Performance of the Gaussino CaloChallenge-compatible infrastructure for ML-based fast simulation in the LHCb Experiment

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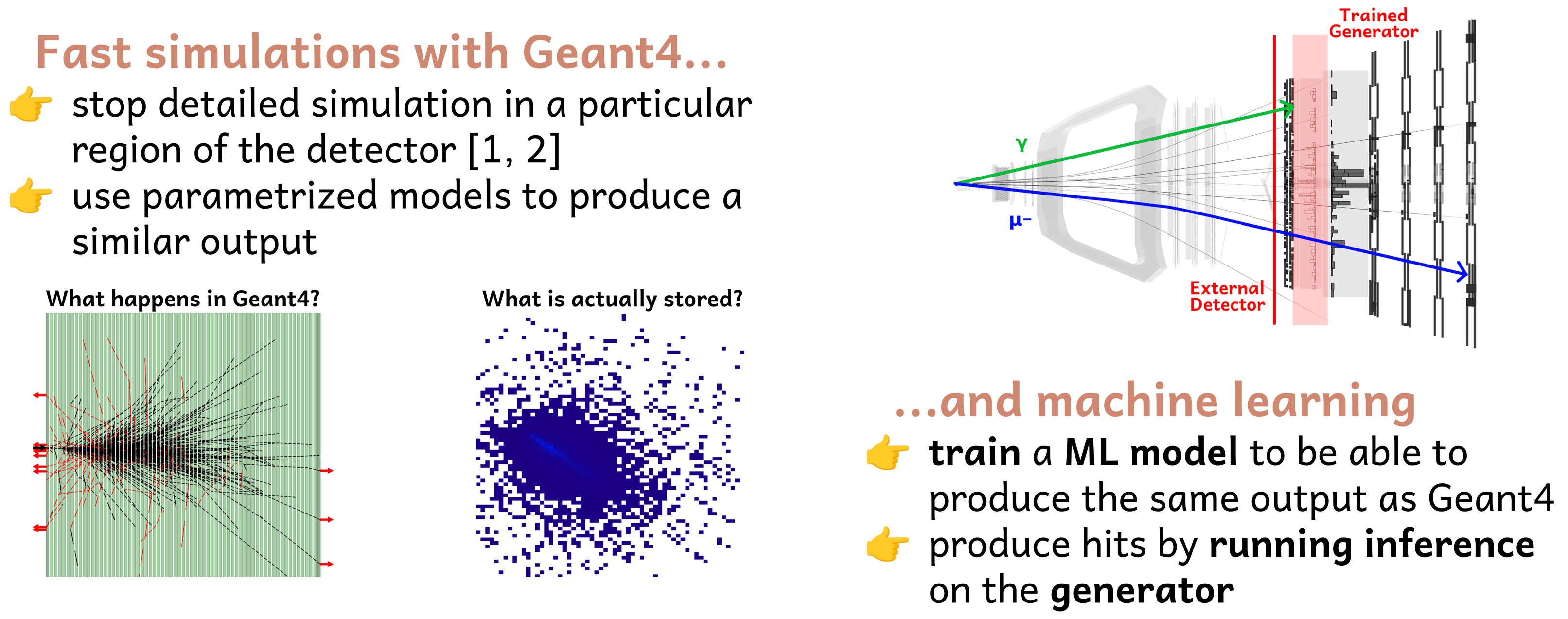
1. ML in Fast Simulations with Geant4

Fast simulations with Geant4...

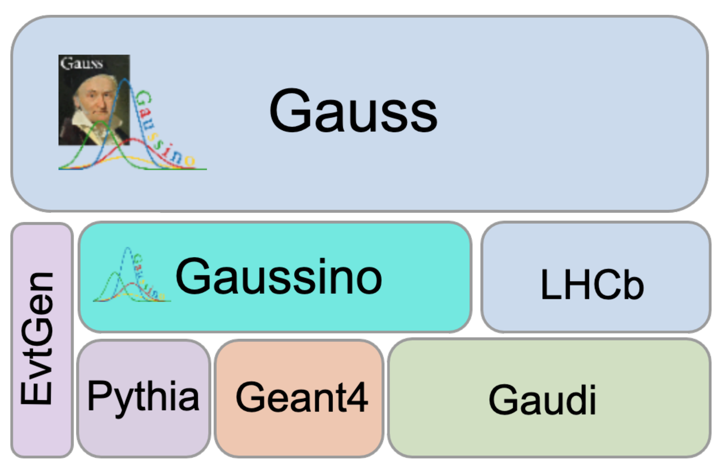
- stop detailed simulation in a particular region of the detector [1, 2]
- use parametrized models to produce a similar output



...and machine learning

- **train** a **ML model** to be able to produce the same output as Geant4
- produce hits by **running inference** on **the generator**

2. LHCb simulation framework



Gaussino

- core simulation framework [3]
- only experiment-independent components
- ideal test bed for new developments

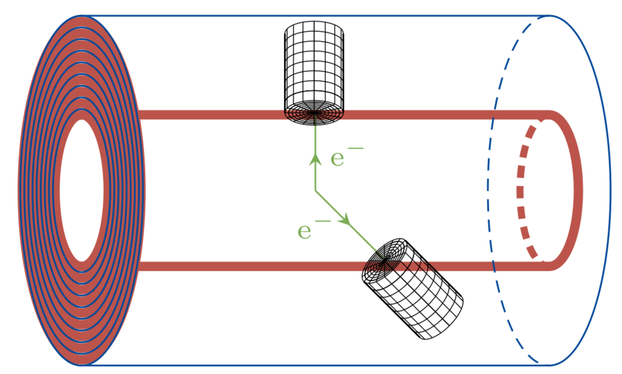
Gauss-on-Gaussino

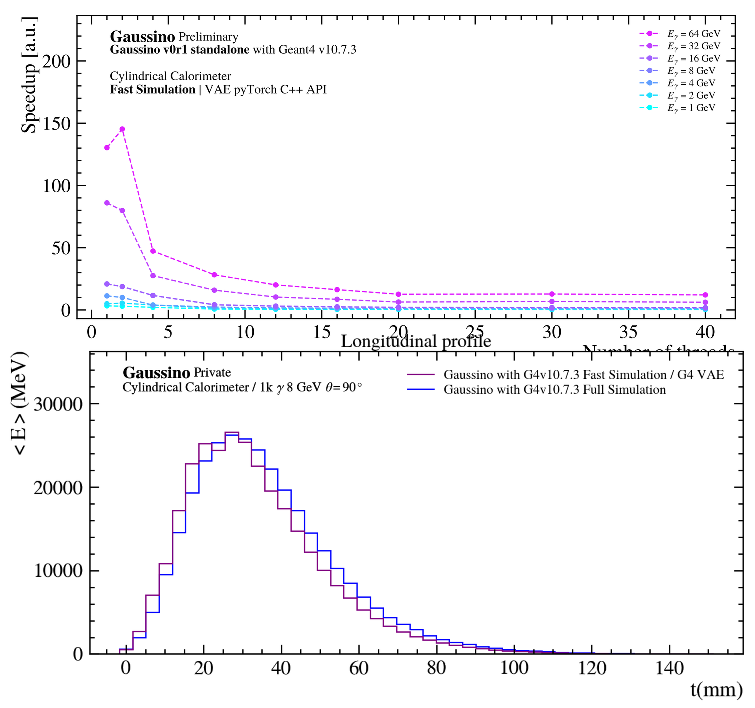
- the latest version of the LHCb simulation framework
- based on Gaussino's core functionalities
- adds LHCb-specific components and configurations

3. CaloChallenge and Gaussino

CaloChallenge...

- new **Geant4** initiative [4, 5]
- train on **experiment-agnostic training dataset**
- **compare** various **models objectively**
- **retrain** the chosen model on the **target geometry!**

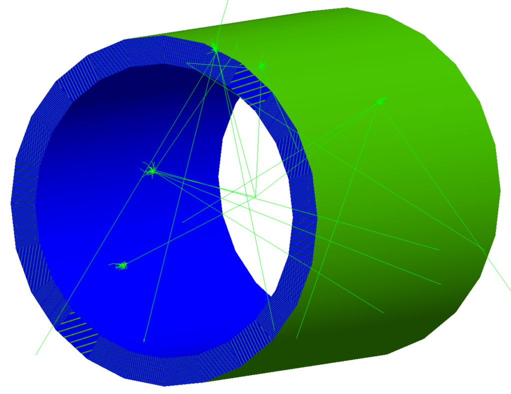




... in Gaussino

- adapt to **Par04** example of CaloChallenge using **Gaudi** core software components
- provides **production-ready** setup for HEP experiments!

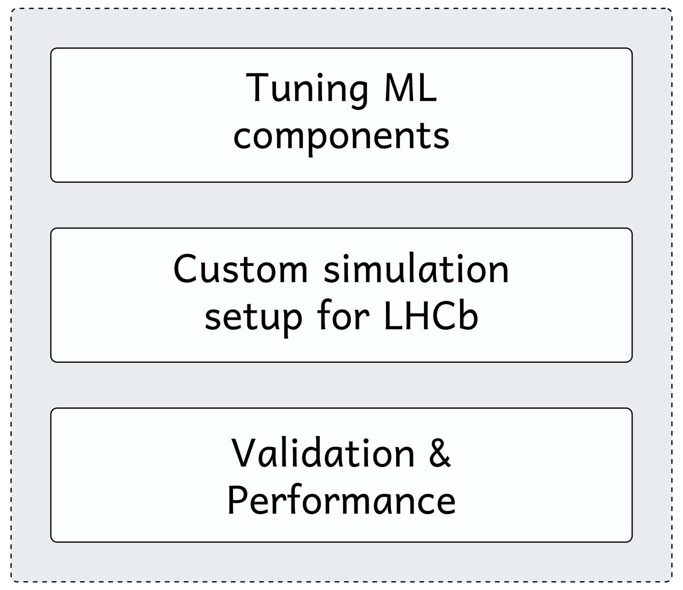
presented at CHEP[6]



4. Running in LHCb

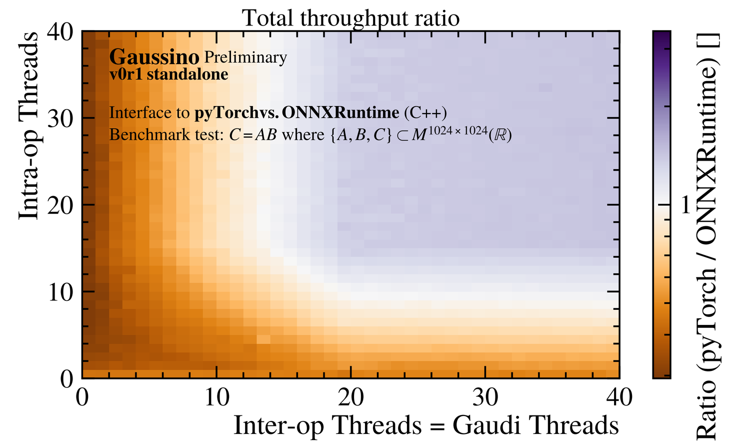
Recipe for production-ready setup in LHCb

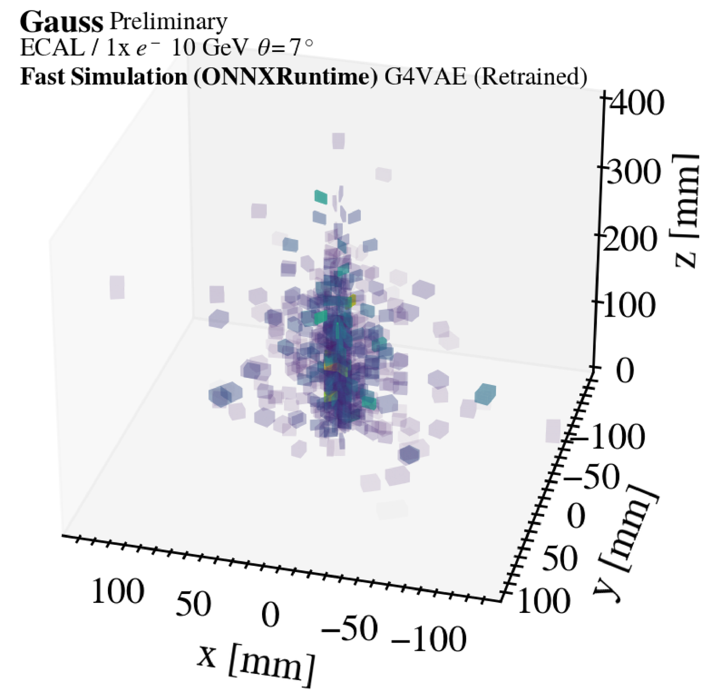
- choose & benchmark C++ interfaces to ML libraries with a chosen ML model
- adapt the model to the LHCb-specific geometry & decide where the fast simulation hooks should be triggered
- validate the model against the LHCb Geant4 detailed simulation data

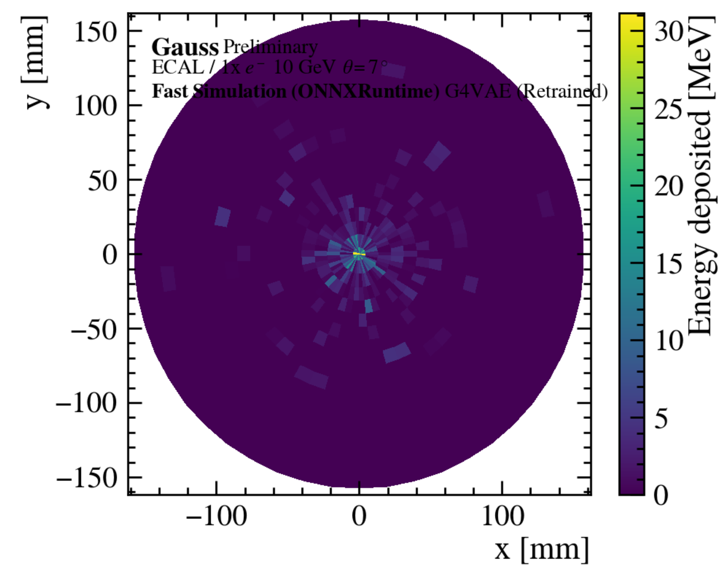


5.Tuning ML components

- adapted & tested **ML interface** to **ONNXRuntime** & **PyTorch** C++ backend
- **Variational Autoencoder (VAE)** model with optimized **custom resampling head** trained on particle gun data

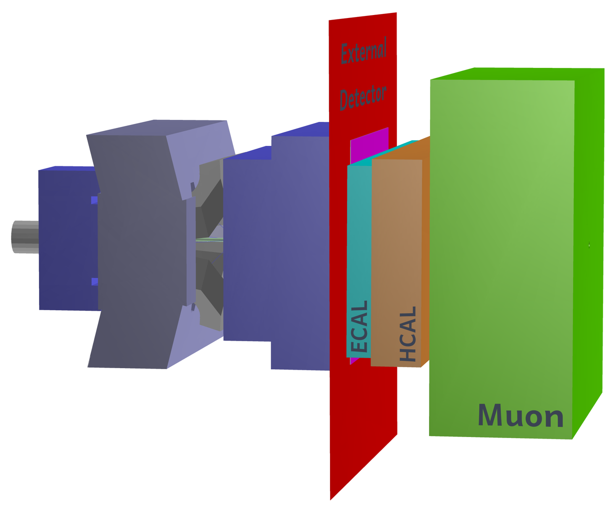


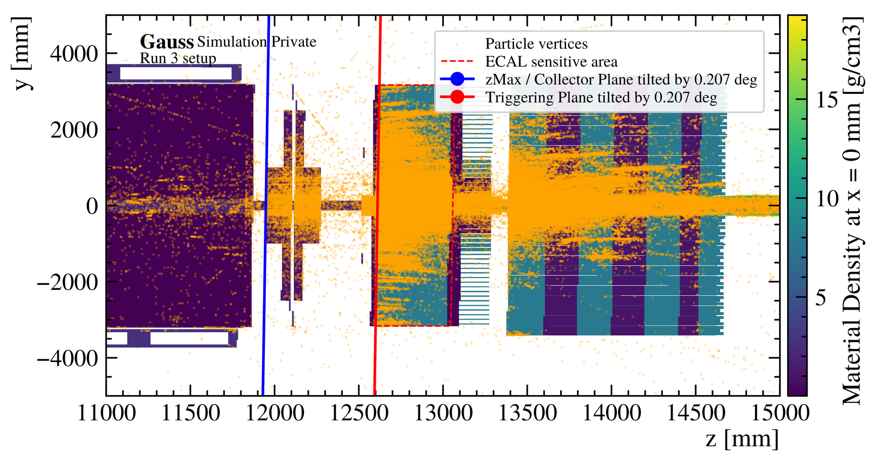




6. Exploit custom simulation interface for LHCb

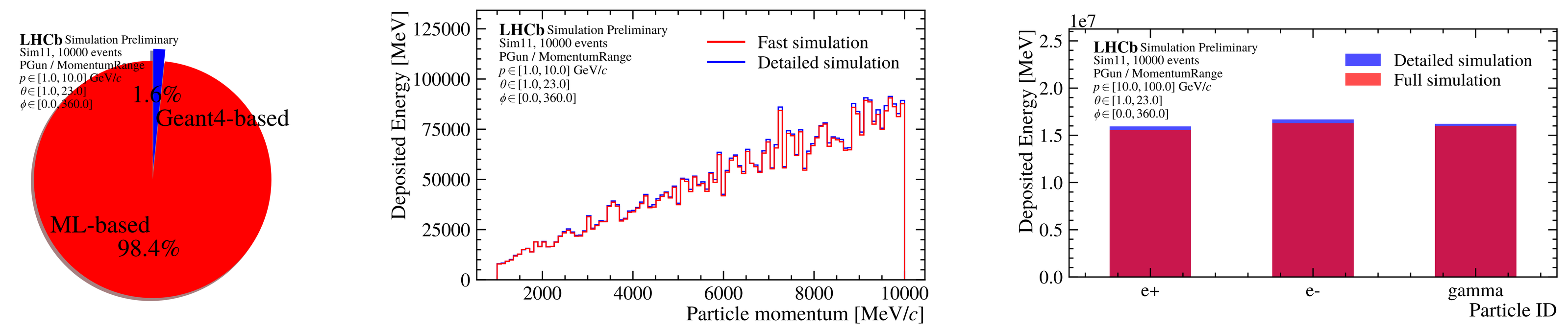
- a very thin plane in front of the calorimeter acts as a triggering point
- works in both cases: inference time and training data production



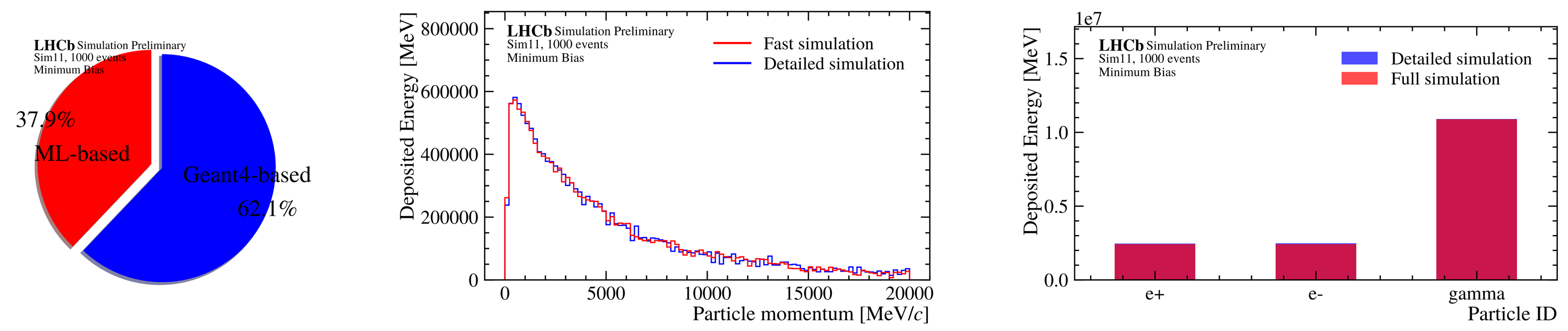


7. Validation & Performance

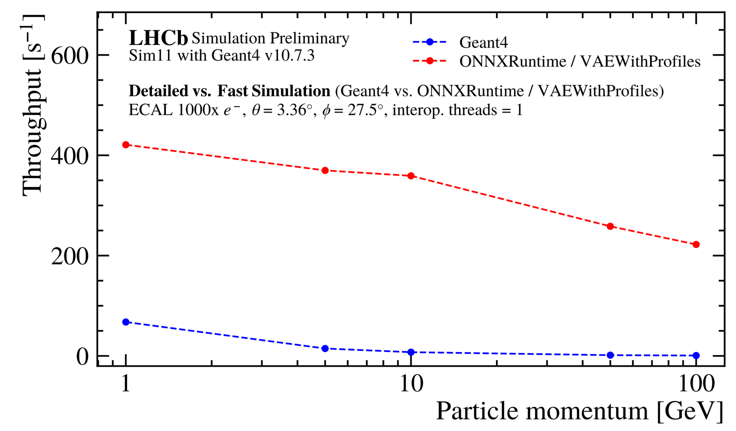
- particle guns

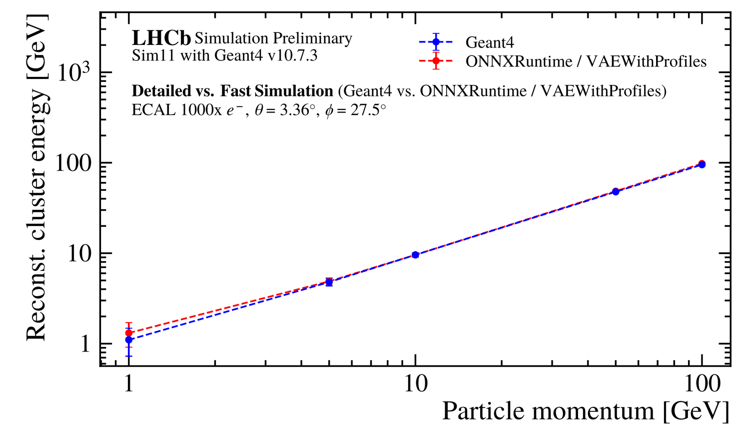


- pp collisions at 13.6 TeV center-of-mass energy

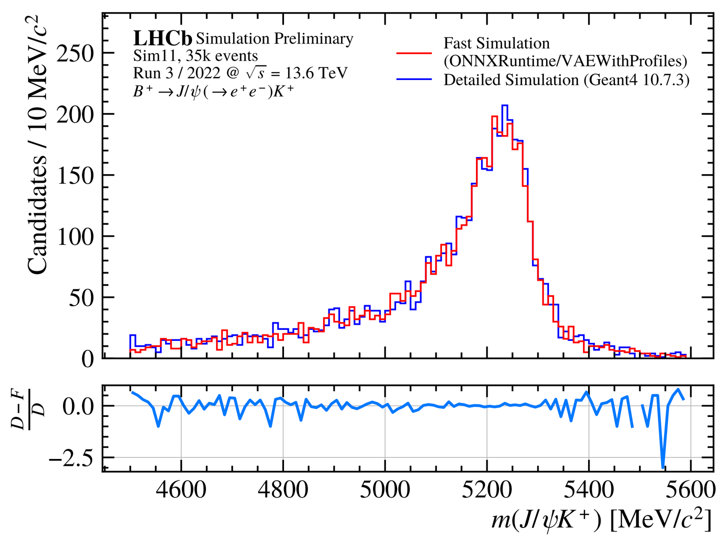


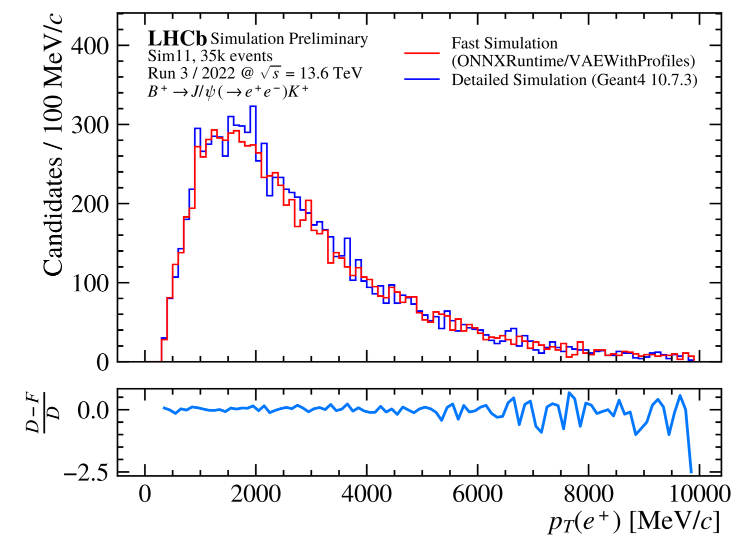
- performance
- reconstructed energy





- a physics channel: $B^+ \to J/\psi\,(\to e^+e^-)K^+$





- **One model only for e^+, e^- and γ in the electromagnetic calorimeter**
- **Up to 400× speedup in the simulation throughput**
- **Around 1-4% energy difference vs. Geant4-based simulation**
- **Try out a first production on the LHCb distributed computing!**

8. References

[1] Michał Mazurek, Gloria Corti, and Dominik Müller. New Simulation Software Technologies at the LHCb Experiment at CERN. https://cds.cern.ch/record/2790591, Nov 2021. LHCb-PROC-2021-011.

[2] S. Agostinelli et al. Geant4: A simulation toolkit. *Nucl. Instrum. Meth.*, A506:250, 2003.

[3] B. G. Siddi and D. Müller. Gaussino - a gaudi-based core simulation framework. In *2019 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)*, pages 1–4, 2019.

[4] Geant4 collaboration. G4FastSim. https://g4fastsim.web.cern.ch/, 2023.

[5] CaloChallenge. https://calochallenge.github.io/homepage/, 2023.

[6] Michał Mazurek. From prototypes to large scale detectors: how to exploit the Gaussino simulation framework for detectors studies, with a detour into machine learning. 2023. LHCb-TALK-2023-110.