Momentum Aperture and Flat Bottom Losses

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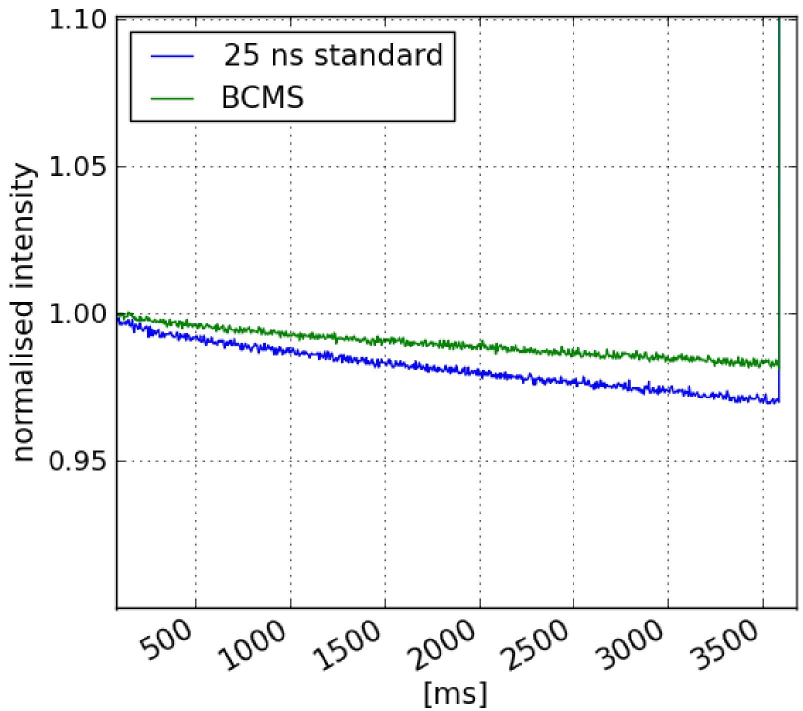
Observation

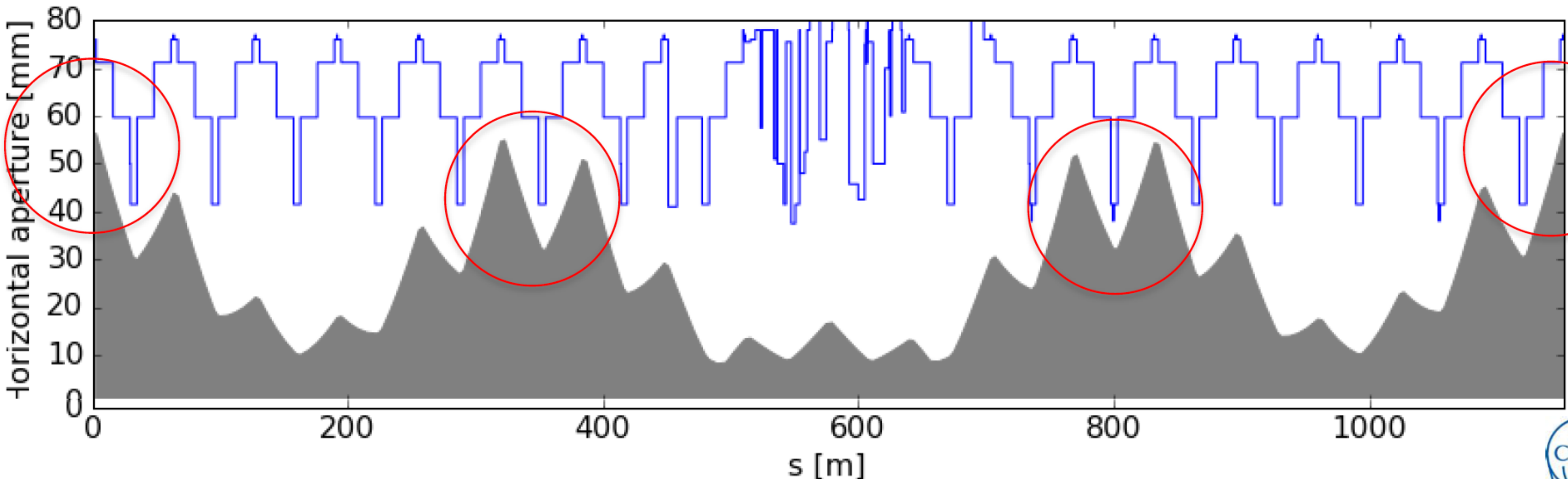
- High intensity run 2017 in the SPS
  - Up 2 x 10^{11} p^+ per bunch
  - Comparison 25 ns standard (48 bunches) with BCMS
  - Standard $\varepsilon \sim 4\ \mu m$, BCMS $\varepsilon \sim 2\ \mu m$
  - Same longitudinal emittances



- Lower losses with lower emittance
  - ~ 5 % @ 11 s for BCMS
  - ~ 7 % @ 11 s for standard

Theoretical aperture bottleneck with Q20

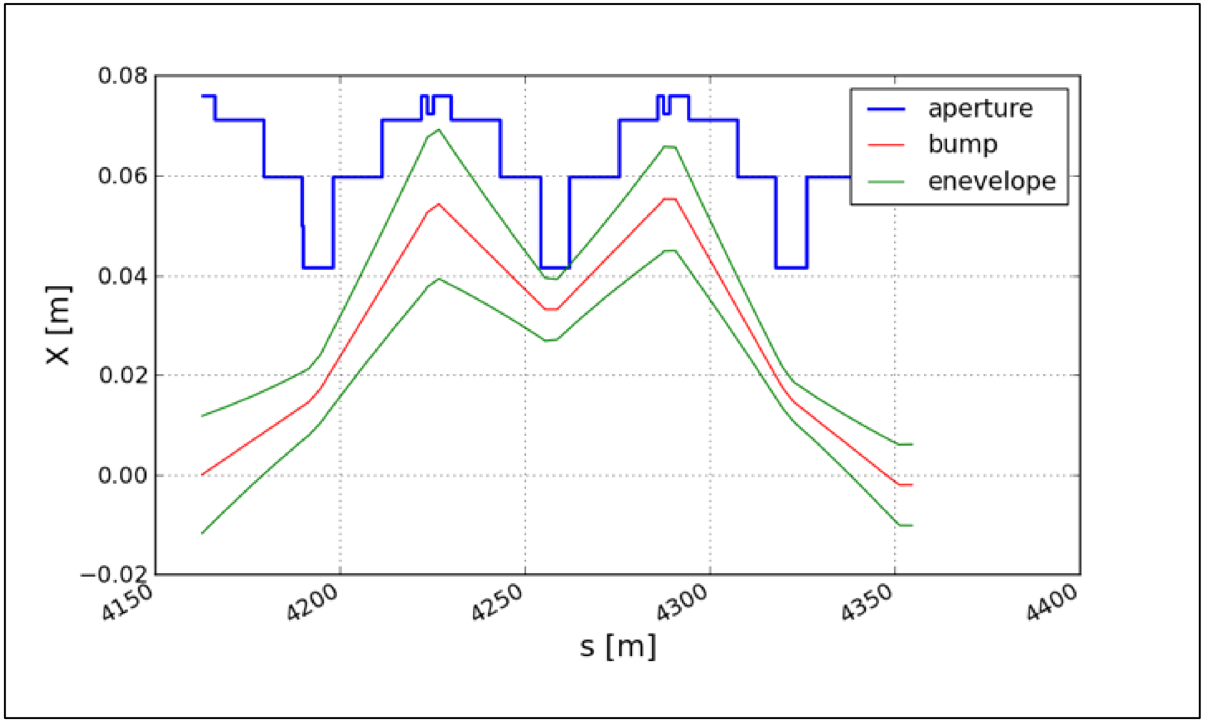
- Beam envelope for Q20 with 2 um emittance



- Aperture tight at QD locations with large dispersion
  - Fits loss pattern

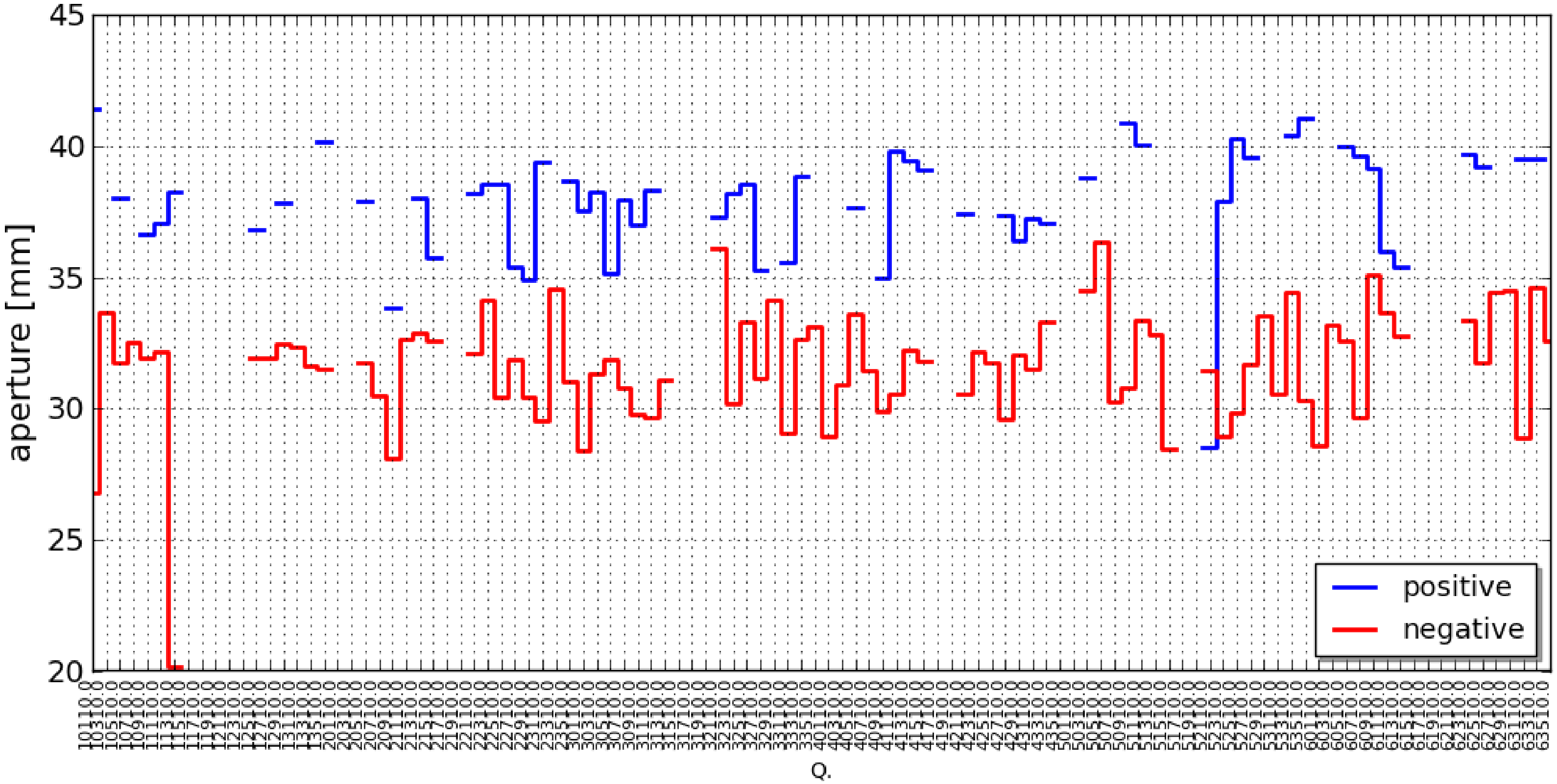
Measurement of mechanical aperture at QDs in H

- Measured at all QDs except locations *17 and *19
- Measurement at 14 GeV, Q26 with 4C bump
- Interpolate orbit at QD location and correct measured max. bump amplitude

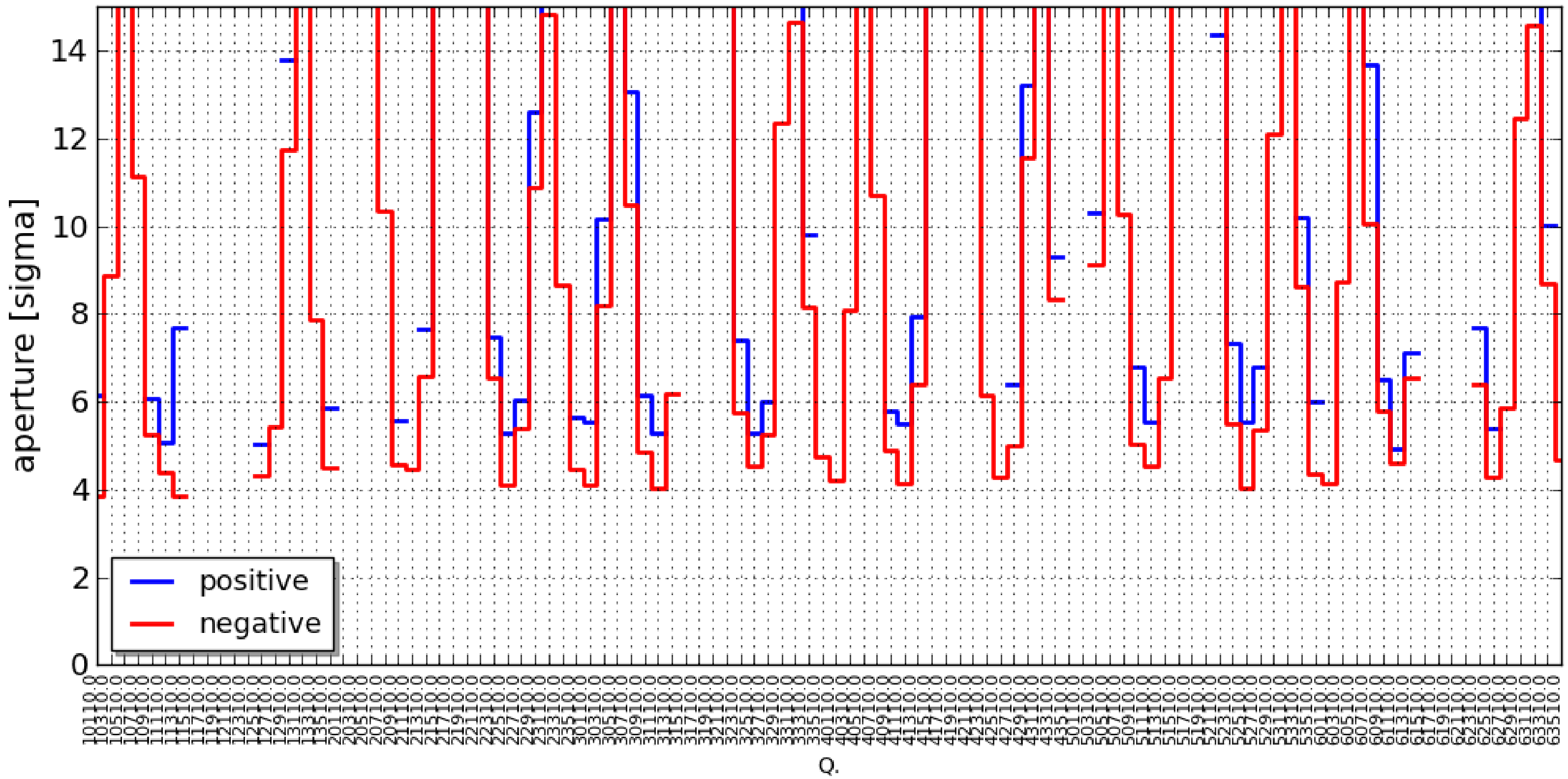


Result in mm

- Systematically smaller aperture towards the inside than towards the outside. Aperture on paper 41.5 mm



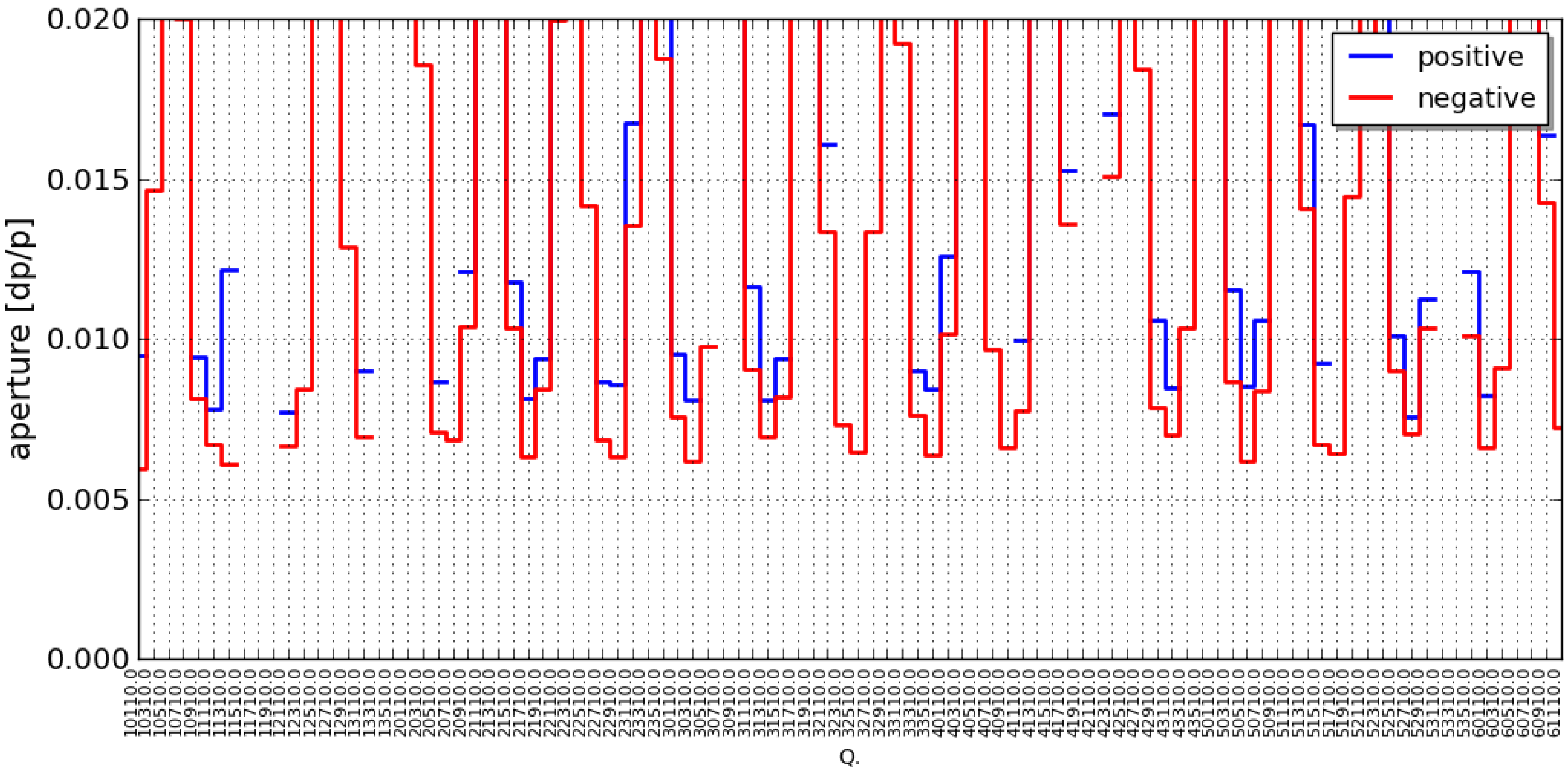
- 2 um emittance, 2 mm orbit error, 1.5e-3 momentum spread



Aperture: +4.9 σ/-3.8 σ

Result in dp/p in Q20

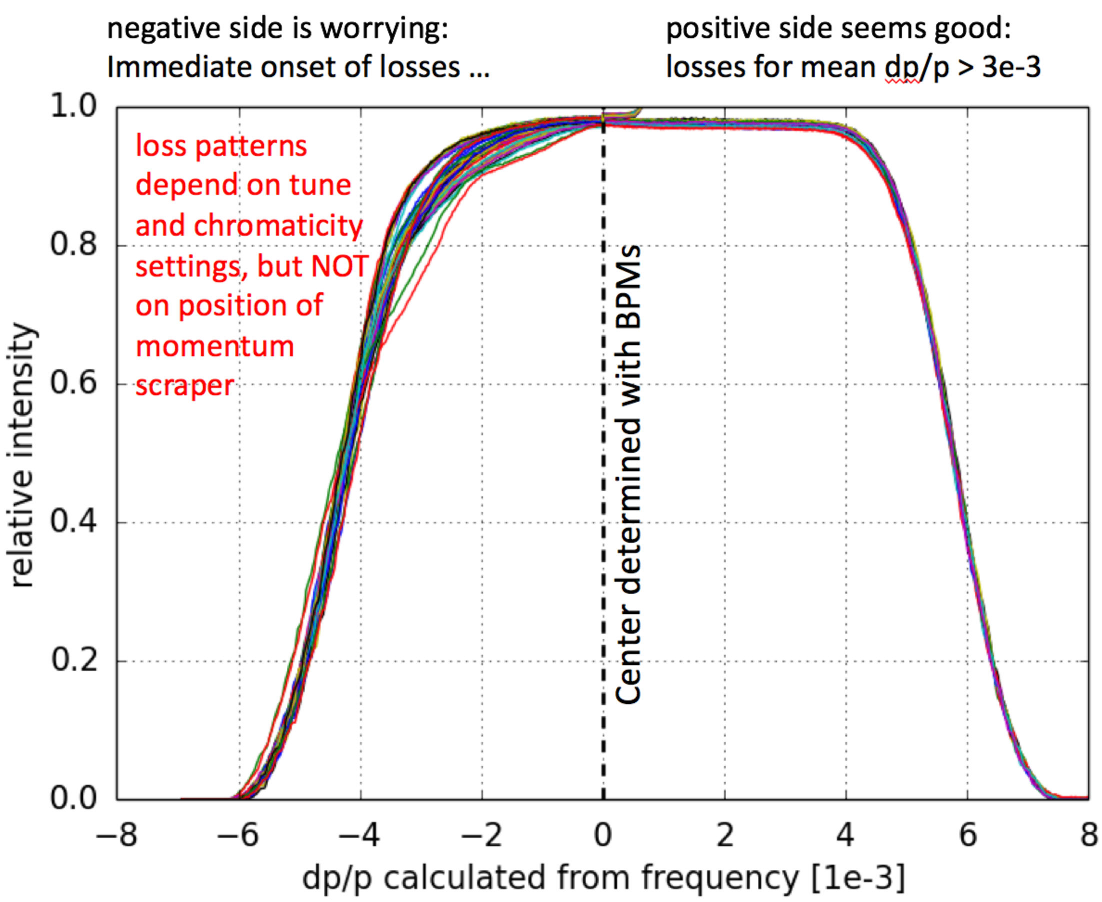
- What is radial steering limit?



Aperture: +0.76 % / -0.59 %

Compare to momentum aperture measurement with radial steering

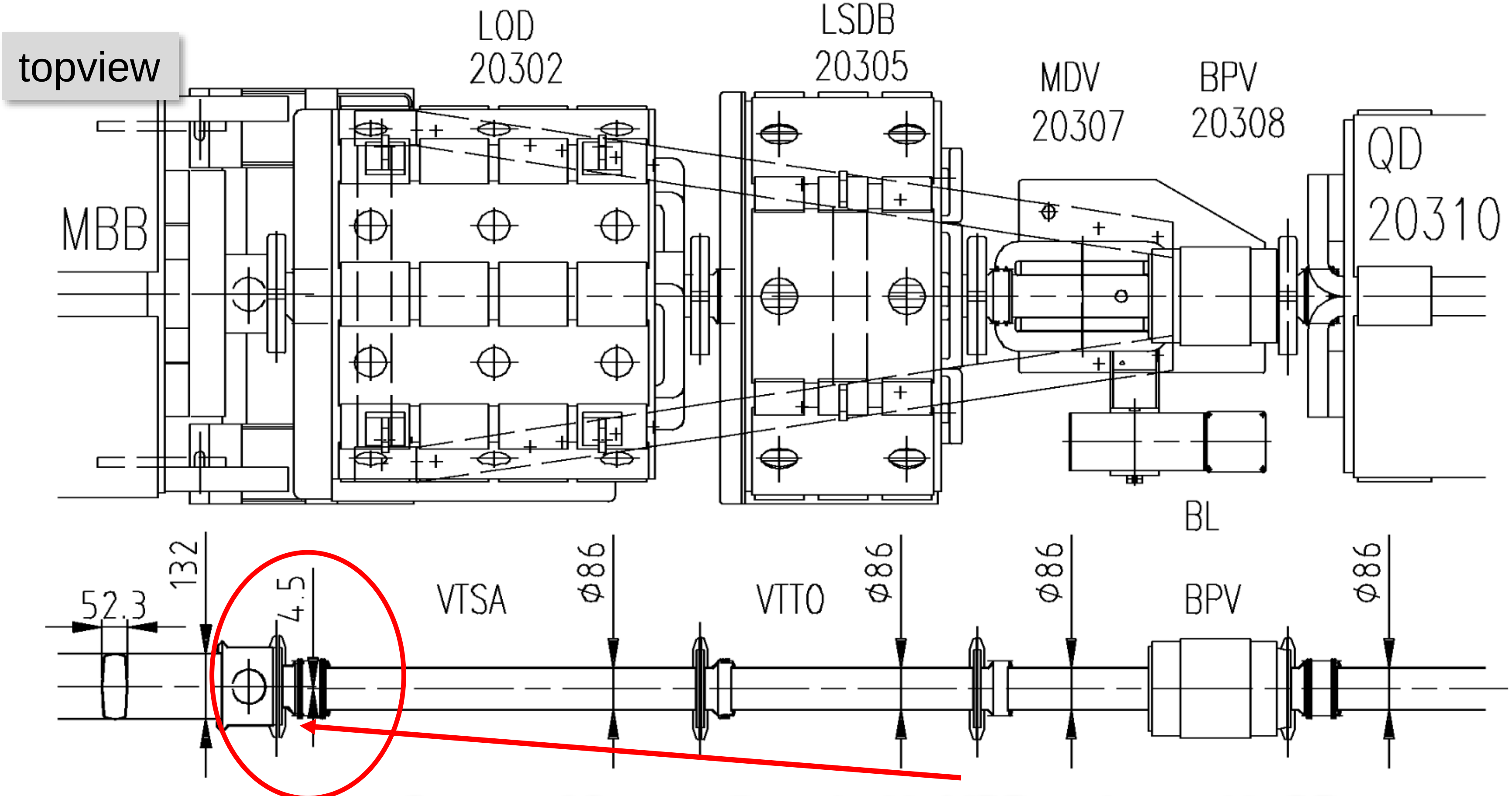
- Assuming 2 mm orbit error



Aperture measurement:
+0.76 % / -0.59 %

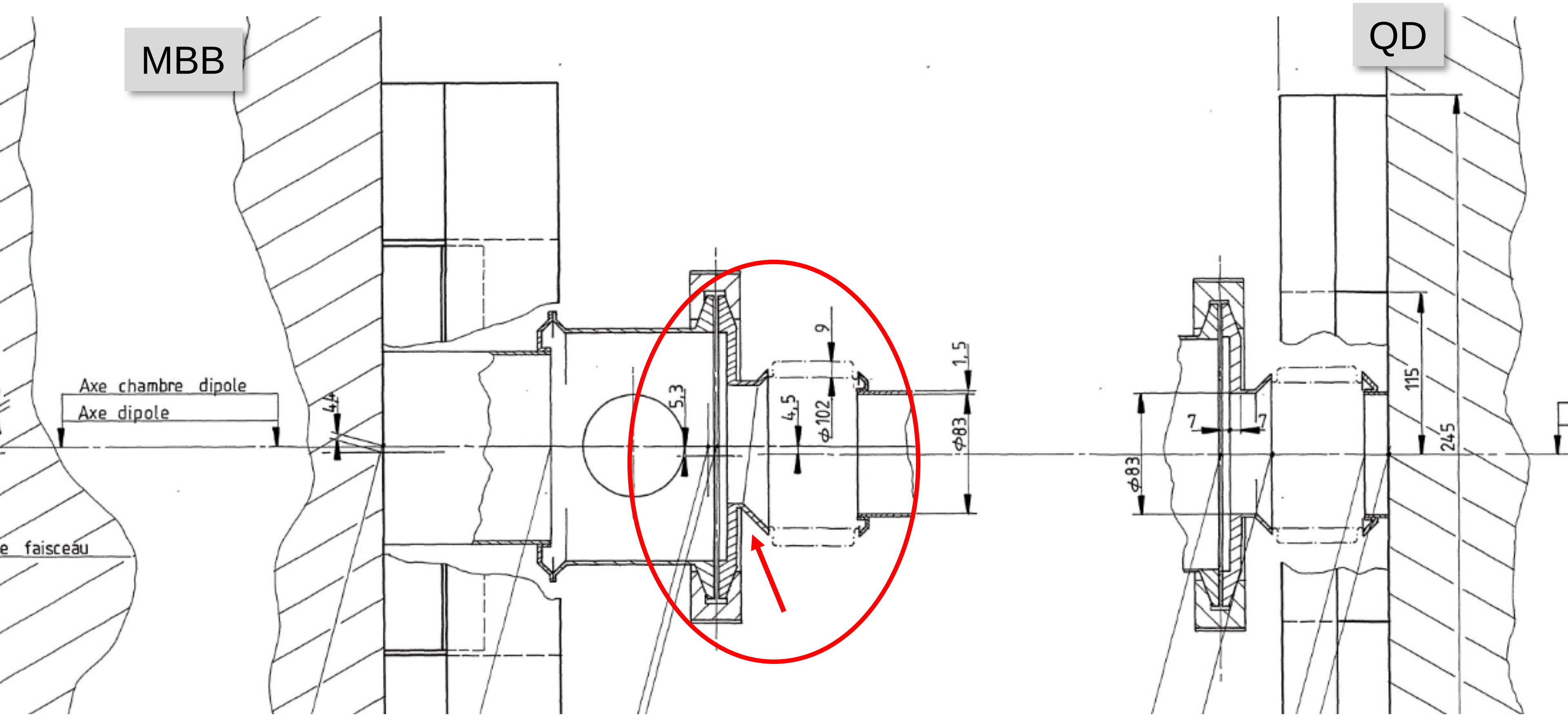
Probable explanation of asymmetric momentum aperture

- Transition MBB – SSS(QD): MBB is aligned 4.5 mm to outside



Center of flange aligned with MBB and not with QD
Transition occurs in bellows
→ miss 5.3 +/- 2 mm on the inside of flange….systematically

MBB – SSS (QD) transition



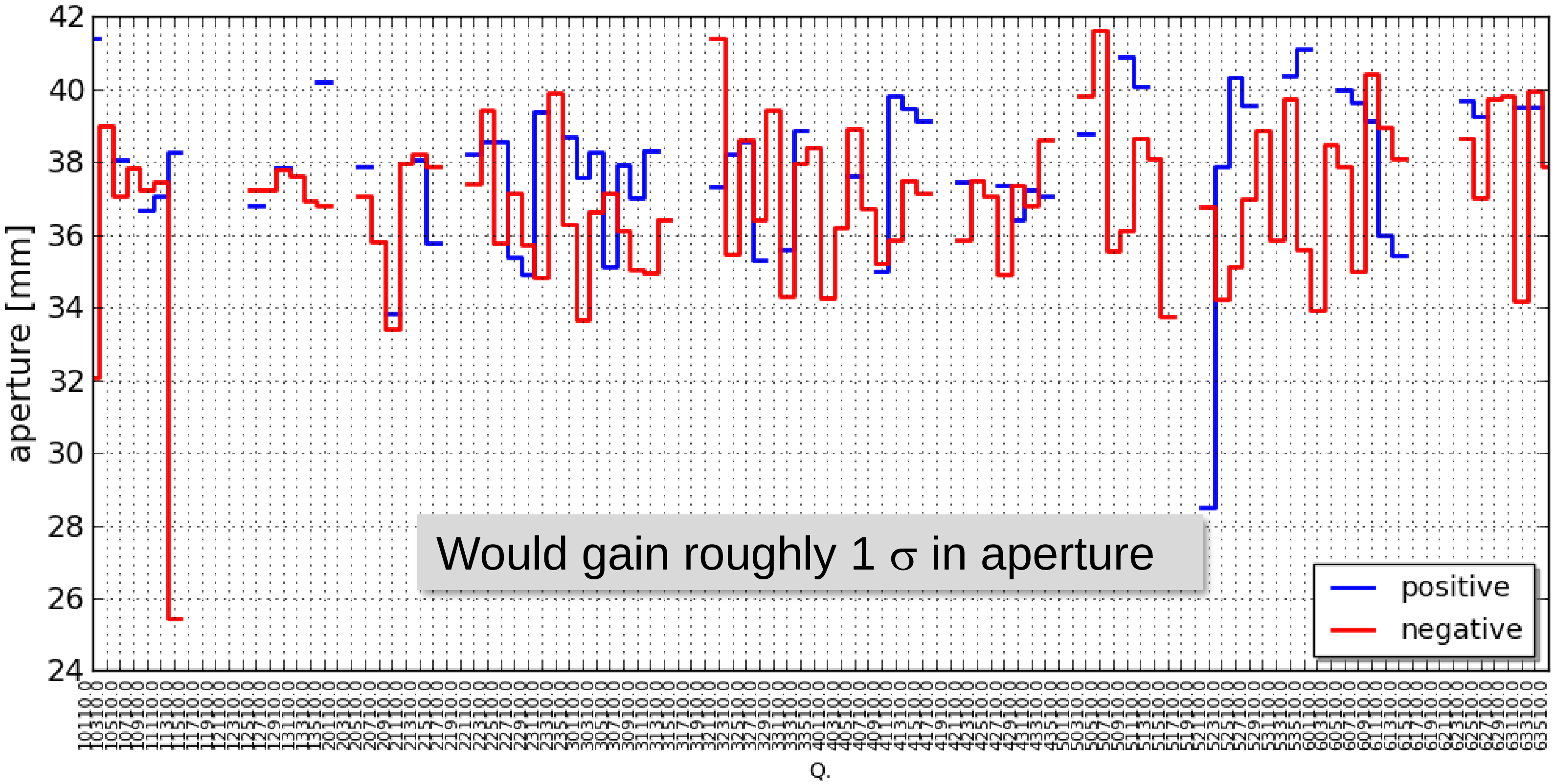
Comparison of different optics

- Given the aperture
  - Assume 2 um emittance, 1.5e-3 dp/p, 2 mm orbit

Optics	dp/p [%]	Aperture [σ]
Q20	+0.76 / -0.59	+4.9 / - 3.8
Q22	+0.9 / - 0.73	+ 5.8 / - 4.8
Q26	+1.7 / - 1.3	+10.5 / - 8.3

Measured aperture corrected by 5.3 mm

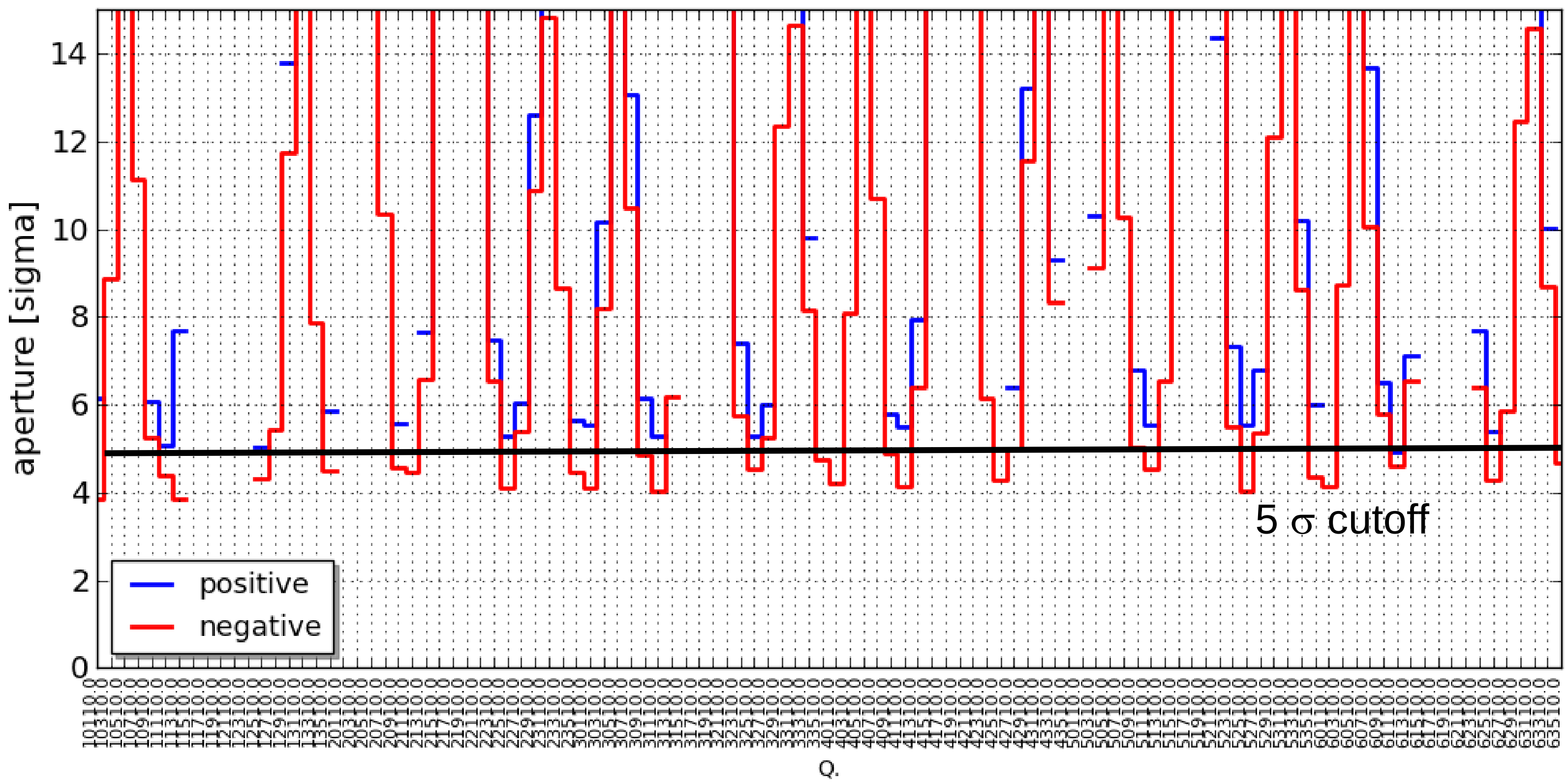
- Difference between negative and positive aperture less pronounced
- Possibly a few locations with pumping port shield flange on QD-MBB transition installed wrongly



Would gain roughly 1 σ in aperture

Locations to increase aperture

~ 26 locations for LS2



Reason for cutoff: QF aperture not larger than 5 σ

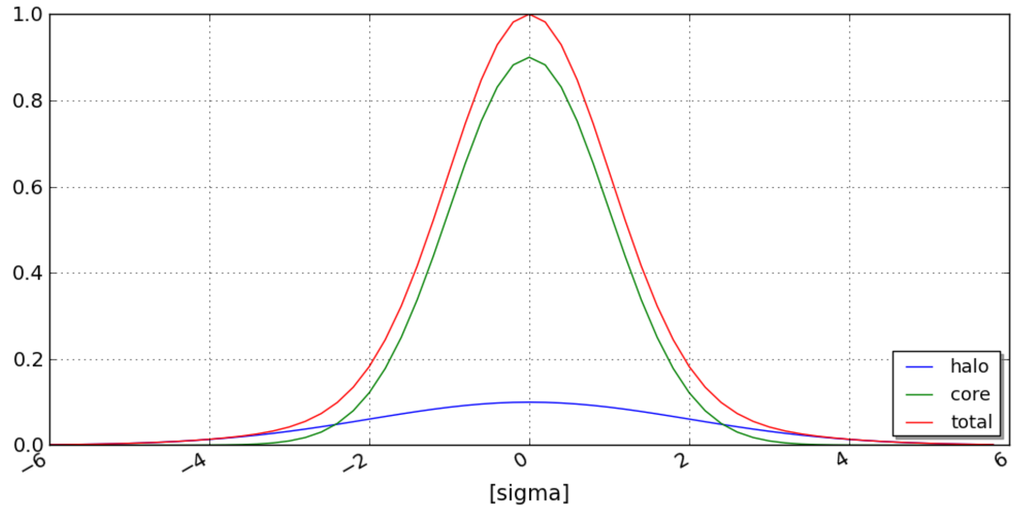
APERTURE INCREASE – IMPACT ON TRANSMISSION

Diffusion

- Ideally could have used Q22 – need comparable dataset Q20/Q22

- Thus : Assume linear diffusion process in the horizontal plane from I_1 to I_2 in Double Gaussian

$$\underbrace{I_1}_{\text{core}} \cdot e^{-\frac{x^2}{2\sigma_1^2}} + \underbrace{I_2}_{\text{halo}} \cdot e^{-\frac{x^2}{2\sigma_2^2}}$$

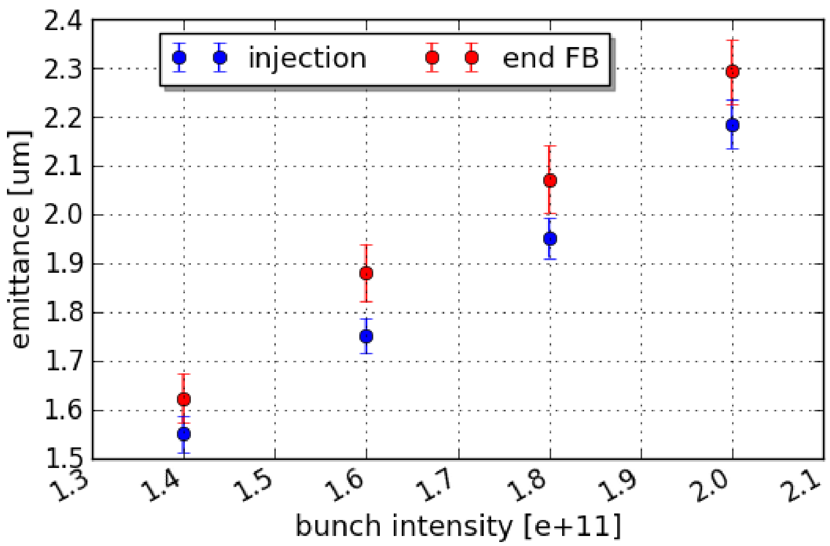


- Use as input: 1.9e+11 ppb; 48 bunches: $\varepsilon = 4$ um for standard, $\varepsilon = 2$ um for BCMS
- Larger losses for 25 ns standard than for BCMS
  - ~ 5 % for BCMS, ~ 7 % for standard

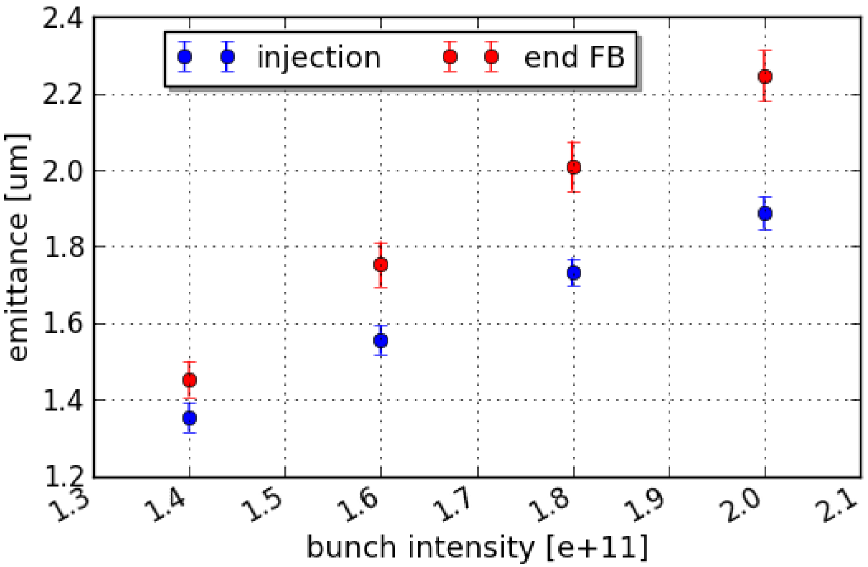
What about emittance growth?

- Measurements for BCMS

Horizontal



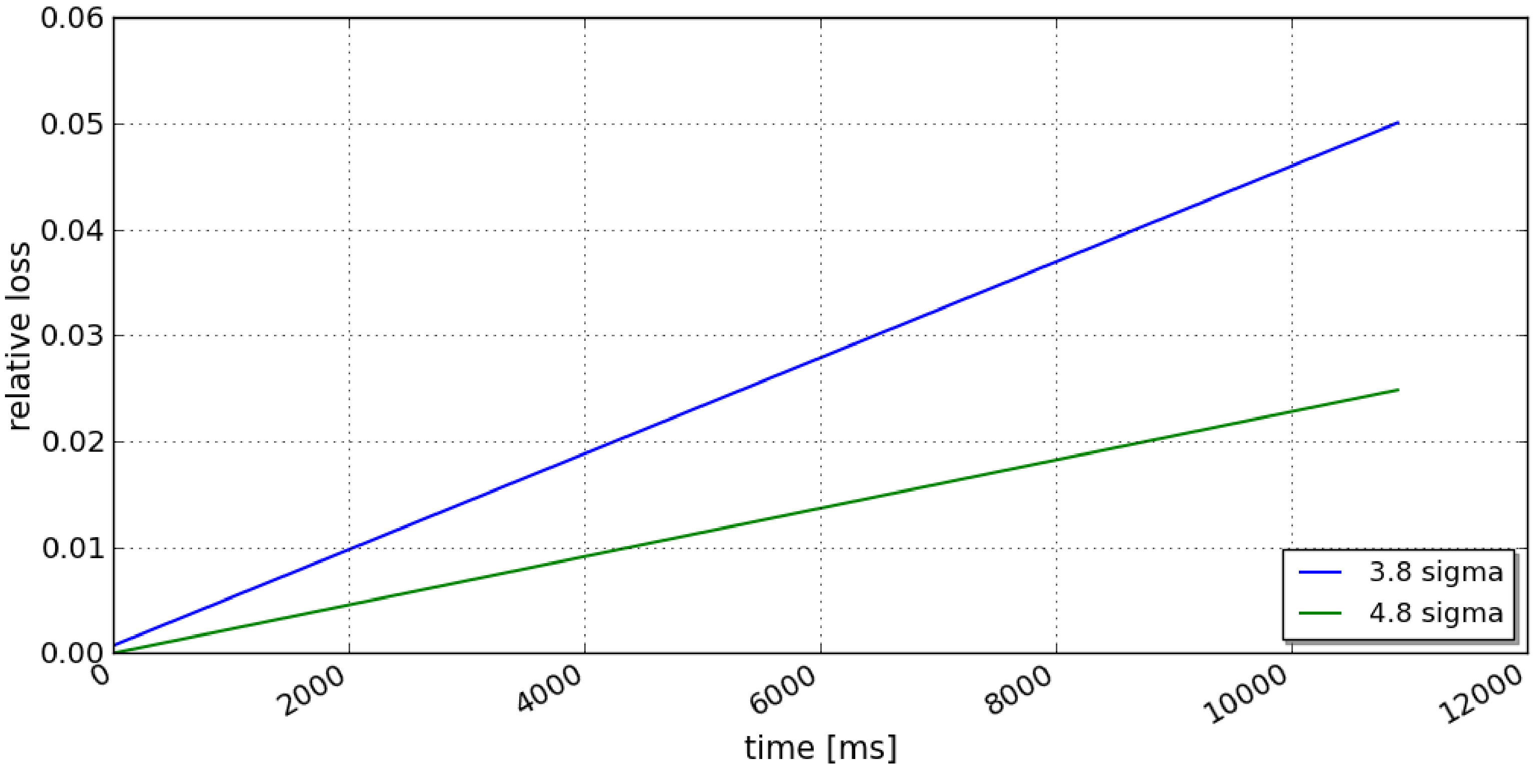
Vertical



- Corresponds to < 1 % of loss

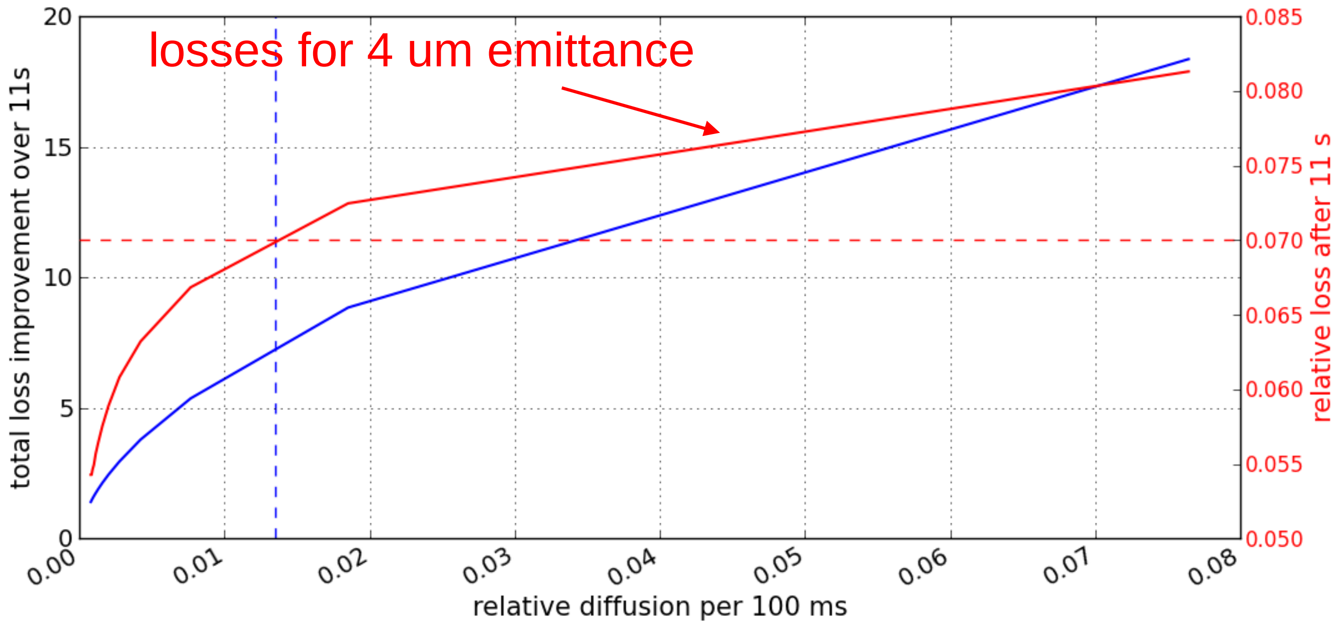
Assumption of diffusion to calculate loss improvement with larger aperture

- For a given assumption on tail distribution and diffusion rate
  - Adjusted such to end up with 5 % loss @ 11 s with 2 um emittance
  - The gain for larger aperture depends on tail distribution and diffusion rate



Assumption of diffusion to calculate loss improvement with larger aperture

- Can fix diffusion rate and tail distribution: needs to give 7 % for ε = 4 um

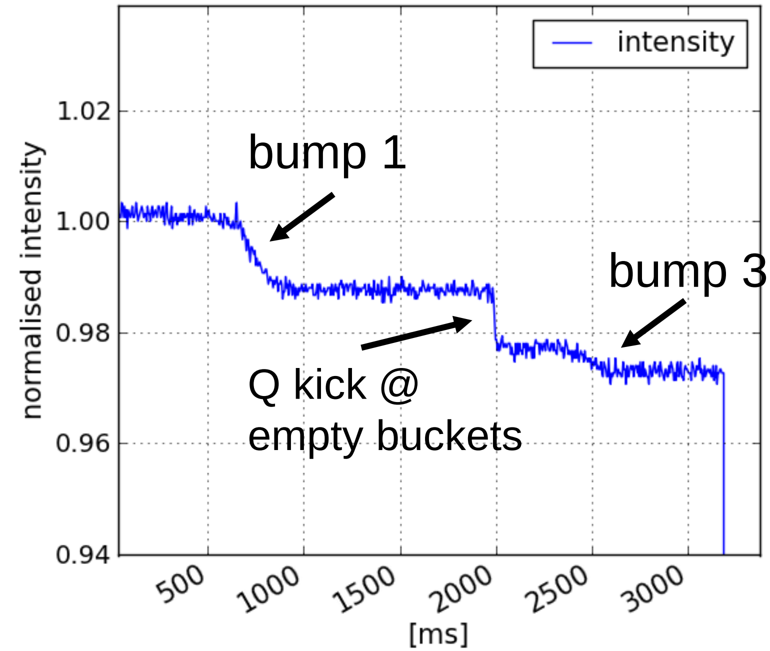


- Blue curve gives loss improvement over 11 s as function of diffusion rate for 3.8 σ $\rightarrow$ 4.8 σ aperture increase
- > factor 5 improvement for 2 um emittance

SCRAPING MDS

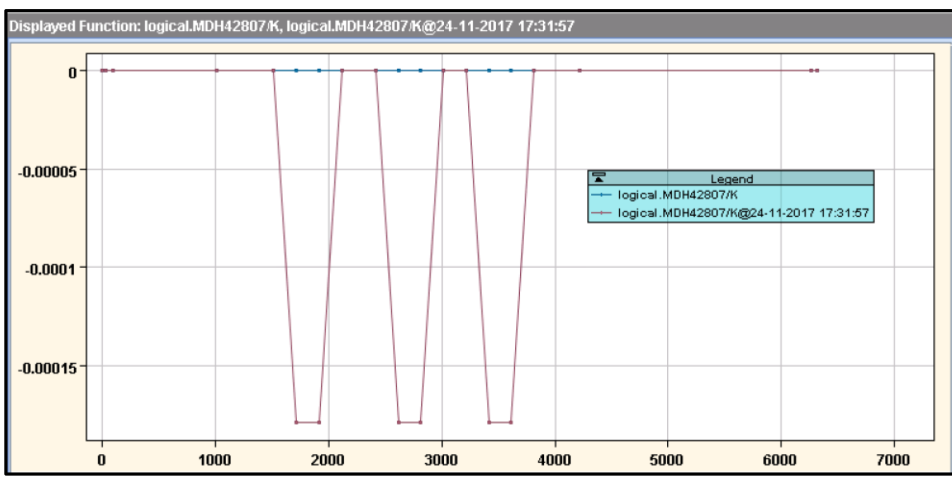
Nature of diffusion? Scraping measurements

- MD 24th of November
  - Q22, 1.5e+11 p+ per bunch, BCMS
  - Establish bump at high dispersion QD location for 200 ms and remove it again
  - Repeat at later time: bump at same amplitude

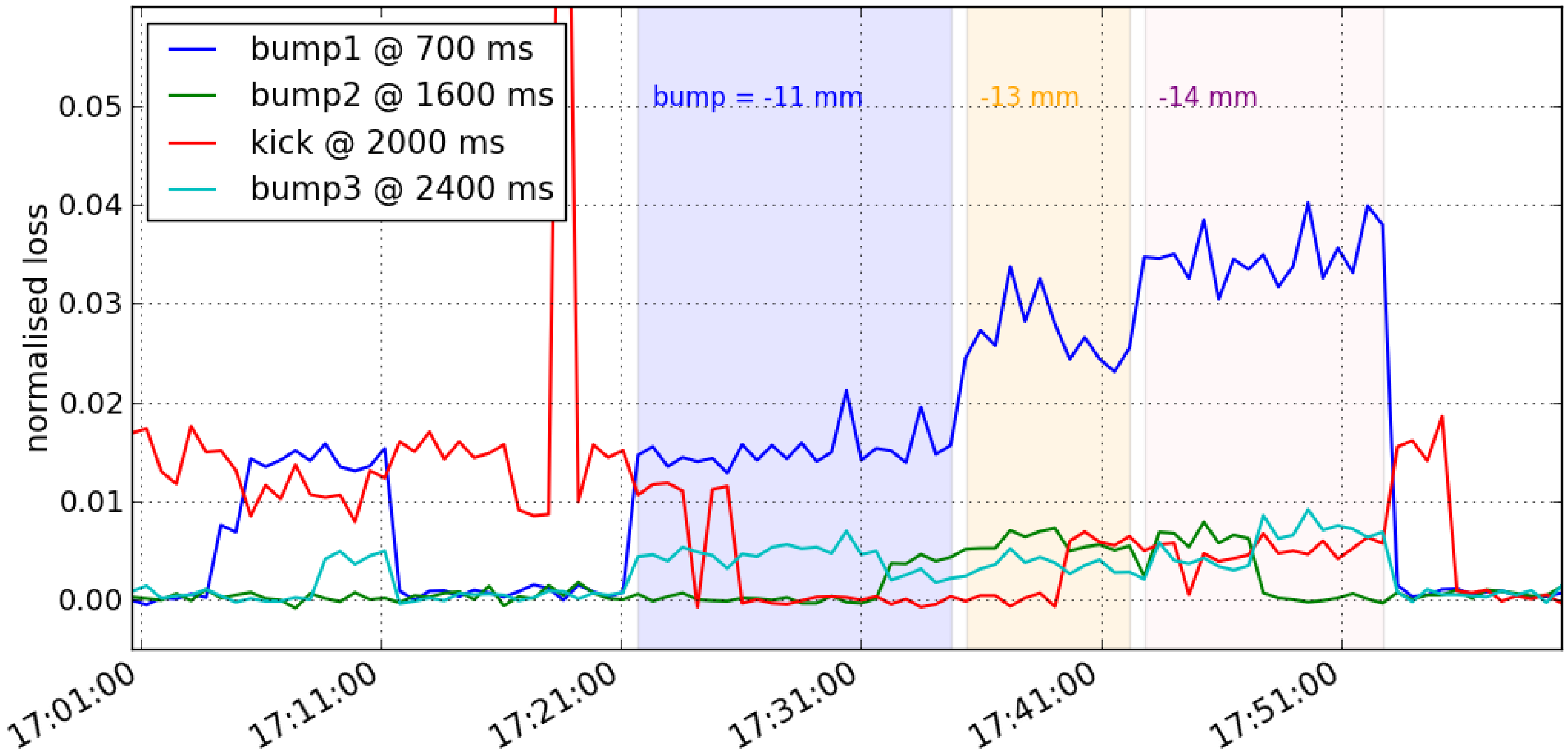


- First bump cleans
- Losses from second (third) bump from diffusion

Example: function for H corrector in bump



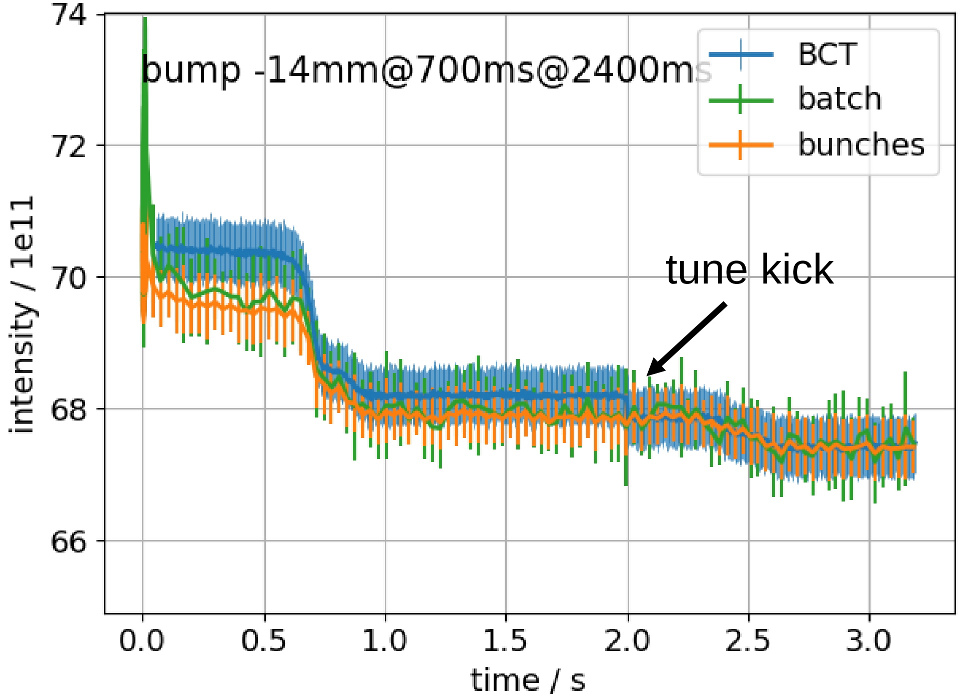
Results of scraping MD



- Particle amplitudes are growing slowly with time
- The losses at bump 3 are not affected by Q kick removal of uncaptured beam
- Q kick losses reduced by first bump

Results of scraping MD

- Example of measurements of longitudinal profiles during scraping MD
  - Comparison of:
    - Intensity integrated over bunch
    - Intensity integrated over batch
    - Intensity measured by BCT

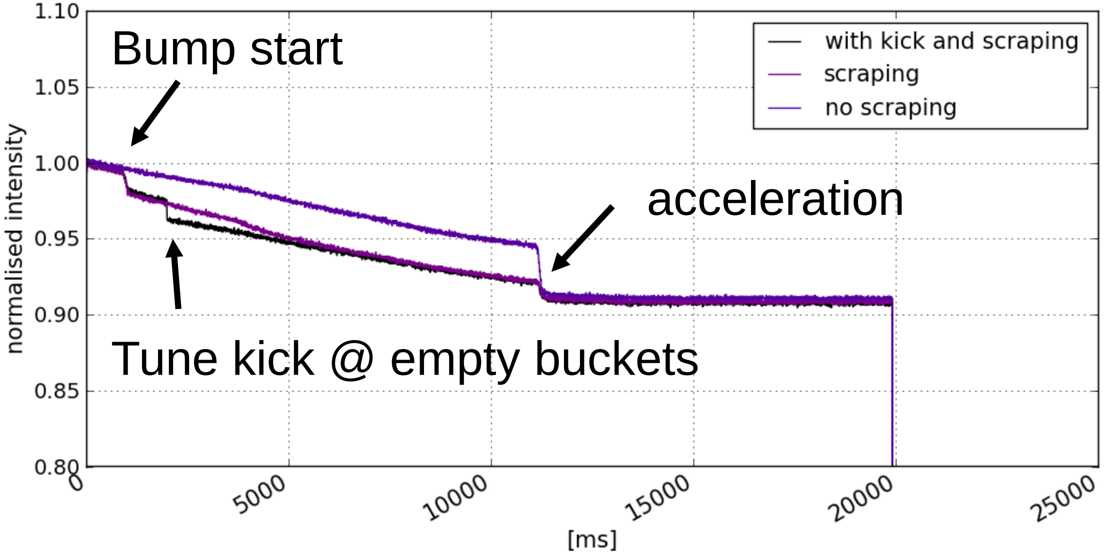


Beam inside buckets is scraped

However…

- MD on 8/11/2017: bump x = - 6.8 mm at QD.325 from 550 ms to end flat bottom
  - Bump and loss at QD.325 did not change overall losses
- Flat bottom losses due to uncaptured beam and large amplitude dp/p particles??

48 bunches, BCMS, 1.7e+11 ppb



Conclusion

- The horizontal aperture is only ~3.8 σ for Q20 and beams of 2 um emittance
  - Aperture limitation due to vacuum **flanges at the MBB-QD transition**

- Increase of MBB-QD vacuum flange aperture will reduce losses at flat bottom
  - 26 locations are proposed for LS2: estimate 7k CHF per location

- Benefit for the overall transmission cannot be guaranteed, as the nature of the lost particles is not fully understood
  - Particles with large dp/p from inside or outside of bucket?
  - More studies with Q22 required where there is ~1 σ more aperture

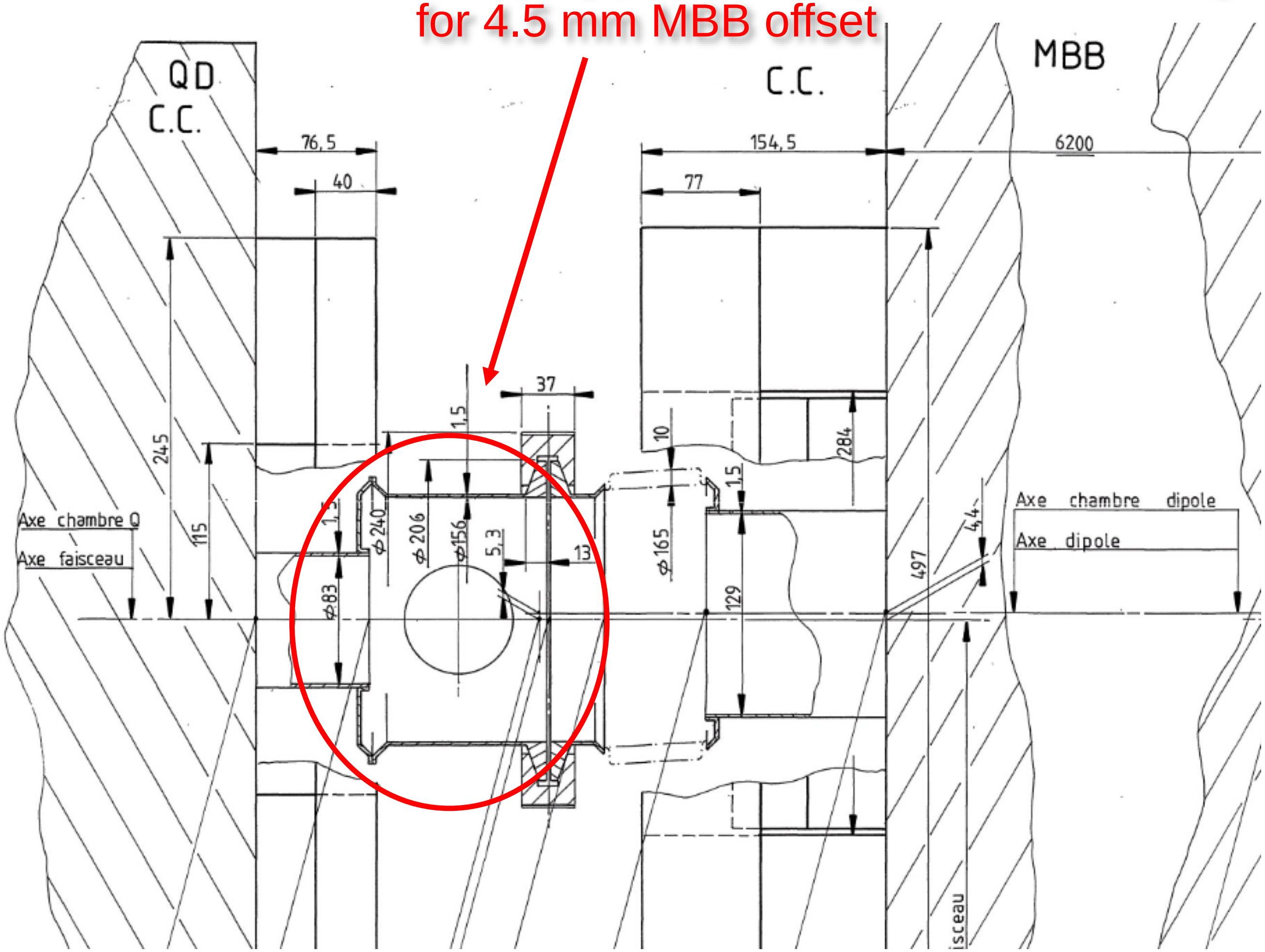
- An increase of the horizontal aperture is nevertheless in our interest
  - Will give margin for voltage and emittance
  - Now there is (virtually) none for Q20…

EXTRA SLIDES

Possible explanation of asymmetric momentum aperture

- Transition QD-MBB

Pumping port with asymmetric shielding for 4.5 mm MBB offset

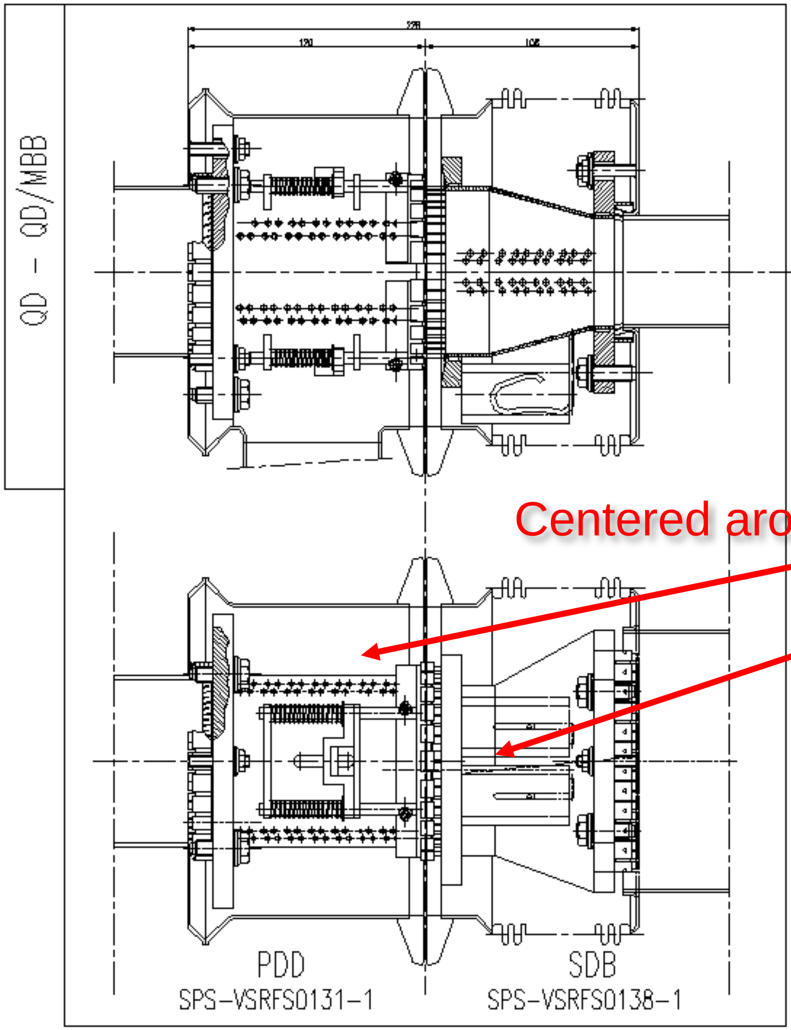


QD – MBB transition

- Pumping port shield

Sideview

Topview



Centered around QD axis

Nominal case: asymmetry of design compensates for 4.5 mm shift

Problem if installed the wrong way: then 9 mm error missing on inside.