The LHC Programme

a brief status report

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CERN

LHC

The Large Hadron collider:

•Exploration of the TeV-scale, study of electroweak symmetry breaking and more

•Upgrades
- •Large aperture inner triplet
- •the LHC injector complex (LINAC4, SPL, PS2,...)

LHC

7 + 7 TeV p p collisions at 10^{34} $cm^{-2}s^{-1}$
1148 + 1148 TeV Pb Pb collisions at ~10^{28} $cm^{-2}s^{-1}$

ATLAS, CMS – 'general purpose' detectors

LHCb – optimized for B physics/CP violation studies

ALICE – optimized for heavy ion physics

TOTEM – precision measurement of total cross section (and more)

LHCf – measurement of forward photon, π^0 production

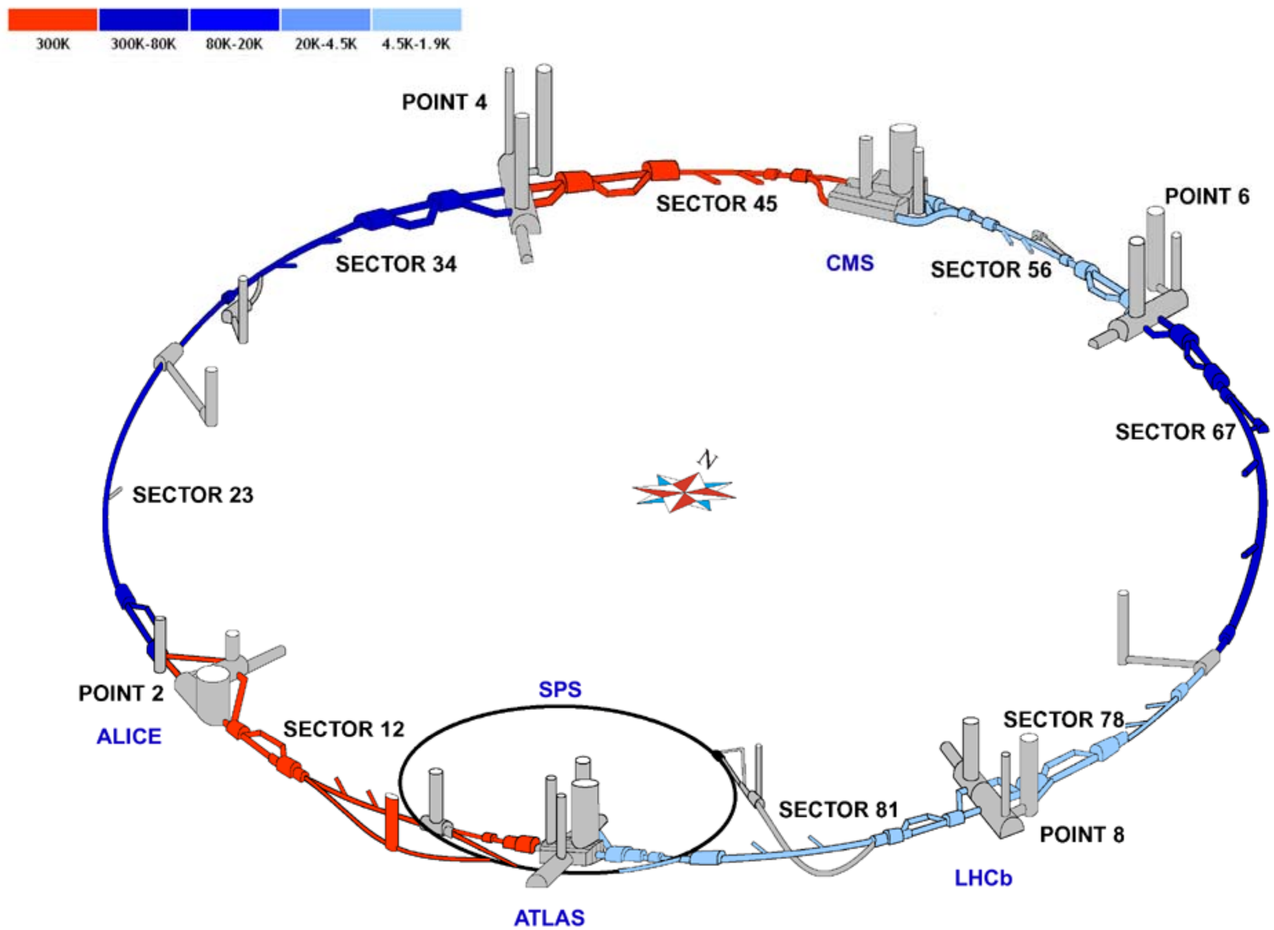
LHC

The accelerator has entered the phase of final cooldown
-it was planned to be cold (1.9K) by the second half of June; it will probably take a few weeks longer
-hardware commissioning (powering the magnets, testing the quench protection system, etc., etc.) is ongoing
(6 out of the 8 sectors are presently cold or being cooled down)

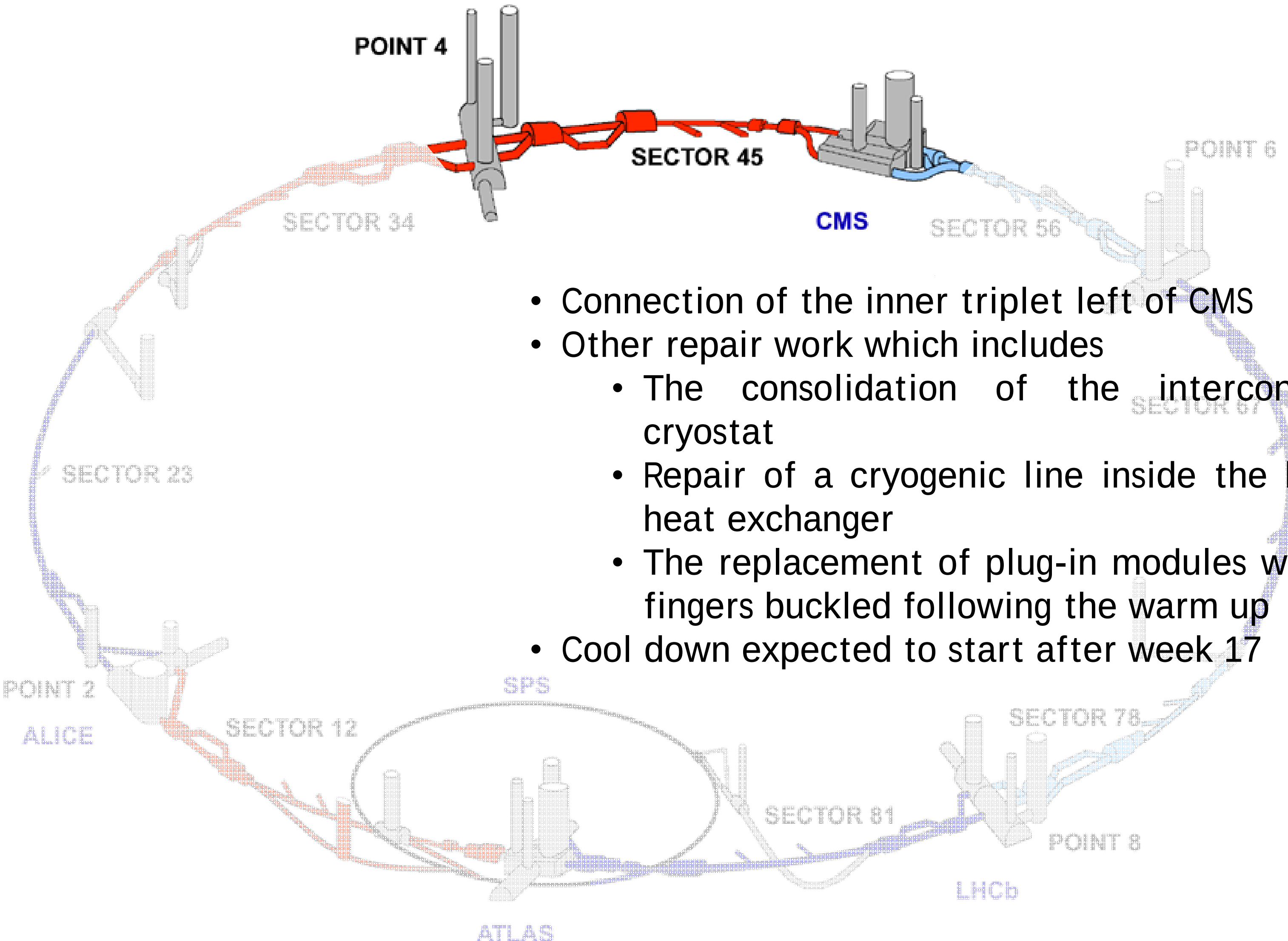
The experiments will have to be closed and ready by the end of June; they probably will have a few weeks more, see above

Schedule to be confirmed by the end of April → beginning of May, i.e. this week

Status of the LHC

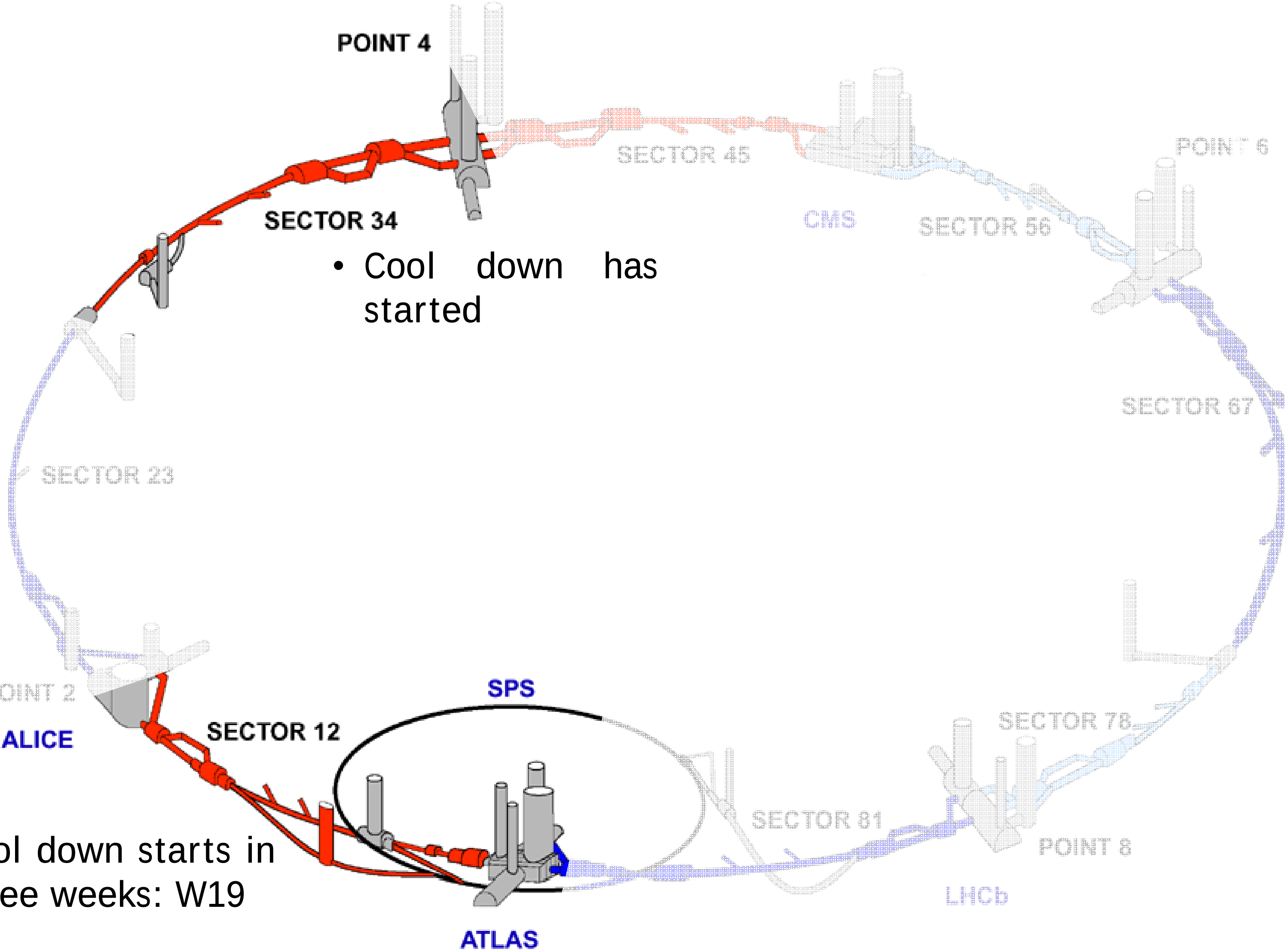


Consolidation



- Connection of the inner triplet left of CMS
- Other repair work which includes
  - The consolidation of the interconnection cryostat
  - Repair of a cryogenic line inside the bayonet heat exchanger
  - The replacement of plug-in modules where RF fingers buckled following the warm up
- Cool down expected to start after week 17

Preparation for Cool down

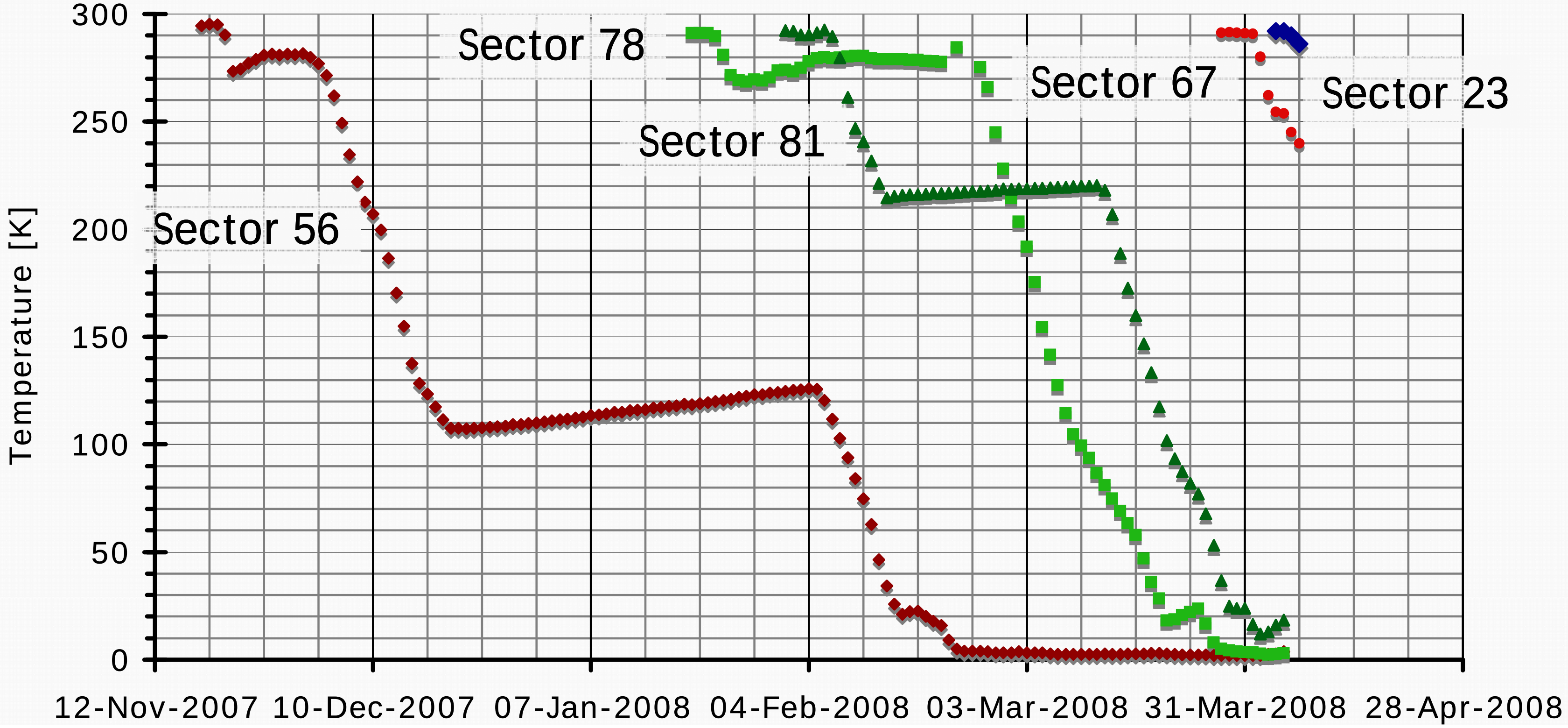


- Cool down has started

- Cool down starts in three weeks: W19

The latest cool downs

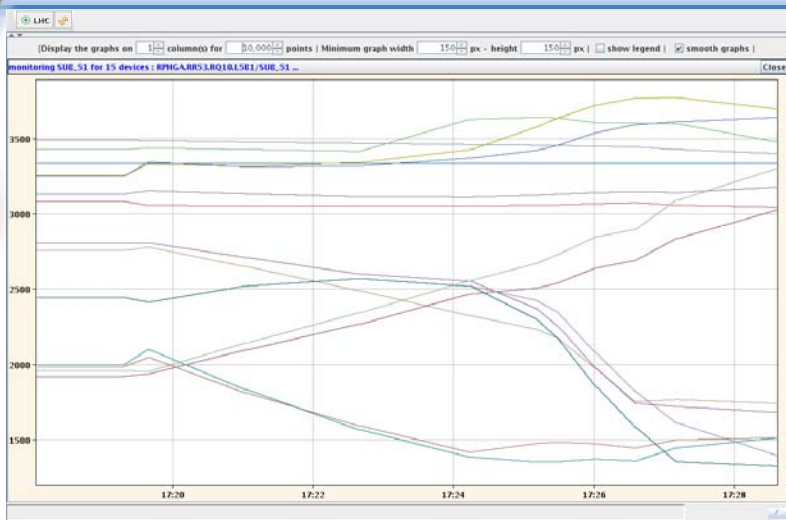
Presently two sectors are below 2K
The helium inventory in the LHC is 62 t



6 weeks to cool down from 300 to 2K +
3 weeks for stabilization at 2K

Courtesy S.Claudet

Software for operation, controls and diagnostics



Using the final software foreseen for operation for the commissioning of the machine systems

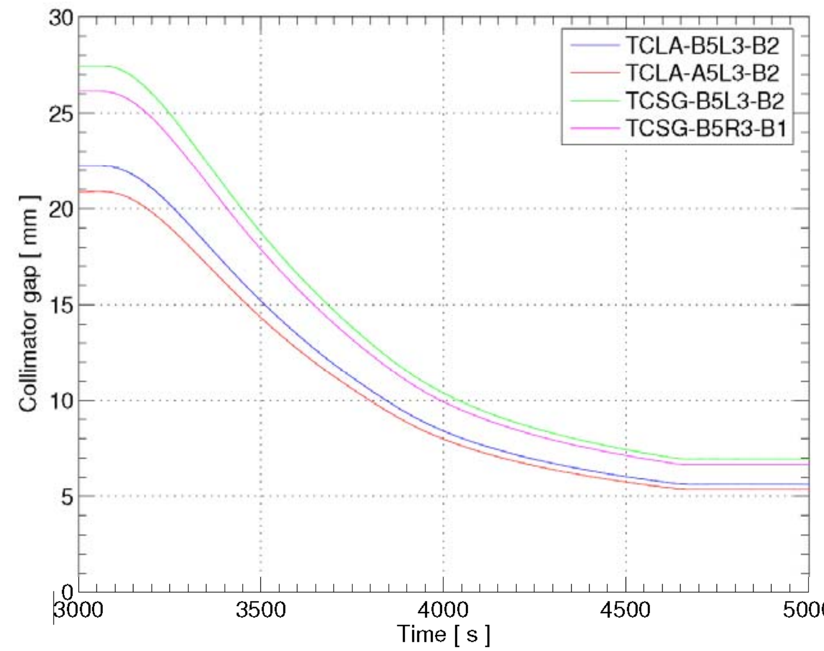
1

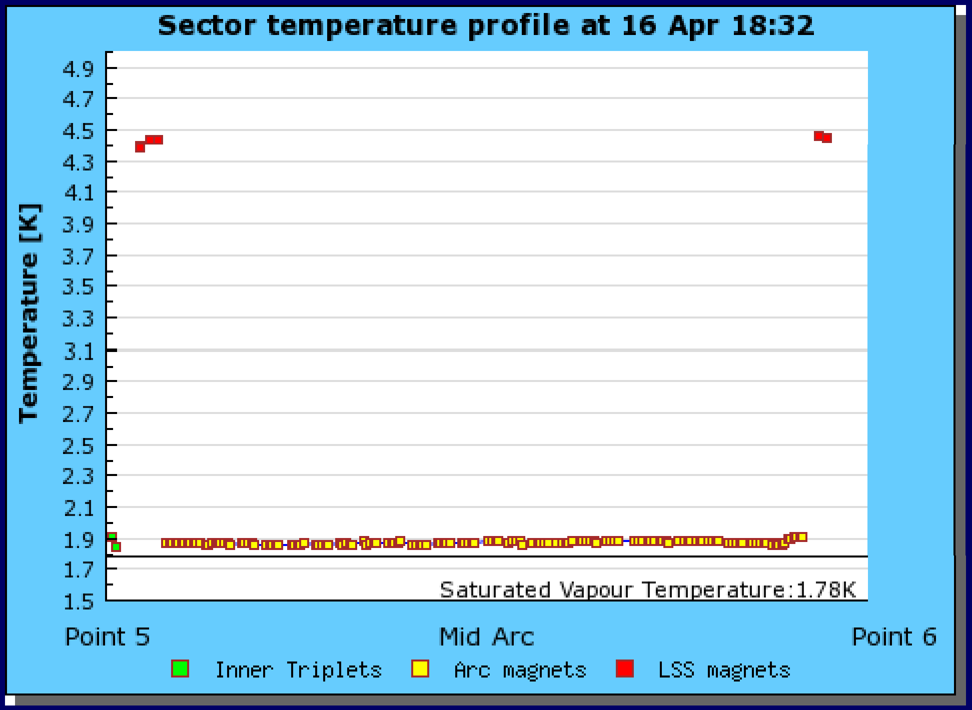
- Sequencer
- Logging system
- Post mortem system
- On-line databases
- Industrial supervision systems

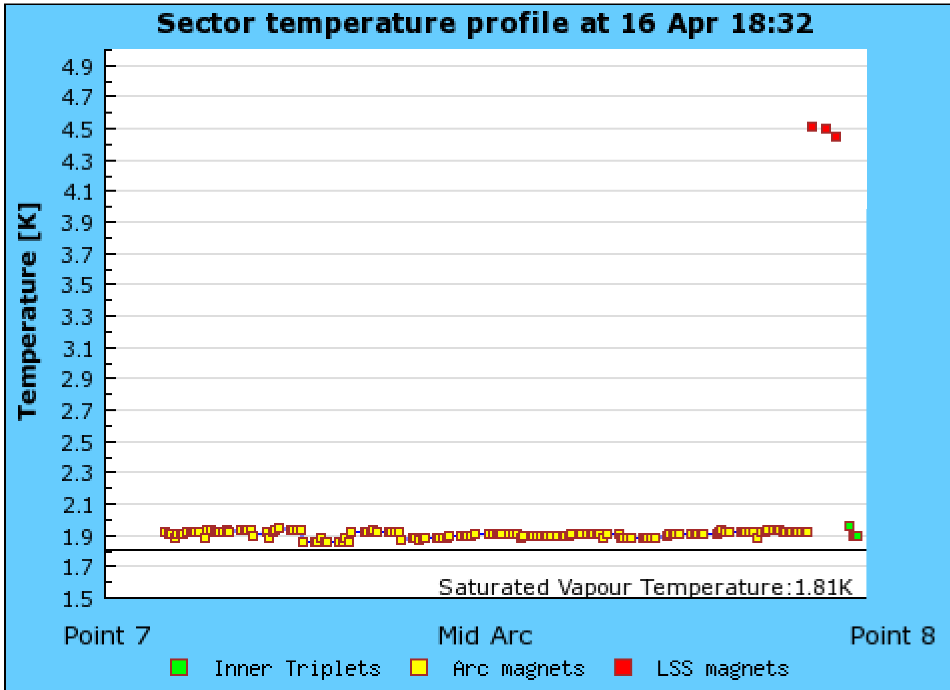
Dry runs

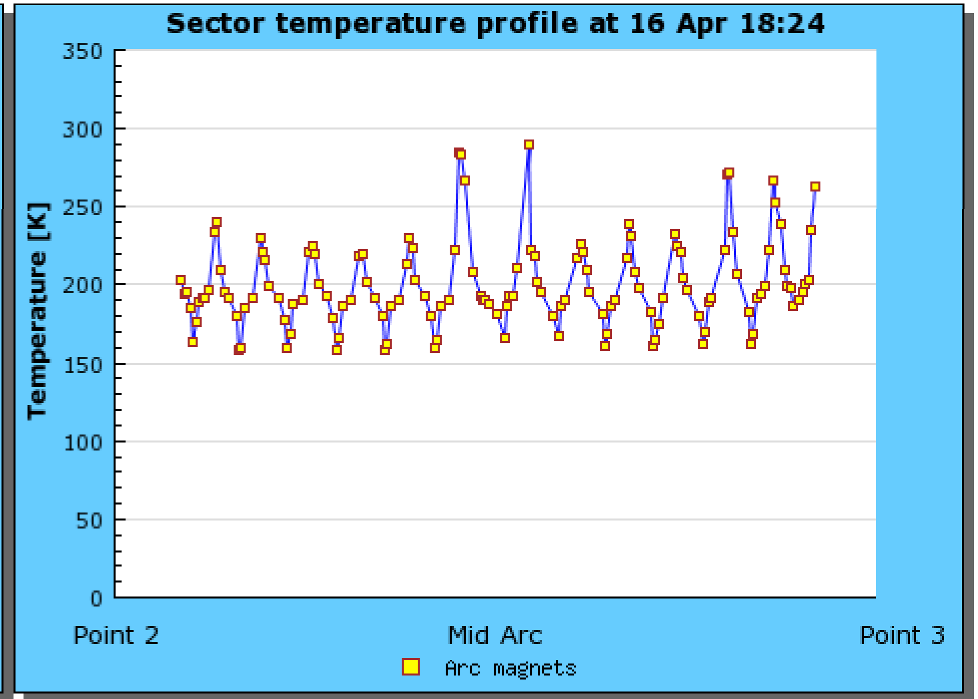
2

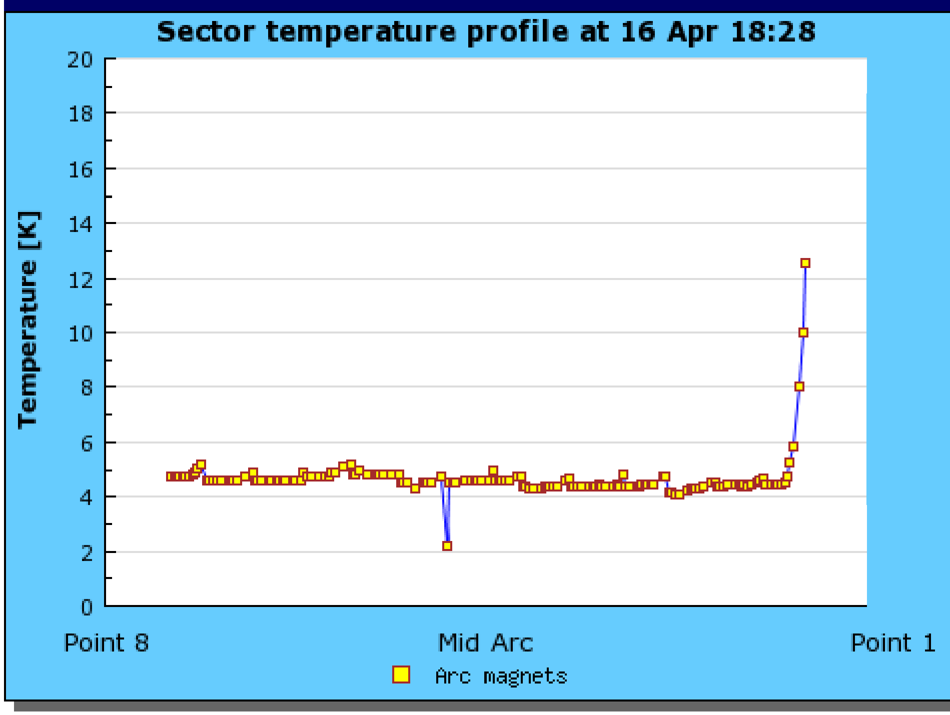
- Injection kickers system
- LHC Beam dumping system (kickers, energy tracking, diagnostics)
- Beam instrumentation (loss monitors, position monitors, current transformers, screens)
- Power converters in simulation mode
- Collimators
- Timing system
- Communication with experiments (handshakes, modes, fill number, beam based measurements, etc.)
- Post mortem data acquisition system
- Squeeze

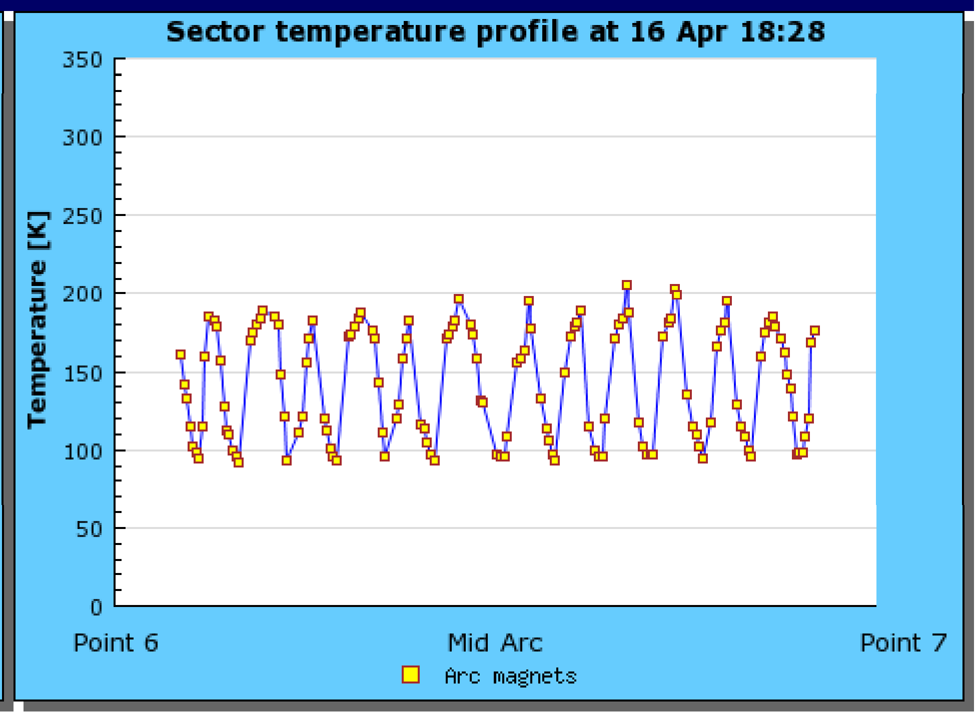



Sector temperature profile at 16 Apr 18:32
Temperature [K]
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
Saturated Vapour Temperature:1.78K
Point 5
Mid Arc
Point 6
Inner Triplets
Arc magnets
LSS magnets


Sector temperature profile at 16 Apr 18:32
Temperature [K]
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
Saturated Vapour Temperature:1.81K
Point 7
Mid Arc
Point 8
Inner Triplets
Arc magnets
LSS magnets


Sector temperature profile at 16 Apr 18:24
Temperature [K]
350
300
250
200
150
100
50
0
Point 2
Mid Arc
Point 3
Arc magnets

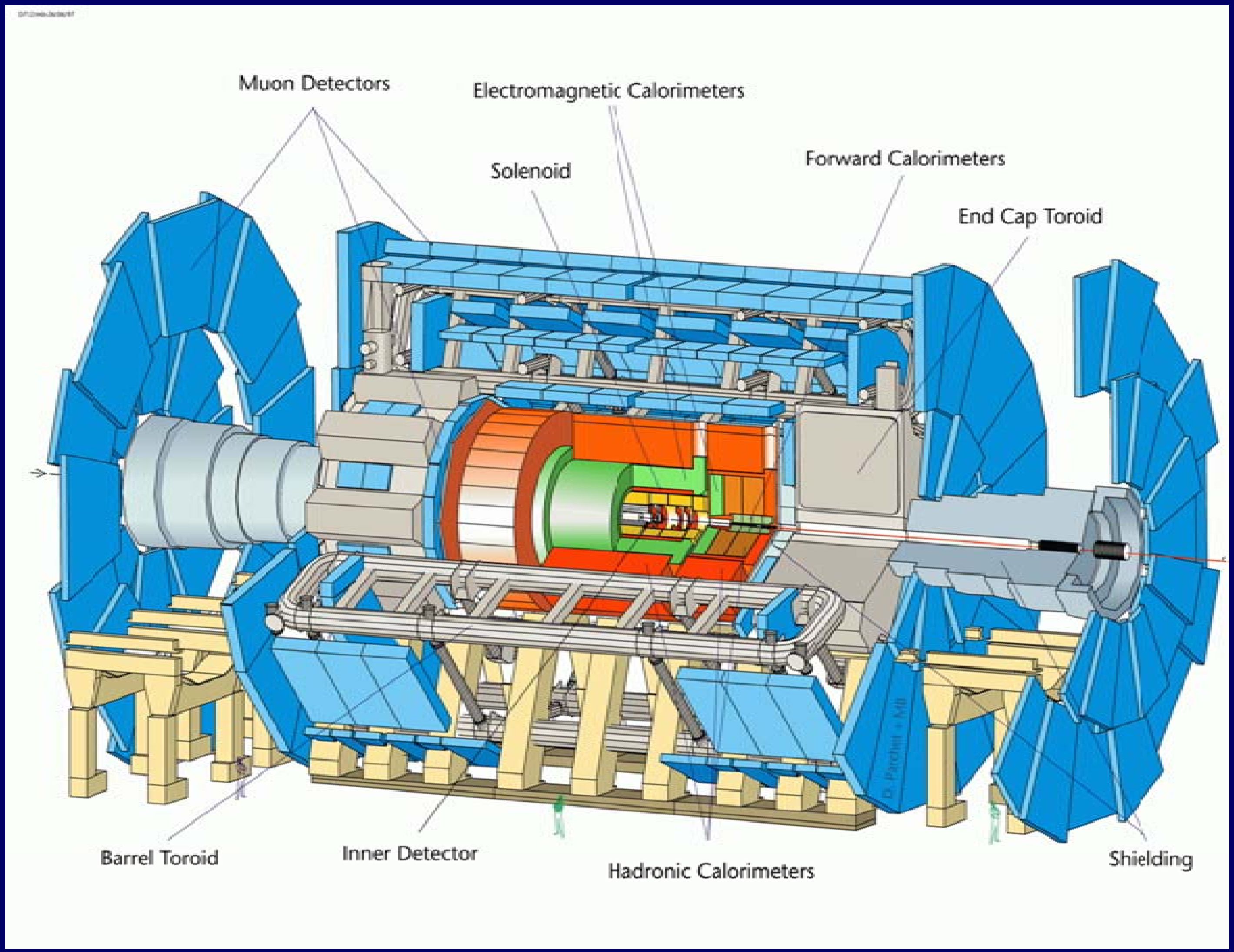

Sector temperature profile at 16 Apr 18:28
Temperature [K]
20
18
16
14
12
10
8
6
4
2
0
Point 8
Mid Arc
Point 1
Arc magnets


Sector temperature profile at 16 Apr 18:28
Temperature [K]
350
300
250
200
150
100
50
0
Point 6
Mid Arc
Point 7
Arc magnets

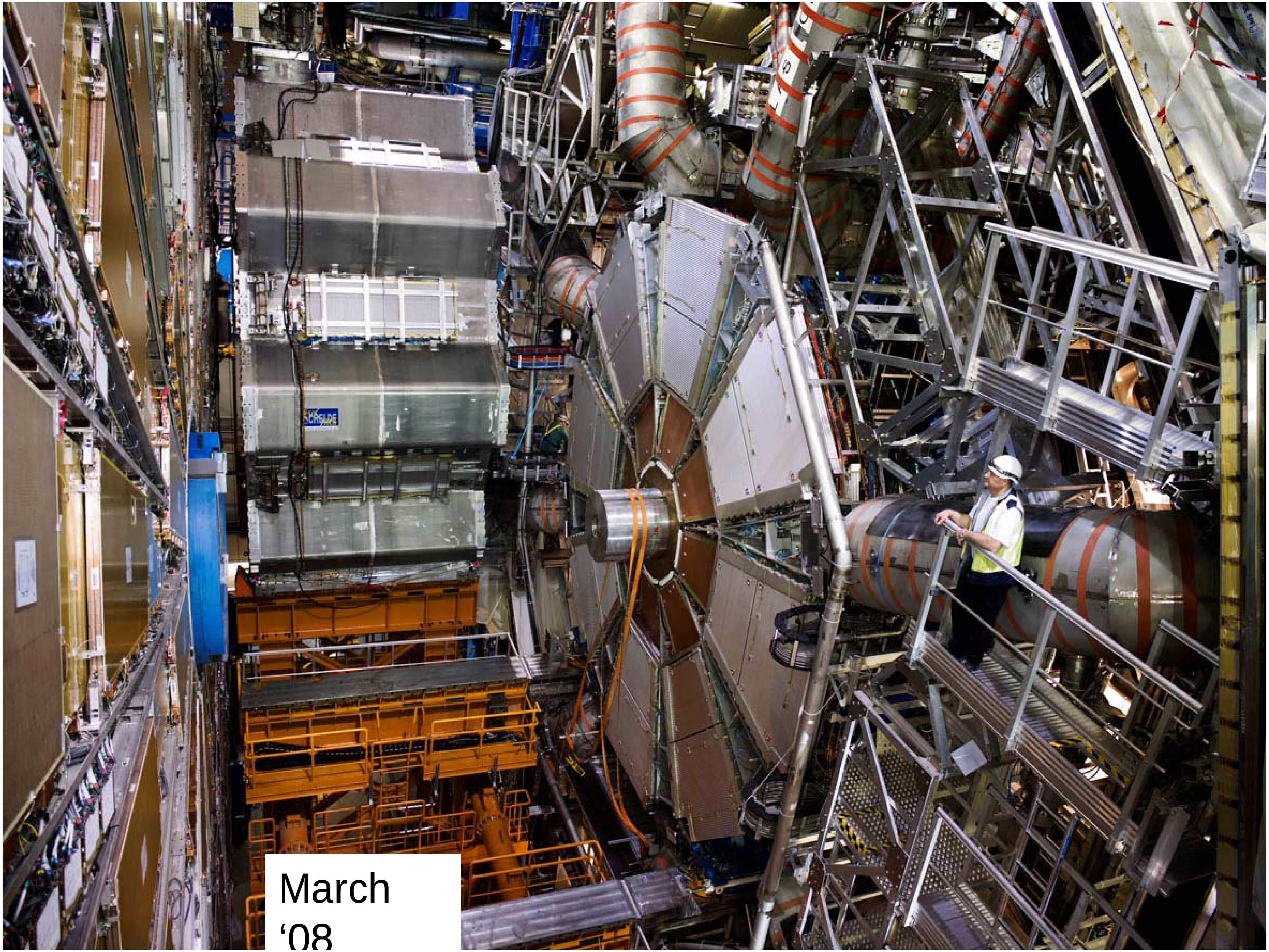
… in summary

- Several teams are busy commissioning the technical systems (the superconducting magnets, the warm magnets, the RF, the injection system, the collimators, the beam dumping system, the access safety and control, the infrastructure systems, the software, etc.) of the LHC in parallel but in a coordinated manner.
- A strategy, where the initial beam energy is at least 5 TeV, is proposed to gain time with the training of magnets and meet the summer deadline.
- Recent results, obtained while commissioning Sector 45, indicate that this is feasible.

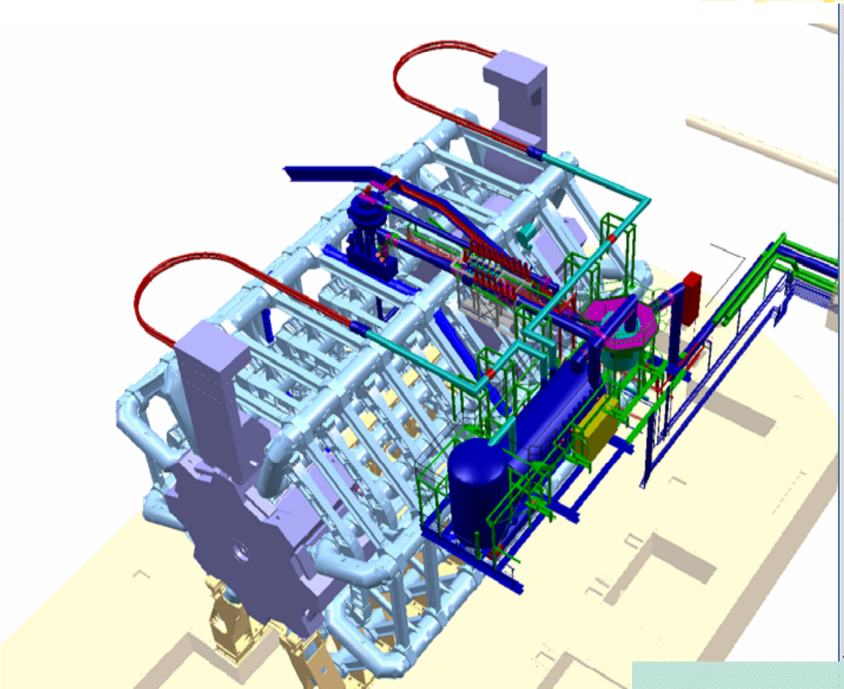
ATLAS

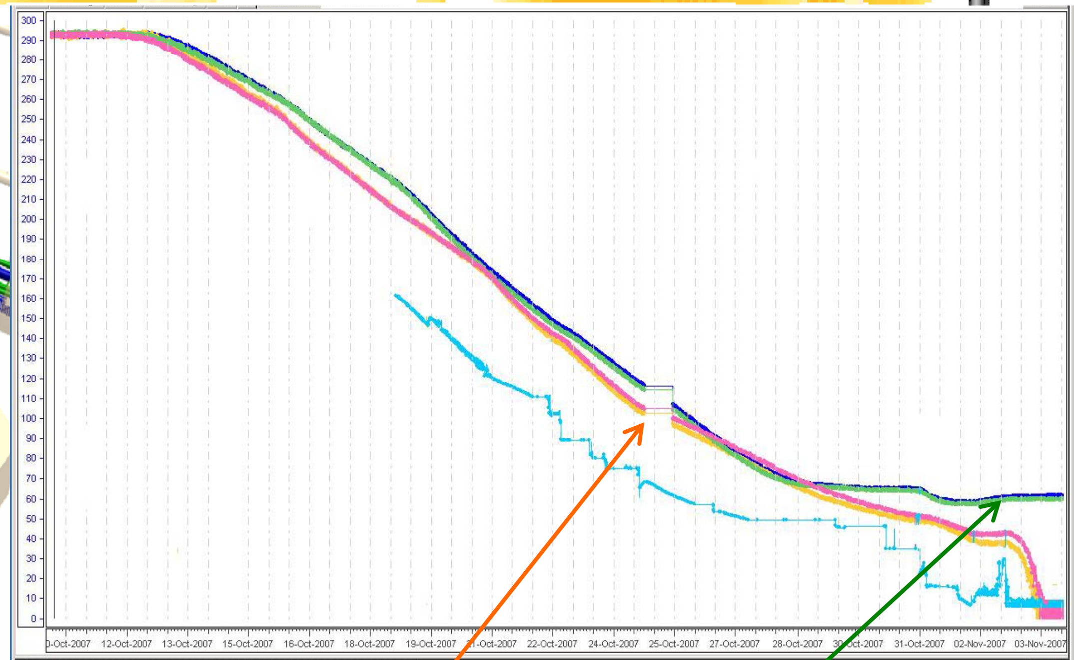


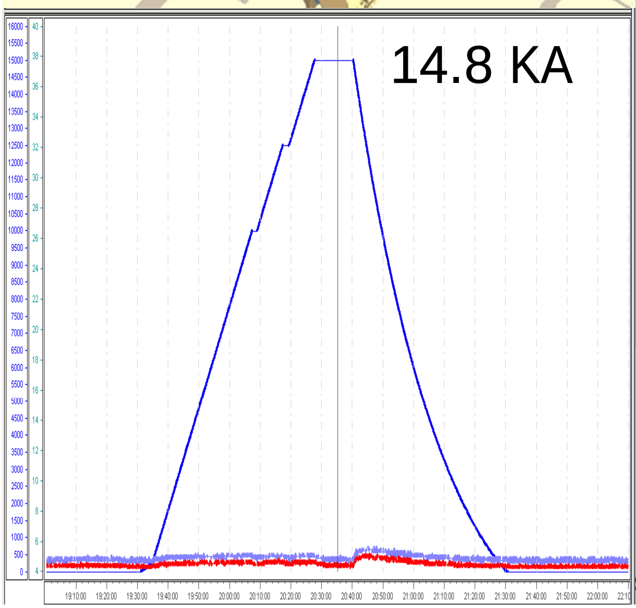
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding


March
'08

End-Cap Toroids test during November







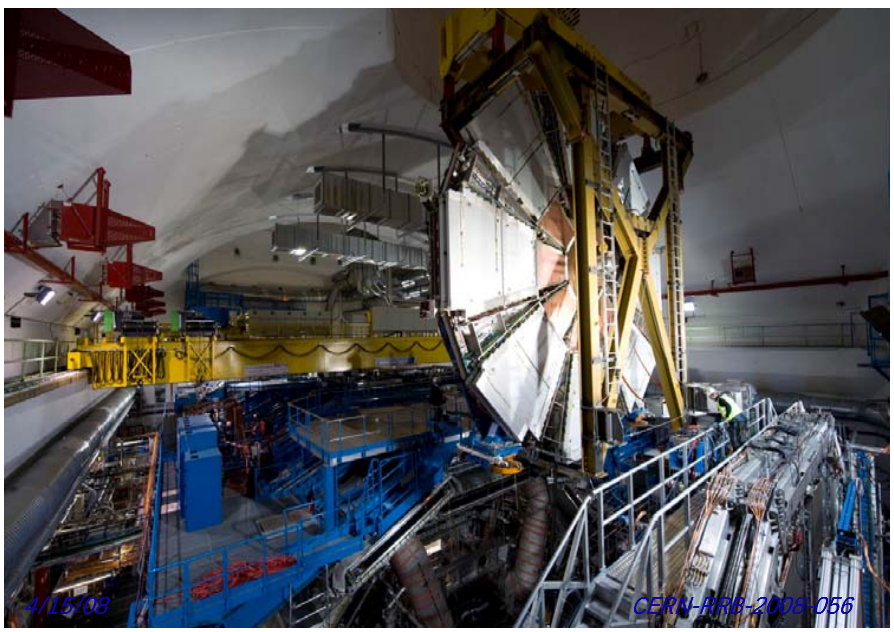
- 5 weeks Cooling down: cold mass at 4.5 K, shields at 50-60K
- ECT-A and ECT-C tested separately

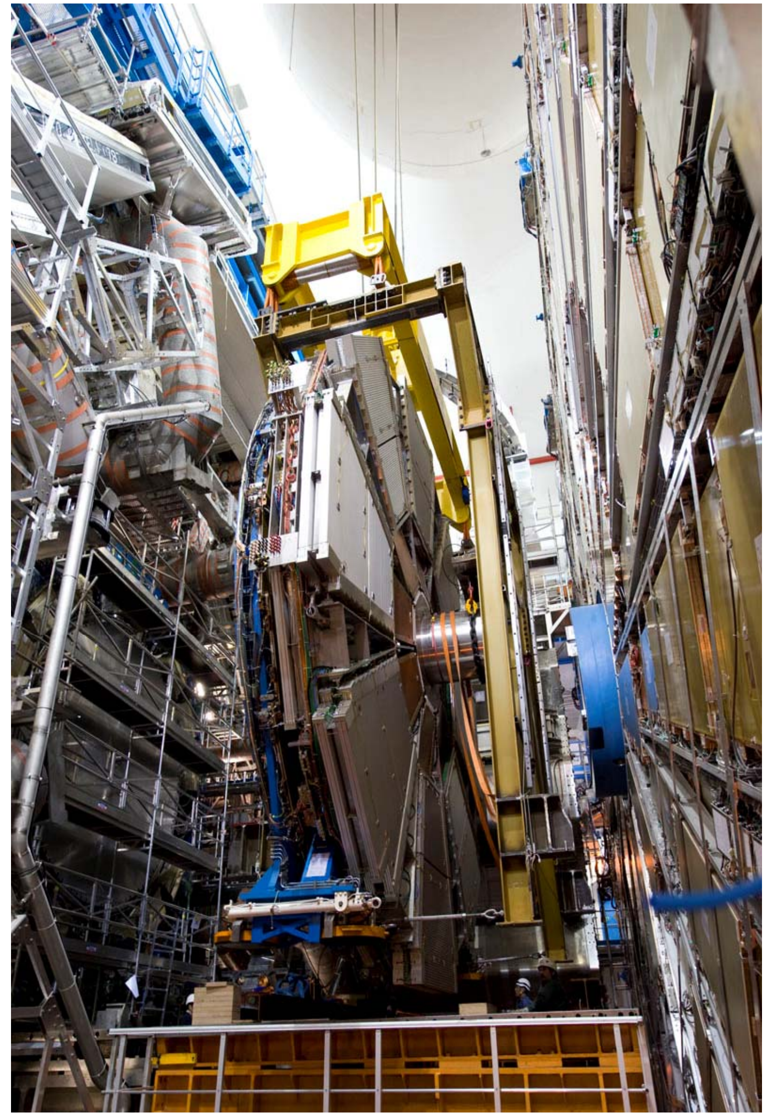
  - safety system quench detection and quench heaters tested first

  - then in steps up to 15 kA with intermediate slow/fast dumps

  - 0-10-12.5-15 kA Slow Dump, then 0-15 kA
  - Toroid behaved fine
  - However, at 14.8 kA the toroid moved unexpectedly towards the calo by a few cm, a slow dump was triggered

Major muon spectrometer event : Small Wheels

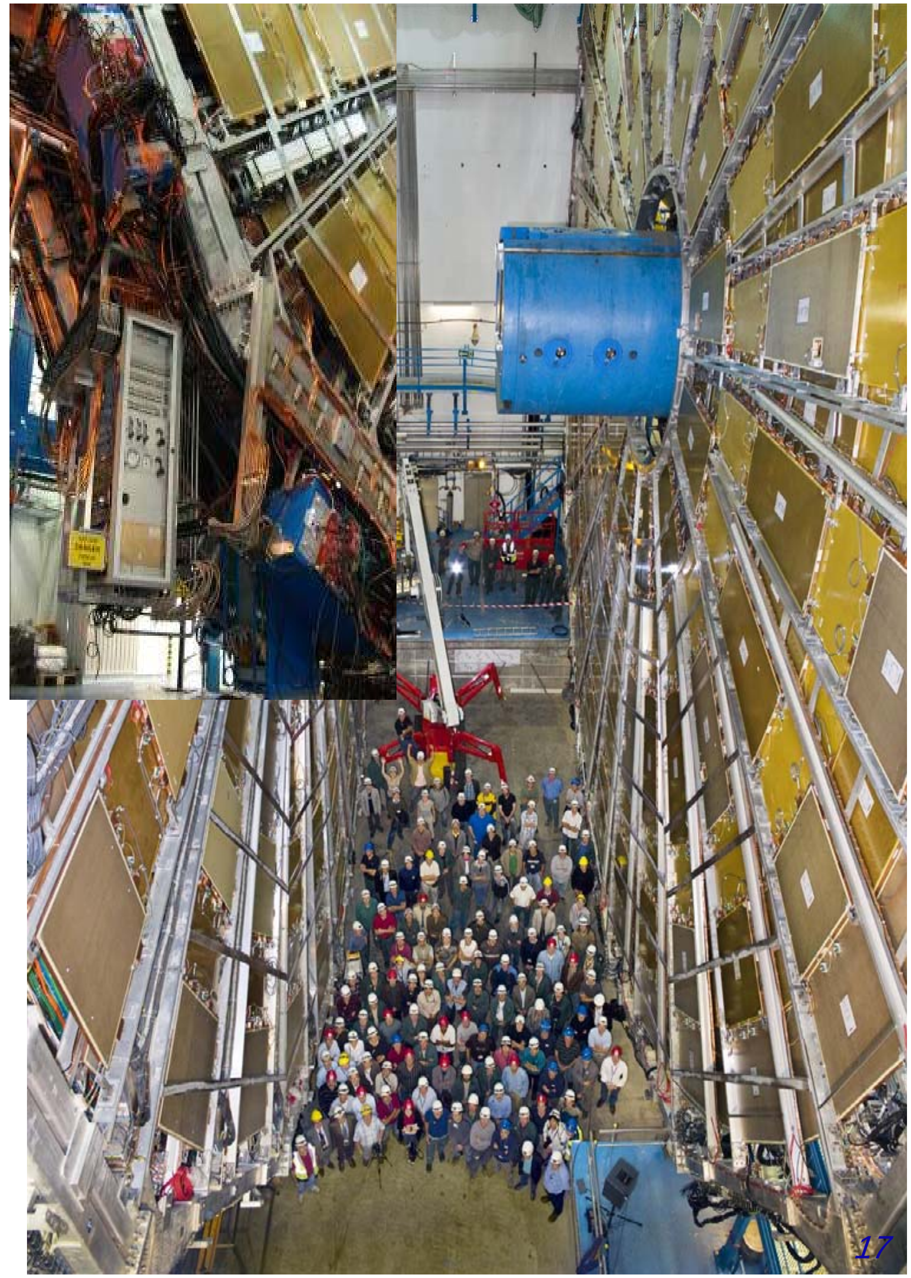




Both wheels are installed, connected and operational

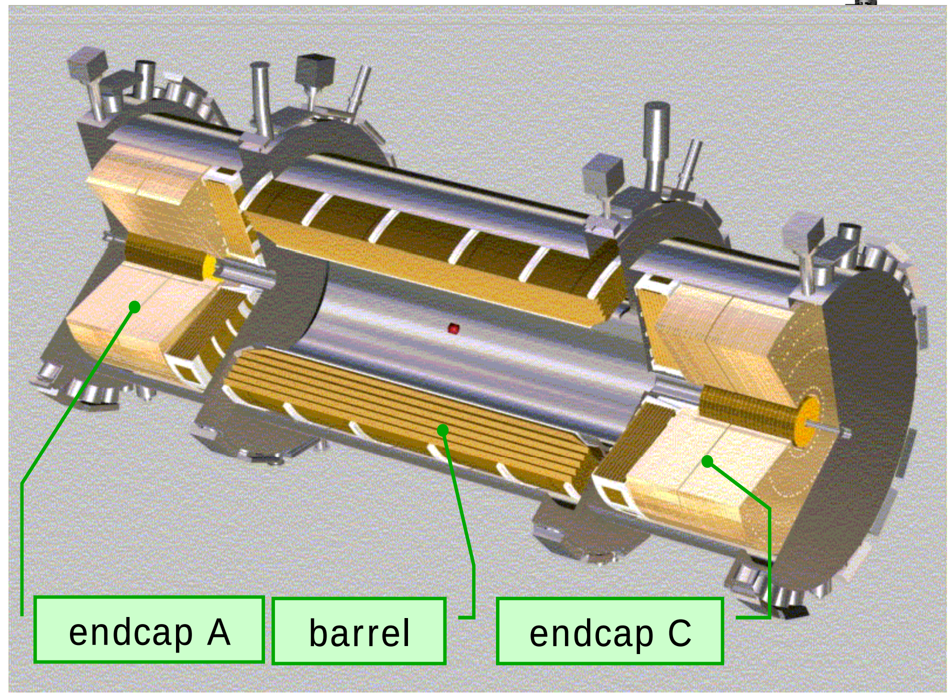
Forward Muon Spectrometer (Big Wheels)

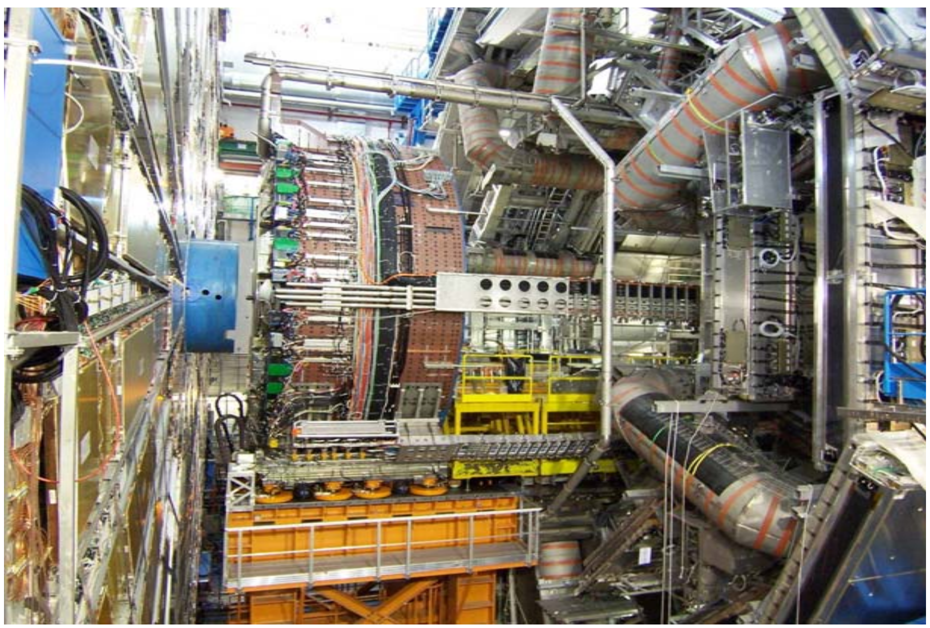
- ✓ Gap between individual wheels fully closed, individual wheels aligned
- ✓ Parked in open position (against EO wheels) as in open scenario
- ✓ Tilting mechanism has been tested (~1^{o})
- ✓ Gas system operational and gas is circulating
- ✓ TGC LV and HV power is in hand and is being installed in situ
- ✓ TGC n-pantene gas will be connected just in running position (June)
- ✓ Wheels inserted in the M6 exercise and readout, trigger operational



The LAr Calorimeters

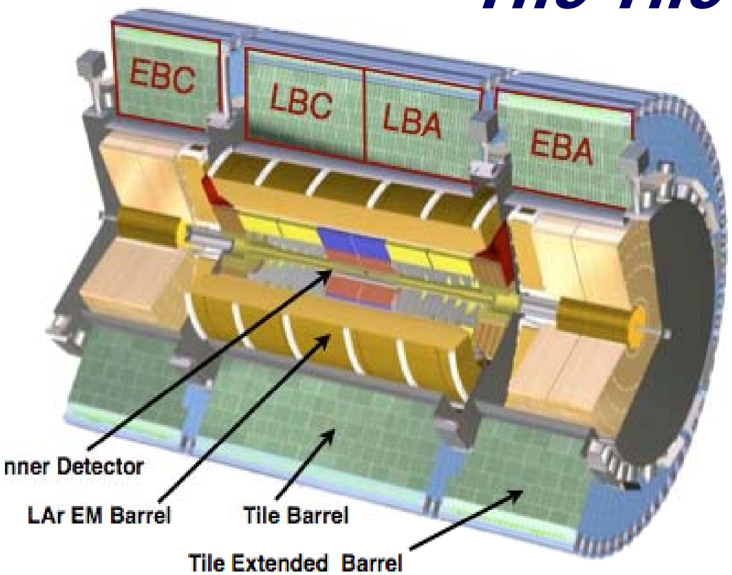
- ✓ All 3 cryostats cold, full of LAr and operational, EC-C just refilled
- ✓ Temperature very stable in time, average within 20 mK
- ✓ Liquid purity stable and well below 0.5 ppm (barrel <210 ppb, EC <150 ppb)
- ✓ Controls, safety system,... unproblematic





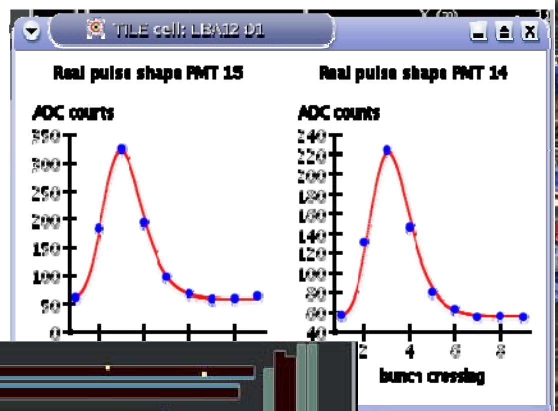
- ✓ *All low voltage power suppliers on the detector retrofitted and re-installed*
- ✓ *All Front-end electronics boards extracted, retrofitted and re-installed*
- ✓ *Final checks of LV power just before closing access*

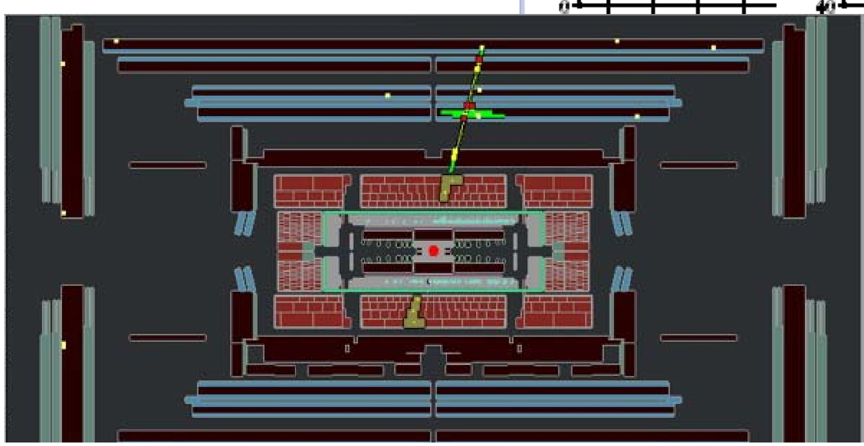
The Tile Hadron Calorimeter

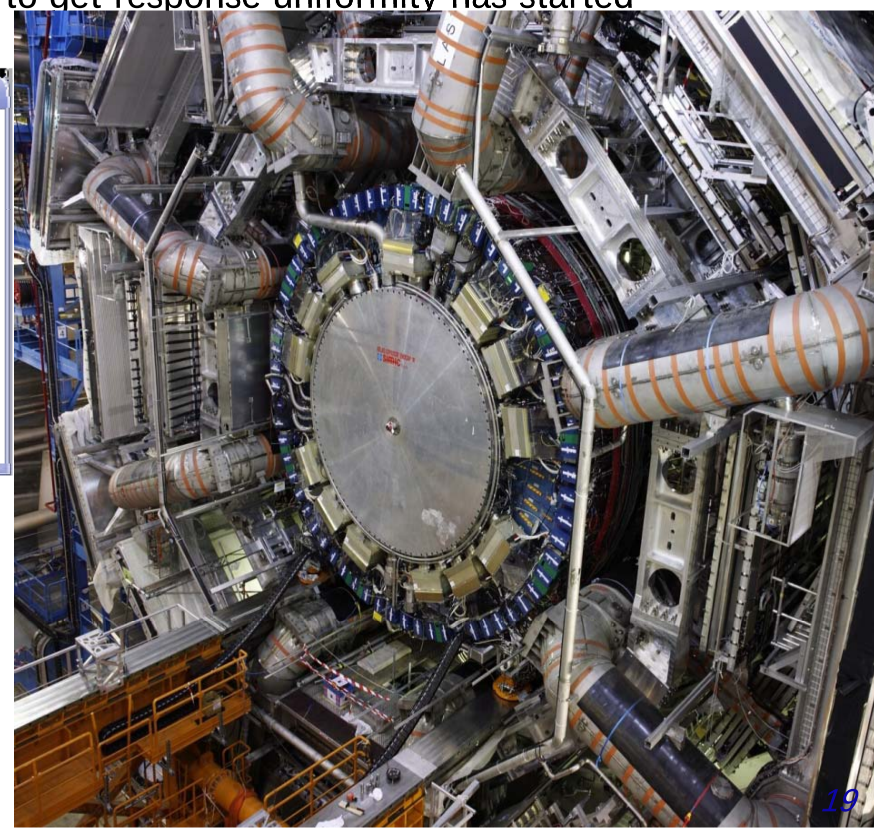


- ✓ Detector fully installed and operational since several months, including a set of dedicated minimum bias scintillators
- ✓ Low voltage power suppliers all refurbished and operational
- ✓ All front end electronics refurbished (drawers)
- ✓ Laser and Cs calibration systems operational. PMT balance to get response uniformity has started

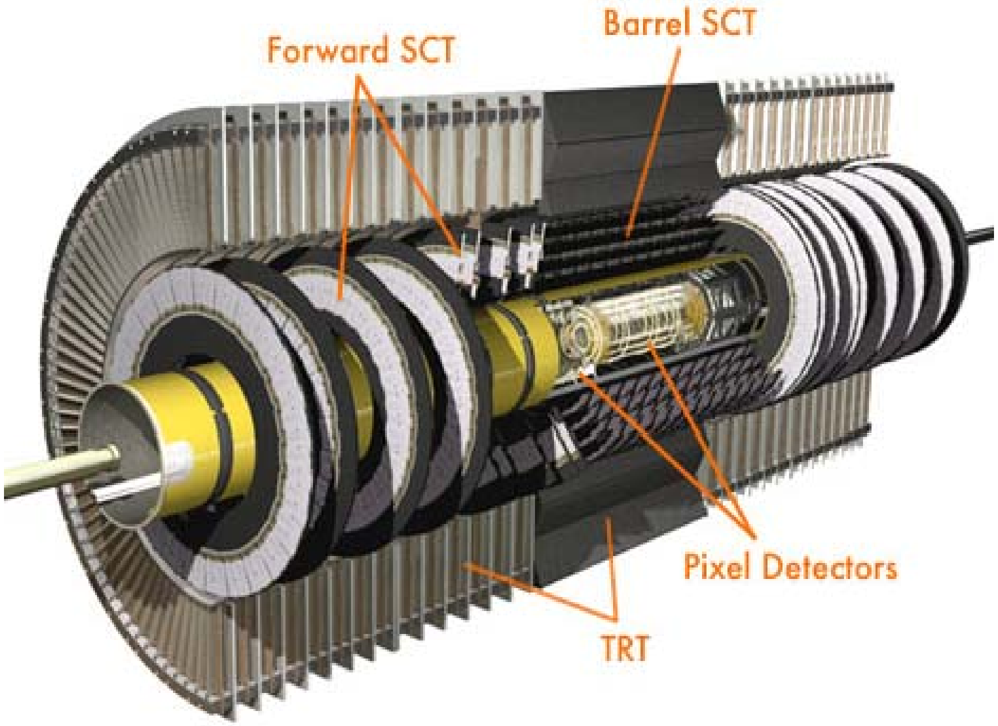
Reconstructed PMT pulses

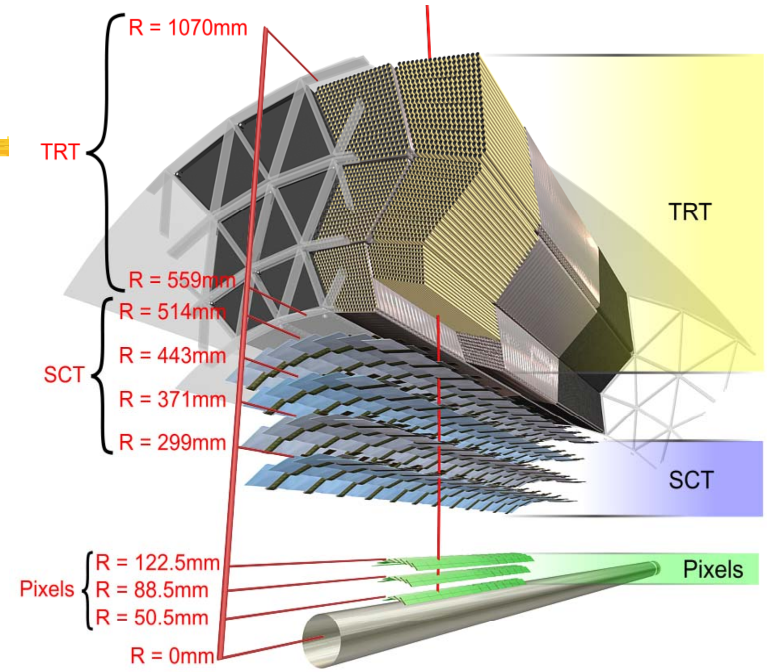






The Inner Detector





All detector components installed in 4 steps

- ✓ Barrel SCT + TRT
- ✓ 2 End-Caps SCT + TRT
- ✓ Full pixel detector + Be beam pipe

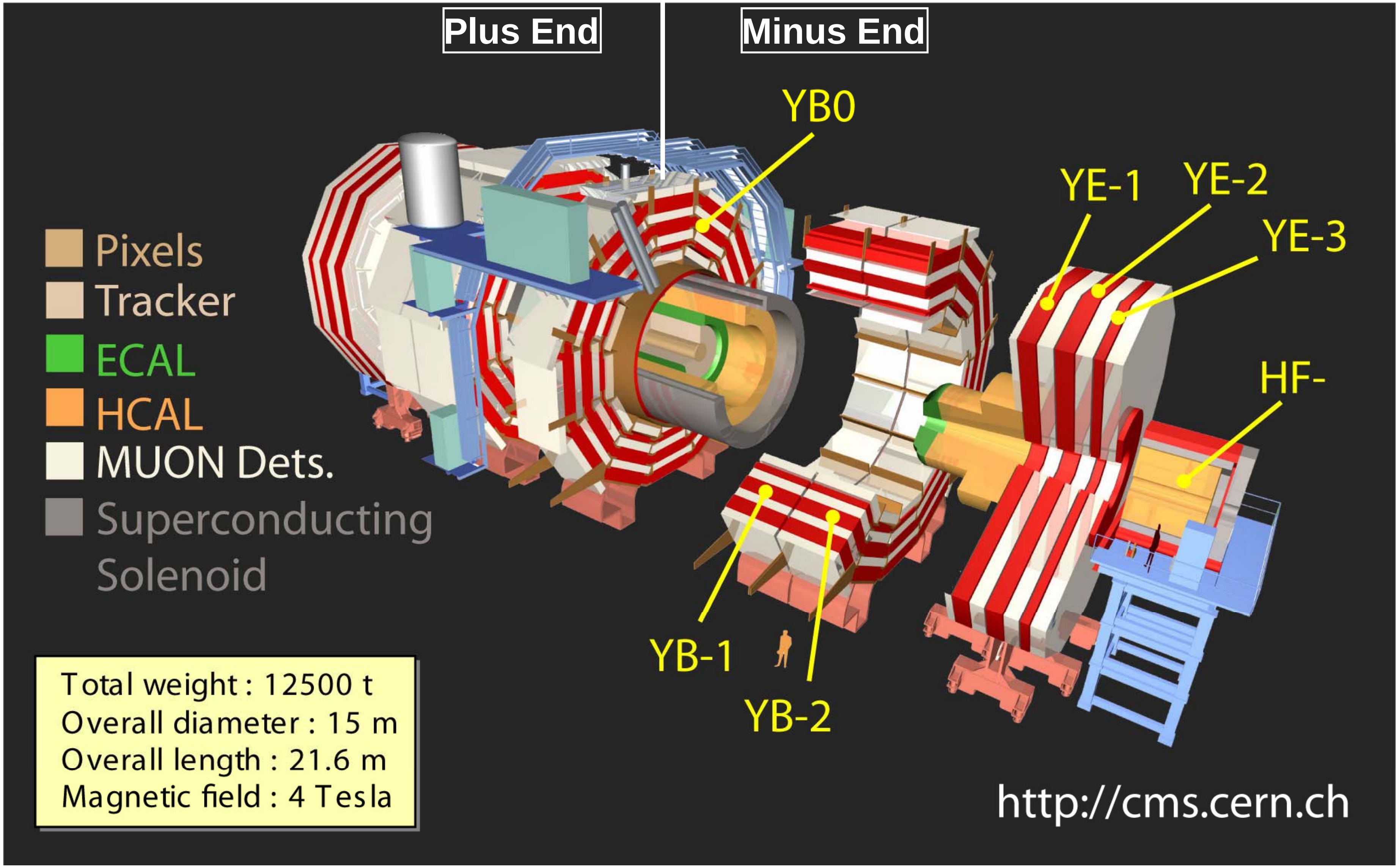
✓ Evaporative cooling system finally operational, SCT and TRT fully connected and signed off

✓ Pixel connection should finish this week, then cooling and final sign off can start

Detector Summary

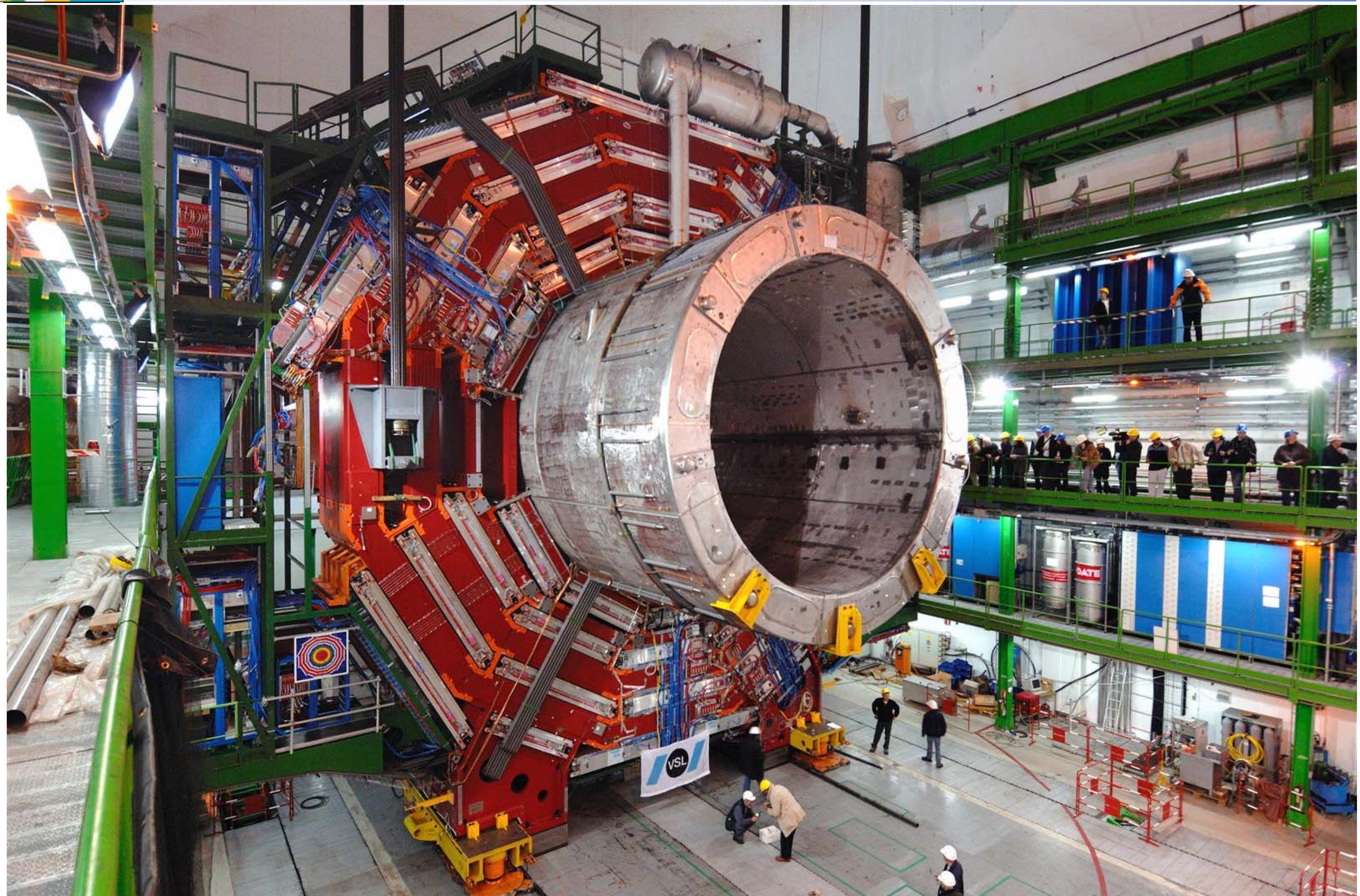
- All major detector components are installed, are being commissioned and debugged.
- Still missing to be installed are few beam pipe sections and the forward shielding
- We will start closing the detector, when the CERN Management will tell us; we need ~2 months notice
- Critical today is the correct sign off of the Pixel system and the end of the Trigger RPC system commissioning
- The control and data flow from the detector is being tested now since several months through an intense commissioning program. We managed to integrate all readout components though the entire readout chain. All system behave as expected, within the design parameters
- During the next 2 months we start manning the control room in shift mode and we slowly move to continuous operation

CMS

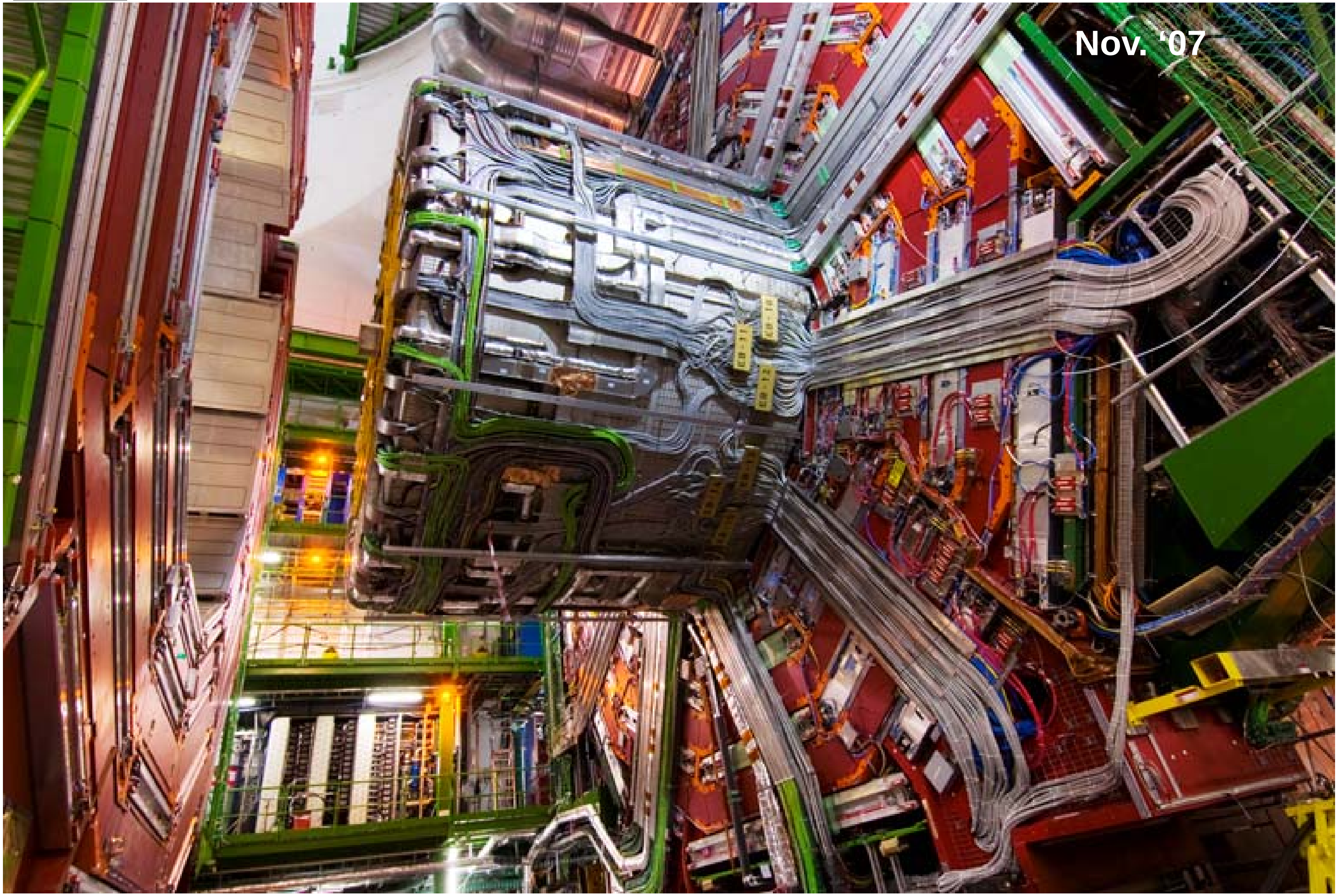


Plus End
Minus End
YB0
YE-1
YE-2
YE-3
HF-
YB-1
YB-2
Pixels
Tracker
ECAL
HCAL
MUON Dets.
Superconducting Solenoid
Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
http://cms.cern.ch

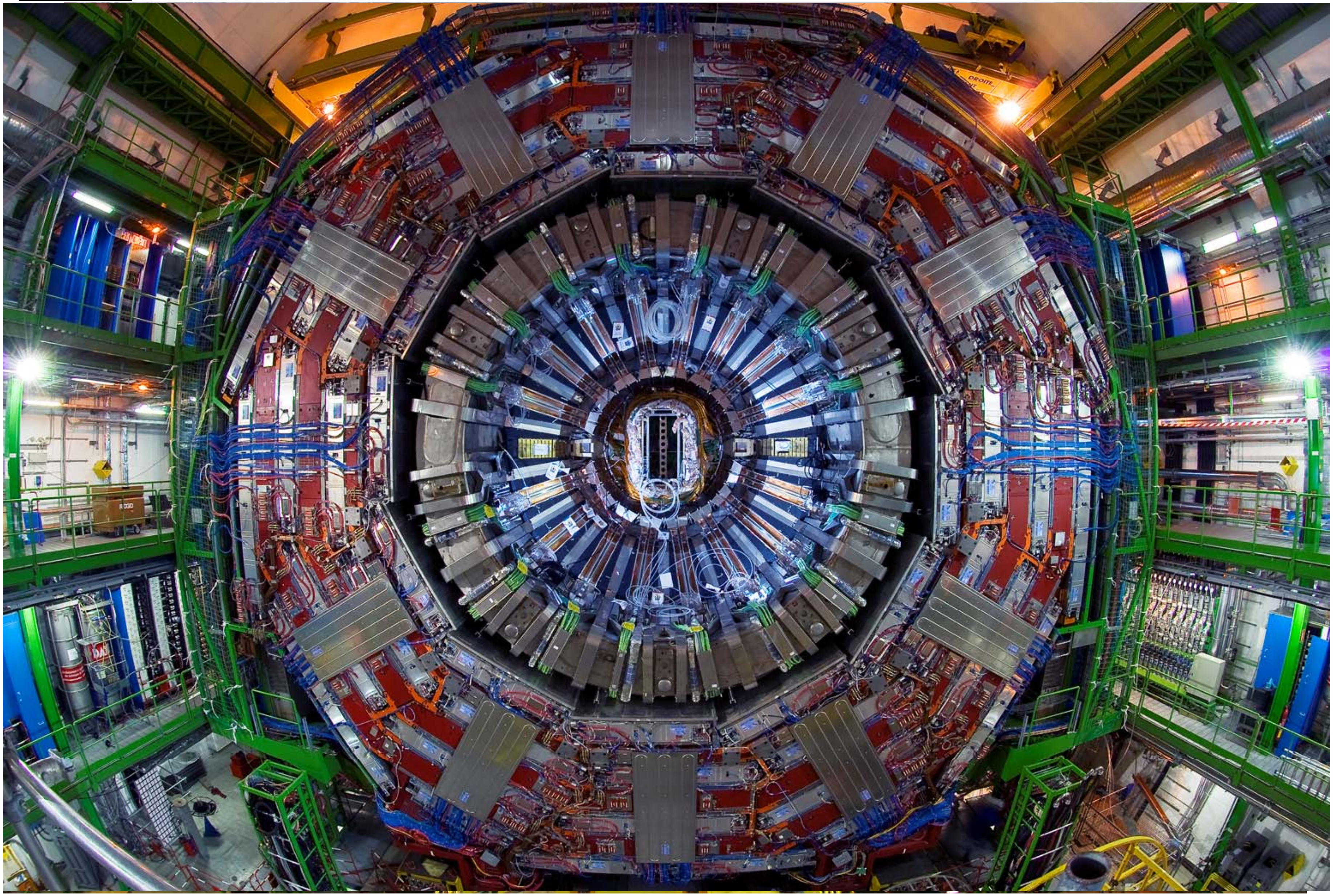
Situation in Feb 2007



Completion of Services Installation on YB0

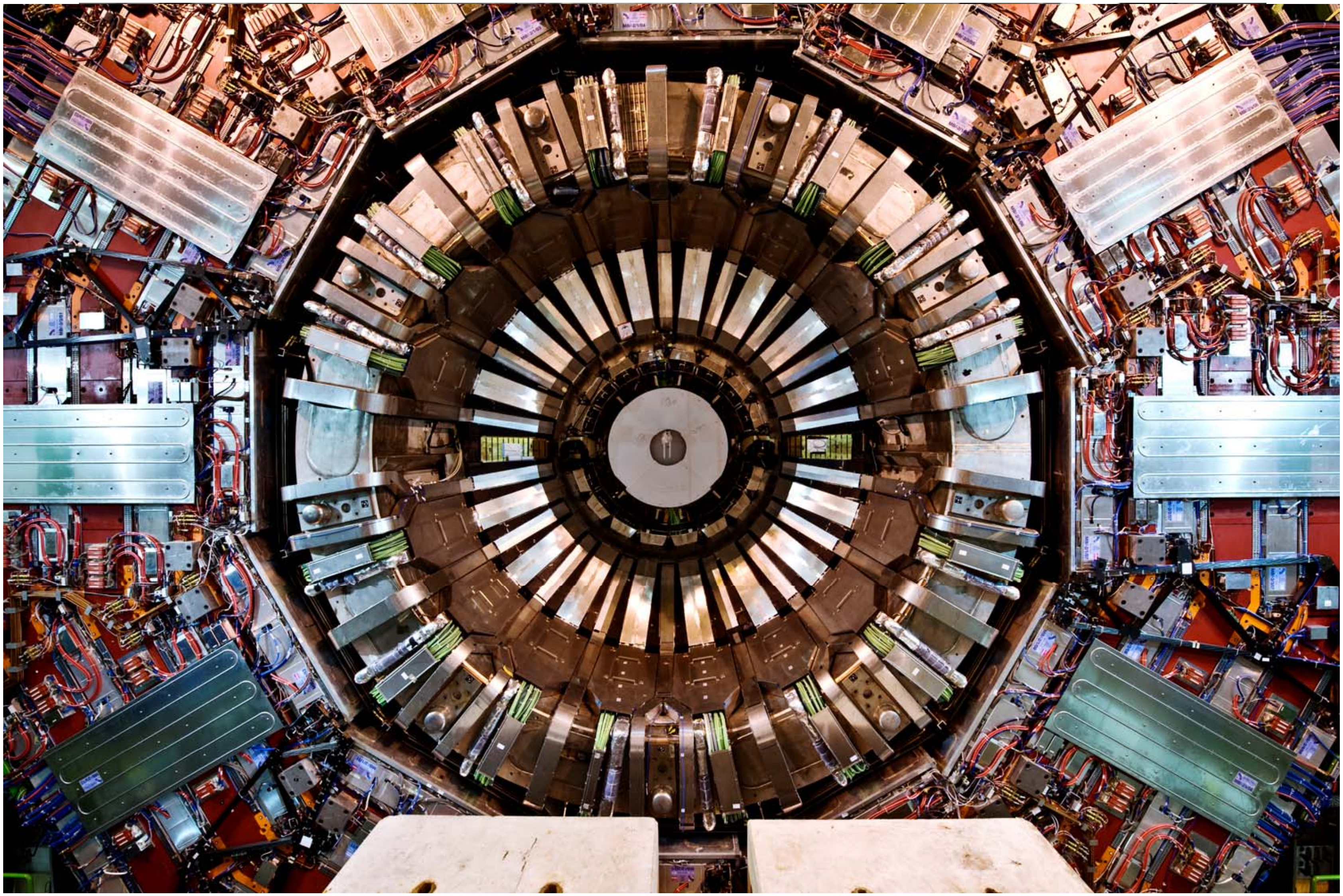


Tracker Insertion (15 Dec'07)



Tracker Connected

Connections from bulkhead to PP1 DONE before Easter



Finishing Construction: Pixels and ECAL EE

Pixels

Install after bakeout of LHC beam pipe (Early June).

ECAL Endcaps

1st EE Dee rfi by mid-May ‘08.

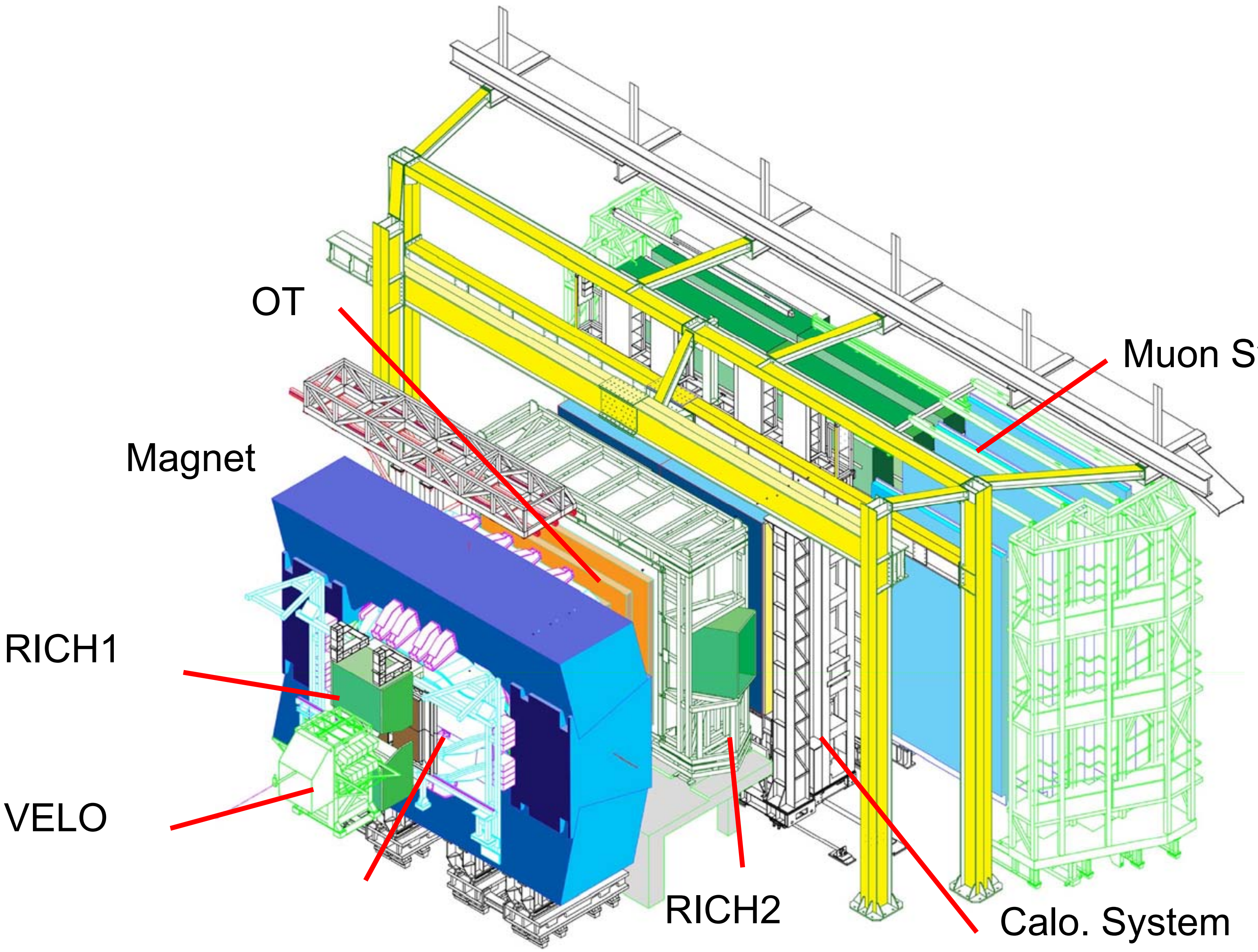
Last EE Dee rfi by end of July.

Conclusions

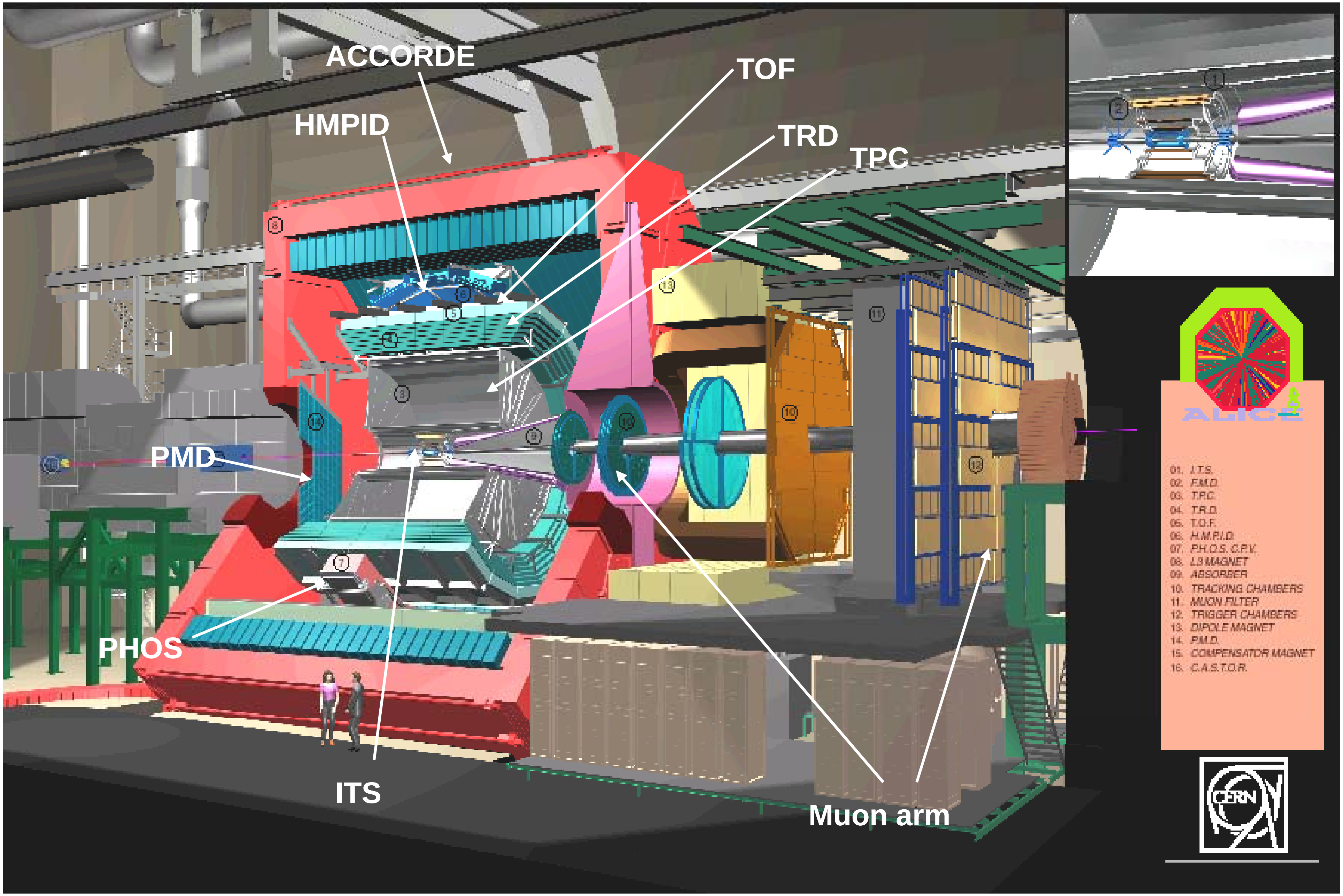
- CMS is continuing to make good progress. All CMS detectors are installed except for pixels and endcap ECAL.
- CMS is aiming to close the experiment at the end of June and take cosmics data at operating field (3.8T).
- In June all detectors should be installed except for one ECAL endcap. Critical path goes through the installation of the beam-pipe.
- Commissioning, including using cosmics, with evermore complete setups (complexity and functionality) proceeding apace. Work already carried out so far gives confidence that CMS will operate with the expected (TDR) performance.

- CMS is eager to take collision data at nominal or close to nominal energy.

LHCb Spectrometer



1) All the subsystems needed for the 2008 run have been installed, except 1/4 of TT ladders and RICH-1 mechanics (quartz windows, photon funnels and the lower HPD box). Expected to be complete by the end of April.
2) M1 installation will continue as long as possible.
3) Commissioning work is in progress and Level-0 trigger now provides cosmic muons (with Calo- or Muon system).
4) Preparation for early physics is underway.


ACCORDE
TOF
HMPID
TRD
TPC
PMD
PHOS
ITS
Muon arm
01. I.T.S.
02. F.M.D.
03. T.P.C.
04. T.R.D.
05. T.O.F.
06. H.M.P.I.D.
07. P.H.O.S. C.P.V.
08. L3 MAGNET
09. ABSORBER
10. TRACKING CHAMBERS
11. MUON FILTER
12. TRIGGER CHAMBERS
13. DIPOLE MAGNET
14. P.M.D.
15. COMPENSATOR MAGNET
16. C.A.S.T.O.R.

ALICE

Early Physics LHCb

Discussion on more concrete plan for the first physics
with very few data, including a case for < 1 pb^{-1}, has started.

After initial calibration and alignment,

some physics can be done with $<10^8$ Min.Bias events

→ No HLT required

inclusive "low p_T" physics

particle ratios +/–, π/K/p, $\Lambda/\bar{\Lambda}$ vs $d\eta dp_T$

Λ polarization

hyperon production

inclusive J/ψ for c and b production

and exclusive $D^0 \to K^- \pi^+$ and $D^+ \to K^- \pi^+ \pi^+$

-those channels are also useful for momentum and

PID calibration-

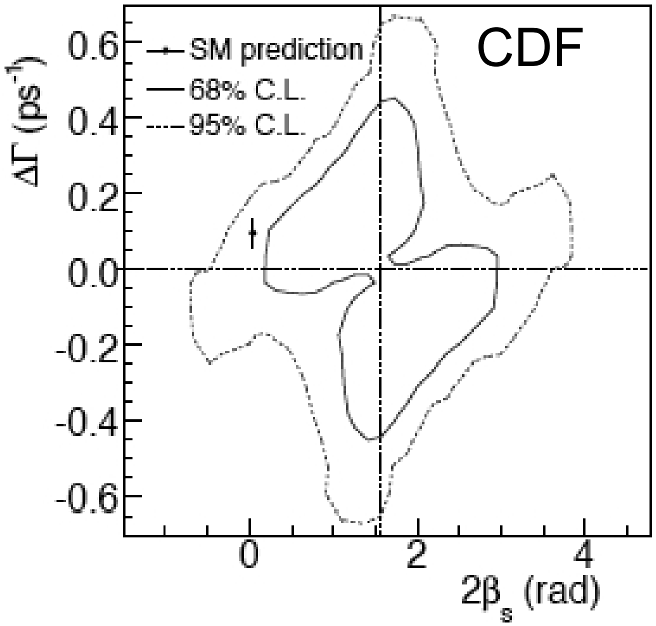
Physics with exclusive B decays requires HLT

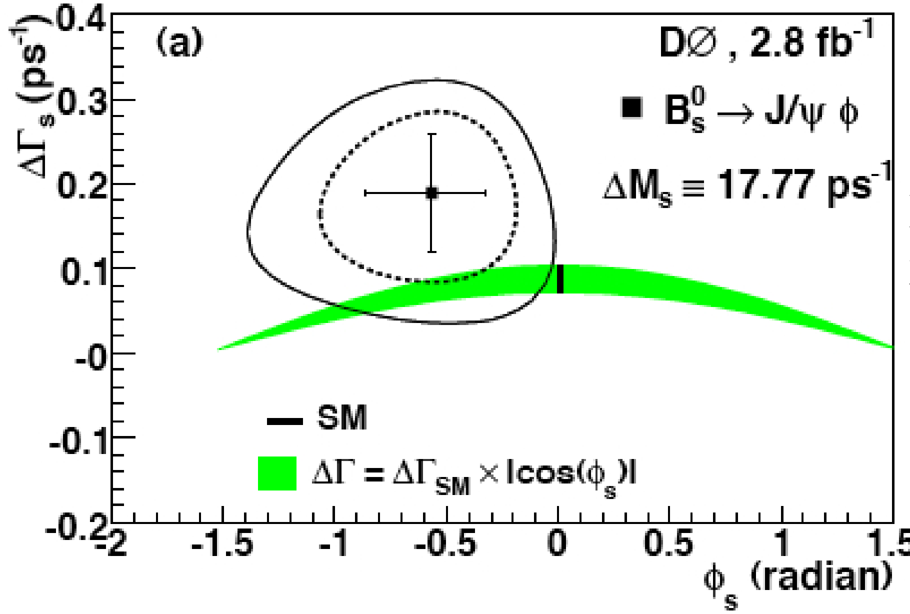
5σ observation of “rare” decays needs up to 2 pb^{-1}

Lumi(pb^{-1})	Channel	MinBias events
0.009	$B_d \to D^{*-}\mu^+\nu$	$9.0 \cdot 10^8$
0.039	$B_u \to J/\psi(\mu^+\mu^-)K^+$	$3.9 \cdot 10^9$
0.046	$B_d \to D^+\pi^-$	$4.6 \cdot 10^9$
0.062	$B_d \to J/\psi(\mu^+\mu^-)K^{*0}$	$6.2 \cdot 10^9$
0.418	$B_d \to K^+\pi^-$	$4.2 \cdot 10^{10}$
0.427	$B_s \to J/\psi(\mu^+\mu^-)\phi$	$4.3 \cdot 10^{10}$
0.500	$B_s \to D_s^-\pi^+$	$5.0 \cdot 10^{10}$
1.176	$B_d \to K^*\gamma$	$1.2 \cdot 10^{11}$
1.490	$B_s \to K^+K^-$	$1.5 \cdot 10^{11}$
2.101	$B_d \to \pi^+\pi^-$	$2.1 \cdot 10^{11}$

And with more data…

CDF and D0 studied time dependent CP asymmetries in $B_s \to J/\psi\phi$: very small in the standard model





NB
$2\beta_s = -\phi_s$

NB: If there were indeed New Physics as suggested by M. Bona et al. (arXiv:0803.0659), who combined all the CDF and D0 results, LHCb would see a 5σ observation of CP in $B_s \to J/\psi\phi$ with ~200 pb^{-1}, i.e. 10% of nominal year of data.

Physics in first year(s)

Expected event rates at production in ATLAS or CMS at L = 10^{33} cm^{-2} s^{-1}

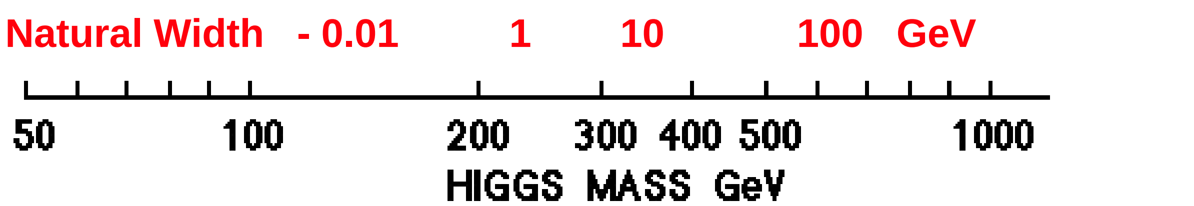
Process	Events/s	Events for 10 fb^{-1}	Total statistics collected at previous machines by 2007
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	1.5	10^7	10^7 LEP
t tbar	1	10^7	10^4 Tevatron
b bbar	10^6	10^{12} – 10^{13}	10^9 Belle/BaBar
H m=130 GeV	0.02	10^5	?
gluino gluino m= 1 TeV	0.001	10^4	---
Black holes m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3	---

Already in first year, large statistics expected from:

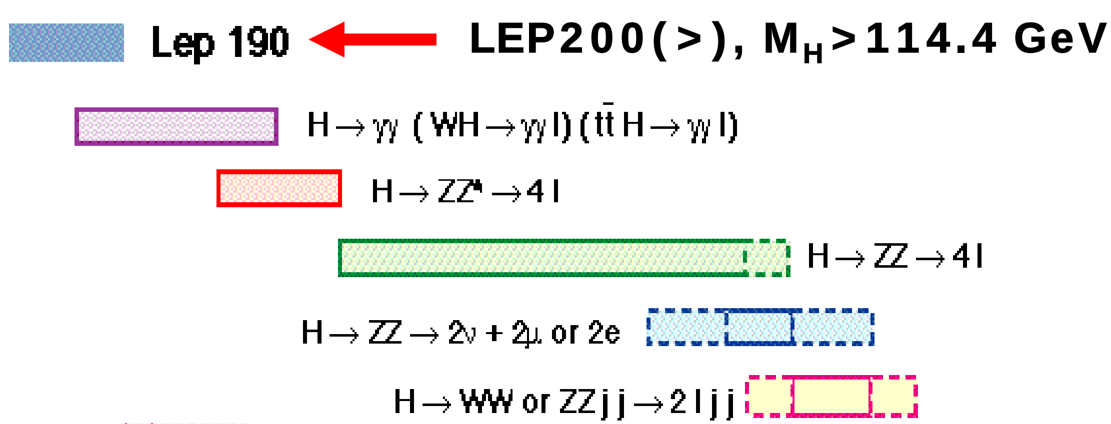
-- known SM processes → understand detector and physics at $\sqrt{s}$ = 14 TeV

-- several New Physics scenarios

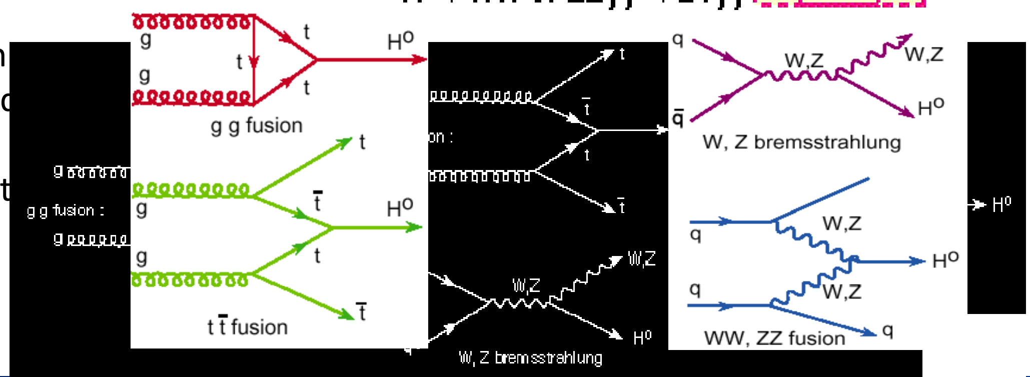
At the LHC the SM Higgs provides a good benchmark to test the performance of a detector

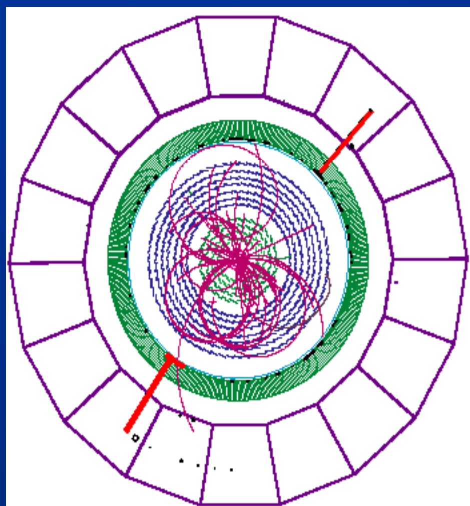


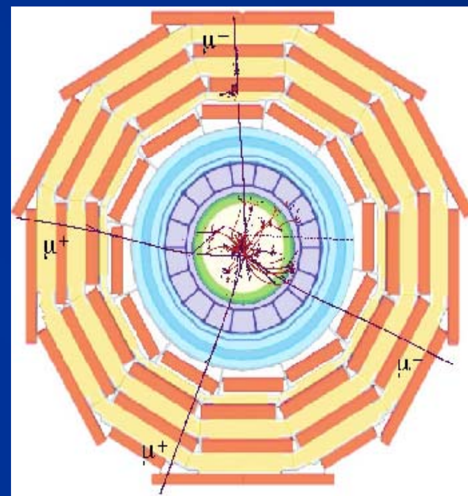
Different decay modes depending on mass

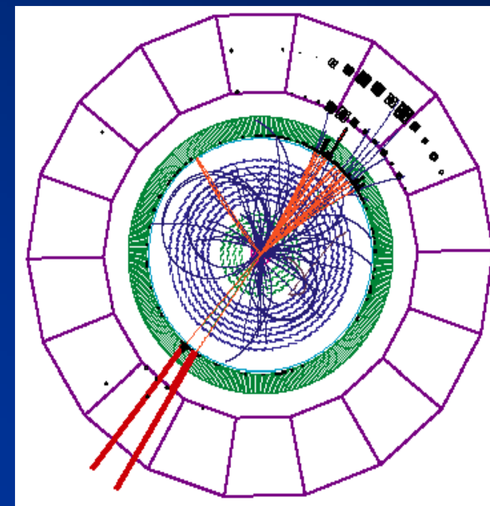


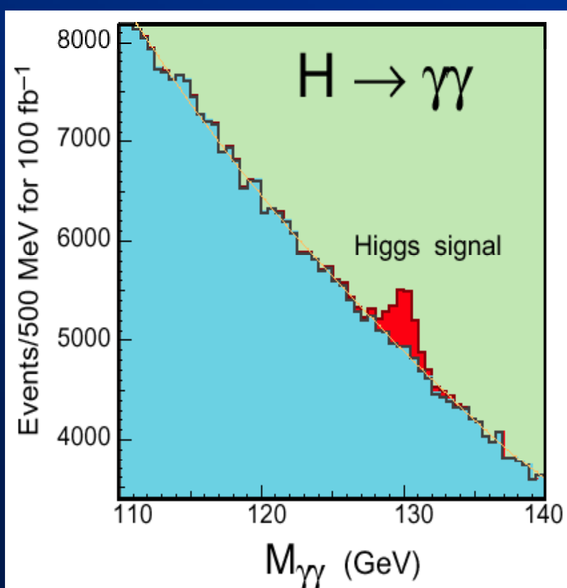
Different production mechanisms, depend somewhat on mass, with typical final stat 'tags'

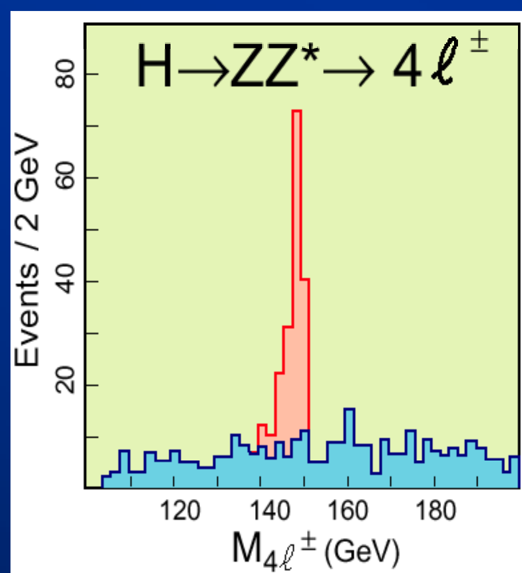


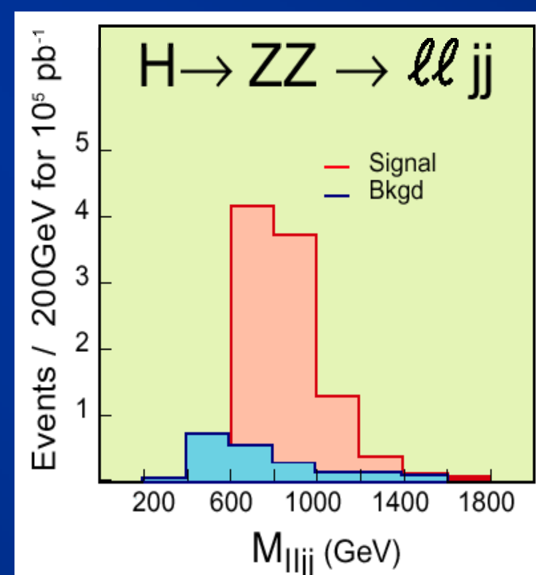



μ^-
μ^+
μ^-
μ^+




$H \to \gamma\gamma$
Higgs signal
Events/500 MeV for 100 fb^{-1}
8000
7000
6000
5000
4000
110
120
130
140
$M_{\gamma\gamma}$ (GeV)


$H \to ZZ^* \to 4\ell^\pm$
Events / 2 GeV
80
60
40
20
120
140
160
180
$M_{4\ell^\pm}$ (GeV)


$H \to ZZ \to \ell\ell jj$
Signal
Bkgd
Events / 200GeV for 10^5 pb^{-1}
5
4
3
2
1
200
600
1000
1400
1800
M_{lljj} (GeV)

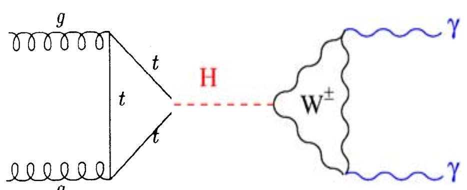
Light Higgs : more difficult ….

m_H ~ 115 GeV 10 fb^{-1} : $S/\sqrt{B} \approx 4$ ATLAS

K-factors ≡ σ(NLO)/σ(LO) ≈ 2
for H →γγ NOT included (conservative)

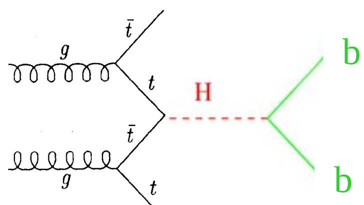
3 (complementary) channels with similar (small) significances:

$H \to \gamma\gamma$



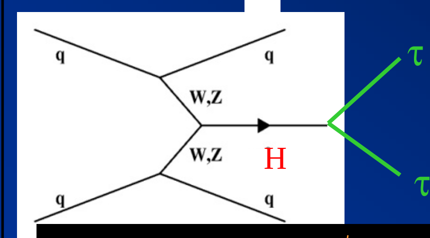
S=130, B=4300, $S/\sqrt{B}$=2

ttH→ttbb → blνbjjbb



S=15, B=45, $S/\sqrt{B}$=2.2

qqH → qqττ



S=10, B=10, $S/\sqrt{B}$=2.7

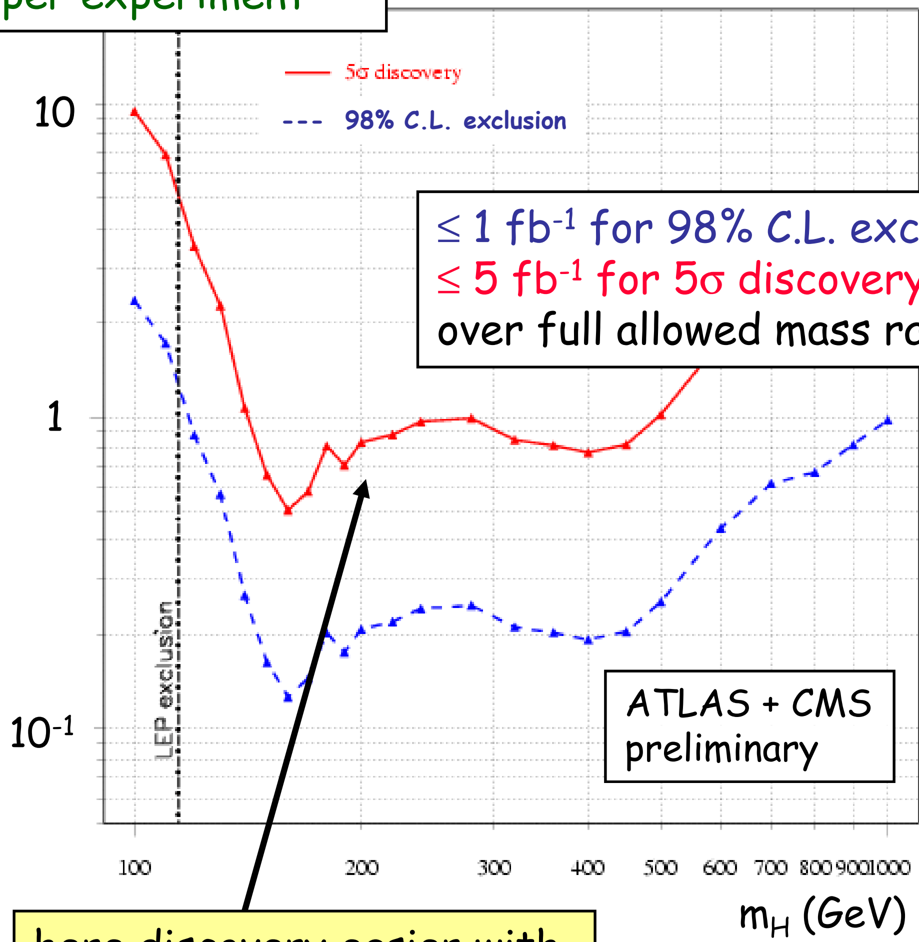
- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - -- ECAL crucial for H → γγ (in particular response uniformity) : σ/m ~ 1% needed
  - -- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics
  - -- efficient jet reconstruction over |η| < 5 crucial for qqH → qqττ : forward jet tag and central jet veto needed against background

All three channels require very good understanding of detector performance and background control to 1-10% → convincing evidence likely to come later than 2008 …

Note: WH→ lνbb (dominant at the Tevatron) provides less sensitivity than ttH at LHC

What about the SM Higgs boson ?

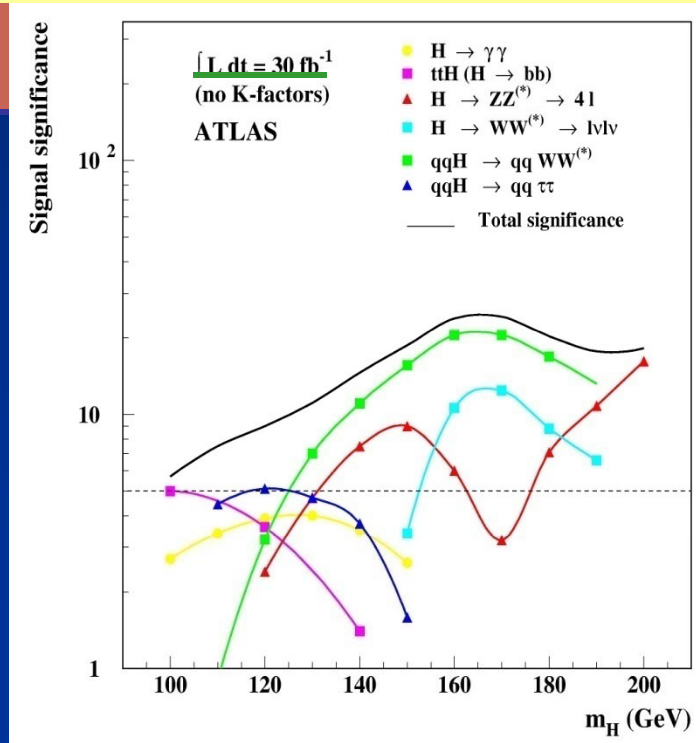
Needed ∫Ldt (fb^{-1})
per experiment



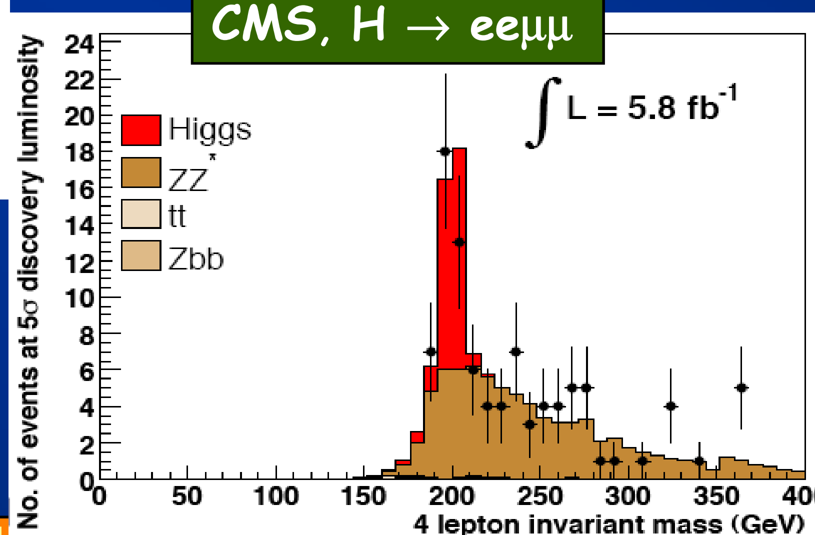
≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

ATLAS + CMS
preliminary

here discovery easier with
gold-plated H → ZZ → 4l
→ **by end 2008 ?**



CMS, H → eeμμ

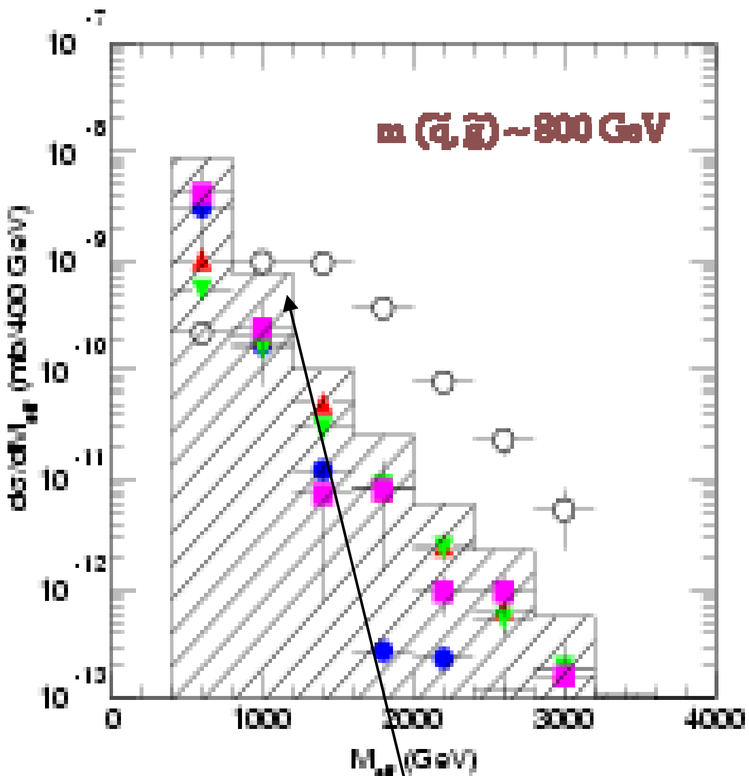


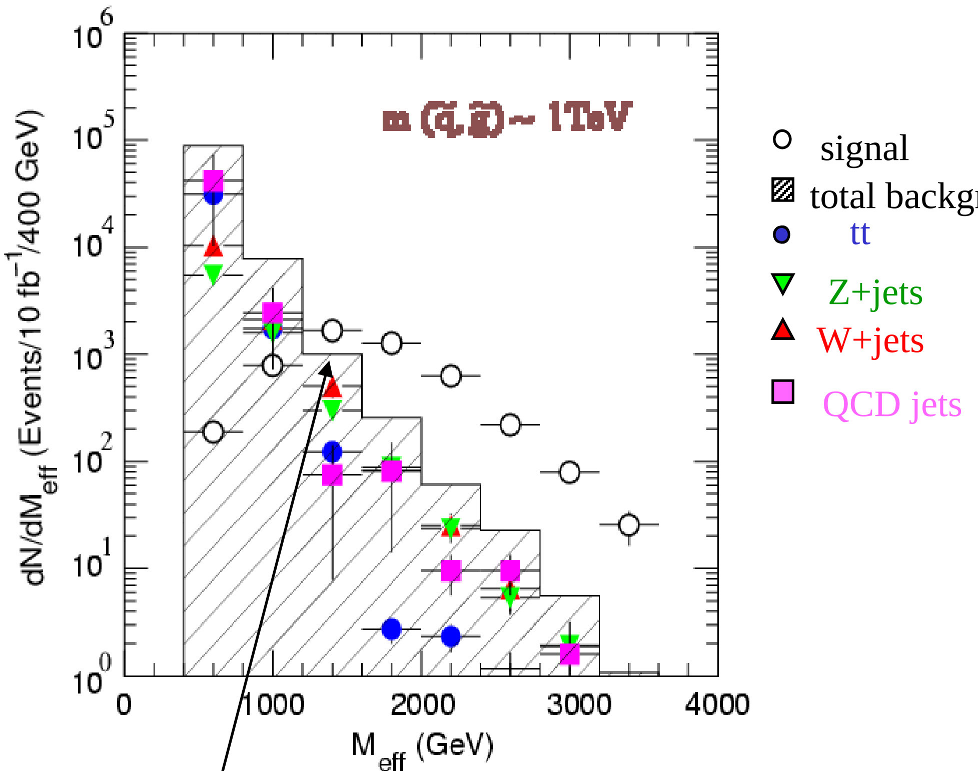
H → 4l : narrow mass peak, small background
H → WW → lνlν (dominant at the Tevatron):
counting channel (no mass peak)

First/fast determination of SUSY mass scale and cross-section

Use e.g. the "effective mass" : $M_{eff} = E_T^{miss} + \sum_{i=1}^{4} p_T(jet_i)$ (GeV)

Best sensitivity from Jets+ MET+ 0ℓ topology





Peak position correlated to $M_{SUSY} \approx \min(m(\tilde{q}), m(\tilde{g}))$

Area under the peak correlated to SUSY cross-section

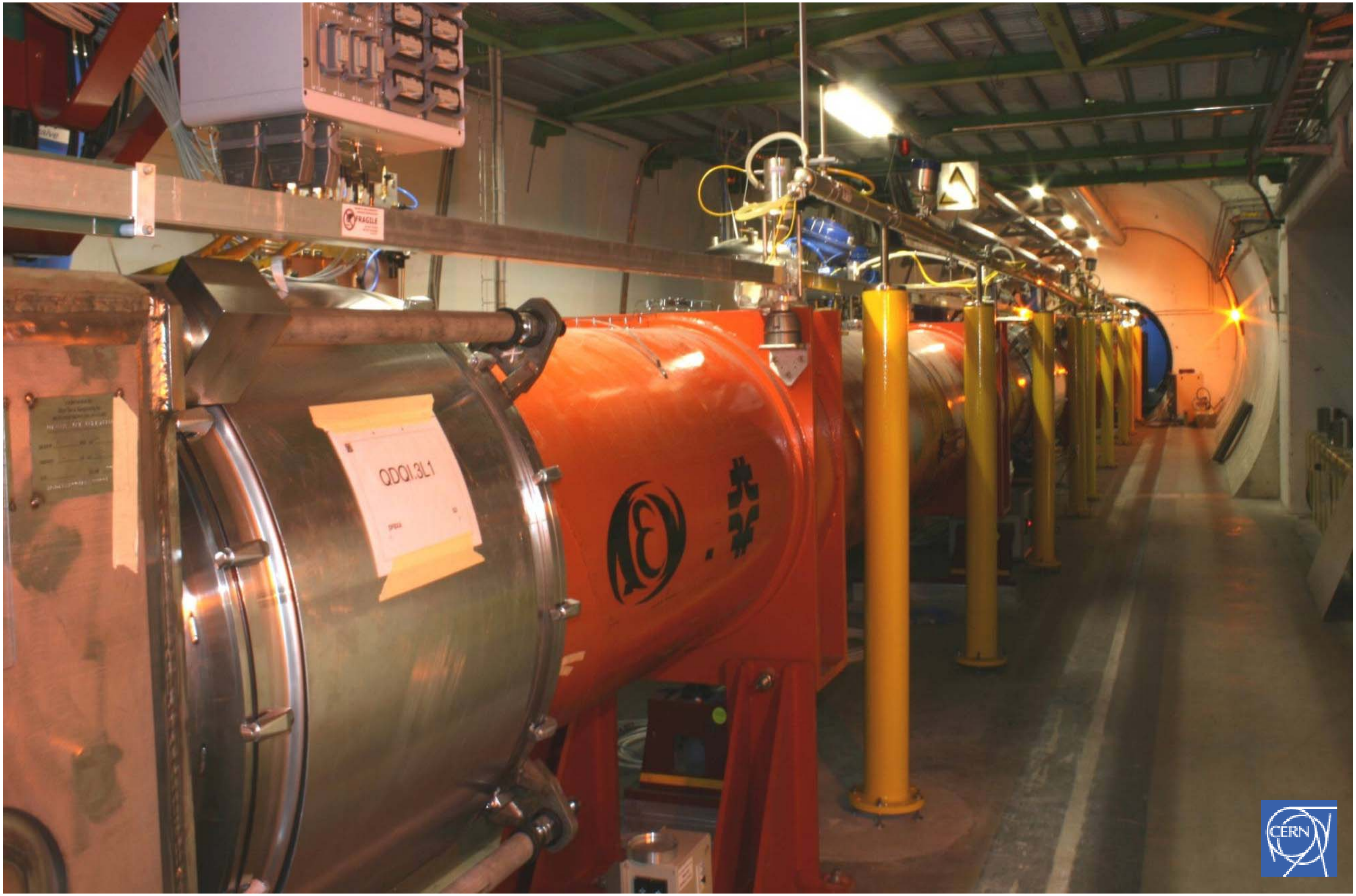
More precise definition:

$$M_{SUSY} \approx \frac{\sum_i \sigma_i \tilde{m}_i}{\sum_i \sigma_i} - \frac{m^2(LSP)}{\frac{\sum_i \sigma_i \tilde{m}_i}{\sum_i \sigma_i}}$$

F. Gianotti

SLHC Accelerator and Injector Upgrades

Lyn Evans



Peak Luminosity

$$L = \frac{N_b^2 n_b f_r \gamma}{4\pi\varepsilon_n \beta^*} F$$

N_b number of particles per bunch

n_b number of bunches

f_r revolution frequency

ε_n normalised emittance

β^* beta value at Ip

F reduction factor due to crossing angle

N_b, ε_n → injector chain

β^* → LHC insertion

F → beam separation schemes

n_b → electron cloud effect

LHC Upgrade-Phase I

Goal of “Phase I” upgrade:

Enable focusing of the beams to $\beta^*=0.25$ m in IP1 and IP5, and reliable operation of the LHC at double the operating luminosity on the horizon of the physics run in 2013.

Scope of “Phase I” upgrade:

1. Upgrade of ATLAS and CMS experimental insertions. The interfaces between the LHC and the experiments remain unchanged at $\pm$ 19 m.
2. Replace the present triplets with wide aperture quadrupoles based on the LHC dipole cables (Nb-Ti) cooled at 1.9 K.
3. Upgrade the D1 separation dipole, TAS and collimation system so as to be compatible with the inner triplet aperture.
4. The cooling capacity of the cryogenic system and other main infrastructure elements remain unchanged.
5. Modifications of other insertion magnets (e.g. D2-Q4) and introduction of other equipment in the insertions to the extent of available resources.

Participants and Milestones

Several departments are involved in the “Phase I” project:

AT Department: low-beta quadrupoles and correctors, D1 separation dipoles, magnet testing, magnet protection and cold powering, vacuum equipment, QRL modifications.

AB Department: optics and performance, power converters, instrumentation, TAS and other beam-line absorbers, …

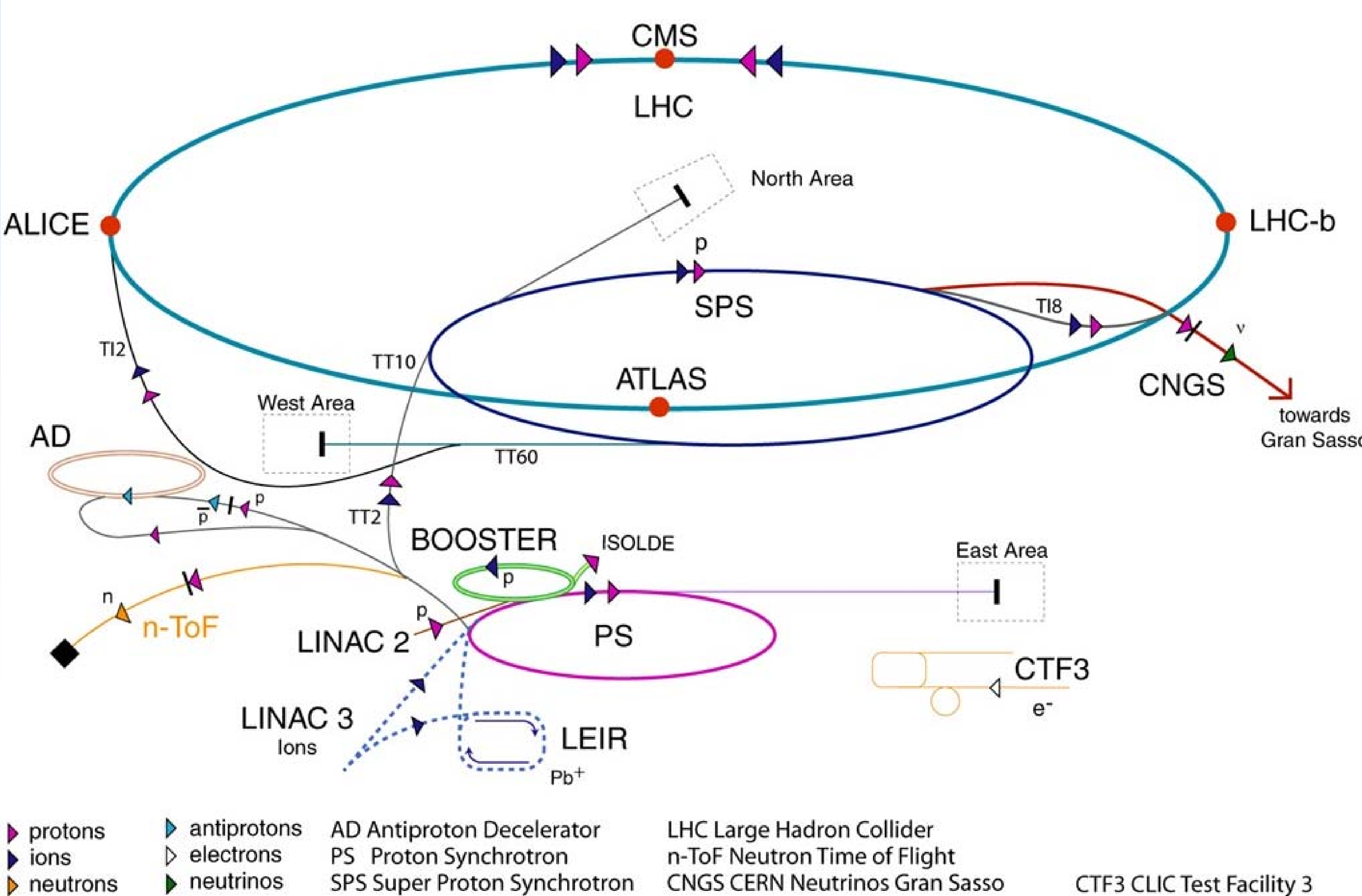
TS Department: cryostat support and alignment equipment, interfaces with the experiments, installation, design effort, …

SLHC-PP collaborators.

Milestones:

Conceptual Design Report	mid 2008
Technical Design Report	mid 2009
Model quadrupole	end 2009
Pre-series quadrupole	2010
String test	2012
Installation	shutdown 2013

CERN accelerator complex



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Present limitations

1. Lack of reliability:

Ageing accelerators (PS is 48 years old !) operating far beyond initial parameters

➡ need for new accelerators designed for the needs of SLHC

2. Main performance limitation:

Excessive incoherent space charge tune spreads DQSC at injection in the PSB (50 MeV) and PS (1.4 GeV) because of the high required beam brightness N/e*.

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot \frac{R}{\beta\gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{X,Y}$: normalized transverse emittances

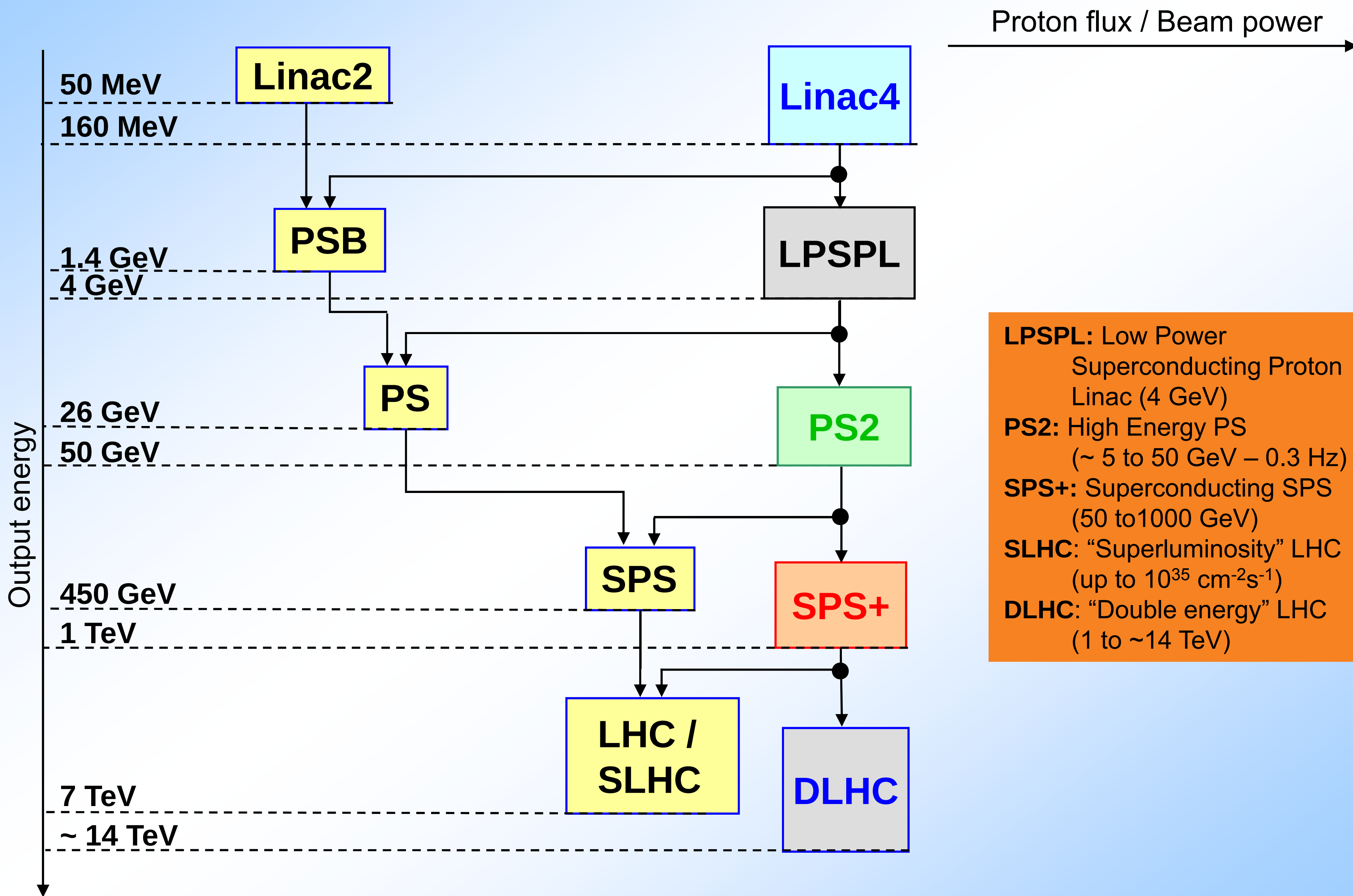
R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

➡ need to increase the injection energy in the synchrotrons

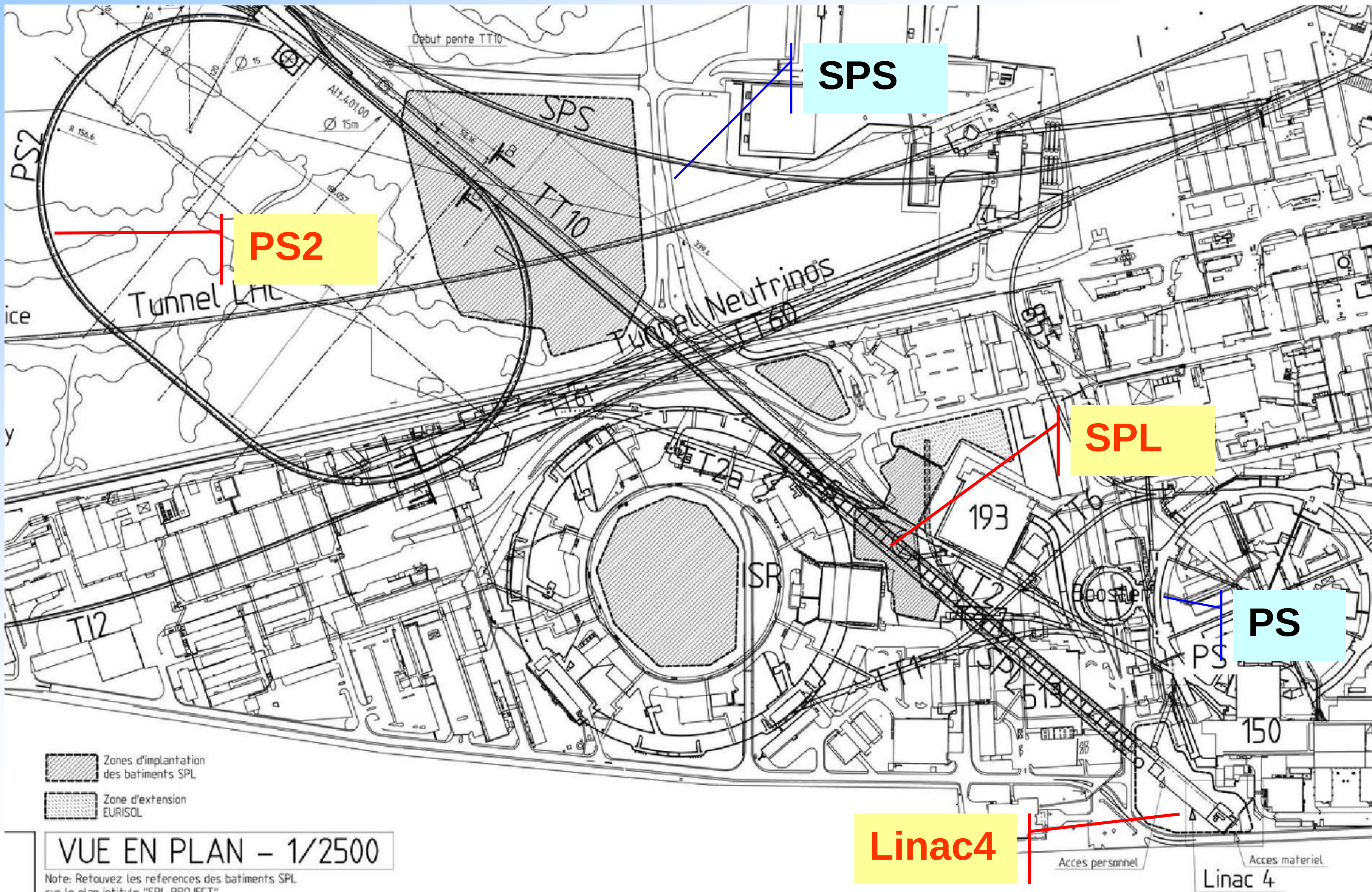
- Increase injection energy in the PSB from 50 to 160 MeV kinetic
- Increase injection energy in the SPS from 25 to 50 GeV kinetic
- Design the PS successor (PS2) with an acceptable space charge effect for the maximum beam envisaged for SLHC: => injection energy of 4 GeV

Upgrade components



LPSPL: Low Power Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: “Double energy” LHC (1 to ~14 TeV)

Layout of the new injectors



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Stage 1: Linac4

- **Direct benefits of the new linac**

  Stop of Linac2:
  - End of recurrent problems with Linac2 (vacuum leaks, etc.)
  - End of use of obsolete RF triodes (hard to get + expensive)

  Higher performance:
  - Space charge decreased by a factor of 2 in the PSB

    => potential to double the beam brightness and fill the PS with the LHC beam in a single pulse,

    => easier handling of high intensity. Potential to double the intensity per pulse.
  - Low loss injection process (Charge exchange instead of betatron stacking)
  - High flexibility for painting in the transverse and longitudinal planes (high speed chopper at 3 MeV in Linac4)

  First step towards the SPL:
  - Linac4 will provide beam for commissioning LPSPL + PS2 without disturbing physics.

- **Benefits for users of the PSB**

  Good match between space charge limits at injection in the PSB and PS

  => for LHC, no more long flat bottom at PS injection + shorter flat bottom at SPS injection: easier/ more reliable operation / potential for ultimate beam from the PS

  More intensity per pulse available for PSB beam users (ISOLDE) – up to 2´

  More PSB cycles available for other uses than LHC

Stage 2: LPSPL + PS2

- **Direct benefits of the LPSPL + PS2**

  Stop of PSB and PS:
  - End of recurrent problems (damaged magnets in the PS, etc.)
  - End of maintenance of equipment with multiple layers of modifications
  - End of operation of old accelerators at their maximum capability
  - Safer operation at higher proton flux (adequate shielding and collimation)

  Higher performance:
  - Capability to deliver 2.2´ the ultimate beam for LHC to the SPS

    => potential to prepare the SPS for supplying the beam required for the SLHC,
  - Higher injection energy in the SPS + higher intensity and brightness

    => easier handling of high intensity. Potential to increase the intensity per pulse.

  First step towards the SPL:
  - Linac4 will provide beam for commissioning LPSPL + PS2 without disturbing physics.

- **Benefits for users of the LPSPL and PS2**

  More than 50 % of the LPSPL pulses will be available (not needed by PS2)

  => New nuclear physics experiments – extension of ISOLDE (if no EURISOL)…

  Upgraded characteristics of the PS2 beam wrt the PS (energy and flux)

  Potential for a higher proton flux from the SPS

Stage 2': SPL

Upgrade the LPSPL into an SPL (multi- MW beam power at 2-5 GeV):

- 50 Hz rate with upgraded infrastructure (electricity, water, cryo-plants, …)
- 40 mA beam current by doubling the number of klystrons in the superconducting part)

Possible users

- **EURISOL (2nd generation ISOL-type RIB facility)**

  => special deflection system(s) out of the SPL into a transfer line

  => new experimental facility with capability to receive 5 MW beam power

  => potential of supplying b-unstable isotopes to a b-beam facility…

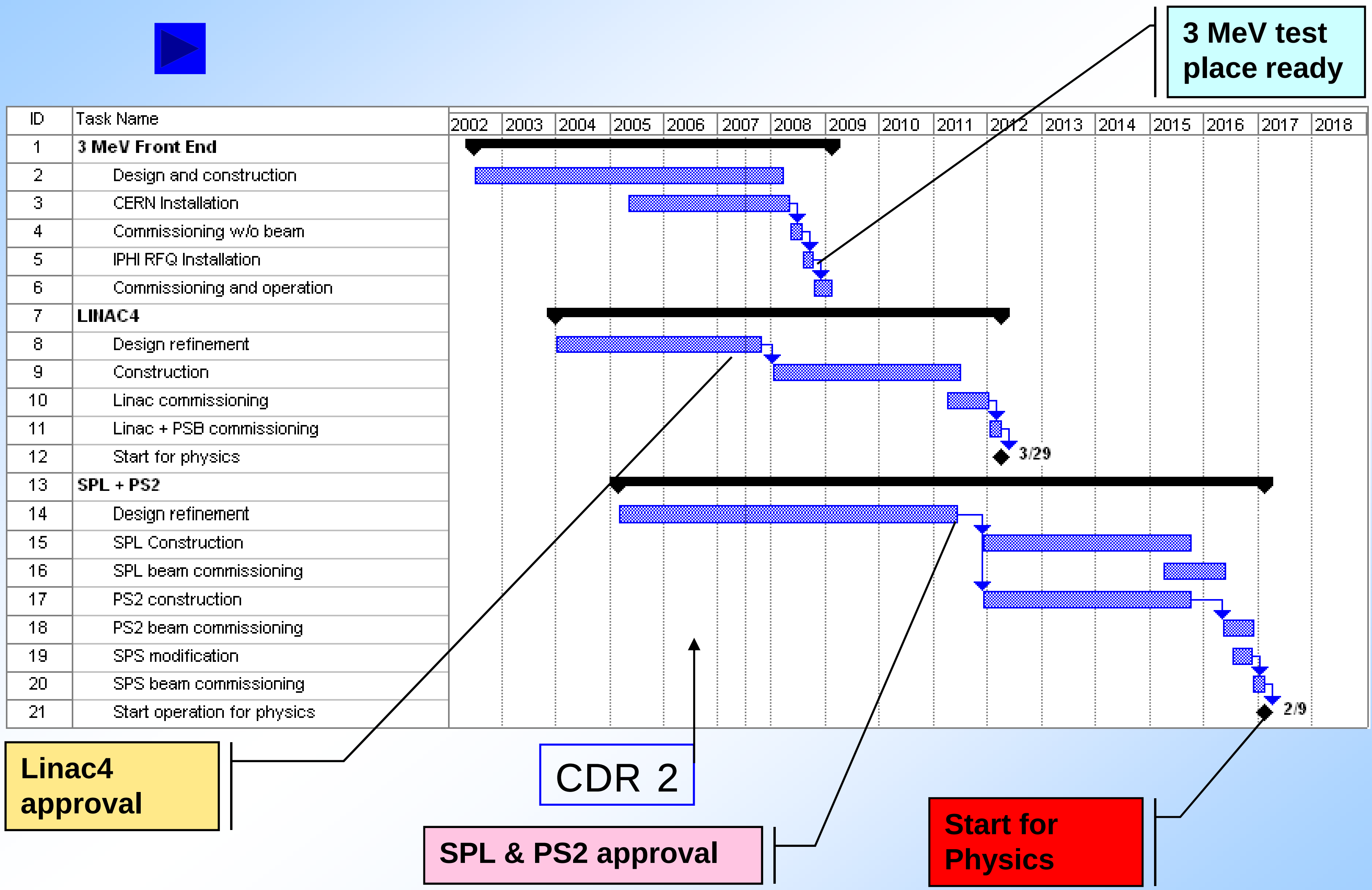
- **Neutrino factory**

  => energy upgrade to 5 GeV (+70 m of sc accelerating structures)

  => 2 fixed energy rings for protons (accumulator & compressor)

  => accelerator complex with target, m capture-cooling-acceleration (20-50 GeV) and storage

Planning …



3 MeV test place ready
ID | Task Name
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
1 3 MeV Front End
2 Design and construction
3 CERN Installation
4 Commissioning w/o beam
5 IPHI RFQ Installation
6 Commissioning and operation
7 LINAC4
8 Design refinement
9 Construction
10 Linac commissioning
11 Linac + PSB commissioning
12 Start for physics
13 SPL + PS2
14 Design refinement
15 SPL Construction
16 SPL beam commissioning
17 PS2 construction
18 PS2 beam commissioning
19 SPS modification
20 SPS beam commissioning
21 Start operation for physics
3/29
2/9
Linac4 approval
CDR 2
SPL & PS2 approval
Start for Physics