LHC and HL-LHC Collimation system simulation

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Outline

High power stored beams

LHC

- $E_p = 7$ TeV
- $N_p = 1.15 \cdot 10^{11}$
- $\mathcal{L} = 1.0 \cdot 10^{34}$ cm^{-2}s^{-1}
- $E_b = 362$ MJ

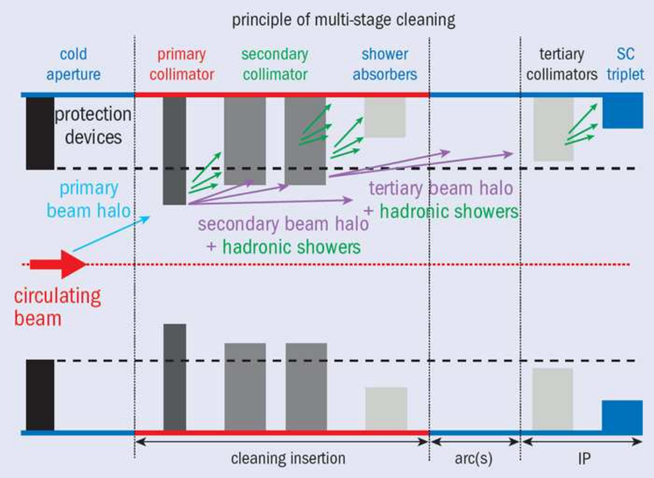
HL-LHC

- $E_p = 7$ TeV
- $N_p = 2.2 \cdot 10^{11}$
- $\mathcal{L} = 7.2 \cdot 10^{34}$ cm^{-2}s^{-1}
- $E_b = 675$ MJ

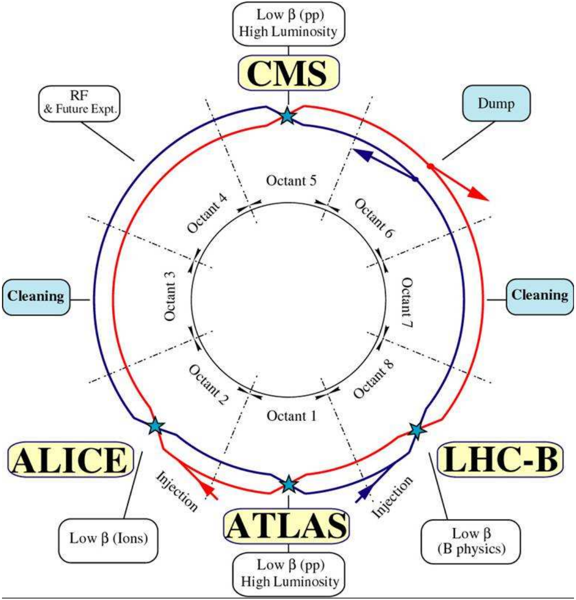
Beam halo issues

- Detector background ⇒ Beam cleaning
- Superconducting magnet quench ⇒ Machine protection

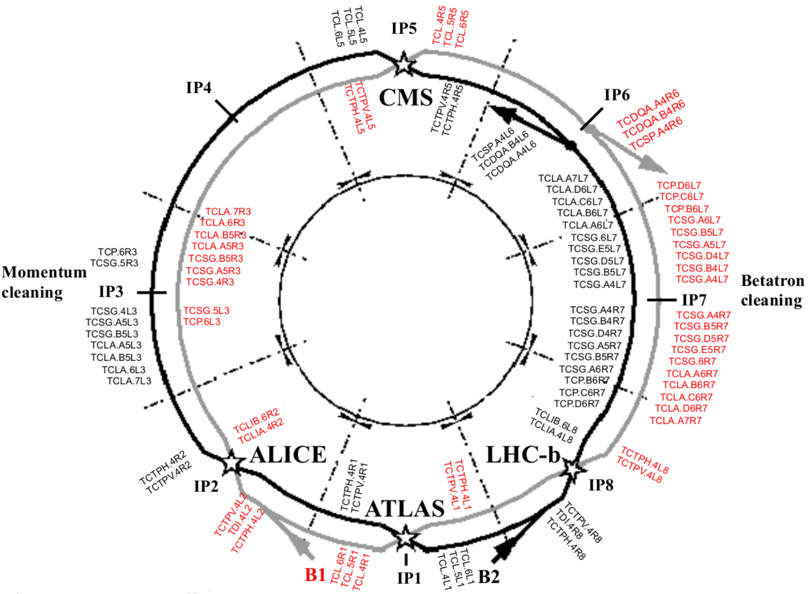
Two stage collimation system



Two stage collimation system



The LHC collimation system

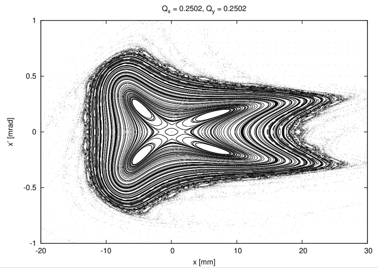


Computational tools

No computer, no collimation

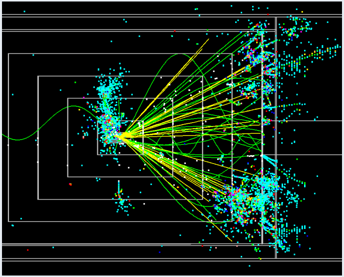
Tracking

- We need to track the position of the bunch of particles ($\sim 10^6$) over hundreds or thousands of turns with enough precision.



Monte-Carlo matter interactions

- We need to simulate a realistic interaction between the lost particles and the material.
- This is done via cross sections.
- Using a Monte-Carlo approach.



SixTrack

- Multiturn tracking code that accounts for the six-dimensional phase space in a symplectic manner.
- Thin lens element-by-element tracking.
- Initially developed for Dynamic Aperture studies.
- More details in F.Schmidt talk.

Collimation module

- Built-in Monte Carlo code used to simulate the particle matter interaction.
- Multiple Coulomb scattering and ionization energy loss.
- Nuclear elastic scattering, nuclear inelastic scattering, single diffractive scattering, Rutherford scattering.
- No secondaries and energy deposition $\Rightarrow$ FLUKA (talks after lunch)

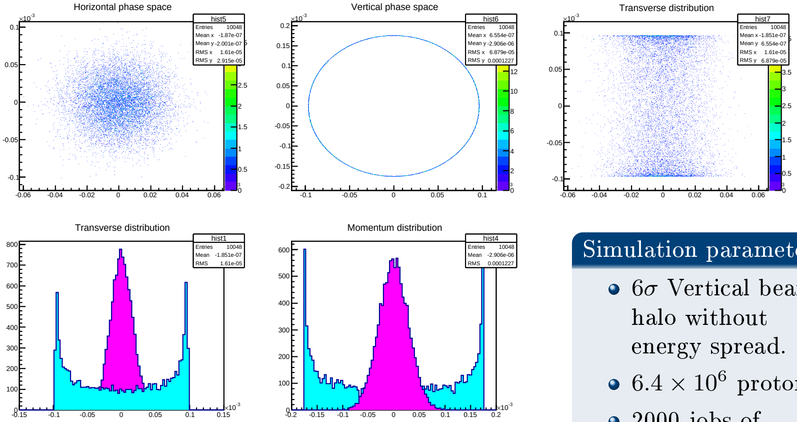
Cleaning simulation settings: Collimators

LHC Collimator half gaps[a]

[a] R.Bruce et al. PRSTAB **17**, 081004 (2014)

Parameter	2011	2012	Nominal
Beam energy (TeV)	3.5	4	7
TCP on IR7 (σ)	5.7	4.3	6.0
TCS on IR7 (σ)	8.5	6.3	7.0
TCLA on IR7 (σ)	17.7	8.3	10.0
TCP on IR3 (σ)	12.0	12.0	15.0
TCS on IR3 (σ)	15.6	15.6	18.0
TCLA on IR3 (σ)	17.6	17.6	20.0
TCT on IR1/IR5 (σ)	11.8	9.0	8.3

Cleaning simulation settings: Beam halo

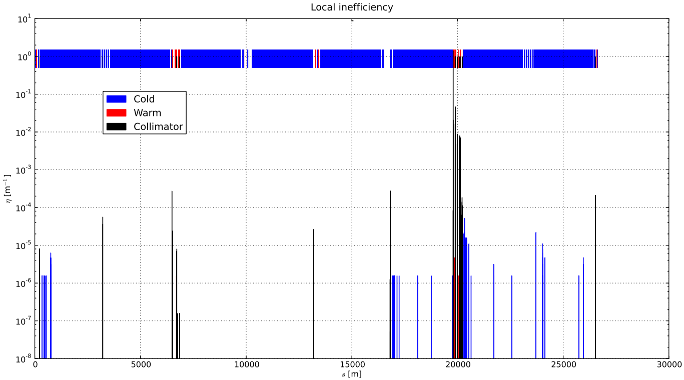


Simulation parameters

- 6σ Vertical beam halo without energy spread.
- 6.4×10^6 protons.
- 2000 jobs of 50×64 protons.
- 200 turns

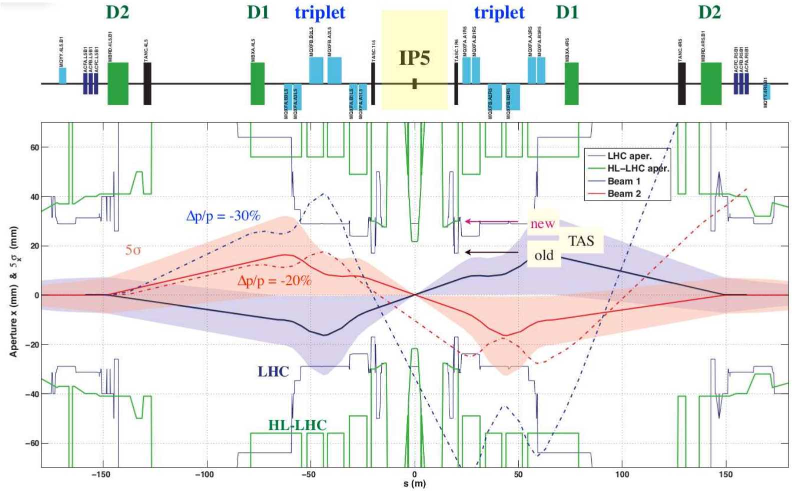
Cleaning simulation example

We can evaluate the efficiency (or inefficiency) of the collimation system looking at the beam losses all along the LHC line.

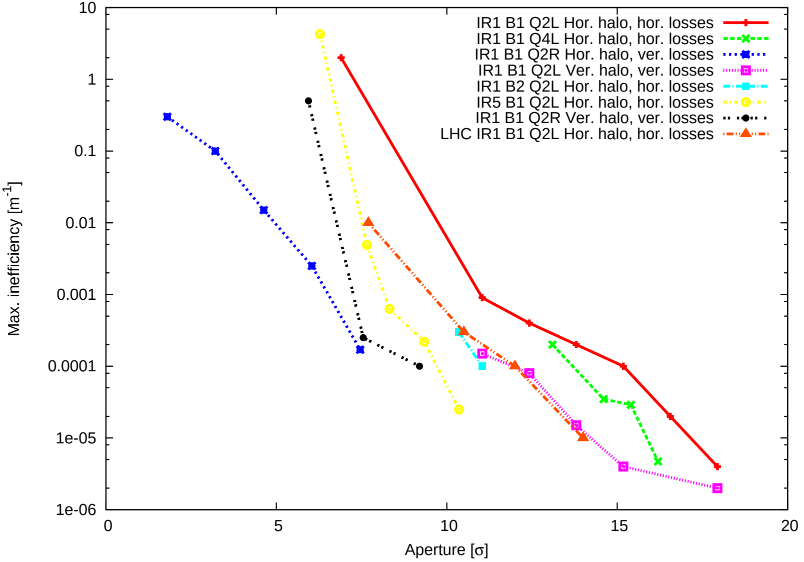


$$\eta_{\text{ineff}} = \frac{N_{\text{loss}}}{N_{\text{total}}\Delta s}$$

IR1/5 Cleaning simulation

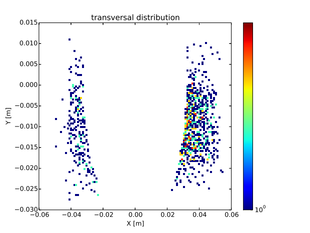


IR1/5 Cleaning simulation

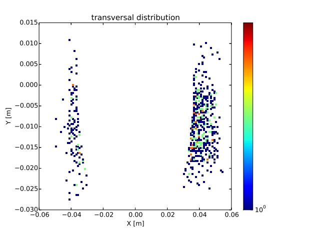


IR1 B1 Q2 Upstream: Spatial distribution of impacts

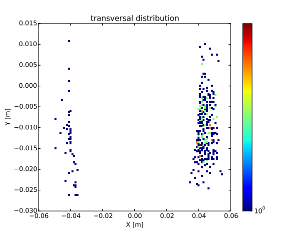
32 mm (8σ)



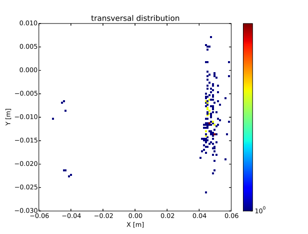
36 mm (9.3σ)



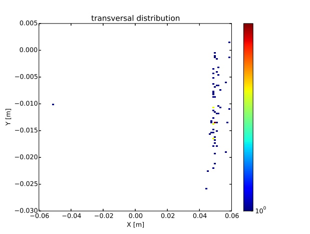
40 mm (10.7σ)



44 mm (12σ)

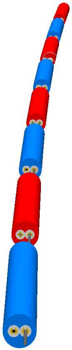


48 mm (13.3σ)



Beam Delivery Simulation - BDSIM

- Tracking code that uses Geant4.
- Previously used for linear accelerators.
- Now upgraded to include circular accelerators.
- Used to simulate beam loss and detector backgrounds.
- Thick lens tracking.
- Geant4 used for interaction with machine, full physics processes list.
- **Tracking of secondaries**

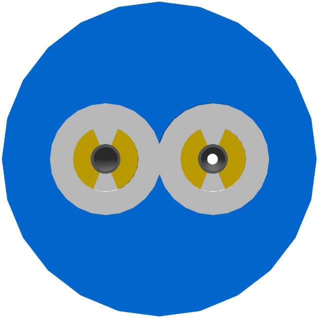


Recent developments

- Geometry detail improvement.
- Improved tracking routines.
- New accelerator models (LHC, HL-LHC).
- Open source based on Geant4.
- ...

BDSIM - Geometry developments

LHC dipole example:



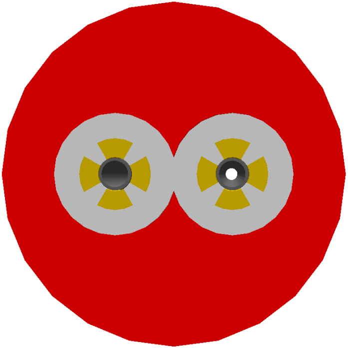
The production of secondaries depends on the correct description of the geometry and the materials of the accelerator components.

- Detailed geometry for warm and LHC magnets.
- Right materials with right cross sections.
- LHC two beampipe implementation.

With these changes we want to perform detailed simulations of the beam losses all around the LHC.

BDSIM - Geometry developments

LHC quadrupole example:



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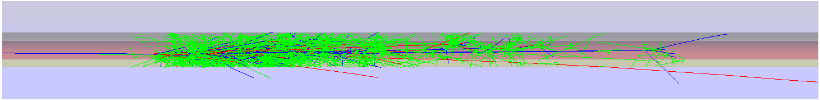
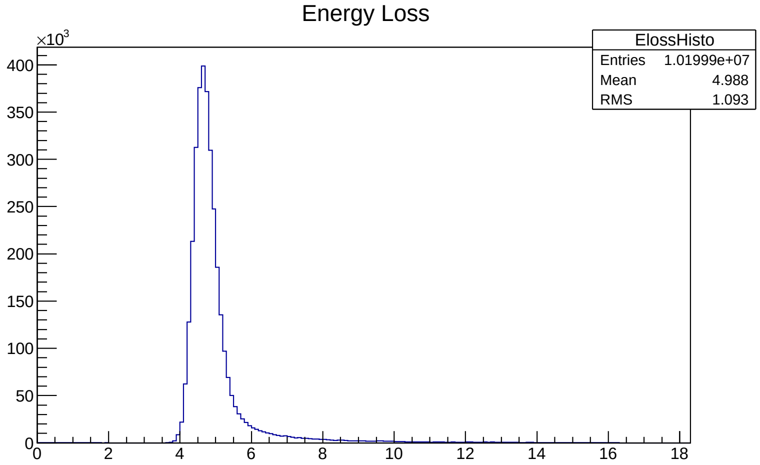
BDSIM - Geometry developments

Example of a particle lost in a dipole (realistic view):



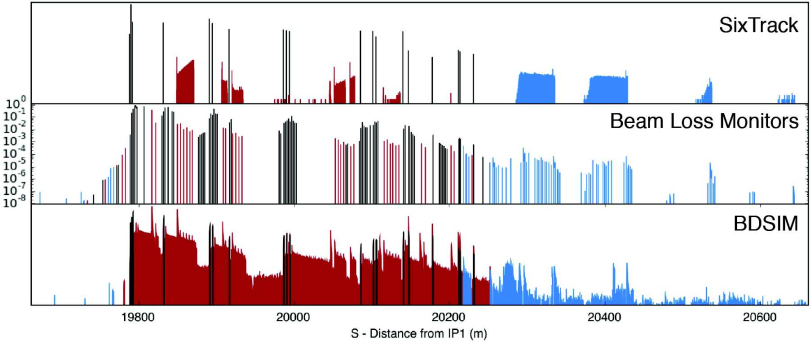
BDSIM - Geometry developments

Example of a particle lost in a dipole (projected histogram):



BDSIM - Cleaning simulations

BDSIM offers a good qualitatively approach compared to the Beam Loss Monitor measurements



Courtesy of L. Nevay

SixTrack and Beam Loss Monitor data from [1].

[1] R.Bruce et al. PRSTAB **17**, 081004 (2014)

Conclusions

- Computational tools are fundamental in order to understand the beam dynamics in a particle accelerator.
- In the particular case of the collimation system, Monte-Carlo simulations are added to the regular particle tracking.
- SixTrack is a robust and well established tracking tool for Dynamics Aperture and Collimation studies.
- BDSIM is improving day by day and we expect to have quantitatively accurate loss maps for the LHC.
- Several BDSIM users already performing promising studies.

Conclusions

Join now to the BDSIM user community!

Thank you!