Machine Induced Background Generator in Gauss-on-Gaussino

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Outline

In 8 weeks:

Understand the Physics

- What is Machine Induced Background?
- Why does it matter for LHCb?
- Key MIB sources

Accelerator Physics

01

Understand Legacy Software

- Understand 15 year old C++ code
- How were the first MIB studies done?

Simulation

02

Modernize the Software

- Update the software to work in current versions of the simulation framework
- Modern C++ and thread safety

Technical C++ Work

03

Enable New MIB Studies

Allow new studies for:
- Run 3
- HL-LHC
- FCC and other future colliders

Future Impact

04

Machine-Induced Background

- **Simple Definition:** Particle flux from beam related sources that depends on the settings of the LHC
- MIB can interfere with the trigger system, reduce accuracy in reconstruction, damage detector components, and contribute to the radiation environment
- **Two main sources:**
  - Beam interactions with the beamline aperture material
  - Beam interactions with residual gasses in the beam pipe
- MIB rates are proportional to beam current
  - More beam particles → more MIB

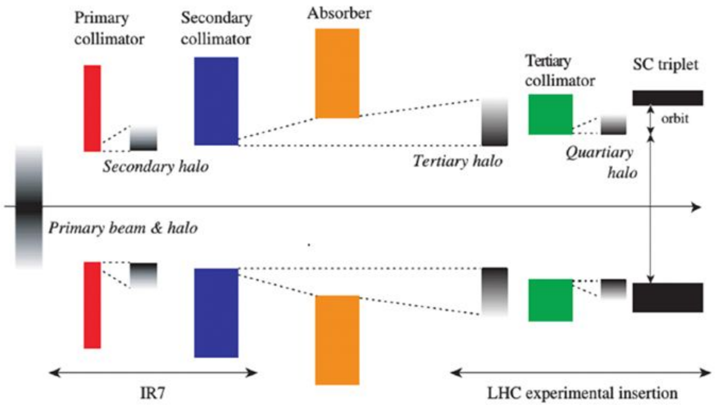


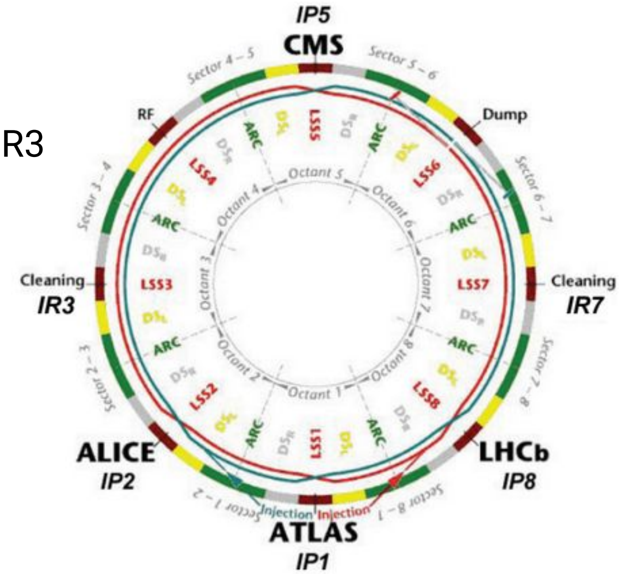
Image source: Accettura, Carlotta. (2017). Ultra-high vacuum characterization of advanced materials for future particle accelerators. 10.5281/zenodo.1420269.

Sources of Machine-Induced Background

For LHCb we care about the following MIB sources:

1. **Inelastic and elastic beam-gas interactions in the LSS close to LHCb**
2. **Elastic and diffractive beam-gas interactions in the entire LHC**
3. **Transverse beam halo from betatron cleaning inefficiencies at IR7**
4. Off momentum beam halo from momentum cleaning inefficiencies at IR3
5. Collision products from other experiments (ATLAS)

- **Bolded sources** are what was simulated previously
- Source **1** is the only direct MIB for LHCb
- All others contribute to beam halo build up.



Motivation

- Original generator was last updated in ~2010 and does not work with current versions of the simulation framework
- New MIB studies are needed for HL-LHC, Heavy Ion collisions, and FCC
- Goal of this project:
  - Allow for new MIB studies by modernizing and reviving the generator to work in both the **Sim10** (Gauss) and **Sim11** (Gauss-on Gaussino) frameworks

Pre Run 1	Run 1				LS 1		Run 2				LS 2			Run 3				LS 3, R4, R5
2001 - 2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026 - 2035
Original MIB Studies					Generator sees limited updates and usage													New MIB Studies

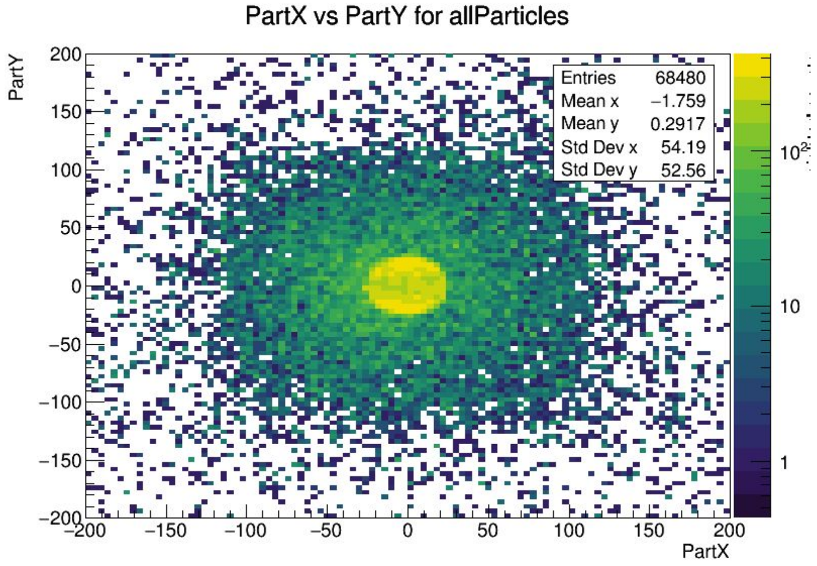
MIB Source Files

The ROOT file includes information about the loss event and its secondary particles:

- **Event tree:**
  - *LossID* -> used to group particles to a single loss event
  - *LossW* -> probability loss occurs

- **Particle tree:**
  - Various spatial and kinematic variables
  - *PartW* -> probability particle survives journey to LHCb
  - *PartDt* -> timing w.r.t. the bunch centroid crossing

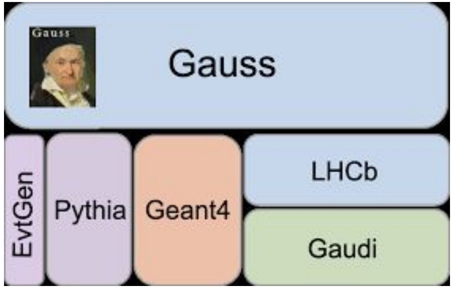
- **Header:**
  - includes information about the beam, interface plane location, etc.
- To perform new MIB studies, new source files will need to be provided by the beam department via the LHC background study group.
- Newest file from 2011 for 3.5 TeV *p* beams, even older for 7.0 TeV sources



Legacy MIB Generator in Gauss (Pre-Sim10)

Gauss:

- Built on the Gaudi framework
- Combines Pythia8 + EvtGen with Geant4
- Single Threaded

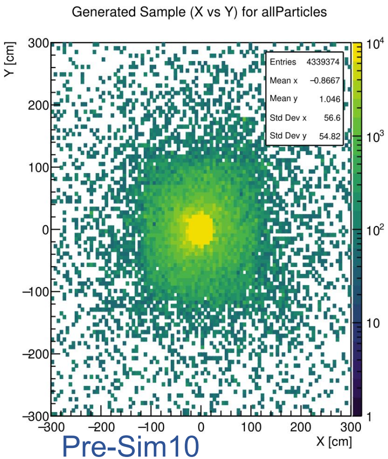


MIB Generator:

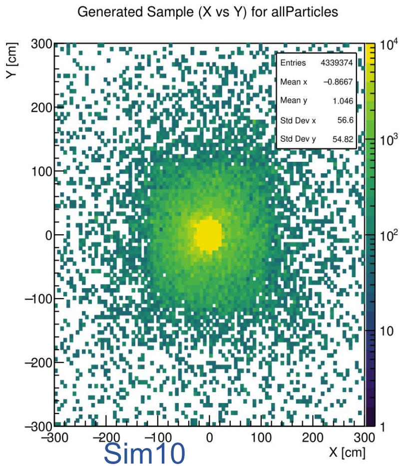
- Loads beam loss events from the ROOT source file
- Samples a Poisson-distribution for number of MIB interactions in event
- For each interaction:
  - Generate a loss event based on *LossW*
  - Generate particles based on *PartW*
  - Assign spatial and kinematic properties
- Store particles in a HepMC2 event to be transported through the detector via Geant4

Modernizing for Sim10

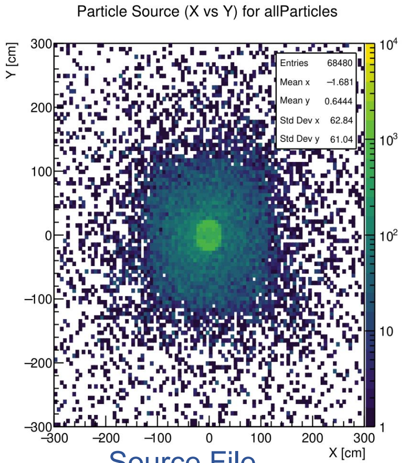
- The old source files stored their header information in a variable type which has since been removed from the RooFit ROOT library (`RooStringVar`)
- A script was written to convert the header information into a `TObjString`
- This fix was straightforward (*after hours of trying to figure out what the problem was)*
- C++ code was also cleaned up to follow modern practices and improve readability



Pre-Sim10



Sim10



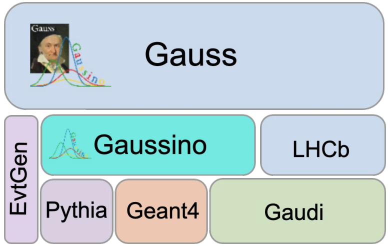
Source File

- Pre-Sim10 and Sim10 are exactly the same!

Porting the MIB Generator to Gaussino

Gaussino:

- LHCb-independent core built directly on Gaudi
- HepMC3 event format instead of HepMC2
- Multi-threading allows for significant performance boost
- Use of functional programing ensures thread safety



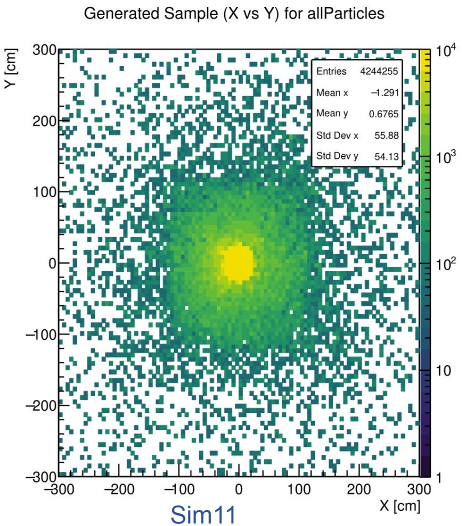
Implementing a 15 year old piece of code into a modern simulation framework should be easy… right?

The port to Gaussino was far from easy and required an almost complete rewrite

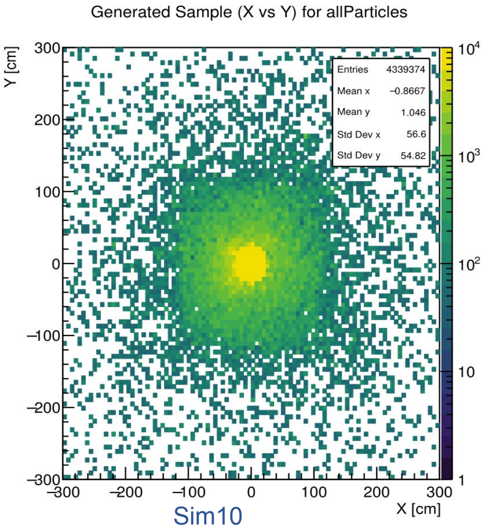
- Moved from the old style of `GaudiAlgorithm` to the new `Gaudi::Functional`
  - This structural shift and the change to HepMC3 forced a near-complete rewrite
- Move ROOT source file access to the memory to ensure thread safety
- Switch to `Gaudi::Accumulator` for thread safe counting and histograms

Porting the MIB Generator to Gaussino Cont.

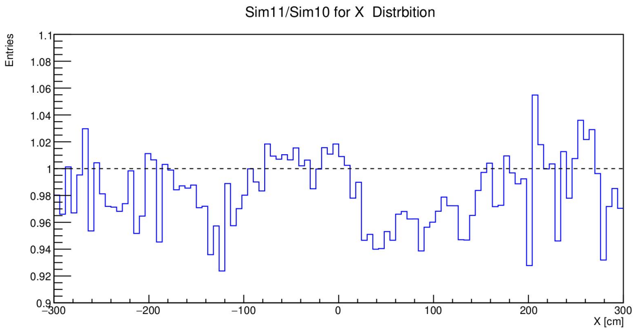
- Differences between Sim10 and Sim11 plots likely due to random sampling not with the changes made to the source code
- Ratio plots show ~5% difference between X and Y distributions

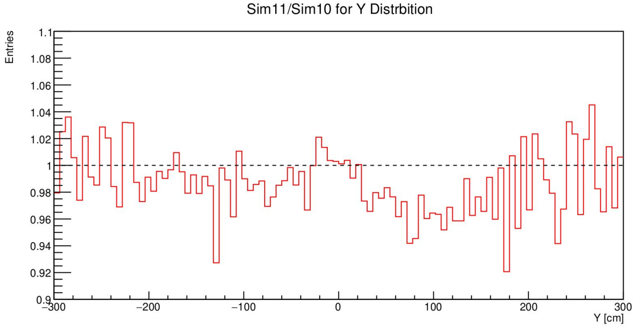


Sim11



Sim10





Conclusions and Future Work

- New MIB studies are essential to understand future LHCb running conditions and performance
- I have successfully brought the MIB generator to the modern era and verified it works by repeating analysis done in the early days of the LHC
- Now that the MIB generator technically works again, we can perform new studies once we have new source files from the LHC
- After my return to the US, I will continue working with the LHCb simulation team to do the new MIB analysis!

Thank you for your attention!
Are there any questions?

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Backup Slides

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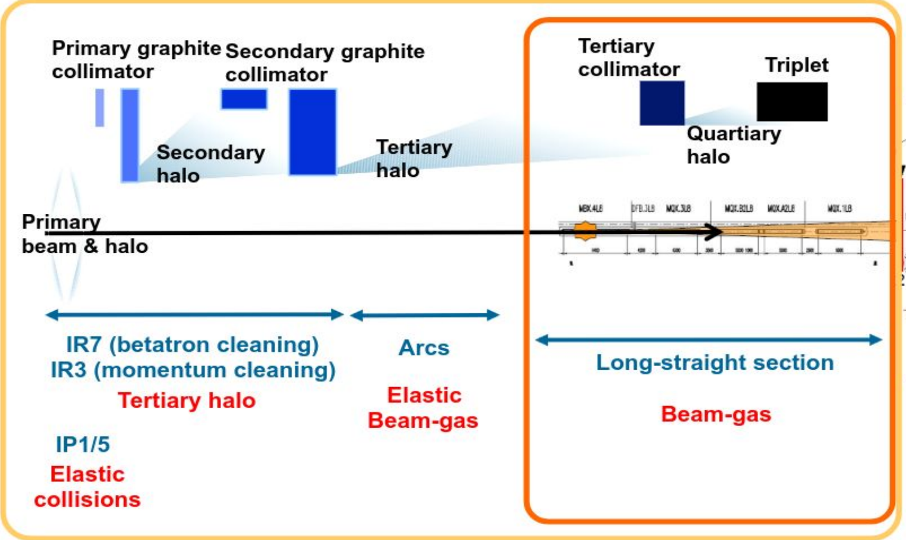
Simulation Procedure

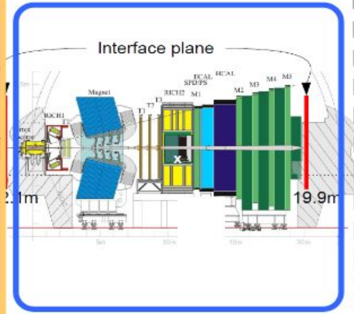
Beam Loss Estimate → **Shower Transport** → **LHCb Simulation** → **Investigate detector response**

Beam Loss Estimate
- Typically multi-turn tracking of protons
- Gives loss probability and kinematics
- Interested in losses close to LHCb

Shower Transport
- Pick up particles at loss location
- Transport with FLUKA to interface plane at LHCb

LHCb Simulation
- MIB generator in Gauss*
- Reads in particles from interface plane
- Generates particles and pass them to transport in detector (Geant4)





Further processing with any LHCb software

Slide from G. Corti: https://cds.cern.ch/record/1316453/files/LHCb-TALK-2010-201.pdf