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Lézeres gyors neutron forrás fejlesztése

Osvay Károly

Magyar Magfizikus Találkozó

Debrecen
2024. szeptember 3-5.

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- Hungarian Government: ITM 1096/2019. (III.8.)
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- Multiscan 3D H2020 project: 101020100

Outline

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Motivation

Laser-based neutron sources

Neutron generation at 10 Hz

Neutron generation at 1kHz – PRELIMINARY!

Application for …

A room for laser-based neutron sources

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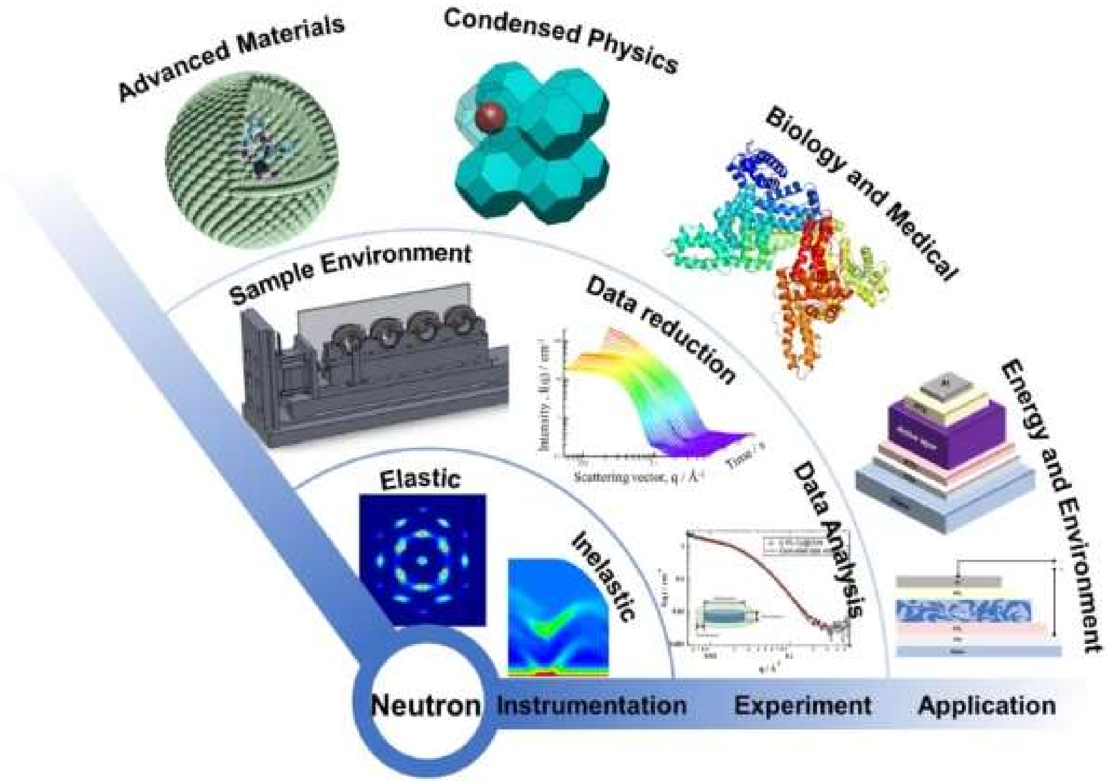
Demand for neutron sources is rapidly increasing

– by academy, industry, and health care



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A room for laser-based neutron sources

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The number of neutron facilities sources is decreasing

- reactors are aging, and closing down.
- big sources are delayed.

Many emerging applications call for neutron sources with

- a yield of 10^8 n/s - 10^{11} n/s;
- relaxed safety and security (compared to reactors);
- compact, efficient;
- reliable.

Specialities of a laser-based neutron source

- neutrons are generated in ultrashort bunches;
- the ”machine” (laser) and the ”source” can be separated;
- the laser is not a nuclear device.

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Laser-based neutron sources
PW class lasers – current situation

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Highest efficiency experiment

PhotoFusion
- Accelerate ion (proton, deuterium)
- Make fusion: Be(p,n), Li(p,n), D(d,n) (T)d,n)

69×10^{7} n/J
2×10^{6} n/s

Günther et al., Nat. Com.13, (2022) 170

Photonuclear
- Accelerate electrons
- Brehmstralung and high Z converter: (γ,n)

2.9×10^{7} n/J
~ 10^{5} n/s

Average power of such lasers is ~1W

Predicted efficiency

Laser spallation
- Accelerate proton
- Make fusion: Be(p,n), Li(p,n), D(d,n) (T)d,n)

~8×10^{10} n/J
~1300×10^{6} n/s
~1% laser->neutron

Martinez et al., MatRadExt 7 (2022) 024401

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Strategies "*en large*" for a laser driven particle (neutron) source

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Use T(P)W lasers from single shot mode
Contrast issues

Increase laser repetition rate
Target development

NLTL approach

Start from "ideal", "Dirac"-pulse
Investigate interactions and optimise yields

High repetition rate target development
Purpose designed laser
Increase pulse energy

Both paths would lead to a laser accelerator based particle source…
… with differences especially in early stage

Laser-fusion
(single shot events)

Tokamak
("continous" operation)

Common challange

High Repetition Rate Targets

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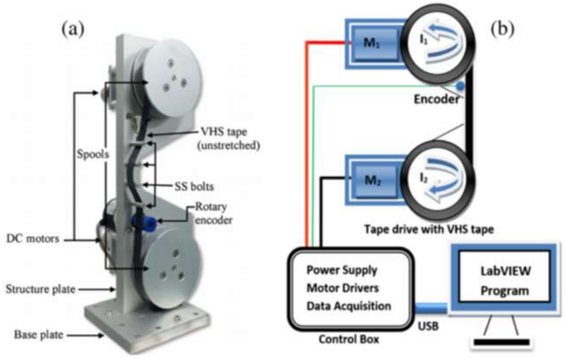
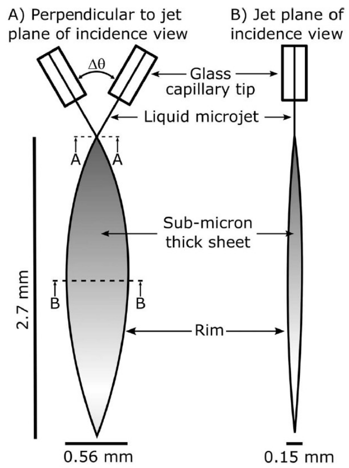
Most promising directions so far

Tape target



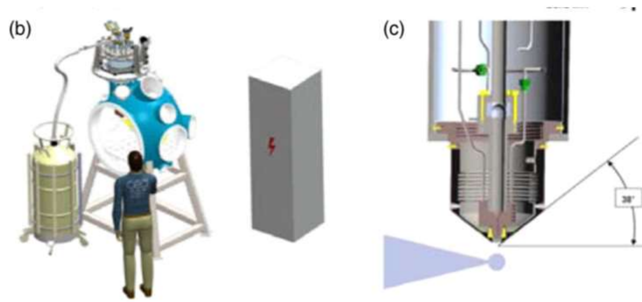
PRAB 20, 041301 (2017)

Liquid jet



HPLSE 7, e50 (2019)

Cryo H (D) ribbon



PHYS. REV. X 6, 041030 (2016)

Scheme of the interactions

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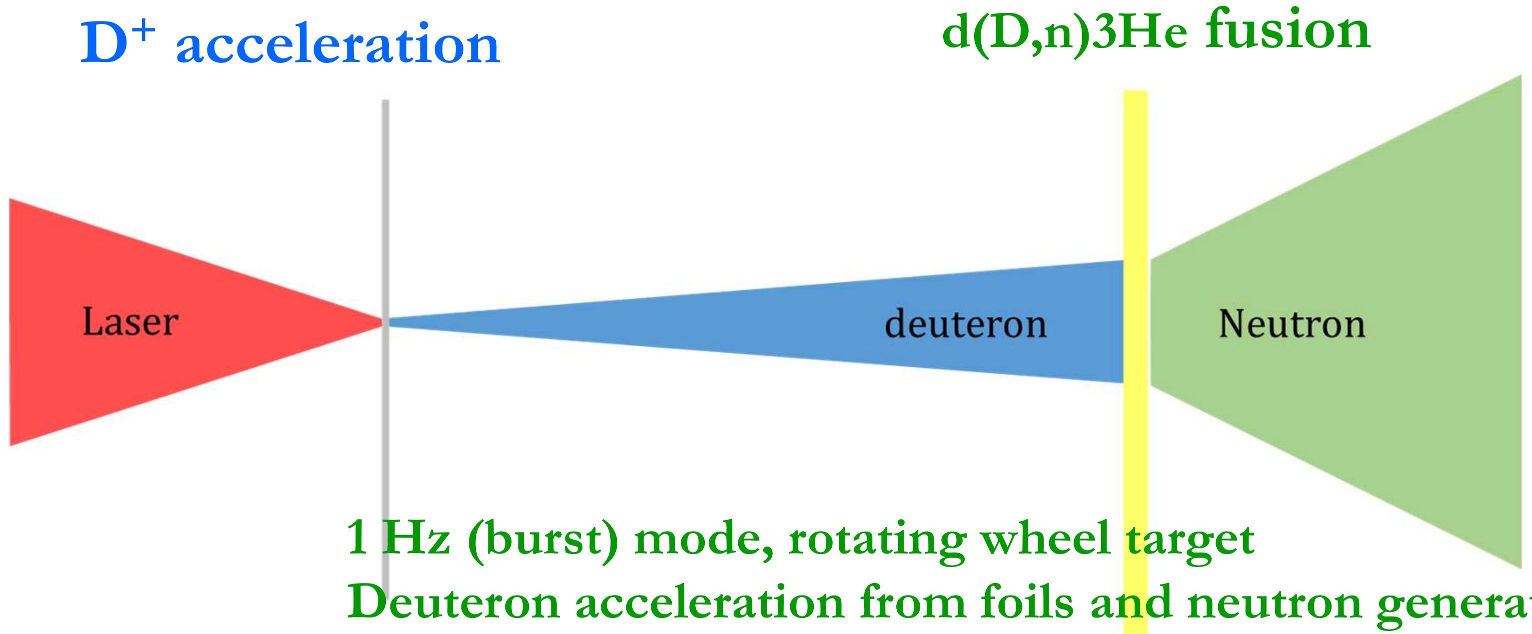

1 Hz (burst) mode, rotating wheel target
Deuteron acceleration from foils and neutron generation

Osvay et al., *EPJ Plus* ***139*** *(2024) 574*

Single shot, few-cycle, single cycle pulses
Study of ion acceleration on ultrathin foils

Singh et al., Sci. Rep. **12** (2022) 8100
Varmazyar et al., Rev.Sci.Instr. **93** (2022) 073301
Ter-Avetisyan et al., PPCF **65** (2023) 085012
Toth et al., Opt. Lett. **48** (2023) 57
Hadjikyriacou et al., in prep.

10 Hz continous mode ultrathin liquid leaf target system
Deuteron acceleration from liquid leaf and neutron generation

Lecz, Varmazyar et al, in prep.
Füle et al, *HPLSE* ***12*** *(2024) e37*
Osvay et al, in prep.

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Ion Acceleration and Neutron Generation with Few-Cycle Lasers

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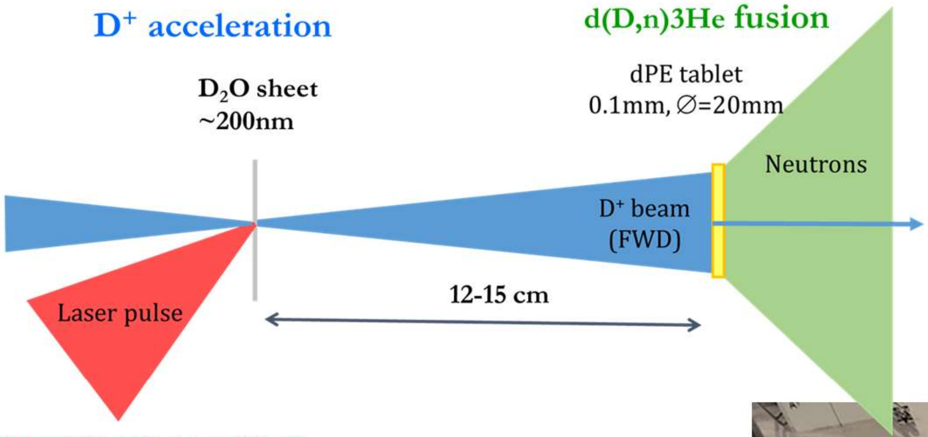
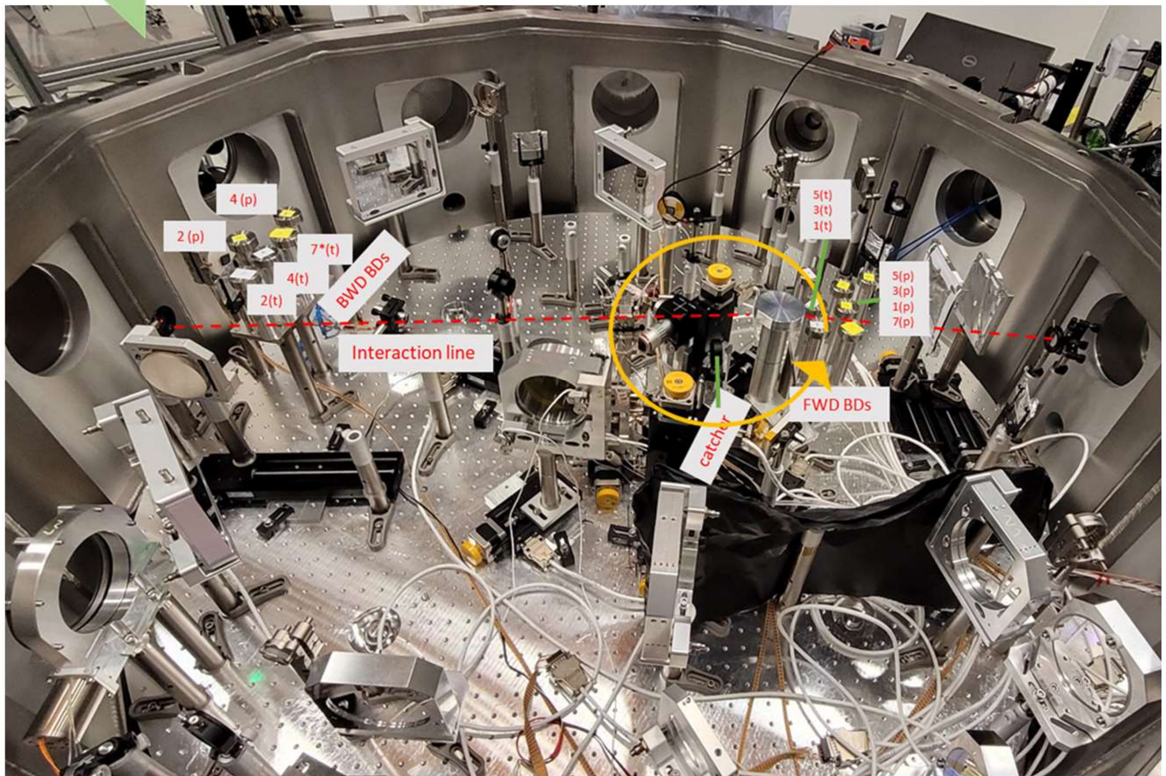


23mJ (8mJ interacting)
12 fs, 10Hz



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Development of a sub-200nm liquid leaf target

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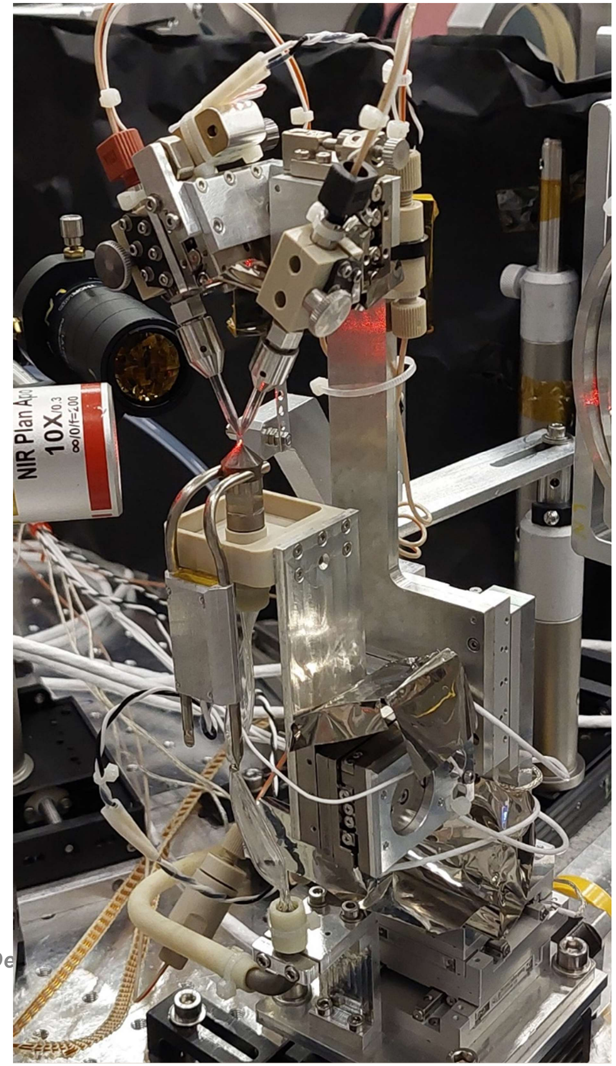
Advanced Microfluidic Systems GmbH

- Two liquid jets collide from two glass nozzles
- Pulsation damping system for *stability*
- Recirculation system for *continous operation*
- Cold finger for 10^{-4} mbar *vacuum*
- Thicknesses measured *in vacuum* (!), and used here: ***~230nm, ~440 nm***



Füle et al., *HPLSE* ***12*** *(2024) e37*

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Ion acceleration at 10 Hz repetition rate from D_2O liquid target

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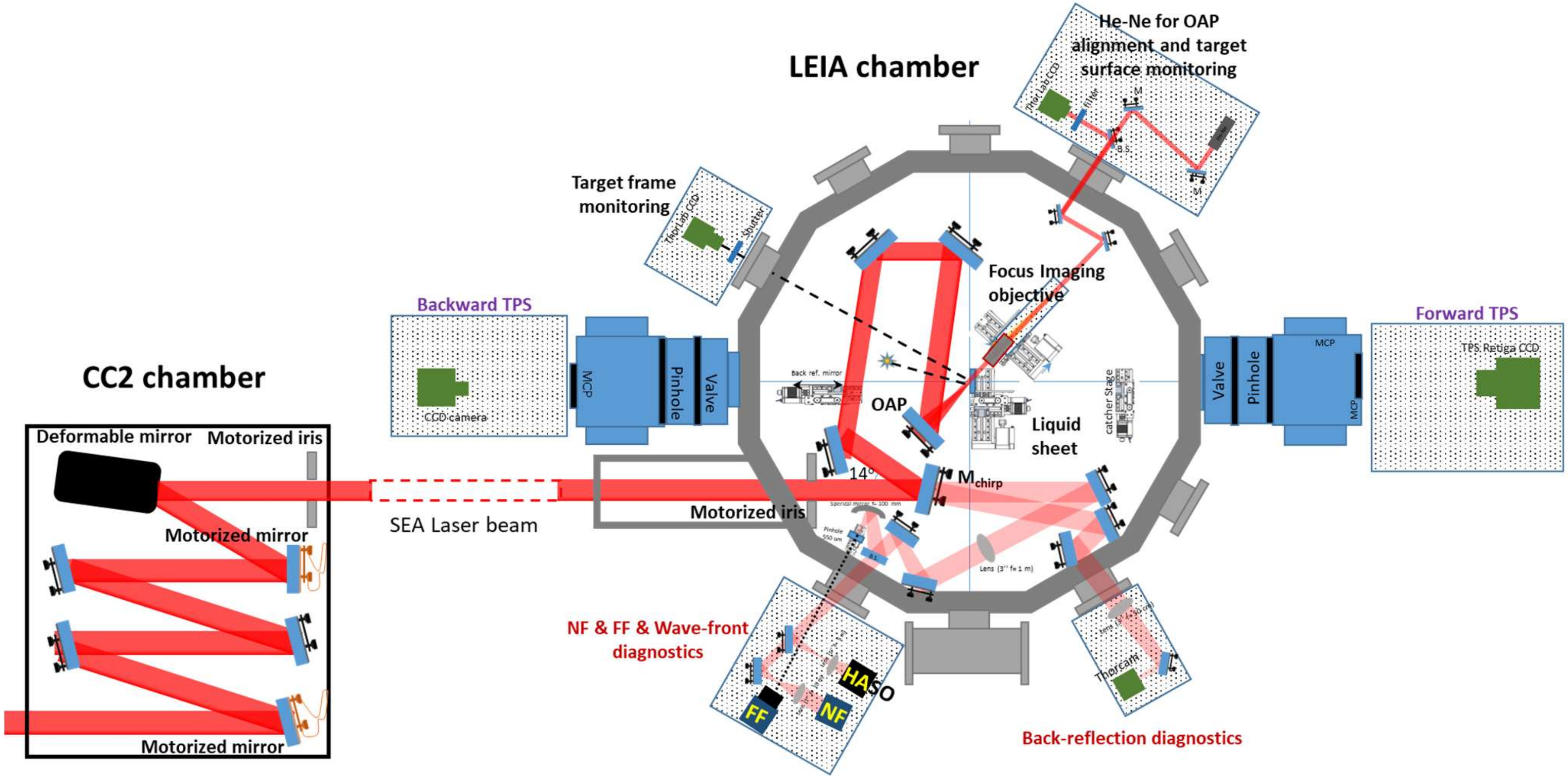

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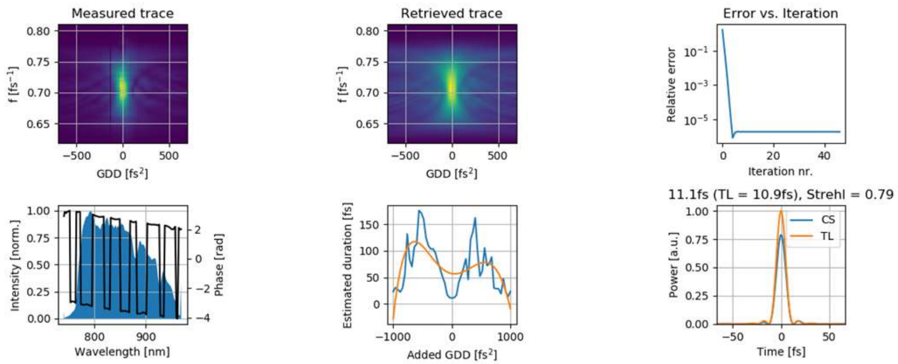
LASER

SEA laser (10Hz, OPCPA) of ELI-ALPS parameters *on target*

Pulse energy: *~23 mJ*
(measured for each shot)

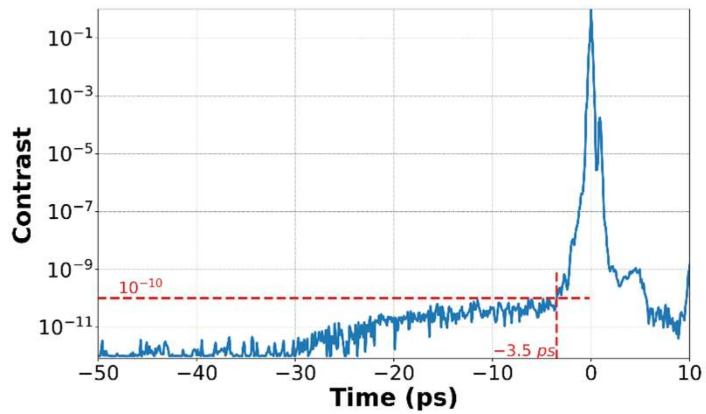
Laser pulse duration: *12.3 fs*
Measured in vacuum, after OAP,
with disp scan



Focal spot FWHM: 3.2×3.8 μm^2

Peak intensity in focus:
4×10^{18} W/cm^2 (a_0~1)

Temporal contrast

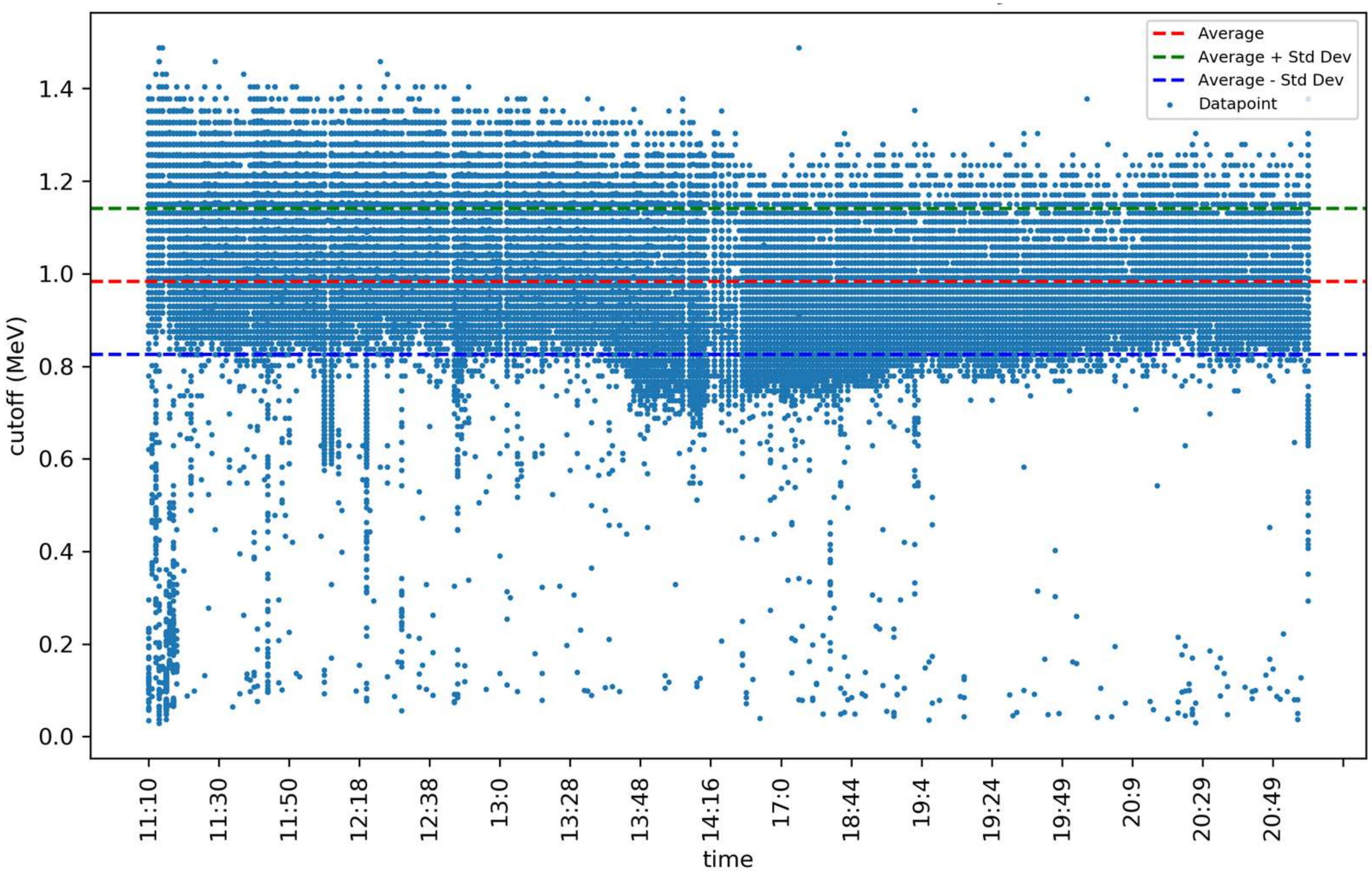


*Toth, et al., Photonics **2**, 045003 (2020)*

Deuterion acceleration at 10 Hz repetition rate

One of the four days – stability studies

cut-off morning: 1.06±0.12 (MeV) **cut-off afternoon: 0.95±0.087 (MeV)**



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DIAGNOSTICS – neutron

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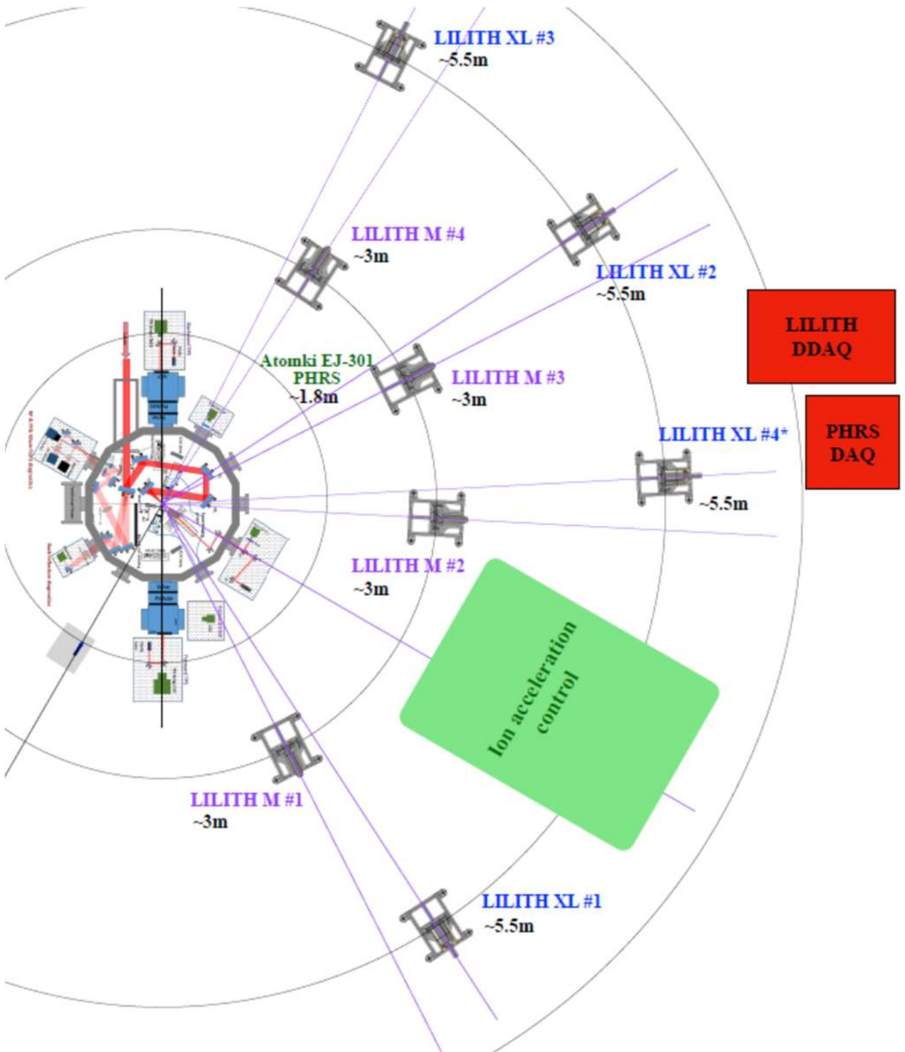
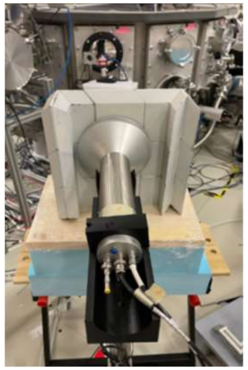


Three independent systems

Outside the chamber

Plastic scintillators: LILITH M, XL systems

Liquid scintillator: PHRS system



Inside the chamber

Bubble Neutron Detector Spectrometer

Osvay et al., *EPJ Plus* ***139*** *(2024) 574*

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Neutron measurements
LILITH system, neutron spectra

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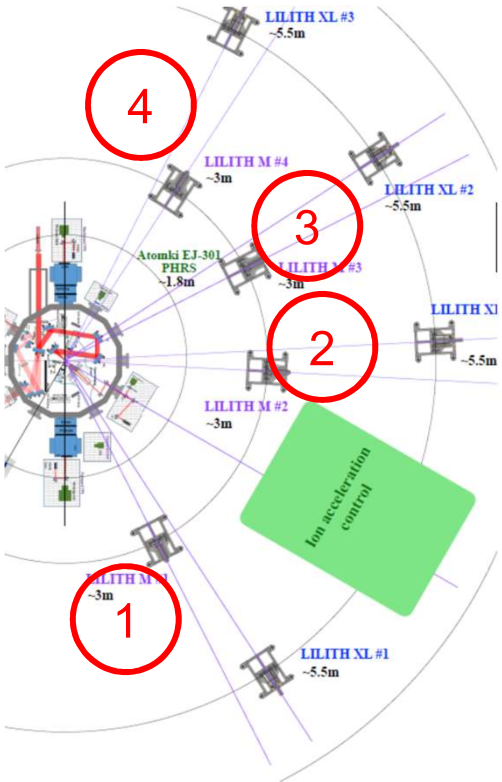
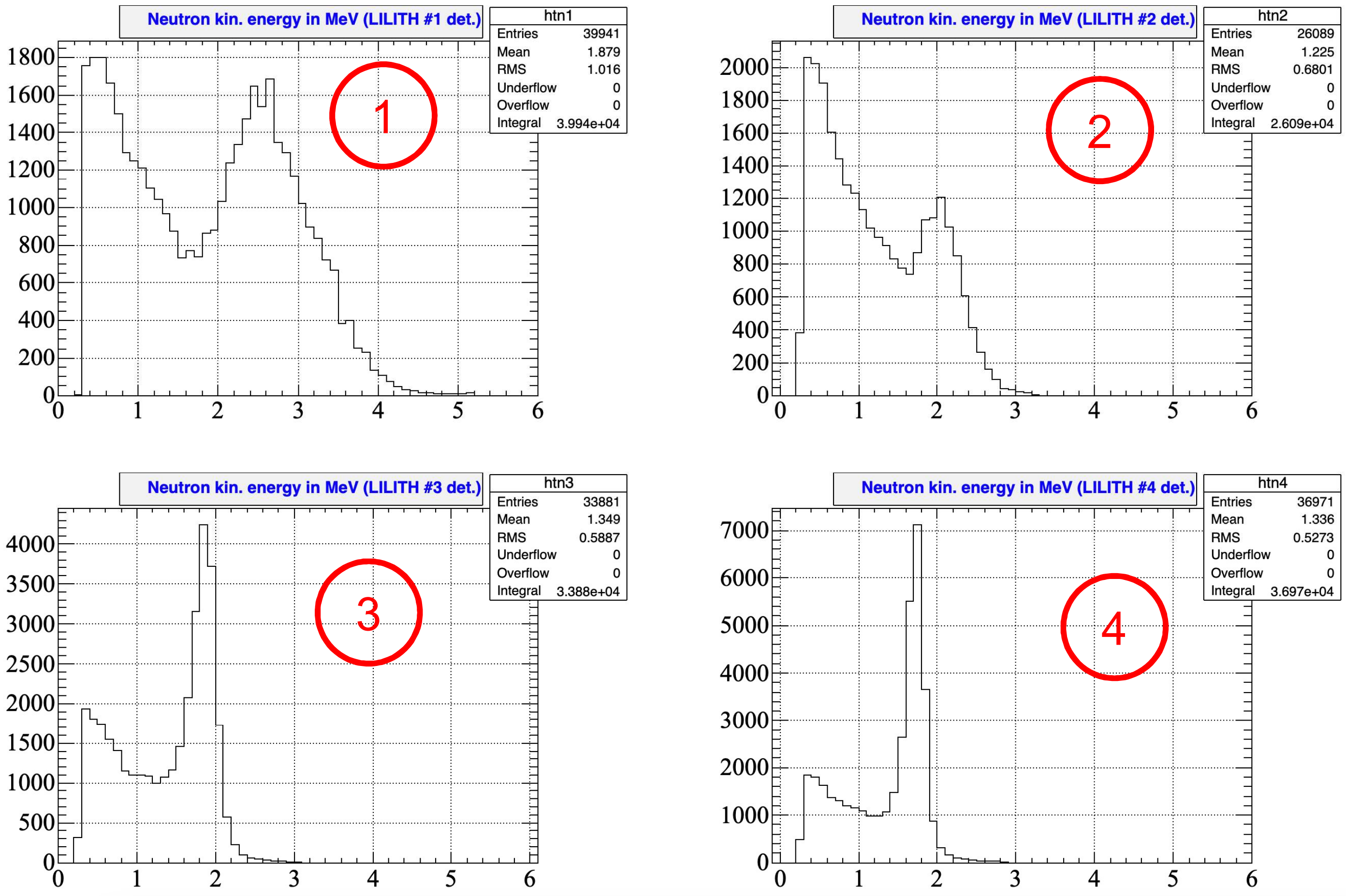
MTA atomki DEBRECEN





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Neutron measurements
LILITH system, neutron events / 600 shots

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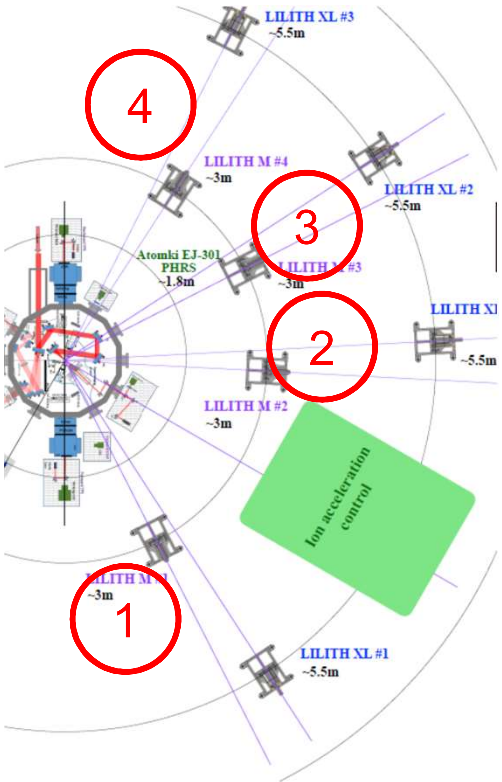

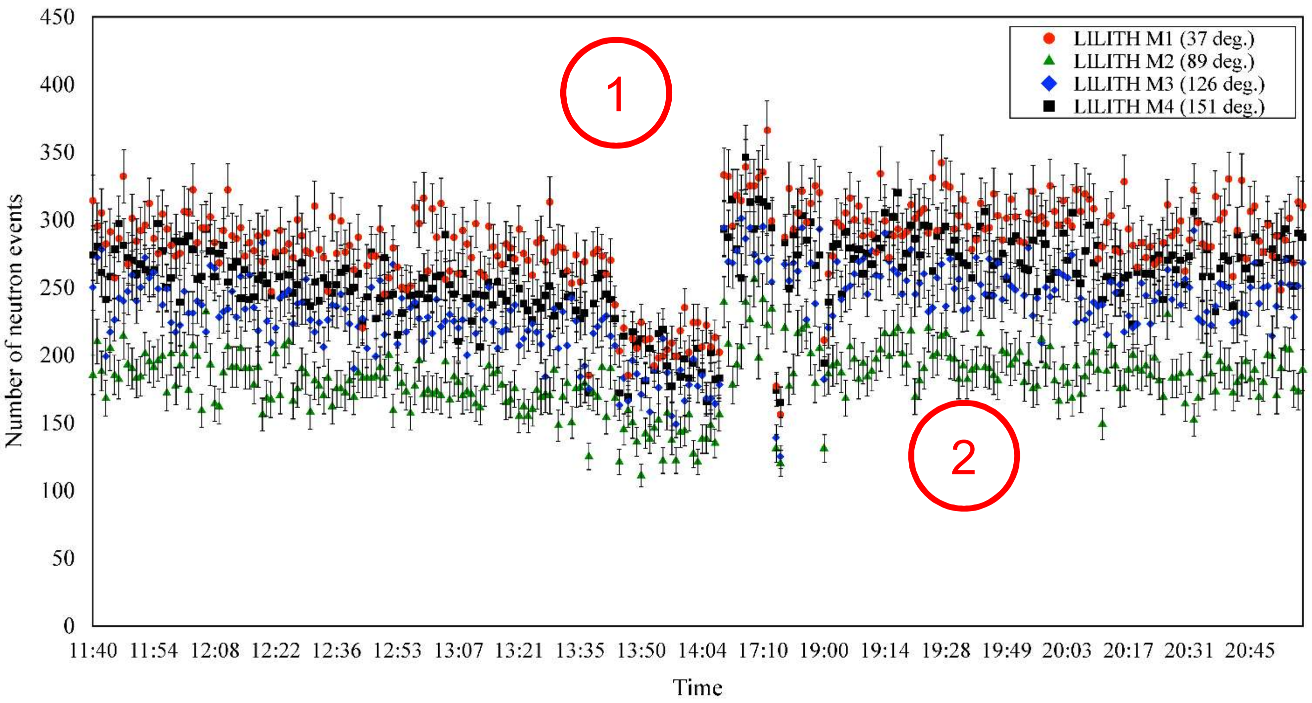

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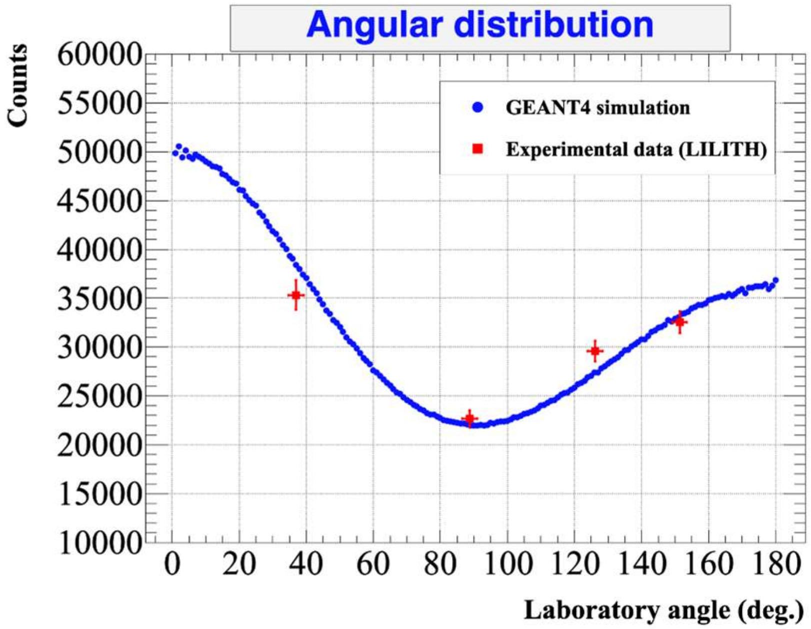
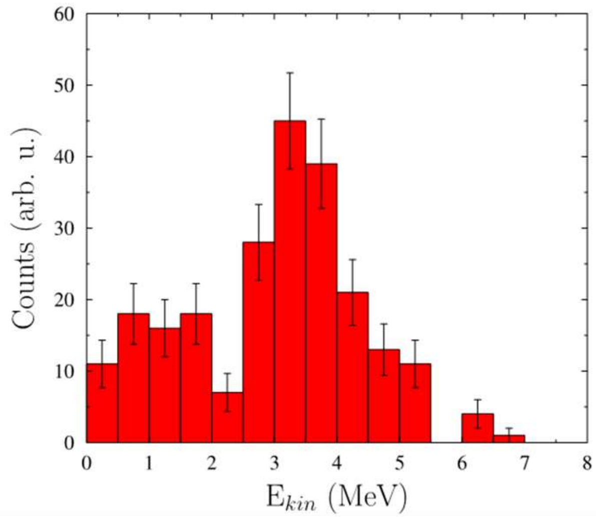
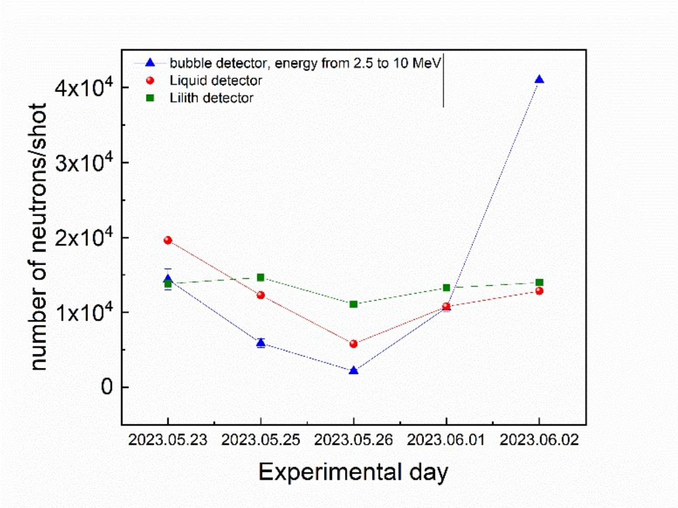
Neutron yield

LILITH, vs angle



FWD Neutron spectrum



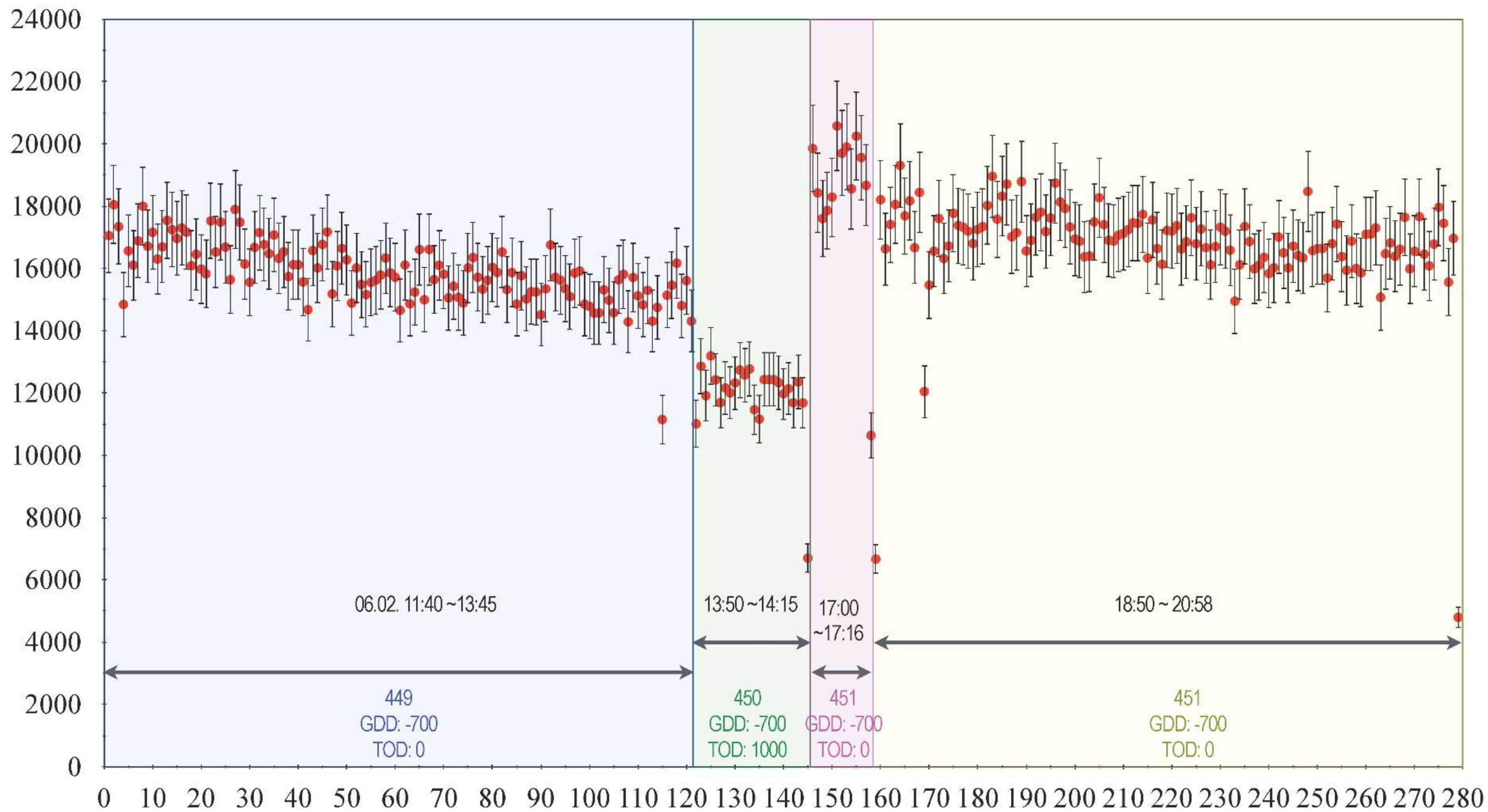


Laser energy on the target: 23mJ
Laser energy within FWHM focal spot: 8mJ

~1.5×10^5 n/s

Towards the optimisation of neutron yield with the change of dispersion of the driver pulse

Error of neutron events: **1%**
Error of neutron number statistics over 600 shots: **5%**



LASER

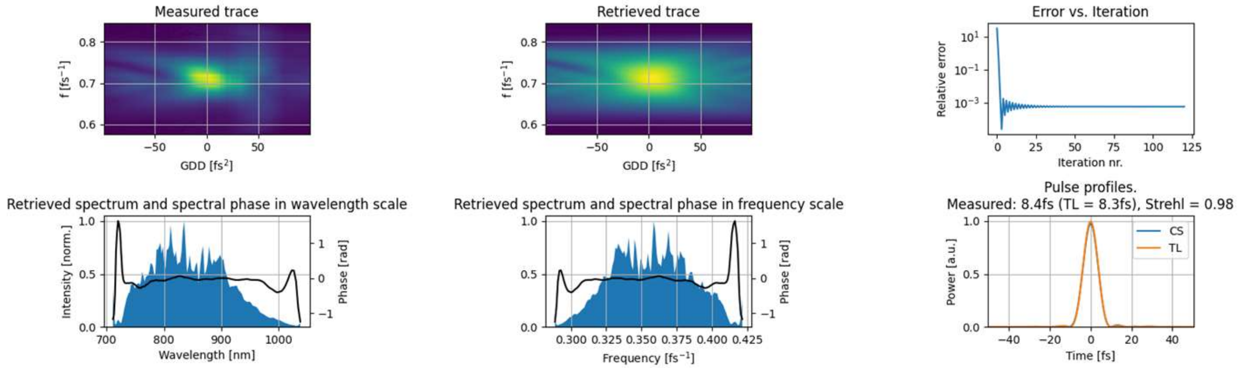
S3 laser (1 kHz, OPCPA) of ELI-ALPS parameters *on target*

Pulse energy: ~90 *mJ*

(average measurement of 10k shot)

Laser pulse duration: *8.4 fs*

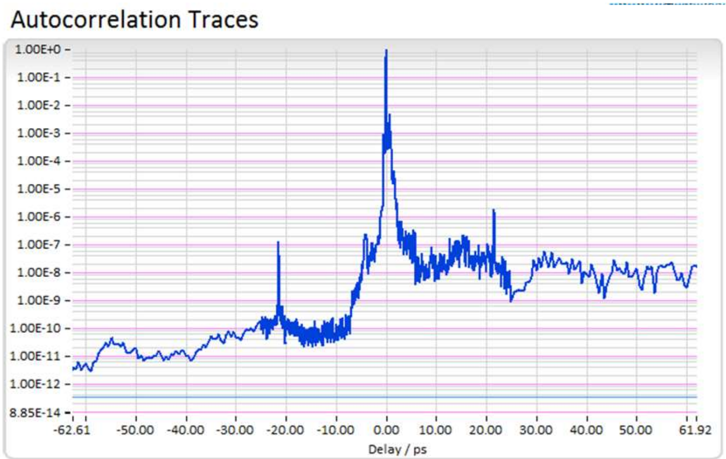
(measured in vacuum, after OAP, with disp scan)



Central wavelength: 826nm

Focal spot FWHM: 2.9×2.6 μm^2

Peak intensity in focus: 1×10^{19} W/cm^2 (a_0~2.2)



Temporal contrast

**peak at +-22ps is estimated to be post-pulse from the variable density filter in the diagnostics arm, not in the main output*

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State of the art neutron generation at 10 Hz repetition rate (~6 hours)

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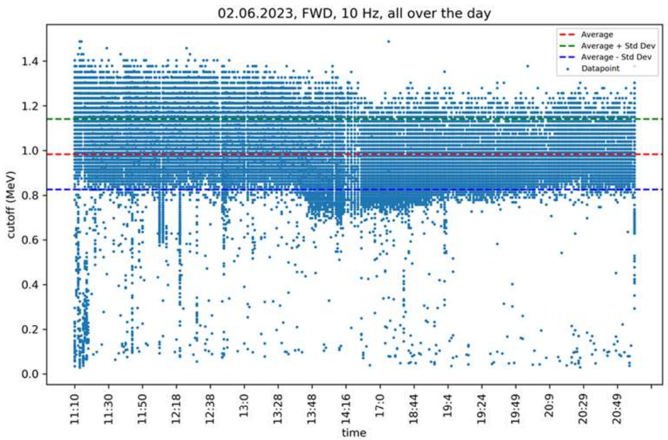
cut-off for the day: 0.98±0.16 (MeV)

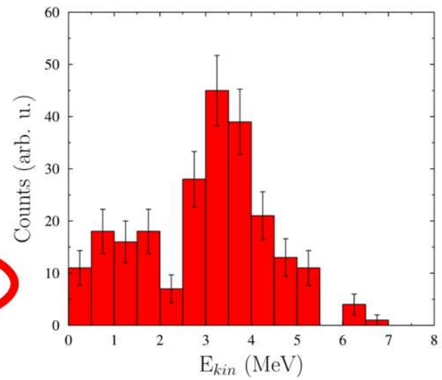


Deuteron acceleration from liquid

- at 10 Hz, SEA laser
- at *230mW (80mW)* average power
- 200nm D_2O leaf + 0.1mm C_2D_4

Neutron generation

- 200nm D_2O leaf + 0.1mm C_2D_4
- fusion neutron spectra peaks ~3 MeV



~1.5×10^5 n/s, rms 5%

Peak yield detected 2023/24 at 1kHz : **~10^8 n/s**

- at *100W (?20W?)* average power

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Laser-based neutron sources for applications

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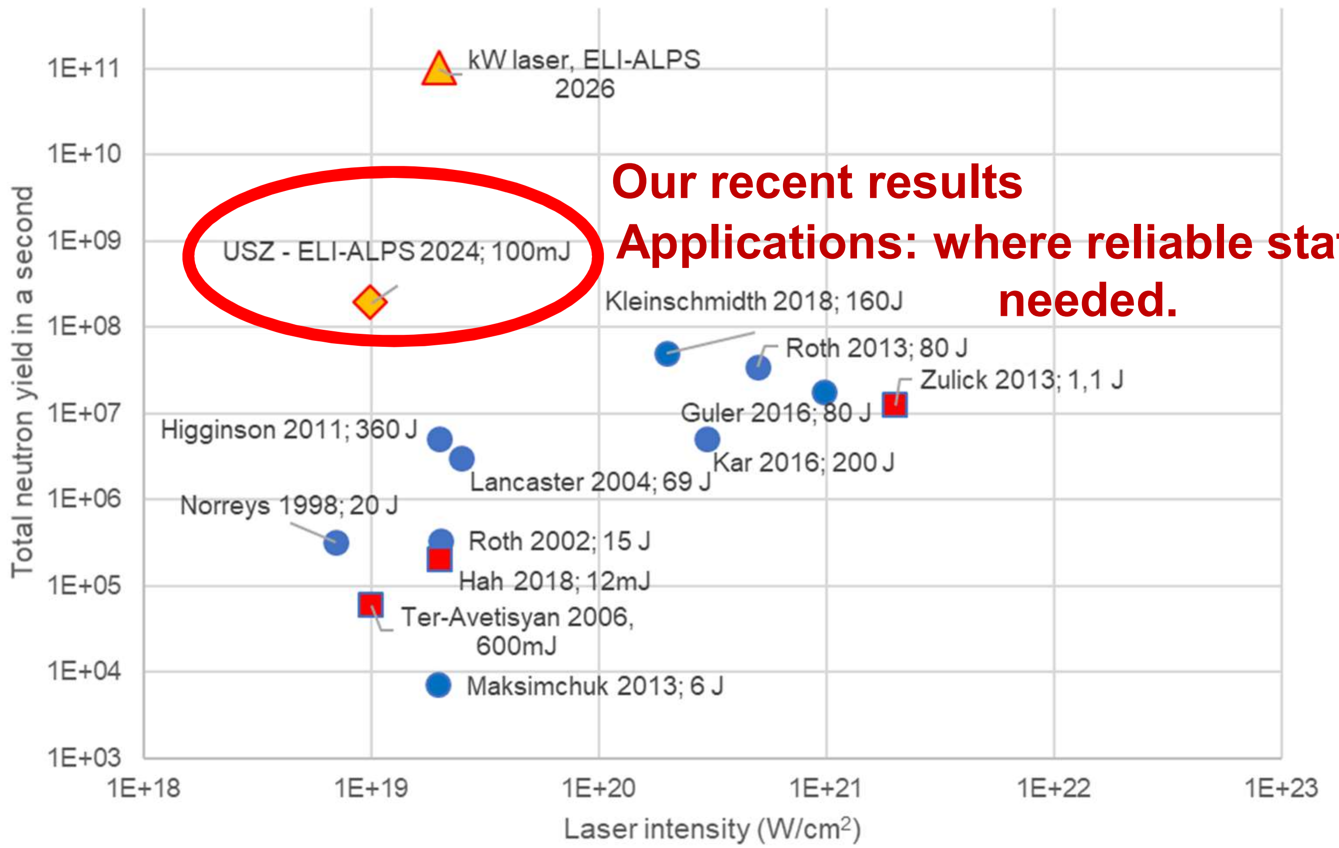

Our recent results

Applications: where reliable statistics are needed.

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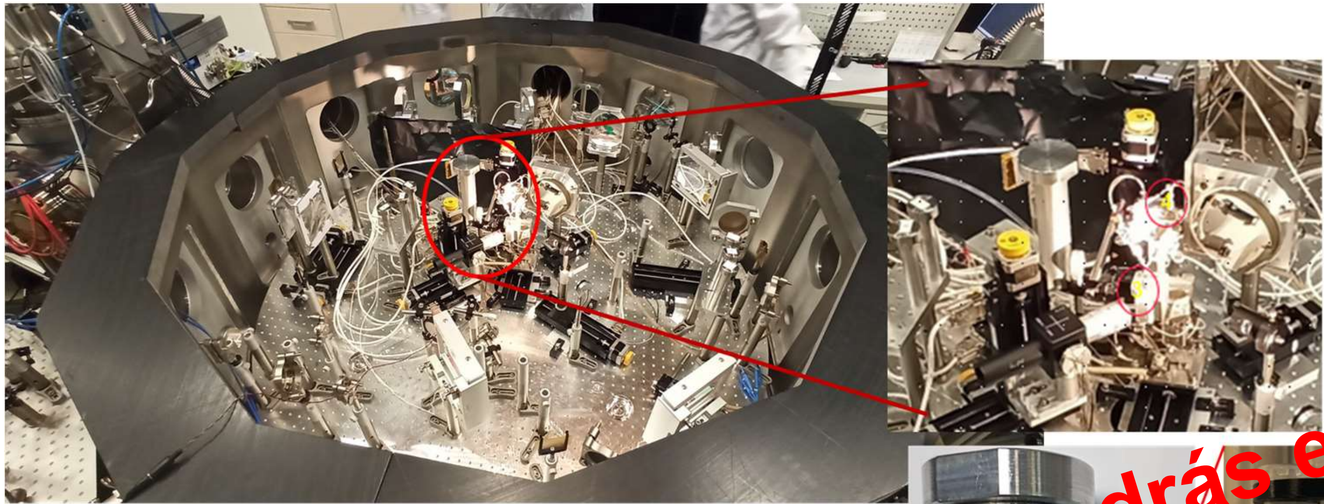
FLASH – with neutrons

First radiobiology experiment with laser-generated neutrons



Experimental chamber…

Lásd még: Fenyvesi András előadása

…. Zebrafish embryos in a vacuum tight container

Osvay et al., *EPJ Plus* ***139*** *(2024) 574*

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Thank you for your attention

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