Sector Test - General objectives

- Commission TI 8 end, injection and thread to IR7
- Commission trajectory acquisition and correction
- Commission Beam Loss Monitor system
- Optics measurements
- Aperture checks
- Effect of magnetic cycle
- Field quality checks
- Quench limits and BLM response
- Setting up of injection machine protection

Unashamed rip-off of Brennan Goddard's Chamonix talk follows

Proposed beam test breakdown

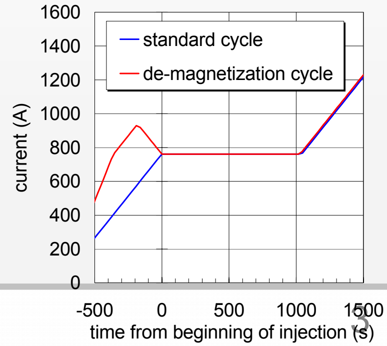
work in progress

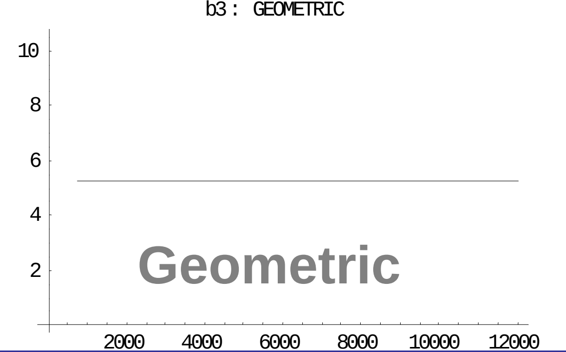
		Priority	Duration	Intensity	# shots	∫ Intensity	Cycle	Comments
			h	p+		p+		
1	End TI8, Injection Steering, commission BDI, timing	1	24	5E+09	500	2.5E+12	de-Gauss	TDI in, protecting LHCb
2	Trajectory acquisition commissioning, trajectory correction, threading, energy	1	24	5E+09	500	2.5E+12	de-Gauss	To IR7 beam dump
3	Linear Optics from kick/trajectory, coupling, BPM polarity checks,	1	12	1E+10	400	4.0E+12	de-Gauss	
4	Check BLM system	1	6	5E+09	100	5.0E+11	de-Gauss	First to TDI, then to IR7 dump
5	Aperture limits, acceptance	1	18	5E+09	1000	5.0E+12	de-Gauss	Oscillations, π bumps, BLMs, BCT
6	Momentum aperture	1?	6	5E+09	100	5.0E+11	de-Gauss	Move energy of SPS beam
7	Commission multi-bunch injection ?	1?	6	6E+10	50	3.0E+12	de-Gauss	BDI acquisition, MKI
8	Determination of quench level - calibrate BLMs	1	36	1E+11	20	2.0E+12	de-Gauss	Start with pilot and work slowly up
9	Commission normal cycle - recheck dispersion, optics, aperture	1	24	5E+09	300	1.5E+12	Nominal	Cycle & wait
10	Effects of magnetic cycle, variations during decay, reproducibility	1	24	1E+10	300	3.0E+12	Nominal	10 cycles
11	Energy offset versus time on FB	2?	12	2E+10	100	2.0E+12	Nominal	Cycle & repeat
12	Field errors (high statistics)	2	12	2E+10	200	4.0E+12	Nominal	Collect data, off-line analysis
13	Transfer line collimation studies - TCDI	2	6	5E+09	800	4.0E+12	Nominal	TDI in - mainly on to TCDI
14	Injection protection studies - TDI	3	6	5E+09	800	4.0E+12	Nominal	On to TDI and IR7 dump
15	IR bumps, aperture, separation, crossing angle bumps [LHCb?]	3	6	5E+09	100	5.0E+11	Nomianl	Careful in LHCb
	TOTAL		222		5270	2.9E+13		On to TED
	DAYS		9.3			6.5E+12		On to TDI
						4.0E+12		On to TCDI

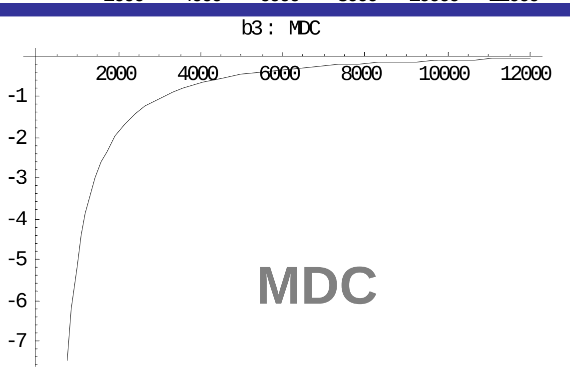
This is not (yet) a test schedule!

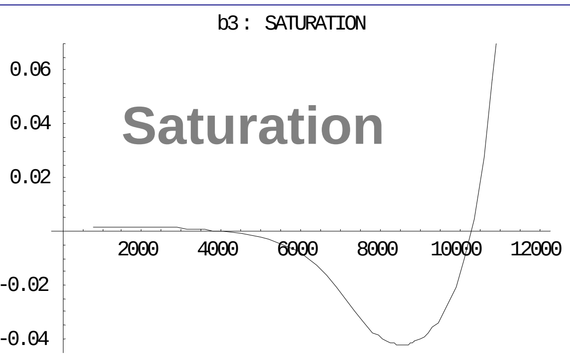
De-Gauss versus Nominal

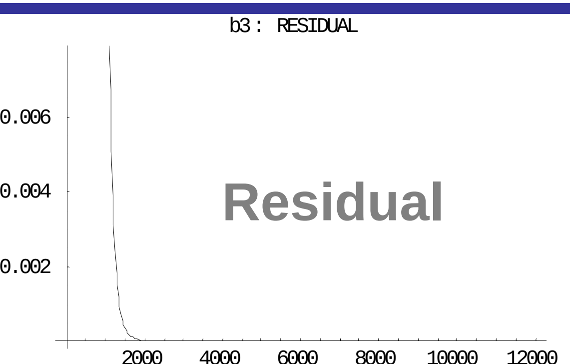
- **De-Gauss**
  - zeros persistent current effects - all multipoles
  - leaving static error component (geometric, beam screen)
  - absolutely stable in time
  - field errors do not depend on the powering history of the magnets
  - allow us to test cleanly the FiDeL predictions of the geometric errors independent of persistent current effects
  - save the 20 minutes wait
  - Switching from a properly corrected De-Gauss cycle to Nominal plus wait would gives us a handle on the b3 persistent etc.

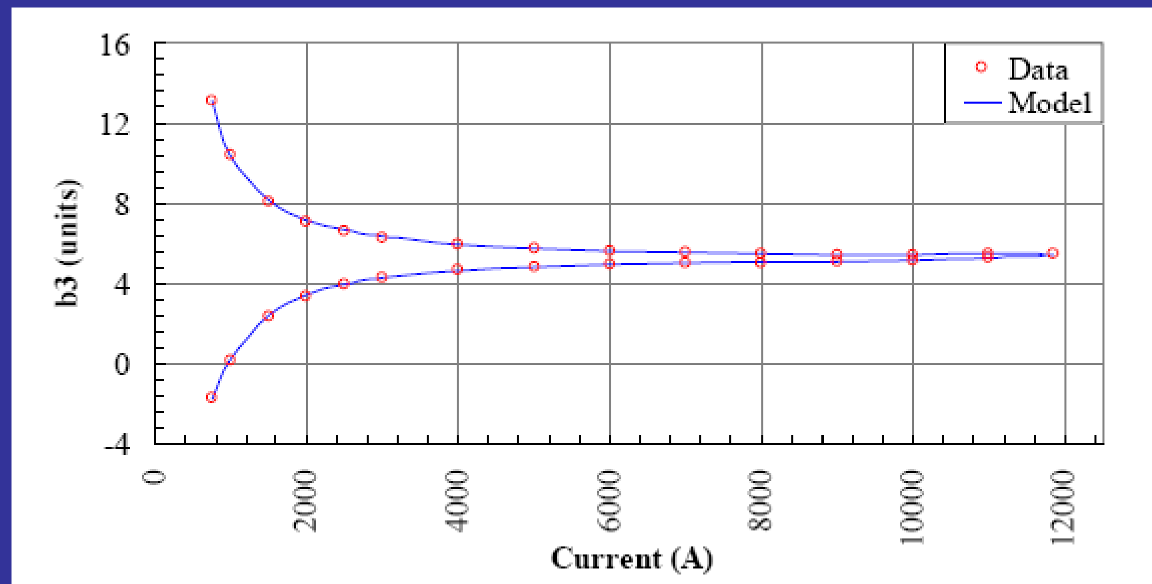



b3 : GEOMETRIC
Geometric
10
8
6
4
2
2000
4000
6000
8000
10000
12000


b3 : MDC
MDC
-1
-2
-3
-4
-5
-6
-7
2000
4000
6000
8000
10000
12000


b3 : SATURATION
Saturation
0.06
0.04
0.02
-0.02
-0.04
2000
4000
6000
8000
10000
12000


b3 : RESIDUAL
Residual
0.006
0.004
0.002
2000
4000
6000
8000
10000
12000


Data
Model
b3 (units)
16
12
8
4
0
-4
0
2000
4000
6000
8000
10000
12000
Current (A)

De-Gauss versus Nominal

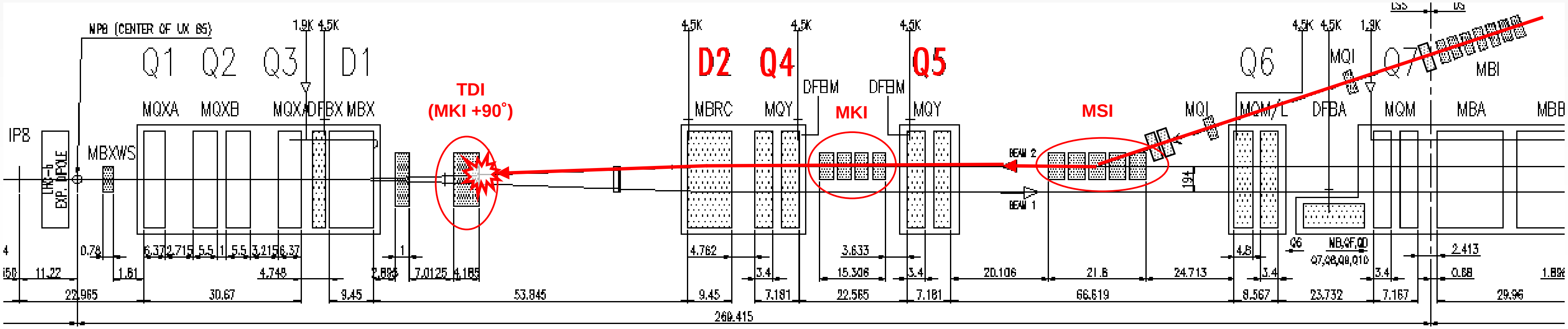
However

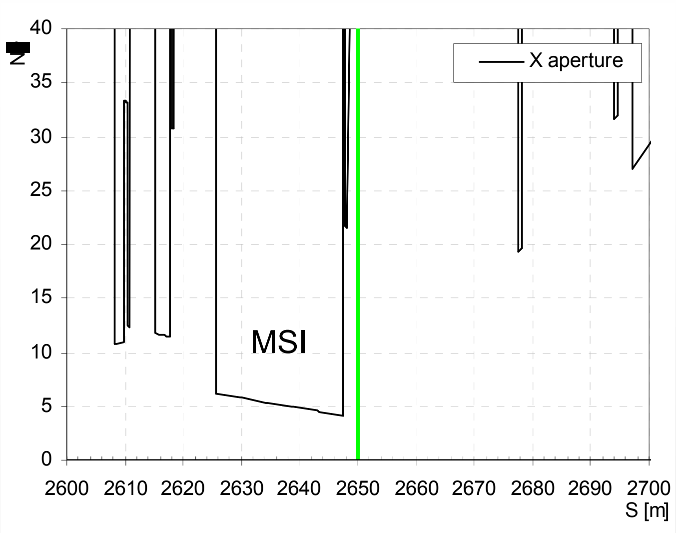
- Measure on the nominal cycle
- Would have to redo, in particular b1 (but persistent not large ≈ 1 unit), on switching from de-Gauss to Nominal

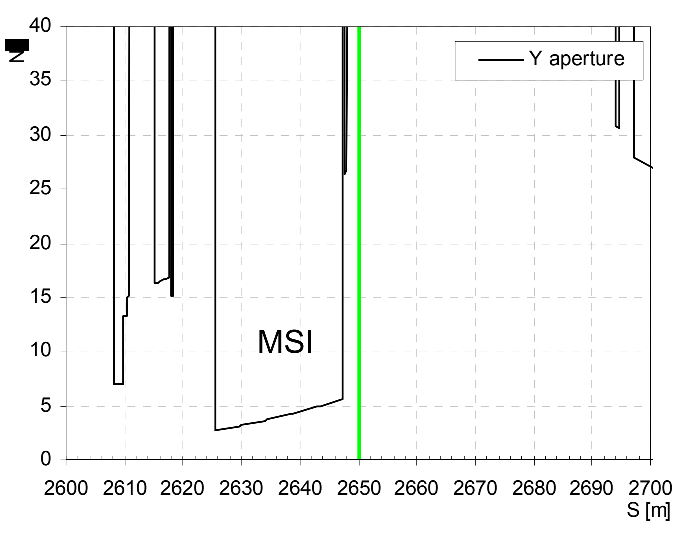
	b3 nominal	b3 de-Gauss
geometric	+5.2	+5.2
persistent	-7.5	-
decay	+1.7	-
total	-0.6	+5.2

End of TI8/injection commissioning

Right of IP8 (H plane)







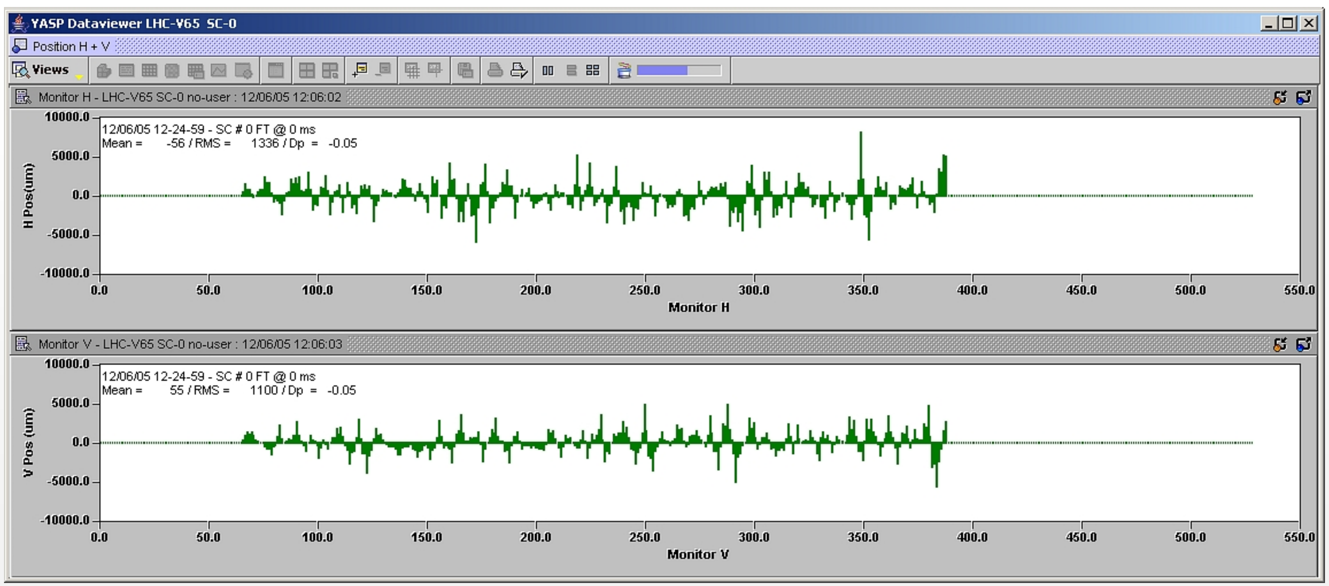
End of TI 8/injection commissioning

- **24 hours foreseen**
- **Dedicated/expert application software**
  - Injection steering, injection post-mortem, TDI positioning, injection fixed displays, equipment expert applications
- **Remaining issues/areas for study**
  - Tight aperture at MSI septum - local correction strategy?
  - Synchronised shot-by-shot logging for each injection (<u>not</u> “Post-Mortem”)
  - Controls across TI 8/LHC interface?

Team BT: Brennan, Jan plus Verena, Mike, Jorg, Helmut

Threading to IR7 dump

- **‘LEP strategy’**
  - Inject & measure; correct over small range (manual BPM rejection); iterate
  - Watch out for the separation/recombination dipoles (transfer functions…)
- **Method checked by coupling MAD-X to YASP steering program, with aperture filter, noise etc. (LHC beam 1)**
  - Results promising (in absence of big problems, eg quad polarity reversals)
    - 13 iterations for <u>full</u> first-turn. Expect 1-4 iterations to IR7 TED?
    - Fairly insensitive to errors, e.g. <u>isolated</u> bad BPMs with >10mm offset



BPMs : ± 3 mm errors, flat distribution
Dipoles : b3 = -20 units (systematic),
other components : error table
Multipole correctors : OFF

J.Wenninger

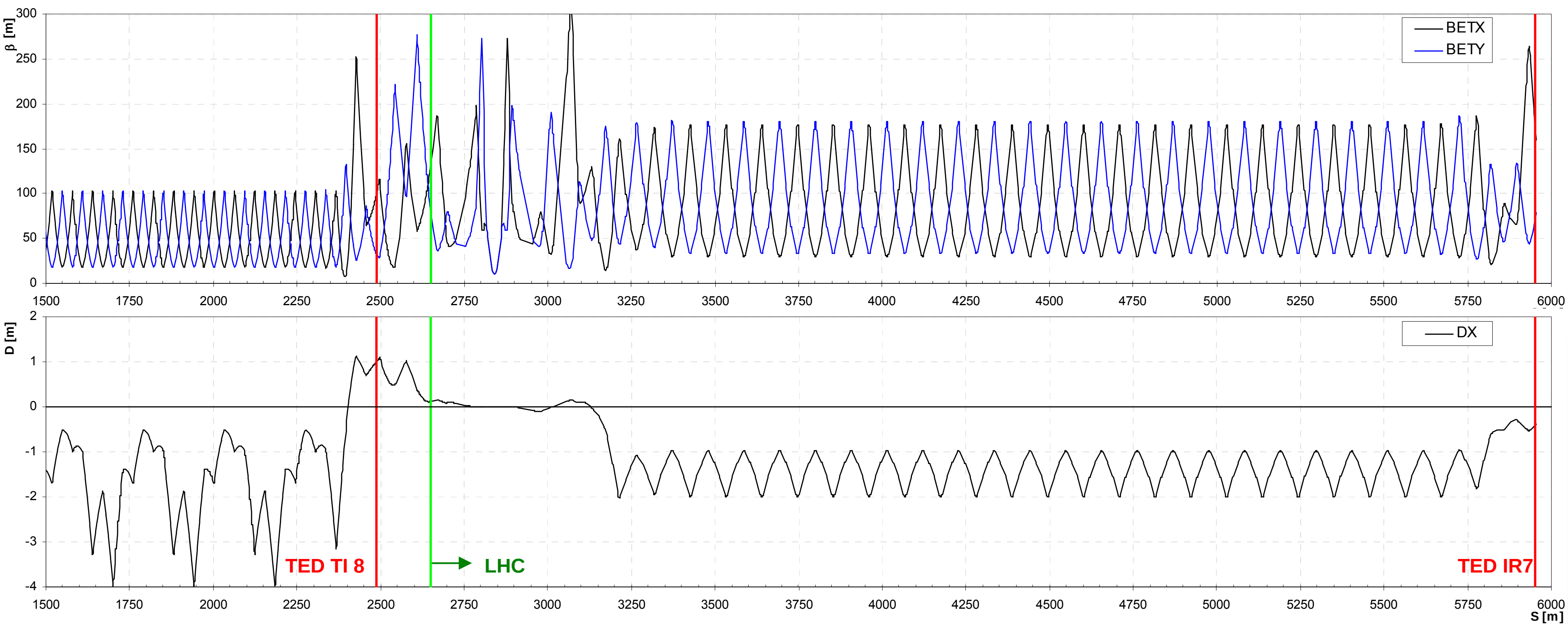
Threading to IR7 dump

- **Dedicated/expert application software**
  - YASP, BPM intensity acquisition and signal display
- **Other stuff**
  - TI 8 + LHC beam 2 MAD-X sequence with full aperture model
- **Remaining issues/areas for study**
  - Extend threading from TI 8 TED87765
  - Extend threading simulations to check sensitivity to:
    - Injection errors, quadrupole polarity errors, …
    - More subtle errors : BPM signs, H/V crossover, calibrations+ energy offsets, mega-offsets, noise, …
  - Still foresee to test an automatic threader? Does not seem justified….

Jorg – YASP etc,   Aperture model - Verena, Stefano, BDI

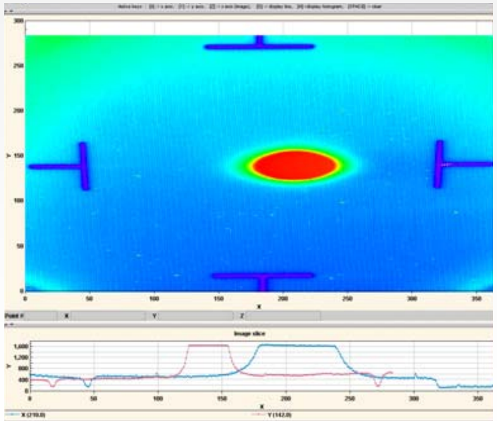
Linear optics tests

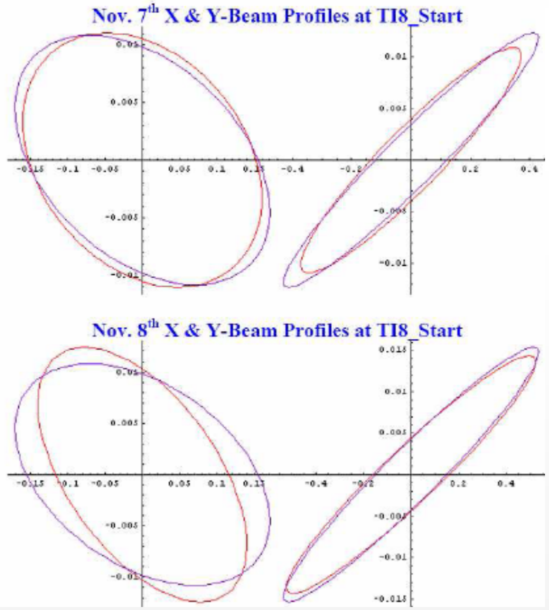
- **Trajectory response using correctors and BPMs**
  - BPM + corrector polarity and calibration errors
  - Phase, coupling, Twiss
- **Dispersion measurement with δp and BPMs**
- **Betatron matching measurement with BTVs**



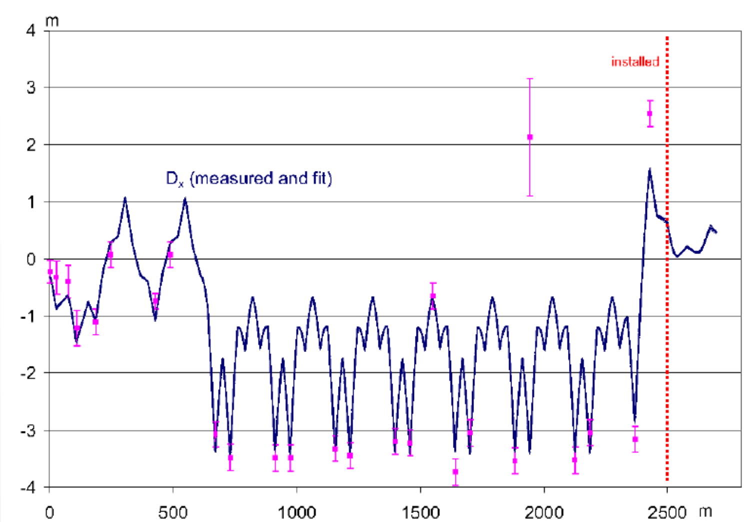
Linear optics tests

- **Many tools already used in 2004 for TI 8**
  - Found error (20%) in 2 matching quads (DB function)
  - Measured 1% V phase shift (QD strength?)
  - Measured coupling of 2-3%
  - Measured betatron mismatch factor λ of ~1.1
  - Measured dispersion function to ±0.2 m



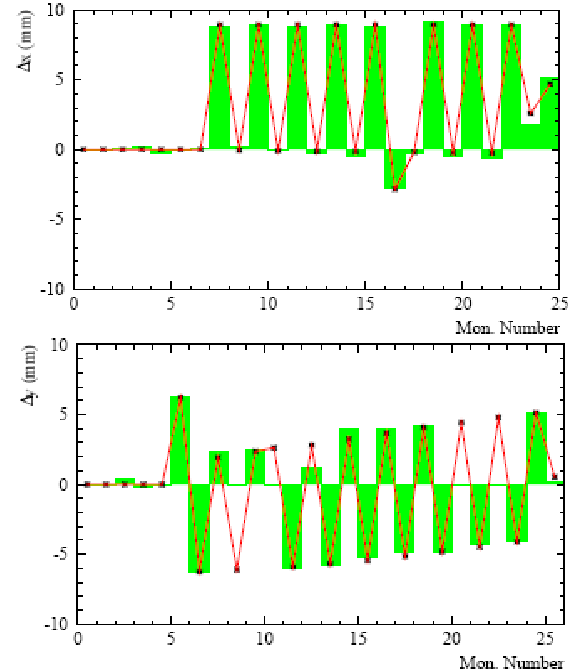


TI 8 β mismatch measurements



TI 8 dispersion measurement

J.Wenninger, LHC Project Note 314
J.Wenninger et al., LHC Project Report 827



TI 8 trajectory response, with effect of QD strength apparent in V phase

Linear optics tests

- **12 hours foreseen early on**
  - 1-2 x 10^{10} p+ for improved BPM and BTV response
  - Semi-automated tests….lots of off-line data analysis to make quickly

Dedicated/expert application software

  - Automatic kick-response measurement and correlation with logging,
  - BTV image processing, online re-matching and analysis tools?
- **Remaining issues/areas for study**
  - Expected measurement accuracies, tools for analysis & re-matching
  - TI 8 beam time in Oct/Nov 2006 for further tests of tools

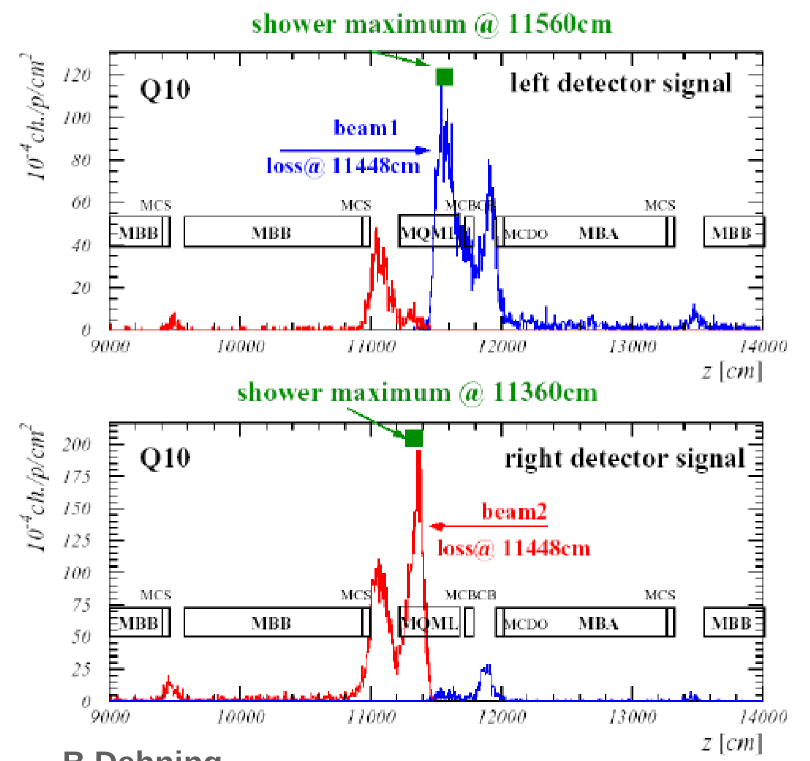
Jorg - LOCO,

Mike, Chao – Screens,

Delphine/Gianluigi - Dispersion

BLM system tests

- **Get the system up and running, recording losses**
  - Prior calibration with source: expect reasonable numbers quickly (factor ~5)
  - Acquisition (& display!) of beam losses for some (many? all?) monitors
  - Some crosstalk studies possible (in principle ‘beam 1’ monitors available…)



B.Dehning

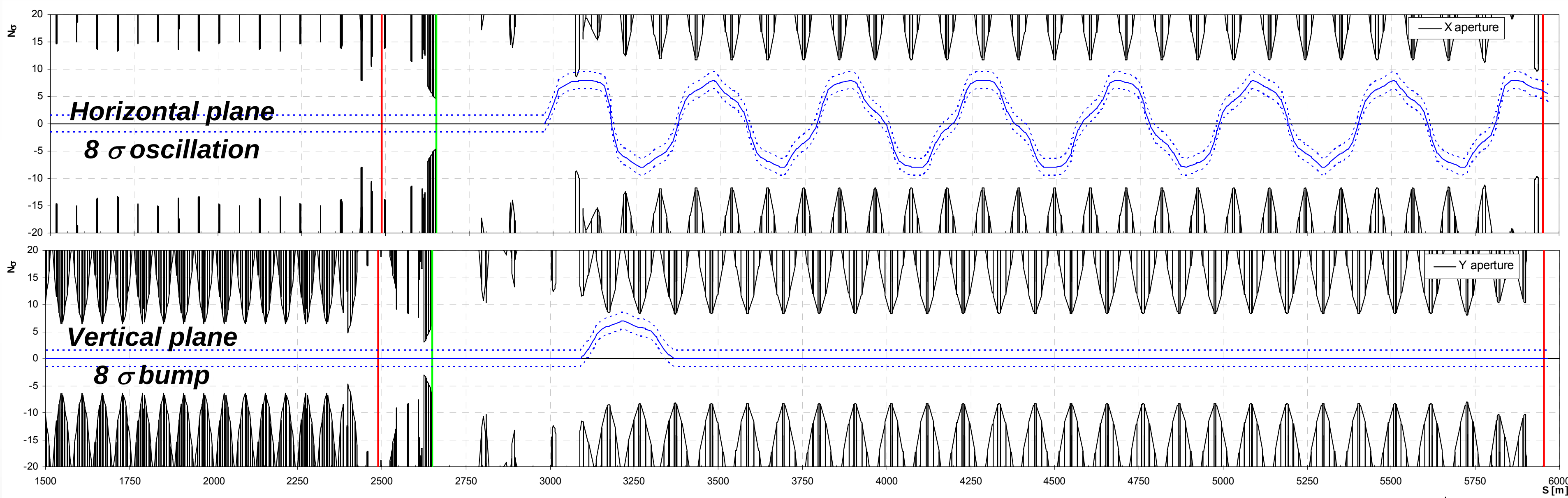
BLM system tests

- **6 hours beam time foreseen early on**
  - Will be plenty of other opportunity for parasitic commissioning
  - Probably to be organised together with the aperture measurements
- **Dedicated/expert application software**
  - BLM displays, MCS?, BLM expert applications
- **Remaining issues/areas for study**
  - Finalise data exchange with control system (logging, PM, thresholds)
  - BLM display (prototype for final LHC version?)
  - Triggering for single-shot logging? Do we need it???
  - Post Mortem to be tested?

Team BLM: Bernd and company

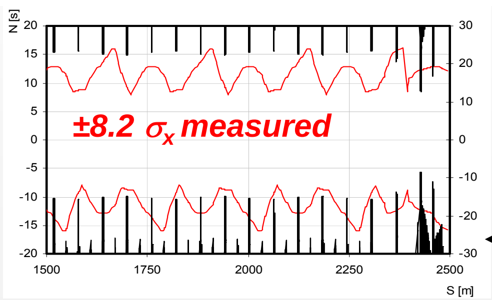
Aperture measurement

- **Verify physical aperture as expected (bottlenecks, arc, IP8)**
  – First iteration : oscillation from 2 correctors at 90º to probe ‘all’ phases
  – Second iteration if needed/time : π bumps (local anomalies, specific regions)



Expected aperture

$$N_\sigma = \frac{\left(A_{1/2} - \delta_{mech} - \delta_{align} - E_{\max}(\beta/\beta_{\max})^{1/2}\right)/k_\beta - D\delta_p/p}{\sqrt{\beta\varepsilon_{nom}}}$$

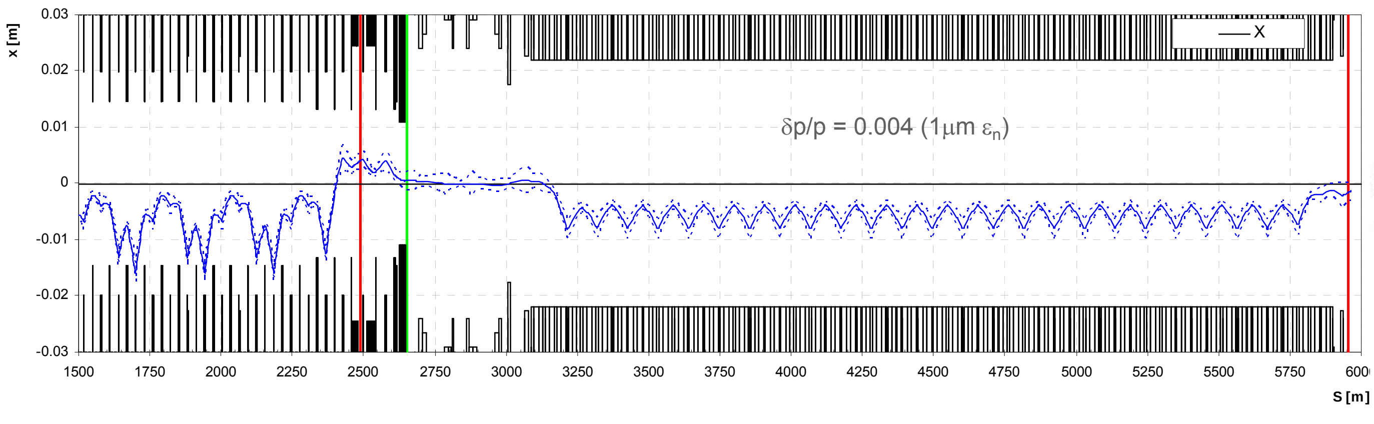


Measured results for TI 8 to TED87765 (horizontal plane)

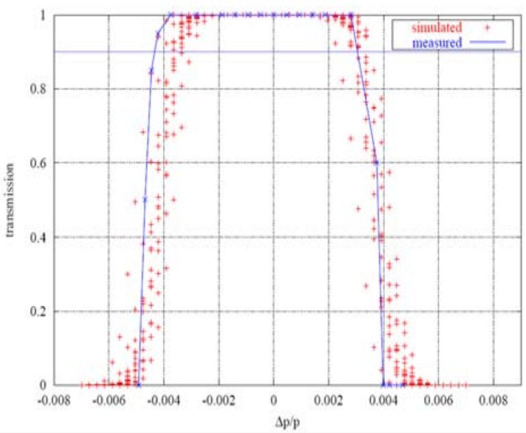
Need corrector strengths of about 50 μrad

Aperture measurement

- **Momentum aperture**
  - Transmission vs momentum offset by changing SPS RF frequency
  - Probably limited by TI 8 arc (max $|D_x| \approx 4$ m, c.f. 2 m in LHC) so maybe not worthwhile as explicit measurement…
  - Could rematch TI 8 to another momentum (present measured acceptance ±0.003)



Momentum acceptance of TI 8



V.Kain

Aperture measurements

- **24 hours beam time foreseen mid-way through**
  - Major problems will already have been discovered…
  - Keep clear of LHC-b
  - 1 μm ε_n for best resolution
- **Dedicated/expert application software**
  - Need automatic “scan ‘n’ measure” applications:
    - Free oscillations (~5 amplitudes, ~12 phases, 2 planes, ~2 starting locations)
    - For sliding bumps (~45 correctors, 2 planes, ~5 amplitudes)
- **Remaining issues/areas for study**
  - Best way to measure LHC momentum aperture

Brennan, Verena, JB Jeanneret

Quench limits and BLM response

- **Magnet exposure to beam and BLM response**
  - Golden opportunity to steer beam into magnets….
- **Foresee 36 hours**
  - Intensity $\leq 1\times10^{11}$ p+ (5% of damage level at nominal ε_n)
  - Higher intensity would require multi-bunch injection to be commissioned

Alex, Helmut, BLM team, Collimation team

Commission nominal cycle

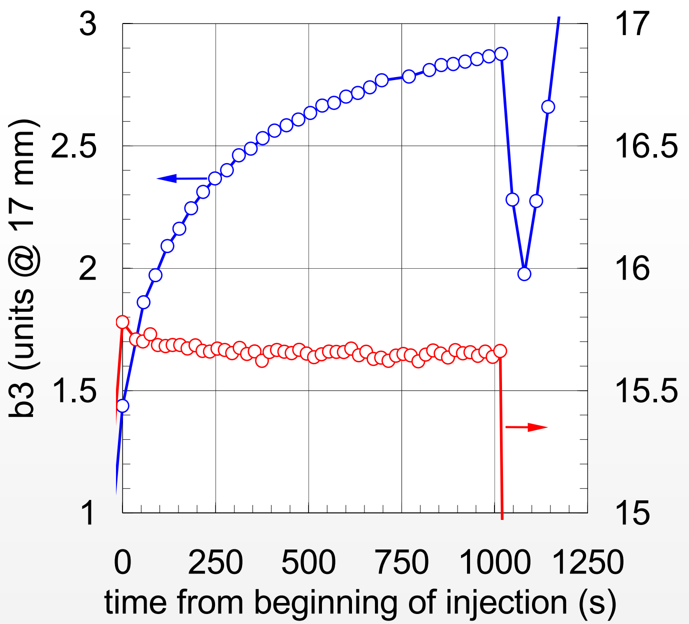
- **Switch to ‘nominal’ cycle (max MB current 30%?)**
  - Get the nominal cycle on the machine
  - Effects on b1 (few units) and b3 (7 units) with respect to de-Gauss
- **Get into reasonable shape**
  - Repeat subset of injection, trajectory & linear optics checks: persistent current effects to wrestle with
- **Foresee 24 hours**
  - Start by waiting ~20 minutes for full decay of persistent currents

OP & FiDeL

Effects of magnetic cycle

- **Machine reproducibility and persistent current effects at injection for 'nominal' cycle**
  - Quantify effects with respect to de-Gauss cycle
  - b3 decay – expect 2 units for nominal cycle
    - With trajectory response, expect to be able to resolve ~0.5 - 1 units of b1, ~1 unit of b3
    - Better resolution for b3 by measuring $\delta\mu$ with large ($\pm$0.002) δp?
    - Decay effects close to limit of measurement resolution
  - Cycling to ~30% (Luca's talk) should not affect magnitude of persistent current effects, but decay will be proportionately lower
  - Important check of magnetic model with beam

- **Foresee 24 hours**
  - Many interesting measurements possible… …needs to be a realistic program
  - Not many machine cycles
  - May need 1-3$\times 10^{10}$ p+ for BPM resolution?
  - Reference measurements needed on de-Gauss cycle – which?



Stephane, Frank, FiDeL, ABP, OP

Effects of magnetic cycle

- **Energy offset vs time on FB**
  - Measurement of effect of b1 decay on trajectory for ‘nominal’ cycle
  - Difference measurements at few minute intervals
  - Expect b1 decay by 1.5 - 2 units for nominal cycle (~0.7 units if we only go to 30%) – at the limit of expected resolution (0.5 – 1 unit)
- **Foresee 12 hours**
  - Need 3×10^{10} p+ for 50 μm BPM resolution

error	Systematic	Random	Decay	
			syst.	*rand*
b1	0.0	±8.0	0.8	±0.7
a1	0.0	±8.0	0.0	±0.0
b2	-1.1	±0.6	0.0	±0.1
a2	-0.4	±1.2	0.0	±0.2
b3	-3.7	±1.4	1.7	±0.4

de-Gauss

Nominal - waiting

Nominal

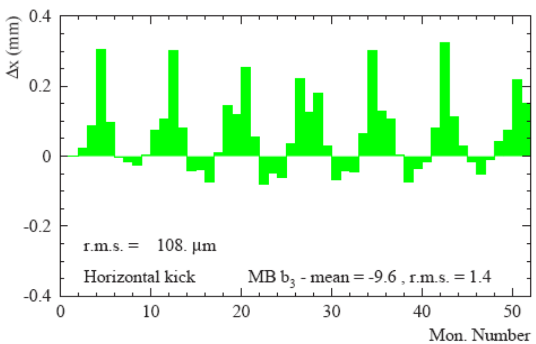
Stephane, Frank, FiDeL, ABP, OP

Values from error table 0510 – sector 7-8 somewhat different

Detailed field errors – high statistics

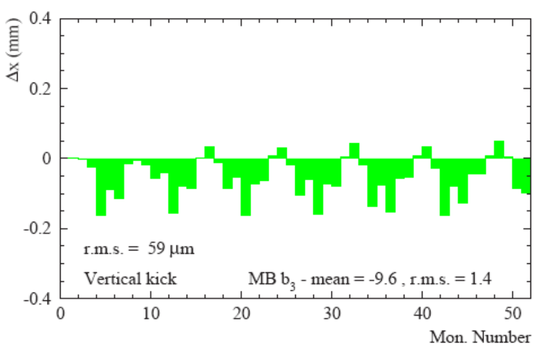
Kick-response and trajectory analysis

- LOCO - average a2, b2 and b3 field errors of MBs, b2 of MQs
  - Need BPM noise & injection errors <200 μm (or ~0.2 σ)
  - Extend method to check multipole corrector polarities (by strong excitation)?
- **Presently foresee 12 hours**



Field errors: Magnet	Field errors: Component f	$f^{fit} - f^{mod}$ in standard units: average	$f^{fit} - f^{mod}$ in standard units: r.m.s.	BPM noise (μm)	Calibration errors (%): BPMs	Calibration errors (%): Corr.	$\|\vec{V}\|^2$
MB	b_2	$+0.00 \pm 0.01$	0.06 ± 0.01	100	4	0.2	~ 5500
MB	a_2	-0.02 ± 0.02	0.08 ± 0.01				
MB	b_3	$+0.01 \pm 0.22$	1.00 ± 0.15				
MQ	b_2	-0.68 ± 0.38	1.72 ± 0.27				

Jorg, Frank



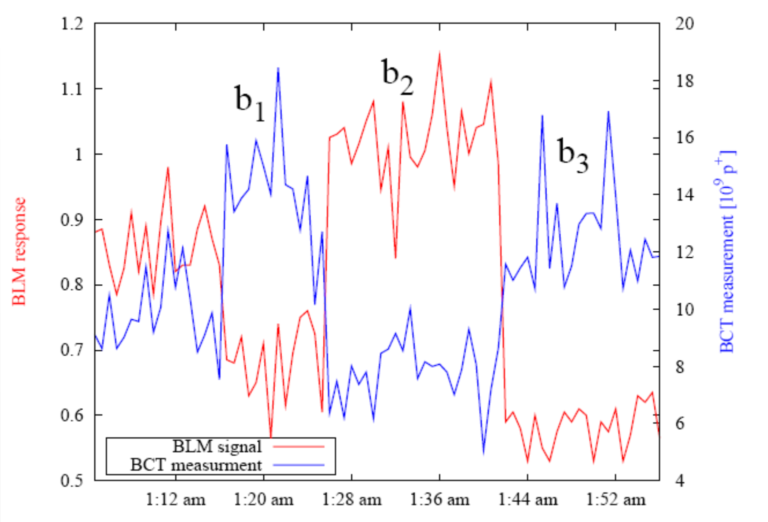
MB b3 field error effect (mean -9.6 units, rms 1.4 units). H trajectory change for 40 μrad H kick (top) and 40 μrad V kick (bottom)

Injection protection studies

- **Passive protection systems setting-up tests**
  - Beam-based alignment of TCDI and TDI jaws with single pass
    - First measurements : TI 8 in 2004 already – results promising
    - Possible interest for other LHC collimators
- **Foresee 12 hours total**
  - Keep 5×10^9 p+ to limit losses (few shots at 3×10^{10} p+ to measure beam axis)

Verena, Helmut, Collimation team

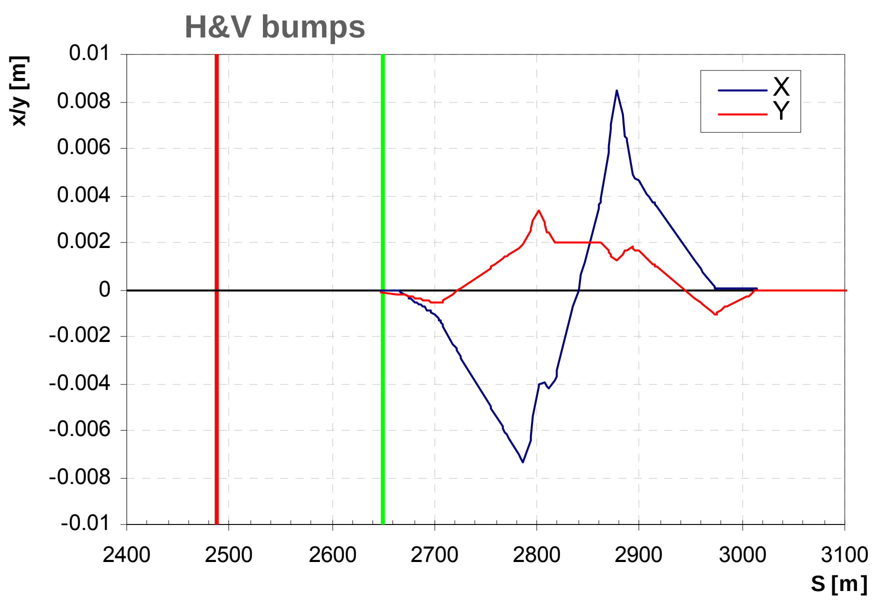
Needs working collimator controls (HW and SW)

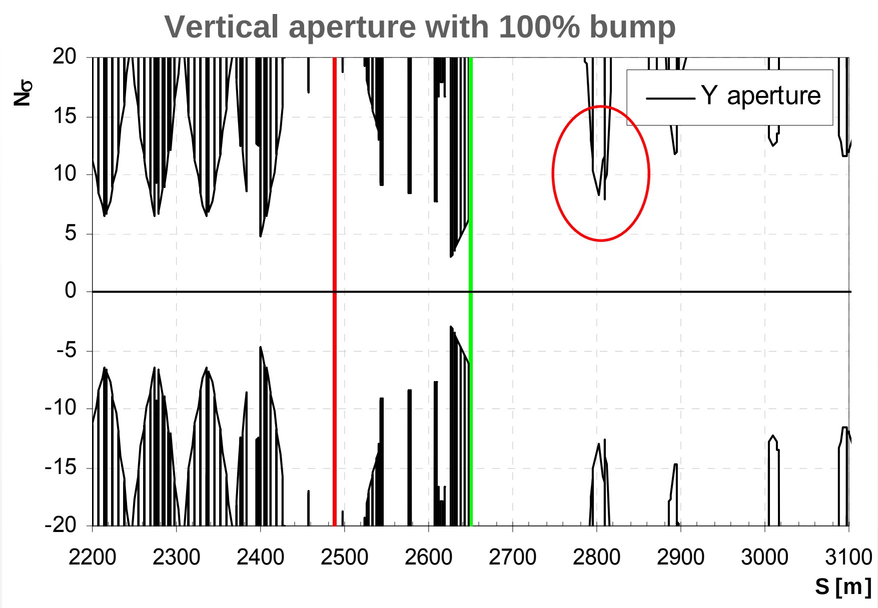


Commission separation & crossing bumps

- **LHC-b spectrometer + compensation off**
- **Plenty to test**
  - Injecting onto vertical separation bump (-0.2 mm, -3.5 μrad)
    - Bump amplitude limited to well below nominal (keep LHC-b pristine)
  - Bump closure, induced dispersion, aperture (?)
  - Injecting onto opposite polarity bump?
- **Foresee 6 hours**

Werner, OP





Map – as it stands

	Commissioners	Team
Injection	BG, JU	BT
Threading	JW, VK, SR	OP
Linear optics	JW, GA, ML	
BLMs	BD	BLM
Aperture	BG, VK, JBJ	
Momentum acceptance	BG, VK	
Multi-bunch injection		OP
Quench levels	AK, HB	BLM
Switch to Nominal	ML	OP, FIDEL
Effects of magnet cycle	SF, FZ, ML	OP, FIDEL
Field errors	JW, FZ	OP,AP
Transfer line collimators	HB, VK	Collimation
Injection protection	HB, VK	BT, Collimation
IR bumps	WH	OP, AP