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NLTL National Laser-Initiated Transmutation Laboratory University of Szeged

Laser plasma deuterium acceleration and neutron generation at 1 Hz repetition rate

Karoly Osvay

AAC'22

9th November 2022

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Outline

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Motivation

Proton acceleration with few-cycle pulses

scaling with target thickness

Deuteron acceleration with few cycle pulses

effect of chirp

Neutron generation

Conclusions and outlook

Hirep target developments

Compression of laser pulses to sub-two cycle duration

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Transmutation of spent nuclear fuel

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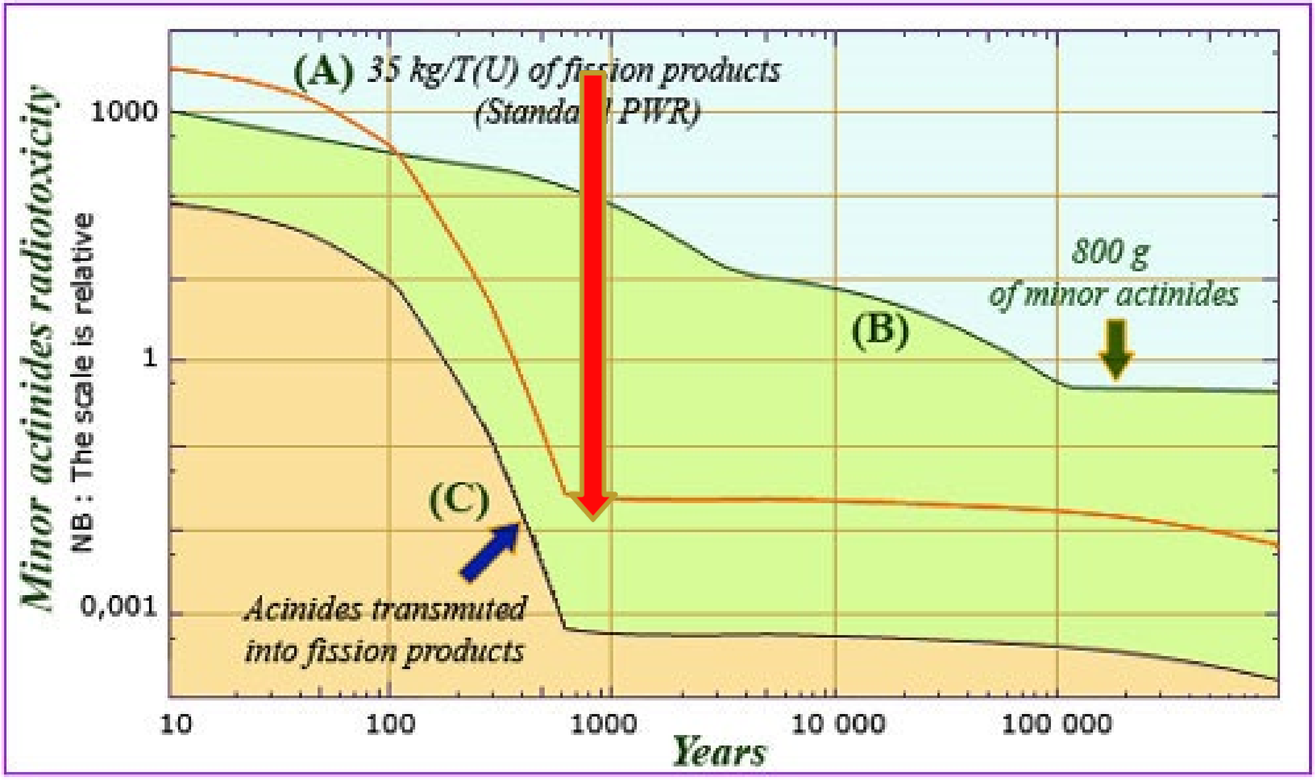

Radiation time reduction: 1,000x

Volume reduction: 100x

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

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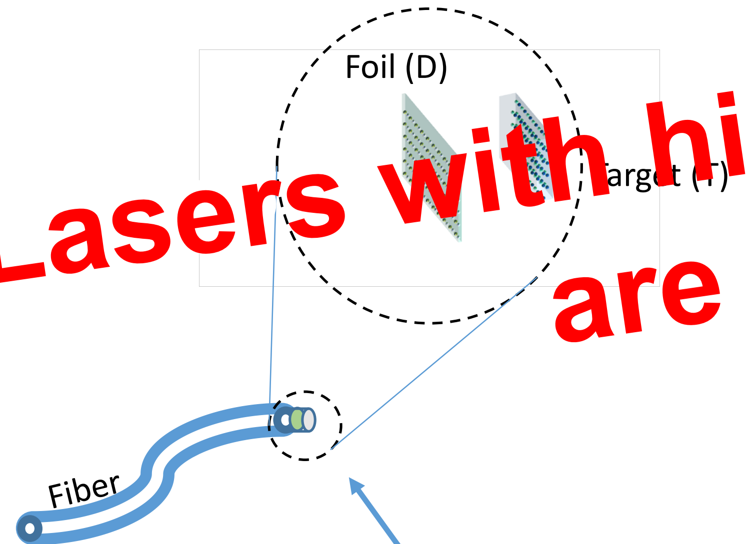

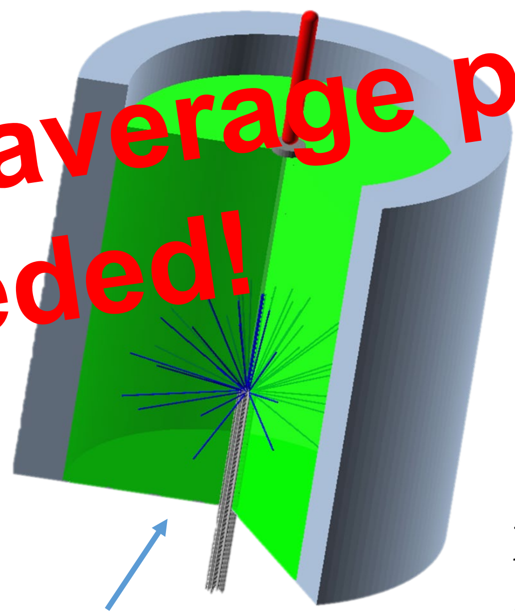

Lasers with high average power are needed!

Laser-based fusion neutron source (DT / DD)

Molten salt sub-critical reactor

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

Laser-based neutron sources
PW class lasers – current situation

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Highest efficiency experiment

3.1×10^{9} n/J
0.05% laser->neutron

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

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)

7×10^{8} n/J
0.02% laser->neutron

Average power of such lasers is <1W

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

Predicted efficiency
~8×10^{10} n/J
~1% laser->neutron

Martinez et al., MatRadExt 7 (2022) 024401

High average power lasers

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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.

↓

Let's investigate neutron generation with few cycle pulses, with / for EXISTING high average power lasers!

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Proton acceleration with few cycle pulses

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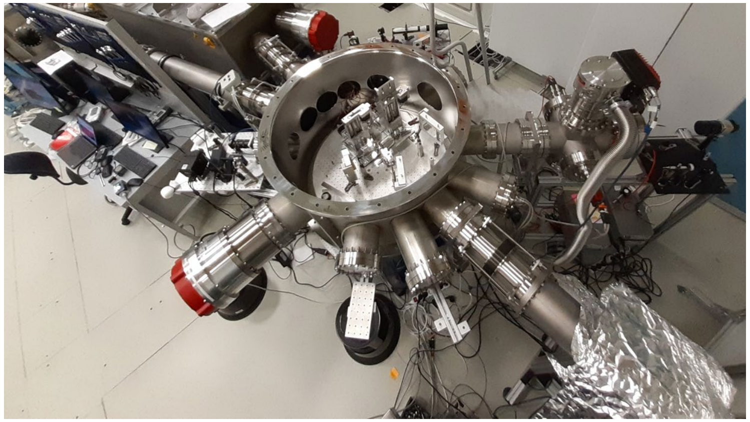
Single shot experimental campaigns in ELI-ALPS

Shooting on target: 26 and 14 working days
>1500 single shots



Target materials:

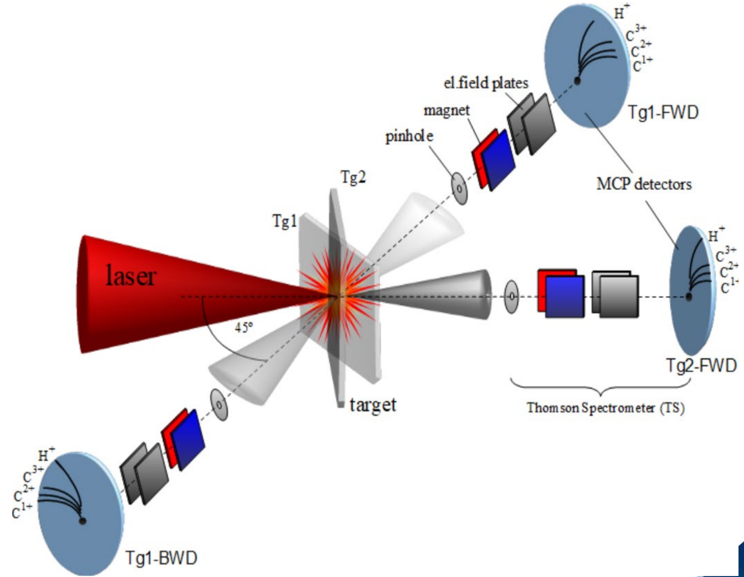
Commercial: Al, C, CH, DLC, PET
Home-made: formvar, dPE

Target thickness:

5nm, 10nm, 20nm, 50nm, 100nm, 200nm, 500nm, 2µm, 9µm

Diagnostics

Thomson ion spectrometers (BWD, FWD)



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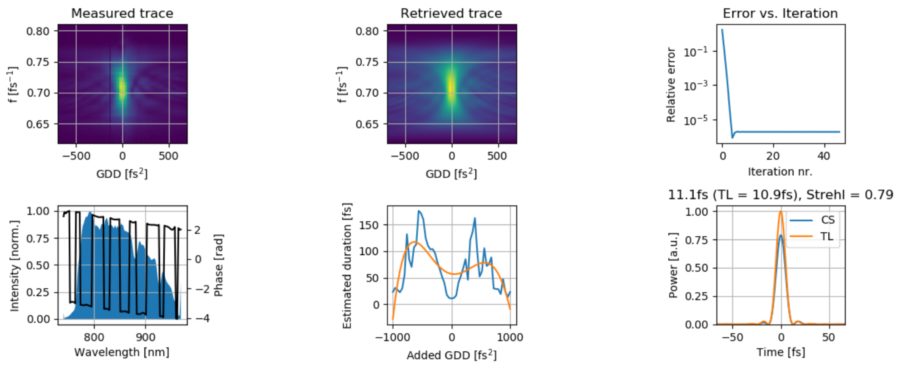
SEA laser (10Hz, OPCPA) of ELI-ALPS parameters *on target*

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

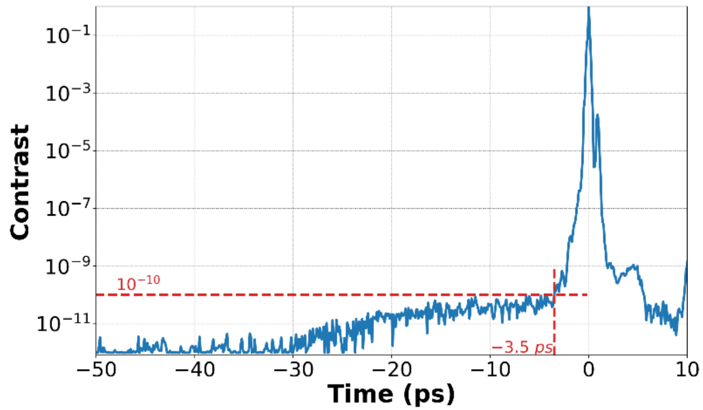
Laser pulse duration: *11.6 fs*
Measured in vacuum, after OAP, with disp scan



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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Study of ion acceleration by few cycle laser pulses

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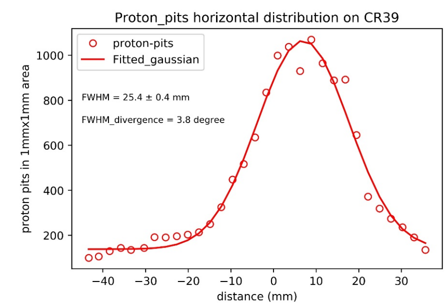
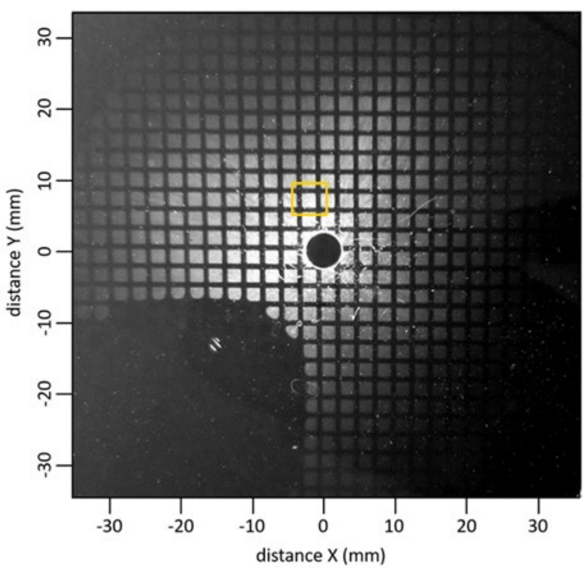
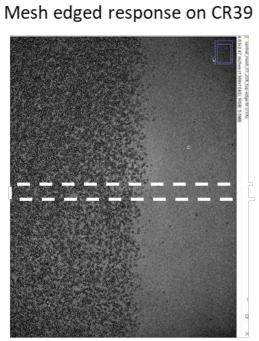
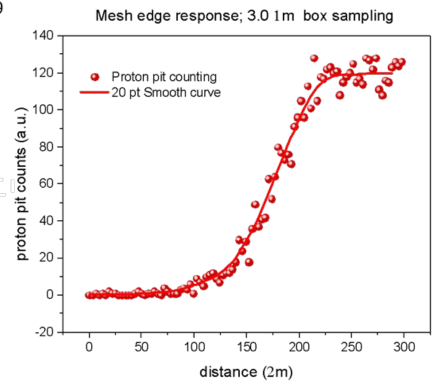
Proton acceleration results – proton beam characterisation

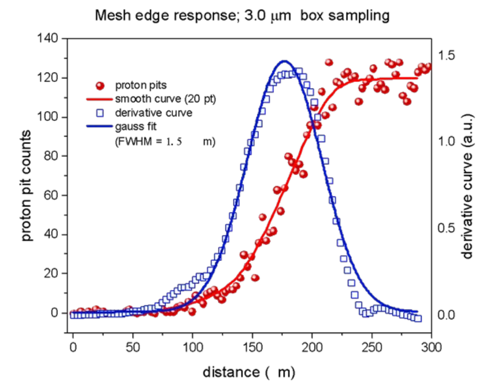
- Large number of protons (above 100keV: 10^{10}/shot);
- Small beam divergence (<65mrad for protons > 250 keV)
- Small emittance   0.00032 π-mm-mrad











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

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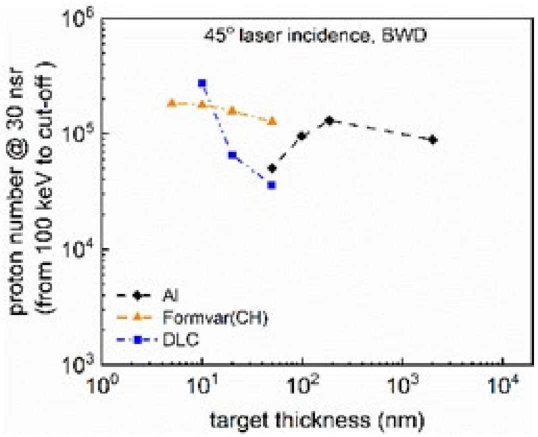
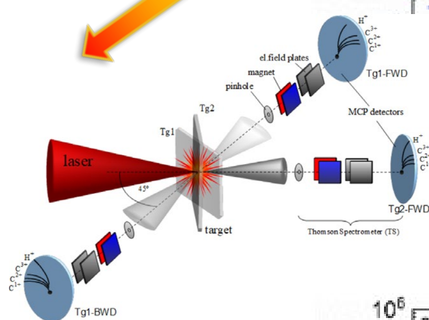
Study of ion acceleration by few cycle laser pulses

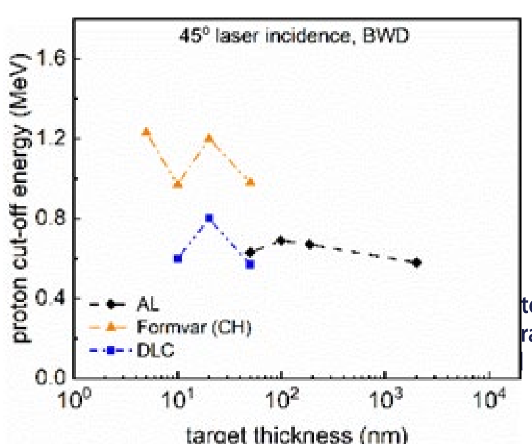
Proton acceleration results – target material and thickness

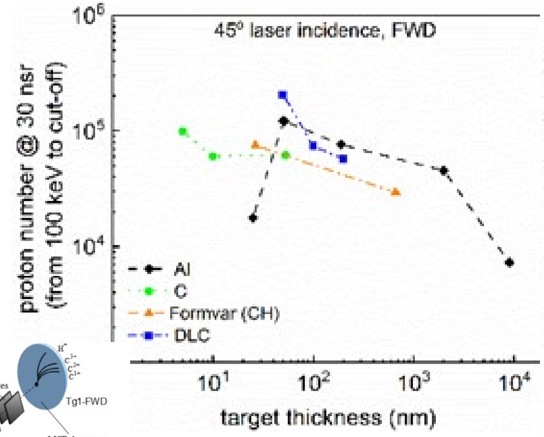
Particle number
1/4

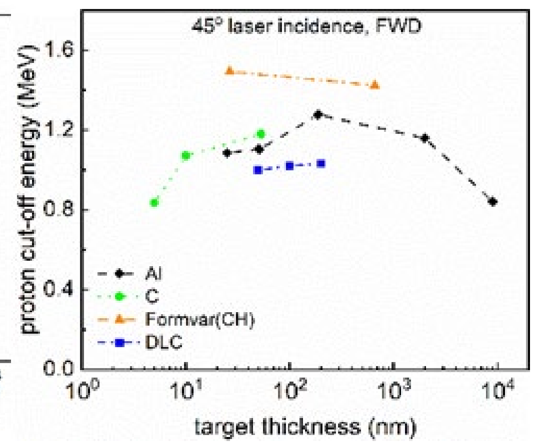




Cut-off Energy
~2/3

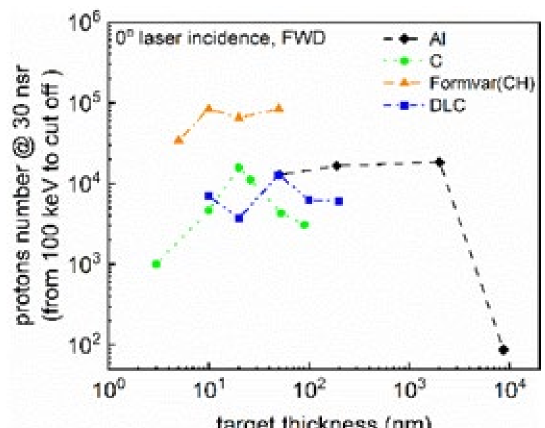


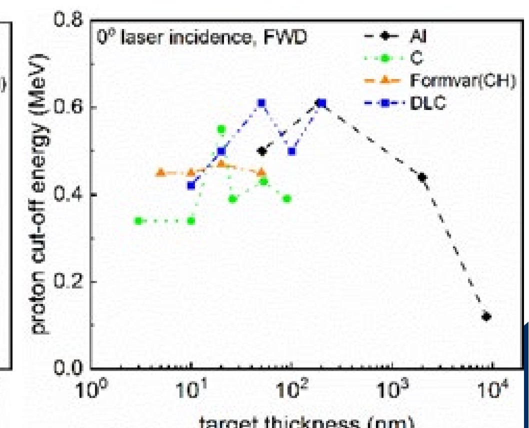




Particle number
1/10 (exc. CH)

Cut-off Energy
1/2





Physics

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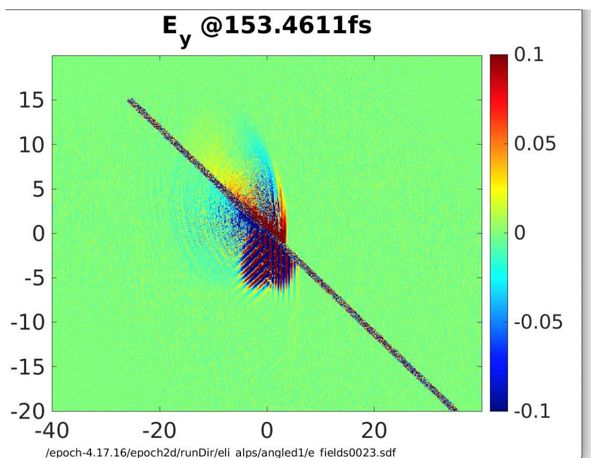
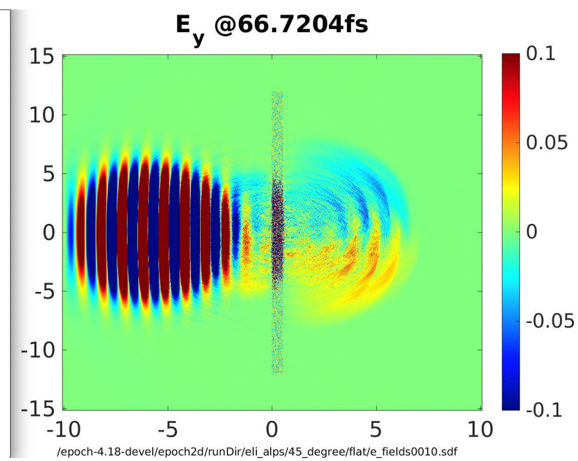
- High cut-off energy protons (compared to the pulse energy)
- Reasonable conversion efficiency (1% – 1.5%)
- Dominant acceleration from thick targets: TNSA and TNSA(+Coulomb)
- Acceleration from ultrathin targets:
  LS or CAIL and (TNSA+)Coulomb;
- Acceleration FWD at 45°: Brunnel-type heating of electrons

Veltcheva et al.,PRL 108, 075004 (2012)





PF + Brunel
E_y is large on the backside

Purely PF driven electrons
E_y is small on the backside

Ter-Avetisyan et al., *submitted (2022)*

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Ion acceleration at 1 Hz repetition rate

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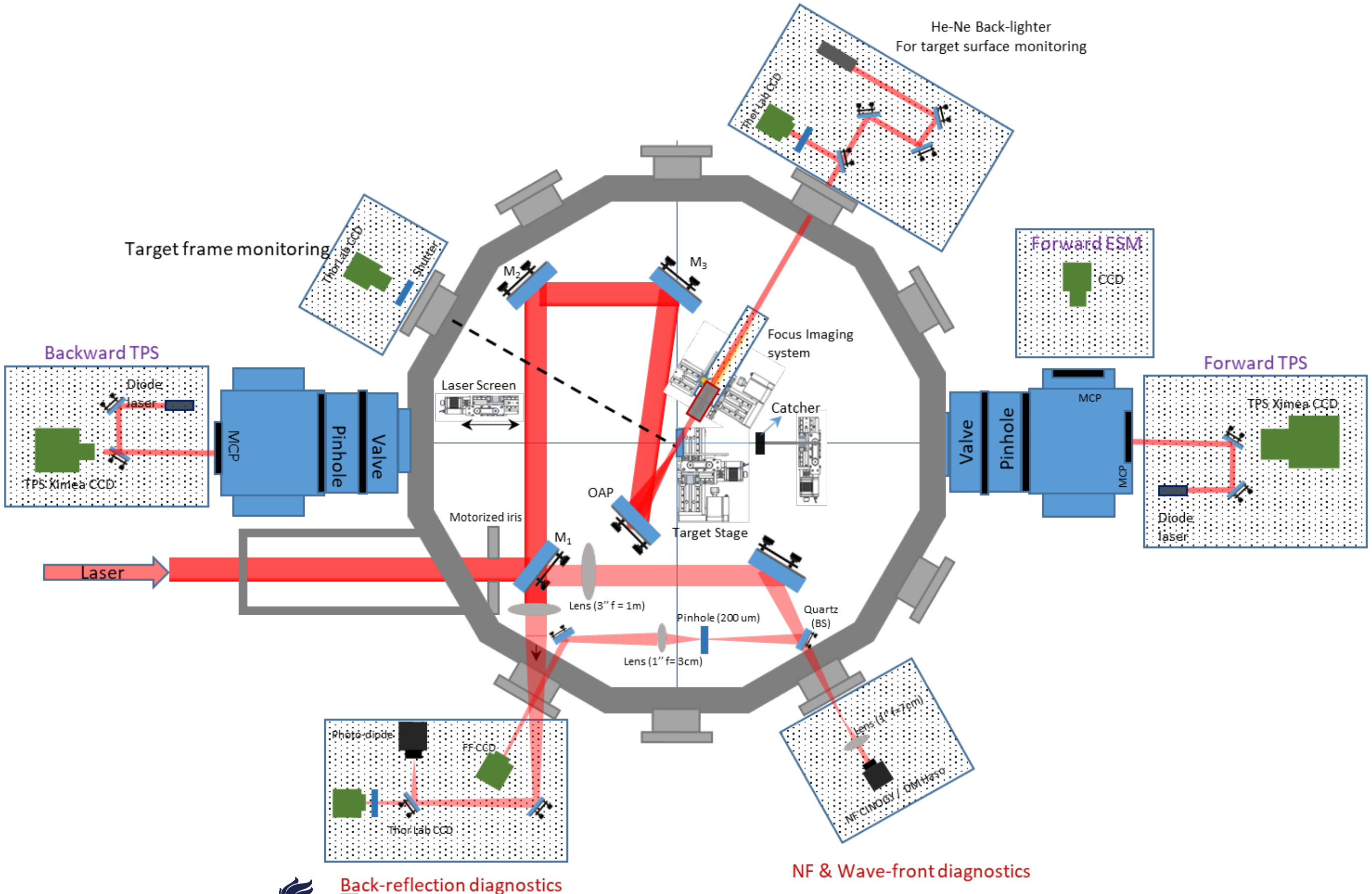
Laboratory time in ELI-ALPS
10.6.22-23.06.22, 7 laser days, ~4000 shots



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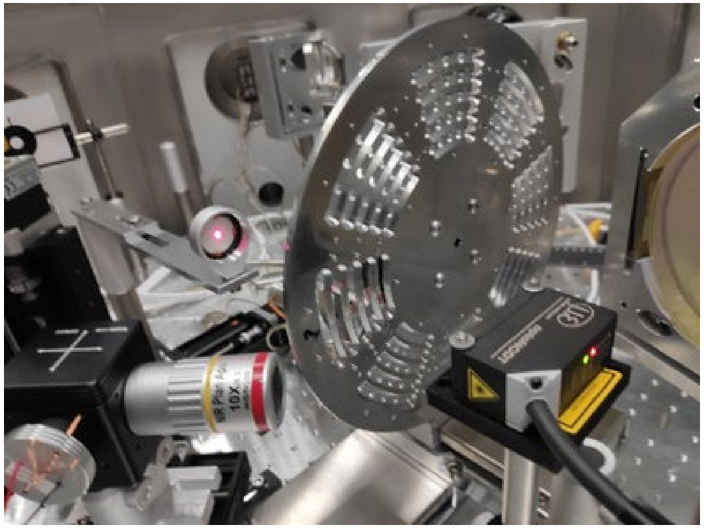
Rotating wheel target

In collaboration with Universidad Santiago de Compostela



7 (+1) segments
25 holes per segment (5x5)

Home-made dPE foil ~200nm
Bar et al., RSI **91**, 103302 (2020)

Prior to shoot - mapping
- target foil position in the center of each hole (5μm precision in *z*)
- 3 shots in each hole

1 Hz operation in burst mode
Bursts: up to one segment (75 shots)

Proton and Deuterion and acceleration at 1 Hz repetition rate

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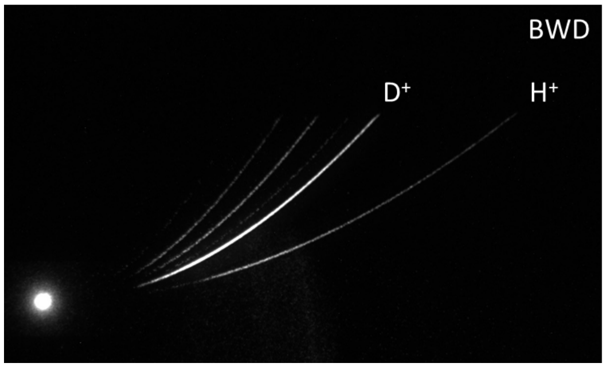
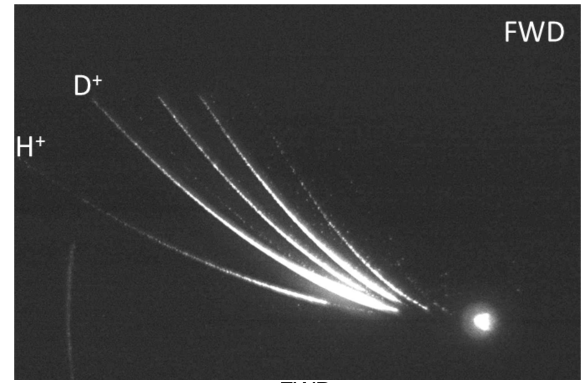
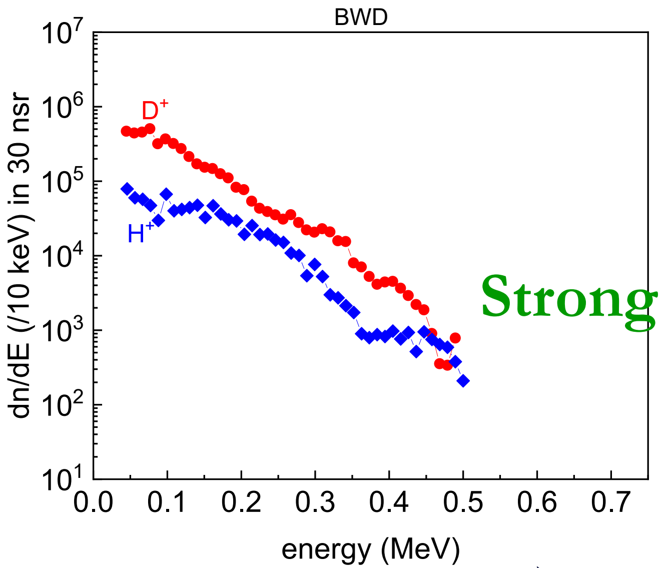
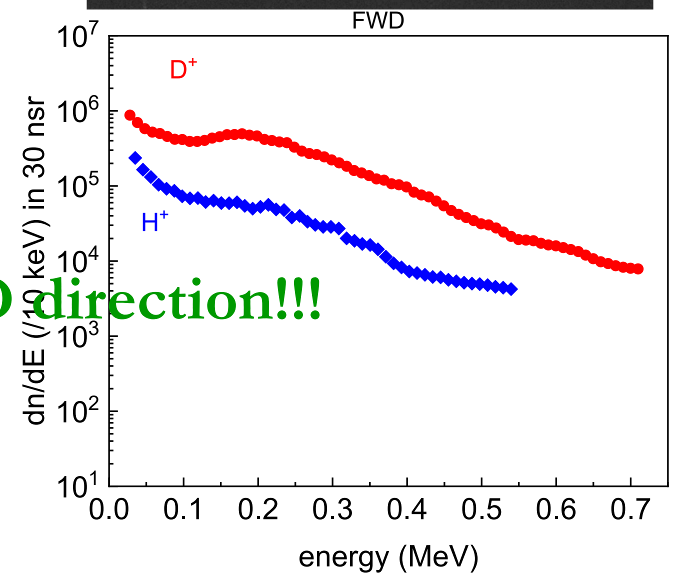
Each shot is recorded and stamped – example shot #976









Strong D+ in FWD direction!!!

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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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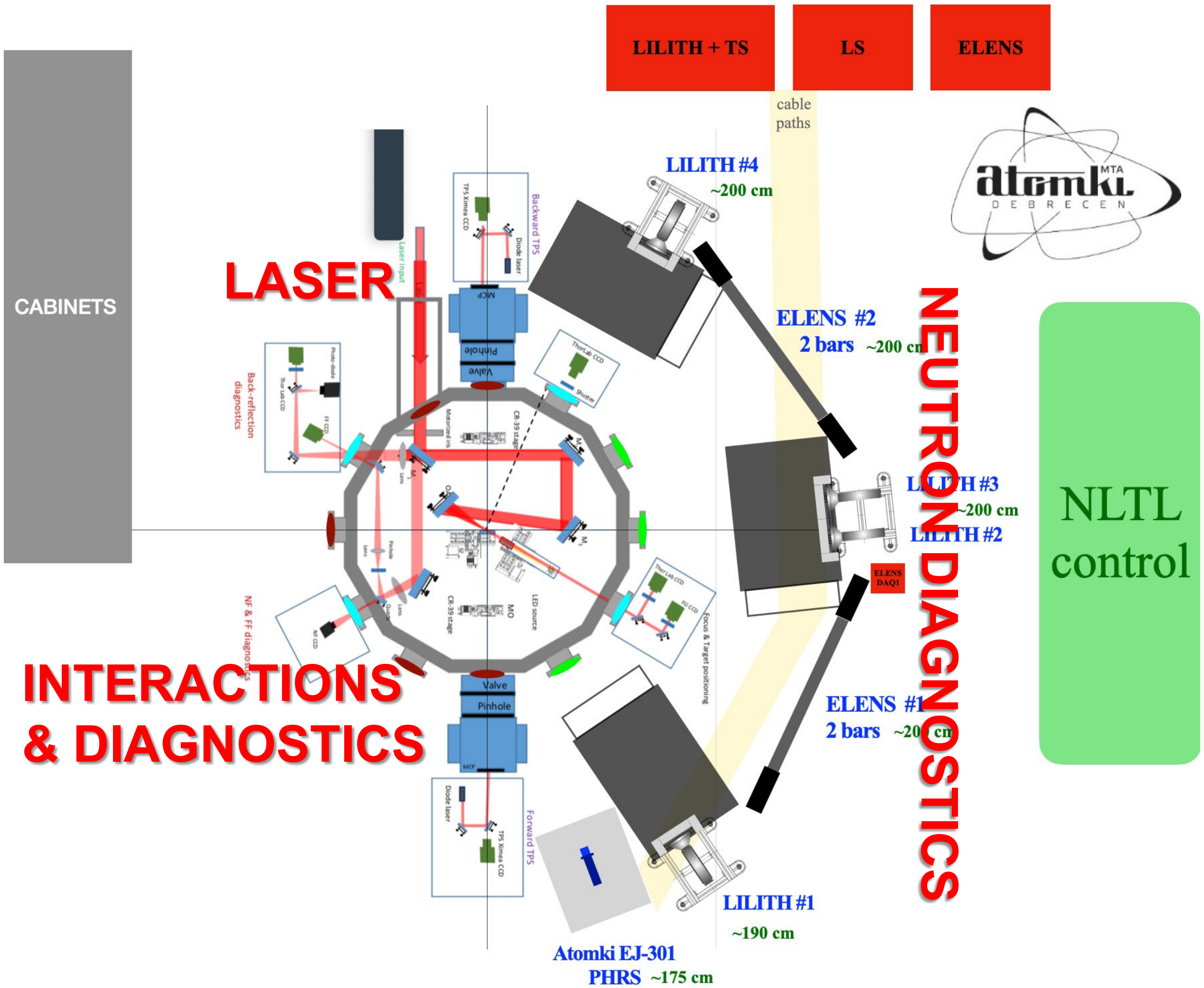

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INTERACTIONS

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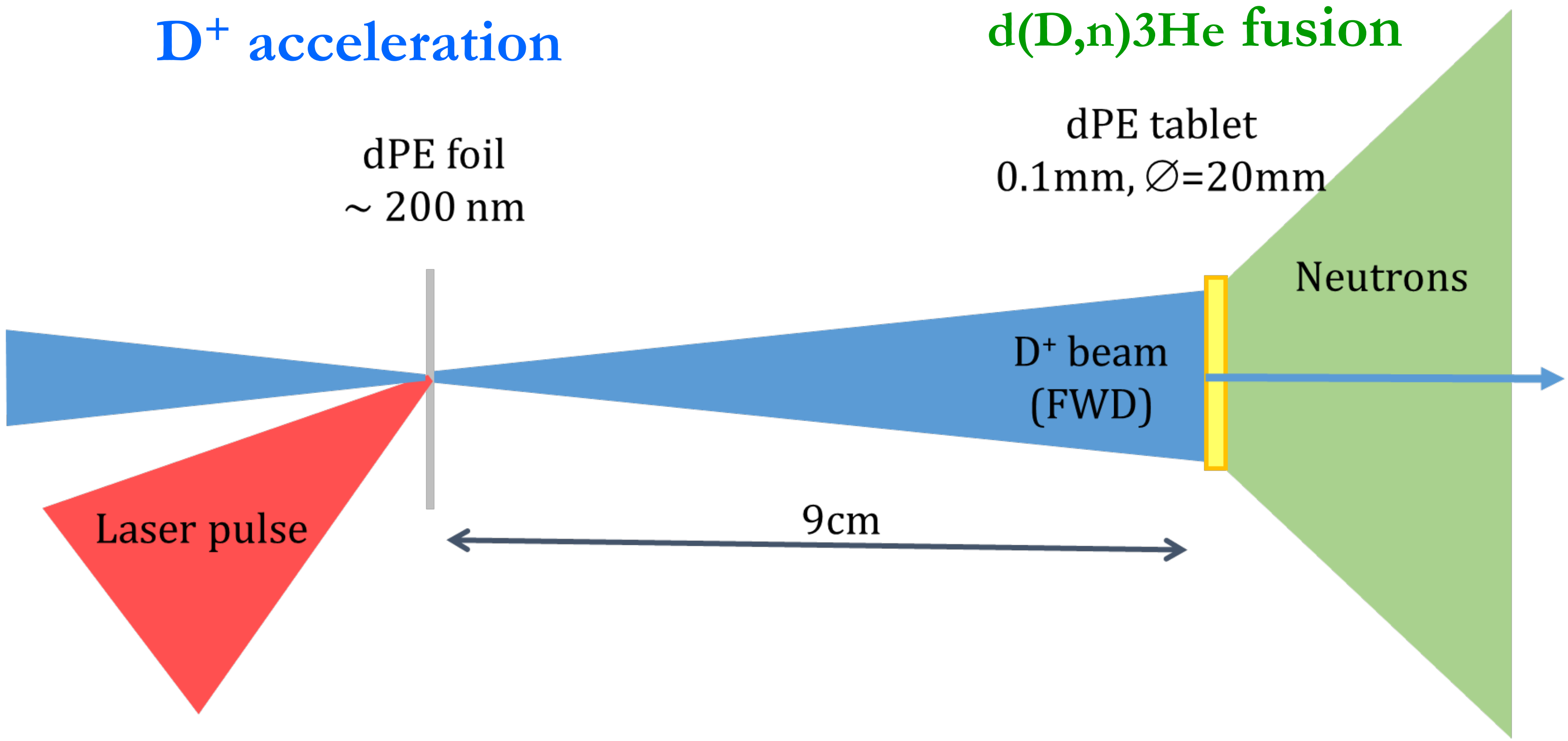

Primary target (pitcher)

Home-made

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

Secondary target (cathcer)

from dPE powder, press-machine

Fast Neutron generation at 1 Hz repetition rate

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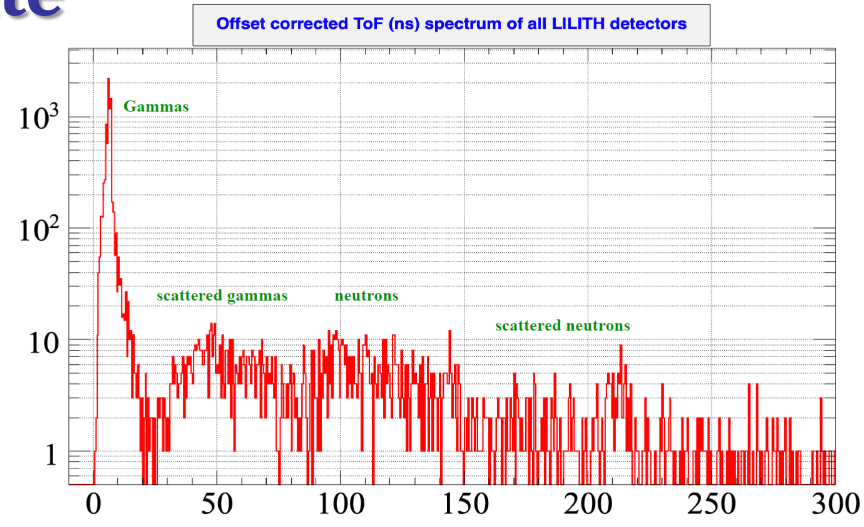
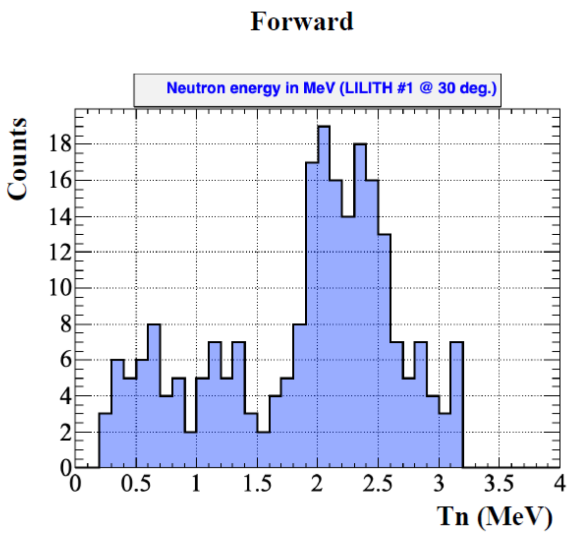
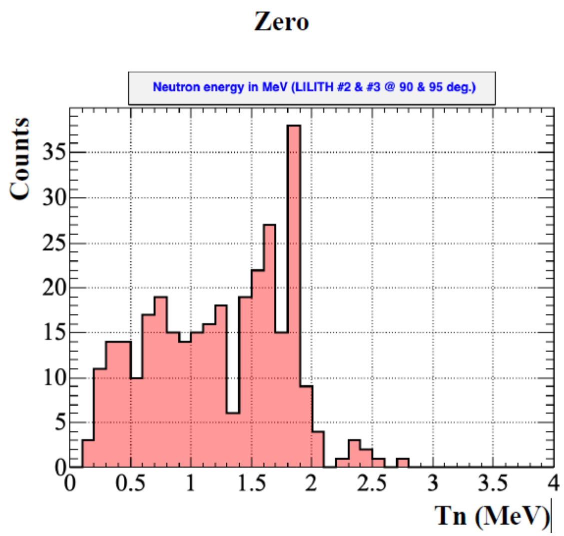
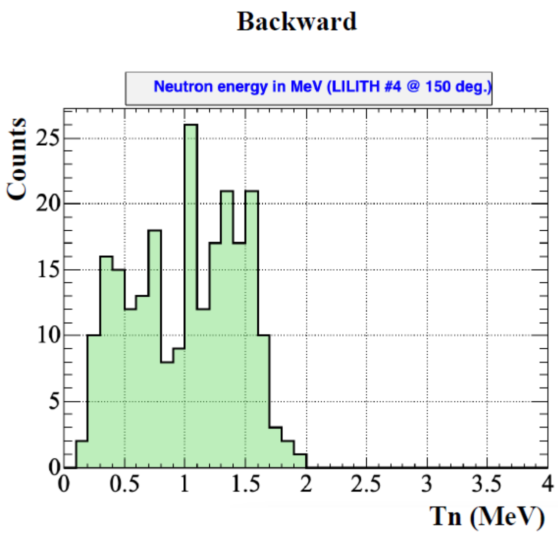
"Time-of-flight" recording of all shots



Neutrons in various directions







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Fast neutron generation with 1 Hz repetition rate

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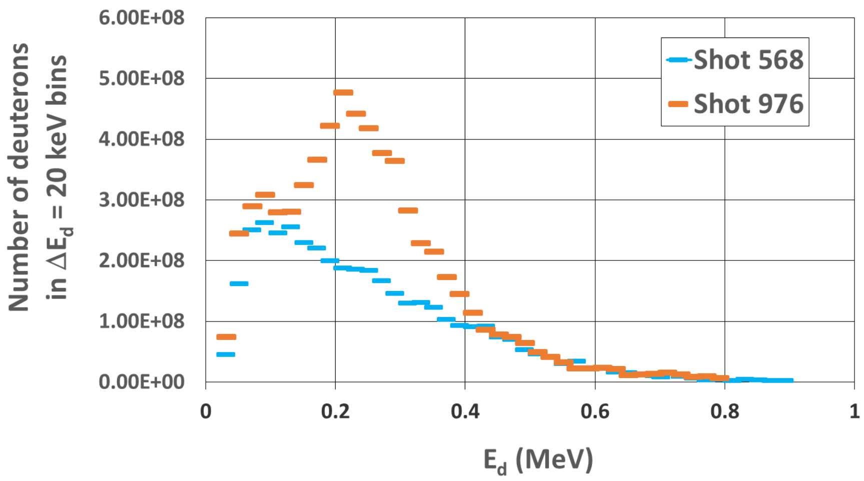
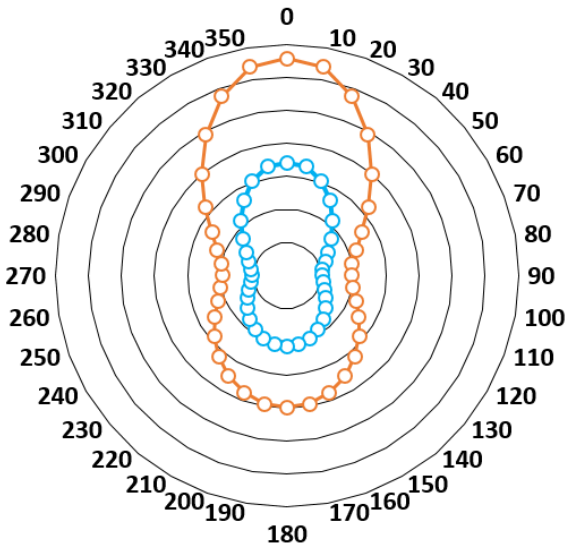
For simulations, so far two typical spectra were considered

one with high cut-off energy
one with high total D+ energy





Neutron yields for $\Theta = 4\pi$

Shot 568: 1978 neutrons per shot

Shot 976: 3649 neutrons per shot

Full evaluation is in progress!

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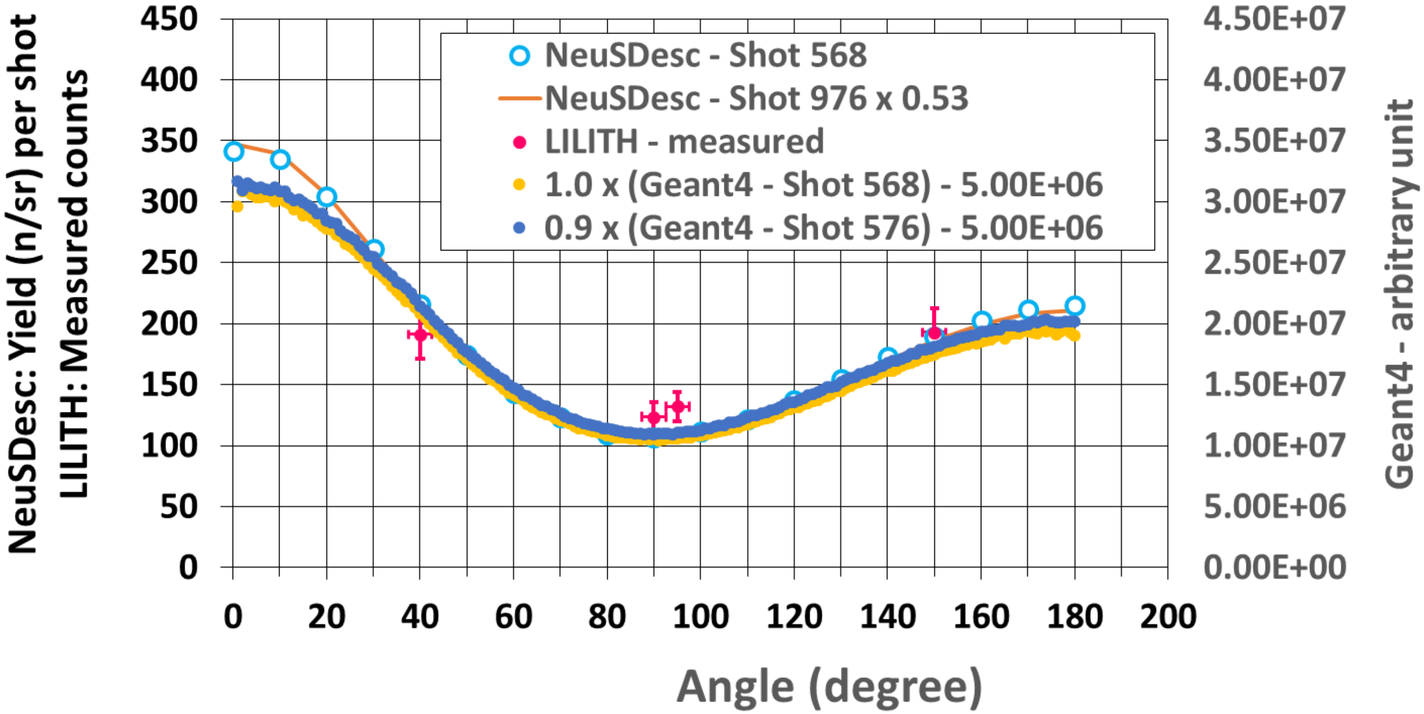
Fast neutron generation at 1 Hz repetition rate

Angular distribution – measurement and simulations

Broad spectrum deuterons + dPE target (6500 μg/cm²)
NeuSDesc: pencil beam; straggling in the target is not considered
Geant4: bunch of deuterons, realistic broad energy spectrum and angular distribution



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Conclusion of *n* generation and outlook

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Proton acceleration with few cycle pulses is a mixed process

D^+ yield depends on the chirp of the pulse

Generated neutrons at 1 Hz (first results) **>3000 n/shot**
~ 2MeV/n

Next steps: *thinner dPE foil* (<10nm) – to reach "RPA / LS" regime
optimise D yield for neutron via chirp, etc.
improve focusing
go for <6fs – pulse compression
go for kHz - further target system developments
deep learning

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Pulse compression towards single-cycle pulse at 10Hz

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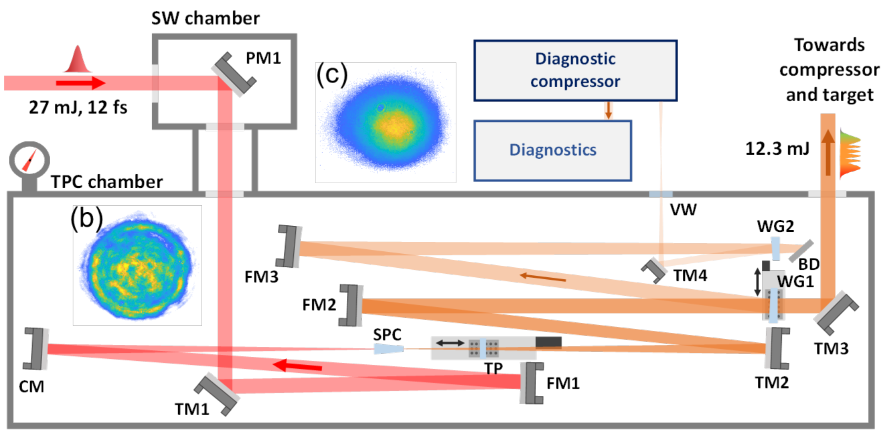
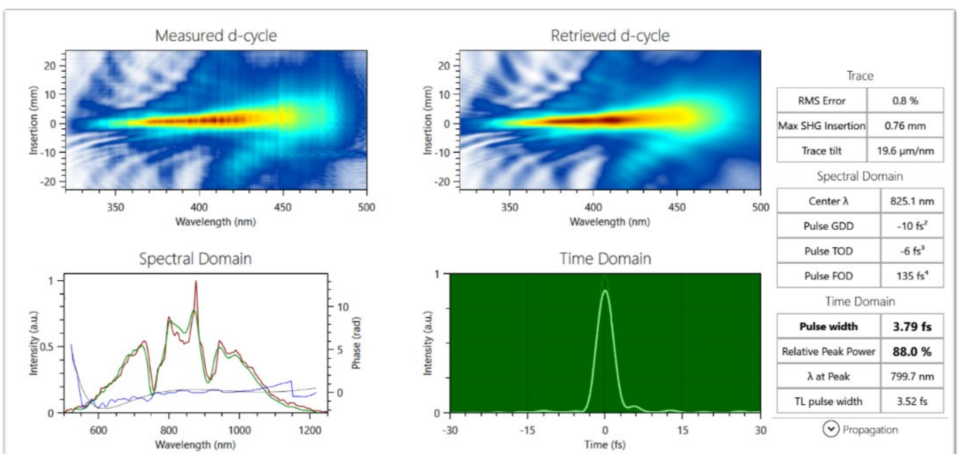
Single-plate pulse compressor





Compressed pulse duration:

- **FTL: 3.52 fs**
- **Measured: 3.79 fs**

1.4 optical cycle
~12mJ

Toth et al, (2022), submitted to OL
Nagymihaly et al., submitted to ASSL

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Fast neutron generation with 1 Hz repetition rate

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G. Mourou, J. Wheeler

S. Figul, G. Marowski

V. Bychenkov

Lebedev Institute

Grants

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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

Thank you for your attention

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