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SZEGEDI TUDOMÁNYEGYETEM

# Neutron generation with few cycle lasers - the Hungarian project

**Károly Osvay, Gábor Szabó**

**Budapest**
**6th November, 2019**

# Outline

Scientific and technological issues

Why ELI facilities?

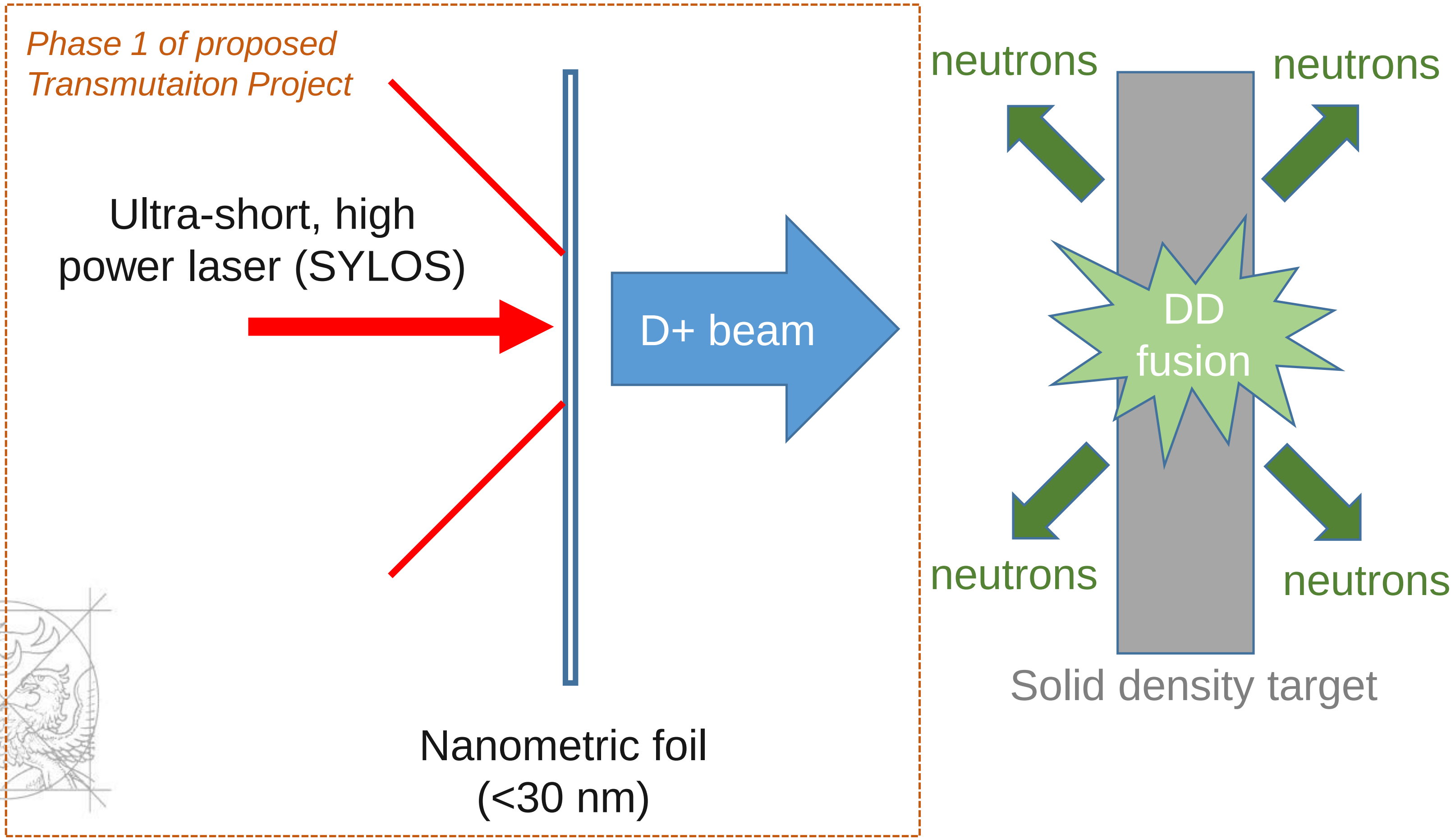
The Hungarian programme

Planned major campaigns 2019-2022

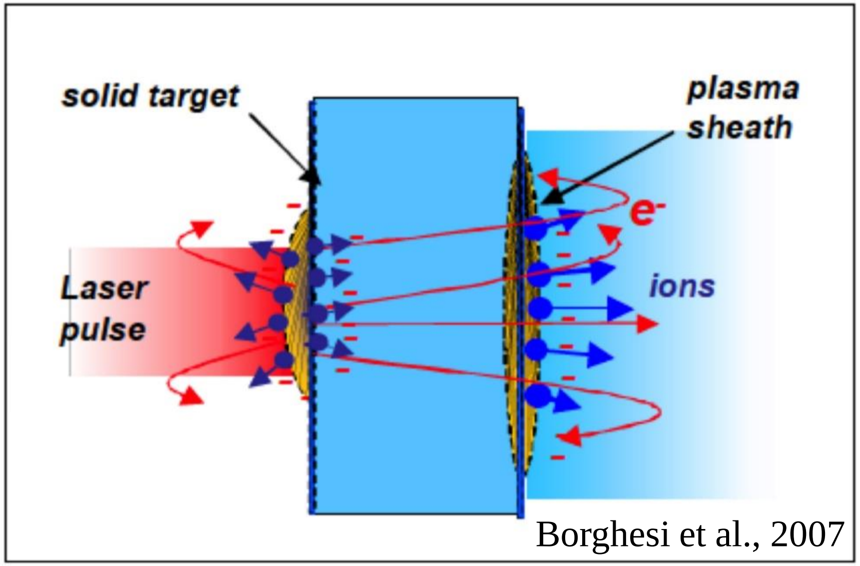
International and national collaborations

Decision points

# The Tajima-Mourou scheme of a neutron source for a laser-based transmutator



# Ion acceleration schemes



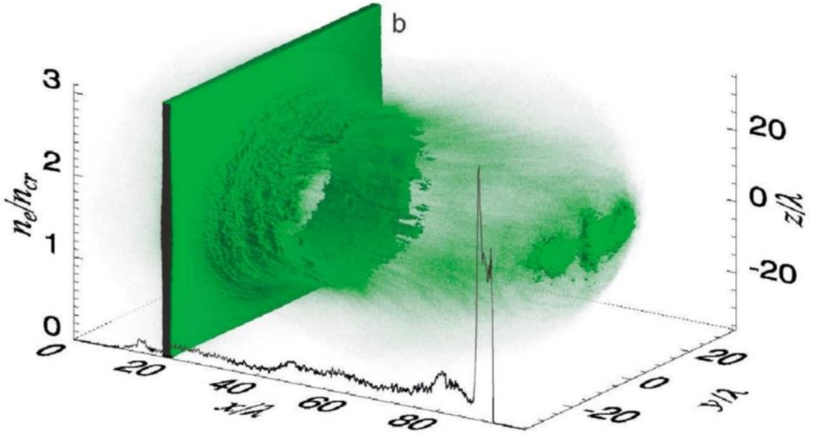
Borghesi et al., 2007

**Target Normal Sheath Acceleration (TNSA)**

**Thick target, multi-cycle (long) pulses**

**Radiation Pressure Acceleration (RPA)**

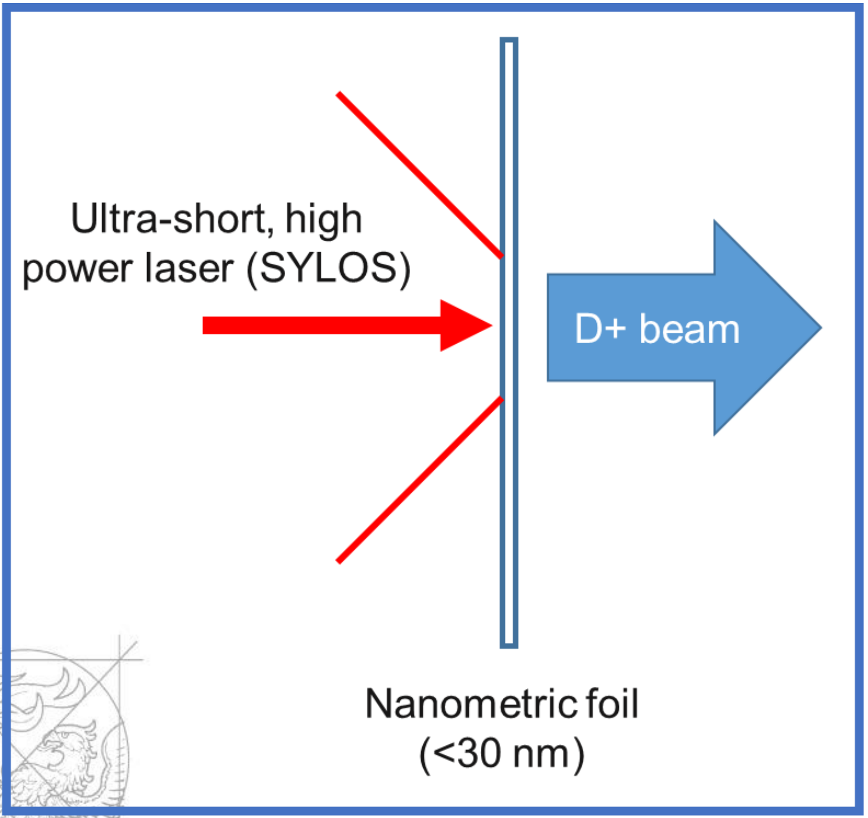
***Thin*** **target, multicycle (long) pulses**



Esirkepov et al., 2004

# Challenge of
# Coherent Acceleration of Ion by Laser (CAIL)
## (thin target, *single- (few-) cycle* laser pulse)






| Laser pulse (fs) | Efficiency (%) |
|---|---|
| 114 | 0.8 |
| 45 | 1.8 |
| 20 | 3.7 |
| 15 | 4.8 |
| **8** | **9** |
| **2** | **40** |

Laser energy to Deuterium energy conversion efficiency

# Critical steps of 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 **few 100s keV**

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

**Step 3** (feasibility to be demonstrated)
High yield neutron generation – towards $10^{13}$-$10^{15}$ n/sec
(high reprate – low pulse energy, low reprate high pulse energy)

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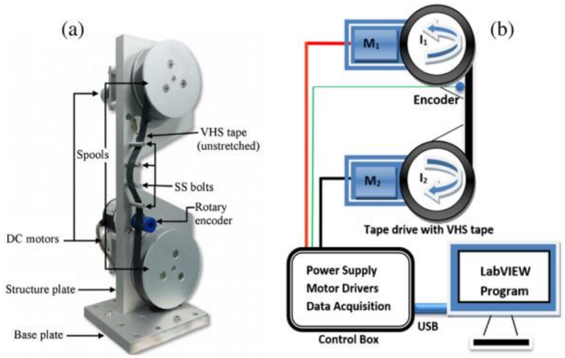
# Challange of high repetition rate targets

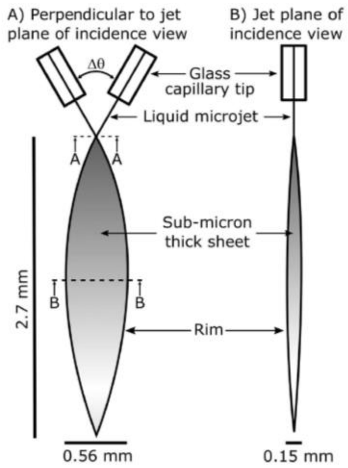
Most promising candidates so far

## Tape target



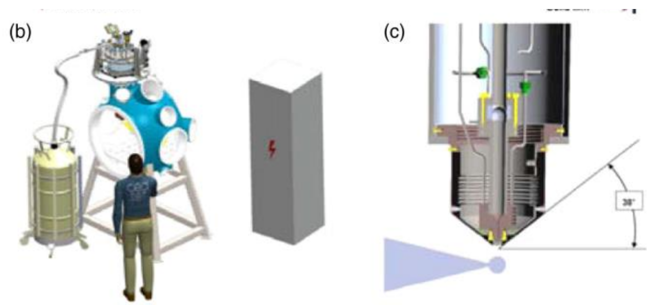

PRAB 20, 041301 (2017)

## Liquid jet




HPLSE 7, e50 (2019)

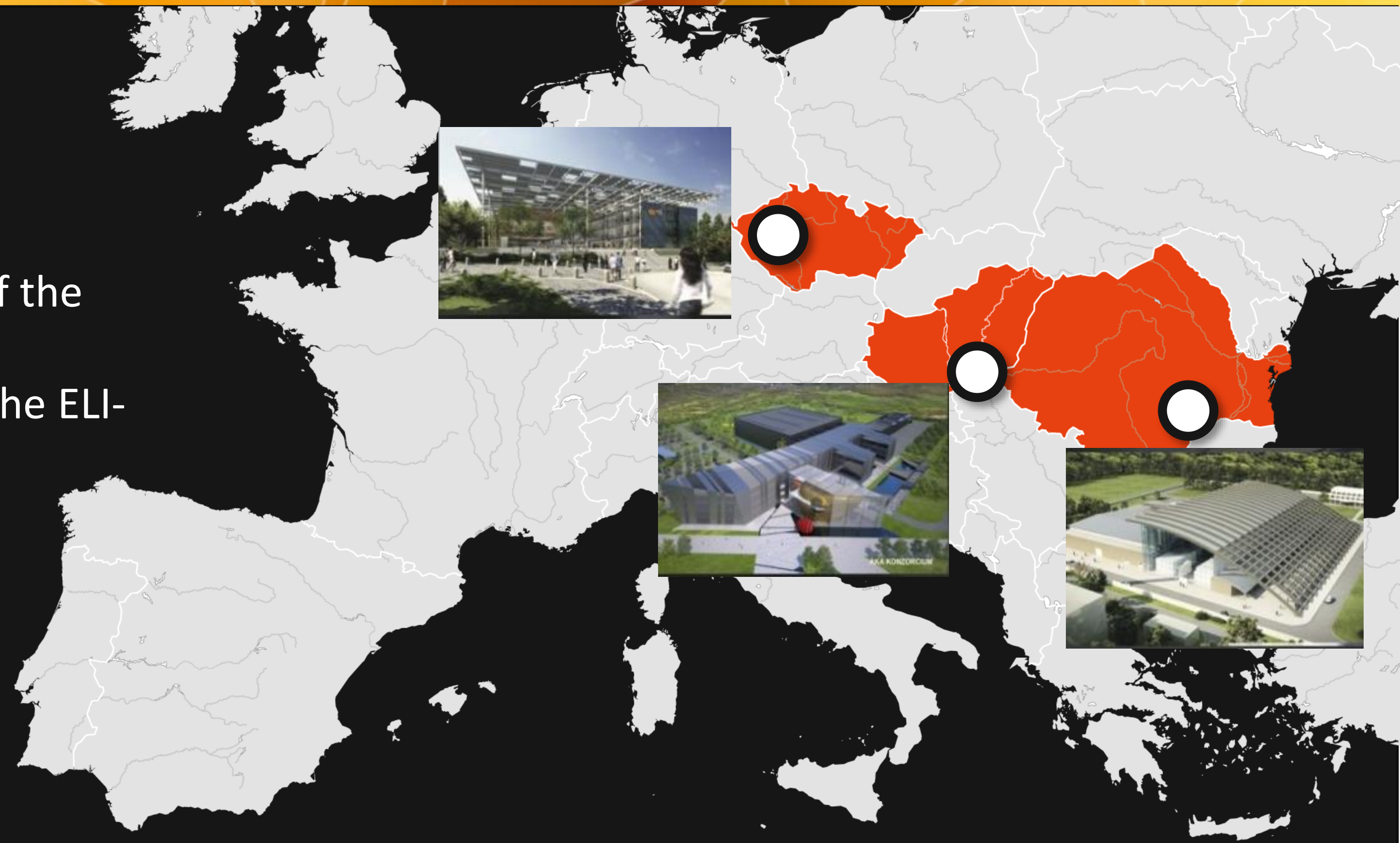
## Cryo target




PHYS. REV. X 6, 041030 (2016)

# Extreme Light Infrastructure
# Pillars, DC, and initial vision

## ELI-DC
The consortium coordinating the implementation of the three pillars & the establishment of the ELI-ERIC



**ELI-ALPS Szeged Hungary**
Investigations of ultra-fast dynamics @ attosecond & nm spatiotemporal scales

**ELI-BL Dolni Brezany Czech Republic**
Applications of ultra-short pulses of high-energy particle & radiation beams

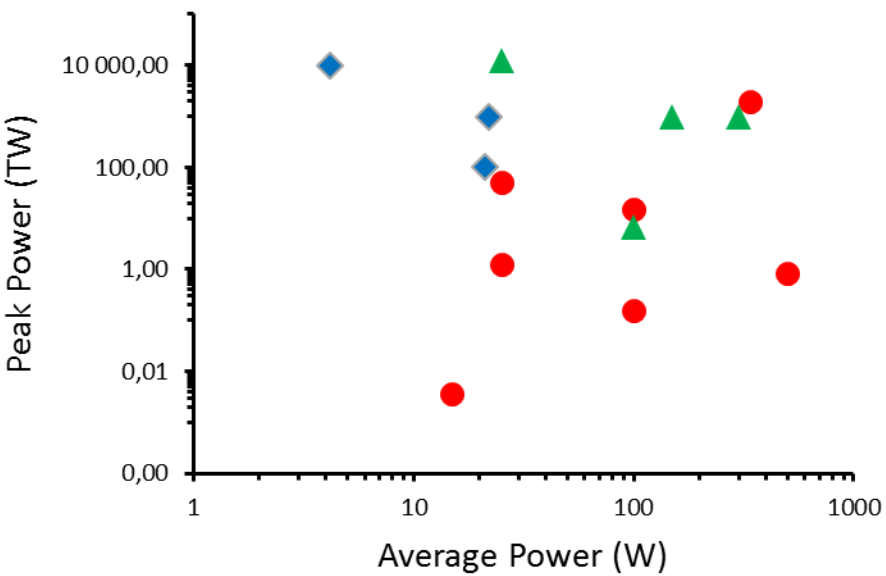
**ELI-NP Magurele Romania**
Ultra-intense laser & brilliant gamma/neutron beams enabling photonuclear studies

**UHFS**
**Ultra-High-Field Science**
@ unprecedented laser field strength (location: to be decided later)

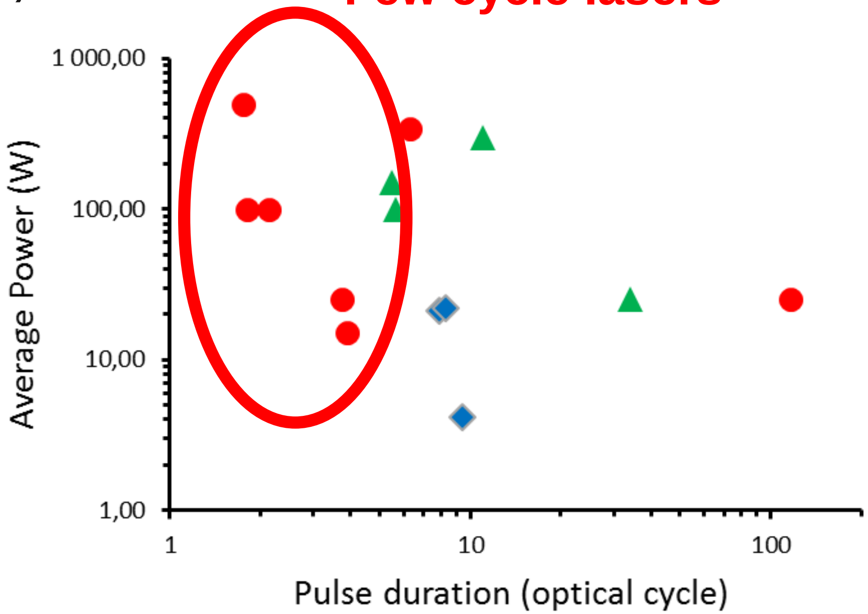
# ELI's Major Laser Systems
# By Q1 2020

## High peak-power, high average power lasers
## (complimentary specs)

ALPS, BL, NP

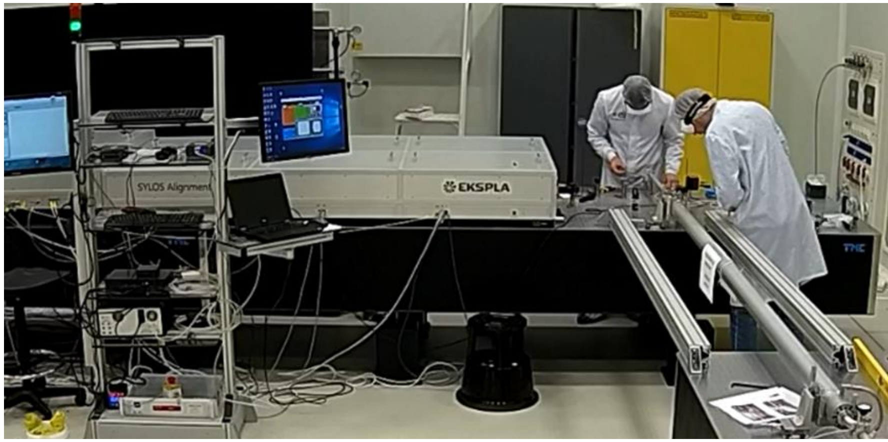


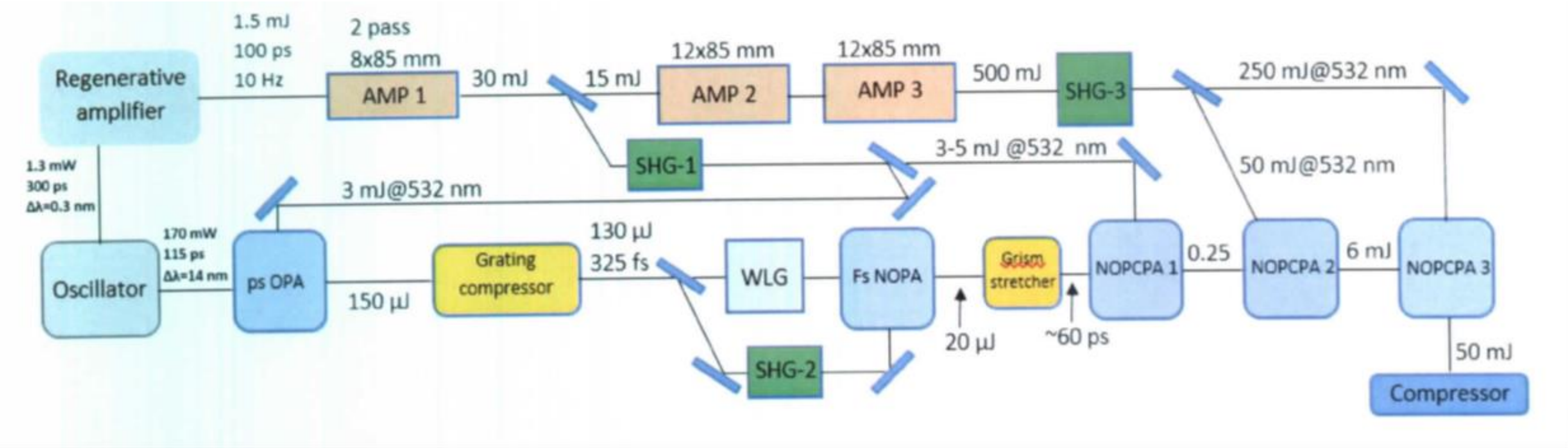

High average power
Few cycle lasers



# SYLOS Experiment Alignment Laser

| | Contracted | Measured at SAT (18/12/2018) |
|---|---|---|
| Pulse energy | >40mJ | 42.5 mJ |
| Energy stability | <2.0% | 0.87% |
| Strahl ratio | >0.7 | 0.93 |
| Pulse duration | 50fs | 12 fs |
| Central λ | 900 ±10 nm | 840 nm |
| Rep.rate | 10Hz | 10 Hz |
| Pointing stability | <0.10 | <0.05 |
| ASE contrast | >$10^6$ | $3x10^7$ |
| Beam ∅ | 80 mm | 82 mm |
| Optics ∅ | 100 mm | 100 mm |
| Problem-free operation | 10 hrs | 19 hrs |
| Warm-up time | 60 min | 20 min |

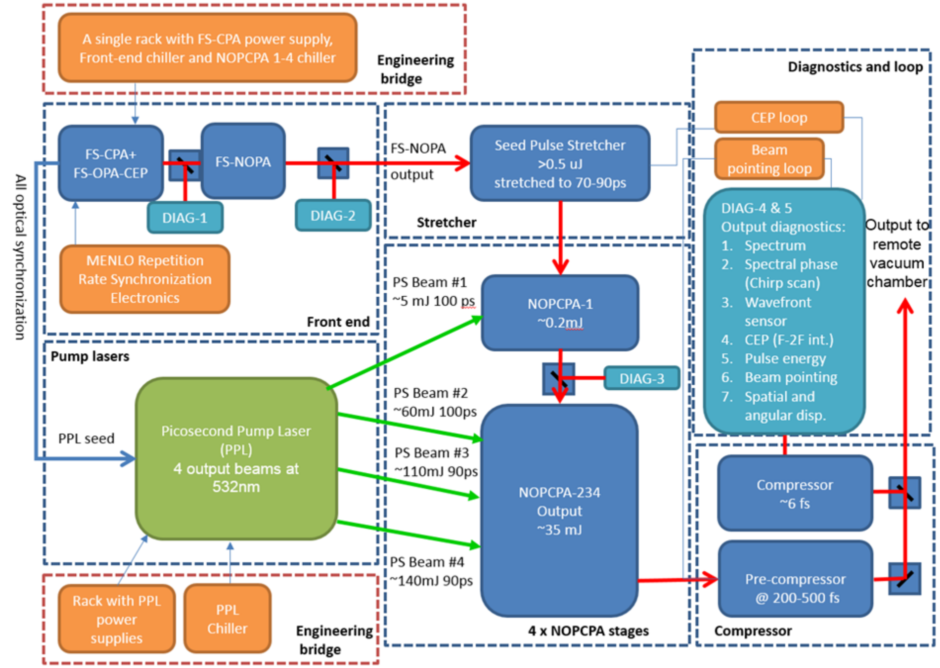


# SYLOS 2A laser

| | Contracted | Measured on SAT (2019/05/13) |
|---|---|---|
| Peak power | ≥4.5 TW | 4.9 TW |
| Pulse duration | <2.2 optical cycles<br>(<6.8 fs) | 2.17 optical cycles<br>6.4 fs |
| Rep.rate | 1 kHz | 1 kHz |
| CEP stability | 250 mrad | 220 mrad |
| Energy stability | <1.0% | 0.7% |
| ASE contrast | $10^{10}$ | $10^{10}$ |
| Strehl ratio | >0.7 | 0.72 |
| Central λ | 850-975 nm | 897 nm |
| Beam pointing | <0.2 | 0.026 |

Joint R&D between
Light Conversion, EKSPLA and ELI-ALPS.



# High Field (HF) laser systems

| Parameters | HF-100 frontend | HF-2PW |
|---|---|---|
| Repetition frequency | 100 Hz | 10 Hz |
| Energy stability | ≤ 1.5% rms over 1000 pulses | ≤ 1.5% rms over 1000 pulses |
| Strehl ratio | SR ≥ 0.9 | SR ≥ 0.9 |
| Pulse duration | ≤ 10 fs (FWHM) | ≤ 17 fs (FWHM) |
| Pulse peak power | ≥ 0.1 TW | ≥ 2 PW |
| Pulse energy | ≥ 1 mJ | ≥ 34 J |
| Intensity temporal contrast (pre-pulse) | ≥ $10^{11}$:1 at 25 ps and before, ≥$10^9$:1 from 25 to 15 ps, ≥$10^7$:1 from 15 to 5 ps, ≥$10^5$:1 from 5 to 1 ps | ≥ $10^{11}$:1 at 25 ps and before, ≥$10^9$:1 from 25 to 15 ps, ≥$10^7$:1 from 15 to 5 ps, ≥$10^5$:1 from 5 to 1 ps |
| CEP stability | drift < 200 mrad rms | N/A |
| Phase front angular dispersion | < 10 µrad/nm | < 10 µrad/nm |
| Warm up time | < 120 min | < 120 min |

**The short pulse PW laser**
**17fs, 2PW, 10Hz**

Amplitude TECHNOLOGIES
*Nothing but ultrafast.*

# First steps – pilot campaigns at ELI-ALPS by a consortium lead by Uni Szeged

**Major aim:**

Experimental demonstration and pilot study of neutron generation with few cycle laser pulses at ~1kHz.

**Consortium partners** (MoU signed on 5th April, 2019)

- Ecole Polytechnique, Saclay, Fr
- TAE Technologies, CA
- University of Szeged

**Expected further collaborators**

- ELI Beamlines, Prague, CZ
- HZDR, DE
- CLF, RAL and IC, UK
- & Hungarian Scientific community

**Financial support**

- Hungarian Government

# On the Hungarian project

Project: a flagship project of the Hungarian Government
via Ministry for Innovation and Technology
(established via government decree 1096/2019)

Duration: July 1st 2019 – 30th Sept, 2022

Support: ~3.6 Mrd HUF (incl.VAT)

Beneficiary: University of Szeged

Institute at Beneficiary: Interdisciplinary Centre of Excellence
from 1st October, 2019: *Institute for Application of High Intensity Lasers in Nuclear Physics*

Primary venue: ELI-ALPS (acceleration and interaction experiments)
USZ as a distuingushed user of ELI-ALPS
~800MHUF is to be spent at ALPS for supporting of the campaigns

Secondary venue: Dept Optics, University of Szeged
(HiRep target developments, training lab for interactions)

Collaborations: international collaboration (MoU) with EP and TAE
international collaborations on special R&D tasks (Beamlines, LOA, …)
national collaborations on special R&D tasks (ATOMKI, BME, EK, Wigner,..)

# Major tasks of the Hungarian project



## 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 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

# Major tasks of the Hungarian project



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- Design considerations for 100 kHz repetition rate operation

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

# 1st Campaign (Nov 2019 – Jan 2020): proton acceleration on thick target with SEA laser

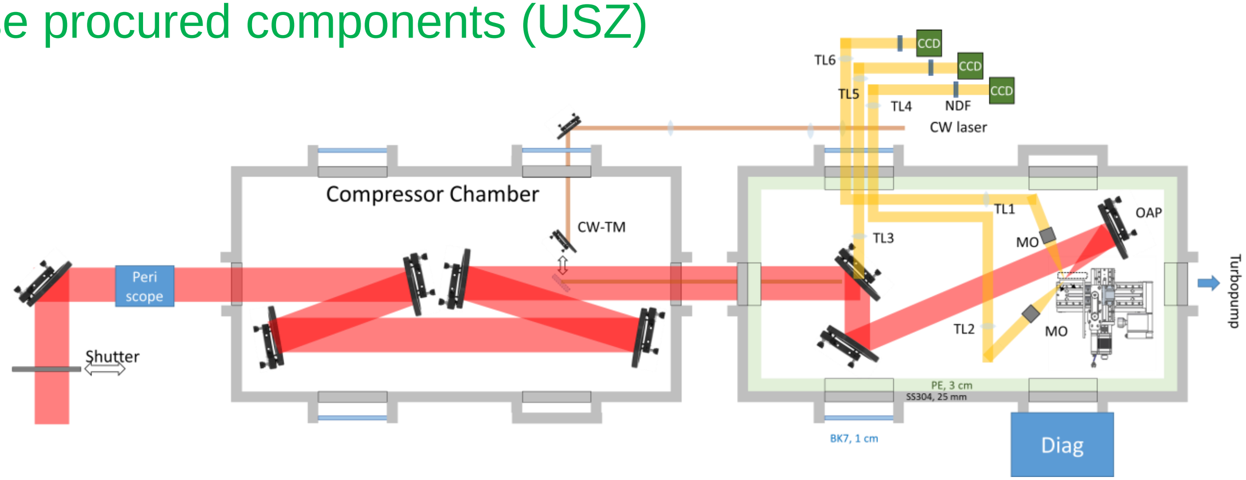
**Type:** Commissioning experiment of the SYLOS Aligment Laser (SEA)

**Aim:** (very first) test of acceleration particles in ALPS (laser, safety, diagnostics, etc.)

**Venue:** ALPS Alignment Lab

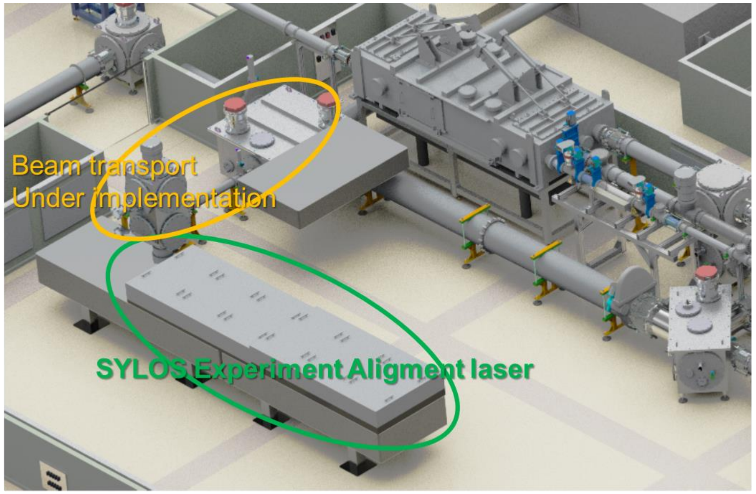
**Parameters:** single shot, <13fs, 40mJ, 1-5 μm target

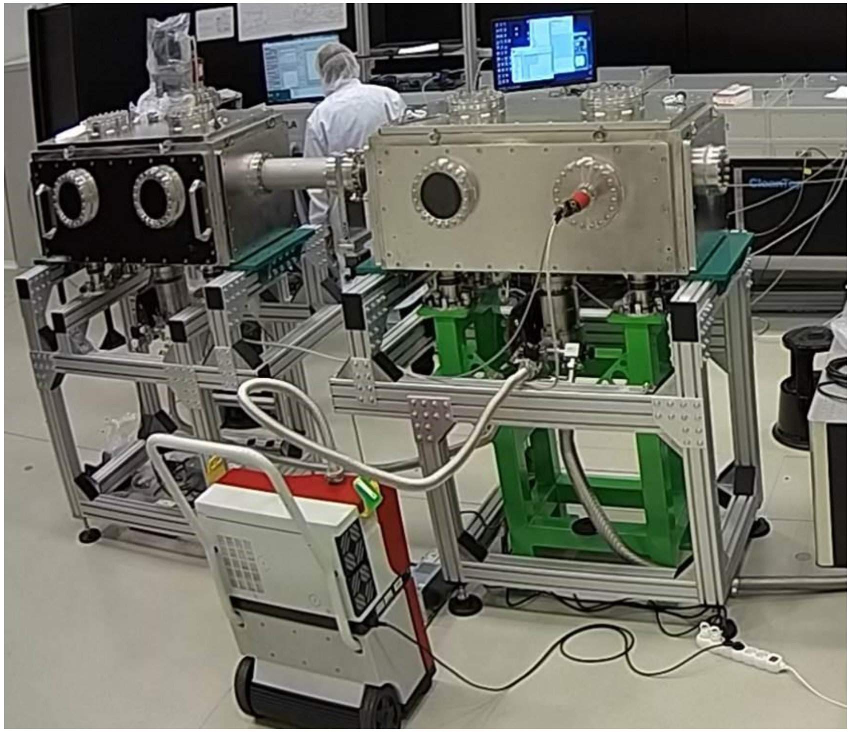
**Equipment:** temporary chambers (ALPS)
off-the shelf components (ALPS and USZ)
purpose procured components (USZ)



# 1st Campaign (Nov 2019 – Jan 2020): proton acceleration on thick target with SEA laser

## Status of preparation



# 2nd Campaign (Febr-May 2020): proton acceleration on thin target with SEA laser

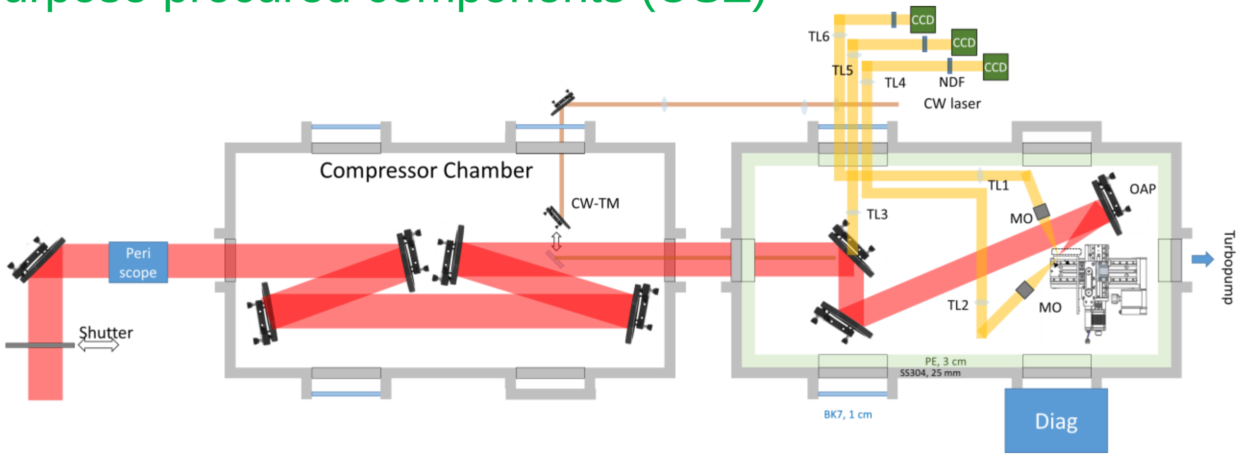
**Type:** distuingushed user experiment

**Aim:** study of proton acceleration vs target thickness and pulse duration

**Venue:** ALPS MTA3 lab

**Parameters:** single shot, 5-10fs, 30mJ, 20nm-500nm target, various polarisations

**Equipment:** temporary chambers (ALPS)
off-the shelf components (ALPS and USZ)
(more) purpose procured components (USZ)



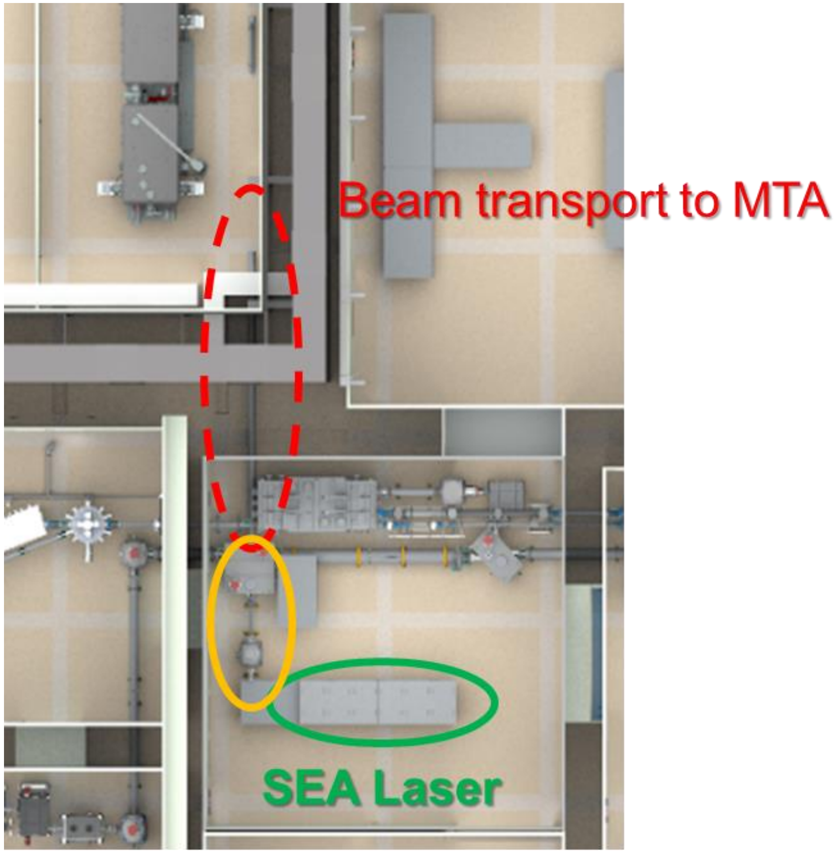
# 2nd Campaign (Febr-May 2020): proton acceleration on thin target with SEA laser

**R&D needed (ALPS and USZ)**

pulse shortening via nonlinear compression schemes

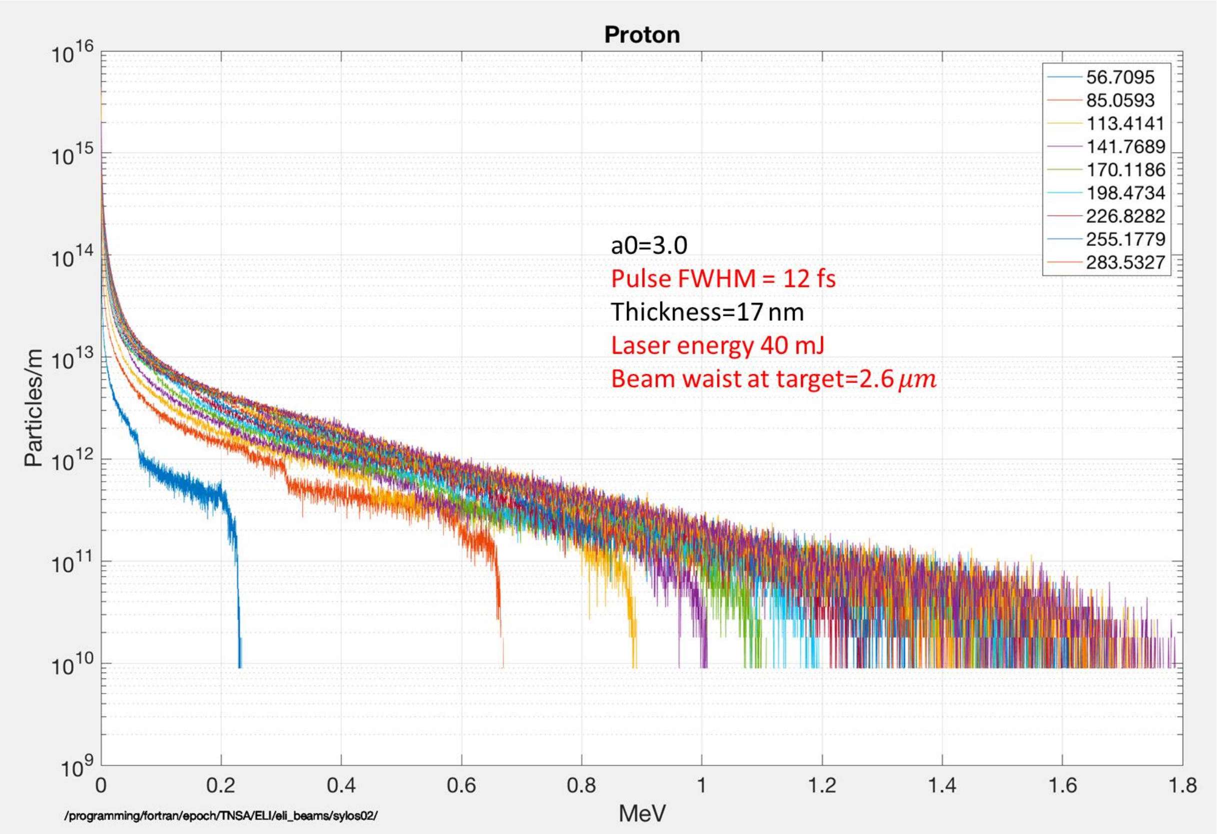
**Engineering needed (ALPS)**

Beam transport to MTA3



# 2nd Campaign (Febr-May 2020): proton acceleration on thin target with SEA laser

## CAIL simulations




By A. Necas

# 7th Campaign (June - Sept 2022): proton acceleration with PW laser

*(depending on the availability of the PW laser and HTA – TBD in 2020)*

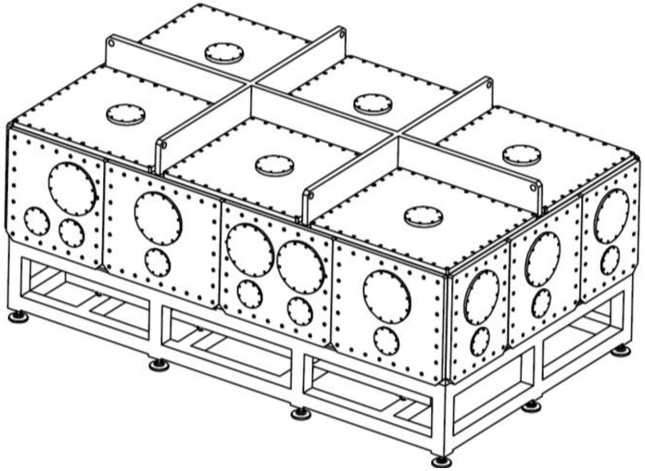
**Type:** distuingushed user experiment

**Aim:** study of proton acceleration on thin target with short pusle PW laser

**Venue:** ALPS HTA

**Parameters:** single shot, 17fs, 30J, 20nm-500nm target

**Equipment:** purpose chambers (USZ)
purpose procured components (USZ+ALPS)



PW chamber design

# Major tasks of the Hungarian project

## 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 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

# 3rd Campaign (Aug 2020 - Jan 2021): neutron generation on thin target with SEA laser

**Type:** distuingushed user experiment

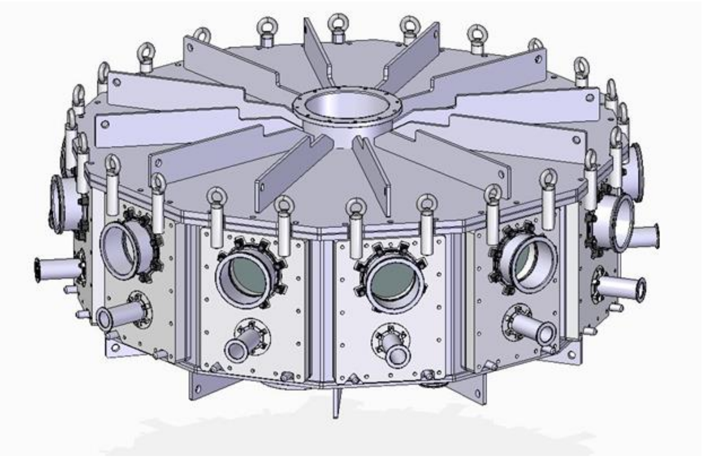
**Aim:** study of neutron generation from the accelerated deuterons

**Venue:** ALPS MTA1 lab

**Parameters:** single shot, 5-10fs, 30mJ, 20nm-500nm target, various polarisations

**Equipment:** purpose chambers (USZ)
(more) purpose procured components (USZ)

Chamber design
Procurement starts soon



# 3rd Campaign (Aug 2020 - Jan 2021): neutron generation on thin target with SEA laser

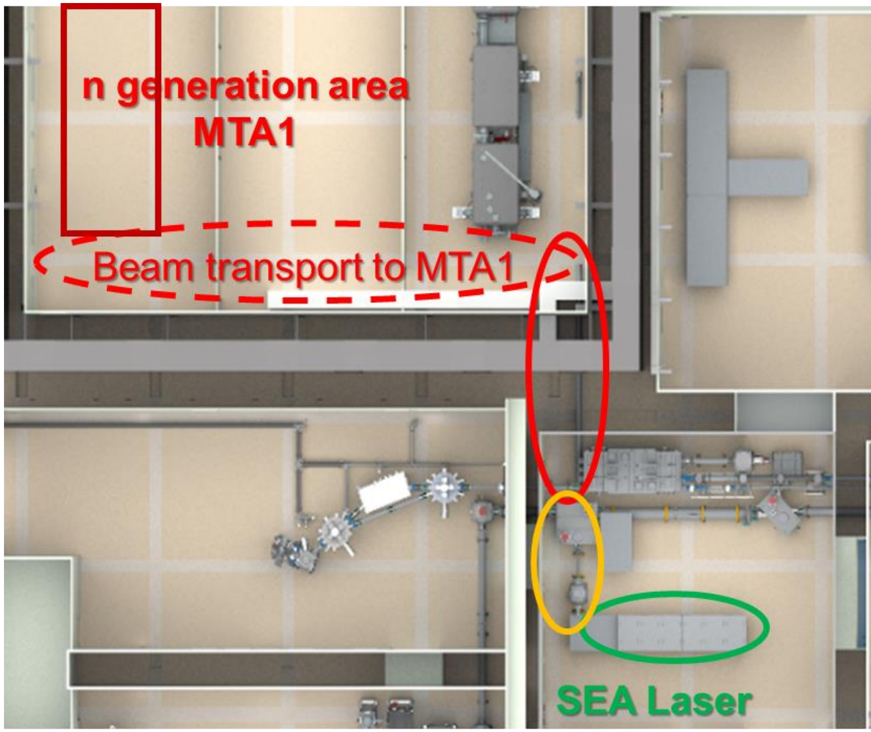
## R&D needed (USZ)

Approrpiate catcher (”neutron”) targets
Neutron diagnostics
In collaboration with ATOMKI, …

Neutron shielding
In collaboration with EK, …

## Engineering needed (ALPS)

Beam transport to MTA1



# Major tasks of the Hungarian project

## 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
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- Development of high repetition rate / renewable combined target system

## A3 Fusion neutron generation with kHz class few cycle lasers

- Development 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

# 4th Campaign (Febr - Nov 2021): deuteron generation on thin target at kHz

**Type:** distuingushed user experiment

**Aim:** study of deuteron acceleration at kHz rep rate

**Venue:** ALPS MTA1 lab

**Parameters:** kHz repetition rate, 4-10fs, <20mJ, 20nm-500nm target,
various polarisations

**Equipment:** purpose chambers (USZ)
purpose procured components (USZ)
high rep rate target systems

# 4th Campaign (Febr - Nov 2021): deuteron generation on thin target at kHz

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## R&D needed (USZ)

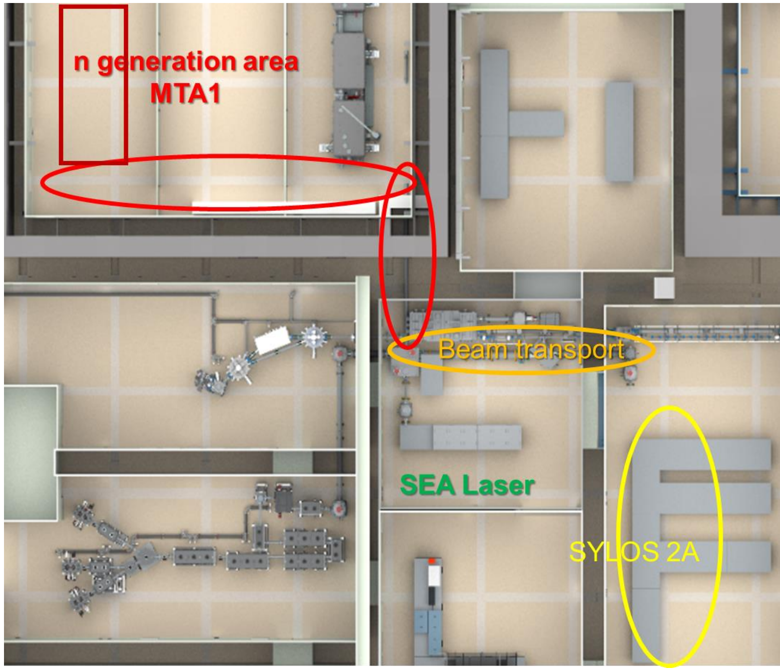
High rep rate target systems

In collaboration with LOA, Beamlines, OSU, CLF, …

Pulse shortening of SYLOS laser to <5fs

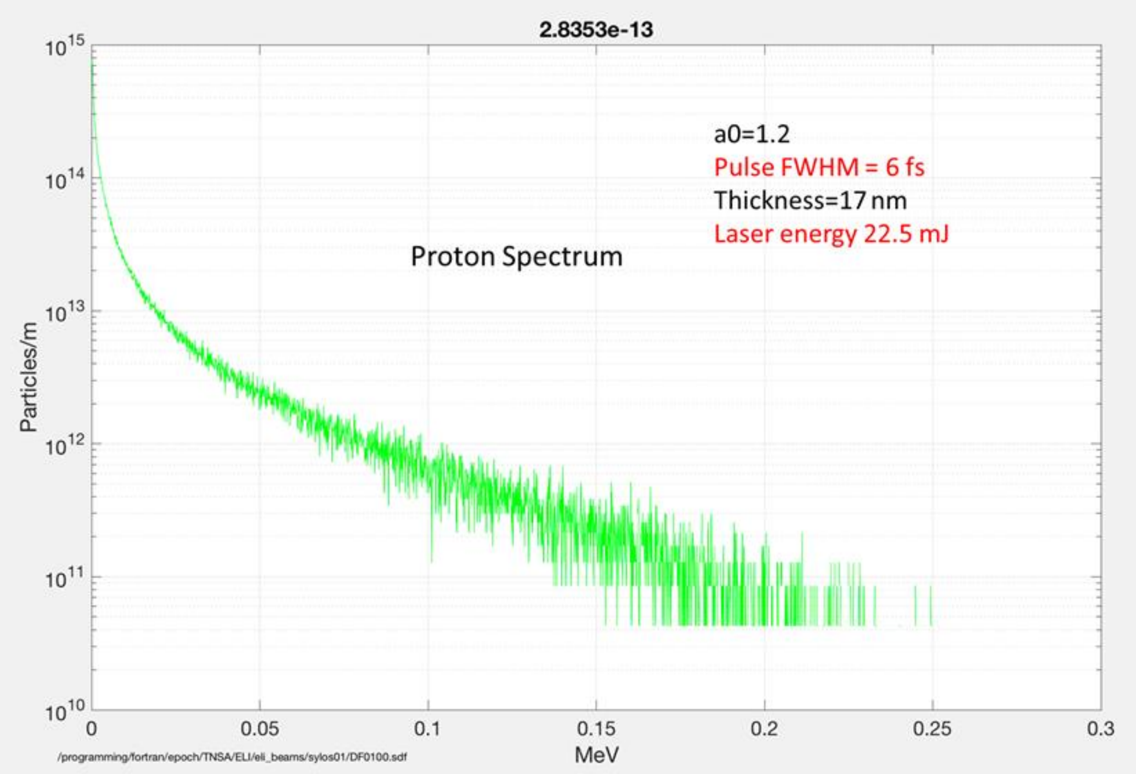
In collaboration with ALPS

## Floor plan (ALPS)



# 4th Campaign (Febr - Nov 2021): deuteron generation on thin target at kHz

## CAIL simulations




By A. Necas

# Major tasks of the Hungarian project

## 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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## A2 Target system developments

- Design and develop a dual target system up to 10 Hz operation
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## A3 Fusion neutron generation with kHz class few cycle lasers

- Development 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

# 5th Campaign (Dec 2021 - Aug 2022): neutron generation at kHz

**Type:** distuingushed user experiment

**Aim:** optimisation of neutron acceleration at kHz rep rate

**Venue:** ALPS MTA1 lab

**Parameters:** kHz repetition rate, 4-10fs, <25mJ, 20nm-500nm target, polarisation

**Equipment:** purpose chambers (USZ)
purpose procured components (USZ)
high rep rate target systems

# Major tasks of the Hungarian project

…

## A3 Fusion neutron generation with kHz class few cycle lasers

- Development 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

- In-situ, non-invasive, laser-driven monitoring of nuclear waste barrel containers
- Diagnostics and delivery of fusion neutrons (Neutronics)
- Study on suitable wall materials for a prototype laser-driven transmutator
- Chemistry and technologies of nuclear waste solvents
- Investigation of the radiobiological applicability of laser driven neutron sources

# 6th Campaign (June - Sept 2022): Application of laser generated neutrons

**Type:** distuingushed user experiment

**Aim:** application of laser generated neutrons in radiobiology

**Venue:** ALPS MTA1 lab

**Parameters:** kHz repetition rate, 4-10fs, <25mJ, 20nm-500nm target

**Equipment:** purpose chambers (USZ+ALPS)
purpose procured components (USZ+ALPS)
high rep rate target systems

# Major tasks of the Hungarian project

…

**A3 Fusion neutron generation with kHz class few cycle lasers**

- Development 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**

- In-situ, non-invasive, laser-driven monitoring of nuclear waste barrel containers
- Diagnostics and delivery of fusion neutrons (Neutronics)
- Study on suitable wall materials for a prototype laser-driven transmutator
- Chemistry and technologies of nuclear waste solvents
- Investigation of the radiobiological applicability of laser driven neutron sources

# Betatron beamline for non-invasive imaging of nuclear containers (May 2020 – Sept 2022)

**Type:** collaborative R&D with ALPS

**Task:** design and implementation of a betatron source from PW-laser accelerated electrons

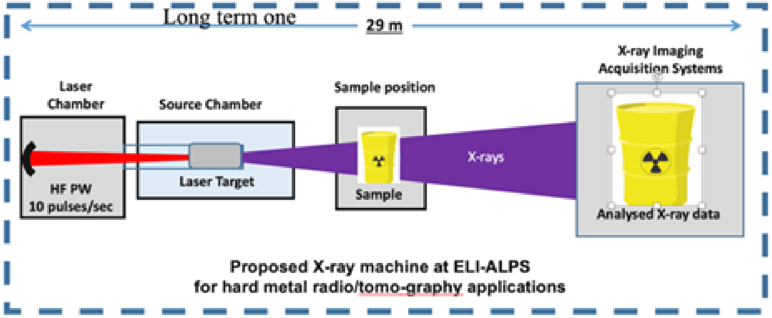
**Venue:** ALPS HTA

**Parameters:** single shot, 17fs, 30J, 20nm-500nm target

| High Field PW Laser | |
|---|---|
| Central wavelength: | 800nm |
| ***Pulse repetition rate:*** | ***10 Hz (4x)*** |
| ***Energy per pulse:*** | ***34 J (>5x)*** |
| Pulse duration: | 17fs |

| Generated X-rays (*tunable*) | |
|---|---|
| Critical Energy | 100 - 300 keV |
| Magnification | x 4 - 5 |
| ***Repetition rate*** | ***10 Hz*** |
| Source - detector distance | 10 - 15 m |

Short term:
Mid-term:
Long term one



# Major tasks of the Hungarian project
# Foresight activity

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…

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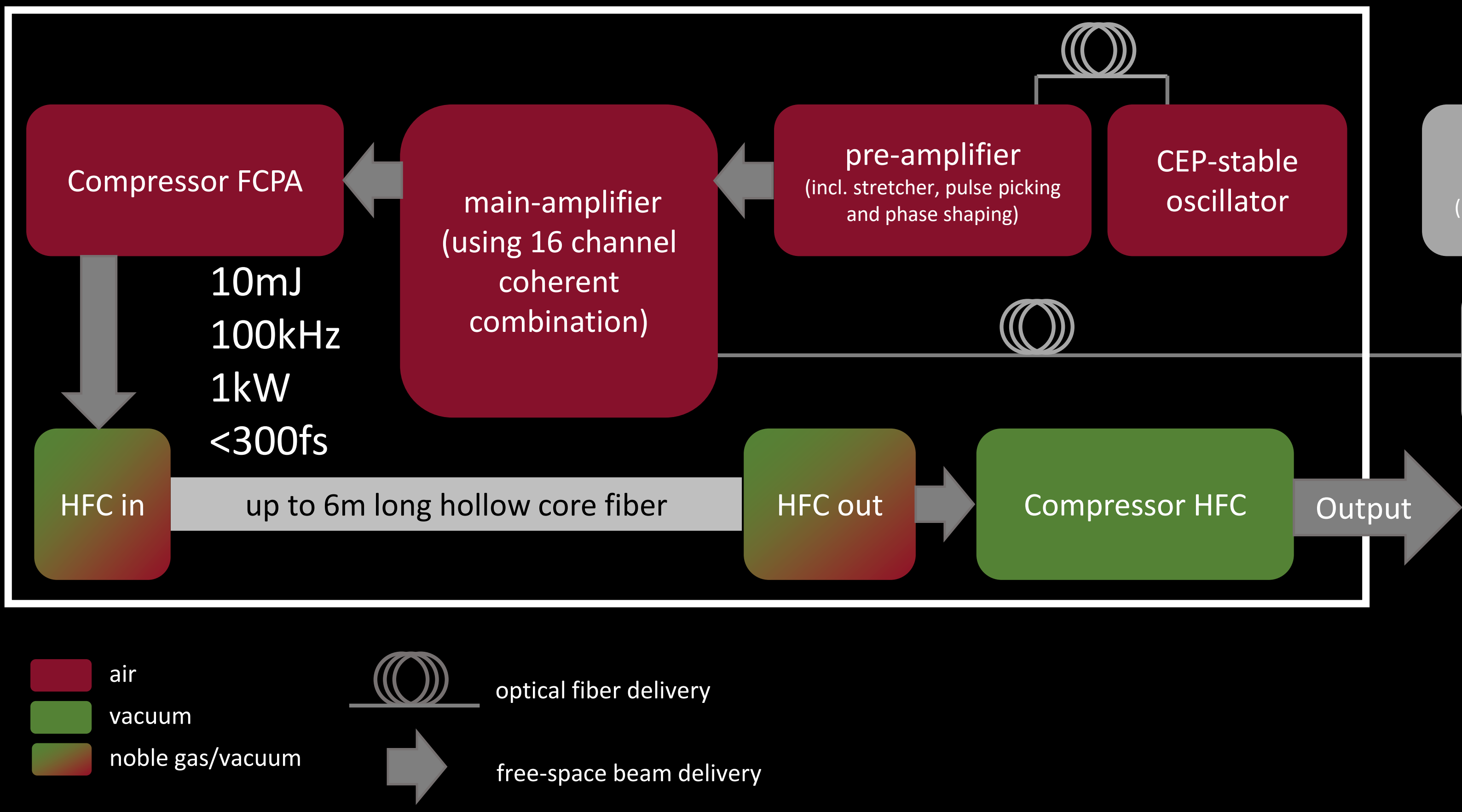
# ELI HR2: System Design of a high-power few-cycle laser




**Goal:**
5mJ
100kHz
500W
<6fs
**CEP-stable**

# Major tasks of the Hungarian project
# Support some activities of Pillar 2, 3, 4

**(To be discussed the details upon the round table.)**

…

## A3 Fusion neutron generation with kHz class few cycle lasers

- Development a deuteron accelerator with the SYLOS laser (1 kHz)
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# Major fields of international collaborations of the Hungarian project

- **Reveail / fully explore the physics of ion acceleration on thin targets with lasers (from single cycle to long pulses).**
  - EP (IZEST, LOA, LULI), TAE Technologies, Beamlines, …
- **Explore neutron generation with ultrashort pulse lasers (in two steps, or single step process).**
  - EP (LOA, LULI), TAE Technologies, Beamlines, …
- **Share the risk and tasks of high rep rate (thin) target development, including debris shielding**
  - EP (LOA), Beamlines, …

# Participation possibilities of the Hungarian scientific community

(To be further refined upon the round table.)

## PILLAR 1 (Laser-based neutron)

Experiment campaigns at ELI-ALPS (2019-2022)

Neutron diagnostics (mind ultrashort neutron bunches!)

Find optimum fusion neutron target in laser/ vacuum environment (mind thickness, mechanical properties, radiation and chemical hazards, …)

ATOMKI, …

## PILLAR 2-4

Neutronics

Proper transport of fusion neutrons to the interaction / transmutator area

ATOMKI, BNC, BME NT, EK …

Wall materials and Nuclear Chemistry

Find molten salt-based chemical processes, proper wall materials, etc. to be industialized.

BME NT, …

# Foreseen roadmap of ion acceleration with few cycle lasers (CAIL scheme)

(To be further refined upon the round table.)

4fs, 3mJ, kHz reprate, thick target, backward acceleration (LOA) **2019**

**12fs, 40mJ, single shot, thick target, forward acceleration (USZ)**

30fs, 1J, 1Hz, cryo target, forward acceleration (Beamlines)

**5fs, 30mJ, single shot, thin target, forward acceleration (USZ)** **2020**

15fs, 20mJ, reprated, thin target, forward acceleration (Beamlines)

4fs, 3mJ, kHz reprate, liquid target, forward acceleration (LOA)

**5fs, 20mJ, kHz reprate, thin target, forward acceleration (USZ)** **2021**

30fs, 30J, 1Hz, cryo target, forward acceleration (Beamlines)

**17fs, 30J, single shot, forward acceleration (USZ)** **2022**

# Information / results are expected by 2022

Exploration of ion acceleration with ultrashort pulses on ultra-thin targets.

Exploration of neutron generation with ultrashort pulses.

Experiences with radiation protection, long term damage tests, operation, etc.

Status of kHz (and beyond) reprated laser developments
(EUPRAXIA, KALDERA, TSL, AFS, …)

Status and operation experience of reprated PW lasers
(ALPS – Amplitude, Beamlines – HALPS, …)

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

**Decision point 2 – go/no-go**
towards laser based neutron generation (in general)

**Decision point 3 – which way?**
towards high repetition rate (100kHz and beyond)
or towards few-cycle reprated PW

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SZTE UNIVERSITY OF SZEGED

Where knowledge meets challenge

# THANK YOU FOR YOUR KIND ATTENTION!