LHC MAGNET MODELING

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Acknowledgements: the FiDeL team

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Strategy: Fit of Measurements

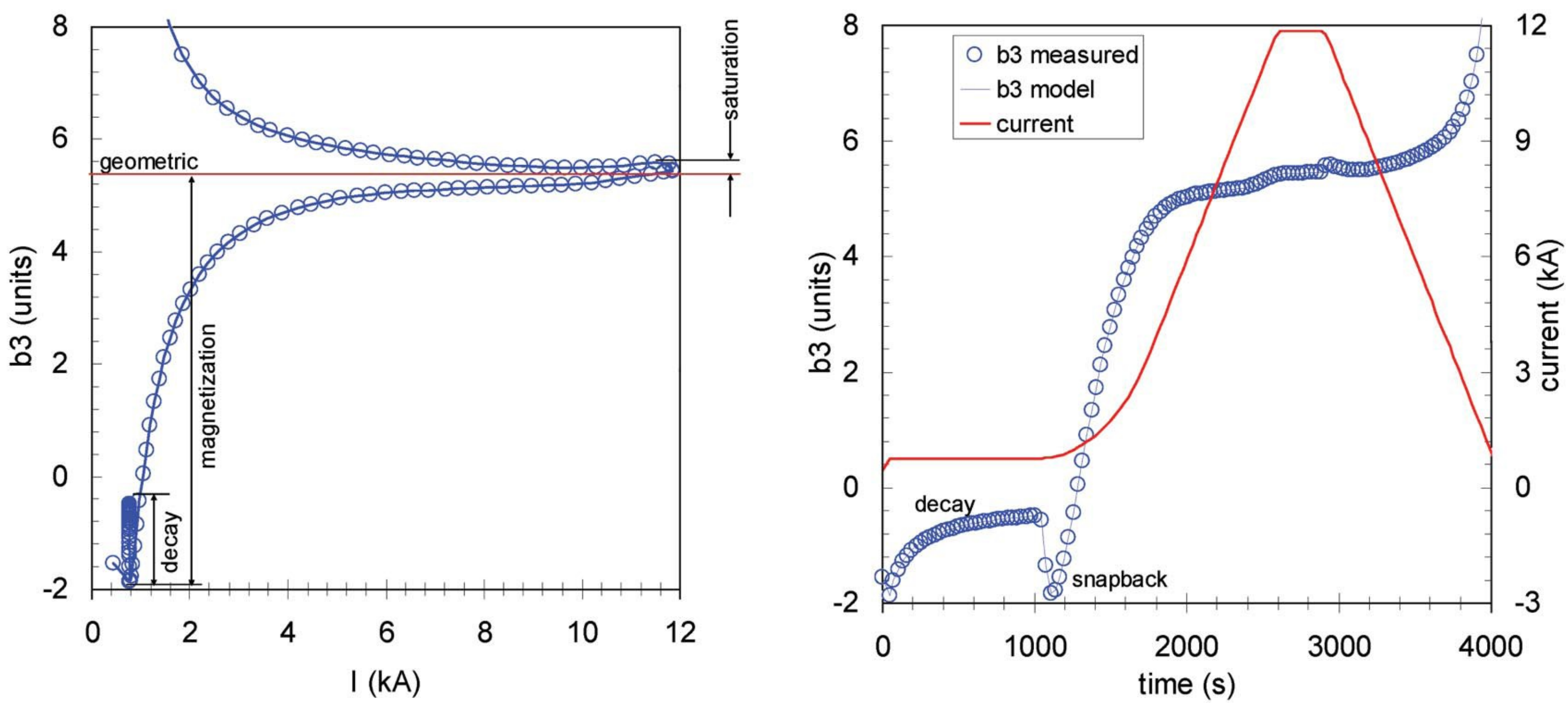
- The LHC magnet zoo includes 20 different superconducting magnets and 10 different resistive magnets

- A decomposition of the field quality (main component and multipoles) has been proposed [N. Sammut, L. Bottura et al, Phys. Rev. STAB]
  - Static: geometric (linear term) + saturation of the iron + magnetization
  - Dynamic: decay at injection, snapback at the beginning of the ramp
- Magnetic measurements have been used to derive the coefficients of this parameterization
  - For each magnet family up to 10-20 coefficients for each quantity (main component, multipoles)
- Please note: from 2 TeV on, model is much more precise
  - Magnetization, dynamic effects significant at 450 GeV and depend on powering history – injection is more challenging!

STRATEGY: FIDEL FIT OF MEASUREMENTS

- Example: FiDeL decay component, three parameters

$$\Delta b_3(t;c,\tau,d) = c\left[d\left(1-e^{-\frac{t}{\tau}}\right)+(1-d)\left(1-e^{-\frac{t}{9\tau}}\right)\right]$$



FiDeL fit of b3 versus I (left) and b3 versus time in the LHC [L. Bottura, N. Sammut et al]

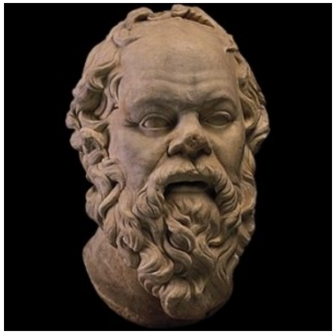
Strategy: Steering the Magnets

- The FiDeL equations are implemented in the LHC control system
- FiDeL coefficients are imported locally
- Quantities for each circuit are evaluated

- FiDeL coefficients are used and for each beam process one generates tables with settings (time-current)
- Correctors:
  - Correction algorithms are implemented in LSA and the settings are estimated with field model
    - One example: local correction of b_3 b_4 b_5 in dipoles
  - Other correctors rely on measurements
    - Example: orbit
  - Others have both ways (both fixed settings and trims on the top)
    - Example: tune, chromaticity

Strategy: simulating the real LHC

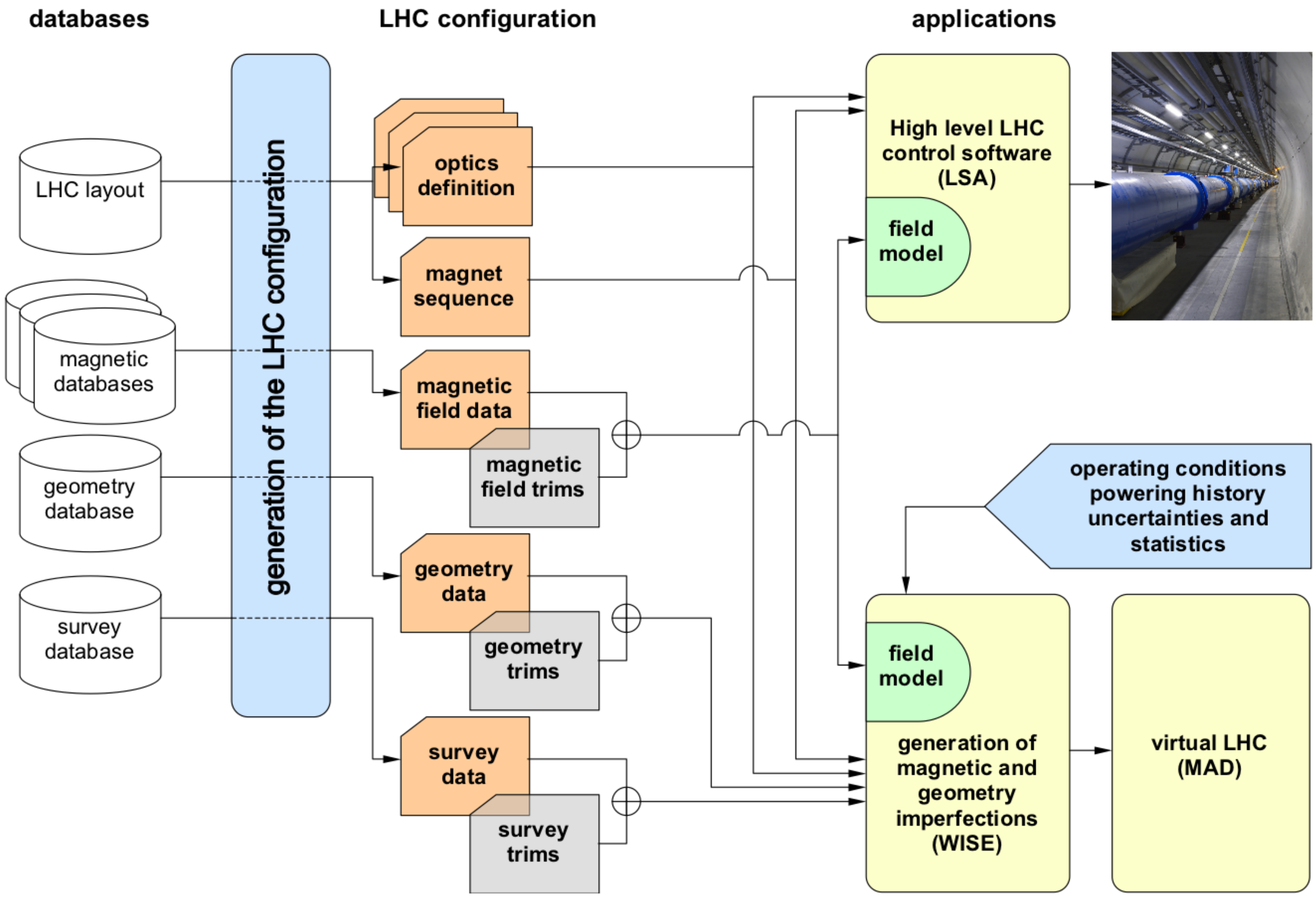
- Field quality in the magnets fit through FiDeL
- Lay out of the machine
- Alignment of the magnets
- Uncertainties



A WISE man: Socrates
[Ist century AD, probab. copy of Lysippos]

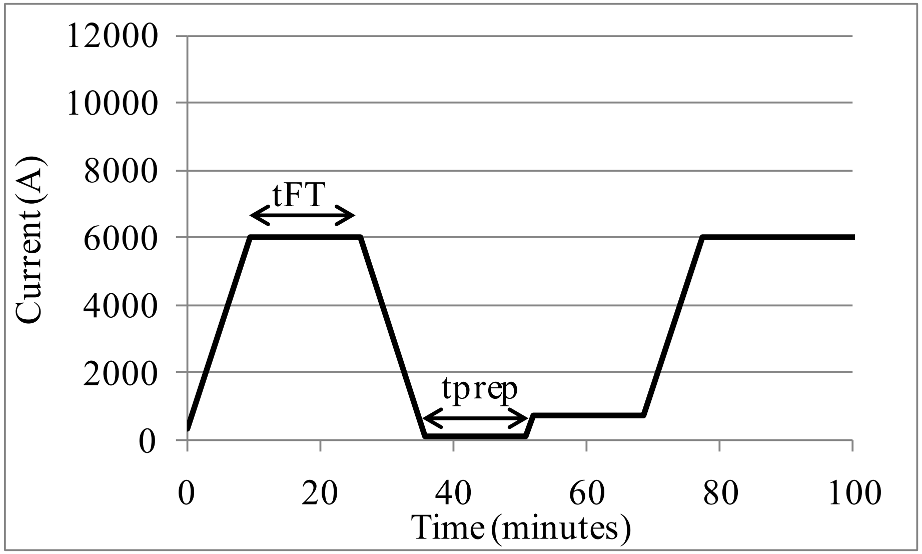
- All these information are put together through an ad-hoc code (WISE [P. Hagen]) to create input files for MAD
  - The machine is modelled at best, at the level of individual magnet (not circuits as in LSA)
- Several users
  - Used to simulate the real machine with imperfections (on line model)
  - Used to check scenarios for upgrade
  - Used to check the effectiveness of sorting …

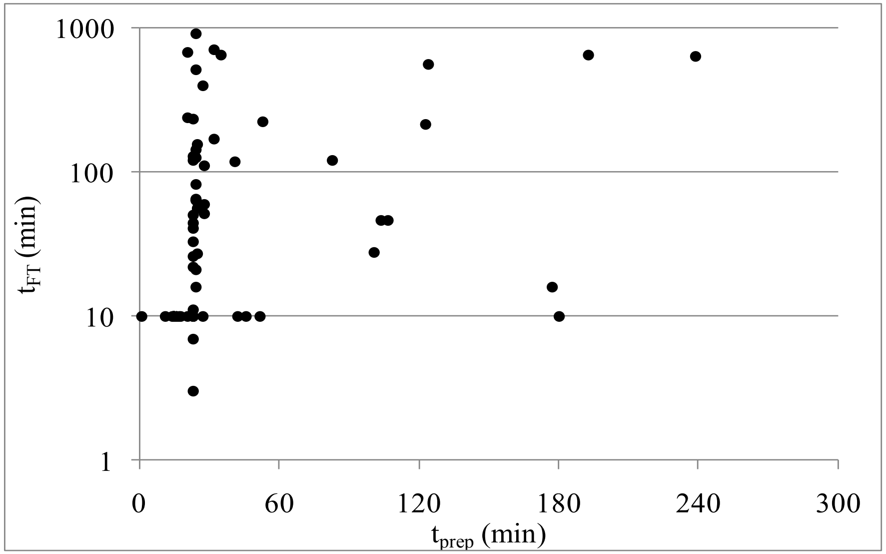
Strategy summary



The precycle strategy

- The cycling strategy is the key of the machine magnetic reproducibility
- All sectors have to be precycled together !
  - At the moment we have two varying parameters
    - Time at flattop (from 0 to 15 h)
    - Preparation time at 100 A (typically 20 minutes, can be several hours)





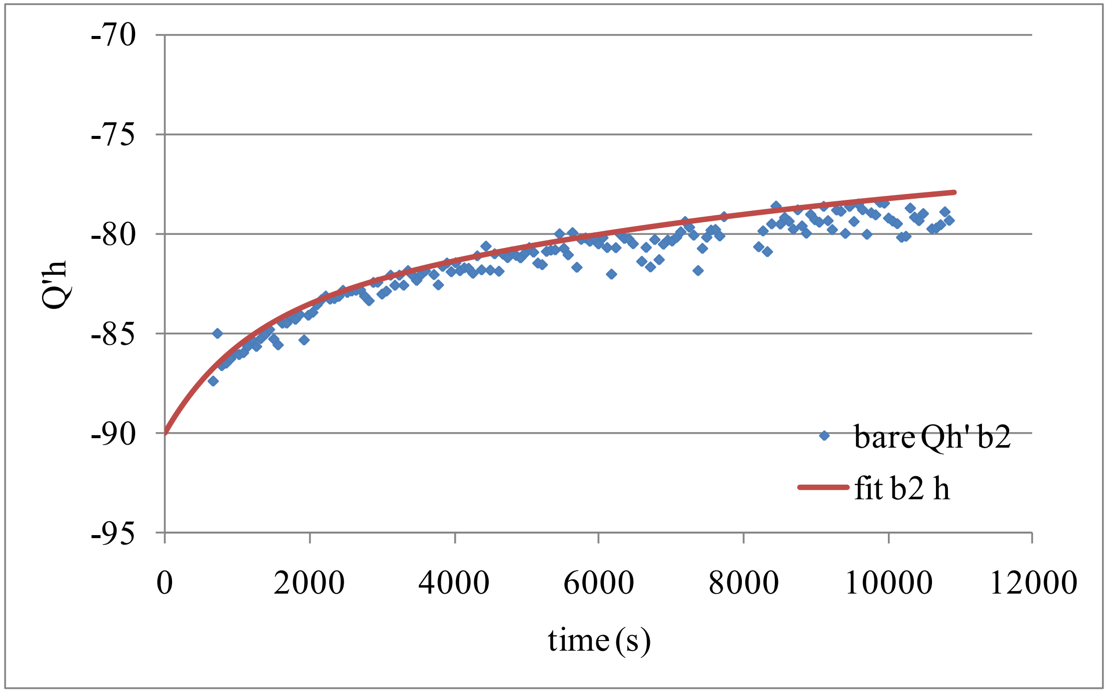
Precycle (left) and preparation time versus flattop in May 2011 [N. Aquilina]

MAIN ISSUES

- 2010
  - Beta beating stemming from resistive quadrupoles [see talk by Glenn]
    - Action: new measurements and model improvement
    - Result: much lower beta beating
  - Reproducibility: review of precycling strategy
    - Found that some magnets were not correctly precyled, and were on wrong hysteresis branch [P. Hagen]
    - Action: lower reset currents
- 2011
  - Decay of chromaticity on time constants much longer than expected (1000 s instead of 200 s) – so it affects operation [W. Venturini et al.]
    - Action: include the correction of decay at injection plateau
    - FiDeL coefficients changed according to beam measurements

Chromaticity decay

- Significant decay after times larger than one hour – not expected
- But the functional form works
  - We update the model coefficients with fit of beam measurements
  - We also try to understand … (additional magnetic measurements)



Measured decay of chromaticity during 3 h injection [N. Aquilina]

A STAGED APPROACH

- In this work, a staged approach is essential
  - Example: chromaticity
    - We started with static model only → reproducibility within 20 units, correction done manually by operators (2010)
    - We included a fixed correction of decay (independent of powering history) → reproducibility within 5 units (April 2010)
    - We now are including correction of decay with powering history → aim at reproducibility within 2 units (July 2010)
  - Example: cycling
    - In early phases (2009) several trips of circuits → cycling strategy was not always followed to avoid wasting time
    - In 2010 wrong cycling proved to have a significant effect on reproducibility and circuits were more stable → cycling strategy enforced
    - Now precycling always correctly followed

MAIN ISSUES

- 2011 (continued)
  - Unexpected decay of tune at injection
    - Action: include the tune correction of decay at injection plateau
    - FiDeL coefficients estimated through beam measurements
  - Unexpected larger influence of powering history on chroma decay
    - Action: include the dependence on powering history
    - FiDeL coefficients based on beam measurements (analysis on going)
    - Complementary magnetic measurements
  - Branching: magnetization is implemented as a single branch (so it models only positive dI/dt)
    - This for the moment is not critical – we had it implemented but we removed since it created jumps in powering
    - For going to β^* below one meter some quads with $dI/dt<0$ will need ad hoc trim

CONCLUSIONS

- The LHC magnetic model is pretty complex
  - A staged approach is needed – do only what is needed otherwise you get lost
- The magnetic measurements provide an extremely solid base
  - Huge efforts carried out during the production
    - To know, and to correct if needed and possible
  - Nominal settings provide good optics
  - New optics commissioned in a few hours!
- When needed, trims based on beam measurements
  - Powerful instrumentation and beam diagnostic techniques are a key element
  - Possibility of having additional magnetic measurements

Questions ?