The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

1970-1

Signaling the Arrival of the LHC Era

8 - 13 December 2008

Current Status of the LHC

Albert De Roeck

CERN

Switzerland

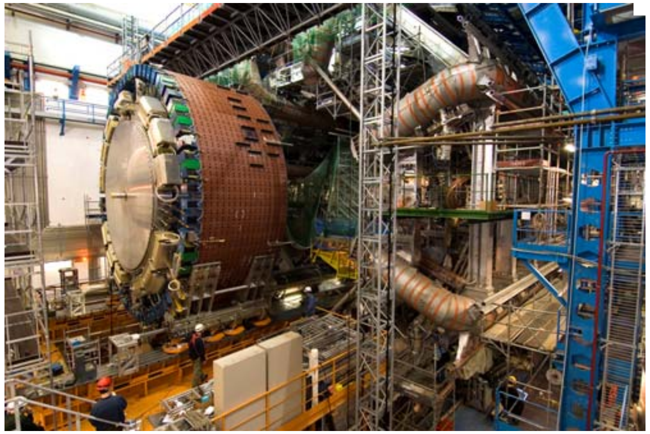
Status of the LHC

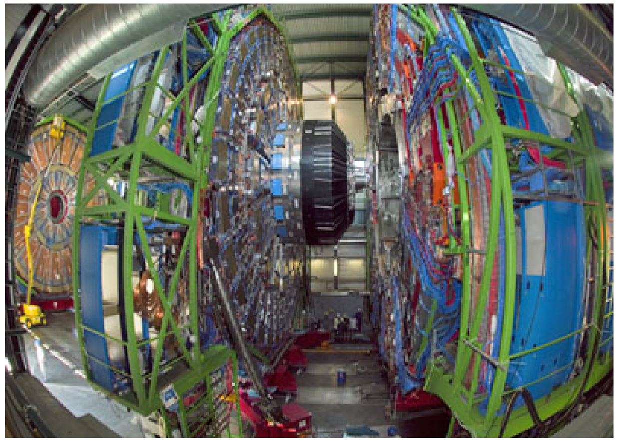
Albert De Roeck
CERN
and University of Antwerp
and the IPPP Durham

SIGNALING THE ARRIVAL OF THE LHC ERA

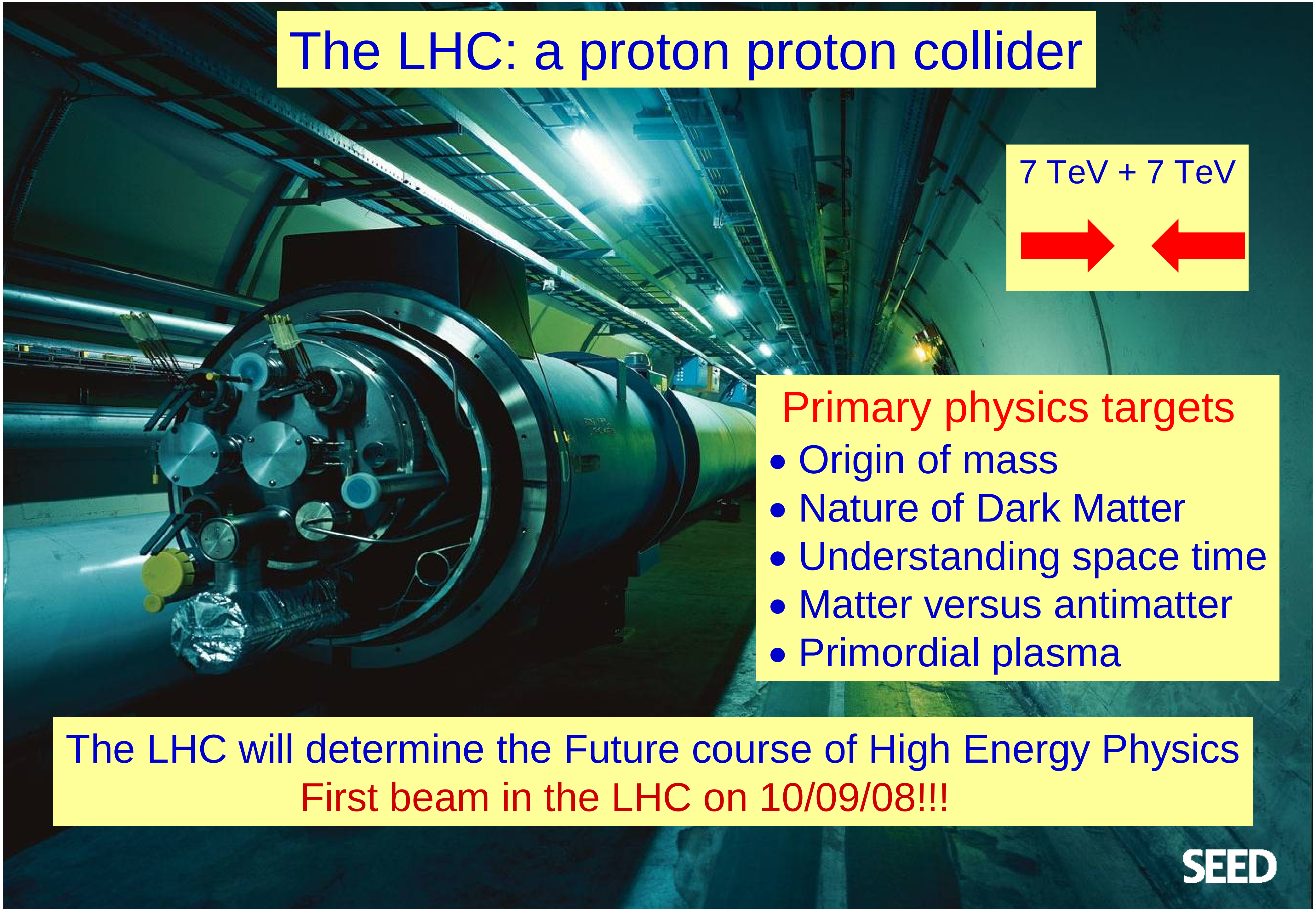
8 - 13 December 2008

Miramare, Trieste, Italy





The LHC: a proton proton collider



7 TeV + 7 TeV

Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

The LHC will determine the Future course of High Energy Physics

First beam in the LHC on 10/09/08!!!

The LHC: 22 Years Already!

LHC History

1982 : First studies for the LHC project

1983 : Z0/W discovered at SPS proton antiproton collider

1989 : Start of LEP operation (Z boson-factory)

1994 : Approval of the LHC by the CERN Council

1996 : Final decision to start the LHC construction

1996 : LEP operation > 80 GeV (W boson -factory)

2000 : Last year of LEP operation above 100 GeV

2002 : LEP equipment removed

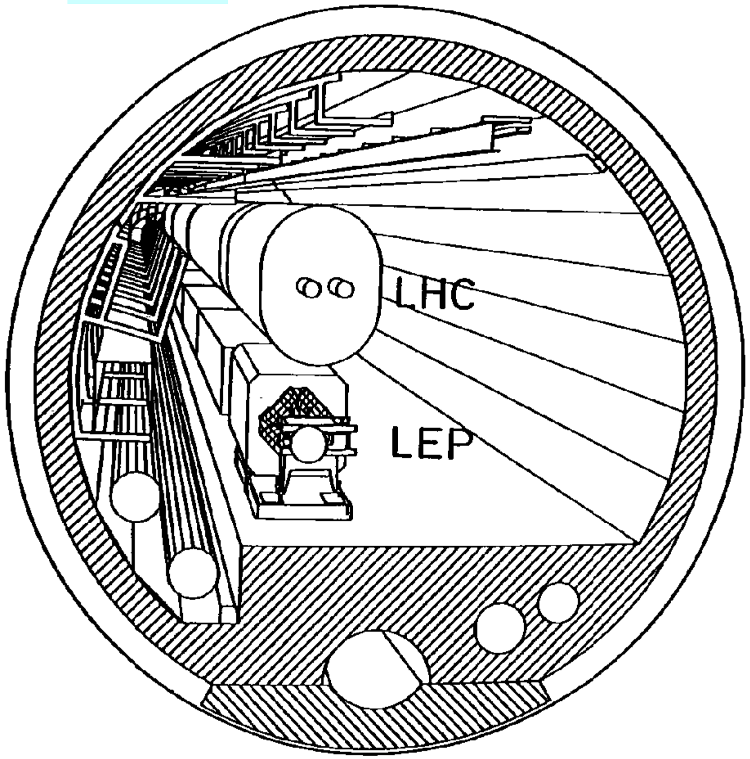
2003 : Start of the LHC installation

2005 : Start of LHC hardware commissioning

2008 : Expected LHC commissioning with beam

1984

ECFA 84/85
CERN 84-10
5 September 1984



1984:	cms energy	10-18 TeV
	Luminosity	10^{31}-10^{33} cm^{-2}s^{-1}
1987:	cms energy	16 TeV
	Luminosity	10^{33}-10^{34} cm^{-2}s^{-1}
Final:	cms energy	14 TeV
	Luminosity	10^{33}-10^{34} cm^{-2}s^{-1}

Recent High Energy Colliders

Highest energies can be reached with proton colliders

Machine	Year	Beams	Energy ($\sqrt{s}$)	Luminosity
SPPS (CERN)	1981	pp	630-900 GeV	$6.10^{30}cm^{-2}s^{-1}$
Tevatron (FNAL)	1987	pp	1800-2000 GeV	10^{31}-$10^{32}cm^{-2}s^{-1}$
SLC (SLAC)	1989	e^+e^-	90 GeV	$10^{30}cm^{-2}s^{-1}$
LEP (CERN)	1989	e^+e^-	90-200 GeV	10^{31}-$10^{32}cm^{-2}s^{-1}$
HERA (DESY)	1992	ep	300 GeV	10^{31}-$10^{32}cm^{-2}s^{-1}$
RHIC (BNL)	2000	pp / AA	200-500 GeV	$10^{32}cm^{-2}s^{-1}$
LHC (CERN)	2009	pp (AA)	10-14 TeV	10^{33}-$10^{34}cm^{-2}s^{-1}$

Luminosity = number of events/cross section/sec

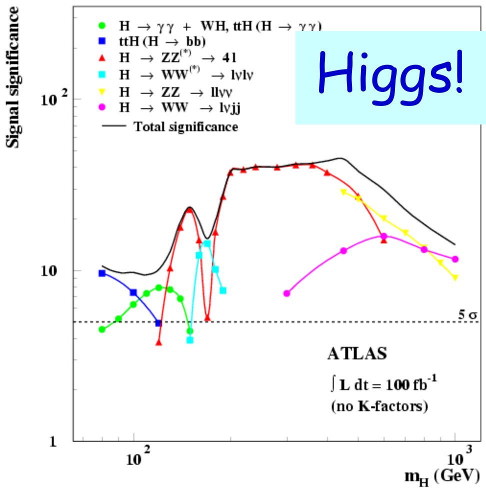
- Limits on circular machines
  - Proton colliders: Dipole magnet strength $\rightarrow$superconducting magnets
  - Electron colliders: Synchrotron radiation/RF power

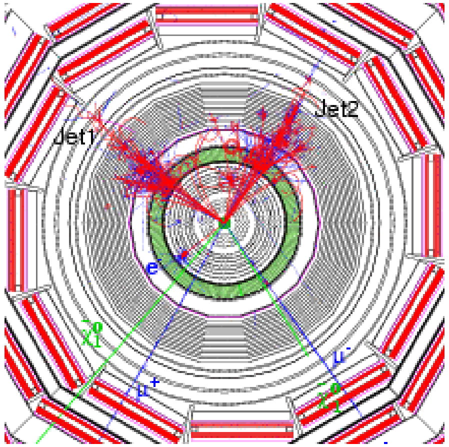
LHC Physics Program

- Discover or exclude the Higgs in the mass region up to 1 TeV. Measure Higgs properties
- Discover Supersymmetric particles (if exist) up to 2-3 TeV
- Discover Extra Space Dimensions, if these are on the TeV scale, and black holes?
- Search other new phenomena (e.g. strong EWSB, new gauge bosons, Little Higgs model, Split Supersymmetry)
- Study CP violation in the B sector,B physics, new physics in B- decays
- Precision measurements of m_{top}, m_W, anomalous couplings…
- Heavy ion collisions and search for quark gluon plasma
- QCD and diffractive (forward) physics in a new regime
- …

Physics at the LHC: pp @ 14 TeV

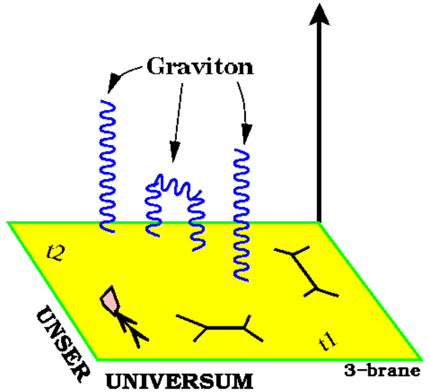
Higgs!



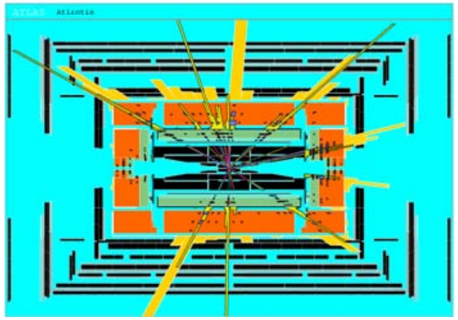


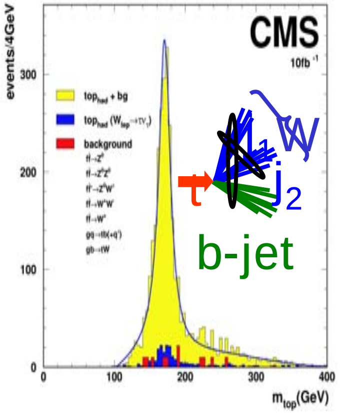
Supersymmetry?

Extra Dimensions?



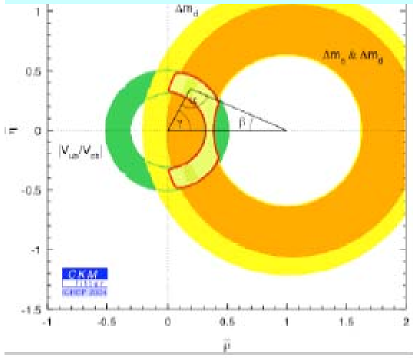
Black Holes???



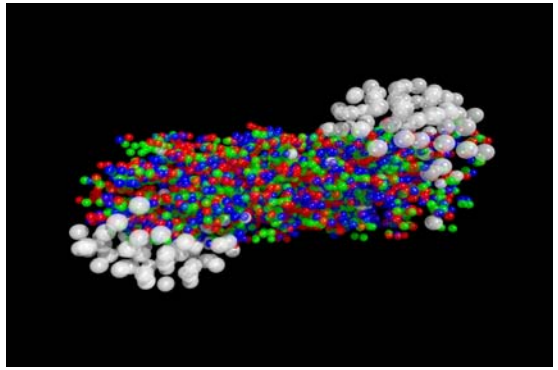


Precision measurements e.g top!

unitarity triangle!



QGP?



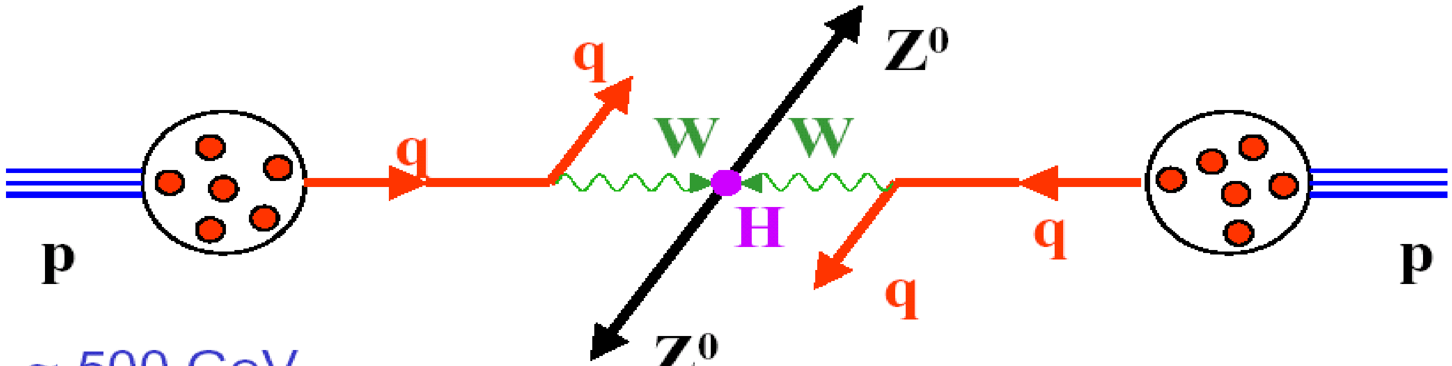
The LHC will be the new collider energy frontier

Requirements for a New Collider

Example: Higgs particle production

Hadron colliders are broad-band exploratory machines

May need to study W_L-W_L scattering at a cm energy of ~ 1 TeV



⇨ E_W ~ 500 GeV

⇨ E_{quark} ~ 1 TeV

⇨ E_{proton} ~ 6 TeV

⇨ **pp collisions at 7 + 7 TeV** → **14 TeV collider**

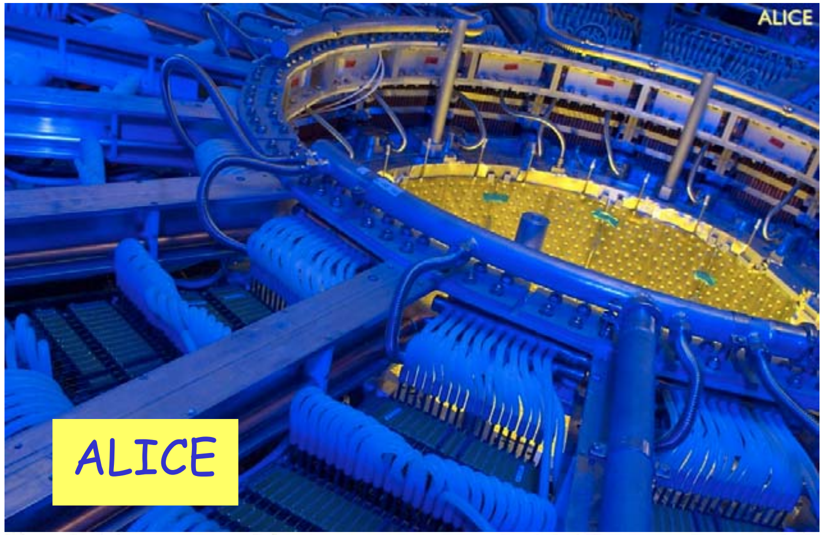
→ **L ~ 10^{34} cm^{-2} s^{-1}**

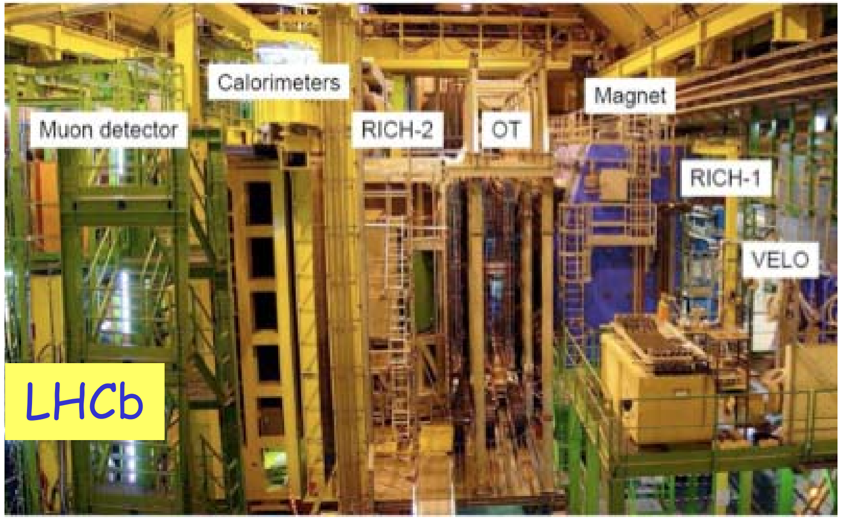
Event Rate = L.σ.BR

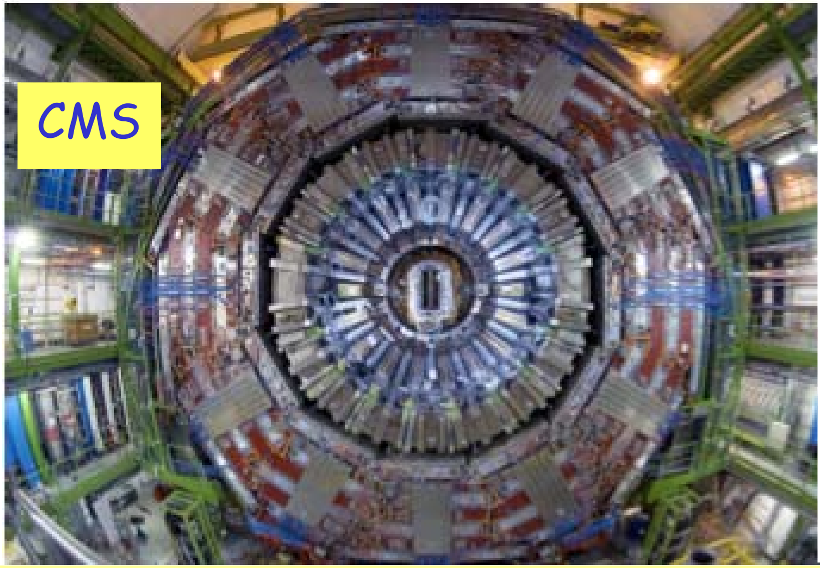
e.g. H(1 TeV) → ZZ → 2e+2μ or 4e or 4μ

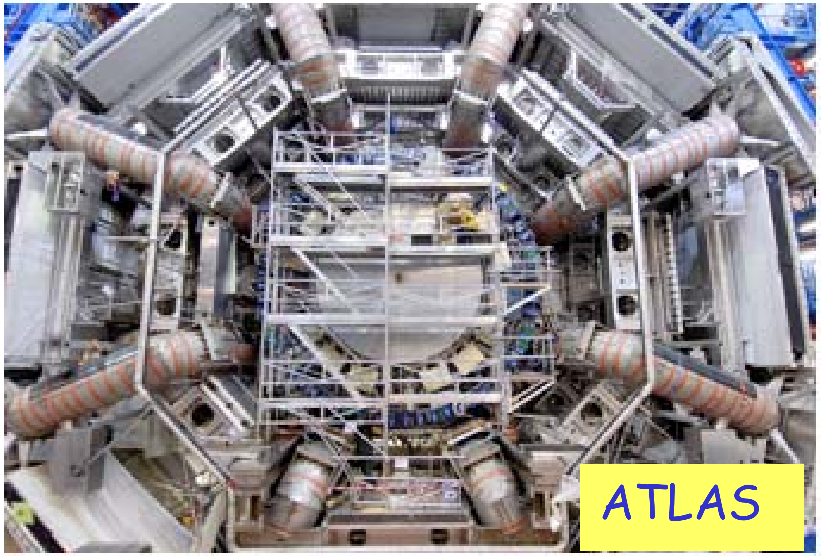
For L ~10^{34} , Evts/yr = **10^{34}** 10^{-37}.10^{-3}.10^{7} ~ 10 /yr !!

Detectors are essentially completed









Atlas & CMS construction started 9 years ago

Now gearing up for first collisions…

+TOTEM, LHCf, MOEDAL

The Large Hadron Collider LHC

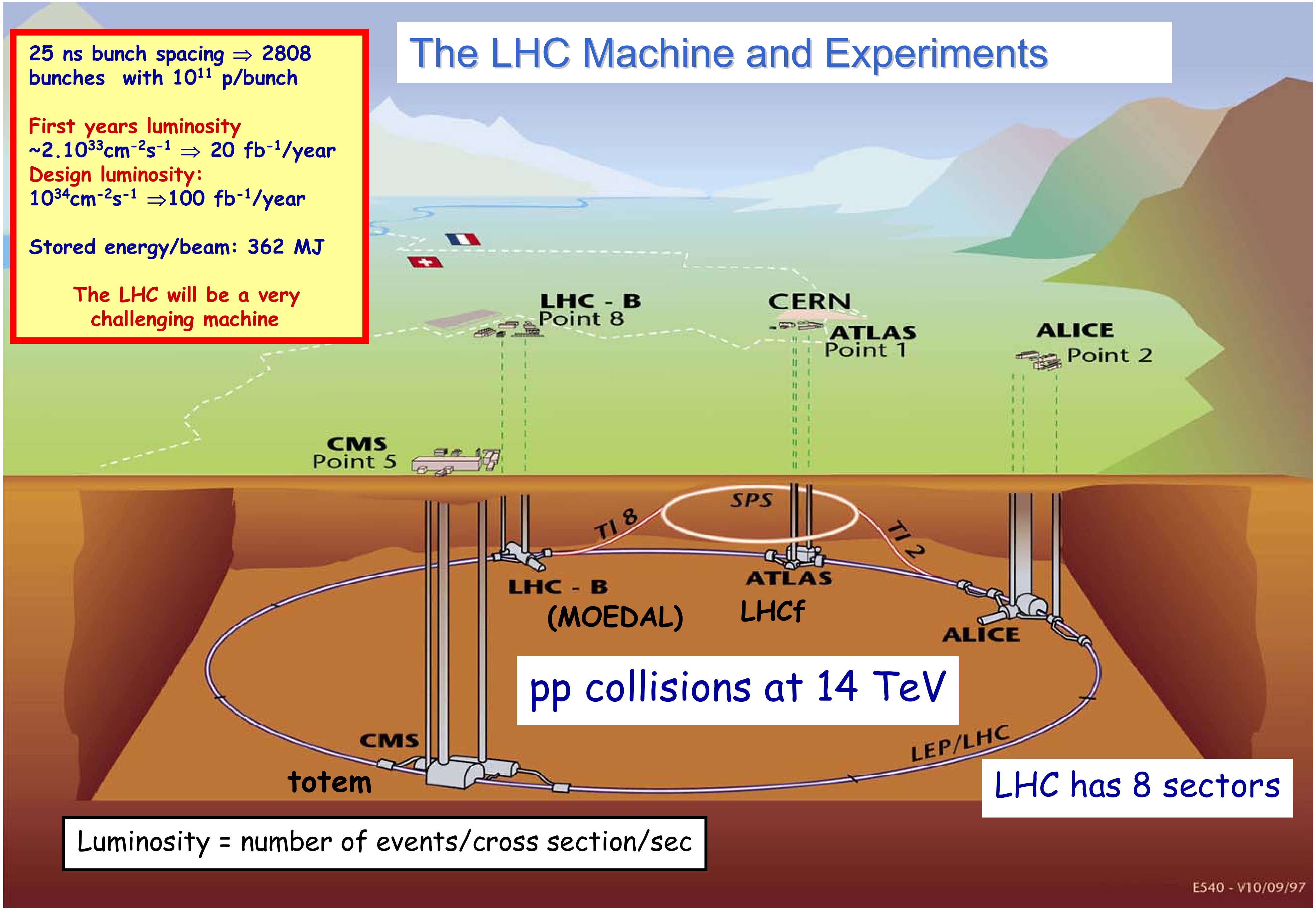
The LHC Machine and Experiments

25 ns bunch spacing ⇒ 2808 bunches with 10^{11} p/bunch

First years luminosity
$\sim 2.10^{33} cm^{-2}s^{-1} \Rightarrow 20\ fb^{-1}/year$
Design luminosity:
$10^{34} cm^{-2}s^{-1} \Rightarrow 100\ fb^{-1}/year$

Stored energy/beam: 362 MJ

The LHC will be a very challenging machine



pp collisions at 14 TeV

LHC has 8 sectors

Luminosity = number of events/cross section/sec

LHC - yet another collider?

The LHC surpasses existing accelerators/colliders in 2 aspects :

- The energy of the beam of 7 TeV that is achieved within the size constraints of the existing 26.7 km LEP tunnel.

LHC dipole field	8.3 T
HERA/Tevatron	~ 4 T

A factor <u>2</u> in field

A factor <u>4</u> in size

- The luminosity of the collider that will reach unprecedented values for a hadron machine:

LHC	pp	~ 10^{34} cm^{-2} s^{-1}
Tevatron	$p\bar{p}$	2×10^{32} cm^{-2} s^{-1}
SppbarS	$p\bar{p}$	6×10^{30} cm^{-2} s^{-1}

A factor <u>100</u> in luminosity

The combination of very high field magnets and very high beam intensities required to reach the luminosity targets makes operation of the LHC a great challenge !

The Accelerator Scheme

Linac

↓

Booster

↓

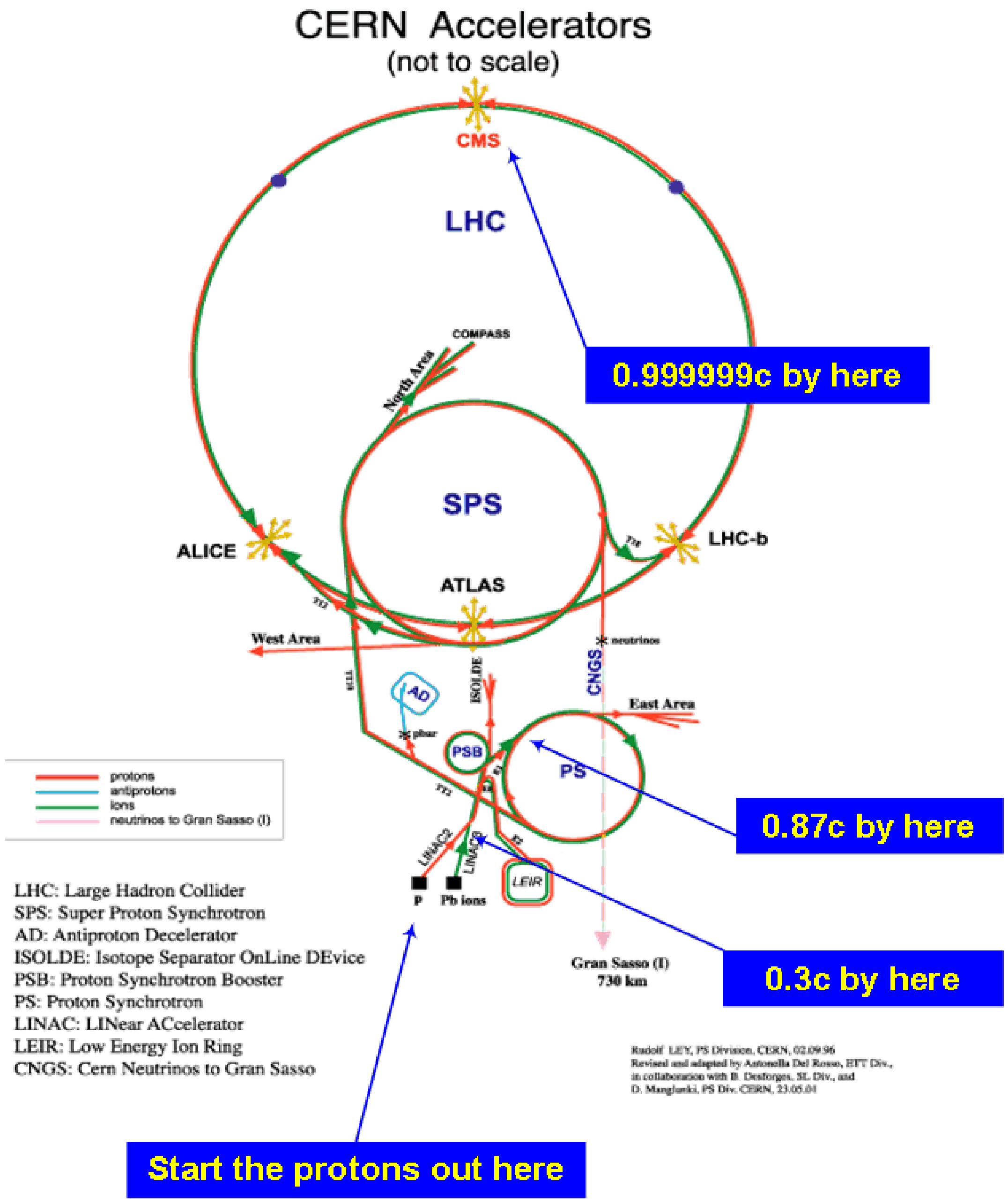
PS

↓

SPS

↓

LHC



LHC Parameters

Momentum at collision	7 TeV / c
Momentum at injection	450 GeV / c
Machine Circumference	26658.883 m
Revolution frequency	11.245 kHz
Number of dipoles	1232
Dipole field at 450 GeV	0.535 T
Dipole field at 7 TeV	8.33 T
Bending radius	2803.95 m
Main Dipole Length	14.3 m

LHC Parameters

Bunch Intensity	1.15×10^{11}
Number of bunches	2808
emittance	5×10^{-10} m
β* fully squeezed	55 cm
beam size at IP	16 μm
Crossing angle	285 μrad
Bunch length	1.06 ns (7.5 cm)
Luminosity	10^{34} cm^{-2}s^{-1}
Total Beam energy	362 MJ per beam

Full list at: http://cern.ch/ab-div/Publications/LHC-DesignReport.html

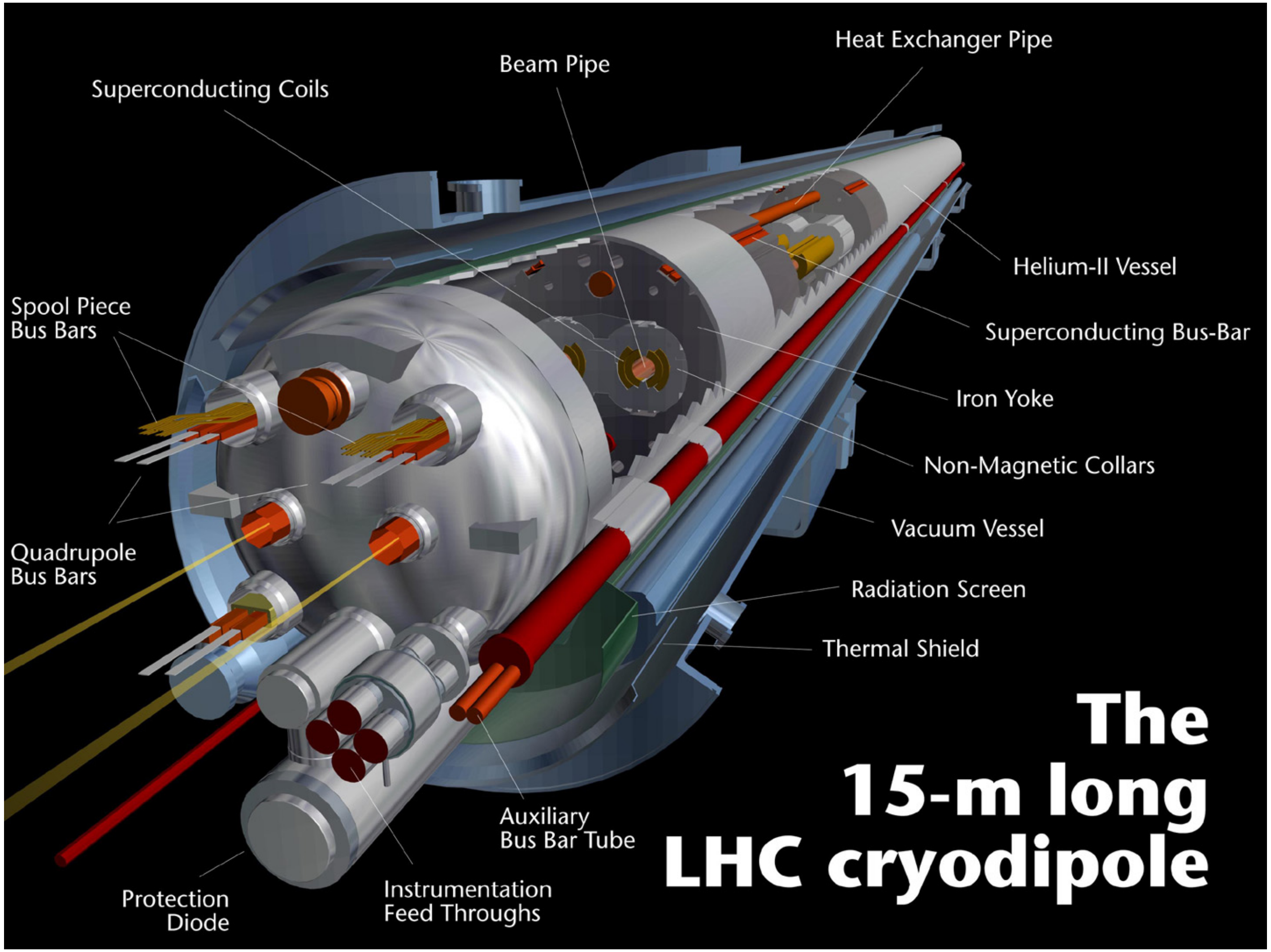
Magnets for the LHC (part of them)

		No. of Magnets	Aperture
Dipole	MB	1232	twin
Lattice quadrupoles	MQ	392	twin
Lattice sextupoles	MS	688	single
Lattice Octupoles	MO	168	twin
Skew quad	MQS	32	twin
Arc skew sext	MSS	64	single
Tuning trim quad	MQT	160	twin
Octupole spool pieces	MCO	1232	single
Decapole spool pieces	MCD	1232	single
Sextupole corrector (b3) in MBA & MBB (spool piece corrector)	MCS	2464	single
Insertion region long trim quads	MQTLI	36	twin
Arc dipole corrector	MCBH	376	single
Arc dipole corrector	MCBV	376	single
Twin aperture separation dipole in IR (194mm). D4	MBRB		twin
Twin Aperture Separation dipole in IR(188mm). D2	MBRC	8	twin

About 9000 magnets of which 1232 are the cryodipoles

The Cryodipole Magnets

- Superconducting (1.9 K) dipoles producing a field of 8.4 T – current 11,700A ⇒ 2-in-1 magnet design
- Cost: ~ 0.5 million CHF each. Need 1232 of them
- Stored magnetic energy up to 1.29 GJ per sector.
- Total stored energy in magnets = 11GJ
- One dipole weighs around 34 tonnes



Superfluid Helium

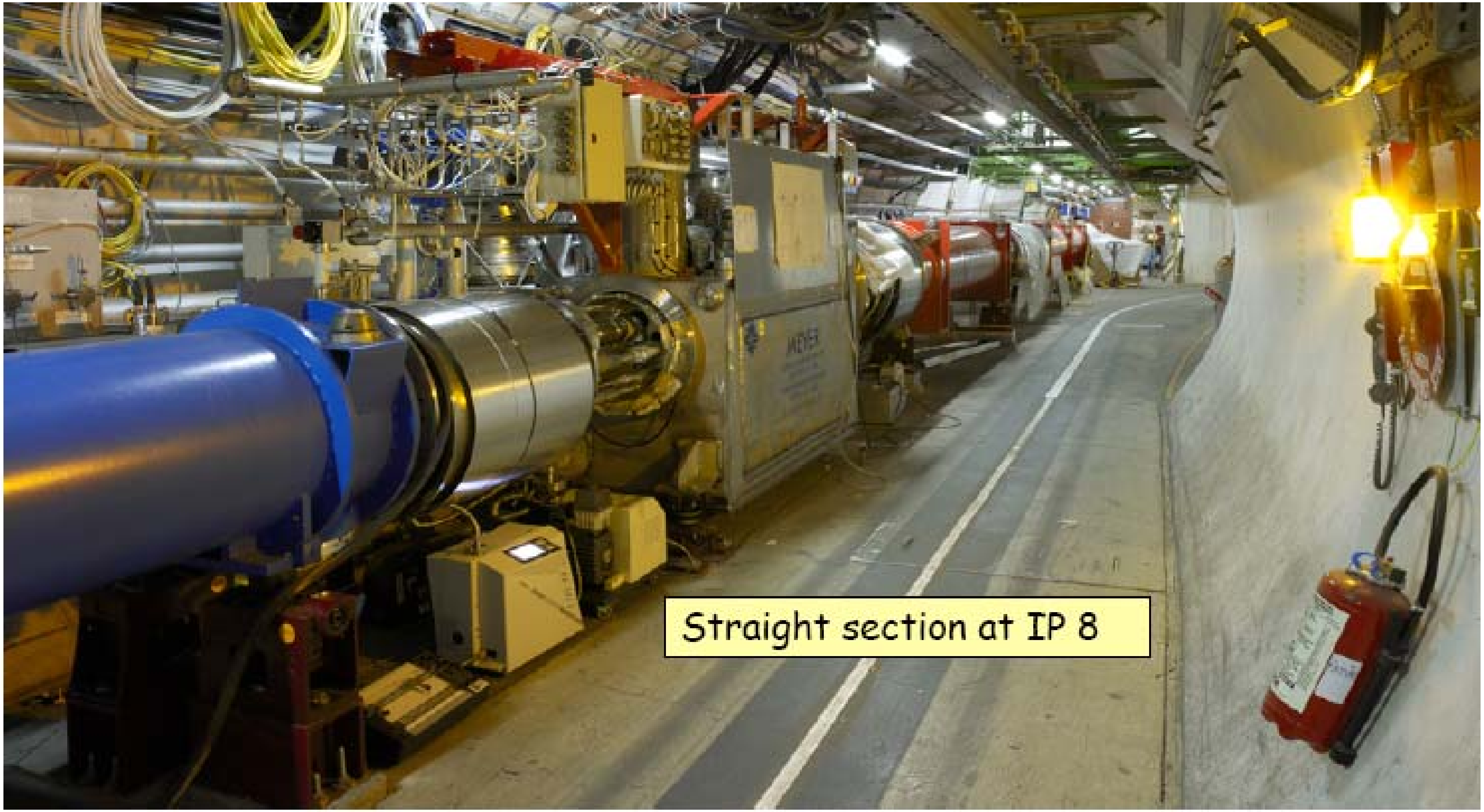
- To produce the high magnetic fields we need very high currents…

- Make use of the remarkable properties of He II

- Superfluid helium:

  - Very high thermal conductivity (3000 time high grade copper)
  - Very low coefficient of viscosity… can penetrate tiny cracks, deep inside the magnet coils to absorb any generated heat.
  - Very high heat capacity…stablizes small transient temperature fluctuations

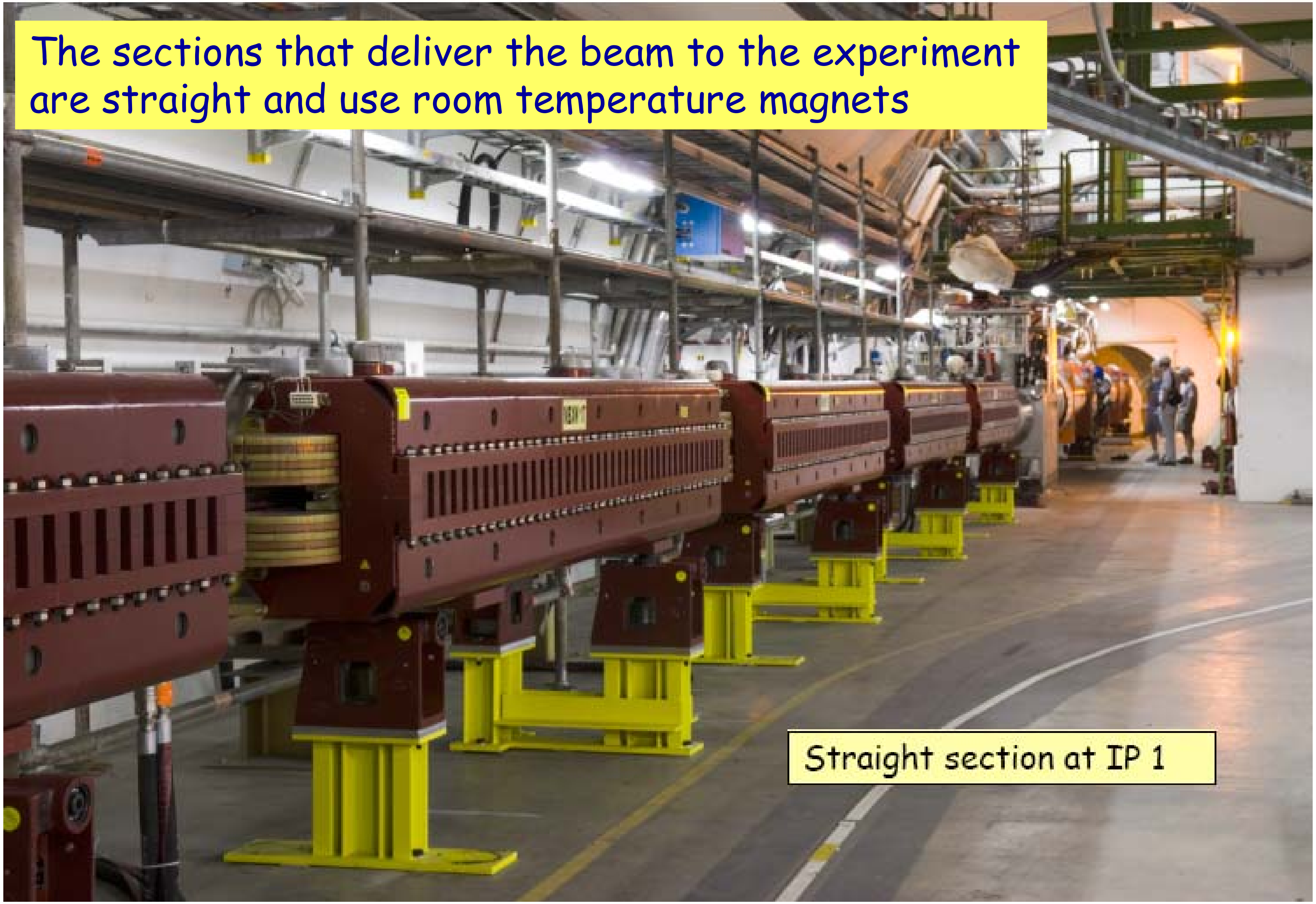
LHC is more than just dipoles…



Straight section at IP 8

Straight Sections

The sections that deliver the beam to the experiment are straight and use room temperature magnets



Straight section at IP 1

Energy in the beam

Comparison…

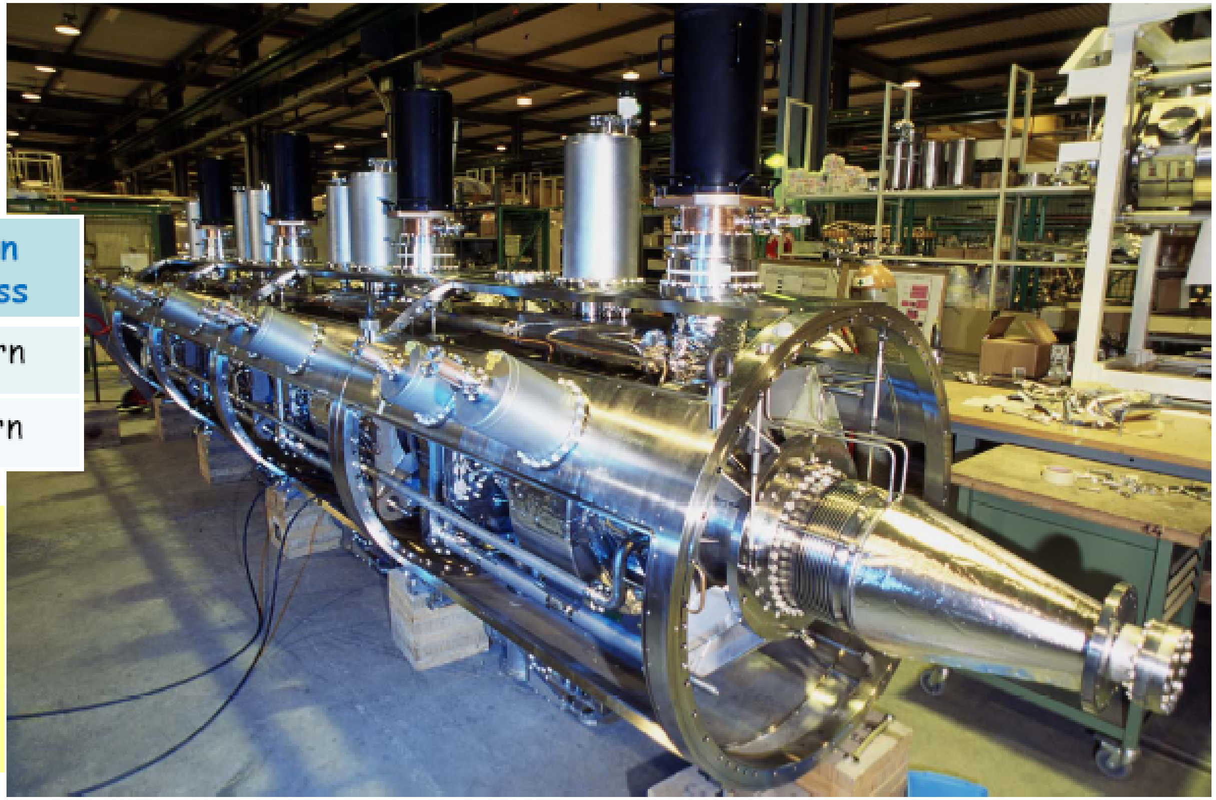
The energy of an A380 at 700 km/hour corresponds to the energy stored in the LHC magnet system :

Sufficient to heat up and melt 12 tons of Copper!!

LHC RF system

- The LHC RF system operates at 400 MHz.
- It is composed of 16 superconducting cavities, 8 per beam.
- Peak accelerating voltage of 16 MV/beam.

For LEP at 104 GeV : 3600 MV/beam !

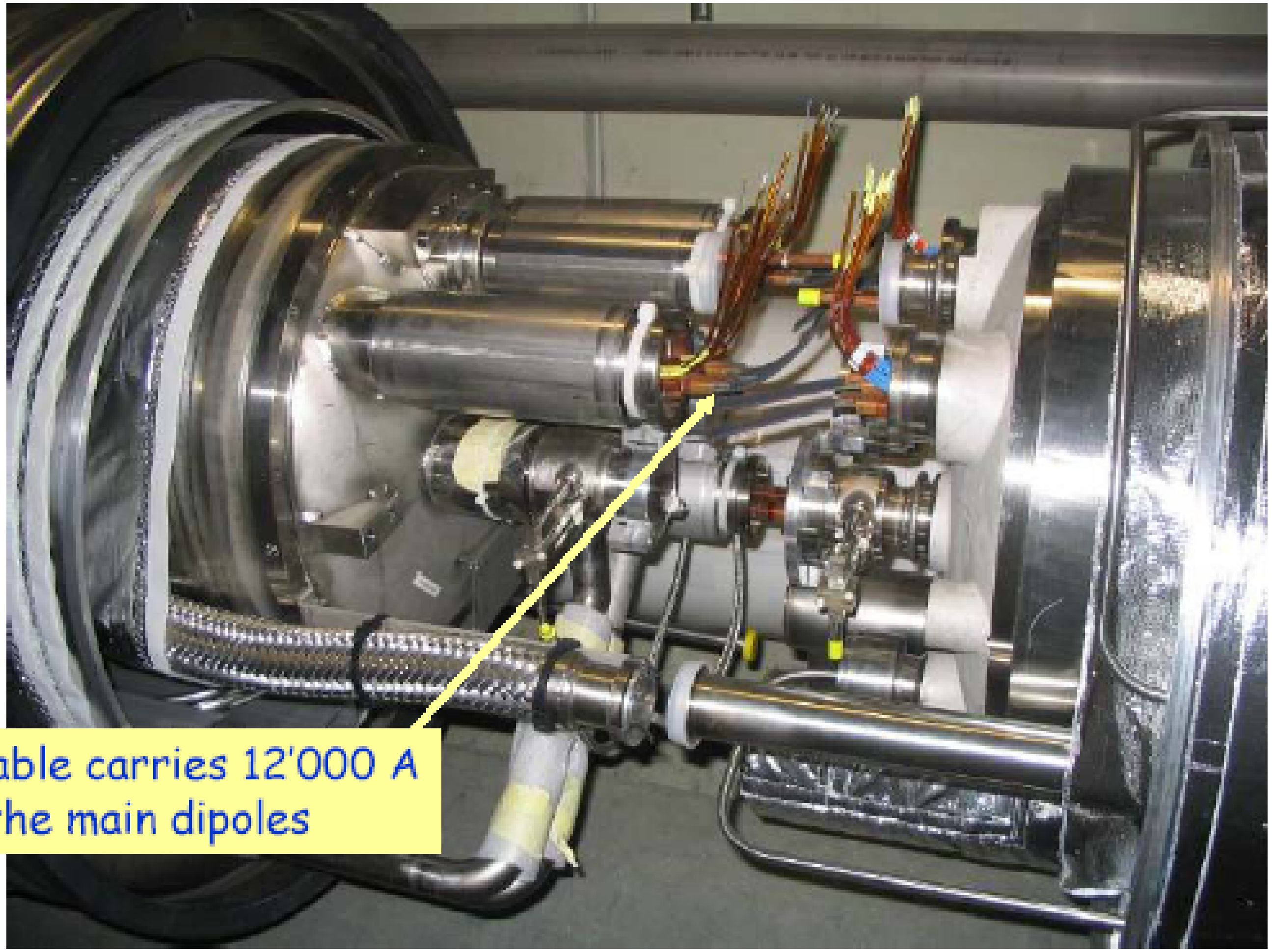


	Synchrotron radiation loss
LHC @ 7 TeV	6.7 keV /turn
LEP @ 104 GeV	~3 GeV /turn

The LHC beam radiates a sufficient amount of visible photons to be actually observable with a camera ! (total power ~ 0.2 W/m)

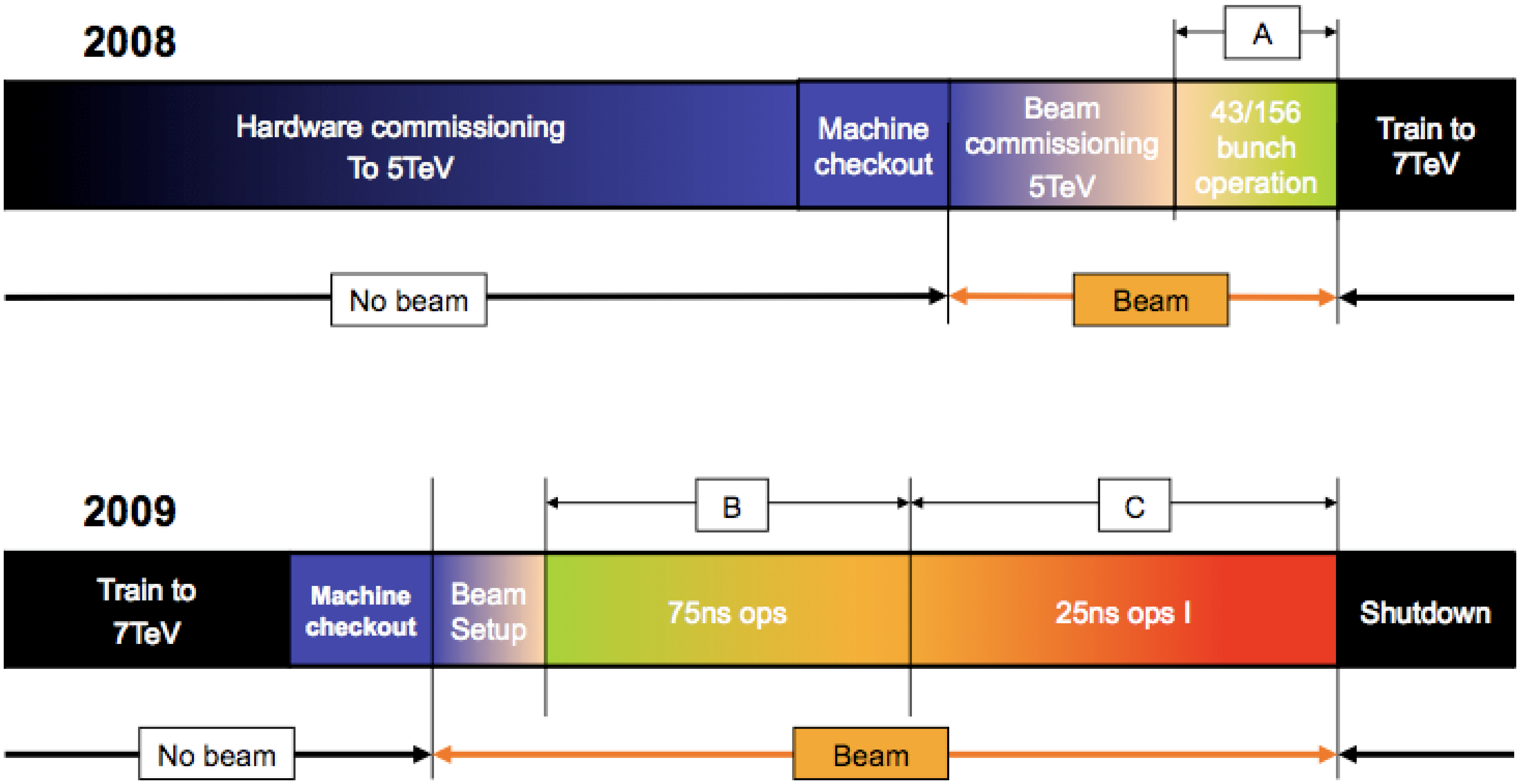
Complex interconnects

Many complex connections of super-conducting cable that will be buried in a cryostat once the work is finished.



Planned Schedule (early summer 08)

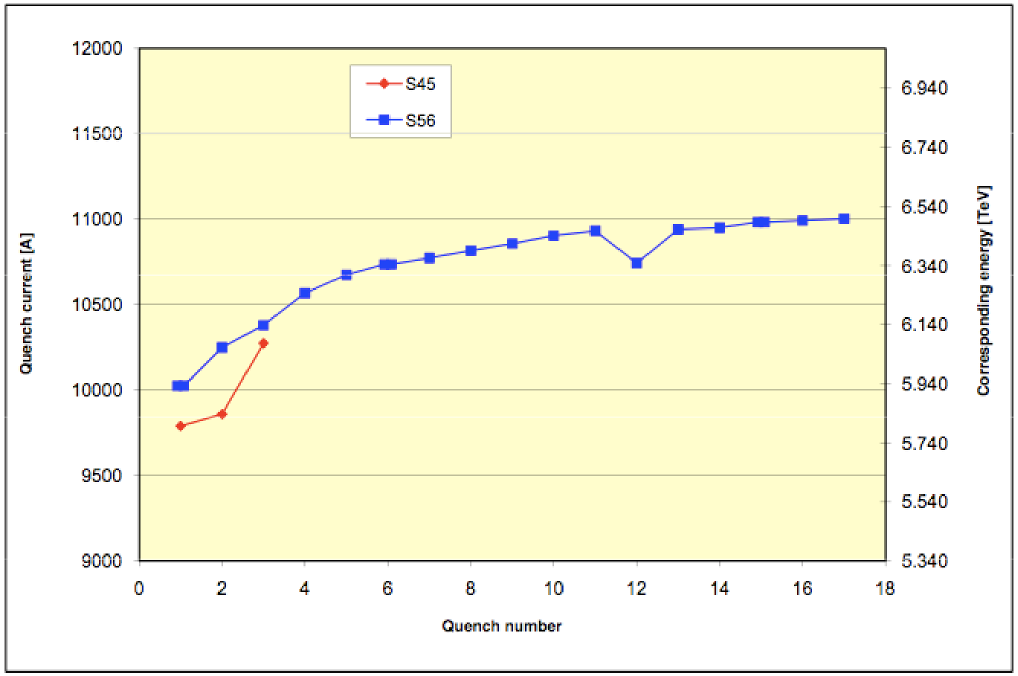
First Beam circulating on 10/9/08



Some Issues Before Starting…

- Some magnets, while being tested before installation to the 7 TeV corresponding current, now seem to quench before (ie they turn from superconducting to normal state).
- Getting all magnets to work safely @ 7 TeV will be some work and was planned for the coming 08-09 winter shutdown

Start in 2008 was planned with 10 TeV

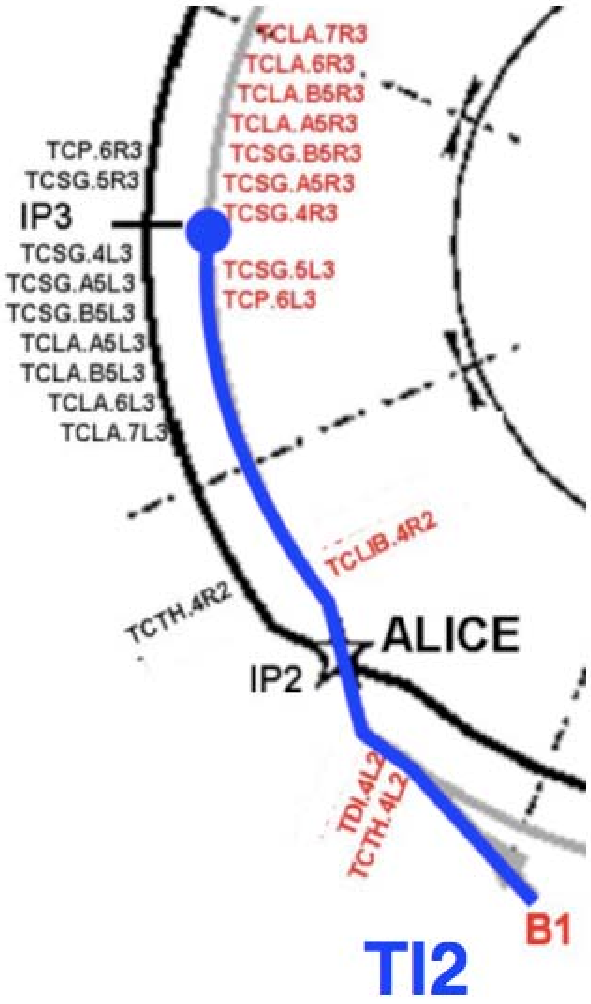


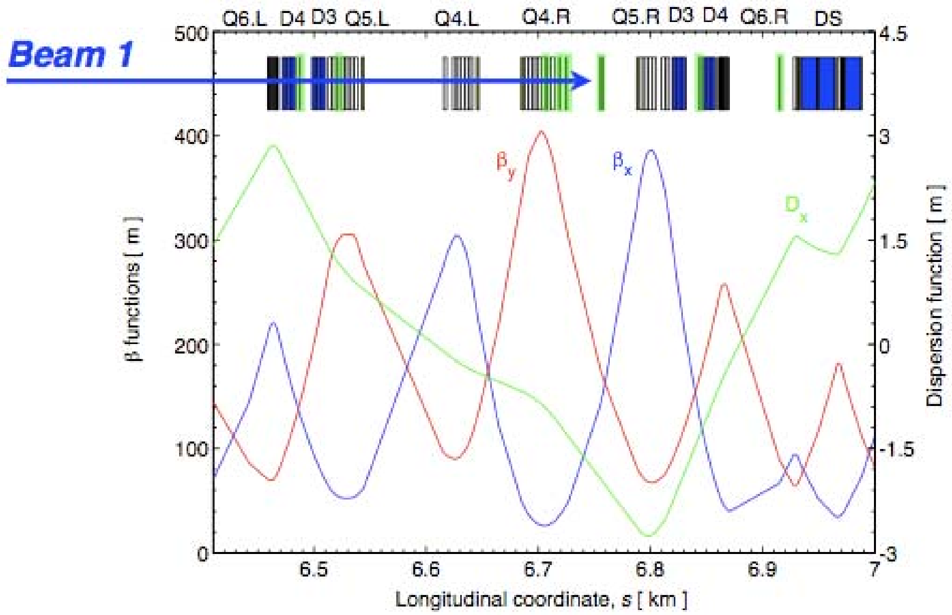
The LHC sectors were all commissioned to 5.5. TeV before first beam

That is, all but one..

Beam Injection on 9/10 August

Layout of beam path





(1) Commission end of TI2

(beam on TDI on IP2-left)

(2) Steer beam up to IR3

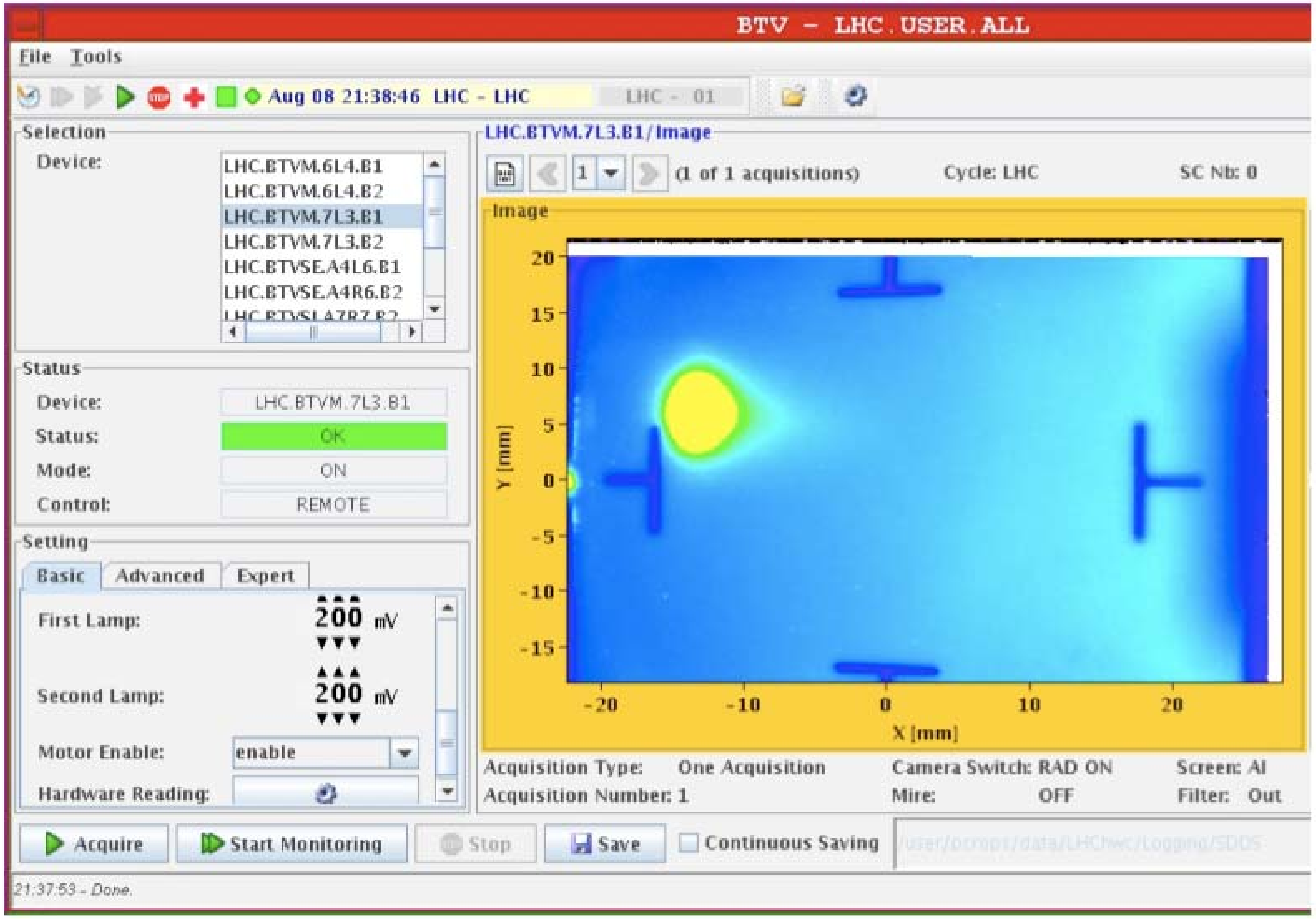
(3) Stop beam on the collimators

(5 Carbon primary+secondary colls;

4 Tungsten absorbers)

Beam Injection on 9/10 August

Beam on screen at IR3 (first shot!)



Checking the machine before D-Day

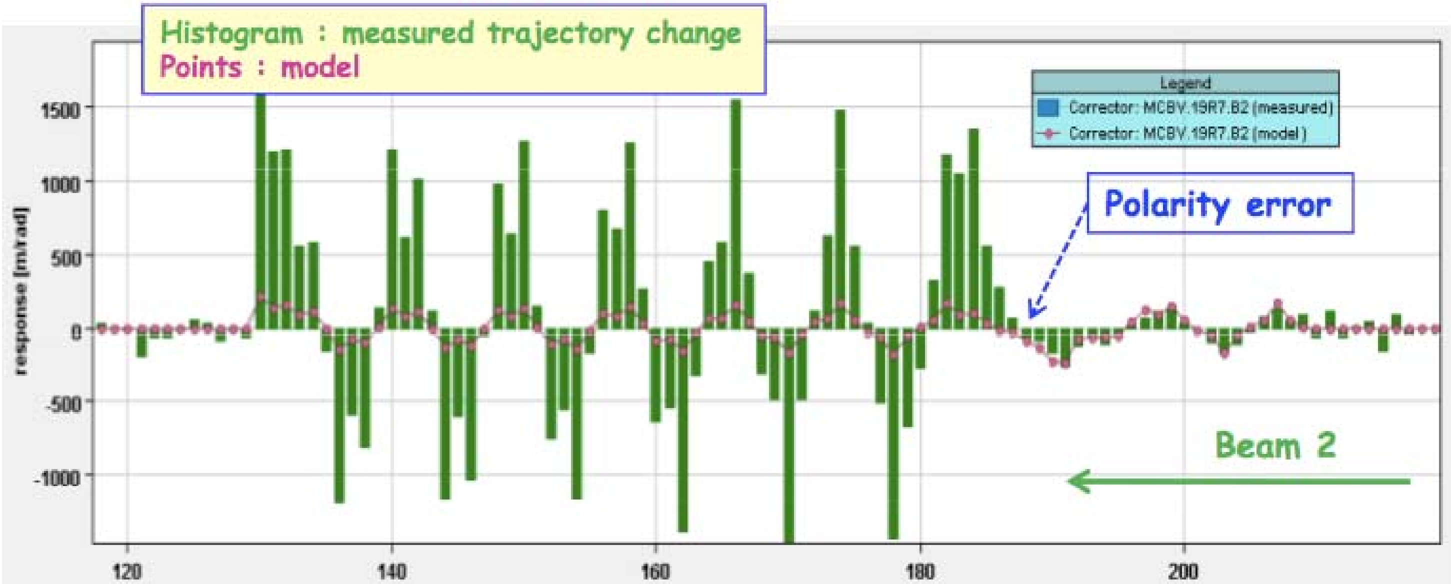
Polarity Errors

In single pass (trajectory) mode, focusing errors can be located by:

- launching controlled trajectory oscillations
- comparing the measurement with the predictions

>> Identified a number of sign errors – some rather severe (see below) !

Example of a polarity inversion of a main quadrupole (IR7). This error would have spoiled the 10th September show – very difficult to get past such an error.



Checking the Machine before D-Day

And we quenched with beam…

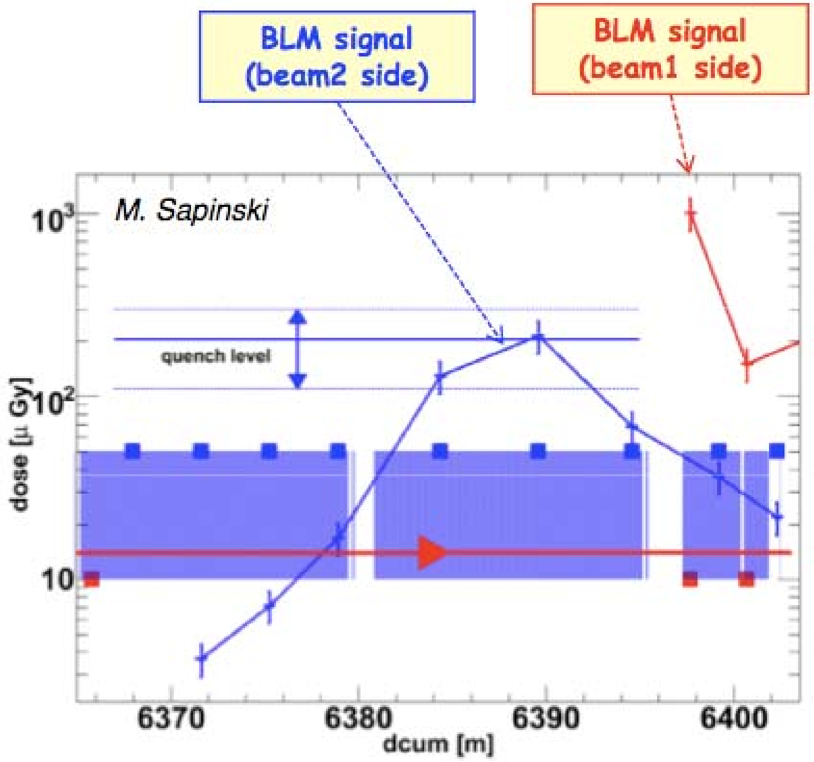
In the very early morning of August 9th during the first test, we provoked the first beam induced quench:

- Bunch intensity ~4×10⁹ p, which is within the expected range.

  >> reduced the commissioning intensity to ~2-3×10⁹ p.

In preparation of the 10th, a test revealed that even with ~2×10⁹ p one can quench

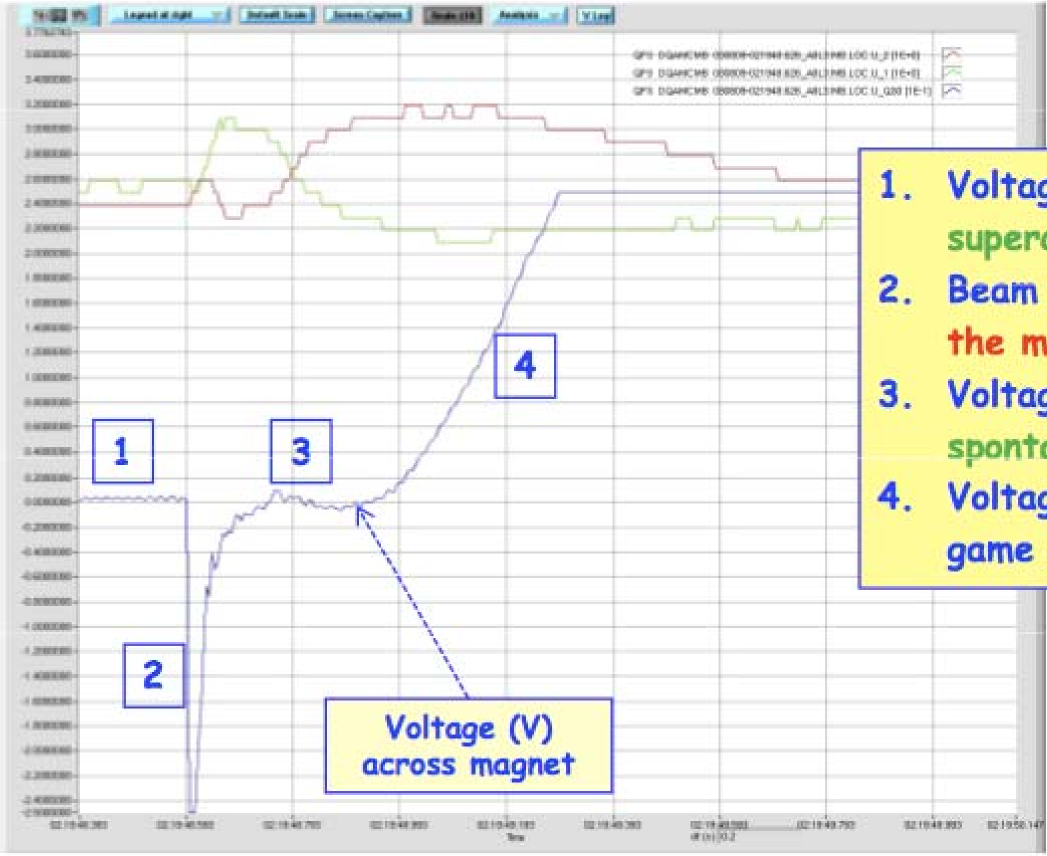
– but very unlikely in normal operation due to the large impact angle.



Preliminary results !

Checking the Machine before D-Day

A look at the first quench : magnet perspective



400 ms

1. Voltage = 0, no resistance, magnet is superconducting.
2. Beam impact, Voltage != 0 : resistive area in the magnet !
3. Voltage back to 0 – magnet has recovered spontaneously – very little energy deposition !
4. Voltage != 0 : protection systems enter the game and force-quench the magnet etc…

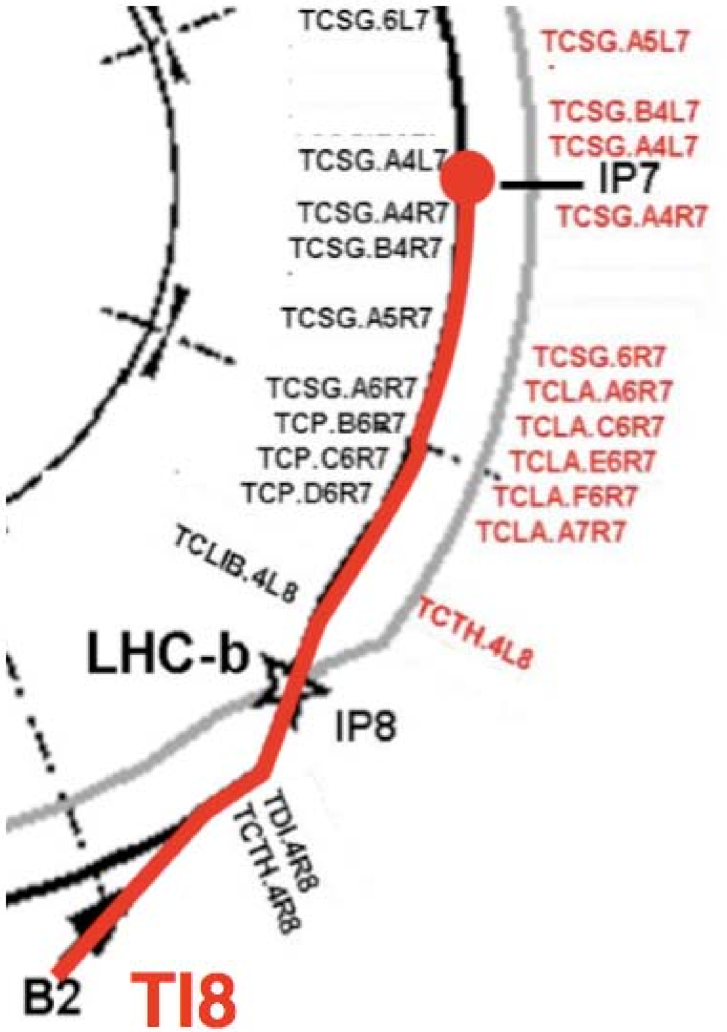
Beam injection on 23/24 August

Outlook

Results of first beam tests are very encouraging...

A journey of a thousand miles begins with a single step!

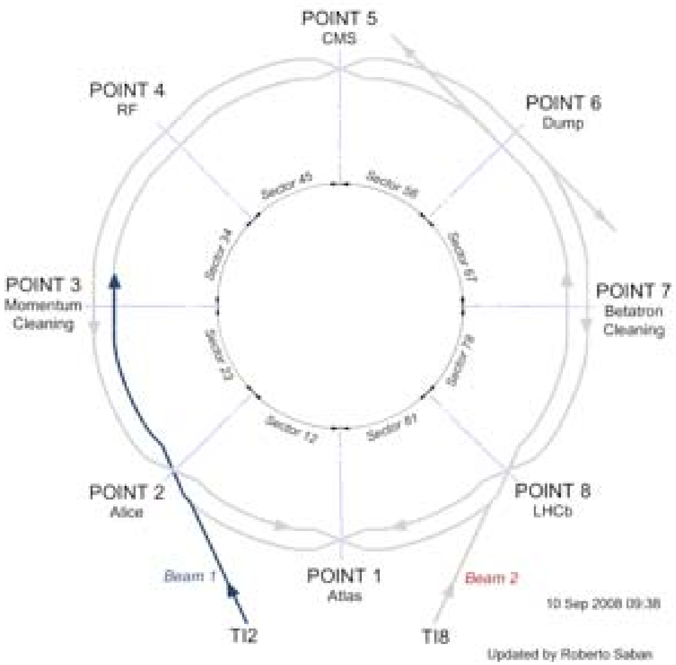
Lao-tzu, The Way of Lao-tzu
Chinese philosopher (604 BC - 531 BC)

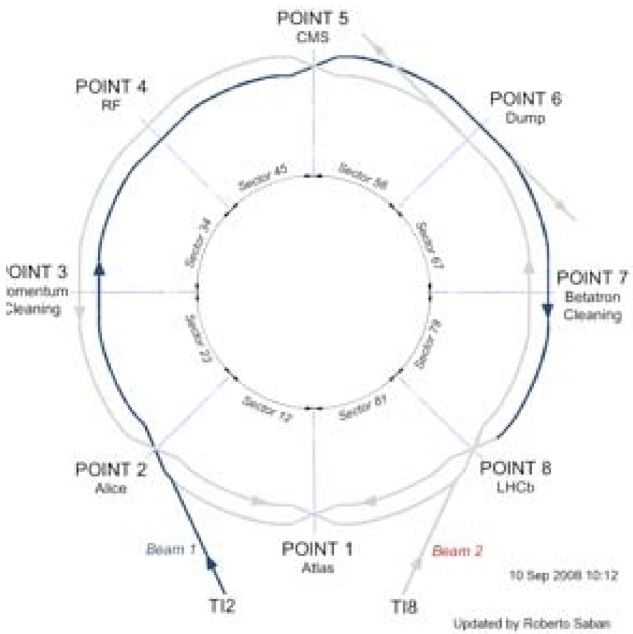


September 10th 2008

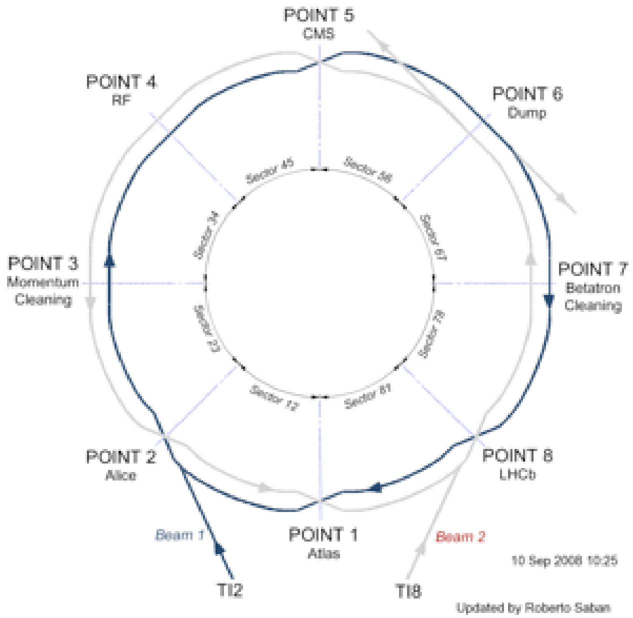
10/9/08

Start 9:30

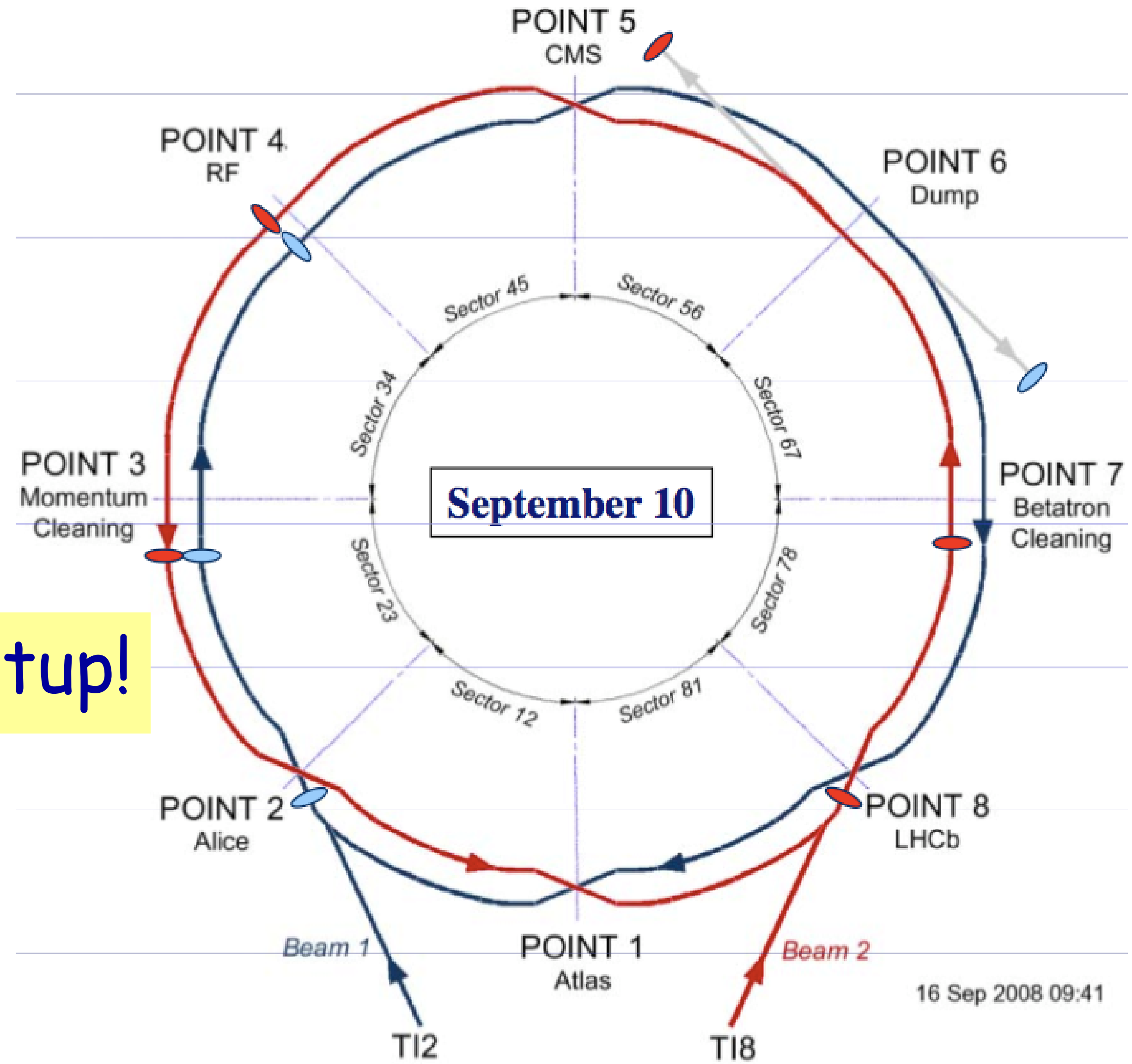




10 SEP, 10:25 FIRST COMPLETE LHC ORBIT!



September 10th 2008

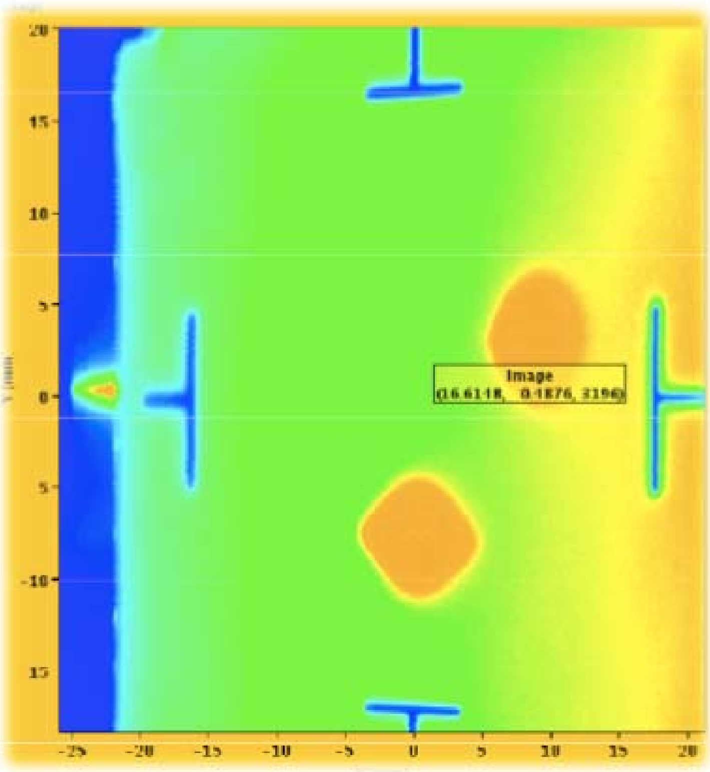


LHC startup!

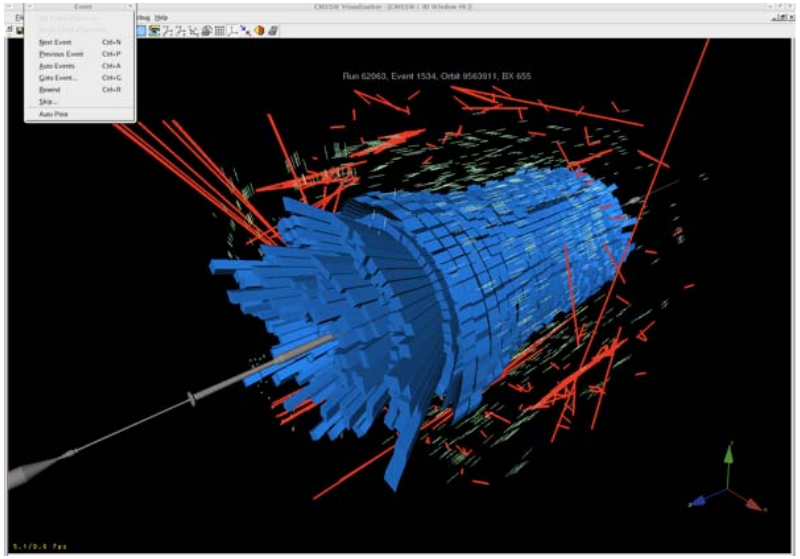
Beam goes around the full LHC

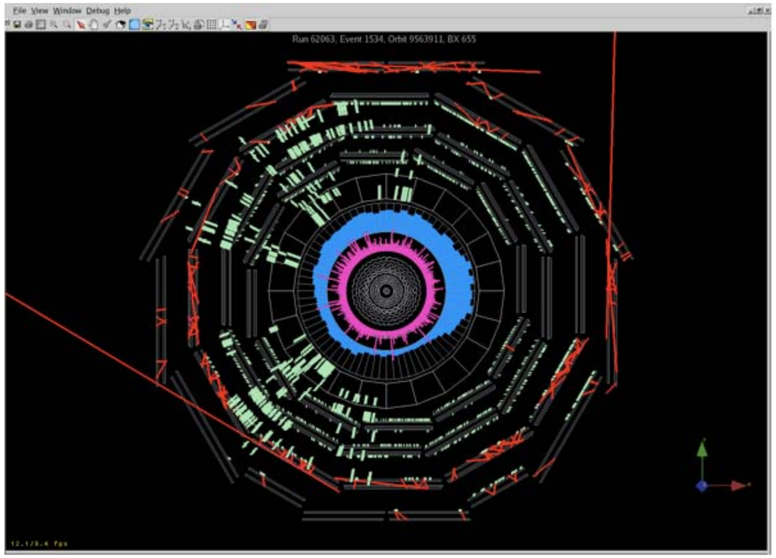
First Beam Around

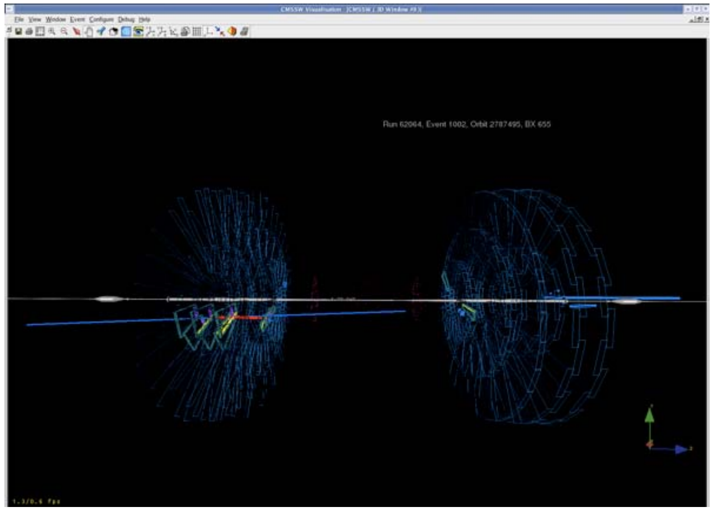
Sept 10th 10:30 : two beam spots on a screen near ALICE indicate that the beam has made 1 turn.

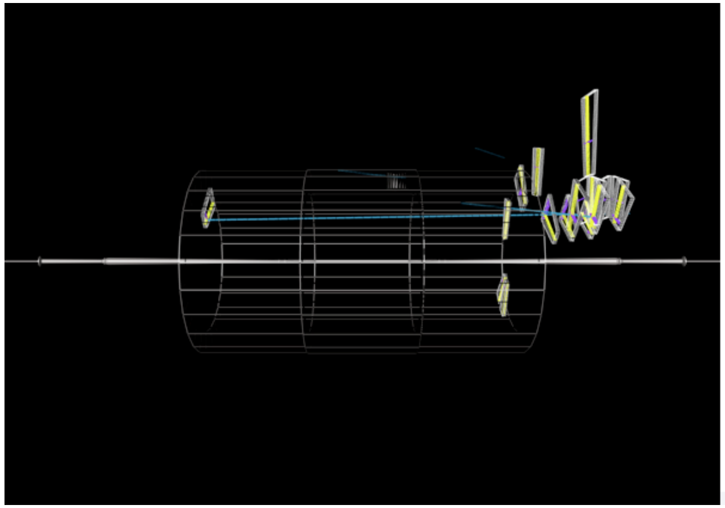


Beam Halo and Splashes in CMS

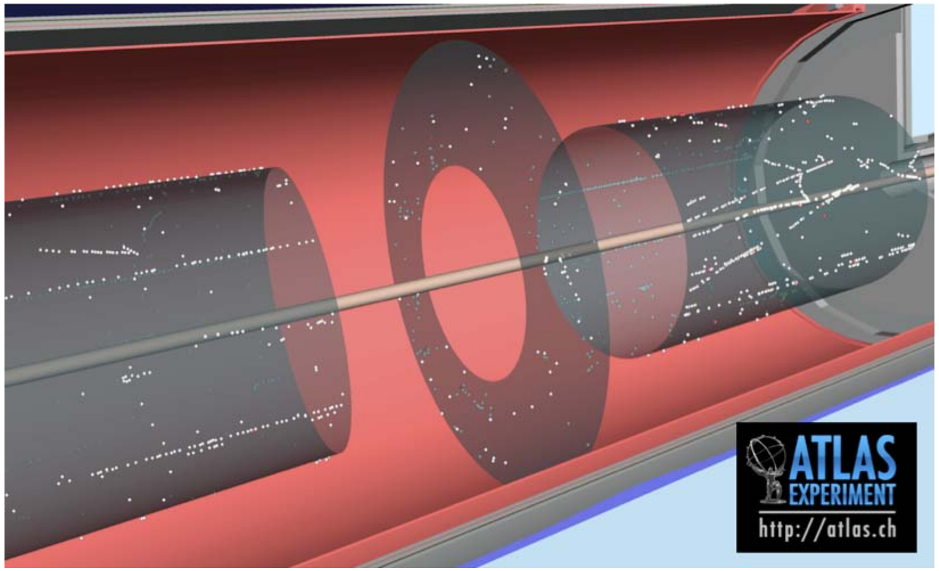


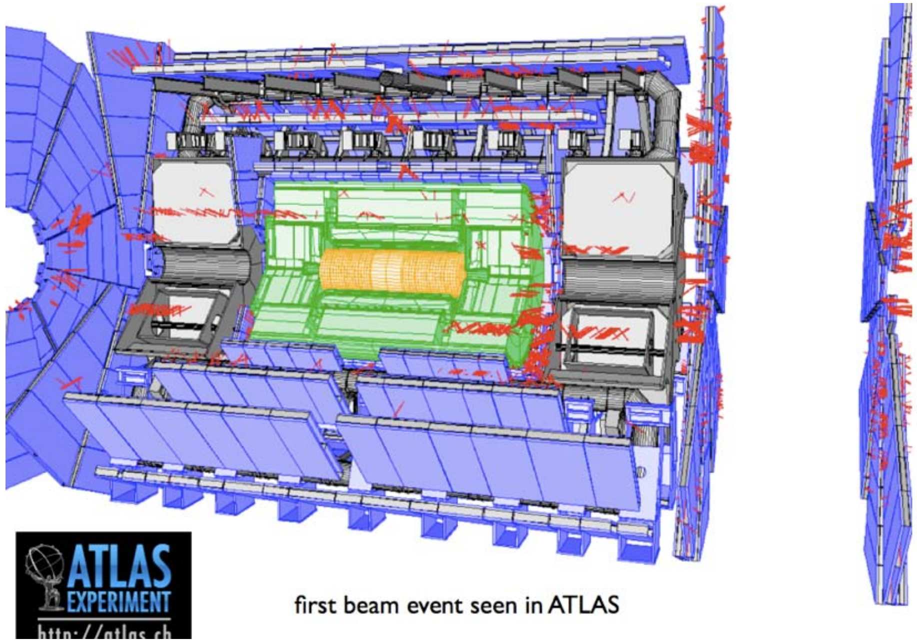




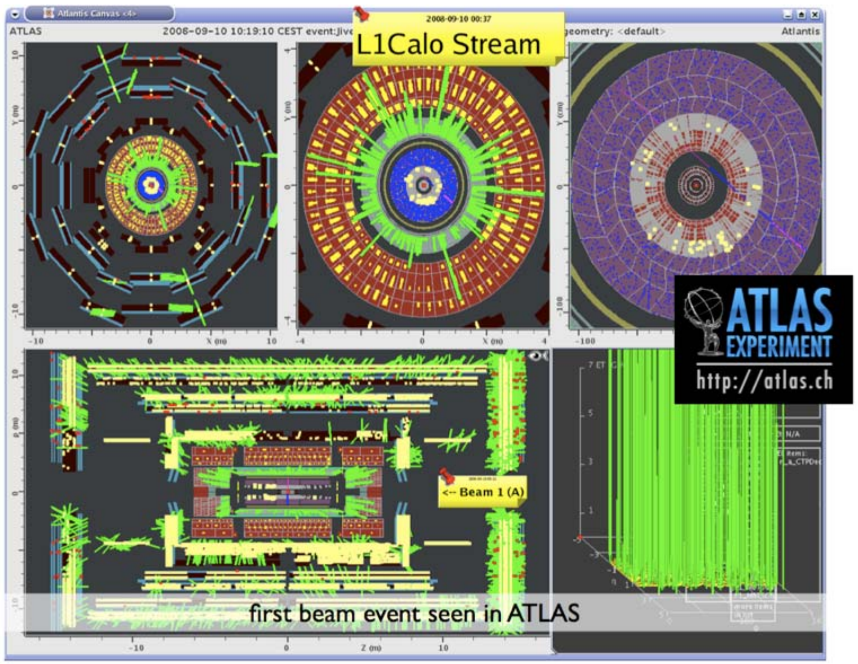


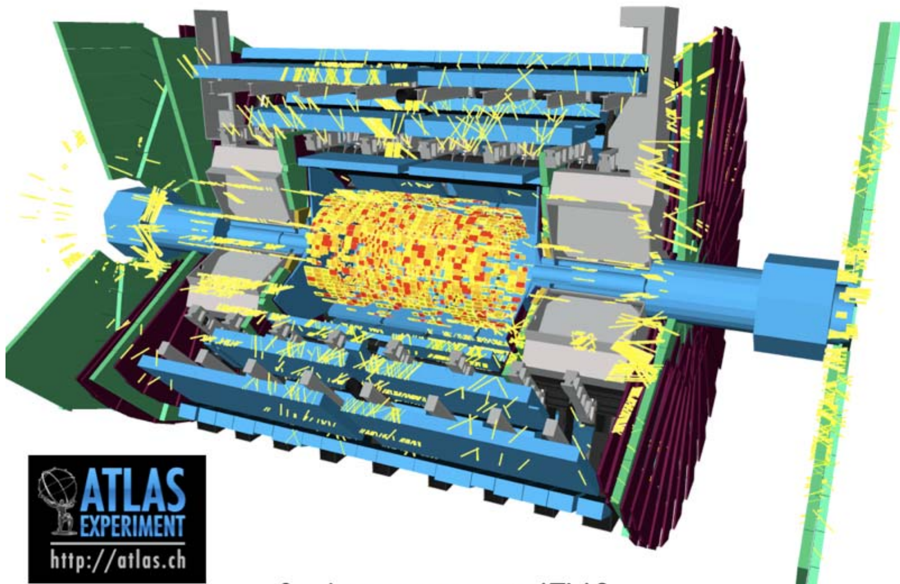
Beam Halo and Splashes in ATLAS





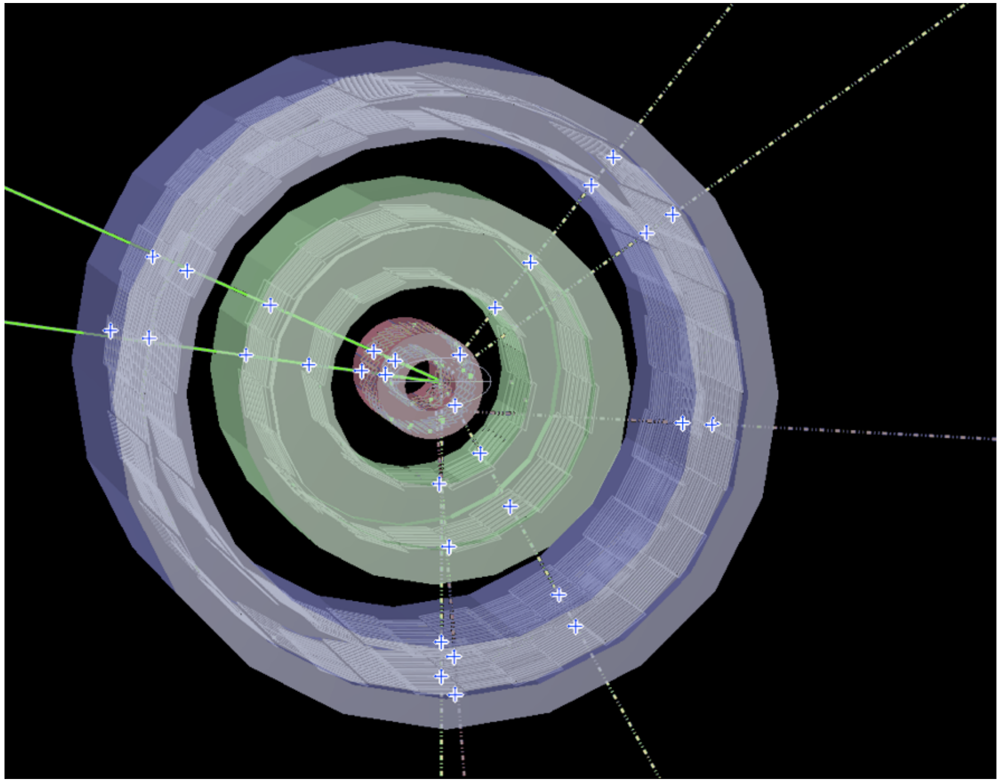
first beam event seen in ATLAS

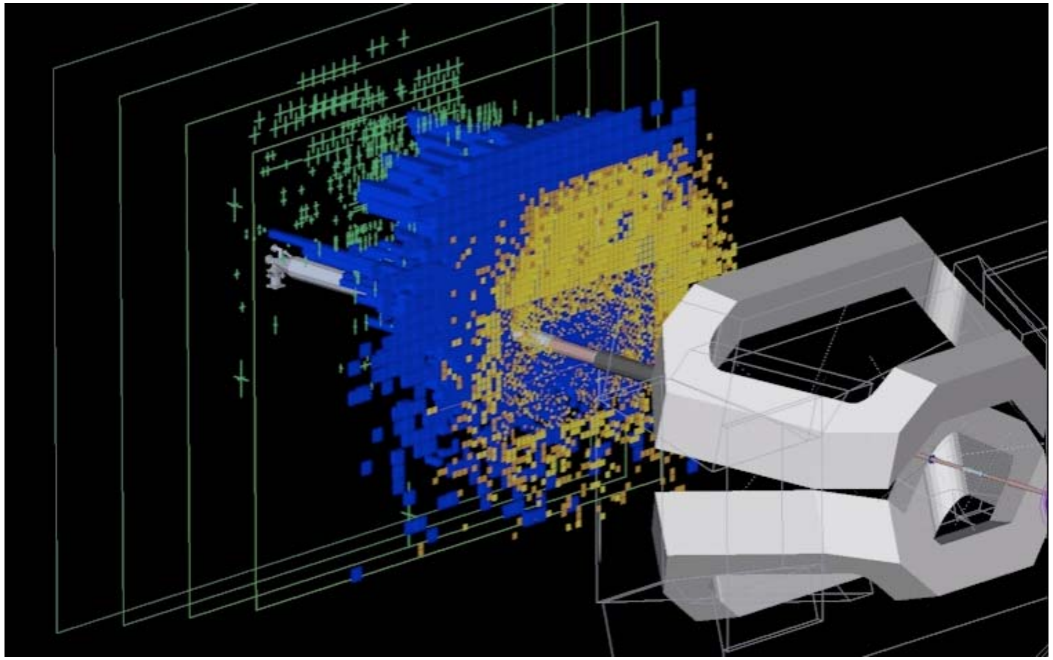




first beam event seen in ATLAS

ALICE and LHCb





For the History Records

September 10th

> 300 Journalist

Despite the presence of an unbelievable crowd of people :

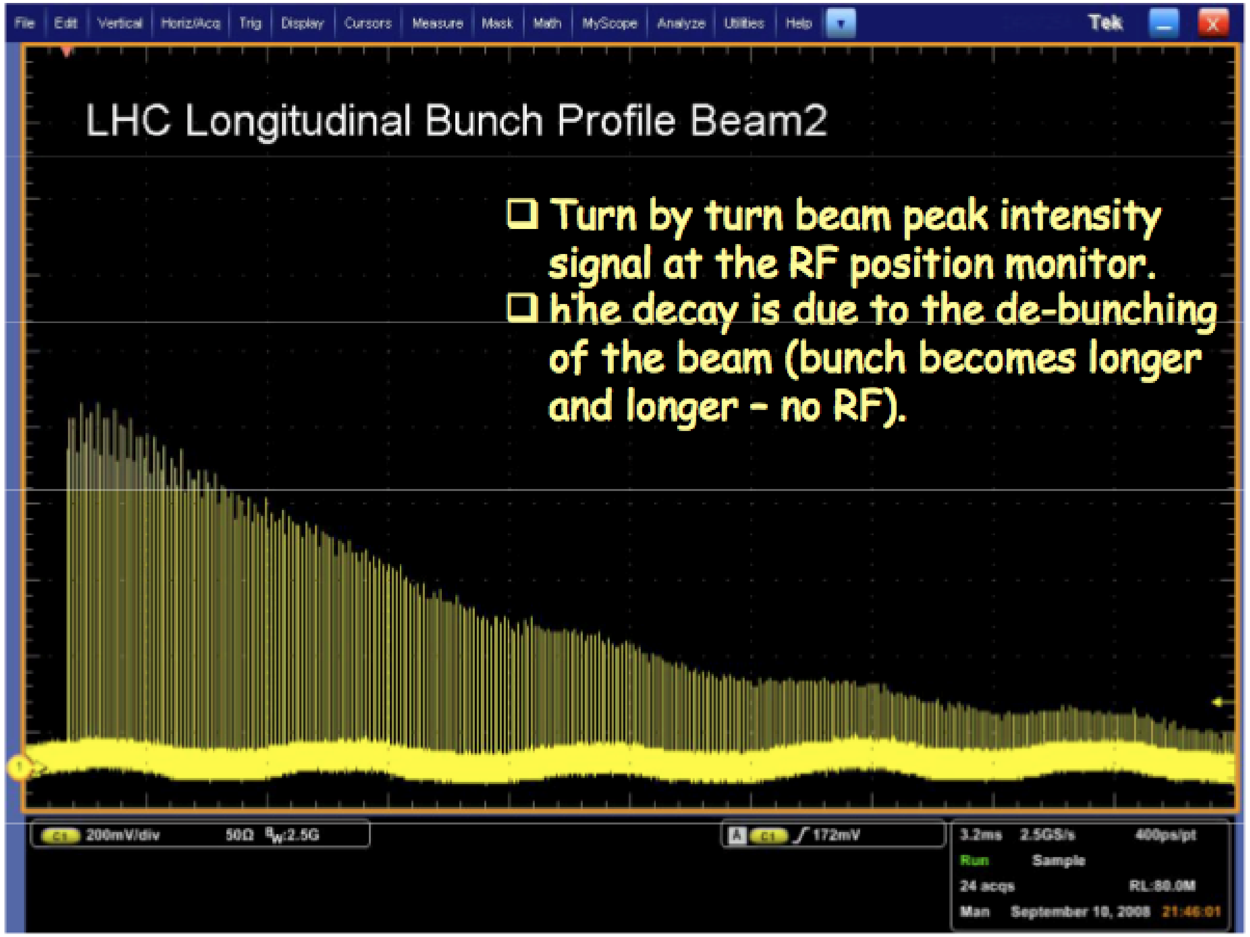
- 10:30 : Beam 1 around the ring (in ~ 1 hour). Beam makes ~ 3 turns.
- 15:00 : Beam 2 around the ring, beam makes 3-4 turns.
- 22:00 : Beam 2 circulates for hundreds of turns…

Circulating Beam

Beam 2 circulating – no RF

Evening of September 10th , after the crowds left :

Beam 2 makes hundreds of turns after some empirical correction (no RF)



Circulating Beam

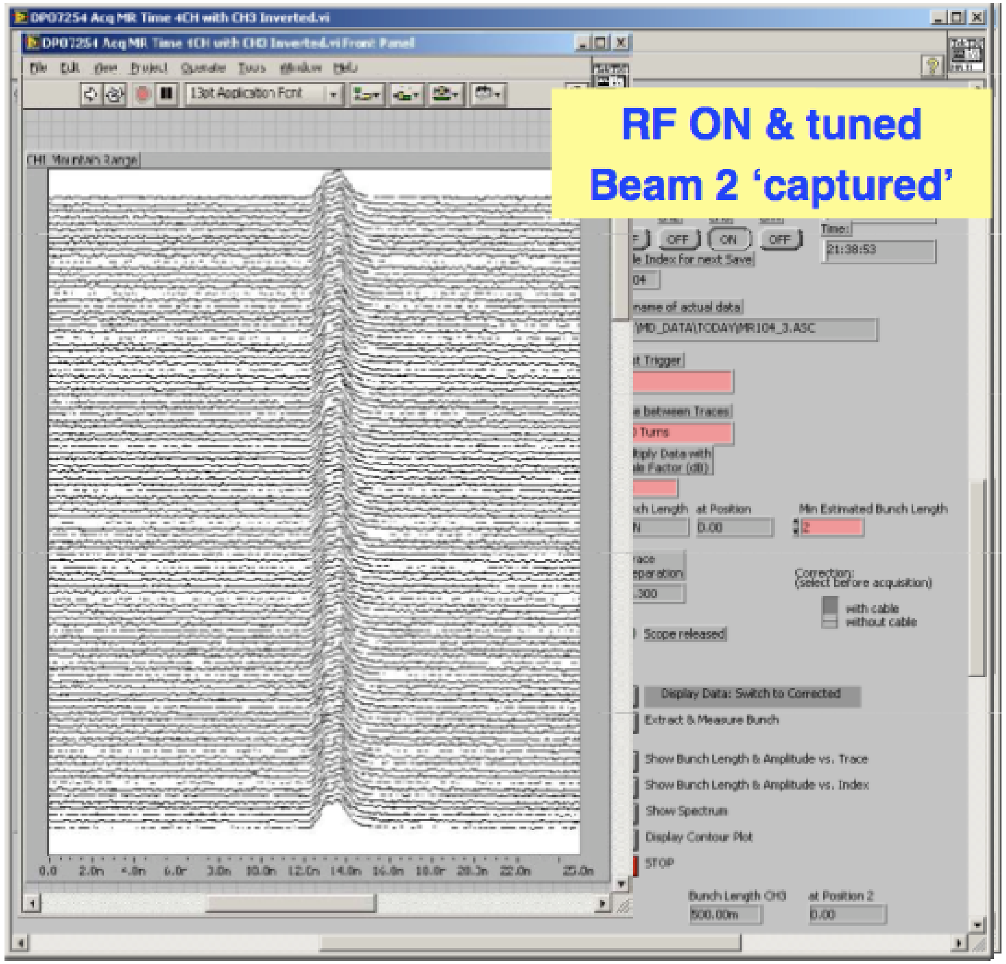
Beam 2 captured by RF system

Evening/Night of September 11th

Beam captured and stored for ~ 30 minutes

Progress was very rapid and swift

Hopes were to have first collisions in ~ a week



But then…

Electrical transformer problem…

Late evening of Friday Sept. 12th an old LEP HV transformer in point 8 failed, leading to a stop of the cryogenics – LHC 'off'.

- TS/EL had no spare (!), but a spare CMS transformer was recuperated and installed during the weekend.
- Due to various other problems, the cryogenic system was only completely back for the Friday 19th.
- In the meantime, access and commissioning of remaining circuits wherever cryogenics conditions were OK.
- Late in the morning of Sept. 19th the last dipole circuit of sector 3-4 is commissioned to 5.5 TeV…

Slides from H. Weninger

Black 19th of September ☹

Status on the morning of Sept. 19th

Beam 2 well advanced:

- Beam captured in RF system, good orbit and lifetimes of hours.
- Optics in ‘reasonable’ shape, preparing for refinements.

Beam 1 in same state as 10th:

- First turn established, beam in for 3-4 turns.

Objectives for the weekend

- Bring beam 1 to same level as beam 2.
- Improve measurement and correction on beam 2.
- Try to circulate both beams together …

But….

And then came September 19th 11:18…

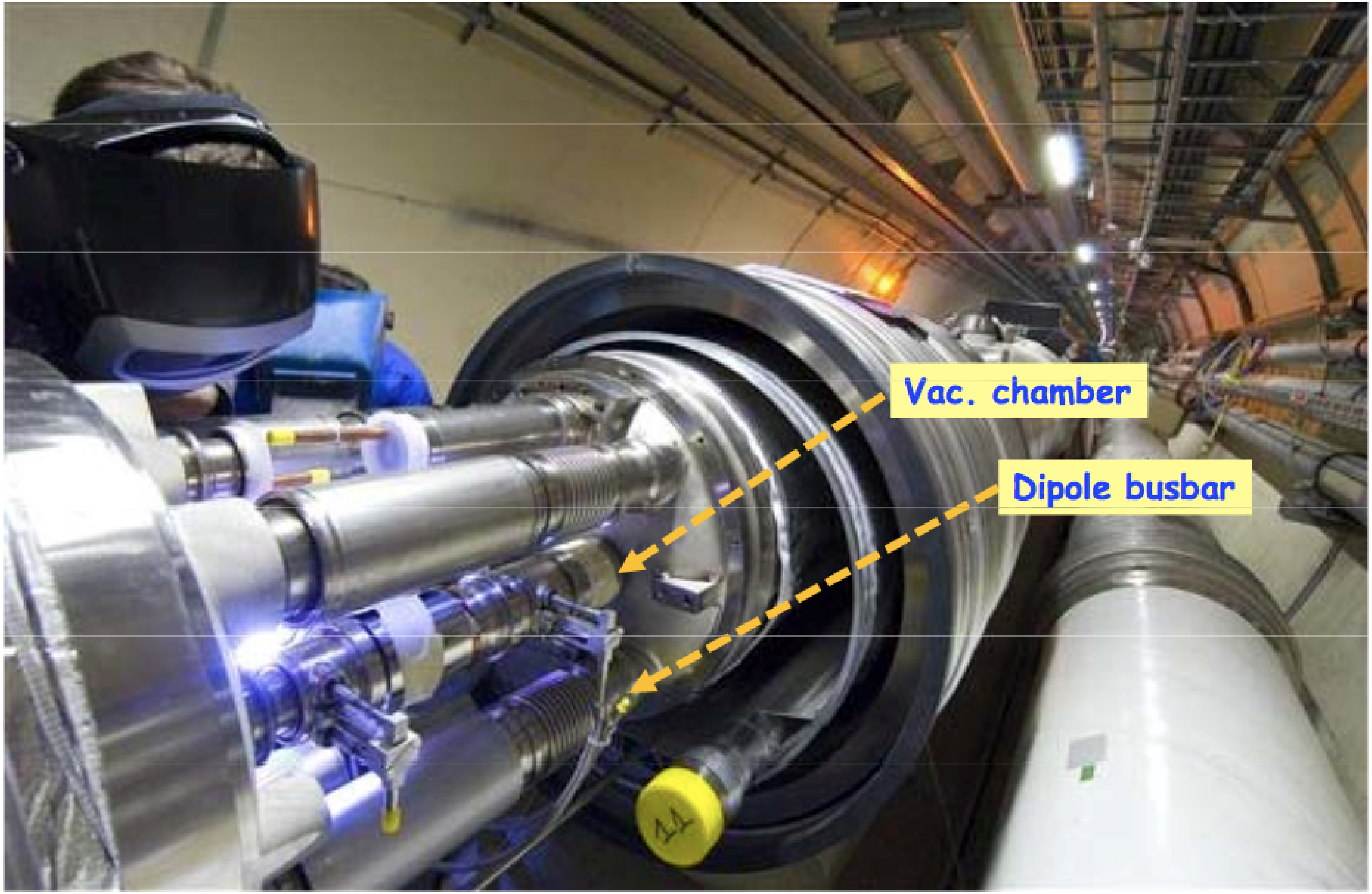
During the last commissioning step of main dipole circuit in sector 34, to 9.3kA :

- At 8.7kA, development of resistive zone in the dipole bus bar between Q24.R3 and the neighboring dipole.

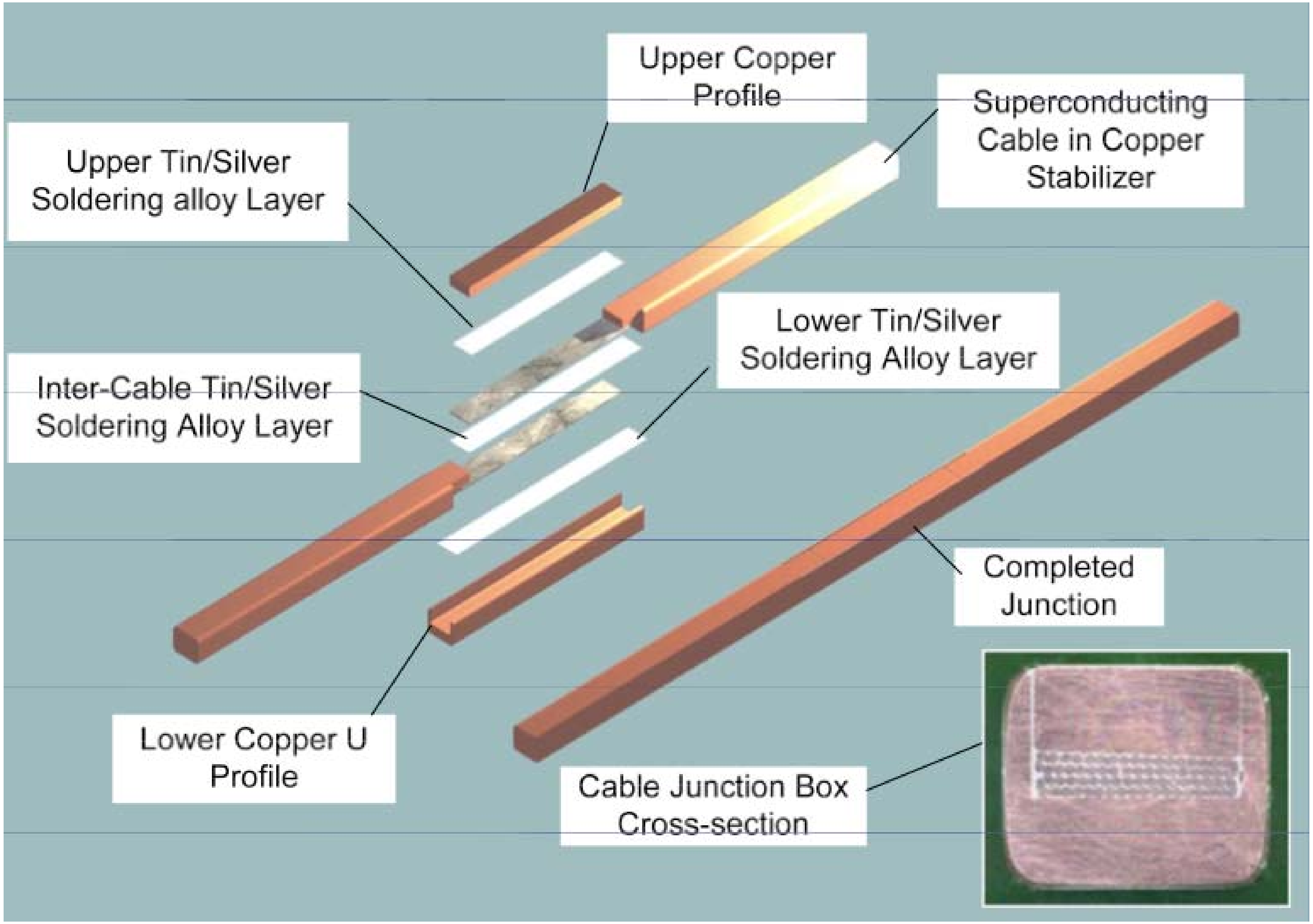
- Most likely an electrical arc developed which punctured the helium enclosure.
- Large amounts of Helium were released into the insulating vacuum.

- Rapid pressure rise inside the LHC magnets
  - Large pressure wave travelled along the accelerator both ways.
  - Self actuating relief valves opened but could not handle all.
  - Large forces exerted on the vacuum barriers located every 2 cells.
  - These forces displaced several quadrupoles by up to ~50 cm.
  - Connections to the cryogenic line damaged in some places.
  - Beam ‘vacuum’ to atmospheric pressure

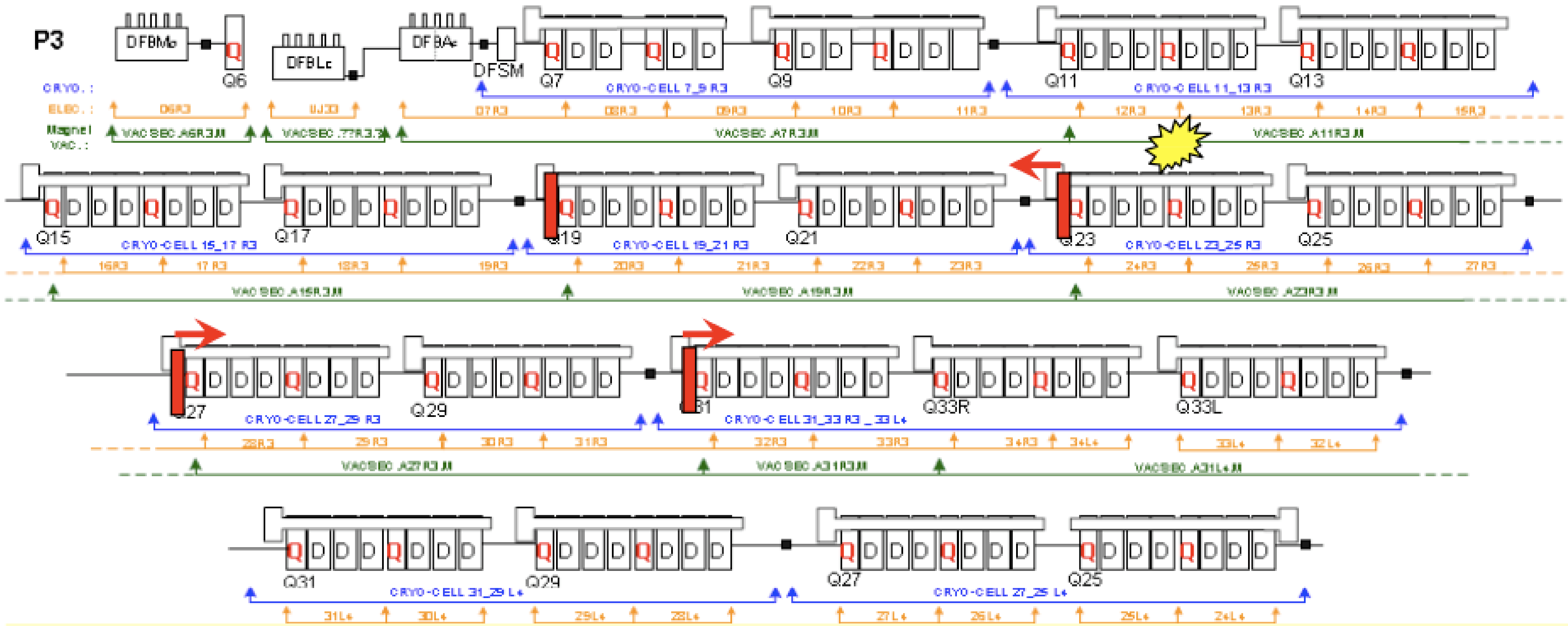
Inter-connection



Splices: quadrupole-dipole interconnect



Damage zone



Insulating vacuum barrier every 2 cells in the arc → Some moved

- Considerable collateral damage over few hundred metres
- Contamination by soot of beam pipes
- Damage to super-insulation blankets
- Large release of helium into the tunnel (6 of 15 tons)

Cryostat Pedestal

R. Aymar
PECFA
28/11/08

Damaged Quadrupole-Dipole Connection

R. Aymar
PECFA
28/11/08

Displacement in mm

Displacements

Displacements status in sector 3-4 (From Q17R3 to Q33R3) : P3 side

Based on measurements by TS-SU, TS-MME and AT-MCS

	Q17	A18	B18	C18	Q18	A19	B19	C19	Q19	A20	B20	C20	Q20	A21	B21	C21	Q21
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	?	?	?	?	?	?	?	?	?	?	<5	<5	<5	<5	<5	<5	<5

	Q21	A22	B22	C22	Q22	A23	B23	C23	Q23	A24	B24	C24	Q24	A25	B25	C25	Q25
Cryostat	<2	<2	<2	<2	-7	<2	<2	<2	-187	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	-25	-67	-102	-144	<5	-190	-130	-60	<5	<5	<5	<5	<5

	Q25	A26	B26	C26	Q26	A27	B27	C27	Q27	A28	B28	C28	Q28	A29	B29	C29	Q29
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	474	-4	<2	<2	11	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	57	114	150?	-45	230	189	144	92? Vert	50	35	<5	<5

	Q29	A30	B30	C30	Q30	A31	B31	C31	Q31	A32	B32	C32	Q32	A33	B33	C33	Q33
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	188	<2	<2	<2	5	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	19	77	148	<5	140	105	62	18	<5	<5	<5	?

SSS with vacuum barrier

>0 Towards P4

[mm] Values are in mm

? Not measured yet

Cold mass displacement

Cryostat displacement

Open interconnection

Electrical interruptions

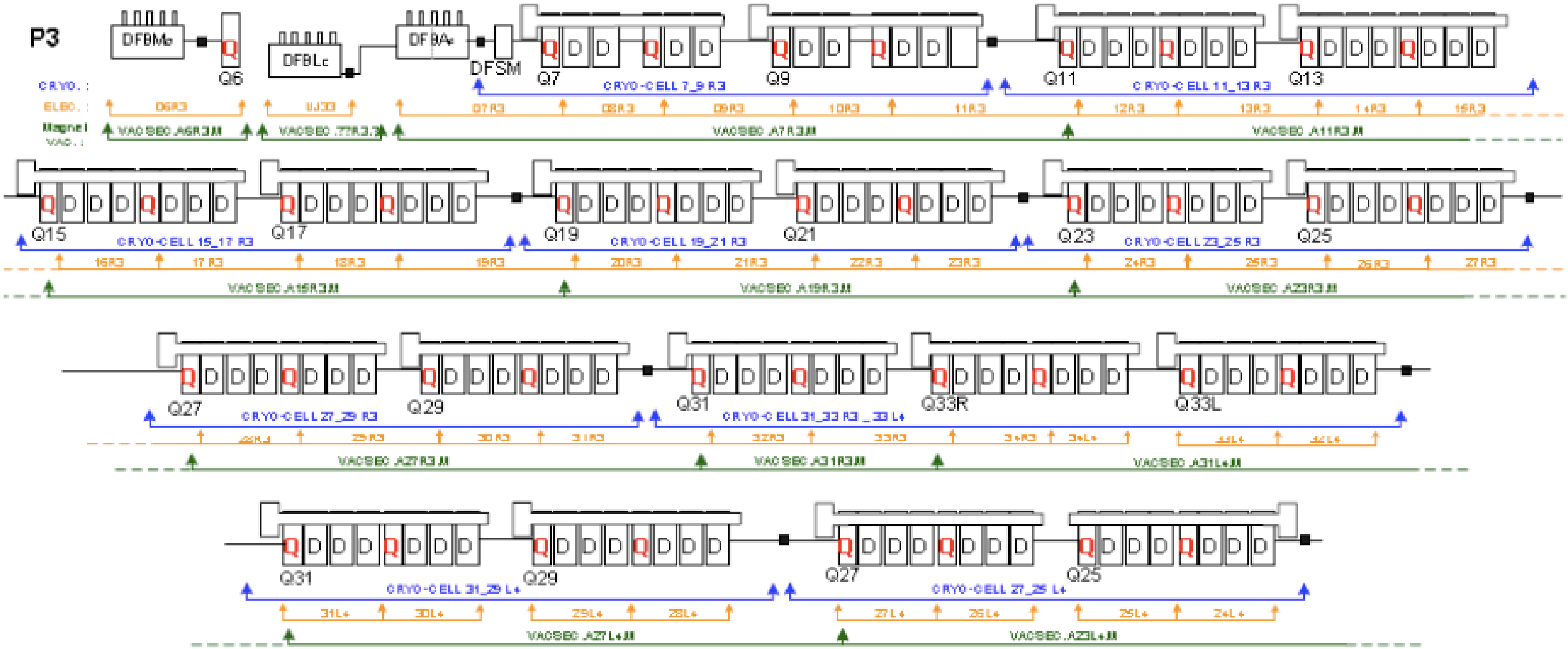
Dipole in short circuit

Electrically damaged IC

Buffer zones

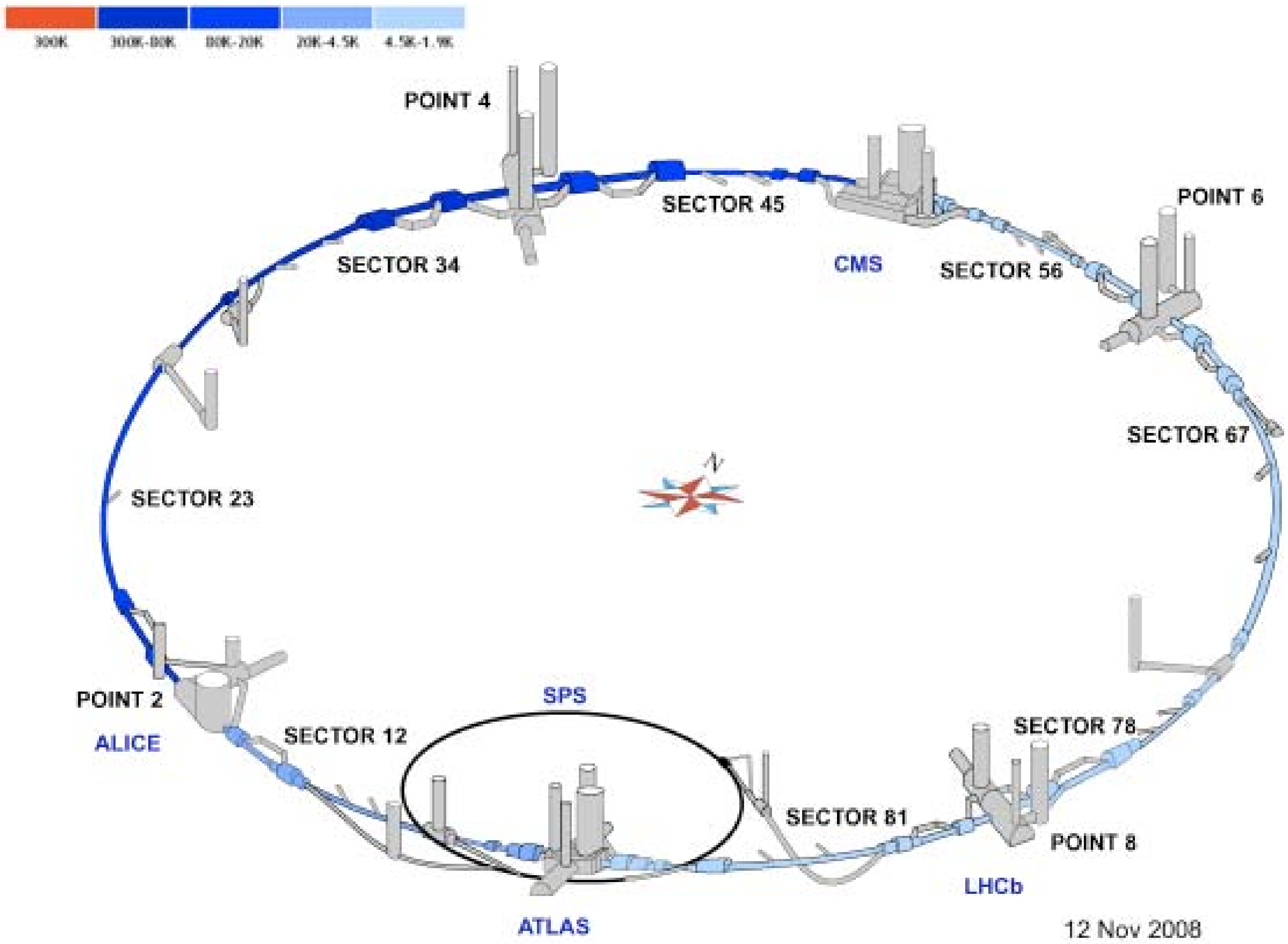
Disconnected

Repair



- Present strategy assumes treating all magnets Q19 to Q31 – 50 magnets out.
- May have to treat slightly further outside this zone (buckled vac. bellows)
- Nearly all the components are at CERN.
- Critical components are beam screens and short straight sections (quadrupoles).
- All magnets out by Christmas.
- Estimate (preliminary) November 08 to March 09.

Machine Status



Can it happen again?

Early Warning Signs

- Following the incident, a closer look at the logged cryogenic data (temperatures and valve states) clearly indicated a heat source in the cell that was at the origin of the S34 incident:
  - The data revealed the presence of a ~ 200 nΩ resistance in that cell (before the incident): most likely the interconnect quality.
- Logged data recorded during commissioning of the 7 other sectors was checked to locate other potential problems : a hint was found in a cell of S12.
- Controlled calorimetric measurements (at different magnet currents) were started in the sectors that are still available to:
  - ✓ Localize cells with current dependent heat sources.
  - ✓ Confirm the source and localize precisely with electrical measurements.

Summary of the Startup

Start-up with beam:

- Despite totally ‚crazy' conditions the beam start-up was excellent.
- The speed of progress with beam2 exceeded even our optimistic hopes.
- A lot was learned, but not enough to be sure that the rest of the early commissioning will proceed as well as the first 3 days…

Sector 34 incident:

- Revealed a weakness in the installation quality assurance.
- Revealed a weakness in the magnet protection system which did not cover dramatic bus-bar/interconnect incidents.
- Inspection and repair of ~ 50 magnets will take most of the shutdown.
- Improvements in the quench protection system, ready summer 2009, should provide early warning/protection against similar events.
- The final improvement of the pressure relief system requires a warm-up of all sectors.

????Schedule in 2009 ????

Next Steps foreseen in 2008

$$L = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L\sigma_{TOT}}{k_b f}$$

- Approx 30 days of beam to establish first collisions
- Approx 2 months elapsed
  - Given optimistic machine availability
  - Un-squeezed
  - Low intensity
- Continue commissioning thereafter
  - Increased intensity
  - Squeeze

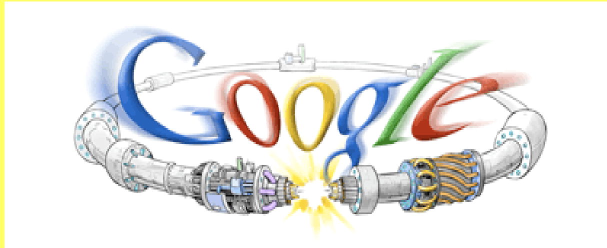
Parameters			Rates in 1 and 5	
k_b	N	β^* 1,5 (m)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1 (3)	10^{10}	11	1.1 10^{27}	<< 1
4	10^{10}	11	4.5 10^{27}	<< 1
43	10^{10}	11	5.0 10^{28}	<< 1
43	4 10^{10}	11	8.0 10^{29}	<< 1
43	4 10^{10}	3	2.9 10^{30}	0.36
156	4 10^{10}	3	1.0 10^{31}	0.36
156	9 10^{10}	3	5.4 10^{31}	1.8

Unclear how the schedule will look like in 2009…

News from December 5th

- Geneva, 5 December 2008. CERN* today confirmed that the Large Hadron Collider (LHC) will restart in 2009..The top priority for CERN today is to provide collision data for the experiments as soon as reasonably possible," said CERN Director General Robert Aymar. "This will be in the summer of 2009”.
- Detailed studies of the malfunction have allowed the LHC's engineers to identify means of preventing a similar incident from reoccurring in the future, and to design new protection systems for the machine.
- A total of 53 magnet units have to be removed from the tunnel for cleaning or repair,of these, 28 have already been brought to the surface and the first two replacement units have been installed in the tunnel. The current schedule foresees the final magnet being reinstalled by the end of March 2009, with the LHC being cold and ready for powering tests by the end of June 2009."We have a lot of work to do over the coming months," said LHC project Leader Lyn Evans, "but we now have the roadmap, the time and the competence necessary to be ready for physics by summer.

Summary



- The LHC has been completed in 2008.
  - Intial commissioning has started
- Start-of of the LHC on 10/9 was really good
  - Beam circulating for 30 minutes within days.
- However on 19/9 an unfortunate incident happened
  - An electrical resistive zone built up and led to an electric arc in the cryogenics part in one of the 8 arcs of the LHC
  - This created a rupture in the helium enclosure of the magnets
- This created considerable damage that needs to be repaired
  - The winter shutdown started earlier than planned
- As of 5/12 a new schedule has been announced
  - LHC back and starting physics program in 2009 after the shutdown
  - Multi-TeV collisions fall 2009?

CERN - FERMILAB
HADRON COLLIDER PHYSICS SUMMER SCHOOL
2009

4th CERN-FERMILAB
HADRON COLLIDER PHYSICS SUMMER SCHOOL
CERN, 8-17 June 2009

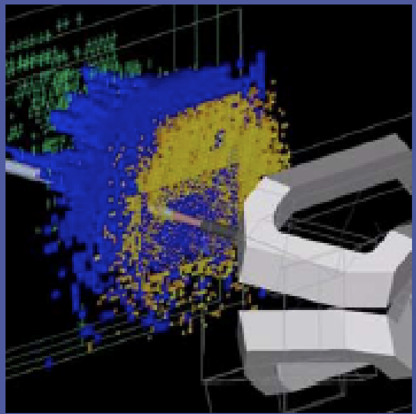
The CERN-Fermilab Hadron Collider Physics schools are targeted particularly at young postdocs and senior PhD students.

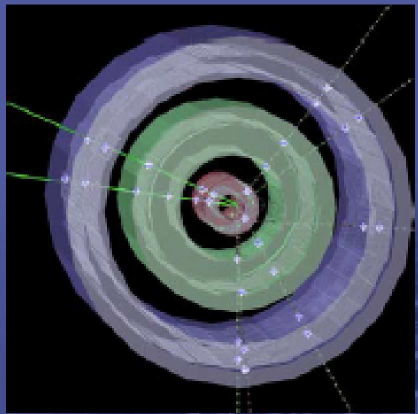
Application deadline
21 February 2009

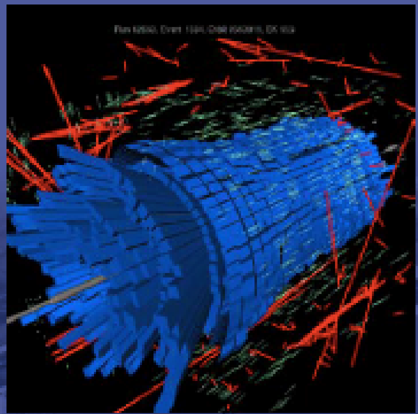
More information at : http://cern.ch/hcpss/
cern-fnal-school-sec@cern.ch

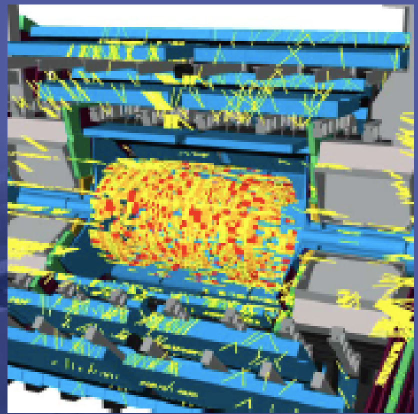
Main topics:

- Electroweak and Higgs Physics
- LHC Accelerator
- Physics of heavy flavours
- Statistics
- Heavy flavours at LHC
- QCD and MC tools
- Particle detection and reconstruction
- Beyond the SM
- Trigger and data analysis
- The road to discovery at the LHC
- Heavy ion Physics









Local Organizing Committee

Albert De Roeck (Co-Chairman), CERN
James Wells (Co-Chairman), CERN
Nick Ellis, CERN
Stefano Frixione, CERN and EPFL
Christos Leonidopoulos, CERN
Patricia Mage, CERN
Andreas Morsch, CERN
Tara Shears, Liverpool
Thorsten Wengler, Manchester

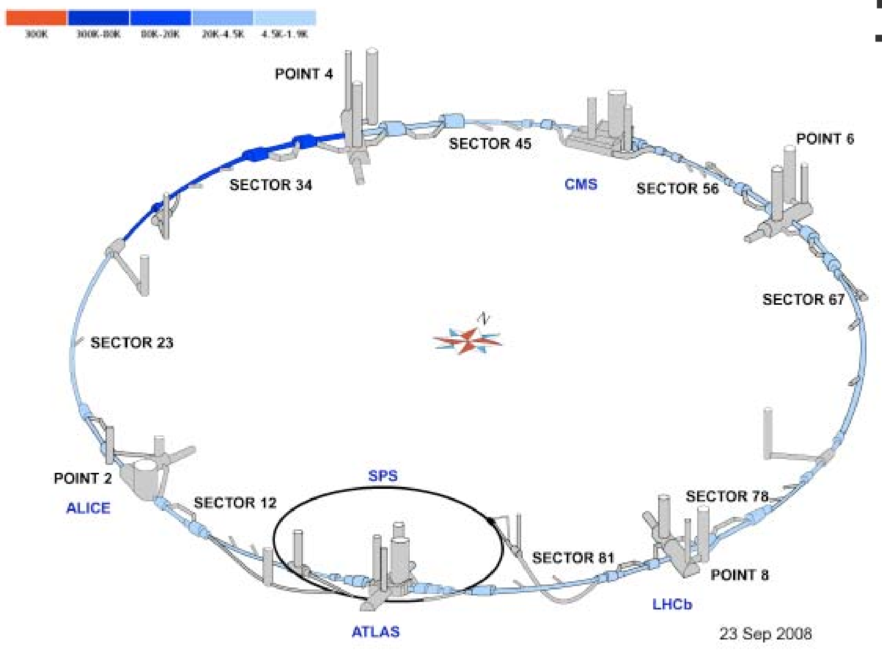
International Advisory Committee

Bogdan Dobrescu (Co-Chairman), Fermilab
Michelangelo Mangano (Co-Chairman), CERN
Fabiola Gianotti, CERN, ATLAS
Paul Grannis, SUNY at Stony Brook, D0
Ian Hinchliffe, LBNL, ATLAS
Rob Roser, Fermilab, CDF
Olivier Schneider, EPFL Lausanne, LHCb
Paris Sphicas , Athens and CERN, CMS
Avi Yagil, University of California, San Diego, CMS

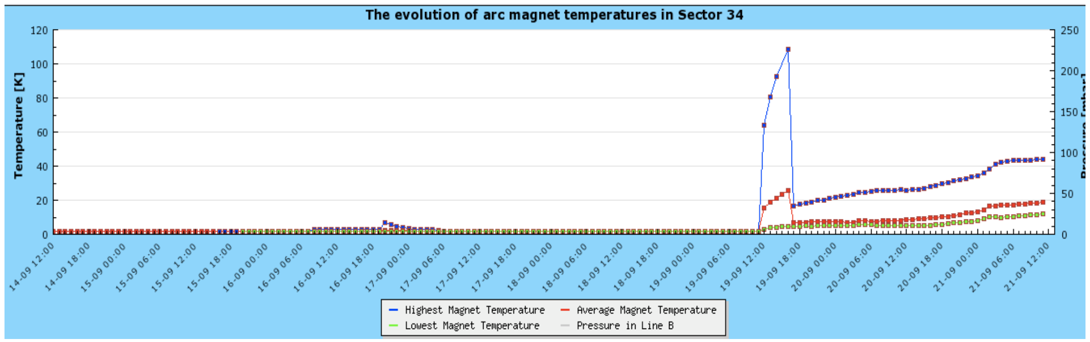
Backup

The LHC startup…

- Great startup on 10/9!   (>300 journalists)
- …Serious problem on 19/9   (> 2 months to fix)
- So, a bit more patience will be required.
- But LHC will come on strongly in 2009



Eg German press:
Teilchenbeschleuniger ist schon kaputt



Breaking news: Tuesday 22/9 evening
"No more beam untill spring 2003"

Write-up

Summary Report on the analysis of the 19th September 2008 incident at the LHC

Incident during powering

The magnet circuits in the seven other sectors of the LHC had been fully commissioned to their nominal currents (corresponding to beam energy of 5.5 TeV) before the first beam injection on 10 September 2008. For the main dipole circuit, this meant a powering in stages up to a current of 9.3 kA. The dipole circuit of sector 3-4, the last one to be commissioned, had only been powered to 7 kA prior to 10 September 2008. After the successful injection and circulation of the first beams at 0.45 TeV, commissioning of this sector up to the 5.5 TeV beam energy level was resumed as planned and according to established procedures.

On 19 September 2008 morning, the current was being ramped up to 9.3 kA in the main dipole circuit at the nominal rate of 10 A/s, when at a value of 8.7 kA, a resistive zone developed in the electrical bus in the region between dipole C24 and quadrupole Q24. No resistive voltage appeared on the dipoles of the circuit, so that the quench of any magnet can be excluded as initial event. In less than 1s, when the resistive voltage had grown to 1 V and the power converter, unable to maintain the current ramp, tripped off, the energy discharge switch opened, inserting dump resistors in the circuit to produce a fast power abort. In this sequence of events, the quench detection, power converter and energy discharge systems behaved as expected.

Summary Report on the analysis of the 19th September 2008 incident at the LHC

Follow-up actions (preliminary)

Two different goals, namely to prevent any other occurrence of this type of initial event, and to mitigate its consequences should it however reproduce accidentally. Precursors of the incident in sector 3-4 are being scrutinized in the electrical and calorimetric data recorded on all sectors, which remain cold, in order to spot any other problem of the same nature in the machine.

- An improvement of the quench detection system is currently tested, before being implemented.
- The relief devices on the cryostat vacuum vessels will be increased in discharge capacity and in number.
- The external anchoring of the cryostats at the locations of the vacuum barriers will be reinforced to guarantee mechanical stability.

Until now, no other interconnection resistance has been identified as above specification, but two (?) connections inside the cold masses (which have been tested successfully to 9T) have been measured higher than specified.

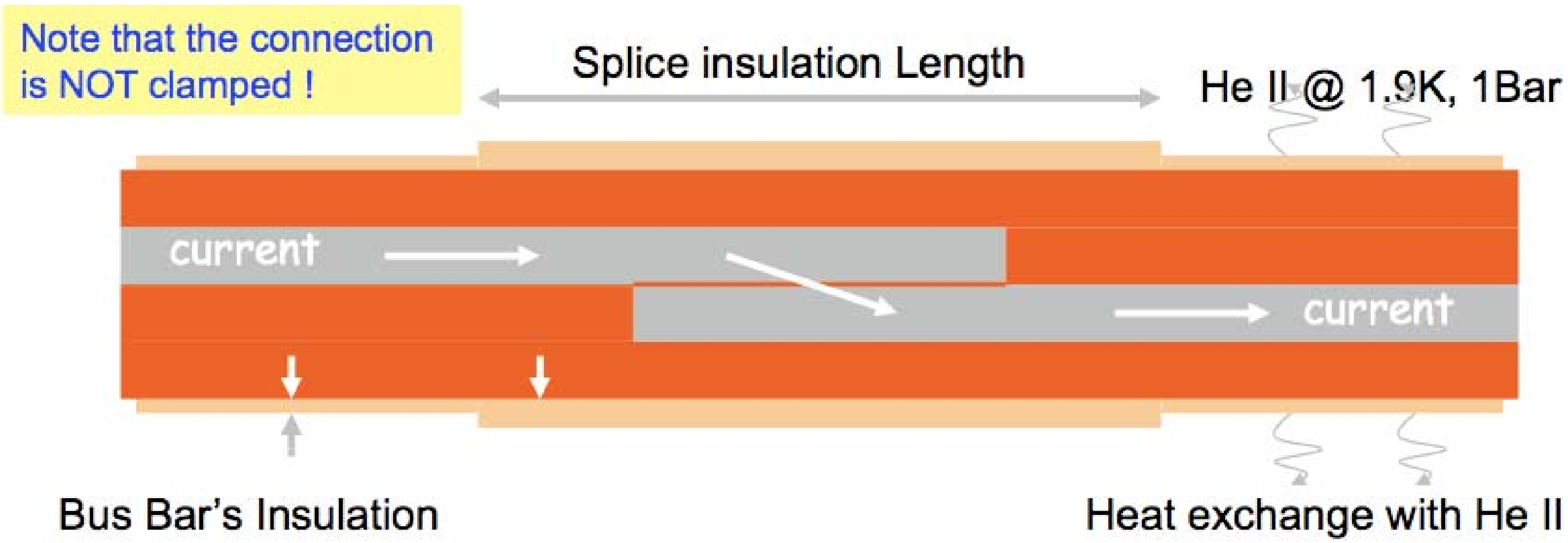
Summary Report on the analysis of the 19th September 2008 incident at the LHC

Sequence of events and consequences

Within the first second, an electrical arc developed and punctured the helium enclosure, leading to release of helium into the insulation vacuum of the cryostat.

The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors, which most probably damaged them. These forces displaced dipoles in the subsectors affected from their cold internal supports, and knocked the Short Straight Section cryostats housing the quadrupoles and vacuum barriers from their external support jacks at positions Q23, Q27 and Q31, in some locations breaking their anchors in the concrete floor of the tunnel. The displacement of the Short Straight Section cryostats also damaged the "jumper" connections to the cryogenic distribution line, but without rupture of the transverse vacuum barriers equipping these jumper connections, so that the insulation vacuum in the cryogenic line did not degrade.

Main Dipole / Quadrupole Interconnection



Favored *hypothesis* for the S34 incident cause :

- Temperature increase due to an excessive resistance (estimate ~ 200 nΩ).
- Superconductor quenches and becomes resistive at high current (temperature increase due to the resistance).
- Up to a certain current, the Copper can take it (cooled by the He II).
- Beyond a certain current, 'run-away' of the temperature, splice opens, electrical arc …

Pilot physics – the first month

- Interleaved physics and commissioning
- Push number of bunches, intensity, squeeze…
  - 156 x 156
  - 3×10^{10} protons per bunch
  - $\beta^* = 2$ m.
- Peak luminosity: $\sim 1.2 \times 10^{31}$
- Integrated: few pb^{-1}

Expected luminosity in 2008 @ 10 TeV

Pushing the bunch intensities with 156x156 with reasonable operational efficiency another month would see 30 - 40 pb^{-1}

Expectation for 2009

- Commission high energy operation
  - Aim for 7TeV (magnets will decide)
  - 43 /156 bunch running to start (brief)
  - 75ns running
  - 25ns running
  - High 1032 cm-2 s-1 is in reach

- Mixture of
  - Operation for physics
  - Machine studies
  - Scheduled stops
  - Access, injection, ramp, squeeze etc
  - Colliding beams
  - Ion run ?

$5\ 10^6$ seconds

Realistically (1 and 5)

150 days of physics
Efficiency for physics 40%
Peak luminosity around 10^{33} cm^{-2} s^{-1}

Integrated luminosity ~ few fb^{-1}

Courtesy Roger Bailey

(10^6 seconds @ <L> of 10^{33} cm^{-2} s^{-1} → 1 fb^{-1})

43

Sector 3-4 recovery + 25/11/2008 / AT-MCS