2022 Ballistic Optics

Overview

- Use of “old” ballistic optics for IR 1/5
  - Q1-4 either side of IP turned off
  - Designed to have enough aperture at 450GeV
  - Currents compatible from 450GeV to 7TeV
  - Used since 2016
- New ballistic optics for IR 4
  - Turning off Q5 either side of RF
    - (Q1-4 don’t exist in IR4)
- Ability to reach 6.8 TeV
  - Not an issue for the actual insertion optics
  - Need integrated ring optics to respect limitations in IR 2/8 triplets

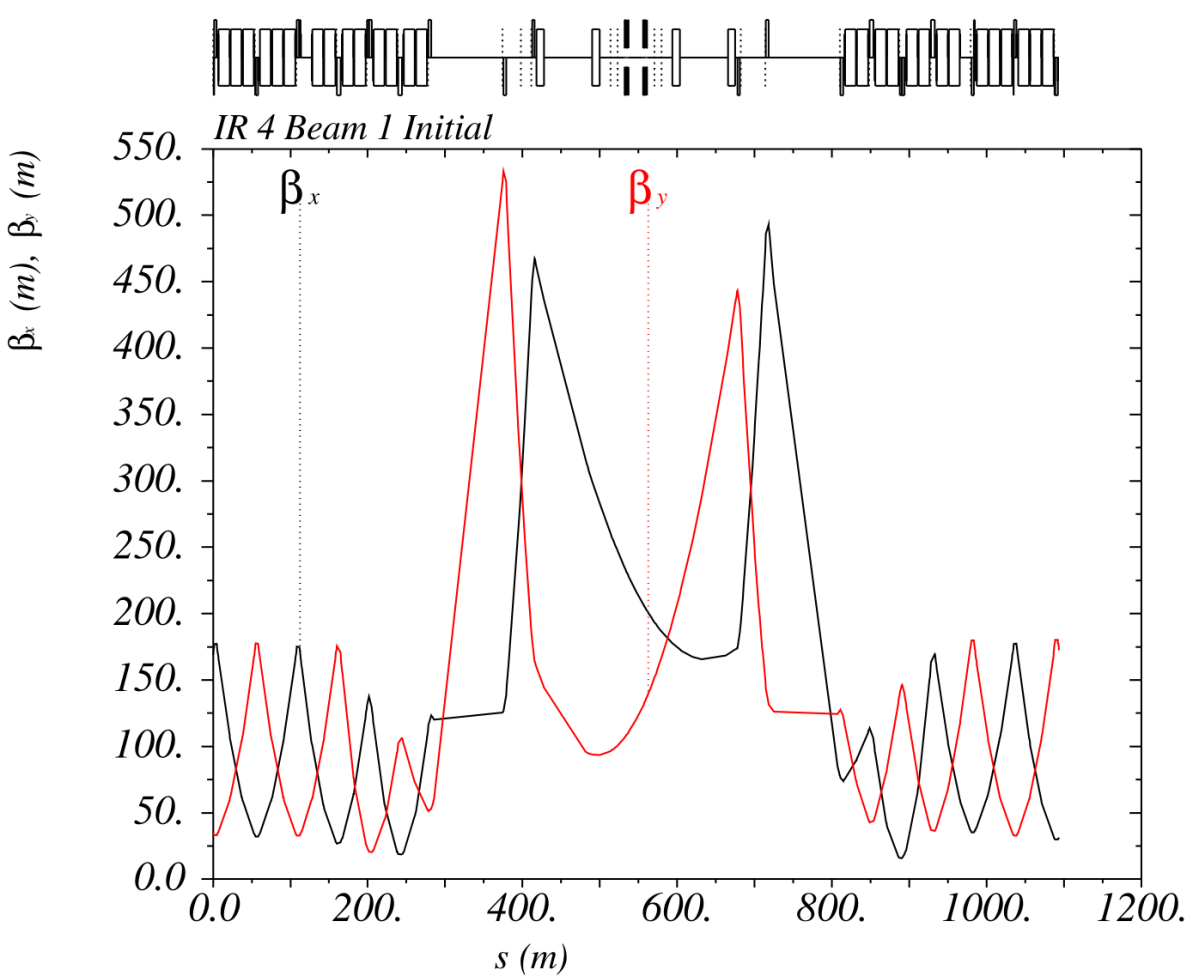
IR 4 Optics Requirements

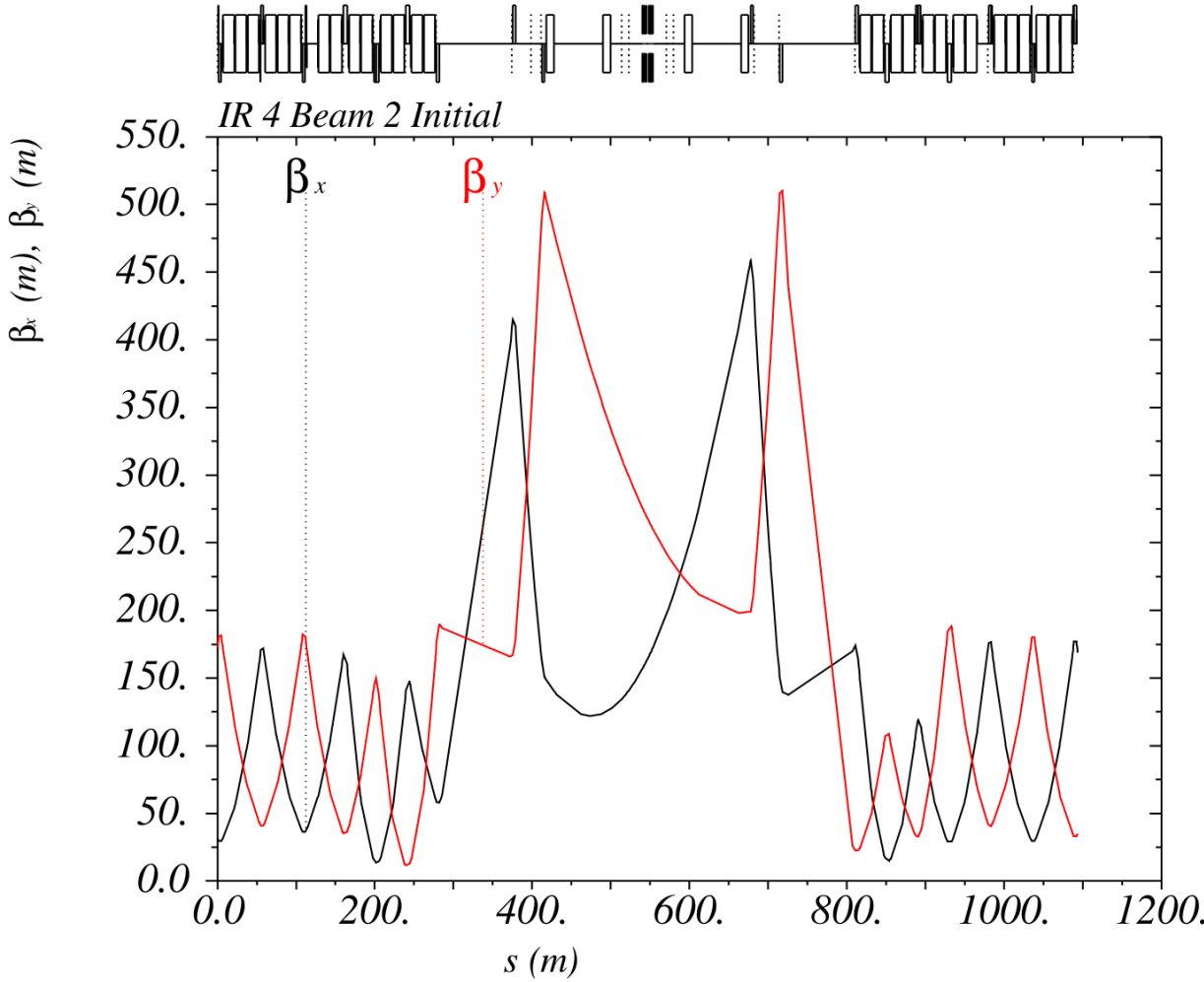
- Magnet strengths
  - Maximum strength of magnet at 7 TeV
  - Aperture imbalance < factor 2 (between B1 and B2)
    - Ideally even < 55% difference
  - Strength ideally >3% of maximum strength
- Matched Optics
  - Matched to the arc
  - Small phase difference matched using arc
- Aperture
  - $1\ \mu m$ pilot, 450 GeV and “HL-LHC” parameters
  - Based on experience in IR1/5

Matching Strategy

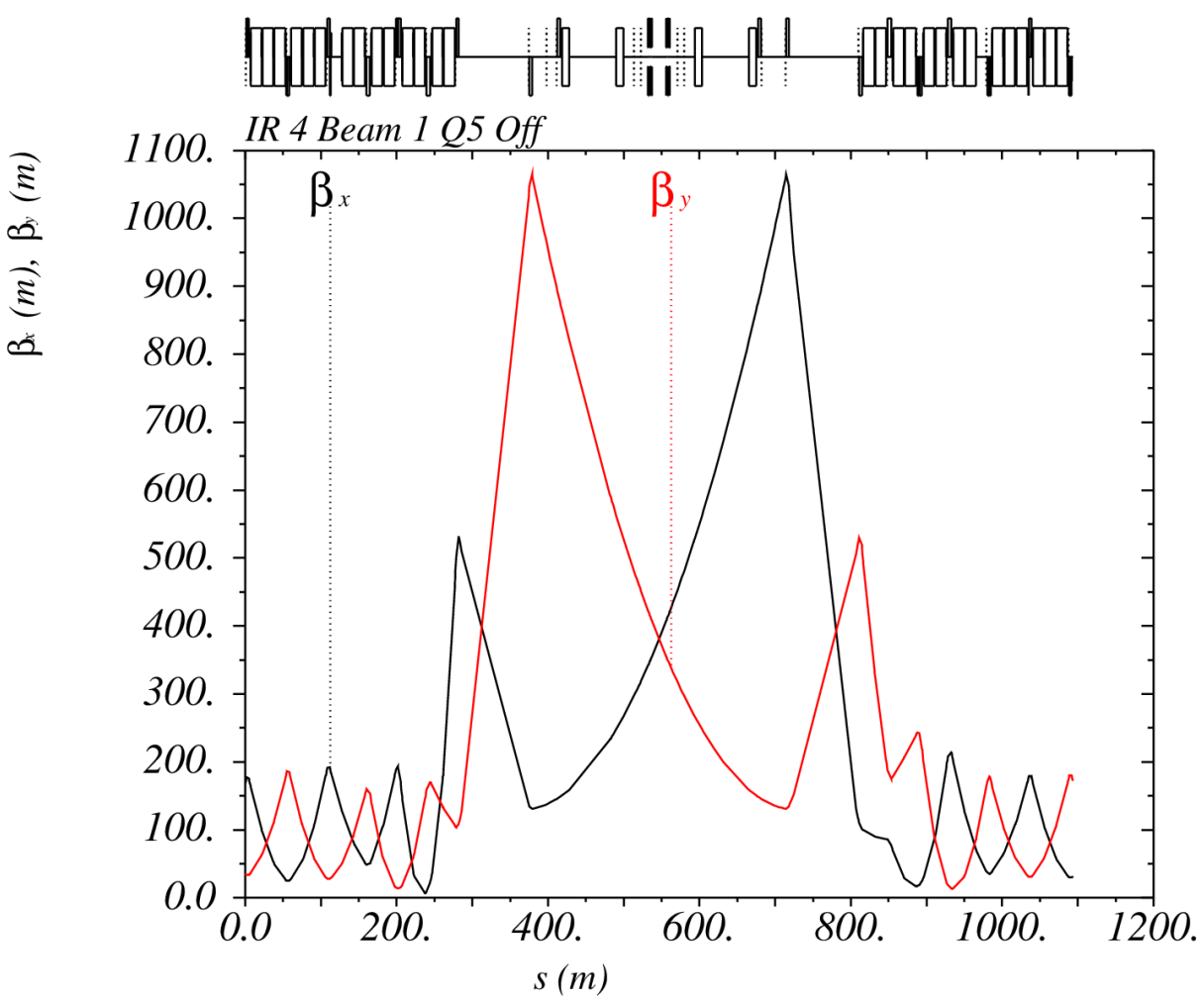
- Full symmetry between two planes
- Macro matching
  - $\alpha_x = -\alpha_y$ and $\beta_x = \beta_y$ @ IP
  - Fix ratio of maximum β in Q6 and Q7
    - Vary this parameter to find maximum aperture
- Allow some small deviations in phase advances
  - Beam 1 phase advance off by
    - $\Delta\mu_x = -0.1\ [2\pi],\ \Delta\mu_y = -0.2[2\pi]$
  - Beam 2 phase advance off by
    - $\Delta\mu_x = -0.14\ [2\pi],\ \Delta\mu_y = -0.21[2\pi]$
  - Can be compensated in arcs

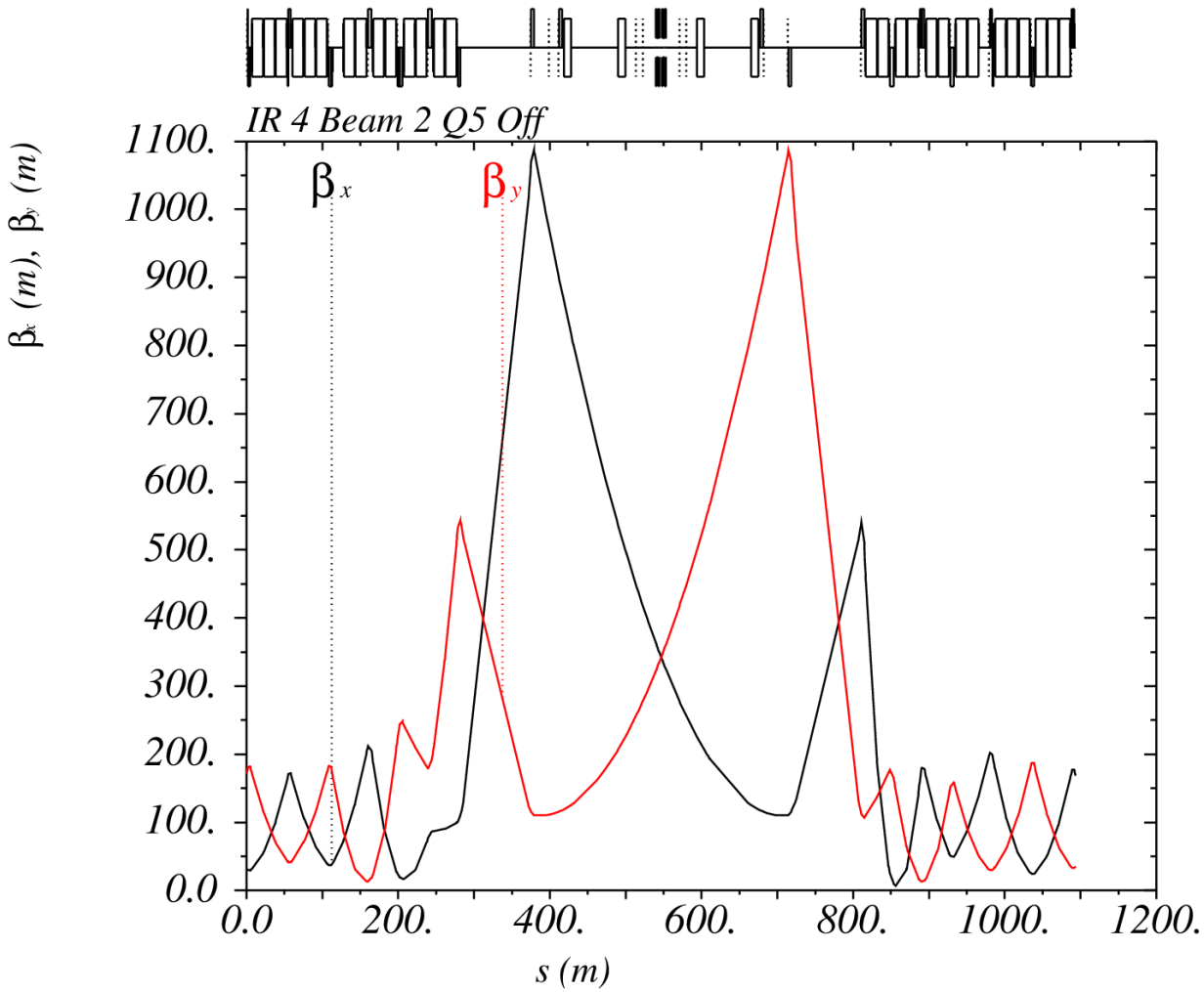
Nominal IR4 Optics





Ballistic IR4 Optics





Strengths (thanks to Helmut)

	Magnet	k-value $[m^{-2}]$			Maximum k at 7 TeV $[m^{-2}]$	% of Maximum		% at 450 GeV	
		Beam 1	Beam 2	Imbalance		Beam 1	Beam 2	Beam 1	Beam 2
Normal Quads	Q5L	0	0	-	-	-	-	-	-
	Q5R	0	0	-	-	-	-	-	-
	Q6L	-2.90E-03	2.97E-03	0.98	6.85E-03	42%	43%	2.72%	2.79%
	Q6R	2.90E-03	-2.97E-03	0.98	6.85E-03	42%	43%	2.72%	2.79%
	Q7L	8.34E-03	-5.23E-03	1.60	8.57E-03	97%	61%	6.26%	3.92%
	Q7R	-5.09E-03	8.44E-03	0.60	8.57E-03	59%	99%	3.82%	6.34%
	Q8L	-6.14E-03	5.04E-03	1.22	8.57E-03	72%	59%	4.61%	3.78%
	Q8R	5.03E-03	-6.16E-03	0.82	8.57E-03	59%	72%	3.77%	4.63%
	Q9L	7.94E-03	-4.50E-03	1.76	8.57E-03	93%	53%	5.96%	3.38%
	Q9R	-4.50E-03	7.96E-03	0.57	8.57E-03	53%	93%	3.38%	5.98%
	Q10L	-7.71E-03	6.96E-03	1.11	8.57E-03	90%	81%	5.79%	5.22%
	Q10R	7.02E-03	-7.73E-03	0.91	8.57E-03	82%	90%	5.27%	5.80%
Trimm Quads	Q11L	-1.11E-03	-4.08E-03	-	5.35E-03	21%	76%	1.34%	4.89%
	Q11R	-5.28E-03	-1.04E-03	-	5.35E-03	99%	19%	6.34%	1.25%
	Q12L	-3.03E-03	-3.73E-03	-	5.27E-03	58%	71%	3.70%	4.55%
	Q12R	-3.53E-03	-1.12E-03	-	5.27E-03	67%	21%	4.31%	1.37%
	Q13L	3.18E-03	4.03E-03	-	5.27E-03	60%	77%	3.88%	4.92%
	Q13R	-1.40E-03	3.65E-03	-	5.27E-03	27%	69%	1.71%	4.45%

“Consultation with Matteo Solfaroli several design iterations, no obvious red flags after first look.” (two years ago…),

Integration (thanks to Riccardo)

- Whole ring matched for injection optics (up to ca. 1900 GeV)
  - Need to repeat and extend to higher energies
- Scheme implemented with Riccardo:
  1. Load nominal injection ATS optics
  2. Load IR 1, 4 and 5 optics over
  3. Match tune using tuning knobs
- Minimal/acceptable beating
- Scheme should be easily extendable to higher energy ATS optics
  - Ensures triplet restrictions
  - Will try and do this this afternoon

Optic Name	Energy	Time	Parabolic Fra...
R2021a_A11mC11mA10mL10m	450.0	0	0.1
R2021a_A11mC11mA10mL10m	452.2	15	0.1
R2021a_A11mC11mA10mL10m	459.0	30	0.1
R2021a_A11mC11mA10mL10m	470.2	45	0.1
R2021a_A11mC11mA10mL10m	486.0	60	0.1
R2021a_A11mC11mA10mL10m	530.9	90	0.1
R2021a_A11mC11mA10mL10m	593.9	120	0.1
R2021a_A11mC11mA10mL10m	705.2	160	0.1
R2021a_A11mC11mA10mL10m	840.9	200	0.1
R2021a_A11mC11mA10mL10m	1048.0	250	0.1
R2021a_A11mC11mA10mL10m	1306.0	300	0.1
R2021a_A11mC11mA10mL10m	1694.5	368	0.1
R2021a_A10mC10mA10mL10m	1905.9	405	0.1
R2021a_A970cmC970cmA10mL970cm	2105.9	440	0.1
R2021a_A930cmC930cmA10mL930cm	2305.9	475	0.1
R2021a_A880cmC880cmA10mL880cm	2505.9	510	0.1
R2021a_A810cmC810cmA10mL810cm	2705.9	545	0.1
R2021a_A700cmC700cmA10mL700cm	2905.8	580	0.1
R2021a_A600cmC600cmA10mL600cm	3105.8	615	0.1
R2021a_A510cmC510cmA10mL510cm	3305.8	650	0.1
R2021a_A440cmC440cmA10mL440cm	3505.8	685	0.1
R2021a_A370cmC370cmA10mL370cm	3705.8	720	0.1
R2021a_A310cmC310cmA10mL310cm	3905.8	755	0.12
R2021a_A250cmC250cmA10mL250cm	4202.9	807	0.1
R2021a_A200cmC200cmA10mL200cm	4505.7	860	0.1
R2021_A155cmC155cmA10mL200cm	5877.0	1100	0.1
R2021_A133cmC133cmA10mL200cm	6716.9	1247	0.1
R2021_A133cmC133cmA10mL200cm	6800.0	1275	0.1

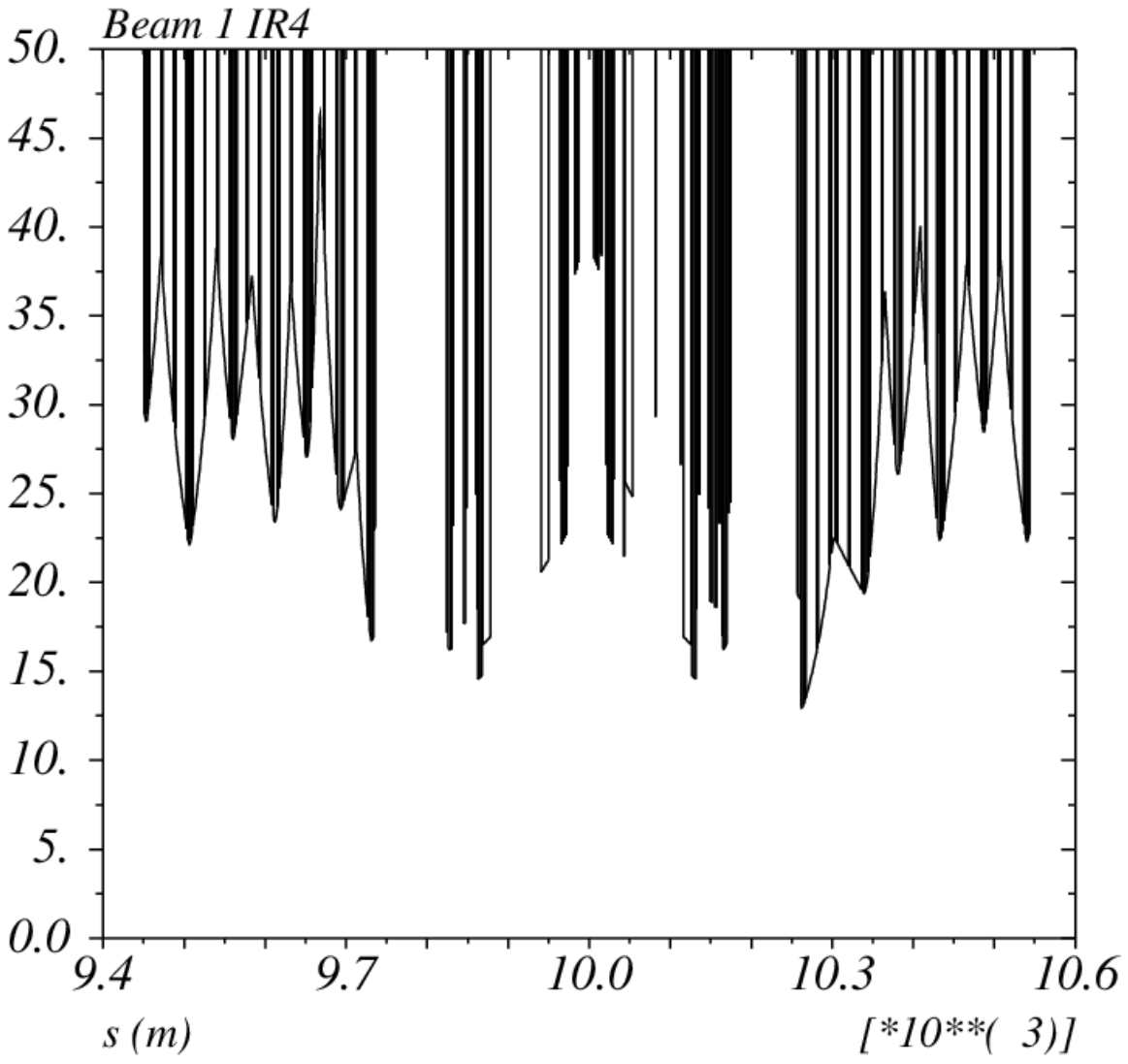
Table of optics for ramp sent by Matteo Solfaroli

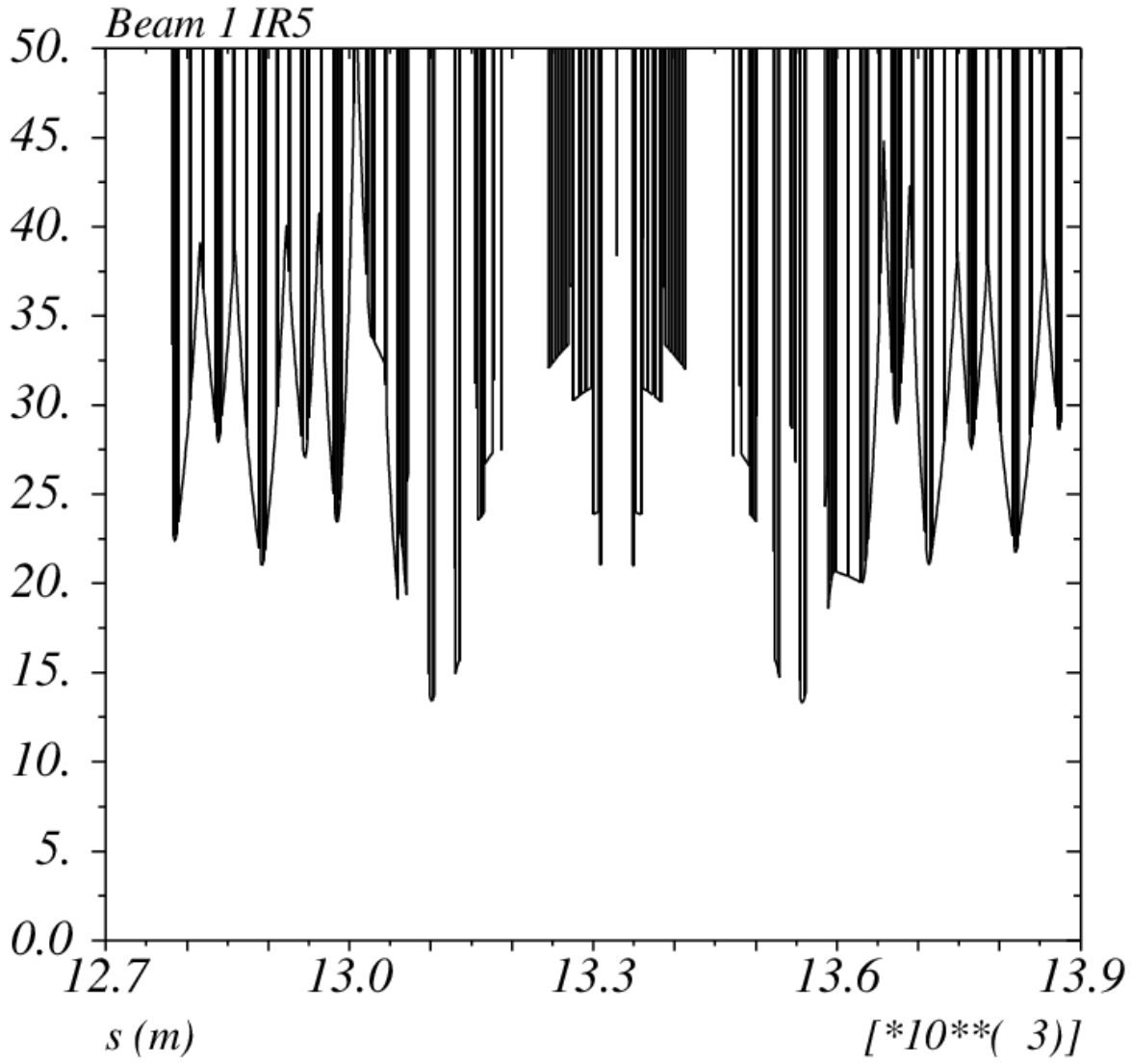
Aperture

- Using “HL-LHC design” parameters from R. Bruce et al. “*Updated parameters for HL-LHC aperture calculations for proton beams*”
- Assuming 1 μm test beam

Parameter set	LHC design	**HL-LHC design**
Primary halo extension	6 σ	**6** σ
Secondary halo, hor./ver.	7.3 σ	**6** σ
Secondary halo, radial	8.3 σ	**6** σ
Normalised emittance ϵ_n	3.75 μm	**2.5** μ**m**
Radial closed orbit excursion x_{co}	3 mm	**2 mm**
Momentum offset δ_p	8.6×10^{-4}	$\mathbf{2 \times 10^{-4}}$
β-beating fractional beam size change k_β	1.1	**1.1**
Relative parasitic dispersion f_{arc}	0.27	**0.1**

Aperture Beam 1





Aperture Beam 2