Measurement of (n,xnγ) reactions at high precision

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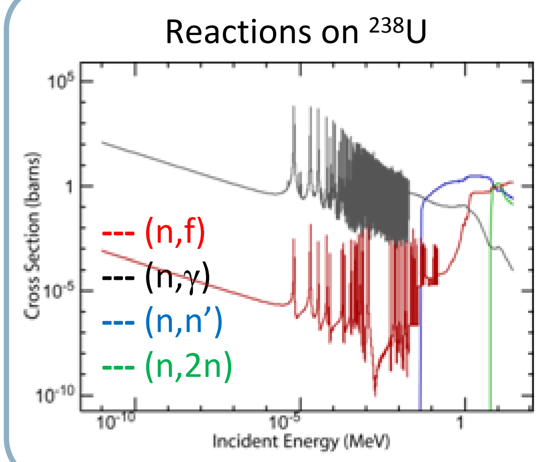
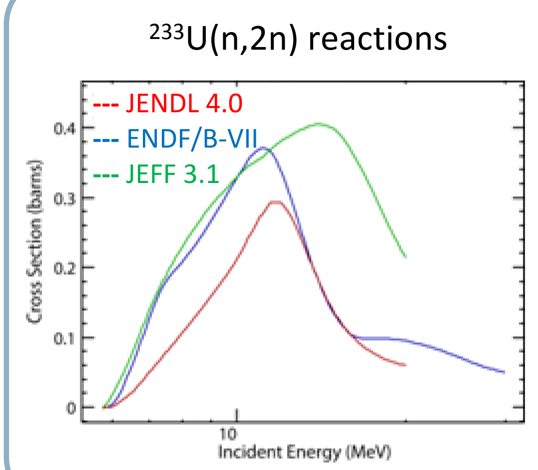
Motivation

- New reactor generation based on fast neutron reactions:
  - neutron induced reactions in these regions not known or not precisely
- Importance of (n,xn) reactions
- Isotopes of interest:
  - ^{232}Th, ^{235}U, ^{233}U
  - NEA high priority list:
    - ^{238}U currently known at 20 %
    - Request for the new reactors: 2 %
- Goal: develop an experimental setup able to measure (n,xn) reactions at less than 5 %

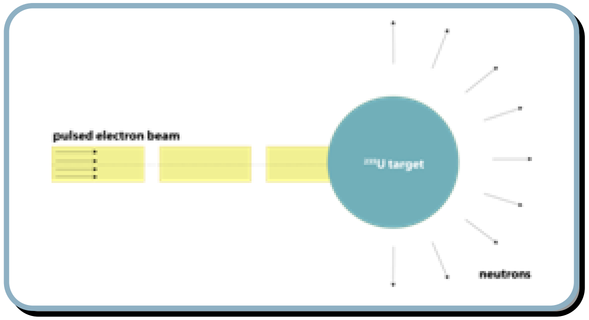




Experimental setup

Experimental setup

- Experiments are performed using a white pulsed neutron beam from Gelina (IRMM, Geel, Belgium)
- A Uranium target is bombarded by a pulsed electron beam: γ radiation is created by *Bremsstrahlung,* neutrons are created by *photofission.*



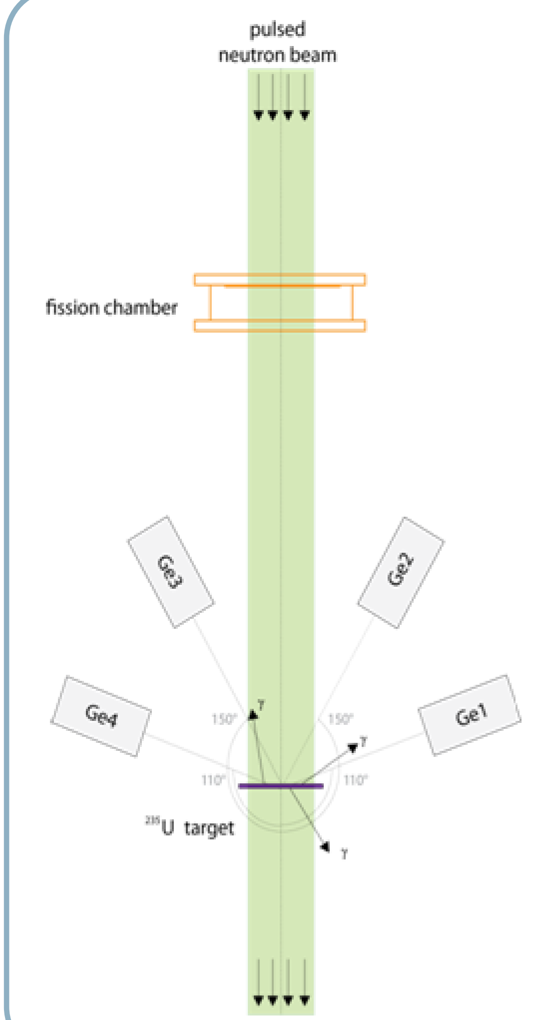
- Neutron energy is determined using the TOF technique

$$E_n = (\gamma - 1) m_n c^2 \quad , \quad \gamma = \sqrt{\frac{1}{1 - \frac{v^2}{c^2}}} \quad , \quad v = \frac{d}{t}$$

Experimental setup

- Experiments are performed at FP16/30m
- Method: Prompt γ ray spectroscopy
  - Ex: $^{235}U(n,n')^{235}U^*$
    $^{235}U(n,2n)^{234}U^*$

- DAQ: Digital TNT2 cards developed at IPHC



Cross sections

- The cross section of a γ transition can be expressed as:

$$\sigma = \frac{n_{det}}{\varsigma\, s\, \Phi\, \varepsilon\, t}$$

Detected hits in a given ray:
- Good statistics
- Low background

Cross section of a given γ ray transition [b]

Acquisition time [s]

Areal density of atoms in target [cm^{-2}]

Detection efficiency
- Measurements
- Simulations

Target surface [cm^{2}]

Incident neutron flux [s^{-1}·cm^{-2}]
- Fission chamber precision

Work on the measurement precision:
Fission chamber

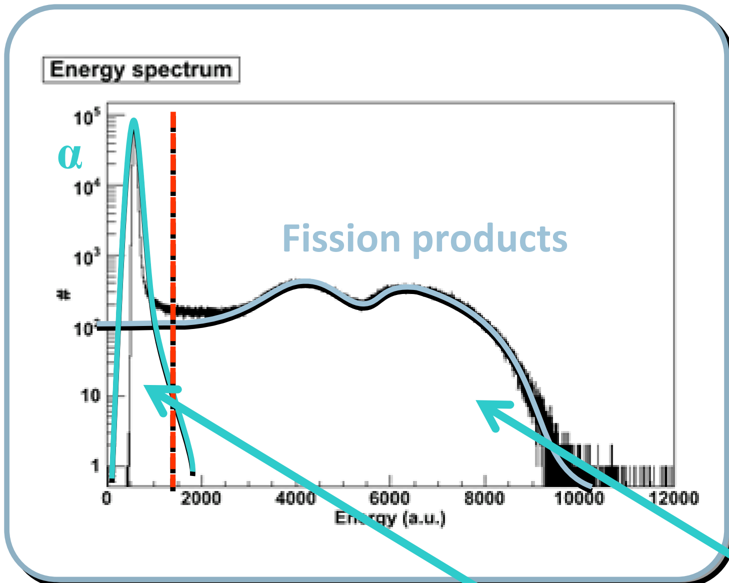
Flux monitoring

- The monitoring is realised with a fission chamber
- Incident neutrons induce uranium fission in the chamber
  - Two fission products are released at 180°, of which one enters the active volume of the chamber
- The incident neutron flux is then given by:

$$\Phi = \frac{n_{PF}}{N_U \, \sigma_{(n,f)} \, \varepsilon \, t}$$

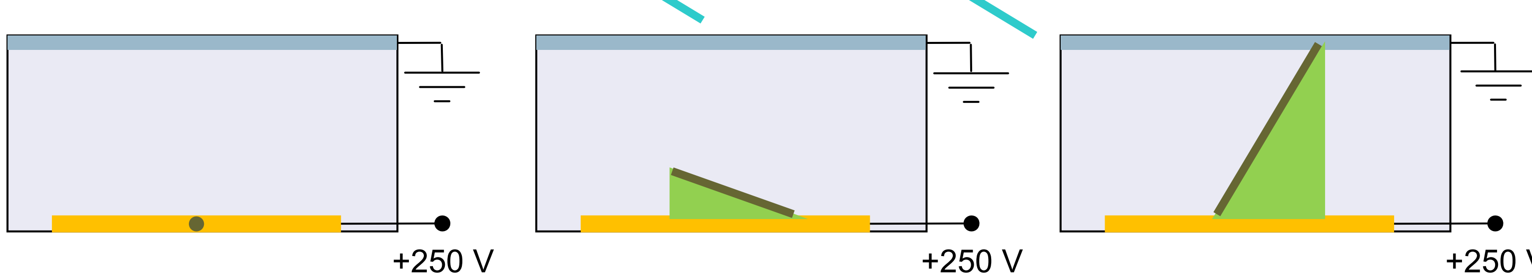
n_{PF}	number of fission products	< 1%
N_U	uranium nuclei in the deposit	< 0.5%
$\sigma_{(n,f)}$	fission cross section (n,f)	< 2%
ε	efficiency	???
t	run time of the experiment	negligible

Possible fission fragment scenarios



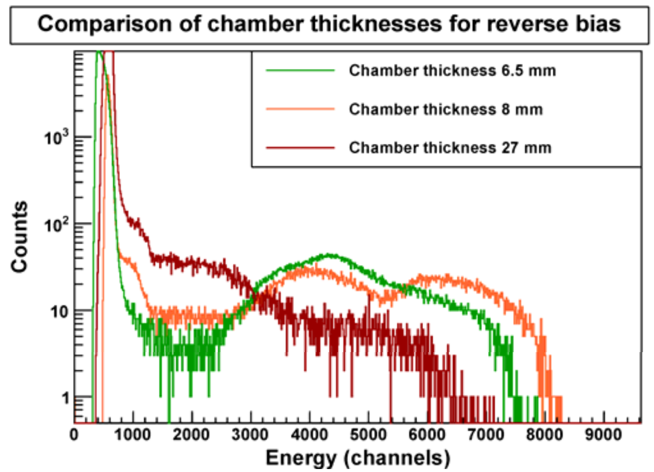
$$S = \sum_i \frac{Q_i}{C} \cdot \frac{d_i}{D}$$

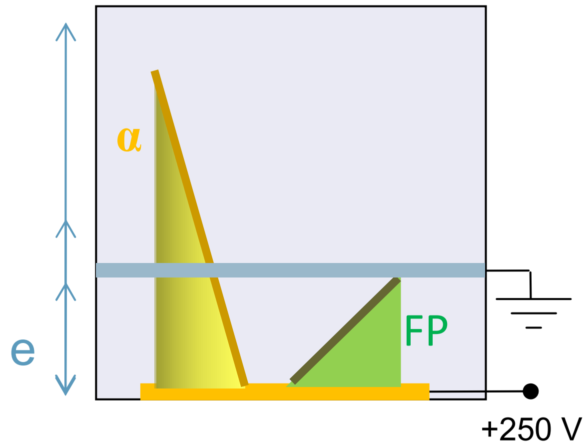
S	detected signal
Q_i	created charge
d_i	distance charge-electrode
C	preamp capacitor
D	chamber thickness



S = 0 | S weak | S strong

Study of the chamber thickness

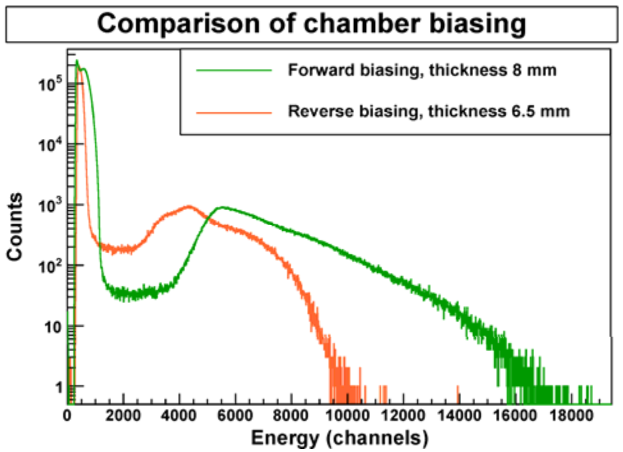


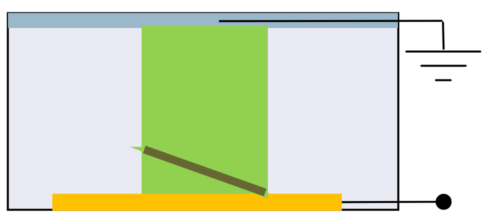


- The α particles have a range of roughly 10 cm in the chamber gas and lose most of their energy in the Bragg peak
- The fission products have a range of 2 to 3 cm in the gas, their kinetic energy is weak and the energy loss in the chamber is almost constant
- By increasing the chamber thickness, the α particle detection is favoured and the overlapping between α signals and FP is increased

⇨ Best thickness: 6,5 mm

Study of chamber biasing





- Reverse or forward bias of the chamber plays a role on the second scenario
- At reverse biasing, fission products losing all their energy in the gas only create a small signal
- By polarisation of the opposite electrode their signal is amplified
- This leads to a better separation of the α particles and the fission products

Best configuration: forward bias

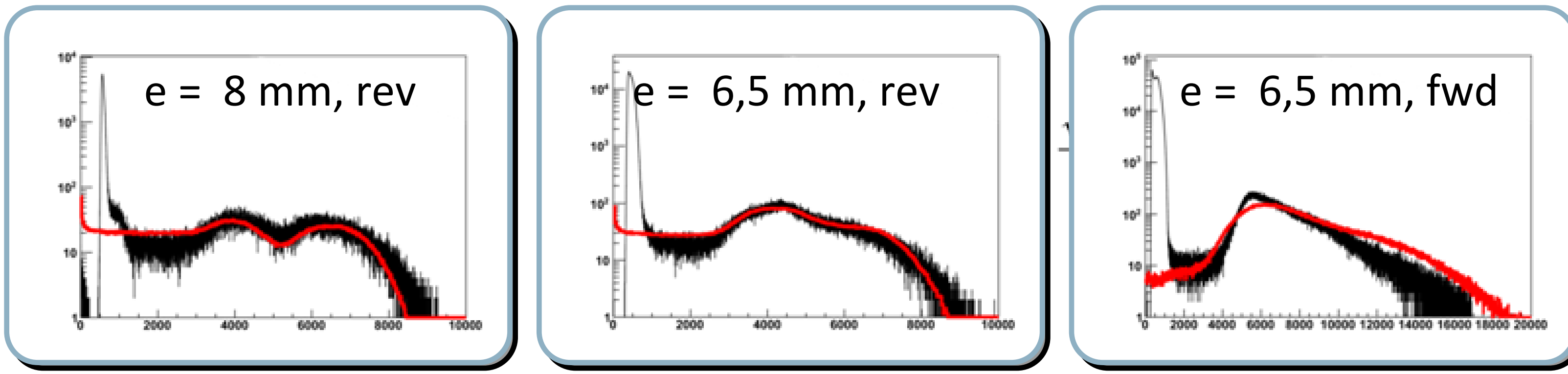
Corrections

- Loss of fission products entirely absorbed in the uranium foil can be estimated to:

$$\Delta_{t/2R} = \frac{t}{2R}$$

- R = 4.76 mg/cm^2 for UF_4 (Budtz-Jørgensen et al.)
- An anisotropy correction in the order of 1% can be applied (Carlson et al.)
- The correction for fission products lost due to the application of a threshold was simulated by Geant4:

--- simulated spectra --- experimental spectra



- This correction is more delicate, as especially the region of interest is not well reproduced

Calibration measurements at PTB

- In order to determine the fission chamber efficiency precisely and to verify the previous … d at the Physikalis…
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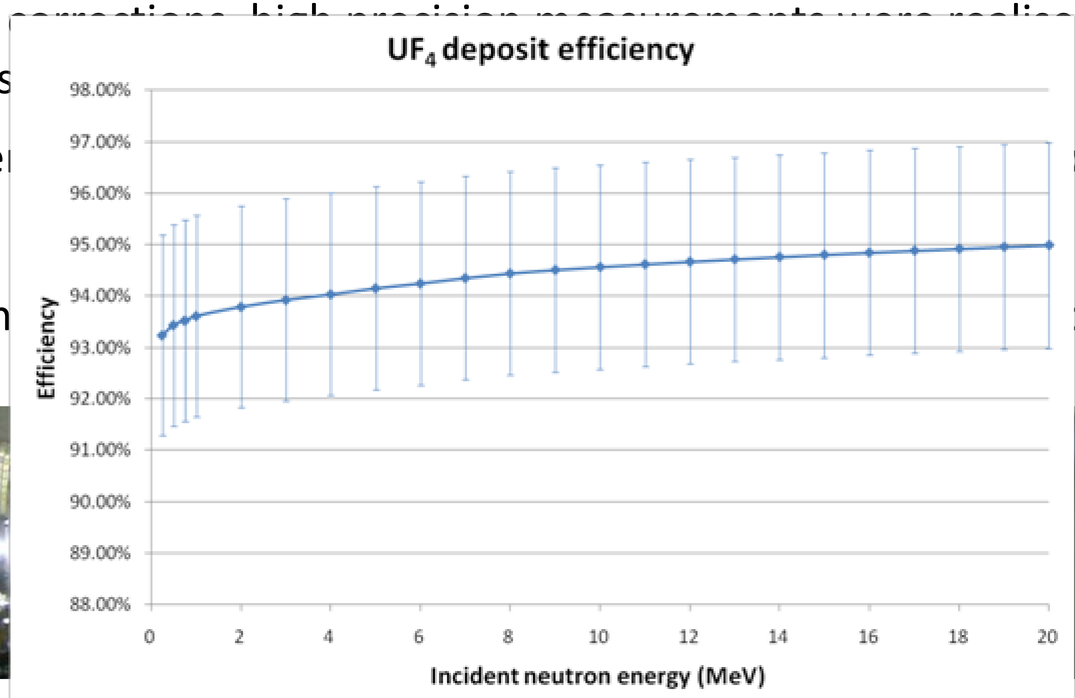
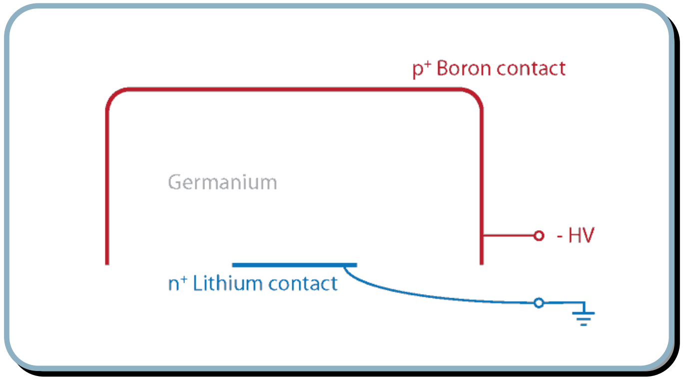


- Results:
  - UF_4: ε_{PTB} = 94.4(2.1)% $\varepsilon_{classical}$ = 94.4(2.1)%

Work on the measurement precision:
HPGe detectors

HPGe γ efficiencies

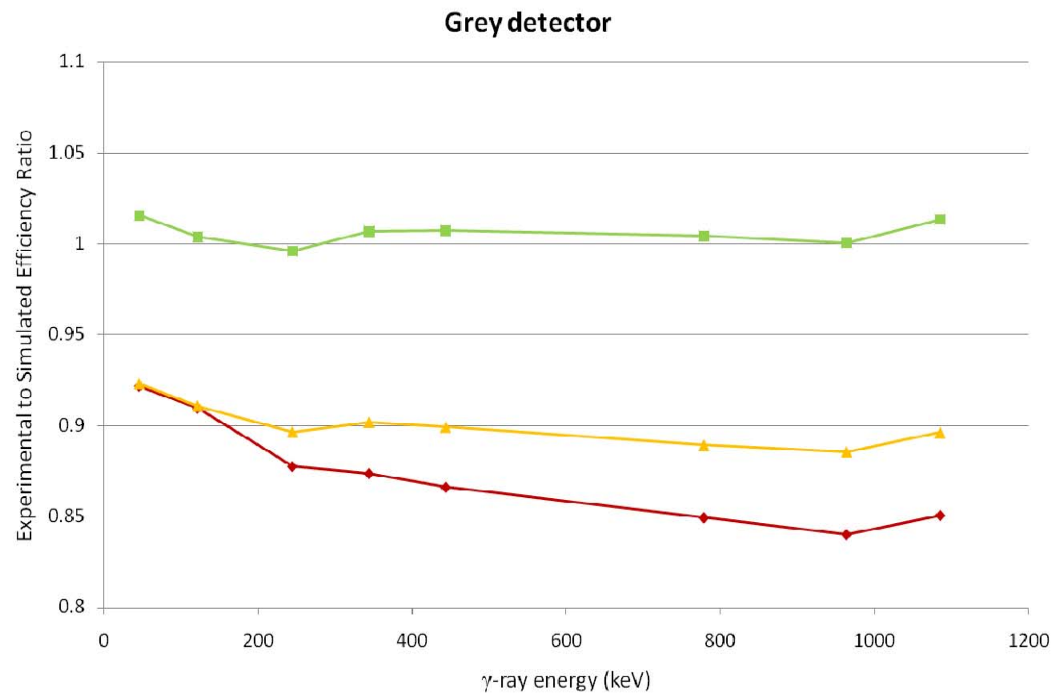
- The γ ray detection of the (n,xnγ) reactions is realised by HPGe detectors
- As the samples used in the experiment are not point-like (beam diameter 55 mm), and as the γ rays are subject to auto-absorption, simple calibration measurements are not sufficient to determine the efficiency precisely



- Needs:
  - Good knowledge of the internal detector geometry
  - Good dead zone estimation of the crystal

Crystal dead zones

- Effect of the dead zones

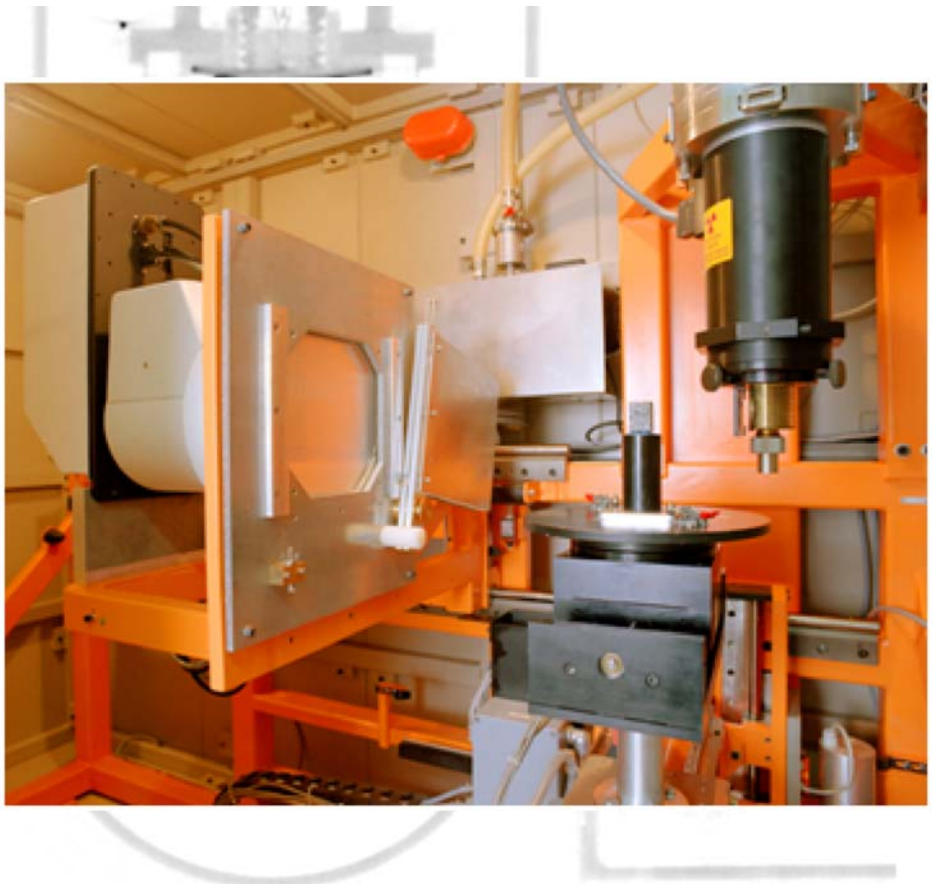


Crystal with:
front dead zone of 25 µm
+ dead back zone of 1,4 mm
+ diameter reduction of 2,8 mm

- The crystal geometry has to be checked!

Microfocus Computer Tomography

- All 4 detectors were analysed
  - At the Katholieke Universiteit Leuven
  - X-ray source: Philips HOMX 161
  - Voltage: 125 KV
  - Current: 0.28 mA
  - Resolution: 110-150 μm



Internal geometry of the green detector

Detector specifications

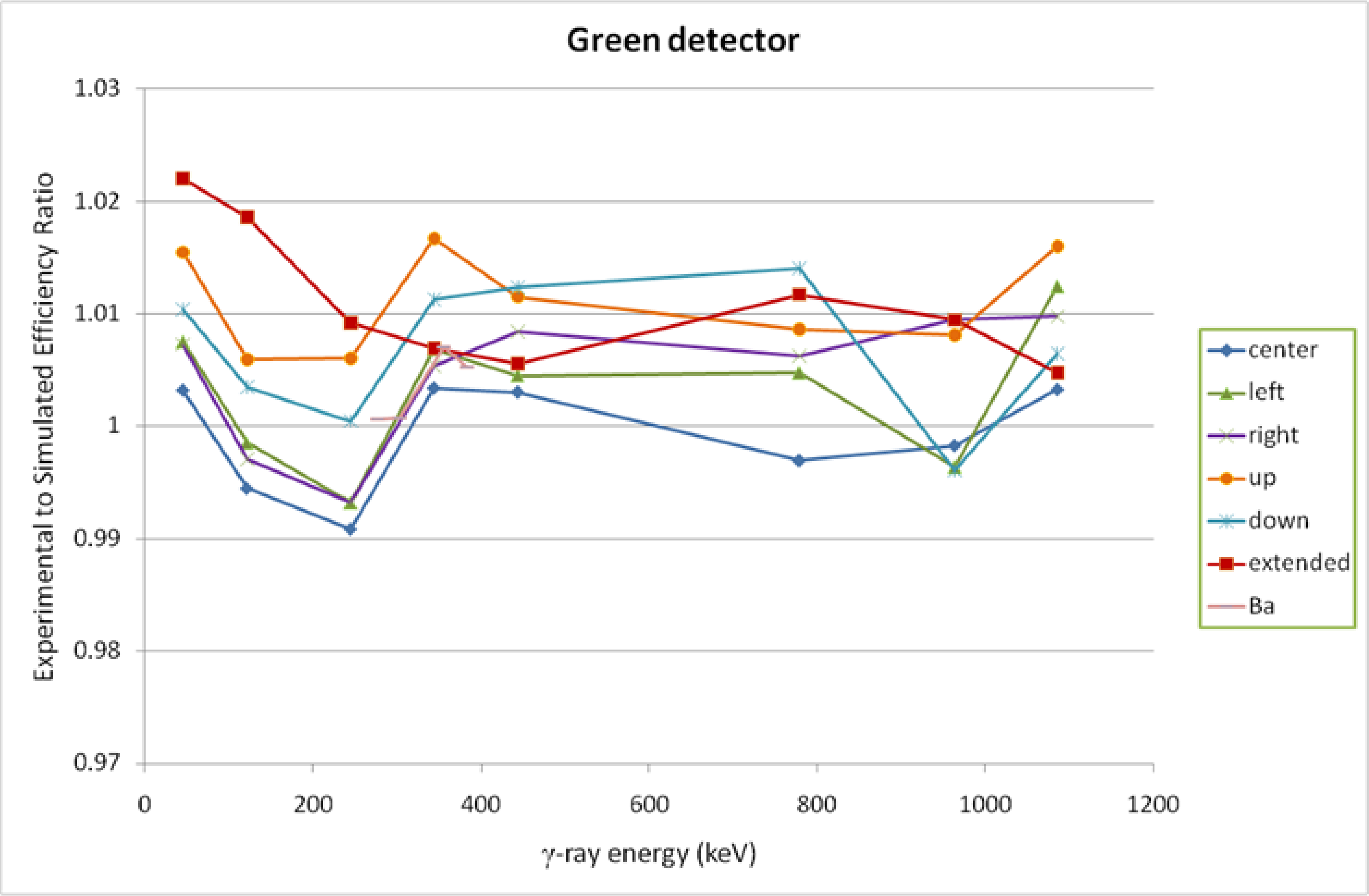
Detector	Component	Constructor data	µ-ct results	Geant4 results	
Blue	Crystal diameter	36.00	35.10	35.05	✓
	Distance to window	5.00	4.50	5.00	✓
	Rounding	3.00	2.80	3.00	✓
	Crystal thickness	19.60	19.60	19.60	✓
	Back dead zone	-	-	0.40	
Green	Crystal diameter	35.50	34.80	34.70	✓
	Distance to window	2.00	5.00	5.00	✓
	Rounding	2.00	3.80	4.00	✓
	Crystal thickness	20.00	20.00	20.00	✓
	Back dead zone	-	-	0.60	
Red	Crystal diameter	59.00	59.00	57.70	✗
	Distance to window	5.00	5.00	5.00	✓
	Rounding	5.00	5.00	5.00	✓
	Crystal thickness	27.50	27.50	27.50	✓
	Back dead zone	-	-	2.30	
Grey	Crystal diameter	59.00	58.00	56.20	✗
	Distance to window	5.00	4.50	5.00	✓
	Rounding	5.00	5.00	5.00	✓
	Crystal thickness	30.00	30.00	30.00	✓
	Back dead zone	-	-	1.40	

Data in mm

Large planar → weak field

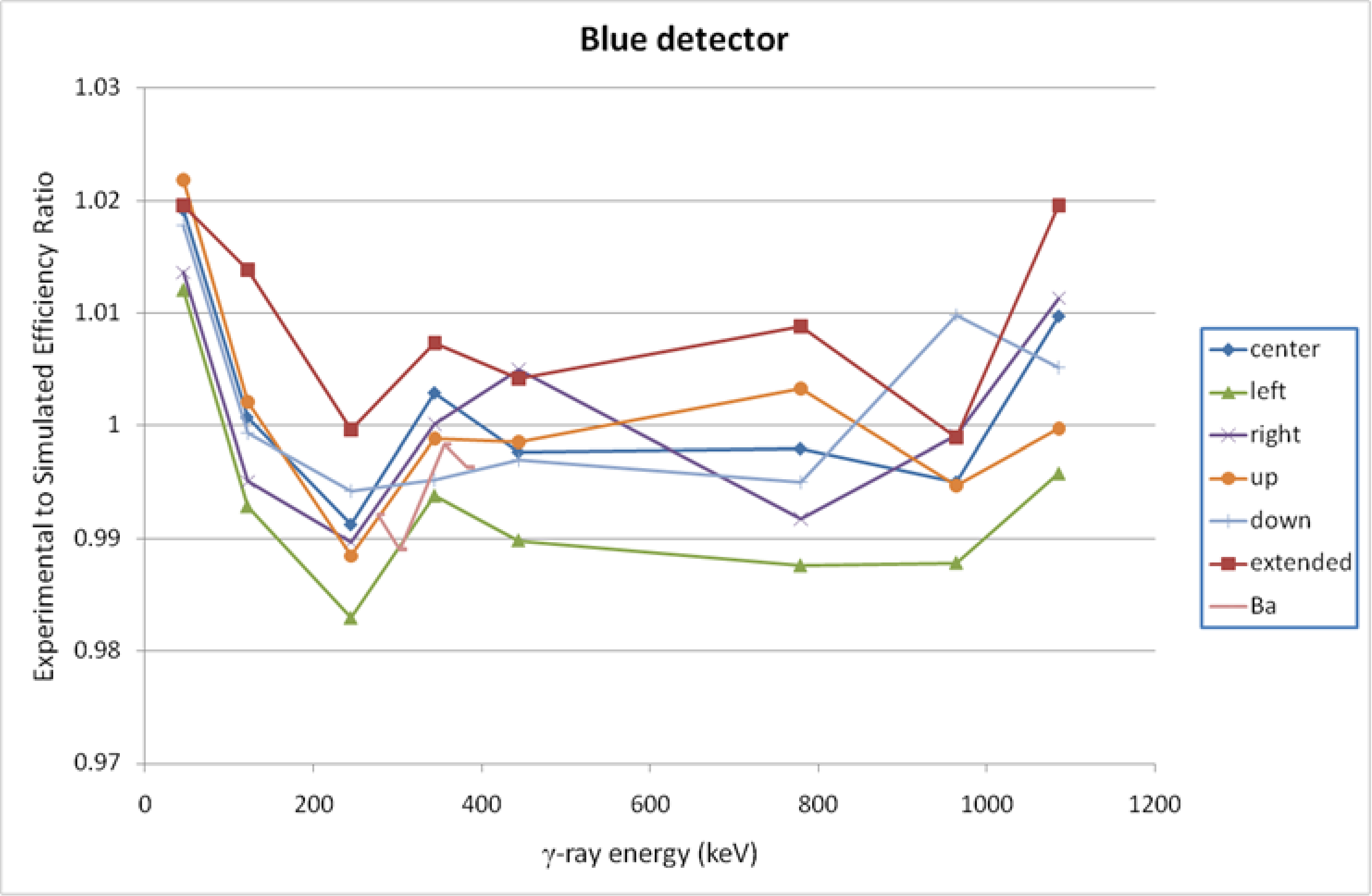
Coaxial

Results for the green detector



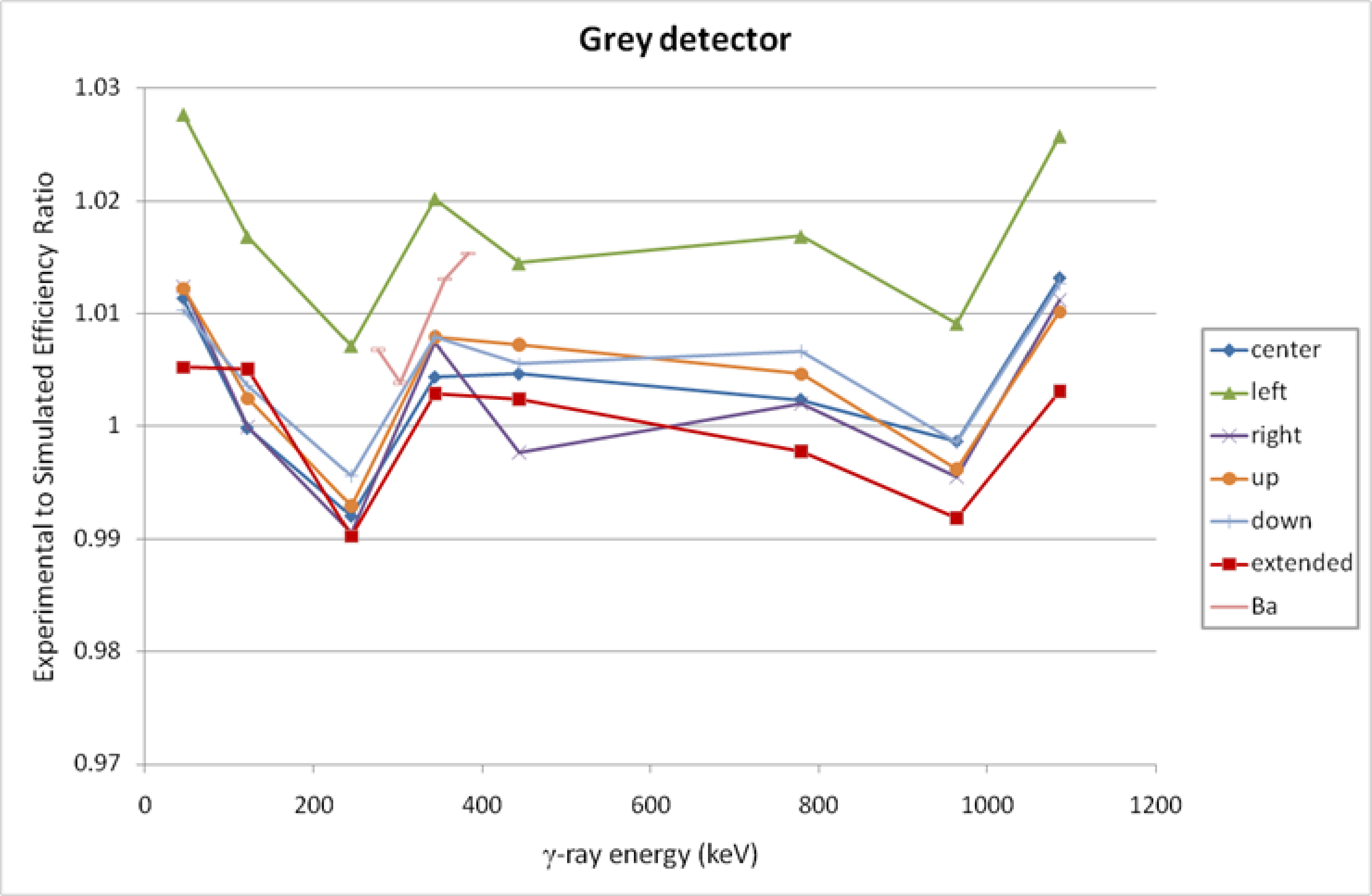
Used sources: ^{152}Eu point-like centered on the beam axis, displaced by 12 mm / ^{152}Eu extended of a diameter of 50 mm / ^{133}Ba point-like

Results for the blue detector



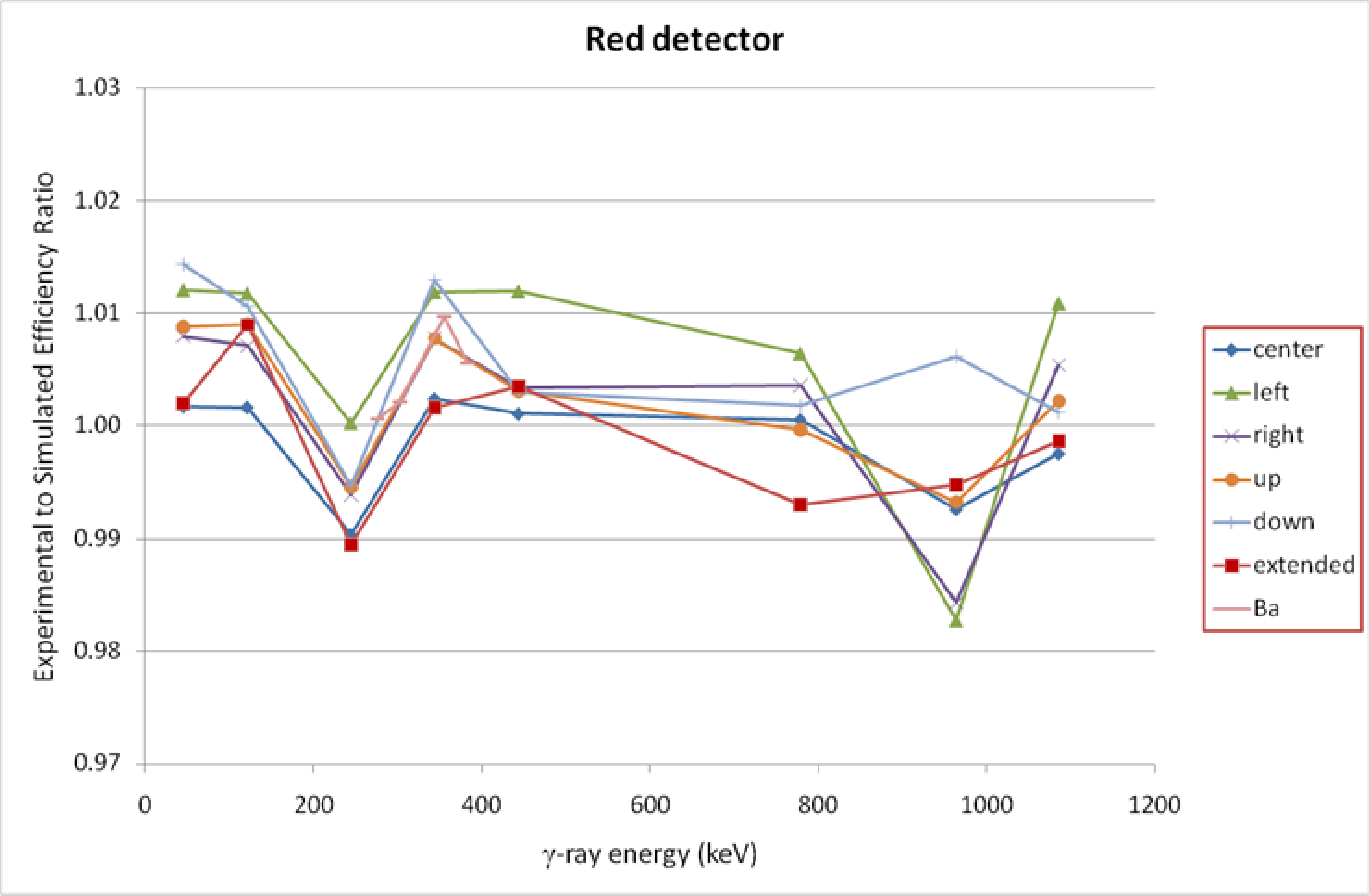
Used sources: ^{152}Eu point-like centered on the beam axis, displaced by 12 mm / ^{152}Eu extended of a diameter of 50 mm / ^{133}Ba point-like

Results for the grey detector



Used sources: ^{152}Eu point-like centered on the beam axis, displaced by 12 mm / ^{152}Eu extended of a diameter of 50 mm / ^{133}Ba point-like

Results for the red detector



Used sources: ^{152}Eu point-like centered on the beam axis, displaced by 12 mm / ^{152}Eu extended of a diameter of 50 mm / ^{133}Ba point-like

Conclusions

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- The PTB calibration measurements together with studied theoretical corrections reduces the uncertainty on the fission chamber efficiency

$$\Delta\varepsilon_{FC} = 2.1\%$$

- The Geant4 simulations based on a μ-ct of the 4 HPGe detectors reduces the γ ray efficiency

$$\Delta\varepsilon_{\gamma} = 2\text{-}3\%$$

- The experimental setup is now able to measure (n,xnγ) reaction cross sections at high precision. In has already been used on isotopes ^{235}U and ^{232}Th and is now ready to be used on ^{238}U

$$\Delta\sigma = 5\text{-}6\%$$

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