LHC Technical Committee

# Maximum crossing angle and spectrometer bump amplitudes for collisions at 450 GeV

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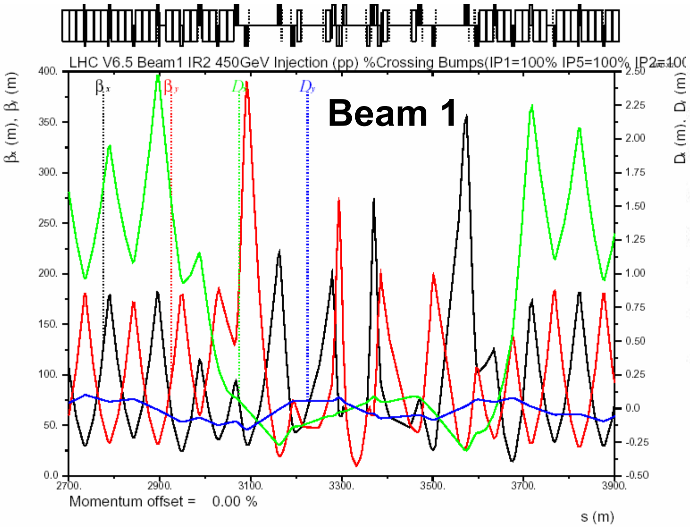
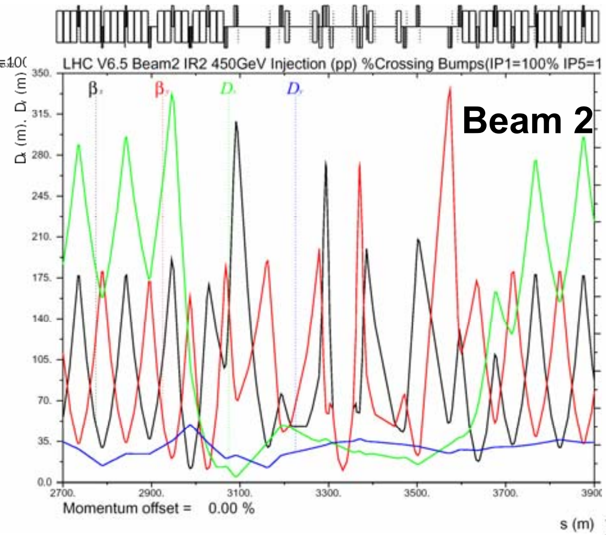
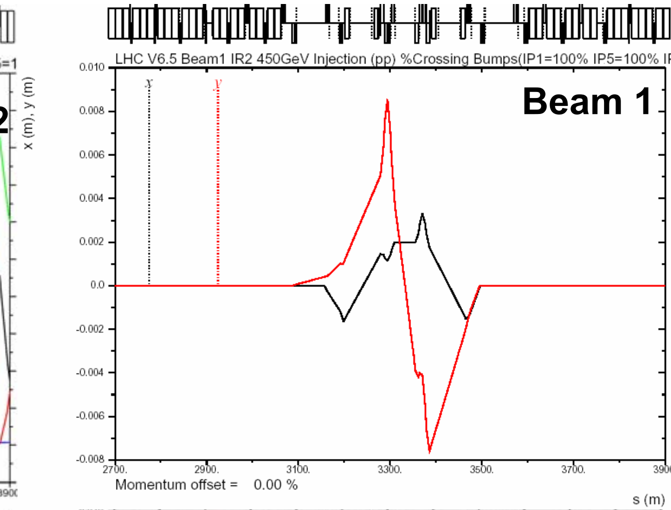
# Outline

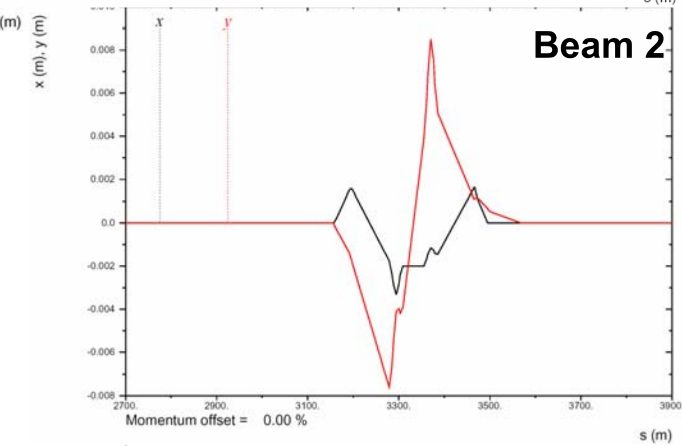
- LTC Action: Can the experimental spectrometer magnets of IR2 and IR8 have their maximum (corresponding to 7TeV) field during the **450 GeV collisions run?**
  - IR2/8 nominal injection optics and crossing schemes
  - IR2/8 spectrometer magnets and internal crossing angles
  - Nominal aperture with different crossing configurations
    - With/without external crossing, different spectrometer polarities and separation
  - Aperture loss when spectrometers are ramped to their maximum value at 450 GeV.
    - Analytical estimates and MADX simulations
  - Available aperture for the VELO detector in IR8
  - Compensator magnets failure considerations
  - Conclusions

# IR2 Injection optics (O. Brüning et al. LHC Project rep 367 – LHC design report 2004)



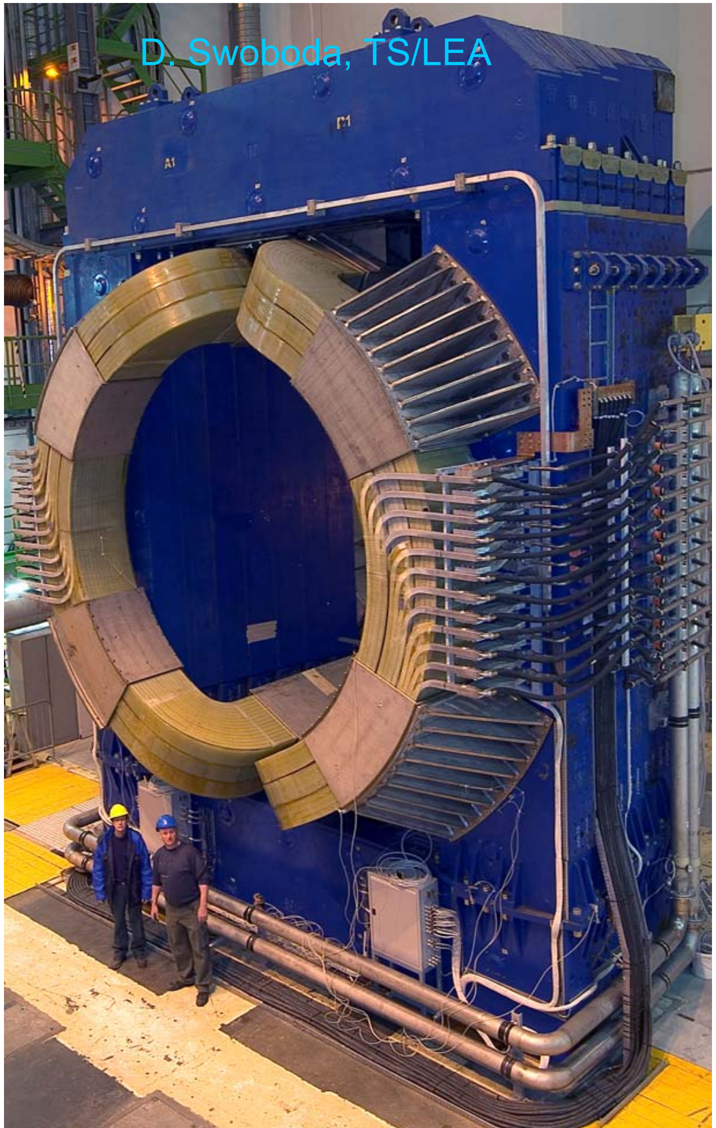



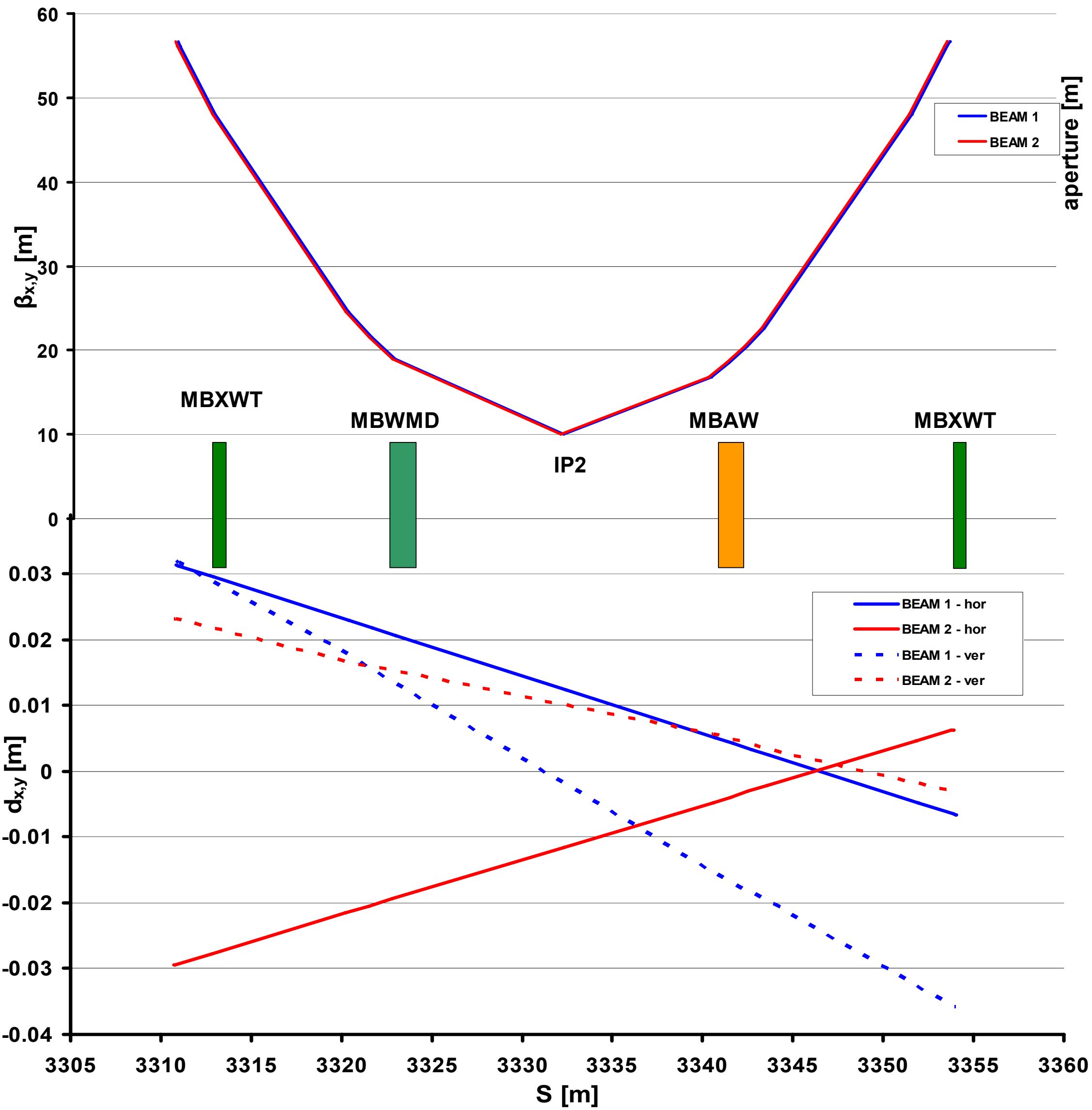

- β*=10m, vertical crossing angle of ±150μrad and horizontal parallel separation of ± 2mm
  - External angle of ±80μrad for reducing the long range beam-beam effect
  - Internal angle of ±70μrad for compensating spectrometer orbit distortion
  - Horizontal separation positive for Beam 1 and negative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

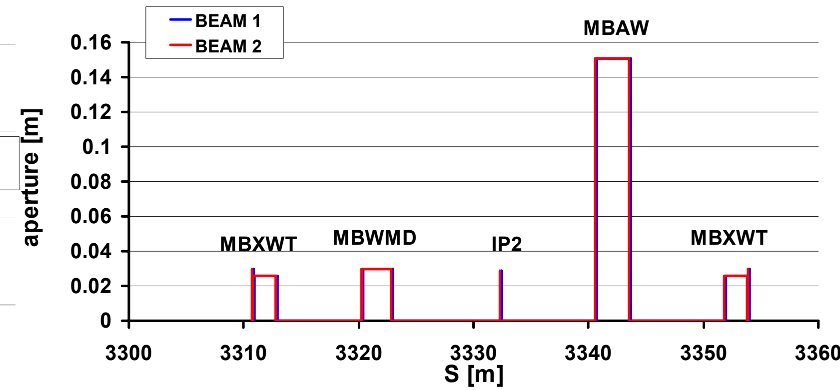
# ALICE dipole magnet and its compensators




- 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

# Injection optics around IR2

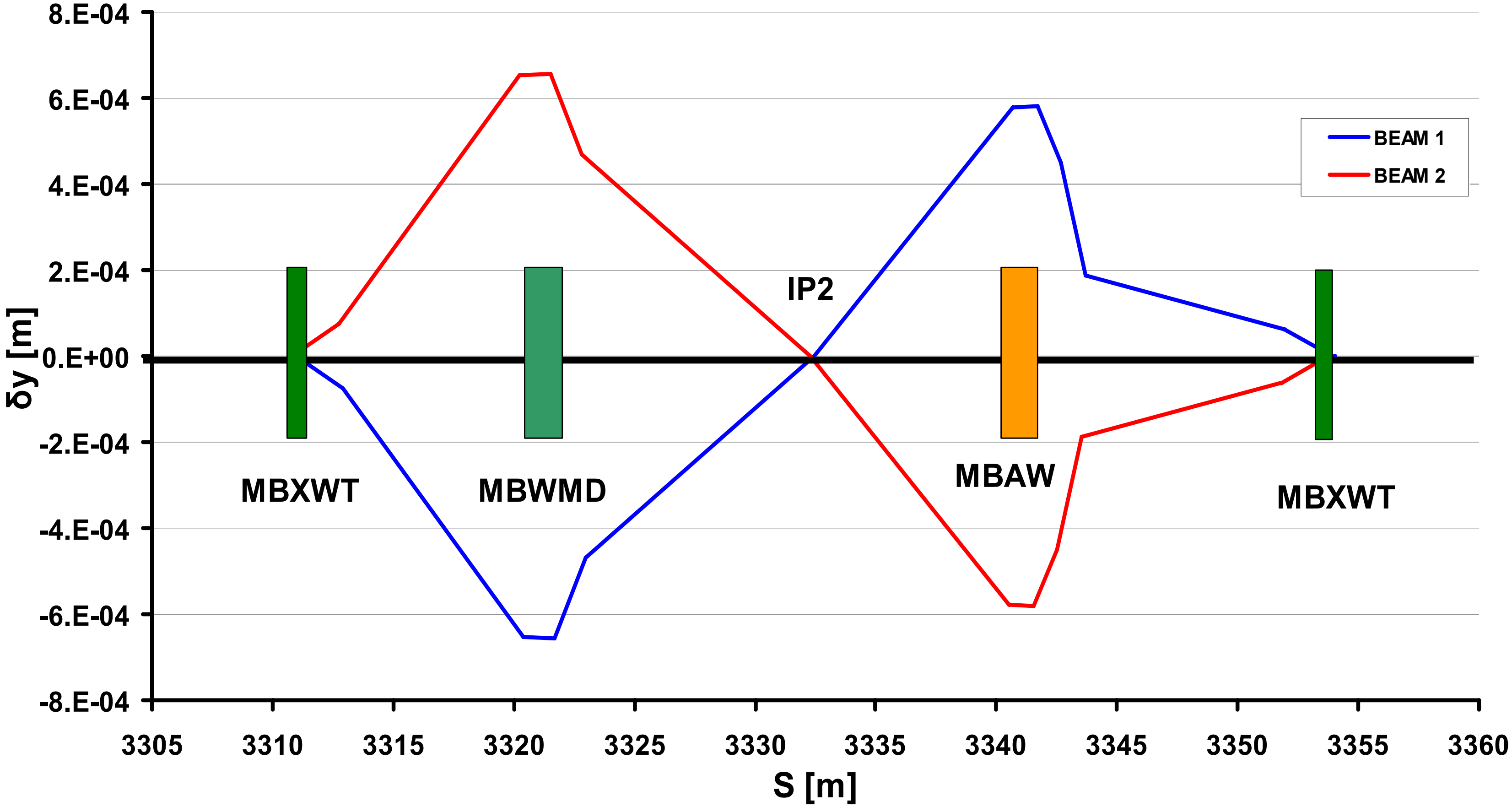



| Equipment | Aperture [mm] | β [m] |
|---|---|---|
| BPMSW.1L2 | **30** | **57** |
| MBXWT.1L2 | **26** | **56 - 48** |
| MBWMD.1L2 | **30** | **24 - 19** |
| IP2 | **29** | **10** |
| MBAW.1R2 | **151** | **17 - 23** |
| MBXWT.1R2 | **26** | **48 - 56** |
| BPMSW.1R2 | **30** | **57** |

- Beam size varies between 0.8 and 0.3mm
- The dispersion is smaller than a few cm

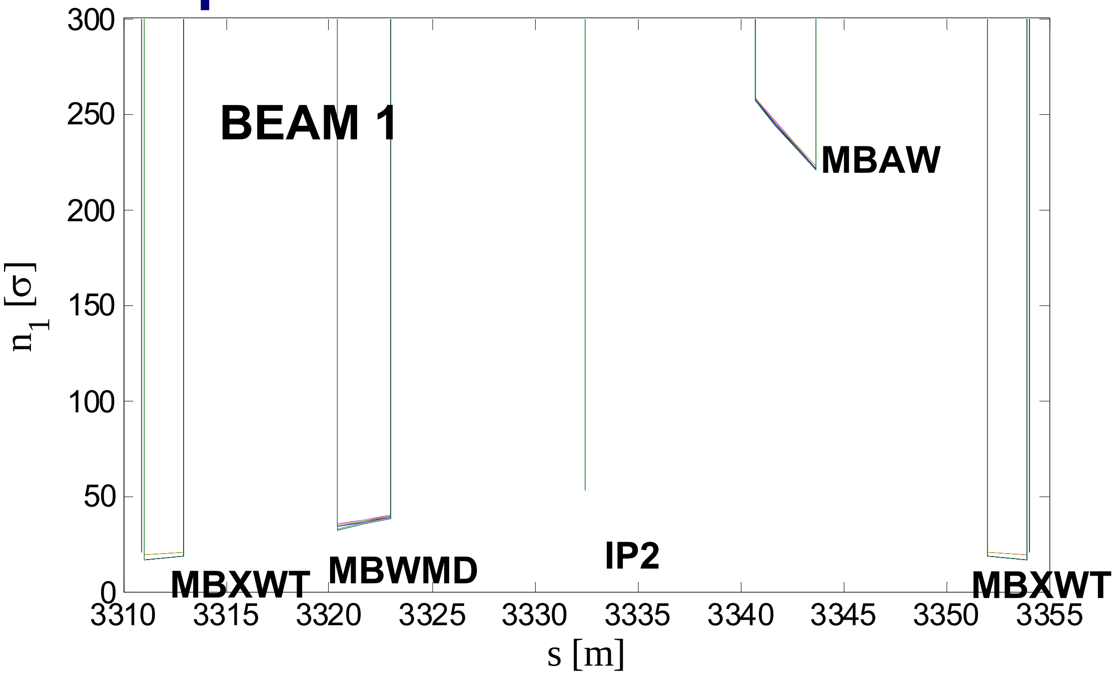
# Internal crossing bump of IR2




- Internal crossing angle of ±70μrad in the vertical plane (maximum deflection of ±0.7mm at **MBWMD**)
- External crossing angle follows spectrometer dipole polarity

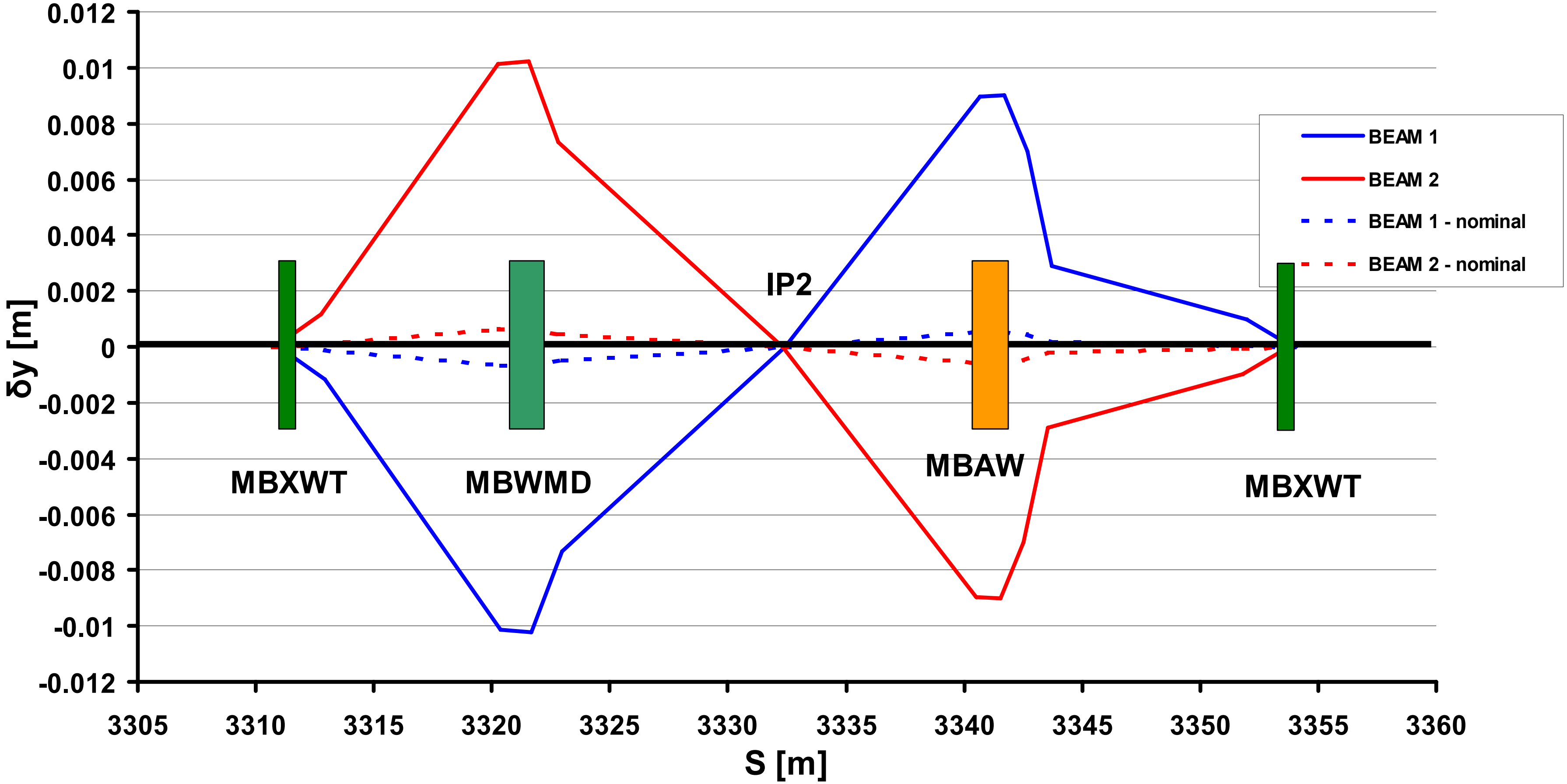
# Nominal injection aperture in IR2

| Equipment | $n_1$ [σ] | $n_1$ [mm] | $n_1$ [%] |
|---|---|---|---|
| BPMSW.1L2 | **20** | **14** | **47** |
| MBXWT.1L2 | **17** | **11** | **42** |
| MBWMD.1L2 | **33** | **14** | **47** |
| IP2 | **53** | **15** | **52** |
| MBAW.1R2 | **221** | **93** | **58** |
| MBXWT.1R2 | **17** | **11** | **42** |
| BPMSW.1R2 | **20** | **14** | **47** |




- Aperture is computed taking into account nominal tolerances (see LHC Design report 2004)
  - β-beating of 20%, spurious dispersion of 0.27, momentum offset of 0.15%, peak closed orbit of 4mm and mechanical tolerances for each magnet
- Different scenarios are considered
  - ± or no external crossing angle, ± internal crossing angle, with/without separation bump
  - Aperture varies for less than 3σ among the different cases and for both beams
- Around 50% of the available aperture is lost in all compensators and 40% in the spectrometer (but a lot of margin in that area)

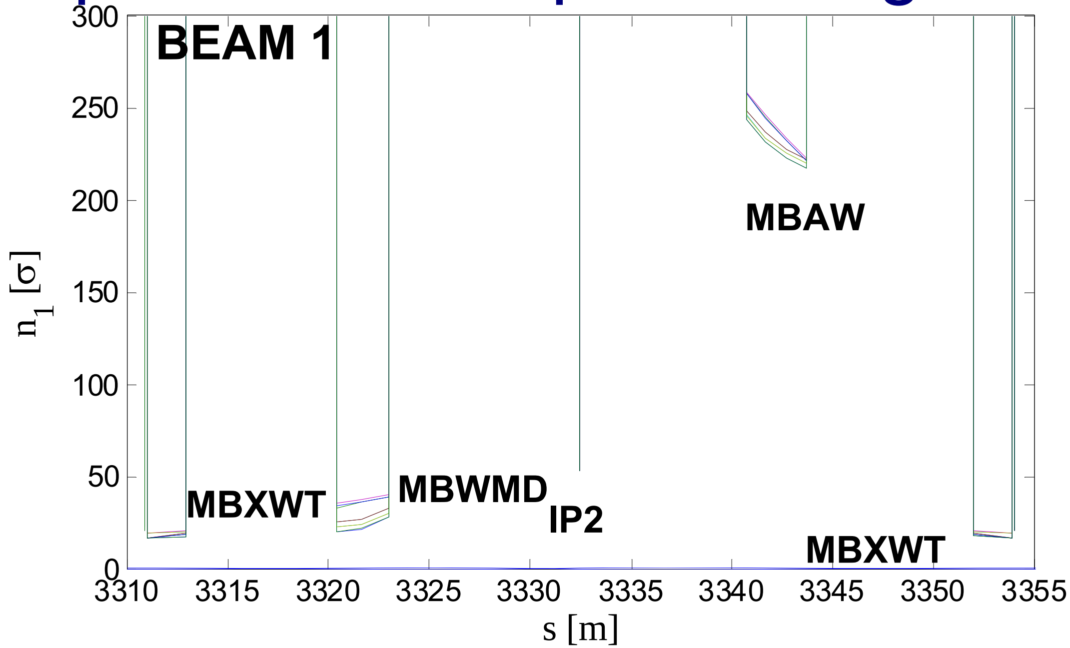
# Internal crossing bump of IR2 with collision strength for the spectrometer dipole




- Internal crossing angle of **±1.1mrad** in the vertical plane
- Maximum deflection of **±11mm** at **MBWMD**, corresponding to **25σ**, as compared to **±0.65mm (1.6σ)** of the nominal injection bump

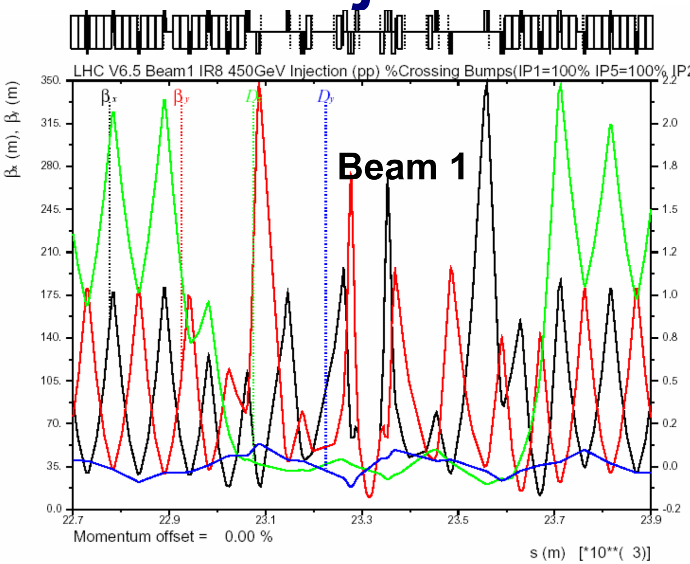
# Aperture in IR2 with full spectrometer dipole strength

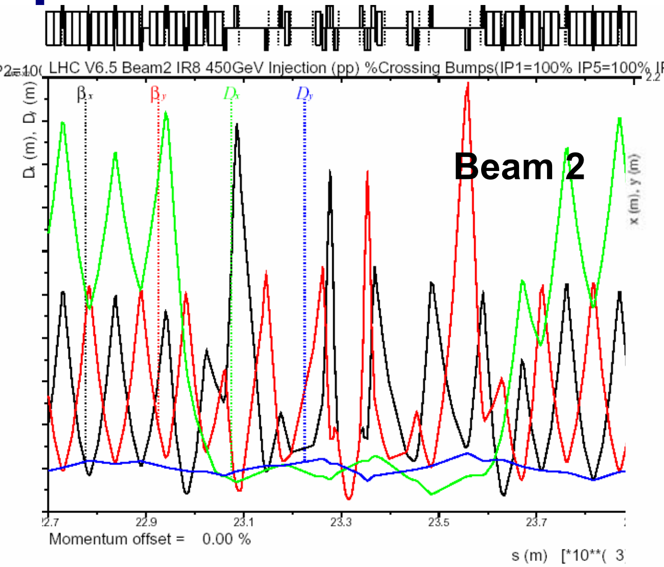
- Not important impact in any element apart **MBWMD**
  - Available aperture of 9mm (with respect to 14mm), corresponding to 13σ of aperture loss
  - Remaining aperture is 30% of the available

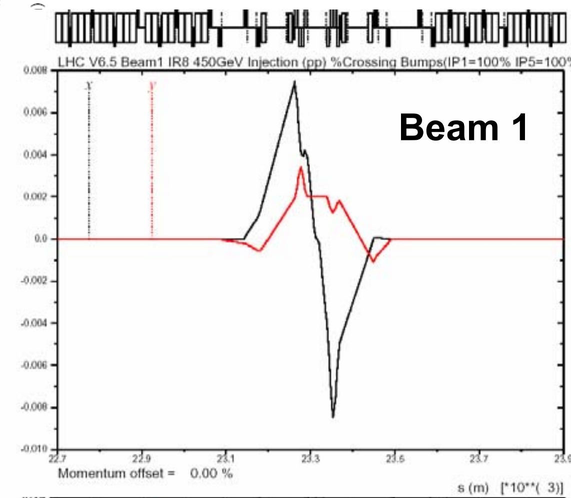


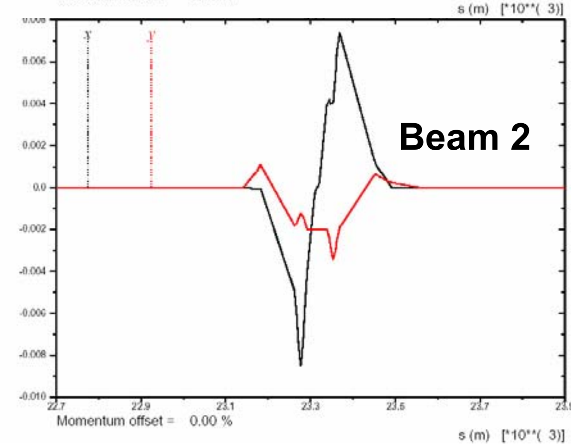

| Equipment | $n_1$ nominal [σ] | $n_1$ full [σ] | $n_1$ nominal [mm] | $n_1$ full [mm] | $n_1$ nominal [%] | $n_1$ full [%] |
|---|---|---|---|---|---|---|
| BPMSW.1L2 | 20 | 20 | 14 | 14 | 47 | 47 |
| MBXWT.1L2 | 17 | 17 | 11 | 11 | 42 | 42 |
| MBWMD.1L2 | 33 | 20 | 14 | 9 | 47 | 30 |
| IP2 | 53 | 53 | 15 | 15 | 52 | 52 |
| MBAW.1R2 | 221 | 217 | 93 | 88 | 62 | 58 |
| MBXWT.1R2 | 17 | 17 | 11 | 11 | 42 | 42 |
| BPMSW.1R2 | 20 | 20 | 14 | 14 | 47 | 47 |

# IR8 Injection optics (O. Brüning et al. LHC Project rep 367 – LHC design report 2004)



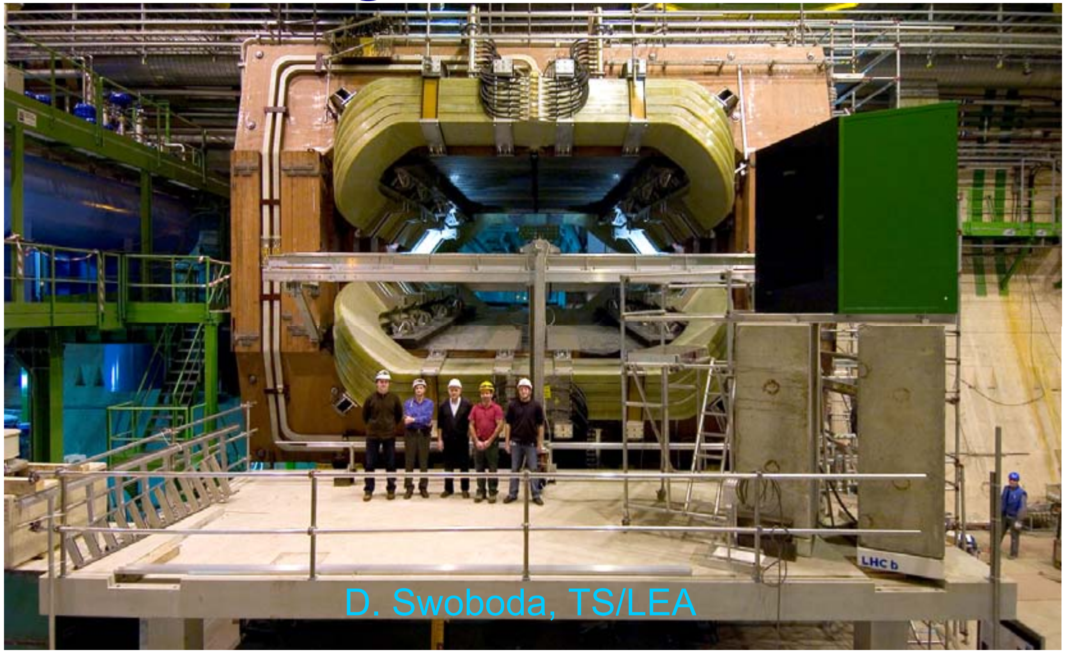



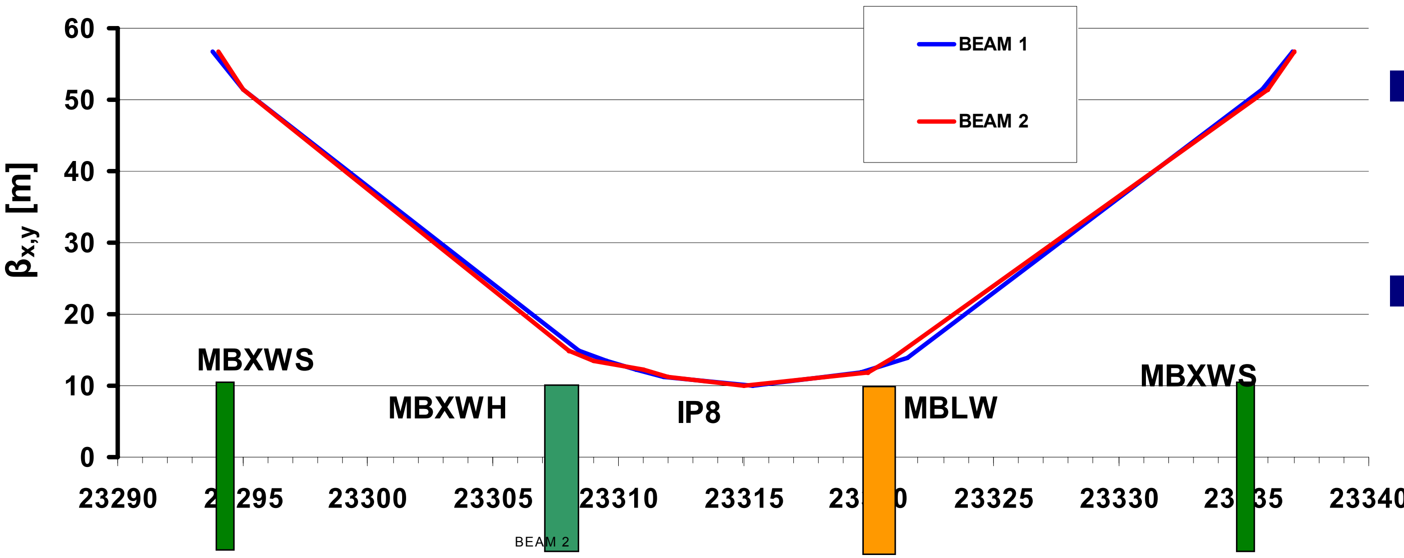

- $\beta^*$=10m, horizontal crossing angle of ±200 or ±75 μrad depending on spectrometer polarity and vertical parallel separation of ±2mm
  - External angle of ±65 (- polarity) or ±210 μrad (+ polarity)
  - Internal angle of ±135 μrad for compensating spectrometer orbit distortion
  - Horizontal crossing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

# LHCb dipole magnet

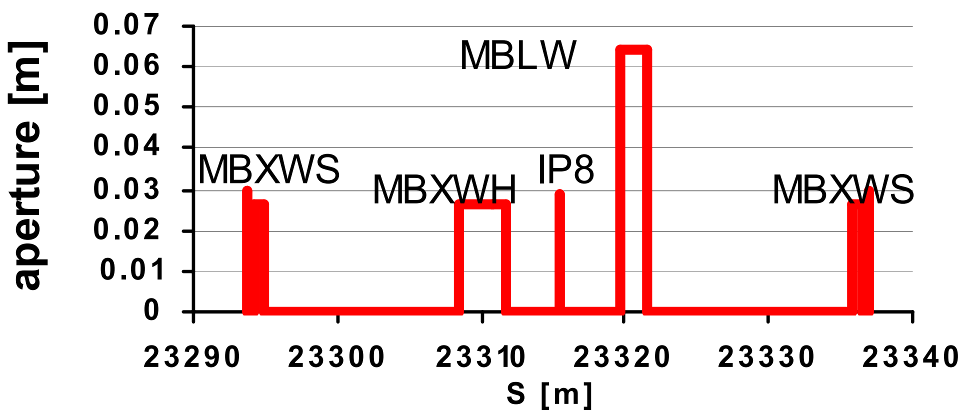



- 1.9m-long spectrometer dipole (**MBLW**) @ 4.9m to the right of the IP
- Horizontal deflection with nominal integrated field of 4.2Tm (deflection of 180μrad @ 7TeV)
- The resulting orbit deflection is compensated by three dipole magnets
  - Two 0.8m-long magnets of type **MBXWS** @ 20m left and right 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

# Injection optics around the IR8

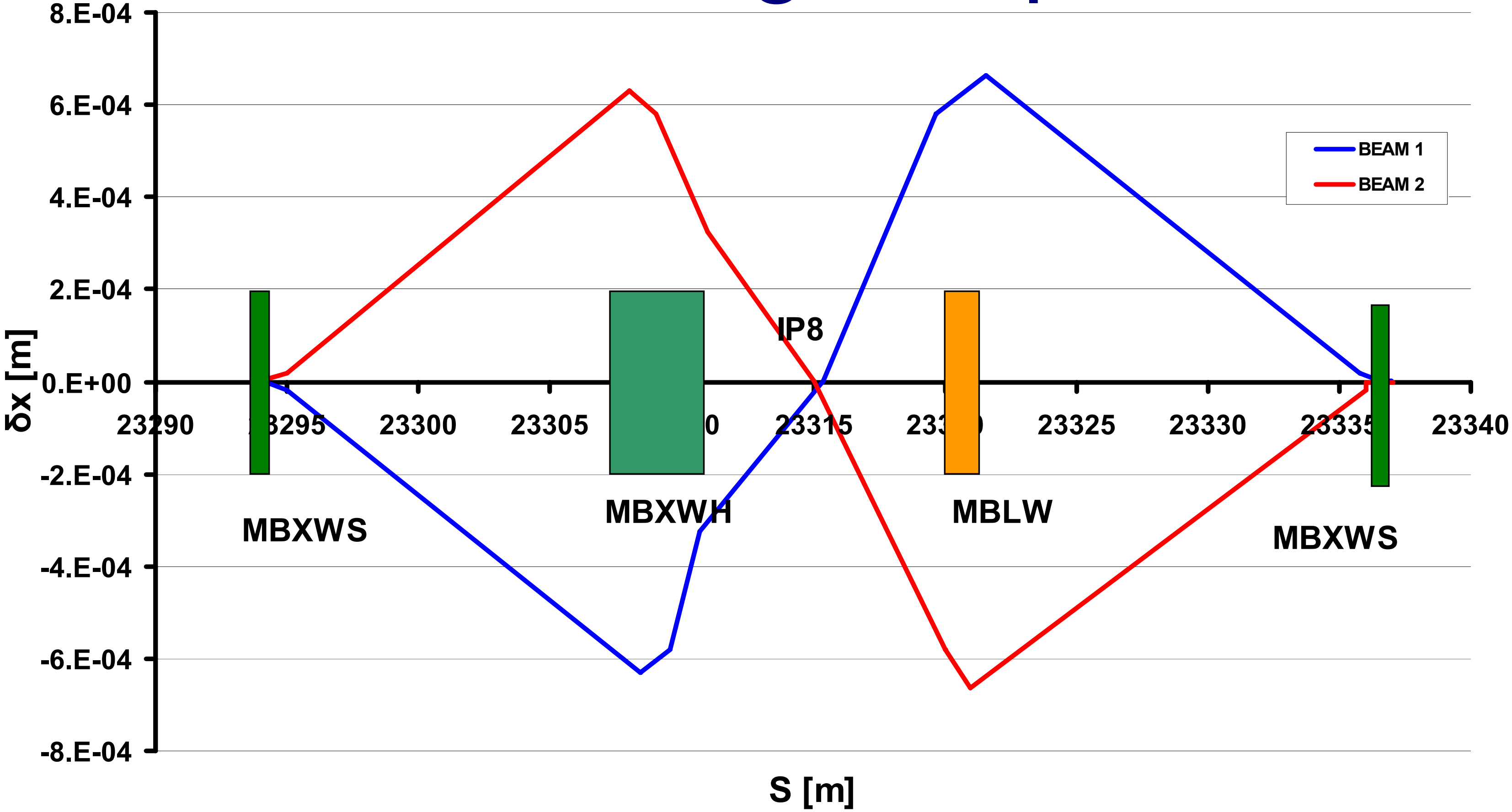



- Beam size varies between 0.7 and 0.3mm
- The dispersion is smaller than a few cm, as in IR2




| Equipment | Aperture [mm] | β [m] |
|---|---|---|
| BPMSW.1L8 | 30 | 57 |
| MBXWS.1L8 | 26 | 55 - 52 |
| MBXWH.1L8 | 26 | 15 - 12 |
| IP8 | 30 | 10 |
| MBLW.1R8 | 64 | 12 - 14 |
| MBXWS.1R8 | 26 | 52 - 55 |
| BPMSW.1R8 | 30 | 57 |

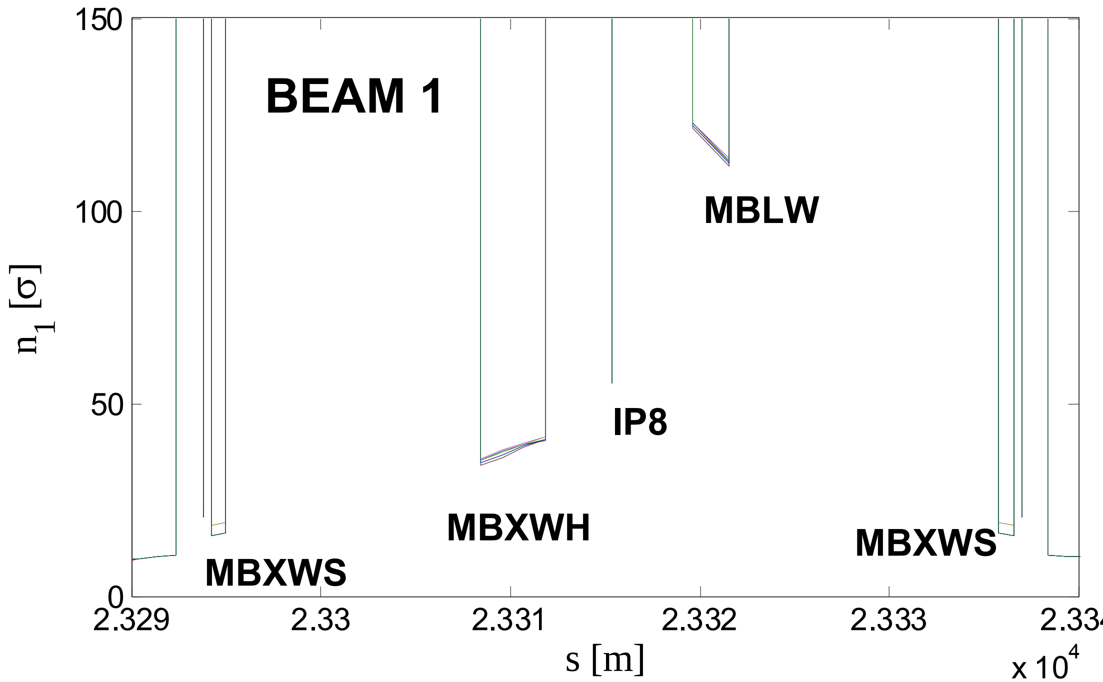
# Internal crossing bump of IR8




- 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

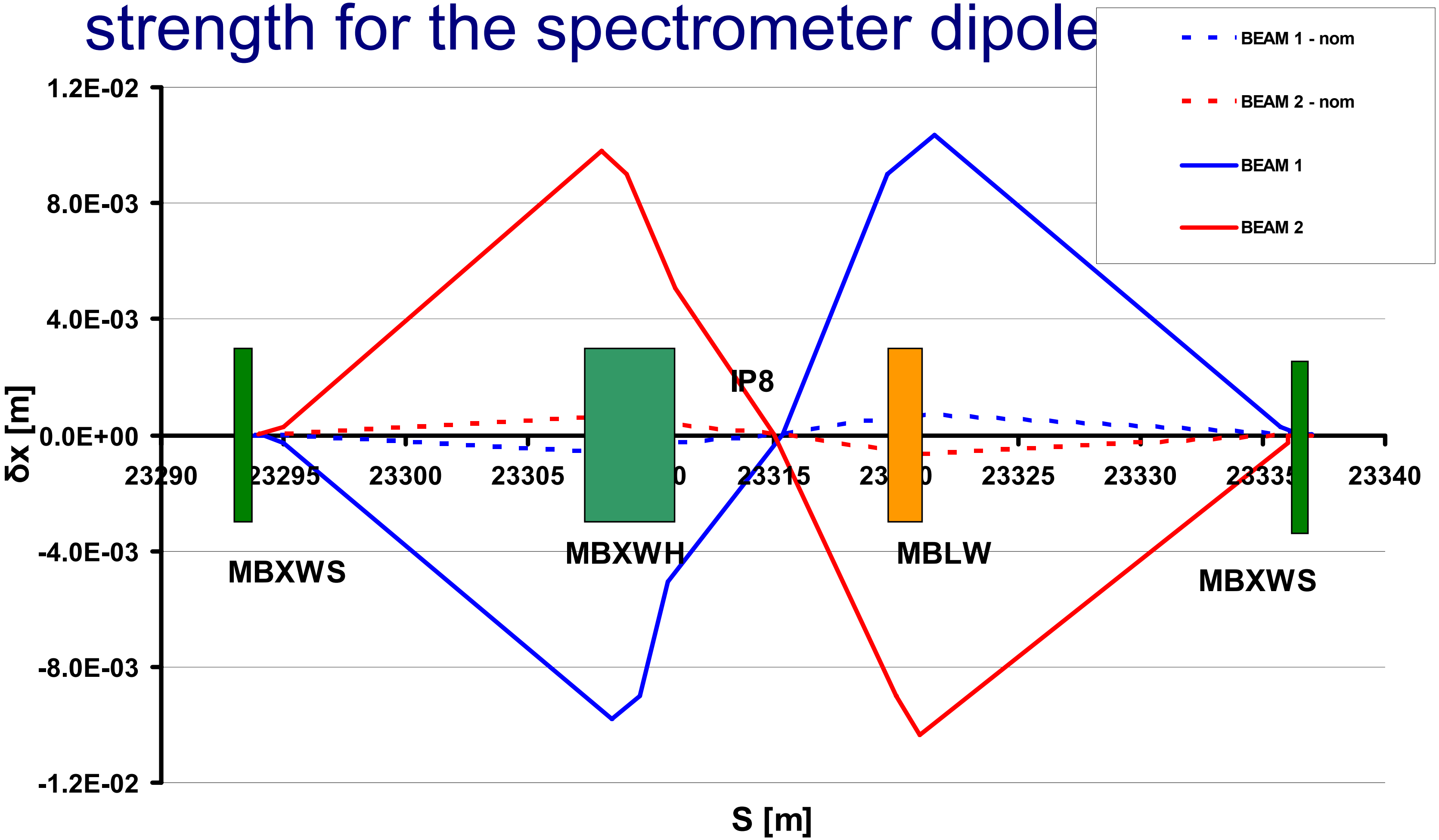
# Nominal injection aperture in IR8

| Equipment | $n_1$ [σ] | $n_1$ [mm] | $n_1$ [%] |
|---|---|---|---|
| BPMSW.1L8 | **20** | **14** | **45** |
| MBXWS.1L8 | **16** | **10** | **40** |
| MBXWH.1L8 | **34** | **12** | **45** |
| IP8 | **56** | **16** | **52** |
| MBLW.1R8 | **111** | **37** | **58** |
| MBXWS.1R8 | **16** | **10** | **40** |
| BPMSW.1R8 | **20** | **14** | **45** |




- Aperture is computed taking into account the nominal tolerances and the scenarios studied for IR2
- Differences with respect to IR2 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 complete crossing scheme and for both beams and separation polarities
- Around 50-60% of the available aperture is lost for all compensators and 40% for the spectrometer

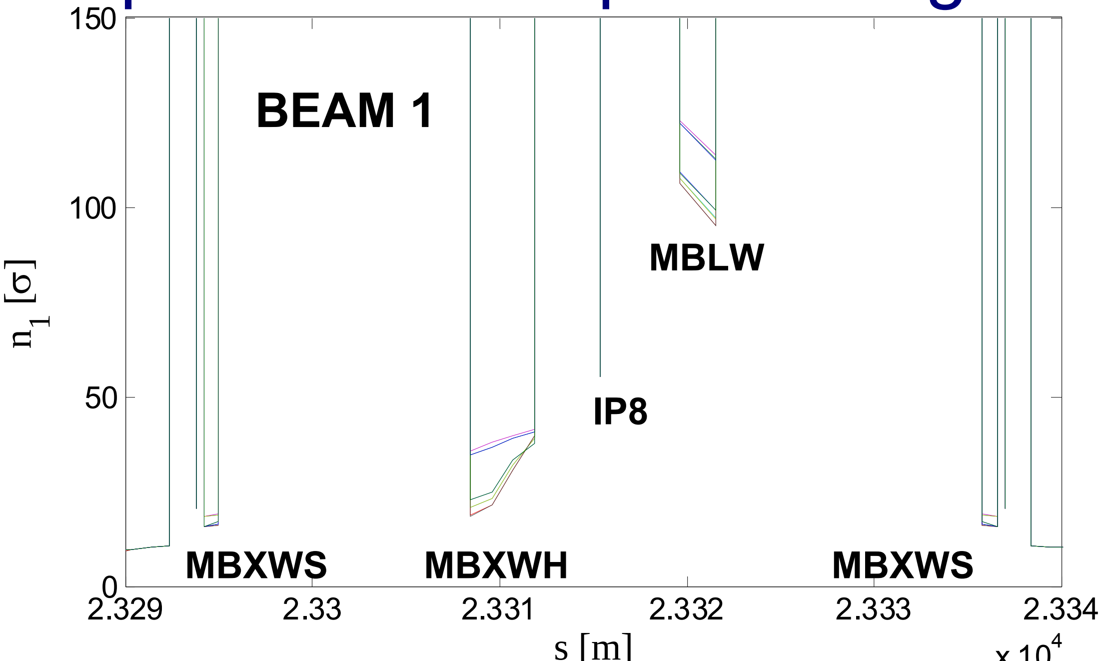
# Internal crossing bump of IR8 with collision strength for the spectrometer dipole




- Internal crossing angle of **±2.1mrad** in the horizontal plane
- Deflection of **10mm** at MBXWH, corresponding to **29σ**, as compared to **0.6mm** (**2σ**) of the nominal bump

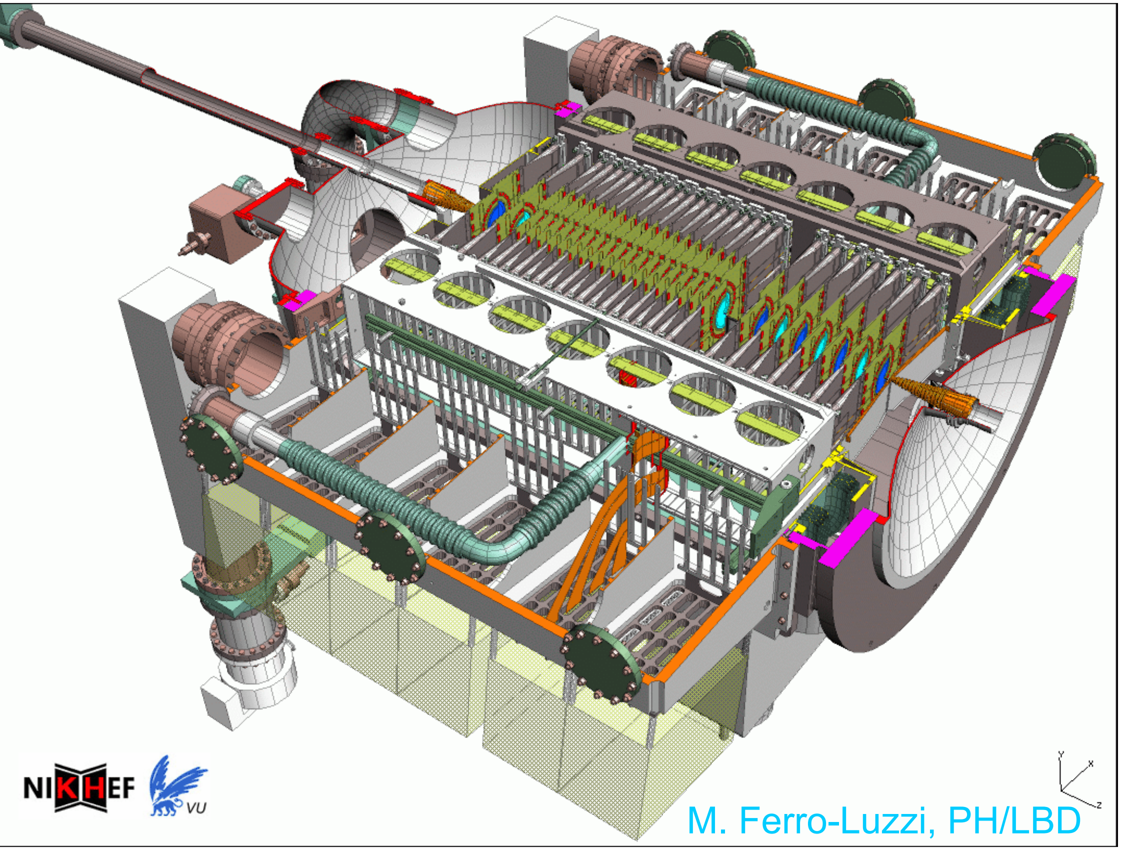
# Aperture in IR8 with full spectrometer dipole strength

- 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



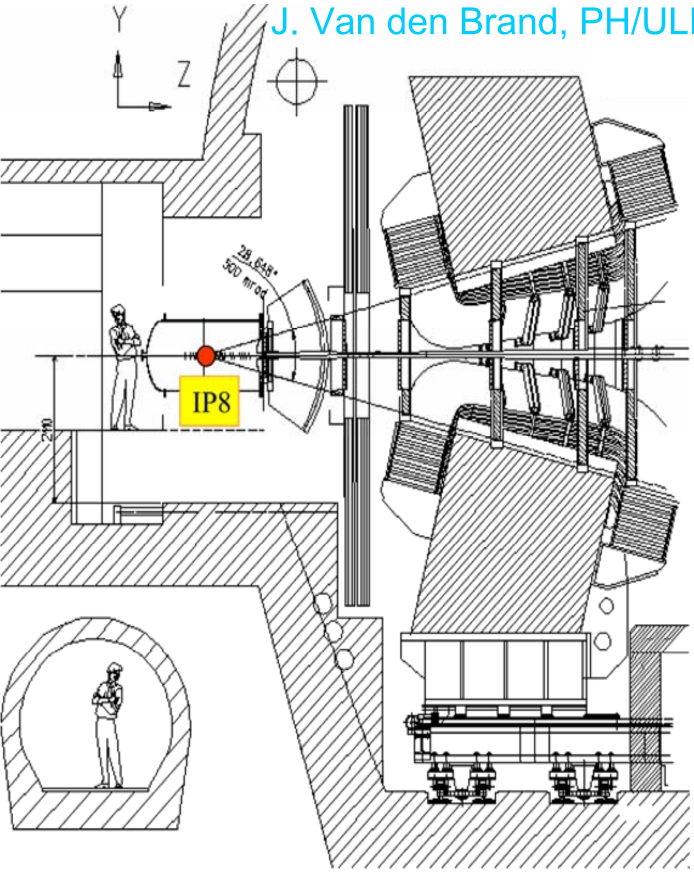

| Equipment | $n_1$ nominal [σ] | $n_1$ full [σ] | $n_1$ nominal [m] | $n_1$ full [m] | $n_1$ nominal [%] | $n_1$ full [%] |
|---|---|---|---|---|---|---|
| BPMSW.1L8 | 20 | 20 | 0.014 | 0.014 | 45 | 45 |
| MBXWS.1L8 | 16 | 16 | 0.010 | 0.010 | 40 | 40 |
| MBXWH.1L8 | 34 | 19 | 0.012 | 0.006 | 45 | 24 |
| 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 |

# VErtex Locator in LHCb




- Used for precise localization of track coordinates close to the interaction region in order to reconstruct production and decay vertices of b-hadrons
- Surrounding IP8 (from **~0.35m** left to **0.75m** right)
- Series of retractable silicon sensors closing down to an aperture of **5mm** radius
- Sensor boxes can be centered around the beam by moving laterally (by **30mm**) and up or down (by **5mm**)
- Ability to locate precisely the beam position from beam gas events
- The experiment is interested in closing the VELO to its minimum aperture during the 450 GeV collisions' run, for calibration purposes

# Simple considerations regarding aperture



J. Van den Brand, PH/ULB

- β-function of 10.07m at right side of VELO
- Beam size of **0.28mm** at injection (**0.07mm** at collision)
  - VELO minimum aperture of **5mm** corresponds to **18σ** (as compared to **72σ** at collision)
  - **7σ** tolerance corresponds to **2mm** (**0.49mm** @ 7TeV)
  - For nominal crossing angle of **±135μrad**, horizontal displacement of **0.1mm** at VELO's right edge (**0.4σ**)
  - For extreme crossing angle of **±2.1mrad**, the horizontal displacement becomes **1.6mm** (**5.6σ**)
  - Peak orbit tolerance of **4mm** corresponds to **14.3σ**
  - "Magnet"-type mechanical tolerance of **2.2mm** corresponds to **7.7σ** (realistic tolerance of **0.2mm**)
- For no crossing and separation, the VELO aperture has to be bigger than **9mm**

- Including above tolerances and 20% for beta beating and spurious dispersion, the VELO radius has to be higher than **11mm** for extreme crossing angle and **9.5mm** for nominal
- Centring the VELO around the beam, allows further **4mm** of closure (**7mm** and **5.5mm**)

# Closure of the VELO for different scenarios

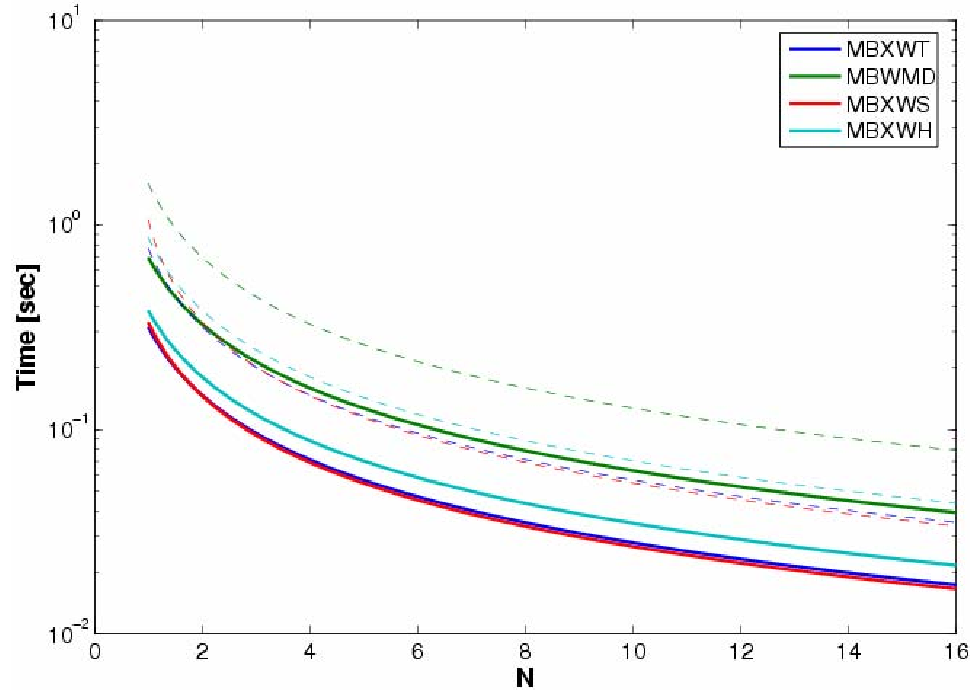
| Internal crossing angle [mrad] | VELO aperture at collision | VELO aperture with loose mechanical tolerances [mm] | | VELO aperture with tight mechanical tolerances [mm] | |
|---|---|---|---|---|---|
| | With CO tol. of 3mm | With CO tol. of 4mm | Without CO tol. | With CO tol. of 4mm | Without CO tol. |
| **2.1** | **-** | **11.1** | **7.1** | **9.1** | **5.1** |
| **0.135** | **4.0** | **9.6** | **5.6** | **7.6** | **3.6** |
| **-2.1** | **-** | **11.2** | **7.2** | **9.2** | **5.2** |
| **-0.135** | **4.1** | **9.7** | **5.7** | **7.7** | **3.7** |
| **0** | **4.0** | **9.6** | **5.6** | **7.6** | **3.6** |

* Minimum VELO closure at 5mm radius

- The VELO apertures quoted allow $\mathbf{n_1 = 7\sigma}$
- They are computed for no separation and external crossing angle
  - Influence of the separation important mostly for small internal crossing angles
  - Influence of the external crossing angle is minimal
  - Different spectrometer polarity has a minor influence in the available aperture
  - Between the nominal and extreme crossing angle the difference is around **1.5mm**
- For the loose mechanical tolerance of **2.2mm**
  - For nominal internal crossing angle, the VELO cannot be closed to less than **9.6mm**
  - After centring it around the CO, it can be closed down to **5.6mm** (for no internal crossing angle) or to **7.1-7.2mm** for extreme crossing angle
- For a tight mechanical tolerance of **0.2mm**, 2mm can be gained for all quoted values
  - The VELO can be closed down to 5.0mm for a internal crossing angle of **~2mrad**
- The precision with which the detector can be centred around the beam is determinant

# Compensator failure considerations

- Time needed for compensator magnets to create a maximum orbit distortion of **1σ** (2σ for dashed lines) as a function of the internal crossing angle (from nominal N=1 to extreme for N=16)
  - For the nominal crossing angle and for all magnets it takes a few **hundreds of ms**
  - For the extreme crossing angle it takes a few **tens of ms**
- Different power converter failures may further reduce the time (need of Fast Current Change Monitors – only in MBXWT up to now)




A. Gomez-Alonso, AB/CO

| | Injection (450 GeV) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Short circuit | | Constant dI/dt | | Max ΔV | |
| | $\beta_{col}$ [m] | $\beta_{magnet}$ [m] | t for 6σ [ms] | $t_{loss}$ [ms] | t for 6σ [ms] | $t_{loss}$ [ms] | t for 6σ [ms] | $t_{loss}$ [ms] |
| MBAW | 392 | 23 | Not reached | 17845.71 | 44204.57 | 19326.21 | 687.26 | 294.62 |
| MBWMD | 392 | 19 | Not reached | 2409.44 | 26632.68 | 11643.79 | 157.38 | 67.82 |
| MBXWT | 392 | 55 | 10117.97 | 625.40 | 7119.79 | 3112.77 | 17.39 | **7.57** |
| MBLW | 342 | 14 | 28026.42 | 5446.31 | 21765.68 | 9515.94 | 426.07 | 184.13 |
| MBXWH | 342 | 11 | Not reached | 1572.32 | 32303.82 | 14123.21 | 47.34 | 20.54 |
| MBXWS | 342 | 55 | Not reached | Not reached | 64241.49 | 28086.34 | 30.71 | 13.25 |

# Conclusions

- Main limitations in IR2 and 8 in the aperture of 2nd compensator
  - **MBWMD** in IR2
    - Available aperture of **9mm** (with respect to **14mm**), corresponding to 13σ of aperture loss
  - **MBXWH** in IR8
    - Available aperture of **6mm** (with respect to **12mm**), corresponding to 15σ of aperture loss
- In both cases, n1 above 7σ, but available aperture quite small, especially in IR8
- It is advisable never to inject with the extreme bump in place
- The VELO detector can be closed to around **5.1-5.2mm** for the extreme bump amplitude depending on the precision with which the beam can be located and the mechanical tolerances of the detector
- Fast Current Change Monitors may be needed for failure protection of all spectrometer compensator magnets