Design, fabrication and characterization of CLYC-based neutron dosimeters for proton therapy

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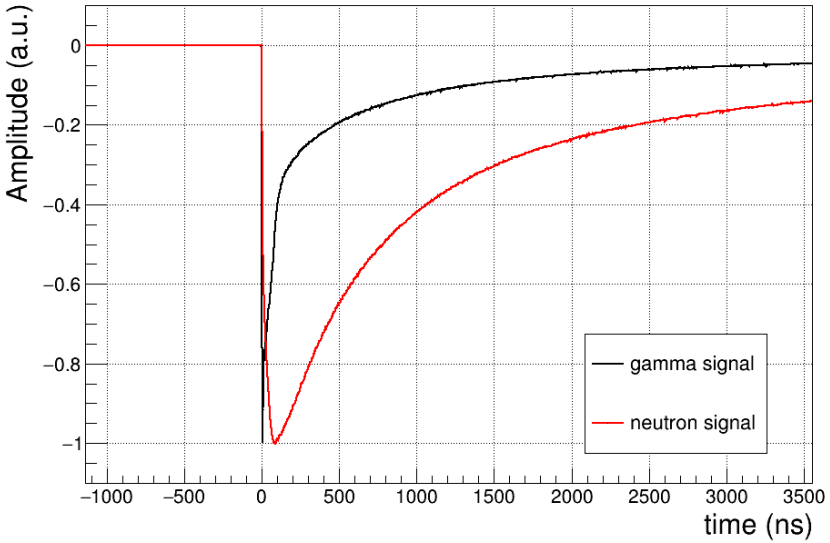
Introduction

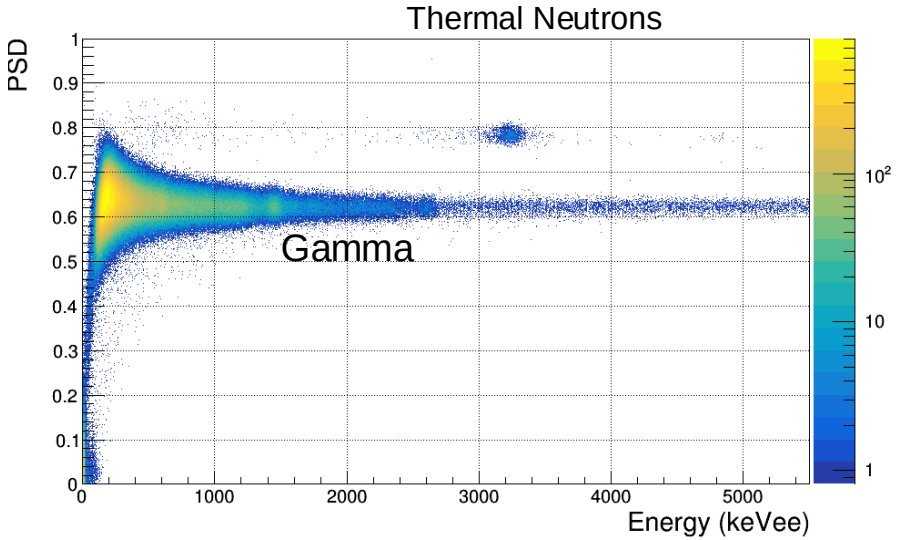
- Proton therapy uses protons with energies ranging from a 70 to 250 MeV to treat cancer.
- Interactions with tissues and materials generate secondary neutrons that pose a risk of irradiation to patients.
- The dosimetry of secondary neutrons must be measured and monitored accurately to minimize the risk of secondary cancers for patients and to protect the exposed workers.
- FLASH therapy: ultrafast delivery of high dose-rates, orders of magnitude greater than conventional proton therapy.
- Look for faster response dosimeters as alternative to commercial solutions (usually ^{3}He)
- These activities are part of the Project Advanced Strategies and new Approaches for Proton therapy (ASAP), coordinated by GFN-UCM.

CLYC scintillator

Assesment of CLYC detectors as dosimeters

- $Cs_2{}^{6}LiYCl_6$:Ce (CLYC) 1'' cubic detector
- Good properties of pulse shape discrimination between gamma and neutron signals.
- Typical gamma resolution ~5% @ 662 keV
- Thermal neutron detection $^{6}Li(n,\alpha)^{3}H$, Fast neutron via ^{35}Cl reactions.
- Fast response .





Working principle of neutron dosimeters

Detector response **R(E)** similar to **h*(10)** coefficients to convert flux to Ambient Dose Equivalent

Dosimeter Sensitivity (S) usually calibrated using ^{252}Cf or AmBe sources.

Count rate

$$S = \frac{C}{D}$$

Dose rate

$$C = \int R(E)\phi(E)dE$$

$$D = \int h^*(10)(E)\,\phi(E)dE$$

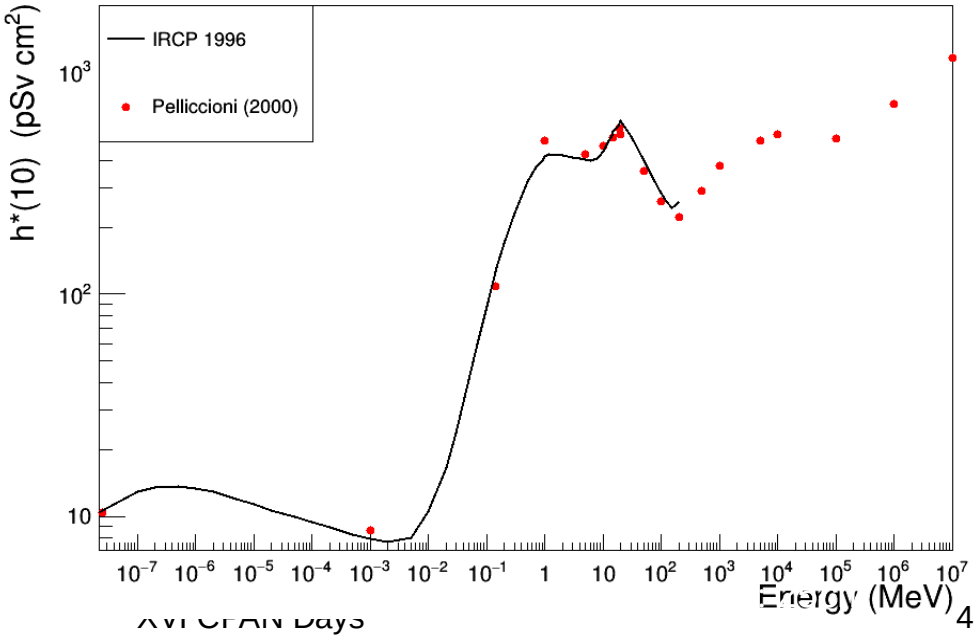
(ISO 8529-1)

^{252}Cf: 385 pSv·cm^2

AmBe: 387 pSv·cm^2

<u>Ideal case</u>

R(E) same shape than h*(10), response is not dependent on the flux shape.

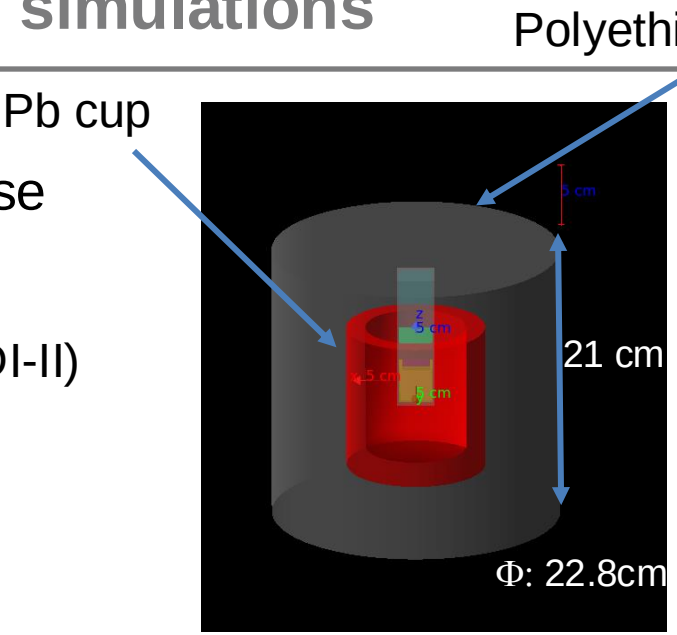


Geant4 design and simulations

- Based on existing ones using CLYC detectors, and small modifications for ease of fabrication

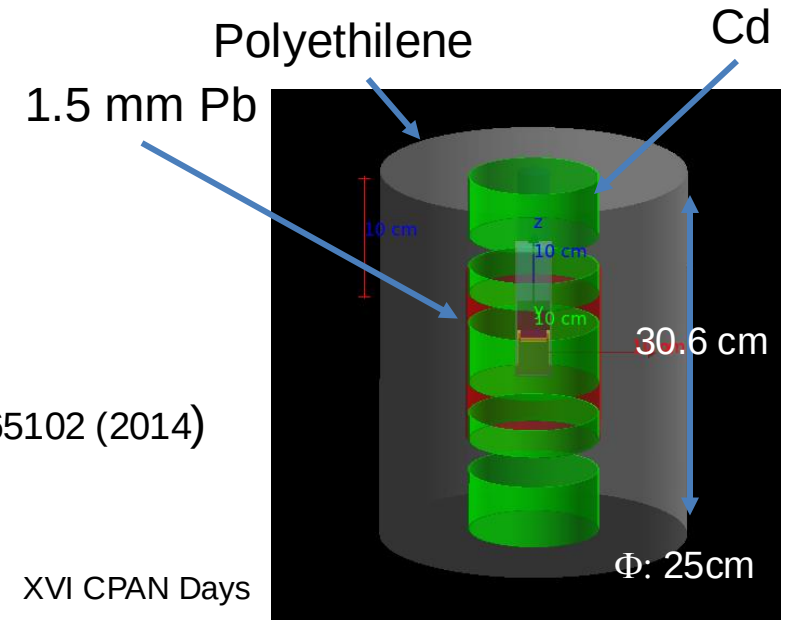
  Wide Energy Neutron Detector (WENDI-II)
  Commercial device
  Original detector ^{3}He
  Tungsten powder changed for Pb

Olsher et al. Health Physics Journal, 79 (2000)170-181

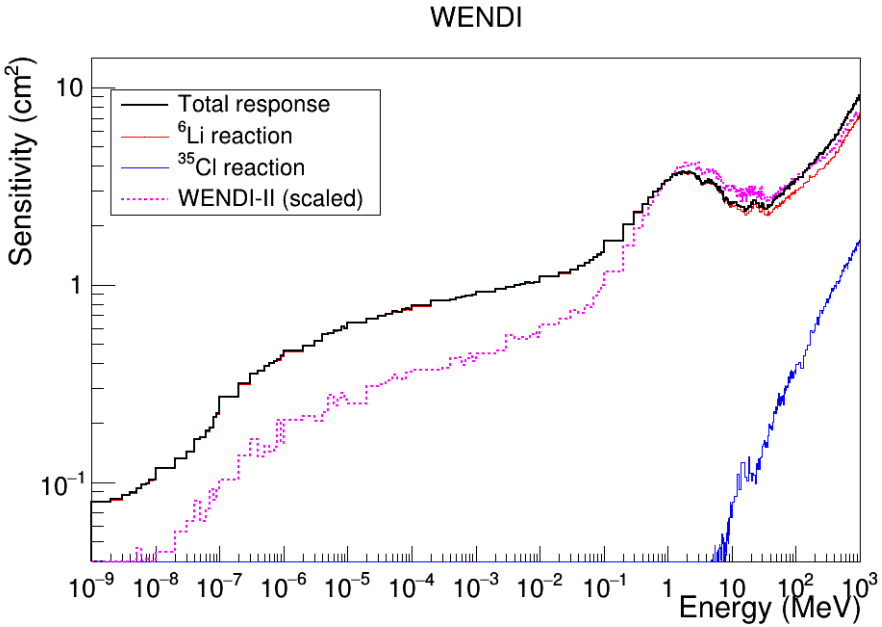


Long-interval Ultra-wide Pileup-free
Neutron dosimeter (LUPIN-II)
Original detector BF_3

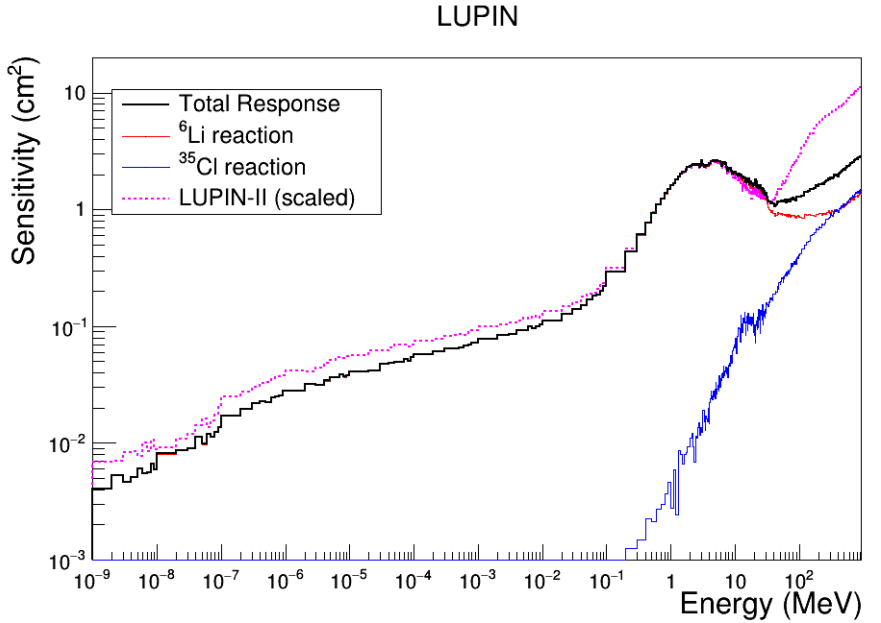
Caresana et al. Review of Scientific Instruments 85,065102 (2014)
dx.doi.org/10.1063/1.4879936

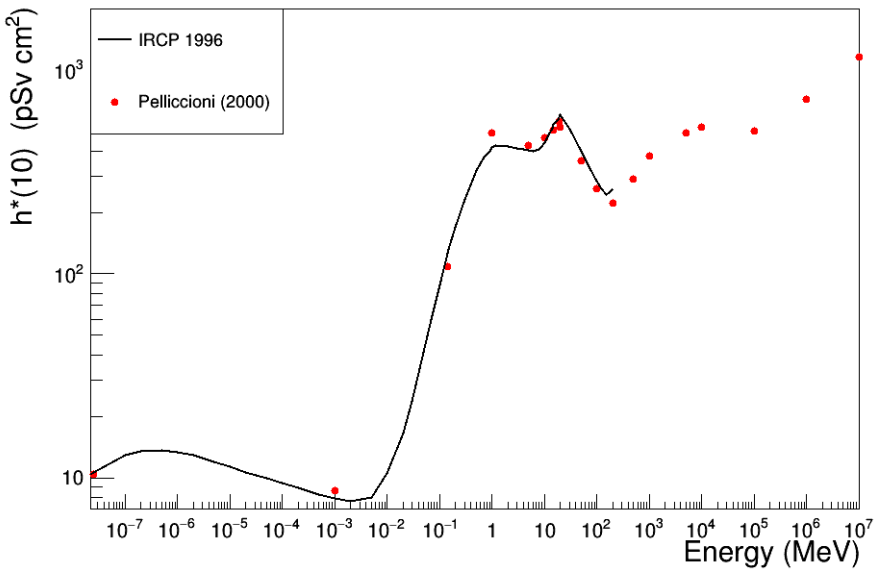


Geant4 design and simulations



- Most of the response due to ^{6}Li reactions
- For E_n>10 MeV, ^{35}Cl reactions may become significant

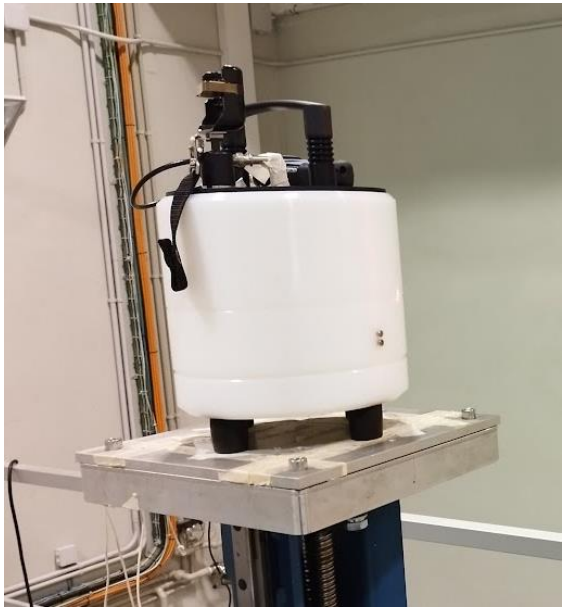




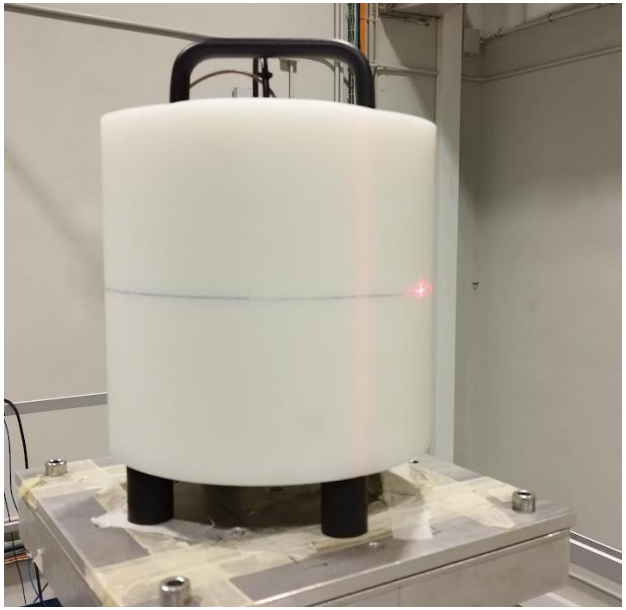
Measurements at LPN

Calibration of dosimeter prototypes at LPN (CIEMAT) using high intensity sources

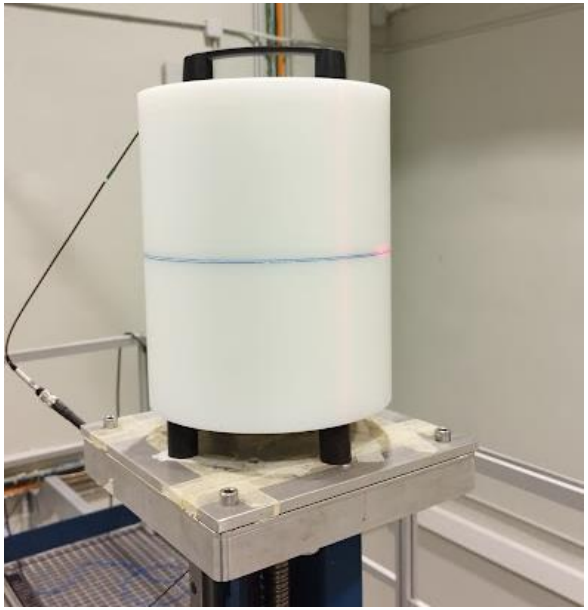
Commercial WENDI-II (^{3}He)



WENDI (CLYC)

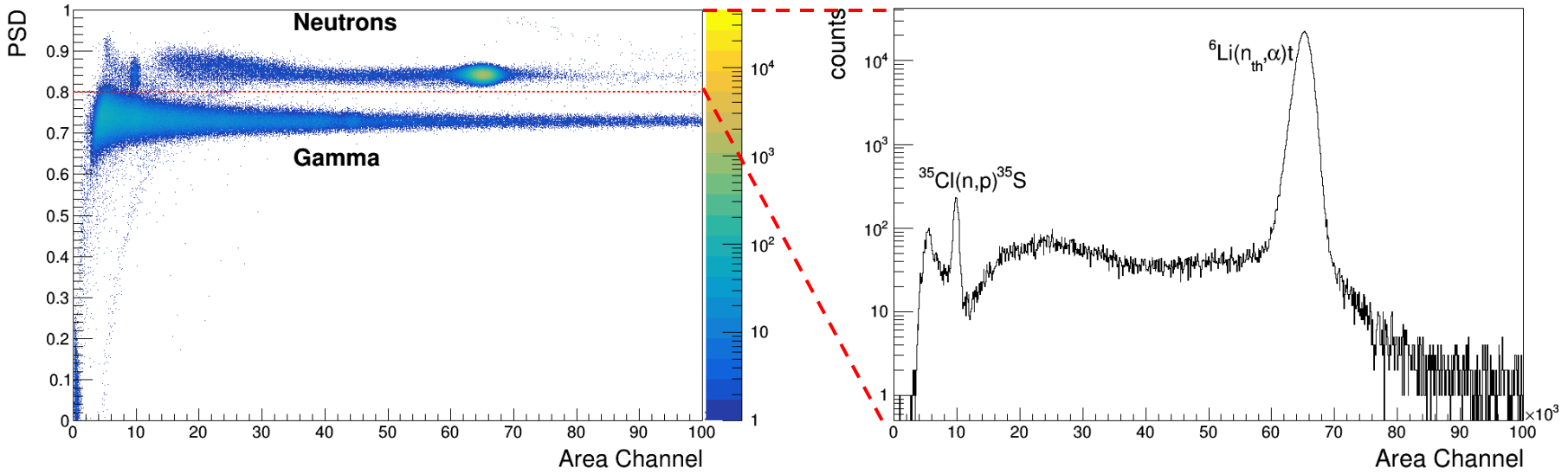


LUPIN (CLYC)



^{252}Cf: 2.43·10^{7} n/s
AmBe: 1.09·10^{7} n/s

Measurements at LPN



Sensitivity measurements: $\longrightarrow S = \frac{C}{D}$

Determination of the count rate (C):

- Measurements with and without shadow cone, and substraction
- Integration over the full absorption peak of ^{6}Li.

Determination of the dose (D):

- Calibrated value supplied by LPN

→ 213.4 μSv/h for ^{252}Cf @ 115 cm from source
97.5 μSv/h for AmBe @ 115 cm from source

Measurements at LPN

Sensitivity measurements (all values are in cps / μSv/h)

Detector	Source: ^{252}Cf		Source: AmBe	
	Measured	Geant4	Measured	Geant4
WENDI – II (Commercial)	0.85±0.03	*	0.85±0.04	*
WENDI – CLYC	**2.38±0.06**	2.345±0.004	**2.46±0.10**	2.248±0.003
LUPIN – CLYC	**1.33±0.03**	1.338±0.004	**1.59±0.07**	1.546±0.003
*Nominal value given by the manufacturer: **0.84 cps / μSv/h**				

- WENDI-II sensitivity (i.e. calibration factor) is the same independently of the source (as it should be!)
- CLYC devices (specially LUPIN) show a dependence of the sensitivity on the neutron energy spectrum: need to change the design to make it less spectrum-dependent
- Good agreement between simulations and measurements, except for Wendi-CLYC with AmBe source (under review)

Measurements at Quiron protontherapy center

Measurement of the Ambient Dose Equivalent H*(10) of the neutrons generated by different proton beam pulses and configurations.

WENDI-II (^{3}He)

- Commercial device
- Commercial readout device
- 1 second interval readings

WENDI-CLYC

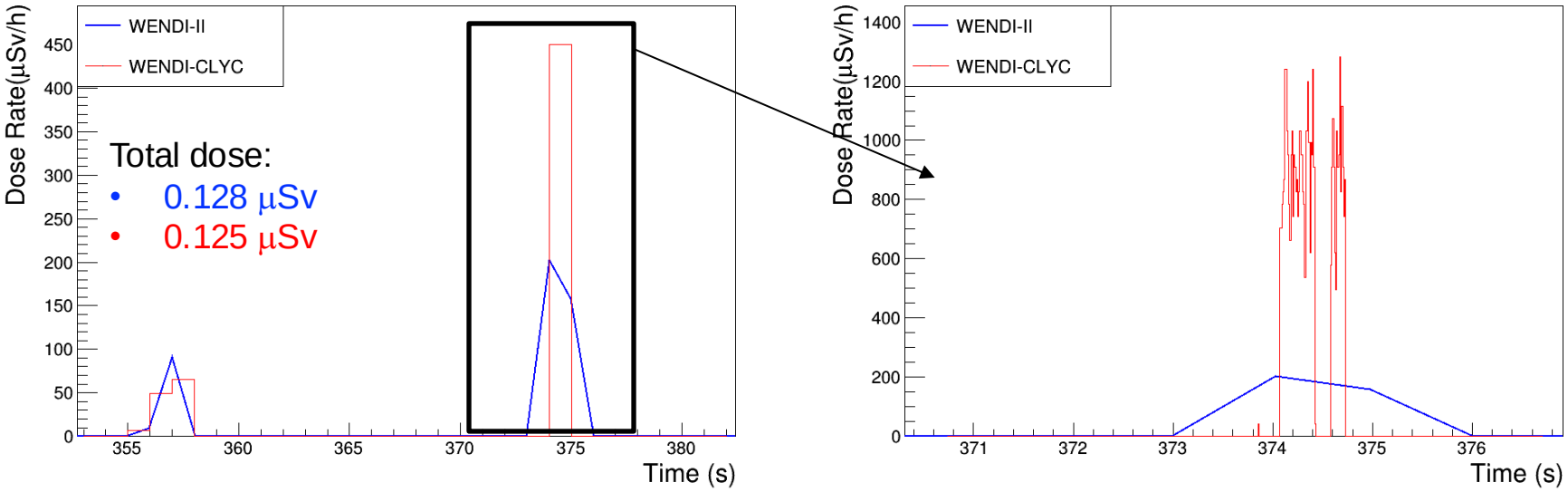
- Connected to DAQ (14-bit 1 Gsample/s)
- User-defined interval readings
- Discrimination of γ/n to obtain the neutron count rate

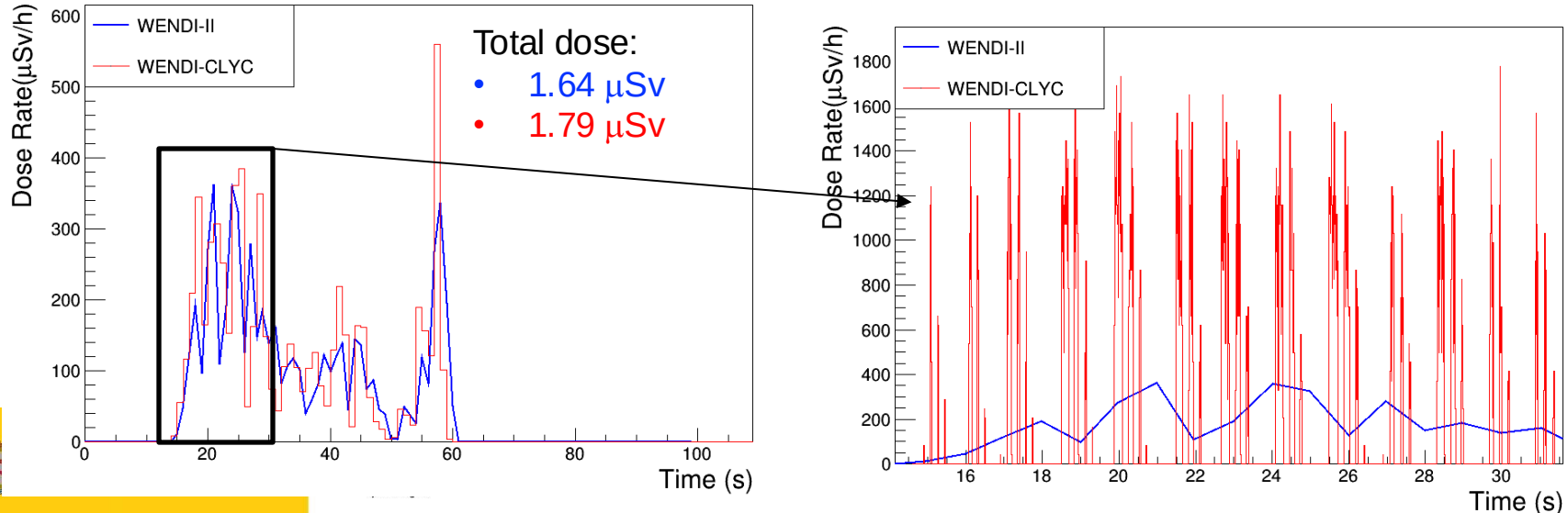
Dose rate = Count Rate / Sensitivity factor

Measurements at Quiron protontherapy center

Preliminary results. Analysis still ongoing

Pulsed irradiations (E_p = 73 MeV)

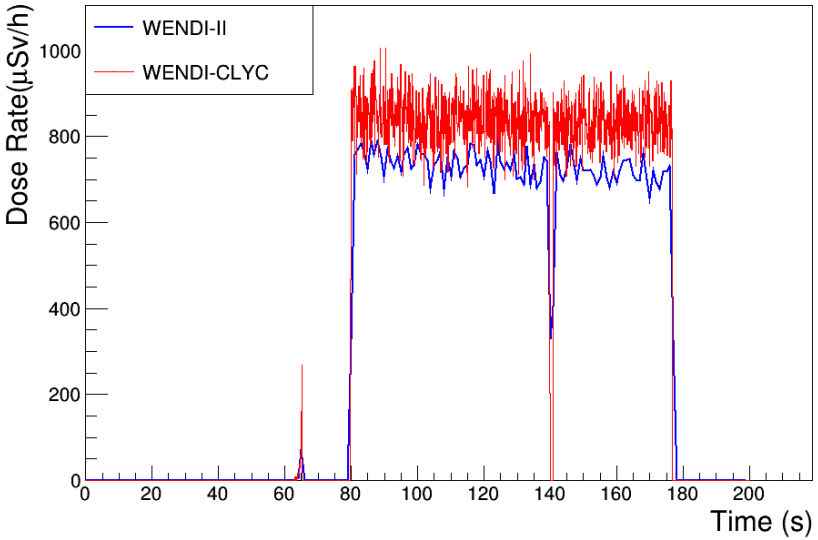




Measurements at Quiron protontherapy center

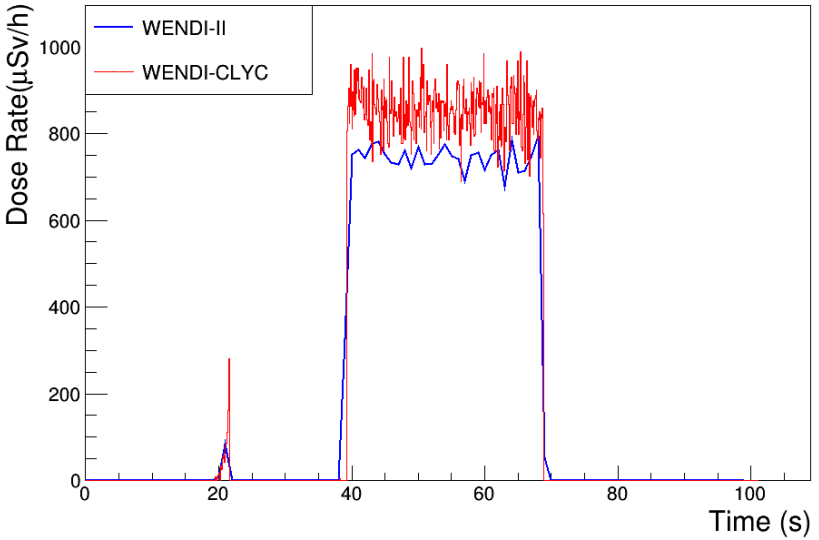
Preliminary results. Analysis still ongoing

Long irradiations, continuous wave (E_p = 200 MeV)



Total dose:

- 19.5 μSv
- 22.4 μSv



Total dose:

- 6.14 μSv
- 6.99 μSv

Conclusions

- Two CLYC-based dosimeters have been fabricated and characterized.
- WENDI-CLYC prototype:
  - Experimental sensitivities for AmBe and Cf-252 are compatible within uncertainties (<3%).
- LUPIN-CLYC prototype:
  - Experimental sensitivities for AmBe and Cf-252 have a 20% difference
- Both designs are under revision to be improved.
- Preliminary analysis of the measurements performed at Quirón Salud Proton Therapy Center show:
  - WENDI-CLYC and WENDI-II show similar dose rate trends.
  - WENDI-CLYC show ~10% higher readings on average (pileup/dead time in the WENDI-II, WENDI-CLYC sensitivity dependence on the neutron spectrum...)
  - WENDI-CLYC shows a discrete time structure (to be correlated with proton beam structure)
- The faster response of CLYC detectors seems promising for its use in neutron dosimetry for FLASH therapy.

Acknowledgements

These activities are part of the Project Advanced Strategies and new Approaches for Proton therapy (ASAP), coordinated by GFN-UCM

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