MAGNET MODEL: 2009 RESULTS AND 2010 PLANS

E. Todesco for the FiDeL team
Magnets, Superconductors and Cryostats Group
Technology Department, CERN

The FiDeL team: B. Auchmann, L. Bottura, M. Buzio, L. Deniau, J. Garcia Perez, M. Giovannozzi, P. Hagen, M. Lamont, G. Mueller, M. Pereira, V. Remondino, S. Redaelli, F. Schmidt, R. Steinhagen, M. Strzelczyk, R. Thomas, E. Todesco, W. Venturini Delsolaro, L. Walckiers, J. Wenninger, R. Wolf
And all EIC and operators !!!

CONTENTS

- What the beams told us about the magnets
  - Orbit
  - Tune
  - Chromaticity
  - Coupling
  - Beta beating
  - Dynamic aperture
- Priorities for 2010

ORBIT

- Difference between sectors
  - From BPM and corrector data, the average sector dipolar field agrees with model within ±3 units
    - Better than last year, thanks to better precycling
    - Some correlation between beams

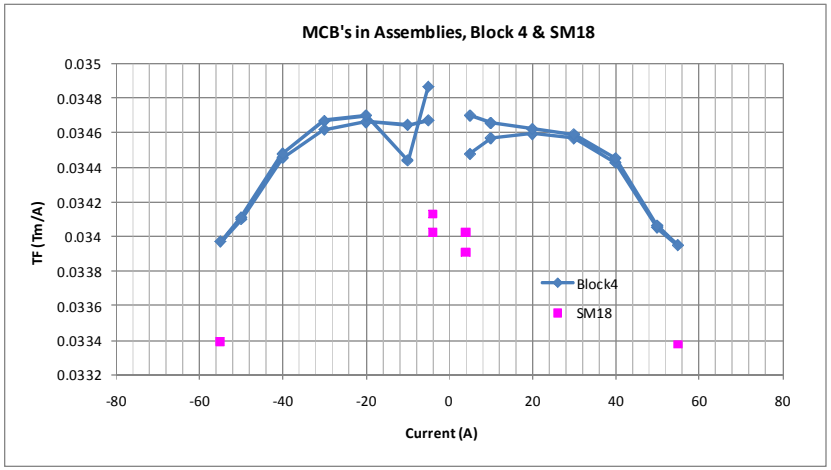
	Error (units)	
Sector	Beam1	Beam2
1 2	-2.3	-2.5
2 3	0.9	-0.5
3 4	2.4	2.5
4 5	0.2	-2.1
5 6	-2.7	-1.5
6 7	-1.2	-1.1
7 8	1.7	3.2
8 1	2.2	0.2

Average error in the dipole field in each sector according to beam measurements (J. Wenninger)

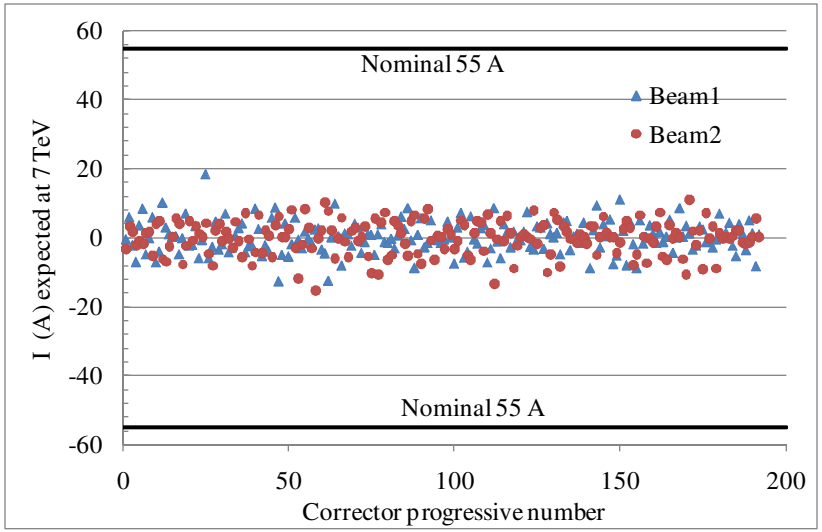
- According to room temperature magnetic measurements, the eight sector are powered with differences in the bending strength up to ±5 units

ORBIT

- How much strenght of the dipole correctors are we using?
  - Corrector (55 A nominal) are powered at injection with currents below 1 A
    - At such low currents, the corrector is affected by hysteresis (but works)
      - (minimum measurement at 5 A, where we have 1% hysteresis)
    - Setting during the ramp may change not linearly
  - Anyway, the present setting scaled at 7 TeV show that correctors are used below 20% in most cases



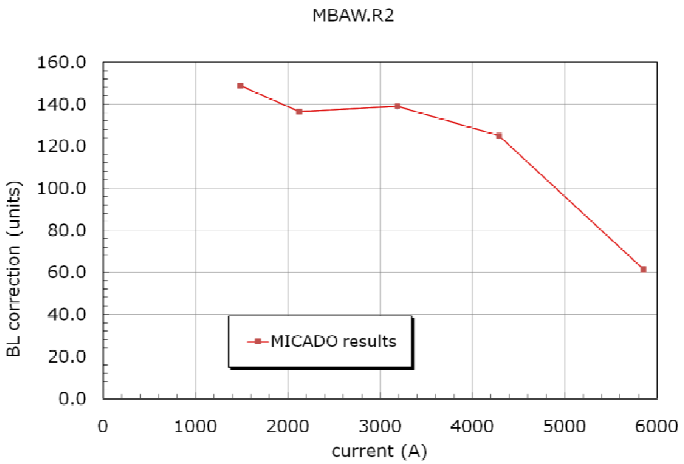
TF measured of an orbit corrector in the cell



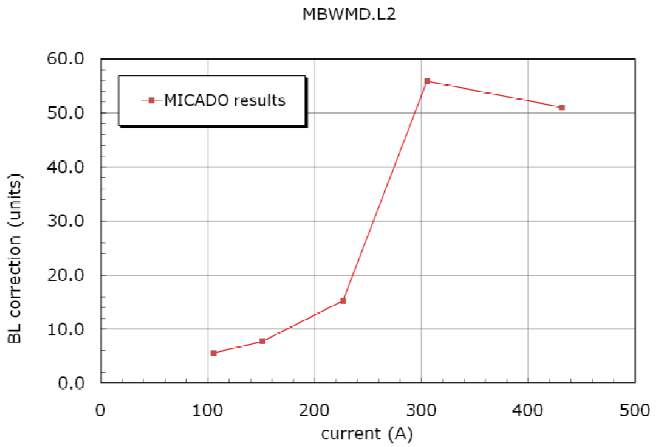
Current used in the cell orbit correctors (6th ramp), scaled at 7 TeV

ORBIT: BUMP AROUND SPECTROMETERS

- The non closure of the bump around Alice and LHCb is larger than expected [J. Wenninger]
  - The problem is over determined, one cannot compute what is wrong
  - The error is of the order of 1% - it is a lot – changes with energy
  - We [L. Bottura and P. Hagen] are going through the model, other measurements are foreseen
  - Better optic model: spectrometers as several kicks and not only one



Guess of the error in the TF model in Alice spectrometer (J. Wenninger)

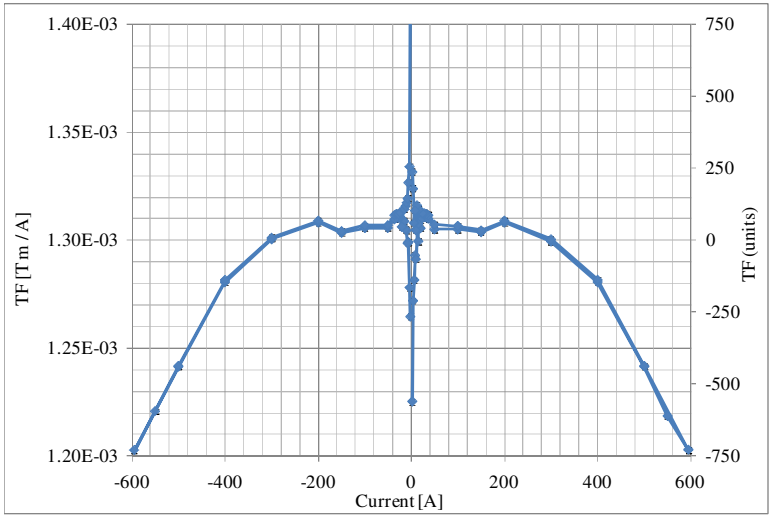


Guess of the error in the TF model in compensator (J. Wenninger)

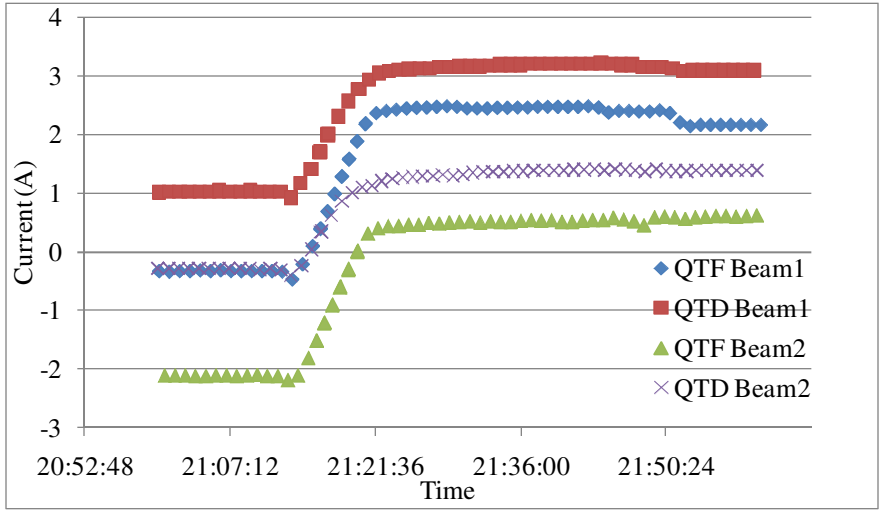
TUNE

- In general, tunes agrees with model within 0.1
  - This corresponds to about 15 units of absolute precision in b2/b1 (very good)
  - Example: during 6th ramp the QTF/D are powered at injection with 1-2 A (nominal of 550 A)
    - Different settings beam1-beam2, within 0.1

Trim	Beam1	Beam2
dQh	-0.02	-0.09
dQv	0.05	0.01
QTD (A)	1.02	-0.29
QTF (A)	-0.34	-2.12



Measured TF of the MQT

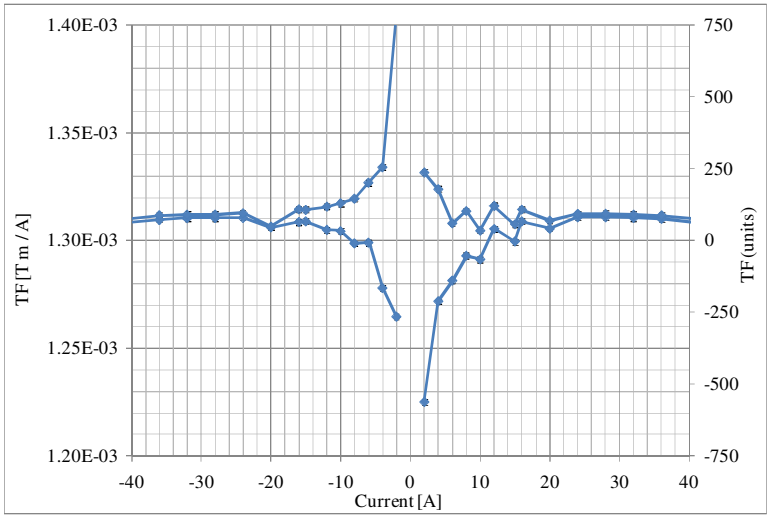


Tuning quadrupoles currents used during the 6th ramp

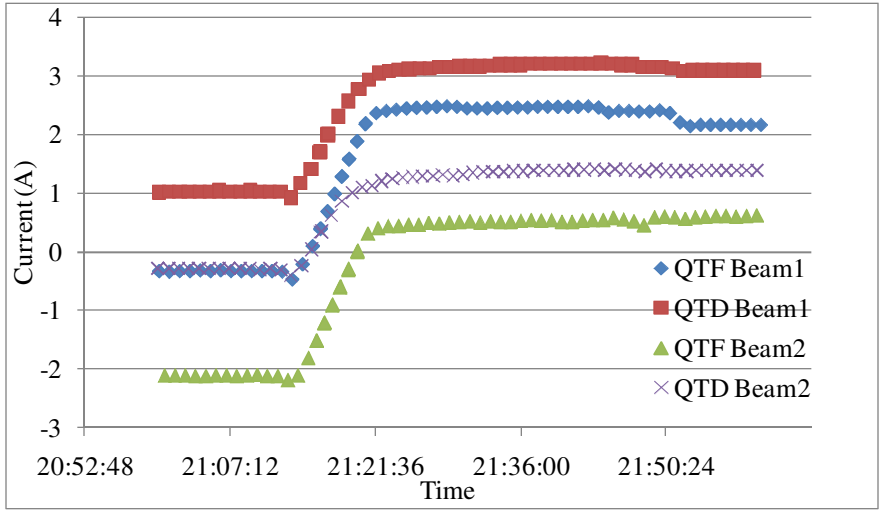
TUNE HYSTERESIS

- In general, tunes agrees with model within 0.1
  - This corresponds to about 15 units of absolute precision in b2/b1 (very good)
  - Example: during 6th ramp the QTF/D are powered at injection with 1-2 A (nominal of 550 A)
    - Hysteresis is not significant

Trim	Beam1	Beam2
dQh	-0.02	-0.09
dQv	0.05	0.01
QTD (A)	1.02	-0.29
QTF (A)	-0.34	-2.12



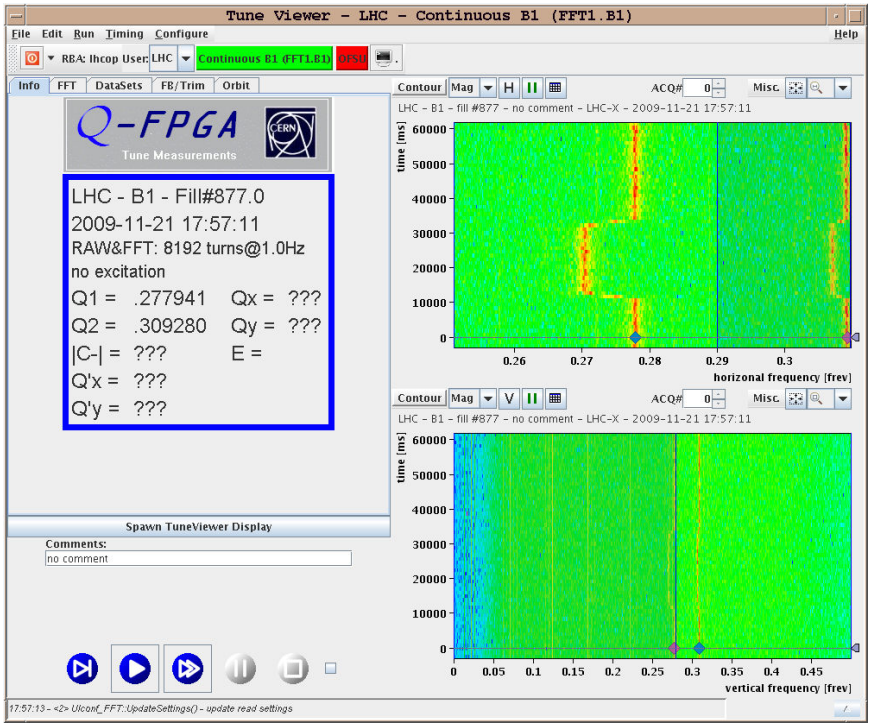
Measured TF of the MQT around 0 A



Tuning quadrupoles currents used during the 6th ramp

TUNE HYSTERESIS

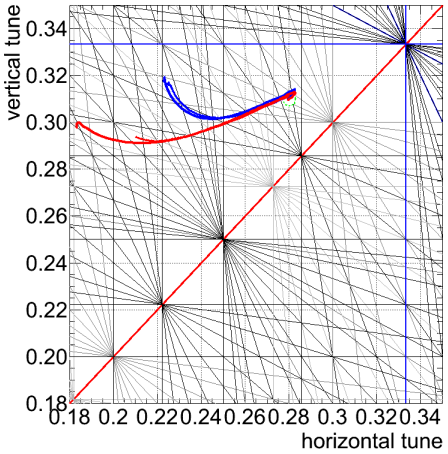
- In the past, several discussions have been made on the MQT hysteresis and its effect on operation
  - MQT hysteresis responsible of bad (0.2) tune reproducibility in 2008?
  - Magnetic measurements excluded this possibility
  - During 2009 a trim has been put on and off, showing that the tune steering is not affected by MQT hysteresis



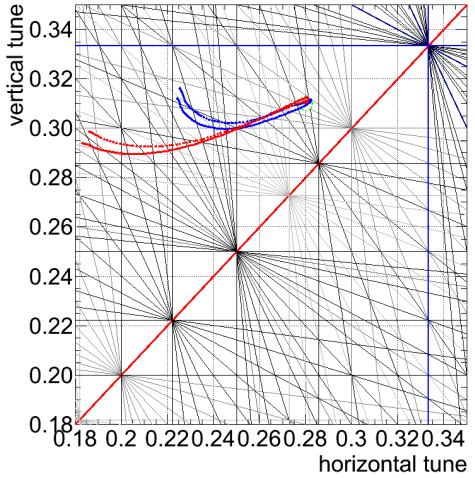
Trimming the tune shows no hysteresis (W. Venturini)

TUNE DURING RAMP

- At the snapback the tune has a change of about 0.005
  - Compatible with tracking error b_2/b_1 of 1 unit (wow, but expected since dipole and quad decay are within 1 units)
- During ramp, tune moves of about 0.1 in H and 0.02 in V
  - Very reproducible in ramp 5 6 7 8 – difference between beam 1 and 2
  - Not a tracking problem b_2/b_1
  - Could come from b_3 feed-down [see W. Venturini talk]



Tune change during 5th and 6th ramp (R. Steinhagen)



Tune change during 7th and 8th ramp (R. Steinhagen)

CHROMATICITY

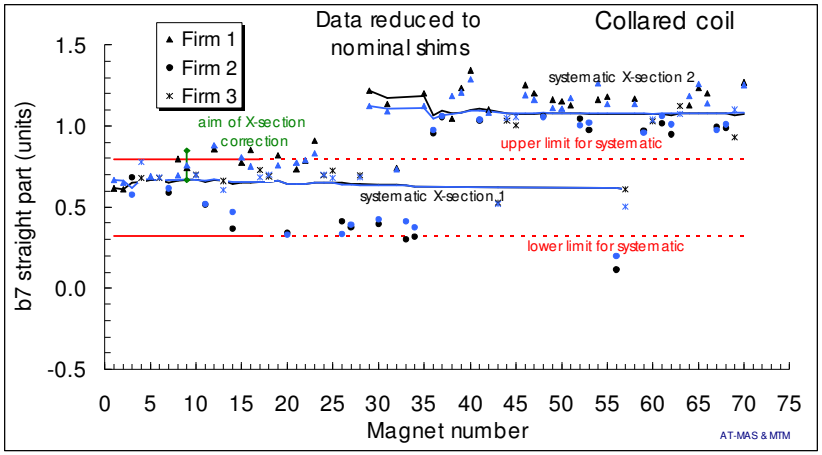
- Chromaticity is trimmed of about 10-15 units
  - This corresponds to an absolute precision of the b_3 correction in the dipoles of 0.2-0.3 units – not fantastic, but not so bad
  - In fact, this also includes also decay of about 0.3 units!
    - Taking into account of this would reduce the trim ?
- At the end of the ramp chromaticity decreases by 5-15 units
  - Translated in b_3 correction, this implies having about 0.1-0.3 uncorrected b_3 – not bad
  - Known effect: the b_3 snapback is under corrected of about 0.2 units according to recent FAME measurements – this accounts for 8 units, with the right sign

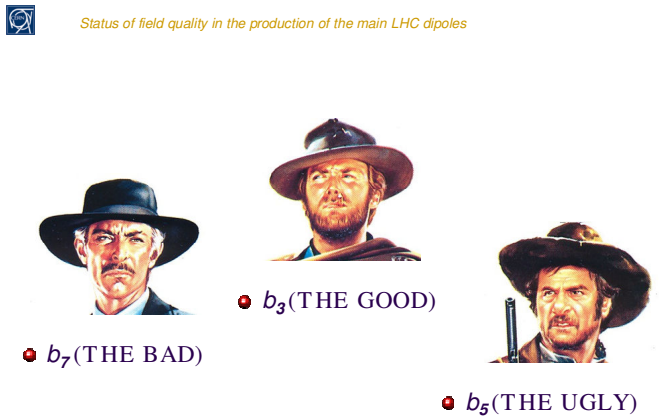
	ΔQ'H	ΔQ'V
ramp4 B1	-6.3	-14.7
ramp5 B1	-2.7	-13.2
ramp6 B1	-3.0	-10.8
ramp6 B2	-9.2	-8.1

Chromaticity change (R. Steinhagen)

HIGH ORDER NONLINEARITIES

- Some years ago, some concerns were expressed about high order multipoles ...
  - After the first correction of the dipole cross-section, b_3 went within spec but b_7 went out; b_5 always stayed on the edge of the targets





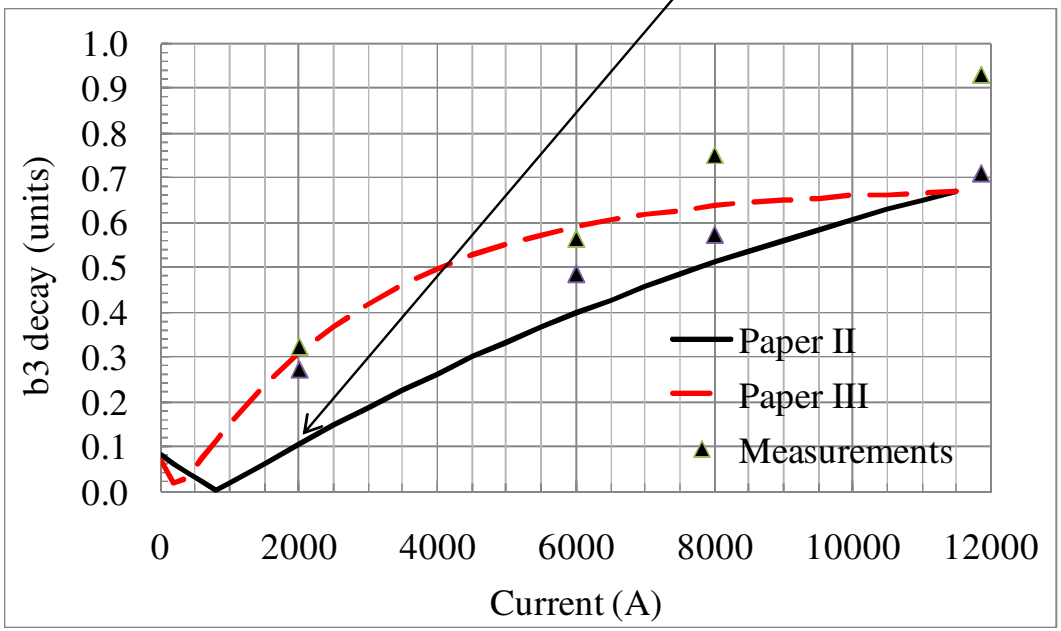
  - Targets had a safety factor 2 (12 σ)
  - Having a nearly nominal emittance in 2009, the phase space has been explored
    - Lifetimes up to 25 hours – phase space looks very clean and stable
    - "I am surprised – it looks as if the dynamic aperture is infinite" (JPK)

SNAPBACK IMPROVED ESTIMATES

- Decay and snapback have been measured during the production in SM18 as a function of pre cycle parameters
  - Systematic exploration around a 50 A/s precycle, but in the machine we have 10 A/s
  - Two equations to model the impact
    - a simplified model [N. Sammut et al., Phys. Rev. STAB 10 (2007) 082802] - this gives a decay of 0.1 units with 2 kA precycle
    - a coupled model [N. Sammut et al., Phys. Rev. STAB 12 (2009) 102401] - this gives a decay of 0.3 units with 2 kA precycle
  - The two models are similar at 7 TeV, but they differ a lot at 1.12 TeV
  - Today the simplified model is implemented
  - Magnetic measurements on a dipole done in 2009 suggest that the coupled model is more precise
    - We are probably compensating the snapback only at 33%, i.e. 0.2 units of b_3 are not compensated

SNAPBACK IMPROVED ESTIMATES

- New measurements in SM18
  - The scaling proposed in paper III seems more correct
  - Today we are correcting snapback only at 30% (0.1 instead of 0.3 units)
  - At 7 TeV we will have about twice what we have today (not 6)



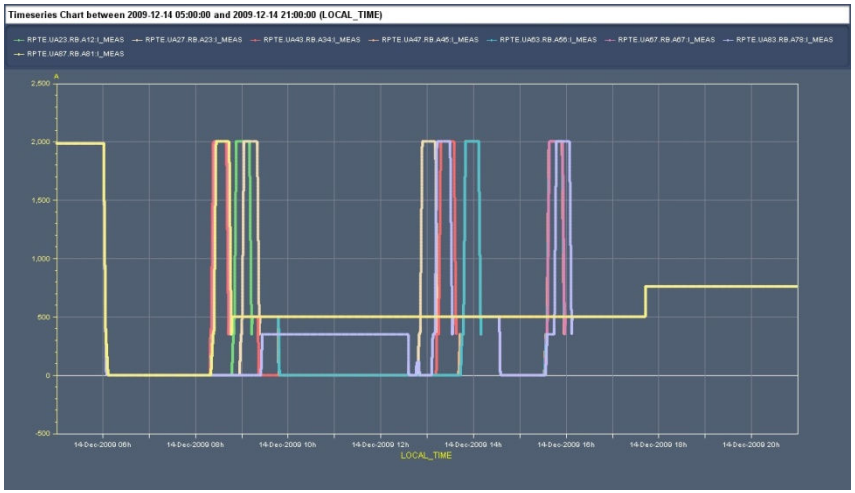
Amplitude of b3 decay versus flattop current of the precycle (G. Montenero, L. Walckiers)

BETA BEATING

- Beta beating has been measured several times at injection and once at 1.12 TeV (R. Thomas)
  - Beta beating is unexpectedly low for a machine in early stage
  - Correct precycling ensures reproducibility of the optics within 5%
  - A beta beating of 40-50% is anyway present is some sections
    - IP are the largest sources
    - Changes of about 1% in some MQX account for this, but this is not physical
    - IR3 and IR7 are also sources of beta beating
  - At 1.12 TeV the beta beating is within specifications ☺
    - The problem is to model at low field, the geometric component of the quadrupoles is good

PRECYCLING

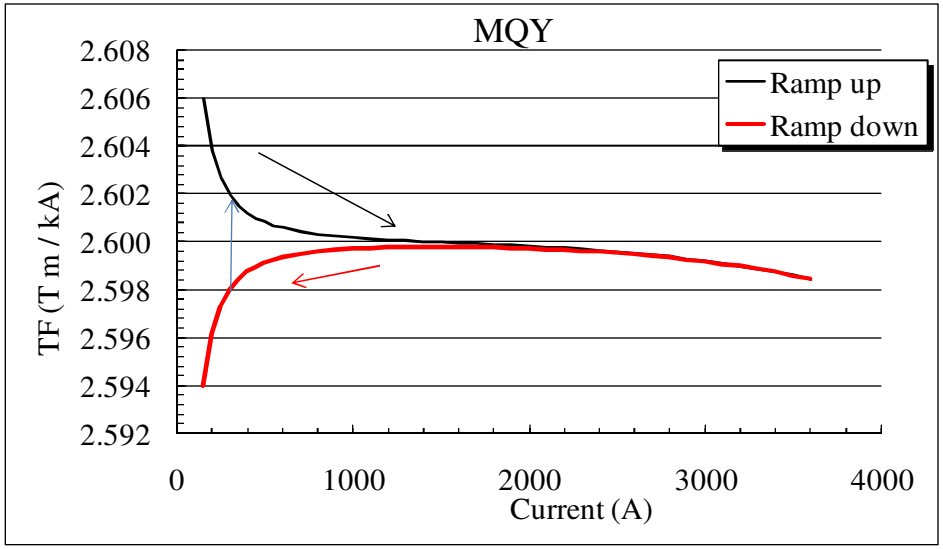
- Precycling
  - In 2009 the precycling has been usually done correctly, but
    - Some circuits (MQTL) not precycled
    - Pretty unstable precycling discouraging operation
  - More stable conditions should be obtained in 2010 (MP3 and QPS)
  - MQTL should be cycled
- Beam experience has proved that precycling is important to have a reproducible machine



MB precycle before the 6th ramp

MQM MQY HYSTERESIS

- Hysteresis
  - In 2010 LSA will be able to change hysteresis branch according to dI/dt
    - This solves the problem of relevant errors in the transfer function of the MQM and MQY during squeeze (visible below 1 m)
    - The squeeze procedures have been tested successfully up to 7 m – but the hard part is below 1 m



MQY hysteresis

VALIDATION – ADDITIONAL MEASUREMENTS

- Validation
  - Ramp up to 3.5 TeV: validation in progress [Per, Marek]
    - At these currents we will not yet be able to see the saturation components → they will have still to be checked for 5 and 7 TeV
  - Squeeze, including the change of branch

- Additional measurements
  - Continue the measurements at SM18 to characterize dipoles with 6 kA and 10 A/s precycle
  - Characterize the spectrometer compensators

CONCLUSIONS

- The knowledge of the magnetic model of the LHC is remarkable and has been one of the key elements of a very smooth beam commissioning
- Future priorities
  - Origin of beta beating in the IP
  - Bump around the spectrometers
  - Correction of the snapback at 6 kA – new equations
  - Tune drift during ramp: origin ?
  - Better understand tune and chrom trims used at injection

  - Implement hysteresis in LSA
  - Continue measurements on dipoles to characterize them at 3.5 and 5 TeV precycle
  - Cross-check, cross-check, cross-check ...