# Simulating an Active Muon Veto

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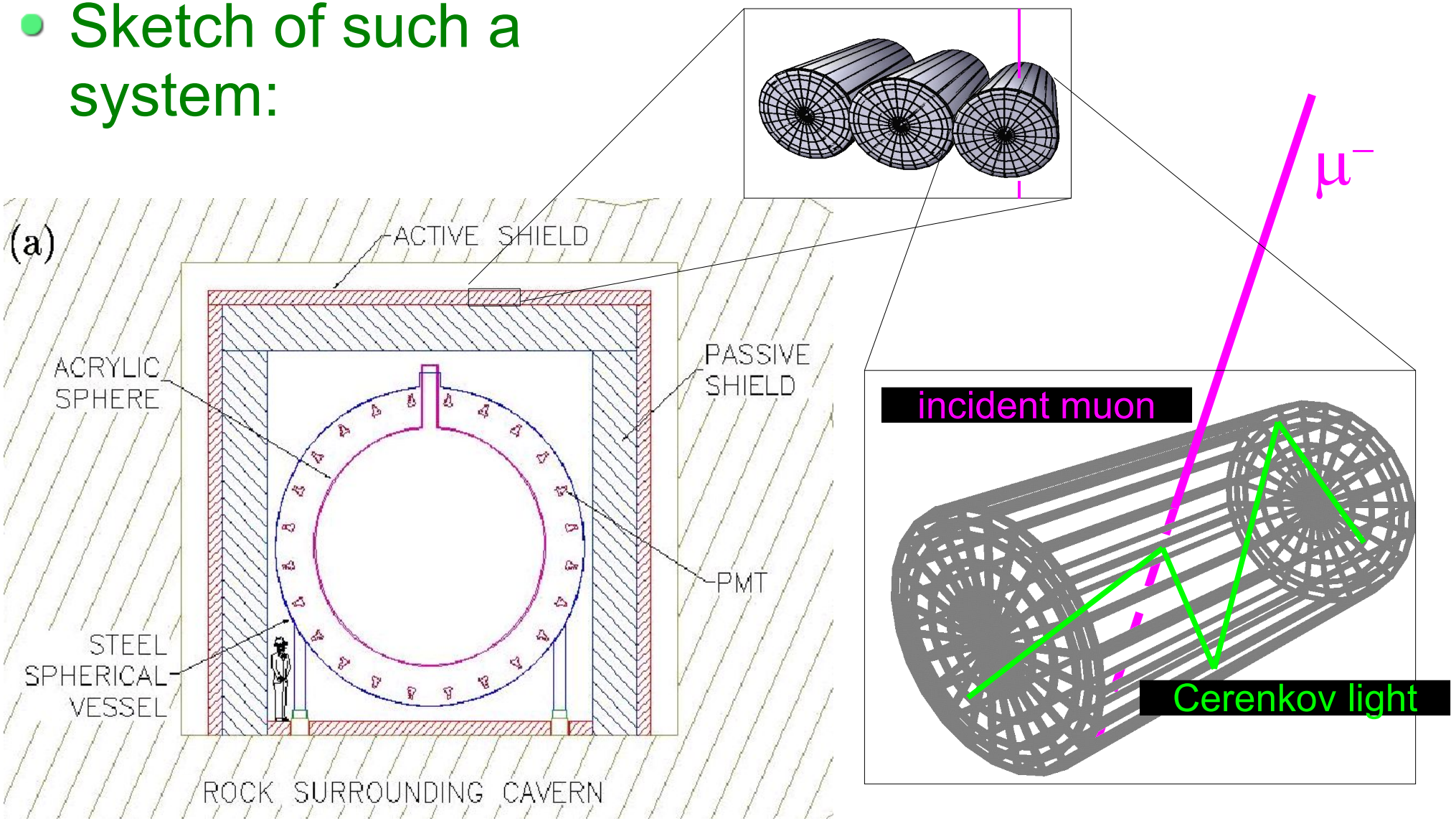
# Overview

- Sketch of the Veto System
- Simulation Toolkit (GEANT4)
- Elements of the Simulation
  - Material
  - Physics Processes
- Expectations and Preliminary Results

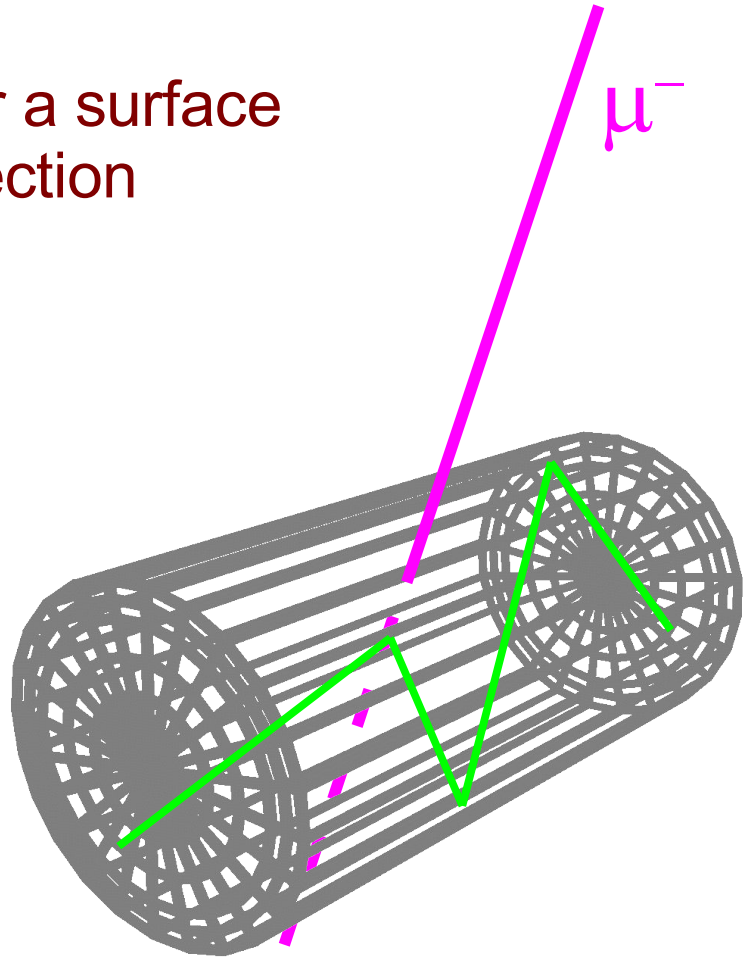
# An Active Muon Veto System

- Sketch of such a system:



# Layout of a "MuTube"

- Active muon veto tube ("MuTube"):
  - cylindrical encasement
    - highly reflective inner surface, or a surface coated to yield total internal reflection
    - dimensions: ~10cm × ~700cm
  - internal liquid medium
    - water or scintillator
  - active endcap readout
    - phototube or fiber-optic "pancake"



# GEANT4: A Simulation Toolkit (C++)

- Simulation platform of choice is GEANT4
  - http://wwwasd.web.cern.ch/wwwasd/geant4/geant4.html
  - Builds on a lot of existing tools and knowledge
- Benefits
  - if familiarity with C++ exists...
    - easy design of materials, and detector elements
  - event visualization
- Drawbacks
  - Large numbers of particles incur a time penalty
    - ... lots of Cherenkov photons ...

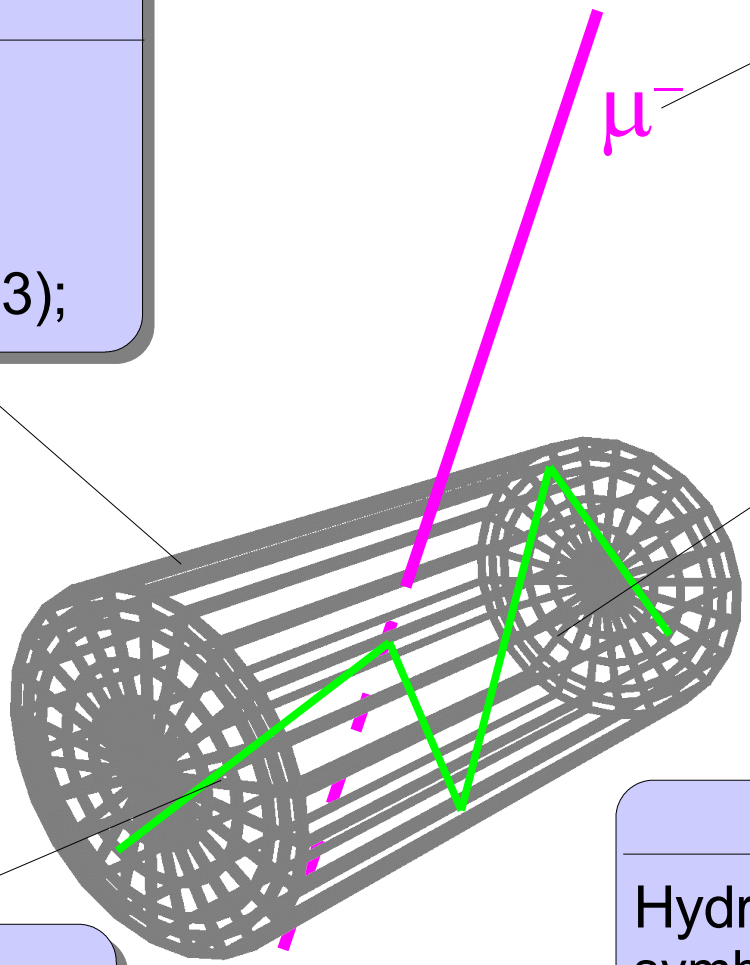
# Sketch of MuTube in GEANT4

**G4Material**

Aluminum:
z= 13.,
a= 26.98*g/mole,
density= 2.7*g/cm3);

**G4ParticleDefinition**

mass, width, charge,
spin, parity, isospin




**G4Material**

Water:
density= 1.000*g/cm3,
ncomponents=2
::AddElement(H, natoms=2);
::AddElement(O, natoms=1);

**G4Element**

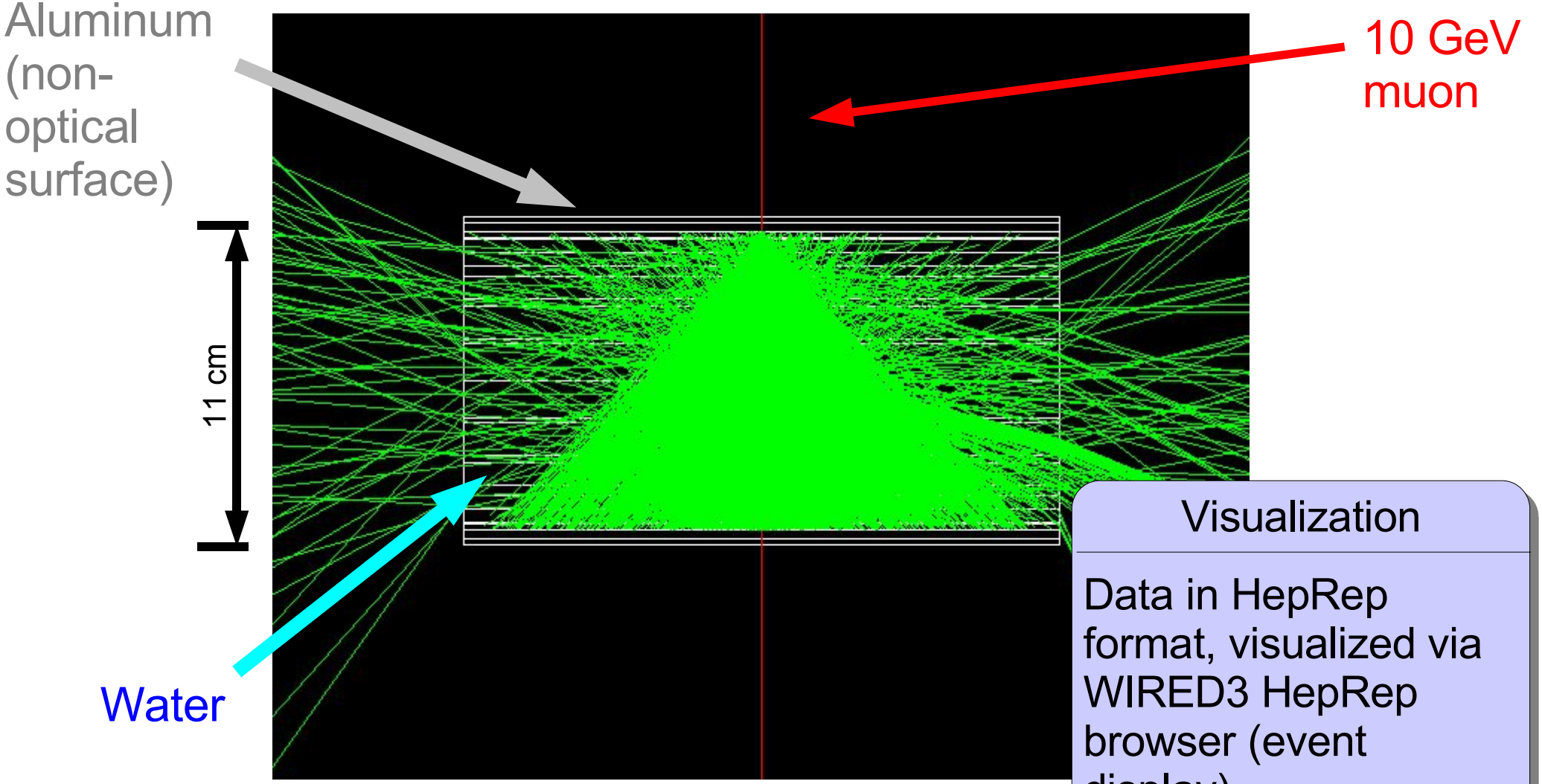
Hydrogen
symbol="H" , z= 1., a=
1.01*g/mole

**G4Cerenkov**

# Physics Processes

- Muon
  - Multiple Scattering
  - Ionization
  - Pair production
  - Bremsstrahlung
  - Cerenkov emission
- Optical Photon
  - Absorption
  - Rayleigh Scattering
  - Boundary processes (reflection, etc)

# Simple Example Simulation




**Visualization**

Data in HepRep format, visualized via WIRED3 HepRep browser (event display)

# Properties of the Water

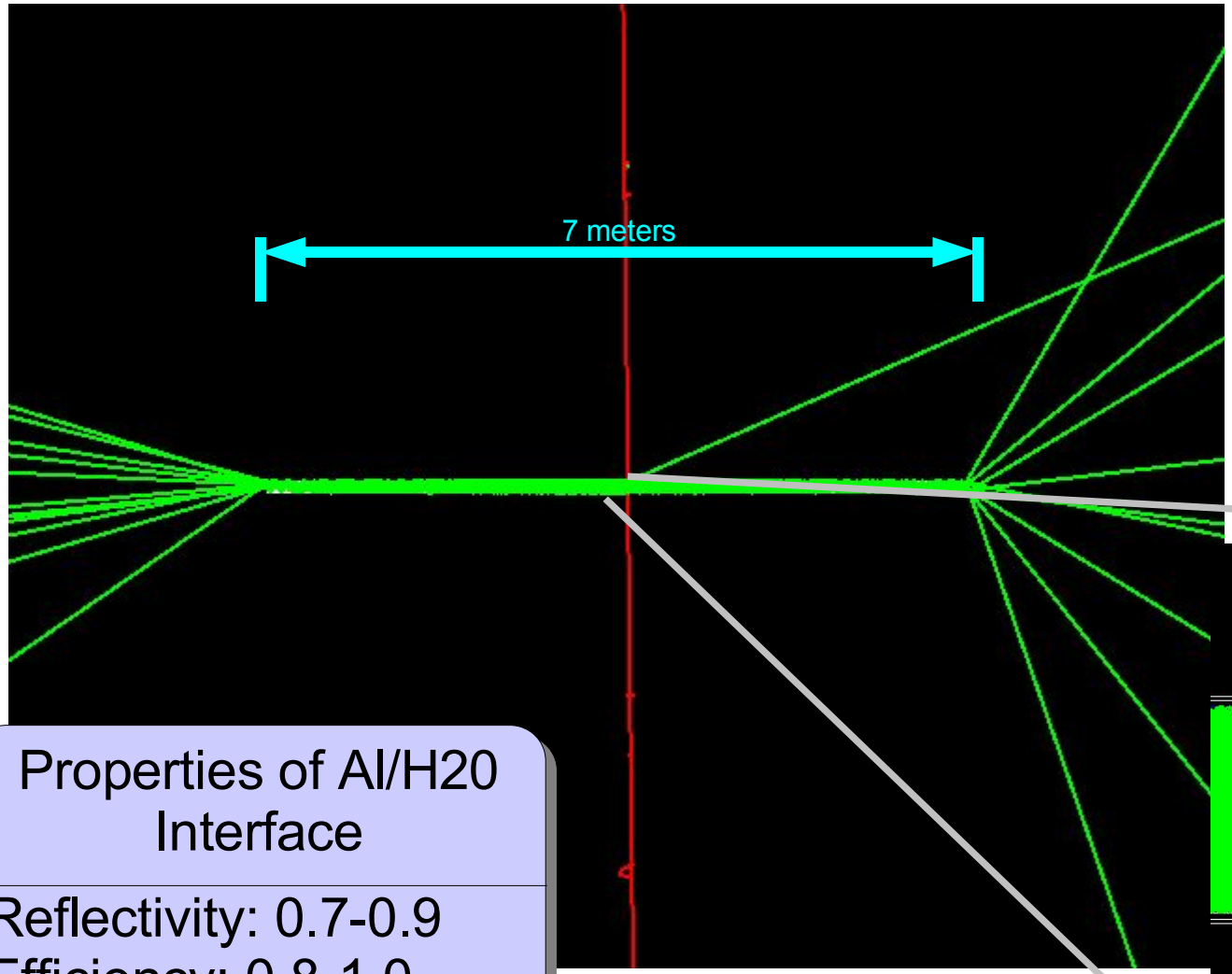
```
G4double PhotonEnergy[nEntries] =
          { 2.034*eV, 2.068*eV, 2.103*eV, 2.139*eV,
            2.177*eV, 2.216*eV, 2.256*eV, 2.298*eV,
            2.341*eV, 2.386*eV, 2.433*eV, 2.481*eV,
            2.532*eV, 2.585*eV, 2.640*eV, 2.697*eV,
            2.757*eV, 2.820*eV, 2.885*eV, 2.954*eV,
            3.026*eV, 3.102*eV, 3.181*eV, 3.265*eV,
            3.353*eV, 3.446*eV, 3.545*eV, 3.649*eV,
            3.760*eV, 3.877*eV, 4.002*eV, 4.136*eV };
//
// H2O
//
G4double RefractiveIndex1[nEntries] =
          { 1.3435, 1.344,  1.3445, 1.345,  1.3455,
            1.346,  1.3465, 1.347,  1.3475, 1.348,
            1.3485, 1.3492, 1.35,   1.3505, 1.351,
            1.3518, 1.3522, 1.3530, 1.3535, 1.354,
            1.3545, 1.355,  1.3555, 1.356,  1.3568,
            1.3572, 1.358,  1.3585, 1.359,  1.3595,
            1.36,   1.3608};

G4double Absorption1[nEntries] =
         {3.448*m,  4.082*m,  6.329*m,  9.174*m, 12.346*m, 13.889*m,
         15.152*m, 17.241*m, 18.868*m, 20.000*m, 26.316*m, 35.714*m,
         45.455*m, 47.619*m, 52.632*m, 52.632*m, 55.556*m, 52.632*m,
         52.632*m, 47.619*m, 45.455*m, 41.667*m, 37.037*m, 33.333*m,
         30.000*m, 28.500*m, 27.000*m, 24.500*m, 22.000*m, 19.500*m,
         17.500*m, 14.500*m };
```

Photon energies...

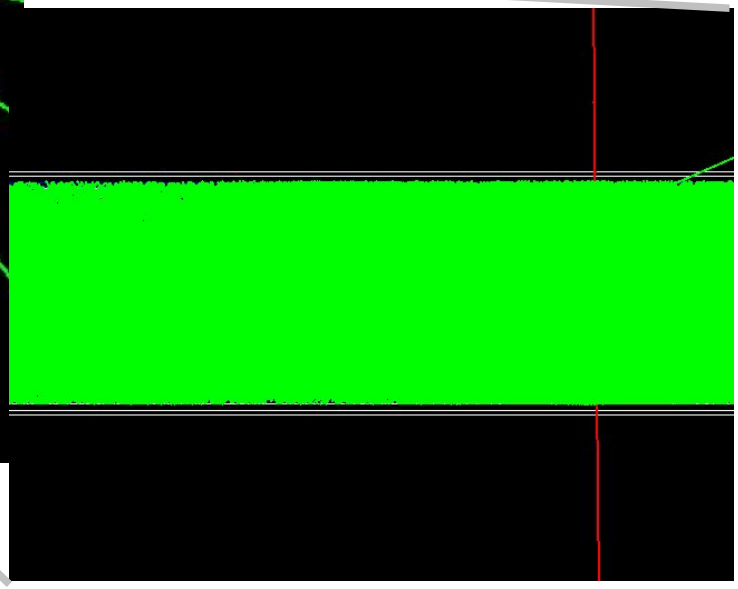
Refractive Index (function of photon energy)

Absorption (function of photon energy)

# More Complex Example Simulation




In this one event, we see ~10 photons leaking out each end



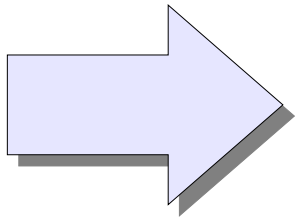
Properties of Al/H20 Interface

Reflectivity: 0.7-0.9
Efficiency: 0.8-1.0

# Expectations and Results

- How many Cerenkov photons are expected?

$$N = 2\pi\alpha l\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\sin^2(\theta_C)$$



**Estimate**

For *l*=10cm, visible light, and $\theta_C \approx 41°$ expect **~2000 photons**

- How many does GEANT4 produce?
  - ~5000 optical photons
    - what is the source of this discrepancy? More work to understand GEANT4, its configuration and behavior...

# Performance Issue

- Potential performance issue:
  - Large number of photons + reflections
    - ~30 seconds/event for a single tube
- Resolution
  - Build on BaBar DIRC (Cherenkov detector) experience with GEANT4...
    - Let GEANT4 generate the optical photon, but use PDFs and/or lookup tables to “propagate” the photon.

# Conclusion and Outlook

- GEANT4 can be used to explore veto scenarios
  - MuTube is a first pass at this...
- GEANT4 is a new experience at this level
  - why so many Cerenkov photons?
  - need to get data out in usable format (ROOT...)
- Plans:
  - Study the veto design and configuration
  - Integrate muon's production of neutrons in rock
    - add more elements to the simulation