The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR 1773 - 15

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**SCHOOL ON PHYSICS AT LHC: "EXPECTING LHC"**
**11 - 16 September 2006**

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# *LHC: Machine and Detectors*
# *(LHC Collider and Experiments)*
# *Part II*

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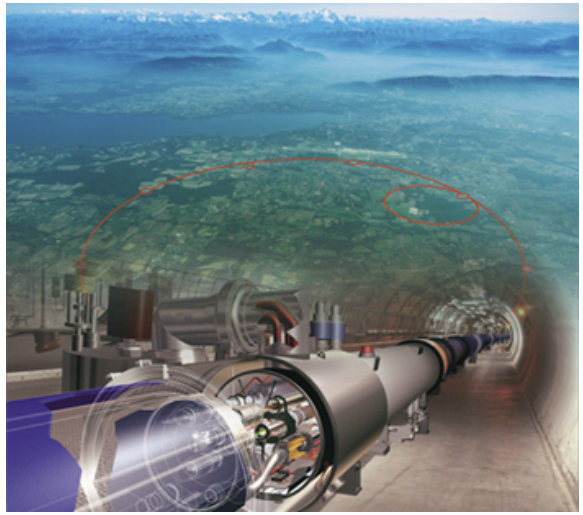
# LHC Collider and Experiments

Albert De Roeck/CERN
ICTP 11-6/09/06

LHC@ICTP 2006

The Abdus Salam
International Centre for Theoretical Physics

INFN
Istituto Nazionale
di Fisica Nucleare

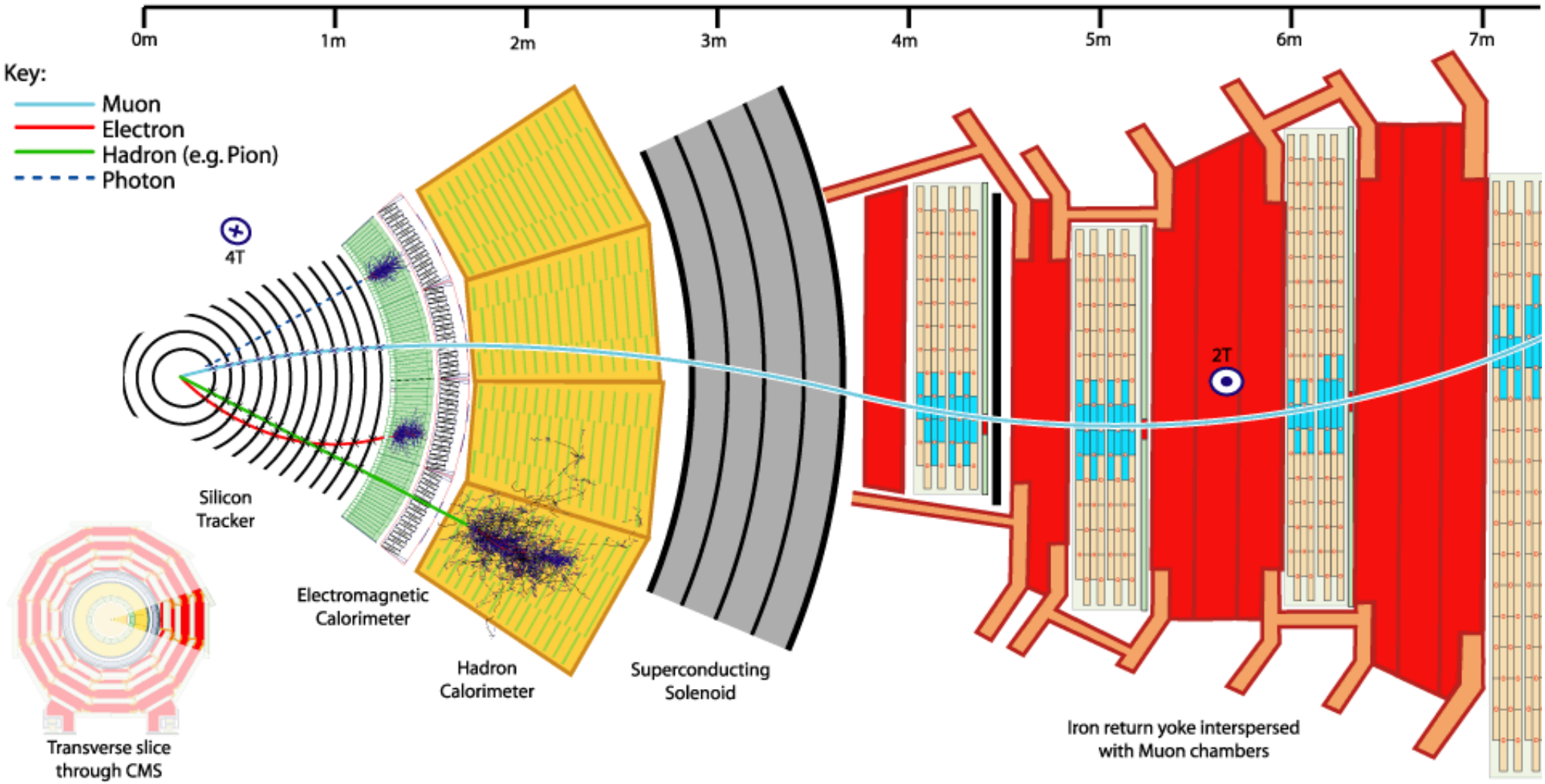


# Lecture Plan

- The LHC Collider
  - Introduction to the LHC
  - Experimental challenges
- The ATLAS and CMS experiments
- The specialised experiments
  - The LHCb experiment
  - The ALICE experiment
  - The forward experiments (TOTEM, LHCf) and MOEDAL
- Startup scenarios and first physics at the LHC

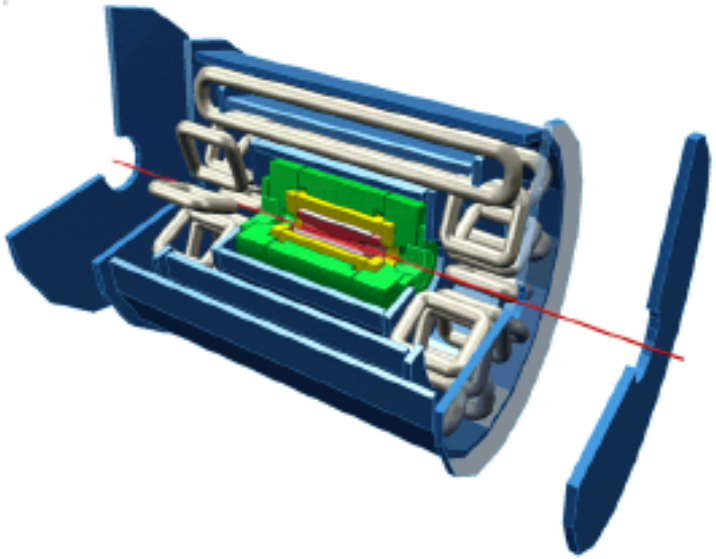
# The CMS & ATLAS Experiments

# Collider Detector

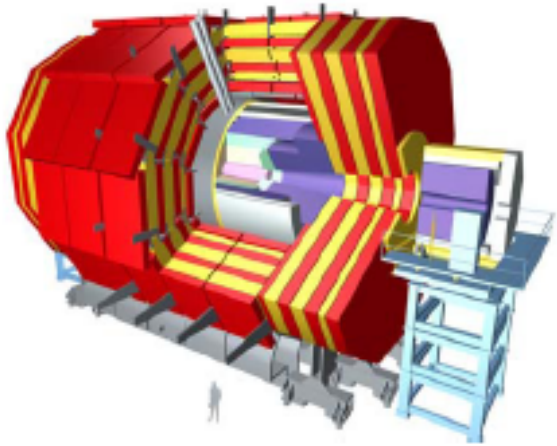


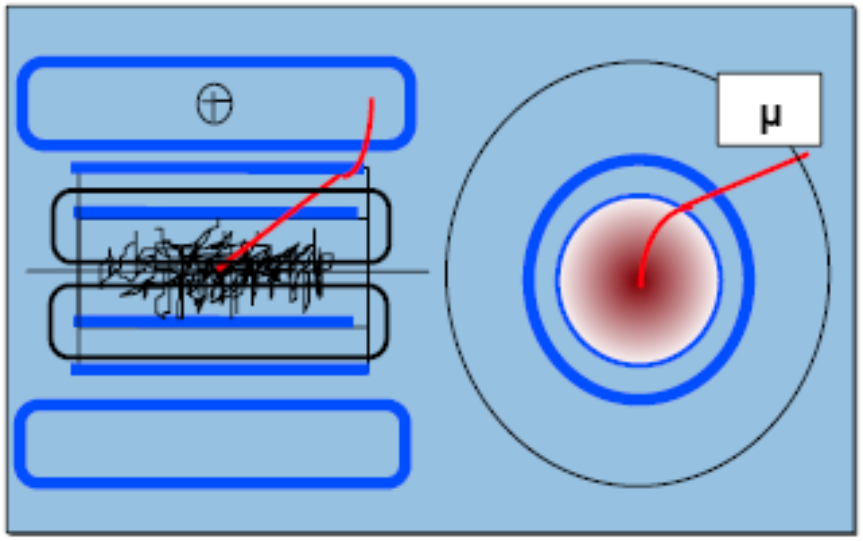
# ATLAS and CMS

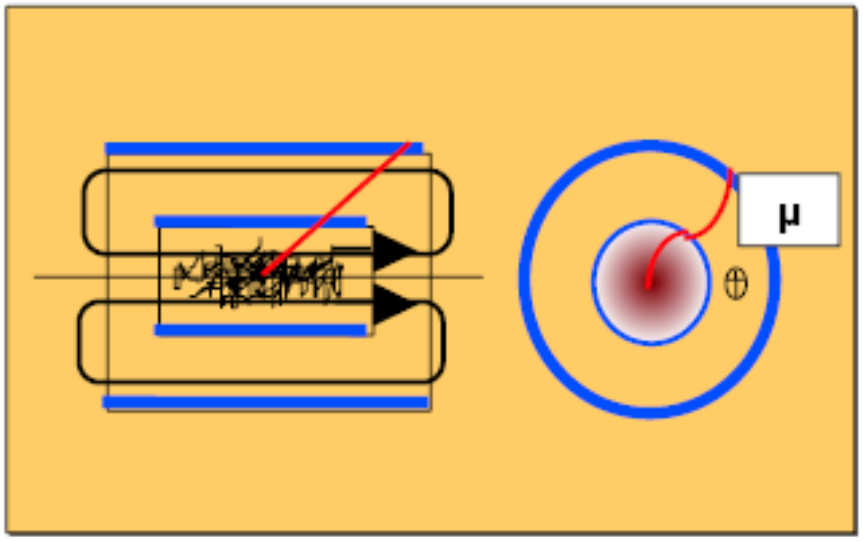
**ATLAS** A Toroidal LHC ApparatuS



**CMS** Compact Muon Solenoid

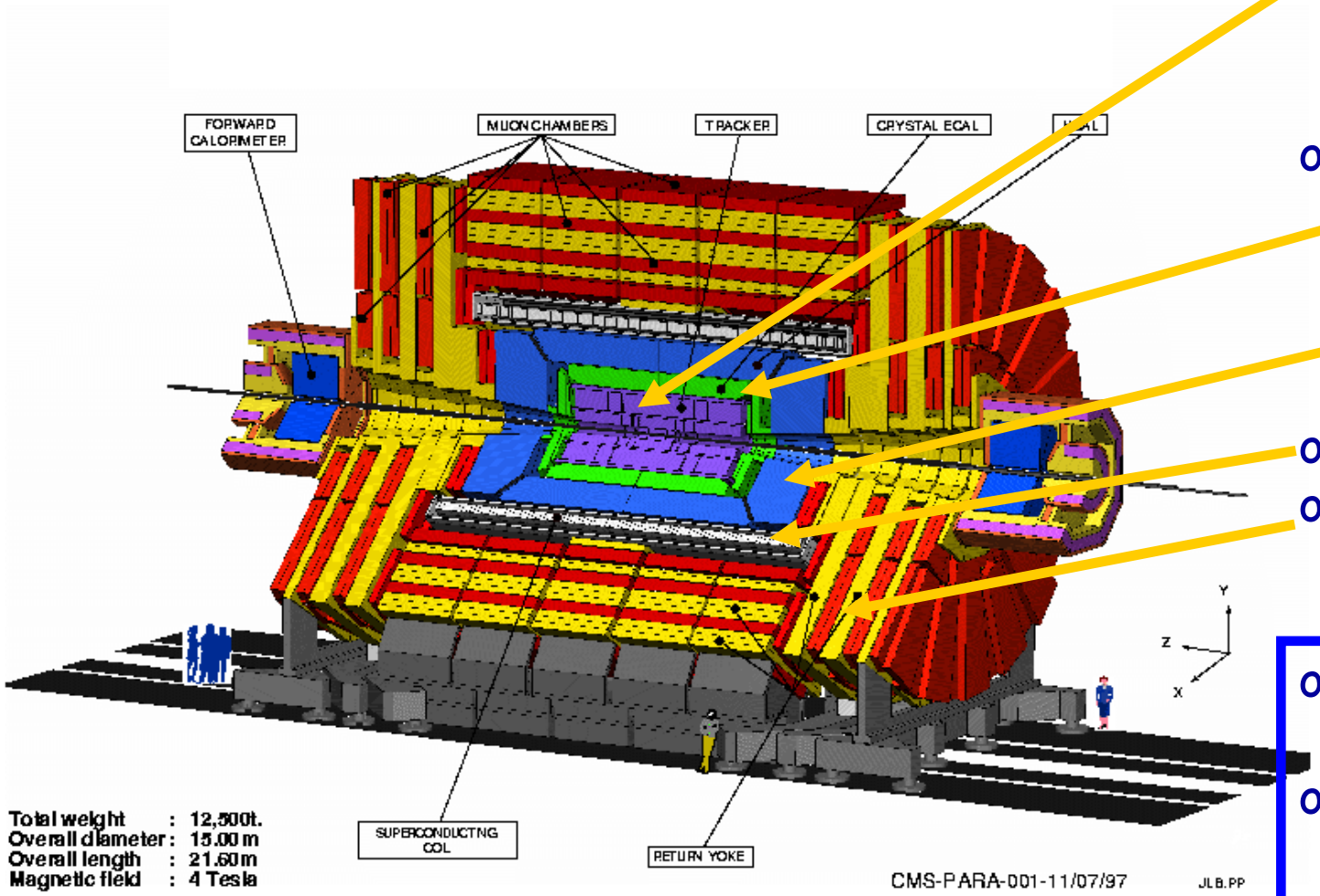





Will size matter?

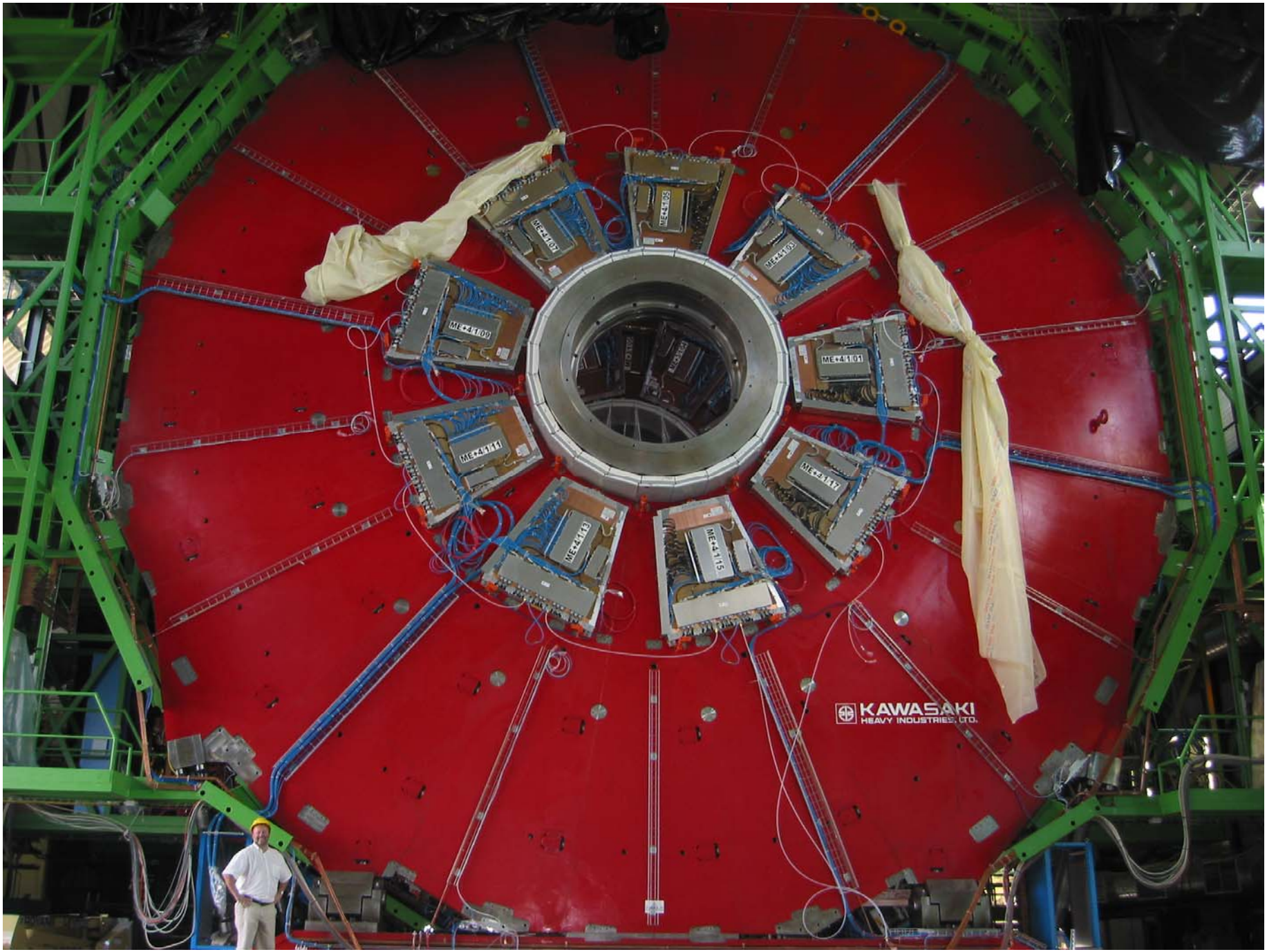
# The CMS experiment




- Tracking
  - Silicon pixels
  - Silicon strips
- Calorimeters
  - PbW04 crystals for Electro-magn.
  - Scintillator/steel for hadronic part
- 4T solenoid
- Instrumented iron for muon detection

- In total about 98 000 000 channels
- Size of 1 event 1 000 000 Bytes
- Readout to disk 100 events/sec

**A Huge enterprise !**

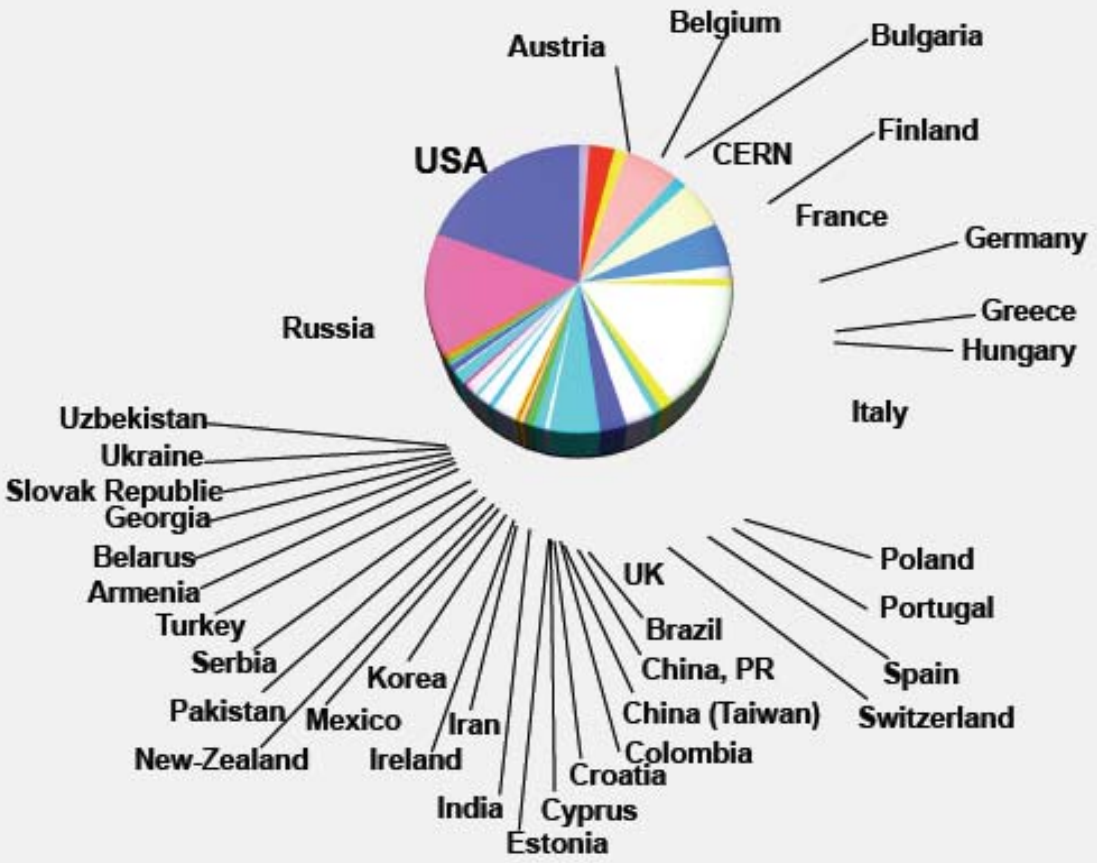

ME+4/100
ME+4/101
ME+4/114
ME+4/115
KAWASAKI
HEAVY INDUSTRIES, LTD.

# CMS Collaboration

| | Institutions |
|---|---|
| Member States | 61 |
| Non-Mem. States | 64 |
| USA | 49 |
| Total | 174 |

| | Scientists |
|---|---|
| Member States | 1055 |
| Non-Mem. States | 428 |
| USA | 547 |
| Total | 2030 |

| Associated Institutes | |
|---|---|
| Number of Scientists | 46 |
| Number of Laboratories | 8 |




**2030 Scientific Authors, 38 Countries, 174 Institutions**

May, 04 2006/gm
http://cmsdoc.cern.ch/pictures/cmsorg/overview.html

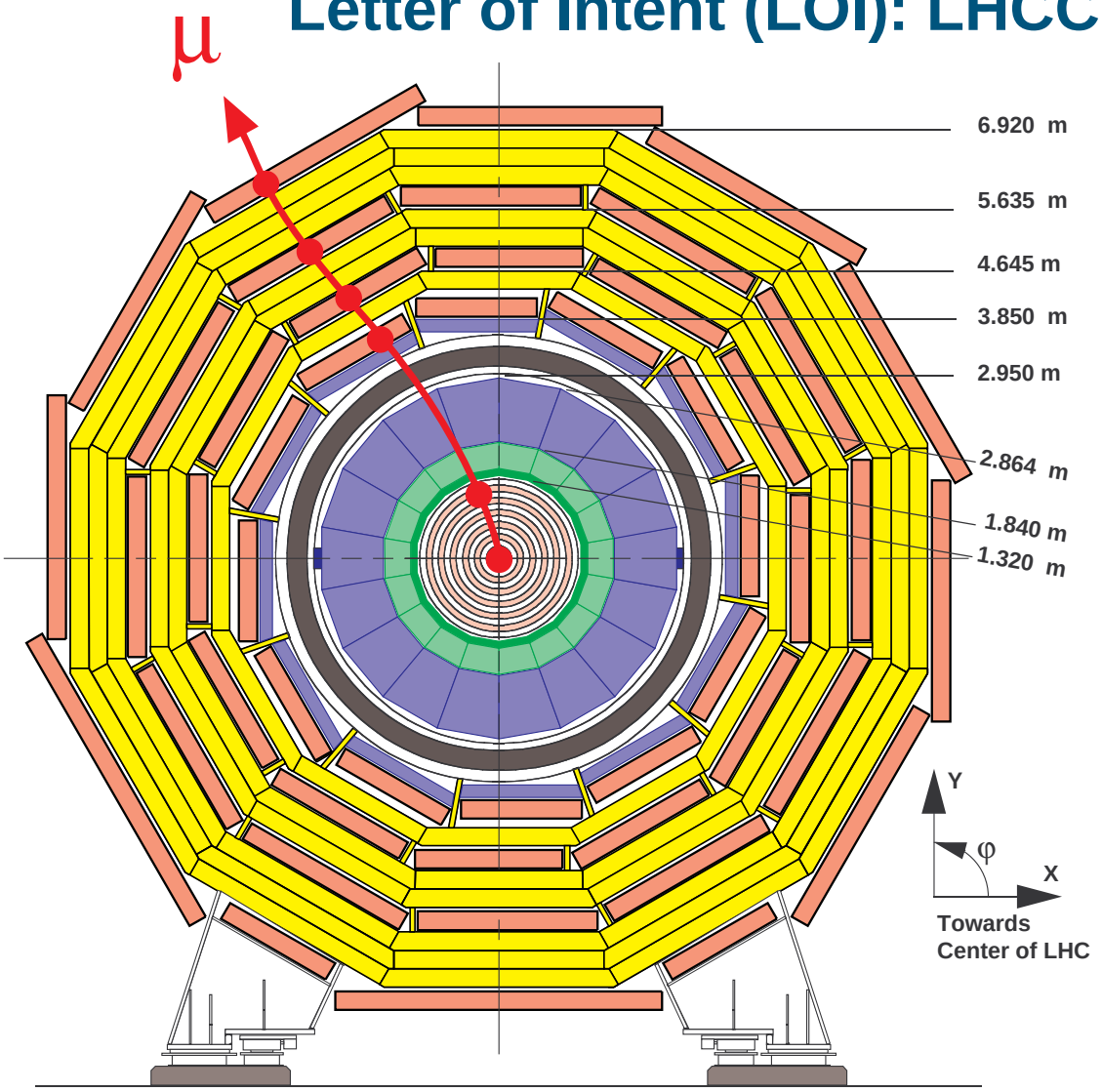
# CMS Detector Design Priorities

Expression of Intent (EOI): Evian 1992

1. A robust and redundant Muon system
2. The best possible e/$\gamma$ calorimeter consistent with 1.
3. A highly efficient Tracking system consistent with 1. and 2.
4. A hermetic calorimeter system.
5. A financially affordable detector.

# Compact Muon Solenoid (CMS)

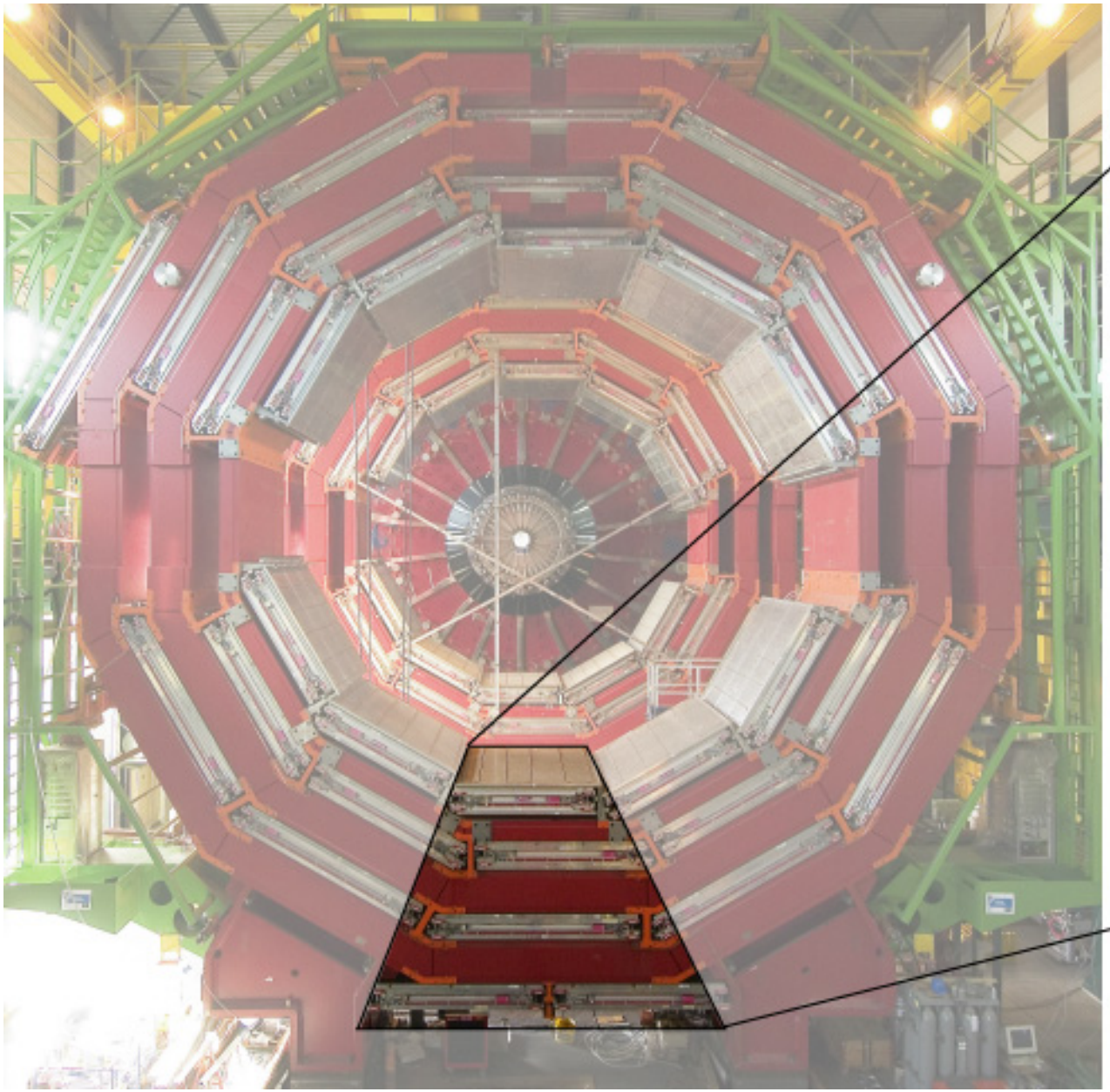
## Letter of Intent (LOI): LHCC, TDR in 1994

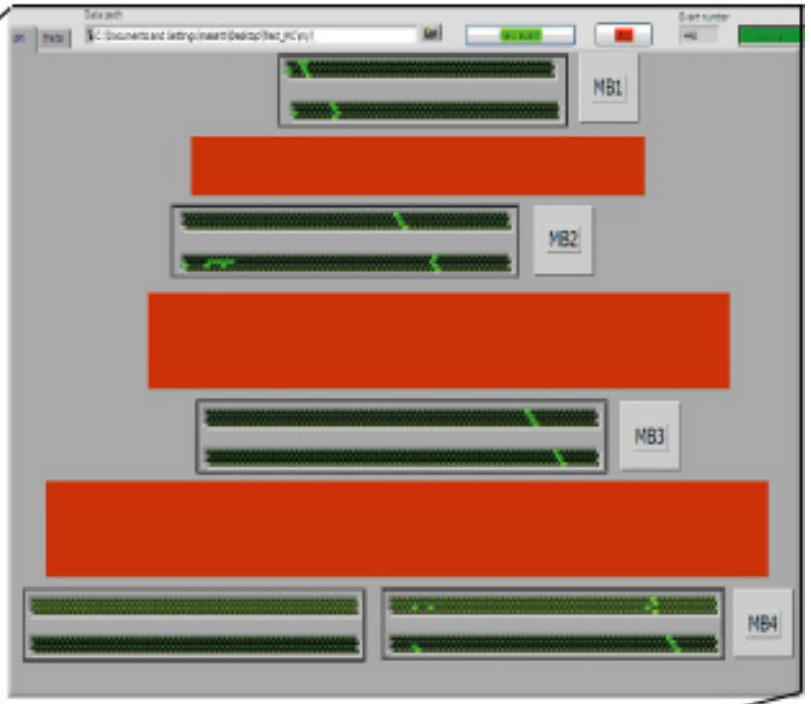


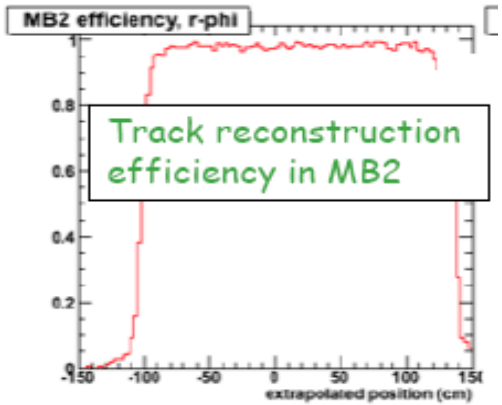

Transverse View

- Strong Field 4T
- Compact design
- Solenoid for Muon $P_t$ trigger in transverse plane
- Redundancy: 4 muon stations with 32 r-phi measurements
- $\Delta P_t/P_t \sim 5\%$ @1TeV for reasonable space resolution of muon chambers (200μm)

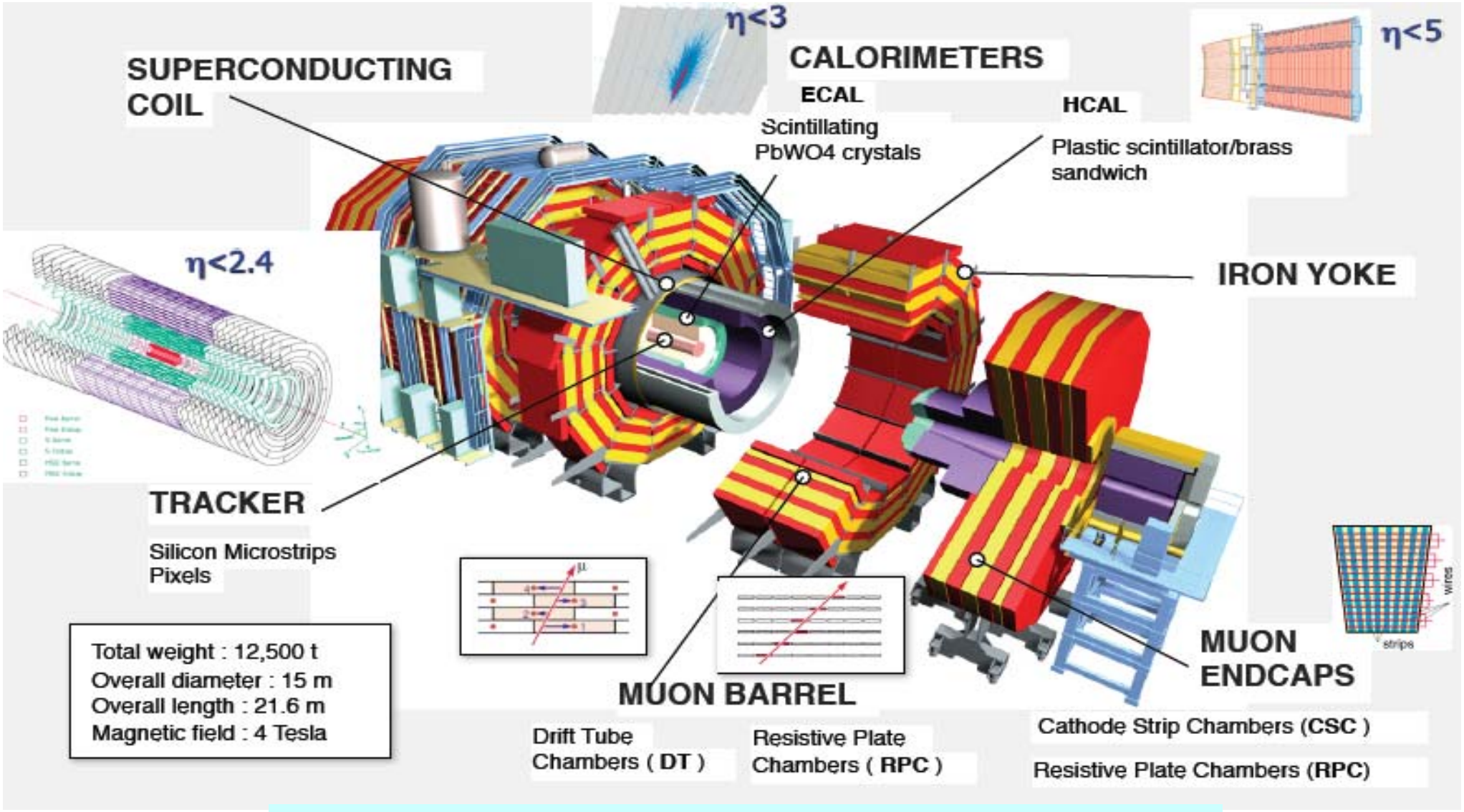
# December 2005
# Cosmic Muons in CMS





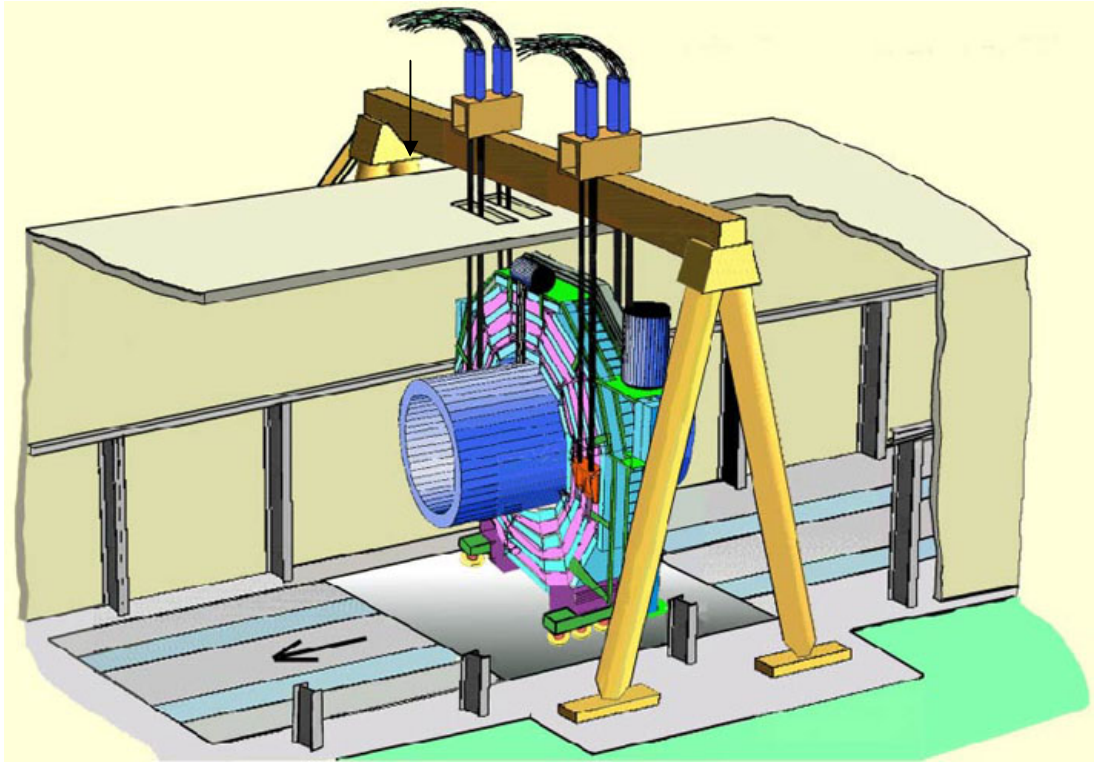
# The Modular Design of CMS




Acceptance: Calorimetry $|\eta| < 5.0$ Tracking $|\eta| < 2.4$

# Transfer CMS Underground in 2006

Gantry installed over PX56. Load test of pit cover 2500t: Apr06
Load test of crane: May06. HF lowering: September 06-February 06




YB0 lowering (2000t): Dec 06

# Getting it to IP5

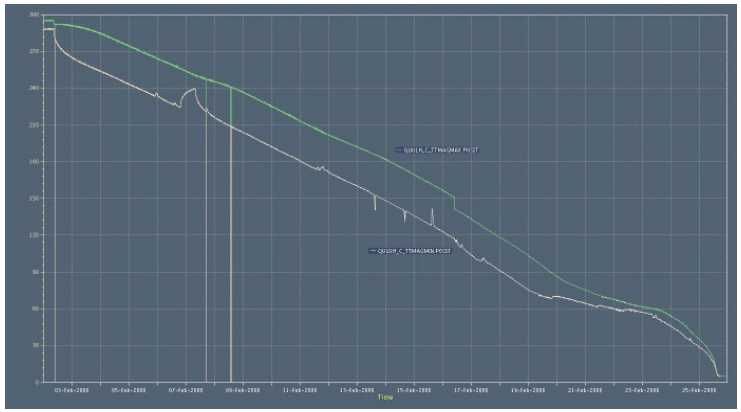
# CMS Solenoid

Swivelling of coil 25 Aug

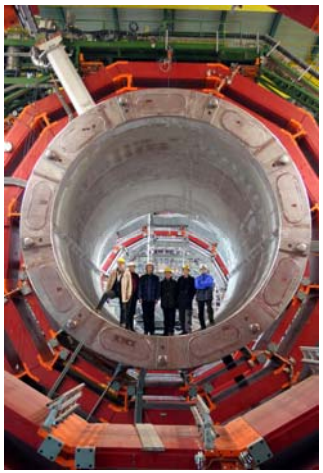
Coil inserted 14 Sep.

| | | |
|---|---|---|
| Magnetic length | | 12.5 m |
| Free bore diameter | 6 m | |
| Central magnetic induction | | 4 T |
| Nominal current | | 20 kA |
| Stored energy | | 2.7 GJ |
| Magnetic Radial Pressure | | 64 Atmospheres! |
| Reinforced Conductor | 53 km (20 x 2.65 km) | |

Coil Cooled down to 4.5ºK in 25 days (Feb). Test on Surface (May-Aug)

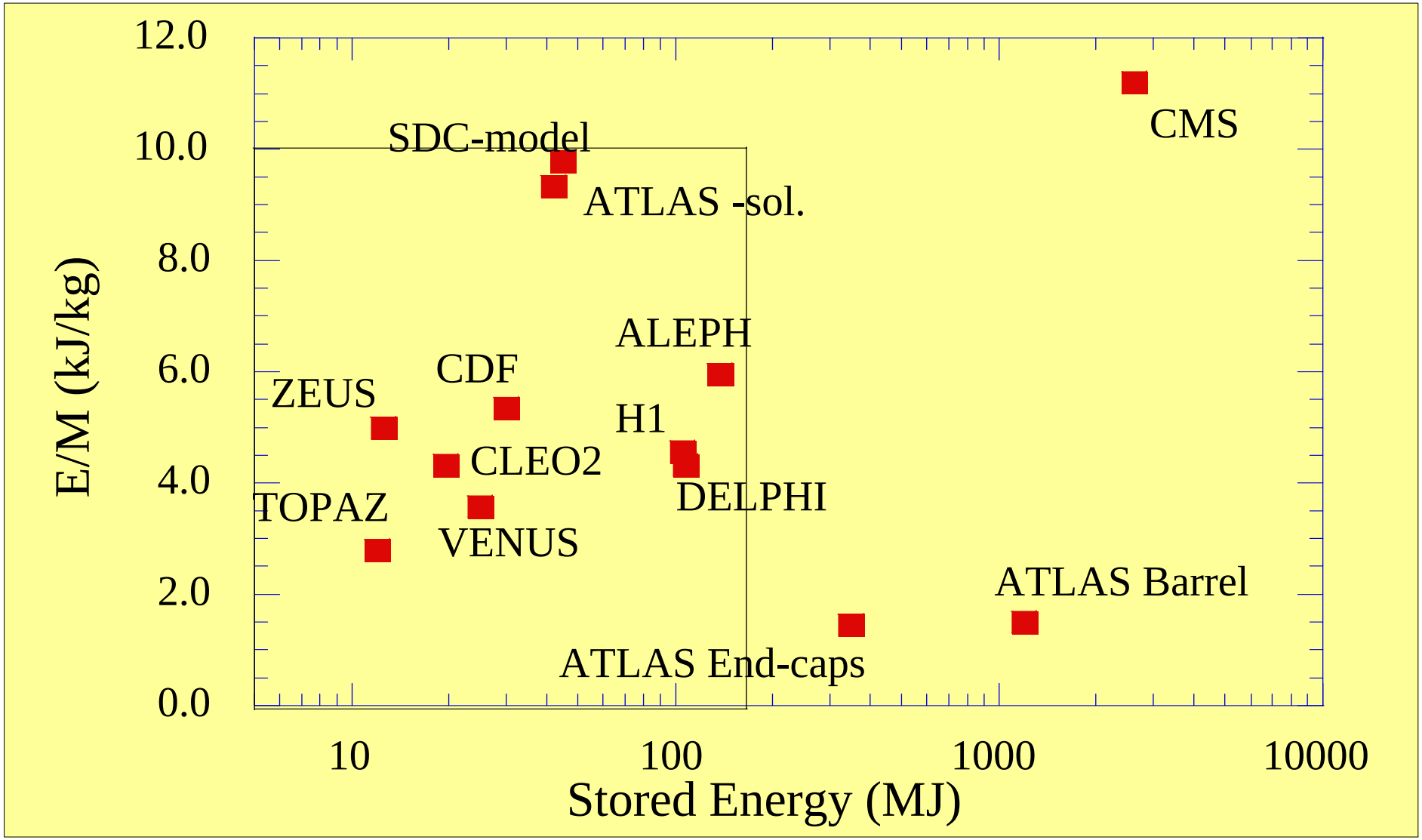


Vacuum Tank welded (Nov-Jan)



Big Milestone for CMS:
August 28: 4Tesla field reached!!

# *Specific Energy of the CMS Coil (kJ/kg of cold mass)*

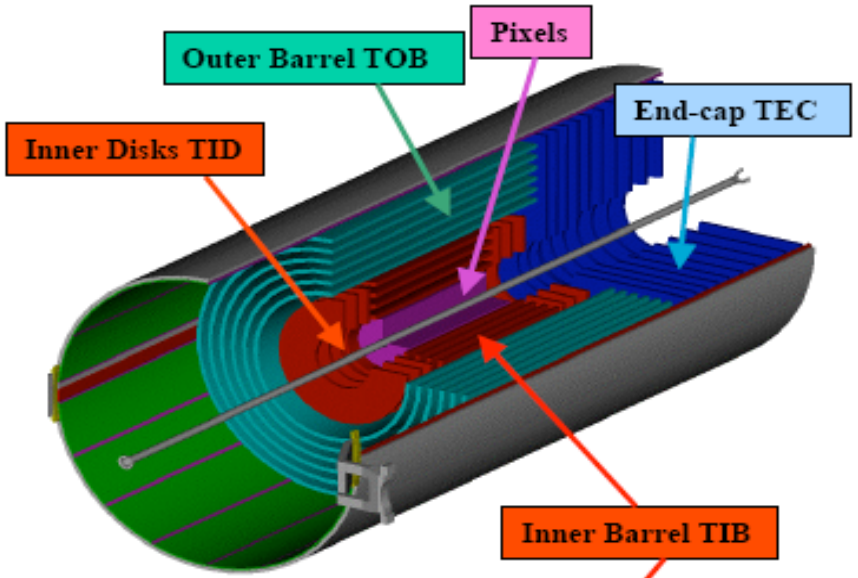


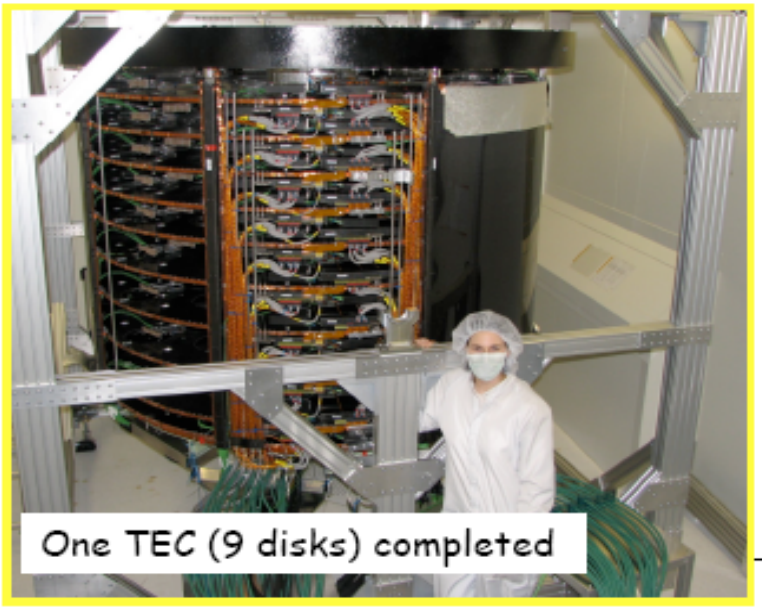

Displacements in endcaps of the order of 2cm if the field is on

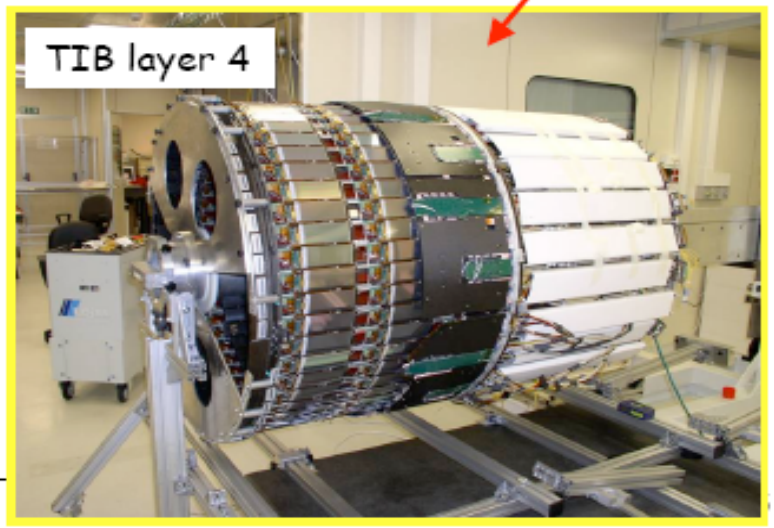
# The Inner Tracker

About 220 $m^2$ of Si Sensors
$\Rightarrow 10^7$ Si strips
$\Rightarrow 6.5 \bullet 10^7$ pixels

All 16000 modules finished
Installation in IP5 in April 07

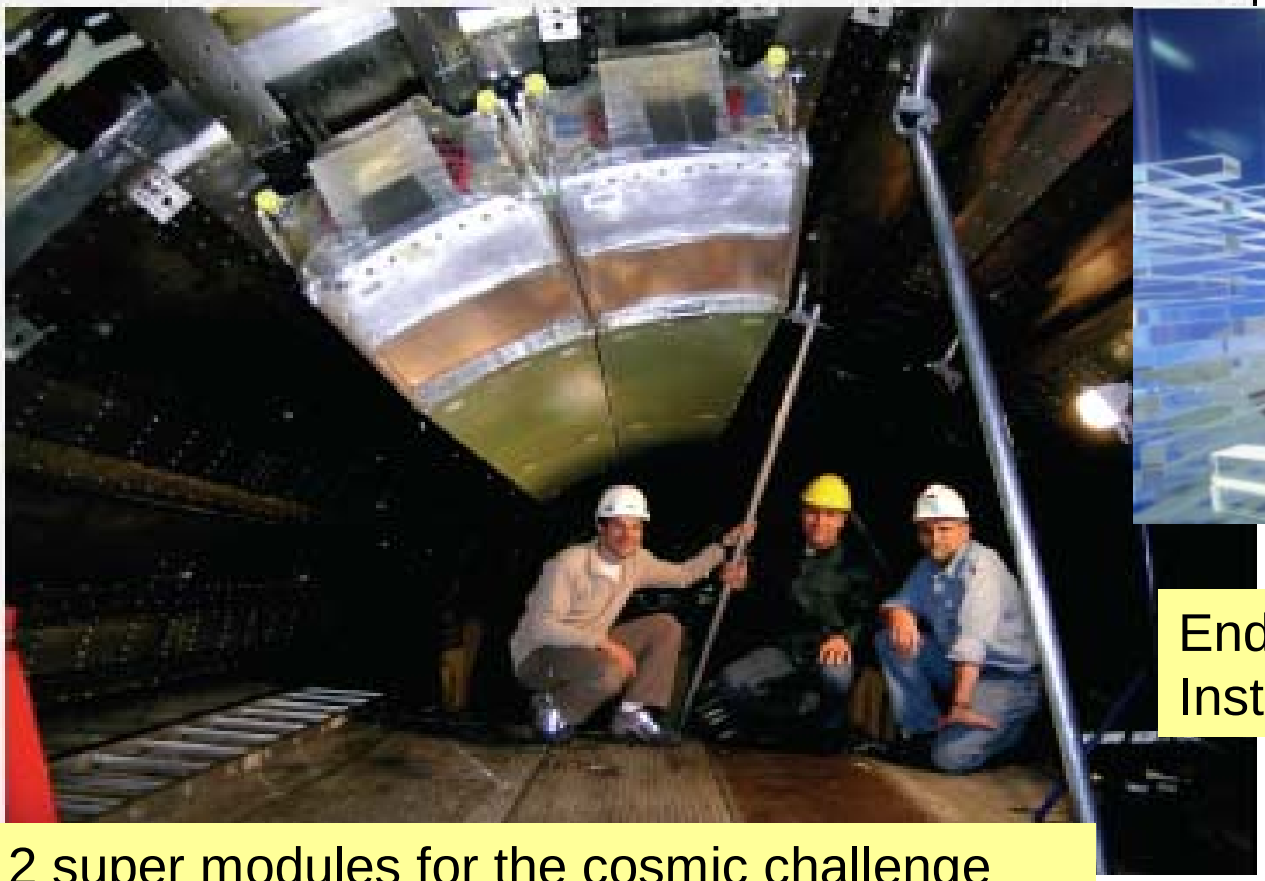




One TEC (9 disks) completed

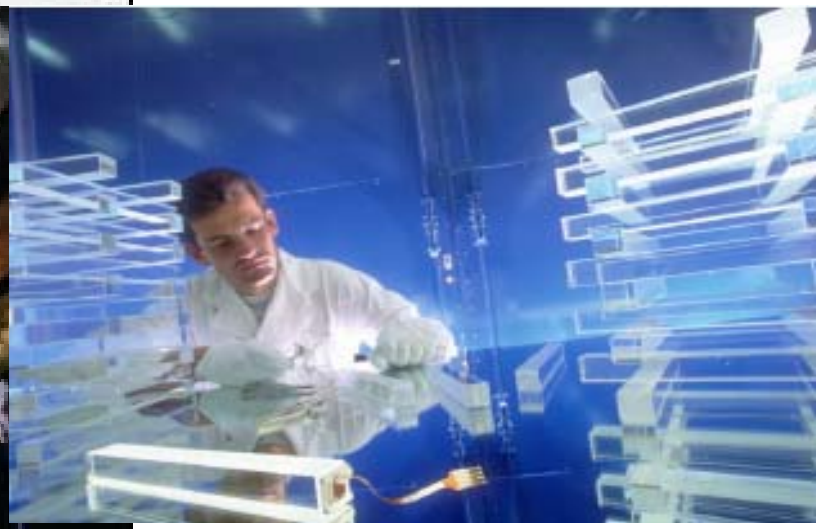

TIB layer 4

# The Electromagnetic Calorimeter

Barrel: 36 super modules/1700 crystals each
Total of 85% delivered (61000) crystals
Finalized February 2007/install for pilot run



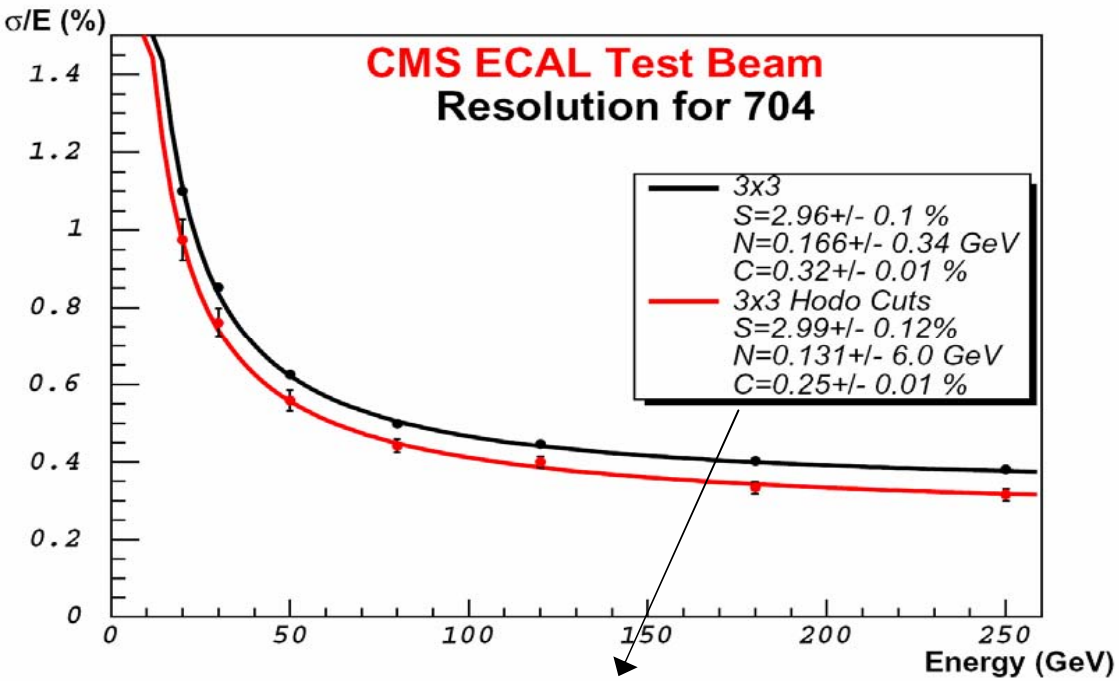
2 super modules for the cosmic challenge



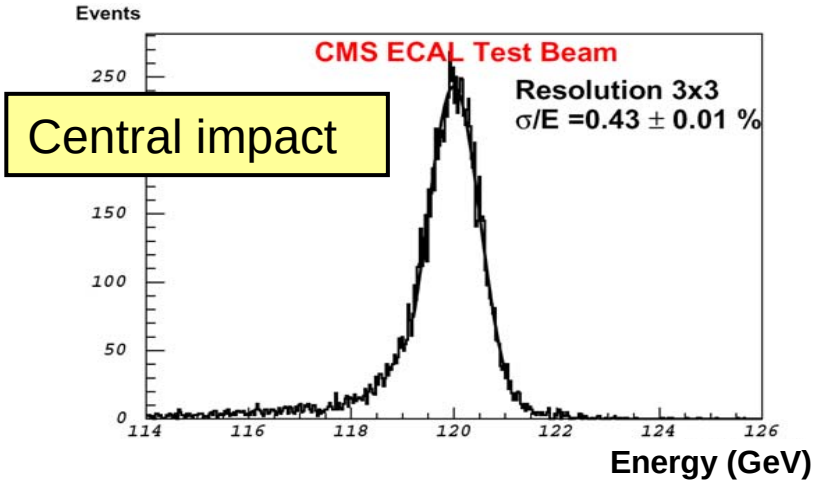
Endcap: Finalized January 2008
Install for first physics run

# ECAL test beam results

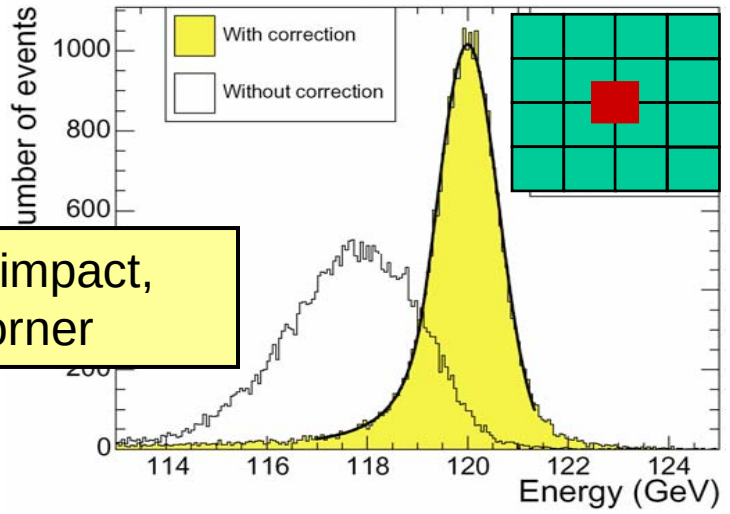
- Supermodule in H4 beam in 2004 (1700 Crystals)
- Demonstrate expected performance




$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2,$$



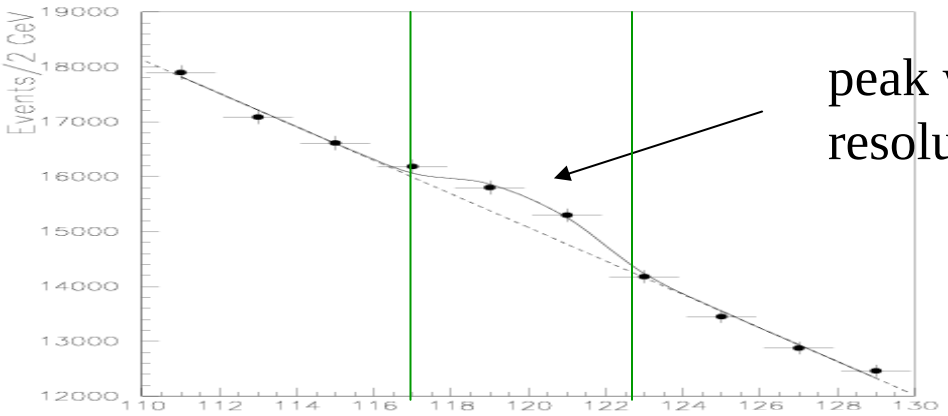

Central impact




20 x 20 mm$^2$ impact, centred on corner

# How can one claim a discovery ?

Suppose a new narrow particle $X \to \gamma\gamma$ is produced:




peak width due to detector resolution

$m_{\gamma\gamma}$

## Signal significance :

$$S = \frac{N_S}{\sqrt{N_B}}$$

$N_S$= number of signal events
$N_B$= number of background events

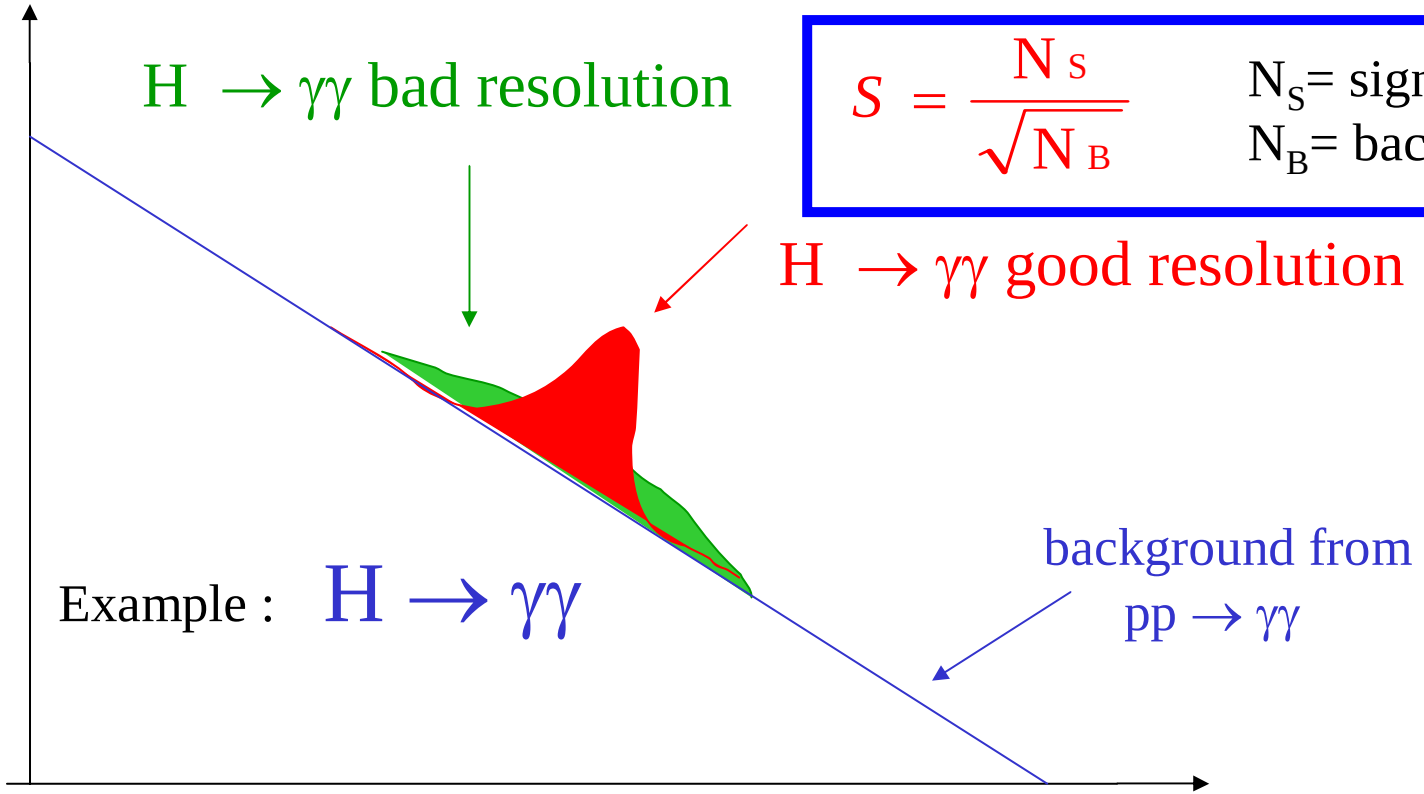
} in peak region

$\sqrt{N_B} \equiv$ error on number of background events

$S > 5$ : signal is larger than 5 times error on background.
Probability that background fluctuates up by more than $5\sigma$ : $10^{-7} \to$ discovery

# SM Higgs Search Strategy

- Excellent energy resolution of EM calorimeters for e/γ and of the tracking devices for μ in order to extract a signal over the backgrounds.

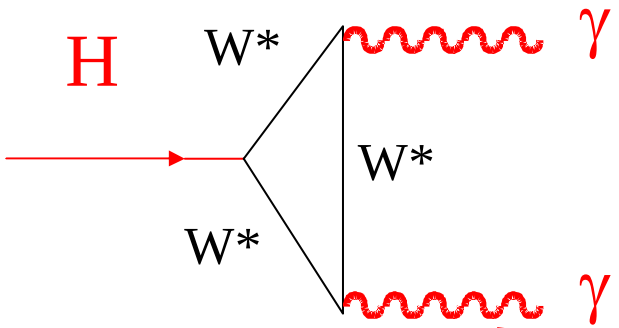


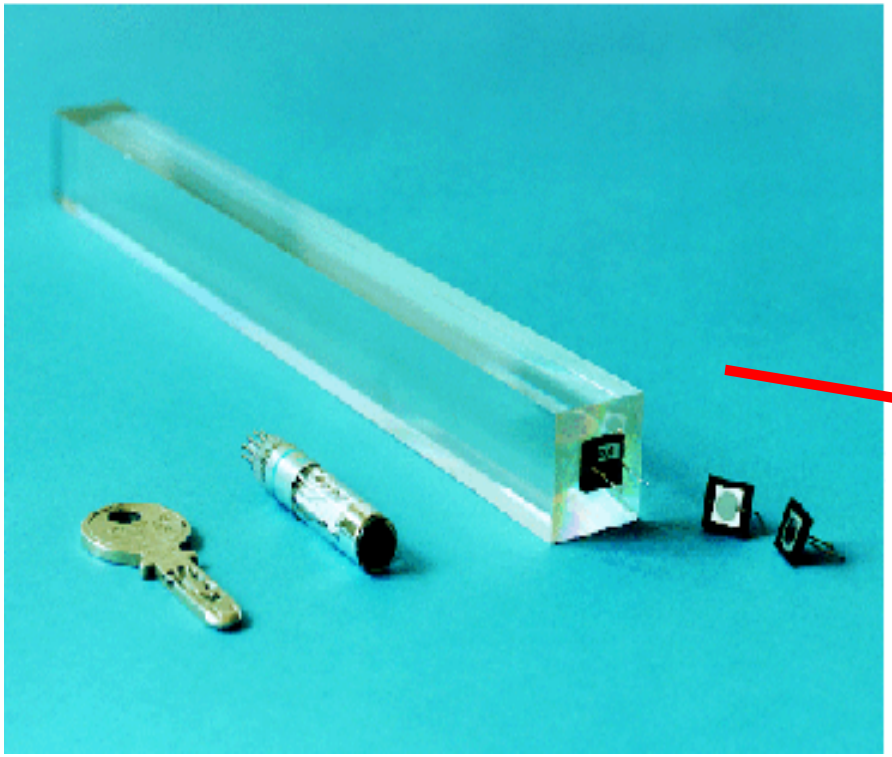

$$S = \frac{N_S}{\sqrt{N_B}}$$

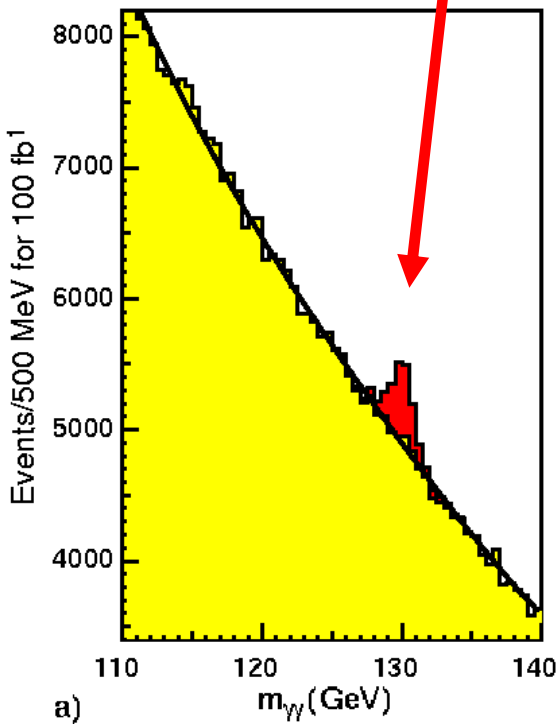
$N_S$= signal events
$N_B$= background events

# Measurements of a light Higgs

If the Higgs is light (115-120 GeV) then one of the most promising signals is $H \rightarrow \gamma\gamma$ (i.e. 2 photons)






100 fb$^{-1}$

Excellent calorimetery needed ($PbWO_4$)

# The Hadronic Calorimeter

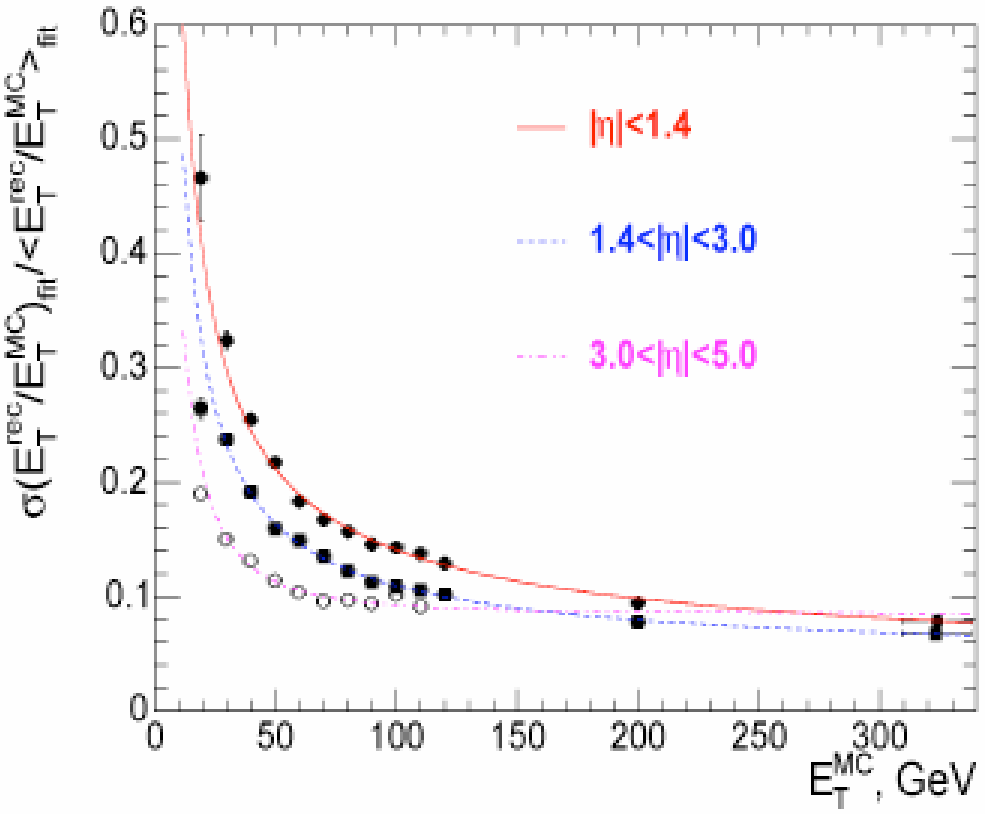
Completed

Being commisioned

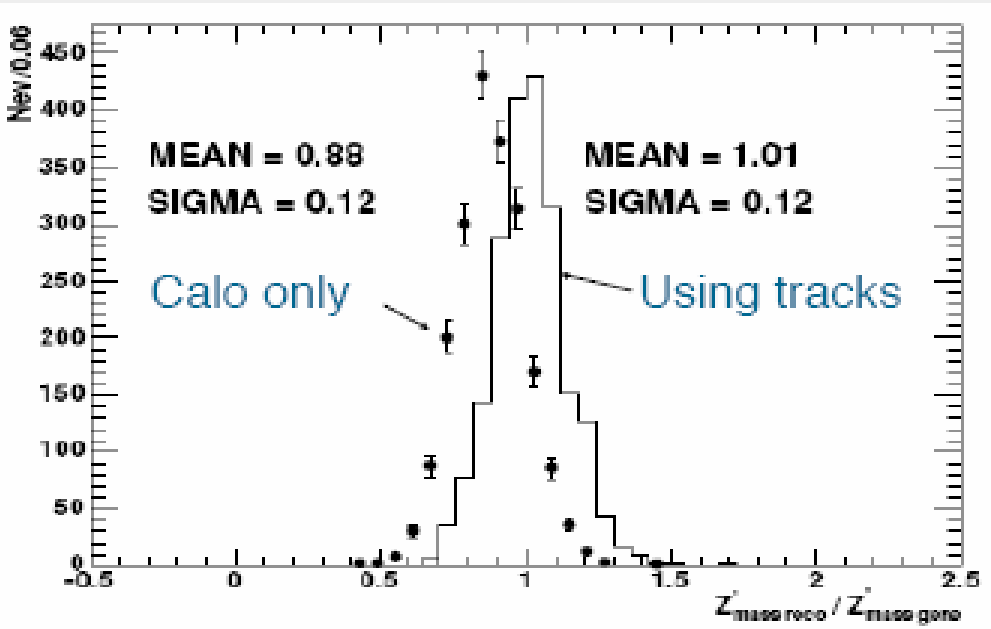
Brass/Scintillator

# Jet and Mass resolutions

Jet $E_T$ resolution



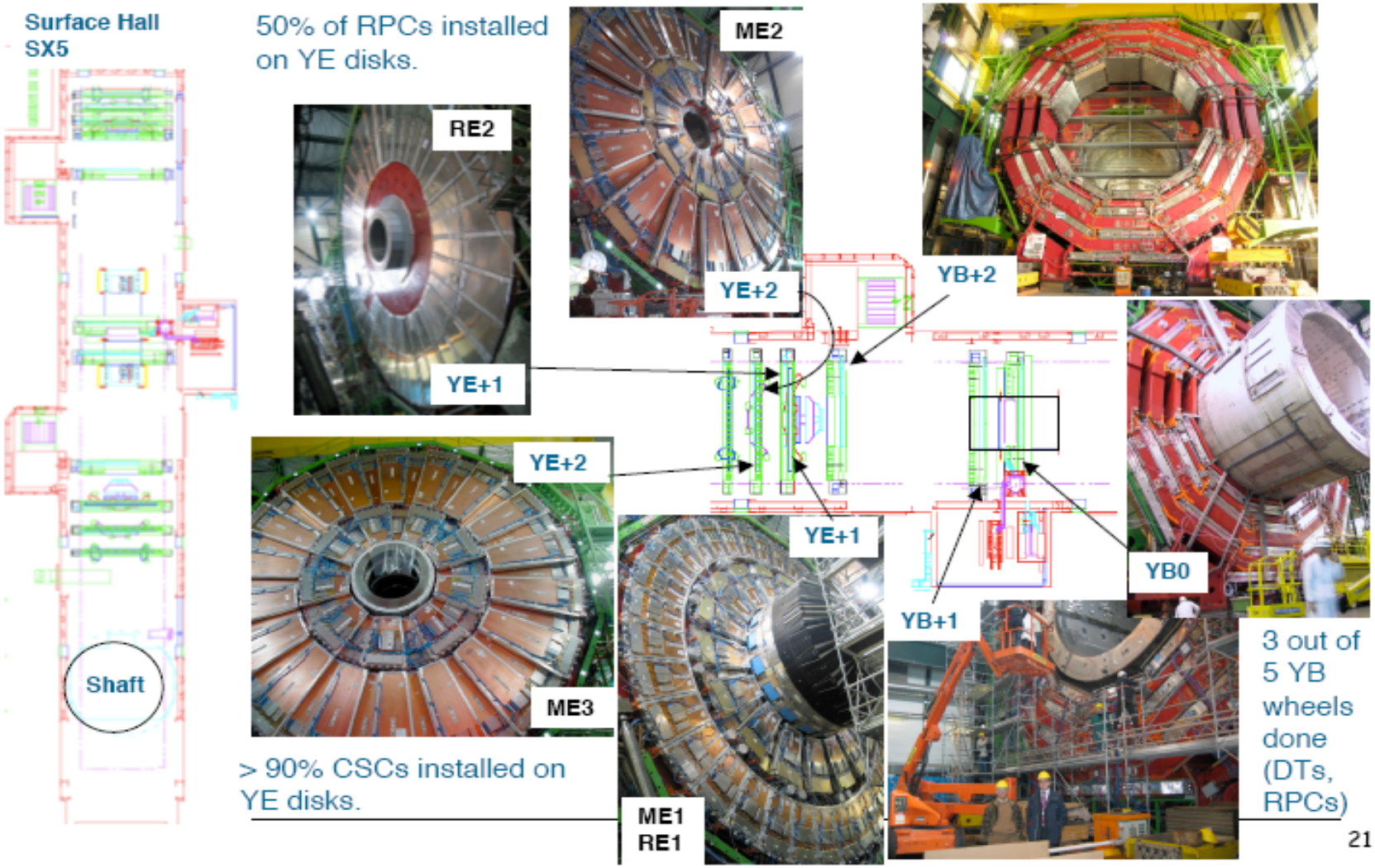

$M_{jj}$ resolution at 120 GeV




$M_{jj}$ resolution ≤ 15%

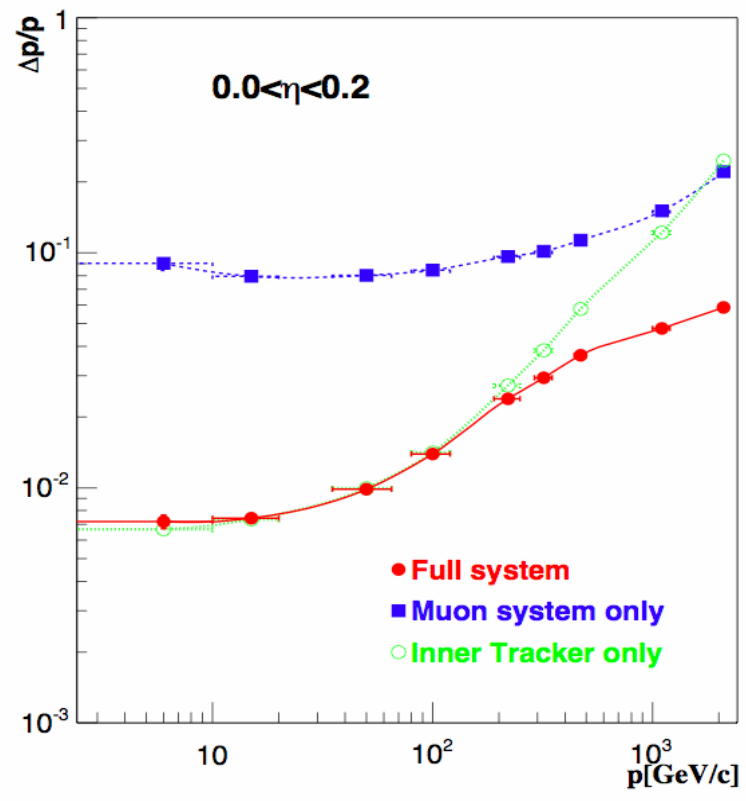
# The Muon System

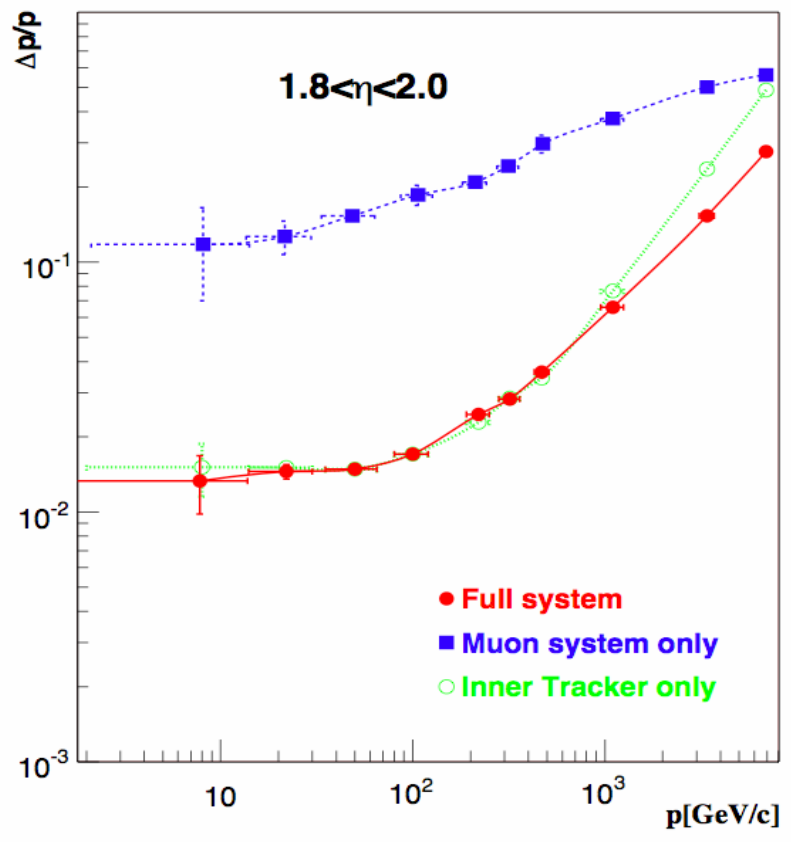
Muon Chambers: Barrel (DT+RPC) 60% complete
Endcap (CSC+RPC) 90% complete



# Muon Reconstruction (Momentum Res.)

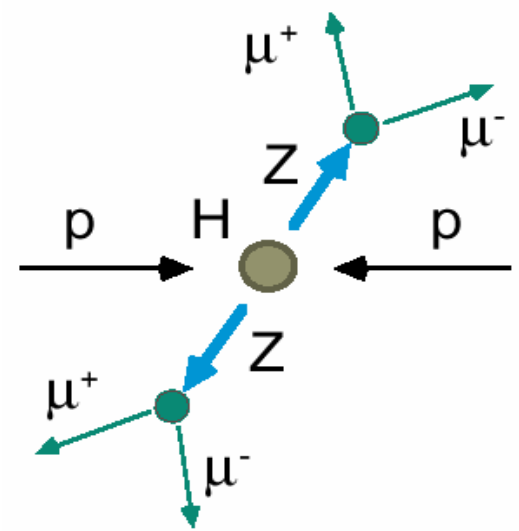
- Stand-alone Muon Reconstruction
  - Muon system only
- Global MuonReconstruction
  - Muon system + silicon tracker

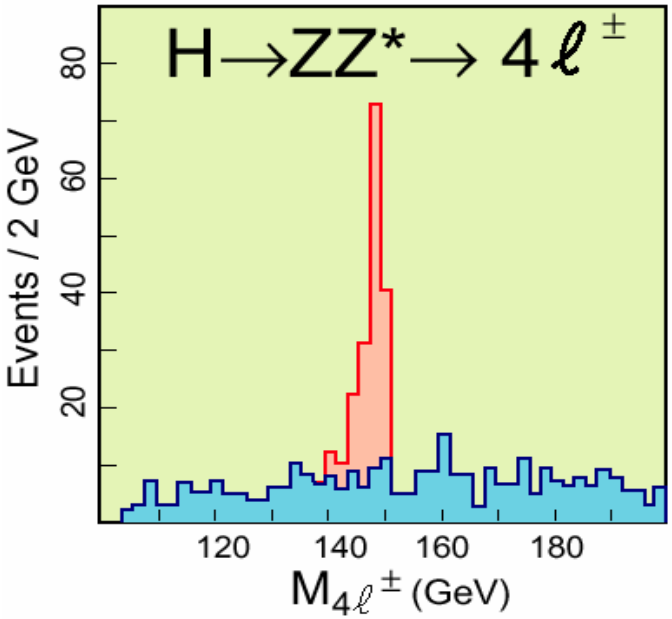


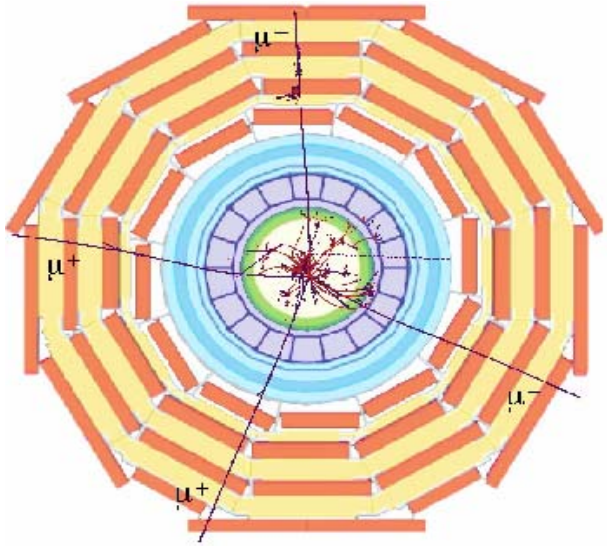



# Example: Intermediate mass Higgs: ZZ*

- $H \to ZZ \to \ell^+\ell^- \ell^+\ell^-$ ($\ell$ =e,μ)
  - Very clean
    - Resolution: better than 1 GeV
  - Valid for the mass range $130 < M_H < 500$ GeV/$c^2$

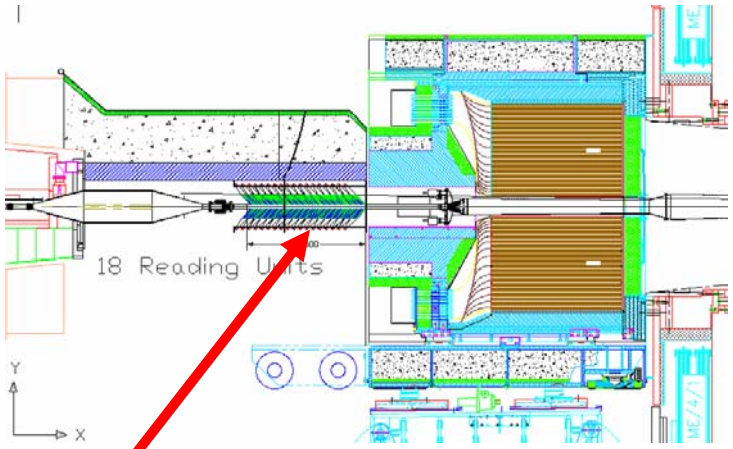


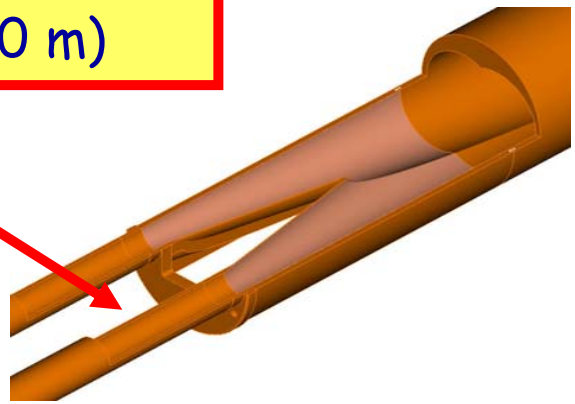



# Forward Detectors

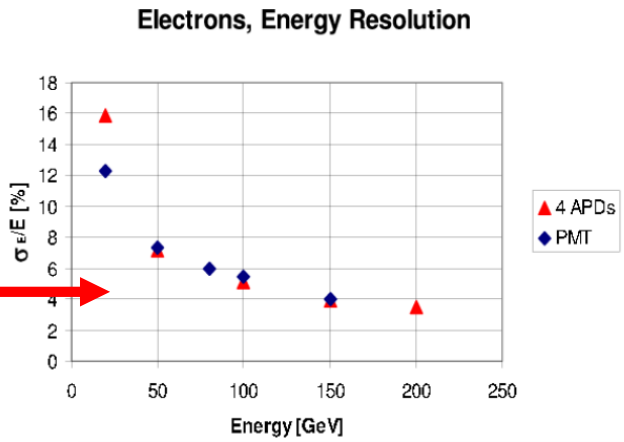
- CASTOR Calorimeter
- ZDC Calorimeter (at 140 m)



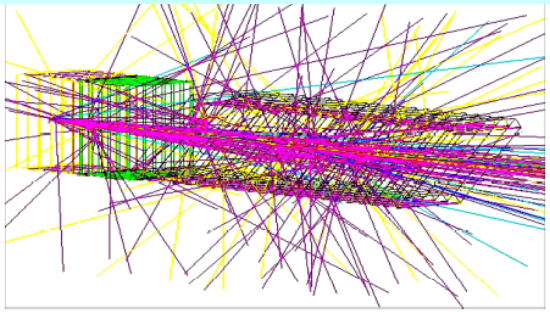

ZDC location
Tungsten/
quartz fibres



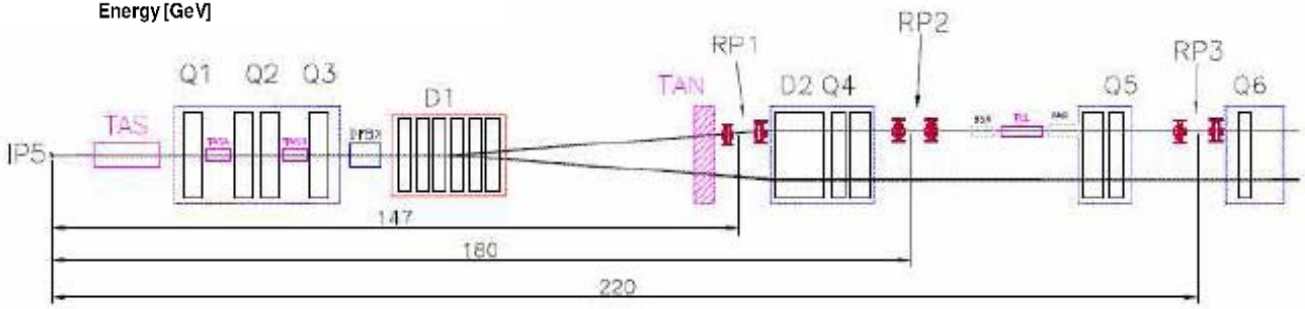
CASTOR 5.25<η <6.5
Tungsten/
quartz plates
Energy resolution



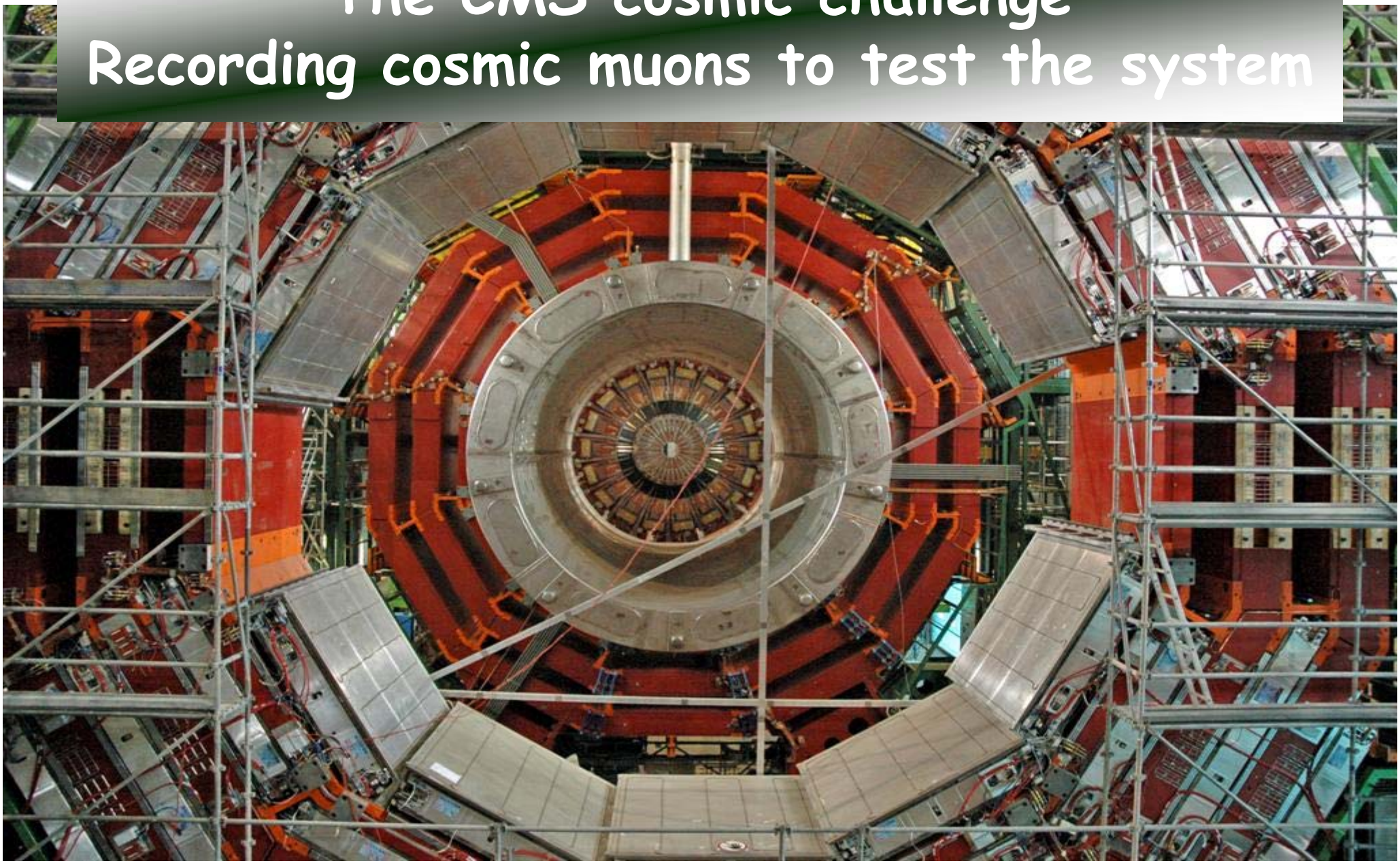

1 TeV neutron shower in ZDC



Common runs planned
with TOTEM:
Roman Pots and T1/T2

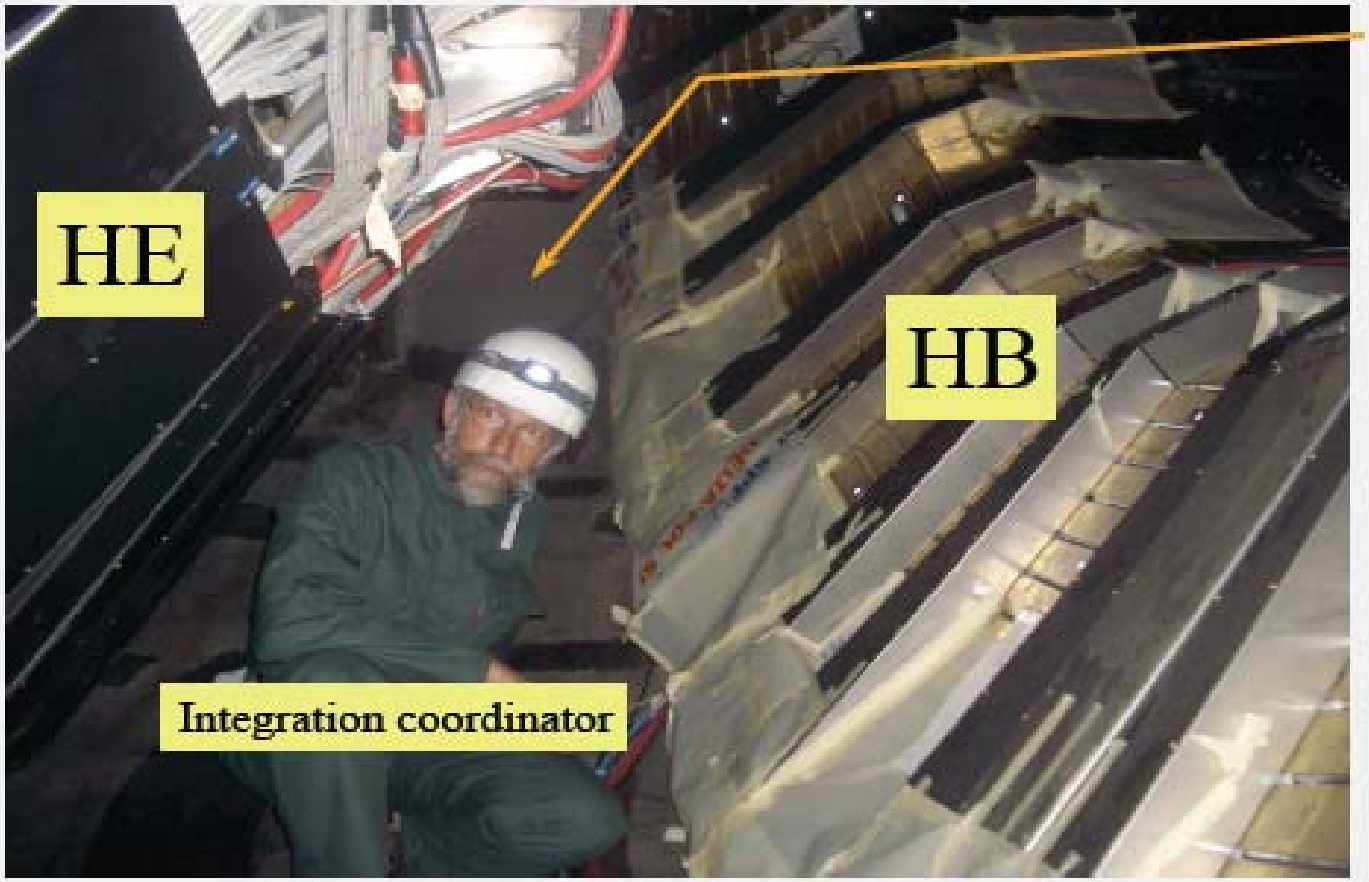


# The CMS cosmic challenge
# Recording cosmic muons to test the system



# Closing the detector

# Integrating it all together

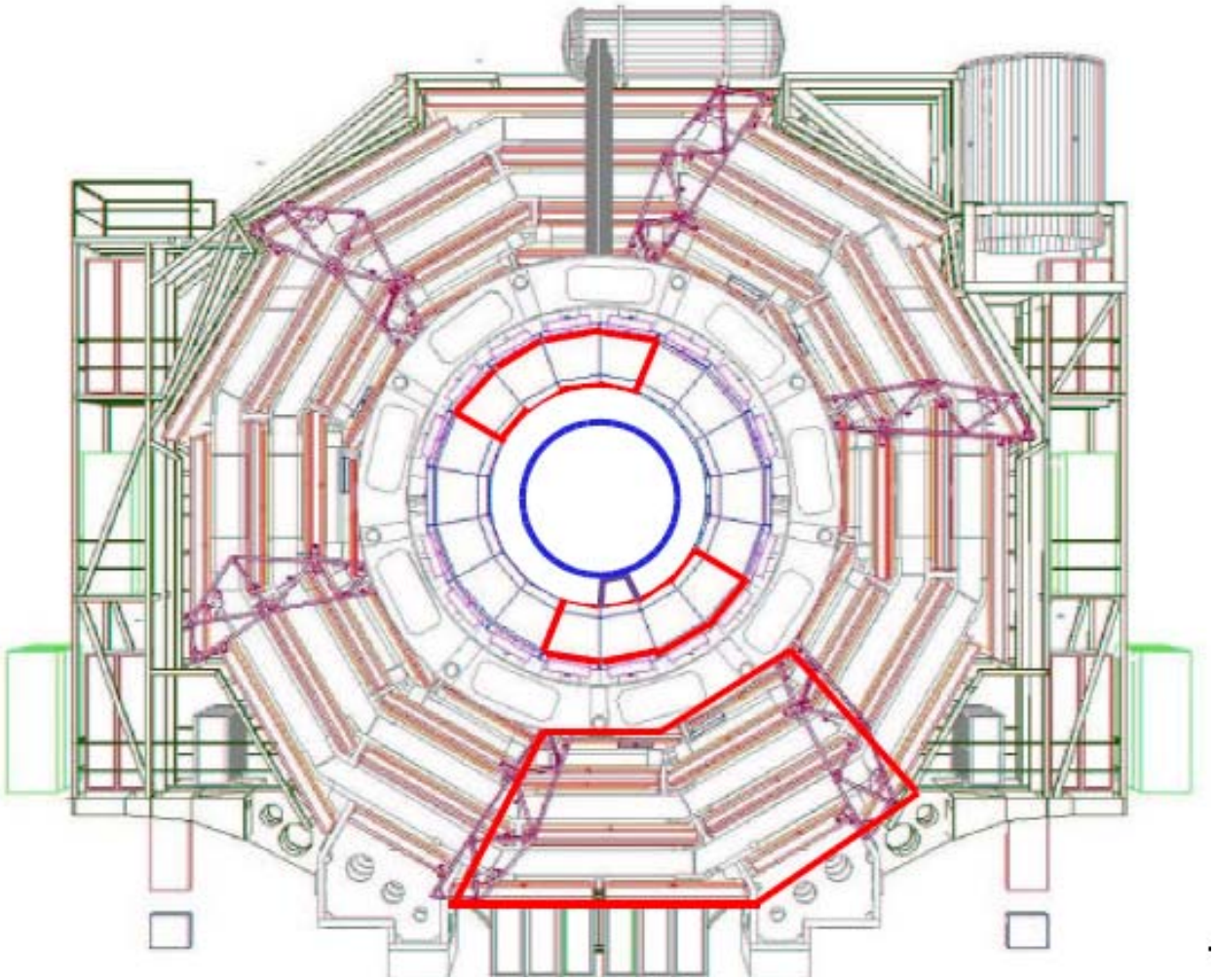



53 degree gap

~40mm when closed, field-off.

We will need people inside for YE+1 closing

# Magnet Test and Cosmic Data Challenge



Detector readiness preparation: Important milestone for 2006⇒

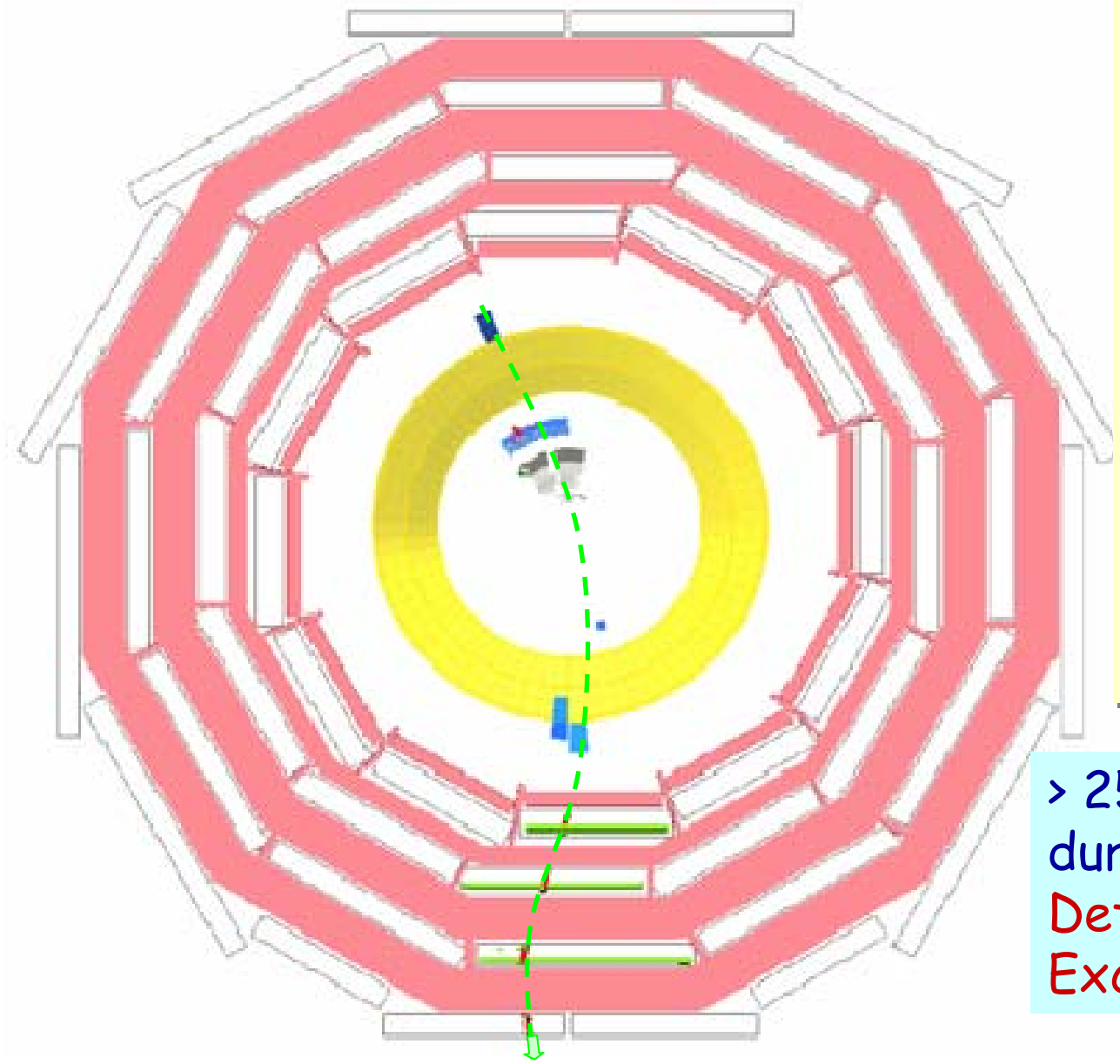
The cosmic data challenge

Combined operation of the all the subdetector systems Tracker/ECAL/HCAL/Muons
About 1-3% of the full subdetectors read out

Starting in August 06

Similar to the combined beamtest of ATLAS in 2004 (a lot of sweat!!)

# Magnet Test and Cosmic Data Challenge

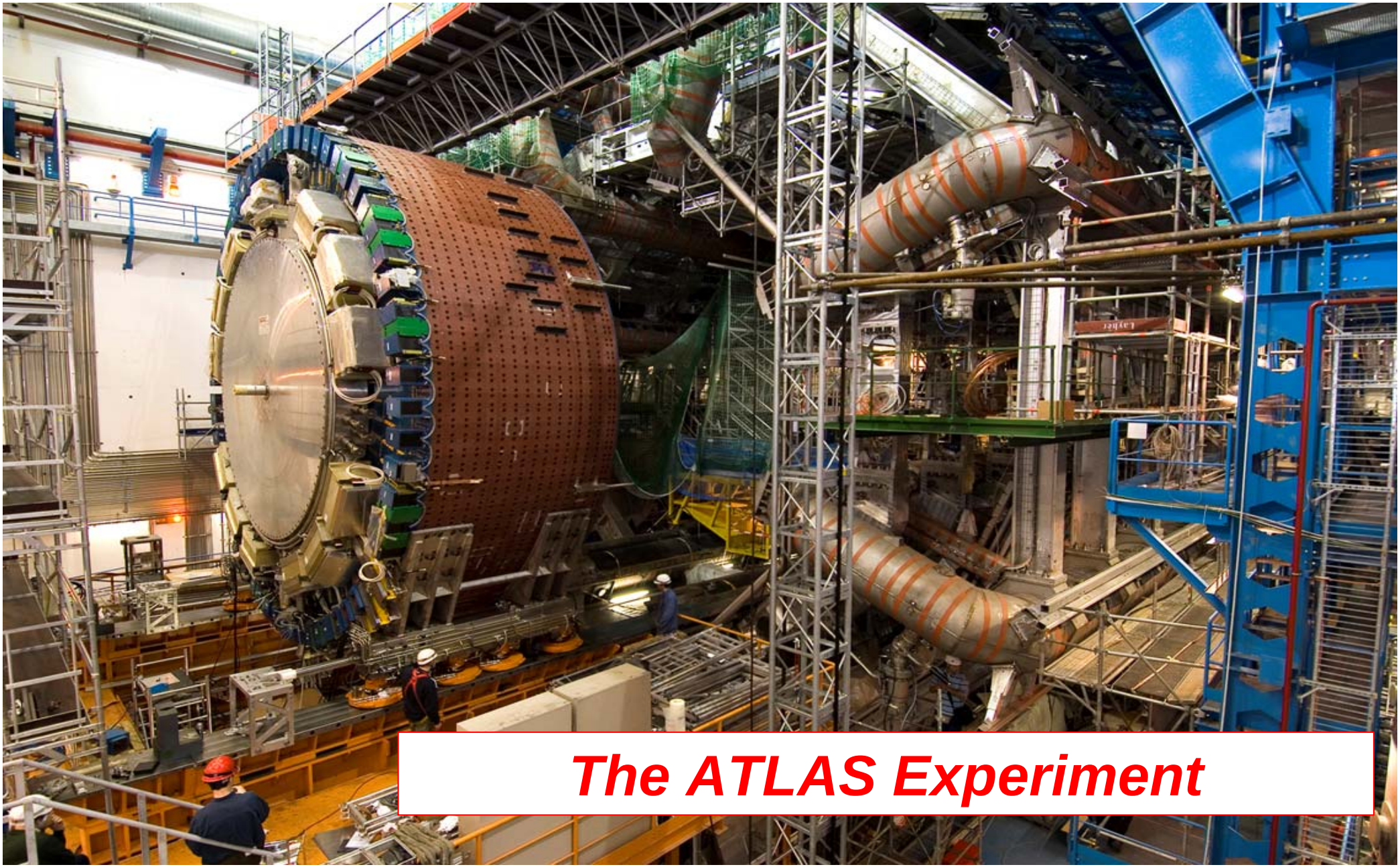


The "gold plated" event going through all central detectors and read out by central DAQ

- ✓ tracker,
- ✓ HCAL (top and bottom),
- ✓ ECAL,
- ✓ Muon Chambers

was caught in MTCC in August Run No. 2378, event 123 at a magnetic field of 3.8 Tesla

> $25 \bullet 10^6$ cosmic muons taken during the cosmic challenge
Detector worked very well!
Excellent prospects for 2007!!



# The ATLAS Experiment

# *ATLAS Collaboration*

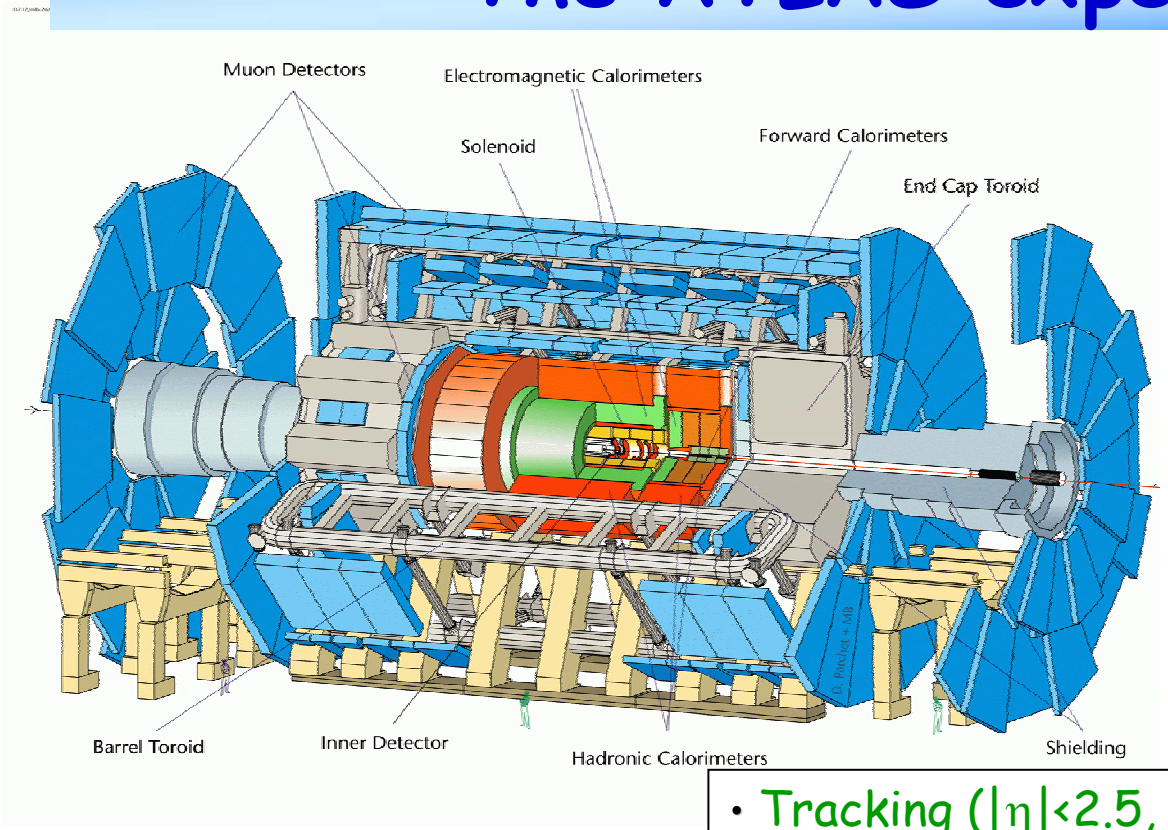
**(As of the March 2006)**

**35 Countries**
**158 Institutions**
**1650 Scientific Authors total**
**(1300 with a PhD, for M&O share)**

***New application for CB decision in July***
**DESY, Humboldt U Berlin**


**Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza,** AGH UST Cracow, IFJ PAN Cracow, **Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Naples, Naruto UE, New Mexico, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Ritsumeikan, UFRJ Rio de Janeiro, Rochester, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yale, Yerevan**

# The ATLAS experiment



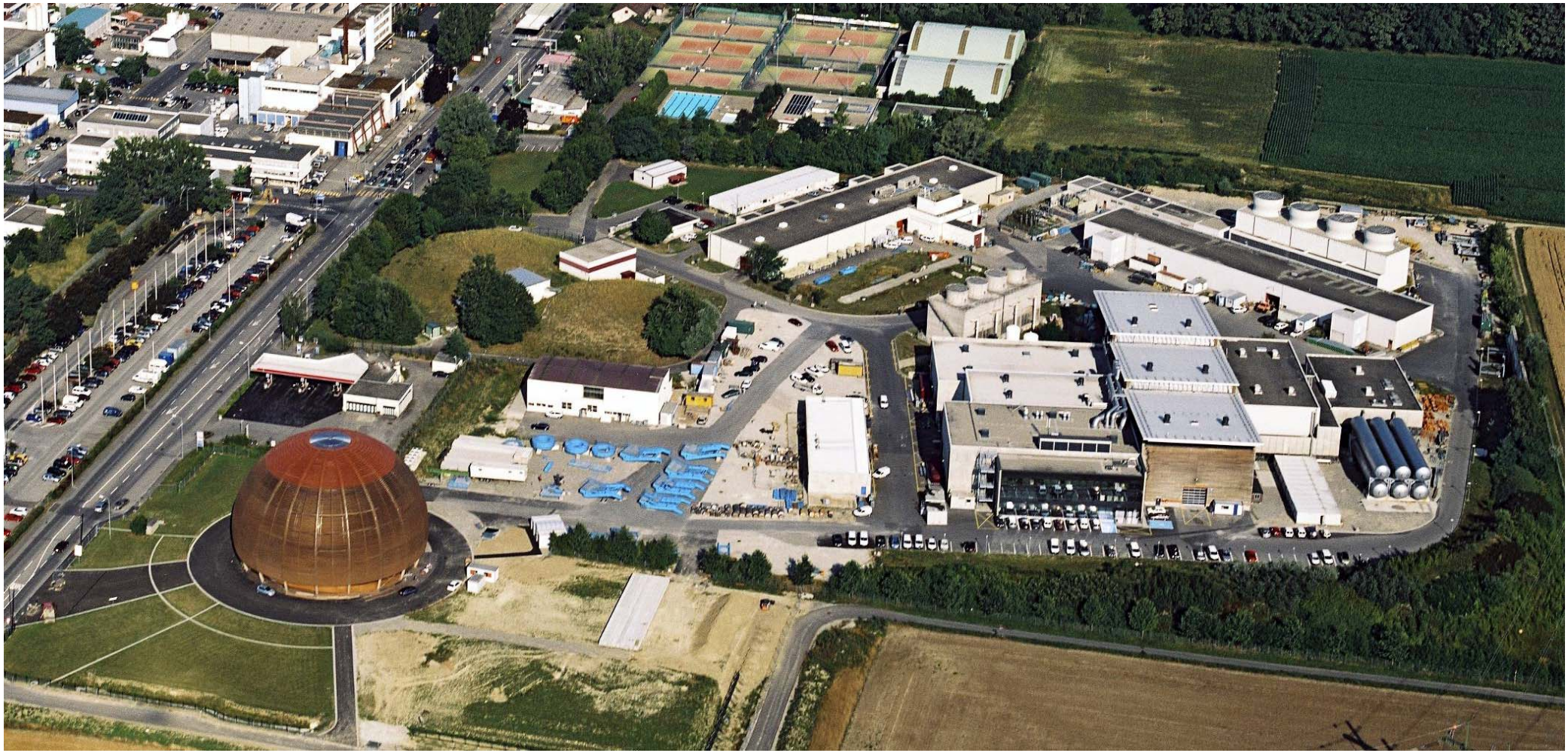

ATLAS

Weight : ~ 7000 tons

**Length = 55 m**
**Width = 32 m**
**Height = 35 m**

- Tracking ($|\eta|<2.5$, B=2T) :
  -- Si pixels and strips
  -- Transition Radiation Detector (e/$\pi$ separation)
- Calorimetry ($|\eta|<5$) :
  -- EM : Pb-LAr
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer ($|\eta|<2.7$) :
  air-core toroids with muon chambers

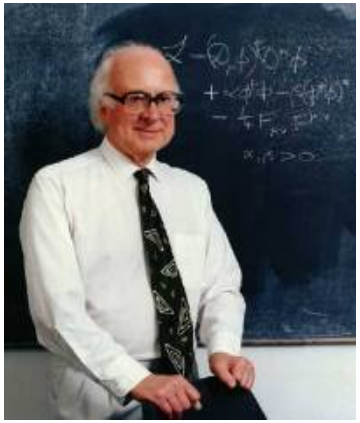
## *An Aerial View of Point-1*



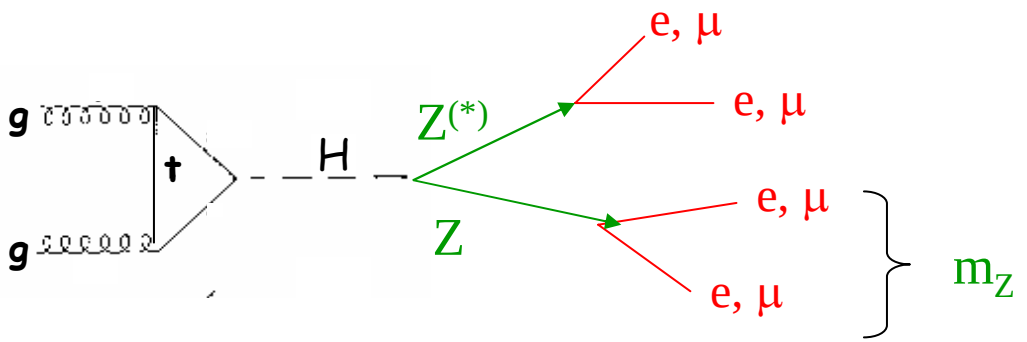
**(Across the street from the CERN main entrance)**

# Physics example

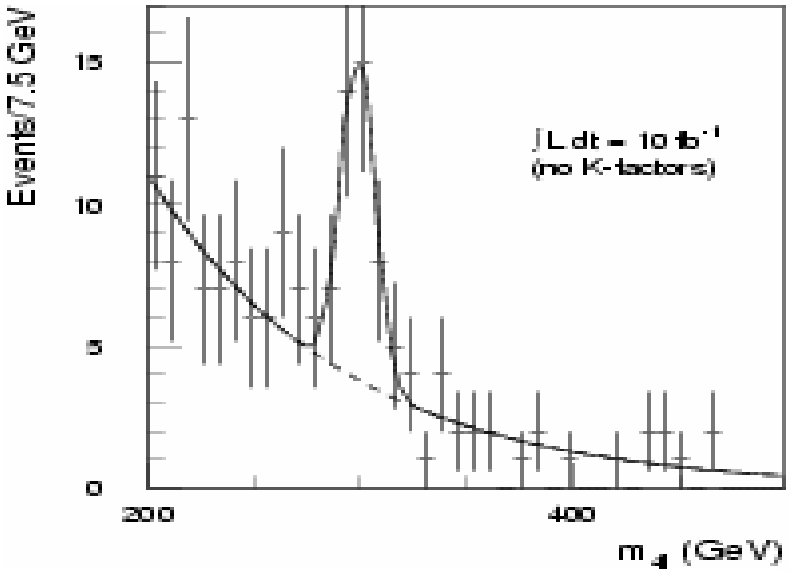
$H \rightarrow ZZ \rightarrow 4\,\ell$

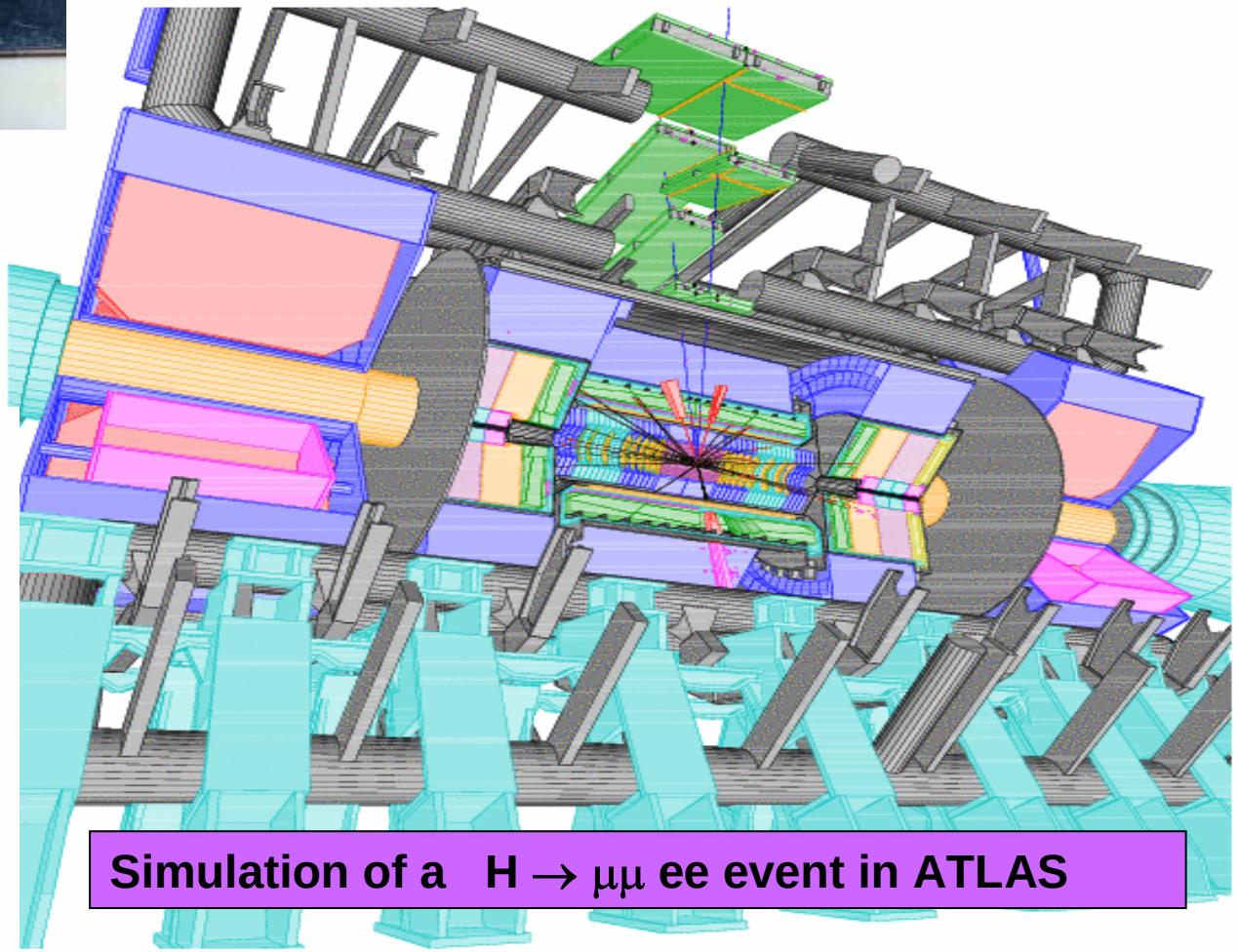


“Gold-plated” channel for Higgs discovery at LHC




**Signal expected in ATLAS after ‘early' LHC operation**



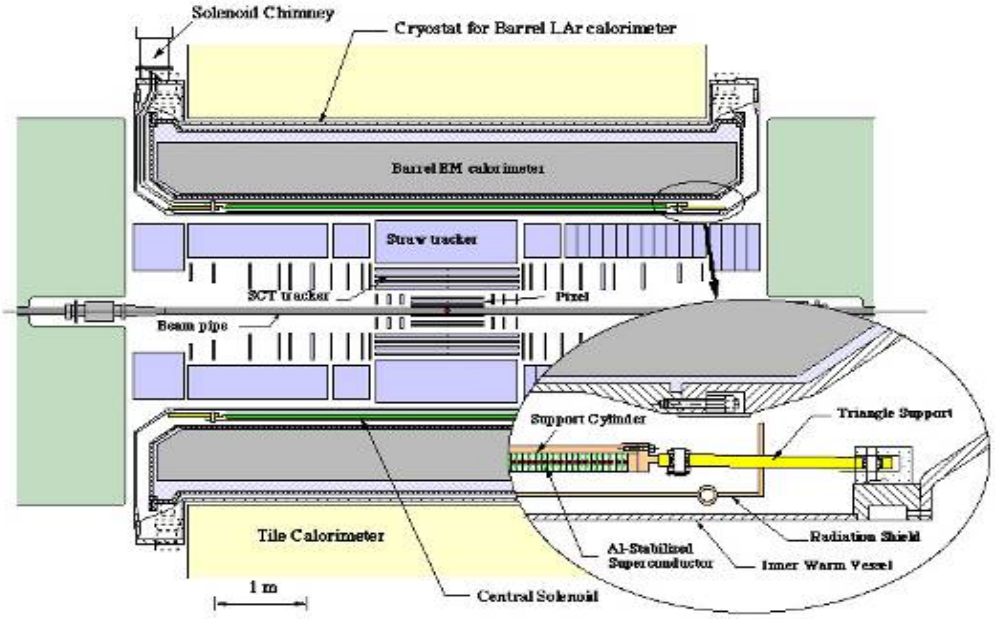



**Simulation of a $H \rightarrow \mu\mu$ ee event in ATLAS**

## *Central Solenoid*

**2T field with a stored energy of 38 MJ**

**Integrated design within the barrel LAr cryostat**



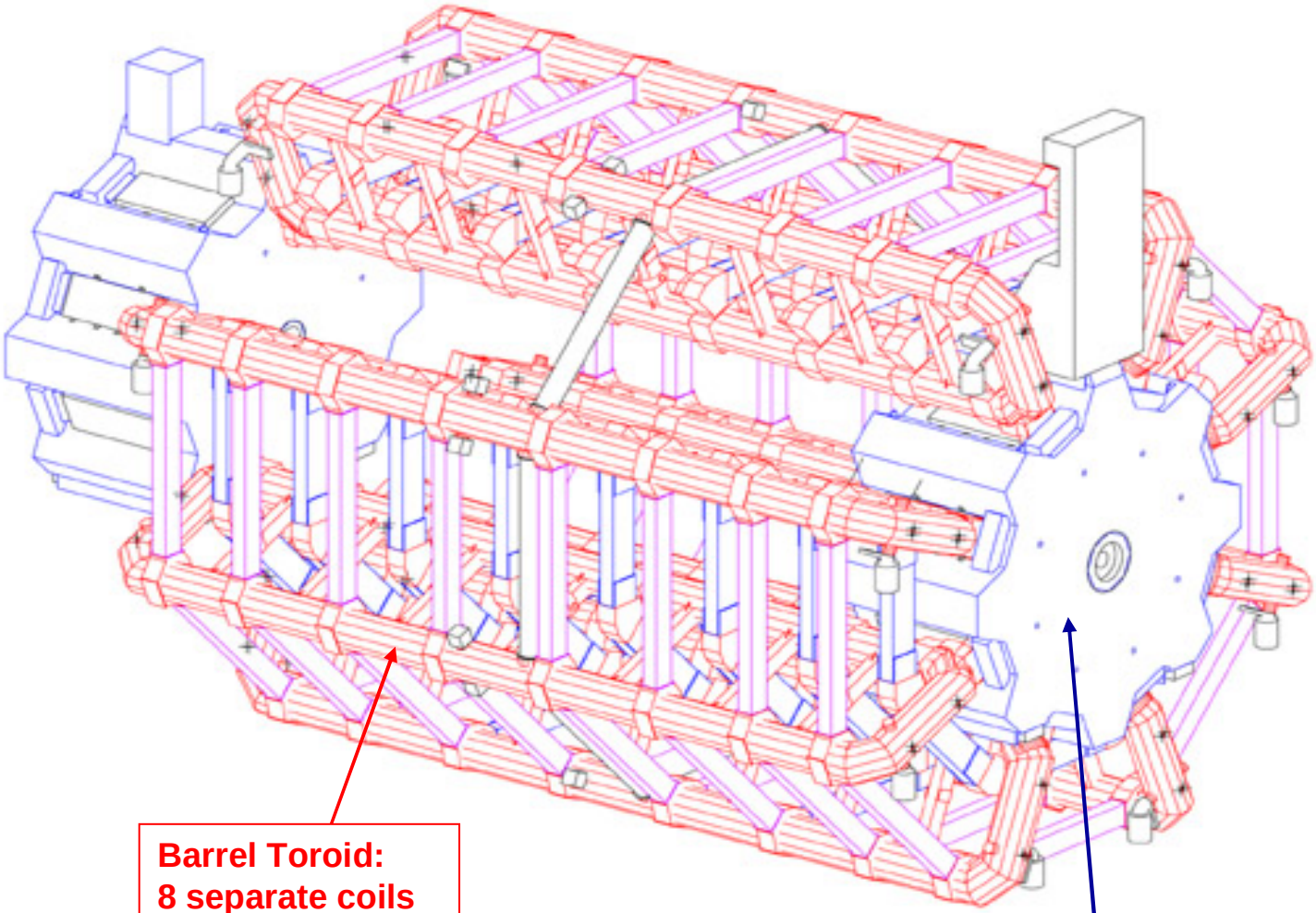

**The solenoid has been inserted into the LAr cryostat at the end of February 2004, and it was tested at full current (8 kA) during July 2004**

**It is now cold, and has been successfully tested *in situ* at a reduced current.**
**Has been successfully brought up to 2 Tesla in August**

# *Toroid system*

***Barrel Toroid parameters***
25.3 m length
20.1 m outer diameter
8 coils
1.08 GJ stored energy
370 tons cold mass
830 tons weight
4 T on superconductor
56 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point

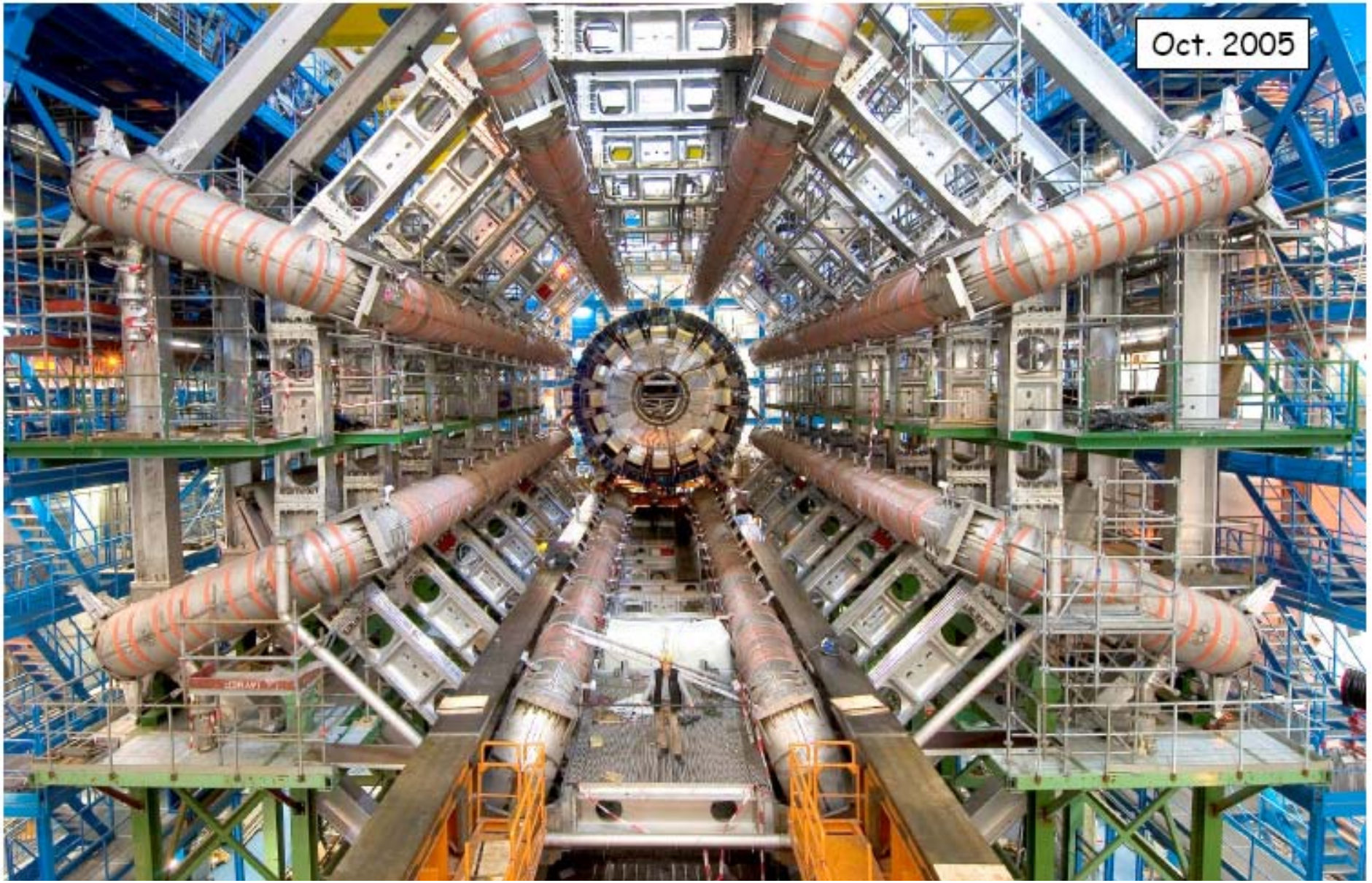
***End-Cap Toroid parameters***
5.0 m axial length
10.7 m outer diameter
2x8 coils
2x0.25 GJ stored energy
2x160 tons cold mass
2x240 tons weight
4 T on superconductor
2x13 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point



**Barrel Toroid:**
**8 separate coils**

**End-Cap Toroid:**
**8 coils in a common cryostat**

## *Barrel Toroid coil transport and lowering into the underground cavern*

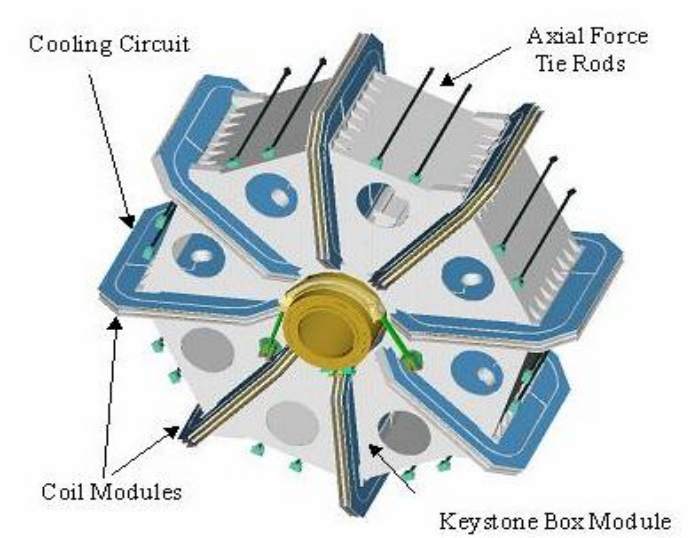

Oct. 2005

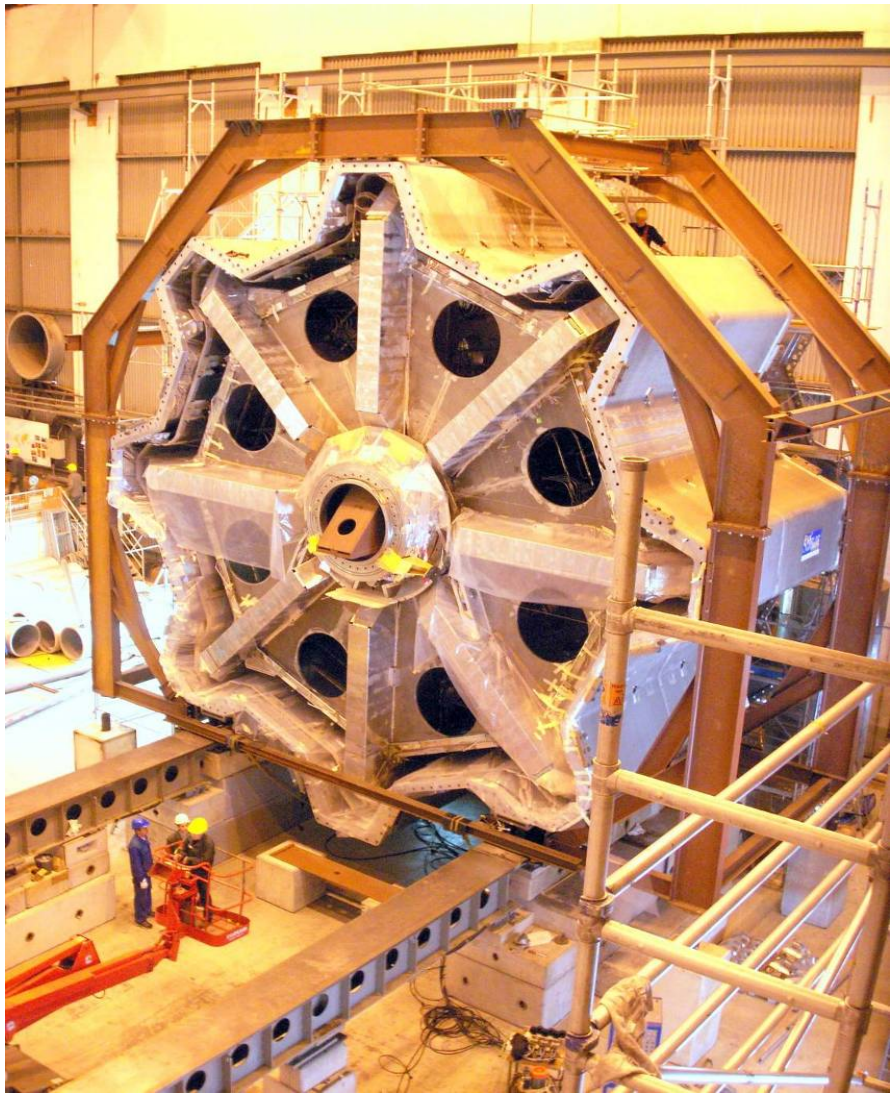
# *End-Cap Toroids*

**All components are fabricated, and the assembly is now ongoing at CERN**

**The ECTs will be tested at 80 K on the surface, before installation and excitation tests in the cavern**

**The first ECT will move to the pit in October 2006, the second one in early 2007**



**The first of the two ECT cold masses inserted into the large vacuum vessel**

*Inner Detector (ID)*

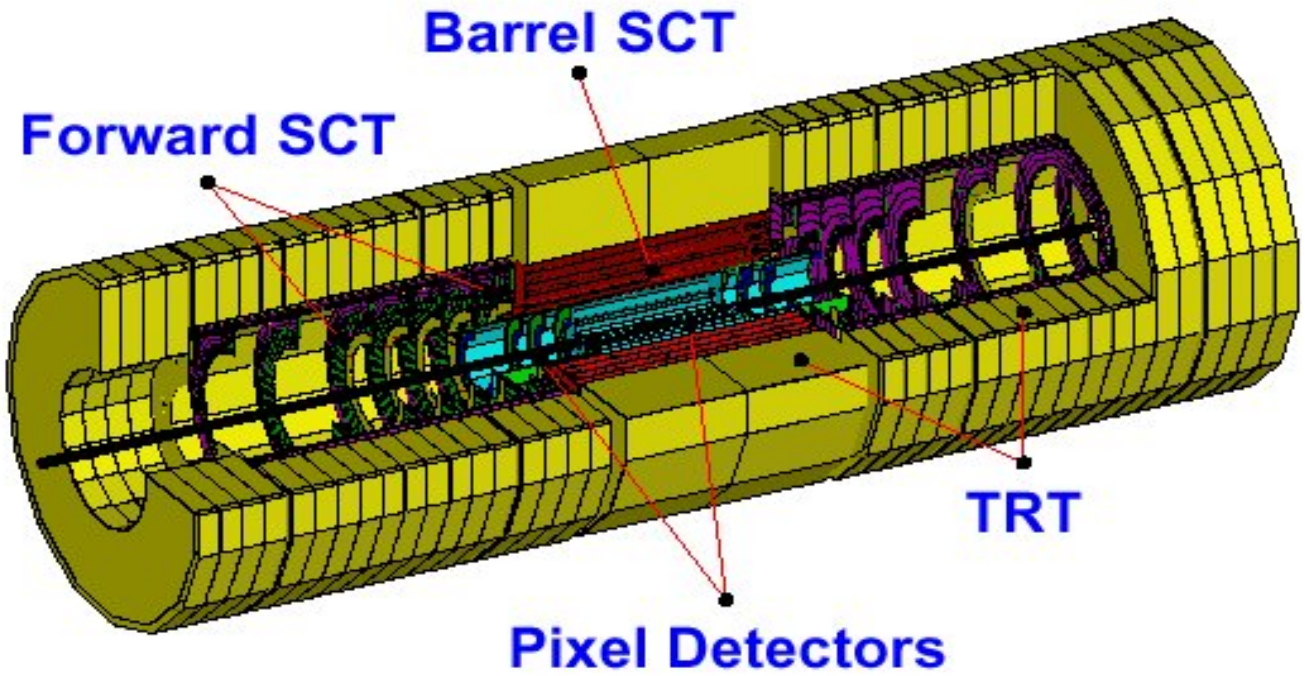
**The Inner Detector (ID) is organized into four sub-systems:**

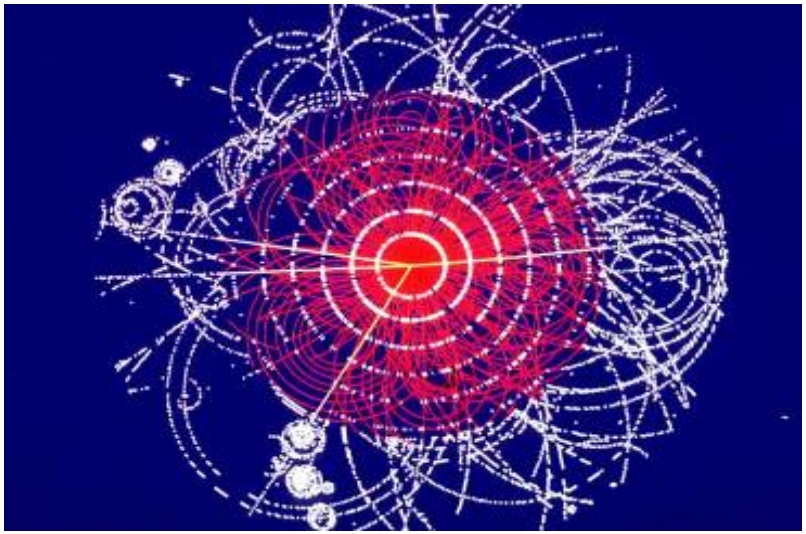
**Pixels**
**(0.8 $10^8$ channels)**

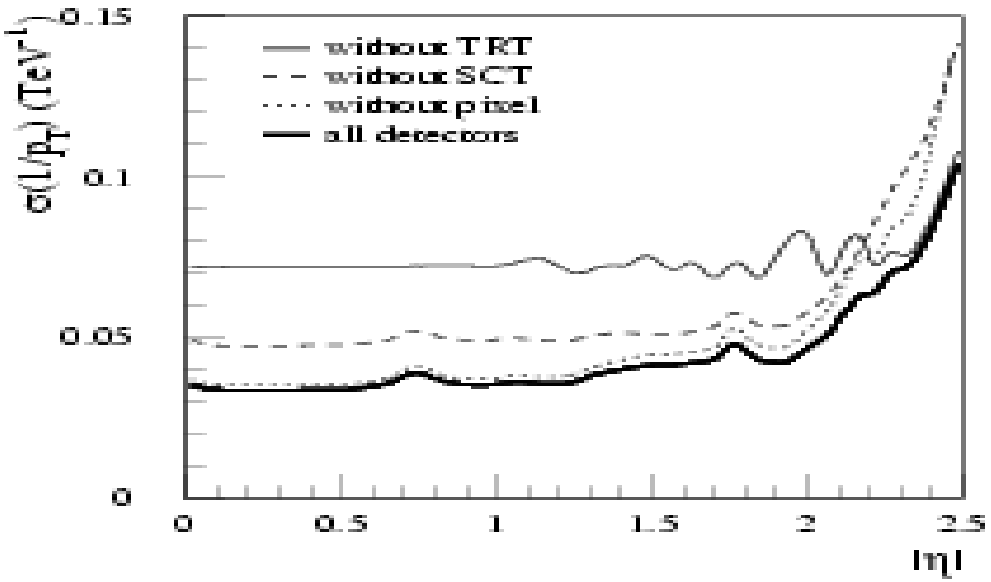
**Silicon Tracker (SCT)**
**(6 $10^6$ channels)**

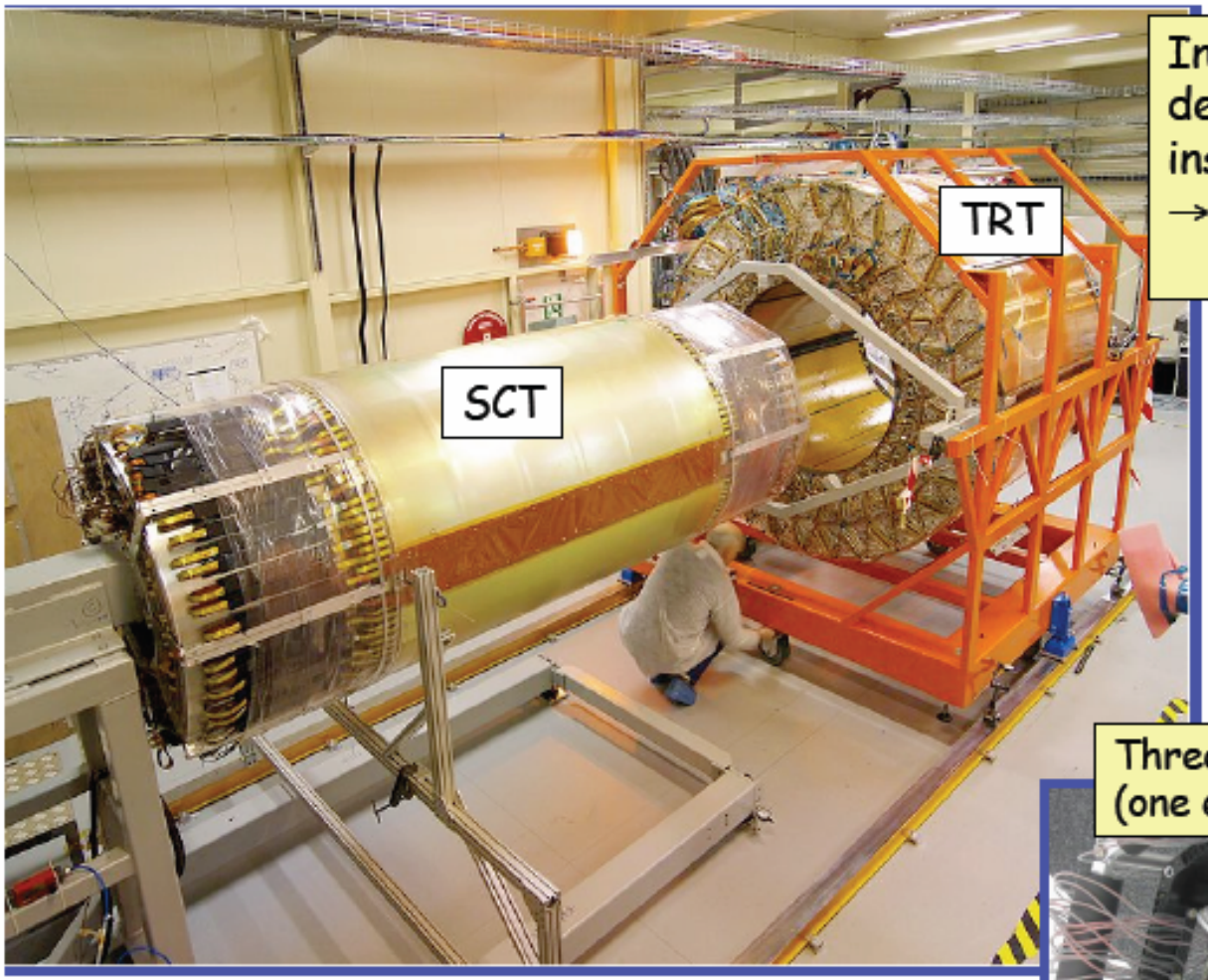
**Transition Radiation Tracker (TRT)**
**(4 $10^5$ channels)**

**Common ID items**



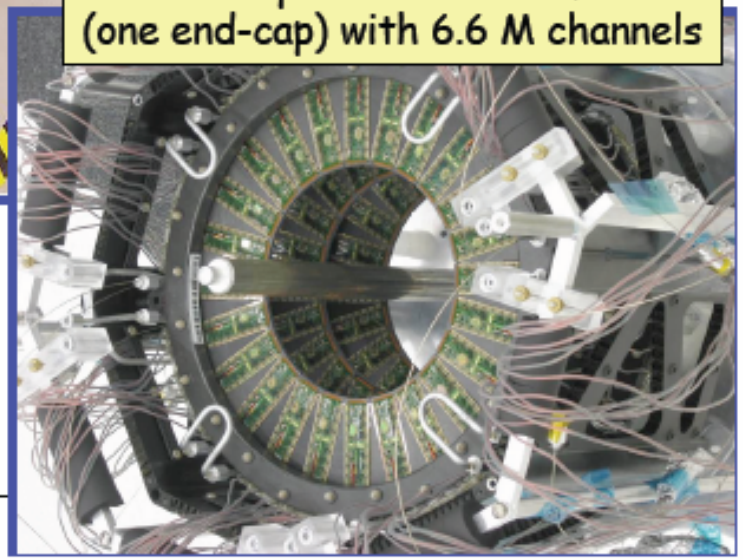







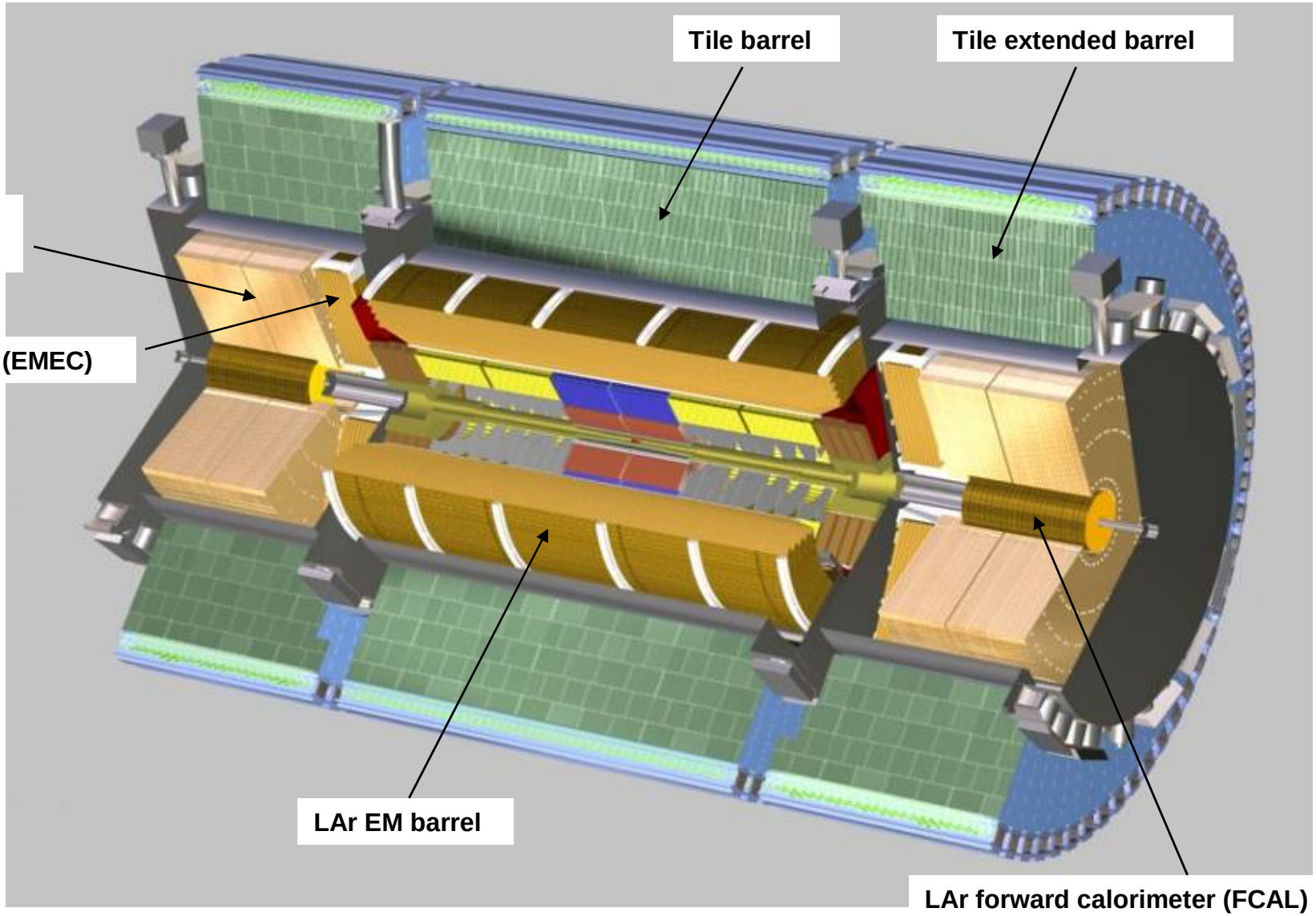

In February, barrel Si detector (SCT) was inserted into barrel TRT
→ ready for installation in the pit in August 2006

Three completed Pixel disks (one end-cap) with 6.6 M channels

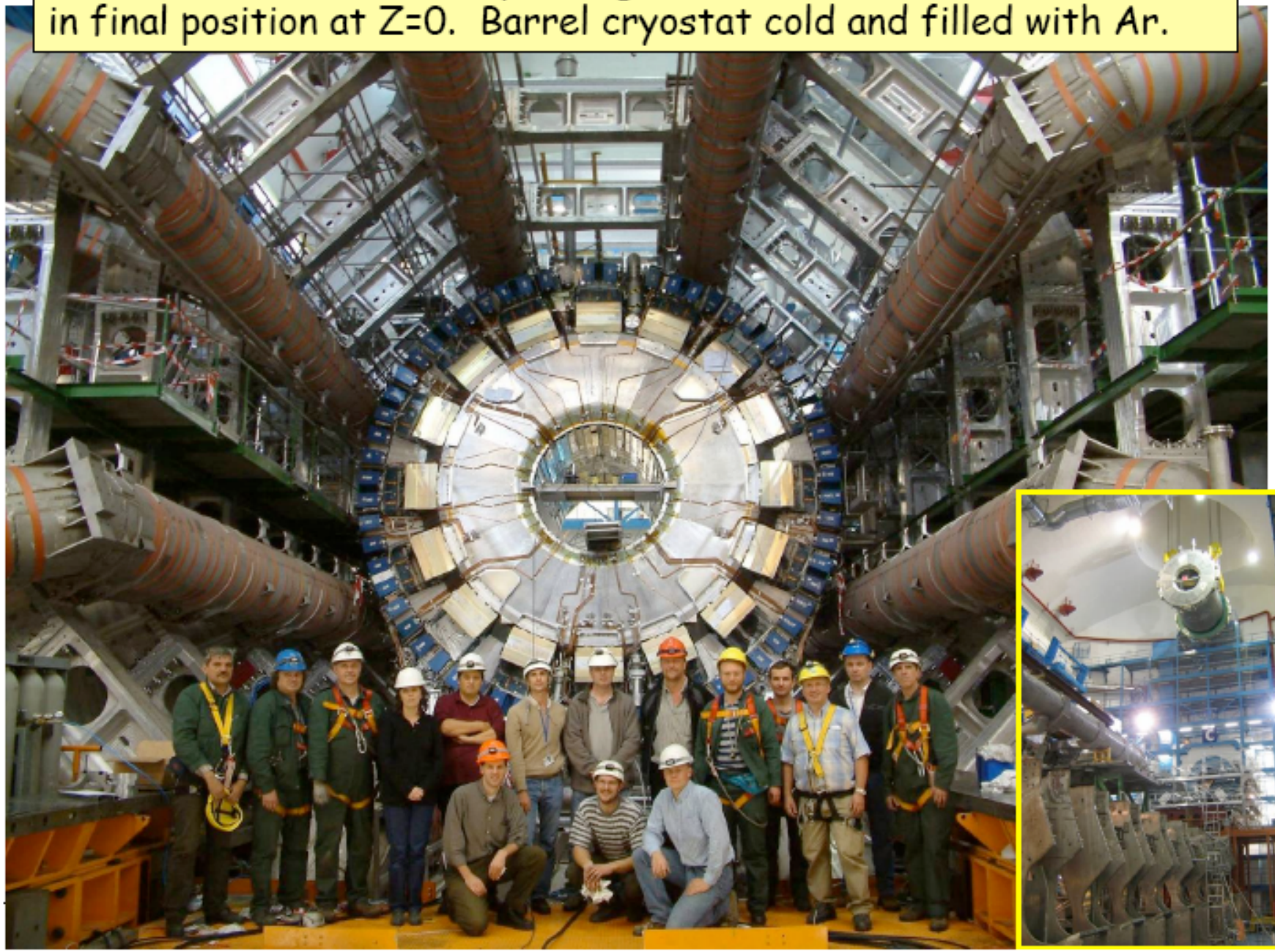


Barrel pixel detector on critical path (problems with low-mass cables), but still scheduled for installation in the pit in April 2007

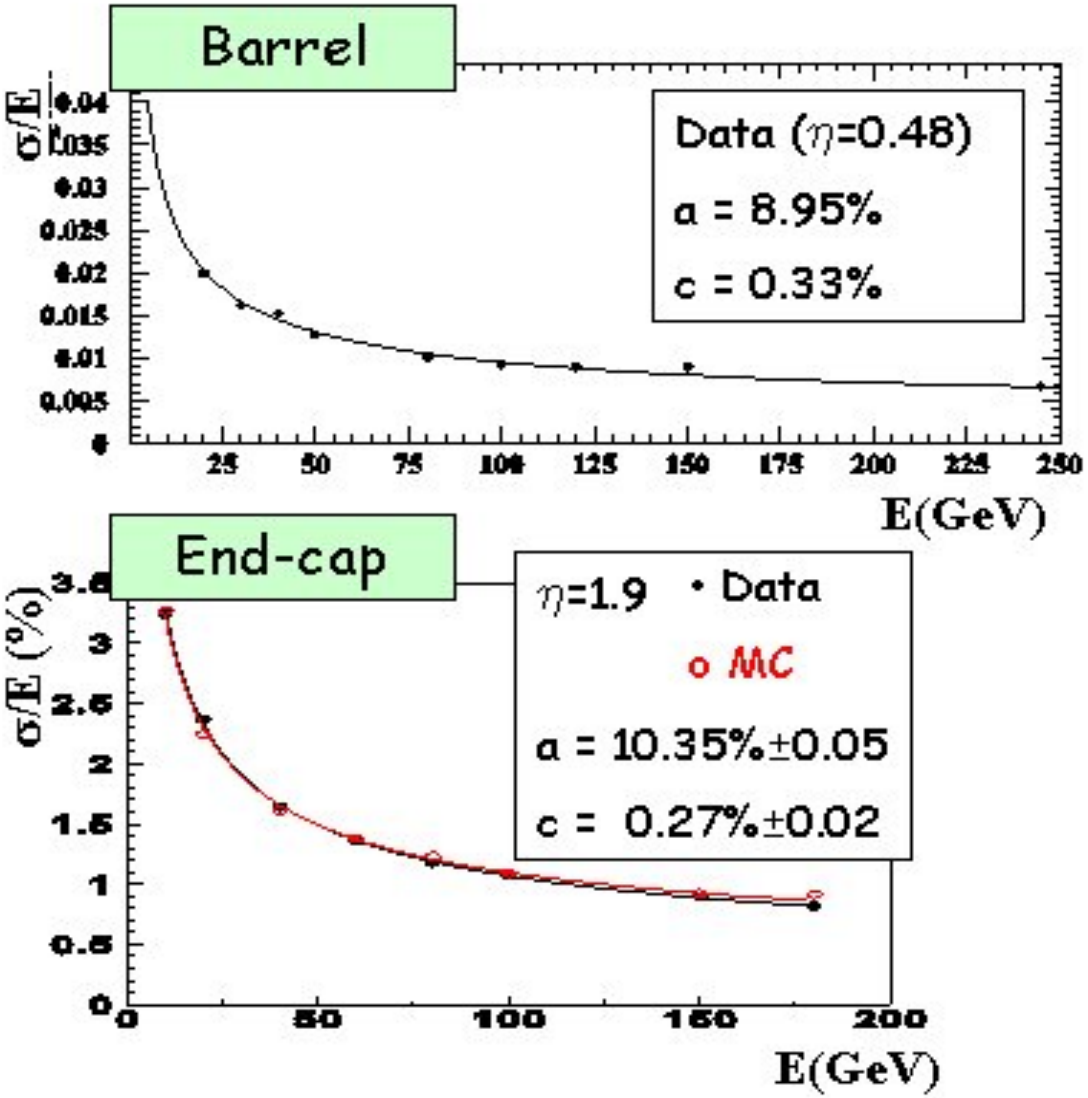
# LAr and Tile Calorimeters



Barrel calorimeter (EM liquid-argon + HAD Fe/scintillator Tilecal) in final position at Z=0. Barrel cryostat cold and filled with Ar.



# EM beam test results:
# Energy resolution




$$\sigma_E/E = a/\sqrt{E} \oplus c \oplus n/E$$

For every tested points:

| Barrel | End-cap |
|---|---|
| a < 10% | a < 12.5% |
| c < 0.4% | c < 0.5% |

- Within specifications
- Good agreement with MC

# Impact on Higgs mass resolution

Simulations, $m_H$=130 GeV

✓ $H \rightarrow \gamma\gamma$

Resolution: 1% (low lum)

1.2% (high lum)

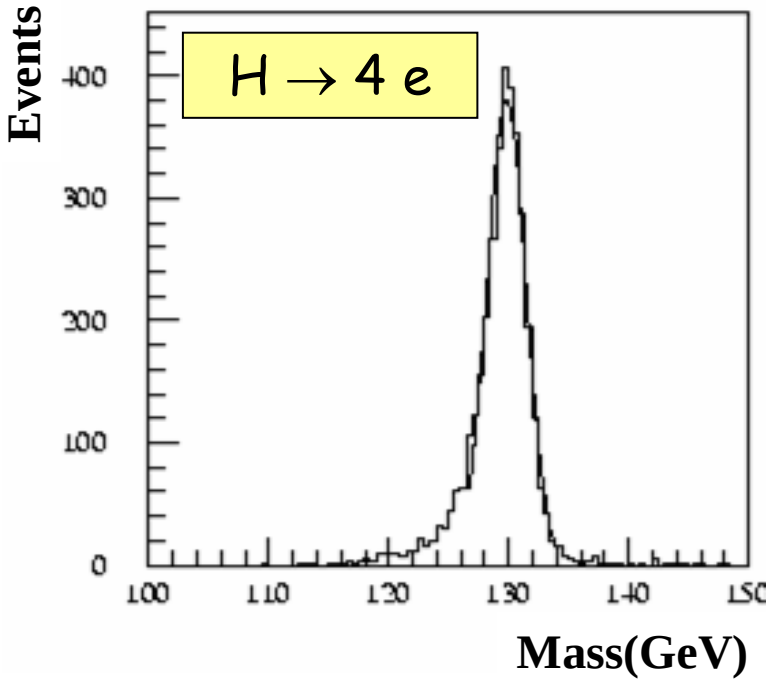
Acceptance: 80% within $\pm 1.4\ \sigma$

✓ $H \rightarrow 4e$

Resolution: 1.2% (low lum)

1.4% (high lum)

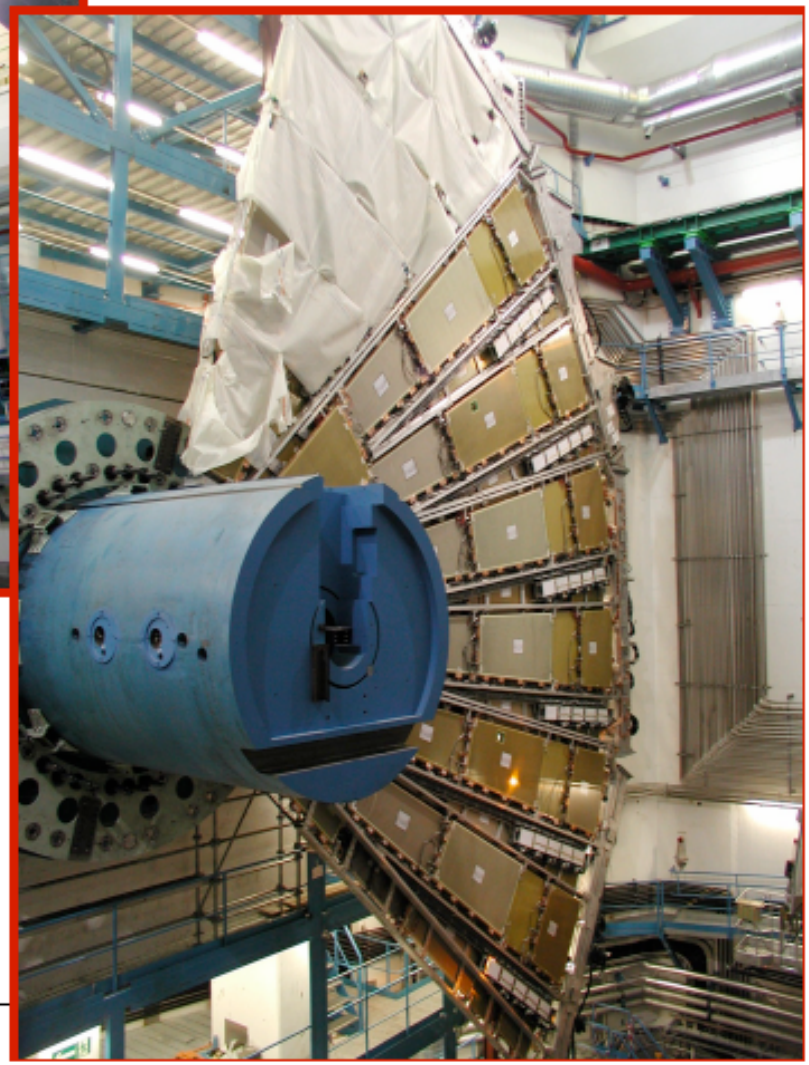
Acceptance: 84% within $\pm 2\ \sigma$



# ATLAS Muons

Muon Spectrometer : measurement chambers MDT, CSC (innermost forward)
trigger chambers RPC (barrel), TGC (end-caps)

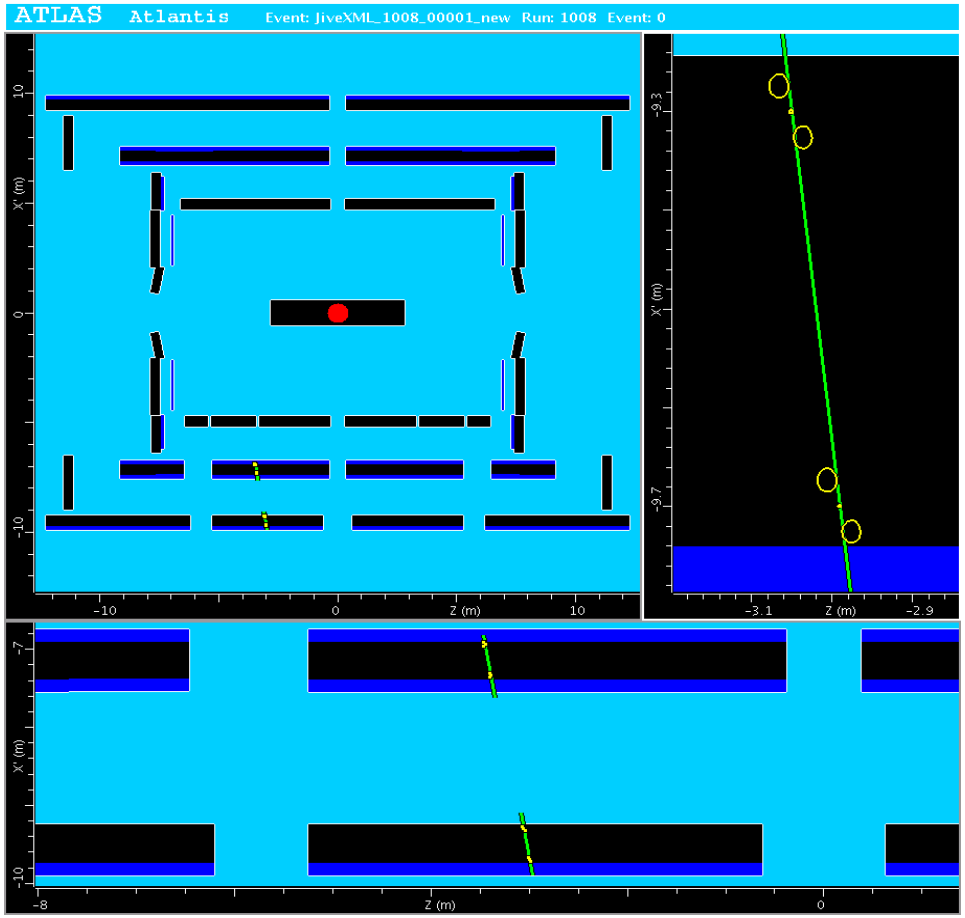
~50% of barrel stations installed
(mostly complete end of Summer '06)



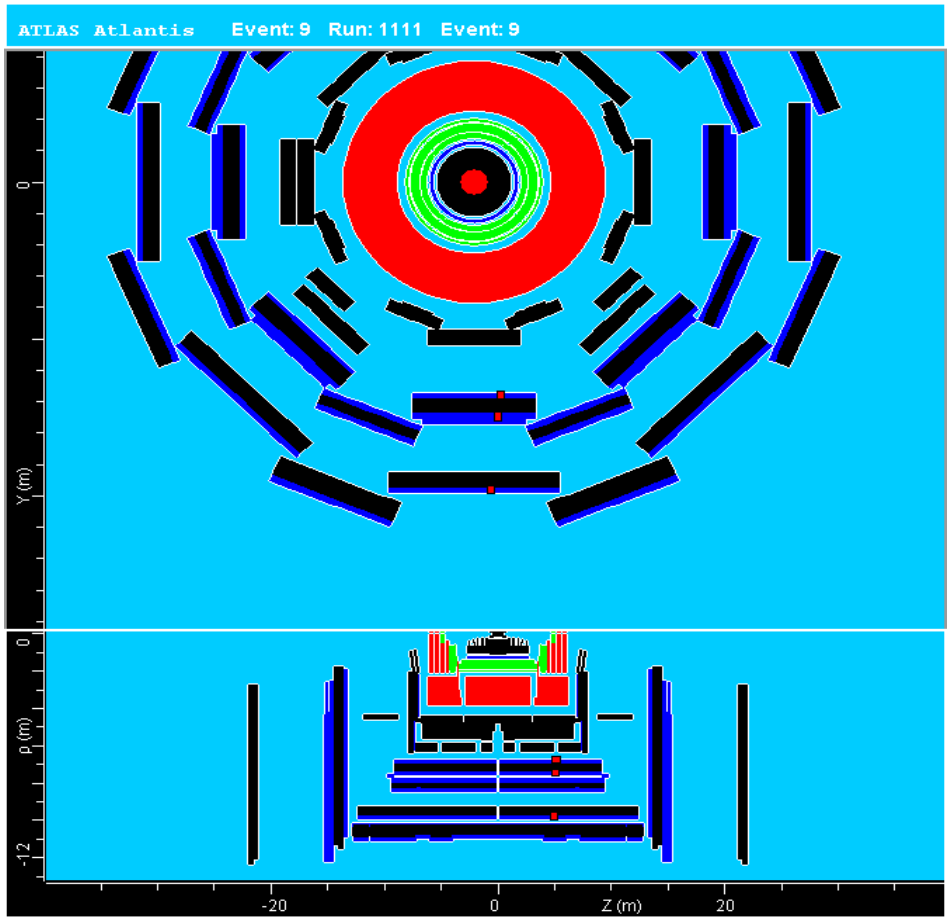
First sectors of TGC end-cap
"big-wheels" installed

# First cosmics have been registered *in situ* for barrel chambers

**In December 2005 in MDTs**

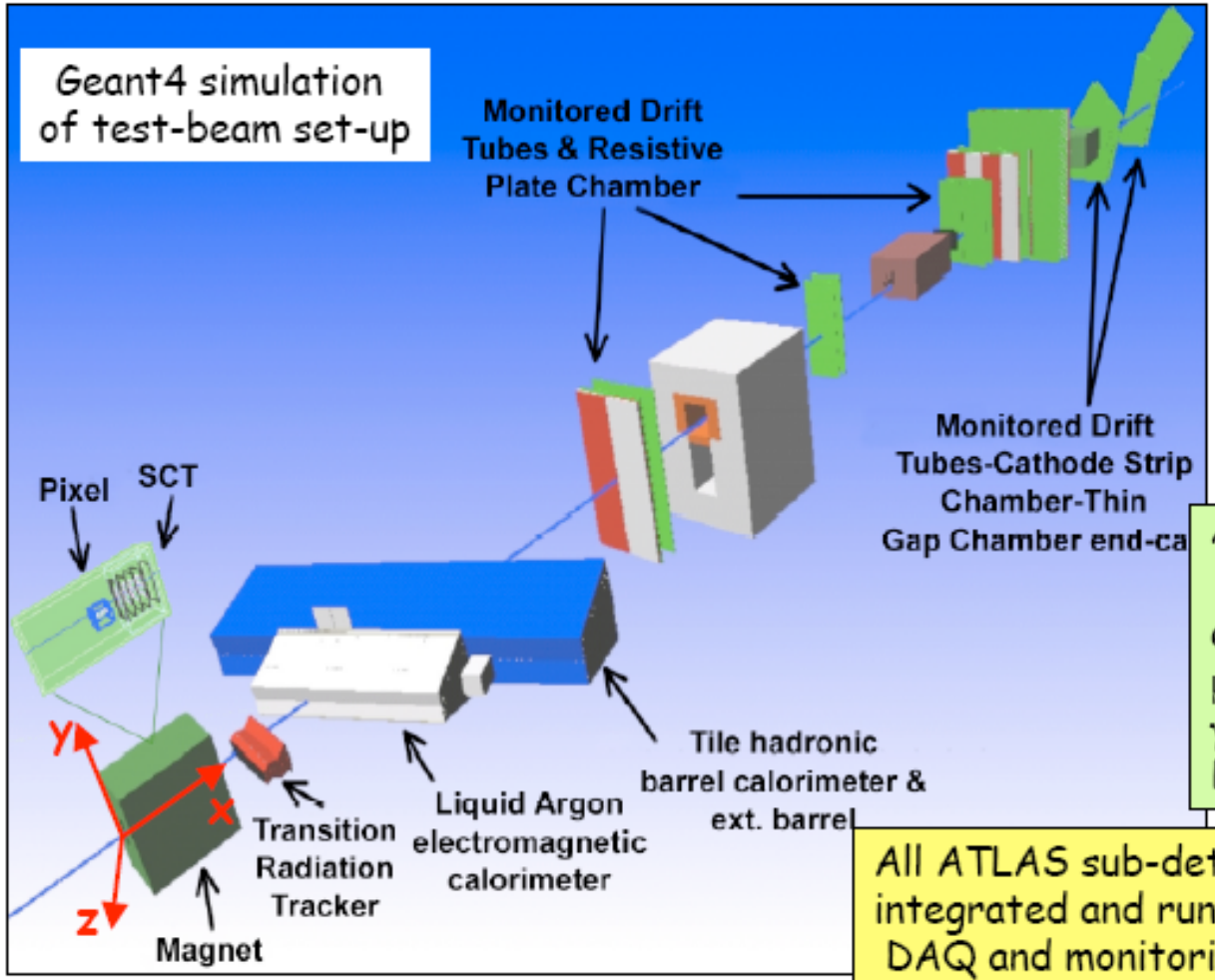



**and in June 2006 in RPCs**



# ATLAS Combined test beam

Full "vertical slice" of ATLAS tested on CERN H8 beam line May-November 2004




O(1%) of ATLAS coverage

~ 90 million events collected (~4.5 TB of data):

| | |
|---|---|
| $e^{\pm}$, $\pi^{\pm}$ | 1 → 250 GeV |
| $\mu^{\pm}$, $\pi^{\pm}$, p | up to 350 GeV |
| $\gamma$ | 20-100 GeV |

B-field = 0 → 1.4 T

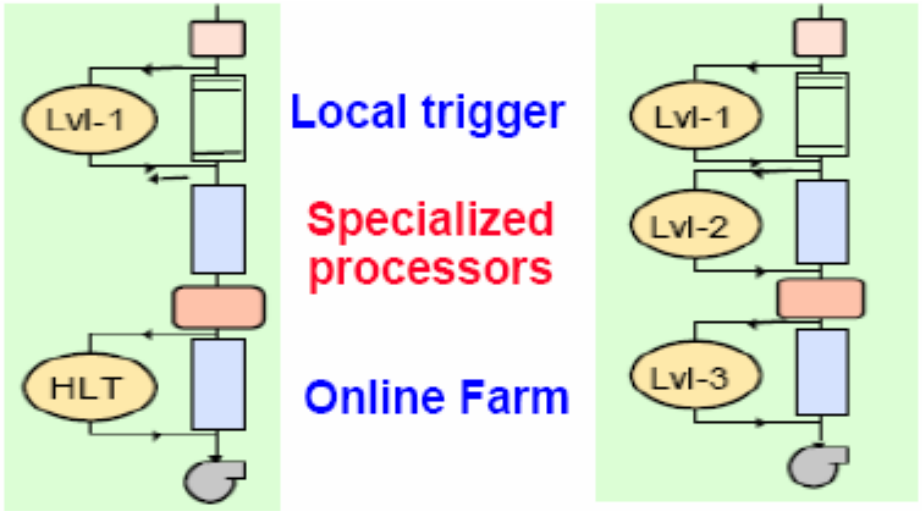
All ATLAS sub-detectors (and LVL1 trigger) integrated and run together with common DAQ and monitoring, "final" electronics, slow-control, etc. Data analyzed with common ATLAS software. Gained lot of global operation experience during ~ 6 month run.

# You can win (or loose) money with ATLAS

# ATLAS ⇔ CMS

| | ATLAS | CMS |
|---|---|---|
| MAGNET (S) | Air-core toroids + solenoid in inner cavity<br>4 magnets<br>Calorimeters in field-free region | Solenoid<br>Only 1 magnet<br>Calorimeters inside field |
| TRACKER | Si pixels+ strips<br>TRT → particle identification<br>B=2T<br>$\sigma/p_T \sim 5\times10^{-4}\ p_T \oplus 0.01$ | Si pixels + strips<br>No particle identification<br>B=4T<br>$\sigma/p_T \sim 1.5\times10^{-4}\ p_T \oplus 0.005$ |
| EM CALO | Pb-liquid argon<br>$\sigma/E \sim 10\%/\sqrt{E}$ uniform<br>longitudinal segmentation | $PbWO_4$ crystals<br>$\sigma/E \sim 2\text{-}5\%/\sqrt{E}$<br>no longitudinal segm. |
| HAD CALO | Fe-scint. + Cu-liquid argon (10 λ)<br>$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ | Cu-scint. (> 5.8 λ +catcher)<br>$\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$ |
| MUON | Air → $\sigma/p_T \sim 7\%$ at 1 TeV<br>standalone | Fe → $\sigma/p_T \sim 5\%$ at 1 TeV<br>combining with tracker |

# ATLAS/CMS trigger




**CMS** **ATLAS**

- **CMS has a two-level DAQ/Trigger architecture:**
  - Low level hardware trigger (L1)
  - Large online farm (HLT) doing event building and traditional L2, L3,…, LN triggering.
    - Full event information available
    - Highly flexible
    - Can be reprogrammed for specialized HI Triggering
      - Jet trigger including BG subtraction,
      - Dimuon trigger (ϒ, J/ψ)

- **ATLAS has a three-level DAQ/Trigger architecture:**
  - Low level hardware trigger (L1)
  - Specialized Processors (L2)
    - ROI triggers
  - Large event filter farm (L3)
    - Evaluates ROIs for trigger decision
  - Trigger options for HI currently under evaluation

# Performance at LHC experiments

Table 8
Mass resolution for various states in the different experiments (at a luminosity of $2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ in the case of ATLAS and CMS)

| | ATLAS ($\mathrm{GeV}\,c^{-2}$) | CMS ($\mathrm{GeV}\,c^{-2}$) | LHCb ($\mathrm{GeV}\,c^{-2}$) | ALICE ($\mathrm{GeV}\,c^{-2}$) |
|---|---|---|---|---|
| $\mathrm{B} \to \pi\pi$ | 0.070 | 0.031 | 0.017 | — |
| $\mathrm{B} \to J/\psi \mathrm{K}^0_\mathrm{S}$ | 0.019 | 0.016 | 0.010 | — |
| $\Upsilon \to \mu\mu$ | 0.152 | 0.050 | — | 0.107 |
| $\mathrm{H}(130\,\mathrm{GeV}\,c^{-2}) \to \gamma\gamma$ | 1.0 | 0.90 | — | — |
| $H(150\,\mathrm{GeV}\,c^{-2}) \to \mathrm{ZZ}^* \to 4\mu$ | 1.60 | 1.35 | — | — |
| $\mathrm{A}(500\,\mathrm{GeV}\,c^{-2}) \to \tau\tau$ | 50.0 | 75.0 | — | — |
| $\mathrm{W} \to$ jet jet | 8.0 | 10.0 | — | — |
| $\mathrm{Z}'(1\,\mathrm{TeV}\,c^{-2}) \to \mu\mu$ | 46.0 | 40.0 | — | — |
| $\mathrm{Z}'(1\,\mathrm{TeV}\,c^{-2}) \to \mathrm{ee}$ | 7.0 | 5.0 | — | — |

T. Virdee
Phys. Rep.

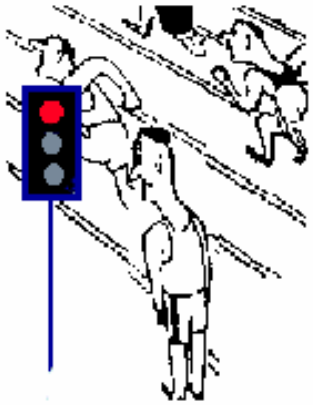
Achieve similar precision with different experimental set-up and detectors

# Detectors at Start-up in 2007

❷ Which detectors the first year ?

RPC over $|\eta|<1.6$ (instead of $|\eta|< 2.1$)
4th layer of end-cap chambers missing

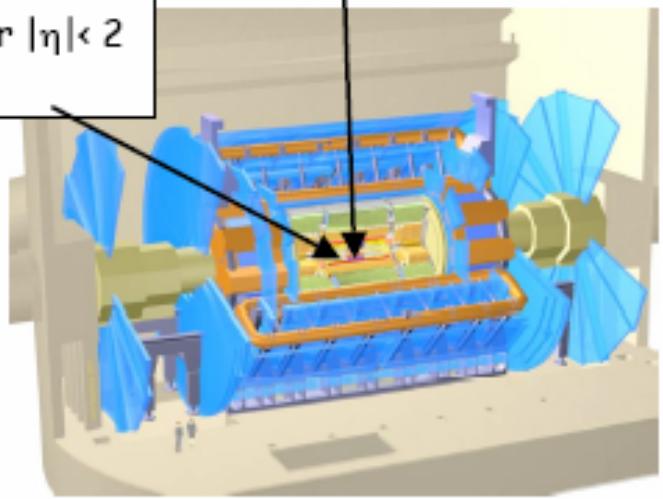
Pixels and end-cap ECAL
installed during first shut-down



Detectors will be fairly complete at start-up

2 pixel layers/disks instead of 3 ?

TRT acceptance over $|\eta|< 2$
(instead of $|\eta|< 2.4$)



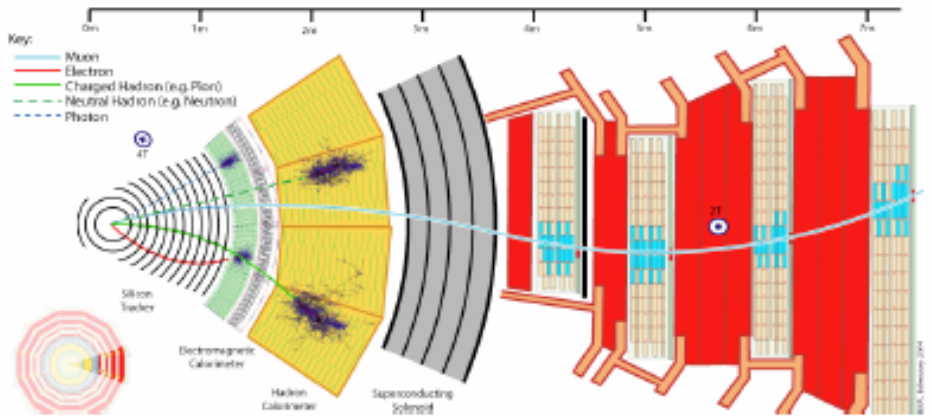
Both experiments:
deferrals of high-level Trigger/DAQ processors
→ LVL1 output rate limited to
~ 50 kHz CMS (instead of 100 kHz)
~ 40 kHz ATLAS (instead of 75 kHz)

Impact on physics visible but acceptable
Main loss : B-physics programme strongly reduced (single μ threshold $p_T$> 14-20 GeV)

# Summary of Lecture 2

- ATLAS and CMS are complementary general purpose detectors for physics at the LHC
- ATLAS and CMS well on track for data taking in 2007 with a fairly complete detector.
  - Many components already shown to work according to expectation
    - Test beams, cosmic events
  - However operating these complex detectors (~ 100 M channels) will certainly be a challenge and will need time at the startup.
- A lot of hard work will be needed to bring up the full detectors to give the high expected quality data
  - This phase is already starting now
- Tomorrow: other LHC experiments and LHC startup

## CMS

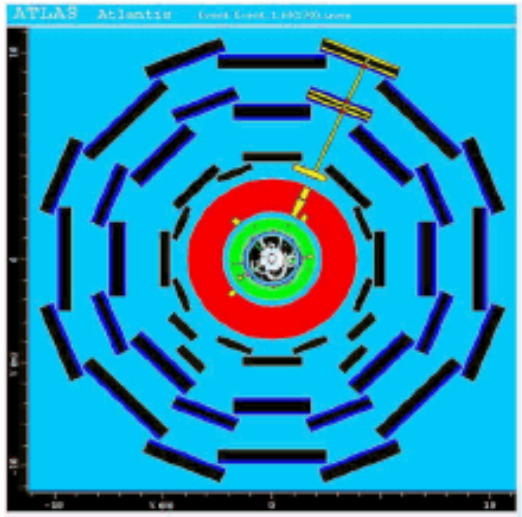



- Tag from Muon chambers
  - Momentum resolution from Silicon Tracker
  - Calo + Magnet Iron absorb hadrons

    Barrel: $p_T^{muon} > 3.5$GeV/c

    Endcap: $p_L^{muon} > 4$ GeV/c
  - Excellent mass resolution for J/ψ and Υ states
  - Coverage in the central rapidity region, $|\eta|<2.5$
  - Reconstruct Z boson

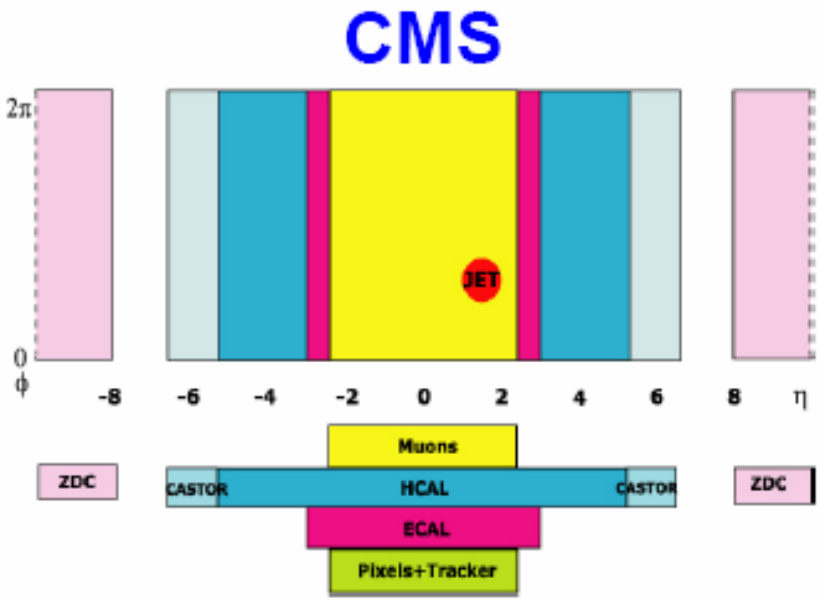
## ATLAS

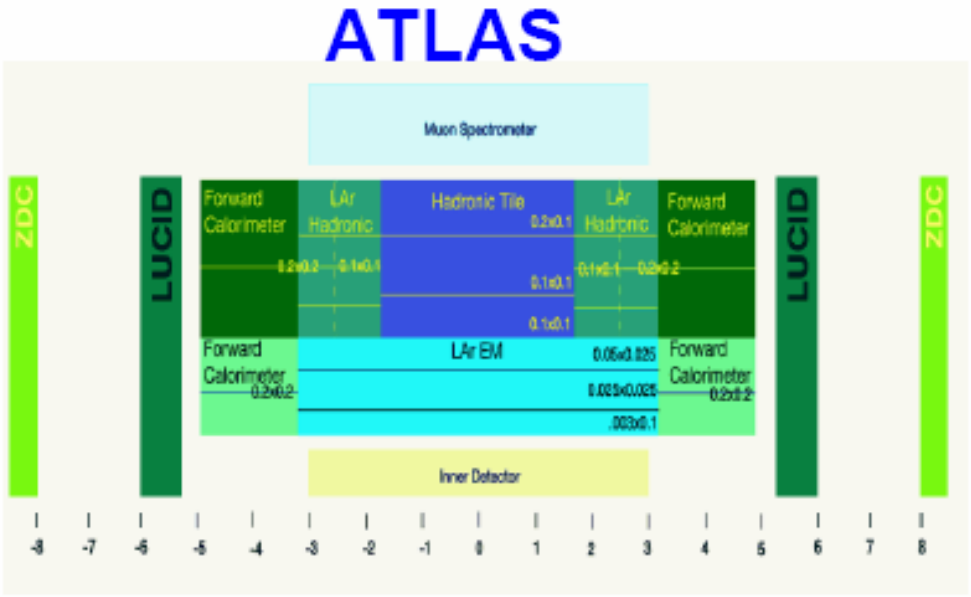



- Standalone μ-Spectrometer
  - Independent of Tracker
  - Toroidal Field outside the calorimeters+Tracking chambers
  - Good mass resolution for J/ψ and Υ states
  - Calos absorb hadrons

    $p_T^{muon} > 3.0$ GeV/c
  - Coverage in the central rapidity region

# ATLAS/CMS Acceptance

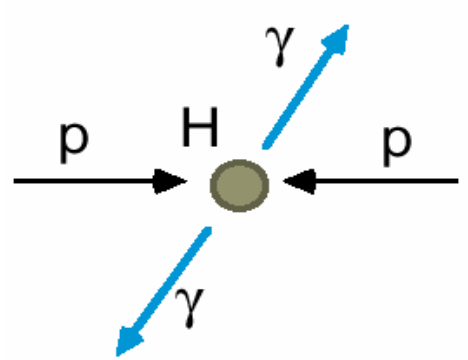


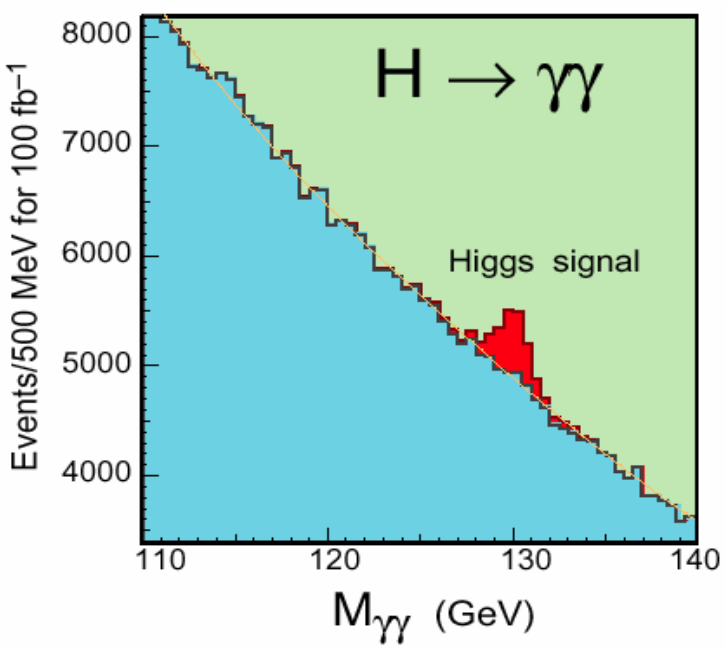



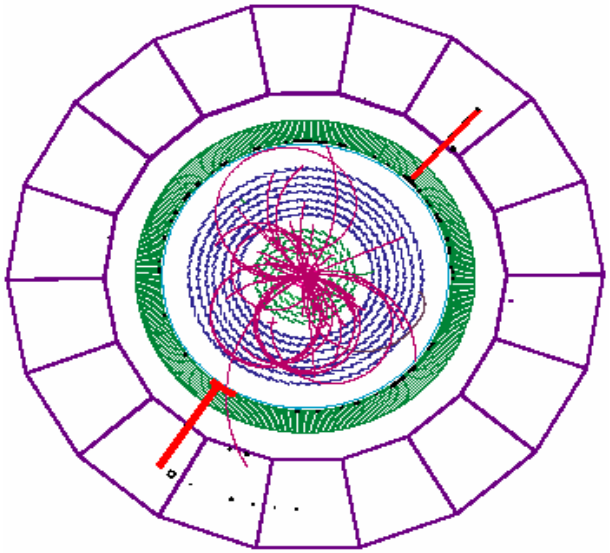

- Hermeticity, Resolution, Granularity
  - Central region $\Delta\eta$~5 equipped with tracker, electromagnetic and hadronic calorimeters and muon detector
- Forward coverage
  - Calorimetric coverage of $\Delta\eta$~10
  - Additional calorimeters proposed to extend the coverage
    - CMS: CASTOR ($\Delta\eta$~14) ATLAS: LUCID ($\Delta\eta$~12)
  - Zero Degree Calorimeter (ZDC)
- Fast Readout for trigger

# Examples: Low mass Higgs ($M_H$<140 GeV/$c^2$)

- $H \rightarrow \gamma\gamma$: decay is rare (B~$10^{-3}$)
  - But with good resolution, one gets a mass peak
  - Motivation for LAr/$PbWO_4$ calorimeters
  - CMS example: at 100 GeV, $\sigma \approx 1$GeV
    - S/B ≈ 1:20

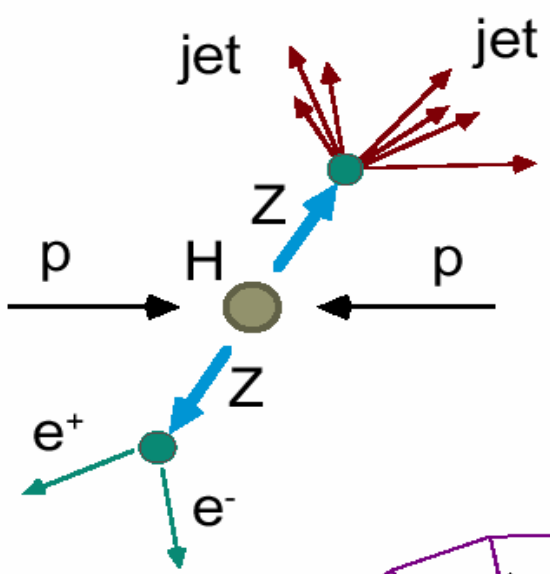


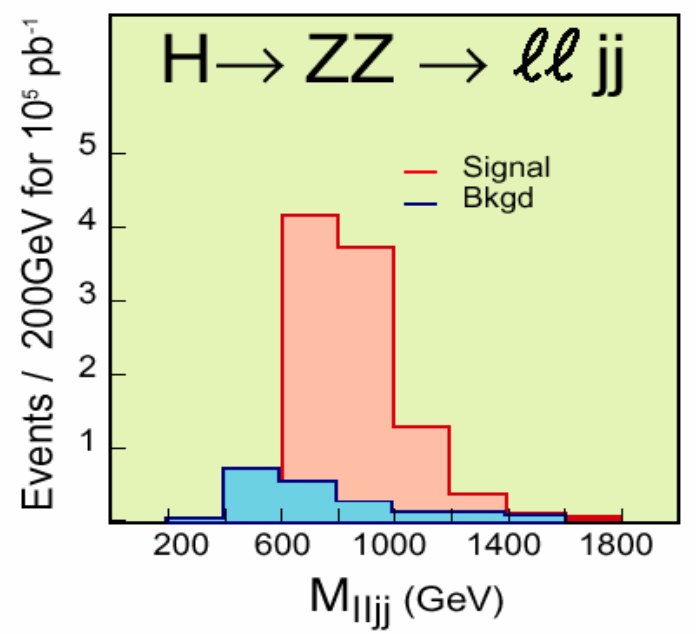



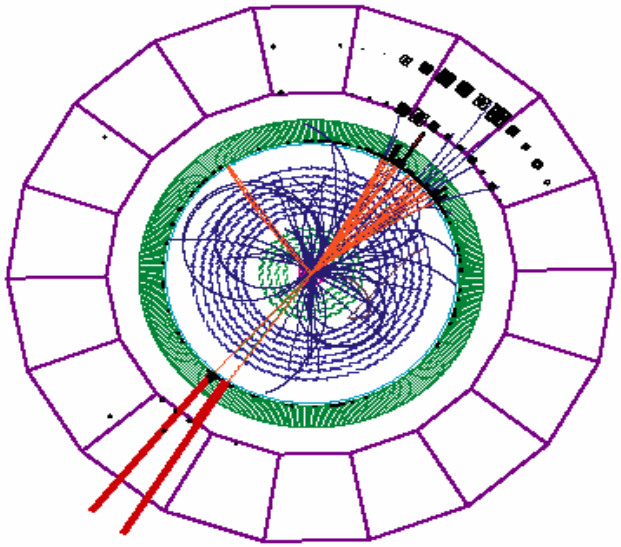



# Example: (Very) High mass Higgs

- $H \to ZZ \to \ell^+\ell^-$ jet jet
  - Need higher Branching fraction (also $\nu\nu$ for the highest masses ~ 800 GeV/$c^2$)
  - At the limit of statistics



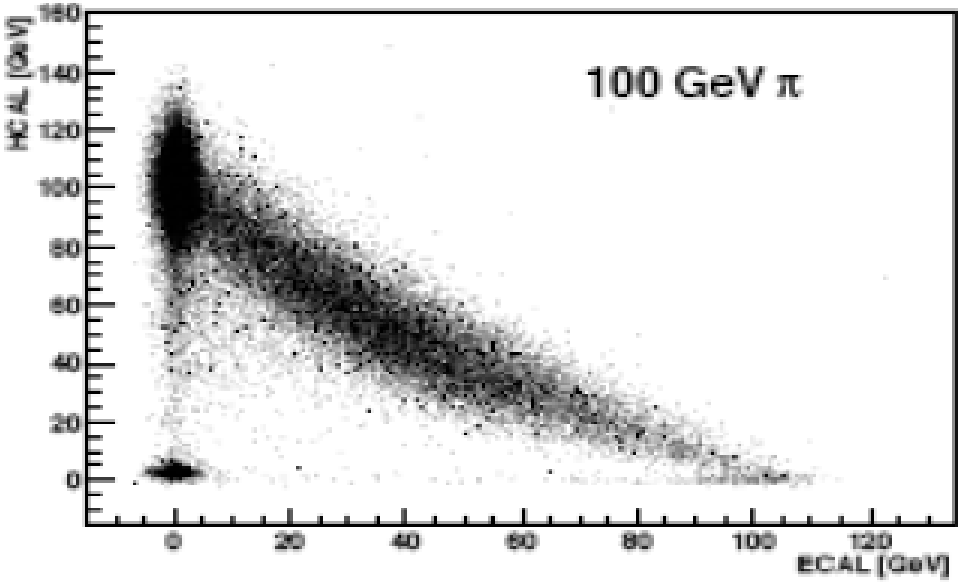



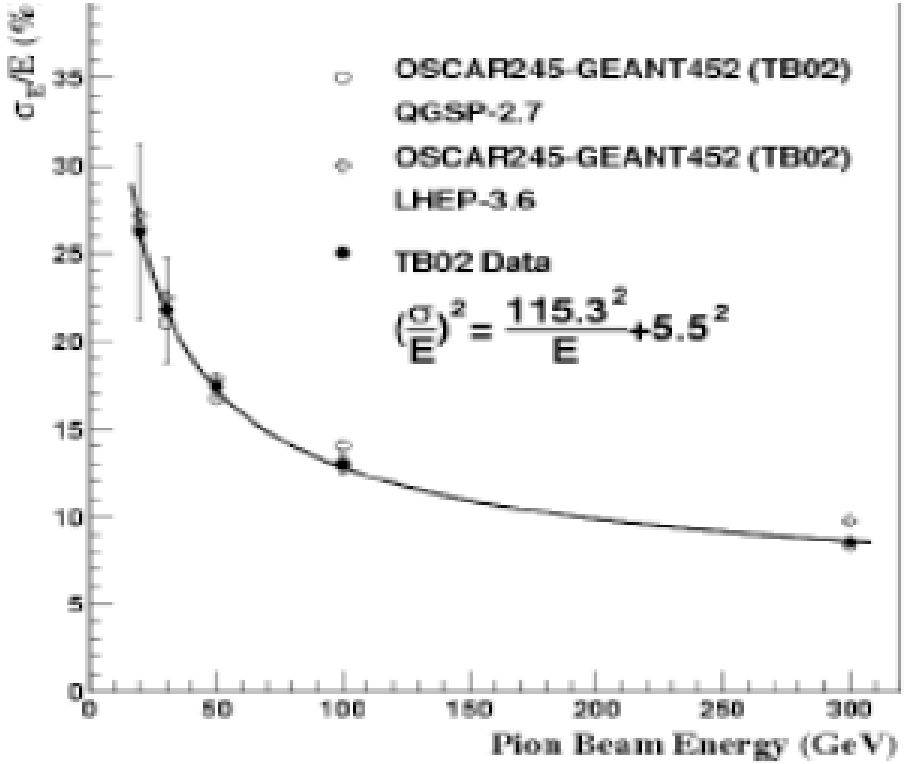



# The Road to Measurements and Discoveries at the LHC

Albert De Roeck / CERN

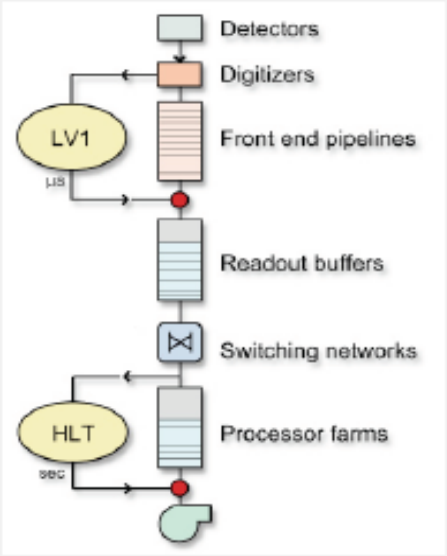
# Testbeam Measurements




Combined Test ECAL SM + HCAL Wedge in Summer 06

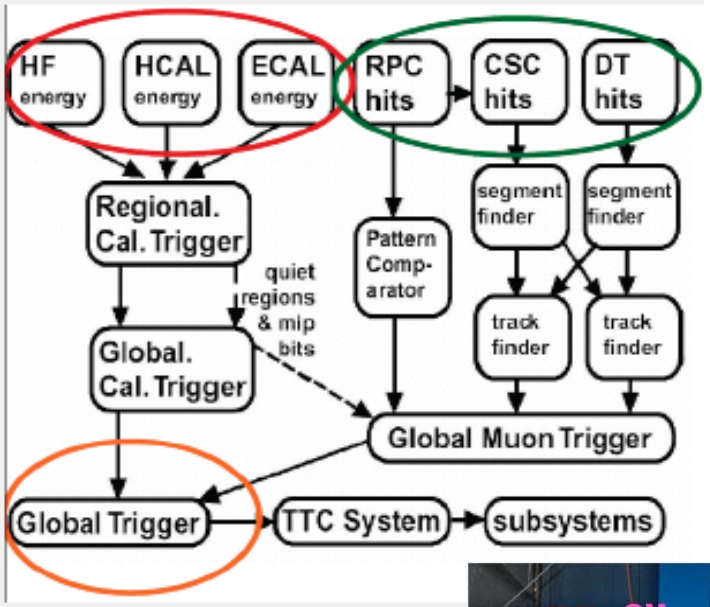
# The CMS Trigger




**40 MHz**
**Clock driven**
**Custom processors**

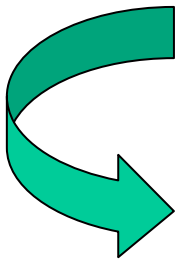
**100 kHz**
**Event driven**
**PC network**
**Totally software**

**100 Hz**
**To mass storage**




## two trigger levels

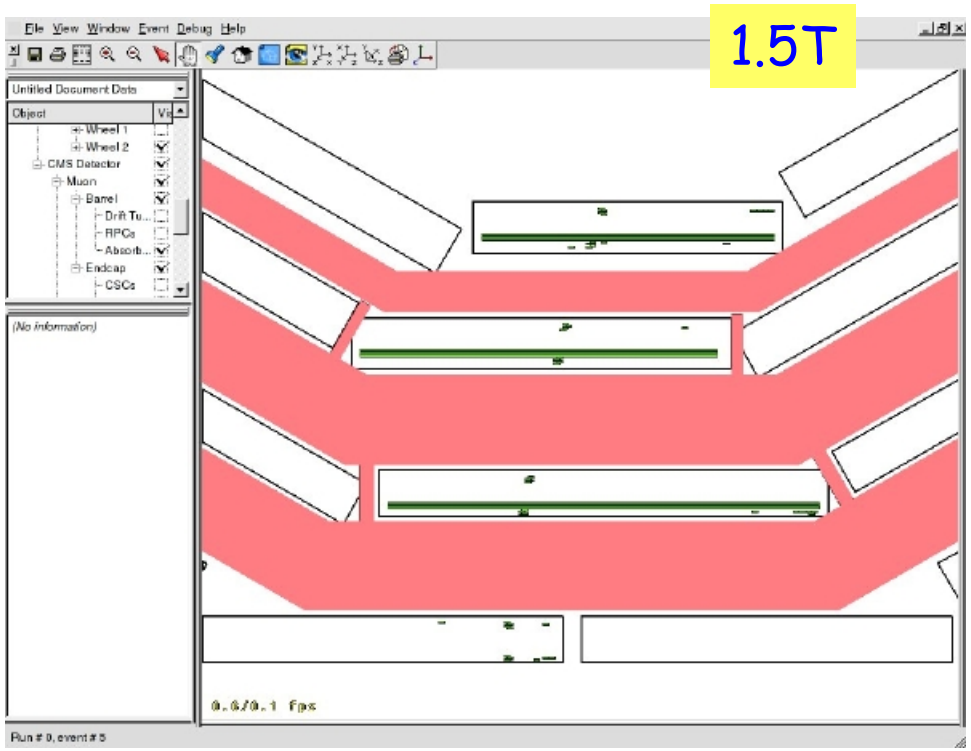
**Level-1 (~μs) 40 MHz**
**High-Level ( ms-sec) 100 kHz**
**Event Size ~ $10^6$ Bytes**

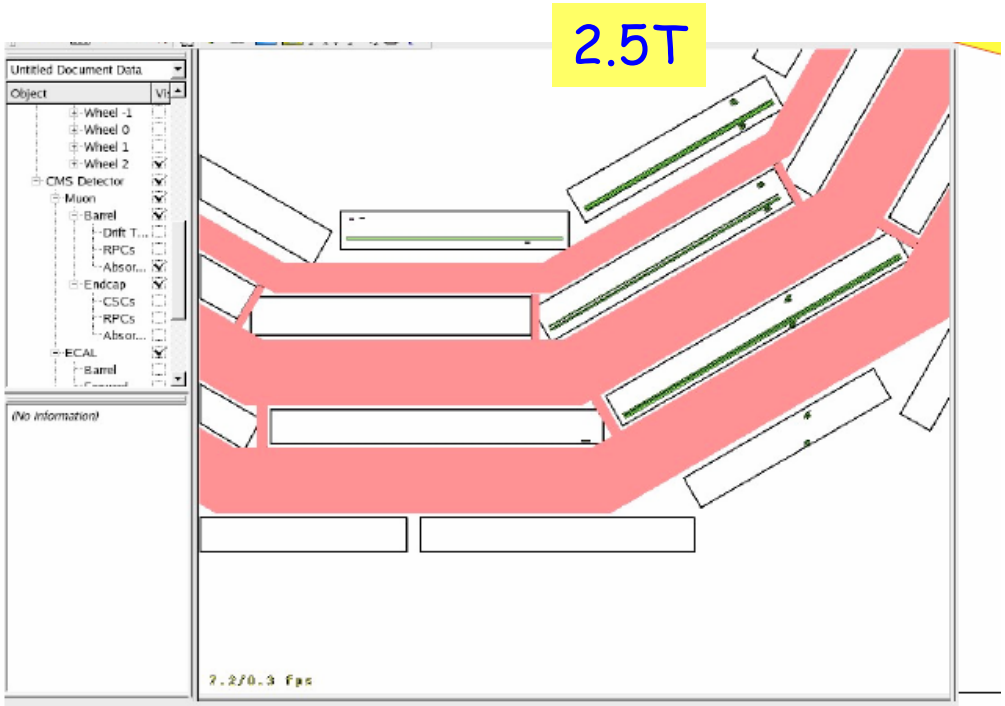


Integration tests

# Muons in the Magnet test

- Meeting tomorrow (15:00-17:00)
- 2.5 Tesla reached last week/this weekend aiming for 3T
- Bend muons in the magnetic field (last week)

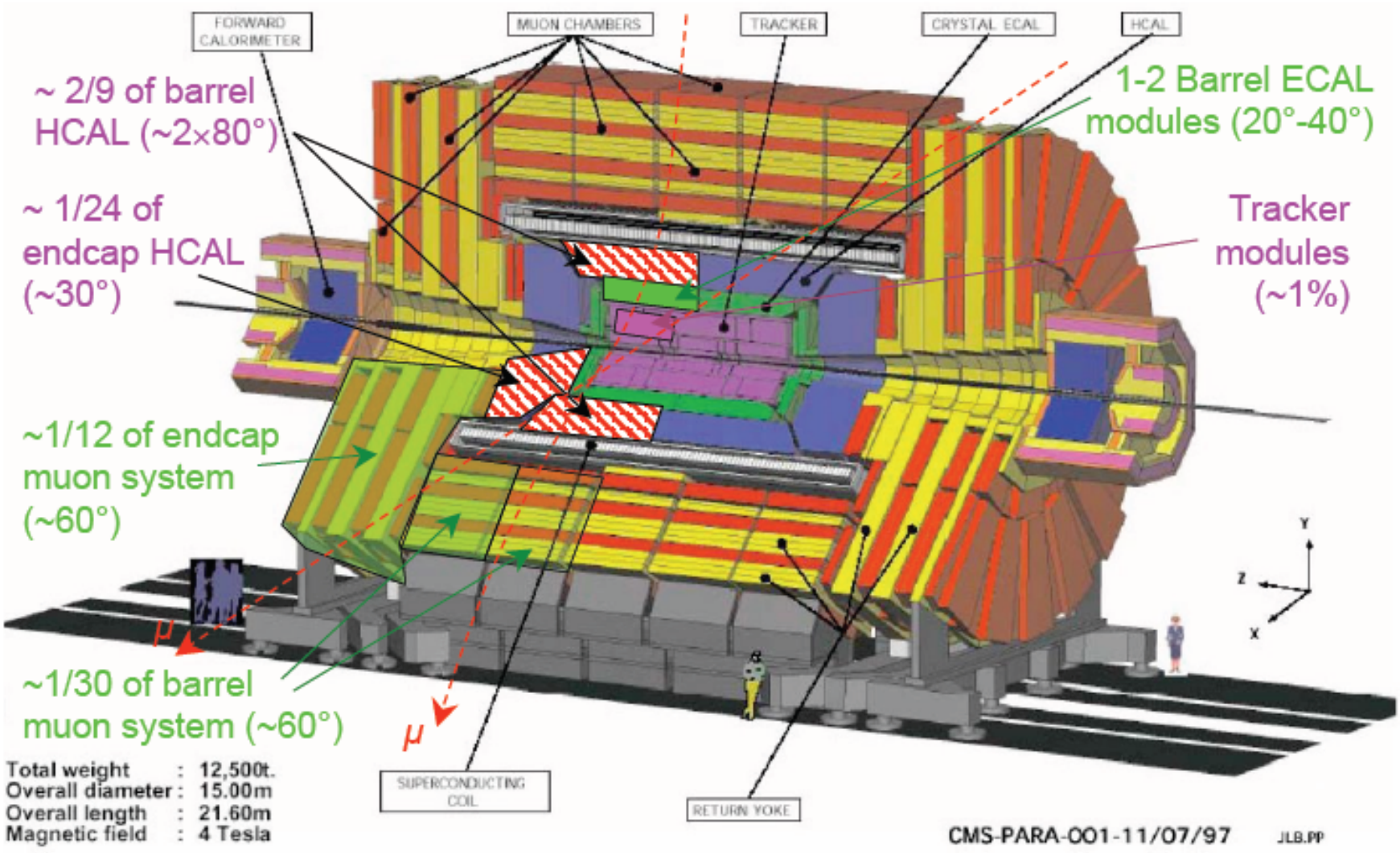


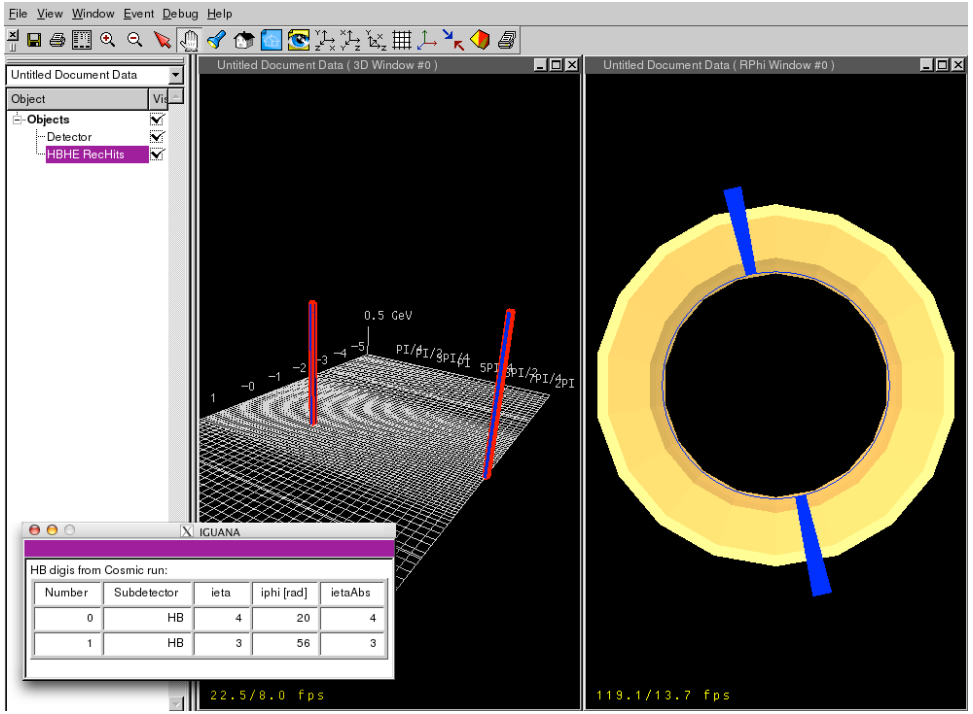

Friday 11/8 Magnet brought up to 3 Tesla

# CMS Magnet Test and Cosmic Challenge (MTCC)

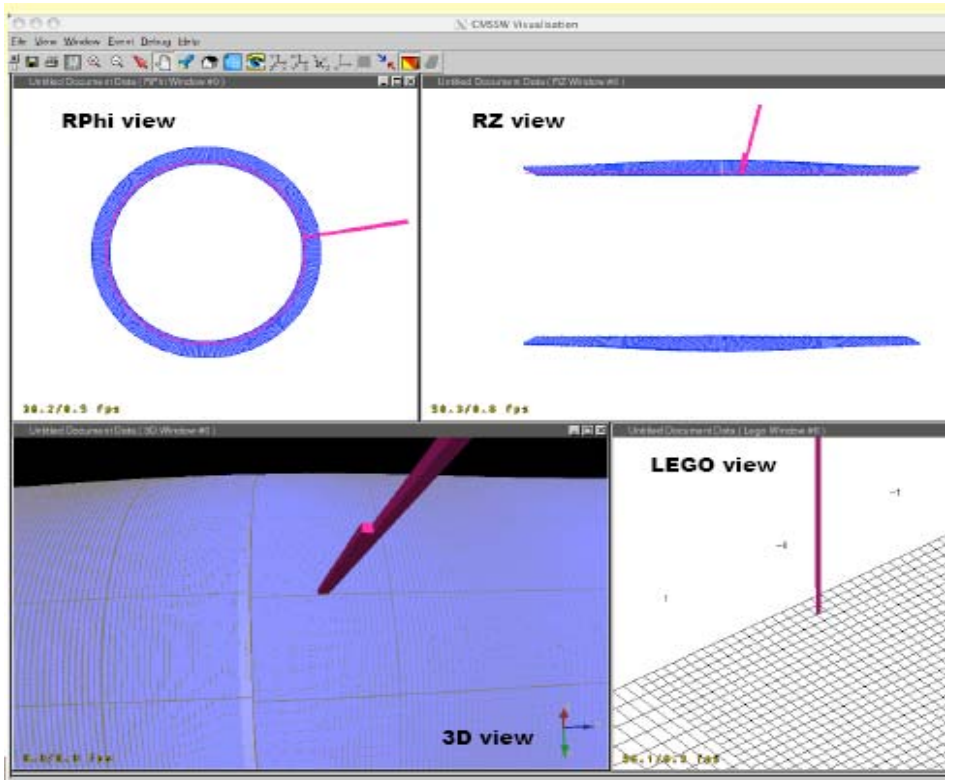
Ramping up of the magnet to nominal field started. A combined test of a slice of CMS will then be performed with cosmics.



# CALO commissioning with cosmics



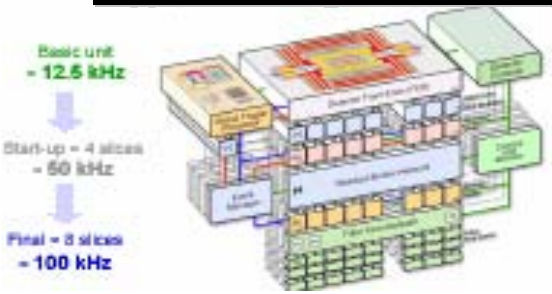

Cosmic muons observed in the ECAL

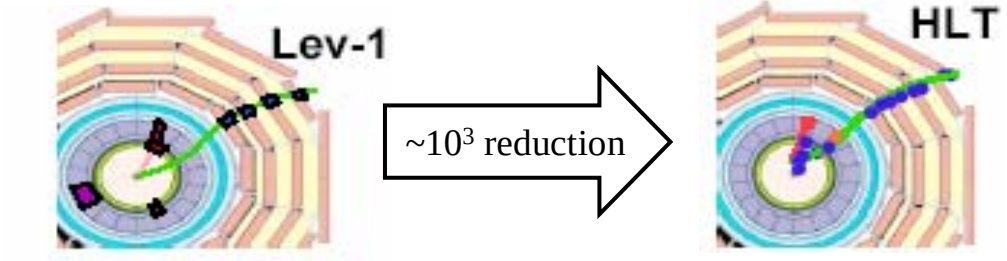



Cosmic muons observed by CMS at IP5 (recorded by hadron barrel calorimeter)

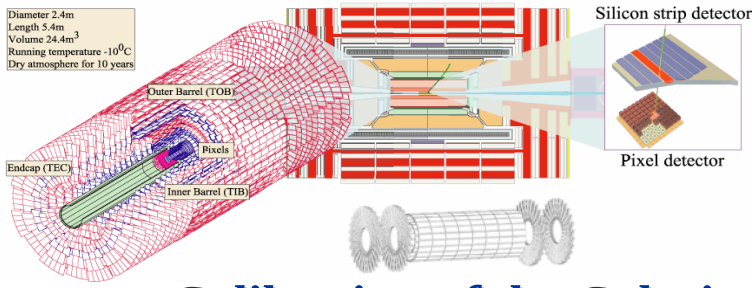
# Major Commissioning Challenges

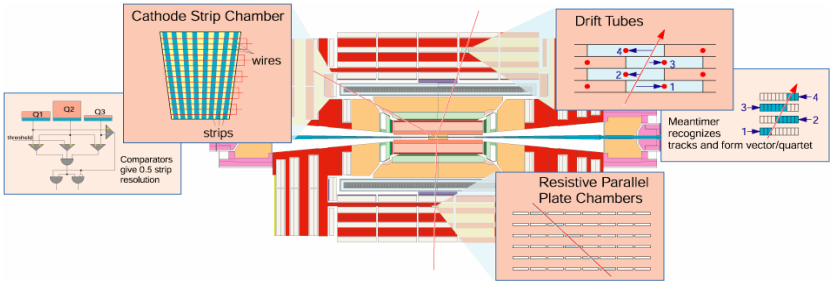
## *Efficient operation of Trigger (Level1/HLT) and DAQ System*



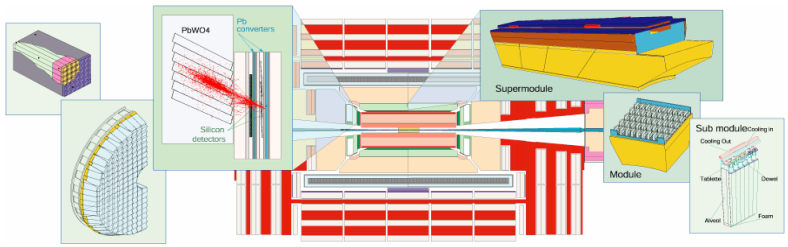



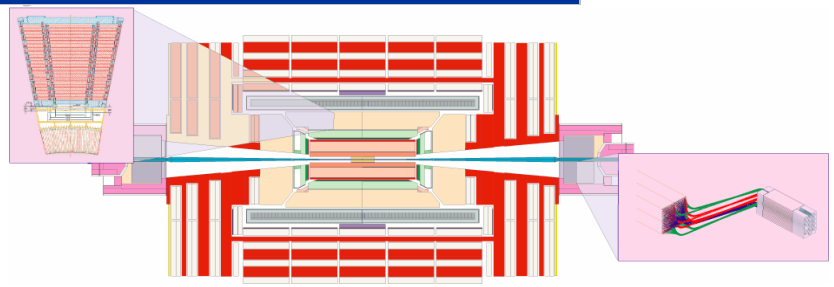

## *Alignment of the tracking devices Tracker(PIXEL,Strip) and Muon System*




## *Calibration of the Calorimeter Systems ECAL and HCAL*



→form the base for the "commissioning of physics tools" like b and τ tagging, jets, missing $E_T$ …

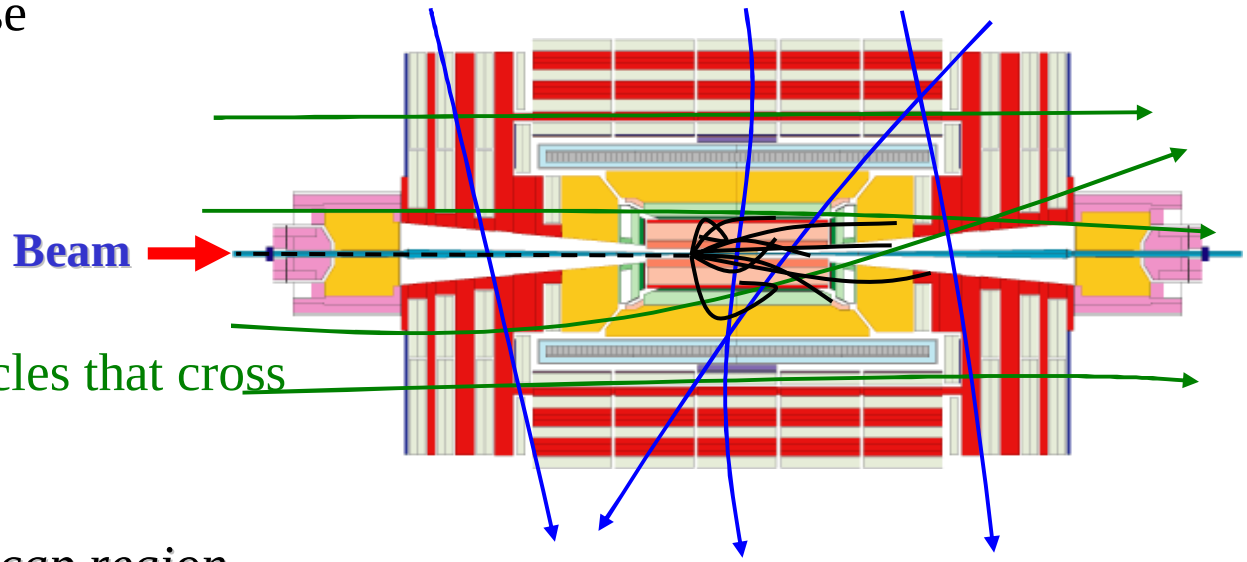
# Calibrating/Alignment Before Collisions

Experiments will have ~ some time before collisions

***Cosmic Muons***

High energetic muons that traverse the detector vertically

→particular useful for alignment and calibration - *barrel region*.




***Beam Halo Muons (Hadrons)***

Machine induced secondary particles that cross the detector almost horizontally

→particular useful for alignment and calibration - *endcap region*.

***Beam Gas Interactions***

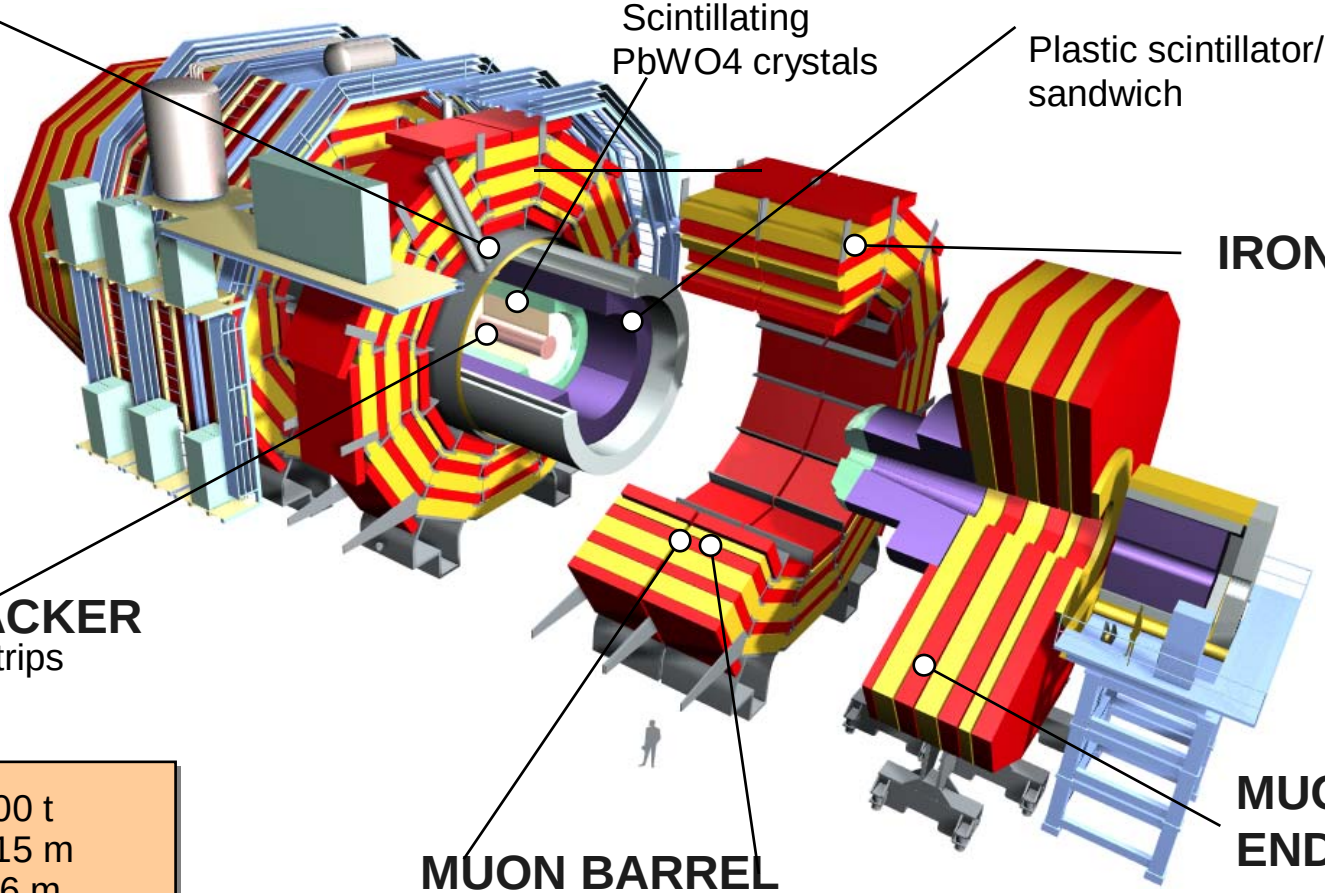
Proton-nucleon interaction in the active detector volume (7TeV→$E_{cm}$=115 GeV)

→resemble collision events but with a rather soft $p_T$ spectrum ($p_T$<2 GeV)

**All three physics structures are interesting for alignment, calibration, gain operational experience, dead channels, debug readout, etc …**

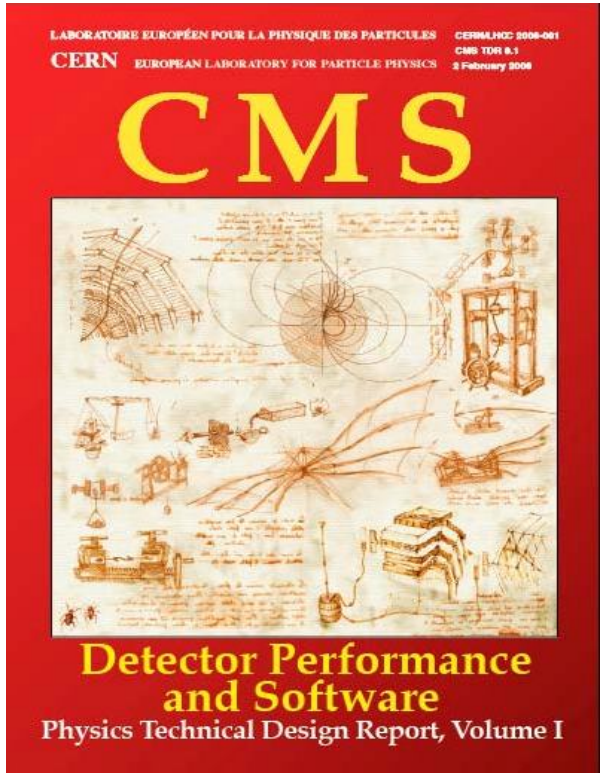
# The Startup detector

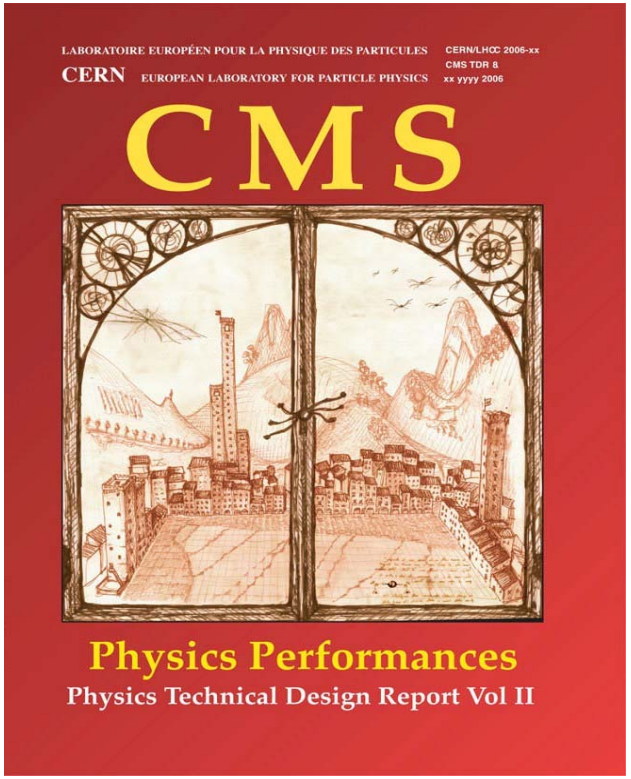
**Initial detectors: (pilot run)**
-**No Ecal endcap**
-**No pixel detector**
**(1 phi slice in barrel/endcap)**
-**1 DAQ slice (12.5 kHz L1)**
**Low luminosity detector**
**(first physcis run in 2008)**
- **Endcap/pixel included**
- **50% DAQ (50 kHz L1)**
**Staged**
-**ME 4/2**
-**RPCs for $|\eta|>1.6$**
**Rather complete detector from the start**




Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

# CMS Analysis projects
# The Physics TDRs




**http://cmsdoc.cern.ch/cms/cpt/tdr/**

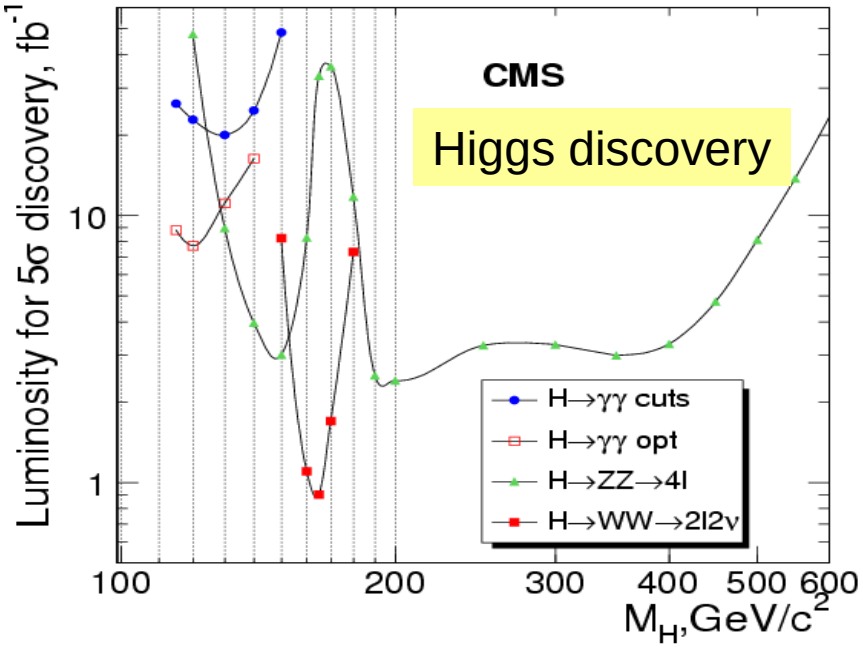
**CERN/LHCC 2006-001**

**February 2006**

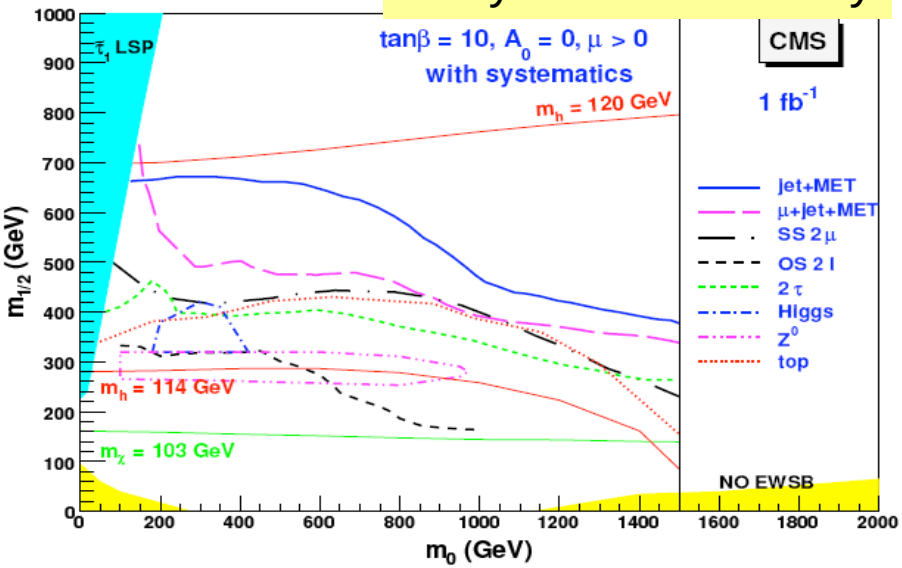
**CERN/LHCC 2006-021**

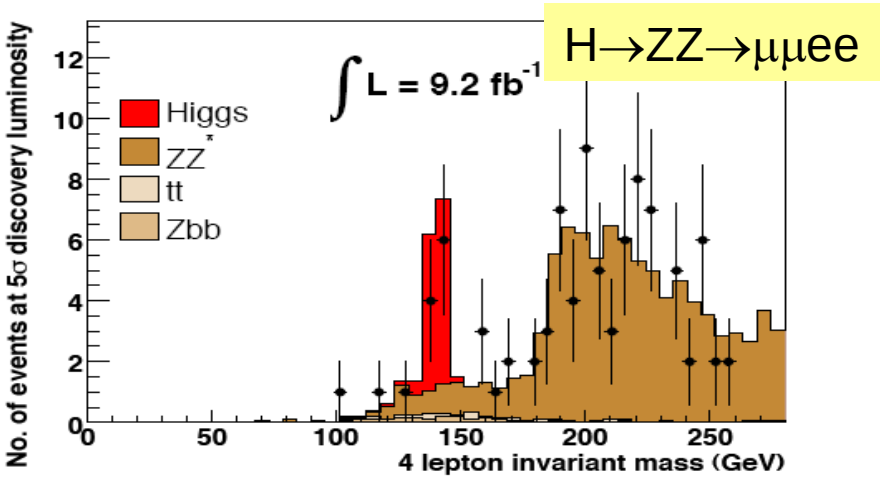
**June 2006**

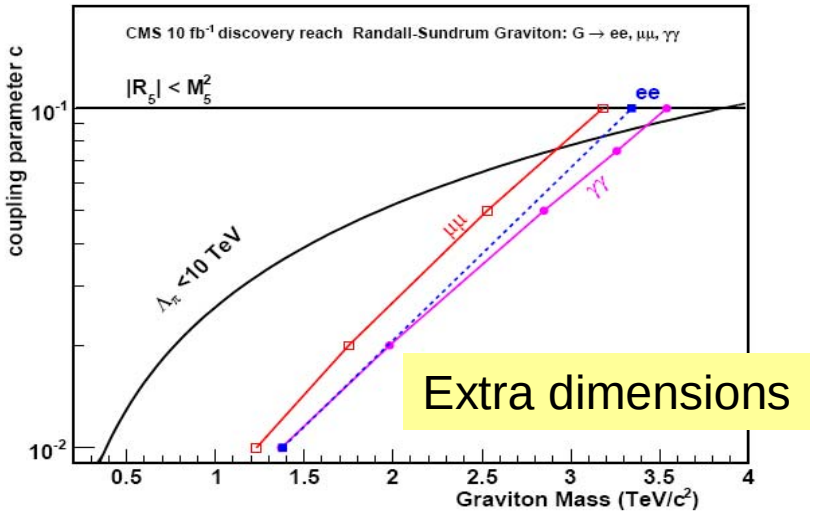
# A few PTDR Results

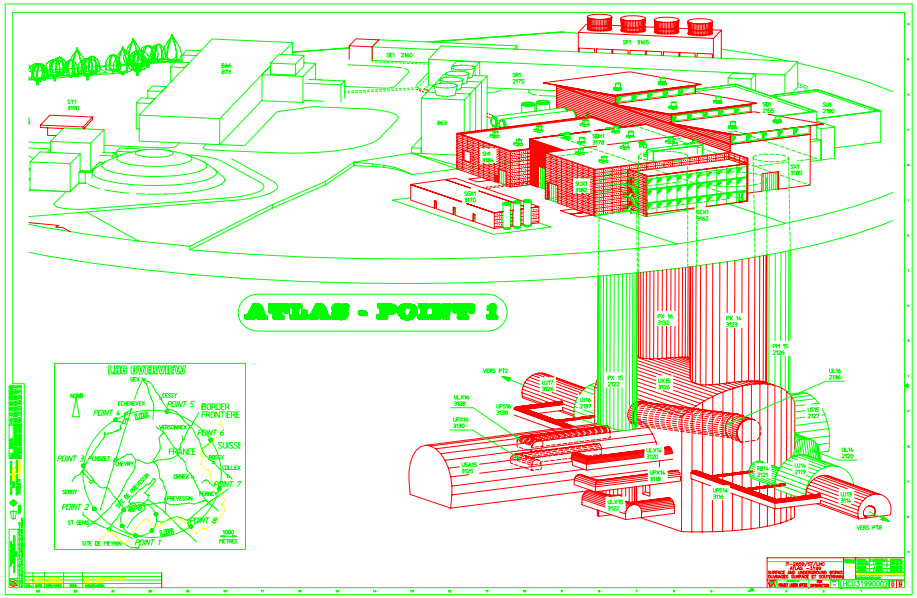



Early SUSY discovery

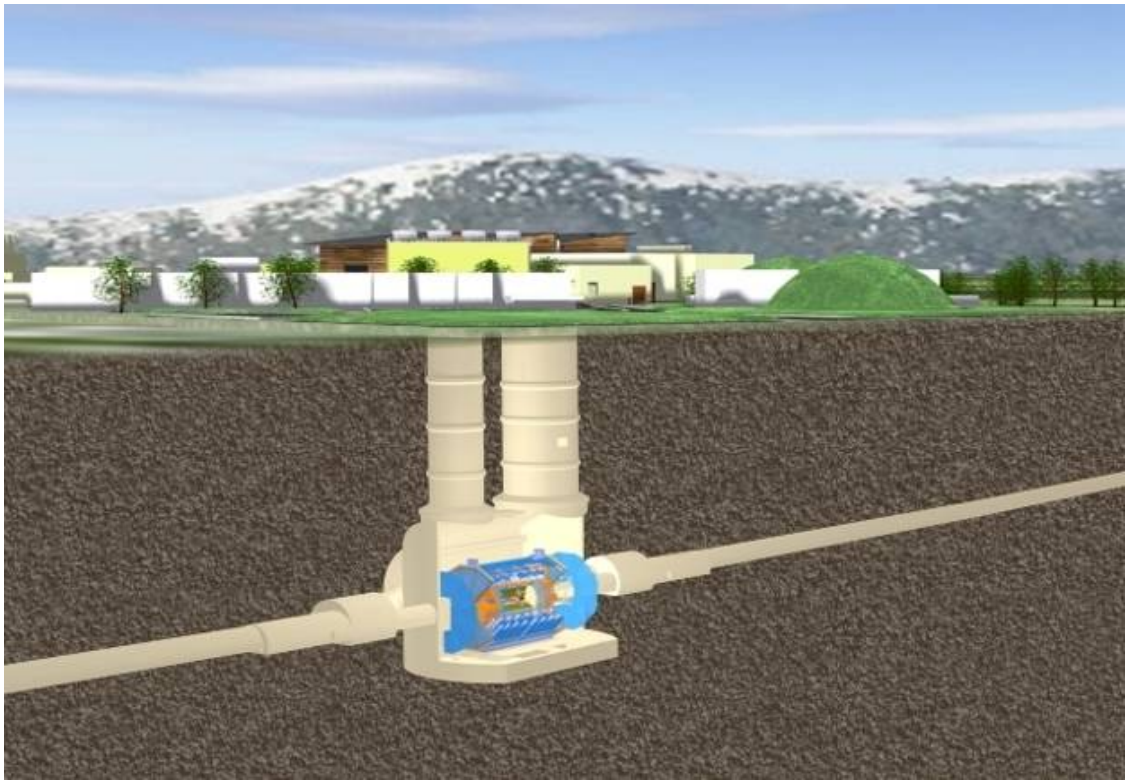


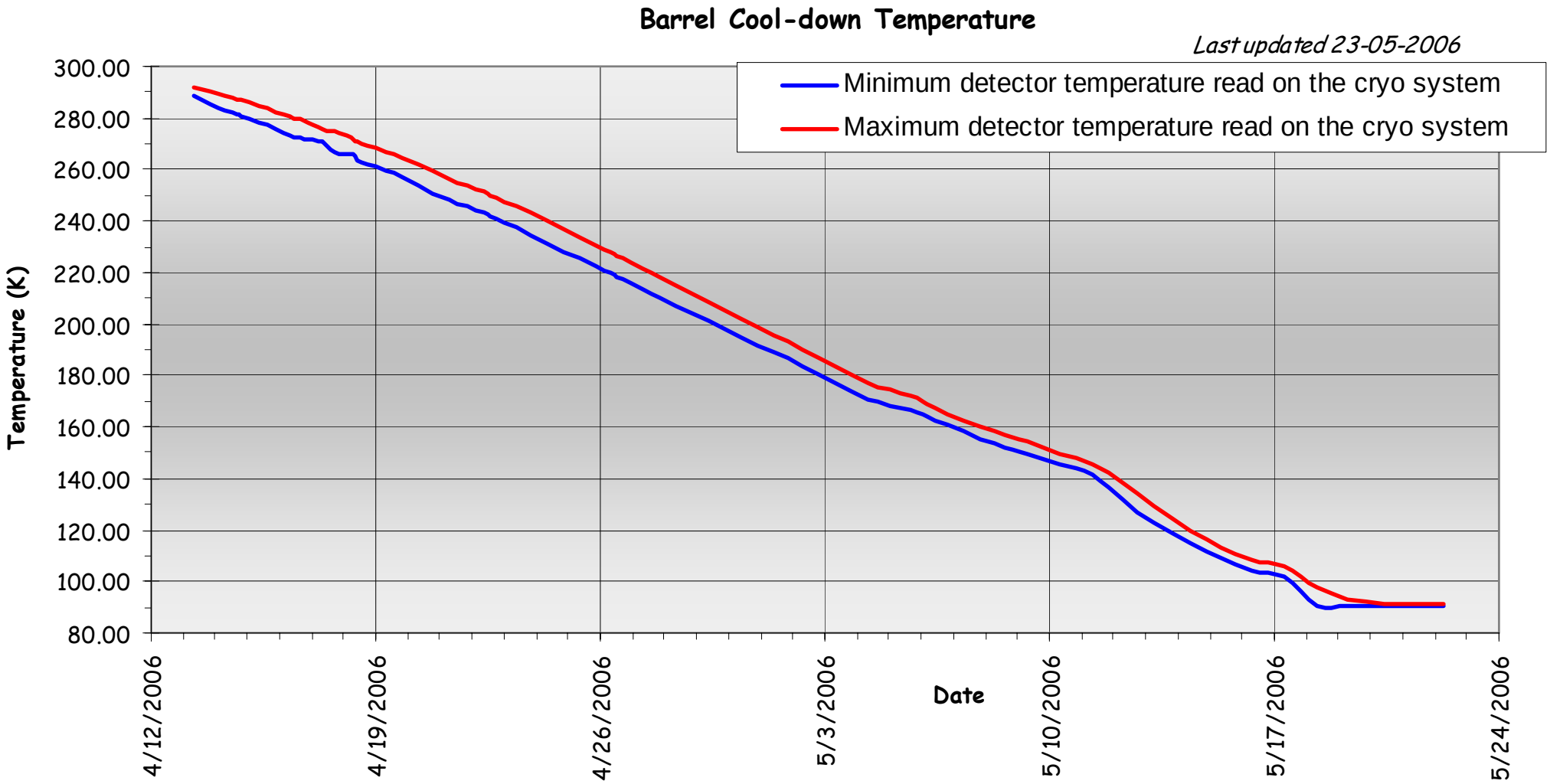



# *The Underground Cavern at Pit-1 for the ATLAS Detector*

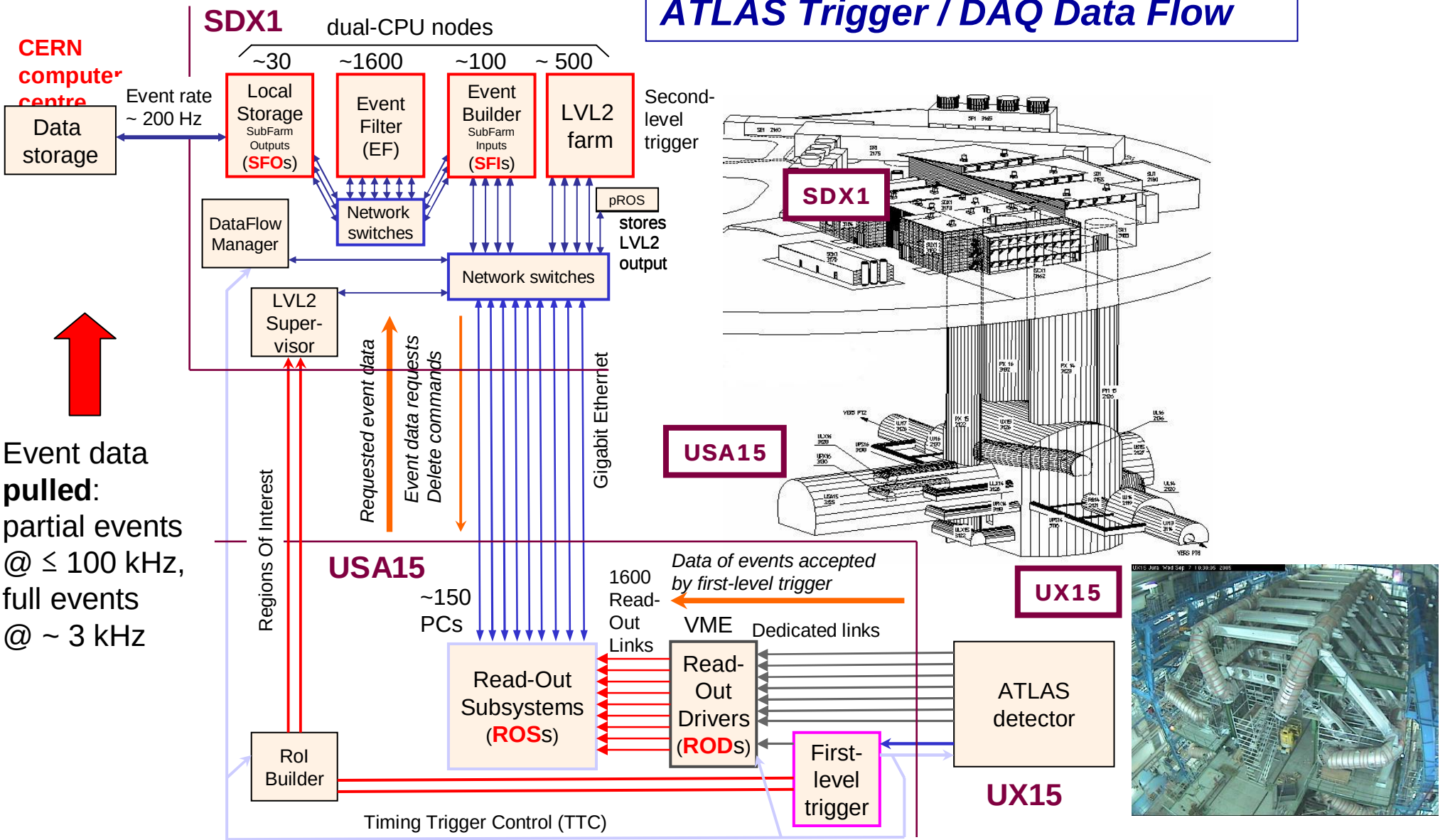


**Length = 55 m**
**Width = 32 m**
**Height = 35 m**

***Latest news: Cool-down completed, filled with LAr, in-situ commissioning started...***



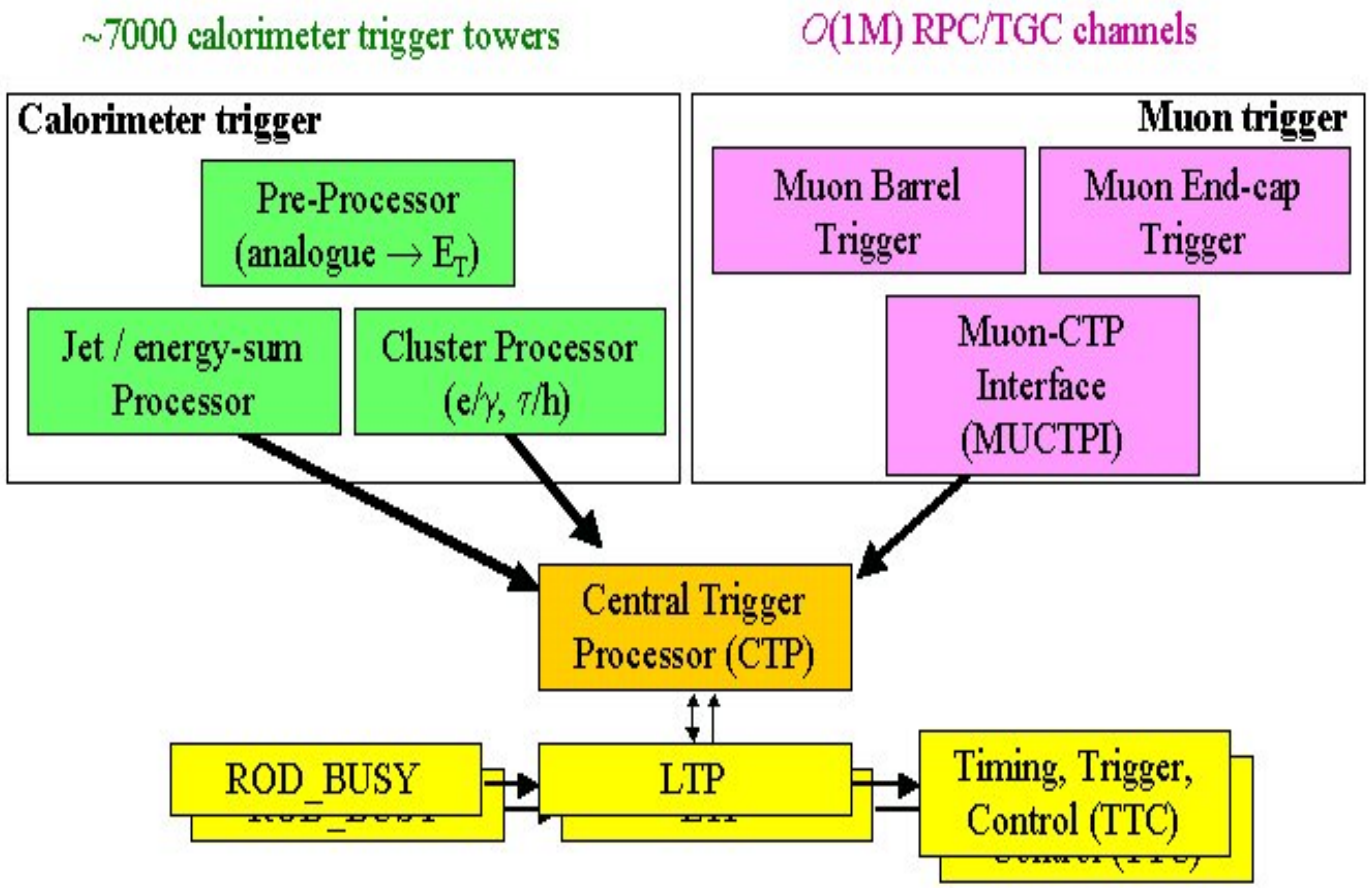
# ATLAS Trigger / DAQ Data Flow



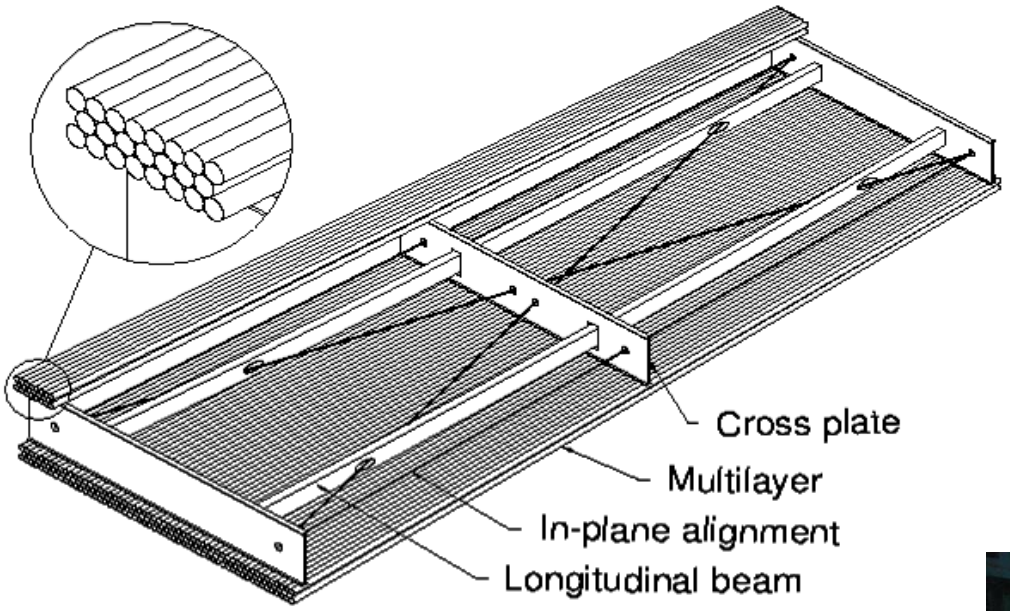
## *Level-1*

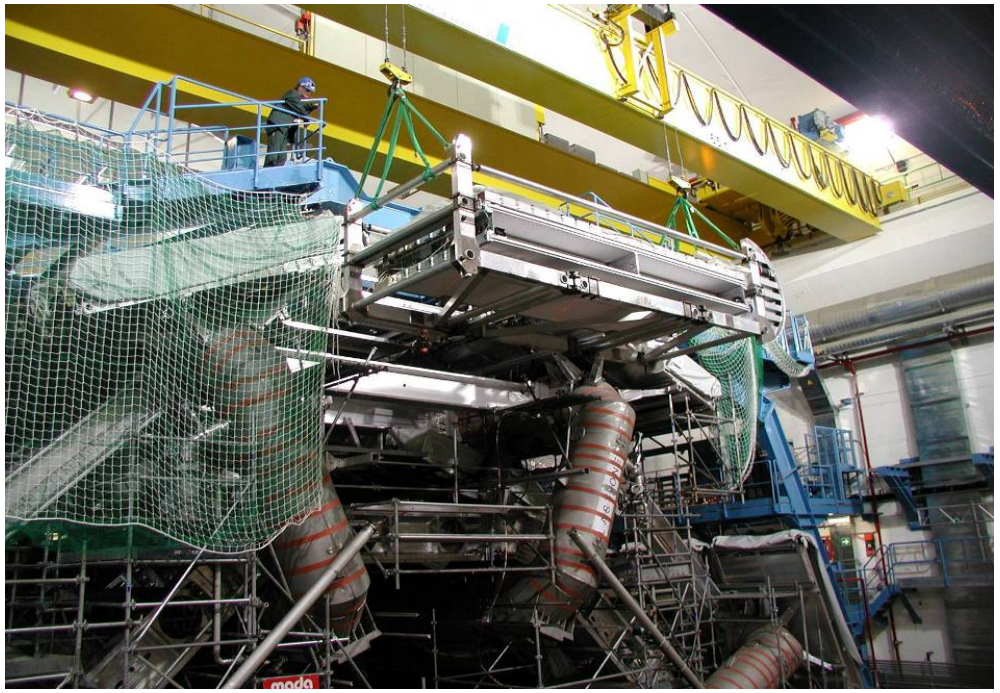
**The level-1 system (calorimeter, muon and central trigger logics) is in the production and installation phases for both the hardware and software**

**The muon trigger sub-system faces a very tight schedule for the on-chamber components, but is now proceeding satisfactorily**



# *Barrel MDTs*



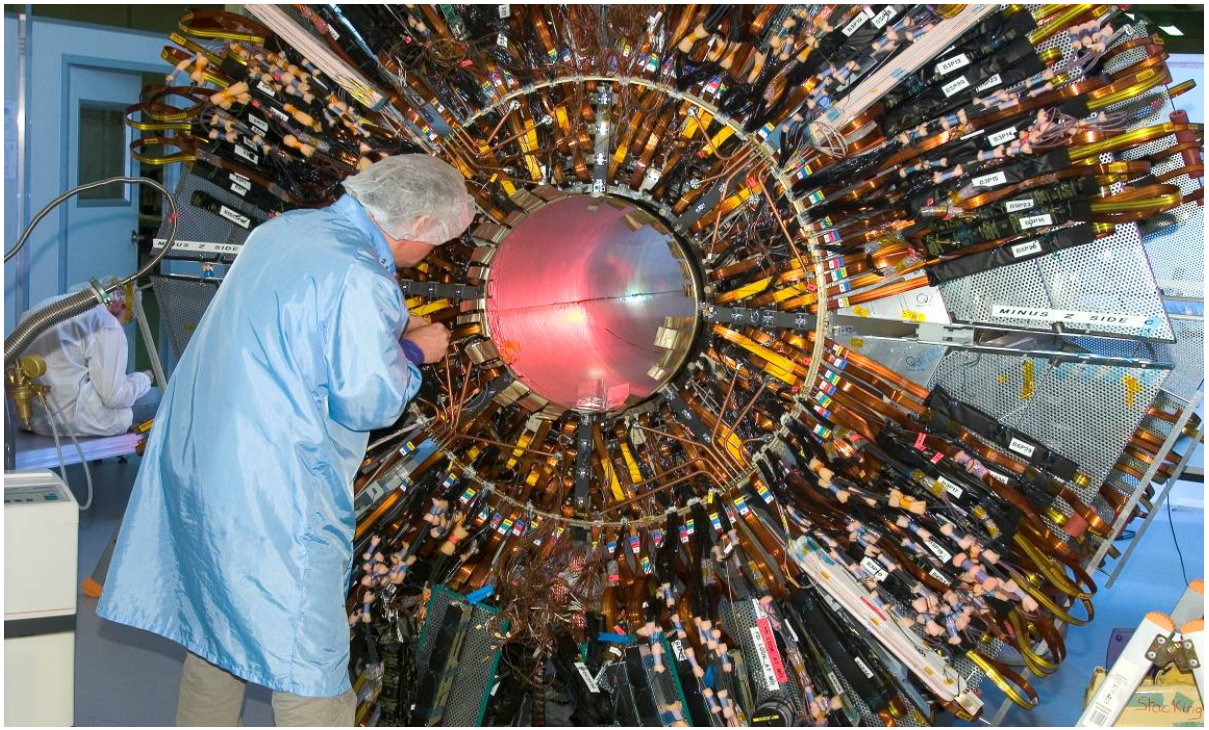
**Installation of barrel muon station (40% done)**

**A major effort is spent in the preparation and testing of the barrel muon stations (MDTs and RPCs for the middle and outer stations) before their installation in-situ**

**The electronics and alignment system fabrications for all MDTs are on schedule**

## *Silicon Tracker (SCT)*

**All four barrel cylinders are complete and at CERN**



**The pictures show different stages of the integration of the four barrel SCT cylinders**

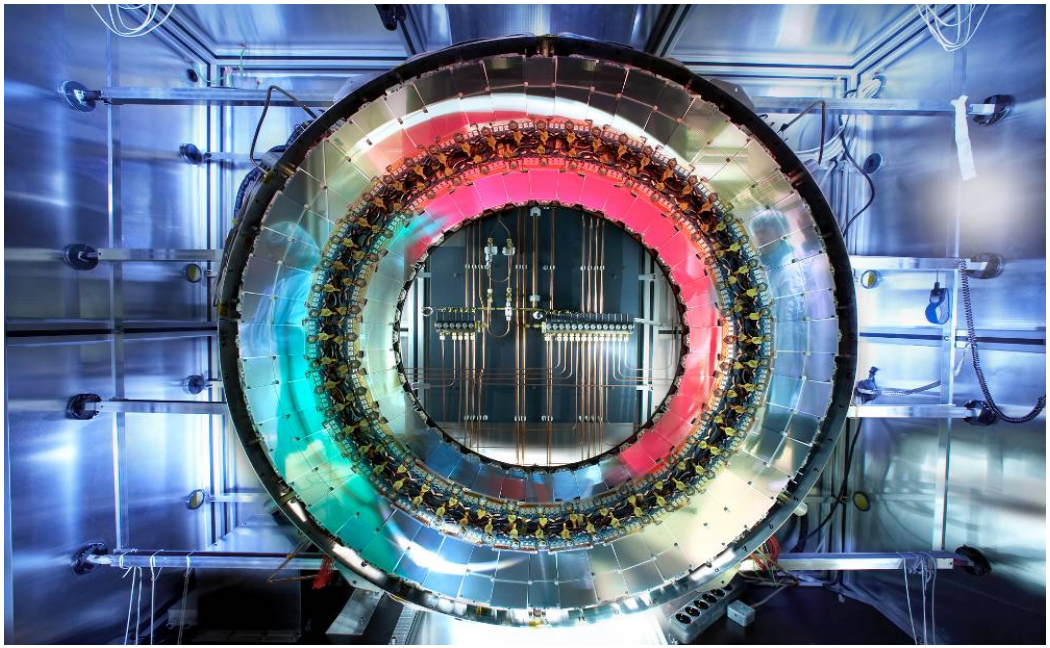
**The cylinders have been tested before: 99.7% of all channels fully functional**

## *End-cap SCT*

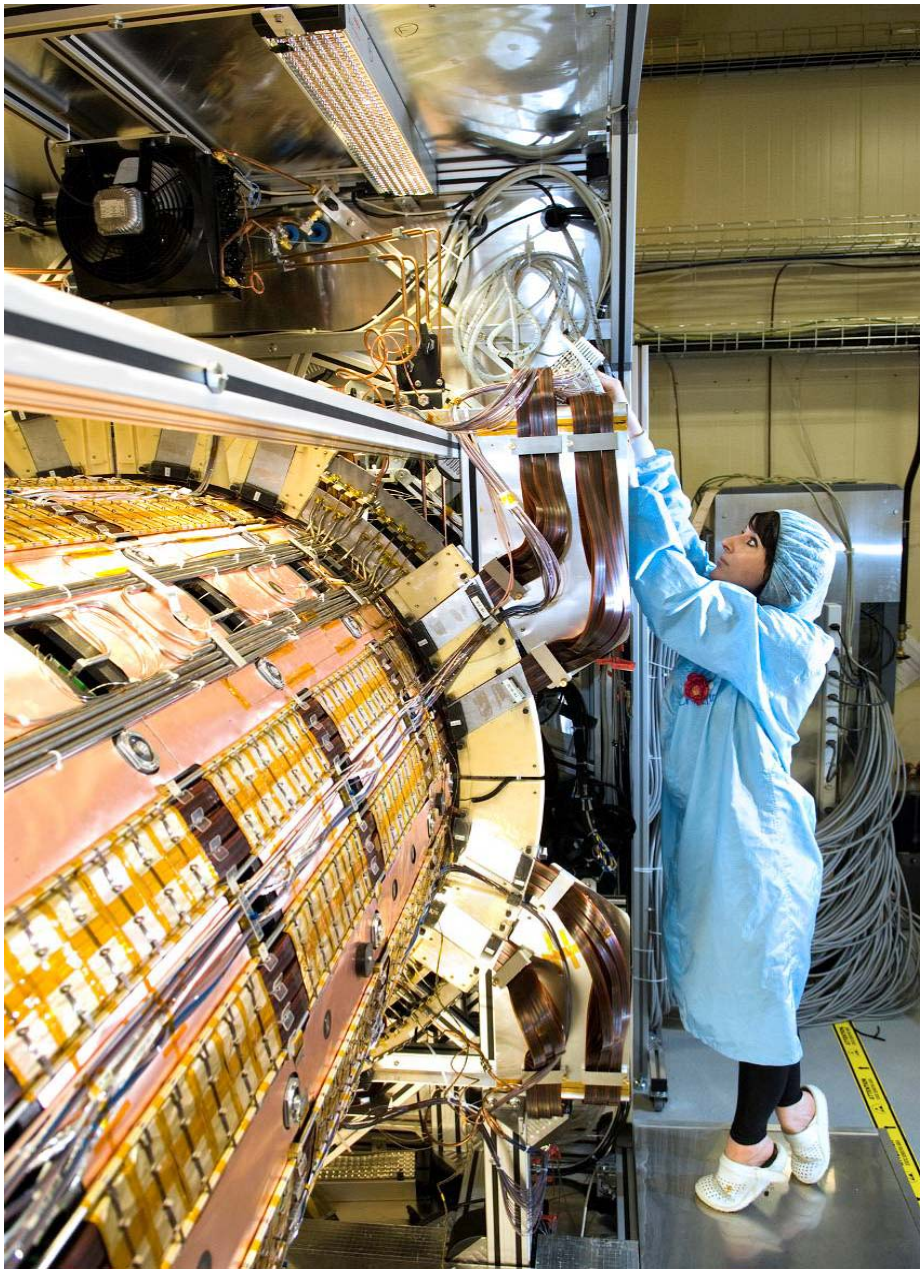
**All disks for the end-caps are finished as well**

**The first end-cap arrived end of February 2006 at CERN, the second one in April 2006**

**A completed end-cap SCT disk**



*(Picture taken by a star-photographer, P. Ginter, as art-work…)*



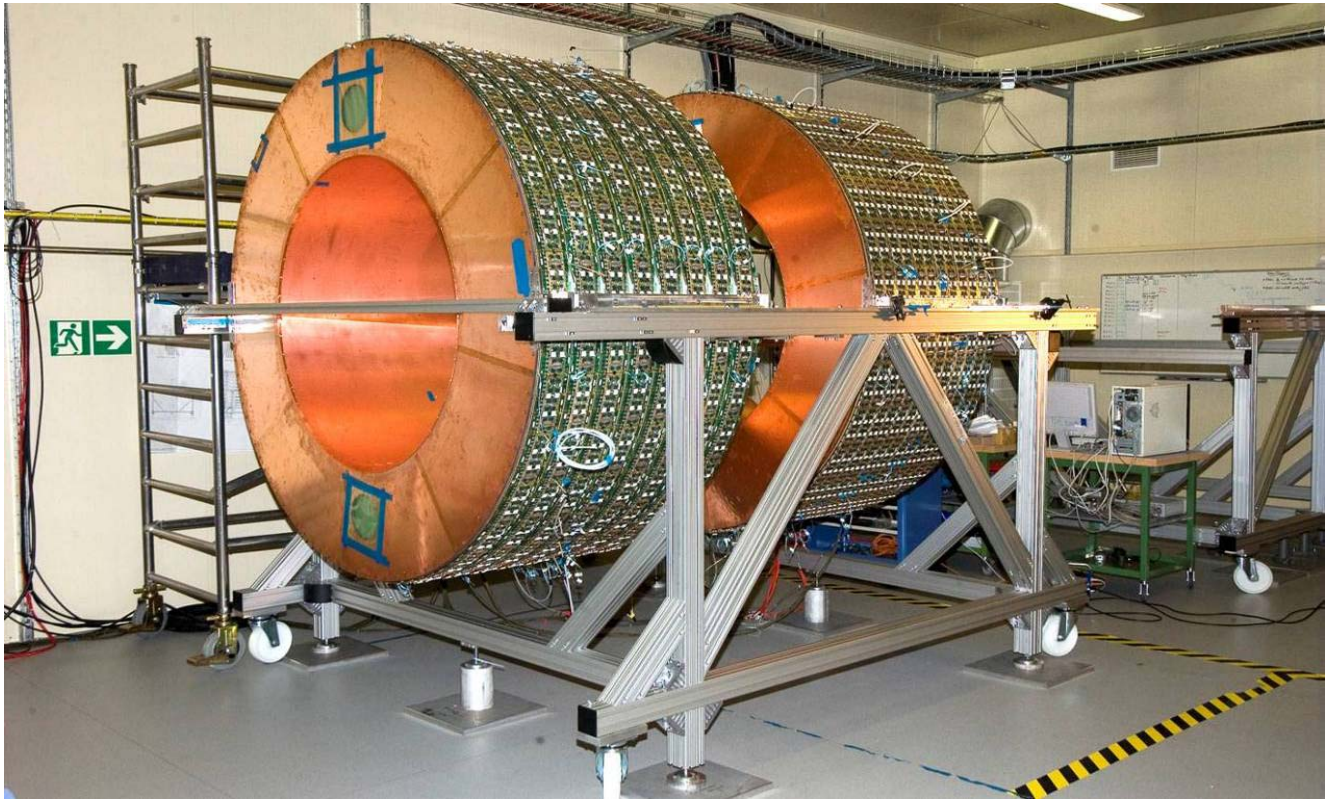
**Integration work on one of the end-cap SCT cylinders**

## *Transition Radiation Tracker (TRT)*

**The module construction for the TRT is complete**

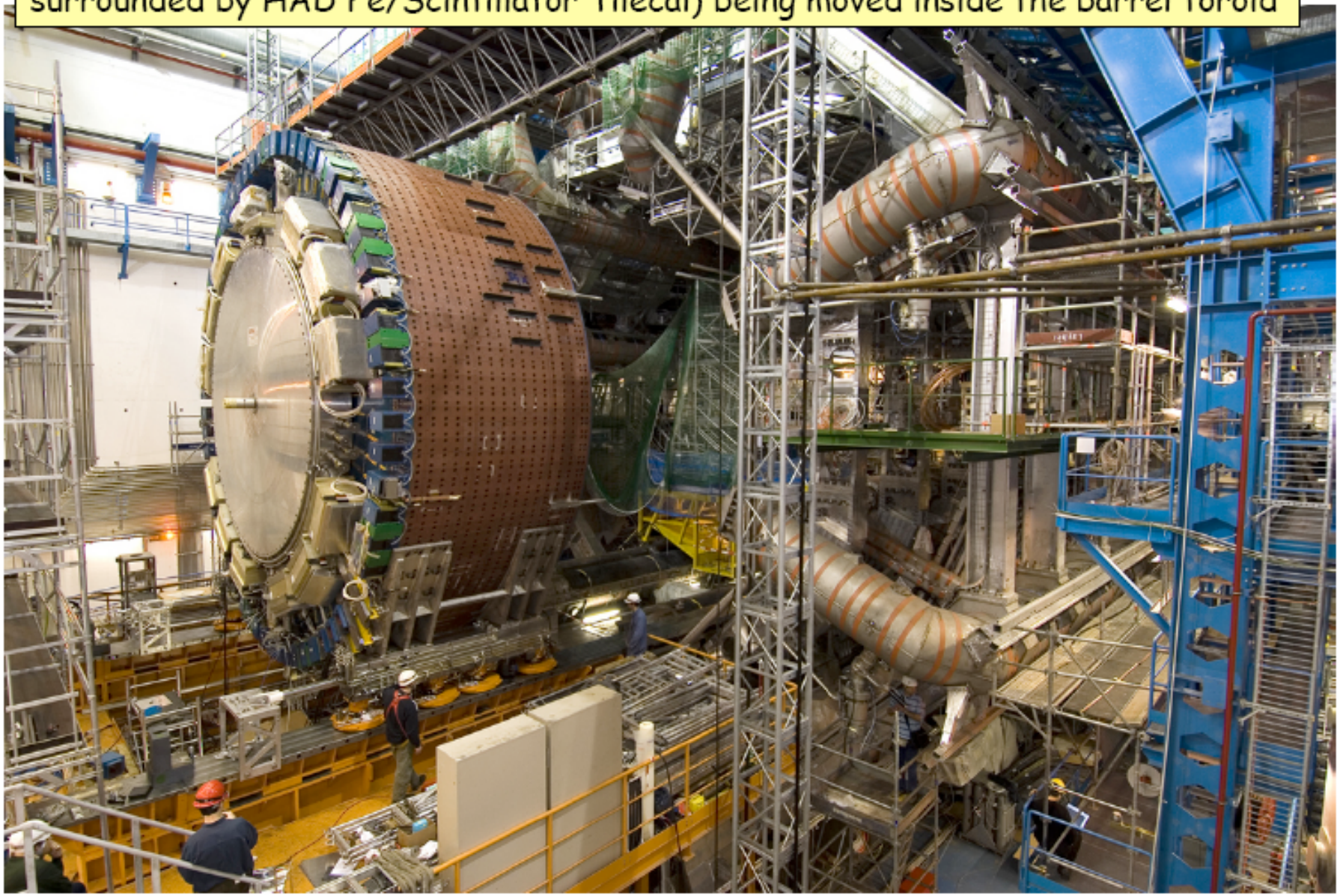
**The barrel integration has been finished since about a year**

**The first end-cap side (A and B wheels) has been stacked, the second side will be ready in June 2006, they are now being equipped with services**

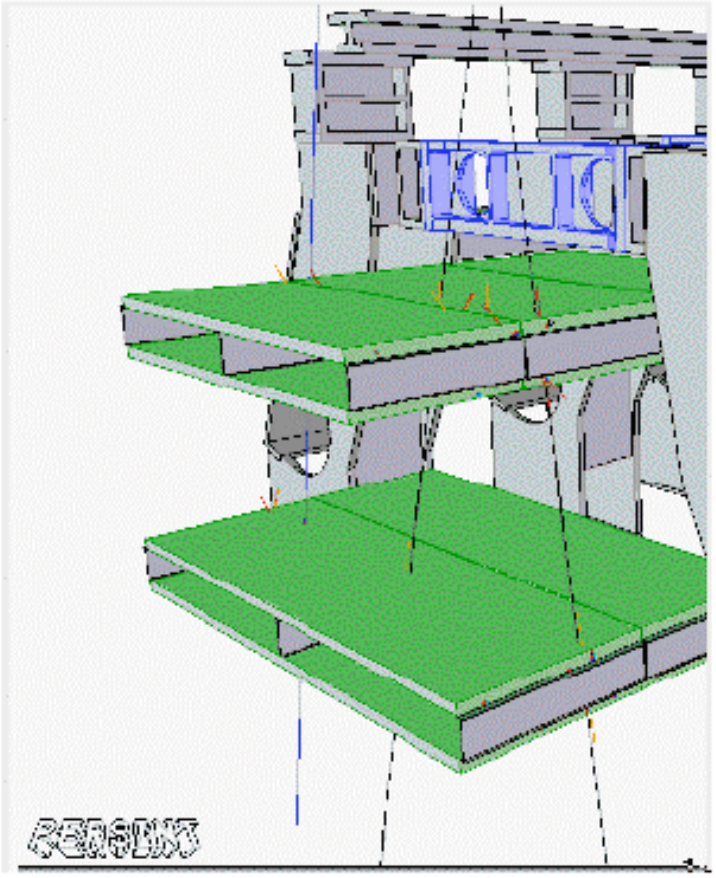


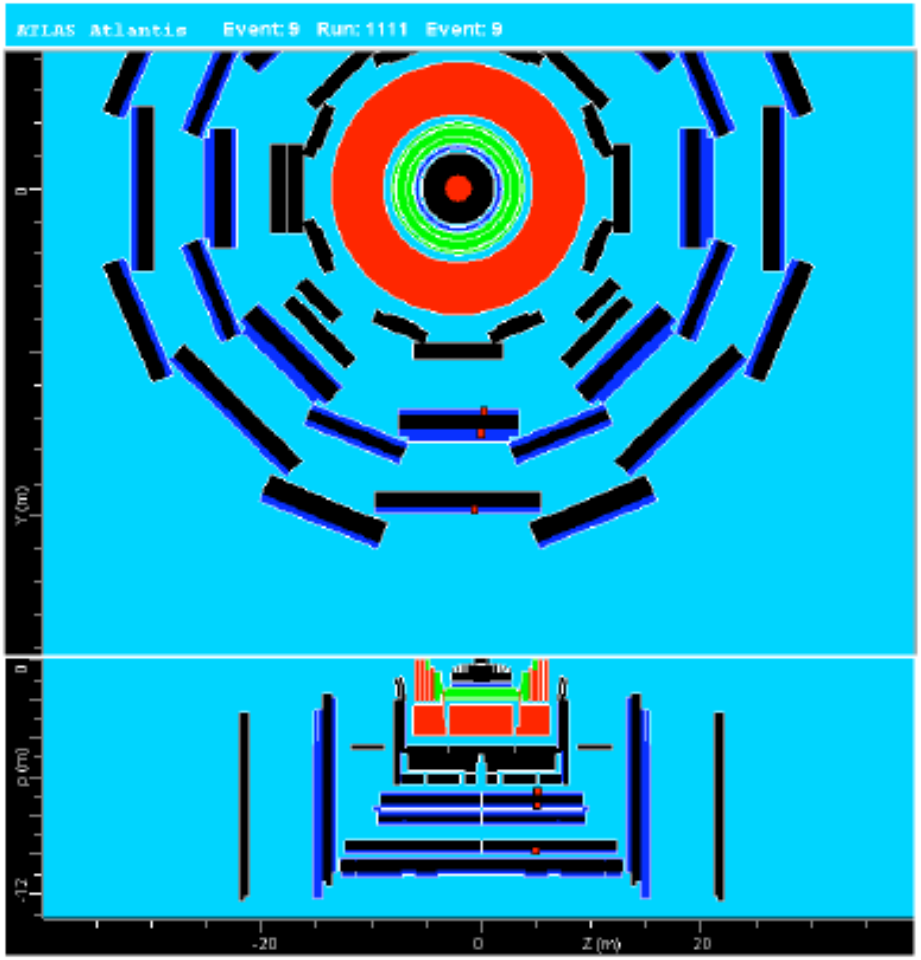
**The first of the two end-cap TRTs (A and B type wheels) fully assembled**

One end-cap calorimeter (LAr EM, LAr HAD, LAr Forward inside same cryostat, surrounded by HAD Fe/Scintillator Tilecal) being moved inside the barrel toroid



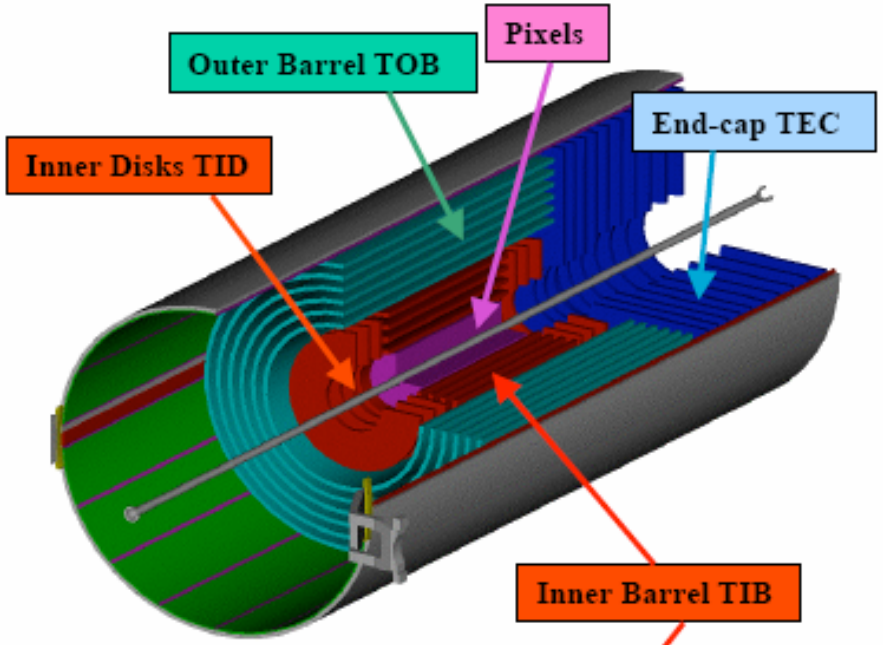
First cosmics have been registered in the underground cavern with barrel Muon chambers (MDT and RPC) and Level-1 μ trigger

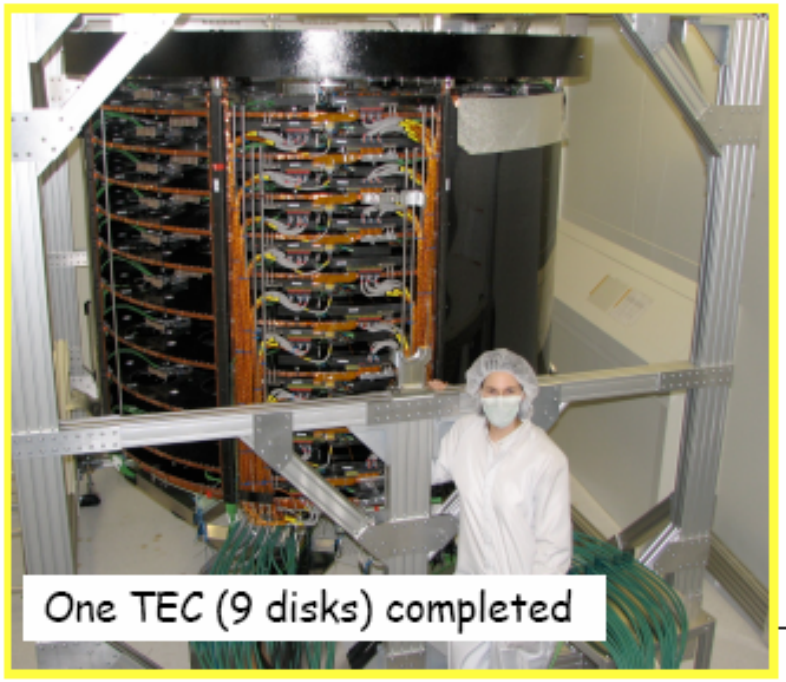


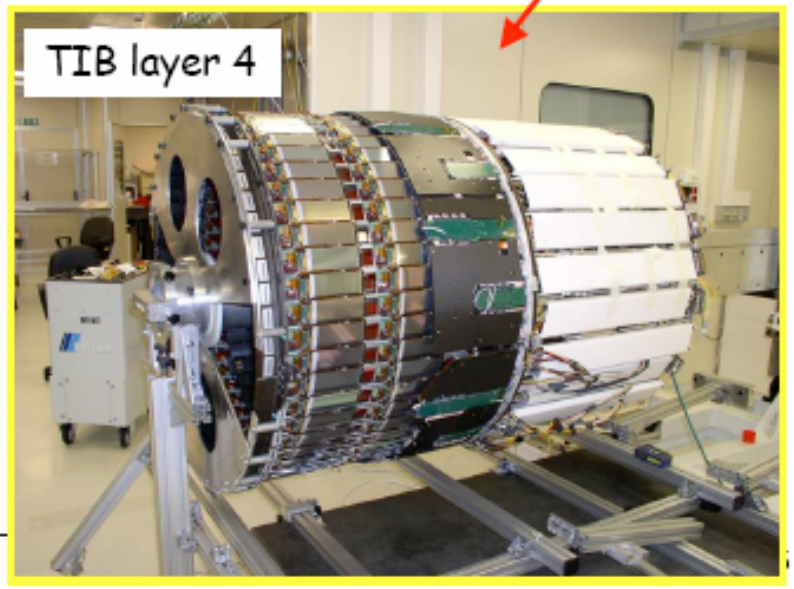


Inner tracker:
~ 220 $m^2$ of Si sensors
10.6 million Si strips
65.9 million Pixels

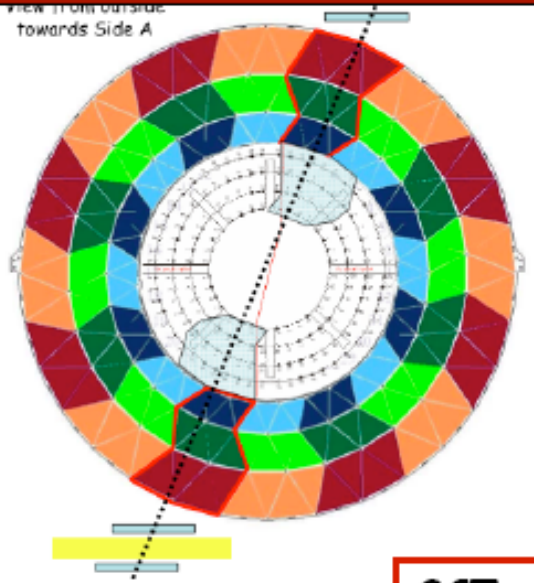
- Assembly of all 16000 modules completed
- Integration progressing well
- Installation at Point 5 in April 2007



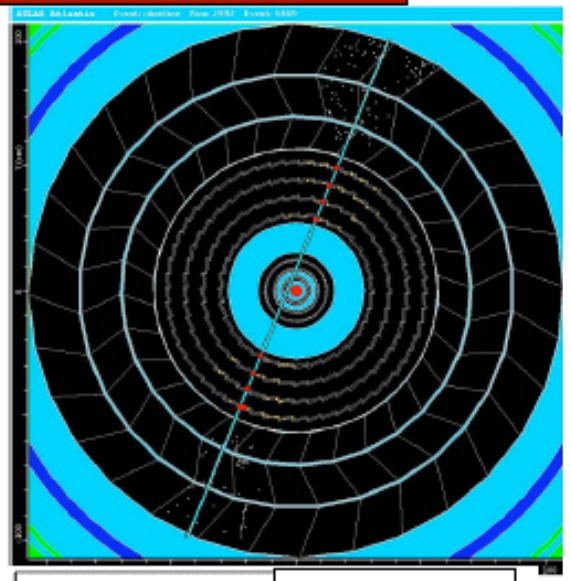


One TEC (9 disks) completed

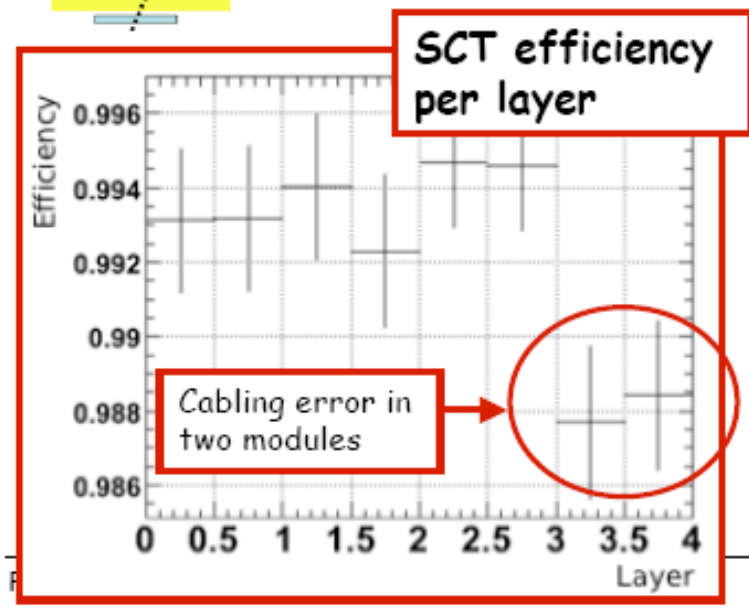


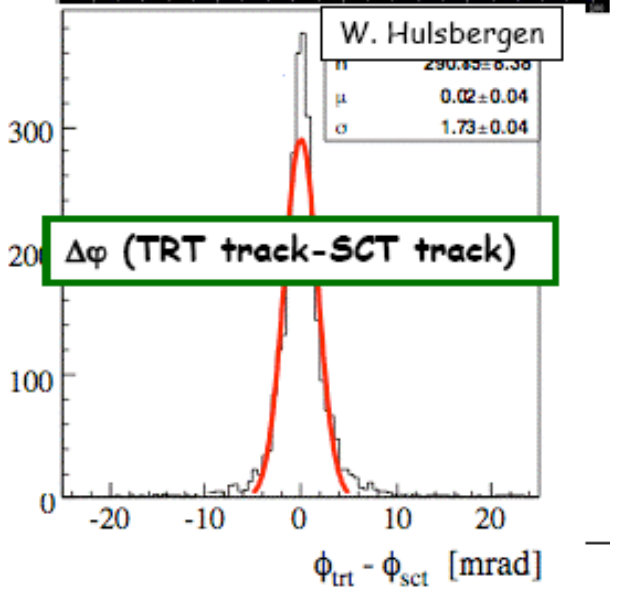
# Cosmics DATA taken in barrel SCT+TRT : ~ 450k events




ATLAS
preliminary

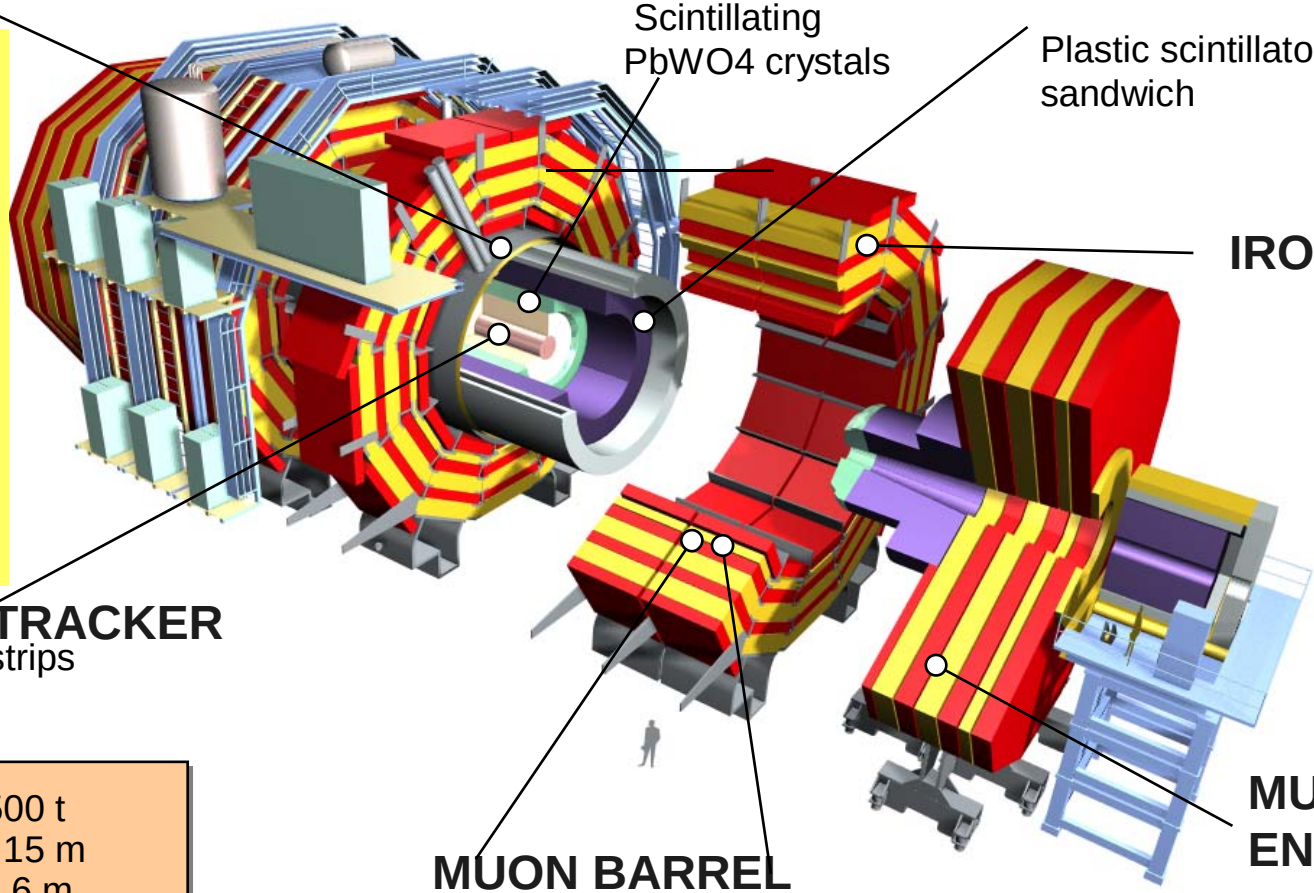




# The Startup detector

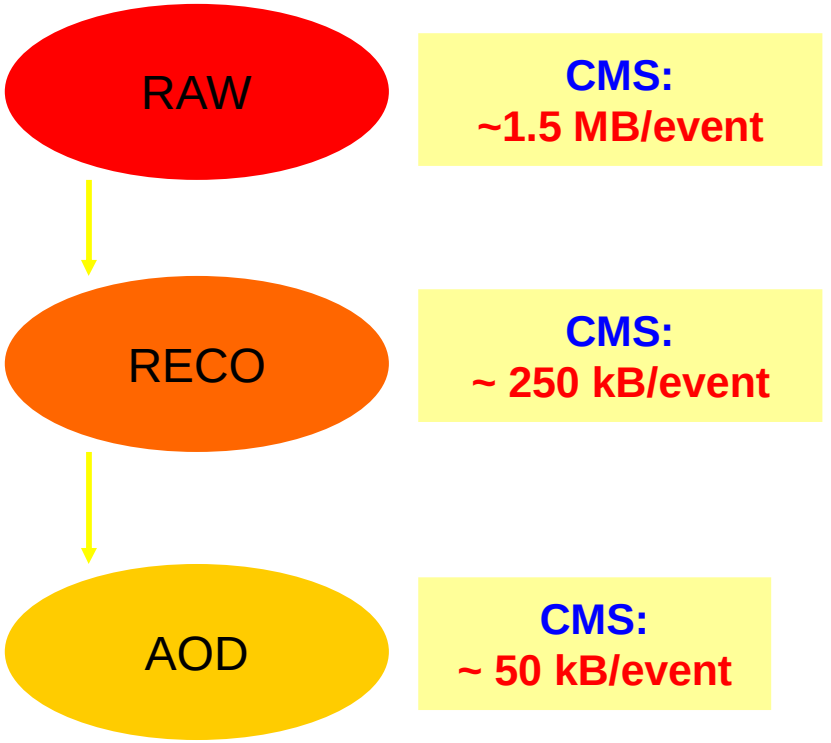
**Initial detectors: (pilot run)**
**-No Ecal endcap**
**-No pixel detector**
**(1 phi slice in barrel/endcap)**
**-1 DAQ slice (12.5 kHz L1)**
**Low luminosity detector**
**(first physcis run in 2008)**
**- Endcap/pixel included**
**- 50% DAQ (50 kHz L1)**
**Staged**
**-ME 4/2**
**-RPCs for $|\eta|>1.6$**
**Rather complete detector from the start**



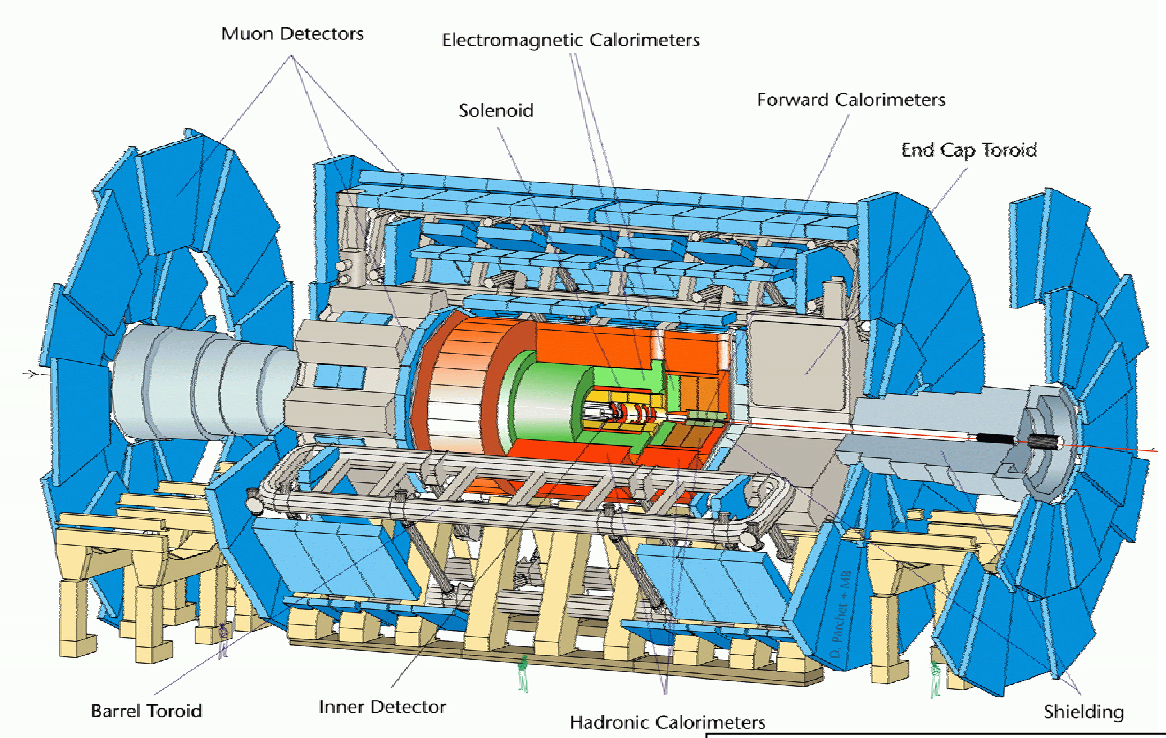

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

# Software: Data Tiers

- CMS plans to implement a hierarchy of Data Tiers
  - Raw Data: as from the Detector
  - RECO: contains the objects created by Reconstruction
  - Full Event: contains the previous RAW+RECO
  - AOD: a subset of the previous, sufficient for a large majority of "standard" physics analyses
    - Contains tracks, vertices etc and in general enough info to (for example) apply a different b-tagging
    - Can contain very partial hit level information



# The ATLAS experiment




ATLAS

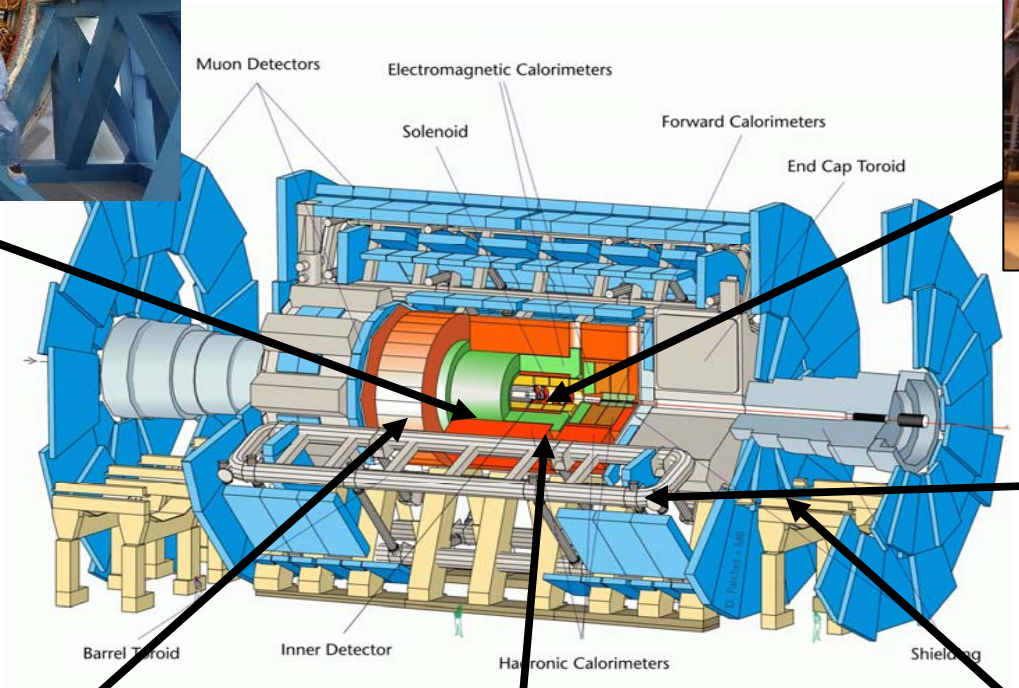
Length : ~40 m
Radius : ~10 m
Weight : ~ 7000 tons

- Tracking ($|\eta|<2.5$, B=2T) :
  -- Si pixels and strips
  -- Transition Radiation Detector (e/$\pi$ separation)
- Calorimetry ($|\eta|<5$) :
  -- EM : Pb-LAr
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer ($|\eta|<2.7$) :
  air-core toroids with muon chambers

| | | Statitics 100 pb-1 | Statistical error on Lifetime | World today (stat + syst) |
|---|---|---|---|---|
| $B^+$ | $B^+ \to J/\psi\, K^+$ | 17000 | 1.5 % | 0.4 % |
| $B^0$ | $B^0 \to J/\psi\, K^{0*}$ | 8700 | 2.2 % | 0.5 % |
| $B_s$ | $B_s \to J/\psi\, \phi$ | 900 | 6 % | 2 % |
| $\Lambda_b$ | $\Lambda_b \to J/\psi \Lambda$ | 260 | 8 % | 5% |

| | 10 pb-1 | 100 pb-1 |
|---|---|---|
| $pp \to \mu 6\, X$ | $60 \cdot 10^6$ | $600 \cdot 10^6$ |
| $bb \to \mu 6\, X$ | $40 \cdot 10^6$ | $400 \cdot 10^6$ |
| $cc \to \mu 6\, X$ | $20 \cdot 10^6$ | $200 \cdot 10^6$ |
| $bb \to \mu 6\, \mu 3\, X$ | $2 \cdot 10^6$ | $20 \cdot 10^6$ |
| $pp \to J/\psi(\mu 6 \mu 3)$ | $2.8\ 10^5$ | $2.8\ 10^6$ |
| $\Upsilon(\mu 6 \mu 3)$ | $0.9 \cdot 10^5$ | $0.9 \cdot 10^6$ |
| $B^+ \to J/\psi\, K^+$ | 1700 | 17 000 |
| $B^0 \to J/\psi\, K^{0*}$ | 870 | 8700 |

# ATLAS

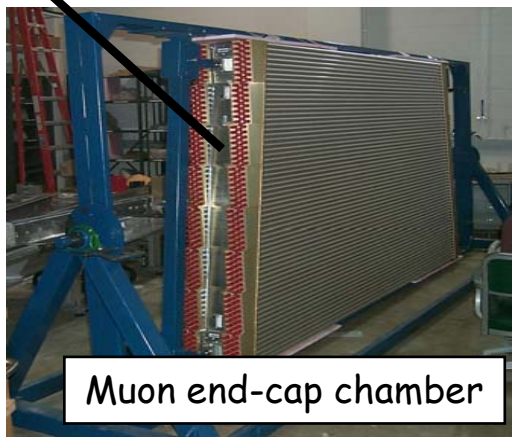

Barrel LAr ECAL

Length : ~40 m
Radius : ~10 m
Weight : ~ 7000 tons

Barrel coil cryostat

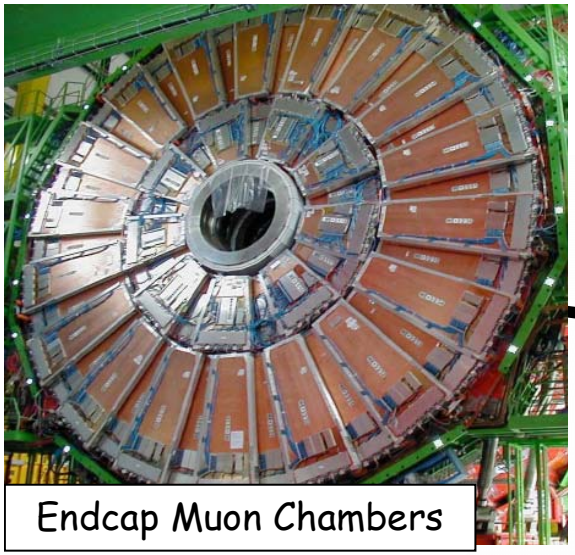
Tilecal

TRT end-cap wheel

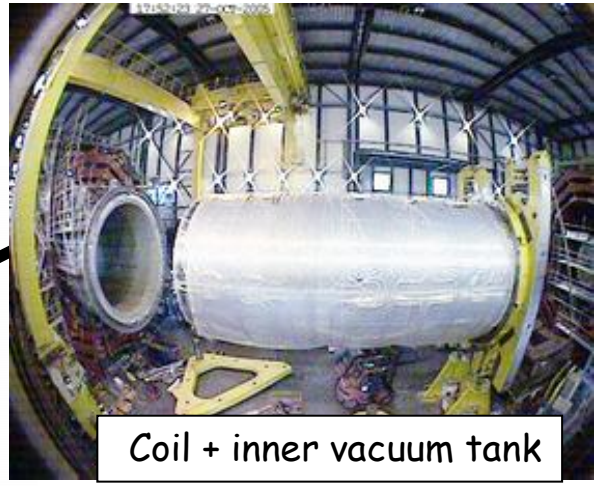


Muon end-cap chamber

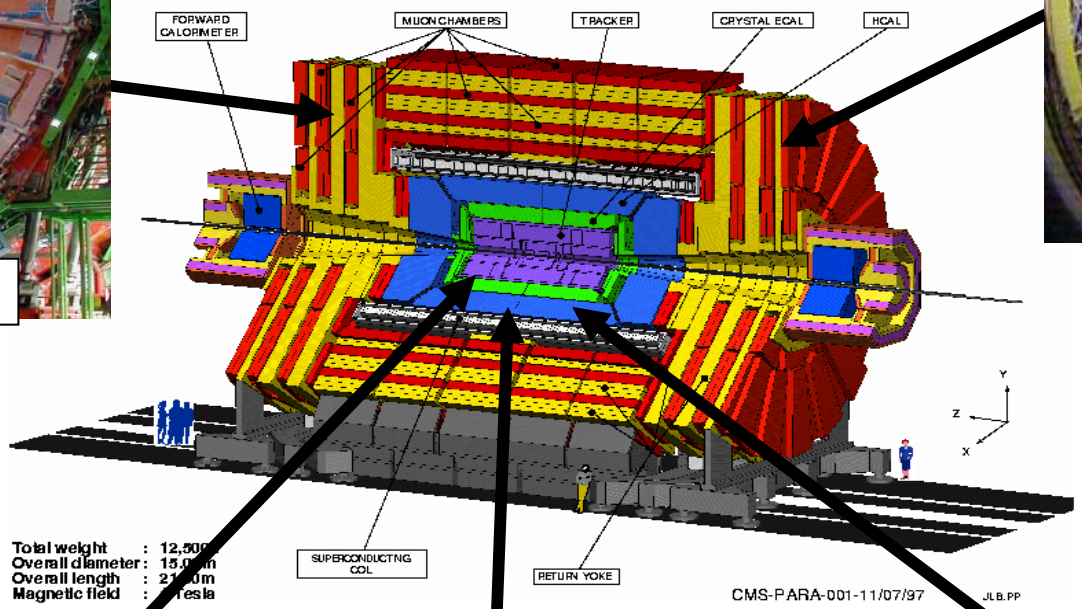
# CMS



Endcap Muon Chambers



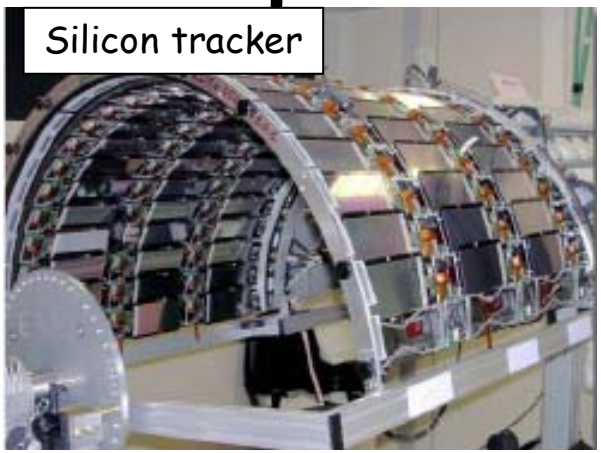
Coil + inner vacuum tank




Length : ~20 m
Radius : ~7 m
Weight : ~ 13000 tons

ECAL crystals

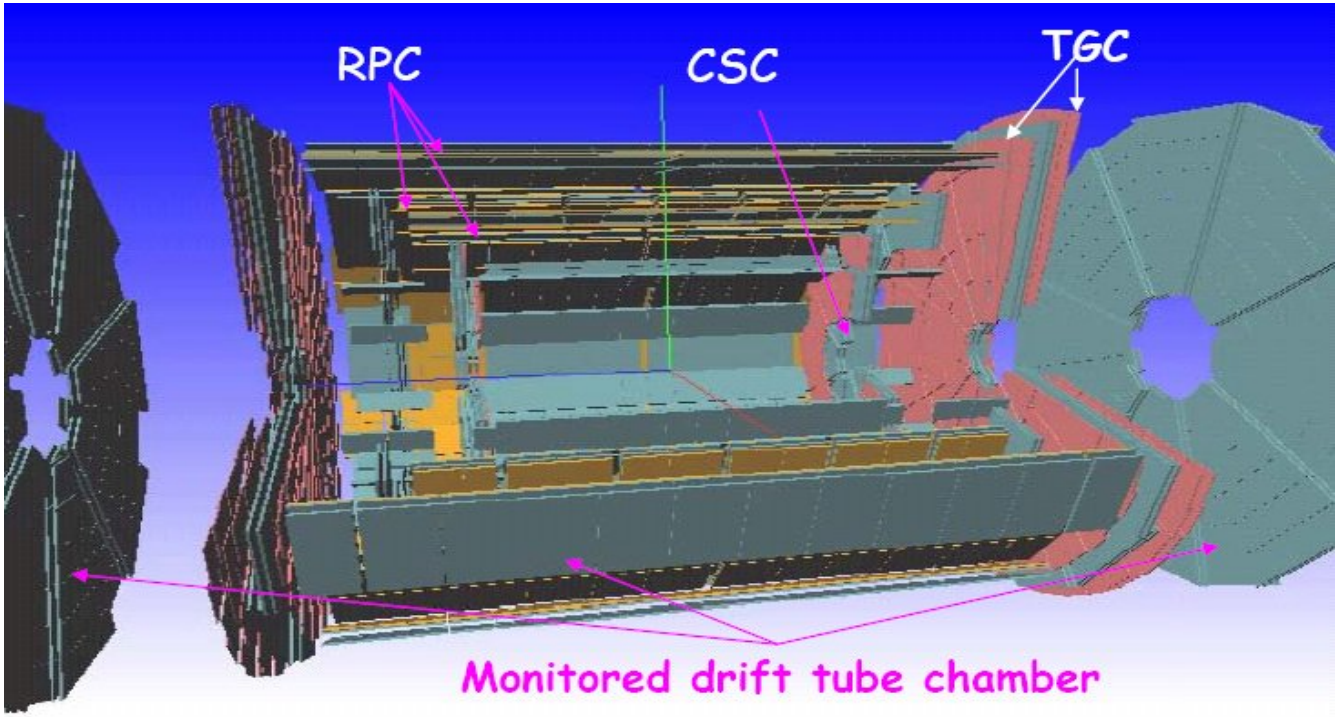
Silicon tracker



Barrel HCAL

# Challenges for Experiments at the LHC

# *Muon Spectrometer Instrumentation*




**The Muon Spectrometer is instrumented with precision chambers and fast trigger chambers**

**A crucial component to reach the required accuracy is the sophisticated alignment measurement and monitoring system**

***Precision chambers:***
- **MDTs in the barrel and end-caps**
- **CSCs at large rapidity for the innermost end-cap stations**

***Trigger chambers:***
- **RPCs in the barrel**
- **TGCs in the end-caps**

***At the end of February 2006 the huge and long effort of series chamber production in many sites was completed for all chamber types***