Simulations of the Muon Veto for the PICO Experiment

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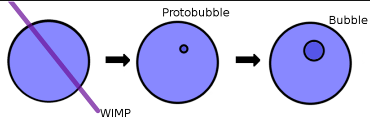
May 30, 2017

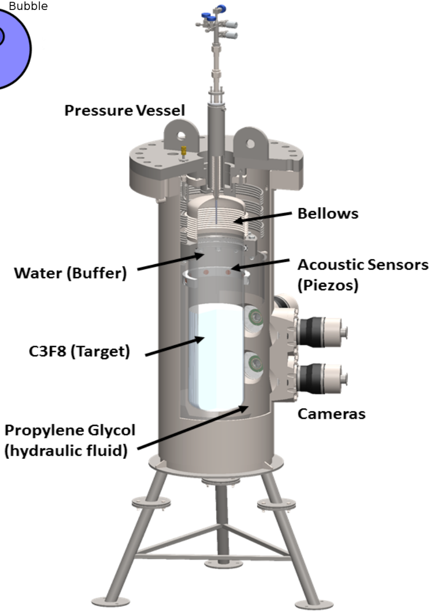
The PICO experiment

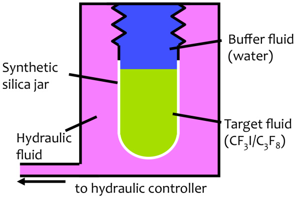
Detection Principles : Physics

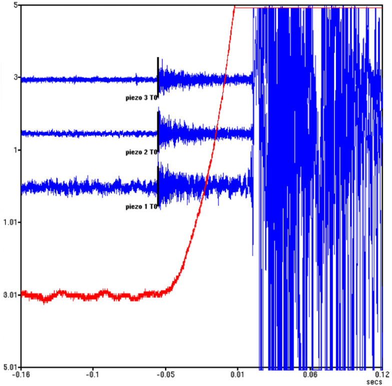


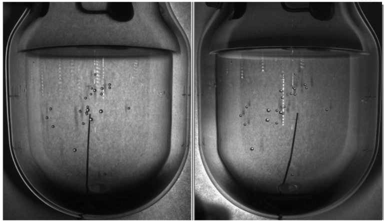
- Radiation induced boiling of superheated liquid : liquid-to-vapour phase transition.

- We put the detector in a metastable state and wait for the heat spike formed by a collision.



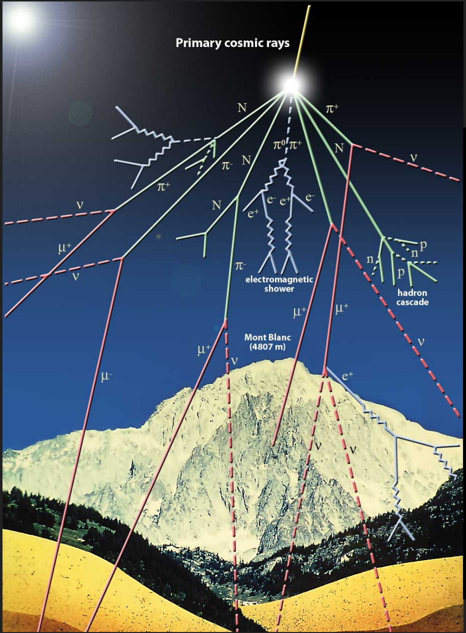




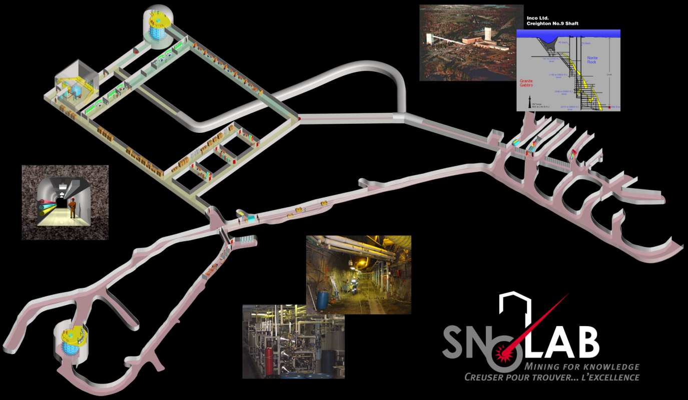


Backgrounds

Cosmic Rays : SNOLAB



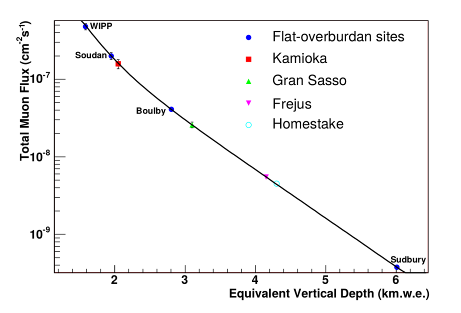
- 2 km underground (6010 MWE shielding)
- Class-2000 cleanroom



Physics and Backgrounds

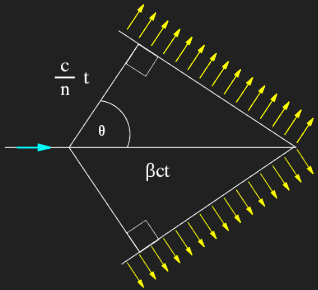
Cosmic Muons

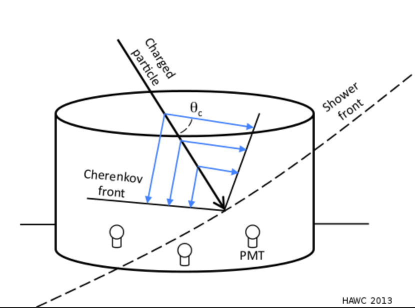
- Muons induce high energy neutrons.
- Muon flux in SNOLAB : 3.77×10^{-10} $cm^{-2}sec^{-1}$
- Detector surrounded by a muon veto



Geant4 Muon Veto Simulations

Physics





Muons travelling faster than the speed of light in water produce Cherenkov radiation.

$$n = 1.33 \text{ for water}$$

$$cos(\theta) = \frac{1}{n\beta}$$

$$\beta = v/c$$

number of optical photons produced :

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

Geant4 Muon Veto Simulations

Geant4 Technicalities

- Full simulation of the already existing veto for PICO-60
- Goal : optimize a geometry for the future veto for PICO-500.

- Geant4.10.03

Particles :

- G4OpticalPhoton
- G4Meson
- G4Boson
- G4Baryon
- G4Ion

Processes :

- G4Cerenkov
- G4OpBoundaryProcess
- G4Scintillation
- G4OpAbsorption
- G4OpRayleigh

Geant4 Muon Veto Simulations

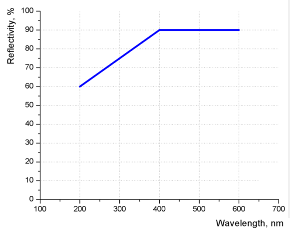
Detector Geometry

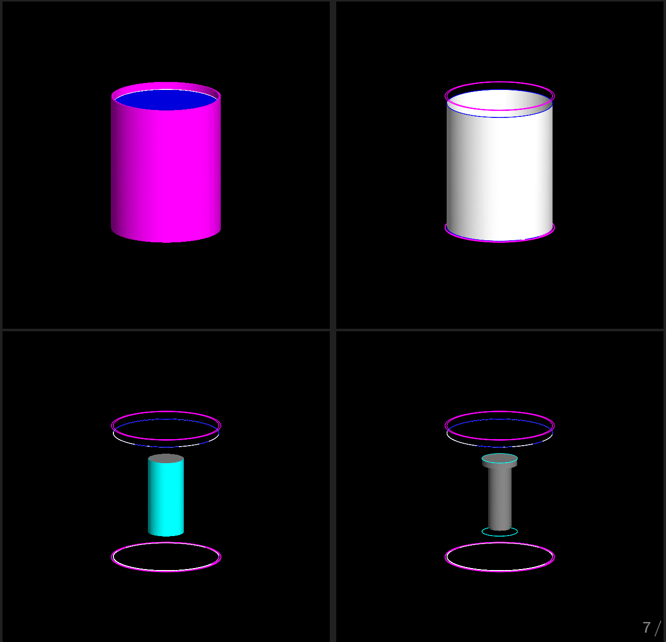
- Water (UPW)
- Water Tank

  3.6m, d=2.8m, thickness=5cm
- PVC liner

  (C_2H_3Cl) density 1.35 g/cm^3
- Pressure vessel

  Stainless Steel 302, density=8.03*g/cm^3
- TYVEK cover



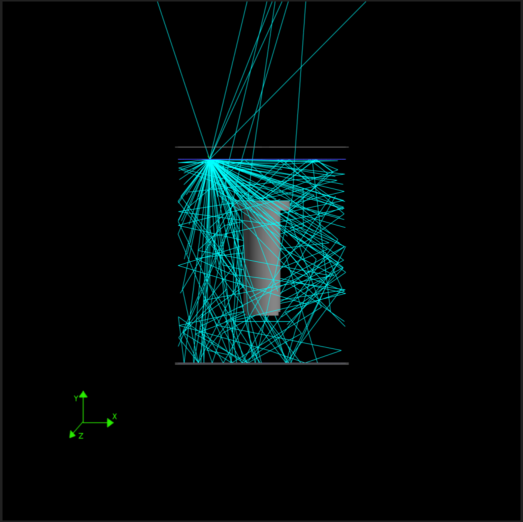


Geant4 Muon Veto Simulations

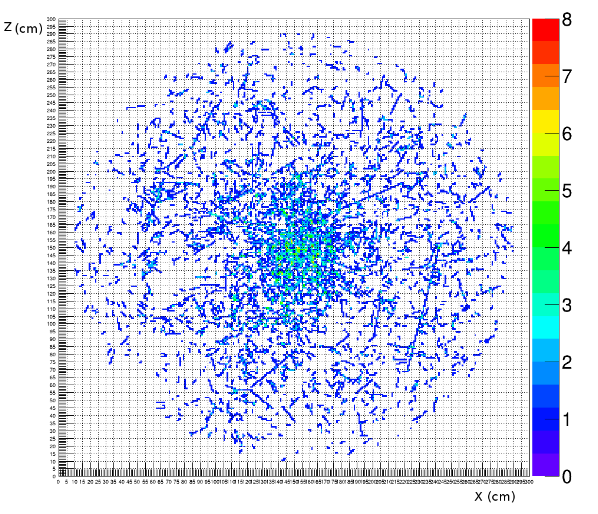
Scoring - Optical Photons Counting

3m x 3m scoring mesh with 1cm x 1cm bins on top of the water tank.

1 MeV e^- :



1000 x 1 MeV e^- :



Geant4 SNOLAB Muon Source

D.-M. Mei, A. Hime. *Muon-Induced Background Study for Underground Laboratories.*

The energy spectrum :

$$\frac{dN}{dE_\mu} = Ae^{-bh(\gamma_\mu - 1)}[E_\mu + \epsilon_\mu(1 - e^{-bh})]^{-\gamma_\mu}$$

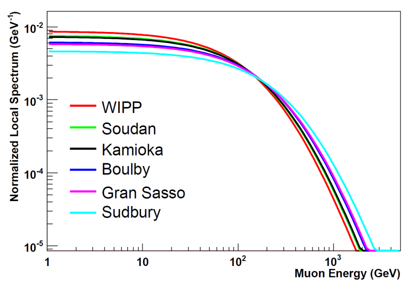
With A the normalization constant with respect to the differential muon intensity at a given depth h, E_μ the muon energy after crossing h.
$b = 0.4/\text{km.w.e.}$, $\gamma_\mu = 3.77$ and $\epsilon_\mu = 693$ GeV.

The muon angular distribution :

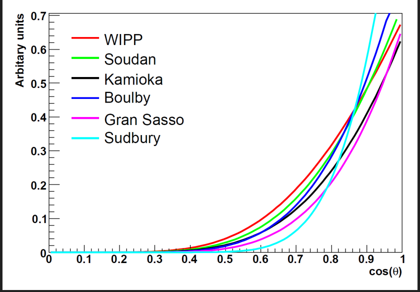
$$I_{th}(h,\theta) = \frac{I_1 e^{\left(\frac{-h_0}{\lambda_1 cos(\theta)}\right)} + I_2 e^{\left(\frac{-h_0}{\lambda_2 cos(\theta)}\right)}}{cos(\theta)}$$

vertical depth h_0, zenith angle θ, $I_1 = (8.60 \pm 0.53) \times 10^{-6}$ sec^{-1} cm^{-2} sr^{-1}, $I_1 = (0.44 \pm 0.0) \times 10^{-6}$ sec^{-1} cm^{-2} sr^{-1}, $\lambda_1 = 0.45 \pm 0.01$ km.w.e.
$\lambda_2 = 0.87 \pm 0.02$ km.w.e.

Muon Energy Spectrum :



Muon Angular Distribution :



Geant4 Muon Veto Simulations

Modelling The Muon Source : Angular distribution

- All muons must hit the detector to reduce computer time.
- Initial position of particles is set as a 8m diameter half dome around the detector.
- Initial momentum is set as "towards center of bottom of detector".

$$I_{th}(h,\theta) = \frac{I_1 e^{\left(\frac{-h_0}{\lambda_1 cos(\theta)}\right)} + I_2 e^{\left(\frac{-h_0}{\lambda_2 cos(\theta)}\right)}}{cos(\theta)}$$

vertical depth h_0, zenith angle θ,
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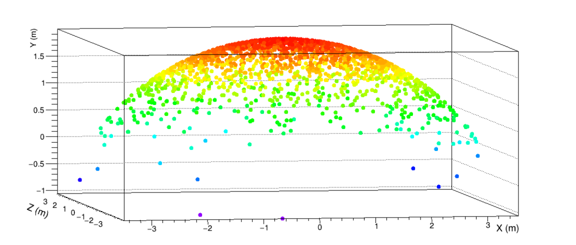
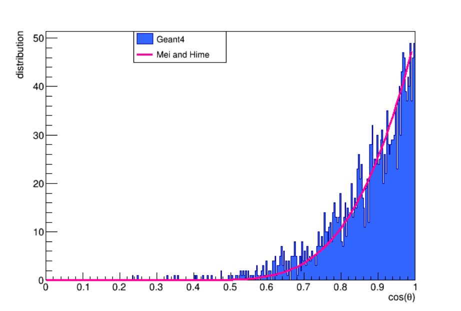
Initial position of 2000 muons :



$cos(\theta)$ (arbitrary units) :



Geant4 Muon Veto Simulations

Modelling The Muon Source : Energy distribution

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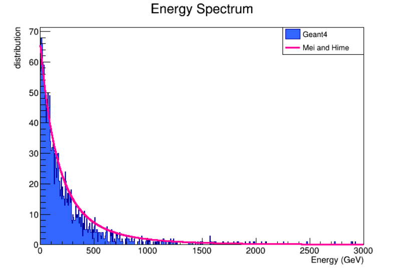
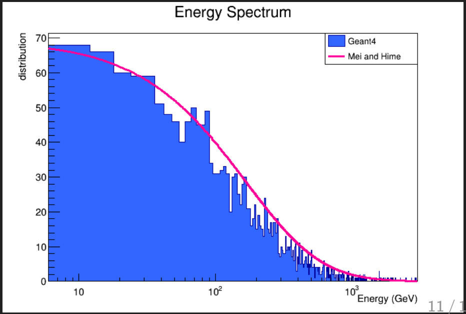
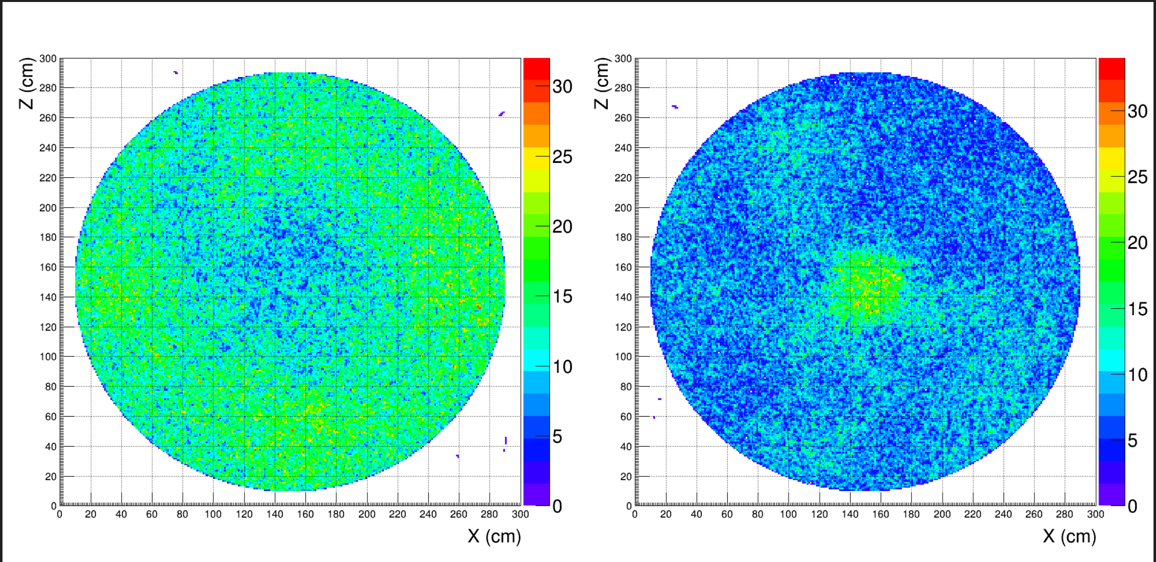




Geant4 Muon Veto Simulations

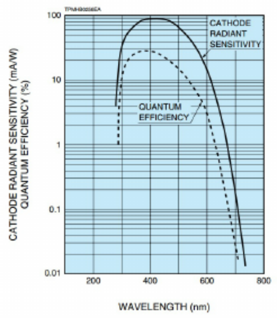
Results for the PICO-60 Veto (bottom and top scoring meshes)



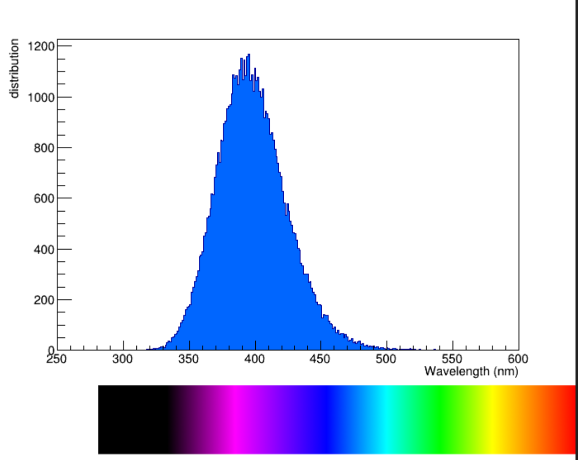
Results

Optical Photon Energy

Efficiency curve for PMT Hamamatsu :



Energy of optical photons in scoring mesh :



- Area of PMTs vs water tank $\sim$ 3.74%
- Total photons detected $\sim$448 photons per muon.

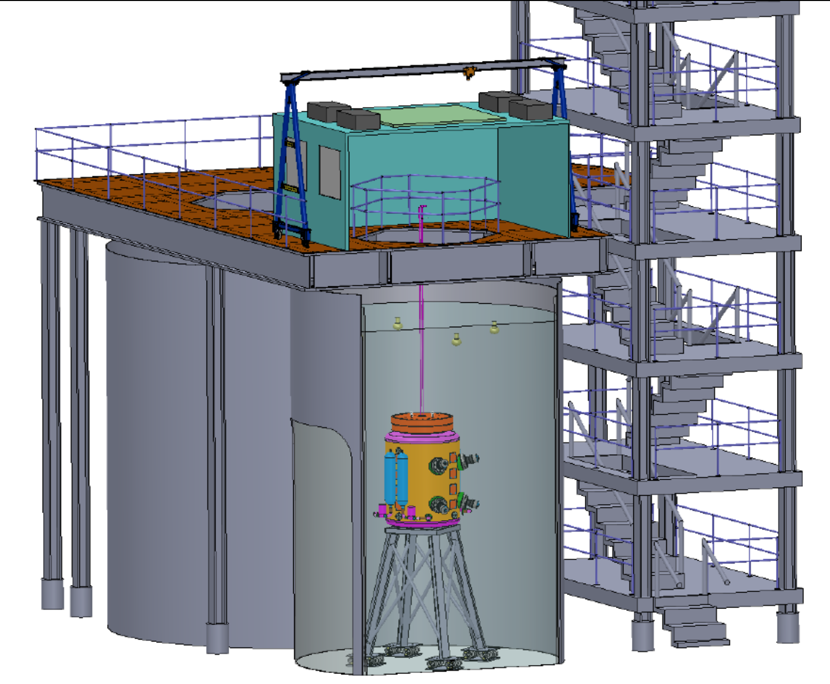
Future Veto for PICO 500

Next Steps

A geometry for a pico500 muon veto has been implemented in Geant4.

- Run simulations on SHARKNET (desktop computer takes $\sim$10h per muon)
- Extract Scoring Meshes to optimize placement of PMTs
- Try other geometries (spherical, cylindrical...)
- Test different reflectivities of tyvek and bottom of tank to maximise photon counting

Future Veto for PICO 500



Thank you for attending!