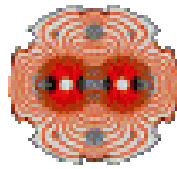




# Optics options for the 2012 proton run



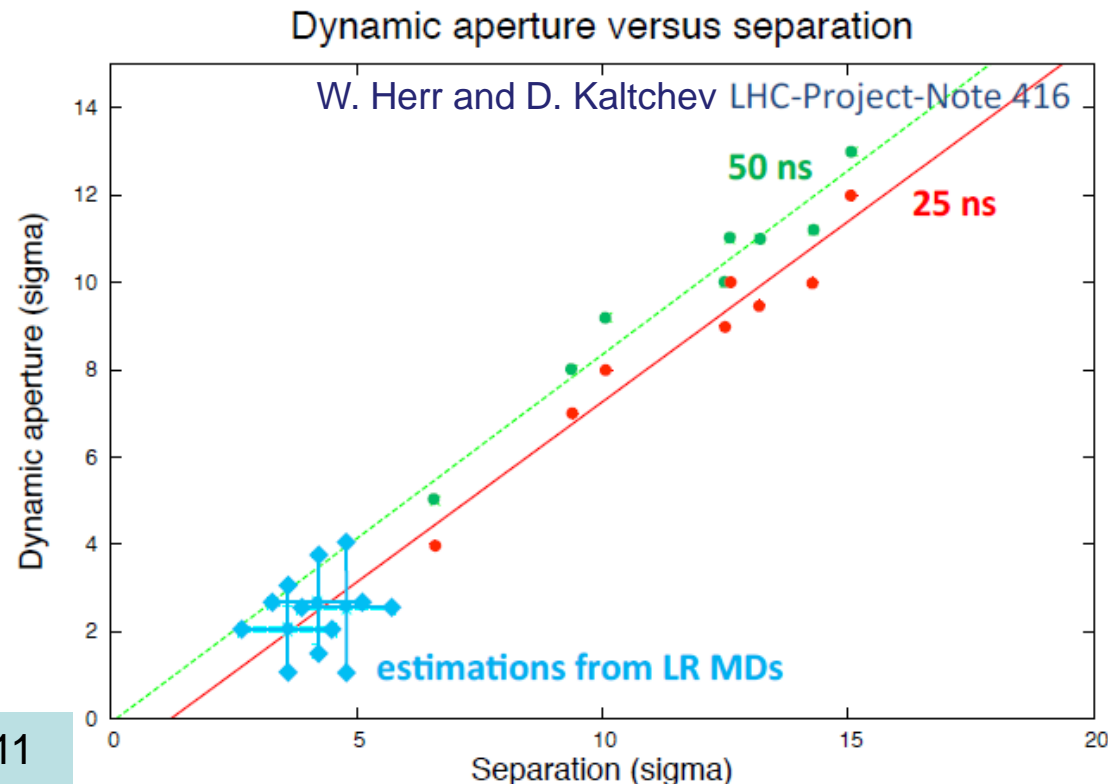
Massimo Giovannozzi

- Injection
- Collision
- Comments on squeeze at 4 TeV
- Digression: special configurations for LHCb and CMS at top energy
- High-beta

Acknowledgements: G. Arduini, R. Bruce, H. Burkhardt, S. Fartoukh, W. Herr, B. Holzer, J. Jowett, M. Lamont, V. Montabonnet, S. Redaelli, T. Risselada, R. Versteegen, J. Wenninger.

# Assumptions

- The key parameters:
  - Energy: 4 TeV
  - Transverse emittances: 2.5  $\mu\text{m}$  (input from 2011 run)
  - Beam-beam separation
    - 50 ns bunch spacing -> 9.3  $\sigma$  (with  $\varepsilon_n=2.5 \mu\text{m}$ )
    - 25 ns bunch spacing -> 12  $\sigma$  (with  $\varepsilon_n=3.5 \mu\text{m}$ )
  - Collimators settings: tight (R. Bruce – Evian and Chamonix).
  - Impedance: imposes the use of strong octupoles (N. Munet – Evian, R. Bruce – Chamonix)



# Injection - I

- Configuration in 2011:

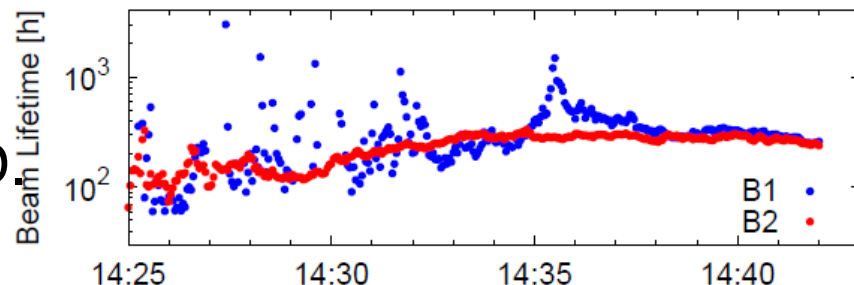
	<b>ATLAS</b>	<b>Alice</b>	<b>CMS</b>	<b>LHCb</b>
Beta* (m)	11	10	11	10
half cross angle  ( $\mu\text{rad}$ )	170	<b>170</b>	170	<b>170</b>
half parallel separation  (mm)	2	2	2	2

For Alice and LHCb the quoted angles are the external ones.

- Values are compatible with 25 ns (nominal as from LHC DR).
- For efficiency reasons (commissioning time)-> keep same values also in 2012.
- What could have been changed?

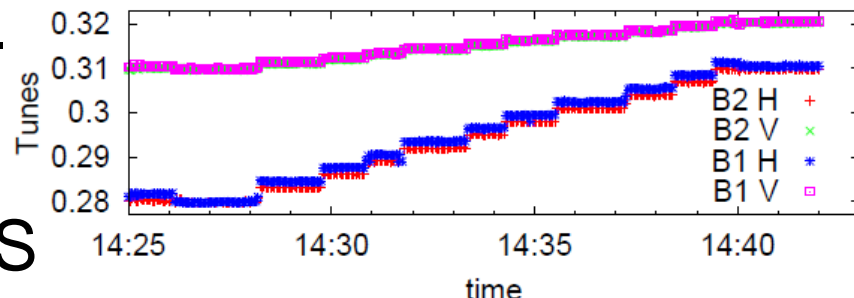
# Injection - II

- Collision tunes at injection:
  - Successfully tested in 2011 in MD
  - Some gain in beam lifetime
  - Less manipulations at top energy.



- Lower beta\* in ATLAS and CMS

- Some gain for the overall squeeze time R. Calaga et al. ATS-MD-Note- 2011-34
- (it would have been interesting with combined ramp & squeeze)



- New optics in IR6 (proposal by S. Fartoukh):

- Improved phase advance between MKD and TCSG.
- Discussed at LBOC: more (and additional) tests to be performed before trying this in operation.

# Top energy - I

- Configuration in 2011 (end of the proton run):

	ATLAS	Alice	CMS	LHCb
Beta* (m)	1	10	1	3
half cross angle  ( $\mu\text{rad}$ )	120	80	120	250
half parallel separation  (mm)	0.7	0.7	0.7	0.7

For Alice and LHCb the quoted angles are the external ones.

- Re-computation of parameters for 2012 run:
  - Parallel separation:
    - Simple scaling with energy -> 0.65 mm
  - Beta\* and crossing angle:
    - Available aperture
    - Collimator settings
    - Beam-beam separation

# Top energy - II

- Proposed configurations in 2012 (50 ns):

Key assumption		ATLAS	Alice	CMS	LHCb
Quadratic sum of tolerances	Beta* (m)	0.60	3	0.60	3
	half cross angle  ( $\mu\text{rad}$ )	145	90	145	230-250
Linear sum of tolerances	Beta* (m)	0.70	3	0.70	3
	half cross angle  ( $\mu\text{rad}$ )	134	90	134	230-250
Fall back solution	Beta* (m)	0.90	3	0.90	3
	half cross angle  ( $\mu\text{rad}$ )	118	90	120	230-250
Valid for any configuration	half parallel separation  (mm)	0.65	0.65	0.65	0.65

For Alice and LHCb the quoted angles are the external ones.

# Top energy - III

- Proposed configurations in 2012 (25 ns) focusing on ATLAS/CMS:

Key assumption		ATLAS/CMS
Quadratic sum of tolerances	Beta* (m)	0.80
	half cross angle  ( $\mu\text{rad}$ )	192
Valid for any configuration	half parallel separation  (mm)	0.65

# Top energy - IV

- Comparison of performance reach for various options at 4 TeV (again focusing on ATLAS and CMS).

Parameter	Unit	50 ns			25 ns
Half crossing angle IP1/5	$\mu\text{rad}$	118.00	134.00	145.00	192.00
Beta * IP1/5	m	0.90	0.70	0.60	0.80
Total number of bunches		1380	1380	1380	2760
Bunch intensity ( $10^{11}$ )		1.50	1.50	1.50	1.15
Normalised transverse emittance	$\mu\text{m}$	2.50	2.50	2.50	3.50
Protons per beam ( $10^{14}$ )		2.07	2.07	2.07	3.17
Current per beam	mA	372.43	372.43	372.43	571.07
Stored energy per beam	MJ	132.69	132.69	132.69	203.46
RMS bunch length	cm	9.40	9.40	9.40	10.10
Beam size IP1/5	mm	0.023	0.020	0.019	0.026
Geometric factor IP1/5		0.901	0.849	0.809	0.797
Number of colliding pairs in IP1/5		1331	1331	1331	2662
Luminosity in IP1/5 ( $10^{33}$ )	$\text{cm}^{-2} \text{s}^{-1}$	4.57	5.54	6.16	3.82
Events per crossing IP1/5 (76 mbarn)		23.22	28.15	31.29	10.0

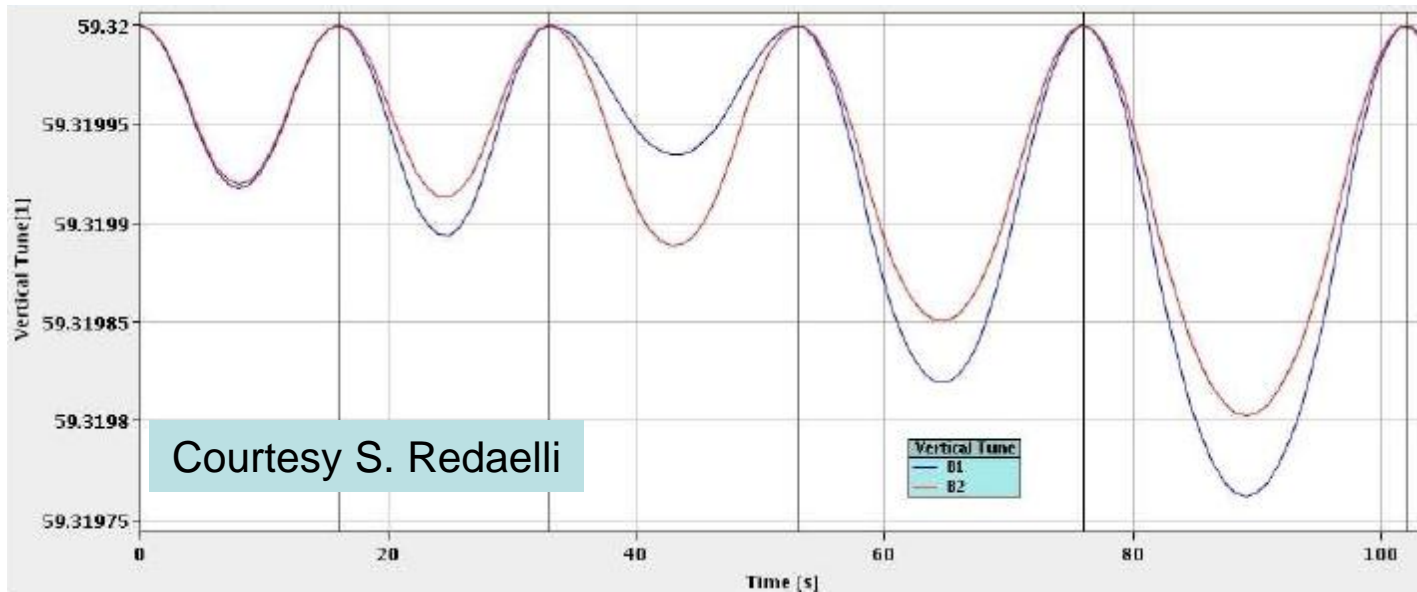


# Comments on squeeze at 4 TeV - I

- Optics availability:
  - New sequence available for settings generation
  - Optics squeeze:
    - IR1/5: available. Matched optics below 1 m in steps of 0.1 m.
    - IR2/8: available. For IR2, improved squeeze sequence (for ions) has been developed in 2011, but not put in operation. The improvement should be assessed -> should this be used in 2012?

Example of  $Q_v$  variation during squeeze:

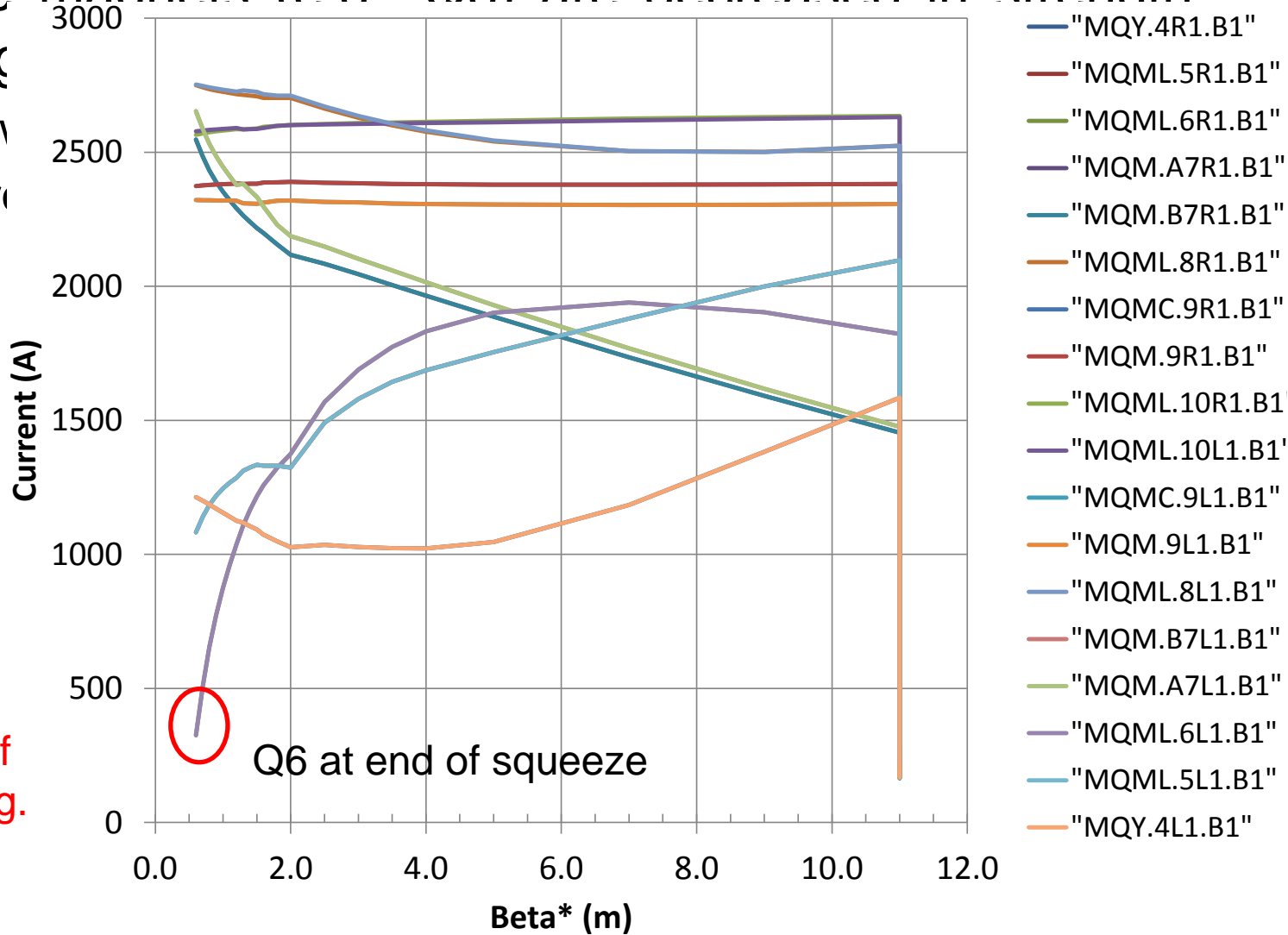
- Number of matched optics -> amplitude of tune variation
- Feed forward tune correction



# Comments on squeeze at 4 TeV - II

- Magnets and power converter behaviour:
  - Some magnets (e.g. Q6) are decreased in strength during

- Power
- Wrt



Q6 reaches:

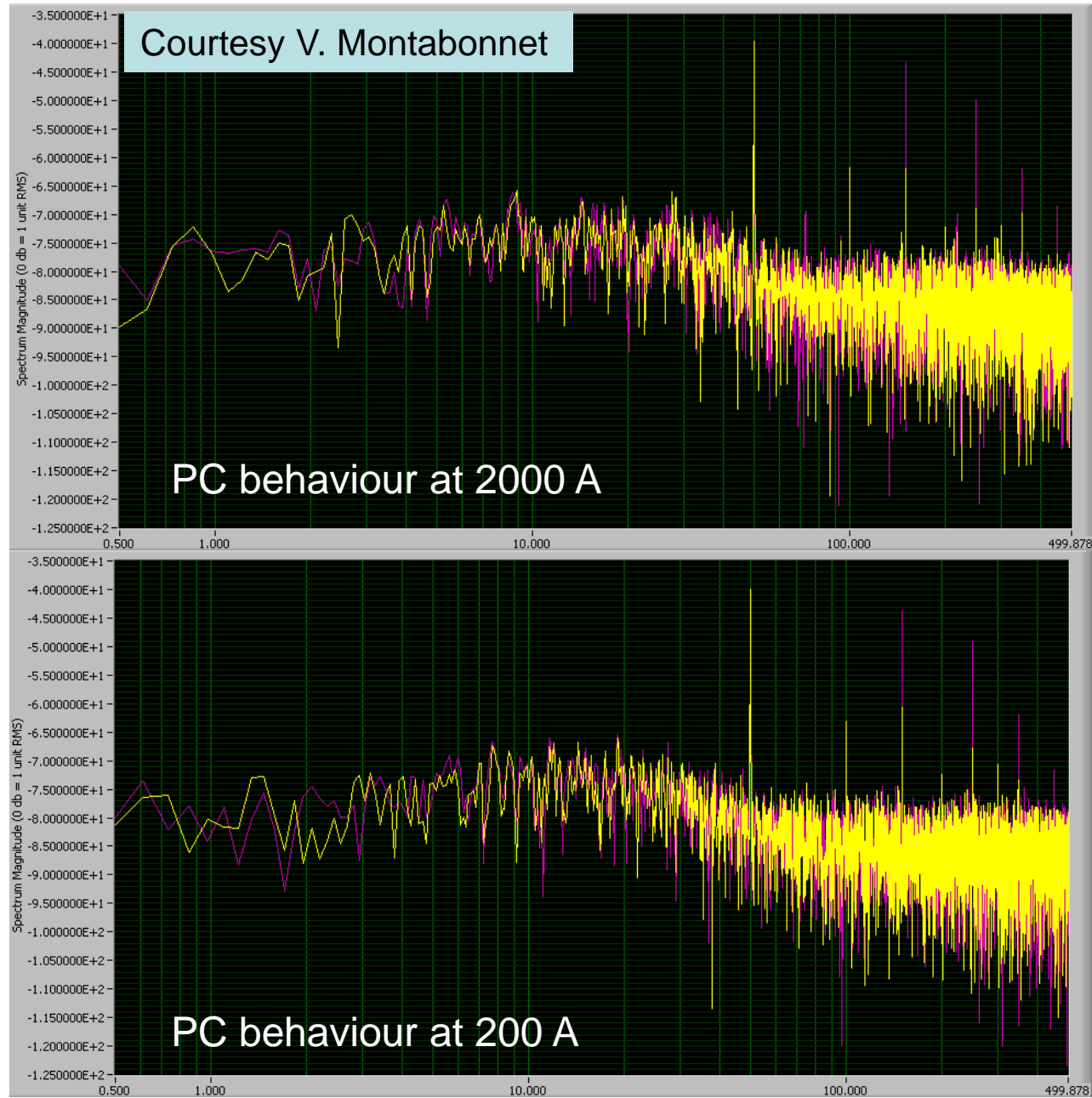
- 325 A (Beam 1, 0.60 m)
- 239 A (Beam 2, 0.60 m) -> 4% of PC current rating.

# Comments on squeeze at 4 TeV - III

Tests performed so far do not show any degradation in terms of current ripple of the PC performance at low current.

New tests will be made during the hardware commissioning period.

February 7th 2012



# Comments on squeeze at 4 TeV - IV

- Hysteresis effect:
  - Old issue already discussed within FiDeL WG in 2009.
  - Hysteresis in squeeze was implemented in 2010, but then removed for the 2011 run due to some technical difficulties and to the small impact on beta-beating.

- Some (old) estimates (to be reviewed):

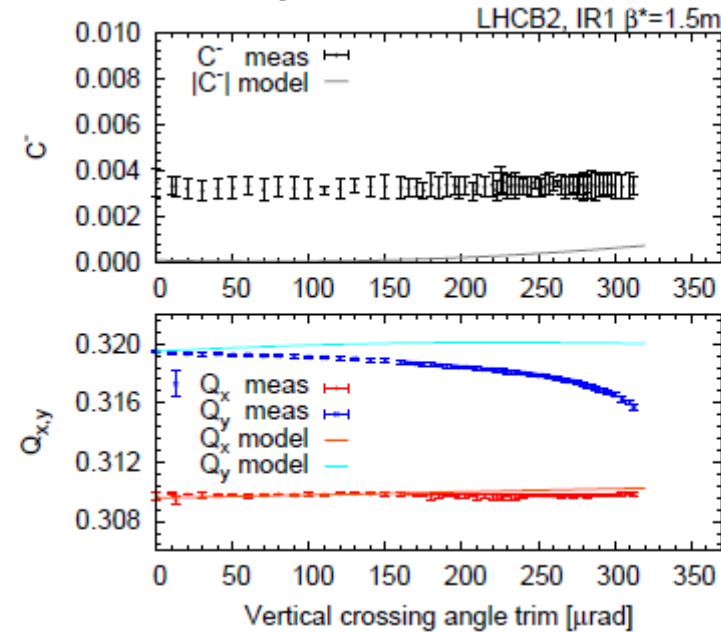
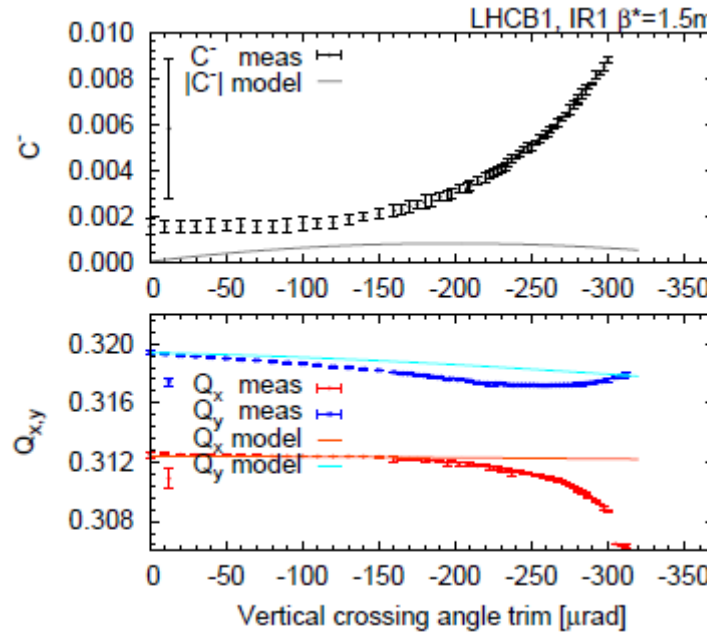
- About 60 units of gradient error if hysteresis is not considered for Q6.
- The beta-beating should be negligible.

Q6 - IP1 and IP5 - 4 TeV			Courtesy E. Todesco	
$\beta^*$ (m)	k (m <sup>-2</sup> )	Gradient (T/m)	Current (A)	Error (units)
11.00	0.002896	67.6	1821	0
9.00	0.003024	70.6	1902	0
7.00	0.003082	72.0	1938	0
5.00	0.003022	70.6	1901	2
4.00	0.002911	68.0	1831	3
3.50	0.002819	65.8	1773	3
2.50	0.002493	58.2	1568	3
2.00	0.002185	51.0	1374	4
1.50	0.001934	45.2	1217	5
1.10	0.001574	36.8	990	7
0.80	0.001066	24.9	671	12
0.65	0.000688	16.1	432	21
0.55	0.000352	8.2	222	60
Nominal	160.0482622.0		0	

# Comments on squeeze at 4 TeV - V

- Non-linear correctors:
  - Probably not needed, except for sextupolar ones.
  - Higher order have been requested for use during MDs.

Parasitic measurements (during aperture sessions) of tune and coupling vs. IR bumps -> useful to study MQX field quality.

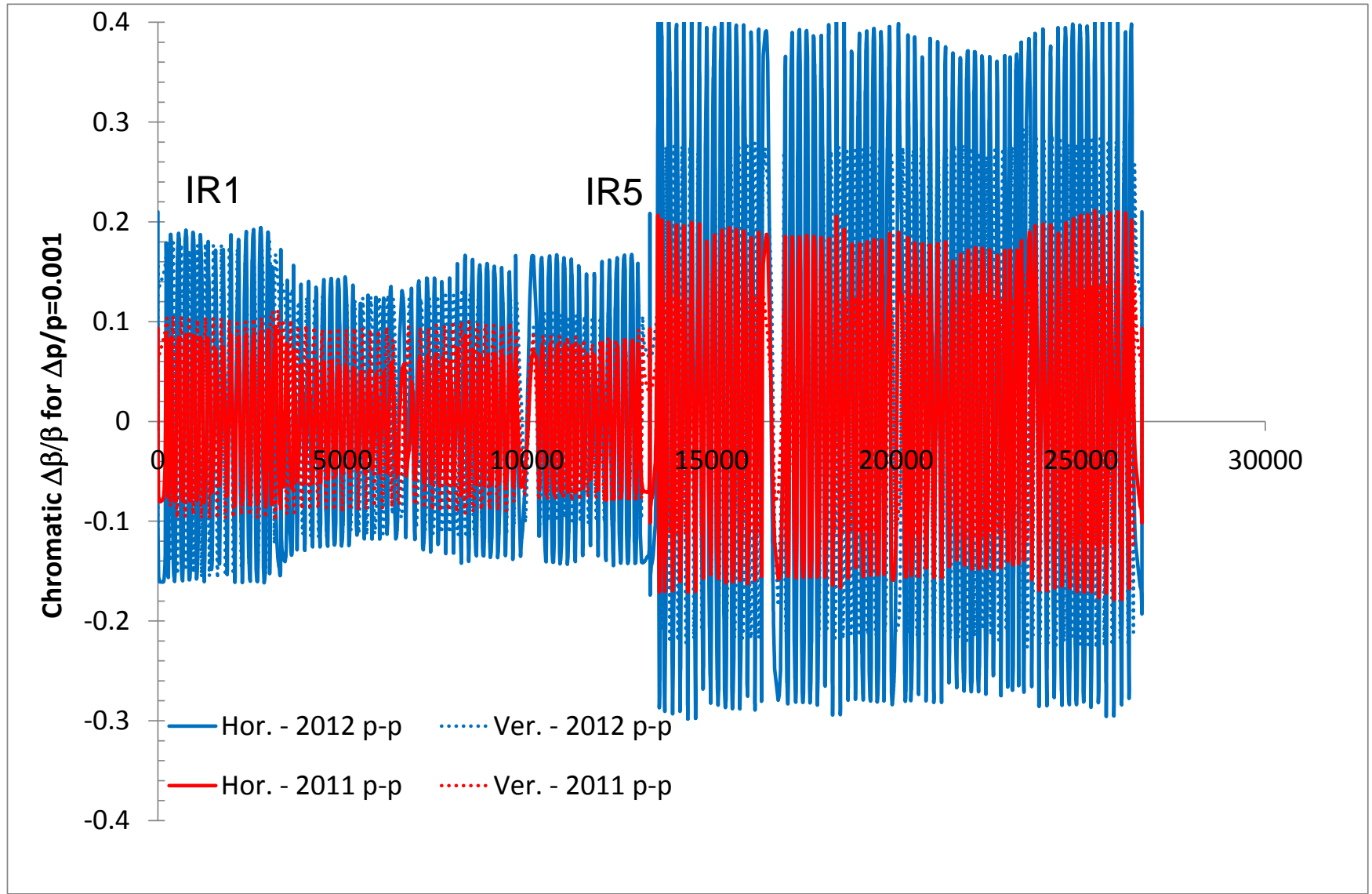


Courtesy E. MacLean, R. Tomás

- Octupoles (instabilities):
  - Effect on: non-linear chromaticity, DA...
- Last but not least: chromatic effects of squeezed IRs

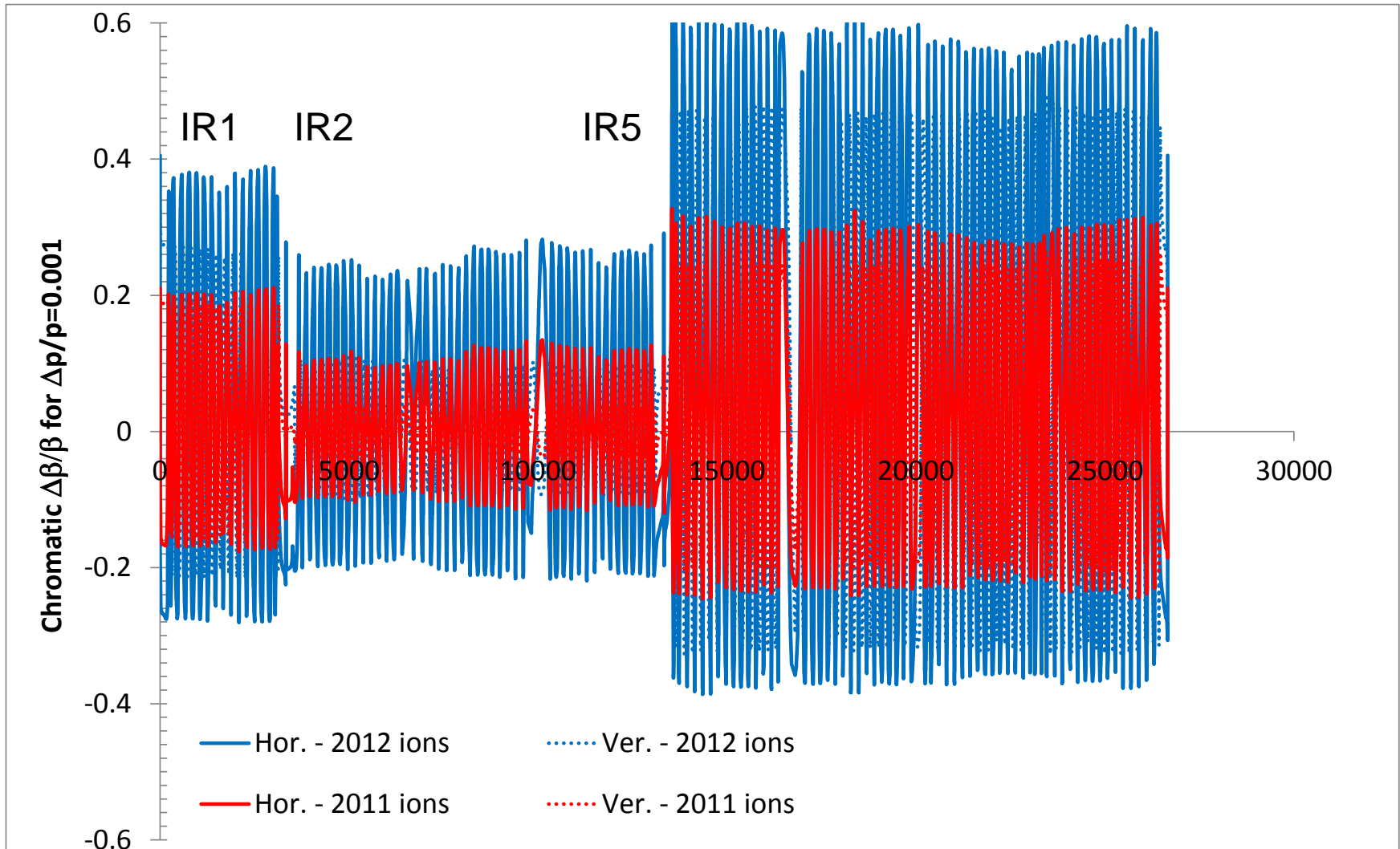
# Comments on squeeze at 4 TeV - VI

A factor of two increase in off-momentum beta-beating is to be expected in 2012 with **two IRs squeezed**: possible impact on collimation efficiency?



# Comments on squeeze at 4 TeV - VII

A factor of two increase in off-momentum beta-beating is to be expected in 2012 with **three IRs squeezed**: possible impact on collimation efficiency?





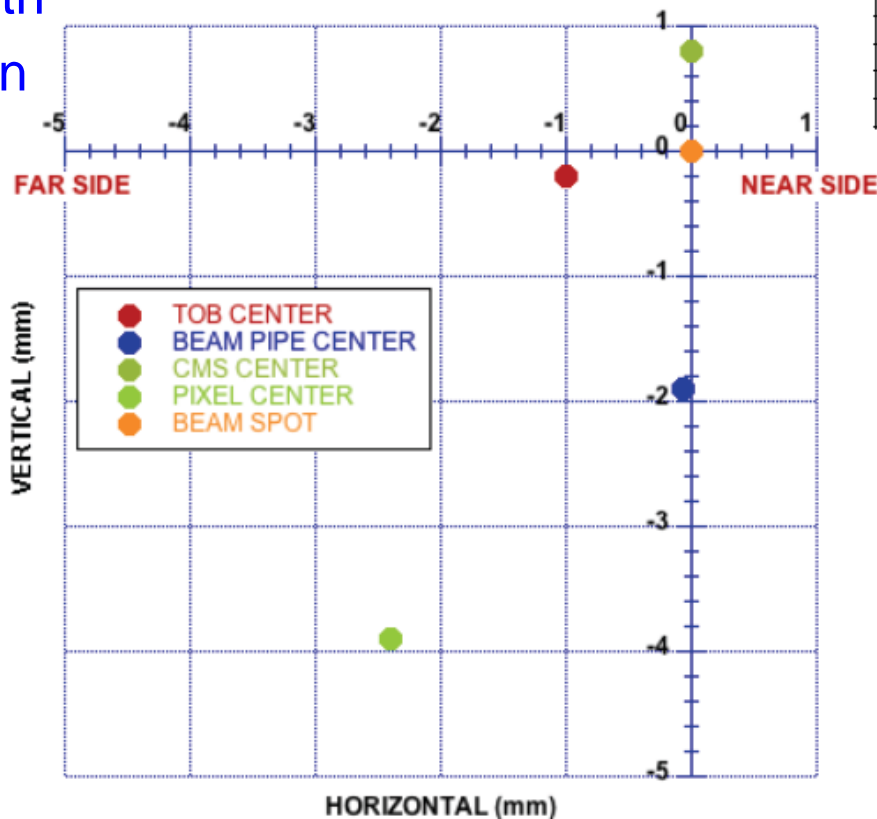
# Digression: special configuration for CMS at top energy - I

- CMS Question/request to shift the IP position in the vertical plane to compensate for the shift of the PIXEL detector.
- Item discussed at LBOC. Potential issues:

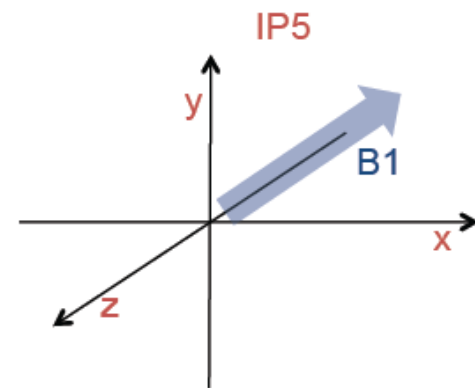
- Aperture
- Correctors' strength
- Machine protection

**No need of a horizontal IP shift.**  
**No need to compensate fully the vertical shift of PIXEL detector: IP shift of -2 mm would be acceptable.**  
**Re-alignment applied during LS1.**

POSITIONS IN THE BEAM REFERENCE SYSTEM



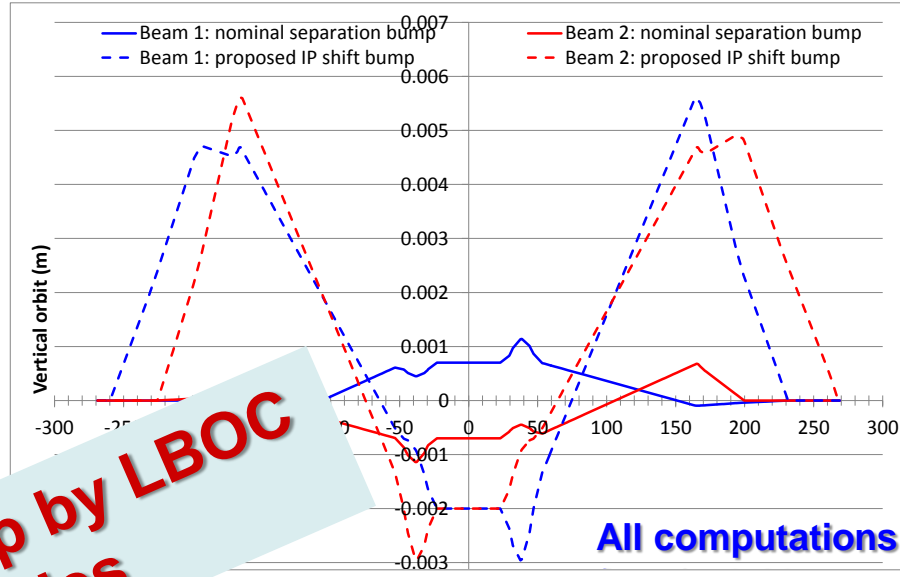
CMS coordinate system (relative to beam spot)		
	X	Y
TOB Center	-1	-0.2
Beam Pipe Center	0.07	-1.9
CMS Center	0	0.8
Pixel Center	-2.4	-3.9
Beam Spot	0	0



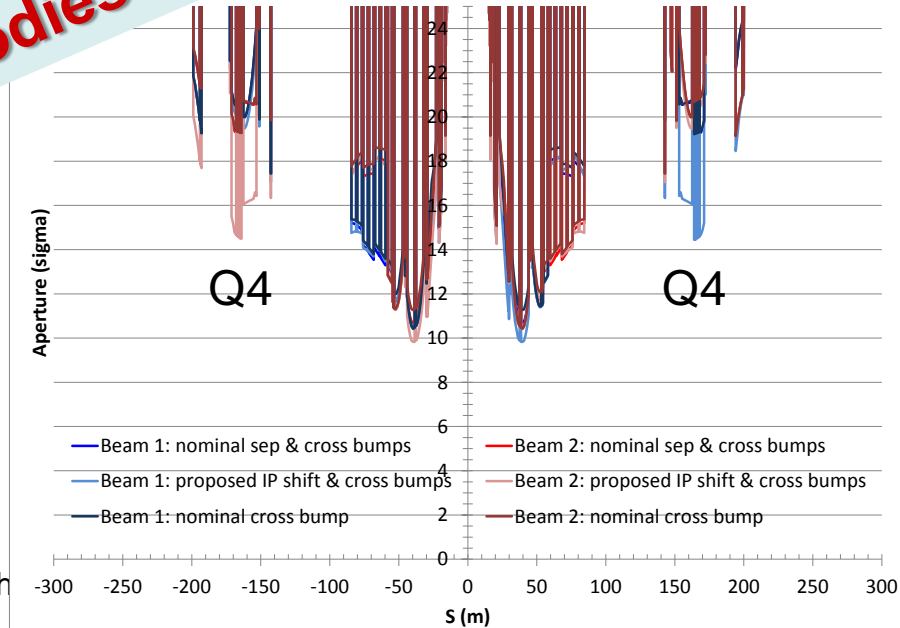
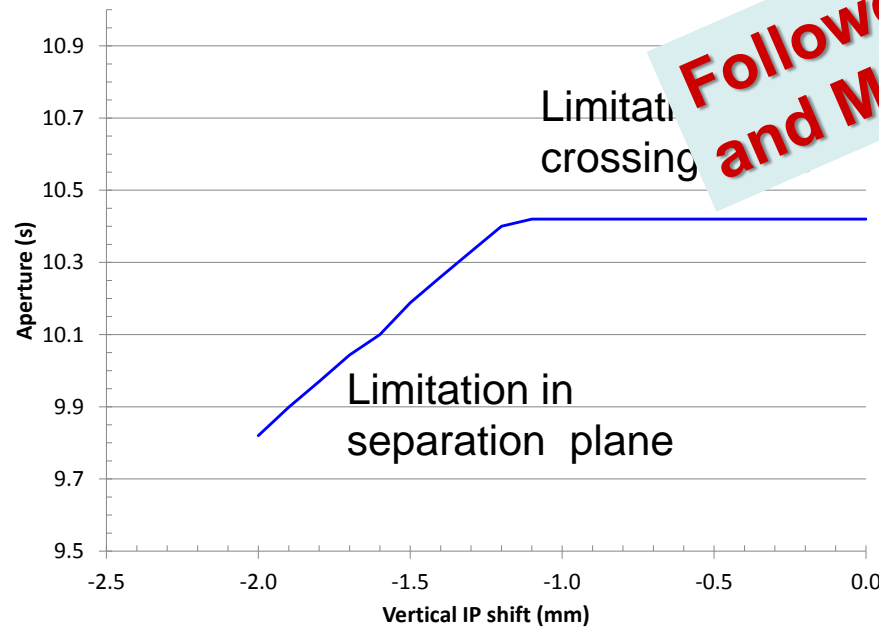


# Digression: special configuration for CMS at top energy - II

- Bump found (T. Risselada). It is fully compatible with correctors strength at 4 TeV (no more than 63% of nominal strength used for bump).
- Aperture reduction;  $10.4 \sigma$  to  $9.8 \sigma$ .
- Lumi scans should be checked, too.
- Two alternatives:
  - Review collimators' settings
  - Increase  $\beta^*$  (0.70 m would be compatible with current collimators' settings)



**Followed up by LBOC and MP bodies**



# Digression: special configuration for LHCb at top energy - I

- The issue: interaction of spectrometer angle and external crossing angle with ring geometry (see, e.g., W. Herr et al. LHC-PN-419).
- The net crossing angle is different for the two polarities of the spectrometer.
- The solution would be to introduce a vertical external crossing angle (see W. Herr, Y. Papaphilippou LHC-PR-1009).
- At injection, aperture is tight (beam-screen orientation is optimised for H-crossing).
- At top energy, there would be enough aperture to apply this approach.
- So far, no aperture measurement in IR8 at top energy has been performed: this should be a mandatory step for implementing this new scheme.

# Digression: special configuration for LHCb at top energy - II

- The required vertical crossing angle is  $100 \mu\text{rad}$  (for both 25 ns and 50 ns options).
- From the operational point of view:
  - Use the standard procedure until flat top (vertical separation, horizontal crossing during injection and ramp)
  - At flat top: apply in addition the following:
    - Reduce the horizontal separation to zero
    - Reduce the dipole bump to adjust the luminosity
  - Leveling and beam separation must be established in a plane that is orthogonal to the plane of beam crossing.
  - A combination of horizontal and vertical bumps will be required.

**Followed up by LBOC and MP bodies**

# High-beta optics - I

- Different regime with respect to the standard squeeze optics.

- Challenges:

- Optics:

- Aperture
- Tune compensation
  - Using QF/QD
  - Using QTF/QTD
  - Re-matching other IRs

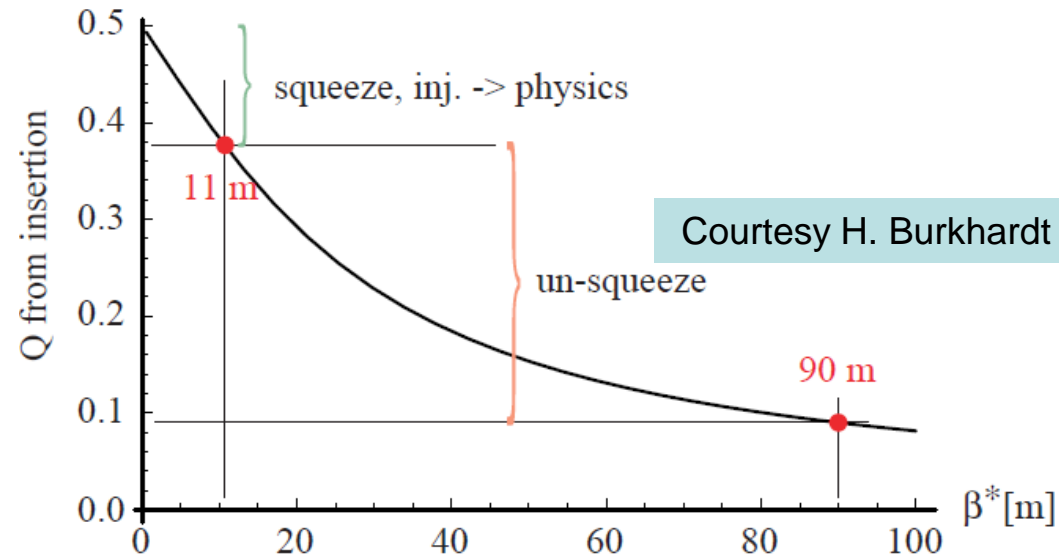
- Separation

- Only parallel separation possible

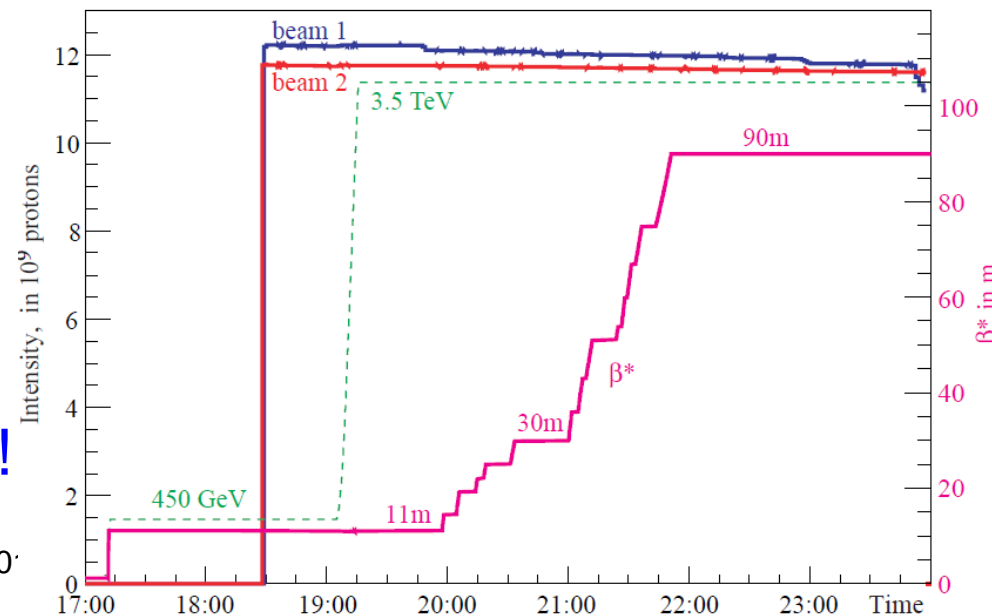
- Hardware:

- Special use of MQX
- Strong powering imbalance of IR quadrupoles: **request for additional cables issued.**

- **90 m is first (successful) step!**



H. Burkhardt et al. ATS-Note-2011-032 MD



# High-beta optics - II

- Activities in 2012:
  - Physics:
    - A  $\beta^*$  of 400-500 m seems feasible and unsqueeze sequence is in preparation.
    - The parallel half separation is 2 mm (corresponding to  $4\sigma$  at 500 m  $\beta^*$ ).
    - 90 m  $\beta^*$  will be the basis of the unsqueeze.
    - Typical beam parameters: bunches of  $3 \times 10^{10}$  p with  $\varepsilon_n \approx 2 \mu\text{m}$ .
  - MDs (in preparation for LS1 and after):
    - Maximum  $\beta^*$  without extra cables
    - Scraping to  $\sim 1 \mu\text{m}$  normalized emittance at top energy
    - Injection at 90 m optics in IP1&5 -- to speed up operation with high- $\beta^*$
    - Squeeze with colliding beams
    - Longitudinal separation using RF
    - Test Q4 inversion, with injection at 200 m

# Summary

- Several options for optics configurations are available for the 2012 proton run.
- Some unknowns:
  - Machine behaviour with pushed configuration (tight collimator settings and small  $\beta^*$ ).
  - Beam behaviour with strong octupoles.
  - Off-momentum beta-beating with squeezed insertions.
- Two options should be considered for CMS and LHCb configuration at top energy.
- High-beta optics can be pushed up to 500 m in 2012.
- A wide range of topics for studies in preparation for LS1 activities and physics beyond should be addressed in 2012.