Experiment Beam Pipes Aperture Study

LHC Phase 1 Upgrade

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

Beam-pipe dimensions

- Current beam-pipe is R29 mm (Inner wall of Be)
- Heaters and aerogel --> 36 mm
- Inner Pixel radius is 45.4 mm
- i.e ~9 mm gap now, to include new IBL, insetion clearance, misalignments, tolerances...
- Reducing Be to R20 mm would be great and cover Phase II also
- Reducing Be to R25 mm for Phase I and possibly compressing aerogel or other optimisations increases gap to over 13 mm
  - Big improvement!
- Only need central ~+-500 mm at this radius – rest can be larger
- (We would like to attach the pixels to the beam-pipe)

Conclusion

- ATLAS needs some large-beta (2500 m) running until 2012
- Probably not needed after that
- We need urgently (< 3 months) commitment to a smaller beampipe diameter to design IBL for phase-I.
  - <= R25 mm is target for berillium inner wall
  - We need a safe value – cannot increase it later
- Smaller for phase-II: ~R20 mm.

Purpose & Scope of Study

- Verify that the aperture of current experiment beam pipes (r_p = 29mm) is sufficient for LHC Phase 1 operation.
- Investigate the possibility of reducing the beam pipe radius by up to 4mm.
- Provide a framework for further studies, as required, using MAD-X together with released machine layouts/optics.

Why use MAD-X?

- Using MAD-X allows us to include the necessary imperfections, such as beta-beating, closed orbit, spurious dispersion etc, together with standard beam separation schemes, at different energies & beta-stars.
- This provides a framework which is consistent with other studies e.g. tracking.

Method

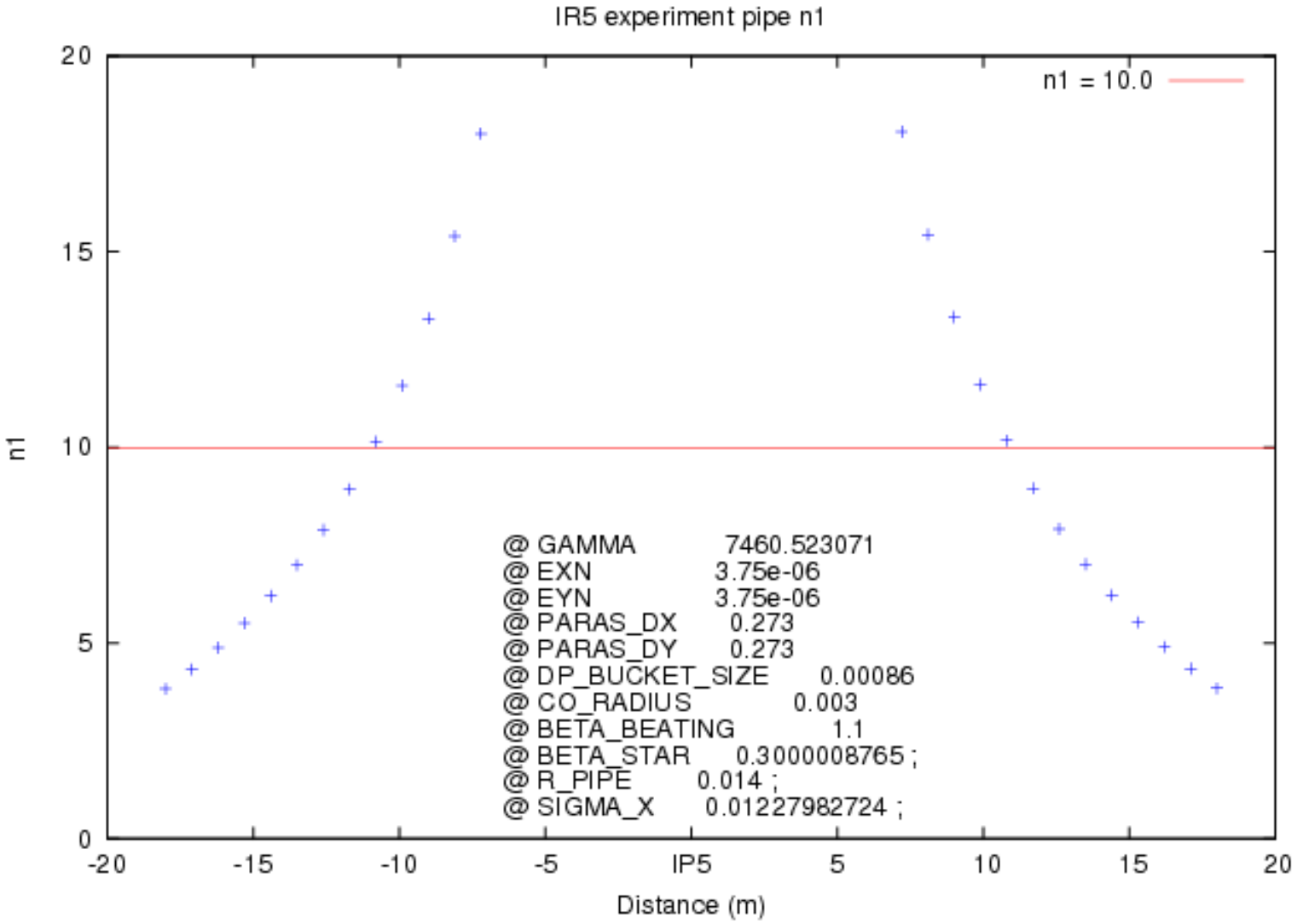
- Assume that the IR aperture is limited to r_c = 14mm (r_c = 10mm), which is the *beam-stay-clear distance (radius).*
- Introduce aperture-limitation markers into the MAD-X input file for the machine lattice, then compute and evaluate the aperture accordingly.
- The 40 markers are spaced apart by 90cm so they cover a region from -18m to +18m on each side of the IP.

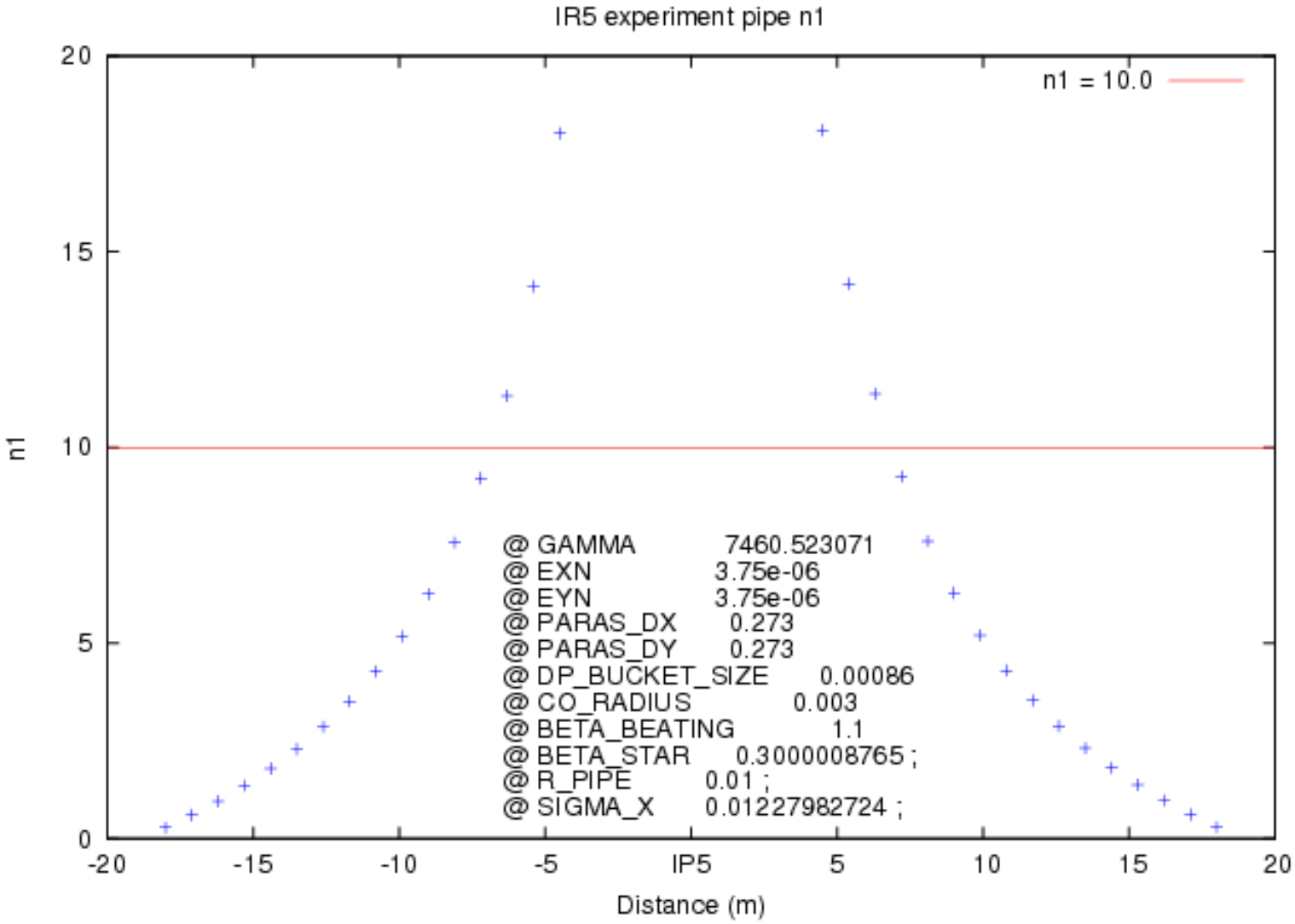
Scenarios

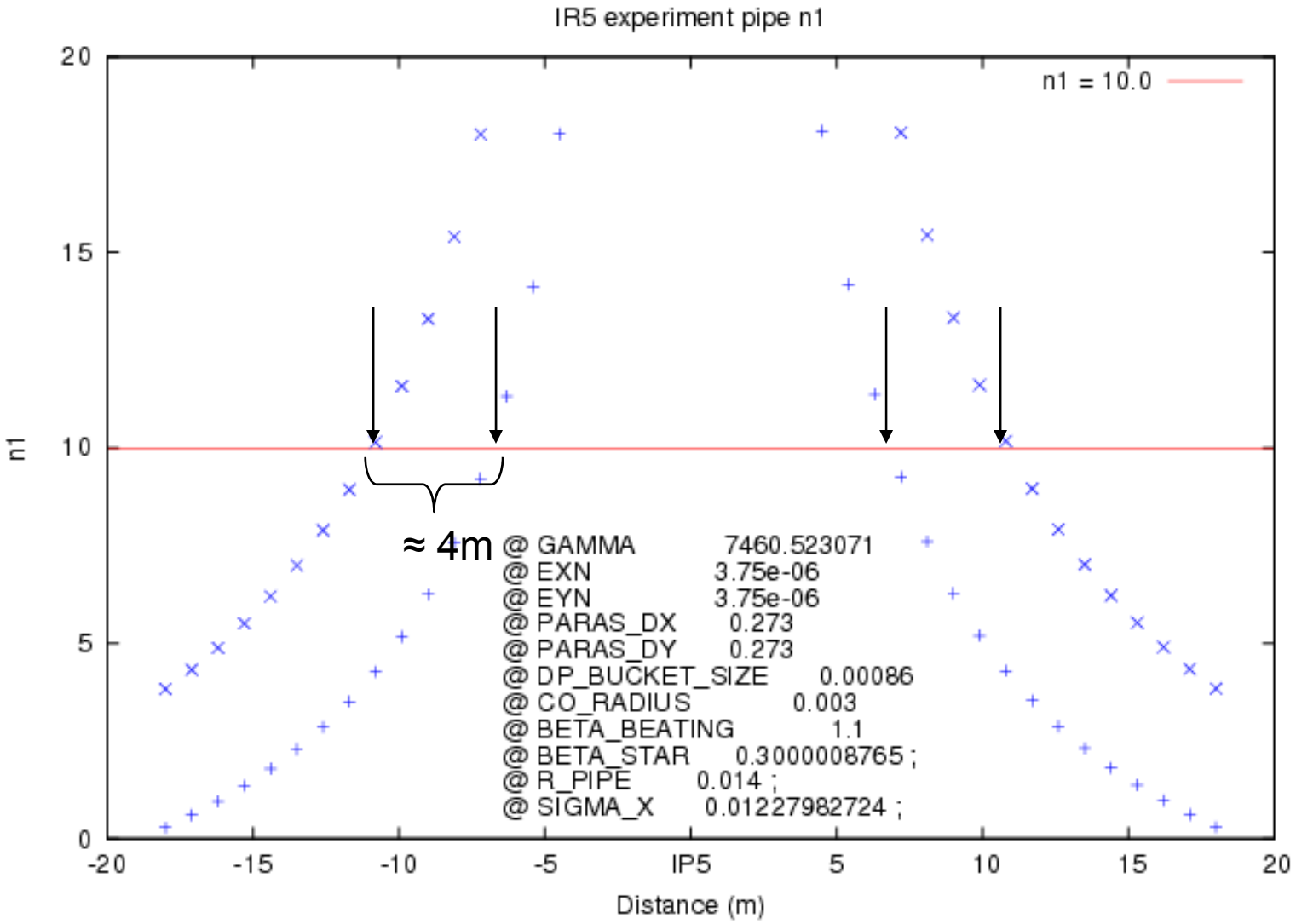
- IR5 low-beta at 7TeV.
- IR5 at injection.
- IR5 hi-beta at 7TeV.
  - All the above apply to IR1.
- IR2 at injection.
  - Also applies to IR8.
  - However, the IR2 and IR8 optics for Phase 1 are currently under revision.
- Operation at 5TeV is not considered.

IR5 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


IR5 experiment pipe n1
n1 = 10.0
n1
Distance (m)
IP5
@ 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 0.3000008765 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.01227982724 ;


IR5 experiment pipe n1
n1 = 10.0
n1
Distance (m)
IP5
20
15
10
5
0
-20
-15
-10
-5
5
10
15
20
@ 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 0.3000008765 ;
@ R_PIPE 0.01 ;
@ SIGMA_X 0.01227982724 ;

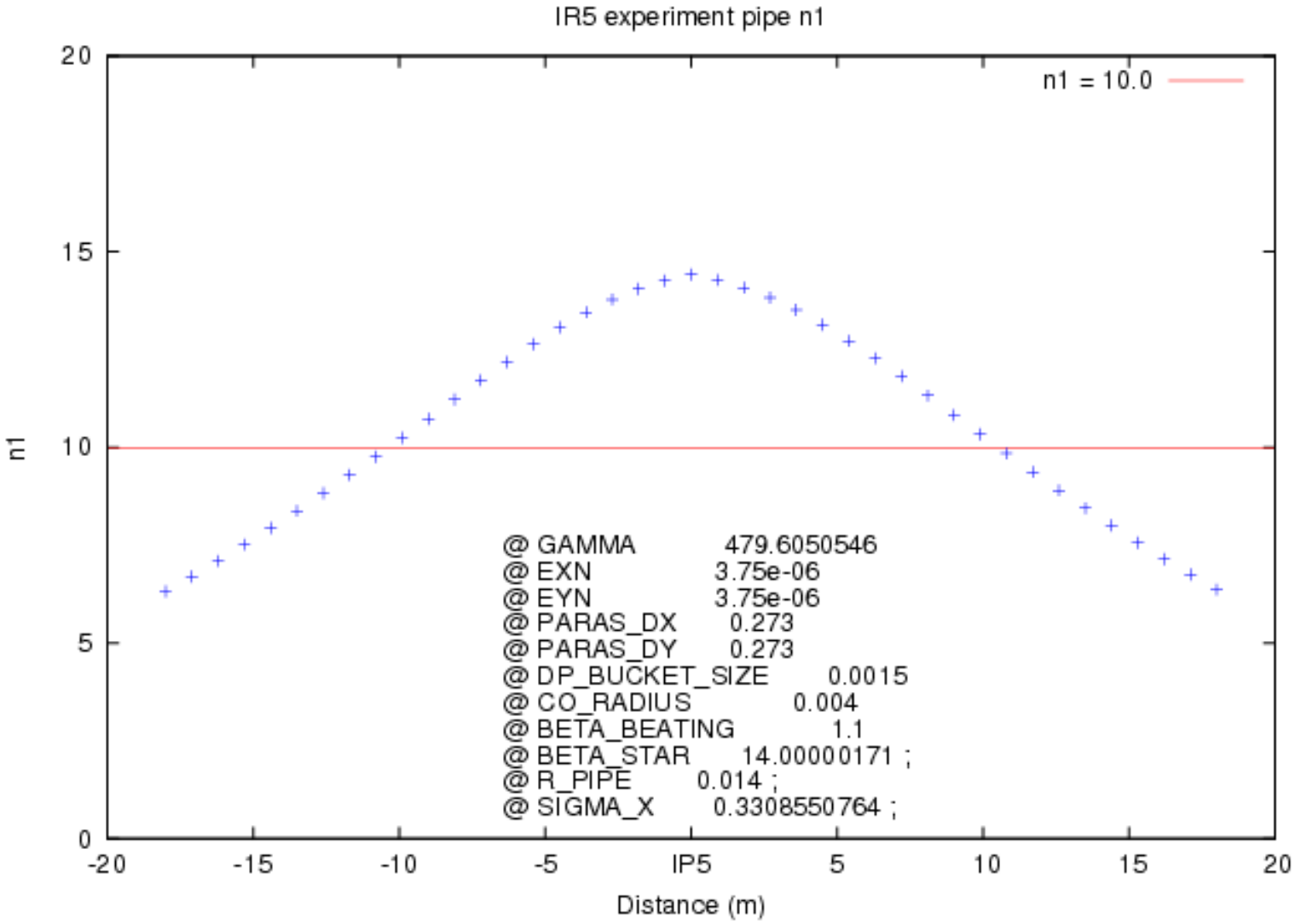

IR5 experiment pipe n1
n1 = 10.0
n1
Distance (m)
IP5
≈ 4m
@ GAMMA 7460.523071
@ EXN 3.75e-06
@ EYN 3.75e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.00086
@ CO_RADIUS 0.003
@ BETA_BEATING 1.1
@ BETA_STAR 0.3000008765 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.01227982724 ;

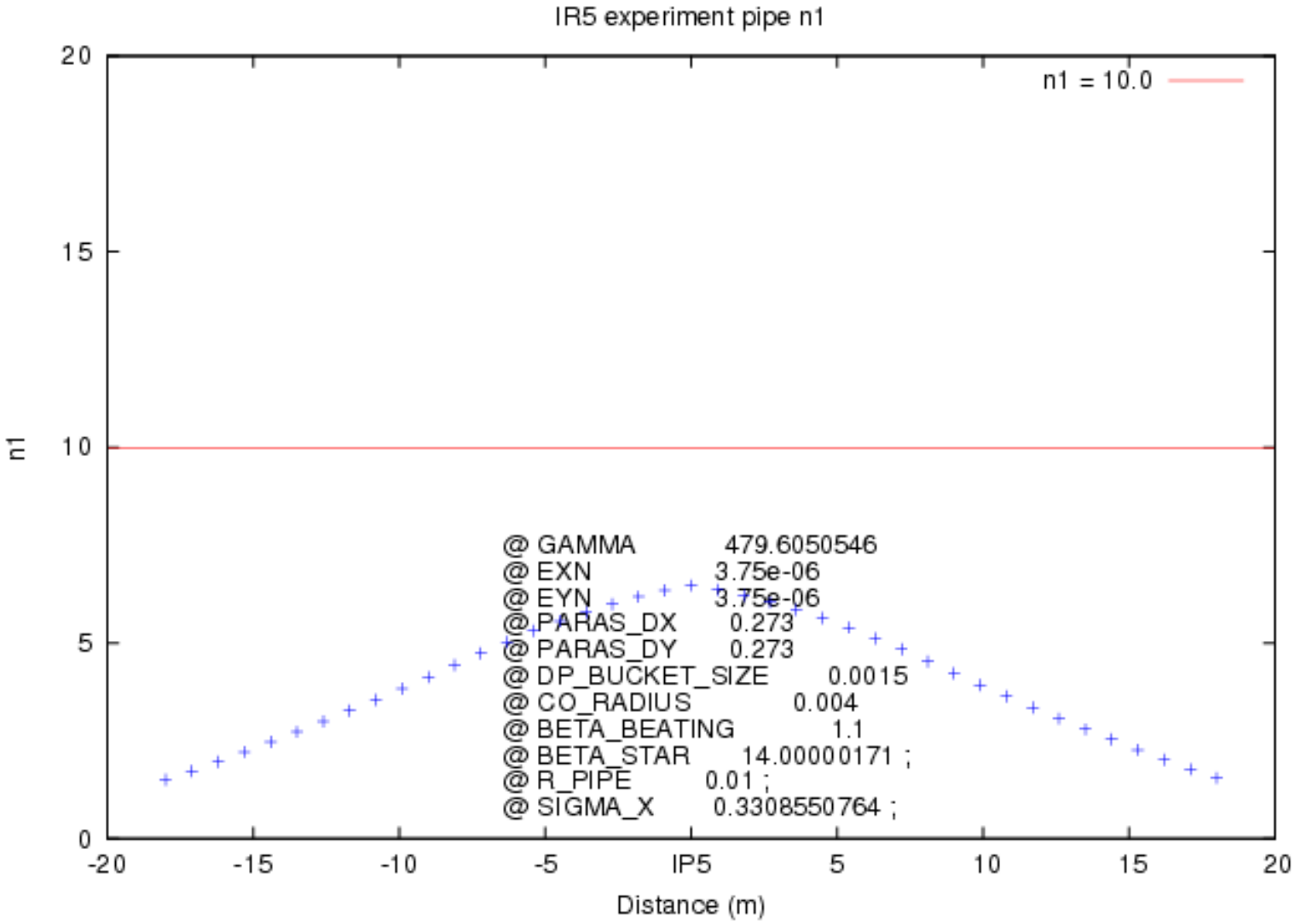
Comment: IR5 Low-beta

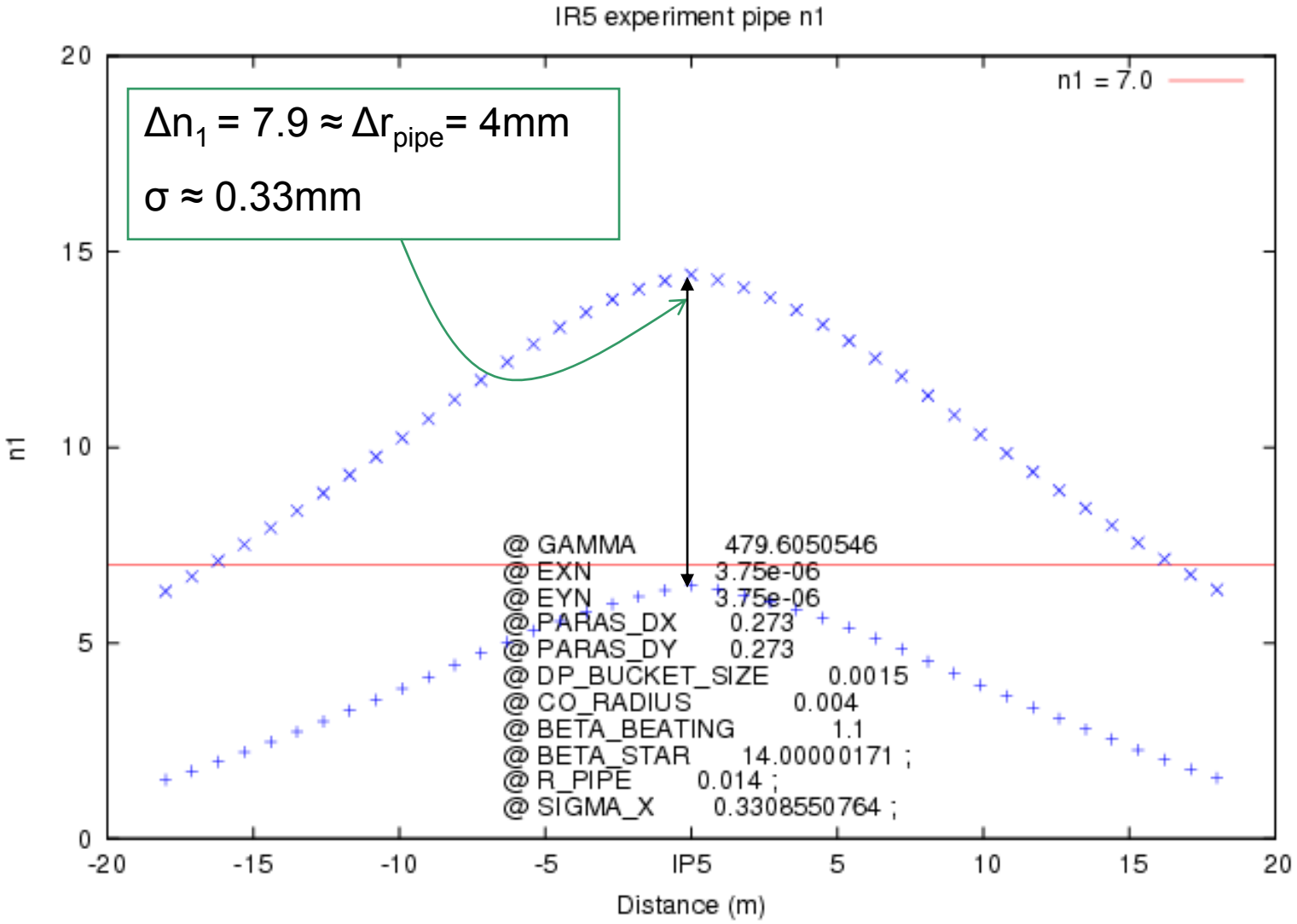
- The r_c = 14mm beam “pipe” has sufficient aperture (more than 10σ) over a length of at least ±10m from the IP.
- The r_c = 10mm beam “pipe” has sufficient aperture (more than 10σ) over a length of at least ±6m from the IP.

IR5 Injection

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


IR5 experiment pipe n1
n1 = 10.0
n1
Distance (m)
IP5
20
15
10
5
0
-20
-15
-10
-5
5
10
15
20
@ 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 14.00000171 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.3308550764 ;


IR5 experiment pipe n1
n1 = 10.0
n1
20
15
10
5
0
-20
-15
-10
-5
IP5
5
10
15
20
Distance (m)
@ 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 14.00000171 ;
@ R_PIPE 0.01 ;
@ SIGMA_X 0.3308550764 ;

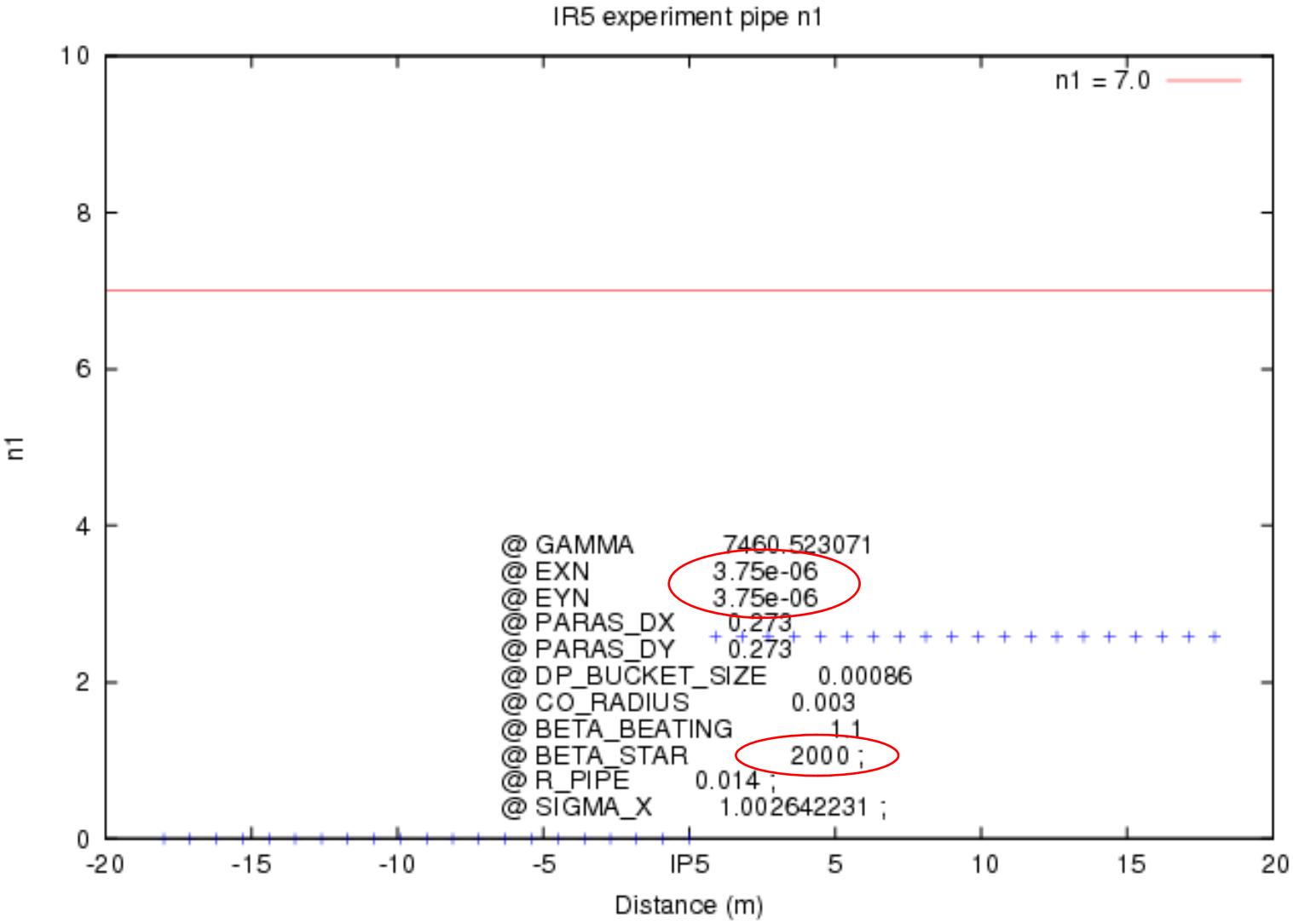

IR5 experiment pipe n1
$\Delta n_1 = 7.9 \approx \Delta r_{pipe} = 4mm$
$\sigma \approx 0.33mm$
n1 = 7.0
@ GAMMA 479.6050546
@ EXN 3.75e-06
@ EYN 3.75e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.0015
@ CO_RADIUS 0.004
@ BETA_BEATING 1.1
@ BETA_STAR 14.00000171 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.3308550764 ;
n1
Distance (m)
IP5

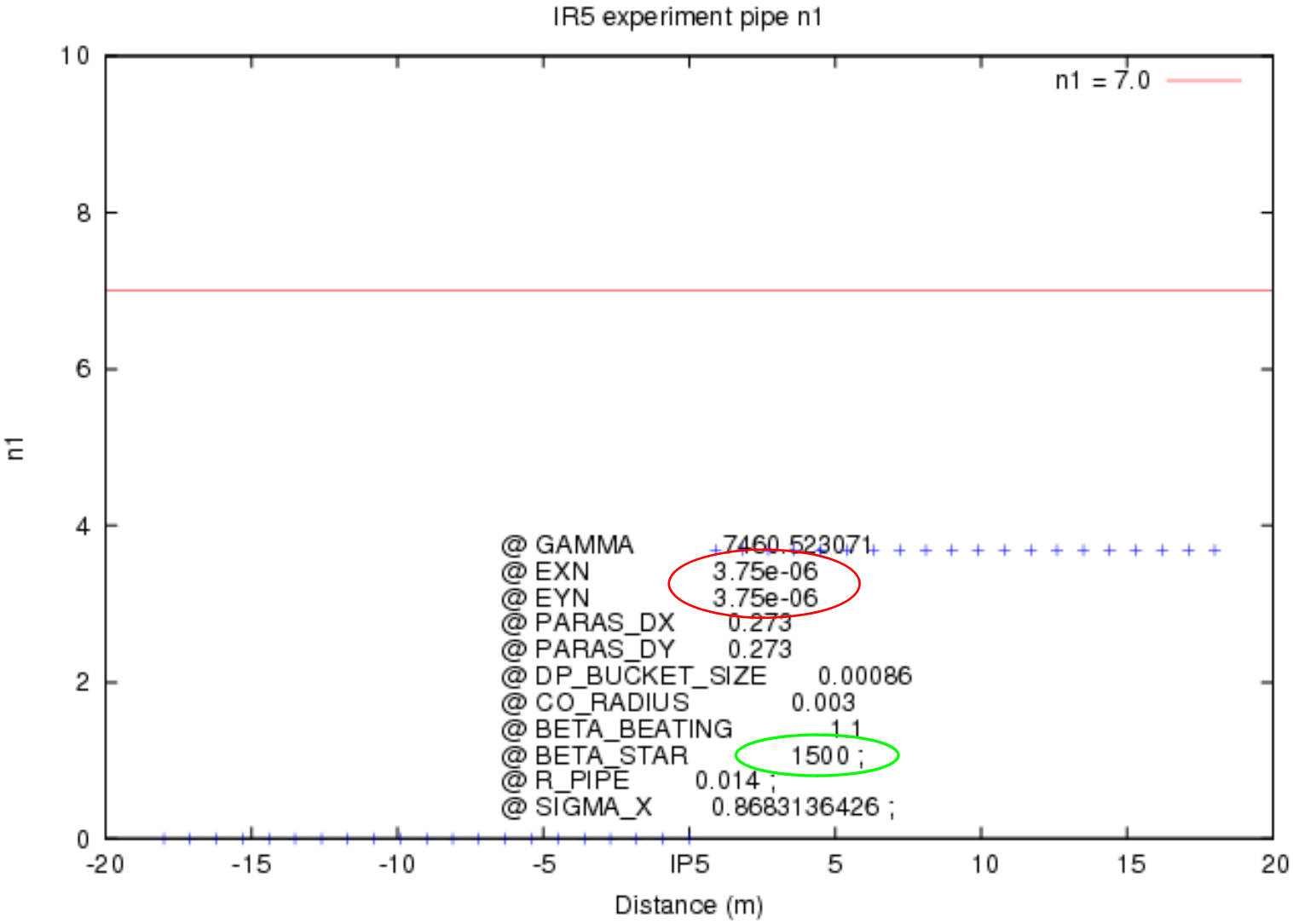
Comment: IR5 Injection

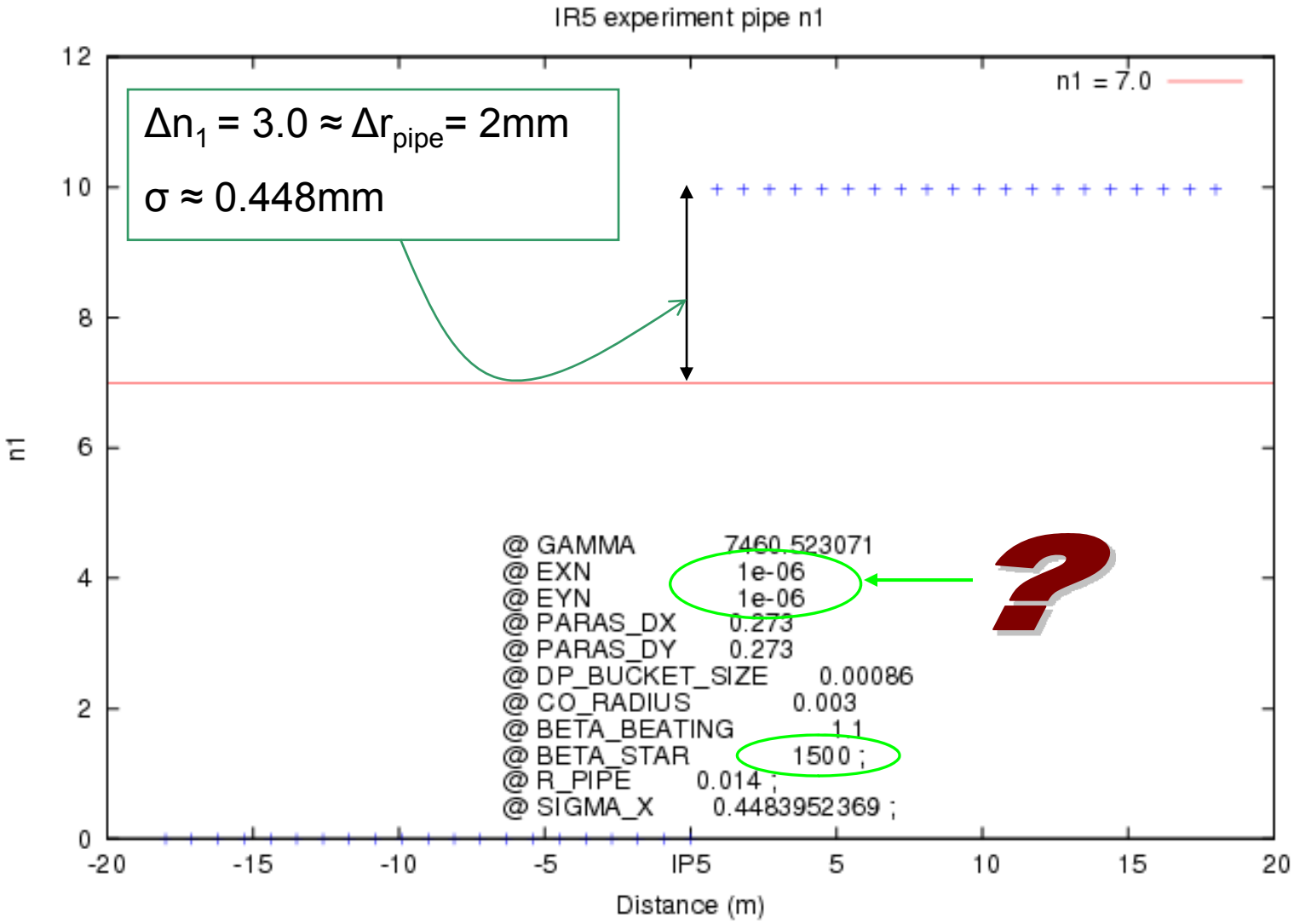
- The r_c = 14mm beam “pipe” has sufficient aperture (more than 10σ) over a length of up to ±10m from the IP.
- The r_c = 10mm beam “pipe” has insufficient aperture over the whole length of the IP region. Therefore, it is unusable.
- A small margin exists for $10mm << r_c \leq 14mm$.

IR5 Hi-beta 7TeV

- (half) separation:
  - $p_{sep} = 5\sigma$ (function of beta and ε_n)
- At present, no optics exist for this option.
  - Optics are computed for a line, starting from the IP, with specific initial conditions.
  - Two values of β*, 1500m and 2000m
  - Not all imperfections are included in the aperture calculation.
- The very low emittance is not guaranteed operationally.


IR5 experiment pipe n1
n1 = 7.0
n1
Distance (m)
IP5
@ 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 2000 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 1.002642231 ;


IR5 experiment pipe n1
n1 = 7.0
@ 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 1500 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.8683136426 ;
n1
Distance (m)
IP5

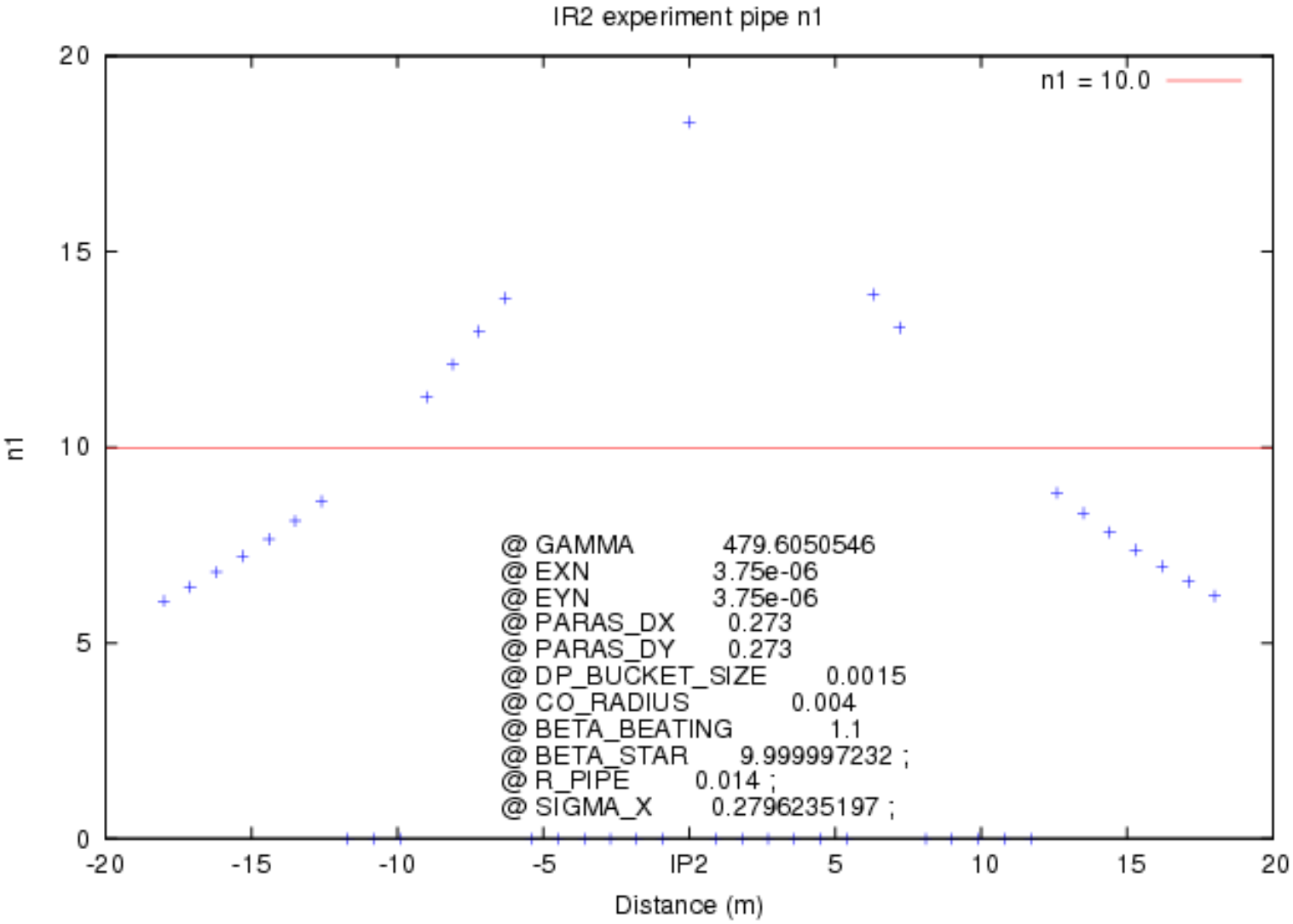

IR5 experiment pipe n1
$\Delta n_1 = 3.0 \approx \Delta r_{pipe} = 2mm$
$\sigma \approx 0.448mm$
n1 = 7.0
@ GAMMA 7460.523071
@ EXN 1e-06
@ EYN 1e-06
@ PARAS_DX 0.273
@ PARAS_DY 0.273
@ DP_BUCKET_SIZE 0.00086
@ CO_RADIUS 0.003
@ BETA_BEATING 1.1
@ BETA_STAR 1500 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.4483952369 ;
?
n1
Distance (m)
IP5

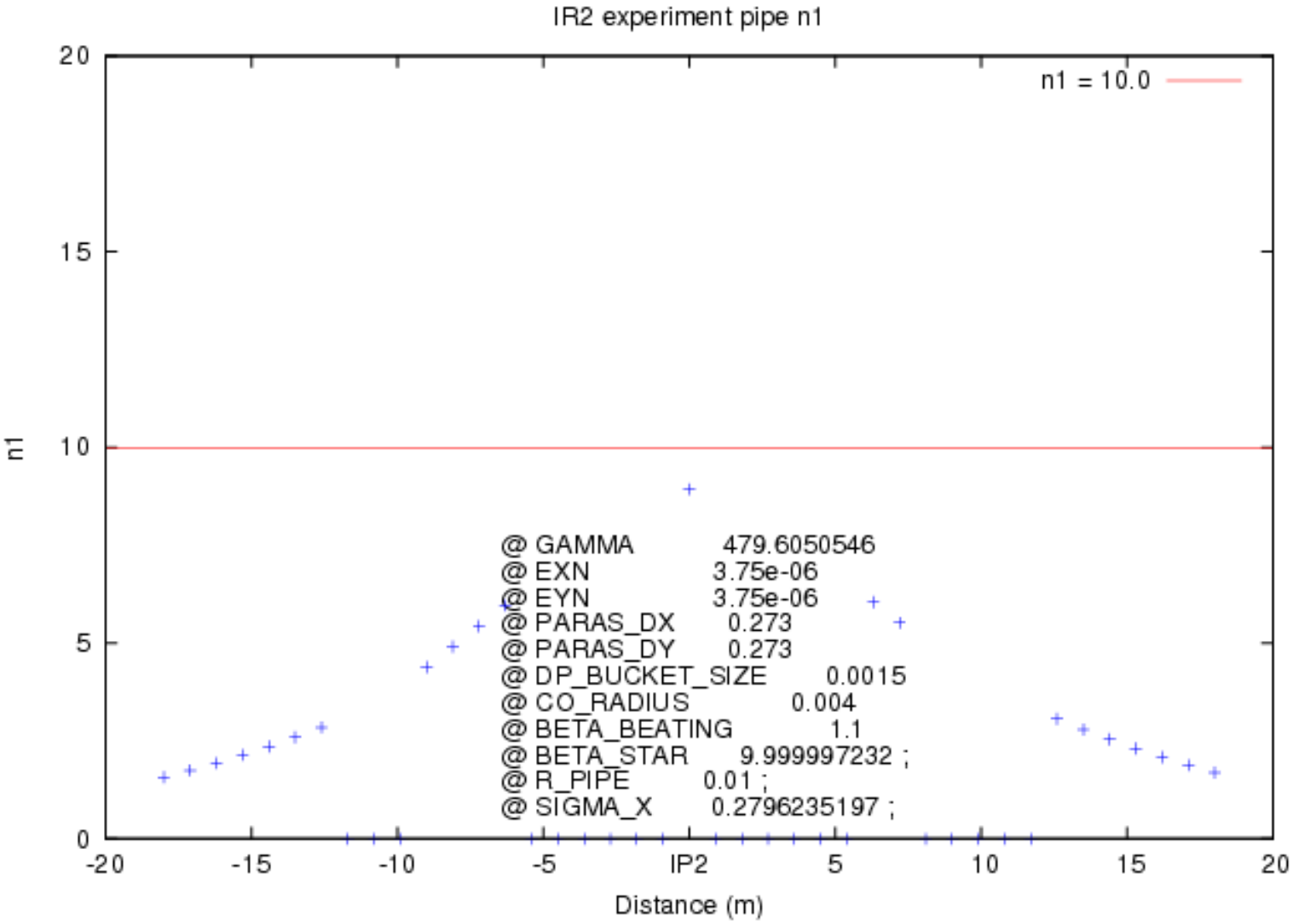
Comment: IR5 Hi-beta

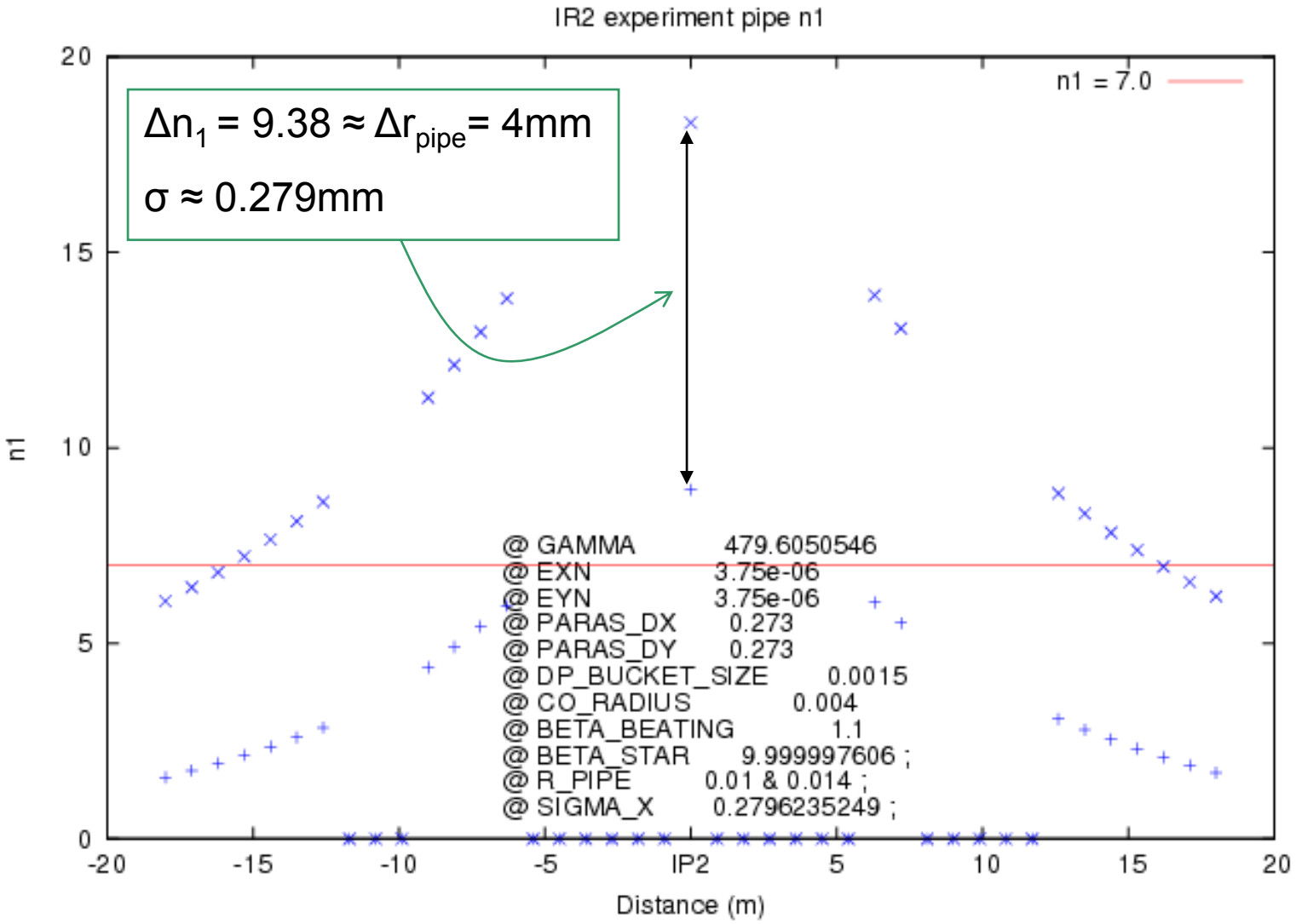
- For the "standard" normalised emittance of 3.75×10^{-6}m, The r_c = 14mm beam "pipe" has insufficient aperture over the whole length of the IP region. Therefore, it is unusable.
- Operation *could* be possible for β* = 1500m *should* a much lower emittance become available – no guarantee!!
- Not all optics imperfections were included in the study, results could be worse!

IR2 Injection

- (half) separation:
  - Θ = 170 μrad
  - p_{sep} = 2mm
- β^* = 10m
- Transverse normalised emittance $\varepsilon_n = 3.75 \times 10^{-6}$m
- IR8 is similar
- Missing markers in locations of spectrometer etc.


IR2 experiment pipe n1
n1 = 10.0
n1
Distance (m)
IP2
20
15
10
5
0
-20
-15
-10
-5
5
10
15
20
@ 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 9.999997232 ;
@ R_PIPE 0.014 ;
@ SIGMA_X 0.2796235197 ;


IR2 experiment pipe n1
n1 = 10.0
n1
Distance (m)
IP2
20
15
10
5
0
-20
-15
-10
-5
5
10
15
20
@ 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 9.999997232 ;
@ R_PIPE 0.01 ;
@ SIGMA_X 0.2796235197 ;


IR2 experiment pipe n1
$\Delta n_1 = 9.38 \approx \Delta r_{pipe} = 4mm$
$\sigma \approx 0.279mm$
n1 = 7.0
@ 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 9.999997606 ;
@ R_PIPE 0.01 & 0.014 ;
@ SIGMA_X 0.2796235249 ;
n1
Distance (m)
IP2
20
15
10
5
0
-20
-15
-10
-5
5
10
15
20

Comment: IR2 Injection

- The r_c = 14mm beam “pipe” has sufficient aperture (more than 10σ) over a length of up to ±10m from the IP.
- The r_c = 10mm beam “pipe” has insufficient aperture over the whole length of the IP region. Therefore, it is unusable.
- A *small* margin exists for $10mm << r_c \leq 14mm$.

Conclusions

- A beam-stay-clear distance of r_c = 14mm over a ***limited*** region on each side of the IP, is consistent with normal operation of the LHC Phase 1 Upgrade in the following scenarios:
  - IR5 (IR1) low-beta with β* = 30cm @7TeV
  - IR5 (IR1) injection with β* = 14m @ 450GeV
  - IR2 (IR8) injection with β* = 10m @ 450GeV
- Operation of IR5 with a high β* ≤ 1500m depends on the availability of a low emittance.

Conclusions

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