Translation of Penelope 2018 to C++ and its interface to Geant4

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Disclaimer

- This particular talk does not represent any part of the Geant4 Collaboration. I'm not speaking on behalf of any part of the Geant4 Collaboration.
- The outcoming code and documents of this work will not be a part of Geant4 release, but will be distributed separately.

Penelope 2018

- The Fortran code system Penelope performs Monte Carlo simulation of coupled electron-photon transport in arbitrary materials for a wide energy range (~1 GeV – 50 eV). Penelope implements the most reliable interaction models that are currently available, limited only by the required generality, and gives results in good agreement with a variety of experimental data.
- We present a translation of the latest Penelope 2018 physics routines to C++ that is designed to be used with the Geant4 toolkit with multithreading capabilities.
  - It runs in both pure Penelope mode as well as in hybrid mode where Geant4 EM physics is used for higher energy region.
- This program effectively uses the available computational resources, giving results equivalent to those from the original Penelope programs with a shorter running time, which is roughly inversely proportional to number of threads used.

Penelope 2018

- Photon interactions
  - Photo-electric effect
  - Coherent (Rayleigh) scattering
  - Incoherent (Compton) scattering
  - Electron-positron pair production
  - Polarized scatterings
- Electron and positron interactions
  - Elastic collision
  - Inelastic collision
  - Bremsstrahlung emission
  - Positron annihilation
  - Multiple-scattering and soft-scattering / soft-energy-loss
- Details can be found in the Penelope Write-up

Two-step translation

Original Penelope 2018 (FORTRAN)

↓

Penelope 2018 (C)

↓

Penelope 2018 (C++) + Geant4 interface

Original Penelope code is kept maintained in FORTRAN.

Line-by-line hand translation to C.

Bit-by-bit comparison and verification with original FORTRAN code.

Line-by-line hand translation to C++ with thread-safety plus Geant4 interface classes.

Bit-by-bit comparison and verification with original FORTRAN code in sequential mode.

Statistical comparison and verification with original FORTRAN code in multithreaded mode.

main()

```
int main(int argc,char** argv)
{
 // Construct the run manager
 G4MTRunManager * runManager = new G4MTRunManager;
 runManager->SetNumberOfThreads(G4Threading::G4GetNumberOfCores());
 G4ScoringManager::GetScoringManager();

 // Set detector construction
 G4VUserDetectorConstruction* detector = new Tst1DetectorConstruction;
 runManager->SetUserInitialization(detector);

 // Set physics list
 G4VModularPhysicsList* physics = new FTFP_BERT;
 physics->RegisterPhysics(new PenelopeEMPhysics( 500.*keV ));
 runManager->SetUserInitialization(physics);
```

Use as many cores as you have

Threshold parameter

Material definition

```
void Tst1DetectorConstruction::DefineMaterials()
{
  auto nistManager = G4NistManager::Instance();
  auto air = nistManager->FindOrBuildMaterial("G4_AIR ");
  auto water = nistManager->FindOrBuildMaterial("G4_WATER")
  auto lead = nistManager->FindOrBuildMaterial("G4_Pb");

//***************************************
// Registering G4Material to Penelope interface
//***************************************

// Use material properties defined in G4Material
//  PeneInterface::GetInstance()->RegisterMaterial(air);
//  PeneInterface::GetInstance()->RegisterMaterial(water);
//  PeneInterface::GetInstance()->RegisterMaterial(lead);

// Use material properties defined in Penelope pre-defined material list
  PeneInterface::GetInstance()->RegisterMaterial(air, 104);
  PeneInterface::GetInstance()->RegisterMaterial(water, 278);
  PeneInterface::GetInstance()->RegisterMaterial(lead, 82);
}
```

Material properties are shared with Geant4 NIST material database

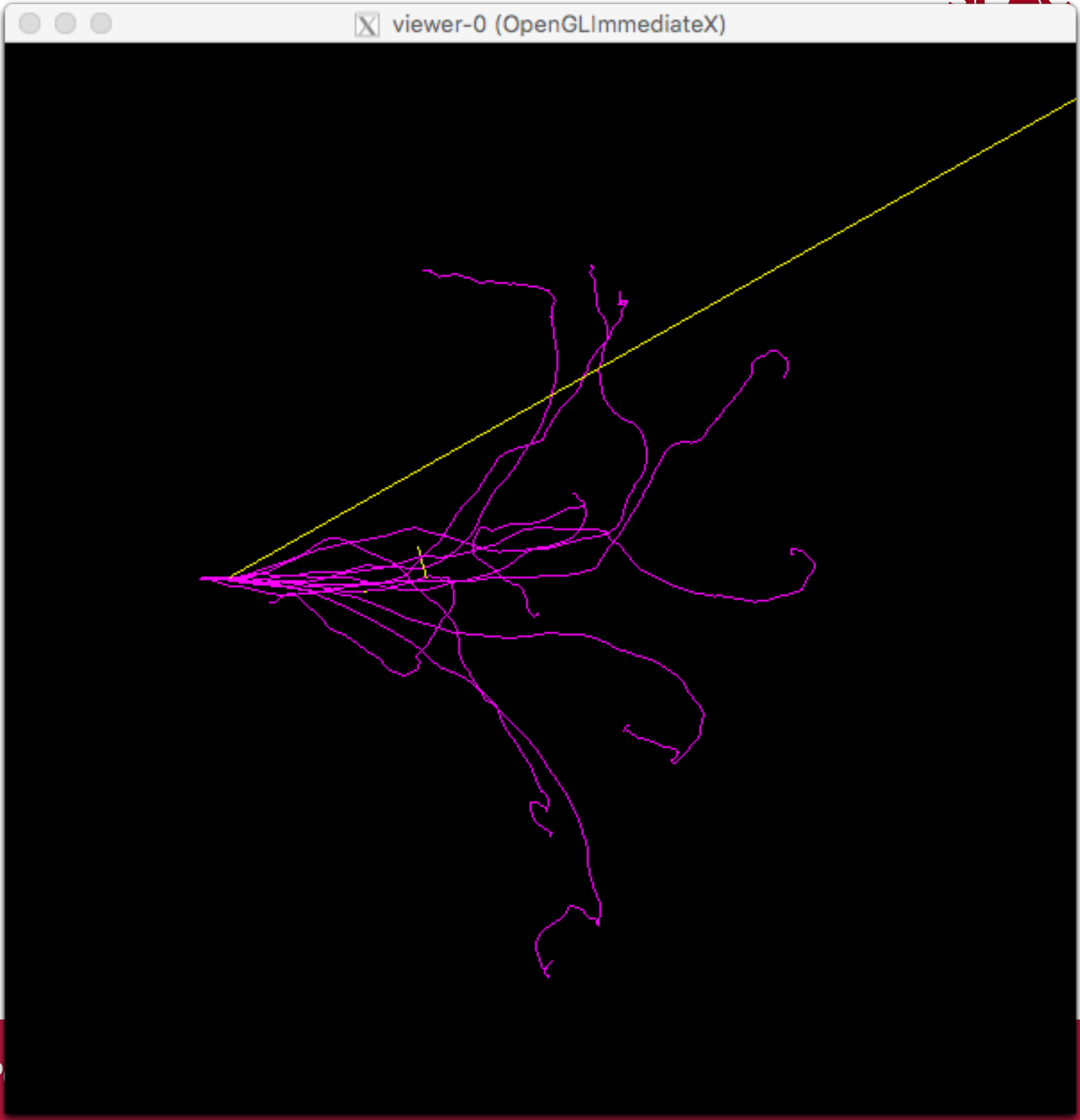
OR

Penelope's material properties are used for Penelope EM physics

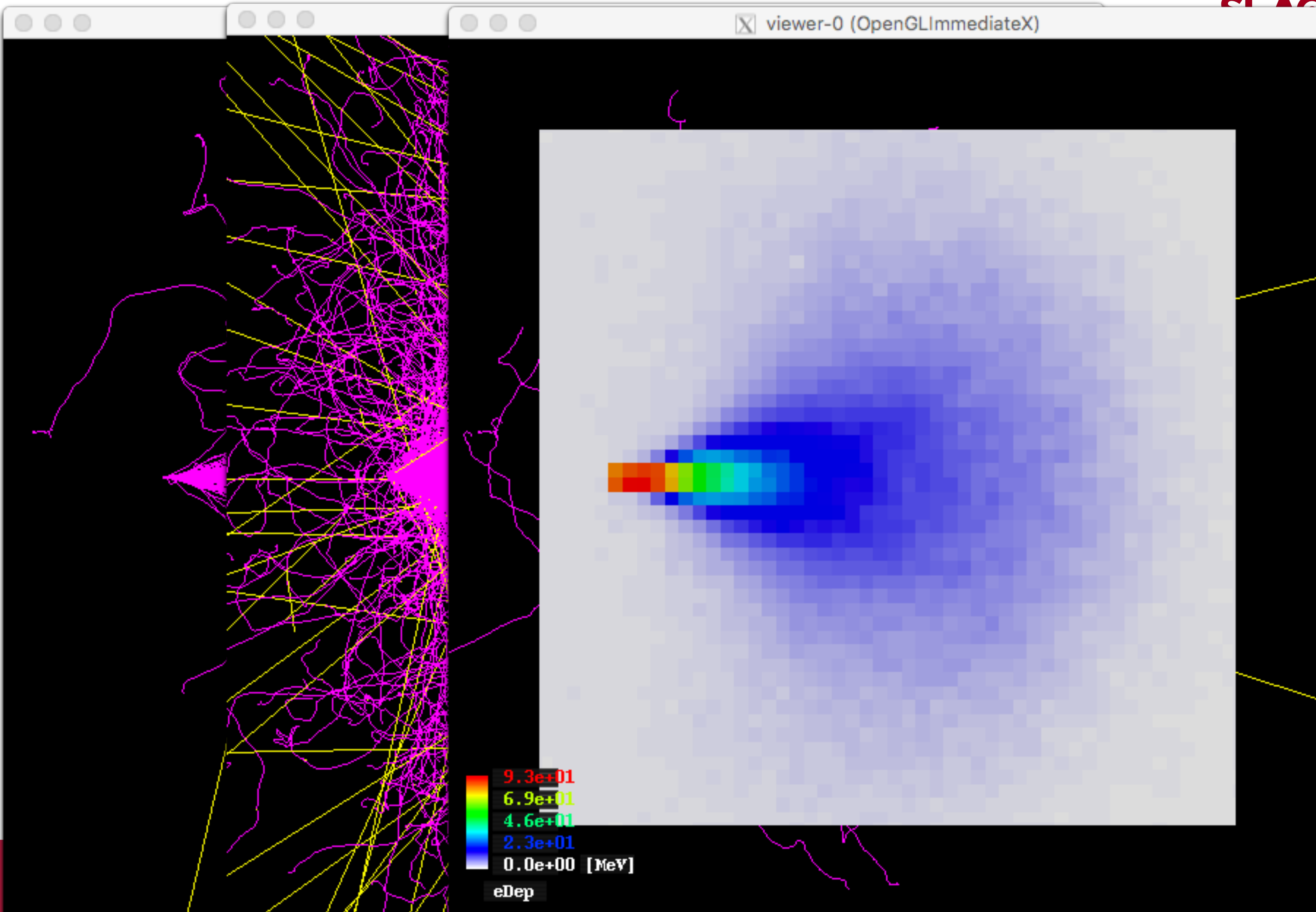
Penelope's material list can be found in [the Penelope Write-up](#)

Pure Penelope mode

- Penelope EM physics covers from ~ 1 GeV down to 50 eV.
- 10 electrons of 1 MeV in water.
  - Purple lines : e-
  - Yellow lines : γ



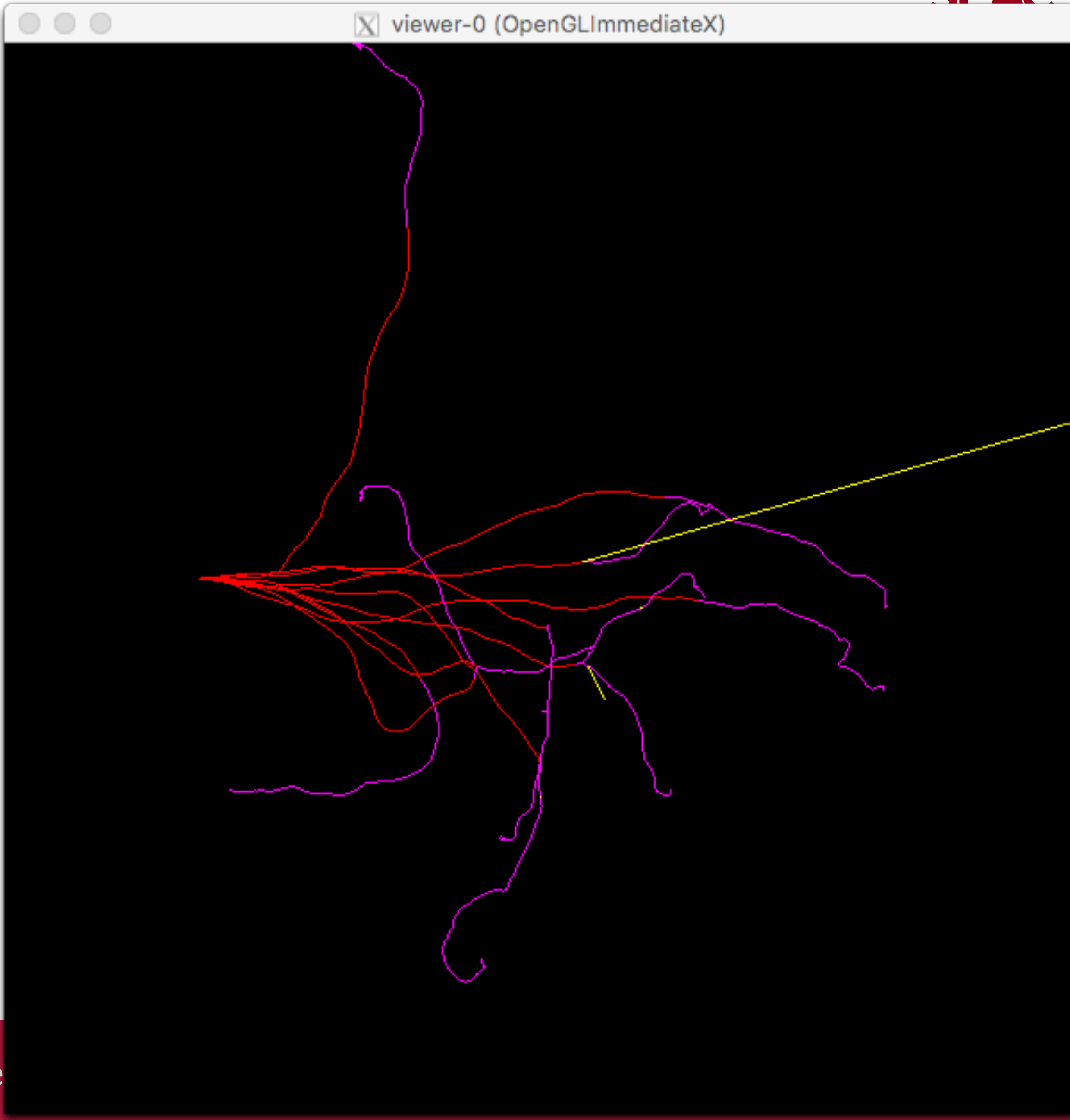
Pure Penelope mode



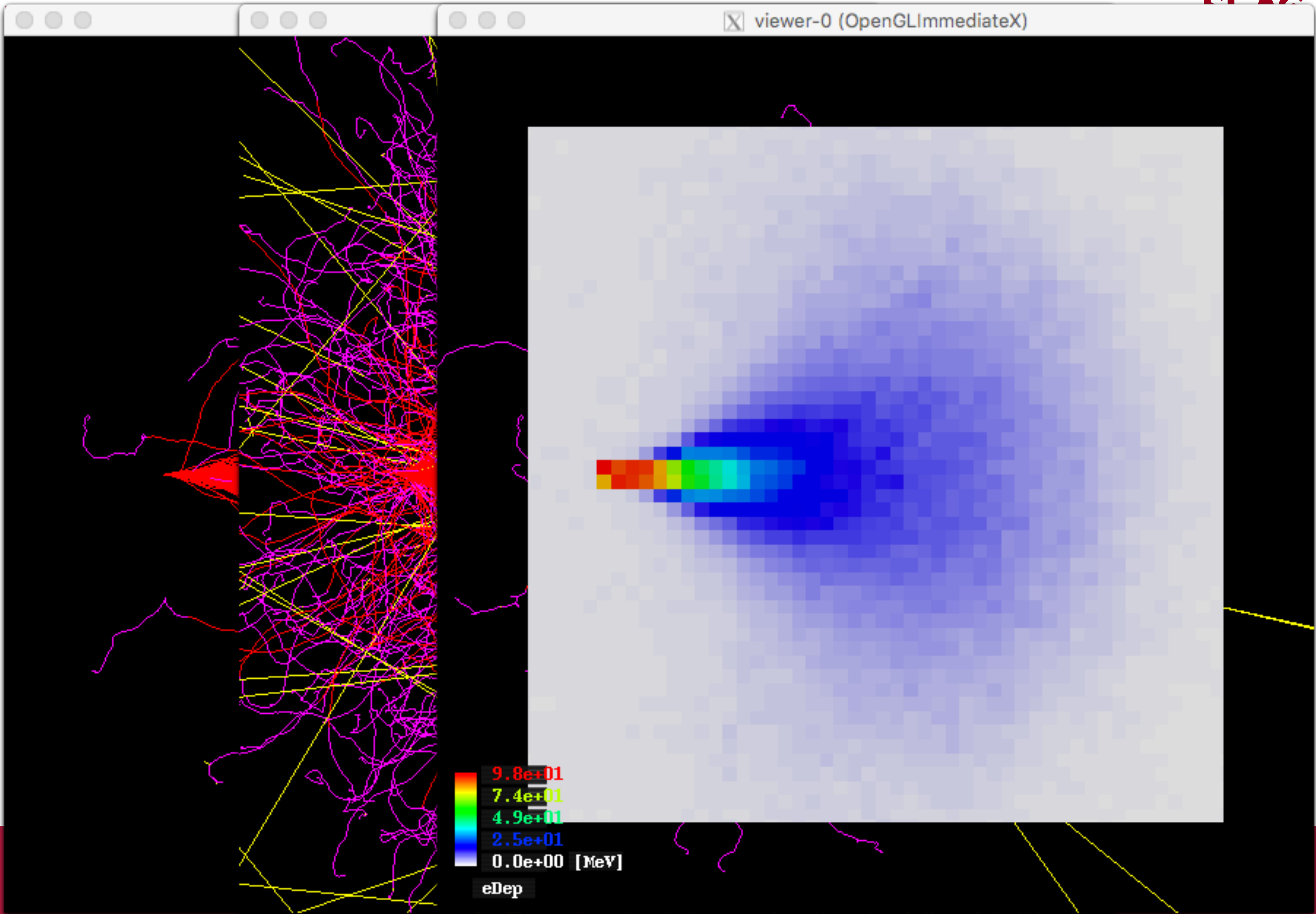
Hybrid mode

- Higher energy particle is taken care by the Geant4 physics (in this case Standard EM).
- Penelope EM physics takes over from a certain energy (in this case 500 keV) down to 50 eV.

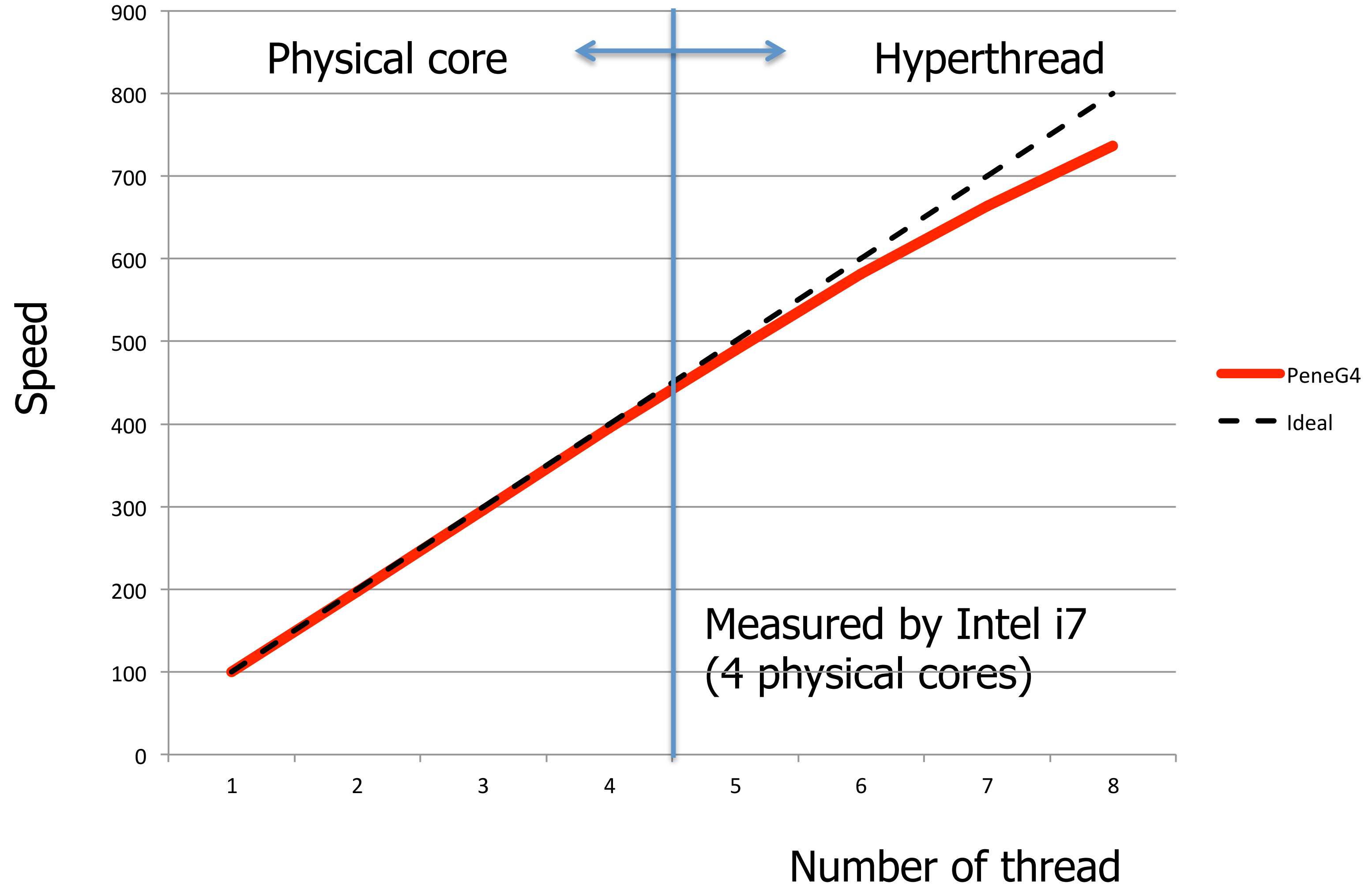
- 10 electrons of 1 MeV in water.
  - Red line : e- with G4 physics
  - Purple lines : e- with Penelope physics
  - Yellow lines : γ with Penelope physics



Hybrid mode


viewer-0 (OpenGLImmediateX)
9.8e+01
7.4e+01
4.9e+01
2.5e+01
0.0e+00 [MeV]
eDep

Linearity (preliminary)



Status and plan

- Large-scale benchmarking and minor code modifications / cleanups are ongoing.
- We are also working on the manuscript to be submitted to CPC.
- We plan to make the code and associated data files downloadable from NEA web site sometime in early/middle 2019.
- Significant C/C++ code rewriting for performance improvement may be considered in 2019 or later (based on budget / manpower).
- Extension to EM physics of proton (and maybe ions) is planned in 2019/2020.