LHC – A Glimpse on 2007

Ralph J. Steinhagen

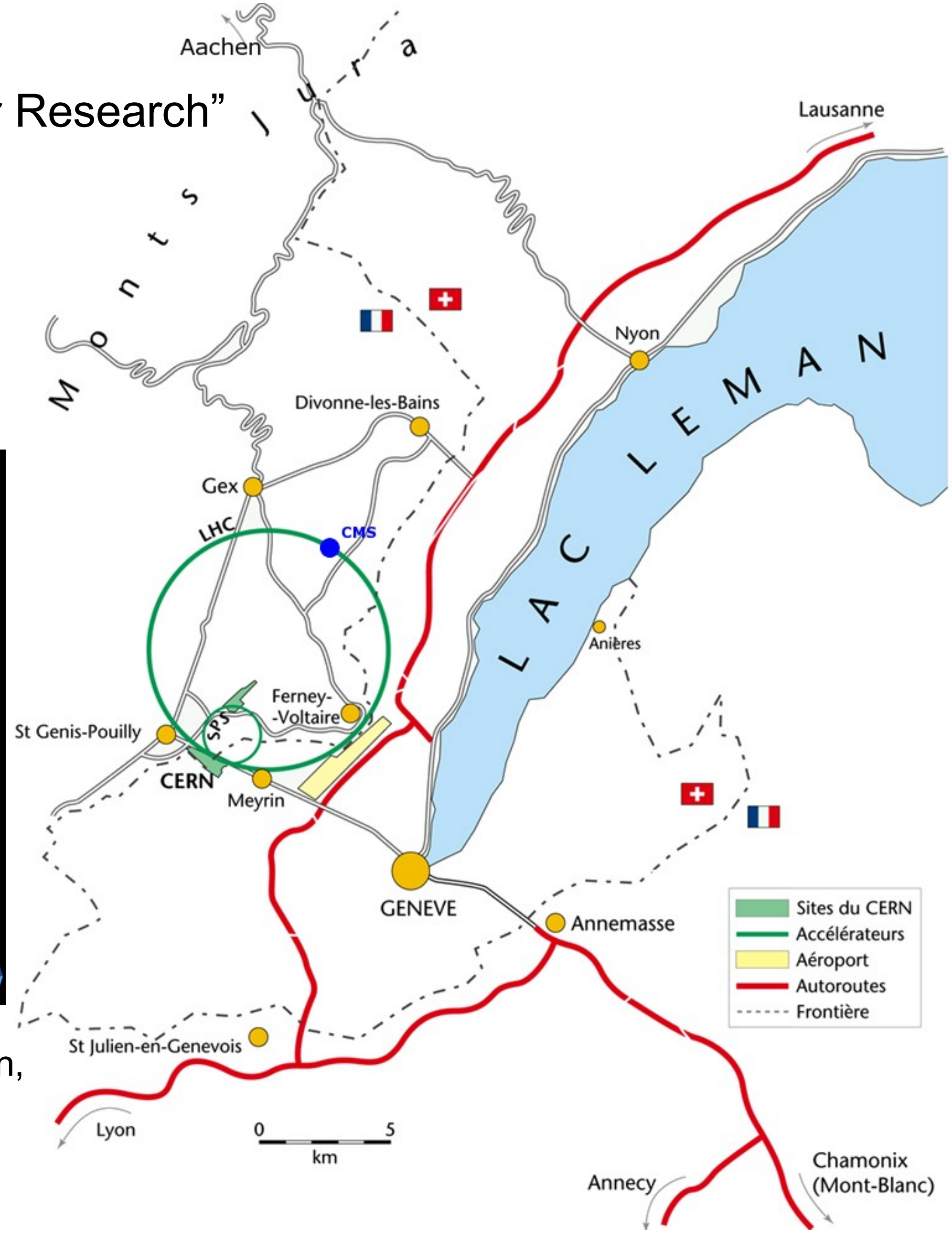
Accelerators & Beams Department, CERN
3rd Physics Institute, RWTH Aachen

- LHC Status
  - Cryogenic system
  - Magnet procurement
  - Installation and hardware commissioning
- Revised beam commissioning plans in 2007
- Questions & Answers

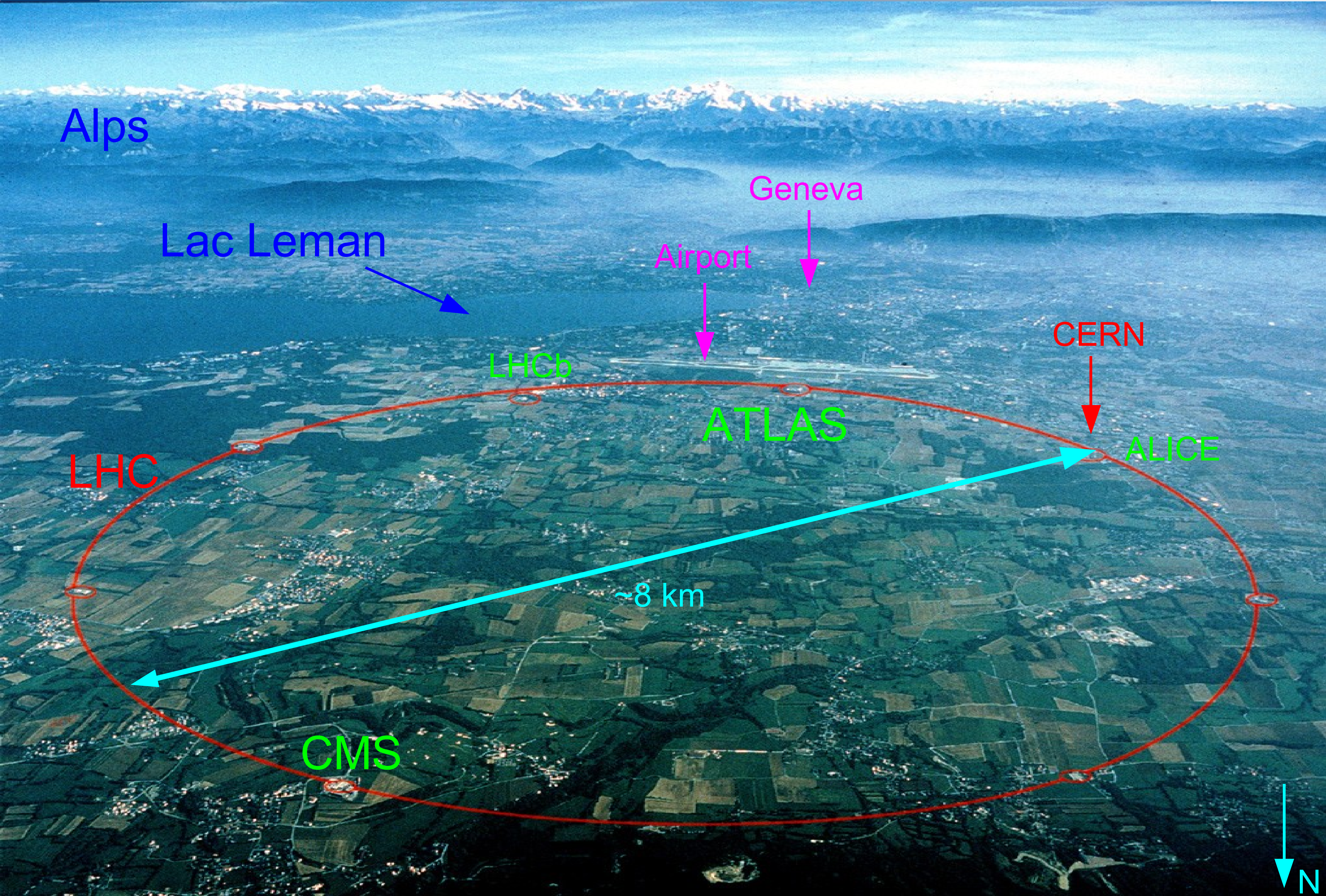
CERN and its Large Hadron Collider (LHC)

- CERN =
  "European Organisation for Nuclear Research"
  - Geneva/Switzerland
  - focuses the effort and offers a facility for HEP exploration
  - 20 member states

  - some observers: India, Israel, Japan, Russian Federation, USA, Turkey, European Commission and UNESCO

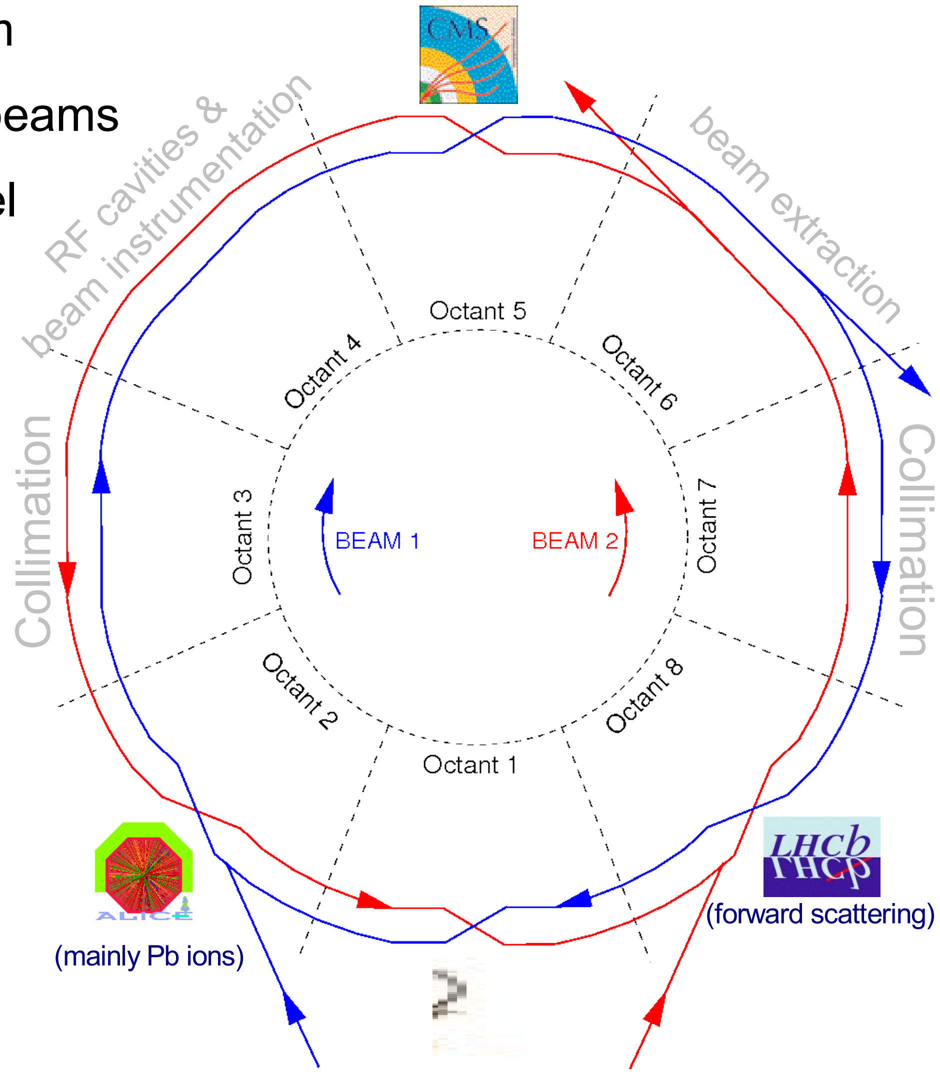


Geneva, Switzerland – aerial view



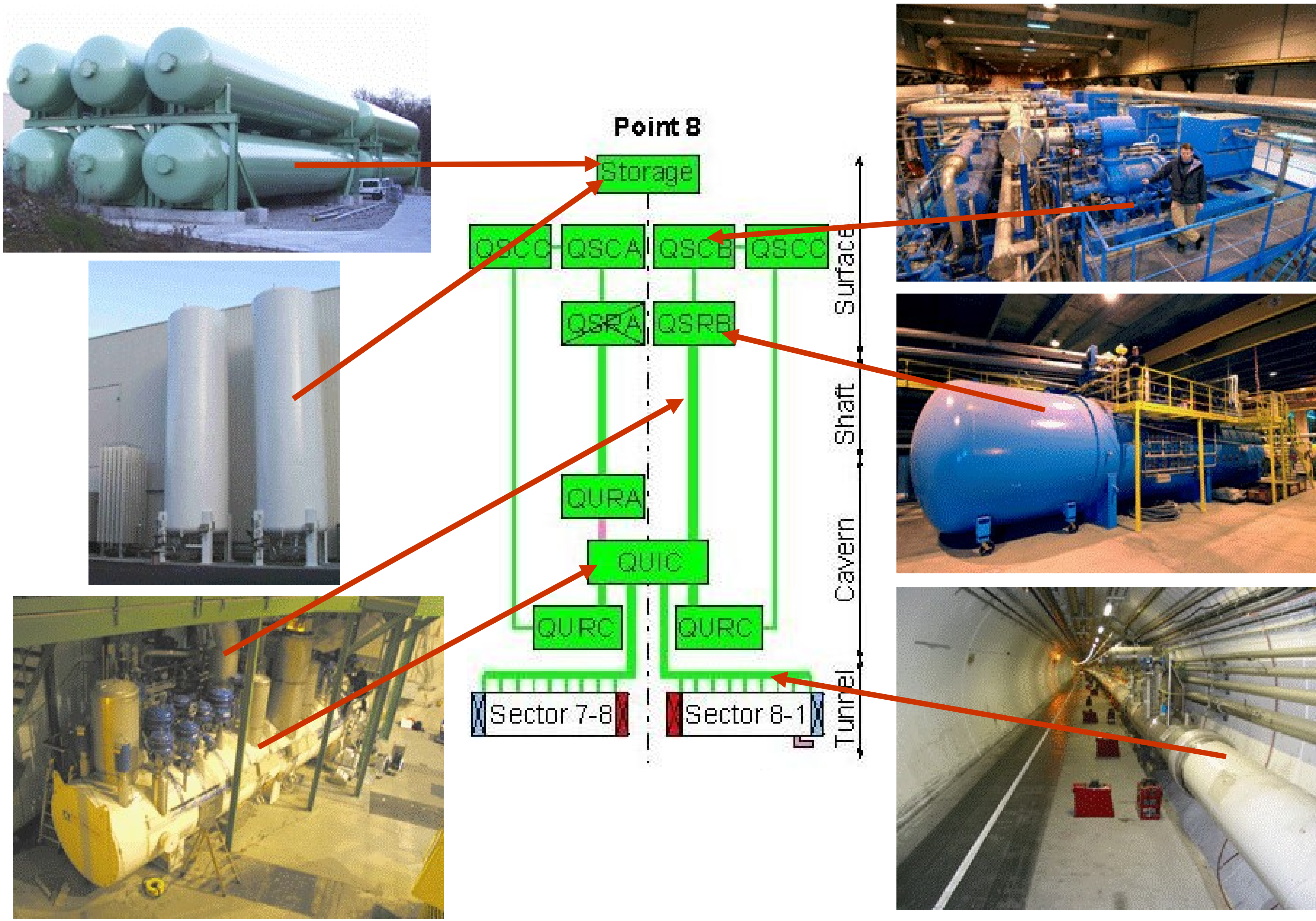
LHC = Large Hadron Collider

- 27 km circumference, depth ~ 100 m
- accelerates two positively charged beams
  → two machines in the same tunnel
- eight-fold symmetry
  – four crossing insertions
- parameters for physics
  – p-p collisions at
    • E_{cms} = 14 TeV (E_{beam}= 7 TeV)
    • nominal L = 10^{34} cm^{-2} s^{-1}
  – Pb-Pb:
    • E_{cms} = 1148 TeV
    • nominal L= 10^{27} cm^{-2} s^{-1}

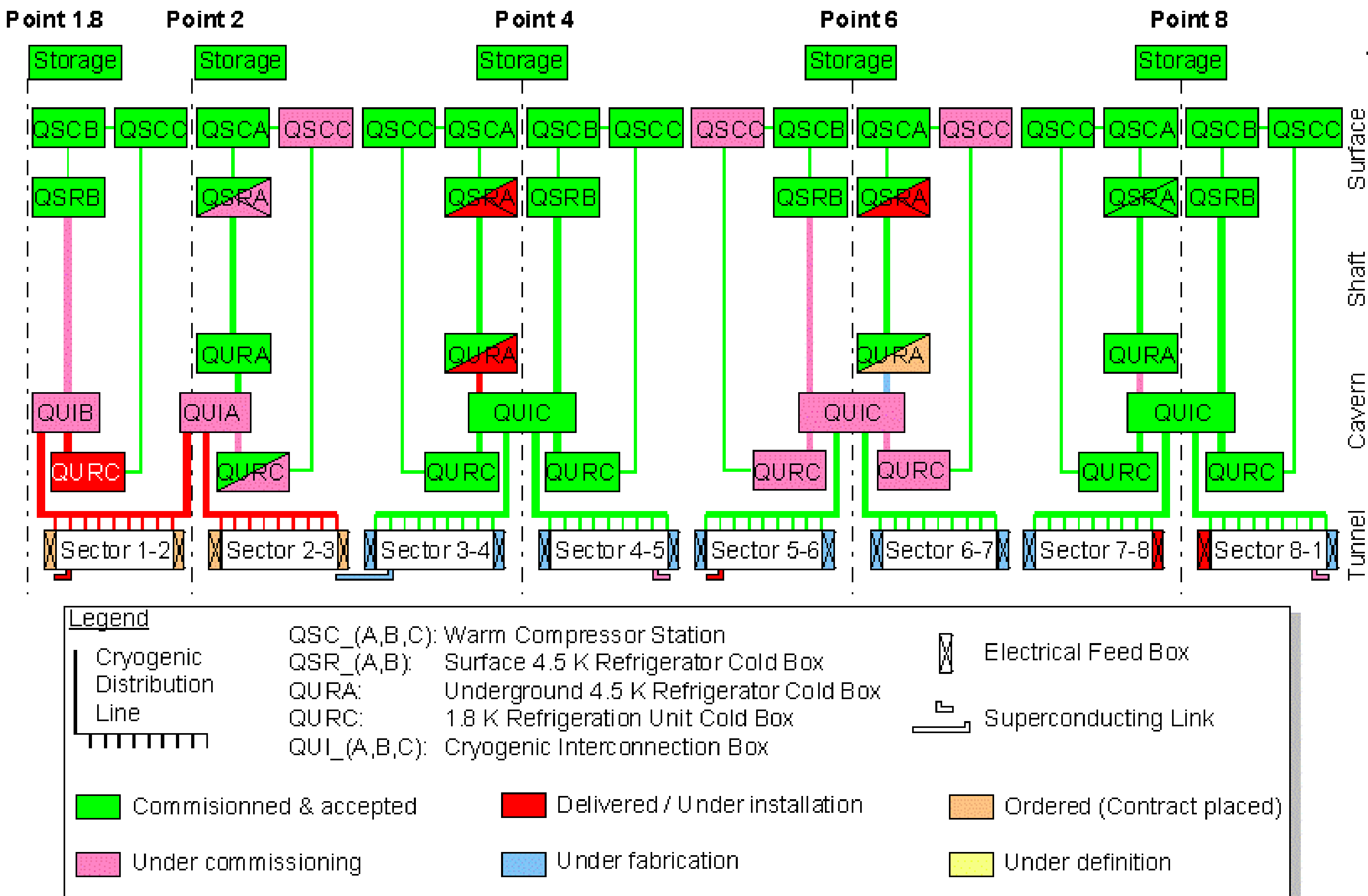


- 137th meeting of the CERN Council 2006-06-08:
  - [..] “experience indicates that [the proposed schedule] is the most efficient way to get to high energy, high luminosity operation at the earliest date.”
  - “Nevertheless, installation presents its own logistical hurdles that will need to be overcome on the way. “With a project such as the LHC, there are bound to be challenges,” said CERN Director General Robert Aymar, “however, the teams constructing the LHC and its detectors have risen to meet these challenges in the past, and I am convinced that they will do so again.”
- Short:
  - Commissioning with beam starts October/November 2007 followed by
  - Two months of “engineering”/calibration run with collisions at 450 GeV
  - Commissioning to full 7 TeV in 2008

LHC Cryogenic System

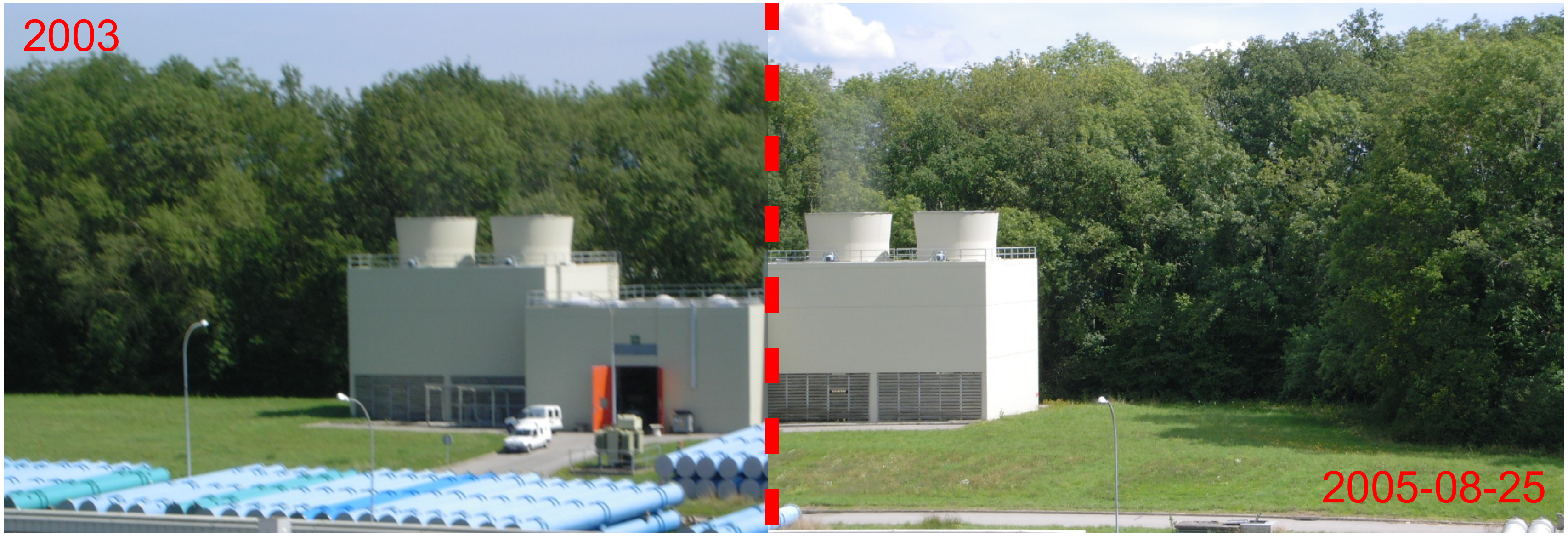


LHC Progress Dashboard: Cryogenic System



Once, not a very unfamiliar view at CERN

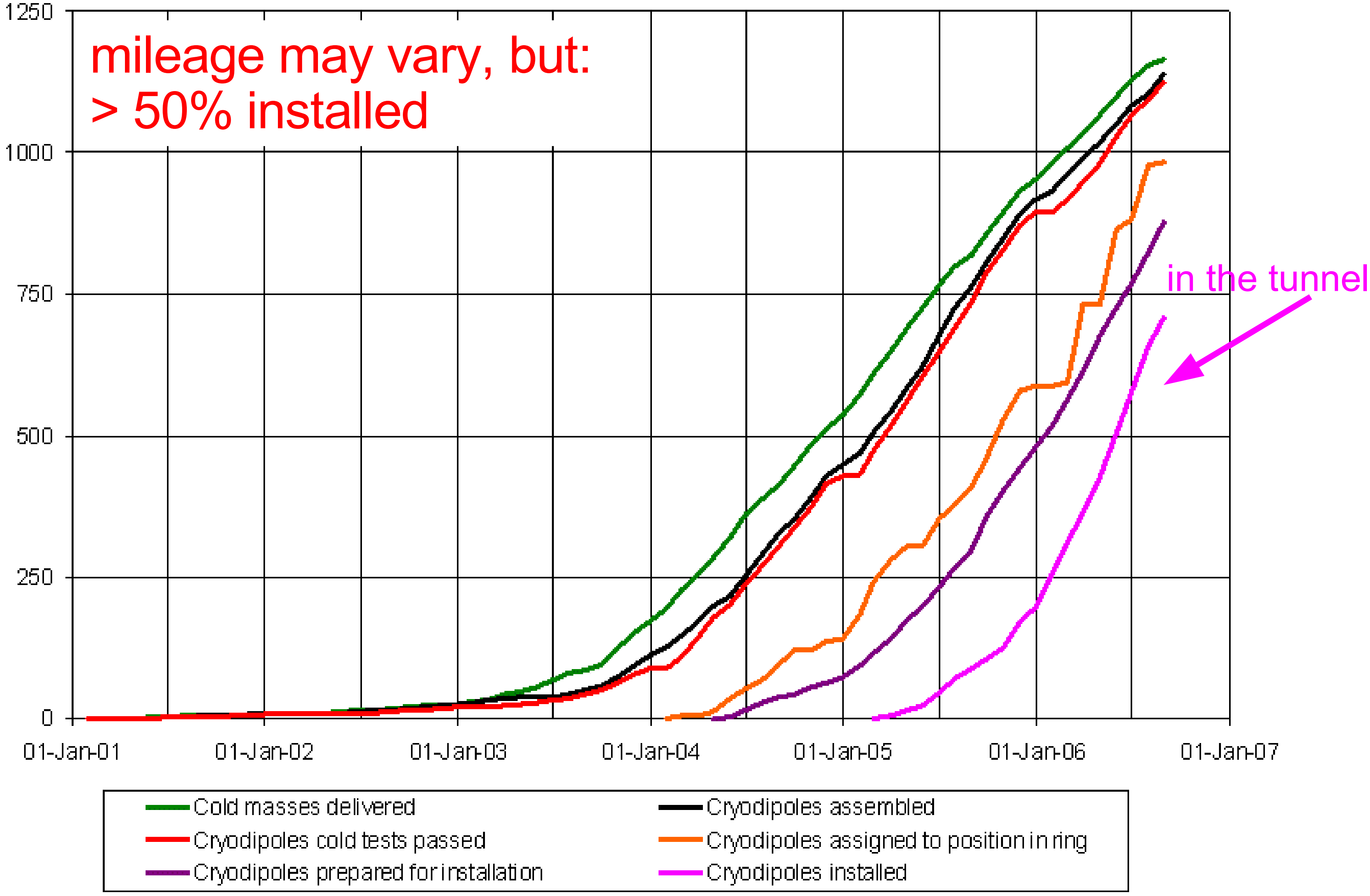
But what was once common life at CERN ...



- The huge number of stored dipoles
  - large logistics involved: magnet assembly → storage → final tests → storage → installation in tunnel
  - ...allowed matching each individual slot to a specific dipole and opened the opportunity to minimise the effect of field quality differences between individual magnets
  - ... similar to "good wine": magnet's mechanical, field quality and quench performance seemed to be preserved/improved (see Chamonix XIV: D. Tommasini)

(→maybe an indication for LHC?)

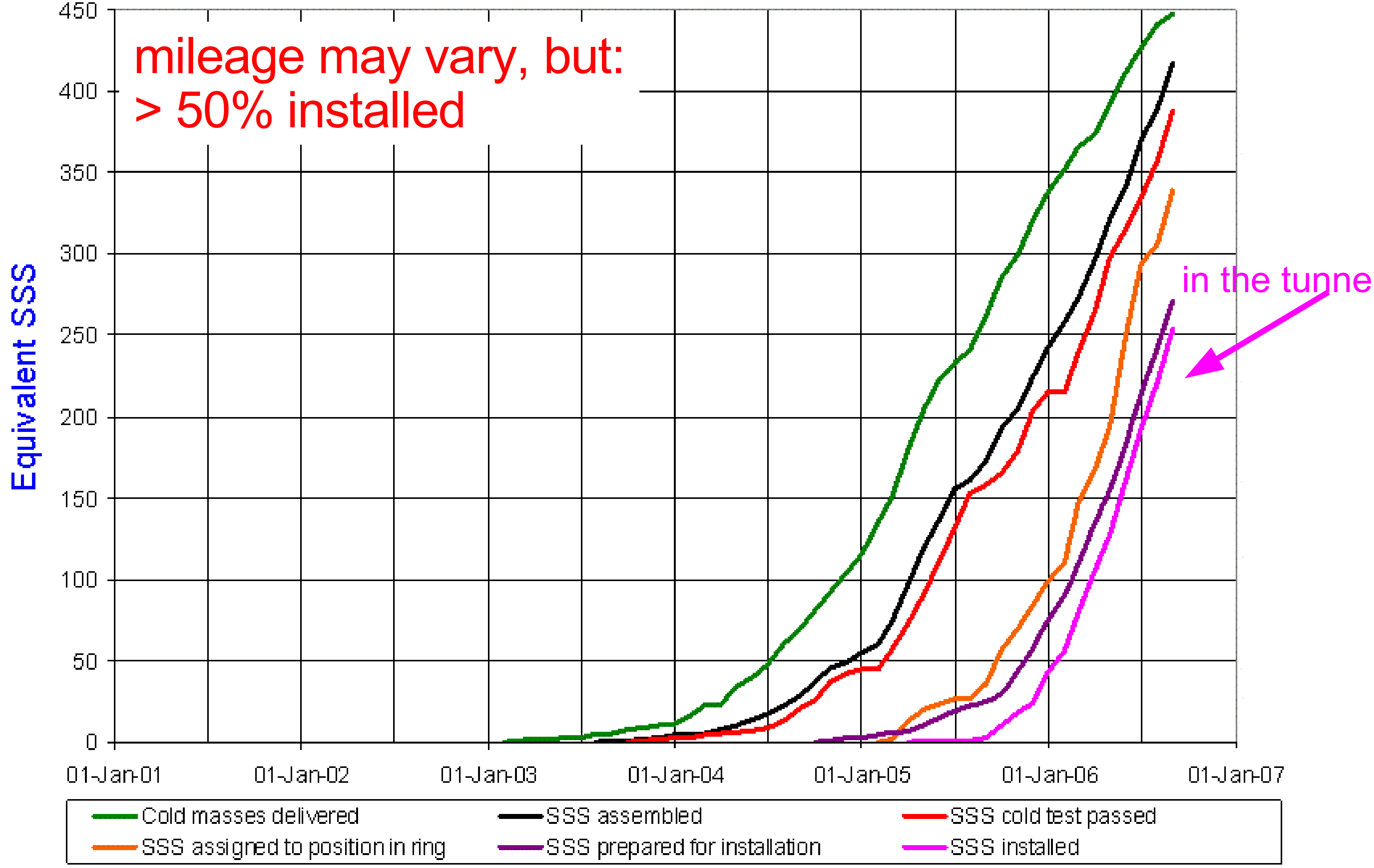
LHC Progress Dashboard: Cryodipoles



Updated 31 Aug 2006

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

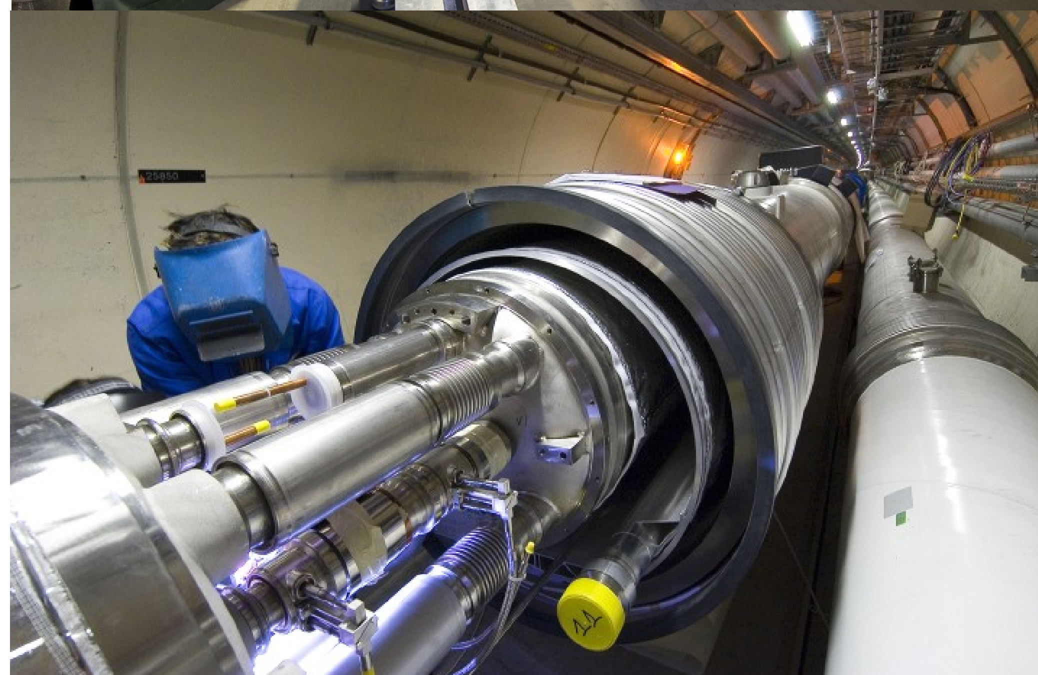
LHC Progress Dashboard: Short-Straight-Sections SSS



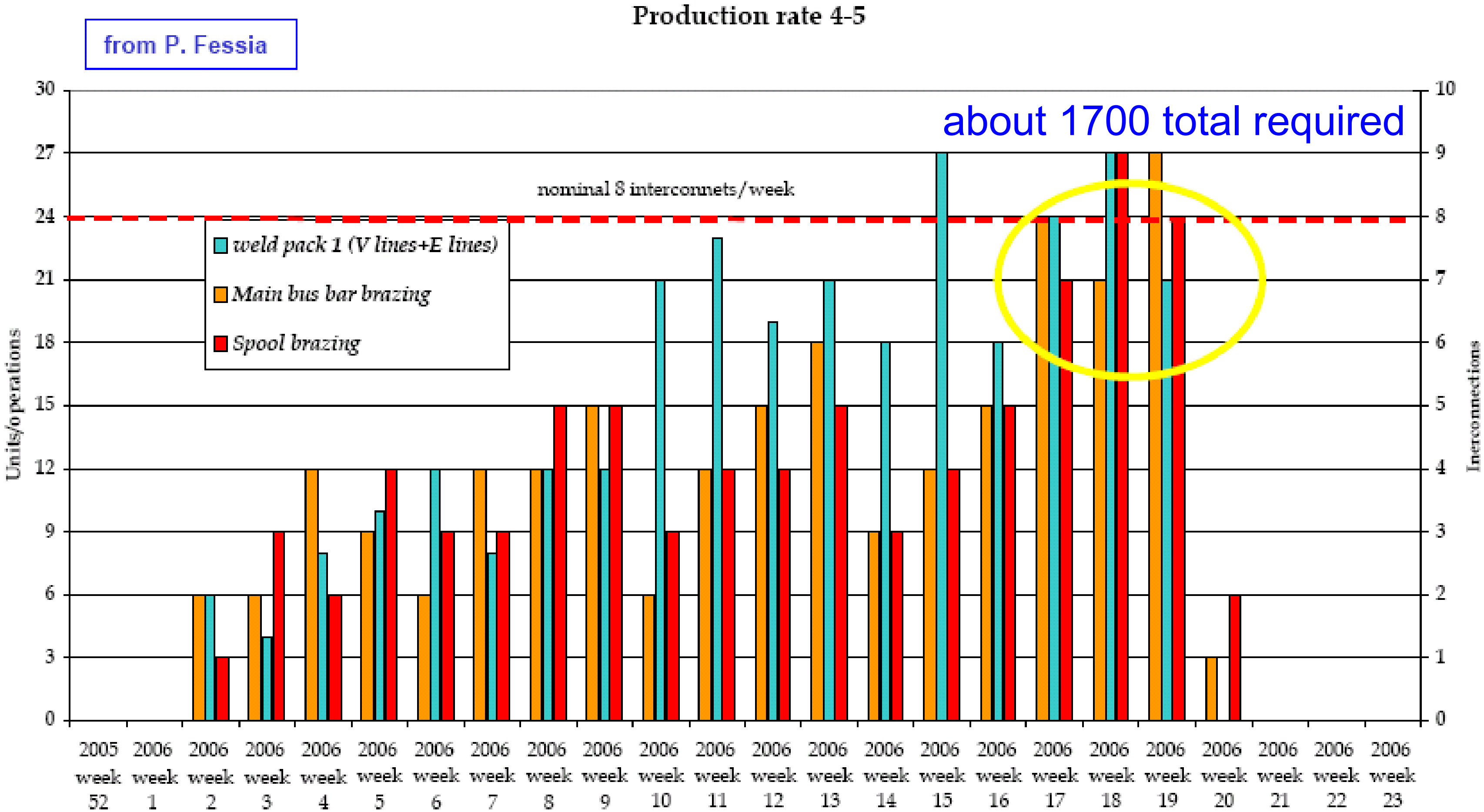
Updated 31 Aug 2006

Data provided by M. Modena AT-MAS, L. Bottura AT-MTM

LHC Underground: Magnet Interconnections

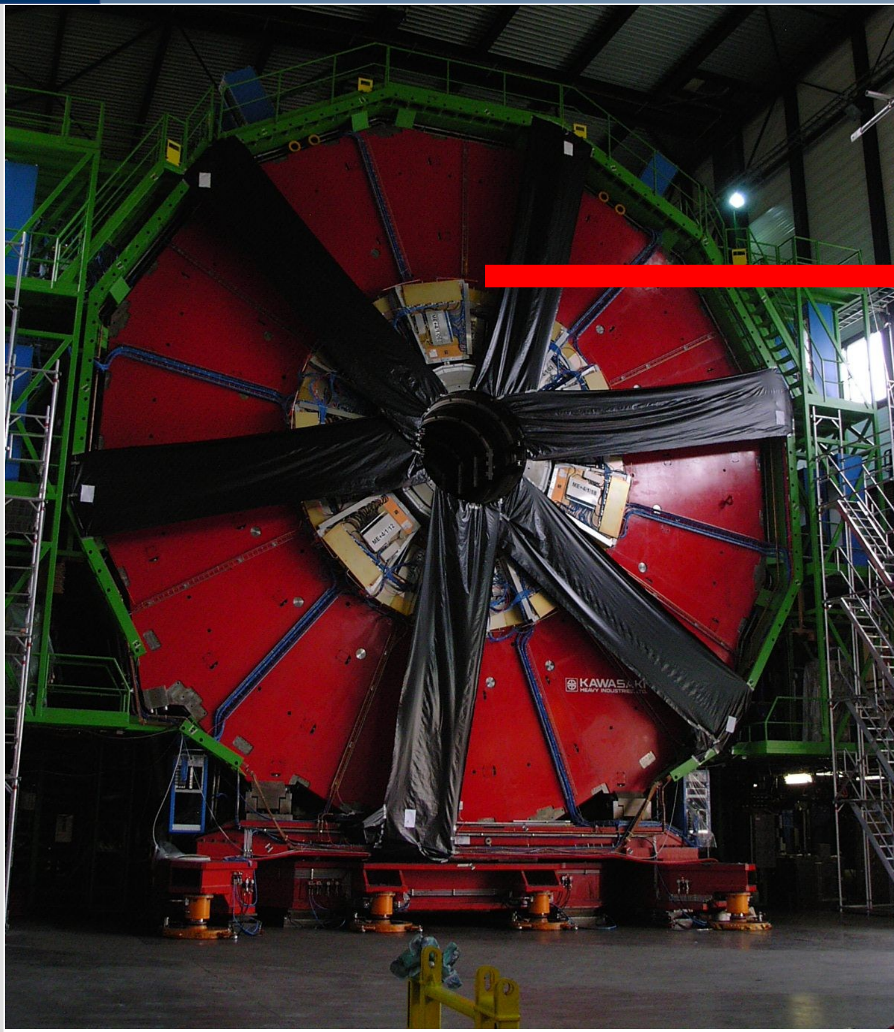


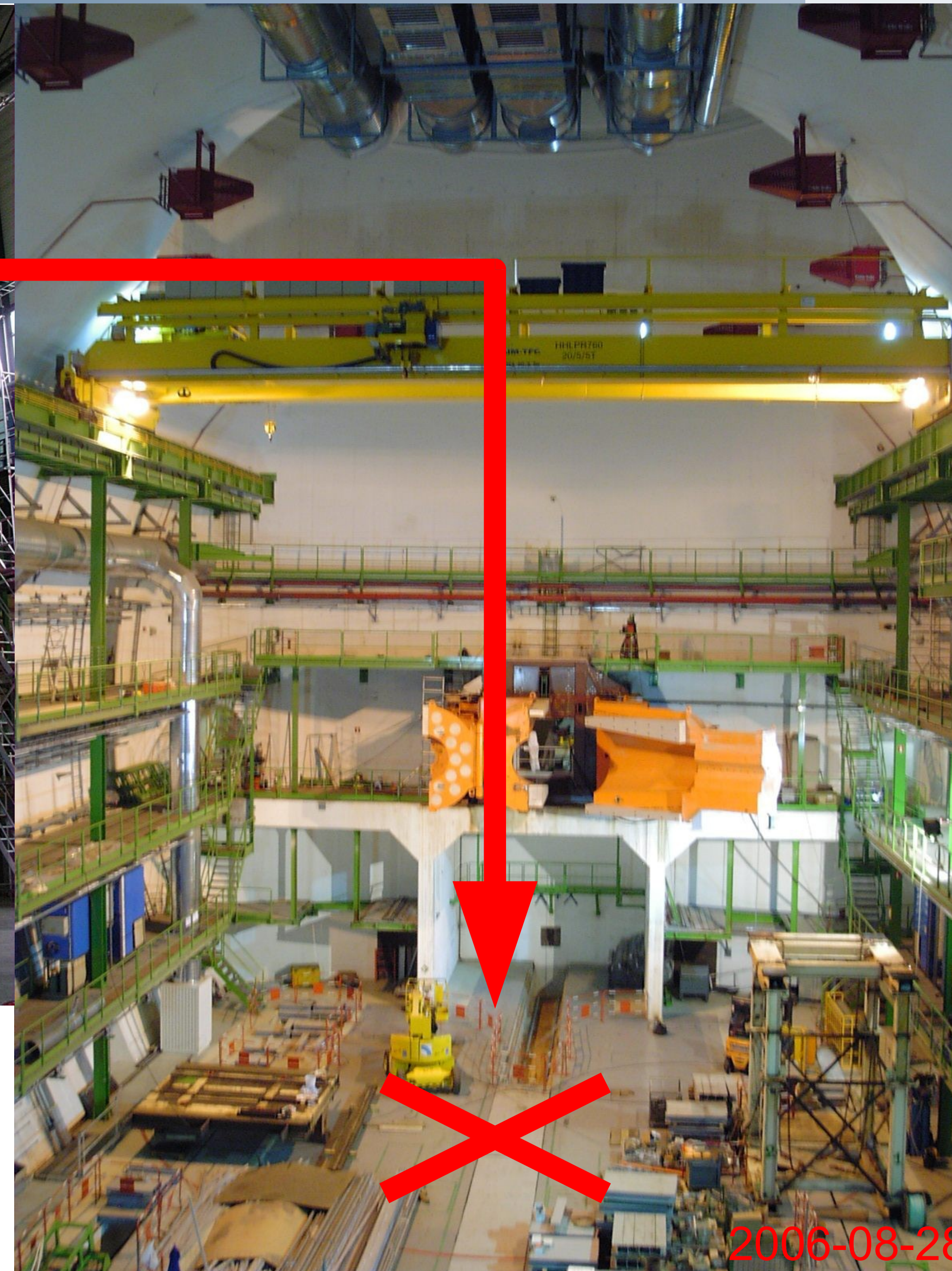
Magnet Interconnections: Learning Curve



- Interconnect rate of one team in sector 4-5
  - Since mid-May: 2 teams in 7-8 (6 days/wk) and 1 team in 8-1 (4 days/wk)

...somewhere in USC 55

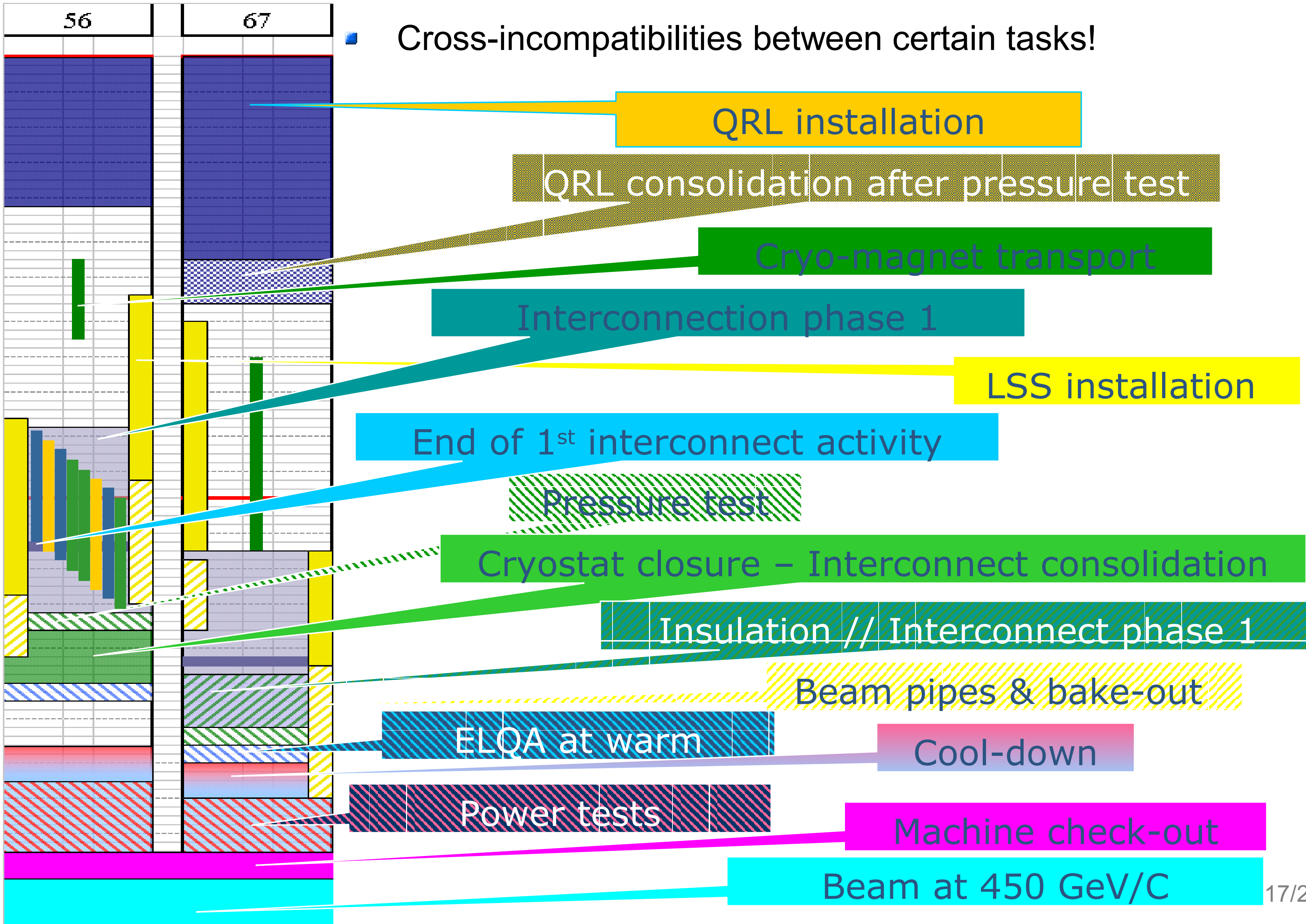




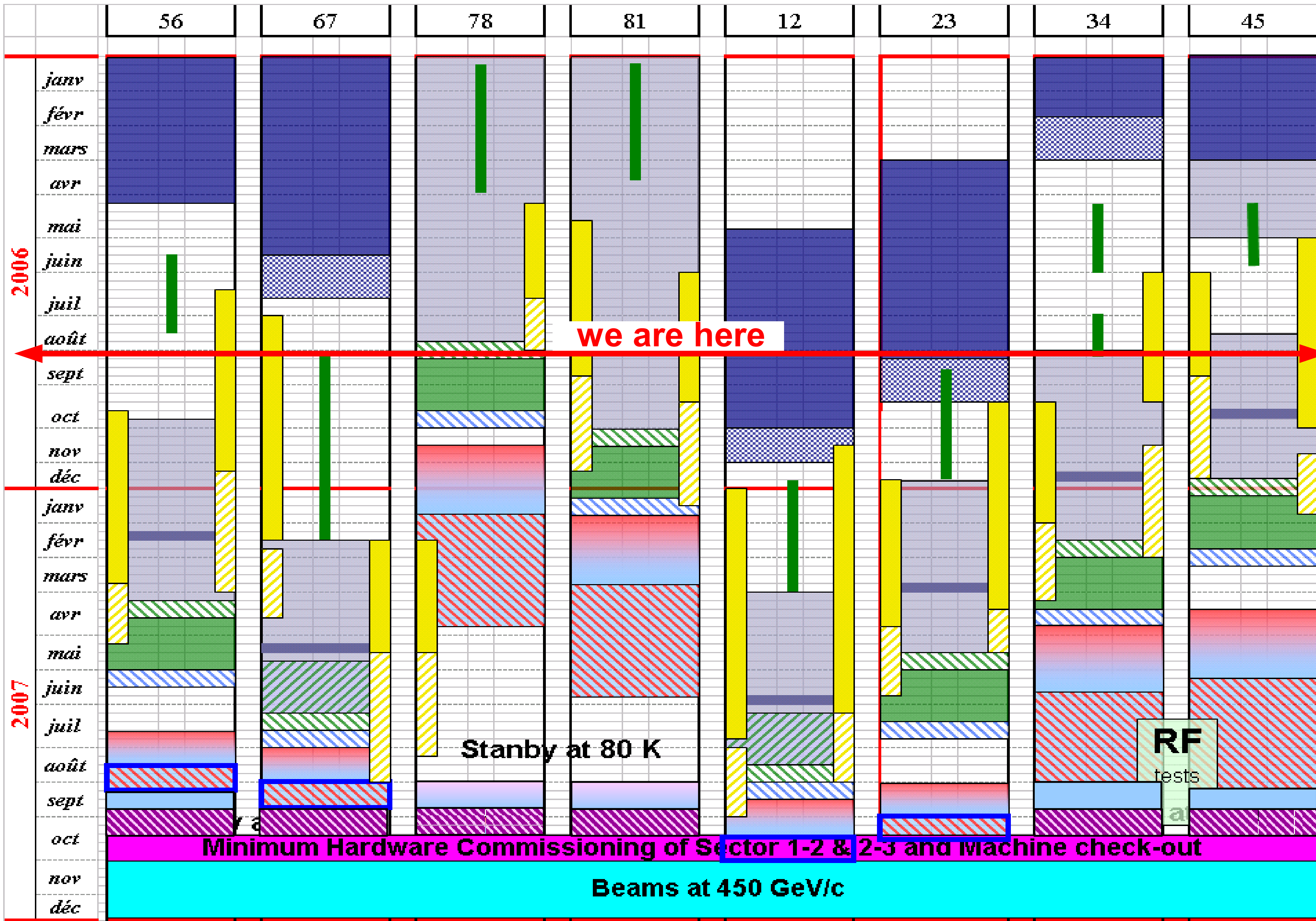
X marks the spot!

Installation and Commissioning Schedule - HOWTO

- Cross-incompatibilities between certain tasks!



Revised Installation and Commissioning Schedule



Commissioning Schedule Detail

	56	67	78	81	12	23	34	45
Oct						**Minimum HWC**		
	Operations testing				Minimum HWC	Operations testing		
Nov	Full Machine Checkout (TI8 & TI2, Access, Vacuum, Equipment Tests, Cycle and Set, BIC and INB)							
Nov / Dec	Beam Commissioning to 450GeV 16days estimated, 60%efficiency assumed							
Dec	Engineering run (Collisions at 450GeV + Ramp Commissioning)							

- An important milestone for both – LHC and its experiments!
  - Magnet alignment, polarities, rough calibration of magnets, injection optics
  - beam instrumentation, timing, control software
  - machine/experiment interfaces, ..
  - (detector alignment, triggers ...)

see: HC Commissioning Review 20060705

Calibration Run 2007 – "Phase 0": Parameters

0

Installation Hardware Commissioning	Hardware Commissioning 450GeV	Engineering Run 450GeV	Shutdown

Machine checkout 450GeV	Beam commissioning 450GeV	Calibration run 450GeV

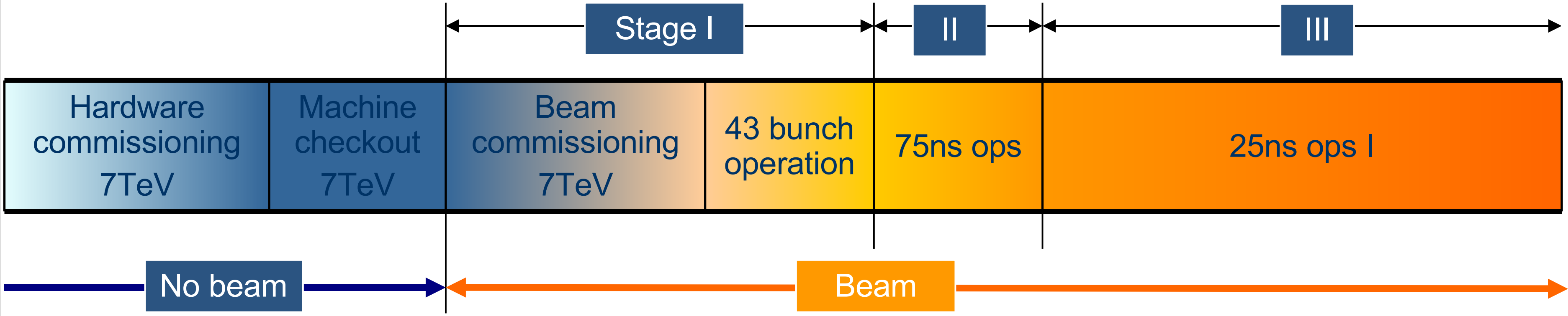
K_b	43	43	156	156
I_b (10^{10})	2	4	4	10
β^* (m)	11	11	11	11
Intensity per beam	$8.6\cdot10^{11}$	$1.7\cdot10^{12}$	$6.2\cdot10^{12}$	$1.6\cdot10^{13}$
Beam energy (MJ)	.06	.12	.45	1.1
Luminosity	$2\cdot10^{28}$	$7\cdot10^{28}$	$2.6\cdot10^{29}$	$1.6\cdot10^{30}$
Event rate [1] (kHz)	0.7	2.8	10	65
W rate [2] (per 24h)	0.8	3	11	70
Z rate [3] (per 24h)	0.08	0.3	1.1	7

1. Assuming 900 GeV inelastic cross section 40mb
2. Assuming 900 GeV cross section $W \rightarrow \mu\nu$ 0.5nb
3. Assuming 900 GeV cross section $Z \rightarrow \mu\mu$ 50pb

(Backgrounds!)

Courtesy R. Bailey, P. Collier

Staged Commissioning for Protons @7TeV in 2008/2009



I. Pilot physics run at 7TeV
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

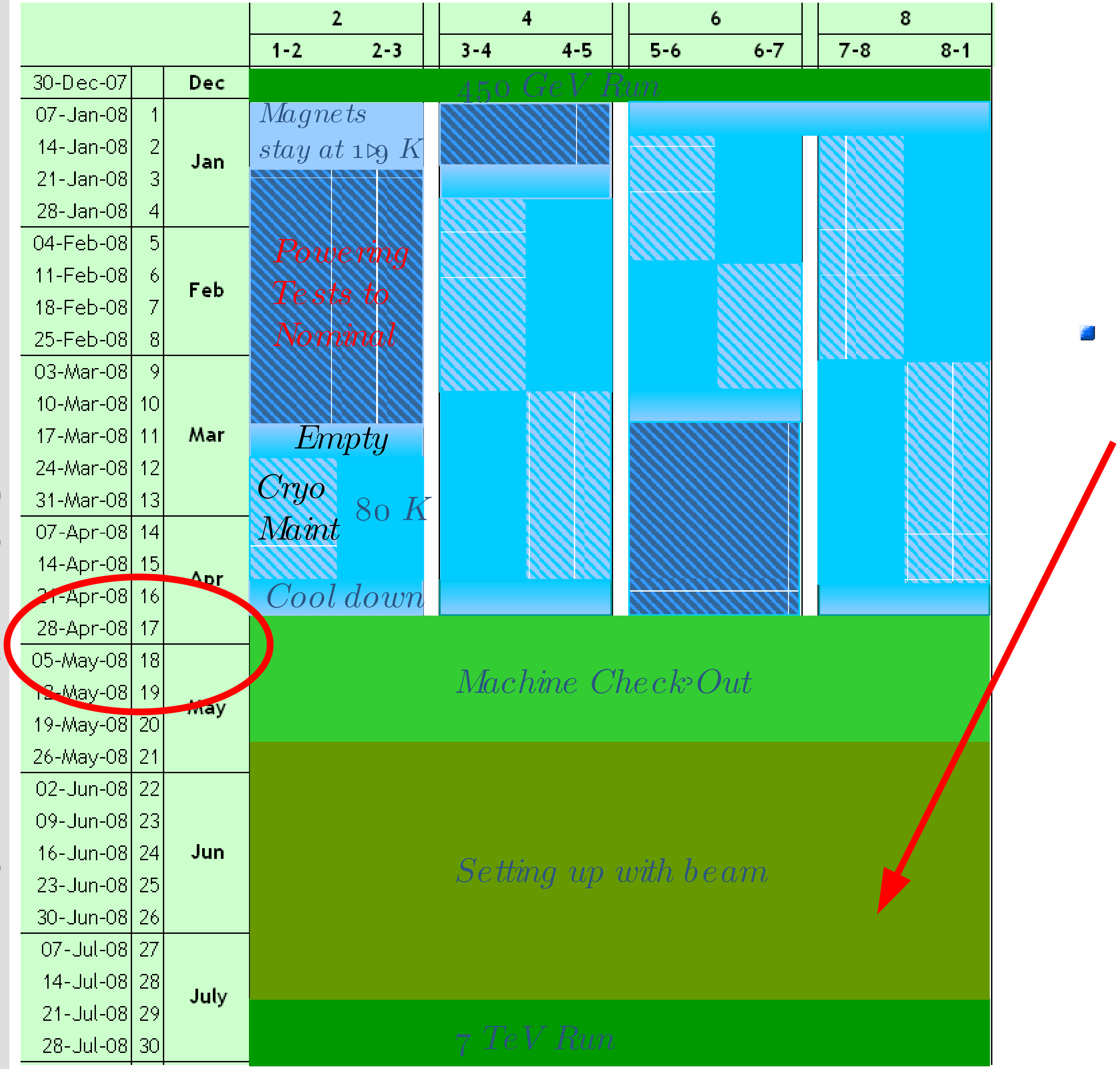
II. 75ns operation
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

III. 25ns operation I
- Nominal crossing angle
- Push squeeze
- Increase intensity
- Performance limit 2 10^{33} cm^{-2} s^{-1}

IV. 25ns operation II (only after installation of full beam dump and collimators)
- Push towards nominal performance

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

Courtesy R. Bailey



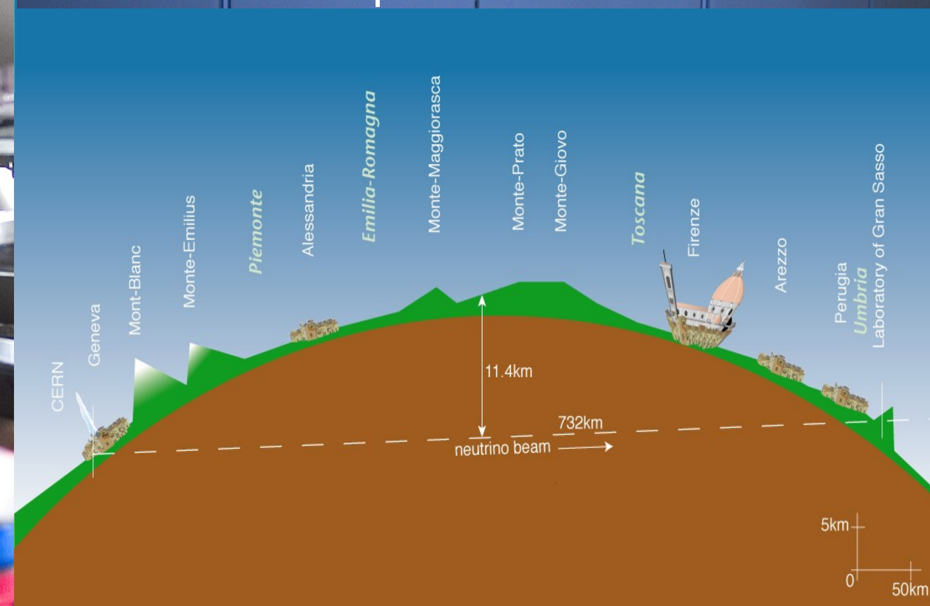
- We may benefit here from Engineering Run:
  - System tests, Polarities, Calibrations, ...
  - learning curves

Courtesy R. Bailey, P. Collier, R. Saban, L. Serio: HC review 20060705

There's also the PS and SPS

- 2006: Successful restart of PS and SPS
  - minor hiccup: phase compensators
  - New SPS control system (test for future LHC)
- Commissioning of
  - CNGS beam line (CERN Neutrinos to Gran Sasso)
  - TT60 (LHC: Beam 1)

All accelerator operation now in CCC



- All HEP particle quests reach a point where:

$$\dot{N}_{event} = L \cdot \sigma_{signal} \quad \text{with} \quad \frac{\sigma_{signal}}{\sigma_{background}} \ll 1 \quad \text{@ achievable Energy E}$$

- Push achievable energy E:
  - Minimise synchrotron radiation losses:
    - $e^+e^- \rightarrow$ hadrons collider ($p^+p^\pm$, ...)
    - Choice: linear vs. circular
      - Optimise RF cavities + normal conducting magnets (CLIC,ILC)
      - Standard RF cavities + superconducting magnets (Tev,RHIC,LHC)
    - LHC: superconducting NbTi alloy @ 1.9K
      - temperature increase due to e.g. particles losses are an issue

- Push maximum peak luminosity
  - essentially: increase number of particles inside the machine

- Storage ring design:

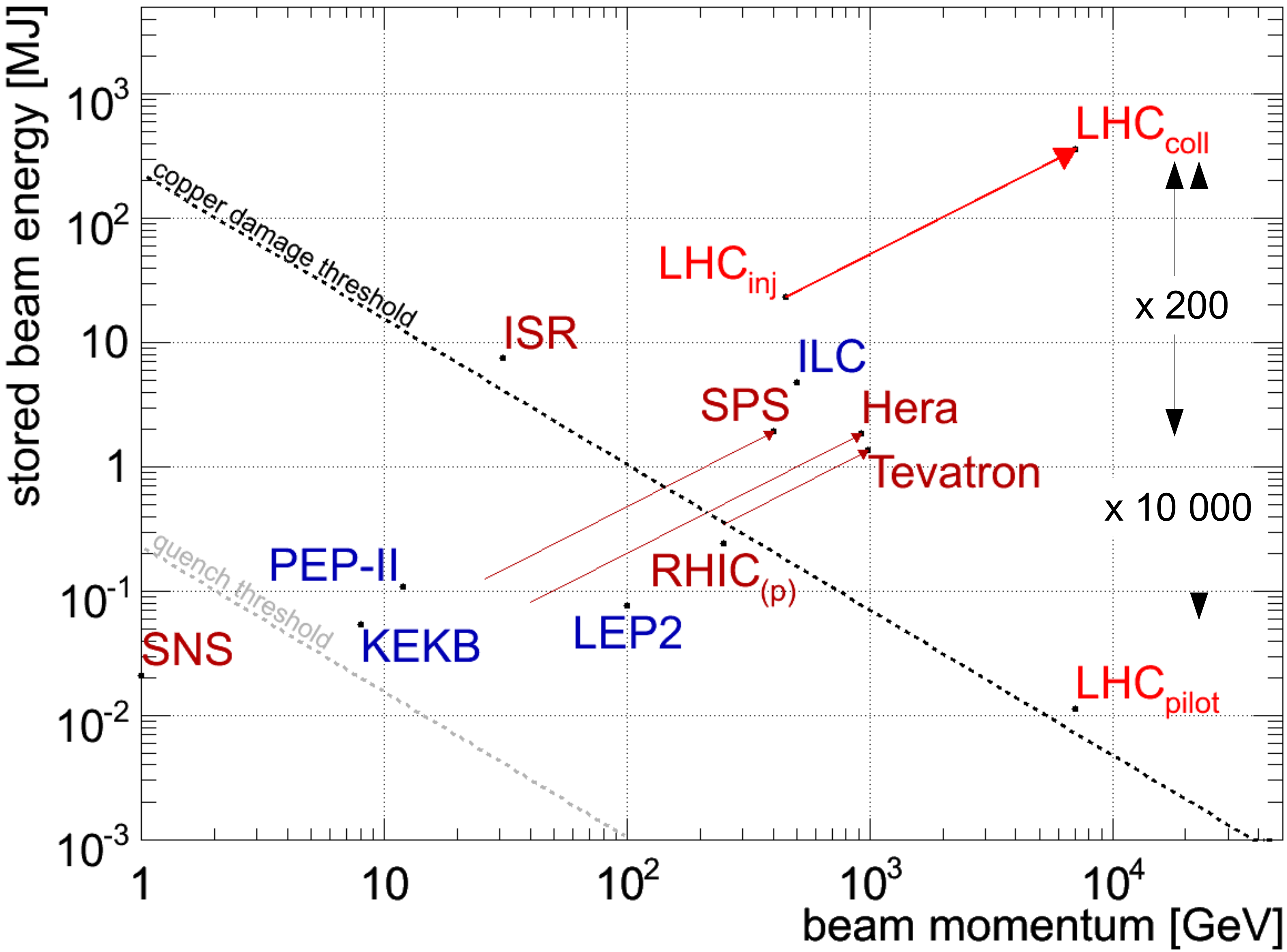
$$L = \frac{N^2 k f_{rev}}{4\pi\sigma_x\sigma_y}\cdot e^{-\frac{1}{4}\left[\left(\frac{\Delta x}{\sigma_x}\right)^2+\left(\frac{\Delta y}{\sigma_y}\right)^2\right]}\cdot F_{crossing}\cdot F_{hour\ glass}\cdot\ldots$$

	LHC	Tevatron
– N: number of particles per bunch,	N_{pilot}=5 10^9, $N_{nominal}$= 12 10^{10}	N_p=30 10^{10}
– k: total number of bunches,	k = 1 ... 2808	k = 36
– σ_x, σ_y: hor./vert. r.m.s. beam size in IR	$\sigma_x=\sigma_y$ ~ 17 µm	$\sigma_x=\sigma_y$~30 µm
– f_{rev}: revolution frequency,	f_{rev}= 11.2 kHz (fixed)	f_{rev}= 47.7 kHz
– Δ_x, Δ_y: hor./vert. beam separation in IR		
– $F_{crossing}$, $F_{hourglass}$: numerical form factors,	$F_{cross.}$(285 µrad)~0.8	$F_{cross.}$(0)=1
	1- $F_{hourgl.}$~ 0.4%	1- $F_{hourgl.}$~ 38%

- Most parameters are defined by the accelerator geometry and lattice
- The "most effective" parameter: total stored intensity $I_{stored} = Nk$

LHC: $I_{stored} \approx 3.2\,10^{14}\ protons \Rightarrow E_{stored} \approx 350\ MJ\ @\ 7\text{TeV}$

IWBS'04: "LHC is a pretty dangerous machine" Livingston Style plot



see Chamonix XIV: "Damage levels - Comparison of Experiment and simulation" and PAC'05 for details

Maximum LHC Energy of 7 TeV

- LHC superconducting dipoles may loose superconducting state ("quench")
  - minimum quench energy E_{MQE} @7 TeV for t~10 – 20 ms

$E_{MQE} < 30$ mJ/cm^{-3} vs. $E_{stored} = 350$ MJ/beam (nominal LHC)

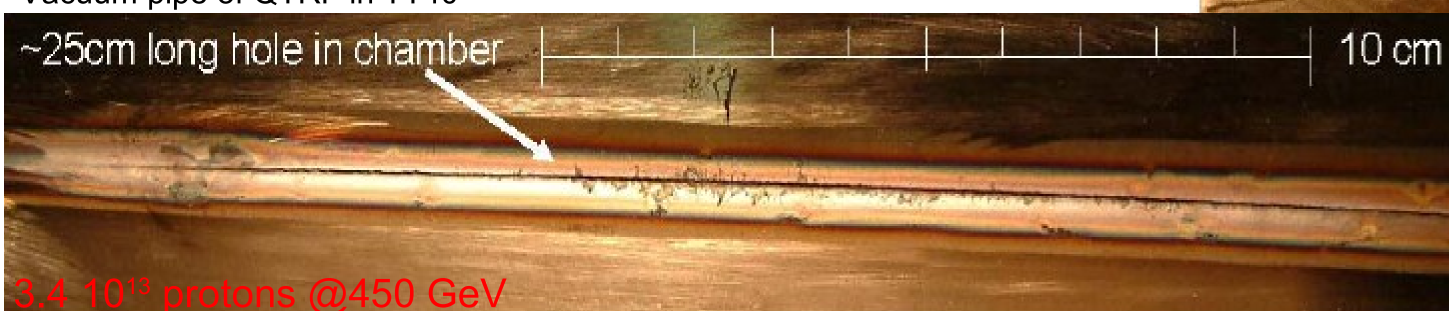
(or: $N_{loss} < 10^8$ protons/m vs. $N_{total} \sim 3\ 10^{14}$ protons)

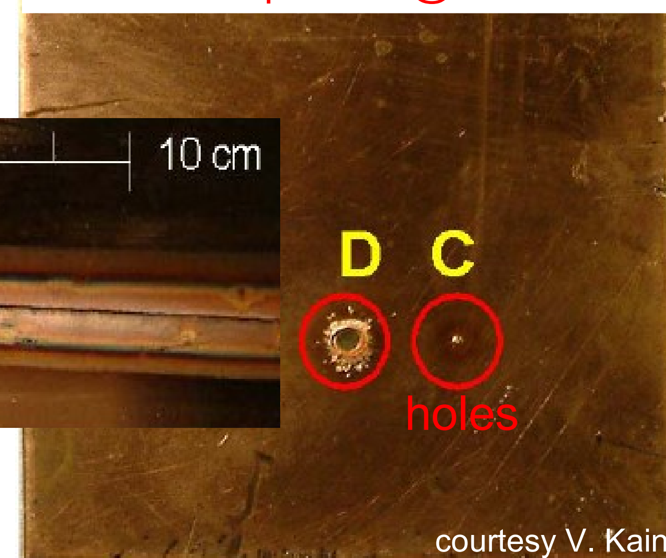
→ sufficient to quench all magnets and/or may cause serious damage

  - requires excellent control of particle losses
- Example: un-controlled vs. controlled energy release

C = 5.4 10^{12} protons @ 450 GeV
D = 7.9 10^{12} protons @ 450 GeV

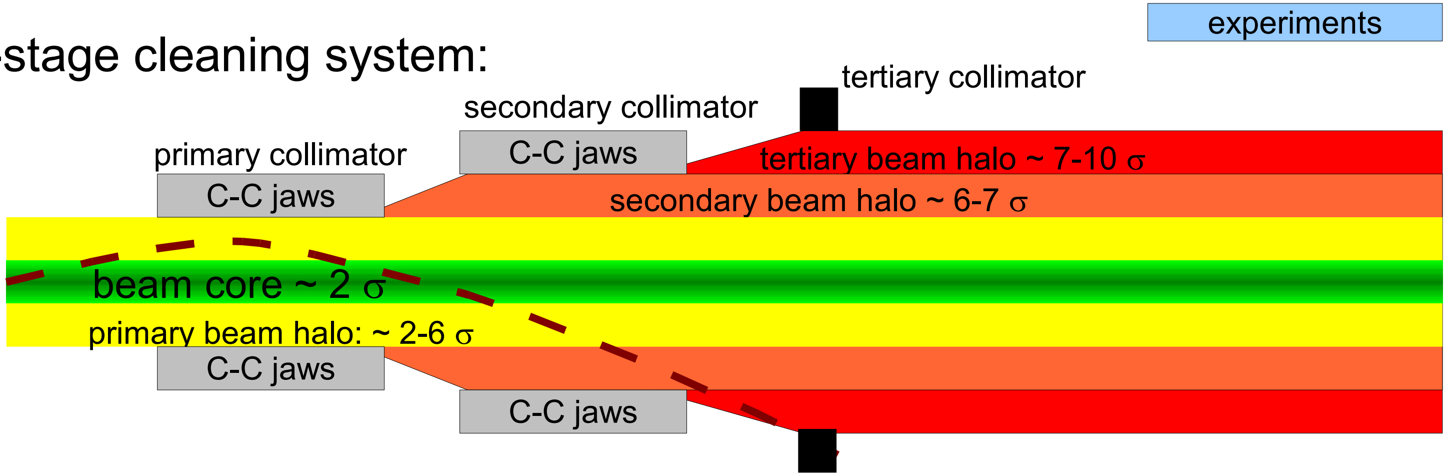
Vacuum pipe of QTRF in TT40



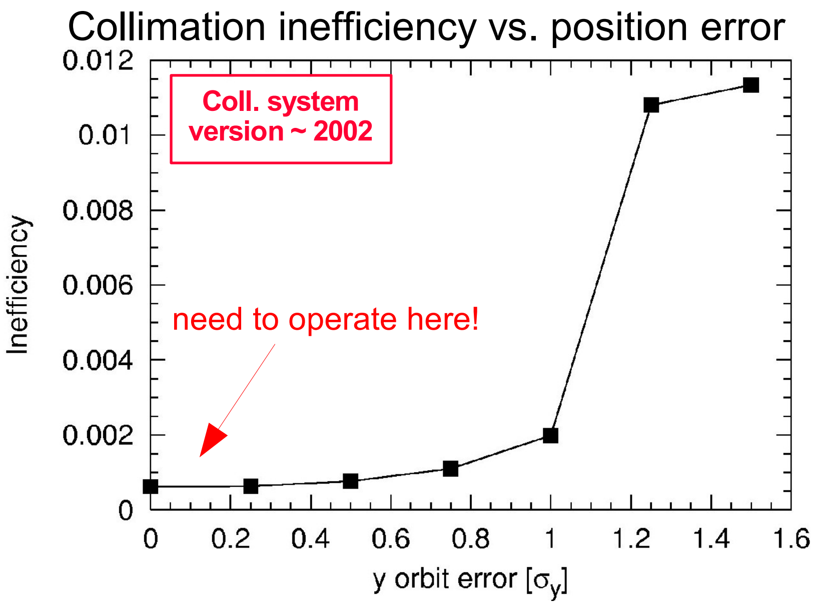


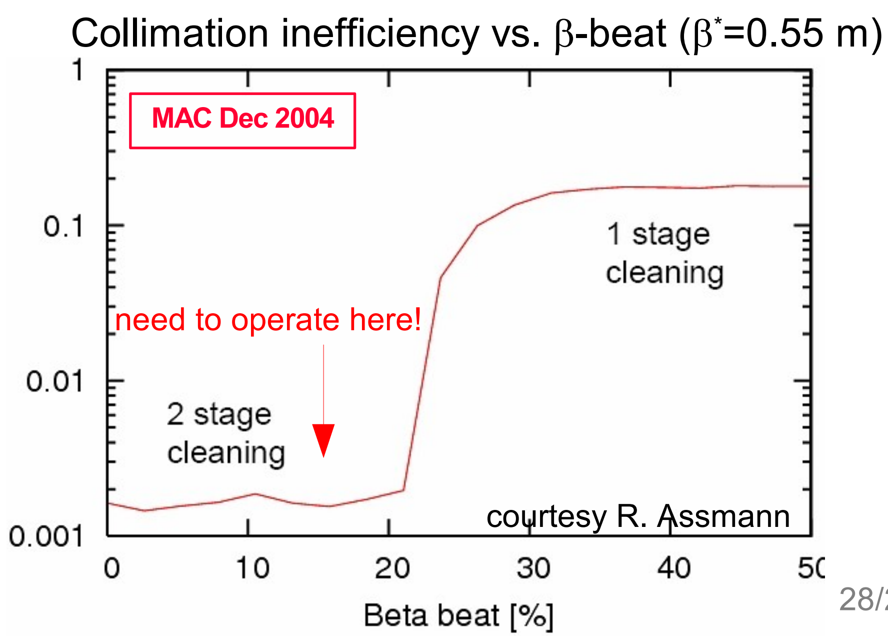
for details see: Chamonix XIV:
"Damage levels - Comparison of Experiment and simulation" and PAC'05

- Two-stage cleaning system:



  – requires tight orbit stability requirement of σ/6: ~ 25 μm at coll. jaws & 7 TeV → less than the thickness of a human hair





Summary

- "LHC is on the horizon"
  - CERN Council confirmed schedule for commissioning with beam in 2007:
    - Commissioning with beam starts October/November 2007 followed by
    - Two months of "engineering"/calibration run with collisions at 450 GeV
    - Commissioning to full 7 TeV in 2008

- LHC operation is very challenging
  - Unprecedented high stored energy per beam in a superconducting environment that does not tolerate particle losses
  - Maximum possible LHC performance may be limited by the stability of the beam and the ability to control particle losses inside the machine.
  - LHC is the first machine that relies on orbit feedbacks for a safe and reliable machine operation.