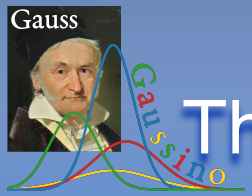
ACAT 2022
23 – 28 oct 2022
Villa Romanazzi Carducci, Bari, Italy



The LHCb simulation software
Gauss & its Gaussino core framework

Motivation

Building blocks

Newest features

Gloria Corti, CERN
on behalf of the LHCb Simulation Project

Setting the scene …

LHCb Upgrade in Run3

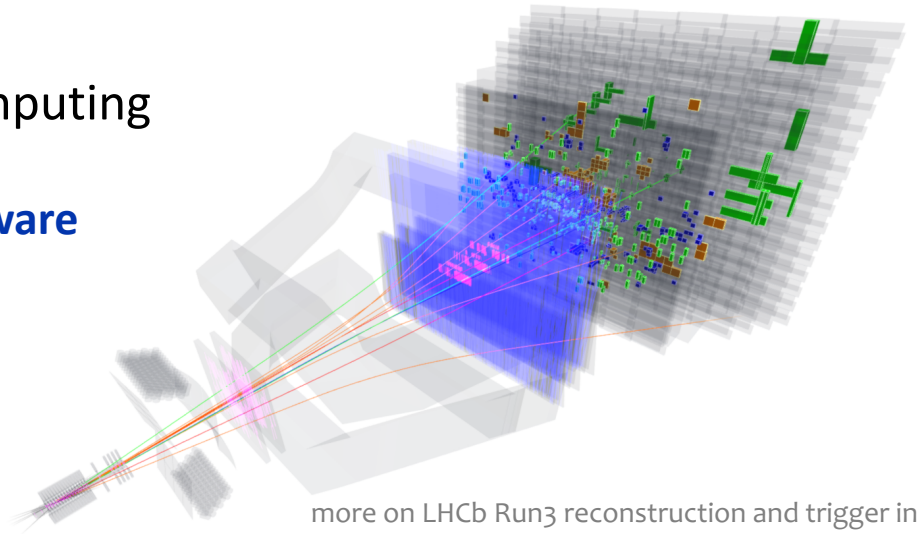
- full software trigger with high signal purity
- analysis directly on trigger output

$\mathcal{L}_{inst}$: 4 x 10^{32} → 2 x 10^{33} cm^{-2} s^{-1}
μ: 1.1 → 7.6
$\mathcal{L}_{int}$: 3 (Run1) + 5 (Run2) fb^{-1} → 50 fb^{-1}

Very challenging for software & computing

Modernization of the whole LHCb software

- Multi-threading
- Better use of multi-processor CPUs
- Reduce **memory usage**
- Optimize cache performance
- Remove dead code
- Move to modern data structures
- Enable **code vectorization**
- Enable **algorithmic optimization**
- HLT1 reconstruction on **GPUs**

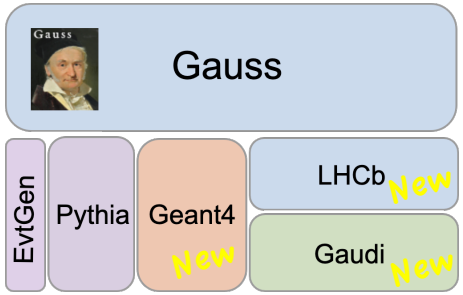


more on LHCb Run3 reconstruction and trigger in ACAT2022 talks by A. Hennequin, N. Schulte and G. Tuci and ACAT 2022 posters by S. Akar and F. Reiss

Upgrade Software and Computing TDR, CERN-LHCC-2018-007

… what about the simulation software ?

Simulation in Run3 will continue to dominate the LHCb CPU needs



Gauss is the LHCb simulation framework

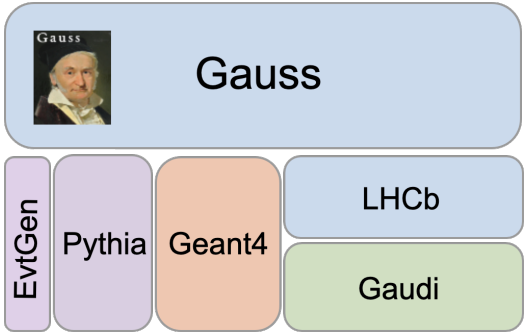
- generates events
- simulates interactions with the detector
- based on Gaudi as core framework and on common LHCb code
- makes use of HEP common simulation software
- first production version in 2004

Simulation software upgrade needed!

- need for code optimization
- reduce memory usage
- adapt to changes in LHCb common software, e.g. use of DD4Hep
- exploit new features of external HEP simulation software, e.g. in Geant4
- use multi-threaded Gaudi and Geant4
- need for extensive palette of fast simulations

💡 Idea: Separate core functionality for simulation

From Gauss to Gaussino …



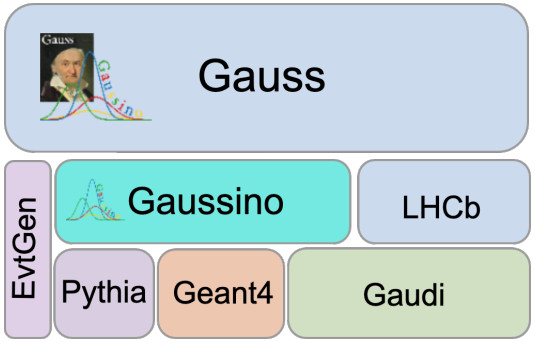
Restructure the code introducing an **experiment-independent layer**

Gaussino Core Simulation framework

- made by extracting experiment-independent functionality from Gauss
- uses Gaudi as core software framework
- run minimal functionality in stand-alone mode
- ideal test-bed for new developments
- started in collaboration with the CERN SFT group
- make it available in Key4Hep Turnkey software stack

more on Key4Hep in ACAT2022 poster by V. Volkl

… back to Gauss[-on-Gaussino]



Restructure the code introducing an **experiment-independent layer**

Gaussino is the new Core Simulation framework

- provides the structure and the hooks
- provides components to use HEP-wide software, e.g. for Pythia8 and Geant4

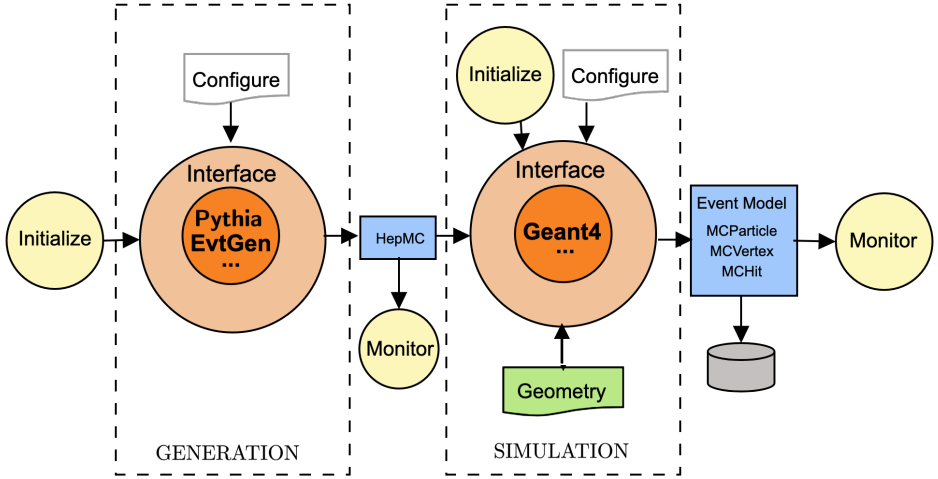
Gauss[-on-Gaussino] is the new version of the LHCb simulation framework

- based on Gaussino's core elements
- adds LHCb-specific components and configurations

Gaussino – keep what's good

i.e. the overall Gauss framework architecture

- similar modularity
- integrated generator and simulation phase
- similar MC truth output
- similar use of Gaudi algorithms, tools, etc.
- python-based configuration



Generator phase kept mostly as-is

Simulation phase redesigned following review of key elements

Gaussino – support what is new

Core elements

- multi-threaded event loop
- multi-threaded Geant4
- interface to subdetectors fast simulations with Geant4
- interface to new external libraries, e.g. DD4Hep

Front-end

- higher level configuration in python
- possibility to run simple set-ups in stand-alone mode

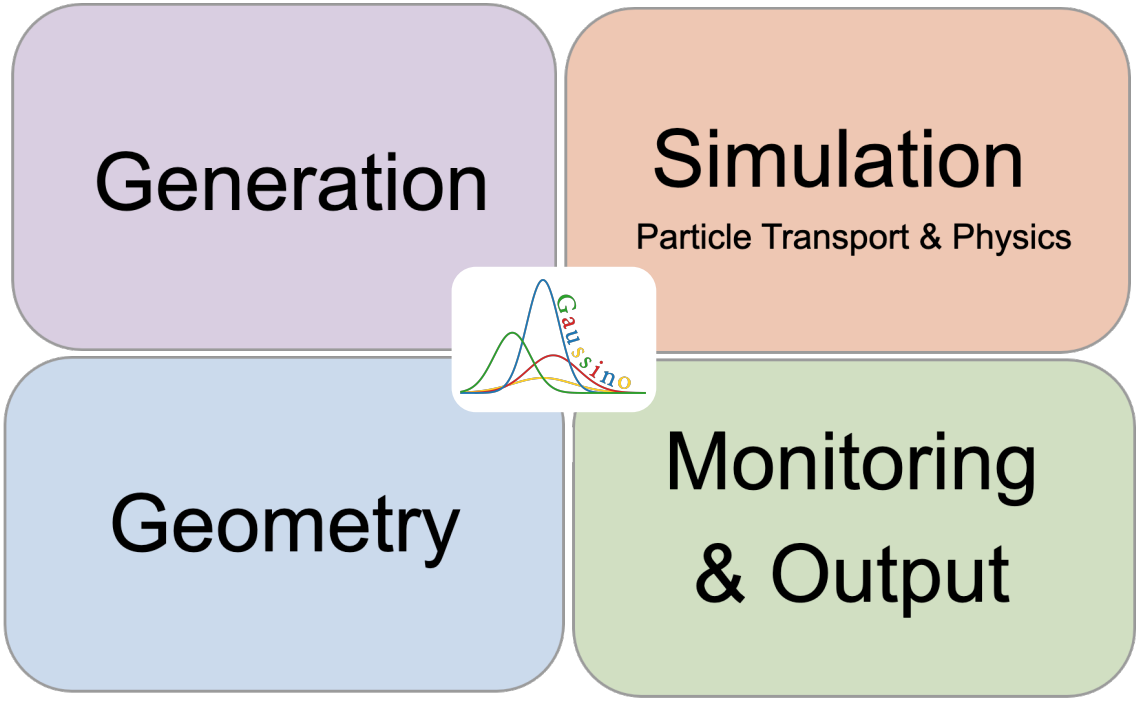
Execution structure

- use Gaudi functional framework
- treat every algorithm as a ‘task’

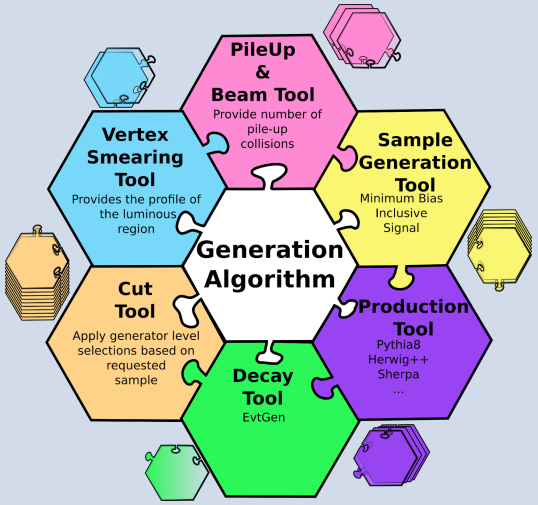
Random numbers

- adapt to multi-threading framework
- create random engine on the stack
- seed initialized with:
  - run#
  - event #
  - algorithm instance name, i.e. largest predictable unit

Configurable building blocks



Generation Phase



Extracted as-is from Gauss
Highly modular
Thread safety of generators
HepMC3 as exchange format

LHCb-PROC-2010-056, NSS2010
LHCB-FIGURE-2019-012

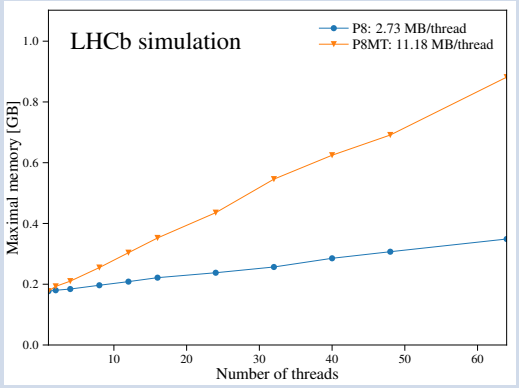
Gaussino

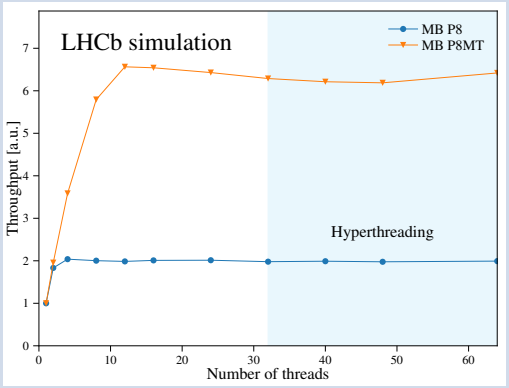
- Pythia 8 and some particle guns

Gauss(-on-Gaussino)

- specific LHCb settings and generators, e.g. EvtGen

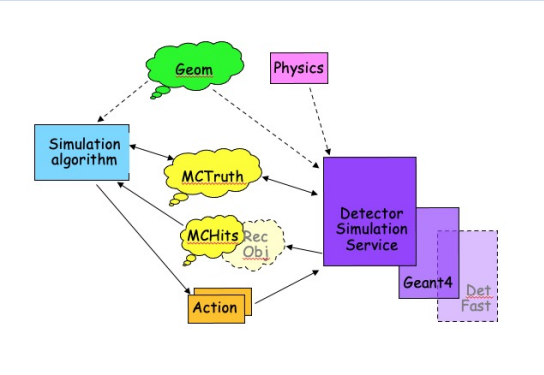
Performance with Pythia8 as generator engine
shared (P8) vs thread local (P8MT)





Generation phase only, minimum bias,
no LHCb-specific setting

Simulation Phase



New implementation with improved modularity

Simulation & Geometry services to steer different backends

Flexible python configuration to combine different setting, e.g. for in time/out of time pileup

Gaussino

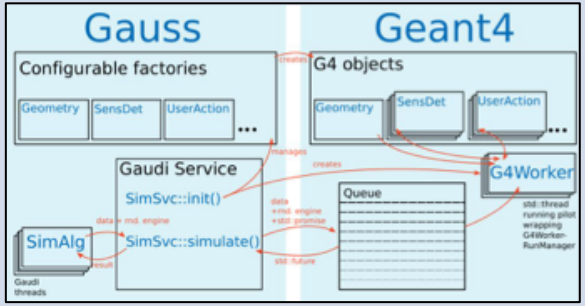
- generic geometry service
- interaction with Geant4
- infrastructure for fast simulations

Gauss(-on-Gaussino)

- LHCb geometry specialization service(s)
- LHCb specific settings and physics extensions
- LHCb fast simulation models

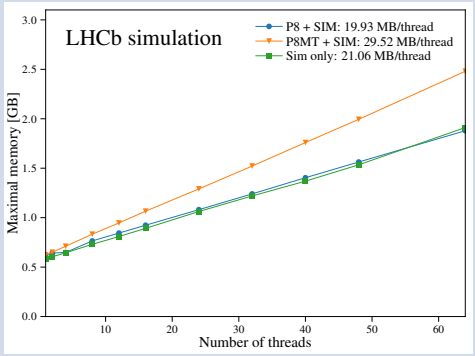
Detailed detector simulation with Geant4

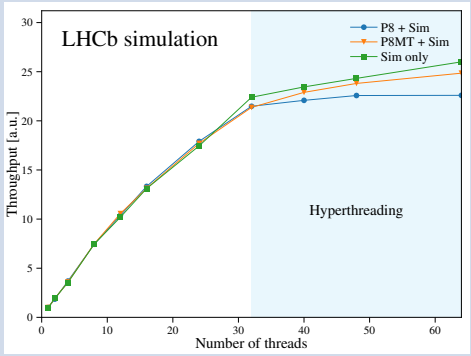
- Geant4 10 multi-threading
- Gaudi tools as factories for Geant4 objects
  - Python configuration of Geant4 settings
  - Geant4 manages its objetcs
- keep the event history in dedicated HepMC3 record while Geant4 process it



Performance of detailed simulation with Geant4

with Pythia8 generation shared (P8) vs thread local (P8MT)
vs reading generated events from file





Simulation with LHCb 2016 conditions
Signal D^0 decays from minimum bias

LHCB-FIGURE-2019-012

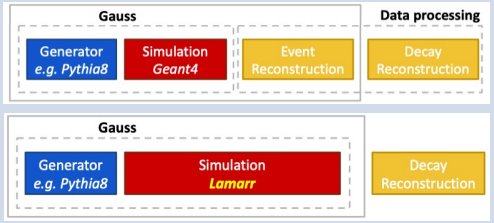
Fast simulations in LHCb

Extensive palette of fast simulations options

Technique	GEN Phase	SIM Phase	Status	Note
ReDecay	+	+	done	infrastructure in Gaussino
SplitSim	+	+	done	infrastructure in Gaussino
ParticleGun	+	-	done	in Gaussino
RICHLess	-	+	under tests	i.e. reduced detector, infrastructure built in Gaussino
TrackerOnly	-	+	under tests	i.e. reduced detector, infrastructure built in Gaussino
Point Library	-	+	in progress	interface in Gaussino, model in Gauss
GANs	-	+	in progress	interface in Gaussino, model in Gauss
Lamarr	-	+	in progress	split between Gaussino and Gauss

PoS ICHEP2018 (2019) 271

Lamarr – ultra fast simulation

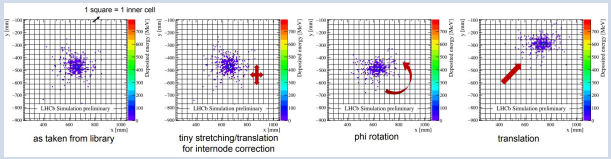


a pipeline of modular parametrizations replacing both the detector simulation and the reconstruction

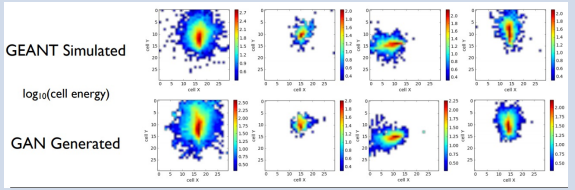
more in ACAT 2022 poster by M. Barbetti; LHCb-FIGURE-2022-014

Fast simulation models
replacing Geant4 for a subdetector

- Point library for calorimeters – extract energy deposits from a collection obtained from a detailed simulation and transform them based on the property of the impinging particle [a]



- GANs – use GANs trained on the data produced by a detailed simulation to generate showers in Electromagnetic Calorimeter [b]



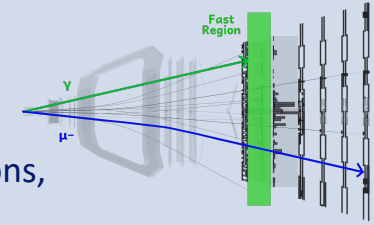
[a] LHCb-TALK-2020-108, ICHEP 2020 [b] EPJ Web Conf 245 (2020) 02026

Interfacing fast simulations with Geant4

The interface steers the fast simulation:

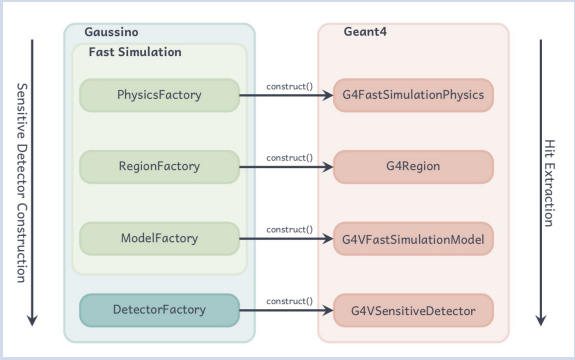
- for which particle to do it
- in which region to do it
- how to do it

  i.e. particle and track conditions, hit generation algorithm



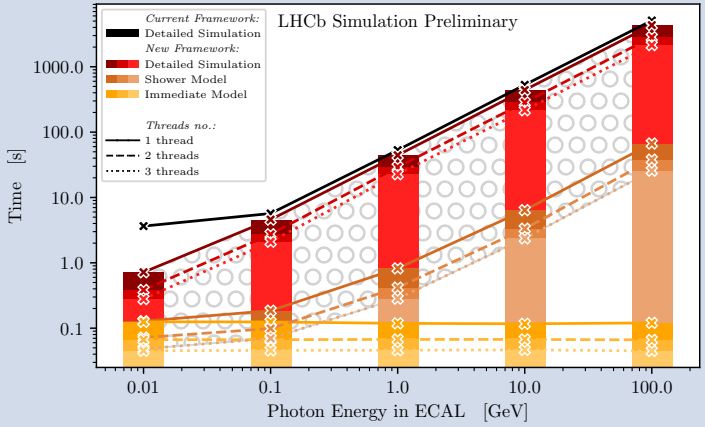
Dedicated high-level configurable

Factories in C++ using Gaudi tools that configure Geant4 objects



Performance with benchmark models

ImmediatedDeposit
vs ShowerDeposit
vs detailed simulation w Gauss[-on-Gaussino]
vs detailed simulation w Gauss[-pre-Gaussino]



ImmediateDeposit – time needed by the infrastructure itself to call a fast simulation

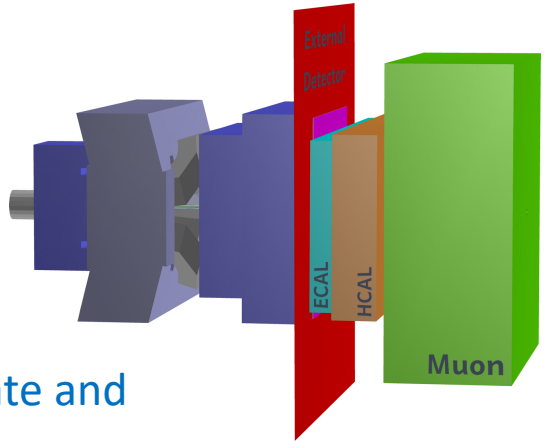
ShowerDeposit – minimum time to generate a specific number of hits with no additional calculation

2021 ACAT poster by M. Mazuerek (LHCb-PROC-2022-003); LHCb-FIGURE-2021-004

Geometry

Gaussino

- **generic service** to steer passing the information to Geant4 from different backends
- **backend** service for **DD4Hep**
- import & export of **GDML** files
- custom service for '**internal**' volumes of simple shapes
  - works **stand-alone**
  - can be **mixed** with other geometry services
  - supports Geant4 **parallel worlds**
  - exploited for **fast simulations**



Gauss[-on-Gaussino]

- high level service to **configure** the geometry to simulate and sensitive detectors
- extension for LHCb **legacy** Detector Description for Run 1&2 and 3
- extension for LHCb **new** description using DD4Hep for Run3 and beyond

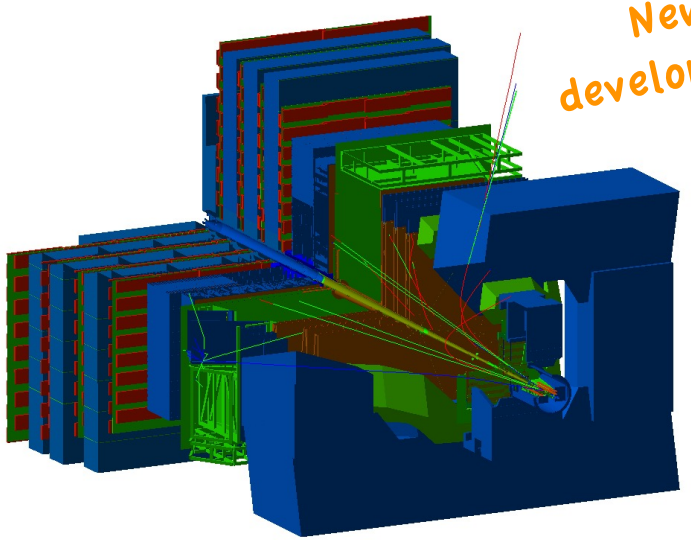
Visualisation of geometry and simulated events

Geant4 visualization drivers
- available at run time
- volume overlap checks possible
- G4 data only
- drivers: ASCIITree, OpenGL, DAWN, HepRep

Geant4 Users' Guides

Phoenix event display
- available as external tool
- geometry to be converted from GDML to a dedicated format
- both Geant4 and LHCb simulation data
- using JSON exporter for LHCb

more on Phoenix in LHCb in ACAT2021 Poster by A. Pappas



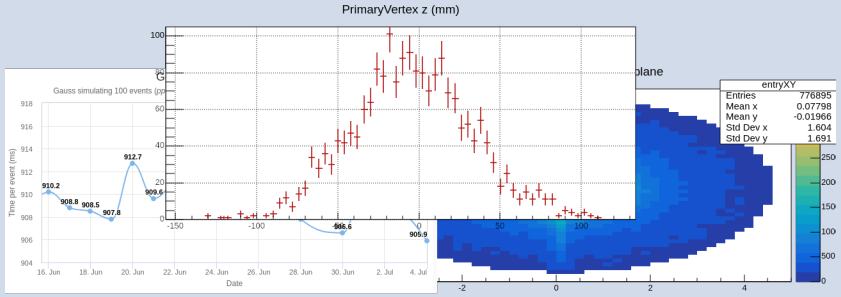
Dedicated steering due to Gaudi & Geant4 multi-threading interplay
- visualisation has its own thread
- information exchange at the right time

Monitoring & Output

Various persistent output formats possible with predefined contents

- conversion to built-in event model with consistent Monte Carlo 'truth'
  - from generators
  - from Geant4 choosing what to keep
- ROOT tuples and histograms
- HepMC3 generator output and EDM4hep sometimes in the future

Exploited in the **monitoring** of the produced simulation **samples** and software **performance** via the **LHCbPR** automatic tool



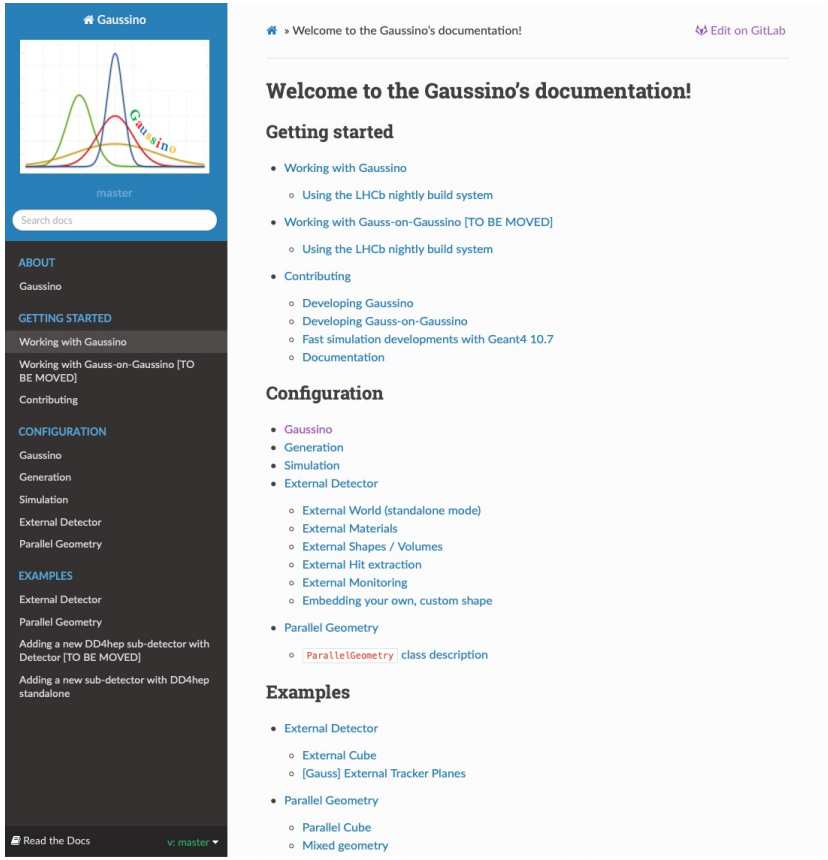
more on Simulation Quality in ACAT2022 Poster by D. Popov

Documentation

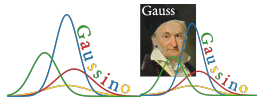
https://gaussino.docs.cern.ch/gaussino

GitLab Repository

- Each new development in Gaussino and Gauss(-on-Gaussino) is documented
- Versioning of the documentation
- Provides
  - how to install and run
  - description of high-level python configurations
  - simple examples



Conclusions & Outlook

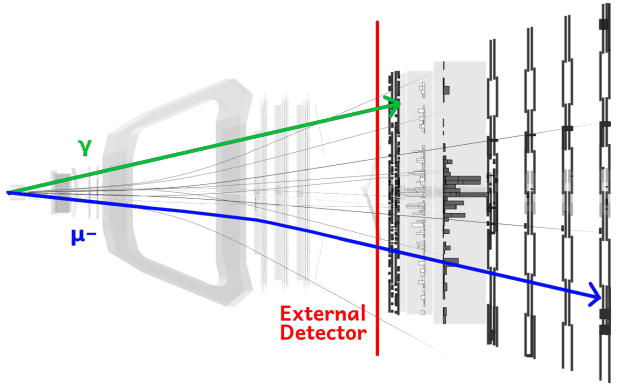


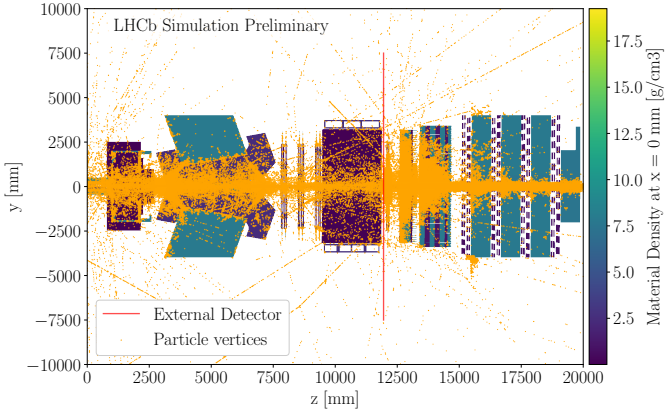
- The LHCb simulation software is undergoing a major upgrade for Run 3
- A new **experiment-independent** simulation framework, **Gaussino**, has been introduced as an intermediate layer
  - Gaussino is built on the Gaudi framework and provides an infrastructure for generators and a Geant4-based detailed simulation
- **Gauss[-on-Gaussino]** is the evolution of the LHCb simulation based on Gaussino and provides **LHCb-specific additions**
  - It will become the simulation framework for all LHCb running periods
- Gaussino is becoming mature for **use outside LHCb**

BACKUP

Example of using internal geometry service

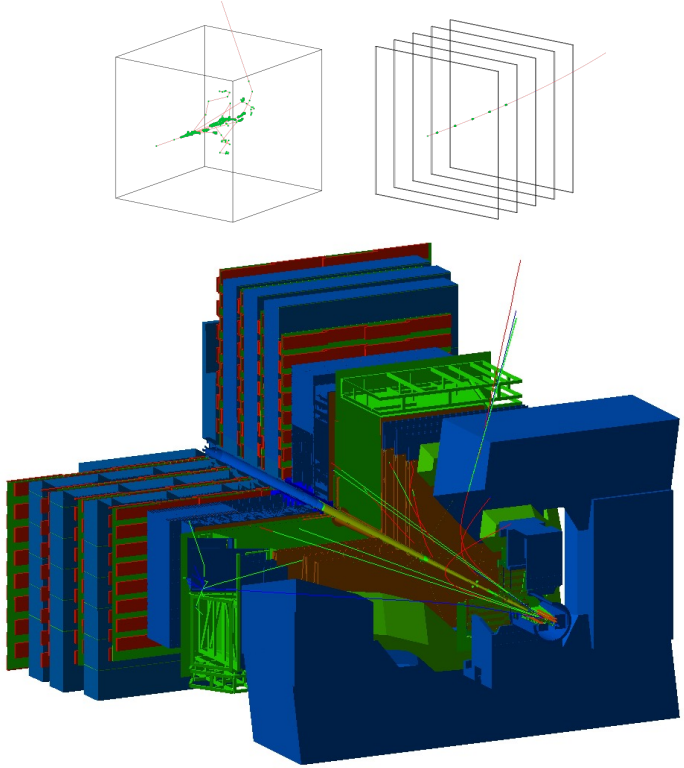
- **Required data** for fast simulation models and other studies **is not always present** in the standard output
- An **abstract custom detector** can be used as a collector of the required information at any position in the detector
- A built-in mechanism can take care of potential volume overlaps by placing the additional volumes in **parallel geometries**



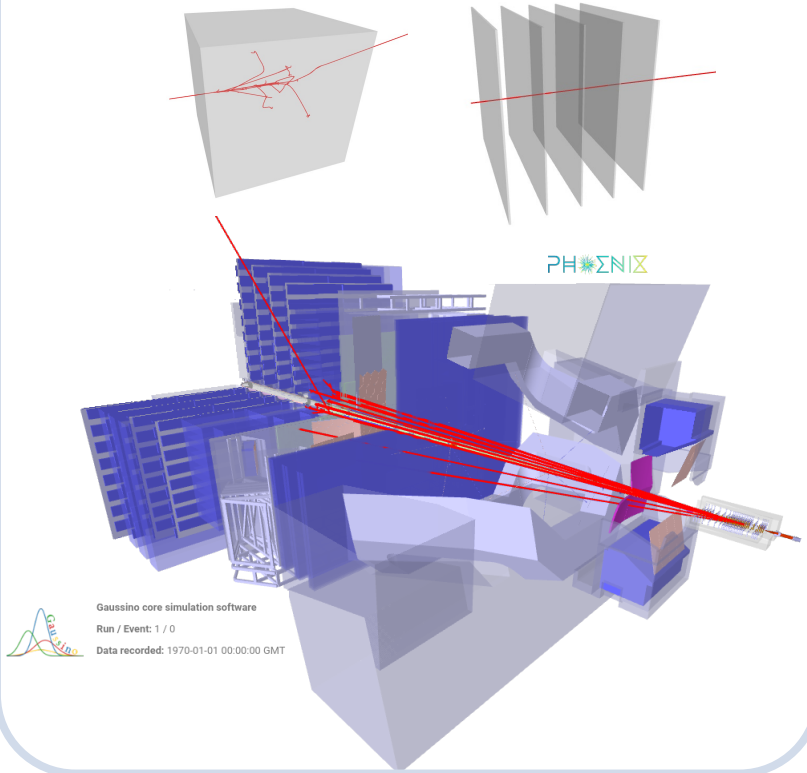


Visualization examples

Geant4 visualisation drivers



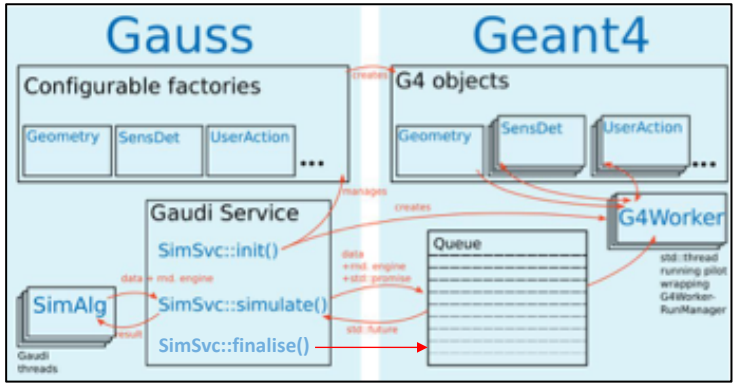
Phoenix event display



Visualization backend in Gaussino/Gauss

Possible data containers

- **Geant4:** G4Trajectories, G4Hits, …
- **LHCb:** MCParticles, MCHits, MCCaloHits, …
- **EDM4Hep** in the future?
- additional optimization
  - only MCThruth
  - only trajectories from tracking, etc.



Recipe for Gaudi and Geant4 MT

- implement `G4VisManager` that spawns an additional `G4Vis` thread
- ensure `G4Event` lives **long enough** for
  - G4 main simulation
  - Visualization post processing
- **information exchange** between custom `G4RunManagers` at the **right moment**