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NLTL National Laser-Initiated Transmutation Laboratory University of Szeged

Generation of fast neutrons with ions accelerated by a far-infrared laser

312792

Karoly Osvay

BNL Users' Workshop

1st March, 2023

National Laser-Initiated
Transmutation Laboratory
University of Szeged

Outline

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Motivation

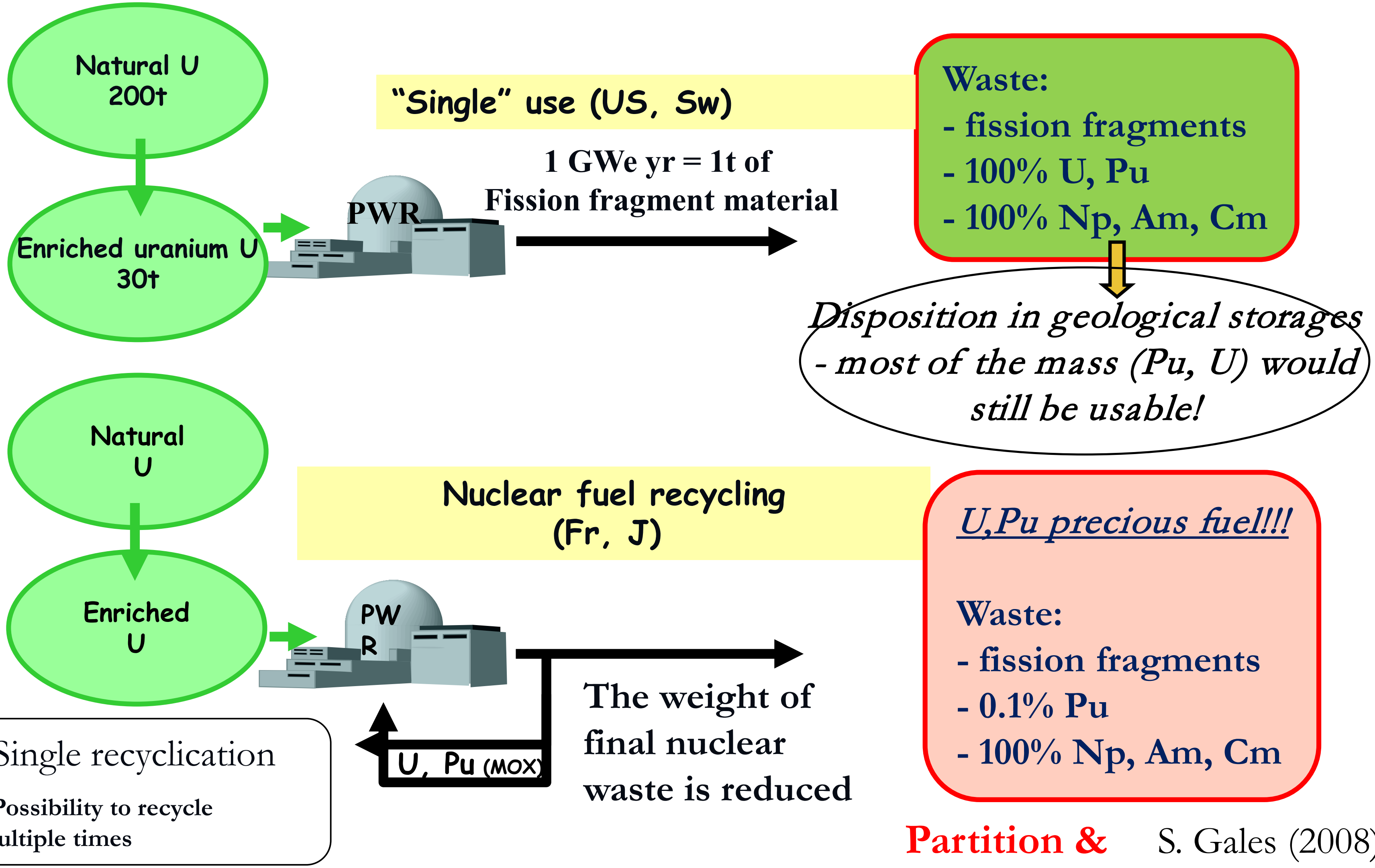
National Laser-Initated Transmutation Laboratory

- **Deuteron acceleration with few cycle pulses**
    - **effect of chirp**
- **Neutron generation**

Proposed experimental series

- **Scientific aims**
- **Activity plan**

Nuclear Waste Management Strategies



Natural U
200t

Enriched uranium U
30t

PWR

"Single" use (US, Sw)

1 GWe yr = 1t of
Fission fragment material

Waste:
- fission fragments
- 100% U, Pu
- 100% Np, Am, Cm

Disposition in geological storages
- most of the mass (Pu, U) would still be usable!

Natural
U

Enriched
U

PWR

Nuclear fuel recycling
(Fr, J)

U, Pu (MOX)

The weight of final nuclear waste is reduced

U,Pu precious fuel!!!

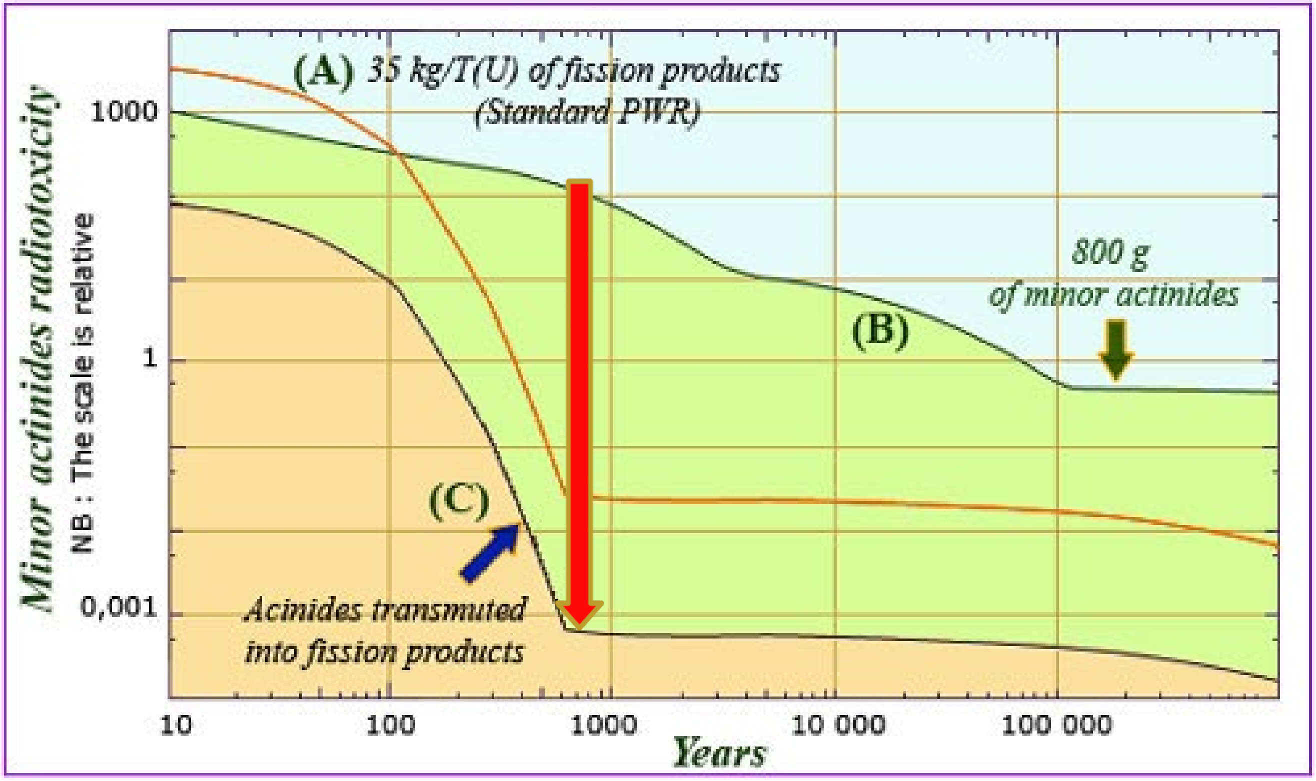
Waste:
- fission fragments
- 0.1% Pu
- 100% Np, Am, Cm

- Single recyclication
- Possibility to recycle multiple times

Partition & Transmutation

S. Gales (2008)

The Significance of Transmutation



Radiation time reduction:
1 000x

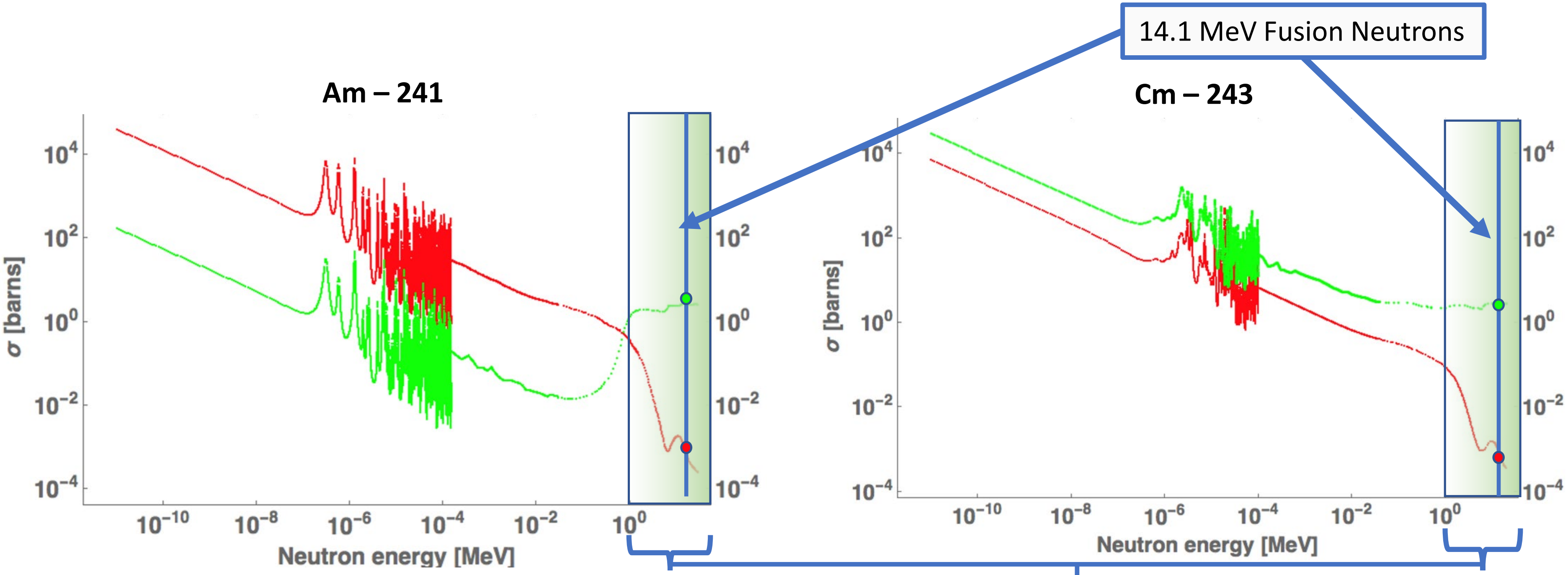
Volume reduction:
100x

Neutron Energy Window: MA Fission Triggered (1-15MeV)

Neutron Absorption vs Fission

$^{241}Am + n \rightarrow {}^{242}Am$

$^{241}Am + n \rightarrow FP_a + FP_b + \ldots + (3\text{-}7)$ “n” s + energy



14.1 MeV Fusion Neutrons

Am – 241

Cm – 243

Favorable Neutron Energy:

Fission > Neutron Absorption

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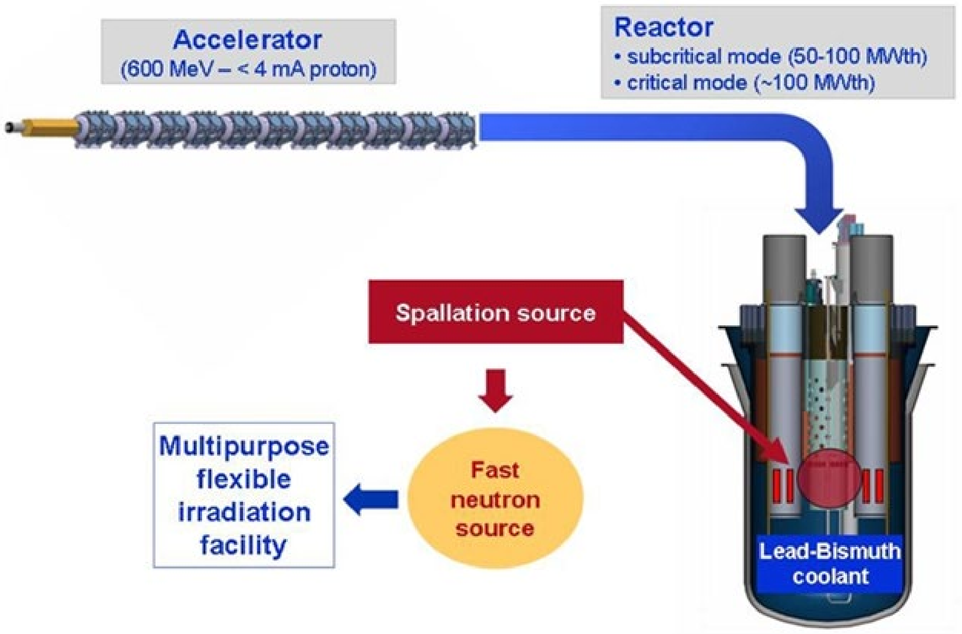
The first AD research reactor - MYRRHA



Accelerator
(600 MeV – < 4 mA proton)

Reactor
- subcritical mode (50-100 MWth)
- critical mode (~100 MWth)

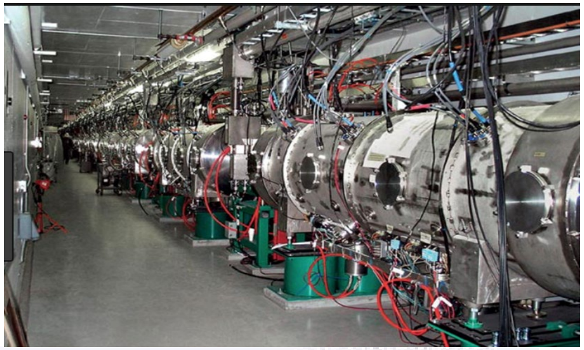
Spallation source

Fast neutron source

Multipurpose flexible irradiation facility

Lead-Bismuth coolant

- Large infrastructure
- 600 MeV – 1.5 GeV Proton Accelerators
  Large undertaking in of itself
- To be operational mid 2030's



Large neutron source (spallation)

Can laser ion acceleration do it *better* (than a linac)?

[Better]: more reliable

(>99% availability vs. 85%, beam trips <5min)

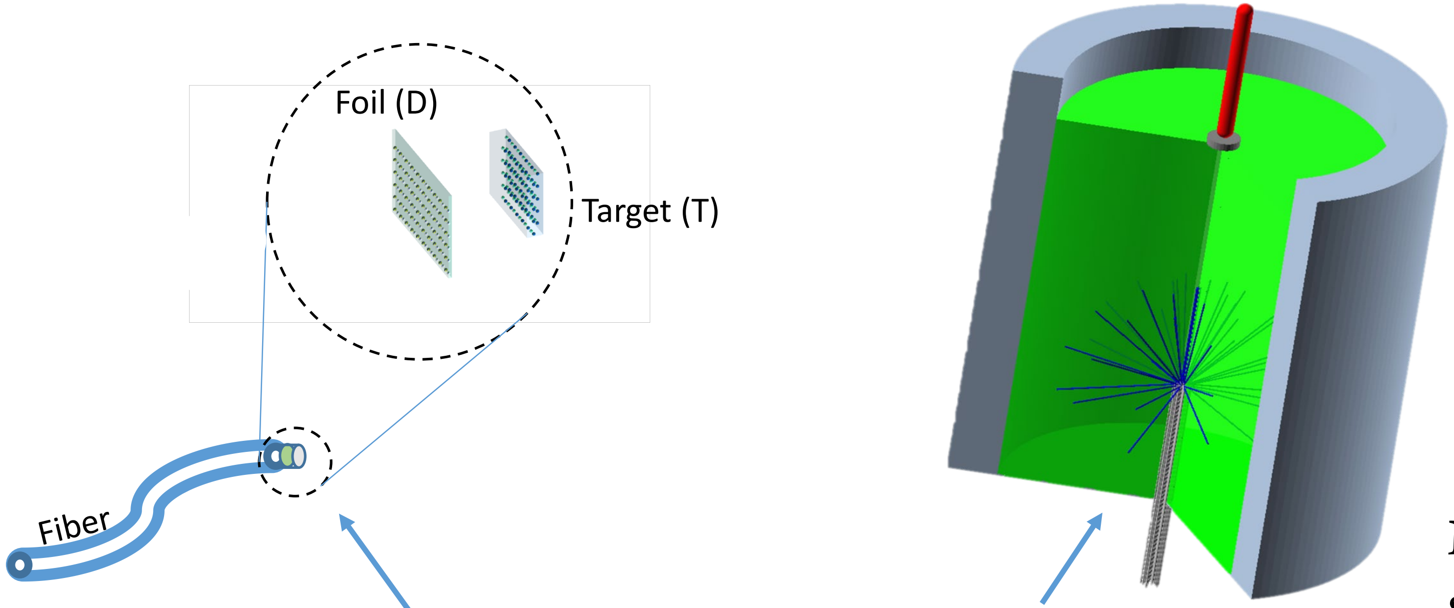
less electrical consumption/higher efficiency

(Myrhha: ~180MW)

smaller footprint, smaller real estate

…

The Tajima-Mourou Scheme of a Neutron Source for a Laser-based Transmutator



Laser-based fusion neutron source (DT / DD)

Molten salt sub-critical reactor

Tajima et al., Fus.Sci.Tech., **77**, 251 (2021)

Neutron needs and lasers – energy conservation

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Sub-critical reactor, *k>0.99* -> 10^{16} n/s, >1 MeV/n

Average power of the neutrons: 1.6 kW (1.6 kJ /s)

Laser needs

1% conversion from laser to neutron: 160 kW laser

0.1% conversion from laser to neutron: 1.6 MW laser

Number of lasers: 10… 100

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1 March 2023

Can laser ion acceleration do it *better* (than a linac)?

Reliability - chance of one laser is broken within a year is < 10^{-7}

Trouble-free operation of a laser (months):	2	10
Number of laser systems:	100	10

Novel reactor architecture

Multiple sources – isotropical burn
Fast feedback and control - AI

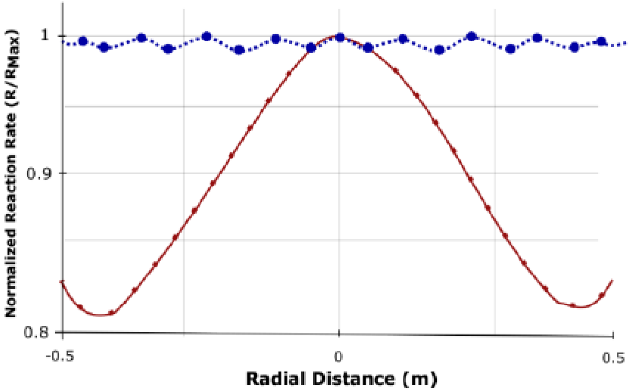

Fig. 11 Relative reaction rate based distance from center of example cylindrical core with reflective wall. Single source vs. multiple sources

J. Tanner et al., PhD Thesis, UCI

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
11×10^{6} n/s

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

Photonuclear

- Accelerate electrons
- Brehmstralung and high Z converter: (γ,n), Li(p,n), D(d,n) (T)d,n)

2.9×10^{7} n/J
0.5×10^{6} 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)

$\sim8\times10^{10}$ n/J
$\sim1300\times10^{6}$ n/s
~1% laser->neutron

Martinez et al., MatRadExt 7 (2022) 024401

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High yield neutron generation
Route A - High average power lasers

Average power of industrial ps lasers is >(>)1kW

Average power of scientific, few cycle pulse lasers (ELI) is >(>)100W.

Current laser technology supporting high average power and relativistic pulse intensity is the high repetition rate, few TW peak intensity one.

↓

Neutron generation with high average power, few cycle laser pulses.

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University of Szeged, Hungary

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Mission
Development of a laser based neutron source for transmutation of nuclear waste

Aim (2019-23/24)

Efficient acceleration of deuterons, and subsequently neutrons with few cycle high repetition rate lasers.

Funds: Hungarian Government (net ~7.6 M€; 20% for ELI-ALPS)

Primary venue: ELI-ALPS (as a duistingushed user)

Secondary venue: Dept Optics, University of Szeged

Consortium: Ecole Politechnique, TAE Technologies, and Uni Szeged
MoU signed 5th April, 2019

Collaborations: ATOMKI, ELI-ALPS, RAL CLF, TU Budapest, …

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Fast neutron generation with 1 Hz repetition rate

Neutron generation

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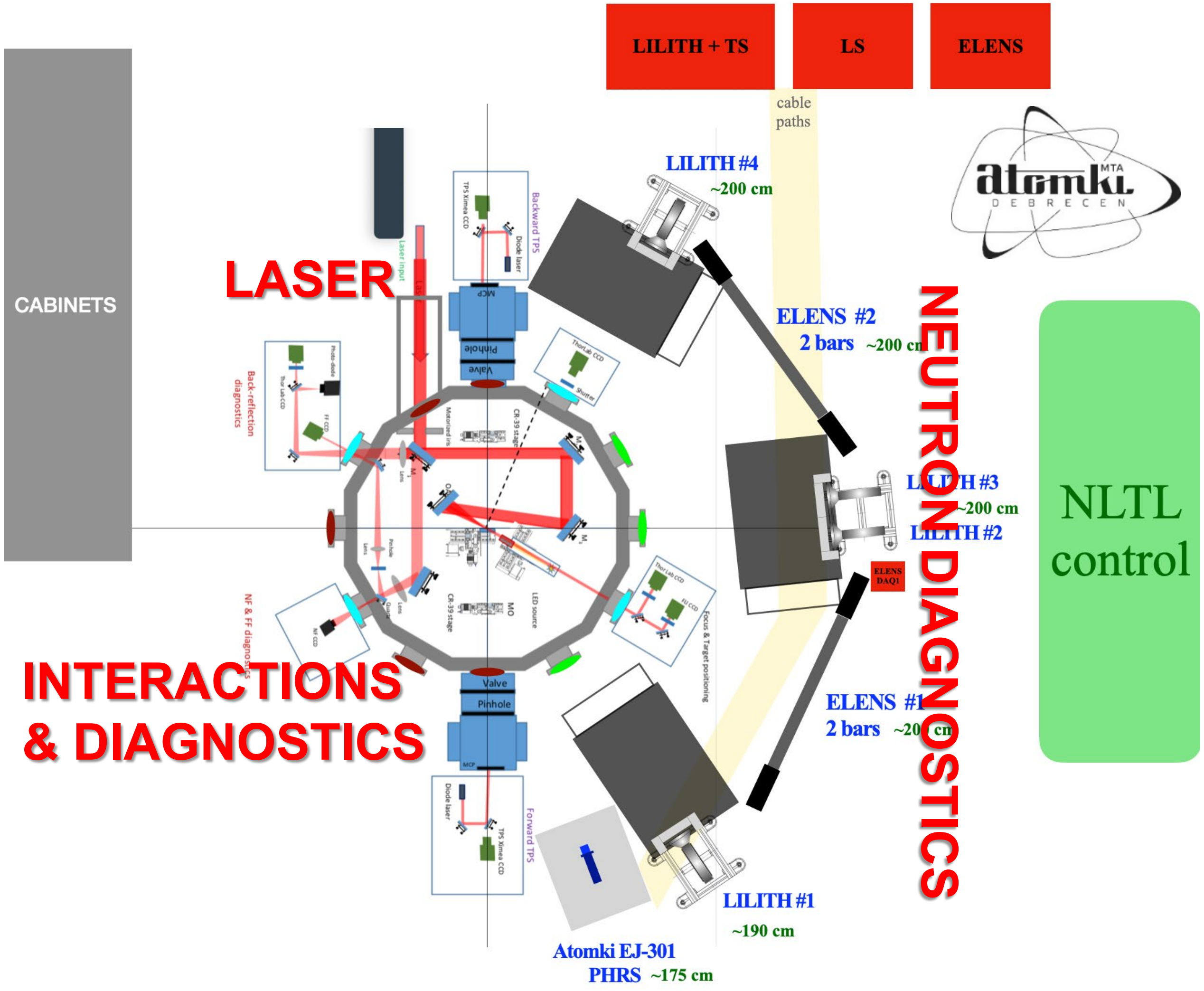
Laboratory time in ELI-ALPS

10.6.22-23.06.22, 7 laser days, ~3000 shots in 3 days



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INTERACTIONS

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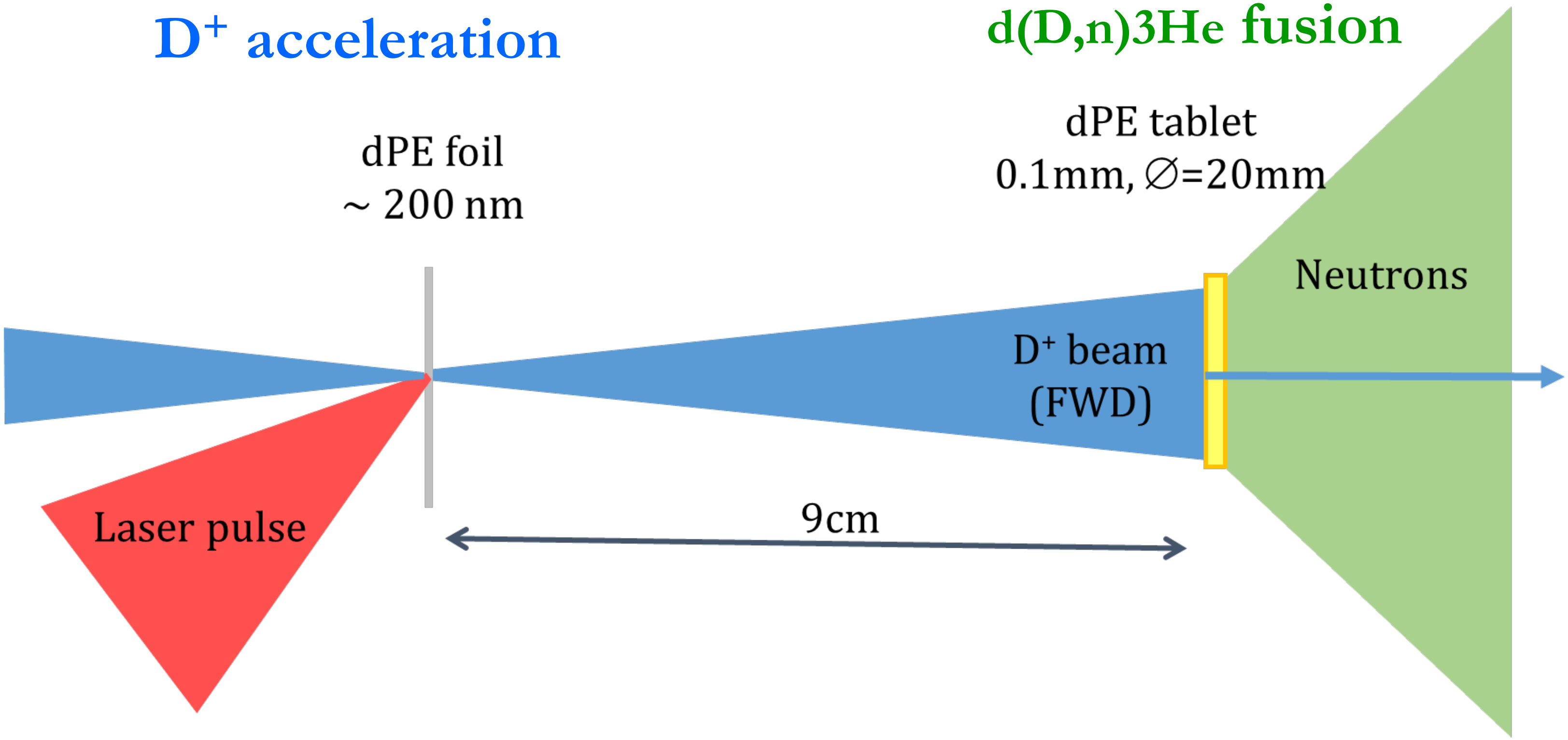

Primary target (pitcher)

Home-made

Bar et al., RSI **91**, (2020) 103302

Secondary target (cathcer)

from dPE powder, press-machine

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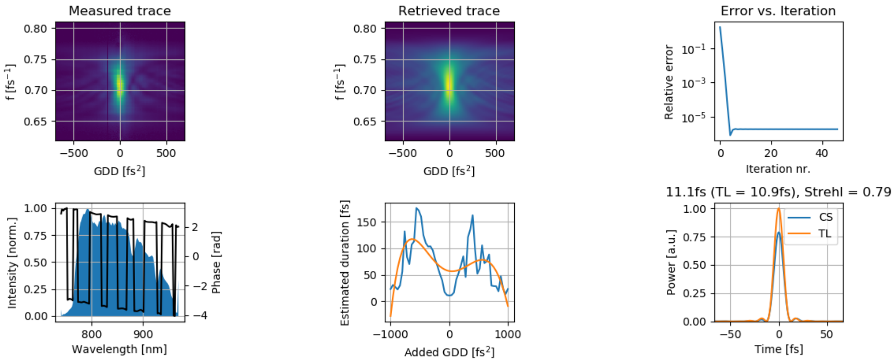
SEA laser (10Hz, OPCPA) of ELI-ALPS parameters *on target*

Pulse energy: ~*35 mJ*
(measured for each shot)

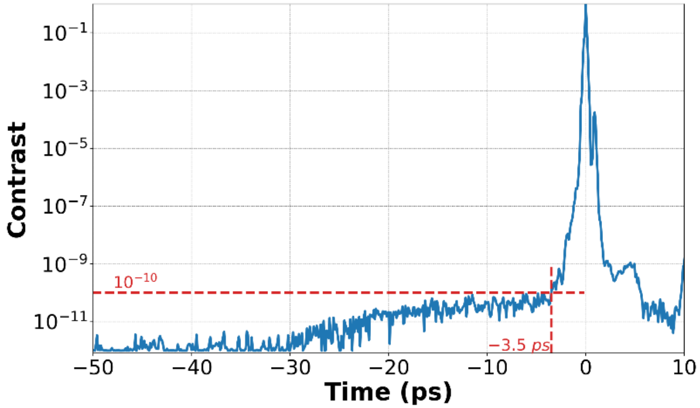


Laser pulse duration: *11.6 fs*
Measured in vacuum, after OAP,
with disp scan

Focal spot FWHM: 2.9×3.5 μm^2,
Strehl ratio: >0.8

Peak intensity in focus:
~10^{19} W/cm^2 (a_0=2.3)

Temporal contrast



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

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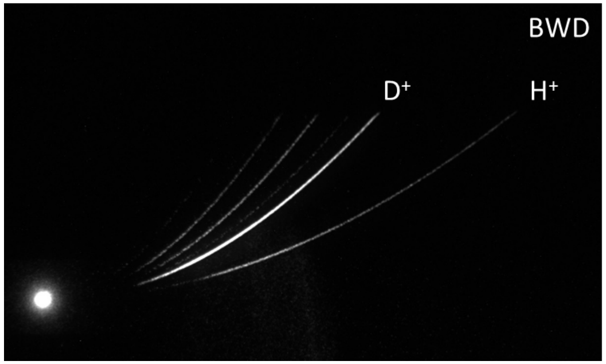
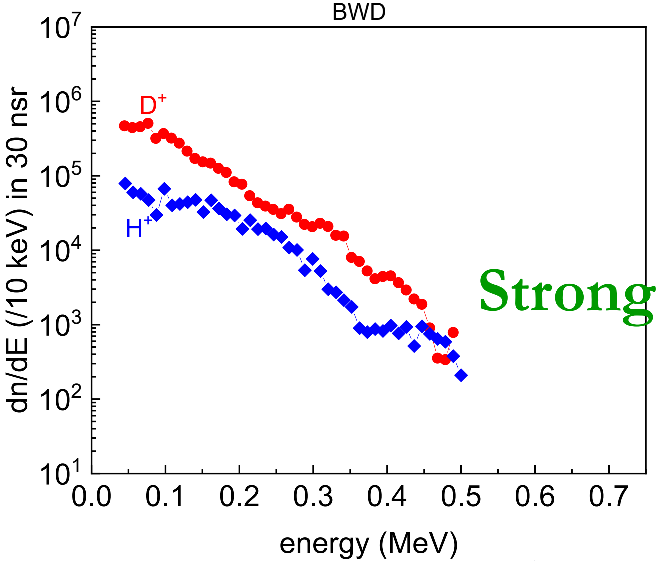
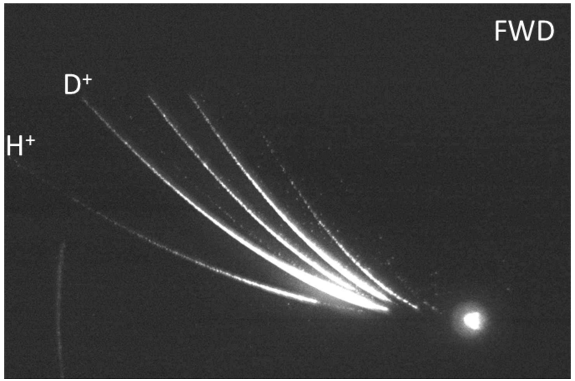
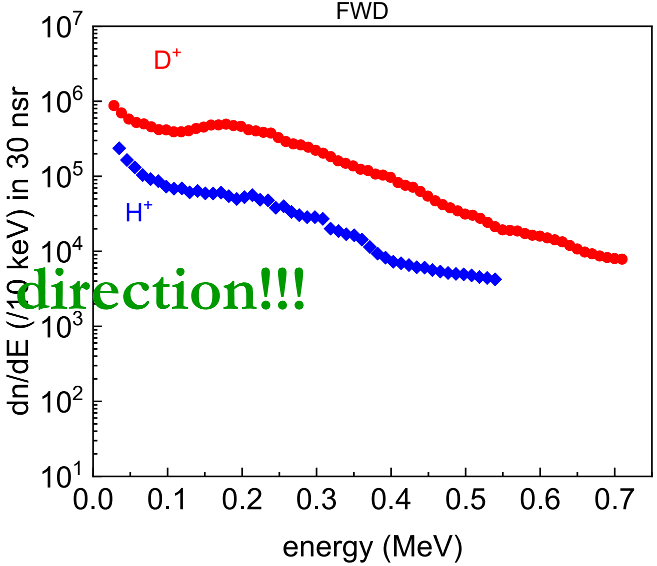
Proton and Deuterion and acceleration at 1 Hz repetition rate

Each shot is recorded and stamped – example shot #976









Strong D+ in FWD direction!!!

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Proton and deuterion acceleration GDD and TOD scan

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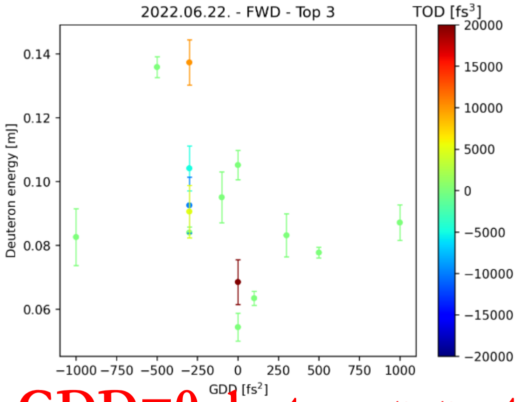
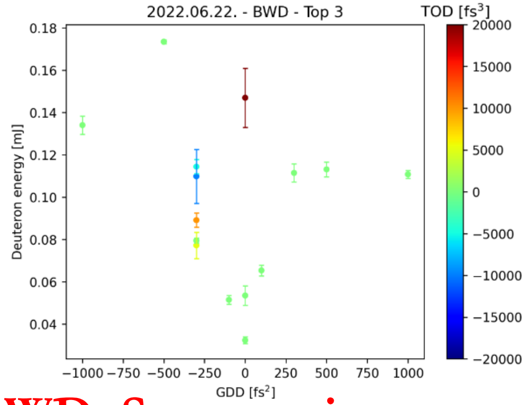
22nd June, per bursts (each of 75shots)

FWD **BWD**

Energy

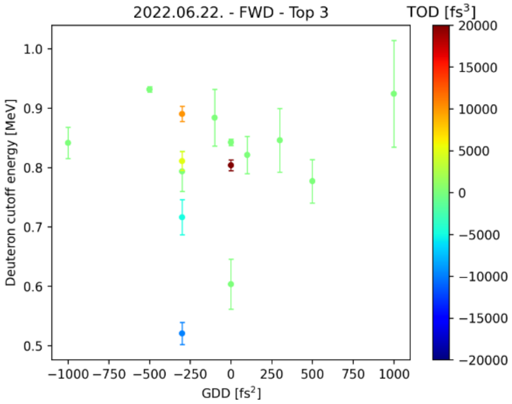


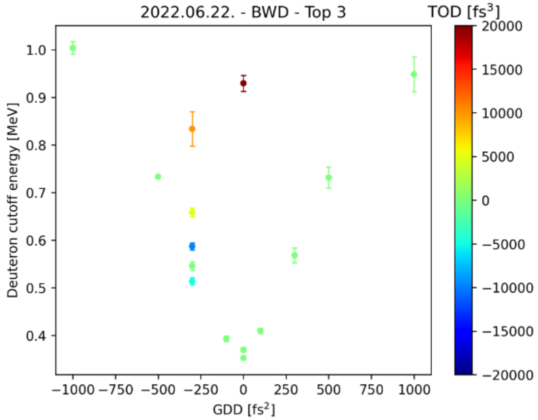


FWD: Min at GDD=0, but asymmetric

BWD: Symmetric to zero GDD

Cut-off





Full evaluation is in progress!

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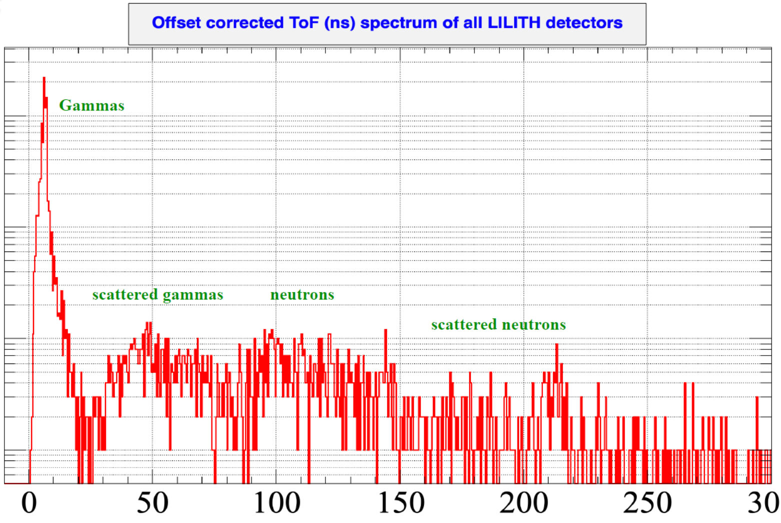
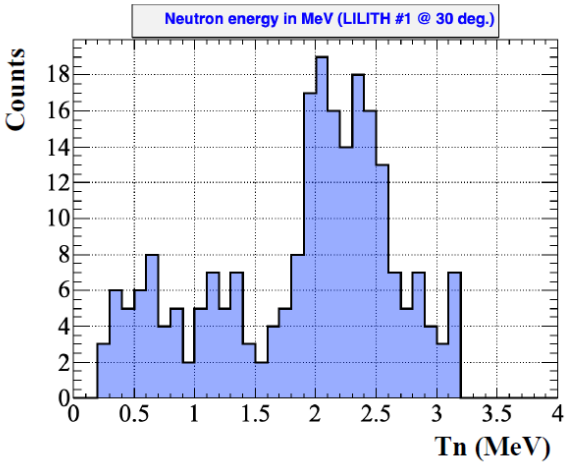
Fast Neutron generation at 1 Hz repetition rate

”Time-of-flight” recording of all shots

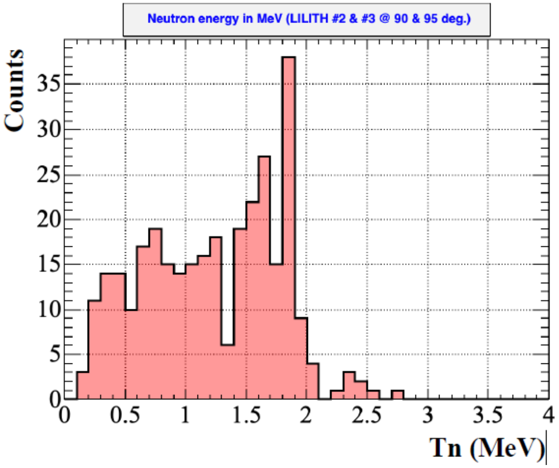


Neutrons in various directions

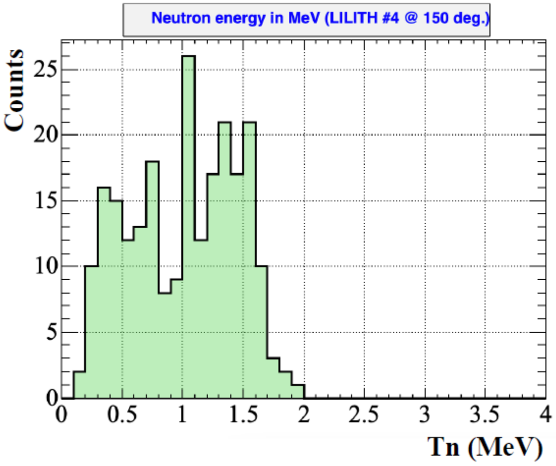
Forward



Zero



Backward



High yield neutron generation

Route B – Increase the laser-to-neutron conversion efficiency

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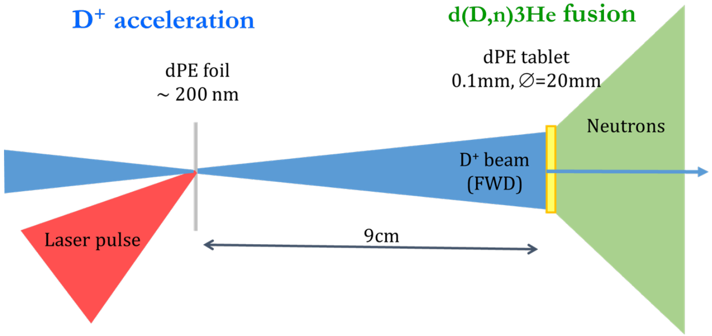
Increase the efficiency of deuteron generation with low (or no) debris targets



Let’s investigate neutron generation with long wavelength, high peak intensity lasers!

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1 March 2023

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Fast neutron generation with ps 5J CO_2 laser

Major scientific aims – expected results

Experimental proof of previous, mainly theoretical results on wavelength-scaling theories for ions heavier than protons.

Scaling of 9.2μm laser-driven proton and deuteron acceleration as a function of
- pulse duration;
- intensity;
- polarisation.

First ion acceleration results from a low density foam target – a kind of intermediate transition between gases and solids.

First generation of neutrons with a ps CO_2 laser.

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Fast neutron generation with ps 5J CO_2 laser

Planned campaigns

1st: Comparative study of proton and deuteron acceleration from gas targets (H2 and D2), with 2 ps, up to 5-10 J pulses.

- Measure proton and deuteron spectra
- Spatial ion beam profile.
- Change of spectral phase (and duration) of the pulses
- Polarisation effect (linear vs circular)
- Calibration of the Thomson ion spectrometer, if needed.

Further potential collaborating partner is John Adams Institute of Imperial College.

2nd : Proton and deuteron acceleration from foam targets, with 2 ps, up to 5-10 J pulses..

- Measure proton and deuteron spectra
- Spatial ion beam profile.
- Change of spectral phase (and duration) of the pulses
- Explore the interactions with circularly polarized pulses
- Effect of pre-pulses

Fast neutron generation with ps 5J CO_2 laser

Planned campaigns

3rd: Comparative study of deuteron acceleration from gas and foam targets, with 0.5 ps, 5J pulses.

- Measure proton and deuteron spectra, spatial beam profile.
- Change of spectral phase (and duration) of the pulses
- Effect of pre-pulses

4th: generation of neutrons with the CO2 laser generated ions on targets and pulse durations, which seemed most promising in the previous campaigns.

- Measure proton and deuteron spectra
- Measure neutron spectrum and yield
- Measure neutron angular distribution.

Fast neutron generation with ps 5J CO_2 laser

Experimental parameters

Pitcher targets:

- Gas jets (to be provided by ATF)
- Gases (H2, D2, to be provided by NLTL USZ)
- Deuterised foam targets (prepared and provided by NLTL USZ)

Catcher target:

- dPET tablet and / or Li target (prepared and provided by NLTL USZ)

Laser parameters

- Laser pulse duration: 2 ps and, from 2024, 0.5 ps.
- Laser pulse manipulation: spectral phase, polarisation, and pre-pulse.

Diagnostics expected from ATF:

- Thomson ion spectrometer with MCP / CCD camera
- Electron spectrometer (with MCP / CCD or other electronic means)
- XUV spectrometer (range up to 1keV)

Diagnostics from NLTL Uni Szeged

- Bubble (neutron) spectrometer detector system
- Plastic scintillator (neutron) detectors.

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- pulse duration;
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- polarisation.

First ion acceleration results from a low density foam target – a kind of intermediate transition between gases and solids.

First generation of neutrons with a ps CO_2 laser.

(Further) applications of laser-generated neutrons

Radiation damage research (space, fusion reactors, etc.)

Home land security (proliferation)

Radiation safety

Isotope production

Radiobiology (very short neutron bunches)

Nuclear physics (very short neutron bunches)

…

NLTL

M. Füle, T. Gilinger, P. Gaál, M. Karnok, B. Kis, **A.P. Kovács,**
B. Nagy, B. Nagyillés, **P. K. Singh, P. Varmazyar, S. Ter-Avetisyan**

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G. Szabó, L. Tóth, **Sz. Tóth**

eli attosecond

atomki MTA DEBRECEN

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

A. Alejo, J. Benlliure, **J.N. Penas,** A.B. Fernandez, M. Seimetz

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

eli beamlines

S. Bulanov, G. Korn, **D. Margarone,** M. Matys, P. Valenta, **A. Velyhan**

tae TECHNOLOGIES

A. Necas, T. Tajima

G. Mourou, J. Wheeler

l'X ÉCOLE POLYTECHNIQUE

INSTITUT POLYTECHNIQUE DE PARIS

Advanced Microfluidic Systems GmbH

S. Figul, G. Marowski

V. Bychenkov

Lebedev Institute

Grants are available until end 2024; further grant applications are in progress

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- Hungarian Government: ITM 1096/2019. (III.8.)

INNOVÁCIÓS ÉS TECHNOLÓGIAI MINISZTÉRIUM

ITM
FELADATUNK A JÖVŐ

- National Research, Development and Innovation Office
  NKFIH-877-2/2020
  NKFIH-476-4/2021
  NKFIH-476-16/2021

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NEMZETI KUTATÁSI, FEJLESZTÉSI
ÉS INNOVÁCIÓS HIVATAL

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CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 Regenerative Amplifier Beam	Wavelength	µm	9.2	*Wavelength determined by mixed isotope gain media*	
	Peak Power	GW	~3		
	Pulse Mode	---	Single		
	Pulse Length	ps	2		
	Pulse Energy	mJ	6		
	M^2	---	~1.5		
	Repetition Rate	Hz	1.5	*3 Hz also available if needed*	
	Polarization	---	Linear	*Circular polarization available at slightly reduced power*	
CO_2 CPA Beam	Wavelength	µm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2*
Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.	Peak Power	TW	5	*~5 TW operation will become available shortly into this year's experimental run period. A 3-year development effort to achieve >10 TW and deliver to users is in progress.*	
	Pulse Mode	---	Single		
	Pulse Length	ps	2		*Adjustable from 2ps – 20ps*
	Pulse Energy	J	~5	*Maximum pulse energies of >10 J will become available within the next year*	*5-10J*
	M^2	---	~2		
	Repetition Rate	Hz	0.05		*Shot on demand*
	Polarization		Linear	*Adjustable linear polarization along with circular polarization can be provided upon request*	*Lin. and circular*

Special Equipment Requirements and Hazards

- CO_2 Laser

  - Pulse duration variable from the transform limit up to 10x transform limit
  - Polarization linear and circular
  - Variable pre-pulse level

  - Diagnostics expected from ATF:
  - Thomson ion spectrometer with MCP / CCD camera
  - Electron spectrometer (with MCP / CCD or other electronic means)
  - XUV spectrometer (range up to 1keV)

- Hazards & Special Installation Requirements
  - Radiation shielding against fast neutrons

Experimental Time Request

CY2023 Time Request

Capability	Setup Hours	Running Hours
Electron Beam Only		
Laser* Only (in Laser Areas)	30	100 (incl. setup)
Laser* + Electron Beam		

Total Time Request for the 3-year Experiment (including CY2023-25)

Capability	Setup Hours	Running Hours
Electron Beam Only		
Laser* Only (in Laser Areas)	120	400 (incl. setup
Laser* + Electron Beam		

* Laser = Near-IR or LWIR (CO_2) Laser

Thank you for your attention

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