β^* determination in van der Meer optics

– LHC Lumi Days –

Hector Garcia-Morales[1,2],
Michael Hofer[2], Rogelio Tomas[2]

[1] University of Oxford
[2] CERN

5th of June 2019

Introduction and Motivation

Goal

Stablish a value for β^* that fits preferences from experiments while keeping the measurement reliable and accurate enough.

Methodology

- Analysis of the measurements carried out during the MD on vdM optics.
- Simulations using MADX to extend the study to different optics.

β^* measurement using k-mod

Modulation of the strength of the last quadrupoles (usuallt Q1) the IP induce a change in tune that allows to determine the β-function at the quadrupole[1].

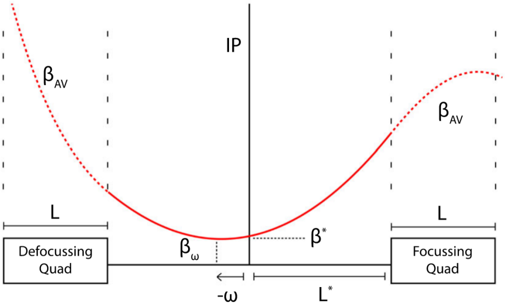
The β at the quadrupole is given by:

$$\beta_{av} \approx \pm 4\pi \frac{\Delta Q}{\Delta k L} \quad (1)$$

The value for β^* is calculated from the value of β at the quadrupole:

$$\beta^{quad}_{AV} \rightarrow (\beta_w, w) \rightarrow \beta^*$$

$$\beta^* = \beta_w + \frac{w^2}{\beta_w} \quad (2)$$



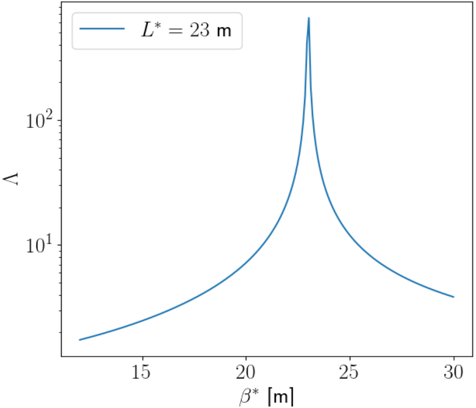
[1] F. Carlier, R. Tomas, Accuracy and feasibility of the β^* measurement for LHC and High Luminosity LHC using k-modulation, PRAB **20**, 011005.

K-mod technique limitation in vdM[2]

- The uncertainty on β^* is closely related to uncertainty in β at the nearest quadrupole.

$$\frac{\sigma_{\beta^*}}{\beta^*} = \frac{\beta^* + \frac{L^{*2}}{\beta^*}}{|\beta^* - \frac{L^{*2}}{\beta^*}|} \frac{\sigma_\beta}{\beta} = \Lambda \frac{\sigma_\beta}{\beta} \qquad (3)$$

- Due to optics properties, when $\beta^* \approx L^*$ (case of vdM optics), a small error in β may drive a huge error in β^*.
- One should avoid $\beta^* \approx L^*$.



[2] L. van Riesen-Haupt, K-modulation developments via simultaneous beam based alignment in t he LHC, Proceeding IPAC17

β^* measurement limitations

Uncertainties in observables have a significant impact on the reconstructed value of β^*.

Uncertainties

- Tune jitter
- β-beating
- Orbit shift/jitter
- Misalignment
- Quadrupole strength
- Coupling
- ...

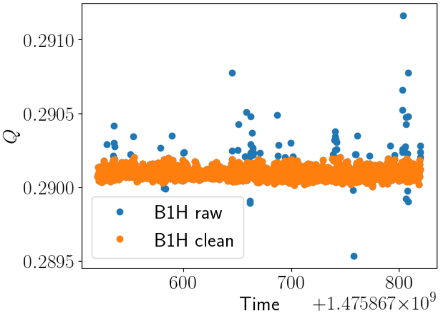
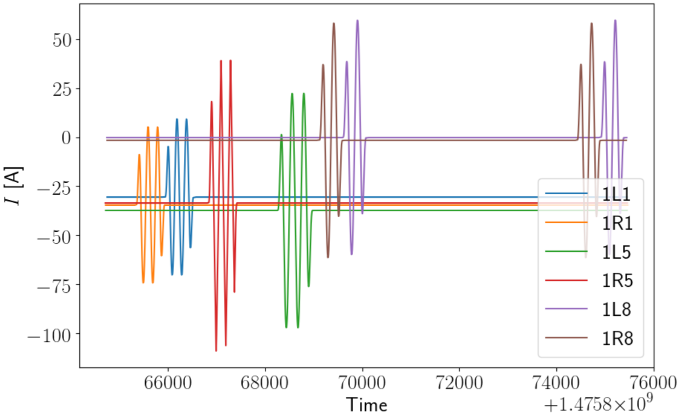


Table: Tune uncertainties during the MD devoted to vdM optics measurements

	B1	B2
$\delta Q_x [10^{-5}]$	3.2	2.3
$\delta Q_y [10^{-5}]$	3.2	3.4

2016 MD on vdM

- One quadrupole modulation per IP (IP1/IP5/IP8) per side (L/R).
- Two modulations in IP8 with and without orbit feedback.



2016 MD on vdM: β^* measurement

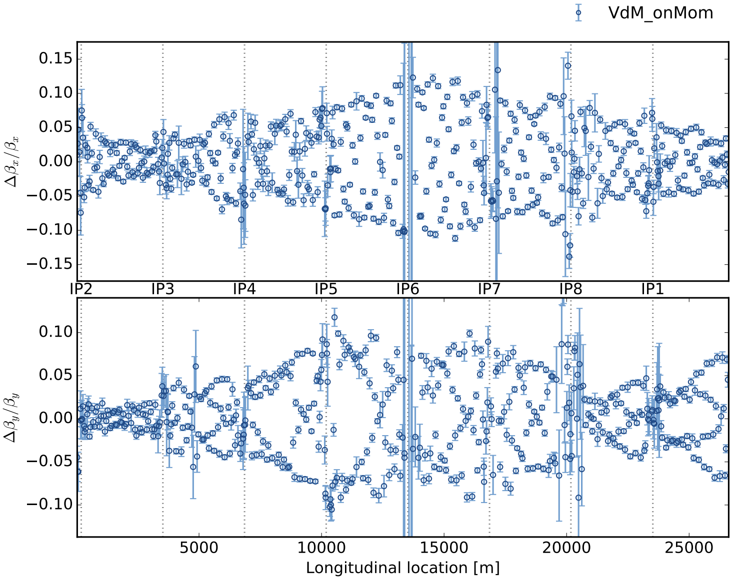
Uncertainties

- Magnet misalignment of 6 mm rms.
- Magnet strength error: $\Delta K/K = 10^{-3}$.
- Tune uncertainty: $\delta Q = 5.0 \cdot 10^{-5}$.

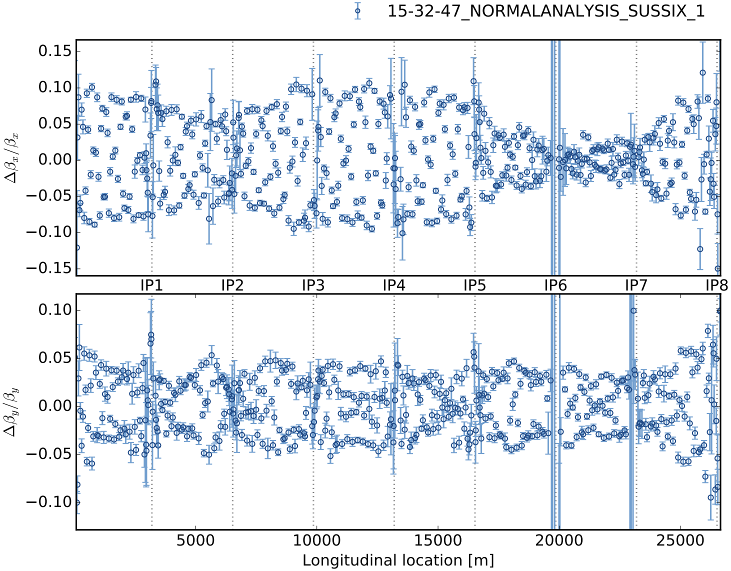
	Beam 1		Beam 2	
IP	β_x^*	β_y^*	β_x^*	β_y^*
IP1	17.4 ± 0.02	18.11 ± 0.02	17.73 ± 0.02	17.20 ± 0.02
IP5	33.06 ± 24.17	18.00 ± 3.7	16.21 ± 0.02	18.7 ± 1.4
IP8	21.52 ± 0.03	19.97 ± 0.03	26.35 ± 2	22 ± 12

- Reasonable for IP1.
- Very bad measurement for β_x^* in IP5 and β_y^* in IP8.

Can we explain the results? β-beating (B1)



Can we explain the results? β-beating (B2)



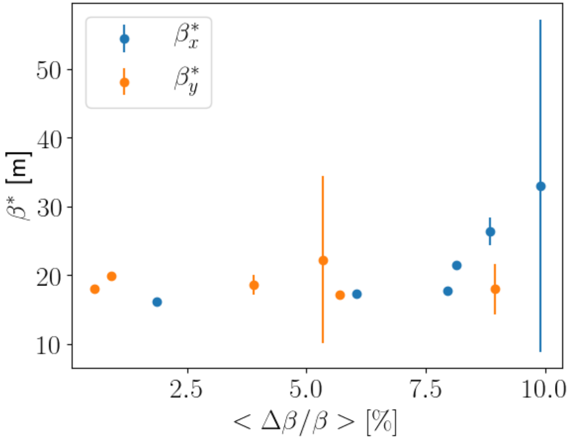
Can we explain the results? β-beating in IRs

Table: β-beating at the location of the BPM of the last quadrupoles on both sides of the IP.

	Beam 1				Beam 2			
IP	$\Delta\beta_x/\beta_x$ [%]		$\Delta\beta_y/\beta_y$ [%]		$\Delta\beta_x/\beta_x$ [%]		$\Delta\beta_y/\beta_y$ [%]	
	L	R	L	R	L	R	L	R
IP1	6.3	5.8	1.0	0.1	8.2	7.7	7.4	4.0
IP5	6.8	13	9.4	8.5	3.6	0.1	4.1	3.7
IP8	8.6	7.7	1.3	0.5	7.8	9.9	5.9	4.8

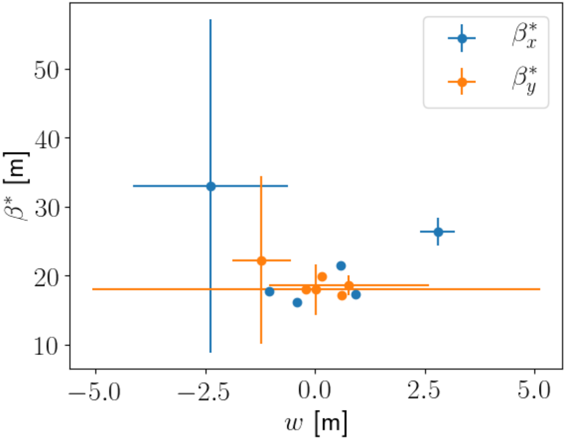
Can we explain the results? β-beating

- Although global β-beating is reasonable, local β-beating at the last quadrupole may have a significant impact on β^*.
- Up to 10% β_x-beating in MQXA.1R5.B1. This could explain the bad result of β_x^* in IP5.
- In general, larger β-beating induces larger errors in β^*.



Can we explain the results? Waist influence

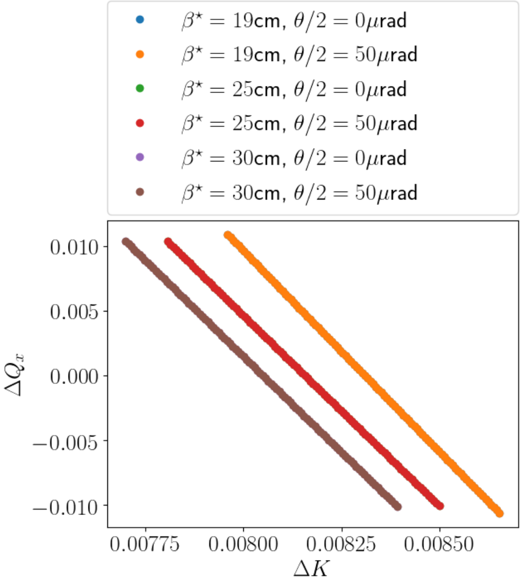
- Large waists lead to large errors in β^*.
- B1H in IP5 has a large waist.
- But small waist does not ensure good measurements.
- It may help to try to correct both β and waist beating.



Simulations

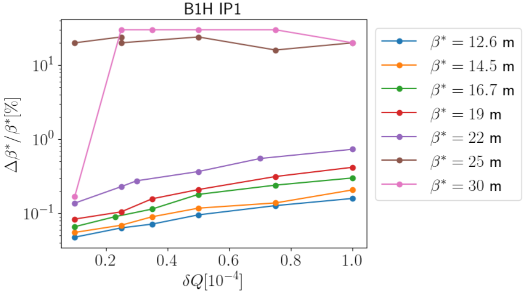
K-mod simulations

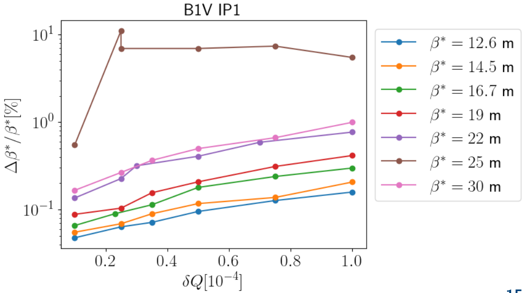
- Evaluate the impact of uncertainties in a wide range of optics possibilities.
- 10 different optics configurations have been tested $\beta^*(IP1/IP5) \approx (12, 14, 16, 19, 22, 25, 30, 33, 40, 50)$ m.
- Crossing angle ($\theta/2 = 50\ \mu$rad) effect is negligible.
- Uncertainties in Q, K and misalignments.
- Ideal machine for the rest.
- As in measurements, modulations are simulated varying the tune by $\Delta Q \sim \pm 0.01$.



Simulations: $\Delta\beta^*/\beta^*$ vs δQ (IP1)

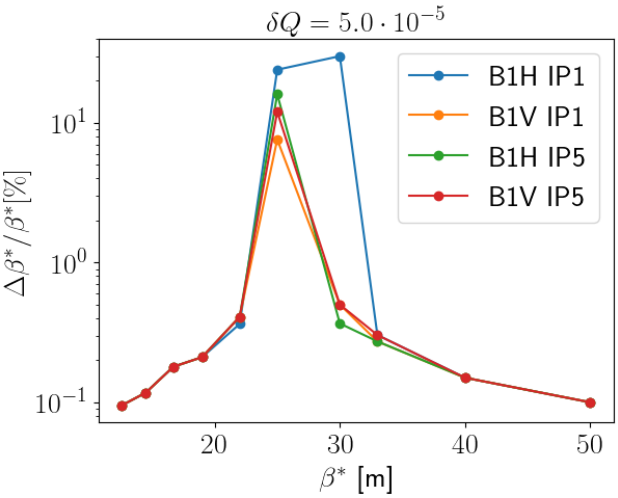
- Increase of uncertainty in β^* with tune uncertainty.
- As seen previously, for $\beta^* \approx L^*$, the error in β^* diverges.
- Current expected tune uncertainty: $3.0 - 5.0 \cdot 10^{-5}$.
- For HL-LHC, it is required a smaller tune uncertainty ($\sim 2.5 \cdot 10^{-5}$).





Simulations: $\Delta\beta^*/\beta^*$ vs. β^*

- Close to ideal case.
- Final value on $\Delta\beta^*/\beta^*$ will be affected by many factors not considered here.
- Error for $\beta^* < L^*$ decreases faster than for $\beta^* > L^*$.
- β^* uncertainty below 0.5% for $\beta^* < 19$ m.



Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.

Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).

Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).
- Safety margin accounting for β-beating.
  - Exlude region: $\beta^* = L^* \pm 20\%$.

Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).
- Safety margin accounting for β-beating.
  - Exlude region: $\beta^* = L^* \pm 20\%$.
- $\beta^* \leq 17$ m seems to be a reasonable choice.
  - Uncertainty below 0.5% for near to ideal case.

Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).
- Safety margin accounting for β-beating.
  - Exlude region: $\beta^* = L^* \pm 20\%$.
- $\beta^* \leq 17$ m seems to be a reasonable choice.
  - Uncertainty below 0.5% for near to ideal case.
- Larger β^* is also possible (40 m?) but not for HL.

Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).
- Safety margin accounting for β-beating.
  - Exlude region: $\beta^* = L^* \pm 20\%$.
- $\beta^* \leq 17$ m seems to be a reasonable choice.
  - Uncertainty below 0.5% for near to ideal case.
- Larger β^* is also possible (40 m?) but not for HL.
- Further analysis required to better estimate β^* uncertainty.
  - MC-like simulations including β-beating and waist beating.

Conclusions

- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).
- Safety margin accounting for β-beating.
  - Exlude region: $\beta^* = L^* \pm 20\%$.
- $\beta^* \leq 17$ m seems to be a reasonable choice.
  - Uncertainty below 0.5% for near to ideal case.
- Larger β^* is also possible (40 m?) but not for HL.
- Further analysis required to better estimate β^* uncertainty.
  - MC-like simulations including β-beating and waist beating.
- The uncertainty on β^* might be further reduced if some time is devoted to vdM optics correction (i.e. reduce waist, β-beating...).

Conclusions

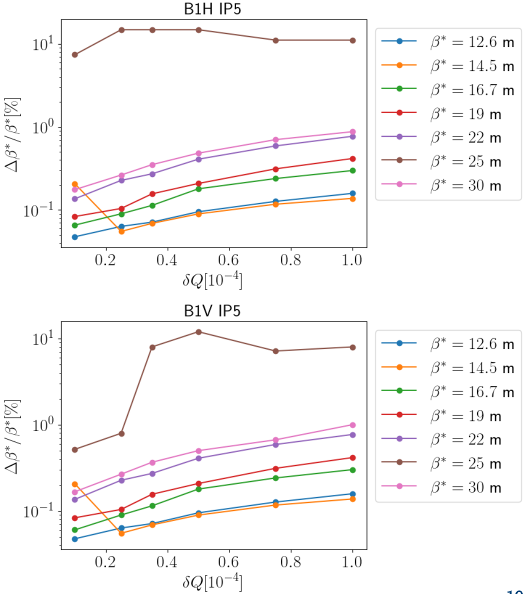
- Experimentally, $\beta^* = 19$ m seems not to be a good choice.
- The smaller β^* the better (from the machine perspective).
- Safety margin accounting for β-beating.
  - Exlude region: $\beta^* = L^* \pm 20\%$.
- $\beta^* \leq 17$ m seems to be a reasonable choice.
  - Uncertainty below 0.5% for near to ideal case.
- Larger β^* is also possible (40 m?) but not for HL.
- Further analysis required to better estimate β^* uncertainty.
  - MC-like simulations including β-beating and waist beating.
- The uncertainty on β^* might be further reduced if some time is devoted to vdM optics correction (i.e. reduce waist, β-beating...).

Thank you!

Back up

Simulations: $\Delta\beta^*/\beta^*$ vs δQ (IP5)

- Same behaviour as that of IP1.



Can we explain the results? Phase influence

- Analyzed phase phase advance between Q1 left and right via AC-dipole and and compared to reconstructed from kmod.
- Expected phase advance $\sim$ 45 degrees.
- Fully confirms that the β^*_x measurement in IP5 is bad.
- Errors in phase beyond 10% make measurement less reliable.