Cascade Monte Carlo (cmc) Overview

icecube simulation workshop

(where we'd all like to be)

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Quick overview

- **cmc** models elongation in cascades above a TeV
- Please see the (recently migrated!) docs: https://docs.icecube.aq/combo/trunk/projects/cmc/index.html
- Developer credit belongs to all the people who worked on **cmc** before me (grabbed from the commit history, sorry if I omitted you!)
  - Gary Binder
  - Juan Carlos Diaz-Velez
  - Don La Dieu
  - Lisa Gerhardt
  - Kotoyo Hoshina
  - Claudio Kopper
  - Alex Olivas
  - Jakob van Santen
  - David Shultz
  - Chris Weaver
  - Nathan Whitehorn
  - Bernhard Voigt

Why cmc?

- Without special treatment, cascades in simulations have no spatial extension
- Above a few TeV, this is is a bad approximation
- CMC addresses this issue
- Two general regimes
  - <1 PeV: “continuous loss” parameterization
  - >1 PeV: 1D shower simulation

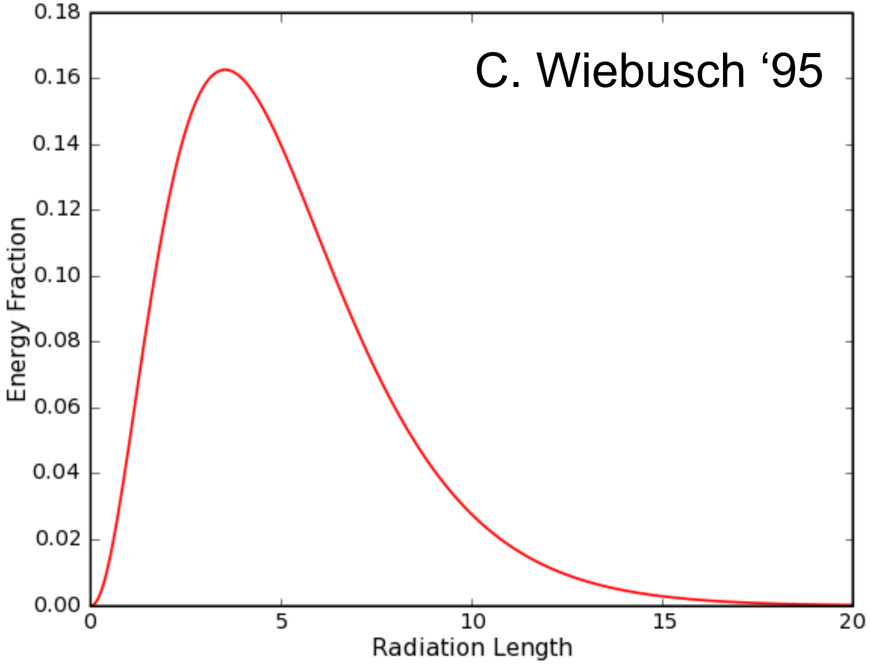
<1 PeV Showers

"Continuous loss" parameterization

- The PDG provides cascade parameterization
  - a and b are fitted from MC
  - Chris Wiebusch did this with GEANT

Cascade depth

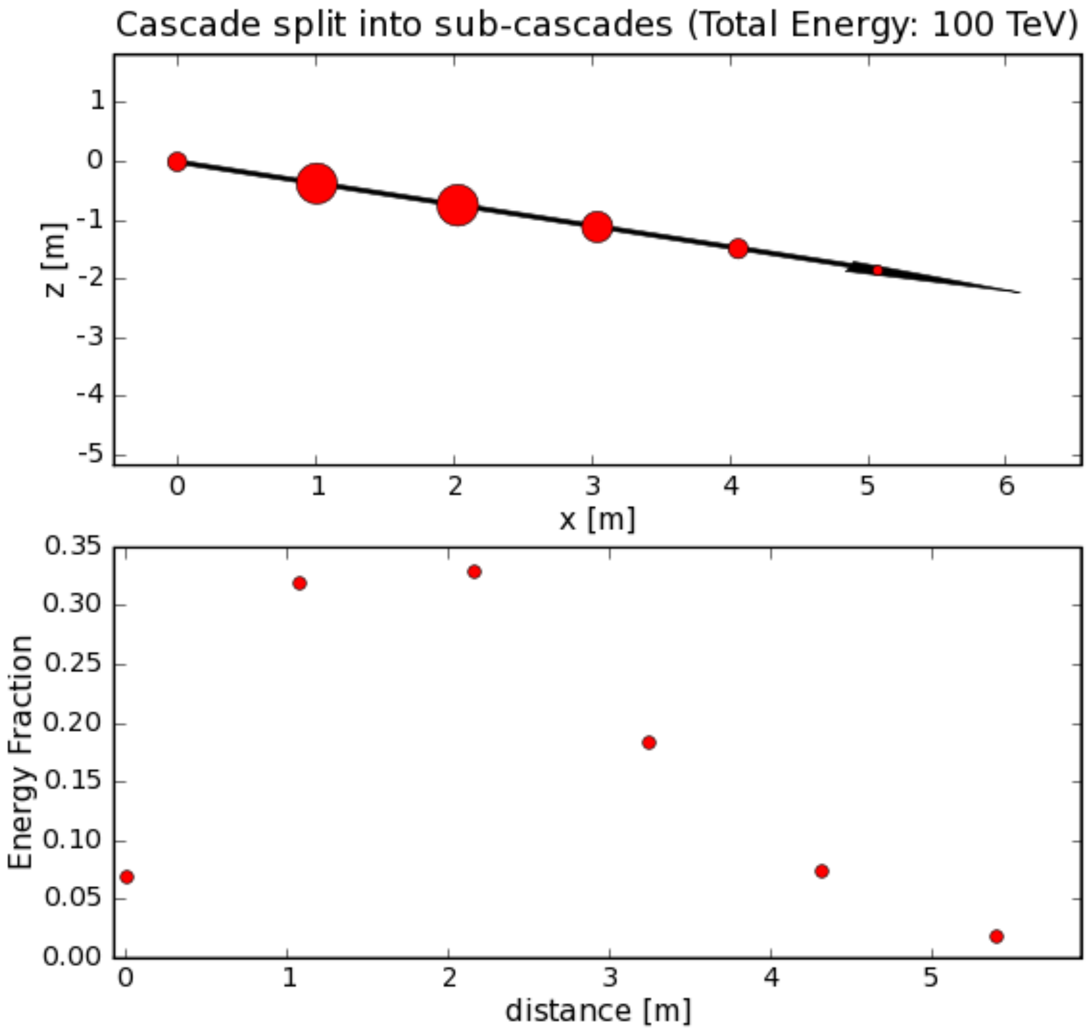
$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$



<1 PeV Showers

“Continuous loss” parameterization

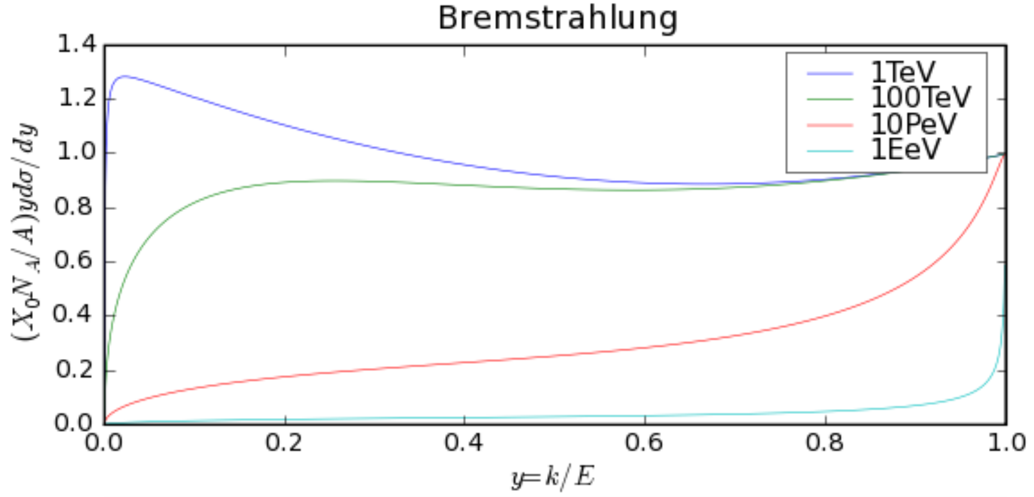
- CMC replaces the single first shower with a series of sub-showers
- Sub cascades are binned in (user configurable) multiples of the radiation length

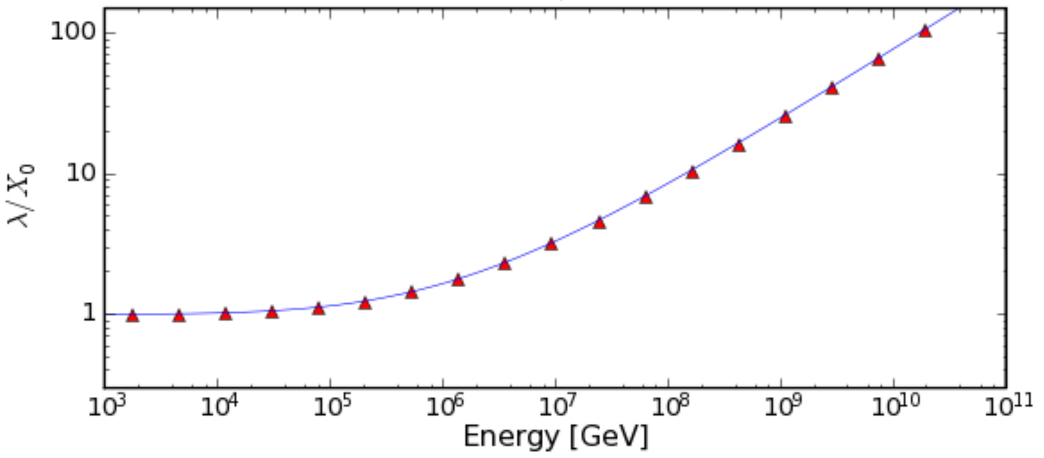


>1 PeV Showers

1D Shower Simulation

- Above 1 PeV, the shower development is simulated
- Includes:
  - Pair-production
  - Bremsstrahlung
  - And LPM (which suppresses both above 10 PeV)



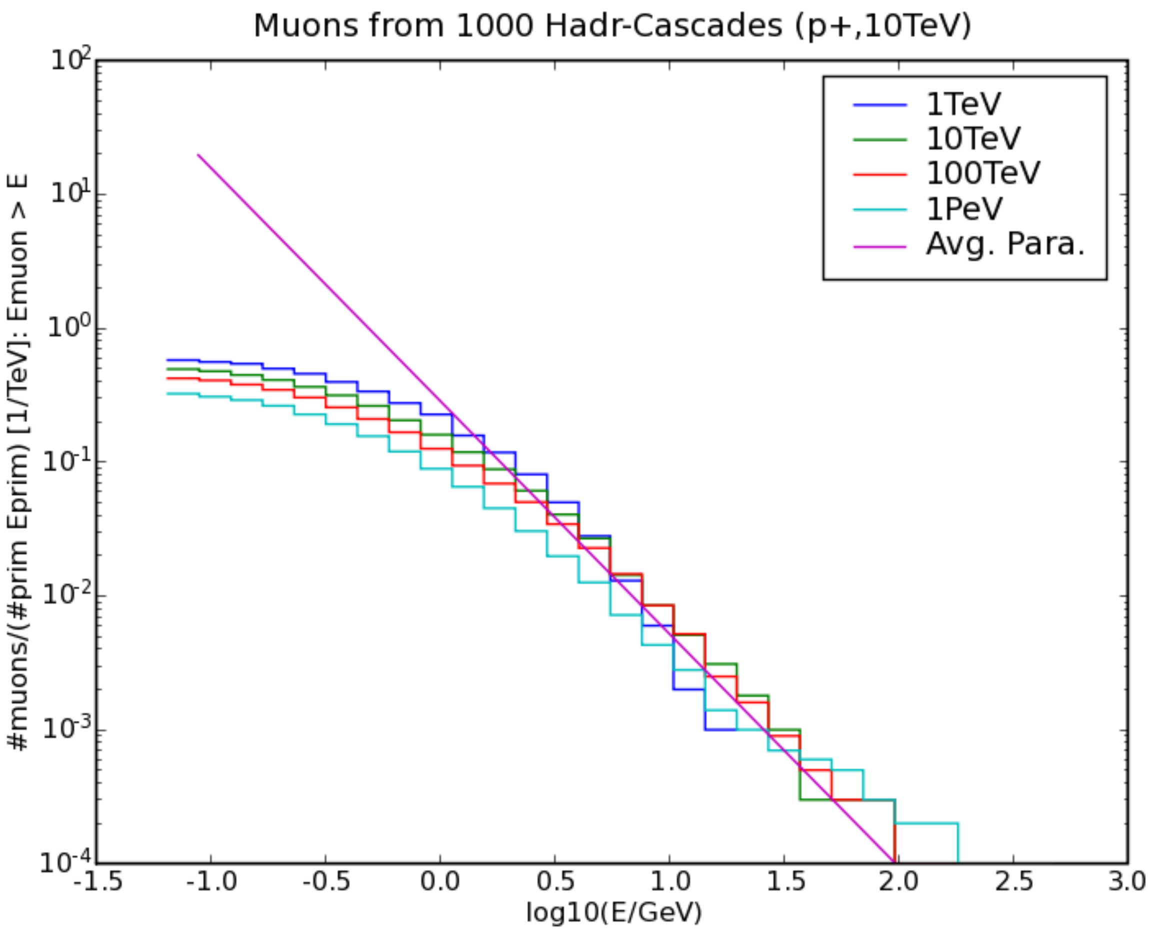


LPM = MFP rises > 10 PeV

Hadronic Showers

Adding muons

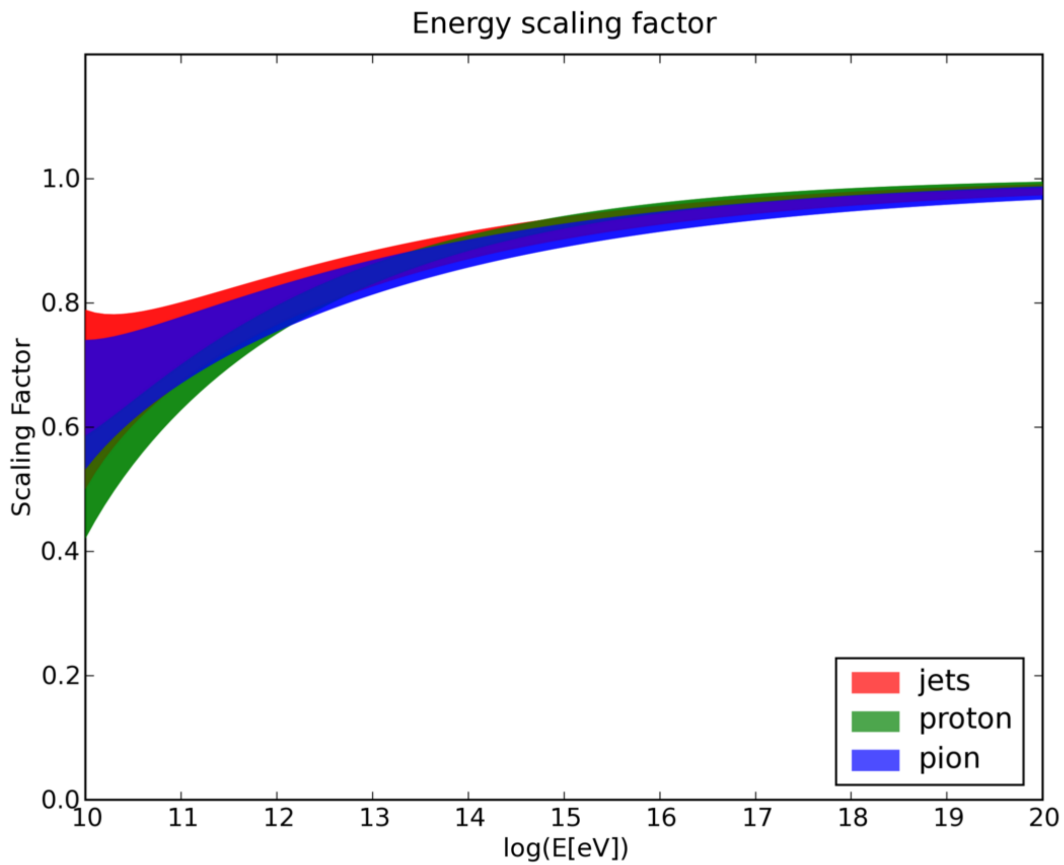
- For hadronic cascades, daughter muons are also produced (and later propagated by PROPOSAL)
- Mean number of muons is parameterized from Corsika simulations
- For each cascade, Poisson random number of muons added



Hadronic Showers

Energy scaling factor

- Two issues at play (see AMANDA internal report from Marek)
  - Hadronic showers produce less light than EM showers (slow neutrons, Cherenkov threshold is higher for hadrons, etc.)
  - Hadronic showers have fluctuations
- Hadronic cascade energies scaled *down* in order to match an EM shower with the same light yield
- And, the energies are (Gaussian) fluctuated about a mean scaling factor



How to use **cmc**

Use in the shiskabob

- Access to **cmc** functionality is mainly provided by the `I3CascadeMCService`
  - Can see it in various simprod segments
  - `prop = icecube.cmc.I3CascadeMCService(…)`
- Configurable thresholds for few critical parameters, including
  - At what energy to transition from parameterization to simulation
  - Maximum number of daughter muons
- **cmc** is called after the first run of `PROPOSAL`, and `PROPOSAL` is called *again* afterward (to propagate daughter muons)

Recent Bugfix

Particles with negative energy

2130621 Hadrons (133.192m, 785.657m, 221.306m) (86.3862deg, 14.519deg) 92927.7ns -2.84217e-14GeV 0m

- Erik found bug where **`cmc`** sets hadronic cascades to have negative energy
  - Causes seg-fault during photon propagation
  - Hint: energy is very near limit of floating point precision
- Solution
  - In rare circumstances, daughter muons can completely exhaust the original hadronic cascade, and cascade energy is reduced to $E_0 - \sum E_\mu$
  - Which can be zero to within machine precision
- Now, **`cmc`** performs check for "near machine precision 0" (eps diff method)
  - And, has new asserts against placing any particles into the I3MCTree with E<0
  - Not the first offense for **`cmc`**…

Conclusion

Wrapping up

- **cmc** simulates spatial extension of high energy EM and hadronic cascades
- **cmc** is Upgrade/Gen2 ready
    - But, runtimes become non-trivial at high energies
    - 3 minutes @ 10 EeV vs milliseconds at PeV energies
- Code recently hardened against negative energy depositions

Backup

>1 PeV Showers

1D Shower Simulation

- Three steps for every cascade (or sub-cascade) above a threshold (usually 1 TeV)
  1. Determine interaction point for e^+e^-/brem production
     1. Mean-free path (λ) calculated from differential cross section
     2. Interaction point is drawn randomly from $\exp(-x/\lambda)$
  2. Create brem or e^+e^-
     1. Sample differential cross section to get fraction energy of secondaries
  3. Create deposition OR further
     1. If energy is > sim threshold, repeat step 1
     2. Otherwise, create an energy deposition according to the "continuous loss" parameterization

>1 PeV Showers

1D Shower Simulation pseudo-code

```
particles = [electron]
while particle = particles.pop():
   dx = sampleFreePath(particle.energy)
   y = sampleCrossSection(particle.energy)
   if particle == ELECTRON:
     photon = Photon(particle.x + dx, particle.energy * y)
   if particle == PHOTON:
     electron1 = Electron(particle.x + dx, particle.energy * y)
     electron2 = Electron(particle.x + dx, particle.energy - electron1.energy)

   if (photon|electron1|electron2).energy > threshold:
      particles.pushback(photon|electron1...)
   else:
      energyLossProfile[x+dx] += getEnergyLossProfile(photon|electron1...)
```

`cmc` under the hood

Important Subclasses

- `I3CascadeMCModule`: adds muons and scales hadronic cascades, calls splitter for EM cascades
- `I3CascadeSplit`: performs splitting of EM cascades
  - `I3CascadeParametrization`: <1 PeV parameterization
  - `I3CascadeSimulation`: >1 PeV simulation tools
    - `I3CascadeSimulationCrossSection`: calculation of cross-section parameterizations
    - `I3MetropolisHastings`: sampling of the differential cross sections