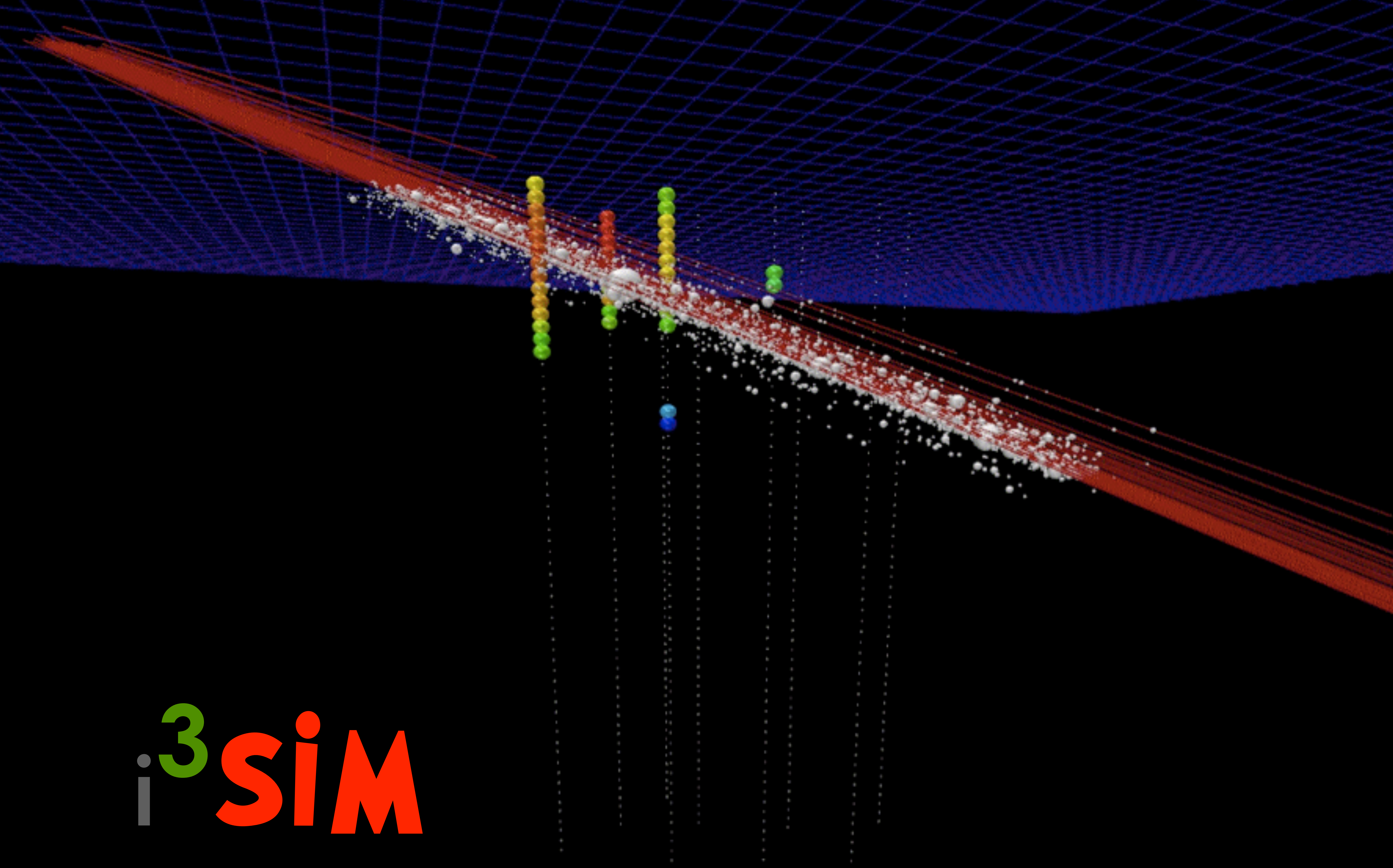


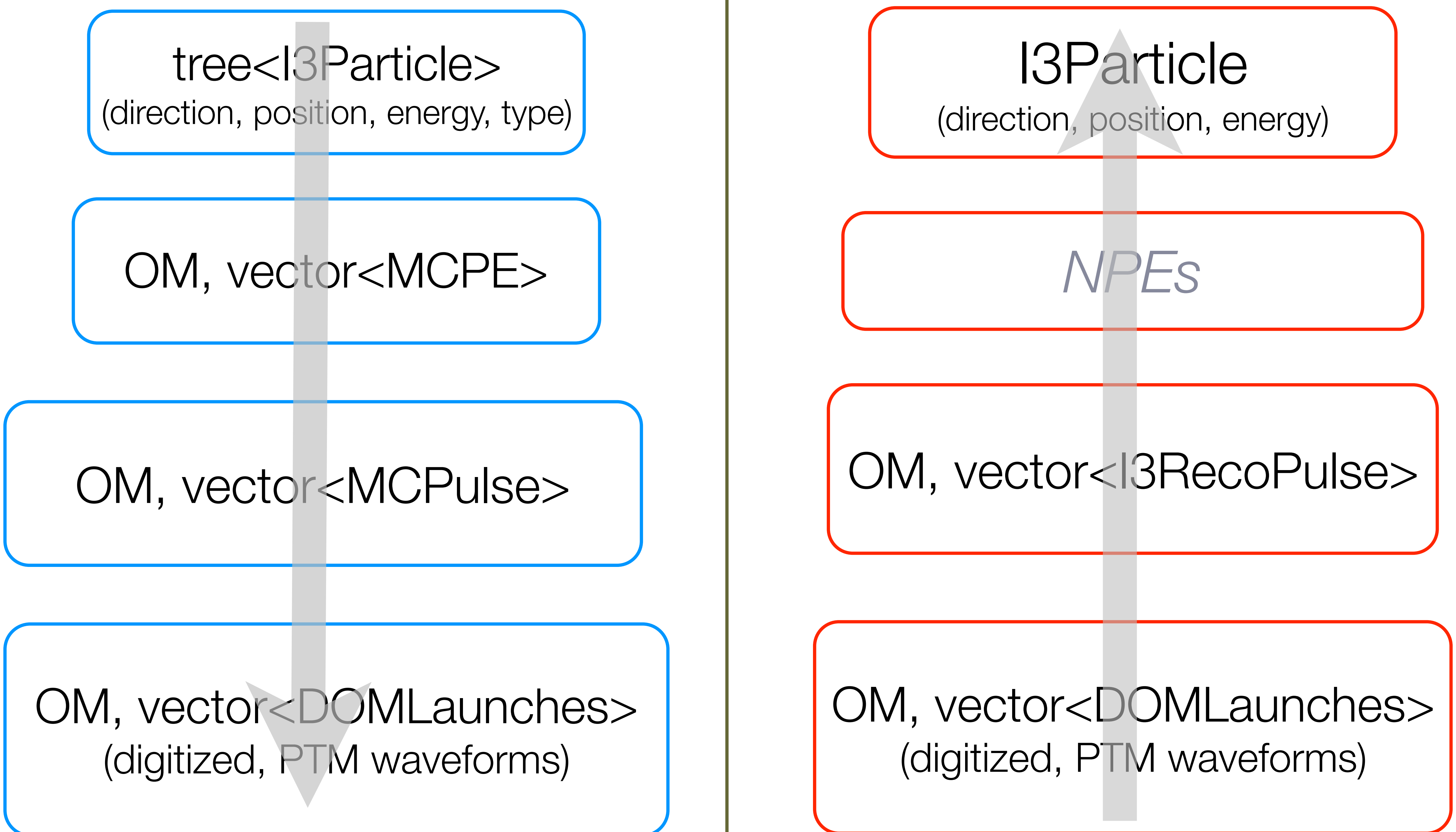
i3sim

IceCube Bootcamp 2017

Juan Carlos Díaz Vélez

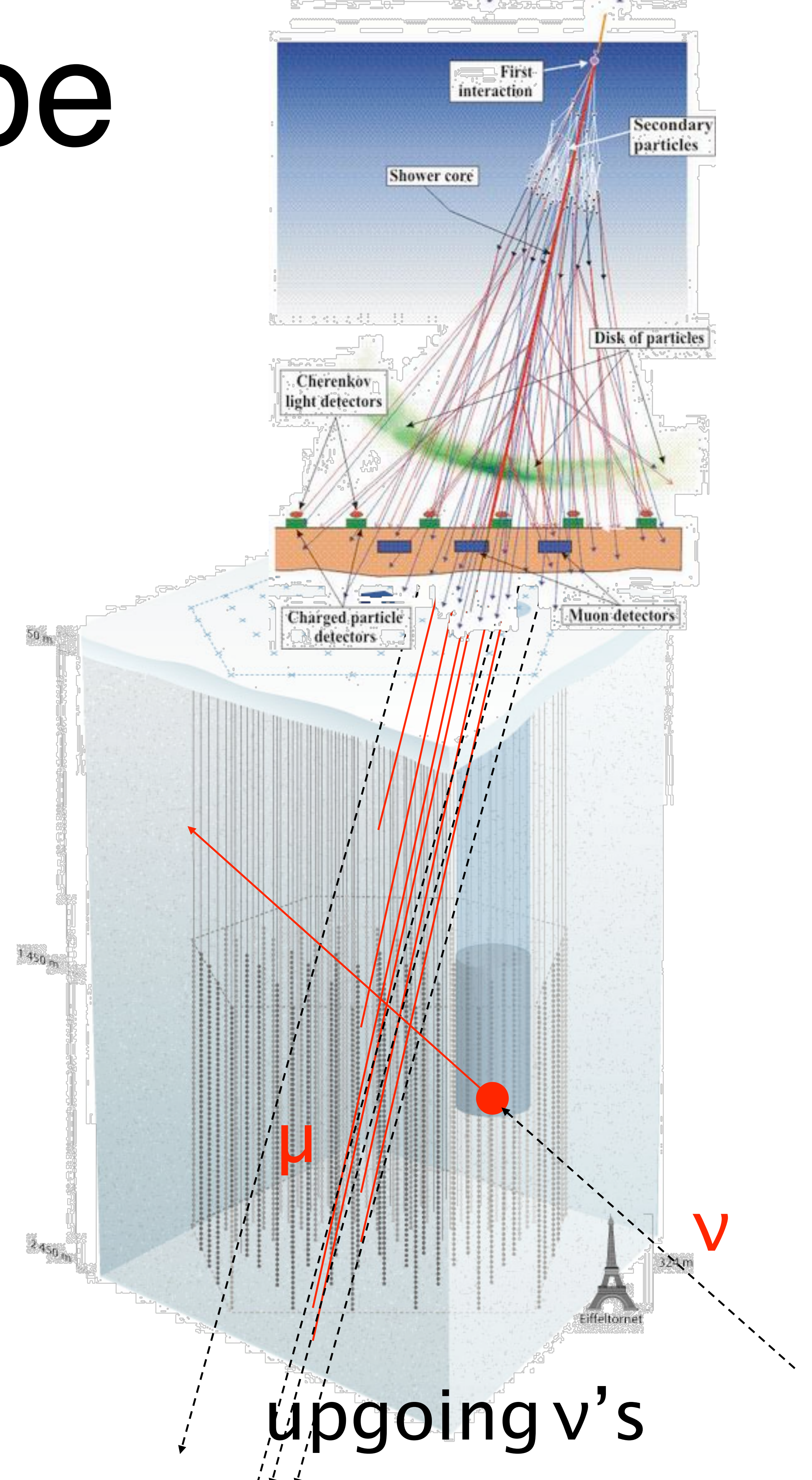
Simulation

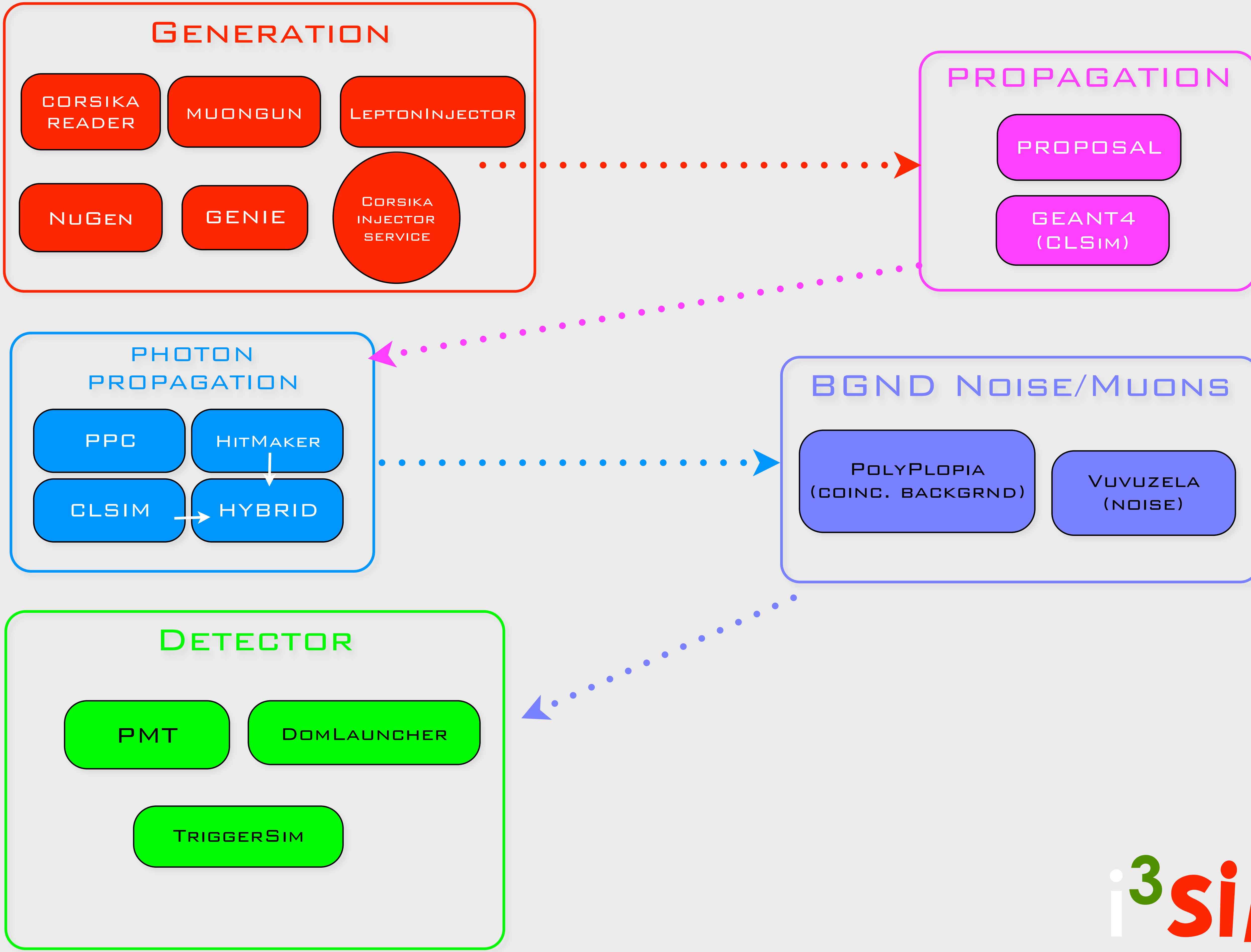
Reconstruction



Events in icecube

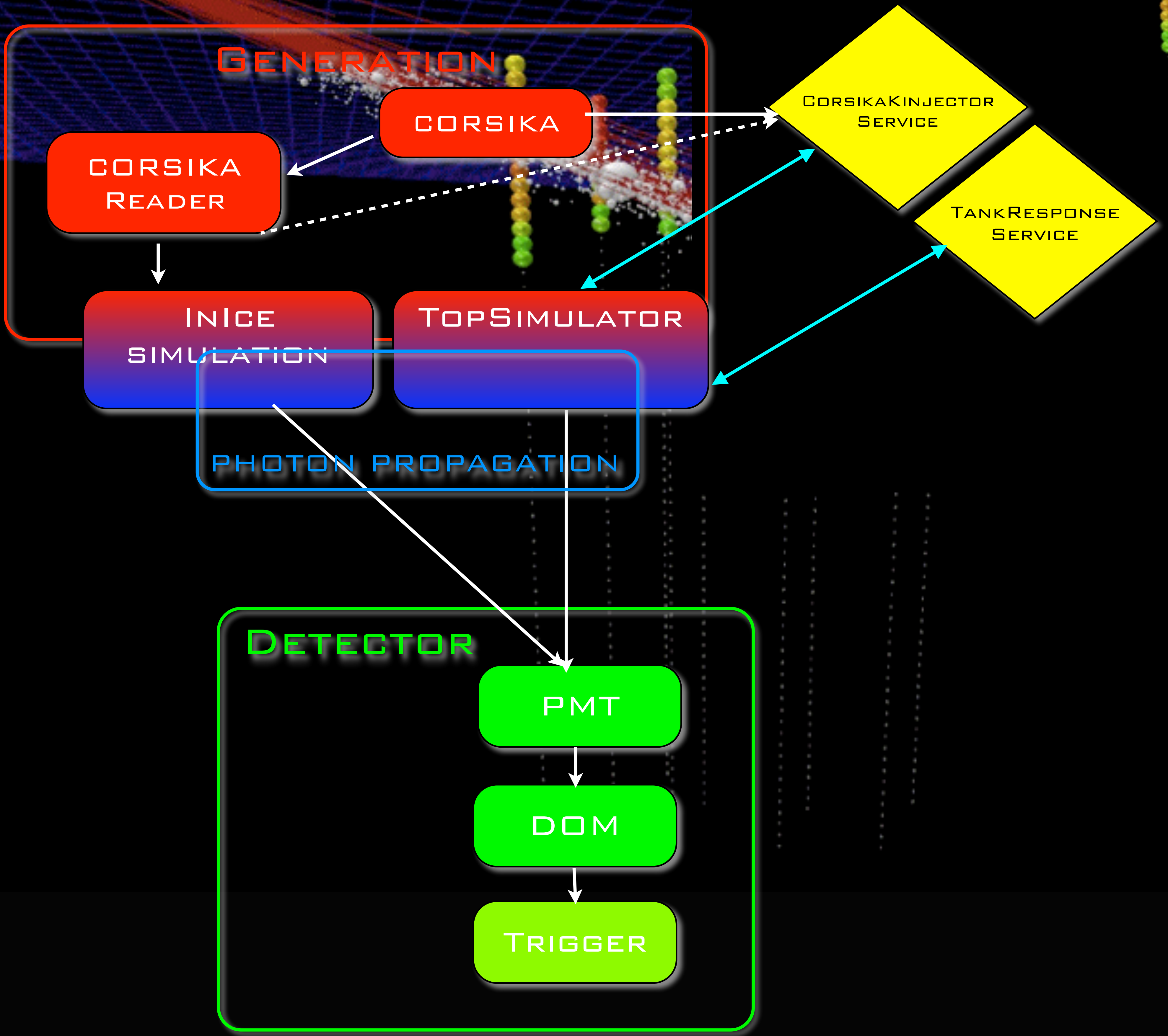
- Air shower detection @ surface
- Penetrating muon detection in deep ice
- Events dominated by cosmic ray muons : 10^6 μ for every ν that interacts in IceCube
- Upgoing ν's (atmospheric)




GENERATION
CORSIKA READER
MUONGUN
LEPTONINJECTOR
NUGEN
GENIE
CORSIKA INJECTOR SERVICE
PROPAGATION
PROPOSAL
GEANT4 (CLSIM)
PHOTON PROPAGATION
PPC
HITMAKER
CLSIM
HYBRID
BGND NOISE/MUONS
POLYPLOPIA (COINC. BACKGRND)
VUVUZELA (NOISE)
DETECTOR
PMT
DOMLAUNCHER
TRIGGERSIM

i^3sim

simulaton chain (IT)



Generators

- Cosmic-ray Air Showers:
  - **CORSIKA** (FORTRAN stand-alone)
  - **corsika-reader**: IceTray reader for standard format
  - **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-icetray**: 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

- Cosmic-ray Air Showers:
  - **CORSIKA** (FORTRAN stand-alone)
  - **corsika-reader**: IceTray reader for standard format
  - **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-icetray**: 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 (cont.)

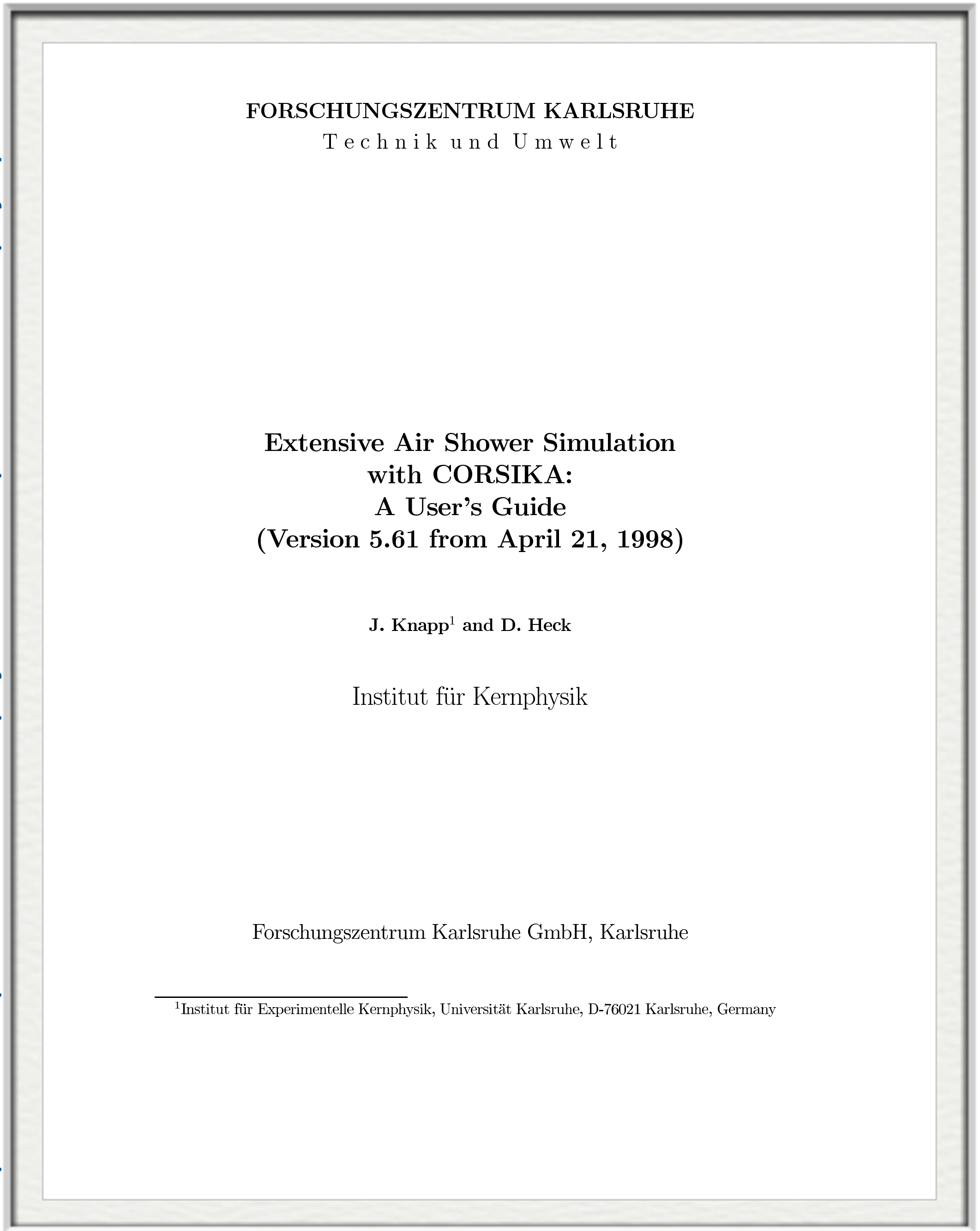
- Other:
  - **wimpsim-reader**: IceTray interface for WimpSim (FORTRAN stand-alone)

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.

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


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

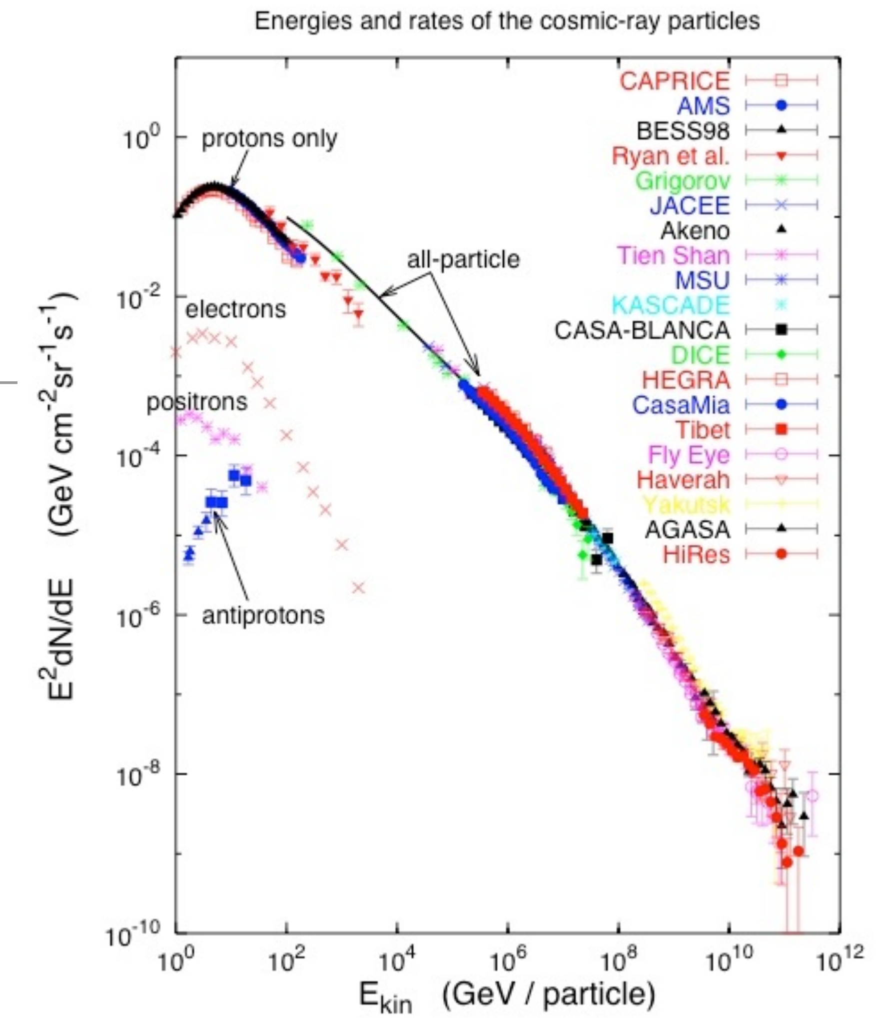
Forschungszentrum Karlsruhe GmbH, Karlsruhe

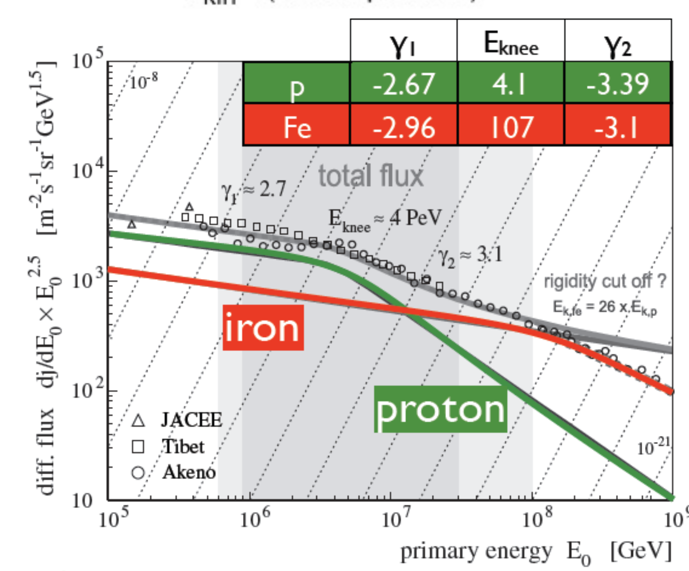
[1]Institut für Experimentelle Kernphysik, Universität Karlsruhe, D-76021 Karlsruhe, Germany

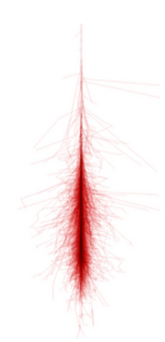
Generators : CORSIKA

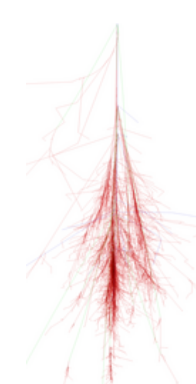
(**CO**smic **R**ay **SI**mulations for **KA**scade)

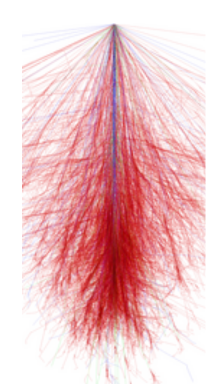
- weighted events : artificially flat spectrum
  - better livetime efficiency @ 10 TeV but poor efficiency @ TeV
  - energy-targeted generation of (H,He,CNO,Mg,Fe) with $E^{-1(2)}$

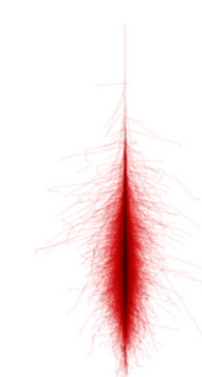





Photon shower


Proton shower


Iron shower


Muon shower

Generators

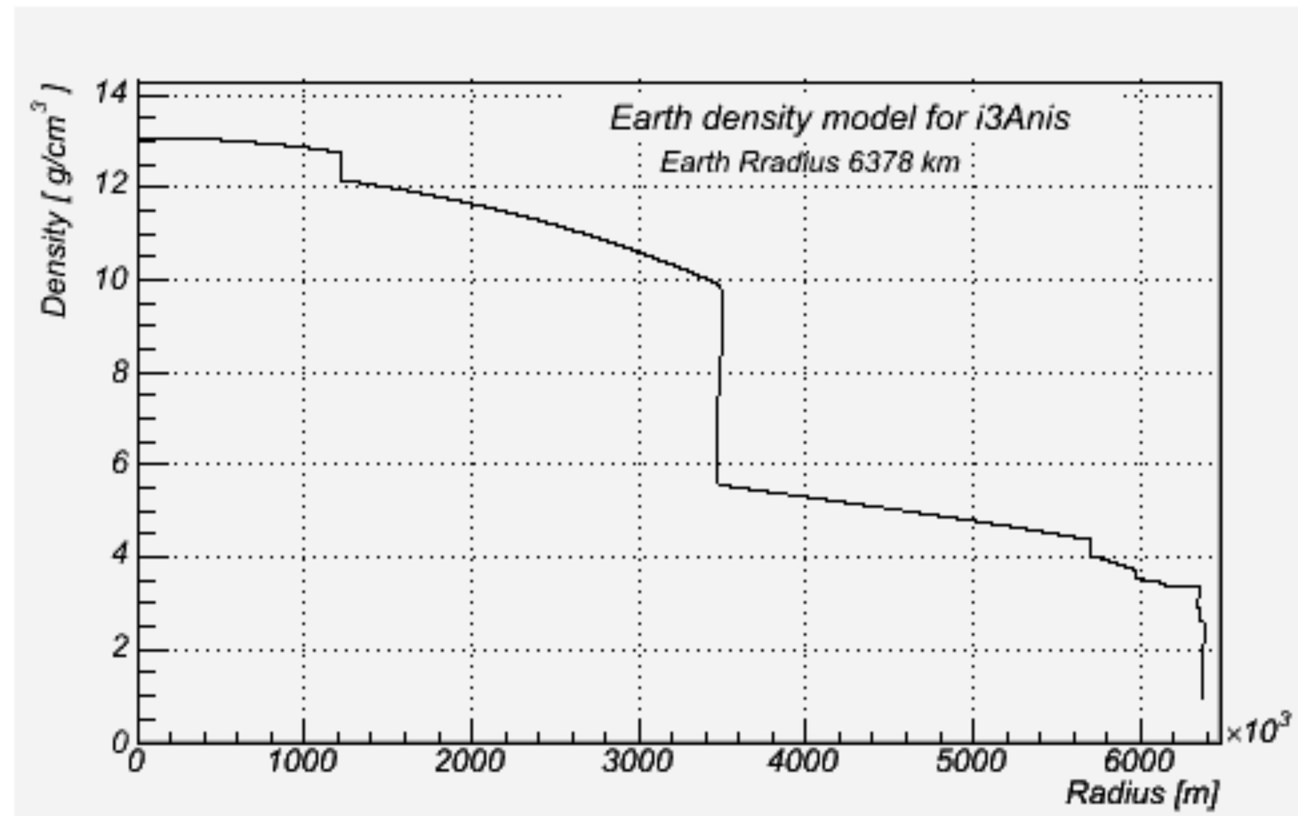
- Cosmic-ray Air Showers:
  - **CORSIKA** (FORTRAN stand-alone)
  - **corsika-reader**: IceTray reader for standard format
  - **CorsikaInjectorService** (IceTop)
- Muons:
  - **MuonGun**: parametrization of flux of atm. muons under the ice.
- Neutrinos:
  - **neutrino-generator**: injects neutrinos, propagates them through Earth, forces interaction in detector volume.
  - **genie-icetray**: 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.

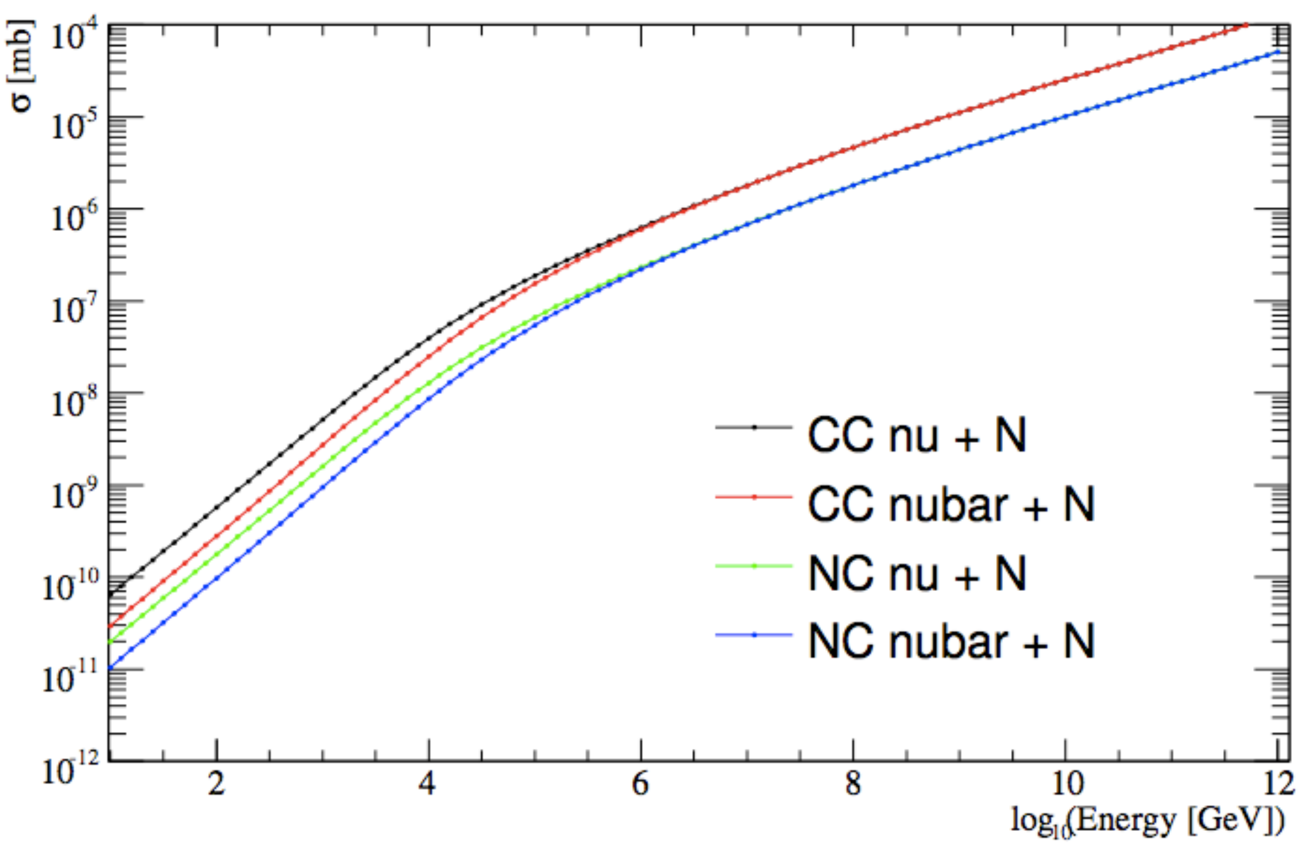
Generators

- Cosmic-ray Air Showers:
  - **CORSIKA** (FORTRAN stand-alone)
  - **corsika-reader**: IceTray reader for standard format
  - **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-icetray**: 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 : neutrino-generator

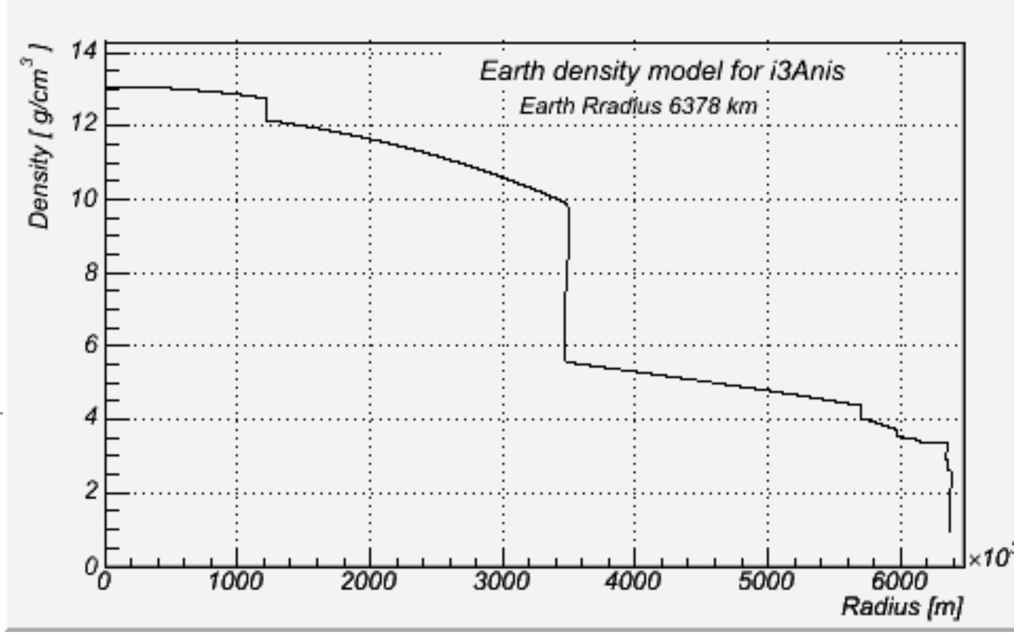
- produce a $E^{-\gamma}$ ν_μ, ν_e, ν_τ with
    - PRELIM Earth's density model





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

Generators : neutrino-generator



Propagation

neutrino on the earth surface and propagate tawards detector until "DistanceExit" (after which charged lepton created are considered invisible)

If initial primary interacted, secondary particles are created. Then we propagate secondaries:

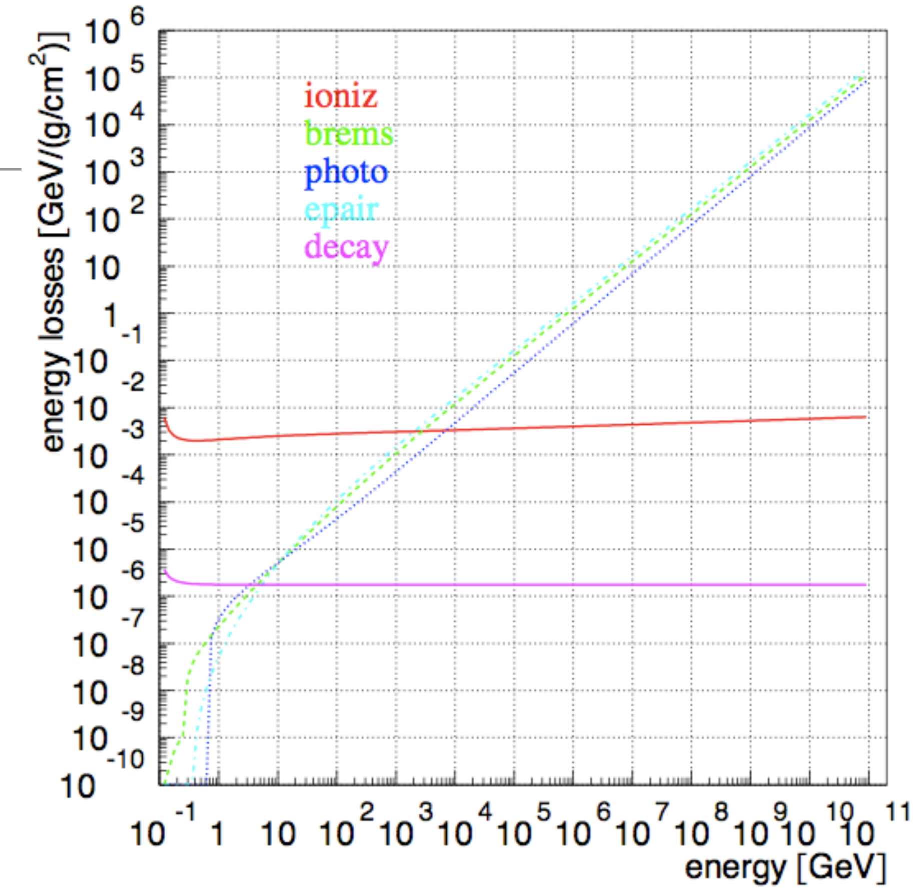
- 1) if neutrinos, propagate further
- 2) if tau, decay
- 3) if charged lepton created inside detection volume --- make it the final inice particle and find its parent neutrino and make it the Primary particle.
- 4) if charged lepton created outside detection volume, see if propagates to inside volume

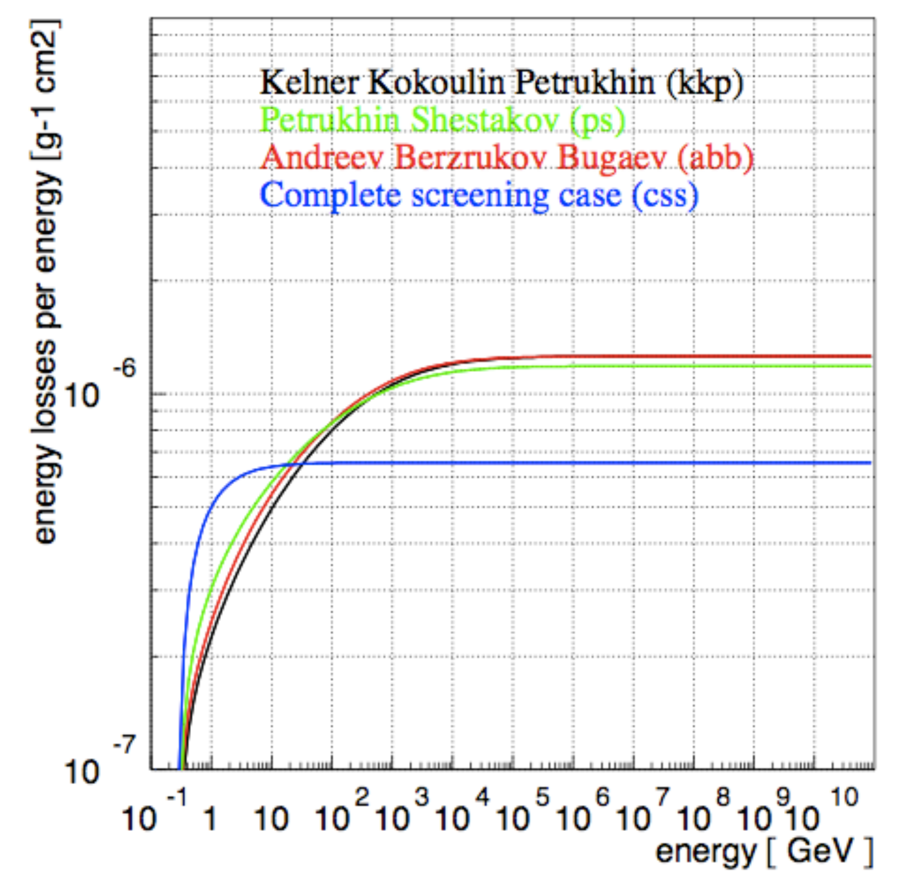
This loops over until every particles reach to the end of volume.

While PropagateParticle is looping over all the particles and neutrino might interact with matter to create secondary neutrino/charged lepton/hadrons and those particles are added to the end of vector of propagated particles to be further searched.

Lepton propagation

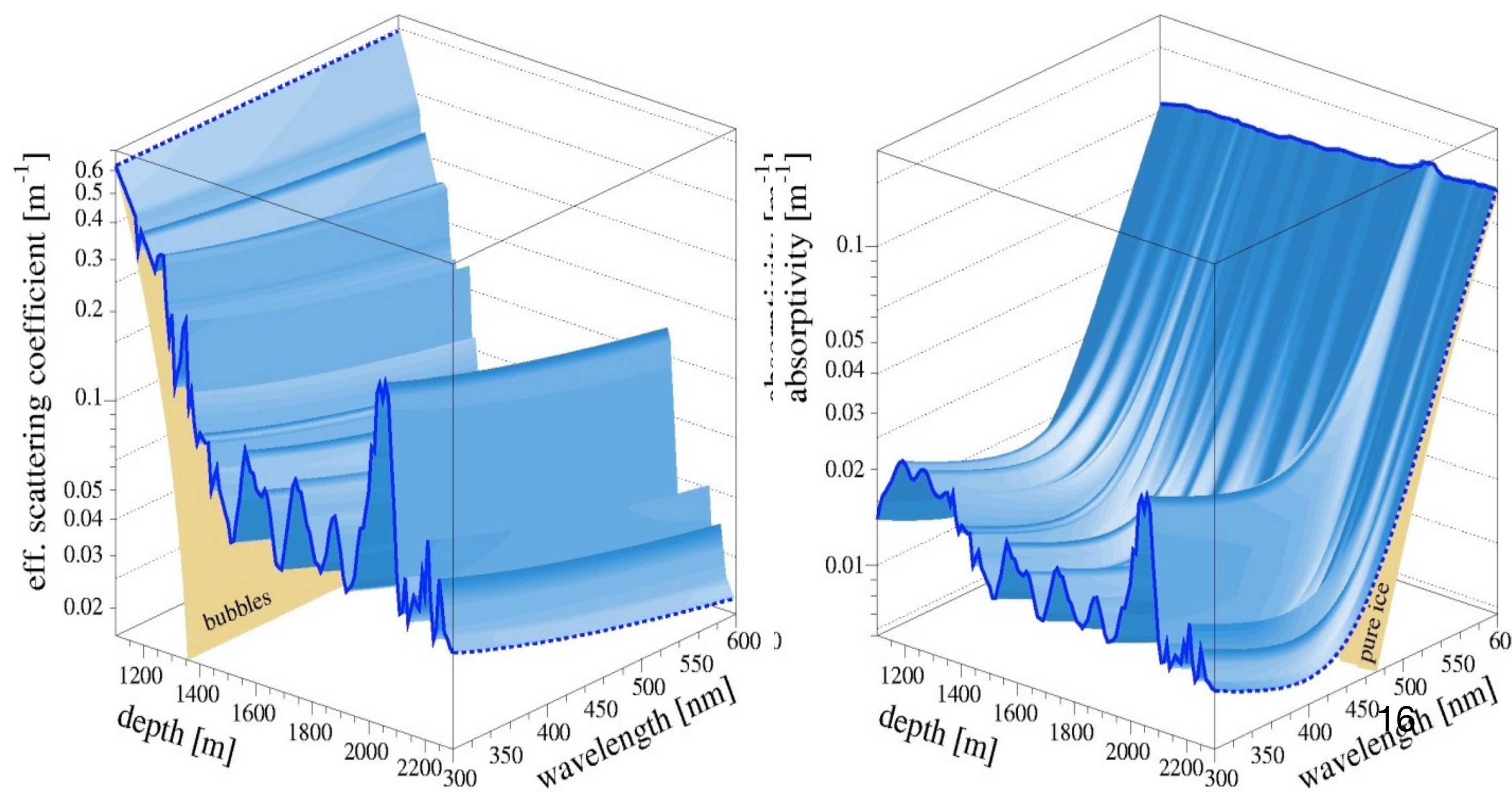
- PROPOSAL: parametrized interactions with the medium.
  - Stochastic energy losses include:
    - Ionization
    - electron-Pairproduction
    - Bremsstrahlung
    - Photonuclear Interaction
    - “Decay”
- GEANT4: Detailed particle propagation in media.
  - 3rd-party G4 library used by CLSim to propagate leptons for low-energy simulations (CPU-intensive).



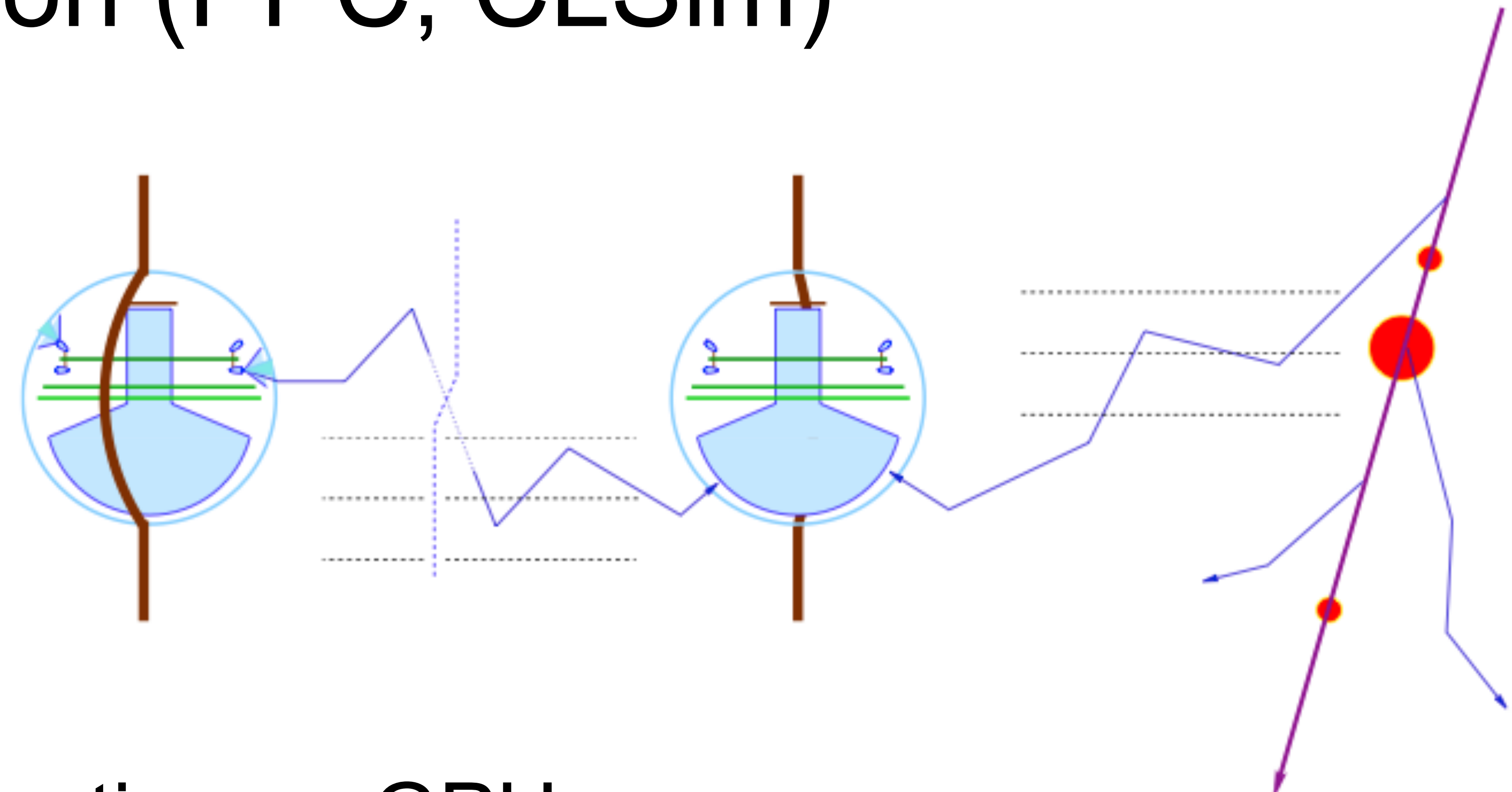


Photon Propagation

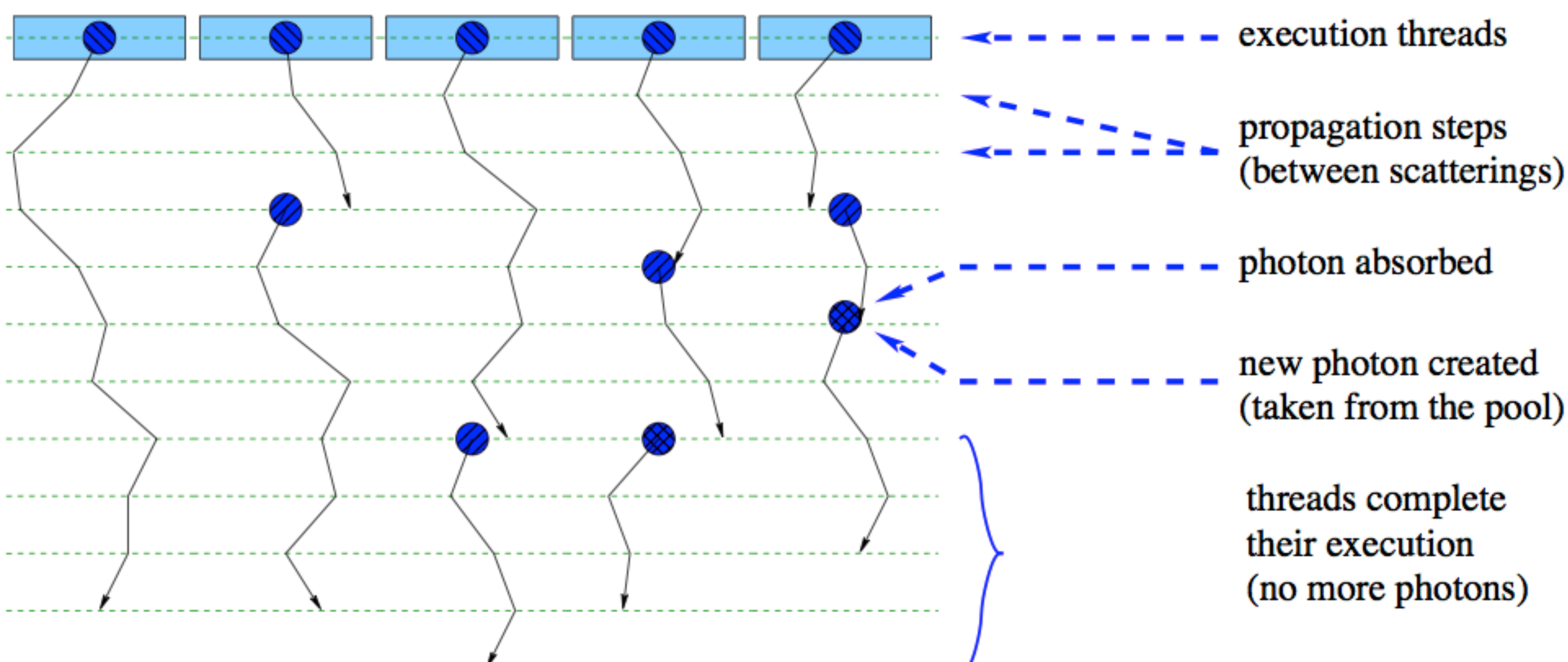
- μ energy lost + cascades ➙ photons ➙ p.e.
  - Photon propagation : ice properties + PMT response + DOM glass/gel
    - Pre-generated lookup splined table :
      - I3PhotonicsHitMaker
      - Amplitude and time distribution
    - Direct photon tracking
      - PPC
      - CLSim
    - Hybrid photon tracking
      - HitMaker + CLSim



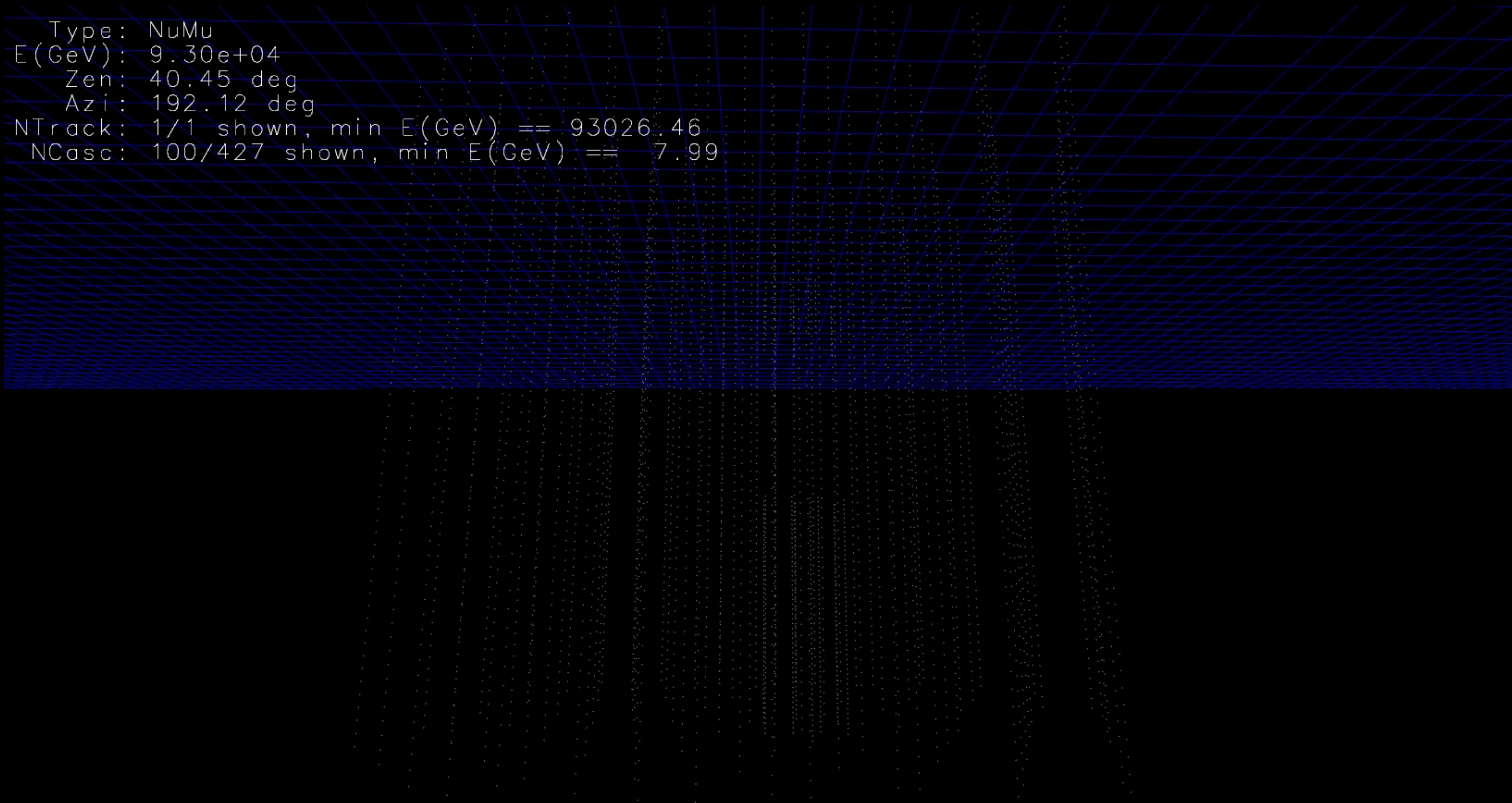
Photon Propagation (PPC, CLSim)



Direct photon propagation on GPU



Photon Propagation (PPC, CLSim)

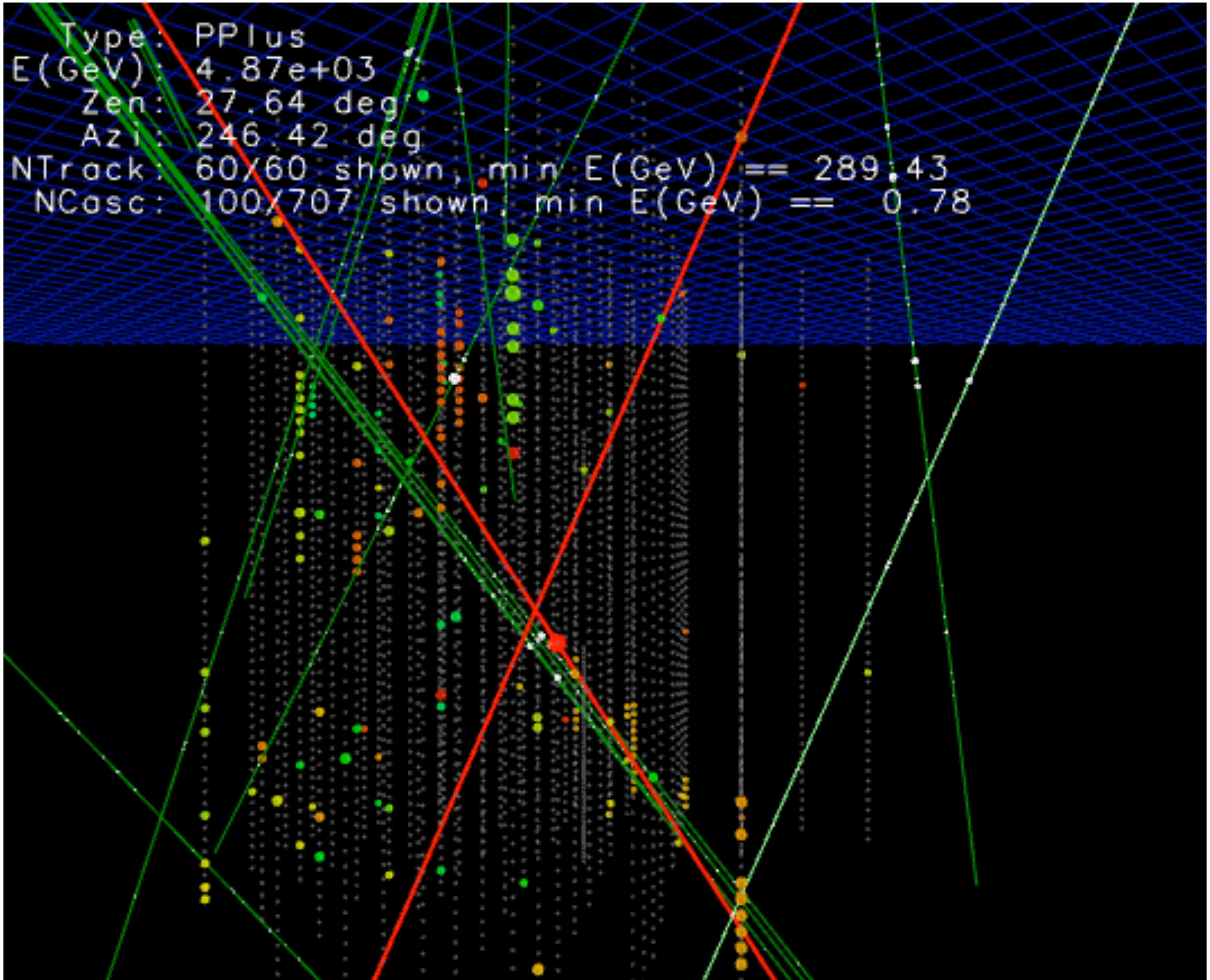


http://icecube.wisc.edu/~ckopper/muon_with_photons.mov

Polyplopia

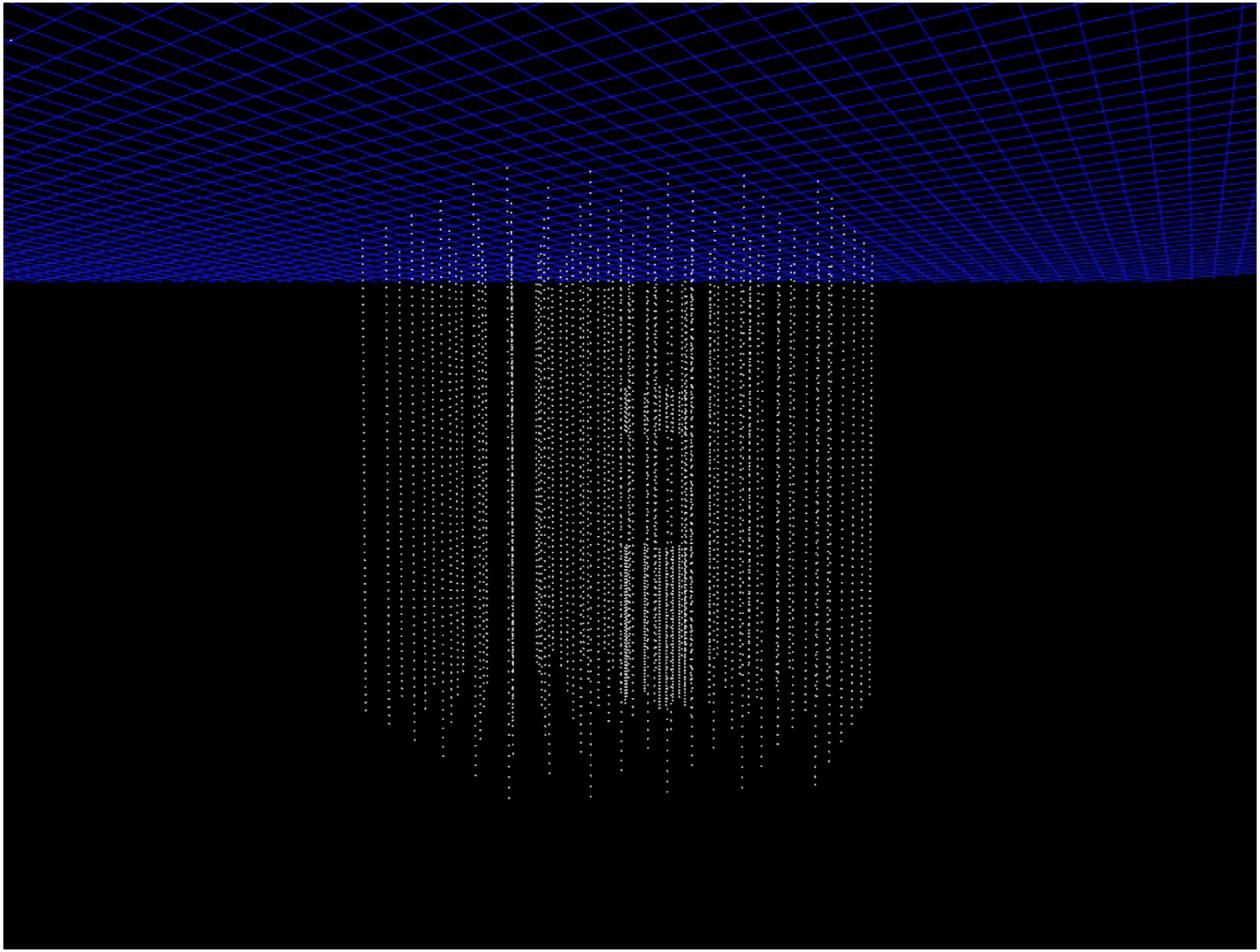
(from gr., πολύς - polús, "many,", and ὄψ-ops , "vision")

Coincident atmospheric shower events in IceCube



Polyplopia

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



http://icecube.wisc.edu/~juancarlos/video/10msec_w_noise.mp4

Polyplopia

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

Coincident atmospheric shower events in IceCube

- poly**plopia::PoissonMerger**
  - Injects background event read from a separate file on top of primary events in the chain by sampling from a Poisson distribution over a time window Δt.
  - Also makes use of a *CoincidentEventService* that could be drop-in replaced with other event services such as a MuonGun-based service.
  - Writes a separate I3MCTree with background particles.
  - Writes a combined I3MCPE map for signal and background.

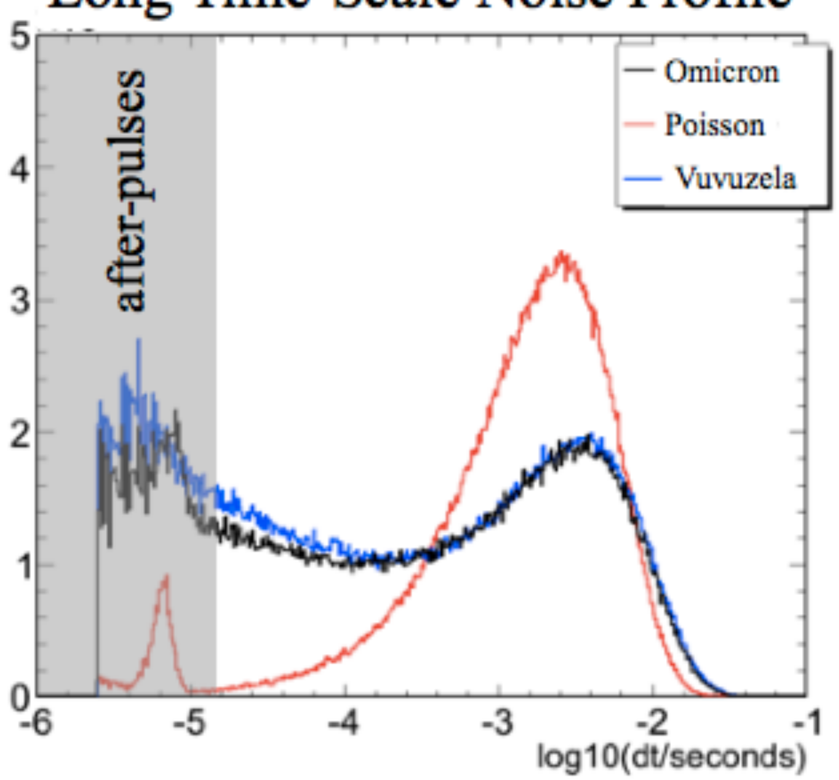
- poly**plopia::MPHitFilter**
  - Removes events that don't produce light in the detector and removes branches of I3MCTrees whose particles don't produce enough PEs in the detector,
  - Reduces the storage requirements.

- It is then up to the trigger-sim to split up Q-frames into P-frames events based on triggers.

Noise Generation

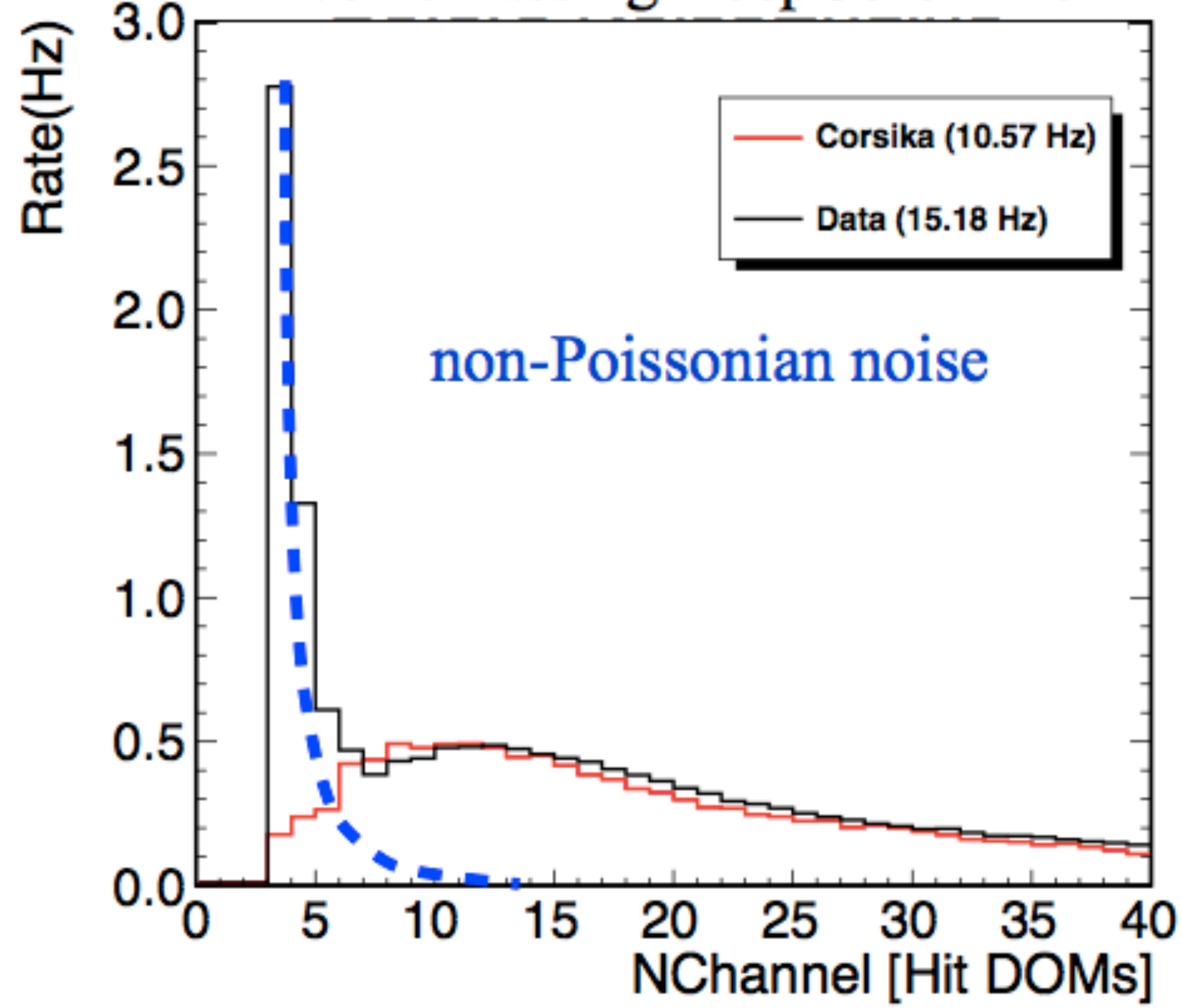
Previous simulation used simplified Poissonian model. Vuvuzela uses exponential for **thermal** and **radioactive decays** and log-normal for **scintillation**.

Long Time-Scale Noise Profile



*Courtesy of M.Larson (U.Alabama)

Events Passing DeepCore Filter



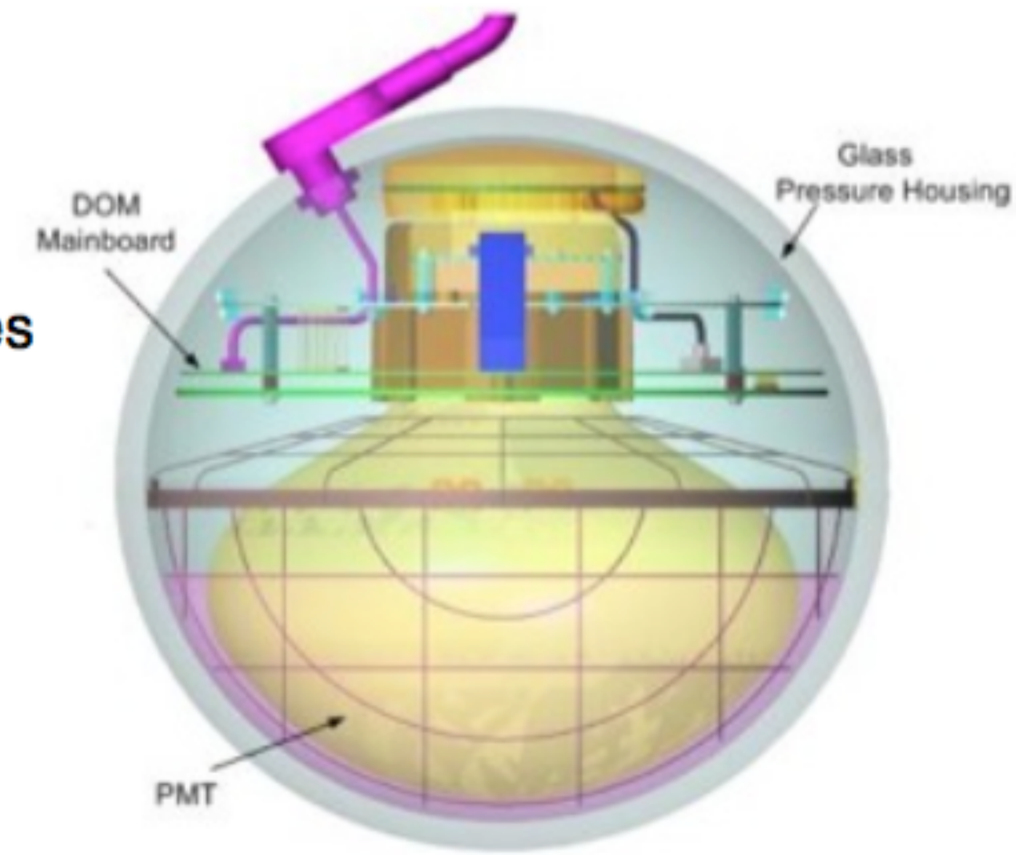
*Courtesy of J.Koskinen (PSU)

Noise Generation

—> (MCPEs)

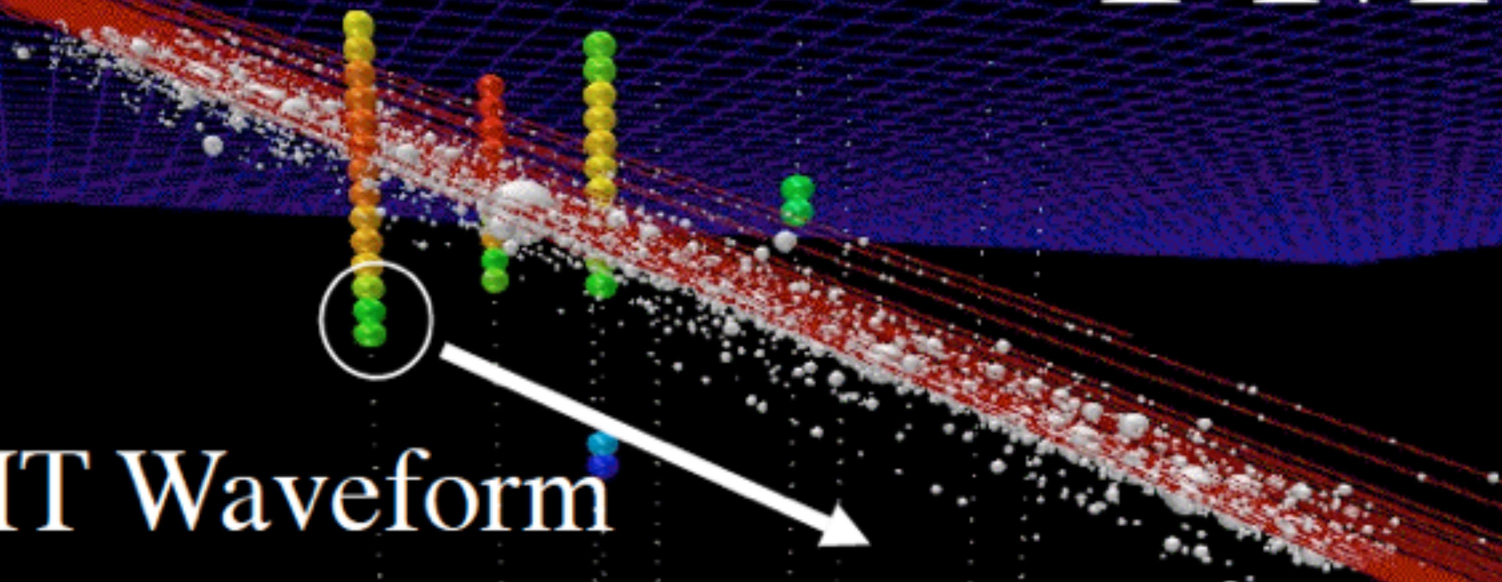
Noise Model

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



DOMLauncher::
PMTResponseSimulator

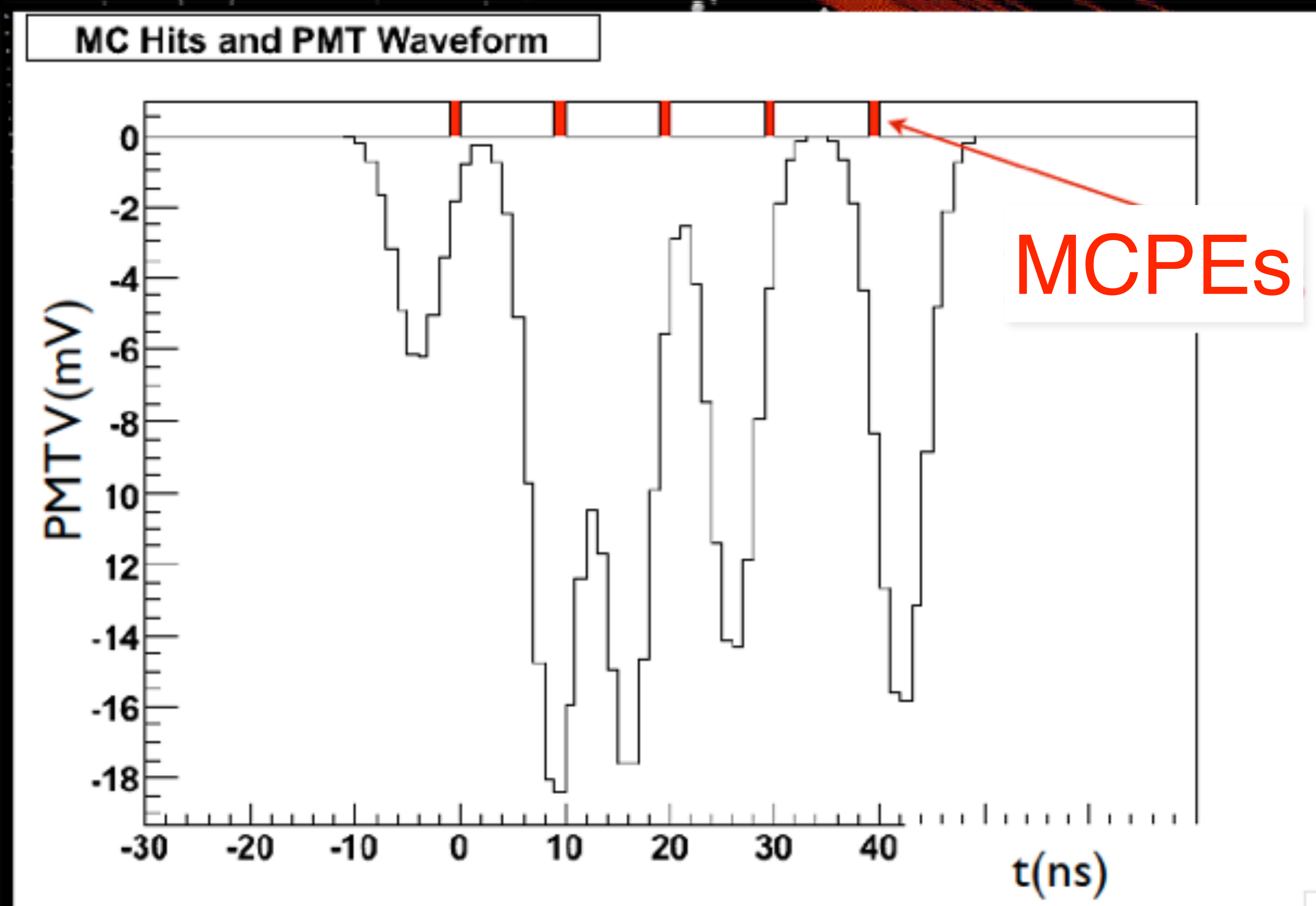
PMT



Generates PMT Waveform

From distribution of (combined) MCPEs.

Outputs I3MCPulseSeries for each DOM.

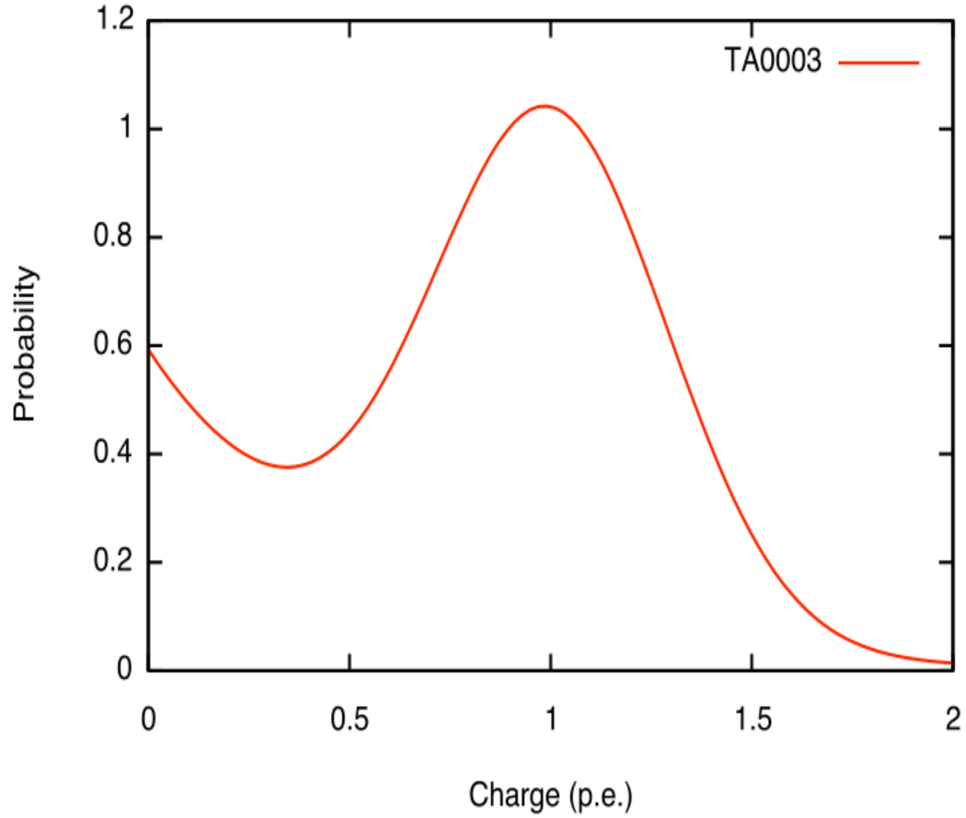


PMTResponseSimulator

Input: I3MCPEs
Output: I3MCPulses

Processing MCPEs :

- Give each MCPE 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.



Weights fromSPE Charge Distribution

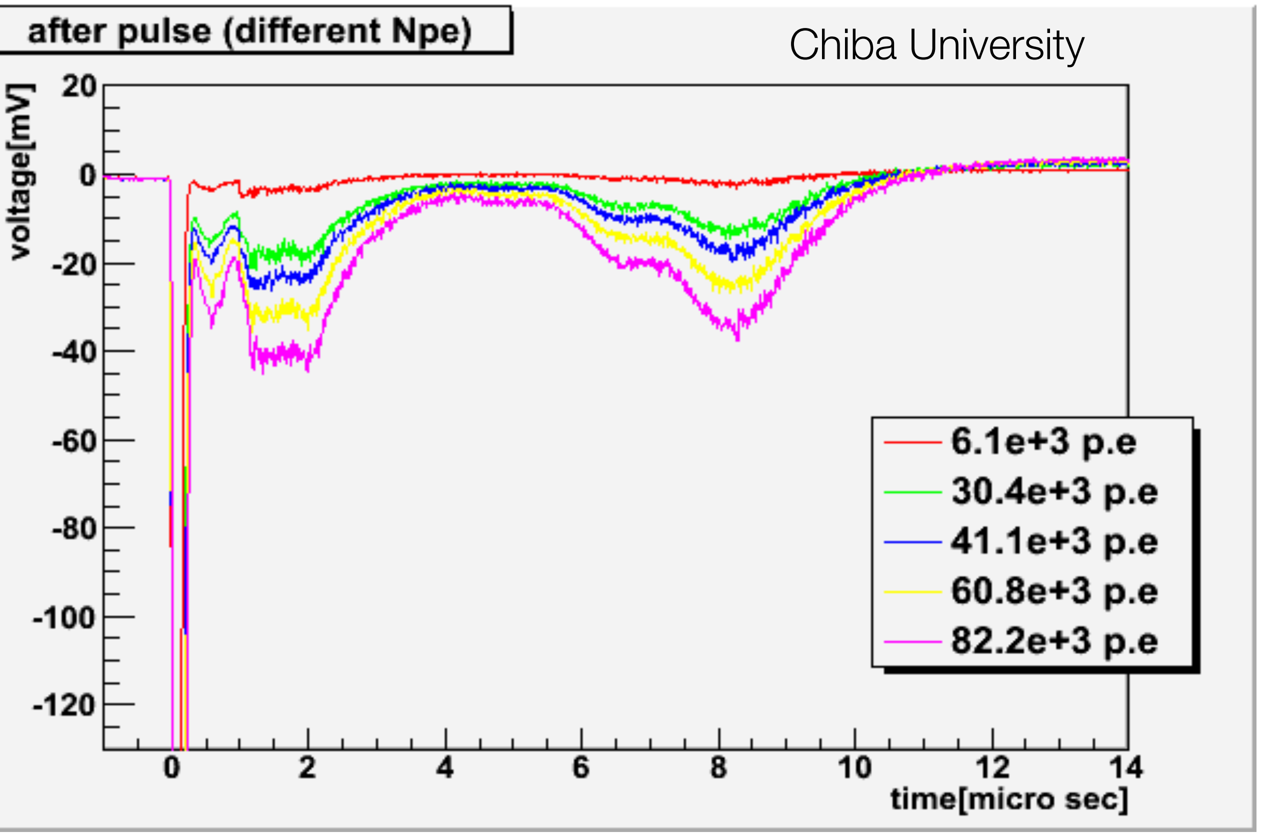
http://software.icecube.wisc.edu/documentation/projects/DOMLauncher/index.html

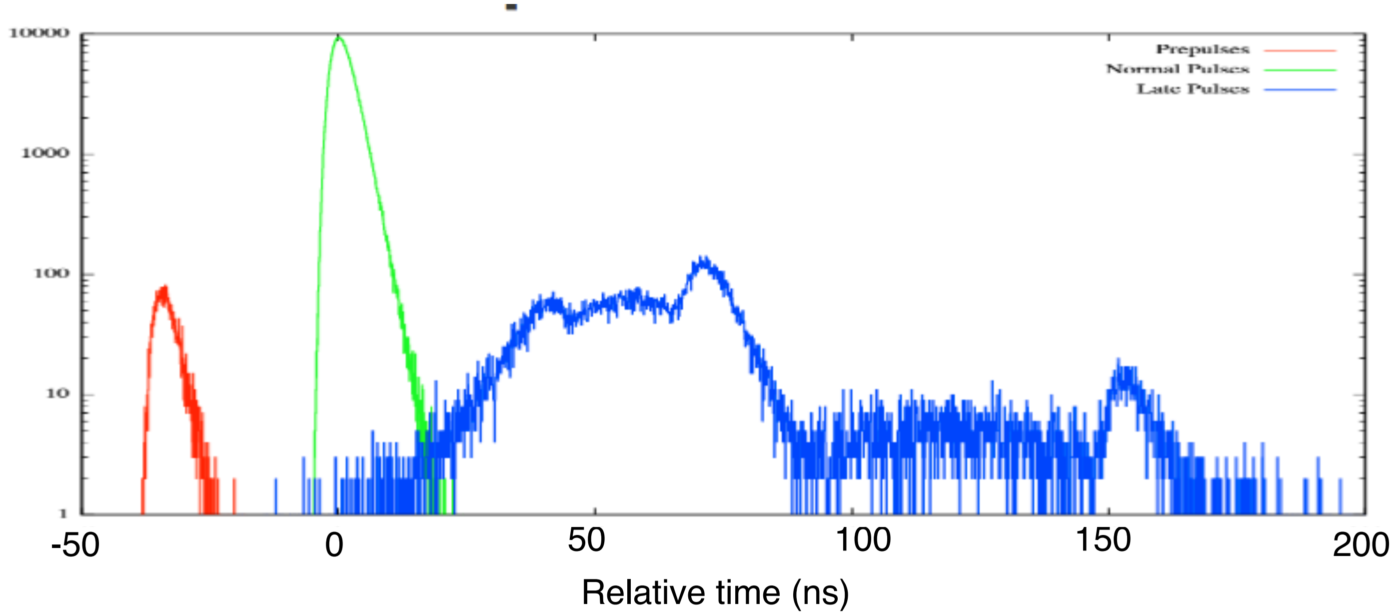
PAL pulses

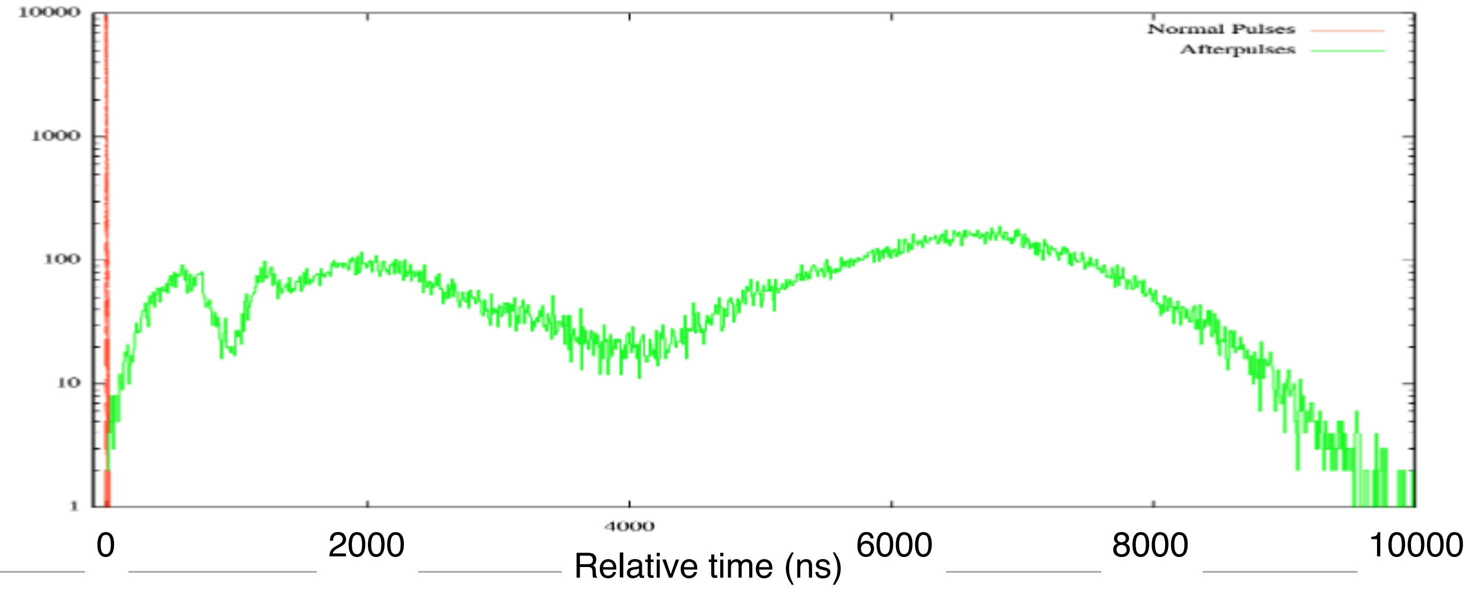
Pre-pulses: photoelectrons ejected from the first dynode,

Late pulses: electrons backscatter from dynode to cathode.

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

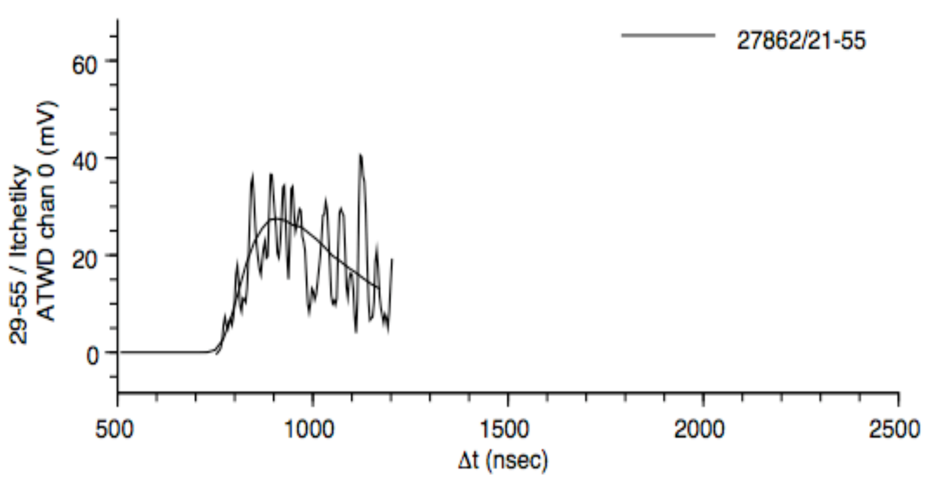


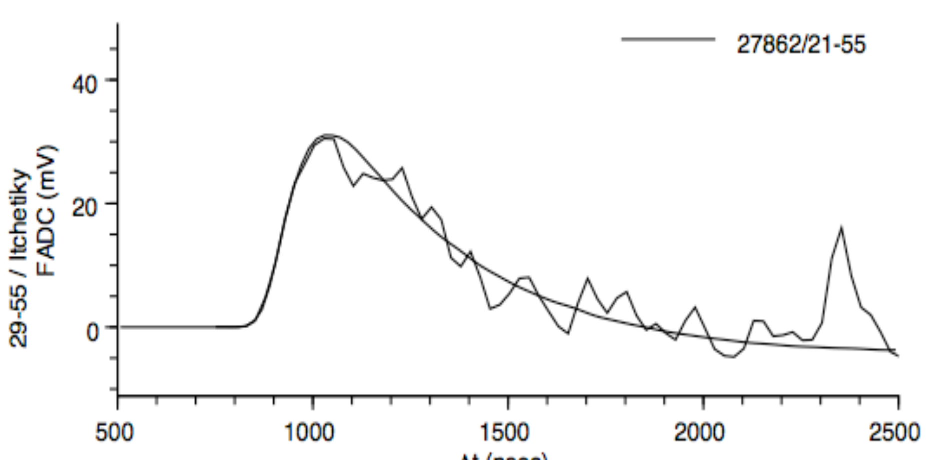


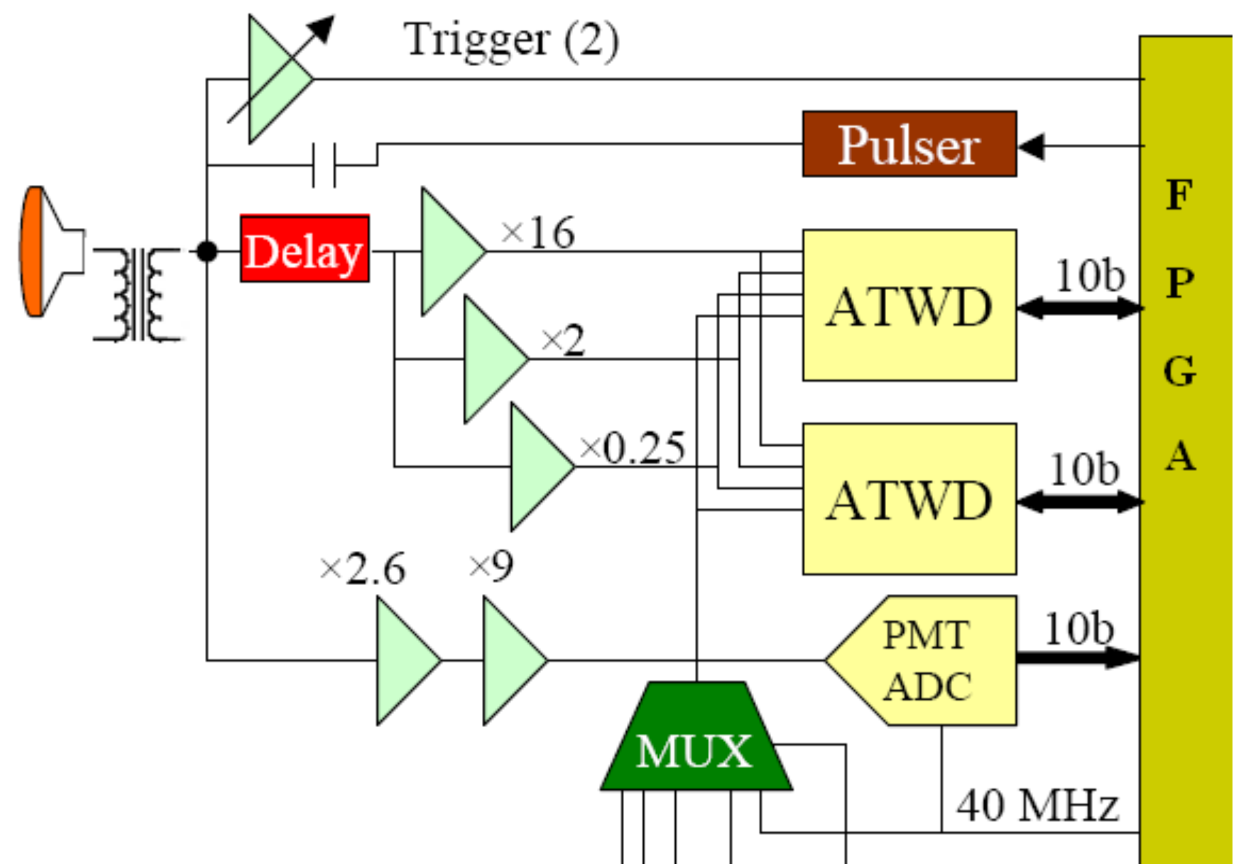


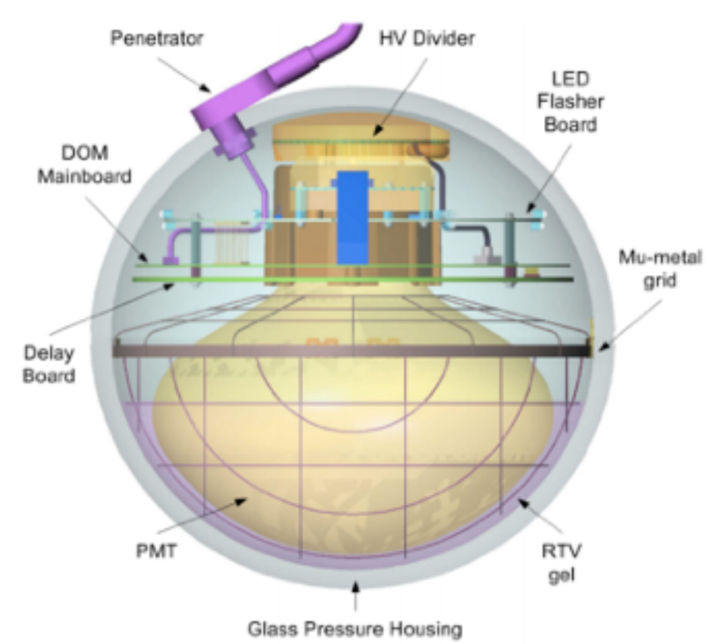
DOMLauncher: DOM mother board simulation

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



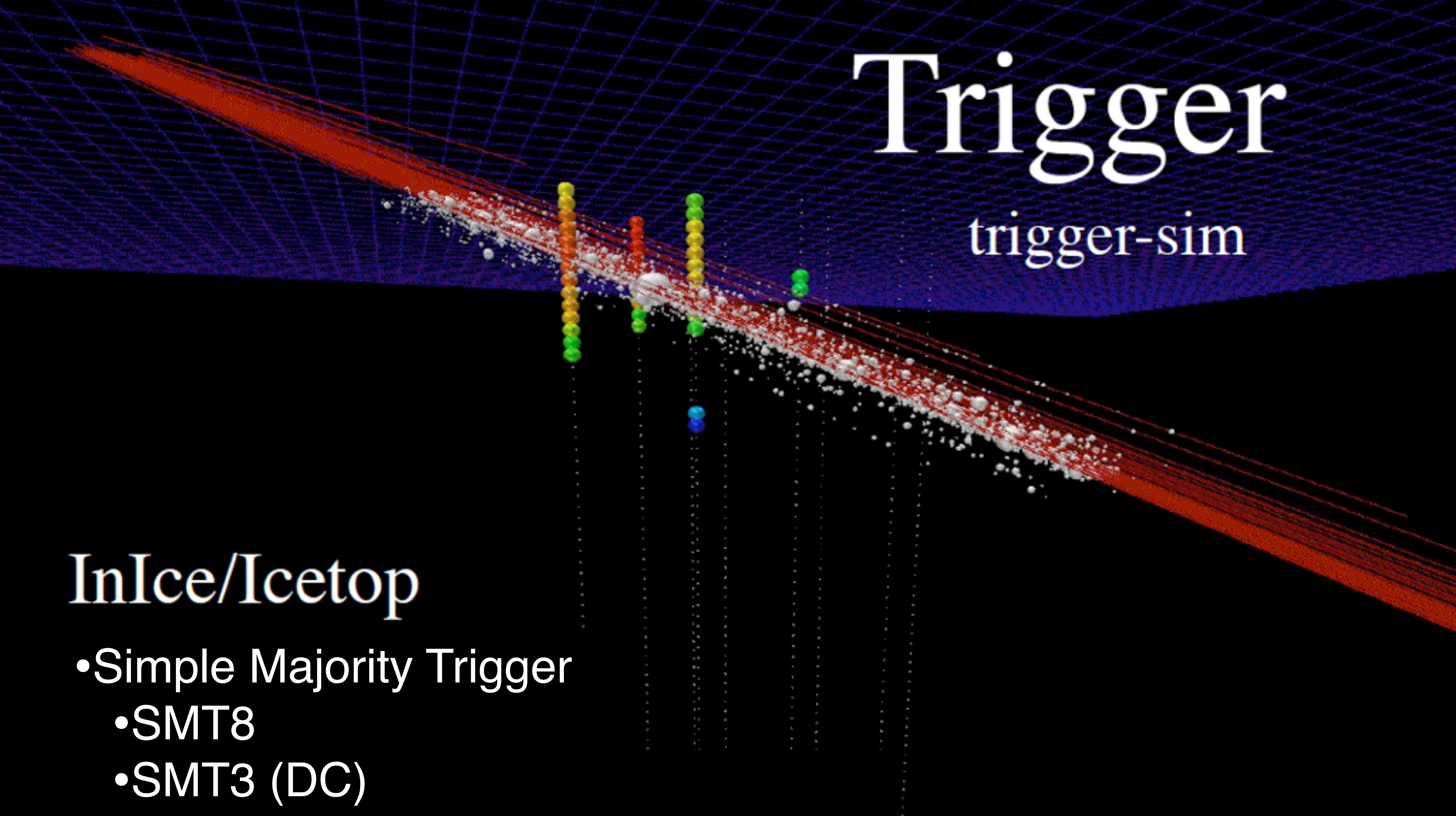






Trigger

trigger-sim



InIce/Icetop

- Simple Majority Trigger
  - SMT8
  - SMT3 (DC)
- Cluster Trigger
- Volume Trigger
- SlowMP

Global Trigger
I3TimeShifter

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

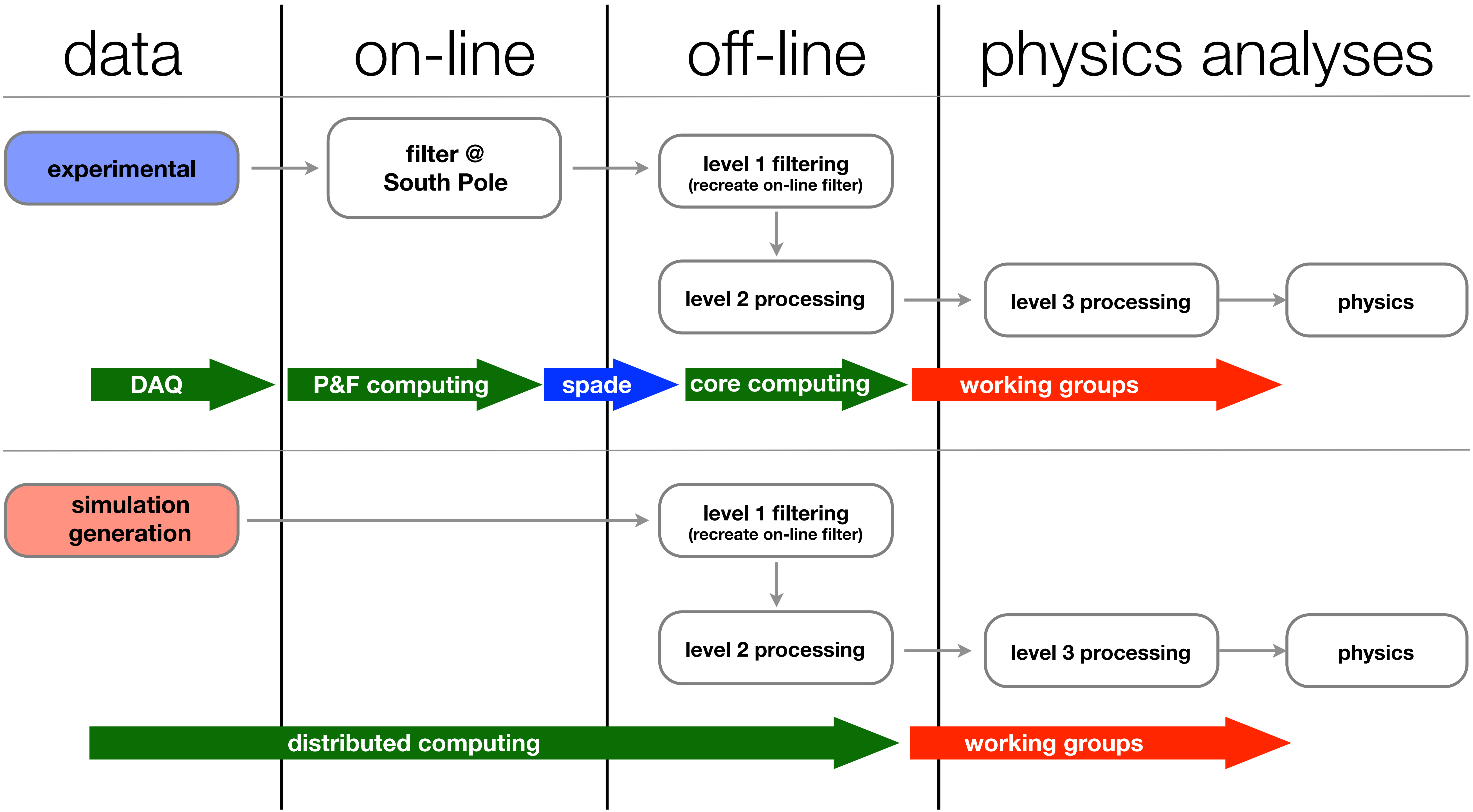
- **Volume** trigger (a.k.a Cylinder trigger in DAQ-land)
  - simple majority of HLC hits (SMT4) with volume element including one layer of strings around a center string
  - cylinder height is 5 DOM-layers (2 up and down from the selected DOM).

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

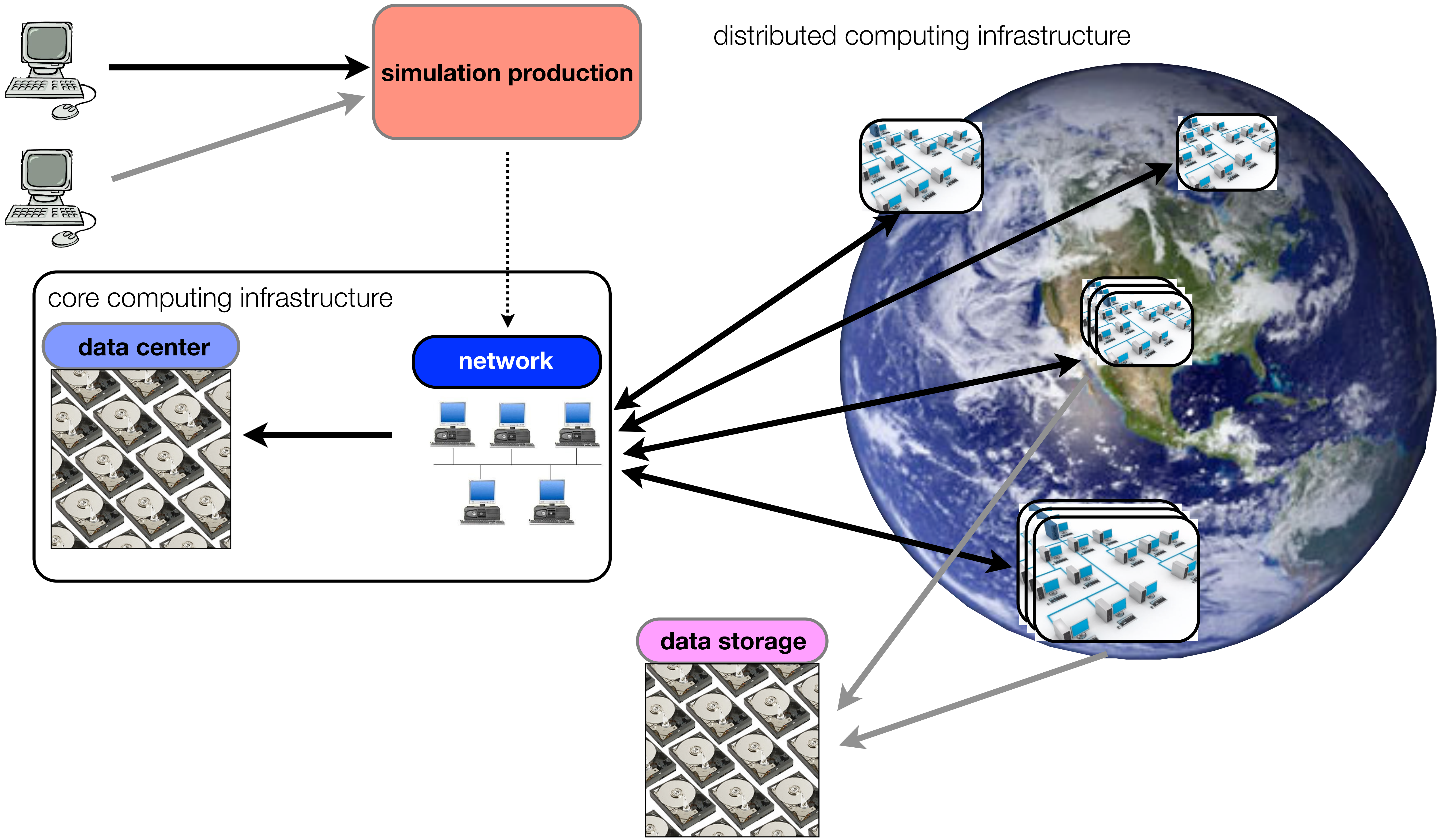
- ~~**F**ixed **Rat**e **t**rigger~~, **Min**imum **Bias** trigger, ~~**Calibration** trigger~~

J. Kelley - DAQ

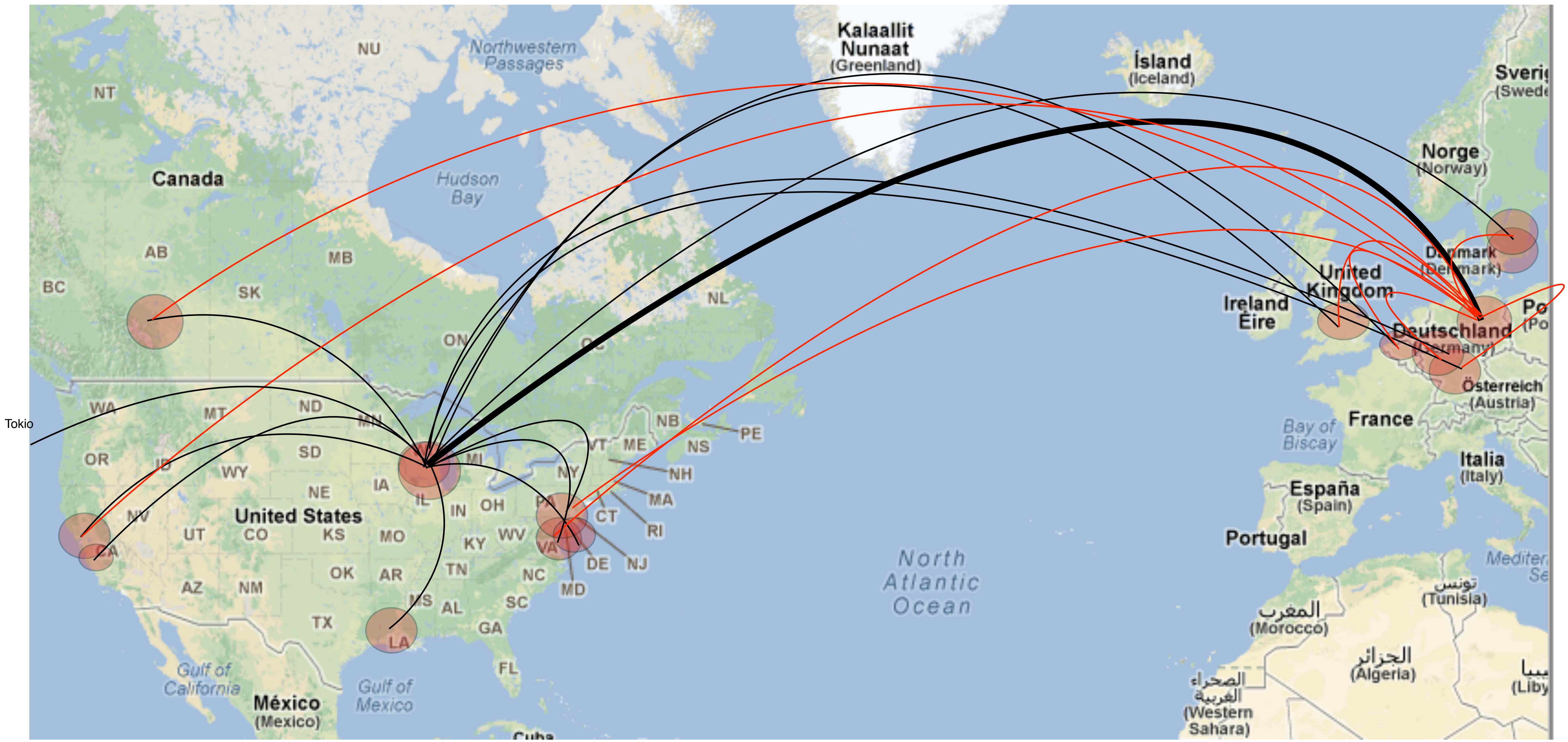
flow of experimental and simulation data



Simulation Production



IceCube Computing Resources



More on simulation

1. http://wiki.icecube.wisc.edu/index.php/Simulation_Documentation_Wiki

2. Weighting tutorial (K. Jero): https://events.icecube.wisc.edu/getFile.py/access?contribId=4&sessionId=11&resId=0&materialId=slides&confId=77

3.http://wiki.icecube.wisc.edu/index.php/IceCuber's_Guide_to_IceSim_2.6

4. http://wiki.icecube.wisc.edu/index.php/Simulation_Production

5.http://internal.icecube.wisc.edu/simulation/datasets/dataset_category/PHYSICS

6.IRC @ irc.efnet.net: /join #icesim