National Laser-Initiated
Transmutation Laboratory
University of Szeged

eli

HUNGARIAN NATIONAL LABORATORY

A laser-based high average yield neutron source for medical applications

Károly Osvay

Advanced Accelerator Concepts

UCLA, LA, USA
28th July, 2026

Motivation

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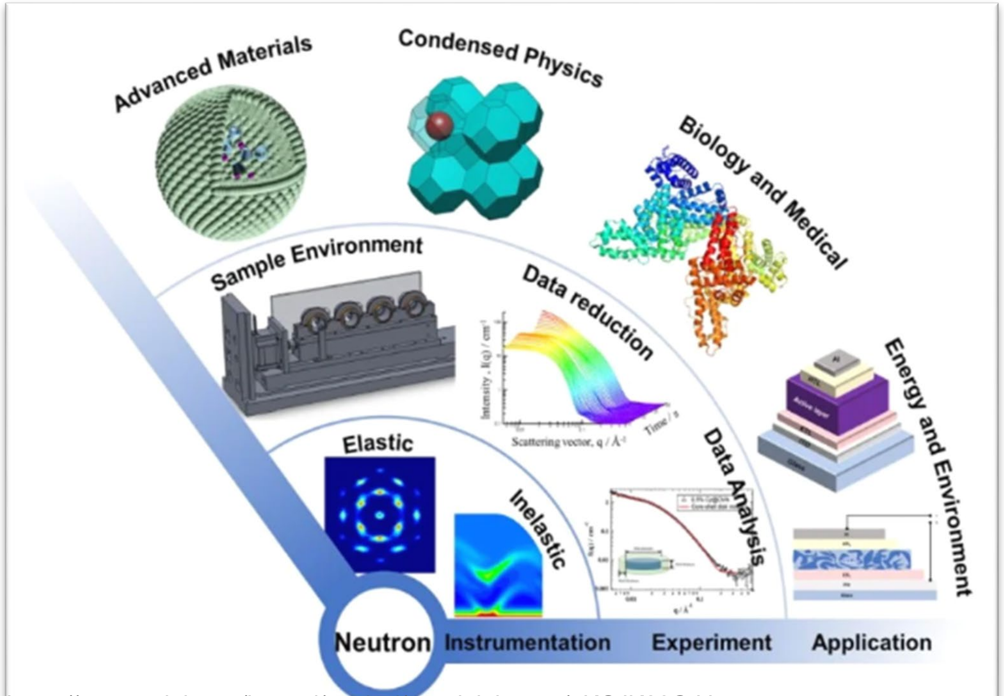
Neutron

- High penetration in material
- Direct interact with nuclei



https://www.mdpi.com/journal/applsci/special_issues/7KCJK80OJJ

The number of neutron facilities sources is decreasing

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

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

A room for laser-based neutron sources

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Many emerging applications call for neutron sources with

- a yield of 10^6 n/s - 10^{10} n/s;
- relaxed safety and security (compared to reactors);
- compact, efficient;
- reliable.

Table II. Selected list of compact accelerator-based neutron sources (CANS).

Name	Country	Accelerator type	Status	Energy	n cm^{-2} s^{-1}	References
FNG	Italy	Deuteron linac	Operational	14.1 MeV	10^8	46
TSL	Sweden	Proton cyclotron	Operational	11–175	10^5	47
FRANZ	Germany	Proton linac	Under-development	epithermal—fast,	10^7	48
LLN	Spain	Proton linac	Under-development	TBC	TBC	
NELBE	Germany	electron linac	Operational	epithermal—fast,	10^4	49
KUANS	Japan	Proton linac	Operational	thermal—fast,	10^8	50
RANS-I	Japan	Proton linac	Operational	epithermal—fast,	10^5	51
HUNS	Japan	Electron linac	Operational	cold—fast	10^4	52

Mirfayzi et. al., Jpn.J.Appl.Phys. **64** (2025) 010002

A room for laser-based neutron sources

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Many emerging applications call for neutron sources with

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Laser-based neutron sources
Multi-J (PW)-class lasers – current situation

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Photonuclear

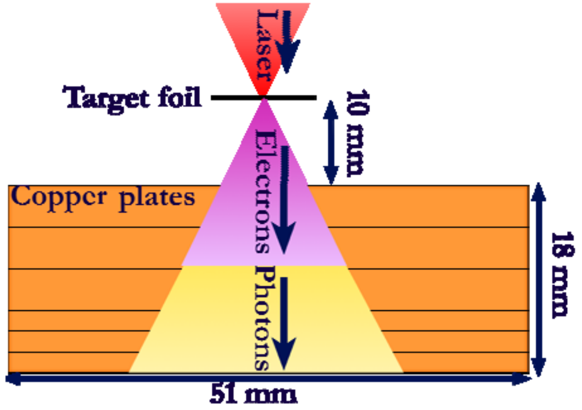
- Accelerate electrons
- Brehmstralung and high Z converter: (γ,n)

Highest efficiency experiment

2.9×10^7 n/J

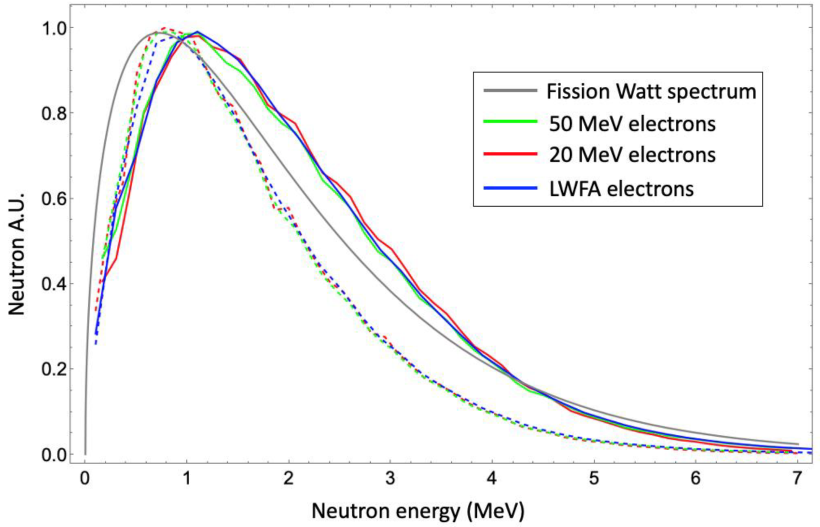
~ 10^5 n/s

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

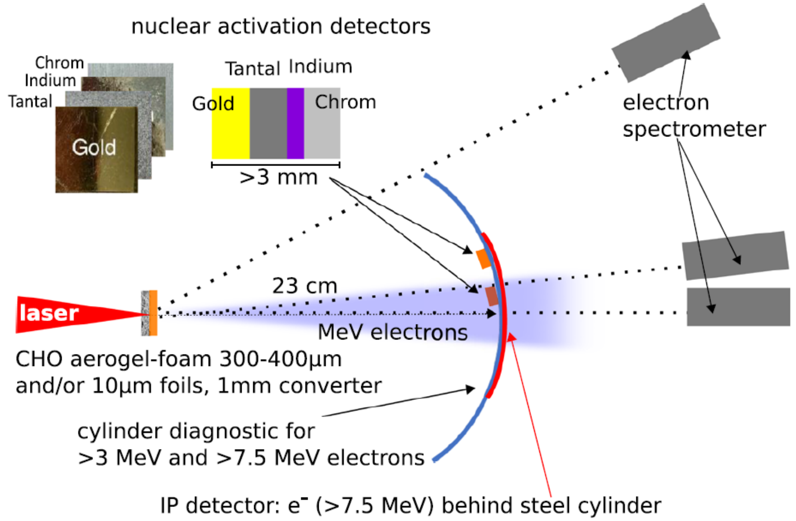


Pomerantz et al., PRL **113** (2014) 184801

Neutron spectra: continous



Papp et al., Photonics **9** (2022) 826

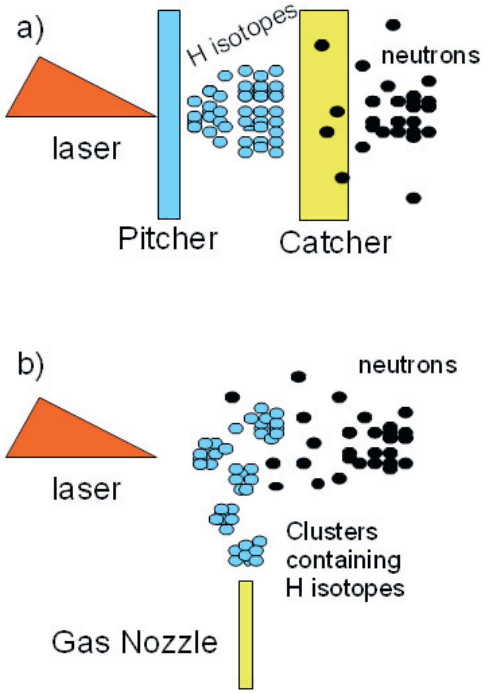


Laser-based neutron sources
Multi-J (PW)-class lasers – current situation

PhotoFusion

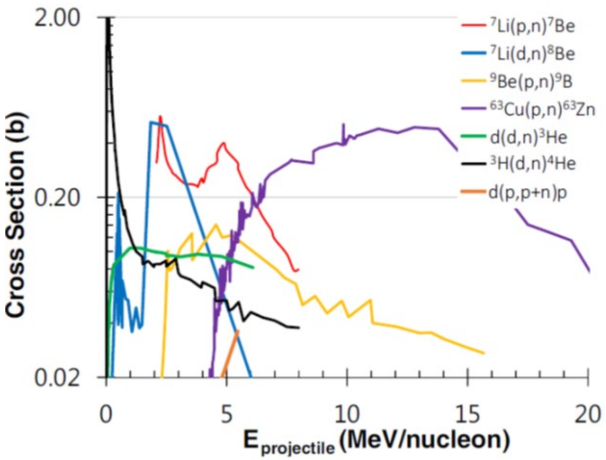
- Accelerate ion (proton, deuterium)
- Make fusion: Be(p,n), Li(p,n), D(d,n) (T)d,n)

Pitcher-catcher:
Complicated, but **higher neutron yield**



Alvarez et al., Phys.Procedia **60** (2014) 29

Neutron spectra: continous or quasi-monochromatic

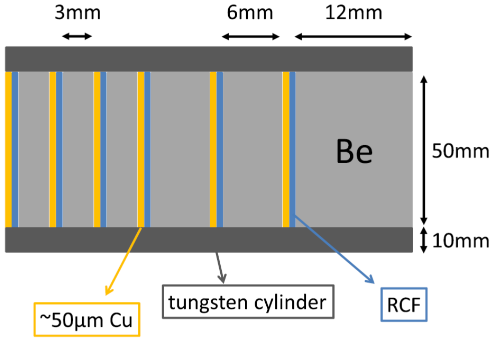


Alejo et al., Il Nuovo Cimento **38 C** (2015) 188

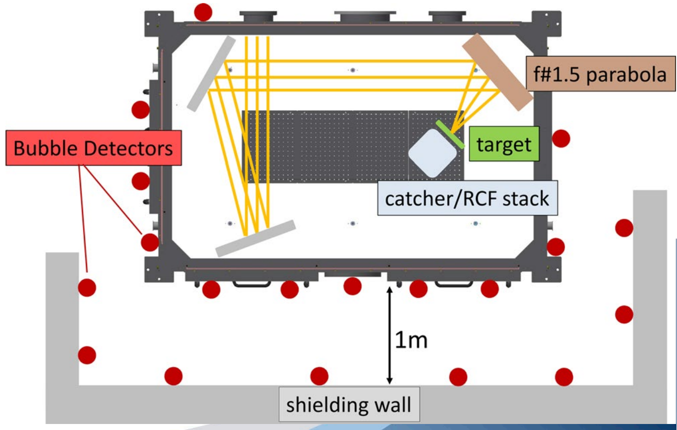
Highest efficiency experiment

69×10^{7} n/J
2×10^{6} n/s

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



Kleinschmidt et al, Phys.Plasmas **25** (2018) 053101



State-of-the-art laser-based neutron sources

Laser-accelerated primary particle			Laser pulse				
	Cut-off energy [MeV]	Particle ↓ neutron process	Duration [fs]	Energy [J]	Neutron [$\times 10^6$] per laser J	Laser average power for 10^{15} n/s [MW]	Experiment/ prediction
p	45	Au(p,n)	750	90	690	1.5	Experiment[169]
p		Li(p,n)	40	1.1	9	111.2	Experiment[217]
d		D(d,n)	40	0.008	0.009	108,700	Experiment[39]
d	0.7	D(d,n)	12	0.023	0.05	11,111	Experiment[37]
d	7.3	D(d,n)	22	3.2	0.156	6410	Experiment[38]
d	1	D(d,n)	12	0.023	0.78	1282	Experiment[40]
d	1.7	D(d,n)	9	0.08	2.5	400	Experiment[225]
d	75	Li(d,n)	330	6.7	150	6.7	Prediction[226]
d	45	Li(d,n)	40	3	93	10.8	Prediction[227]
d	0.4	T(d,n)	6	0.1	60	16.7	Prediction[47]
e	90	Au(γ,xn)	1200	1675	0.6	1661	Experiment[228]
e	100	Au(γ,xn)	750	90	155	6.43	Experiment[169]
e	20	Cu(γ,xn)	150	90	26	38	Experiment[219]
e	30	Au(γ,xn)	45	3	0.1	10,000	Experiment[220]
e	220	Pb	9	0.1	600	1.7	Prediction[229]
p	270	Pb	25	230	4300	0.3	Estimation[230]
p	120	Pb	20	12	12	83.3	Prediction[231]

Canova et al., HPLSE **13** (2025) e79

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

Curiosity-driven research
Full understanding physics
Proof-of-principle experiments

Increase laser repetition rate
Target development

NLTL approach
Existing 100 W lasers
Peak intensity issues
Physics with low pulse energy

Continuous operation
Neutron yield for application regime > 10^7 n/s
Data aquisition, monitoring and control

High repetition rate target development
Increase pulse energy

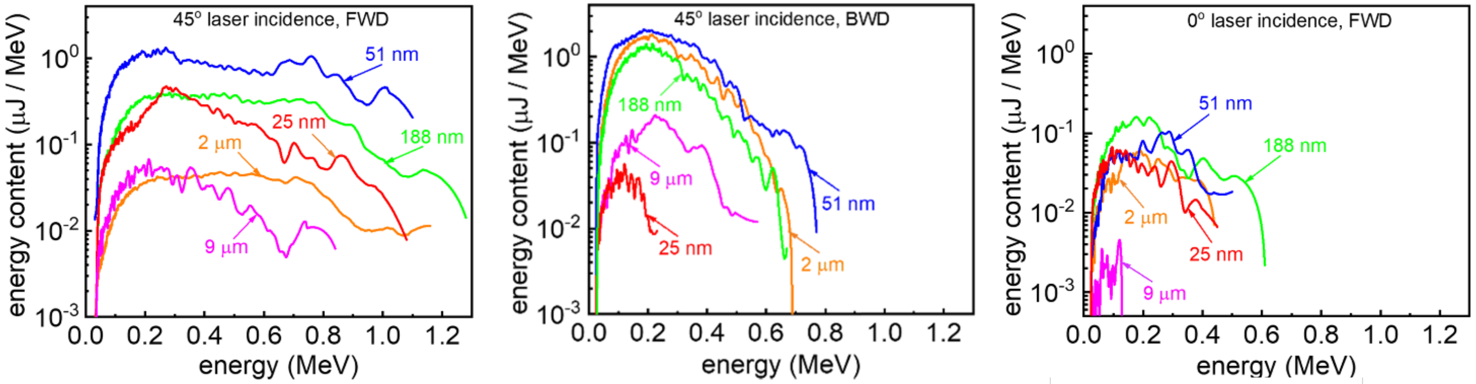
Both paths would lead to a laser accelerator based particle source…
… with differences especially in early stage

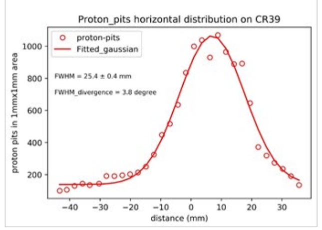
Challange 1
What are the properties of ion acceleration by few-cycle lasers pulses?

Study of ion acceleration by few-cycle pulses from ultrathin foils

Large number of low energy protons (above 100keV: 10^{10}/shot)

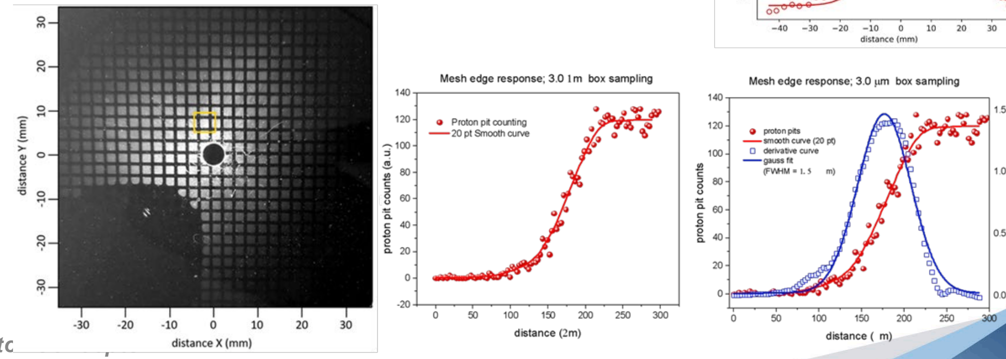
Ter-Avetisyan et al., PPCF **65** (2023) 085012





Small beam divergence (<65mrad for protons > 250 keV)
Small emittance 0.00032 π-mm-mrad

Singh et al., Sci.Rep. **12** (2022) 8100

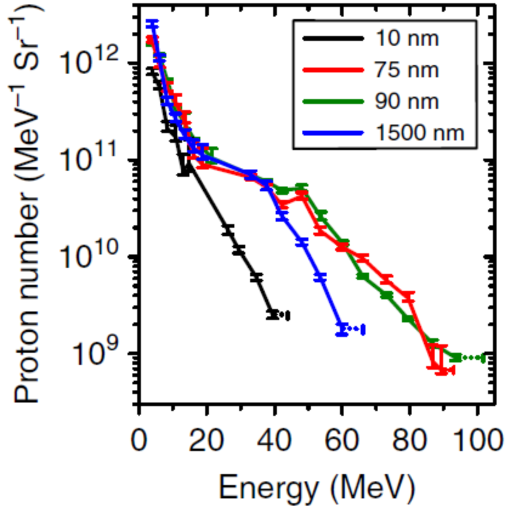


Challenge 2
Match the material of the catcher to the ion spectra for The highest neutron yield

Characterisation of ion acceleration

most common: cut-off (attractive, but…)

Higginson et al., Nat.Commun. **9** (2018) 724



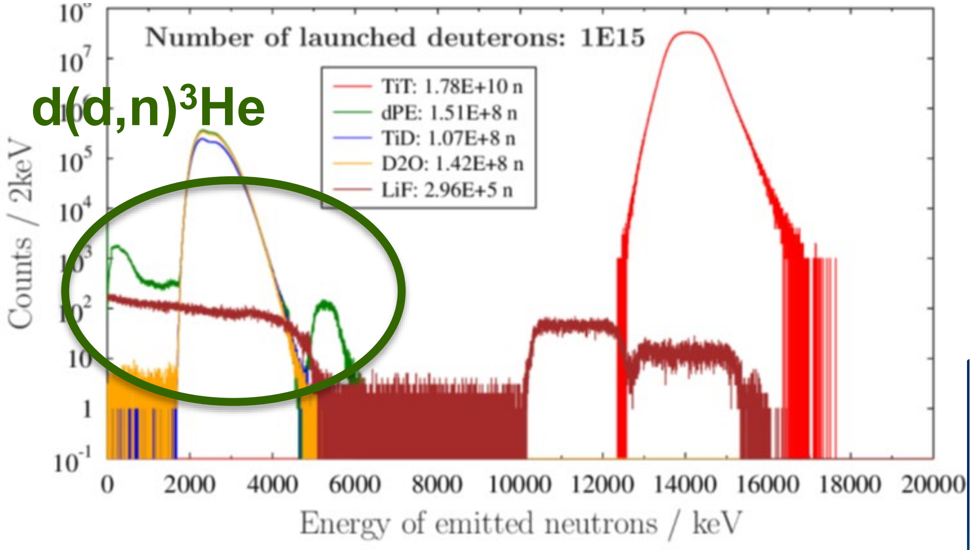
Practically what matters (NOT only for neutron generation!)

mean kinetic energy

bunch energy

(conversion from laser to total particle energy)

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



Challenge 3
High repetition rate target systems

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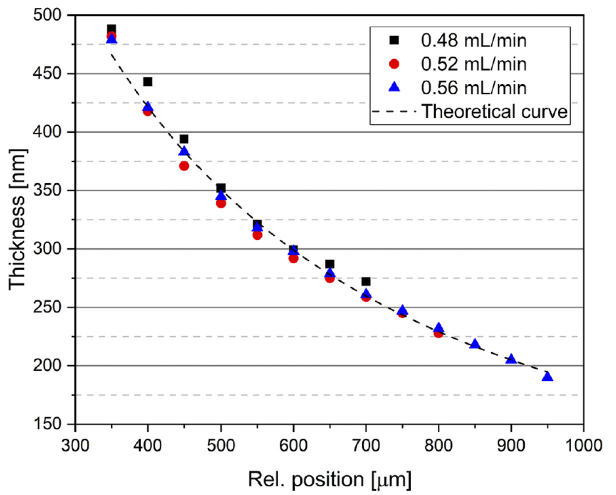
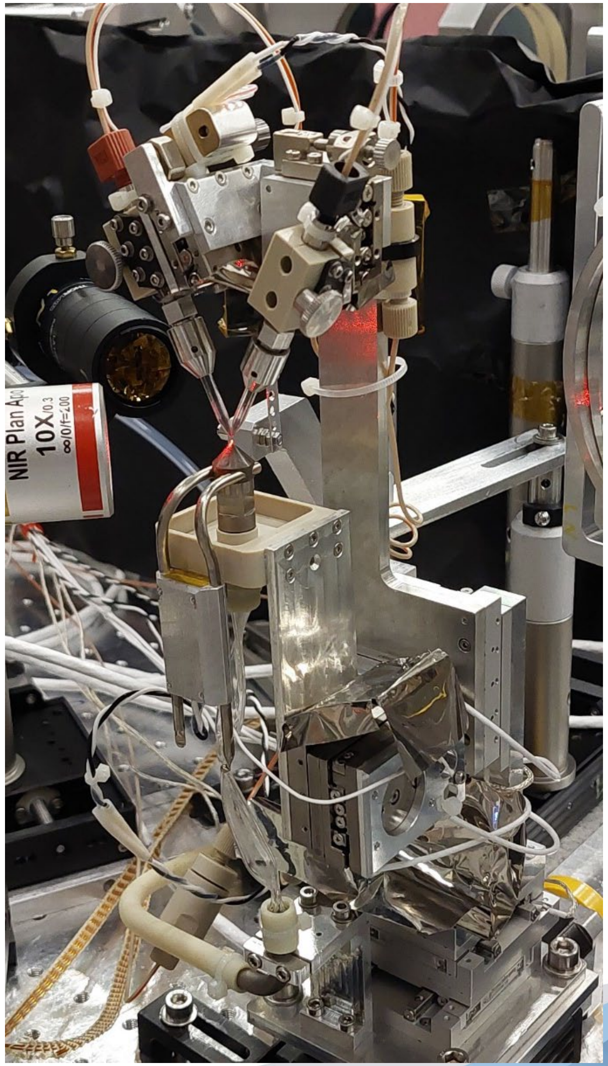
Advanced Microfluidic Systems GmbH

Development of a colliding jet liquid leaf system

- Two liquid jets collide from two glass nozzles
- Pulsation damping system for *stability*
- Recirculation system for *continous operation*
- Thicknesses measured *in vacuum (!)*
- **Thinnest liquid sheet is 190 nm**



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



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

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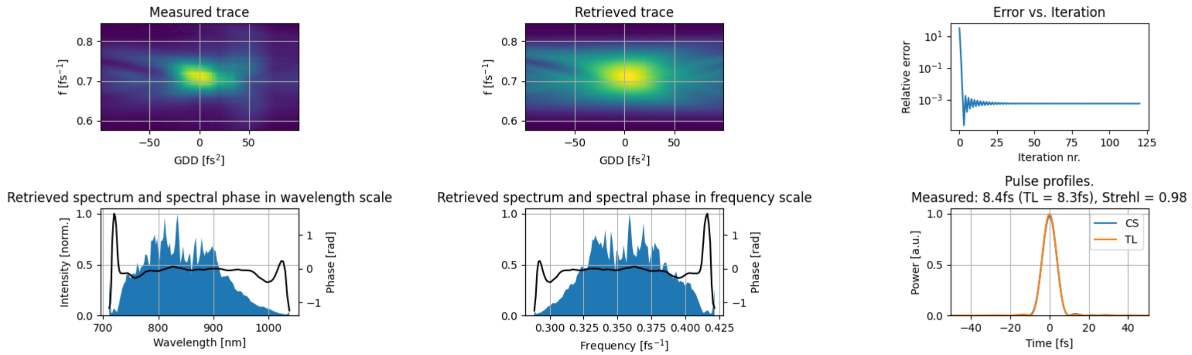
Pulse energy: ~80 mJ
(105 mJ in laser)

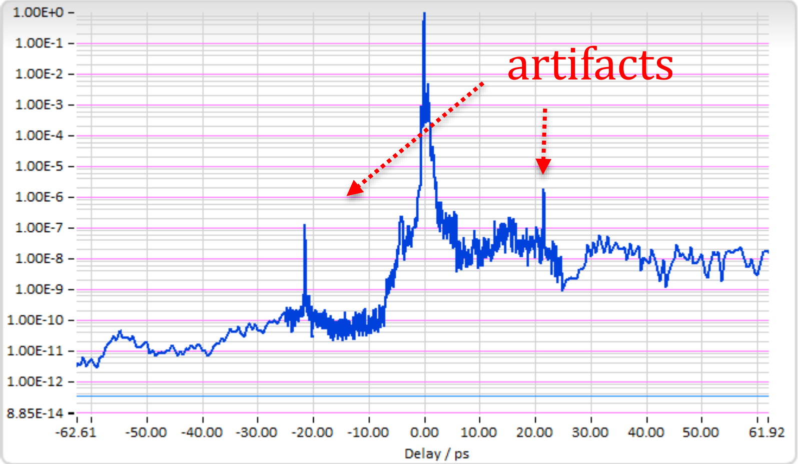
Laser pulse duration: 8.4 fs
(measured in vacuum,
after OAP, with disp scan)

Central wavelength: 826nm

Focal spot FWHM: 2.9×2.6 μm^2

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

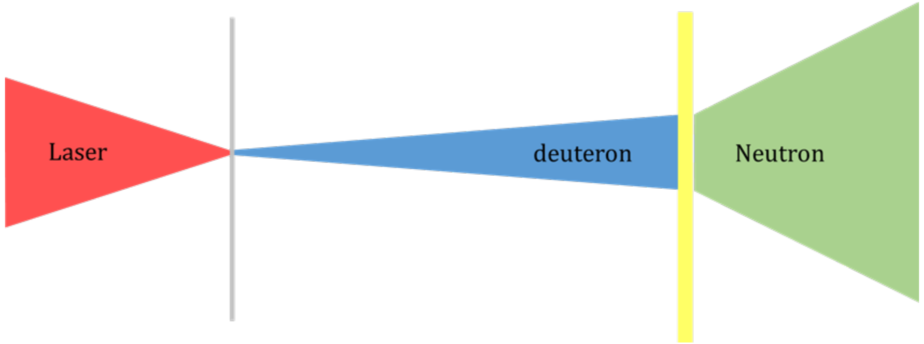


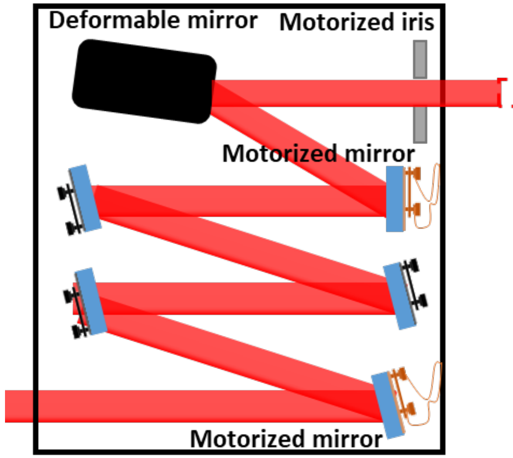


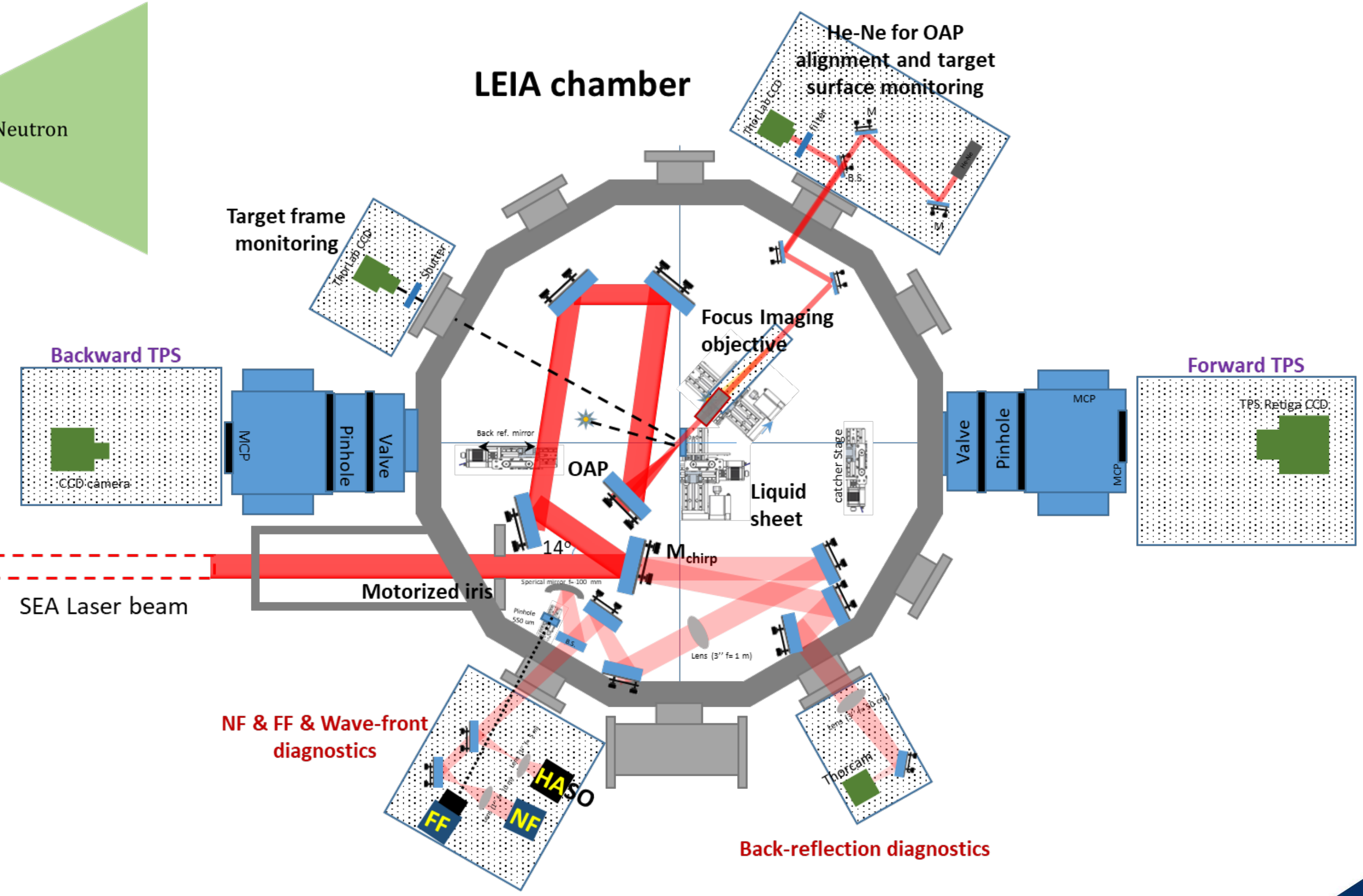
Temporal contrast

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

Neutron generation – experimental setup







Low-Energy Ion Acceleration beamline

for high average power ion beam

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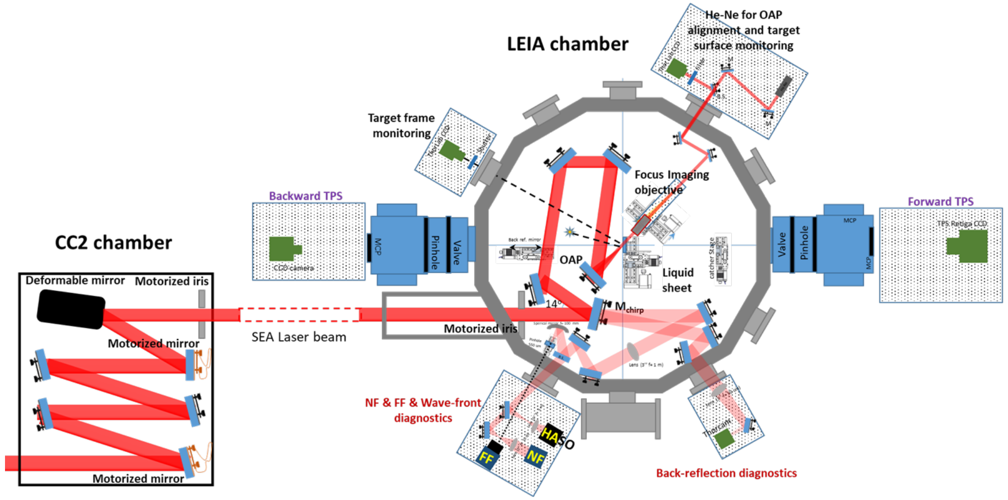
University of Szeged



Peak ion beam Performance

- Ion (p^+,d^+) cutoff: > 2.5 MeV (±6% rms)
- *Ion average current* ***~20 μAmp***
- *Ion peak current* ***~20 kAmp (10^{11} ions/pulse)***
- Ion beam divergence: <5°
- Emittance: 0.00032 π-mm×mrad
- *Regular stable operation:* ***> 6 h***

Singh et al., Sci.Rep. **12** (2022) 8100
Ter-Avetisyan et al., PPCF **65** (2023) 085012
Füle et al, HPLSE **12** (2024) e37
Varmazyar et al, Comm.Phys. **8** (2025) 350

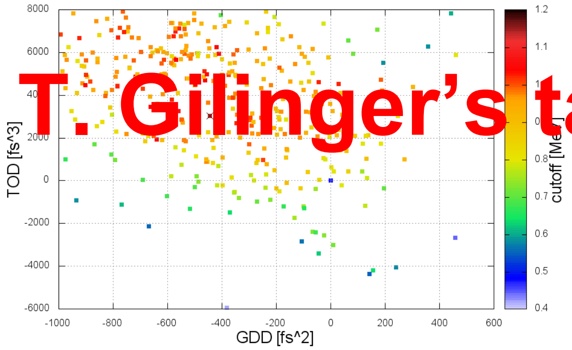
Unique Specs

- Single-shot – ***kHz repetition rate***
- *On target*, TL pulse duration: *4 fs – 12 fs*
- *On target*, energy: 12 mJ – *80 mJ*
- Angle of incidence: 2° - 75°
- Solid-state targets, XYZ stages
  Liquid sheet (H_2O, D_2O): *200 nm – 1 μm*
- Thomson Parabola Spectrometers, e^- (in prog.)
  Back-reflection diagnostics

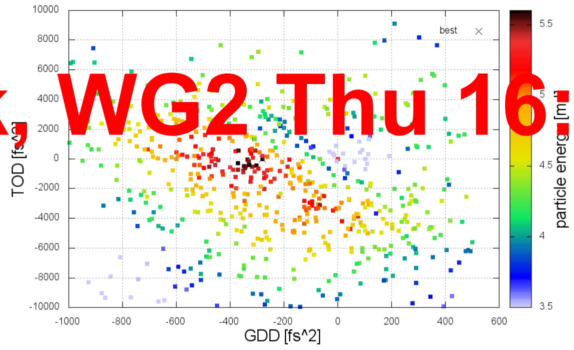
Markov-chain Monte-Carlo optimisation for an ion parameter

(at a laser pulse energy, liquid, thickness, and ion; <15 min)

60mJ, D_2O, d^+, 760nm, cutoff



80mJ, H_2O, p^+, 300nm, bunch energy



T. Gilinger's talk, WG2 Thu 16:20

DIAGNOSTICS – neutron

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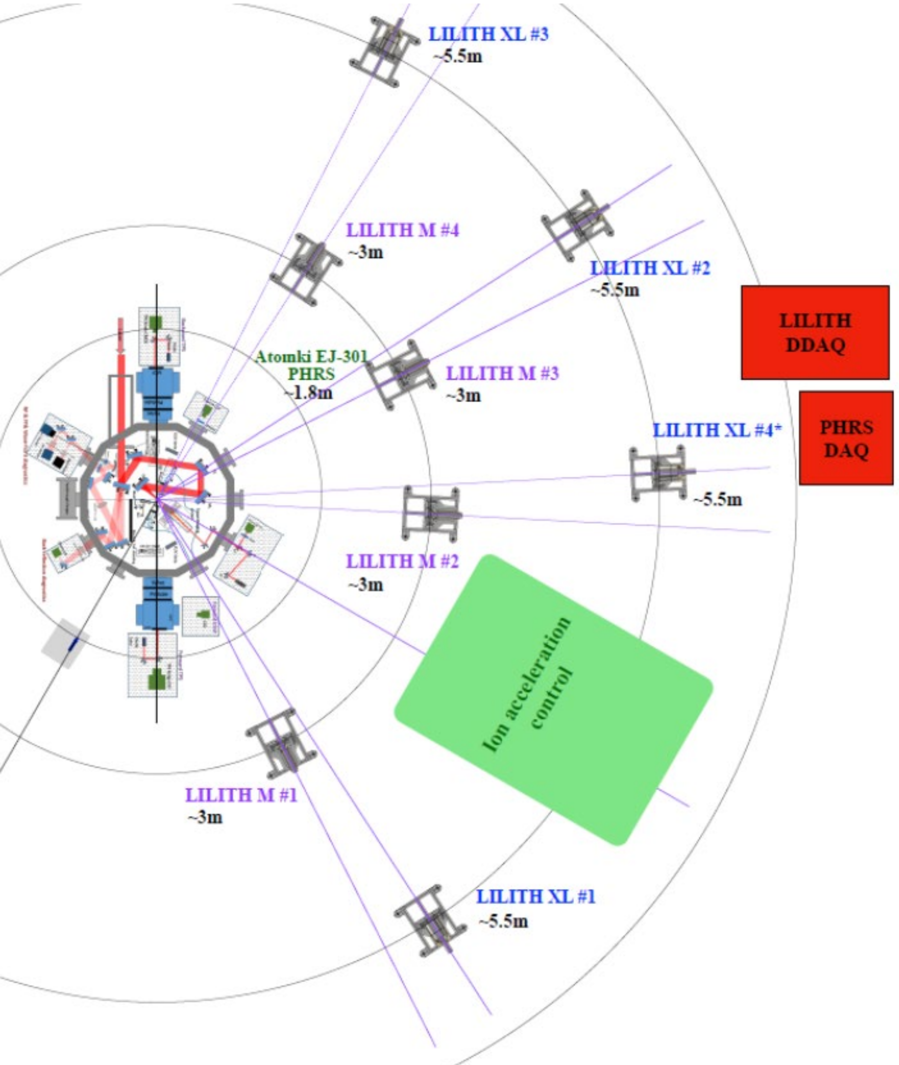
Two independent systems

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

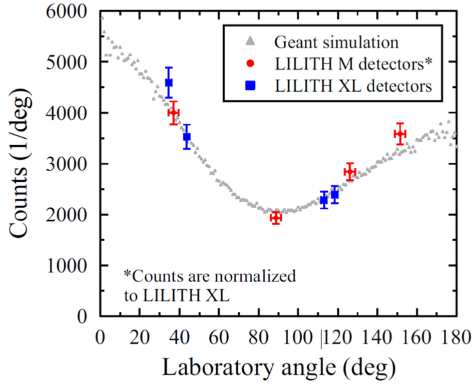


Outside the chamber

Plastic scintillators: LILITH M, XL systems

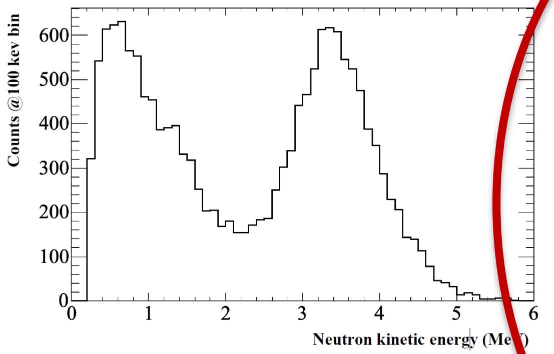
Liquid scintillator: PHRS system

Neutron angular distribution

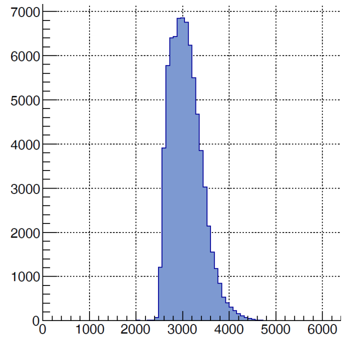


Neutron energy spectrum

Measured outside



At the source



Quasi-monoenergetic

Control and log of (almost) all parameters upon operation

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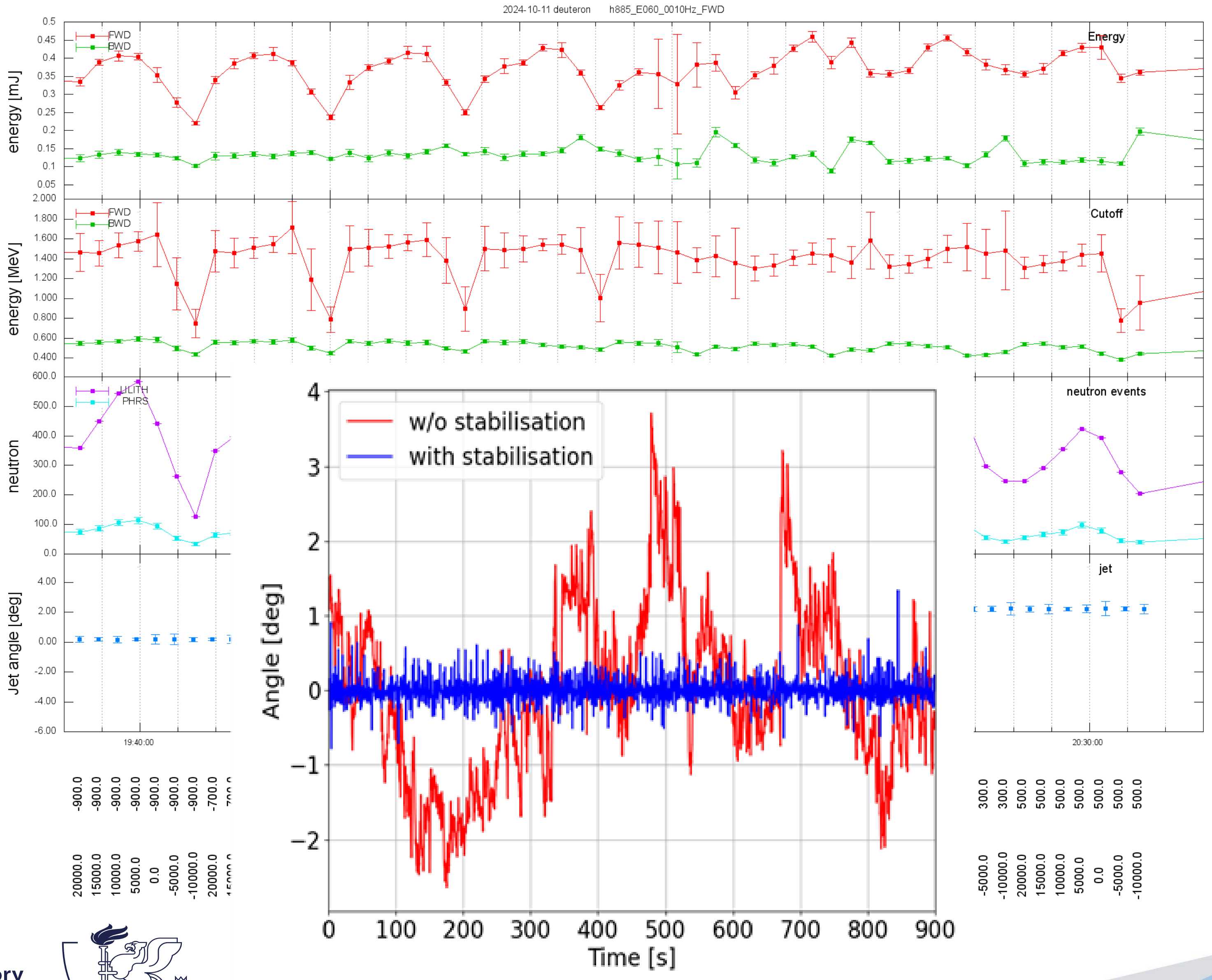
Bunch energy of deuteron

Cutoff energy deuterons

Neutron event LILITH

Liquid Scint

Stability of liquid jet



Neutron generation at 1kHz repetition rate
dPE neutron converter

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***Neutron* generation:** 450nm D_2O leaf + 1mm C_2D_4

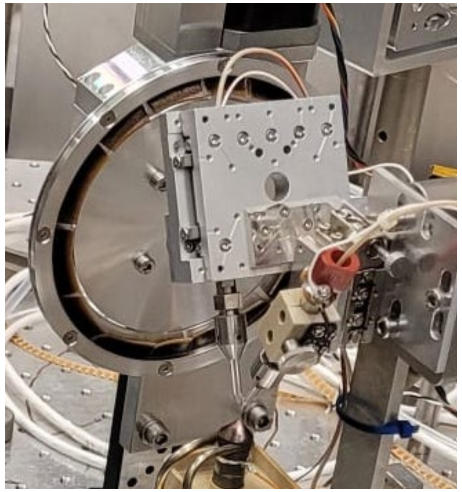
Peak yield detected at 1kHz : **7×10^7 n/s**

Average yield over 1 hour at 1kHz : **1.5×10^7 n/s**

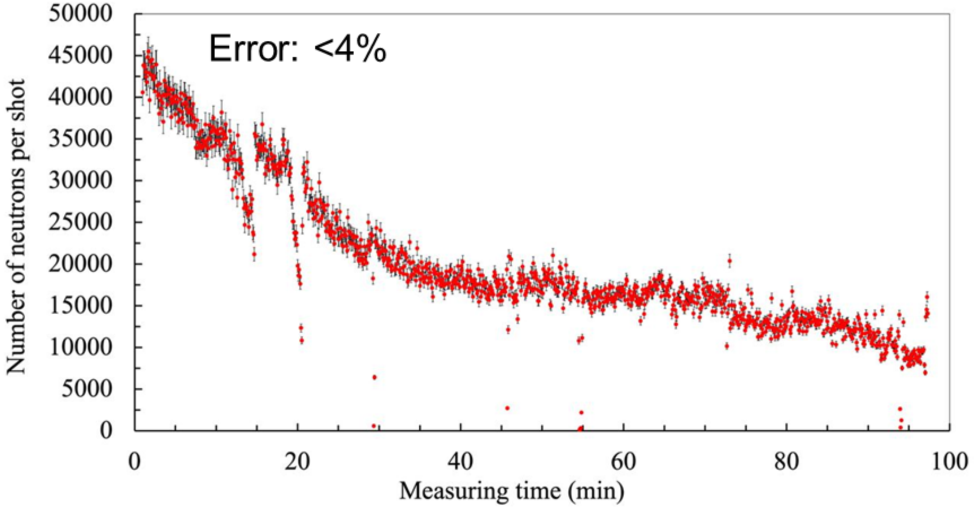
Average neutron flux at 1kHz : **2×10^7 n/cm^2/s**

Peak neutron *flux rate* / shot: **> 10^{13} n/cm^2/s**

Irradiation demonstrated: *3×100 min/day* (exchange of dPE)



Ageing (burning) of the dPE



Neutron generation at 1kHz repetition rate
D_2O neutron converter

HUNGARIAN NATIONAL LABORATORY

Neutron **generation:** 410nm D_2O leaf + 0.5 mm D_2O

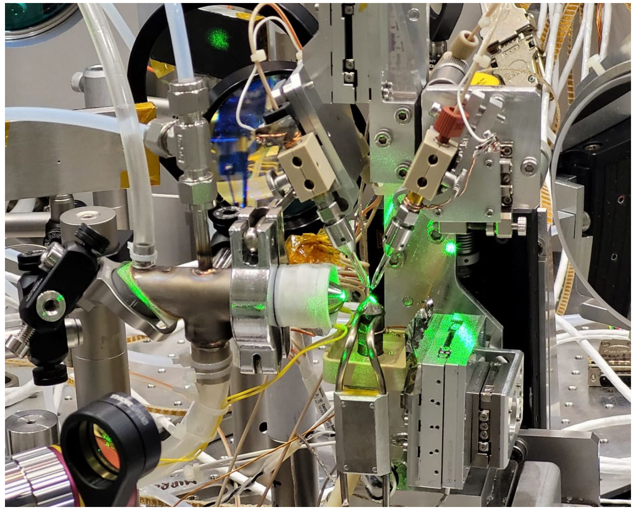
Peak yield detected at 1kHz : **4×10^7 n/s**

Average yield over 1 hour at 1kHz : **4×10^7 n/s, 1.7% rms**

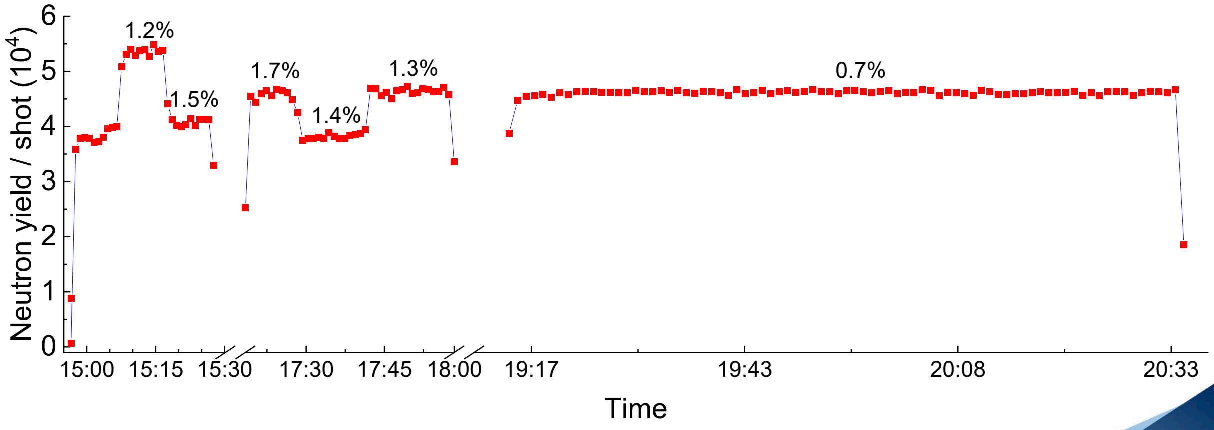
Average neutron flux at 1kHz : **~10^8 n/cm^2/s**

Peak neutron *flux rate* / shot: **> 10^{13} n/cm^2/s**

Irradiation demonstrated: ***210 min continous***



Osvay et al., *patent pending*



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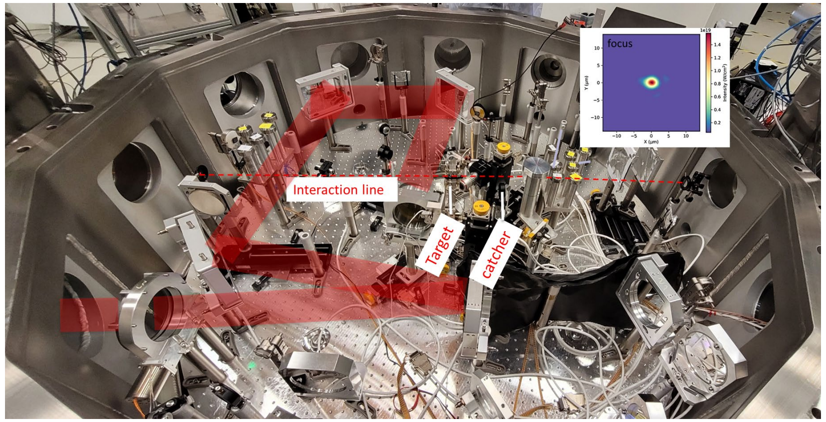
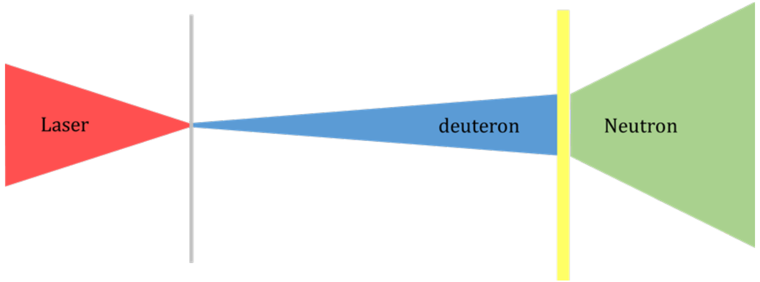
LEIA-n(eutron) beamline



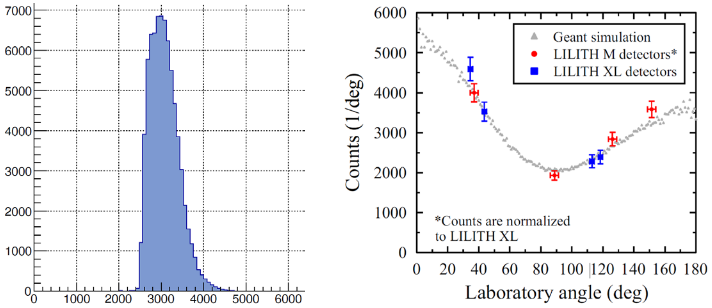
Pitcher-Catcher scheme

D^+ acceleration d(D,n)3He fusion

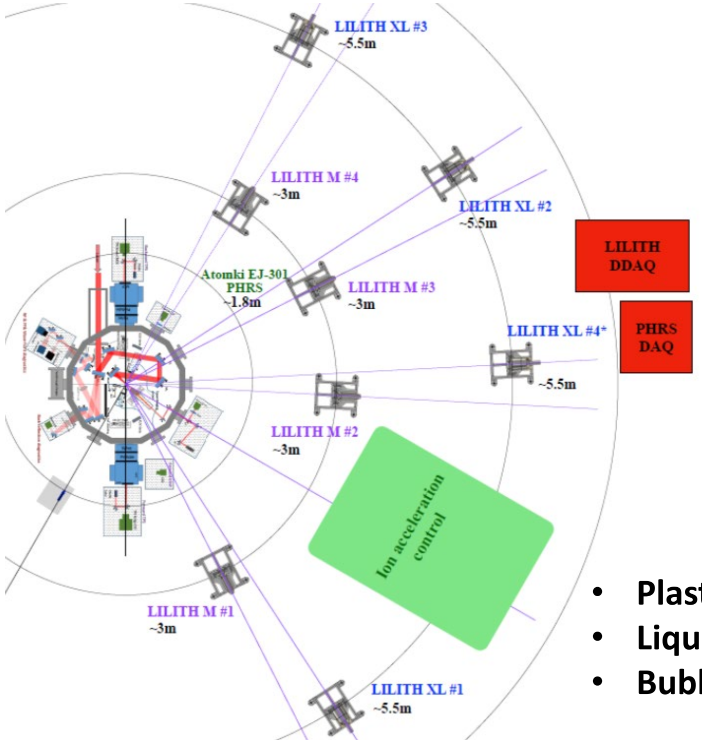


Osvay et al., *EPJ Plus 139 (2024) 574*

Neutron spectrum and angular distribution



Osvay et al., Sci.Rep. **14** (2024) 25302
Stuhl et al, PRR *7* (2025) 023137
Osvay et al., *in prep*



Neutron Performances

- **Catcher: rotating dPE, flowing D_2O**
- **Peak neutron yield (kHz): 10^8 n/sec**
- ***Peak neutron flux-rate: 10^{13}n/cm^2/shot***
- ***Operation (±3% rms): > 6 h @10 Hz***
- ***Regular operation: >2 Gy/h, @ 1kHz***

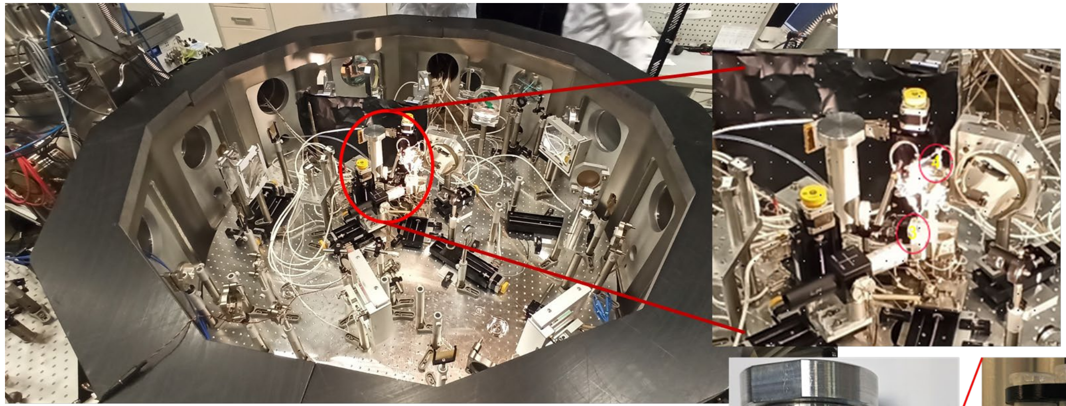
Applications & user experiments

- **Radiobiology of ultrashort, fast neutron pulses**
- **Neutron-induced therapy**
- **Medical isotope production**
- **Material science for IFE**

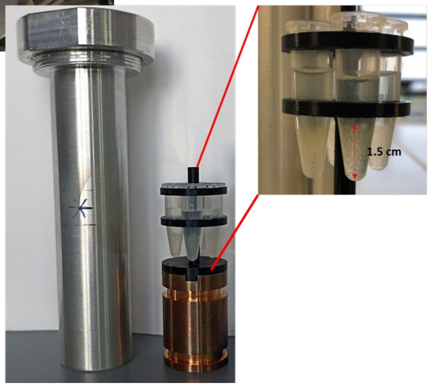
- **Plastic scintillators EJ-240, 4 pcs.**
- **Liquid scintillator EJ-309, 4 pcs.**
- **Bubble-detector neutron spectrometer**

First radiobiology experiments with laser-generated fast neutrons

PI: Katalin Hideghety

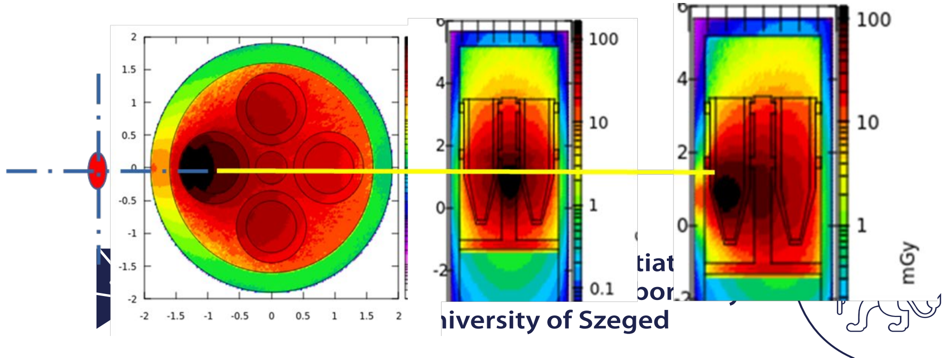


Experimental chamber…

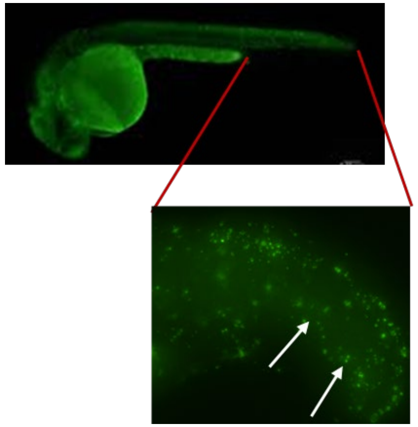


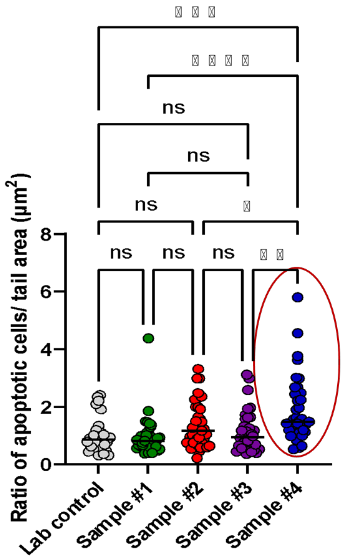
…. Zebrafish embryos in a vacuum tight container

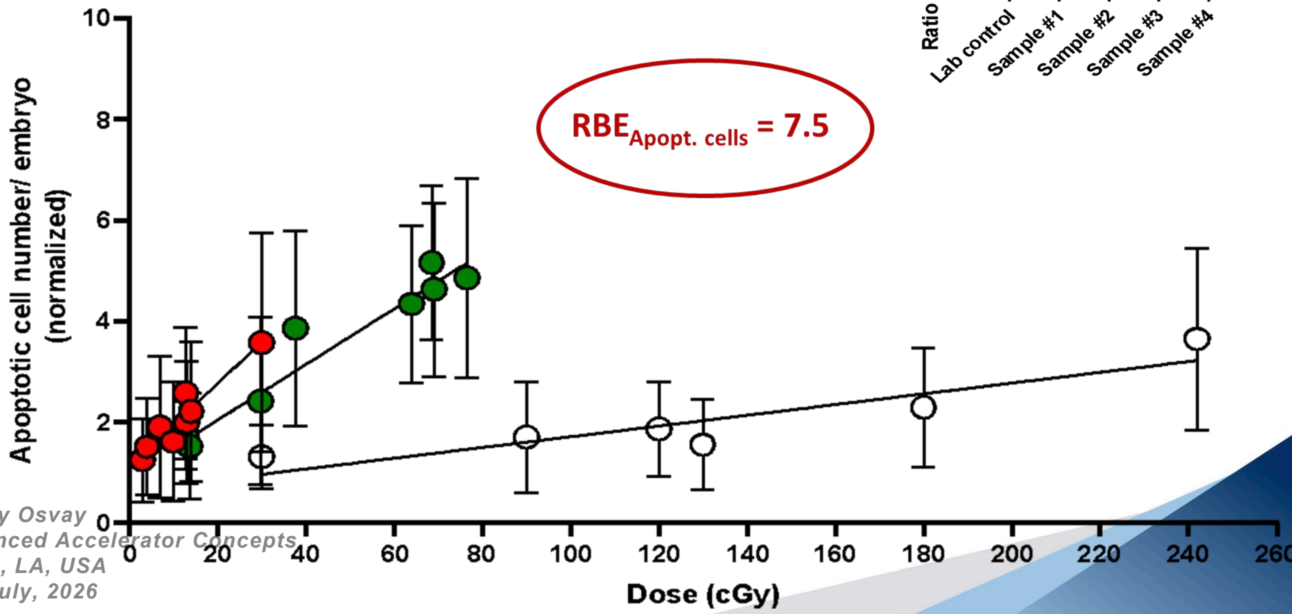
Neutron dose simulation



Apoptotic cell density measurement after irradiation



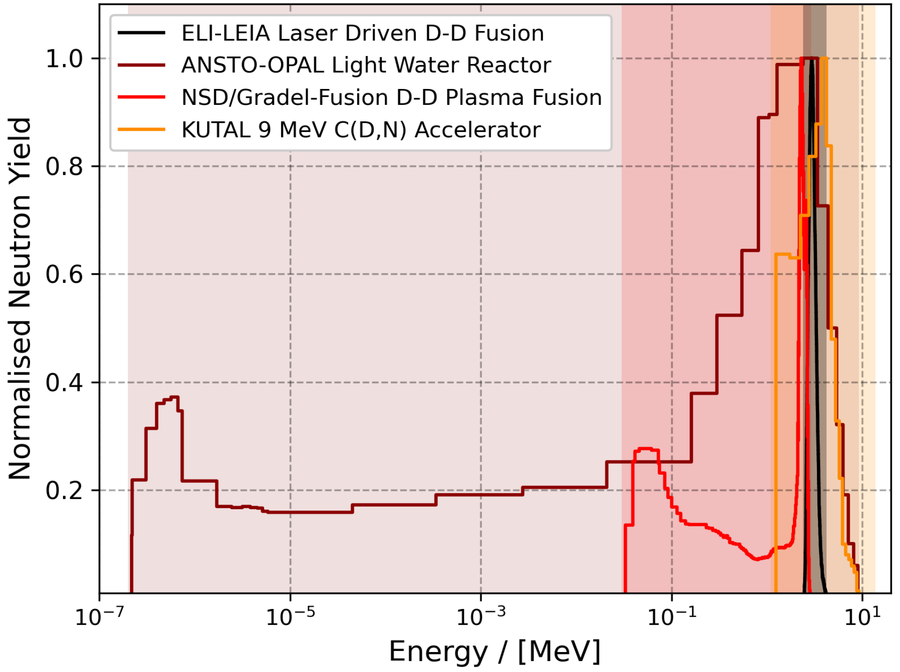




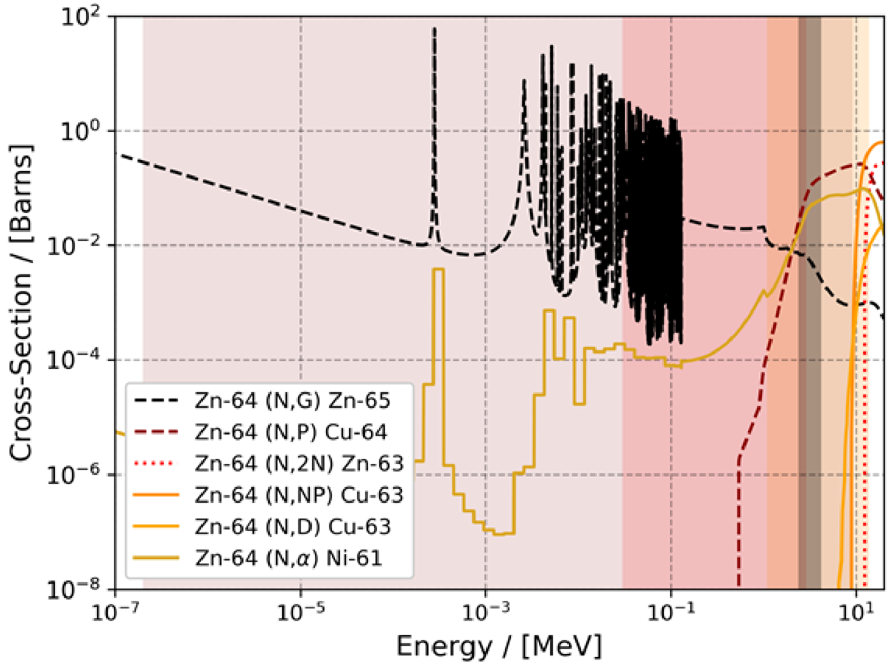
Direct Production of >99.95% Radioisotopic Pure Cu-64 from Natural Zinc Targets

PI: Jeremy Brown

Comparison of neutron spectra of different kinds of sources



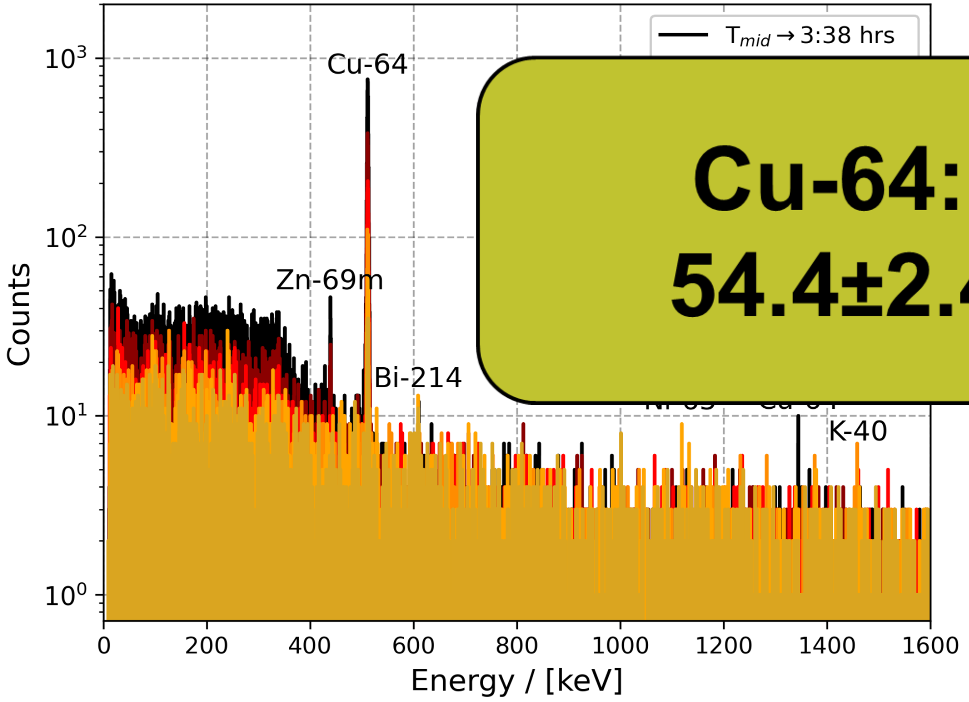
Comparison of neutron spectra of different kinds of sources



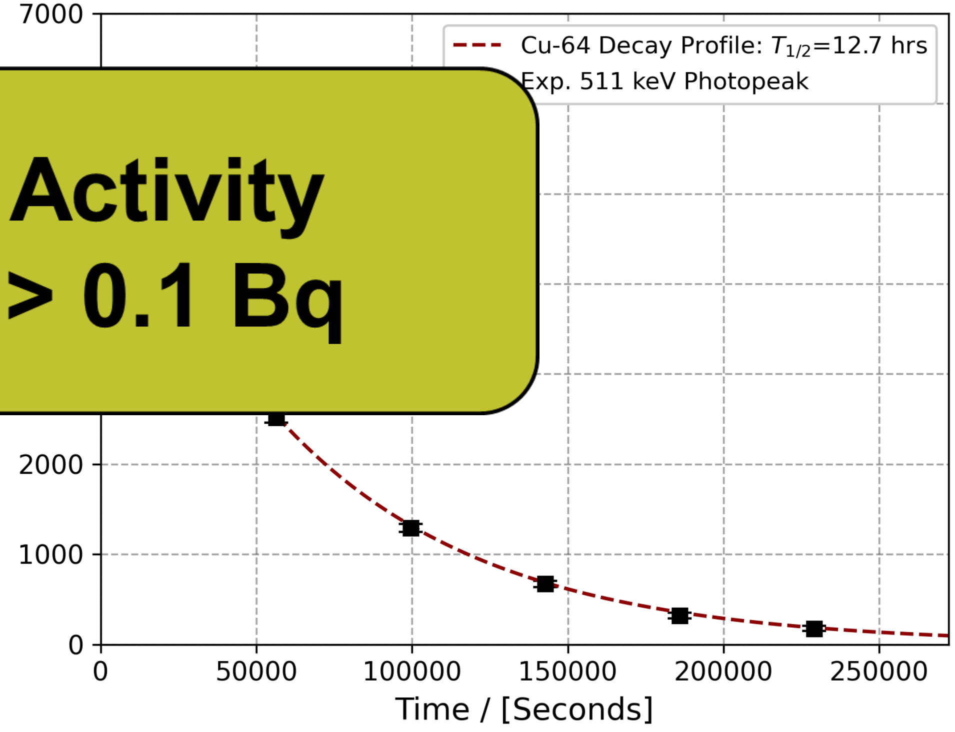
National Laser-Initiated Transmutation Laboratory University of Szeged

Direct Production of >99.95% Radioisotopic Pure Cu-64 from Natural Zinc Targets

Background Corrected Gamma-Spectra



511 keV Photopeak Half-Life



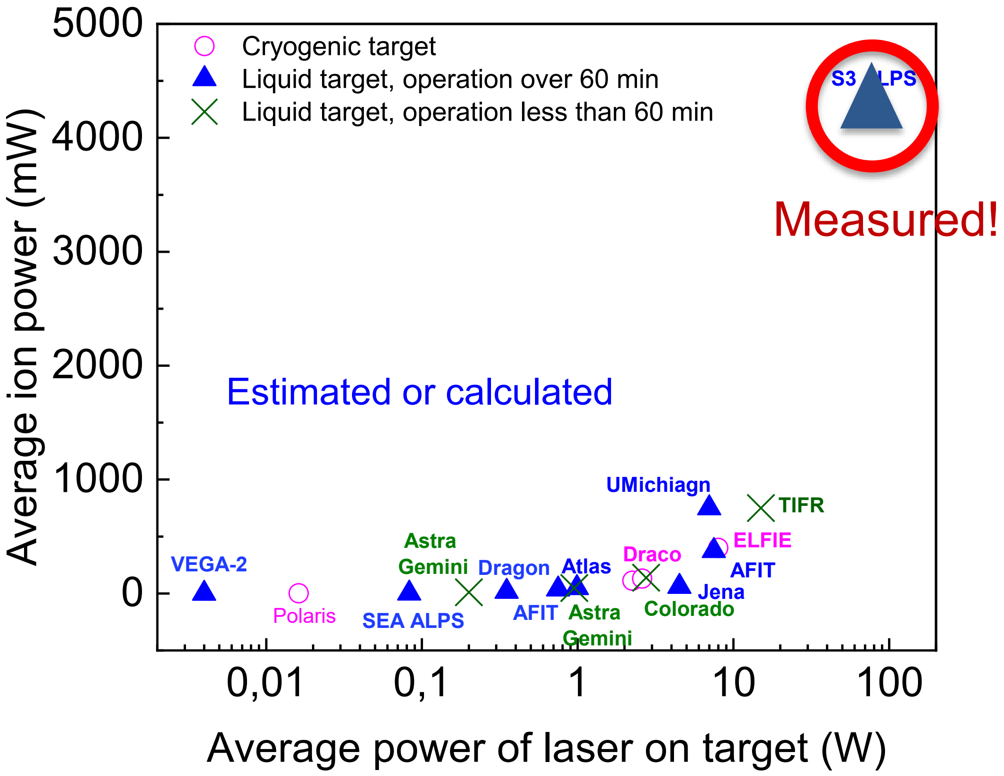
Cu-64:Cu-67 Activity

54.4±2.4 Bq : > 0.1 Bq

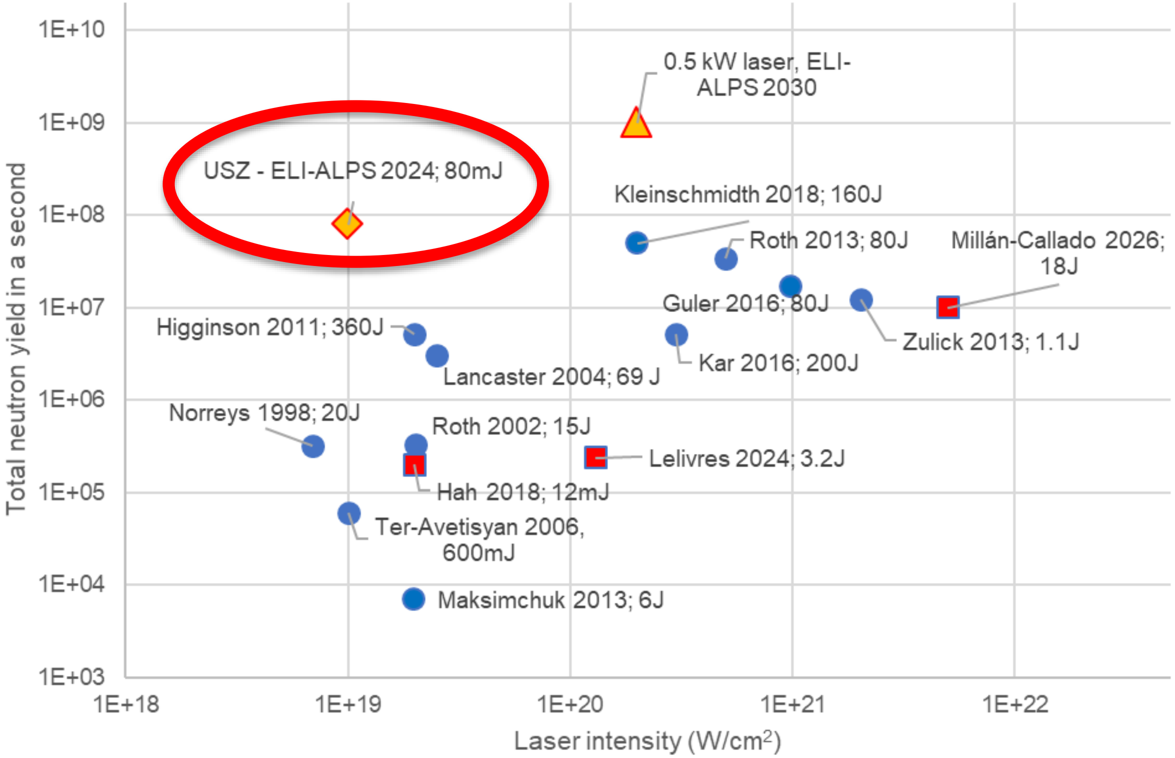
State-of-the-art

HUNGARIAN NATIONAL LABORATORY

High average power ion acceleration



Neutron yield per second



Real practical breakthrough is expected for once the average power of high peak power lasers reaches kW level – foreseen in 3-5 years.

Summary

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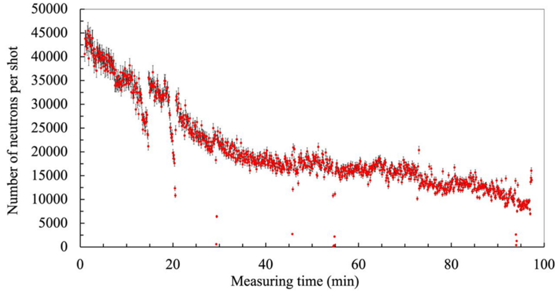
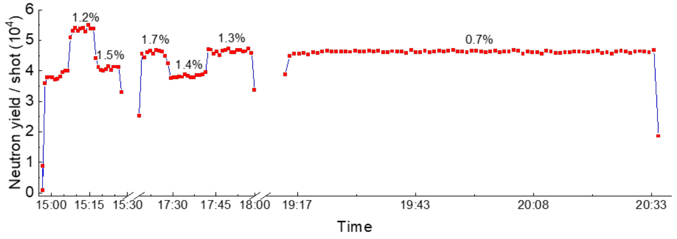
- **Neutron generation from dPE @ 1 kHz, 80 mJ (2024)**
  - at 1 kHz (continous)
  - 450 nm D_2O leaf + 1mm C_2D_4

Peak yield: 7×10^7 n/s
~10^7 n/s, 3x100min



- **Neutron generation from D_2O @ 1 kHz, 80mJ (2025)**
  - at 1 kHz (continous)
  - 420 nm D_2O leaf + D_2O

Peak yield: 4×10^7 n/s
4×10^7 n/s, hours



- **Future work:**
  - optimisation directly for neutron yield
  - increase stability (below 1%)
  - increase trouble-free continous operation (>6 h)
  - use high(er) average power laser(s)

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- 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

Thank you for your attention

NLTL National Laser-Initiated Transmutation Laboratory University of Szeged