Imaging by muons and their induced secondary particles – a novel technique

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Outline

1. Motivation
   - Cosmic muons for imaging
   - Cosmic muon induced secondaries
2. Secondaries produced by cosmic muons
   - Ionization, Bremsstrahlung, pair production (and nuclear interaction)
3. MUon CAmera (MUCA)
   - Setup
   - Results
   - Geant4 simulations

- Muons with cosmic origin have been used to imagine by their:
  - absorption of large volumes (several radiation length)
  - scattering in high density material ($\propto Z^2$)
- Could the secondary particles created in the muon-material interaction be used as well?
- The MUon CAmera (MUCA) system developed to investigate the possible usage of this phenomena by
  - University of Novi Sad
  - Wigner Research Centre for Physics

Secondaries produced by cosmic muons

Relevant processes

μ - material interactions:

- Ionization
- Bremsstrahlung
- Pair production
- (Nuclear interaction)

What secondaries can we measure?

μ critical E typically $\sim$ TeV

- More e- are created
- e- are also suppressed upon leaving the material

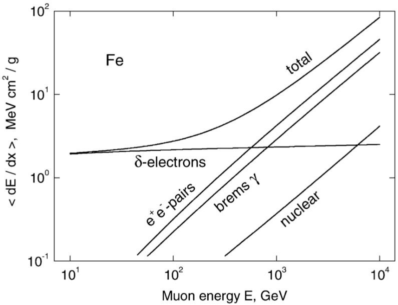

Figure 1: Energy loss of μ in iron due to different proccesses[1]

- 4 Close Cathode Chambers
  - for tracking μ
- A HPGe detector
  - inside the target for secondary e^- and γ
- Hit defined by the coincidence of secondary and primary tracks

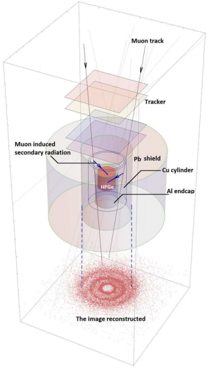

Figure 2: First design of the MUCA system. A cosmic μ is identified by trackers, while the secondaries are detected by a HPGe detector [2]

MUon CAmera (MUCA)

Current setup

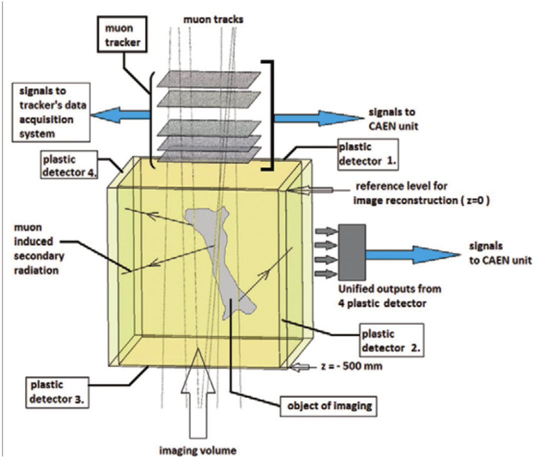

Figure 3: First design of the MUCA system. A cosmic μ is identified by trackers, while the secondaries are detected by 4 scintillators [2]

Results

Bone

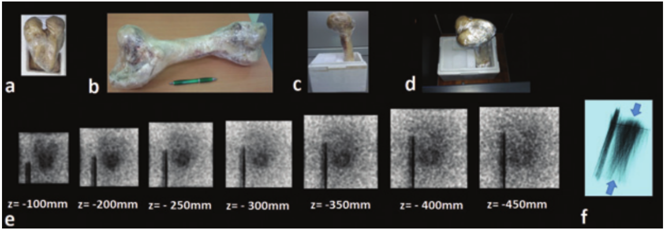

Figure 4: A cow femur bone investigated. (a) Top view of the bone. (b) Full view of bone. (c) Side view of bone prepared for imaging. (d) Bone with styrofoam holder placed inside the volume of imaging. (e) 2D image slices of the bone for different depths along the bone axis. (f) 3D view of the bone reconstructed from 2D image slices. The arrows mark the orientation of the bone axis. Acquisition time $\sim$ 4 day [2]

Results

Low and high Z materials

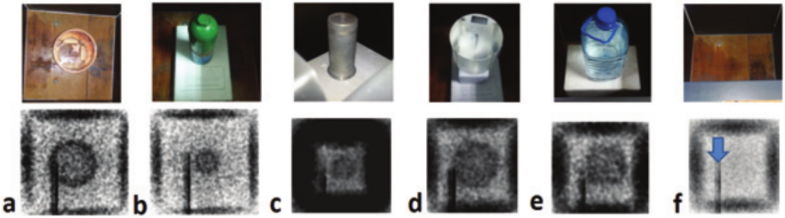

Figure 5: (a) Cu cylinder (b) Iron cap (c) Aluminum cap (d) Headphantom (e) Water in plastic bottle (f) Background image (empty imaging volume) an arrow appeared due to electronic noise in the trackers layer. Acquisition time ∼ 1 day [2]

Questions to be answered:

- How does the secondary:
  - spectrum look like?
  - angle distribution look like?
- How does the ratio of e^- and γ change by atomic number?
  - Could it be used to distinguish different materials?
- How can we decrease acqusition time?

- 4 plastic scintillators
- 1 PMT for each scintillator
- Target of 10x10x0.5 cm^3
- Optical photon propagation included
- Optical properties of materials and PMT included

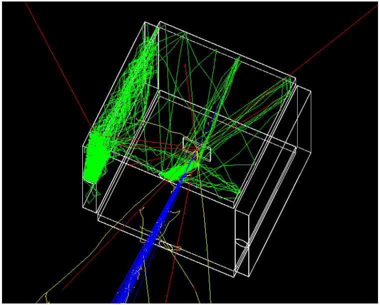

Figure 6: Simulation of the MUCA system with a 10x10x0.5 cm^3 lead brick in the middle being hit by 50 muons

Output:

- Energy of e^- and γ created
- Energy of e^- and γ leaving target
- Direction of these "secondaries"
- Detected photon spectrum for each scintillator

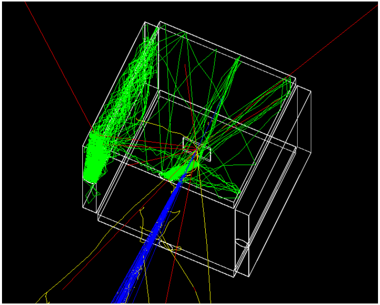

Figure 7: Simulation of the MUCA system with a 10x10x0.5 cm^3 lead brick in the middle being hit by 50 muons

Geant4 simulations

Lead target, 1 GeV muons

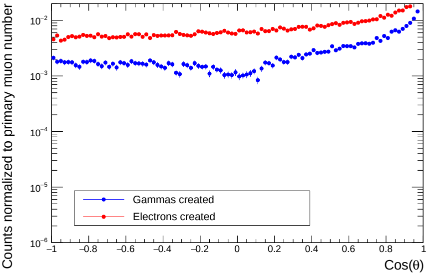

Figure 8: Azimuthal angle of produced particles

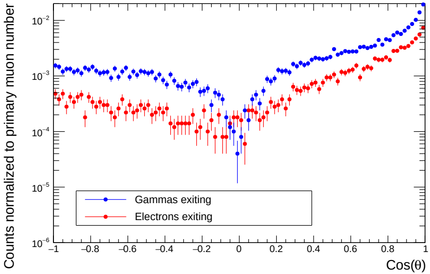

Figure 9: Azimuthal angle of particles leaving the target

Geant4 simulations

Lead target, 1 GeV

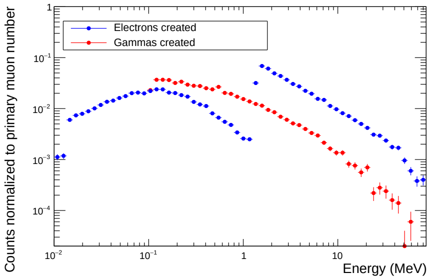

Figure 10: Energy distribution of produced particles

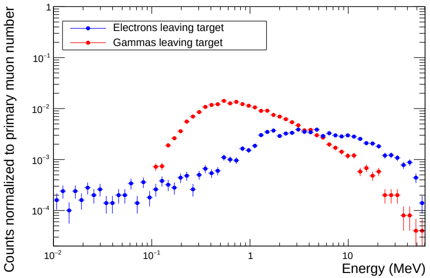

Figure 11: Energy distribution of particles leaving the target

Geant4 simulations

Secondary production for different materials

	Lead	Copper	Water	Polystyrene
γ, E $\geq$ 0.1 MeV	20.7 %	10.6 %	0.14 %	0.14 %
e^-, E $\geq$ 1 MeV	6.68 %	13.1 %	6.08 %	4.7 %

Table 1: Number of particles produced in the target which leave the target with a given energy treshold

Geant4 simulations

How to improve the system?

- More than 50 % of secondaries leave the target with azimuthal angle $\leq 45^{\circ}$
- 4 additional scintillators included
- Not only there are more detections but the spectrum is harder for the scintillators on the bottom!

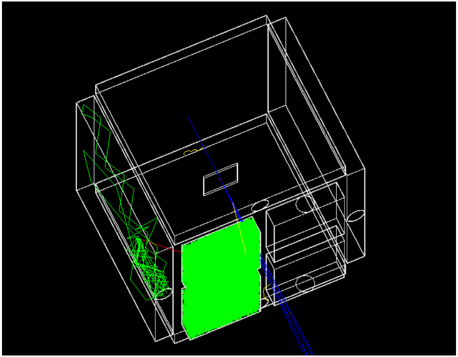

Figure 12: Simulation with four additional scintillators included to investigate their possible contribution

Geant4 simulations

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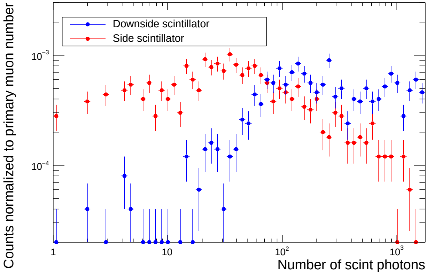

Figure 13: Detected optical photon spectrum in the bottom and the side scintillators. There is more and more energetic secondaries in the bottom detectors.

Summary

- A novel technique that takes advantage of the secondaries produced by cosmic muons
- Images obtained with the current setup including low Z targets
- Geant4 simulations:
  - understand the particle production
  - optimize the system
  - understand whether the secondaries give information on the target material

Bibliography I

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