Options for LHC Phase 1 upgrade

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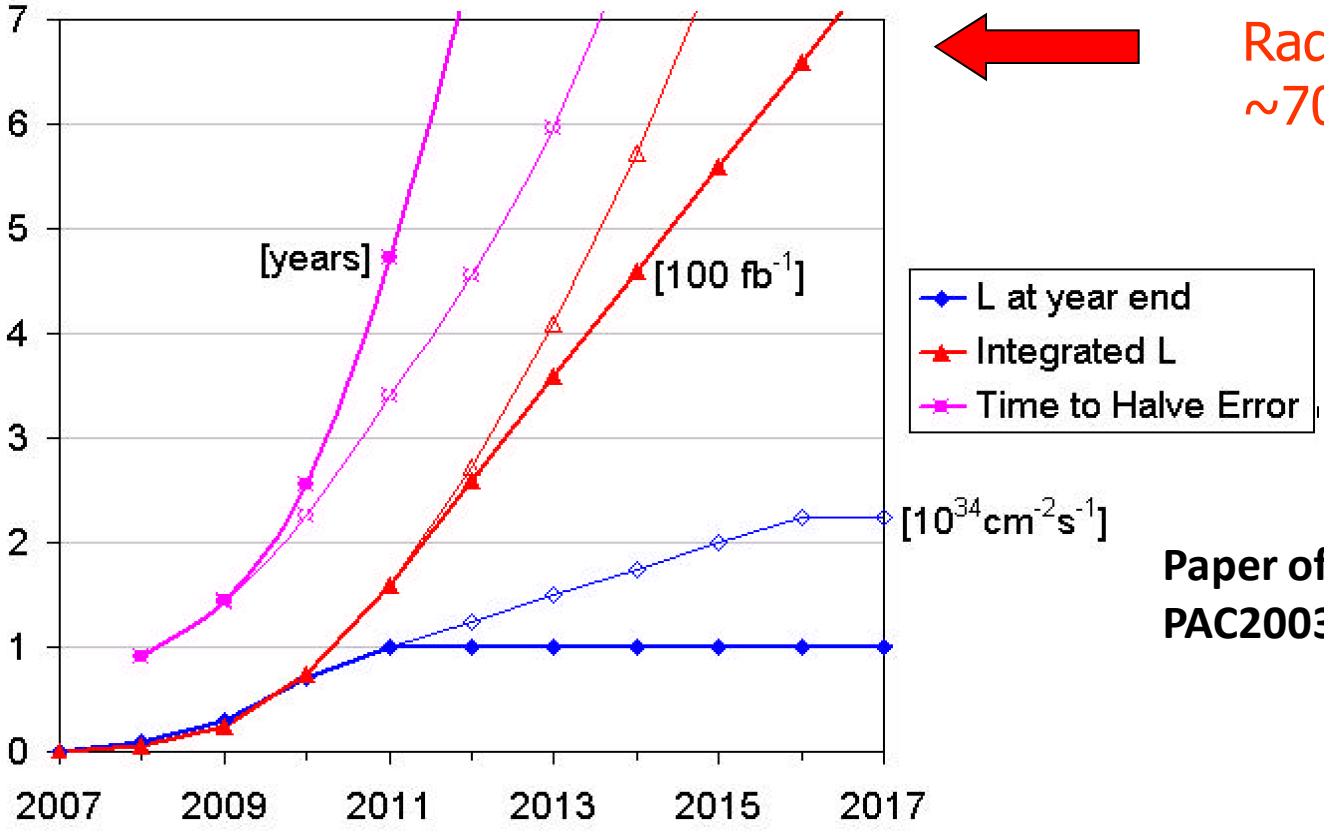
The LHC Lumi up : why (2001-06)

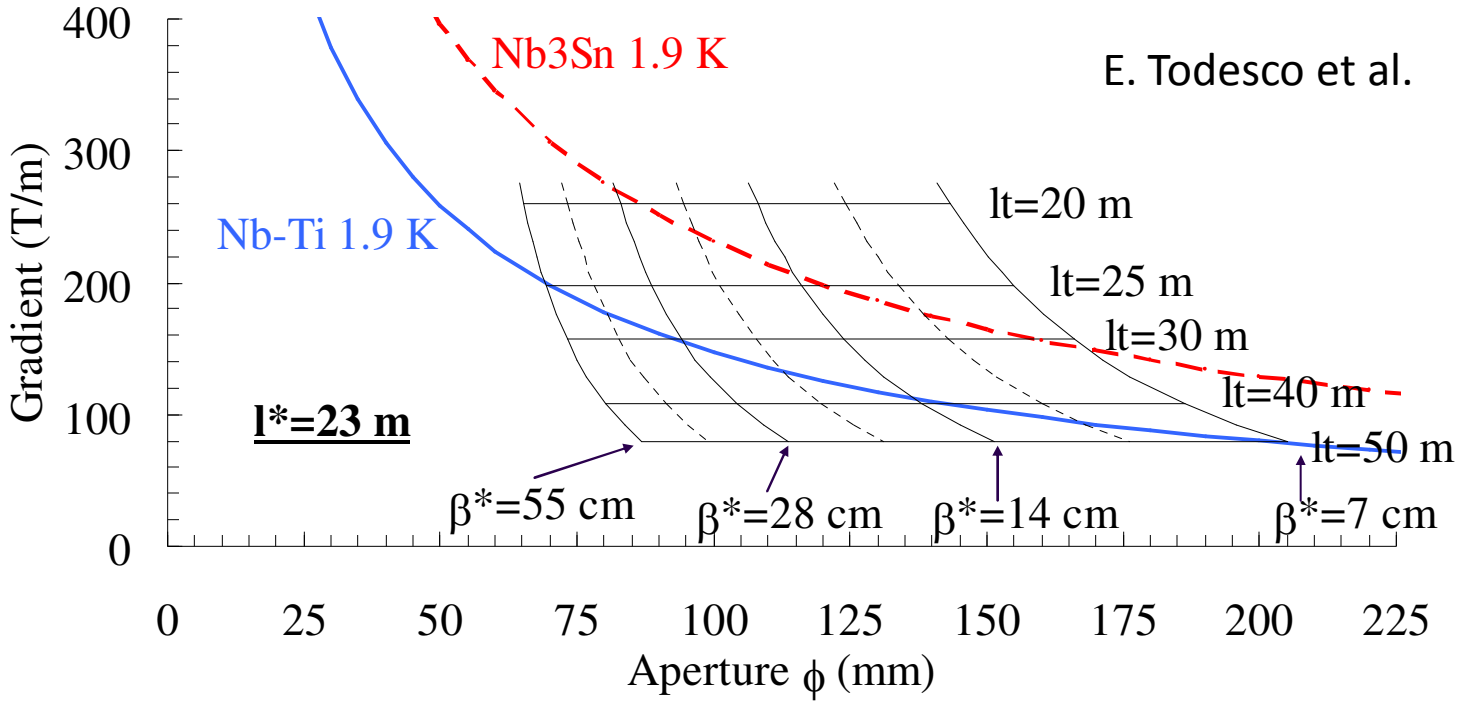


Radiation damage limit
~700 fb^{-1}

Paper of J. Strait et al.
PAC2003

Beam commissioning 2007 – full luminosity in 4 years – ultimate luminosity in 5 years
Needs of stronger triplet ⇒ Nb3Sn technology ⇒ LARP (US program for LHC)

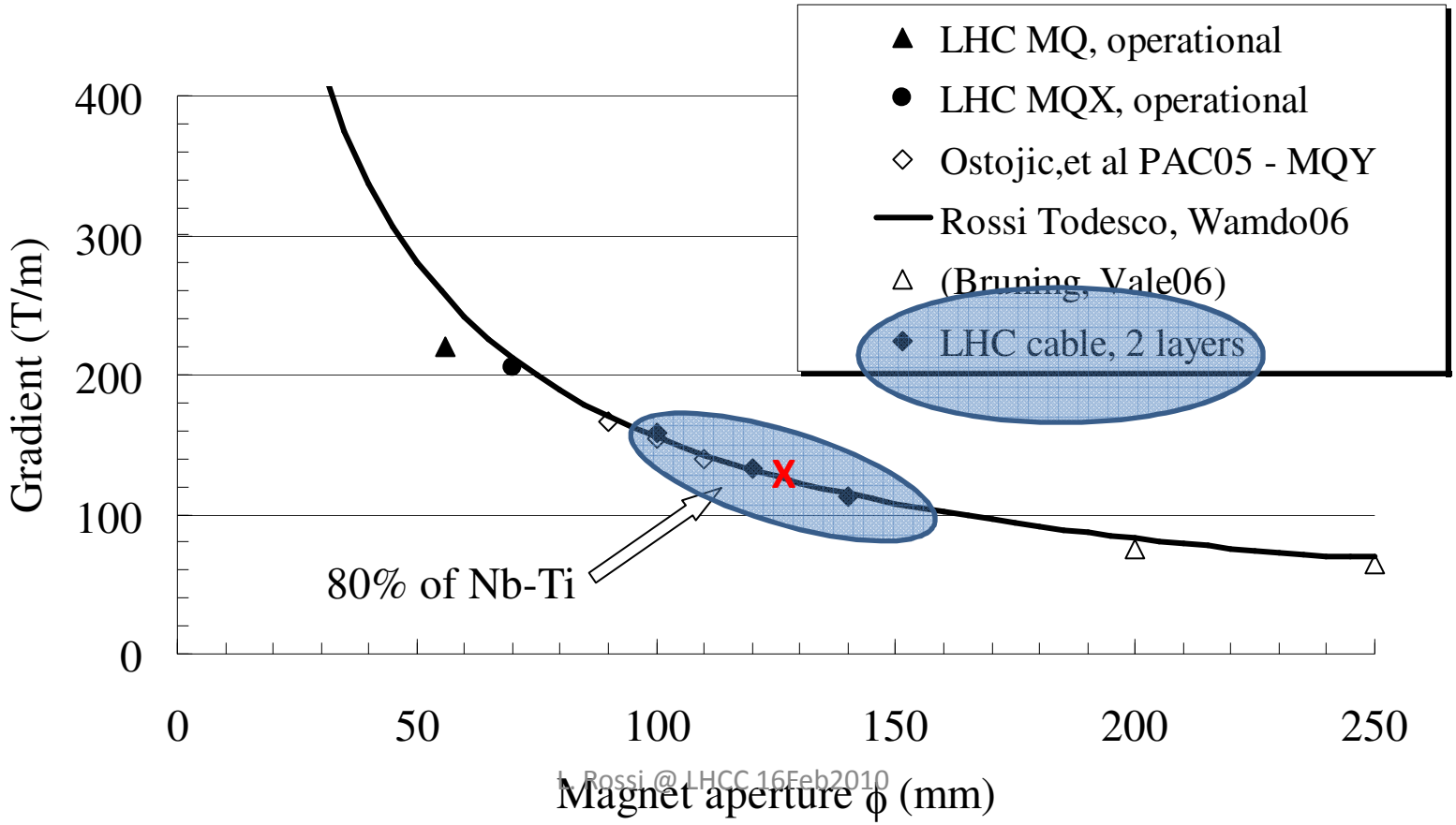
Lumi Nov.2006 workshop in Valencia



This was the base to explore a wide parameter range also with Nb-Ti
Confirming (and correcting) the first results of F. Ruggiero et al. (Epac04) showing that there was room for a first upgrade with Nb-Ti.

Proposal in January - March 2007

- We computed three lay-outs with LHC MB cable, of apertures 100, 120, 140 mm – still at the max of what can be obtained



The reason of phase 1 Started in May 2007

- The luminosity would have saturated quickly.
  - Needs to do something to sustain increase in 2013
  - Hyper-optimistic assumption ?
- Nb3Sn was still far, certainly not available on the horizon of 2009 when prototyping was needed
- Nb-Ti, LHC-like with no R&D was perceived as simple and quick. Proposed 130 mm aperture.
- An upgrade limited in scope and budget (involving ONLY the triplet and – maybe – the D1) was seen as a key to sustain Lumi increase meanwhile preparing the big upgrade (L_{peak} 10^{35})
- Goal : β^* of 25 cm, with potential of 20 cm, gain in luminosity of a factor 1.5 with no increase of beam current

Then…

- Decision on aperture (120 mm) only in August 2008.
- Later re-discussion of the X-section lay-out
- Decision to change D1, to go SC, to assign to US as contribution
- Decision to move out the Electrical feed boxes (DFBX)
- Needs to place many equipment in low radiation zone
- Deep dynamic study revealed many issues, not trivial, to exploit fully the potential of the triplet.
  - Chromatic correction more difficult, at the limit of the capability of the sextupole strength of whole LHC
  - The strength of other corrector (MQT) may be not sufficient
- The 3-4 incident…

Chamonix 2010 : problems emerged

- The present LHC yield 2.3 10^{34} if beam current is pushed to ultimate (1.7 10^{11} p/bunch). But…
- On paper the present phase 1 upgrade yields $L_{peak} > 2\ 10^{34}$,
  - $\beta^* \geq 30$ cm
  - Optical constraints coming from aberrations requiring a sextupole correction at the limit of the LHC arc capability
  - Some other correctors are at their limit (MQT)

Consideration on present LHC Luminosity performance

- The present LHC yield 2.3 10^{34} if beam current is pushed to ultimate (1.7 10^{11} p/bunch). But…
  - The present collimation system may not handle more than 40% of nominal intensity ($L \propto I^2$)
  - The new collimation scheme is in the R&D phase, must be proved to be sound first for nominal than for ultimate.
  - LHC is probably limited by beam-beam. This may be solved by compensating wires (tbv).
  - Other bottlenecks may appears in intensity not necessarily due to collimation…
  - The injector chain must deliver beam intensity better than the beam circulating in the LHC. Today is not…

Consideration on the proposed phase 1 upgrade

- The machine has certainly margin for a factor 1.4 in luminosity
- The triplet zone will be with better protection of the quadrupole, full use of the cryo-capacity, and separation of triplet from arc
- Building new triplets is equivalent to built spares…
- However
  - The optical constraints translate in a new optics
  - New machine to be commissioned (optic-wise!) much less flexible. Squeeze is predicted to be more complicated.

Consideration on the proposed phase 1 upgrade – cont. 2

- The schedule is success-oriented, especially for the initial part:
  - We cannot have the model magnet (2 m) built by end 2010
  - It is out of question to have the prototype (a full length magnet, with all bus bars, extremities, cryostating) ready to be tested by mid-2011.
  - In addition, the manpower needed for:
    - InterConnect consolidation (including the R&D and preparation that is going on now). Already this has penalized the NIT project.
    - Setting the MAR (MAgnet Rescue facility) and repair the magnets damaged in the 3-4 incident.
    - Study and carry out the displacement of 48 magnets necessary to accommodate phase 2 collimations (2014 ? 2016?)

  will inevitably spread the work for the triplet (1-2 year ?)

Consideration on the proposed phase 1 upgrade – cont. 3

- Accessibility and maintenance: all electronics equipment for the triplets and the DFBX should be located in “low-radiation” areas. Severe space constraints around IP1 and IP5 for any new equipment.
  - A painful solution is available for IP1; not yet for IP5
  - Probably a big benefit from the improvement proposed (S. Weisz , Chamonix 2010)
    - Excavation of new galleries
    - or removal of all power supplies in surface by use of SC lines.

Consideration on the proposed phase 1 upgrade – cont. 4

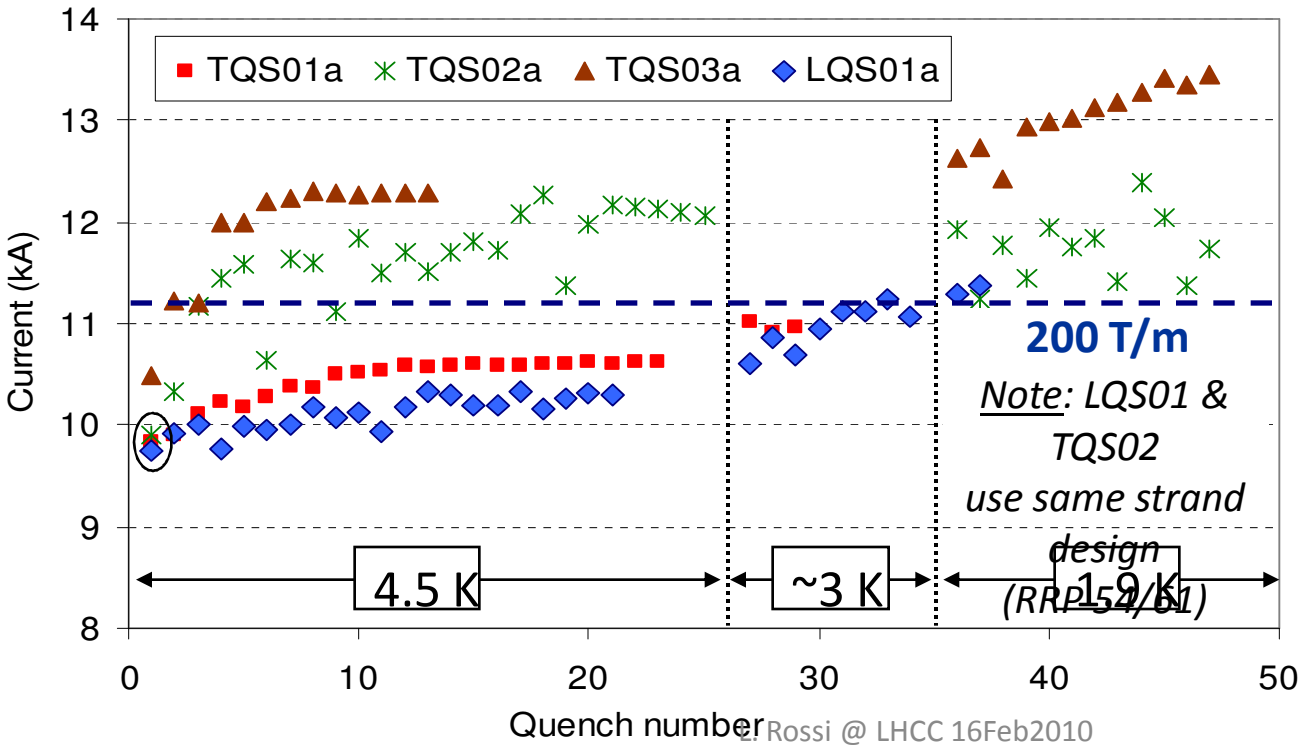
- Installation longer than six month shutdown.
  - 9 months per IP (S. Weisz, Chamonix)
  - With good overlapping : 1 year for the two IPs.
- Other limitations are underlying the phase 1:
  - The machine would be optically more performing and more flexible with new matching sections:
  - Displacing it (D2-Q4-Q5-Q6) : 16 magnets
  - Rebuilding with larger aperture (best solution compatible with Phase II)
- Better cryo in 5L (i.e. new cryoplant for RF Point 4) desirable
- The installation of the triplet and ALSO **desinstallation of the present triplet** is NOT part of the project. Implication in time and resources will be not negligible (ALARA issue)

Facts

- In 2013 LHC will start to produce luminosity, after 1 y of shutdown in 2012 – hopefully!
- Experience and studies (V. Shiltev- JP Koutchouck):machines have a physiological time of 5 years to reach the designed luminosity (unless big stopper).
- LHC will need an other stop to accommodate new collimation system (48 magnet to be shifted)
- It is reasonable to assume that luminosity will not saturate before 2018 (and saturation at 50 fb^{-1}/y max). Probably later.
- The time of installation being not transparent must be synchronized with detector improvements/upgrade

Nb_3Sn is coming…

- Nb_3Sn is becoming a reality (first long -3.6 m – quad 90 mm)
- This year we expect a second one and a 1 m long m 120 mm.
- Still the route to a full accelerator magnet needs 3-4 year.



Options

- The saturation (2-3 years at 50 fb-1 to reach 200-250) will happen around 2020.

1. We can change the triplet keeping this same project, shifted 1 year (usable for 2016).
   - Stop 1 year, about further 3 years to recovery, so we catch up at the end of 2018 and then we gain.
   - The second upgrade must be around 2022, synchronized with detector.
2. Go directly to the big upgrade in 2018-2020.
   - We don't touch the machine for 4-5 years (apart collimations) after Ic repair
   - Solution radiation: either more cavern or P.S. on surface
   - Further collimation/protection to swallow ultimate beam (or more…)
   - Based on larger/shorter Nb_3Sn triplet magnets, with change also of matching sections
   - New cryo in Point 4; possible upgrade of the cryo in IP5 and IP1.
   - Crab cavities
   - …

Conclusions

- The separation between phase 1 and phase 2 upgrade, introduced in 2007 is now questionable.
- LHC will improve by a series of continuous measures. Anyway at least 1 change of inner triplet is mandatory but it is only 1 unknown of the equation: collimation, protection cryopower, crab cavities, logistics for rad-prot...
- The actual direction and optimization of the upgrade probably needs inputs from LHC itself, that may come from first year(s) of operation near nominal.

Conclusions

- First we need a wide-aperture quadrupoles in Nb-Ti and in Nb_3Sn tested and validated. We can't wait in 2018 to decide. Decision must come at latest in 2013-14. True for magnets and crab cavities.
  - Selected work to prepare magnet technology must continue vigorously, given the long lead time
    - On Nb-Ti 120 mm (CERN+EU) model
    - On Nb_3Sn 120/160mm (LARP, CERN+EU,KEK)
    - On effective SC cable **(HTS)** to link remote P.S./DFB to tunnel magnets
    - On design option to prepare decision (corrector at ultimate current? Large MQY?)
  - **Collimation development/Machine protection**
  - **Crabs** (to make room for them probably Nb_3Sn is imperative)