Gauss and Gaussino
the LHCb simulation software
and its core framework

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on behalf of the LHCb Simulation Project

on 11 May, 2023
CHEP 2023, Norfolk VA, USA
Simulation software in LHCb

Gauss is the LHCb simulation framework:
- generates primary events,
- simulates the interaction with the detector,
- based on Gaudi as a core software framework.

Landscape for Run3 and future runs
- large increase in luminosity very challenging for computing,
- simulation for Run 2, takes up to 90% of the experiment computing resources,
- major rewrite of the software in LHCb.

Simulation software upgrade needed!
- need for code optimization,
- clean up of ‘dead’ code,
- fix memory usage issues,
- use multi-threaded Gaudi and Geant4,
- extensive fast simulation models,
- new external software technologies.

Separate simulation core functionalities!

M. Mazurek  The LHCb simulation software Gauss and its Gaussino core framework  CHEP 2023, Norfolk, USA
From Gauss to Gauss-on-Gaussino

Introduce an experiment-independent layer!

Gaussino

- new core simulation framework,
- created by extracting experiment-independent components from Gauss,
- ideal test bed for new developments,
- idea came up in collaboration with the CERN SFT group / FCC,
- more on Gaussino in the following talk!

Gauss-on-Gaussino

- new version of LHCb simulation framework,
- based on Gaussino’s core functionalities,
- adds LHCb-specific components and configurations,
What is the **status** of the new framework?

- multi-threading prototype,
- early benchmarks,
- first DD4hep sub-detectors,
- extensive testing,
- Gaussino standalone,
- configuration revisited,
- stable software,
- custom simulations,
- full testing,
- port all needed functionality from Gauss (Sim10). e.g. full generators palette,
- test productions with LHCbDirac,
- full scale physics validation,
Configuration

- python configurables steering C++ classes,
- modular structure with 4 main configurables, one for each module

More on the Gaussino structure itself in the next talk!

Gauss()
GaussGeneration()
GaussSimulation()
GaussGeometry()
+ optional (ParticleGun, etc.)
Generation phase

New features from Gaussino
- highly modular,
- thread safety of generators,
- HepMC3 as an exchange format,

Structure
- Gaussino: Pythia8 and some particle guns,
- Gauss: EvtGen and specific LHCb settings,

Performance
- shared (P8) vs. thread-local (P8MT) interface to Pythia8

Pythia 8 + EvtGen in Run 2 conditions

Pythia 8 + EvtGen in Run 3 conditions

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Detector simulation phase

New features from Gaussino
- Geant4 10.7
- multi-threading,
- fast simulation hooks,

Structure
- Gaussino: interfaces to Geant4,
- Gauss: LHCb specific settings & models,

Performance
- Geant4 10.7 simulation with shared vs. thread-local interface to Pythia8

Geant4 10.7 in Run 2 conditions

Geant4 10.7 in Run 3 conditions

LHCb Simulation Preliminary
Gauss v60r1 with Geant4 v10.7.3
Detailed Simulation
p+p-collisions $\sqrt{s} = 13$ TeV
$L = 10^8$ cm$^{-2}$ s$^{-1}$

LHCb Simulation Preliminary
Gauss v60r1 with Geant4 v10.7.3
Detailed Simulation
p+p-collisions $\sqrt{s} = 14$ TeV
$L = 10^8$ cm$^{-2}$ s$^{-1}$
**Fast simulations in LHCb**

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<th>Status in G-on-G</th>
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**In-house parametrizations**

**Lamarr**

*Idea:* ultra-fast simulation option where not only the detector response, but also the reconstruction is parametrized

👉 *more on Lamarr* in M.Barbetti’s talk

**Fast simulation models with Geant4**

**Point library**

*Idea:* Extract points from a collection and transform them based on properties of the particle

**Generative Adversarial Networks (GANs)**

*Idea:* use GANs trained on the data produced by a detailed simulation to generate showers in ECAL
Geometry

- LHCb specific detector description tool used for Run 1, 2 & 3,
- LHCb description using DD4Hep toolkit for Run3 and beyond,
- Gaussino’s internal geometry service for non-standard geometry setups (adding volumes at runtime, fast simulations, etc.)

Geometry in Gauss-on-Gaussino

Geometry in Gaussino

DD4hep

DetDesc

Internal
Example of using internal geometry service

⚠ Required data for fast simulation models and other studies is not always present in the standard output.

瘘 An abstract, external detector can be used as a collector of the required information at any position in the detector.

 güçlü A built-in mechanism can take care of potential volume overlaps by placing extra volumes in parallel geometries.
Example of custom datasets

Crucial for fast simulation training datasets and sub-detector studies!
Example: external plane (incident particles info) ECAL hits

Evenly-spaced grid of photons
Minimum bias sample
Visualizations in Geant4

💡 available at runtime (in multi-threaded environment),
💡 crucial for validating geometries, overlap checks and the comparison of different description tools,

DetDesc (legacy)

DD4hep (new)
Visualizations in Phoenix

💡 available as an external tool based on data produced in the simulation, simulation and reconstruction data comparisons possible,
Monitoring & Output

Output files
- simulated data in the LHCb event model,
- monitoring histograms,
- custom n-tuples,

Monitoring and production tools
- **LHCb Nightly builds**: small jobs with validation of the code and checks on expected output, counter, etc.
- **LHCbPR**: provides statistical checks and comparisons on larger data samples,
- **LbMCSSubmit**: new scriptable large submission system of large production requests of the simulation samples,

👉 more on LbMCSSubmit in C. Burr’s talk
👉 more on Simulation Data Quality in LHCb in B. Couturier’s talk
Documentation

- https://gitlab.cern.ch/lhcb/Gauss
- https://lhcb-gauss.docs.cern.ch/

- each new development in Gauss(-on-Gaussino) is documented,
- the documentation provides the description of:
  - how to install and run simulations,
  - high-level python configuration,
  - simple examples,
- versioning of the documentation.
Conclusions

- Simulation framework in LHCb had to be re-written to meet the requirements of Run3 and future runs.
- Gauss-on-Gaussino is the new version of Gauss based on Gaussino with LHCb-specific additions.
- More on Gaussino and its use for early detector studies and experiment-independent use in the next talk!
- Gauss-on-Gaussino is mature enough and is ready for its beta release!
- First production tests and porting of the rest of the components soon!
Thank you!