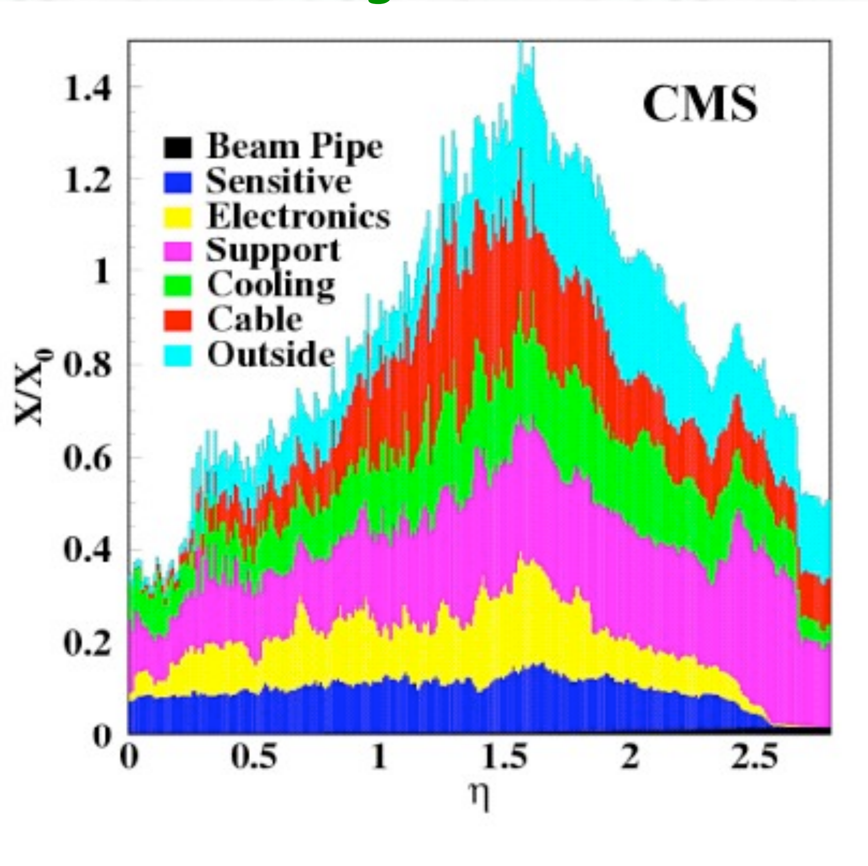



# Amount of material in ATLAS and CMS inner trackers

Weight: 4.5 tons




Weight: 3.7 tons

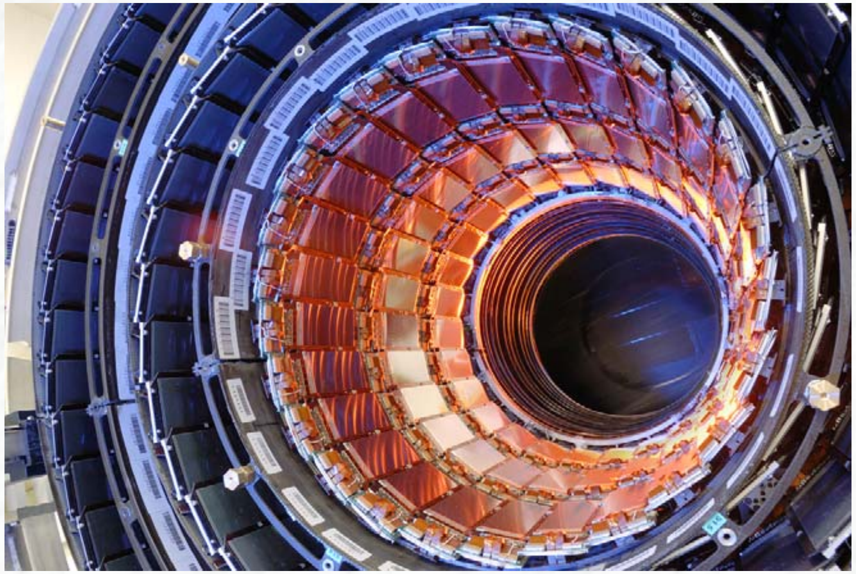



- Active sensors and mechanics account each only for ~ 10% of material budget
- Need to bring 70 kW power into tracker and to remove similar amount of heat
- Very distributed set of heat sources and power-hungry electronics inside volume: this has led to complex layout of services, most of which were not at all understood at the time of the TDRs

**Important differences II:**

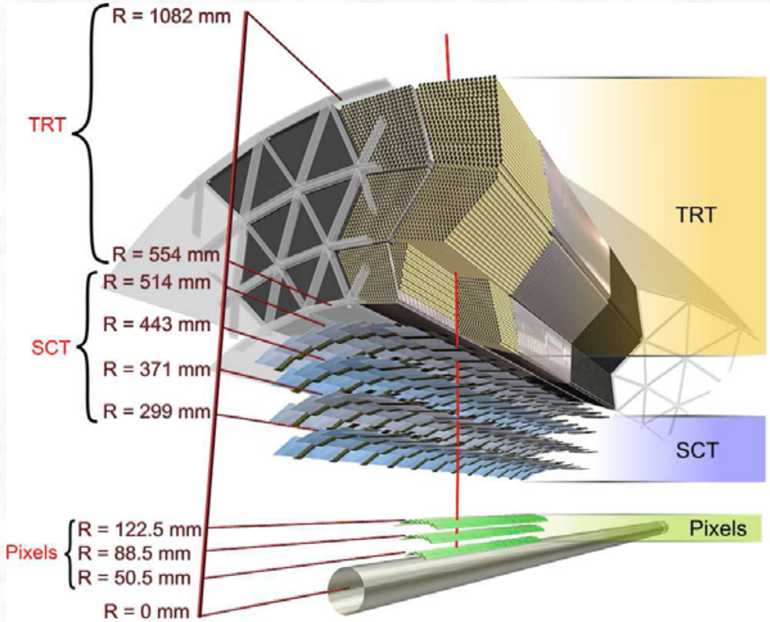
• Inner detectors / tracker

Both use solenoidal fields
ATLAS: 2 Tesla
CMS: 4 Tesla



• CMS: full silicon strip and pixel detectors
- high resolution, high granularity

• ATLAS: Silicon (strips and pixels)
+ Transition Radiation Tracker
- high granularity and resolution close to interaction region
- “continuous” tracking at large radii



# Main performance characteristics of the ATLAS and CMS trackers

| | ATLAS | CMS |
|---|---|---|
| Reconstruction efficiency for muons with $p_T = 1$ GeV | 96.8% | 97.0% |
| Reconstruction efficiency for pions with $p_T = 1$ GeV | 84.0% | 80.0% |
| Reconstruction efficiency for electrons with $p_T = 5$ GeV | 90.0% | 85.0% |
| Momentum resolution at $p_T = 1$ GeV and $\eta \approx 0$ | 1.3% | 0.7% |
| Momentum resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ | 2.0% | 2.0% |
| Momentum resolution at $p_T = 100$ GeV and $\eta \approx 0$ | 3.8% | 1.5% |
| Momentum resolution at $p_T = 100$ GeV and $\eta \approx 2.5$ | 11% | 7% |
| Transverse i.p. resolution at $p_T = 1$ GeV and $\eta \approx 0$ (µm) | 75 | 90 |
| Transverse i.p. resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ (µm) | 200 | 220 |
| Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$ (µm) | 11 | 9 |
| Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$ (µm) | 11 | 11 |
| Longitudinal i.p. resolution at $p_T = 1$ GeV and $\eta \approx 0$ (µm) | 150 | 125 |
| Longitudinal i.p. resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ (µm) | 900 | 1060 |

- Performance of CMS tracker is undoubtedly superior to that of ATLAS in terms of momentum resolution.
- Vertexing and b-tagging performances are similar.
- However, impact of material and B-field already visible on efficiencies.

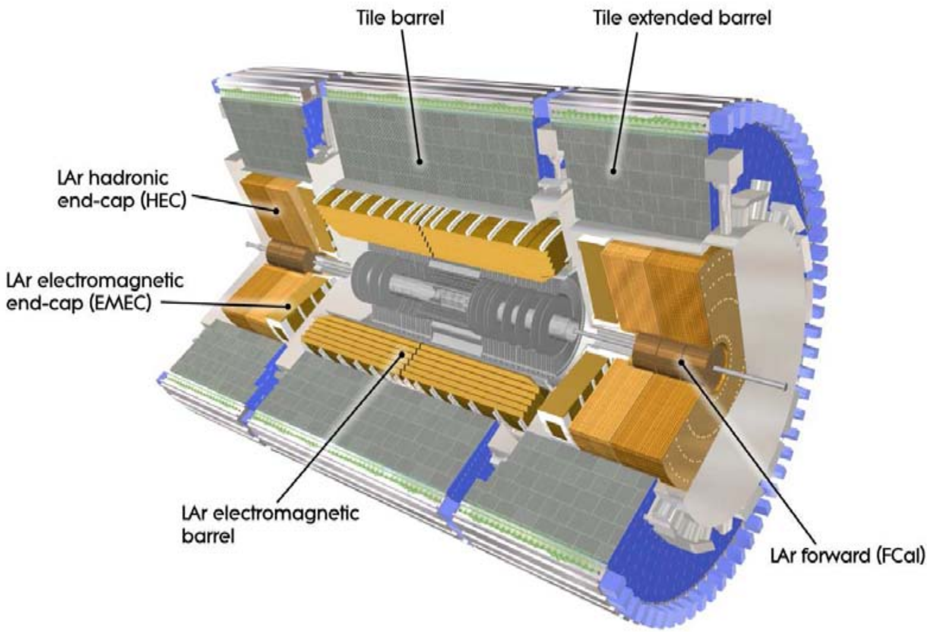
**Important differences III:**

• Coil / Hadron calorimeters

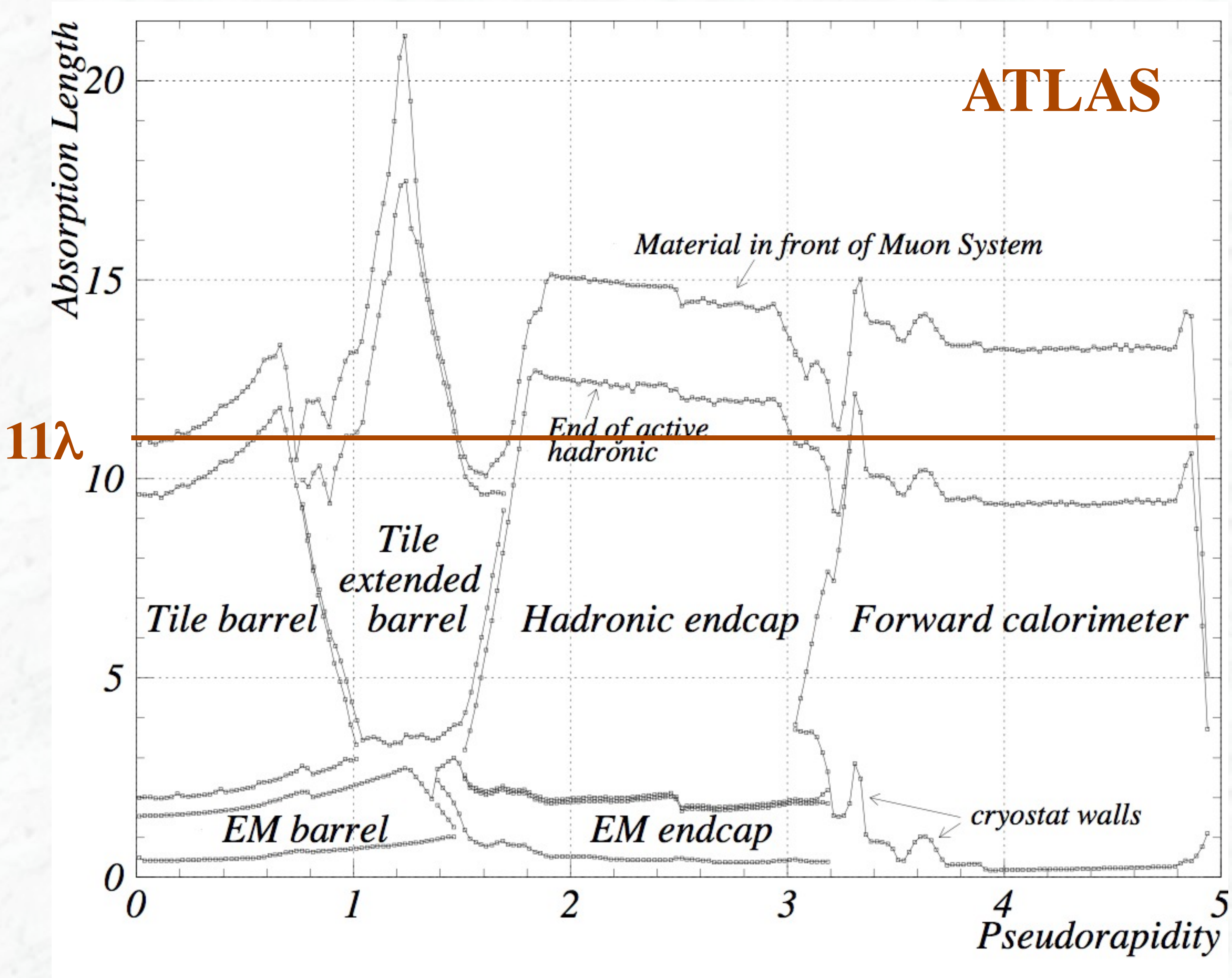
• CMS: electromagnetic calorimeter and part of the hadronic calorimeter (7λ) inside the solenoidal coil + tail catcher, return yoke

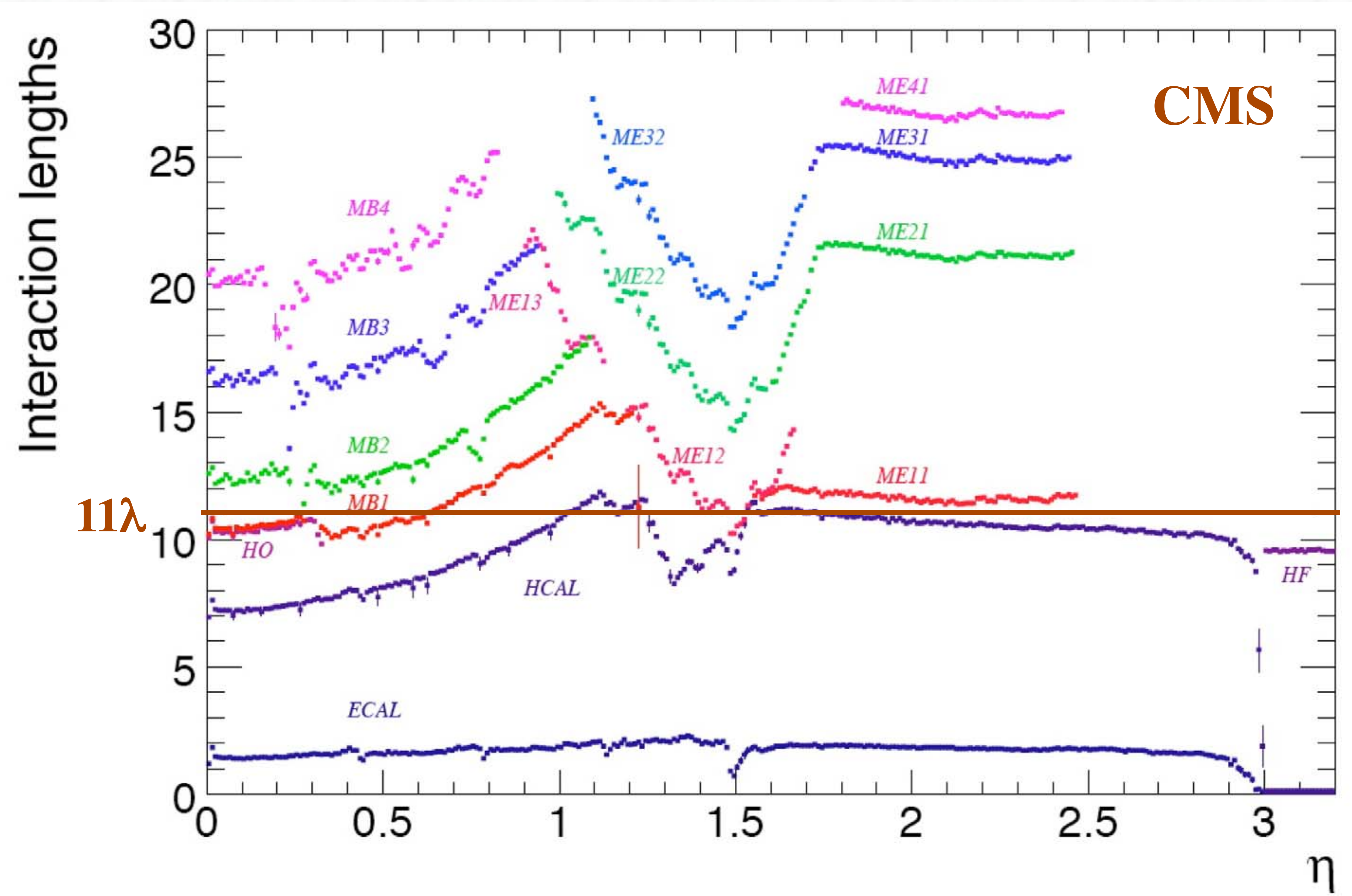
good for e/γ resolution
bad for jet resolution

• ATLAS:
calorimetry outside coil



# Hadronic absorption length of the calorimeters




CMS
11λ
Interaction lengths
η
MB4
MB3
MB2
MB1
HO
HCAL
ECAL
HF
ME13
ME12
ME11
ME22
ME21
ME32
ME31
ME41
0
5
10
15
20
25
30
0.5
1
1.5
2
2.5
3

Main performance parameters of the different hadronic calorimeter components of the ATLAS and CMS detectors, as measured in test beams using charged pions in both stand-alone and combined mode with the ECAL

| | ATLAS | | | | CMS | |
|---|---|---|---|---|---|---|
| | Barrel LAr/Tile | | End-cap LAr | | | |
| | Tile | Combined | HEC | Combined | Had. barrel | Combined |
| Electron/hadron ratio | 1.36 | 1.37 | 1.49 | | | |
| Stochastic term | $45\%/\sqrt{E}$ | $55\%/\sqrt{E}$ | $75\%/\sqrt{E}$ | $85\%/\sqrt{E}$ | $100\%/\sqrt{E}$ | $70\%/\sqrt{E}$ |
| Constant term | 1.3% | 2.3% | 5.8% | $< 1\%$ | | 8.0% |
| Noise | Small | 3.2 GeV | | 1.2 GeV | Small | 1 GeV |

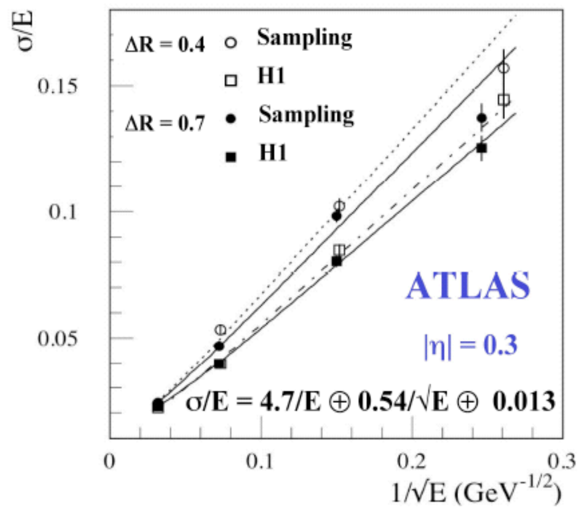
The measured electron/hadron ratios are given separately for the hadronic stand-alone and combined calorimeters when available, and for the contributions (added quadratically except for the stand-alone ATLAS tile calorimeter) to the pion energy resolution from the stochastic term, the local constant term, and the noise are also shown, when available from published data.

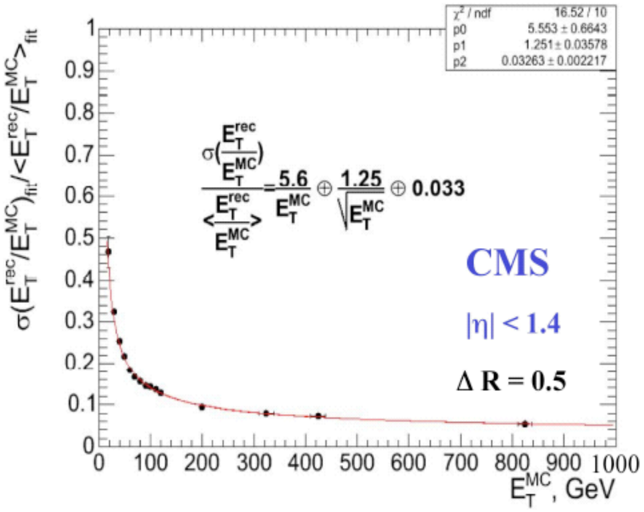
**Biggest difference in performance perhaps for hadronic calorimetry**

**Jets at 1000 GeV**

ATLAS: ~ 2%
energy resolution
CMS: ~ 5%
energy resolution,

But expect sizable
improvement using tracks
(especially at lower E)



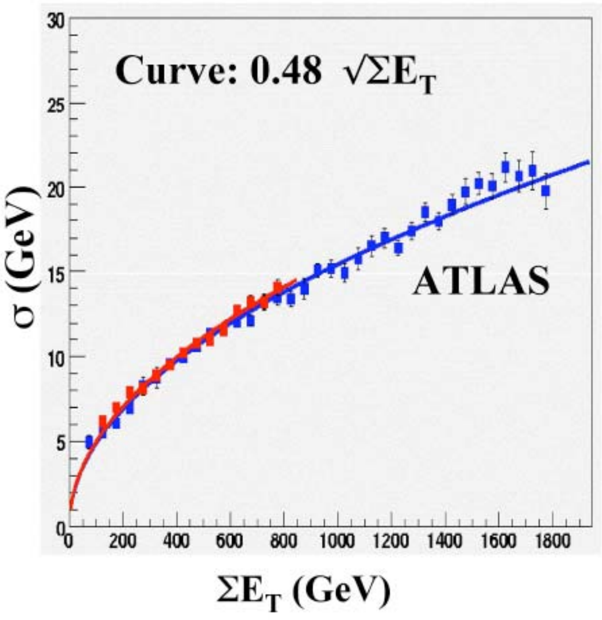



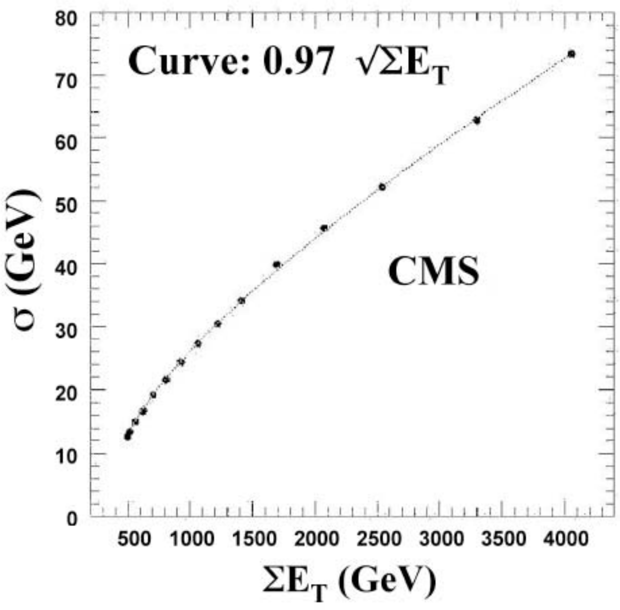

**$E_T^{miss}$ at $\Sigma E_T$ = 2000 GeV**

ATLAS: σ ~ 20 GeV

CMS: σ ~ 40 GeV

This may be important for
high mass H/A → ττ



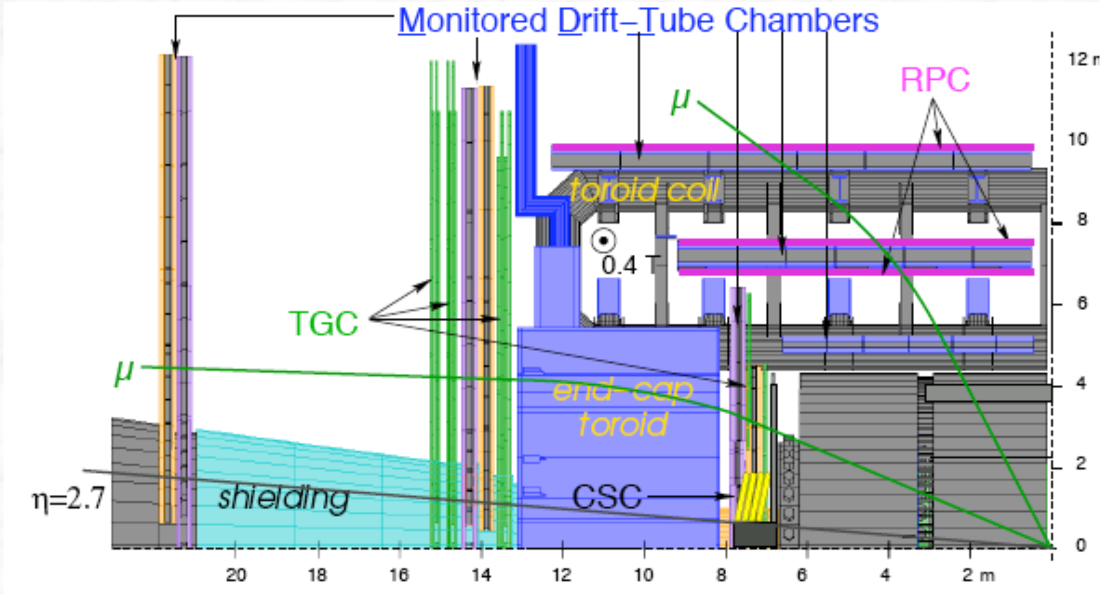



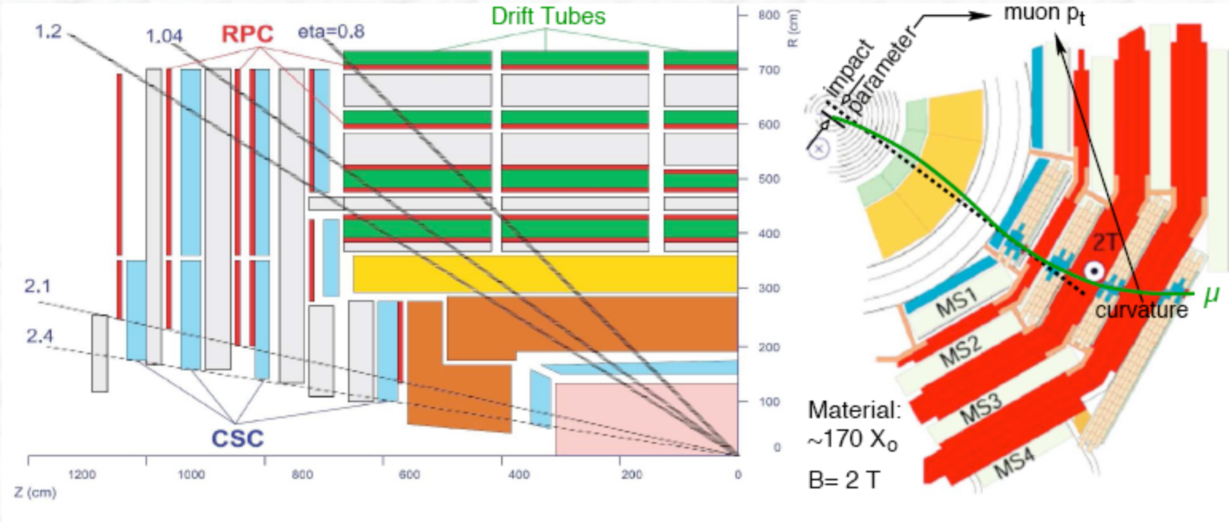
## Important differences IV:

• Muon spectrometer

• ATLAS: independent muon spectrometer;
→ excellent stand-alone capabilities

• CMS: superior combined momentum resolution in the central region;
limited stand-alone resolution and trigger capabilities
(multiple scattering in the iron)



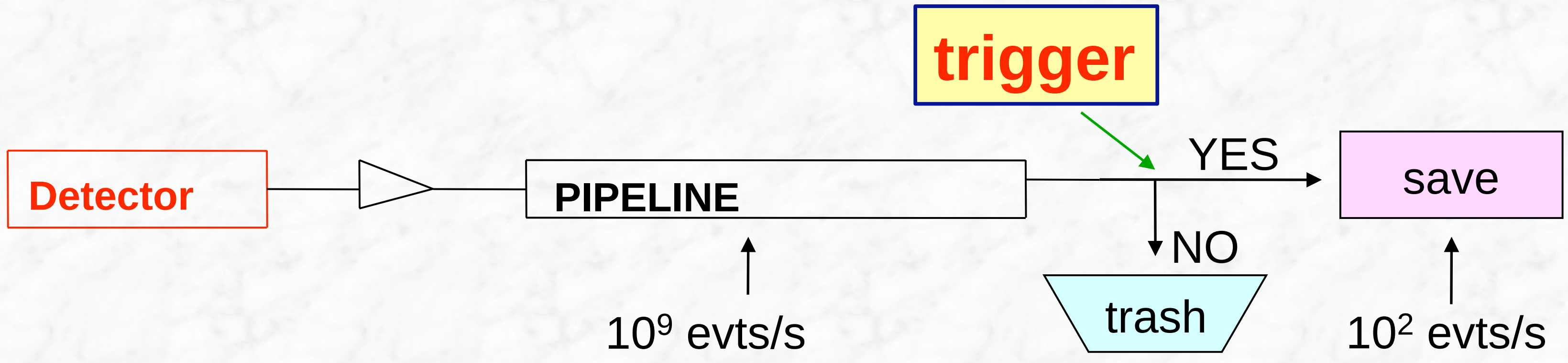
Main parameters of the ATLAS and CMS muon measurement systems as well as a summary of the expected combined and stand-alone performance at two typical pseudorapidity values (averaged over azimuth)

| Parameter | ATLAS | CMS |
|---|---|---|
| Pseudorapidity coverage | | |
| -Muon measurement | $\|\eta\| < 2.7$ | $\|\eta\| < 2.4$ |
| -Triggering | $\|\eta\| < 2.4$ | $\|\eta\| < 2.1$ |
| Dimensions (m) | | |
| -Innermost (outermost) radius | 5.0 (10.0) | 3.9 (7.0) |
| -Innermost (outermost) disk ($z$-point) | 7.0 (21–23) | 6.0–7.0 (9–10) |
| Segments/superpoints per track for barrel (end caps) | 3 (4) | 4 (3–4) |
| Magnetic field B (T) | 0.5 | 2 |
| -Bending power (BL, in T$\cdot$ m) at $\|\eta\| \approx 0$ | 3 | 16 |
| -Bending power (BL, in T$\cdot$ m) at $\|\eta\| \approx 2.5$ | 8 | 6 |
| Combined (stand-alone) momentum resolution at | | |
| -$p$ = 10 GeV and $\eta \approx 0$ | 1.4% (3.9%) | 0.8% (8%) |
| -$p$ = 10 GeV and $\eta \approx 2$ | 2.4% (6.4%) | 2.0% (11%) |
| -$p$ = 100 GeV and $\eta \approx 0$ | 2.6% (3.1%) | 1.2% (9%) |
| -$p$ = 100 GeV and $\eta \approx 2$ | 2.1% (3.1%) | 1.7% (18%) |
| -$p$ = 1000 GeV and $\eta \approx 0$ | 10.4% (10.5%) | 4.5% (13%) |
| -$p$ = 1000 GeV and $\eta \approx 2$ | 4.4% (4.6%) | 7.0% (35%) |

CMS muon performance driven by tracker: better than ATLAS at $\eta \sim 0$;
ATLAS muon stand-alone performance excellent over whole $\eta$ range

# How to Select Interesting Events?

- Bunch crossing rate: 40 MHz, ~20 interactions per BX ($10^9$ evts/s)
  - can only record ~200 event/s (1.5 MB each), still 300 MB/s data rate
- Need highly efficient and highly selective TRIGGER
  - raw event data (70 TB/s) are stored in pipeline until trigger decision




- ATLAS trigger has 3 levels (CMS similar with 2 levels)
  - Level-1: hardware, ~3 μs decision time, 40 MHz → 100 kHz
  - Level-2: software, ~40 ms decision time, 100 kHz → 2 kHz
  - Level-3: software, ~4 s decision time, 2 kHz → 200 Hz

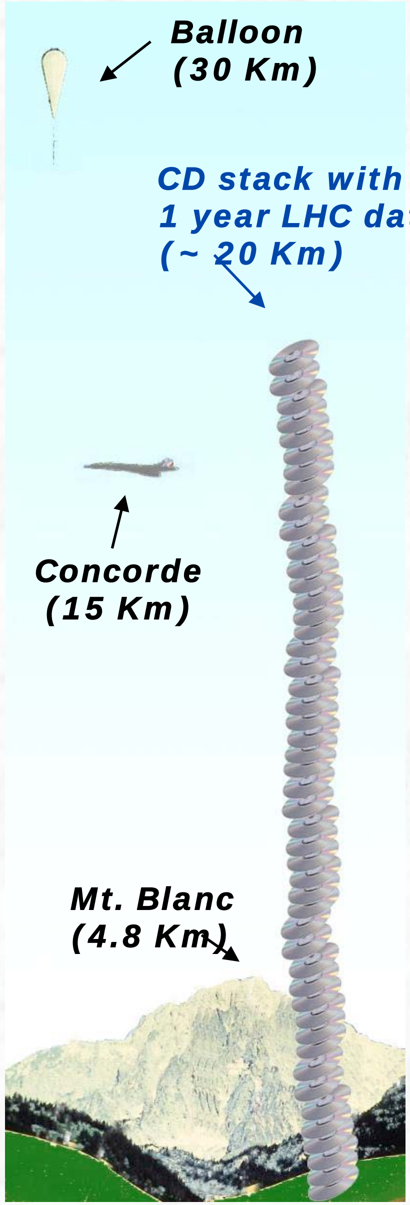
# LHC data handling, GRID computing

A typical Tier-2 GRID center
(example: Tokyo University)

**Trigger system selects ~200 "collisions" per sec.**

**LHC data volume per year: 10-15 Petabytes**

= 10-15 $\cdot 10^{15}$ Byte

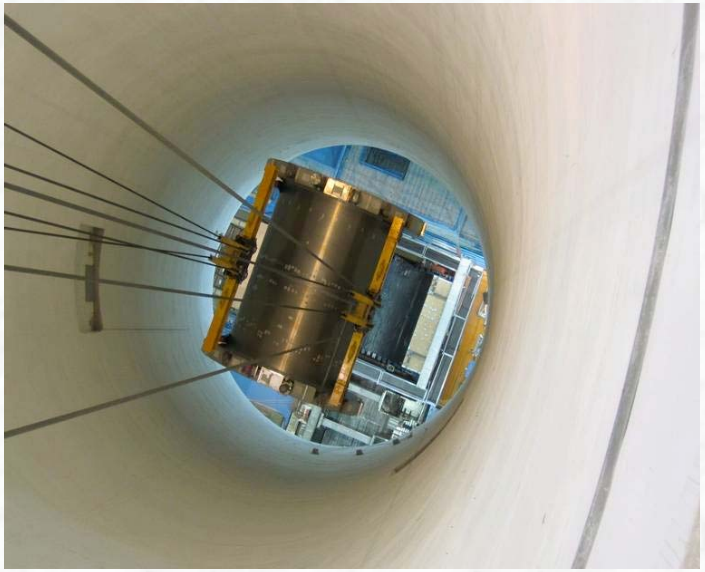


A few pictures from

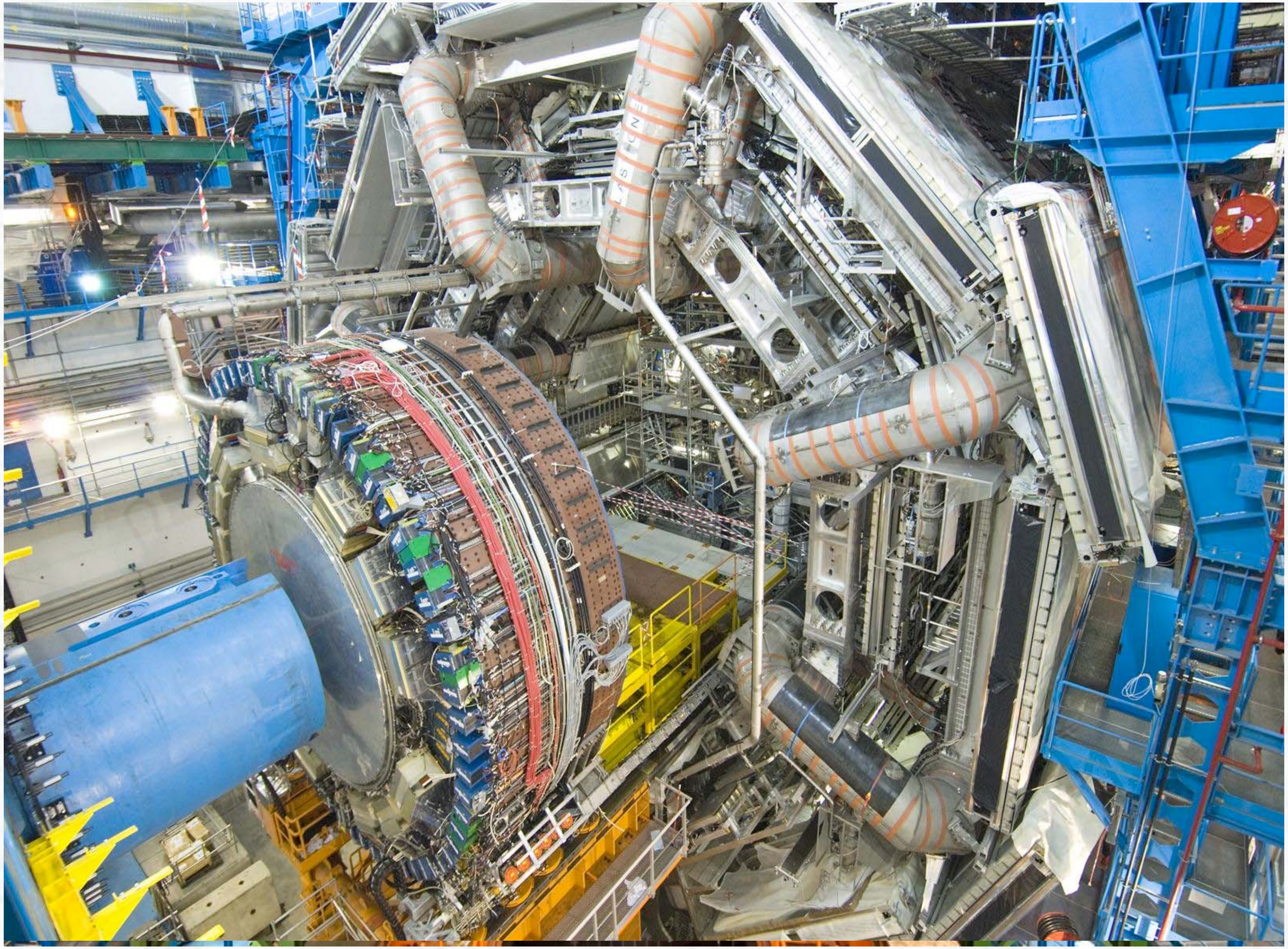
the detector installation

# ATLAS detector construction and installation

# ATLAS detector construction: Calorimeters

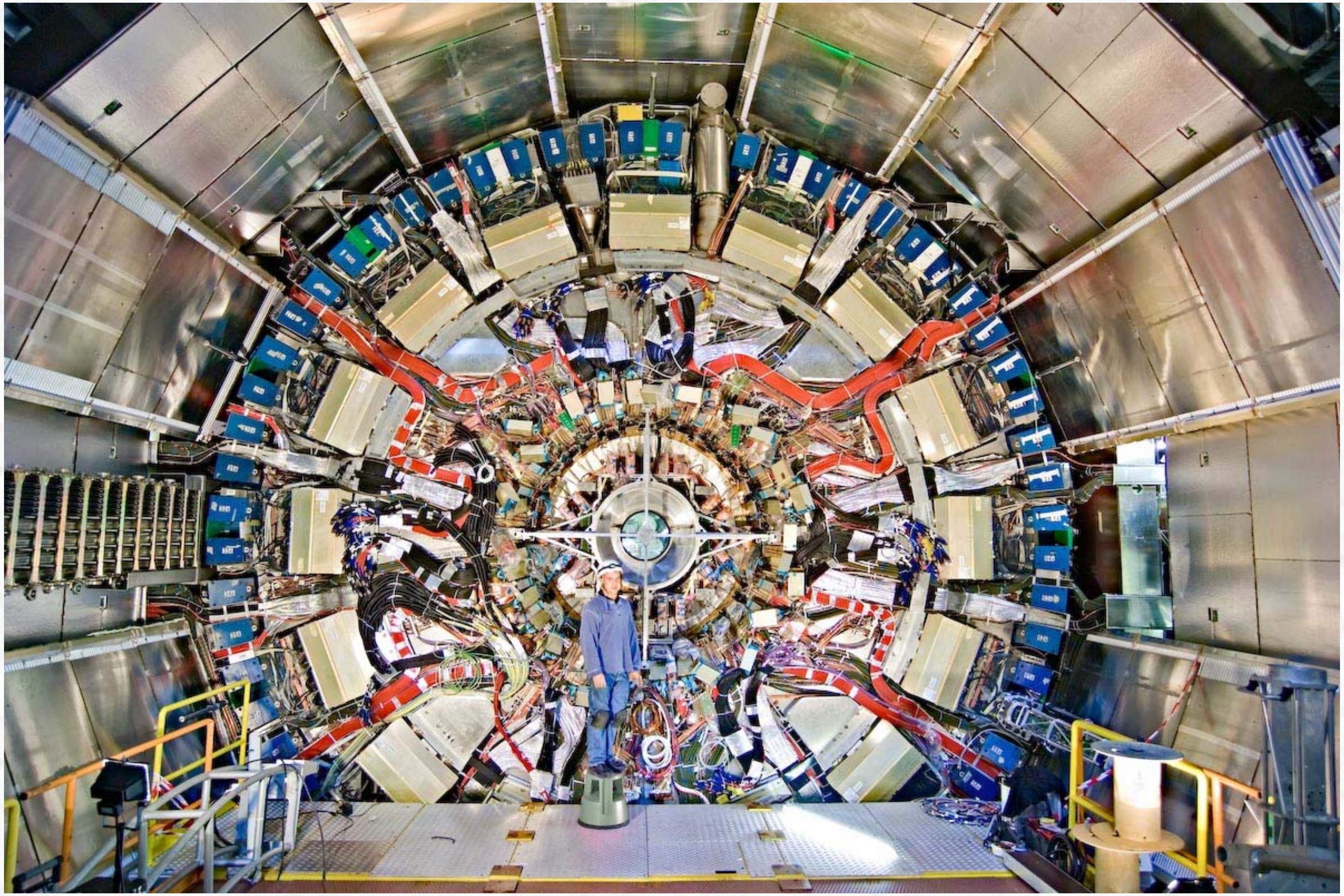


# ATLAS Installation

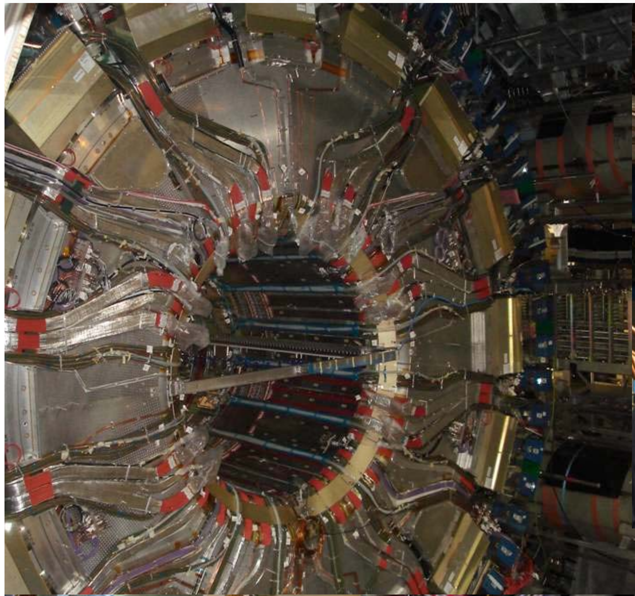


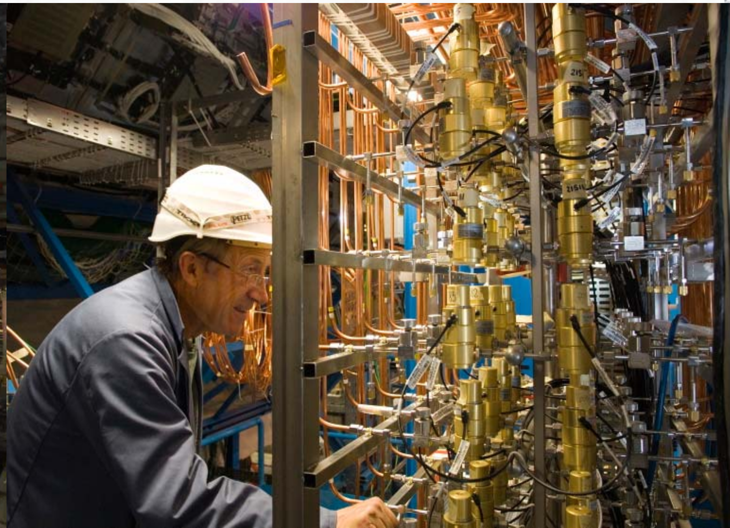
October 2006

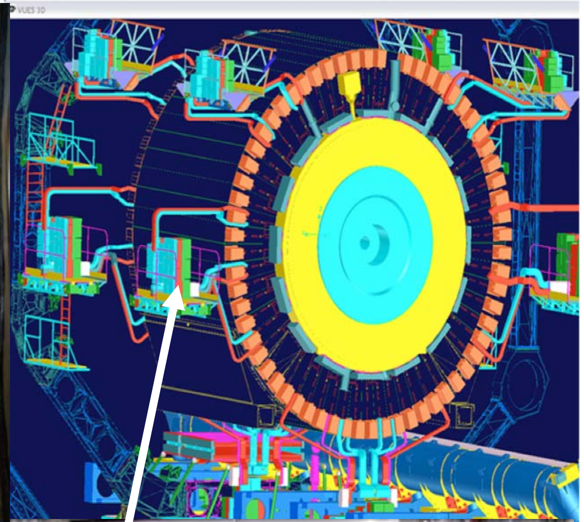
# Installation of one of the ATLAS Endcap Tracking Detectors (completed on 29. May 2007)



# Installation of Inner Detector Services







*~ 800 man-months of installation work over*

*~18 months, ~ 45 people involved/ day*

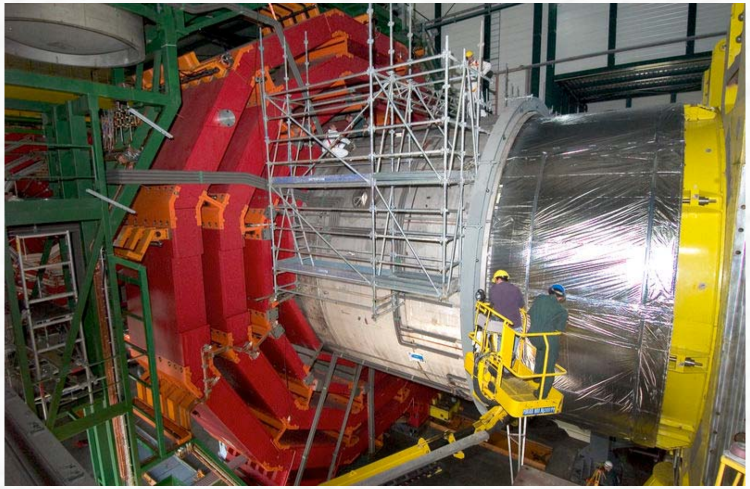
- ✓ ~ 9300 SCT cable-bundles
- ✓ ~ 3600 pixel cable-bundles
- ✓ ~ 30100 TRT cables
- ✓ ~ 2800 cooling & gas pipes

*All tested and qualified*

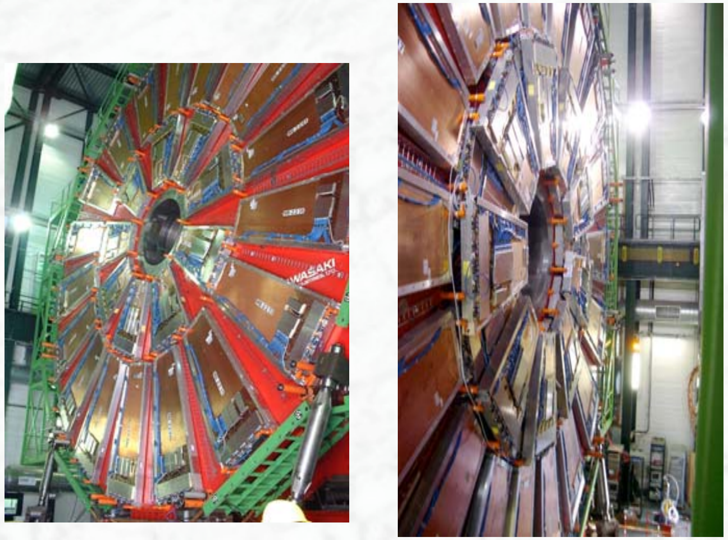
# Muon detectors and endcap toroid magnets


Installation of the second (last) endcap toroid: 12. July 07

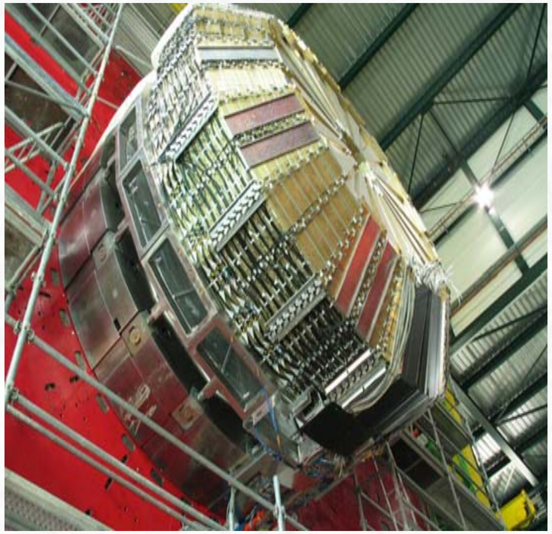
# CMS Installation

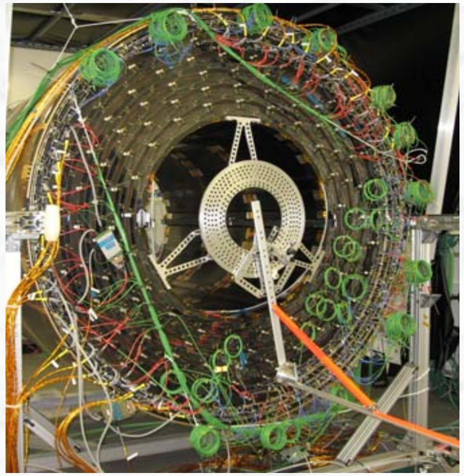
Coil inserted, 14. September 2005



Cathode Strip chambers and yoke endcaps

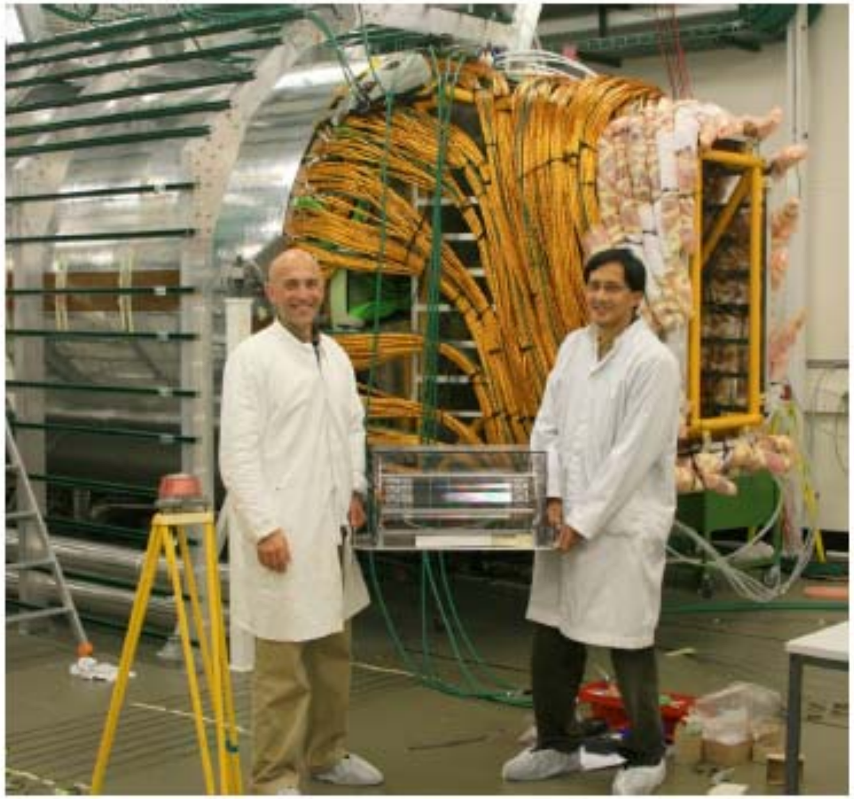


Hadronic calorimeter, endcap



Tracker, outer barrel

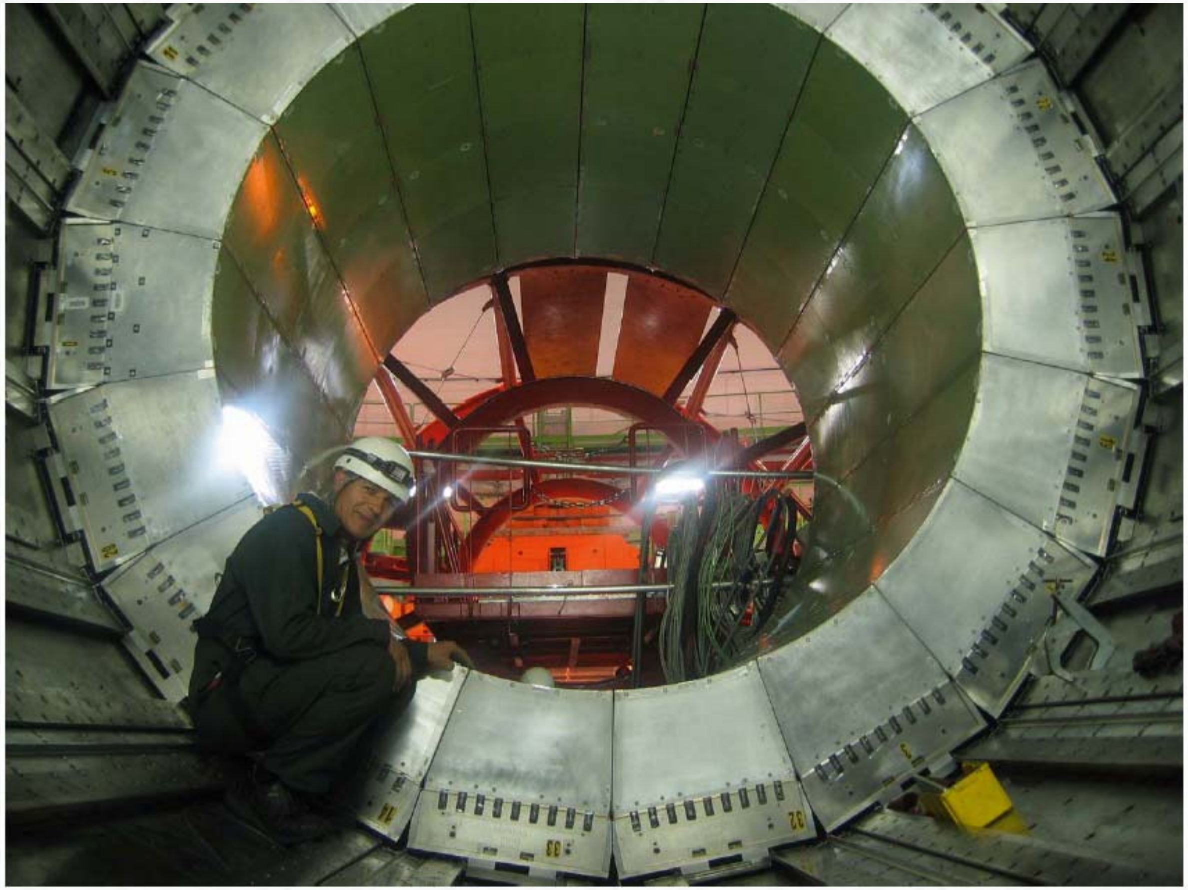
# CMS Tracker & ALICE TPC

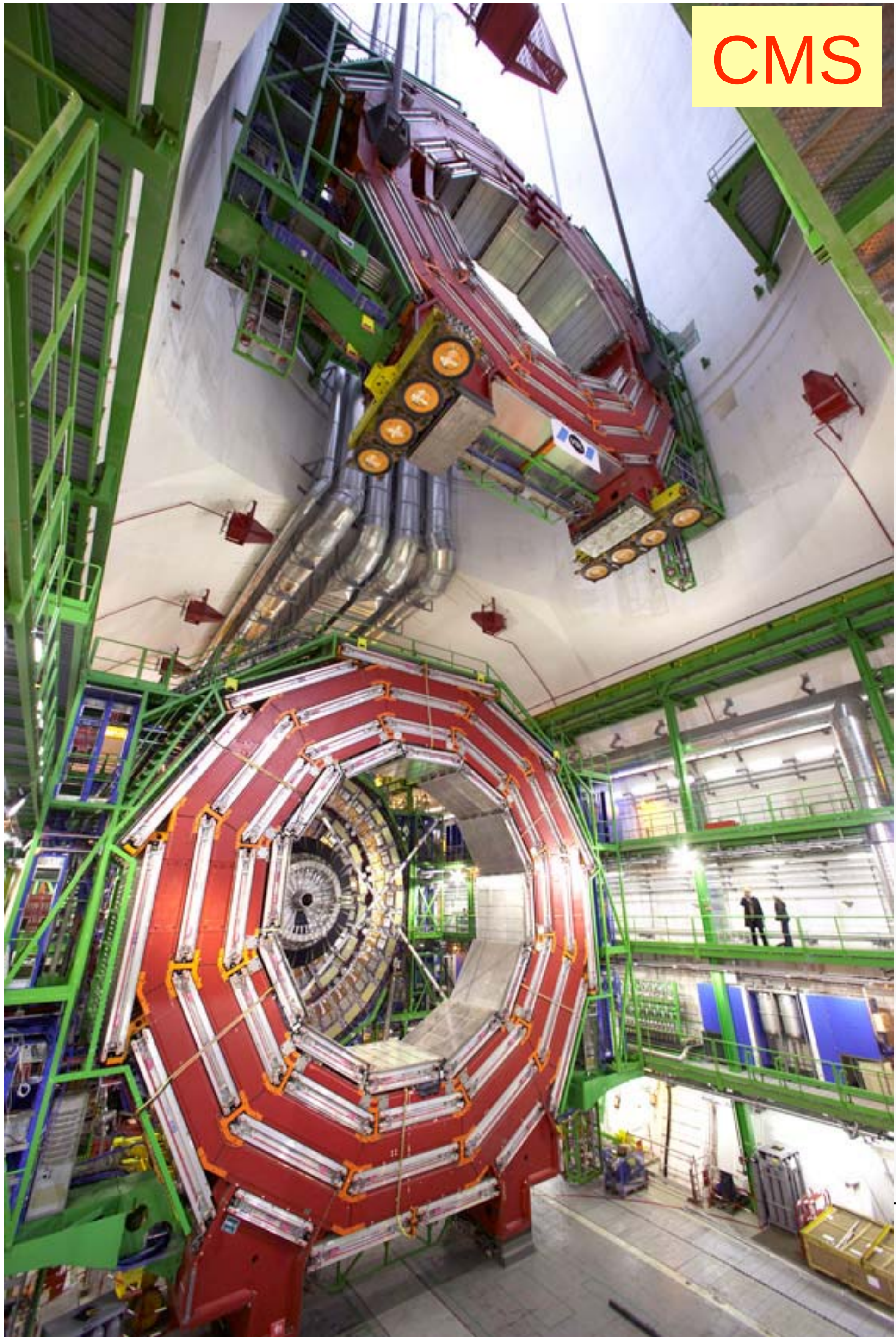


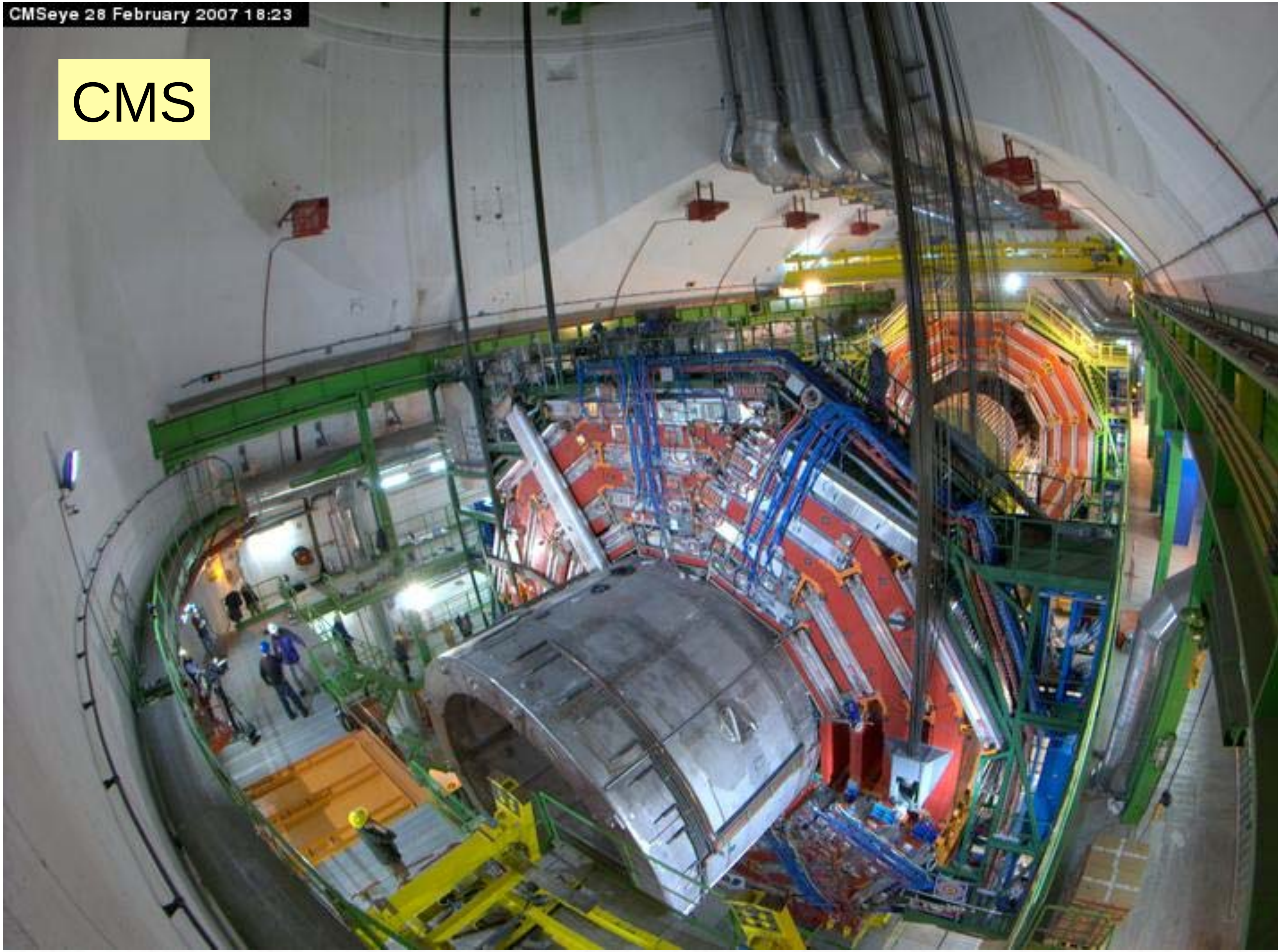
(plus a LEP silicon detector!)

# Installation of the CMS Electromagnetic Barrel Calorimeter

(1. half, completed on 22. May 2007)




CMS


CMSeye 28 February 2007 18:23
CMS

# CMS Detector closed for 10th Sep.