中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Status of JUNO simulation software

Tao Lin, IHEP

lintao@ihep.ac.cn

(on behalf of the JUNO Collaboration)

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Outline

- JUNO experiment
- Offline software
- Simulation software
- Challenges of muon simulation
- Conclusions & Outlook

JUNO Experiment

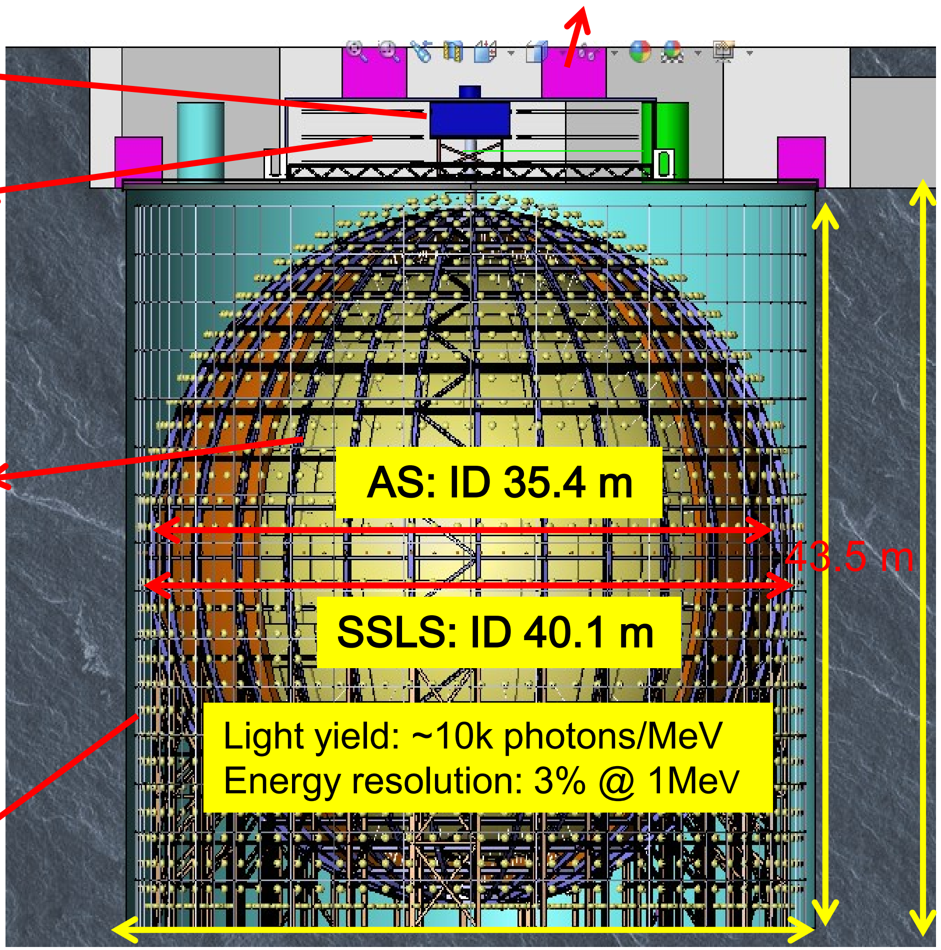
IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **43** (2016) 030401 (188pp) — doi:10.1088/0954-3899/43/3/030401

Technical Report

Neutrino physics with JUNO

- Reactor Neutrinos (→ Mass hierarchy)
- Supernova Neutrinos
- Geo-neutrinos, Solar Neutrinos etc

J. Phys. G: Nucl. Part. Phys. 43 (2016) 030401



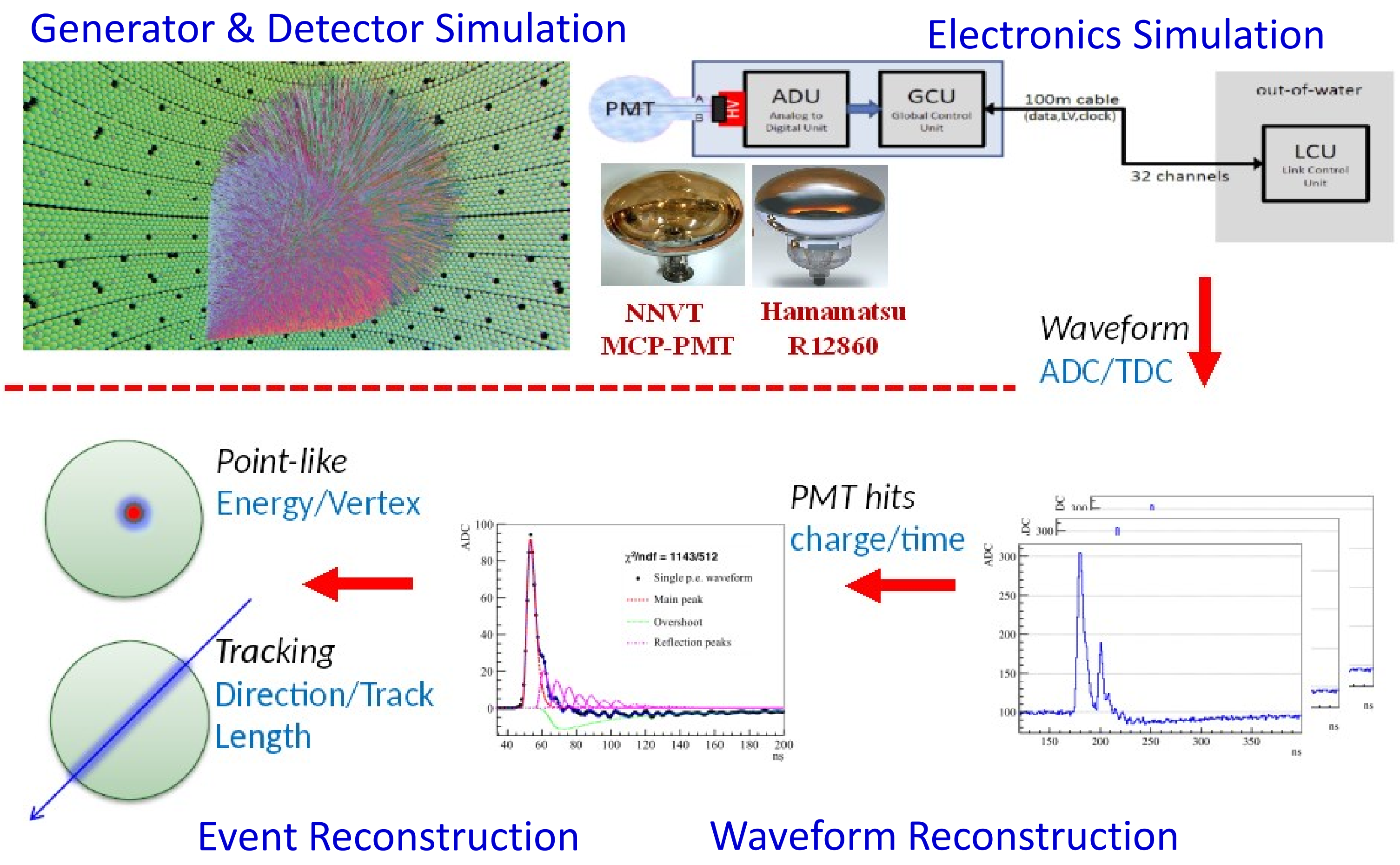
Central detector (CD)
Acrylic sphere+
20kt Liquid Scin.+
~18,000 20'' PMT+
~25,000 3'' PMT

Water Cherenkov (WP)
~2,000 20'' PMT

AS: Acrylic sphere;
SSLS: stainless steel latticed shell

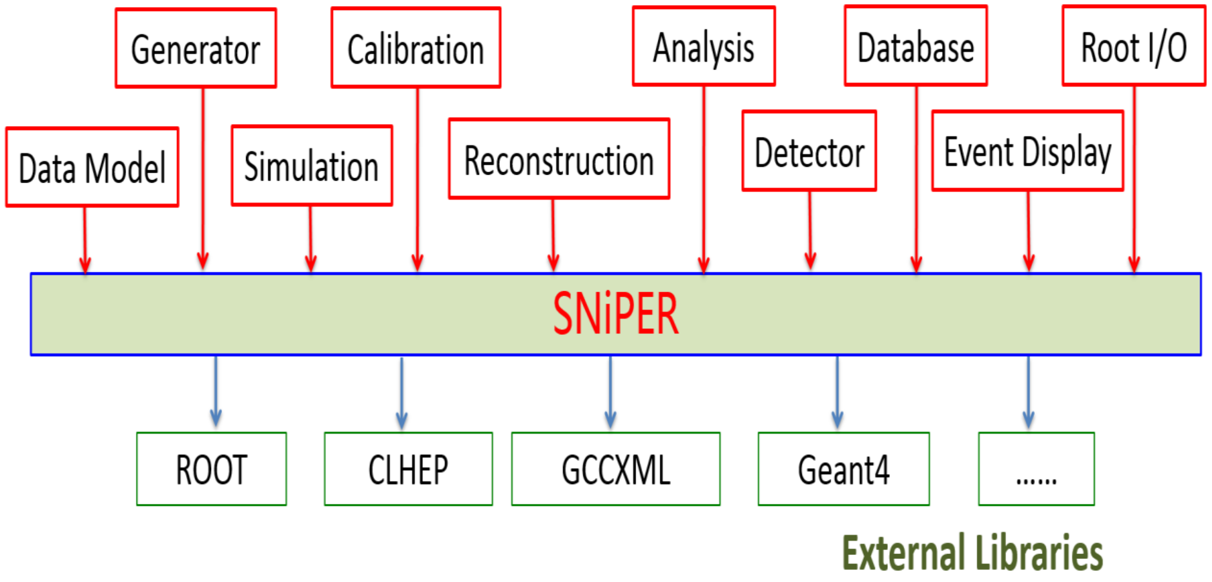
JUNO offline data processing

- Detector simulation
  - Neutrino signals
  - Cosmic ray muons
  - Radioactivity
- Electronics simulation
  - Effects of PMTs & electronics
  - FADC @ 1 GHz
- Waveform reconstruction
- Event reconstruction
  - Point-like (CD)
  - Tracking (CD, WP, TT)



JUNO offline software

- Developed since 2012.



Lightweight & compact: less dependencies & portable

- SNiPER Framework is adopt.
- 15 External Libraries and Tools are used.

- Software Development Environment
  - Language: C++ and Python 2 (Boost Python)
  - OS: Scientific Linux 6 & 7
  - Framework: SNiPER
  - Simulation: Geant4 10.4
  - Others: XercesC, CLHEP, HepMC
  - Software management: CMT & SVN
  - Installation Tool: junoenv (bash)

- ~10 versions have been released.
  - Deployed using junoenv at IHEP, CNAF, IN2P3 etc.
  - Also available in cvmfs.

SNiPER framework

Software for Non-collider Physics Experiments

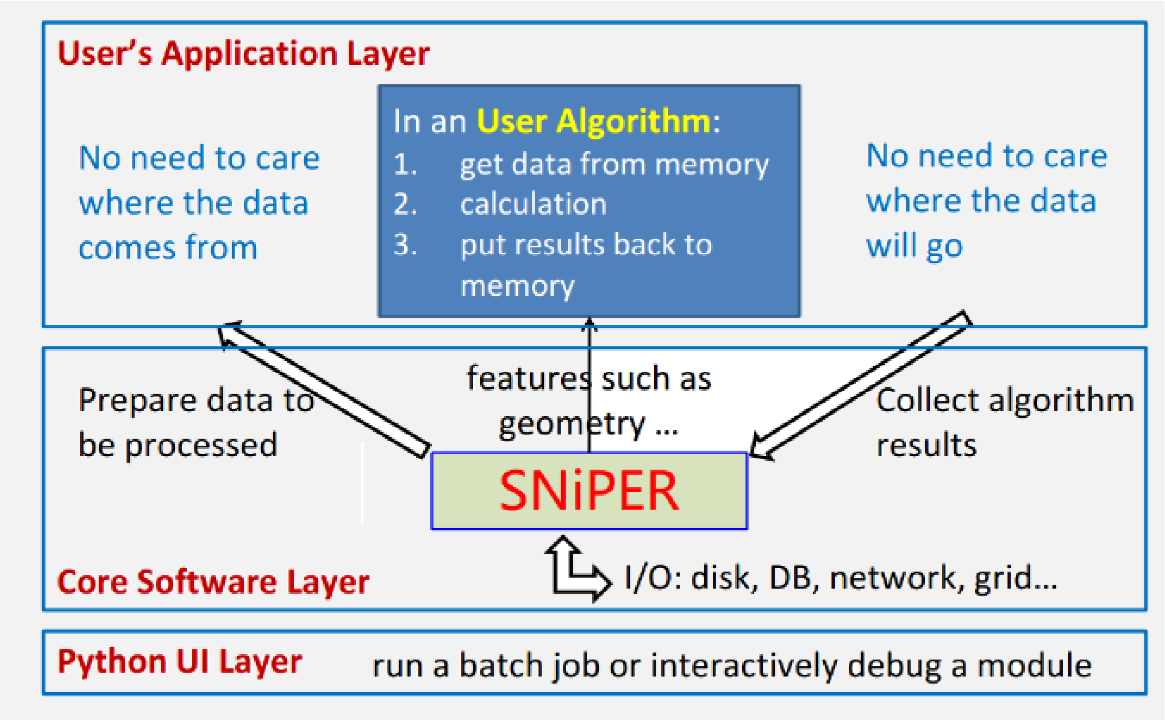
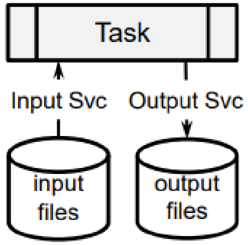
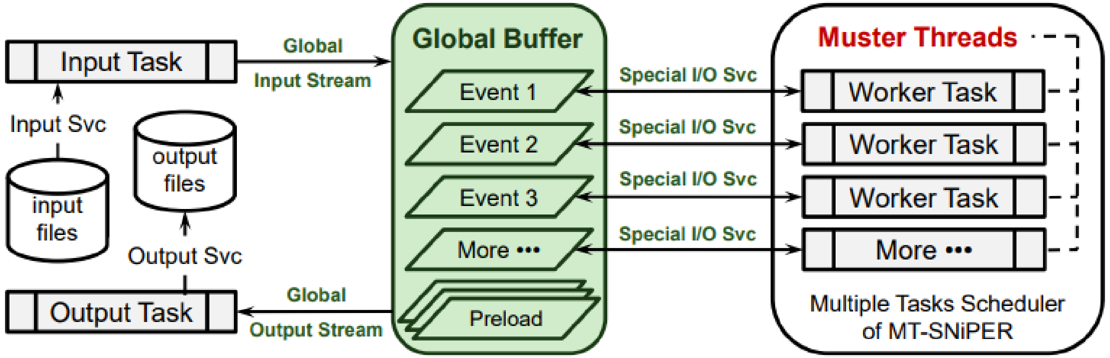


Figure 1: An overview of SNiPER

- What can be reused from serial version
  - I/O services
  - Algorithms and other services in a Task
- What's new with MT-SNiPER
  - Global I/O Stream and Global Buffer
  - Specialized I/O services to access the Global Buffer in Worker Task(s)
  - Configure multiple Task instances for I/O and Worker of MT-SNiPER

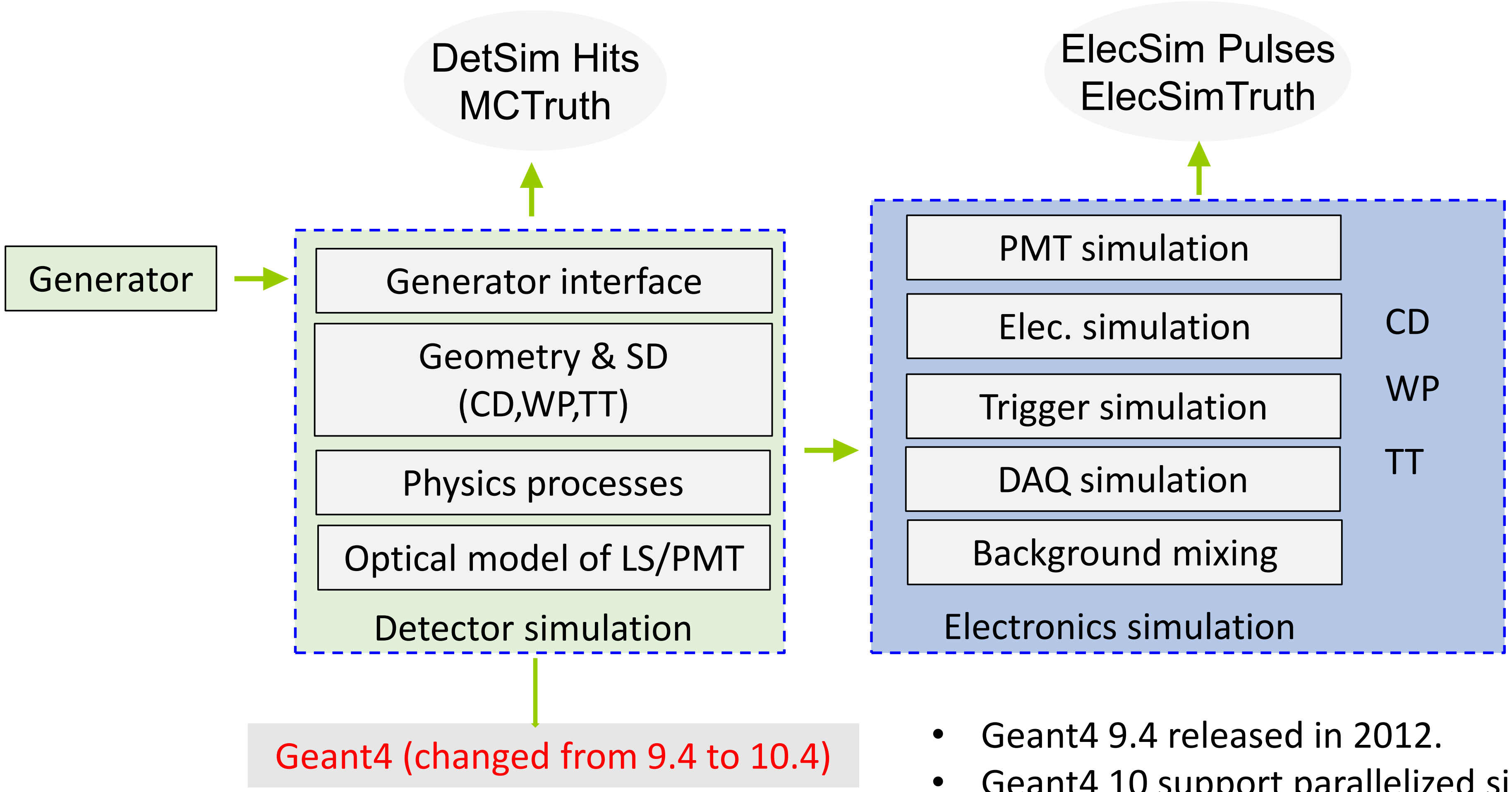




Link: https://github.com/SNiPER-Framework/sniper
Used by JUNO, nEXO, LHAASO (cosmic ray)

Intel TBB based MT-SNiPER is available in 2018.
Support time correlation analysis.

Simulation software



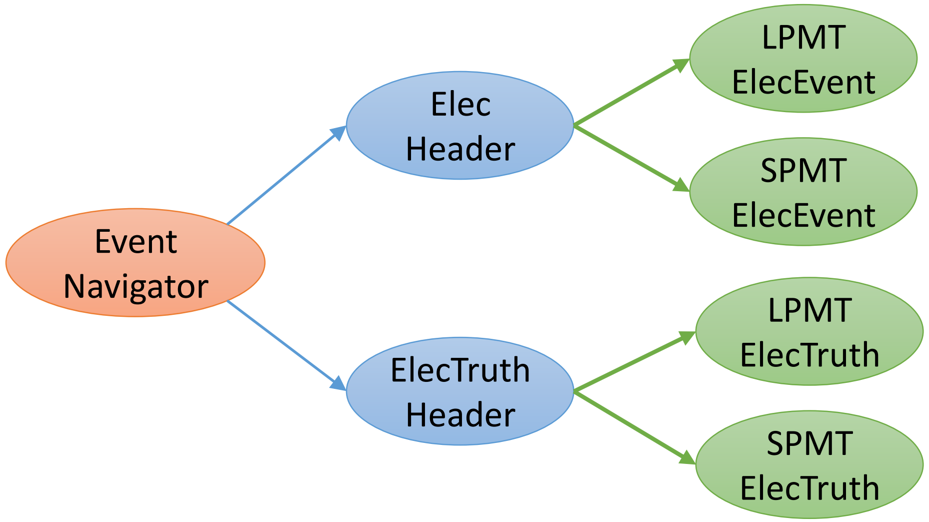
- Geant4 9.4 released in 2012.
- Geant4 10 support parallelized simulation.

Event Data Model

- Separation of Header and Event, for lazy loading.

Physics Generator	HepMC	
Detector Simulation	SimHeader	
	SimEvent	
		SimTrack
		SimPMTHit
		SimTTHit
Electronics Simulation	ElecHeader	
	ElecEvent	
	ElecTruthHeader	
	ElecTruthEvent	

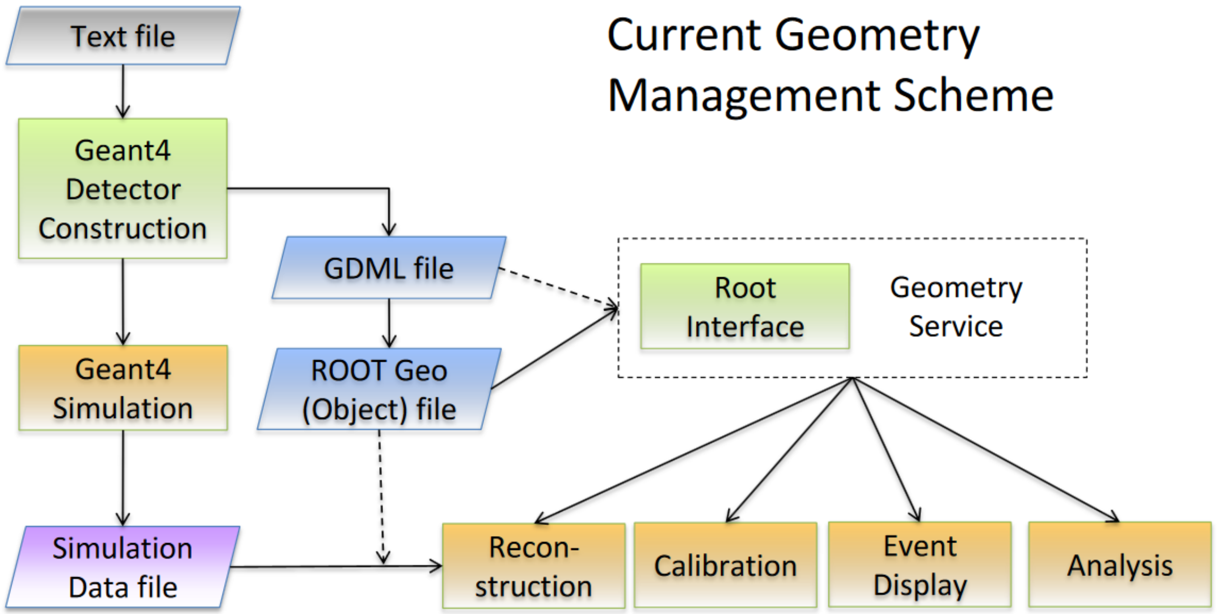
- Compatible between MC and real raw data in the later reconstruction.
  - ElecHeader/ElecEvent are for both MC and real data.
  - ElecTruthHeader/ElectTruthEvent are only available for MC data.

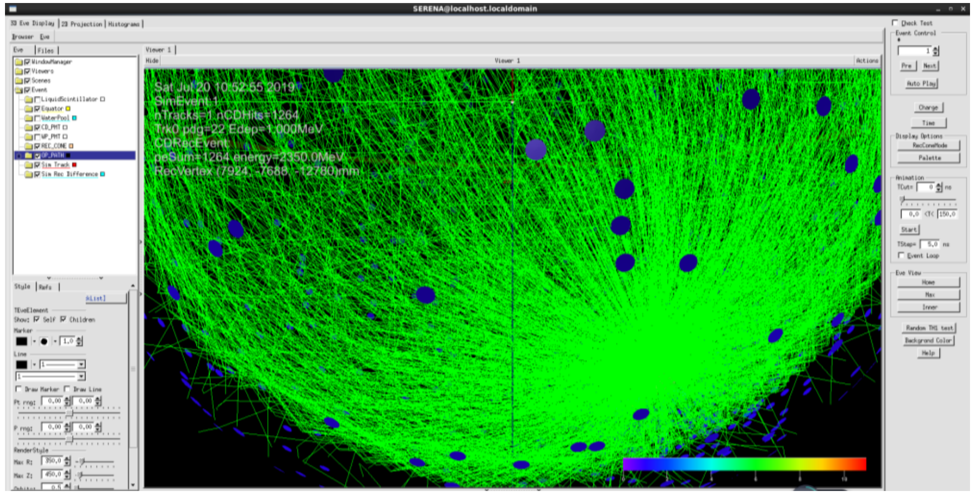


Unified Geometry

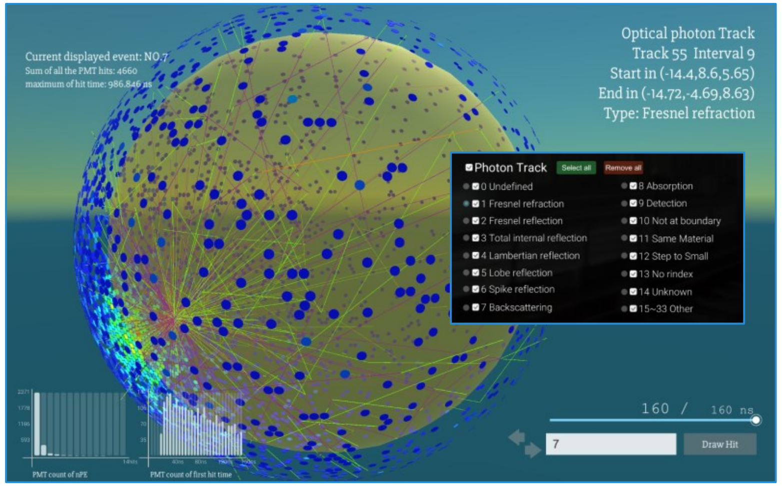
- Event data and geometry are saved in the same file to keep the consistency between simulation and reconstruction.

Current Geometry Management Scheme



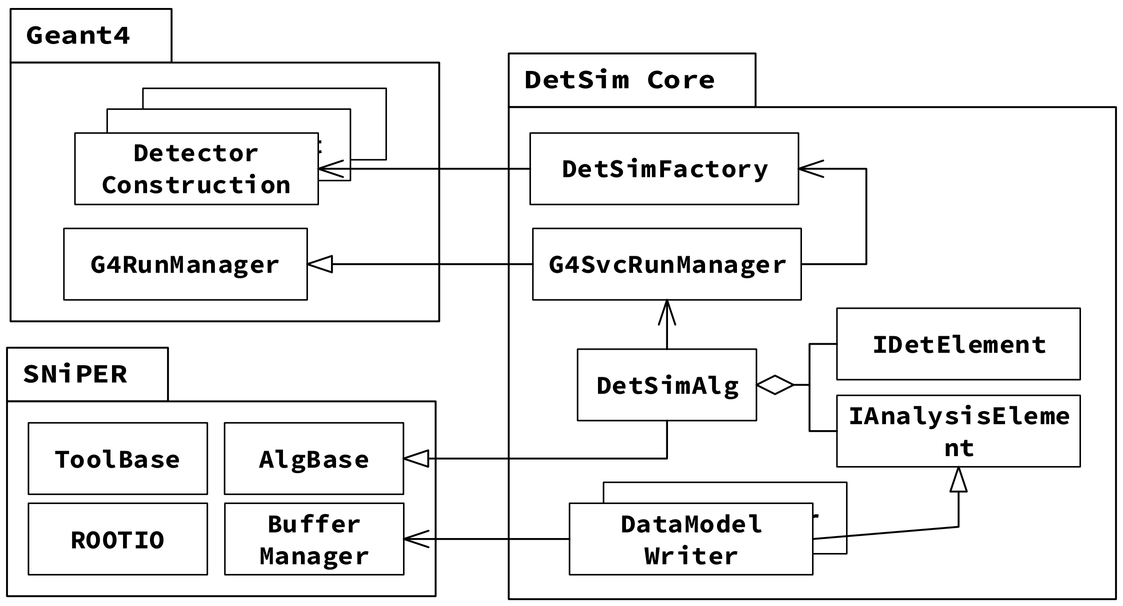


ROOT based event display

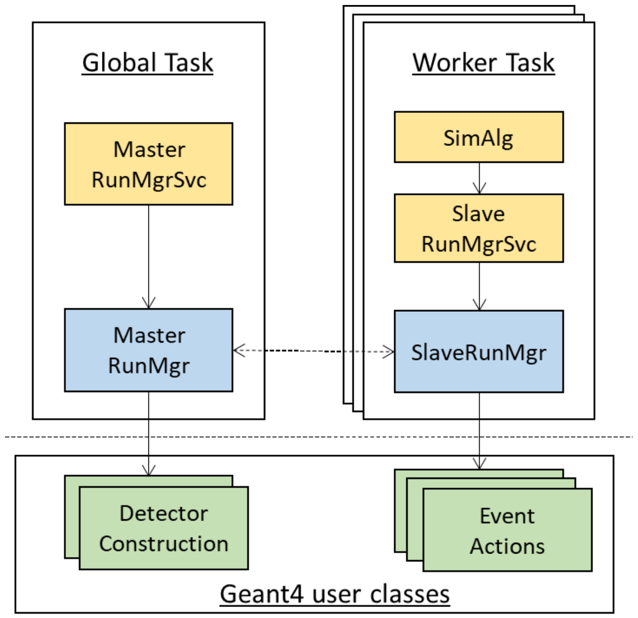


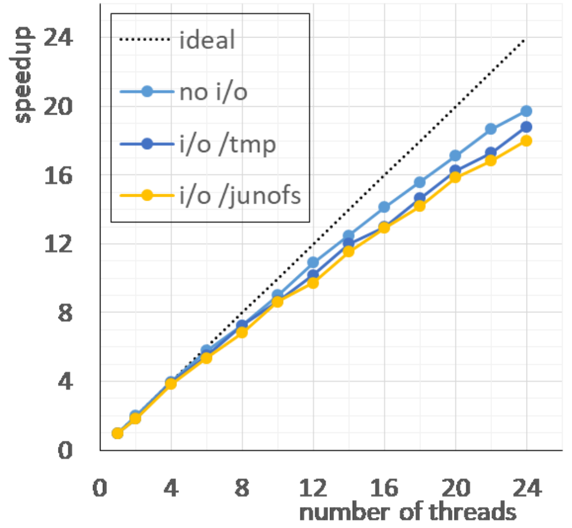
Unity based event display

Detector Simulation Framework



Integration of SNiPER & Geant4 (9.x & 10.x).



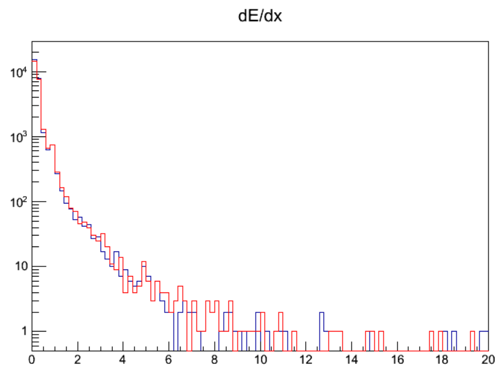


Support TBB-based multi-threading with Geant4 (10.x).

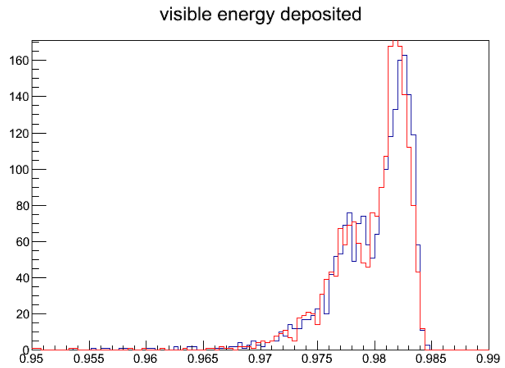
Validation of Geant4 update

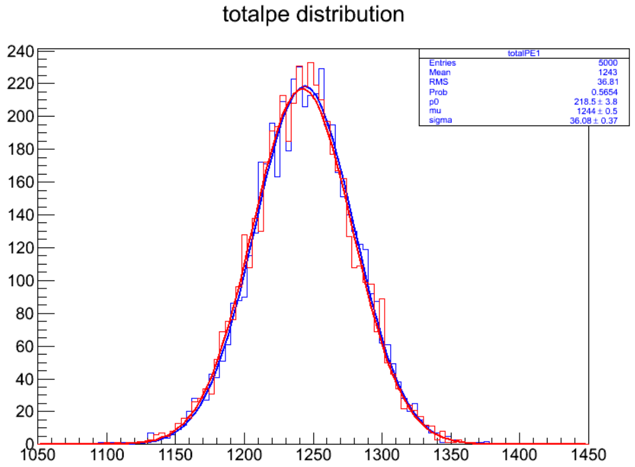
A lot of work had been done to validate the update. Now, it is ready for use.

- Samples
  - e+, e-, gamma(0~10MeV)
  - alpha, proton, neutron
  - high energy particles(0~500MeV)
- Distributions
  - dE/dx, Energy deposit, TotalPE, ……
  - Neutron capture
- Offline software releases
  - J18v1r99-Pre1 (Geant4.9.4.p04)
  - J18v2r1-Pre4 (Geant4.10.4.p02)
- Geometry and optical parameters keep the same during the validation of Geant4 update



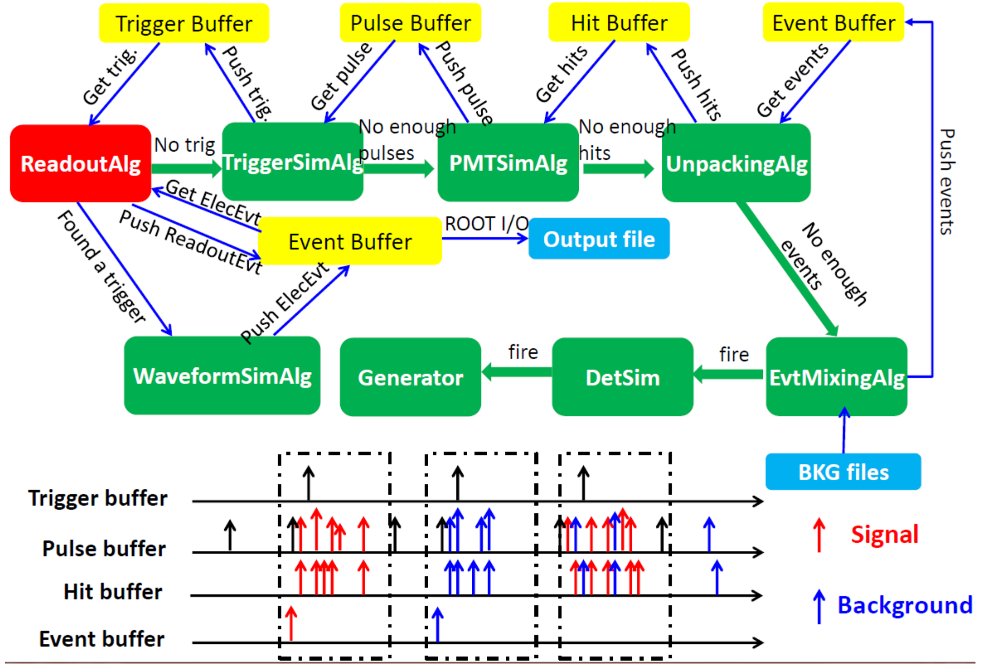
An example: 20,000 e- @(0, 0, 0).
Red line is G4 9.4,
blue line is G4 10.4.





Electronics and Digitization Simulation

- “PULL” workflow (data-driven)
  - Starts from ReadoutAlg.
  - Using SNiPER’s Task+Incident to call TriggerSimAlg when buffer is empty.
- Handle event mixing and event splitting gracefully.
  - Such as IBD events (prompt and delay signals)
- Each part is designed and implemented as a module.
- All the simulation of sub-detectors are done in the same software.

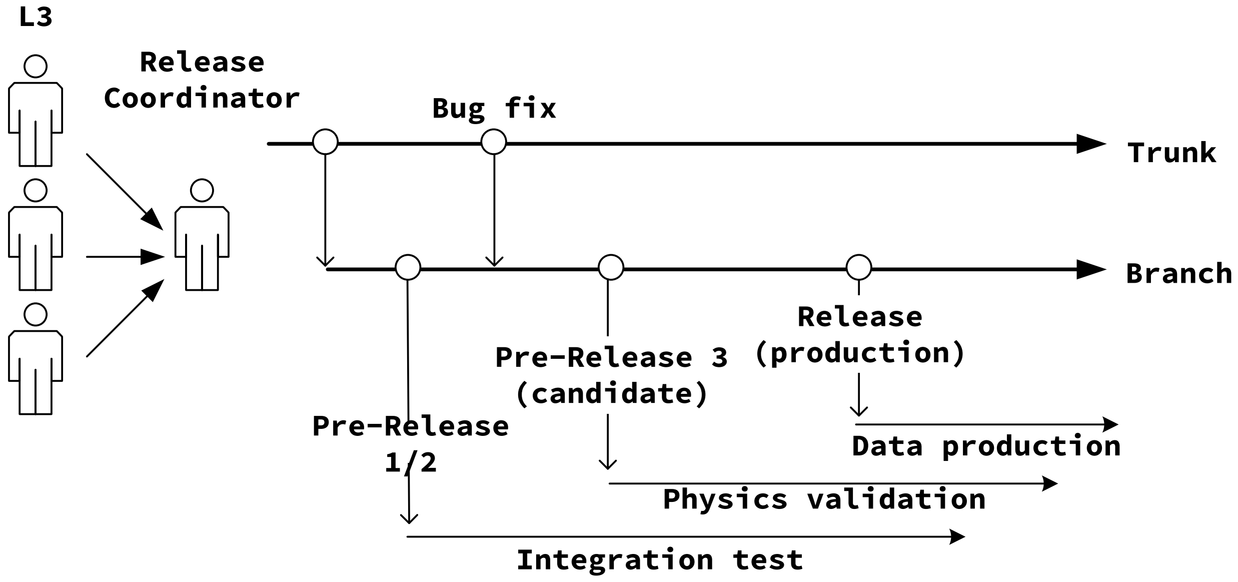



```
python tut_det2elec.py \
        --input IBD:ibd1.root \
        --input U:u.root \
        --rate IBD:1.0 \
        --rate U:3.0
```

IBD

U

MC Data validation and production



- "JunoTest Production" supports both validation and production.
- ".ini file" is used for configuration.

```
Validation.ini
[Chain]
seed = 42
evtmax = 500
njobs = 1
tags = e+_0.0MeV e+_1.398MeV
```

```
Production.ini
[Chain]
seed = 42
evtmax = 1000
njobs = 100
tags = e+_0.0MeV e+_1.398MeV
```

UPDATED Proposal: chains to test

- 3 chains to compare the outputs of:

(1) DetSim → "Calib" converter → Vtx+Ene rec (the 'old' way)

(2) DetSim → ElecSim in deterministic mode (no evt mixing) → Waveform rec → Vtx+Ene rec (the 'new' way)

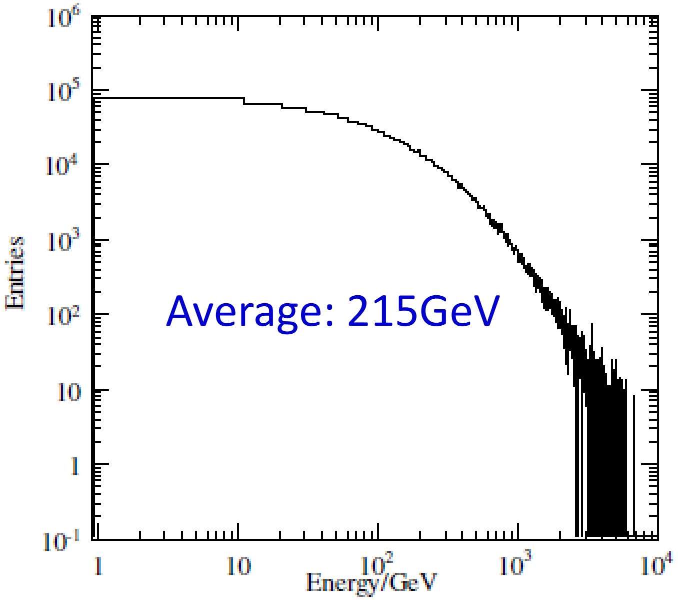
- *no evt mixing, so that each simulated event is digitized 1-to-1 and can be inspected before and after ElecSim*

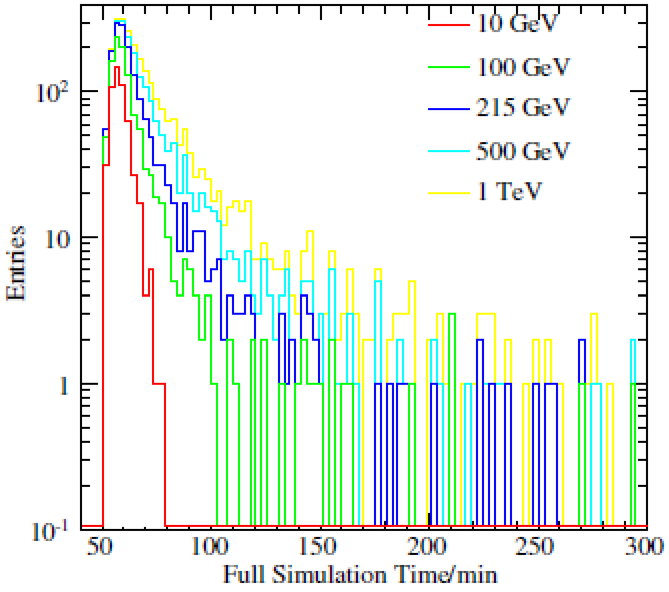
(3) DetSim → ElecSim with evt mixing → Waveform rec → Vtx +Ene rec (the 'new' way)

- *with evt mixing, so that each simulated event is overlapped with bkgs as it happens in real life.*
- *Bkgs = simulate natural ^{238}U + overlap Dark Noise at 50 KHz?*

Full chains of simulation and reconstruction are ready.

Challenges of muon simulation

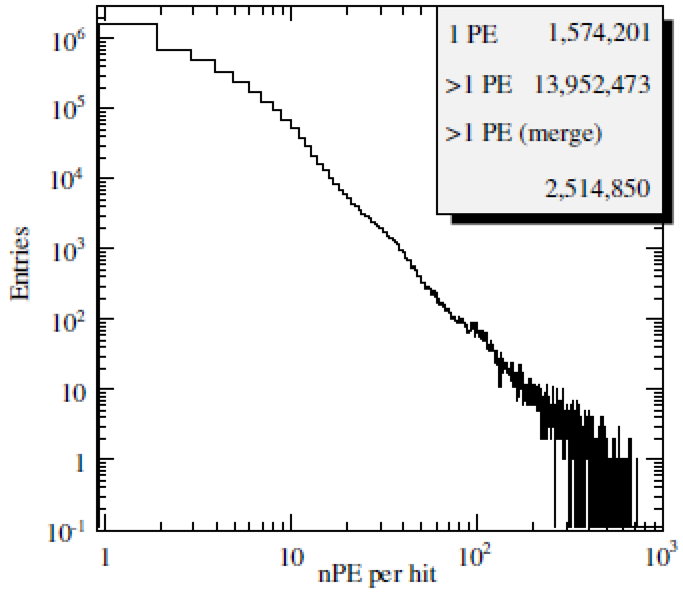




Optimizations:

⇒ Use special object for muon simulation.

⇒ Merge generated hits in 1 ns time window.



Light yield: 10^4/MeV, dE/dx: ~2 MeV/cm, Track length: 35.5 m

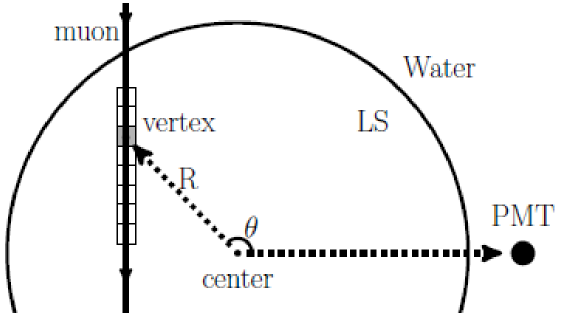
⇒ Deposit 7 GeV.

⇒ Generated 70 Million photons.

Both CPU and I/O consuming.

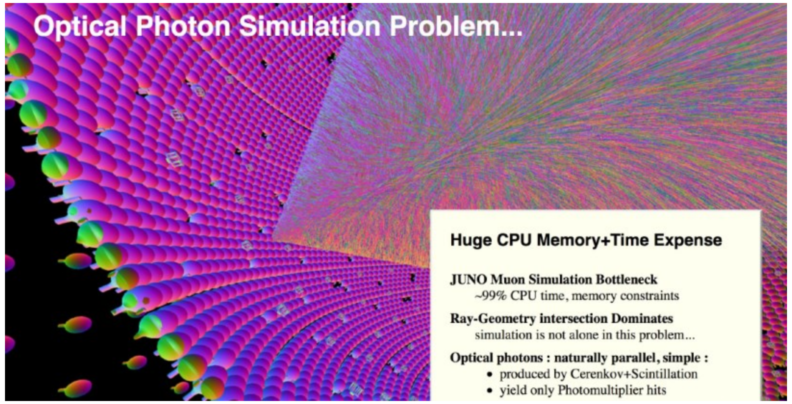
Solutions and Plans

(1) Fast simulation: voxel method, implemented in both CPU/GPU version

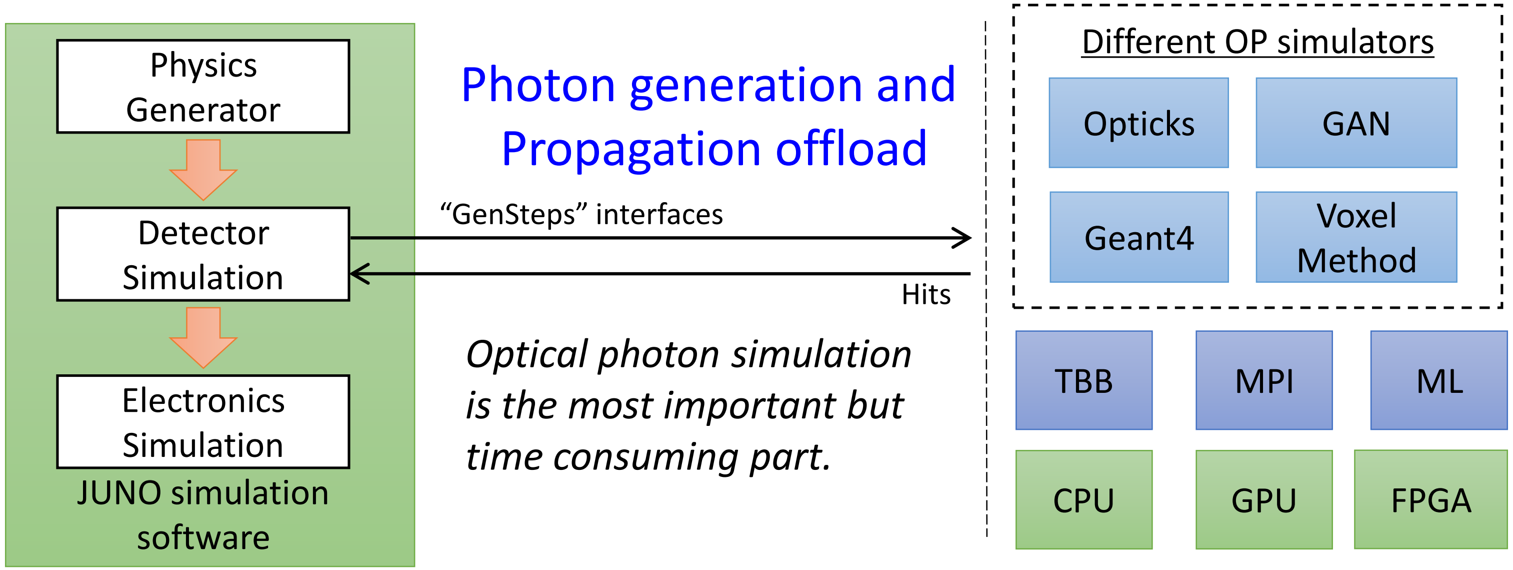


Pre-generated histograms for nPE and hit time.

(2) Opticks: GPU based full simulation.



Plans: Unified deferred optical propagation



The key idea is to offload the photon generation and propagation.

- Speedup: using different accelerators (GPU/FPGA/ML).
- Memory: reducing the memory usage in the CPU side, e.g. muon & proton decay.

One of the important features is to defer the OP simulation until we are interested in the events.

Conclusions & Outlook

- JUNO simulation software was developed since 2012.
  - Detector simulation framework integrates SNiPER and Geant4.
  - Electronics simulation supports "PULL" workflow, allows hit level mixing.
- The full data processing chain and data production is ready.
  - O(100) TB data are produced.
- The challenge is the muon simulation, which produces ten millions of photons.
  - Working on both fast simulation and full simulation.
  - A unified deferred optical propagation is under design.

Thank you!