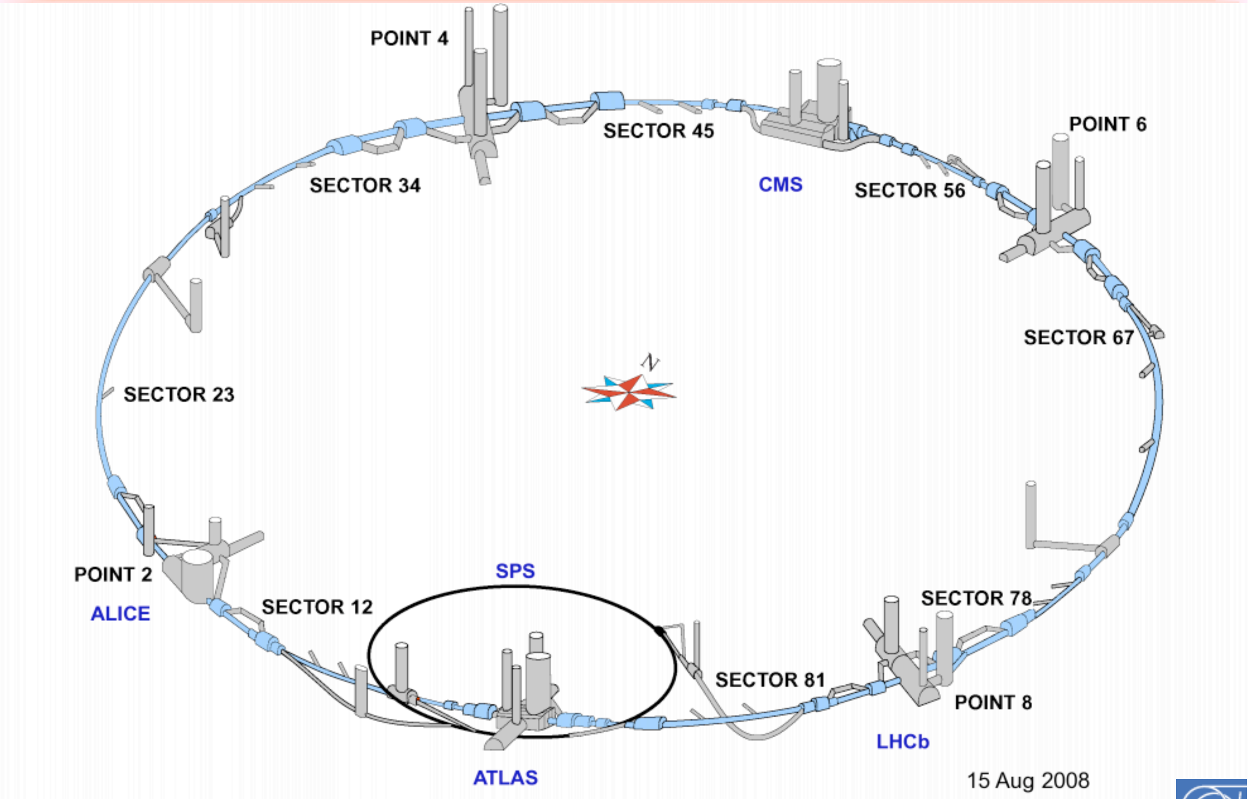
LHC Machine Status

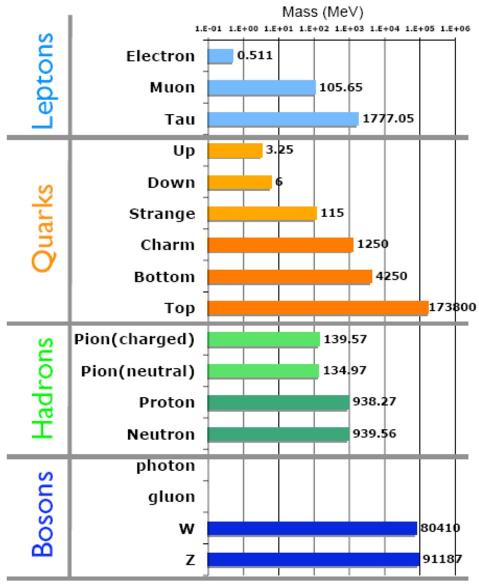
Lyn Evans



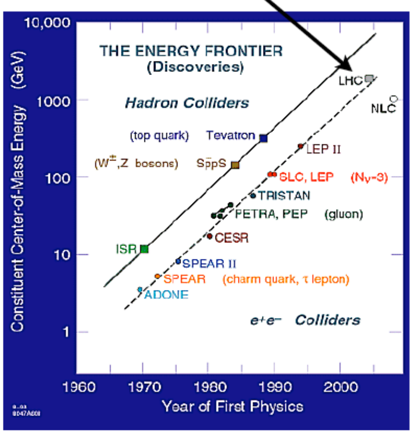
Strings 2008, CERN 18th August 2008

---

history/energy line vs discovery



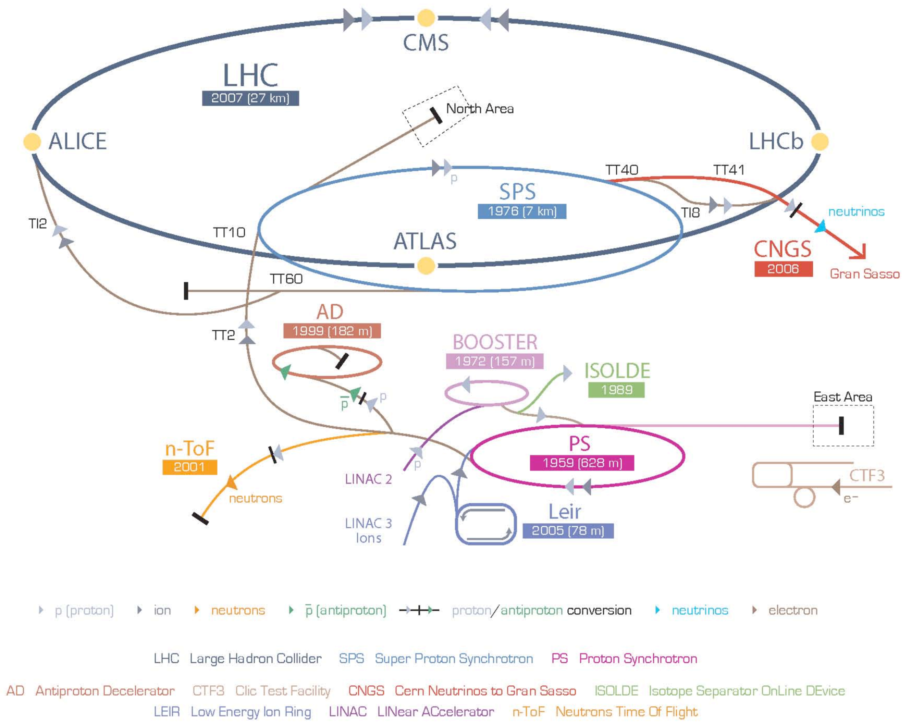
Higgs and super-symmetry ?
Or something else maybe



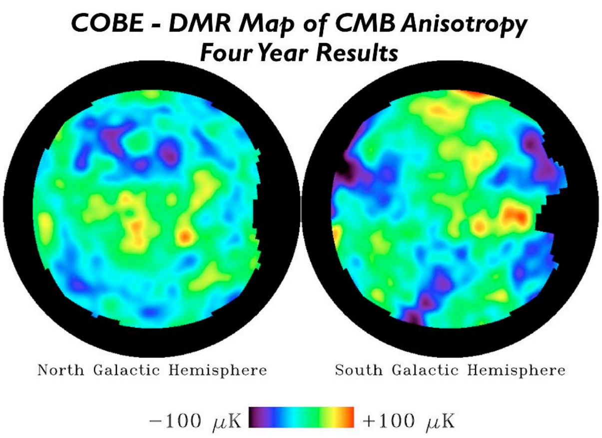
Behind the history plot is hidden the technological development required for each step

Obs: you can notice different particle species used in the different colliders electron-positrons and hadron colliders (either $\bar{p}$-p as Tevratron, p-p as LHC)

CERN accelerator complex

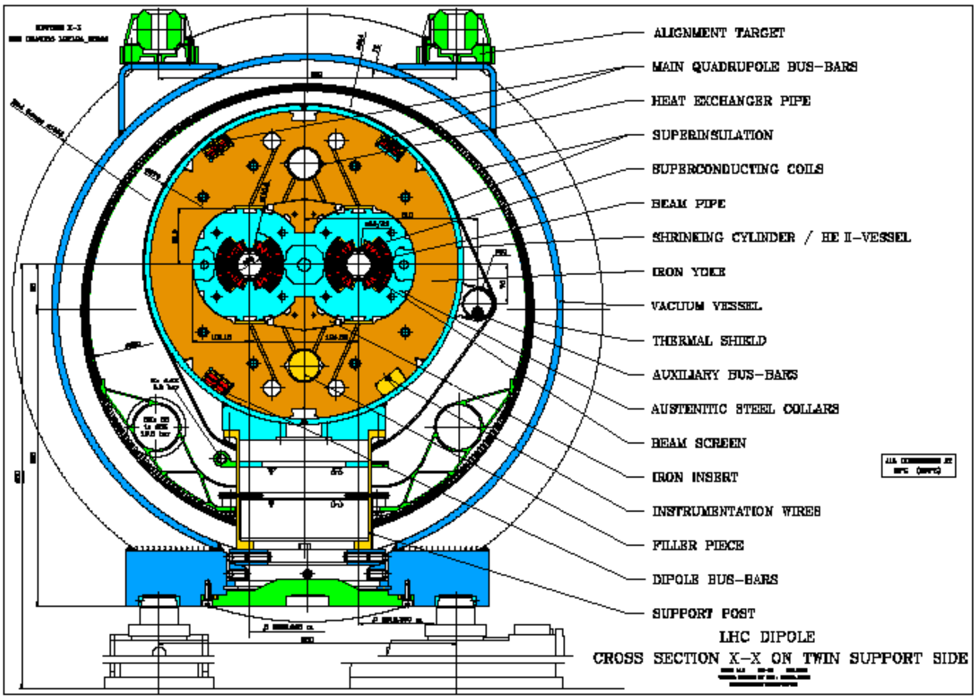


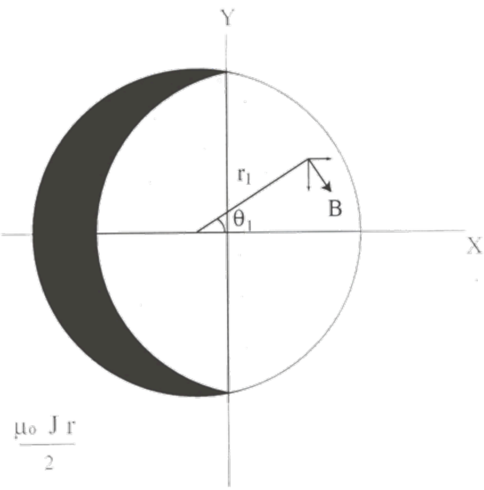
The Large Hadron Collider

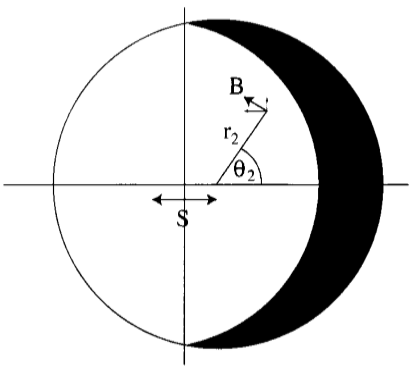


The coldest ring in the universe!

cross-section of LHC cryodipole





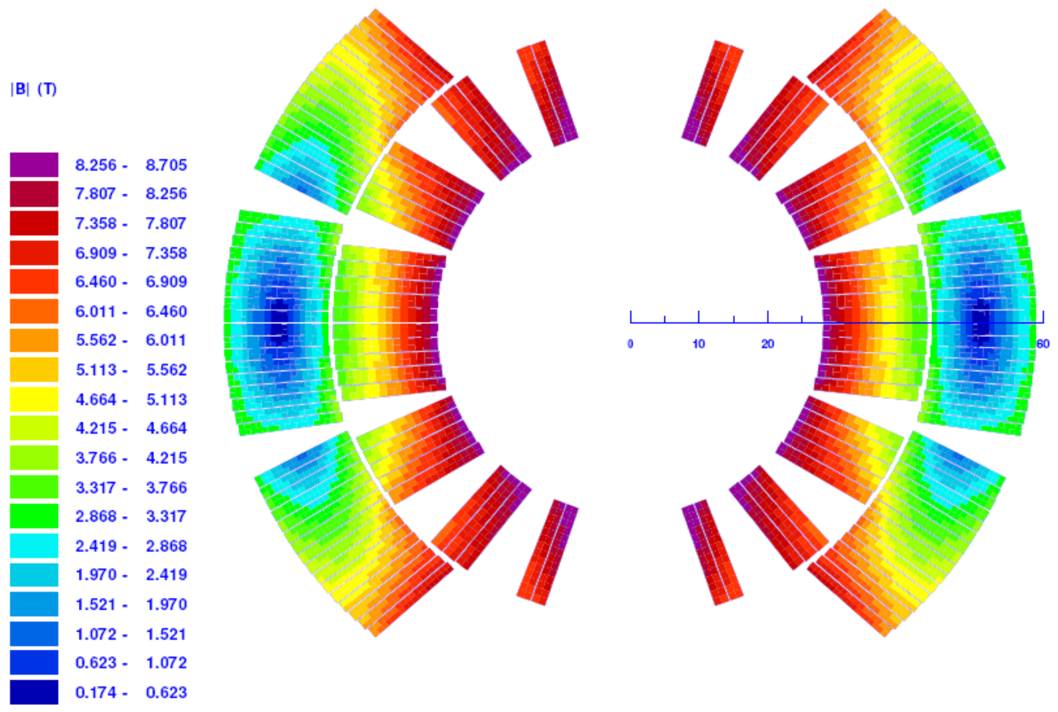


$$B = \frac{\mu_0 J r}{2}$$

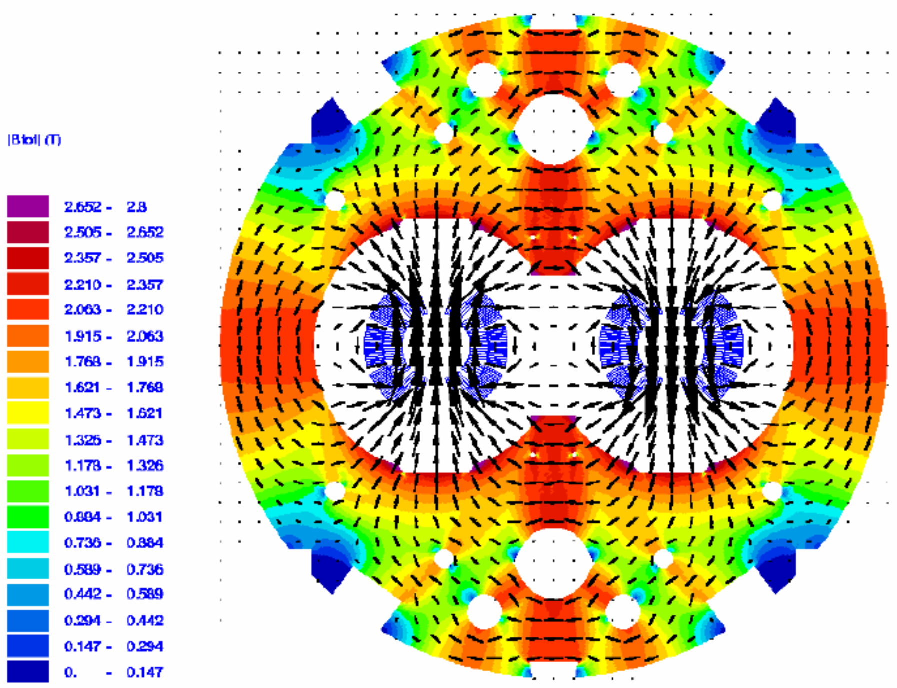
$$B_Y = \frac{\mu_0 J}{2}\left\{-r_1 \cos\theta_1 + r_2 \cos\theta_2\right\} = -\frac{\mu_0 J s}{2}$$

$$B_X = \frac{\mu_0 J}{2}\left\{r_1 \sin\theta_1 - r_2 \sin\theta_2\right\} = 0$$

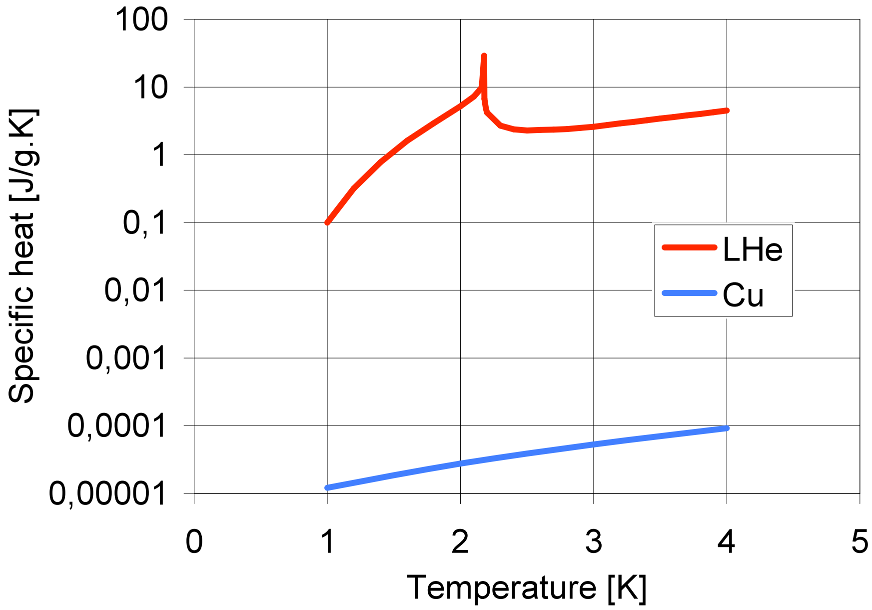
distribution of conductors in dipole coil



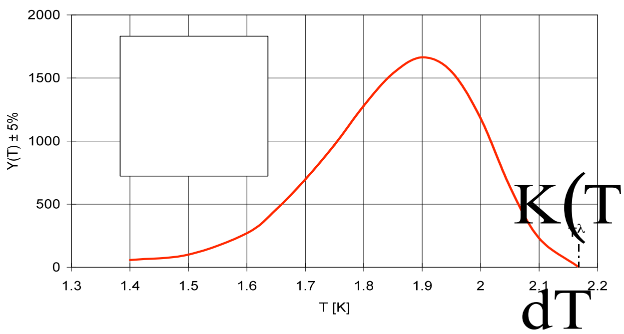
dipole magnetic flux plot



specific heat of LHe and Cu



equivalent thermal conductivity of He II



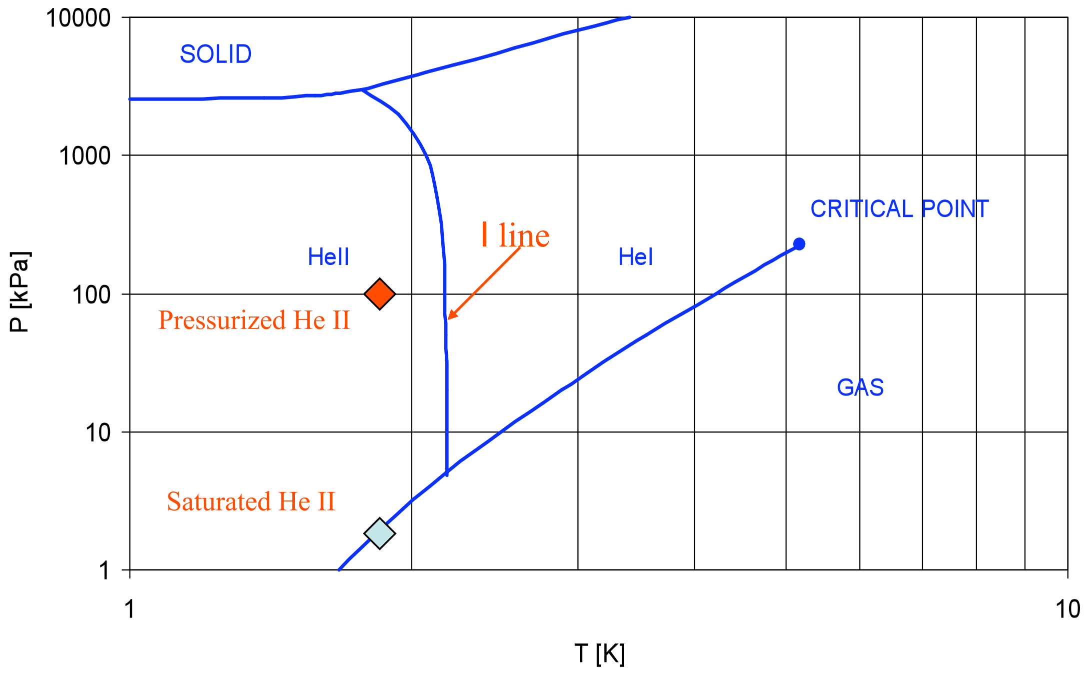
K(T

dT

Helium II

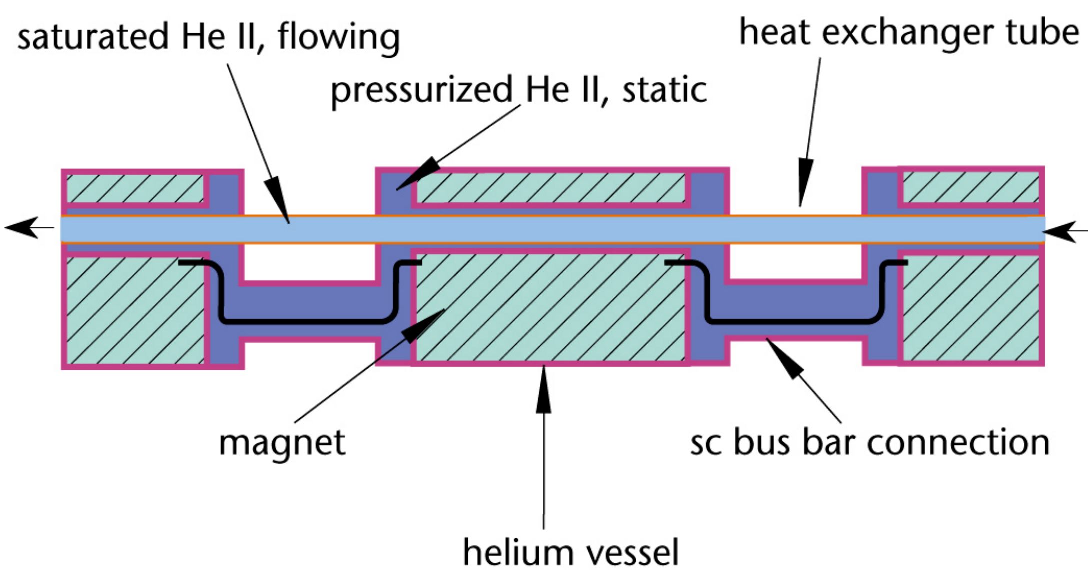
OFHC copper

phase diagram of Helium



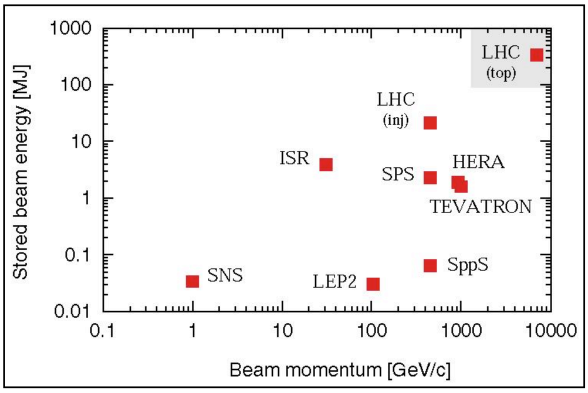
linear heat exchanger

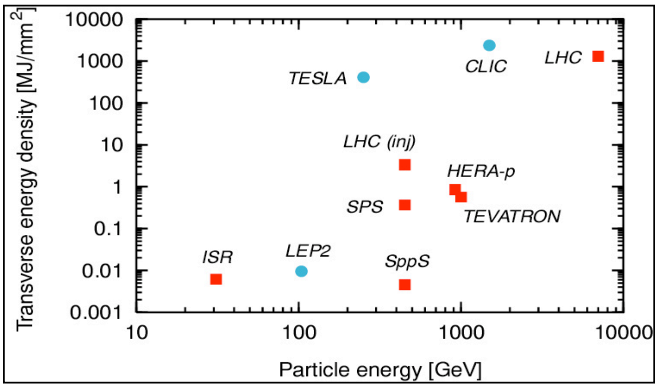
LHC magnet string cooling scheme



CERN AC _ EI2-12 VE _ V9/9/1997

beam momentum & stored energy of colliders

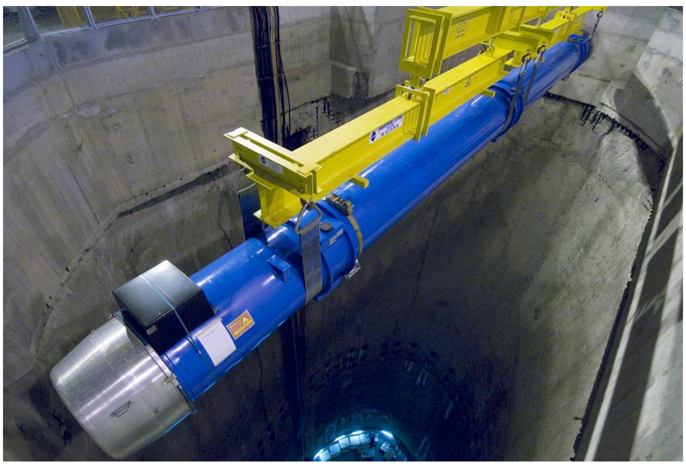




Energy stored in the accelerator beam, as a function of beam momentum. At less than 1% of nominal intensity LHC enters new territory.

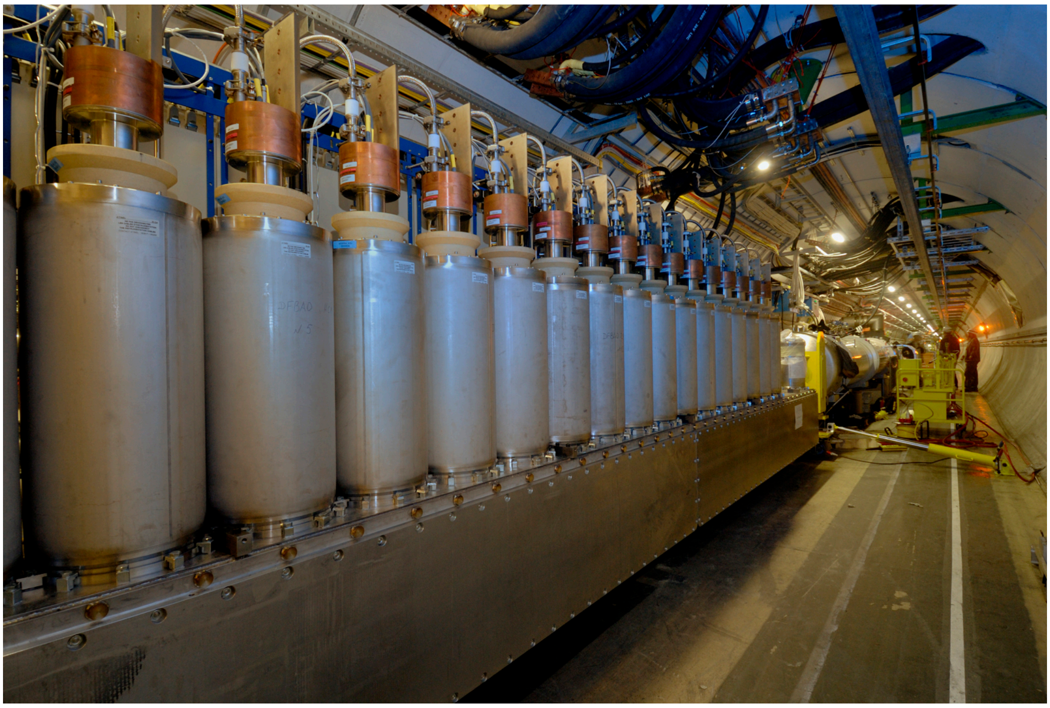
Stored energy density as a function of beam momentum. Transverse energy density is a measure of damage potential and is proportional to luminosity.

descent of the last magnet, 26 April 2007

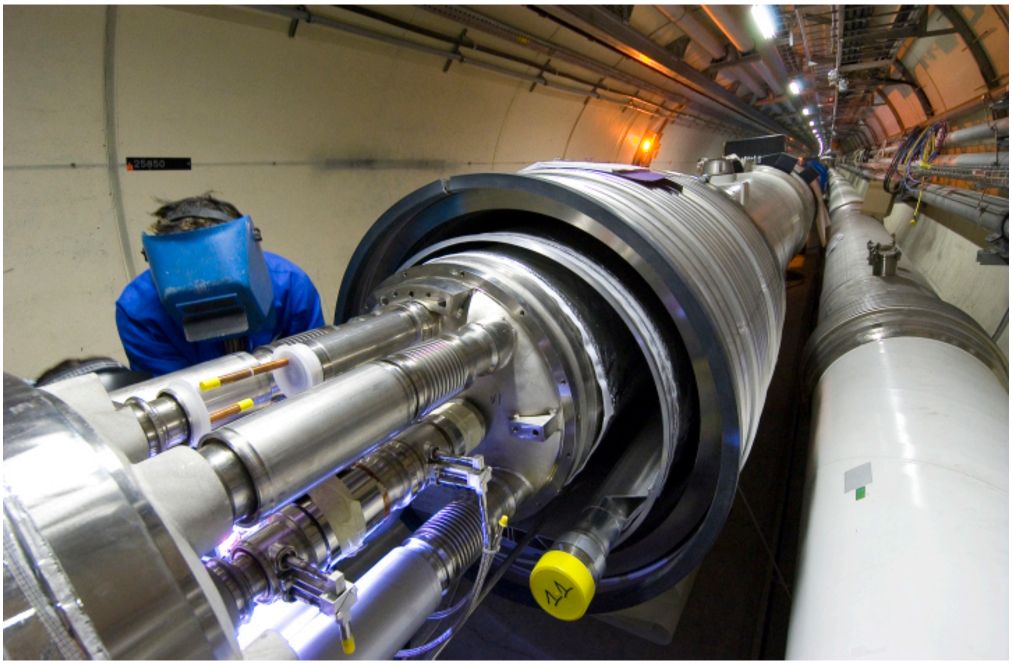


30’000 km underground at 2 km/h!

DFBAO in Sector 7-8



dipole-dipole interconnect



dipole-dipole interconnect: electrical splices

cooldown of sectors

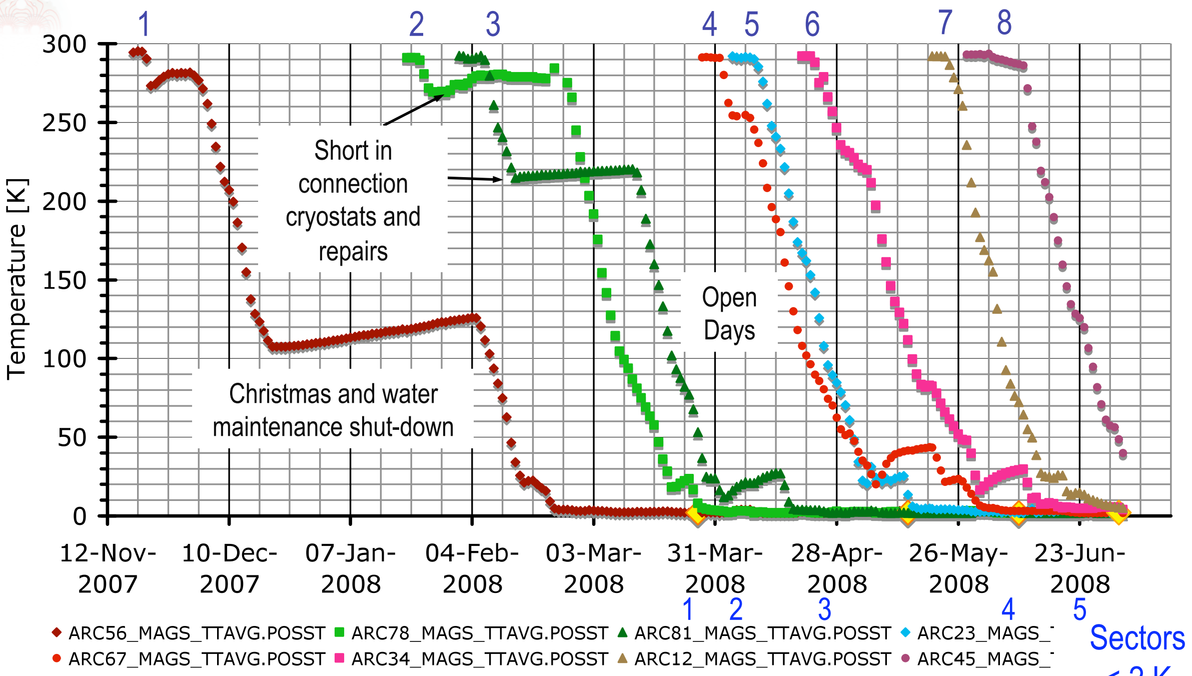
- From RT to 80K precooling with LN2. 1200 tons of LN2 (64 trucks of 20 tons). Three weeks for the first sector.
- From 80K to 4.5K. Cooldown with refrigerator. Three weeks for the first sector. 4700 tons of material to be cooled.
- From 4.2K to 1.9K. Cold compressors at 15 mbar. Four days for the first sector.

large helium refrigerator for cooling down to 4.5 K

33 kW @ 50 K to 75 K
23 kW @ 4.6 K to 20 K
41 g/s liquefaction

600 kW precooling to 80 K with LN2 (up to ~5 tons/h)

cool-down of LHC sector

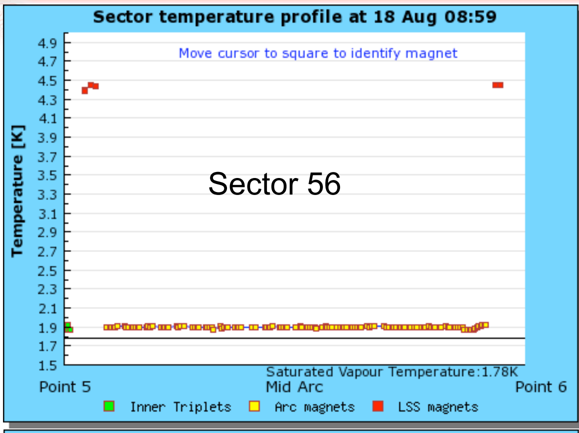


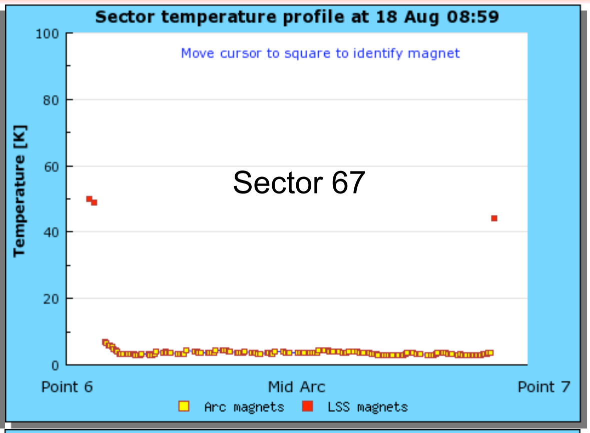
Cooling sectors + Cryo tuning + Powering activities

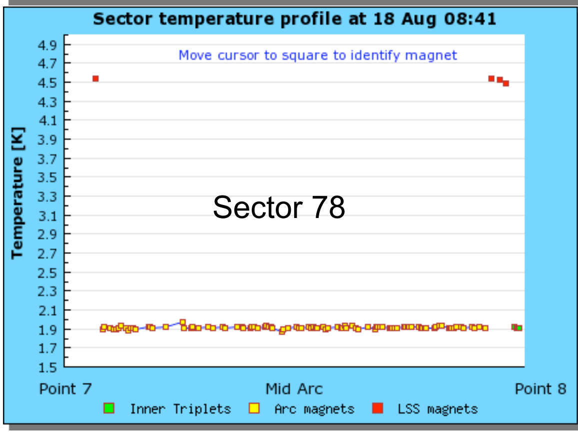
SC - 04Jul'08

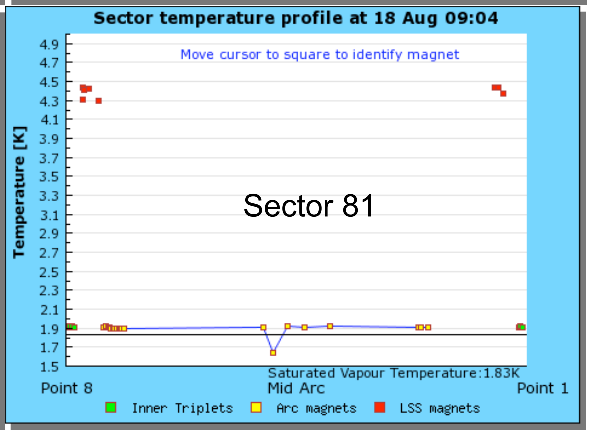
LHC Cryogenics - Status for ICC

cooldown status

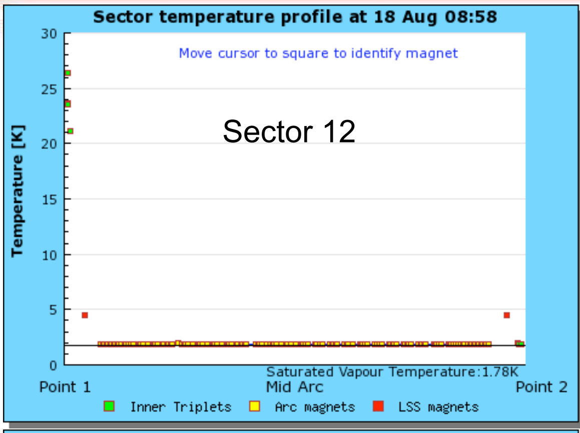


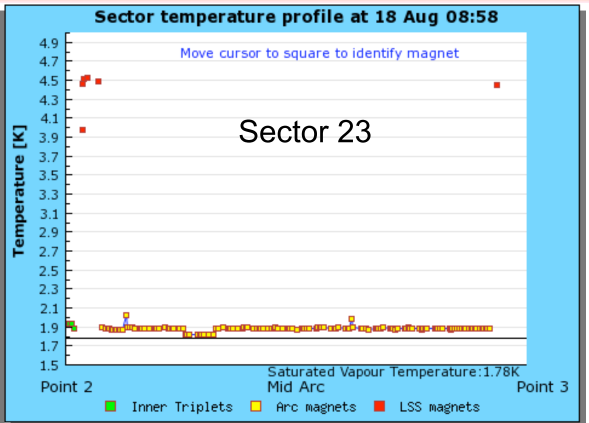


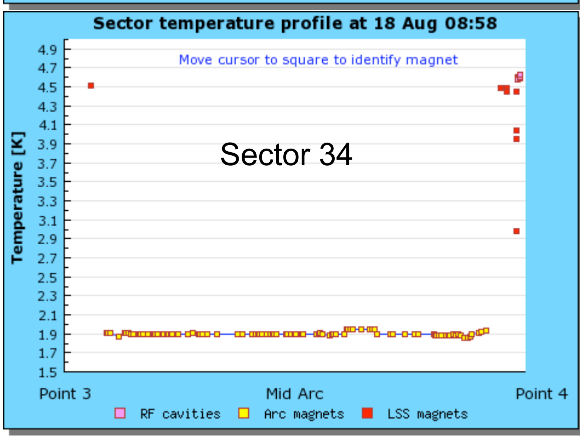


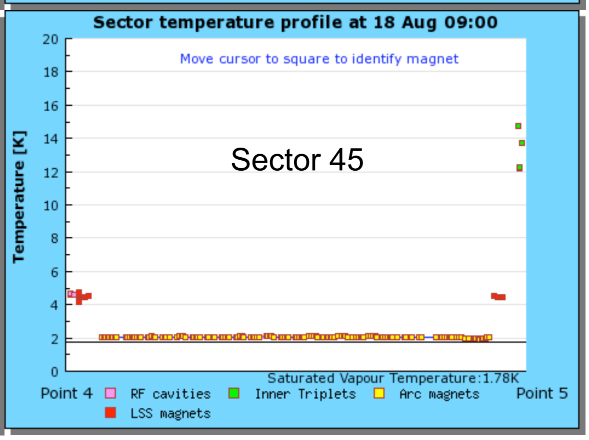


cooldown status

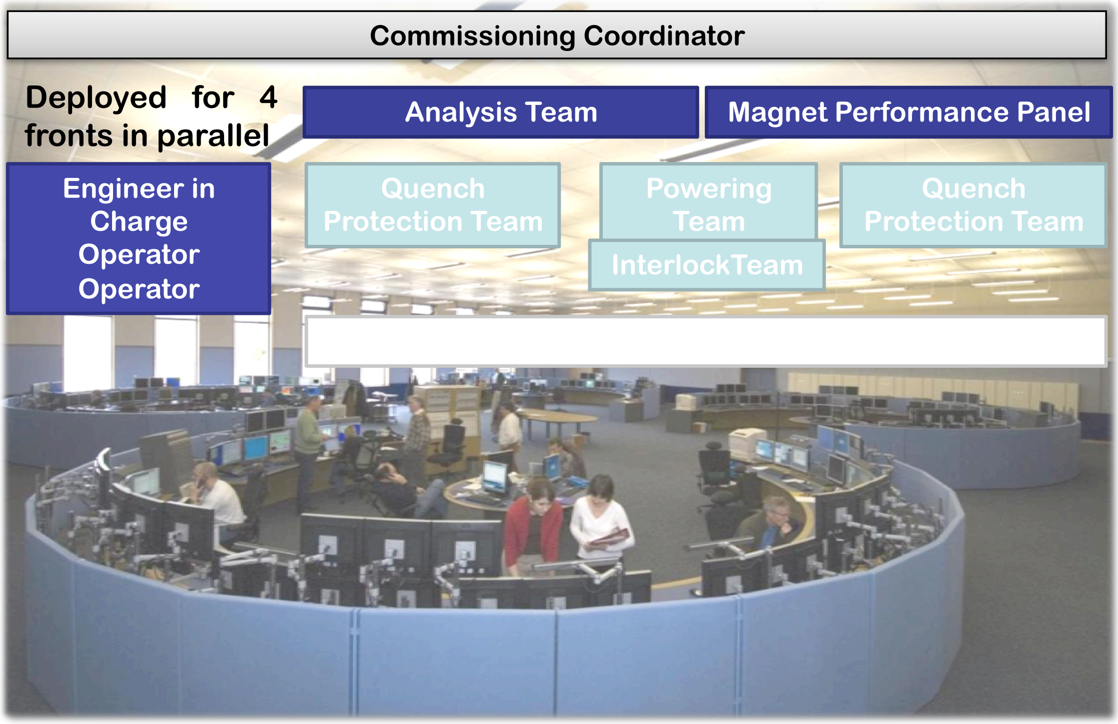




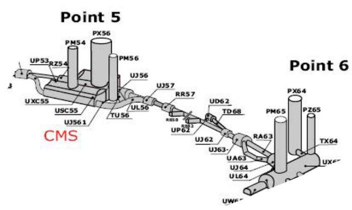




the organization



the superconducting circuits of an LHC sector



XR5			LR5			A56							ML6	
IT	600A	80 120A	IPQ	IPD	80 120A	RB	QD	QF	IP	80 120A	600A	60A	IPQ	80 120A
1	7	5	3	1	10	1	1	1	7	14	39	94	2	4
1.9 K			4.5 K			1.9 K							4.5 K	
13 circuits			14 circuits			157 circuits							6 circuits	

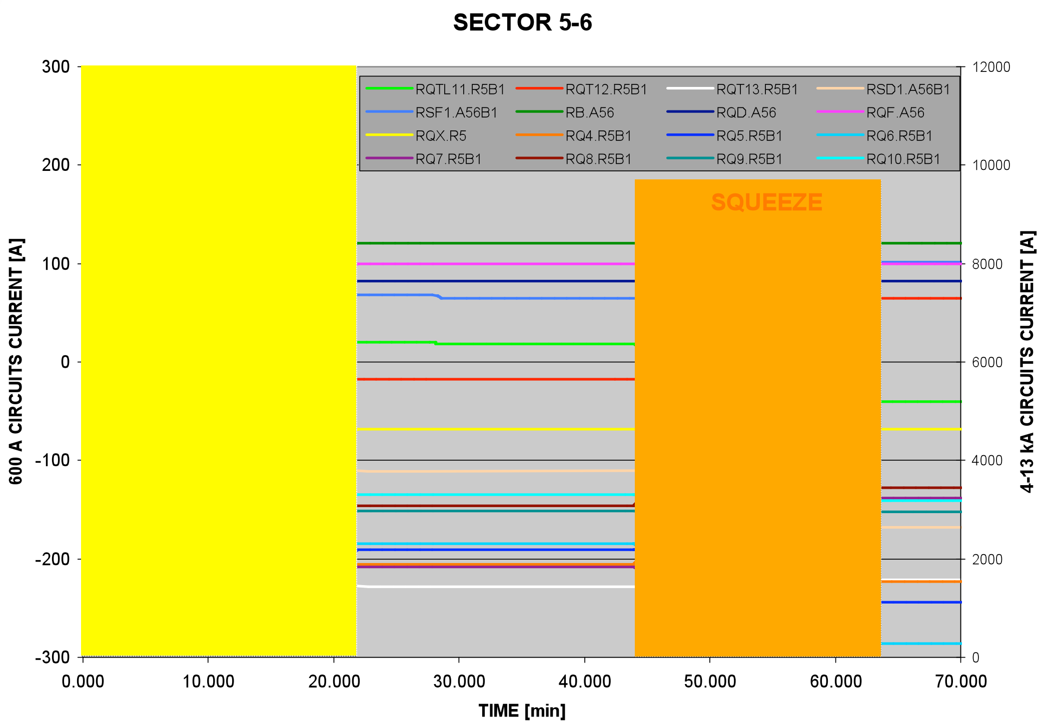
Totalling 190 circuits

the superconducting circuits of the LHC

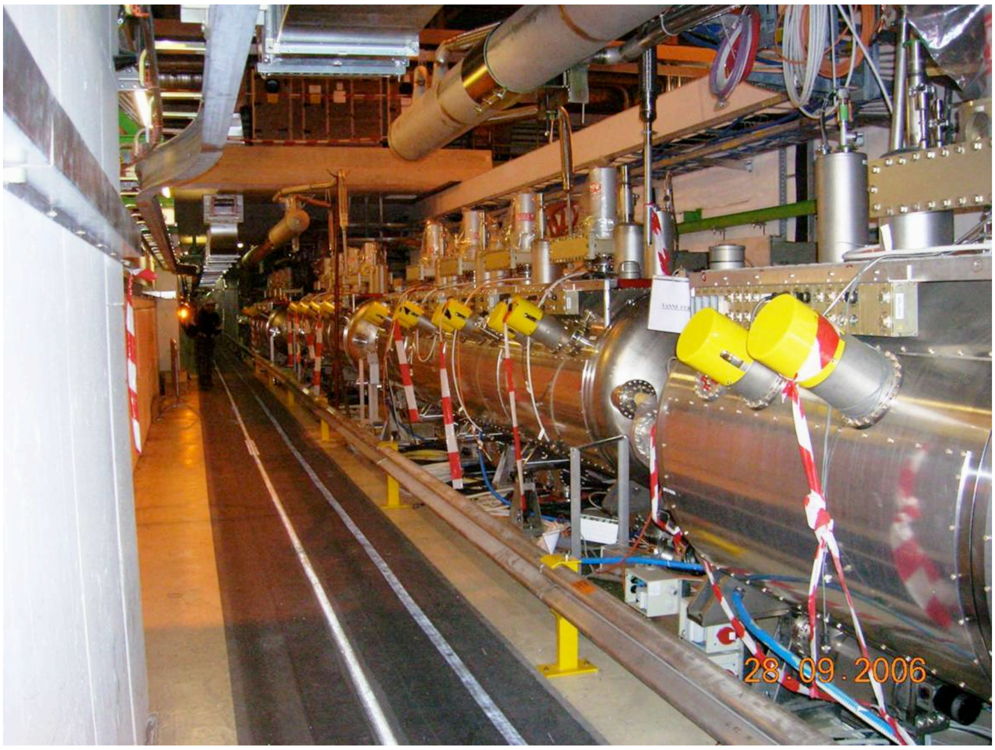
Circuit Type	Sector 1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1	LHC
13 kA	3	3	3	3	3	3	3	3	**24**
Independently Powered Dipoles	3	2	2	3	1	0	2	3	**16**
Independently Powered Quadrupoles	14	7	6	13	12	5	7	14	**78**
600A with Energy Extraction	23	27	28	24	23	27	27	23	**202**
600A Energy Extraction in Converter	14	20	20	14	14	20	20	14	**136**
600A no Energy Extraction	16	9	2	9	9	2	9	16	**72**
80-120A Correctors	50	37	22	33	33	22	37	50	**284**
TOTAL	**123**	**105**	**83**	**99**	**95**	**79**	**105**	**123**	**812**

Circuit Type	Sector 1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1	LHC
60A Closed Orbit Correctors	94	94	94	94	94	94	94	94	**752**

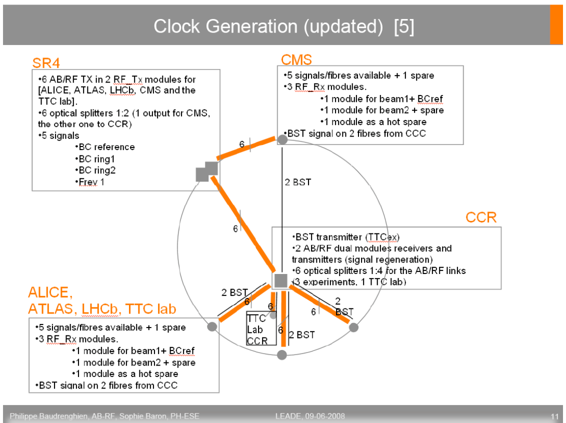
ramp and squeeze of main circuits



RF cavities



the RF cavities and transverse dampers



Fibre-optics signal distribution from RF in SR4 to Experiments, BT & BI equipment and to CCC.

40 MHz bunch clocks, revolution frequencies,
40 MHz 7TeV reference. Injection & dump kicker pulses

Preparation for Beam

RF synchronization in place – clocks and timing now going from SR4 to all users. Recent successful *dry run tests* with all users and OP group, including basic software.

Cavity Beam Control systems in advanced state but some items on critical path.

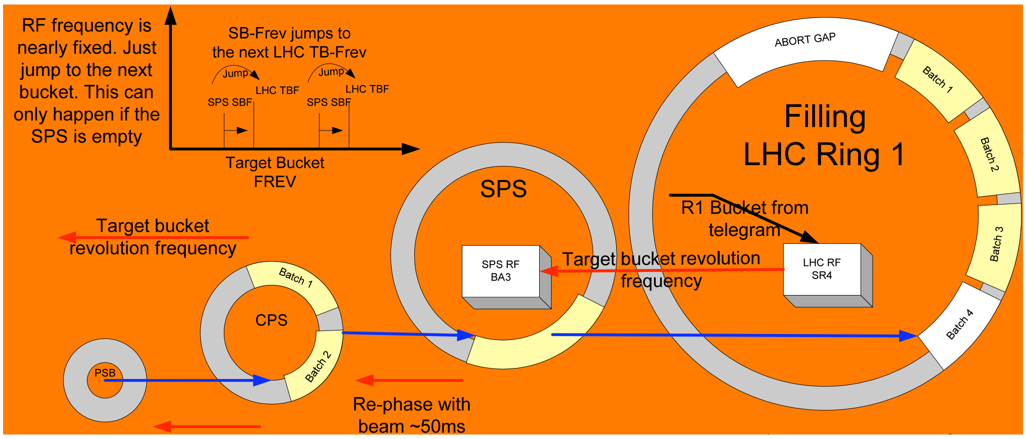
Transverse Damper electronics being tested.

Software for beam control also critical, but basic functionality will be available for this run.

Procedures for beam commissioning well defined.

Longitudinal diagnostics in good shape to study and commission first beams….

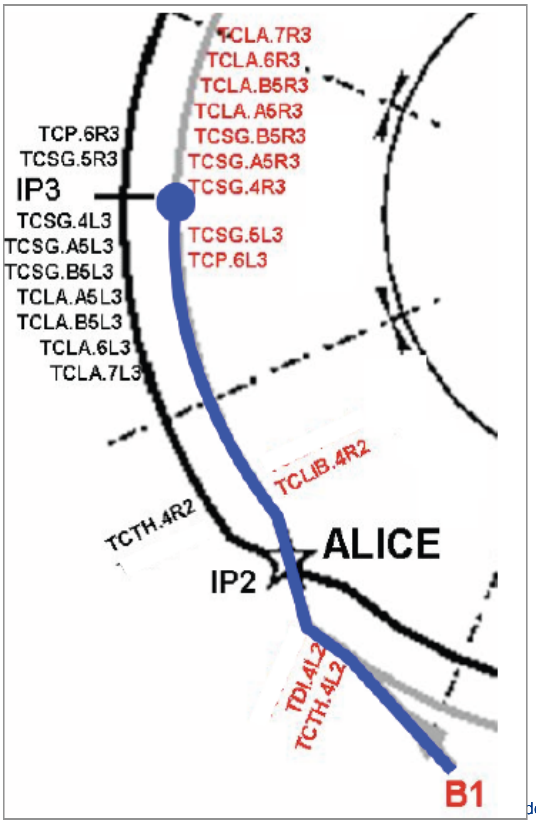
synchronisation



- Fast timing/synch: new prepulse system, stable – some GMT issues (configuration events arriving too late – CBCM issue) which caused random "synch" of kicker pulse. Solved manually for the test – temporary fix being conceived to test on 22rd.
- RF frequency control – phasing from LHC back to SPS – limited F range to +/-800 Hz – can double this for measurements. Used rephasing error signal – worked nicely

Courtesy Roger Bailey

injection test beam 1 – August 8 to 11 2008 (RB ML BG)

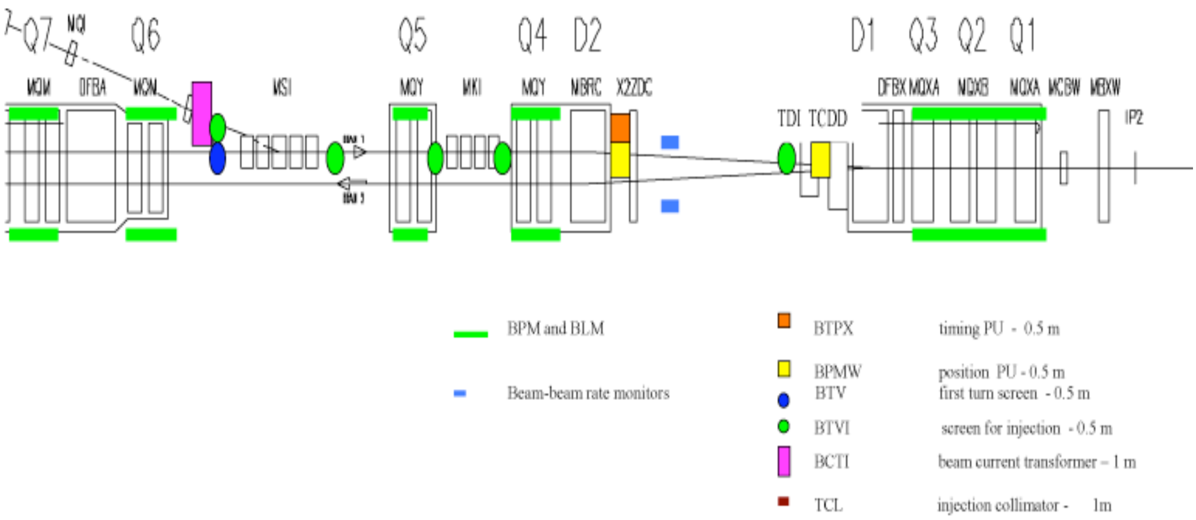


- Aims
- Champagne
- Instrumentation & controls
- Measurements

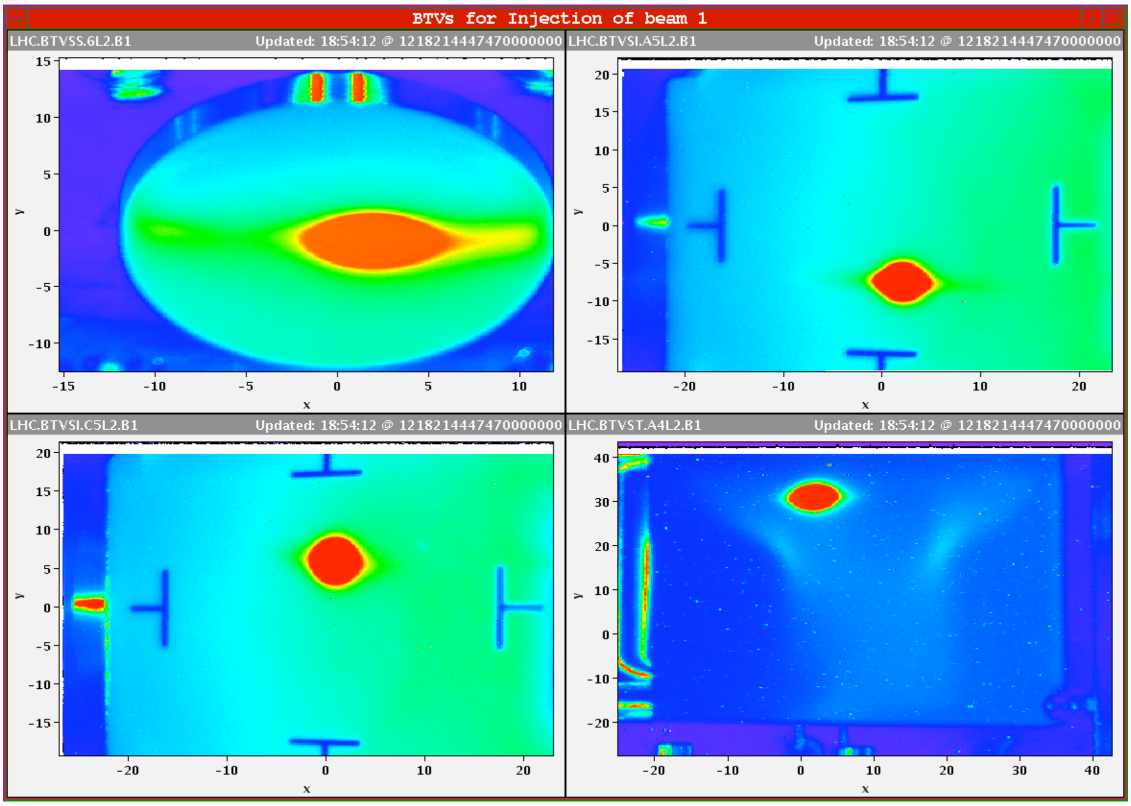
08 08 08

Friday 15:20	Beam on to TI2 TED MSI etc pulsing Cycle LHC Sector 23	OP	Beam down TI2 first shot
Friday 19:00	TI2 TED out, beam to TDI, kickers off Give Alice 20 minute warning before taking TED out	INJ	Beam on TDI after correction end TI2
Friday 21:00	Kickers on, time in, position checks Resolve timing issues	INJ	Interesting collaboration between timing and RF
Friday 21:40	TDI out - threading - momentum matching - beam to IR3 - beer	Jorg & team	Beam to IR3 first shot. Tweak SPS.

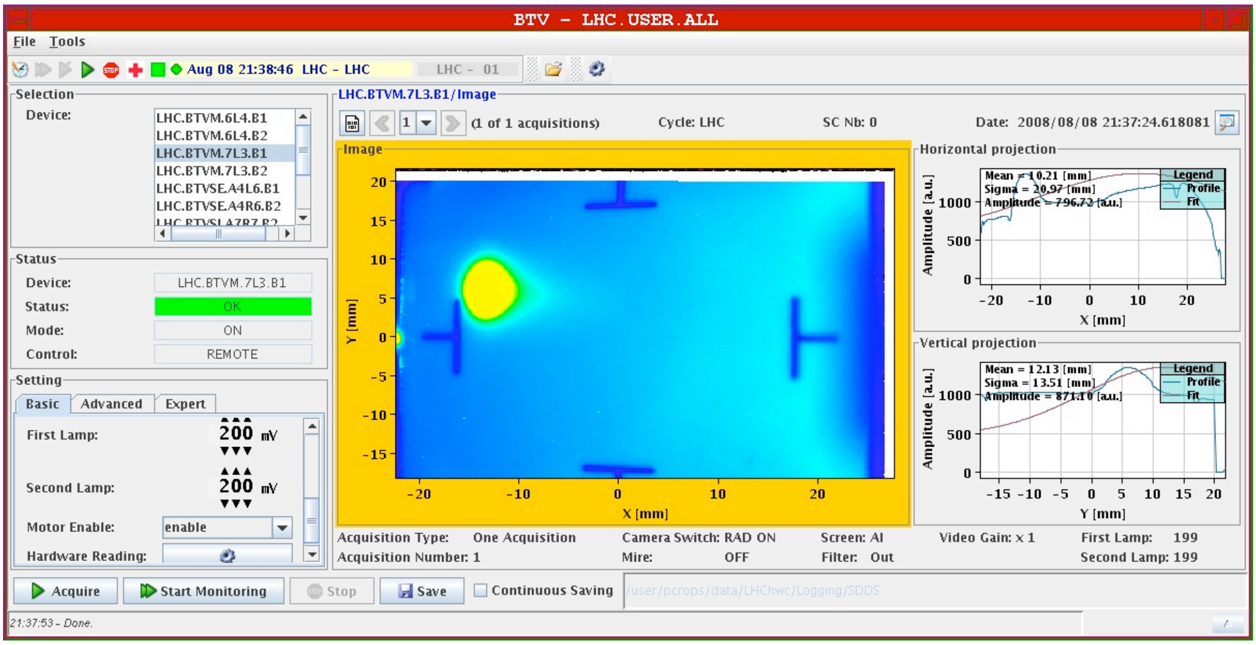
injection region



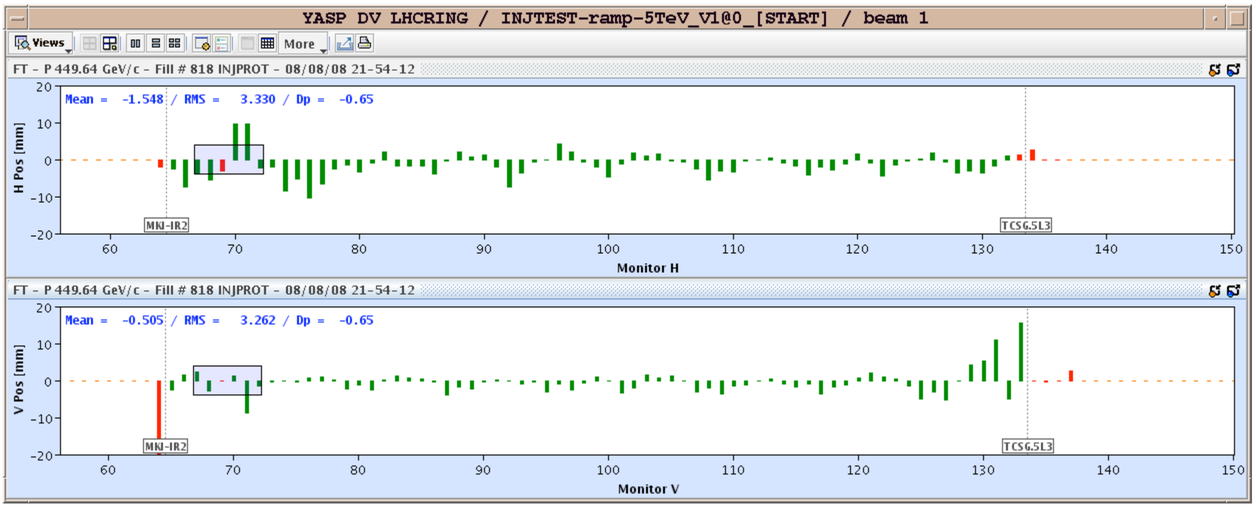
screens in injection region (septa, kickers, TDI)



screen at point 3 – first shot



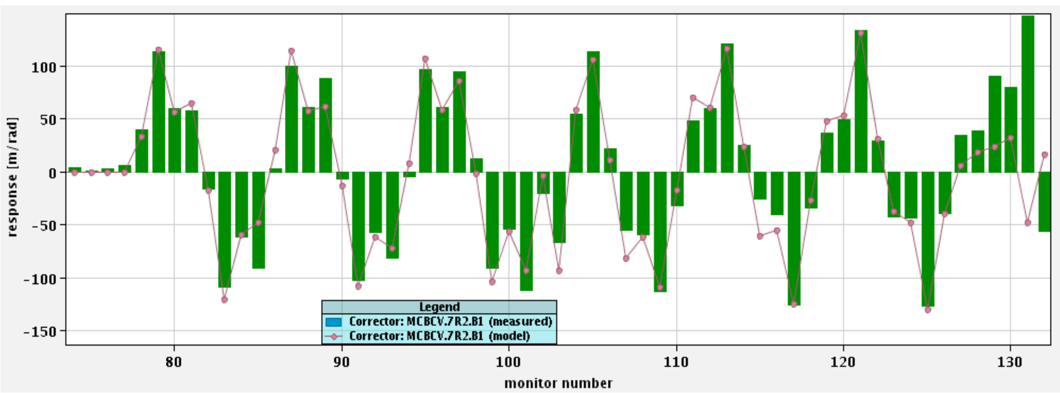
first trajectory



Courtesy Roger Bailey

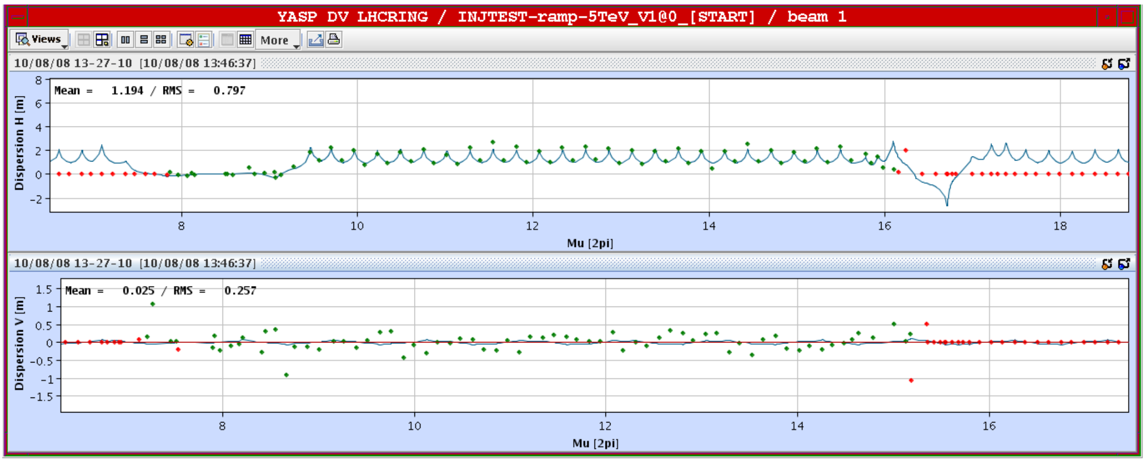
kick / response

- Response measurements – used about 50% of correctors and all BPMs – found a few issues (1 dead BPM, 1 inverted BPM, BPMWs systematically with inverted non-linear calibration factors). Found main focusing quadrupole strength about 1% too high. Monitor and corrector gains all look good, correctors within 15%, with one exception. See clear family dependence. Need error bars. Saw problems with fit after ~11L3. Candidate was polarity of MQTL1.11L3 – tried to verify this experimentally – results inconclusive
- Energy matching – trimmed SPS by 0.2% - had a residual of about 0.05%. Some effect seen after recycling



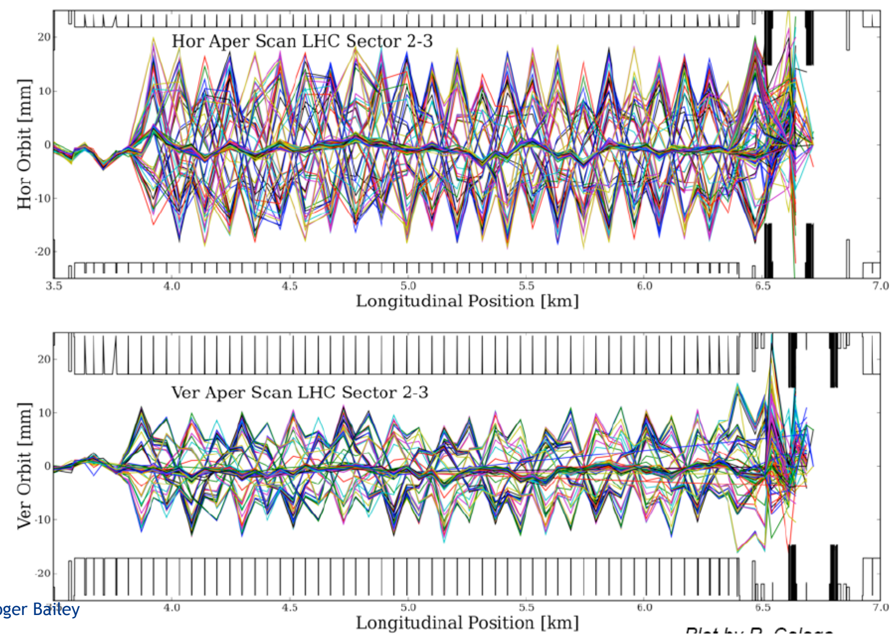
dispersion

- Dispersion measurement – SPS frequency trim limited to 800 Hz (+/-0.1%). Looks very good in the horizontal plane – starts diverging after ~11L3. In vertical plane might be a bit of residual dispersion, but maybe just due to the noise on the BPMs at these low intensities.

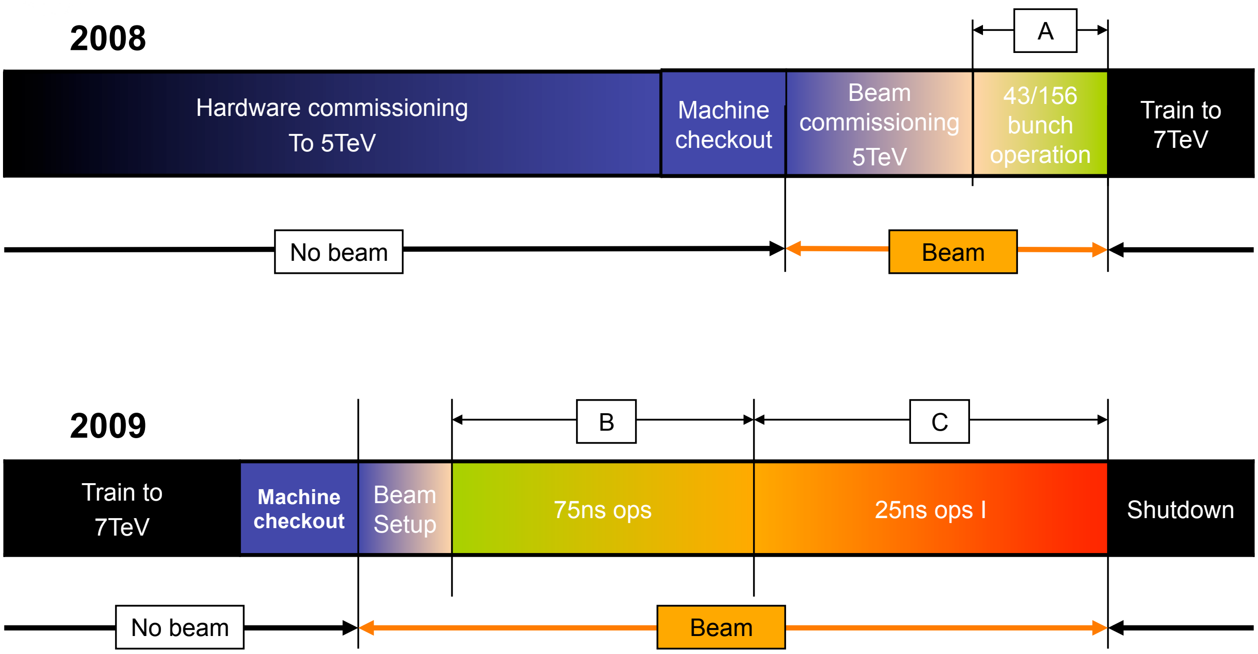


aperture in the arc

- Free oscillations to check overall clear aperture.
- H +/-18-20 mm in arc, losing in Q6.L3.
- V at least +/-10 mm, again found bottleneck in Q8 and Q7 to about 10 sigma. Did not go to aperture limit in the arc.



strategy for 2008 and 2009

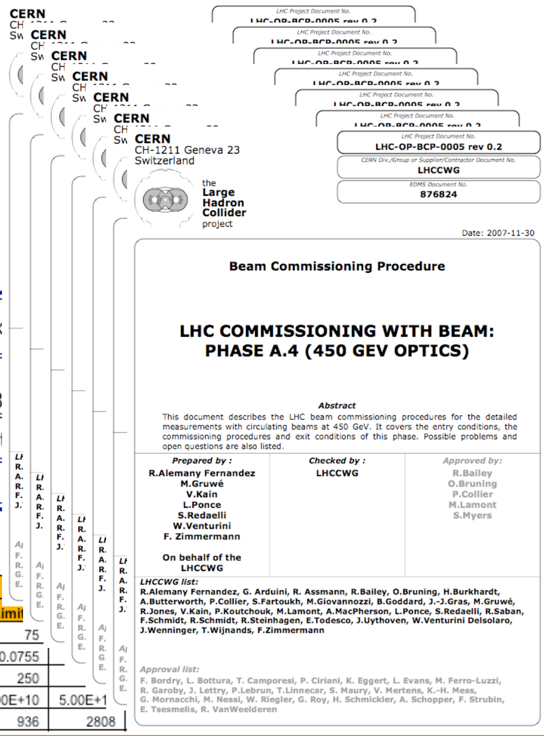


commissioning procedures (LHCCWG)

Commissioning Procedures

Beam Commissioning of the LHC

Phase A.1	First turn
Phase A.2	Circulating pilot
Phase A.3	450 GeV first commissioning
Phase A.4	450 GeV optics
Phase A.5	450 GeV, increasing intensity
Phase A.6	450 GeV, two beam operation
Phase A.7	450 GeV, collisions
Phase A.8	Snap-back and ramp
Phase A.9	Top energy, checks
Phase A.10	Top energy, collisions
Phase A.11	Squeeze
Phase A.12	Experimental magnets



Web based with EDMS approval
http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/stageA_index.htm

stage A: 5TeV collisions

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

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

- 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

aims for 2008

- Commission machine to 5TeV
  - Multiple bunches circulating in each ring (43)
  - Moderate intensities (few 10^{10})
  - Single beam lifetimes ~ 30h
  - Injection optics (β*= 11 m in IR 1 & 5, β*= 10 m in IR 2 & 8)
  - No squeeze
  - No crossing angle
  - Collisions
- Secondary aims
  - Commission squeeze in 1 and 5 to 3m
  - Commission squeeze in 8 to 6m
  - Push intensities (156 bunches, high 1010)
- Tertiary aims
  - Commission crossing angle
  - Commission 75ns beams

10^6 seconds

Realistically (1 and 5)

30 days of physics
Efficiency for physics 40%
Peak luminosity around 10^{31} cm^{-2} s^{-1}

Integrated luminosity ~ 10 pb^{-1}

(10^6 seconds @ <L> of 10^{30} cm^{-2} s^{-1} → 1 pb^{-1})

aims 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} $\rightarrow$ 1 fb^{-1})

summary

- The whole machine is now cold and in the final stage of commissioning.
- Both the detectors and the machine have converged remarkably well to termination considering the 14-years construction period. No one is sitting around waiting for the others to finish.
- Three weeks from now the first beam will be injected into the full machine and beam commissioning will begin.
- The first physics run will be at 10 TeV to speed up commissioning and to give adequate operational margin during the learning phase.
- The machine will be trained to 14 TeV during the winter shutdown.