Investigation of shielding powers of different materials and shielding depths for secondary cosmic rays

Aaron Michel, Allen Caldwell, Béla Majorovits, Christopher O'Shaugnessy
for the GERDA-Collaboration

Max-Planck-Institut für Physik

Outline:

- **Introduction**
- **Simulation of shields**
- **Shielding efficiency**
- **Results & Summary**

Feb 29 2012

The Problem:

- Usually the detector is well-shielded far underground
- In some cases that is not possible and the detector material needs to be on earth' surface
  - during transport
  - during production

  These processes happen only with minimal shielding!
- Activation of detector material due to secondary cosmic rays

  → production of radioactive isotopes

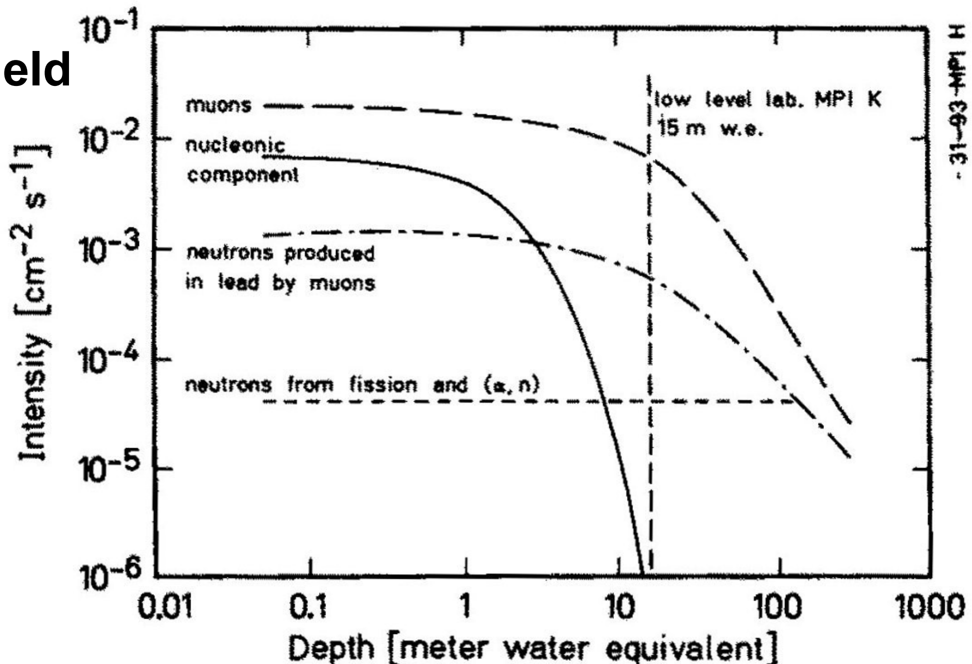
  → significant effect on background for experiment
- Shielding needs to be optimized
  - minimize exposure to cosmic rays
  - minimize cosmogenic activation

- **Characterization of shielding powers**
  - **Different materials usually distinguished by:**

water-equivalent

→ depth of the shield multiplied with the material's density (area density)

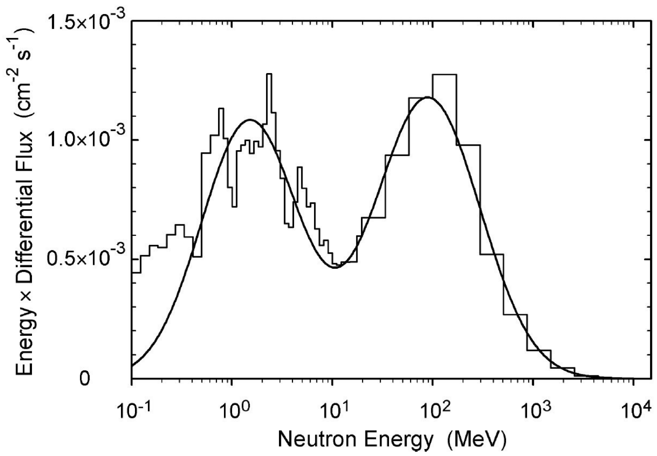
- **Questions:**
  - **How does the depth of the shield affect the shielding power?**
  - **Is there a minimal depth?**
  - **Is there an optimal material?**
  - **At what shielding depth is the nucleonic component negligible to the neutrons produced by muons?**

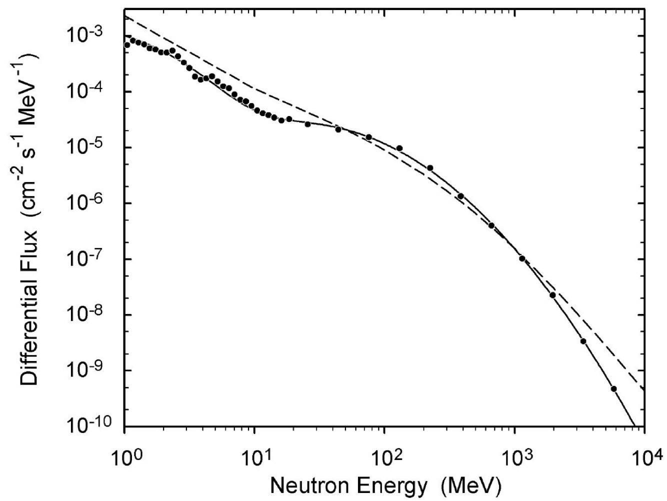


G. Heusser: Cosmic-ray induces background, NIM B, '93

- **Interested in:**
  - **amount & energy of the neutrons exiting a shield**

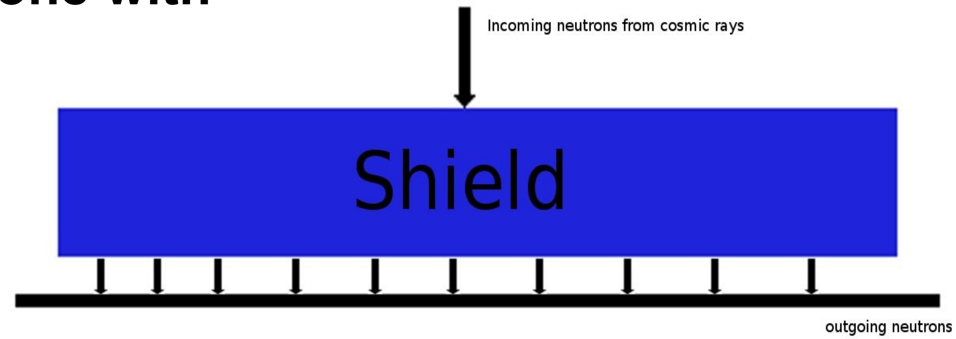
    → **How is the cosmogenic activation of the detector material reduced?**
    - **In relation to shielding depth and material**
- **Using a secondary cosmic ray neutron spectrum (measured in New York City)**
  - **changes in the order of a magnitude**
    - **for different locations**
    - **for different times**
- **This spectrum is the base for a series of Monte-Carlo simulations**





Gordon et al.: Measurement of cosmic-ray induced neutrons,TNS 51,'04

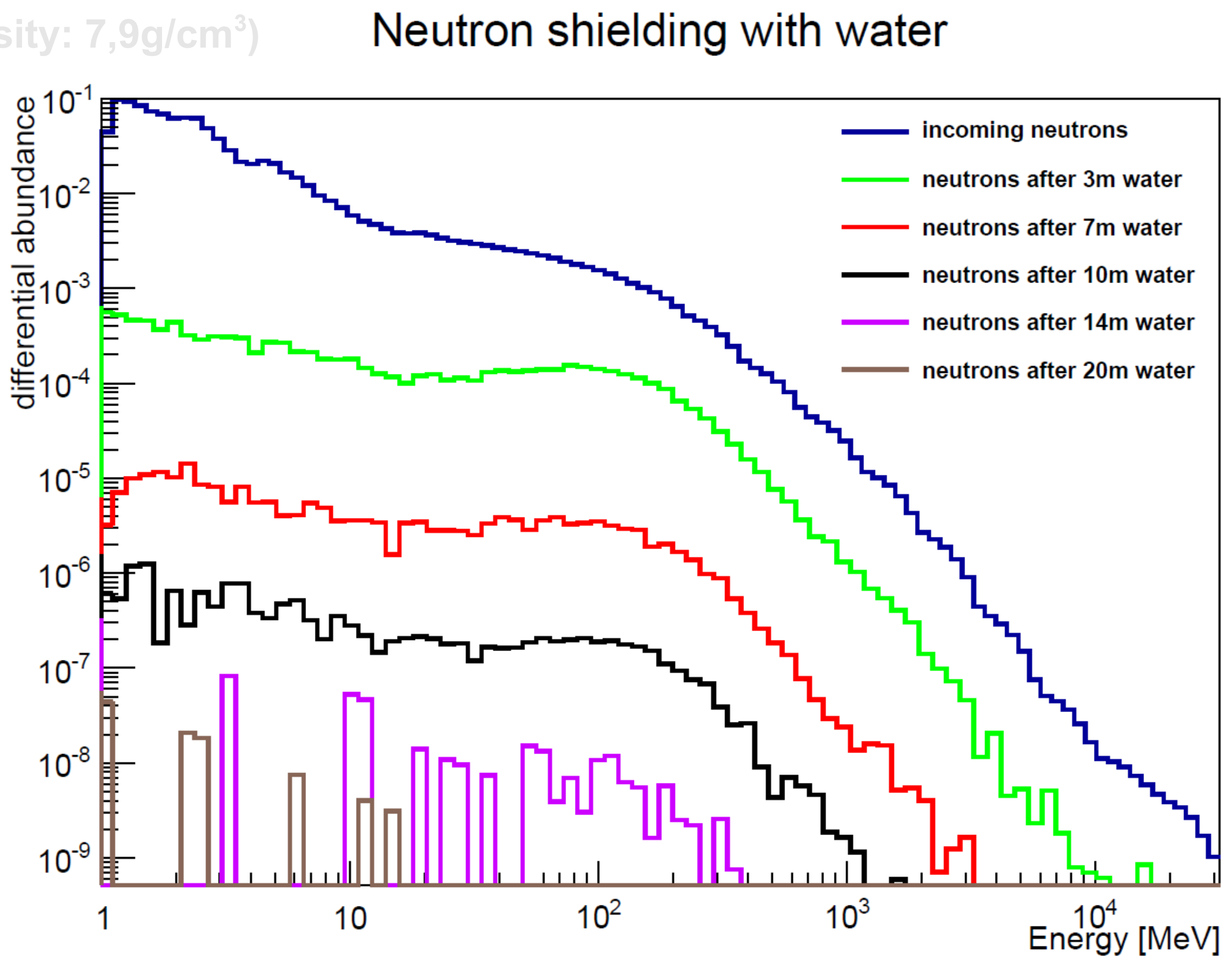
- **Monte-Carlo simulations of the shields**
  - **Geant4 9.4 with the help of MaGe[1] is used**
    - **physics-list carefully selected for high-energy processes**
      - **Lelastic-LENeutron-Neutronfission-Neutroncapture-BinaryCascade-QGSP**
  - **~ 10M neutrons (1 – 10^5 MeV) simulated coming from above through a shield**
  - **The energy spectrum of the outgoing neutrons gets recorded**
  - **Processing of the output done with Root 5.30**



[1] **Majorana Gerda simulation package**

Simulated neutron spectra

- **water** **(Density: 1g/cm³)**
  polyethylene (Density: 0.95g/cm³)
  steel (Density: 7,9g/cm³)

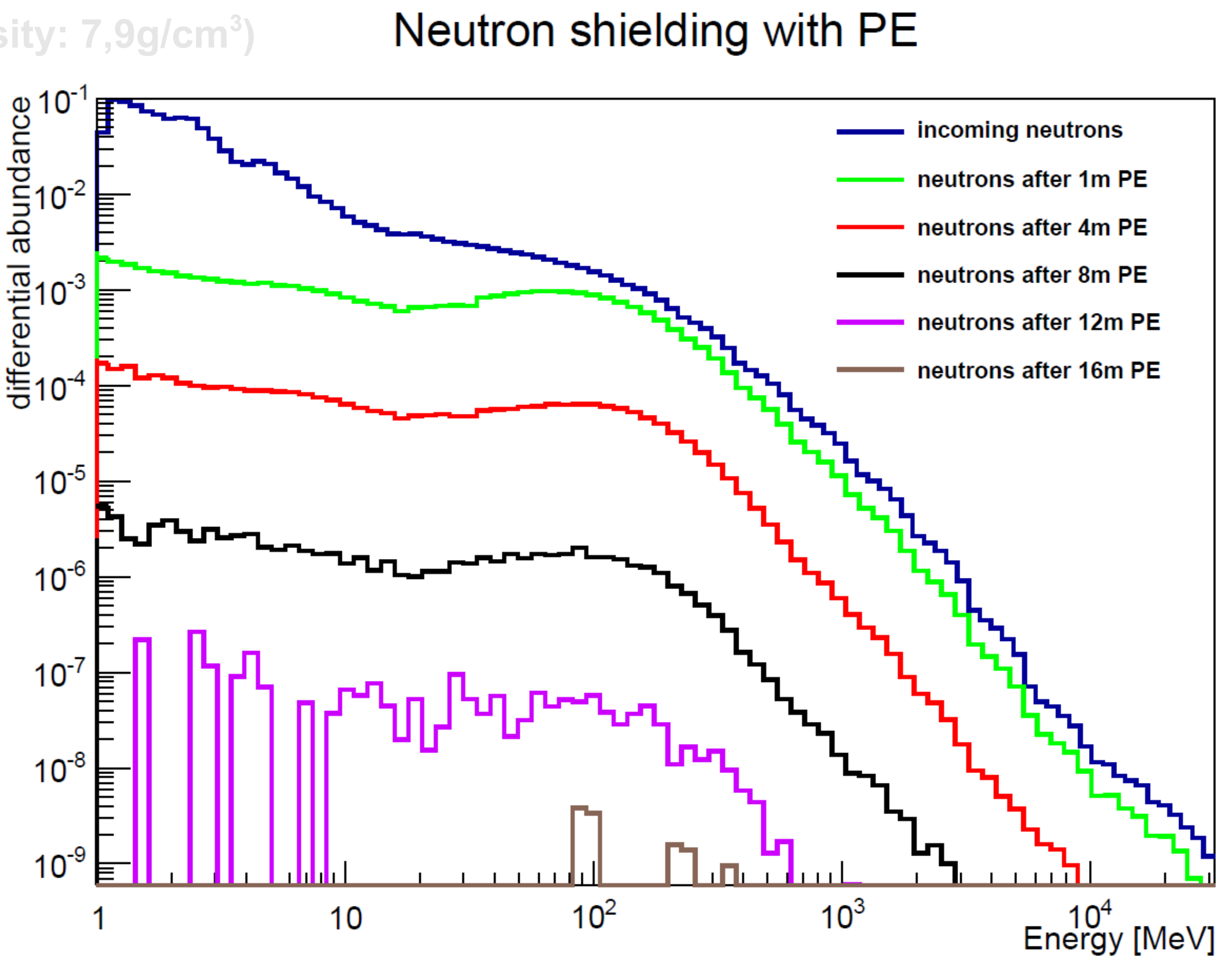


Simulated neutron spectra

water (Density: 1g/cm³)

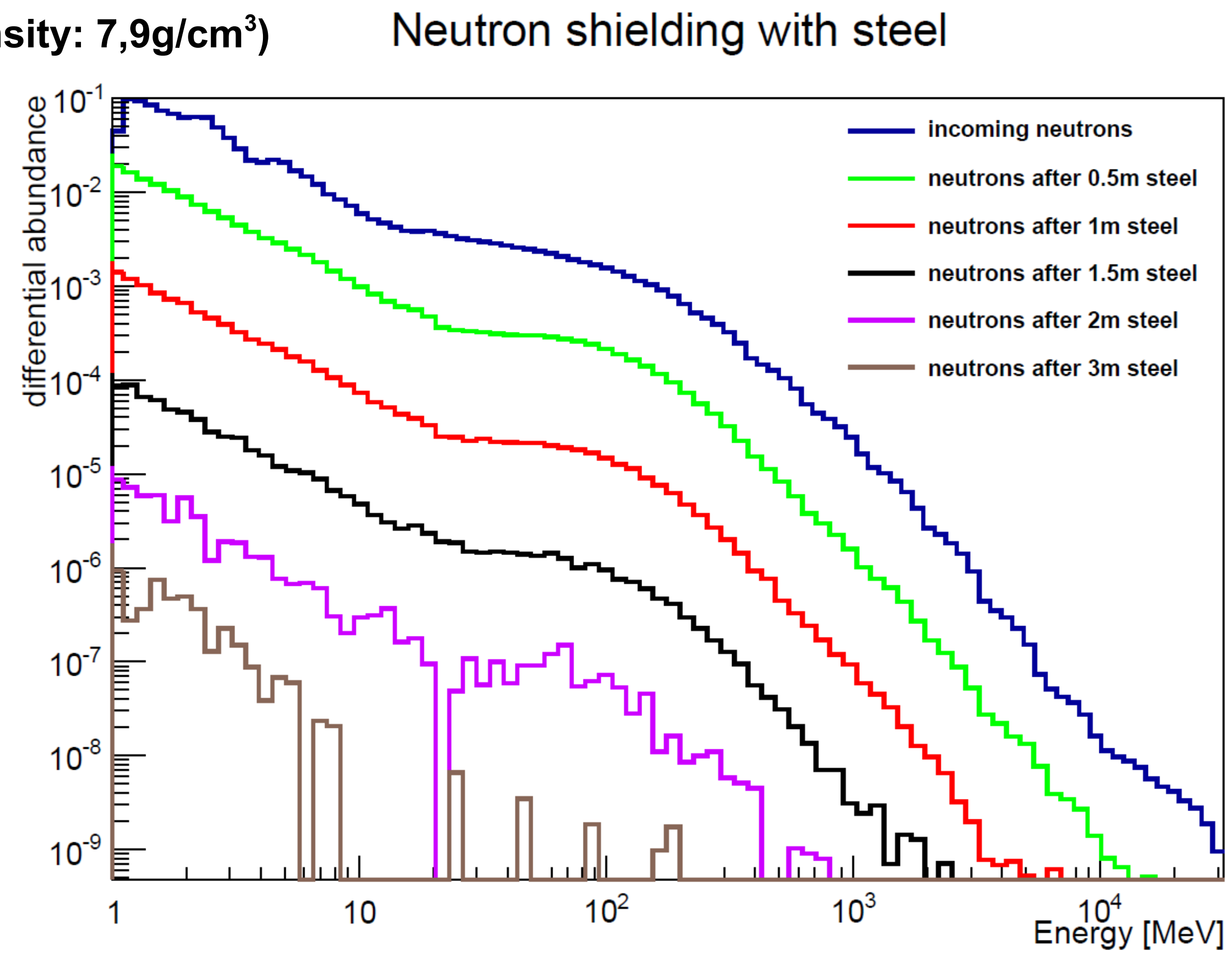
- **polyethylene (Density: 0.95g/cm³)**

steel (Density: 7,9g/cm³)

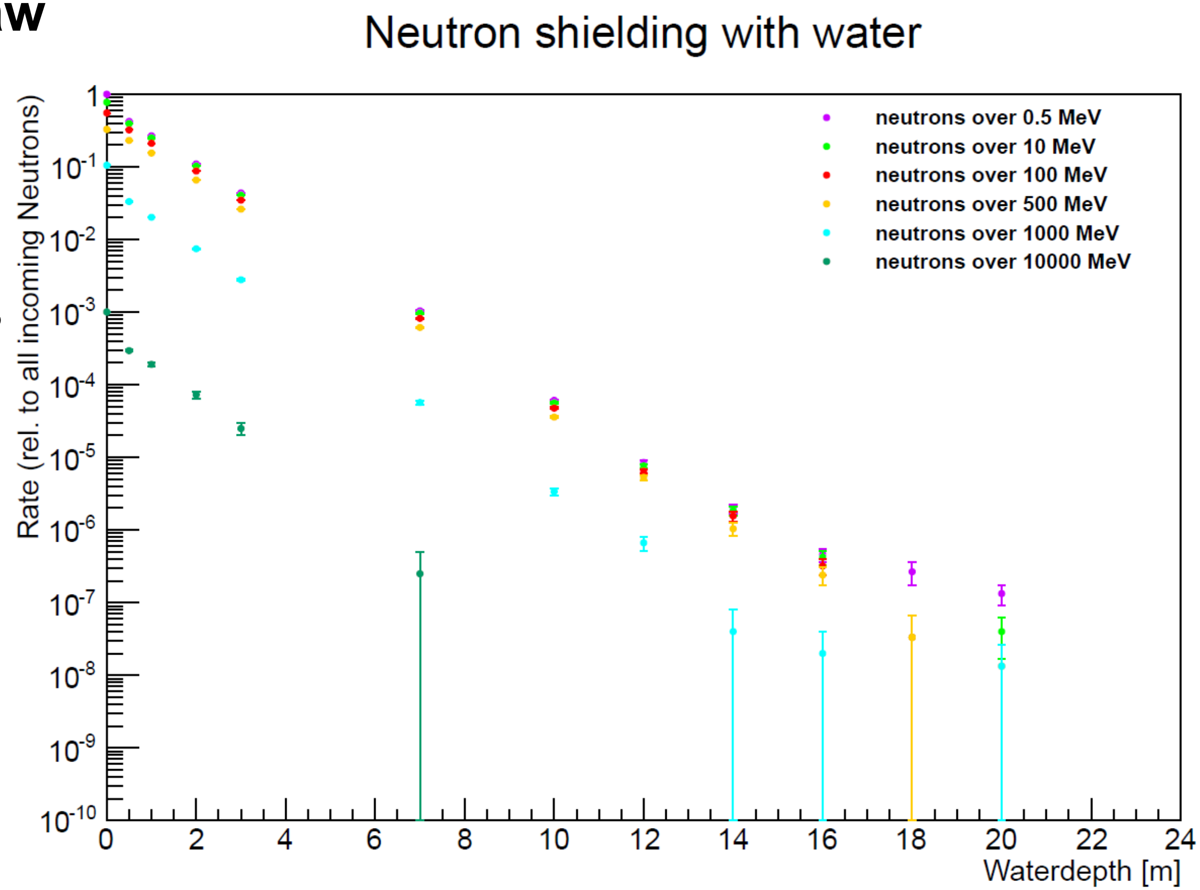


Simulated neutron spectra

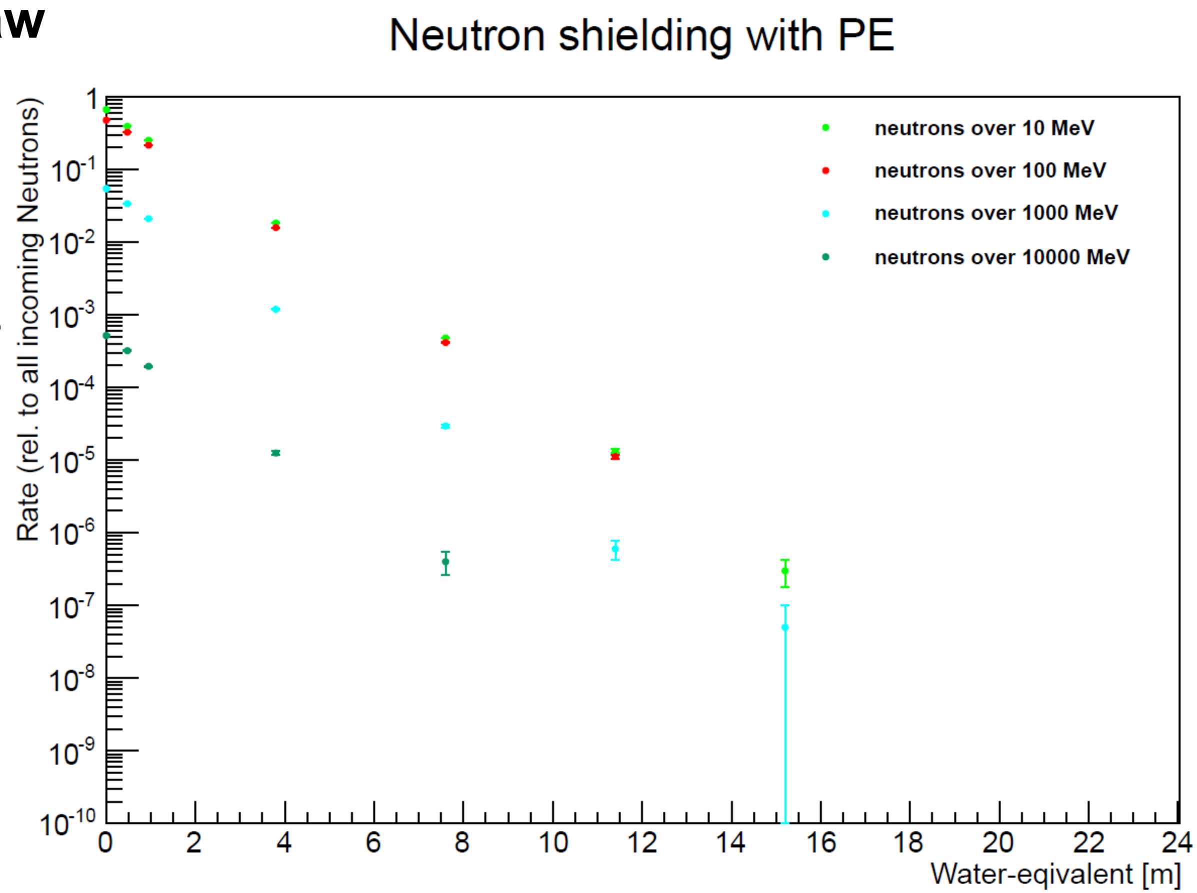
- water (Density: 1g/cm³)
- polyethylene (Density: 0.95g/cm³)
- **steel** **(Density: 7,9g/cm³)**



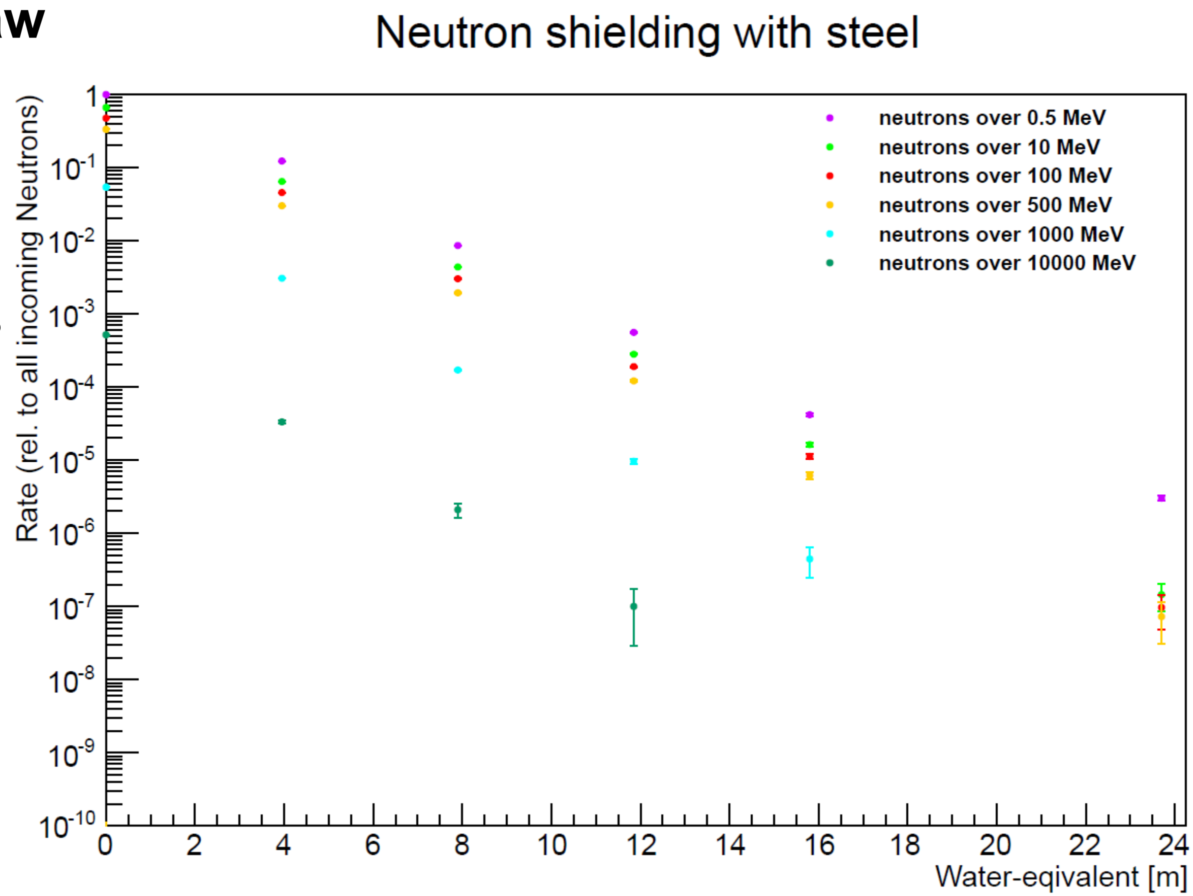
- **Rate (neutron abundance in relation to all incoming neutrons) below shield as function of m water-equivalent:**
  - **Follows a power-law**
  - **Exponent is nearly constant for all energy thresholds**
  - **Exponent depends on the material:**
    - **Water**
    - PE
    - Steel



- **Rate (neutron abundance in relation to all incoming neutrons) below shield as function of m water-equivalent:**
  - **Follows a power-law**
  - **Exponent is nearly constant for all energy thresholds**
  - **Exponent depends on the material:**
    - Water
    - **PE**
    - Steel

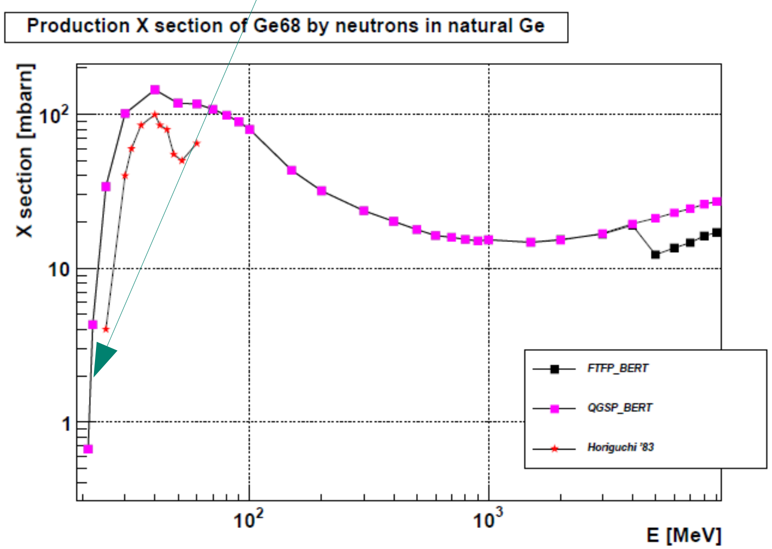


- **Rate (neutron abundance in relation to all incoming neutrons) below shield as function of m water-equivalent:**
  - **Follows a power-law**
  - **Exponent is nearly constant for all energy thresholds**
  - **Exponent depends on the material:**
    - Water
    - PE
    - **Steel**

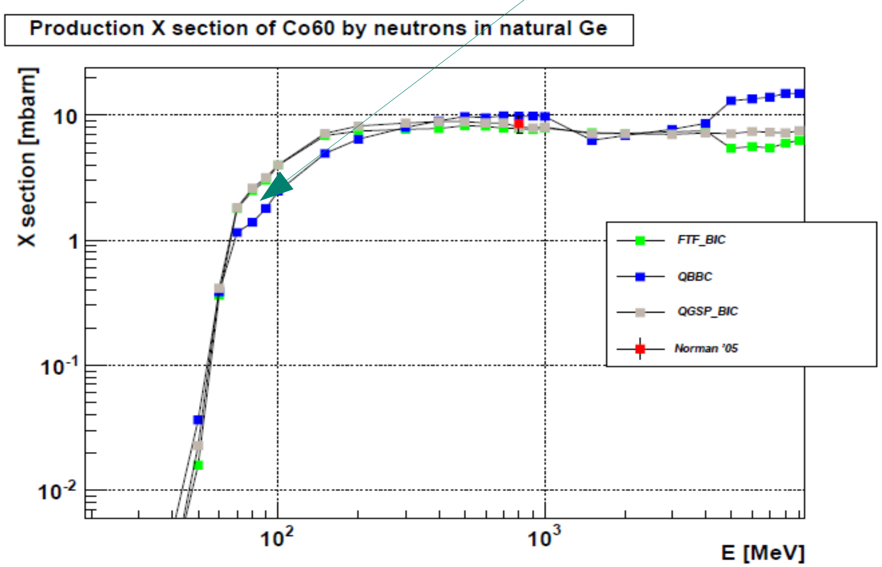


- **Germanium is a common detector material**
- **In Germanium ^{68}Ge and ^{60}Co can and will be produced due to neutrons**
- **Cross-section for production of these isotopes in natural Germanium is extracted from Geant4**

Threshold: ~ 20MeV

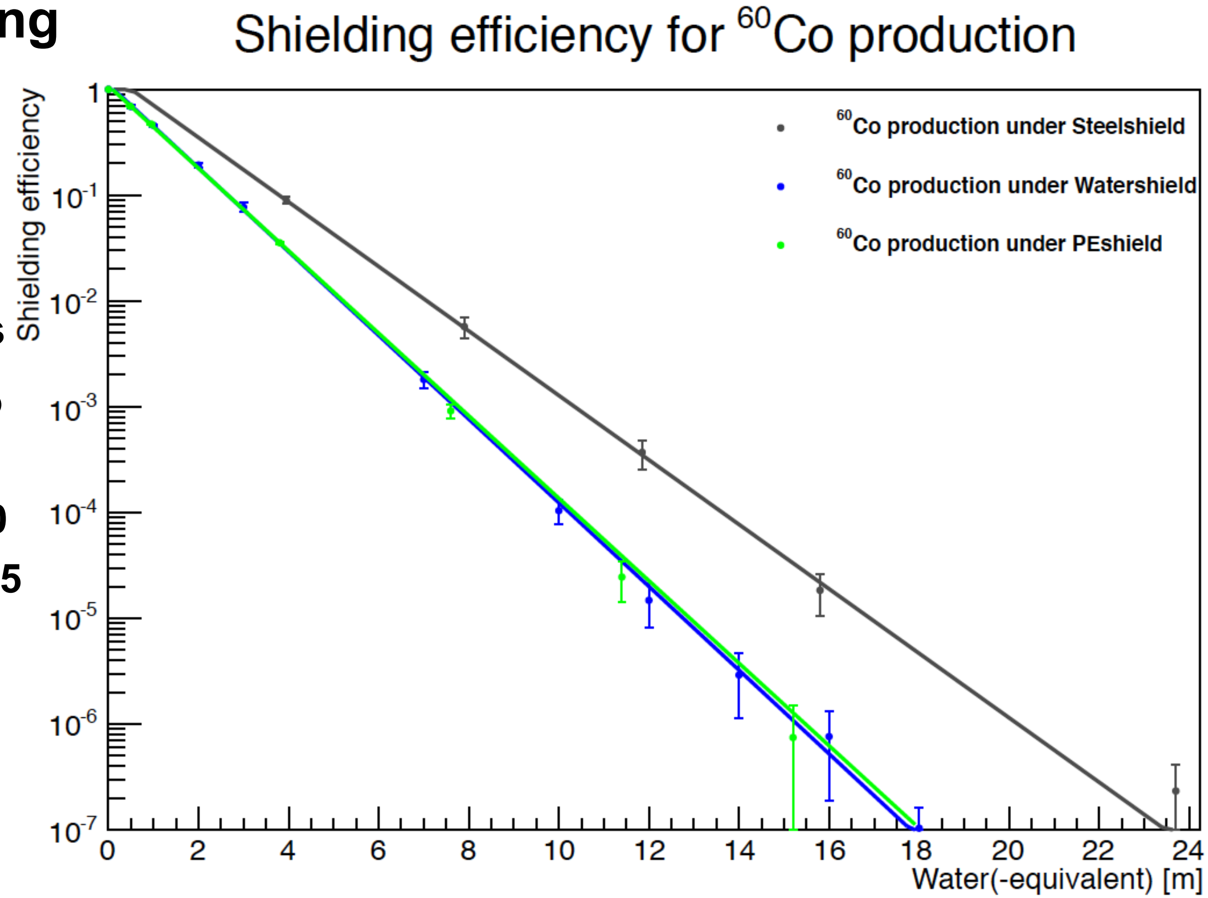


Threshold: ~ 90MeV

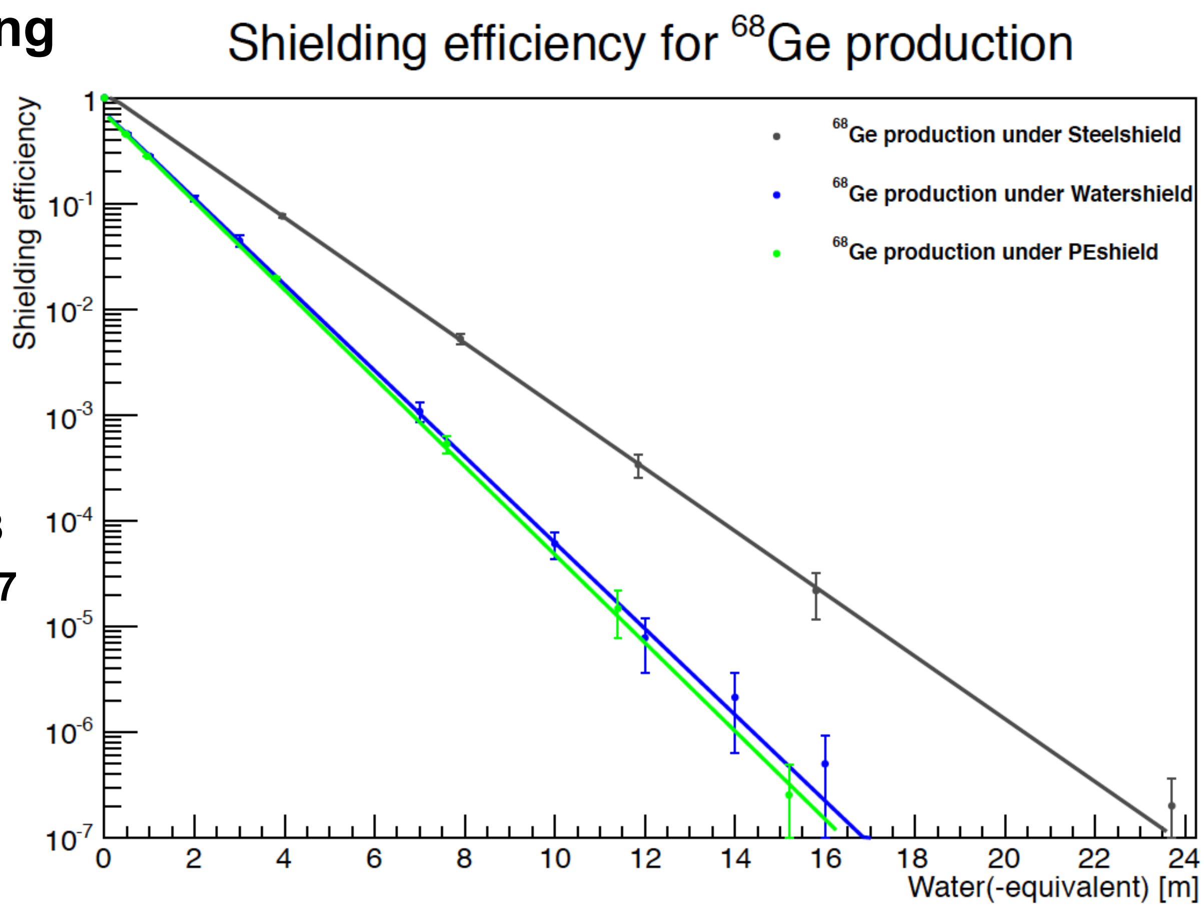


Cross sections extracted from Geant4 simulations

- **Convolution of the energy spectra with the production cross section for ^{68}Ge and ^{60}Co in natural Germanium**
  - **The overall shielding efficiency follows a power law to the shielding depth**
    - **Different between shielding materials**
    - **Exponents for ^{60}Co production ($\cdot 10^{-1}$):**
      - **Steel: 3.05±0.10**
      - **Water: 3.96±0.05**
      - **PE: 3.90±0.03**



- **Convolution of the energy spectra with the production cross section for ^{68}Ge and ^{60}Co in natural Germanium**
  - **The overall shielding efficiency follows a power law to the shielding depth**
    - **Different between shielding materials**
    - **Exponents for ^{68}Ge production ($\cdot 10^{-1}$):**
      - **Steel: 2.97±0.08**
      - **Water: 4.07±0.07**
      - **PE: 4.17±0.04**



Summary & Results

- **In shallow underground:**
  - **water-equivalent is not the right attribute to characterize shielding properties of materials**
- **Lighter material shields better with the same depth water-equivalent**
- **What would be a good way to parameterize shielding power?**
  - **Different for each component of the cosmic rays**

→ Need for more investigations to find the parameters for different materials