Simulations of the Muon Veto for the PICO Experiment

Olivia Scallon

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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: \(3.77 \times 10^{-10}\) \(cm^{-2}sec^{-1}\)
- Detector surrounded by a muon veto
Muons travelling faster than the speed of light in water produce Cherenkov radiation.

\[ n = 1.33 \text{ for water} \]

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

\[ \beta = \frac{v}{c} \]

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

1 MeV $e^-$:

1000 x 1 MeV $e^-$:
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 \(h\), \(E_{\mu}\) the muon energy after crossing \(h\).

\(b = 0.4/\text{km.w.e.}, \gamma_{\mu} = 3.77\) and \(\epsilon_{\mu} = 693\ \text{GeV}\).

The muon angular distribution:

\[
l_{th}(h, \theta) = l_1 e^{\frac{-h_0}{\lambda_1 \cos(\theta)}} + l_2 e^{\frac{-h_0}{\lambda_2 \cos(\theta)}} \cos(\theta)
\]

vertical depth \(h_0\), zenith angle \(\theta\), \(l_1 = (8.60 \pm 0.53) \times 10^{-6}\) sec\(^{-1}\) cm\(^{-2}\) sr\(^{-1}\), \(l_2 = (0.44 \pm 0.0) \times 10^{-6}\) 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.
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”.

\[
I_{th}(h, \theta) = \frac{l_1 e^{-\frac{h_0}{\lambda_1 \cos(\theta)}} + l_2 e^{-\frac{h_0}{\lambda_2 \cos(\theta)}}}{\cos(\theta)}
\]

vertical depth \( h_0 \), zenith angle \( \theta \),

\( l_1 = (8.60 \pm 0.53) \times 10^{-6} \text{ sec}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \),

\( l_2 = (0.44 \pm 0.0) \times 10^{-6} \text{ sec}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \),

\( \lambda_1 = 0.45 \pm 0.01 \text{ km.w.e.} \),

\( \lambda_2 = 0.87 \pm 0.02 \text{ km.w.e.} \).
Geant4 Muon Veto Simulations

Modelling The Muon Source: Energy distribution

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

A the normalization constant with respect to the differential muon intensity at a given depth \( h \),
\( E_\mu \) the muon energy after crossing \( h \).
\( b = 0.4/\text{km.w.e.} \),
\( \gamma_\mu = 3.77 \)
\( \epsilon_\mu = 693 \text{ GeV} \)
Geant4 Muon Veto Simulations

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

- Area of PMTs vs water tank $\sim 3.74\%$
- Total photons detected $\sim 448$ photons per muon.
A geometry for a pico500 muon veto has been implemented in Geant4.

- Run simulations on SHARKNET (desktop computer takes \(\sim 10\)h 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!

Seminar Appeal = \frac{Relevance \times Food}{(Distance)^2}