Status of
The Large Hadron Collider Project

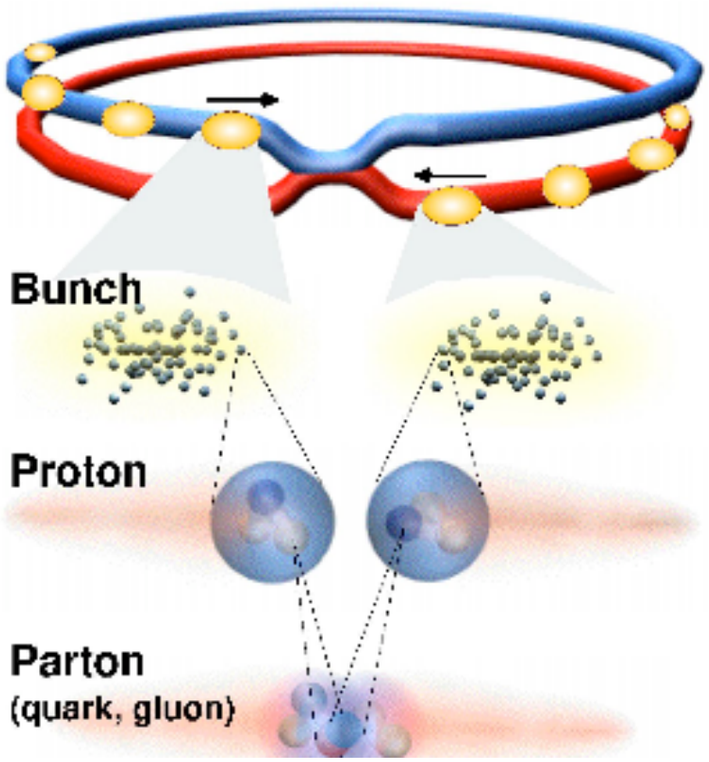
- from visions to reality
- successes (until Sept 19, 2008)
- the „incident" (Sept. 19, 2008)
- implications & repair
- current status and actual time plan
- plans for early LHC running

The Large Hadron Collider

Visions (1980's)

- Build a particle accelerator with the highest technically achievable energies, aiming at:
  - testing the Standard Model at energies beyond 1 TeV
  - finding the missing pieces of the SM: the top-quark ...
  - exploring the mechanism of electroweak symmetry breaking (i.e., find the Higgs Boson)
  - searching for new physics beyond the Standard Model (SUperSYmmetry; large extra dimensions; ...)
  - finding the unexpected ....

the Large Hadron Collider (LHC)



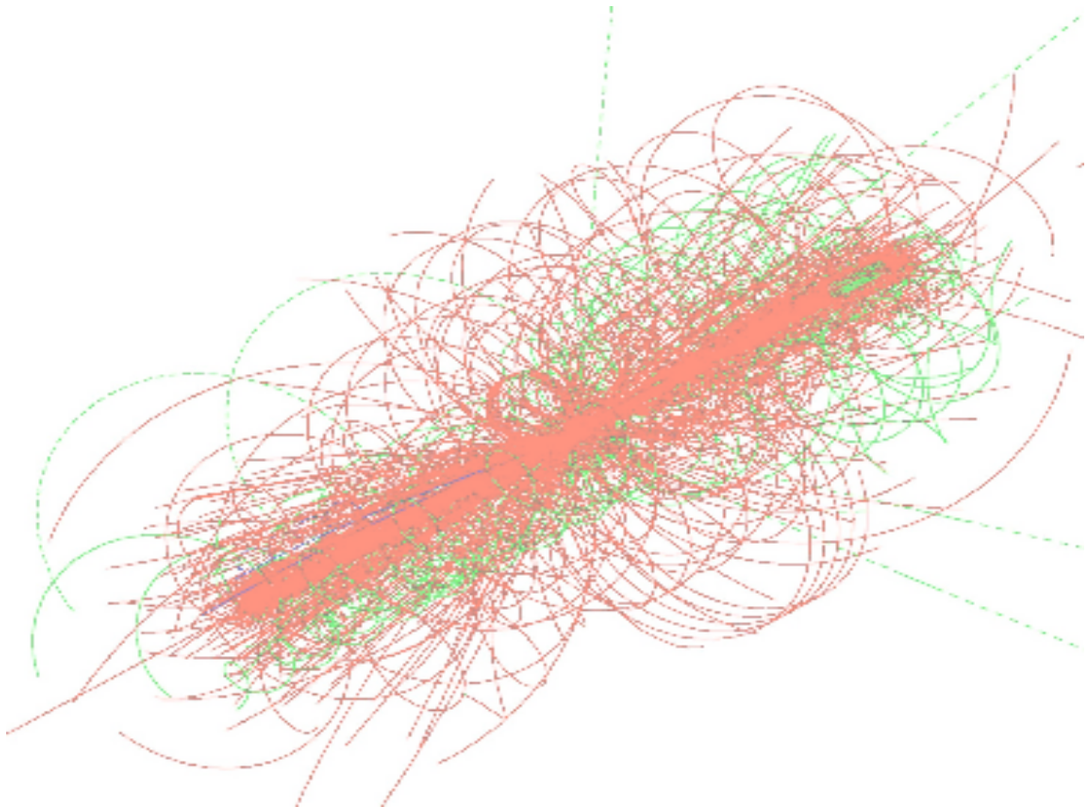
proton – proton collisons: $\sqrt{s}$ = 14 TeV, L = $10^{34}cm^{-2}s^{-1}$

experiments: ALICE, ATLAS, CMS, LHCb, TOTEM, LHCf

27 km circumference (LEP tunnel)

1232 dipol magnets (15m, 35 tons, 8.33T@ 1.9K)

2808 x 2808 proton bunches, 7.5m distance (25 ns)



10^{11} protons / bunch

362 MJ kin. energy per beam (100 tons @ 200 km/h)

collision rate: 40 MHz

p-p collisions @ $10^{34}cm^{-2}s^{-1}$: ~ 10^{9} / sec
(about 25 collisions per beam crossing)

~1600 charged particles in detector

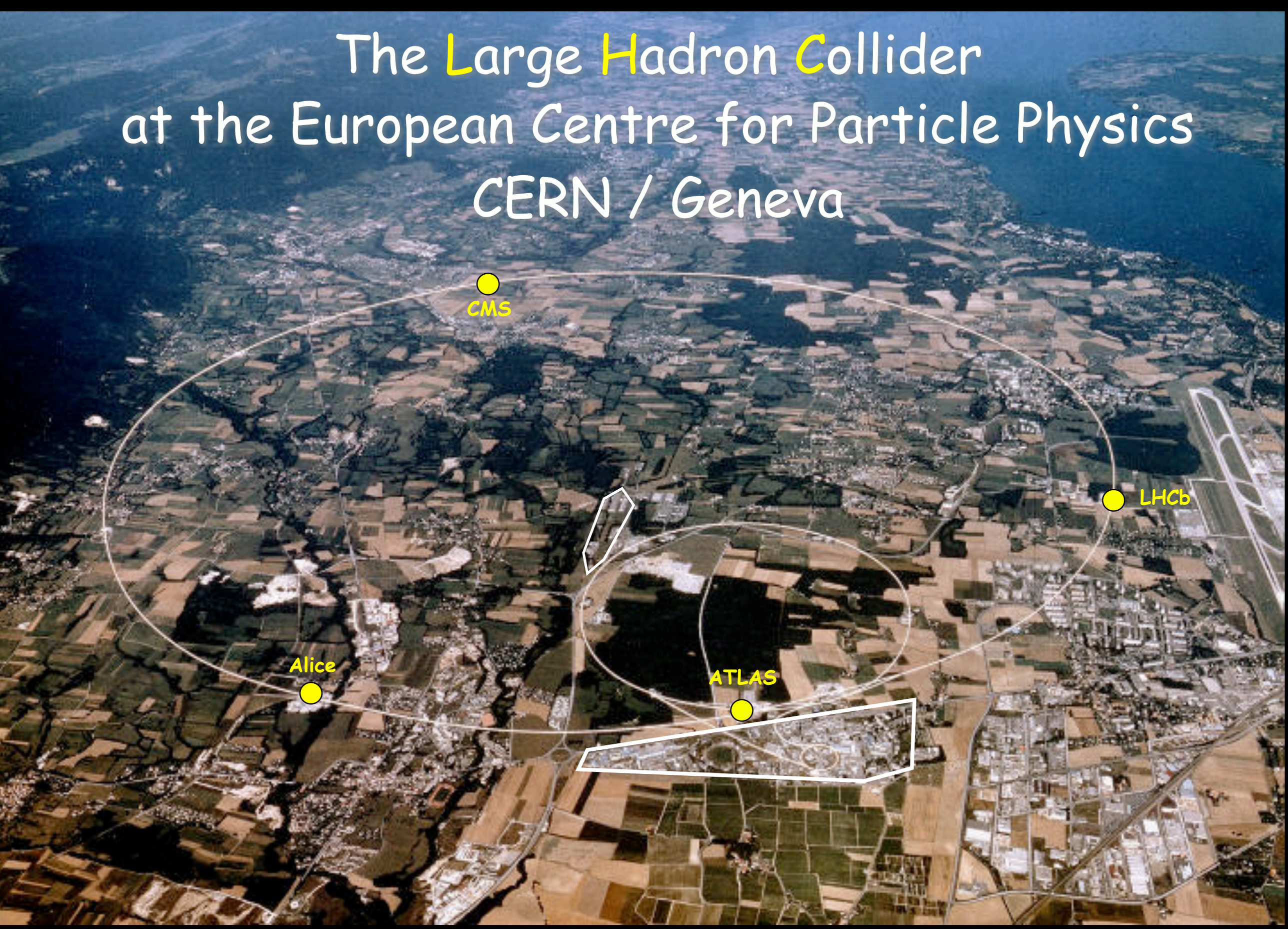
⇒ high demands on detectors
(radiation; resolution)

The LHC Project - from visions to reality:

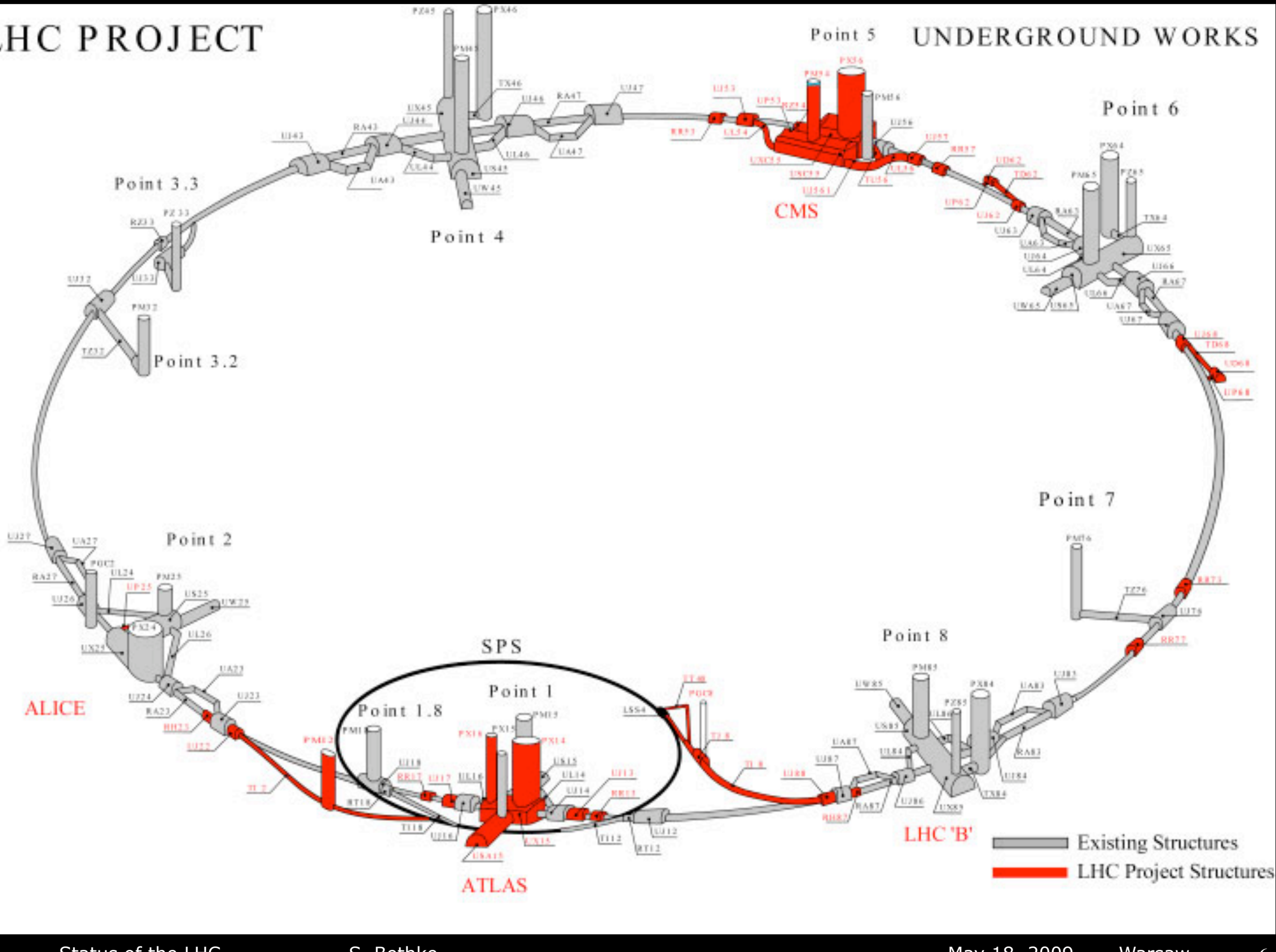
- ~1981: first ideas; basic design of machine
- 1984: ECFA meeting at Lausanne ("Start of LHC")
- 1990: Aachen workshop: physics, detectors, machine

  C. Rubbia: - LHC in competition to SSC, but cheaper and earlier (~1998)!
  - factor 10 in luminosity is worth factor 2 in energy
  (LHC: $\sqrt{s}$ = 16 TeV SSC: $\sqrt{s}$ = 40 TeV)
- 1992: Letters of intent for LHC program
- 1994: ATLAS & CMS technical proposals
- 1994: CERN Council approval of (stage 1) LHC
- 1995: approval of full (single stage) LHC (start in 2005)
- 2000: shutdown and dismantling of LEP
- 2005: start of installation of LHC dipoles;
- 2009: colliding beams (November)

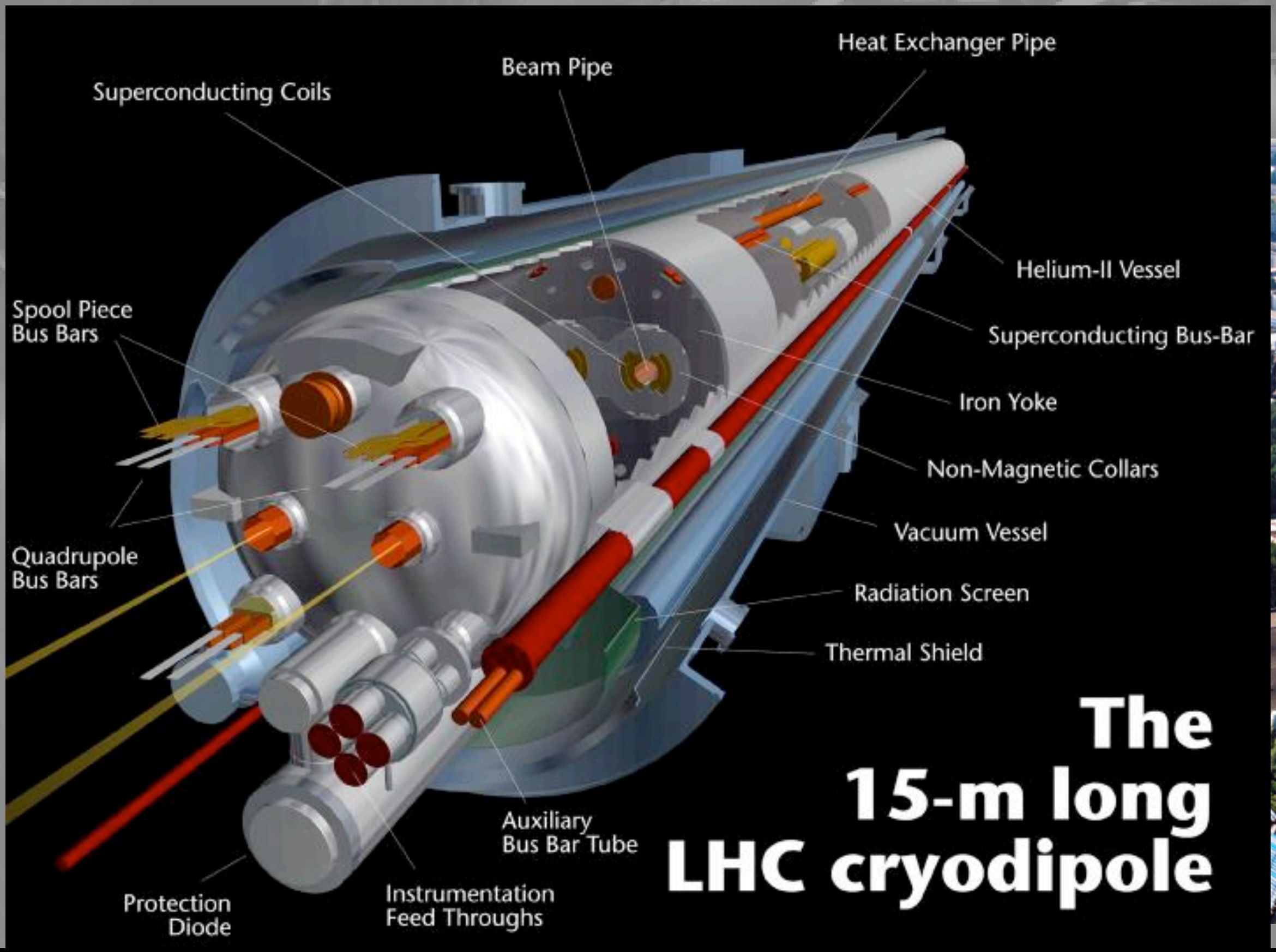
The Large Hadron Collider at the European Centre for Particle Physics CERN / Geneva

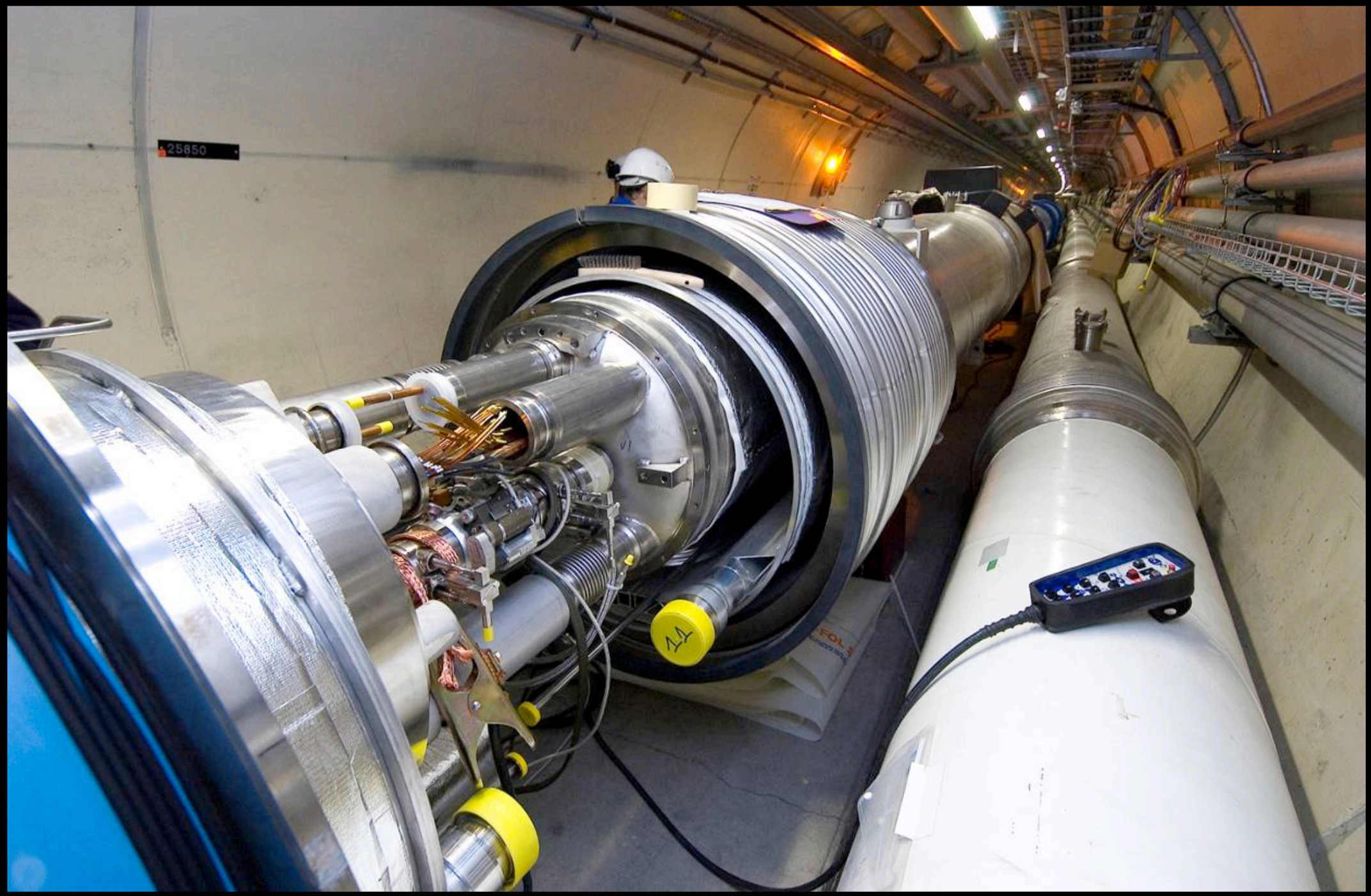


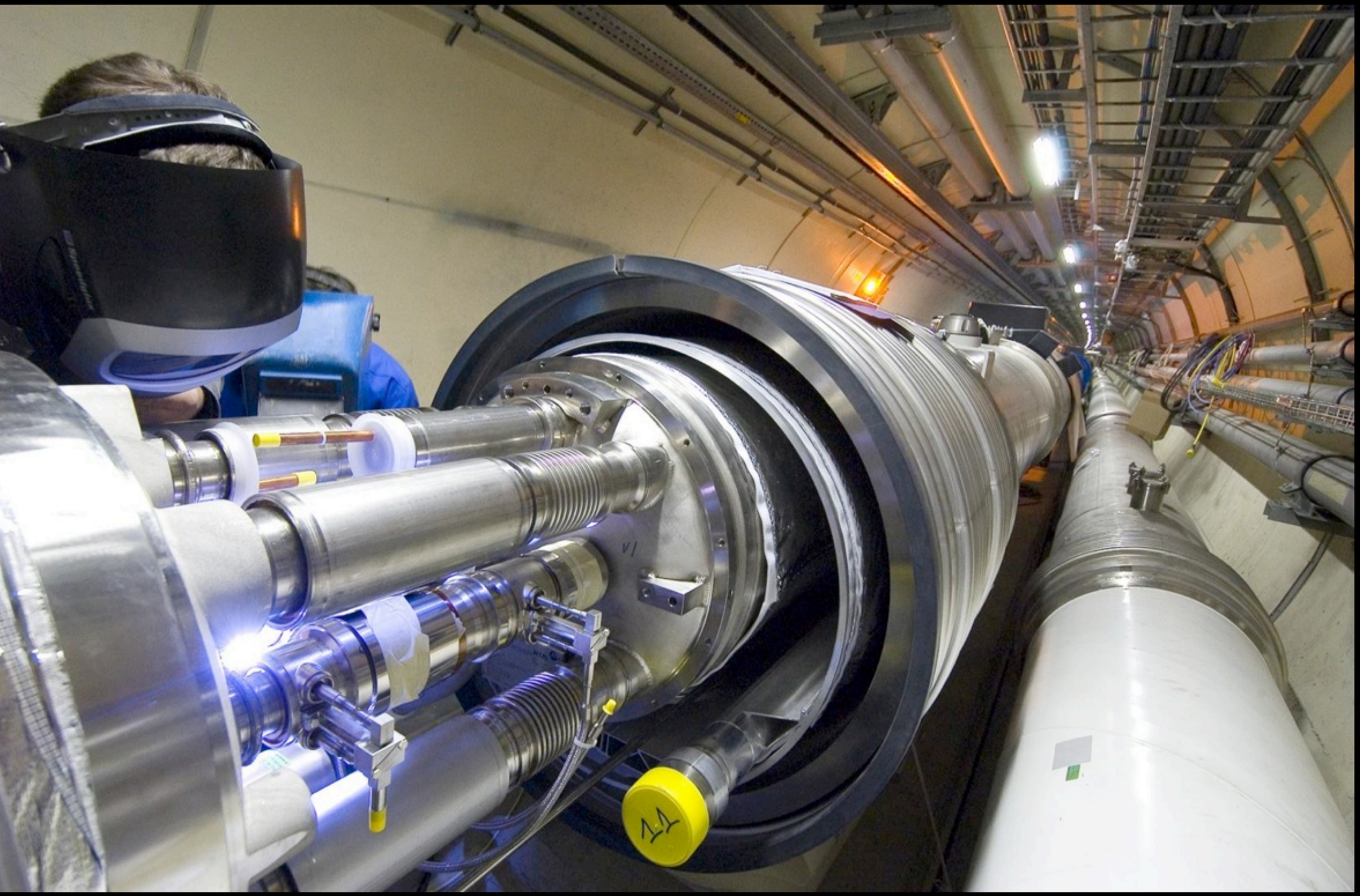
LHC PROJECT


Point 5
UNDERGROUND WORKS
Point 6
Point 4
Point 3.3
Point 3.2
CMS
Point 7
Point 2
SPS
Point 1
Point 1.8
Point 8
ALICE
ATLAS
LHC 'B'
Existing Structures
LHC Project Structures

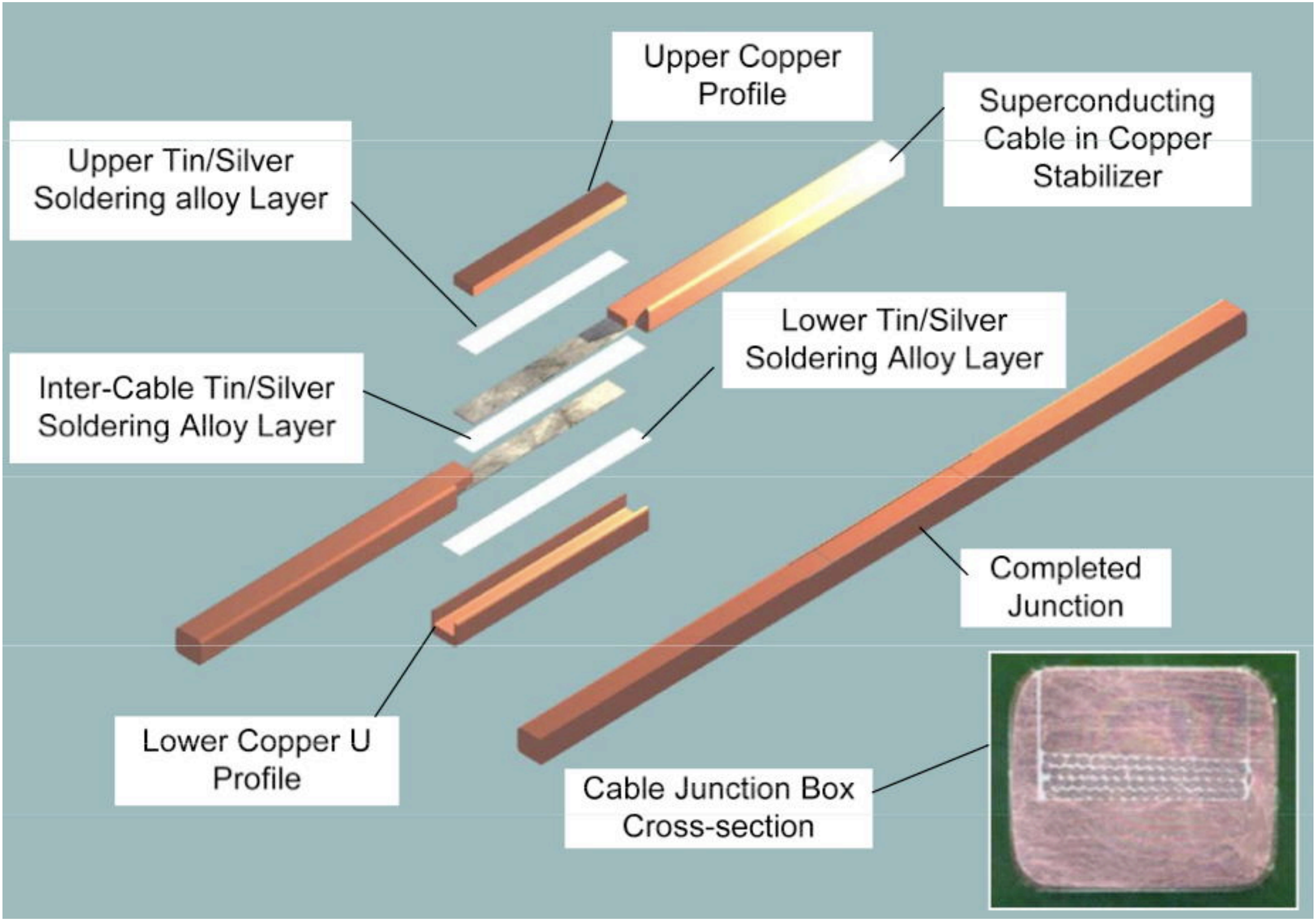
The LHC Dipol Magnets




25850



how to connect sc cables ... ? „splices"



n.b.: there are ~24.000 splices in and between all LHC magnets !

circuit	splice type	splices per magnet	number of units	total splices
RB	inter pole	2	1232	2464
RB	inter aperture	1	1232	1232
RB	interlayer	4	1232	4928
RB	internal bus	1	1232	1232
RB	interconnect	2	1686	3372
RQ	Inter pole	6	394	2364
RQ	internal bus	4	394	1576
RQ	interconnect	4	1686	6744
total				23912

The LHC project: approaching operation

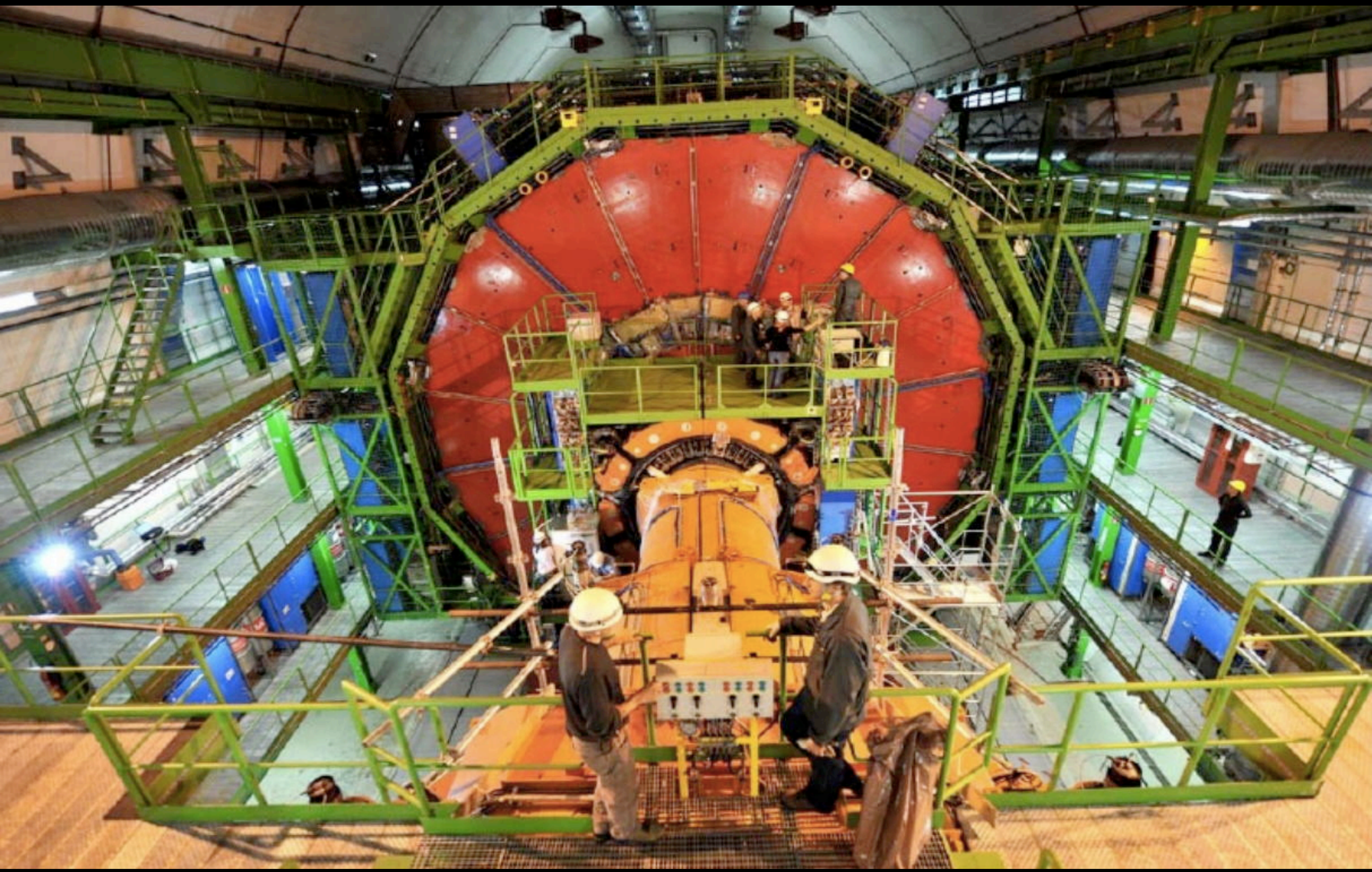
- March 2005 : lowering down of 1st dipole
- April 2007 : installation of last dipole
- Nov. 2007 : last connection of magnets completed
- July 2008 : LHC at operation temperature

- Aug. 8, 2008 : beam 1 up to LHC point 3 (ALICE)
- Aug. 22, 2008: beam 2 up to LHC point 7 (LHCb)
- Sep. 10, 2008 : circulating beam 1, later beam 2 !!!
  magnets sector 34 tested up to 4 TeV,
  all other sectors up to 5 TeV; then:
  ~ 40 hours of single rotating beam
- Sep. 19, 2008 : major incident in sector 34 when
  testing magnets to 5 TeV (w/o beam)

LHC Tunnel (12/2005)


16 June 2008: Last piece of LHC ring being put in place

September 8, 2009: CMS closed; ready for beam



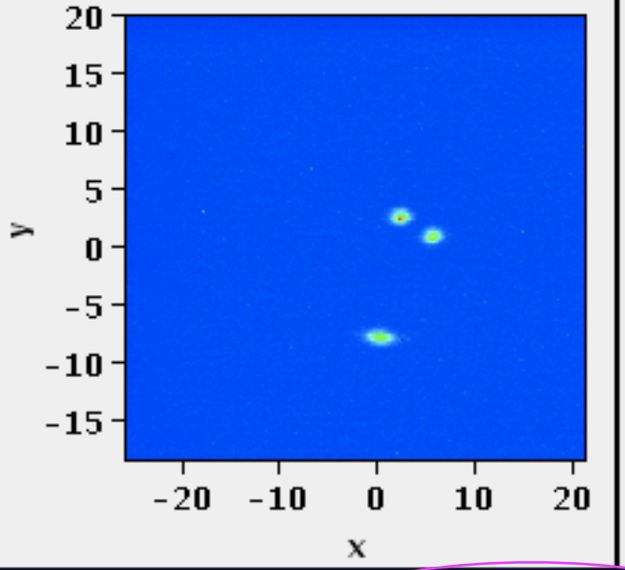
BEAM SETUP: INJECT AND DUMP

TED TI2 position:	BEAM	TED TI8 position:	DUMP

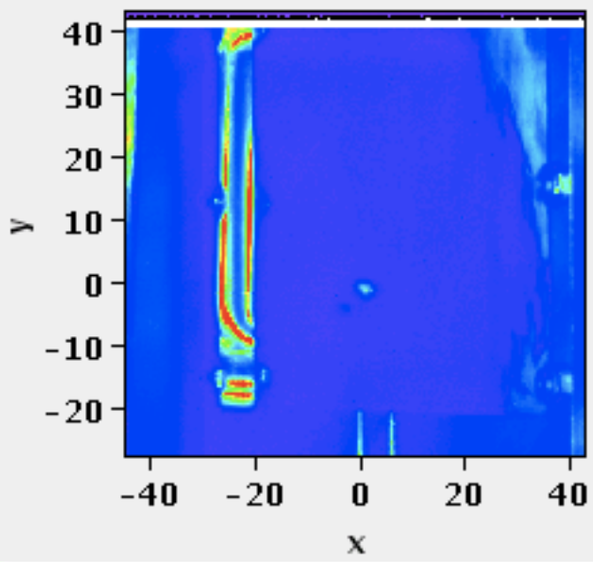
TDI P2 gaps/mm	upstream: 29.82	downstream: 30.14
TDI P8 gaps/mm	upstream: 3.32	downstream: 3.28

BCT TI2:	0.00e+00	BCT TI8:	0.00e+00

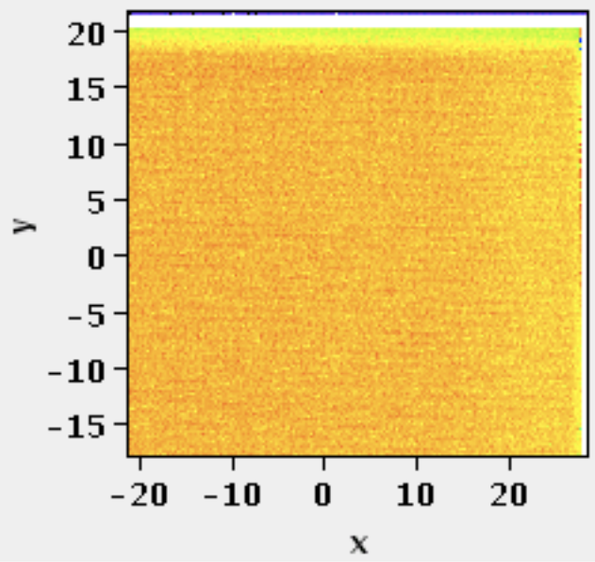
BTVSI.C5L2.B1 Updated: 10:31:46



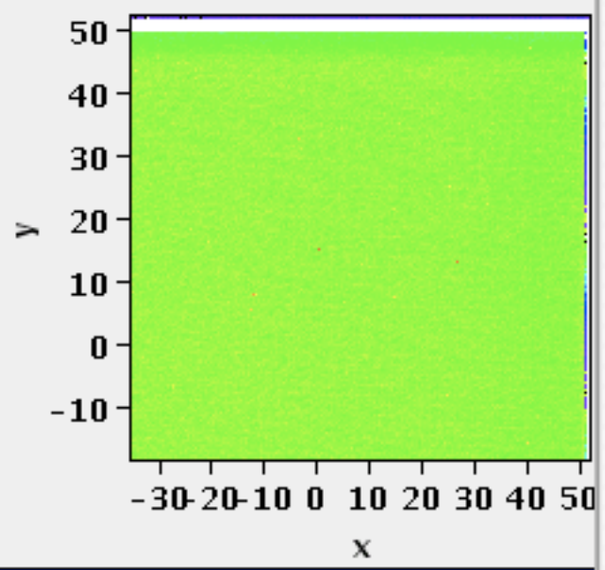
BTVST.A4L2.B1 Updated: 10:31:46



BTVSI.C5R8.B2 Updated: 10:31:46



BTVST.A4R8.B2 Updated: 10:31:4



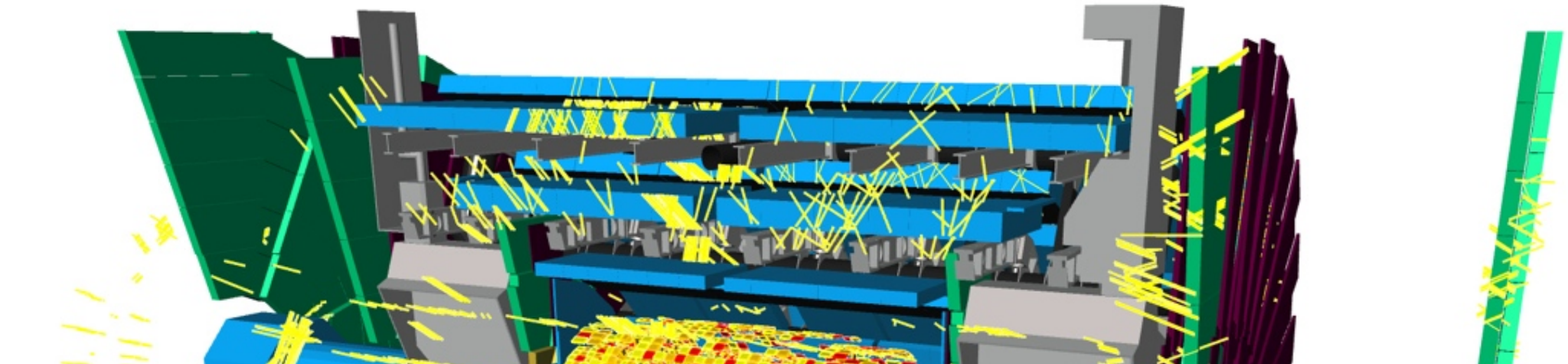
Comments 10-09-2008 10:31:29 :

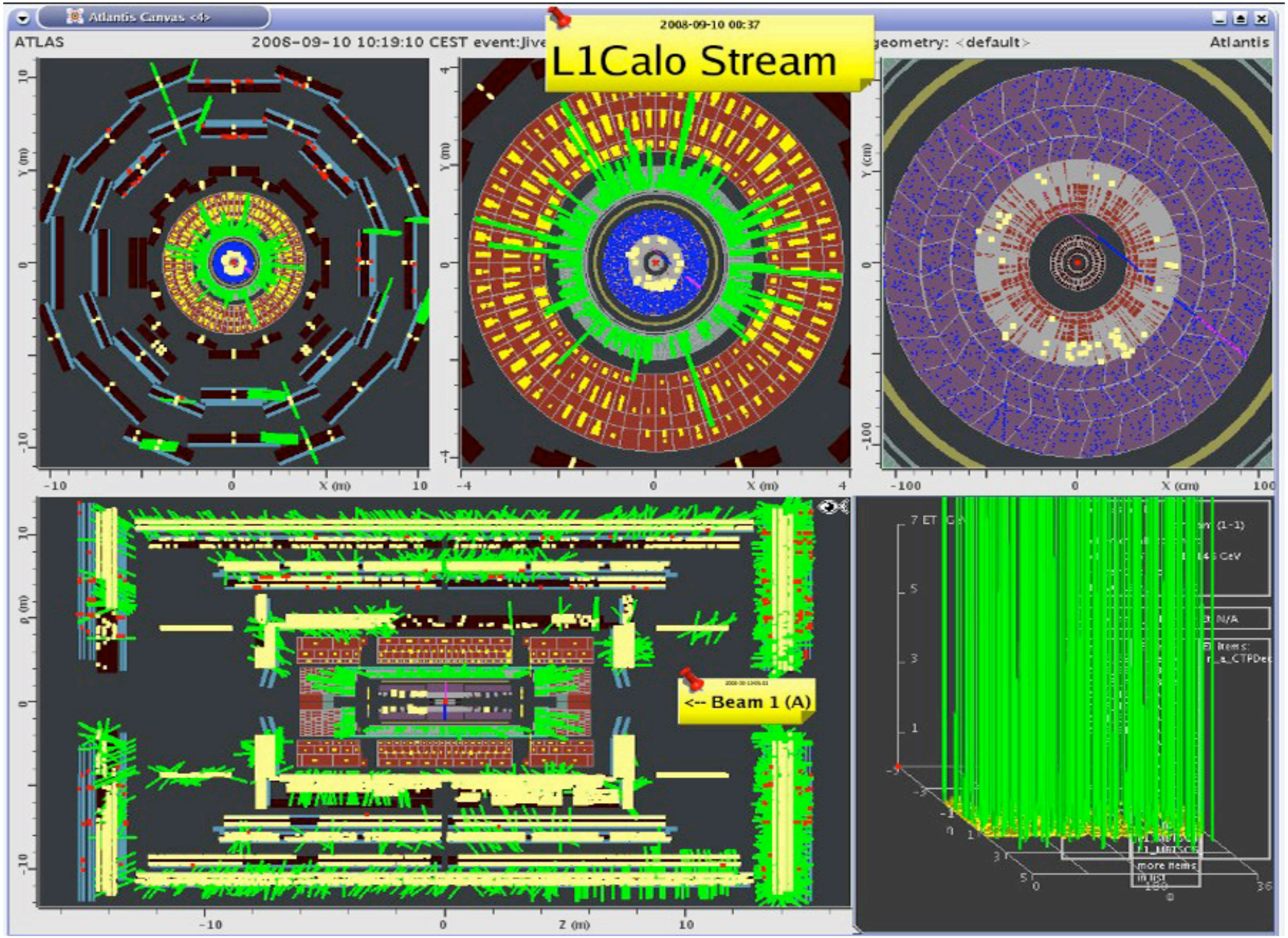
B1 extraction only

Beam1: correcting the orbit.

We did three turns!

first beam splash recorded by ATLAS




Atlantis Canvas <4>
ATLAS
2008-09-10 10:19:10 CEST event:Jive
geometry: <default>
Atlantis
2008-09-10 00:37
L1Calo Stream
Y (m)
X (m)
Y (cm)
X (cm)
<-- Beam 1 (A)
Z (m)
7 ET
GeV
N/A
Items:
more items

The LHC incident: what happened and why?

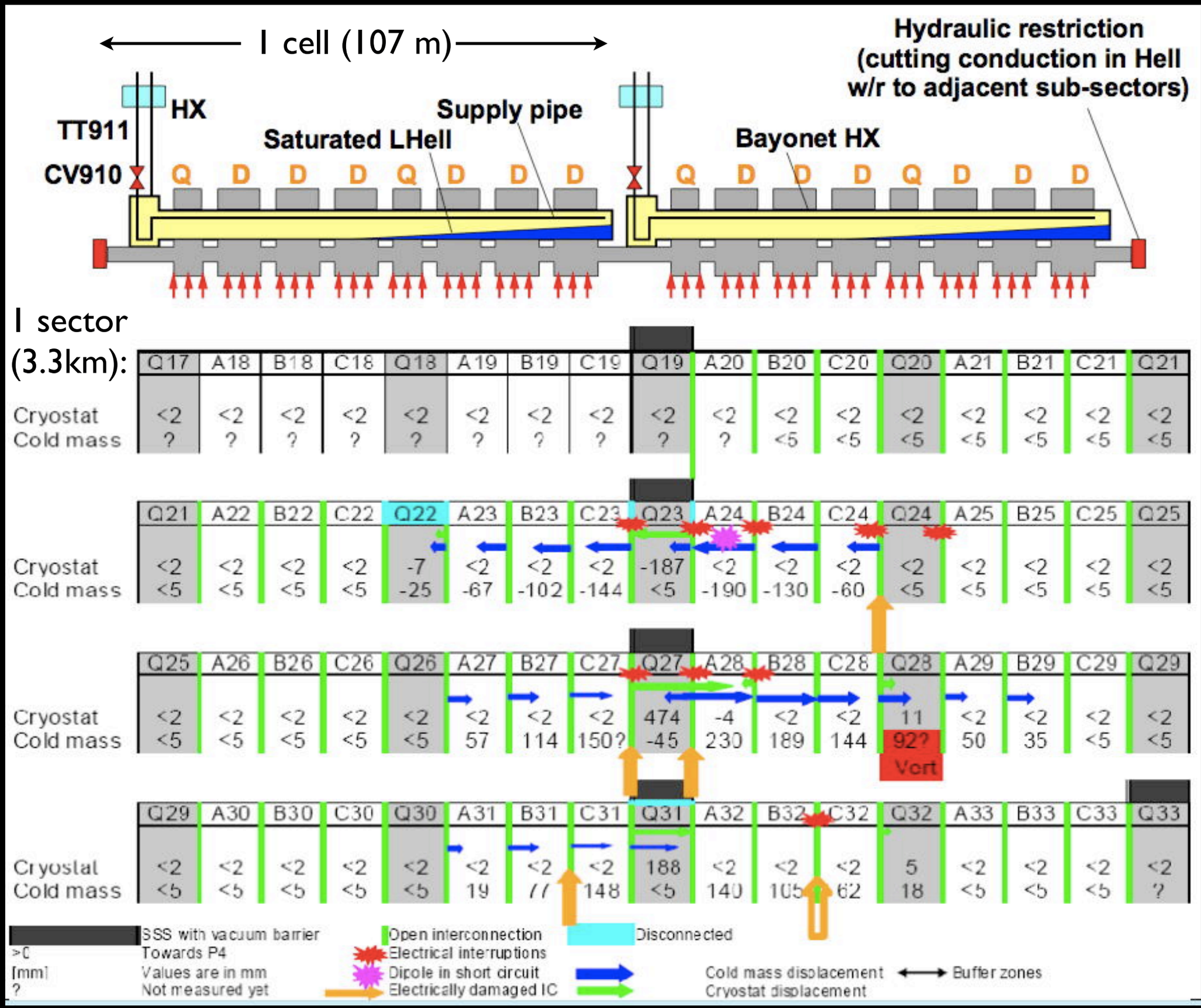
- a bad electrical connection between dipole C24 and quadrupole Q24 of ~200 nΩ results in ΔU~2mV at 9kA, generating ~16W of heat load, which cannot be cooled away by HeII -> „thermal runaway"
- transition to normal conductivity (quench) of sc cable (which is not in the quench protection system of magnets) -> melting and boiling away of conductor
- formation of electrical arc, punctuating the He vessel
- outflow of ~2 tons of He into the cryostat
- overpressure valves cannot release mass flow (design: 2kg/s; actual at incident: 20 kg/s)
- pressure of 7 bar (design: 1.5) on vacuum barriers
- severe mechanical destruction

the blown-up connection between C24 and Q24

physical displacement of many magnets; destruction of connections

support jacks ripped out of concrete socket

inventory of damages



inventory of damages, actions for repair and improvement of safety

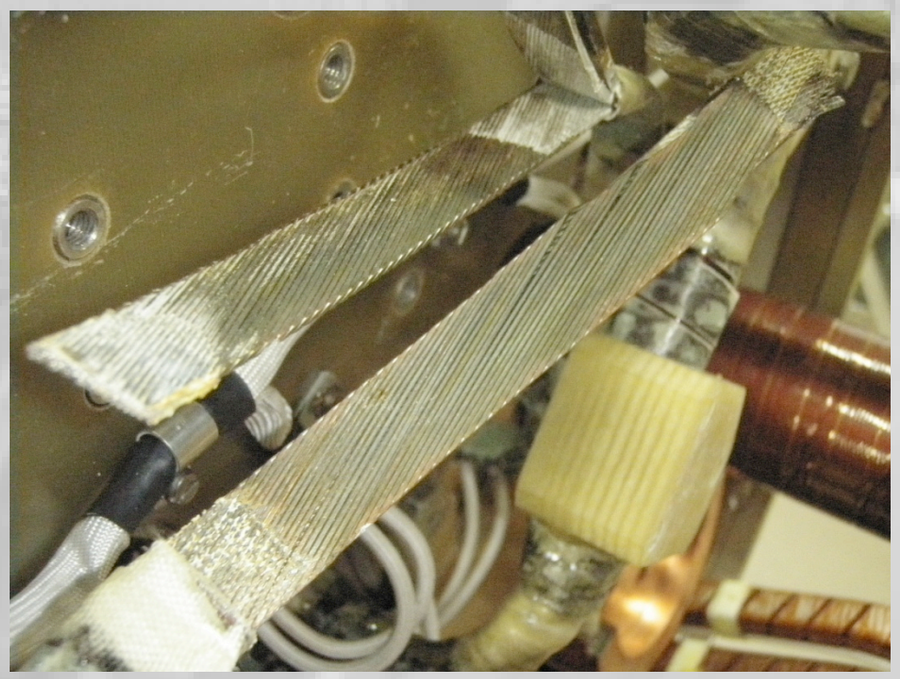
- about 50 magnets and short straight sections (SSS) to be brought to surface
- ~10 magnets to be replaced, others to be repaired
- tunnel & magnets to be cleaned

- quench protection system for bus-bars (electronics; 160 km cables)
- install large capacity pressure valves (must happen in warm!)
- measure and detect other posible bad sc connections (sufficient sensitivity only when cold!)

search for bad sc connections „successful“:

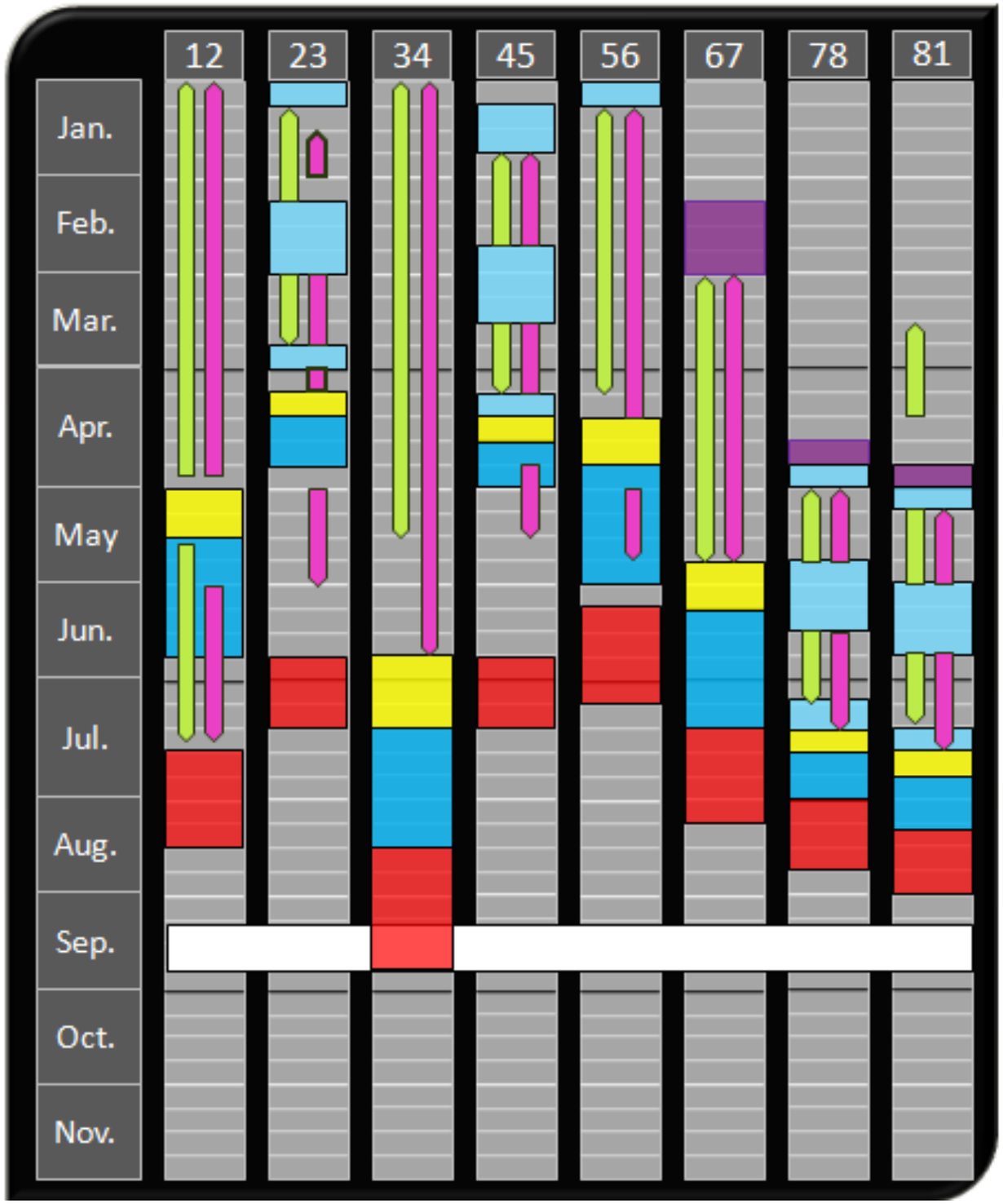
- two magnets found with ~100 nΩ resistence in inner splices; sectors (12 and 56) warmed up, magnets de-installed and brought on surface -> lack of solder!

Splice resistance non-conformities – example



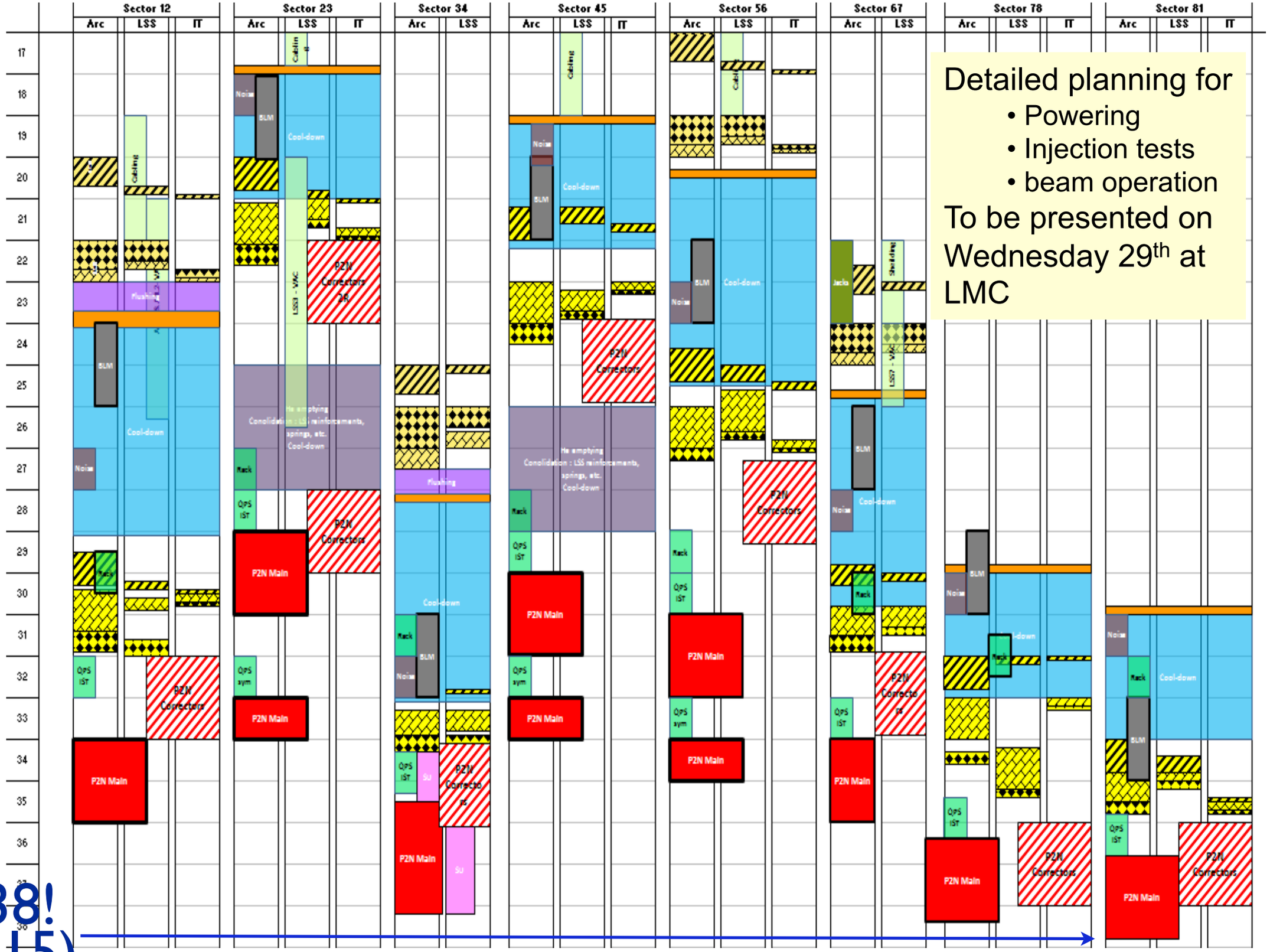
- magnets of other sectors (not being cold) investigated by analysis of old test data

baseline schedule (Feb. 09):



- Machine cold
  wk 34
- Powering Tests start
  wk 24
- LHC Machine starts
  wk 39 (~Sept 22)

optimised schedule (April 29, 2009):



Detailed planning for
- Powering
- Injection tests
- beam operation

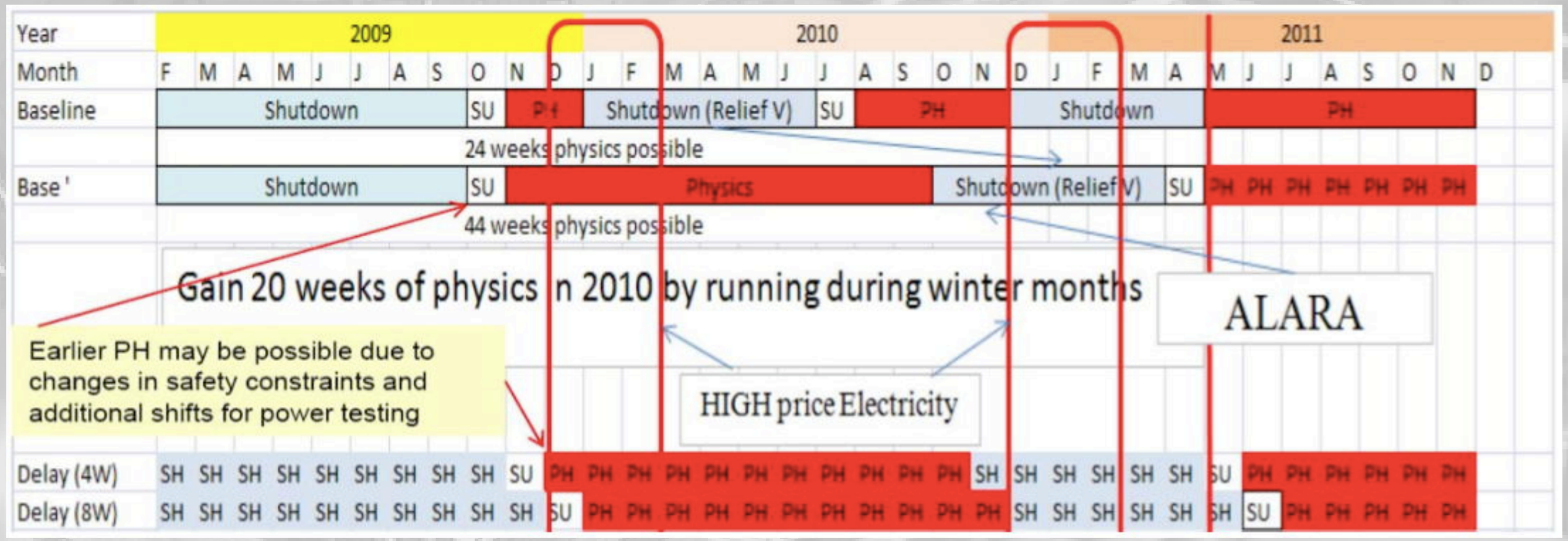
To be presented on Wednesday 29th at LMC

week 38!
(~Sept. 15)

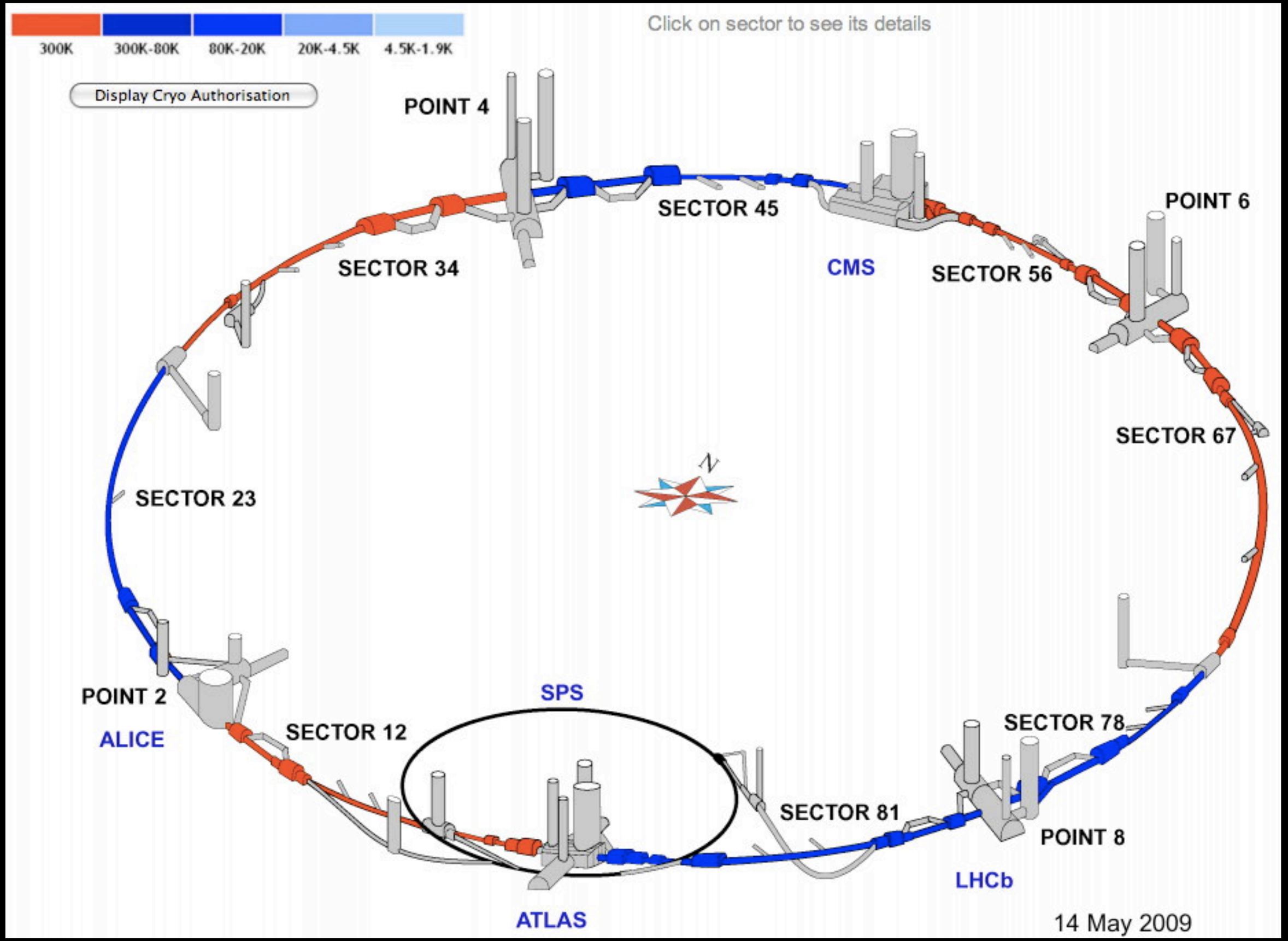
current LHC status (May 15):

- no delay w.r.t. above schedule (daily struggles with e.g. technological problems, purchasing, admin ... but still within schedule)
- re-installation of last dipole on (April 30)
- replacement of new valves (warm sectors) finished
- parts for new quench protection tested, ordered
- decisions taken on 2009/2010 LHC running:

LHC schedule for 2009-2011:



- **continuous** LHC physics run from 11/09 - 10/10
- limited to 5 TeV beams (valves; retraining of magnets to 7 TeV needs ~60 days and ~1000 magnet quenches!)
- possible initial „stops" at 0.5 , 1 and 2 TeV beams
- expect peak L~5 10^{31}... 2 10^{32}; int. L ~ 250 pb^{-1}
- possibly ~1 month heavy ion running at the end


300K
300K-80K
80K-20K
20K-4.5K
4.5K-1.9K
Click on sector to see its details
Display Cryo Authorisation
POINT 4
SECTOR 45
POINT 6
SECTOR 34
CMS
SECTOR 56
SECTOR 67
N
SECTOR 23
POINT 2
ALICE
SECTOR 12
SPS
SECTOR 78
SECTOR 81
POINT 8
LHCb
ATLAS
14 May 2009

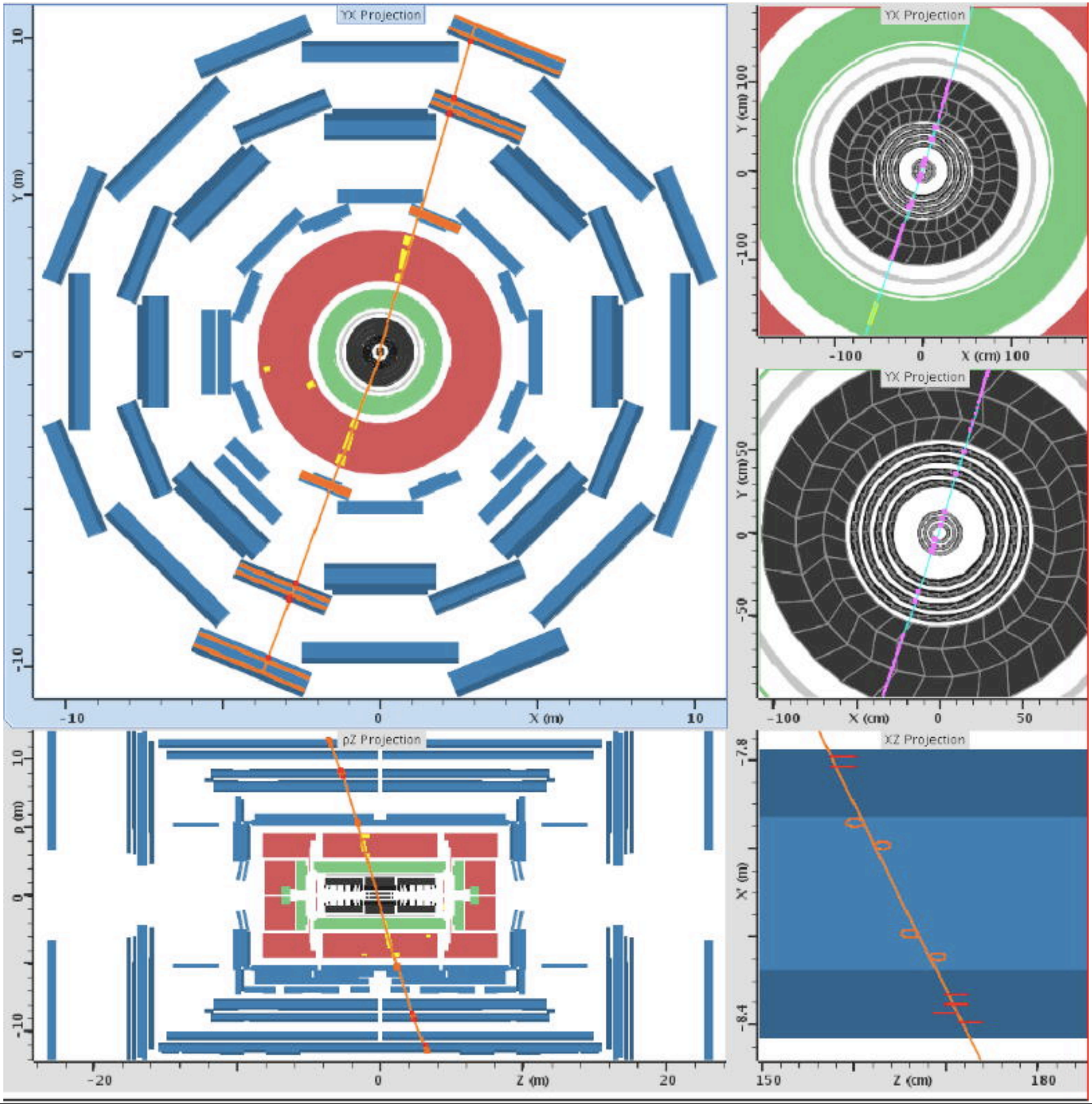
one year completely lost for physics ?

no - not entirely!

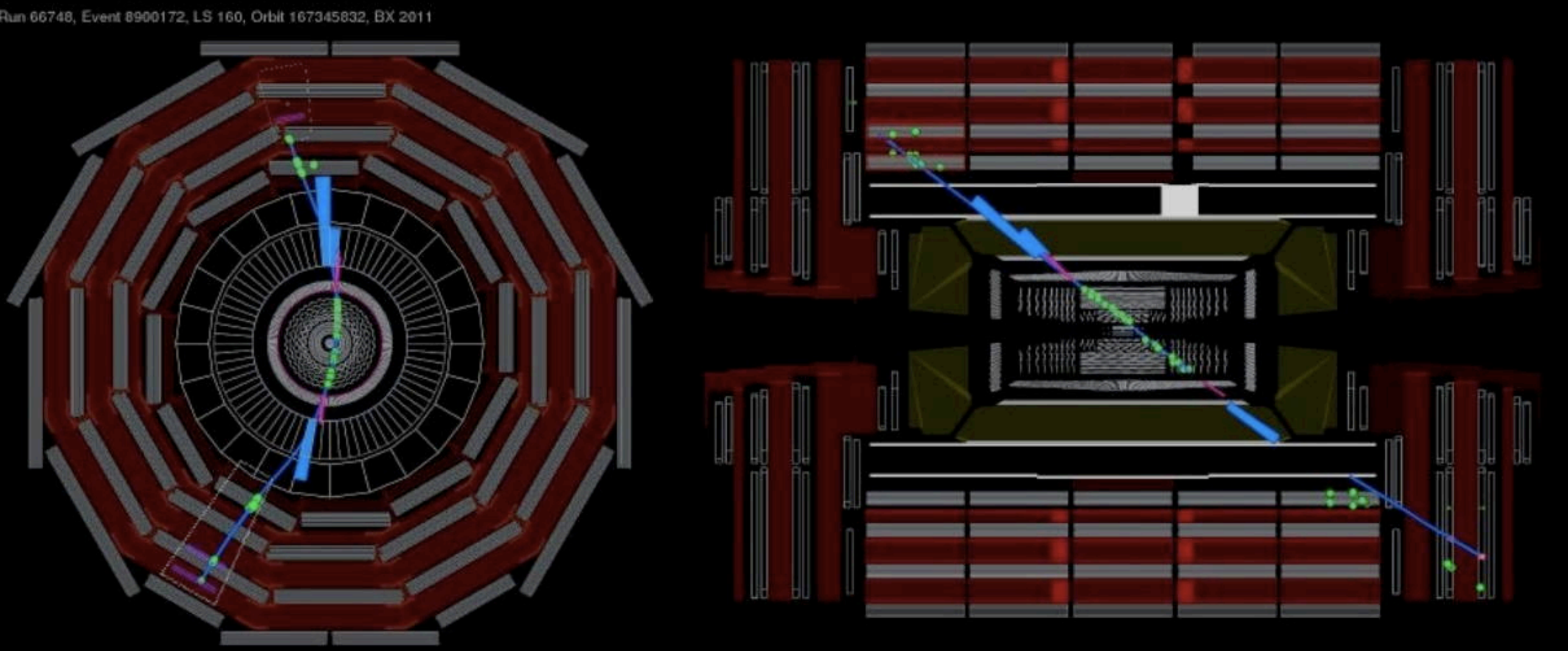
down-time used for:

- maintenance and repair wherever possible and needed
- installation of some (previously staged) detector parts
- **data runs with cosmic muons** (abt. 216 million events; >1.2 PB on disk)
  - commissioning of detector, trigger, readout, software, grid computing, shift & maintenance crews, ...
  - calibration and alignment of subdetectors
- **write-up and document**, (e.g. ATLAS computing & software challenge, CSC)
- **start to develop plans for detector upgrades for sLHC**
- generate large MC samples

cosmic muon in ATLAS

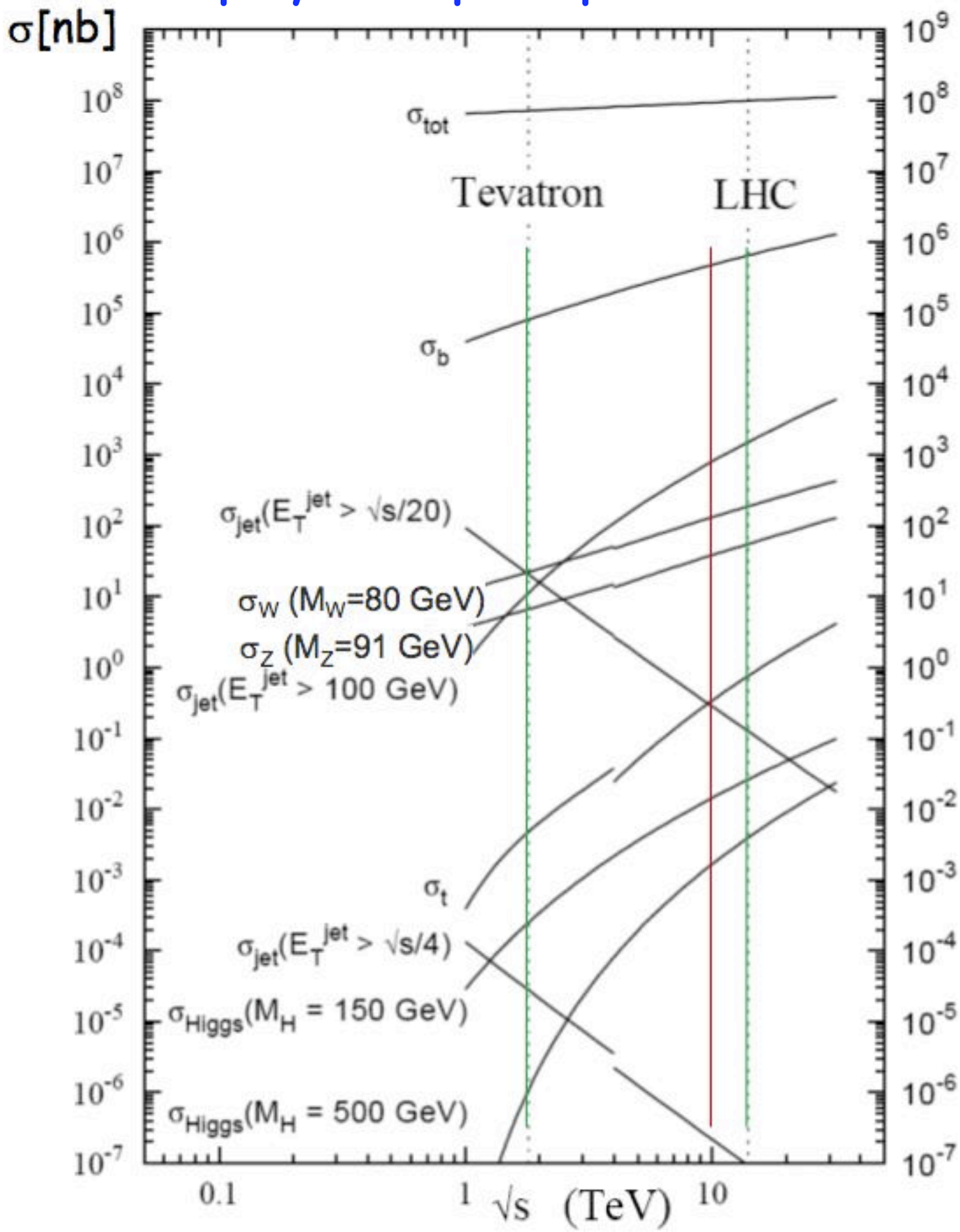


cosmic muon in CMS

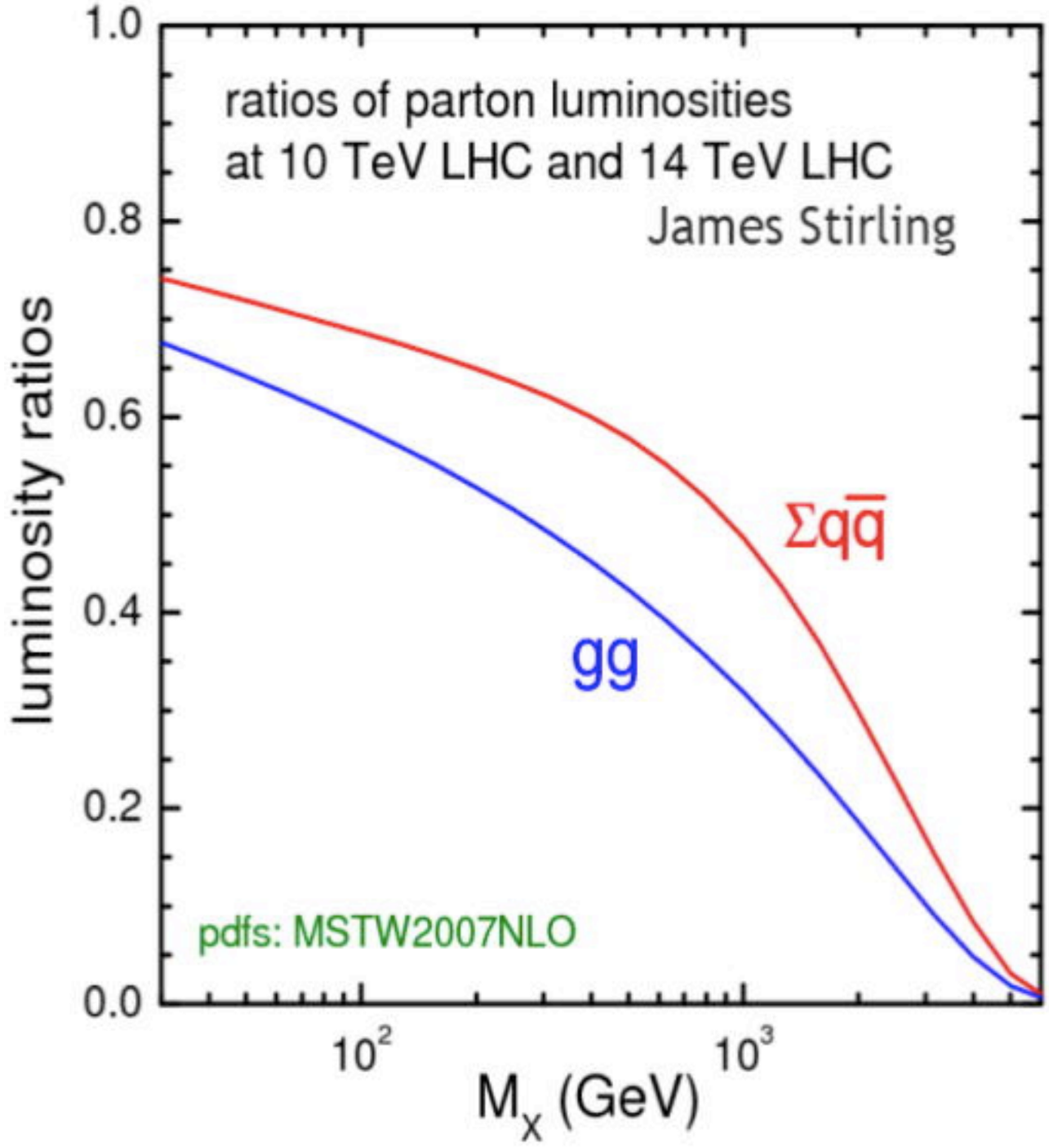


… passing all subdetecors incl. pixel …

physics prospects:



evts/s at $L=10^{32}/cm^2/s$:
100.000
10.000
1000
100
10
1
1/10
1/100
1/1000
1/10.000

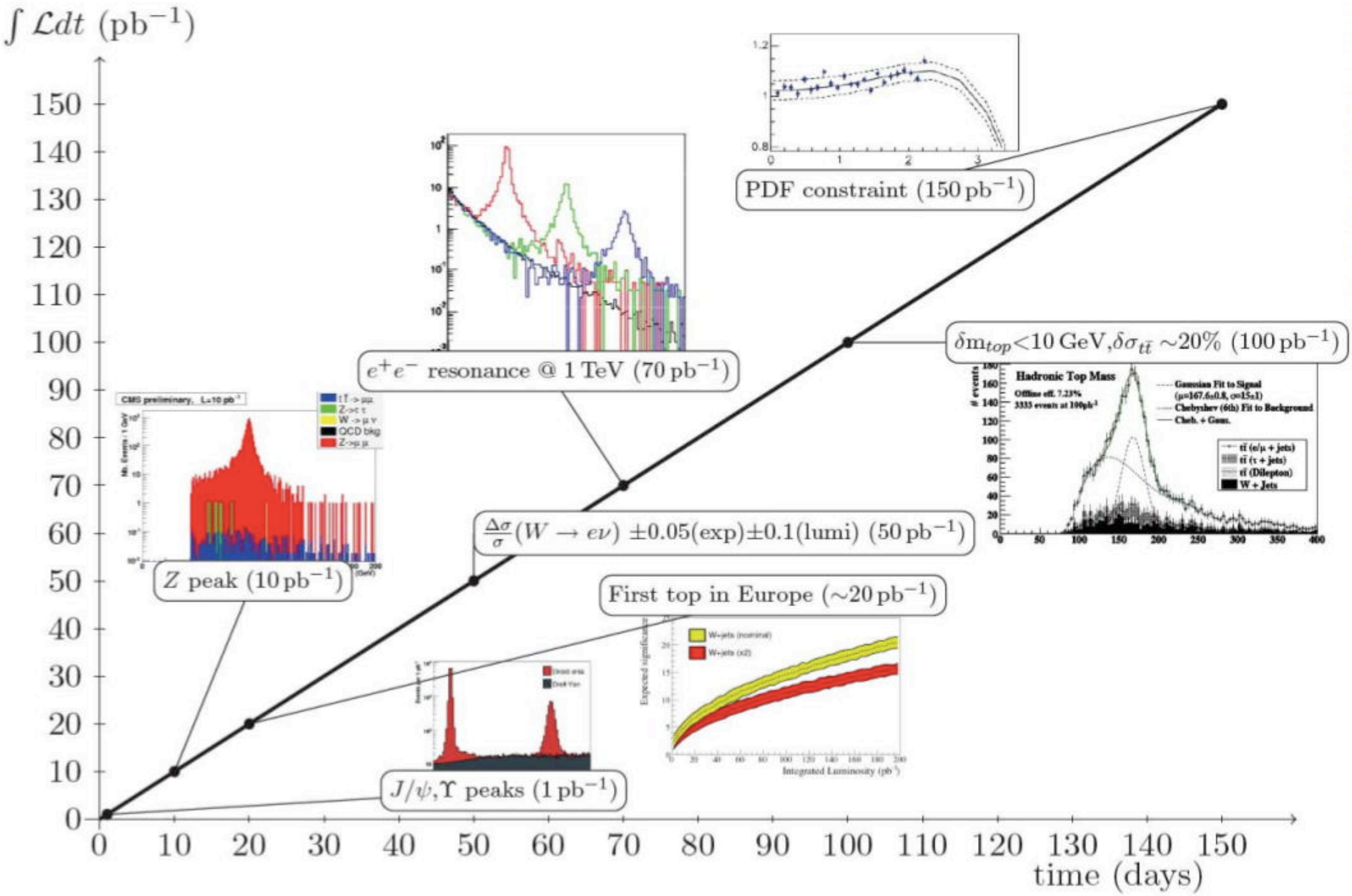

ratios of parton luminosities
at 10 TeV LHC and 14 TeV LHC
James Stirling
Σqq̄
gg
pdfs: MSTW2007NLO
luminosity ratios
1.0
0.8
0.6
0.4
0.2
0.0
10^2
10^3
M_X (GeV)

roadmap for first LHC collision data:

- 1 - 10 pb^{-1} : detector calibration with real data
  first measurements (e.g. „minimum bias")
- ~ 100 pb^{-1} : precision calibration
  SM measurements (re-establishment)
  first sensitivity for new physics
  expect (10 TeV, 100 pb^{-1}):
  - > 5 10^6 triggered minimum bias events
  - ~ 10^8 jet events
  - 2.5 10^5 W -> l ν events
  - 2.5 10^4 Z -> l l events
- ~1 fb^{-1} : sensitivity to discover Higgs bosons, SUSY, new resonances (O(TeV))

from: S. Tapprogge

roadmap for first LHC collision data:



Summary

- repair and recuperation from Sept. 19 incident in full swing and on schedule for restart of LHC in mid September 2009
- measures taken to prevent re-occurance of incidents like Sept-19 (bus bar quench protection; valves; magnet tests; 5 TeV)
- plan for long and continuous data run from 11/09 - 10/10 at 10 TeV and with $L \sim 5\ 10^{31} \ldots 2\ 10^{32}$; int. $L \sim 250\ pb^{-1}$
- physics roadmap for that initial run:
  - lots of Z's, W's, jets and first t-quarks in Europe
  - with a little luck, first sensitivity for new physics
- precise measurement of top-quark mass, and significant sensitivity for Higgs, SUSY, extra dimensions etc. will have to wait for times beyond 2010/2011 ...