

# Aperture and protection tolerance for the injection into LHC

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W. Bartmann, B. Goddard, M. Meddahi,  
V. Kain, J. Uythoven...all LIBD WG  
and thanks to: R. Bruce, R. De Maria, M. Giovannozzi, S.  
Redaelli



# Outline

## Introduction

- LHC Injection System
- Injection protection devices
- New TDI-S
- Optics

## Injection Failures Simulations

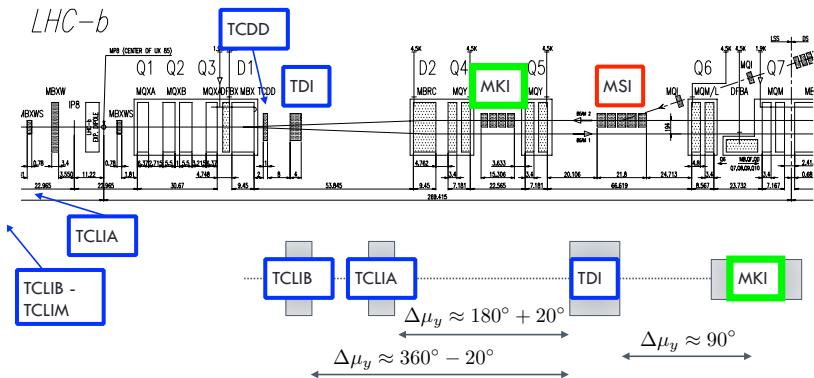
- Assumptions
- Beam 1
- Beam 2
- Halo Escaping - Vertical plane
- Halo Escaping - Horizontal plane

## Summary and Conclusion

# LHC Injection System

The LHC injection system is composed by:

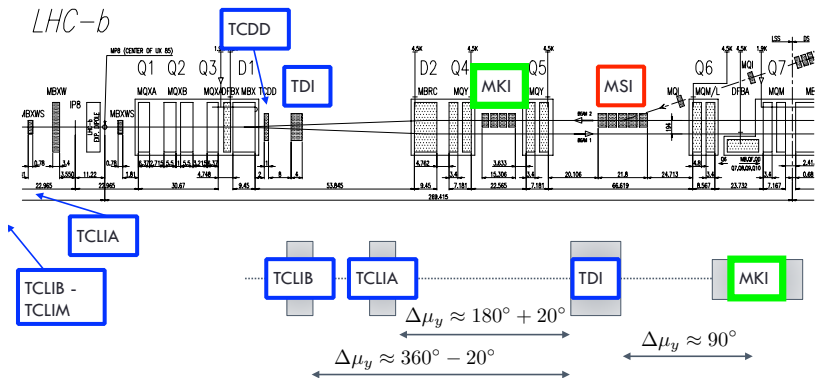
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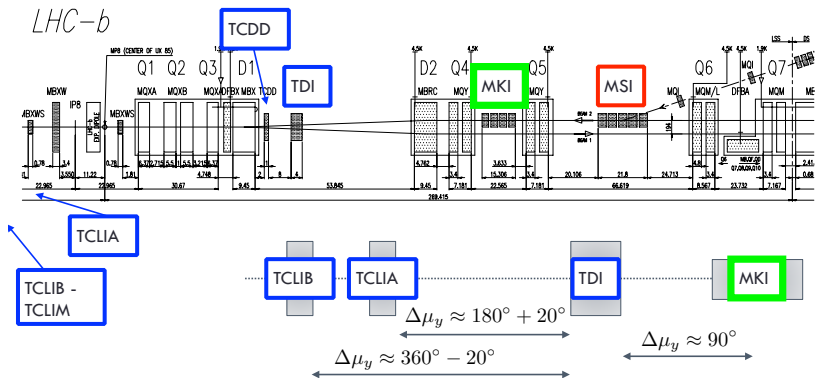
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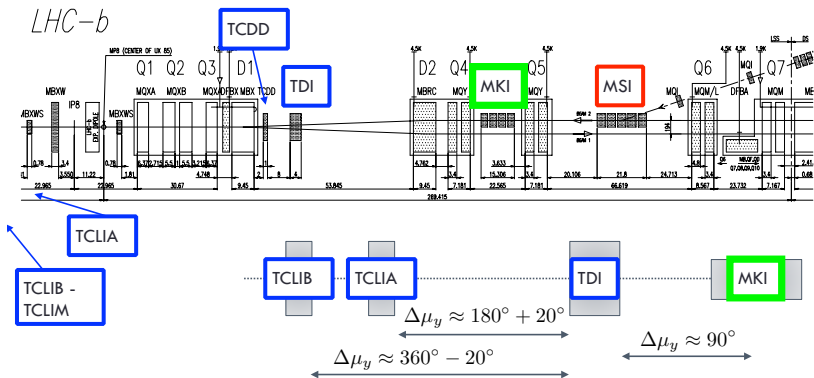
- ▶ horizontal septum - MSI;
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- ▶ vertical kicker - MKI;



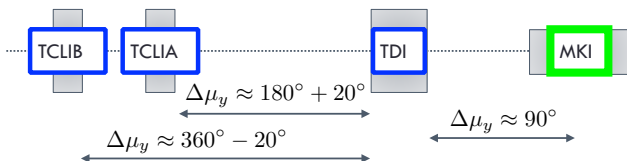
# LHC Injection System

The LHC injection system is composed by:

- ▶ horizontal septum - MSI;
- ▶ quadrupole - Q5;
- ▶ vertical kicker - MKI;
- ▶ protection devices - TDI, TCLIA/B, TCDD.



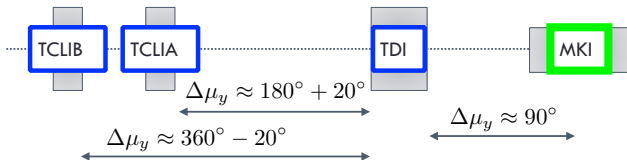
# Injection protection devices



## TDI:

- ▶ ~ 4 m long;
- ▶ 2 vertical jaws;
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- ▶ protection against MKI failures.

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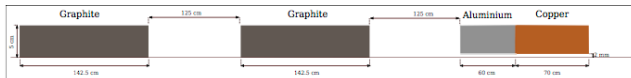
## TCLIA/B:

- ▶ 1 m;
- ▶ 2 vertical jaws;
- ▶ nominal half gap:  $6.8/8.3 \sigma$ ;
- ▶ protection against phase-advance errors between MKI and TDI.

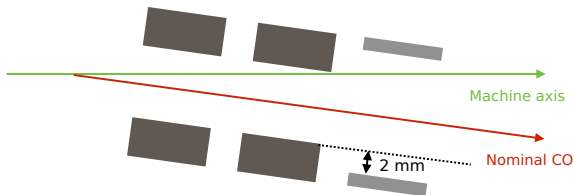


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- For HL-LHC a new TDI is foreseen to be installed;

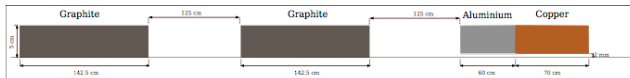


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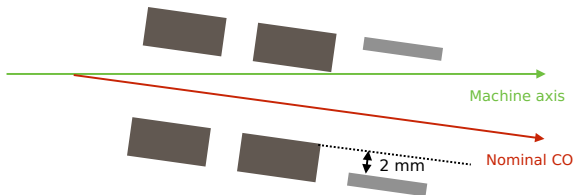


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  - ▶ 3 separate blocks: 2 of graphite (R4550 or similar) and 1 block of higher Z material (the following simulations have been done assuming aluminium);

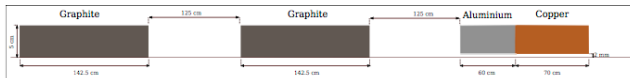


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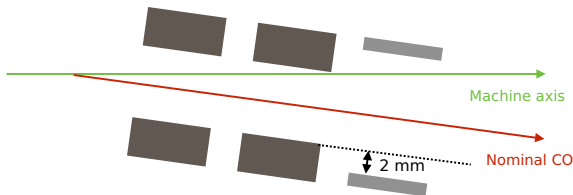


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- ▶ the last block has 2 mm larger aperture than the others.

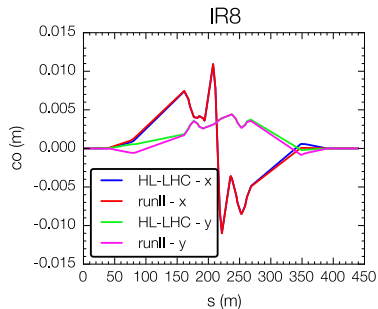
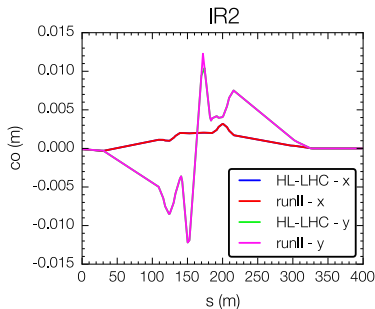


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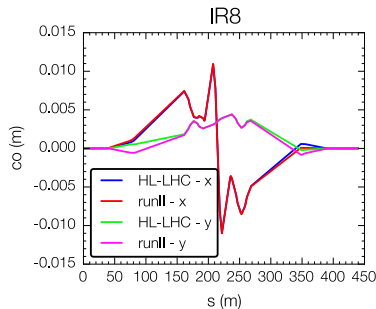
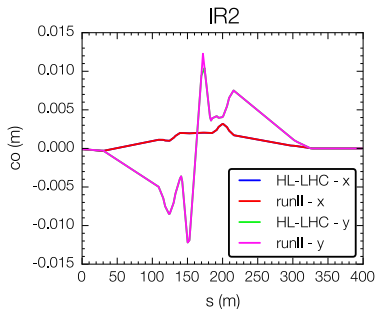
# Optics

- Optics HLLHC v1.1 used for simulations;



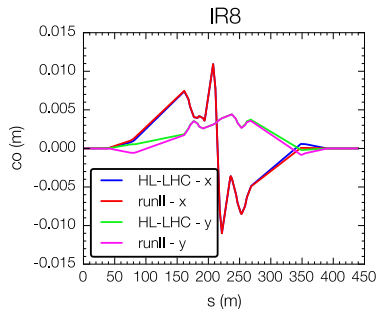
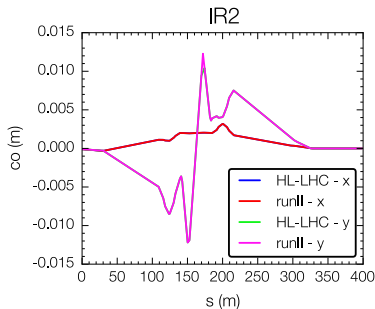
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- ▶ basically no differences between HLLHC v1.1 and the present optics (runII);
- ▶ also crossing and separation schemes in both IR2 and IR8 almost unchanged.



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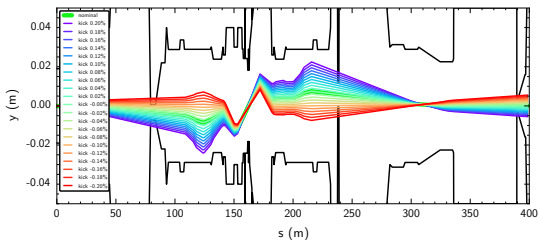


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  - ▶ **above 100% (for the circulating beam) it becomes double failure** → this is considered beyond design;
- ▶ above |20|% the impact parameter onto the TDI is above  $5\sigma$  hence almost the whole beam will be lost on the TDI.

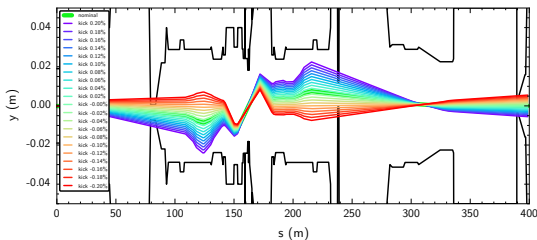
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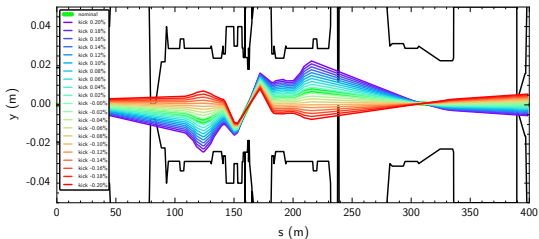
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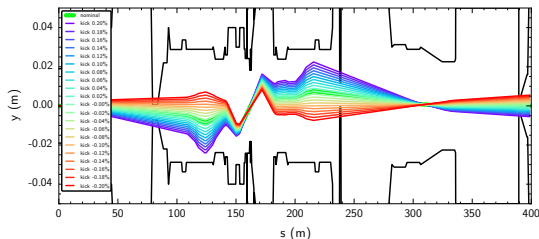
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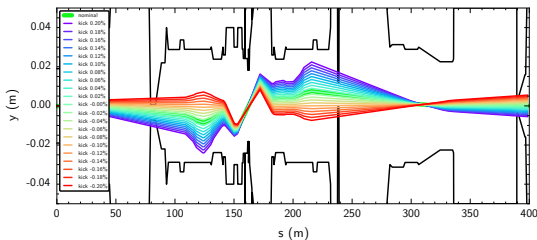
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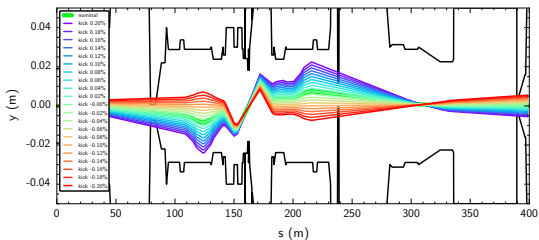
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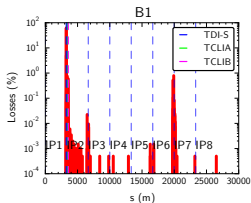
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# Loss maps at injection - Beam 1

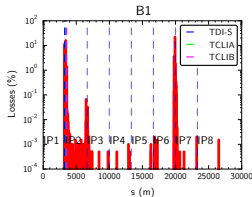
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- ▶ TDI-S, TCLIA and TCLIB at  $6.8 \sigma_y$  and grazing impact on the TDI-S
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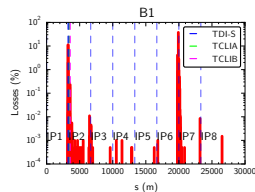
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## Scenario 2

- ▶ TDI-S, TCLIA and TCLIB at  $7.8 \sigma_y$  and  $1 \sigma$  impact on the TDI-S
- ▶ tracking for 1 turn:

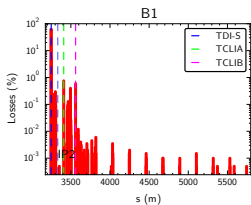




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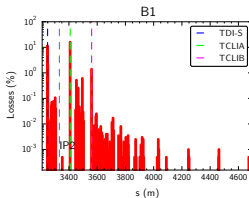
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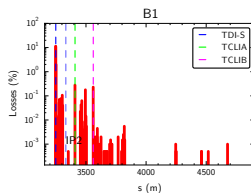
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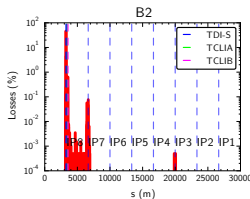
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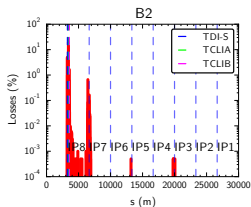
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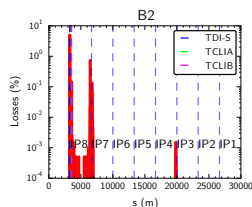
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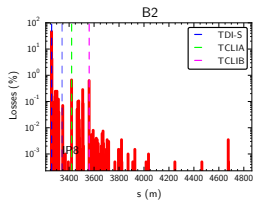
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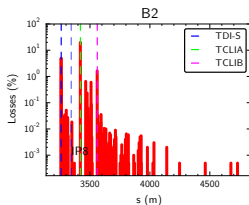
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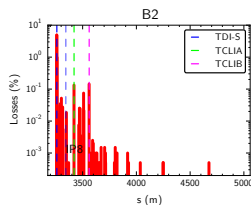
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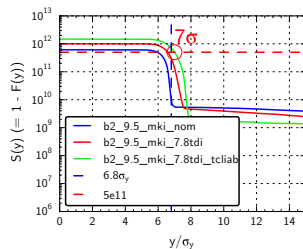
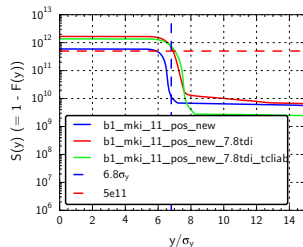
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# Halo Escaping - Vertical plane

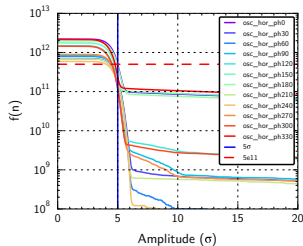
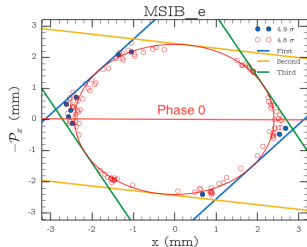
- ▶ The halo escaping the injection protection system can be calculated with the survival function;
- ▶ macro particles tracked  $2 \times 10^5$ , normalised to the beam intensity  $I = 288 \times 2.2 \times 10^{11} \text{ p}^+$ ;
- ▶ the max amplitude escaping the protection system with intensity above safe flag beam ( $5 \times 10^{11} \text{ p}^+$ ) is  $7 \sigma$  (for the vertical plane);
- ▶  $Y/\sigma_y =$

$$\sqrt{y^2 + (\alpha_y y + \beta_y y')^2} / \sqrt{\epsilon \beta_y}.$$



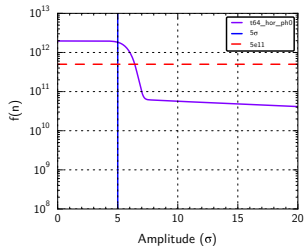
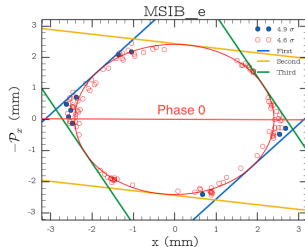
# Halo Escaping - Horizontal plane

- ▶ The maximum error we can have at the TCDIs is estimated to be  $1.4 \sigma$ ;
- ▶ the maximum amplitude escaping the TCDIs is  $g_{TCDI} / \cos(\Delta\psi/2)$  (without intercepting the TCDIs);
- ▶ with a  $5 \sigma$  oscillation in the line, for a very unlucky phase, the beam core ( $\sim \pm 1 \sigma$ ) could escape the TL collimation system completely;
- ▶ maximum amplitude escaping the TL collimators with intensity above safe beam flag is  $7.4 \sigma_x$ .



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- ▶ maximum amplitude escaping the TL collimators with intensity above safe beam flag is  $7.4 \sigma_x$ .



# Summary and Conclusion

- ▶ The maximum primary halo amplitude escaping the injection protection system, in case of MKI failure (kick of  $6.8 \sigma$  at the TDI) and with intensity above the safe beam flag, is  $7 \sigma_y$ ;
- ▶ for the horizontal plane, the only protection is given by the TCDIs (injection protection elements are only vertical)  $\Rightarrow$  the primary halo with intensity above the safe beam flag is  $7.4 \sigma_x$  ( $\Rightarrow$  to compare with  $9.07\sigma$ );
- ▶ the tolerances that should be included, in order to consider realistic machine configurations, are:
  - ▶  $1.5 + 1.5 \sigma$  for orbit and injection oscillations;
  - ▶ 10% of beta-beat;
  - ▶  $\delta_p = 0.6 \times 10^{-3}$  and  $k_D = 1.4$ .
- ▶ this gives a total of  $10.3 \sigma_y$  and  $11.05 \sigma_x$  ( $\Rightarrow$  to compare with  $12.3\sigma$ ) for the vertical and horizontal plane respectively.

# Summary and Conclusion

- ▶ The current settings of the injection protection elements guarantee the localisation of the losses in case of MKI failures in the injection regions;
- ▶ different settings would move the losses elsewhere in the machine (e.g. IR7);
- ▶ the present TCDI settings permit to achieve the required protection;

## Outlook:

- ▶ due to the large part of the beam surviving the first turn ( $\sim 50\%$ ) the tracking has been extended;
- ▶ this will translate in higher load on some of the collimators (TCLIB especially);
- ▶ evaluation with simulations the different possible settings of TCLIB.



Thank you!

## Backup

