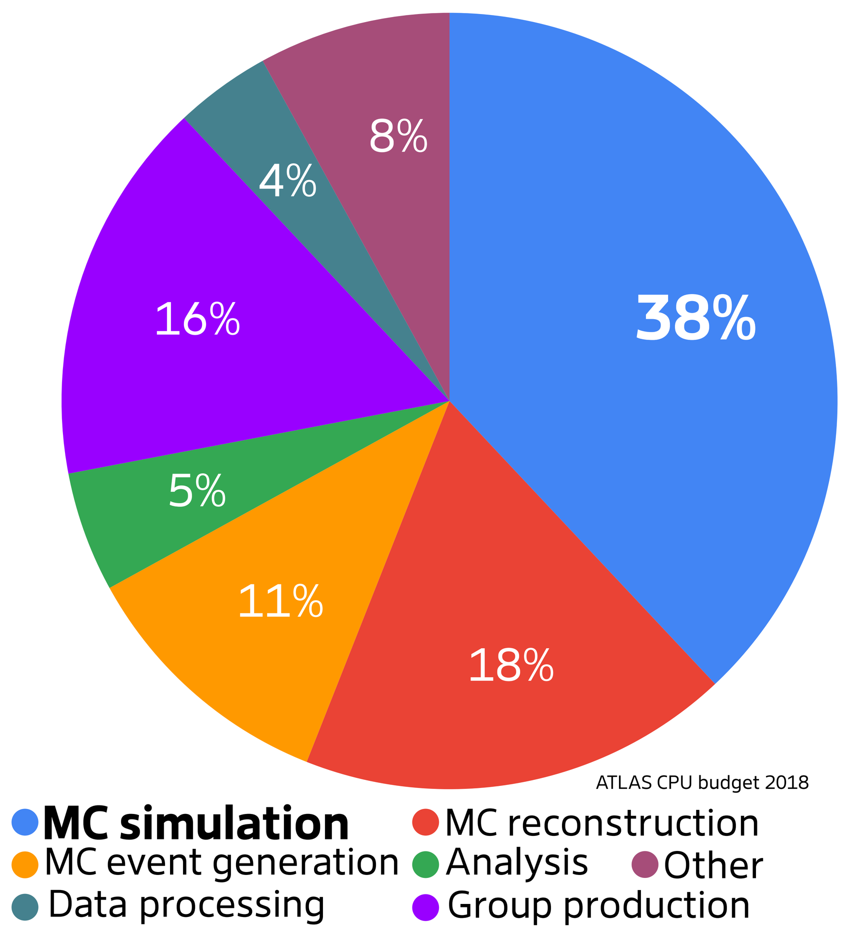
Fast calorimeter shower simulation with generative Machine Learning

Computing Resources

- HEP experiments require vast amounts of computing resources
- majority of resources spent on detector (MC) simulation
- **calorimeter simulation is the most expensive part by far**



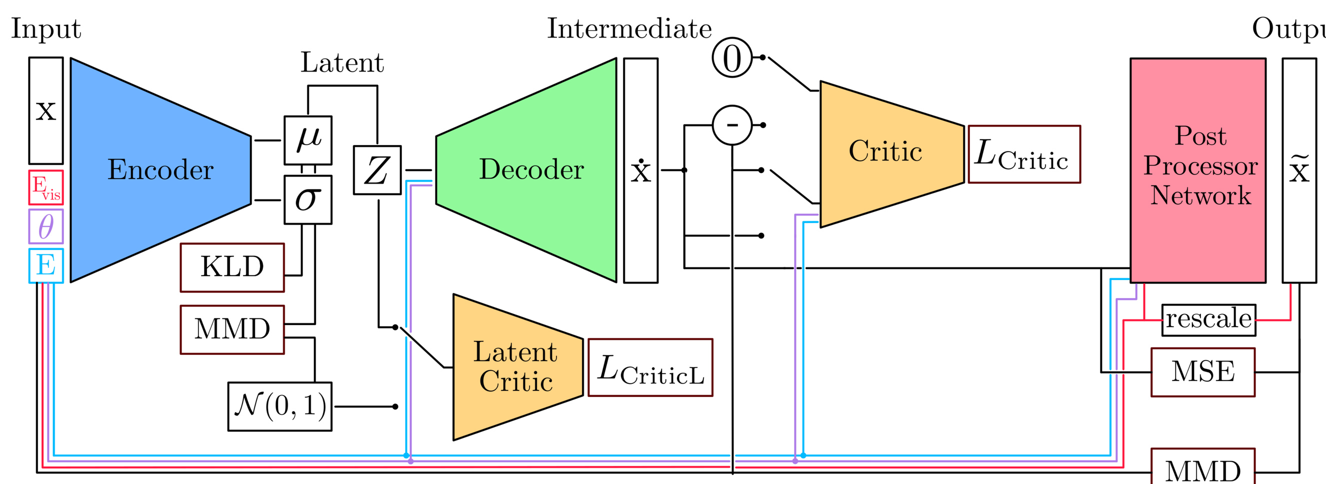
Generative Machine Learning

- ML has the potential to speed up simulation by orders of magnitude
- reduce the required computing resources and increase sustainability
- generative models can be used for fast calorimeter shower simulation
- generate calorimeter response directly or energy deposits for further processing
- *conditioned* on e.g. incident particle energy, direction, etc.

Generative Adversarial Networks and Auto-Encoders

- powerful generative models that learn how to generate "fake" data
- basic principle: try to fool discriminator with the generated fake showers
- discriminator and generator trained in tandem

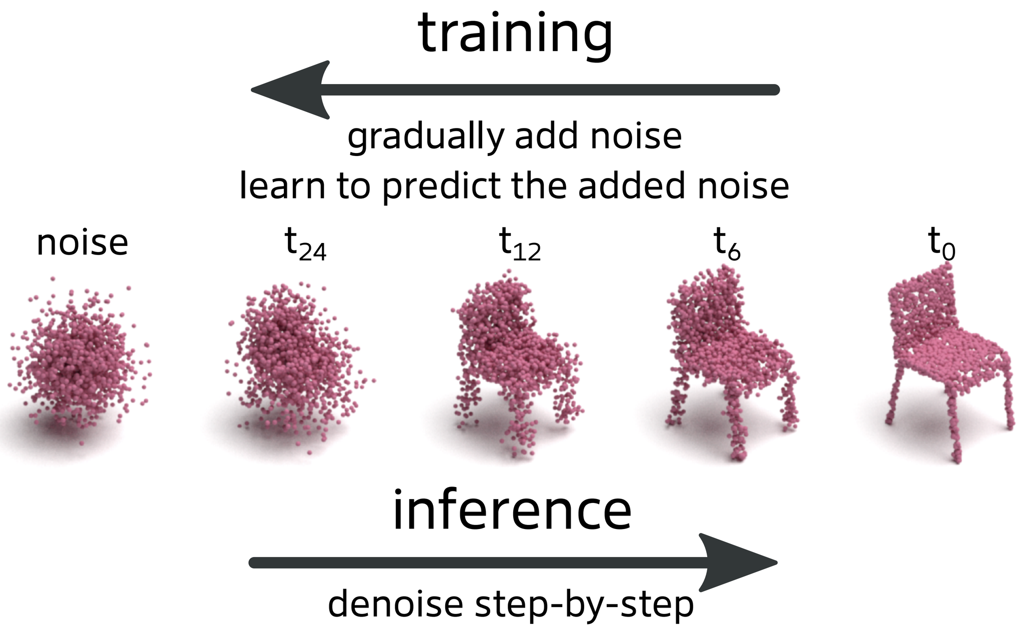
BiB-AE



- complicated model based on an Auto-Encoder
- generates the detector response directly
- model with best physics performance at the moment

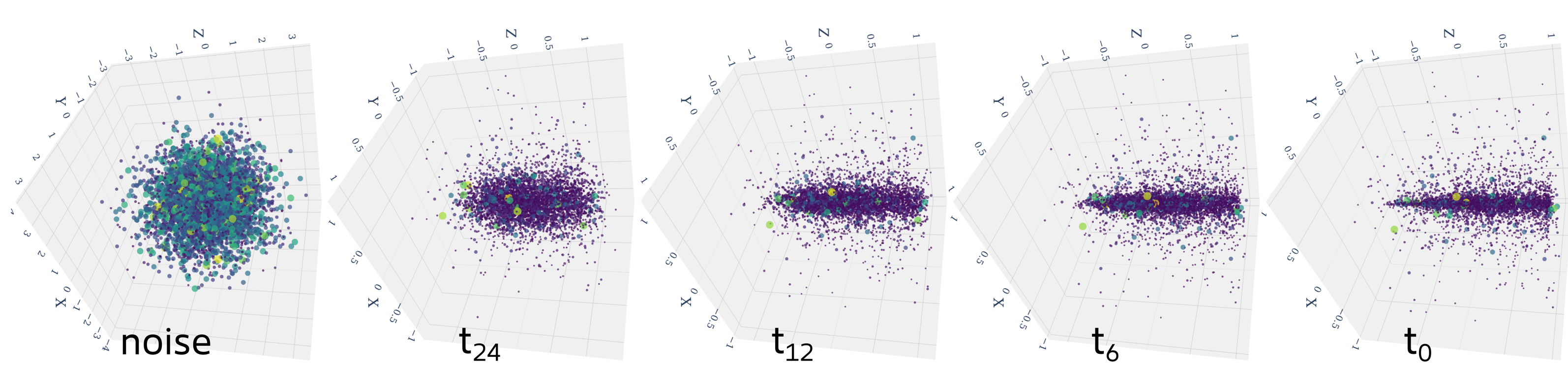
Diffusion Model

- state of the art ML technique that became popular in the last few years
- used e.g. by **Stable Diffusion** (StabilityAI), **Dall-E** & **Sora** (OpenAI), etc.



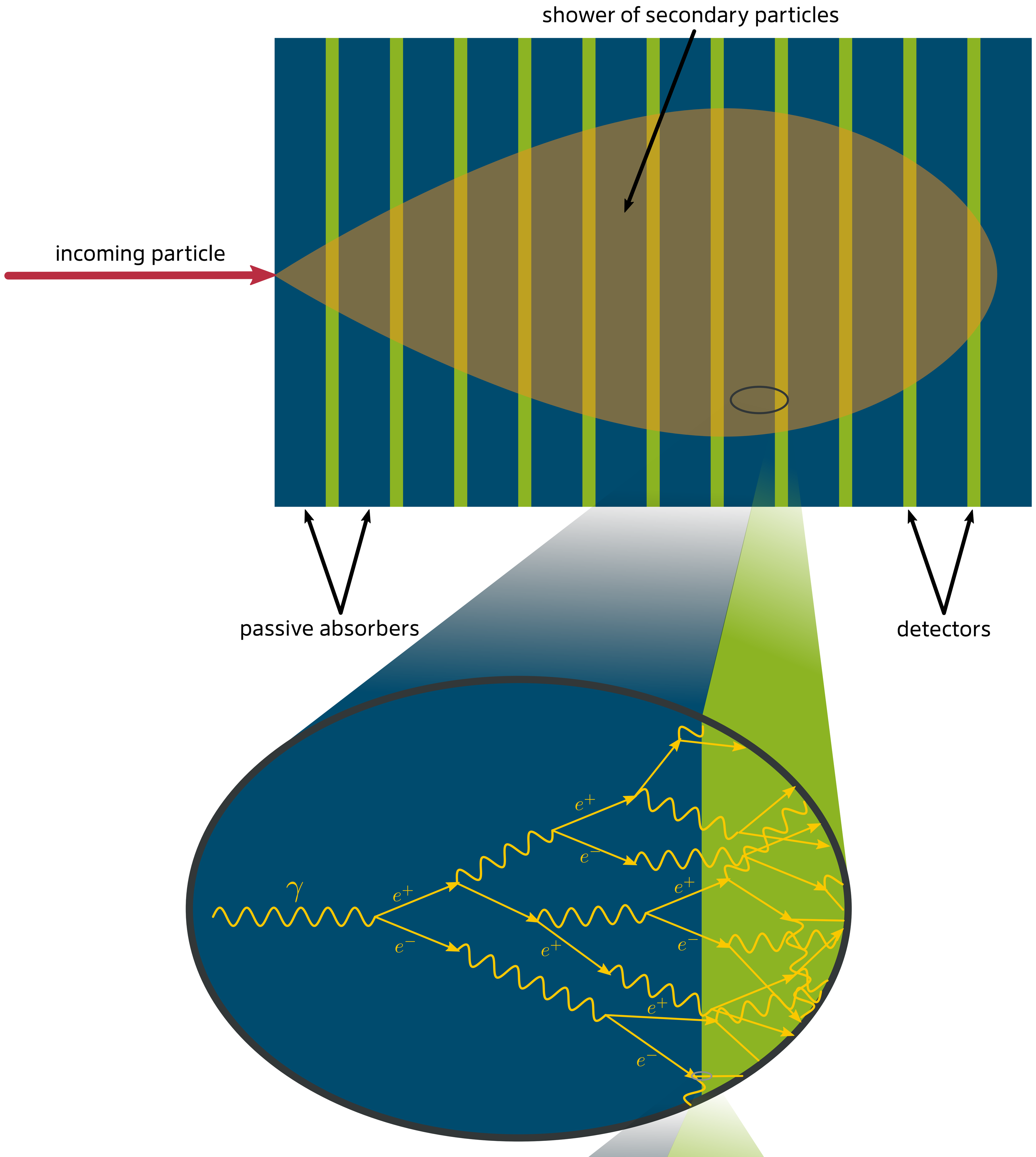
CaloClouds

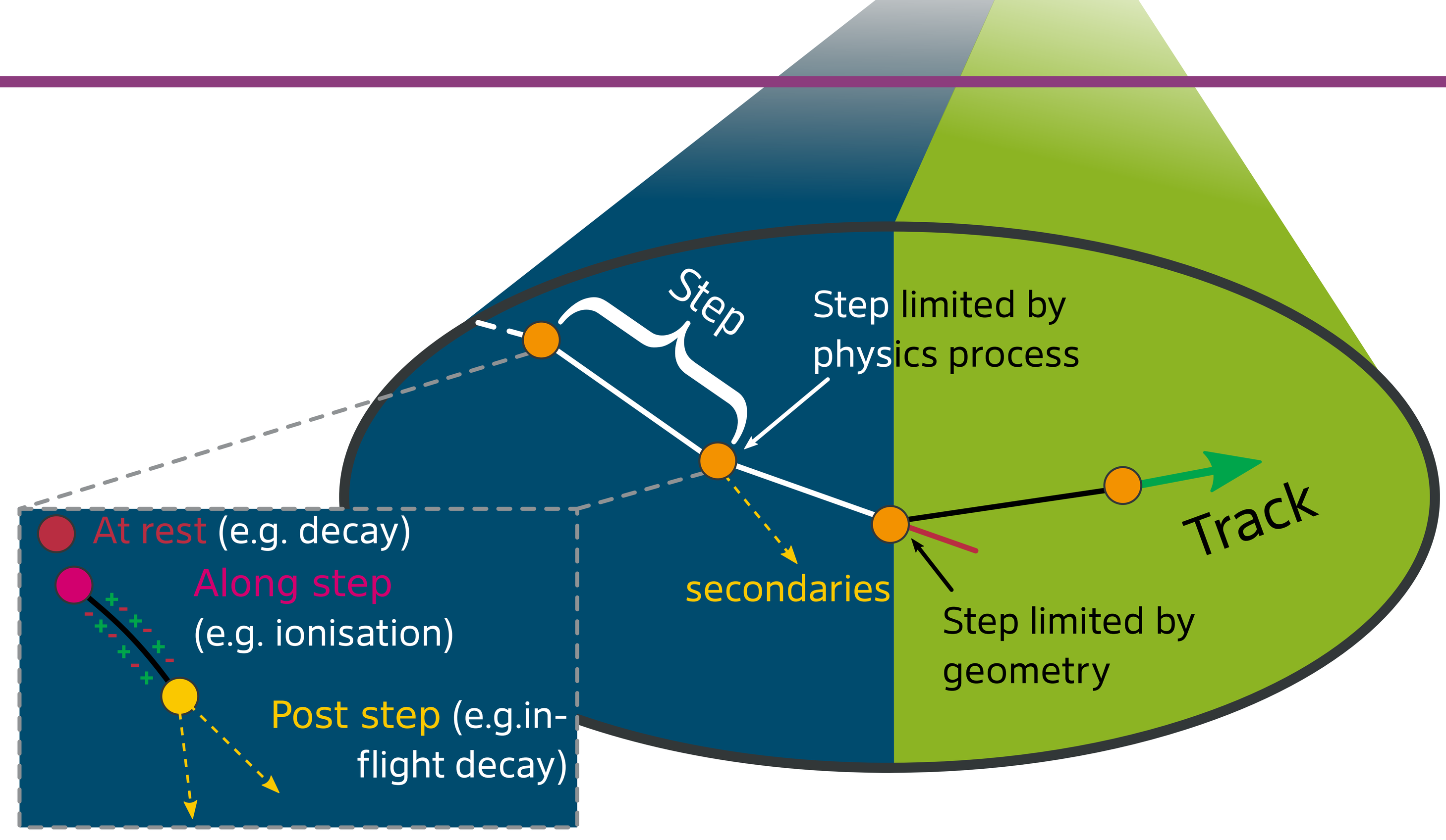
- a diffusion model for fast calorimeter shower generation
- generates a point cloud of energy deposits



Sampling calorimeter

- alternating layers of passive absorber and sensitive detector material
- materials can be separately chosen to optimize performance
- only a fraction (few percent) of the total deposited energy is measured

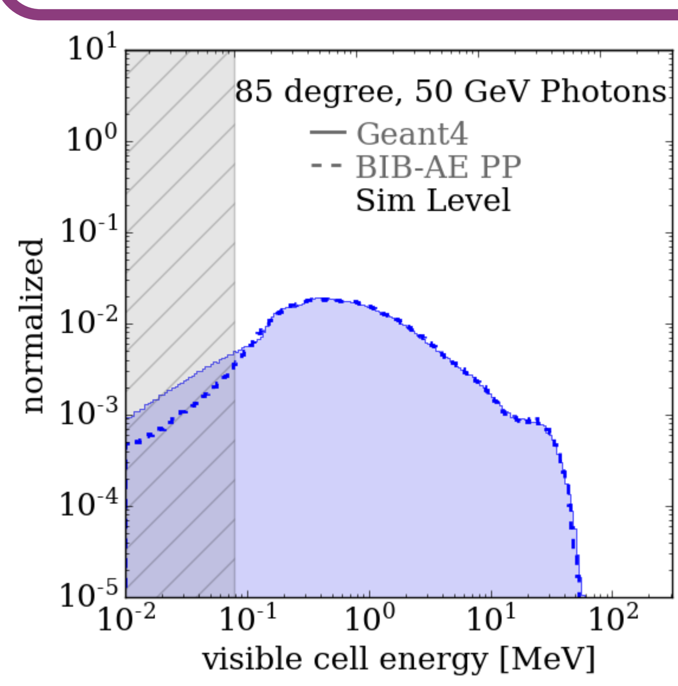


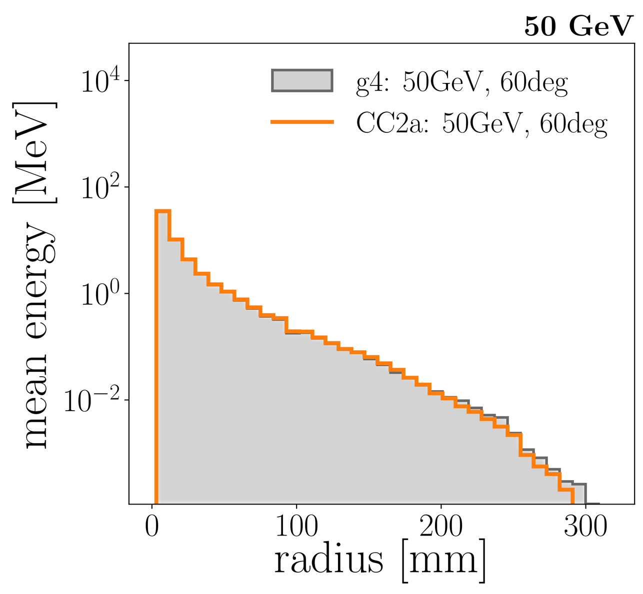


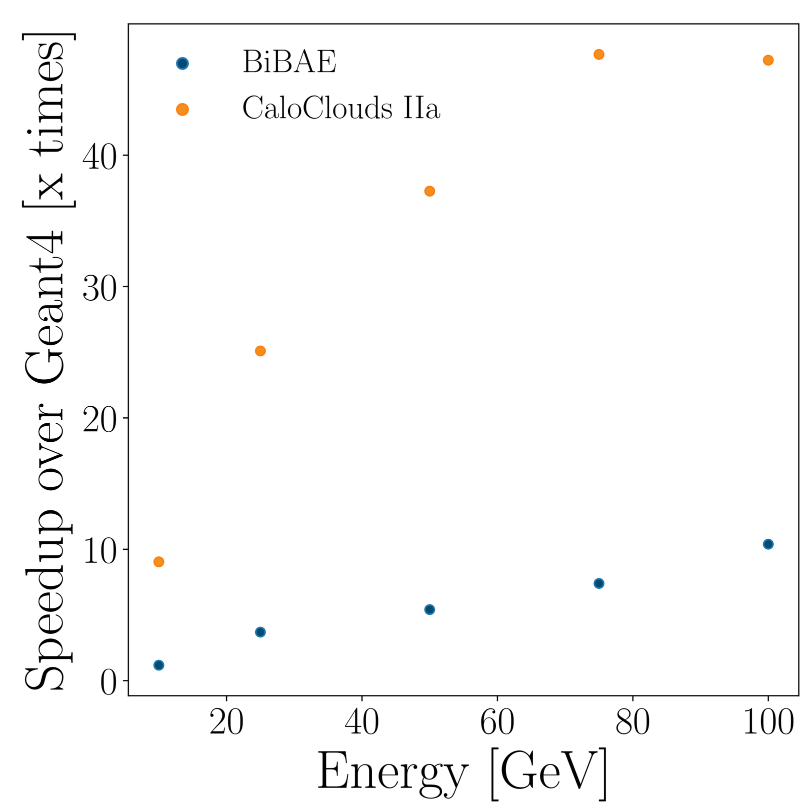
Geant4 simulation

- standard toolkit for simulations of particles propagating through matter
- used in HEP and other areas (e.g. medicine)
- detailed simulation of all physics processes on a microscopic scale
- tracking all particles until they have deposited all their energy

Results







up to **factor 50 quicker** than Geant4!

retaining important physics observables

Come and see it yourself

DESY.