Internship defence

The Nuclear Measurement Laboratory

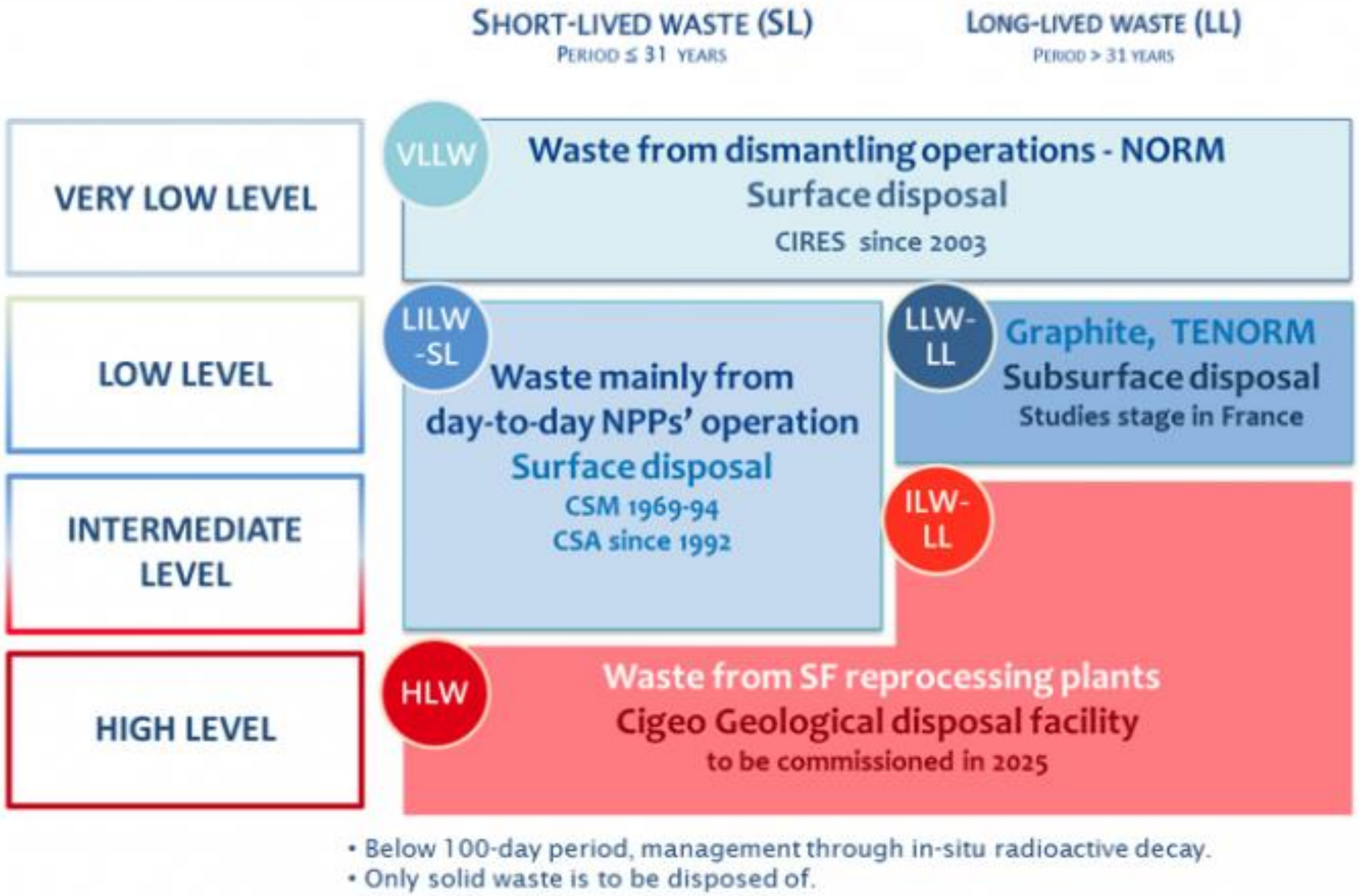
- 25-30 permanent staff
- 5-10 non-permanent staff (PhD, trainees, temporary research contracts)
- More than 50 projects or collaborations (on R&D and application topics)

Faculté de **physique** et **ingénierie**
Université de Strasbourg

Monte Carlo model of Active Photon Interrogation measurements
for the characterisation of nuclear waste packages

master PSA
Physique Subatomique
Astroparticules

Introduction



SHORT-LIVED WASTE (SL)
PERIOD ≤ 31 YEARS

LONG-LIVED WASTE (LL)
PERIOD > 31 YEARS

VERY LOW LEVEL

VLLW
Waste from dismantling operations - NORM
Surface disposal
CIRES since 2003

LOW LEVEL

LILW-SL
Waste mainly from day-to-day NPPs' operation
Surface disposal
CSM 1969-94
CSA since 1992

LLW-LL
Graphite, TENORM
Subsurface disposal
Studies stage in France

INTERMEDIATE LEVEL

ILW-LL

HIGH LEVEL

HLW
Waste from SF reprocessing plants
Cigeo Geological disposal facility
to be commissioned in 2025

- Below 100-day period, management through in-situ radioactive decay.
- Only solid waste is to be disposed of.

Detection methods

Destructive: sampling the content of the package

- Inaccurate if heterogenous
- Radiological exposition of operators

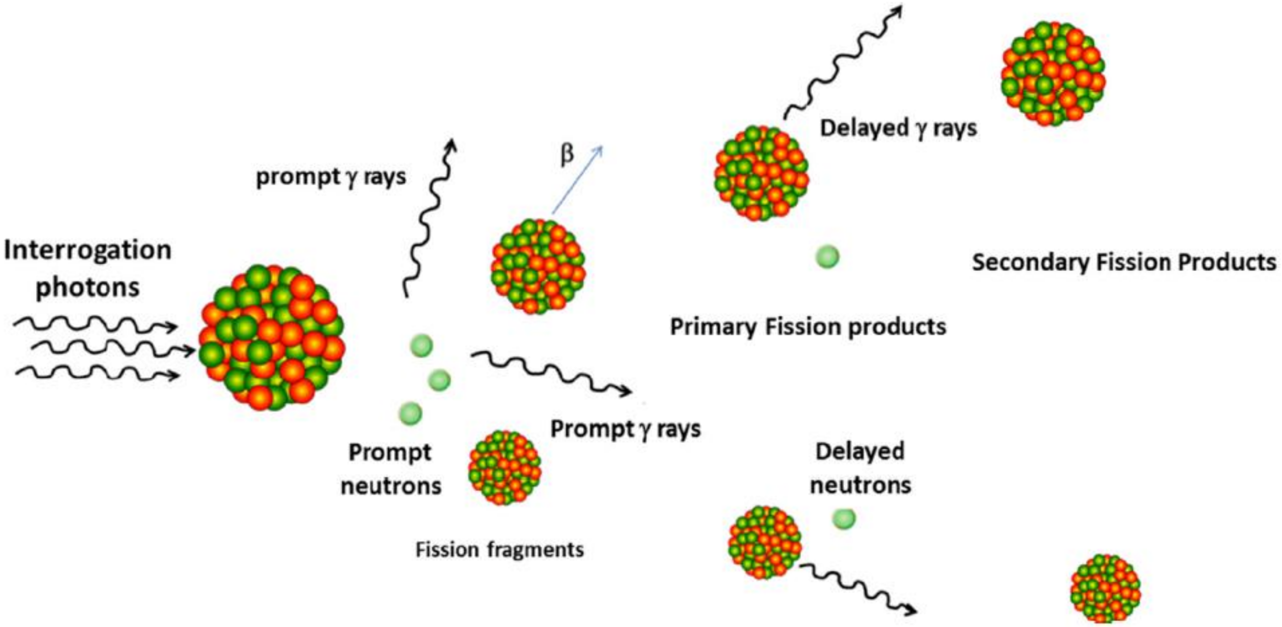
Passive: detecting natural activity of package

- Low energy
- Low activity

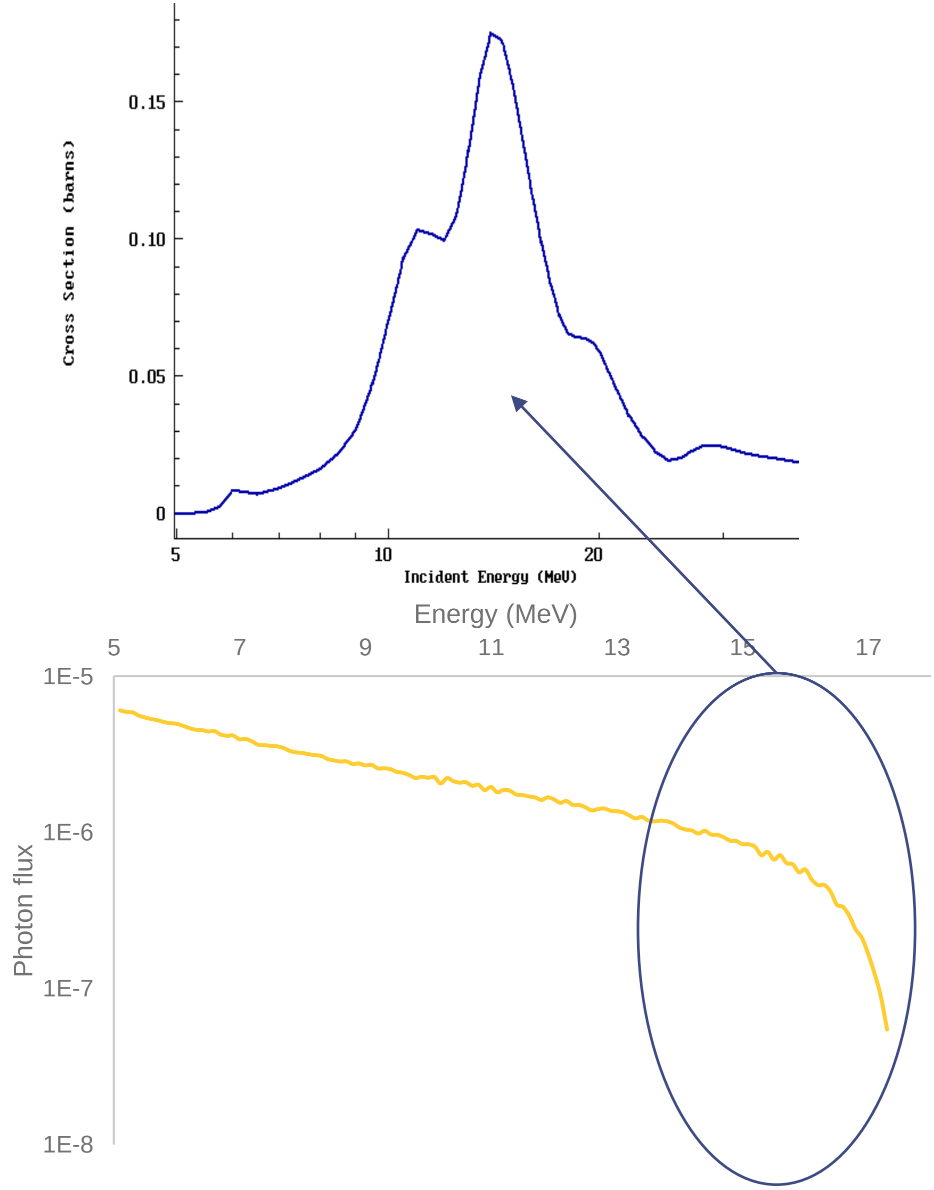
Active: probing the content with neutrons/photons

CEA 870L cemented waste drums

Physics behind API

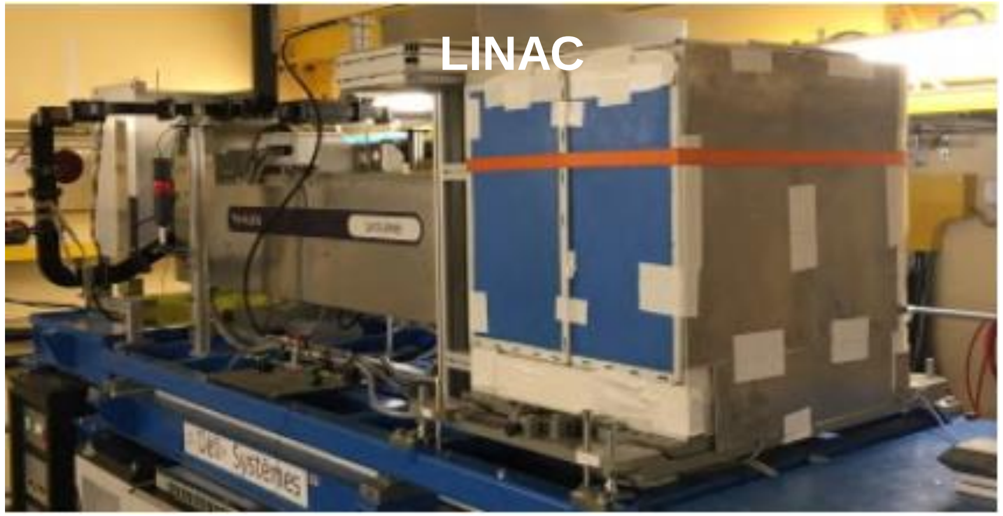


Photofission cross-section for U^{238}



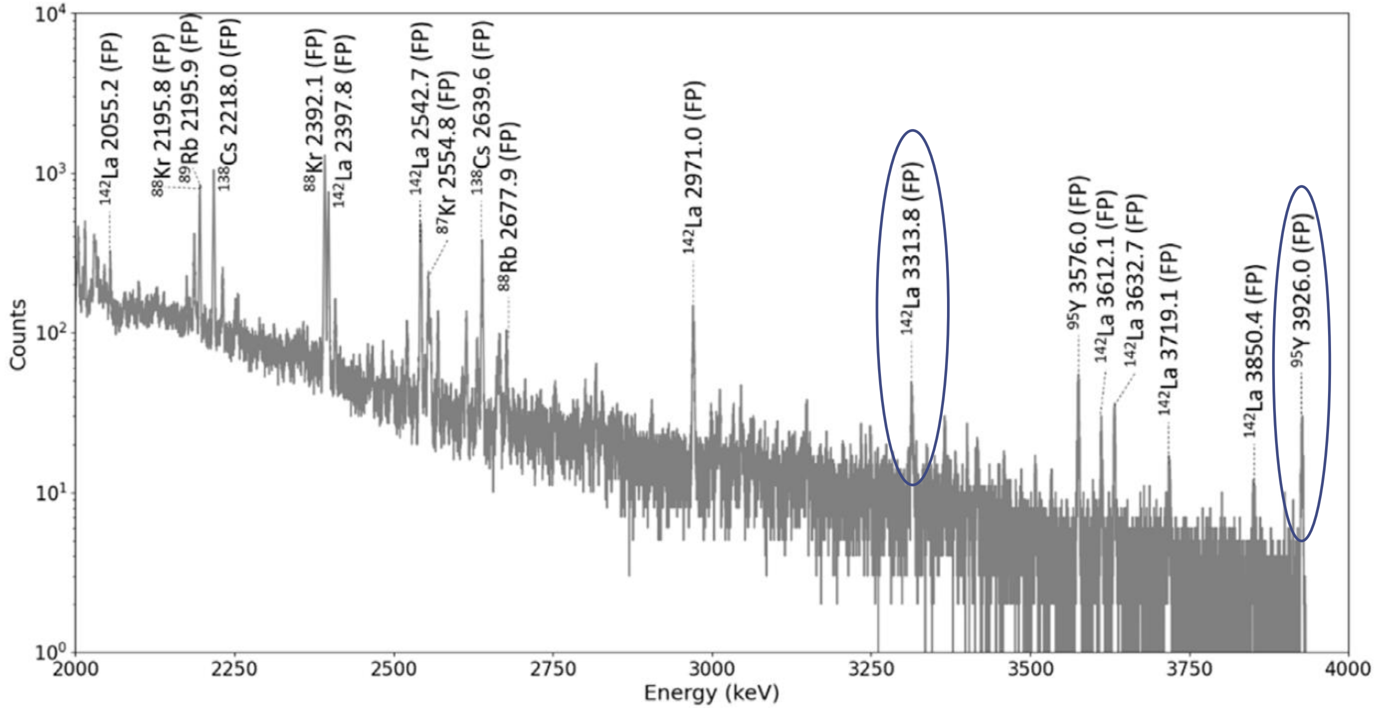
LINAC x-ray spectrum

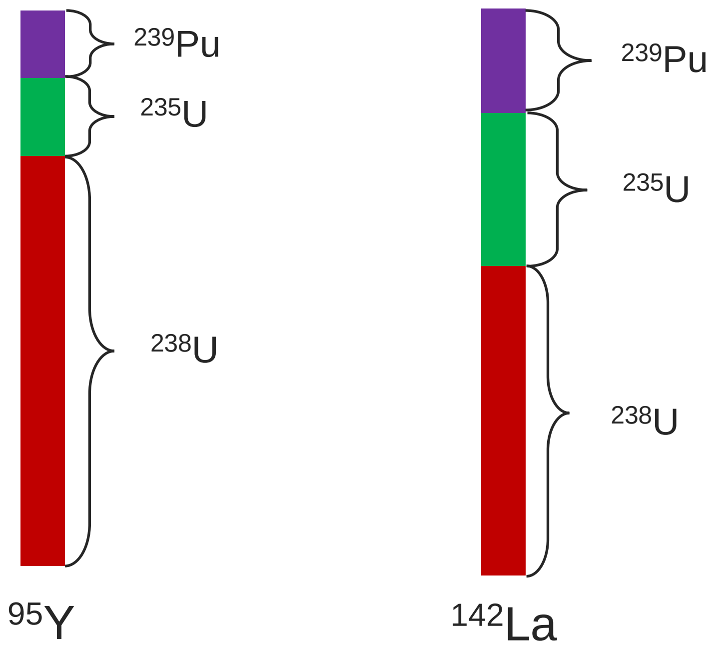
HPGe photofission Setup for CINPHONIE casemate



- Detect
- Localize
- Quantify

HPGe signal analysis





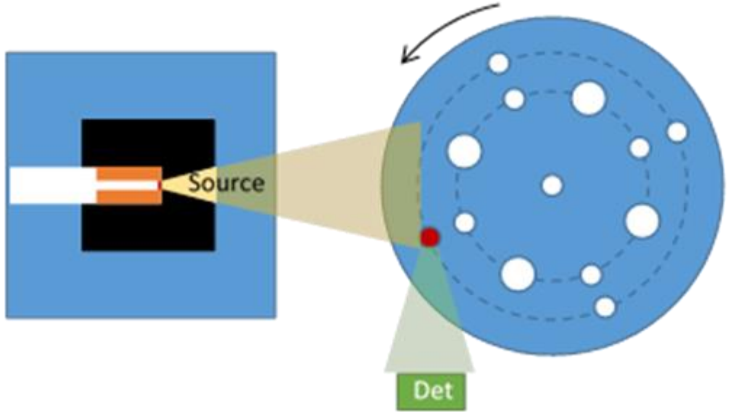
HPGe gamma spectrometry

Quantity/Identify actinides

Hours of irradiation
Days of measurement
Detection limit: dozen of grams

Experimenting with LaBr$_3$ fast scintillators

- 1s irradiation
- 1s cooling
- 1s measurement



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Full Length Article

Photofission delayed gamma-ray measurements in a large cemented radioactive waste drum during LINAC irradiation

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A R T I C L E I N F O

Keywords:
Radioactive waste characterization
Photofission
LINAC
Nuclear data

A B S T R A C T

Nuclear materials characterization in 870 L cemented waste drums is challenging due to significant neutron and gamma ray attenuation. Among the existing non-destructive approaches, photon active interrogation is of particular interest. A LINAC accelerates electrons to energies greater than 10 MeV, leading to highly penetrating interrogating bremsstrahlung photons that can reach nuclear materials in the depth of the 870 L waste drum and allow the detection of delayed gamma rays emitted by photofission products. Because the interrogating photon and neutron fluxes are extremely high during irradiation, measurements with high purity germanium detectors are usually performed after a long irradiation time, for example by moving the detector or the waste drum. Therefore, such measurements are only sensitive to delayed gamma rays associated to photofission products having sufficient long half-life of at least tens of seconds, which cuts a valuable signal coming from fission products with a shorter half-life. In this paper, we report gamma rays measurements of very short lived photofission products using a 3 in × 3 in cylindrical LaBr$_3$(Ce) fast scintillation detector. A depleted uranium sample was irradiated by a pulsed bremsstrahlung source with maximum energy 17.5 MeV in a macro pulsing mode (1 s irradiation, 2 s cooling). This allowed to acquire a strong delayed gamma signal within a time window of 2 s.

A clear signature of nuclear materials was observed even in the depth of a concrete mock-up, with an excellent signal-to-noise ratio beyond 3.5 MeV where the background of nonnuclear activated materials is negligible. These results are compared to a semi analytical model that qualitatively agrees but underestimates the measurements by a constant factor 1.7, probably caused by a wrong beam intensity normalization. Indeed, in this work the LINAC pulse time structure (macro pulsing) was different from its nominal working point used to characterize the beam (usual pulsing mode). Since it allows direct calculations of the detector response to delayed gamma-ray photofission measurements, this model is a fast calculation alternative to time-consuming Monte Carlo simulations, in view of further studies that will follow this feasibility demonstration.

1. Introduction

Standard 100 L radioactive waste drums from the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) having a dose greater than 2 mSv/h at contact are compacted and embedded in a concrete matrix inside 870 L metallic containers [1]. The 870 L containers, referred as 870 L drums in the following, have an external diameter of about 100 cm and a height of about 115 cm. The total waste weight is comprised between 300 and 500 kg, approximately, with an apparent density between 1 and 2 g cm^{-3}. The block is surrounded by a concrete envelop of about 5 cm in the periphery (walls) and above the waste, and 10 cm below. The mean mass of the 870 L drum after adding cement is globally between 1.5 and 2 tons.

To obtain allowance for transporting a drum or for its acceptance in interim storage or final repository, the waste producer must guaranty that the amount of fissile material in the drum is bellow a certain limit, for instance 200 g [2]. In smaller radioactive wastes packages, the amount of fissile materials is often measured by gamma ray spectrometry and passive neutron measurements. However, given the large gamma and neutron attenuation in 870 L cemented drums, passive measurements lead to large detection limits, and even in the case of a detection, to unacceptable uncertainties related to the generally unknown position of nuclear materials. Active neutron measurement is also difficult due to the large attenuation of both interrogating and induced fission neutrons by the hydrogen nuclei present in the concrete matrix. An alternative to neutron interrogation is to measure photofission delayed gamma rays induced by the high-energy bremsstrahlung photon beam of an electron Linear Accelerator (LINAC), both interrogating and induced photons having enough energy to reach nuclear materials in the depth and to escape the drum, respectively. The use

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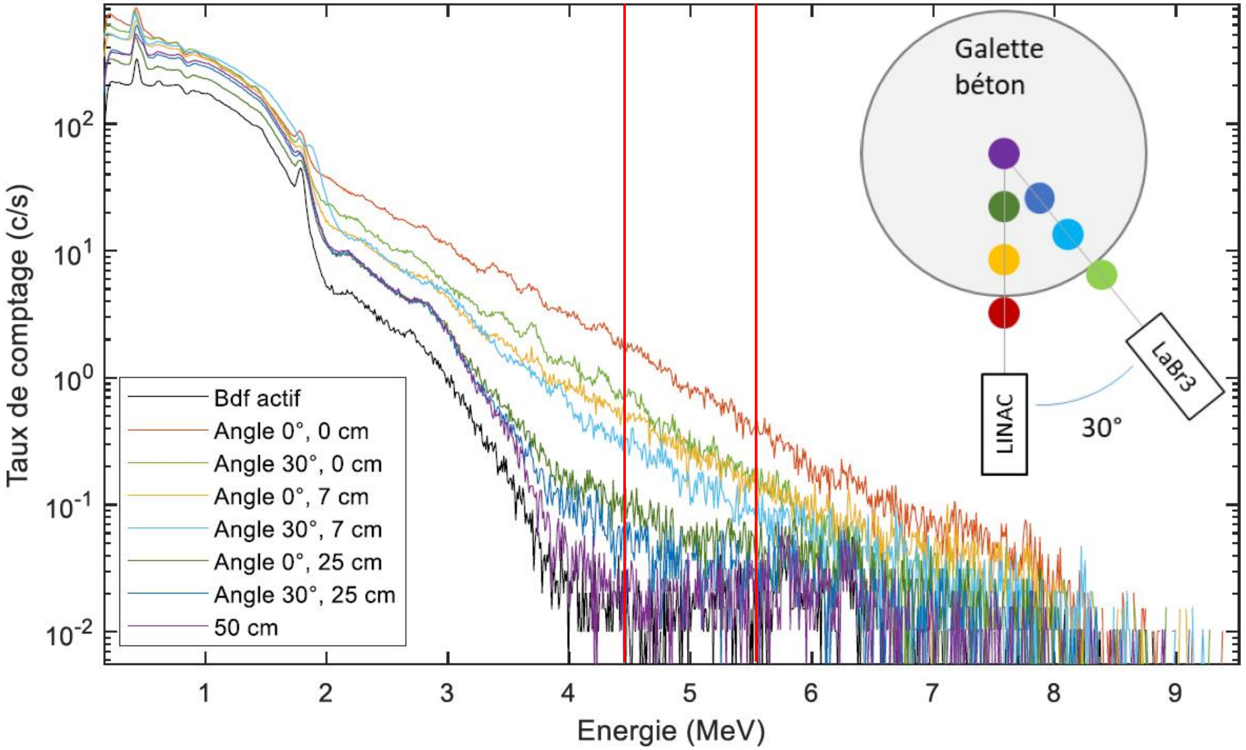
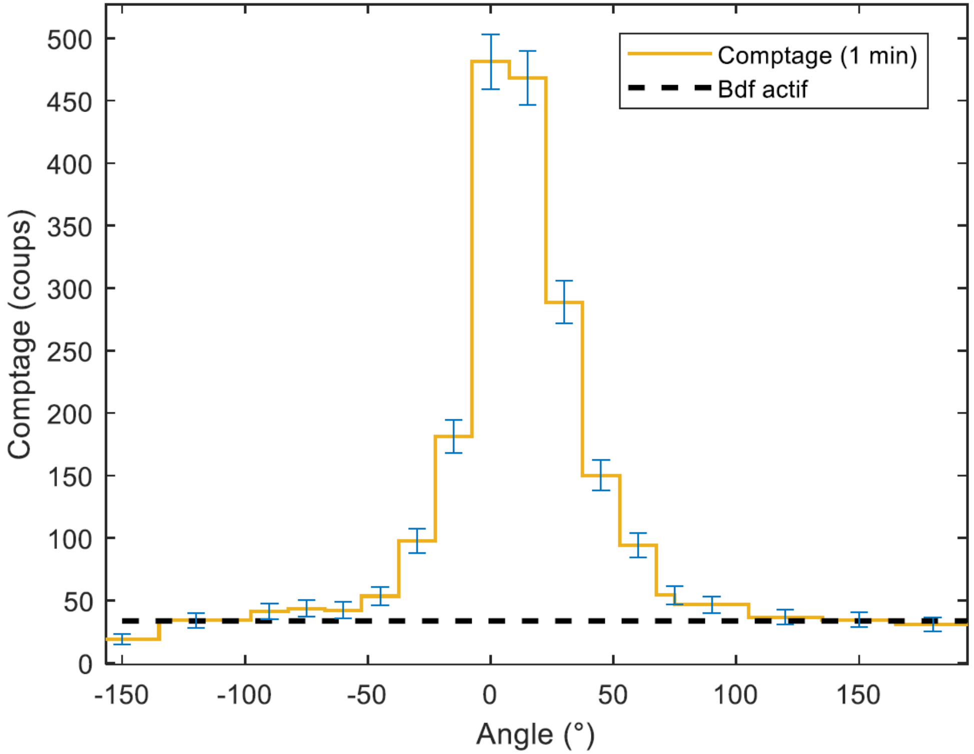
Results



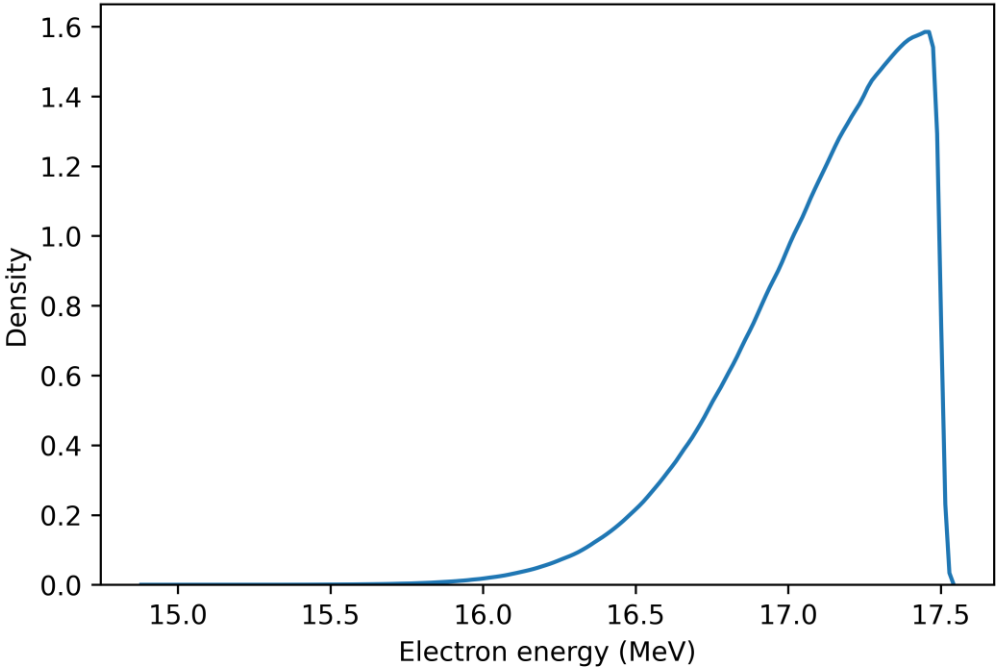
10 min measurements



1 min measurements

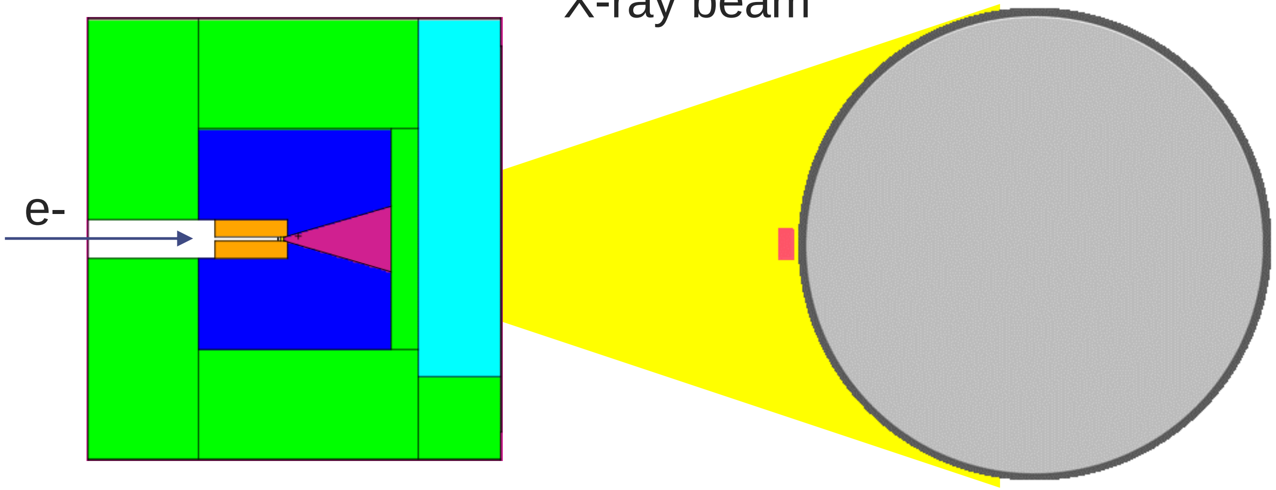
Modelling of the experiments

LINAC electron spectrum

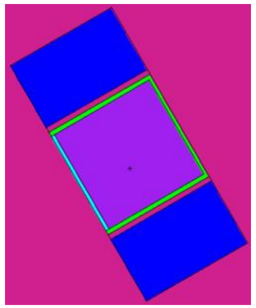


LINAC head

X-ray beam

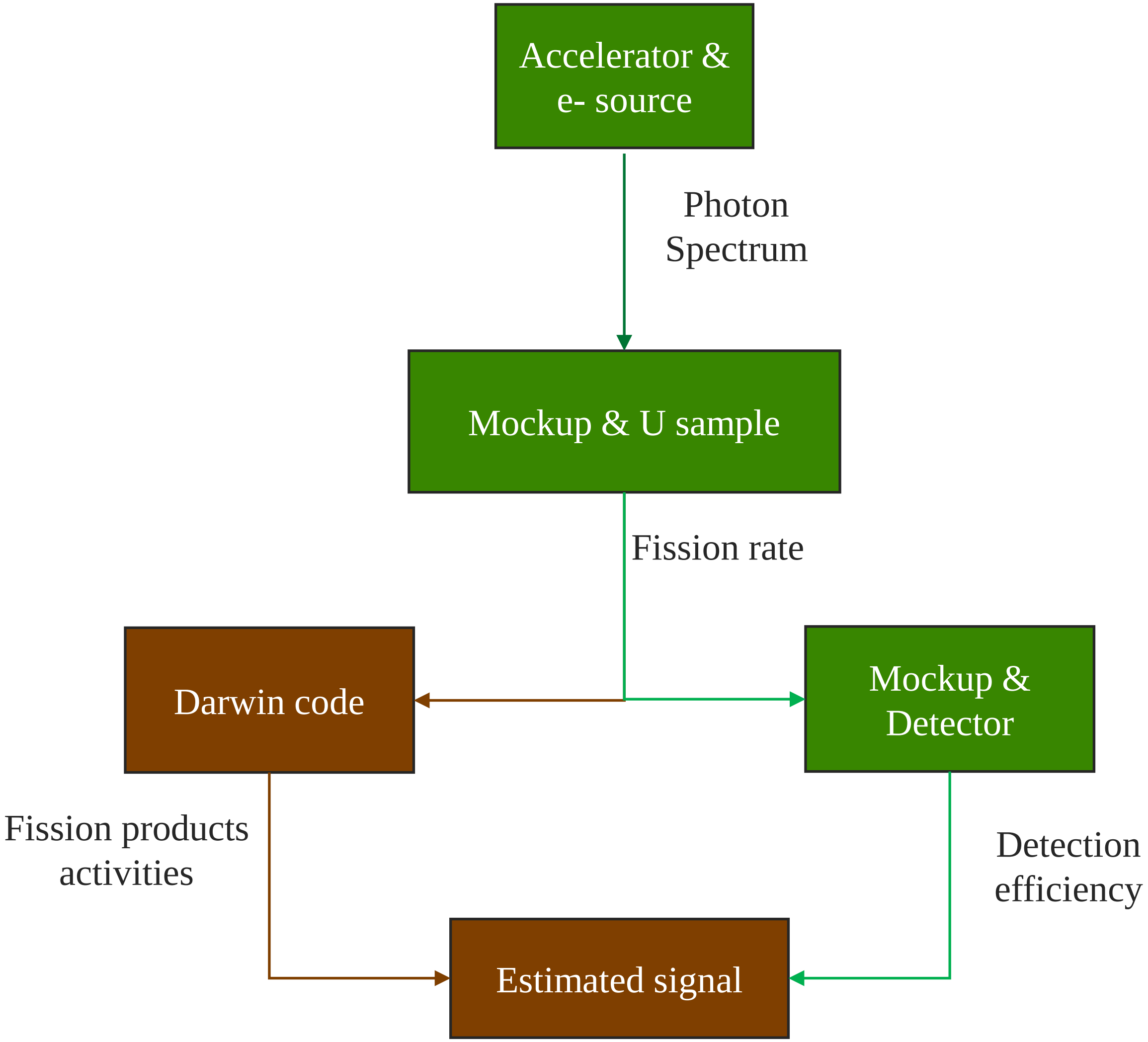


Concrete mock-up



LaBr$_3$ detector

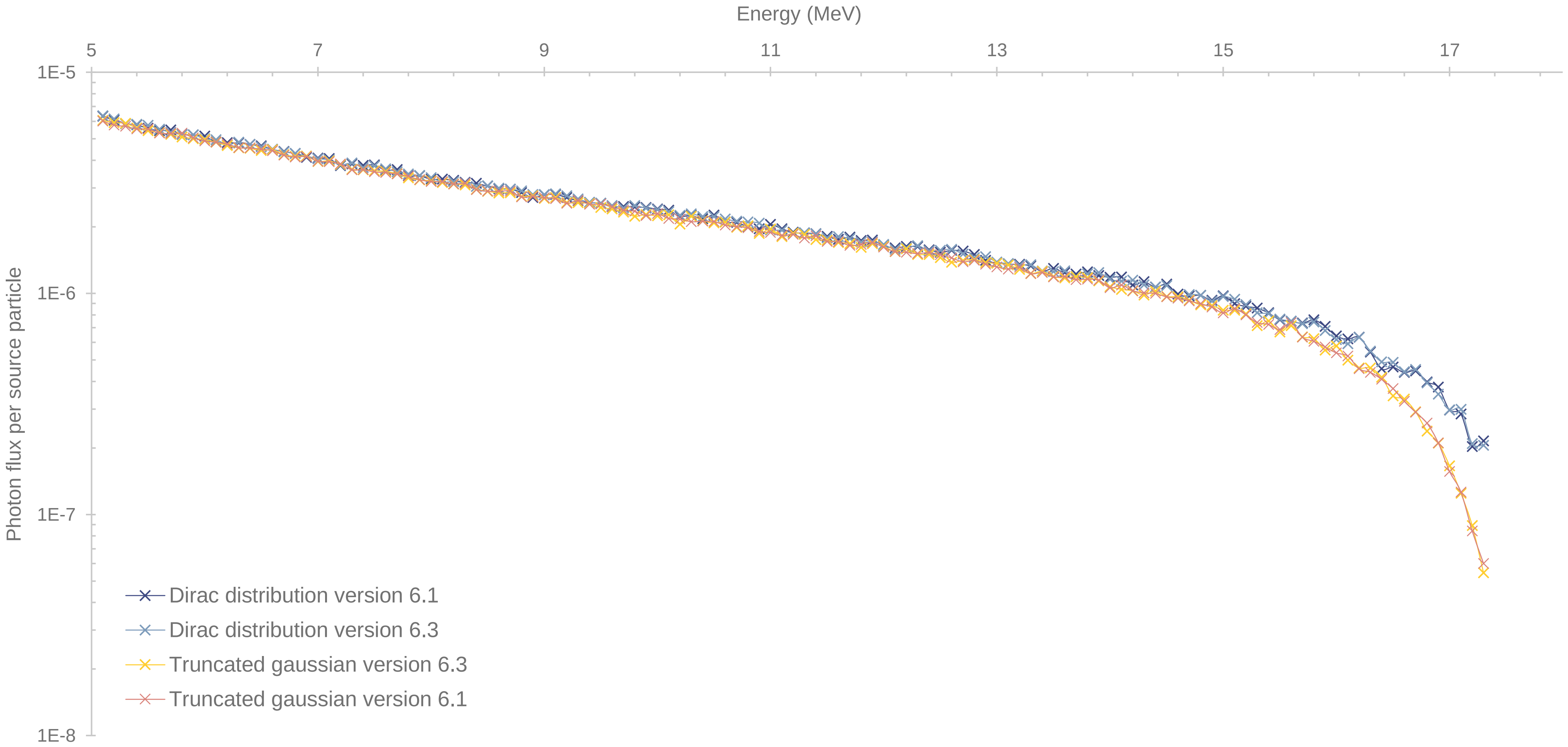
Sequential method



🟩 Finished work

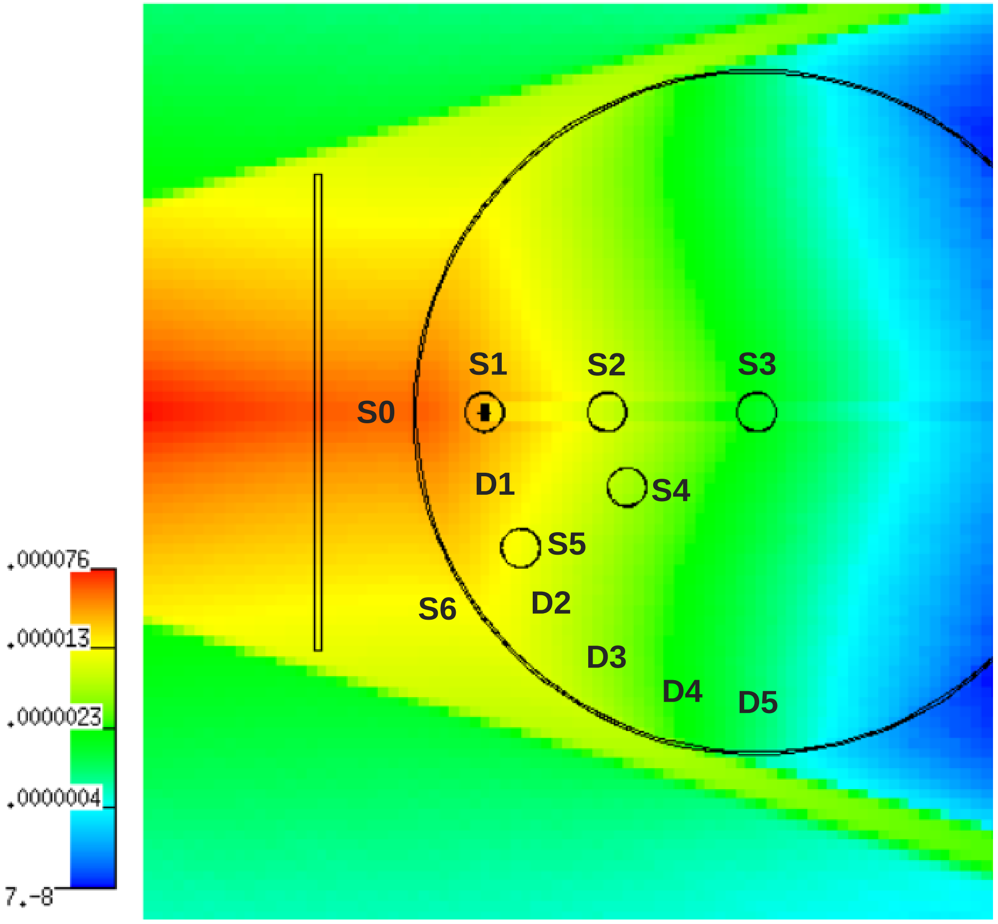
🟫 Planned work

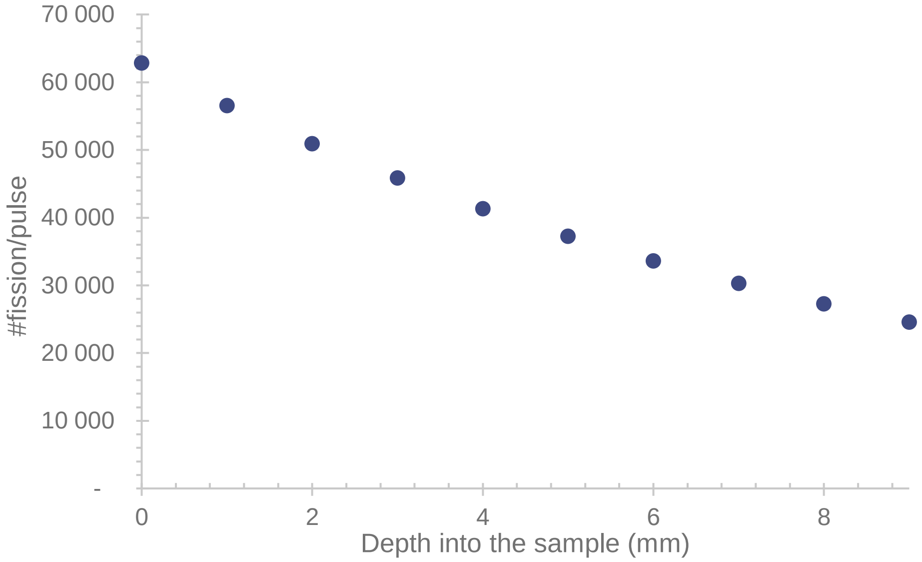
1st step: Photon Spectrum



Source distribution	Dirac	Gaussian	Truncated Gaussian
Fission per e- source @ 30cm ($\times 10^{-7}$)	5.94	6.11	6.62

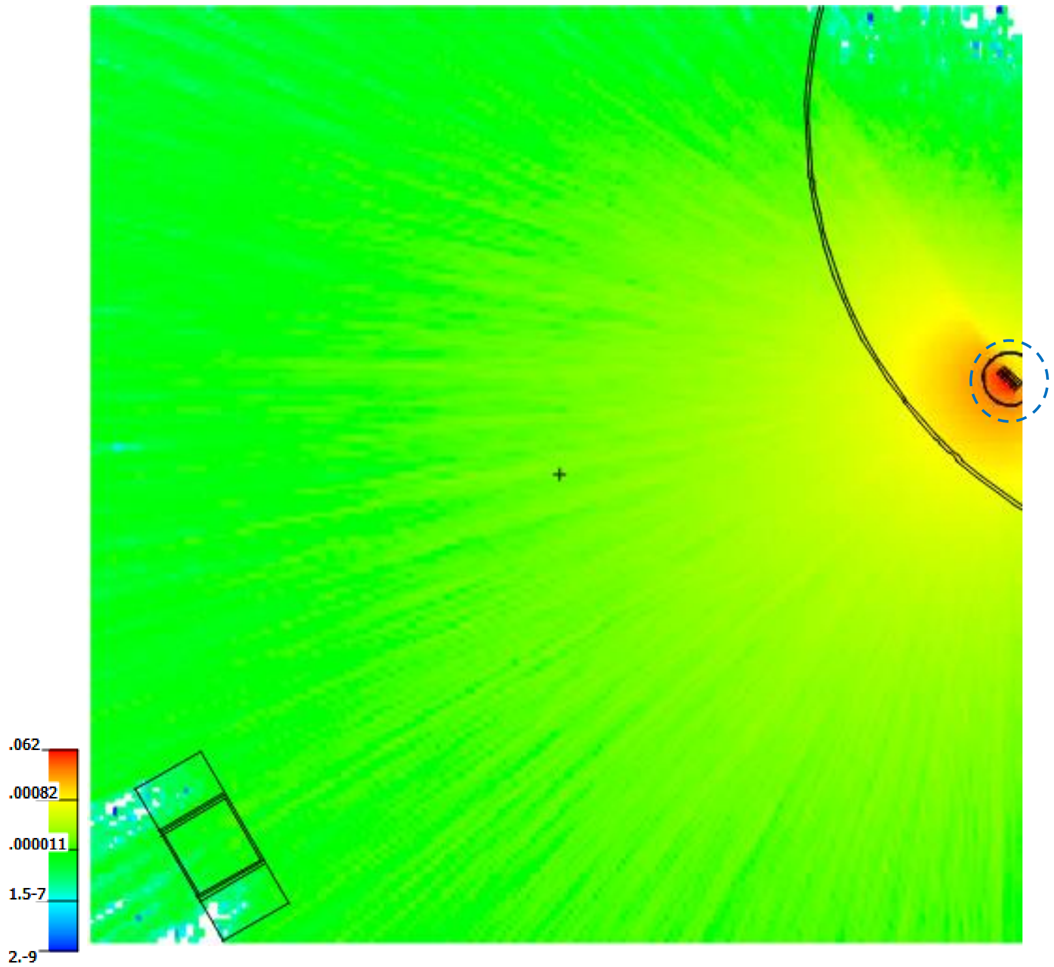
2nd step: Fission rate



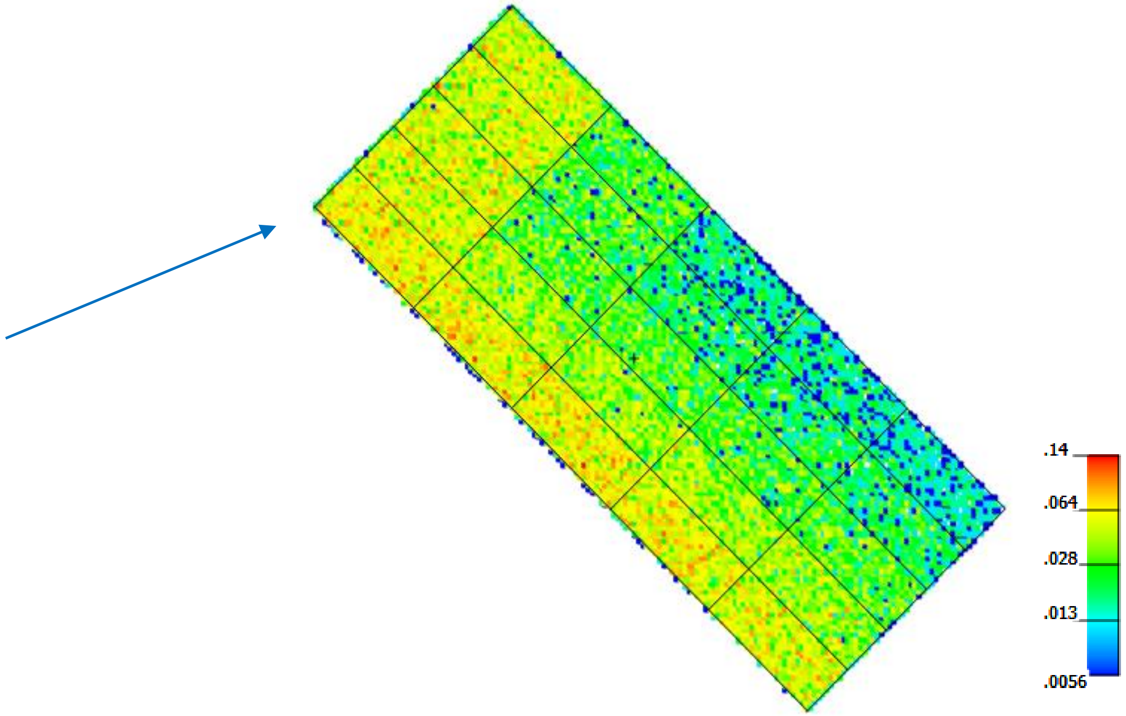


Geometry	Depth (cm)	Angle (°)	#fission/pulse	Uncertainty
S0	0	0	749 650	0.1%
S1	7	0	410 350	0.1%
S2	25	0	136 300	0.3%
S3	50	0	34 800	0.2%
S4	25	30	69 600	0.3%
S5	7	30	120 350	1.3%
S6	0	30	162 400	0.5%
D1	7	15	227 650	0.4%
D2	7	45	62 350	0.7%
D3	7	60	30 450	1.5%
D4	7	75	14 500	2.3%
D5	7	90	8 700	3.7%

3rd step: detection efficiency

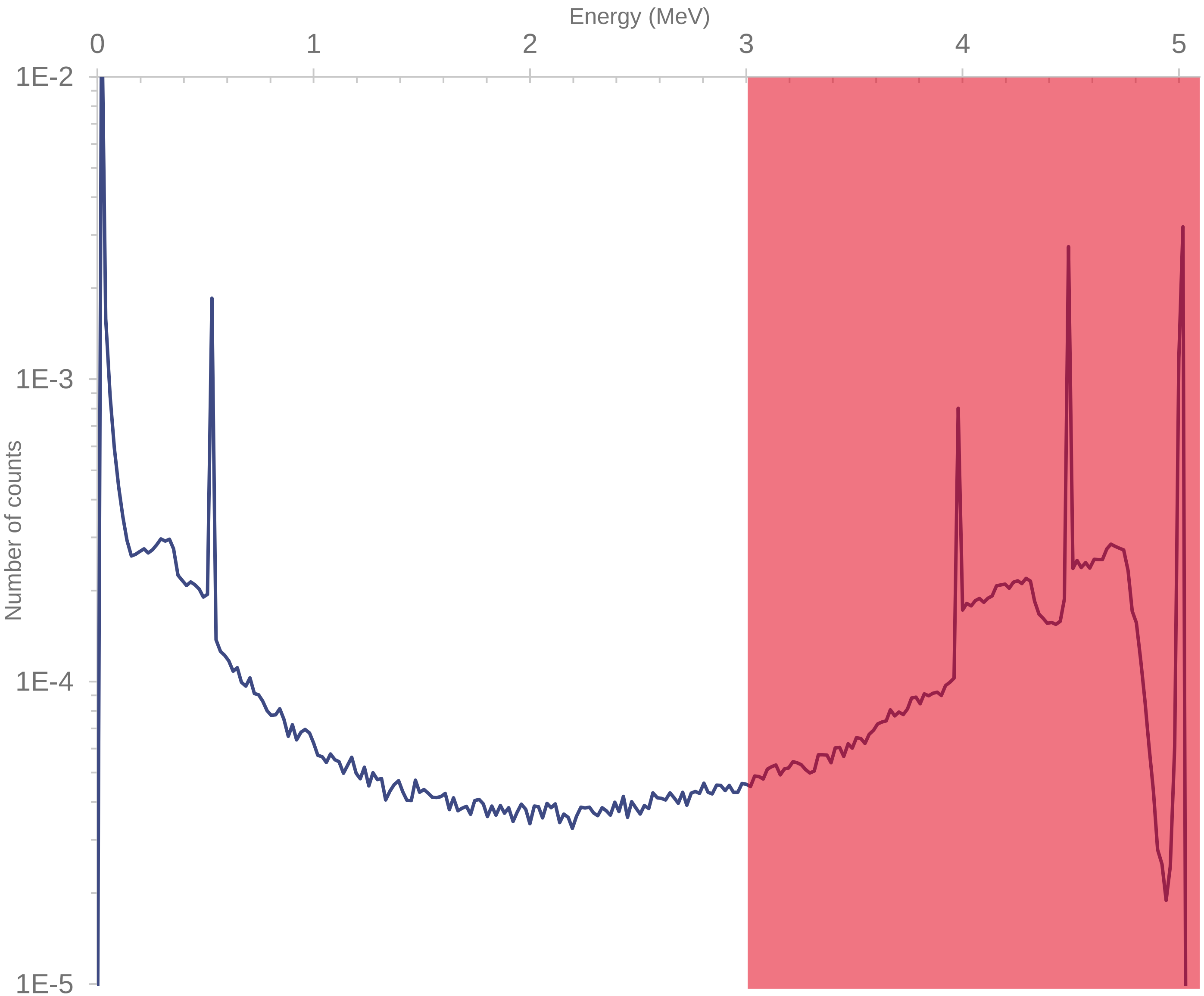


Generate gamma for all energy between
2 MeV to 8 MeV with 100keV steps

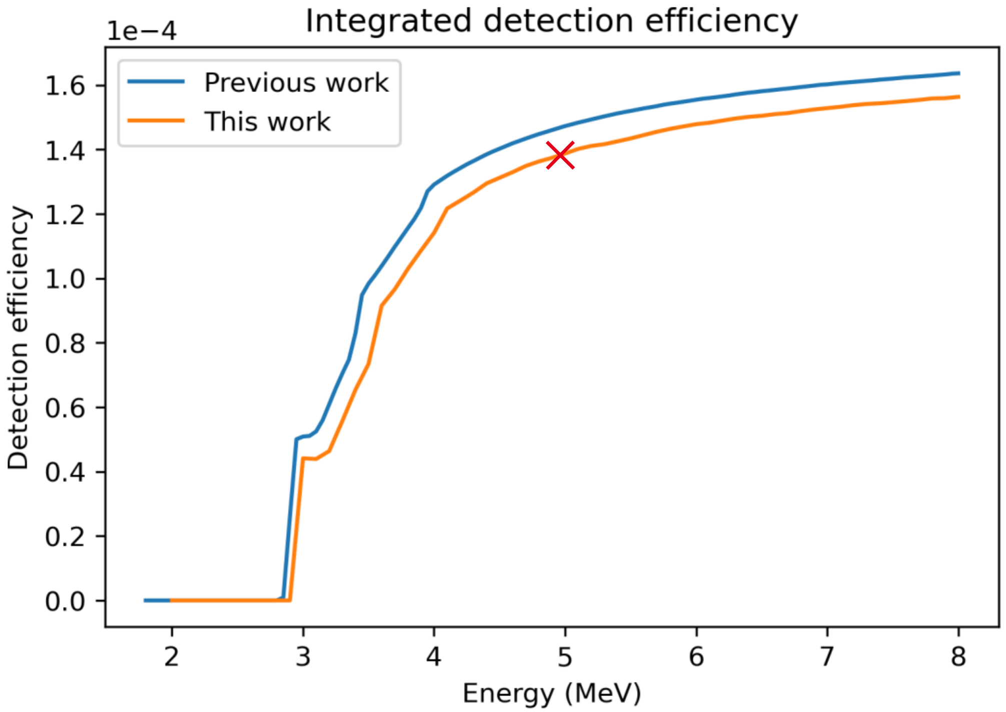


Uranium sample and gamma
generation probability

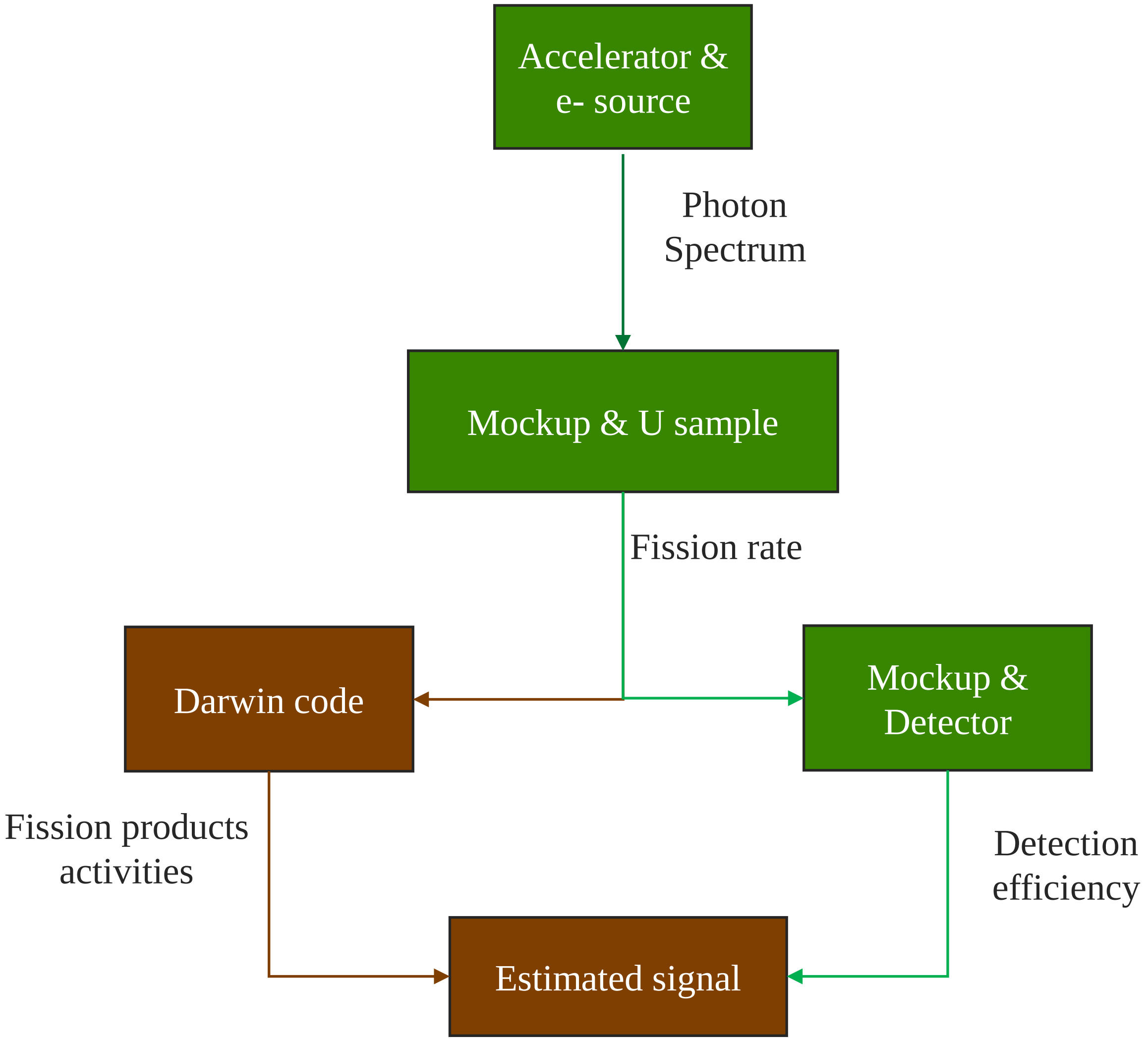
Detection efficiency: results



Detector signal, 5 MeV source, S3 geometry



Conclusion and prospects


Accelerator &
e- source

Photon
Spectrum

Mockup & U sample

Fission rate

Darwin code

Mockup &
Detector

Fission products
activities

Detection
efficiency

Estimated signal

🟩 Finished work

🟫 Planed work

Thanks for your attention !