Status of CEPC Simulation Framework

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CEPC PhysDet plenary meeting

Outline

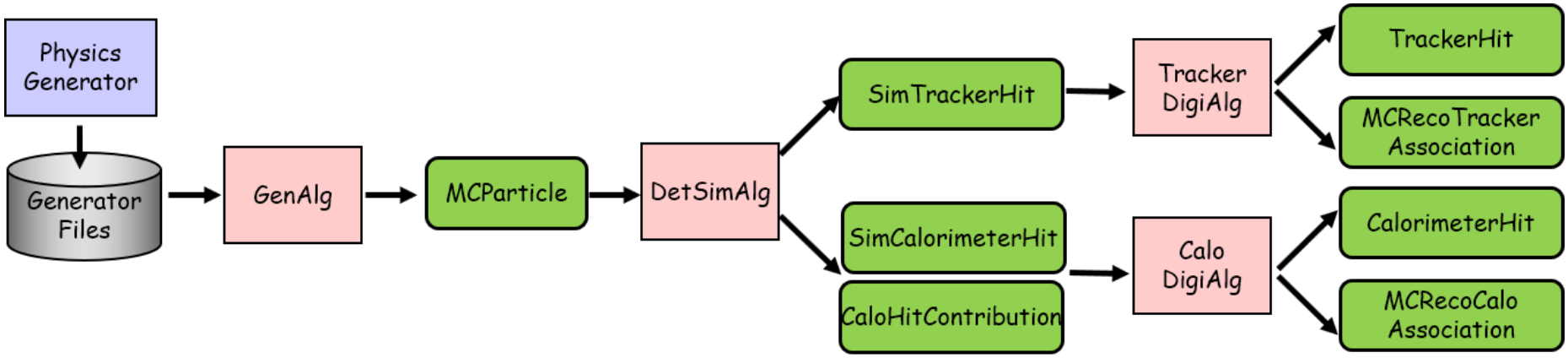
- Overview and recent developments of simulation framework
- Explore Gaussino: a simulation framework from LHCb
- Summary

Overview of Simulation Framework

A simulation framework is being developed for CEPC.

- A complete simulation chain for physics and detector performance studies.
  - Event generation with different physics generator
  - Detector simulation with Geant4 and fast simulation
- Well integration with Key4hep software stack.
  - EDM4hep as Event Data Model
  - DD4hep as Detector Description (including magnetic fields)
  - Gaudi as underlying framework
- Lightweight and modular design.
  - Gaudi Algorithms to take charge of the complete simulation workflow
  - A customized G4 Run Manager to integrate Gaudi and Geant4
  - Detector response and the MC truth information handling as plugins
  - Support of full and fast simulation transparently
  - Support of background mixing

Simulation data flow with EDM4hep

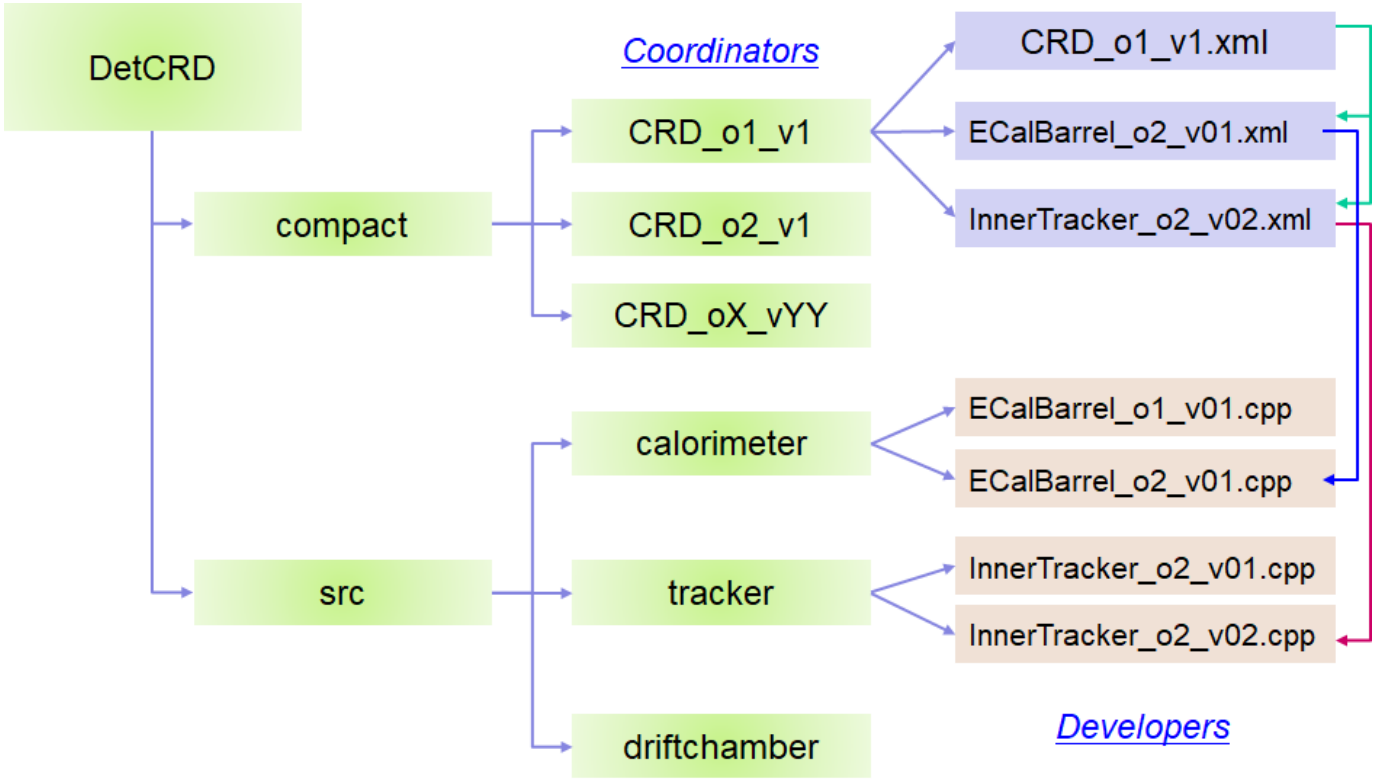


Simulation is flexible: run all steps in one job or run them separately

- Physics generator
  - MCParticle
- Detector Simulation
  - MCParticle (with secondaries), SimTrackerHit, SimCalorimeterHits
- Digitization
  - TrackerHit, CalorimeterHit

Detector Description with DD4hep

- Both geometry and magnetic field are described by DD4hep. Then, DDG4 is used to convert them to Geant4 automatically.
- All the detector options are managed in CEPCSW git repository.



Non-uniform magnetic fields

- A DD4hep extension is developed to support non-uniform magnetic fields in CEPCSW. The Br/Bz csv files are provided by magnetic group.

```
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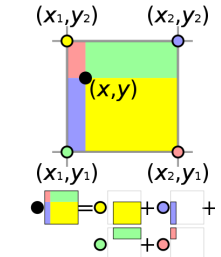
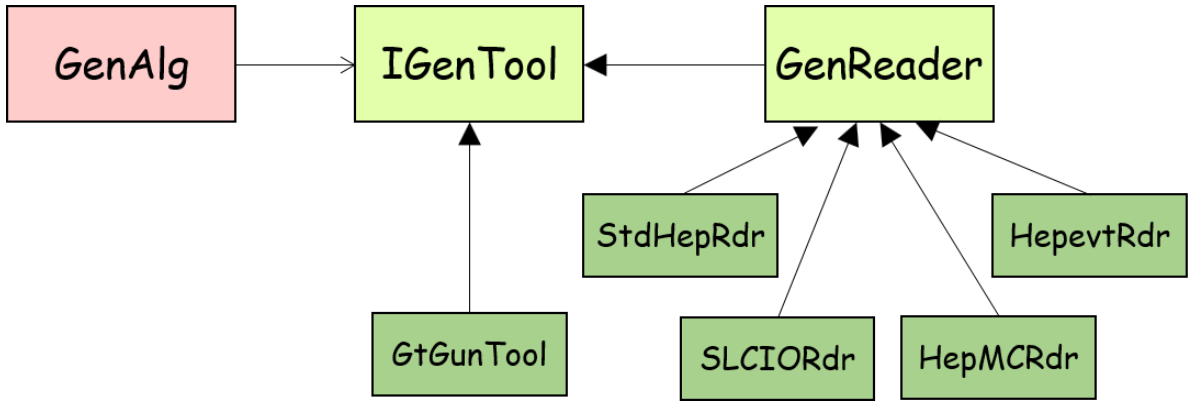


bilinear interpolation

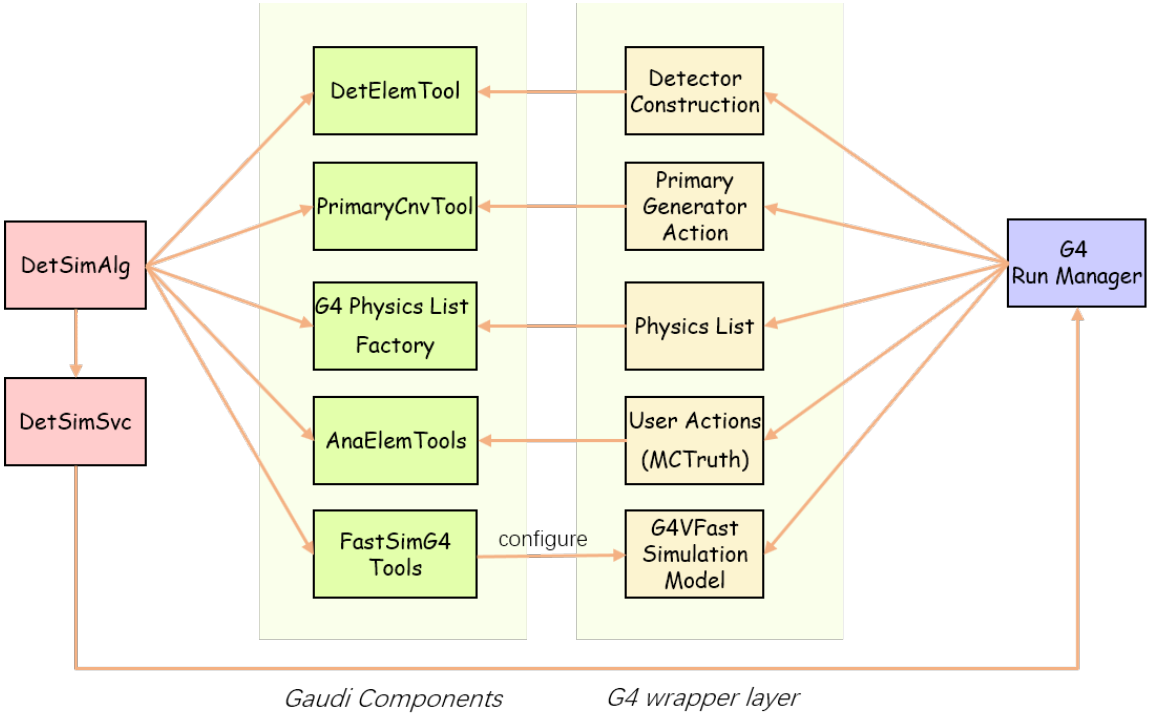
Physics generator interface

Different physics generators are integrated, including StdHep, HepEvt, LCIO, HepMC formats. Particle gun is also supported.

- A physics generator algorithm is in charge of a list of GenTools.
- Easy to extend by adding a new tool.



Integration with Geant4 and Gaudi



Detector simulation is fully integrated with the framework.

- A thin layer is developed to manage corresponding Geant4 objects.
  - All parameters could be configured in Python script.
- Event loop is controlled by an algorithm and a customized run manager.

Detector response and MC Truth

Detector response of all the detectors are available, including silicon detectors, time projection chamber, drift chamber and calorimeters.

- Generation of hits in different detectors are handled by corresponding Geant4 sensitive detectors.
- For each hit: ID is calculated by DD4hep; position/energy is from Geant4.
- At end of each event, store all the hit collections in EDM4hep format.

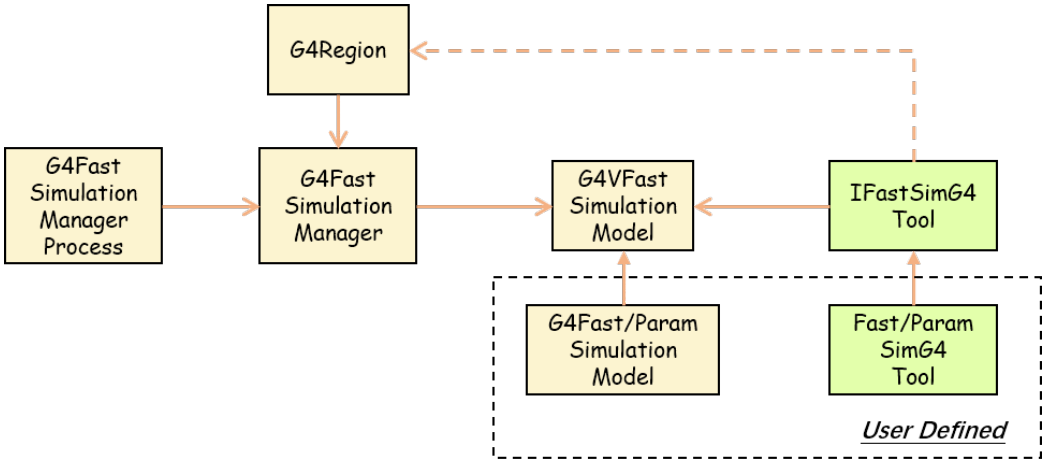
All necessary relationship are stored to rebuild relation between reconstructed particles and MC particles.

- Primary particles are cloned from generation stage
- Decayed secondaries are collected during Geant4 simulation
- Retrieve MC particle from a hit.

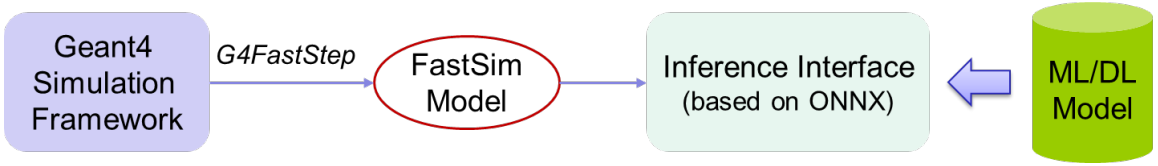
Integration with Fast Simulation

Fast simulation interface is developed to integrate different fast simulation models into Geant4.

- Region based: when a particle enter a region, fast simulation will be triggered by Geant4.



- Support ML methods via ONNX inference interface.

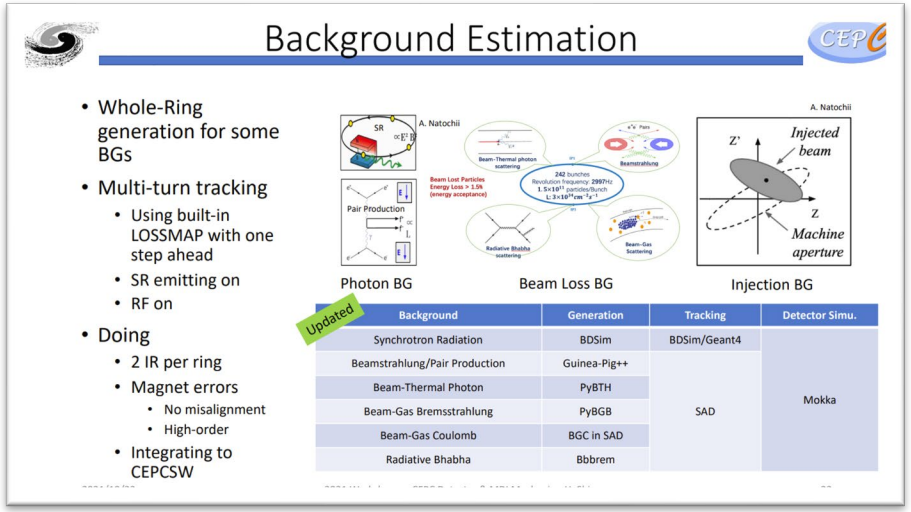


Background Simulation

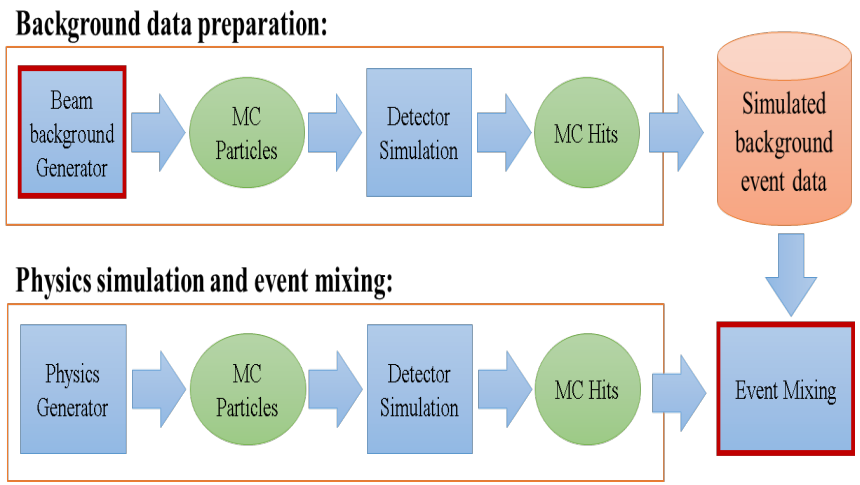
Tao, Haoyu Shi, Wei Xu

Simulation of background is supported in CEPCSW.

- A unified solution for different backgrounds by using the GenTools design.
- Integration of beam gas, pair production (Guinea-Pig) have been done.
- Hit level background mixing: store the hits and used as a library.



Summary of backgrounds. From Haoyu Shi



Hit-level background mixing

Towards multi-threaded simulation

CEPC simulation framework needs further developments.

- The current simulation framework in CEPCSW is single threaded.
- However, both Gaudi and Geant4 already support multi-threading.
- Need work to integrate them and simulate events in parallel.

Examples

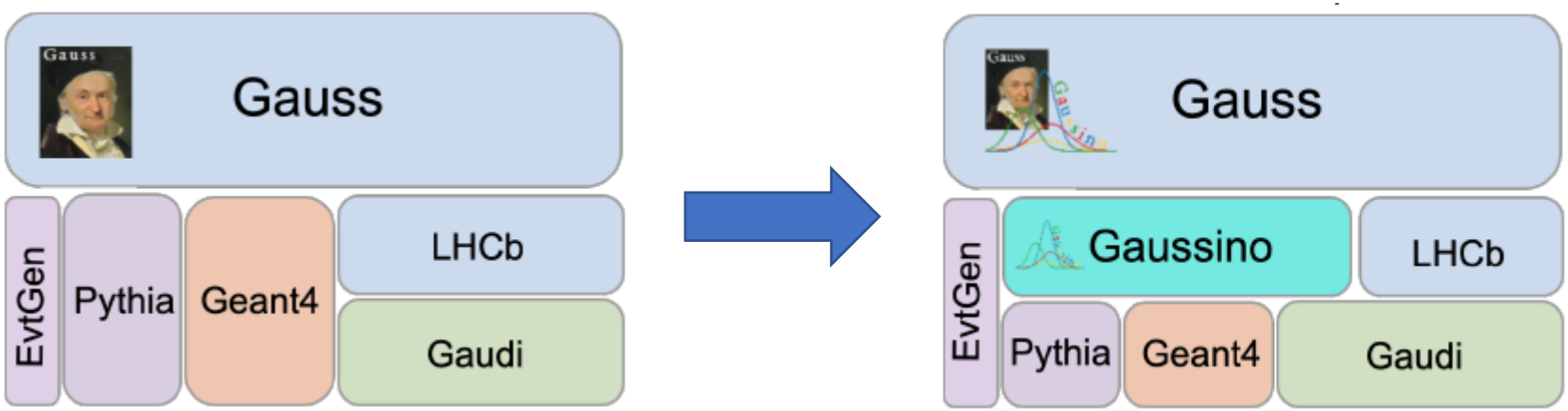
- ATLAS: from AthenaMP to AthenaMT
- LHCb: from Gauss to Gauss-on-Gaussino
- CMS: CMSSW
- ALICE: FairROOT and O2

=> Gaussino: experiment independent framework based on Gaudi

Ref: See Talk given by Michał Mazurek, Gauss and Gaussino, ICHEP 2022

Explore Gaussino

Evolution of simulation software in LHCb

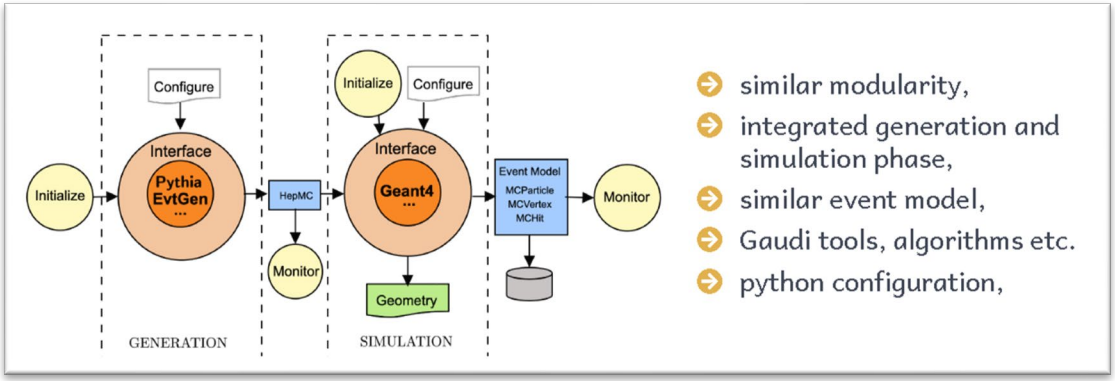


- Gaussino as the new core simulation framework, created by extracting experiment-independent from Gauss.
- Gauss-on-Gaussino as the new version of LHCb simulation framework, based on Gaussino's core functionalities.

Ref: See Talk given by Michał Mazurek, Gauss and Gaussino, ICHEP 2022

Features of Gaussino

- A complete simulation framework architecture with multi-threaded implementation



- similar modularity,
- integrated generation and simulation phase,
- similar event model,
- Gaudi tools, algorithms etc.
- python configuration,

Key concepts

- higher-level configuration in python,
- multi-threaded event loop,
- multi-threaded Geant4,
- interface to fast simulations,
- interfaces to new external libraries, e.g. DD4Hep,
- possibility to run in a standalone mode,

Execution structure

- use Gaudi functional,
- every algorithm as a 'task',

Random numbers

- ensure reproducibility,
- seed initialized with:
  - run #,
  - event #,
  - algorithm instance name,
- create random engines on the stack,

Ref: See Talk given by Michał Mazurek, Gauss and Gaussino, ICHEP 2022

Multi-threaded simulation in Gaussino

- Integrate multi-threaded Gaudi and multi-threaded Geant4.
- Achieve good scalability (see example below)

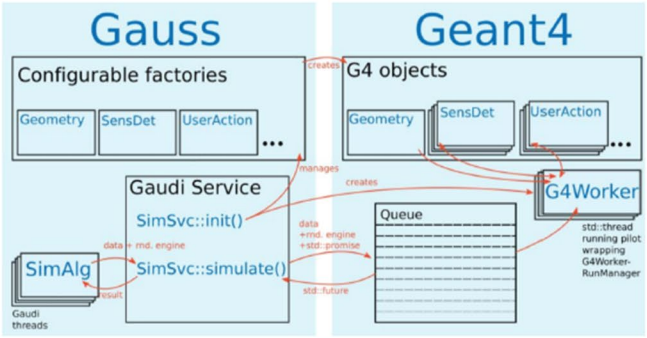
- Geant4 with multi-threading,
- Gaudi tools as factories for G4 objects,
- flexible python configuration:
  - pile-up – spillover – main event,
  - signal – other particles,
  - fast simulations,

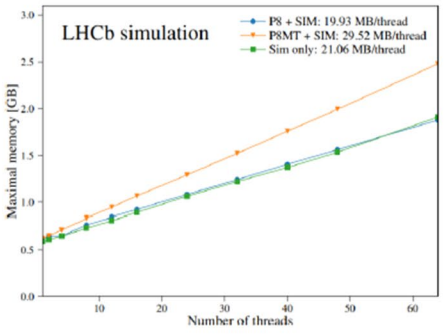
Layout

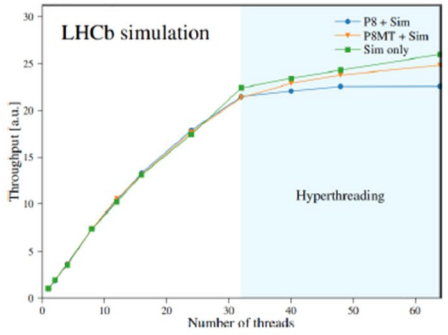
- **Gaussino:** interface to Geant4MT & fast simulations,
- **Gauss:** LHCb specific settings & models,

Performance

- simulation with Pythia8 interface







Ref: See Talk given by Michał Mazurek, Gauss and Gaussino, ICHEP 2022

Fast simulation in Gaussino

- Rich models for LHCb.
  - Maybe reuse them in CEPC.

Model	Generation	Decay	Propagation	Status in G-on-G
ReDecay	✓	✓	✓	done
ParticleGun	✓	✓	✓	done
SplitSim	✓	✗	✓	done
RICHless	✗	✗	✓	under tests
TrackerOnly	✗	✗	✓	under tests
Lamarr	✗	✗	✓	in progress
Point library	✗	✗	✓	in progress
GANs	✗	✗	✓	in progress

In-house parametrizations

Lamarr

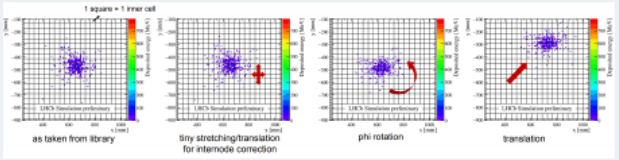
Idea: ultra-fast simulation option where not only the detector response, but also the reconstruction is parametrized

☞ more on Lamarr in another ICHEP 2022 talk by L.Anderlini

Fast simulation models with Geant4

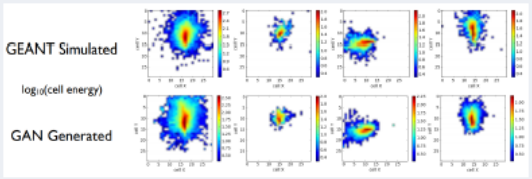
Point library

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



Ref: See Talk given by Michał Mazurek, Gauss and Gaussino, ICHEP 2022

Possibility of using Gaussino in CEPC

Gaussino and the current simulation framework in CEPCSW share a lot of similar underlying libraries, such as Gaudi, Geant4, DD4hep. Therefore, it is possible to use a unified simulation framework.

Several major technical issues need to be solved.

- How to build the Gaussino in CEPCSW environment?
- How to use EDM4hep in Gaussino?
- How to reuse the existing geometry service and detector description?
- How to reuse the detector response?

Current status and Plan

✓ Build and run Gaussino in LHCb build environment

☐ Build and run Gaussino in CEPCSW environment

☐ Integration with CEPC geometry

Testing Gaussino in LHCb env

- There is no valid grid certificate, so we can't deploy the software via LbEnv.
- The nighties builds in CVMFS are used for the testing.
- External Libraries: LCG 101x + x86_64_v2-centos7-gcc11-dbg
- Dependencies of Gaussino

```
export CMAKE_PREFIX_PATH=/cvmfs/lhcbdev.cern.ch/nightlies/lhcb-gaussino/latest:$CMAKE_PREFIX_PATH
export CMAKE_PREFIX_PATH=/cvmfs/lhcbdev.cern.ch/nightlies/lhcb-gaussino/latest/GaussinoExtLibs/InstallArea/x86_64_v2-centos7-gcc11-dbg:$CMA
export CMAKE_PREFIX_PATH=/cvmfs/lhcbdev.cern.ch/nightlies/lhcb-gaussino/latest/LHCb/InstallArea/x86_64_v2-centos7-gcc11-dbg:$CMAKE_PREFIX_P
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export CMAKE_PREFIX_PATH=/cvmfs/lhcbdev.cern.ch/nightlies/lhcb-gaussino/latest/Detector/InstallArea/x86_64_v2-centos7-gcc11-dbg:$CMAKE_PREF
export CMAKE_PREFIX_PATH=/cvmfs/lhcbdev.cern.ch/nightlies/lhcb-gaussino/latest/Geant4/InstallArea/x86_64_v2-centos7-gcc11-dbg:$CMAKE_PREFIX
```

- Detector setup: "External Tube" in example
- Testing result

	Single threaded	Multi threaded
Gen only	OK	OK
Gen + Sim	OK	OK (sometimes)

Break when using multithreading is under investigation

Summary and Plan

Summary

- CEPC simulation framework is developed to support the physics and detector performance studies.
- Explore Gaussino from LHCb as a possibility of unified simulation framework.

Plan

- Evaluate the integration of Gaussino into CEPCSW while reuse the existing code.

Thank you!