LINrem project: ambient neutron dosimetry for continuous and pulsed neutron fields

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Active ambient neutron dosimeters



- **Big science projects**
- **Particle therapy facilities**
- **Industrial applications**

Neutrons can dominate the total radiation dose received by workers, patients and public. **Proper detection techniques of neutrons are required** (**energy sensitivity, time structure, real time monitors**).

Limitations current commercial solutions:

- Classical technology: radiation sensor (**60's**), acquisition/read-out (**90-2000's**)
- Limited portability, **9-18kg** per unit.
- **Poor response** for high neutron energies (> 20MeV).
- Not well suited for complex quasi-continuous or **pulsed neutron fields**.

Some challenges:

+ High energy neutron fields in particle therapy facilities.

+ Pulsed neutron fields by beam losses in synchrotron or cyclotron facilities.

+ Pulsed sources for fundamental research and applications (spallation, fusion neutron sources or high intensity lasers, flash therapy)

"The development of new neutron dosimetry techniques" / Second priority among nineteen challenges identified in 2018 by EURADOS.

Market price **10 – 15 k€** per unit.

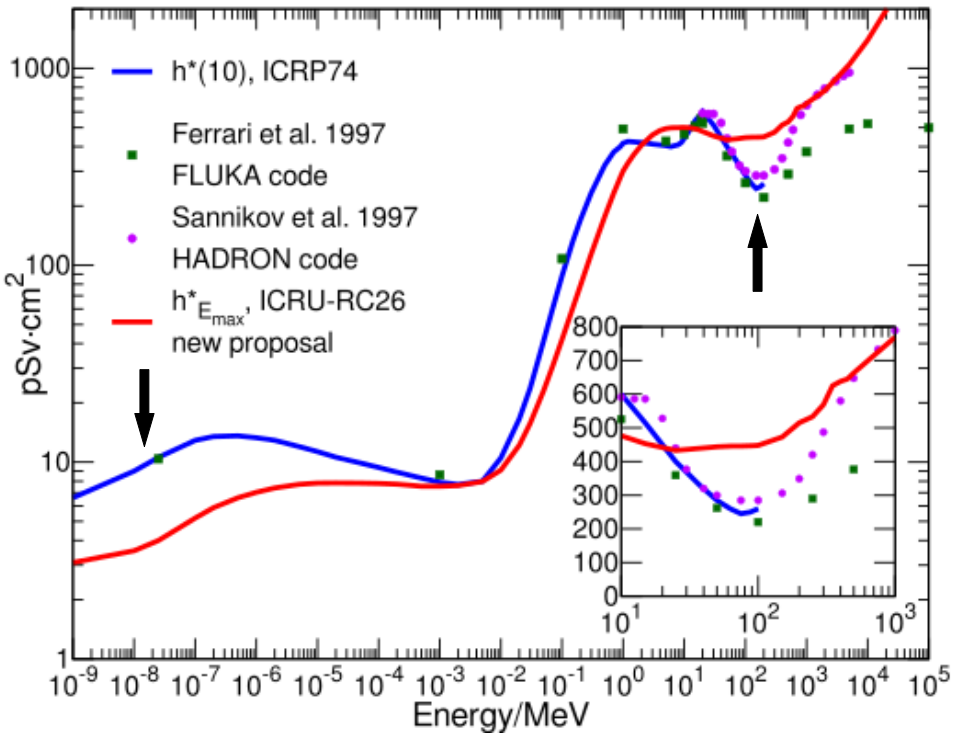

Berthold GmbH.


Ludlum Inc.

Thermo Fisher


Studsvik

New recommendations on Operational Quantities for External Radiation Exposure (ICRU95, 2021)



Some designs become obsolete as soon as ICRU95 is incorporated into legal frameworks (5-10 years)

NEEDS ⟶ Opportunities for R&D+i

- Industry and workers: cost reduction and optimization of processes in routinary radiation protection
- Patients: risk control of secondary cancers in modern medical facilities (proton therapy)
- New facilities: radiation protection challenges associated to big science projects

Eakins+ 2018

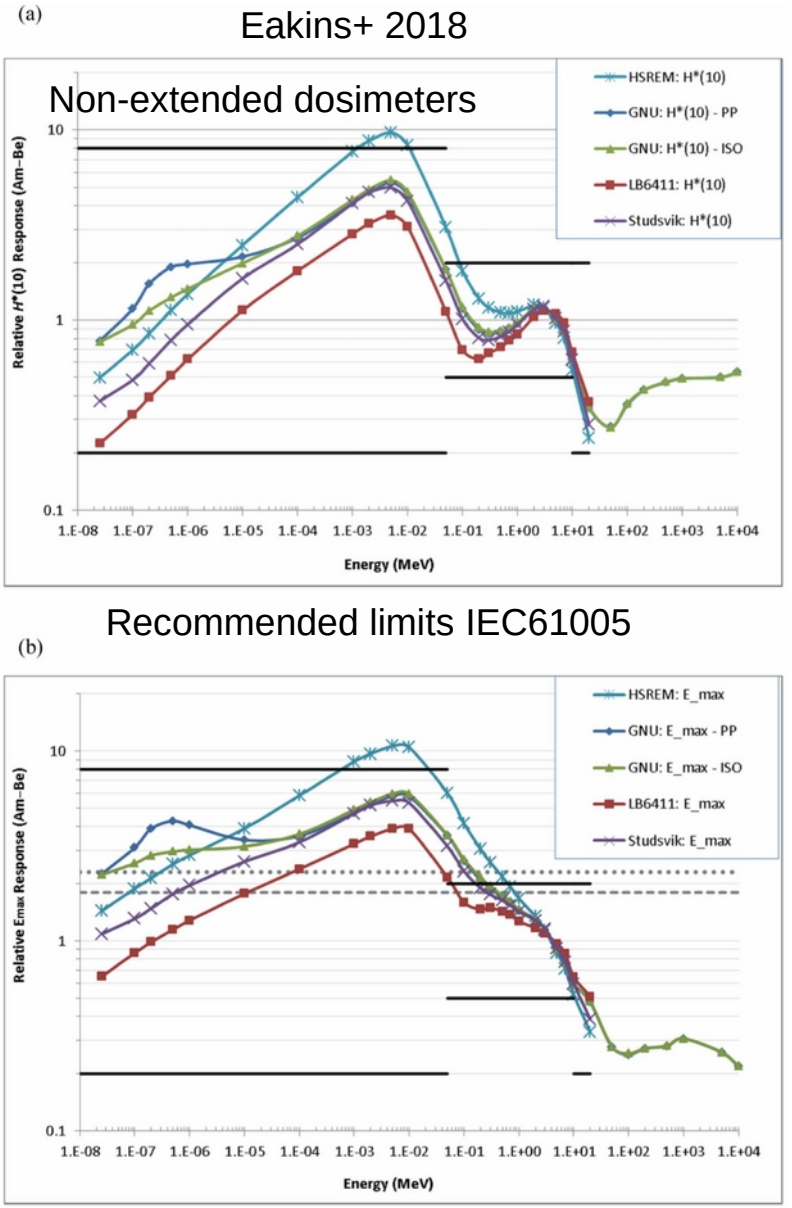


Figure 3. Relative (a) $H^*(10)$ and (b) E_{max} responses of the LB6411, Studsvik 2202D HSREM and GNU, normalized to their respective responses to ^{241}Am-Be Recommended limits (*solid lines*), and the effects of recalibrations to the response at 144 keV (*dotted line*) and 565 keV (*dashed line*), are also indicated.

Ambient neutron dosimetry in pulsed fields

Nuclear Instruments and Methods in Physics Research A 737 (2014) 203–213

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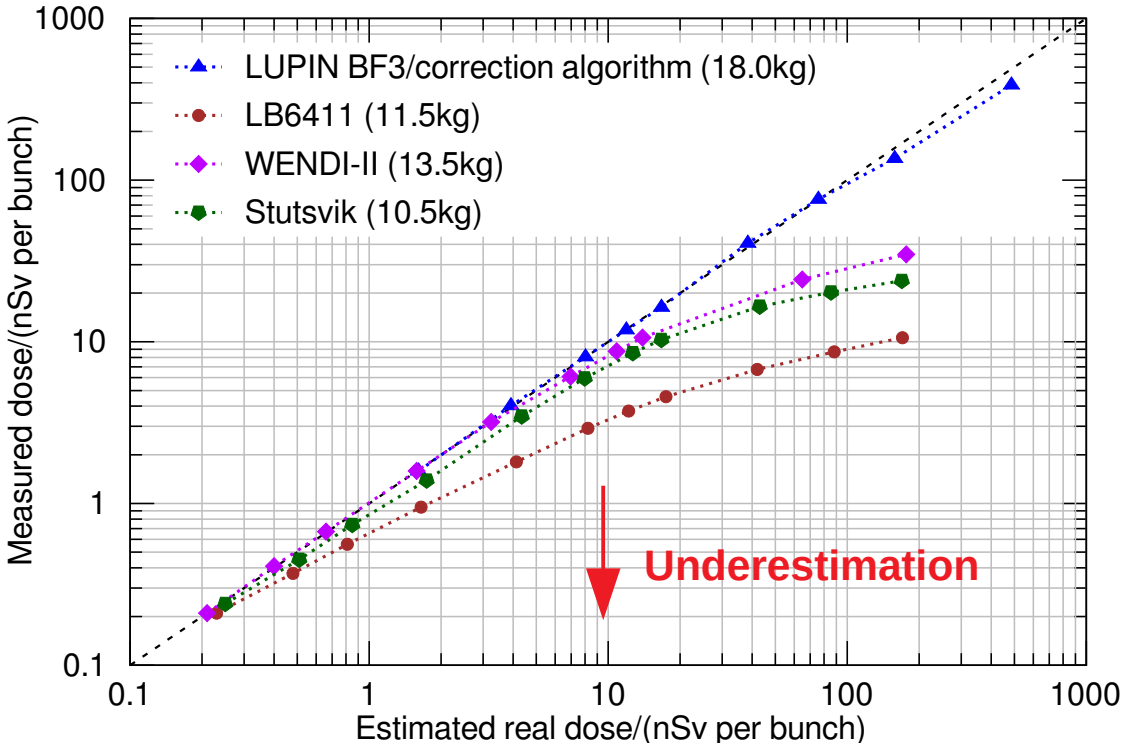
journal homepage: www.elsevier.com/locate/nima

Intercomparison of radiation protection instrumentation in a pulsed neutron field

M. Caresana [a,*], A. Denker [b], A. Esposito [c], M. Ferrarini [d], N. Golnik [e], E. Hohmann [f], A. Leuschner [g], M. Luszik-Bhadra [h], G. Manessi [i,j], S. Mayer [f], K. Ott [k], J. Röhrich [b], M. Silari [i], F. Trompier [l], M. Volnhals [m], M. Wielunski [m]

- Most of the commercial dosimeter are not suited for pulsed neutron fields (pile-up effect). **They present underestimation of the dose beyond 10 nSv/burst.**
- Dosimeter based on activation (AGREM, REM-2) do not suffer pile-up effect, however they do not provide online shot-to-shot monitoring.
- Latest dosimeters based on proportional counters rely on LOG-current preamplifiers and make use of pile-up correction models.



Neutron dosimeters for particle therapy applications

Farah et. al. 2015:
"Measurement of stray radiation within a scanning proton therapy facility: EURADOS WG9 intercomparison exercise of active dosimetry systems", Med. Phys. 42 (5), pp. 2572-2584 (2015)
http://dx.doi.org/10.1118/1.4916667

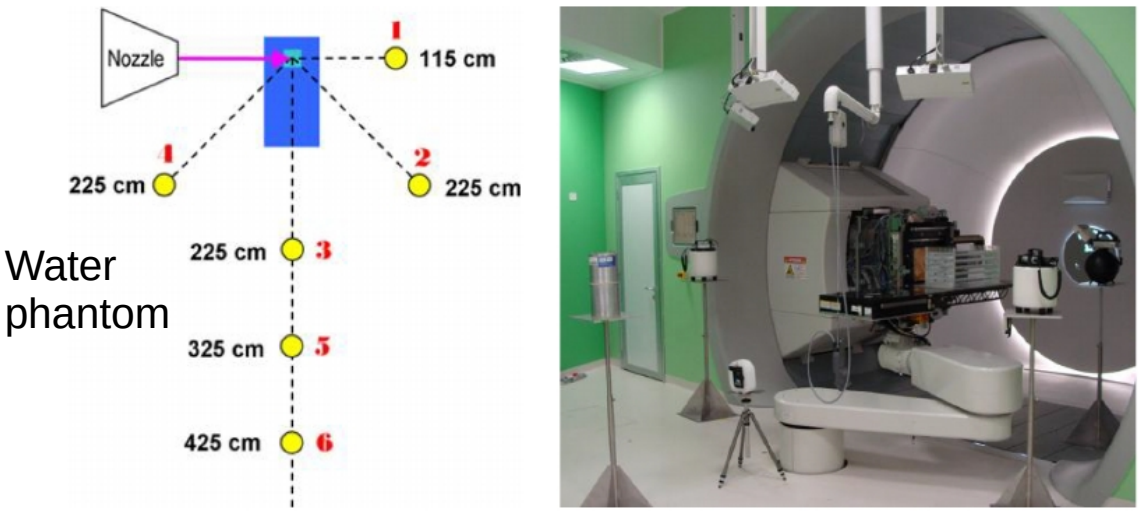
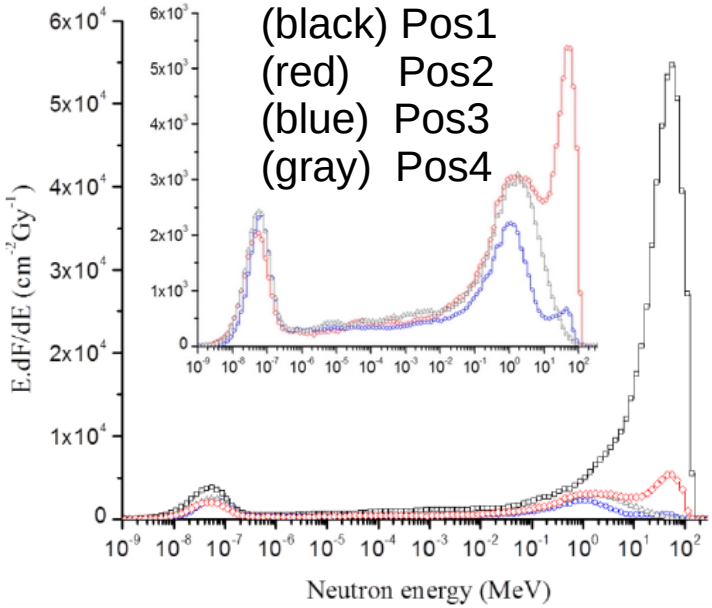
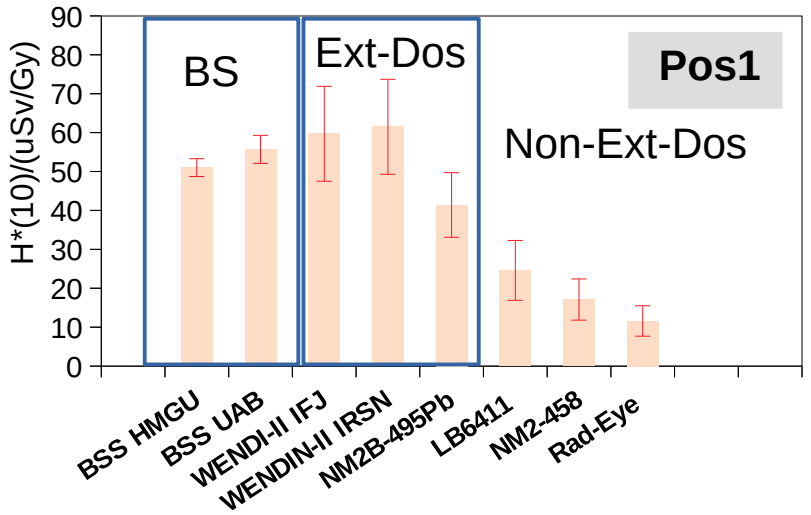


FIG. 1. Schematic view of measurement positions around the water tank phantom (left) and picture of the actual setup within the Trento gantry room (right).



- Measurements at a clinical dose rate 0.5Gy/min.
- Bonner spheres provides dose measurements with an accuracy within 5%.
- WENDI-II is the gold standard extended neutron dosimeter for high energy fields (up to 30% including uncertainties)
- Non-extended dosimeters provides underestimated dose measurements 20-50% from the expected value.



The proposed solution and goals

***LINrem* solution:**

→ **Modern design technology**: Numerically assisted optimization of the detection module.

→ **Novel concept**: Implementation of new acquisition technology suitable complex radiation fields.

→ **Make it digital**: Acquisition and readout based on digital electronics and apps.

Electronics module:
+ Power source
+ Signal shaping
+ Data acquisition

Detection module:
+ Lightweight
+ Based on thermal neutron detector
+ Moderator
+ Absorption/converter materials
+ Response according to ICRP74 or the **new ICRU95**

Cloud data:
+ Databases
+ Data mining
+ Local or remote display

Sensor read-out:
+ Wireless data transfer
+ Remote controlling
+ Smart monitors (App based)

Detector performance:
+ Good compromise between sensitivity & portability for industrial and high energy neutron fields
+ Suited for continuous and pulsed neutron fields
+ Able to provide temporally resolved dosimetry in medical applications.

*Demonstrator prototypes already developed
*Prototypes have been tested in relevant environments (TRL6)
***PCT/EP2021/052074 FAVOURABLE** (focus on pulsed neutron fields). Now starting national phases (EU, USA)

LINrem project: status

LINrem project

LINrem
Non-extended dosimeter
Thermal up to 10 MeV

Version 1: 3.3 kg
Design focused on pulsed fields (up to 200 nSv/bunch) and fast neutrons

Version 2: 3.5 kg
Improved response for pulsed fields (up to 2000 nSv/bunch) and thermal/epithermal energy region

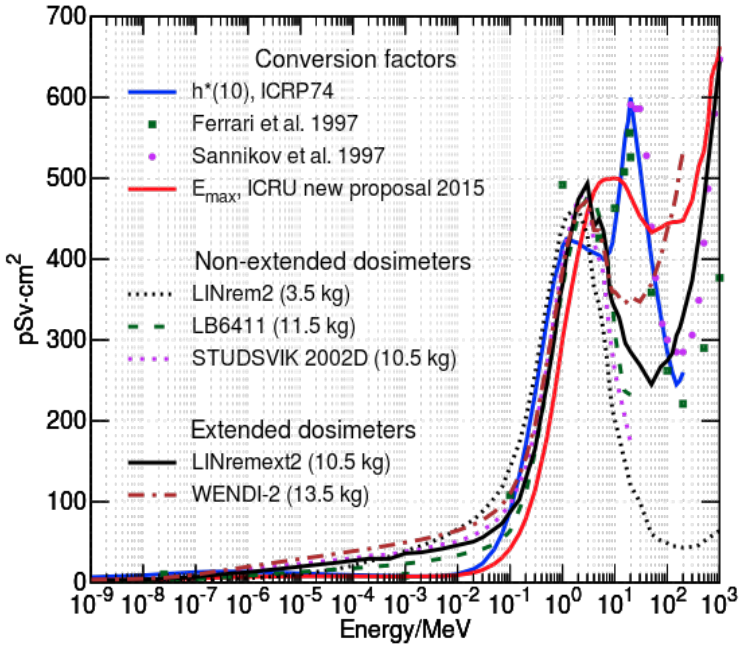
LINremext
Extended dosimeter
Thermal up to GeV

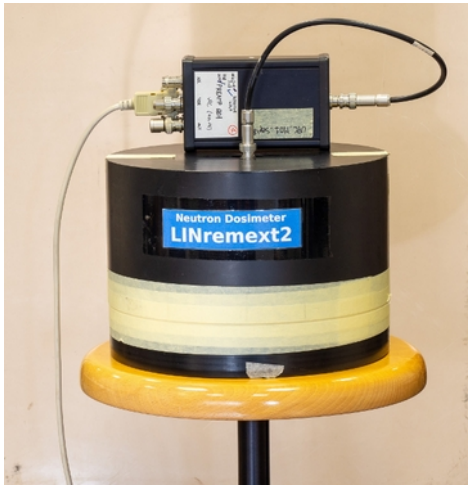
Version 1: 10 kg
Design focused on proton therapy facilities

Version 2: 10.5 kg
Improved response in the thermal/ epithermal energy region, pulsed fields up to 1000 nSV/bunch

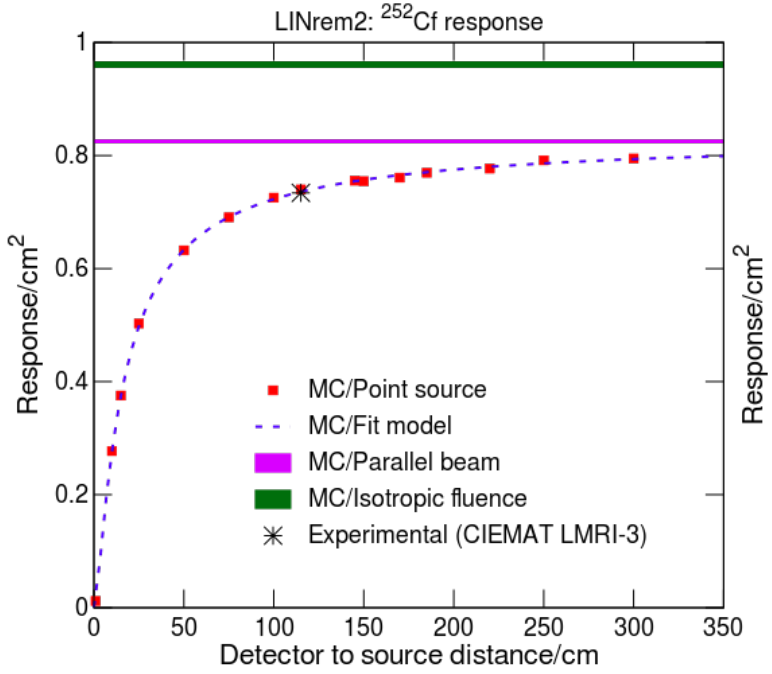
TRL6
(Demonstrated)

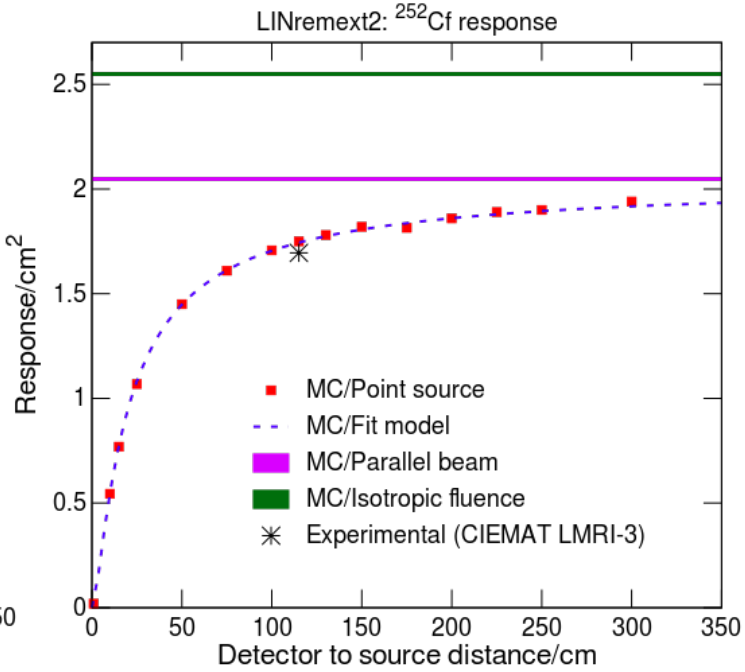
TRL7 (work in progress): System prototype, including dedicated digital electronics and readout, demonstrated in relevant enviroments (proton therapy, continuous and pulsed fields)



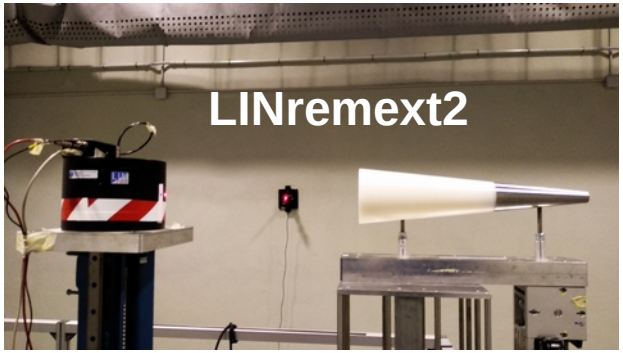


Calibration of LINrem2/ext2 dosimeters at LMRI-3 CIEMAT facility





Collaboration with R. Méndez

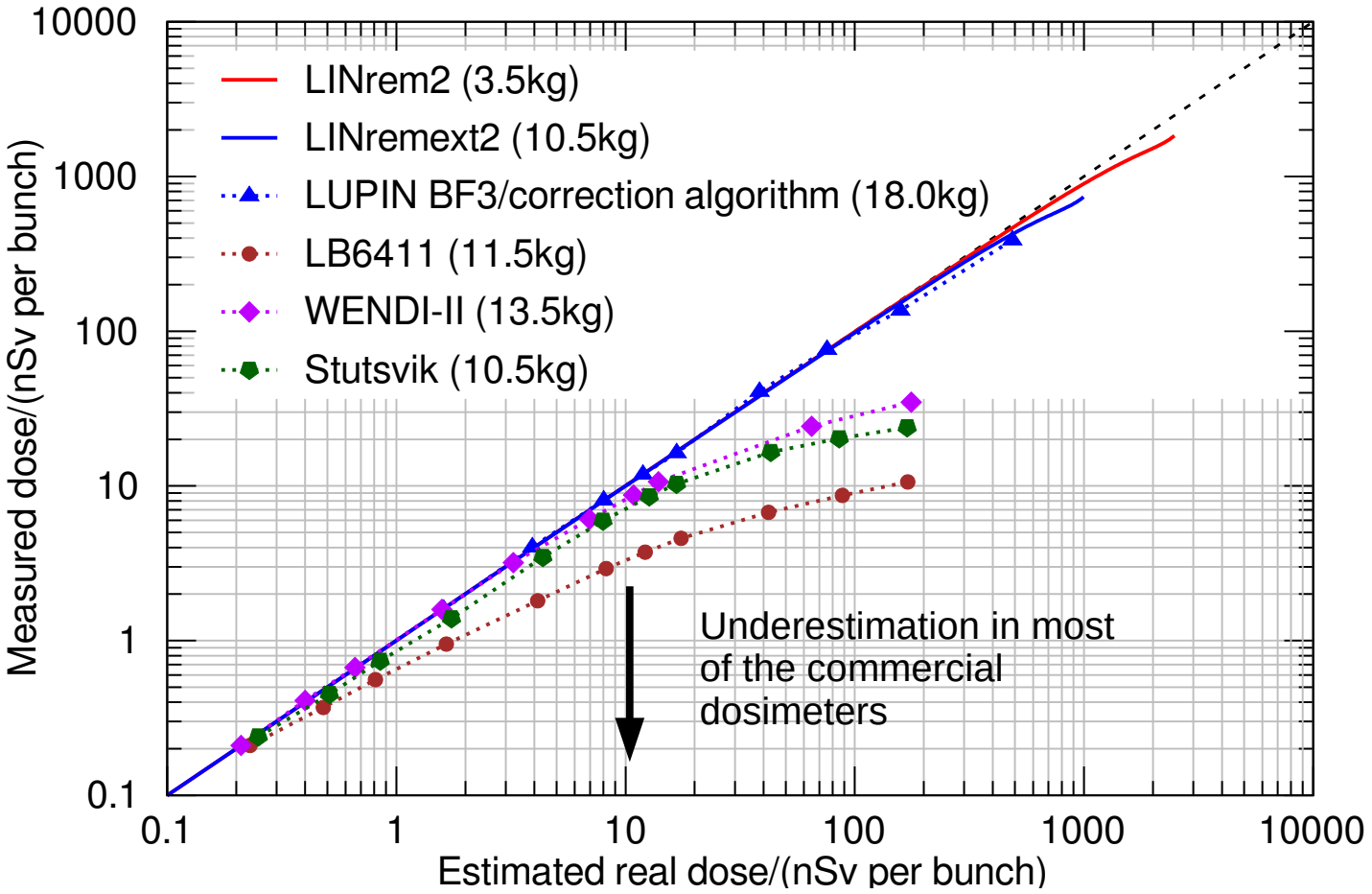


Detector	MC/Parallel beam	Experimental/CIEMAT	Ratio
	pSv/count	pSv/count	MC/EXP
LINrem2	466.7	525	0.889
LINremext2	188	227.1	0.828

COMMENTS:
+ “Excellent” agreement in the benchmark of the calculated responses for LINrem2.
+ 3% overestimation in calculated response for LINremext2.
+ Experimental calibration factor will introduce an overestimation of ~10-20% with respect to the design calculations.

LINrem response in pulsed fields

- Response in pulsed fields depends on: the neutron counter (non-linearity by charge density effects), preamplifier electronics and the “counting” technique
- Counting by “charge integration” can be implemented with proportional counters + charge sensitive preamps (or current sensitive) + post-processing with digital electronics (Tarifeno-Saldivia+2014)
- For LINrem dosimeters, response to pulsed fields has been characterized at n_TOF at different proton bunch intensities.



Most of the commercial dosimeters significantly underestimates pulsed doses when H*(10) > 10nSv/bunch.

LINrem1 dosimeter, with just 3.3kg, is able to provide reliable dose readings for H*(10) >100 nSv/bunch without any correction algorithm.

Applications to pulsed neutron sources, laser driven facilities and possibilities in ultrahigh dose (FLASH) therapy.

Data from EURADOS intercomparison exercise, M. Caresana et al., NIMA 737 (2014) 203-313

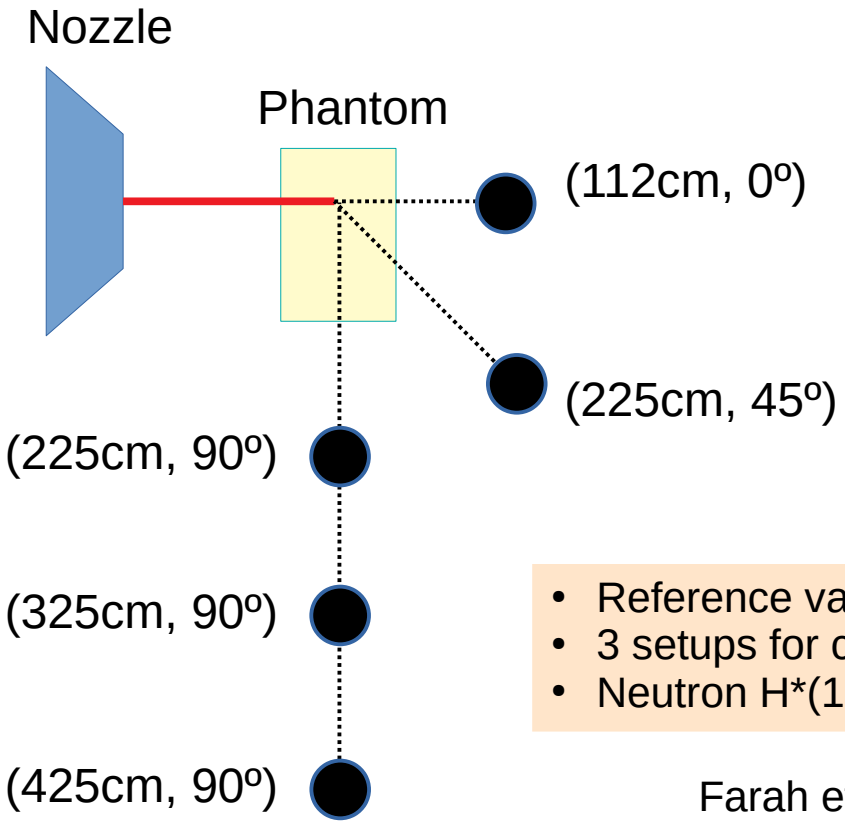
Out-of-field time resolved neutron measurements in PBS

- Prototype of extended range dosimeter: **LINremext1, 10kg, sensitivity from thermal up to GeV's.**
- LINremext1 designed focusing on the application in proton therapy facilities. Uncertainties in dose determination estimated to be ~10% by detector energy response (systematic).
- Technical validation in Pencil Beam Scanning (PBS) at West German Proton Therapy Centre Essen (WPE).
- Temporally resolved measurements of the out-of-field secondary neutron dose in PBS proton therapy achieved.

LINrem detectors @ WPE @ Dec. 18

- Phantom 30x30x60, water equivalent RW3 material.
- R20M10

Angle/deg	D/cm	Eq_Setup
0	112	Farah.Pos1
45	225	Farah.Pos2
90	225	Farah.Pos3
90	325	Farah.Pos5
90	425	Farah.Pos6

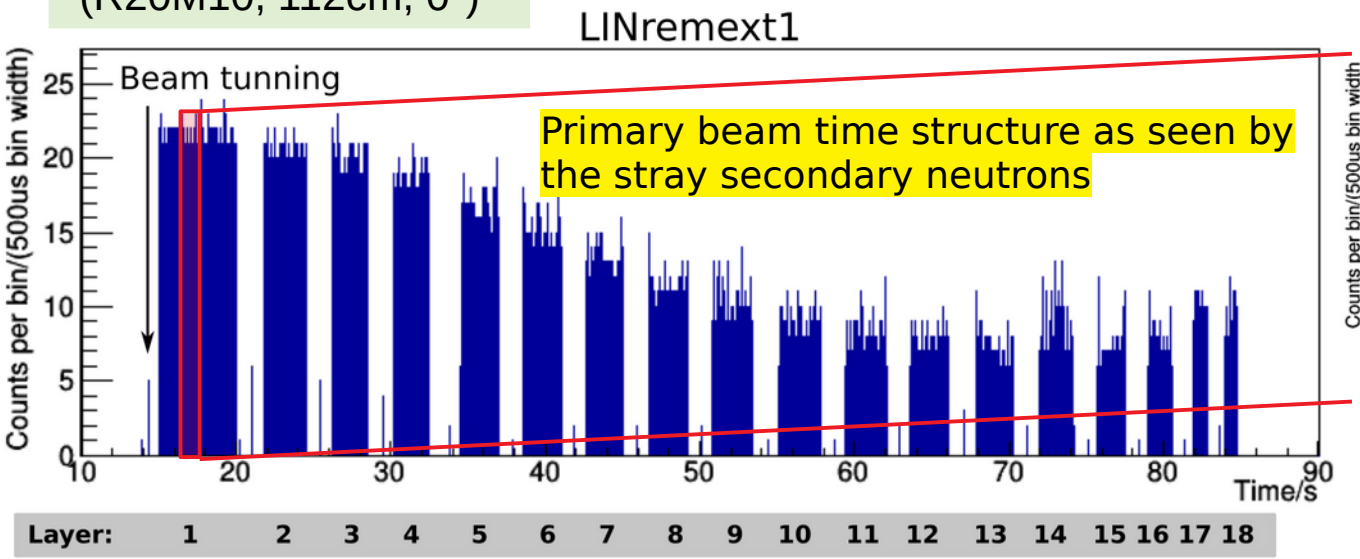


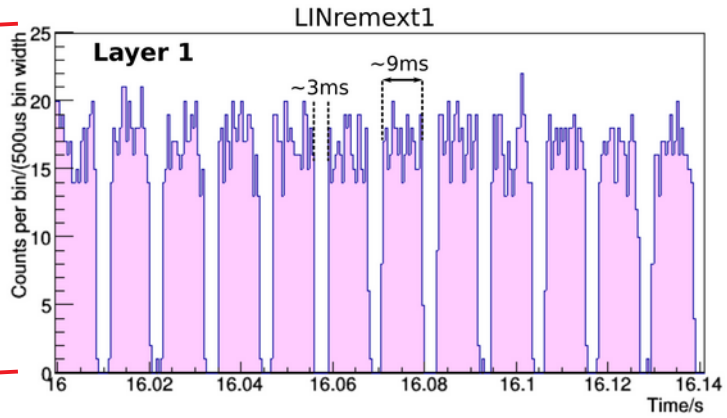
- Reference values from Bonner sphere spectrometers (EURADOS).
- 3 setups for comparison.
- Neutron H*(10) from BS in Pos. 5 and 6 is not provided in the article.

Farah et. al. Med. Phys. 42 (5), pp. 2572-2584 (2015)

Time resolved measurements in PBS

(R20M10, 112cm, 0º)

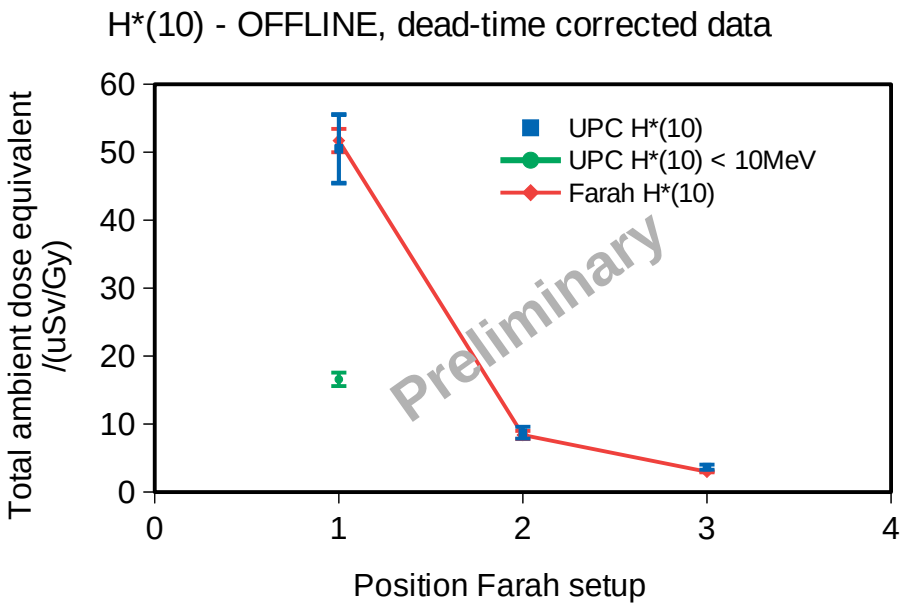


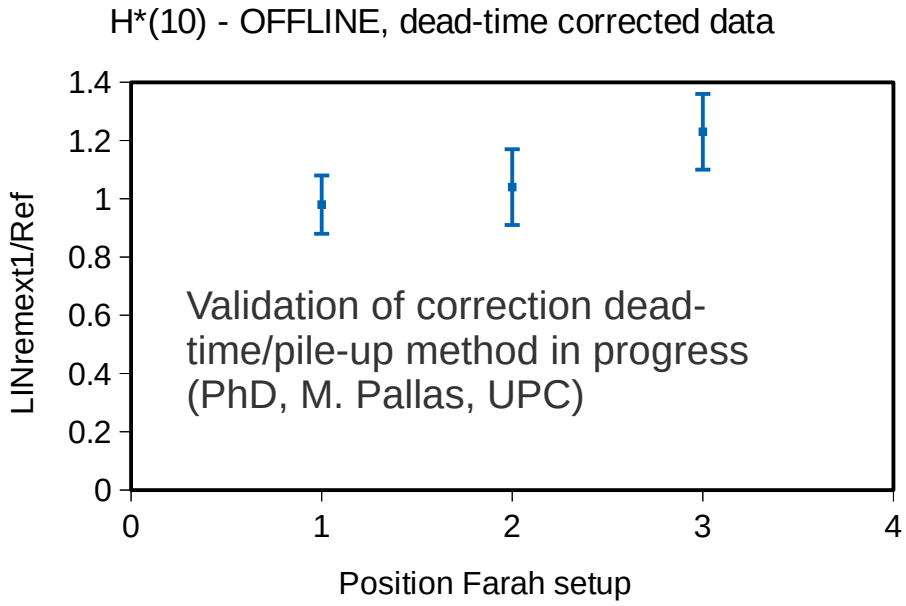


- **Complex time structure.**
- 18 “layers” identified, each layer separated by time periods of seconds.
- A flash of neutron emission is observed between layers due to the beam tunning.
- Blocks of steady neutron emission can be identified inside the layers (“spots”). Each spot is separated by periods of no emission (~ms).
- Dead-time correction methods have to be applied.

Dose measurements results (preliminary)

Run	Angle	Distance	Position	Dead-time corrected neutrons counts	Dose	err_Dose	PrimDose	Total dose (LINremext1) UPC H*(10)	err	Farah H*(10)	err	UPC/ref	
	/deg	/cm			/uSv		/Gy	/(uSv/Gy)		/(uSv/Gy)		Value	Error
49	0	112	1	830079.1	90.81	9.08	1.80090909	50.42	5.04	51.7	1.72	0.98	0.1
50	0	112	1	832150.8	91.04	9.1	1.80090909	50.55	5.05	51.7	1.72	0.98	0.1
34	45	225	2	143517.1	15.7	1.57	1.80090909	8.72	0.87	8.38	0.6	1.04	0.13
53	90	225	3	60166.2	6.58	0.66	1.80090909	3.65	0.37	2.97	0.08	1.23	0.13
33	90	325	4	--	--	--	1.80090909	--	--	--	--	--	--
24	90	425	5	--	--	--	1.80090909	--	--	--	--	--	--





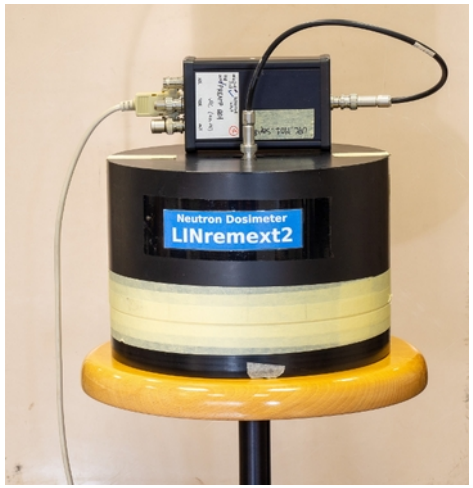
- Reasonable agreement is found between the experimental H*(10) measurements with LINremext1 and the Bonner spheres reference values (Farah et al 2015) obtained after dead-time correction.
- Deviations from the reference values provided by LINremext1 are consistent with expected systematic deviations.
- From LINrem1 detector, the contribution from high energy neutrons (En > 10 MeV) to the total ambient dose equivalent is estimated to be as high as 65%.

What is next?

- **LINrem prototypes able to be transfer to users (TRL>=7)**: I+D for integration of electronics, DAQ and front-end into a single/portable module (continuous & pulsed fields).

- **LINdos**: detector design adapted for ICRU95 (new recommendation).

- **SINERGY4HT**: **SI**multaneous **NE**ut**R**on and prompt **G**amma-ra**Y** imaging system for in-vivo diagnosis in **H**adron-**T**herapy



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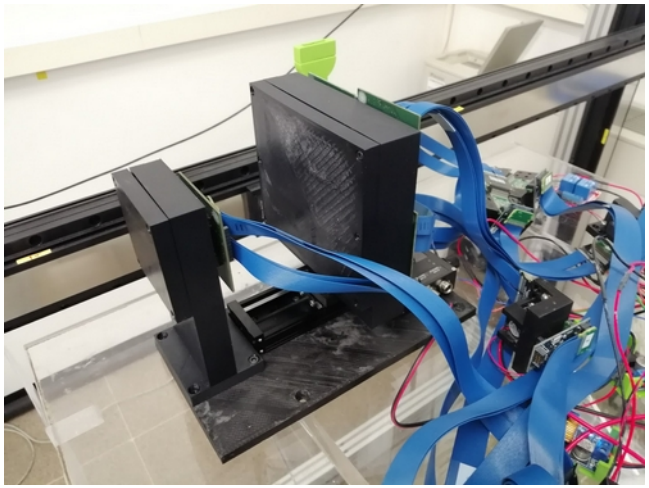

LINrem

Next talk!

i-TED