Intro to
IceCube Simulations

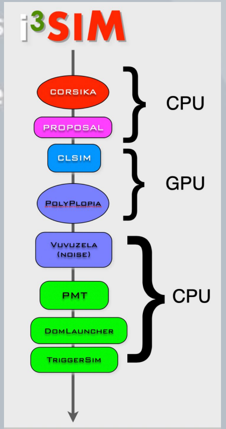
Presenter: Maxwell Nakos

Slides by: Juan Carlos Díaz-Vélez

IceCube Summer School

Madison, WI

June 4, 2026



Monte Carlo Simulations

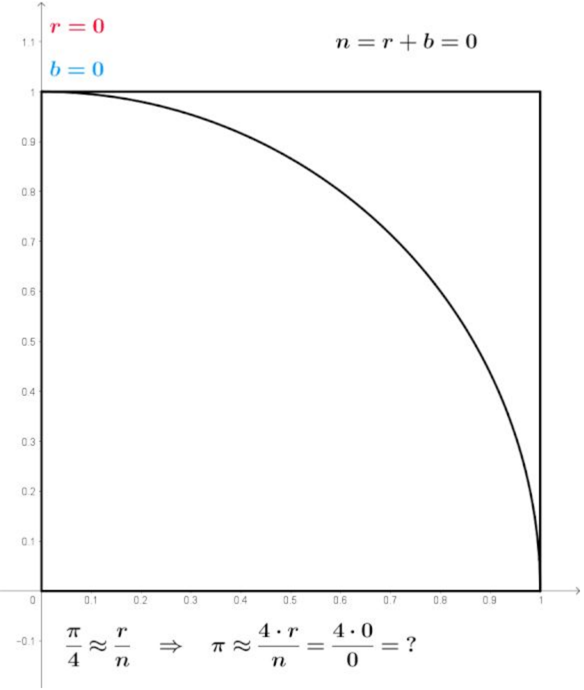
Monte Carlo methods vary, but tend to follow a particular pattern:

1. Define a domain of possible inputs
2. Generate inputs randomly from a probability distribution over the domain
3. Perform a deterministic computation of the outputs
4. Aggregate the results

Example: Monte Carlo method applied to approximating the value of π

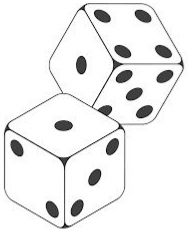
Consider a quadrant (circular sector) inscribed in a unit square. Given that the ratio of their areas is $\pi/4$, the value of π can be approximated using a Monte Carlo method:

1. Draw a square, then inscribe a quadrant within it
2. Uniformly scatter a given number of points over the square
3. Count the number of points inside the quadrant, i.e. having a distance from the origin of less than 1
4. The ratio of the inside-count and the total-sample-count is an estimate of the ratio of the two areas, $\pi/4$. Multiply the result by 4 to estimate π.

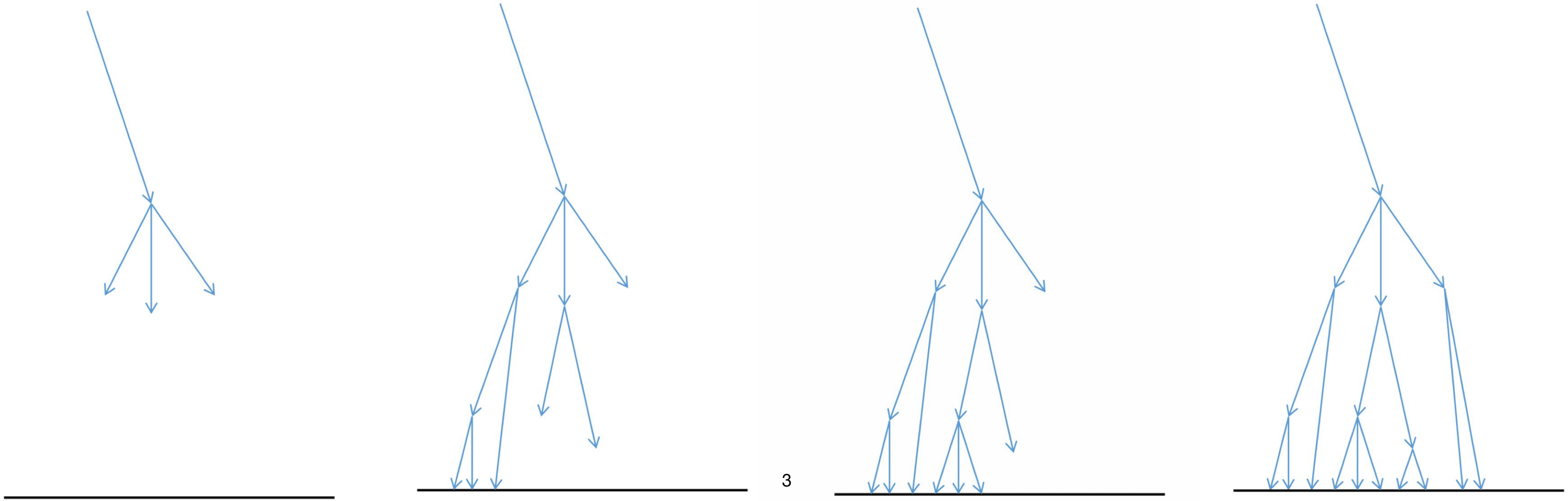


source:https://en.wikipedia.org/wiki/Monte_Carlo_method

Monte Carlo Simulations: Cosmic-Ray Showers

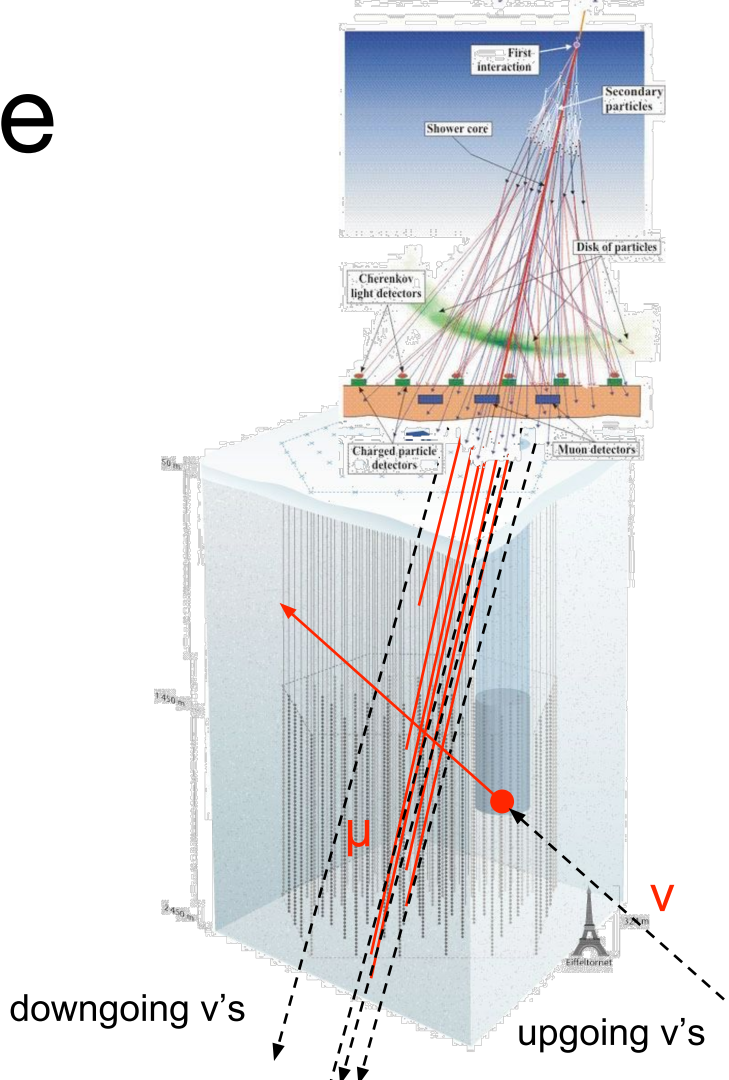


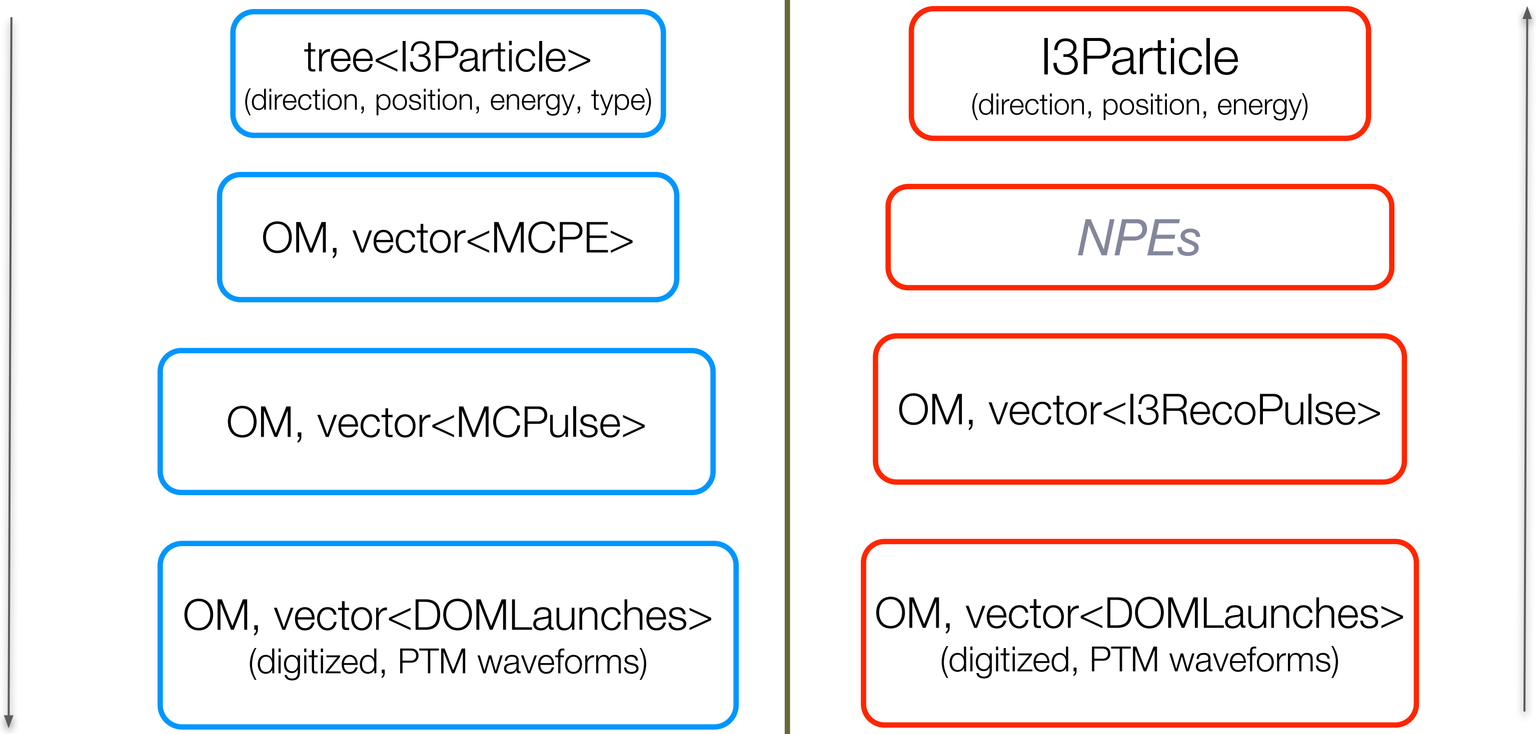
- Propagate through step calculate probability of interaction from probability distribution
- Choose interaction from distribution
- Repeat process for each of the interaction (decay products)



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





Simulation

tree<I3Particle>
(direction, position, energy, type)

OM, vector<MCPE>

OM, vector<MCPulse>

OM, vector<DOMLaunches>
(digitized, PTM waveforms)

Reconstruction

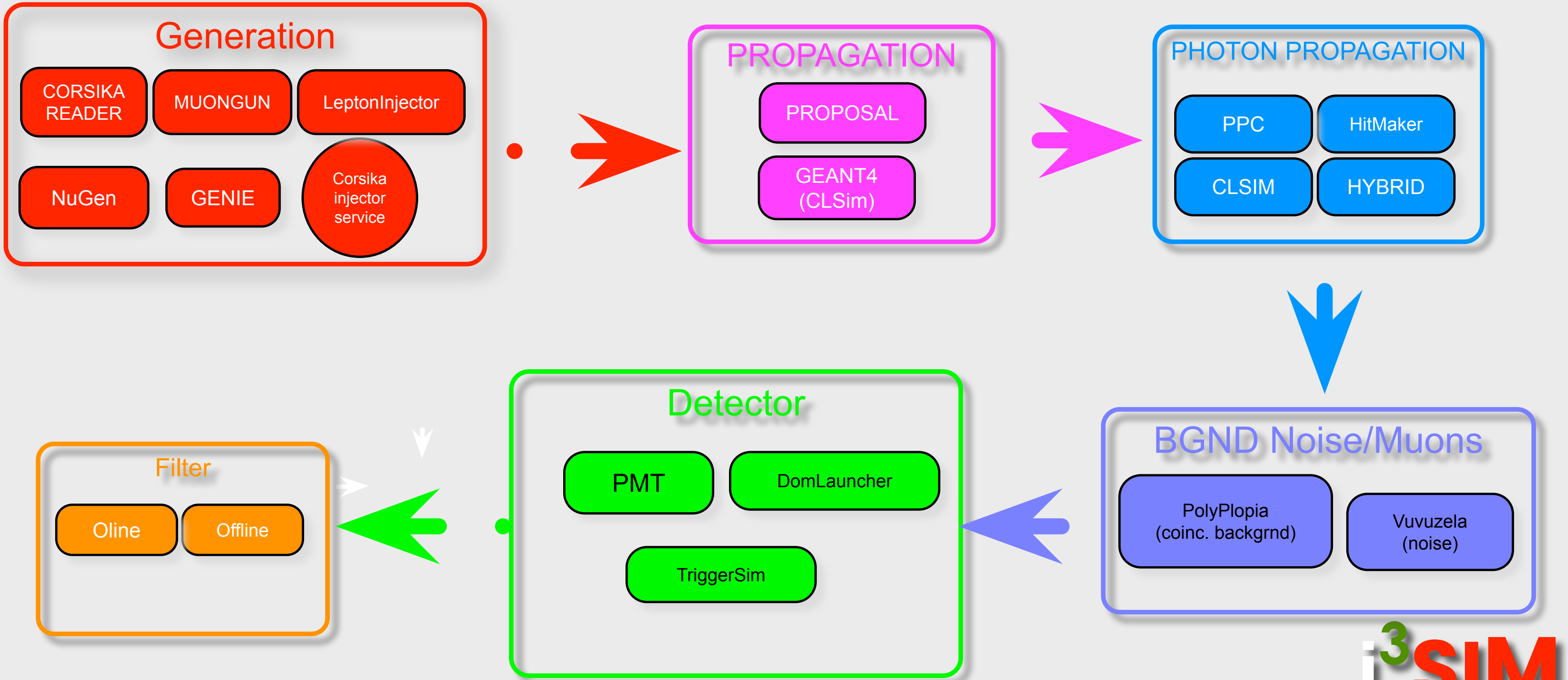
I3Particle
(direction, position, energy)

NPEs

OM, vector<I3RecoPulse>

OM, vector<DOMLaunches>
(digitized, PTM waveforms)

Simulation Chain



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

Filter

Oline

Offline

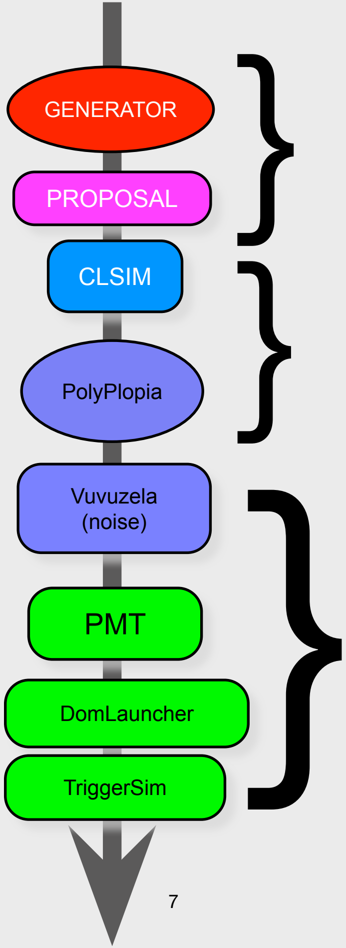
i³SIM

The Simulation Shish Kabob

(Computing Resource Optimization)

i3SIM

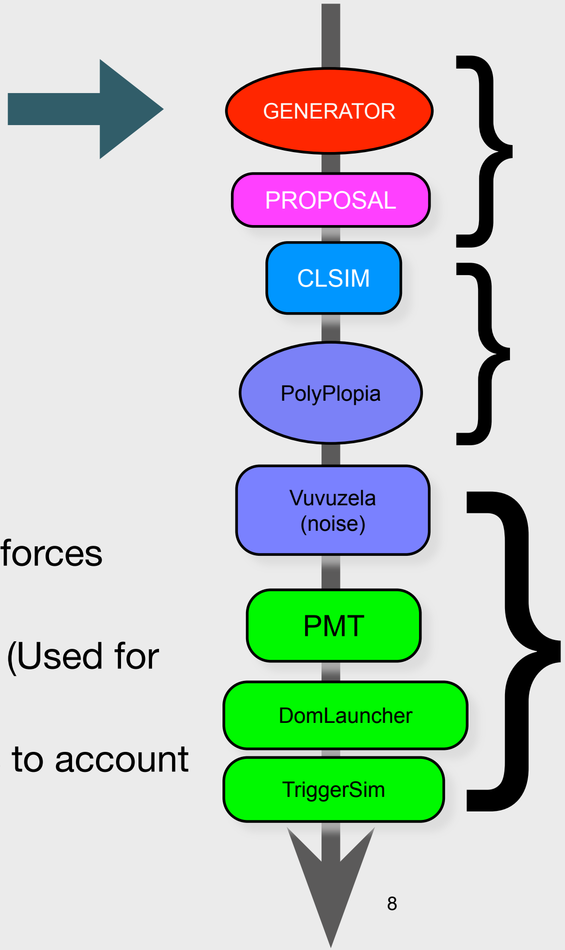
- Optimizing the shish kabob:
  - Different parts of the simulation chain have different resource requirements.
    - CORSIKA is CPU-intensive and requires little RAM
    - Photon propagation run almost exclusively on GPUs
    - Detector simulation is CPU bound and requires more memory.
- Things to keep 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

i^{3}SIM

- 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.



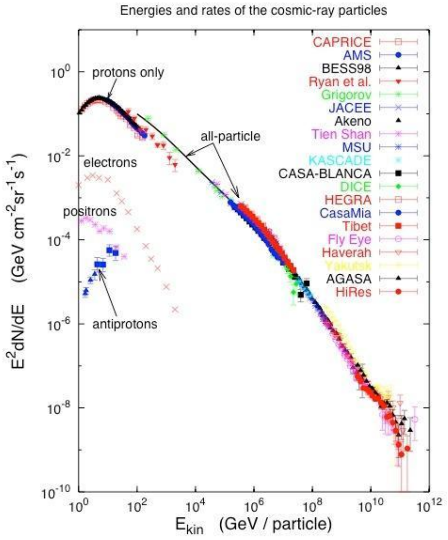
Generators : CORSIKA

(**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

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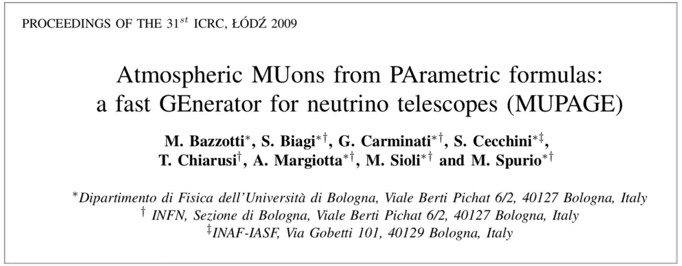
[1] Institut für Experimentelle Kernphysik, Universität Karlsruhe, D-76021 Karlsruhe, Germany

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

MuonGun (IceCube implementation of MUPAGE)

- 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)

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T. Chiarusi†, A. Margiotta*†, M. Sioli*† and M. Spurio*†

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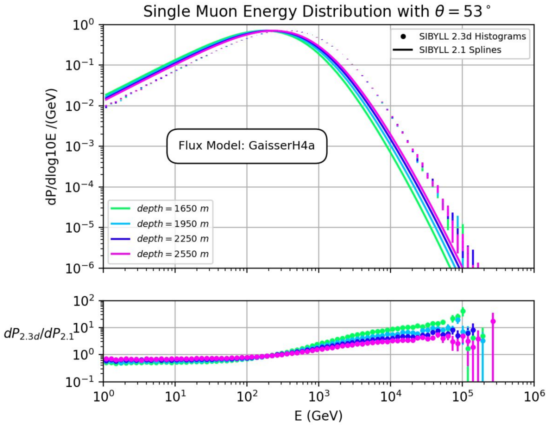
arXiv:0907.5563v1 [astro-ph.IM] 31 Jul 2009



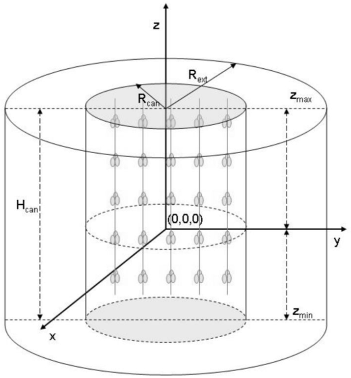
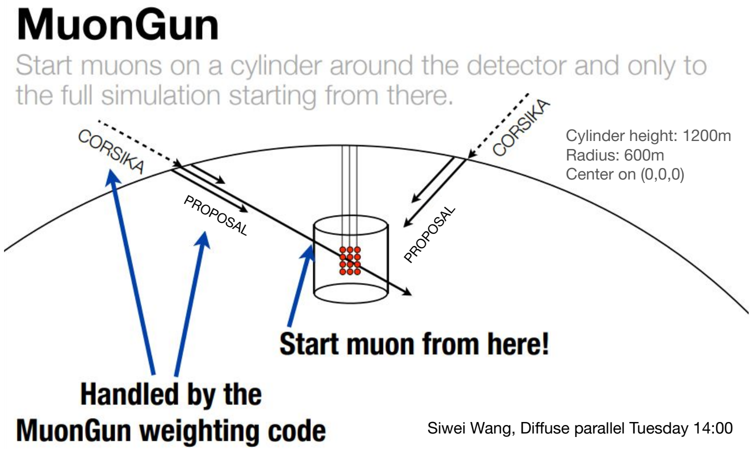


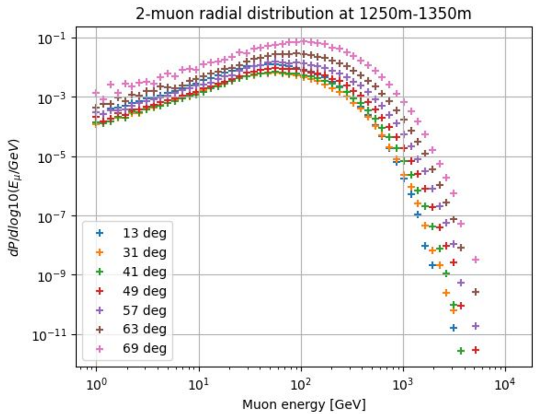
Fig. 1: Sketch of some input parameters. The cylinder surrounding the instrumental volume is the *can*, with radius R_{can} and height H_{can}. The events are generated on an extended can with R_{ext}. The origin of the coordinate system does not have to be located at the center of the detector. The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



MuonGun

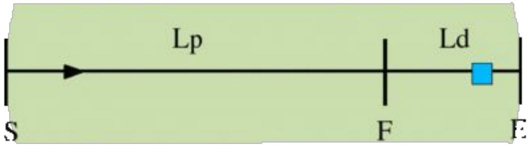
Start muons on a cylinder around the detector and only to the full simulation starting from there.

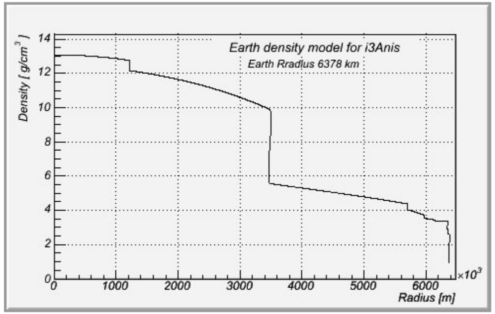
Siwei Wang, Diffuse parallel Tuesday 14:00



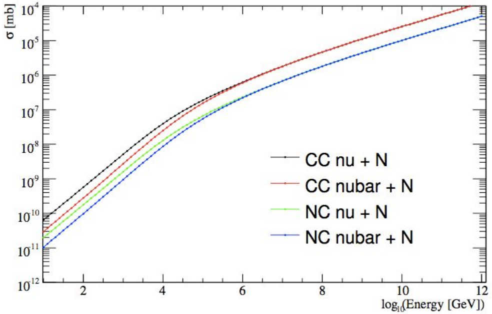
neutrino-generator

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

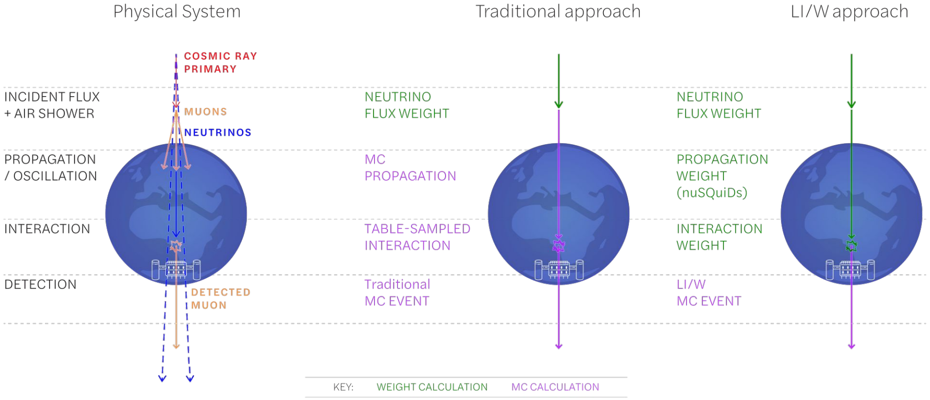
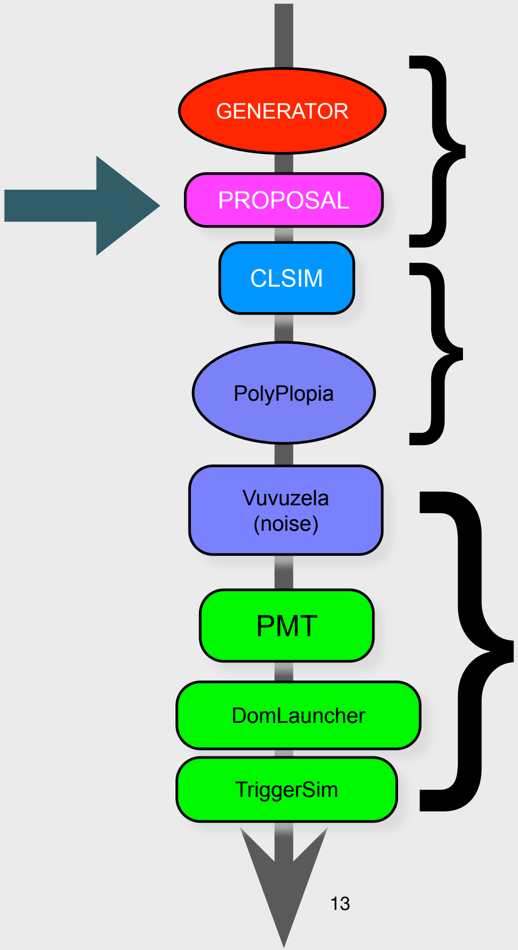


Figure 1.1: A diagram illustrating the different event generation and weighting steps for traditional methods compared with the `LeptonInjector` and `LeptonWeighter` philosophy.

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).

i^{3}SIM

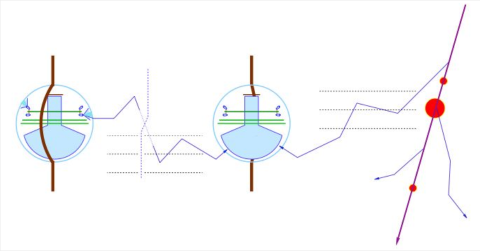


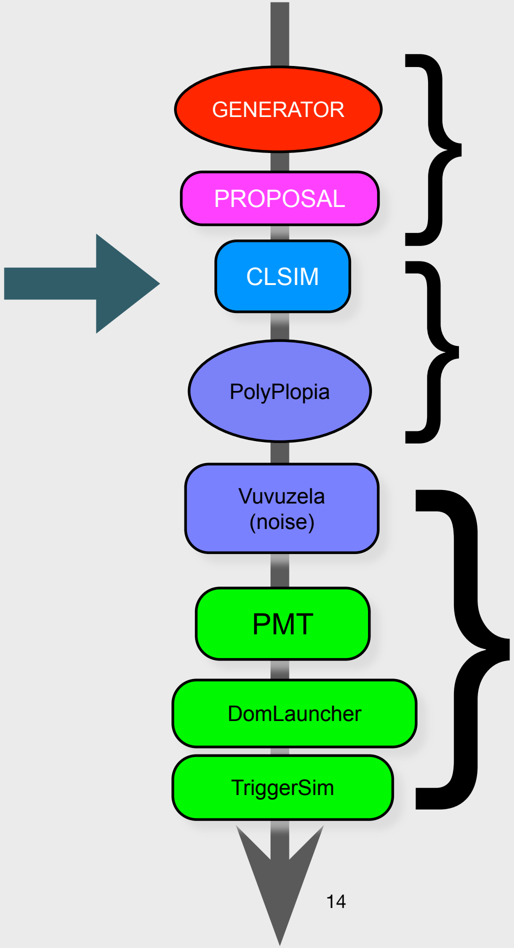
Photon Propagation (PPC, CLSim)

i^{3}SIM

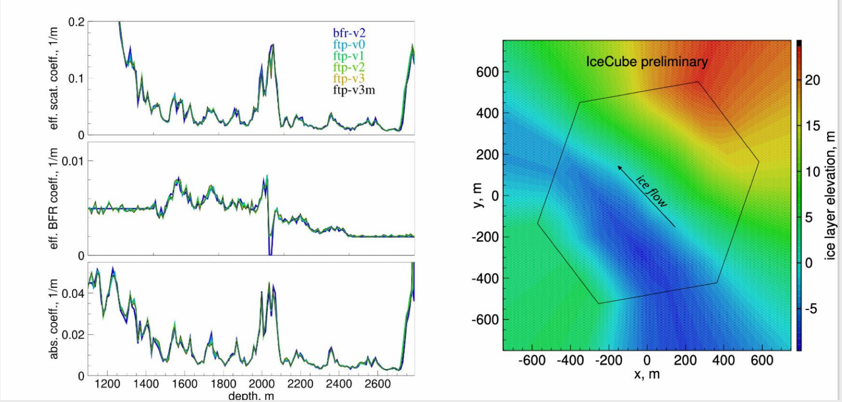
μ energy loss + cascades ➙ photons ➙ p.e.

Photon propagation : ice properties + PMT response + DOM glass/gel

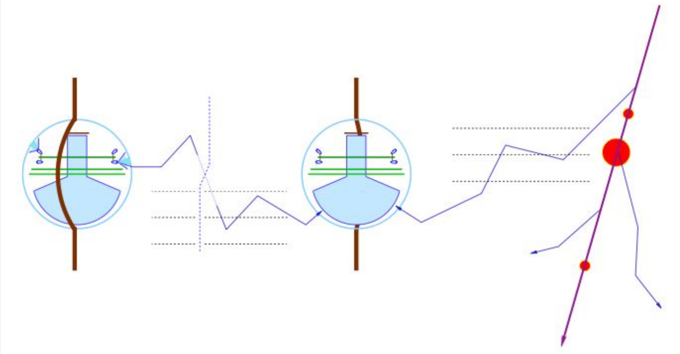


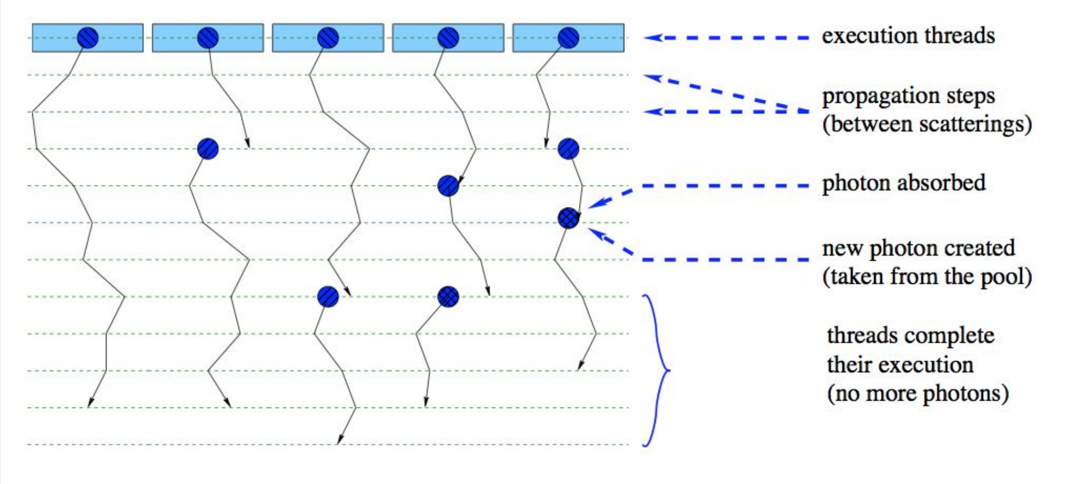


IceModel

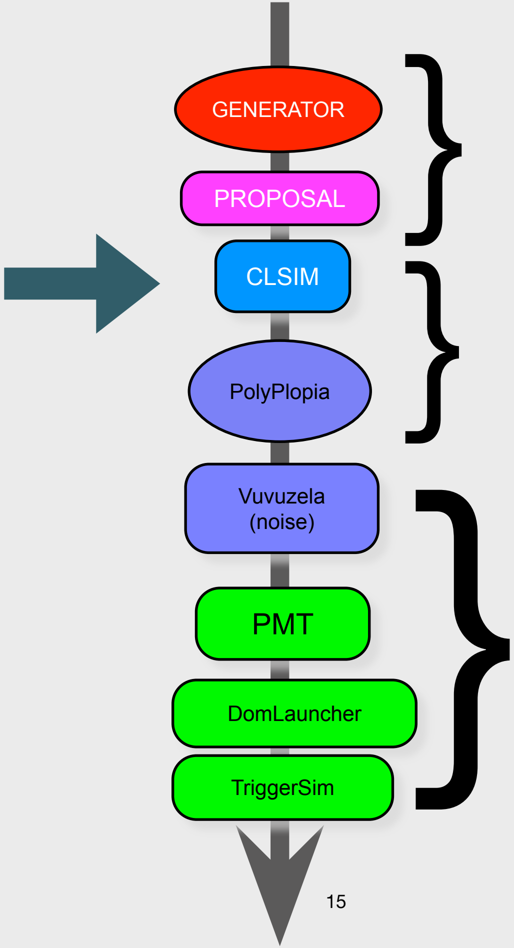


Photon Propagation (PPC, CLSim)





i3SIM



GENERATOR

PROPOSAL

CLSIM

PolyPlopia

Vuvuzela
(noise)

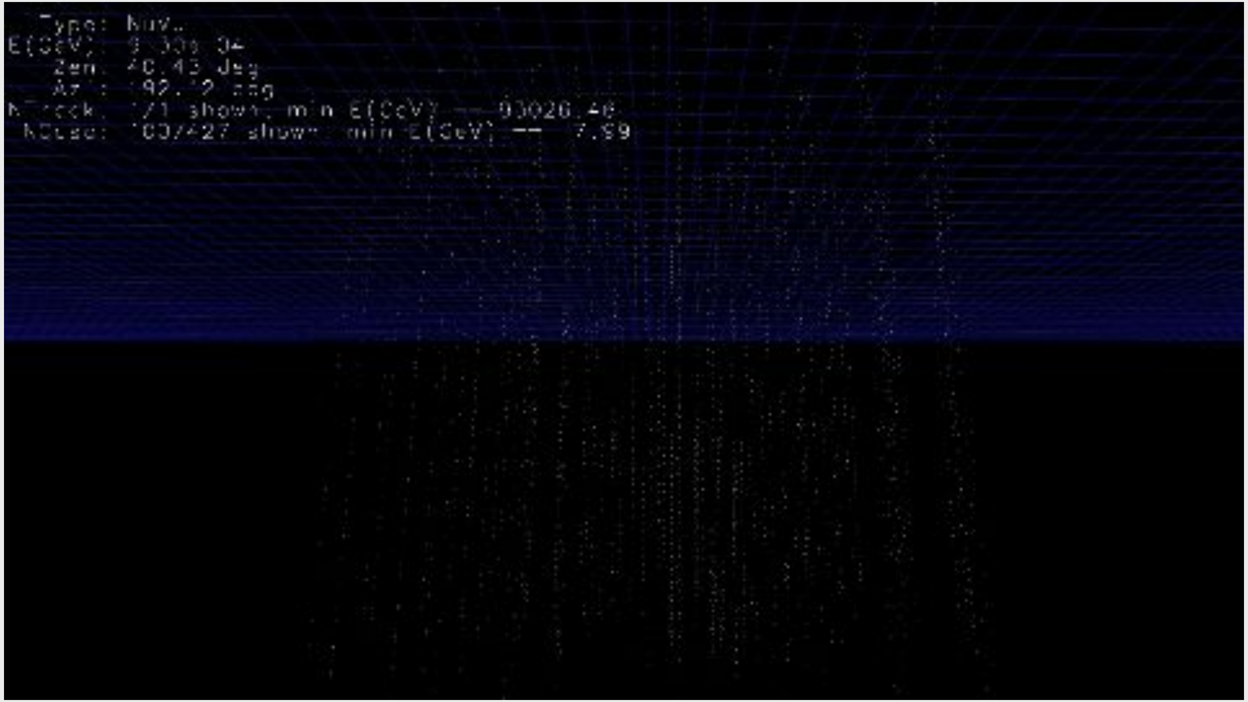
PMT

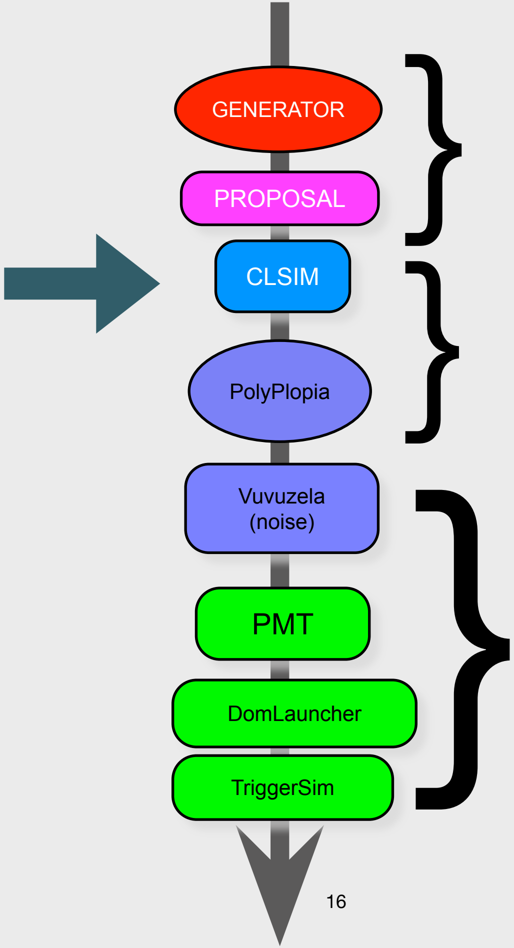
DomLauncher

TriggerSim

Photon Propagation (PPC, CLSim)

i^{3}SIM





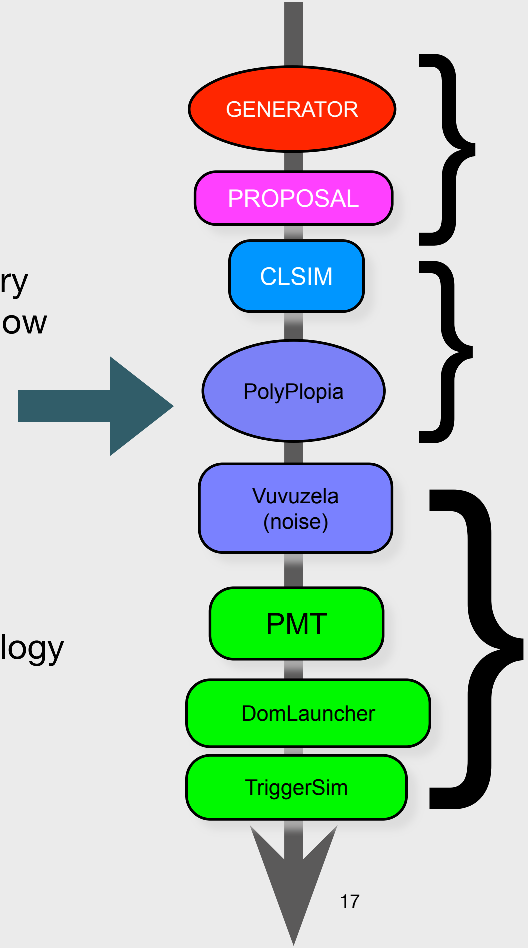
Polyplopia

(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.
- Q-frames are later split into P-frames by trigger-splitter based on timing, topology

i3SIM



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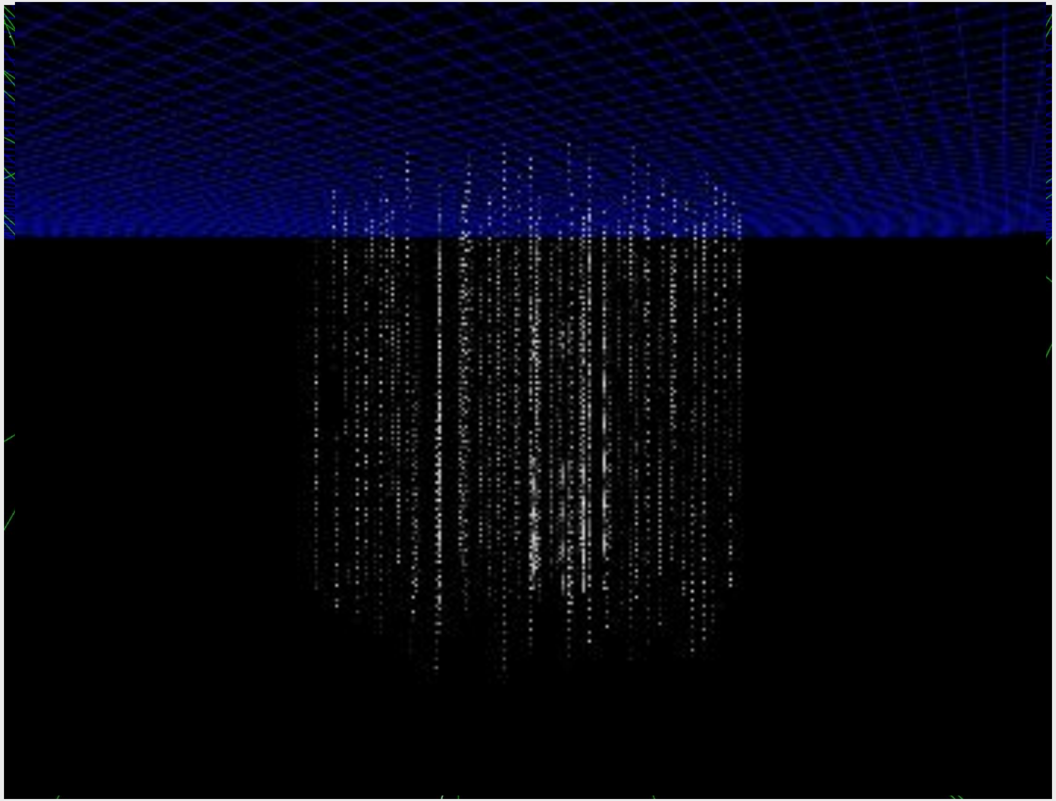
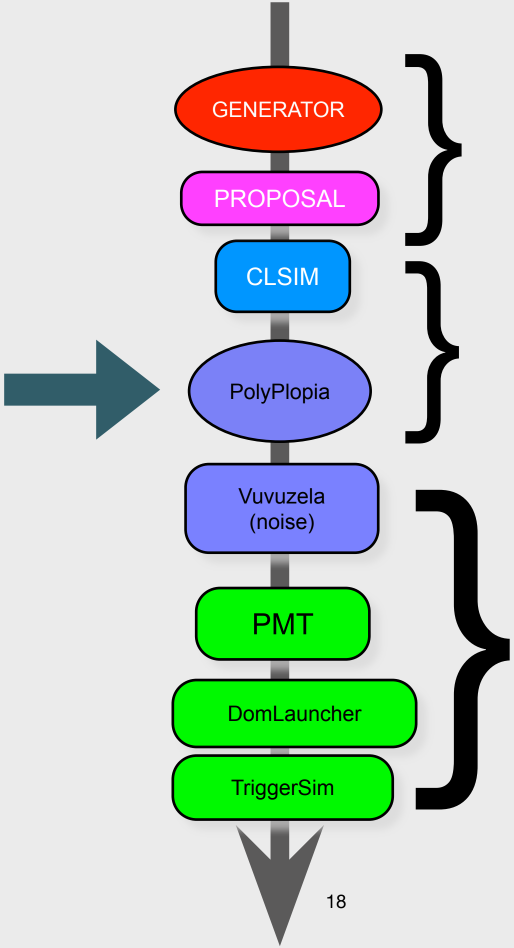


i3SIM



GENERATOR

PROPOSAL

CLSIM

PolyPlopia

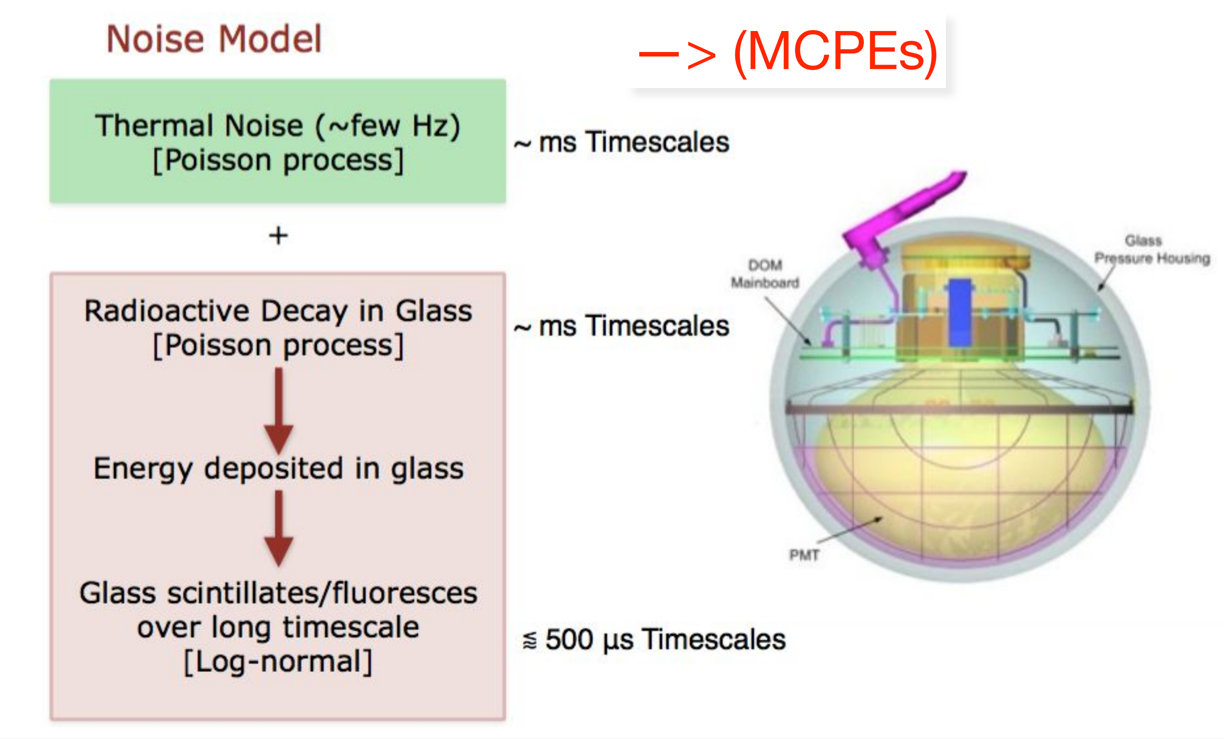
Vuvuzela (noise)

PMT

DomLauncher

TriggerSim

Vuvuzela (Noise)



Noise Model

—> (MCPEs)

Thermal Noise (~few Hz)
[Poisson process]

~ ms Timescales

+

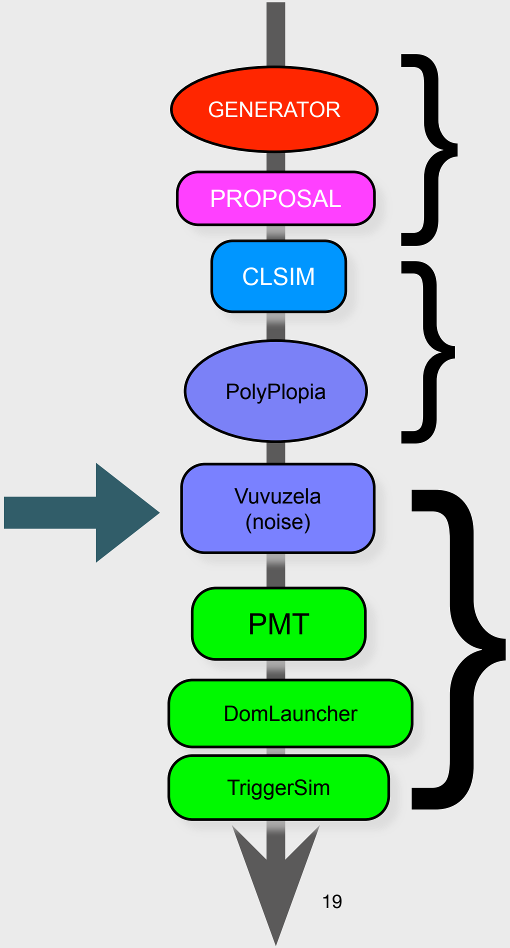
Radioactive Decay in Glass
[Poisson process]

~ ms Timescales

Energy deposited in glass

Glass scintillates/fluoresces
over long timescale
[Log-normal]

≲ 500 µs Timescales



GENERATOR

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Vuvuzela
(noise)

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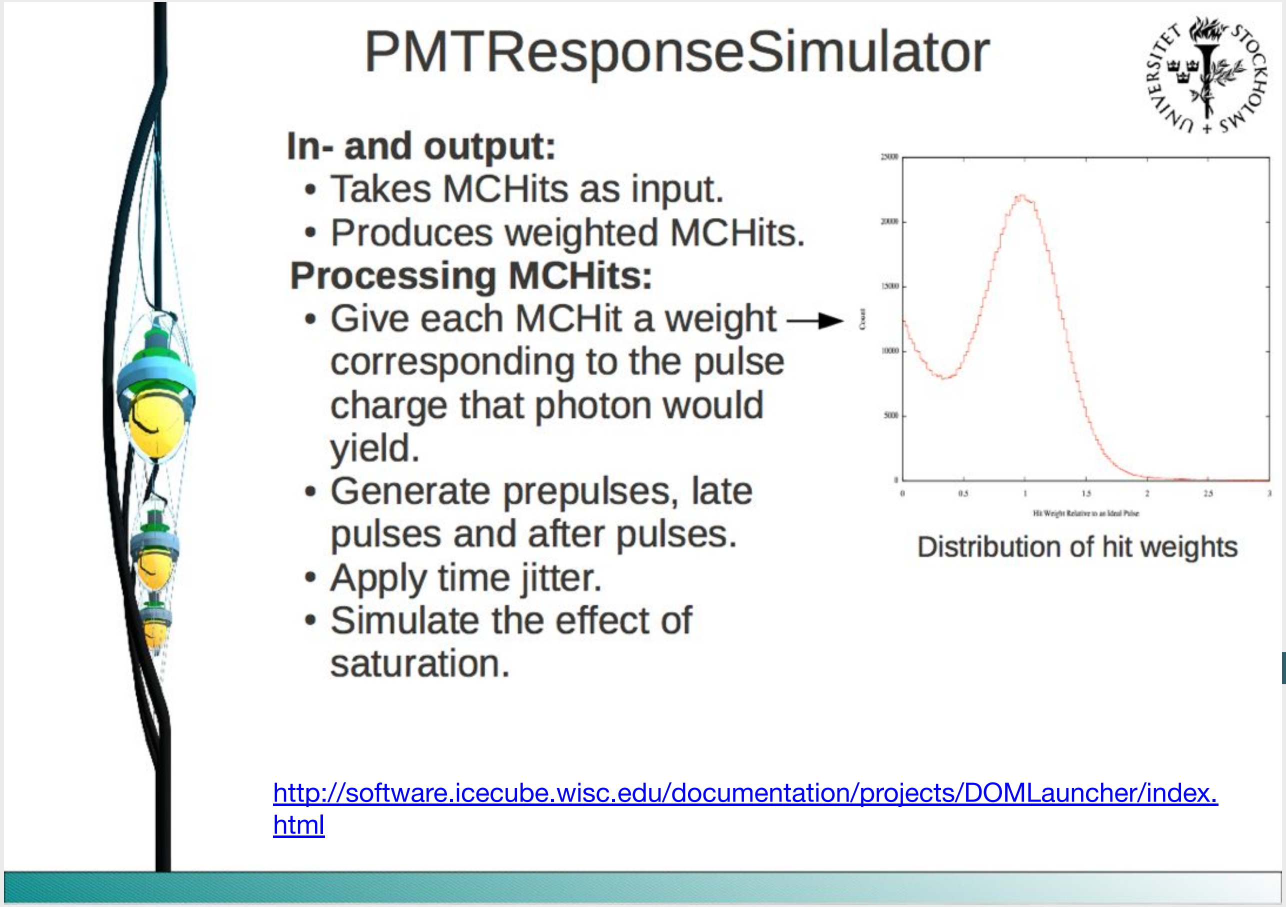
i^{3}SIM



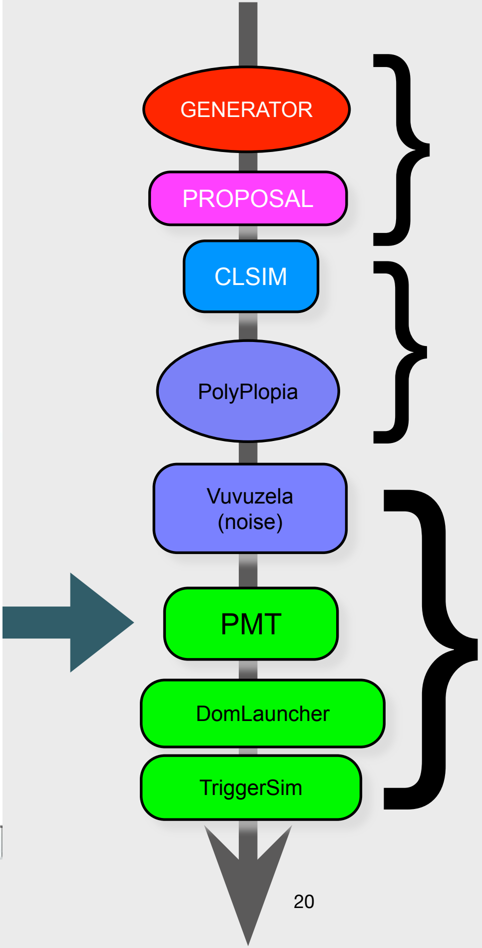
PMTResponseSimulator

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



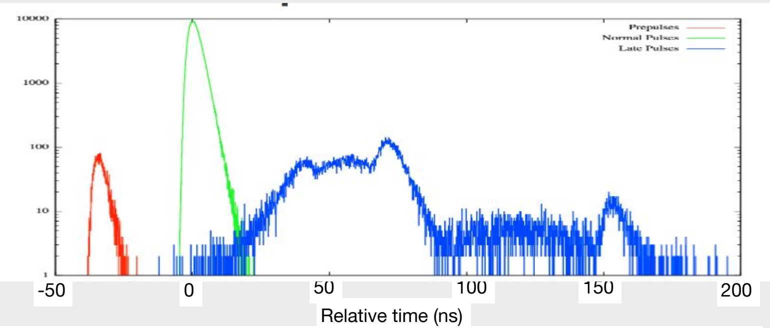
PMT Simulation

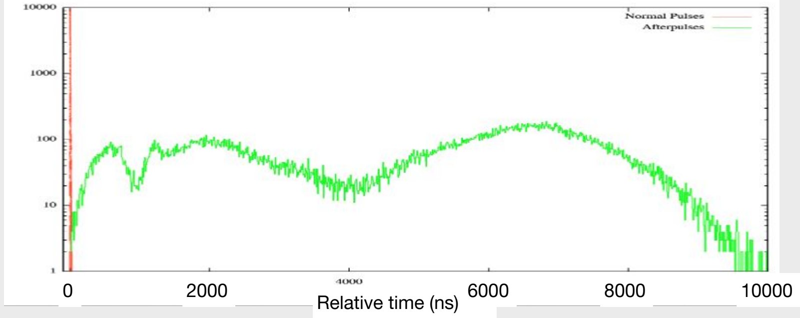
i^3SIM

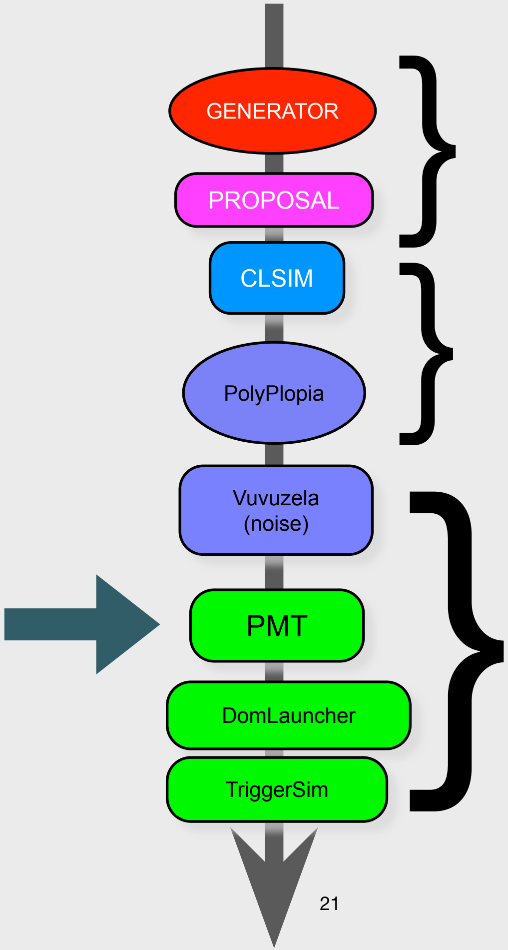
Pre-pulses: photoelectrons ejected from the first dynode,

Late pulses: electrons backscatter from dynode to cathode.

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



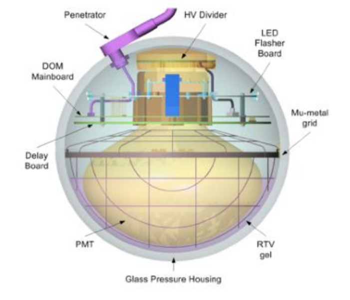


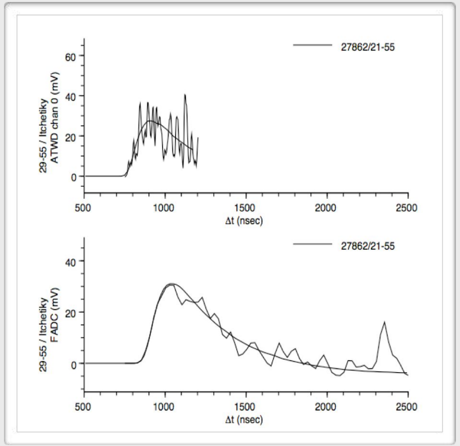


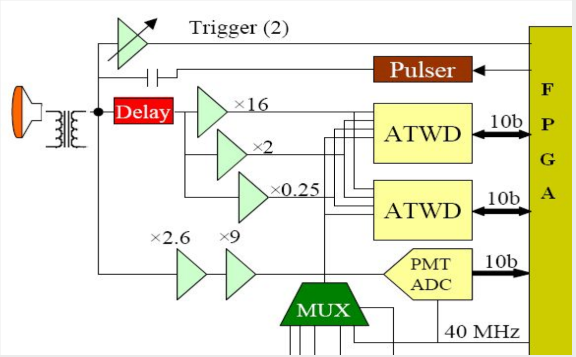
DOMLauncher: DOM electronics simulation

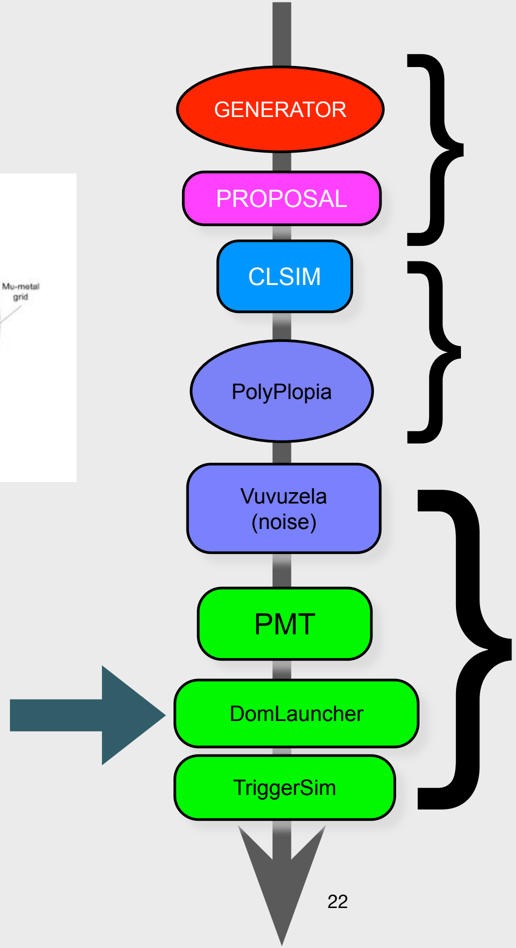
i³SIM

- 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

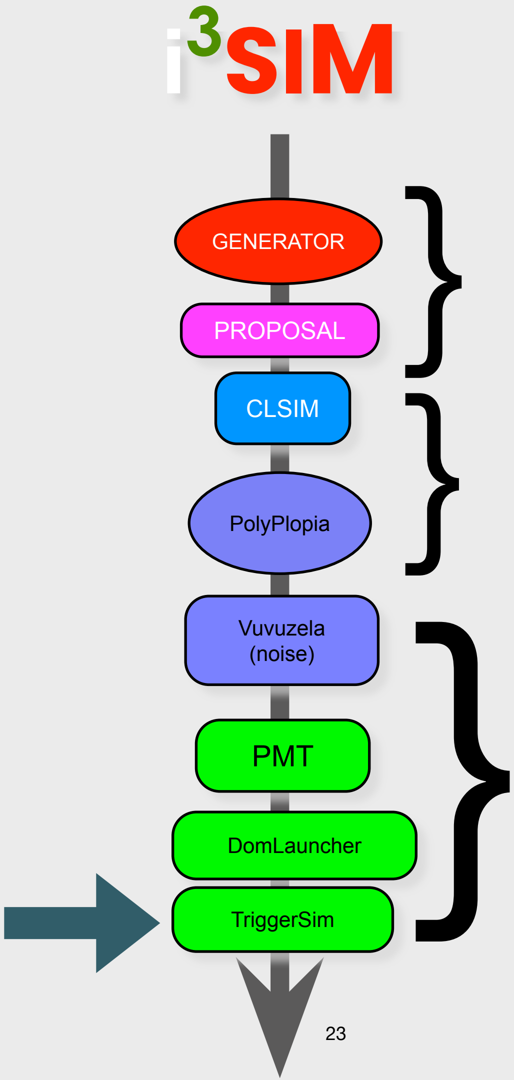
- **S**imple **M**ultiplicity **T**rigger (SMT)
  - *N* HLC hits or more in a time window
  - Example: InIce SMT8 with N_hits ≥ 8 in 5 μs
  - readout window around this captures early and late hits (-4 μs, +6 μs)

- **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).

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

- **Fixed 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 ~~and IceProd modules~~ used in simulation production. Central place with standard segments for running simulation in both official production and private simulations.

- **Tray Segments**: IceTray meta-modules that contain several I3Modules with default parameters.
- **Scripts**: collection of python scripts used in simulation production

simprod-scripts

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

Tray Segments $I3_SRC/simprod-scripts/python/segments

GenerateNeutrinos

GenerateAirShowers

GenerateCosmicRayMuons

GenerateIceTopShowers

HybridPhotonicsCLSim

Polyplopia

PropagateMuons

DetectorSim

simprod-scripts

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

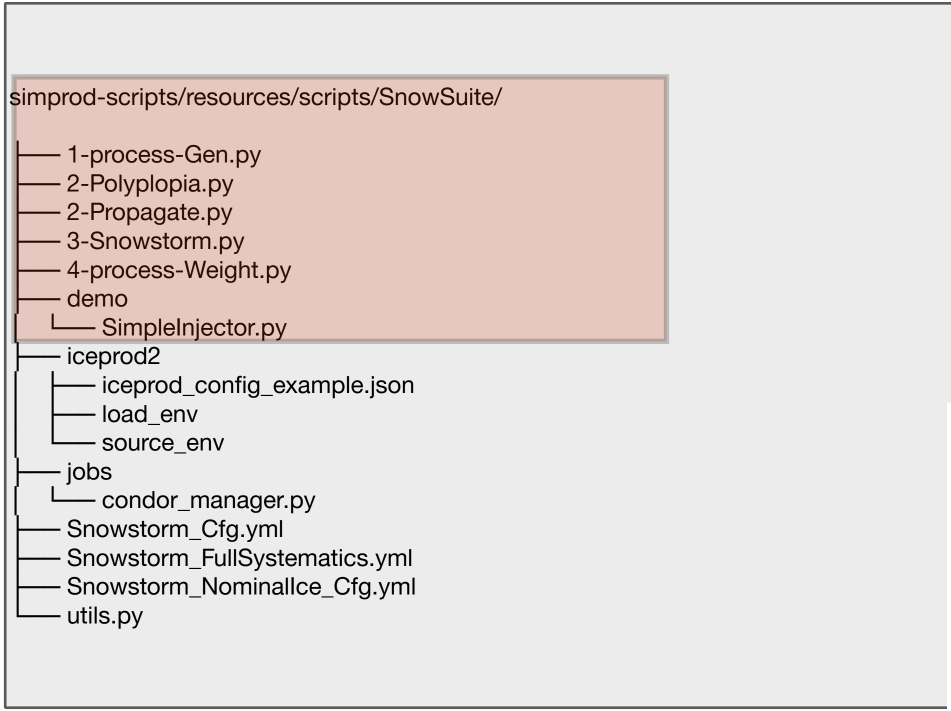
(run the individual pieces as broken down by production tasks)

```
$  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
                    …
```

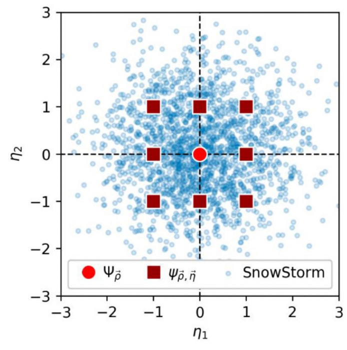
simprod-scripts (SnowSuite)

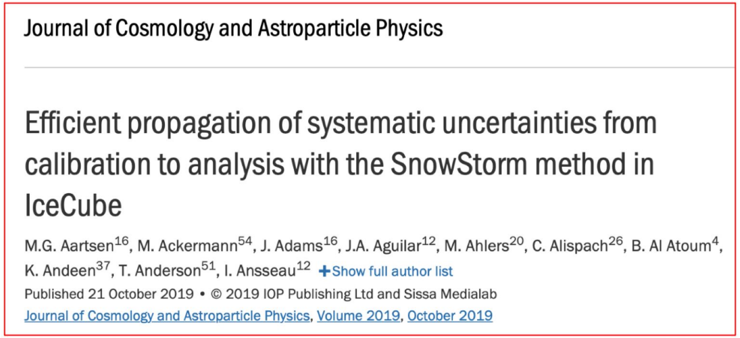
Scripts: $I3_SRC/simprod-scripts/resources/scripts

(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

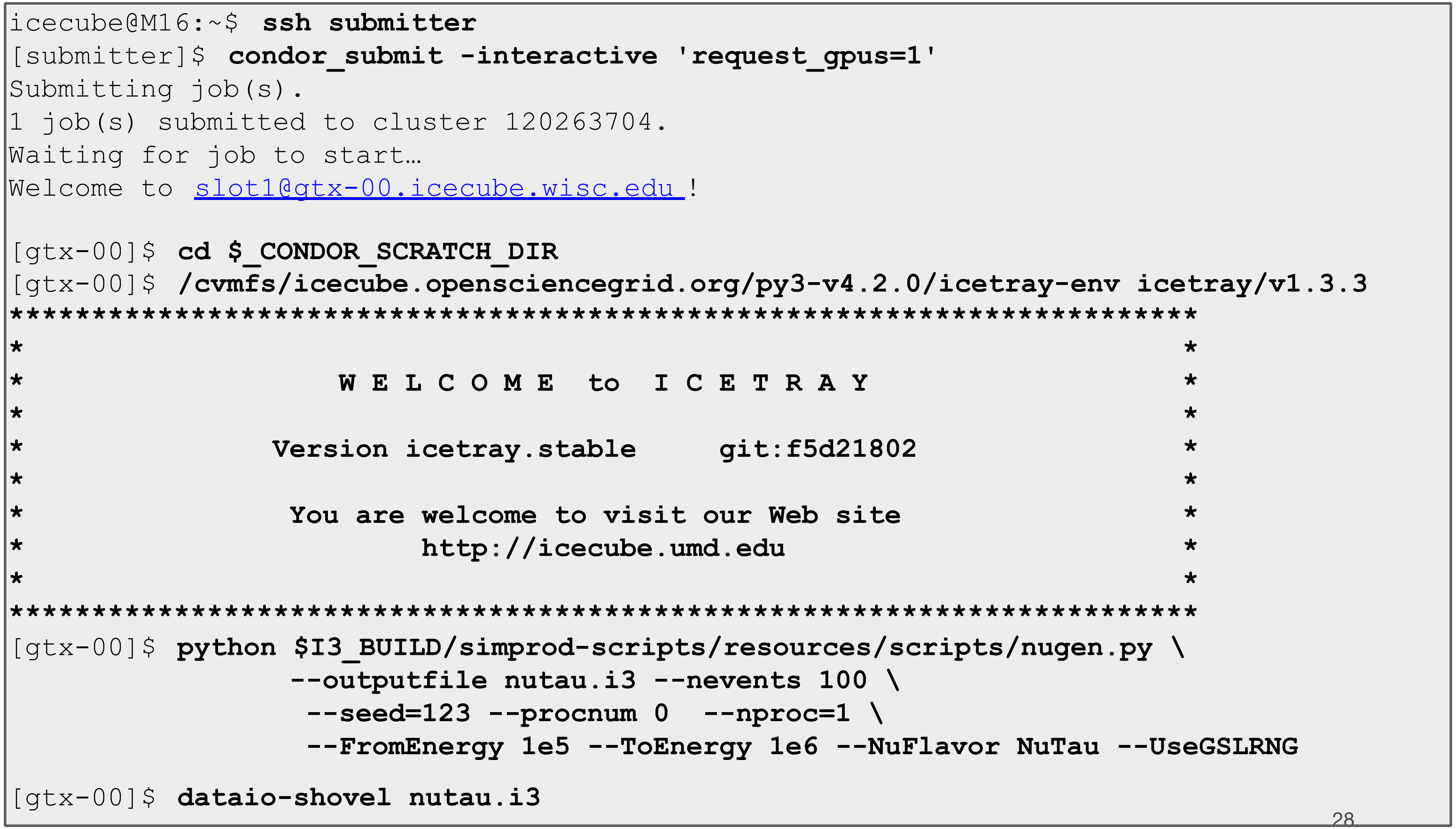
M.G. Aartsen[16], M. Ackermann[54], J. Adams[16], J.A. Aguilar[12], M. Ahlers[20], C. Alispach[26], B. Al Atoum[4], K. Andeen[37], T. Anderson[51], I. Ansseau[12] +Show full author list

Published 21 October 2019 • © 2019 IOP Publishing Ltd and Sissa Medialab

Journal of Cosmology and Astroparticle Physics, Volume 2019, October 2019

simprod-scripts

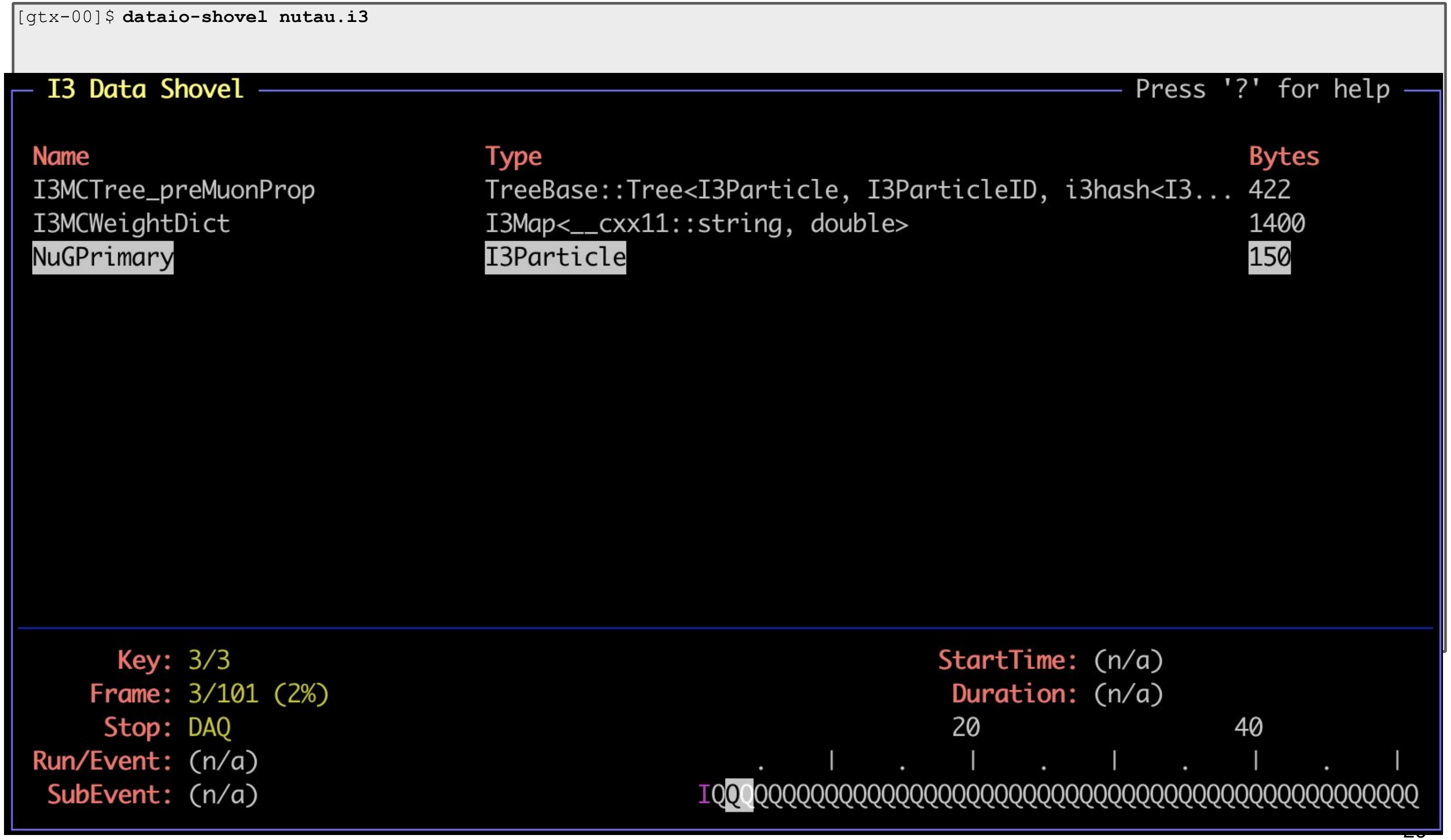
Example: Running scripts**:**



```
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-v4.2.0/icetray-env icetray/v1.3.3
************************************************************************
*                                                                      *
*                   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**:**



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

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

 Name                        Type                                                Bytes
 I3MCTree_preMuonProp        TreeBase::Tree<I3Particle, I3ParticleID, i3hash<I3... 422
 I3MCWeightDict              I3Map<__cxx11::string, double>                      1400
 NuGPrimary                  I3Particle                                          150

        Key: 3/3                                     StartTime: (n/a)
      Frame: 3/101 (2%)                               Duration: (n/a)
       Stop: DAQ                                        20            40
  Run/Event: (n/a)                             .    |    .    |    .    |    .    |    .    |
   SubEvent: (n/a)                           IQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
```

simprod-scripts

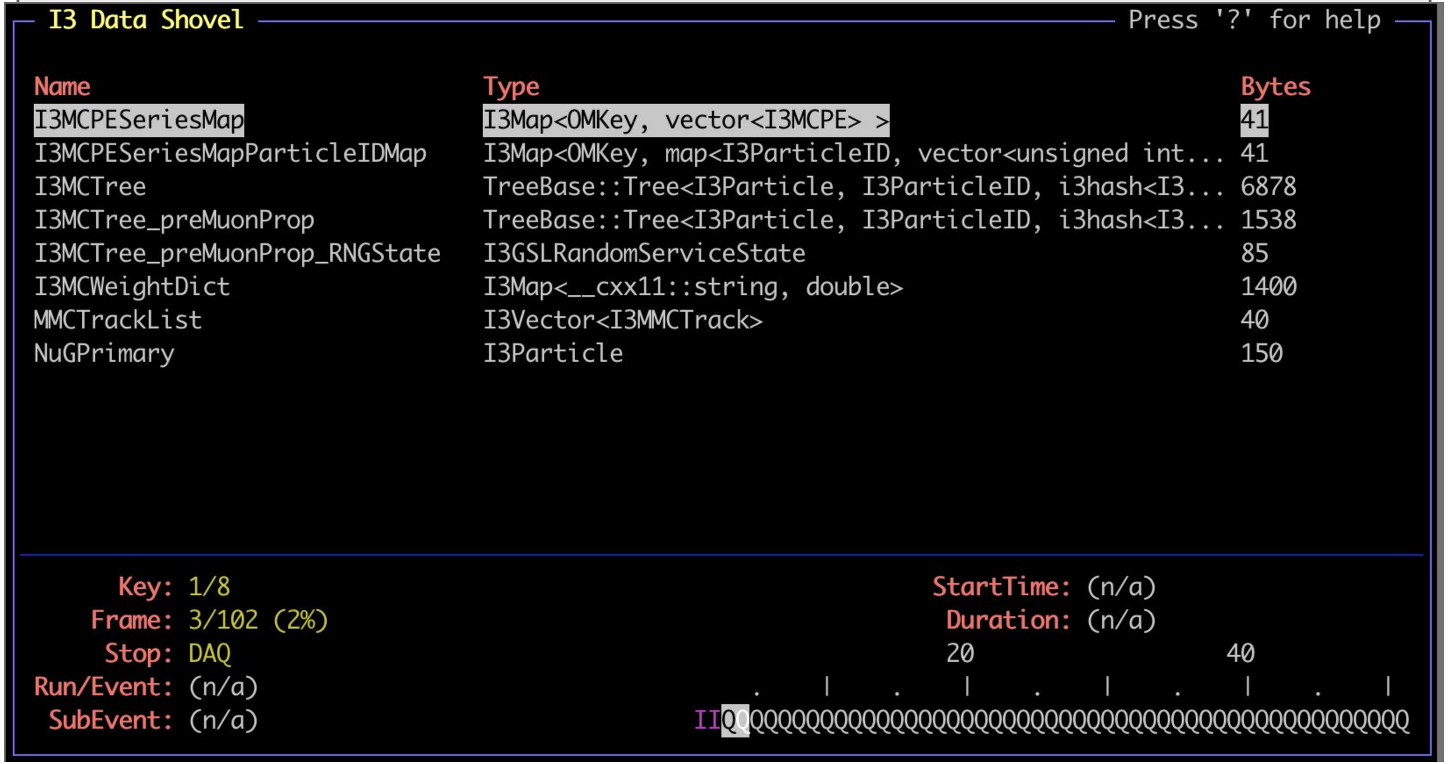
Example: Running scripts:

```
[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 gcdfile.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 gcdfile.i3.gz
            --inputfile mcpes.i3 --outputfile det.i3 \
            --seed 123 --procnum 0 --nproc 1 --RunID 123 —UseGSLRNG


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

simprod-scripts

Example: Running scripts:

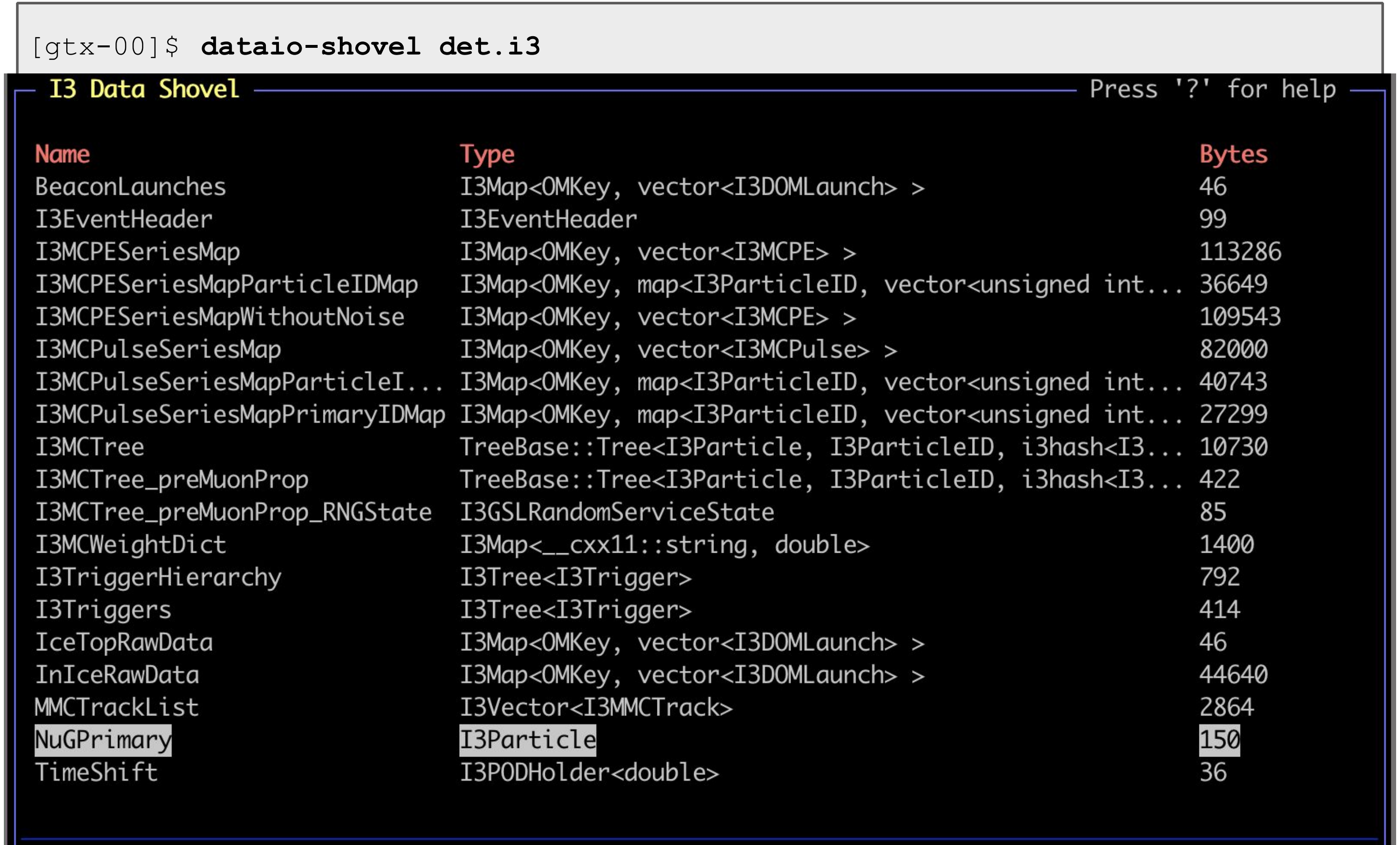
```
[gtx-00]$ dataio-shovel mcpes.i3
```



```
 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

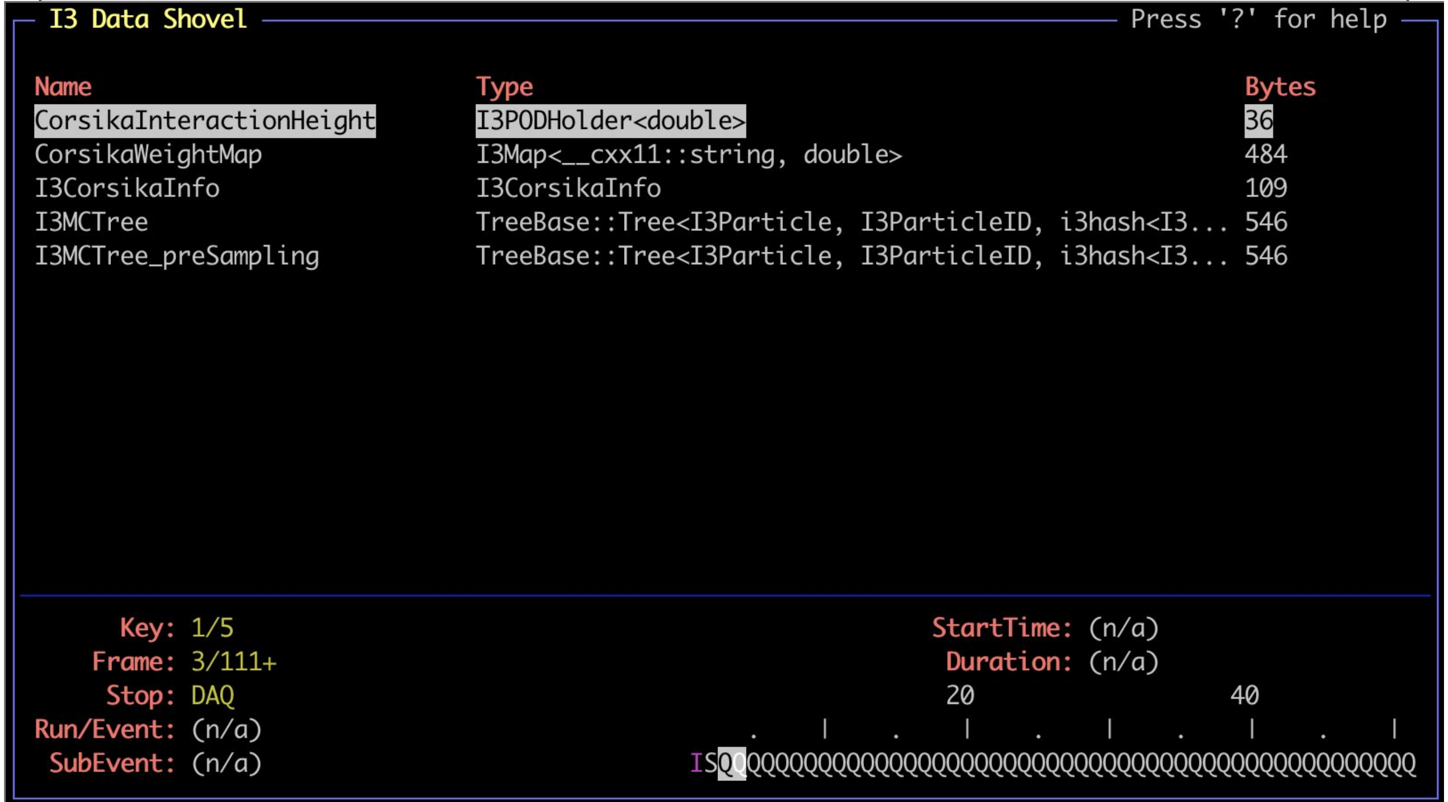
Exercise: Running scripts**:**

```
[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 gcdfile.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  gcdfile.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**:**

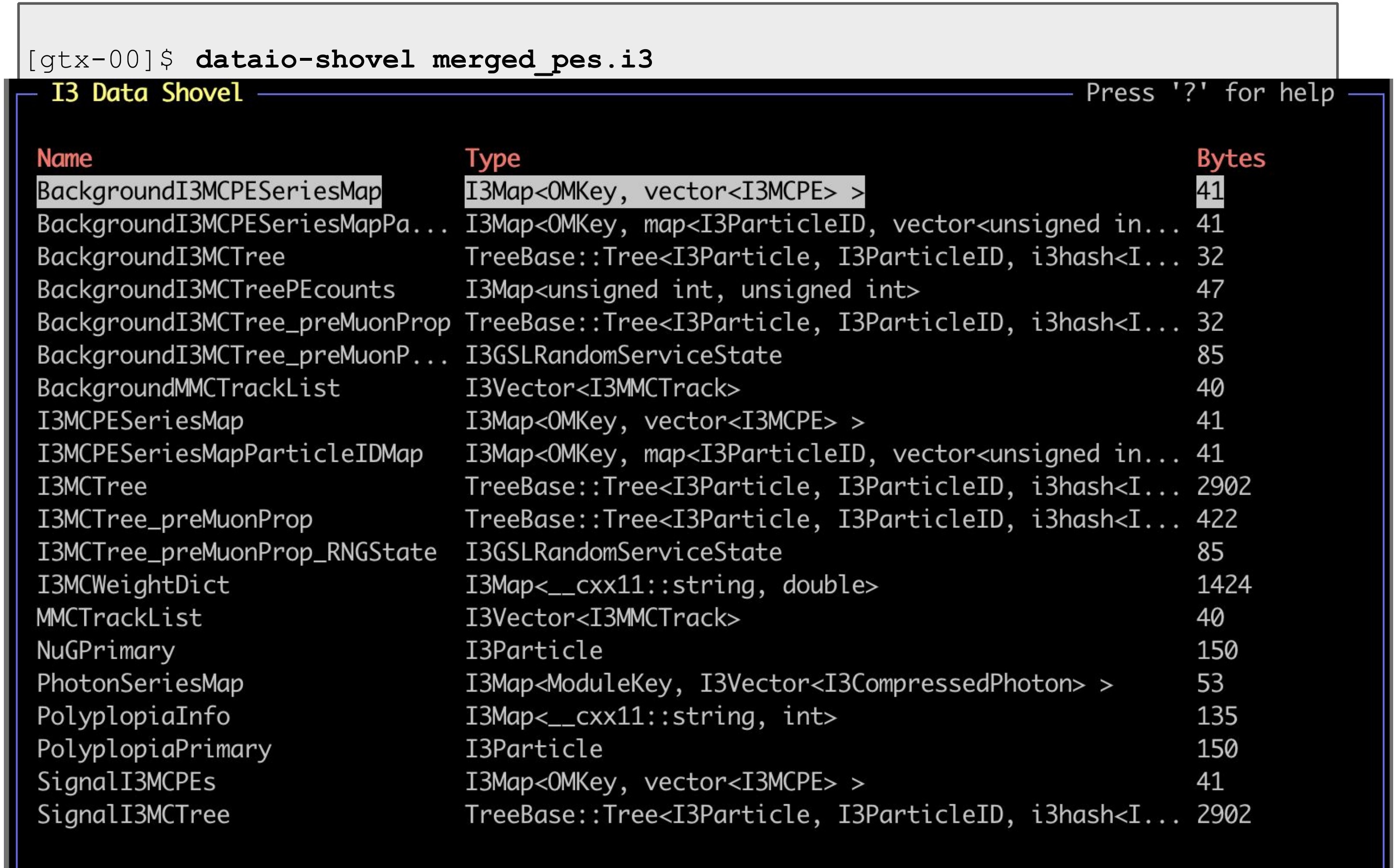
```
[gtx-00]$ dataio-shovel corsika_bg.i3
```



```
 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)                                   ISQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
```

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
```

Weighting

https://docs.icecube.aq/simweights/main/

Neutrino Generator Tutorial

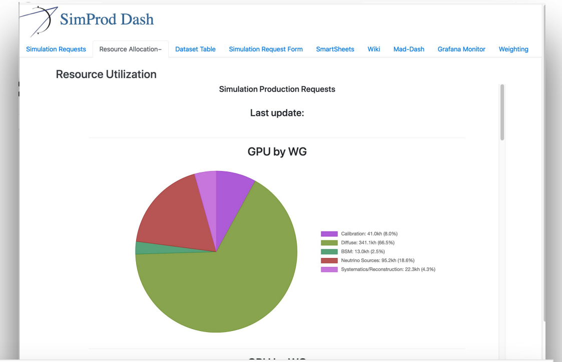
The easiest way to use simweights is to book your data to hdf5files using tableio.

```
#!/usr/bin/env python3

# SPDX-FileCopyrightText: © 2022 the SimWeights contributors
#
# SPDX-License-Identifier: BSD-2-Clause

from pathlib import Path

from I3Tray import I3Tray
from icecube import hdfwriter, simclasses

FILE_DIR = Path("/data/sim/IceCube/2016/filtered/level2/neutrino-generator/21217/0000000-00009
files = sorted(str(f) for f in FILE_DIR.glob("Level2_IC86.2016_NuMu.021217.00000*.i3.zst"))

tray = I3Tray()
tray.Add("I3Reader", FileNameList=files)
tray.Add(
    hdfwriter.I3HDFWriter,
    SubEventStreams=["InIceSplit"],
    keys=["PolyplopiaPrimary", "I3MCWeightDict"],
    output="Level2_IC86.2016_NuMu.021217.hdf5",
)

tray.Execute()
```

Simprod DashBoard

https://simprod.icecube.wisc.edu

- Catalog of official MC datasets
- Simulation Requests
- Dataset and resource Monitoring

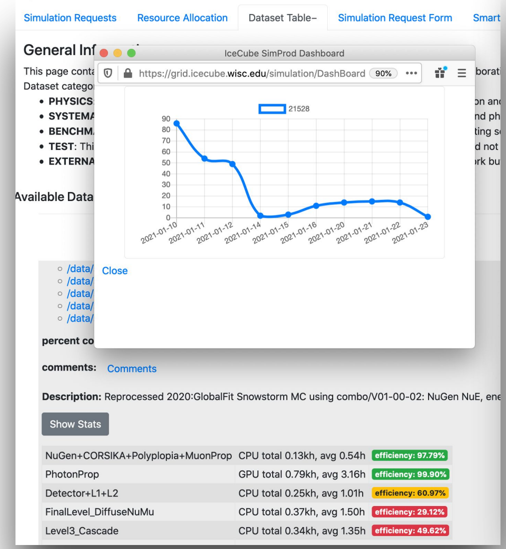


Resource Utilization

Simulation Production Requests

Last update:

GPU by WG



General Inf

This page conta

Dataset catego

- **PHYSICS**
- **SYSTEMA**
- **BENCHM**
- **TEST**: Thi
- **EXTERNA**

Available Data

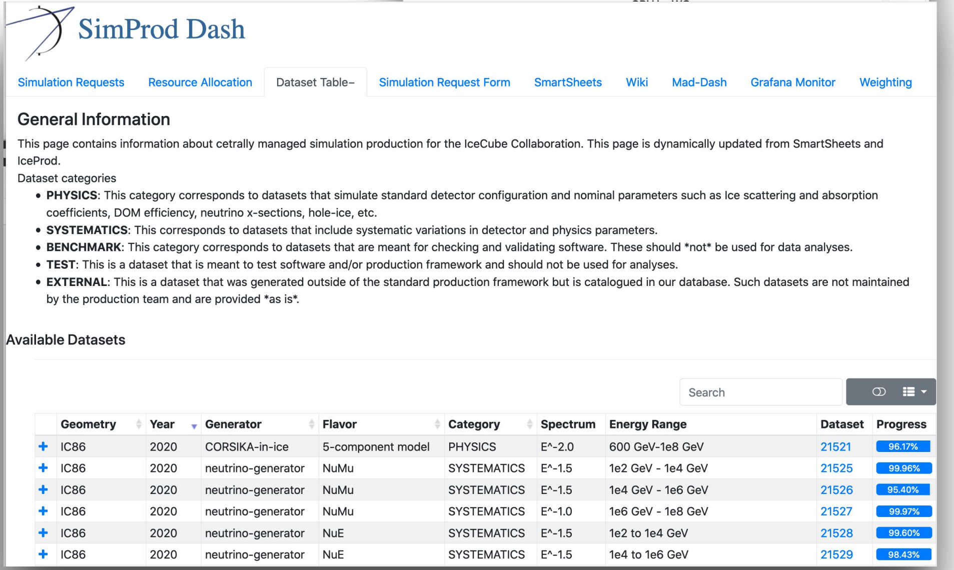
- /data/
- /data/
- /data/
- /data/
- /data/

percent co

comments: Comments

Description: Reprocessed 2020:GlobalFit Snowstorm MC using combo/V01-00-02: NuGen NuE, ene

NuGen+CORSIKA+Polyplopia+MuonProp	CPU total 0.13kh, avg 0.54h	efficiency: 97.79%
PhotonProp	GPU total 0.79kh, avg 3.16h	efficiency: 99.90%
Detector+L1+L2	CPU total 0.25kh, avg 1.01h	efficiency: 60.97%
FinalLevel_DiffuseNuMu	CPU total 0.37kh, avg 1.50h	efficiency: 29.12%
Level3_Cascade	CPU total 0.34kh, avg 1.35h	efficiency: 49.62%



General Information

This page contains information about cetrally managed simulation production for the IceCube Collaboration. This page is dynamically updated from SmartSheets and IceProd.

Dataset categories

- **PHYSICS**: This category corresponds to datasets that simulate standard detector configuration and nominal parameters such as Ice scattering and absorption coefficients, DOM efficiency, neutrino x-sections, hole-ice, etc.
- **SYSTEMATICS**: This corresponds to datasets that include systematic variations in detector and physics parameters.
- **BENCHMARK**: This category corresponds to datasets that are meant for checking and validating software. These should *not* be used for data analyses.
- **TEST**: This is a dataset that is meant to test software and/or production framework and should not be used for analyses.
- **EXTERNAL**: This is a dataset that was generated outside of the standard production framework but is catalogued in our database. Such datasets are not maintained by the production team and are provided *as is*.

Available Datasets

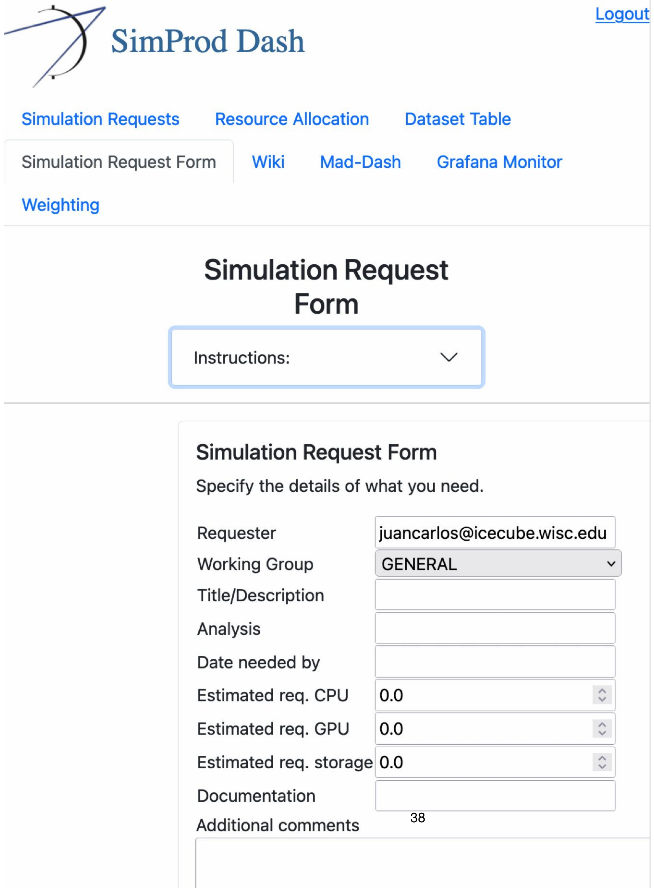
	Geometry	Year	Generator	Flavor	Category	Spectrum	Energy Range	Dataset	Progress
+	IC86	2020	CORSIKA-in-ice	5-component model	PHYSICS	E^-2.0	600 GeV-1e8 GeV	21521	96.17%
+	IC86	2020	neutrino-generator	NuMu	SYSTEMATICS	E^-1.5	1e2 GeV - 1e4 GeV	21525	99.96%
+	IC86	2020	neutrino-generator	NuMu	SYSTEMATICS	E^-1.5	1e4 GeV - 1e6 GeV	21526	95.40%
+	IC86	2020	neutrino-generator	NuMu	SYSTEMATICS	E^-1.0	1e6 GeV - 1e8 GeV	21527	99.97%
+	IC86	2020	neutrino-generator	NuE	SYSTEMATICS	E^-1.5	1e2 to 1e4 GeV	21528	99.60%
+	IC86	2020	neutrino-generator	NuE	SYSTEMATICS	E^-1.5	1e4 to 1e6 GeV	21529	98.43%

SimProd Requests

https://simprod.icecube.wisc.edu/submit

Need new simulations?

1. Discuss with your WG
2. Submit a request
   a. If possible provide estimates of resource utilization
   b. If self-generated, test and benchmark
3. In case of competing requests, priority will be evaluated and determined by WG tech leads



Simulation Request Form

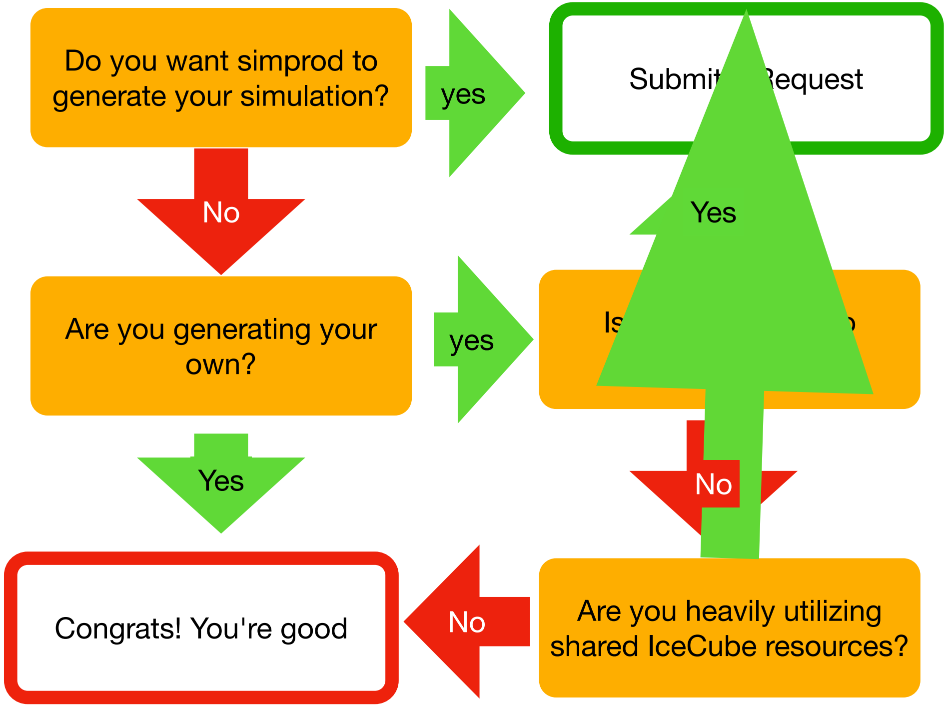
Simulation Request Form

Specify the details of what you need.

Requester: juancarlos@icecube.wisc.edu
Working Group: GENERAL
Title/Description:
Analysis:
Date needed by:
Estimated req. CPU: 0.0
Estimated req. GPU: 0.0
Estimated req. storage: 0.0
Documentation:
Additional comments:

SimProd Requests

https://simprod.icecube.wisc.edu/submit



Do you want simprod to generate your simulation?

yes

Submit equest

No

Are you generating your own?

yes

Is

Yes

Yes

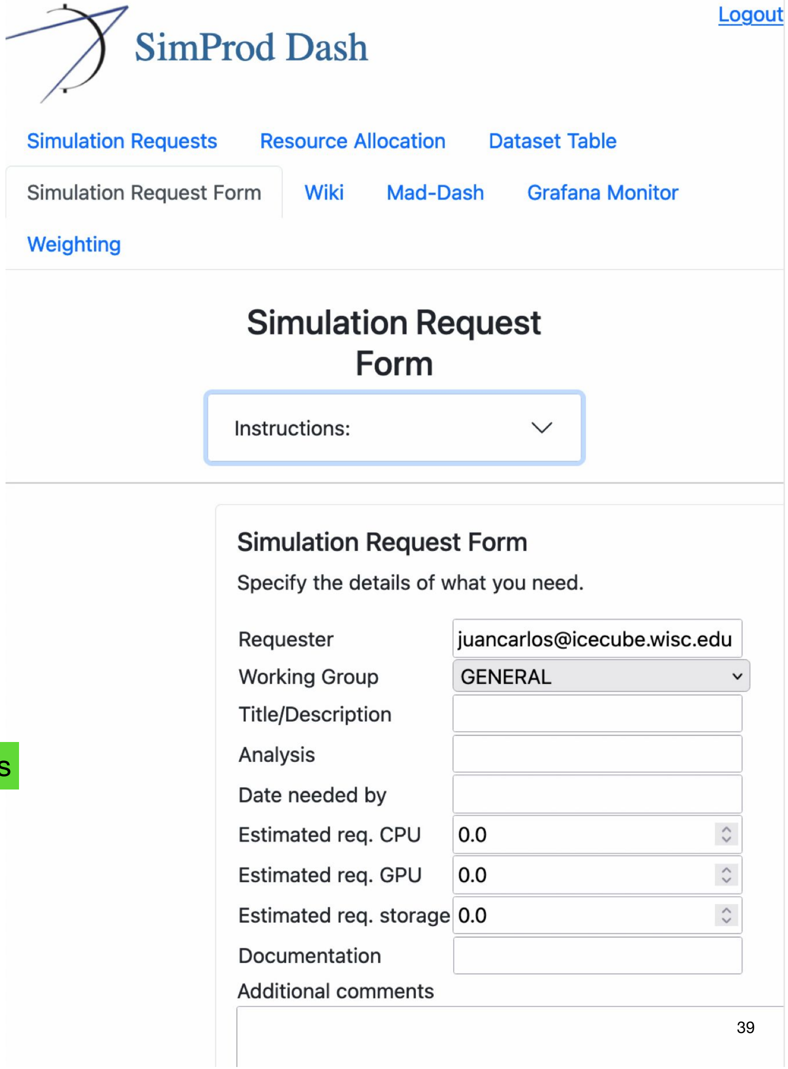
No

Congrats! You're good

No

Are you heavily utilizing shared IceCube resources?

Yes



Simulation Request Form

Simulation Request Form

Specify the details of what you need.

Requester	juancarlos@icecube.wisc.edu
Working Group	GENERAL
Title/Description	
Analysis	
Date needed by	
Estimated req. CPU	0.0
Estimated req. GPU	0.0
Estimated req. storage	0.0
Documentation	

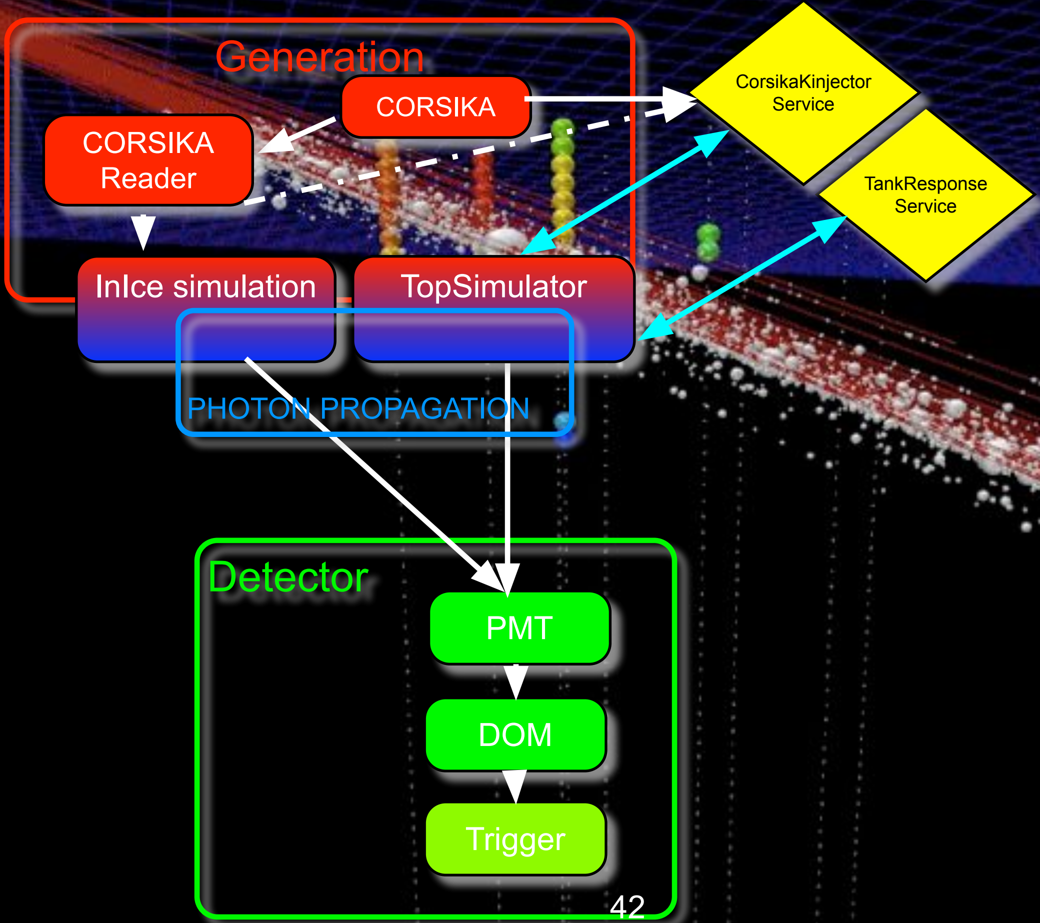
Additional comments

More on Simulation

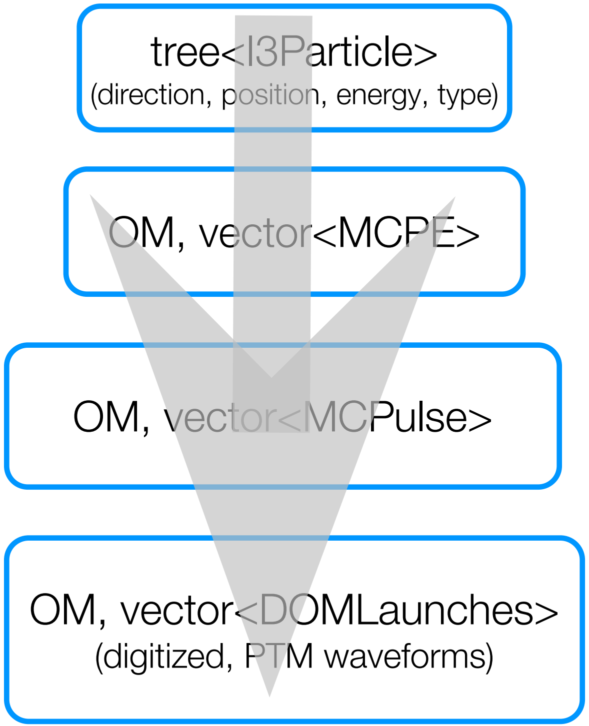
- GitHub repository: https://docs.icecube.aq/icetray/main/
- SimProd Portal: http://grid2.icecube.wisc.edu
- IceProd Docs: https://wipacrepo.github.io/iceprod/
- JSON Templates: https://github.com/icecube/simprod-templates/
- Wiki: http://wiki.icecube.wisc.edu/index.php/Simulation_Production
- Weighting: https://docs.icecube.aq/simweights/main/
  - Simweights Tutorial
- SLACK: #simulation

Backup

simulaton chain (IT)



Simulation



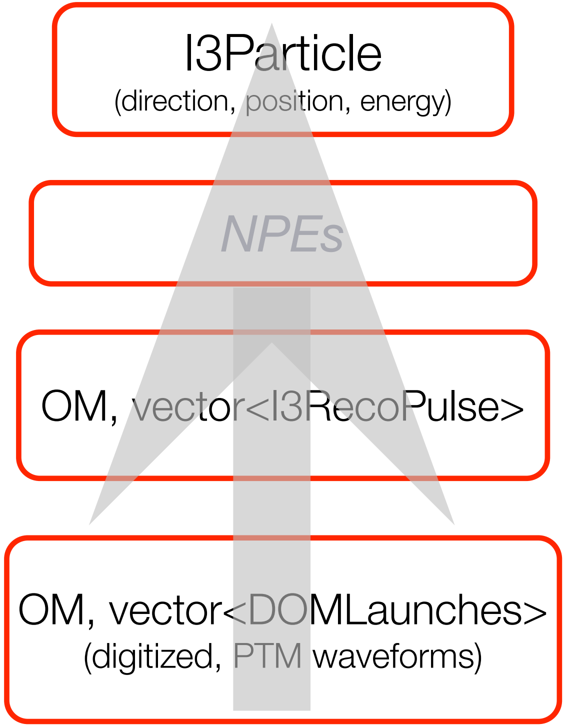
tree<I3Particle>
(direction, position, energy, type)

OM, vector<MCPE>

OM, vector<MCPulse>

OM, vector<DOMLaunches>
(digitized, PTM waveforms)

Reconstruction



I3Particle
(direction, position, energy)

NPEs

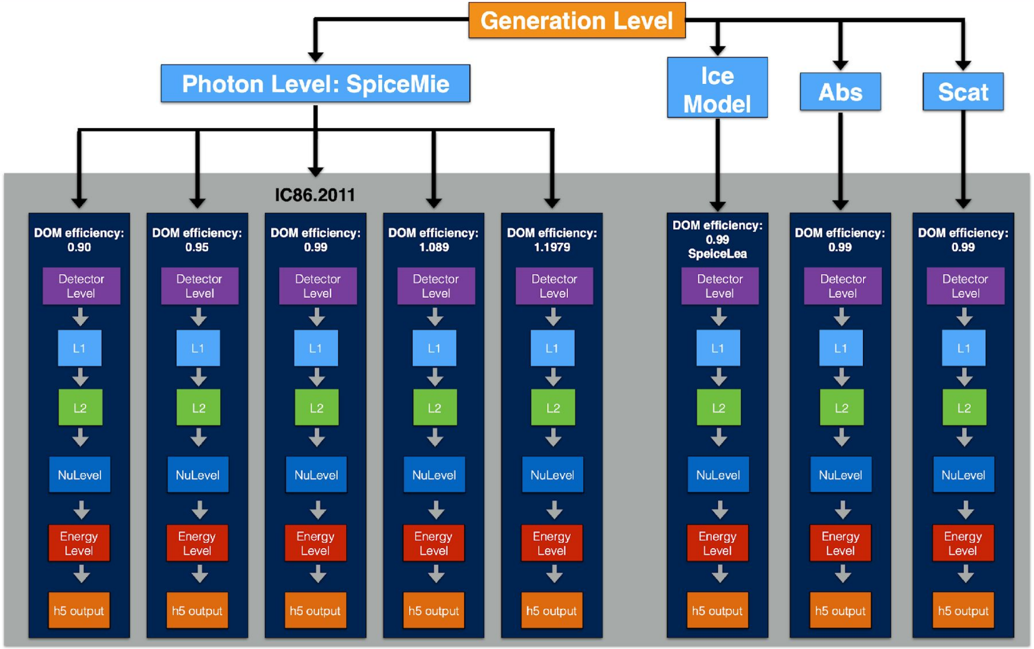
OM, vector<I3RecoPulse>

OM, vector<DOMLaunches>
(digitized, PTM waveforms)

Simulating Systematic Uncertainties

Example: High-Energy Sterile Neutrino MC Generation

Spencer N. Axani



Generation Level

Photon Level: SpiceMie

Ice Model

Abs

Scat

IC86.2011

DOM efficiency: 0.90

DOM efficiency: 0.95

DOM efficiency: 0.99

DOM efficiency: 1.089

DOM efficiency: 1.1979

DOM efficiency: 0.99 SpeiceLea

DOM efficiency: 0.99

DOM efficiency: 0.99

Detector Level → L1 → L2 → NuLevel → Energy Level → h5 output

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

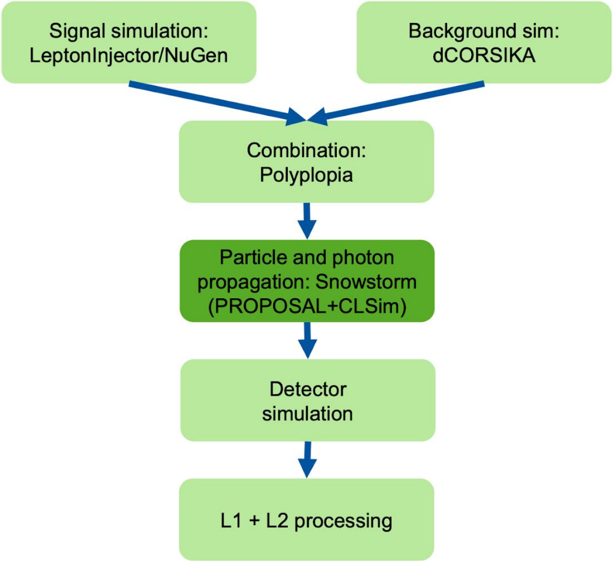
Erik Ganster

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*



Signal simulation: LeptonInjector/NuGen

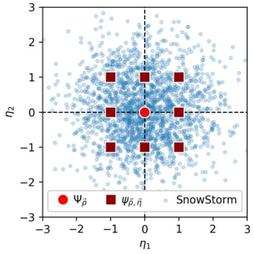
Background sim: dCORSIKA

Combination: Polyplopia

Particle and photon propagation: Snowstorm (PROPOSAL+CLSim)

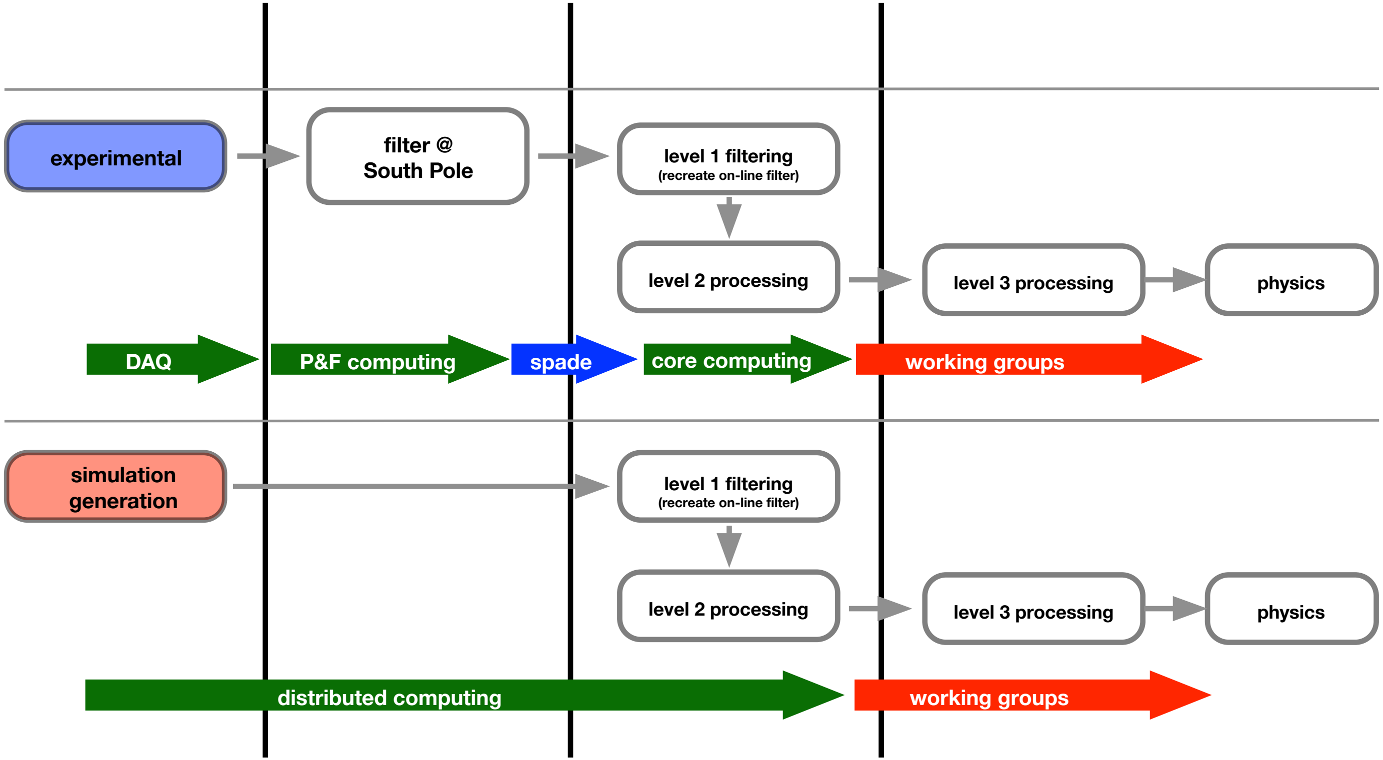
Detector simulation

L1 + L2 processing



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

flow of experimental and simulation data



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.
```

IceProd

Distributed Computing

- IceCube Specific scheduler
- Used by Simulation Production to create official datasets
- Describe jobs to run using JSON
- Handles File transfer to data warehouse
- Web Interface /API
- Data provenance
  - Configuration
    - which software, what versions,
  - when/where it ran, ...
- Dataset submission
  - Monitor job status, resource usage
  - Retry failed jobs - resubmit with different requirements

https://github.com/icecube/simprod-templates/

Dataset 21889 Details

Settings

description: ME IC86.2016 Triggered CORSIKA-in-ice 5-component model Sibyll2.3c (CORSIKA 77401) with weighted spectrum of E^-2.6, using Spice3.2 ClSim. Angular range of 0deg < theta < 89.99deg and energy range of 3e4GeV < Eprim < 1e6GeV. DOM oversize = 5
jobs_submitted: 100000
tasks_submitted:300000
tasks_per_job: 3
group: simprod
dataset_id: 5deb19300c1411eca9f2141877284d92
dataset: 21889
status: processing
start_date: 2021-09-02T17:36:55.621073
username: kmeagher
priority: 0.5
debug: False
jobs_immutable: False

Jobs

processing 1
complete 99999

Tasks

complete 299997

Task Status by Task Name

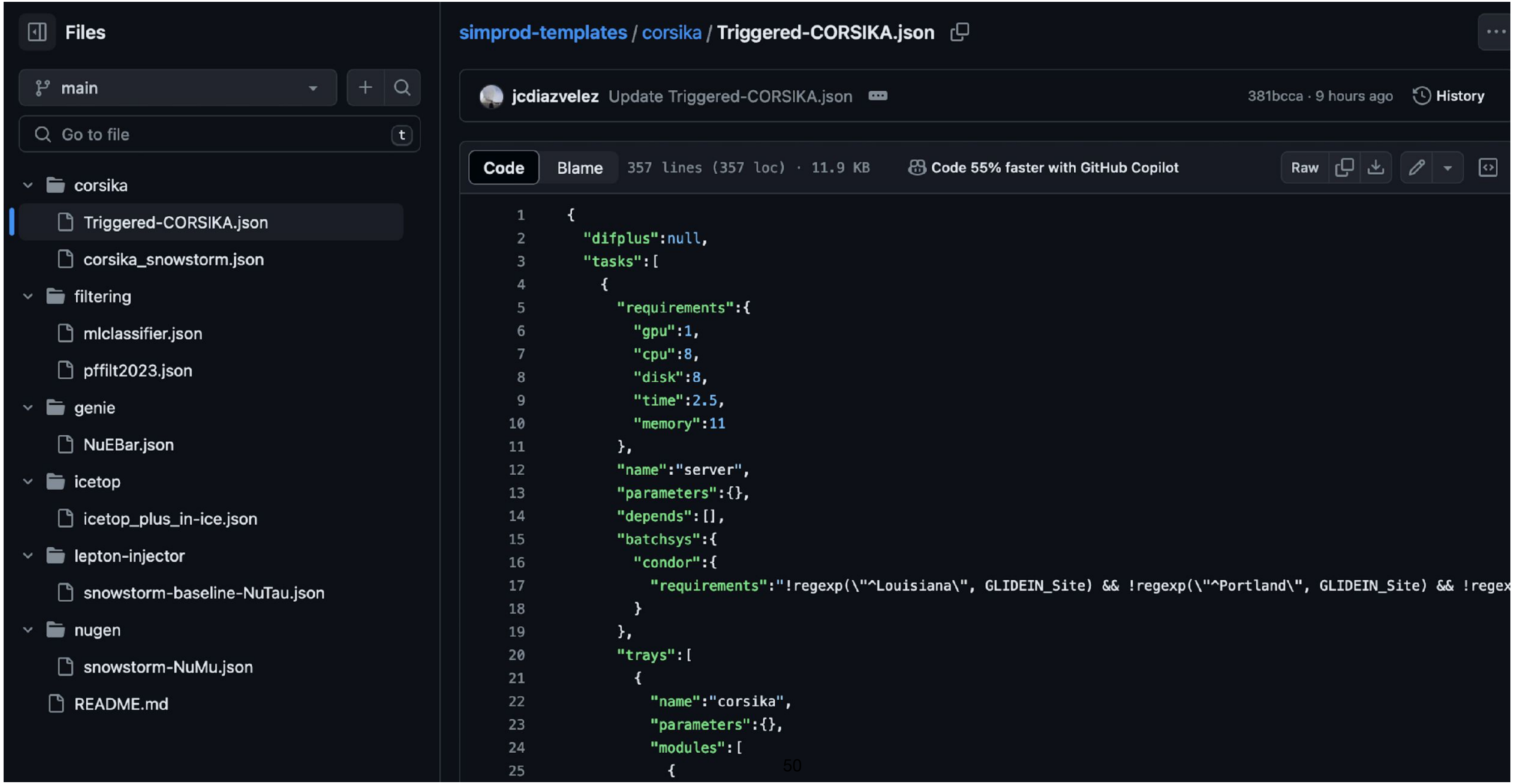
Name	Type	Waiting	Queued	Running	Complete	Error
server	GPU	0	0	0	99999	0
filtering	CPU	0	0	0	99999	0
L1L2	CPU	0	0	0	99999	0

Completion Statistics

Name	Avg/stddev (hours)	Max/min (hours)	Eff
server	0.31 / 0.14	3.00 / 0.17	84%
filtering	3.92 / 1.55	45.14 / 1.49	95%
L1L2	3.05 / 1.04	35.38 / 1.65	95%

IcePROD

https://github.com/icecube/simprod-templates/



- corsika
  - Triggered-CORSIKA.json
  - corsika_snowstorm.json
- filtering
  - mlclassifier.json
  - pffilt2023.json
- genie
  - NuEBar.json
- icetop
  - icetop_plus_in-ice.json
- lepton-injector
  - snowstorm-baseline-NuTau.json
- nugen
  - snowstorm-NuMu.json
- README.md

simprod-templates / corsika / Triggered-CORSIKA.json

jcdiazvelez Update Triggered-CORSIKA.json

381bcca · 9 hours ago

357 lines (357 loc) · 11.9 KB

```
{
  "difplus":null,
  "tasks":[
    {
      "requirements":{
        "gpu":1,
        "cpu":8,
        "disk":8,
        "time":2.5,
        "memory":11
      },
      "name":"server",
      "parameters":{},
      "depends":[],
      "batchsys":{
        "condor":{
          "requirements":"!regexp(\"^Louisiana\", GLIDEIN_Site) && !regexp(\"^Portland\", GLIDEIN_Site) && !regex
        }
      },
      "trays":[
        {
          "name":"corsika",
          "parameters":{},
          "modules":[
            {
```