A Holistic Approach To Simulating Beam Losses in the Large Hadron Collider using BDSIM

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Thanks to: N. Fuster-Martinez, R. Bruce, J. Molson

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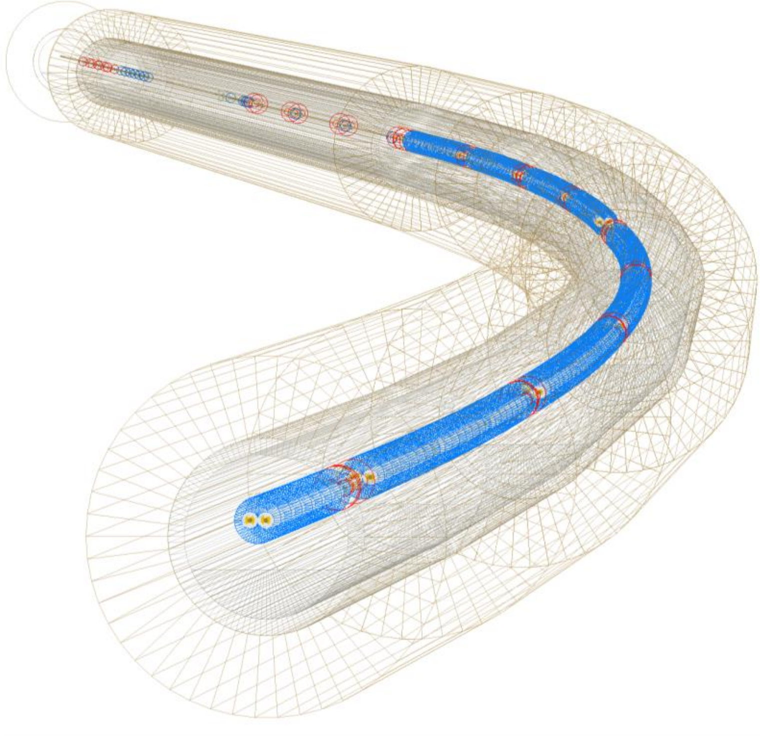
http://www.pp.rhul.ac.uk/bdsim/

Beam Delivery Simulation

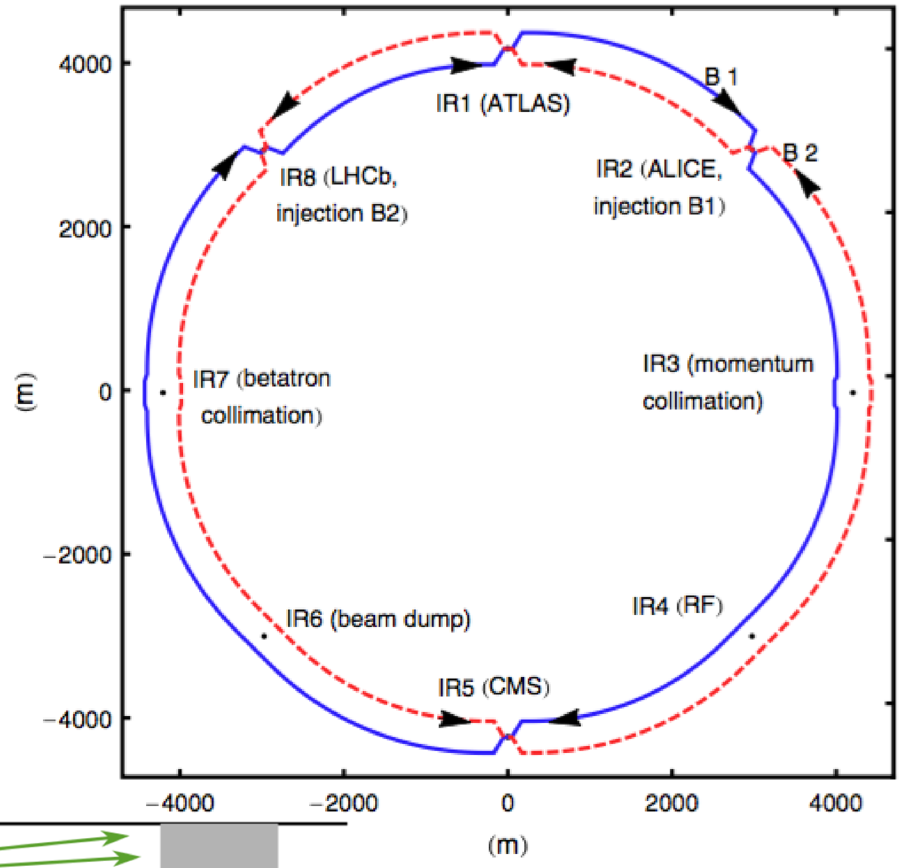


Outline

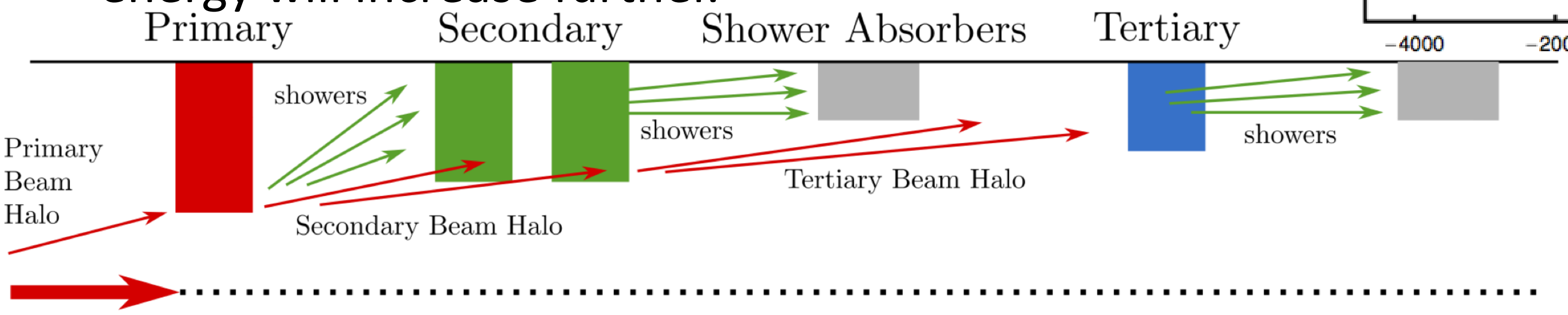
1. Introduction
2. Overview of the code we develop, Beam Delivery Simulation (BDSIM).
3. Model description
4. Comparisons with existing code, and beam loss monitor (BLM) data from a recent run.
5. Summary and future work.

Introduction

- Beam losses are inevitable in accelerators.
- LHC storing unprecedented energy in beams: 350 MJ (80kg of TNT) stored per beams at design energy.
- ~10^{-9} of full beam in a single superconducting magnet can be sufficient to cause a quench.
- Dedicated collimation system in LHC needed for basic functioning.
- Situated in 2 insertion regions (IRs): momentum cleaning in IR3, betatron cleaning in IR7
- For High Luminosity LHC (2025 onwards), stored energy will increase further.

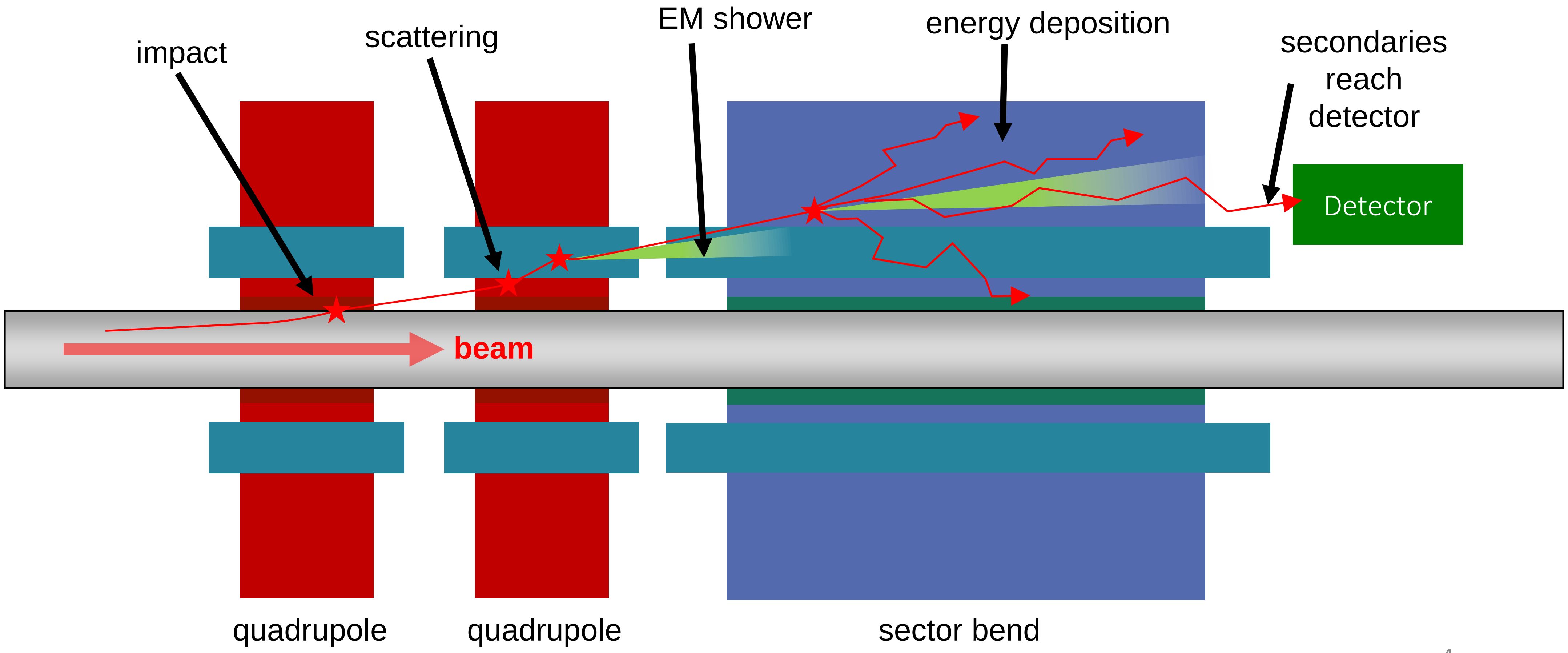


R. Bruce, et al. "Simulations and measurements of beam loss patterns at the CERN Large Hadron Collider., PRSTAB2014



Beam Loss

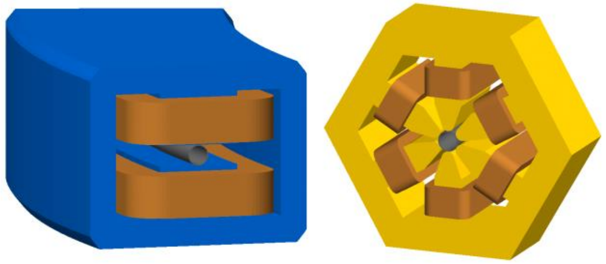
- Cut-through of accelerator
- Particle impacts aperture at some point
- Secondary particles and radiation propagate some distance
- Energy deposited in many components

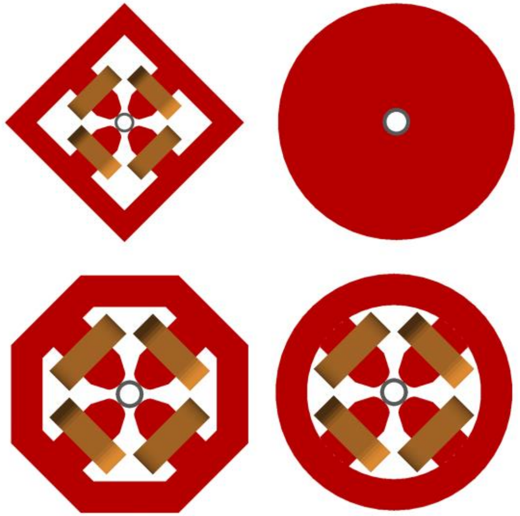


BDSIM

Beam Delivery Simulation

- BDSIM automatically builds a 3D, Geant4 model, from generic accelerator components.
- This gives us access to all of Geant4's well-tested physics processes out of the box.
- Geant4 model is cartesian but use of curvilinear transforms allows us to use accelerator tracking routines (matrices for linear elements, including fringe fields, and so on) to speed up simulation time.
- Combine particle physics code with accelerator tracking code.
- Together, this give us a *holistic* approach to simulating beam losses in particle accelerators.



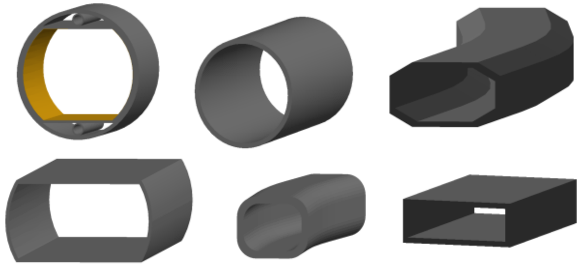


Different yoke styles

arXiv:1808.10745 http://www.pp.rhul.ac.uk/bdsim/

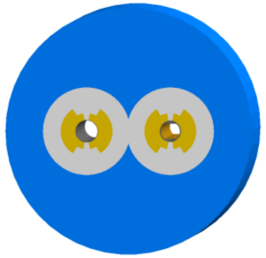
BDSIM LHC Model

- LHC beam 1, 6.5 TeV, 2018, β*=30cm, end of squeeze optics.
- Converted automatically from MADX output using conversion utility *pybdsim.*
- Extra information (apertures, collimator openings, materials etc.) supplement the optical description.

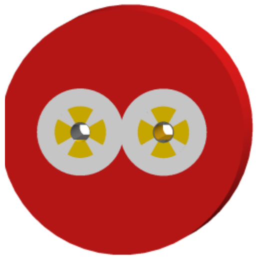


Aperture types

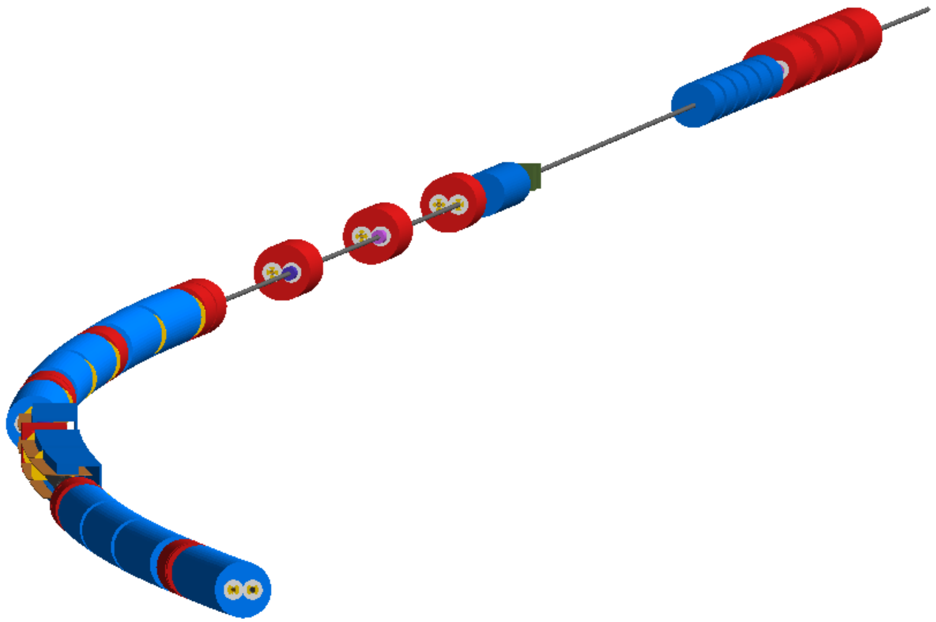
COLLIMATOR



LHC SBEND



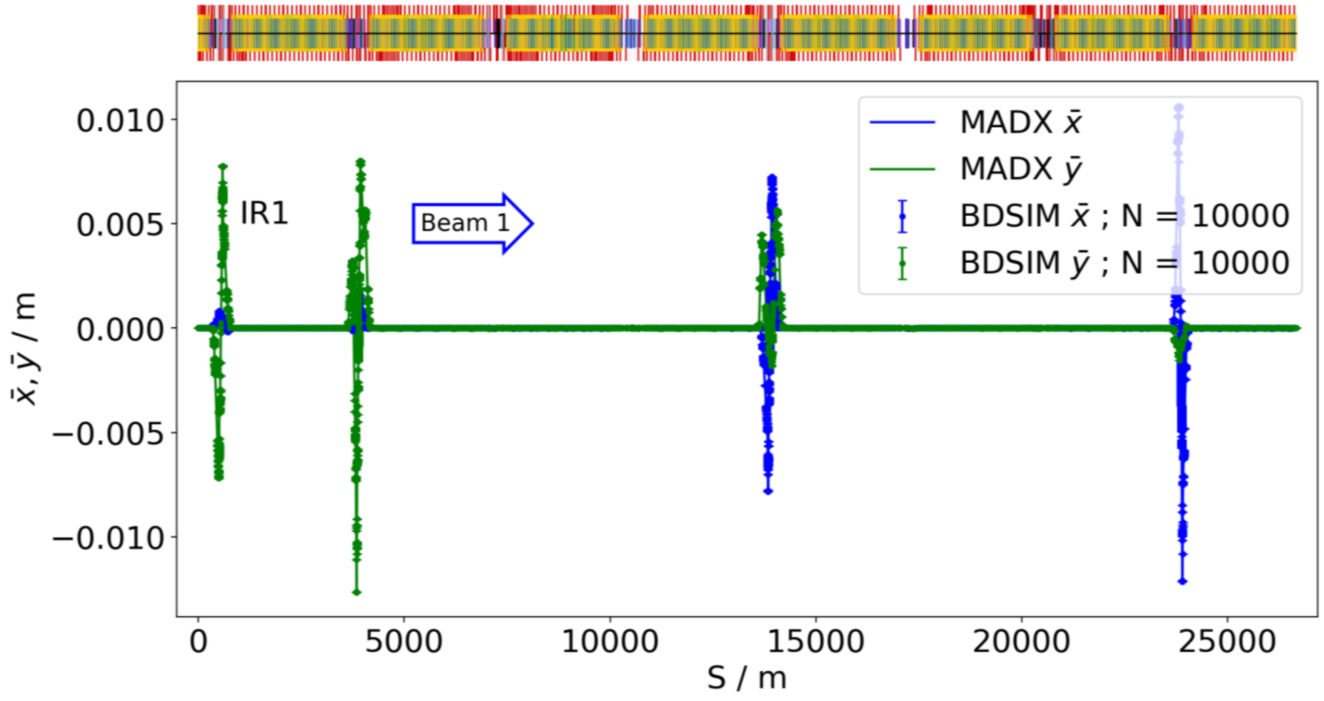
LHC QUAD

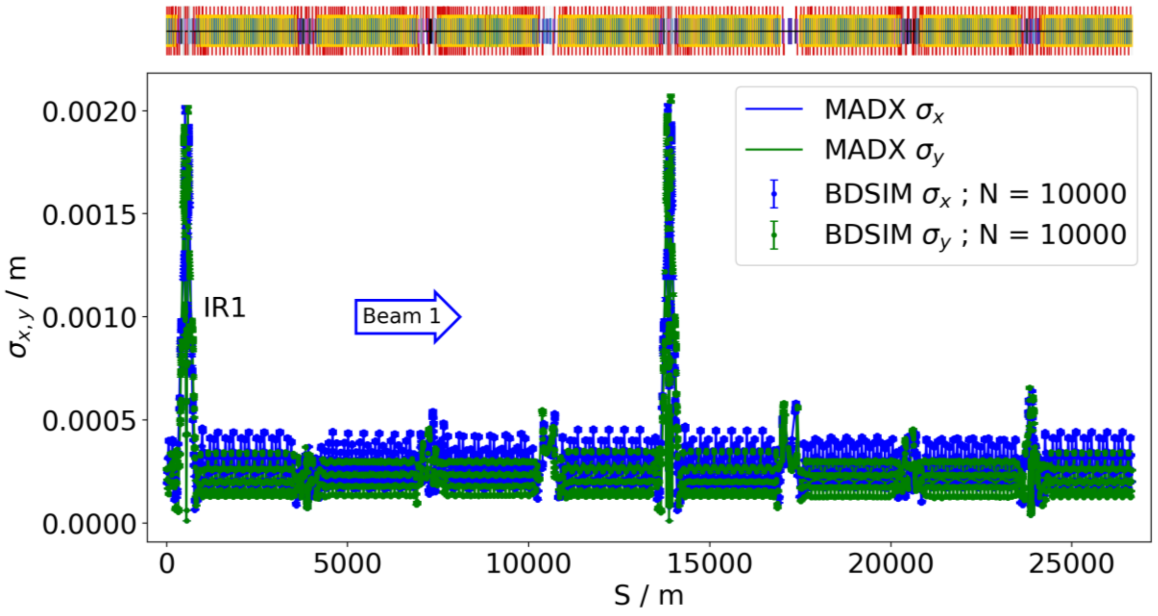


LHC model section 550m upstream of ATLAS

Particle Tracking Validation

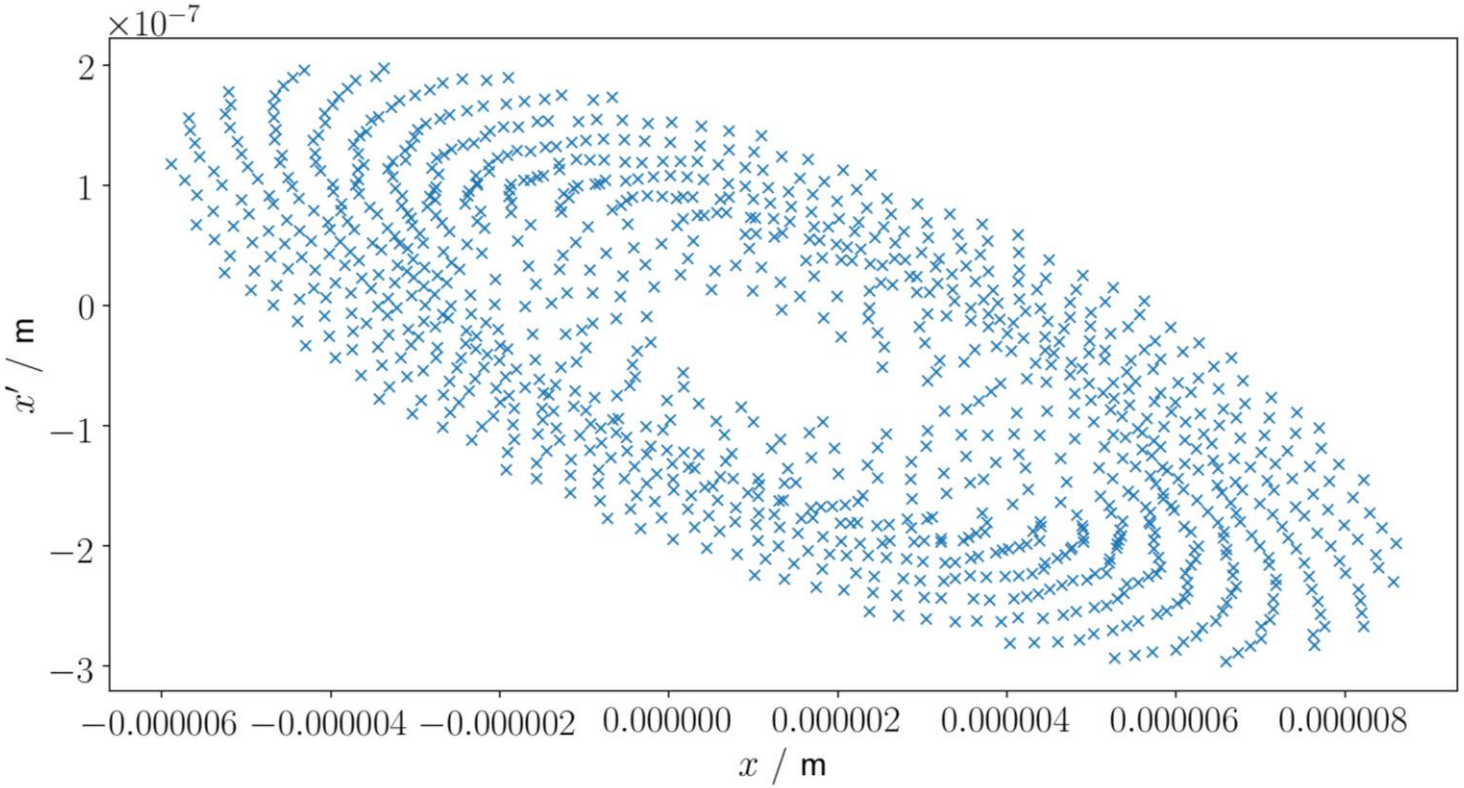
- Excellent agreement between BDSIM and MADX.

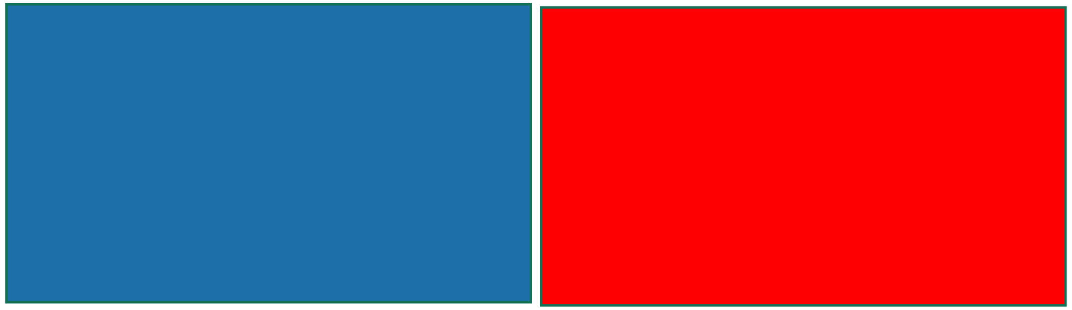




Particle Tracking Validation

- Tracking directly in Geant4 accurate for a few turns, but presence of thin gaps between elements will manifest itself as an emittance growth.
- Dramatic emittance growth over over several turns.
- 2,000 turns for the reference particle shown on the right.

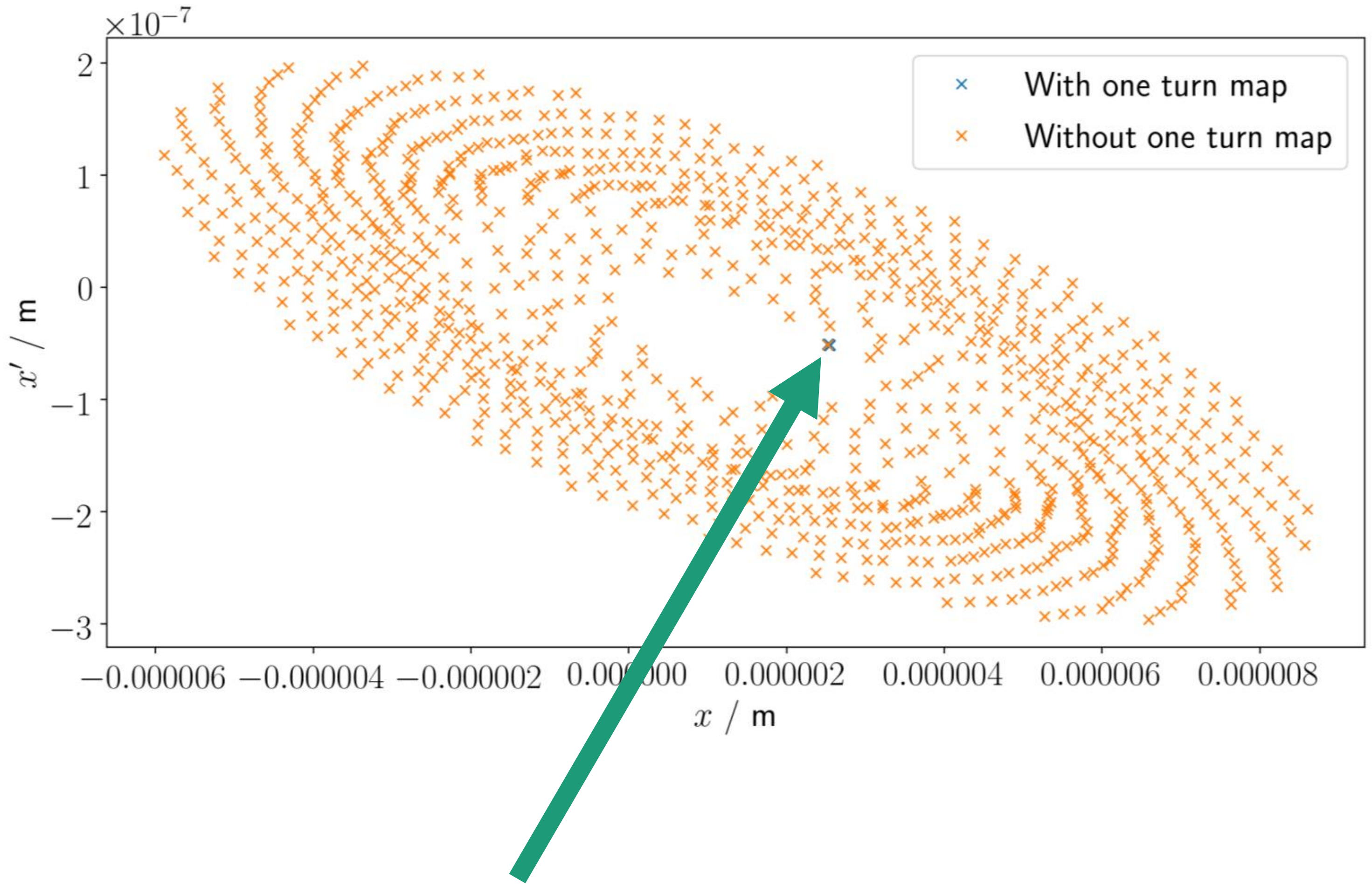




RBEND QUAD

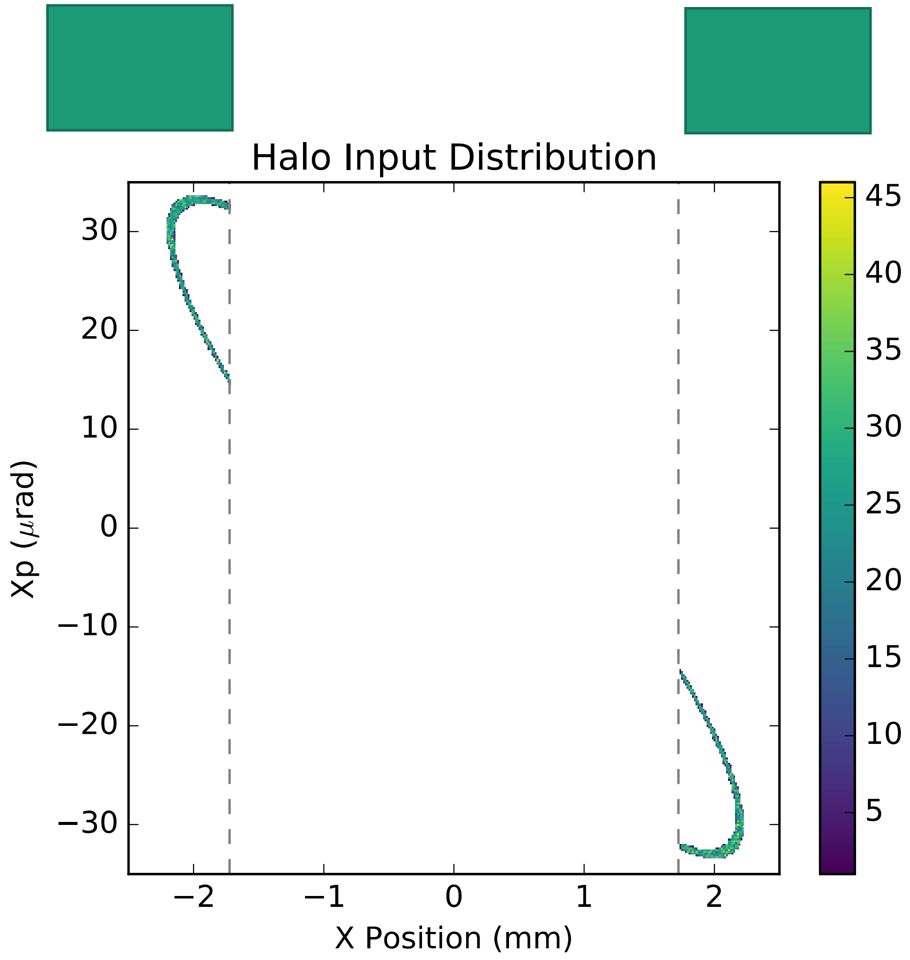
Particle Tracking Validation

- The error is corrected by using a one turn map to set each primary back onto its correct trajectory at the end of each turn.
- The use of 14th order one turn map from MAD-X PTC allows us to keep tracking accurately for thousands of turns.



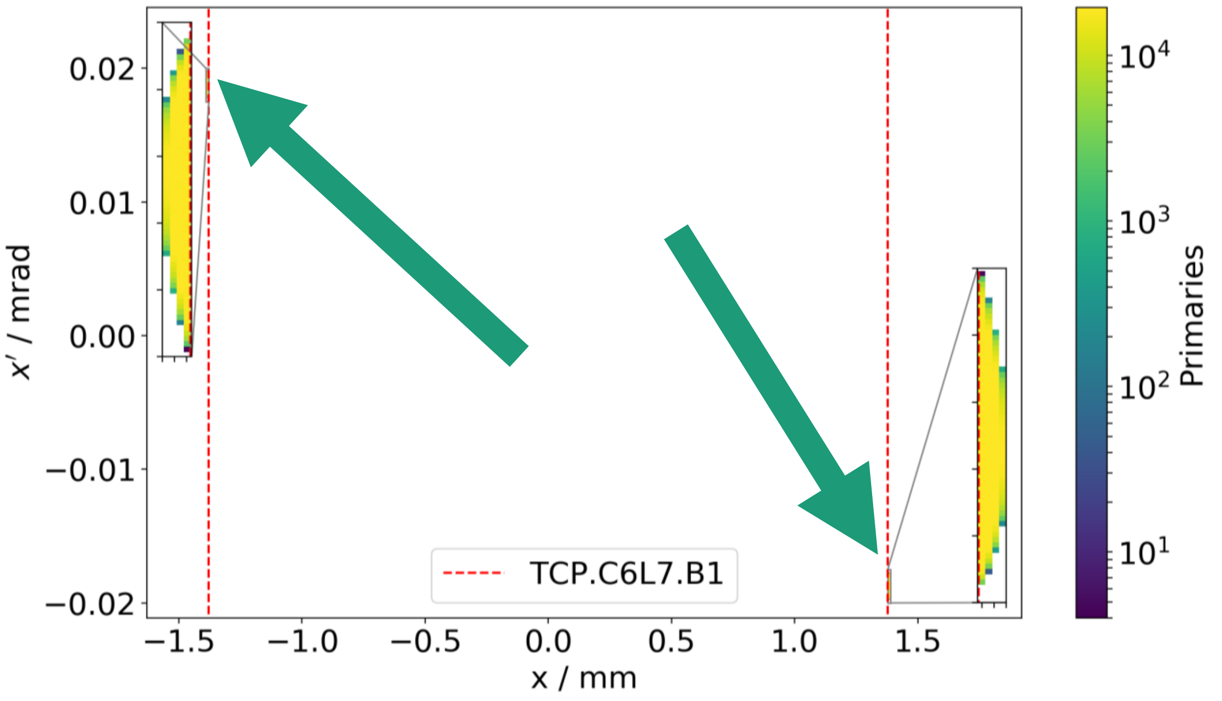
Simulation

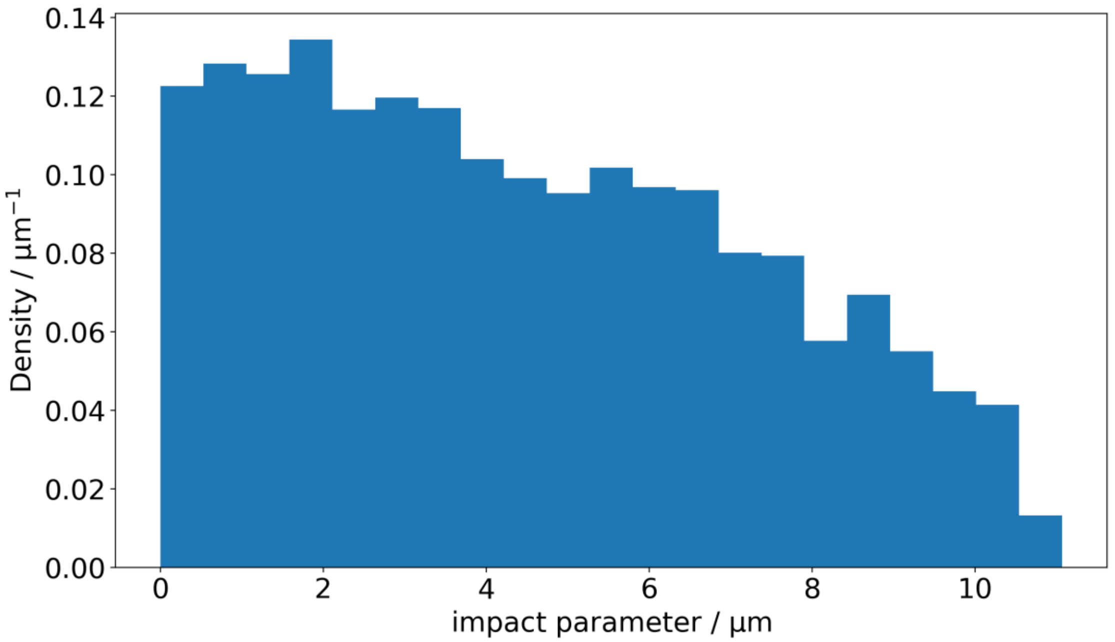
- The presence of particles far from the core of the beam is referred to as the beam halo. Continuously populated.
- These particles will be cleaned by the betatron collimation system in IR7.
- We simulate the direct impact of these halo particles on the horizontal collimator.
- Aim to show correlation between hits in SixTrack, energy deposition in BDSIM and BLM data from qualification loss map.
- Energy deposition in BDSIM recorded in all accelerator geometry.



Primary Distribution

- We use identical primary distribution in BDSIM and Sixtrack.

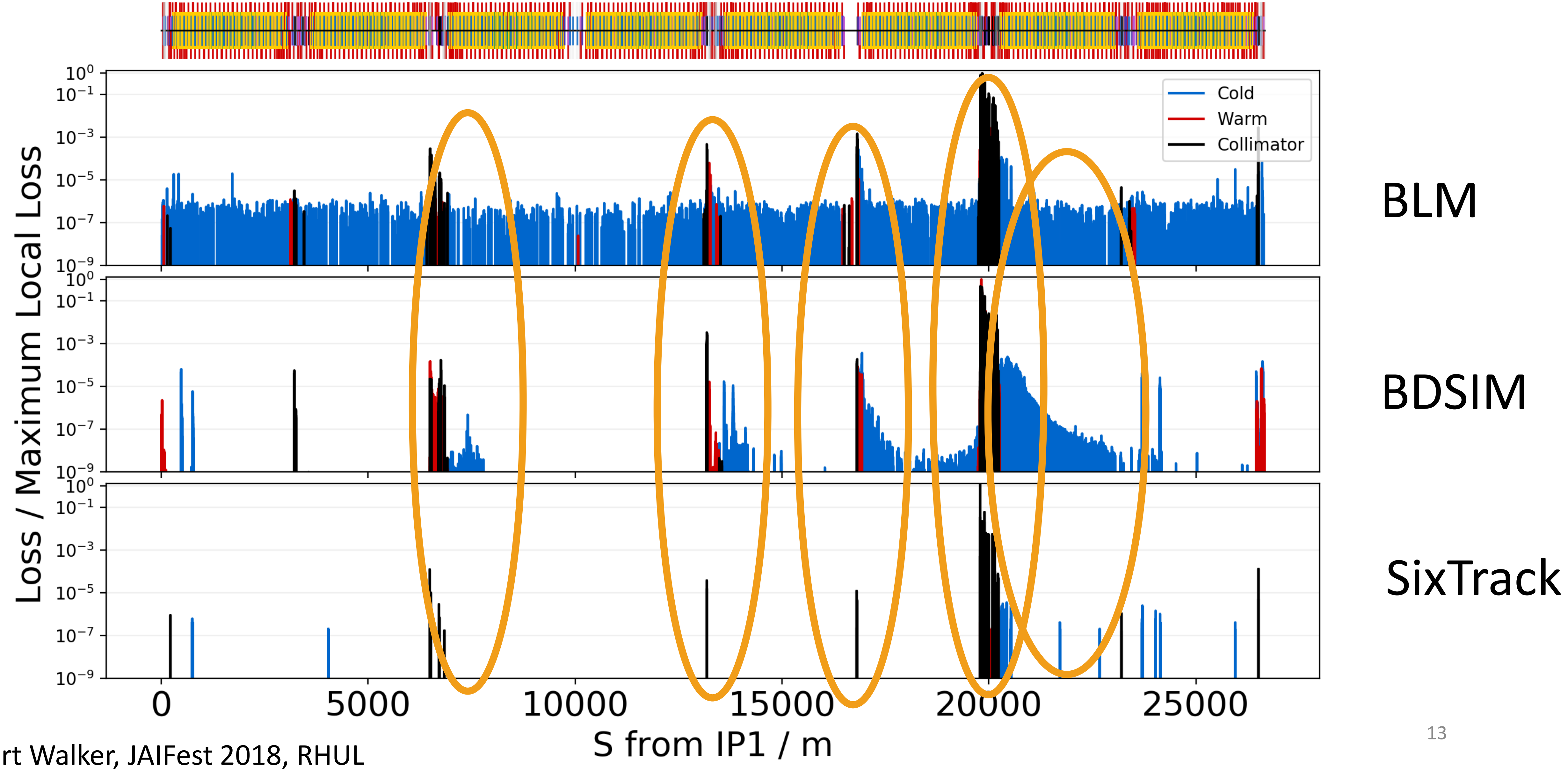




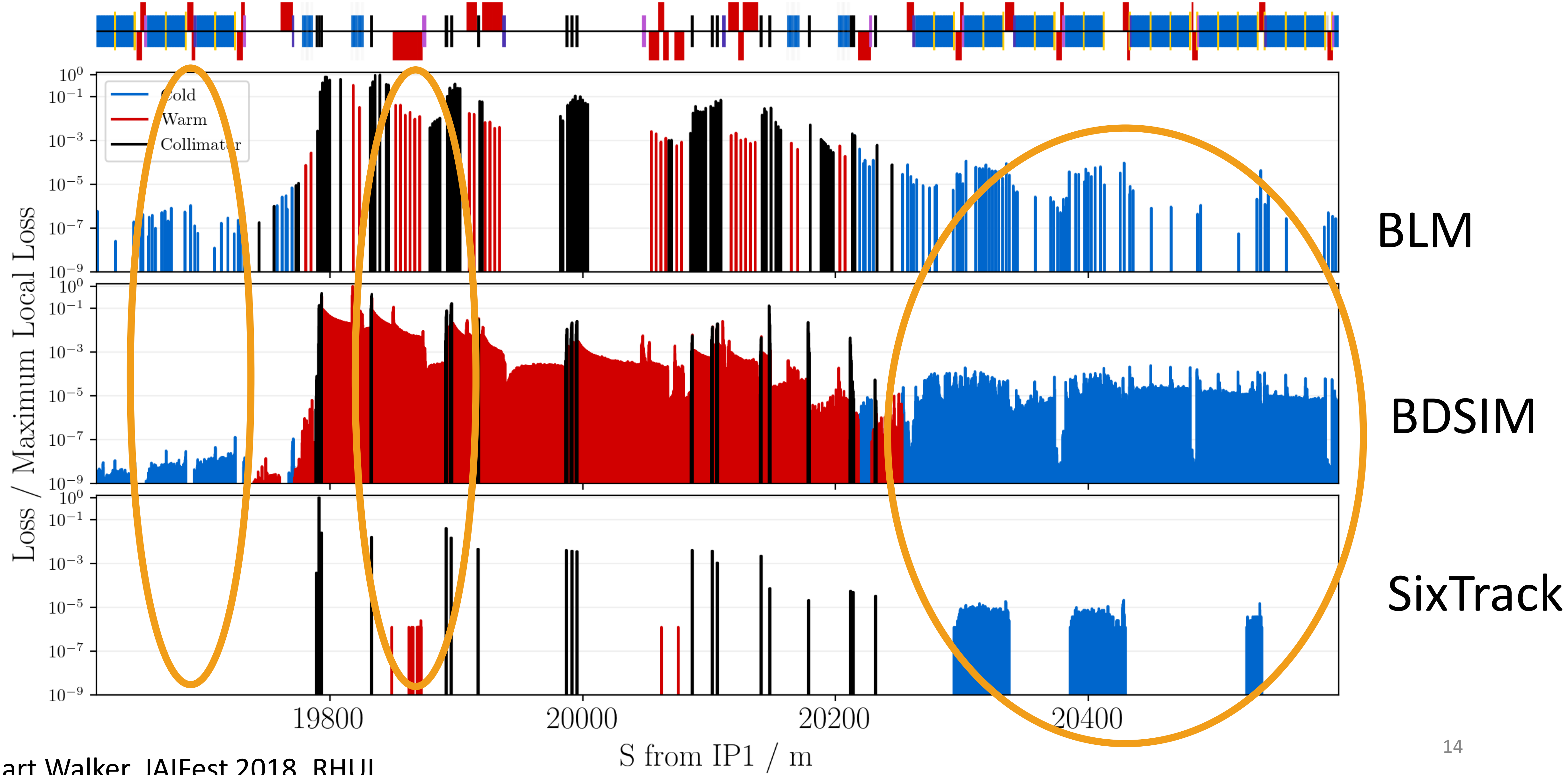
Simulations and Data

- BLM: Beam loss monitor signal from recent qualification run, where a low-intensity beam is used and losses are provoked deliberately in the betatron cleaning IR (IR7).
- BDSIM: Energy deposition from both primaries and secondaries is recorded in the whole material of the elements down to resolution of 0.1m. 3 million primaries simulated, 200 turns.
- SixTrack: Primaries hitting collimators undergo Monte Carlo scattering routines, and may re-enter the tracking code. Primaries outside of apertures are killed immediately. 6.4 million primaries simulated, 200 turns.
- In all three cases: normalised with respect to peak in IR7.

Energy deposition of LHC with BDSIM



LHC IR7 Loss Maps



Stuart Walker, JAIFest 2018, RHUL

Summary and future work

- We have built a Geant4 model of the LHC to study the collimation system.
  - Geometry may be further refined to add increasing levels of detail to the model. E.g. add BLMs to the model and compare simulated dose with real data.
- Excellent agreement shown between BLM and BDSIM.
  - Able to recreate some features in the BLM signal not present in SixTrack.
- Further upgrades to the tracking planned.
- Application to future circular colliders (Hi lumi, High energy (H Pikhartova), FCC (A Abramov)).

Thank you

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http://www.pp.rhul.ac.uk/bdsim/