ATLAS & CMS Beam Pipes Aperture Study

LHC Phase 1 Upgrade

Purpose & Scope of Study

- Verify that the apertures of the current ATLAS and CMS beam pipes are sufficient for LHC Phase 1 operation.
  - The LHC Phase 1 upgrade program will replace the triplets in IR1 & IR5 by new wide-aperture magnets to achieve a β* of 30cm at 7TeV.
  - A new D1 is foreseen.
  - A new TAS and TAN will be required.

Beampipe Diameter for LHC Baseline (1997 values)

- Beam stay-clear 14mm
  - Composed of beam size, beam separation, closed orbit and crossing angle components
  - within the tracker region (±5 m) at injection
  - In forward regions, this may be higher for collision optics
- Survey Precision ~ 2.6mm
  - See presentation from survey
- Mechanical construction ~ 2.6mm
  - Tolerances on straightness, circularity, wall thickness, sag under self-weight and construction of survey targets
- Instabilities ~ 9.8mm
  - Stability of the cavern, detector movements due to electro-magnetic forces and thermal expansion

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Beam-Stay-Clear, conclusions of a previous study†

- It would seem prudent to maintain a beam-stay-clear distance of not less than 14mm for LHC Phase 1 Upgrade operation.

†"Experiment Beam Pipes Aperture Study LHC Phase 1 Upgrade", LHC Experimental Beampipes WG 3rd Technical Meeting, 28th May 2009.

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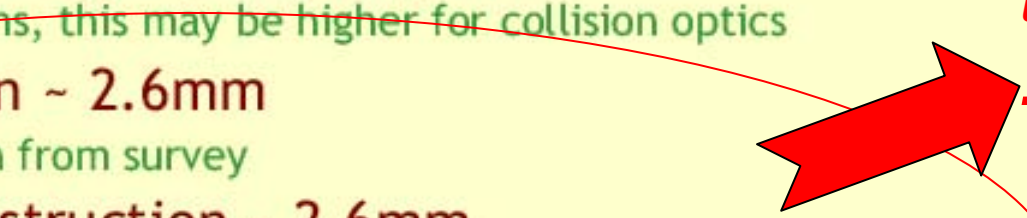


tolerance

15mm

Method

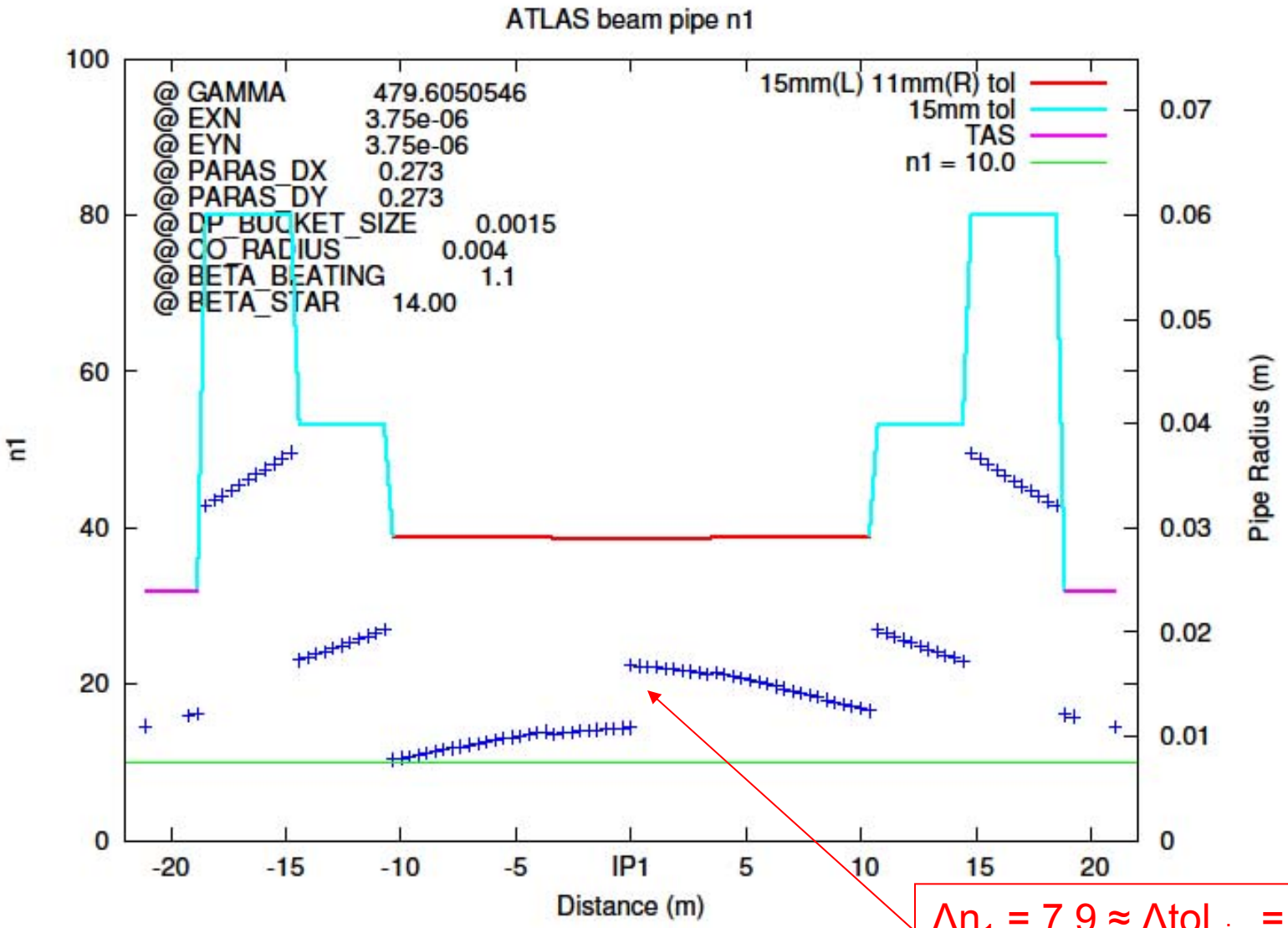
- Use MAD-X to compute the aperture.
  - The beam pipes are represented by a series of markers in the MAD-X input file:
    - Compiled by Massimo Giovannozzi, based on recent input from Adriana Rossi and previous work by Stefano Redaelli.
    - Tolerances are included.
  - The LHC Phase 1 Upgrade Version 1 optics are used:
    - Separation bumps, crossing angles and major imperfections are included.

Scenarios

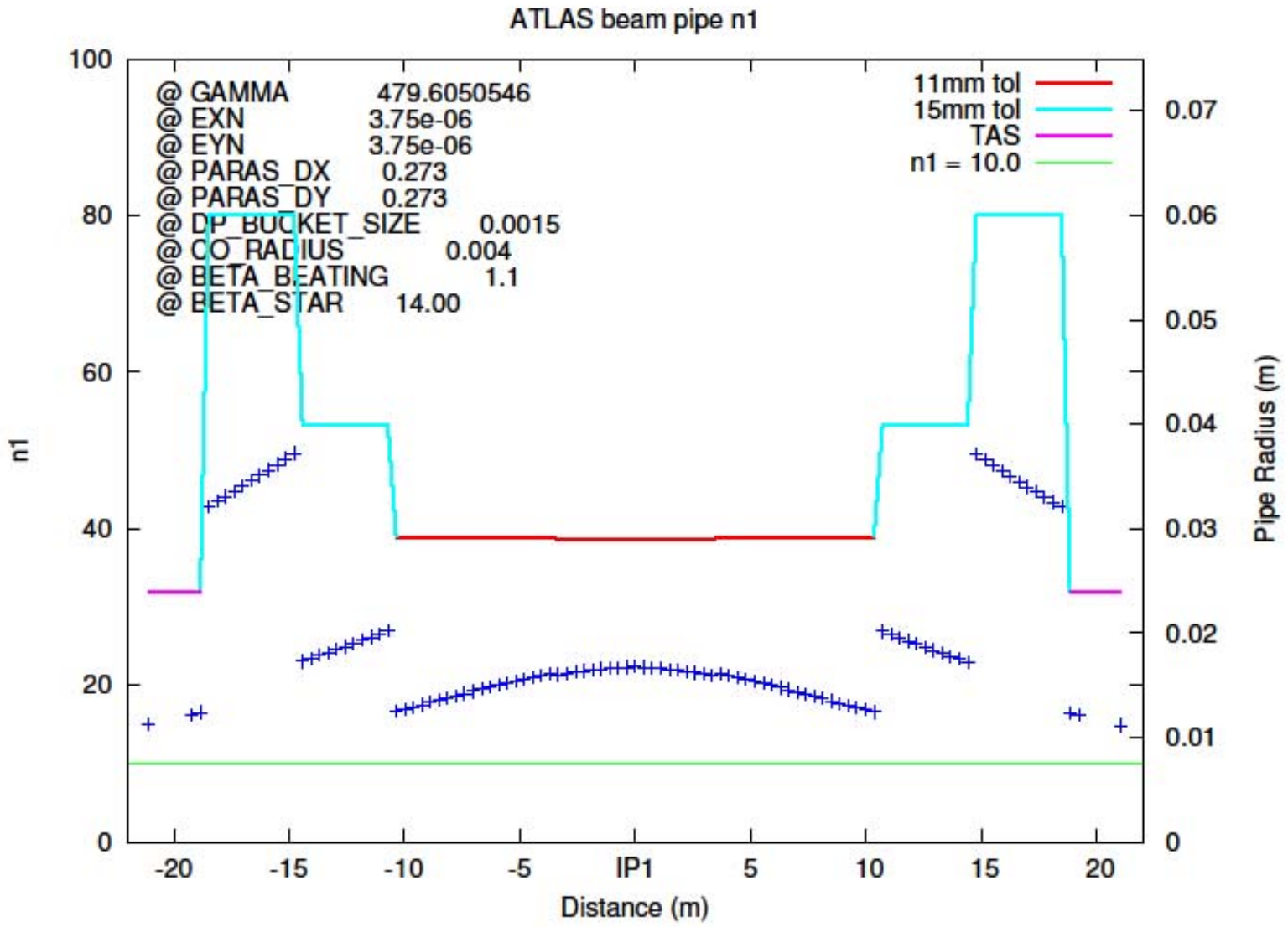
- ATLAS & CMS at injection.
- ATLAS & CMS low-beta at 7TeV.
- Include a plausible model for the TAS.
- Neither 3.5TeV nor high-beta operation is considered.

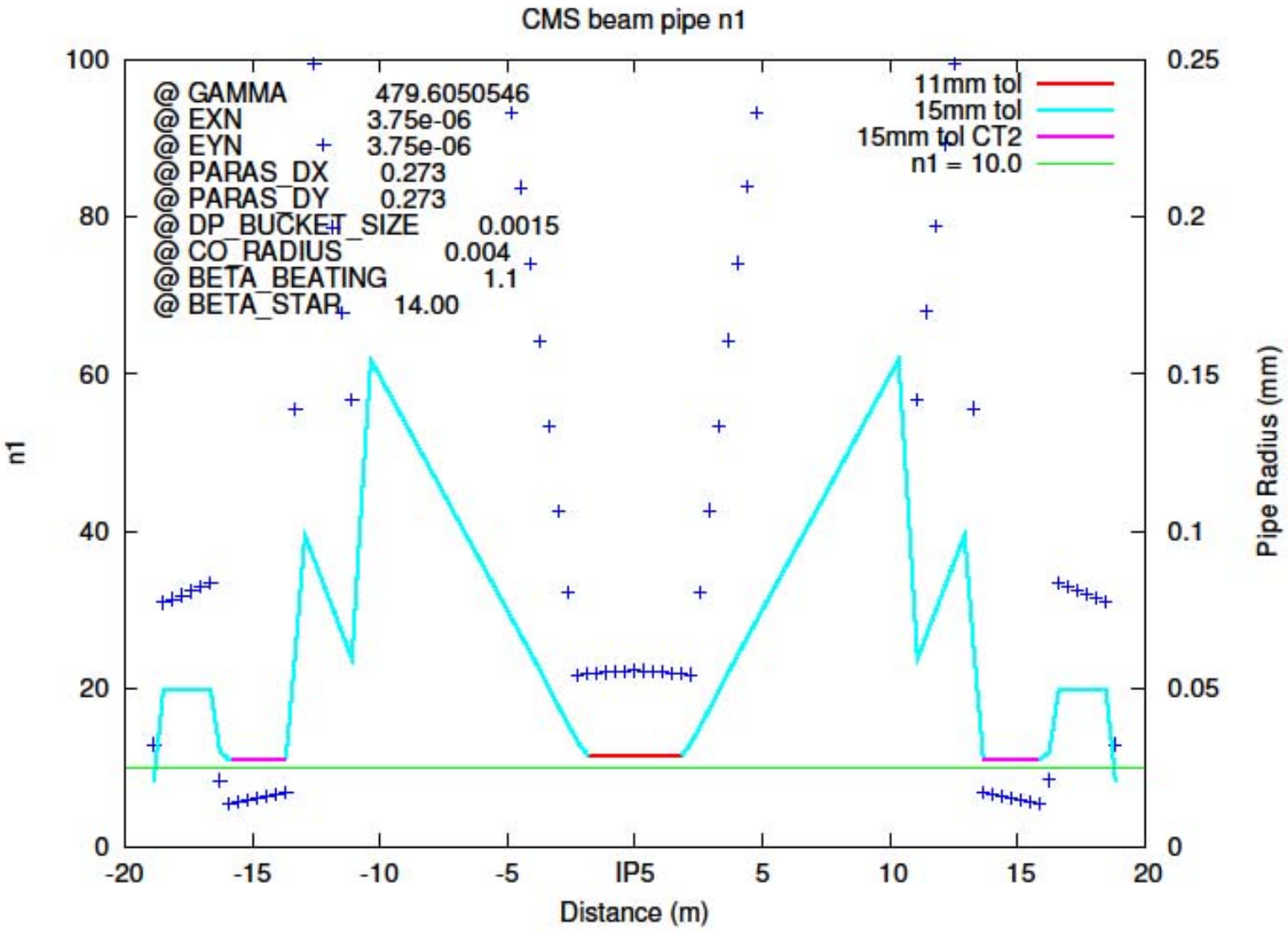
Injection @ 450GeV

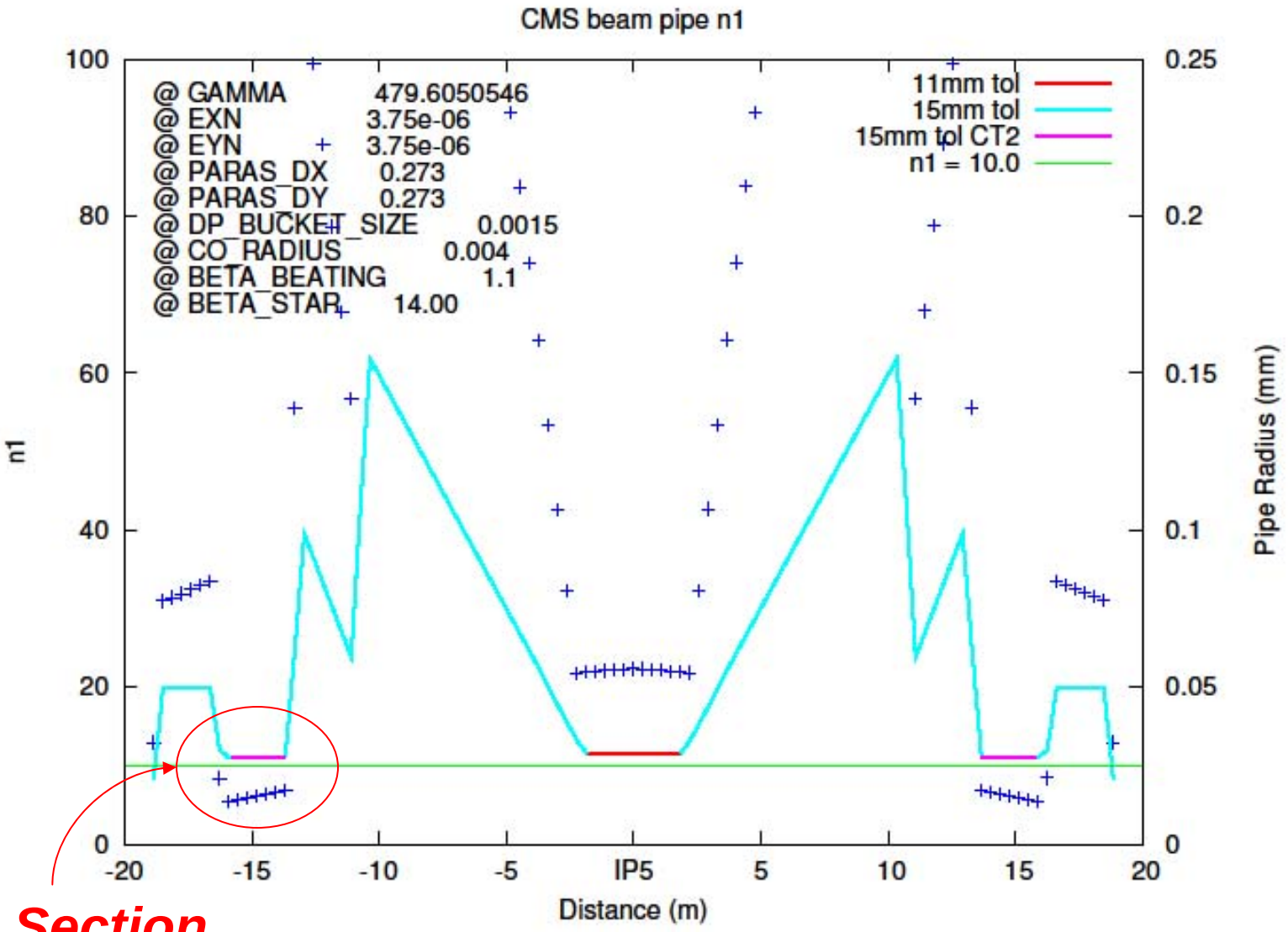
- (half) separation:
  - Θ = 175 μrad
  - p_{sep} = 2.5mm
- β^* = 14m
- Transverse normalised emittance $\varepsilon_n = 3.75 \times 10^{-6}$m



$\Delta n_1 = 7.9 \approx \Delta tol_{pipe} = 4mm$
$\sigma \approx 0.33mm$


ATLAS beam pipe n1
@ GAMMA 479.6050546
@ EXN 3.75e-06
@ EYN 3.75e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.0015
@ CO_RADIUS 0.004
@ BETA_BEATING 1.1
@ BETA_STAR 14.00
11mm tol
15mm tol
TAS
n1 = 10.0
n1
Pipe Radius (m)
Distance (m)
IP1
100
80
60
40
20
0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-20
-15
-10
-5
5
10
15
20


CMS beam pipe n1
@ GAMMA 479.6050546
@ EXN 3.75e-06
@ EYN 3.75e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.0015
@ CO_RADIUS 0.004
@ BETA_BEATING 1.1
@ BETA_STAR 14.00
11mm tol
15mm tol
15mm tol CT2
n1 = 10.0
n1
Pipe Radius (mm)
Distance (m)
IP5
100
80
60
40
20
0
0.25
0.2
0.15
0.1
0.05
0
-20
-15
-10
-5
5
10
15
20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@ BETA_STAR 14.00
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15mm tol
15mm tol CT2
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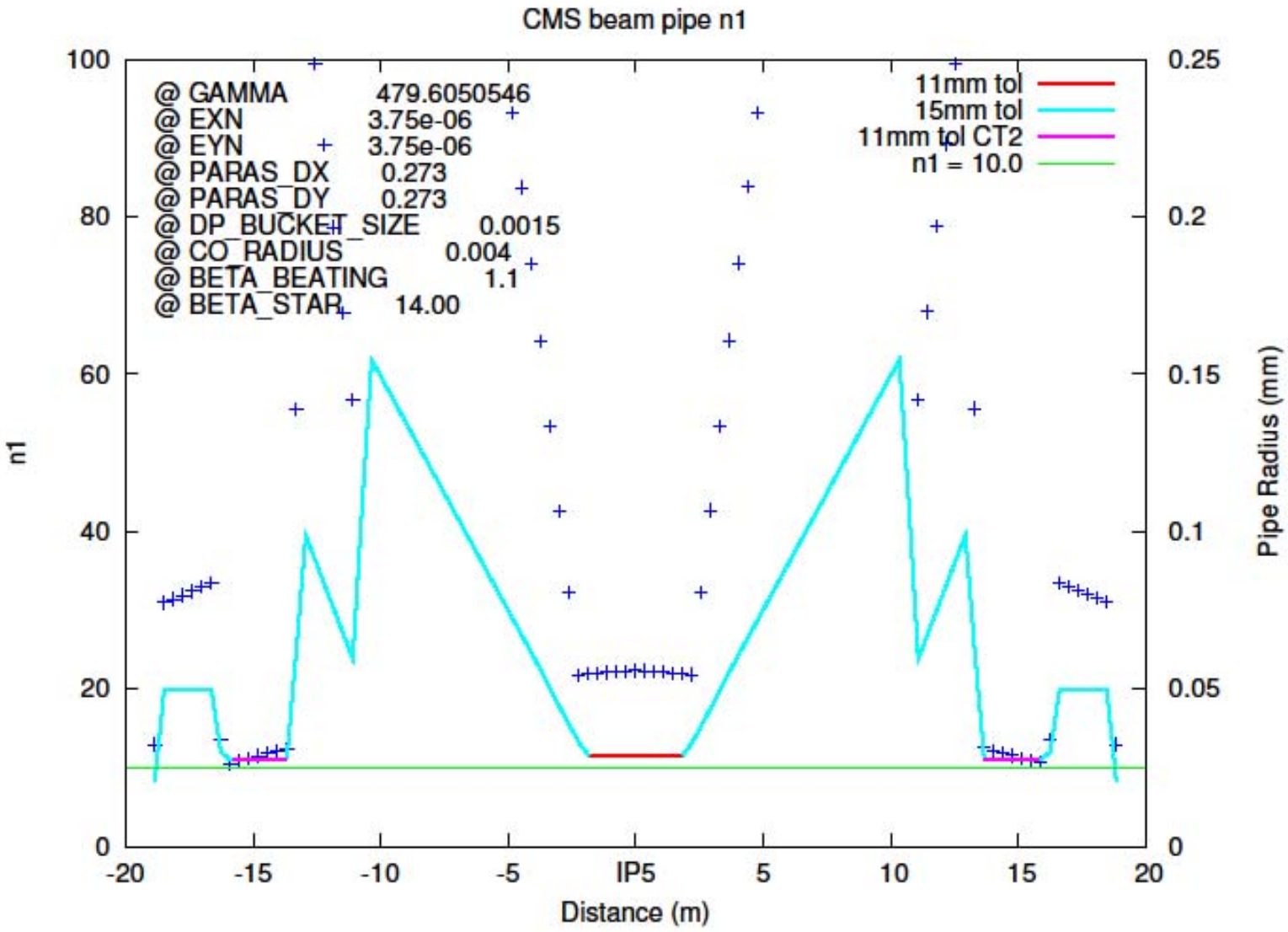
n1
Pipe Radius (mm)
Distance (m)
IP5
100
80
60
40
20
0
0.25
0.2
0.15
0.1
0.05
0
-20
-15
-10
-5
5
10
15
20

CT2 Section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@ CO_RADIUS 0.004
@ BETA_BEATING 1.1
@ BETA_STAR 14.00
11mm tol
15mm tol
11mm tol CT2
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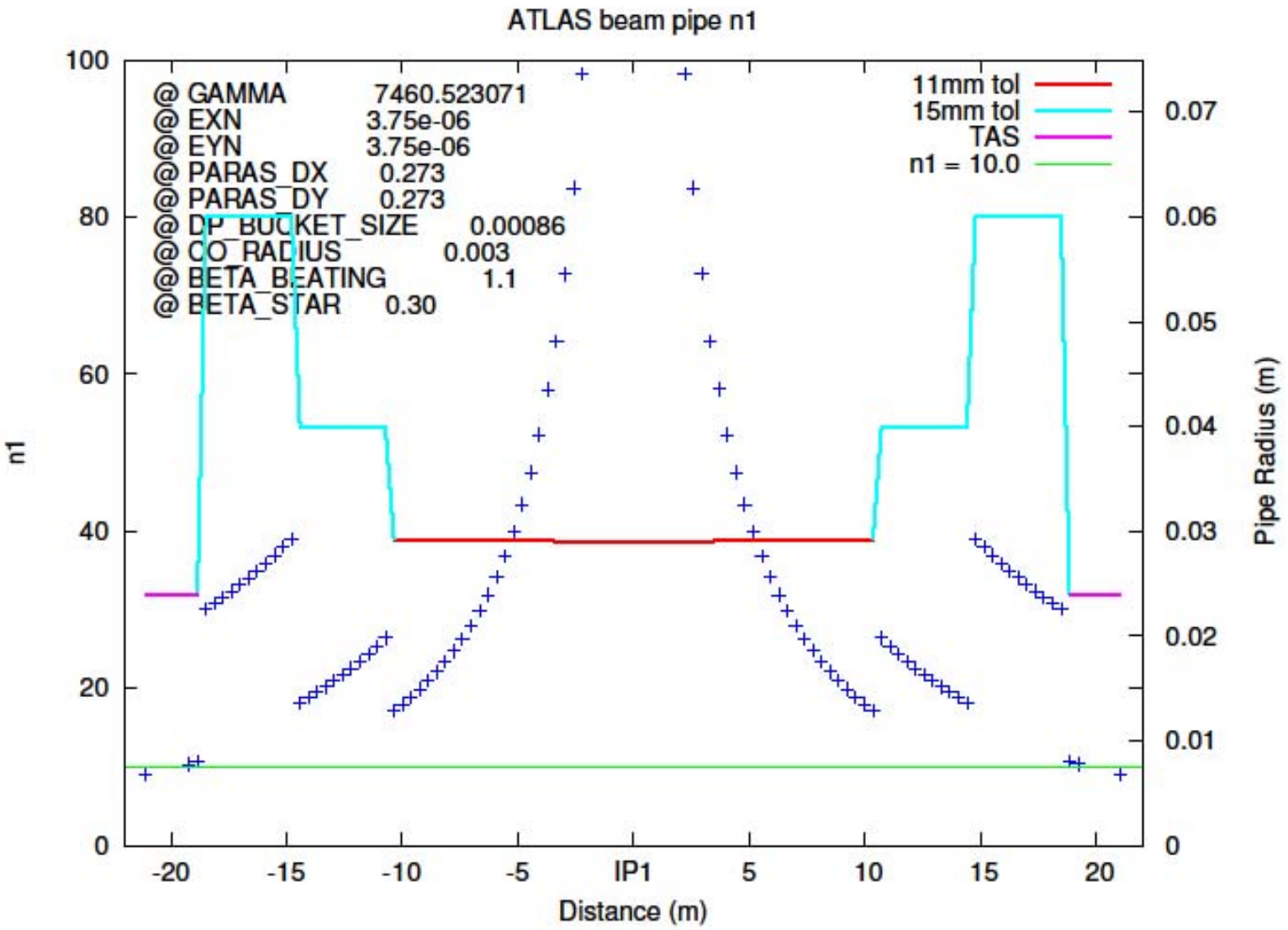
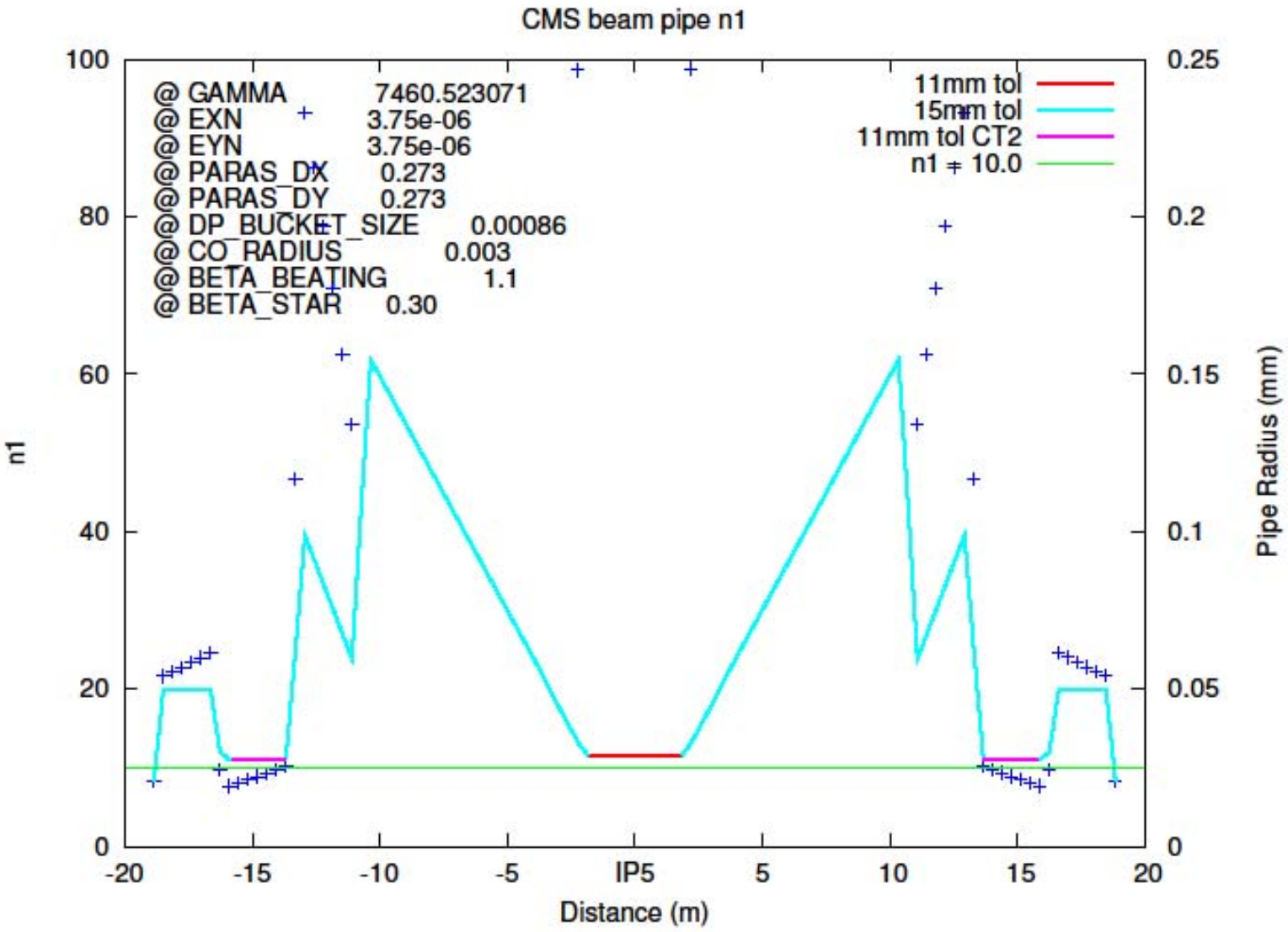
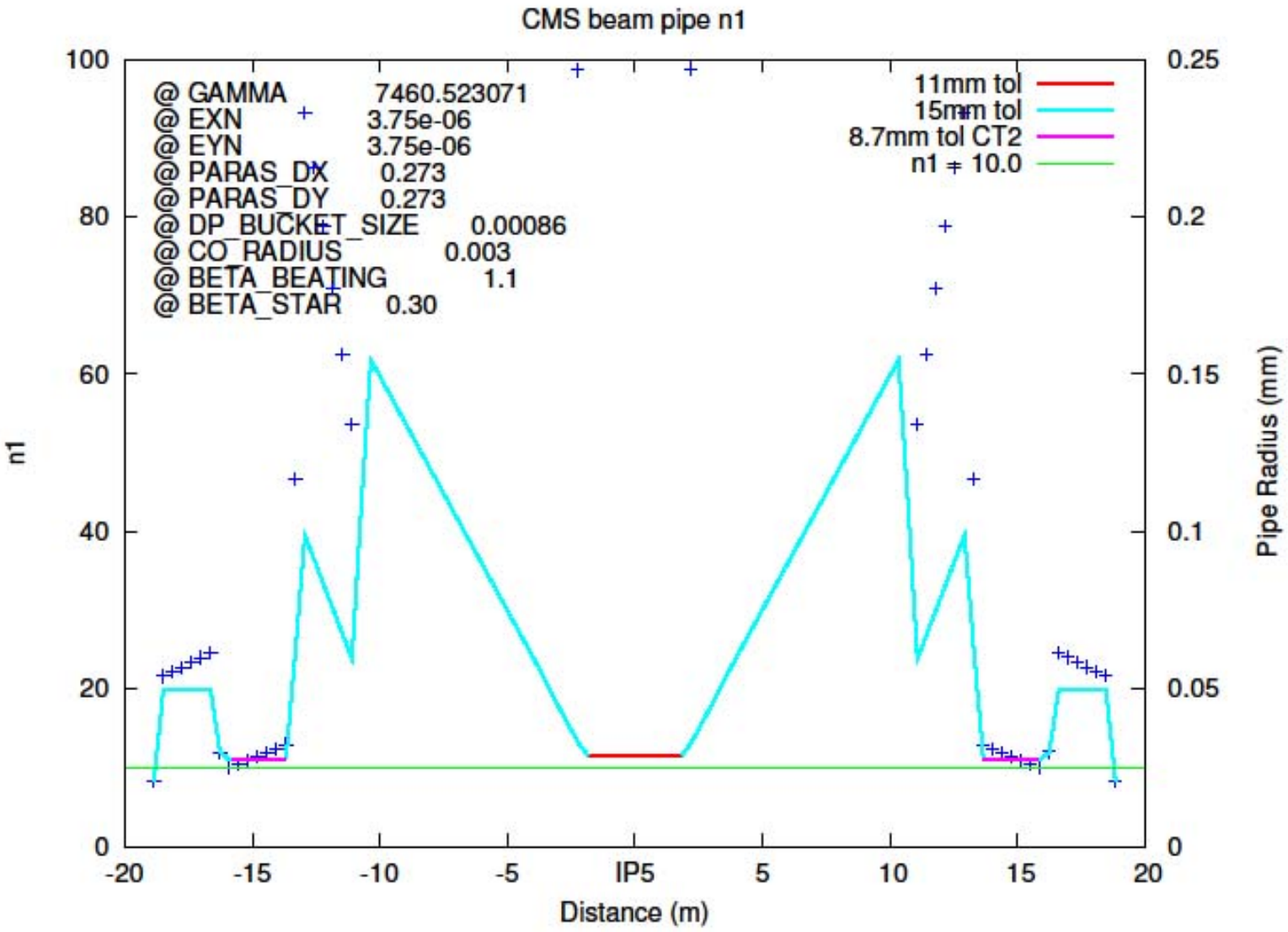
n1
Pipe Radius (mm)
Distance (m)
IP5
0
20
40
60
80
100
0
0.05
0.1
0.15
0.2
0.25
-20
-15
-10
-5
5
10
15
20

Low-beta @ 7TeV

- (half) separation:
  - Θ = 205 µrad
  - p_{sep} = 0.5mm
- β^* = 30cm
- Transverse normalised emittance $\varepsilon_n = 3.75 \times 10^{-6}$m


ATLAS beam pipe n1
@ GAMMA 7460.523071
@ EXN 3.75e-06
@ EYN 3.75e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.00086
@ CO_RADIUS 0.003
@ BETA_BEATING 1.1
@ BETA_STAR 0.30
11mm tol
15mm tol
TAS
n1 = 10.0
n1
Pipe Radius (m)
Distance (m)
IP1
0
20
40
60
80
100
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
-20
-15
-10
-5
5
10
15
20


CMS beam pipe n1
@ GAMMA 7460.523071
@ EXN 3.75e-06
@ EYN 3.75e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.00086
@ CO_RADIUS 0.003
@ BETA_BEATING 1.1
@ BETA_STAR 0.30
11mm tol
15mm tol
11mm tol CT2
n1 = 10.0
n1
Pipe Radius (mm)
Distance (m)
IP5
0
20
40
60
80
100
0
0.05
0.1
0.15
0.2
0.25
-20
-15
-10
-5
5
10
15
20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@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.00086
@ CO_RADIUS 0.003
@ BETA_BEATING 1.1
@ BETA_STAR 0.30
11mm tol
15mm tol
8.7mm tol CT2
n1 = 10.0
n1
Pipe Radius (mm)
Distance (m)
IP5
0
20
40
60
80
100
0
0.05
0.1
0.15
0.2
0.25
-20
-15
-10
-5
5
10
15
20

Conclusions

- Assuming a central region tolerance of 11mm, the ATLAS beam pipe aperture at injection and 7TeV is sufficient for LHC Phase 1 operation.
- Similarly, with a tolerance of 11mm also in the central region, the CMS beam pipe aperture is generally sufficient, except for the CT2 region. By reducing the CT2 tolerance to 8.7mm, the aperture becomes ≥ 10σ.
- The 48mm TAS aperture at 7TeV is marginal and warrants detailed study.