



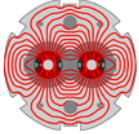
Implications of Higher Intensities in the LHC

R. Assmann, CERN

Thanks to

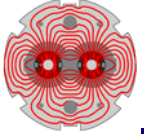
J. Tuckmantel, J.M. Jimenez, S. Roesler,
F. Zimmermann, S. Claudet, L. Rossi, ...

Chamonix 2010

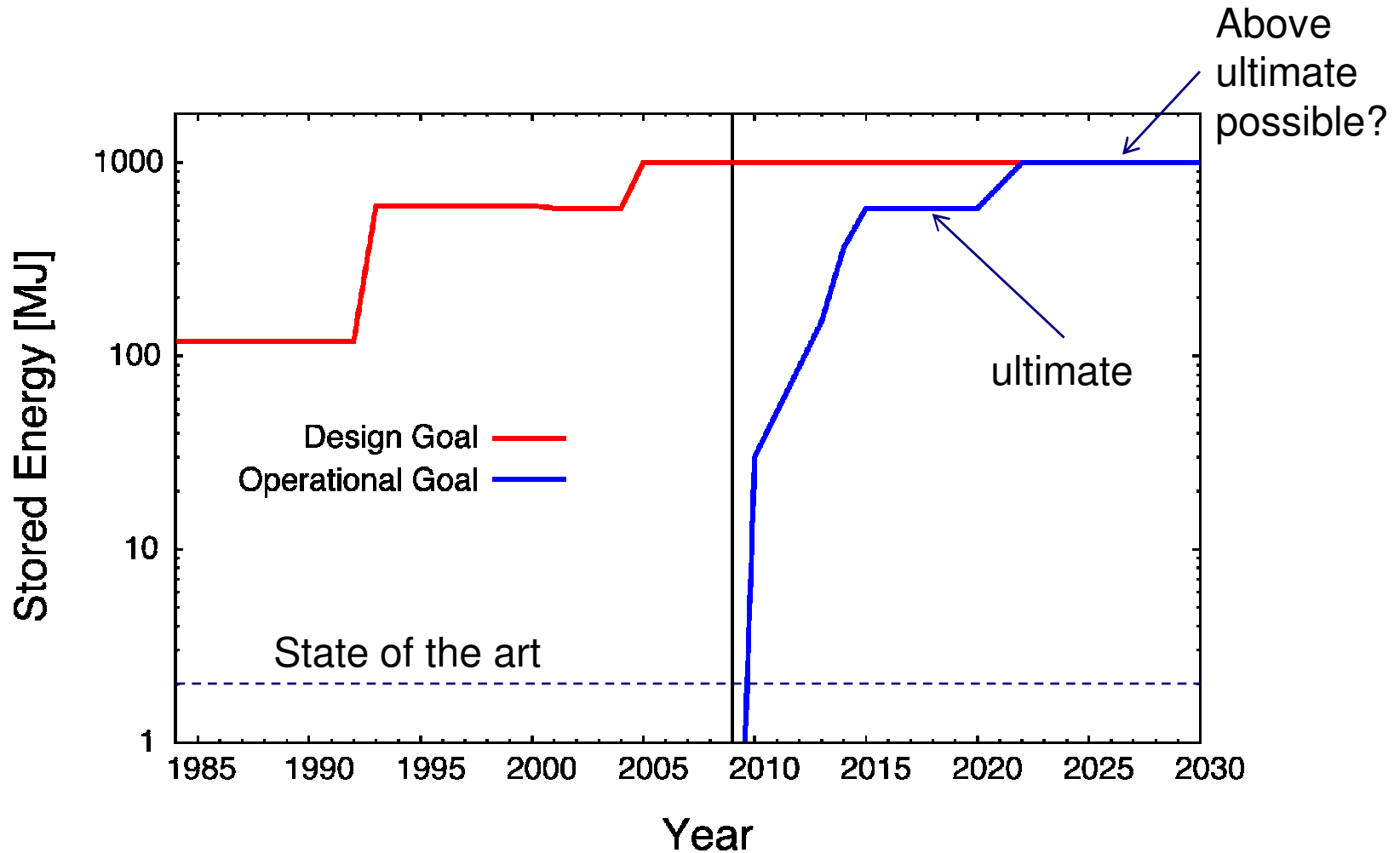


Introduction

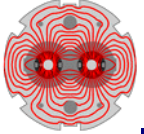
- Can the LHC accept more than ultimate intensity in the LHC?
- Answer: **“With enough money everything is possible...;-)”**
“Mit genuegend Geld ist bei uns alles moeglich...;-)”
- Collection of various issues that were pointed out to me.
- Everybody focuses on more immediate problems, so difficult to get complete picture within available time. Thanks to all who send me input!
- **No guarantee for completeness.** For example, radiation to electronics is not covered (whole session on this).



LHC Challenges: Stored Energy



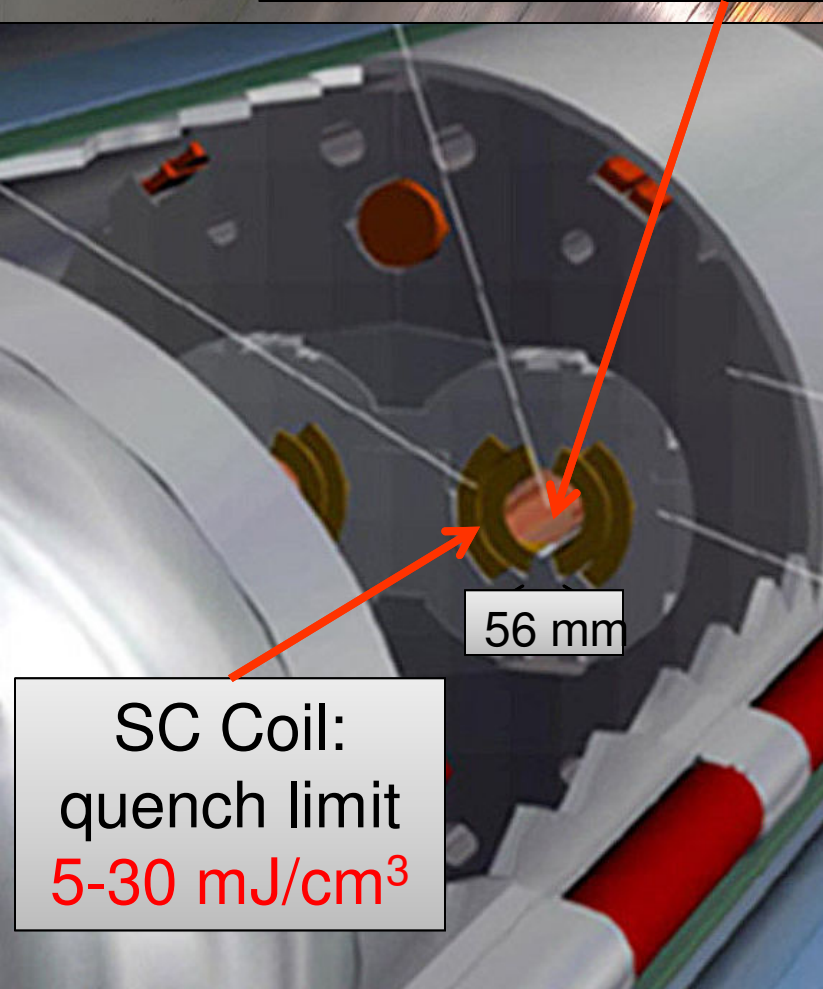
➔ Over time the design stored energy went significantly up. **More demand on RF, cryo, beam stability, collimation efficiency, radiation handling, ...!**



Quench Limit versus Stored Energy

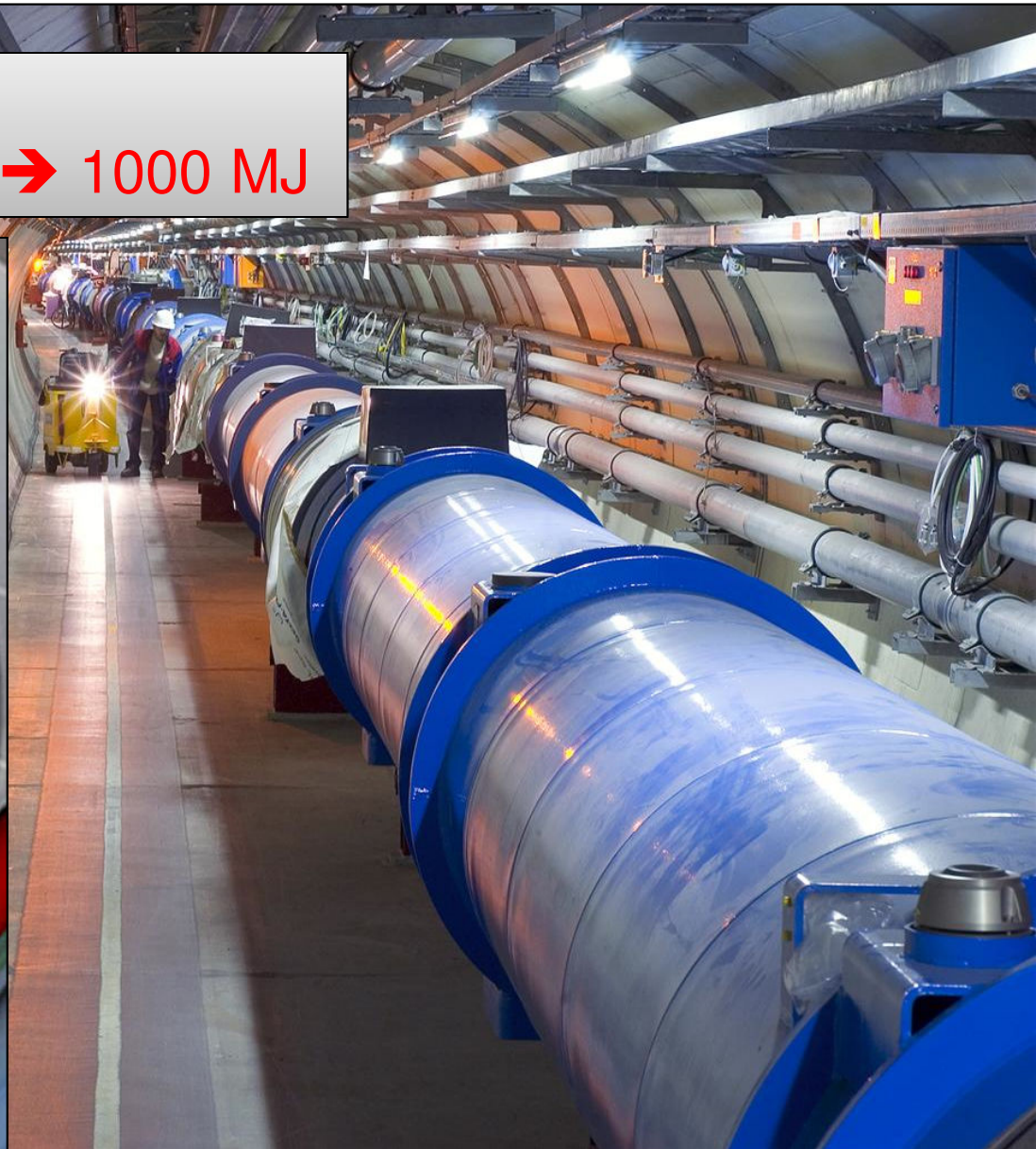
Beam

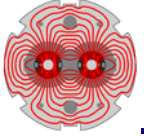
362 MJ → 580 MJ → 1000 MJ



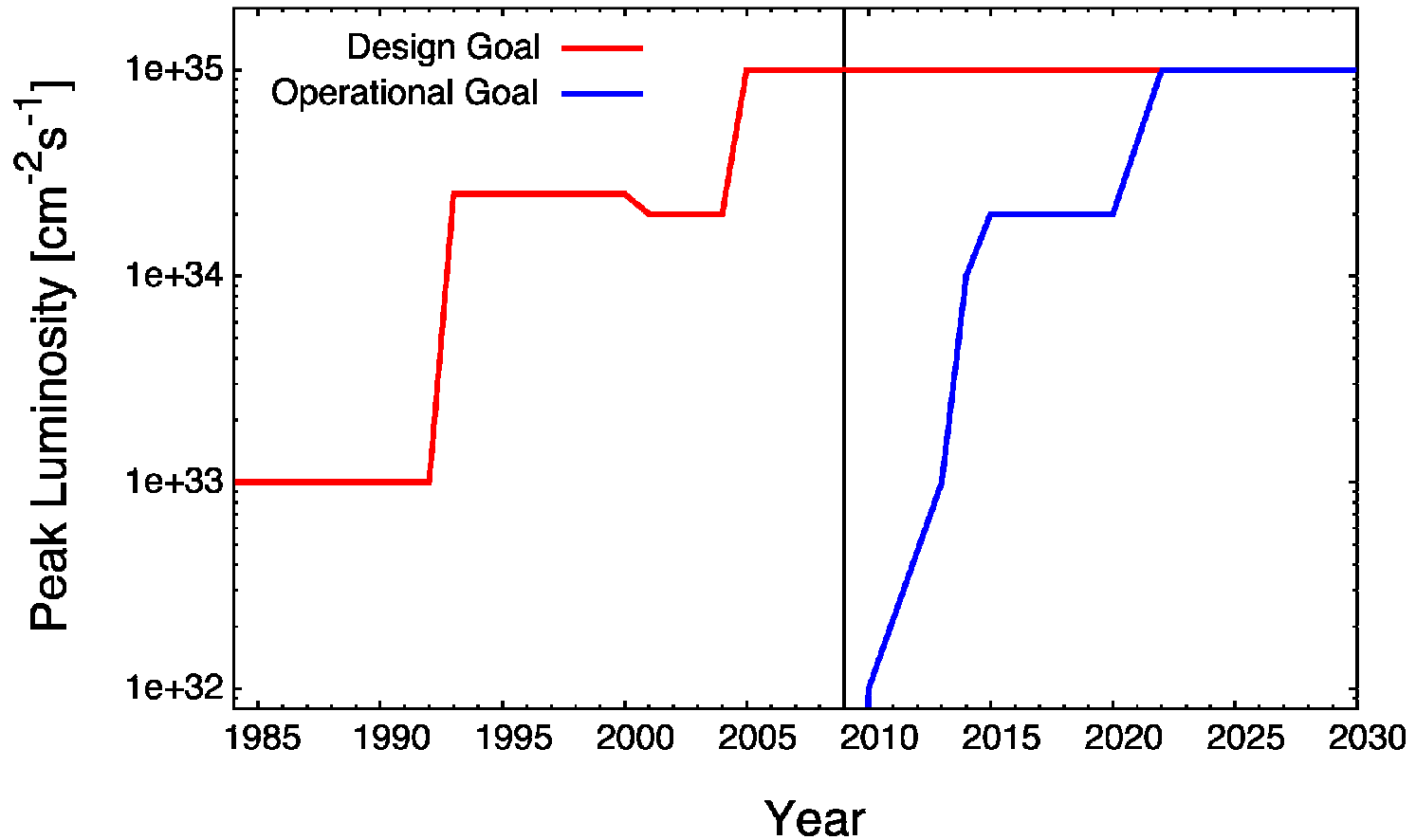
56 mm

SC Coil:
quench limit
5-30 mJ/cm³

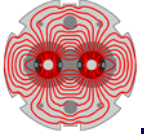




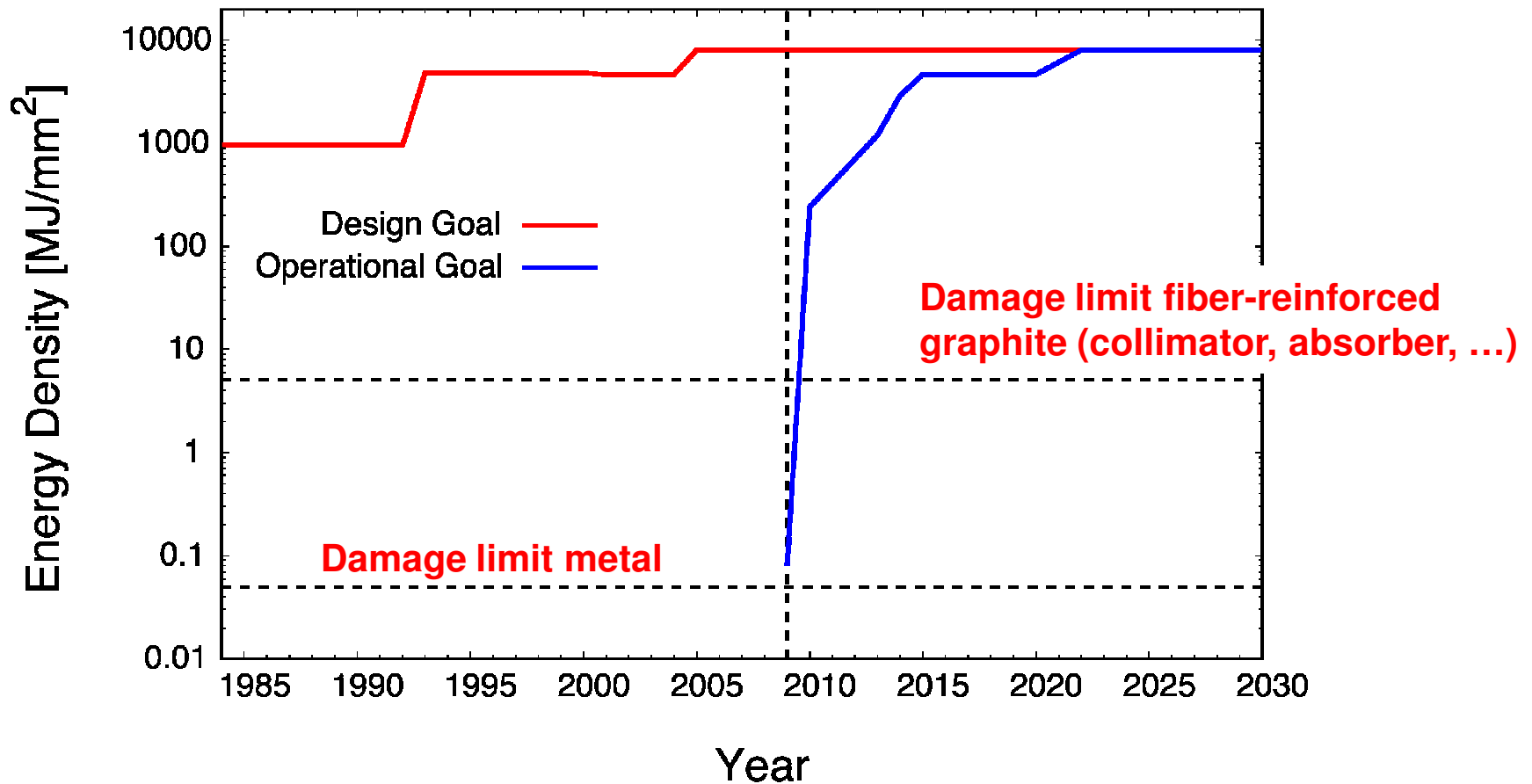
LHC Challenges: Luminosity



➔ Nice increase in design luminosity for the experiments...



LHC Challenge: Transverse Energy Density



- ➔ Transverse energy density is pushed further, **way above damage limits of materials!** At some point classical protection is not feasible. Must look at advanced technologies (e.g. SLAC rotatable collimator).

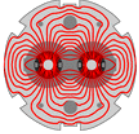


Smaller Emittance versus Higher Intensity

- Transverse energy density depends strongly on beam energy (γ) and is independent of number of protons (N_p^{tot}) over normalized emittance (ε_n):

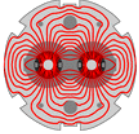
$$\rho_E = \gamma^2 \cdot \frac{N_p^{\text{tot}}}{\varepsilon_n} \cdot C \qquad C = \frac{m_p c^2}{\pi \sqrt{\beta_x \beta_y}}$$

- Higher intensity or smaller emittance put similar strain on material survival!
- Unfortunately, low emittance upgrade options are no magic bullet. Solves some issues (RF, radiation, ...) but does not address others.



LHC RF System (J. Tuckmantel)

- Problem is handling of transients, e.g. at edge of abort gap (high intensity → gap → high intensity).
- Already at limit for ultimate intensity.
- To go beyond:
 - Increase the available RF power IN the cavity
 - New transmitters, requiring possibly civil engineering to house a larger installation.
 - New coupler, that would probably not fit on the existing cavities and cryostats (ports).
 - HOM coupler power capability to be assessed for higher intensity.
 - Other (not yet present) installations (as 200 MHz capture or 800 MHz HH) are not foreseen for higher currents than ultimate.



LHC RF System

- Summary from J. Tuckmantel:

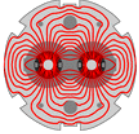
For a beam current higher than ultimate you would (very probably) need a completely new RF system including transmitters, couplers and cavities (and space?!).

- Clear that detailed RF analysis is required for any upgrade beyond ultimate.



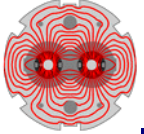
LHC Vacuum System (J.M Jimenez)

- Fast **pressure transients** which can lead to the **closure of the sector valves** during the setting of the collimators with high proton intensities.
- **Thermal induced desorption**. In case of huge flux of protons onto the collimator jaws, we should expect the pressures to rise resulting from the combination of the proton induced desorption and thermal stimulated desorption. The vacuum stability RELIES on the cooling of the collimator jaws (<50 °C MAX).
- In case of strong halo or beam losses, we should also expect a faster **deterioration of the bake-out material on the collimators but also on the chambers of the downstream magnets** (wrapping technology).



LHC Vacuum System

- Upgrade beyond ultimate might require:
 - New and more resistant permanent bakeout equipment.
 - Measures to counteract increased outgassing rate at collimators and other equipment.
 - Handling of pressure transients at sector valves.



E-Cloud Heat Load (F. Zimmermann & H.M Cuna)

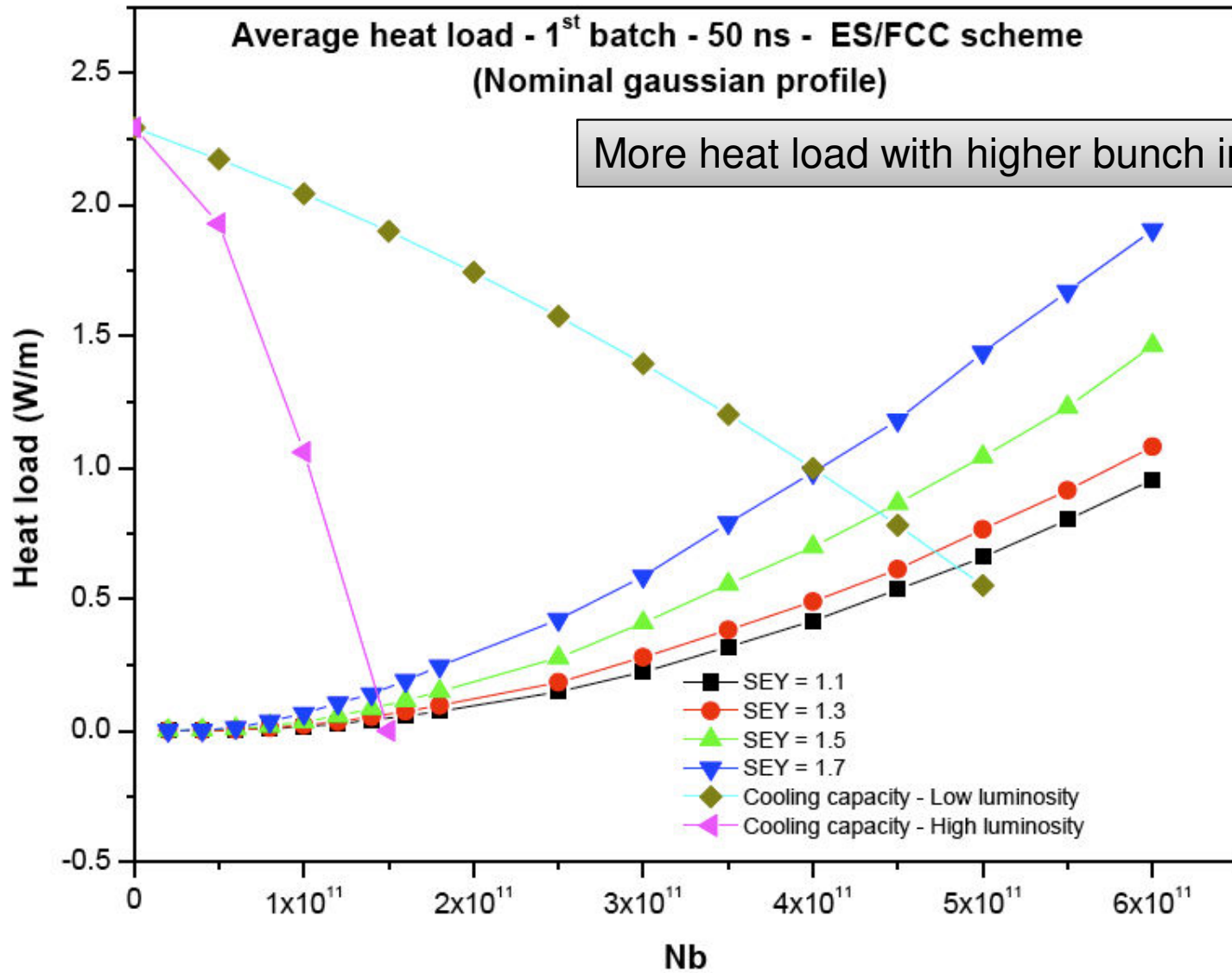
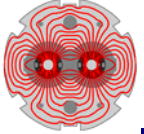


Figure 4.5 Average heat load for the simulation set C, 1st batch.

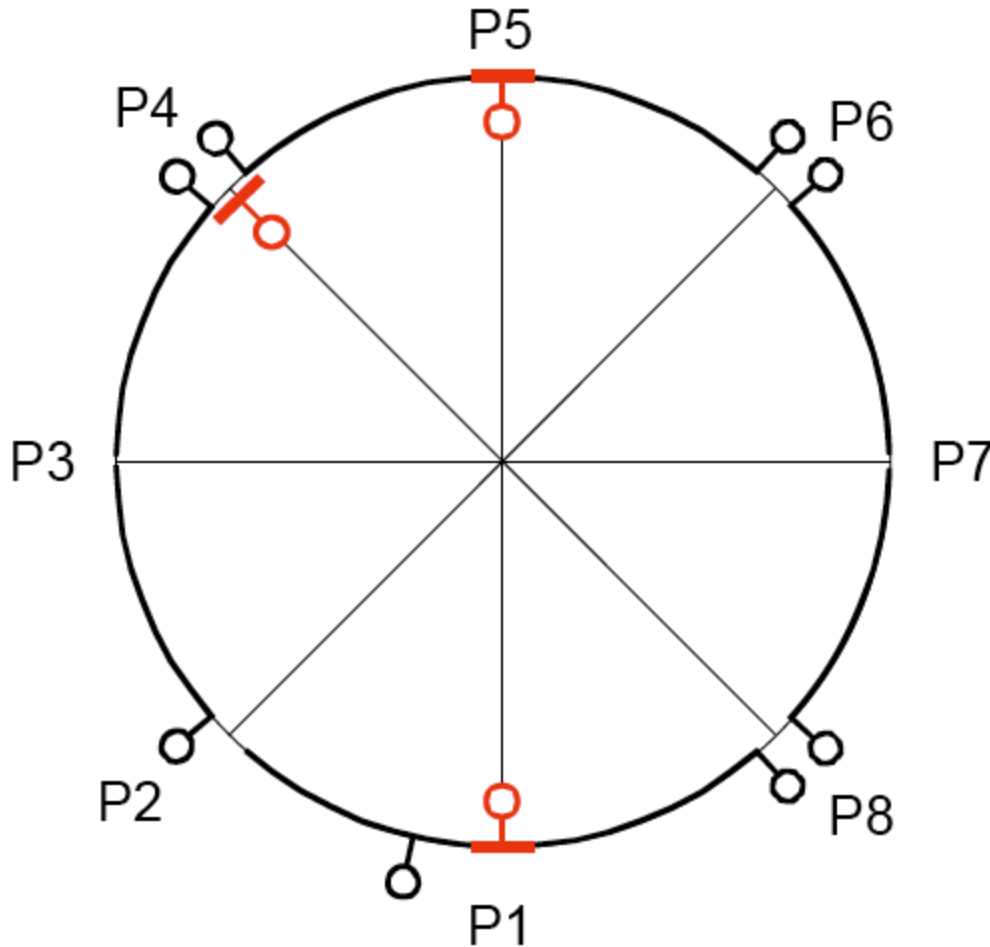


LHC Cryo System (L. Tavian, S. Claudet)

Legend:

Existing Cryoplant

New Cryoplant



Above ultimate requires **3 new cryoplants in addition to the 8 existing cryoplants for nominal intensity.**

Limitations in **beam screen cooling loops** to be taken into account and to be addressed.

Layout 4:
Baseline + separate RF & IT cryoplants

AT-ACR/LT 13.04.2006



LHC Magnets (L. Rossi)

- The magnet system has been designed to withstand the so-called ultimate intensity with 25 ns spaced bunches of 1.7×10^{11} .
- Triplet limitations → Talk R. Ostojic.
- Main magnets: If beam losses will be proportional to the beam intensity: **how much quench margin do we have?** The LHC can give us an answer.
- We may become limited not in the main magnets but in some special magnets, or in the **corrector magnets which are potted**.
- The **DSL** (SC link in 3-4) is also not too far from the limit...
- **Radiation damage** to magnets (also warm magnets) to be considered...



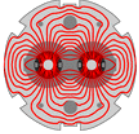
LHC Injection and Protection (B. Goddard)

- In case of different filling schemes:
 - **SPS extraction kicker** maximum flat-top length is presently about 10 us for both LSS4 and LSS6
 - To increase significantly beyond this would need a lot of upgrade work on **PFNs and new switches**.
 - **LHC injection kicker** maximum flat top length is about 8.0 us, with a rise time of 1 us and fall time of about 2.5 us. Changing any of these numbers on MKI would require big investment, and might not even be technically possible for the rise/fall time.
- SPS extraction protection devices:
 - **TPSG4/6** are designed to protect the MST/E septa up to ULTIMATE LHC intensity, which means maximum $288 \times 1.7e11$ p per injection into LHC, with 3.5 um transverse emittance. Higher intensity or smaller e_n will need a redesign, and this will be VERY difficult in LSS4 where we are **absolutely at the limit already due to the longitudinal space constraints**.



Injection & Dump Protection

- **TCDI** transfer line protection devices (14) were specified to work for ULTIMATE intensity. Simulations showed that these are already on the limit at this intensity/emittance, mainly because of the high energy deposition in the downstream TL masks and magnets (e.g. at MSI the **mask temperature reaches over 990 C**). So again a redesign would be needed, probably with longer TCDIs and maybe even new layout/optics.
- **TDI** - not sure of what the limits are. However likely to need redesigning, maybe with **TCDD**.
- **TCLI** - will be similar to TCDI.



Injection & Dump Protection

- **TCDS** - FLUKA studies with the upgraded version (as installed) showed that this is limited to ULTIMATE intensity - anything above this the **Ti part of the diluter will deform plastically**.
- **TCDQ** - preliminary FLUKA results show that an **upgrade is required to reach even nominal intensity**. This will be straightforward and done in next shutdown (replacing C by C-C blocks), but the operational limit is not yet known and anyway the **device will be designed to go only to ultimate** (reduces protection of Q4).



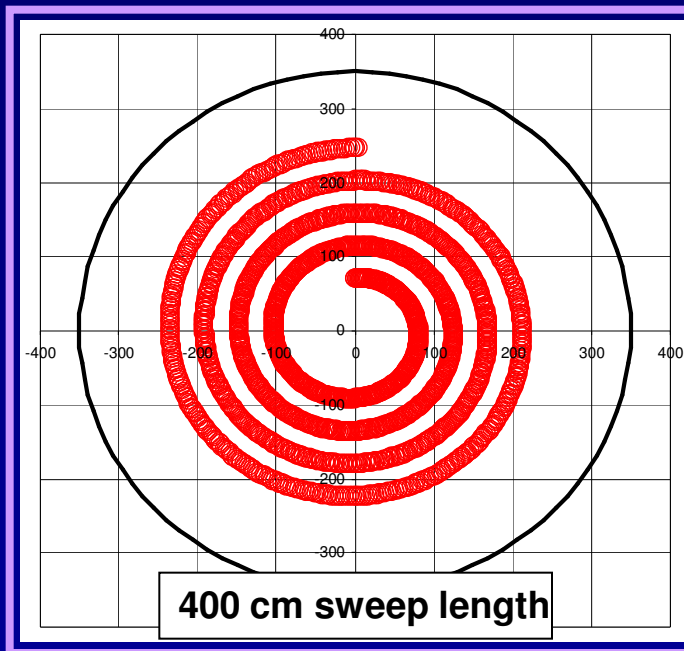
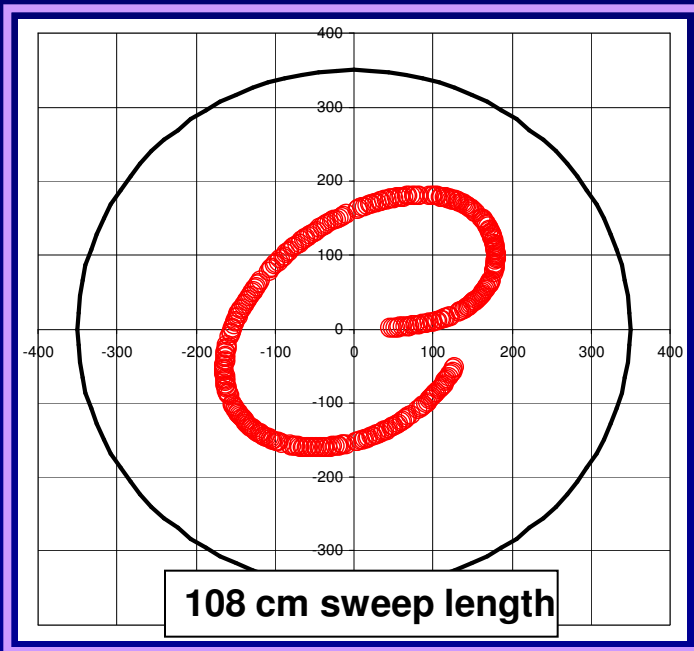
Injection & Dump Protection

- **TDE** - OK for ULTIMATE intensity - going above this will require an **upgrade of the dilution kicker system**, to increase the sweep length by increasing the frequency - more MKB tanks will be required - no technical feasibility or integration study made yet.
- A 'superbunch' with intensity concentrated in a few bunches is very bad for the dump (no sweep possible)
- **VDWB** - OK for ULTIMATE intensity - going above this will need study.
- **BTVDD** - OK for ULTIMATE intensity - going above this will need study.

Dilution with spiral sweep

- Dilution kicker frequency increased – x4 sweep length

– 14 to 56 kHz... would require ~4 times more kicker length



- Increase sweep length (higher $f_0 \Rightarrow$ more kickers)
- Upgrade dump block (longer, lower density C);
- Upgrade protection devices (longer, lower density C , more λ_r).

- At 7 TeV would allow currents of ~4 A in distributed bunches
- At 14 TeV would allow ~1 A in distributed bunches



Injection & Dump Protection

- In conclusion there are lots of potential issues with protection devices; most are already at their technological limits and we would have to start working on **'disposable' or sacrificial absorbers**, or make **significant layout changes**.



LHC Collimation System (R. Assmann)

- **Primary and secondary collimators** of phase 1 are robust for ultimate intensity:
 - Design accident (nominal): ~ 1 MJ in ~ 200 ns \rightarrow 0.5 kg TNT
- Above ultimate we expect onset of damage due to thermo-mechanical shock waves...
- Can be tested in **HiRadMat facility**. Helps to push to limit.
- If damage is found, require new design for primary and secondary collimators.
- **Replace 38 primary and secondary collimators.**
- Must evaluate **impedance** for higher intensities. At some point might be show-stopper!



- Residual dose rates around loss points scale with intensity (collimators, dumps, etc) and/or luminosity (low-beta insertions, TAS, TAN).
- Examples (assume few hours cooling time):

	nominal	sLHC
IR7 collimators/magnets	1-20 mSv/h	10-200 mSv/h
low-beta insertions	0.5-2 mSv/h	5-20 mSv/h
Compare to limits :	>100mSv/h	Prohibited area,
	2-100mSv/h	High radiation area
	0.5-2mSv/h	Limited stay area

- Consequences:
 - remote handling becomes mandatory
 - fast accesses difficult or impossible
 - high reliability of components (low maintenance & failure) essential
 - additional service galleries could be required



LHC Radiation Protection: Activation of Air

- Activation of air scales with intensity and/or luminosity. Airborne releases are estimated for nominal parameters and yield up to a few $\mu\text{Sv}/\text{year}$ for the reference group of the population. **Scaling by a factor of 10 gives values exceeding the threshold value of $10\mu\text{Sv}/\text{year}$ above which optimization of the releases must be demonstrated.**
- Furthermore, all requirements for the ventilation system related to its safety functions must be consistently implemented (not the case for the present system).
- Consequences:
 - installation of absolute filters
 - modification of ventilation schemes
 - modification or replacement of ventilation system



LHC Radiation Protection: Shielding

- The shielding of underground areas accessible during operation must protect personnel from normal losses (e.g., pp collisions) as well as accidental beam losses. Thus, doses scale with luminosity (normal losses) or total beam intensity (accidental beam-losses).
- Example:
 - Shielding of the LHCb counting rooms between UX85A and UX85B. Dose in UX85A due to accidental loss of one beam:
 - nominal 3.1 mSv
 - sLHC 31 mSv
 - Compare to annual dose limit: 20 mSv
- Consequences: shielding of accessible might not be adequate and might have to be re-enforced.



Conclusion I

- Ultimate intensity is challenging for the LHC. Many systems at technological limits with little or no margin.
- Long (incomplete) list of required LHC work collected:
 - “New” RF system, possibly requiring civil engineering.
 - New DSL in IR3, review of potted magnets, radiation damage.
 - Two new cryoplants (assuming one installed for ultimate).
 - Essentially all protection devices to be replaced with more robust designs, possibly requiring also layout changes.
 - Upgrade of the beam dump system. Additional hardware.
 - Half of the phase 1 collimation system to be reviewed (replaced).
 - Remote handling mandatory in parts of the machine.
 - Additional service galleries?
 - Absolute filters and modifications of ventilation system.
 - Additional shielding in some areas.
 - Upgrade of permanent vacuum bake-out system.



Conclusion II

- A coherent upgrade plan **should also address the LHC system limits!**
- To get a clear picture **further work is required**. All colleagues pointed out that detailed work is required to understand feasibility and limitations.
- Detailed studies and **HiRadMat tests** will give clearer picture.
- Nobody argued that an LHC intensity upgrade to beyond ultimate is impossible.
- **“With enough money everything is possible...;-)”**
- Yes, but effort and cost might be significant...