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Experience with field modeling in the LHC

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Thanks to the FiDeL team

CONTENTS

- The approach: FiDeL, LSA, Wise
- The gold mine: LHC magnets production data
- Details of modeling and operation

FIDEL AND WISE

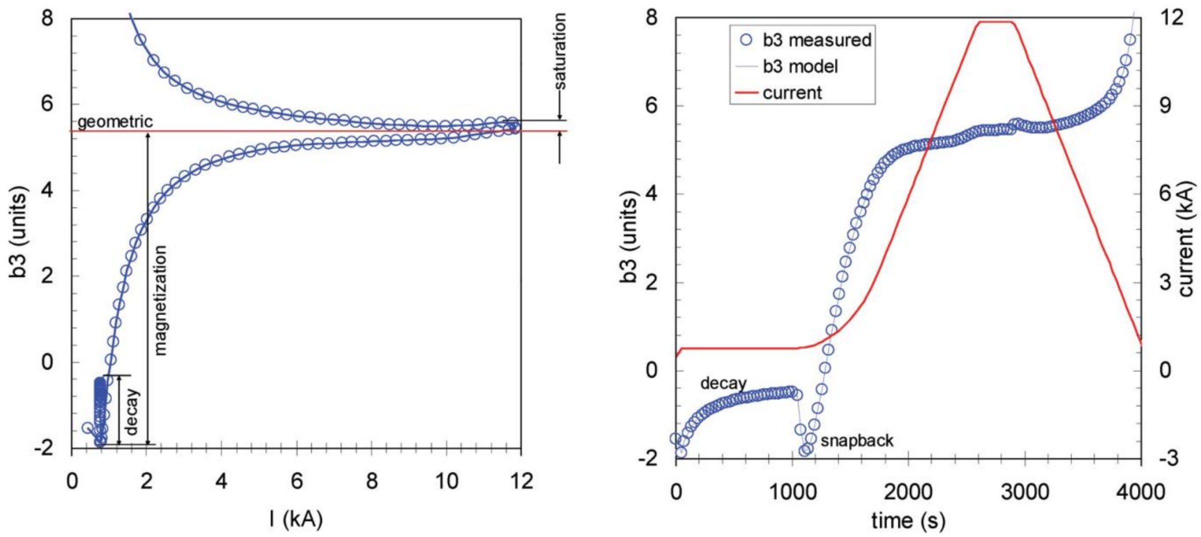
- FiDeL (Field Description of the LHC)
  - is the conversion of fields/gradients to currents
  - plus the recipe to precycle magnets to ensure reproducibility and correct modeling

Field & Gradients ← FiDeL → Currents

- It consists of
  - A set of equations describing the relation field(current)
    - Done for the main component + multipoles
    - So it also models imperfections and field errors
  - These equations have components
    - Geometric (linear)
    - Saturation (high fields)
    - Magnetization both of iron and of conductor (low fields)

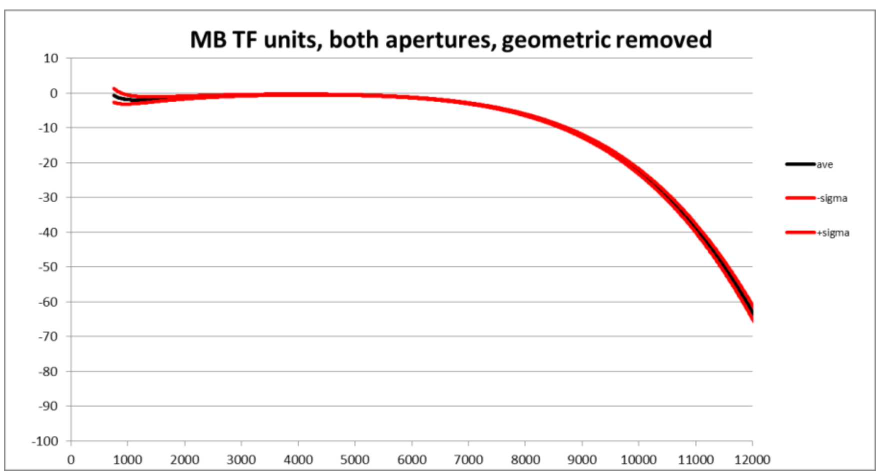
FIDEL AND WISE

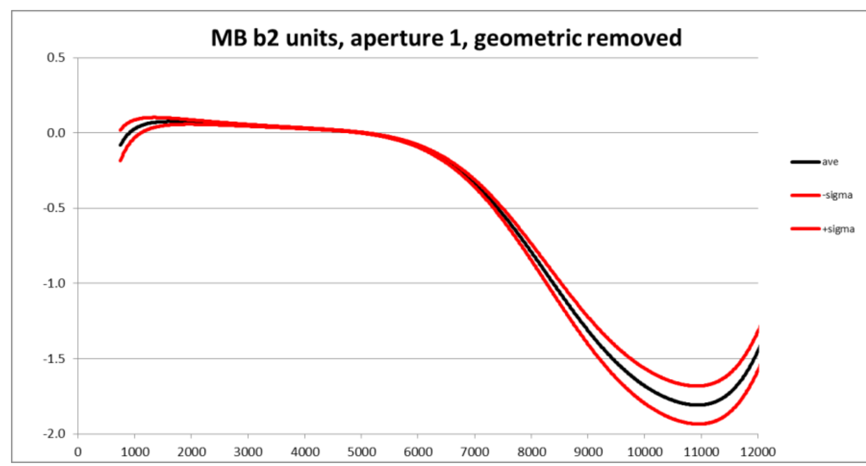
- FiDeL (Field Description of the LHC)
  - Each component depends on several parameters
  - The functional form of each component is specified in [N. Sammut, L. Bottura, J. Micalef et al. Phys. Rev. STAB 012402 (2006)]
  - In some cases relies on a physical model, in others it is a nonlinear fit
    - Saturation is modeled through a double erf function
    - Magnetization relies on the known fits of the critical current



FIDEL AND WISE

- First step (FiDeL) – magnet experts
  - Fit the magnetic measurements with the FiDeL parametrization
  - Extract the fit parameters
  - Construct a DB with these parameters magnet by magnet
  - Associate to each parameter uncertainties (recent development [P. Hagen, P. Ferracin])
    - The result is the summa of the knoweldge on our magnets



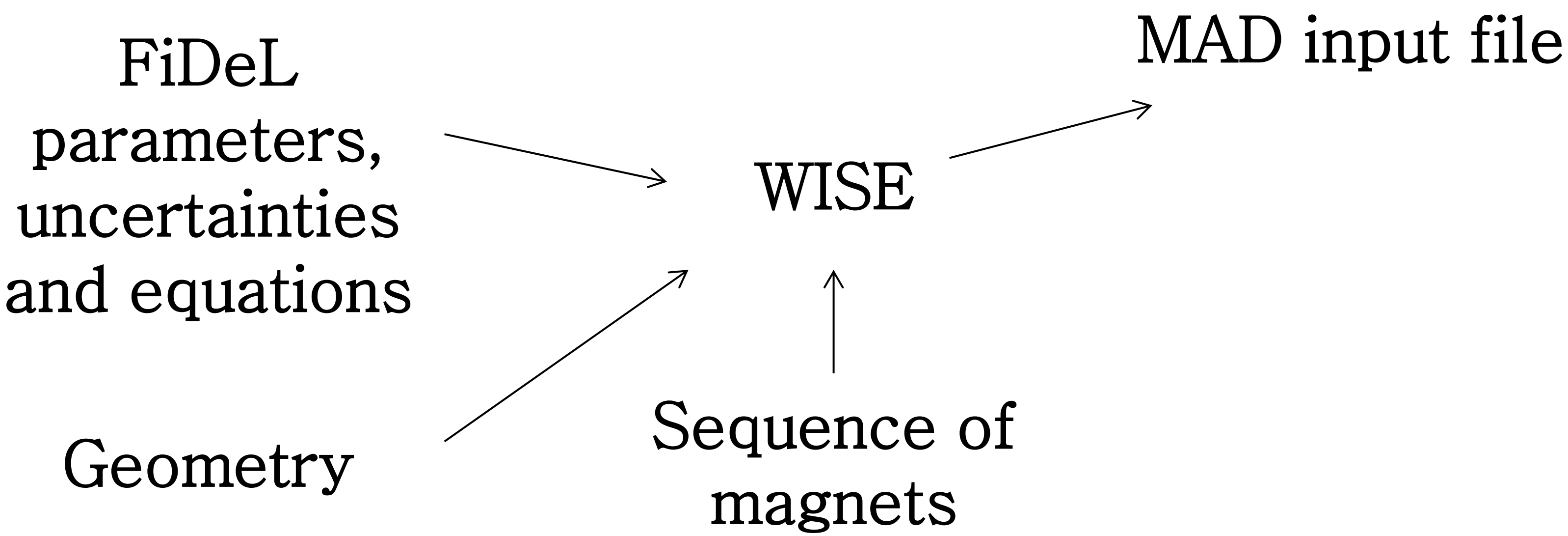


FIDEL AND WISE

- Second step: export towards CCC – OP group
  - This is the need of the control room:
    - Currents to steer the circuits of the main magnets
    - Currents to steer the circuits of the correctors
  - The control room system (LSA) has the FiDeL parametrization independetely implemented
  - The DB is reduced from magnet to magnet to circuit to circuit
    - This is the LSA DB used to steer the accelerator according to the optic files
    - Trims are also based on FiDeL parametrization (tune, chroma, …)
  - Obviously, a lot of information is not used (magnet by magnet, high order multipoles for which we have not correctors …)

FIDEL AND WISE

- Third step: export towards modeling – ABP group
  - WISE: Windows Interface for Sequence of Elements [P. Hagen]
    - Builds the best input for MAD or tracking codes based on our knowledge of the magnets
    - It also relies on the information about alignement and geometry
    - It can associate uncertainties to each component to account for the measurements errors or for missing information



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- The gold mine: LHC magnets production data
- Detail of modeling

THE GOLD MINE

- Magnetic measurements are the key point
- Room temperature: providing geometric
  - 100% of magnets measured – full knowledge
  - Done at the industries, in two different stages (redundancy)
- Operational conditions (20% dipoles, 10% quadrupoles, 100% triplet)
  - Done at CERN or in US (triplet)
- Phenomenology of superconducting magnets radically different from resistive
  - Magnetization and dynamic effects are the most challenging
  - Saturation proves to be easier and with less variation from magnet to magnet

CONTENTS

- The approach: FiDeL, LSA, Wise
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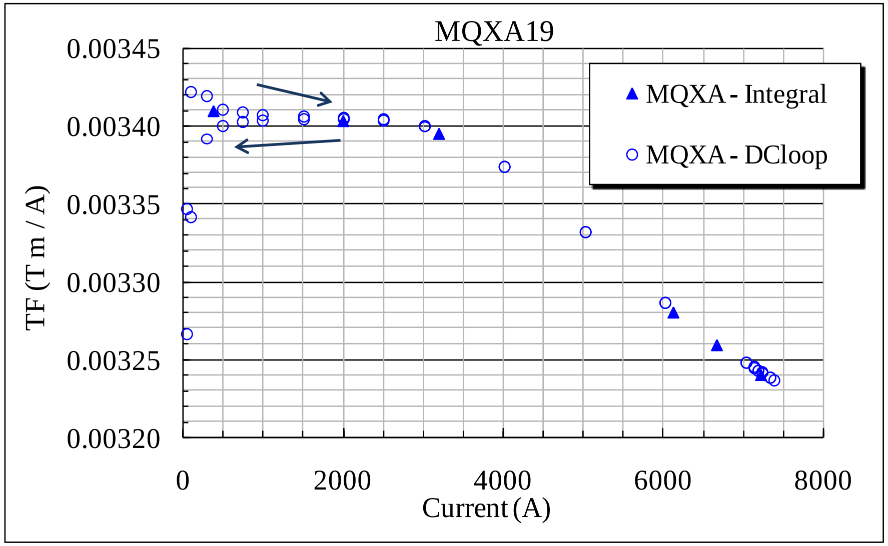
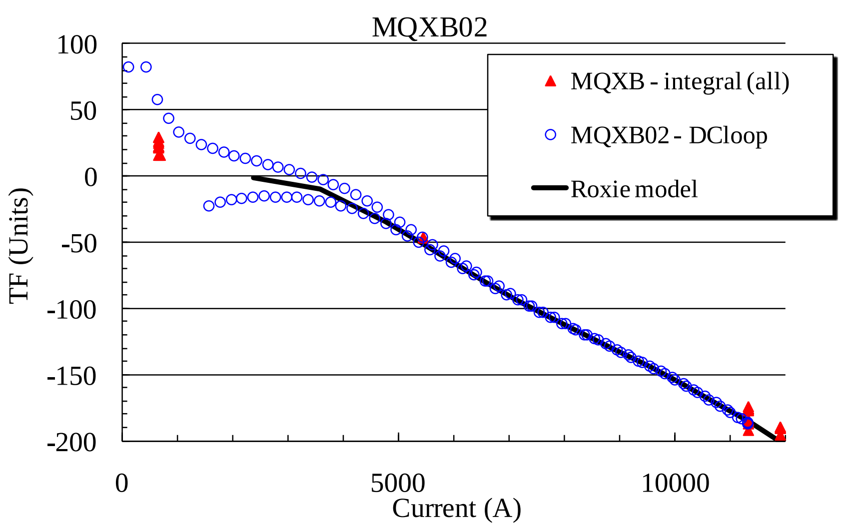
Details of modeling

- Each model is developed with a level of detail appropriate for its relevance in the LHC
  - We do not model everything for every magnet …
- Dipoles and quadrupoles
  - Geometric is estimated magnet by magnet
  - Persistent and saturation component are estimated family by family (i.e. one for each magnet type)
    - Also because we do not have measurements at 1.9 K for each magnet
- Triplet
  - Geometric, persistent, saturation are estimated magnet by magnet
  - Here we have all the measurements
- Correctors
  - Only the transfer function is modeled, not the multipoles
    - We have measurements but we do not want to complicate the model

Details of modeling

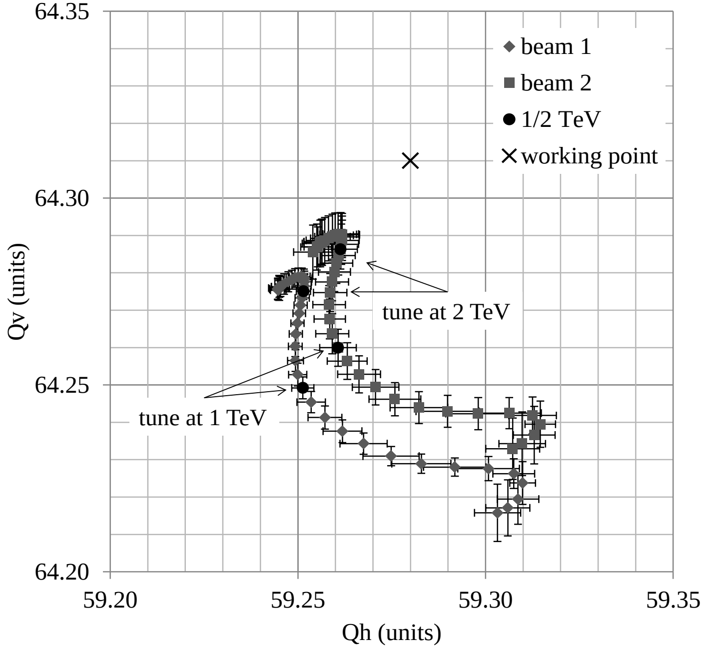
- Example: measurements of the triplet





Details of operation

- Precision achieved can be measured by the beam
  - Tune control during ramp is within 0.05 [N. Aquilina, et al, PAC 2012]
    - Not enough for operation, but a very good starting point for the tune feedback
  - Precision in absolute tune is 0.1 (out of 60) – quad trasfer functions absolute model within 0.15%



Details of operation

- Precision achieved can be measured by the beam
  - Beta beating within 40% at injection, 20% at high field [R. Garcia Tomas, et al. Phys. Rev. STAB 13 (2010) 121004]
    - Model at injection much more difficult – not a surprise
  - Chromaticity control within 10 units [N. Aquilina, M. Lamont]
    - Large contribution from sextupolar error in the dipole (200) on the top of nominal chromaticity (60)
    - Snapback (typical of sc magnets) controlled and corrected – not an issue for LHC operation at 4 TeV
  - Impact of octupole and decapèole on nonlinear chromaticity Q'' and Q''' [E. McLean, F. Schmidt]

CONCLUSIONS

- We outlined the strategy followed in the LHC for modelling field vs current and expected field errors
- FiDeL: the best knowledge of our magnets and of their nonlinearities
  - Built on considerable effort in measuring magnets during production
- WISE: creates instances of the LHC sequence of magnets with their nonlinearities
  - Uncertainties are being included in the model, so different instances of the machine can be generated