Recent results on laser ion acceleration from the Uni Szeged NLTL beamline at ELI-ALPS

Károly Osvay

ELI-ALPS User Workshop
8th November, 2021
Outline

Motivation of a laser-based neutron source
  Energy challenge
  Nuclear energy and Transmutation

National Laser-Initiated Transmutation Laboratory
  Mission and aims
  Working areas
  Beamline development at ELI-ALPS

Ion acceleration with few cycle laser pulses – results of the first campaigns

Outlook
Global warming – climate change

CO₂ Levels Are Rising
Carbon dioxide concentrations in the atmosphere have been rising since the Industrial Revolution. The chart shows evidence from ice cores before 1958 and daily measurements taken in Hawaii after 1958.

ATMOSPHERIC CARBON DIOXIDE CONCENTRATIONS
Parts per million, 1700-present

- March 1958: 315 ppm
- May 4, 2018: 409.4 ppm

SOURCE: Scripps Institution of Oceanography
InsideClimate News
Energy challenges and global warming

Energy – CO₂ footprint of the big(ger) economies of EU
CO₂ emission and electricity generation (CO₂ equivalent/ Kwh)

Relative emission compared to power generation
Source: ENTSO-E, IPCC 2018
From: 01-Jan-2018 to: 31-Dec-2018
Nuclear Energy – *much beyond* Net Zero Emission

**Economic/political disadvantages:**
- PR: fears regarding atomic bombs, military applications
- Huge investment, long return time

**Issues to be considered more significantly:**
- Nuclear weapon stop / controlling, compliance
- Nuclear plant safety (design: Fukushima, human: Chernobyl, etc.)
- Nuclear waste / used fuel rods

430 operational power station
- ~350 Gwe energy / y
- ~2500 t nuclear waste / y

~93.5% U
1.2% Pu
0.2% MAs (~500 t)
5% non TRU
The Significance of Transmutation

Radiation time reduction: 1000x

Volume reduction: 100x
Transmutation

www.assignmentpoint.com/science/physics/nuclear-transmutation.html
The Tajima-Mourou Scheme of a Neutron Source for a Laser-based Transmutator
Neutron Energy Window: MA Fission Triggered (1-15MeV)

Neutron Absorption vs Fission

\[ ^{241}\text{Am} + n \rightarrow ^{242}\text{Am} \]
\[ ^{241}\text{Am} + n \rightarrow \text{FP}_a + \text{FP}_b + \ldots + (3-7) "n" s + \text{energy} \]

Favorable Neutron Energy: Fission > Neutron Absorption

14.1 MeV Fusion Neutrons
Concept of Transmutation Channel – "Catapult" of Energy (Tajima-Mourou)

140 keV Deuteron Beam

14 MeV Neutron

200 MeV Fission-Q

1000 x
The first AD research reactor - MYRRHA

- Large infrastructure
- 600 MeV – 1.5 GeV Proton Accelerators
  - Large undertaking in of itself
- Very Localized
- To be operational in 2030’s

Large, non-efficient neutron source
Critical Steps Towards the Conceptual Design of a Neutron Source for a Laser-based Transmutator

Step 1 (to be demonstrated)
Efficient acceleration of deuterium nuclei with few-cycle laser pulses (CAIL scheme) to only few 100s keV

Step 2 (to be demonstrated)
Efficient generation of neutrons (few MeV) with the accelerated deuterons via DD fusion

Step 3 (feasibility study)
High yield neutron generation – towards $10^{13}$-$10^{15}$ n/sec
scaling from DD to DT
high reprise – low pulse energy OR low rep.rate high pulse energy
(CAIL / RPA or TNSA)
Challenge 1
Coherent Acceleration of Ion by Laser (CAIL)
(thin target, single- (few-) cycle laser pulse)
\(a_0 \sim \sigma\)

Ultra-short, high power laser (SYLOS)

D+ beam

Nanometric foil (<30 nm)

<table>
<thead>
<tr>
<th>Laser pulse (fs)</th>
<th>Efficiency (%)</th>
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<tbody>
<tr>
<td>114</td>
<td>0.8</td>
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<tr>
<td>45</td>
<td>1.8</td>
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<tr>
<td>20</td>
<td>3.7</td>
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<tr>
<td>15</td>
<td>4.8</td>
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<td><strong>9</strong></td>
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Laser energy to Deuterium energy conversion efficiency
**Challenge 2**

**High Repetition Rate Targets**

Most promising candidates so far

- **Tape target**
  - PRAB 20, 041301 (2017)

- **Cryo H (D) ribbon**
  - HPLSE 7, e50 (2019)

- **Liquid jet**
  - PHYS. REV. X 6, 041030 (2016)
Mission

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

Aim (2019-23)

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

Funds: Hungarian Government (bruto ~3500MHUF -> net ~7.8 M€)

Primary venue: ELI-ALPS (as a distinguished 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, ...
A1 Study of fusion neutron generation by few cycle laser pulses
- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

A2 Target system developments
- Design and develop a dual target system up to 10 Hz operation
- Development of high repetition rate / renewable single target system
- Development of high repetition rate / renewable combined target system

A3 Fusion neutron generation with kHz class few cycle lasers
- Development of a deuteron accelerator with the SYLOS laser (1 kHz)
- Development of a neutron generator based on the SYLOS laser
- Design considerations for 100 kHz repetition rate operation

A4 Feasibility studies of advanced aspects of a laser-driven transmutator
Admin status

"Green field" project
It was started from "ground zero" (except for lasers at ELI-ALPS)
The mission has been to enhance the use of ELI-ALPS

Employees (currently)
Seniors: 11
Students: 12 (BSc, MSc)
PM: 3

Equipment, materials, services contracted (till now)
Public procurements: 6 pcs, total ~760MHUF
Materials: ~240MHUF
R&D procurements: 4 pcs, total ~500MHUF
ELI-ALPS (special R&D) 790MHUF
A1 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
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Z. Halász
Z. Korkulu

TAE Tech
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A. Necas

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J. Csontos
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K. Mogyorósi
S. Mondal
K. Nelissen
D. Papp
T. Somoskői
L. Tóth
Sz. Tóth
A1 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

First campaign in ELI-ALPS

17.02-03.18 and 05.05-03.07, 2020
Shooting on target: 26 working days
1264 single shots

Commissioning of the SEA laser

Target materials:
  Commercial: Al, C, CH, DLC, PET
  Home-made: CH, DH

Target thickness:
  5nm, 10nm, 20nm, 50nm, 100nm, 200nm,
  500nm, 2µm, 9µm
**A1 Study of fusion neutron generation by few cycle laser pulses**

- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

**Second campaign in ELI-ALPS**

19.01-06.05, 2021  
Shooting on target: 14(+3) working days  
306 single shots

Commissioning the LTA1 lab
A1 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

**SEA laser parameters on target**

**Pulse energy:** 30 mJ – 35 mJ
(measured for each shot)

**Laser pulse duration:** 11.1 fs
Measured in vacuum, after OAP, with disp scan

**Focal spot FWHM:** 5.1 μm, **Strehl ratio:** >0.8

**Peak intensity in focus:** \(~1 \times 10^{19} \text{ W/cm}^2\) \((a_0=2.3)\)

**Temporal contrast**
A1 Study of fusion neutron generation by few cycle laser pulses

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Proton acceleration results I

- Relatively high cut-off energy protons (compared to the pulse energy)
- Cut-off is different for FWD and BWD directions
- Some dependence on target thickness and materials
- Large number of protons (above 100keV: $10^{10}$/shot)
A1 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
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Proton acceleration results II

- Insensitive to stretched pulse duration

- Proton (plasma) source size is small (<2.3 \( \mu \text{m} \)) vs laser focii
A1 Study of fusion neutron generation by few cycle laser pulses

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Calibration of CR39 to 40keV – 500keV, with ATOMKI

- Laser plasma accelerator vs tandetron-based accelerator

Calibration of MCP to 40keV – 500keV
**A1 Study of fusion neutron generation by few cycle laser pulses**

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**Modelling of proton acceleration on ultrathin targets**

- Effect of leading edge (pre-heating), plasma expansion: Zsolt Lecz
A1 Study of fusion neutron generation by few cycle laser pulses

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Modelling of proton acceleration on ultrathin targets, with TAE
A1 Study of fusion neutron generation by few cycle laser pulses

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Modelling of proton acceleration on ultrathin targets, with TAE

- 2D and 3D simulations
- Low dimension simulations overestimates the energies
A2 Target system developments

- Design and develop a dual target system up to 10 Hz operation
- Development of high repetition rate / renewable single target system
- Development of high repetition rate / renewable combined target system

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AdMiSys GmbH / LLG
S. Figul
et. al.
A2 Target system developments

- Design and develop a dual target system up to 10 Hz operation
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Laser development at TeWaTi lab, Uni Szeged
To provide a laser source for target development

200 Hz, 1mJ, 30fs  $\rightarrow$  100 Hz, >30mJ, <10 fs

1st phase: end January, 2022
2nd phase: Summer, 2022
A2 Target system developments

- Design and develop a dual target system up to 10 Hz operation
- Development of high repetition rate / renewable single target system
- Development of high repetition rate / renewable combined target system

Tape target (1 µm) development, with TU Budapest

Prototype: 12th November, 2021

Liquid jet (<<1 µm) development, with AdMiSys & LLG, Göttingen

Prototype: end November, 2021
A2 Target system developments

- Design and develop a dual target system up to 10 Hz operation
- Development of high repetition rate / renewable single target system
- Development of high repetition rate / renewable combined target system

Liquid jet thickness measurement in Tewati

Challenges: on-line monitoring
- range: ~ 100nm
- working distance: ~1 m

High pressure gas(jet) development with ?

R&D proposals: under evaluation
Estimated prototyping: end 2022.
A3 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

<table>
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<tr>
<th>Uni Szeged</th>
<th>ATOMKI</th>
<th>Few Cycle</th>
<th>ELI-ALPS – Laser Compression</th>
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A3 Study of fusion neutron generation by few cycle laser pulses

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- Demonstration of neutron generation from CAIL deuterons with the SEA laser

Pulse compression via HCF, with ELI-ALPS & Few Cycle

SEA Laser, 10Hz rep.rate, 12fs $\Rightarrow$ 6fs

First experimental campaign at ELI-ALPS: January, 2022
Estimated final setup: summer 2022.

Pulse compression via MPC, with ELI-ALPS

SYLOS2 Laser, 1kHz rep.rate, 8 fs $\Rightarrow$ <5fs

First experimental campaign at ELI-ALPS: April, 2022
Estimated final setup: end 2022.
A3 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

Final experimental setup & complete beamline in ELI-ALPS

Commissioning the MTA lab: 25th October, 2021
Generation of D from home-made CD film
A3 Study of fusion neutron generation by few cycle laser pulses

- Deuteron generation via the CAIL scheme with the SEA laser
- Demonstration of neutron generation from CAIL deuterons with the SEA laser

**Final experimental setup & complete beamline in ELI-ALPS**

First experiment: December, 2021.
A4 Feasibility studies of advanced aspects of a laser-driven transmutator

- In-situ, non-invasive, laser-driven monitoring of nuclear waste barrel containers
- Investigation of the radiobiological applicability of laser-driven neutron sources

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Isotoptech
A4 Feasibility studies of advanced aspects of a laser-driven transmutator

- In-situ, non-invasive, laser-driven monitoring of nuclear waste barrel containers
- Investigation of the radiobiological applicability of laser-driven neutron sources

CT imaging with hard X-rays

Starting point: Tire CT developed by Uni Szeged and Griffsoft Ltd.
300keV photon

Development directions (until betatron source is available at ELI-ALPS)
- visible spectrally resolved CT
- micro CT with x-ray
Laser-plasma based source 3D Tomography for cargo inspection

H2020 project

Duration: 42 months, start at 01.09.2021
Consortium: 18 establishments
Leader: CEA
Support: 6M€

USZ: Neutron source for nuclear spectroscopy
Summary

Design, procurement and installation most of the equipm’s.
Build up the team(s), collaborators

Commissioning the SEA laser of ELI-ALPS
Commissioning the LTA1 lab of ELI-ALPS
Commissioning the MTA lab of ELI-ALPS

New results and insights on few-cylce laser driven ion acceleration
Outlook

High repetition rate target developments

Ion source for applications & (user) experiments at ELI-ALPS
Fusion neutron source for experiments at ELI-ALPS
Fusion neutron source for homeland security

Physics of ion acceleration with <2 cycle laser pulses

Decision point 1 – go/no-go
towards laser-based transmutation (efficient source of enough neutrons?)

Decision point 2 – go/no-go
towards laser-based neutron generation (for many other applications)

Decision point 3 – which way?
towards high repetition rate, <<10fs (100kHz and beyond)
or towards few-cycle rep-rated PW
THANK YOU FOR YOUR KIND ATTENTION!