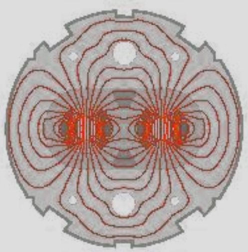
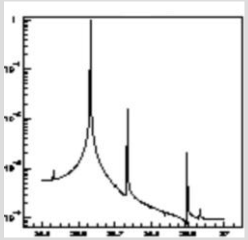
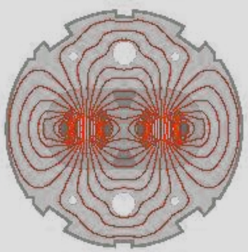


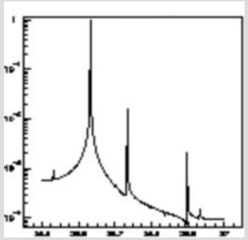
Non-linear (Effective) Modeling of Accelerators



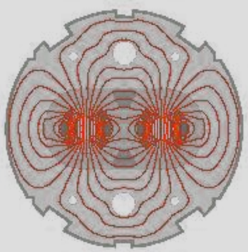
- Definition: Effective Model of an Accelerator
- Effective Model of the LHC (schematic)
- Optic Code Advancements
- Effective Modeling for the LHC
- Tools for n.l. Analysis and Measurements
- References



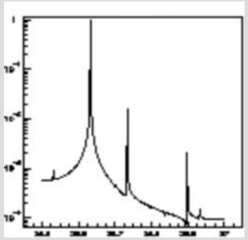
Definition of Effective Modeling of an Accelerators

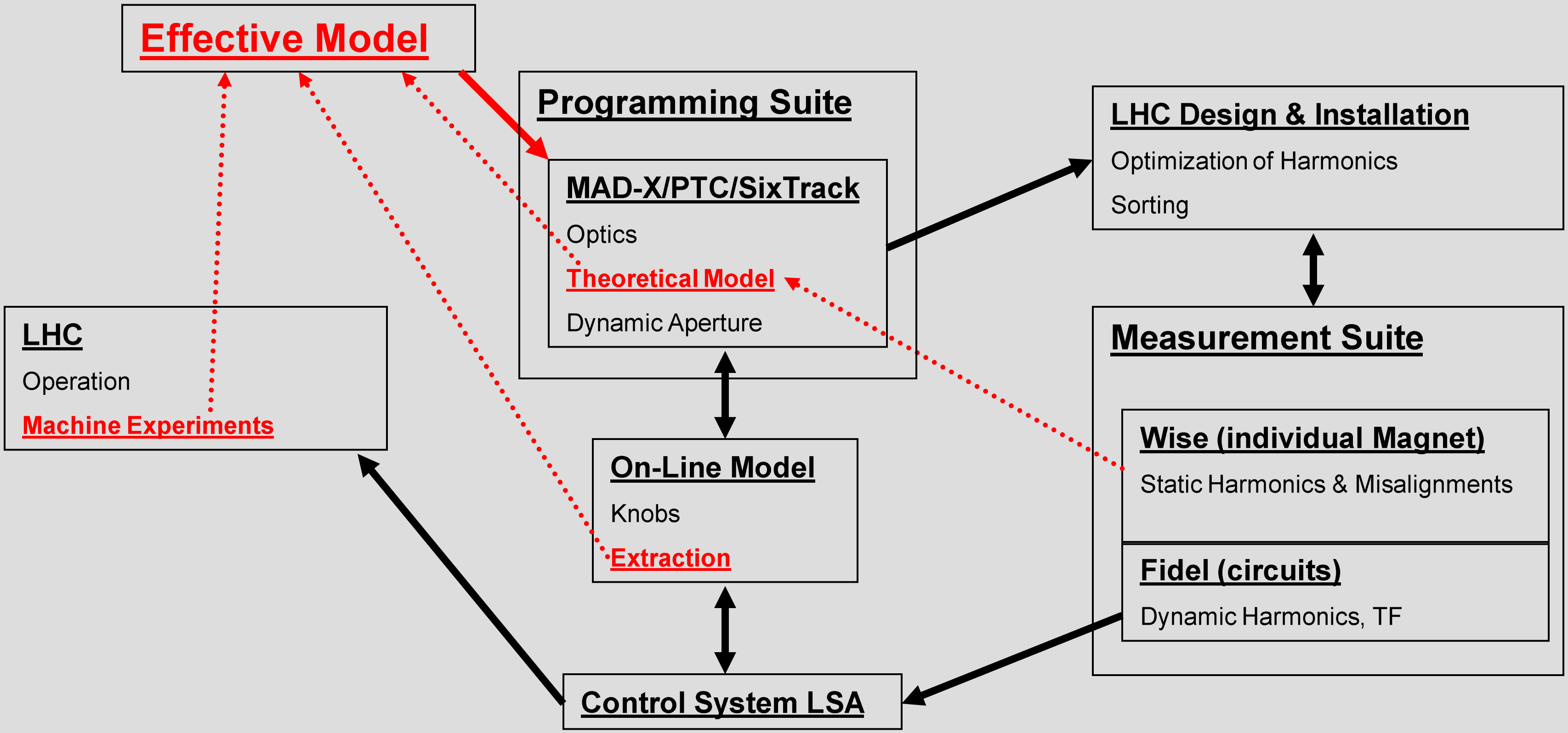


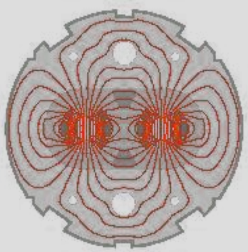
- Starting point is a good knowledge of the harmonics and misalignments of the accelerator.
- Equally important is an optics code with a solid physics description of the accelerator elements and a flexible toolkit.
- This allows the construction of the best theoretical n.l. model of the machine.
- The remaining difference to the "real" machine is that what cannot be known which includes errors in the measurements.
- The next step is to measure the missing linear and non-linear components directly from the machine.
- The "effective" model is then constructed by fitting the relevant components to the measured values.
- Lastly, one can attempt to adjust the theoretical model, in particular when additional measurements at the magnets can confirm the experimental findings.



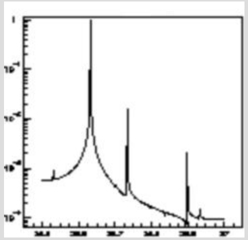
Effective Model of the LHC (schematic)



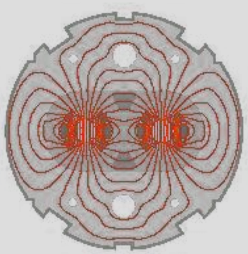




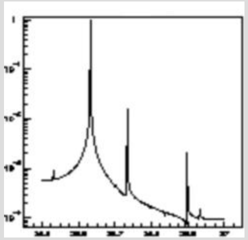
Optics Code Advancement



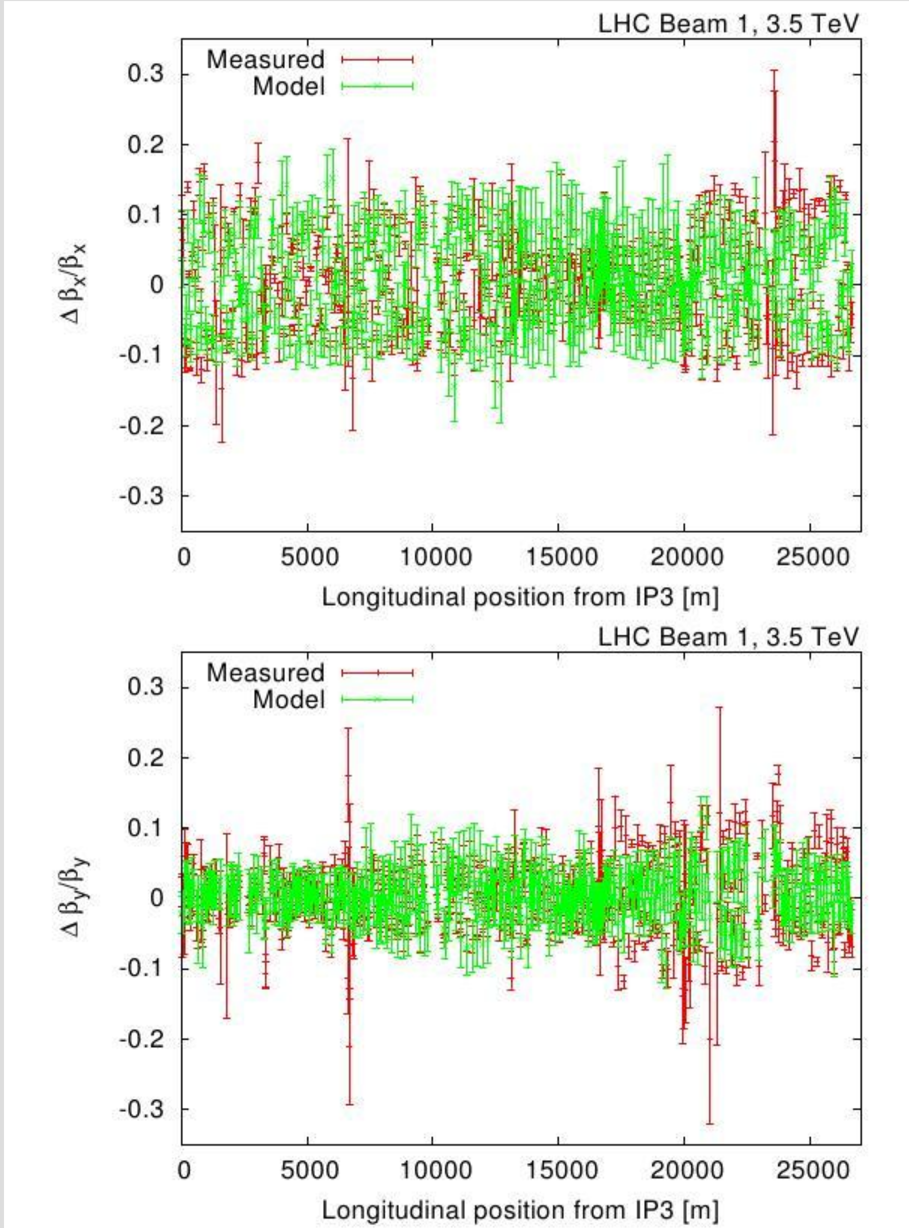
- MAD-X has been operational for the entire design phase and the commissioning of the LHC.
- Its main advantage is its input flexibility and the many tools like matching, error assignment etc.
- MAD-X transforms the LHC optics including harmonics and misalignment into SixTrack. All dynamic aperture studies have been performed with SixTrack on large computing clusters.
- The main upgrade item has been the inclusion of the PTC module with more sophisticated physics models to overcome certain known limitations of MAD-X.
- The PTC approach allows for a modern design approach which is being applied for the LHC.
- Definitely we have to go further in that direction for future design studies!

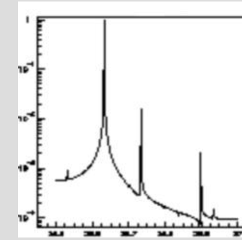


Second Best Theoretical Model for the LHC

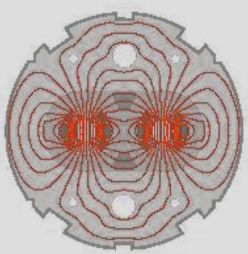


- We are presently preparing the "second" best model of the LHC. By that I mean that we are operating entirely within the MAD-X PTC framework.
- Starting point is the latest optics version of the LHC.
- However we DO NOT split its elements to include thin-lens multipole kicks that we have been doing since decades for the dynamic aperture studies.
- Instead we are using PTC facilities to apply the harmonics to thick elements.
- We are applying the measured misalignments to all elements. (A reminder: harmonics and misalignments are provided by Wise.)
- The measured LHC closed-orbit is taking into account which represents the first "effective" component of the model.
- We cannot expect that we can reproduce the machine parameters like closed-orbit, tunes, coupling and chromaticities and therefore perform PTC based matching.
- The first goal is to reproduce the measured beta-beating but n.l. will be next!

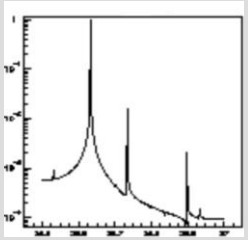




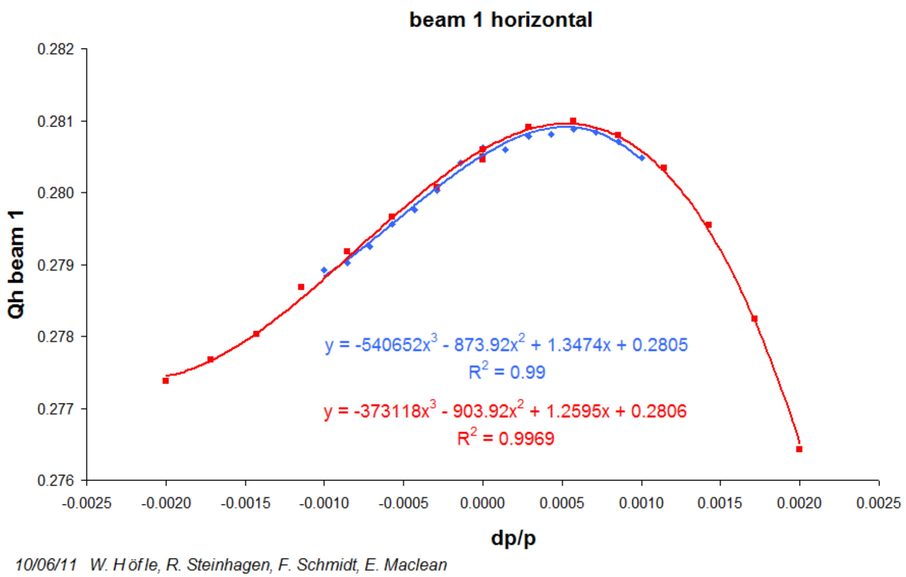
Effective Modelling of the Beta-beating of the LHC at 3.5 TeV

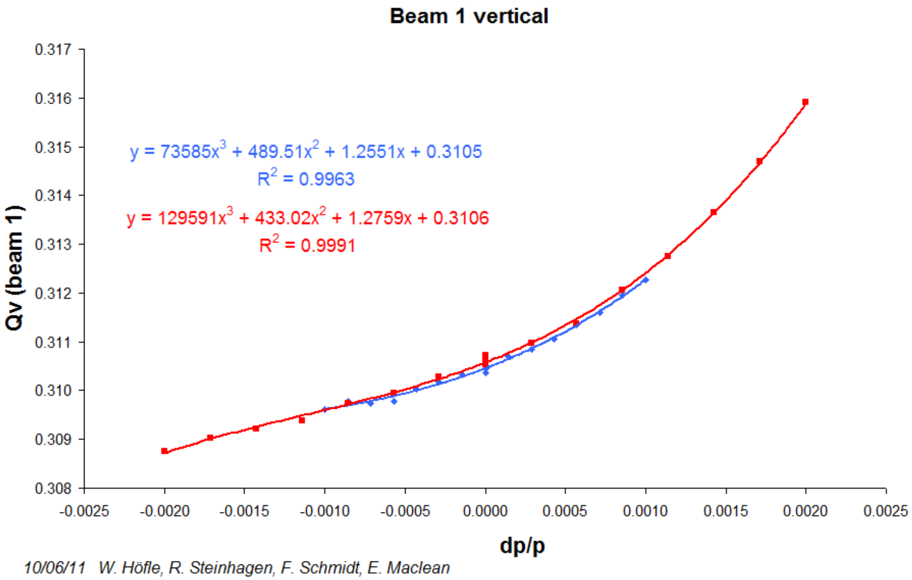


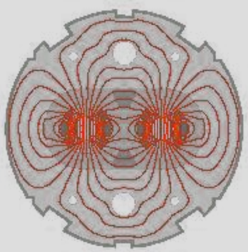
N.L. Chromaticity Measurements



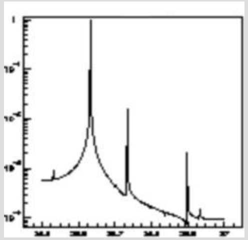
PhD student Ewen Maclean student is presently looking at this in great detail!







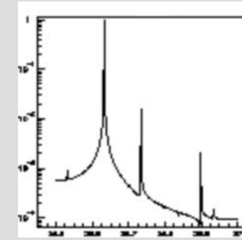
PTC standalone Model for the LHC



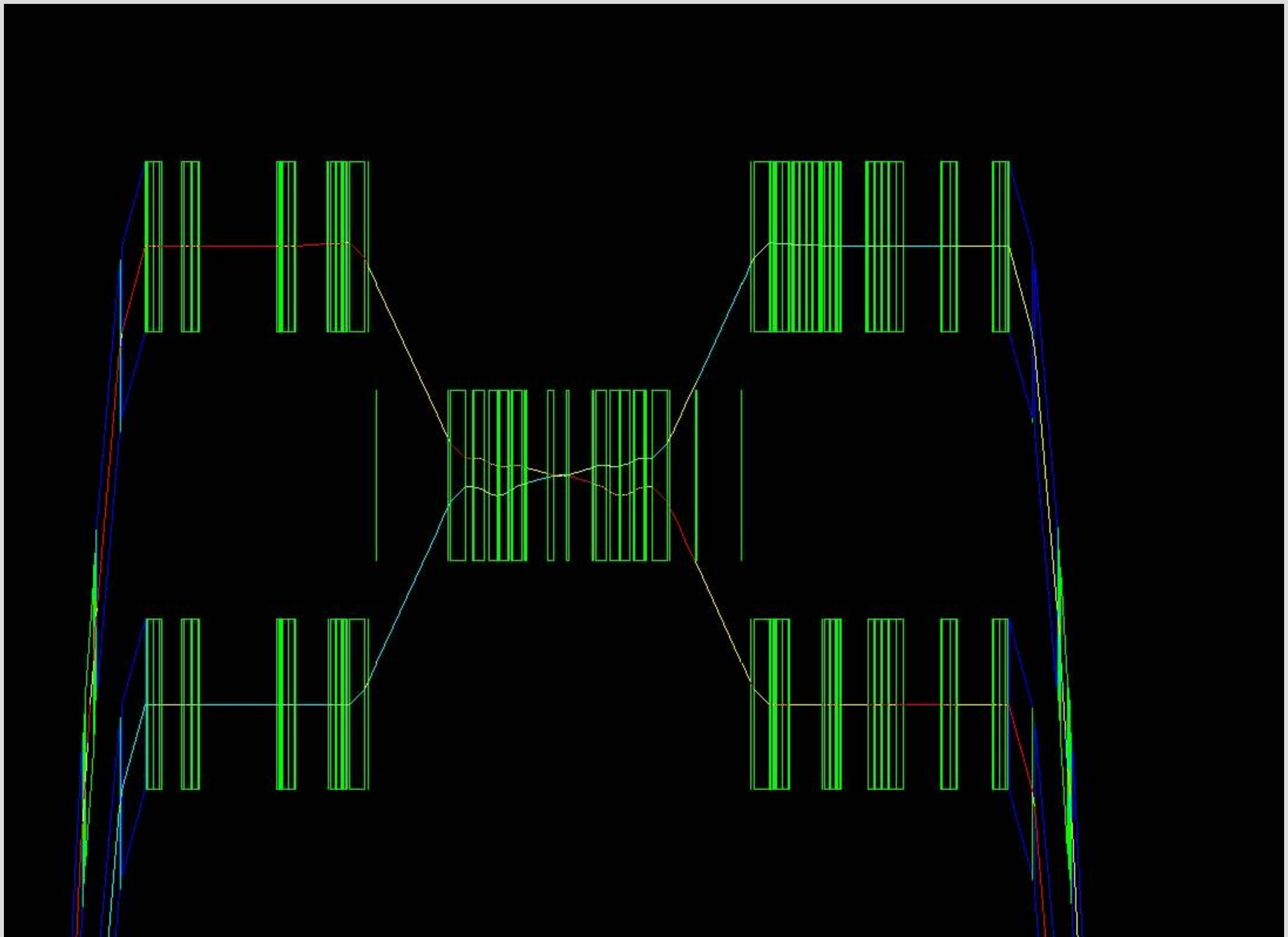
- PTC has more powerful features that can presently not be steered by MAD-X*.
- The standard MAD-X thick lattices of Beam1 and Beam2 are used and transferred into PTC format.
- Harmonics and misalignment are taken from WISE except that the misalignment of both elements and the assemblies will be used separately.
- In a first step the 2 rings are properly separated in the arcs and oriented in 3D space according to SURVEY data. Special care has to be taken in the regions where the arcs join into the common areas.
- Then all assemblies are bound into "GIRDERS" and 2-in-1 magnets are linked as "SIAMESE" and the misalignments are put into place for both elements and assemblies.
- All harmonics are read-in.
- After attaching the transfer lines in 3D the whole super structure is track-able in both directions.

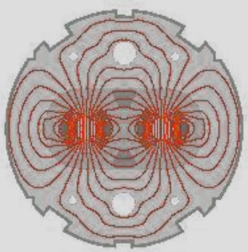
(* Hans Grote in collaboration with Etienne Forest and myself are planning a MAD-X extension to overcome this problem.)

IR5 of LHC in PTC Stand-alone

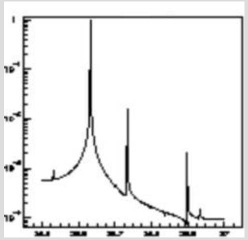


PhD student Ewen Maclean student will look into this in more detail!





Tools for N.L. Analysis and Measurements



- The classical non-linear measurement are:
    - Detuning with Amplitude
    - Resonance Driving-Term Analysis
    - Tune Scan
    - Dynamic Aperture
- The driving-term analysis has been advanced in the last 23 years due to the availability of high resolution 1000 turn BPM systems.
- This driving-terms can be identified at each BPM via a harmonic analysis. It allows for a direct comparison with what the effective model predicts for the accelerator.
- A simple example of PSB shows a driving term correction in practice.
- All that will now be tested for the LHC!

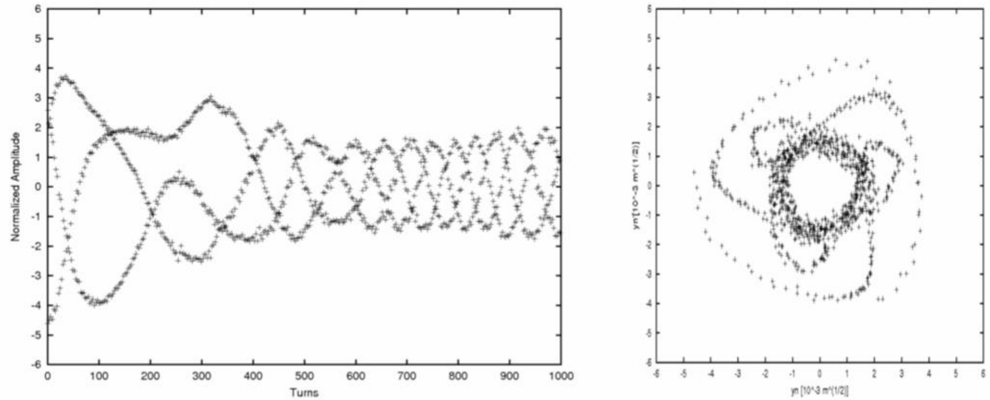
Results 2003 – systematic $3Q_y=16$

Situation for the bare machine.

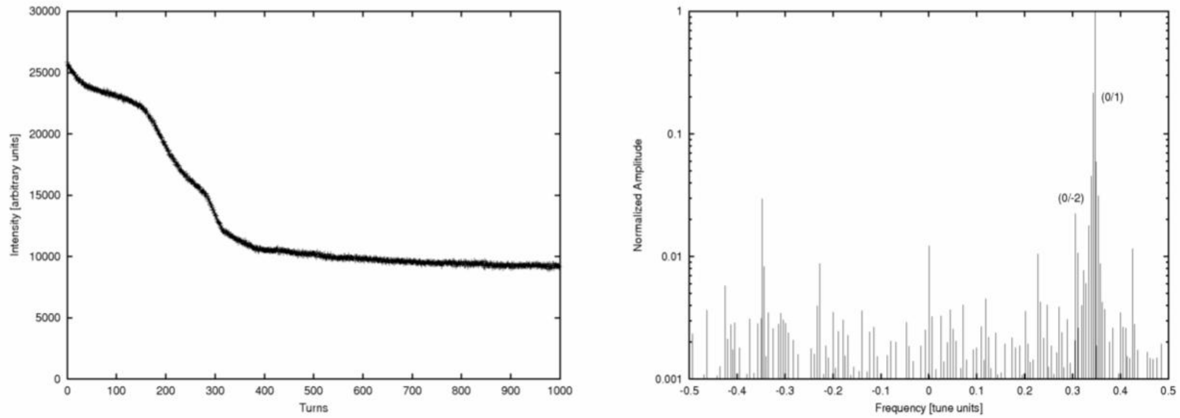
$|h_{0030}| = 9.0 \pm 0.6^*$

$10^{-3}\ \mathrm{mm}^{-1/2}$

$\psi_{0030} = -21.4^{\circ} \pm 13.9^{\circ}$



Vertical beam position and phase space



Intensity curve and Fourier spectrum (res. line: (0/-2))

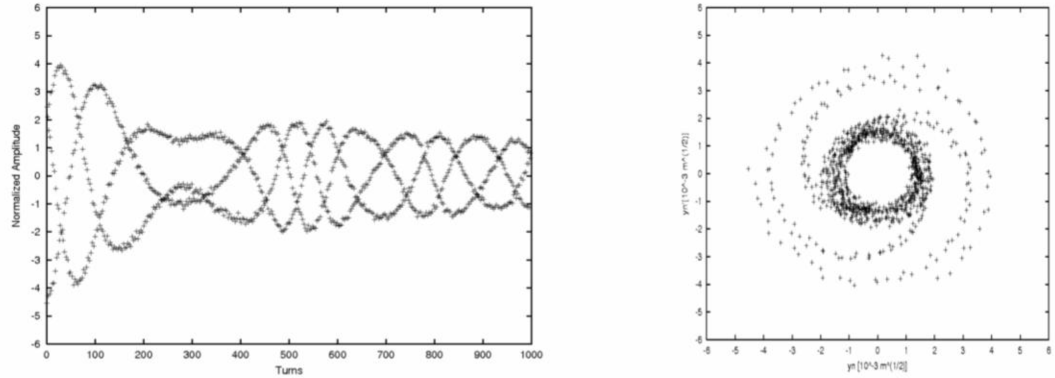
Results 2003 – $3Q_y$=16

Resonance compensated with the calculated currents:

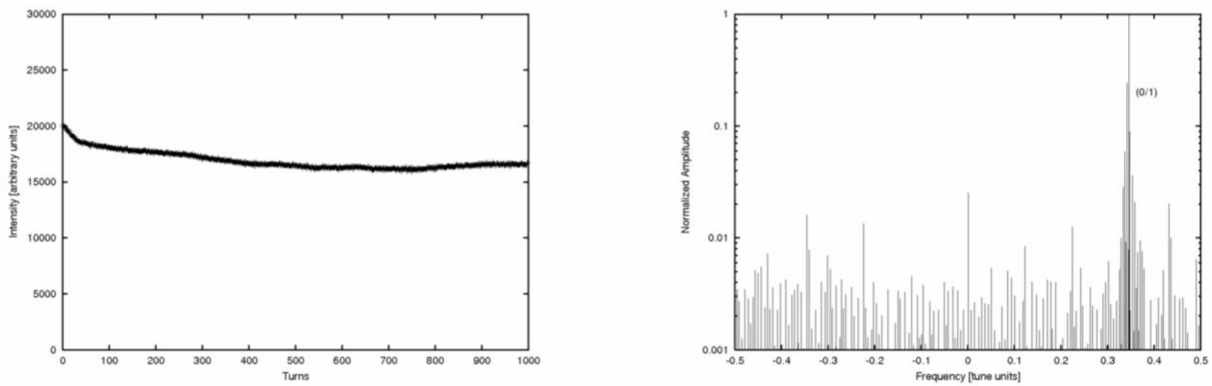
I_{XSK2L4} = -12.3A,

I_{XSK9L1} = +15.3A

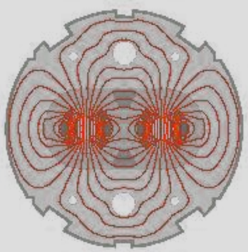
(XSK…skew sextupoles)



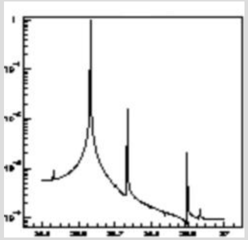
Vertical beam position and phase space



Intensity curve and Fourier spectrum

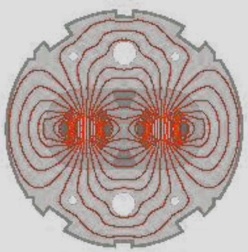


References I

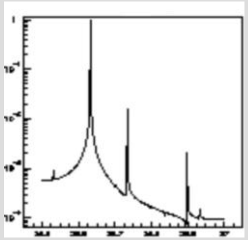


I have collected relevant papers and provide them at: http://frs.web.cern.ch/frs/Source/OMCM/

- Fidel working group
  - E. Todesco, http://fidel.web.cern.ch/fidel/
  - L. Bottura et al., “FIRST FIELD TEST OF FIDEL THE MAGNETIC FIELD DESCRIPTION FOR THE LHC”, in the proceedings of PAC09, Vancouver, BC, Canada.
- Wise team
  - P. Hagen et al., “WISE: A SIMULATION OF THE LHC OPTIC INCLUDING MAGNET GEOMETRICAL DATA”, in the Proceedings of 10th European Particle Accelerator Conference (EPAC 06), Edinburgh.
- LSA
  - G. Kruk et al., “LHC SOFTWARE ARCHITECTURE [LSA] – EVOLUTION TOWARD LHC BEAM COMMISSIONING”, in the proceedings of ICALEPCS07, Knoxville, Tennessee, USA.
- BBQ
  - M. Gasior et al. ,"An overview of the LHC Transverse Diagnostics Systems", Proceedings fo BIW'08, CERN BE-2009-002, 2009.
  - R.J. Steinhagen et al., "Advancements in the Base-Band-Tune and Chromaticity Instrumentation [..]", DIPAC'11, 2011.



References II



- PTC
  - E. Forest et al., “Introduction to the Polymorphic Tracking Code”, KEK-Report 2002-3.
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