Fast Simulation of ToF detectors at the LHC

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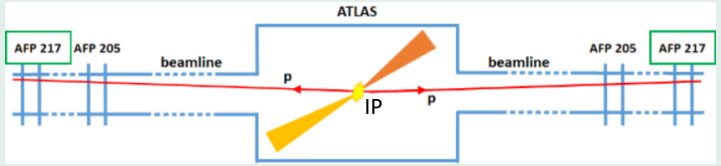
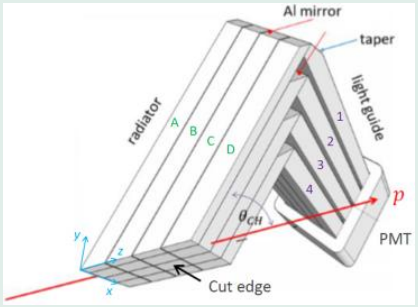
1. Example of study: ATLAS Forward Proton Time-of-Flight detector

The ATLAS Forward Proton (AFP) detector aims at measuring soft and hard diffractive protons leaving under very small angles (order of hundreds of µrad) the ATLAS interaction point (IP). The AFP stations are placed 205 m and 217 m in both directions from the ATLAS IP .





Far stations consist of two subdetectors: Silicon Tracker (SiT) and ToF detector. Time-of-Flight (ToF) system is used to reduce the background from multiple proton-proton collisions; it has an "L-shape" and consists of several parts: radiator - light guide - photomultiplier - back-end electronics.

2. Geant4 simulation vs Fast simulation

Geant4: Monte Carlo toolkit to simulate the passage and interactions of elementary particles with matter. It has been used to optimize the optical shape and performance of ToF detector.
Disavantage: very time-consuming (simulation of a thousand events takes few hours).

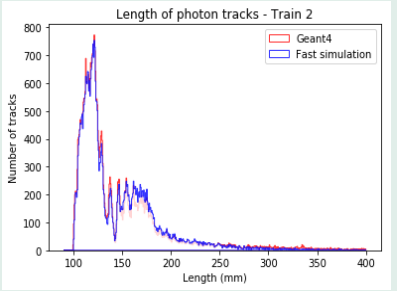
We expect the geometrical method to be faster than Geant4. The fast Cherenkov model is based on efficient photon path length calculations, which use the laws of geometrical optics and some approximations. It uses the programming language Python and the module Numba (high performance compiler) to speed up the process.

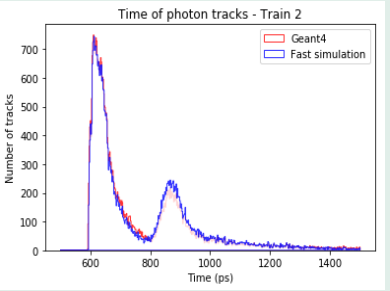
Fast simulation flow:

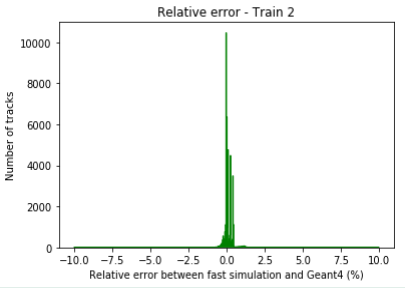
1. Generation of Proton trajectories
2. Generation of Cherenkov photons
3. Photon tracking through ToF detector (radiator and light guide)
4. Photons reach the Photomultiplier (conditions of reflection are fulfilled)

3. Results of Fast Simulation and comparison with Geant4

Comparison of length and time distributions for the case of the full train 2:
We performed the simulation by generating 10^5 Cherenkov photons with random positions of vertices, for a fixed trajectory of proton. About 43 % of initial photons reach the PMT.







Duration of simulations for the generation of 3.3×10^6 photons:

Geant4 simulation	Geometrical method in C++	Fast simulation
11,5 minutes	20 seconds	3 seconds

Computation of the time resolution, by assuming $\sigma_t \propto 1/\text{Amplitude}$.

4. Conclusion

The distribution of lengths obtained by the Fast simulation and Geant4 have the same shapes, with relative difference < 2%. Fast simulation is then in a good agreement with Geant4.
More, Fast simulation is about 200 times faster than Geant4 .
Code of Fast simulation (with Python 3): *https://github.com/ olivierrousselle/Fast-simulation-AFP*
Opening: such a Fast simulation with Python and Numba could be used to model other types of ToF detectors; it seems more convenient and faster than Geant4.

5. Bibliography

ATLAS Collaboration, *ATLAS Forward Proton – Technical Design Report*, ATLAS-TDR-024, 009 (2015)
A. Marowka, *Python accelerators for high-performance computing*, The Journal of Supercomputing , 74 (2018)
O. Rousselle, *Fast simulation of the ATLAS Forward Proton detector*, CERN Summer student report (2019)