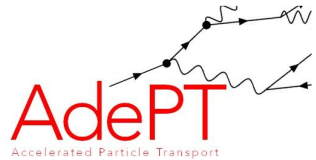

AdePT status

Accelerated demonstrator of electromagnetic Particle Transport

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26th Geant4 Collaboration Meeting
Sep 16, 2021

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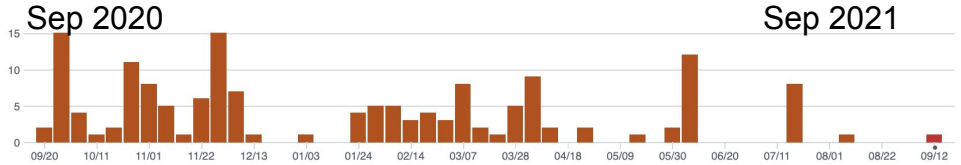
R&D for EM physics transport simulation on GPU

- Project started one year ago, trying to address inability to use GPU cards for detailed simulation of collider experiments
  - Transforming simulation code to be more GPU-friendly, see how far we can go…
  - Some initial ideas shown last year
- Now close to having a complete prototype for e^+, e^- and γ shower simulation
  - Completing the set of EM interactions with the last models supported by G4HepEm
  - Magnetic field propagation in detector geometry
  - Code producing user `hits` data transferred from the GPU back to the host
- Support for both GPU standalone and hybrid modes
  - Integrating with Geant4 CPU workflow, `stealing` particles and offloading to GPU
- Optimizing performance on realistic use-cases
  - To understand usability and realistic benefits for the current workflows

The AdePT project



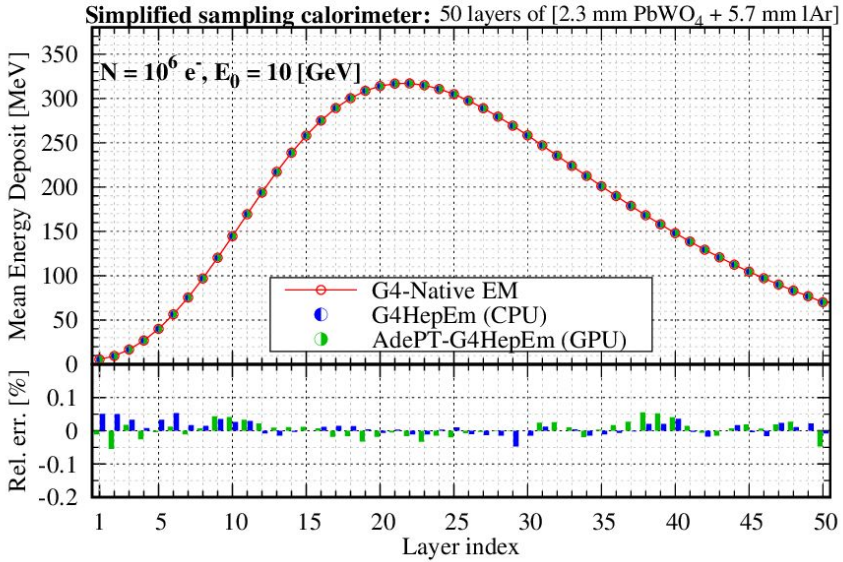
- GitHub repository
  - Started in September 2020, 11 contributors so far
- Strategy: evolve to a prototype based on gradually more complex examples
  - Core types/macros/abstractions: ***CopCore***
  - External physics: ***G4HepEm*** and geometry: ***VecGeom***
- One year project roadmap
  - Moving from a toy version to a real prototype implementation
  - **Sep 2021:** First complete AdePT simulation running, including all EM interactions, tracking in non-constant magnetic field (optionally), sensitive detector functionality
  - **~ Jan 2022:** HSF meeting to plan next steps and seek convergence of efforts on a common project
  - Some delay, but really close to these objectives now

AdePT ingredients: G4HepEm physics

- G4HepEm: compact library of EM processes for HEP
  - Covers interactions of $e^-/e^+/\gamma$, including multiple scattering (not yet integrated into AdePT)
  - Separation between data initialization (relies on Geant4) and computation of cross-sections and final state sampling during run-time (standalone, independent of Geant4)
- Design of library very supportive for heterogeneous simulations
  - Implicit support in the interfaces: Standalone functions without global state
  - Explicit support for transfer of physics tables and other data structures to GPUs
  - Makes it possible to re-use > 95% of the code from G4HepEm for GPU shower simulation
- For details, see presentations by M. Novák in December, at Geant4 Technical Forum in March, and recent status update
  - Also talk in the Kernel parallel session and in Plenary 3 next Wednesday

G4HepEm validation

- Previously validated simulation results on GPU against Geant4
  - Agreement at per-mill level in the mean energy deposit (shown below) and other quantities (number of secondaries, number of steps, charged track length)



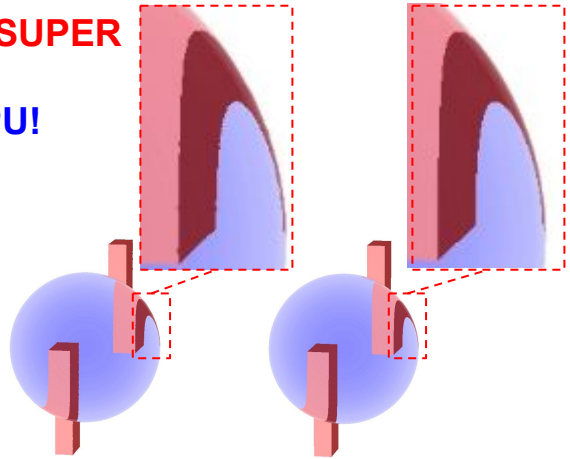
AdePT ingredients: VecGeom geometry

- Using VecGeom as GPU-aware library describing the detector geometry
  - Same CPU and GPU algorithms compiled separately for host and device
  - Geometry data re-constructed on GPU based on the transient data on the host
  - Navigation layer customized for GPU use
- Improving gradually GPU support
  - Developed custom optimised navigation state, single-precision support
  - Moving to a simple looper to an optimized BVH navigator (see talk of G.Amadio)
  - Adopting modern CMake GPU support
  - See talks in the Geometry working session
- Moving forward: specializing the VecGeom GPU navigation support
  - Important step towards portability and performance

Performance impact of single-precision

- Tested impact on performance in the AdePT examples
  - After doing several fixes for importing VecGeom precision type and using it in the navigators
    - LoopNavigator (simple looper for daughters), and BVHNavigator
- RaytraceBenchmark example (using BVHNavigator)
  - Reading a GDML file and modeling reflections/refractions and specularity
  - Validated by the output image
    - Very simple geometry: ~ 7.5% speedup
    - Complex geometry (trackML): ~ 44% GPU, ~ **13.6% CPU!**
- Physics-enabled GPU examples
  - Exa9 + trackML + LoopNavigator: ~ 2.8x speedup
  - Exa11 + trackML + BVHNavigator: ~ 30% speedup

RTX 2080 SUPER



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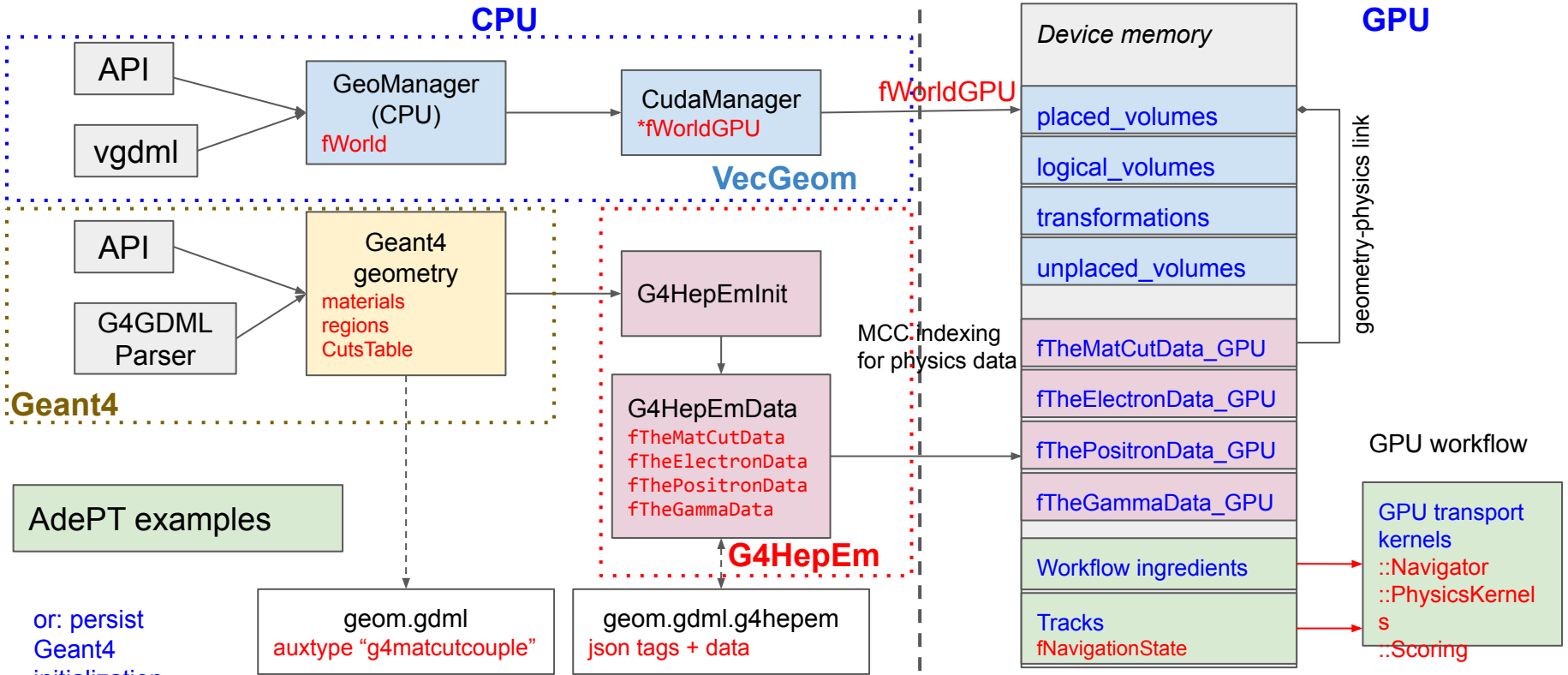
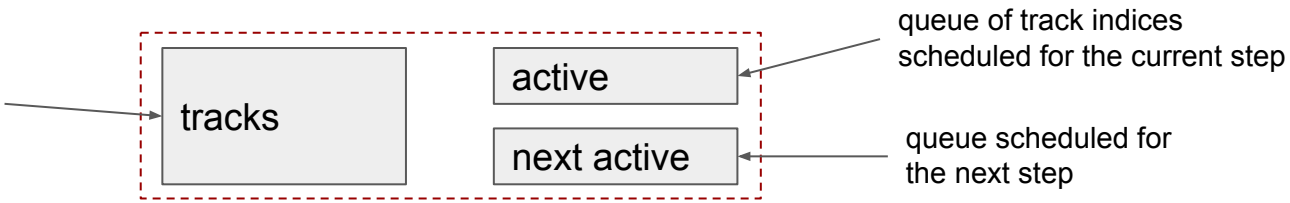
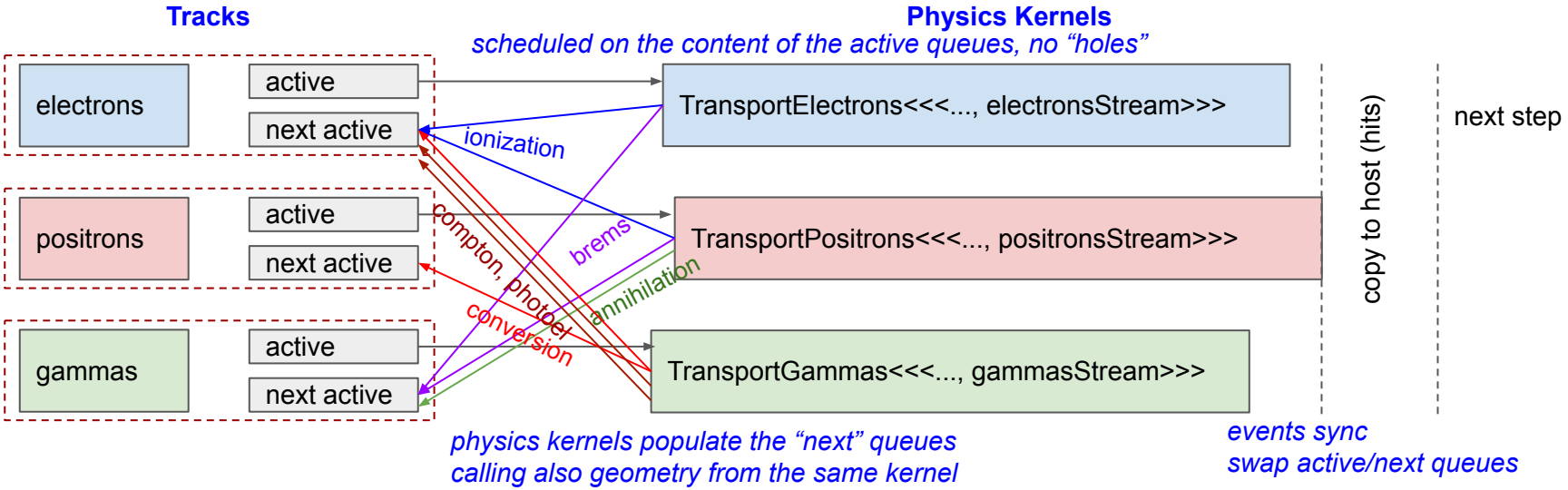
The AdePT “cookbook”



AdePT recipes: stepping loop workflow

- contiguous
- next slot atomic
- no slot reuse
- different for e+/e-/gamma





More recipes: AdePT Geant4 integration

- Integrate AdePT GPU workflow with standard Geant4 simulation on CPU
  - One of the main goals of the AdePT prototype
  - We target a Geant4 plug-in to offload work to GPU for increased throughput and improved energy/cost efficiency
    - If proven efficient, this can become a plug-in for offloading part of Geant4 simulation on device
- Inserted in the Geant4 stepping loop using the *FastSimulationModel* interface
  - Intercepts and removes from stack all EM particles entering the region(s) where the “model” triggers
  - Buffering and showering them in AdePT (now synchronous)
  - Return escaping particles and hits to CPU
  - Flushing the buffer until empty before ending the Geant4 event
- Detailed showcase of the recipe in Witek’s presentation

AdePT: evolving via examples

- Set of documented examples demonstrating different features
  - Starting with preliminary embryonic ideas implementing a Fisher-Price-like workflow
  - Adding new components in the stepping loop: pRNG, geometry, physics, magnetic field
  - Testing or demonstrating features: geometry navigation via ray-tracing, SoA vs. AoS, G4HepEm persistency, Alpaka, ...
  - Evolving the workflow: more steps per kernel, parallel relocation, multiple feeding threads
- More complete examples validating against Geant4
  - Measuring and optimizing performance
  - Common components refactored as services: navigation, field, physics
    - Recent examples share many commonalities
- Targeting a complete prototype integrated with Geant4
  - Realistic experiment geometry and physics settings + some basic scoring

Advanced examples

- Sampling calorimeter example (TestEm3)
  - Constant field on/off, Physics = ALL except MSC + photoelectric, Geant4 and GPU versions
  - Quite similar throughput for Geant4 MT on AMD Ryzen 9 3900 (12C/24T), versus AdePT on GeForce RTX 2070 SUPER after some performance improvements (J. Hahnfeld talk)
  - MT example shows limited benefits in the current workflow due to bottleneck in feeding concurrently input particle buffers
- Generic geometry with generic scoring example (CMSapp, currently PR)
  - Field on/off, Physics = ALL except MSC + photoelectric, AdePT version only for now
  - Doing initialization of Geant4, G4HepEm and VecGeom data structures based on GDML info
  - Generic scoring in all volumes, in the future only for sensitive volumes
  - Example recipe will be adopted in the integration prototype

Porting AdePT to oneAPI

- oneAPI - unified programming model by Intel
  - Uses DPC++ as programming language, implementing SYCL
- oneAdePT - port to oneAPI of an AdePT snapshot
  - core utilities, magnetic field, RNG, G4HepEM
  - Attempt to use legacy CUDA code compiled in VecGeom
- Many obstacles for migrating CUDA to DPC++ code
  - SYCL limitations in calling virtual functions or function pointers, non-const globals, support for std:: math functions, support for CUDA compiled libraries, documentation
- Triggered investigations and work in VecGeom
  - Non-virtual dispatch and CUDA compilation using clang, deeper restructuring needed
- Calling into CUDA libraries now possible, but examples on GPU still crash
  - First compile CUDA code to LLVM bitcode, then follow an obscure 10-step manual linking procedure

In preparation

- Interfacing the last physics interactions available in G4HepEm
  - Adding multiple scattering will probably change dramatically the picture
  - Testing with CMSapp example for both Geant4 and AdePT
- Finalizing the Geant4 AdePT integration
  - Now including MT support, buffering and flushing sequence
  - Understand *G4VTrackingManager* interfaces usability for GPU integration
- Putting together the complete CMS example using the integration
  - Most ingredients already integrated, but for a simpler setup
  - Performance study in standalone and combine workflows

Overlook

- Converging to a prototype combining complete particle transport features
  - Most functionality demonstrated in examples, combined CPU-GPU workflow for a realistic LHC geometry being developed
- R&D work and improvement of components
  - Several improvements and adaptations in VecGeom: navigation and state, optimizers, single-precision support
  - Support for EM physics in a GPU-friendly way
  - RNG optimisation, magnetic field support, workflow optimization
- We can answer the question “can it work?”, now assessing the “how efficient?” part
  - Only a realistic full prototype can give us an unbiased measure of performance