TIFR

Status of LHC

Outline

Machine
Experiments
Computing

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The Large Hadron Collider

TIFR

The first collider to probe physics at TeV scale

14 TeV pp collisions at 10^{34} $cm^{-2}s^{-1}$

New energy domain (x10), new luminosity domain (x100)

Will cross threshold of electroweak symmetry breaking;

Unitarity of WW scattering requires $M_h < 850$ GeV

Many possibilities of physics beyond Standard Model:

SUSY, Large Extra Dimension, ……

Also results on CP violation, QGP, QCD, …

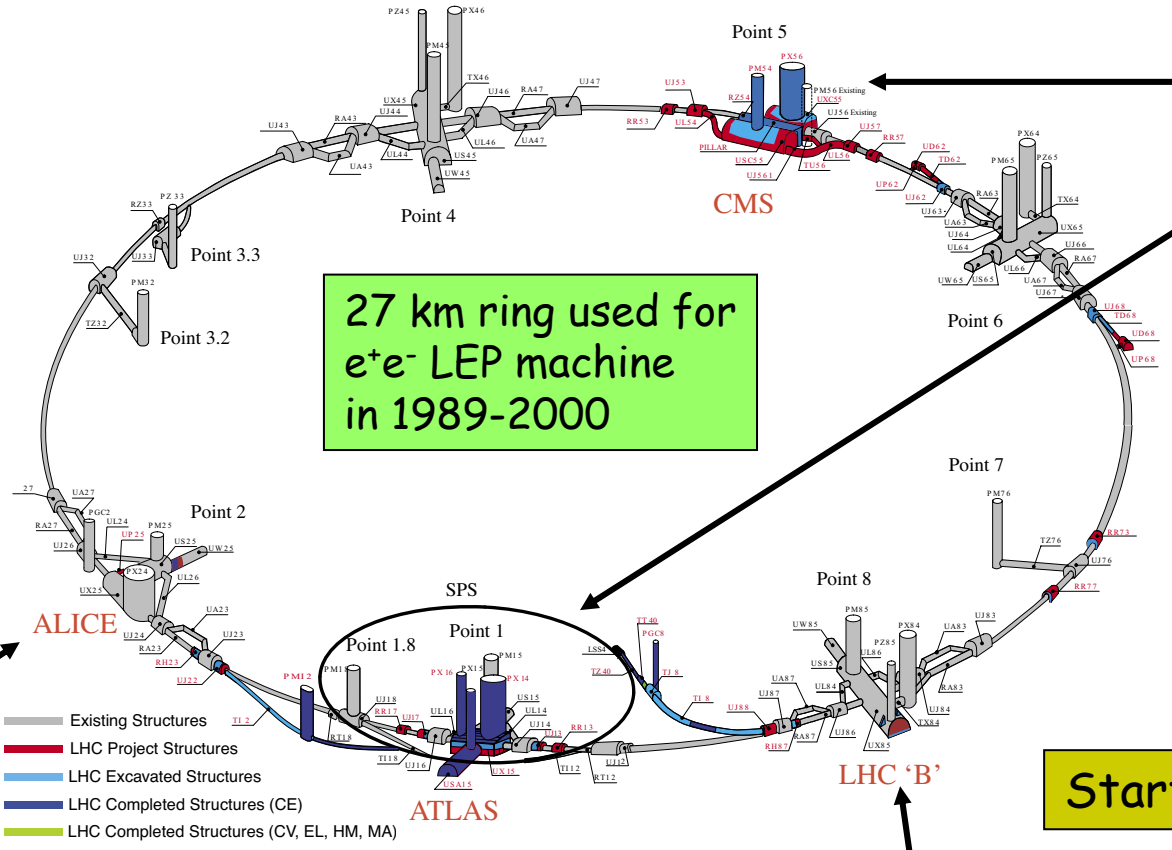
LHC results will determine future course of HEP

- $\sqrt{s}$ = 14 TeV (7 times higher than Tevatron/Fermilab)
  → search for new massive particles up to m ~ 5 TeV

LHC

pp

- $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (>10^2 higher than Tevatron/Fermilab)
  → search for rare processes with small σ (N = Lσ)



27 km ring used for e^+e^- LEP machine in 1989-2000

ATLAS and CMS : pp, general purpose

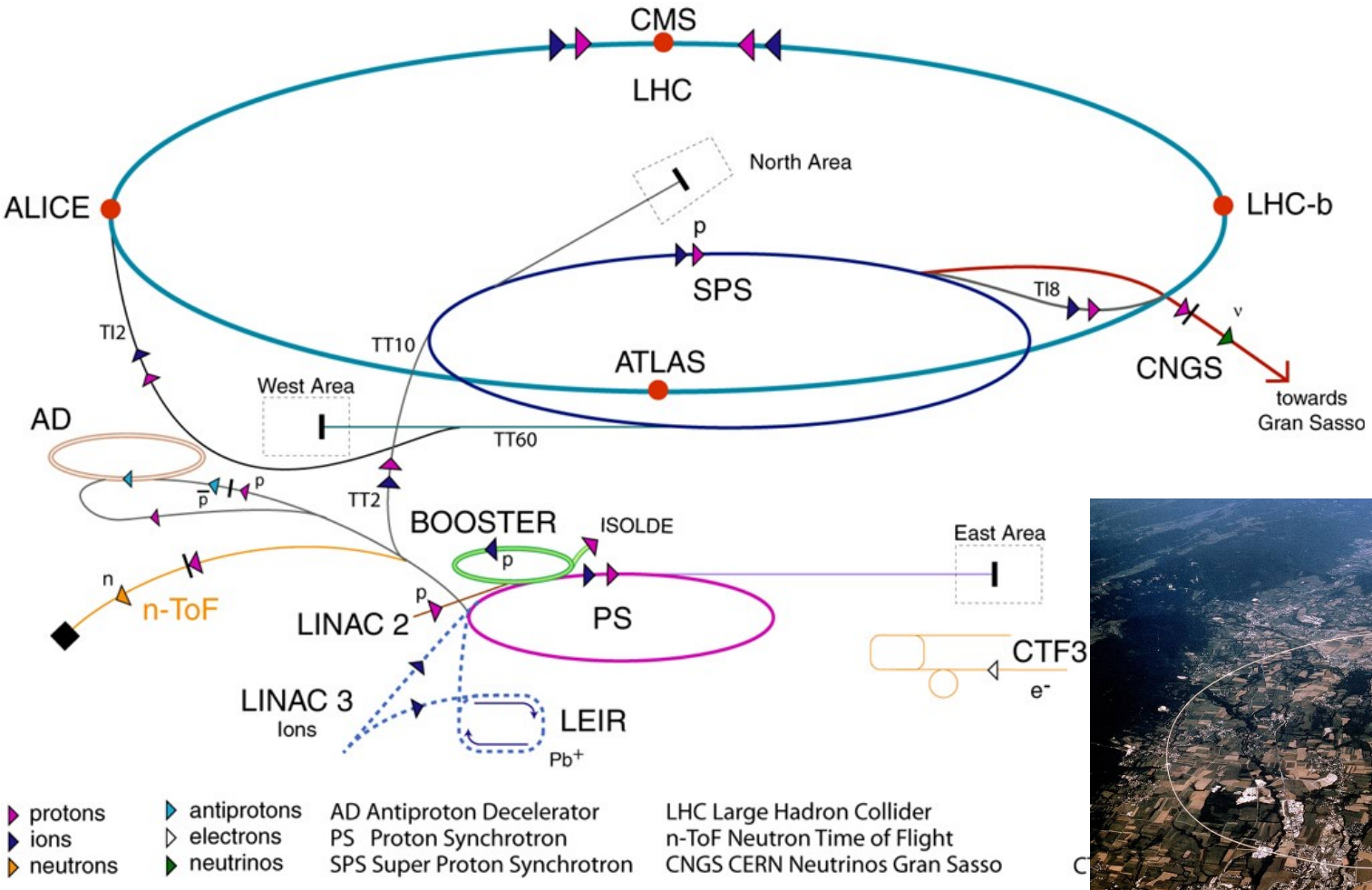
ALICE : heavy ions

LHCb : pp, B-physics

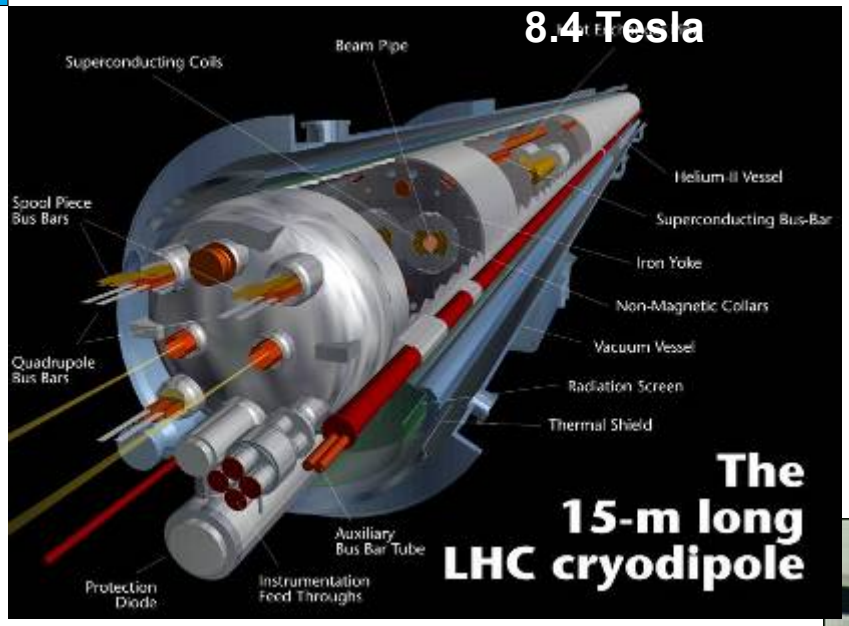
Start : Summer 2007

Accelerator complex at CERN

(Not to scale)



The LHC machine



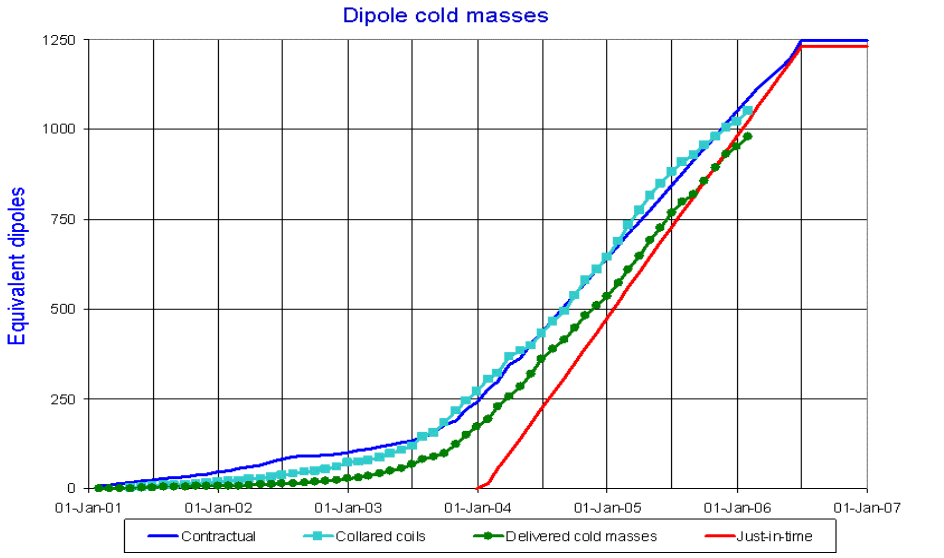
About 1000 of 1232 dipoles are now assembled at CERN

All dipoles are tested at warm (magnetic tests) and at cold (quench behaviour)

15% are also subject to detailed magnetic tests at cold → required quality is achieved

LHC Progress Dashboard

Accelerator Technology Department

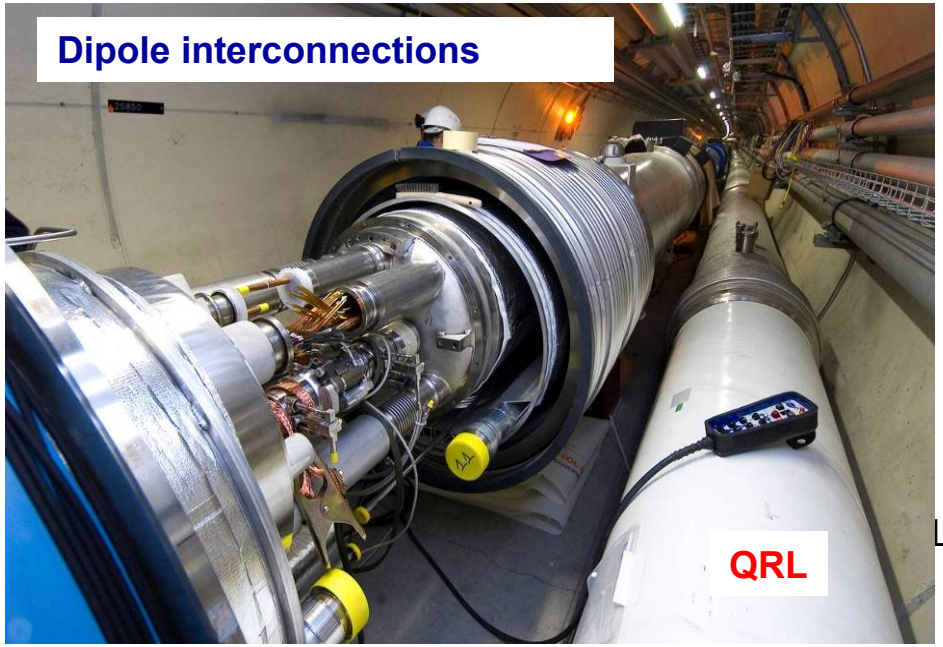


Updated 31 Jan 2006 Data provided by F. Savary AT-MAS

More than 250 dipoles installed in the underground tunnel

Installation rate:
20 dipoles/week reached for several weeks
(goal during 2006 is 20-25/week constantly)

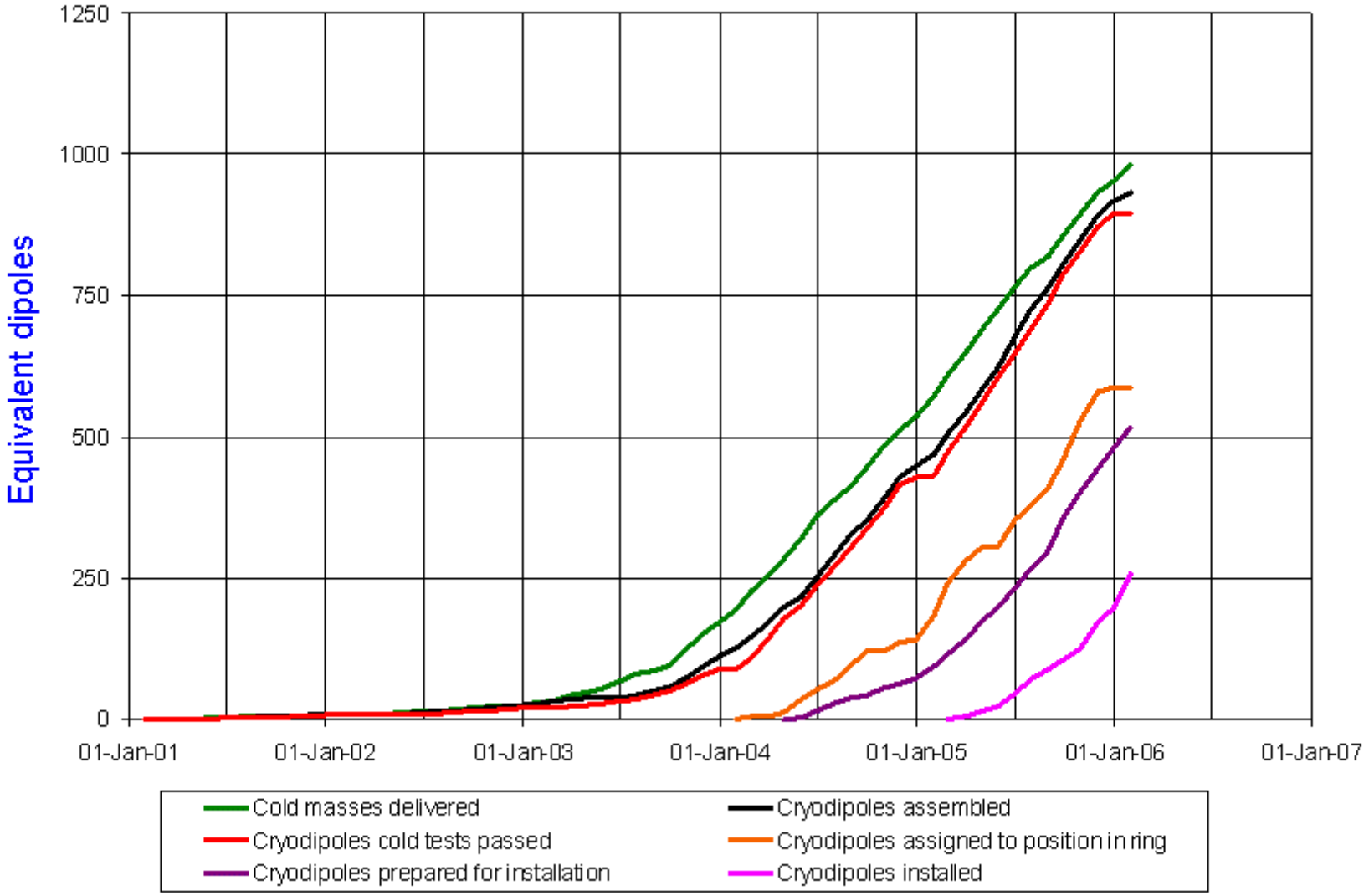
First 600 m of cryoline (QRL) successfully cooled down on September 14, recently followed by cool-down of full cryoline sector 8-1 end of November



LHC Progress Dashboard

Accelerator Technology Department

Cryodipole overview



Updated 31 Jan 2006

Data provided by D. Tommasini AT-MAS, L. Bottura AT-MTM

Not only dipoles ….

Dipoles	1232
Quadrupoles	400
Sextupoles	2464
Octupoles/decapoles	1568
Orbit correctors	642
Others	376
Total	~ 6700

All coming along well …

Assembly of Short Straight Sections

Inner triplet quads assembly hall 181

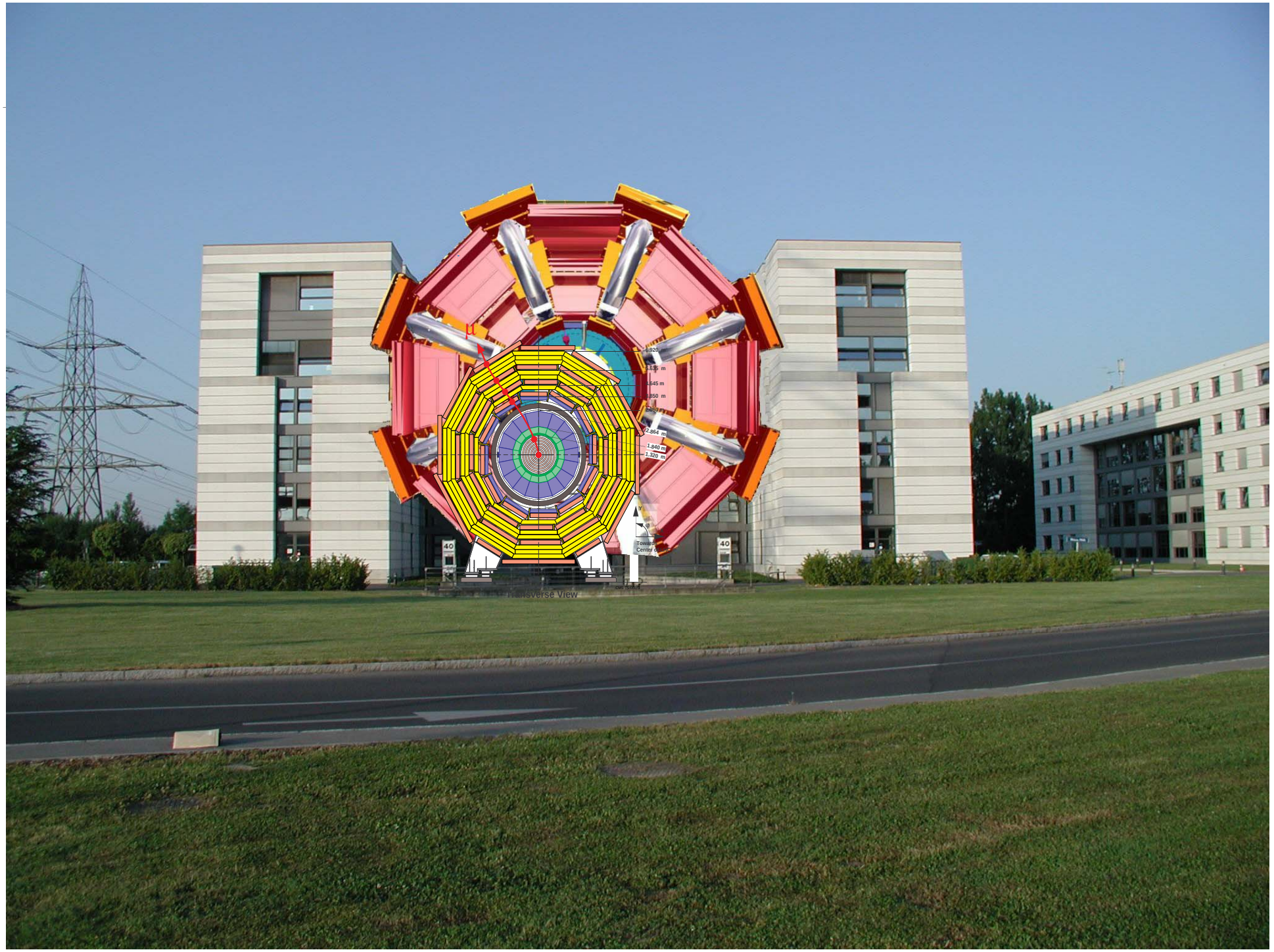
Conclusions LHC machine status

- All key objectives have been reached for the end of 2005.
  - End of repair of QRL, reinstallation of sector 7-8 and cold test of sub-sectors A and B.
  - Cool-down of full sector 8-1.
  - Pressure test of sector 4-5.
  - Endurance test of full octant of power converters.
- Magnet installation rate is now close to 20/week, with more than 200 installed. This, together with interconnect work, will remain the main bottleneck until the end of installation.

General purpose experiments: ATLAS & CMS

- Optimized for pp interactions but designed to be also effective for heavy ion and b-physics.

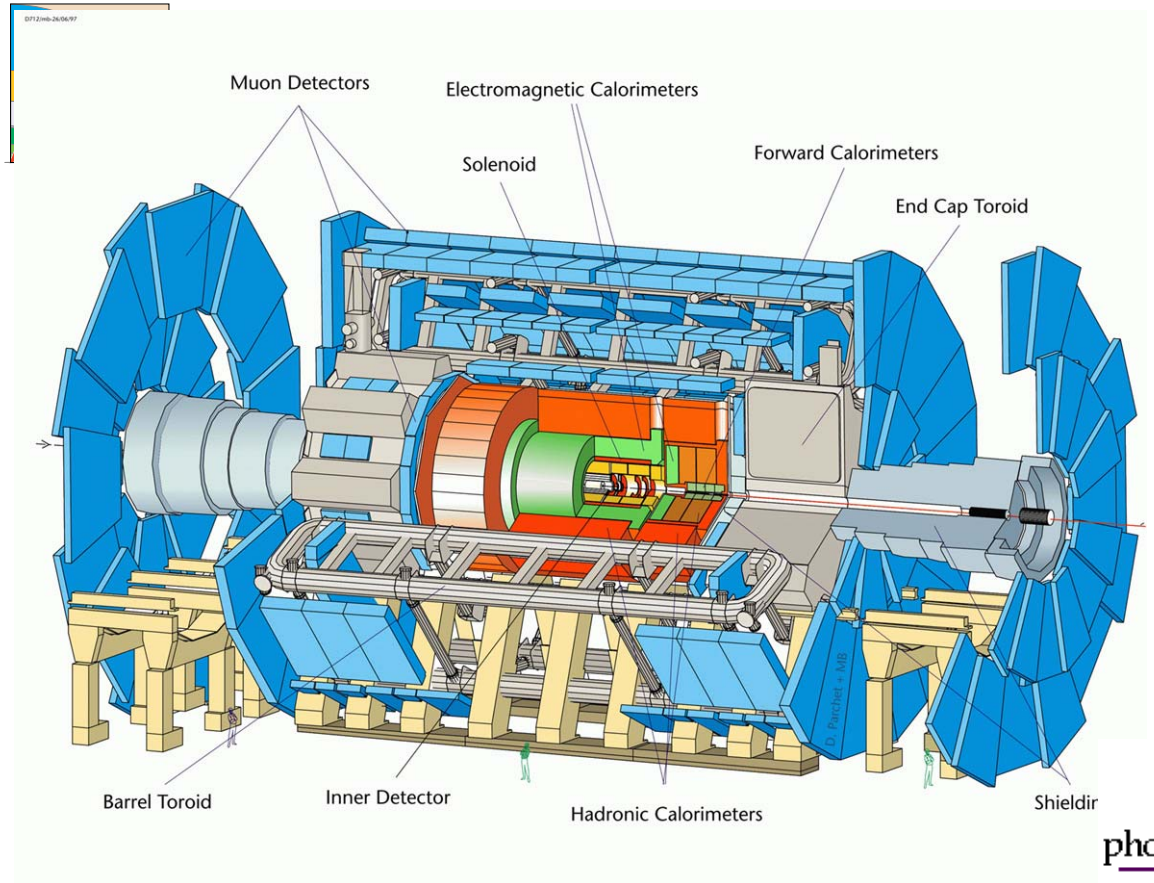
- General layout is “standard”:
- Inner vertex and tracking detectors
- Electromagnetic & hadron calorimeters
- Muon chambers


Transverse View

ATLAS and CMS detectors

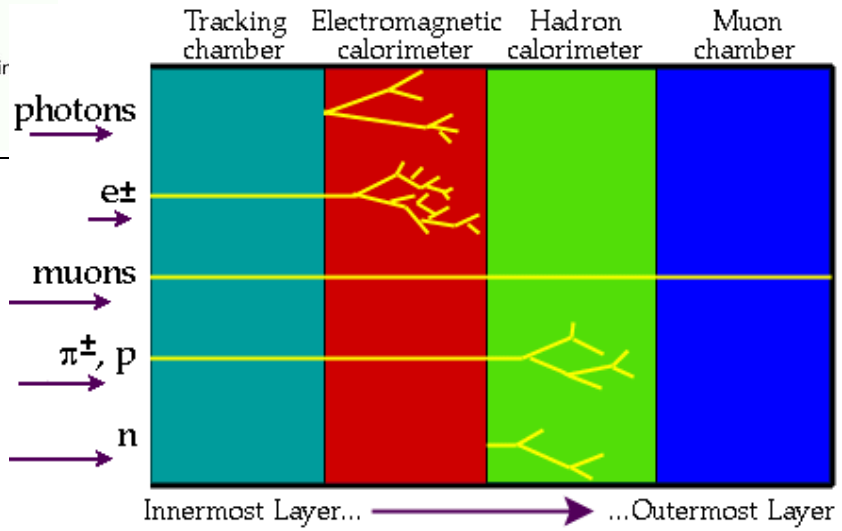
TIFR

	ATLAS	CMS
Magnet:	Inner 2T Solenoid surrounding Tracker. 4T Air core Toroid in the barrel & end-cap	Single 4T Solenoid Encompassing tracker+ calorimeters
Vtx+Tracker:	Silicon pixels, strip, transition radiation detector	Silicon pixels + strip
EM Cal:	Liquid Argon	$PbWO_4$ crystals
Hadron Cal:	Liq Ar + scint. Tile	scintillator tile
Muon syst:	Drift tube + Cathode strip + RPC's (trigger)	



ATLAS

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~ 10^8 electronic channels
~ 3000 km of cables

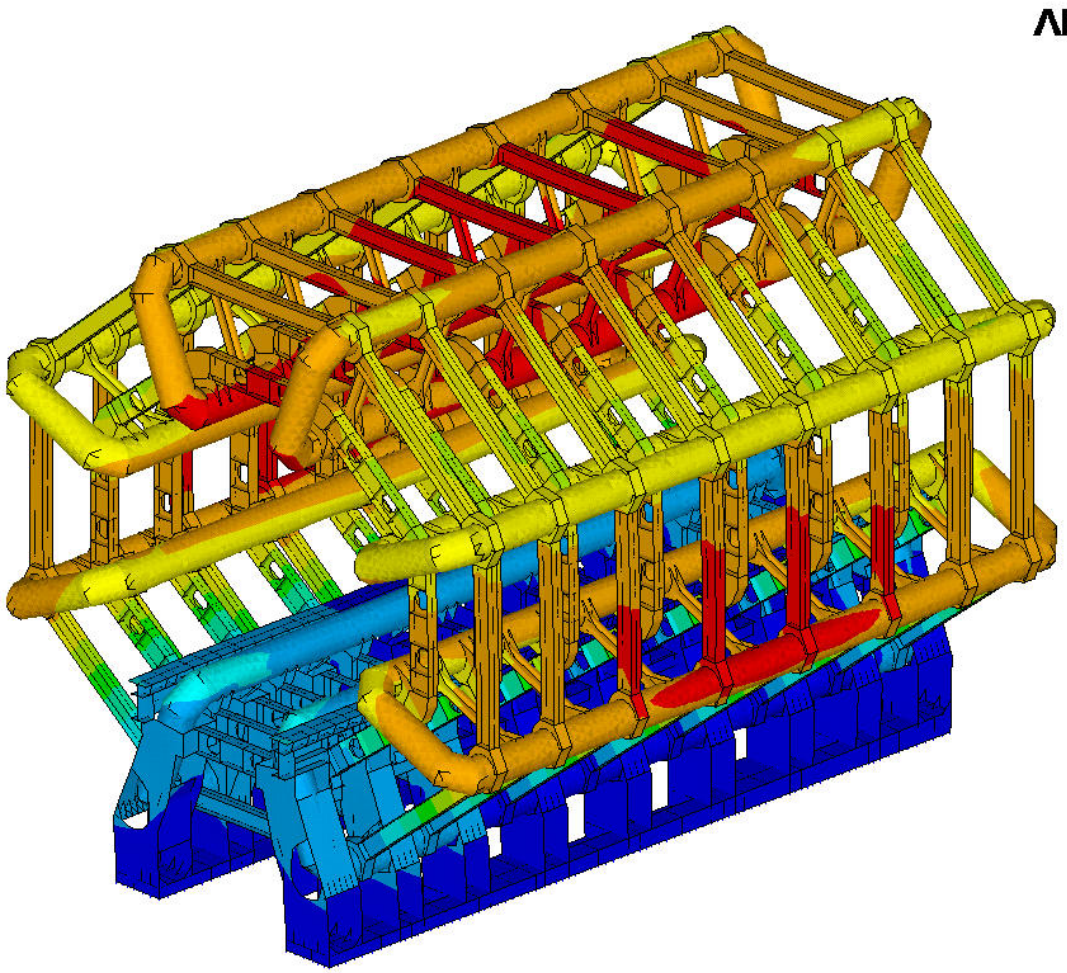


- **Tracking (|η|<2.5, B=2T) :**
  - **-- Si pixels and strips**
  - **-- Transition Radiation Detector (e/π separation)**

- **Calorimetry (|η|<5) :**
  - **-- EM : Pb-LAr**
  - **-- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)**

- **Muon Spectrometer (|η|<2.7) :**
  air-core toroids with muon chambers

The Barrel Toroid

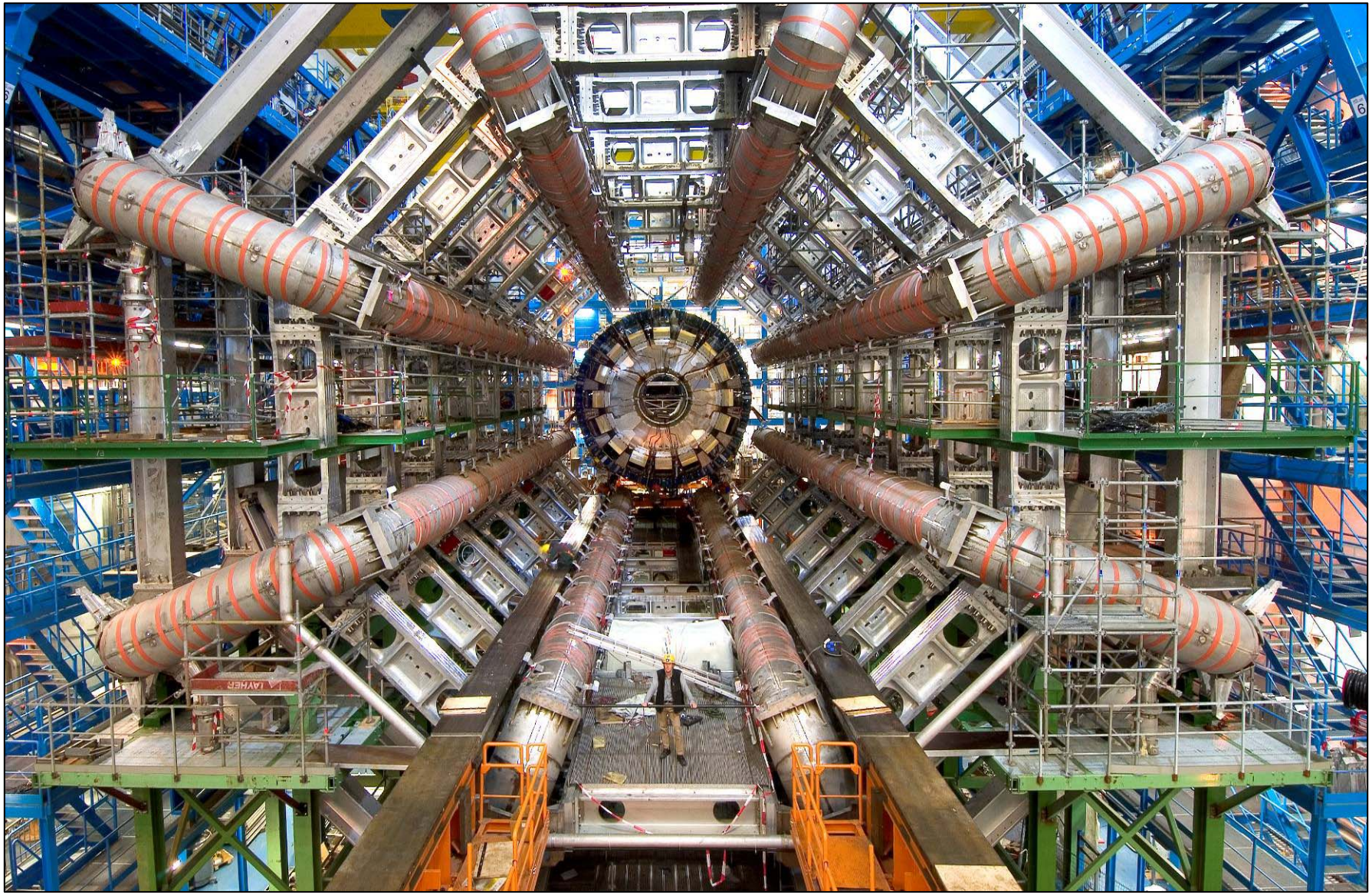


- 20 m diam. x 25 m length
- 8200 m^3 volume
- 170 t superconductor
- 700 t cold mass
- 1320 t total weight
- 90 km superconductor
- 20.5 kA at 4.1 T
- 1.55 GJ stored Energy

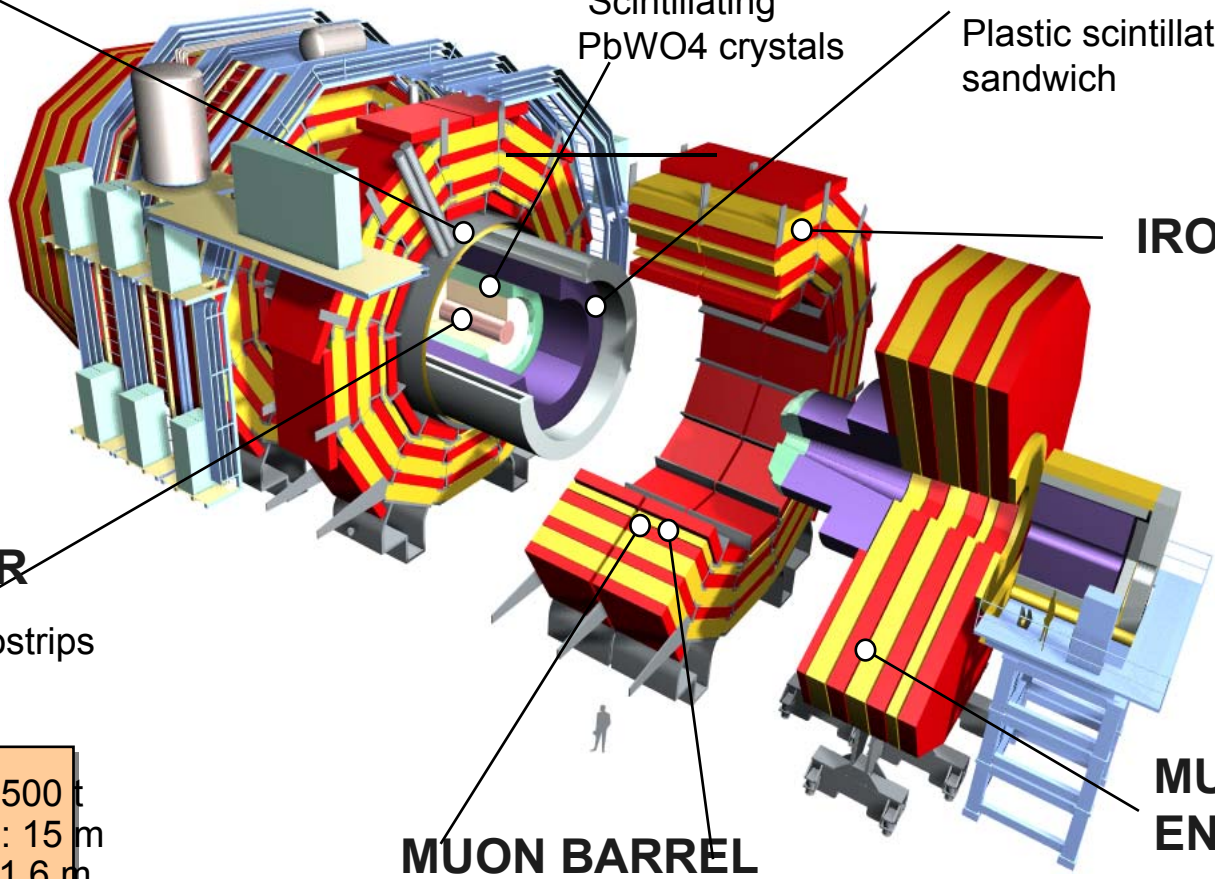
8 coils interconnected with an aluminum warm structure

Barrel Toroid installation status

The mechanical installation is complete, electrical and cryogenic connections are being made now, for a first in-situ cool-down and excitation test in spring 2006



CMS Detector

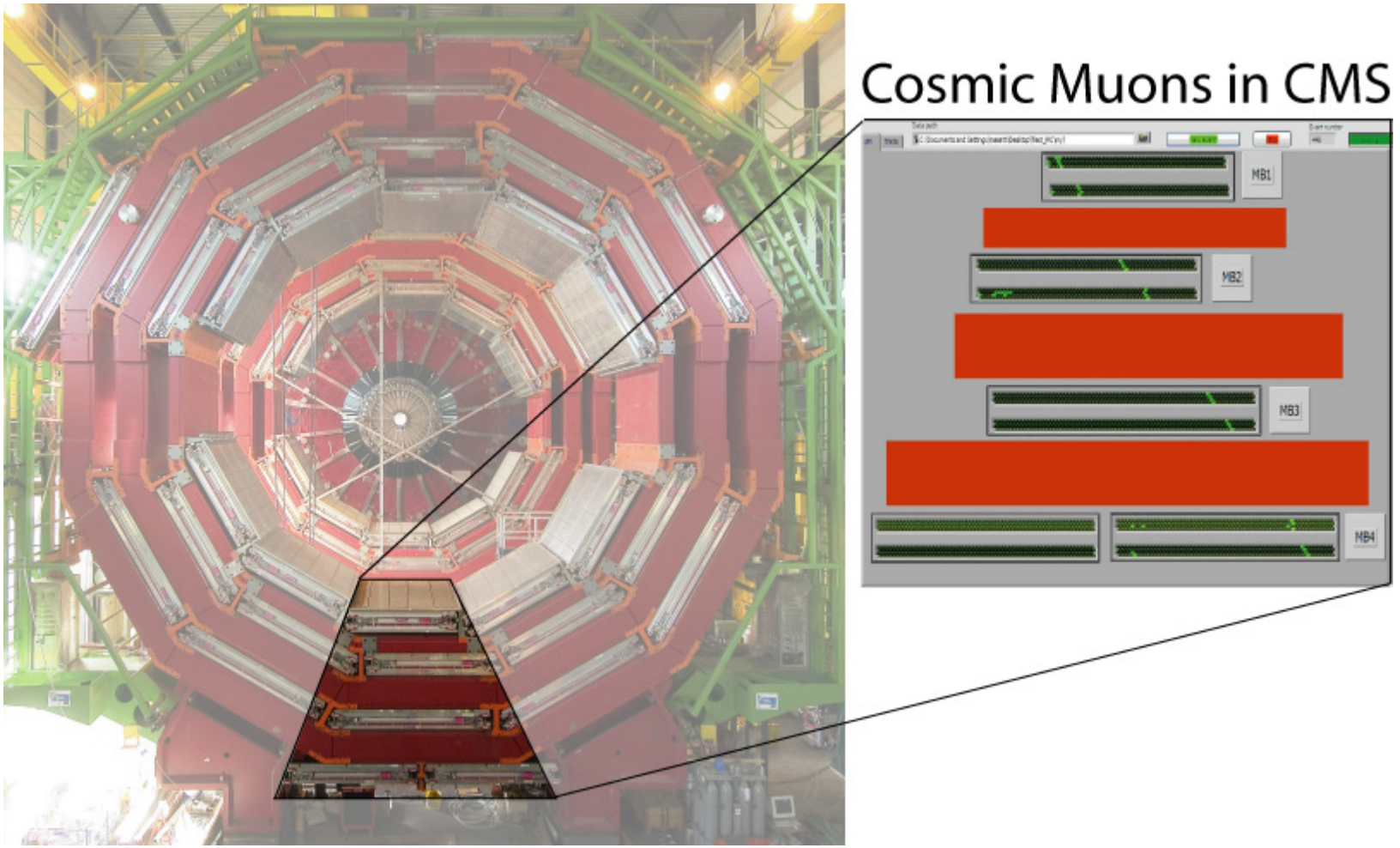


Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

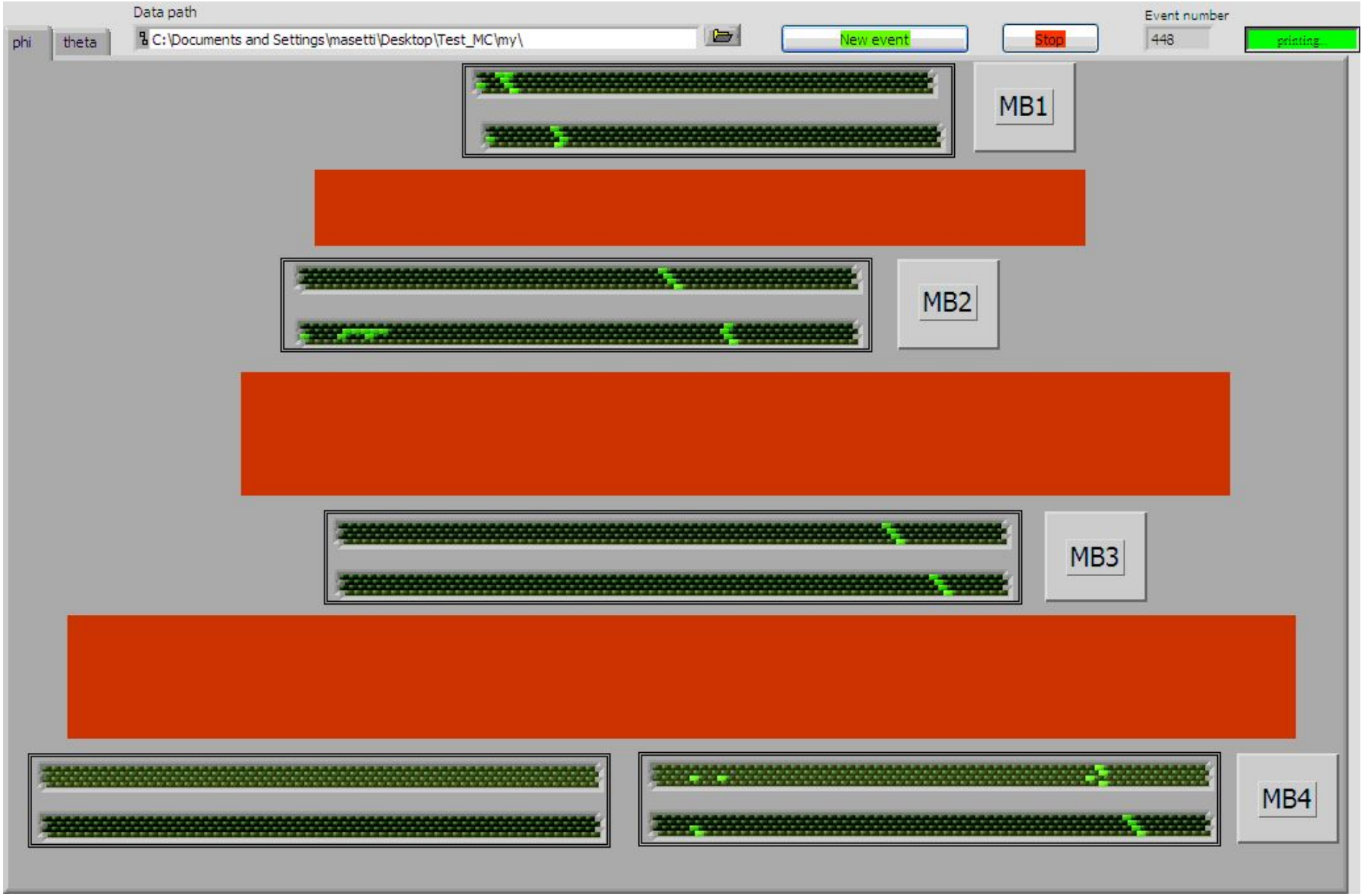
Platform disconnected from Coil (28 Sep)

Swivelling of inner vac tank: ~ 20 Oct
Coil cool-down and start of electrical tests : Jan 06

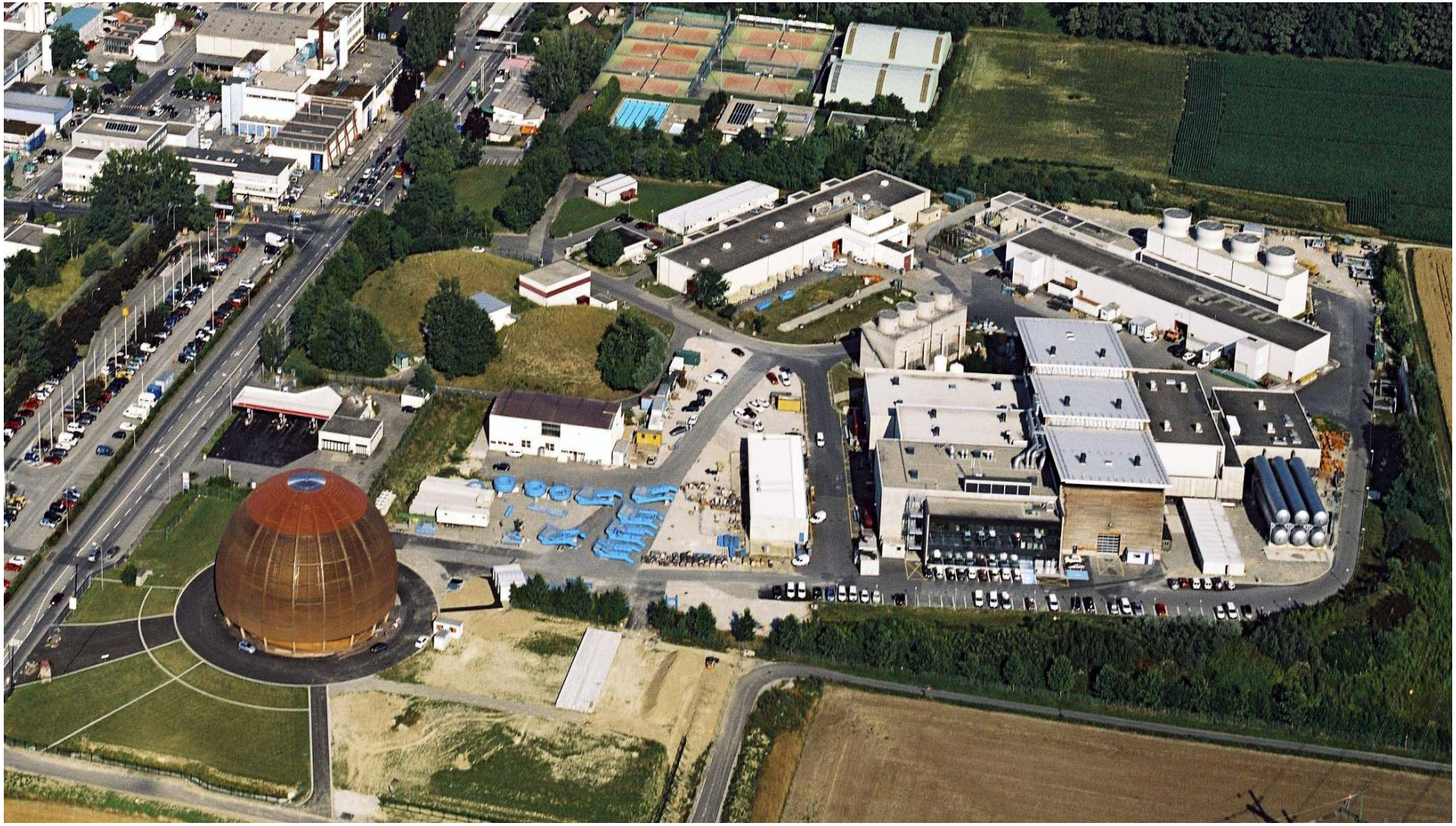
Slice Test for CMS



LHC experiments - CMS

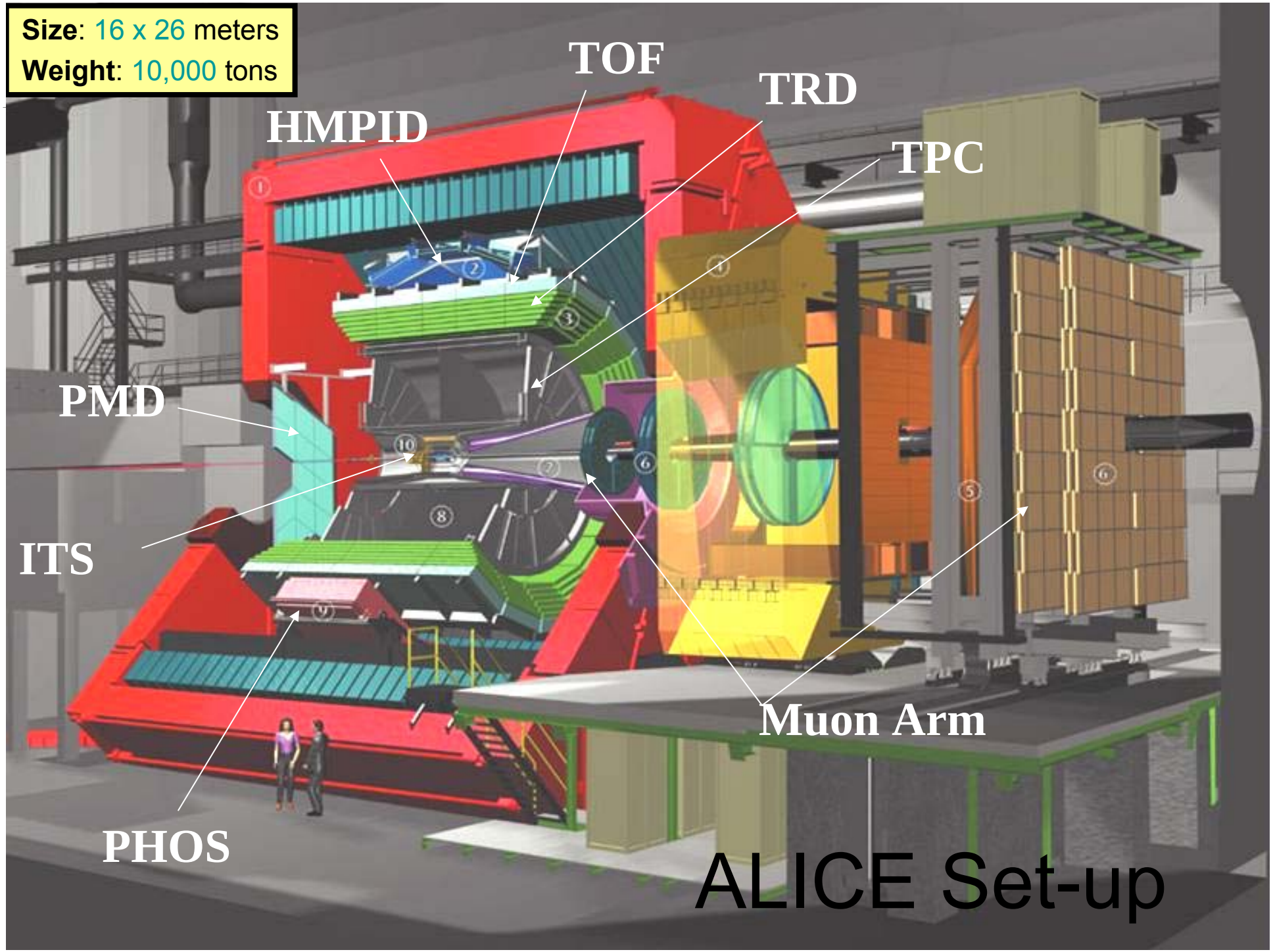


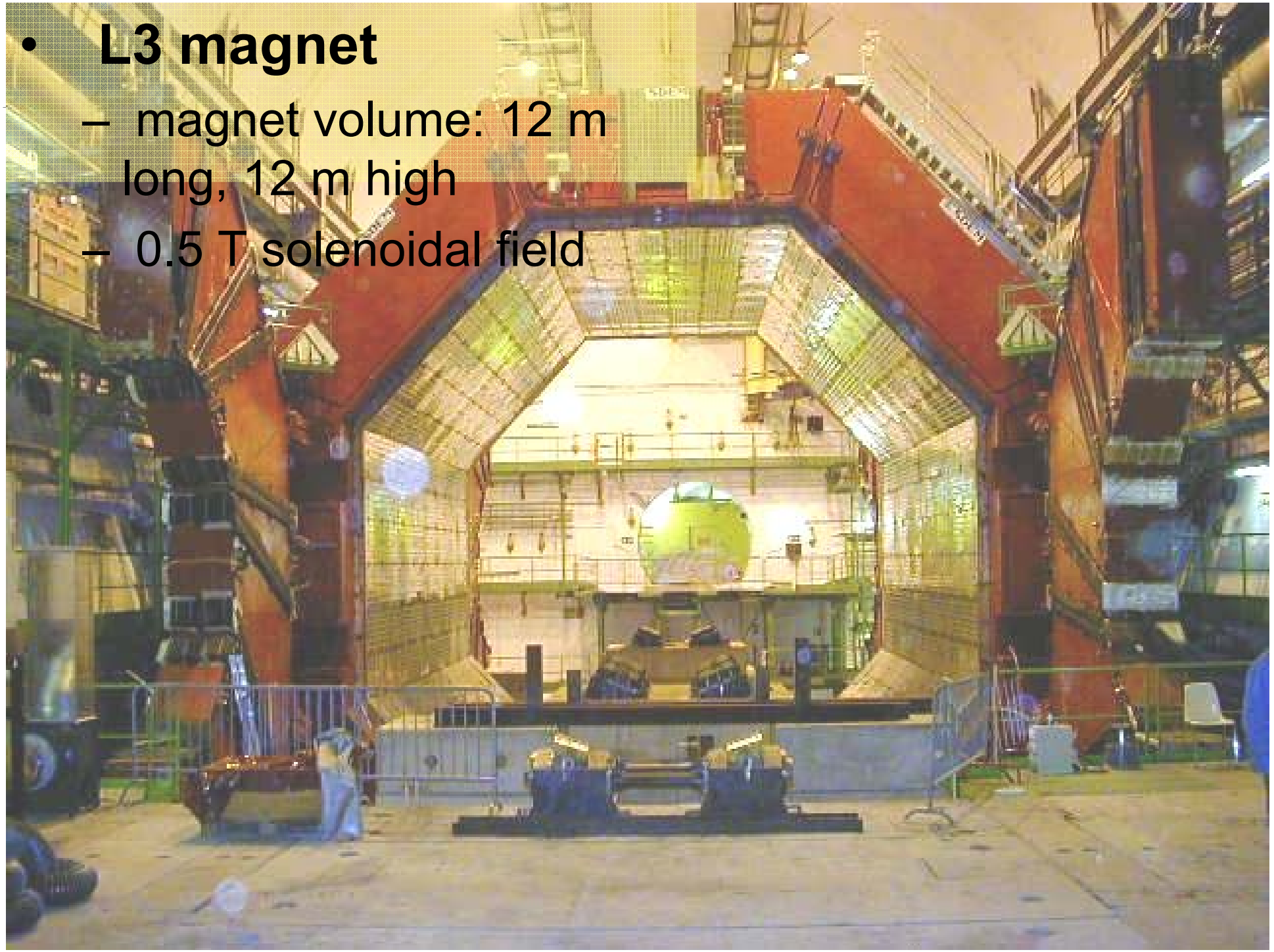
Experimental Area is getting ready (Point 1)



LHC Heavy Ion Program

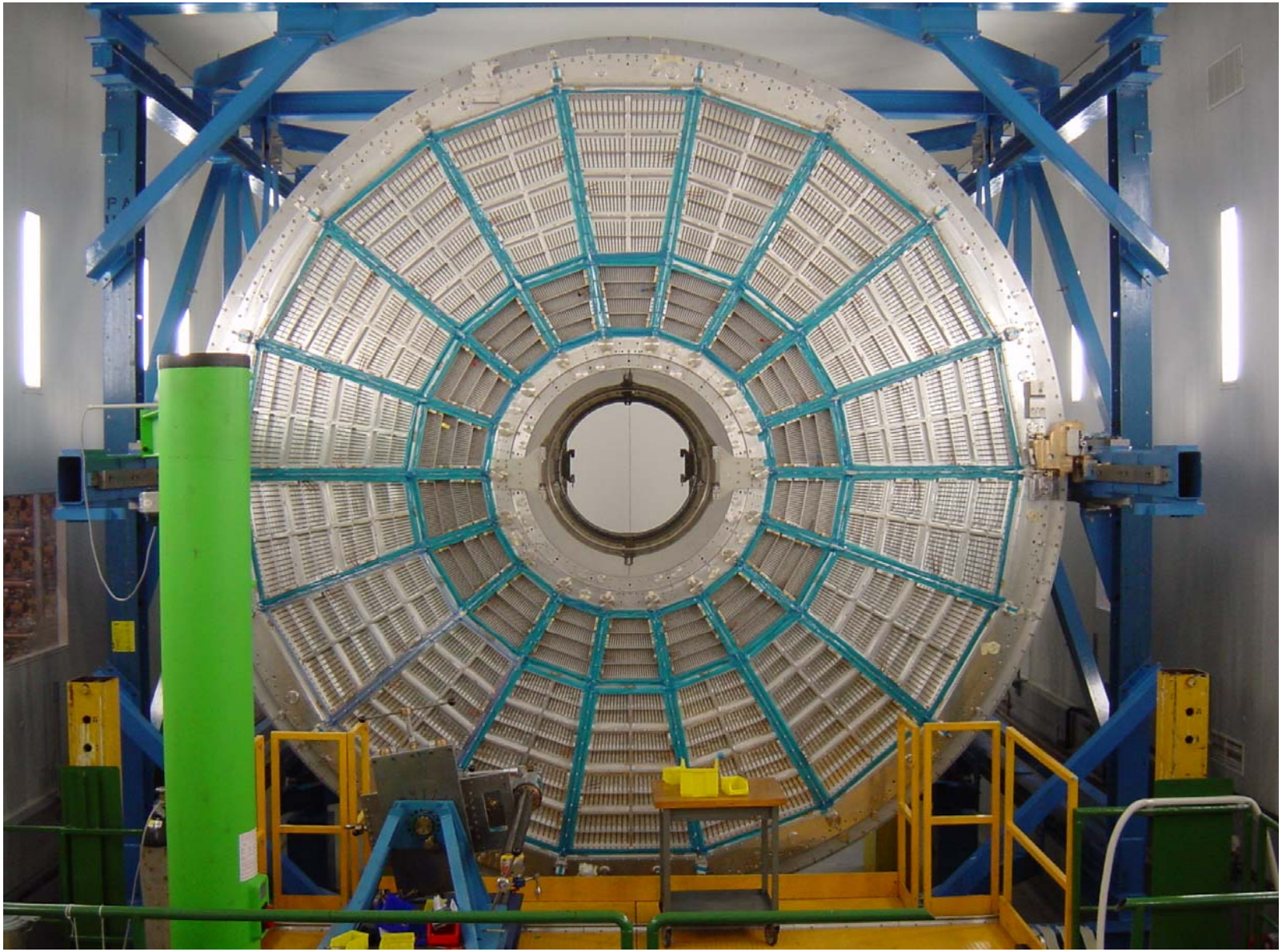
- Machine
  - **energy**:
    - **E_{beam} = 7 x Z/A** TeV => **$\sqrt{s}$ = 5.5 TeV/A** or **1.14 PeV** (Pb-Pb)
  - **beams:**
    - **possible combinations: pp, pA, AA**
  - **heavy ion running:**
    - **~ 4 weeks/year**(10^6 s effective); typically after pp running (**like at SPS**)
    - first normal HI run expected end 2008 (1/20 design L)
  - **luminosity**:
    - 10^{27} $cm^{-2}s^{-1}$ (Pb) to 10^{29} (light ions), => between 10 kHz to 200 kHz rate


Size: 16 x 26 meters
Weight: 10,000 tons
TOF
TRD
HMPID
TPC
PMD
ITS
Muon Arm
PHOS
ALICE Set-up



- **L3 magnet**
  - magnet volume: 12 m long, 12 m high
  - 0.5 T solenoidal field

TPC Readout Chambers



Major Infrastructure items: status

Item	Status	Completion
Central solenoid magnet	Tested, field-mapped	Done
Muon dipole	Tested, field-mapped	Done
support rails for inner detector, PHOS, EMCal	All installed	Done
Platforms for experiment	All installed	Done
Cooling infrastructure	All installed, commissioned	Done
Absorber + vacuum chamber	Commissioning in progress	Jan. 2006
Muon filter	Pre-assembled	Mar. 2006
Services on 'Backframe'	Ongoing	Feb. 2006
Services on Baby frame	Started	Apr. 2006
Installation of fibre Network	Started	June 2006
Installation of detector services (cooling, gas, cables)	Final layout drawings completed	Aug. 2006

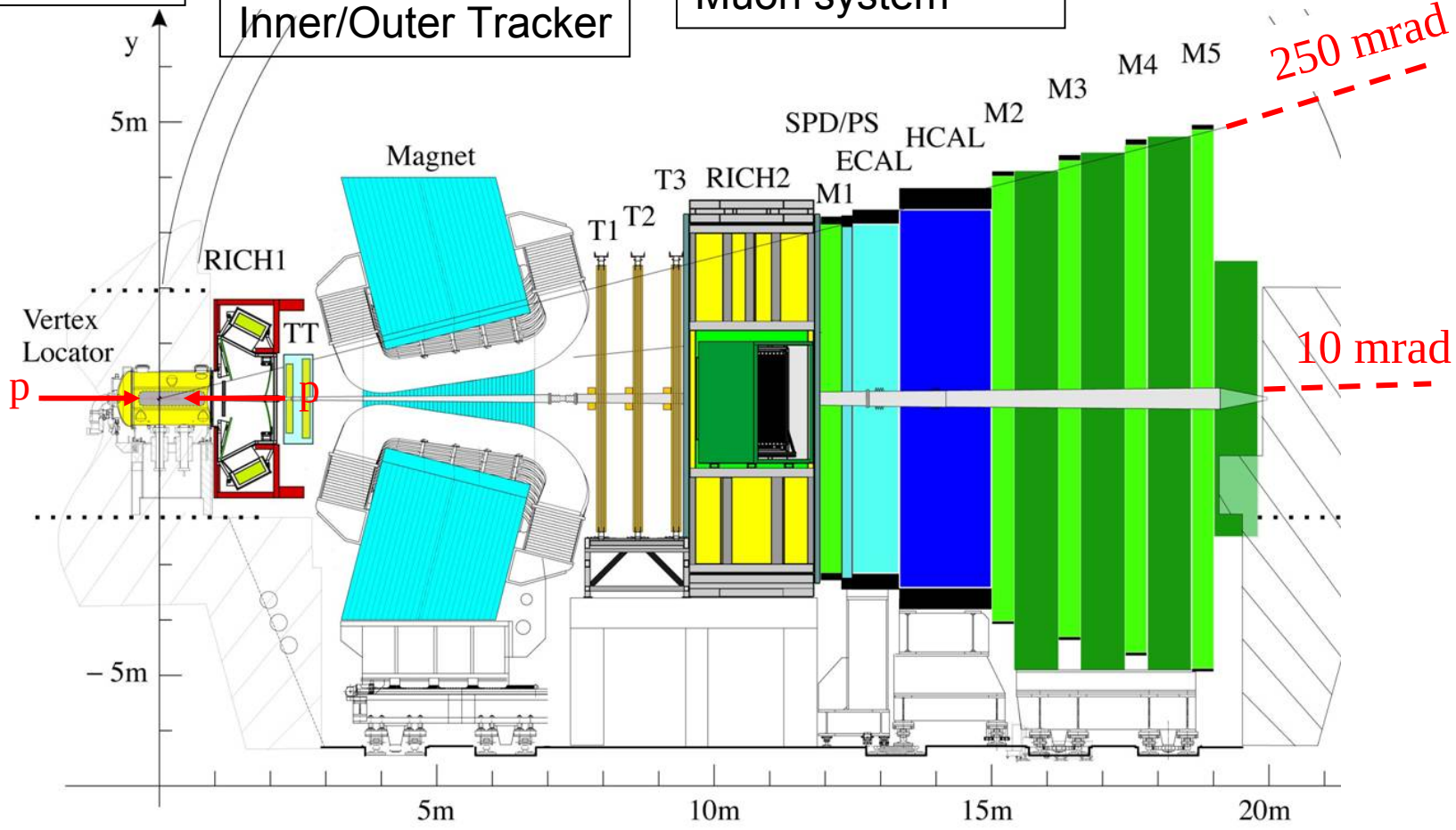
LHCb detector

Vertex Reconstruction
VELO

Tracking system
VELO
Trigger Tracker
Inner/Outer Tracker

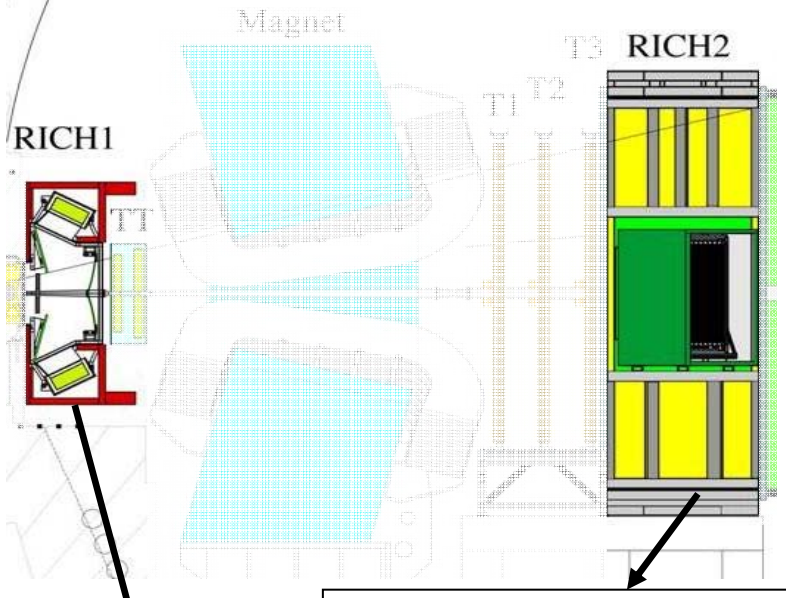
Particle ID
RICH1 and RICH2
Calorimeters
Muon system

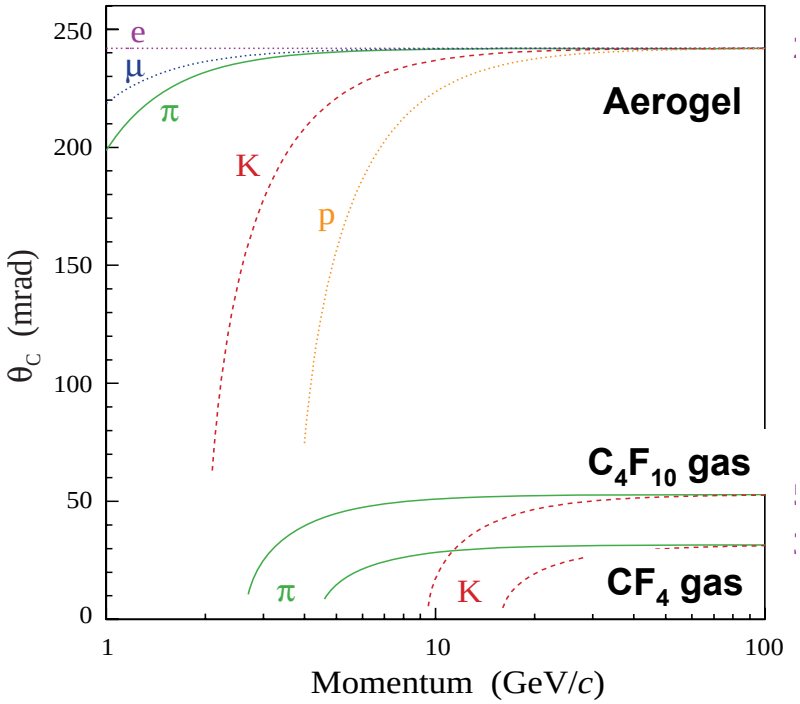
Kinematics
Magnet + Trackers
Calorimeters



Detector status – RICH

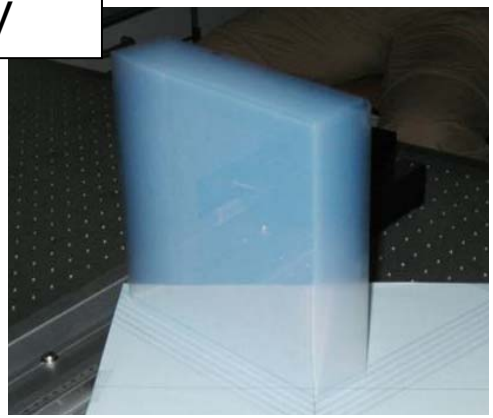
For hadron ID
Efficient π/K separation up to 100 GeV





RICH2:
High momentum tracks
•CF_4: 16 - ~100 GeV

RICH1:
Low momentum tracks
•Aerogel: 2 - ~10 GeV
•C_4F_{10}: 10 - ~60 GeV



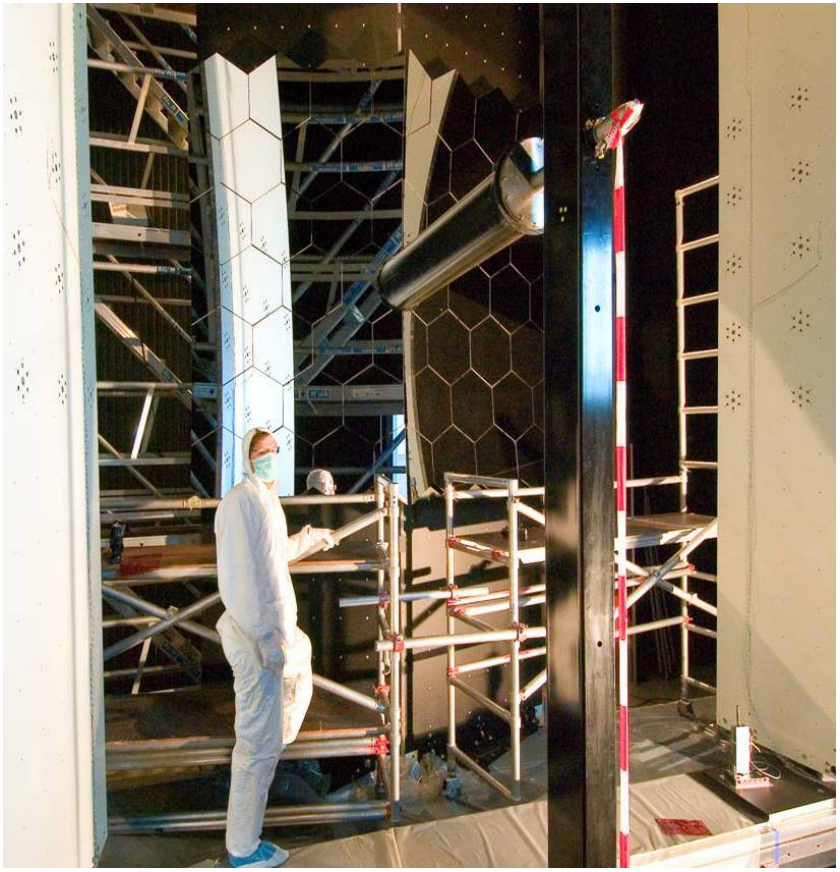
5cm Aerogel
n=1.030

Detector status – RICH

- Novel photon detectors: Hybrid Photon Detectors
  → Si pixel detectors encapsulated in photo-tube
- ~ 500 tubes, each with ~1000 pixels
- Production underway

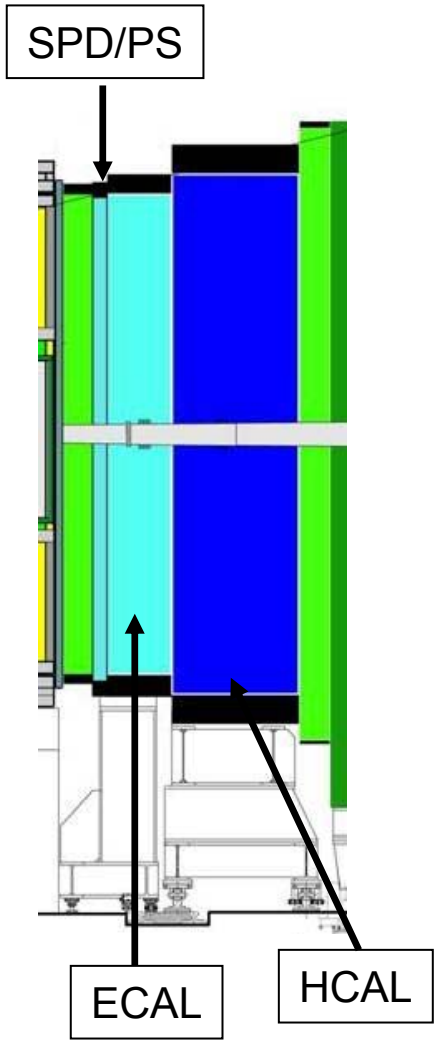
HPD tubes

RICH2 in Point 8
HPDs in production
RICH1 in production



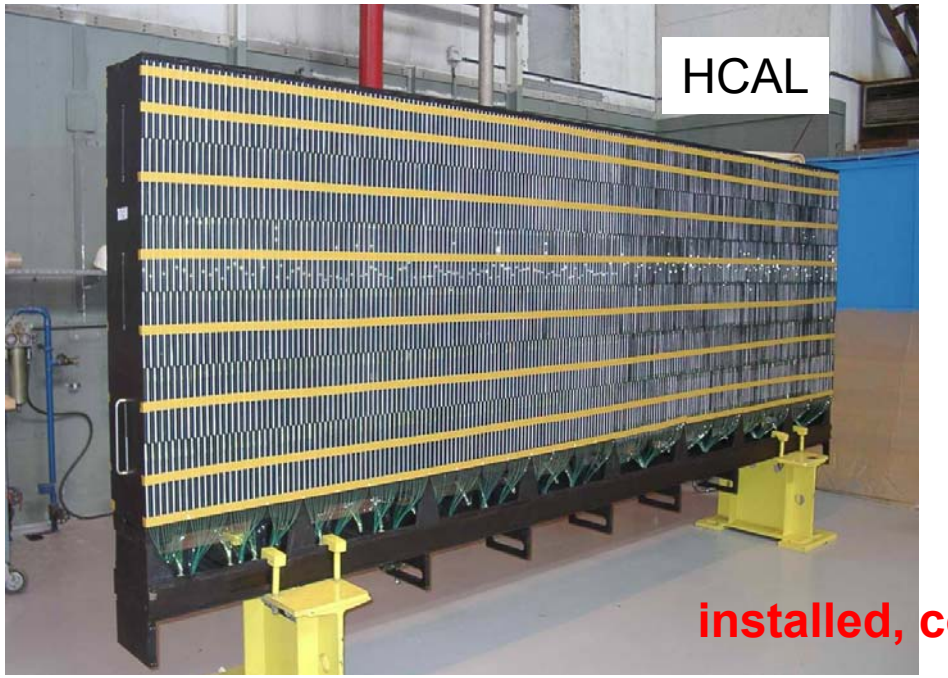
RICH2 Spherical mirrors aligned to 50μrad

Detector Status – Calorimeters



•Scintillating Pad Detector/PreShower
2.5 X_0 Pb between 2 Scintillator planes
size corresponds to size of ECAL pads
in production

•Hadronic Calorimeter (HCAL)
Fe/Scintillator tile calorimeter, 5.6 λ_I
Granularity varies transversally 13x13 and 26x26cm



installed, commissioning starts

Computing during LHC

LHC will provide several PB of data per year per experiment. Need to be processed and made available to thousands of users all around the world → **Tiered structure**

- Tier0 (CERN): safe keeping of RAW data (first copy); first pass reconstruction, **distribution of RAW data and reconstruction output to Tier1**; reprocessing of data during LHC down-times;
- Tier1: safe keeping of a proportional share of RAW and reconstructed data; large scale **reprocessing** and safe keeping of corresponding output; **distribution of data products to Tier2s** and **safe keeping** of a share of simulated data produced at these Tier2s;
- Tier2: Handling **analysis** requirements and proportional share of **simulated event** production and reconstruction.

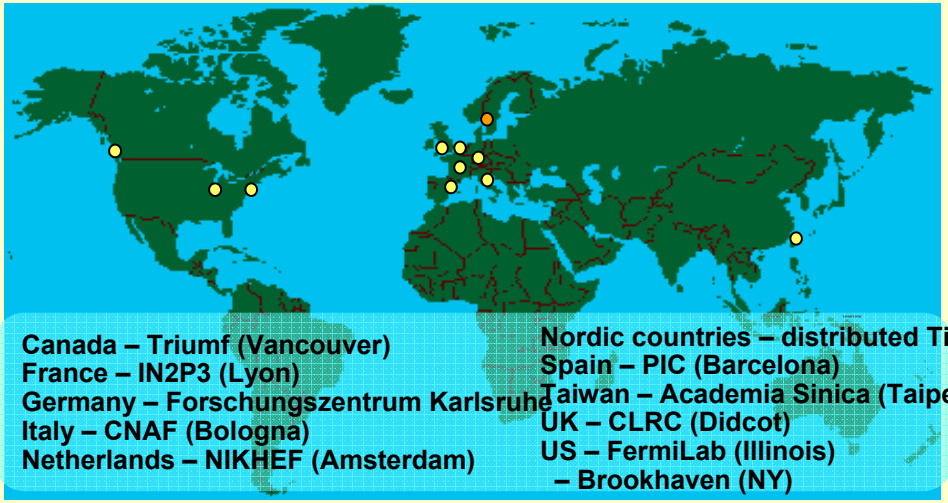
N.B. There are differences in roles by experiment
Essential to test using complete production chain of each!

Sunanda Banerjee: Status of LHC, LCWS06, Bangalore, March 9-13, 2006

LCG Service Hierarchy

Tier-0 – the accelerator centre

- Data acquisition & initial processing
- Long-term data curation
- Distribution of data → Tier-1 centres



Tier-1 – "online" to the data acquisition process → high availability

- Managed Mass Storage – → grid-enabled data service
- Data intensive analysis
- National, regional support
- Continual reprocessing activity (or is that continuous?)

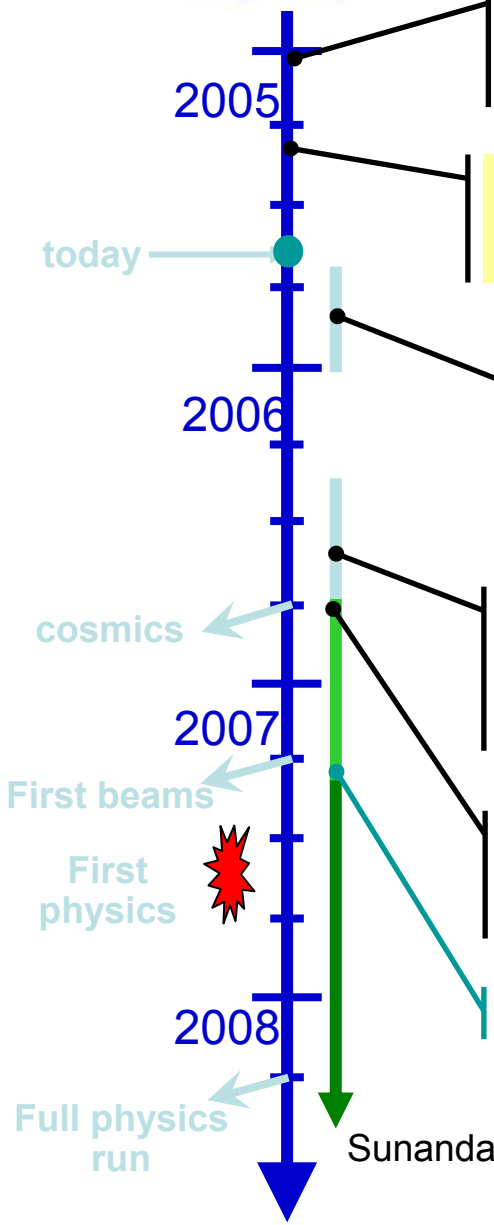
Tier-2 – ~100 centres in ~40 countries

- Simulation
- End-user analysis – batch and interactive

Sunanda Banerjee: Status of LHC, LCWS06, Bangalore, March 9-13, 2006

Les Robertson

Building the Service



SC1 - *Nov04-Jan05* - data transfer between CERN and three Tier-1s (FNAL, NIKHEF, FZK)

SC2 – *Apr05* - data distribution from CERN to 7 Tier-1s – 600 MB/sec sustained for 10 days (one third of final nominal rate)

SC3 – *Sep-Dec05* - demonstrate reliable basic service – most Tier-1s, some Tier-2s; push up Tier-1 data rates to 150 MB/sec (60 MB/sec to tape)

SC4 – *May-Aug06* - demonstrate full service – all Tier-1s, major Tier-2s; full set of baseline services; data distribution ***and*** recording at nominal LHC rate (1.6 GB/sec)

LHC Service in operation – *Sep06* – over following six months ramp up to full operational capacity & performance

LHC service commissioned – *Apr07*

SC4 Timeline - 2006

January	SC3 disk repeat – nominal rates capped at 150MB/s SRM 2.1 delivered (?)	July	Tape Throughput tests at full nominal rates!
February	CHEP w/s – T1-T1 Use Cases, SC3 disk – tape repeat (50MB/s, 5 drives)	August	T2 Milestones – debugging of tape results if needed
March	Detailed plan for SC4 service agreed (M/W + DM service enhancements)	September	LHCC review – rerun of tape tests if required?
April	SC4 disk – disk (nominal) and disk – tape (reduced) throughput tests	October	WLCG Service Officially opened. Capacity continues to build up.
May	Deployment of new M/W and DM services across sites – extensive testing	November	1st WLCG 'conference' All sites have network / tape h/w in production(?)
June	SC4 production - Tests by experiments of 'T1 Use Cases'. 'Tier2 workshop' – identification of key Use Cases and Milestones for T2s	December	'Final' service / middleware review leading to early 2007 upgrades for LHC data taking??

O/S Upgrade? (SLC4) Sometime before April 2007!

Software for LHC Experiments

- LCG Application Area software delivers the common physics software for the LHC experiments

- Organized to ensure focus on real experiment needs
  - Experiment-driven requirements and monitoring
  - Architects in management and execution
  - Open information flow and decision making
  - Participation of experiment developers
  - Frequent releases enabling iterative feedback

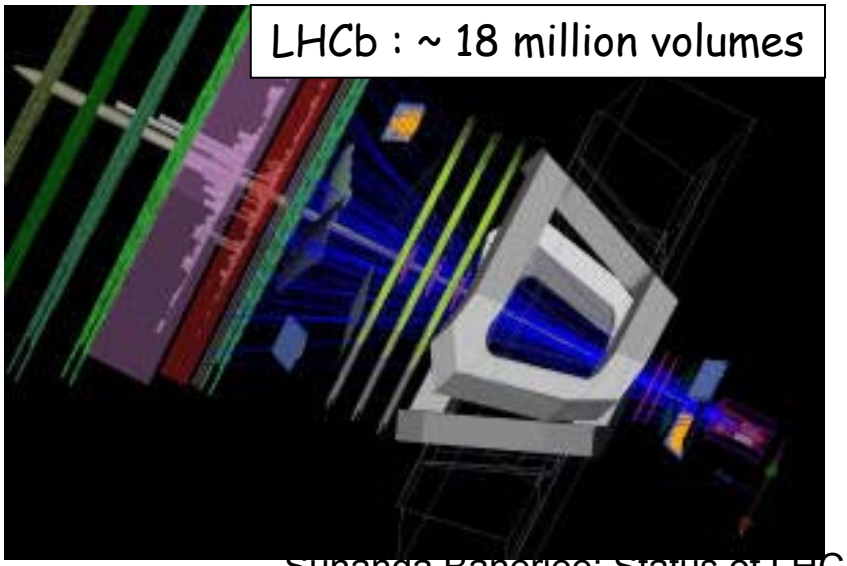
- Success is defined by adoption and validation of the products by the experiments
  - Integration, evaluation, successful deployment LCG

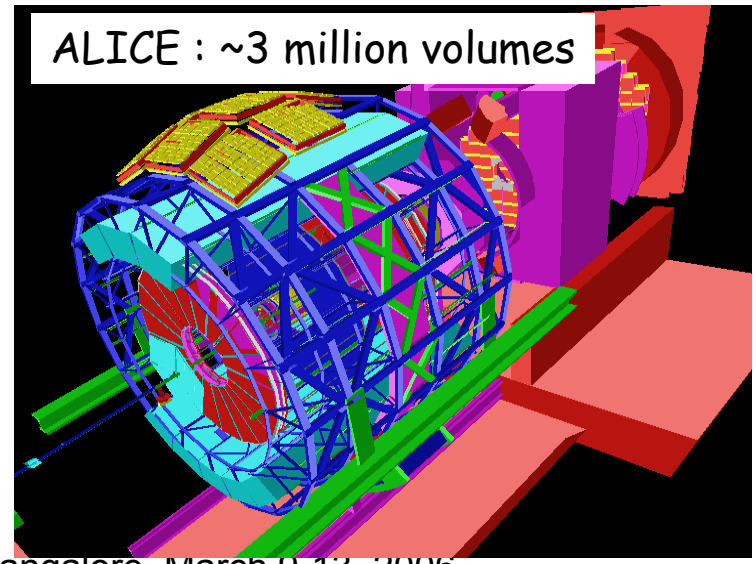
LCG AA Projects

- SPI – Software process infrastructure
  - Software and development services: external libraries, savannah, software distribution, support for build, test, QA, etc.
- ROOT – Core Libraries and Services
  - Foundation class libraries, math libraries, framework services, dictionaries, scripting, GUI, graphics, SEAL libraries, etc.
- POOL – Persistency Framework
  - Storage manager, file catalogs, event collections, relational access layer, conditions database, etc.
- SIMU - Simulation project
  - Simulation framework, physics validation studies, MC event generators, Garfield, participation in Geant4 and Fluka.

Simulation

- Geant4: success story; Deployed by all experiments.
  - Functionality essentially complete. Detailed physics studies performed by all experiments.
    - Very reliable in production (better than 1:10^4)
  - Good collaboration between experiments and Geant4 team
  - Lots of feedback on physics (e.g. from test beams)
  - LoH (Level of Happiness): very high



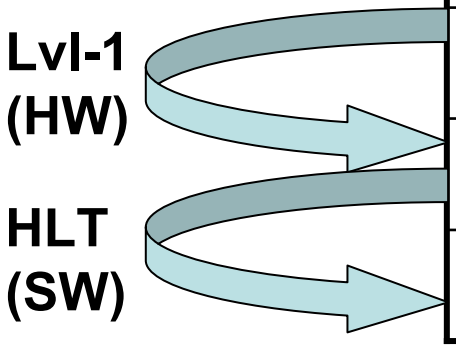


Reconstruction, Trigger, Monitoring

- General feature: all based on corresponding framework (AliRoot, Athena, Gaudi, CMSSW)
  - Multi-threading is necessary for online environment
  - Most Algorithms & Tools are common with offline
- Two big versions:
  - Full reconstruction
  - “seeded”, or “partial”, or “reconstruction inside a region of interest”
    - This one used in HLT
- Online monitoring and event displays
  - “Spying” on Trigger/DAQ data online
    - But also later in express analysis
- Online calibrations

High-Level Trigger

- A huge challenge; large (small) rejection (accept) factor



	ATLAS/CMS	LHCb	ALICE
Interaction rate	10^9 Hz	10^7 Hz	10^4 Hz
HLT input	100 kHz	1 MHz	1 kHz
HLT accept	100-200 Hz	2000 Hz	~50 Hz

  - In practice: startup will use smaller rates.
    - CMS example: 12.5 kHz (pilot run) and 50 kHz (10^{33} $cm^{-2}s^{-1}$)
    - Real startup conditions (beam, backgrounds, expt) unknown
      - Startup trigger tables: in progress. ATLAS/CMS have prototypes. Real values: when beam comes…

LHC startup plan

Stage 1
Initial commissioning
43x43 to 156x156, N=3×10^{10}
Zero to partial squeeze

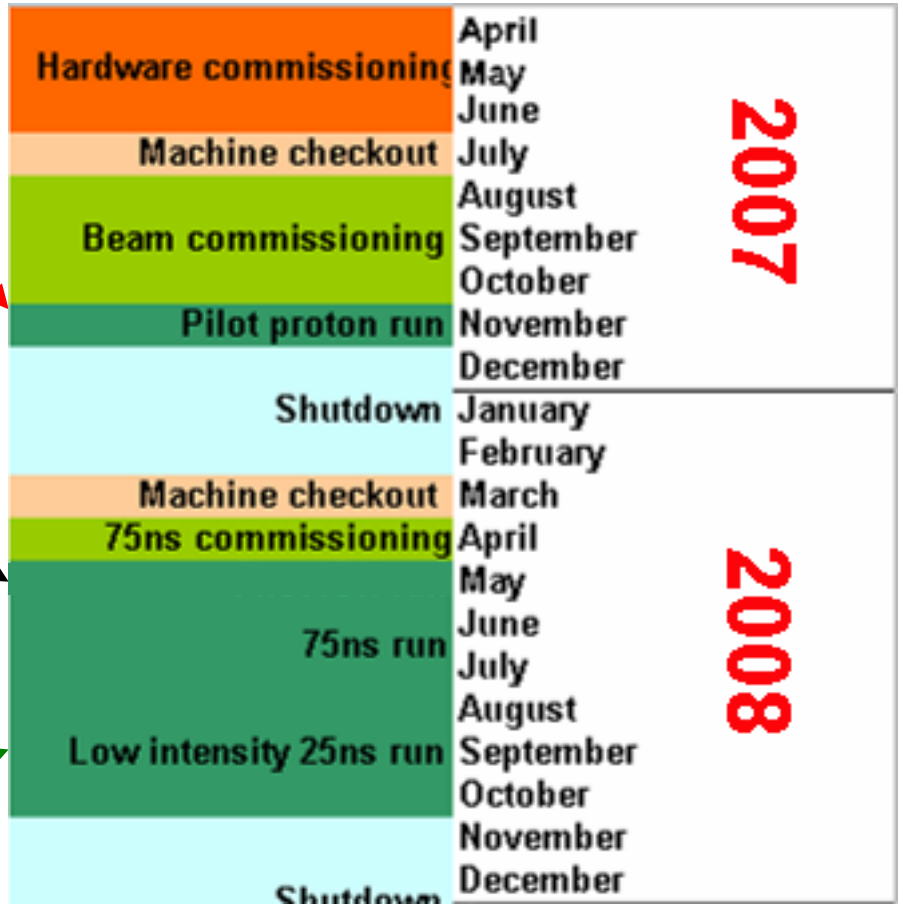
$L=3\times10^{28}$ - 2×10^{31}

Stage 2
75 ns operation
936x936, N=3-4×10^{10}
partial squeeze

$L=10^{32}$ - 4×10^{32}

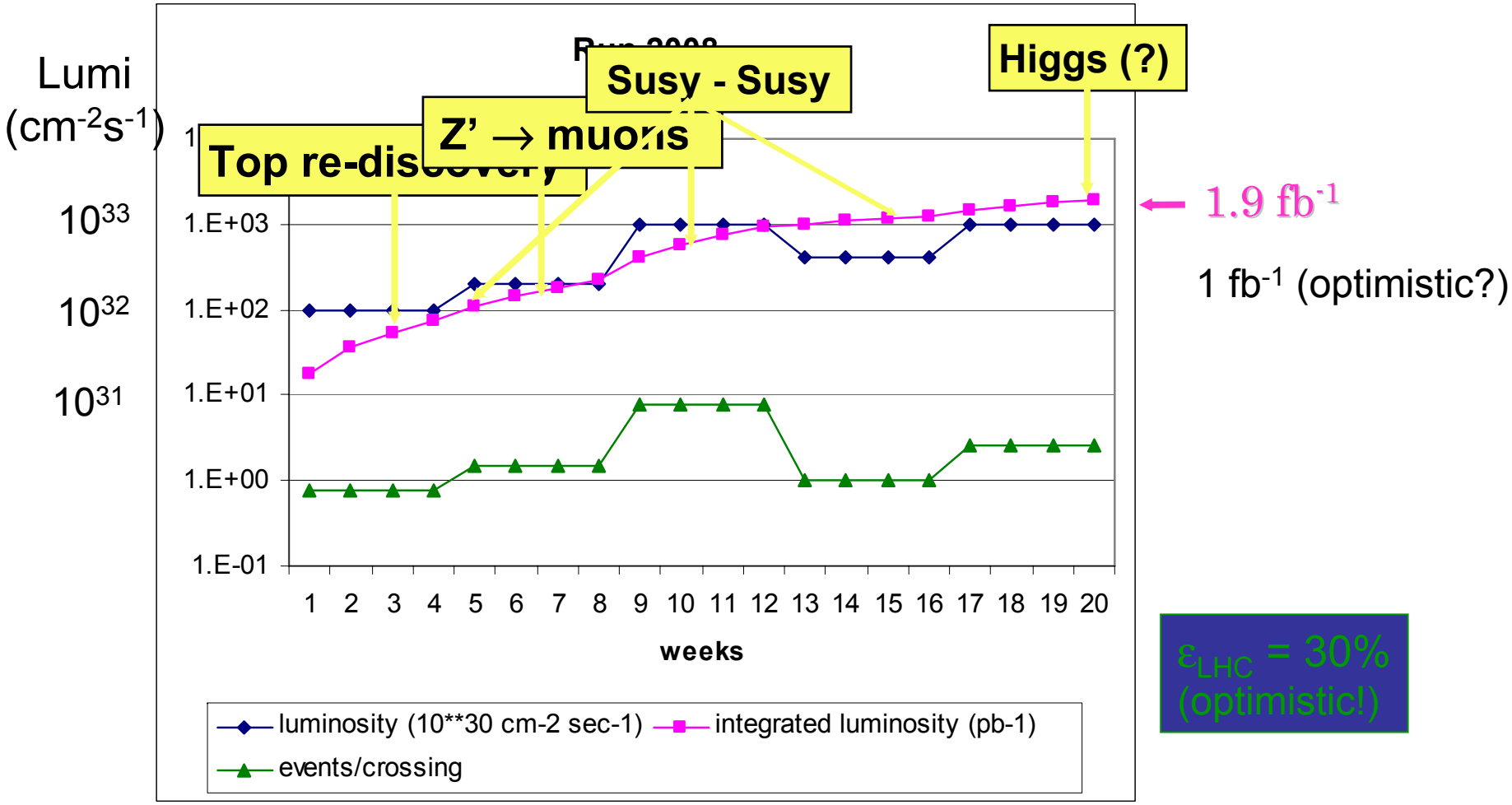
Stage 3
25 ns operation
2808x2808, N=3-5×10^{10}
partial to near full squeeze

$L=7\times10^{32}$ - 2×10^{33}



LHC startup: CMS/ATLAS

- Integrated luminosity with the current LHC plans



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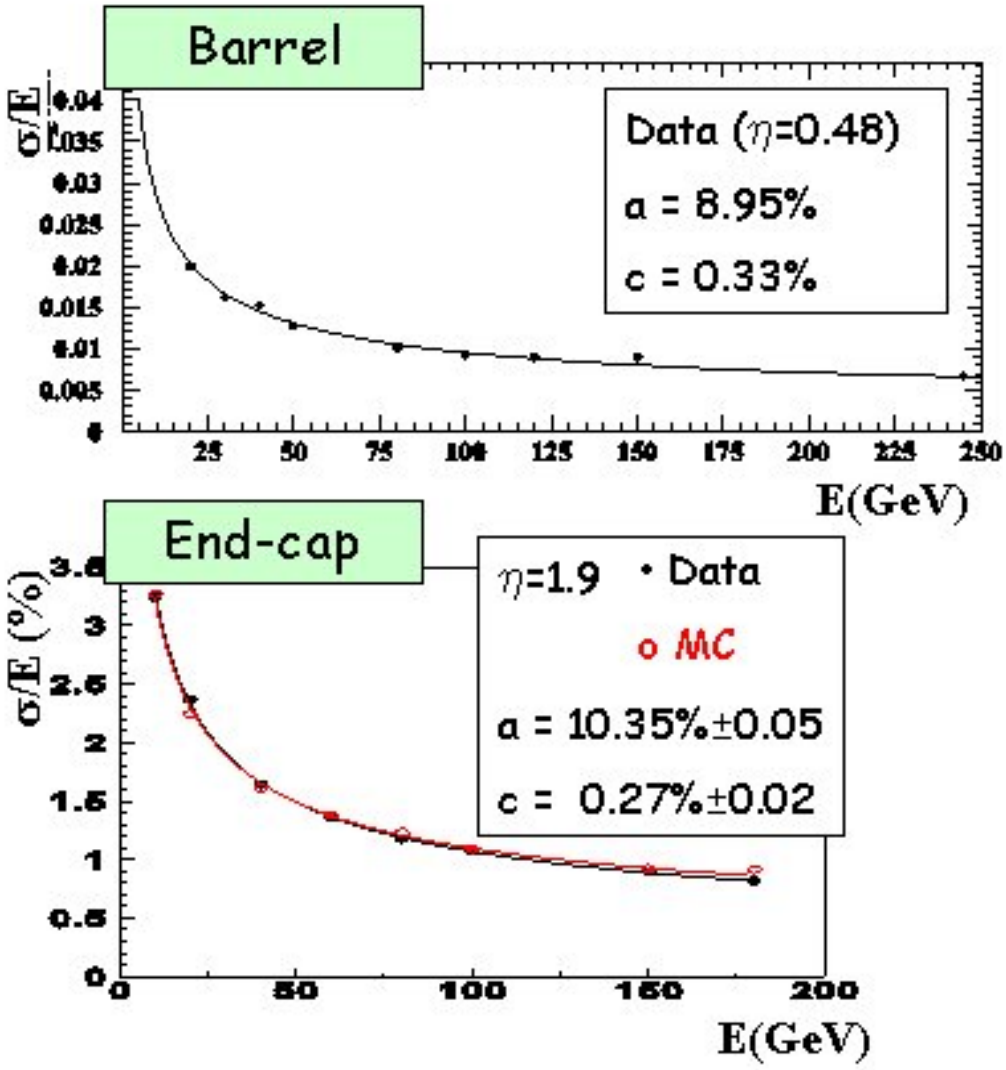
ATLAS:
EM beam test results: Energy resolution



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

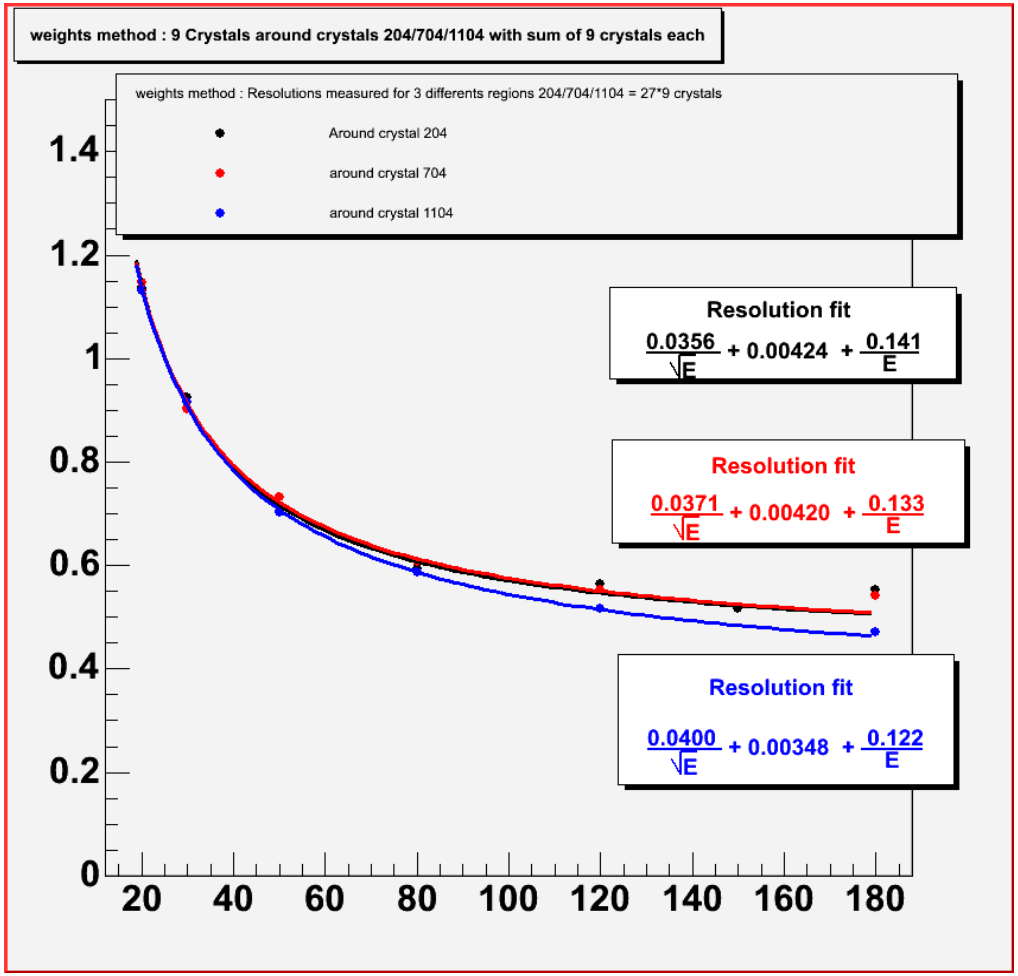
For every tested points:

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

- Within specifications
- Good agreement with MC

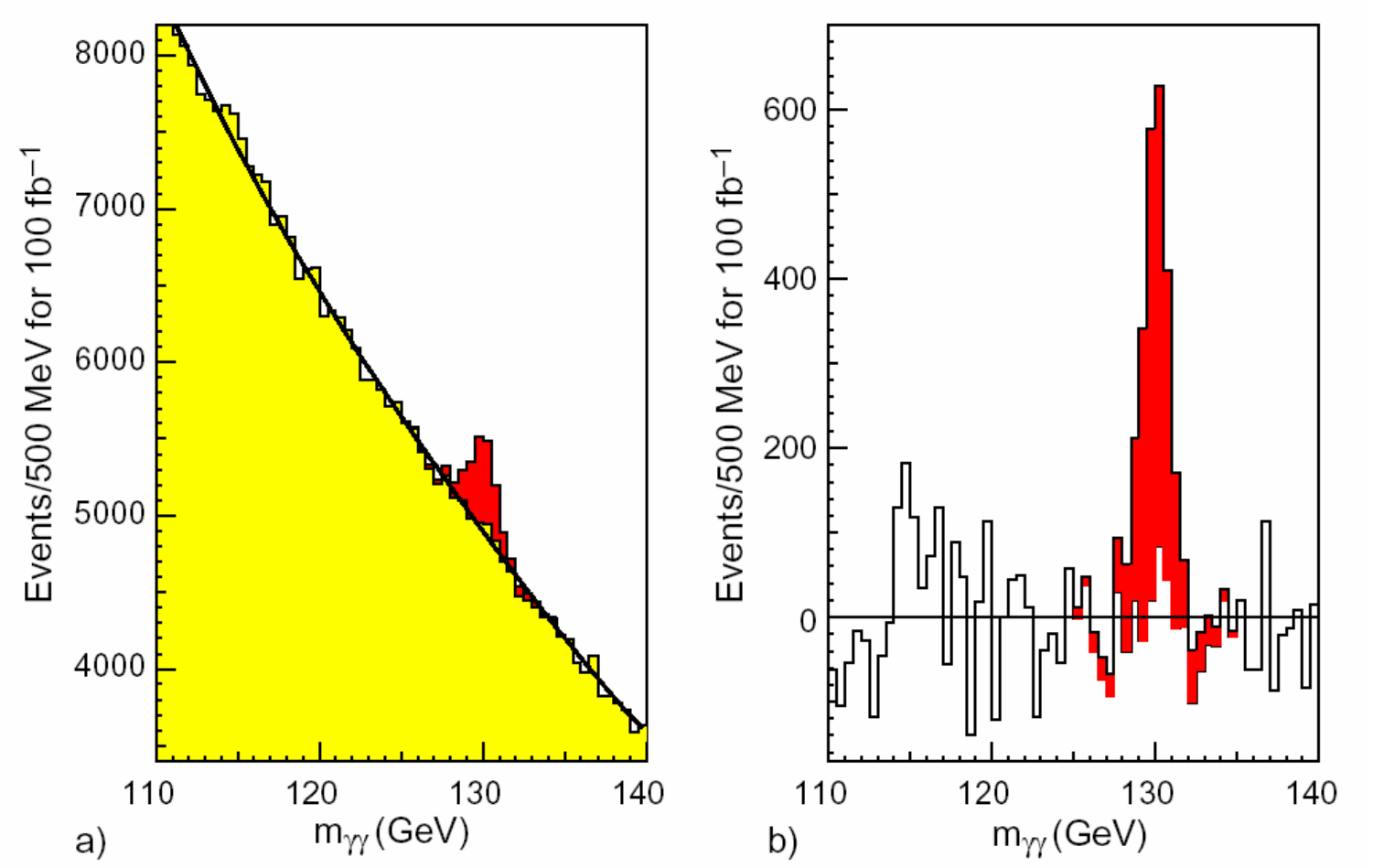
CMS PbWO4 Crystals: Energy Resolution

Beam Test 2005



CMS H → γγ mass resolution

$H \rightarrow \gamma\gamma$ Simulation (100 fb^{-1})



Sunanda Banerjee: Status of LHC, LCWS06, Bangalore, March 9-13, 2006

TIFR

Acknowledgements

- Status of LHC machine, experiments, software and computing
- Thanks to the Spokespersons of ALICE, ATLAS, CMS, LHCb for providing links to their recent status reports
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- For Software and Computing related status of LHC experiments, the presentations of Paris Sphicas and Jamie Shiers at CHEP06 have been used.