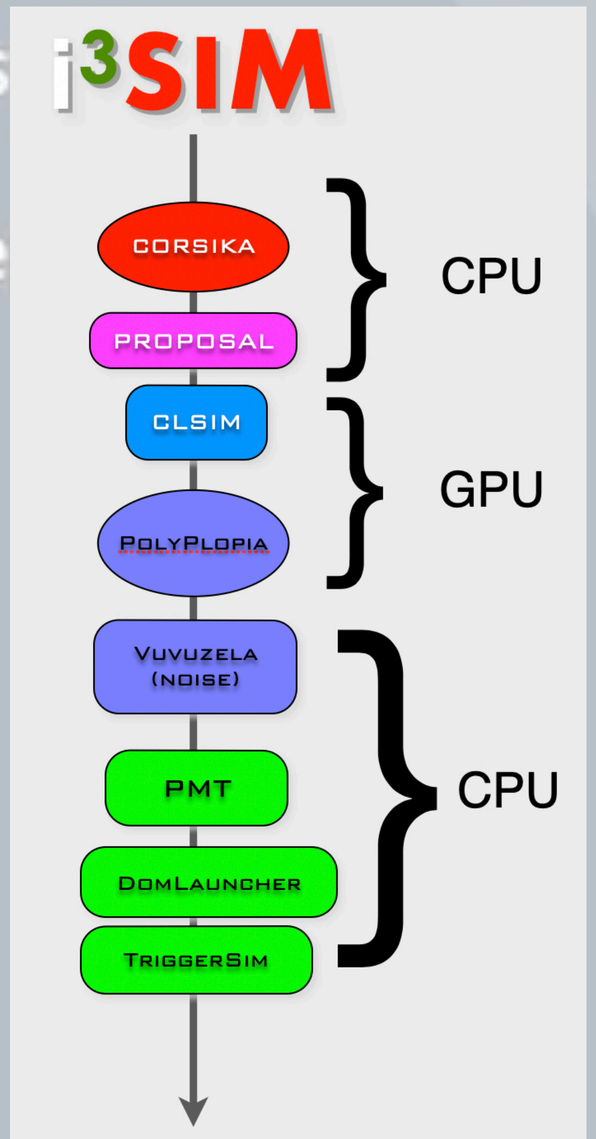
Intro to IceCube Simulation

Juan Carlos Díaz-Vélez

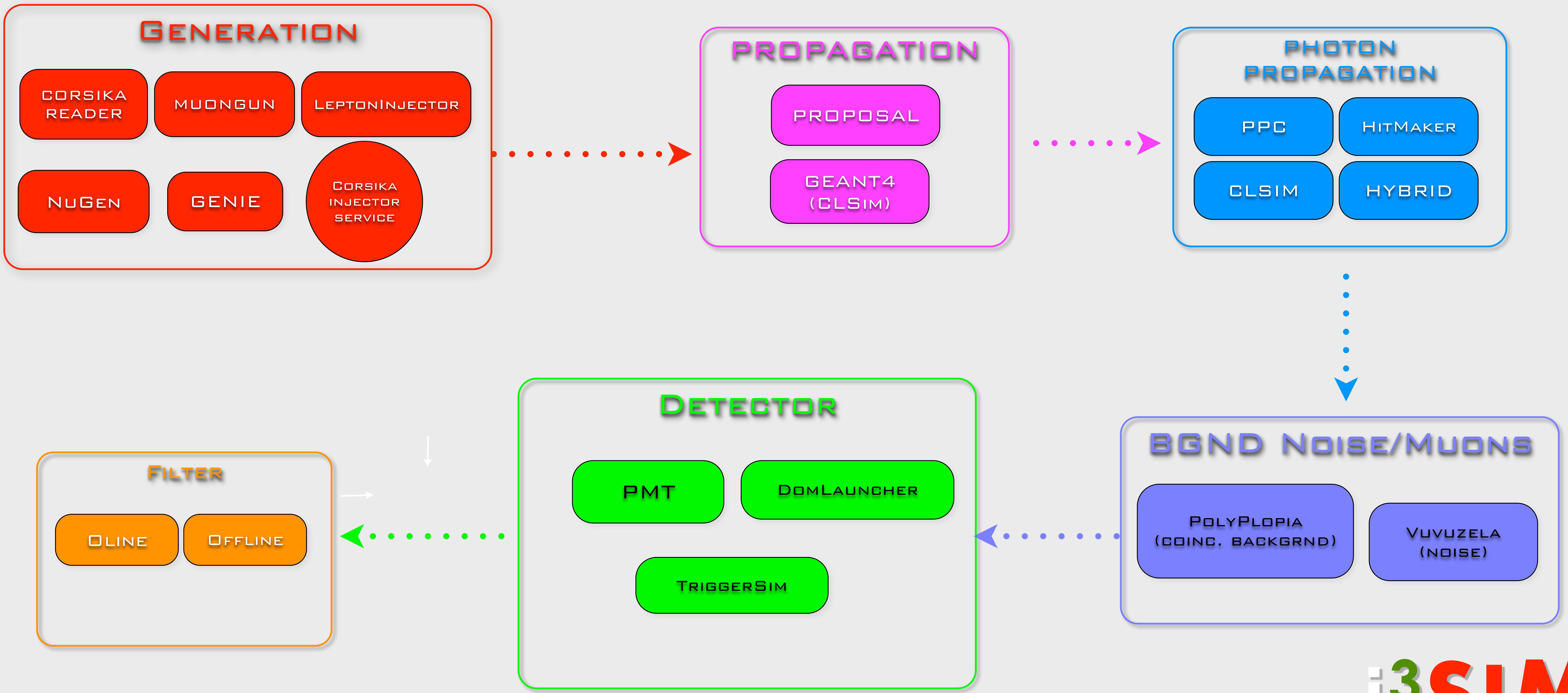
IceProd/SimProd Workshop

Madison, WI USA

June 14, 2024

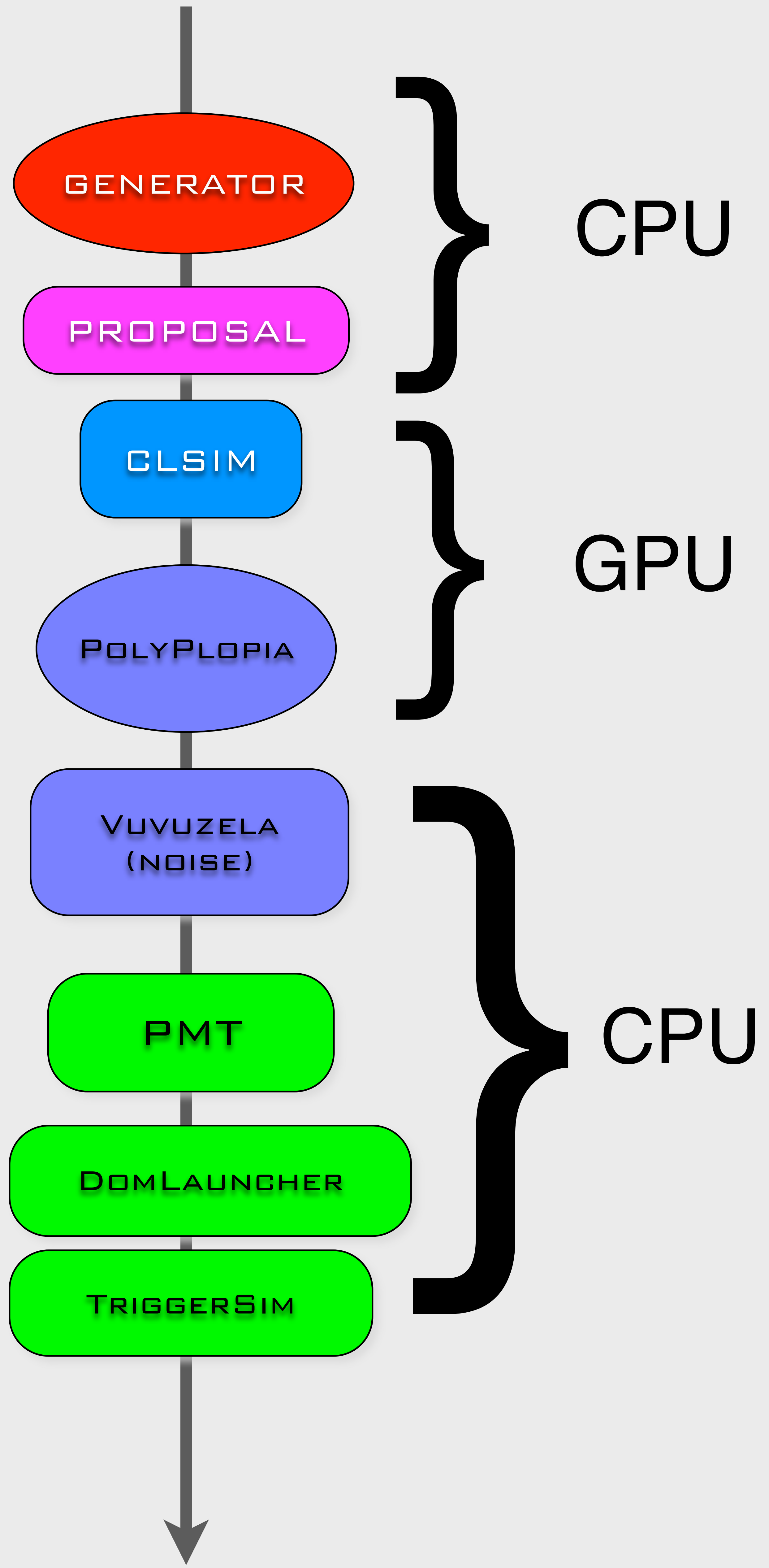


Simulation Chain



The Simulation Shish Kabob
(Computing Resource Optimization)

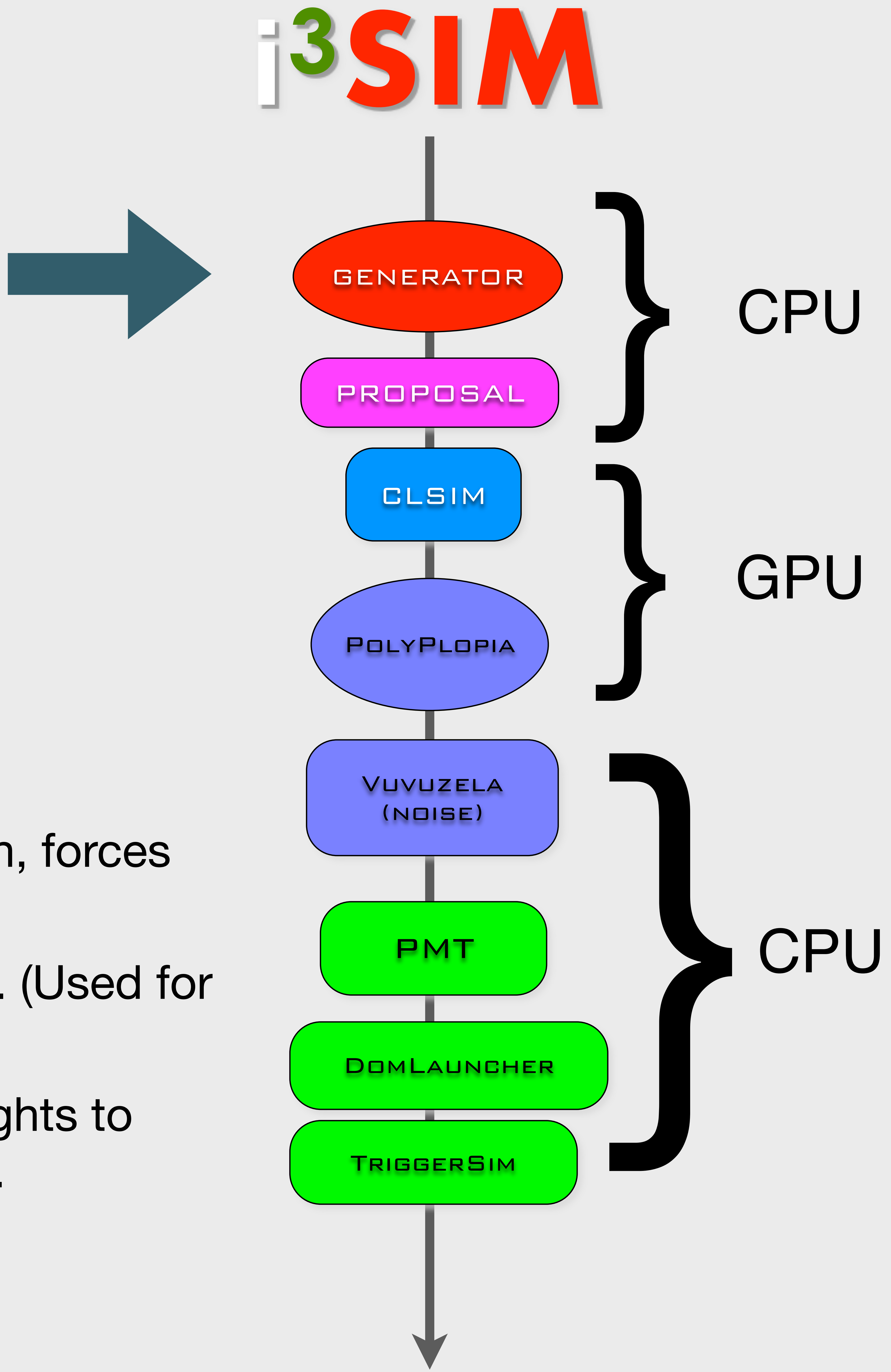
i^{3}SIM



- Optimizing the shish kabob:
  - Different parts of the simulation chain have different resource requirements.
    - CORSIKA is CPU-intensive and requires little RAM
    - Photon propagation run almost exclusively on GPUs
    - Detector simulation is CPU bound and requires more memory.
- Things to keep in mind:
  - Running whole chain on a GPU node will waste GPU resources and limit throughput.
  - Intermediate storage:
    - breaking up chain requires transfering/storing intermediate files.
  - Reduce complexity in workflow

Generators

- Cosmic-ray Air Showers:
  - **Triggered-CORSIKA** (parallel corsika client/server w clsim)
  - **corsika-reader**: IceTray reader for standard format (deprecated)
  - **CorsikaInjectorService** (IceTop)
- Muons:
  - **MuonGun**: parametrization of flux of atm. muons under the ice.
- Neutrinos:
  - **neutrino-generator**: injects neutrinos, propagates them through Earth, forces interaction in detector volume.
  - **genie-reader**: detailed simulation of neutrino interactions with GENIE. (Used for low-energy simulations)
  - **LeptonInjector / NuFSGen** (not yet available): weighted leptons+weights to account for flux models, interaction models, in-earth propagation, etc.

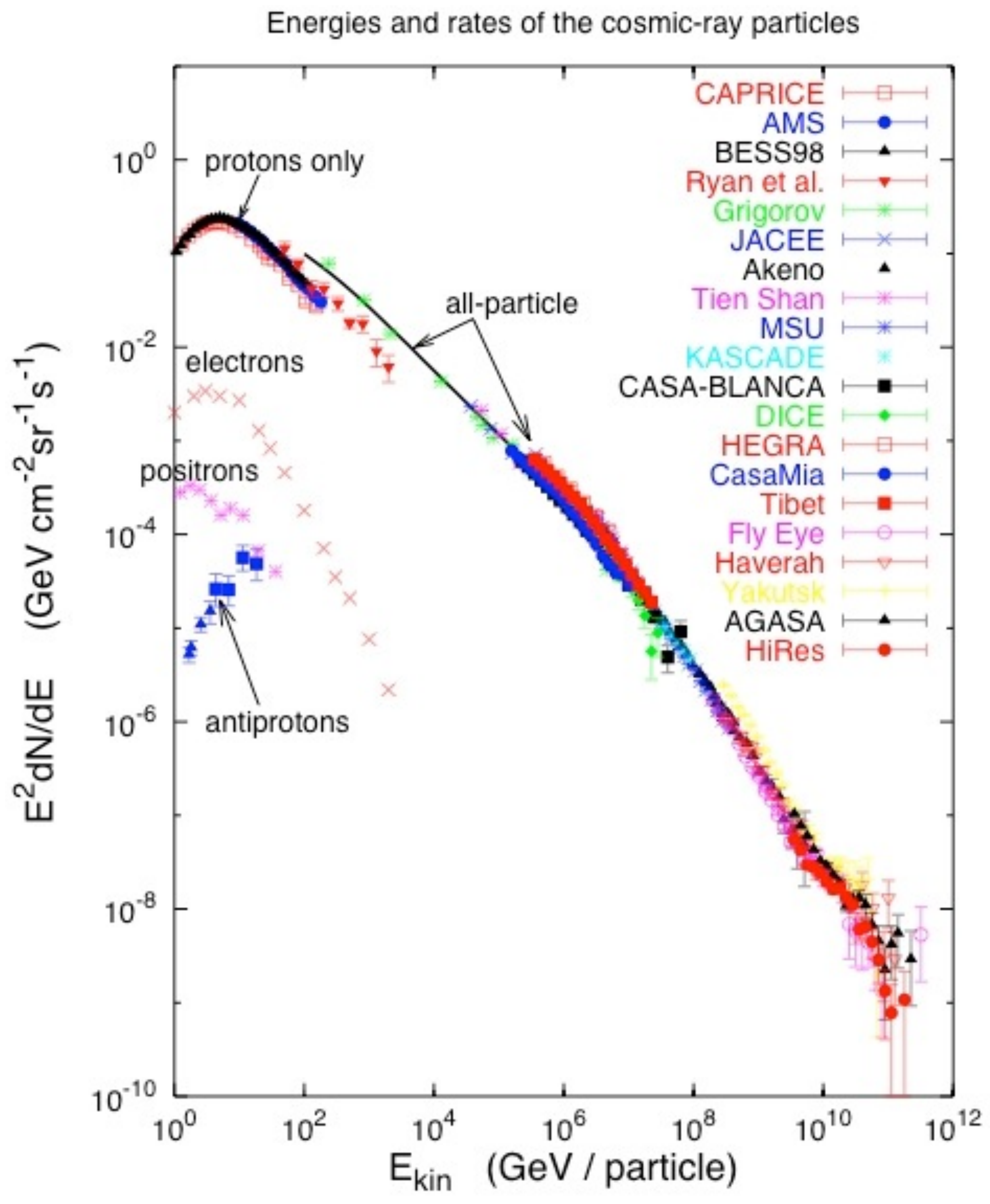


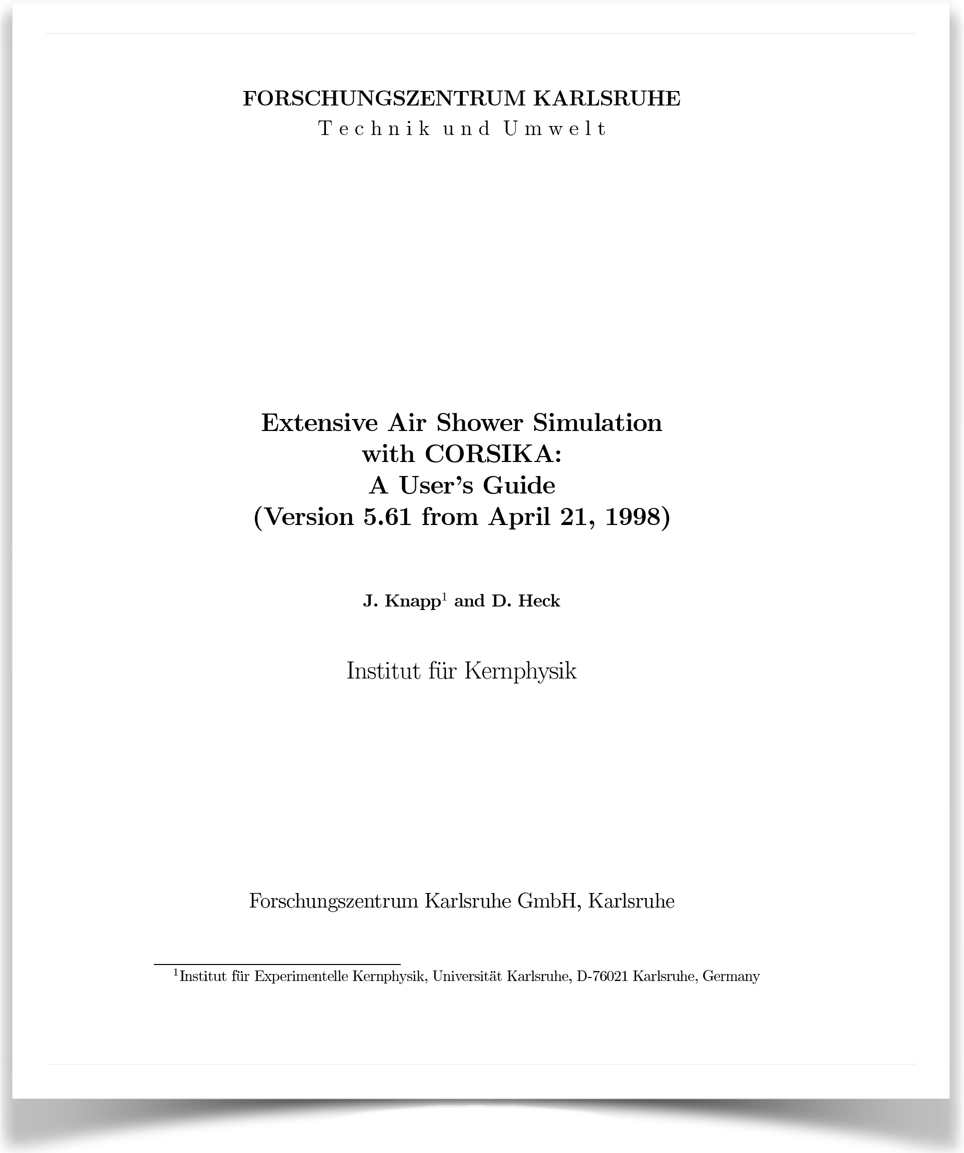
Generators : CORSIKA

(**CO**smic **R**ay **SI**mulations for **KA**scade)

- Particles are tracked through the atmosphere until they undergo reactions with the air nuclei or - in the case of instable secondaries - decay.
- The hadronic interactions at high energies may be described by several reaction models alternatively:
  - *VENUS*, *QGSJET*, and *DPMJET* (Gribov-Regge theory),
  - SIBYLL (minijet model).
  - *neXus*, *EPOS* (combination of *QGSJET* and *VENUS*).
  - *HDPM* (Dual Parton Model).
- Hadronic interactions at lower energies:
  - *GHEISHA*, *FLUKA* , or *UrQMD* models.
- For electromagnetic interactions
  - Tailored version of *EGS4*.
  - Analytical *NKG* formulas.

> - weighted events : artificial spectrum $E^{-\gamma}$
> - 5 representative mass groups: (H,He,CNO,Mg,Fe)





FORSCHUNGSZENTRUM KARLSRUHE
Technik und Umwelt

Extensive Air Shower Simulation
with CORSIKA:
A User's Guide
(Version 5.61 from April 21, 1998)

J. Knapp[1] and D. Heck

Institut für Kernphysik

Forschungszentrum Karlsruhe GmbH, Karlsruhe

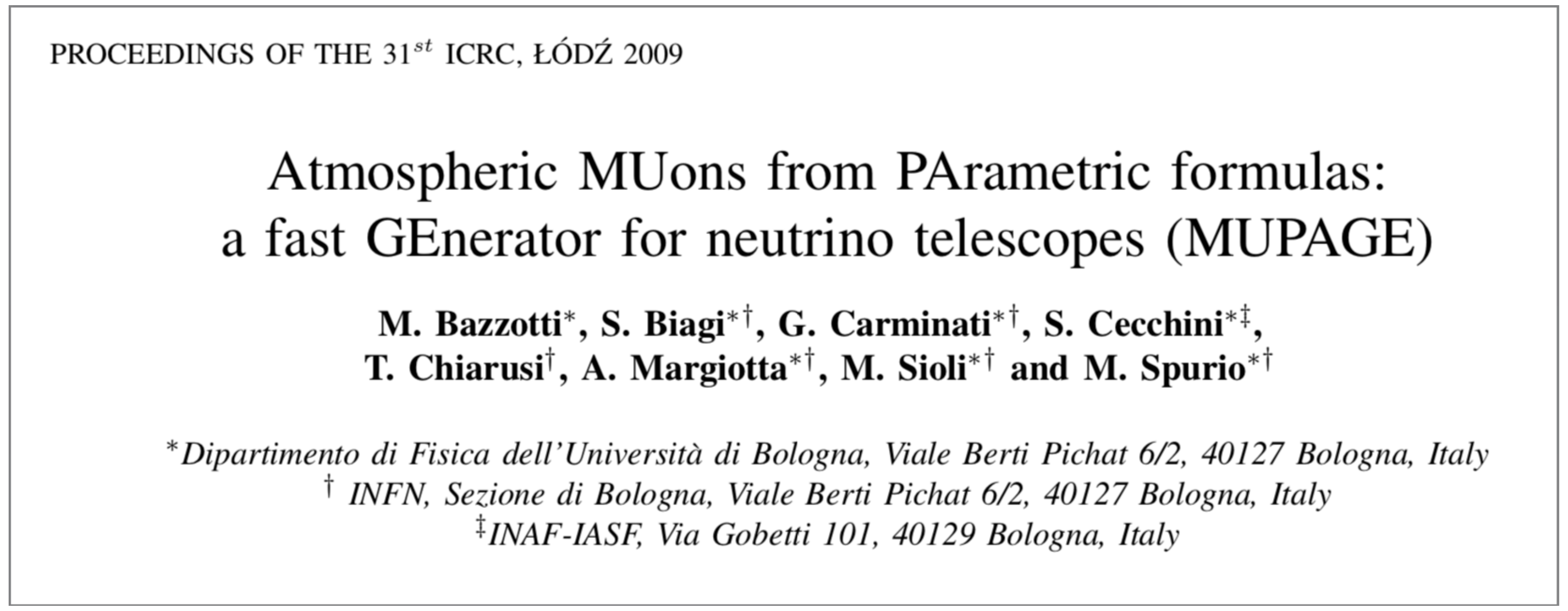
[1] Institut für Experimentelle Kernphysik, Universität Karlsruhe, D-76021 Karlsruhe, Germany

https://web.ikp.kit.edu/corsika/physics_description/corsika_phys.pdf

MuonGun (IceCube implementation of MUPAGE)

arXiv:0907.5563v1 [astro-ph.IM] 31 Jul 2009

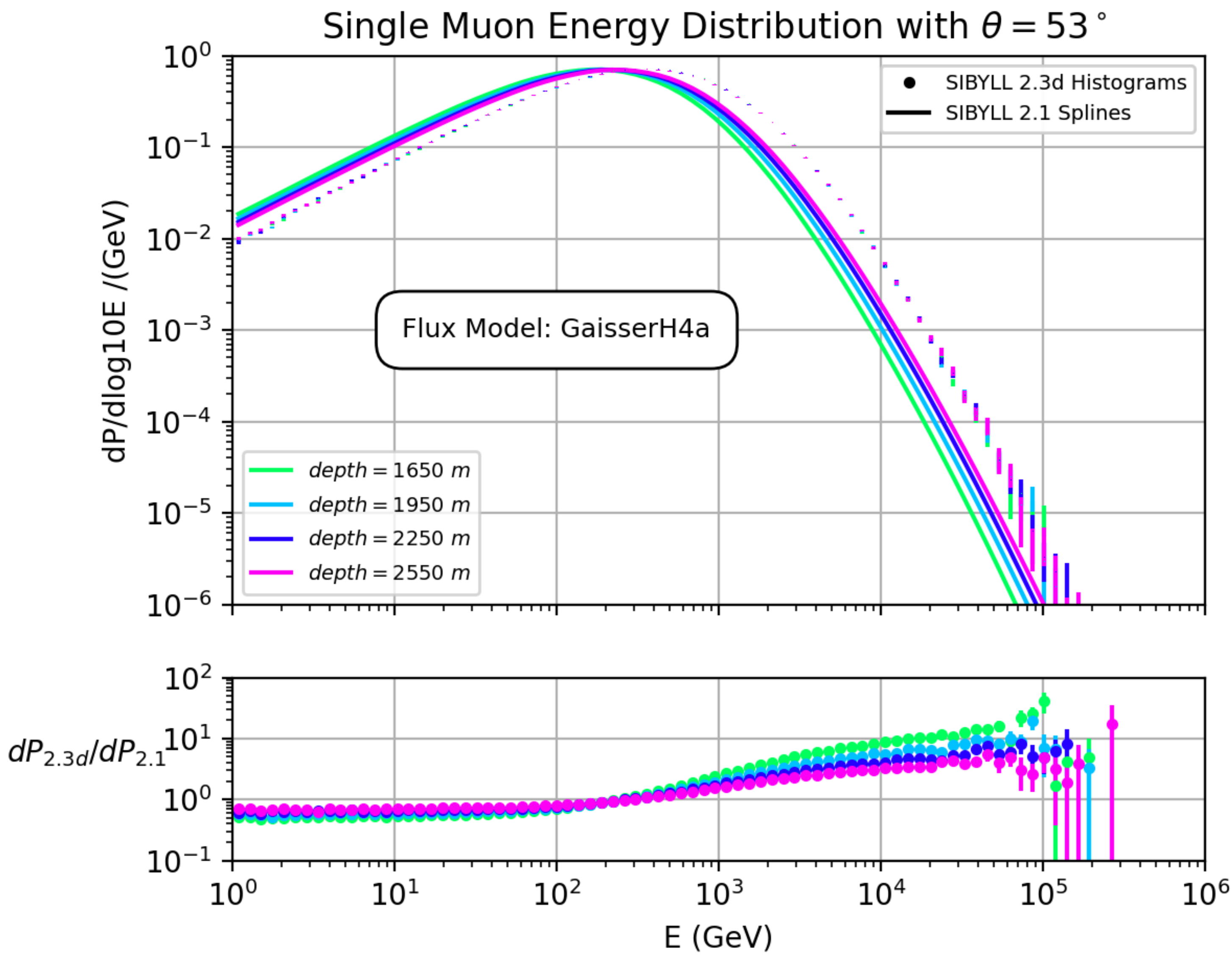
- Parametrized muon distributions from many, many CORSIKA showers.
- Produce muons in detector volume by sampling from splinned PDF tables
  - zenith angle
  - depth
  - energy
  - bundle multiplicity
  - radius


PROCEEDINGS OF THE 31st ICRC, ŁÓDŹ 2009

Atmospheric MUons from PArametric formulas: a fast GEnerator for neutrino telescopes (MUPAGE)

M. Bazzotti*, S. Biagi*†, G. Carminati*†, S. Cecchini*‡, T. Chiarusi†, A. Margiotta*†, M. Sioli*† and M. Spurio*†

*Dipartimento di Fisica dell'Università di Bologna, Viale Berti Pichat 6/2, 40127 Bologna, Italy
† INFN, Sezione di Bologna, Viale Berti Pichat 6/2, 40127 Bologna, Italy
‡INAF-IASF, Via Gobetti 101, 40129 Bologna, Italy



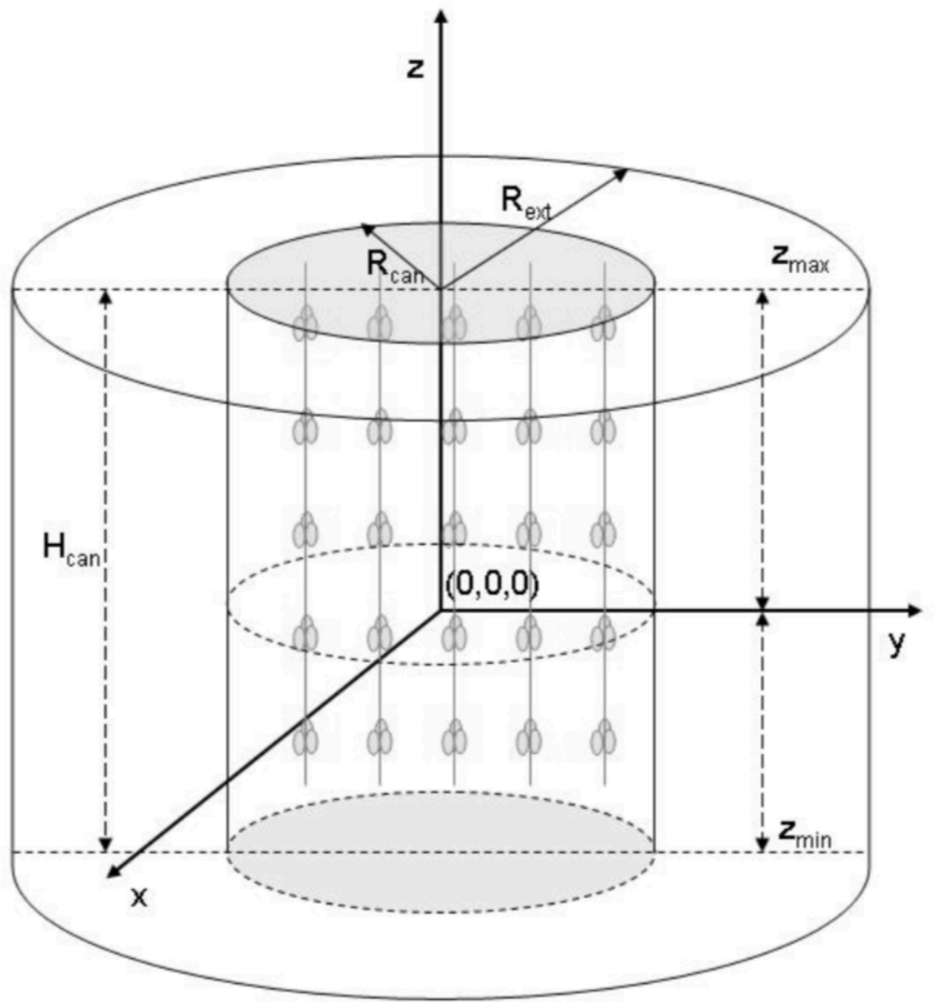
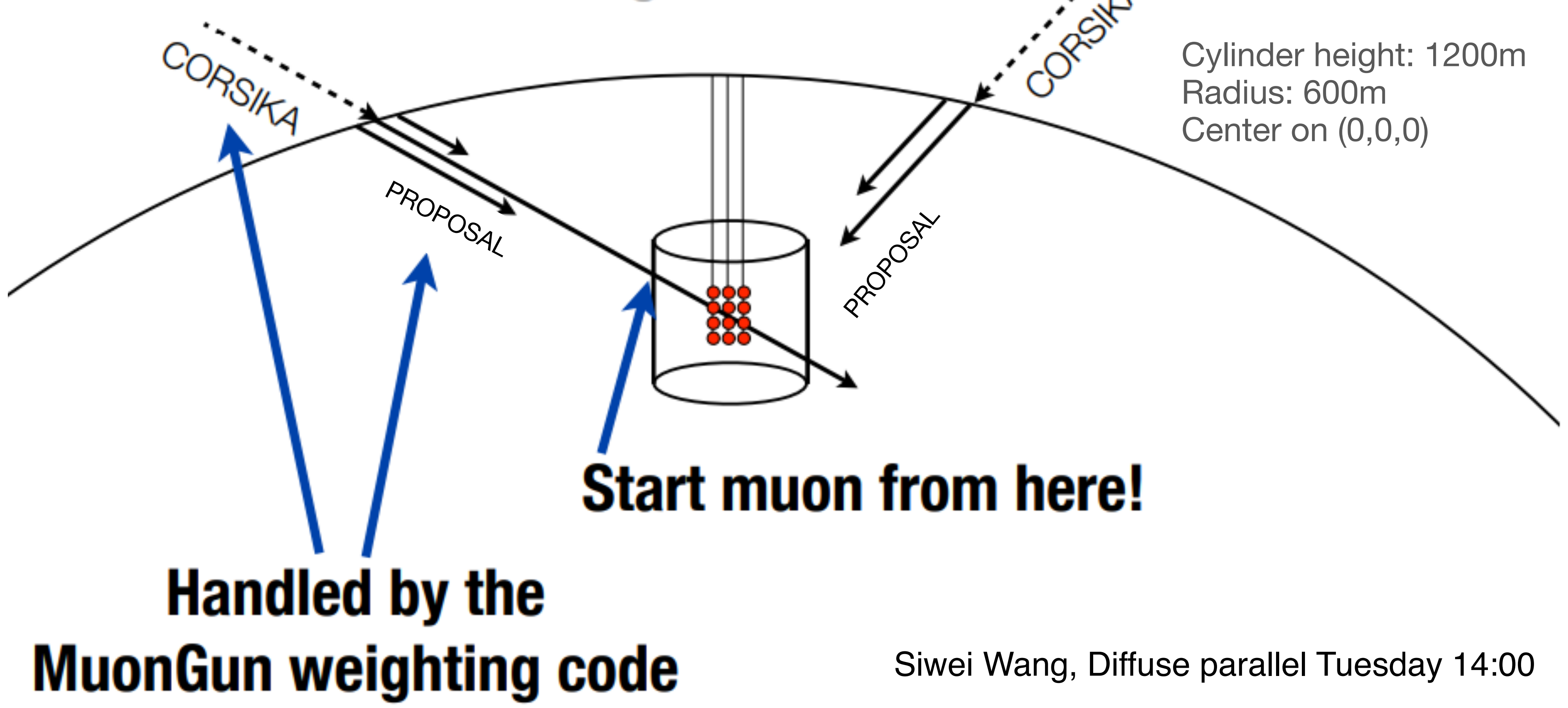
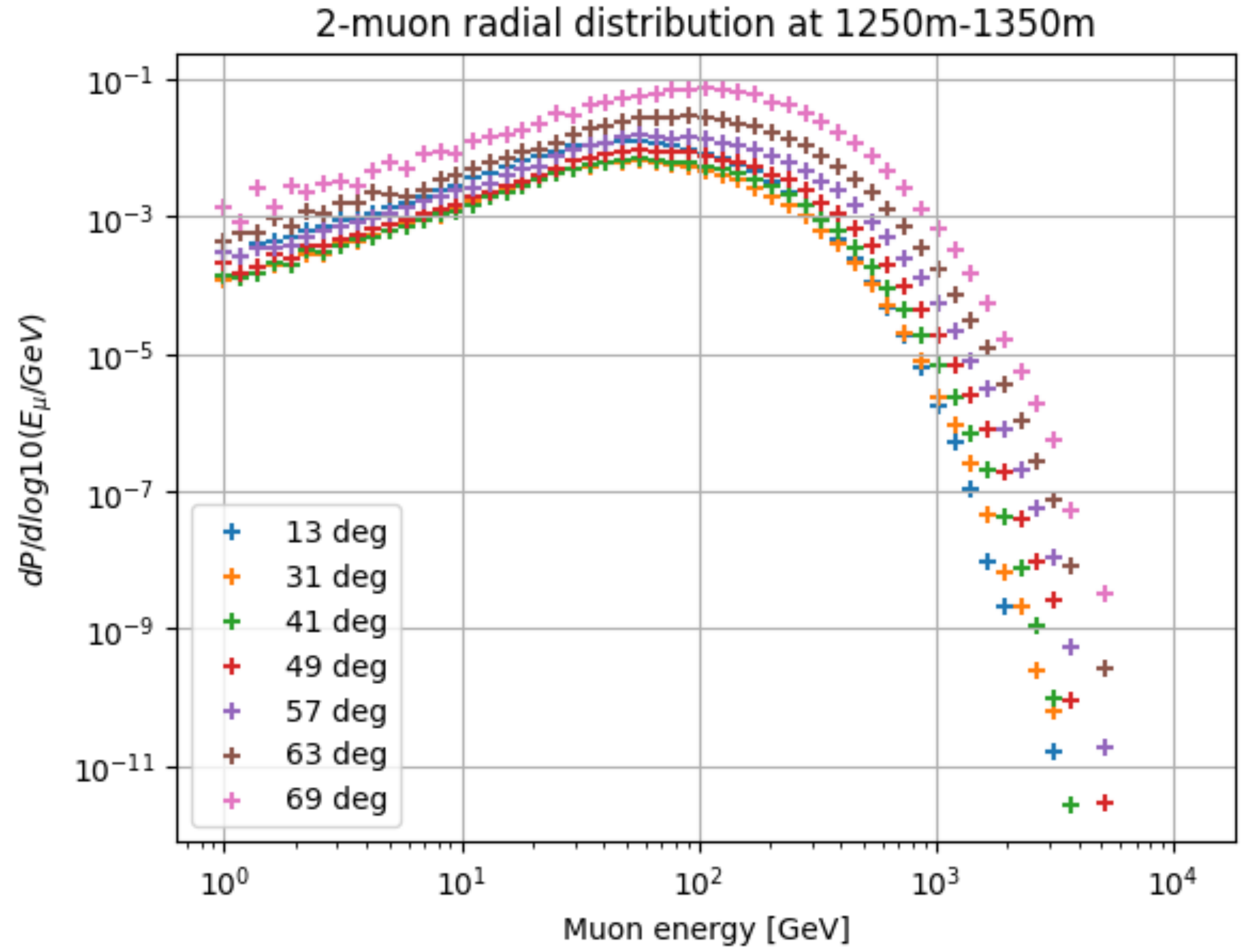


Fig. 1: Sketch of some input parameters. The cylinder surrounding the instrumental volume is the *can*, with radius $R_{\rm can}$ and height $H_{\rm can}$. The events are generated on an extended can with $R_{\rm ext}$. The origin of the coordinate system does not have to be located at the center of the detector. The lower disk is at a depth $H_{\rm max}$ with respect to the sea/ice surface.

MuonGun

Start muons on a cylinder around the detector and only to the full simulation starting from there.

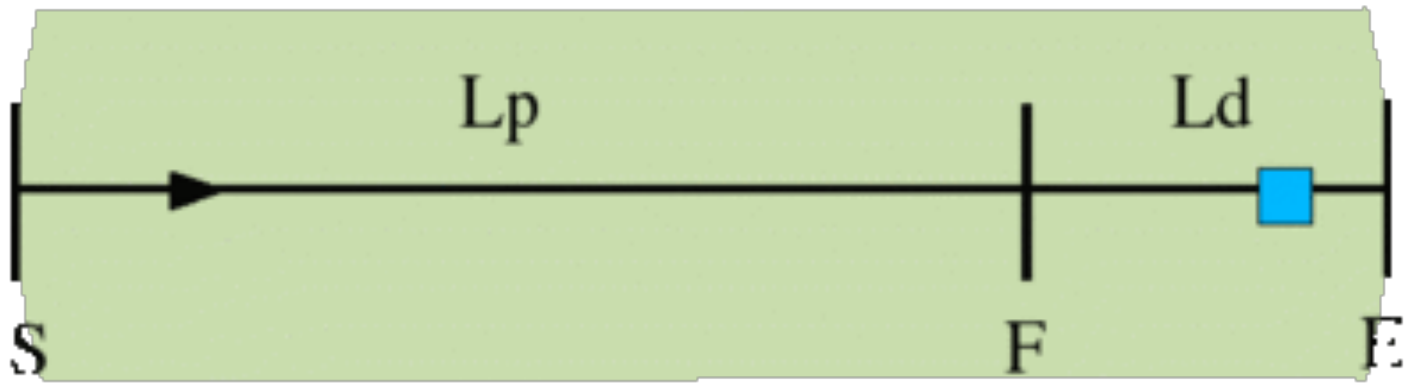


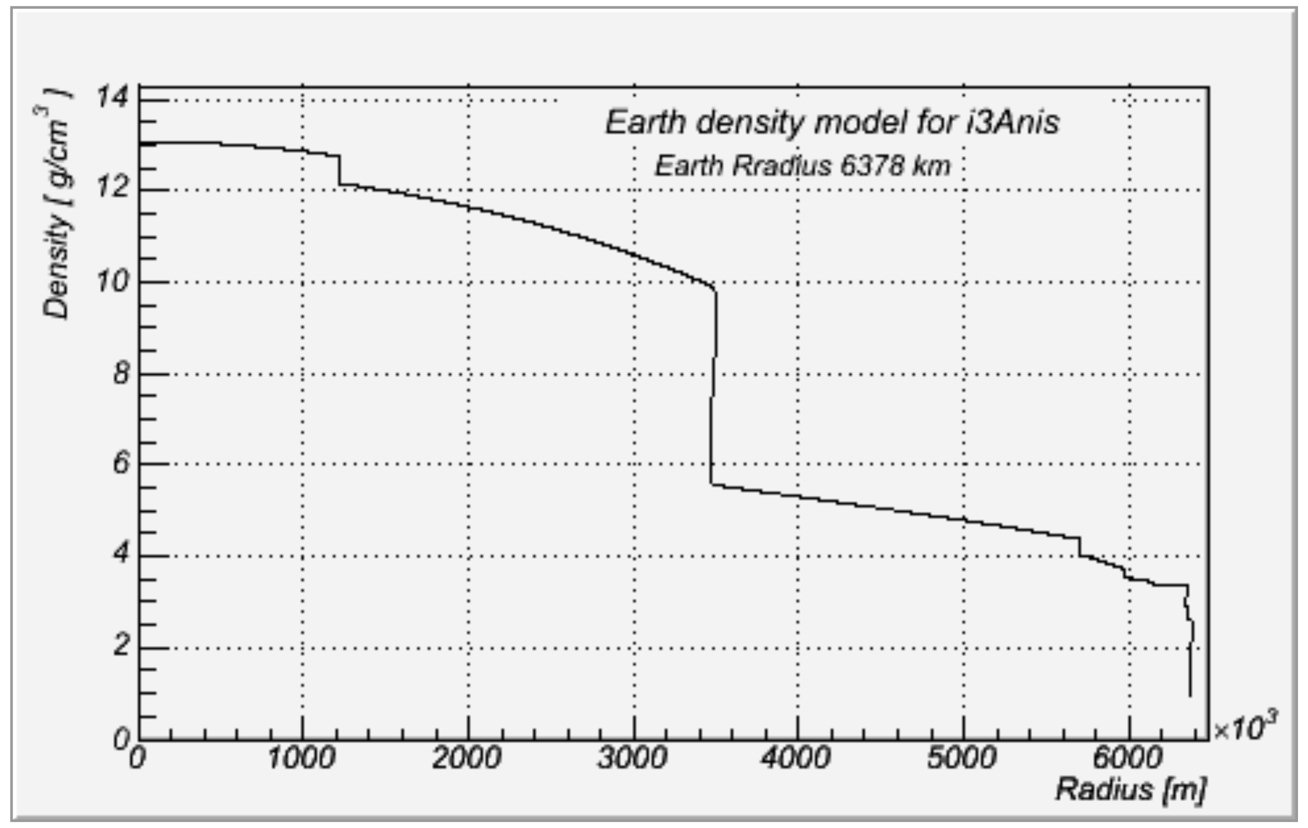


Siwei Wang, Diffuse parallel Tuesday 14:00

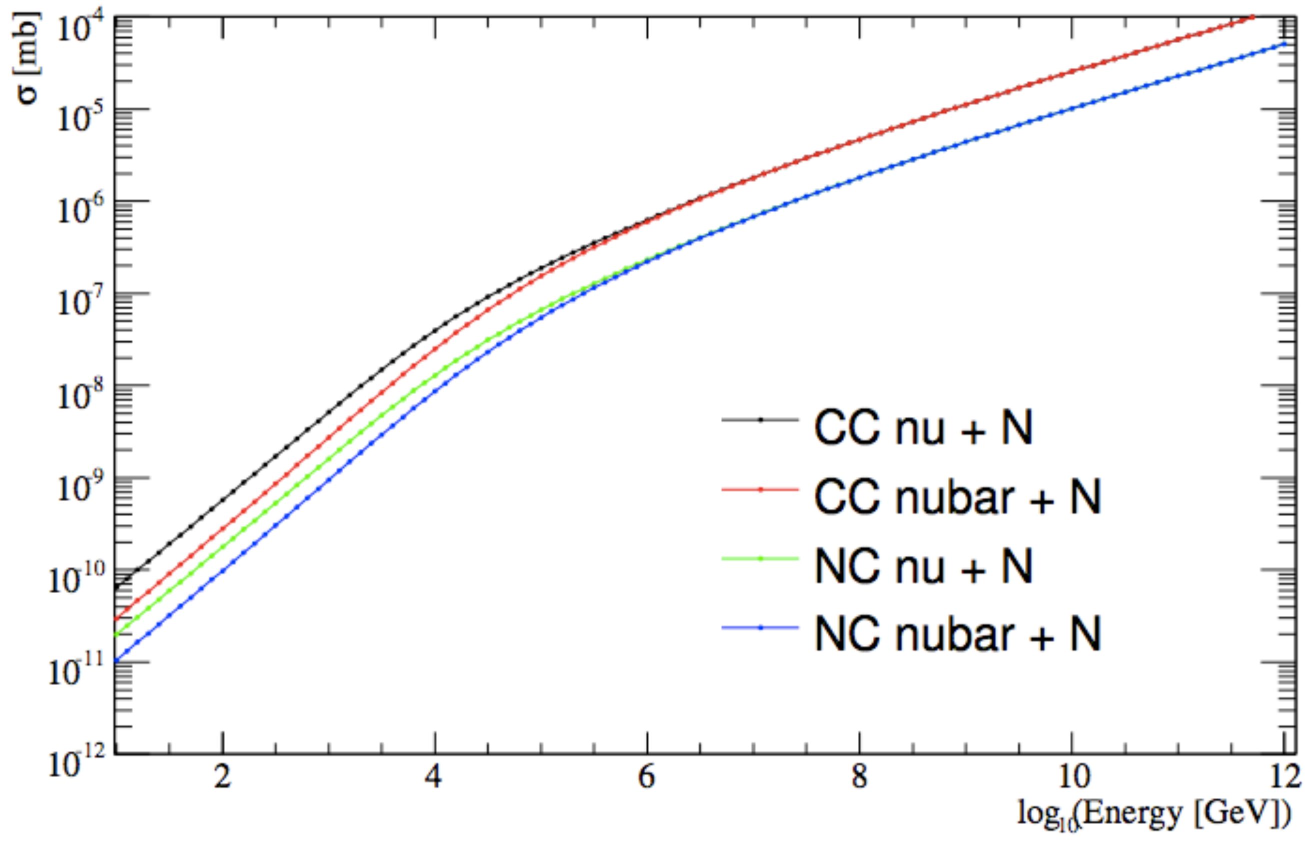
neutrino-generator

1. Calculate total path length inside the Earth using injected neutrino geometry.
    a. Separate the total path length into propagation area (SF) and
    b. detection volume (FE).
2. Define a step length dx[m] using propagation area and step number.
3. For each step:
    a. Calculate a column depth and Earth's density at the step point.
    b. Calculate a total cross section at the step point.
    c. Calculate a probability that the injected neutrino interacts within the step. Try Monte-Carlo, and decide whether an interaction happened within the step.
    d. If interaction occurred: choose interaction randomly.
        i. If CC-interaction is selected with injection particle NuMu or NuE, break (event is killed).
        ii. else, generate secondaries and continue to next step.
    e. If nothing happens, continue next step.
4. Finish propagation when injected neutrino + secondaries reach surface of detection volume (point F), then process a weighted interaction.





- produce a $E^{-\gamma}$ ν_μ, ν_e, ν_τ with
    - PRELIM Earth's density model



    - parton distribution functions
    - prop & interaction of neutrinos into a weight

LeptonInjector/LeptonWeighter

- LeptonInjector and LeptonWeighter are designed for large-volume Cherenkov neutrino telescopes such as IceCube.
- The neutrino event generator allows for quick and flexible simulation of neutrino events within and around the detector volume
- Implements the leading Standard Model neutrino interaction processes relevant for neutrino observatories:
  - neutrino-nucleon deep-inelastic scattering
  - neutrino-electron annihilation.

This is publicly available code.

https://arxiv.org/abs/2012.10449

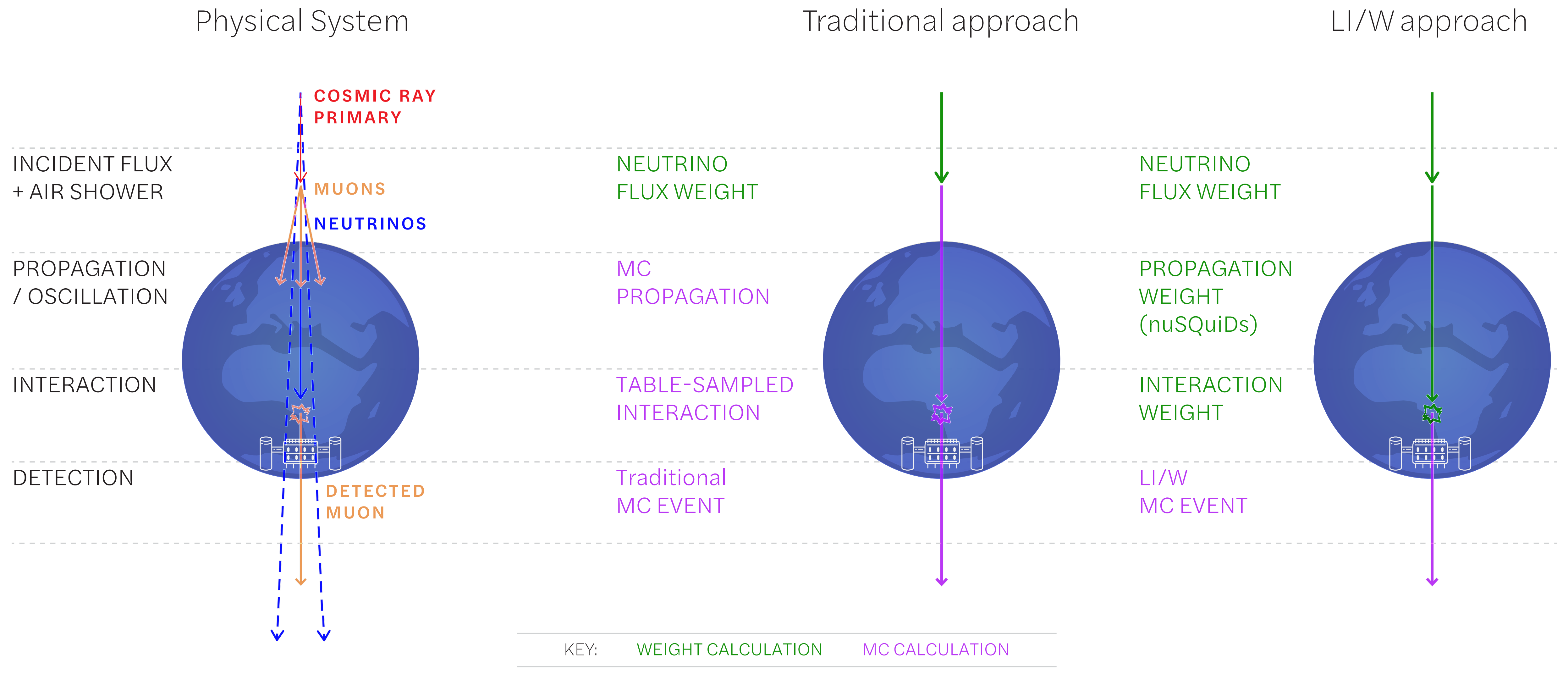


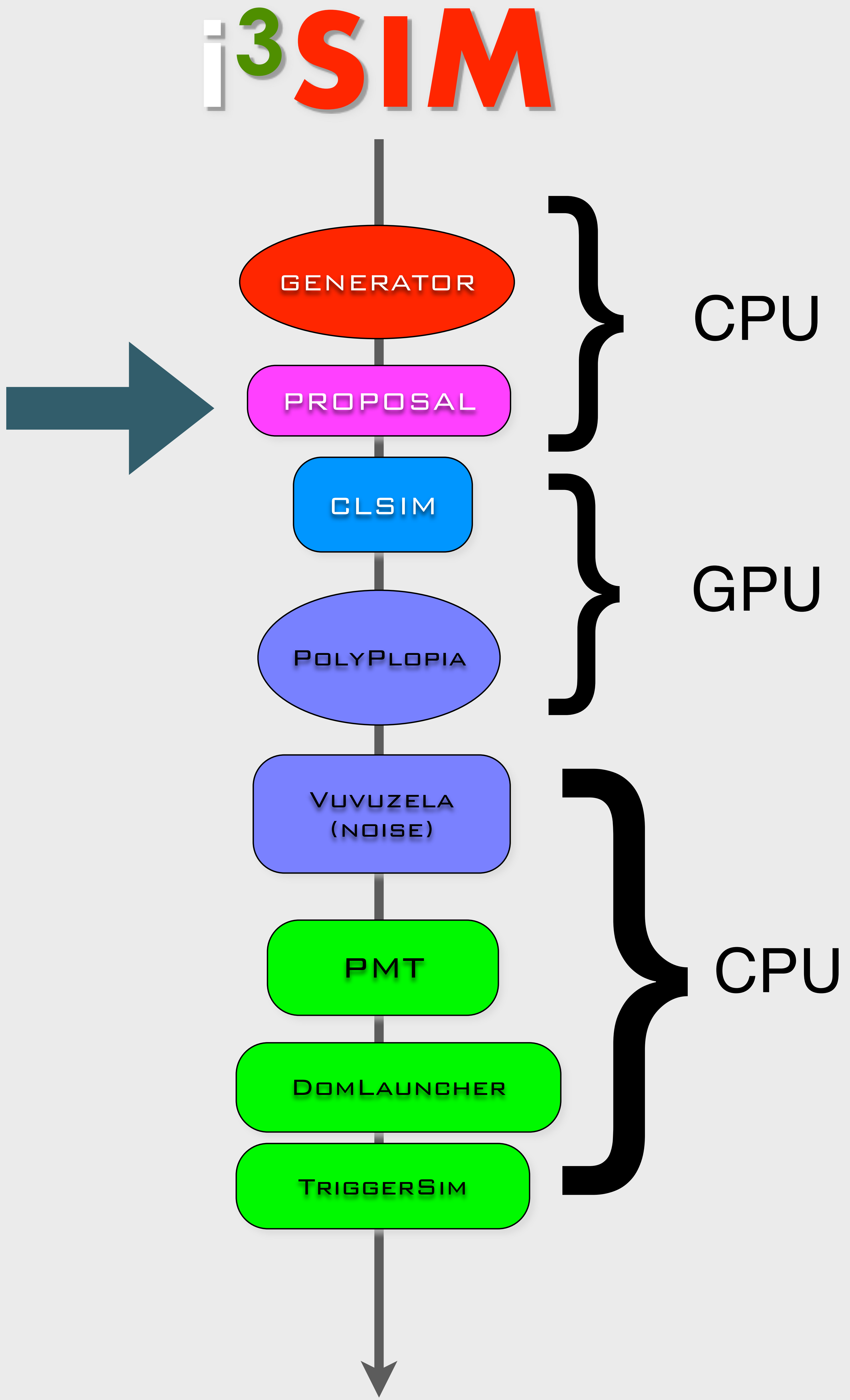
Figure 1.1: A diagram illustrating the different event generation and weighting steps for traditional methods compared with the `LeptonInjector` and `LeptonWeighter` philosophy.

Lepton propagation

- PROPOSAL: parametrized interactions with the medium.

  Comp. Phys. Com. 184, 9 (2013), p2070-2090
  - Stochastic energy losses include:
    - ionization
    - electron-pair production
    - bremsstrahlung
    - photo-nuclear interaction
    - decay
- GEANT4: Detailed particle propagation in media.

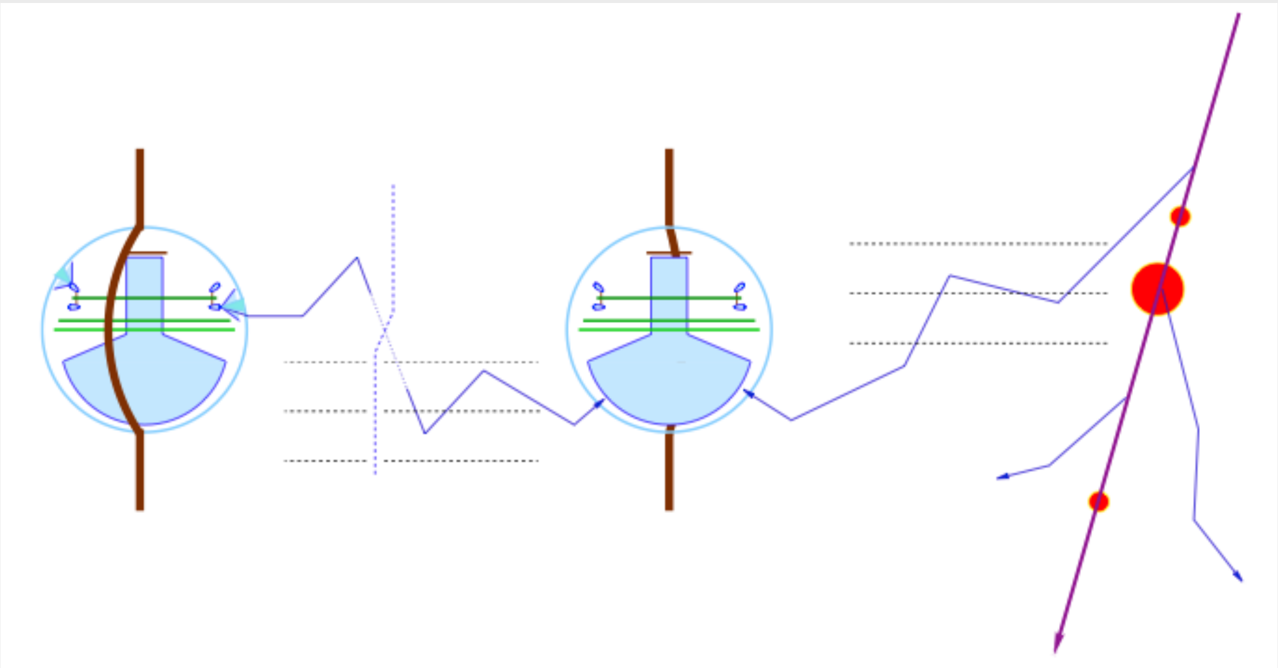
  https://geant4.web.cern.ch/
  - 3rd-party G4 library used by CLSim to propagate leptons for low-energy simulations (CPU-intensive).

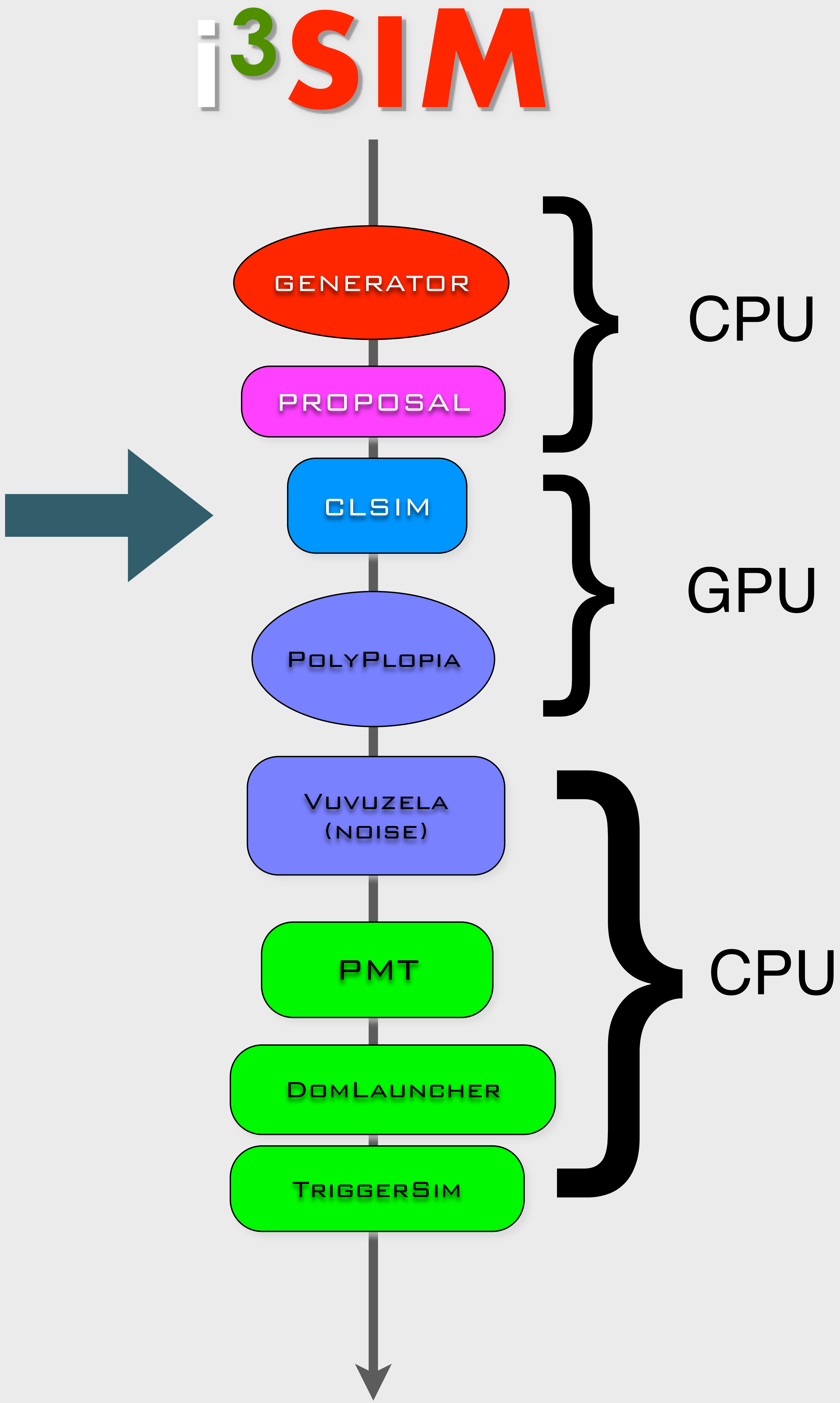


Photon Propagation (PPC, CLSim)

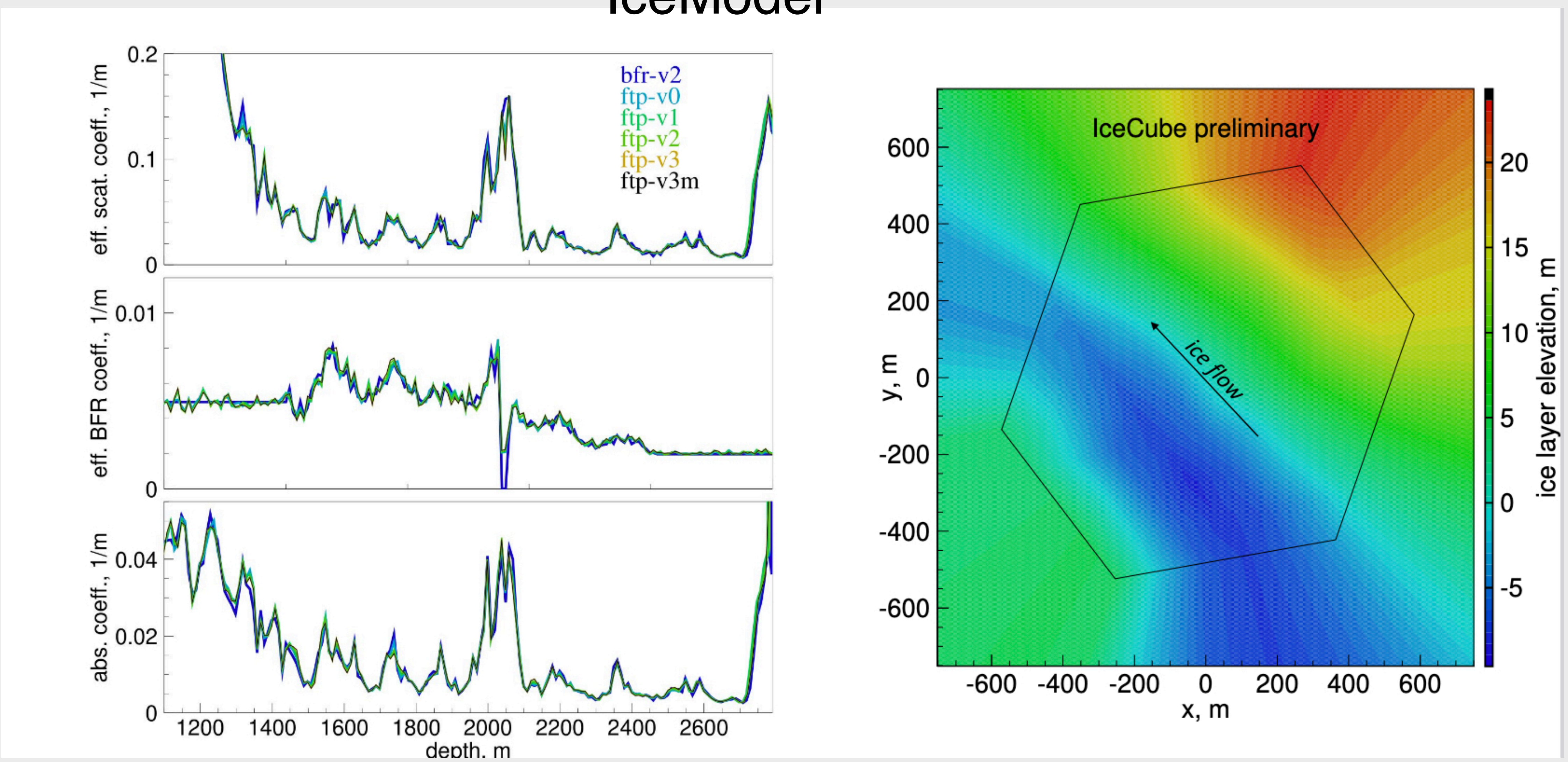
μ energy loss + cascades ➙ photons ➙ p.e.

- Photon propagation : ice properties + PMT response + DOM glass/gel
  - Direct photon tracking
    - CLSim, PPC
  - Hybrid photon tracking
    - CLSim + Splined PDF lookup of amplitude and time distribution

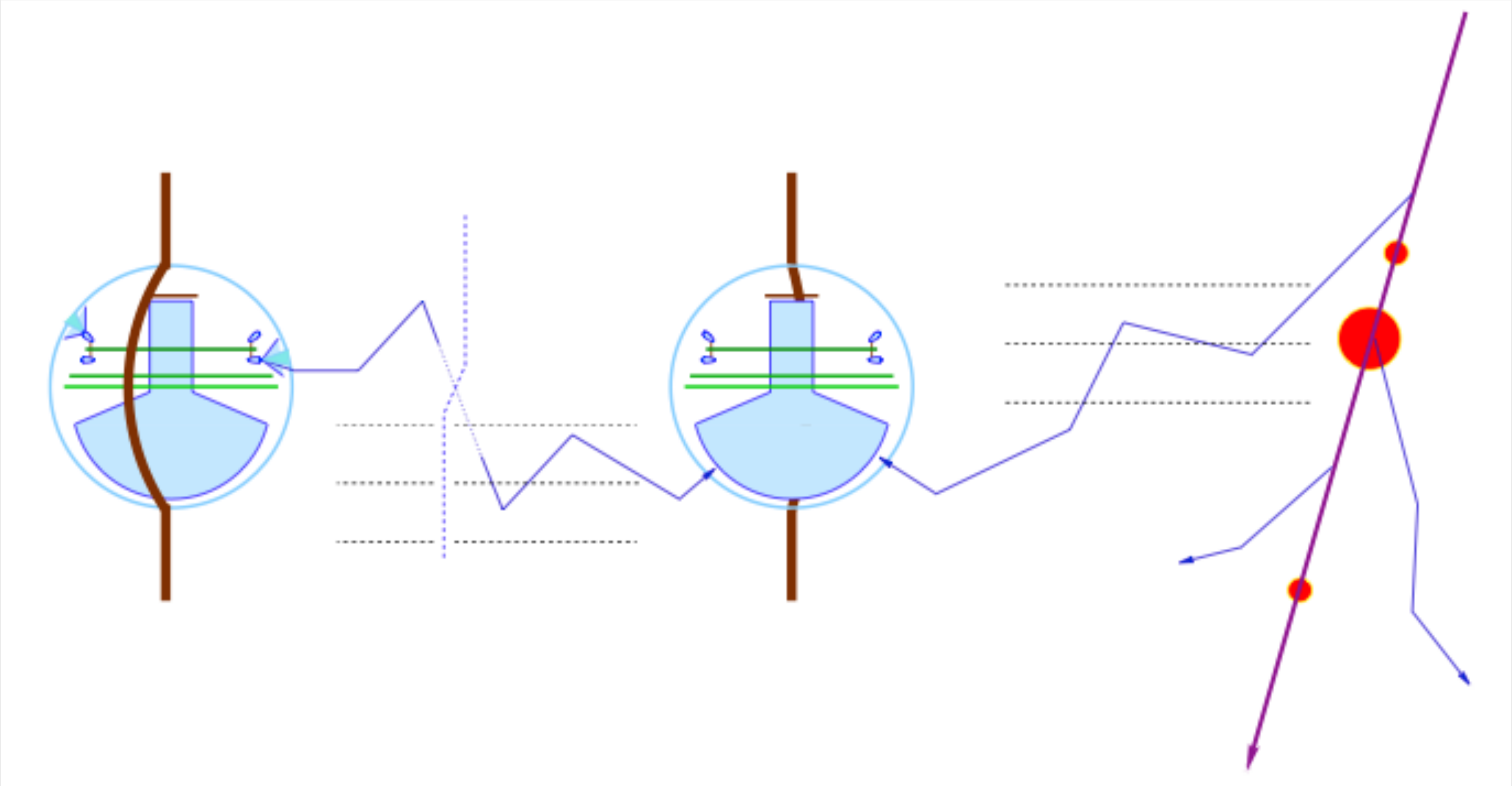


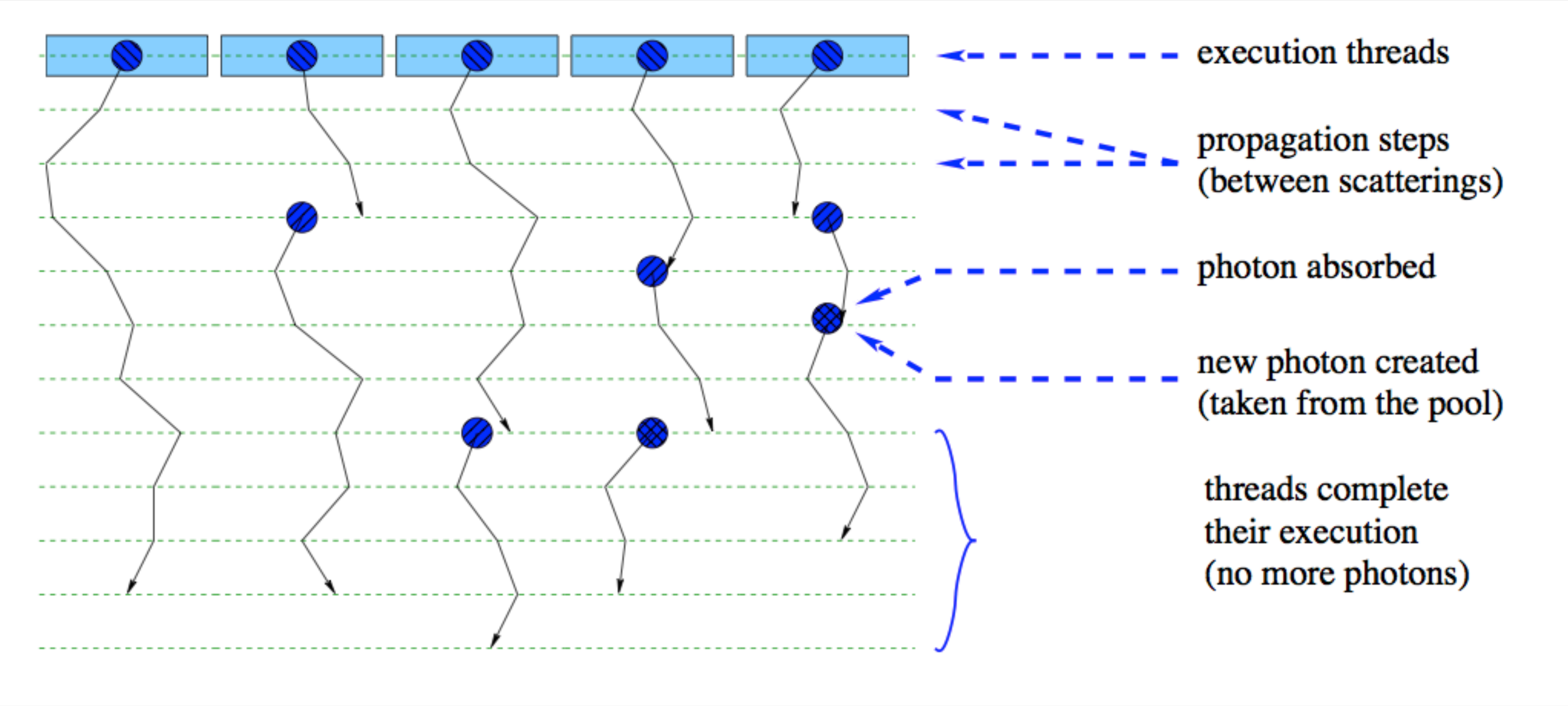


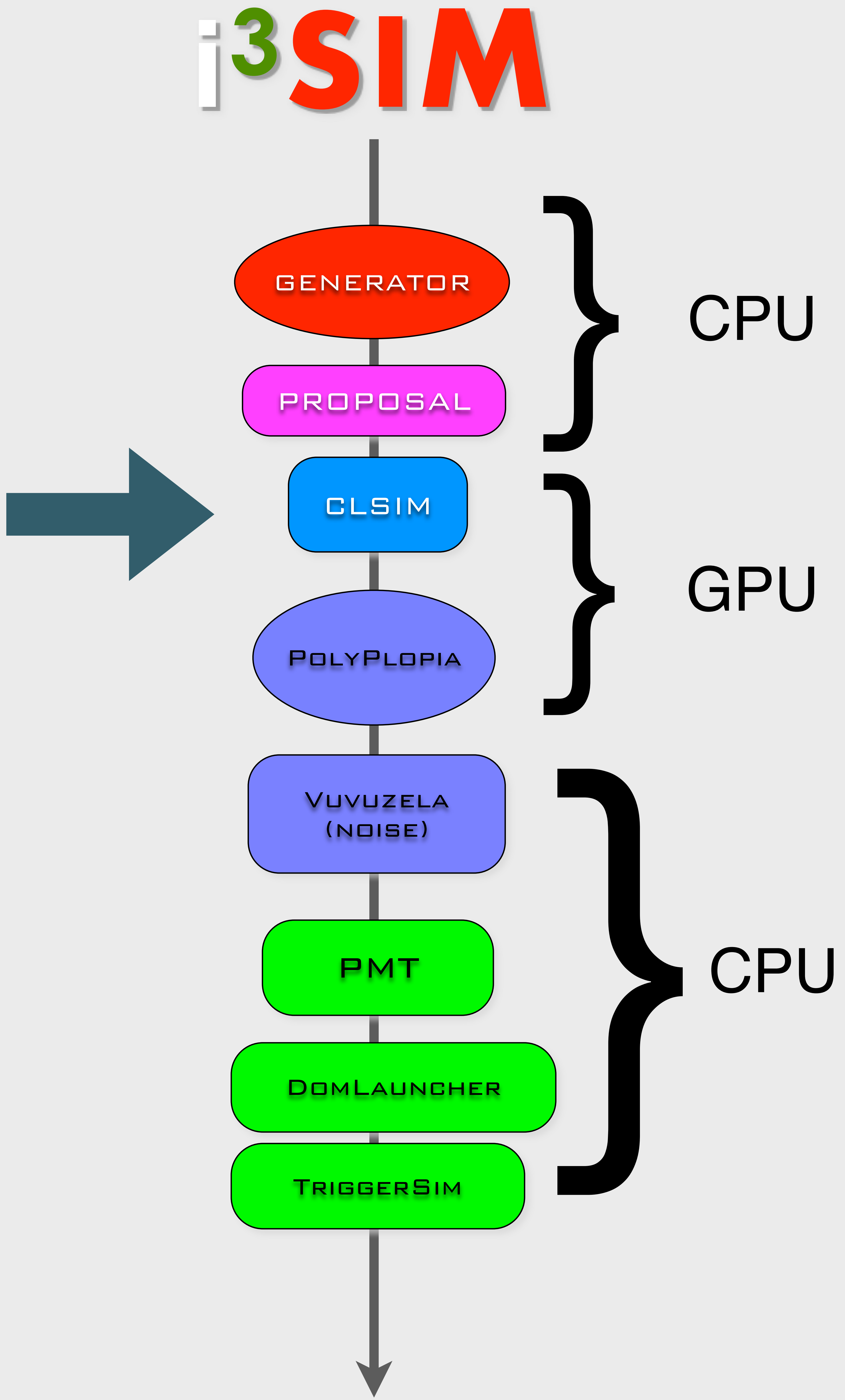
IceModel



Photon Propagation (PPC, CLSim)







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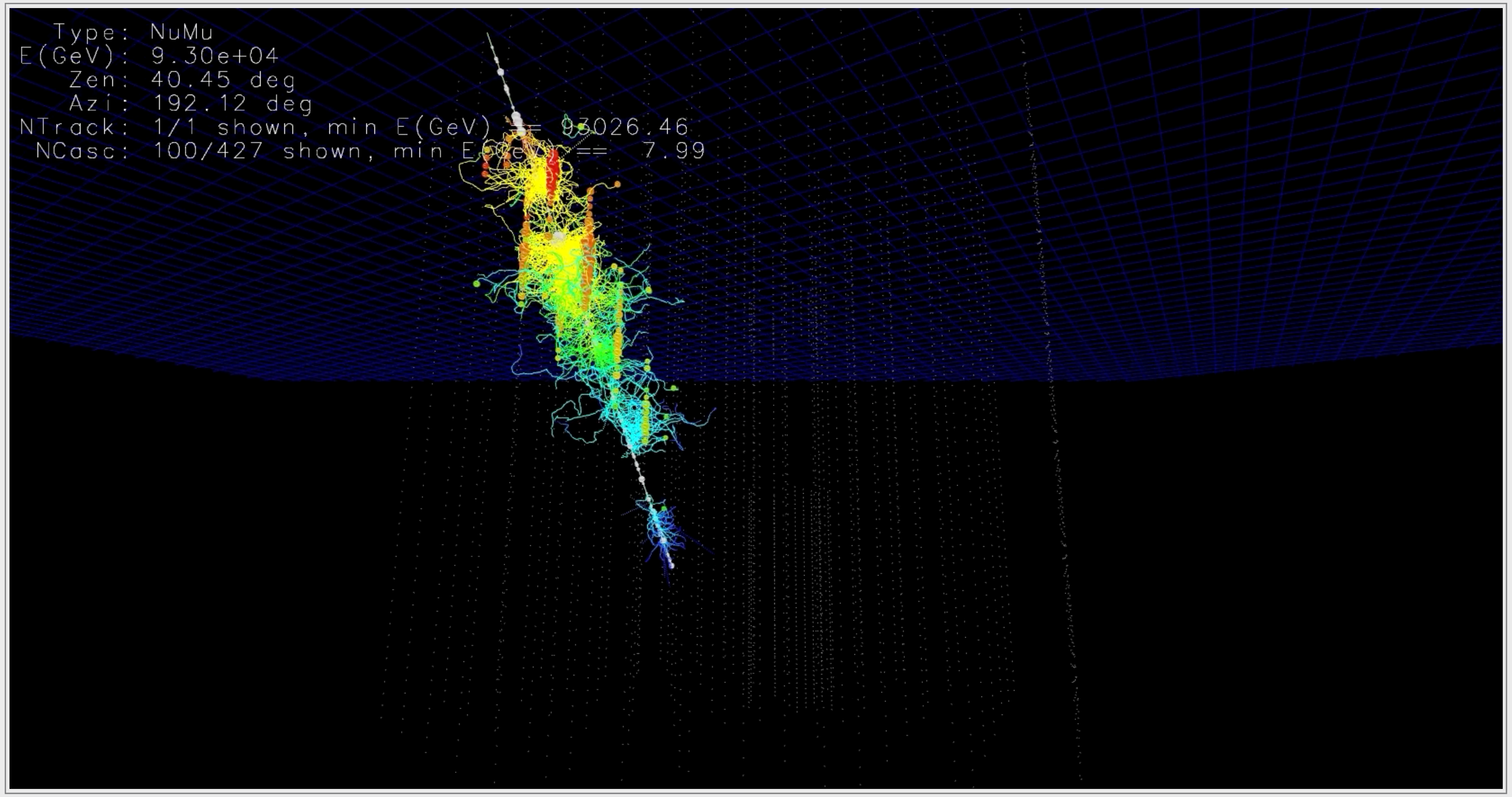
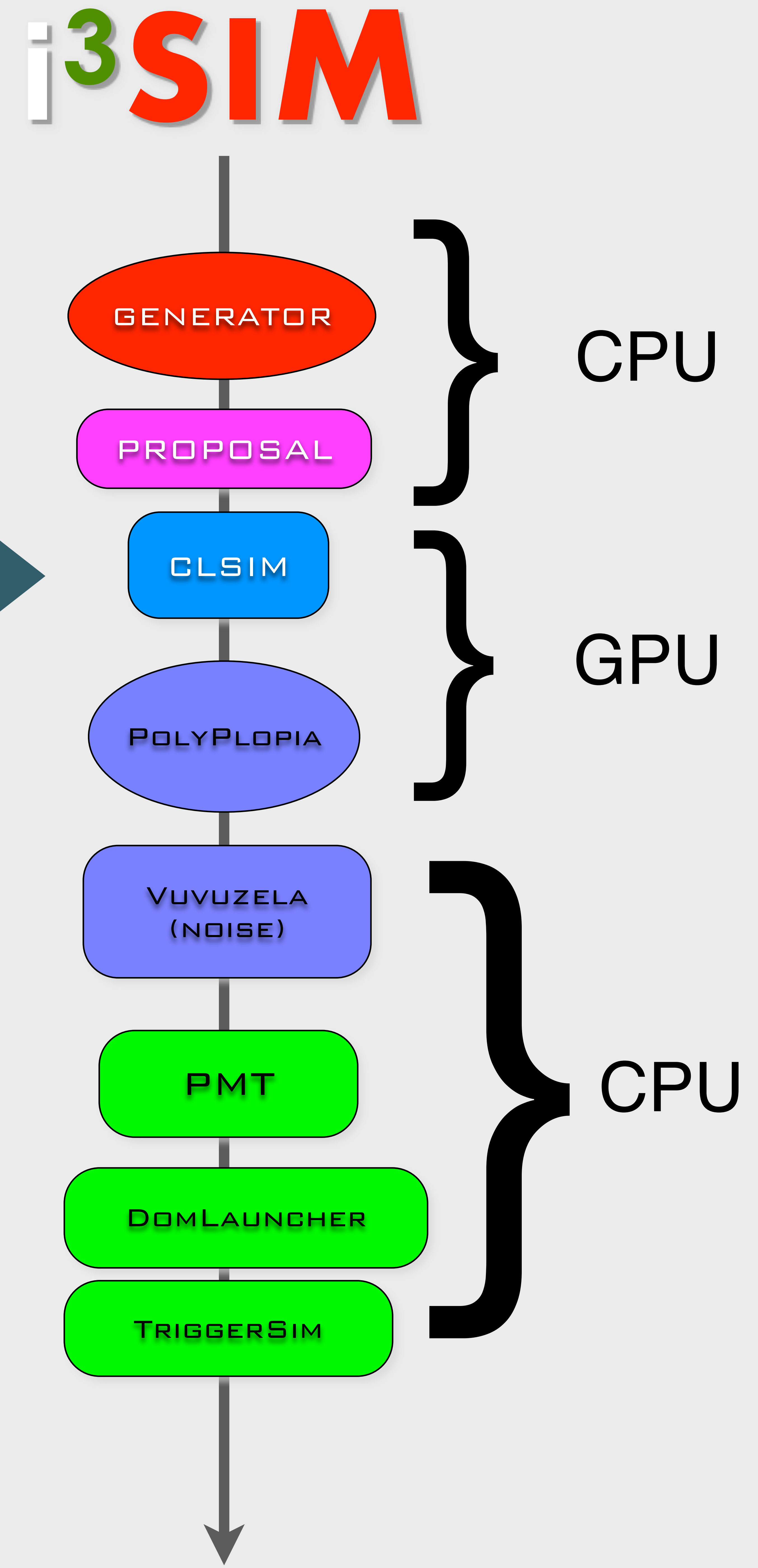


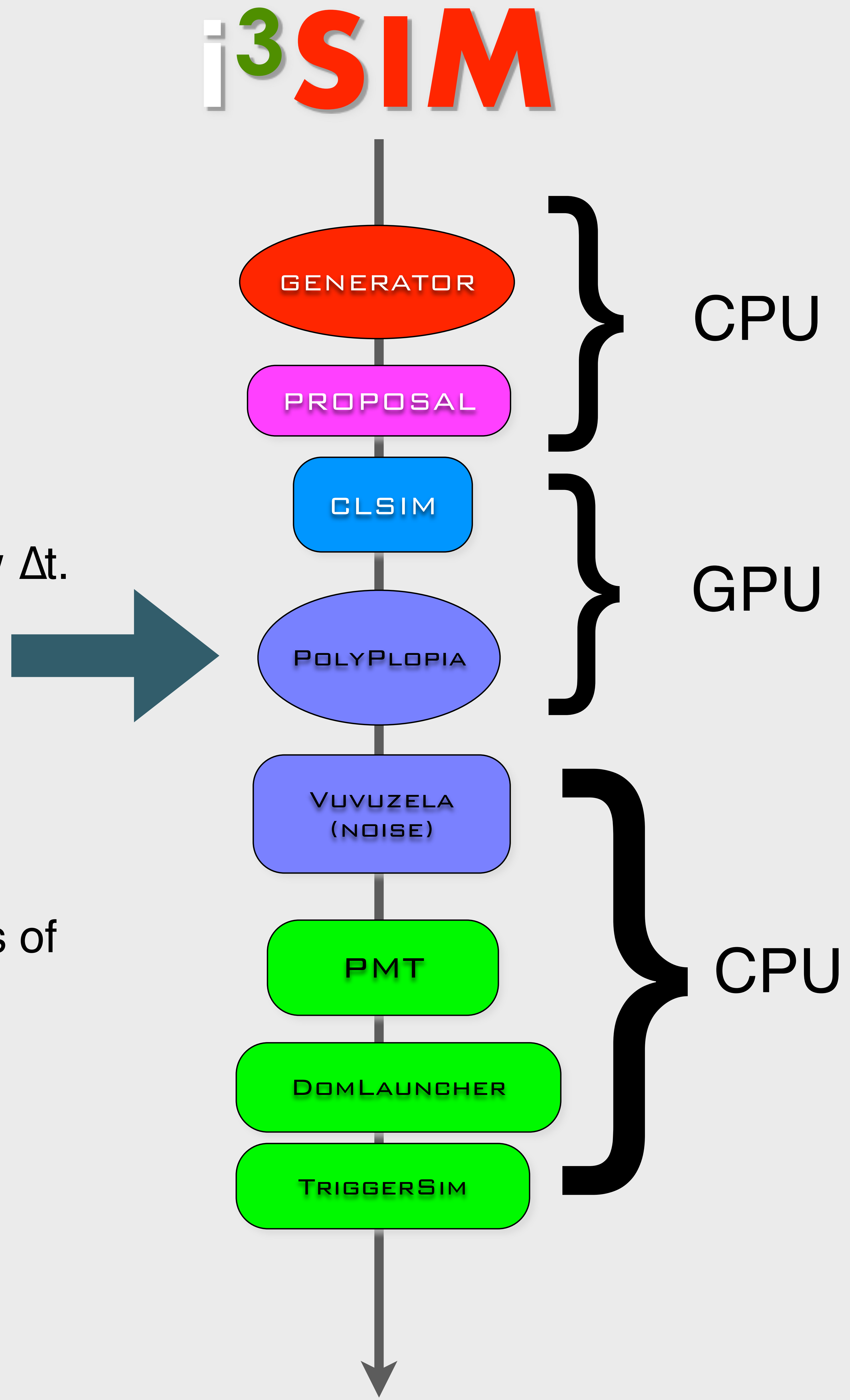


Polyplopia

(from gr., πολύς - polús, “many,”, and ὄψ-ops , "vision")

Coincident atmospheric shower events in IceCube

- **PoissonMerger**
  - Injects background event read from *CoincidentEventService* on top of primary events in the chain by sampling from a Poisson distribution over a time window Δt.
  - Writes a separate I3MCTree with background particles.
  - Writes a combined I3MCPE map for signal and background.
- **MPHitFilter**
  - Removes events that don’t produce light in the detector and removes branches of I3MCTrees whose particles don’t produce enough PEs in the detector,
- Q-frames split into P-frames based on timing, topology



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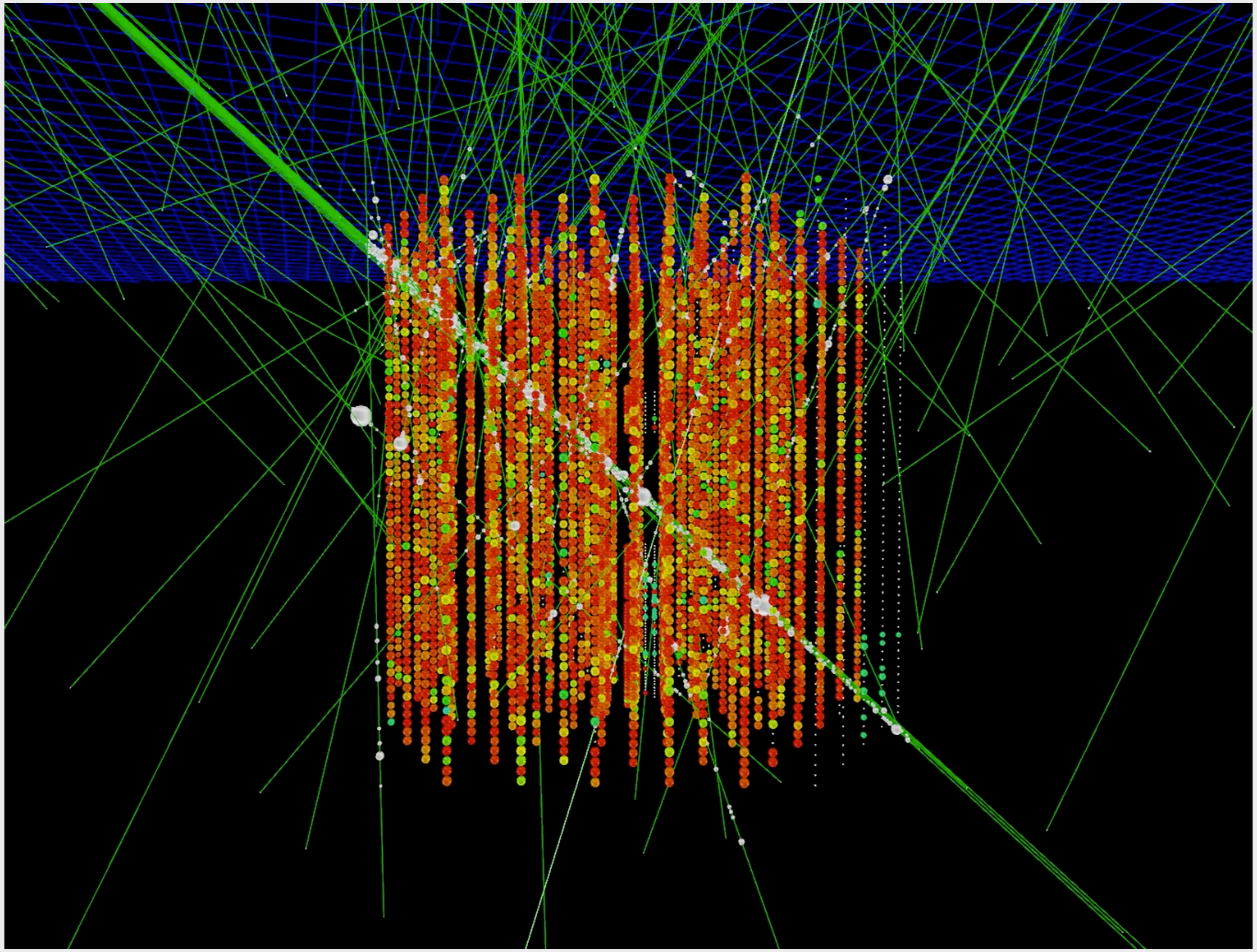
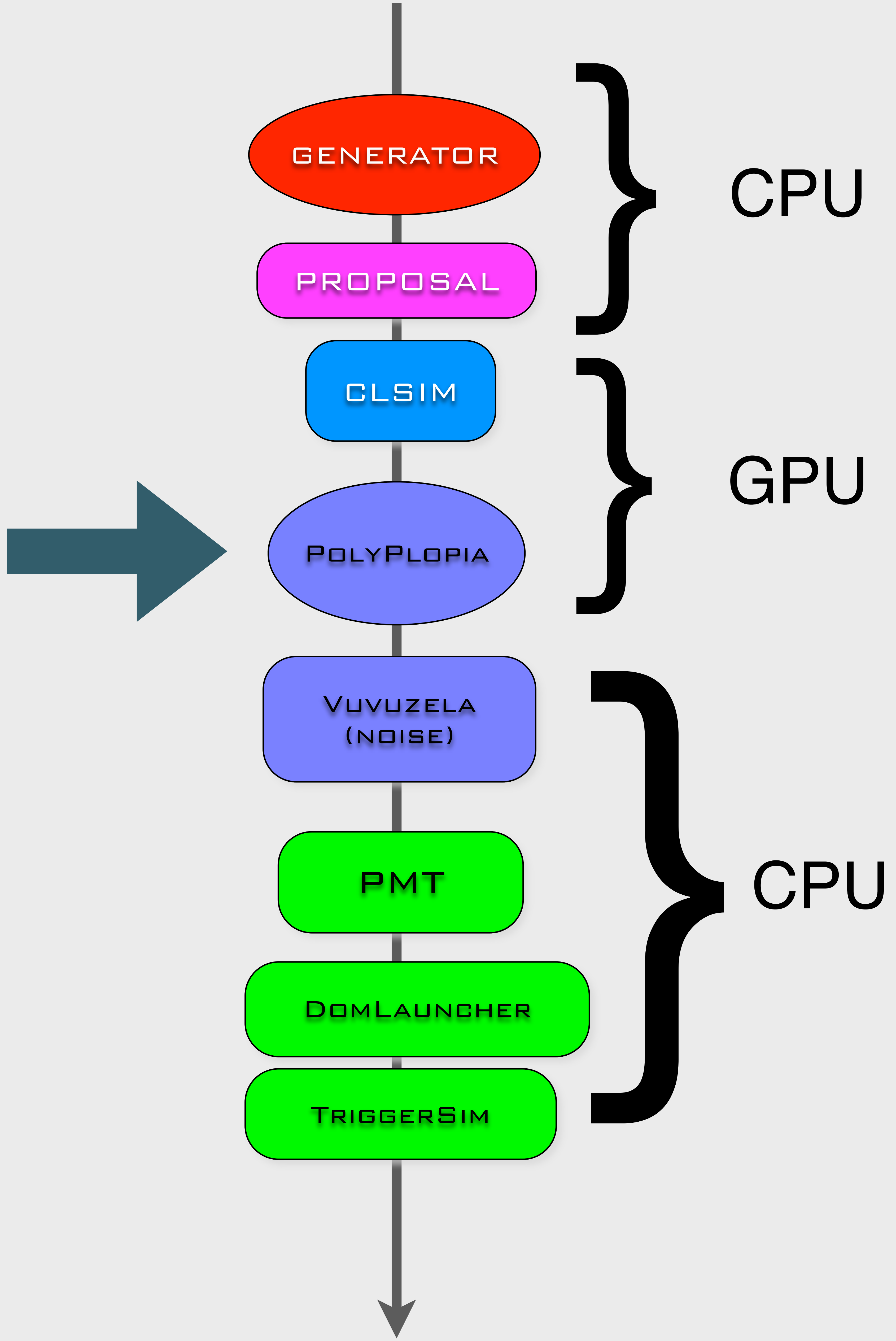
Coincident atmospheric shower events in IceCube



i3SIM



Vuvuzela (Noise)

Noise Model

—> (MCPEs)

Thermal Noise (~few Hz) [Poisson process] — ~ ms Timescales

+

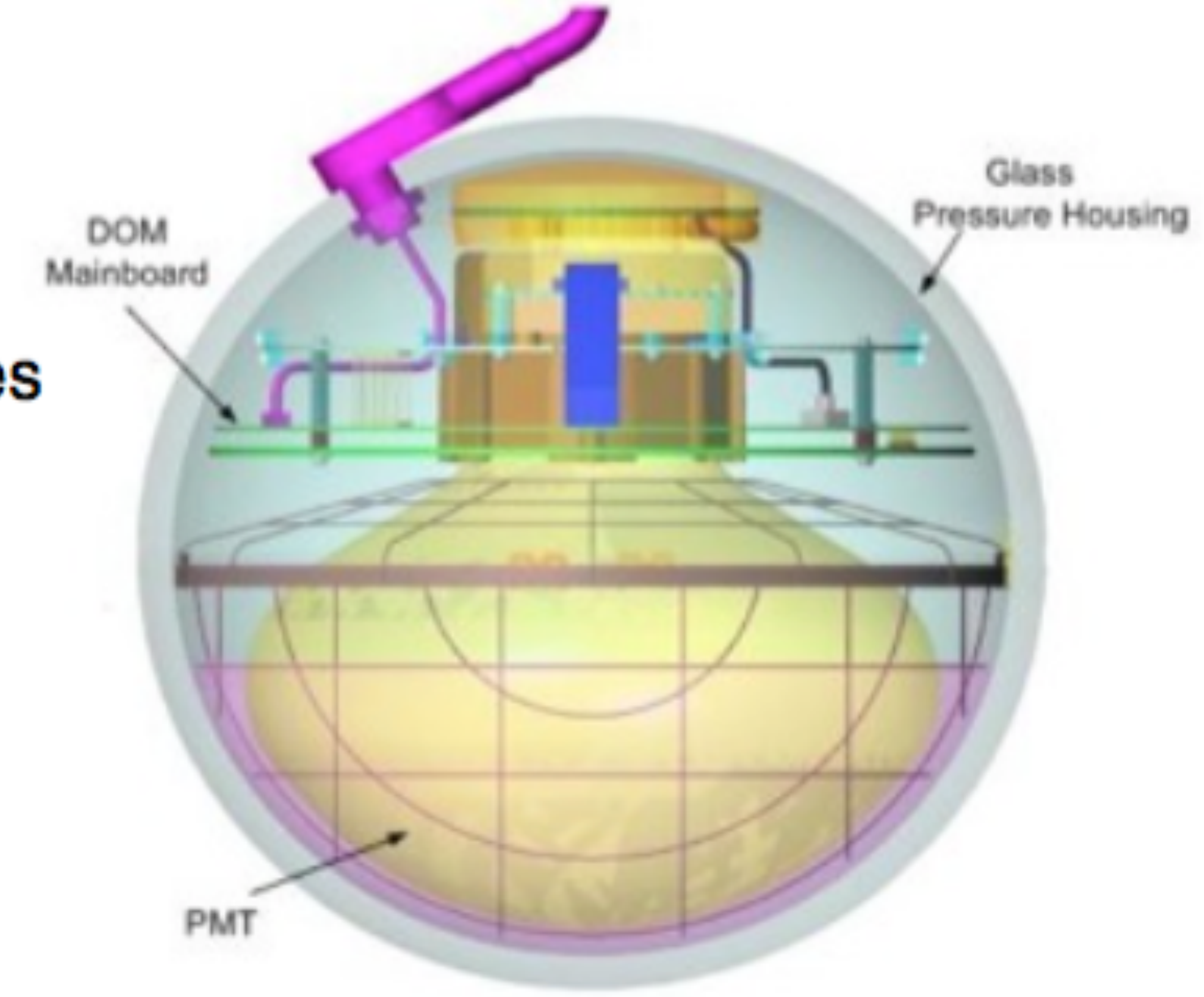
Radioactive Decay in Glass [Poisson process] — ~ ms Timescales

↓

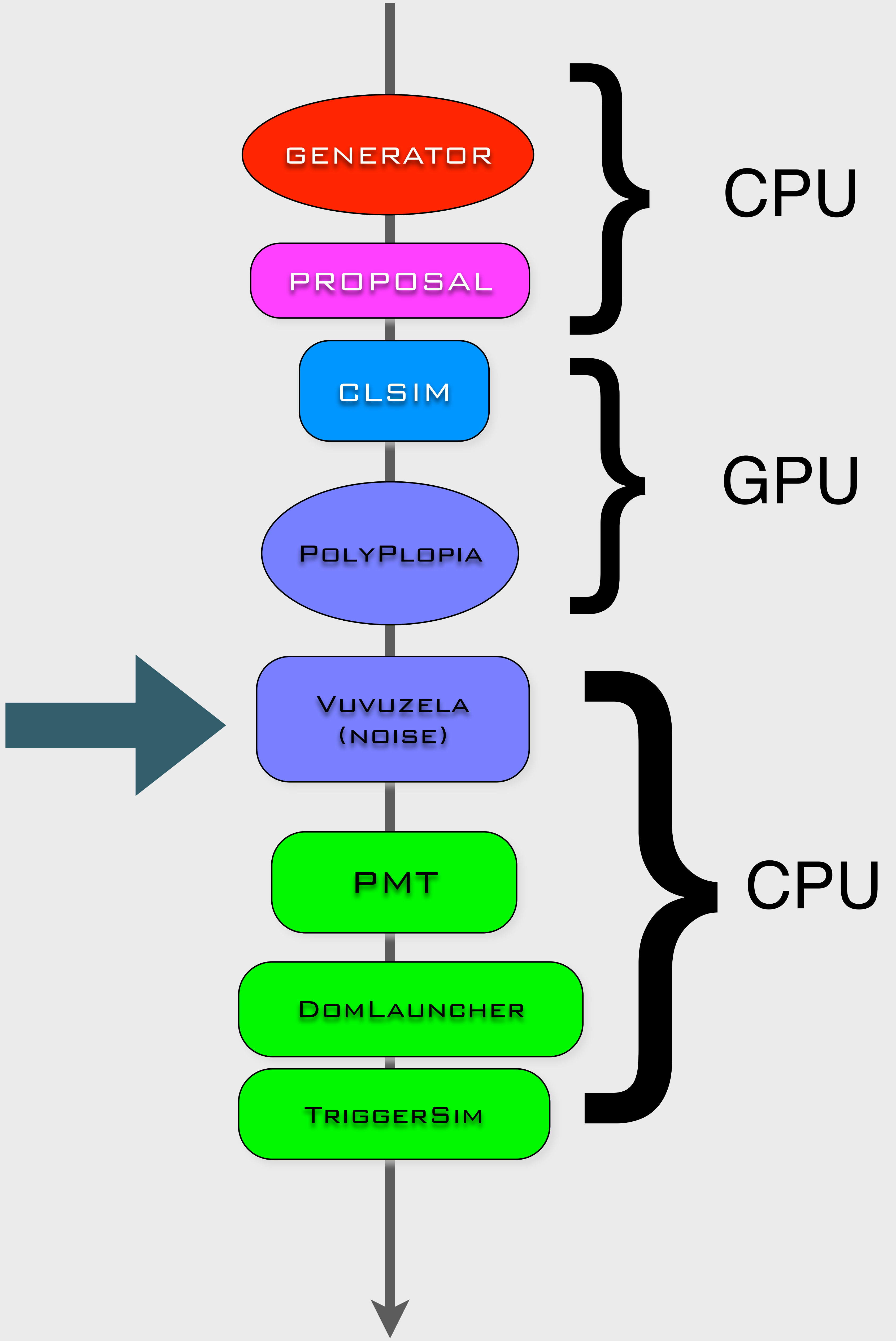
Energy deposited in glass

↓

Glass scintillates/fluoresces over long timescale [Log-normal] — ≲ 500 µs Timescales



i3SIM



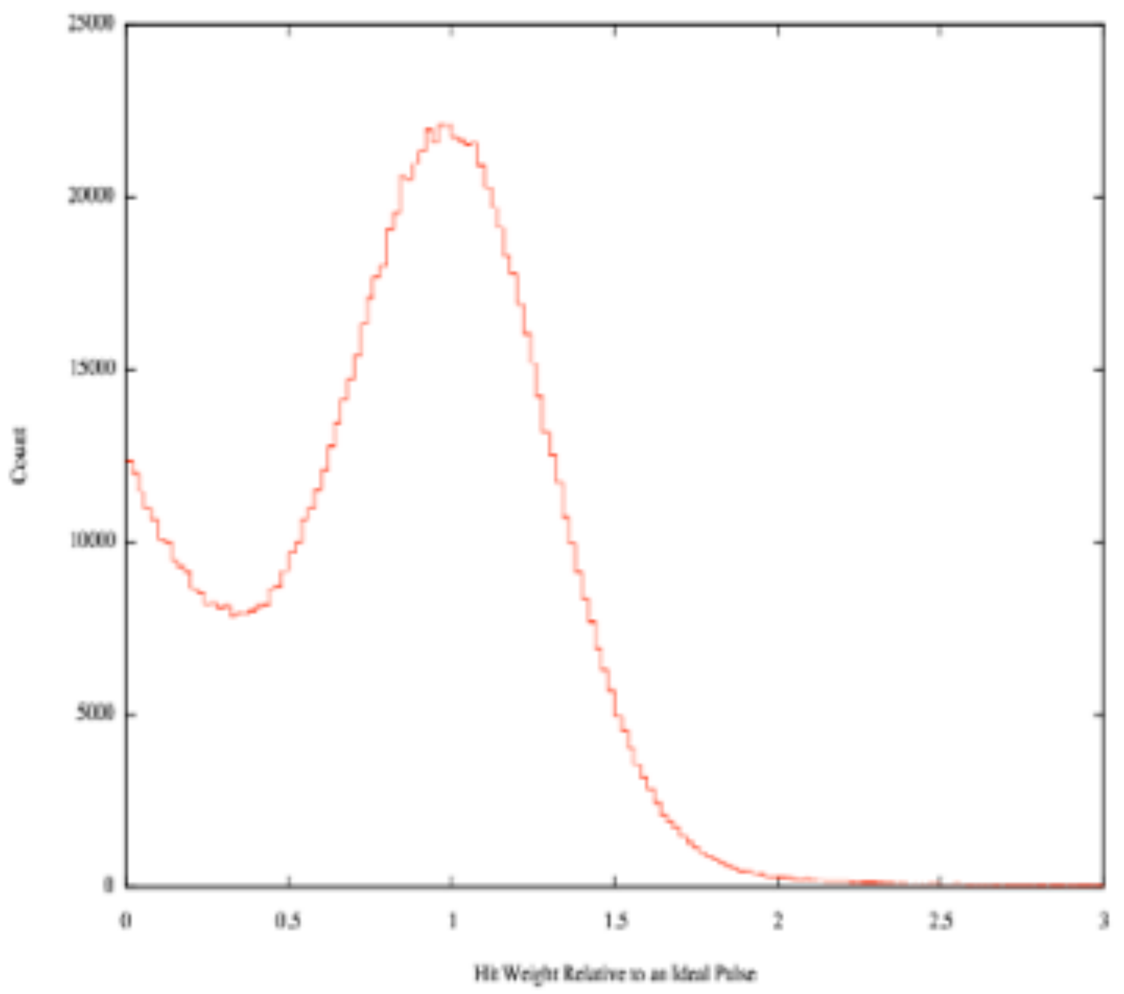
PMTResponseSimulator

In- and output:

- Takes MCHits as input.
- Produces weighted MCHits.

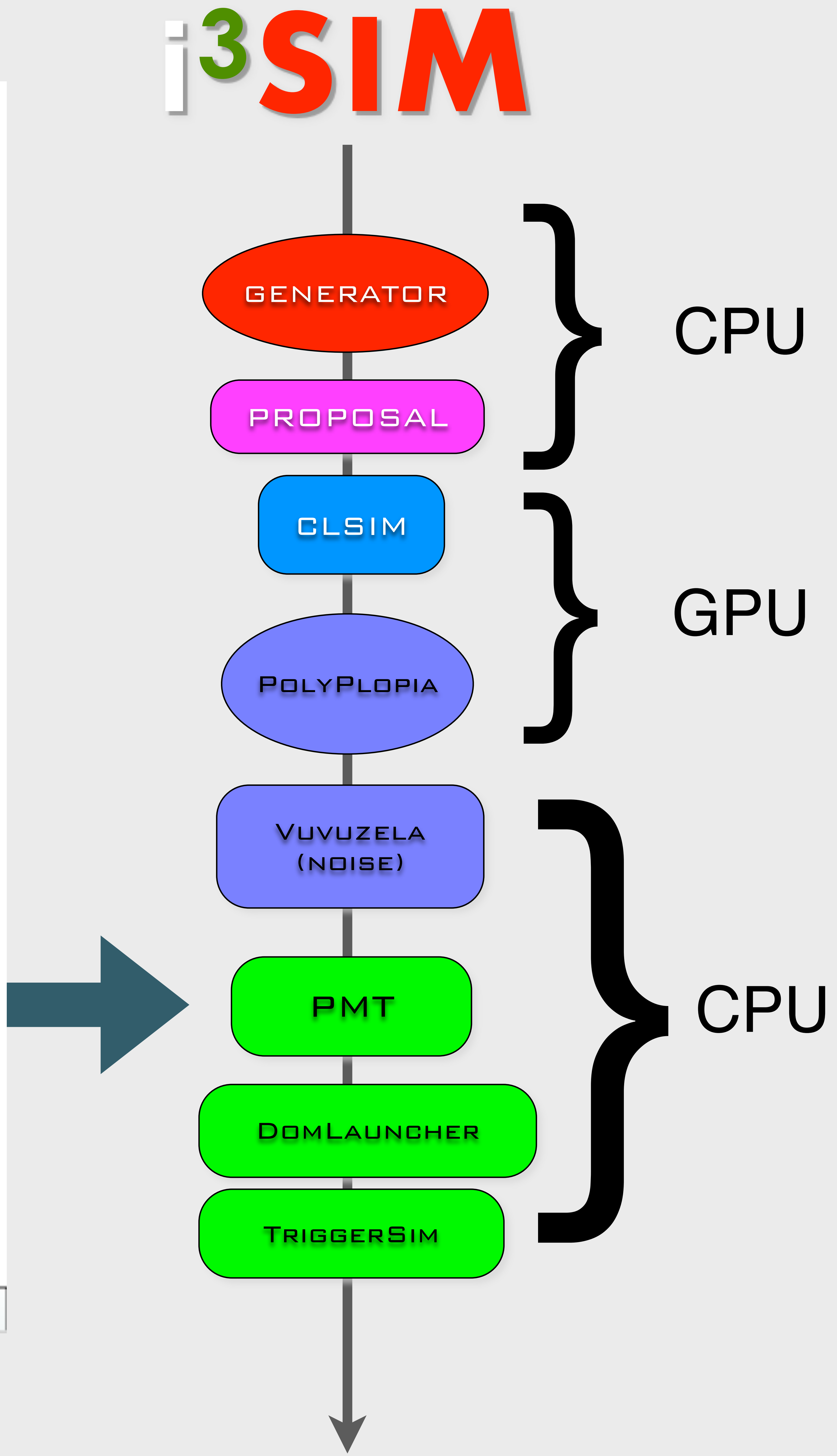
Processing MCHits:

- Give each MCHit a weight → corresponding to the pulse charge that photon would yield.
- Generate prepulses, late pulses and after pulses.
- Apply time jitter.
- Simulate the effect of saturation.



Distribution of hit weights

http://software.icecube.wisc.edu/documentation/projects/DOMLauncher/index.html

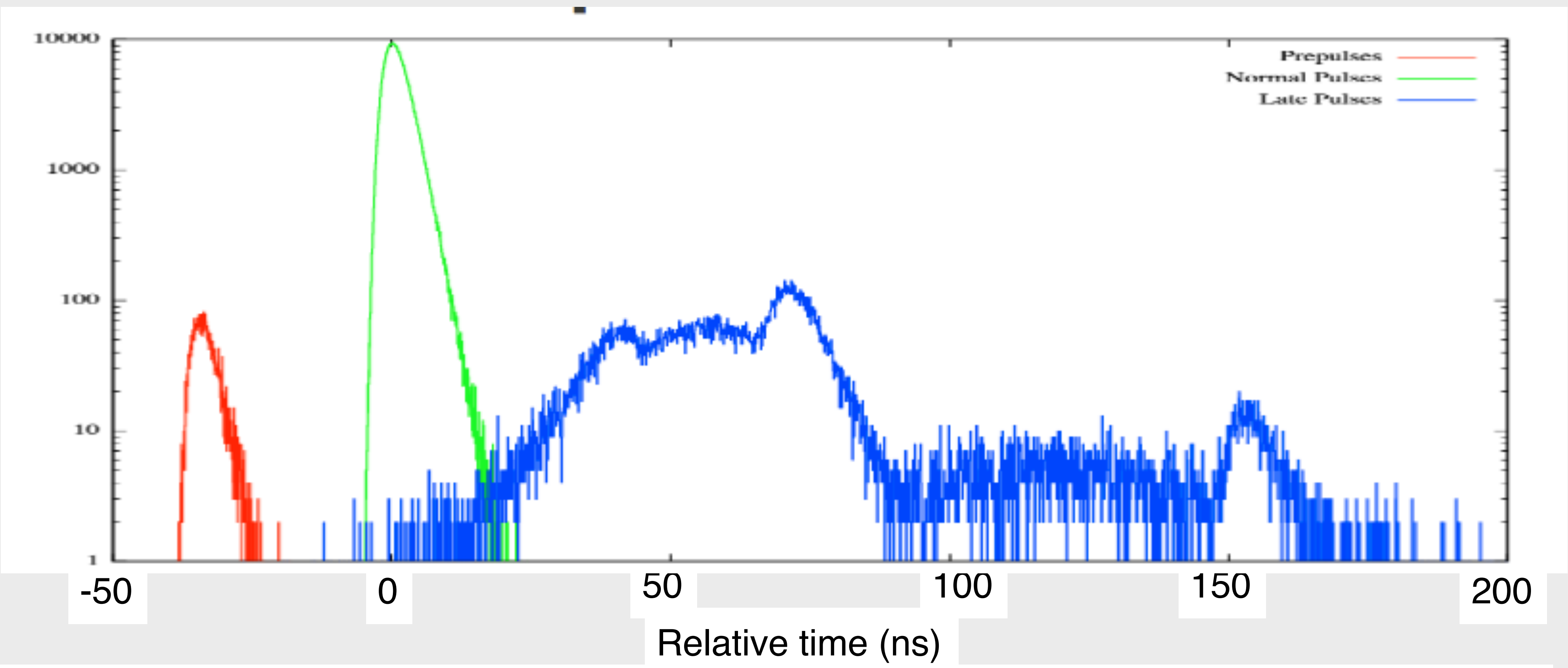


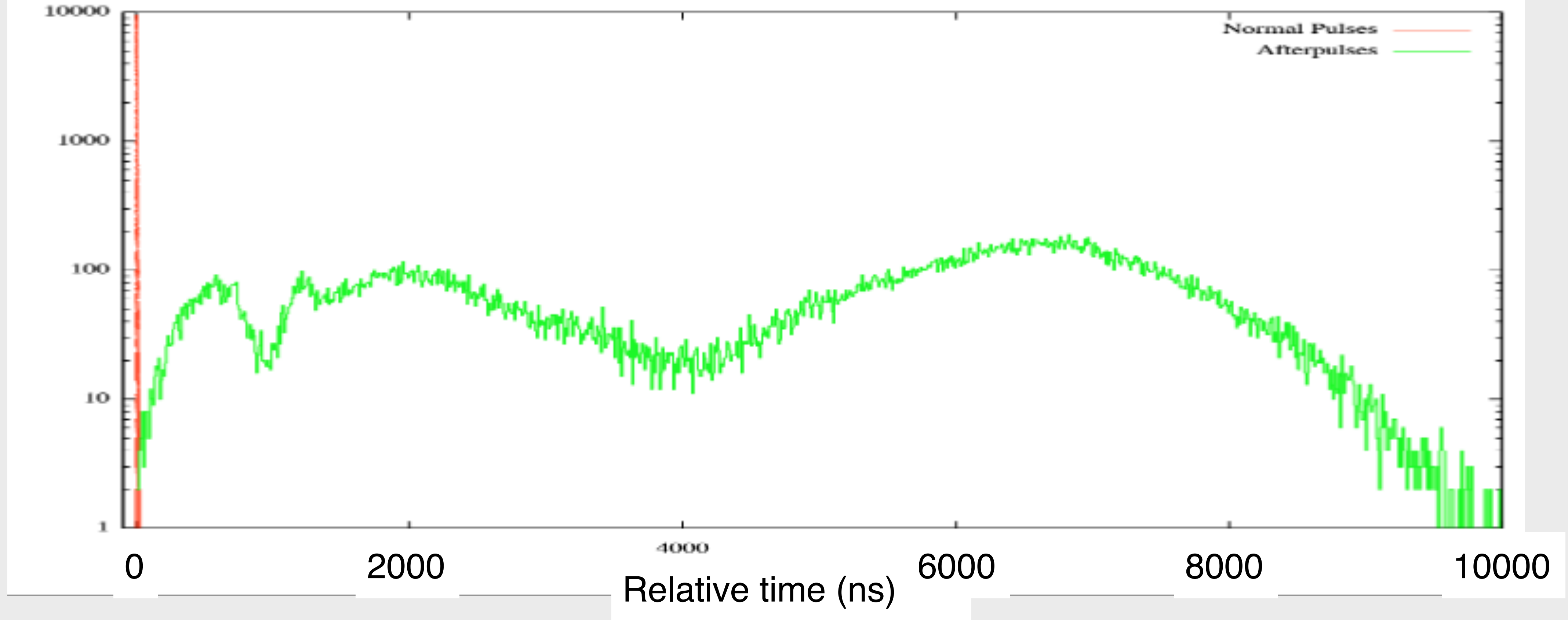
PMT Simulation

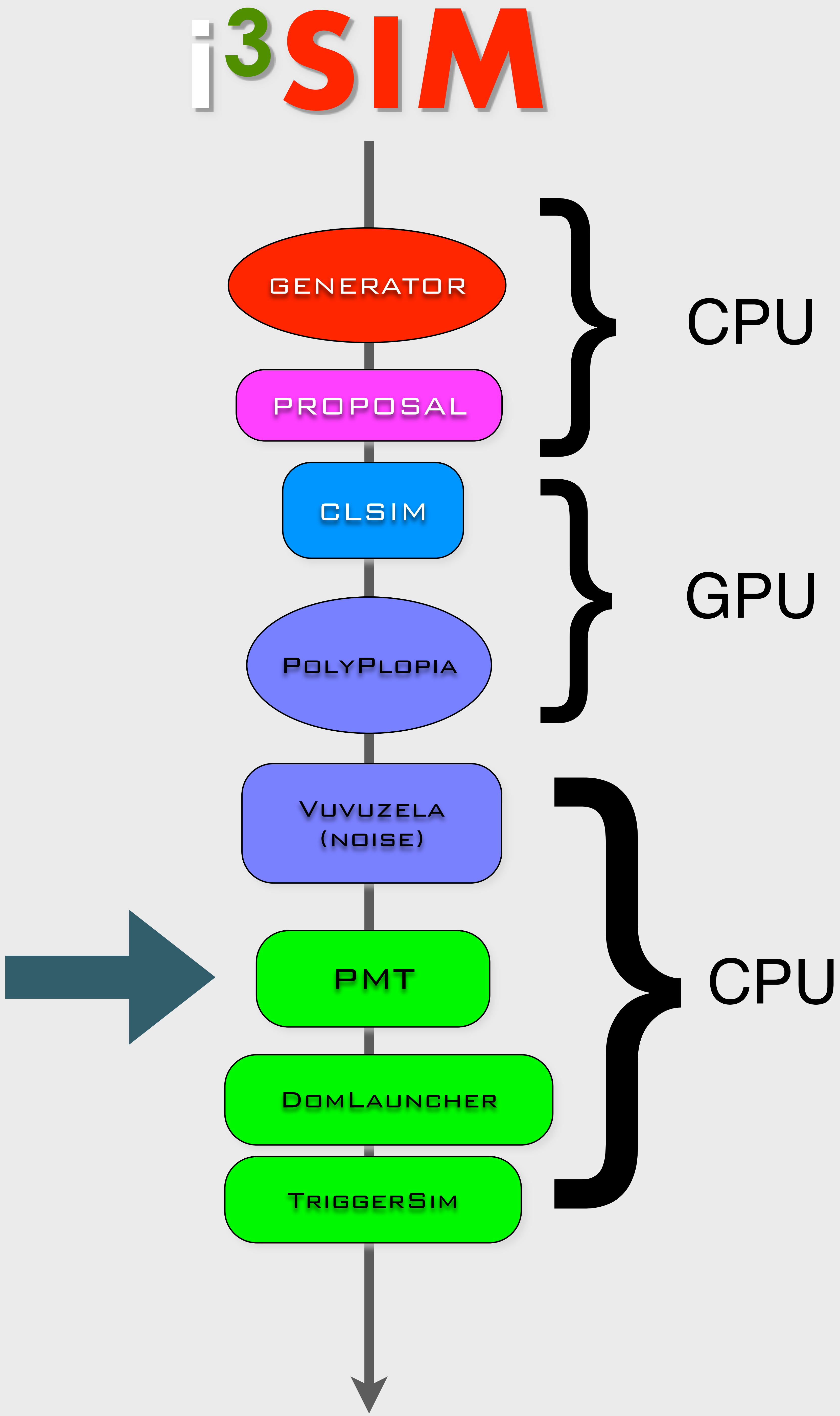
Pre-pulses: photoelectrons ejected from the first dynode,

Late pulses: electrons backscatter from dynode to cathode.

After-pulses: ionization of residual gases by electrons accelerated in the space between dynode.



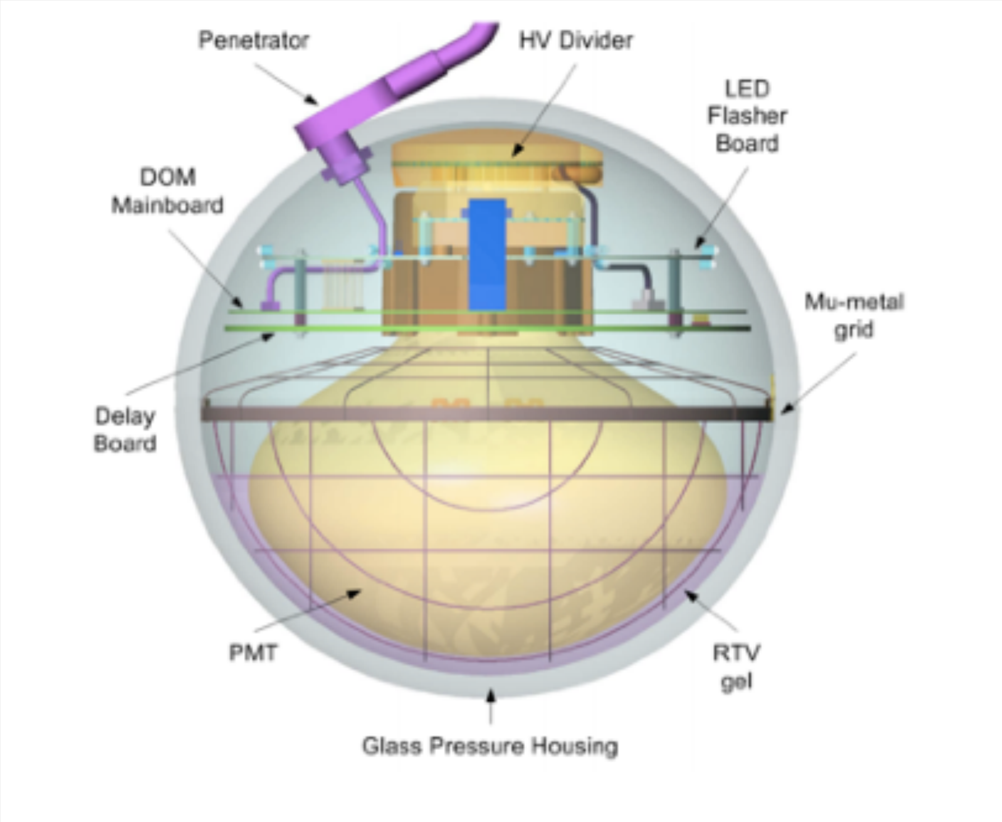


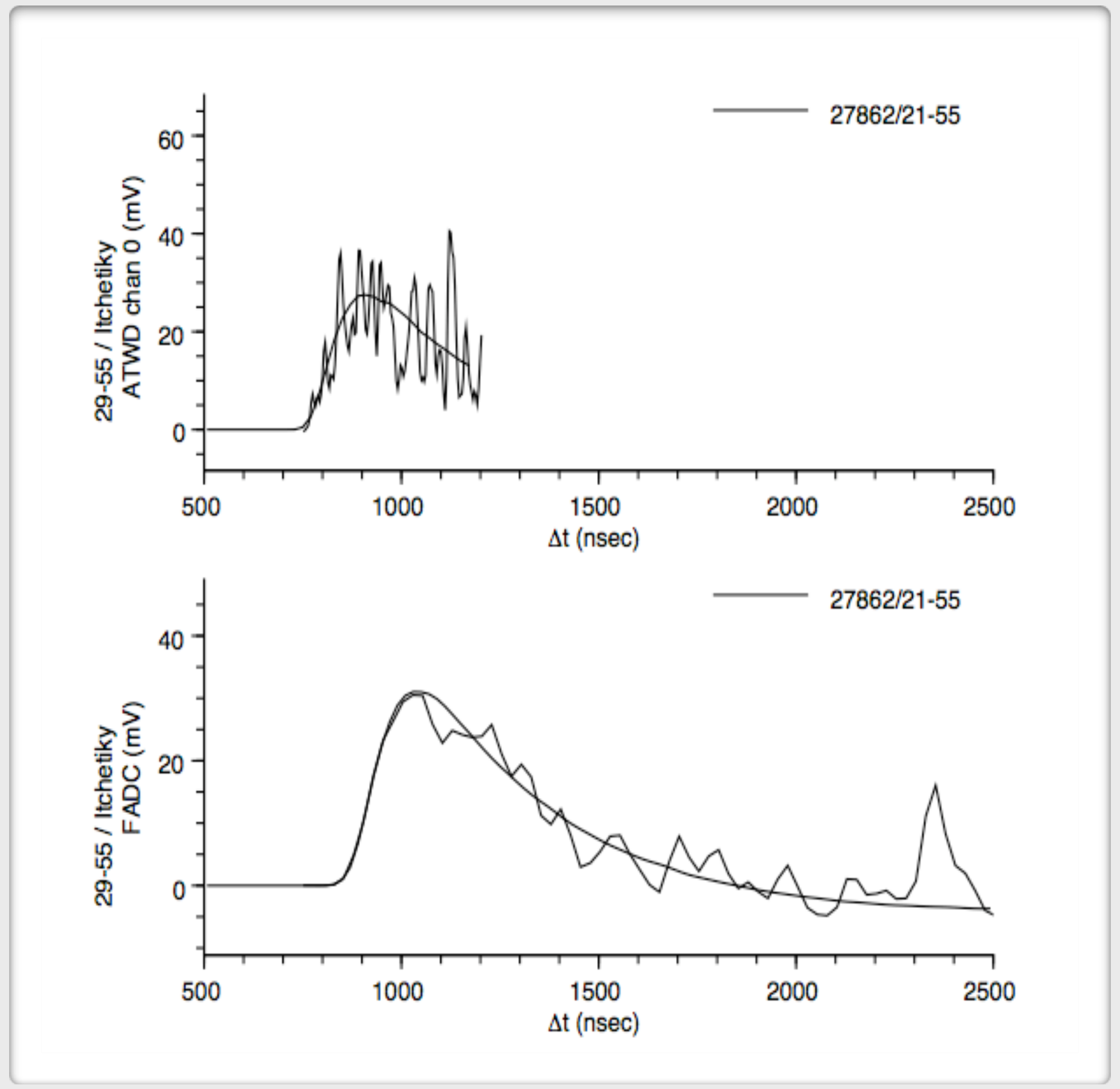


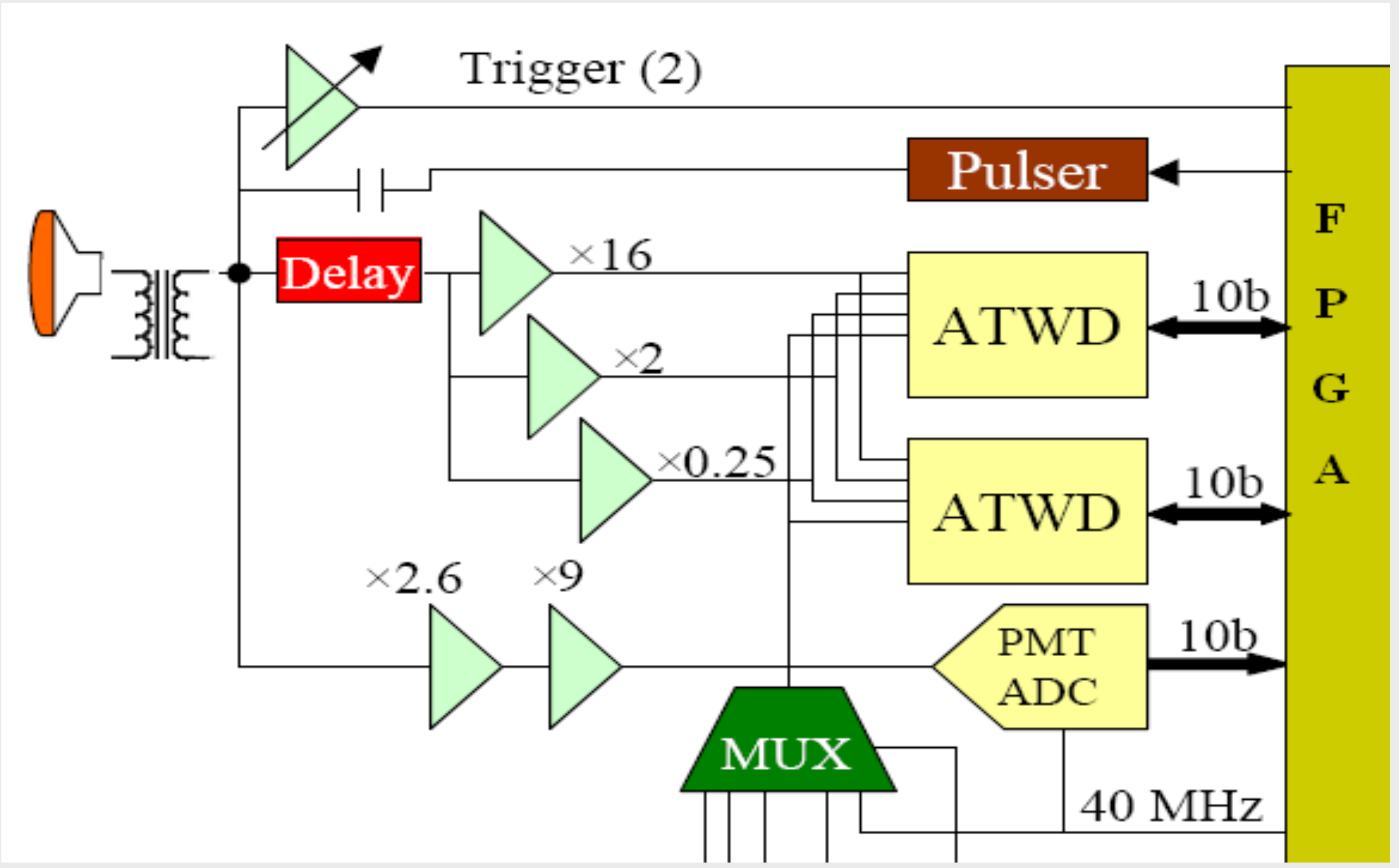
DOMLauncher: DOM electronics simulation

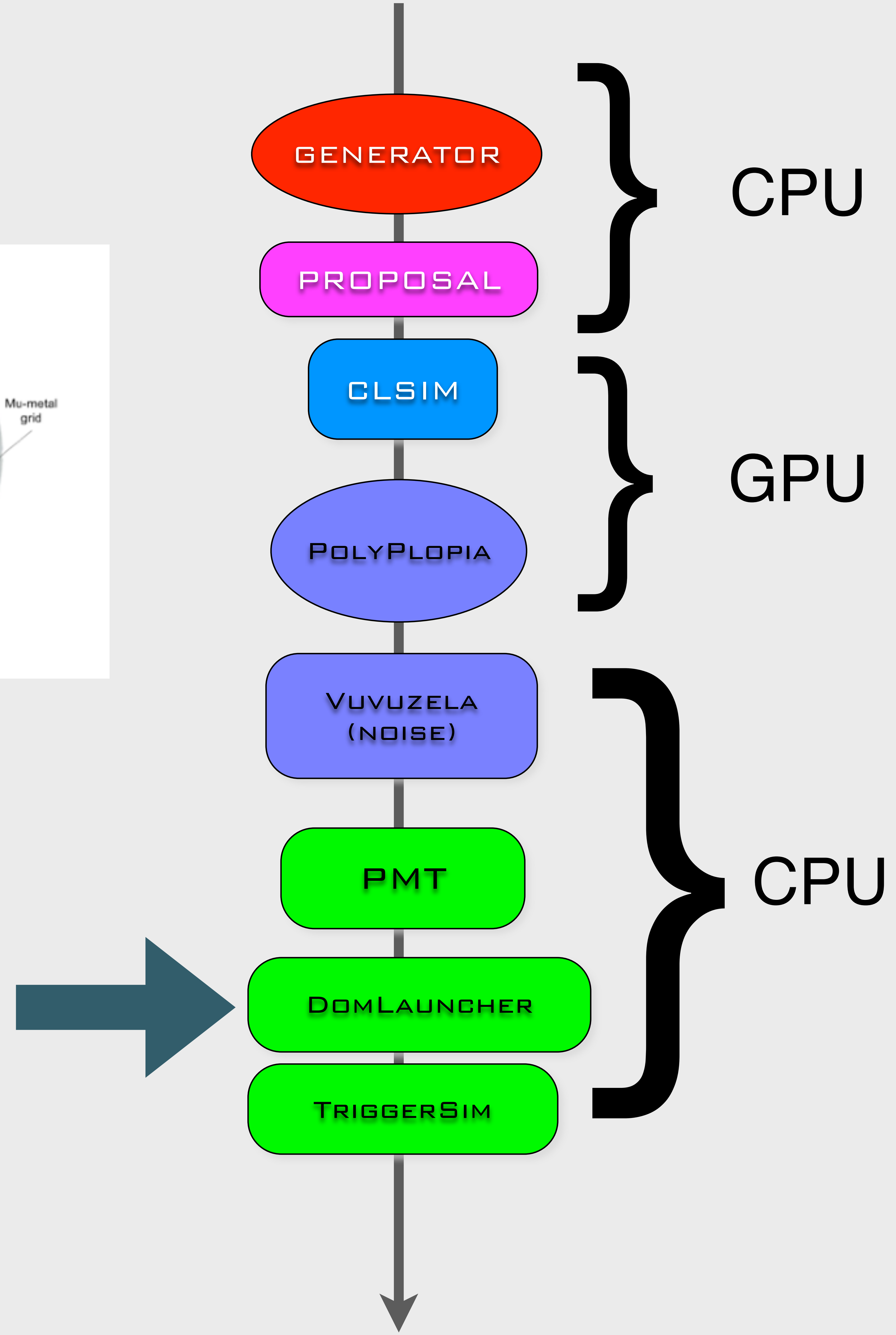
i3SIM

- Discriminator
- LC-logic
- Digitization
- Simulated effects
  - Electronic noise in the digitizers
  - Beacon launches (CPU triggered launches)
  - The FPGA Clock phase
  - RAPcal time uncertainty









Trigger Types

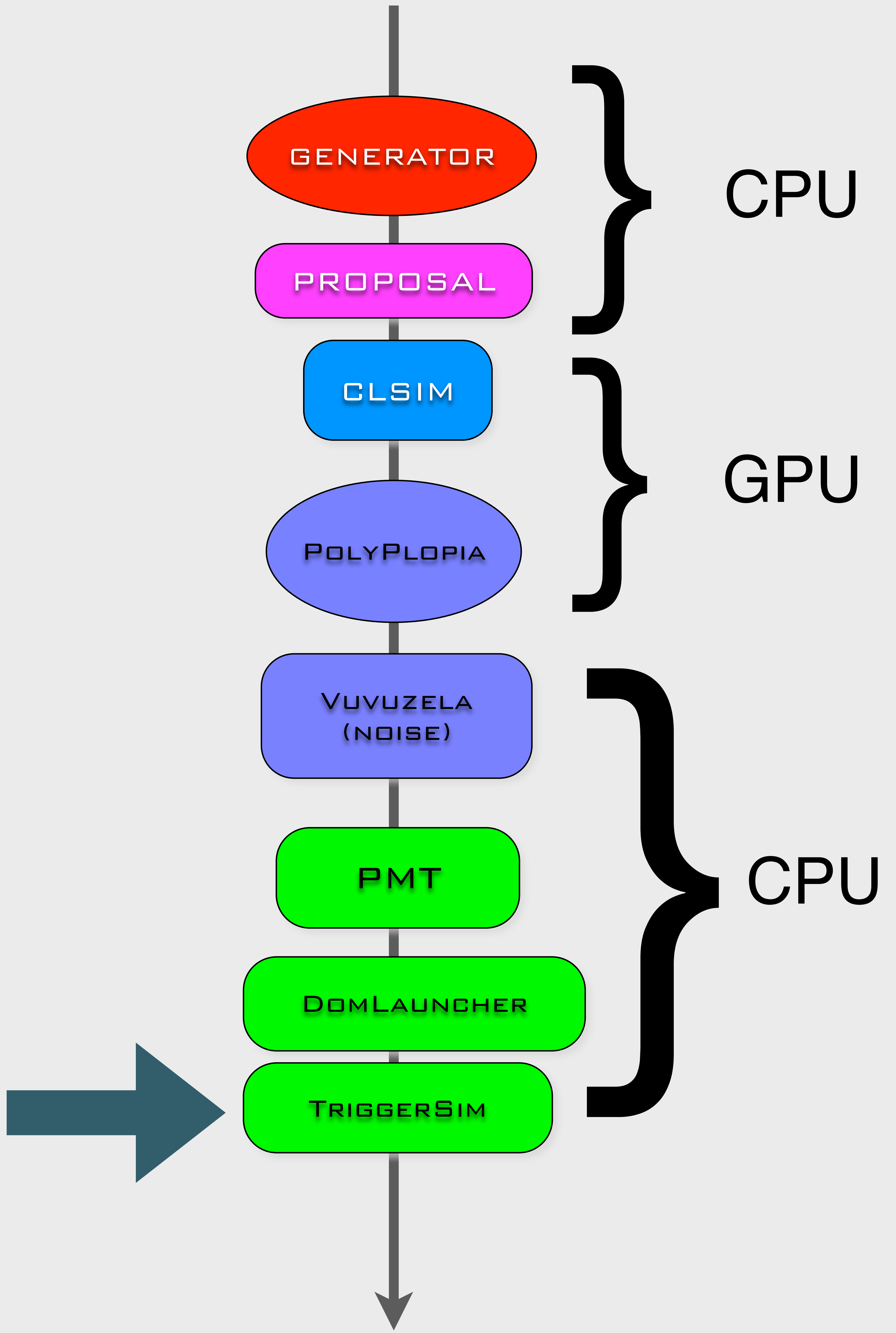
- **S**imple **M**ultiplicity **T**rigger (SMT)
  - *N* HLC hits or more in a time window
  - Example: InIce SMT8 with N_hits ≥ 8 in 5 μs
  - readout window around this captures early and late hits (-4 μs, +6 μs)

- **String** trigger (a.k.a. Cluster trigger in DAQ-land)
  - *N* HLC hits out of *M* DOMs on a string in a time window
  - Example: 5 hits from a run of 7 adjacent DOMs in a time window of 1500 ns

- **Volume** trigger (a.k.a Cylinder trigger in DAQ-land)
  - simple majority of HLC hits (SMT4) with volume element including one layer of strings around a center string
  - cylinder height is 5 DOM-layers (2 up and down from the selected DOM).

- **Slo**w **P**article trigger (SLOP)
  - slow-moving hits along a track
  - lengths of the order of 500μs and extending up to milliseconds

- **F**ixed **R**ate **t**rigger, **Min**imum **Bias** trigger, **Calibration** trigger



simprod-scripts

https://github.com/icecube/icetray/tree/main/simprod-scripts

Collection of scripts, tray segments used in simulation production.
Central place with standard segments for running simulation in both official production and private simulations.

simprod-scripts

Scripts: $I3_SRC/simprod-scripts/resources/scripts

(run the individual pieces as broken down by production tasks)

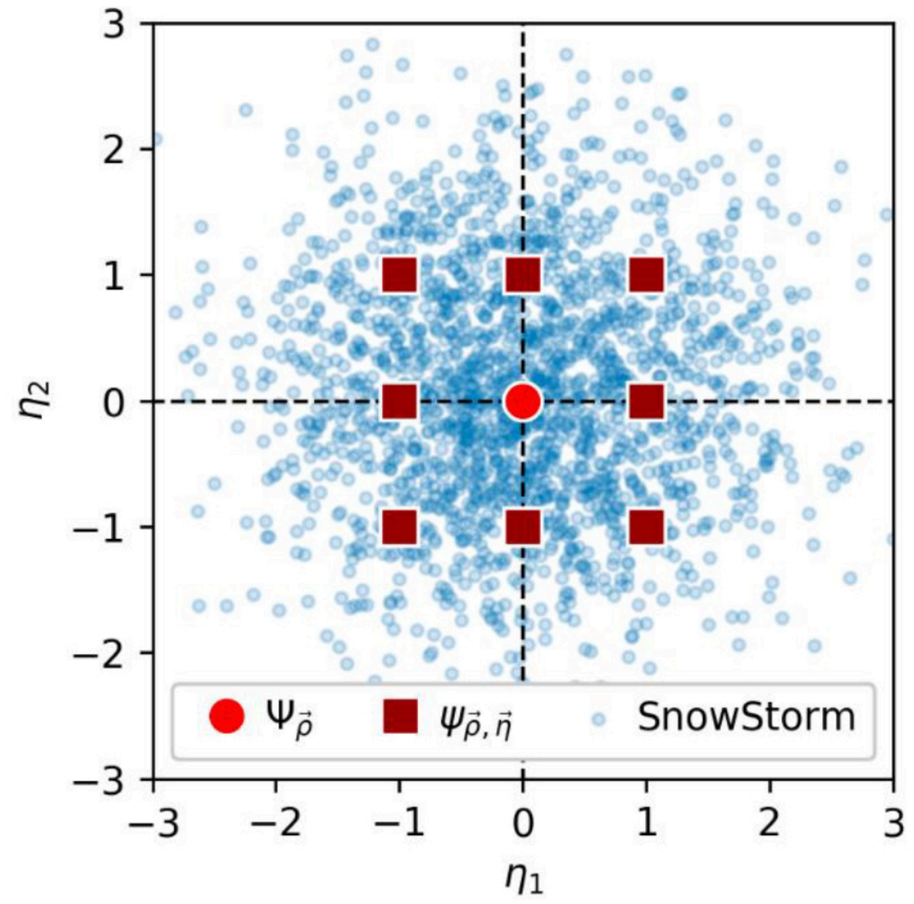
```
$  python nugen.py -h

Usage: nugen.py [options]

Options:
  -h, --help            show this help message and exit
  --no-execute          boolean condition to execute
 --outputfile=OUTPUTFILE
                        Output filename
  --summaryfile=SUMMARYFILE
                        XMLSummary filename
  --mjd=MJD             MJD for the GCD file
  --seed=RNGSEED        RNG seed
  —UseGSLRNG
…
```

simprod-scripts (SnowSuite)

Scripts: $I3_SRC/simprod-scripts/resources/scripts

(run the individual pieces as broken down by production tasks)

```
simprod-scripts/resources/scripts/SnowSuite/
├─── 1-process-Gen.py
├─── 2-Polyplopia.py
├─── 2-Propagate.py
├─── 3-Snowstorm.py
├─── 4-process-Weight.py
├─── demo
|    └─── SimpleInjector.py
├─── iceprod2
|    ├─── iceprod_config_example.json
|    ├─── load_env
|    └─── source_env
├─── jobs
|    └─── condor_manager.py
├─── Snowstorm_Cfg.yml
├─── Snowstorm_FullSystematics.yml
├─── Snowstorm_NominalIce_Cfg.yml
└─── utils.py
```



Journal of Cosmology and Astroparticle Physics

Efficient propagation of systematic uncertainties from calibration to analysis with the SnowStorm method in IceCube

M.G. Aartsen[16], M. Ackermann[54], J. Adams[16], J.A. Aguilar[12], M. Ahlers[20], C. Alispach[26], B. Al Atoum[4], K. Andeen[37], T. Anderson[51], I. Ansseau[12] +Show full author list

Published 21 October 2019 • © 2019 IOP Publishing Ltd and Sissa Medialab
Journal of Cosmology and Astroparticle Physics, Volume 2019, October 2019

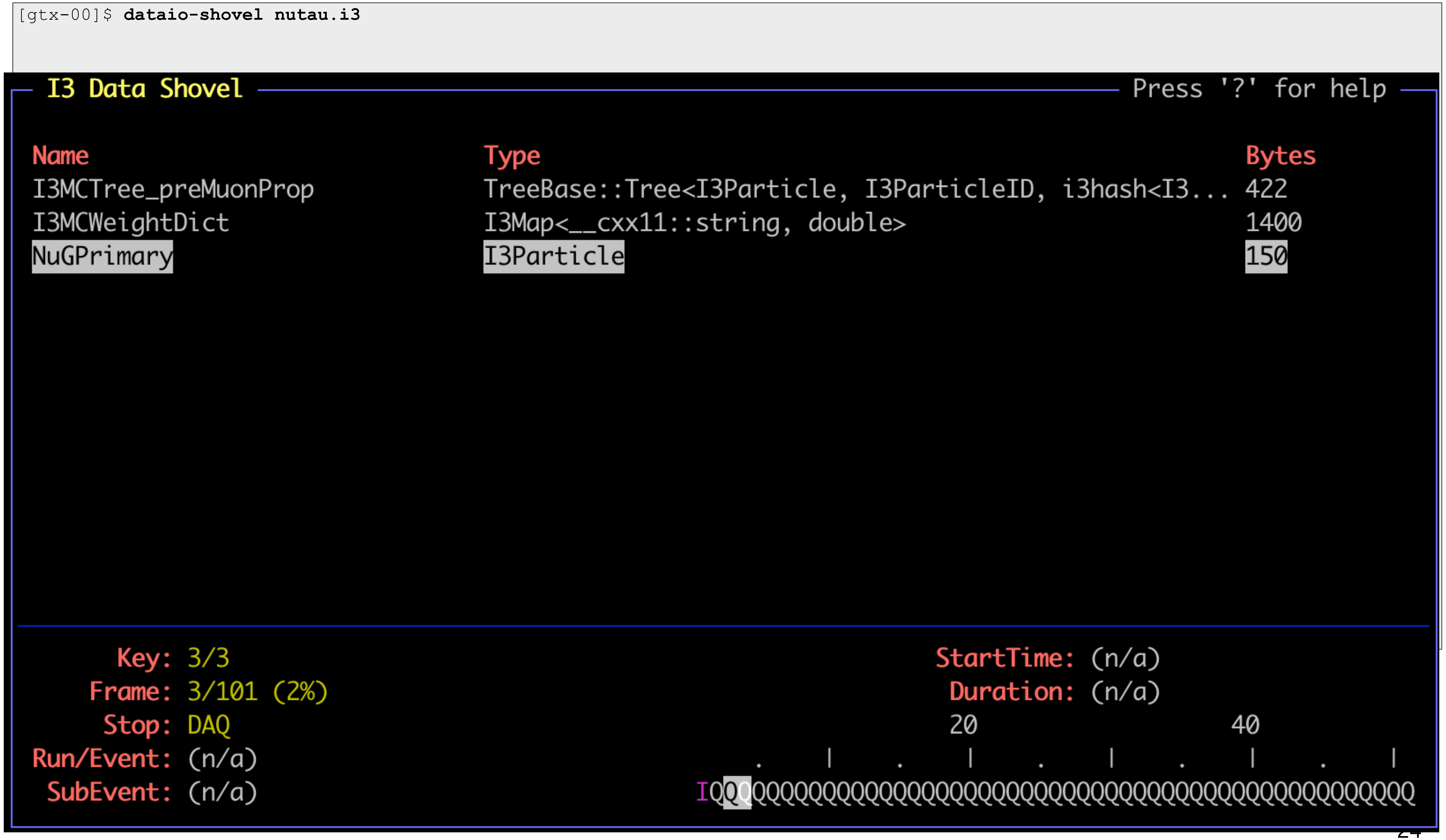
simprod-scripts

Example: Running scripts**:**

```
icecube@M16:~$ ssh submitter
[submitter]$ condor_submit -interactive 'request_gpus=1'
Submitting job(s).
1 job(s) submitted to cluster 120263704.
Waiting for job to start…
Welcome to slot1@gtx-00.icecube.wisc.edu!

[gtx-00]$ cd $_CONDOR_SCRATCH_DIR
[gtx-00]$ /cvmfs/icecube.opensciencegrid.org/py3-v4.3.0/icetray-env icetray/v1.10.0
************************************************************************
*                                                                      *
*                   W E L C O M E  to  I C E T R A Y                   *
*                                                                      *
*               Version icetray.stable     git:f5d21802                *
*                                                                      *
*                You are welcome to visit our Web site                 *
*                        http://icecube.umd.edu                        *
*                                                                      *
************************************************************************
[gtx-00]$ python $I3_BUILD/simprod-scripts/resources/scripts/nugen.py \
                --outputfile nutau.i3 --nevents 100 \
                 --seed=123 --procnum 0  --nproc=1 \
                 --FromEnergy 1e5 --ToEnergy 1e6 --NuFlavor NuTau --UseGSLRNG

[gtx-00]$ dataio-shovel nutau.i3
```

simprod-scripts

Example: Running scripts:



simprod-scripts

Example: Running scripts:

```
[gtx-00]$ python $I3_BUILD/simprod-scripts/resources/scripts/clsim.py \
                  --gcdfile /cvmfs/icecube.opensciencegrid.org/data/GCD/
GeoCalibDetectorStatus_2020.Run134142.Pass2_V0.i3.gz  \
                --inputfilelist nutau.i3 --outputfile mcpes.i3   \
                  --seed 123 --procnum 0 --nproc 1 --no-RunMPHitFilter \
                  --UseGPUs --UseGSLRNG


[gtx-00]$ dataio-shovel mcpes.i3


[gtx-00]$ python $I3_BUILD/simprod-scripts/resources/scripts/detector.py \
                  --gcdfile /cvmfs/icecube.opensciencegrid.org/data/GCD/
GeoCalibDetectorStatus_2020.Run134142.Pass2_V0.i3.gz \
                  --inputfile mcpes.i3 --outputfile det.i3 \
                  --seed 123 --procnum 0 --nproc 1 --RunID 123 —UseGSLRNG
```

simprod-scripts

Example: Running scripts:

```
[gtx-00]$ dataio-shovel mcpes.i3
```

```
 I3 Data Shovel                                                    Press '?' for help

 Name                            Type                                               Bytes
 I3MCPESeriesMap                 I3Map<OMKey, vector<I3MCPE> >                      41
 I3MCPESeriesMapParticleIDMap    I3Map<OMKey, map<I3ParticleID, vector<unsigned int... 41
 I3MCTree                        TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 6878
 I3MCTree_preMuonProp            TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 1538
 I3MCTree_preMuonProp_RNGState   I3GSLRandomServiceState                            85
 I3MCWeightDict                  I3Map<__cxx11::string, double>                     1400
 MMCTrackList                    I3Vector<I3MMCTrack>                               40
 NuGPrimary                      I3Particle                                         150

       Key: 1/8                                             StartTime: (n/a)
     Frame: 3/102 (2%)                                       Duration: (n/a)
      Stop: DAQ                                             20                  40
 Run/Event: (n/a)                                   .    |    .    |    .    |    .    |    .    |
  SubEvent: (n/a)                               IIQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
```

simprod-scripts

Exercise: Running scripts:

```
[gtx-00]$ dataio-shovel det.i3
```

```
I3 Data Shovel                                                    Press '?' for help

Name                            Type                                                  Bytes
BeaconLaunches                  I3Map<OMKey, vector<I3DOMLaunch> >                    46
I3EventHeader                   I3EventHeader                                         99
I3MCPESeriesMap                 I3Map<OMKey, vector<I3MCPE> >                         113286
I3MCPESeriesMapParticleIDMap    I3Map<OMKey, map<I3ParticleID, vector<unsigned int... 36649
I3MCPESeriesMapWithoutNoise     I3Map<OMKey, vector<I3MCPE> >                         109543
I3MCPulseSeriesMap              I3Map<OMKey, vector<I3MCPulse> >                      82000
I3MCPulseSeriesMapParticleI...  I3Map<OMKey, map<I3ParticleID, vector<unsigned int... 40743
I3MCPulseSeriesMapPrimaryIDMap  I3Map<OMKey, map<I3ParticleID, vector<unsigned int... 27299
I3MCTree                        TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 10730
I3MCTree_preMuonProp            TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 422
I3MCTree_preMuonProp_RNGState   I3GSLRandomServiceState                               85
I3MCWeightDict                  I3Map<__cxx11::string, double>                        1400
I3TriggerHierarchy              I3Tree<I3Trigger>                                     792
I3Triggers                      I3Tree<I3Trigger>                                     414
IceTopRawData                   I3Map<OMKey, vector<I3DOMLaunch> >                    46
InIceRawData                    I3Map<OMKey, vector<I3DOMLaunch> >                    44640
MMCTrackList                    I3Vector<I3MMCTrack>                                  2864
NuGPrimary                      I3Particle                                            150
TimeShift                       I3PODHolder<double>                                   36
```

simprod-scripts

Exercise: Running scripts:

```
[gtx-00]$ python $I3_BUILD/simprod-scripts/resources/scripts/corsika.py \
                 --nshowers 10000 --outputfile corsika_bg.i3 --seed 1234 \
                 --CORSIKAseed=123 --ranpri 2  \
                 --corsikaVersion v6960-5comp \
                 --corsikaName dcorsika --UseGSLRNG  \
                 --skipoptions compress

[gtx-00]$ dataio-shovel corsika_bg.i3

[gtx-00]$ python $I3_BUILD/simprod-scripts/resources/scripts/polyplopia.py  \
               --gcdfile /cvmfs/icecube.opensciencegrid.org/data/GCD/
GeoCalibDetectorStatus_2020.Run134142.Pass2_V0.i3.gz \
               --inputfile mcpes.i3 --outputfile merged_pes.i3 \
               --seed 1234 \
               --backgroundfile corsika_bg.i3 --mctype NuTau \
               --UseGSLRNG

[gtx-00]$ python $I3_BUILD/simprod-scripts/resources/scripts/detector.py \
                 --gcdfile  /cvmfs/icecube.opensciencegrid.org/data/GCD/
GeoCalibDetectorStatus_2020.Run134142.Pass2_V0.i3.gz \
                 --inputfile merged_pes.i3 --outputfile det_wcoinc.i3 \
                 --seed 123 --RunID 123 --UseGSLRNG

[gtx-00]$ dataio-shovel det_wcoinc.i3
```

simprod-scripts

Exercise: Running scripts:

```
[gtx-00]$ dataio-shovel corsika_bg.i3
```

```
 I3 Data Shovel                                                        Press '?' for help

 Name                         Type                                          Bytes
 CorsikaInteractionHeight     I3PODHolder<double>                           36
 CorsikaWeightMap             I3Map<__cxx11::string, double>                484
 I3CorsikaInfo                I3CorsikaInfo                                 109
 I3MCTree                     TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 546
 I3MCTree_preSampling         TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 546

       Key: 1/5                                         StartTime: (n/a)
     Frame: 3/111+                                       Duration: (n/a)
      Stop: DAQ                                          20                  40
 Run/Event: (n/a)                           .    |    .    |    .    |    .    |    .    |
  SubEvent: (n/a)                        ISQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
```

simprod-scripts

Exercise: Running scripts:

```
[gtx-00]$ dataio-shovel merged_pes.i3
```

```
 I3 Data Shovel                                                Press '?' for help

Name                           Type                                                 Bytes
BackgroundI3MCPESeriesMap      I3Map<OMKey, vector<I3MCPE> >                        41
BackgroundI3MCPESeriesMapPa... I3Map<OMKey, map<I3ParticleID, vector<unsigned in... 41
BackgroundI3MCTree             TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I... 32
BackgroundI3MCTreePEcounts     I3Map<unsigned int, unsigned int>                    47
BackgroundI3MCTree_preMuonProp TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I... 32
BackgroundI3MCTree_preMuonP... I3GSLRandomServiceState                              85
BackgroundMMCTrackList         I3Vector<I3MMCTrack>                                 40
I3MCPESeriesMap                I3Map<OMKey, vector<I3MCPE> >                        41
I3MCPESeriesMapParticleIDMap   I3Map<OMKey, map<I3ParticleID, vector<unsigned in... 41
I3MCTree                       TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I... 2902
I3MCTree_preMuonProp           TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I... 422
I3MCTree_preMuonProp_RNGState  I3GSLRandomServiceState                              85
I3MCWeightDict                 I3Map<__cxx11::string, double>                       1424
MMCTrackList                   I3Vector<I3MMCTrack>                                 40
NuGPrimary                     I3Particle                                           150
PhotonSeriesMap                I3Map<ModuleKey, I3Vector<I3CompressedPhoton> >      53
PolyplopiaInfo                 I3Map<__cxx11::string, int>                          135
PolyplopiaPrimary              I3Particle                                           150
SignalI3MCPEs                  I3Map<OMKey, vector<I3MCPE> >                        41
SignalI3MCTree                 TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I... 2902
```

Simulating the online filter and L2 processing

```
[gtx-00]$  python filterscripts/resources/scripts/SimulationFiltering.py -h

usage: SimulationFiltering.py [-h] [-i INFILE] [-g GCDFILE] [-o OUTFILE]
                              [-n NUM] [--qify]
                              [--MinBiasPrescale MINBIASPRESCALE]
                              [--photonicsdir PHOTONICSDIR] [--enable-gfu]
                              [--log-level LOG_LEVEL] [--log-filename LOGFN]
                              [--needs_wavedeform_spe_corr]

optional arguments:
  -h, --help            show this help message and exit
  -i INFILE, --input INFILE
                        Input i3 file(s) (use comma separated list for
                        multiple files)
  -g GCDFILE, --gcd GCDFILE
                        GCD file for input i3 file
  -o OUTFILE, --output OUTFILE
                        Output i3 file
  -n NUM, --num NUM     Number of frames to process
  --qify                Apply QConverter, use if file is P frame only
  --MinBiasPrescale MINBIASPRESCALE
                        Set the Min Bias prescale to something other than
                        default
  --photonicsdir PHOTONICSDIR
                        Directory with photonics tables
  --enable-gfu          Do not run GFU filter
  --log-level LOG_LEVEL
                        Sets the logging level (ERROR, WARN, INFO, DEBUG,
                        TRACE)
  --log-filename LOGFN  If set logging is redirected to the specified file.
  --needs_wavedeform_spe_corr
                        apply_spe_corection in wavedeform.
```

Simulating the online filter and L2 processing

```
[gtx-00]$  python filterscripts/resources/scripts/offlineL2/process.py -h

usage: process.py [-h] [-s] [-i INFILE] [-g GCDFILE] [-o OUTFILE] [-n NUM]
                  [--dstfile DSTFILE] [--gapsfile GAPSFILE]
                  [--icetopoutput ICETOPOUTPUT] [--eheoutput EHEOUTPUT]
                  [--slopoutput SLOPOUTPUT] [--rootoutput ROOTOUTPUT]
                  [--photonicsdir PHOTONICSDIR] [--log-level LOG_LEVEL]
                  [--log-filename LOGFN]

optional arguments:
  -h, --help            show this help message and exit
  -s, --simulation      Mark as simulation (MC)
  -i INFILE, --input INFILE
                        Input i3 file(s) (use comma separated list for
                        multiple files)
  -g GCDFILE, --gcd GCDFILE
                        GCD file for input i3 file
  -o OUTFILE, --output OUTFILE
                        Output i3 file
  -n NUM, --num NUM     Number of frames to process
  --dstfile DSTFILE     DST root file (should be .root)
  --gapsfile GAPSFILE   gaps text file (should be .txt)
  --icetopoutput ICETOPOUTPUT
                        Output IceTop file
  --eheoutput EHEOUTPUT
                        Output EHE i3 file
  --slopoutput SLOPOUTPUT
                        Output SLOP file
  --rootoutput ROOTOUTPUT
                        Output root file
  --photonicsdir PHOTONICSDIR
                        Directory with photonics tables
  --log-level LOG_LEVEL
                        Sets the logging level (ERROR, WARN, INFO, DEBUG,
                        TRACE)
  --log-filename LOGFN  If set logging is redirected to the specified file.
```

More on Simulation

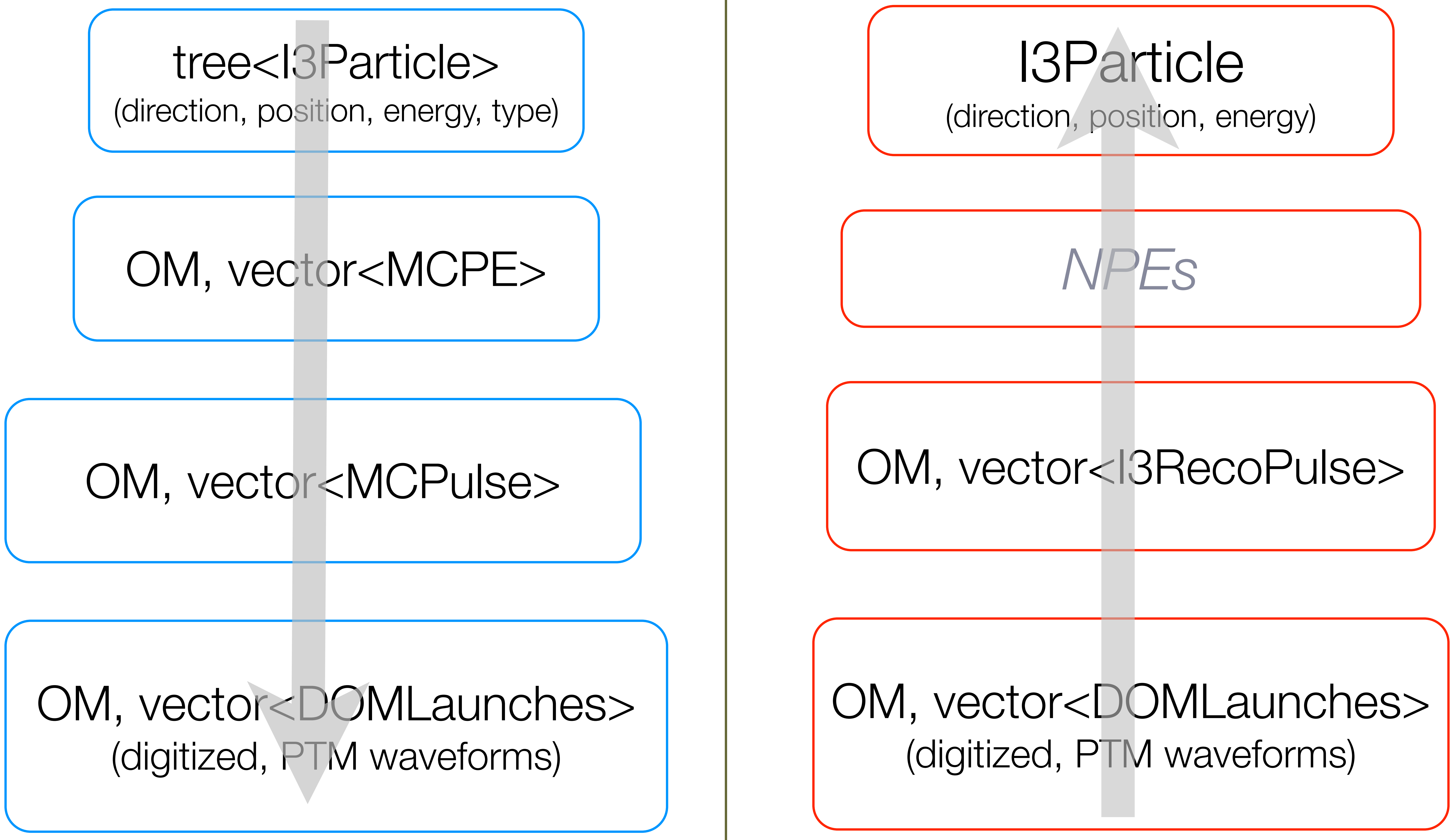
- GitHub repository: https://docs.icecube.aq/icetray/main
- SimProd Portal: http://simprod.icecube.wisc.edu
- IceProd Docs: https://wipacrepo.github.io/iceprod/
- JSON Templates: https://github.com/icecube/simprod-templates
- Weighting: https://docs.icecube.aq/simweights/main/
- SLACK: #simulation

Backup

simulaton chain (IT)

Simulation

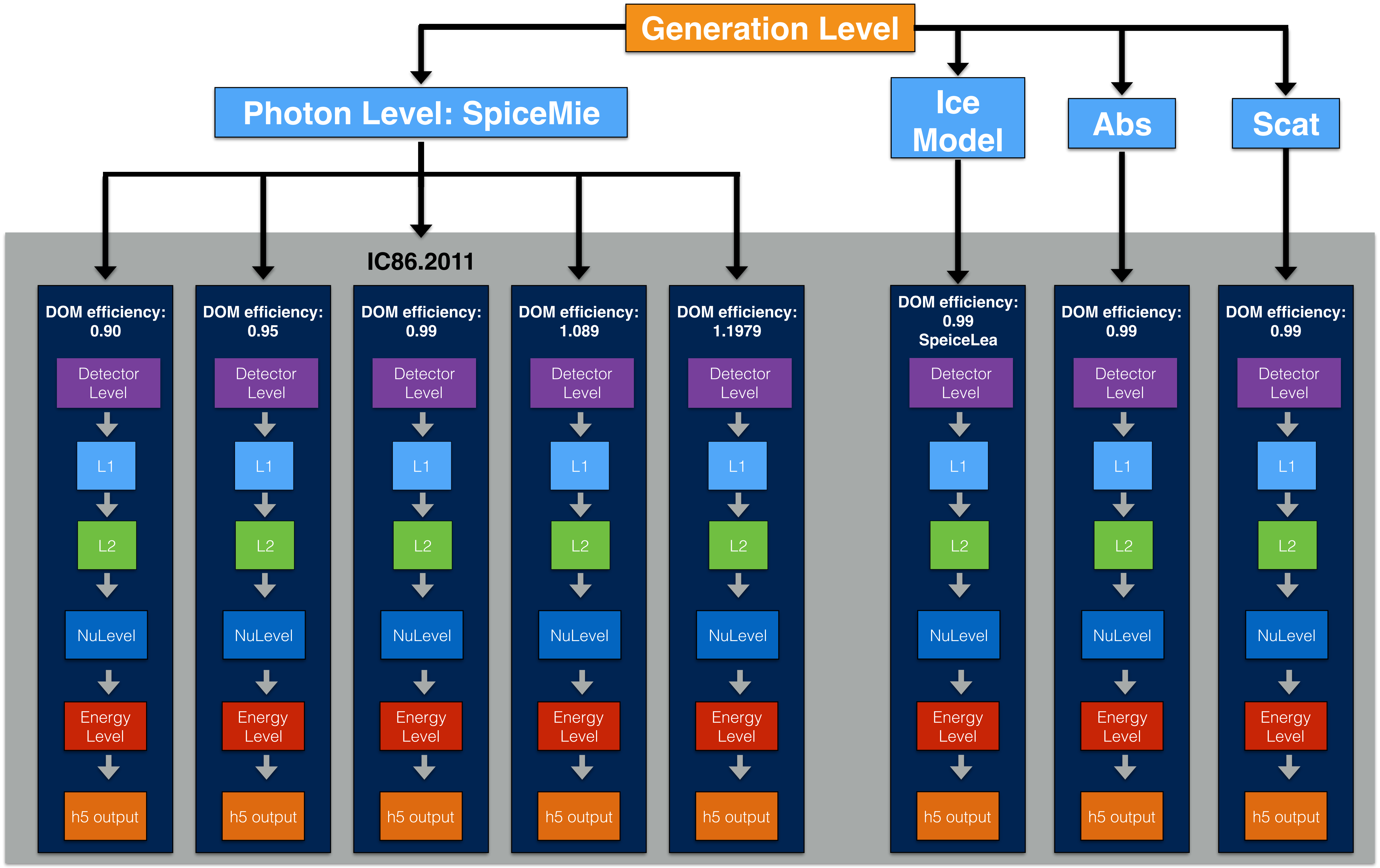
Reconstruction



Simulating Systematic Uncertainties

Example: High-Energy Sterile Neutrino MC Generation

Spencer N. Axani



Generation level:

- MuonInjector
- Spectrum = E^{-2}
- Energy = 2E2 to 1E6 GeV
- NEvents = 1.2e9 events

Photon Level:

- DOM efficiency: 1.1979
- SpiceMie

It took almost a year to produce this MC for the IC86.2011 analysis.

We do not have the resources to do this for a 6 year analysis.

We need to find ways to optimize and cut back!

SnowStorm

https://events.icecube.wisc.edu/event/118/contributions/6499/attachments/5362/6082/DiffuseParallel_Brussels_SnowStormMCGlobalfit.pdf

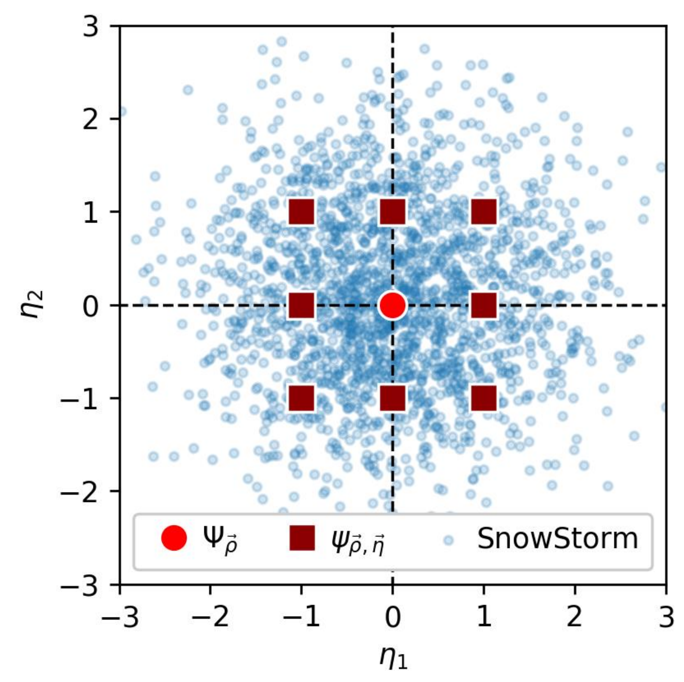
Erik Ganster

SnowStorm Simulation Chain – SnowStorm

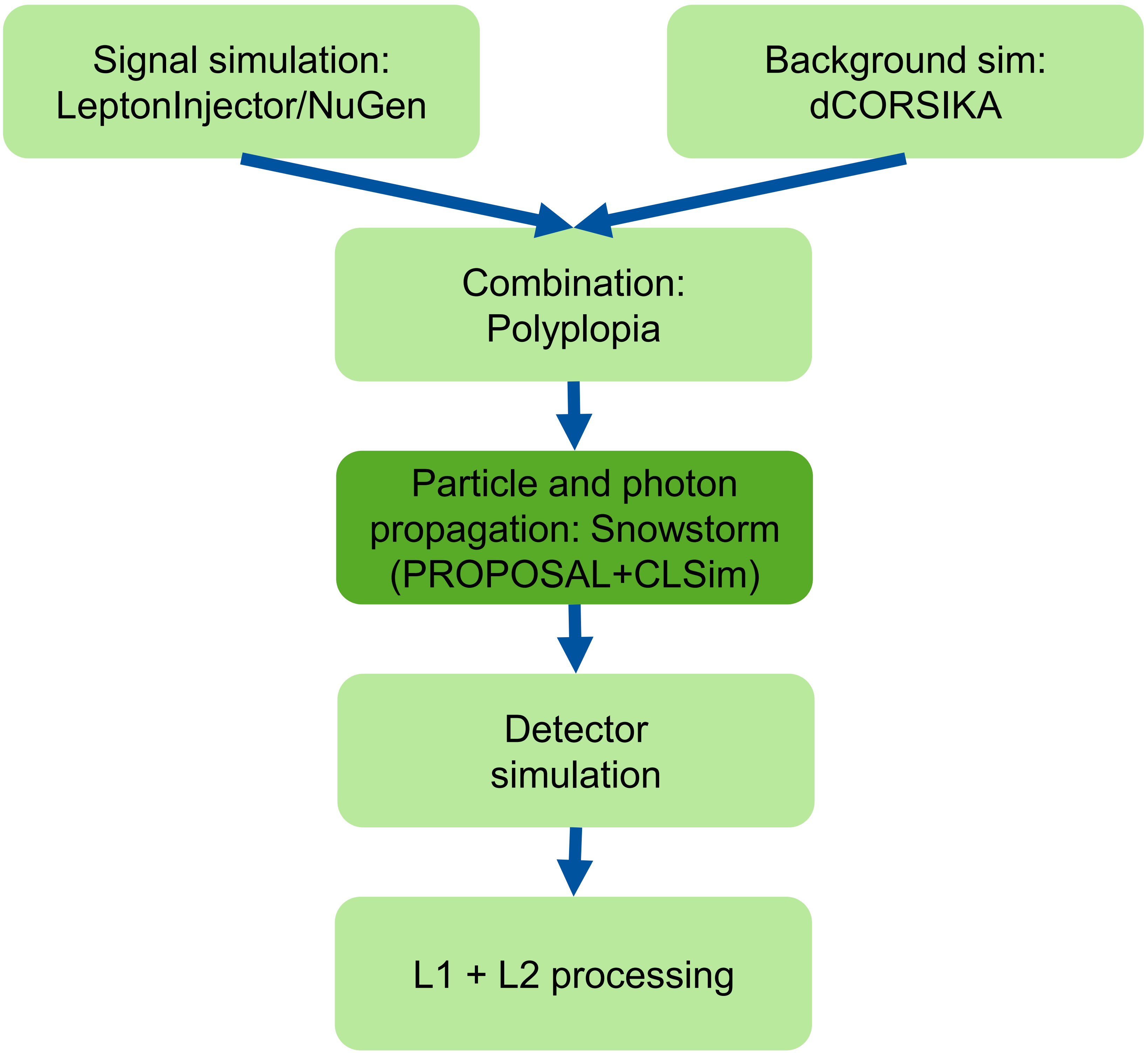
- Based on "standard" simulation chain
- Merge of signal+background I3MCTrees before any particle or photon propagation
  → Ensures that all particles get treated/propagated with the exact same parameters/settings further on

➢ Main SnowStorm simulation step:
  ➢ Particle (muon) propagation with PROPOSAL
  ➢ Photon propagation using CLSim

➢ Perturbing the ice model properties for chunks of frames using the *SnowStorm perturber*



SnowStorm short: Continuos variation of nuisance parameters (detector systematics) (blue) instead of discrete sets for specific values (red)



flow of experimental and simulation data