LHC Commissioning Working Group

450 GeV Optics: IR aperture and IR Bumps

W. Herr and Y. Papaphilippou

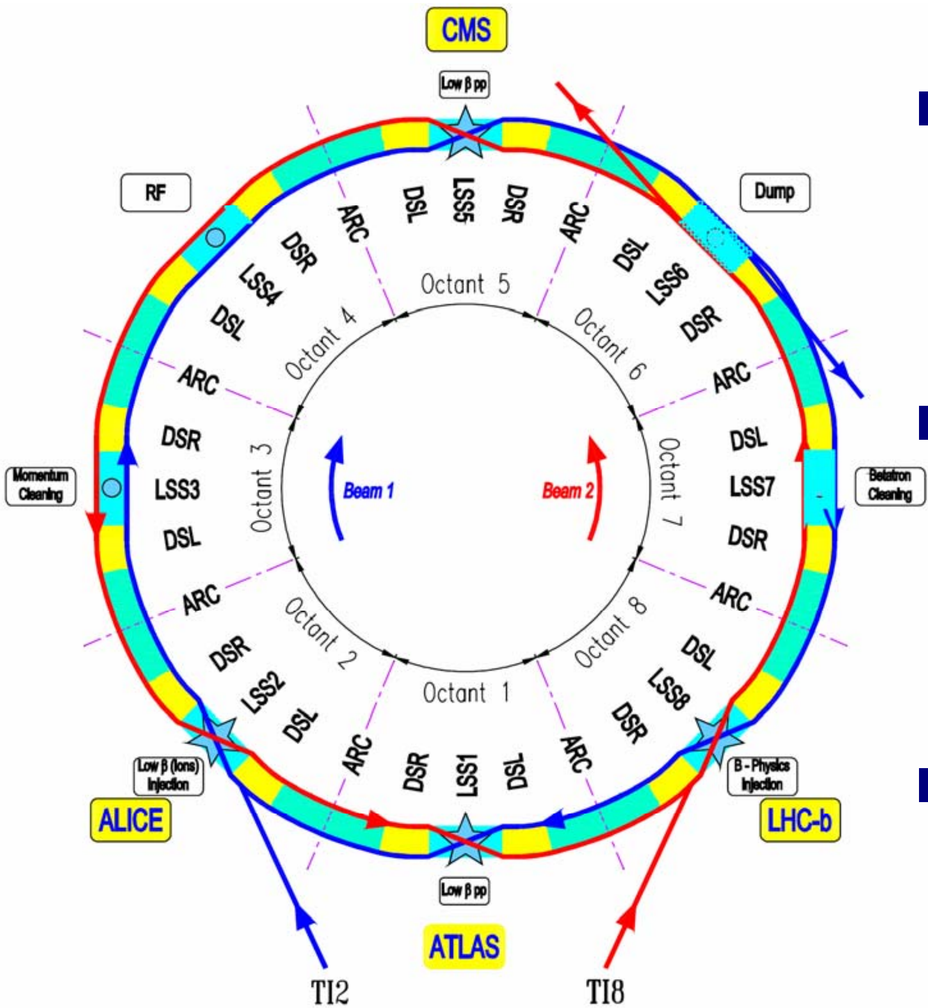
Thanks to R. Assmann, R. Bailey, O. Brüning, S. Fartoukh, M. Giovannozzi, B. Jeanneret, J. Jowett, L. Ponce, S. Redaelli, G. Robert Demolaise, J. Wenninger, F. Zimmermann

September 20th, 2006

Guidelines and suggestions (from R. Bailey and F. Zimmermann)

- What do we need to measure?
  - Apertures across individual IRs and exploration of local aperture bottlenecks ⟶ mostly covered by previous LHCCWG presentation
    - Expected aperture bottlenecks, identification and correction
  - Setting of tertiary collimators ⟶ covered by collimation team
  - **Commissioning of separation bumps and eventually crossing angle**
    - Description of crossing schemes (separation bumps, crossing angles)
    - Experimental magnet effects and correction
- Available facilities needed
  - Orbit correctors (calibration)
  - Diagnostics (BPMs, BLMs, BCTs)
  - Application software
- Measurement and correction methods
  - Crossing scheme commissioning procedure
    - Beam conditions
    - Orbit measurement resolution and correction accuracy
- Who will do it and how long will it take?

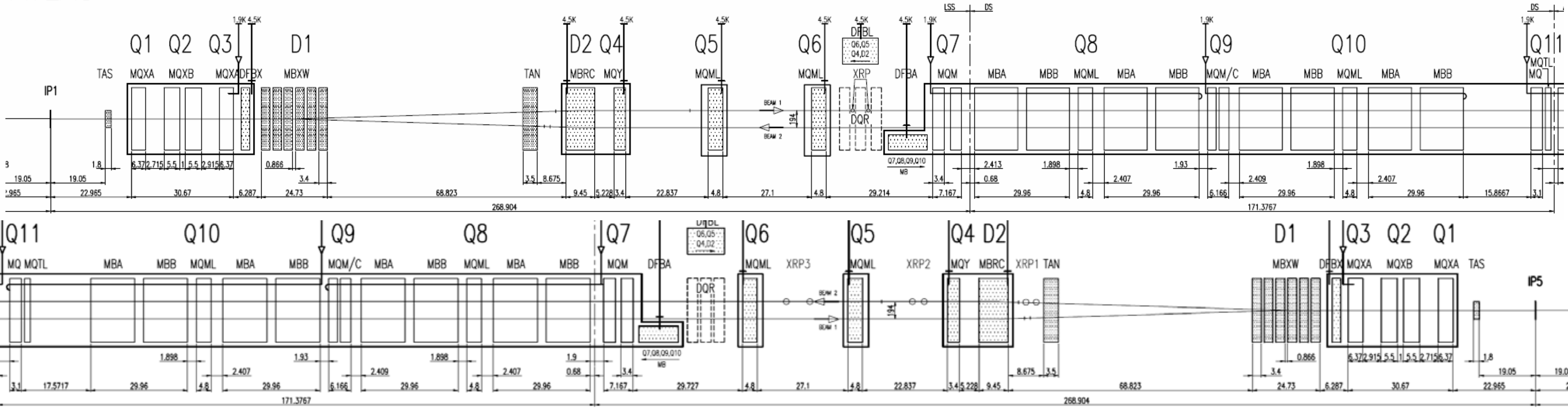
LHC experimental IRs



- Two high luminosity experiments
  - **ATLAS** in IP1 (vertical crossing)
  - **CMS** in IP5 (horizontal crossing)
- B-physics with lower luminosity in asymmetric IP8
  - **LHCb** (horizontal crossing)
  - Injection of beam 2
- Heavy ion experiment (and p-p collisions with offset beams)
  - **ALICE** (vertical crossing)
  - Injection of beam 1

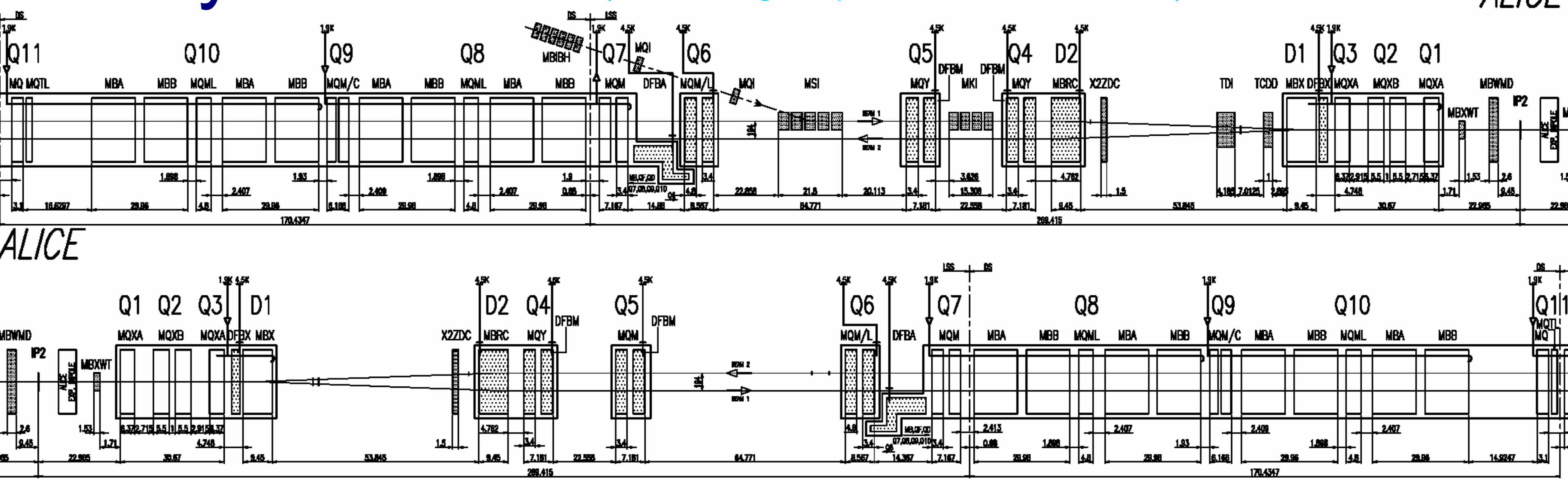
ATLAS

Layout of IR1 and IR5 (LHC design report, CERN-2004-003)



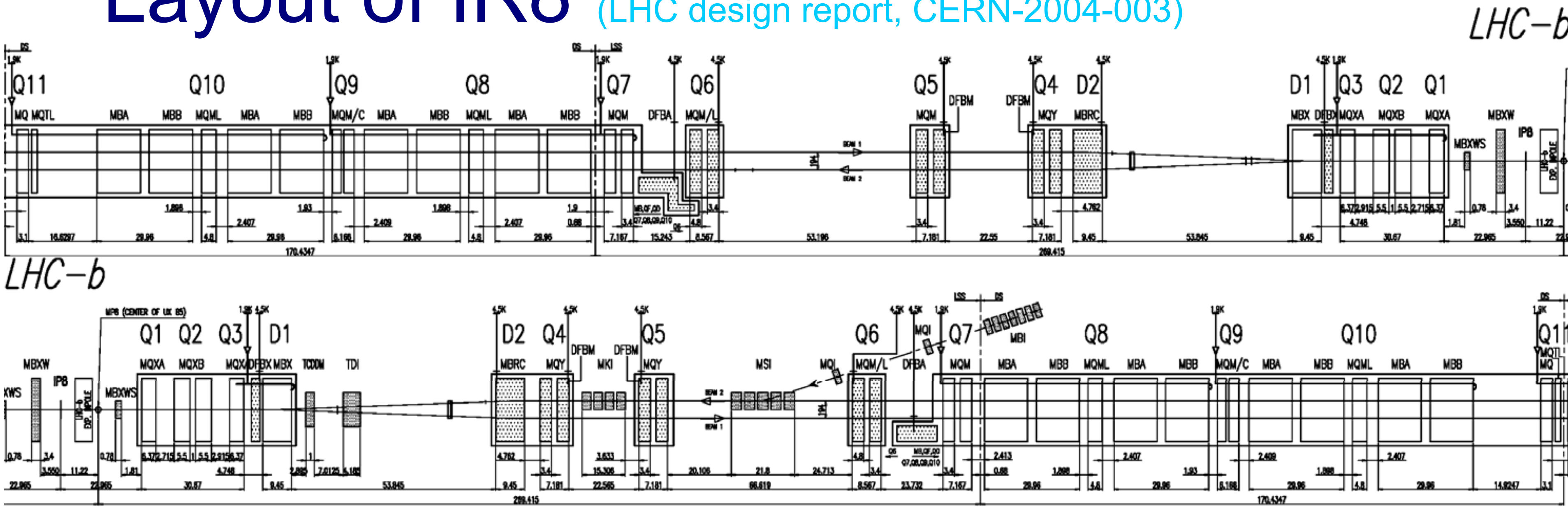
- Identical layouts and optics in both IRs.
  - Exceptions: Crossing scheme, tunnel slope, beam screen orientation ⟶ different cryostats
- Super-conducting low beta triplets (Q1-Q3)
- One warm, 6-module (D1-MBXW) and one cold single-module (D2-MBRC) separation-recombination dipole
- 4 matching quads (Q4-Q7) + 4 dispersion suppressor quads (Q8-Q11)
- Experimental solenoids in both ATLAS and CMS
- 2 absorbers in front of triplet (TAS) and D2 (TAN)
- Mirror symmetry around IP apart Q8-Q10 (0.5m closer to IP on right side)

Layout of IR2 (LHC design report, CERN-2004-003)

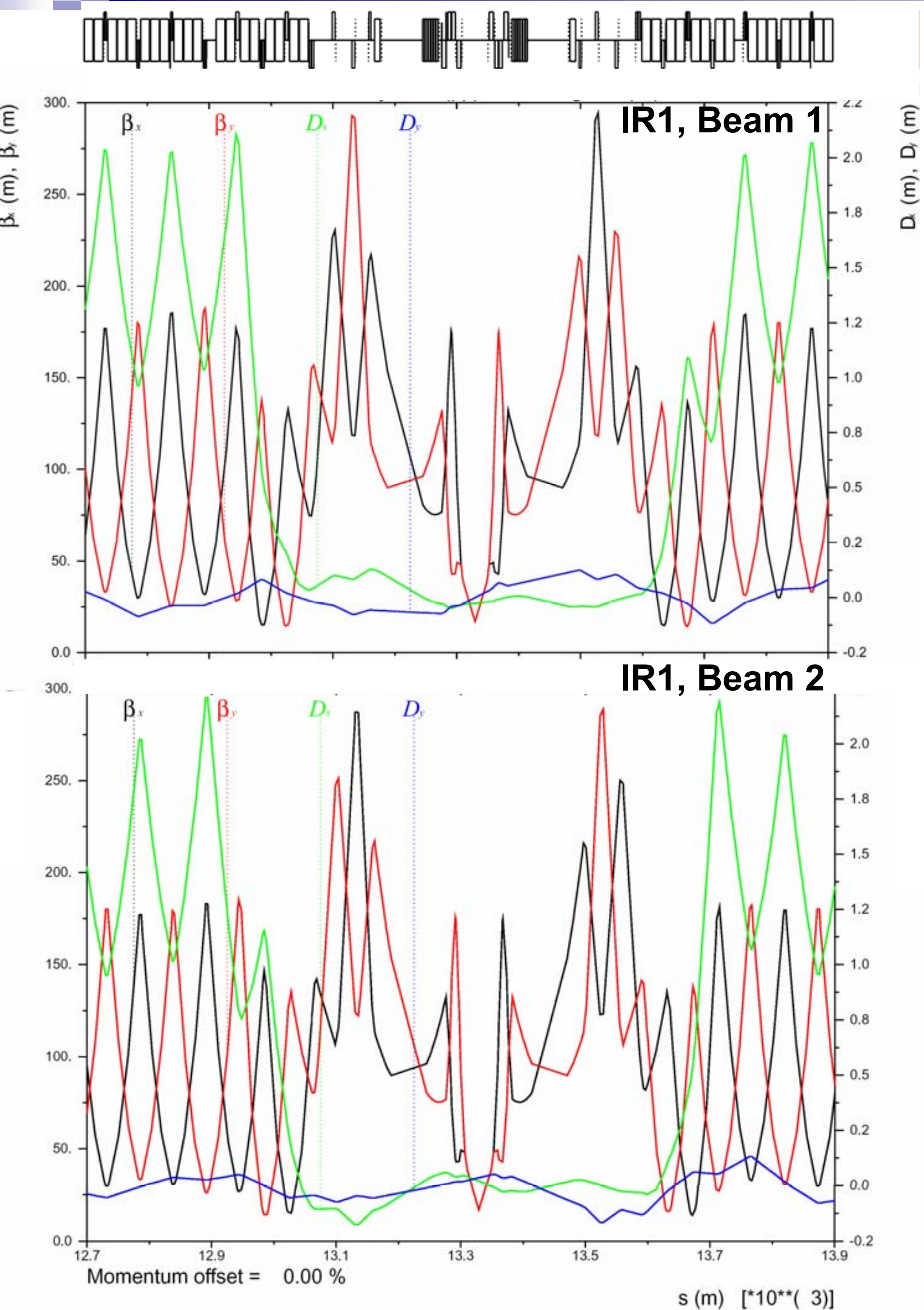


- Includes injection elements for beam 1 (left side) and heavy ion experiment ALICE
- Super-conducting in low beta triplets (Q1-Q3), and dispersion suppressor quads (Q8-Q11), as in IR1/5
- Two cold single-module separation-recombination dipoles (D1-MBX, D2-MBRC)
- Four 2-module matching quads (Q4-Q7)
- Experimental dipole (MBAW) with 3 warm compensator magnets and solenoid
- Absorber TDI and TCDD for injection failure protection in front of D1L
- Injection septum MSI between Q5L-Q6L and injection kicker MKI between Q5L-Q4L
- Mirror symmetry around IP apart Q8-Q10 (0.5m closer to IP on right side)

Layout of IR8 (LHC design report, CERN-2004-003)



- Includes injection elements for beam 2 (right side) and LHCb experiment
- Super-conducting quads and separation-recombination dipoles, as in IR2
- Experimental dipole (MBLW) with 3 warm compensator magnets
- Absorber TDI and TCDD for injection failure protection in front of D1R
- Injection septum MSI between Q5R-Q6R and injection kicker MKI between Q5R-Q4R
- IP8 shift of 11.25m implies non-symmetric magnet layout in matching section (apart from Q8-Q10 which are also 0.5m closer to IP as for other IRs)



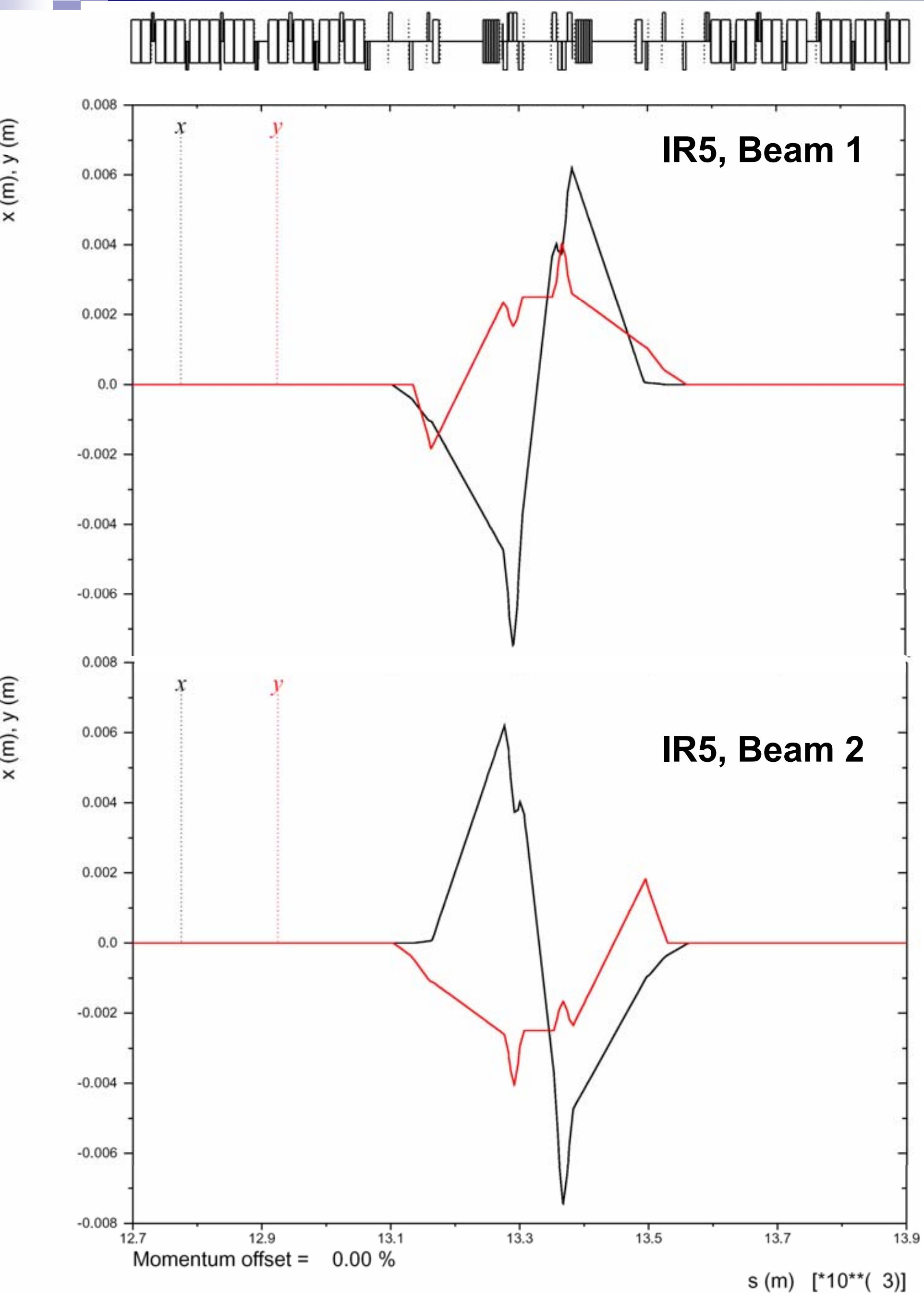
IR1/5 injection optics

(S. Fartoukh, LTC 31/03/04)

- β^*=17m
- (μ_x,μ_y)= 2π(2.618,2.644)
- β_{max} ~ 300m around Q5 (MQML)
- D_{max} ~ 2.1m around Q10 (MQML)
- Small vertical dispersion due to vertical separation bump (IR5) or crossing angle (IR1)
- Matching uses all quads from Q11L-Q11R and the MQT12-13

IR1/5 crossing scheme

(O. Brüning et al., LHC Project report 315,1999 and LHC design report)



- Horizontal/Vertical parallel separation bump ±2.5mm (13.7σ) in IR1/5
- Vertical/Horizontal crossing angle of ±160μrad in IR1/5 to reduce long range beam beam encounters
  - Not needed for 43 bunches operation (stage I), but experience should be gained early enough
- The sign of the vertical crossing angle (IR1) and separation bump (IR5) are arbitrary
- The sign of horizontal crossing angle (beam 1 in IR5) and separation bump (beam2 in IR1) must be positive, due to ring geometry

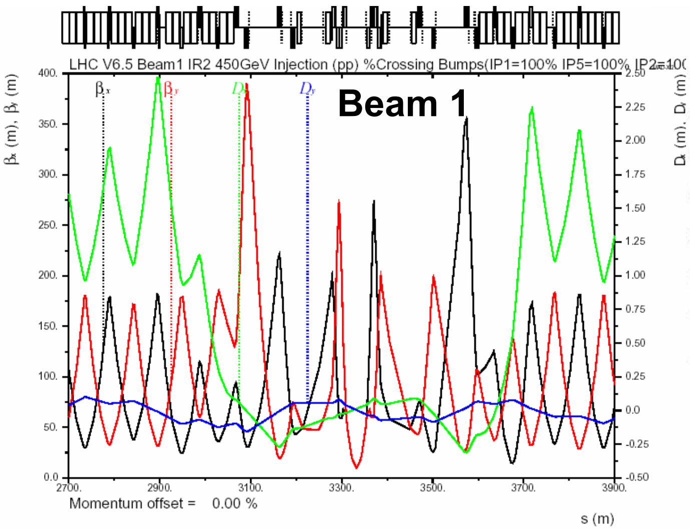
Steerers for crossing scheme in IR1/5

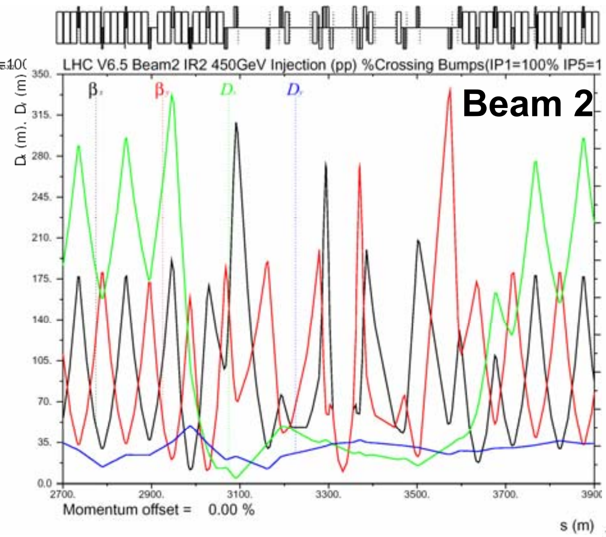
Separation bump			
IR1		IR5	
Beam 1	Beam 2	Beam 1	Beam 2
MCBCH.6L1	MCBCH.5L1	MCBCV.5L5	MCBCV.6L5
MCBYH.B4L1	MCBYH.4L1	MCBYV.4L5	MCBYV.B4L5
MCBYH.A4L1	MCBXA.3L1	MCBXA.3L5	MCBYV.A4L5
MCBXA.3L1	MCBX.2L1	MCBX.2L5	MCBXA.3L5
MCBX.2L1	MCBX.1L1	MCBX.1L5	MCBX.2L5
MCBX.1L1	MCBX.1R1	MCBX.1R5	MCBX.1L5
MCBX.1R1	MCBX.2R1	MCBX.2R5	MCBX.1R5
MCBX.2R1	MCBXA.3R1	MCBXA.3R5	MCBX.2R5
MCBXA.3R1	MCBYH.A4R1	MCBYV.A4R5	MCBXA.3R5
MCBYH.4R1	MCBYH.B4R1	MCBYV.B4R5	MCBYV.4R5
MCBCH.5R1	MCBCH.6R1	MCBCV.6R5	MCBCV.5R5

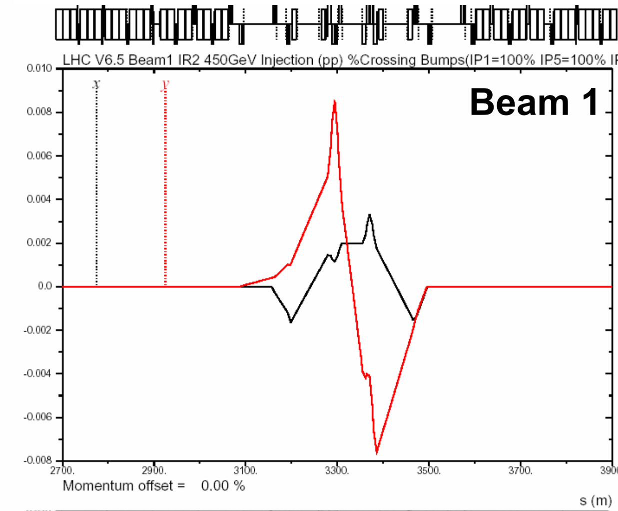
Crossing angle			
IR1		IR5	
Beam 1	Beam 2	Beam 1	Beam 2
MCBCV.5L1	MCBCV.6L1	MCBCV.5L5	MCBCV.6L5
MCBYV.4L1	MCBYV.B4L1	MCBYV.4L5	MCBYV.B4L5
MCBXA.3L1	MCBYV.A4L1	MCBXA.3L5	MCBYV.A4L5
MCBX.2L1	MCBXA.3L1	MCBX.2L5	MCBXA.3L5
MCBX.1L1	MCBX.2L1	MCBX.1L5	MCBX.2L5
MCBX.1R1	MCBX.1L1	MCBX.1R5	MCBX.1L5
MCBX.2R1	MCBX.1R1	MCBX.2R5	MCBX.1R5
MCBXA.3R1	MCBX.2R1	MCBXA.3R5	MCBX.2R5
MCBYV.A4R1	MCBXA.3R1	MCBYV.A4R5	MCBXA.3R5
MCBYV.B4R1	MCBYV.4R1	MCBYV.B4R5	MCBYV.4R5
MCBCV.6R1	MCBCV.5R1	MCBCV.6R5	MCBCV.5R5

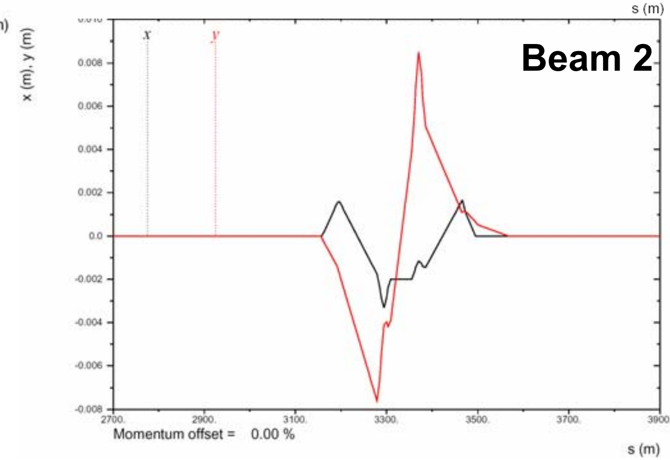
- 11 + 11 steerers per beam and IR
  - MCBX.2 and MCBX.3 are used for orbit correction, the rest for the crossing scheme
- Same steerers used per beam and IR but different purpose (separation – crossing)
- Both signs of the vertical separation bump (IR5) and crossing angle (IR1) should be commissioned
- Calibration of all these elements with beam is necessary

IR2 Injection optics (O. Brüning et al. LHC Project rep 367)



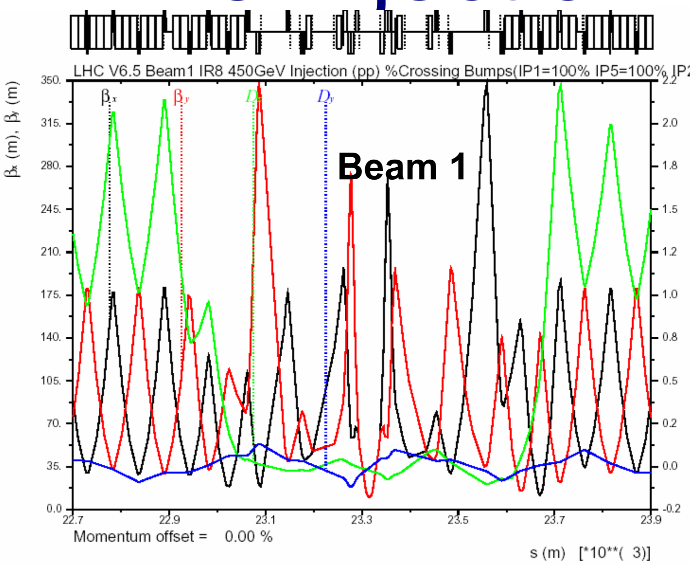


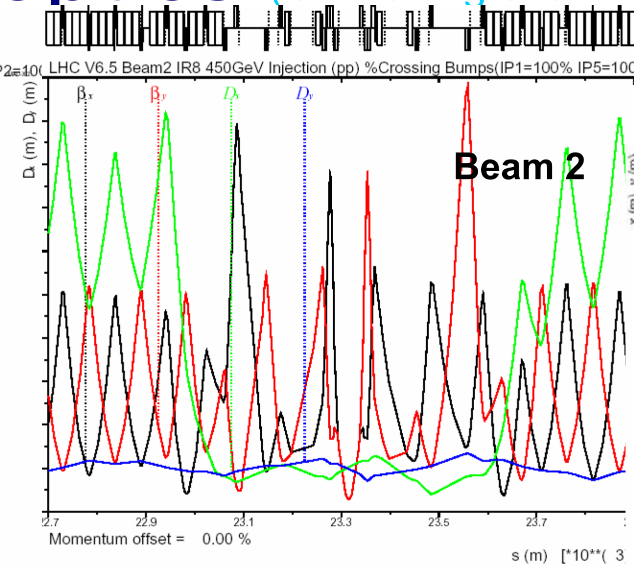


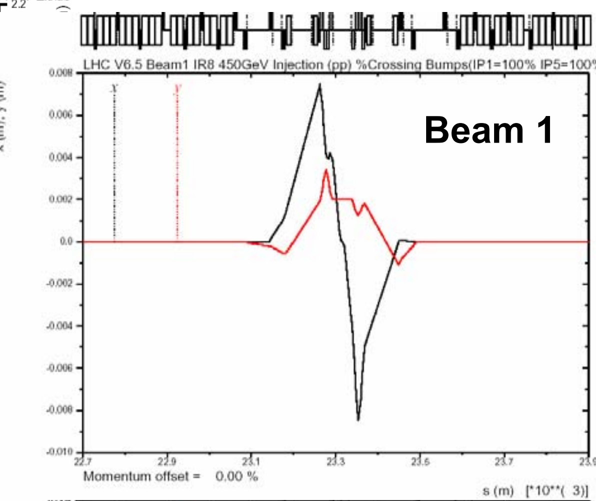


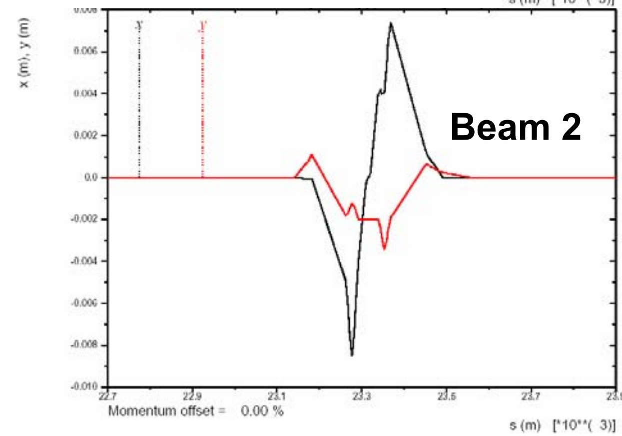
- β*=10m, vertical crossing angle of ±150μrad and horizontal parallel separation of ± 2mm
  - External angle of ±80μrad for reducing the long range beam-beam effect
  - Internal angle of ±70μrad for compensating spectrometer orbit distortion
  - Horizontal separation positive for Beam 1 and negative for Beam 2
  - Angle sign can be chosen arbitrarily (following spectrometer polarity)

IR8 Injection optics (O. Brüning et al. LHC Project rep 367)

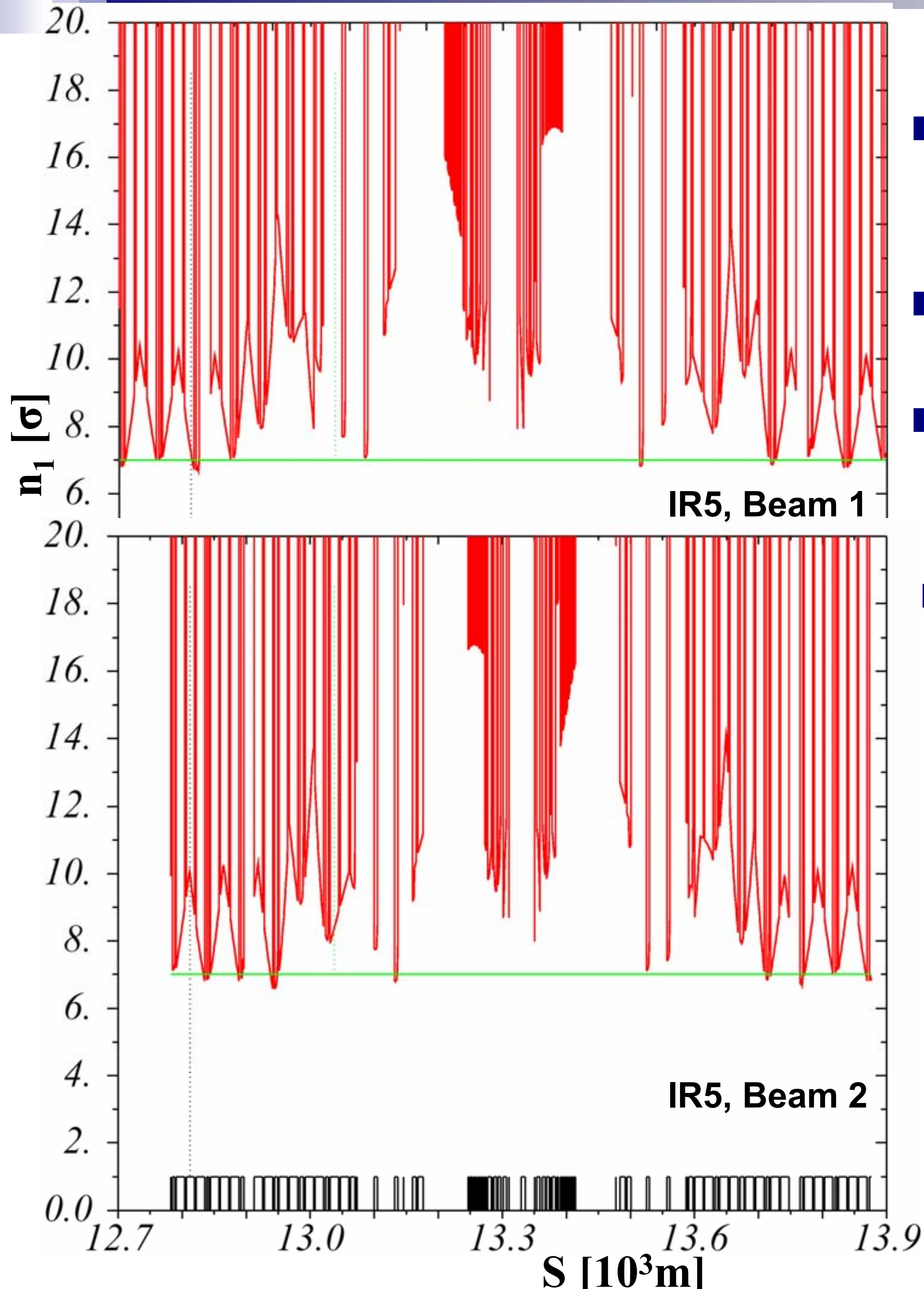








- β*=10m, horizontal crossing angle of ±200 or ±75 μrad depending on the polarity and vertical parallel separation of ± 2mm
  - External angle of ±65 (- polarity) or ±210 μrad (+ polarity)
  - Internal angle of ±135 μrad for compensating spectrometer orbit distortion
  - Horizontal crossing angle always negative for Beam 1 and positive for Beam 2
  - Vertical separation sign can be chosen arbitrarily

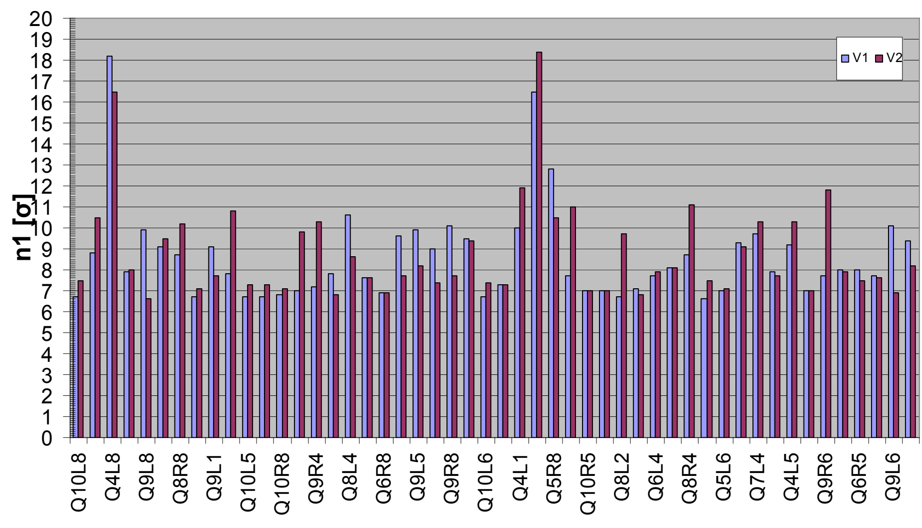


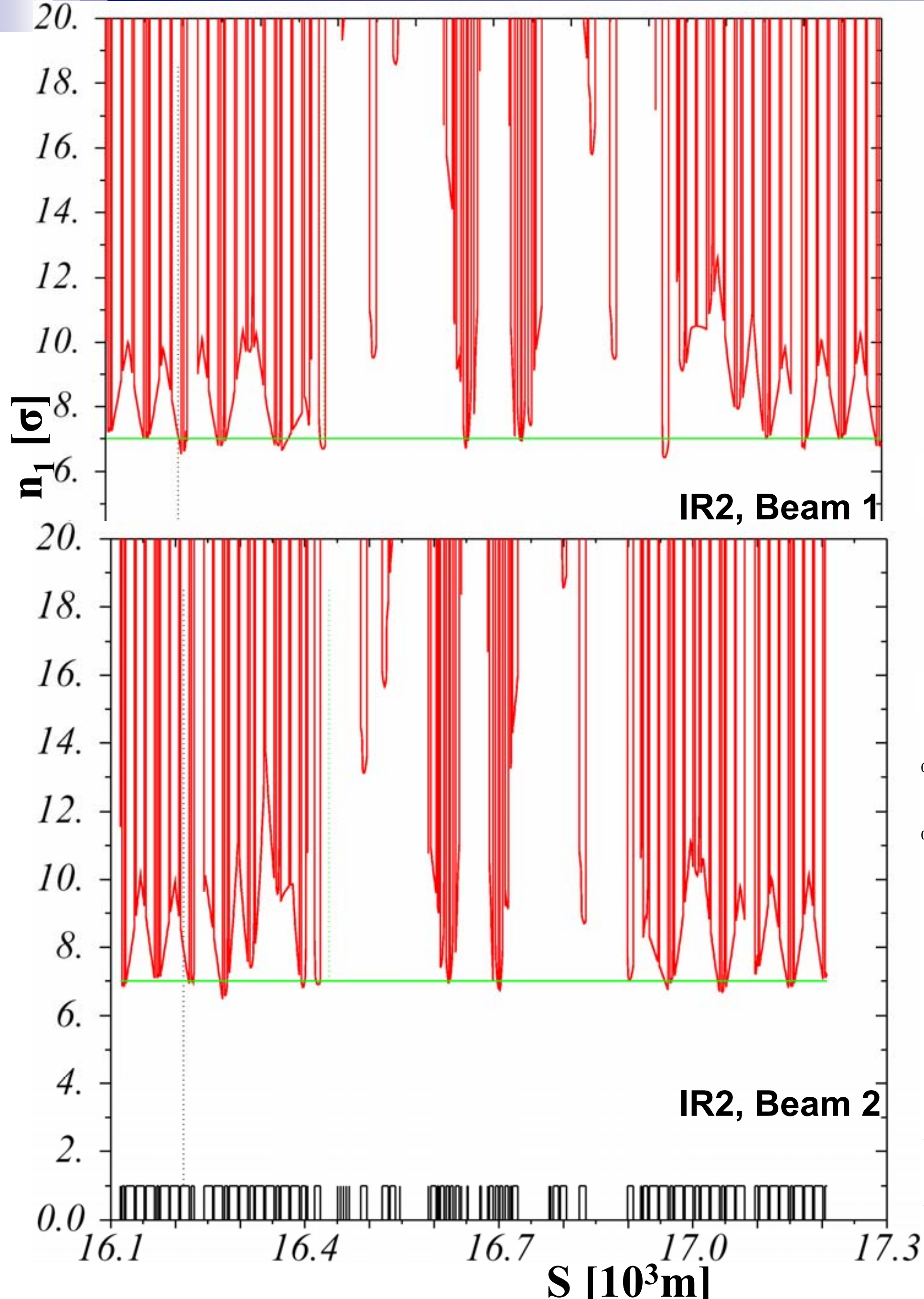
IR1/5 aperture

- A few locations are below the specification for QF of 7σ
- Note that for QD the spec is 6.7σ
- Magnets are shifted when installed in order to increase acceptance
- Alignment data can be included in model

IR1/5	
Beam 1	**Beam 2**
MQ.11L	MQ.11L
MQTLI.11L	MB.A11L
MS.11L	MQML.10L
MCBV.11L	MB.B10L
MQML.5R	MQML.5L
MQML.10R	MQML.10R
MB.A11R	MB.A11R
	MQ.11R
	MQTLI.11R
	MS.11R
	MCBV.11R

M. Giovannozzi, AB/ABP

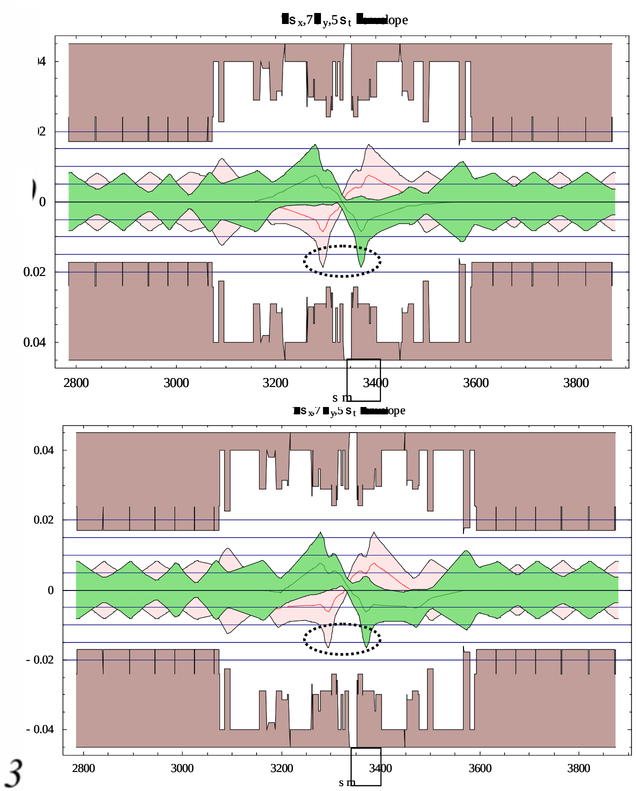




IR2 aperture

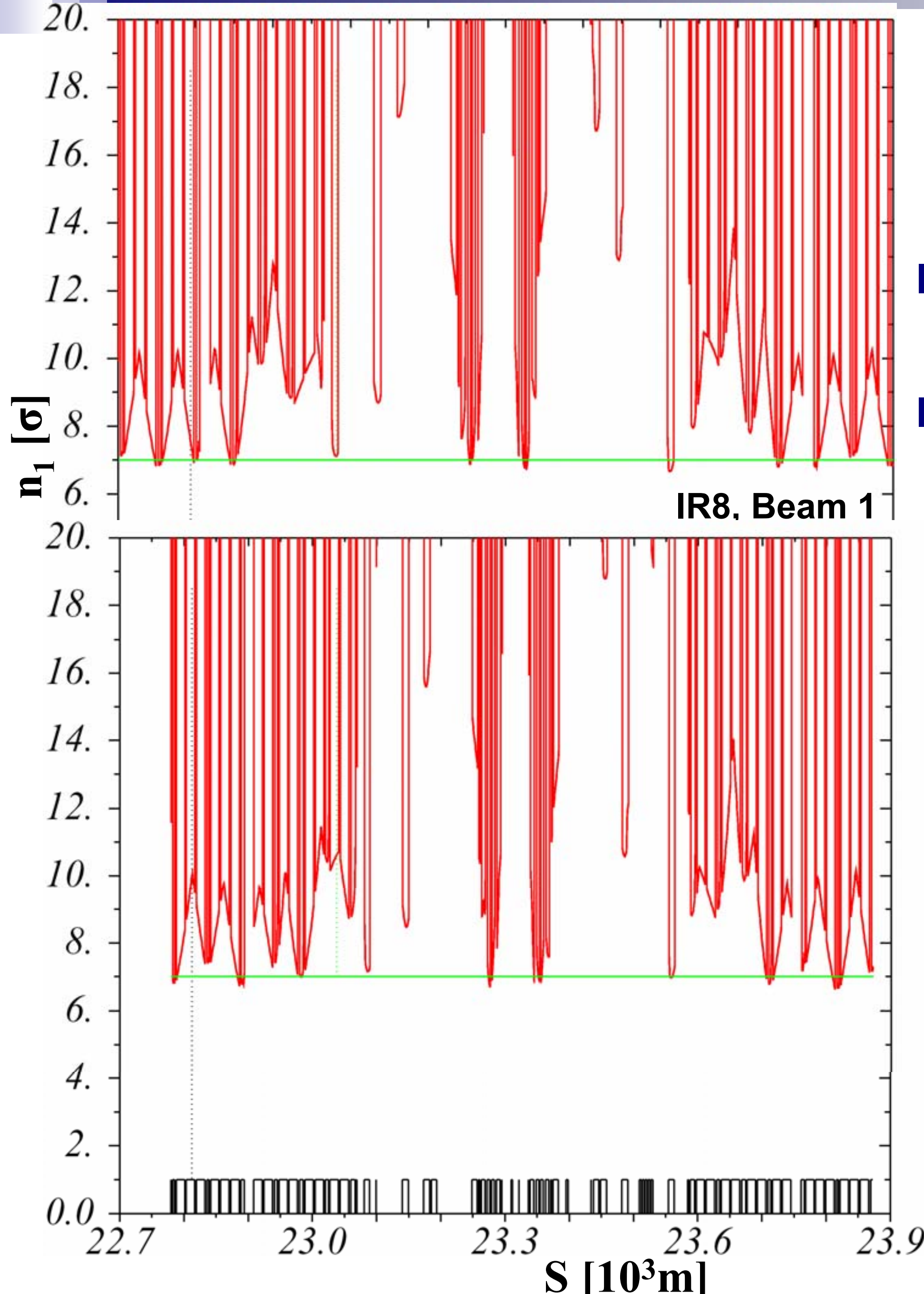
- Locations which are below 7σ (including Q2L/R)
- Minimum of 6.4σ near Q6R
- Vertical orbit displacement of +1.5mm improves aperture near triplets

J.Jowett, LOC meeting 24/04/2006



IR2	
Beam 1	**Beam 2**
MQ.11L	MQ.11L
MS.11L	MQTLI.11L
MCBH.11L	MB.A11L
MB.A11L	MQML.10L
MQML.10L	MQM.B7L
MQML.8L	MQML.6L
MB.B8L	MQM.6L
MQML.6L	MQXB.A2R
MQM.6L	MCBX.2R
MQXB.B2L	MQXB.B2R
MCBX.2L	MB.B8R
MQXB.A2L	MQML.8R
MQXB.B2R	MB.B10R
MQML.6R	MQML.10R
MQM.6R	MB.A11R
MB.A11R	
MQ.11R	
MQTLI.11R	
MS.11R	

IR8 aperture

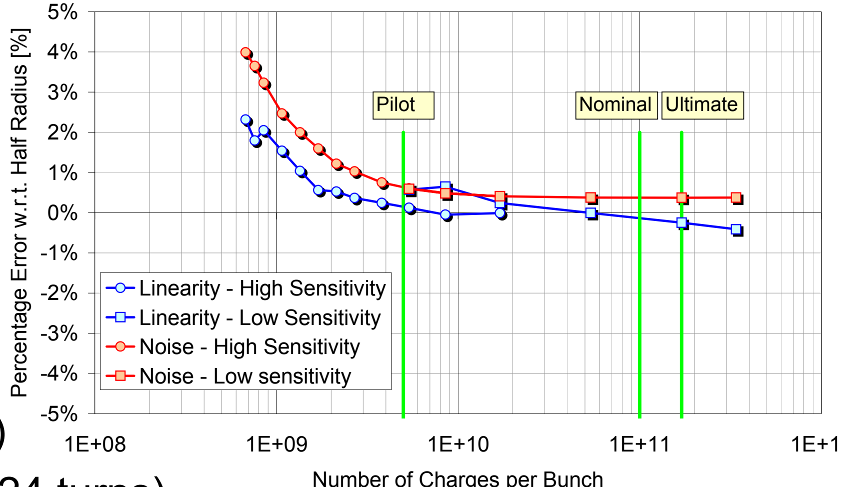


- Critical locations (including Q1, Q2)
- Same solution with orbit displacement at the IP may be feasible for IR8 as well (done for IP1/5 @ collision and IP2 @ injection)

IR8	
Beam 1	**Beam 2**
MQ.11L8	MQ.11L8
MB.A11L8	MQTLI.11L8
MQML.10L8	MS.11L8
MQXB.A2L8	MCBV.11L8
MQXA.1L8	MQM.9L8
MQXB.A2R8	MQXB.B2L8
MCBX.2R8	MCBX.2L8
MQXB.B2R8	MQXB.A2L8
MQML.6R8	MQXA.1R8
MQM.6R8	MQXB.A2R8
MQML.10R8	MQXB.B2R8
MB.A11R8	MQML.6R8
MQ.11R8	MB.B10R8
MQTLI.11R8	MQML.10R8
MS.11R8	MB.A11R8
MCBV.11R8	

IR Beam Position Monitors

- 12 + 12 beam position monitors in either side of the IRs
  - 5 + 5 standard 24mm buttons (BPM), near Q7-Q11
  - 2 + 2 for magnets with vertical beam screen (BPMR), near Q5-Q6
  - 1 + 1 enlarged aperture (34mm) buttons with horizont al beam screen (BPMYA), near Q4
  - 1 + 1 enlarged (34mm) warm buttons (BPMWB), near D2
  - 1 + 1 directional stripline couplers (120mm) for DFBX (BPMSY)
  - 1 + 1 directional stripline couplers (120mm) for Q2 (BPMS)
  - 1 + 1 directional stripline couplers (120mm) for Q1 (BPMSW)
- Performance
  - Range of operation: ±6mm
  - Non-linearity: ±100μm
  - Resolution:
    - Pilot (5×10^9): 130μm (single), 9μm (average/224 turns)
    - Nominal – ultimate ($1\text{-}1.7 \times 10^{11}$) 50μm (single), 5μm (average/224 turns)



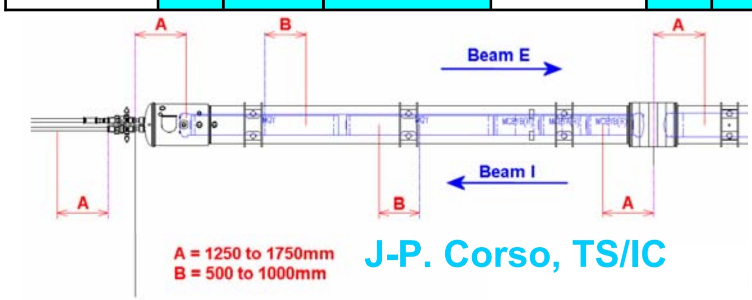
R.Jones, AB/BI

IR BPM
BPM.11L1
BPM.10L1
BPM.9L1
BPM.8L1
BPM.7L1
BPMR.6L1
BPMR.5L1
BPMYA.4L1
BPMWB.4L1
BPMSY.4L1
BPMS.2L1.
BPMSW.1L1
BPMSW.1R1
BPMS.2R1
BPMSY.4R
BPMWB.4R
BPMYA.4R
BPMR.5R1
BPMR.6R1
BPM.7R1
BPM.8R1
BPM.9R1
BPM.10R1
BPM.11R1

IR Beam loss monitors

B. Dehning AB/BI, L. Ponce, AB/OP

Location	IC	SEM	Patch	Location	IC	SEM	Patch
TAS.1L1	1	1	BJBAP.A1L1	TAS.1R1	1	1	BJBAP.A1R1
BPMSW.1L1	1	1		BPMSW.1R1	1	1	
MQXA.1L1	6		BJBAP.B1L1	MQXA.1R1	6		BJBAP.B1R1
MQXB.A2L1	6		BJBAP.A2L1	MQXB.A2R1	6		BJBAP.A2R1
MQXA.3L1	6		BJBAP.A3L1	MQXA.3R1	6		BJBAP.A3R1
TAN.4L1	1	1	BJBAP.A4L1	TAN.4R1	1	1	BJBAP.A4R1
TCTV.4L1.B1	1	1		TCTV.4R1.B2	1	1	
TCTH.4L1.B1	1	1		TCTH.4R1.B2	1	1	
TCL.4L1.B2	1	1		TCLP.4R1.B1	1	1	
MQY.4L1	6		BJBAP.B4L1	MQY.4R1	6		BJBAP.B4R1
TCL.5L1.B2	1	1	BJBAP.A5L1	TCL.5R1.B1	1	1	BJBAP.A5R1
MQML.5L1	6			MQML.5R1	6		
MQML.6L1	6		BJBAP.A6L1	MQML.6R1	6		BJBAP.A6R1
XRP.A7L1	2		BJBAP.A7L1	XRP.A7R1	2		BJBAP.A7R1
XRP.B7L1	2			XRP.B7R1	2		
MQM.A7L1	6		BJBAP.B7L1	MQM.A7R1	6		BJBAP.B7R1
MBA.8L1	6		BJBAP.A8L1	MBA.8R1	6		BJBAP.A8R1
MQML.8L1	6		BJBAP.B8L1	MQML.8R1	6		BJBAP.B8R1
MQM.9L1	6		BJBAP.A9L1	MQM.9R1	6		BJBAP.A9R1
MBA.10L1	2		BJBAP.A10L1	MBA.10R1	2		BJBAP.A10R1
MQML.10L1	6		BJBAP.B10L1	MQML.10R1	6		BJBAP.B10R1
MBA.11L1	6		BJBAP.A11L1	MBA.11R1	6		BJBAP.A11R1
MQ.11L1	6		BJBAP.B11L1	MQ.11R1	6		BJBAP.B11R1

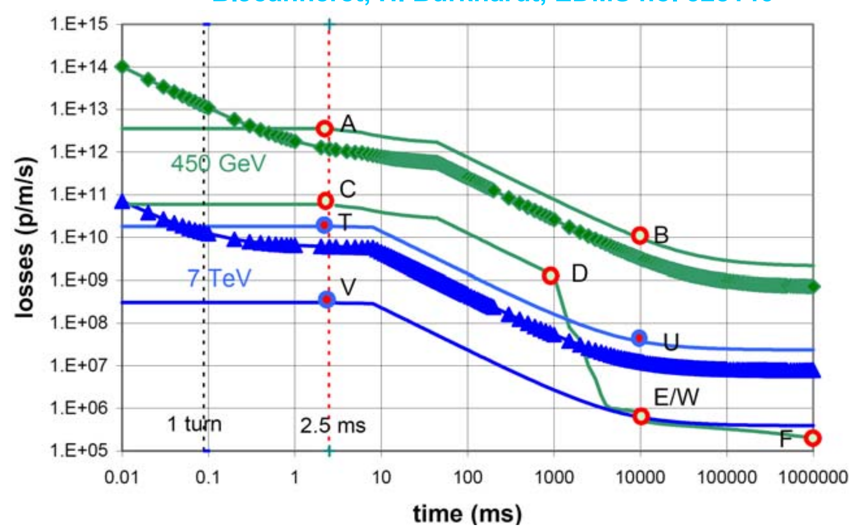


J-P. Corso, TS/IC

- 6 ionisation chambers (IS) per cryostat, 2 IS close to roman pots
- Secondary emission monitors added in special locations (collimators, injection kickers,…)
- Dynamic range @ 450 GeV

	2.5 ms (BLMA) 0.1ms (BLMS)		1 s		10s		100s	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
450 GeV	6×10^{10} (C)	3.6×10^{12} (A)	1.3×10^{9} (D)		8×10^{5} (E)	9.6×10^{9} (B)	2×10^{5} (F)	

B.Jeanneret, H. Burkhardt, EDMS no. 328146



- Pilot bunch losses can be detected for relatively long integration times ~ 1sec
- Intermediated bunches of $3\text{x}10^{10}$p can be detected in ~ 10-100msec
- For fast response (<2.5ms), more than $6\text{x}10^{10}$p needed

Beam current transformers

- DC beam transformers (BCTDC)
  - 2 instruments per ring, for redundancy, located in IR4
  - Resolution of ~ 10 μA when integrating over 20 ms, equivalent to 1.2×10^{12} p, or loss rate of 6×10^{10} p/ms ⟶ just capable of detecting fast nominal bunch losses but with slow response time (40ms)
  - 20% resolution for pilot bunches ⟶ not sufficient
- The alternative are fast BCT
  - 2 transformers per ring, for redundancy, located on either side of IR4
  - Capable of resolving bunch by bunch current variation
  - 5-10% measurement precision for the pilot bunch (1% for averaging over 20 ms)
  - 1% precision for nominal bunch

Measurement Mode	Beam type	Accuracy/ Resolution	Fast BCT (BCTFR)	DC BCT (BCTDC)
Injection	Pilot bunch	±20% / ±20%	$\pm10^{9}$ (OK)	N/A
	Nominal bunch	±3% / ±1%	$\pm3\cdot10^{9}$ / $\pm10^{9}$ (OK)	N/A
Circulating Beam (>200 turns)	Pilot bunch	±10% / ±10%	$\pm0.5\cdot10^{9}$ (OK)	1μA (on 10μA) (resolution ~2-10μA)
	Nominal bunch	±1% / ±1%	$\pm10^{9}$ (OK)	2μA (on 180μA) (limit for short int time)
	43 pilot bunches	±1% / ±1%	$\pm10^{9}$ (OK)	2μA (on 390μA) (limit for short int time)
Lifetime	Pilot bunch	10% (10hrs/1min)	(OK)	N/A
	Nominal bunch	10% (30hrs/10sec)	(OK)	N/A

R.Jones, LHCCWG 25/04/06

Machine conditions and requirements

- Well corrected and stable closed orbit
- Measured, stable and possibly well corrected linear optics
- Measured optics model (response matrix analysis)
- Well calibrated machine elements (especially steerers, tune/aperture kicker)
- Stable injected beams with reproducible emittance
- Beam of around 10^{10}p (or below the quench limit)
- Calibrated, corrected and well-synchronized BPMs, with turn-by-turn acquisition available
- Calibrated BLMs
- Wire scanners and IPMs for profile measurements
- Cross-calibrated fast BCTs and DC BCTs
- Application software for control and acquisition of beam positions (TBT, COD modes), losses, profiles, current and lifetime
- Application software for (sliding) bumps (YASP) and kicker control, synchronized with current/lifetime and beam loss measurements

(J. Wenninger AB/OP)

IR aperture measurements

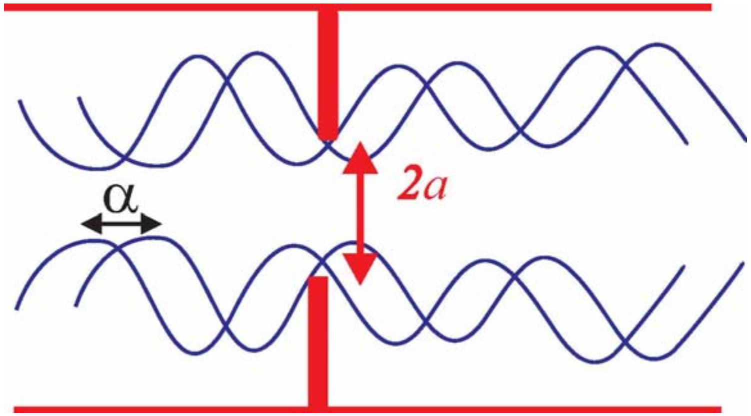
- Purpose: find and correct major aperture bottlenecks in view of intensity/energy ramping **(S. Redaelli, LHCCWG 26/07/06)**
- For the IRs, important to identify particular limitations that may become critical at top energy, including crossing scheme and squeeze (triplets)
- Measurement methods
  - Two steerer orbit oscillation (global aperture)
  - Local or sliding closed bumps across IR
- Note that available aperture (measured in n_1) by the model uses specific tolerances for the orbit distortion, optics beating, alignment and mechanical tolerances
  - Data from magnet evaluation activity to machine operation database
- The comparison with the measured available aperture will depend on the knowledge of these quantities
- Knowledge of the triplet aperture can be used for the set-up of the tertiary collimators

Orbit oscillation

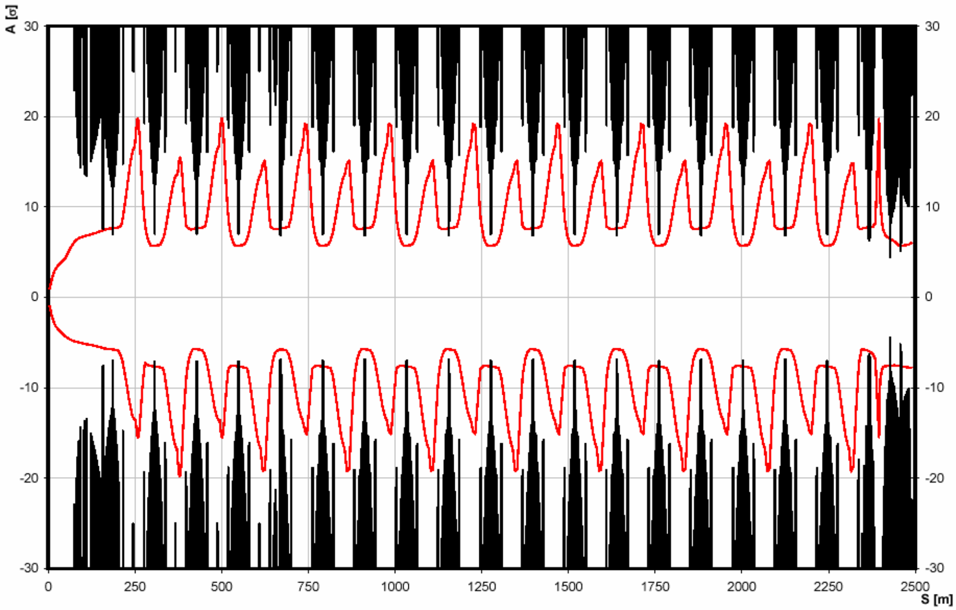
- Create orbit oscillation by two orthogonal correctors (90° apart)
- Beam has to be centered for each corrector
- Observe beam loss and correlate it with current drop
- Need calibrated steerers and knowledge of the optics at these locations

TI8 line aperture measurements, by B.Goddard, V. Kain, J.Wenninger and R. Schmid, EPAC 2005

$$A = \frac{a^2}{\beta_a} = \frac{1}{4}\left(\frac{\sin^{-2}(\pi Q)\theta_1^2\beta_1\theta_2^2\beta_2}{\theta_1^2\beta_1 + \theta_2^2\beta_2 - 2\theta_1\theta_2\sqrt{\beta_1\beta_2}\cos\alpha}\right)$$

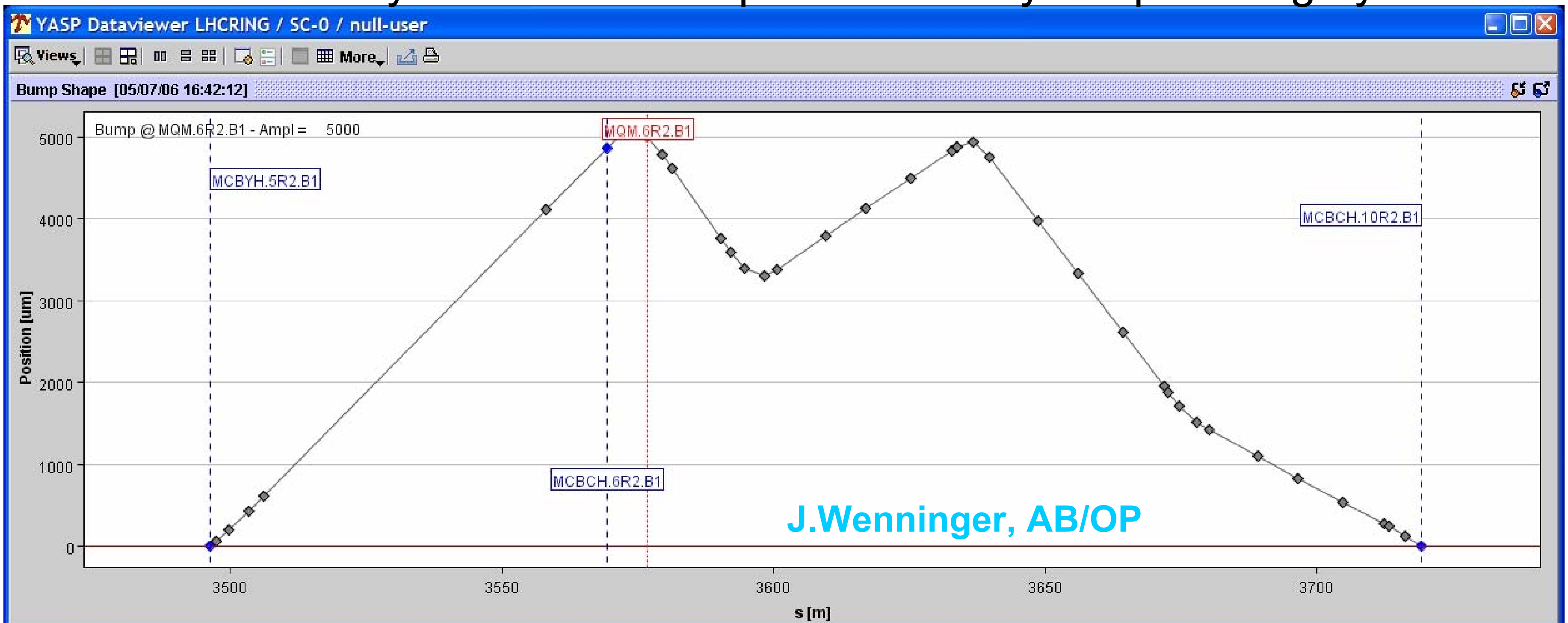


F.Zimmermann, Chamonix 2006



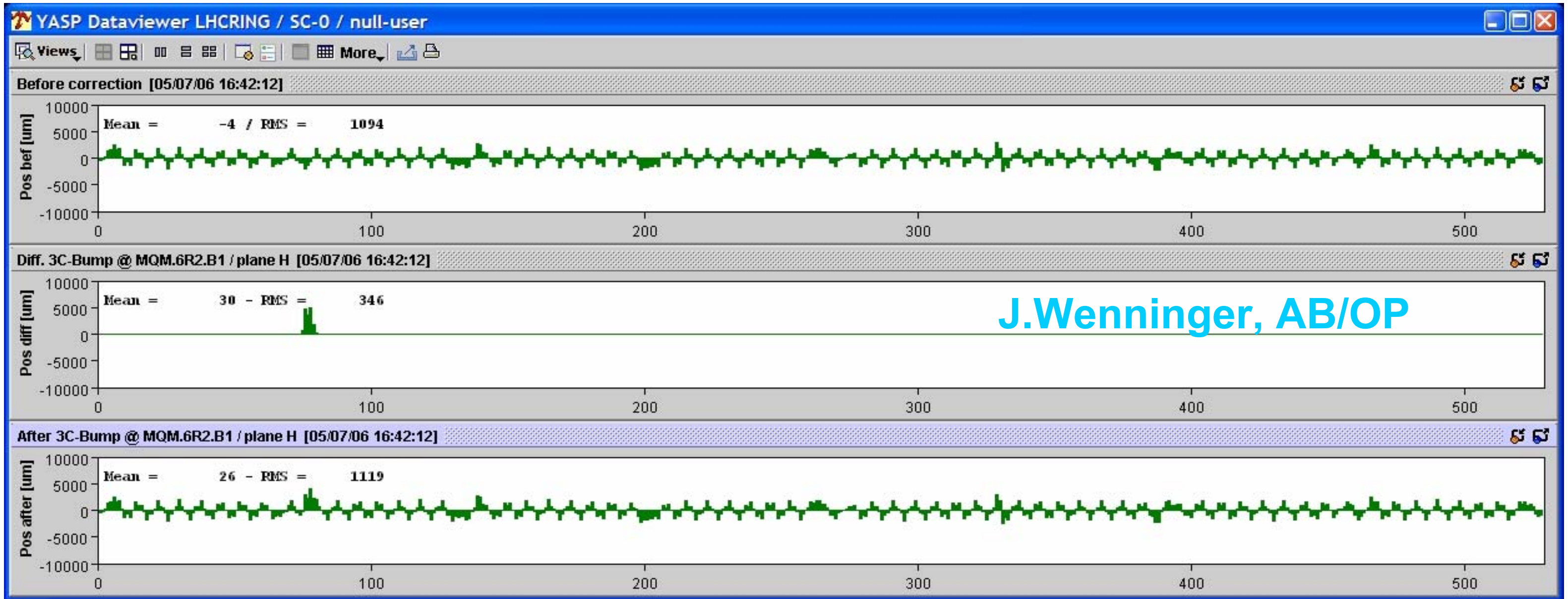
Local and sliding bumps

- Scan over the amplitude of a closed bump for a specific location, until a beam loss occurs
  - YASP has the ability of choosing the location of the bump and than calculate the corresponding corrector currents
  - Some cross-calibration of steerers or optics should be possible
- Slide the bumps along all elements of the IR to establish a complete aperture map
- A lot of refills may be needed and procedure may be quite lengthy

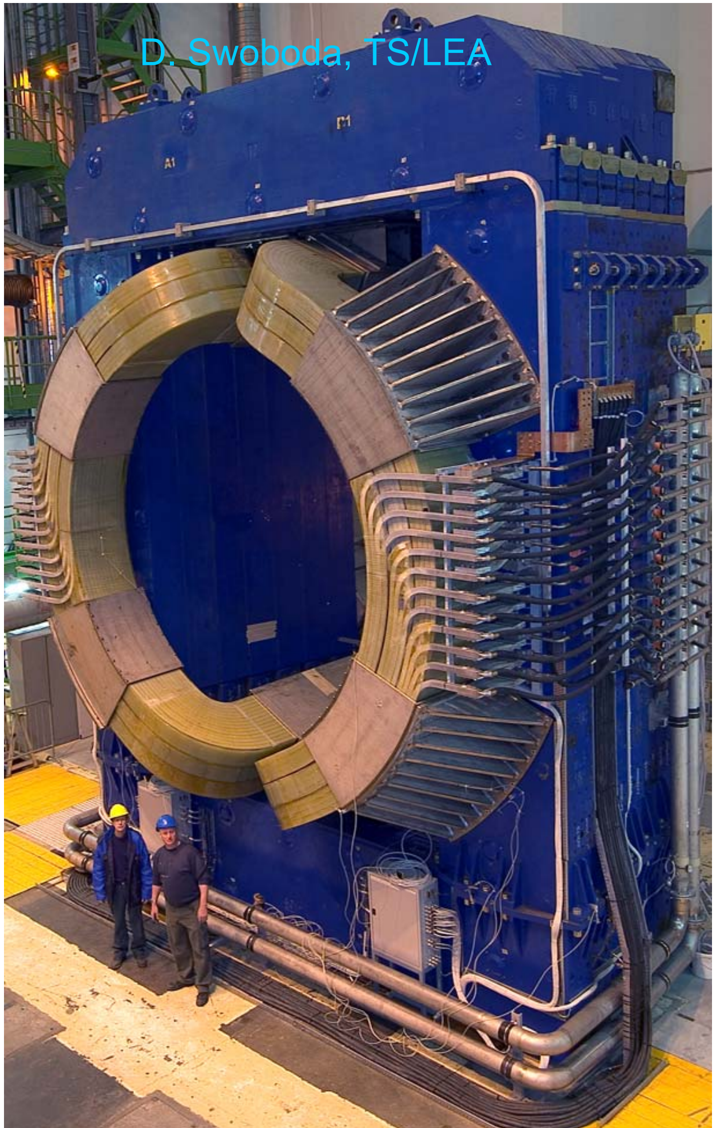


Separation bumps

- Ideally should follow the aperture measurements for each beam in all IRs, but already experience may be gained during the 450GeV collisions' run
- Need a good knowledge of the orbit (work with difference orbits)
- Step by step increase of the bump amplitude until nominal (pilot beam)
- At each step measure bump closure (effect in the orbit)
- When bump is vertical (IR5, IR8) repeat procedure for opposite sign and keep the optimal one
- Measure optics (especially dispersion) and aperture with separated beam
- Check validity of the bump with other beam and then inject both beams for final optimisation

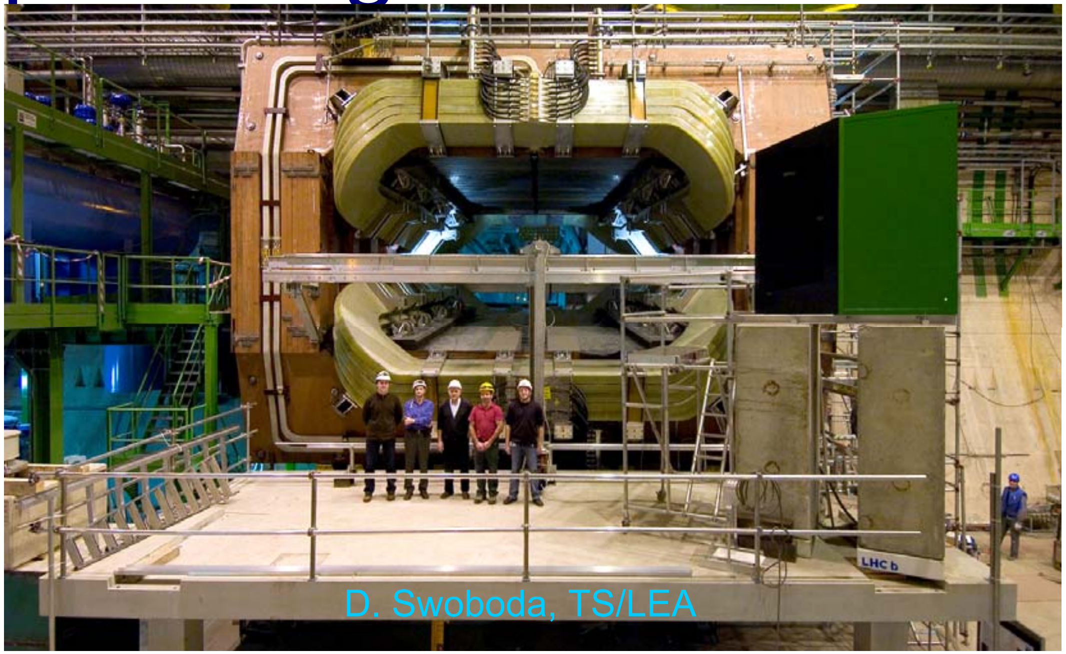


ALICE dipole magnet and its compensators



- 3m-long spectrometer dipole (MBAW) @ 10m to the right of the IP
- Vertical deflection with nominal integrated field of 3Tm (deflection of 130μrad @ 7TeV)
- The resulting orbit deflection is compensated by three dipole magnets
  - Two 1.5m-long magnets of type MBXWT @ 20m left and right of the IP
  - One 2.6m-long magnet of type MBWMD @ 10m to the left of the IP
- Two Beam Position Monitors (BPMWS) are located upstream and downstream of the two MBXWT to monitor the internal bump closure

LHCb dipole magnet

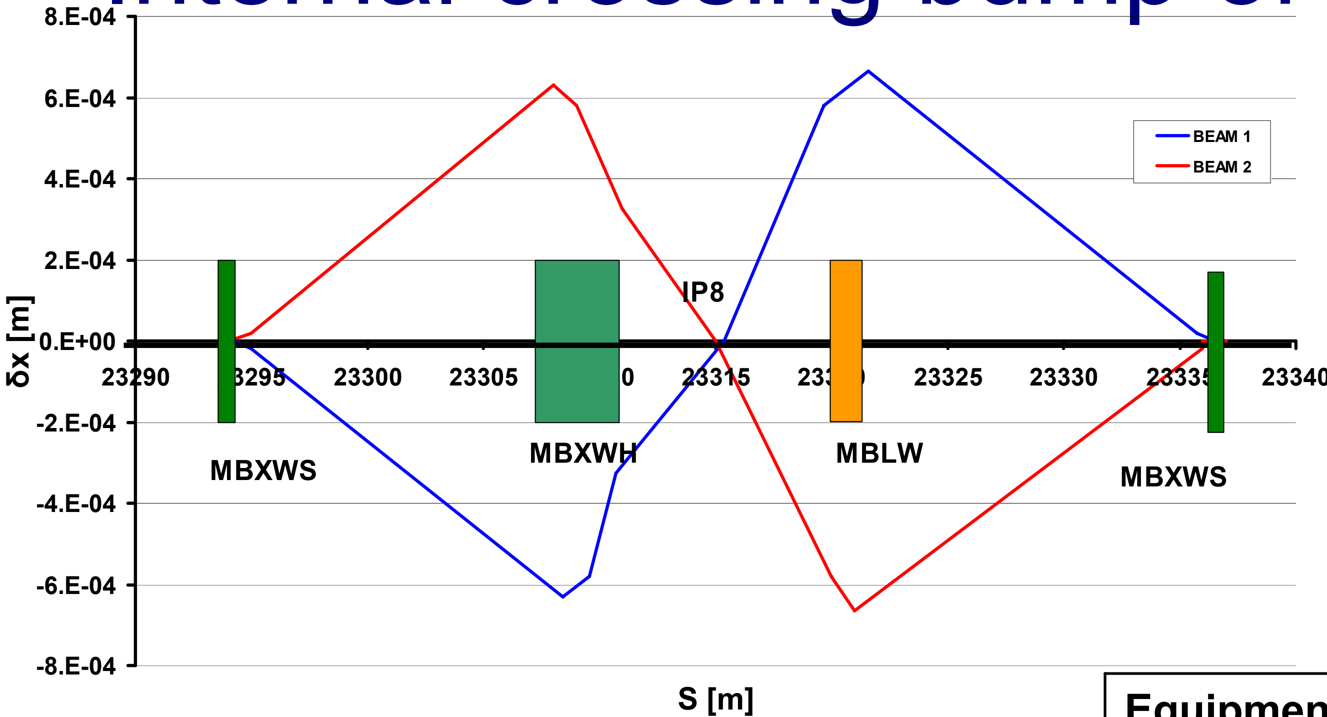


- 1.9m-long spectrometer dipole (MBLW) @ 4.9m to the right of the IP
- Horizontal deflection with nominal integrated field of 4.2Tm (deflection of 180μrad @ 7TeV)
- The resulting orbit deflection is compensated by three dipole magnets
  - Two 0.8m-long magnets of type MBXWS @ 20m left and right of the IP
  - One 3.4m-long magnet of type MBXWH @ 5m to the left of the IP
- Two Beam Position Monitors (BPMWS) are located upstream and downstream of the two MBXWS to monitor the internal bump closure

Internal crossing angle in IR2 and IR8

- Can be established independently of the separation bump (in opposite plane, with dedicated compensators)
- Need a good knowledge of the orbit as before (work with difference orbits)
- Use pilot bunches and always check induced beam losses
- Step by step increase of the experimental dipoles’ strength, measurement of the orbit deflection in nearby BPM and correction with the compensators, until reaching nominal
- Repeat procedure for opposite polarity of the experimental magnets
- Add beam separation and measure optics and aperture
- Check the bump settings for the other beam and then inject both beams for final optimisation
- Collapse the separation bump and measure luminosity
- Measure the aperture when dipoles pushed at their collision strength

Internal crossing bump of IR8

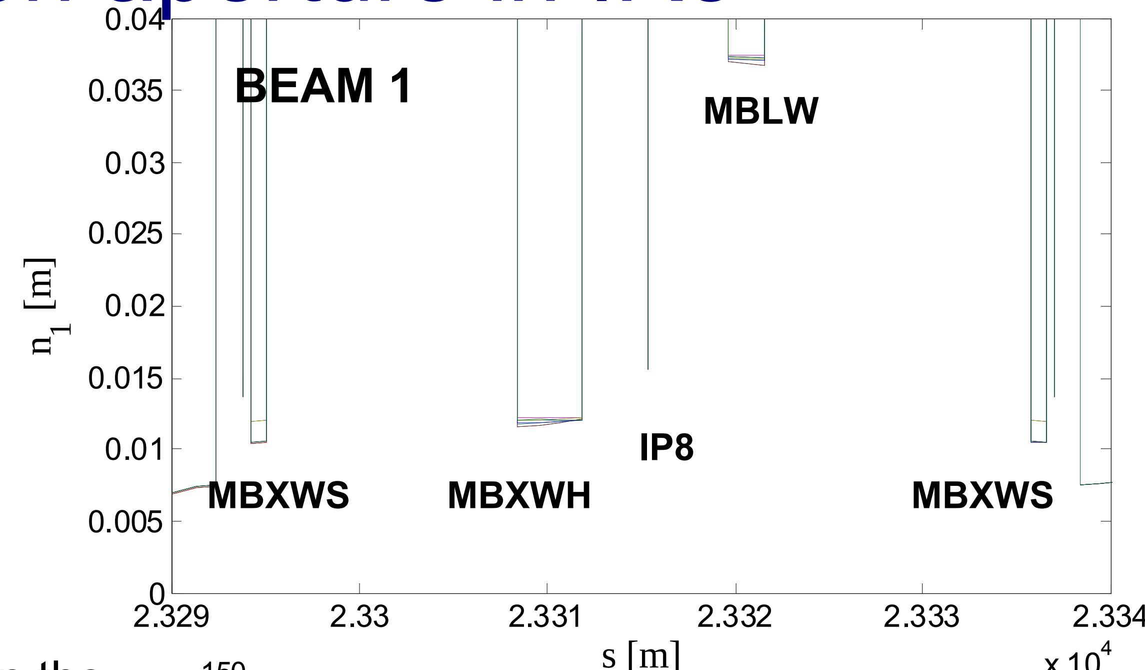


Equipment	Aperture [m]	β [m]
BPMSW.1L8	0.030	57
MBXWS.1L8	0.026	55 - 52
MBXWH.1L8	0.026	15 - 12
IP8	0.030	10
MBLW.1R8	0.064	12 - 14
MBXWS.1R8	0.026	52 - 55
BPMSW.1R8	0.030	57

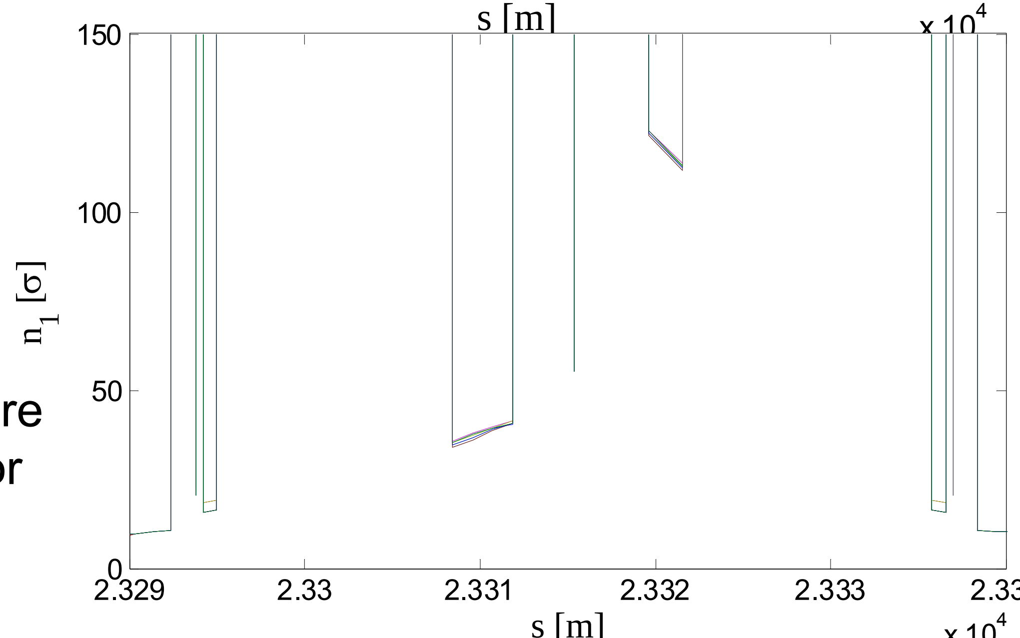
- Internal crossing angle of ±135μrad in the horizontal plane (maximum deflection of ±0.6mm at MBXWH)
- External crossing angle does not follow spectrometer dipole polarity

Nominal injection aperture in IR8

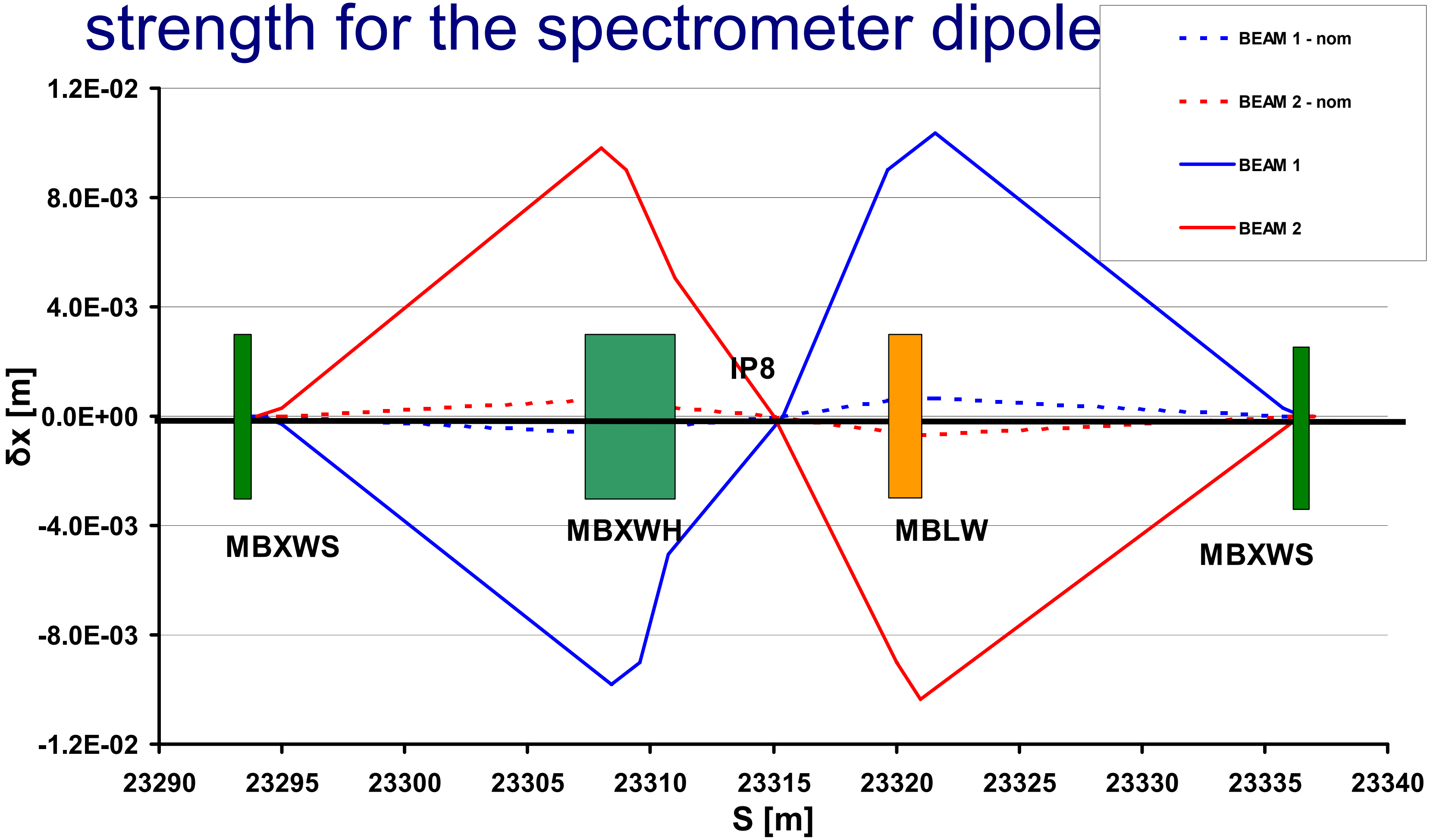
Equipment	n_1 [σ]	n_1 [m]	n_1 [%]
BPMSW.1L8	**20**	**0.014**	**45**
MBXWS.1L8	**16**	**0.010**	**40**
MBXWH.1L8	**34**	**0.012**	**45**
IP8	**56**	**0.016**	**52**
MBLW.1R8	**111**	**0.037**	**58**
MBXWS.1R8	**16**	**0.010**	**40**
BPMSW.1R8	**20**	**0.014**	**45**



- Differences with respect to IP2 on the 2nd compensator (smaller β) and spectrometer (smaller β and aperture)
- Aperture varies for less than 3σ between the scheme with only internal and full crossing scheme
- Around 50-60% of the available aperture is lost for all compensators and 40% for the spectrometer



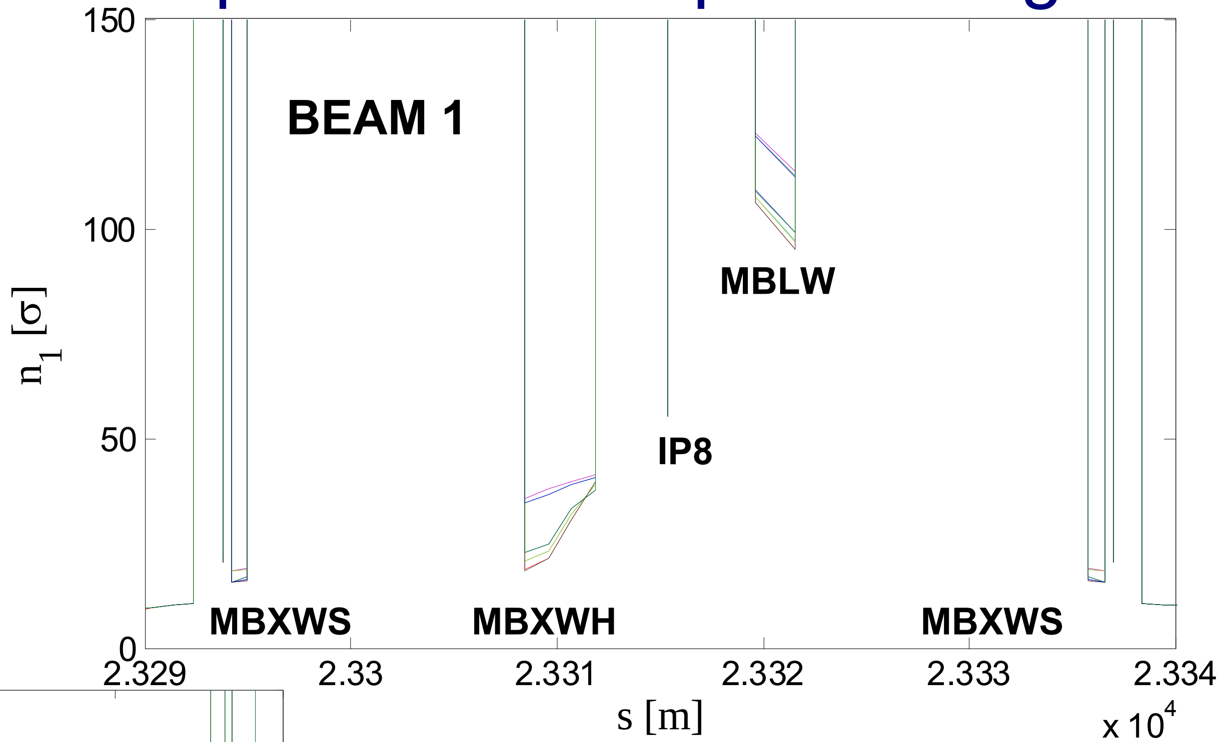
Internal crossing bump of IR8 with collision strength for the spectrometer dipole

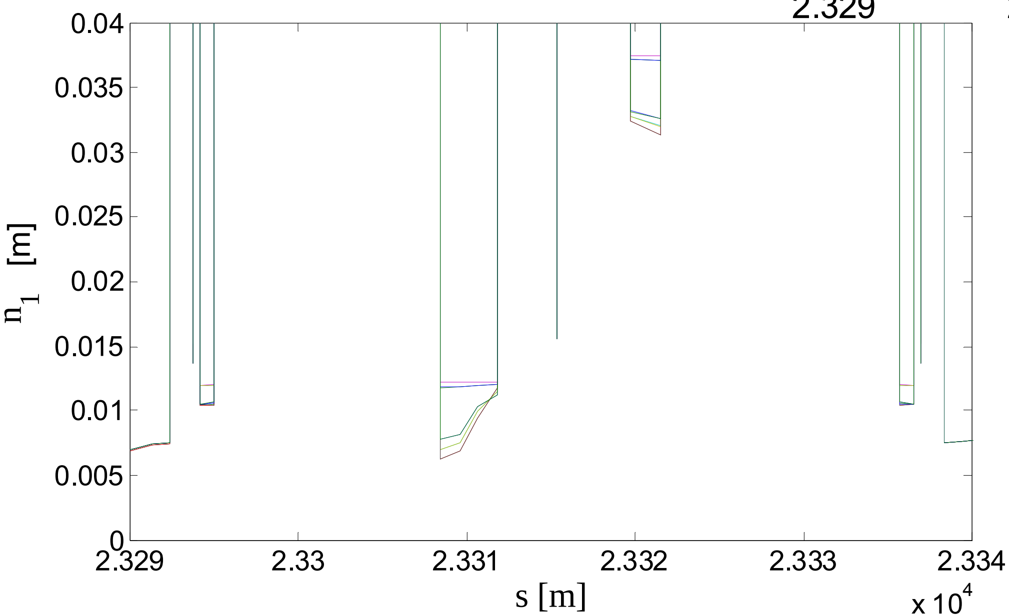


- Internal crossing angle of ±2100μrad in the horizontal plane!
- Deflection of ±0.010m at MBXWH, corresponding to 29σ, as compared to 0.0006m (2σ) of the nominal bump

Aperture in IR8 with full spectrometer dipole strength

- When crossing angle is added beam excursion of 0.011m (33σ) at MBXWH, as compared to 0.0004m (6σ) for the nominal scheme
- When polarity and external crossing angle sign are mismatched, two additional crossings occur ~15m left and right of the IP (in total 4 crossings)





- Biggest loss in aperture around MBXWH
- n_1 correspond to even smaller values than MBWXS in mm

Aperture loss in IR8 by element

Equipment	n_1 nominal [σ]	n_1 full [σ]	n_1 nominal [m]	n_1 full [m]	n_1 nominal [%]	n_1 full [%]
BPMSW.1L8	20	20	0.014	0.014	45	45
MBXWS.1L8	16	16	0.010	0.010	40	40
MBXWH.1L8	34	19	0.012	0.006	45	24
IP8	56	56	0.016	0.015	52	52
MBLW.1R8	111	95	0.037	0.031	58	50
MBXWS.1R8	16	16	0.010	0.010	40	40
BPMSW.1R8	20	20	0.014	0.014	45	45

- Not important impact in any element apart MBXWH
  - Available aperture of 6mm (with respect to 12mm), corresponding to 15σ of aperture loss
  - Remaining aperture corresponds 24% of the available

Aperture loss in IR2 by element

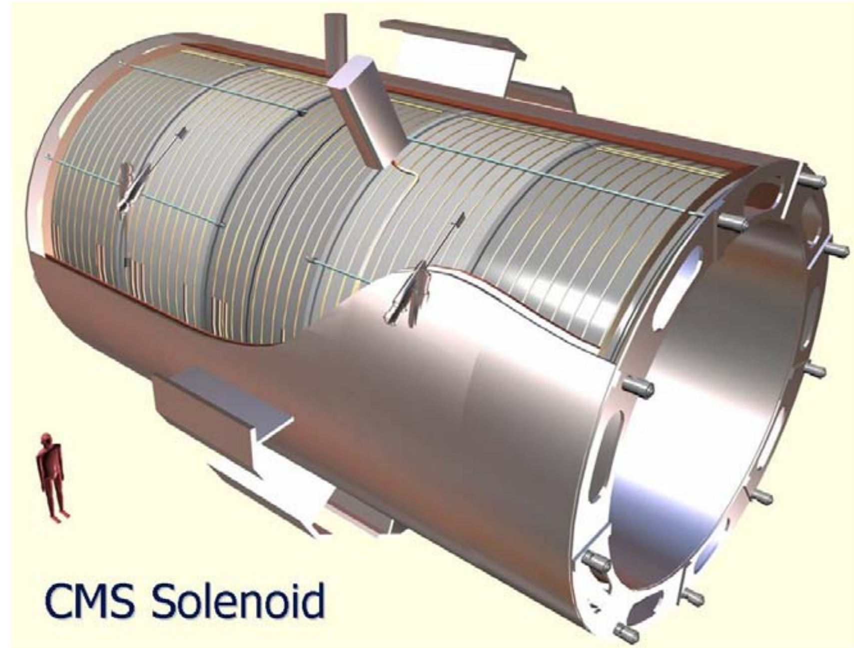
Equipment	n_1 nominal [σ]	n_1 full [σ]	n_1 nominal [m]	n_1 full [m]	n_1 nominal [%]	n_1 full [%]
BPMSW.1L2	**20**	**20**	**0.014**	**0.014**	**47**	**47**
MBXWT.1L2	**17**	**17**	**0.011**	**0.011**	**42**	**42**
MBWMD.1L2	**33**	**20**	**0.014**	**0.009**	**47**	**30**
IP2	**53**	**53**	**0.015**	**0.015**	**52**	**52**
MBAW.1R2	**221**	**217**	**0.093**	**0.088**	**62**	**58**
MBXWT.1R2	**17**	**17**	**0.011**	**0.011**	**42**	**42**
BPMSW.1R2	**20**	**20**	**0.014**	**0.014**	**47**	**47**

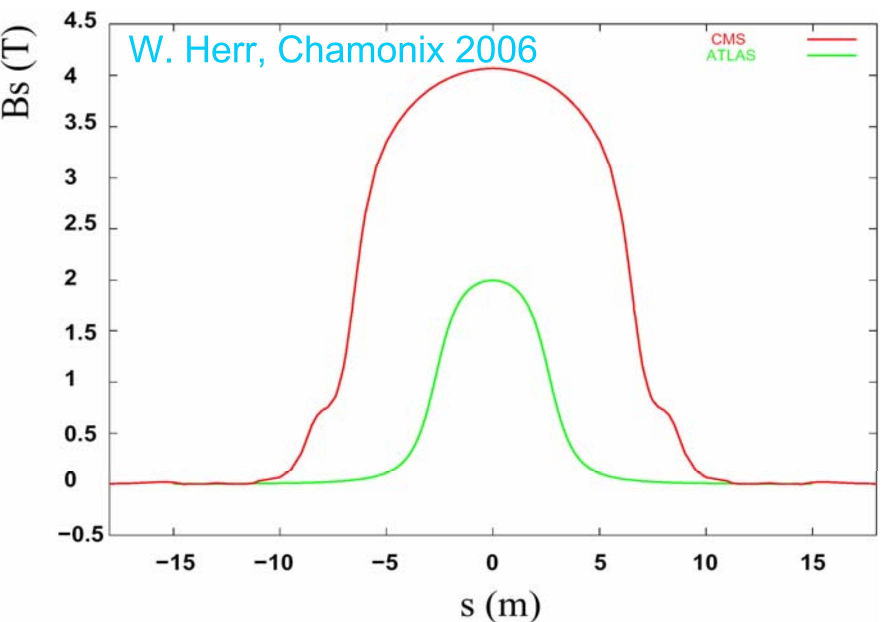
- Not important impact in any element apart MBWMD
  - Available aperture of 9mm (with respect to 14mm), corresponding to 13σ of aperture loss
  - Remaining aperture is 30% of the available
- **In conclusion:**
  - Possible during 450GeV collision run but not while injecting
  - For 450 GeV injection run the nominal scheme is kept (magnets should be ramped)

External crossing angles

- Even if external crossing angles are not needed for stage I (43 bunch operation), it would be useful to pre-commission them for facilitating the task in a later stage (already done during 450 GeV collisions' run for IR2 and IR8)
- Certainly not a priority for IR1 and IR5
- Use one beam at a time, without separation bumps and internal crossing angles
- Step by step increase of the crossing angle and position measurements, until reaching nominal
- Switch on the experimental magnet and check effects on orbit, coupling and tune-shift
- Repeat procedure for opposite sign angle
- Add beam separation, measure optics and aperture and repeat with internal crossing angle, for both compensator polarities
- Add all three and measure aperture and optics
- Inject both beams, collapse the separation bump and measure luminosity

ATLAS and CMS experimental solenoids

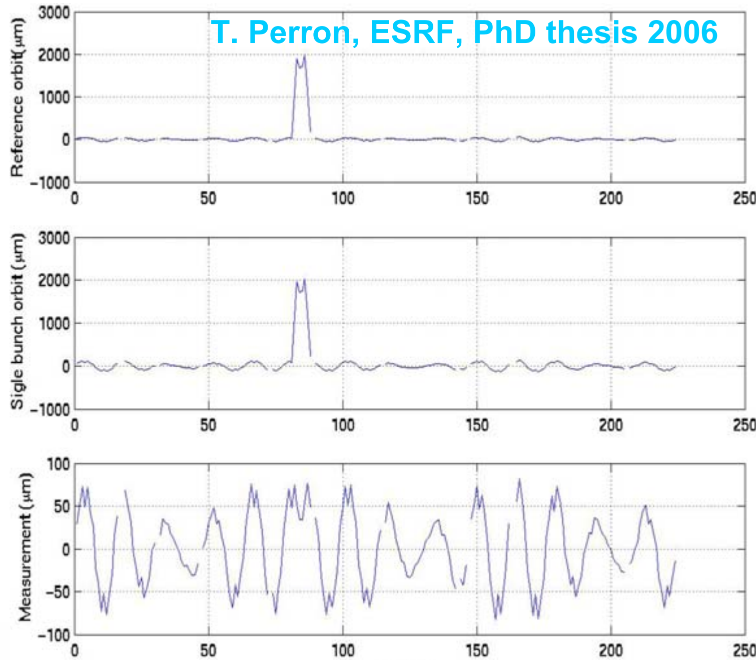


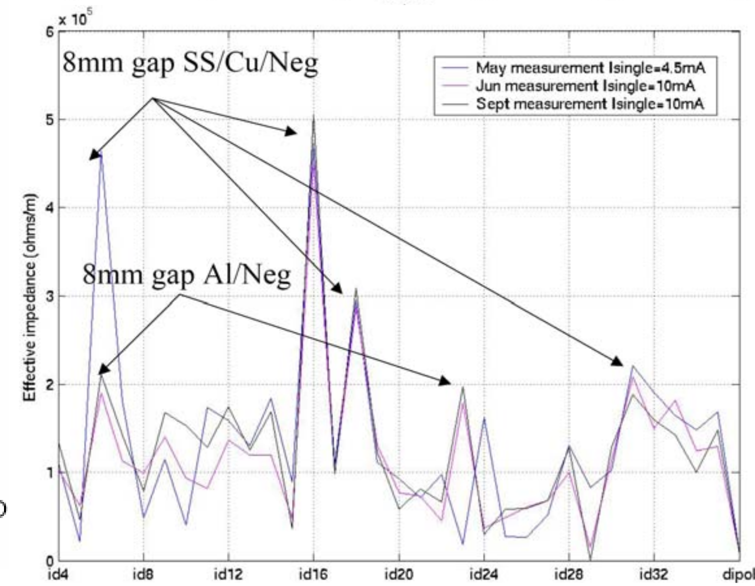


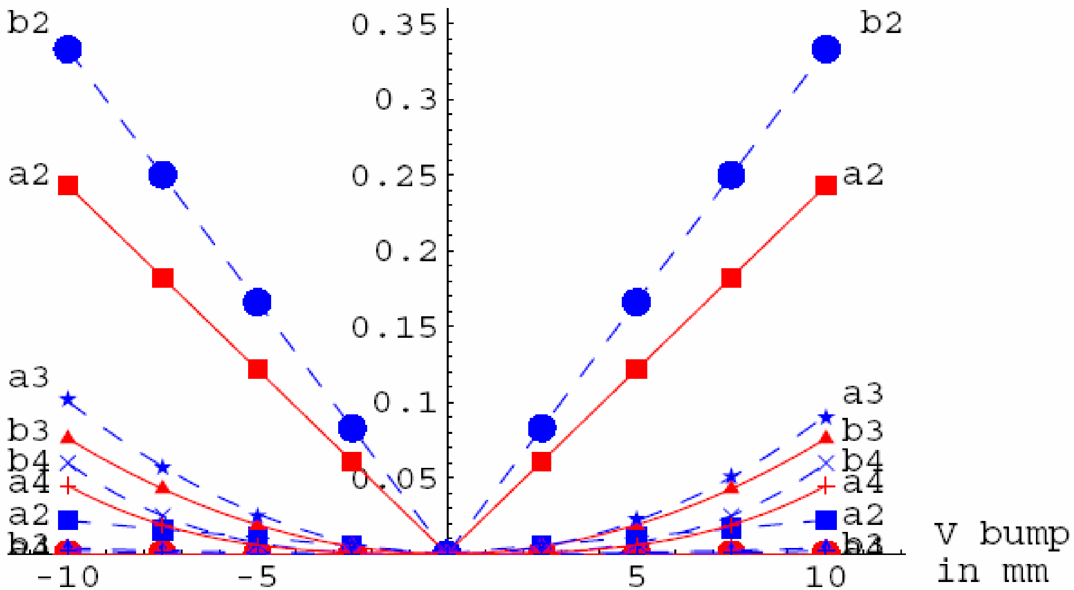
- 5.3m-long ATLAS solenoid, providing a 2T maximum field
- 13.2m-long CMS solenoid, providing a 4T maximum field
- Produce orbit, coupling and focusing
- Especially CMS solenoid produces a 5μrad vertical deflection (~0.1mm rms orbit distortion) in the presence of crossing angle

Other possible measurements with bumps

- Identification of IR triplet errors with 3-bumps around the triplets
- Measurement of long range beam beam effects
  - Varying the amplitude of the separation bump for different bunch currents
  - Same approach with the crossing angle for different filling patterns
- Impedance measurements
  - Sliding bumps of variable amplitude and measurement of the orbit kick induced on the beam for several beam currents
- **Not a priority for this commissioning stage**







J.P. Koutchouk F. Pilat, V. Ptytsin, PAC 2001

Time needed and measurement teams

- Very difficult to foresee and estimate how long each measurement may take as it will depend on
    - Status of the machine
    - Availability and calibration of different equipments
    - Availability of application software for automatic bump setting and position acquisition for a series of machine locations
    - Other unexpected problems (aperture bottlenecks, machine protection issues,…)
- Measurements teams
  - Aperture measurements
    - Colleagues from ABP and OP (collimation project)? Others?
- IR Bumps and crossing schemes
  - W. Herr, Y. Papaphilippou F. Zimmermann(ABP), OP, IR optics' responsibles
  - Colleagues from TeVatron and RHIC (LARP)

Summary

- Overview of IR optics in view of 450 GeV commissioning
  - IR aperture
  - Separation bumps
  - Internal crossing angles in IR2 and IR8
  - External crossing angles
- Aperture loss was evaluated in IR2 and IR8 when spectrometers are switched to their maximum value (LTC action) for the 450GeV collision run
- Follow-up may be needed for specific items
  - Establishing a commissioning procedure for bumps and crossing schemes
  - Application software development for IR bump commissioning