Study of the 2625 m Atlas optics

- **Introduction: the high-beta experiment, requirements for the beam properties.** (from Atlas TDR)
- **Optics solution for physics: local matching, tunes, aperture.**
- **Optics solution for injection: limits, tunes, aperture.**
- **The next step => the un-squeeze.**

The high-beta experiment

- **Goal:** Measurement of the Atlas luminosity
- **Idea:** Measure the elastic scattering at very small angles => Luminosity

$\sigma_{tot} = 4\pi . \mathrm{Im}[f_{el}(t=0)]$ with momentum transfer: $-t = (p\theta)^2$

The rate of elastic scattering at small t-value can be written as:

$\frac{dN}{dt} = L\pi \left| f_C + f_N \right|$ where the first term corresponds to the Coulomb

=>Working in the Coulomb region allows determination of both Luminosity and total cross section

At 7 TeV the Coulomb region is expected to be reached at $|t|=0.00065$ GeV^2. This corresponds to a scattering angle of 3.5μrad.

Requirements for the beam properties

• The betatron oscillation between the interaction point and the detector has a 90 degree phase difference: the particles scattered at the same angle are focused on the same locus at the detector.
• The intrinsic beam divergence at the interaction point must be significantly smaller than the smallest angles to be observed.

The divergence at the IP is given by: $\sqrt{\varepsilon/\beta^*}$

=> A small emittance and a large β^* are required.

For $\Delta\mu_d=90^\circ$ and $\alpha^*\sim 0$ we have: $t_{\min} \propto \frac{1}{\sqrt{\beta\beta^*}}$

=> β at the detector not too small.

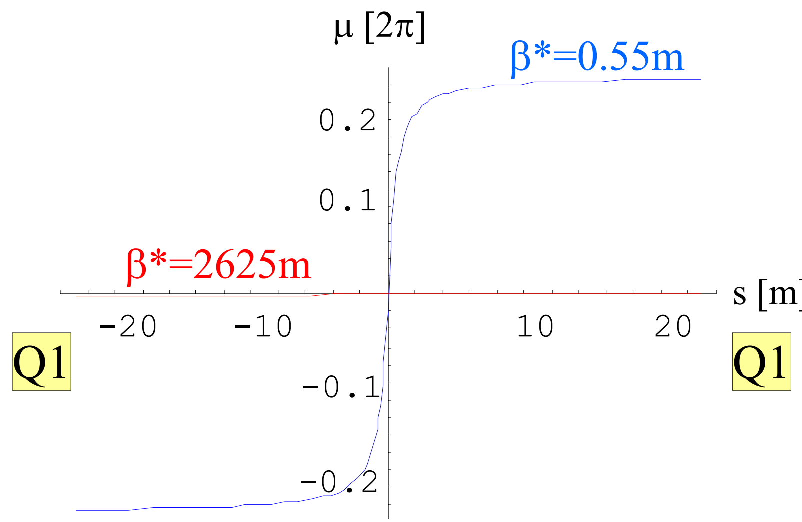
=> To reach the Coulomb region we finally have the following requirements:

• $\beta^*>2600$m, $\beta_d>70$m, $\alpha^*\sim 0$.
• 90° phase advance between the IP and the detector in the vertical plane.

Target tunes for high-beta

• Target physics tunes are Qx = 64.31 and Qy = 59.32 for both beams in the LHC.

• In a free field region the contribution is 0.5 in tune for low beta whereas for high-beta it is almost 0.



=>The Roman pots constraint makes it difficult to adjust the tune in the vertical plane. The solution could be to run Atlas and Totem together to go down one whole integer in the vertical plane.

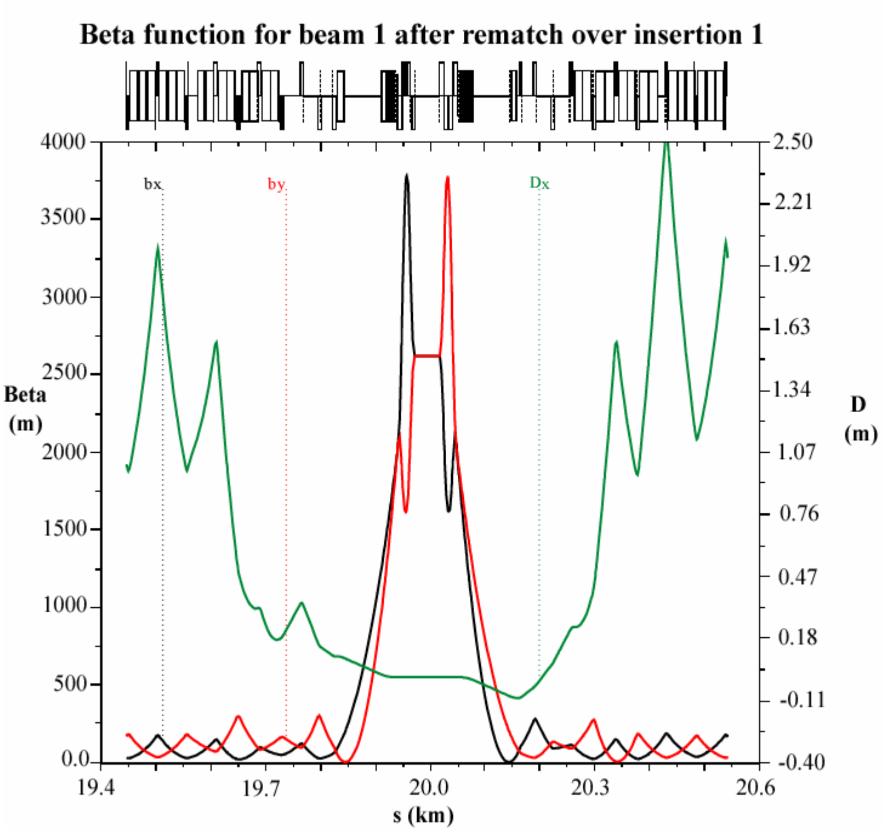
=> Needs new injection.

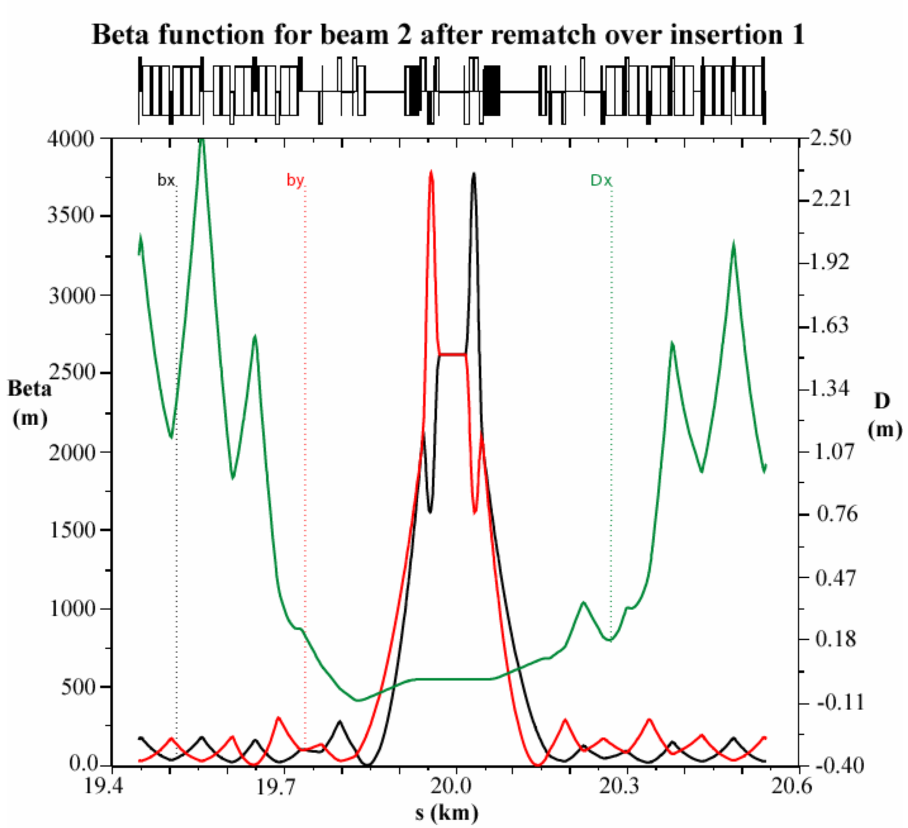
=> Target tunes for high-beta: Qx = 64.31

Qy = 58.32

Optics solution for physics

• Existing solution for beam1 => start from there for beam2, β^*=2625 m.





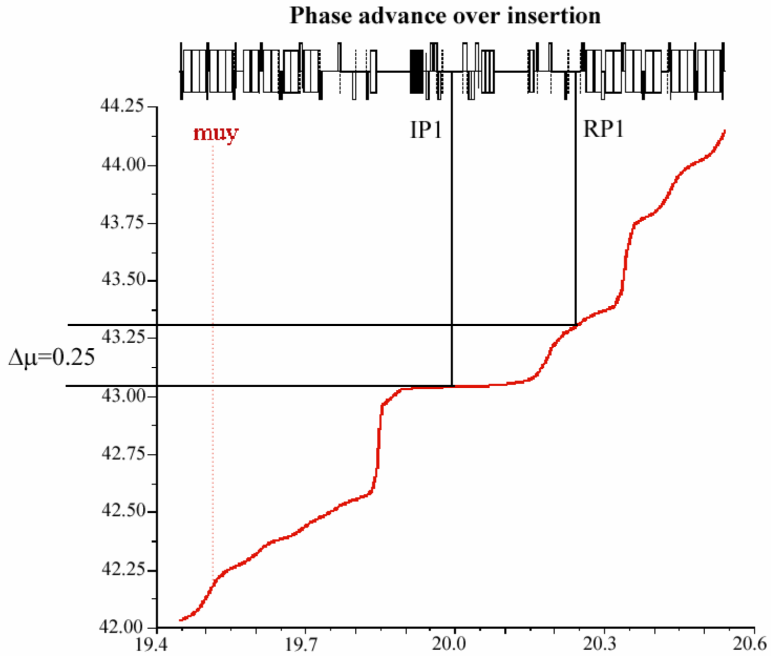
=> Anti-symmetry between beam1 and beam2. We can expect the same results for both beams.

Results after rematch

	Beam 1	Beam 2		Beam 1	Beam 2
At the interaction point			At the Roman pot		
β*(m)	2625	2625	βx(m)	96.5	92.3
α*	0	0	βy(m)	120.2	123.4
Dx(m)	0	0	Δμx(2π)	0.54	0.54
Dy(m)	0	0	Δμy(2π)	0.25	0.25

- As expected the solutions are almost the same for both beams and respect all the constraints given by Atlas.

- Matching solution with no crossing angle and β*=2625 m.
- The symmetry in the inner triplet was kept and ktqx2 was set to 0.
- The polarity of Q4 was inverted so that all the other quads stay in the limits (see LHC project report 770).



Tunes after rematch

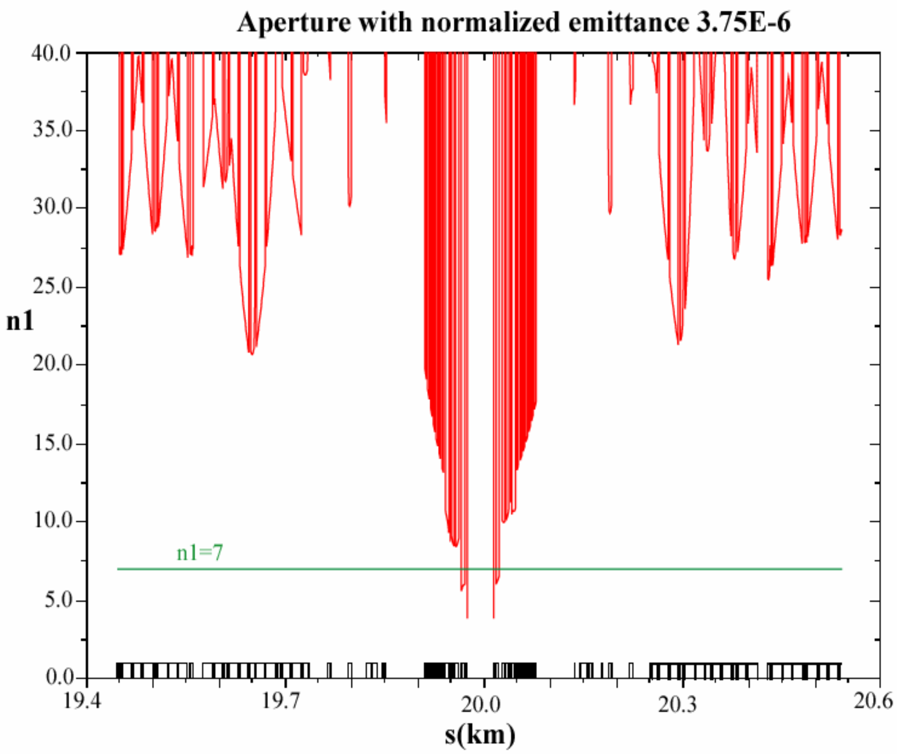
- Individual contribution from arcs and insertions.
- Same tunes for both beams over insertion 1.
- Could not get to the target values in tunes over the whole ring only by matching IR1.

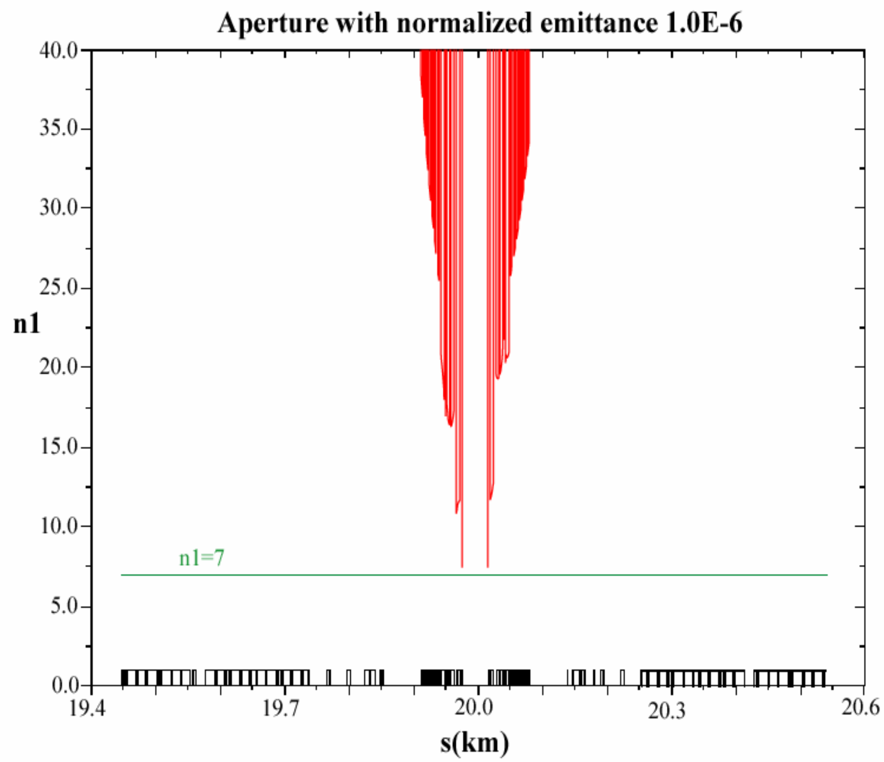
→

	LHC version 6.500			
	Beam 1		Beam 2	
arcs	44.1040	40.6890	44.1040	40.6890
IR1	2.4400	2.1200	2.4400	2.1200
IR2	2.9740	2.7980	2.9910	2.8440
IR3	2.2480	1.9430	2.2494	2.0066
IR4	2.1430	1.8700	2.1430	1.8700
IR5	2.6925	2.0840	2.6993	2.0808
IR6	2.0150	1.7800	2.0150	1.7800
IR7	2.3770	1.9680	2.4826	2.0504
IR8	3.1830	2.9740	3.0590	2.7820
tune	64.1765	58.2260	64.1833	58.2228

=> $\Delta Qx \sim 0.14$ and $\Delta Qy \sim 0.1$ => the trim quads might be enough.
An alternative solution could be to rematch another insertion point.

Aperture





=> For the standard LHC emittance the minimum n1 (at the TAS) is 3.84 but with the emittance value needed for the Atlas high-beta experiment it is above 7.

Optics solution for injection

• The main constraints are the aperture and the lower-limits due to the power converters. (the lower-limit was confirmed by Frederick Bordry to be 2% of Kmax).

• Existing solution for beam1 => first check the limits.

		Solution with β^*= 200 m					
		Beam1			Beam2		
	Kmax (T/m)	kinj(m^-2)	Kinj (T/m)	% of Kmax	kinj(m^-2)	Kinj(T/m)	% of Kmax
Q5L	160	4.64E-03	6.97	4.36%	8.39E-04	1.26	0.79%
Q5R	160	6.89E-04	1.03	0.64%	4.64E-03	6.97	4.36%

• Two quads under the limits => rematch needed.

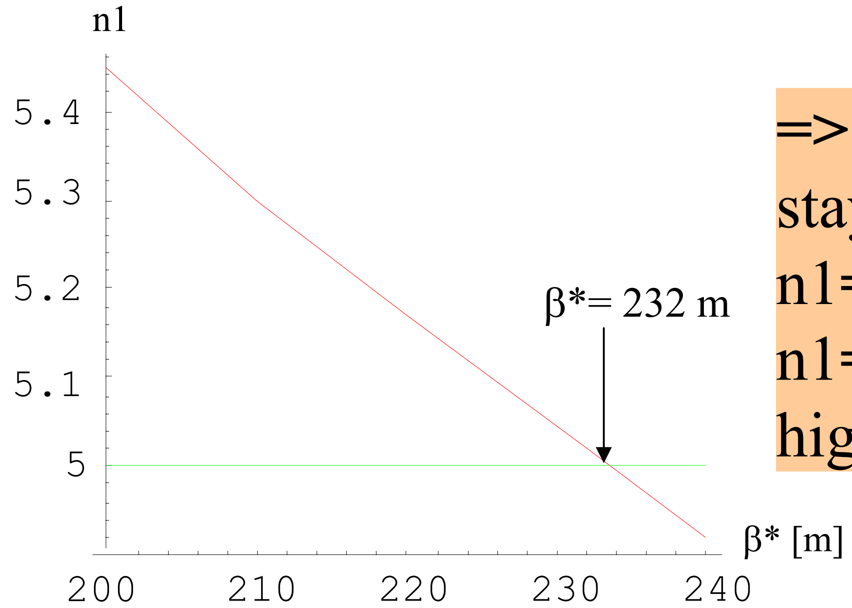
		Injection with limits (lower limit=2% of Kmax)					
		Beam1			Beam2		
	Kmax (T/m)	kinj(m^-2)	Kinj (T/m)	% of Kmax	kinj(m^-2)	Kinj(T/m)	% of Kmax
Q4L	160	2.13E-03	3.20	2.00%	2.19E-03	3.29	2.05%
Q5L	160	2.18E-03	3.27	2.04%	2.13E-03	3.20	2.00%
Q4R	160	2.37E-03	3.56	2.23%	2.17E-03	3.26	2.04%
Q5R	160	2.13E-03	3.20	2.00%	2.17E-03	3.26	2.04%

• Pushing the quads to the limits no flexibility for tunes adjustments.

• Using the same file for IR1 and IR5 $\Delta Qx = 0.32$. It will be hard to reach target value (64.28 in x and 58.31 in y) => better solution needed.

New solution β^*= 232 m

• Increasing β^* adds flexibility for tune adjustments but will induce aperture losses => n1 = 5σ seems a reasonable value for the lower limit (taking into account the small number of bunches ~ 40, the low intensity ~10^{10} particles per bunch and the low emittance will probably bring it back to the 7σ standard value).



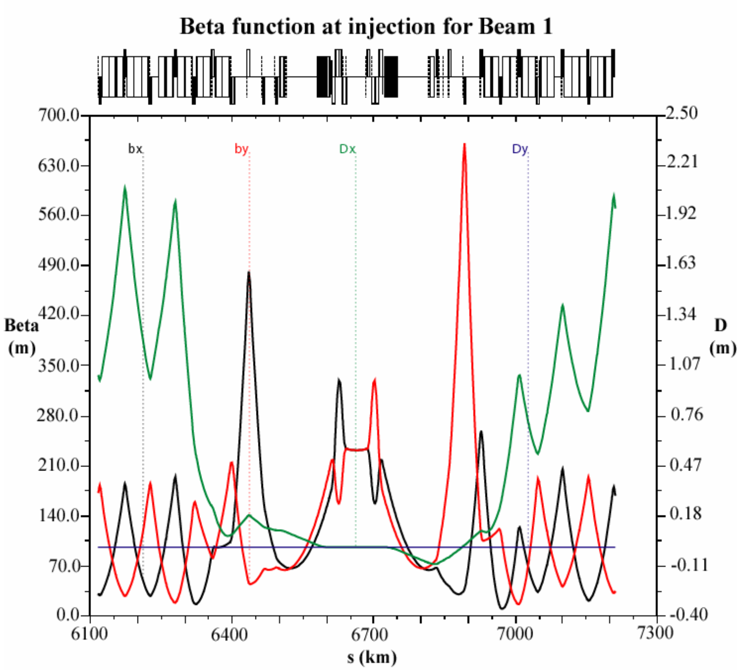
=> The highest possible value for β^* to stay in the 5σ limit is 232 m with n1=5.02 (for a β^* of 200 m we had n1=5.45 so the aperture losses are not too high compared to the old solution).

Results with the new solution

• Solution for β*= 232 m with adding the new constraints ΔQx = 0.1 and ΔQy = 0 with the same file IR5 and IR1.

	Injection β*=232m (lower limit=2% of Kmax)						
		Beam1			Beam2		
	Kmax (T/m)	kinj(m^-2)	Kinj (T/m)	% of Kmax	kinj(m^-2)	Kinj(T/m)	% of Kmax
Q4L	160	2.13E-03	3.20	2.00%	4.58E-03	6.87	4.29%
Q5L	160	2.76E-03	4.14	2.59%	2.13E-03	3.20	2.00%
Q4R	160	4.69E-03	7.04	4.40%	2.21E-03	3.32	2.07%
Q5R	160	2.13E-03	3.20	2.00%	2.75E-03	4.13	2.58%

=> All the quadrupoles are in the limits.

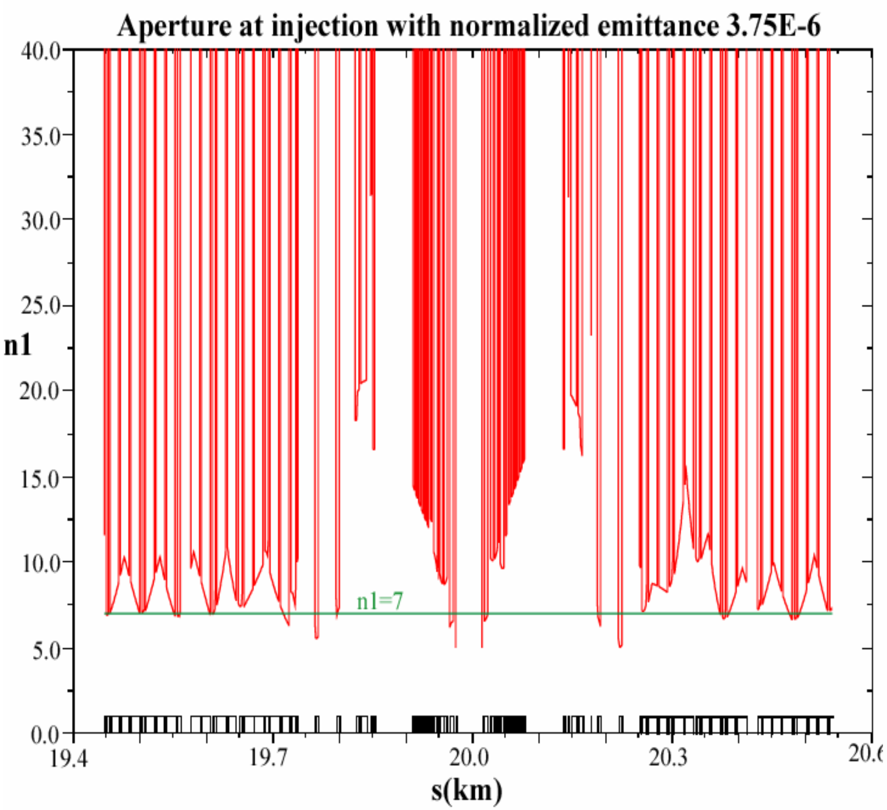


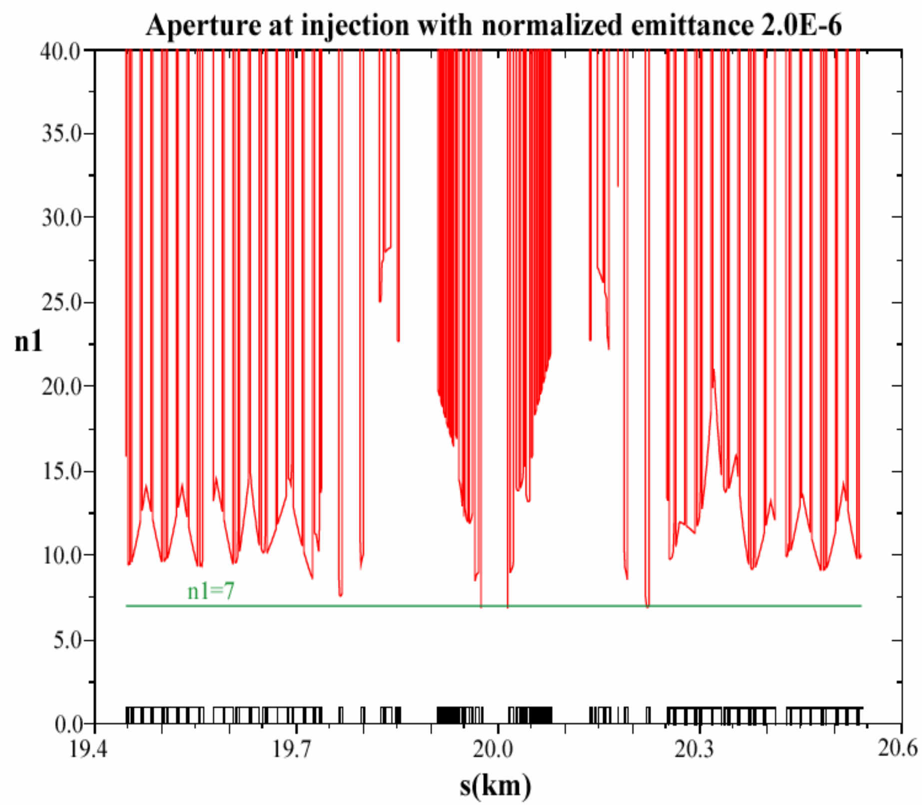
• The phase advances for both beams at IR5 and IR1 are μ=2.568 in the horizontal plane and μ=2.144 in the vertical plane.

• Only 0.1 is missing in the horizontal plane and the vertical plane is already set to 58.31.

=> Adjusting the tune to the standard LHC value should not be an issue,

Aperture

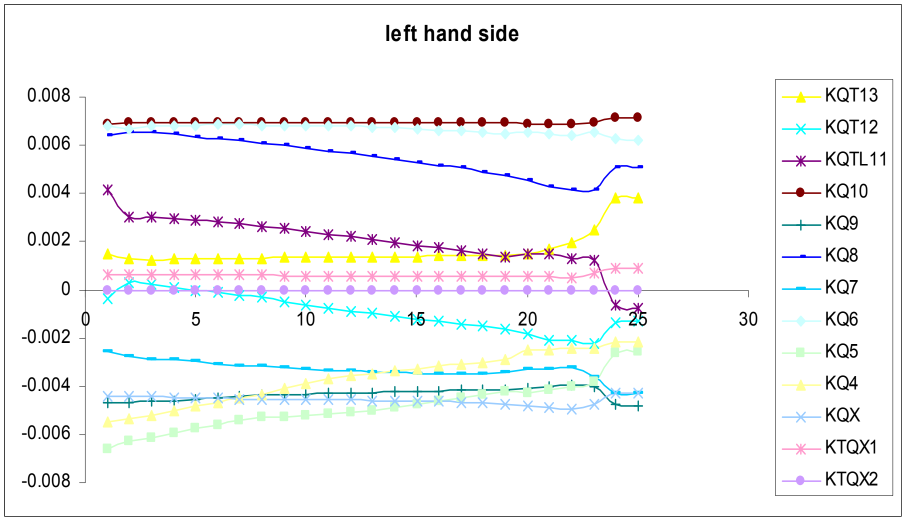


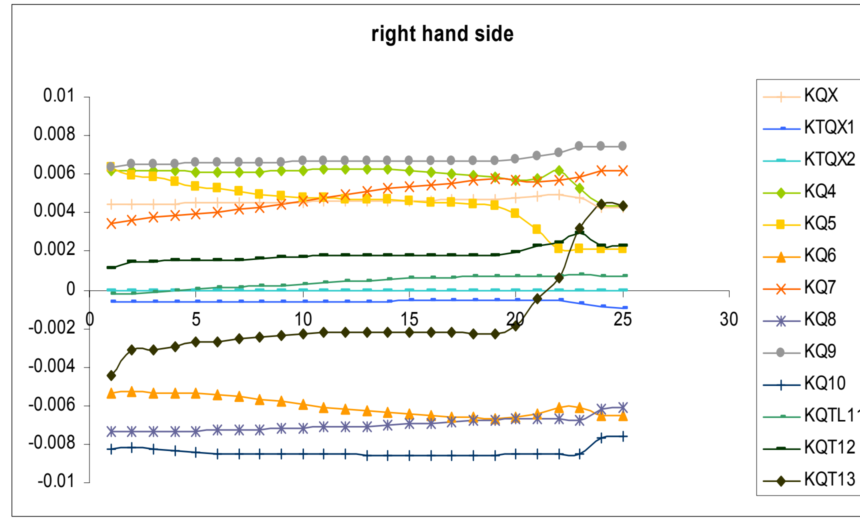


=> We can see here that for the LHC emittance the minimum n1 (at the TAS) is 5.02 whereas for small emittance it is 6.89.

The next step

- Now working on the un-squeeze from 232 m to 2625 m.





=> Works well between 2625 m and approximately 500 m but does not work after 500m for now.

- Could not yet get to the optics solution for injection found before.

=> quadrupoles too close to limits?

=> another solution for injection might be needed.