β^* reach studies

R. Martin

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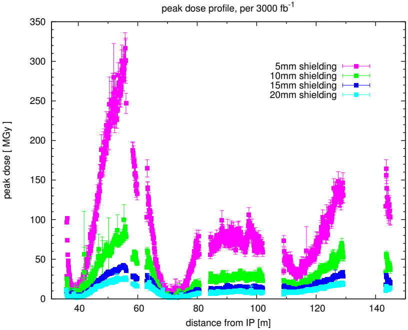
Radiation load



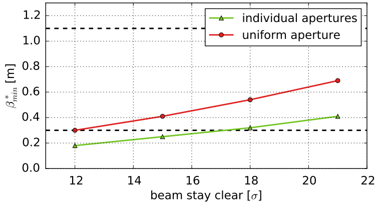
FLUKA simulations of physics debris. Courtesy of M. I. Besana and F. Cerutti.

- Radiation load is main driver of development
- Large amounts of shielding needed inside of quadrupoles (15 mm - 20 mm)
- Reduced aperture reduces β^* reach
- Simple quadrupole model:

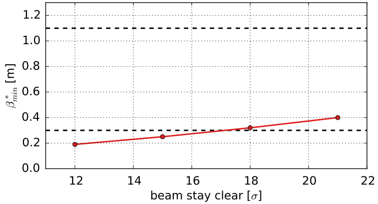
$$x_{ap} = \frac{e}{p} \frac{B_{max}}{k}$$

- Flux at coil aperture B_{max} given by magnet technology

$L^* = 36\,\text{m}$

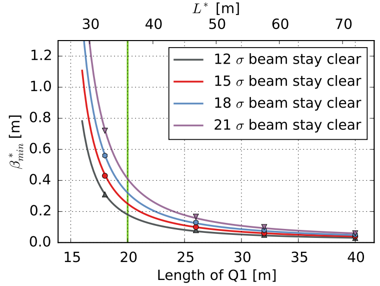


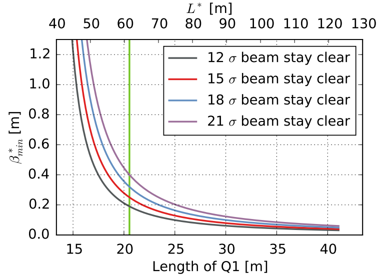
$L^* = 61.5\,\text{m}$



- Assuming $B_{max} = 11\,\text{T}$
- $\beta^* = 1.1\,\text{m}$ (Baseline) not an issue
- $\beta^* = 0.3\,\text{m}$ ("Ultimate") reachable up to $\approx 17\,\sigma$ beam stay clear
- $\beta^* = 0.2\,\text{m}$ leaves $\approx 13\,\sigma$ beam stay clear

L^* range and aperture





- Longitudinal scaling (**of both L^* and triplet**) used to explore L^* range
- At reference points ($L^* = 36$ m and $L^* = 61$ m, triplet lengths are approximately same
- **Difference in both lattices:** ratio of triplet magnet length to L^*
- **Conclusion 1:** aperture limitation on β^* is lower for longer L^* and longer triplet
- **Conclusion 2:** triplet length seems to have a larger impact

Conclusion and implications for L^*

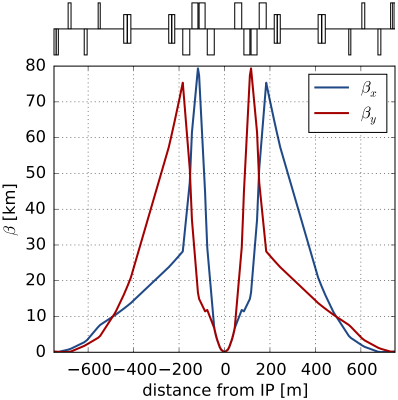
- L^* and/or triplet length can easily be increased until chromaticity and DA limitation are issues
- Triplet length has larger impact on β^* reach than L^*

Strategy

Choose **smallest** L^* that does not restrict detector design, then **increase triplet length** until DA becomes a problem

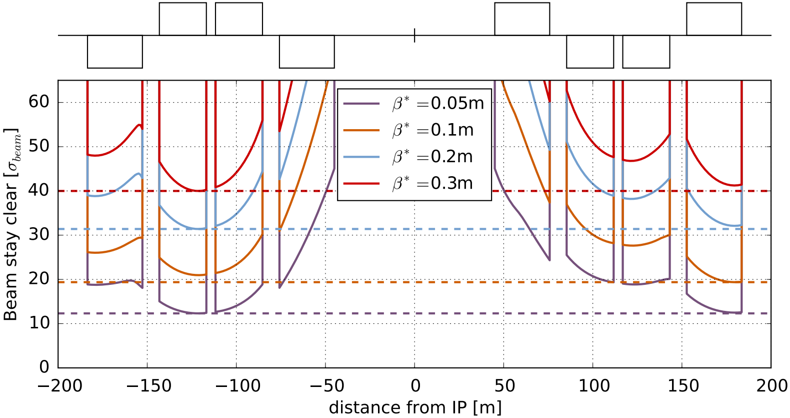
$L^* = 45\,\mathrm{m}$ lattice

- Driven by current detector design
- Forward spectrometer and compensator dipole
- Shortest $L^* \approx 45\,\mathrm{m}$
- Triplet length increased by 50 % $\Rightarrow L_{Q1/Q3} \approx 30\,\mathrm{m}$, $L_{Q2a/b} \approx 26\,\mathrm{m}$
- Currently too long by 50 m per side and per IP
- For details, see talk by A. Langner



Optics for $\beta^* = 0.3\,\mathrm{m}$

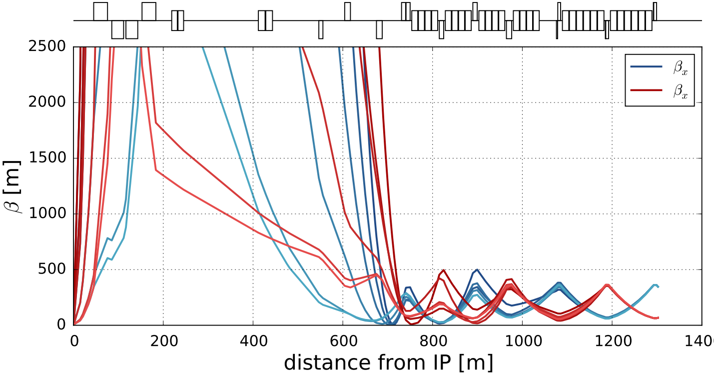
β^* limit from aperture



- "Ultimate" β^* of 0.3 m leaves 40 σ beam stay clear
- With 12 σ beam stay clear, we can accomodate a β^* of down to 5 cm
- $\beta^* = 5$ cm lower useful limit for luminosity production rate (talk by X. Buffat)

β^* limit from Matching Section

- $\beta^* = 6\,\mathrm{m} - 0.2\,\mathrm{m}$ have been successfully matched
- For $\beta^* = 0.1\,\mathrm{m}$ matched optics were found but Q6 changed sign
- $\beta^* = 0.05\,\mathrm{m}$ could not be matched yet



- focal point shifting towards Q7 is limiting factor ⇒ optimization or new concept for MS is required

Expectations for DA

- Magnet field errors depend on **axis offset**:

$$B_y + iB_x = 10^{-4} B_2 \sum_{n=2}^{\infty} (b_n + ia_n) \left(\frac{x + iy}{R_{ref}} \right)^{n-1}$$

- We assume **same magnet technology** as HL-LHC for triplet (i.e. same a_n, b_n, B_2/R_{ref})
- With large amount of **shielding**, we can use less of the coil aperture
- ⇒ **Smaller effect** of nonlinear forces is expected
- **Tracking studies needed** for verification

Triplet errors

- HL-LHC error table suggested by E. Todesco (CERN-ACC-2014-103)
- Updated integrated strength for new magnet length (not 100% exact as we will need to split the magnets)
- b1, b2, a1, a2 turned off

$$b_n = b_{n_s} + \frac{\xi_U}{1.5} b_{n_U} + \xi_R b_{n_R}$$

- no non-linear field correctors implemented yet

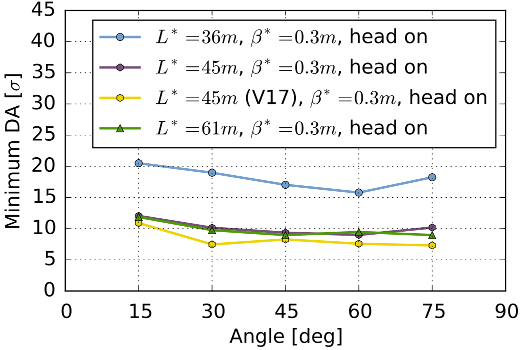
	Systematic		Uncertainty		Random	
Normal	Injection	High Field	Injection	High Field	Injection	High Field
1	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	(10)	(10)
3	0.000	0.000	0.82	0.82	0.82	0.82
4	0.000	0.000	0.57	0.57	0.57	0.57
5	0.000	0.000	0.42	0.42	0.42	0.42
6	-20.332	-0.428	1.1	1.1	1.1	1.1
7	0.000	0.000	0.19	0.19	0.19	0.19
8	0.000	0.000	0.13	0.13	0.13	0.13
9	0.000	0.000	0.07	0.07	0.07	0.07
10	3.728	-0.124	0.2	0.2	0.2	0.2
11	0.000	0.000	0.26	0.26	0.26	0.26
12	0.000	0.000	0.18	0.18	0.18	0.18
13	0.000	0.000	0.009	0.009	0.009	0.009
14	0.173	-0.867	0.023	0.023	0.023	0.023
15	0.000	0.000	0.000	0.000	0.000	0.000
Skew						
1	0.000	0.000	0.000	0.000	0.000	0.000
2	-0.627	-0.627	0.000	0.000	(10)	(10)
3	0.000	0.000	0.65	0.65	0.65	0.65
4	0.000	0.000	0.65	0.65	0.65	0.65
5	0.000	0.000	0.43	0.43	0.43	0.43
6	0.044	0.044	0.31	0.31	0.31	0.31
7	0.000	0.000	0.19	0.19	0.19	0.19
8	0.000	0.000	0.11	0.11	0.11	0.11
9	0.000	0.000	0.08	0.08	0.08	0.08
10	0.013	0.013	0.04	0.04	0.04	0.04
11	0.000	0.000	0.026	0.026	0.026	0.026
12	0.000	0.000	0.014	0.014	0.014	0.014
13	0.000	0.000	0.01	0.01	0.01	0.01
14	-0.004	-0.004	0.005	0.005	0.005	0.005
15	0.000	0.000	0.000	0.000	0.000	0.000

$R_{ref} = 0.05\,\text{m}$

DA results without crossing angle

Inputs for long-term DA study:

- 100,000 turns
- 60 seeds
- 30 particle pairs
- norm. Emit. 2.2 mrad
- $E_0 = 50$ TeV
- $Q^{'} = 2$
- $dp/p = 0.00027$
- dp/p max $= 0.002$
- σ step $= 2$, $\sigma \in [5, 45]$
- 5 angles
- head on collision



Lattice V17: phase advance in short arcs $= 90°$

Tracking studies with crossing angles found no DA yet. Correction strategies will have to be implemented next.

Conclusions and Outlook

- Longer triplet results in huge aperture gain, that can be used to:
  - ease collimation
  - increase shielding thickness
  - decrease β^* down to lower limit for luminosity production rate
- Limitation from matching section is far below current “ultimate” scenario
- Reasonable DA with triplet errors but without crossing angles
- Triplet error correction needed to improve DA with crossing angles