

FAST NEUTRON-INDUCED REACTION MEASUREMENTS WITH A LASER-DRIVEN NEUTRON SOURCE

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¹⁴ Instituto de Física Corpuscular (IFIC, CSIC-UV), Paterna, Spain.

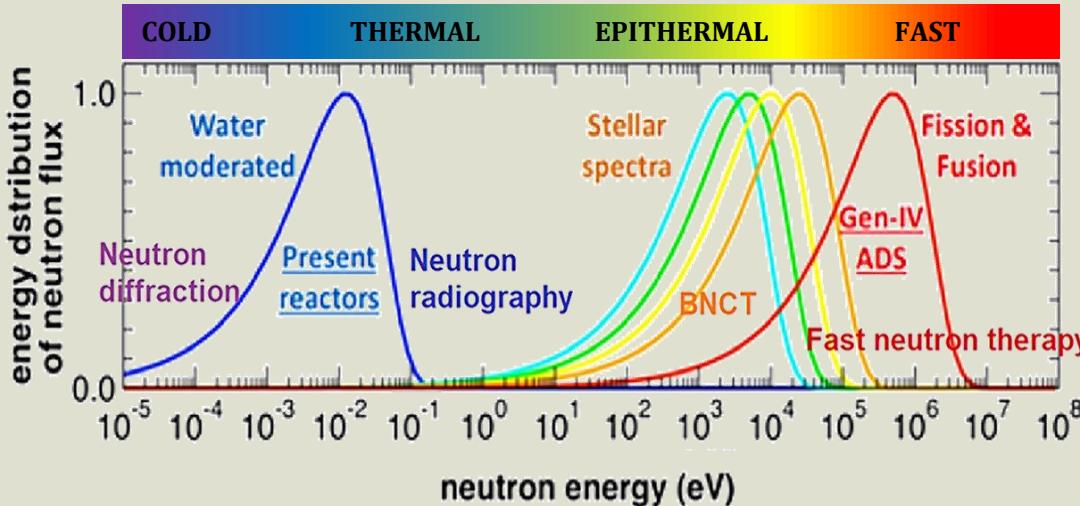
¹⁵ IJCLab, CNRS/IN2P3, Université Paris-Saclay, Orsay, France.

¹⁶ Institut de Techniques Energetiques (INTE), Universitat Politecnica de Catalunya (UPC), Barcelona, Spain



NEED FOR SMALL-SCALE NEUTRON SOURCES

Image credit: n_TOF collaboration



- Restricted transfer of knowledge outside a research center.
- Not exploited to their full capacity.

WHY?

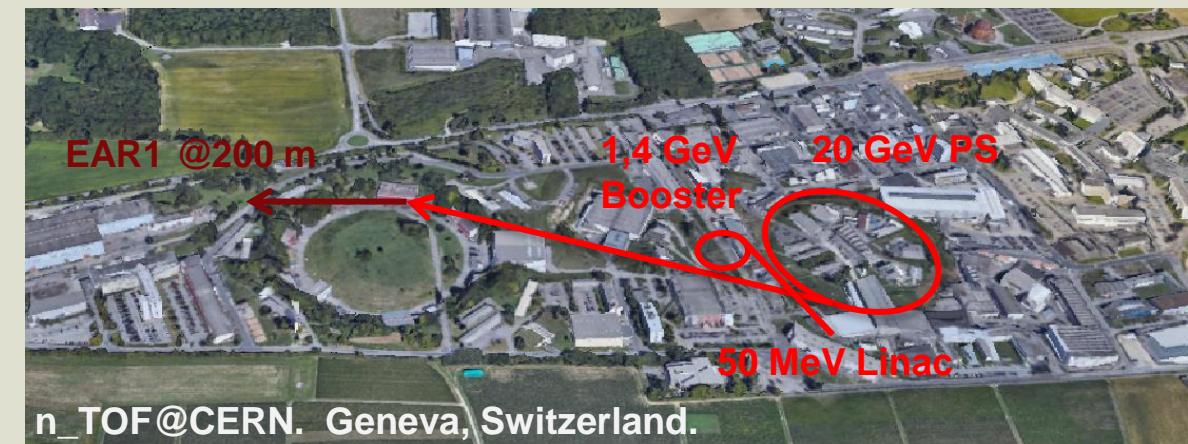
- Huge size and complexity of conventional high intensity neutron sources.
- Progressive shut down of research reactors.

“

There is a general belief in the life sciences community that neutron methods are an emerging technique and not exploited to their full capacity. This is partly due to the fact that useful neutron beams can only be generated at advanced research reactors and/or high energy neutron spallation sources.

”

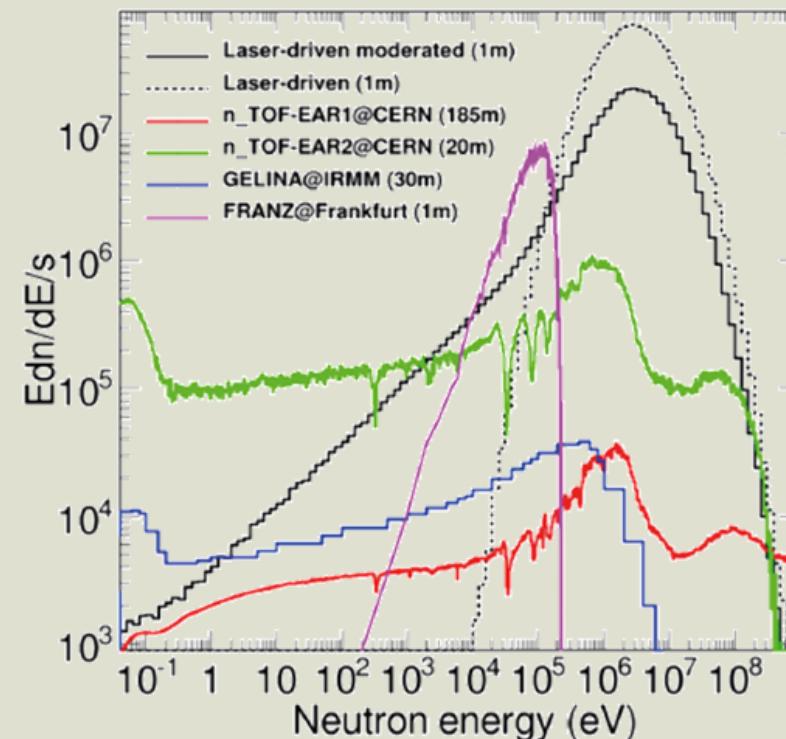
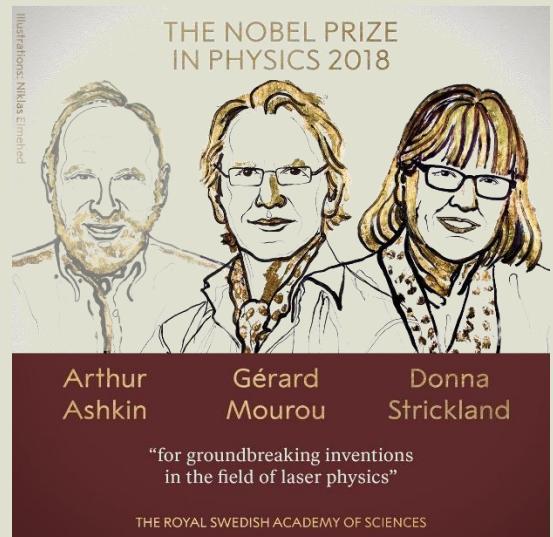
- IAEA-TECDOC-1439, Development opportunities for small scale accelerator driven neutron sources, Report of a technical meeting, Vienna, 18-21 May 2004



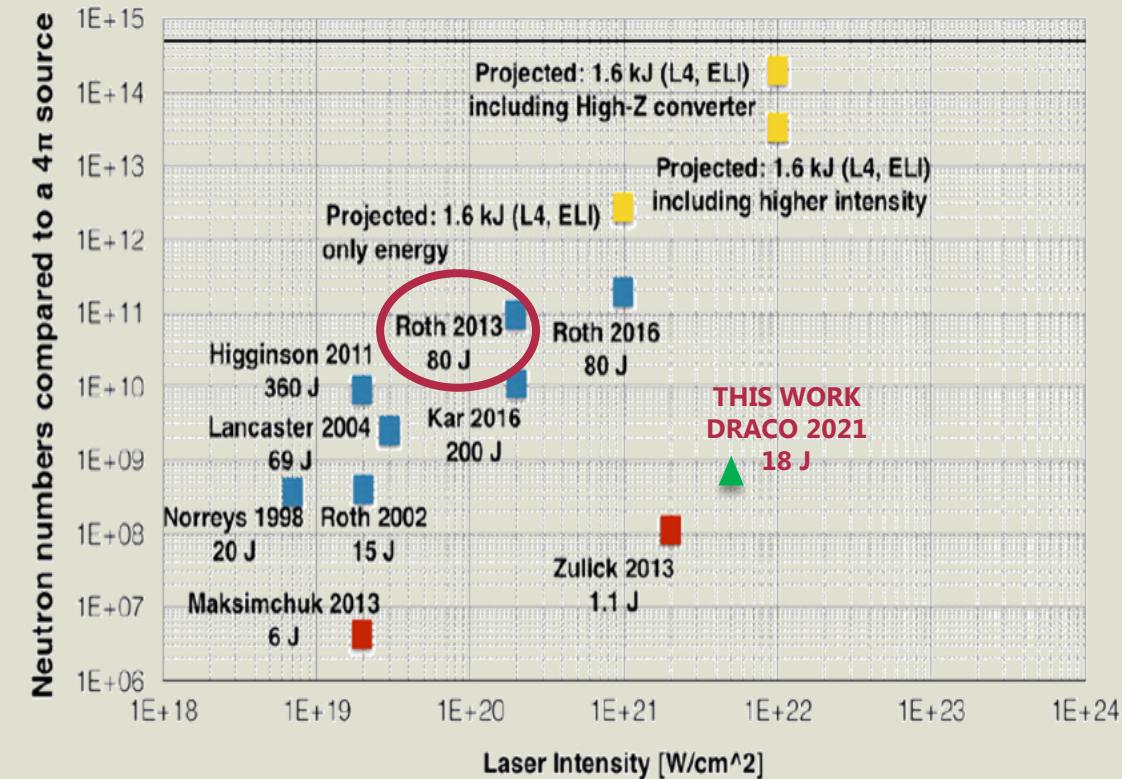
LASER-DRIVEN NEUTRON SOURCES



DRACO@HZDR amplifier path



Neutron flux based in M. Roth, et al. results from 2013 experiments at TRIDENT PW Laser System. 1m of flight path and 10Hz repetition rate are supposed. – C. Guerrero et al. *Eur. Phys. J. A*, **53**, 87 (2017). <https://doi.org/10.1140/epja/i2017-12261-2>



Neutrons per pulse of a laser-driven neutron source vs laser intensity. – Roth, M. et al. *Los Alamos National Lab. (LANL) Technical Report. LA-UR-17-23190.* (2017). <https://doi.org/10.2172/1352436>

Laser-driven acceleration: a really hot topic!

Vacuum laser acceleration of super-ponderomotive electrons using relativistic transparency injection

P. K. Singh, F.-Y. Li, C.-K. Huang, A. Moreau, R. Hollinger, A. Junghans, A. Favalli, C. Calvi, S. Wang, Y. Wang, H. Song, J. J. Rocca, R. E. Reinovsky & S. Palaniyappan 

Nature Communications 13, Article number: 54 (2022) | [Cite this article](#)

Robustness of large-area suspended graphene under interaction with intense laser

Y. Kuramitsu , T. Minami, T. Hihara, K. Sakai, T. Nishimoto, S. Isayama, Y. T. Liao, K. T. Wu, W. Y. Woon , S. H. Chen, Y. L. Liu, S. M. He, C. Y. Su, M. Ota, S. Egashira, A. Morace, Y. Sakawa, Y. Abe, H. Habara, R. Kodama, L. N. K. Döhl, N. Woolsey, M. Koenig, H. S. Kumar, ... Y. Fukuda [+ Show authors](#)

Scientific Reports 12, Article number: 2346 (2022) | [Cite this article](#)

Enhanced ion acceleration from transparency-driven foils demonstrated at two ultraintense laser facilities

Nicholas P. Dover, Tim Ziegler, Stefan Assenbaum, Constantin Bernert, Stefan Bock, Florian-Emanuel Brack, Thomas E. Cowan, Emma J. Ditter, Marco Garten, Lennart Gaus, Ilja Goethel, George S. Hicks, Hiromitsu Kiriya, Thomas Kluge, James K. Koga, Akira Kon, Kotaro Kondo, Stephan Kraft, Florian Kroll, Hazel F. Lowe, Josefine Metzkes-Ng, Tatsuhiko Miyatake, Zulfikar Najmudin, Thomas Püschel, ... Mamiko Nishiuchi  [+ Show authors](#)

Light: Science & Applications 12, Article number: 71 (2023) | [Cite this article](#)

Tumour irradiation in mice with a laser-accelerated proton beam

Florian Kroll , Florian-Emanuel Brack, Constantin Bernert, Stefan Bock, Elisabeth Bodenstein, Kerstin Brückner, Thomas E. Cowan, Lennart Gaus, René Gebhardt, Uwe Helbig, Leonhard Karsch, Thomas Kluge, Stephan Kraft, Mechthild Krause, Elisabeth Lessmann, Umar Masood, Sebastian Meister, Josefine Metzkes-Ng, Alexej Nossula, Jörg Pawelke, Jens Pietzsch, Thomas Püschel, Marvin Reimold, Martin Rehwald, ... Elke Beyreuther [+ Show authors](#)

Nature Physics 18, 316–322 (2022) | [Cite this article](#)

A theoretical model of laser-driven ion acceleration from near-critical double-layer targets

Andrea Pazzaglia , Luca Fedeli, Arianna Formenti, Alessandro Maffini & Matteo Passoni

Communications Physics 3, Article number: 133 (2020) | [Cite this article](#)

2204 Accesses | 13 Citations | 1 Altmetric | [Metrics](#)

Laser-driven proton acceleration from ultrathin foils with nanoholes

Giada Cantono , Alexander Permogorov, Julien Ferri, Evgeniya Smetanina, Alexandre Dmitriev, Anders Persson, Tünde Fülöp & Claes-Göran Wahlström

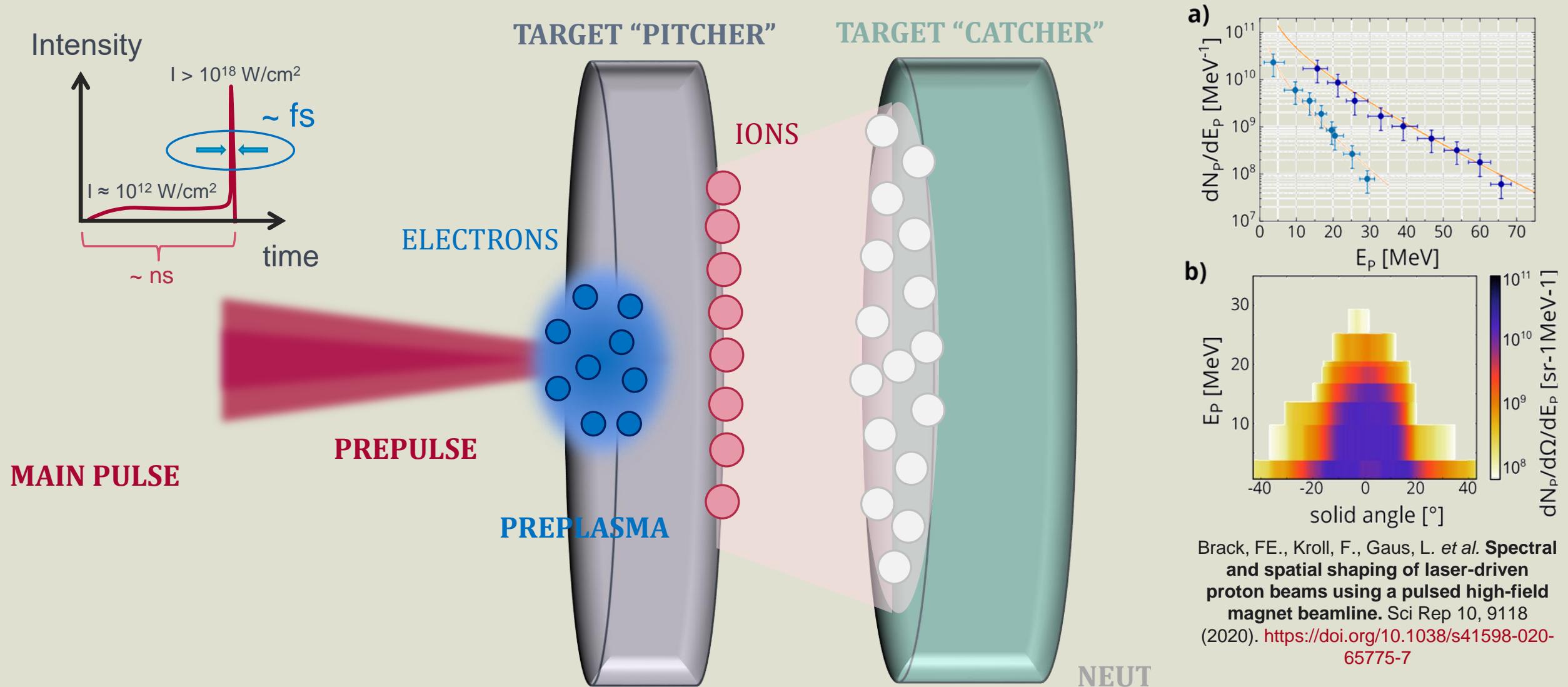
Scientific Reports 11, Article number: 5006 (2021) | [Cite this article](#)

Laser-driven multi-MeV high-purity proton acceleration via anisotropic ambipolar expansion of micron-scale hydrogen clusters

Satoshi Jinno, Masato Kanasaki, Takafumi Asai, Ryutaro Matsui, Alexander S. Pirozhkov, Koichi Ogura, Akito Sagisaka, Yasuhiro Miyasaka, Nobuhiko Nakajii, Masaki Kando, Nobuko Kitagawa, Kunihiro Morishima, Satoshi Kodaira, Yasuaki Kishimoto, Tomoya Yamauchi, Mitsuru Uesaka, Hiromitsu Kiriya & Yuji Fukuda 

Scientific Reports 12, Article number: 16753 (2022) | [Cite this article](#)

TNSA & “PITCHER-CATCHER” DOUBLE TARGET SETUP



EXPERIMENTAL CAMPAIGN AT DRACO@HZDR (Germany)

Accelerator and Research reactor Infrastructures for Education and Learning

ARIEL



1. Establishing a link between the laser acceleration community and the neutron-users community.
2. Performing a series of experiments at a laser facility to produce and characterize the neutron beam resulting from laser-driven ion beams.
3. Assessing the feasibility of laser-driven neutron beams for nuclear physics experiments depending on the corresponding detector type response.
4. Depending on the results before, carrying out the first neutron induced cross section measurement at a laser-driven neutron beam facility.

DRACO@HZDR

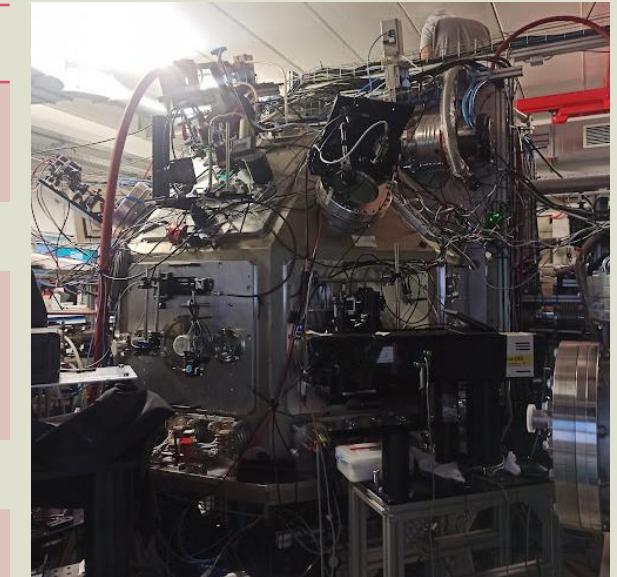
PW-class 30 J Laser System
(18 J on target)

30 fs laser pulse / ~ps ion pulse

Up to 1 Hz (compressor)
(~1 shot/minute during the experiment)

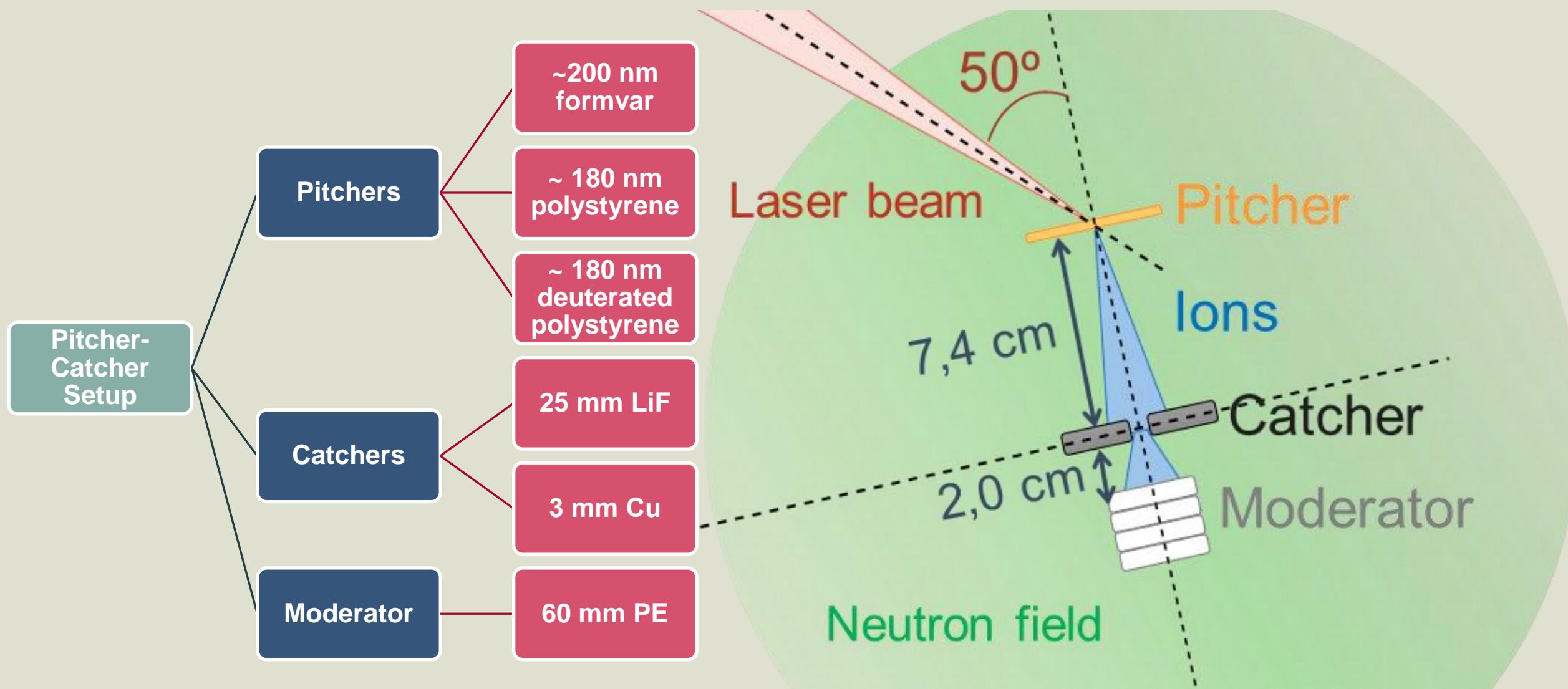
~200 shots/day

~ 7-8·10⁸ neutrons/shot

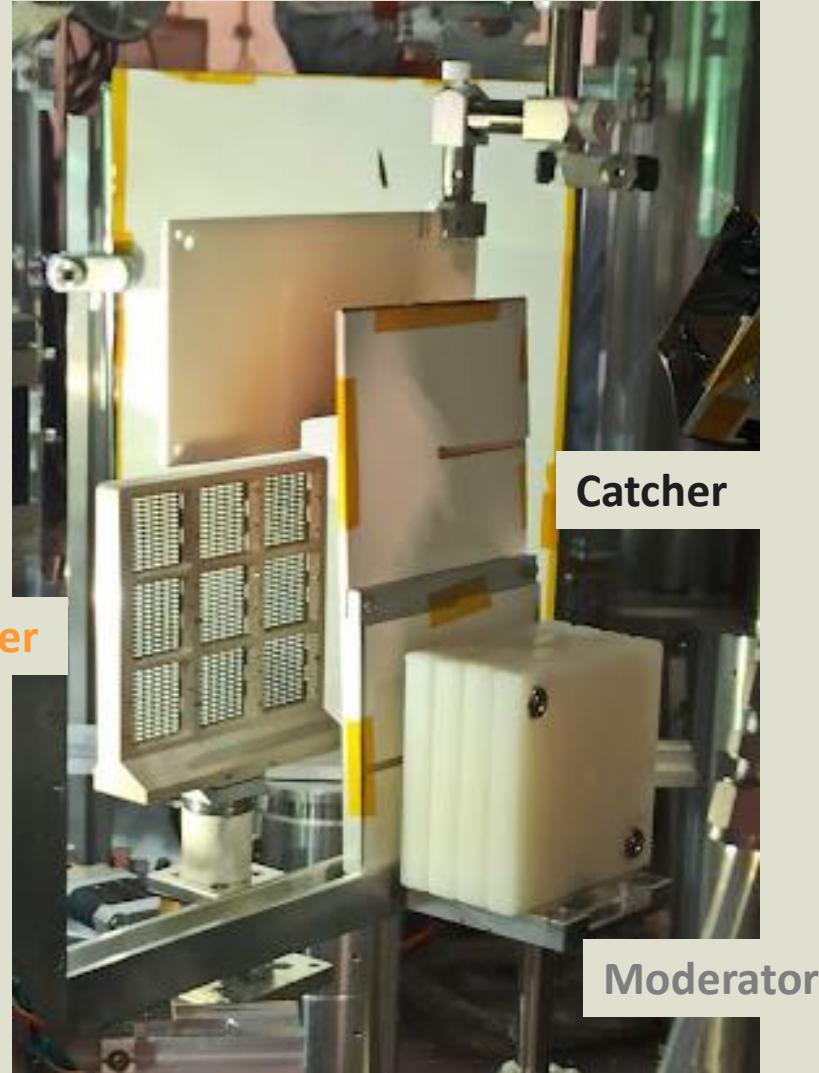


HZDR hosts both the nELBE neutron facility and the DRACO laser facility, a combination of facilities that make it the best suited research center for the purpose discussed herein

DEDICATED NEUTRON PRODUCTION EXPERIMENT

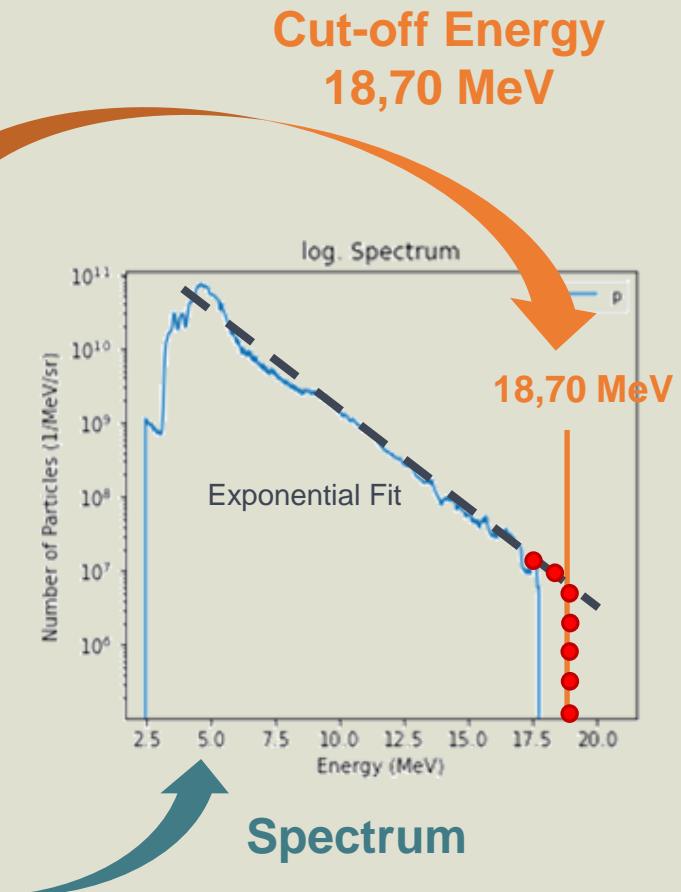
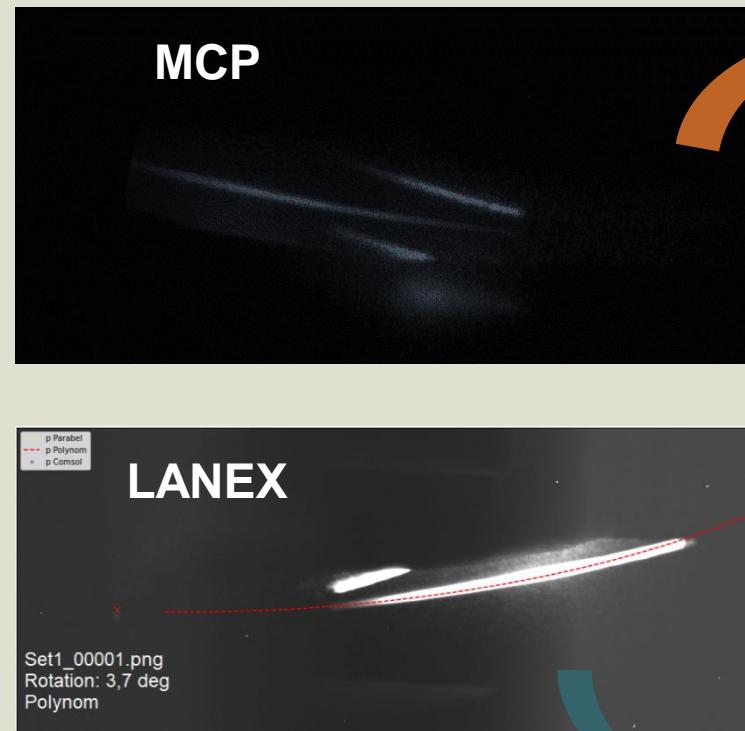
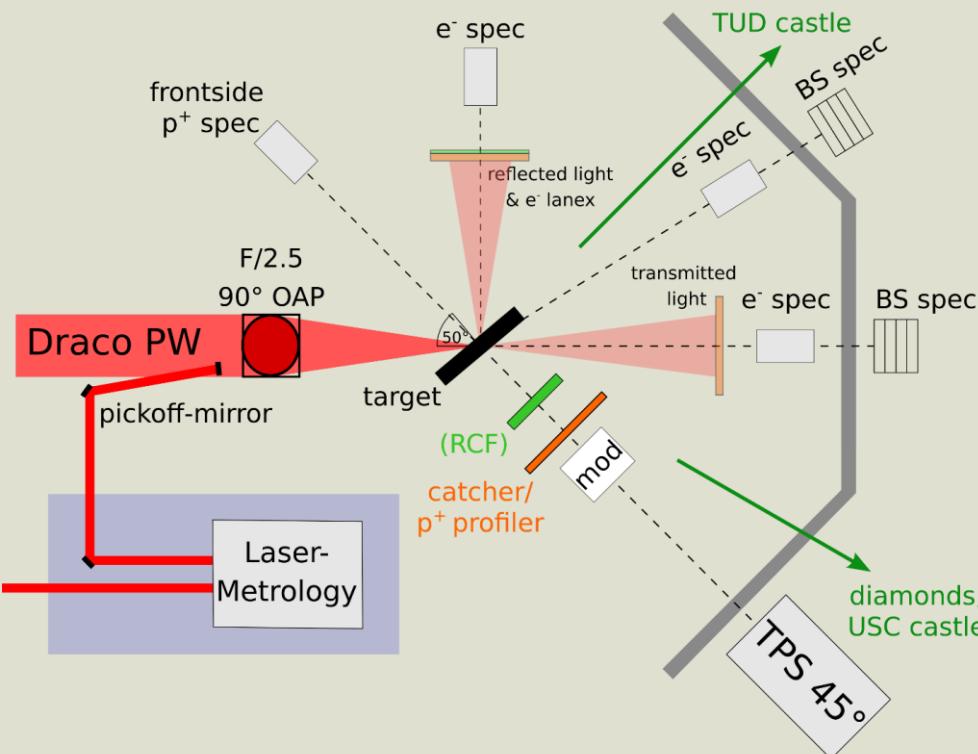


NEUTRON PRODUCTION SETUP



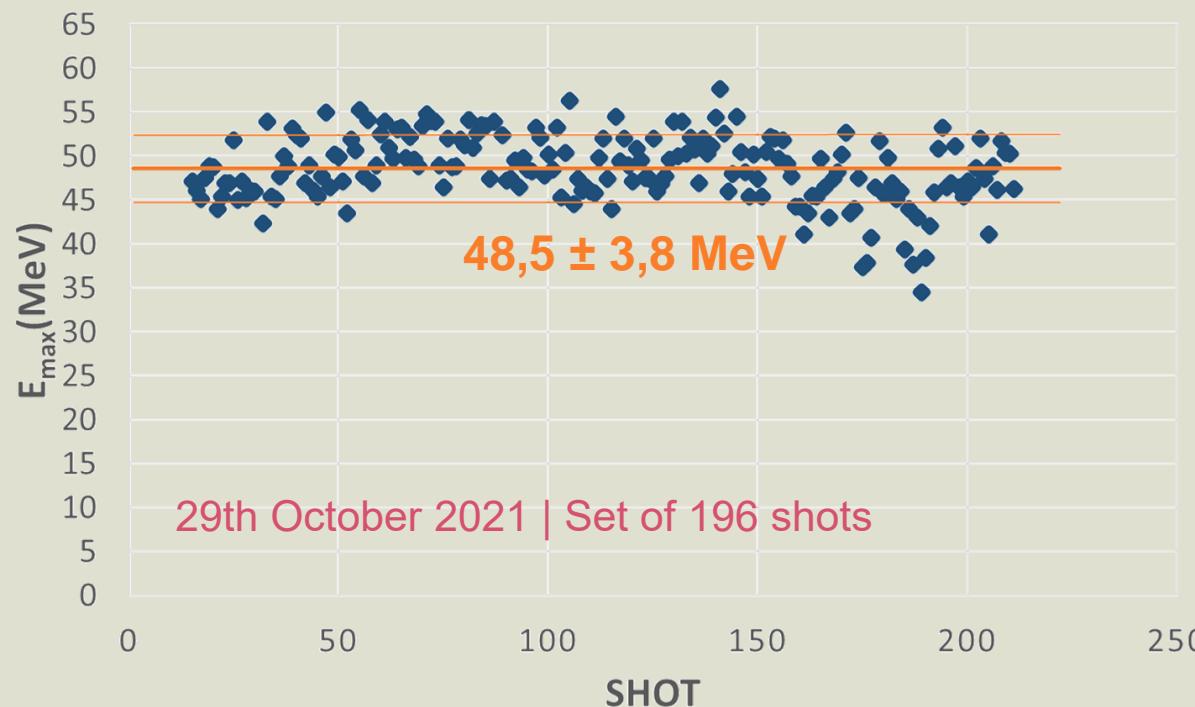
ION BEAM DIAGNOSTICS

TPS 45°

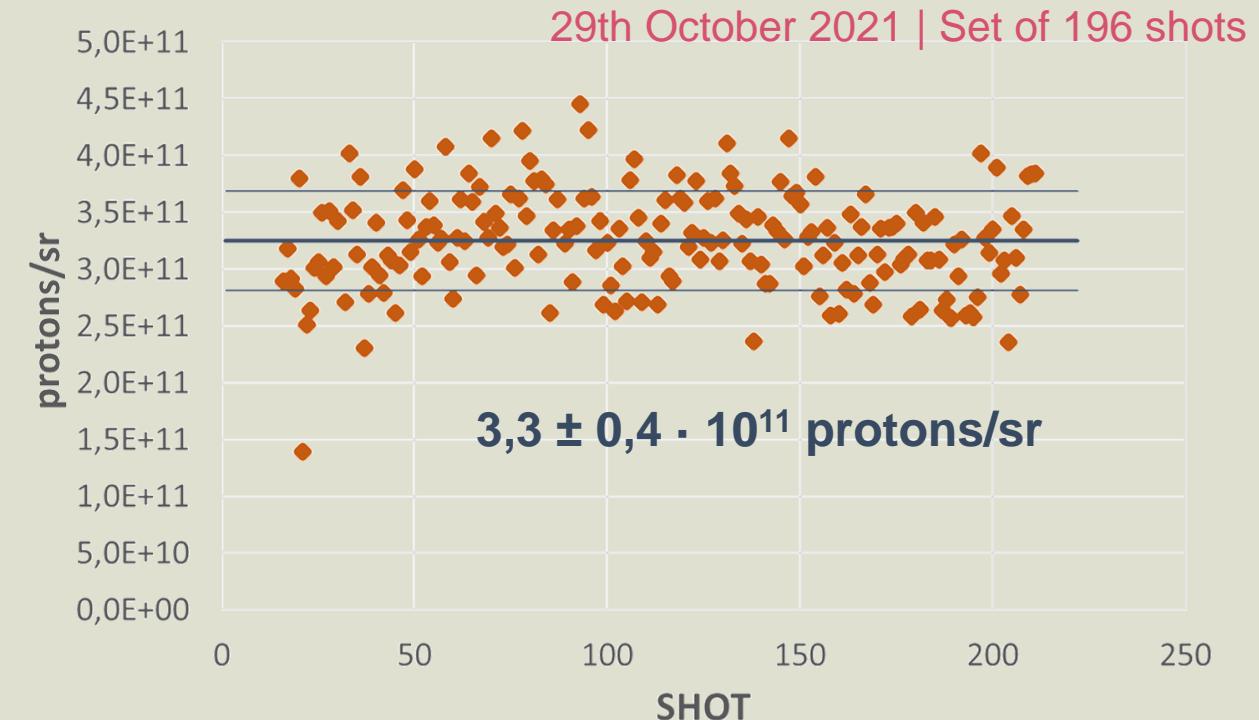


Combining this information we can obtain the complete spectrum

ION SOURCE STABILITY



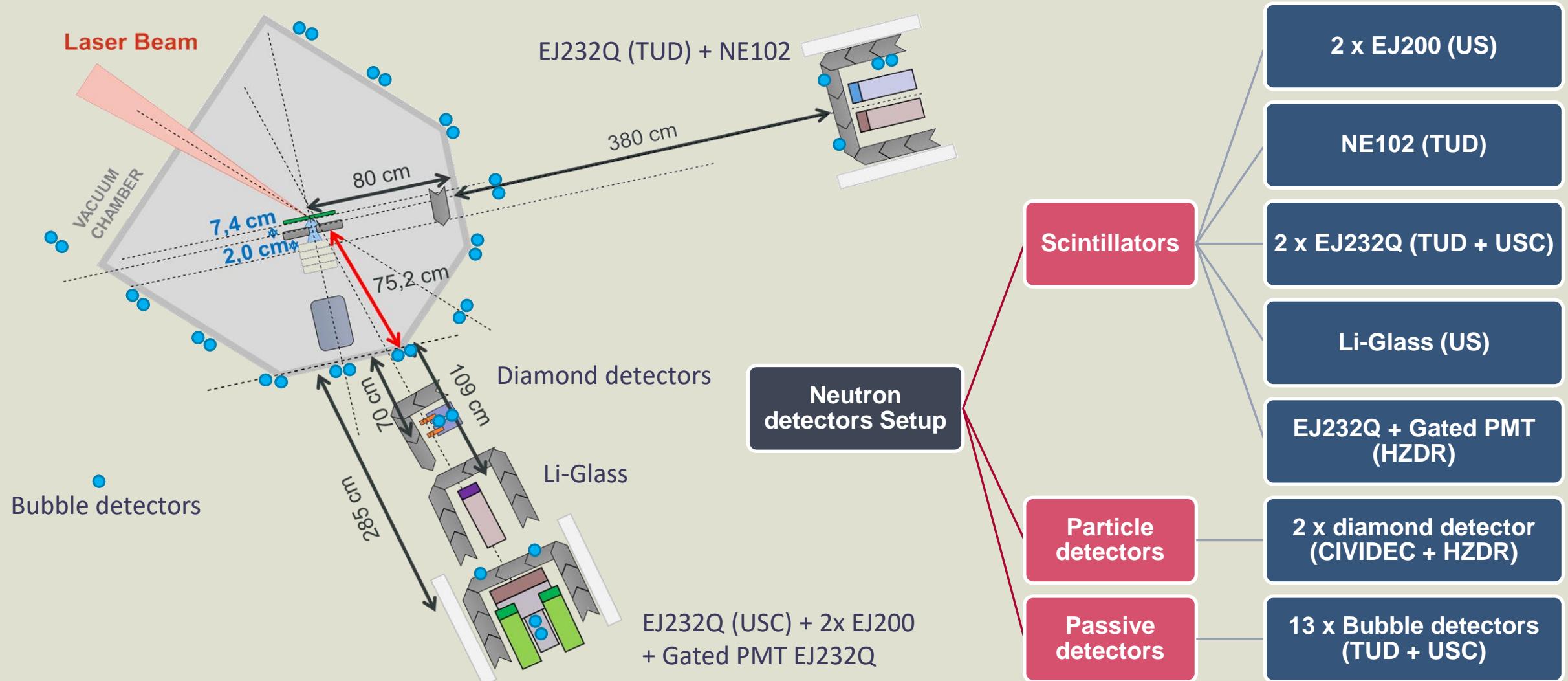
Reproducibility ~8%



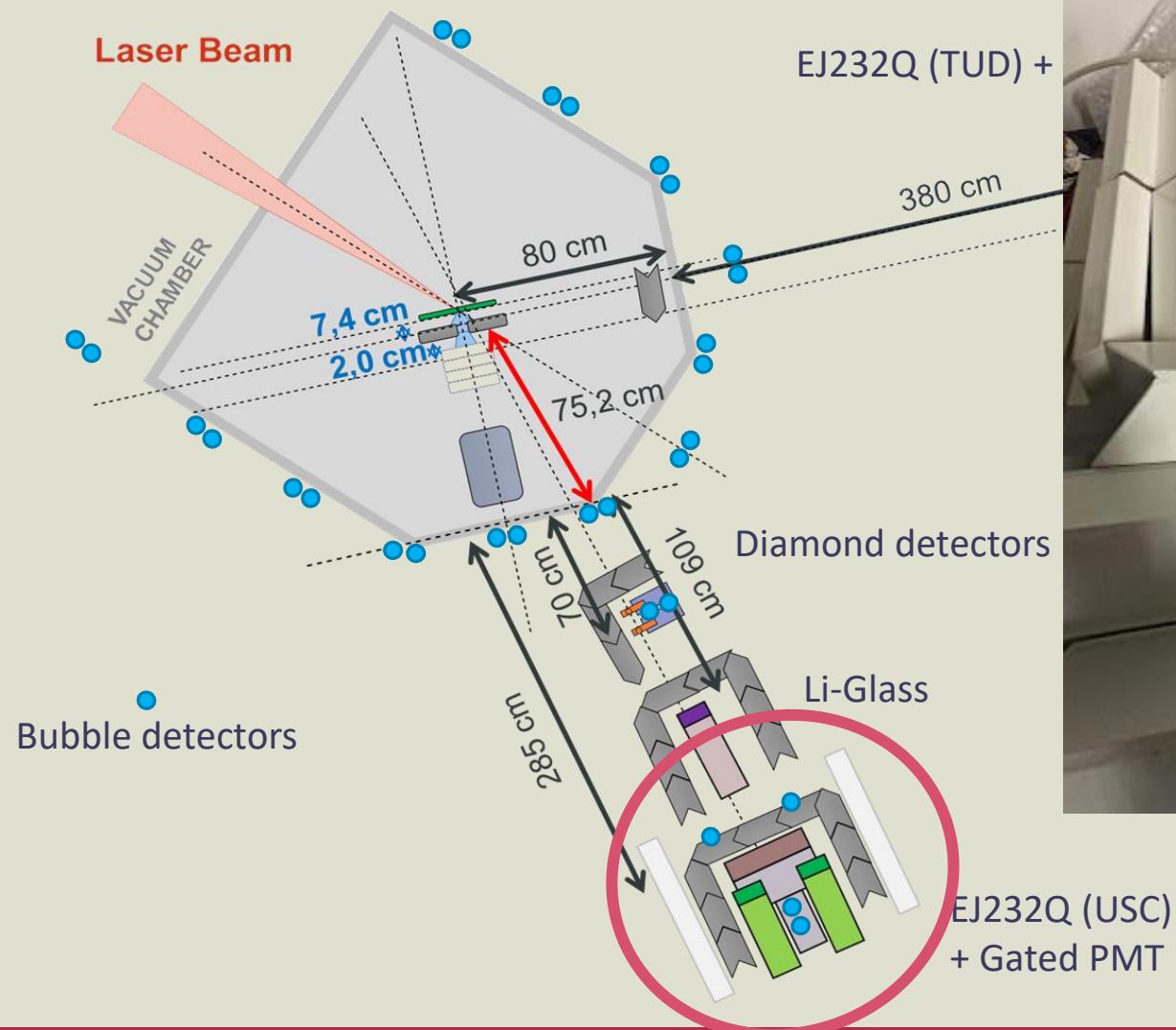
Reproducibility ~12%

CRUCIAL for the widespread use
of laser-driven ions beams for several applications

NEUTRON DETECTION SETUP

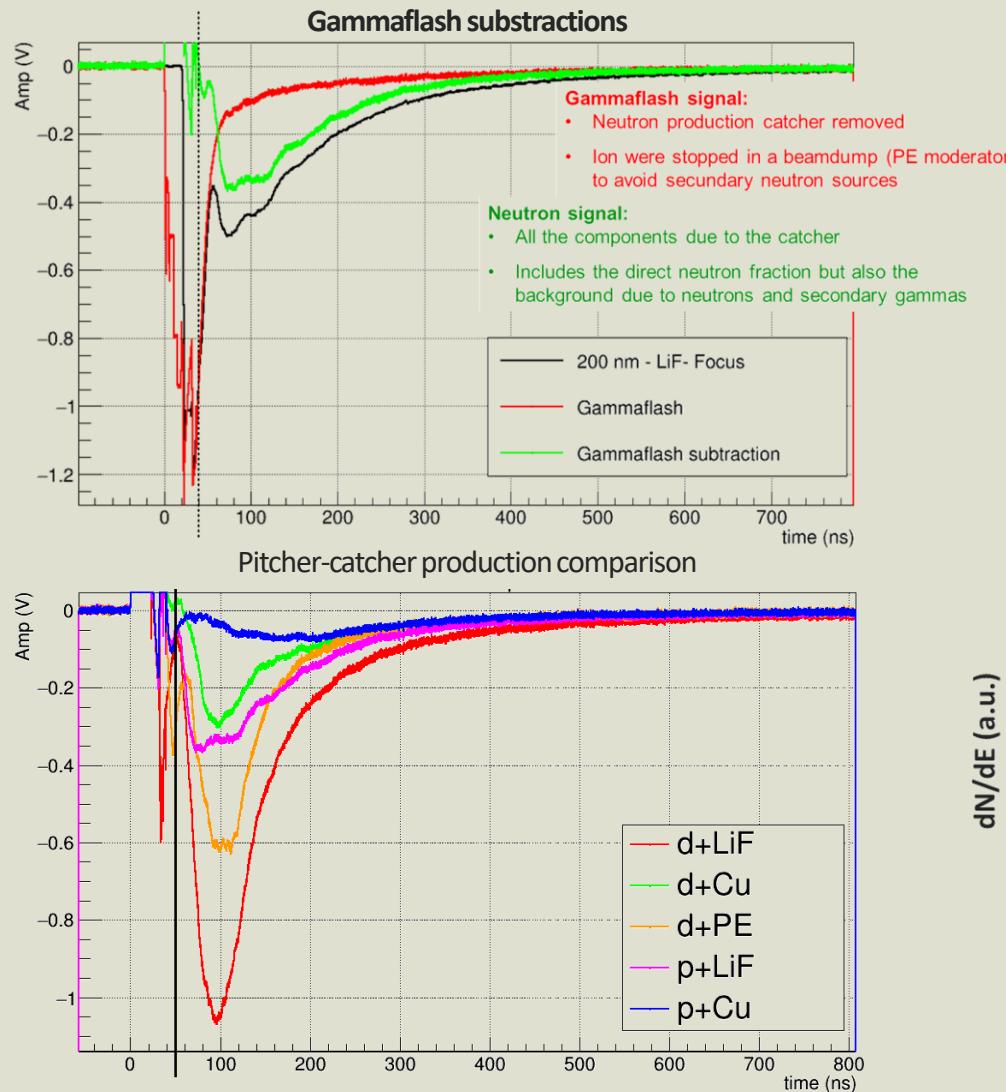


SCINTILLATORS



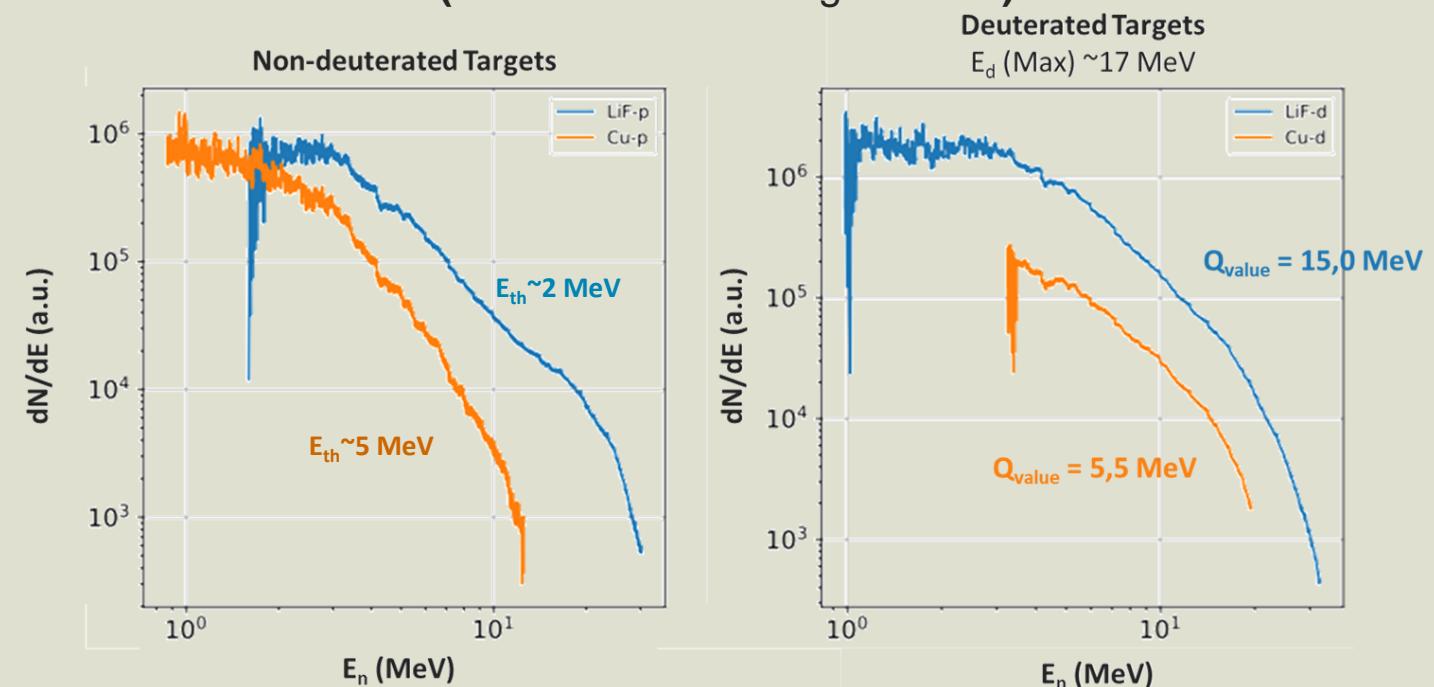
**15 cm Pb (front side)
10 cm Pb + 8 cm PE (lateral + top)**

SIGNALS FROM THE SCINTILLATORS



These traces are the result of the superposition of all the signals produced during each shot (pile-up)

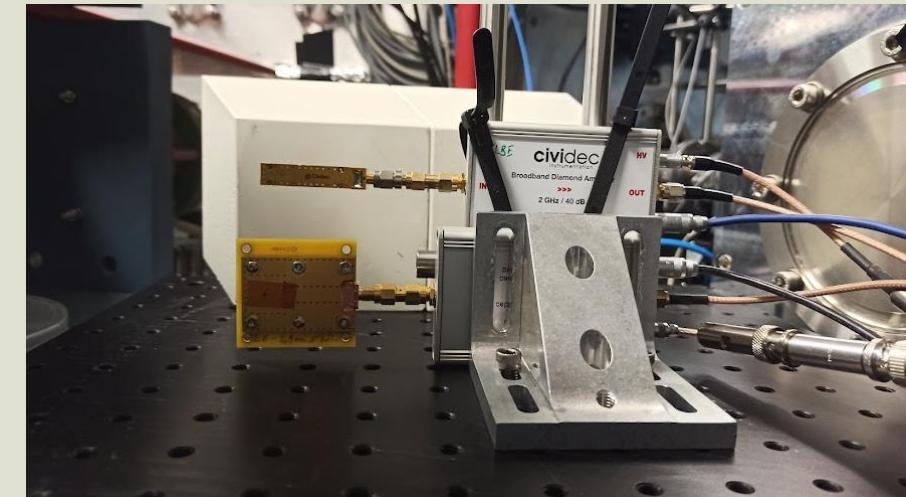
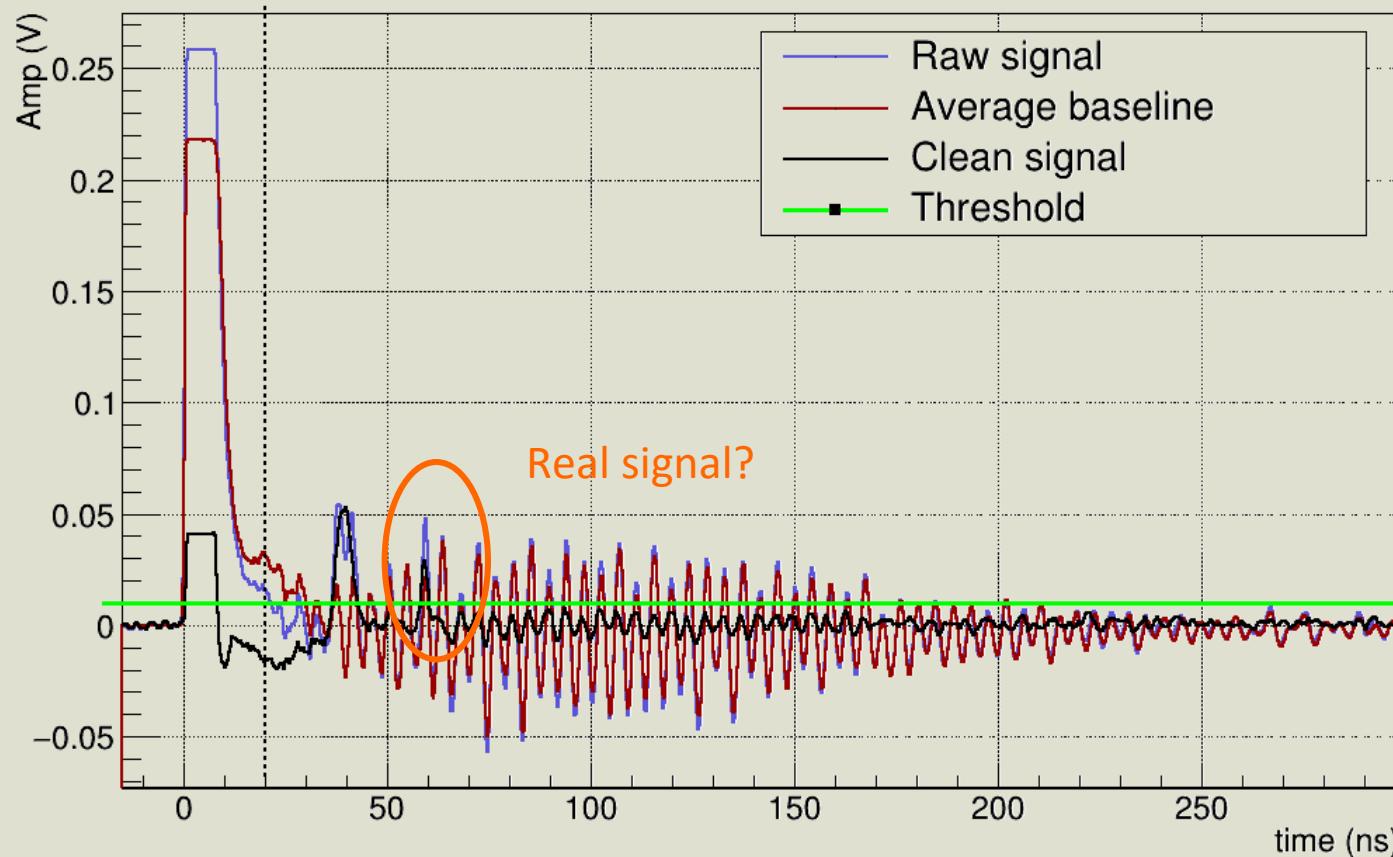
+
Mixed field of gammas and neutrons
↓
Extra effort to be unfolded
(what about shielding effects?)



SINGLE-EVENT DETECTORS (DIAMONDS)

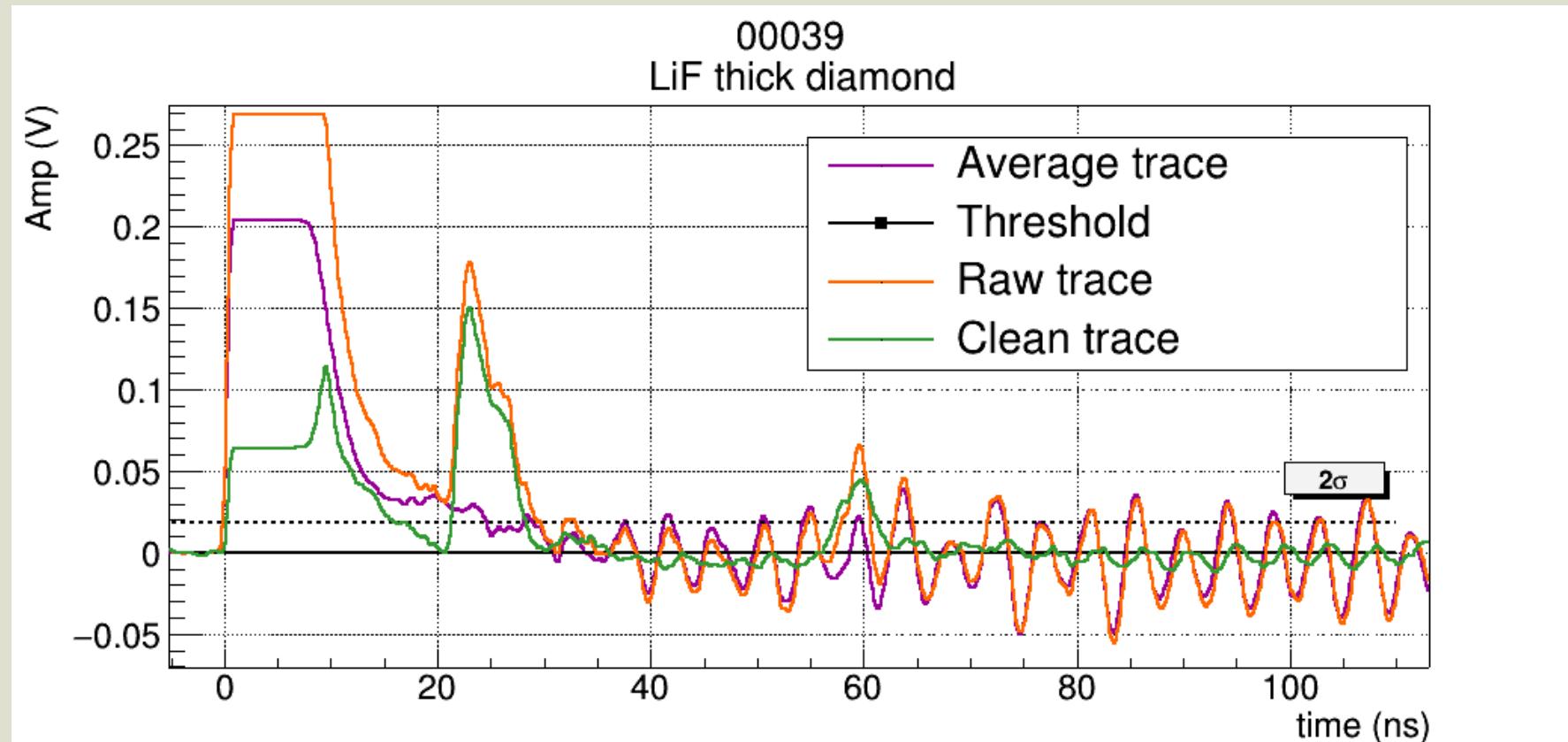
Operated with a 2 GHz
Broadband Amplifier (low-
noise)

Diamond detector

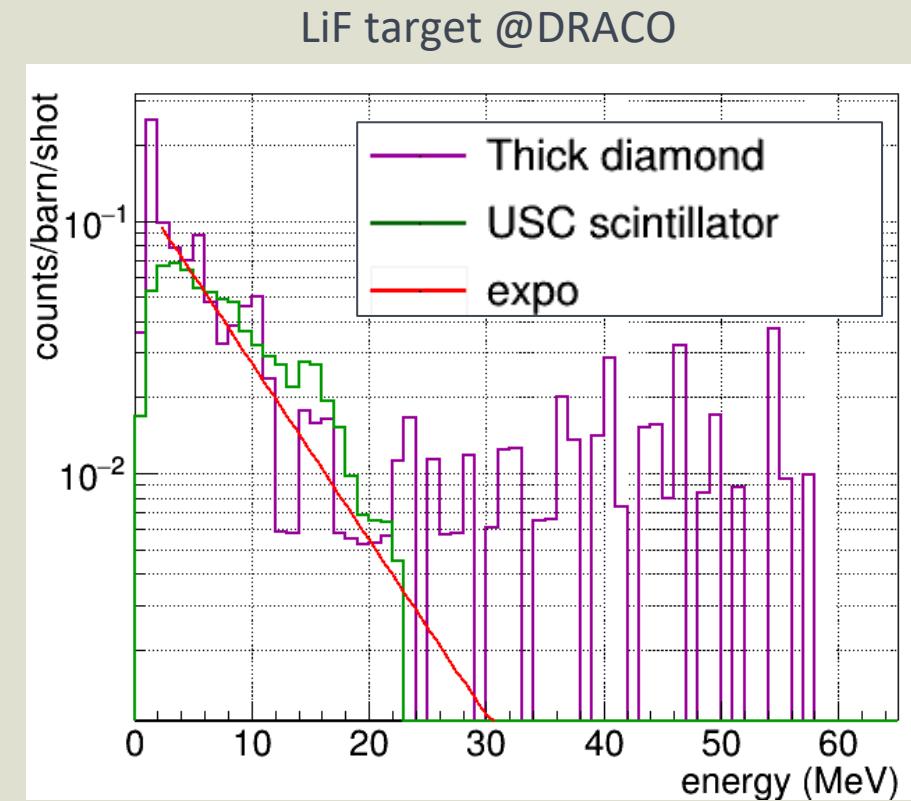
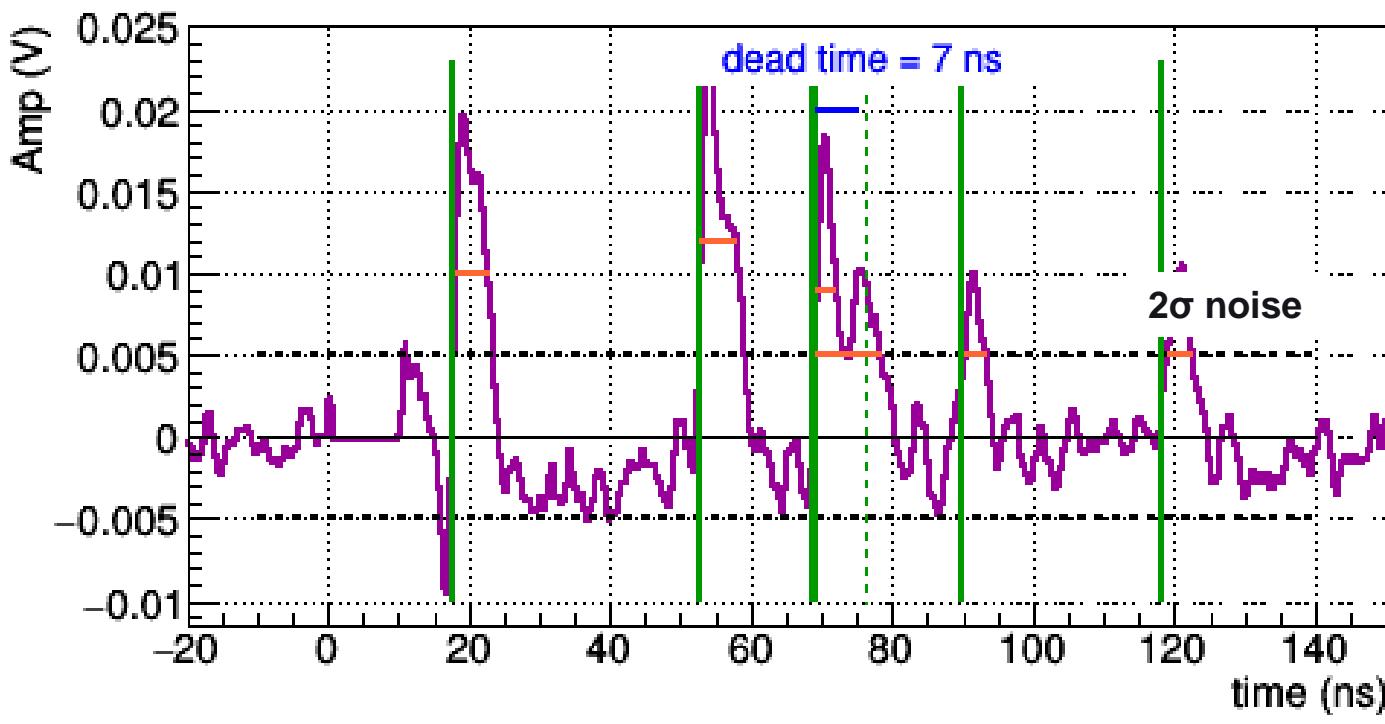


- For **fast neutrons** detection
- **Not sensitive to gammas.** → Small shielding needed.
- **Fast response (sub ns rise time) and small size** → Fast recovery after saturation.
- **Sensitive to charged particles** in (n, chp) reactions. → Suitable for nuclear physics measurements
- **Need of a high repetition source**

SINGLE-EVENT DETECTORS (DIAMONDS): signal analysis



SINGLE-EVENT DETECTORS (DIAMONDS): 1st results



Ongoing:

- Refinement and QA of the PSA routine
- Geant4 Monte Carlo simulations of the " $p \rightarrow \text{LiF} \rightarrow \text{Pb} \rightarrow \text{diamond}$ " set-up

CONCLUSIONS AND OUTLOOK

- **Harsh radiation environment:** Strong detector saturation due to prompt components (with limited duration) → Need of huge shielding (extra source of background) or ultrafast detectors with low efficiency (e.g. diamonds. Need of a high repetition source).
- **Strong EMP:** High frequency noise ringing in diamond signals. → Reduced, but not avoided, with EM shielding.

- **Almost 1300 shots & laser-plasma source setup mostly unchanged** → Statistical analysis of shot-to-shot fluctuations and proton acceleration stability
- **Single event fast neutron ToF spectrum in a PW laser system!** → First steps for nuclear reactions measurements in a laser facility.
- **Future experimental campaigns**
 - Testing faster particle detectors (PPACs)



EXPERIMENTAL CAMPAIGN AT VEGA@CLPU (Spain)

VEGA3@CLPU

PW-class 30 J Laser System

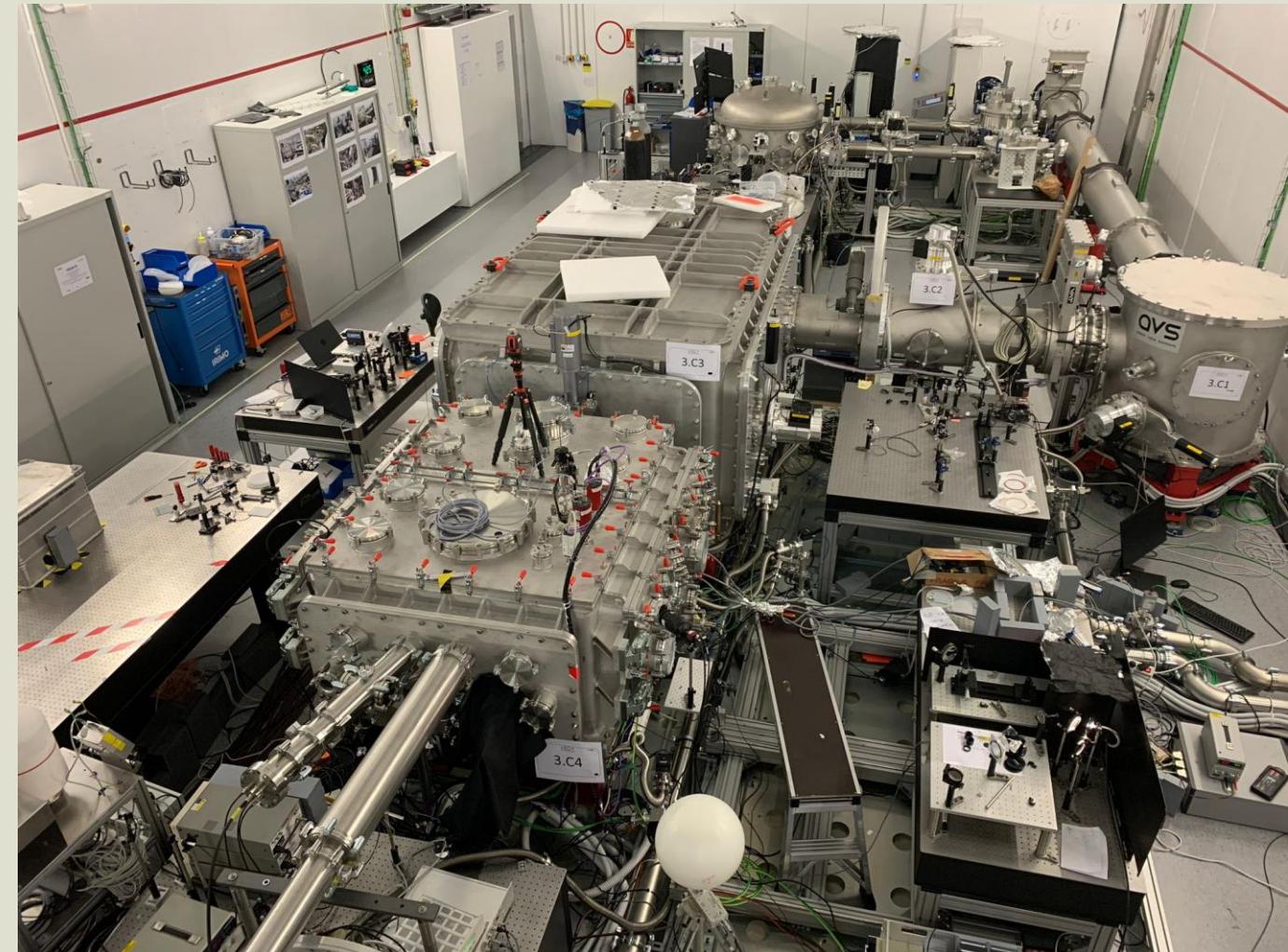
30 fs laser pulse / ~ps ion pulse
(200 fs during the experiment)

Up to 1 Hz (compressor)
(~ 0,1 Hz during the experiment)

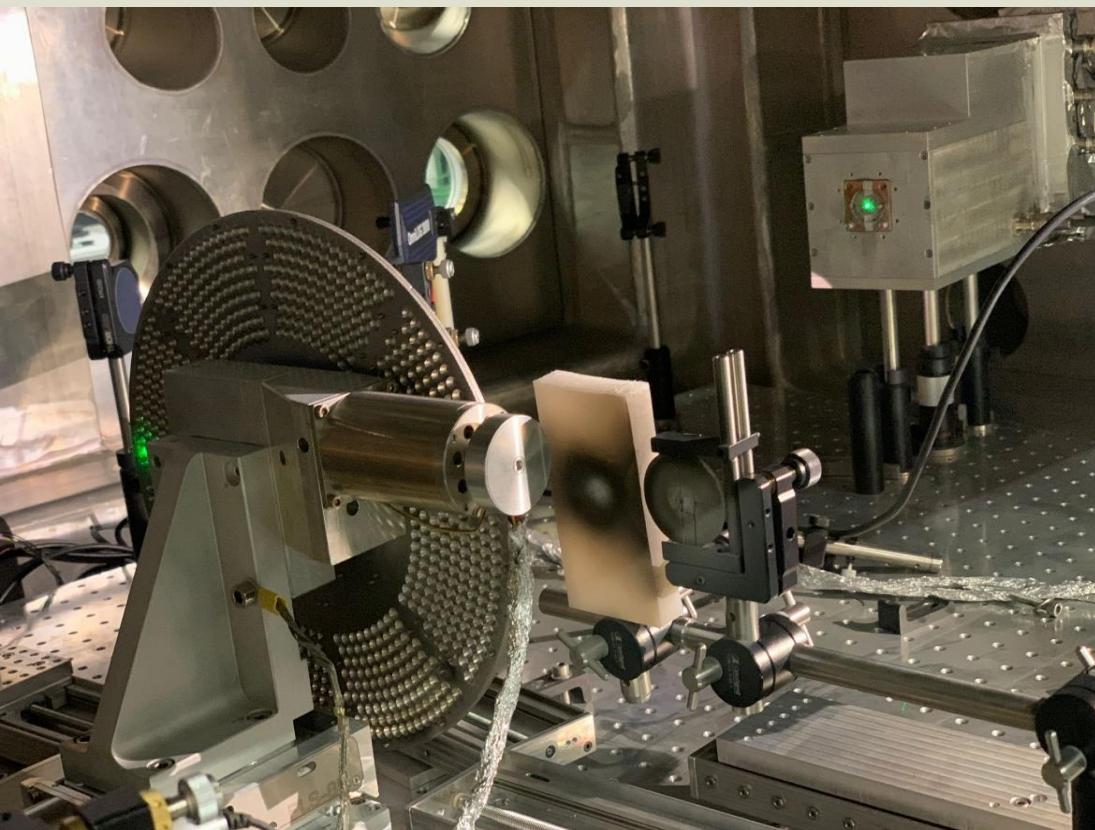
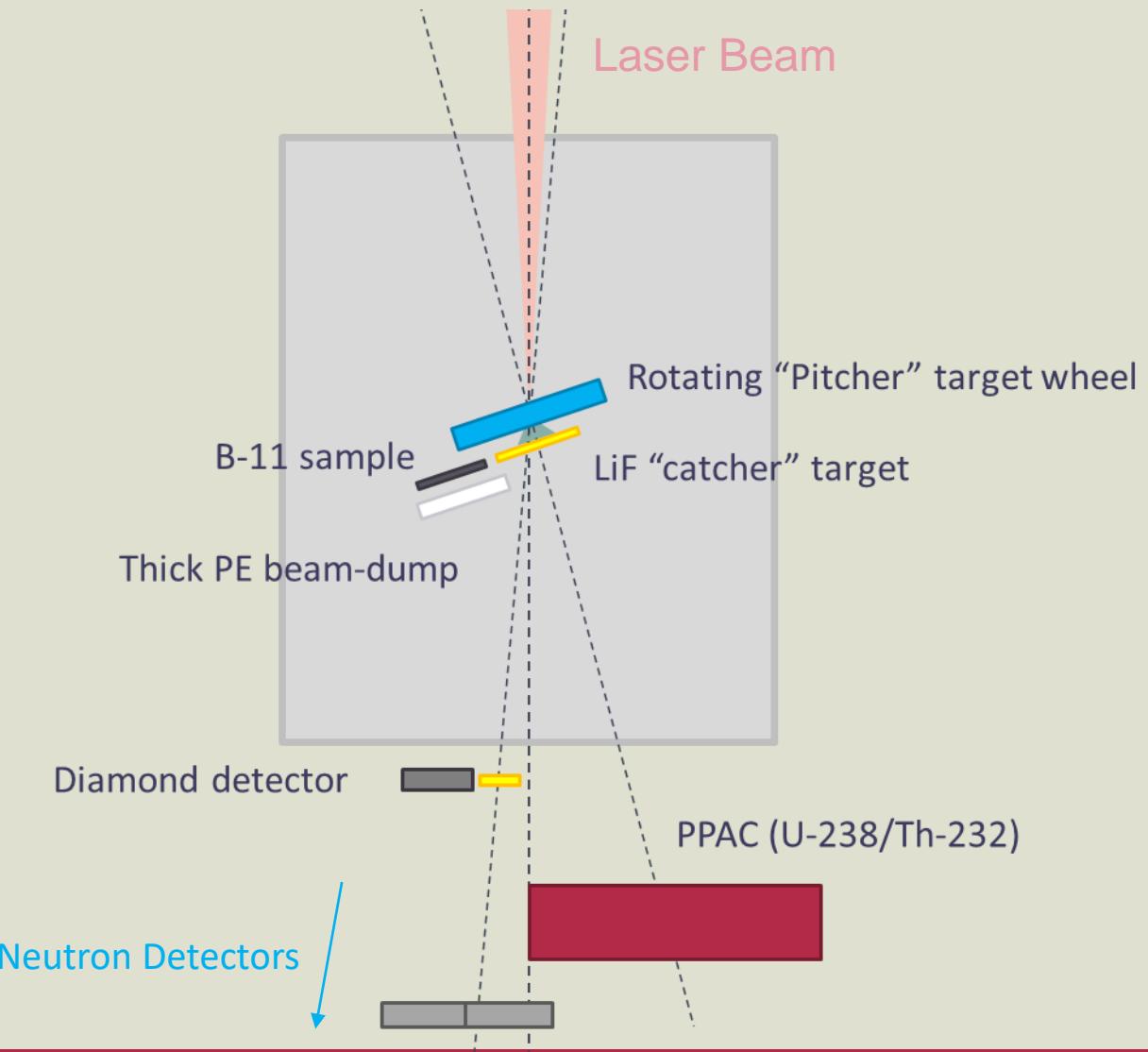
~ 500 shots/day
(+ 3500 during the whole campaign)

~ $1 \cdot 10^7$ neutrons/shot
(Based on LiF activation)

CLPU (*Centro de Láseres Pulsados*) is an ICTS (Unique research facility) opened to external users and located in Salamanca (Spain). It hosts the **VEGA** laser facility with 3 different beamlines (VEGA1, VEGA2 and VEGA3).



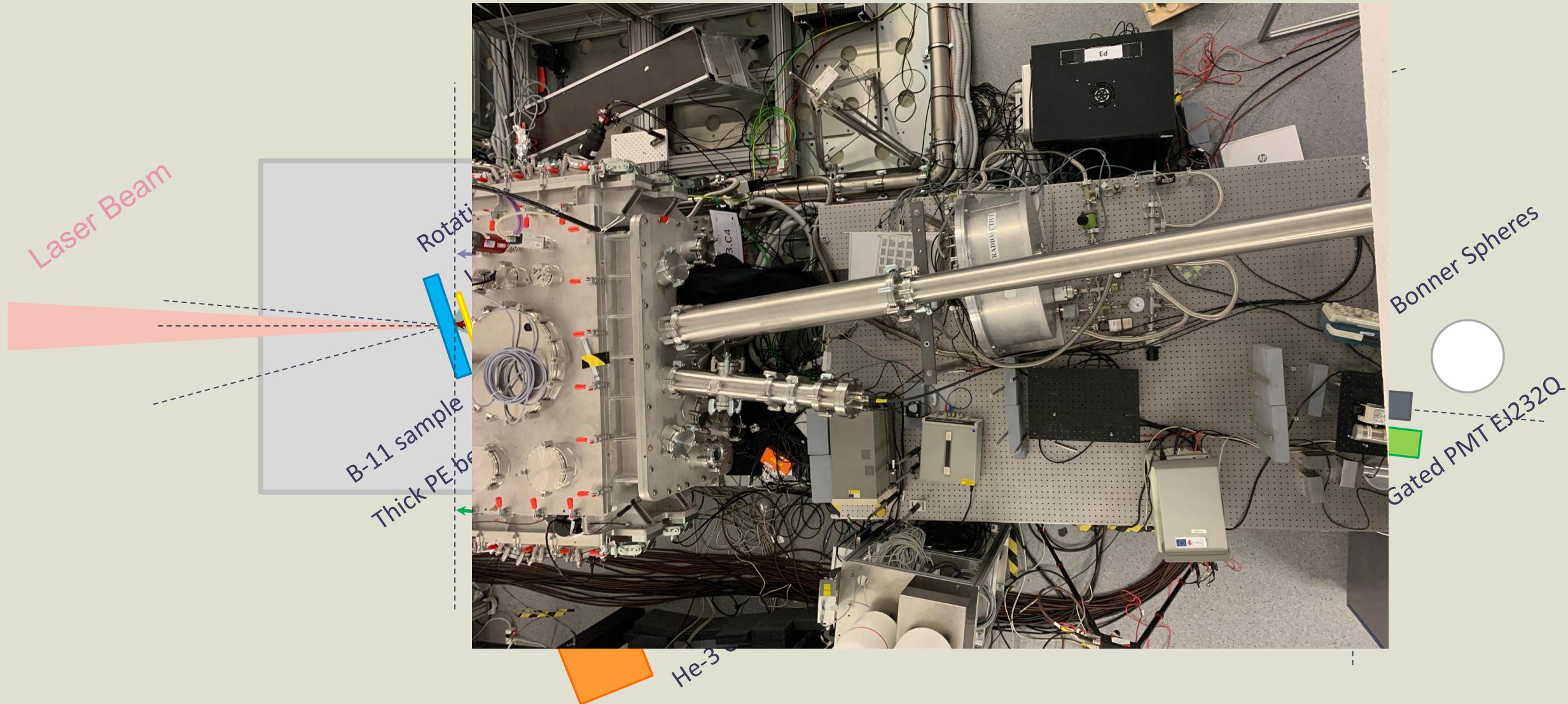
Campaign VEGA3 @ CLPU: Pitcher-Catcher



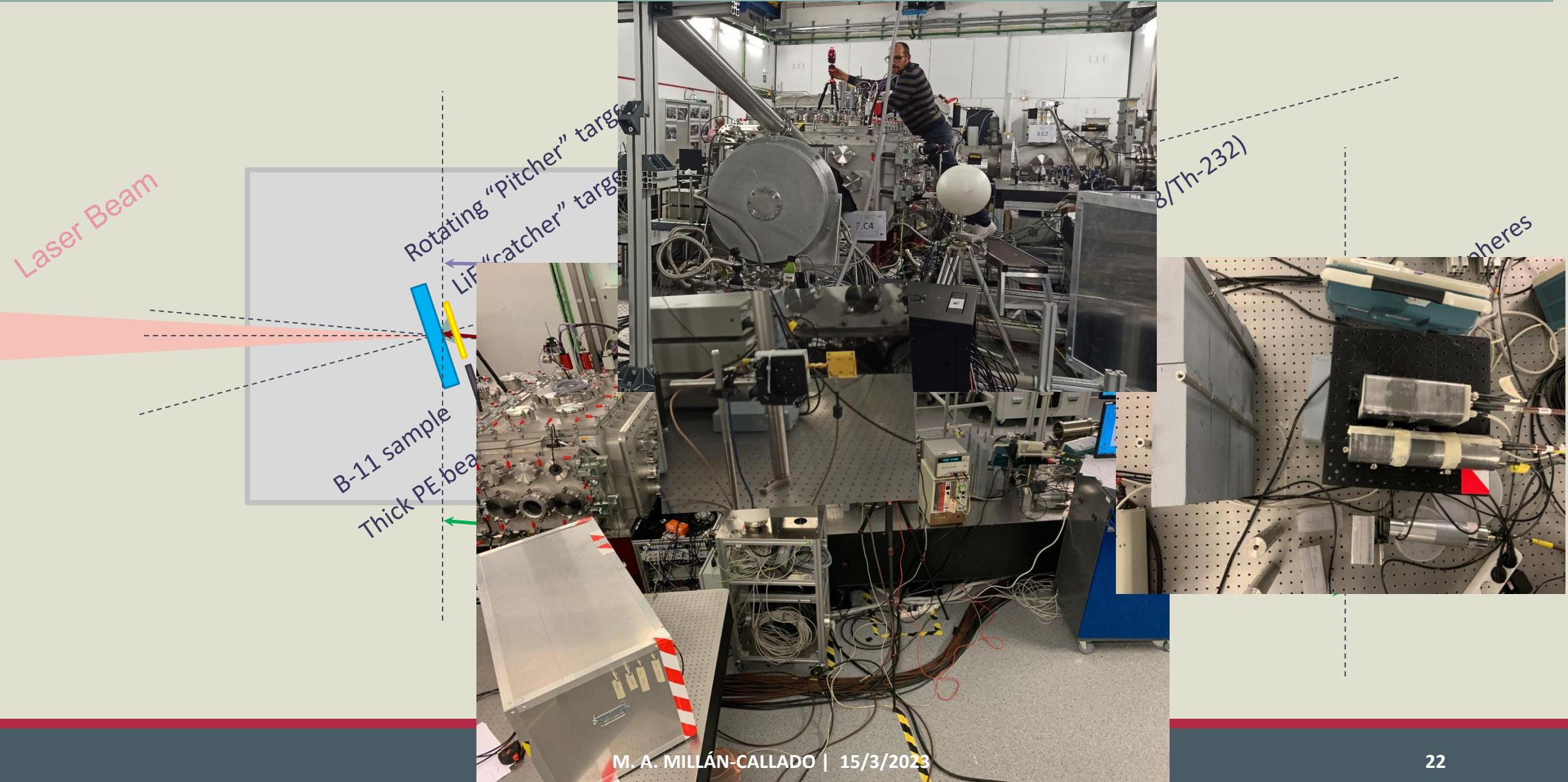
Rotating Wheel target:

- 808 targets
- Capable to rotate at 0.1 Hz @ 30 J
- 1 Hz @ 12 J

Campaign VEGA3 @ CLPU: Neutron Detectors



Campaign VEGA3 @ CLPU: Neutron Detectors



FIRST CONCLUSIONS

- **Harsh radiation environment:** Strong detector saturation due to prompt components (with limited duration) → Need of huge shielding (extra source of background) or ultrafast detectors with low efficiency (e.g. diamonds). Need of a high repetition source).
- **Strong EMP:** High frequency noise ringing in diamond and PPAC signals. → Reduced, but not avoided, with EM shielding.

- **More than 3500 shots & laser-plasma source setup mostly unchanged** → Statistical analysis of shot-to-shot fluctuations and proton acceleration stability.



- **Bigger room + Longer flightpath** → Reduction of the number of signal in the detector and increasing the signal to noise ratio.
- **Lower power** → Less neutron production and lower cut-off energy (Still suitable for nuclear physics) → Compensated with a high repetition neutron source (0,1 Hz)



We were able to measure with conventional scintillators in single signal mode and substituting the massive lead shielding for a 5 cm Pb filter far away from the detectors

But all these factors reduce the counting in the low efficiency detectors (PPACs + Diamonds)



iiGRACIAS!!

Any question?

Acknowledgements

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