National Laser-Initiated Transmutation Laboratory
University of Szeged

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A high repetition rate, stable source of neutrons generated by few-cycle lasers

Károly Osvay

AAC’24

Naperville, IL
25th July, 2024

National Laser-Initiated Transmutation Laboratory
University of Szeged

NLTL

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eli attosecond

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Z. Korkulu, I. Kuti, **L. Stuhl**

MTA atomki DEBRECEN

S. Figul, G. Marowski

Advanced Microfluidic Systems GmbH

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tae TECHNOLOGIES

- Hungarian Government: ITM 1096/2019. (III.8.)
- National Research, Development and Innovation Office
  NKFIH-877-2/2020, NKFIH-476-4/2021, NKFIH-476-16/2021
- Multiscan 3D H2020 project: 101020100

Innovációs és Technológiai Minisztérium – ITM – Feladatunk a jövő

Outline

Motivation

Laser-based neutron sources

Neutron generation at 10 Hz

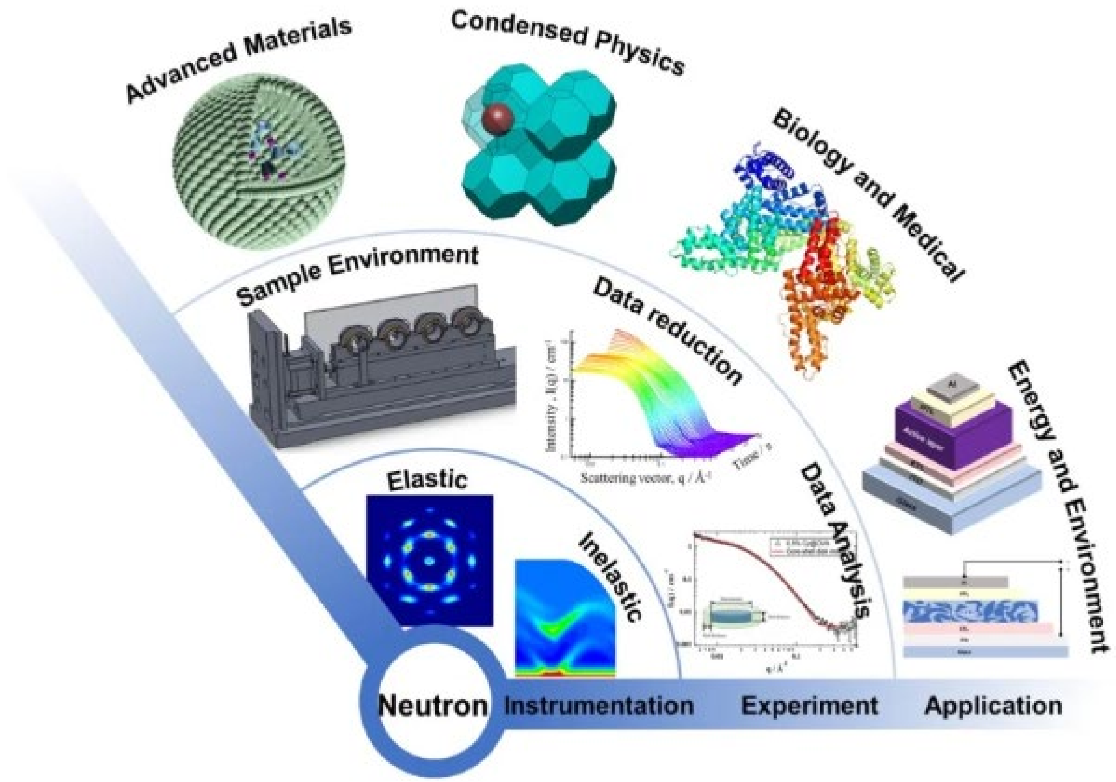
Neutron generation at 1kHz – PRELIMINARY!

Application for …

A room for laser-based neutron sources

Demand for neutron sources is rapidly increasing

– by academy, industry, and health care



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.

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

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

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NLTL approach

Use T(P)W lasers from single shot mode

Contrast issues

Start from ”ideal”, ”Dirac”-pulse

Investigate interactions and optimise yields

Increase laser repetition rate

Target development

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

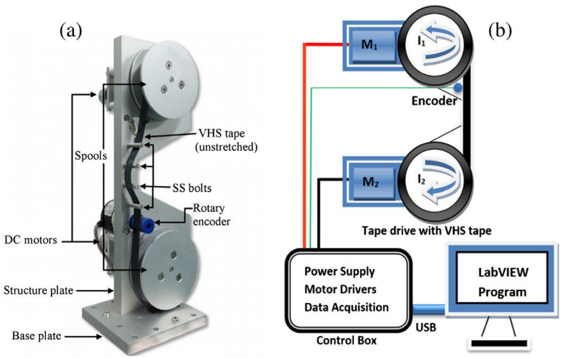
Laser-fusion
(single shot events)

Tokamak
(”continous” operation)

Common challange
High Repetition Rate Targets

Most promising directions so far

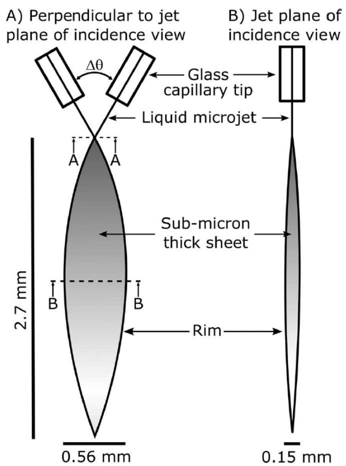
Tape target



PRAB 20, 041301 (2017)

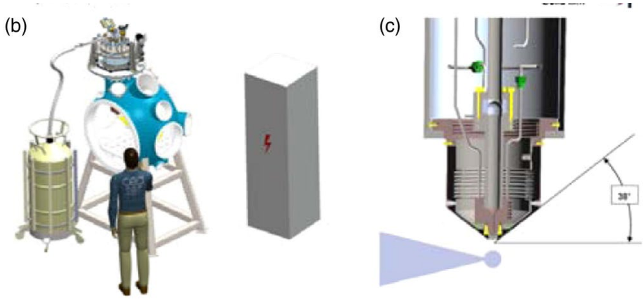
See also C. Palmer's and L. Obst-Hübl's plenaries on Tuesday

Liquid jet



HPLSE 7, e50 (2019)

Cryo H (D) ribbon



PHYS. REV. X 6, 041030 (2016)

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Scheme of the interactions

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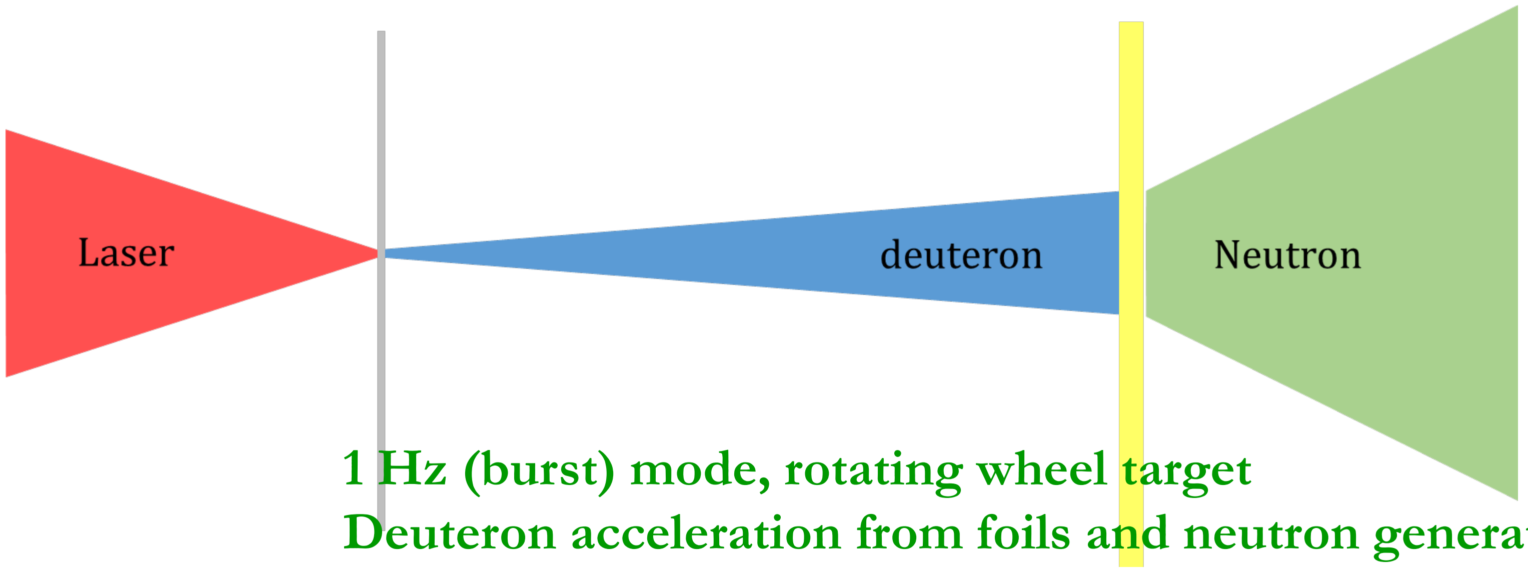
D^+ acceleration

d(D,n)3He fusion



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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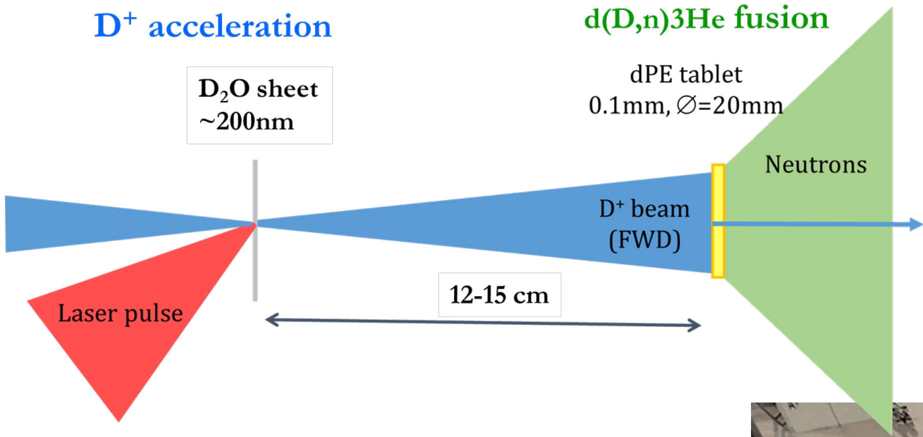
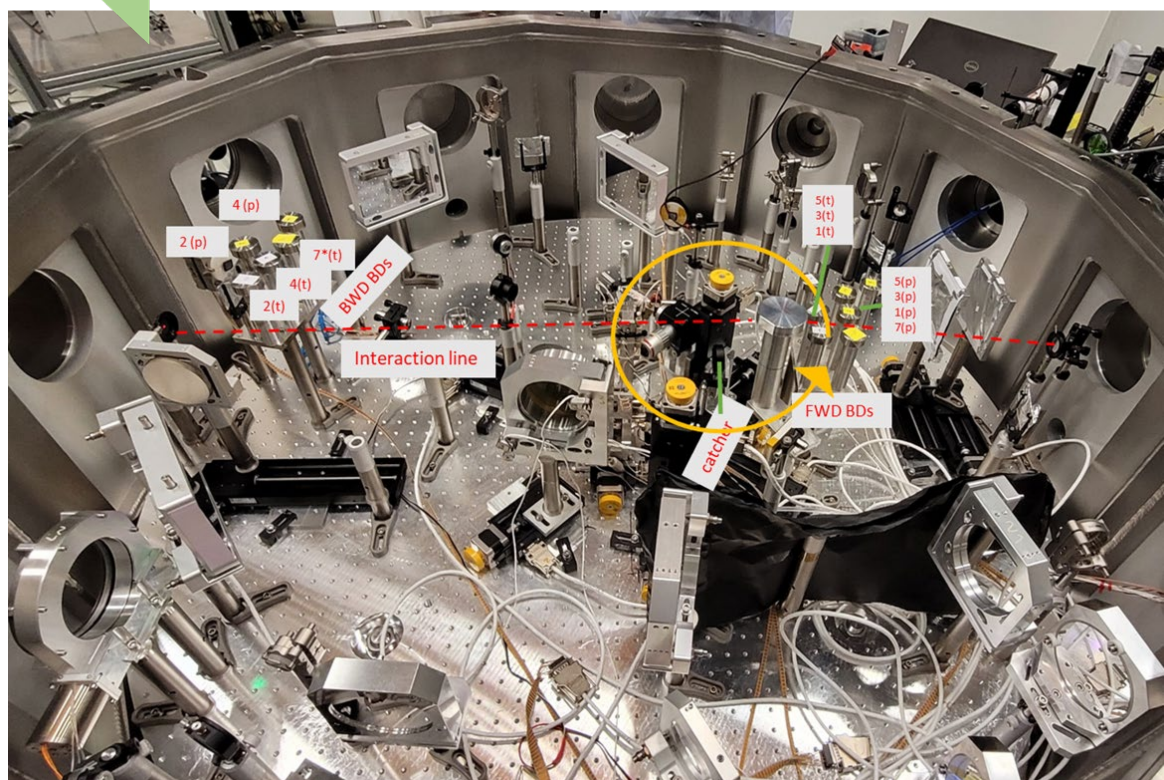


23mJ (8mJ interacting)
12 fs, 10Hz



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Development of a sub-200nm liquid leaf target

- 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***

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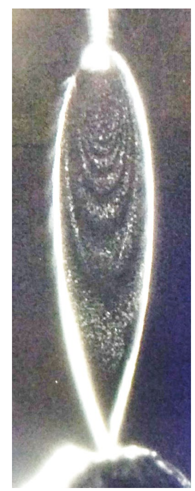
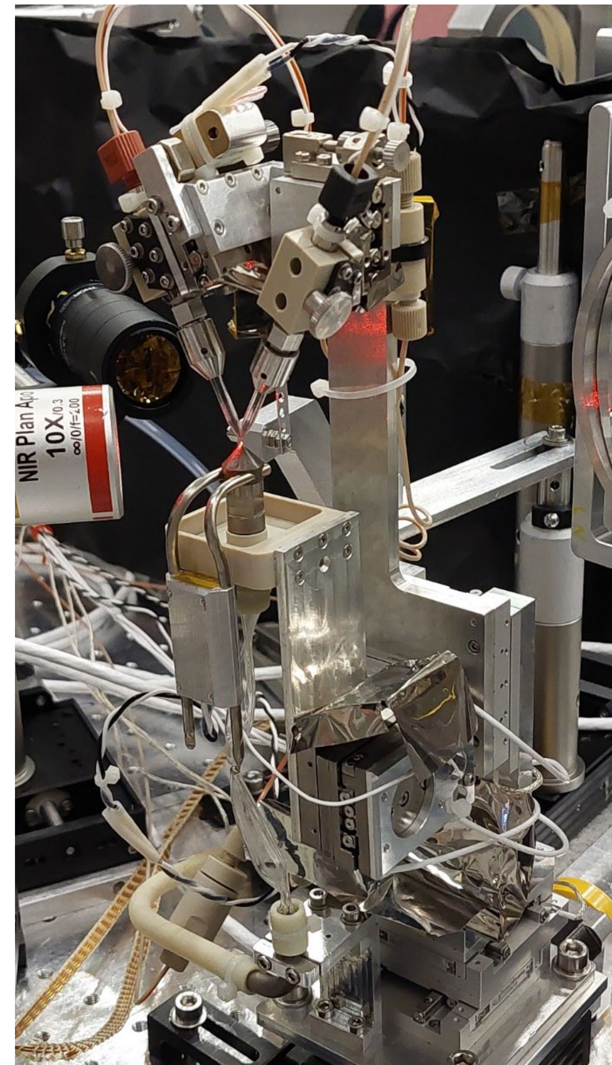
Advanced Microfluidic Systems GmbH

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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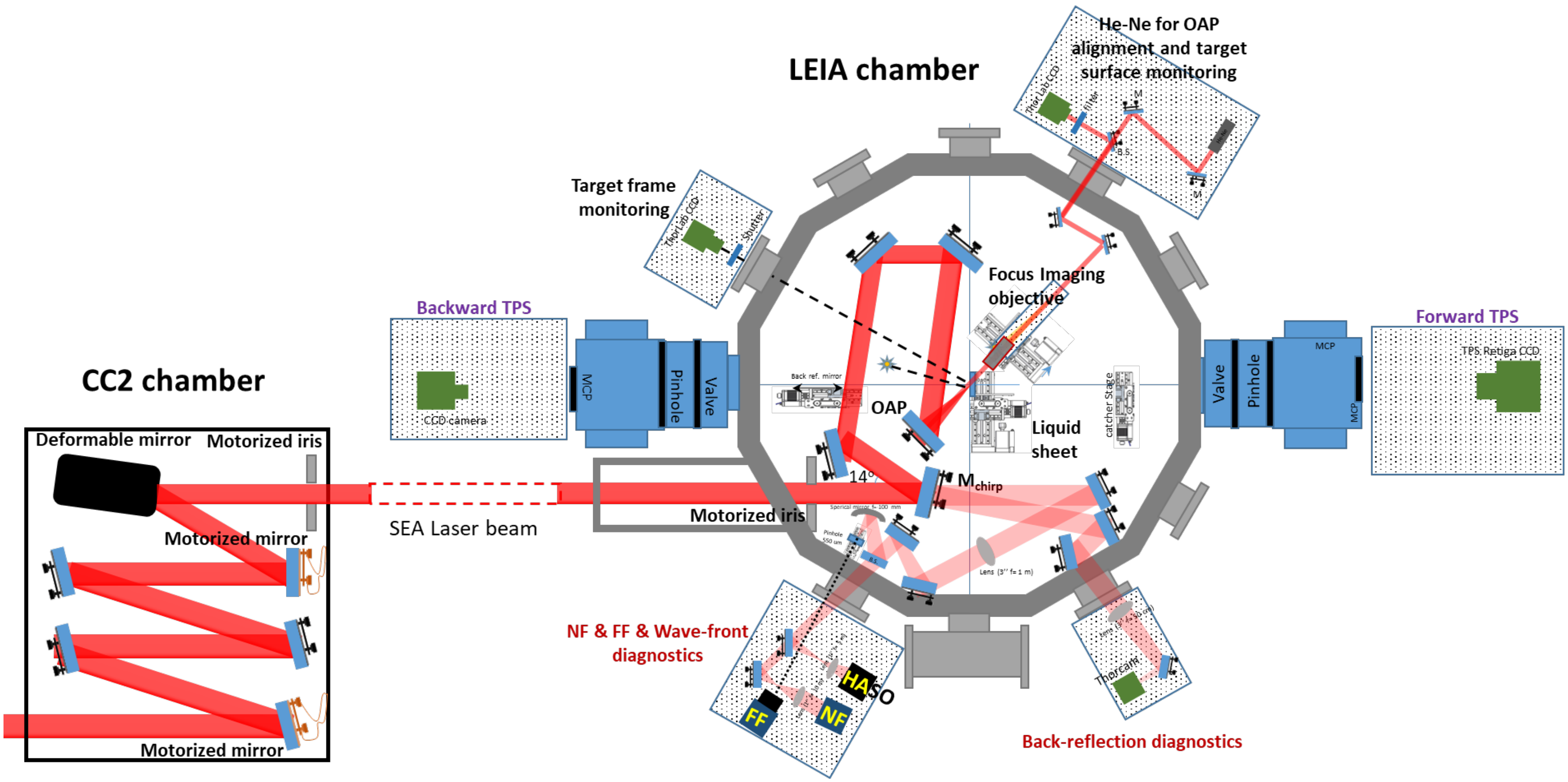

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LASER

EKSPLA

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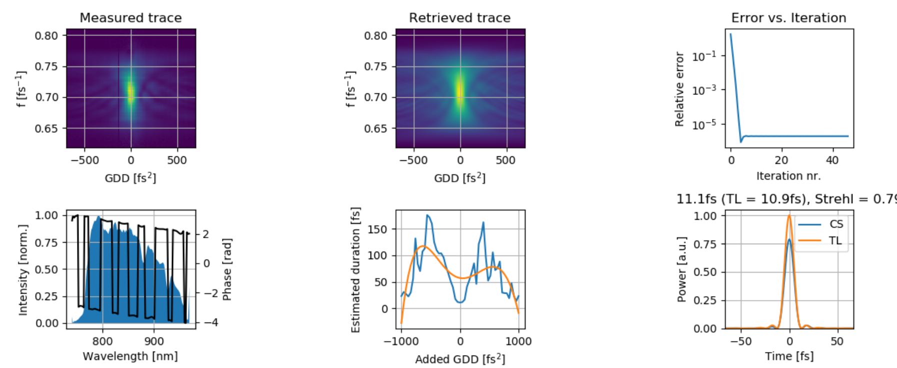
SEA laser (10Hz, OPCPA) of ELI-ALPS parameters *on target*

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

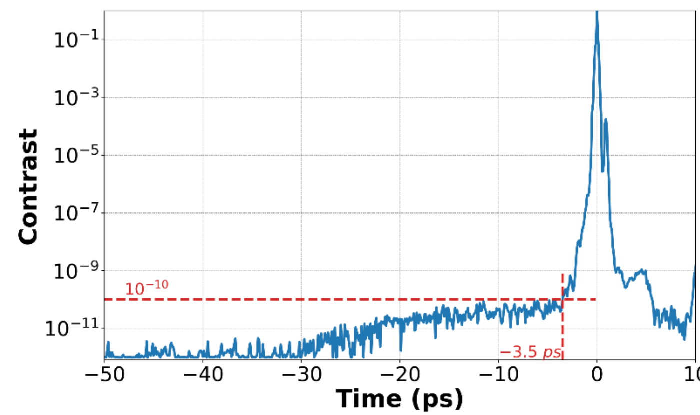
Laser pulse duration: *12.3 fs*
Measured in vacuum, after OAP, with disp scan



Focal spot FWHM: $3.2\times3.8\ \mu m^2$

Peak intensity in focus: $\mathbf{4\times10^{18}\ W/cm^2}$ ($a_0 \sim 1$)

Temporal contrast



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

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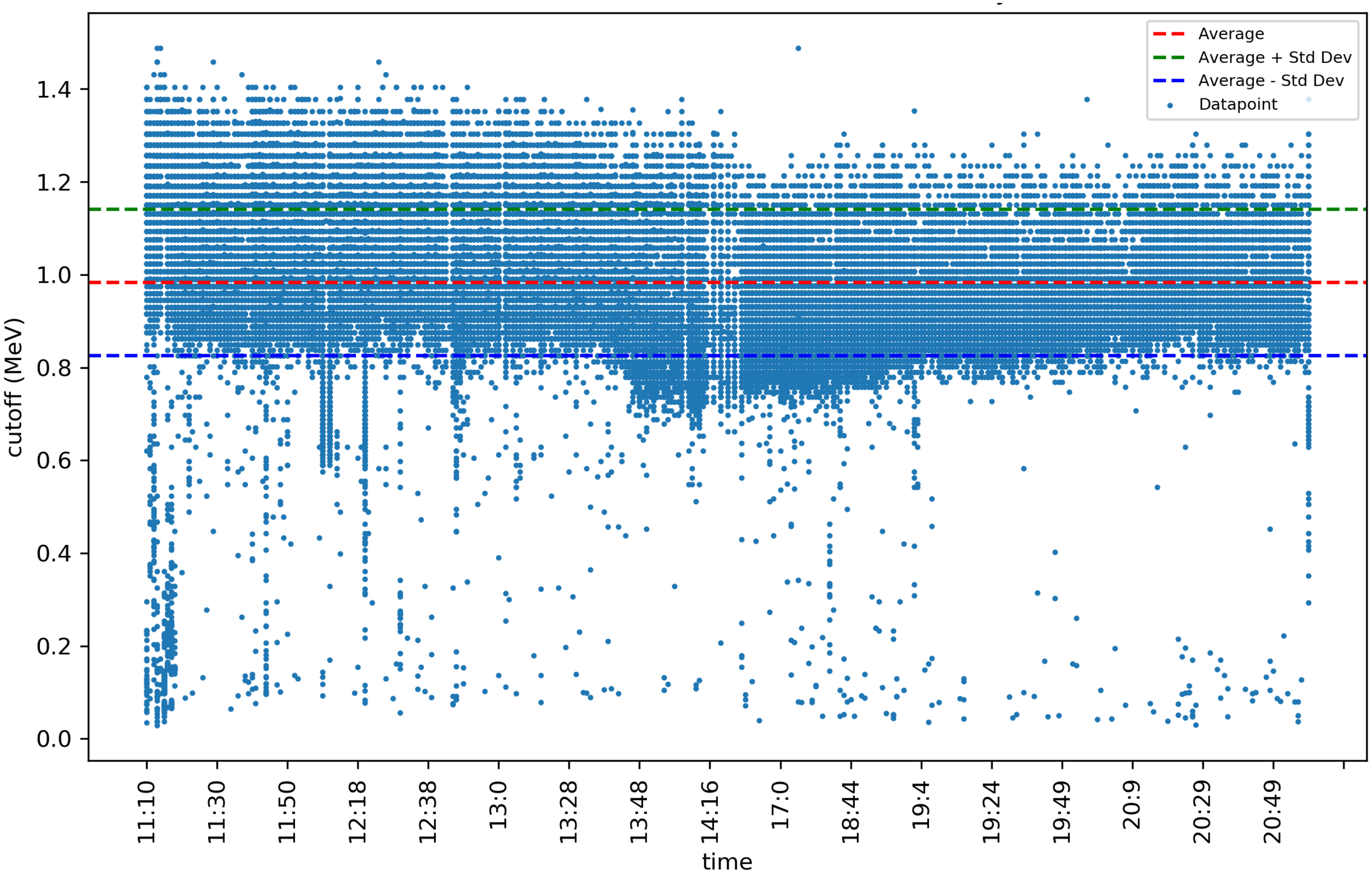
Deuterion acceleration at 10 Hz repetition rate

One of the four days – stability studies

cut-off morning: 1.06±0.12 (MeV)

cut-off afternoon: 0.95±0.087 (MeV)



DIAGNOSTICS – neutron

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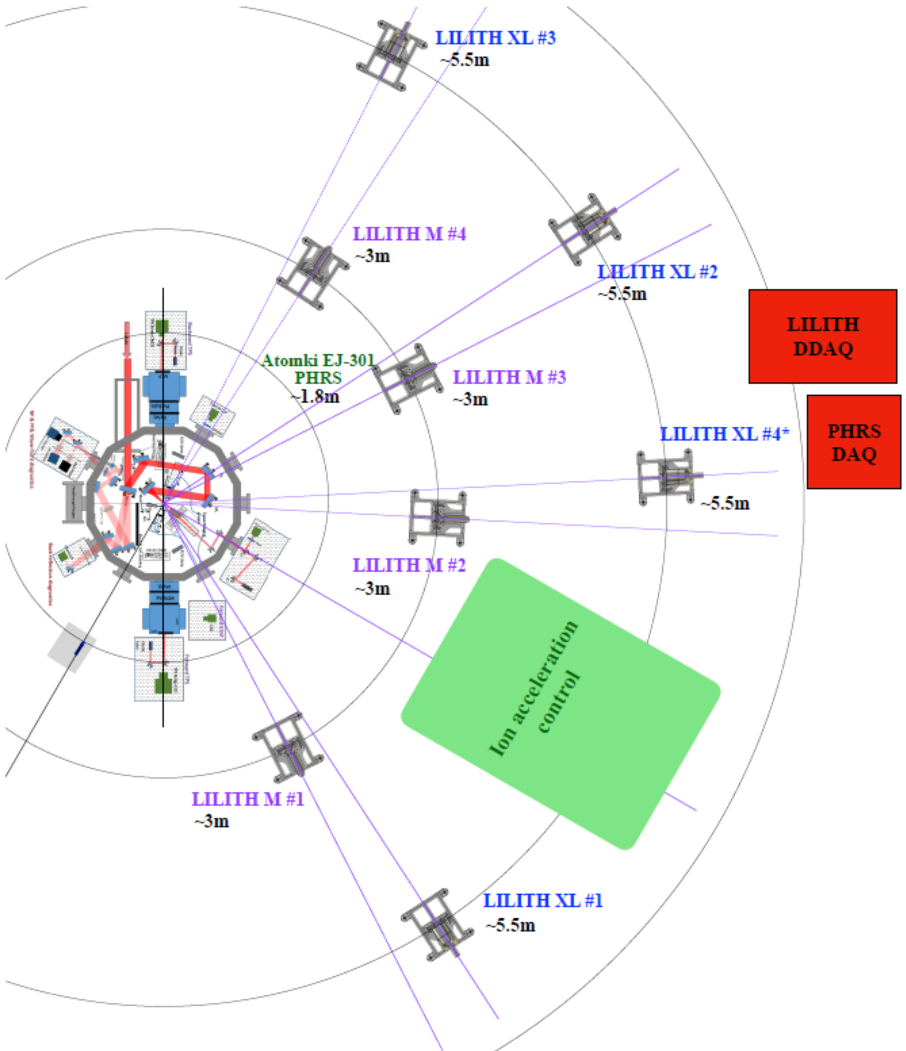
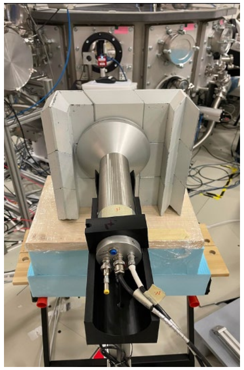


Three independent systems

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*

Neutron measurements
LILITH system, neutron spectra

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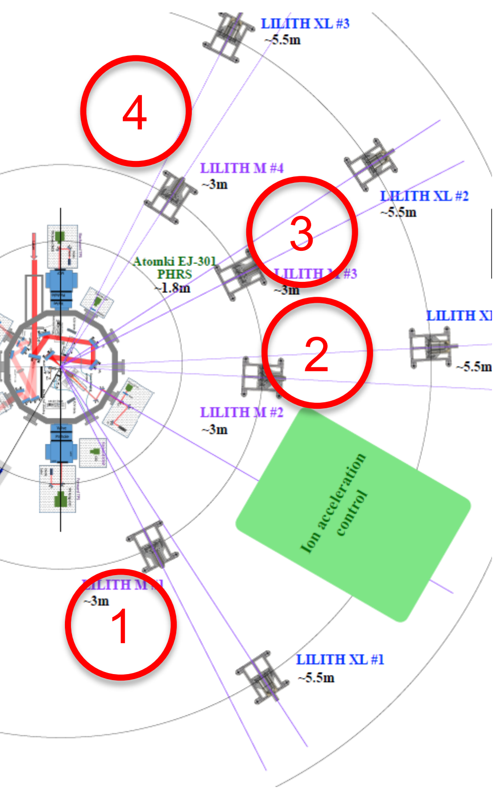
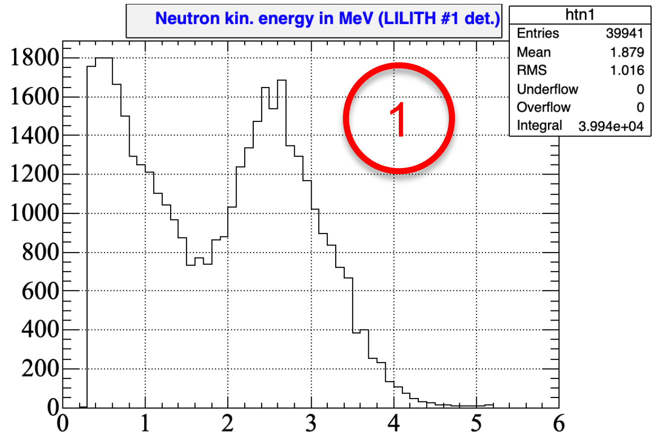
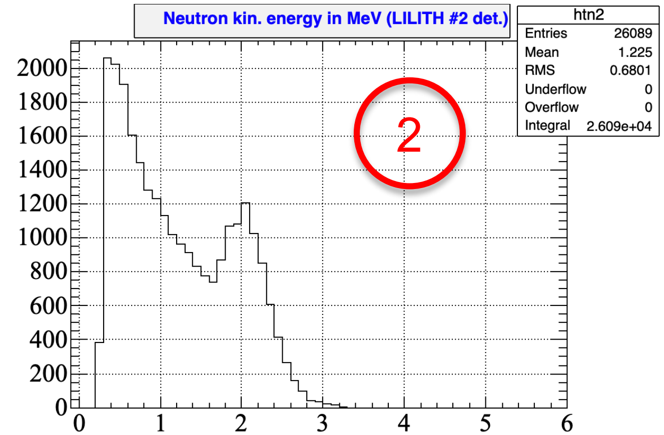
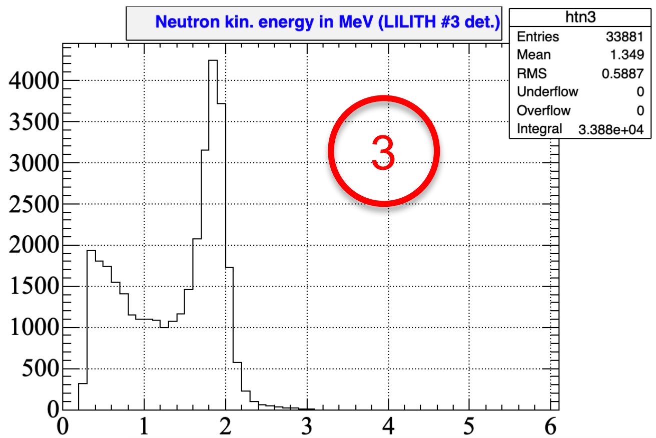
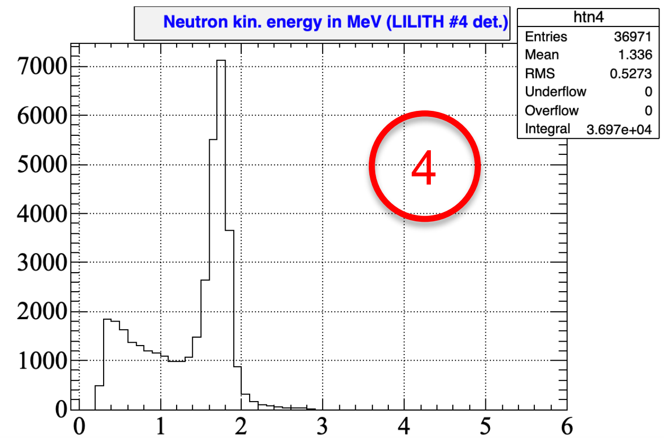
atomki MTA DEBRECEN











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Neutron measurements
LILITH system, neutron events / 600 shots

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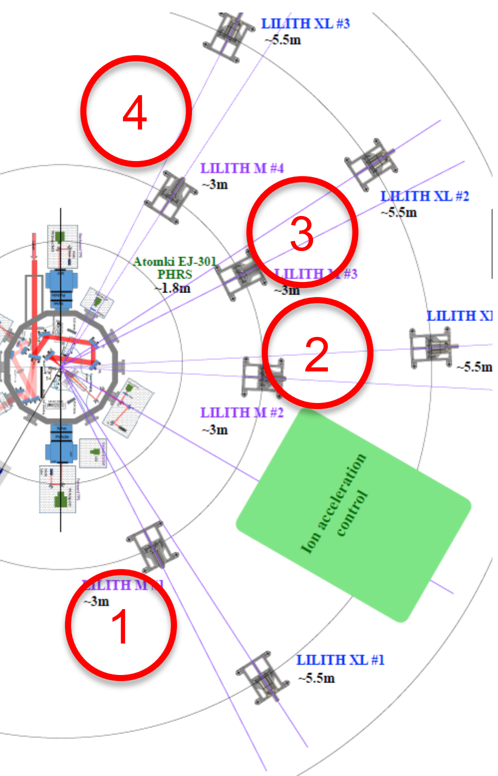

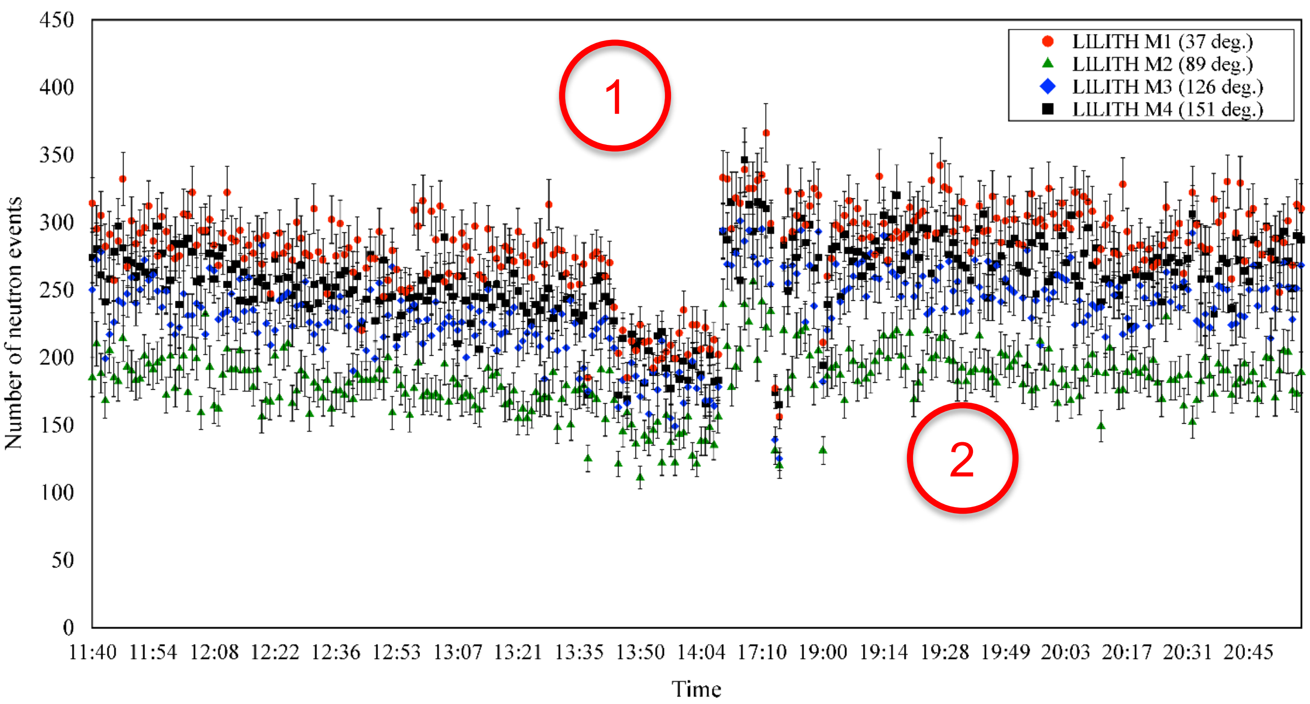

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Neutron yield

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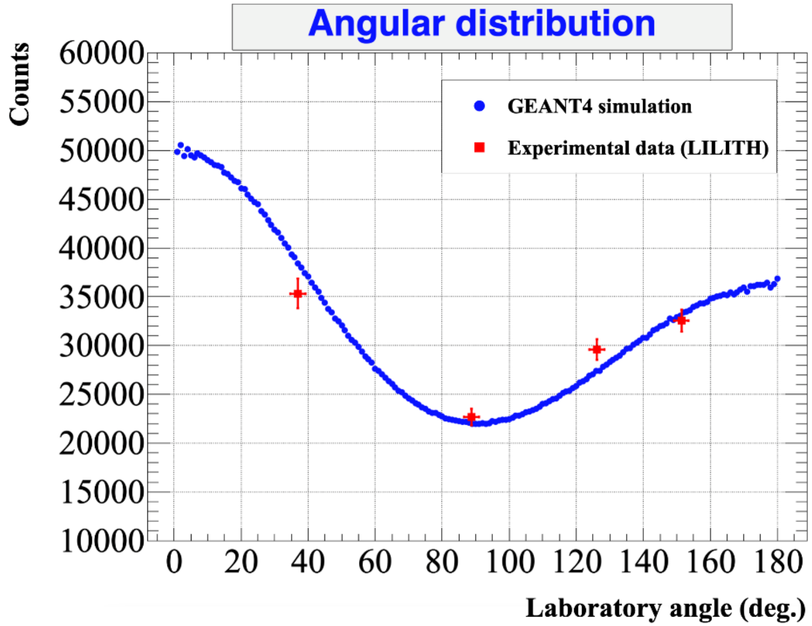
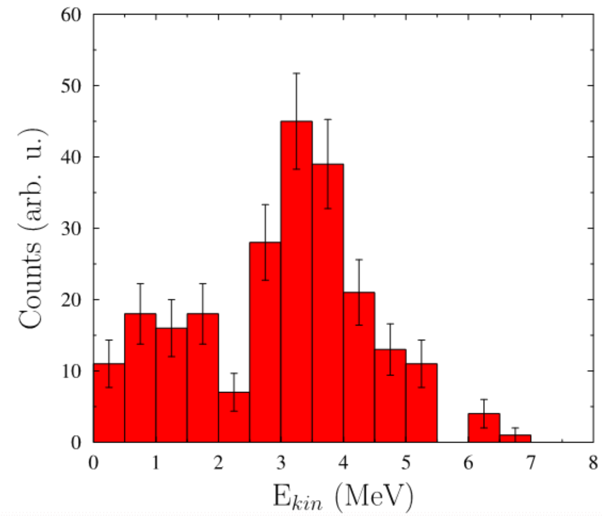
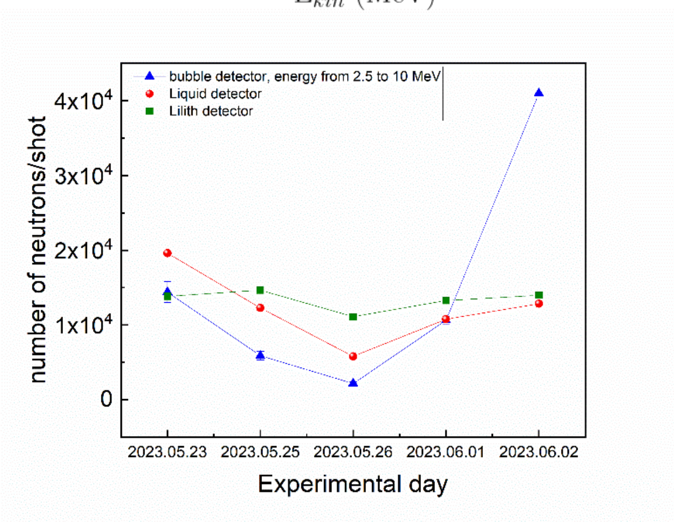
LILITH, vs angle



FWD Neutron spectrum





Laser energy on the target: 23mJ

Laser energy within FWHM focal spot: 8mJ

~1.5×10^5 n/s

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attosecond

LASER

EKSPLA

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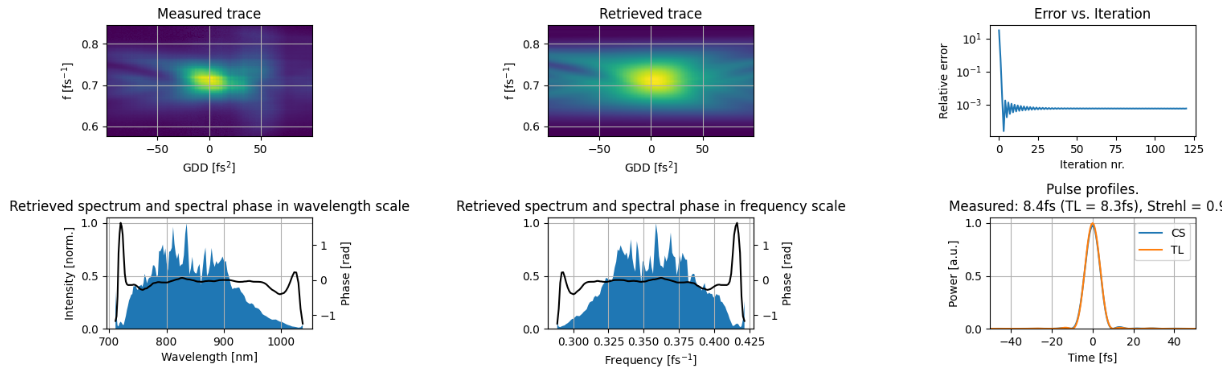
S3 laser (1 kHz, OPCPA) of ELI-ALPS parameters *on target*

Pulse energy: ~90 *mJ*
(average measurement of 10k shot)

Laser pulse duration: *8.4 fs*
(measured in vacuum, after OAP, with disp scan)

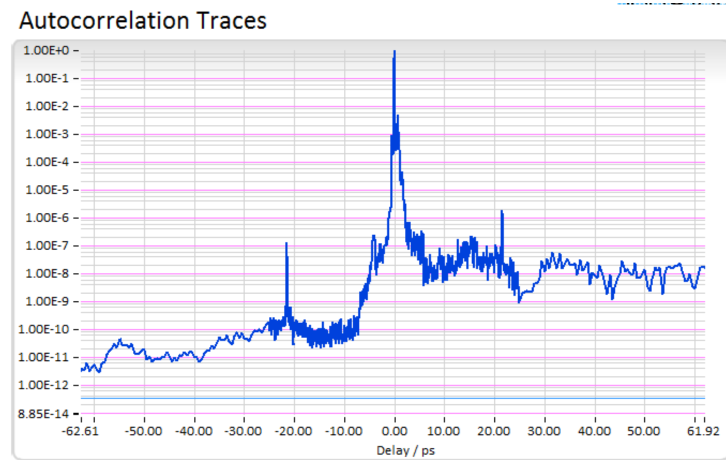


Central wavelength: 826nm

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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Deuterion acceleration at 1 kHz repetition rate
100 mJ (20mJ ”FWHM”) energy on target

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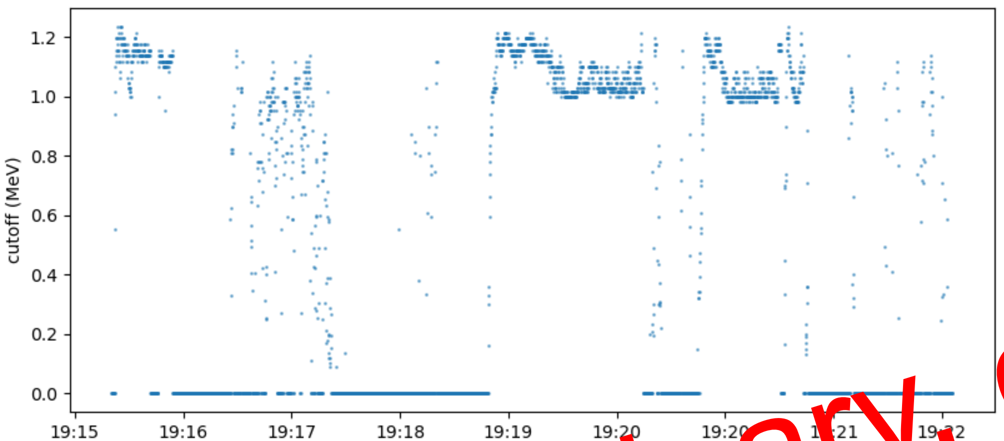
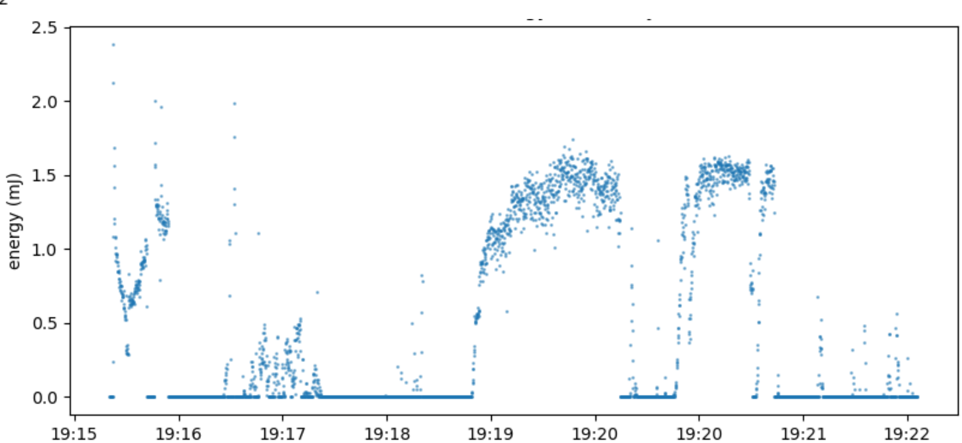
Cut-off energy of deuterons



Preliminary, confidential

Energy of deuteron pulses



- Liquid jet instabilities;
- Optimisation with contrast and focusing
- Reneweable catcher

... all to be solved in the next months

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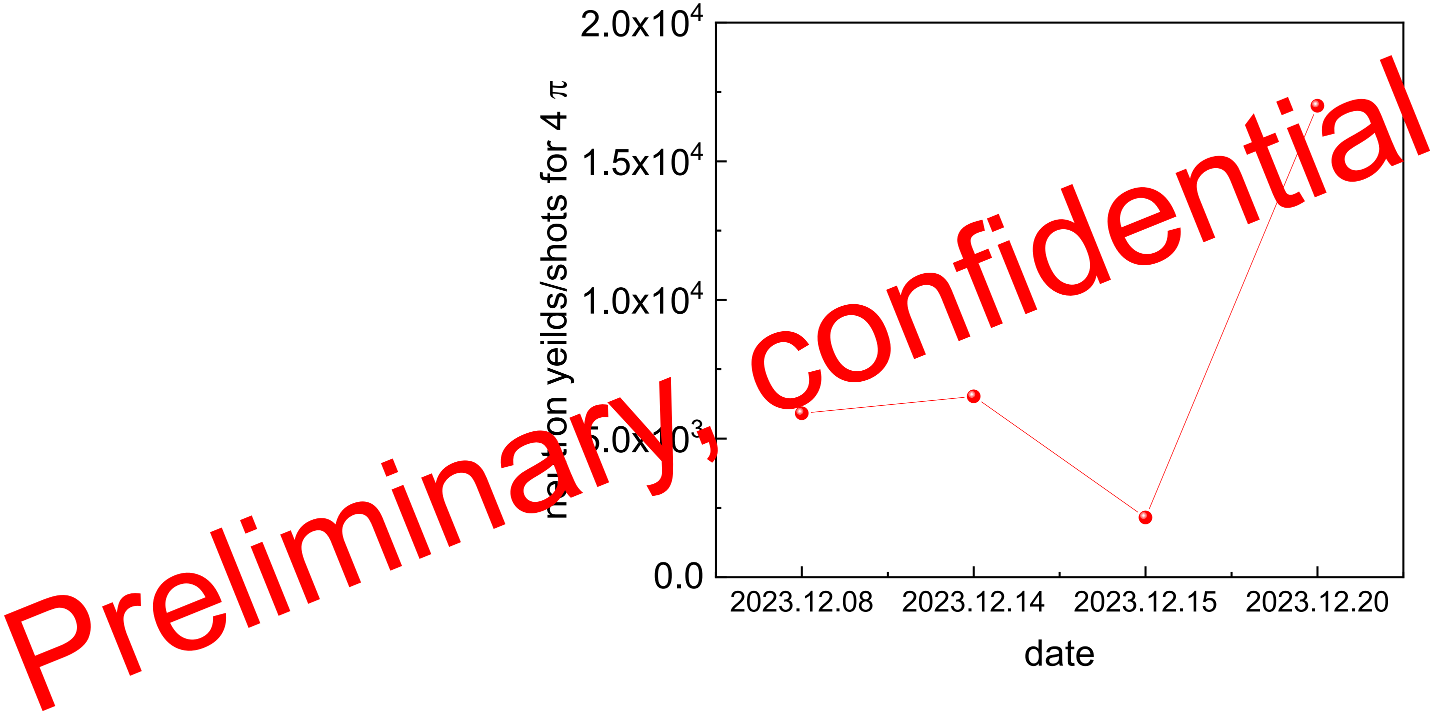
Bubble detector measurements of 1kHz neutron source

Neutrons measured with bubble detectors – AVERAGE numbers!



Average neutron per shot on Dec 20th: **~ 17×10^3 n/shot**

1.7×10^7 n/sec

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ToF measurements of a 1kHz neutron source
("Seven seconds of grace")

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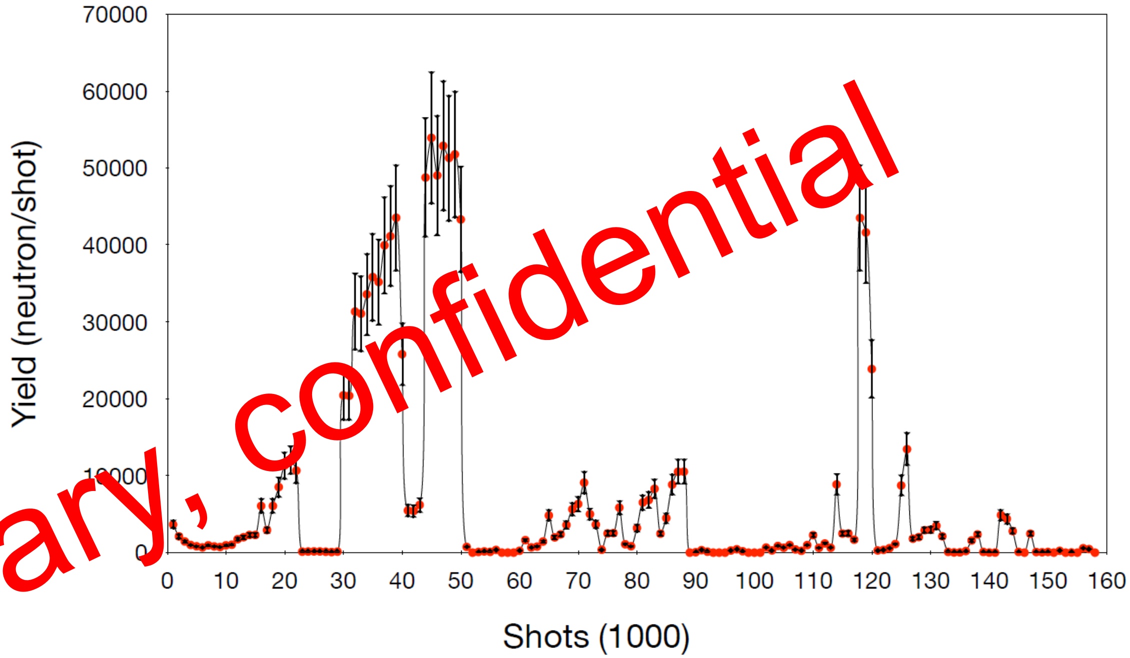
ToF measurement of the generated neutrons – average for 100 shots.



Preliminary, confidential

Peak neutron per shot (average of 100) : **70×10^{3} n/shot**

7×10^{7} n/sec

Neutron dosimeters of the laboratory upon the operation of our 1kHz neutron source

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Neutron radiation measured by the neutron detectors within the MTA area (~9m from the neutron source)

Peak: 11.5 μSv/h

Average neutron per shot: **~ 16×10^3 n/shot**

Peak neutron per shot: **~ 300×10^3 n/shot**

Peak neutron yield / sec: **~ 3×10^8 n/s**

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

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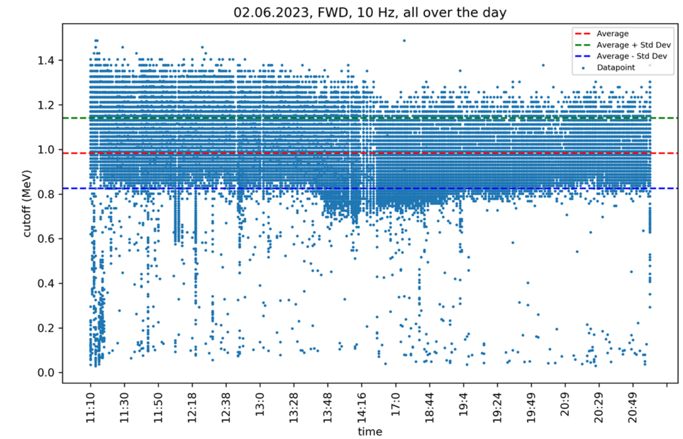
cut-off for the day: 0.98±0.16 (MeV)



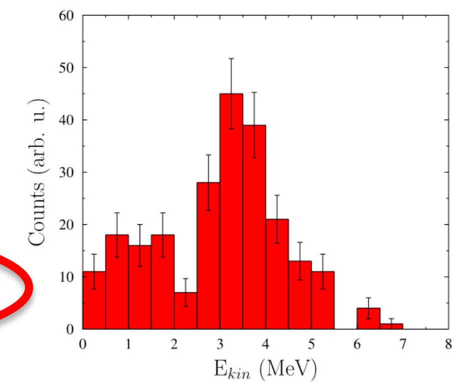
Deuteron acceleration from liquid

- 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

~1.5×10⁵ 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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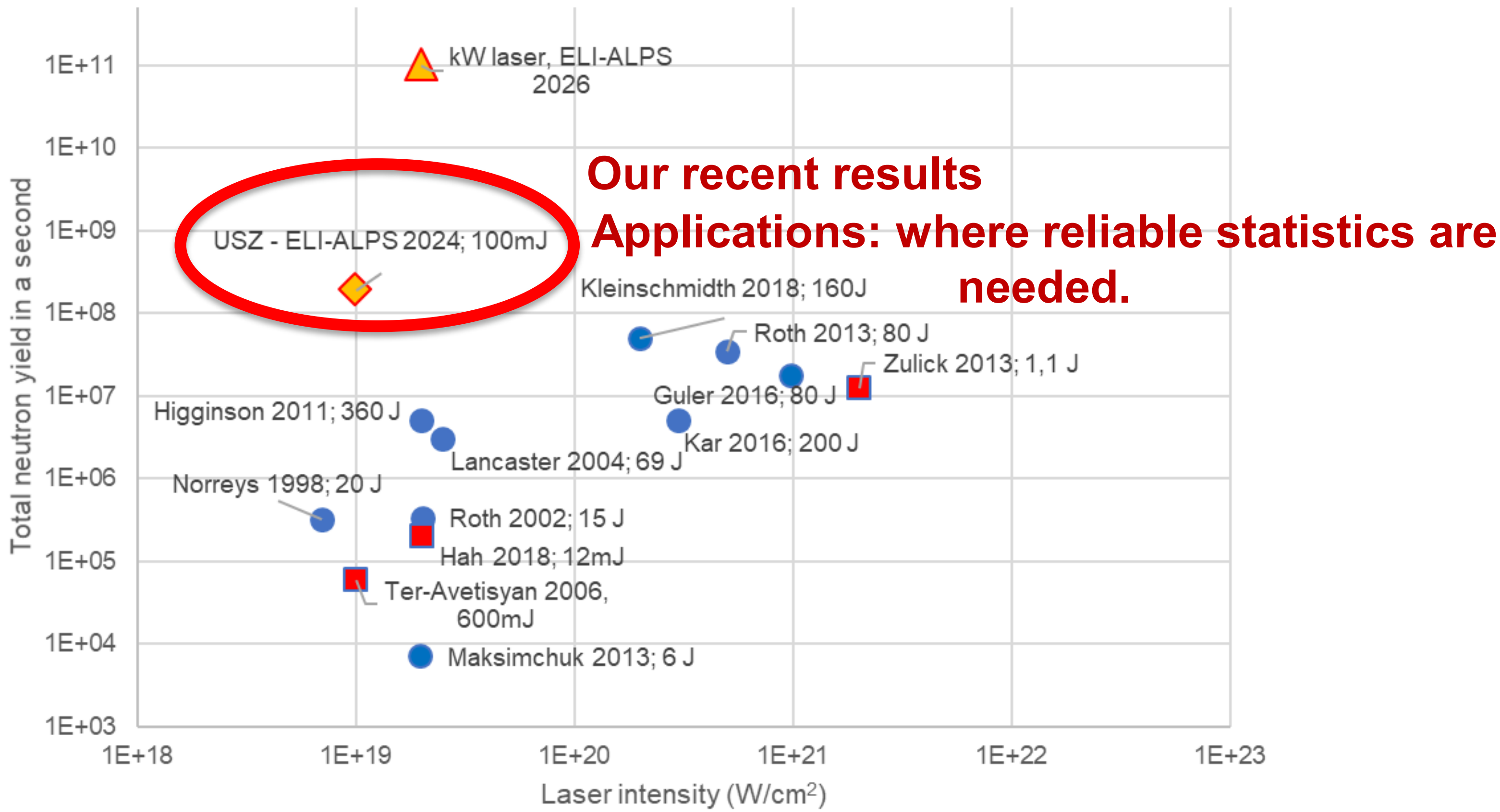

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FLASH – with neutrons

First radiobiology experiment with laser-generated neutrons

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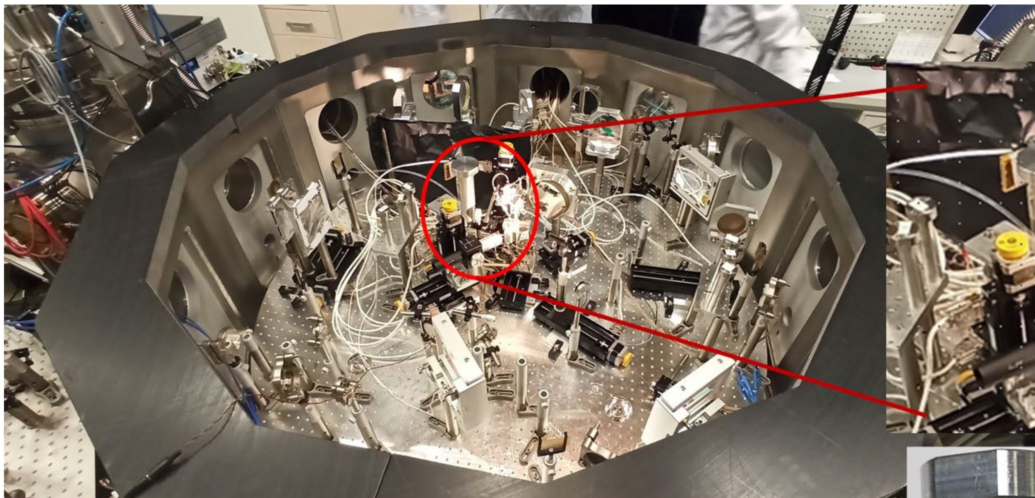
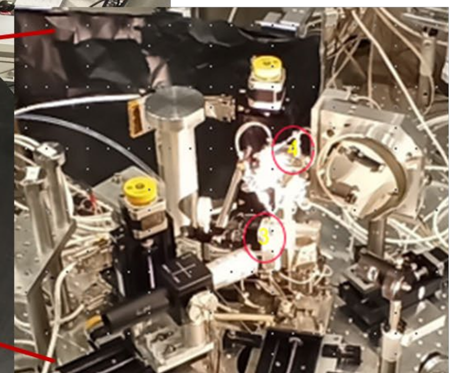
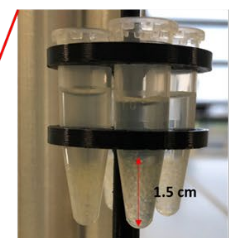




Experimental chamber…



…. Zebrafish embryos in a vacuum tight container

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

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First radiobiology experiment with laser-generated fast neutrons

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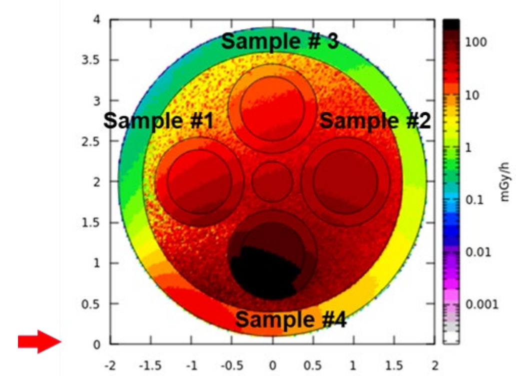
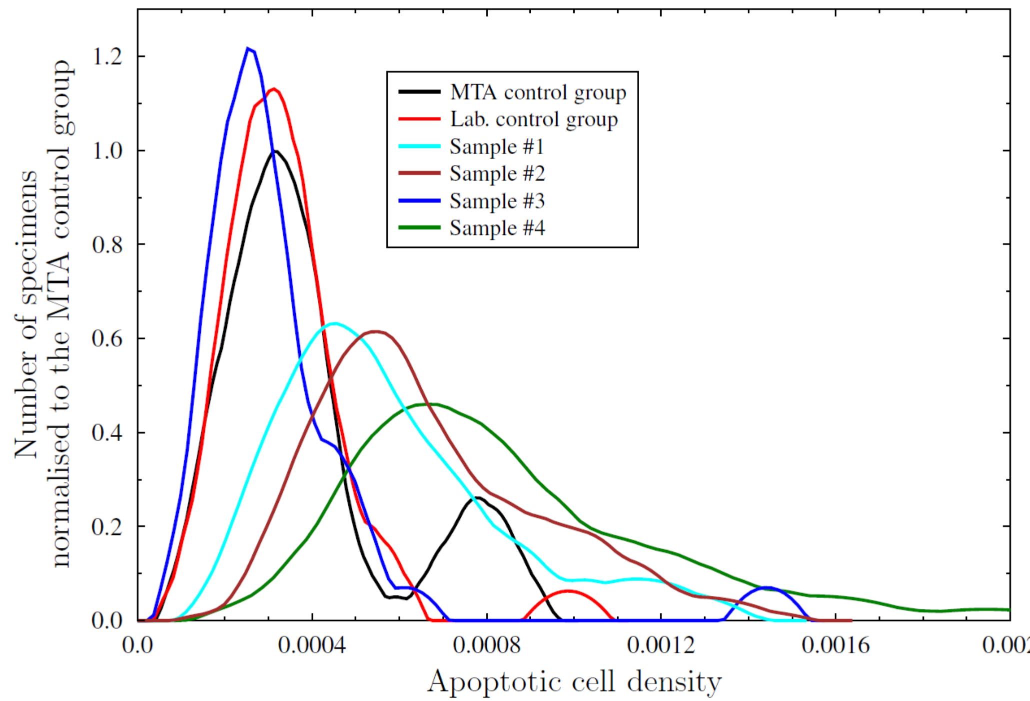
Apoptotic cell density





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eli 5th Joint ELI Call for Users

- **ELI Facilities:**
  - **ELI ALPS,** Szeged, Hungary
  - **ELI Beamlines,** Dolní Břežany, Czech Republic
  - **ELI NP,** Magurele, Romania
- **5th Call period: 25 September - 29 October 2024**
- **Unique scientific opportunities provided by access to a wide range of complementary instruments**
- **Single point of access (https://up.eli-laser.eu)**
- **Access is free** based on a **peer-reviewed** evaluation of **scientific excellence**
- Contact Integrated **ELI User Office**
  user-office@eli-laser.eu
  or **technical contacts** listed on **User Portal.** 1

The instrument run by NLTL of University of Szeged is ”LEIA”.

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The Light Energy Ion Acceleration (LEIA)
The First University beamline in ELI-ALPS

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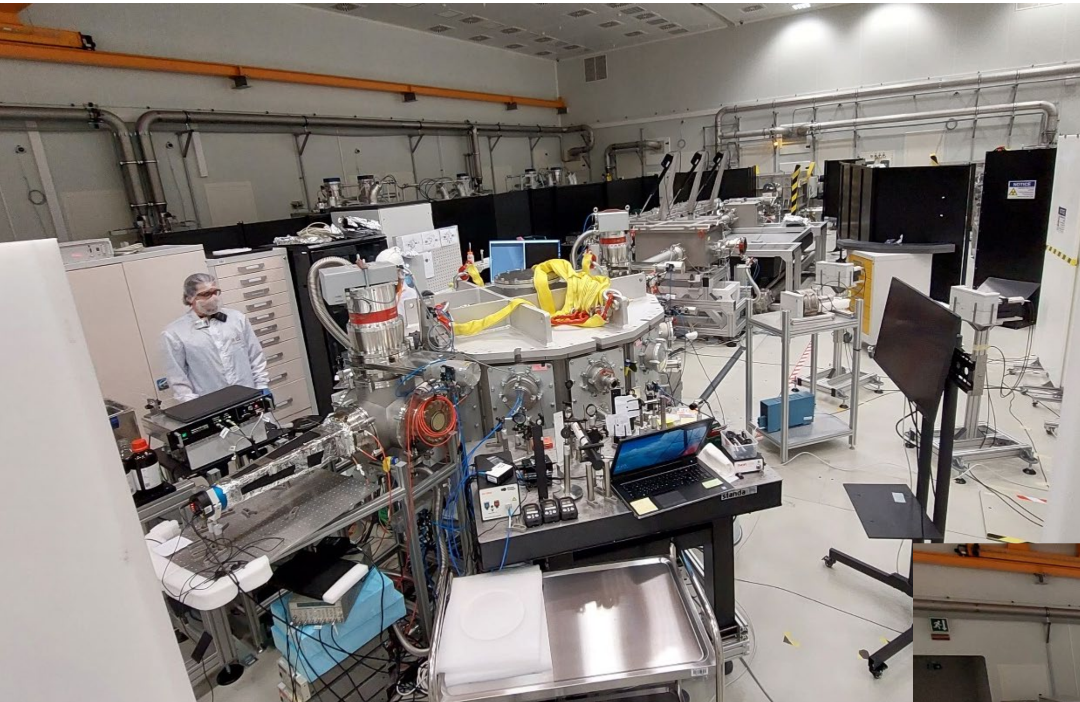

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Thank you for your attention

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