Thanks to:
B. Dalena, A. Langner, R. Tomás
Radiation load

- Radiation load is main driver of development
- Large amounts of shielding needed inside of quadrupoles (15 mm - 20 mm)
- Reduced aperture reduces $\beta^*$ reach
- Simple quadrupole model:
  $$x_{ap} = \frac{e B_{max}}{p \ k}$$
- Flux at coil aperture $B_{max}$ given by magnet technology

FLUKA simulations of physics debris. Courtesy of M. I. Besana and F. Cerutti.
Aperture limitation on $\beta^*$ reach/performance

$L^* = 36\, m$

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

$L^* = 61.5\, m$

- $\beta^* = 1.1\, m$ (Baseline) not an issue
- $\beta^* = 0.3\, m$ ("Ultimate") reachable up to $\approx 17\, \sigma$ beam stay clear
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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 $\beta^*$ 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 $\beta^*$ reach than $L^*$.

**Strategy**

Choose smallest $L^*$ that does not restrict detector design, then increase triplet length until DA becomes a problem.
$L^* = 45\text{ m lattice}$

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

Optics for $\beta^* = 0.3\text{ m}$
"Ultimate" $\beta^*$ of 0.3 m leaves 40 $\sigma$ beam stay clear

With 12 $\sigma$ beam stay clear, we can accommodate a $\beta^*$ of down to 5 cm

$\beta^*$ = 5 cm lower useful limit for luminosity production rate (talk by X. Buffat)
**β** limit from Matching Section

- **β** = 6 m – 0.2 m have been successfully matched
- For **β** = 0.1 m matched optics were found but Q6 changed sign
- **β** = 0.05 m could not be matched yet

- focal point shifting towards Q7 is limiting factor ⇒ optimization or new concept for MS is required
Magnet field errors depend on **axis offset**:

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

- We assume **same magnet technology** as HL-LHC for triplet (i.e. same \(a_n, b_n, B_2/R_{\text{ref}}\))
- With large amount of **shielding**, we can use less of the coil aperture
- \(\Rightarrow\) **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)
- $b_1, b_2, a_1, a_2$ turned off

\[ b_n = b_{ns} + \frac{\xi U}{1.5} b_{n U} + \xi_R b_{n R} \]

- no non-linear field correctors implemented yet

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$R_{ref} = 0.05 \text{ m}$
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
- $Q' = 2$
- $dp/p = 0.00027$
- $dp/p\ max = 0.002$
- $\sigma\ step = 2$, $\sigma \in [5, 45]$
- 5 angles
- head on collision

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 $\beta^*$ 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