SPS-to-LHC Transfer Line Collimators and LHC Injection Protection System

F.M. Velotti, C. Bracco, W. Bartmann, M. Fraser, B. Goddard, M. Meddahi, V. Kain, J. Uythoven
and thanks to: R. Bruce, R. De Maria, M. Giovannozzi, S. Redaelli

30th October 2015
Outline

Introduction
  What are the dangers at injection in LHC?
  How do we deal with that?
  TCDI Setup Validation Simulations

TCDI Setup Validation Simulations
  Procedure
  Simulations and Measurements

Injection Failures Simulations
  New TDI-S
  Assumptions
  Beam 1
  Beam 2

Conclusions and Outlook
What are the dangers at injection in LHC?
What are the dangers at injection in LHC?

- Extraction errors from the SPS;
What are the dangers at injection in LHC?

- Extraction errors from the SPS;
- errors in the field/powering of the transfer line active elements;
What are the dangers at injection in LHC?

- Extraction errors from the SPS;
- errors in the field/powering of the transfer line active elements;
- failures of the injection septum MSI;
What are the dangers at injection in LHC?

- Extraction errors from the SPS;
- errors in the field/powering of the transfer line active elements;
- failures of the injection septum MSI;
- failures of the injection kicker MKI.
How do we deal with that?
How do we deal with that?

- Constant surveillance of TL active elements current;
## How do we deal with that?

- Constant surveillance of TL active elements current;
- series of passive protection devices:
How do we deal with that?

- Constant surveillance of TL active elements current;
- series of passive protection devices:
  - TPSGs (SPS extraction septa);
How do we deal with that?

- Constant surveillance of TL active elements current;
- series of passive protection devices:
  - TPSGs (SPS extraction septa);
  - TCDIs (TL elements and MSI);
How do we deal with that?

- Constant surveillance of TL active elements current;
- series of passive protection devices:
  - TPSGs (SPS extraction septa);
  - TCDIs (TL elements and MSI);
  - TDI, TCLIA & B (LHC elements).
How do we deal with that?

- Constant surveillance of TL active elements current;
- series of passive protection devices:
  - TPSGs (SPS extraction septa);
  - TCDIs (TL elements and MSI);
  - TDI, TCLIA & B (LHC elements).
TCDI Setup Validation Simulation

Motivation

- The TCDIs need to be aligned and their settings need to be validated with beam;
- this process is quite tedious due to the assumptions needed and the single passage nature of the TLs;
TCDI Setup Validation Simulation

Motivation

▶ The TCDIs need to be aligned and their settings need to be validated with beam;
▶ this process is quite tedious due to the assumptions needed and the single passage nature of the TLs;

▶ Loss maps simulations needed to ease and improve the validation methodology;
▶ no ready-to-use simulation tools available for this kind of tracking ⇒ simple and easily usable for beam lines (target mainly single turn tracking);
▶ scattering routine developed in python ⇒ pycollimate;
▶ interfaced with both MADX-PTC and MADX (directly under the hood).
How do we do that?

- Tracking inside active elements done with MADX (or MADX-PTC);
How do we do that?

- Tracking inside active elements done with MADX (or MADX-PTC);
- when a collimator is encountered the external scattering routine is called;
How do we do that?

- Tracking inside active elements done with MADX (or MADX-PTC);
- when a collimator is encountered the external scattering routine is called;
  - it is developed as a python module;
  - different classes and functions to help the production of input files and analysis are also available;
- modular;
How do we do that?

- Tracking inside active elements done with MADX (or MADX-PTC);
- when a collimator is encountered the external scattering routine is called;
  - it is developed as a python module;
  - different classes and functions to help the production of input files and analysis are also available;
  - modular;
- particles are sent back to MADX as lost and added to "trackloss" table or kept for further tracking.
HL-LHC Injection Protection System

- The change that will be introduced for HL-LHC in the injection protection devices (new TDI) and the new high-brightness beams needed to be simulated to understand if the protection was still sufficient and if the auxiliary collimators (TCLIA/B) needed to be upgraded as well;
HL-LHC Injection Protection System

- The change that will be introduced for HL-LHC in the injection protection devices (new TDI) and the new high-brightness beams needed to be simulated to understand if the protection was still sufficient and if the auxiliary collimators (TCLIA/B) needed to be upgraded as well;
- good occasion to use the new simulation tool;
HL-LHC Injection Protection System

- The change that will be introduced for HL-LHC in the injection protection devices (new TDI) and the new high-brightness beams needed to be simulated to understand if the protection was still sufficient and if the auxiliary collimators (TCLIA/B) needed to be upgraded as well;
- good occasion to use the new simulation tool;
- gain more experience with it.
Procedure

- TCDIs centred using beam-based measurement ⇒ new operational tool does it automatically;
Procedure

- TCDIs centred using beam-based measurement ⇒ new operational tool does it automatically;
- calibration of BLM shooting a pilot on a closed jaw at $-5 \sigma$;
Procedure

- TCDIs centred using beam-based measurement $\Rightarrow$ new operational tool does it automatically;
- calibration of BLM shooting a pilot on a closed jaw at $-5\sigma$;
- gaps set to $5\sigma$;
Procedure

- TCDIs centred using beam-based measurement $\Rightarrow$ new operational tool does it automatically;
- calibration of BLM shooting a pilot on a closed jaw at $-5\sigma$;
- gaps set to $5\sigma$;
- oscillations in the lines with amplitude of $5\sigma$ for each phase sampled;
Procedure

- TCDIs centred using beam-based measurement ⇒ new operational tool does it automatically;
- calibration of BLM shooting a pilot on a closed jaw at $-5 \sigma$;
- gaps set to $5 \sigma$;
- oscillations in the lines with amplitude of $5 \sigma$ for each phase sampled;
- check if the expected phase-space coverage is guaranteed.
Procedure

- TCDIs centred using beam-based measurement ⇒ new operational tool does it automatically;
- calibration of BLM shooting a pilot on a closed jaw at \(-5\ \sigma\);
- gaps set to \(5\ \sigma\);
- oscillations in the lines with amplitude of \(5\ \sigma\) for each phase sampled;
- check if the expected phase-space coverage is guaranteed.
Simulations and Measurements

- Measured trajectory reconstructed with MADX using SVD;
- loss maps generated with MADX-PTC + pycollimate.
Simulations and Measurements

- Measured trajectory reconstructed with MADX using SVD;
- loss maps generated with MADX-PTC + pycollimate.
Simulations and Measurements

- Measured trajectory reconstructed with MADX using SVD;
- Loss maps generated with MADX-PTC + pycolimate.
Simulations and Measurements

- Measured trajectory reconstructed with MADX using SVD;
- Loss maps generated with MADX-PTC + pycollimate.
Simulations and Measurements

- Measured trajectory reconstructed with MADX using SVD;
- Loss maps generated with MADX-PTC + pycollimate.

![Diagram showing loss measurements](image-url)
New TDI-S

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

![Diagram of TDI-S design](image-url)

- 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*
New TDI-S

- For HL-LHC a new TDI is foreseen to be installed;
- to date, the most likely design foresees:
  - 3 separate blocks: 2 of graphite (R4550 or similar) and 1 block of higher Z material (the following simulations have been done assuming aluminium);
New TDI-S

- For HL-LHC a new TDI is foreseen to be installed;
- to date, the most likely design foresees:
  - 3 separate blocks: 2 of graphite (R4550 or similar) and 1 block of higher Z material (the following simulations have been done assuming aluminium);
- the last block has 2 mm larger aperture than the others.

![Diagram of TDI-S design](image-url)

Courtesy of A. Lechner
Assumptions

The following studies are done using:

- MKI strength of $\sim 11\%$ of the nominal for $B_1 \Rightarrow$ grazing (zero impact parameter);
- MKI strength of $\sim 9.5\%$ of the nominal for $B_2 \Rightarrow$ grazing (zero impact parameter);
Assumptions

- The following studies are done using:
  - MKI strength of ~ 11% of the nominal for B1 ⇒ grazing (zero impact parameter);
  - MKI strength of ~ 9.5% of the nominal for B2 ⇒ grazing (zero impact parameter);
  - tracking of the primaries done using MADX + pycollimate (IPAC15 for more details);
Assumptions

- The following studies are done using:
  - MKI strength of $\sim 11\%$ of the nominal for B1 $\Rightarrow$ grazing (zero impact parameter);
  - MKI strength of $\sim 9.5\%$ of the nominal for B2 $\Rightarrow$ grazing (zero impact parameter);
  - tracking of the primaries done using MADX + pycollimate (IPAC15 for more details);
  - Normalised emittance used $\Rightarrow \epsilon_{x,y}^N = 1.37 \, \pi \text{mm.mrad}$;
Assumptions

- The following studies are done using:
  - MKI strength of $\sim 11\%$ of the nominal for B1 ⇒ grazing (zero impact parameter);
  - MKI strength of $\sim 9.5\%$ of the nominal for B2 ⇒ grazing (zero impact parameter);
  - tracking of the primaries done using MADX + pycollimate (IPAC15 for more details);
  - Normalised emittance used ⇒ $\epsilon_{x,y}^N = 1.37 \pi \text{mm.mrad}$;
  - TDI-S, TCLIA and TCLIB nominal half-gaps $6.8\sigma_y$ ⇒ scenario 0;
Assumptions

- The following studies are done using:
  - MKI strength of ~11% of the nominal for B1 ⇒ grazing (zero impact parameter);
  - MKI strength of ~9.5% of the nominal for B2 ⇒ grazing (zero impact parameter);
  - tracking of the primaries done using MADX + pycollimate (IPAC15 for more details);
  - Normalised emittance used ⇒ $\epsilon_{x,y}^N = 1.37 \, \pi \text{mm.mrad}$;
  - TDI-S, TCLIA and TCLIB nominal half-gaps $6.8\sigma_y$ ⇒ scenario 0;
  - TDI-S half-gap of $7.8\sigma_y$ and TCLIA/B with half-gap of $6.8\sigma_y$ ⇒ scenario 1;
Assumptions

- The following studies are done using:
  - MKI strength of ~11% of the nominal for B1 ⇒ grazing (zero impact parameter);
  - MKI strength of ~9.5% of the nominal for B2 ⇒ grazing (zero impact parameter);
  - tracking of the primaries done using MADX + pycollimate (IPAC15 for more details);
  - Normalised emittance used ⇒ $\epsilon_{x,y}^N = 1.37 \, \pi \, \text{mm.mrad}$;
  - TDI-S, TCLIA and TLIB nominal half-gaps $6.8\sigma_Y$ ⇒ scenario 0;
  - TDI-S half-gap of $7.8\sigma_Y$ and TCLIA/B with half-gap of $6.8\sigma_Y$ ⇒ scenario 1;
  - TDI-S, TCLIA and TLIB half-gaps $7.8\sigma_Y$ ⇒ scenario 2;
Loss maps at injection - Beam 1

**Scenario 0**
- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

**Scenario 1**
- TDI-S at 7.8 $\sigma_y$, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

**Scenario 2**
- TDI-S, TCLIA and TCLIB at 7.8 $\sigma_y$ and 1 $\sigma$ impact on the TDI-S
- tracking for 1 turn:
Loss maps at injection - Beam 1

Scenario 0

- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

Scenario 1

- TDI-S at 7.8 $\sigma_y$, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

Scenario 2

- TDI-S, TCLIA and TCLIB at 7.8 $\sigma_y$ and 1 $\sigma$ impact on the TDI-S
- tracking for 1 turn:
What happens to the surviving particles?

Scenario 0

- TDI-S, TCLIA and TCLIB at 6.8 \( \sigma_y \) and grazing impact on the TDI-S

Scenario 0 \( \Rightarrow \) TCLIB @ 8.3 \( \sigma \)

- TDI-S and TCLIA 6.8 \( \sigma_y \) and TCLIB 8.3 \( \sigma \)
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

Scenario 0

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

Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**
- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**
- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

Scenario 0

- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_f$ and grazing impact on the TDI-S

Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$

- TDI-S and TCLIA 6.8 $\sigma_f$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

- TDI-S, TCLIA and TLIB at $6.8 \sigma_y$ and grazing impact on the TDI-S

**Scenario 0 $\Rightarrow$ TLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA $6.8 \sigma_y$ and TLIB $8.3 \sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**
- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S

---

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**
- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
TCLIB - Zoom in

To be noticed that, when the TCLIB is at 6.8 \( \sigma \), a quite significant part of the beam will intercept it at the third turn (just before dump)
Loss maps at injection - Beam 2

**Scenario 0**
- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

**Scenario 1**
- TDI-S at 7.8 $\sigma_y$, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

**Scenario 2**
- TDI-S, TCLIA and TCLIB at 7.8 $\sigma_y$ and 1 $\sigma$ impact on the TDI-S
- tracking for 1 turn:
Loss maps at injection - Beam 2

**Scenario 0**
- TDI-S, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

**Scenario 1**
- TDI-S at 7.8 $\sigma_y$, TCLIA and TCLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S
- tracking for 1 turn:

**Scenario 2**
- TDI-S, TCLIA and TCLIB at 7.8 $\sigma_y$ and 1 $\sigma$ impact on the TDI-S
- tracking for 1 turn:
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

Scenario 0

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

Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

Scenario 0

- TDI-S, TCLIA and TLIB at 6.8 $\sigma_y$ and grazing impact on the TDI-S

Scenario 0 $\Rightarrow$ TLIB @ 8.3 $\sigma$

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**
- TDI-S, TCLIA and TCLIB at $6.8 \sigma_y$ and grazing impact on the TDI-S

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**
- TDI-S and TCLIA $6.8 \sigma_y$ and TCLIB $8.3 \sigma$
What happens to the surviving particles?

**Scenario 0**

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

---

**Scenario 0 $\Rightarrow$ TCLIB $\@$ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
What happens to the surviving particles?

**Scenario 0**

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

**Scenario 0 $\Rightarrow$ TCLIB @ 8.3 $\sigma$**

- TDI-S and TCLIA 6.8 $\sigma_y$ and TCLIB 8.3 $\sigma$
Conclusions and Outlook

- To perform tracking of primary protons, taking into account also the ones scattered from collimators, in the SPS-to-LHC transfer lines a scattering routine has been implemented and interfaced with MADX and MADX-PTC;
- simulations of the expected loss maps for the TCDIs setup validation have been performed, as well as benchmarked with actual beam measurements;
- the same simulation tools have been used to evaluate the injection protection system with HL-LHC beams;
- studies to evaluate different settings of the injection protection absorbers are ongoing;
- the same tool will be also used to estimate the danger of an asynchronous extraction from the SPS for the TL elements (and injection into LHC as well) (M. Fraser);
- LHC asynchronous beam dump studies and benchmark calibration measurements for TCDQ re-qualification (C. Bracco).
Thank you!