Development of RICH software using GPUs

ECFA - DRD4 Workshop

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Introduction

- Graphics Processing Units (GPUs) are already used for various applications in HEP in recent years.
- In this context, I focus on the usefulness of GPUs for the software related to Cherenkov detectors.
- In the coming years experiments need to simulate and reconstruct billions of events which have RICH data.
  - This is specially important for experiments at the LHC.
  - If one uses the standard CPUs, the cost of running these programs will become prohibitively expensive.
- Simulation:
  - RICH simulation requires single photon transport.
  - Until recently, RICH simulation consumed ~30% of the CPU time of LHCb simulations.

    We would like to reduce the fraction of time taken up by the RICH
  - GPUs are used efficiently by the industry for ray tracing optical photons.

    Example: OptiX from NVIDIA is used in video games.
  - Optical photon simulation is well suited for GPUs
- Reconstruction:
  - The parallelization offered by the GPUs can be useful for various parts of the particle identification procedure in the context of large number of track-hit combinations.

Outline

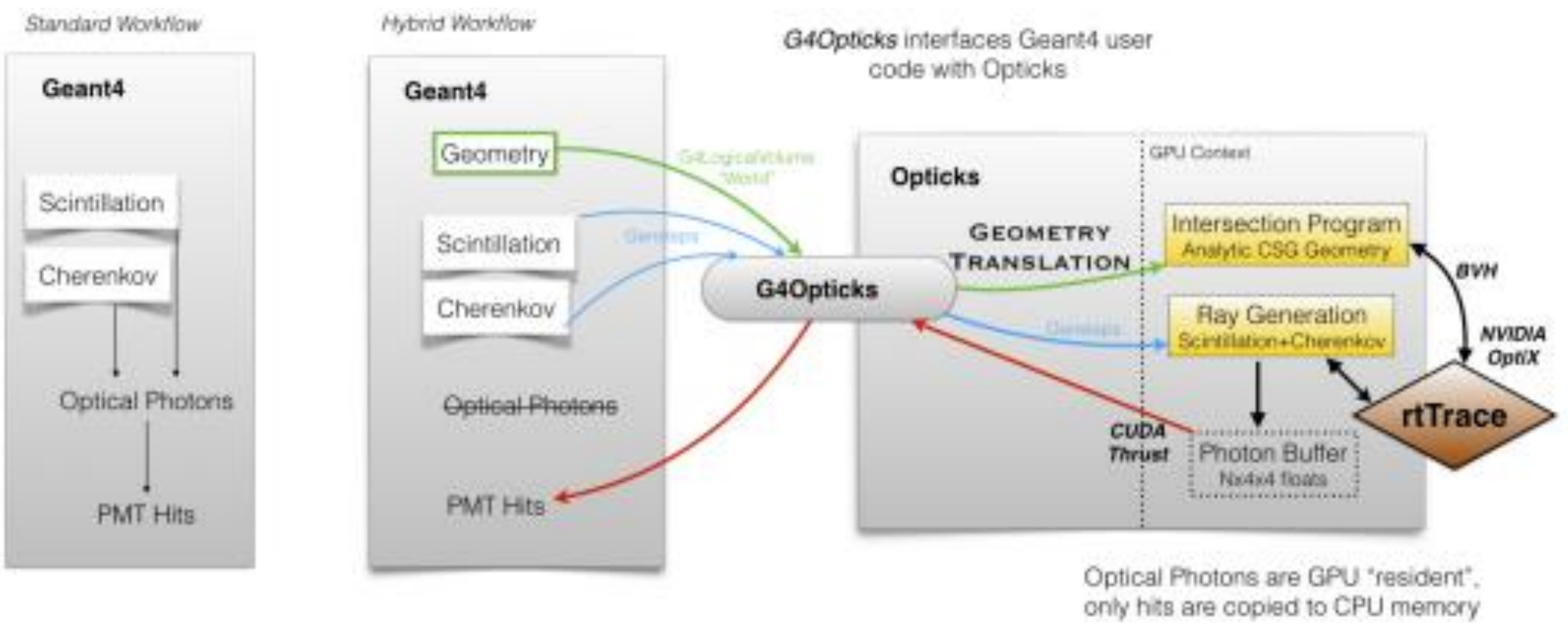
- Pioneering work in JUNO for using GPUs
- General structure of the program for simulation using GPUs
- Proof-of-principle implementation in LHCb.
- RICH reconstruction: usefulness of GPUs
- Prospects

JUNO Simulation

- The Dayabay and JUNO neutrino experiments have large water Cherenkov detectors.
- The detector simulation is based on the GEANT4 package.
- GEANT4 is used for the simulation of all the particles other than optical photons
- The OptiX package from NVIDIA is used for optical photon simulation.
- An interface package named Opticks was developed to provide the interface between GEANT4 and OptiX Simon Blyth is author and maintainer of this interface package.
- This was the first attempt to use the OptiX for simulating optical photons in a HEP experiment.
- At present many HEP groups are starting to use this method for photon simulation.

General structure

Ref: S.Blyth,
EPJ Web Conf, 251 (03009) , 2021

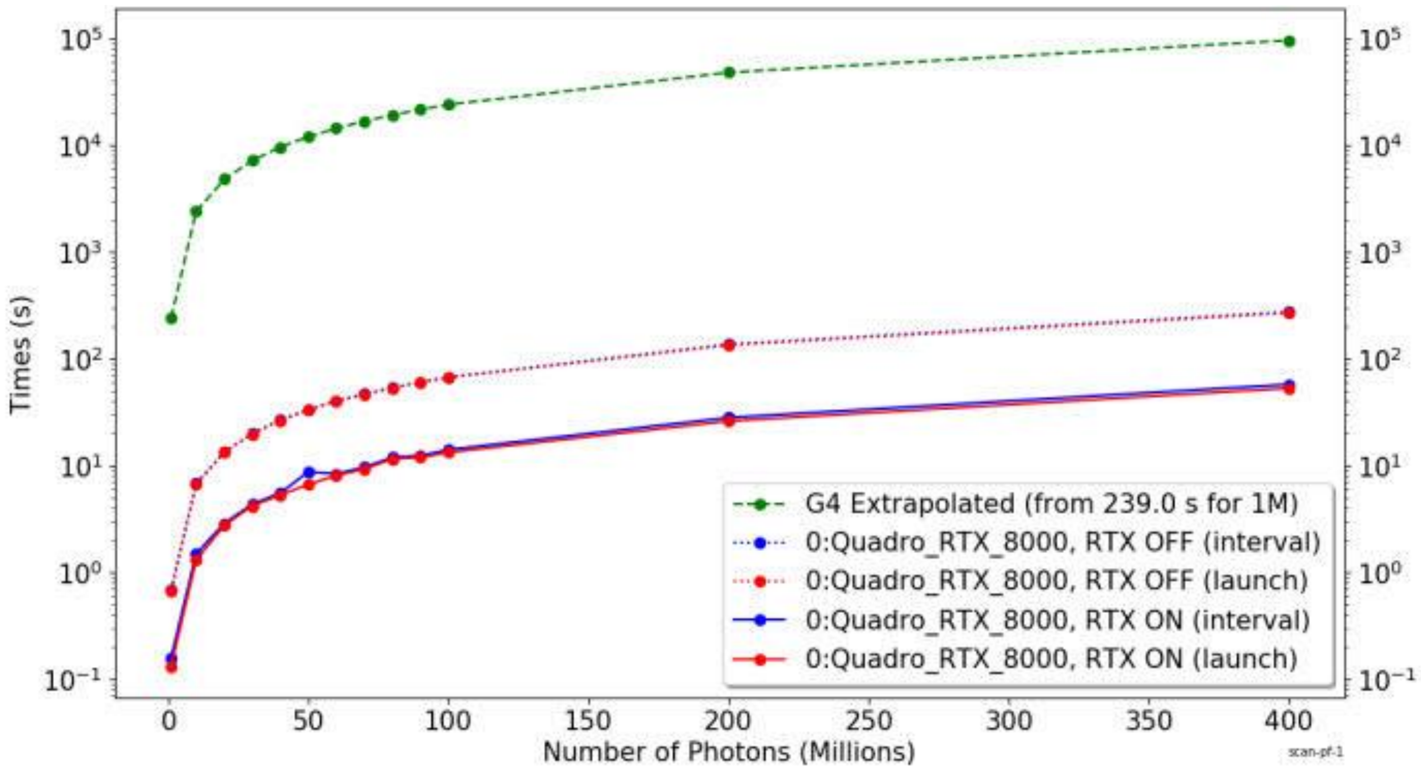


Recently this structure is modified with OptiX7. See backup slide

- Optical processes: For the creation and transport of optical photons in the standard GEANT4 workflow
- Hybrid Workflow:
  - Instead of using GEANT4 optical processes, the corresponding methods in OptiX are used
  - All other particles are tracked by GEANT4 as in the standard workflow.
- Opticks
  - This enables to translate the required parts of geometry and optical properties, into a format needed by OptiX
  - This also facilitates copying the information on the ‘hits’ in photon detectors, back into GEANT4.

Performance in JUNO

Simulation time versus number of photons



Ref: S.Blyth,
EPJ Web Conf, 251 (03009) , 2021

Green: GEANT4 alone

Solid Red: GPU with RTX option
Dotted Red: GPU without RTX option

Red: Without overhead for upload/download each event
Blue: With overhead for upload/download each event

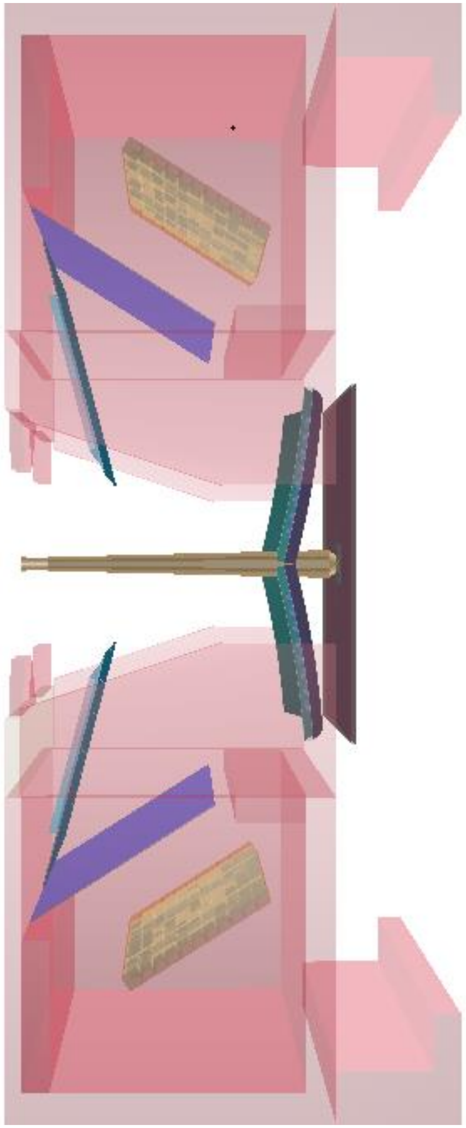
(Difference between Red and Blue is small on the scale of these plots, with log scale along the vertical axis)

- In this illustration, for 400 million photons
  - Time taken by GEANT4 : 95600 seconds (Using GEANT4 version 10.4.2 in single threaded mode)
  - Time taken by OptiX (with Opticks) : 58 seconds (Using a single GPU)

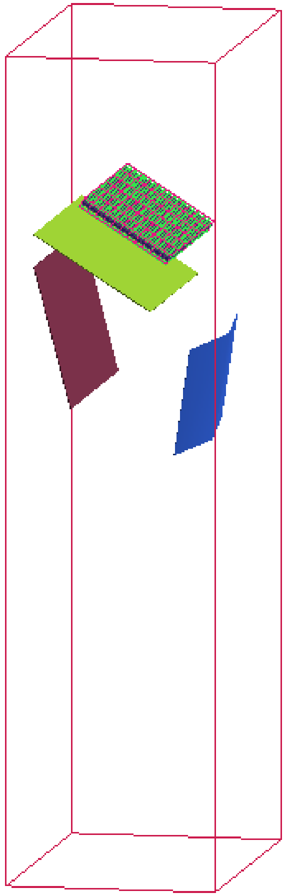
Goals in LHCb

- We would like to eventually achieve similar success in LHCb and other experiments which use RICH detectors.
- To this end we started an R&D program within the scope of LHCb
- Goals of the R&D project :
  - Use the Opticks and OptiX in a simple RICH system as proof-of-principle
  - Compare the results from the new system with those from running GEANT4 alone.
  - Transform the full LHCb-RICH simulation to be able to use the GPUs
  - Integration into the LHCb software framework, which uses DD4HEP and Gaussino

Full and simplified RICH



LHCb-RICH1



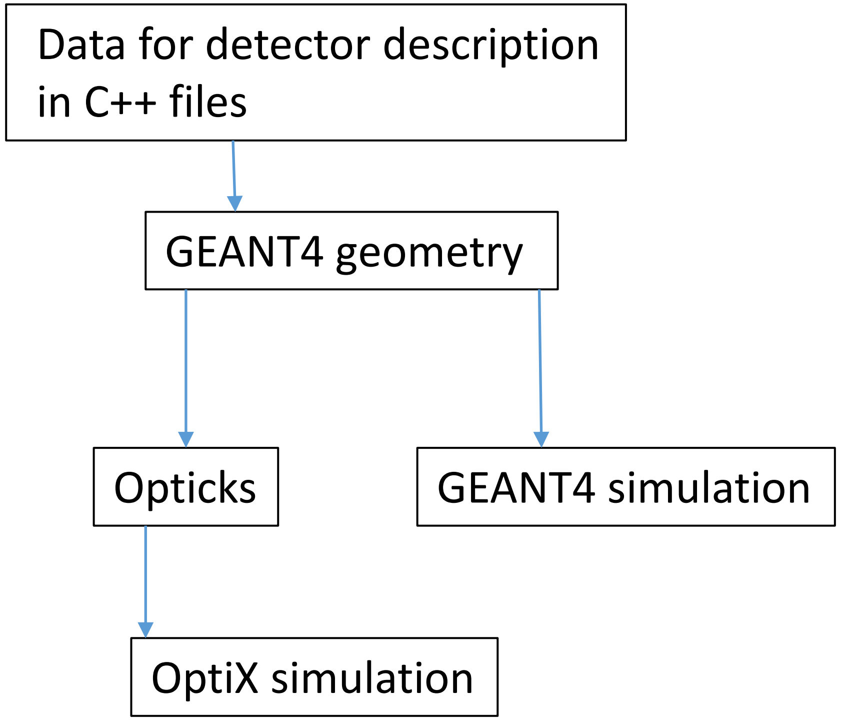
Simplified RICH

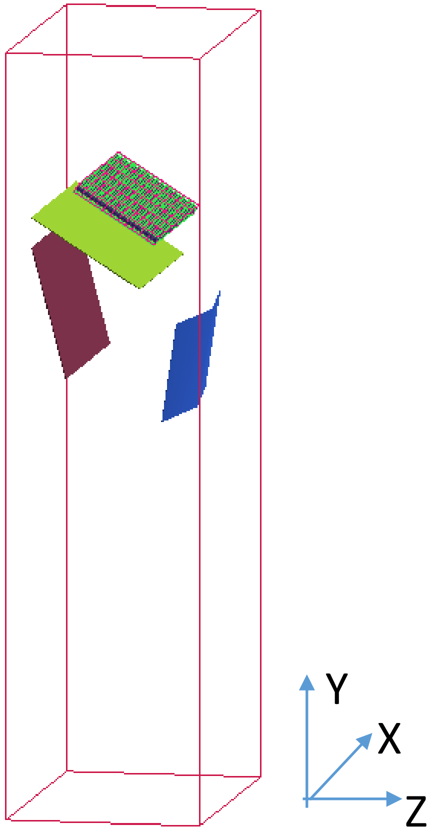
- Simplified RICH description :
  - It has the same optical geometry, radiator and photon detector system as that of LHCb-RICH1
    The optical properties (Mirror reflectivities, QE etc) are same as those used for LHCb-RICH1
  - However there is only a single set of spherical and 'flat' mirrors in the top half, without their supports.
    There is no beam pipe, exit window and magnetic shielding

Simplified RICH

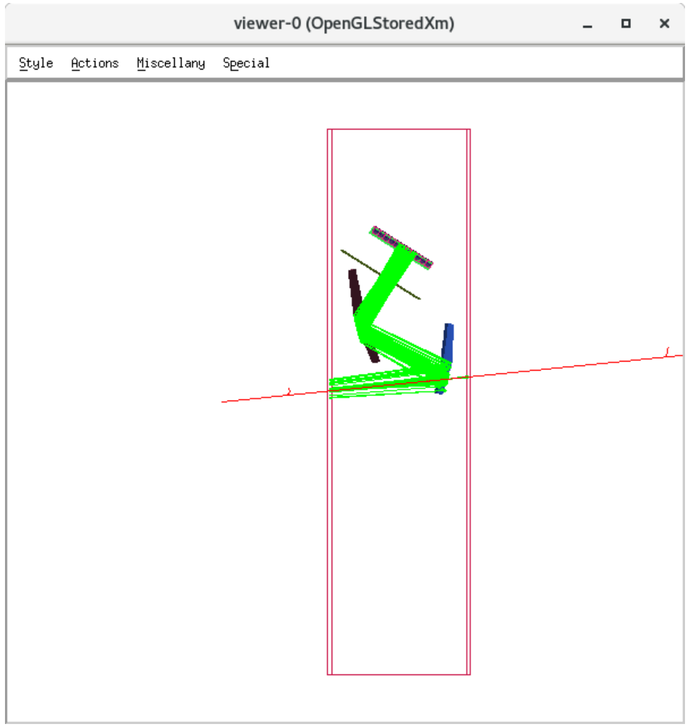
- Many issues were solved in translating the geometry from the GEANT4 into Opticks.
  - *This enables CSG (constructive solid geometry) → BREP (Boundary representation)*

- Work flow:





GEANT4 : OpenGL graphics

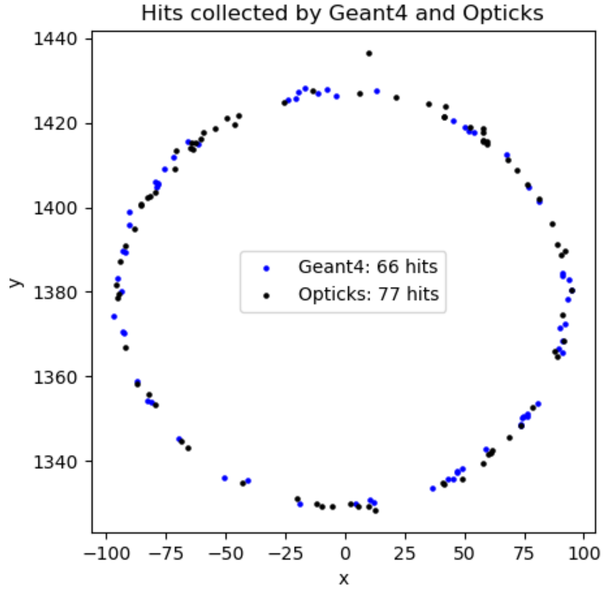


Particle gun used in simplified RICH

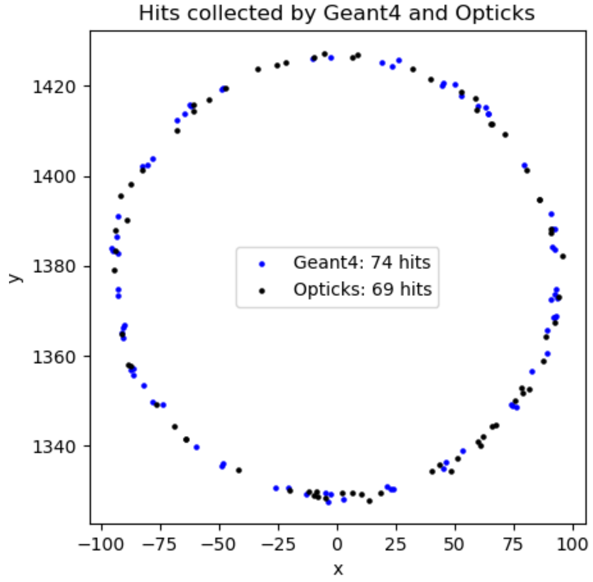
Simplified RICH

- Comparison between GEANT4 and Opticks+OptiX simulations
  - Detailed comparisons of the various steps of the simulation were done
  - A few problems in using Opticks were solved, along the way

Example Event 1



Example Event 2



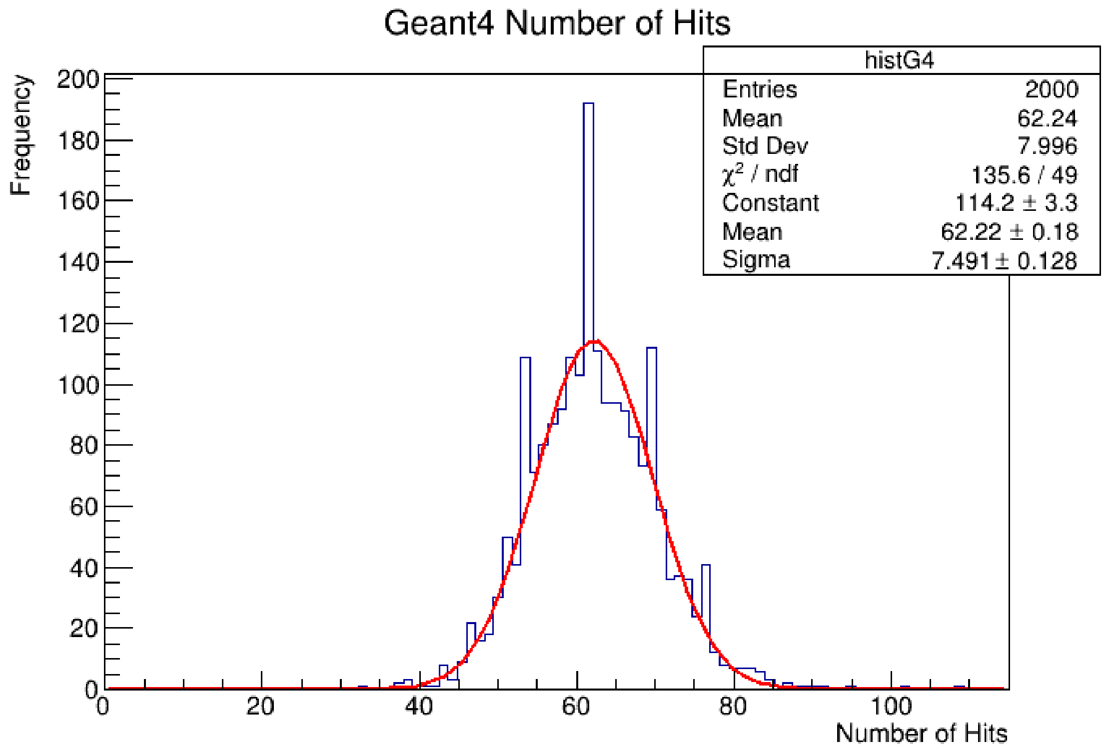
- XY coordinates of hits on the detector plane from single events from GEANT4 simulation and Opticks+OptiX simulation
- Hit distributions obtained from the two simulations are similar to each other

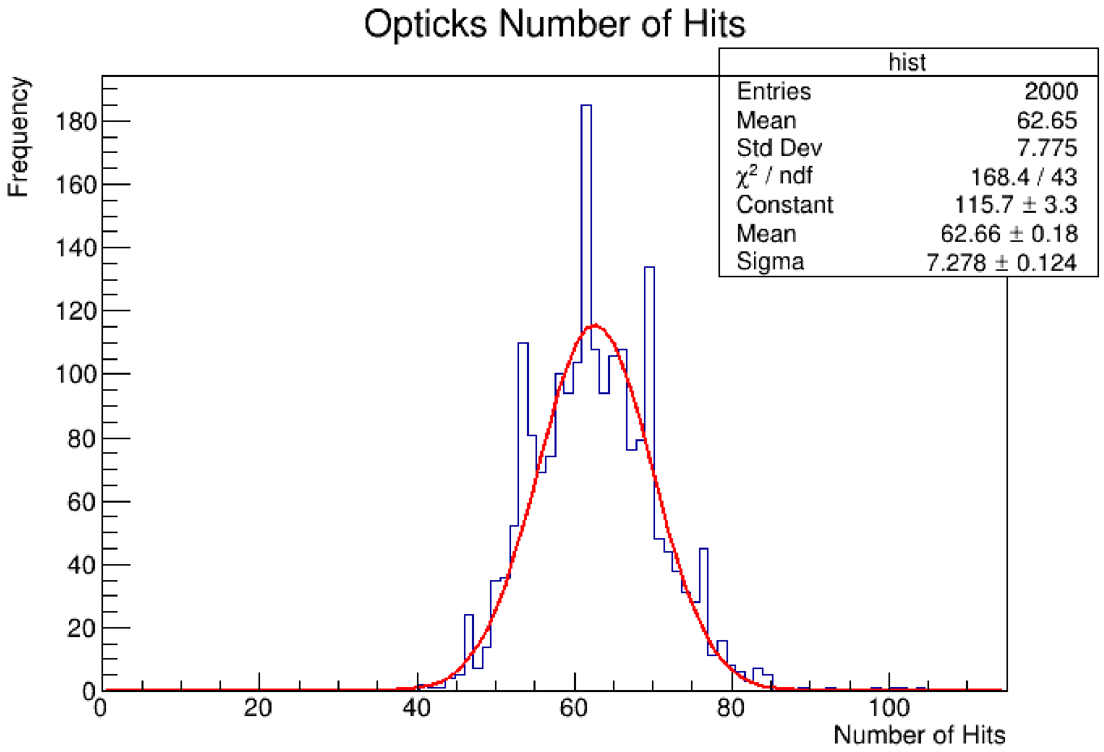
Hits obtained from using a particle gun with 4 GeV/c electron

Simplified RICH

- Yield comparison between GEANT4 and Opticks+OptiX simulations

Yield obtained from running 2000 events with particle gun





	Simplified RICH: GEANT4	Simplified RICH: Opticks+OptiX
Mean yield	62.2	62.7

Opticks+OptiX produces a yield similar to that from GEANT4 for the Simplified RICH configuration.

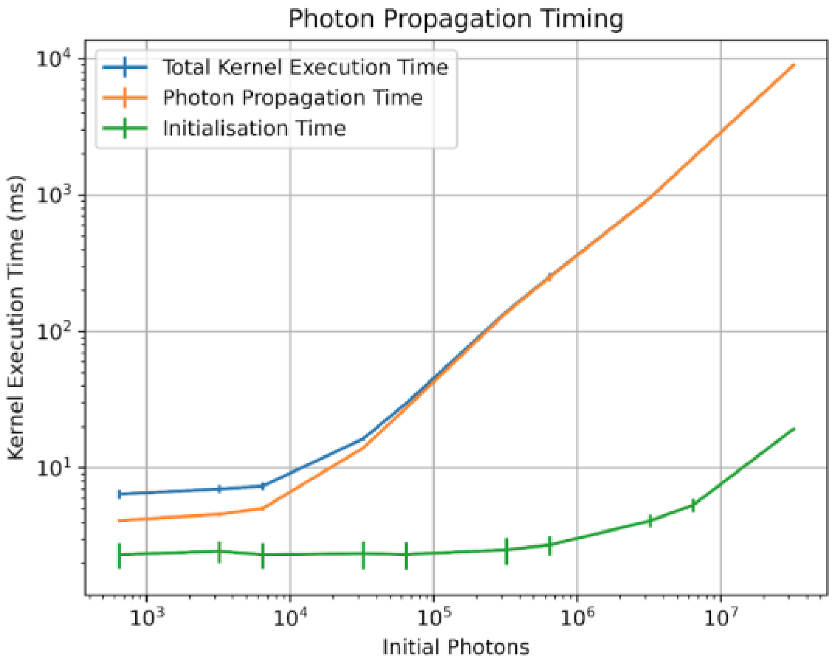
This is also same as the simulated mean yield obtained for the full LHCb-RICH1

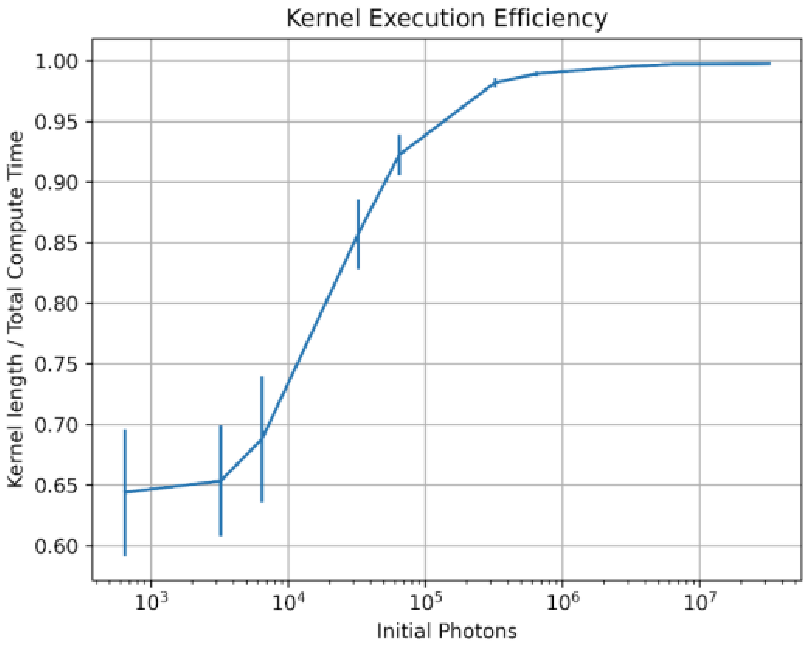
K.Evans

Profiling : initial studies

- Effectively, re-sample single events to generate very large events with lot of photons
  - Using Simplied RICH geometry, for now

- Plot the ‘execution time’ as function of the number of photons





Further details in
SwiftHep workshop-March-2022

Simulation - prospects

- ❖ The initial goal of creating a program as proof-of-principle is achieved.
- ❖ Based on this, in LHCb efforts are underway to use the full RICH system with Opticks.
- ❖ Most of the software developed for this purpose would be useful for different experiments.
- ❖ For this, eventually the Opticks would need to be maintained within the CERN-LCG similar to the way GEANT4 software is maintained.
- ❖ Geometry integration using Opticks:
    - Helps to run OptiX and GEANT4 during simulation.
    - It can also help to provide the programs in the GPUs with the information needed during reconstruction.

GPUs for data reconstruction

- Example of GPU usage:
  - The starting point of the PID algorithm procedure is to reconstruct the Cherenkov angle
  - When using optical geometry similar to that in LHCb, this will involve solving a quartic equation.
  - For ‘N’ number of charged tracks and ‘M’ number of photon detector hits in the appropriate regions of the detector plane, the reconstruction is done for N x M photon combinations. This is best done in the GPU threads.
  - LHCb has a prototype implementation of this.
  - Performance in terms of the ratio of number of photon combinations processed per second.

Scalar (CPU)	:	SIMD (CPU)	:	Device (GPU)
1	:	7.1	:	35.9

GPUs for data reconstruction

- The algorithm used for PID involves summing likelihood over a matrix of tracks and hits, for different mass hypothesis and get a scalar number.
- This is a ‘data reduction’ problem and it is efficient to implement this the GPU rather than in a CPU.
- LHCb has a prototype implementation of this. (Using CUDA, Thrust etc)
- Example performance :

For an example of 100 tracks and 50000 hit pixels in LHCb upgrade2

Time taken to calculate the likelihood for one mass hypothesis :

CPU	GPU	Ratio
4. 5 ms	0.61 ms (0.3 ms using an LHCb implementation)	7.4

- LHCb-Allen project aims to implement LHCb reconstruction software in GPUs
- LHCb plans to create a version of the PID algorithm that can run in the GPU

Prospects

- In LHCb, it is planned to integrate the usage of Opticks into the software framework.

- However, one needs to address issues related to program maintenance at the LCG level.

  At present, there is only one expert. We need an organization (within LCG) to acquire the expertise for this.

- Alternatives to Opticks are being explored, however they will have the same issues regarding program maintenance.

- The OptiX is made by NVIDIA. It can update according to the needs of the industry.
  In this case the Opticks interface package need to be adapting accordingly.

- A continued engagement between representatives of the industry and HEP software people would be be needed.

- Some other projects beginning to use the GPUs for optical photon simulation using OptiX / Opticks:
  - LUX-ZEPLIN for liquid xenon TPC
  - IceCube experiment in Antartica
  - Fermilab Calorimeter Tracker simulation (CaTs) project

Prospects

- Once GPU based programs are available for RICH detectors:

  - Different HEP experiments which have RICH detectors may access the Opticks and configure their simulation programs. This thus becomes useful for them also.

  - Using GPUs, the cost of running programs at the computer centers can be reduced in the HL-LHC era.

- Resources :

  - Eventually acquire GPUs at the computer centers

  - Human resources needed to
    - ❖ Implement the updates needed
    - ❖ Use this technology in different experiments

Summary

- The usage of GPUs would be needed to simulate the RICH detectors in the future
- They will be useful for the reconstruction of the RICH data collected .
- This will require significant investment in human resources in the coming years.
- This development would be useful for many experiments using Cherenkov detectors.
  - It is useful for all detectors which make use of optical photons
- Prototypes were developed in LHCb to compare the performance between GPU and CPU
  - Simulation of the RICH
  - Some aspects of reconstruction and particle identification
- **We would be happy to integrate future efforts towards DRD4**

Extra pages

General structure with OptiX7

Ref:
S.Blyth, CHEP conference
Presented on 08-05-2023
at Norfolk,VA,USA