EIC-Opticks / Simphony: MC with ray tracing of optical photons on GPU

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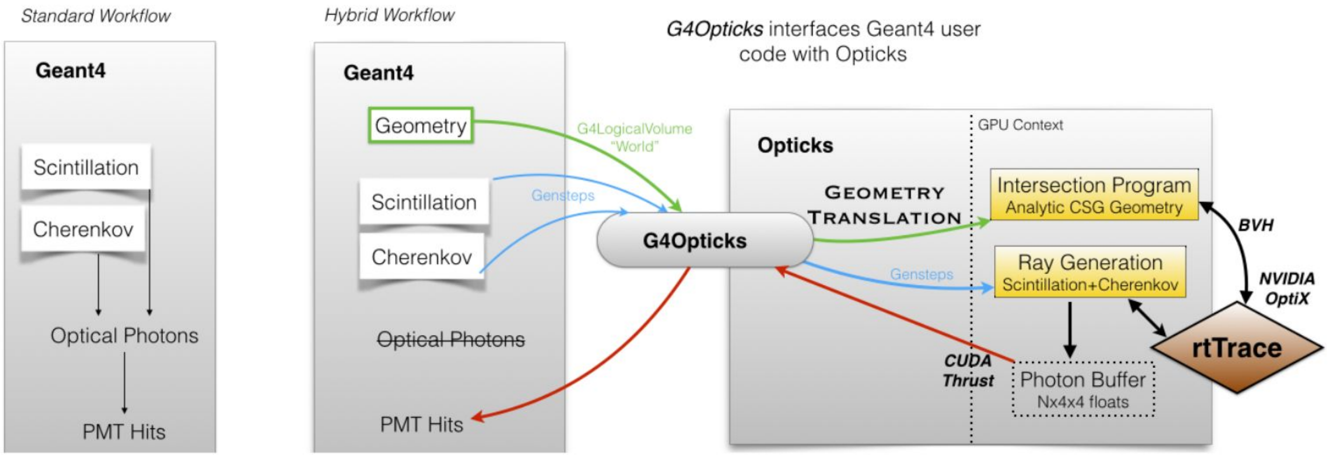
eic-opticks / simphony

- eic-opticks[1]: fork of Opticks, uses NVIDIA OptiX framework to simulate photons on GPU
- Now interest from neutrino physics side
  - Renamed to Simphony: SIMPHONY (SIMulation of PHOtons on NVIDIA with high Yield)
- Works together with Geant4:
  - Hadronic, EM etc. are done on CPU, only photons are offloaded to GPU
- Today's topics:
  - Simphony updates
  - DD4hep integration
  - Validation results for hpDIRC and dRICH
  - Integrating AdePT and Simphony -> EM + Optical simulations on GPU!
  - Simphony application in neutrino simulations

[1]github.com/BNLNPPS/eic-opticks

Architecture

- EM, Hadronic done in Geant4 with CPU
  - For Cherenkov/scintillation, Geant4 calls G4Opticks API instead of creating photons
- G4Opticks records production distributions (position, direction, polarization, Nγ, event ID, …)
- Simphony uses these records to generate and propagate photons on the GPU with NVIDIA OptiX
- Hits are sent back through G4Opticks and the user can do whatever they want -> DD4Hep, ROOT…
- Geometry and optical properties are translated from Geant4 to GPU → same physics, much faster optical simulation



Simon Blyth, EPJ Web of Conferences 245, 11003 (2020)

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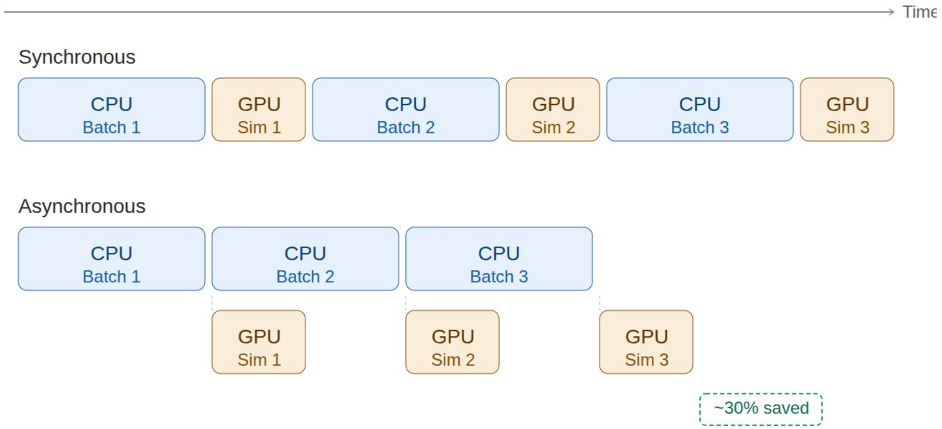
Simphony updates

- Implemented support for:
  - Trapezoid volumes (G4Trd, G4Trap -> important for hpDIRC and pfRICH)
  - Spherical, cylindrical wedges (important for dRICH)
- Monte Carlo truth propagation
- Sub-event level parallelism:
  - Implemented sub-event level parallelism for optical photons
- Implemented asynchronous running and offloading into simphony

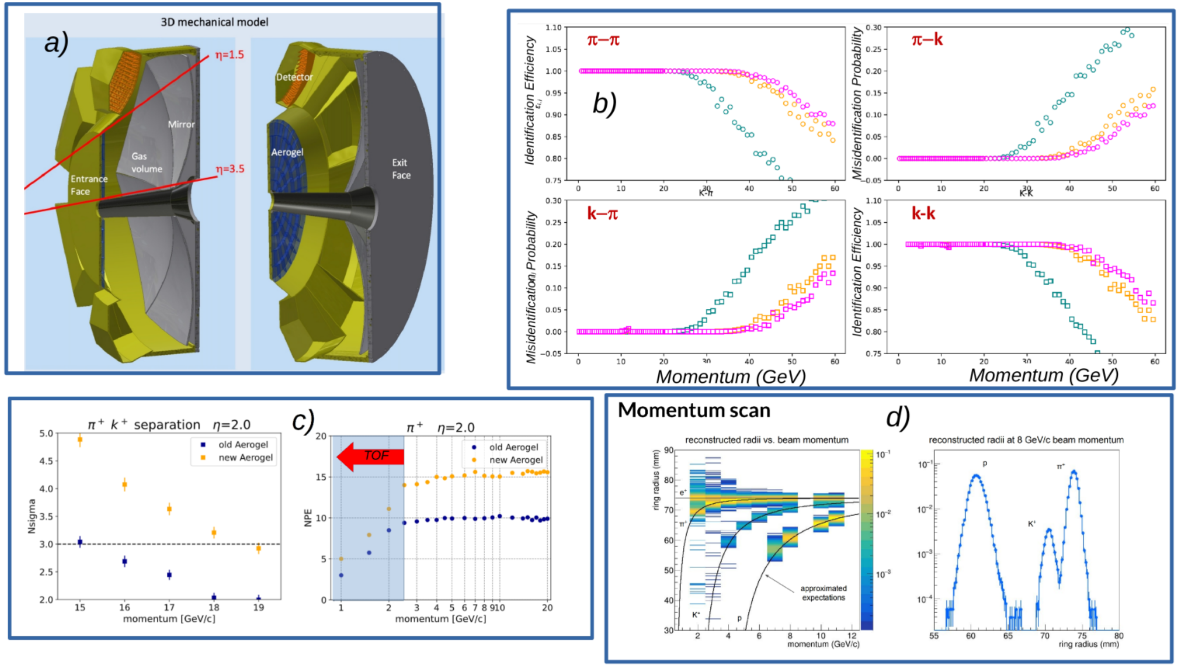


DD4hep integration

- ePIC uses dd4hep for MC simulations
- To make Simphony available for ePIC users we have integrated it into dd4hep
    - Could use Simphony in production too!
- Already available in eic_dev_cuda image for a simple benchmark geometry
- Users can run our GPU simulation with a few lines of python
- Three DDG4 plugins:
    - Stepping -> collects Cerenkov/Scintillation gensteps from G4
    - Run -> Geometry retrieval and GPU geometry offload
    - Event -> Injects GPU hits into DD4hep (if batching is not used)
- Full steering via DDG4 Python API

dRICH detector

- Charged hadron PID
- Dual radiator
  - 2 Cherenkov cones
- Spherical mirrors
- 6 sectors



arXiv:2410.20410

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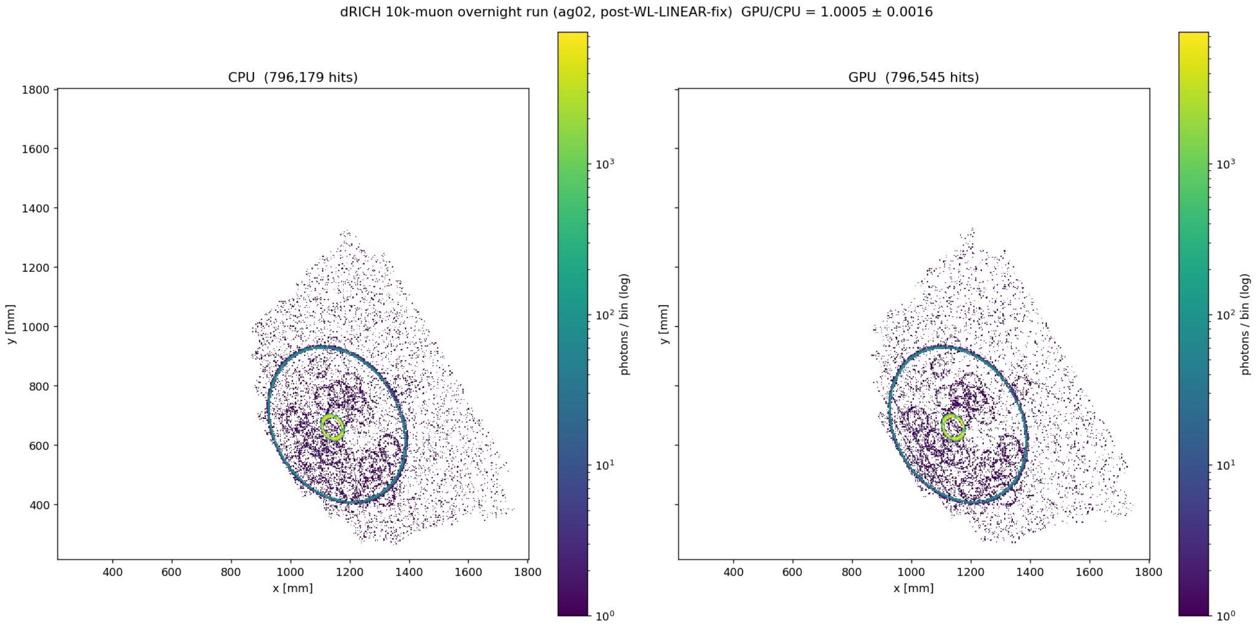
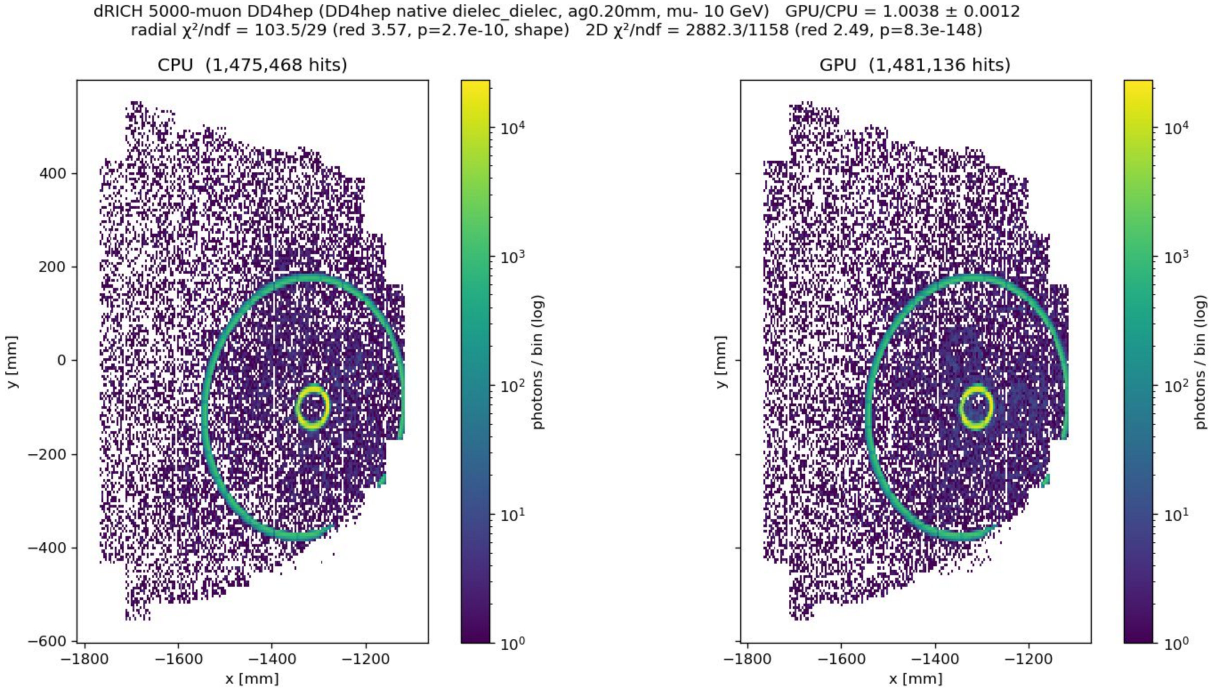
dRICH validation without DD4hep

- Cylindrical wedges and spherical wedges are not supported in Opticks
- Opticks GPU propagation didn't carry the photon's actual medium across sibling volume faces
  -> Had to update in Simphony core propagation and geometry conversion code
- Implemented the support in Simphony for these volumes
- 10k muons
- Hit ratio: 1.0005±0.0016
- χ^2/dof = 1.02 (2D)



dRICH with DD4hep

- 5k 10 GeV muons
- GPU / CPU hit ratio: 1.0038 ± 0.0012 (3.2σ)
- 2D χ^2/ndf: 2.49 -> need investigation
- Preliminary speed-up vs. single-thread G4 CPU:
  - ~200x



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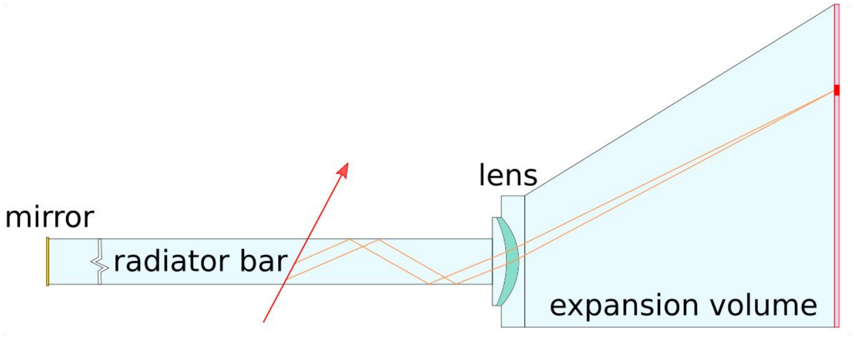
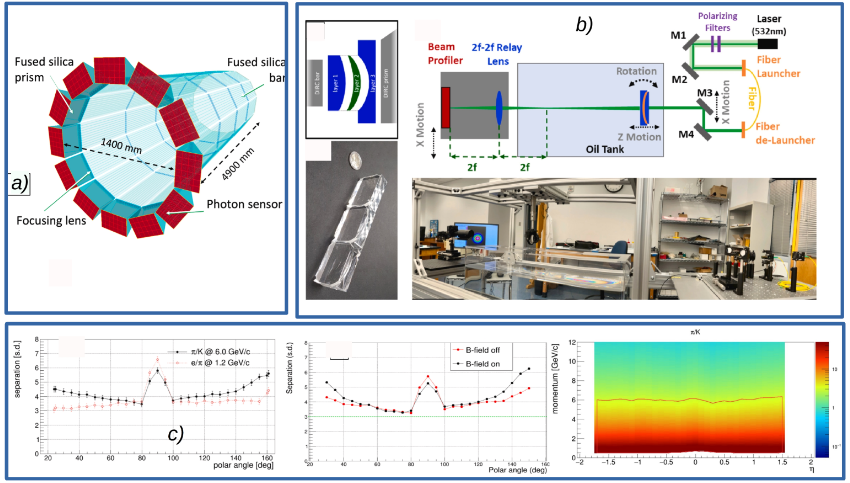
hpDIRC detector

- Long fused silica bars
- Has complex optical system:
  - Scintillator bars
  - Lens
  - Optical couplings
- Takes 10% of total ePIC production sim. time!



arXiv:2202.06457



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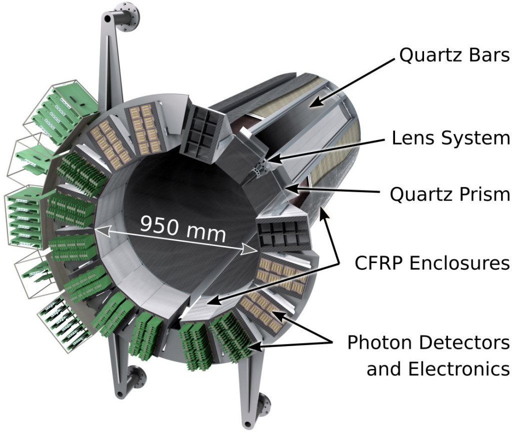

NIM A 169168

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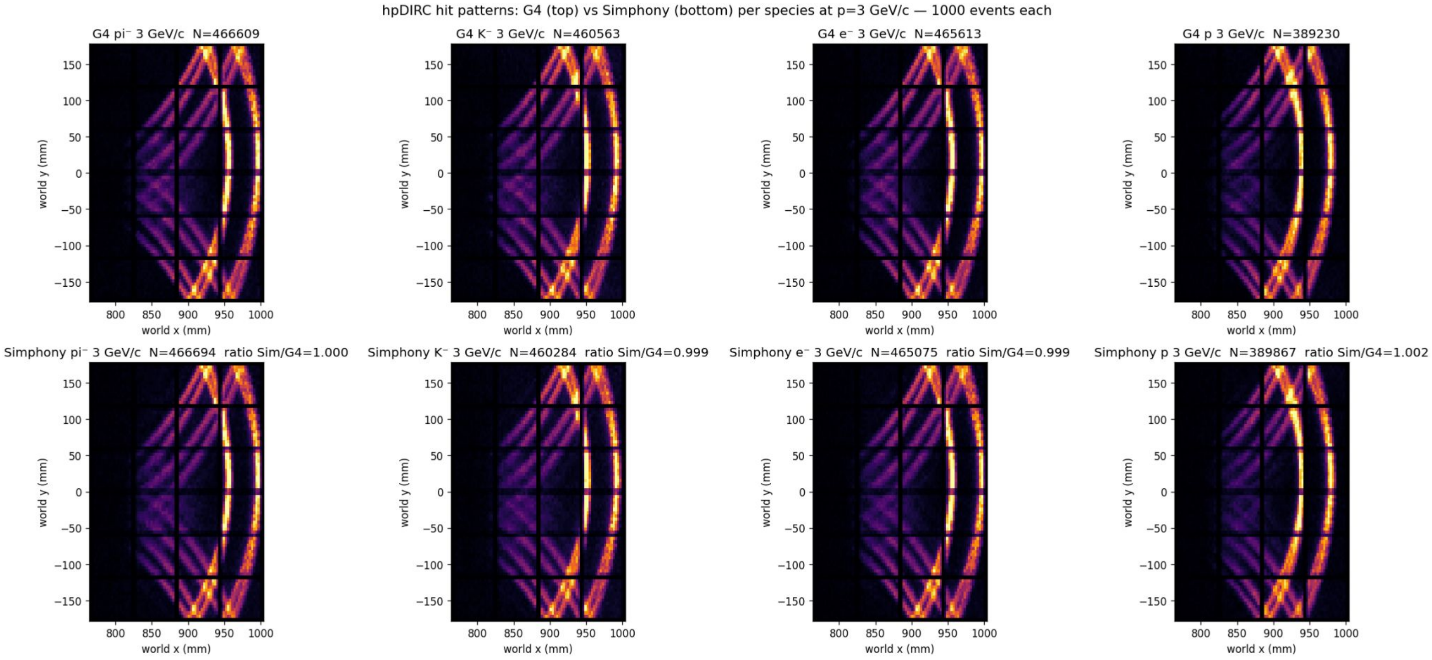
hpDIRC results

- Validated Simphony vs. G4 CPU: all hitmaps below have 2D χ^2/ndf: 1 - 1.5
- Implemented support for trapezoid volumes in Simphony
- Next step:
  - DD4hep validation not done: 200 μ^- 3 GeV, hits: CPU 28838, GPU 28474, ratio 0.987±0.008
  - Running Simphony in production environment



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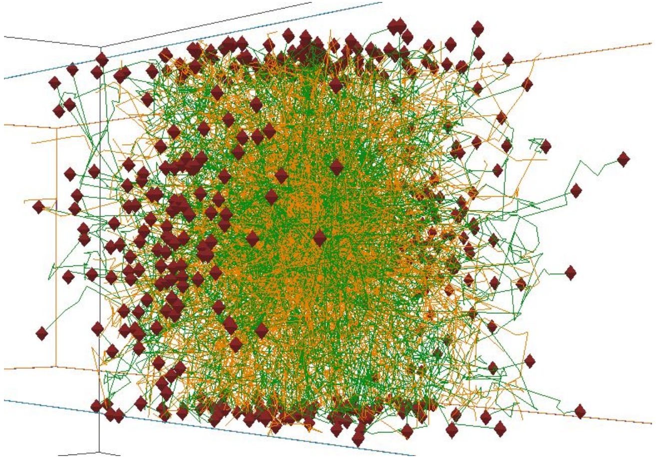
AdePT + Simphony: end-to-end GPU simulation

- Initial integration AdePT + Simphony with help from Severin Diederichs and Mihaly Novak:
  - AdePT transports e/γ on GPU
  - AdePT copies each step to CPU side, reconstructs G4Step
  - Optical photons harvested and Simphony compatible data format created
  - Simphony runs GPU MC after AdePT finishes
- Tested integration on 15 kt LAr volume
  - Results agree with pure G4
  - Not a good test use case as optical workload dominates
- Plans:
  - Since in current integration 80% of time of AdePT is bookkeeping
    - Add a GPU side buffer to collect optical photons on GPU side
  - Test this on LHCb where EM, optical workload is similar
  - Understand whether any ePIC detector simulation would benefit
  - Sub-event level parallelism:
    - Would be proper mechanism to offload
      - EM tracks to AdePT
      - Optical photons (eg. from hadrons) to Simphony

Simphony in high energy neutrino simulations

- Neutrino experiments (e.g. DUNE) have ~10-100 M optical photons created per neutrino event
- Currently in simulation mostly look up tables are used:
  - Run CPU once and then use the built table
- With Simphony we could simulate optical photons ~1000x faster then 1 CPU G4 thread
- We receive funding from BNL through a dedicated LDRD
- In this plot showing GPU tracks of ~1000 photons
- In typical event there are 60 M photons!



- Will submit a paper to JINST this week on this:
  - “GPU optical photon Monte Carlo for noble liquid detectors: validation against Geant4 in a large liquid argon TPC benchmark”

Summary and plans

- Implemented many new features in Simphony
- Validated hpDIRC, dRICH Simphony simulation against vanilla G4 using GDML files
- Applied Simphony to a neutrino application

- Validate hpDIRC, dRICH, pfRICH in DD4hep
    - After successful integrate them into production
- Develop a GPU side buffer that would allow an end-to-end GPU EM+optical sim.
    - Understand whether ePIC sim. could benefit from this
- Compare Simphony with (ML) fast sim. solutions for hpDIRC, dRICH, pfRICH