Update on cross-media showers and ICRC 2023 poster

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Introduction

- Cross-media showers: a shower going from one medium to another.

- Naturally carried out by Corsika 8:
  - As another interaction length, the distance to the next volume (medium) is sampled.
  - If the distance to the next volume is smaller than all other interaction lengths, the particle is advanced to the interface.
  - The next particle track will be fully contained in the next volume.

- To run them, one just needs to construct the desired medium.

Introduction: Building the media

```cpp
MassDensityType const rho5 = grammage(1222.6562) / 994186.38_cm;
auto node5 = EnvType::createNode<Sphere>(center, EarthRadius+4_km);
```

⟶ Sphere for layer 5 of atm

```cpp
auto const medium5 =
      std::make_shared<
      UniformRefractiveIndex<MediumPropertyModel<UniformMagneticField<SlidingPlanarExponential<EnvironmentInterface>>>>>(
      1.000327, Medium::AirDry1Atm, Vector(rootCS, 0_T, 0_T, 0_T), center, rho5, -994186.38_cm, nucl_comp_air, EarthRadius);
```

⟶ Medium properties: refr. Index, type of medium, mag. Field, exponential density model

```cpp
node5->setModelProperties(medium5);
```

⟶ Add medium properties to layer 5 of the atm.

```cpp
auto ice_sphere = EnvType::createNode<Sphere>(center, EarthRadius);
NuclearComposition const nucl_comp_ice{{Code::Hydrogen, Code::Oxygen}, {0.11, 0.89}};
MassDensityType const density_ice = 0.918_g / (1_cm * 1_cm * 1_cm);
auto const medium_ice =
    std::make_shared<UniformRefractiveIndex<MediumPropertyModel<UniformMagneticField<HomogeneousMedium<EnvironmentInterface>>>>>(
      1.43, Medium::WaterIce, Vector(rootCS, 0_T, 0_T, 0_T), density_ice, nucl_comp_ice);
ice_sphere->setModelProperties(medium_ice);
```

⟶ Medium properties: refr. Index, type of medium, mag. Field, uniform density model

```cpp
VolumeTreeNode<EnvironmentInterface>* const universe = env.getUniverse().get();

node5->addChild(std::move(ice_sphere));
node4->addChild(std::move(node5));
node3->addChild(std::move(node4));
node2->addChild(std::move(node3));
node1->addChild(std::move(node2));
universe->addChild(std::move(node1));
```

Setting up the environment taking into account the hierarchy between volumes (from the outermost to the innermost).

⟶ Universe is the volume that englobes the "world" we create

Layer 5 is a child node of atm layer 4

Atm layer 5

Ice sphere

Ice sphere is a child node of atm layer 5

Verification against C7+Geant4

- Study done by S. De Kockere ,K. D. de Vries ,N. van Eijndhoven and U. A. Latif. PhysRevD.106.043023

- C7 simulated the air shower and then the particles at ground were propagated in ice with Geant4.

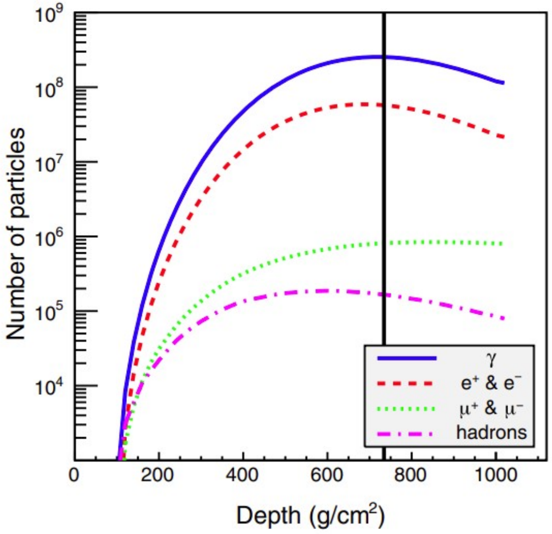
- Ice medium density: $\rho(z) = 0.460 + 0.468 \cdot (1 - e^{0.02 \cdot z})$, $z \equiv$ ice depth

- Medium density implemented in slices of 1 cm of constant density.

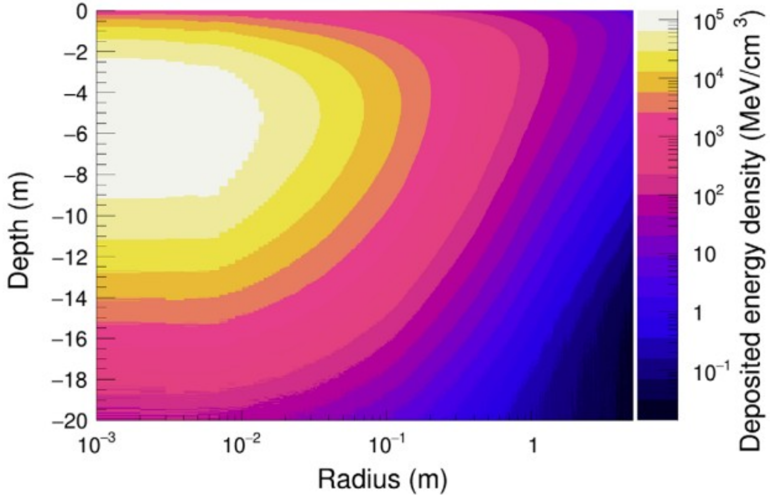
Verification against C7+Geant4

- Some of the plots they produced could be used for the comparison:

Longitudinal profile



Radial deposited energy density distribution in ice



Verification against C7+Geant4

- The energy thresholds in Geant 4 are set by the minimum interaction length allowed.
- For the first steps of the comparison we agreed to start using a threshold of 10 MeV, if they agree, lower it more.
- If none of this works because of the different energy thresholds methods and mediums, a homogeneous block of ice could be done (constant density=specific energy cut).

C8 cross media shower

- To implement the ice medium one needs to create a class that calculates:
  - Density of the medium at a point.
  - Grammage from metric length.
  - Metric length from grammage.

$$\rho(z) = 0.460 + 0.468 \cdot (1 - e^{0.02 \cdot z})$$

$$\chi = \int_{h_1}^{h_2} \rho(h) \frac{dh}{\cos(\theta)} = (a_1 + a_2)l + \frac{a_2}{\cos(\theta) b} \cdot e^{-b \cdot (h_{int} - h_1)} \cdot (1 - e^{bl\cos(\theta)})$$

$$\chi \approx (a_1 + a_2)l + \frac{a_2}{\cos(\theta) b} \cdot e^{-b \cdot (h_{int} - h_1)} \cdot [bl\cos(\theta) - \frac{1}{2} b^2 l^2 \cos^2(\theta)]$$

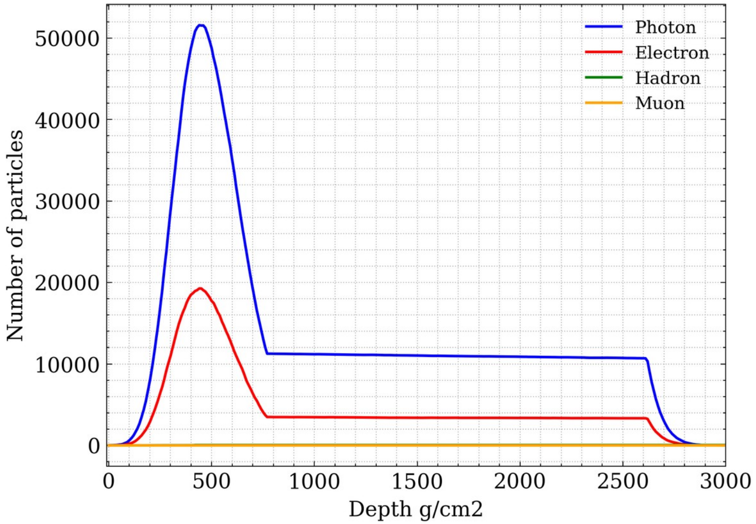
C8 cross media shower

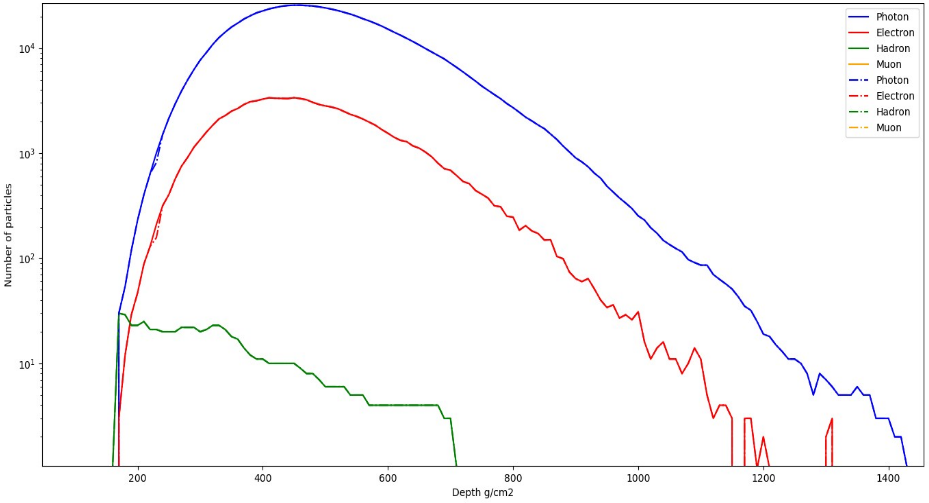
- Details when implementing a new medium:
  - One can get infinite grammages to convert to length.
  - Your particle may go outside the medium.

- Another option could be tabulating the medium, but a modification to the existing class is needed to take care of the previous details.

Issues encountered: Longitudinal profile

- Longitudinal profile does not work for cross media showers.
  - The issue comes from interpolating the depth travelled in the bin where the interface is.
- Solved by telling the shower axis where the interface is. Generalizable? Worth it?





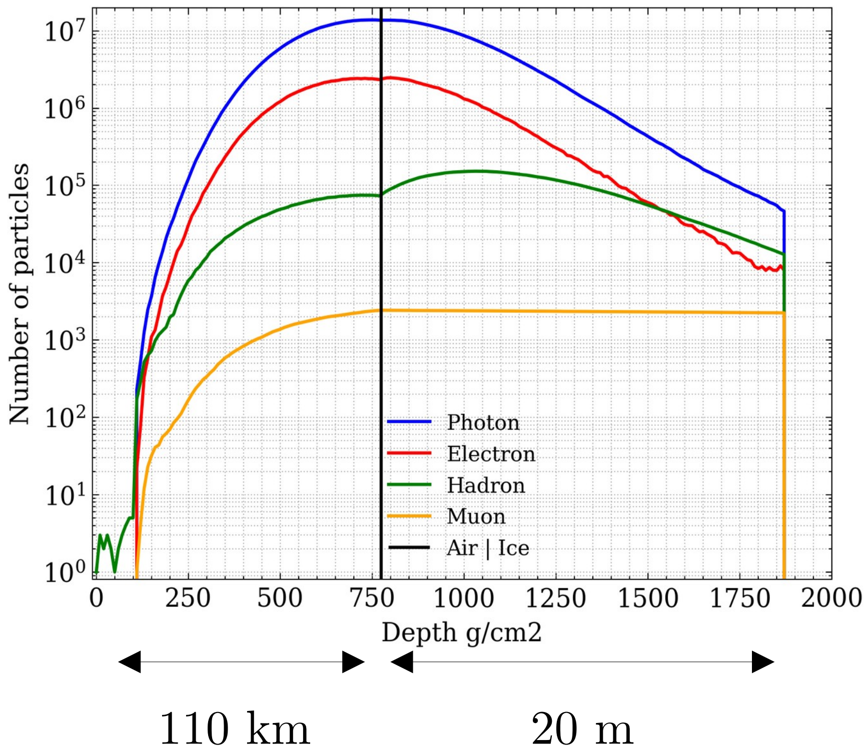
Issues encountered: Step class

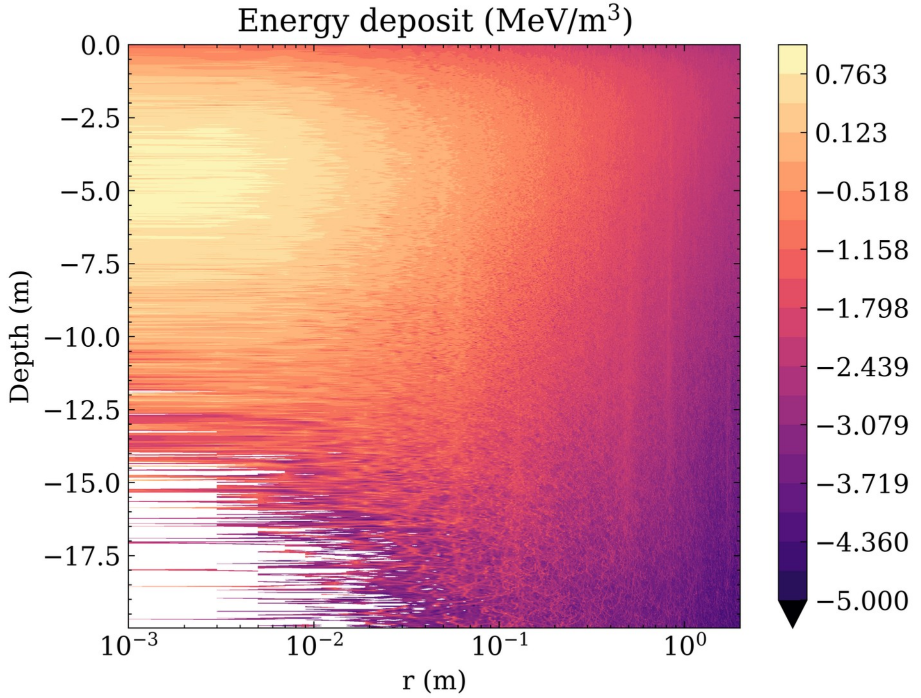
- Small distance traveled by decaying rho-, 3.14..10^{-14} m → precision problem when creating a step object in Cascade.inl.
- When quering the last point of the step, it was doing an operation of adding 6371000 + 3.14..10^{-14} m, which was rounded to the first float.
- This produced a direction vector of a particle (nan, nan, nan).
- Solved by adding a check in the constructor of Step.hpp, not sure if it is the best option.
- While checking this I also found particles with v>c, no idea why...

Some first results

- 10 PeV showers with 10^{-6} thinning, 200 maximum weight.
- First showers with real ice composition thanks to Fluka !
- Corsika.cpp example plus ice core at 2.4 km altitude.
- Thresholds: 10 MeV for all particles.
- Running testing-branch-May23 plus my additions $\rightarrow$ dev-cross-media.

Some first results



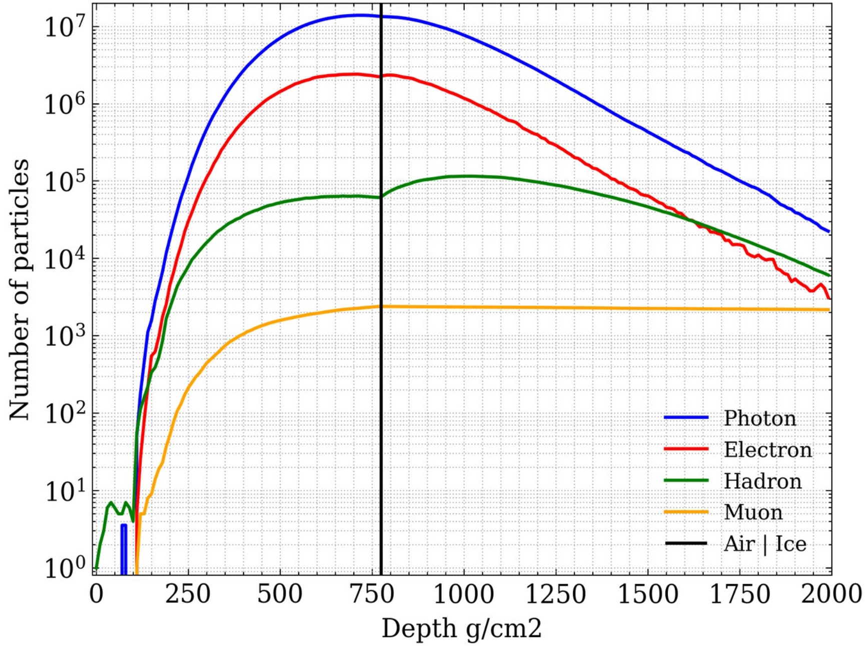


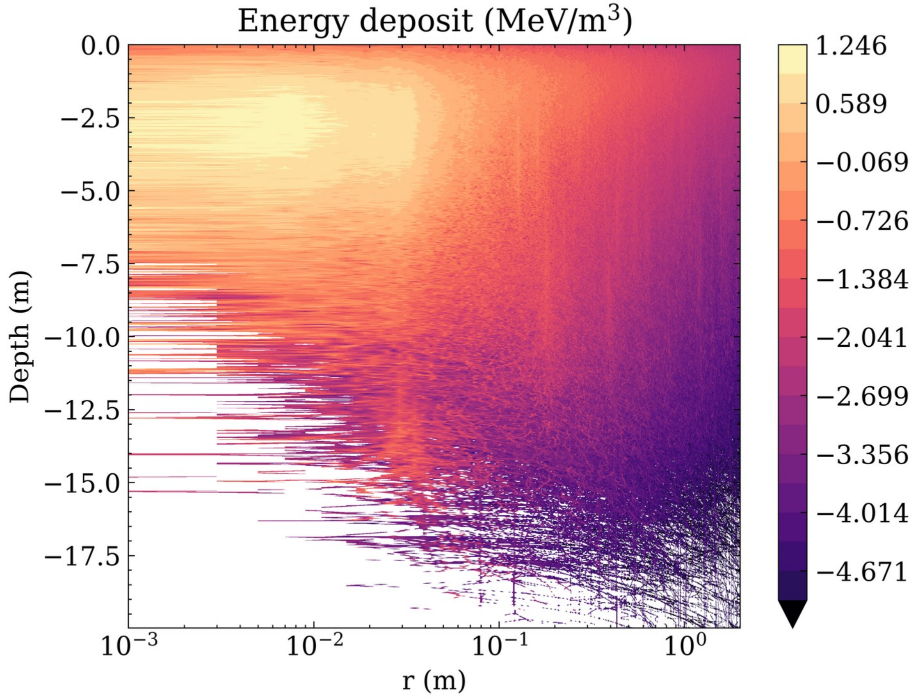
Poster contents/objectives

- Introduction to Corsika 8 structure (volume nodes, distance to next volume...).
- Show the flexibility of Corsika 8 for different experimental situations and how you can construct a medium.
- Show that cross-media showers work by comparing to C7+Geant4.
- Show with a simple example the possibility of medium specific radio propagators.

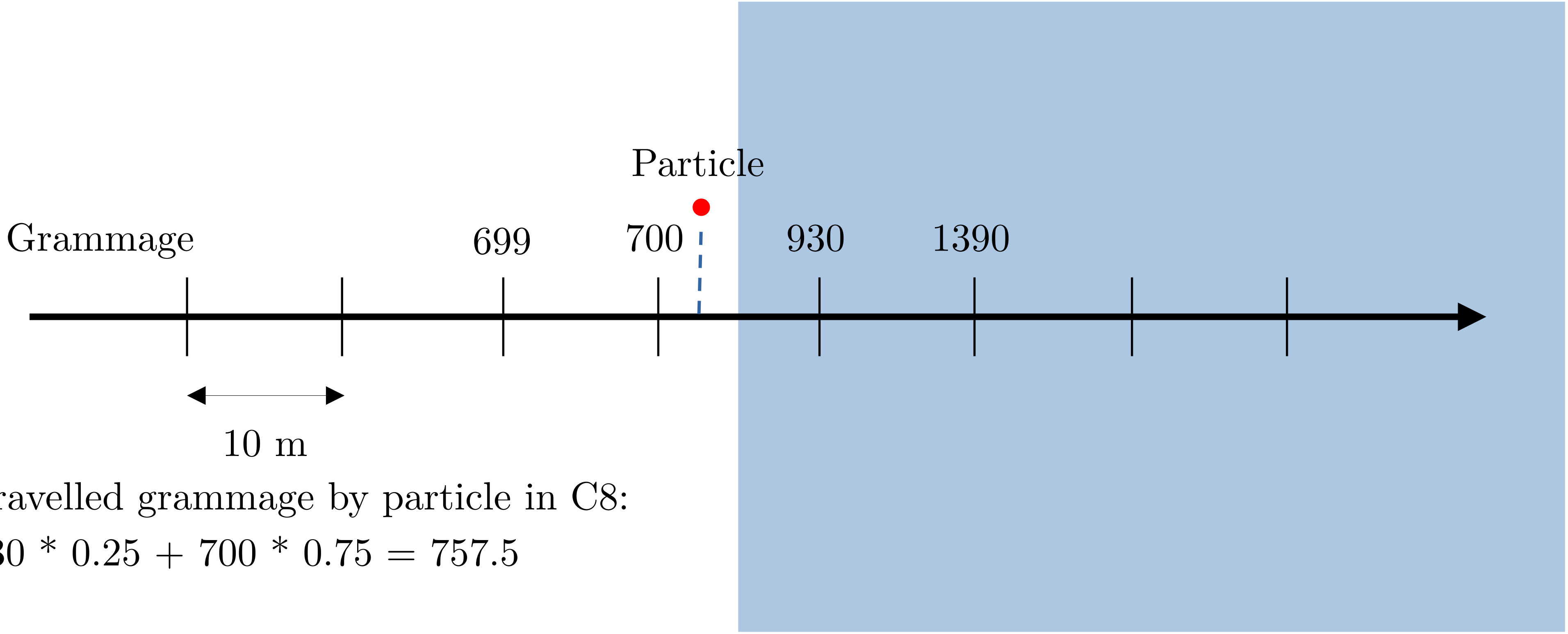
Backup Slides

Some results: hom. ice





Shower axis problem



Travelled grammage by particle in C8:

930 * 0.25 + 700 * 0.75 = 757.5

Real grammage travelled: ~ 700.25

Last year pulses in ice: