Minimum required machine aperture for injection failures

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Thanks to: R. De Maria, M. Giovannozzi

Outline

- Introduction
  - LHC injection protection system
  - TDI post LS2 (TDI-s)
  - Optics used for simulations
- Simulation results
  - MKI and TDI failure cases
  - Survival function after LHC injection protection system
- Conclusions

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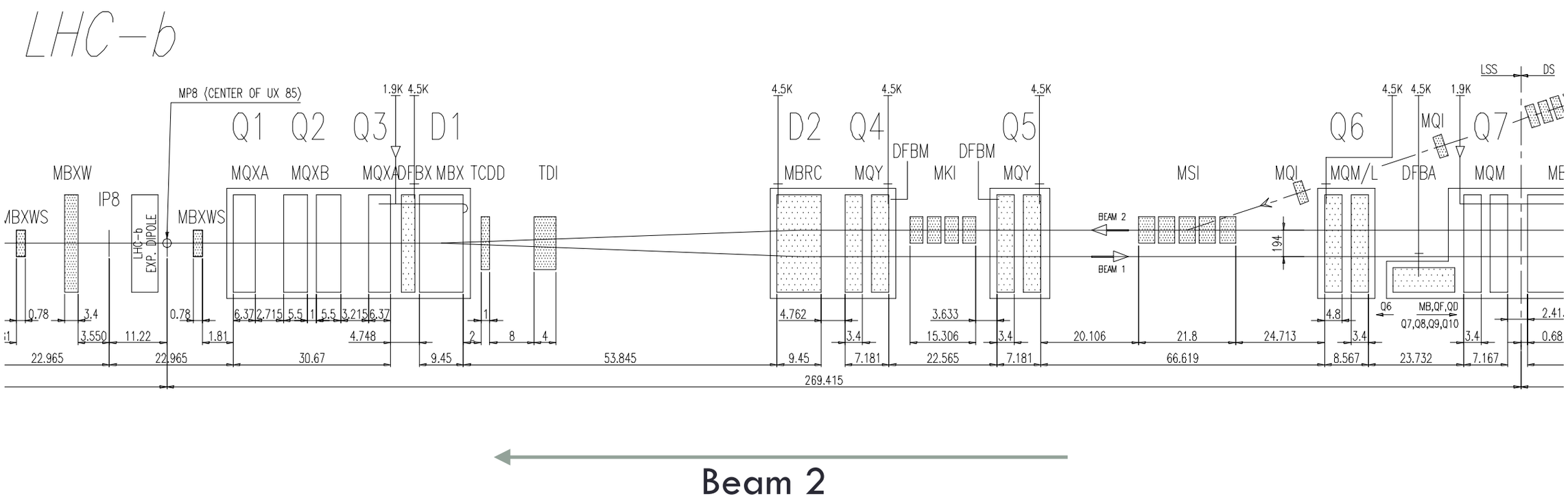
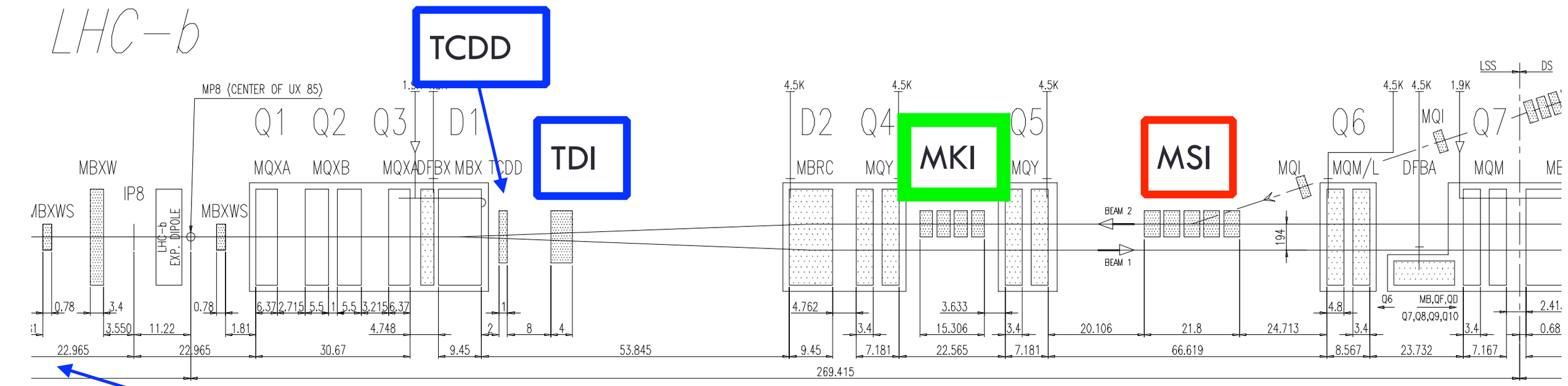
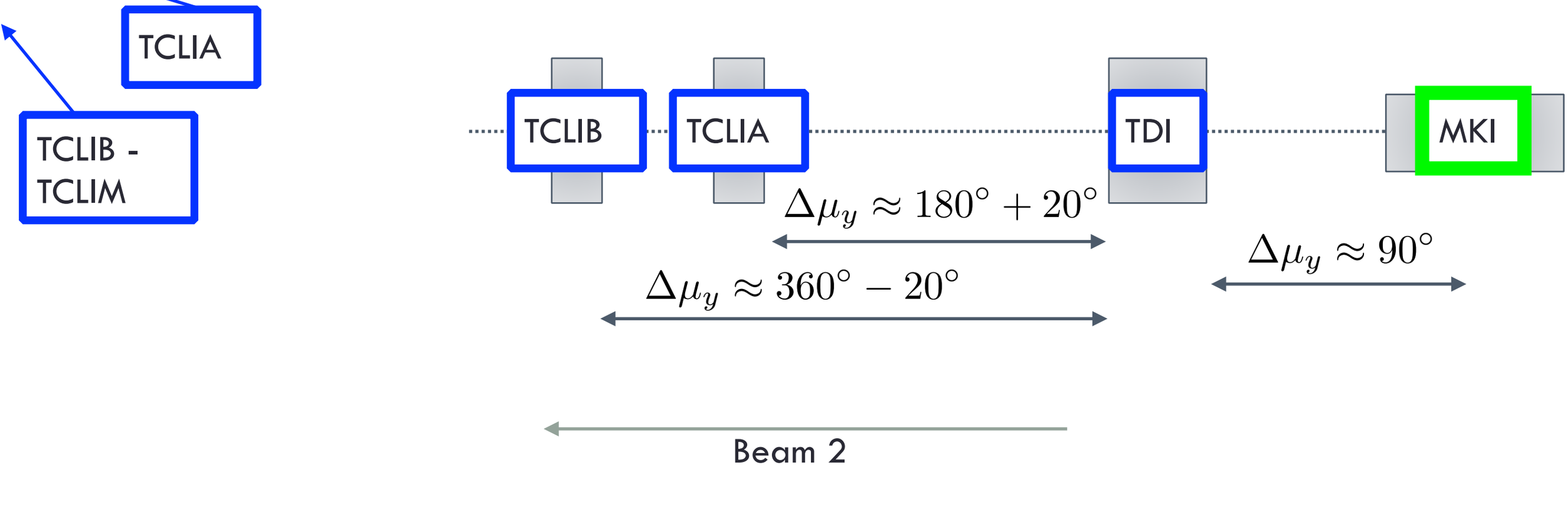
LHC Injection System

- The injection system is composed by:
  - Horizontal septum - MSI
  - Quadrupole - Q5
  - Vertical kicker - MKI
  - Protection devices - TDI, TCLIA/B, TCDD



LHC Injection System





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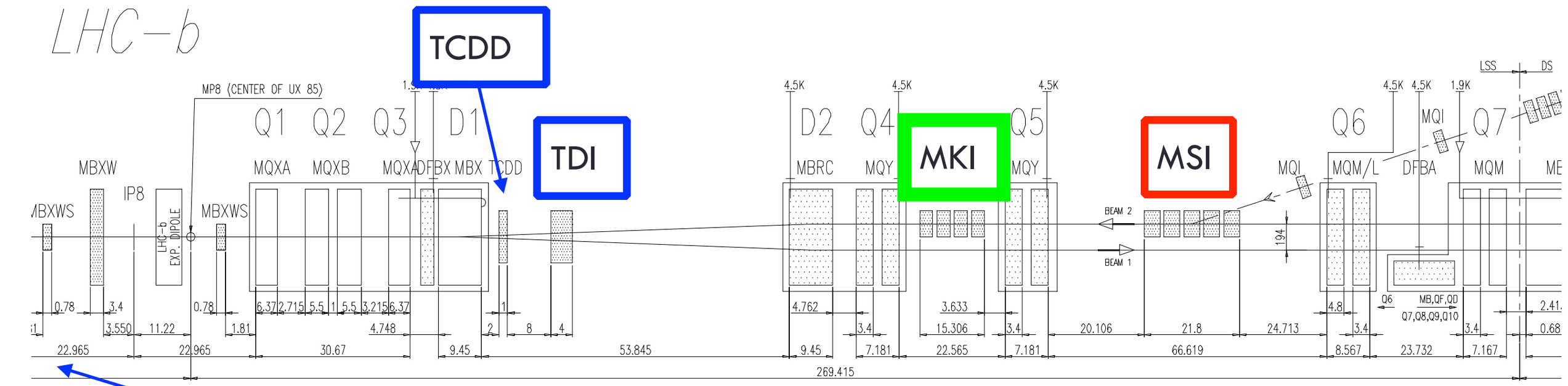
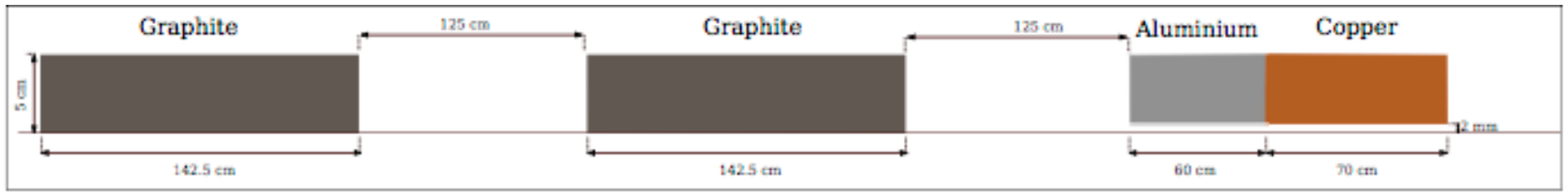


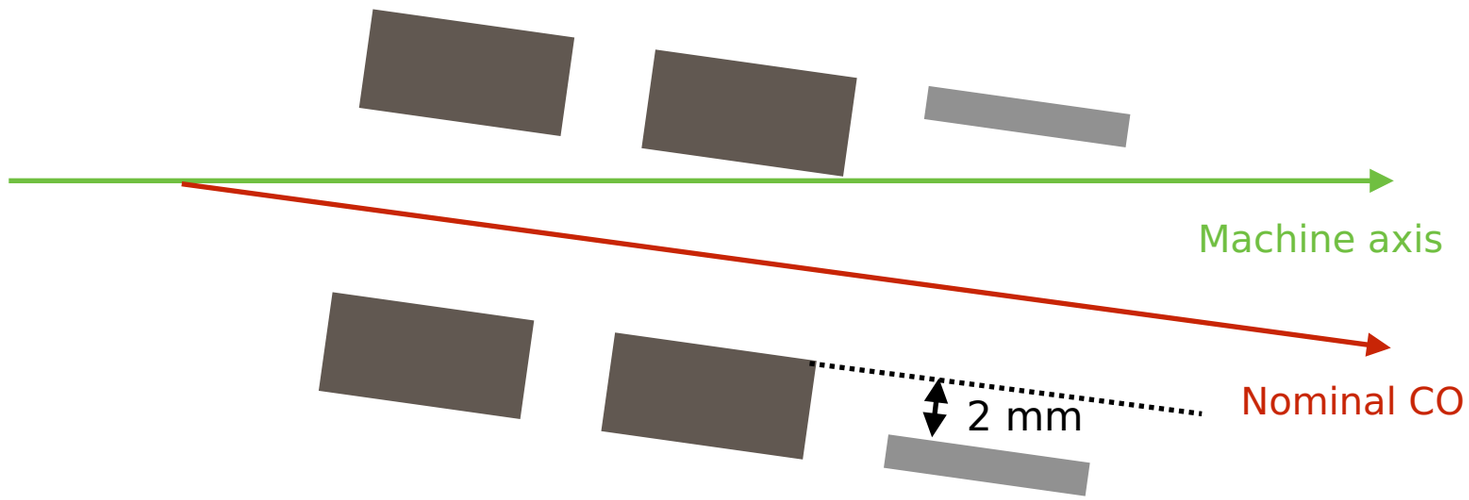
- TDI:
  - ~4 m long
  - 2 vertical jaws
  - Nominal aperture: 6.8 σ
  - Protection against MKI failures
- TCLIA/B
  - 1 m
  - 2 vertical jaws
  - Nominal aperture: 6.8/8.3 σ
  - Protection against phase errors between MKI and TDI

New TDI-S

- For HL-LHC the TDI will be redesigned
- The most likely design foresees:
  - **3 separate blocks: 2 of graphite (R4550) and 1 of high Z materials**
- For the following simulations, the last TDI-S block has been considered only Aluminum
- The last block has 2 mm larger aperture than the upstream one



Courtesy of A. Lechner

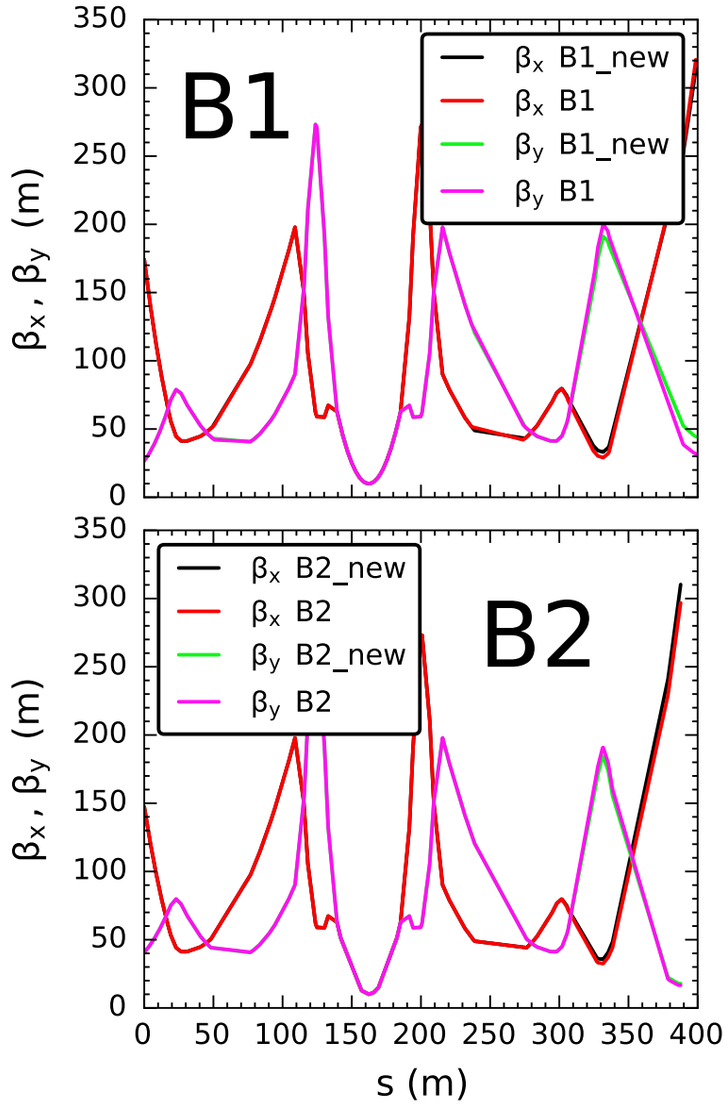


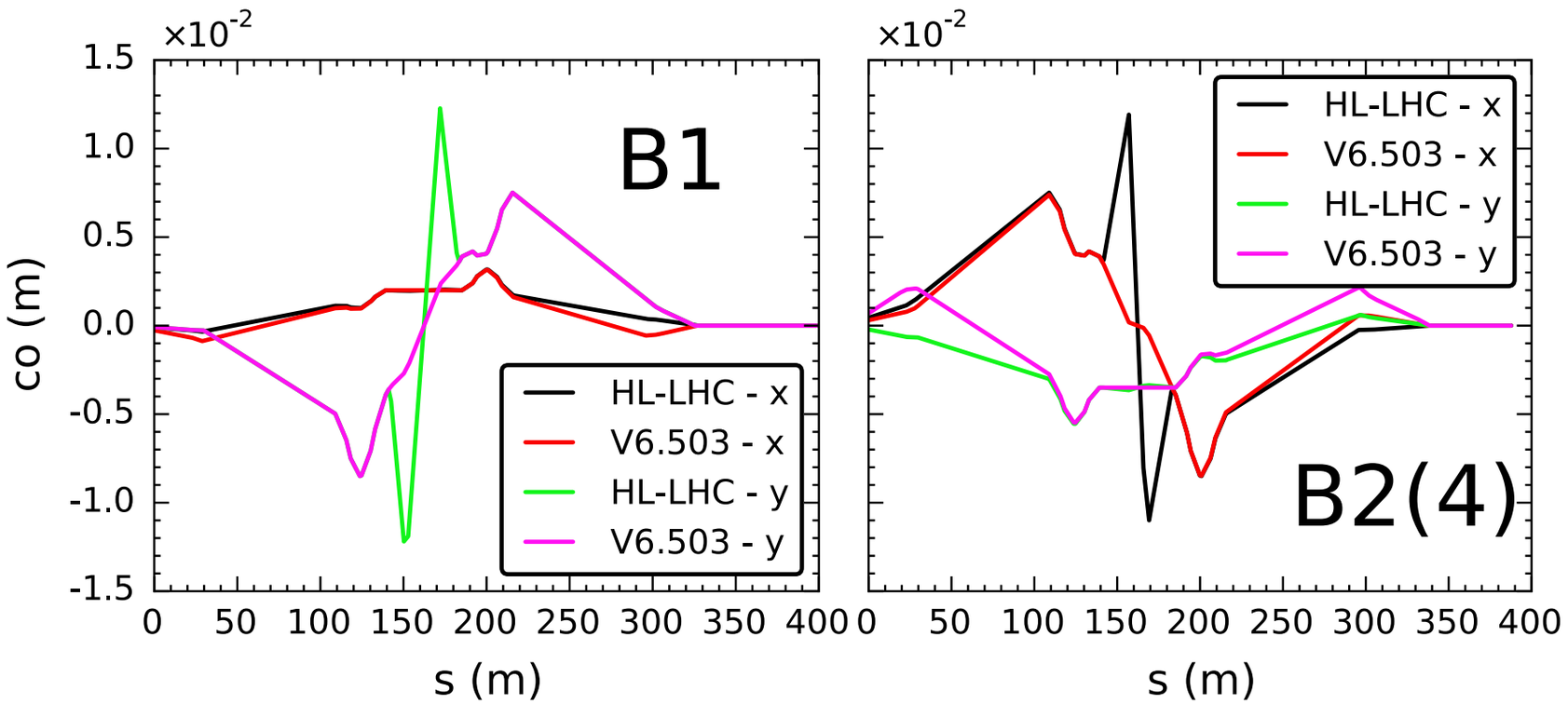
HL-LHC Optics

- The optics used for the simulations is HL-LHC V1.1

- It very very similar to the current one

  - The main differences are in crossing and separation bumps





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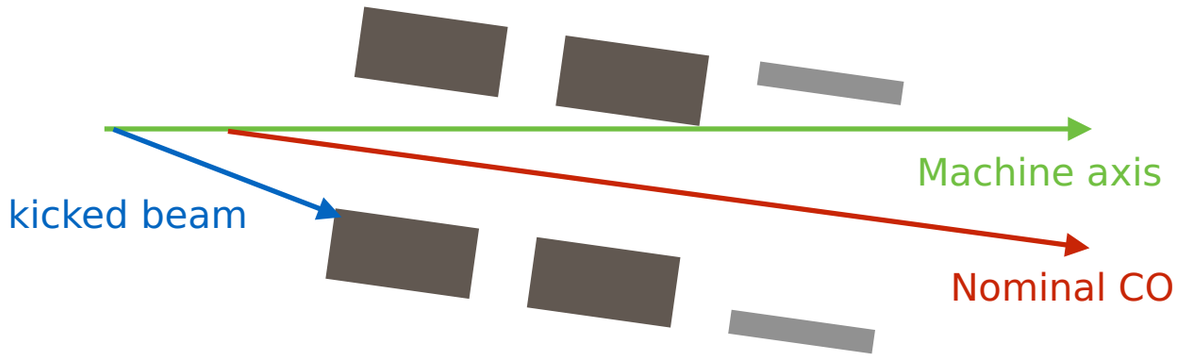
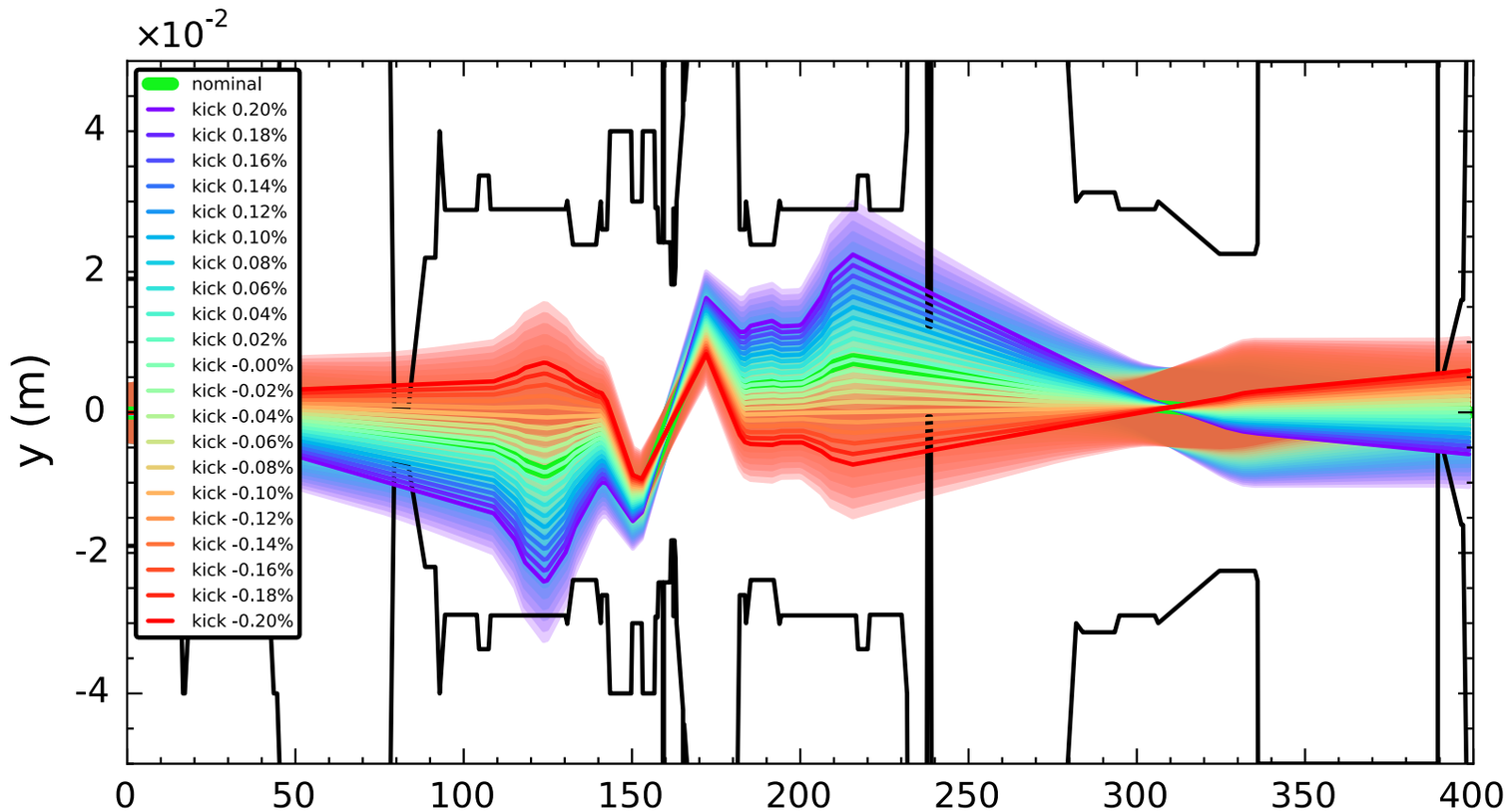
Injection failures - simulation

- The MKI deflects vertically the injected beam to bring it onto the nominal trajectory
- Nominal deflection assumed: θ = 0.85 mrad
- Kicker failures can concern both injected or circulating beam:
  - For the injected beam, the MKI strength considered is between 0 and 125% (100% nominal)
  - For the circulating beam, the MKI strength considered is between 0 (nominal) and 100%
  - Above 100% (for the circulating beam) becomes double-failure -> combination of two different failure modes which are excluded
- Above +/- ~20% of the MKI strength, the whole beam (> 5σ) is lost on the TDI

Injection failures - simulation

- **Studies are done considering:**
  - TDI aperture 6.8 σ (ϵ_{nom})
  - TCLIA/B aperture 6.8 σ (ϵ_{nom})
  - Grazing impact on the TDI at nominal position
    => ~11% of nominal kick for B1
    => ~9.5% of nominal kick for B2





$$E(s) = 5\sqrt{\epsilon_y \beta_y(s)} + |D_y|\delta_p + O_y\sqrt{\beta_y(s)/\beta_y^{MAX}} + M_y$$

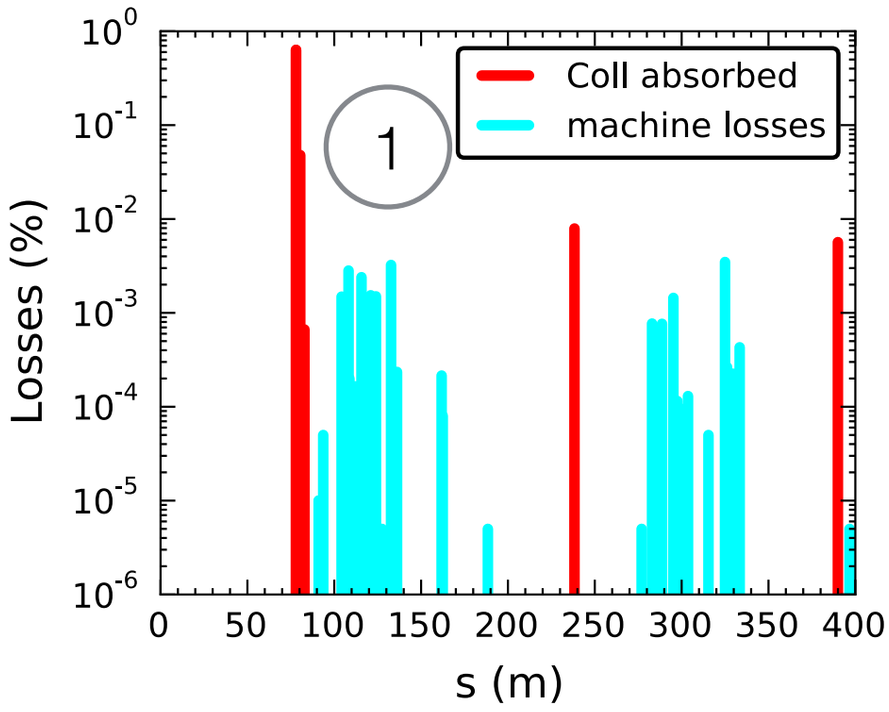
$$O_y = 2\ mm$$
$$M_y = 2\ mm$$

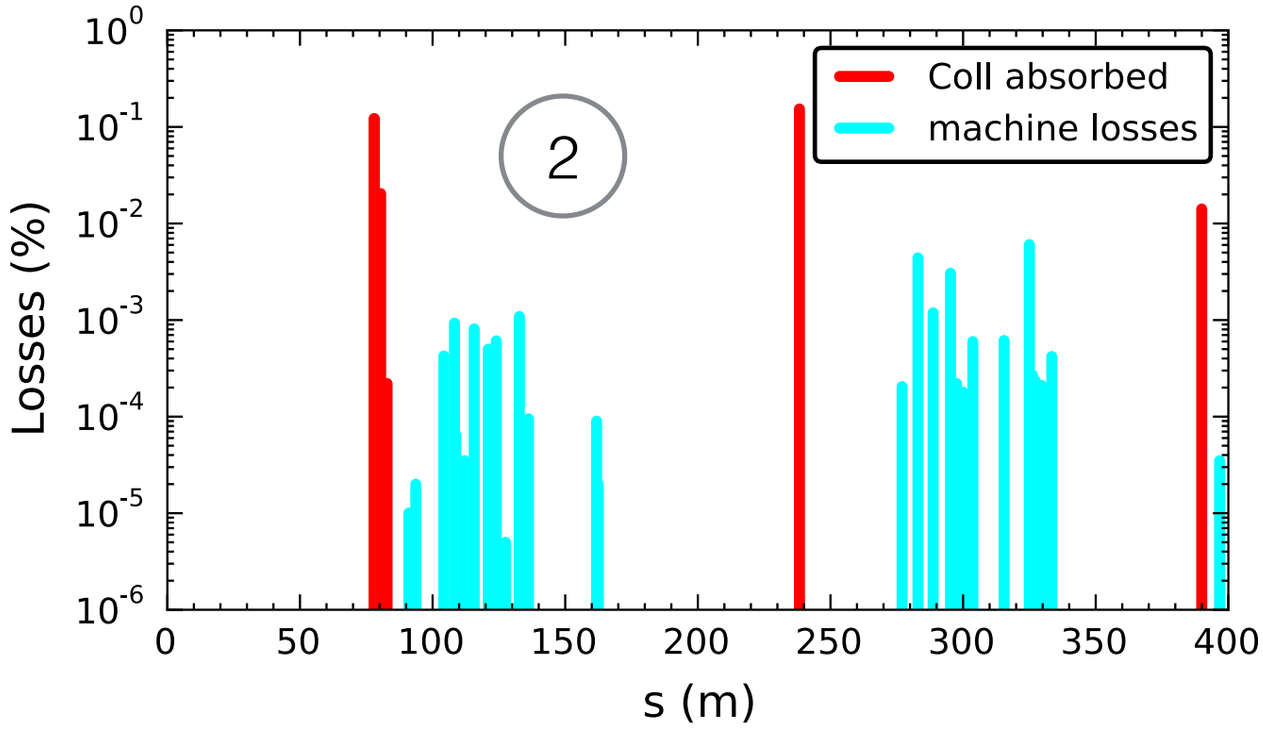
B1 Simulation results

- Highlight on two cases using ideal machine:

1. MKI kick of 11% its nominal with protection devices at nominal settings

2. MKI kick of 11% its nominal, TDI at 7.8σ and TCLIA/B at 6.8σ





MADX-PTC + pycollimate => SPStoLHC Transfer Lines Loss Map Generation Using pycollimate, IPAC15

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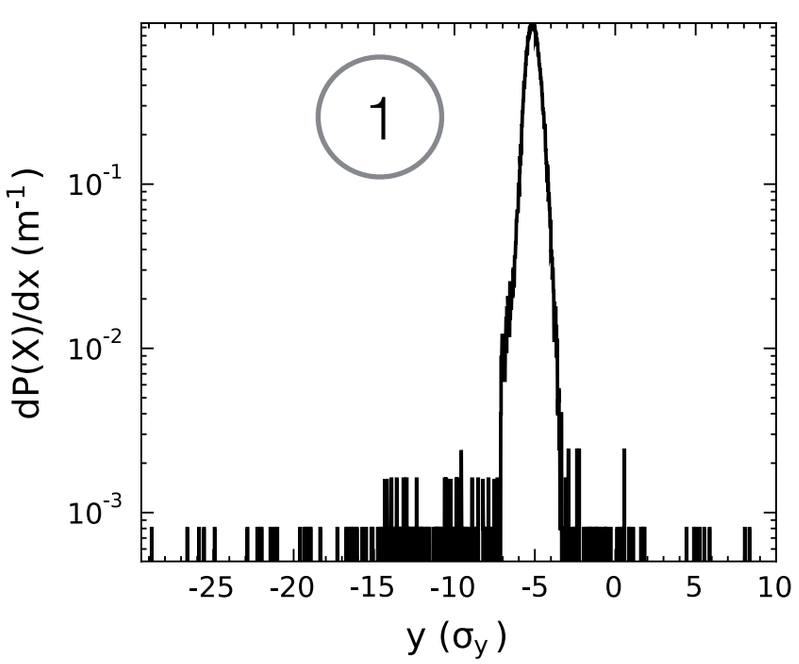

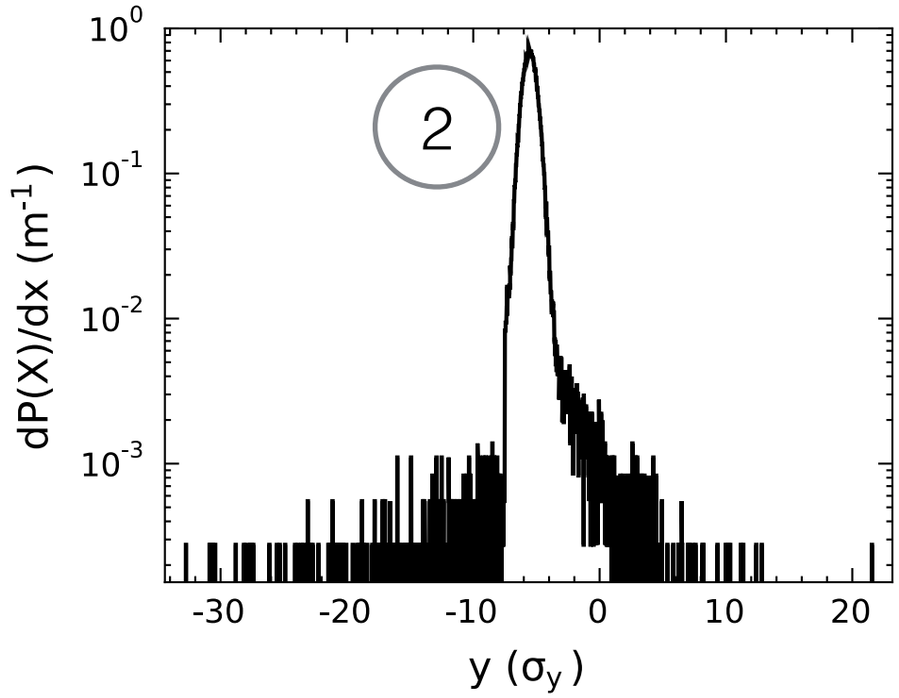

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B2 Simulation results

- Highlight on two cases using ideal machine:

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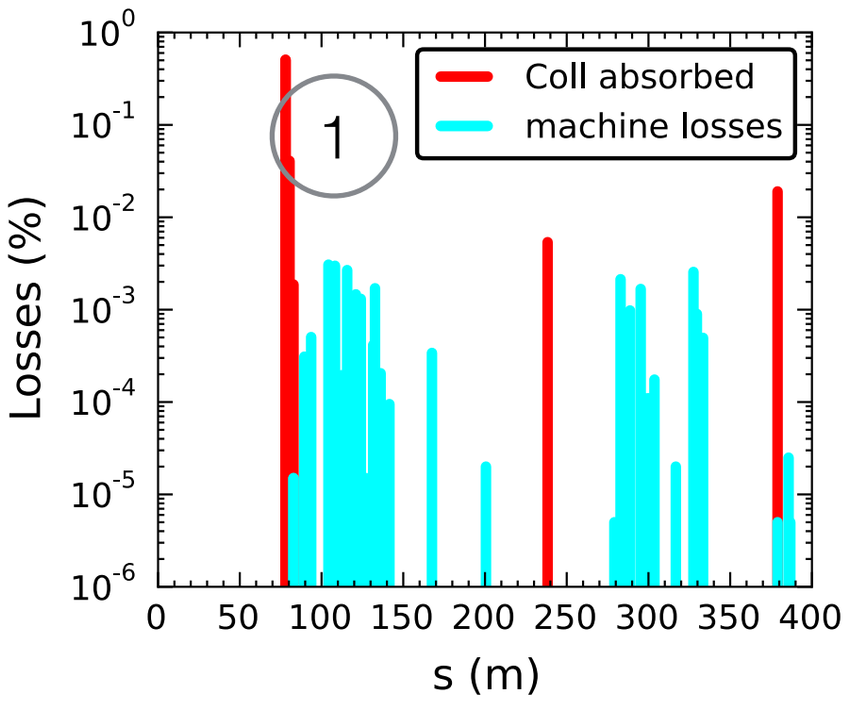

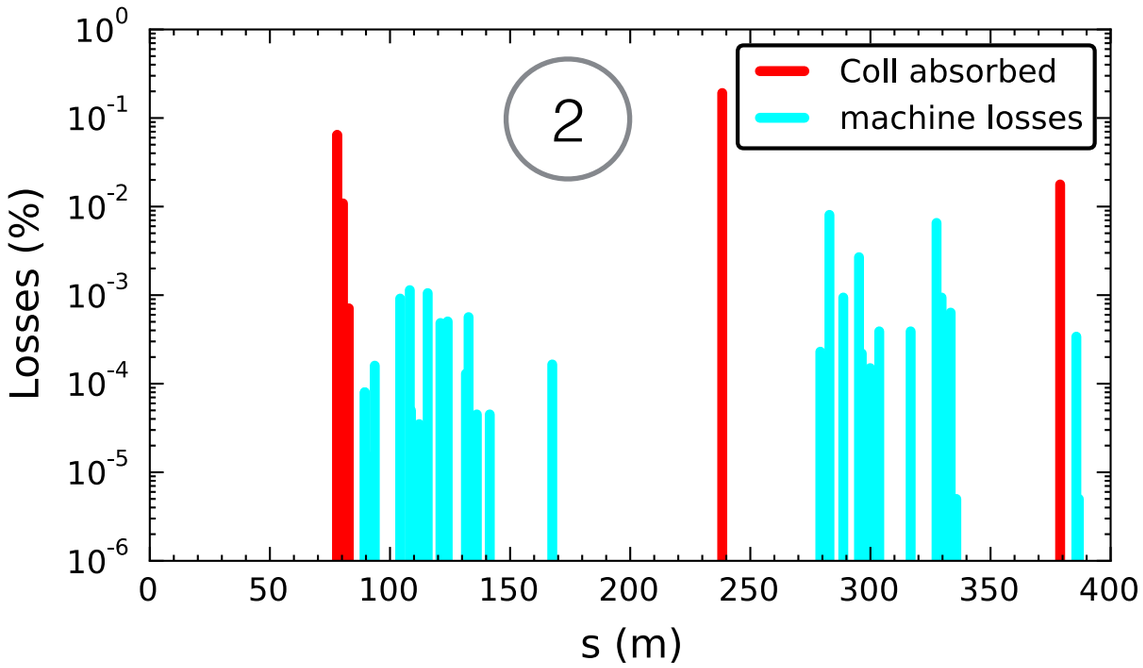

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B2 Simulation results

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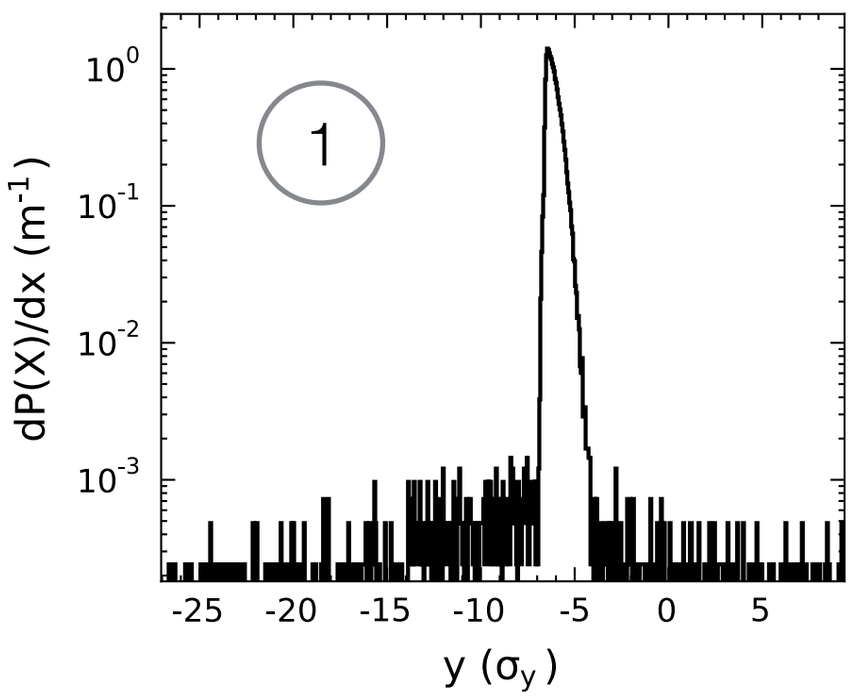

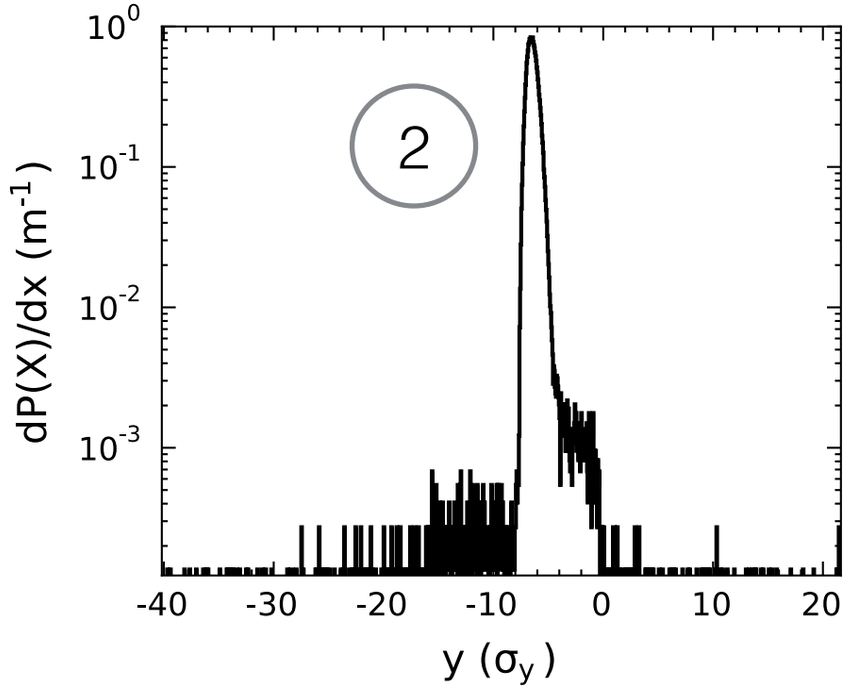

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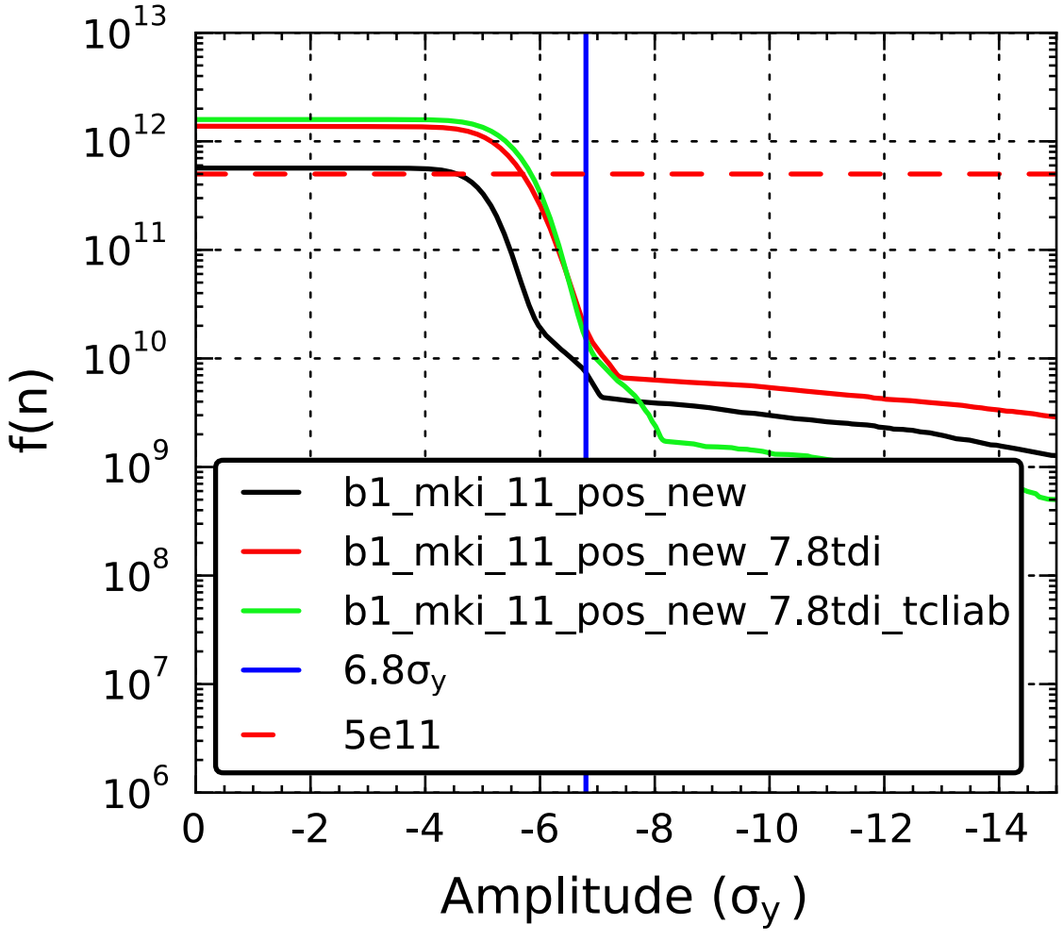
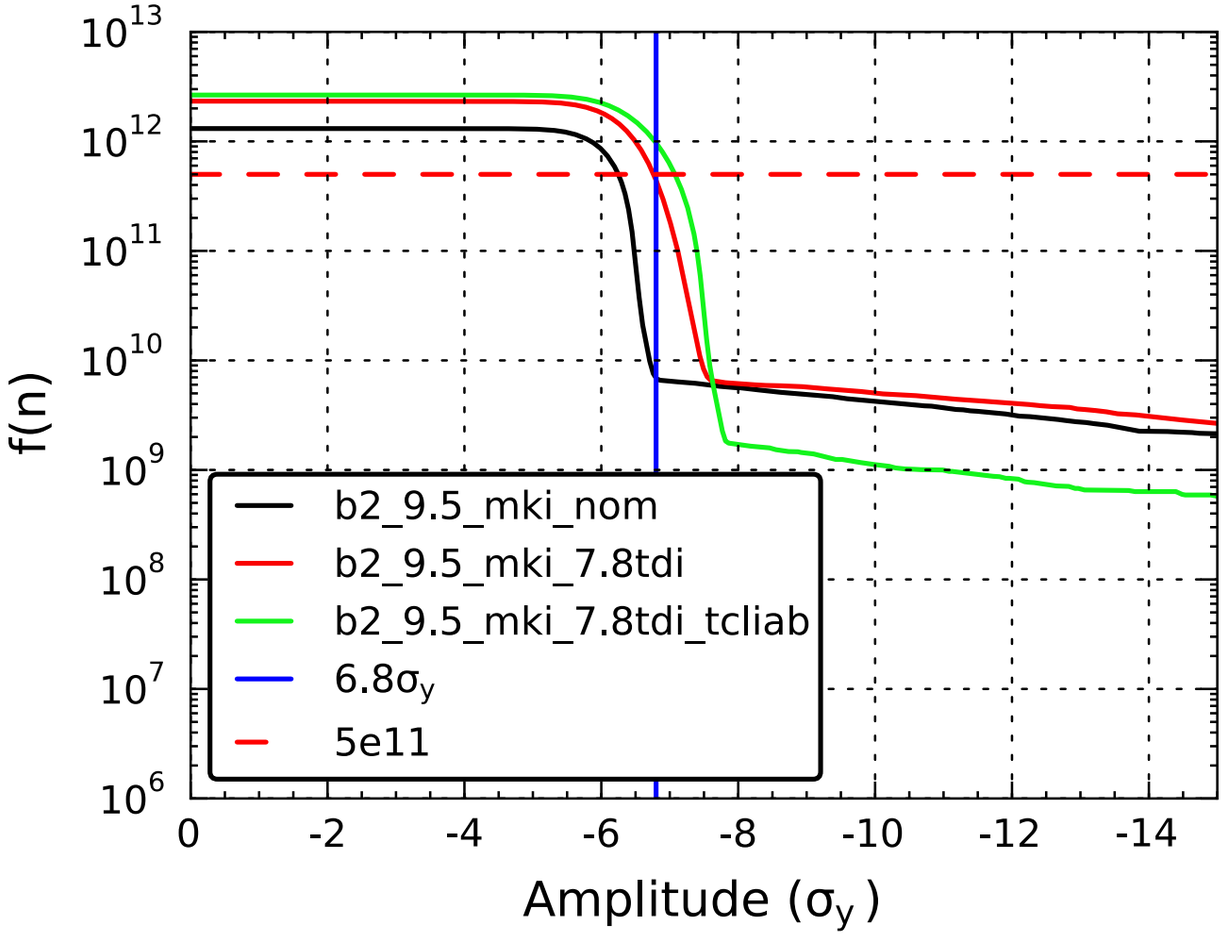
Surviving Function

- Integrating the escaping proton distribution (2e5 macro particles used => normalising to 2.2e11 p/bunch) (R. Bruce)

- Max amplitude escaping the injection protection system above 5e11 p is **7.2σ**





Minimum required aperture

- Summing to the previous result the tolerances in table:
  - 1σ at the TDI already included in the simulation
  - CO and injection oscillations to be considered together
- Assumptions: 1σ = 1mm, δ_p = 1.5e-3, k_d = 0.27, k_β = 1.2

Tolerances [1]	TDI (V)	TCDI (V)*	TCDI (H)*
Max A (with err)	7.2	6.8	6.8
Orbit	1.5	1.5	1.5
Injection osc	1.5	1.5	1.5
Beta beat	0.5	0.5	0.5
Energy err	0.1	0.1	1
Total	10.8	10.4	11.3

[1] ANGULAR ALIGNMENT OF THE LHC INJECTION PROTECTION STOPPER, C. Bracco et al., IPAC12

* TCDIs at nominal 4.5s

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Conclusions

- MKI injection failures have been analysed and simulated
- B2 represents the worst case in terms of intensity of high-amplitude escaping particles
- The injection protection system in the LHC is only on the vertical plane - horizontally only protected by TCDIs in the TLs => minimum allowed hor aperture is 11.5σ
- The minimum vertical amplitude protected by the injection protection system, considering injection failures, in HL-LHC is 11σ

Thank you!

Backup

- pycollimate - SixTrack extended for collimation