Centre for Medical Radiation Physics

University of Wollongong

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From imaging to dosimetry: Geant4-based study on the application of Medipix2 to neutron personnel dosimetry

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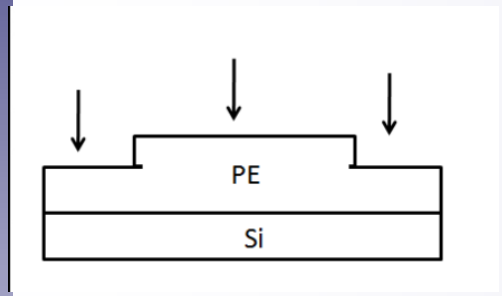
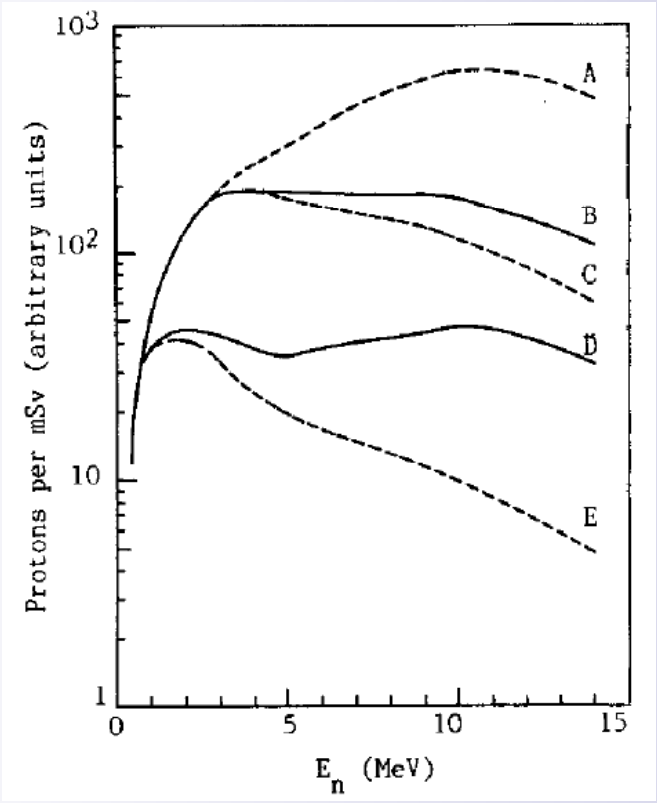
Single Detector for Neutron Dosimetry

- Silicon p-i-n diode detector covered with polyethylene converter
- Limited possibility of adjustment of energy dependence for dose equivalent measurements
- Limited possibility in discrimination of Compton and inelastic reaction in silicon





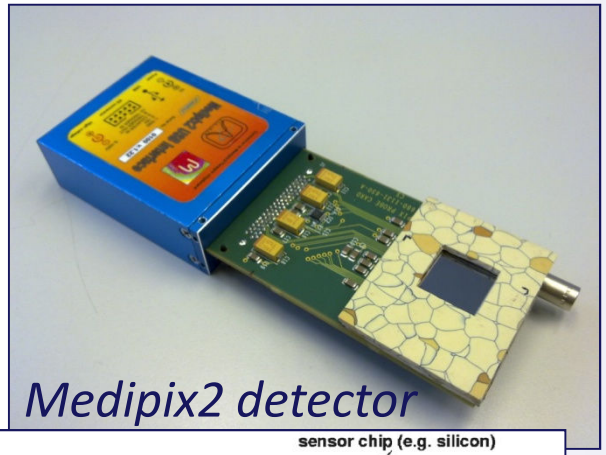
A – 1mm
B – 89% 0.1mm + 11% 1mm
C – 0.1mm
D – 94% 0.01mm + 6% 1mm
E – 0.01mm

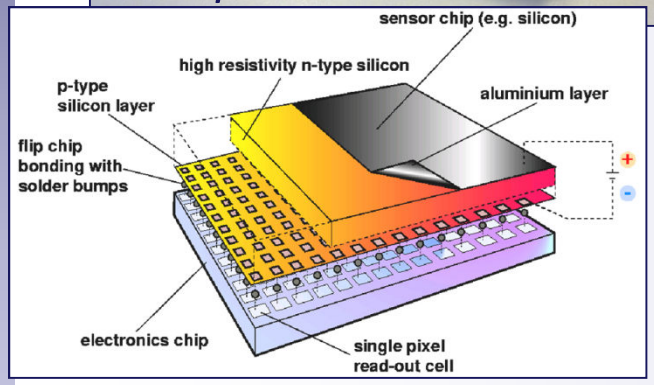
Reference

Eisen, Y. et al. A small size neutron and gamma dosemeter with a single silicon surface barrier detector. Radiat Prot Dosim. 15, 16 (1986).

CMRP Solution: pixelated detector

- Develop an energy independent fast neutron dosemeter

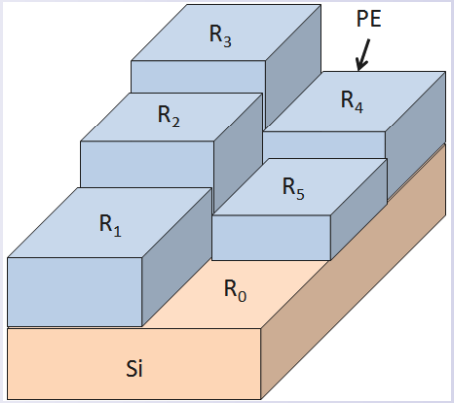




56,000 independently readout 55x55 μm^2 pixels.
Thickness of the detector = 0.3 mm

Hydrogen-rich polyethylene (PE) converter

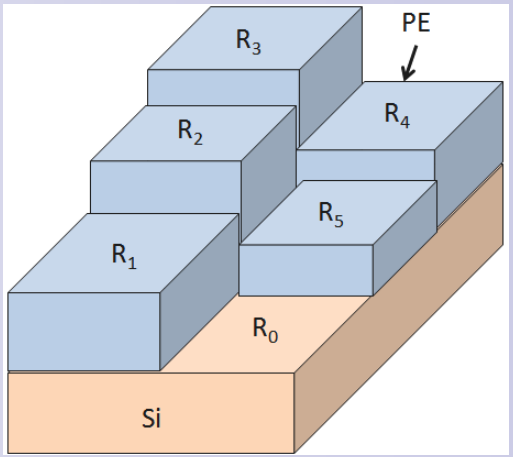
to produce recoil protons from the elastic interaction with incident n



Advantage of pixelated detector:
- Easy to remove Compton and *Si(n,…)* background
- Lower energy threshold of detection for neutrons

Llopart, X. Design and characterization of 64K pixels chips working in single photon processing mode. (Sundsvall: Mid Sweden University) (2007).

Pixelated Detector for Neutron Dosimetry



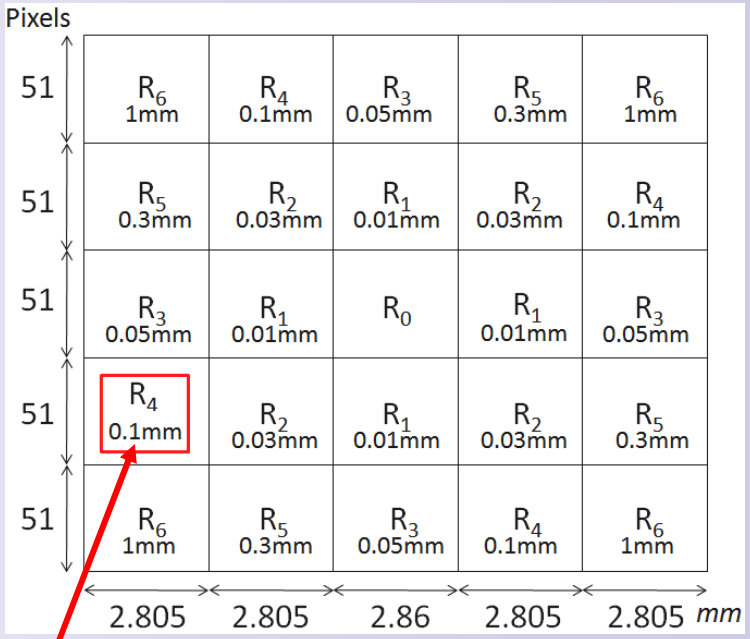
- **Problem**: optimize the converter thickness in order to obtain counts of protons in Medipix,
  - independent from energy of incident neutron
  - proportional to dose equivalent H

- **Solution**:
  - Perform a Geant4 simulation to study the response of each PE thickness, for neutron energy range: 0.3 MeV – 15 MeV
  - Validate the Geant4 simulation
  - Study an algorithm to obtain recoil proton counts
    - independent of neutron energy
    - proportional to dose equivalent H

Geant4 simulation

- Experimental set-up
- Physics list: QGSP_BIC_HP
- Threshold of production of secondary particles is 0.004 mm
- Parallel mono-energetic neutrons, with energy 0.3 MeV - 15MeV, incident on top of the Medipix2
- Simulation result: counts of recoil protons tallied per event, depositing an energy above 6*keV* in each segment

Medipix + PE converter



Sensitive volume

Reduction of cross talk between segments and higher flexibility in adjustment of energy response

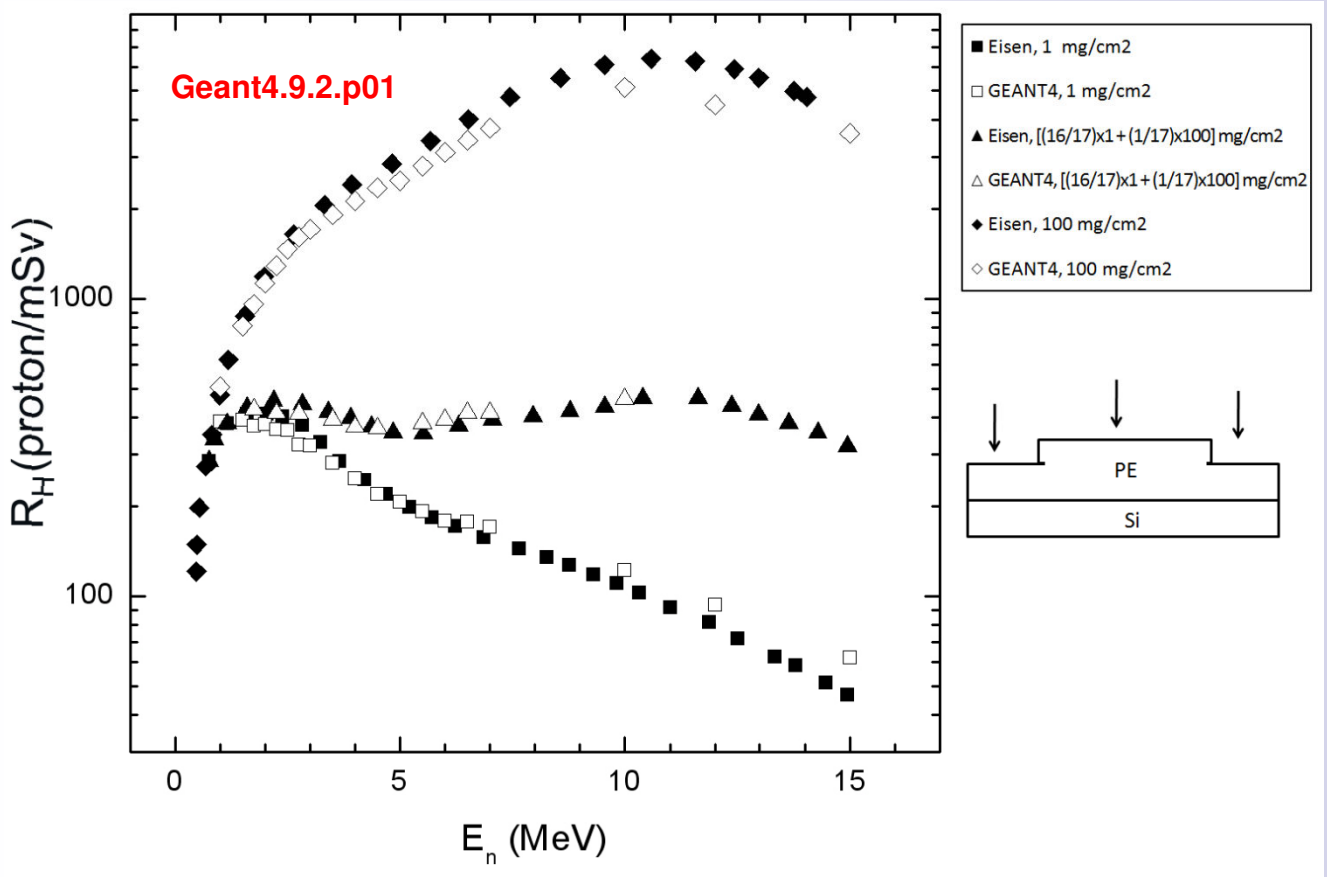
Validation of the Geant4 simulation

with respect to

Published reference data

Experimental measurements performed at
Australian Nuclear Science and Technology Organization *(ANSTO)*
Commonwealth Scientific and Industrial Research Organisation (*CSIRO*)

Comparison with respect to published reference data



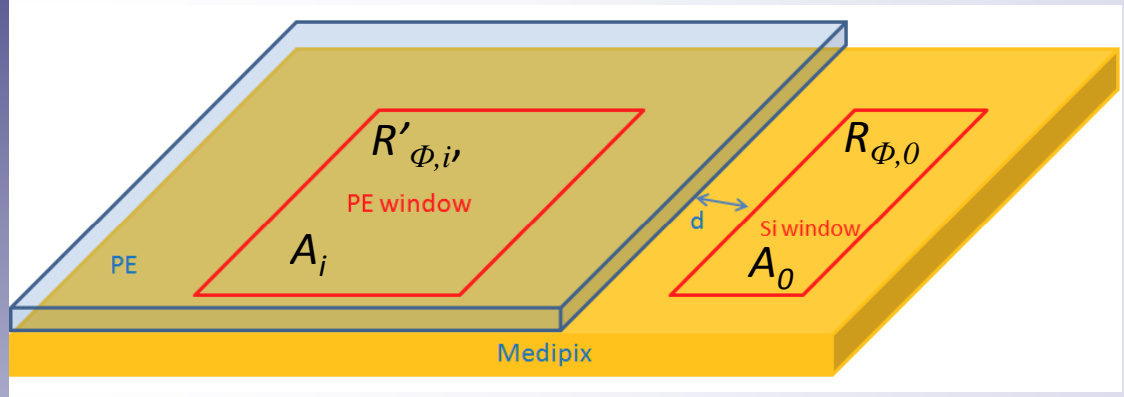
Reference

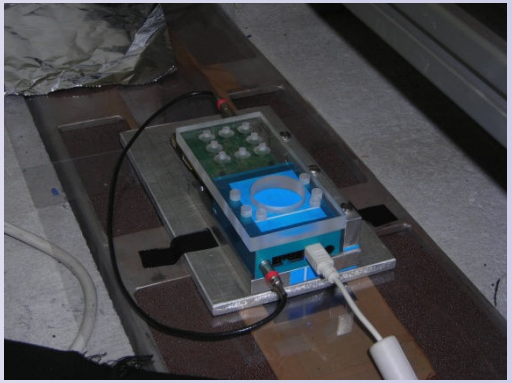
Eisen, Y. et al. A small size neutron and gamma dosemeter with a single silicon surface barrier detector. Radiat. Prot. Dosim. 15, 16 (1986)

Very good agreement

Medipix response to γ-n field

- Medipix2 has been irradiated with 14MeV D-T and Am-Be neutron sources in CSIRO
- Two third of the detector was covered with PE



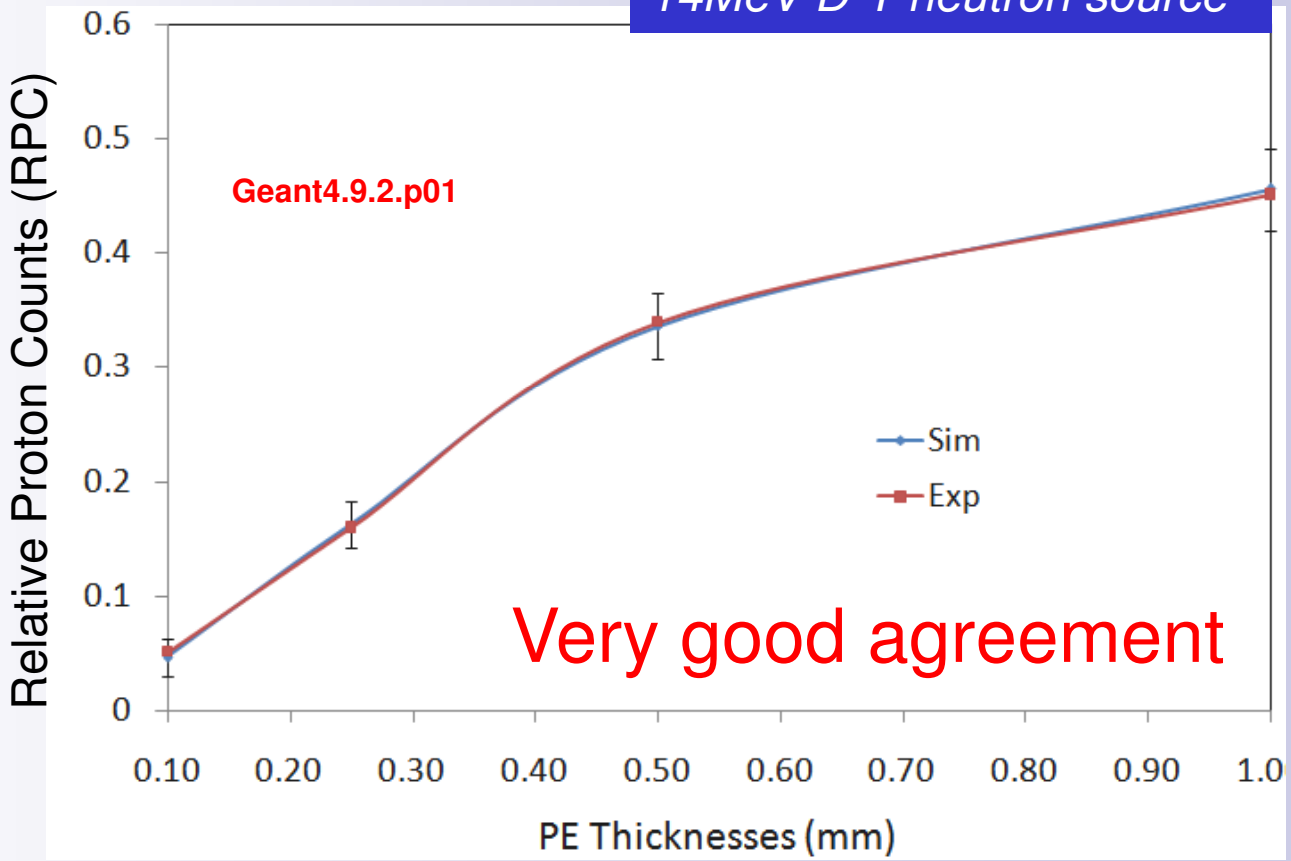


- Net proton counts: $R_{\Phi,i} = R'_{\Phi,i} - (A_i/A_0)R_{\Phi,0}$.

Comparison w.r.t. experimental data

$$RPC = \frac{R_i}{\sum_{i=1}^{4} R_i}$$

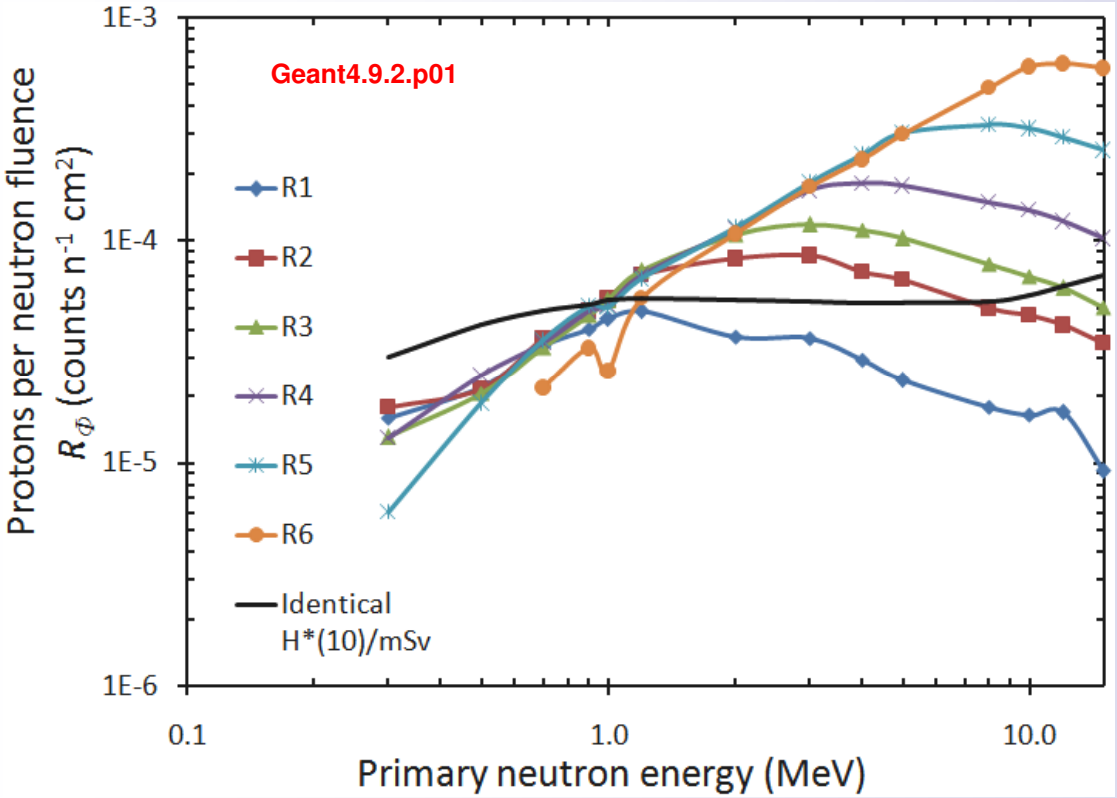
14MeV D-T neutron source



Polyethylene converter optimization

Results

Geant4 results: proton counts in Medipix segments



$$R_{\Phi,i}(E) = R'_{\Phi,i} - \left[\frac{A_i}{A_0}\right] R_{\Phi,0}$$

Pixelated Detector Optimisation Procedure

$$R_{\Phi,total}(E) = \sum_{i=1}^{N} \beta_{\Phi,i} R_{\Phi,i}(E)$$

where

- $\beta_{\Phi,i}$ = area weighting factor associate with thickness-*i*,
- $R_{\Phi,i}$ = response of the segment with thickness-*i*.

- $R_{\Phi,1}$ to $R_{\Phi,6}$, are the responses of Medipix2 segments, covered by PE converter

- $R_{\Phi,7}$ to $R_{\Phi,9}$ are: $R_{\Phi,7} = \left(\frac{R_{\Phi,5}}{R_{\Phi,4}}\right) R_{\Phi,1}, R_{\Phi,8} = \left(\frac{R_{\Phi,4}}{R_{\Phi,3}}\right) R_{\Phi,2}, R_{\Phi,9} = \left(\frac{R_{\Phi,2}}{R_{\Phi,3}}\right) R_{\Phi,6}$

Optimisation

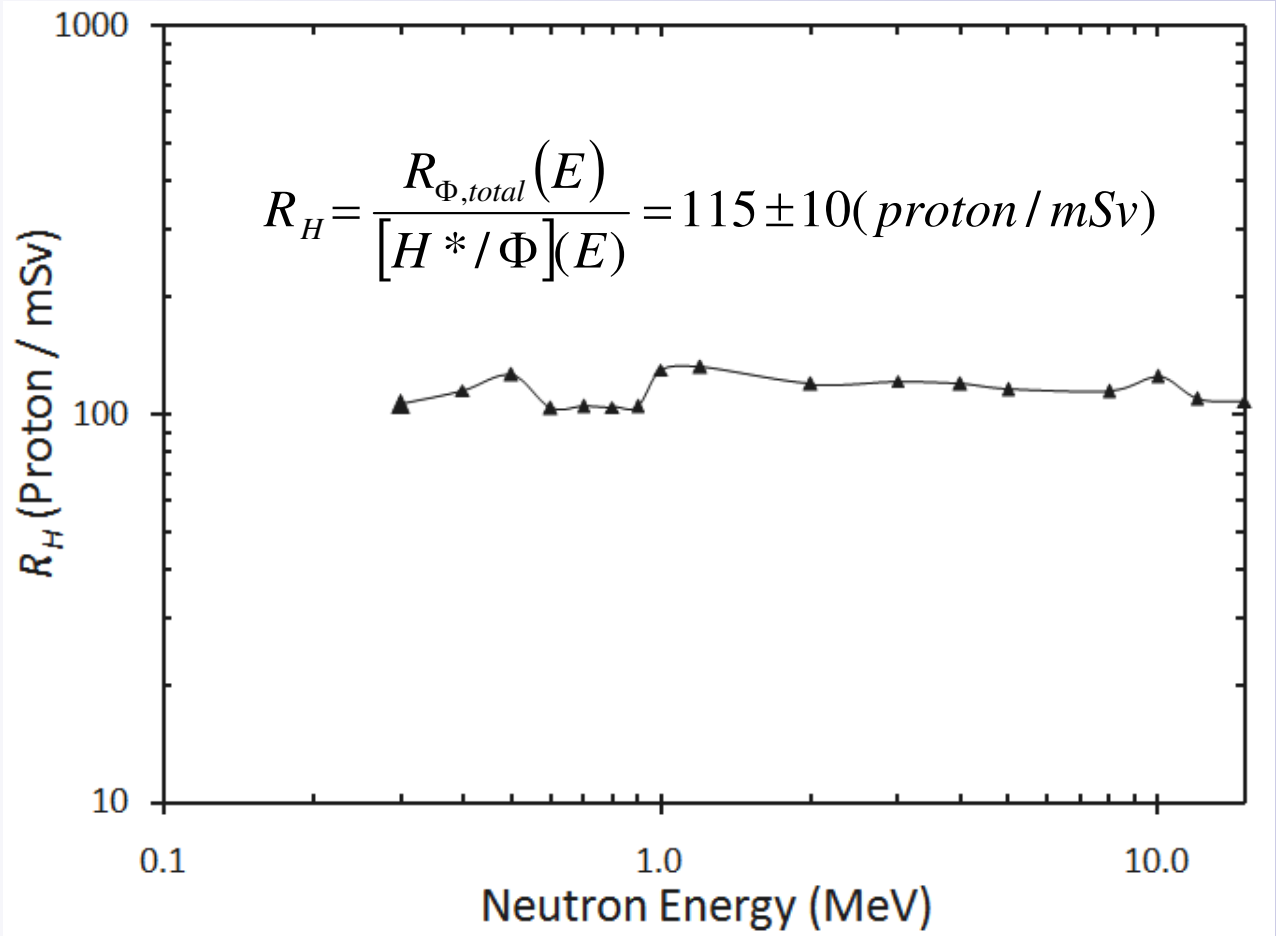
$$R_H = \frac{R_{\Phi,total}(E)}{[H^*/\Phi](E)} = const$$

Where H*/ Φ is defined in ICRP 74 Annex 2--Tables. Ann ICRP. 26, 157-205 (1996)

Pixelated Detector Optimisation Procedure: result

Energy independent response of the neutron detector

β_i	Value
1	5.984
2	-6.652
3	4.826
4	-2.437
5	0.598
6	-0.593
7	-2.890
8	1.938
9	0.898



Conclusion

- Geant4 simulation developed to study a **novel detector for neutron dosimetry**
  - Medipix2 + structured PE converter
  - Based on the counts of recoil protons only
  - **Aiming**: optimization of the thicknesses of PE segments of the converter to obtain personal dose equivalent response independent from neutron energy
- The Geant4 simulation was validated with respect to experimental measurements
- The thicknesses of the structured PE converter were optimized
- **Future research**:
  - Realisation of the optimised converter
  - Irradiation of optimised neutron dosimeter on well known neutron fields
  - Geant4 simulations will be carried out to characterize the detector response in more detail

Thank you