Shielding Investigations

Young Scientist Workshop 2012

Aaron Michel

Source: mpg.de

- Introduction in low background challenges (esp. Gerda)
- Implementation of a Monte Carlo shielding simulation
- Intentions and the Goal of the simulation
- Information about the results and outcome
- Investigation of the details
- Importance of the results
- In the near future

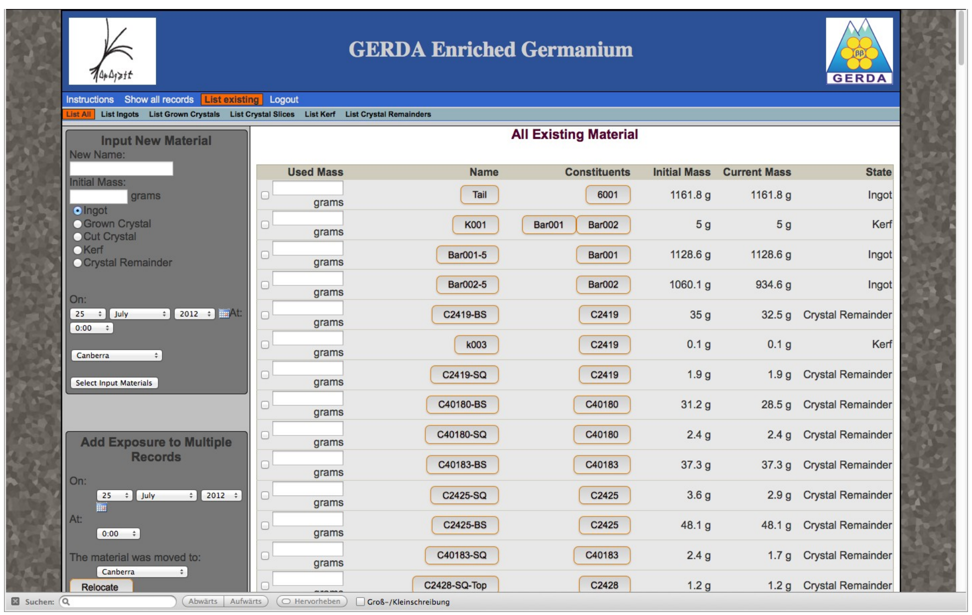
- Low Background experiments
  - e.g. the neutrinoless doublebeta decay
    - Expected event rate 0.1 - 1 counts per kg and year
  - A very low background is needed to see the relevant signal
  - Common Background sources:
    - Environmental radioactive background
    - Cosmic rays

→ Internal detector contamination

- Can't be removed once the detector is contaminated
- Most important in Germanium detector: ^{60}Co and ^{68}Ge due to spallation reaction of hadrons with ^{76}Ge

→ Construction and deployment of transport & storage shields to use during production of the detectors

- Example: Germanium detector production for the GERDA experiment:
  - Extraction & enrichment (Krasnoyarsk), purification (Gosslar), zone refinement & crystal growing (Oak Ridge), final processing & testing (Olen/Mol), experimental setup (Gran Sasso)
- Shielding is needed during transport & production



Online exposure database:
How big is the cosmogenic activation?

Find a way to take into account the different shields?

Right now, shielding factors:

0 for the cave
1 in the open, car, canberra
0.12 for the shipping container

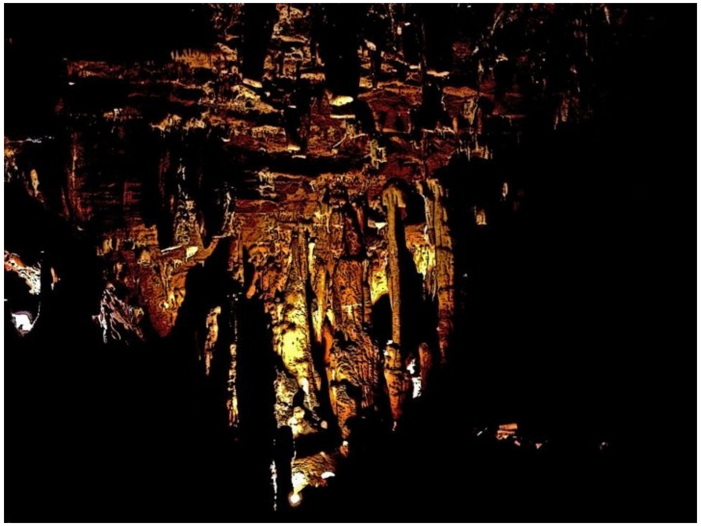
Pictures: Gerda detector production

Cherokee Cave in Oak Ridge

Some stations of the detector production:

Gerda Shielding Container

Truck transport



Simulation of shielding scenarios:

- Using GEANT4 (GEometry ANd Tracking 4)
  - Huge Collection of Libraries and Code
    - To create virtual geometries up to the last screw
    - Possibility to put together all the materials from isotopes
    - Includes parametrization and tables for physics processes from low to very high energies
    - Used also in medicine simulations (concerning cancer treatment etc) besides physics simulations for the particle tracks within detectors
    - Particles can be injected (shot) at any point, with any energy
    - Events (hits, geometric boundary crossing etc can be recorded and stored in a root file
    - Implementation done with C++

- Monte Carlo Shielding Simulations
  - For two Cosmic Ray Particles (secondaries)
    - Cosmic ray neutrons
    - Cosmic ray muons
  - With different Shielding Materials
    - Water (density 1g/cm^3)
    - Steel (density 7.9g/cm^3)
    - PE (density 0.97g/cm^3)

Source: wikimedia.org

→ Possibility to compare with 'water equivalent' (area density)

- Analysis:
  - Compare spectra for different shielding depth
  - Compare particle count w/ different energy threshold

→ Properties of different shielding materials

- In this simulation:
- MaGe, a framework on top of Geant4 was used (MaGe for Majorana GERDA)
  - Many detector geometries already implemented
  - Already some physics list compilations included
  - Different predefined output schemes available
  - Continuously updated with new developments
- Possibility to add the shielding scenarios as a 'detector' geometry
  - To record the particles at different depth, 'slices' of the shield put together
  - Double backscatter adds some false particles to the outcome
    - Small systematic effect which is not noticeable

- Monte-Carlo-Simulations of the shields
  - MaGe with the QGSP Hadron List enabled:
    - Lelastic-LENeutron-Neutronfission-Neutroncapture-BinaryCascade-QGSP ◄── Physics List used
- Gives the best results in comparison to other simulations and also measurements
- A spectrum of sea-level neutrons & muons used to simulate C.R. coming from above through a shield
- The energy spectrum of the particles below shield gets recorded

──► Investigations for different Energies (Thresholds) possible

e.g. Isotope production within detector material

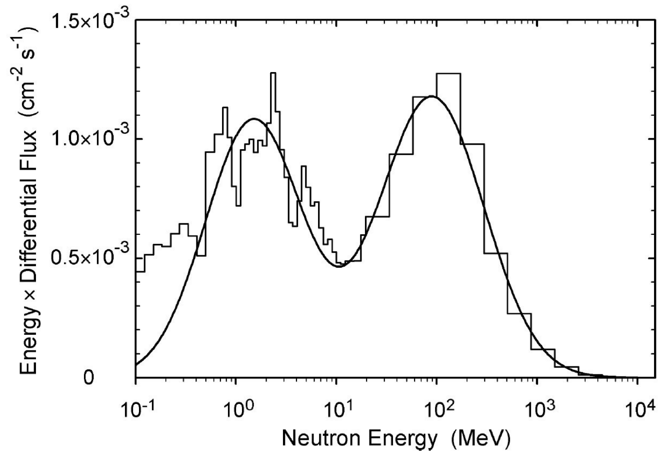
Goal of this study

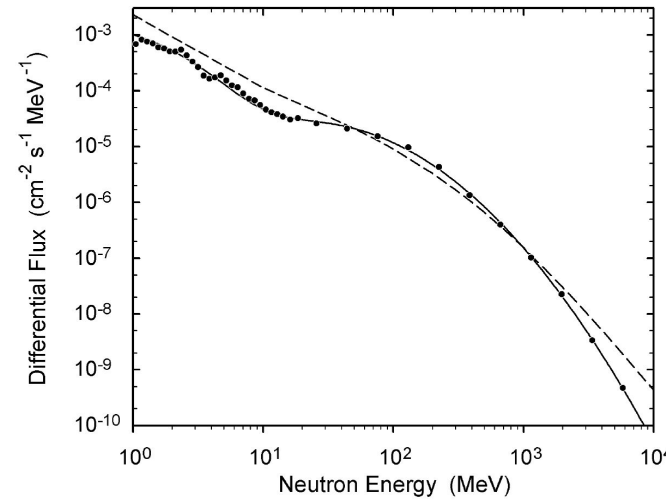
- Ultimate goal:
  - Prevent the detector material to be activated by cosmic rays
- First steps:
  - Understand the influence of different cosmic ray components
  - Understand the shielding powers of the materials used
- Further steps:
  - Adapt the transportation shield accordingly – e.g. add more water on top of the steel etc.

- A spectrum of secondary cosmic neutrons is used from a measurement in New York City
  - Will look different for other locations
  - Will look different for other times
- This spectrum is the base for a series of Monte-Carlo-Simulations
- Interested in:
  - Amount of neutrons below shield
  - Energy of these neutrons

  In what way is the cosmogenic activation of the detector material reduced?

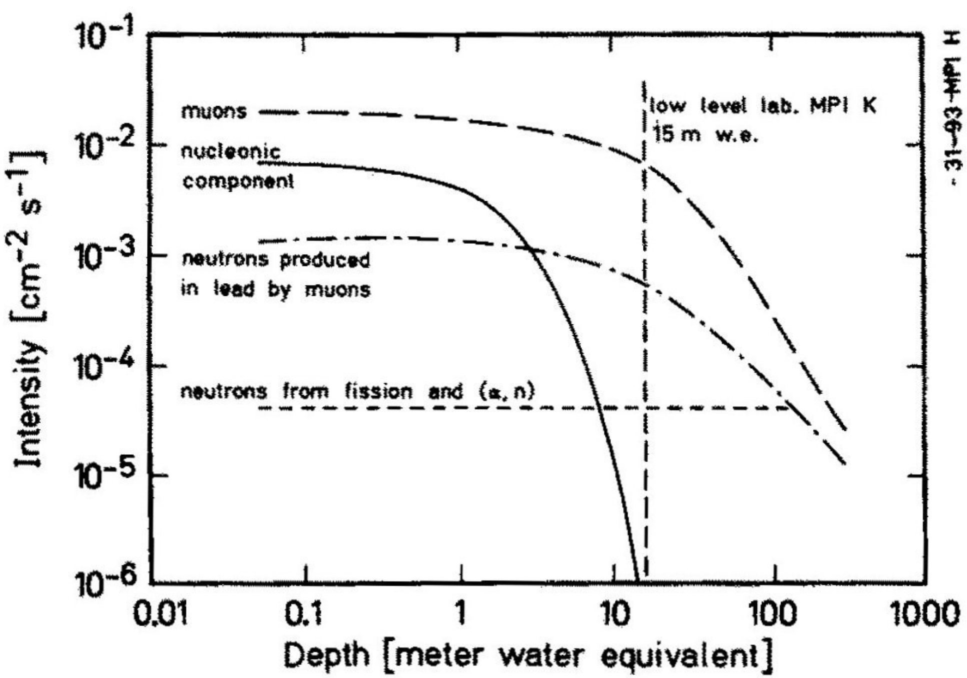
    - In relation to shielding depth
    - In relation to shielding material





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

- First intent:
  - Reproduce the plot shown below (nucleonic component & neutrons from muons)
    - For different materials
    - For different energy thresholds of neutrons

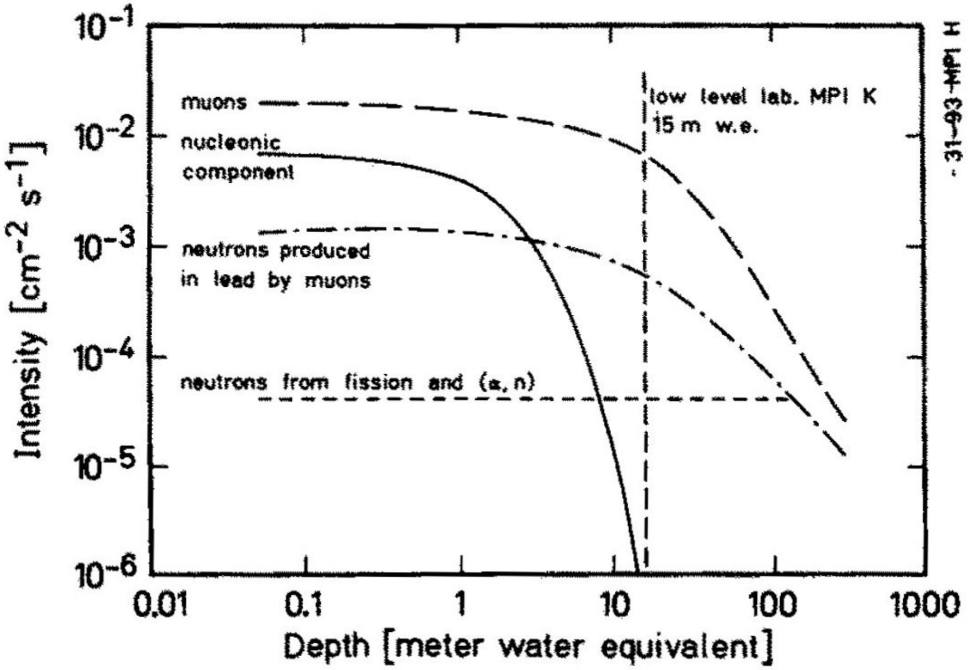


G. Heusser: Low-radioactivity background techniques, Annu. Rev. Nucl. Part. Sci. 1995. 45:543-90

Problems with this Plot:

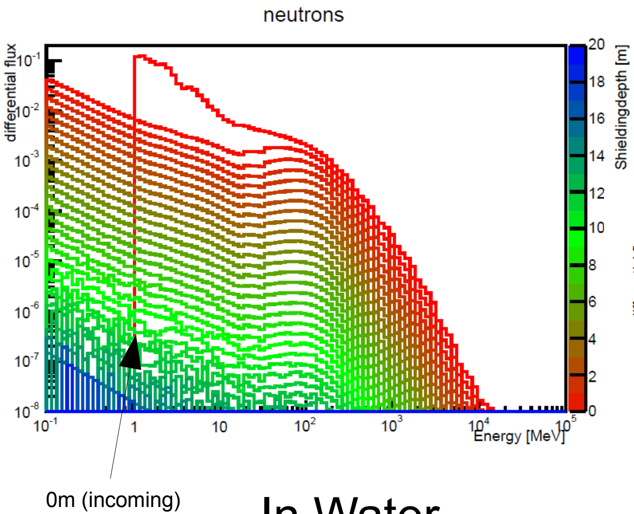
- Semi-empirical calculations and assumption of 'water equivalent'.
- Also: no energy information.

- Concerning shallow underground / shallow shielding
  - At which depth are there as many neutrons from muons than from the nucleonic component
  - This the amount of shielding that ideally should always provided

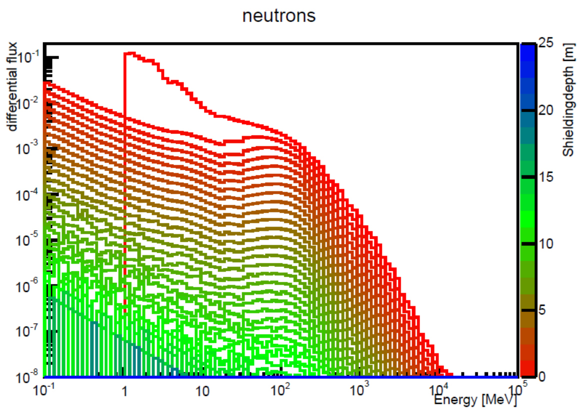


This simulation will try to reproduce the plot but also with energy information and different materials!

- Neutron flux before and after shield
  - Arbitrary spectrum of cosmic ray neutrons at sea level

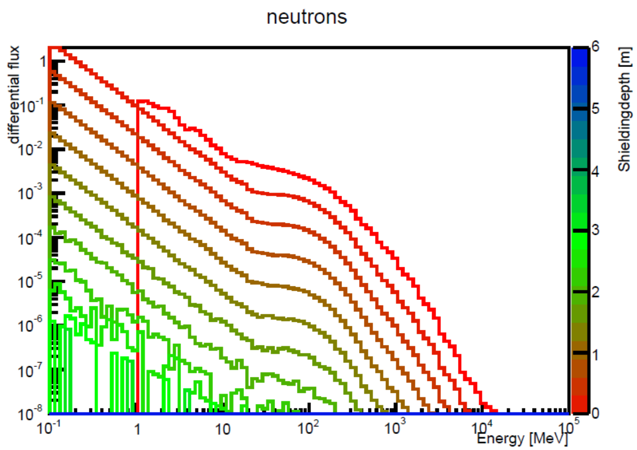


In Water



In PE

- Visible difference for low energy neutrons with the steel shielding!

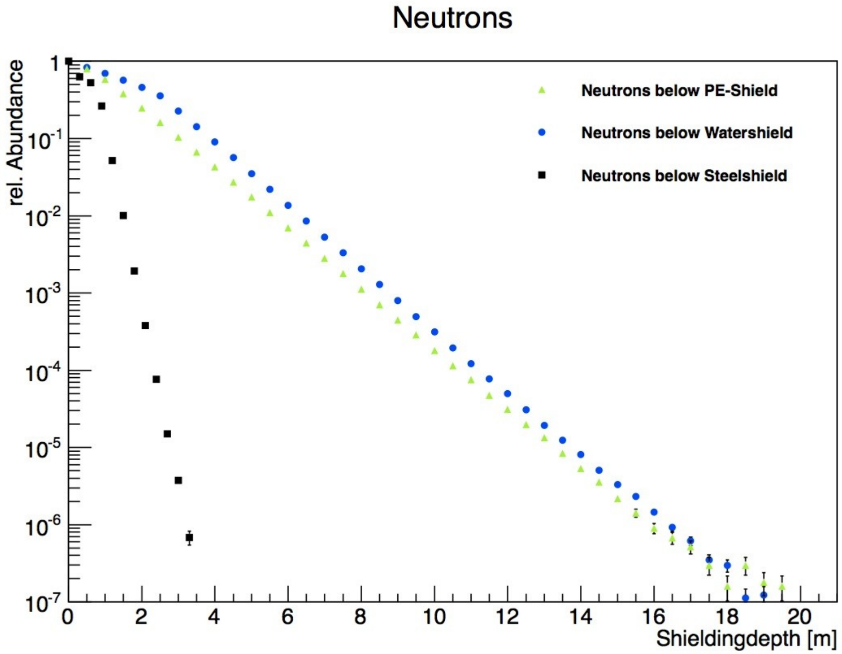


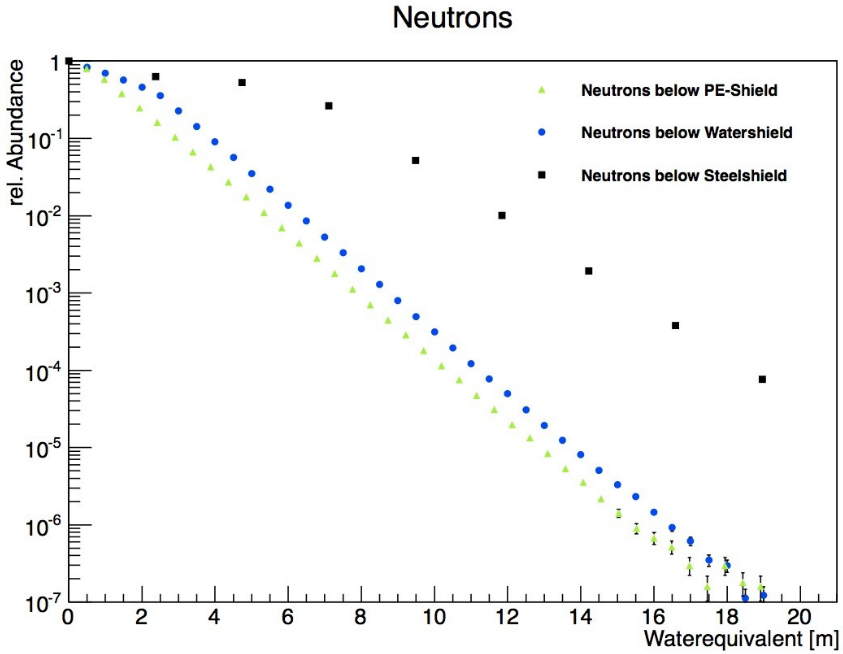
In Steel

Colors represent different shielding depth!

- Water & PE look similar!

- Neutron count before and after shield

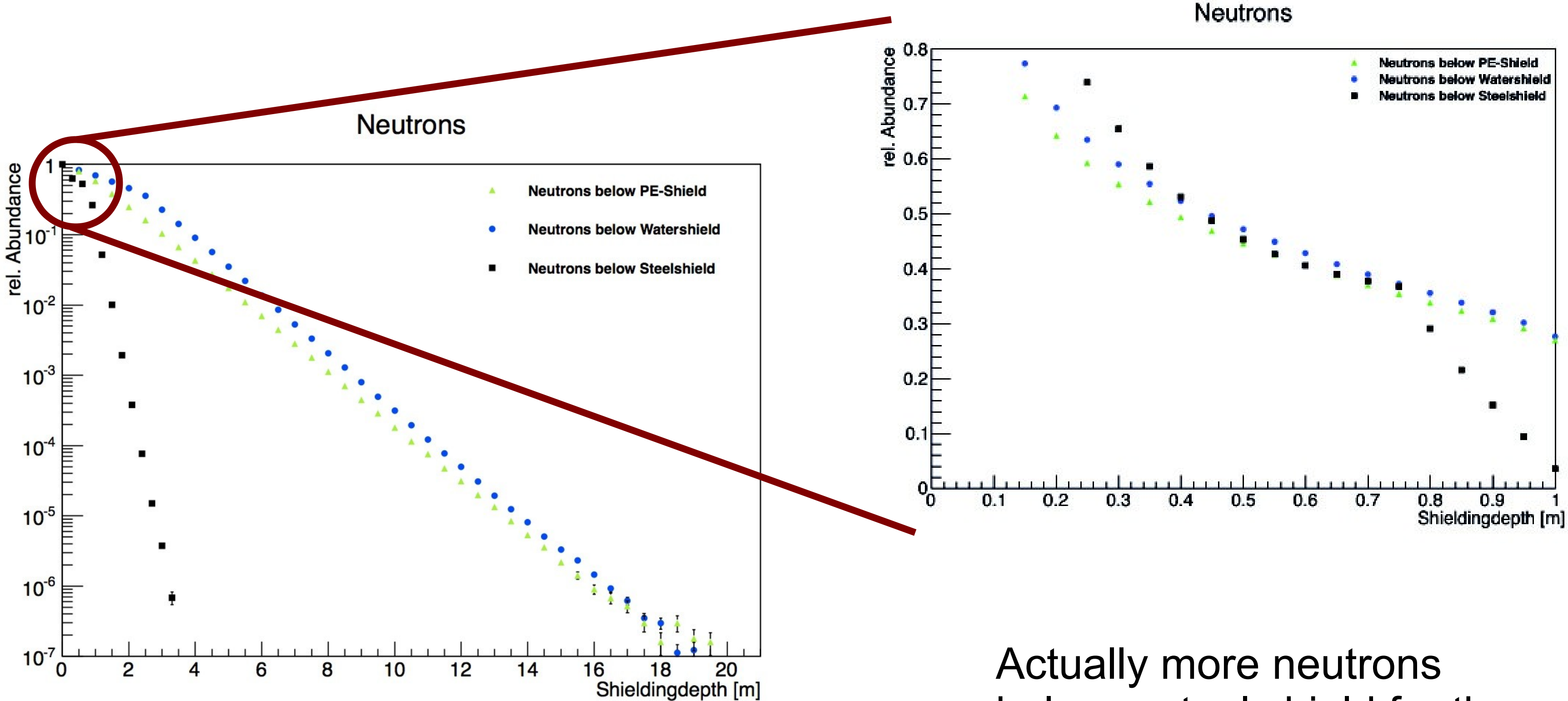




Basically no more neutrons below 4m of Steel or 20m of Water/PE!

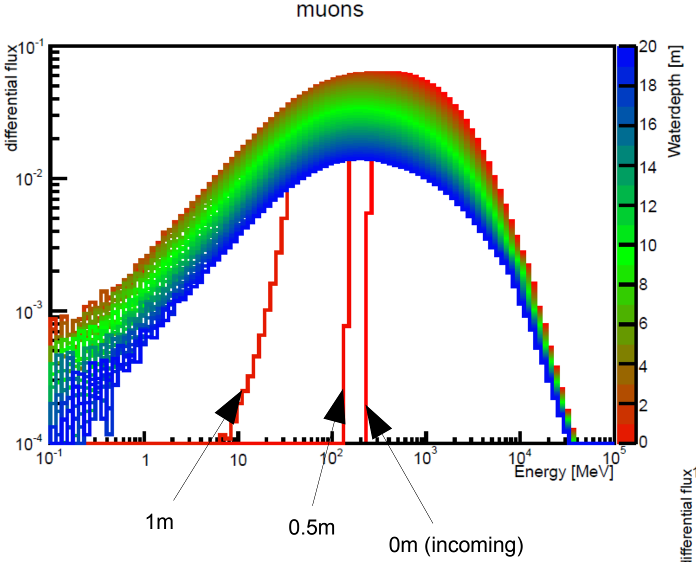
Water-equivalent quite different for different materials!

- Neutron count before and after shield

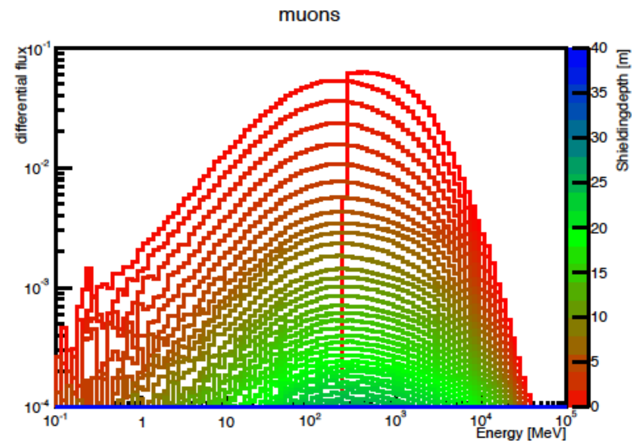


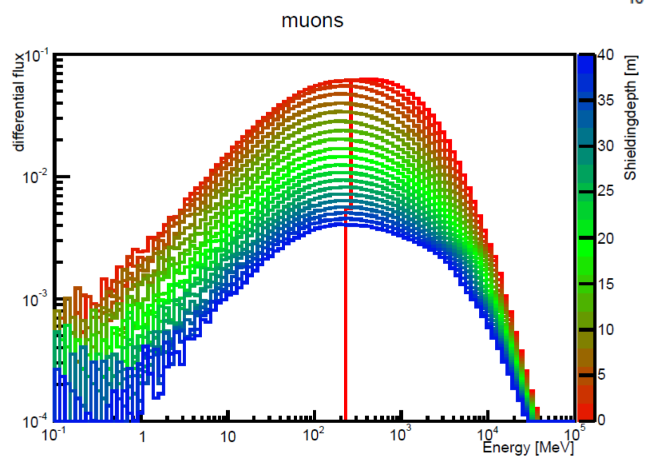
Actually more neutrons below a steel shield for the first 0.5m!

- Muon flux before and after shield:



In Water (up to 20m)



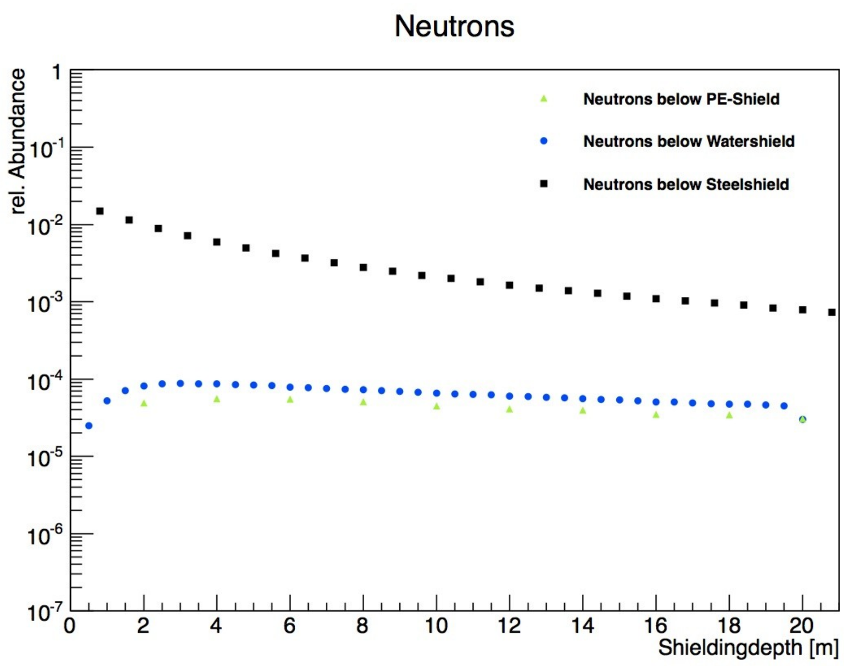


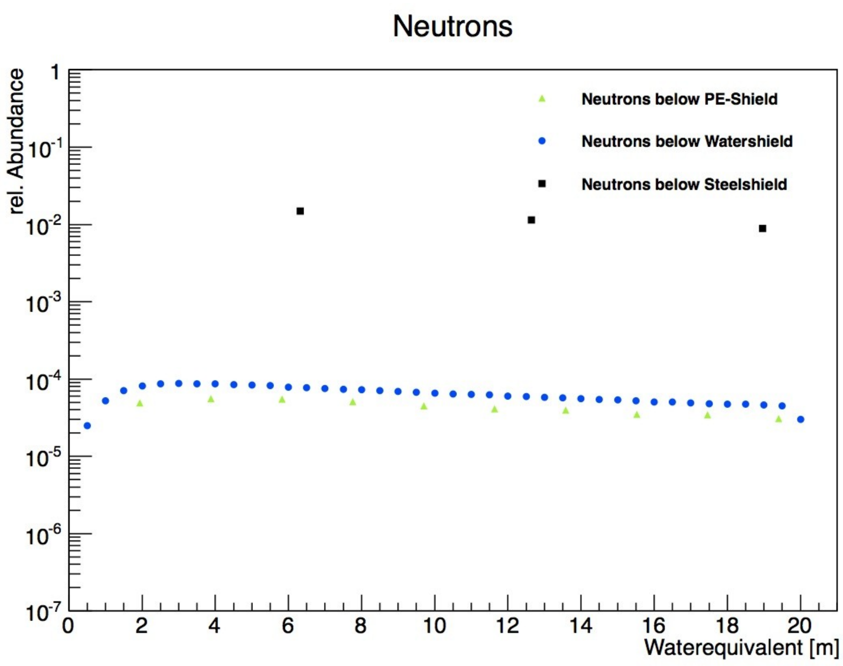
In Steel (up to 40m)

Colors represent different shielding depth!

In PE (up to 40m)

- Neutron count (relative to 1 muon hitting the shield):





At some depth the neutrons from steel might eventually level up with the lighter material

Much more neutrons below a steel shield!

Only very slow drop of the Neutronrate

For the Isotope production inside the detector below a shallow shield:

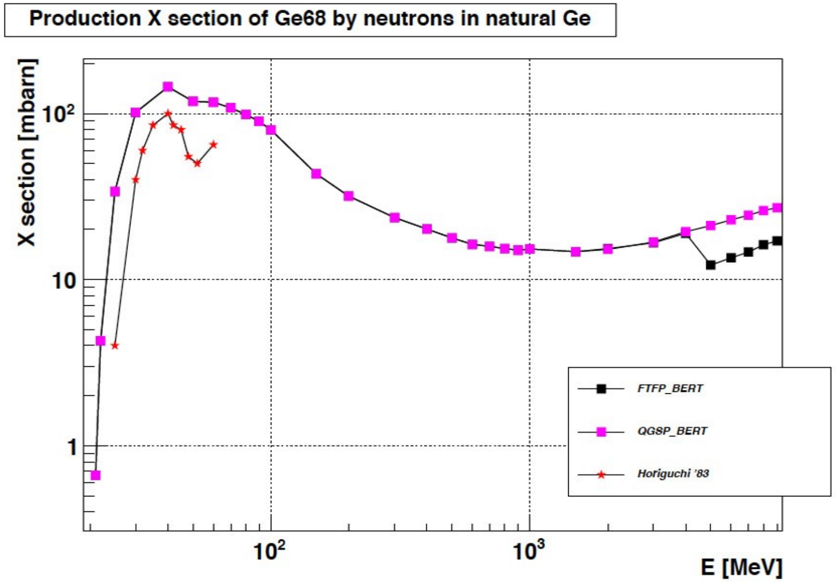
- We find following particles below shield:
  - Neutrons, Protons, Electrons, Gamma, Muons, Pions, Neutrinos, Ions, other Hadrons(K, Λ, Σ)
- Largest contribution leading to isotope production in Ge: Neutrons (directly or produced inside shield)

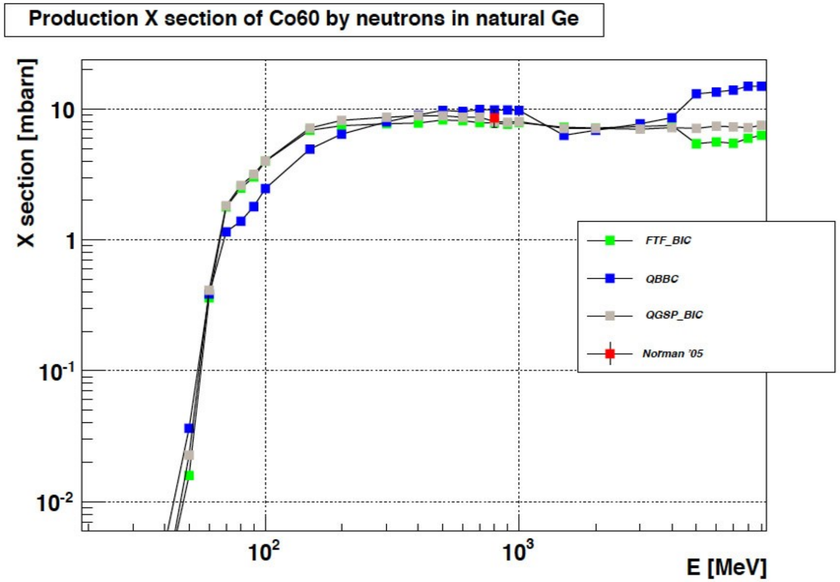
→ Focus on Isotope production from the neutron component

- – gives a first idea how to protect the detector more efficiently

- Neutron induced ^{60}Co and ^{68}Ge production within Ge
  - Excitation function extracted from Geant4

→ Thresholds 20MeV (^{68}Ge) & 90Mev (^{60}Co)

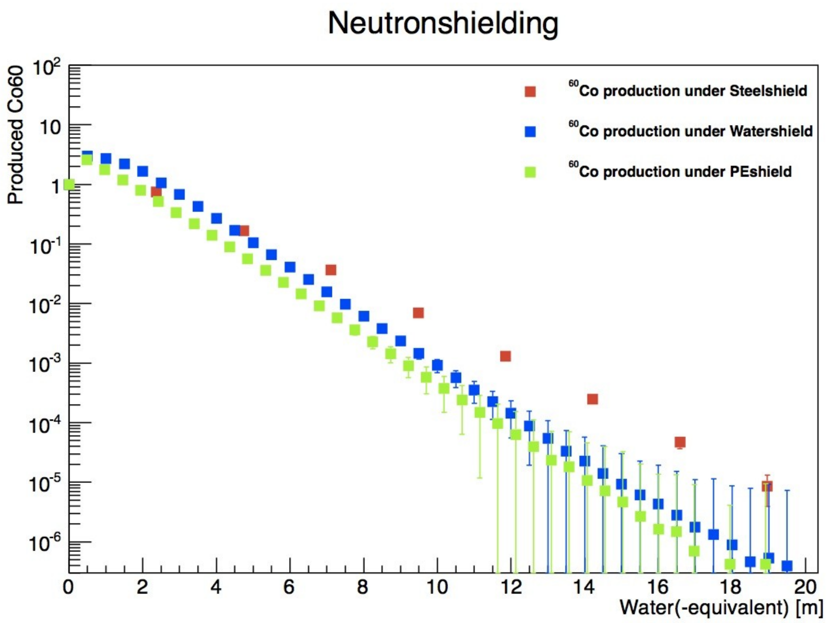


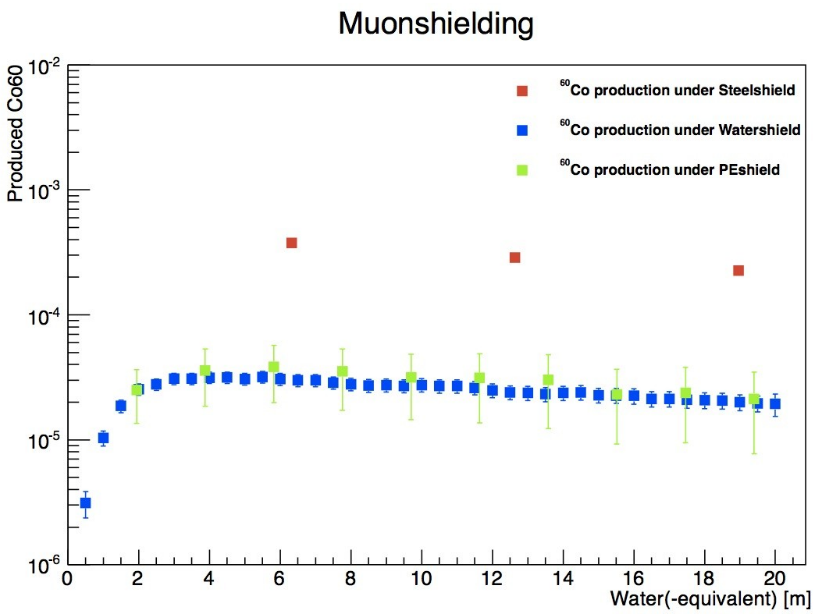


from GSTR-08-002 by J. Janicsko

^{60}Co Production (from neutrons)

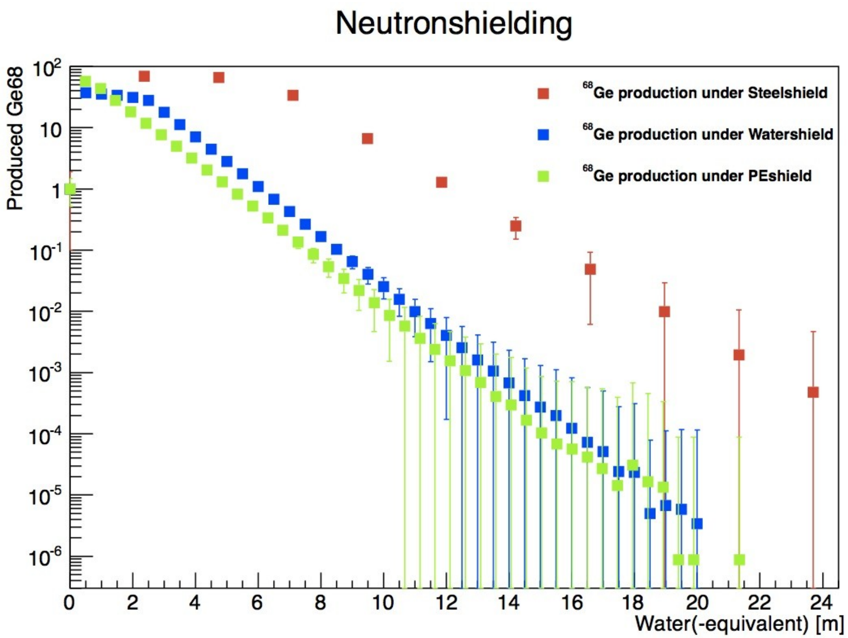
- After shielding neutrons
- After shielding muons

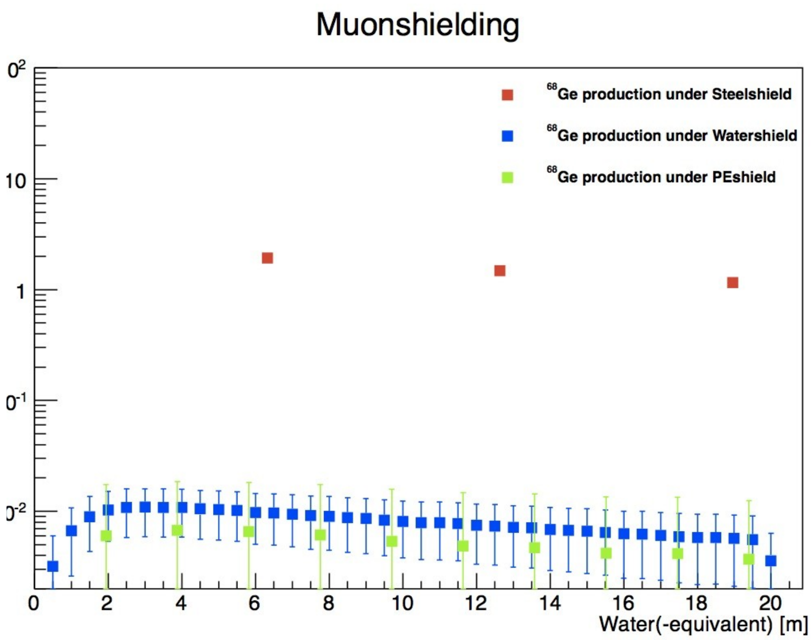




relative to 0m shield!

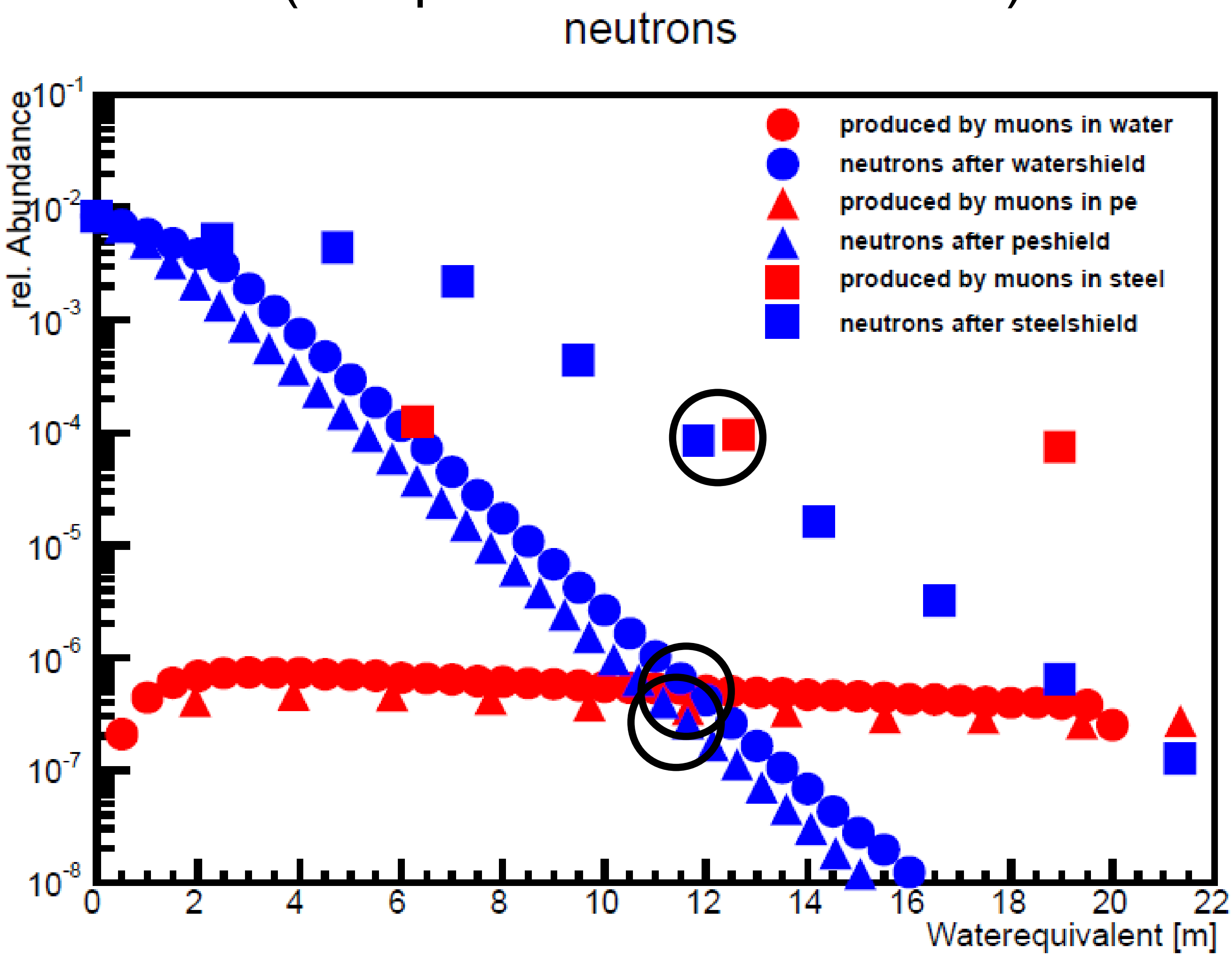
- After shielding neutrons
- After shielding muons



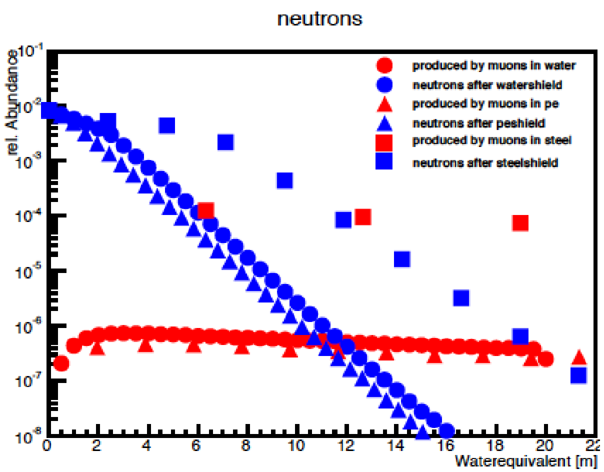


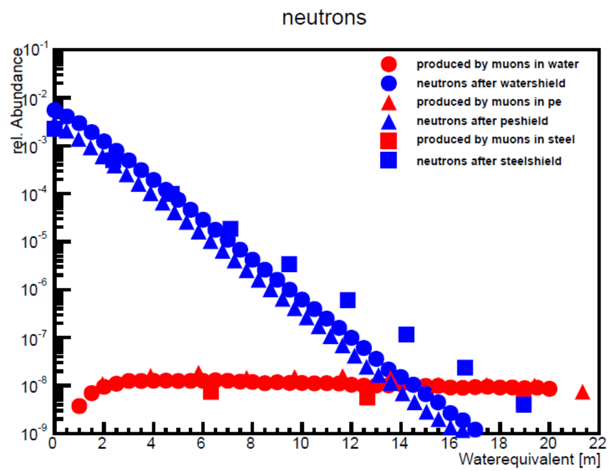
relative to 0m shield!

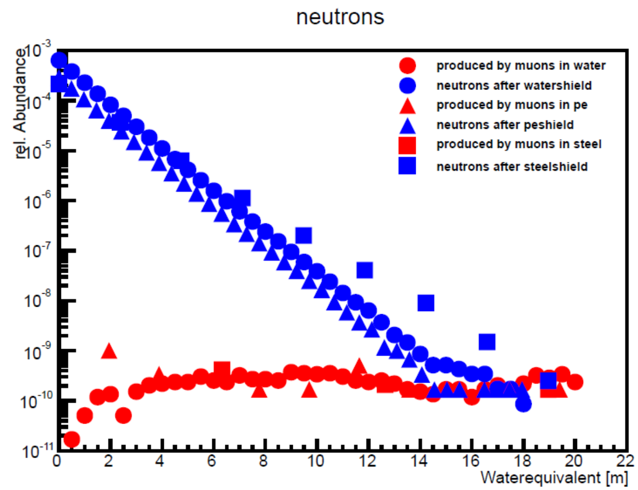
- For all neutrons (compare to Heusser's Plot)



- For different energy thresholds:
  - Intersection point changes!



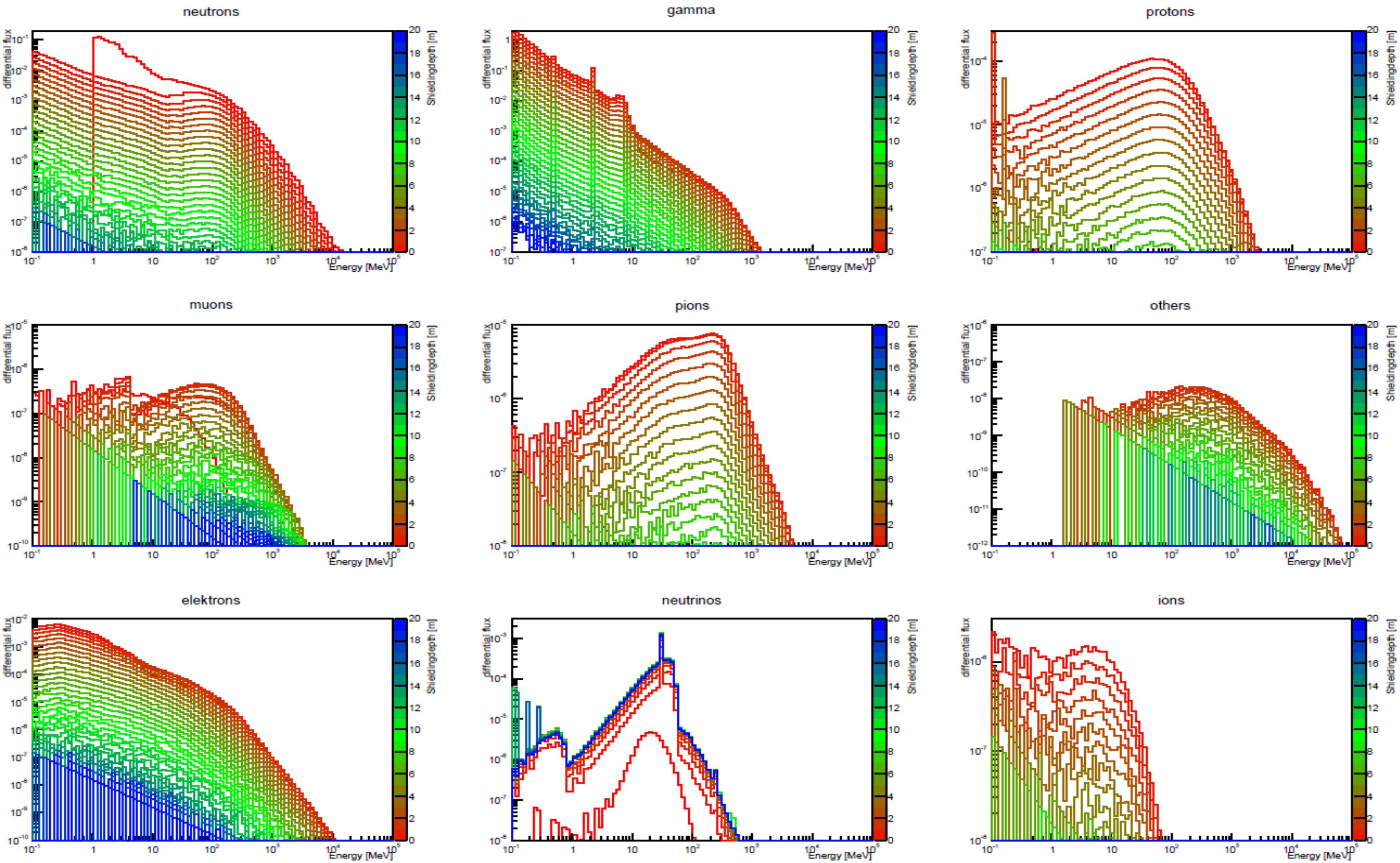




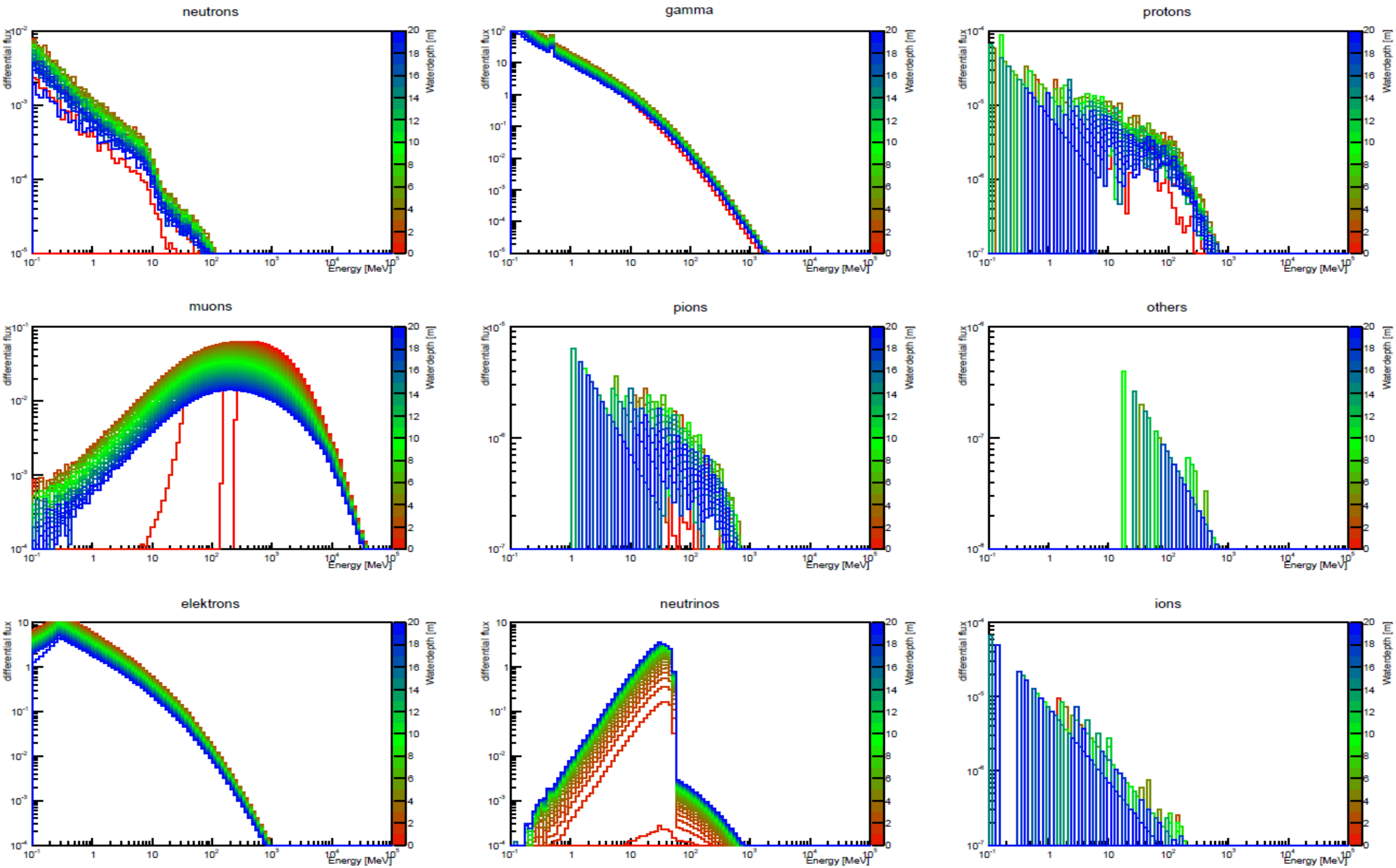
All neutrons	Above 200Mev	Above 1Gev
11-12m w.e.	14-17m w.e	15-19m w.e.

- Important outcome:
  - For shallow shields water-equivalent not the proper value to compare different materials
  - For the first meter: many more neutrons below steel shield but they have rather low energy – low contribution to spallation
  - For different shielding materials and energy thresholds the intersection-point between neutron component and muon-produced neutrons changes
- Next steps:
  - Measurements to compare simulations to actual data
  - Simulations for more materials → actual shielding container geometry
  - Include all other excitation functions for gamma & other particles for better understanding of the C.R. influence on Germanium

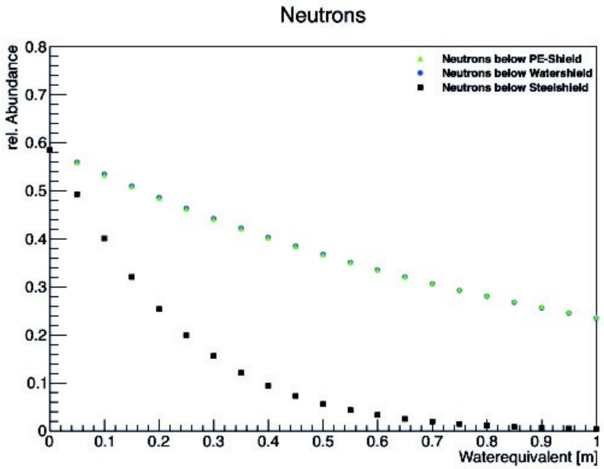
More slides (spectra after shielded neutron)



More slides (spectra after shielded muon)



More slides (some other stuff)



20 MeV threshold