Review of the experimental beam pipes aperture for the nominal LHC

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- Aperture computation
- Aperture model
- Tolerances
- Results
- Conclusions

Acknowledgements: S. Redaelli and A. Rossi

Aperture computation

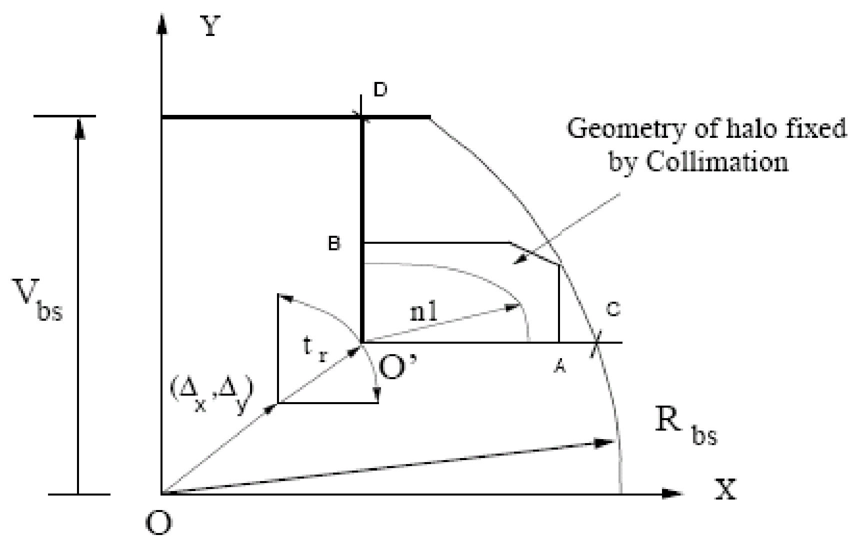
- Brief recap of input required for aperture computation, n1 parameter, (reference LHC PN 66, 111 or LHC DR):
  - LHC sequence -> from layout database
  - Aperture description -> see next slides
  - Optics setting -> from optics database
  - Tolerances:
    - Beam dynamics: closed orbit budget, beta-beating, off-momentum, spurious dispersion…
    - Mechanical: shape, alignment, tunnel

$$\vec{\Delta}(s) = \vec{d}_{\rm sep}(s) + \vec{d}_{\rm axis}(s) + \vec{d}_{\rm inj}(s)$$

$$\vec{u} = (t_r + CO)(\cos\alpha, \sin\alpha) \quad \text{with} \quad \alpha \,\epsilon \,[0\,,\,\pi/2]$$

$$\vec{d}_{\rm disp}(s) = (1 + k_\beta)\left[\vec{D} + k_D \frac{D_{\rm x,QF}}{\sqrt{\beta_{\rm x,QF}}}\sqrt{\vec{\beta}}\right]\,\delta_p$$

$$\overrightarrow{OO'}\,(s) = \vec{\Delta}(s) + \vec{u} + \vec{d}_{\rm disp}(s)$$



Aperture model - I

- In principle the information should be extracted from the layout database…
- In reality:
  - Aperture description for the magnets was built during the Magnet Evaluation Board activities.
  - Aperture description of the vacuum elements (other than the experimental vacuum pipes) is currently extracted from layout database. The information is still under verification.
  - Aperture description for the experimental vacuum pipes was derived manually (S. Redaelli – 2004, who also worked on the previous items).

Aperture model - II

- The aperture model for the experimental vacuum pipe is currently based on the information extracted by A. Rossi from the following drawings:
  - ATLAS: LHCVC1I_0009, LHCVC1A_0021, LHCVC1T_0036, LHCVC1J_0003, LHCVBX__0018, LHCVBX__0017, LHCTAS__0078
  - ALICE: LHCVC2__0002, LHCVC2U_0034, LHCVC2U_0036, LHCVMAAC001, LHCVC2U_0035, LHCVCR__0067, LHCVC2U_0034, LHCVC2C_0001, LHCVC2A_0001, LHCVC2A_0002, LHCVC2A_0012, LHCVSR__0055, LHCVC2__0003
  - CMS: LHCVC5C_0002, LHCVC5C_0003, LHCVC5E_0012&16, LHCVC5E_0001, LHCVC5E_0024, LHCVC5H_0002, LHCVC5H_0003, LHCVC5H_0007, LHCVC5H_0009, LHCVC5CT0003, LHCVBX5_0002, LHCVC5F_0002, LHCVP5__0014, LHCVBX__0018, LHCVBX__0017, LHCTAS__0078, LHCVAX__
  - LHCb: LHCVC8B_0043, LHCVMADA0001, LHCVCRLC0001 , LHCVC8B_0043, LHCVMACA0001, LHCVC8B_0043, LHCVC8B_0063, LHC VC8B_0076, LHCVC8B_0002, LHCVC8B_0008, LHCVC8B_0151, LHCVC8B_0148, LHCVC8B_0010, LHCVC8B_0011, LHCVC8B_0151, LHCVCRLA0001, LHCVC8B_0053

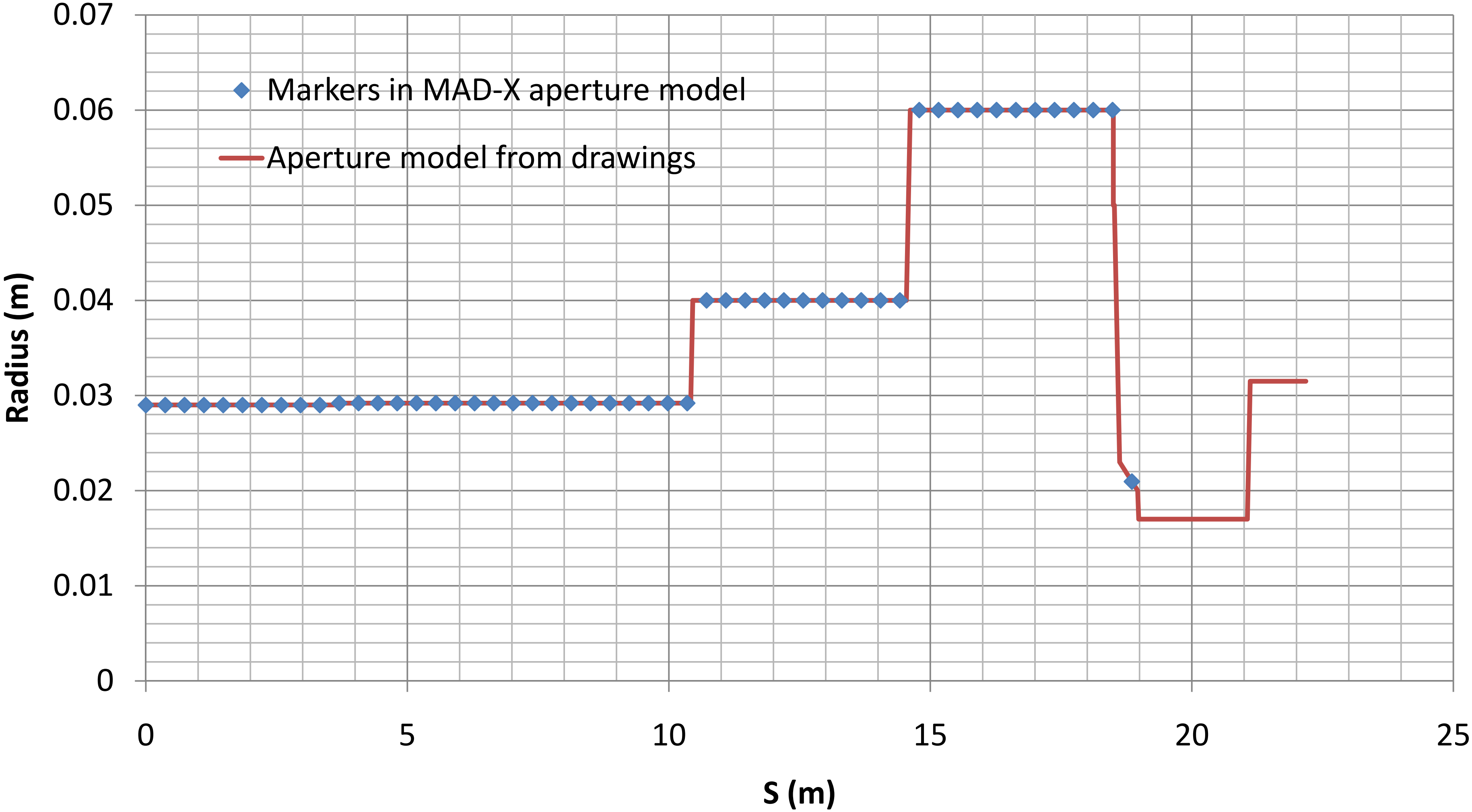
Tolerances

- For the experimental beam pipes:
  - Radial tolerance of 15 mm, representing:

2.6 mm (alignment) + 2.6 mm (mechanical) + 9.8 mm (other sources)

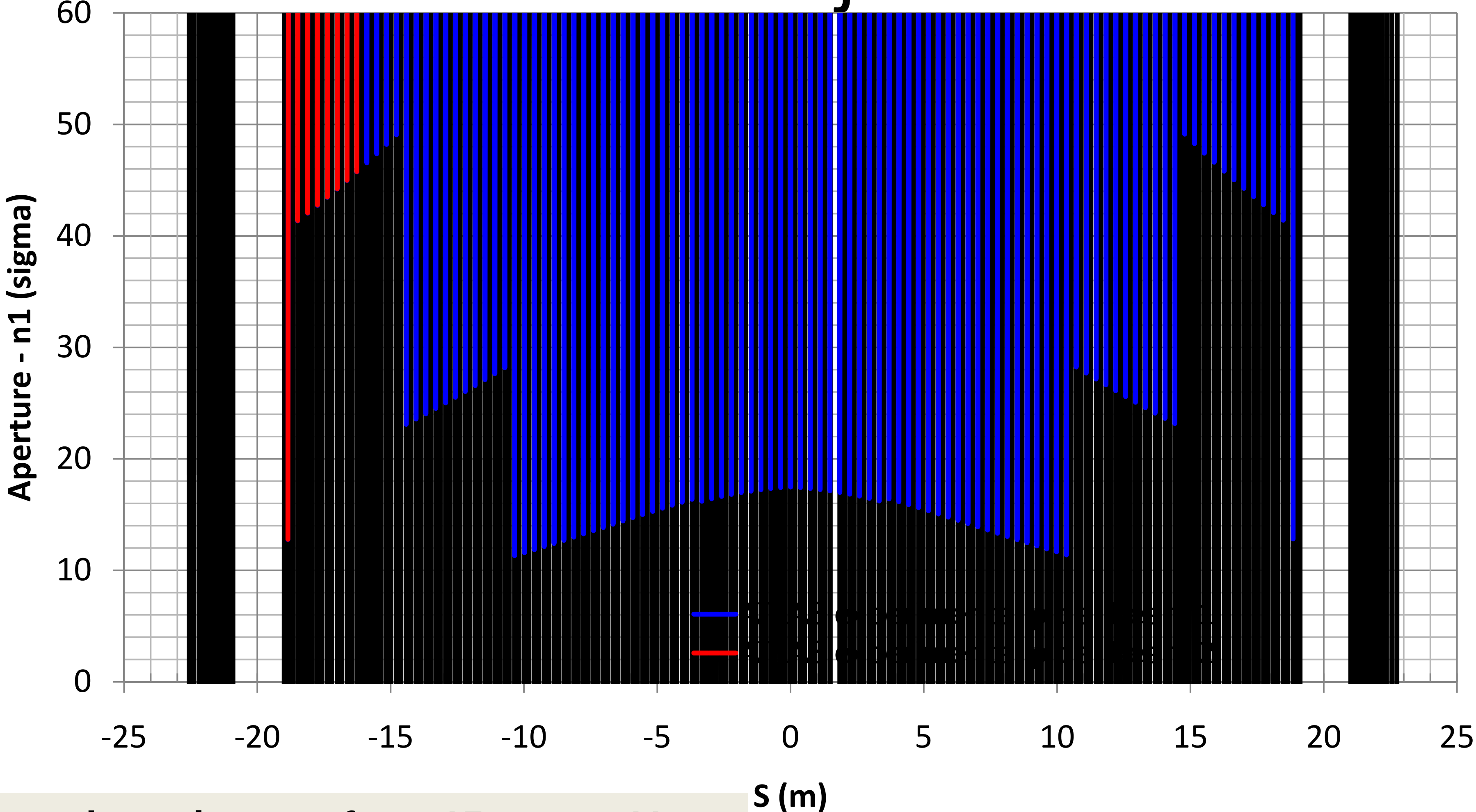
  - The tolerance is assumed to be independent of s.
- NB: all the configurations considered in the following slides refer to nominal parameters, i.e.:
  - Top energy: 7 TeV
  - Transverse emittance: 3.75 μm (rms normalised)
  - Beta* at top energy: 0.55 m (IP1/5) and 0.5 m (IP2 with ions).
  - The beam are separated (0.5 mm) at top energy (pre-collision).

ATLAS pipe



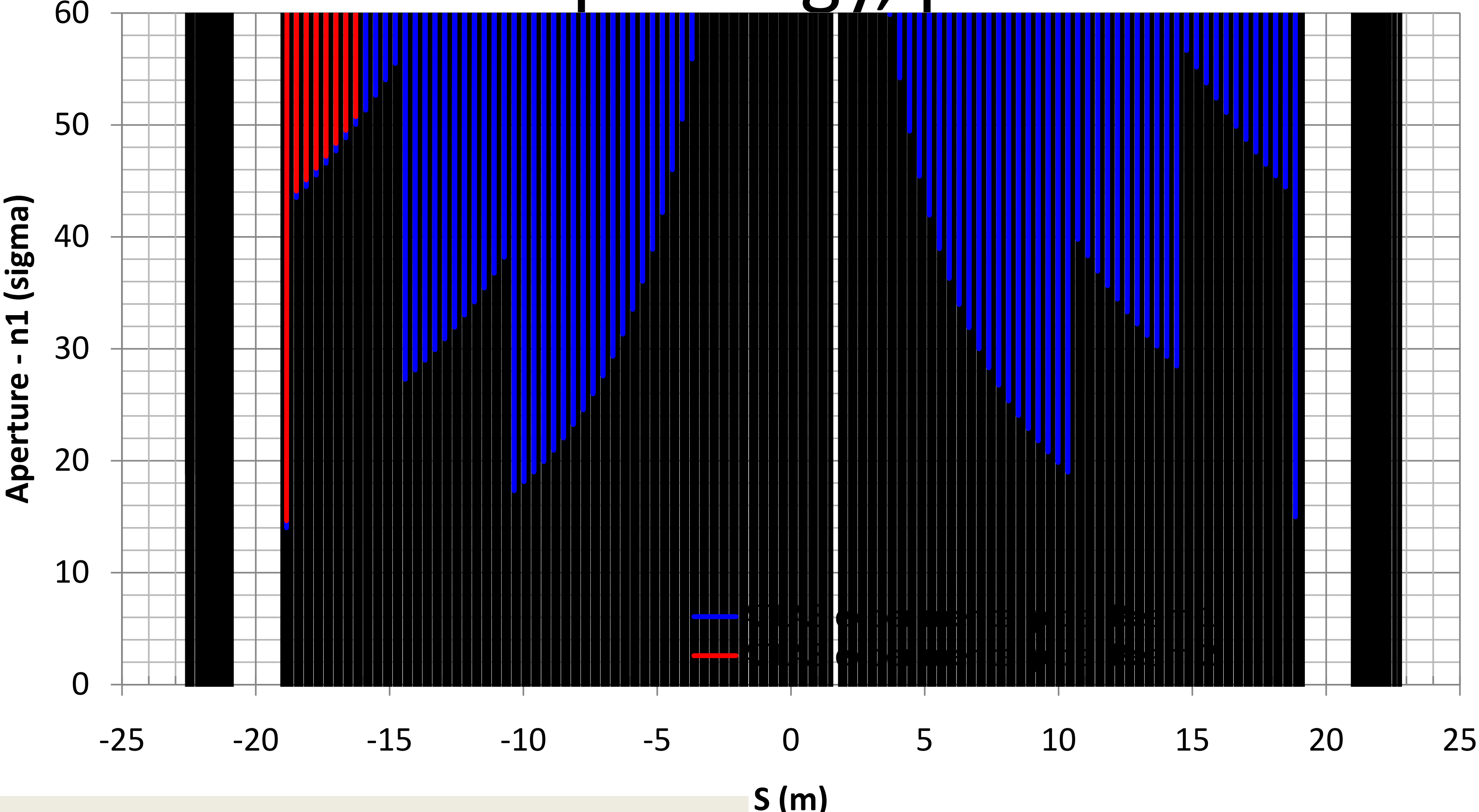
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Radius (m)
Markers in MAD-X aperture model
Aperture model from drawings
0
5
10
15
20
25
S (m)

Aperture for ATLAS with 15 mm tolerance: injection



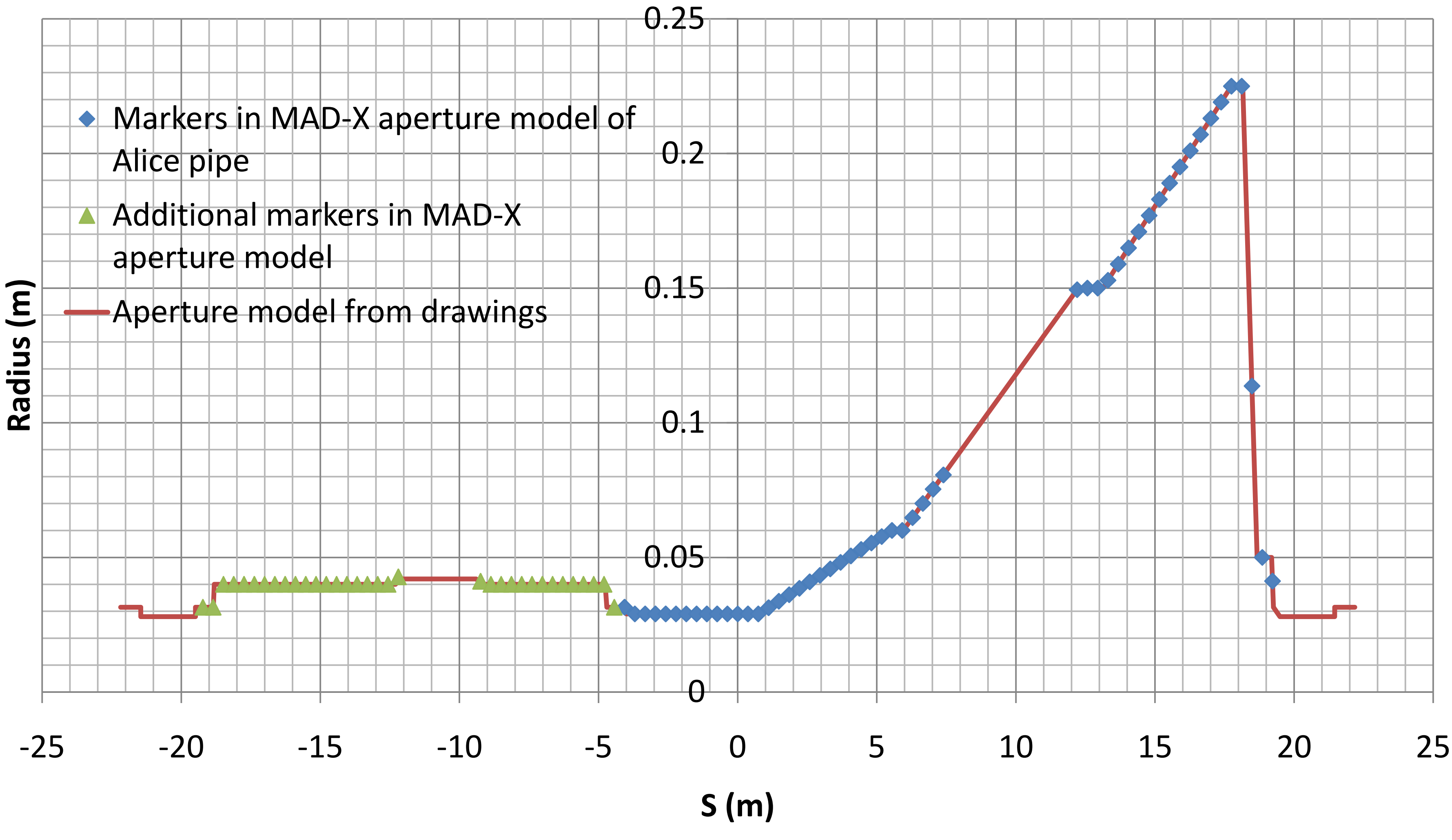
Changing tolerance from 15 mm to 11 mm increases n1 by 4.5 σ (far from the IP) and up to 8.9 σ (next to the IP).

Aperture for ATLAS with 15 mm tolerance: top energy, pre-collision



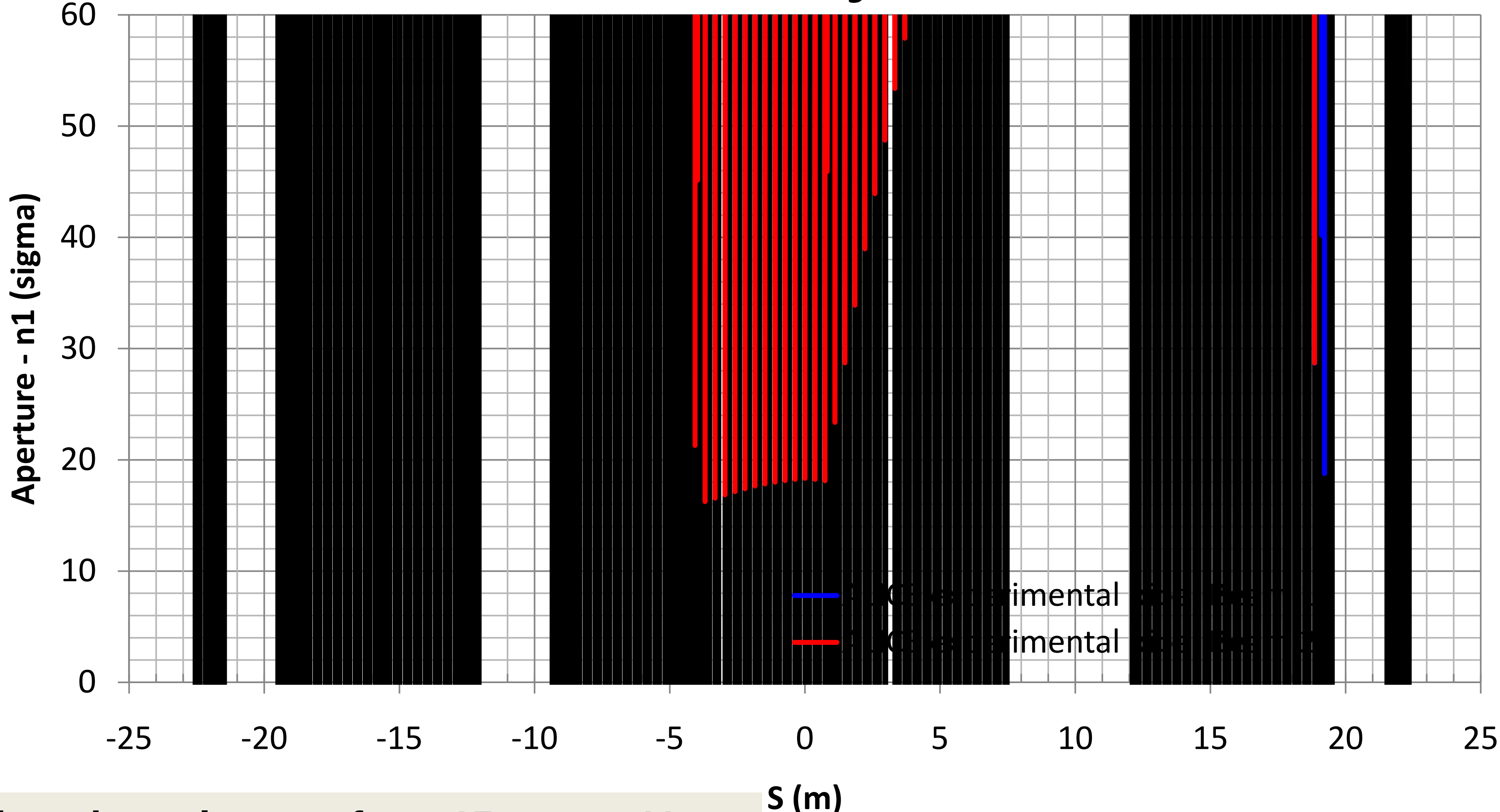
Changing tolerance from 15 mm to 11 mm increases n1 by 4.5 σ (far from the IP) and up to 150 σ (next to the IP).

ALICE pipe



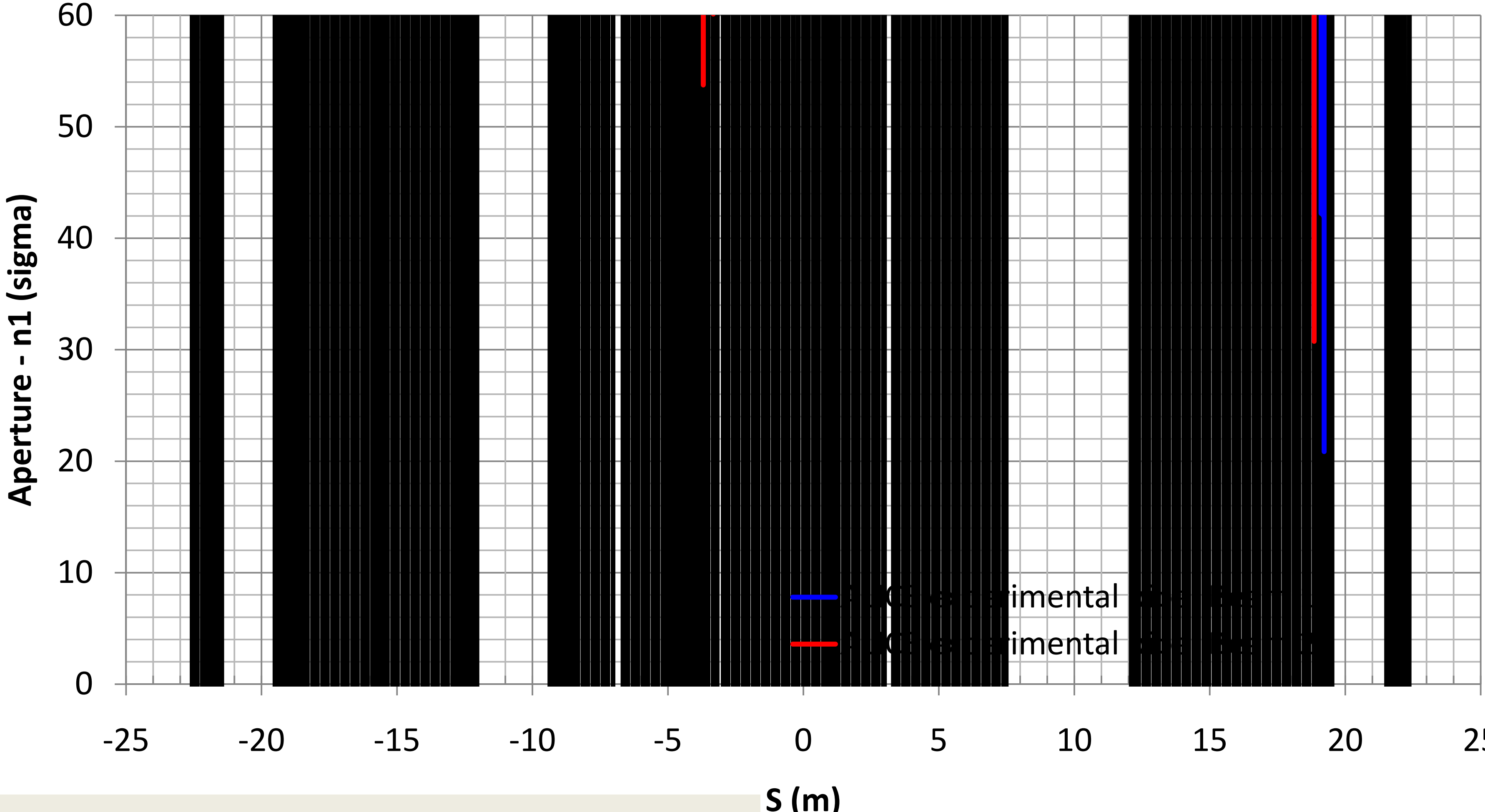
Markers in MAD-X aperture model of Alice pipe
Additional markers in MAD-X aperture model
Aperture model from drawings
Radius (m)
S (m)
0.25
0.2
0.15
0.1
0.05
0
-25
-20
-15
-10
-5
0
5
10
15
20
25

Aperture for ALICE with 15 mm tolerance: injection



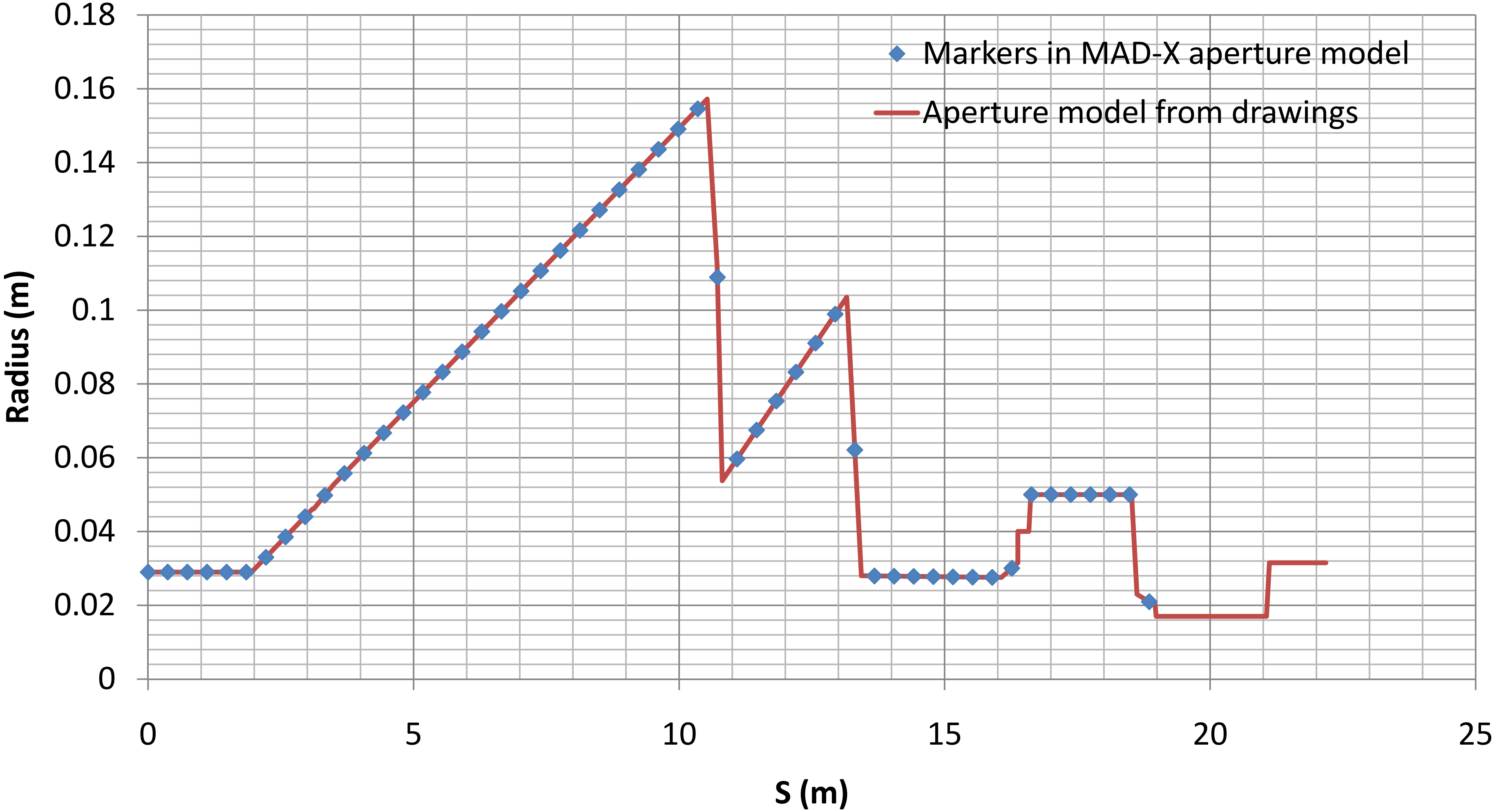
Changing tolerance from 15 mm to 11 mm increases n1 by 4.3 σ (far from the IP) and up to 9.3 σ (next to the IP).

Aperture for ALICE with 15 mm tolerance: top energy, pre-collision (ions)



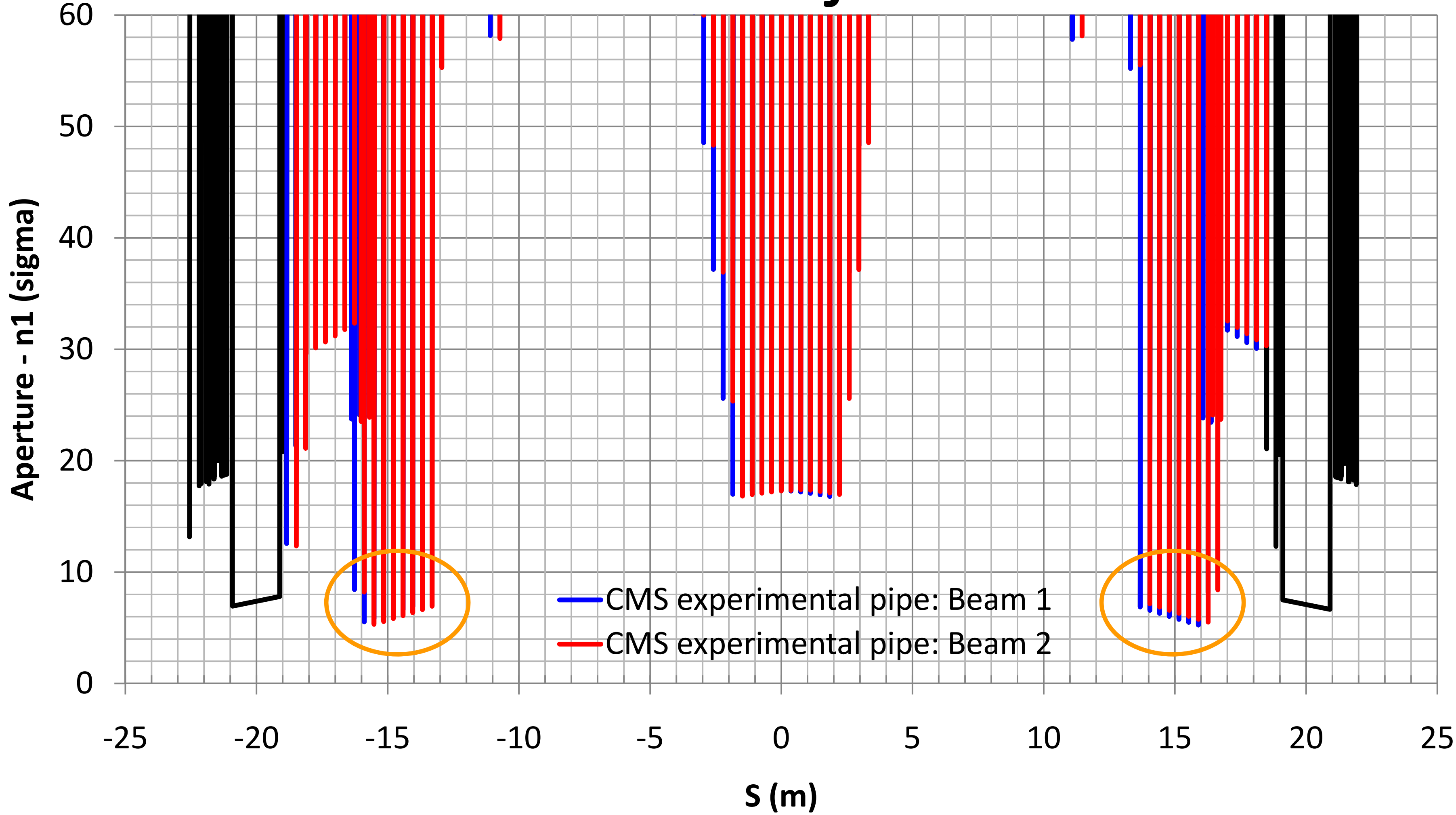
Changing tolerance from 15 mm to 11 mm increases n1 by 4.3 σ (far from the IP) and up to 160 σ (next to the IP).

CMS pipe



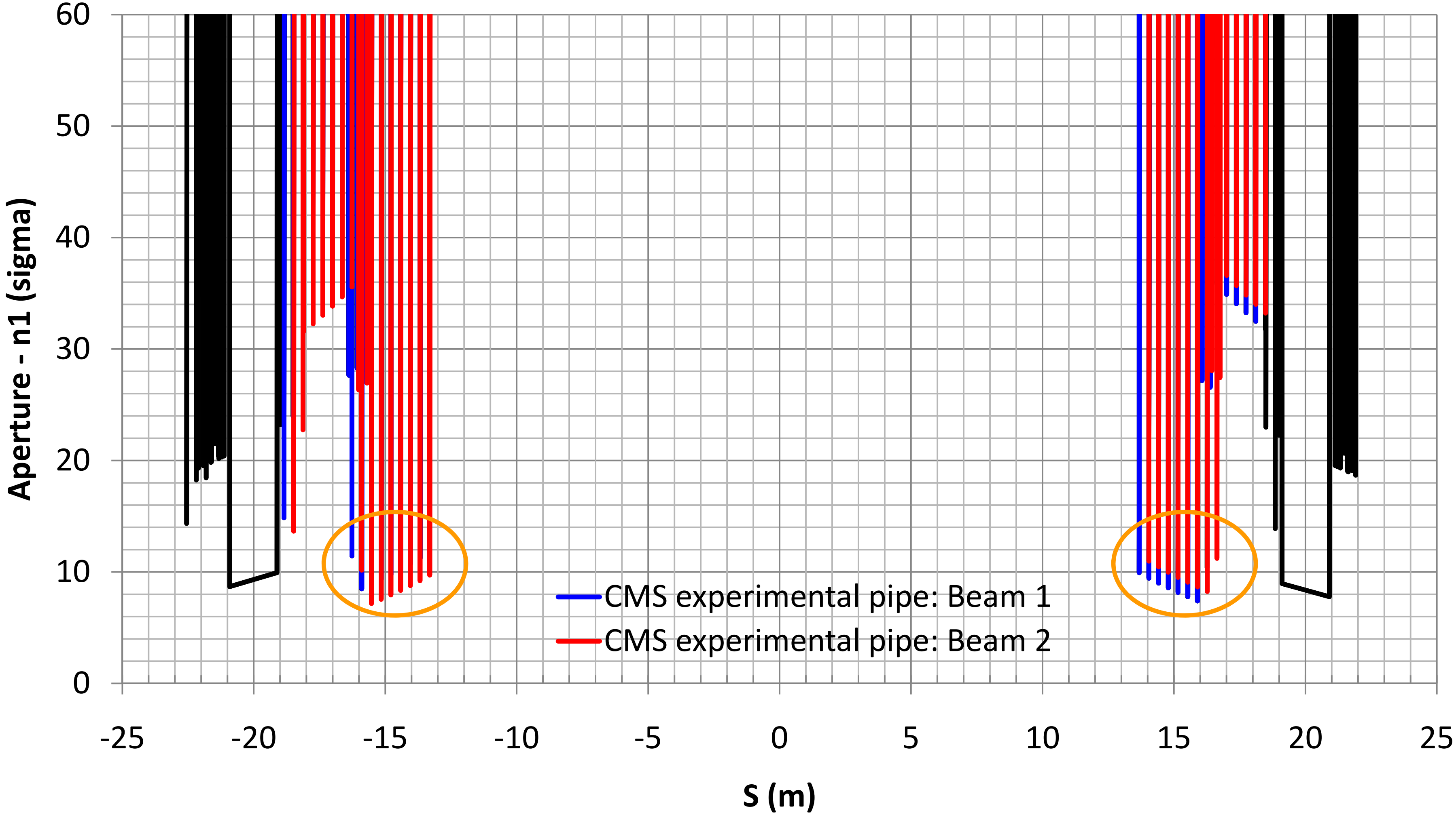
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Radius (m)
0
5
10
15
20
25
S (m)
Markers in MAD-X aperture model
Aperture model from drawings

Aperture for CMS with 15 mm tolerance: injection



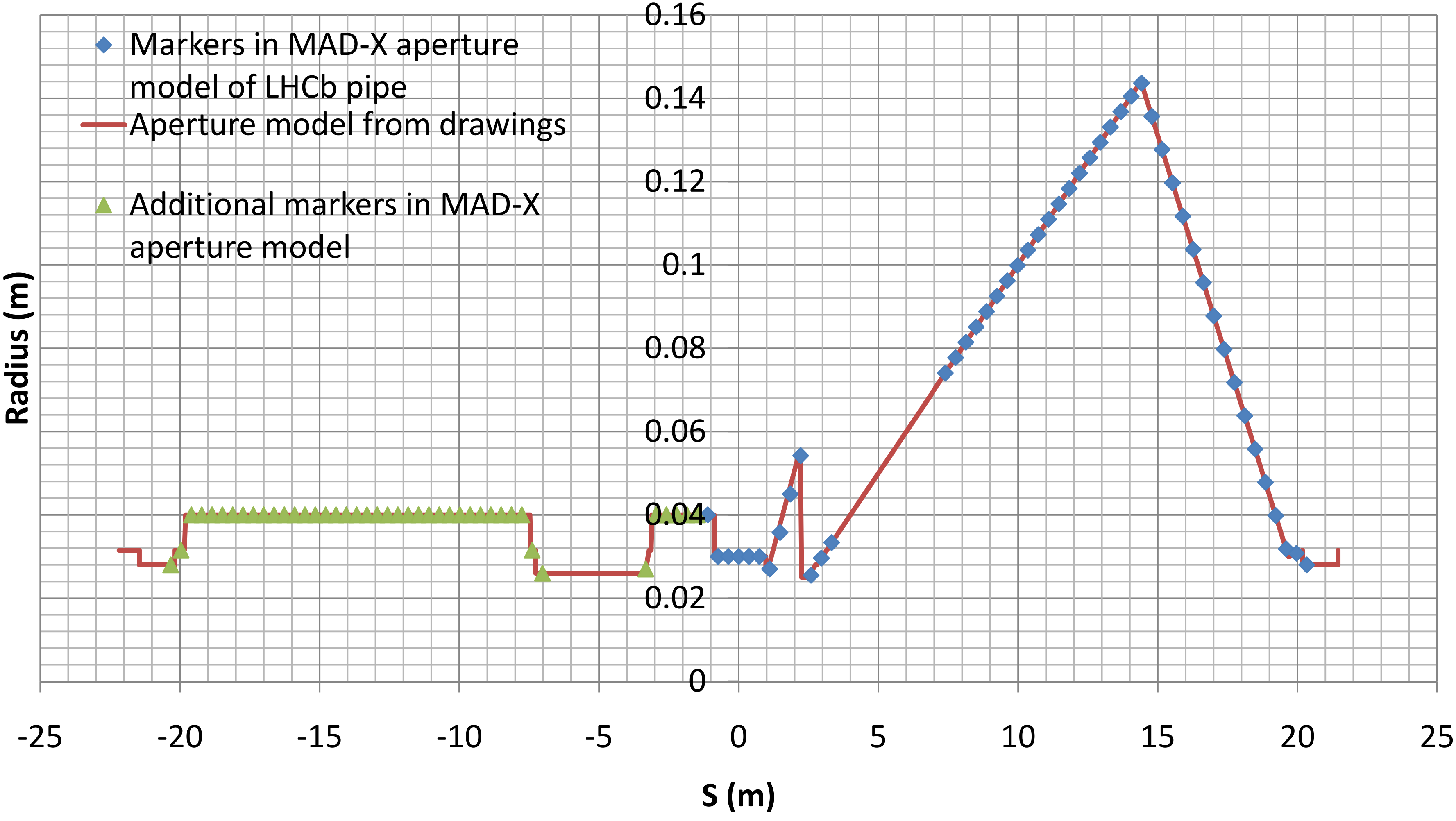
Changing tolerance from 15 mm to 11 mm increases n1 by 4.5 σ (far from the IP) and up to 8.9 σ (next to the IP). This puts in specs the CT2 section of the pipe

Aperture for CMS with 15 mm tolerance: top energy, pre-collision



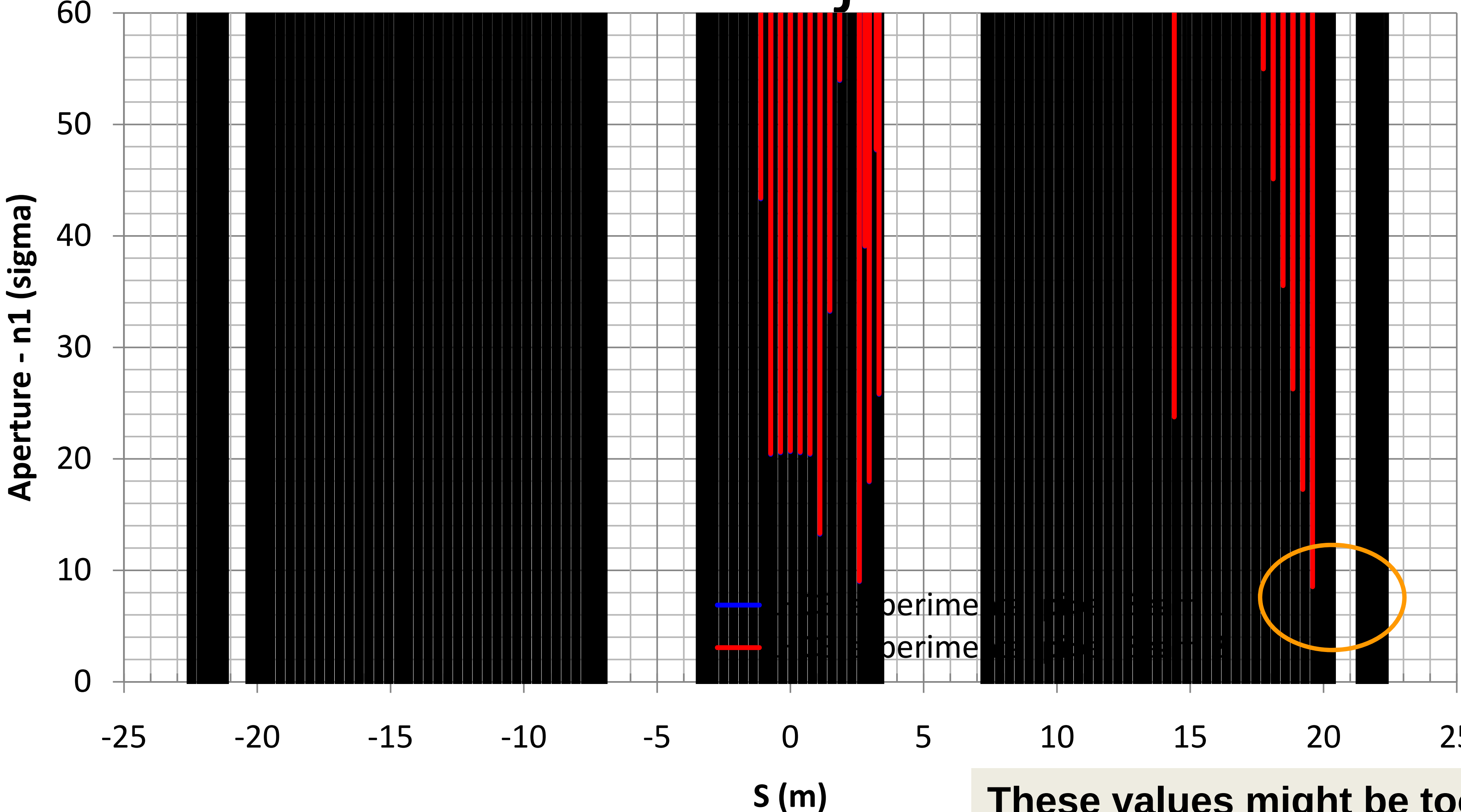
Changing tolerance from 15 mm to 11 mm increases n1 by 4.5 σ (far from the IP) and up to 150 σ (next to the IP). This puts in specs the CT2 section of the pipe

LHCb pipe



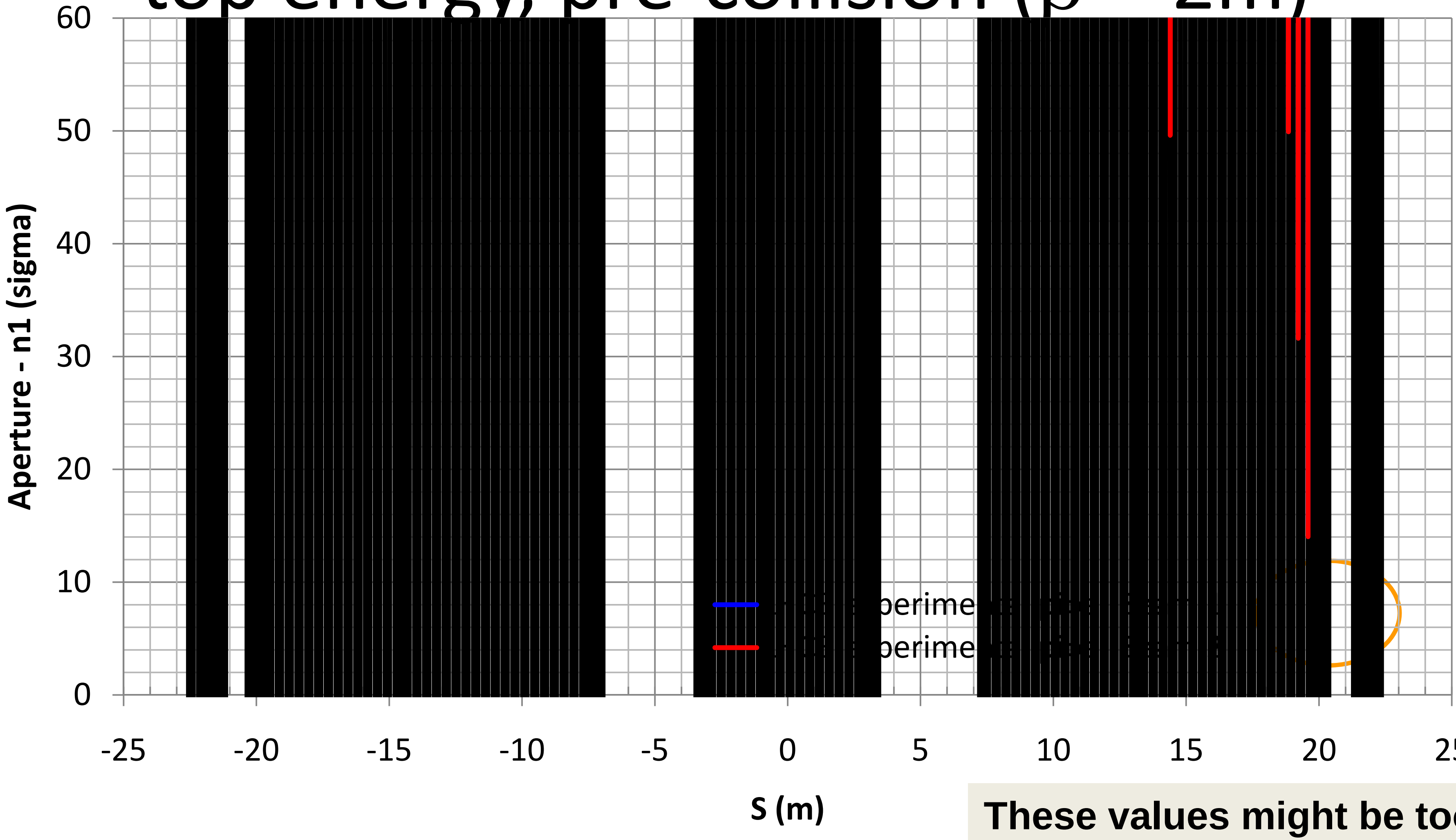
Markers in MAD-X aperture model of LHCb pipe
Aperture model from drawings
Additional markers in MAD-X aperture model
Radius (m)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-25
-20
-15
-10
-5
0
5
10
15
20
25
S (m)

Aperture for LHCb with 15 mm tolerance: injection



These values might be too pessimistic !

Aperture for LHCb with 15 mm tolerance: top energy, pre-collision (β*=2m)



These values might be too pessimistic !

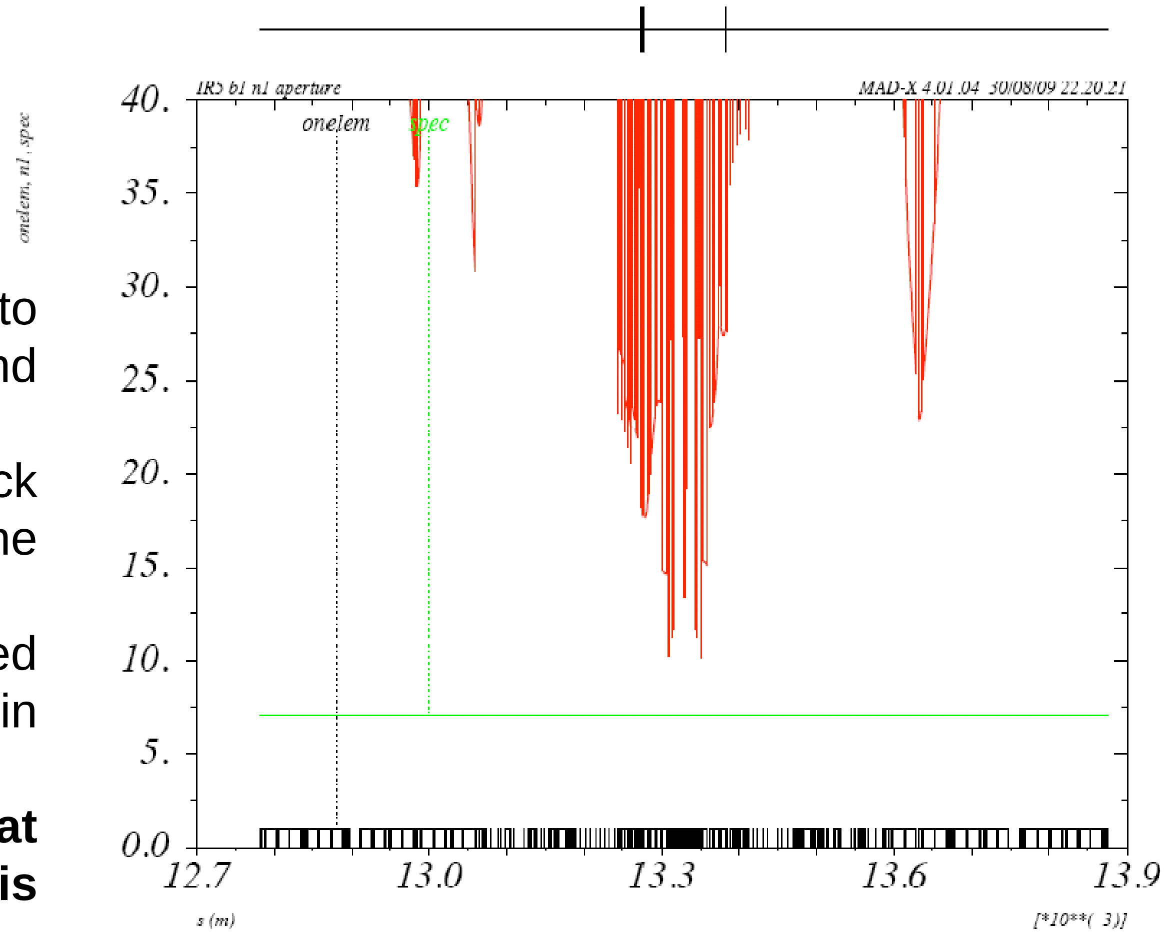
High-beta* optics: TOTEM

High-beta* optics are planned to be used both in IR1 (ATLAS) and IR5 (TOTEM).

The potential aperture bottleneck is the central section of the experimental beam pipe.

A detailed analysis is performed by H. Burkhardt and a report is in preparation.

Preliminary results indicate that the tolerance of 11 mm is needed.



Courtesy H. Burkhardt

Conclusions

- Injection: the 15 mm tolerance is in general acceptable in the central part of the experimental pipe (ATLAS, CMS). Locally (CT2 section of the CMS vacuum pipe), there are aperture bottlenecks requiring a reduction of the tolerance to 11 mm. No particular issues for ALICE and LHCb
- Collision: the 15 mm tolerance is in general acceptable (apart from CMS in the CT2 section of the vacuum pipe).
- High-beta* optics: the aperture is tight in the central part of the experimental vacuum pipe. A reduction of the tolerance to 11 m is needed to ease operation (release constraint on emittance values).