National Laser-Initiated Transmutation Laboratory
University of Szeged

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Deuteron acceleration and fast neutron generation with a 10Hz few-cycle laser

Károly Osvay

EAAC’23, Isola d’Elba

19th September, 2023

National Laser-Initiated Transmutation Laboratory
University of Szeged

NLTL

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eli attosecond

atomki MTA DEBRECEN

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USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

Advanced Microfluidic Systems GmbH

S. Figul, G.Marowski

- 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 projekt: 101020100

nkfih

Innovációs és Technológiai Minisztérium

ITM FELADATUNK A JÖVŐ

MULTI SCAN 3D

Motivation

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Demand for neutron sources is rapidly increasing

– by academy, industry, and health care

The number of neutron facilities sources is decreasing

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

Many emerging applications call for neutron sources with

- a yield of 10^8 n/s - 10^{11} n/s;
- relaxed safety and security (compared to reactors)
- compact, efficient.
- Reliable.

Neutron needs and lasers – energy conservation

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Demand: 10^{10} n/s, >1 MeV/n

Average power of the neutrons: 1.6 mW (1.6 mJ /s)

Laser needs

0.01% conversion from laser to neutron: 160 W laser

0.001% conversion from laser to neutron: 1.6 kW laser

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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
2×10^6 n/s

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

Photonuclear

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

2.9×10^7 n/J
~ 10^5 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)

~8×10^{10} n/J
~1300×10^6 n/s
~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 high average power laser technology supports the necessary relativistic peak intensity with pulses of few cycle duration.

↓

Let's investigate neutron generation with few cycle, 10's mJ pulses!

Scheme of the interactions

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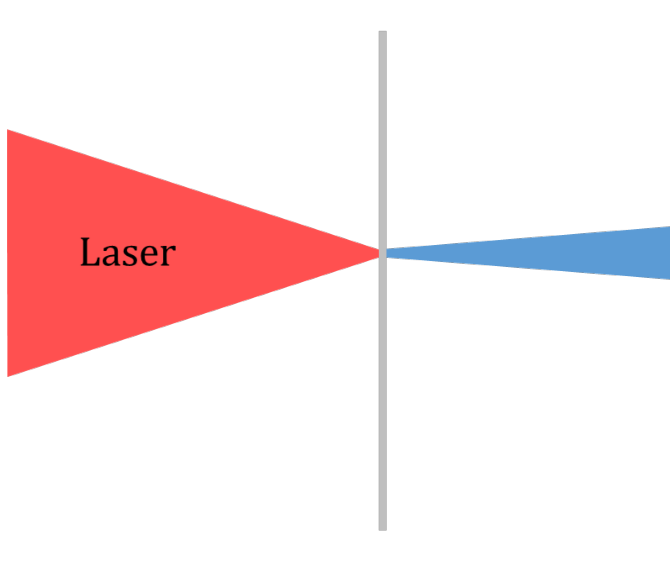
D^+ acceleration

d(D,n)3He fusion



Primary target (pitcher)

Secondary target (cathcer)

NLTL's R&D strategy (2020-24)

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Single shot
Study of ion acceleration on ultrathin foils

Singh et al., Sci. Rep. **12** (2022) 8100
Varmazyar et al., Rev.Sci.Instr. **93** (2022) 073301
Ter-Avetisyan et al., PPCF **65** (2023) 085012

Single shot
Study of deuteron acceleration on ultrathin foils

1 Hz (burst) mode — rotating wheel target
Deuteron acceleration from foils and neutron generation

Osvay et al., submitted
Lecz et al, in prep.

10 Hz continous mode — ultrathin liquid leaf target system
Deuteron acceleration from liquid leaf and neutron generation

Füle et al, in prep.
Osvay et al, in prep.

1 kHz continous mode — reprate target development
Deuteron acceleration on liquid leaf and neutron generation

end 2023 - 2024

Ion acceleration at 1 Hz repetition rate from C_2D_4 foils

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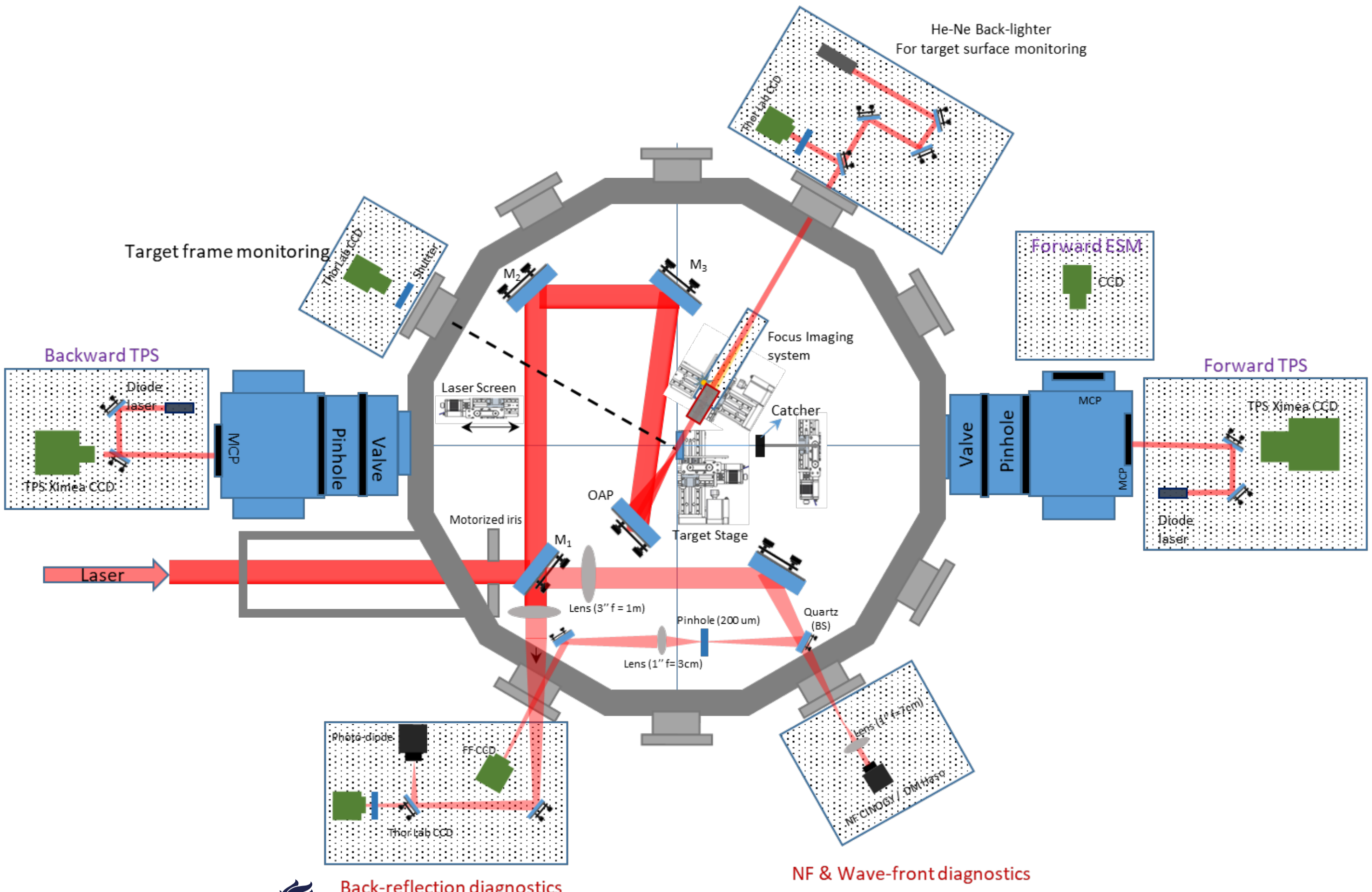
Laboratory time in ELI-ALPS
10.6.22-23.06.22, 7 laser days, ~4000 shots



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eli attosecond

LASER

EKSPLA

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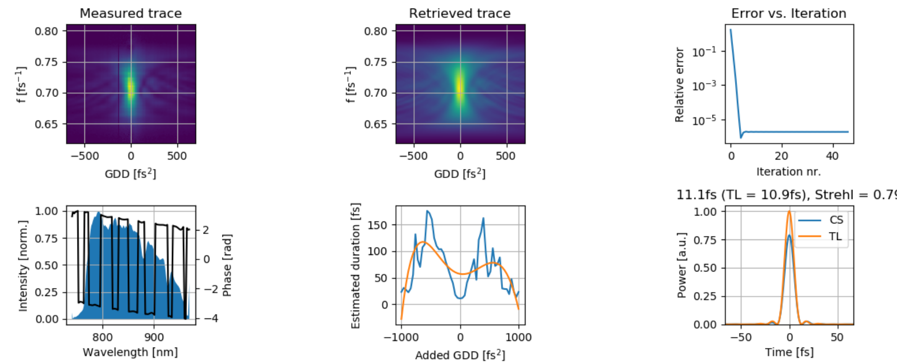
SEA laser (10Hz, OPCPA) of ELI-ALPS parameters *on target*

Pulse energy: ***~21 mJ***
(measured for each shot)

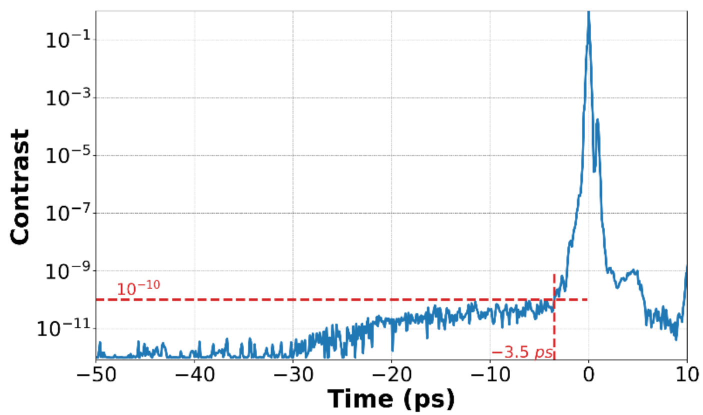
Laser pulse duration: ***12.3 fs***
Measured in vacuum, after OAP, with disp scan



Focal spot FWHM: 3.2×3.8 μm^2

Peak intensity in focus: **4×10^{18} W/cm²** (a_0~1)

Temporal contrast



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

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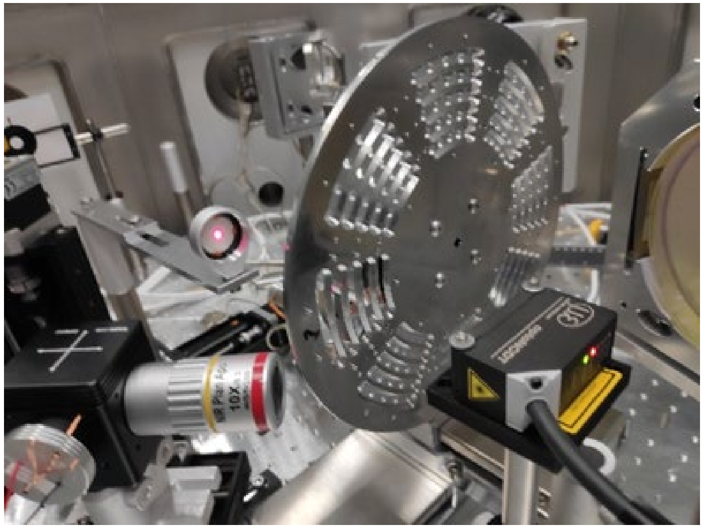
Rotating wheel target

In collaboration with Universidad Santiago de Compostela



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

Home-made C_2D_4 foil ~200nm

Prior to shoot - mapping

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

See also **the poster by Fernandez** et al., Radioisotope production using a high-repetition-rate…

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

Osvay et al., submitted

Proton and Deuterion acceleration at 1 Hz repetition rate

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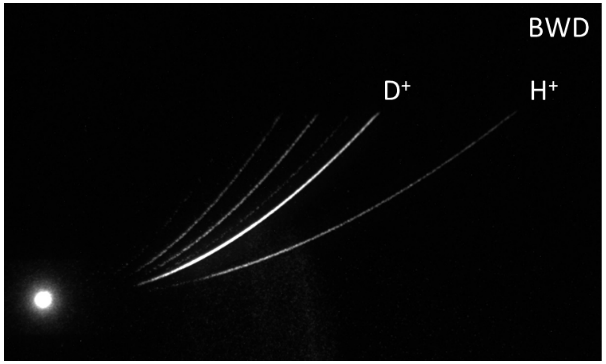
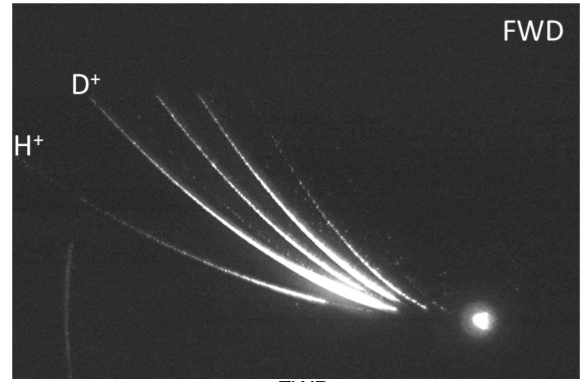
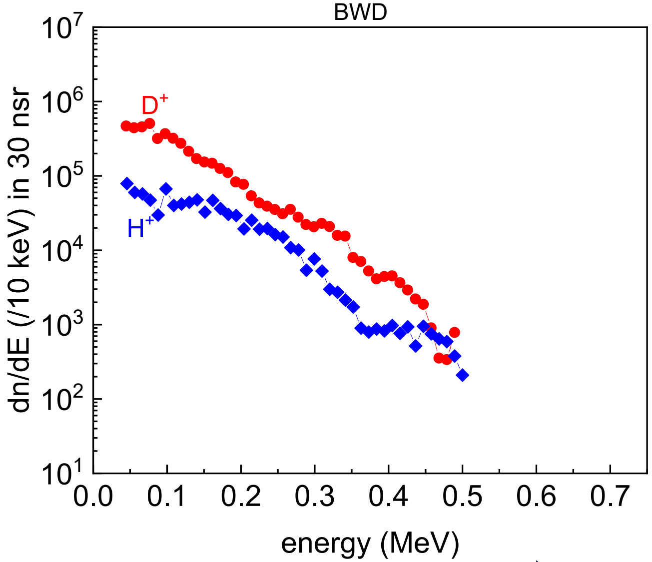
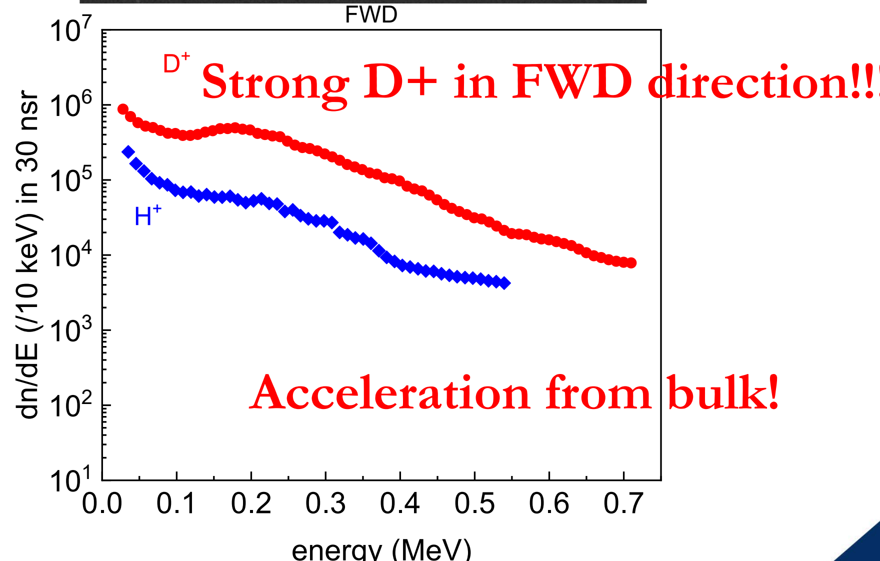
Each shot is recorded and stamped – example shot #976









Osvay et al., submitted

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Neutron generation at 1Hz

Laboratory time in ELI-ALPS

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

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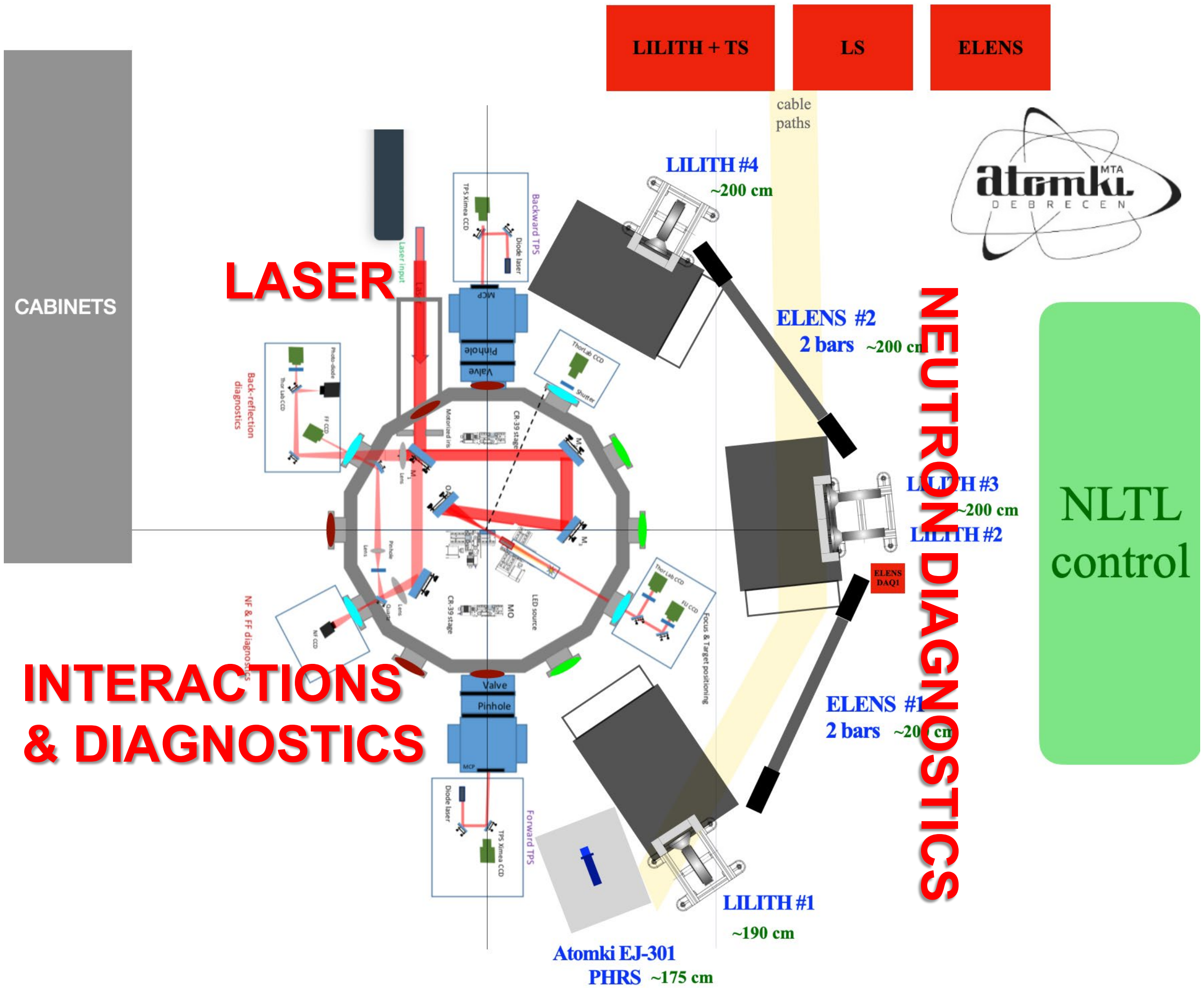

INTERACTIONS

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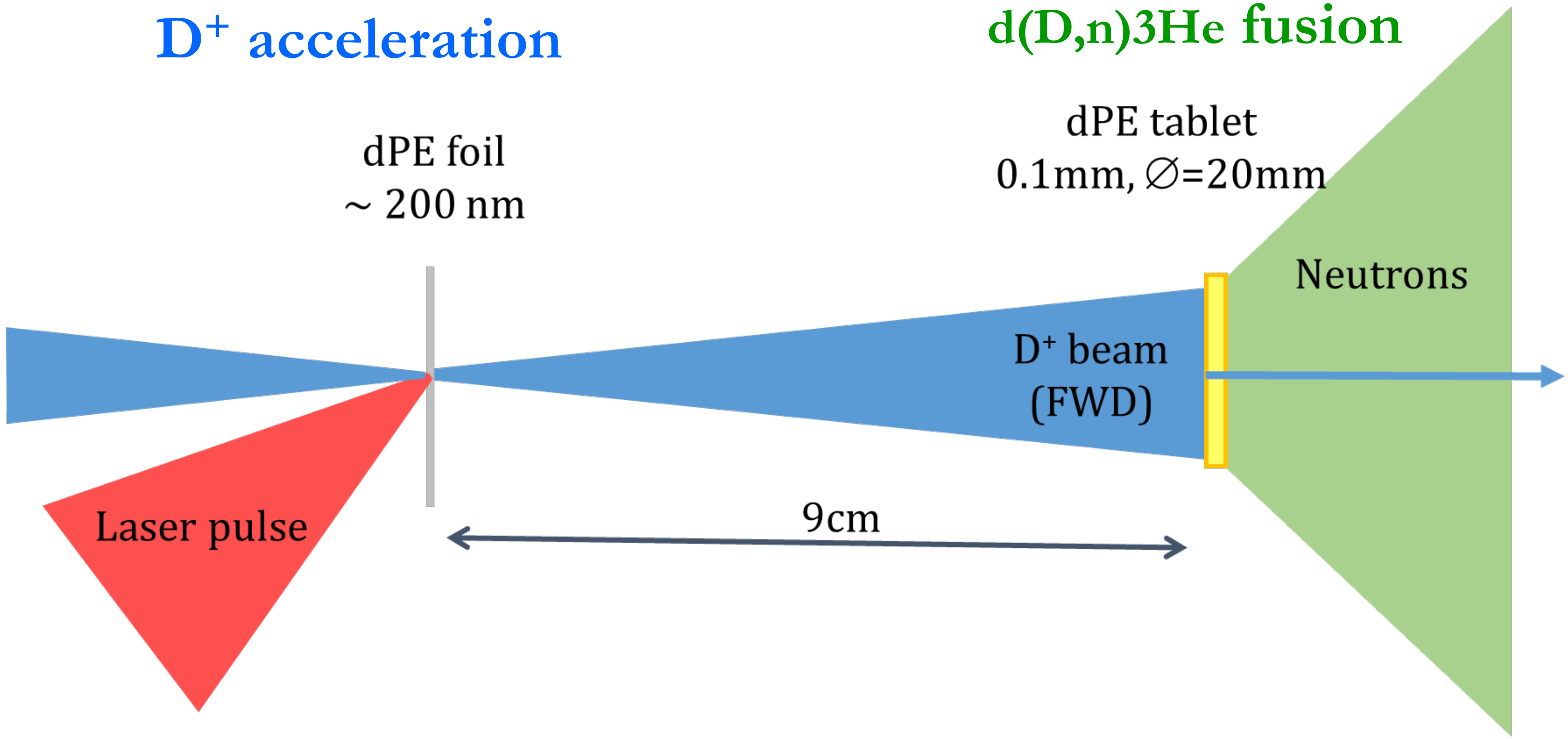
D^+ acceleration

d(D,n)3He fusion



Primary target (pitcher)

Home-made

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

Secondary target (cathcer)

from dPE powder, press-machine

DIAGNOSTICS – neutron
LILITH system

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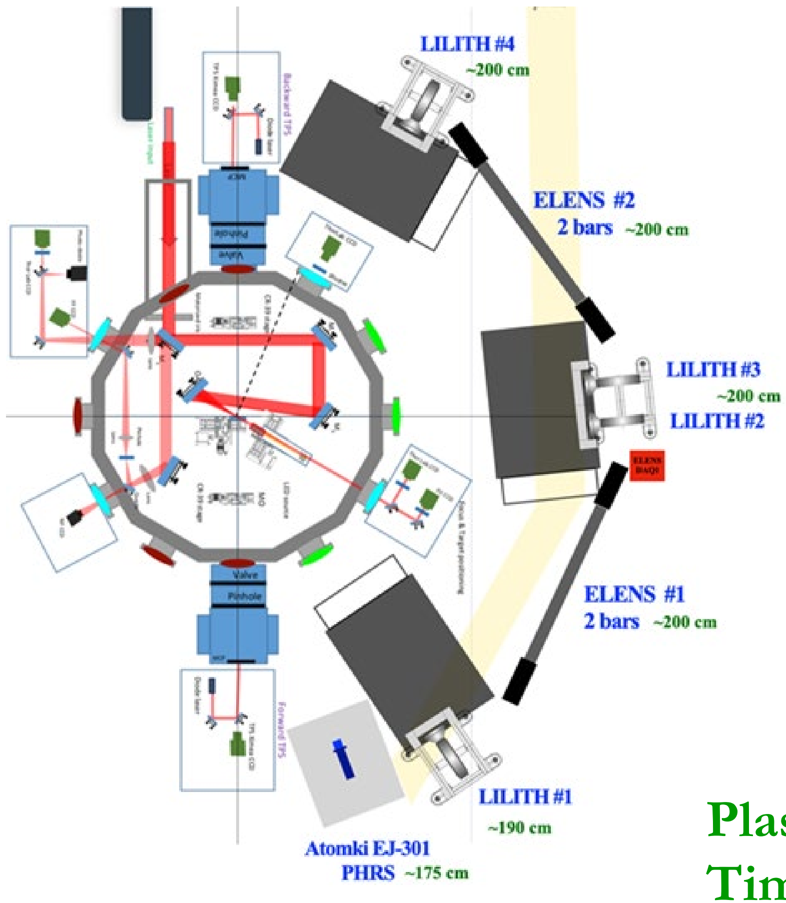

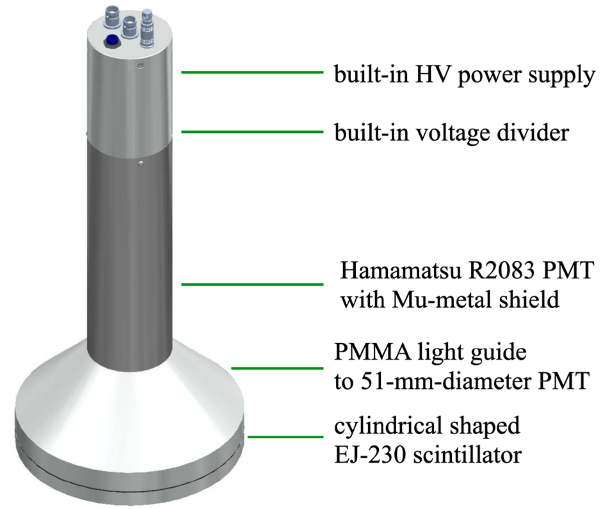

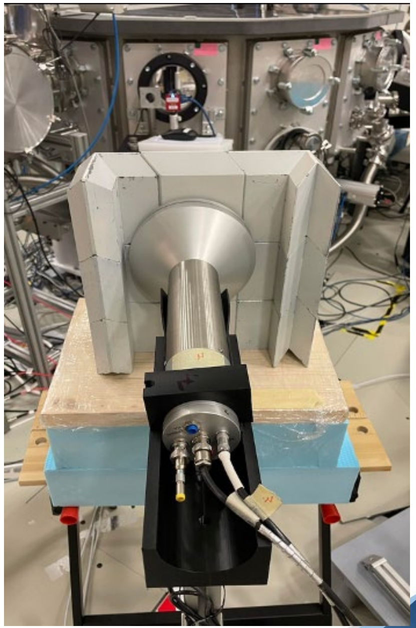

Plastic detectors
Time-of-Flight detection

Fast Neutron generation at 1 Hz repetition rate

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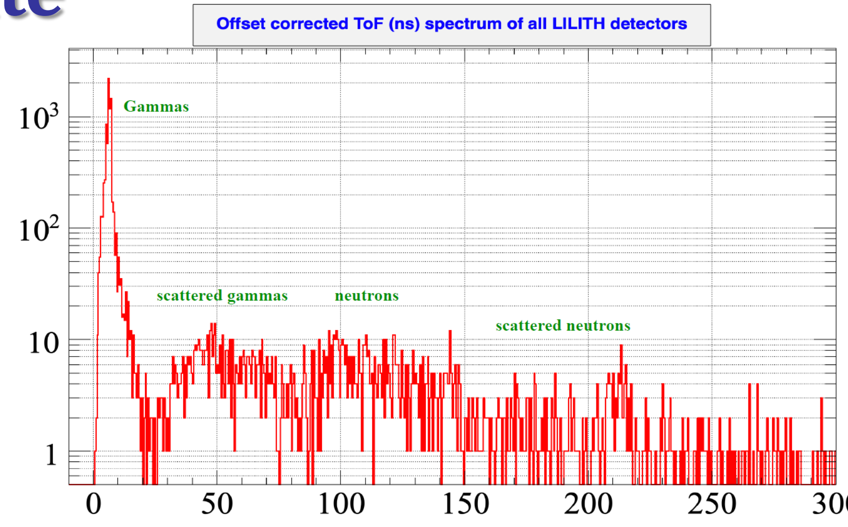
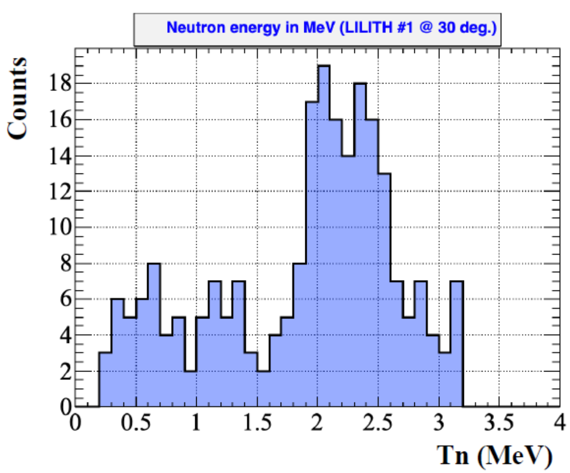
"Time-of-flight" recording of all shots

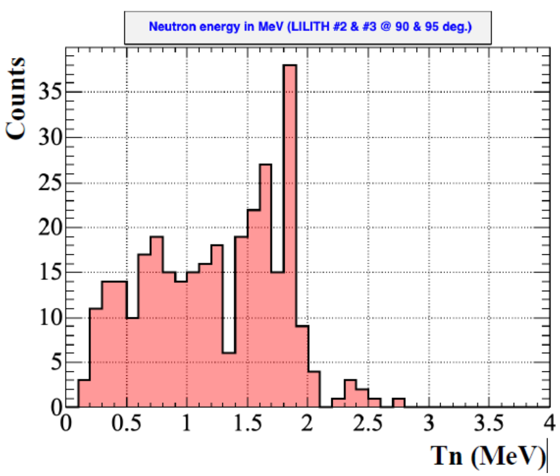


Neutrons in various directions

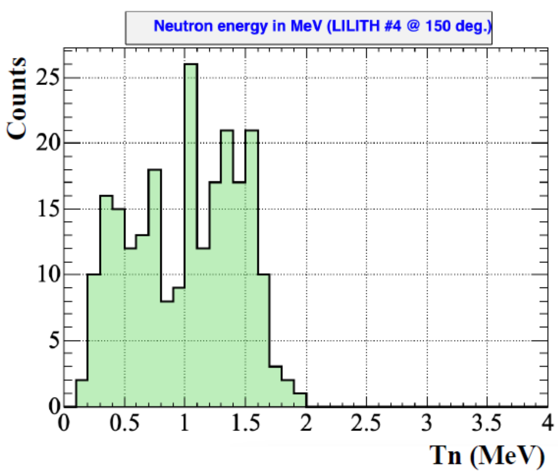
Forward



Zero



Backward



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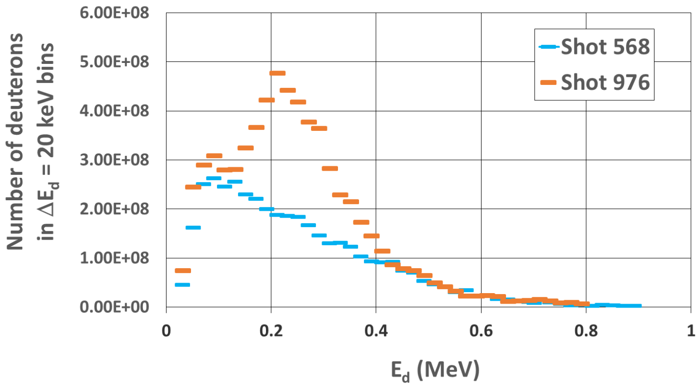
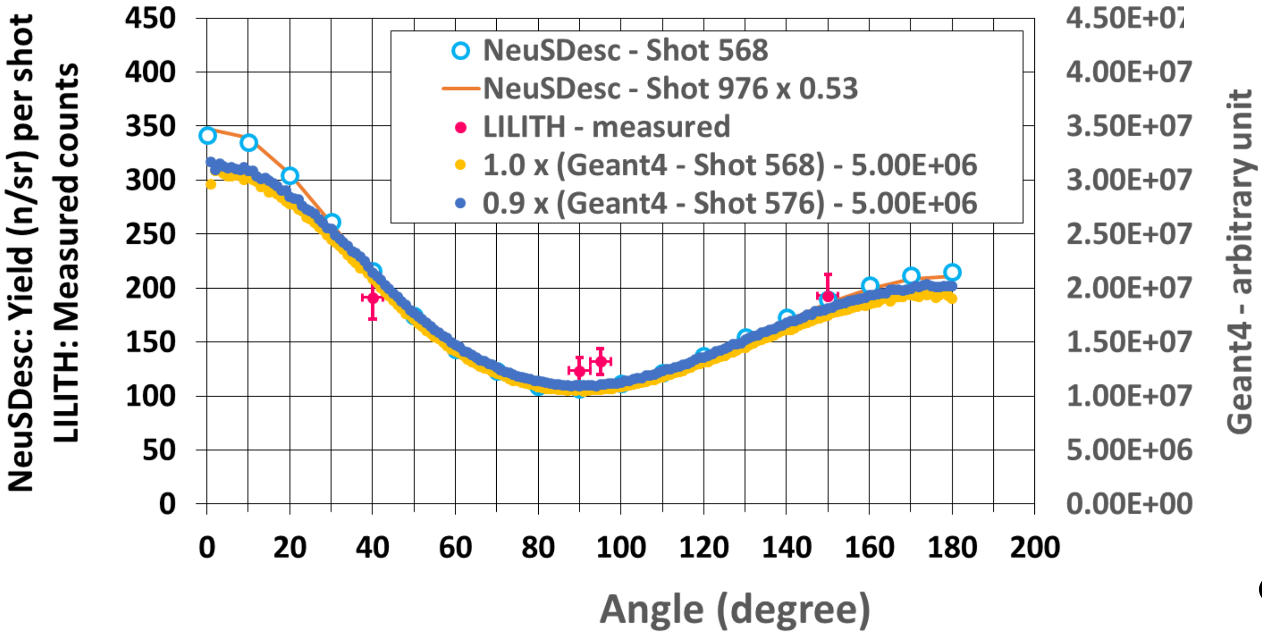
Fast neutron generation with 1 Hz repetition rate

For simulations, so far two typical spectra were considered

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



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



Osvay et al., submitted

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Development of an ultrathin liquid leaf target

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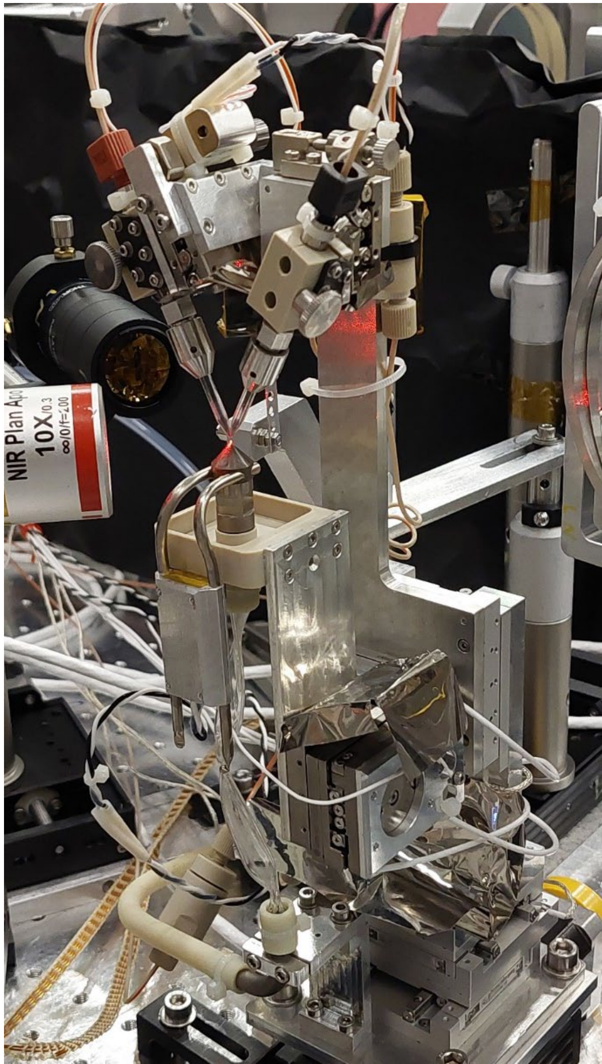
Advanced Microfluidic Systems GmbH

- Two liquid jets collide from two glass nozzles
- Pulsation damping system for *stability*
- Recirculation system for *continuous operation*
- Cold finger for 10^{-4} mbar *vacuum*



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Thickness measurement

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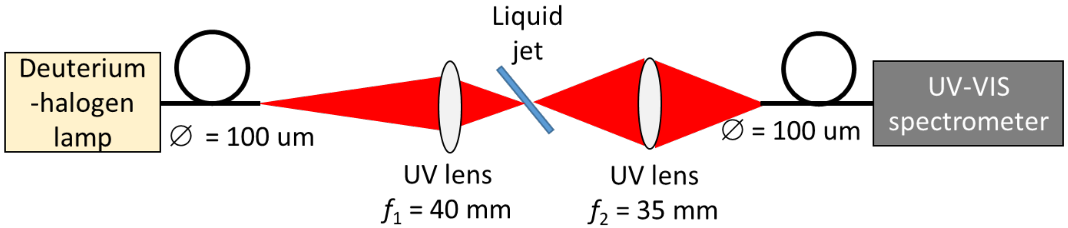
Thickness measurement with white light spectral interferometry

Vacuum compatible (with fibers):



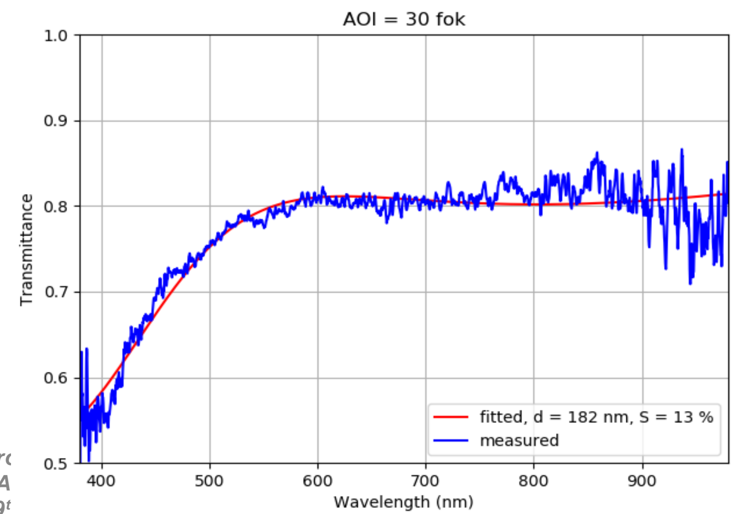
- light spot diameter on the target: 50 μm.

- modulation of the spectral transmittance due to the interference between the transmitted beam and the beams arising from the reflection on the front and back surfaces of the layer.

The resolution is:

~180 nm (PTFE foil)

With extension to UV → ~100nm



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Thickness variation and tuning in situ in air and *in vacuum*

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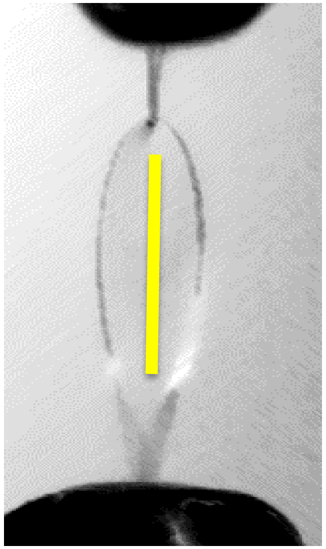
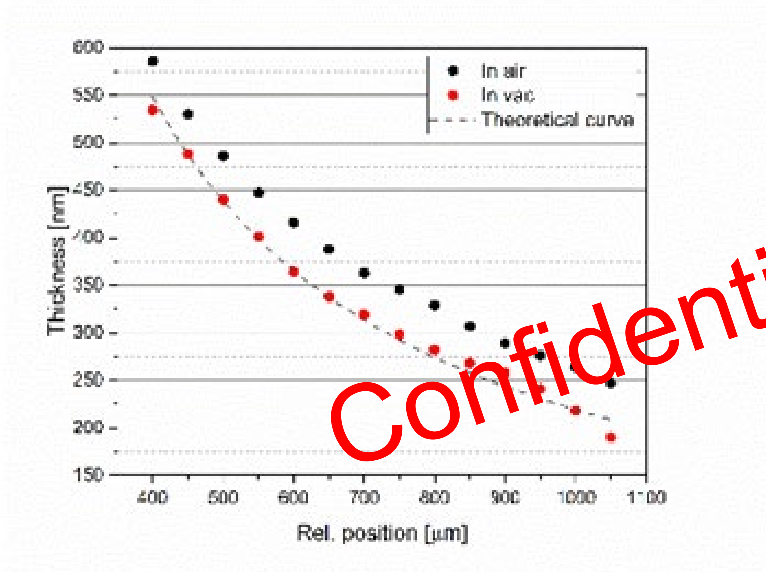
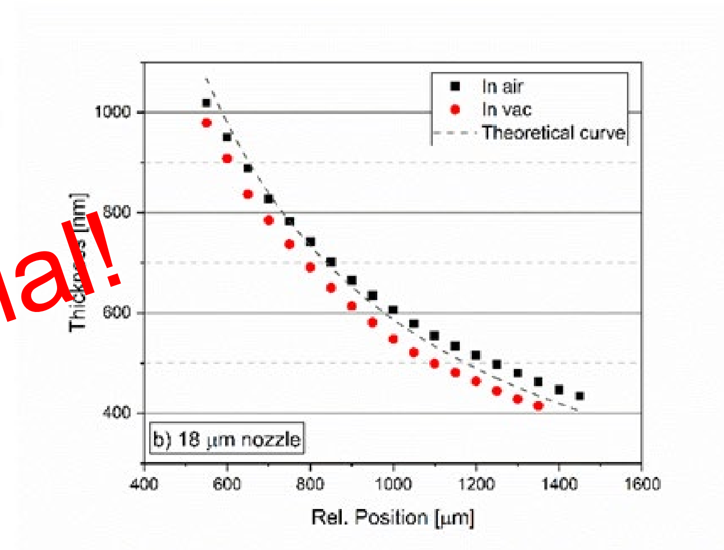


∅: 11 μm



∅: 18 μm



Thickness of the liquid sheet

- Varies along the flat surface;
- Depends on the size of microjets;
- Thinner in vacuum

Vacuum: <10^{-4} mbar

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Füle et al., in prep.

Mechanical stability

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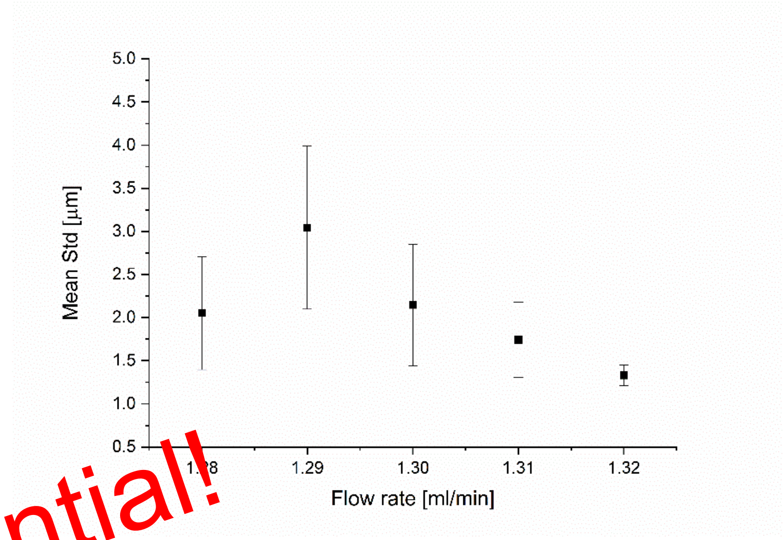
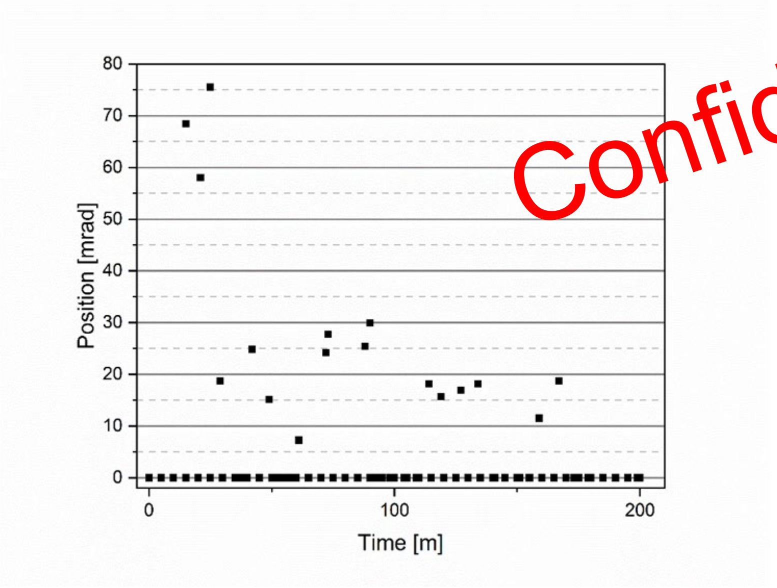
Position in the focal point

by MicroEpsilon ILD2300-20



Confidential!



Angular position in vacuum

by human intelligence correction

Füle et al., in prep.

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First test - proton acceleration
Leaf thickness: ~200nm

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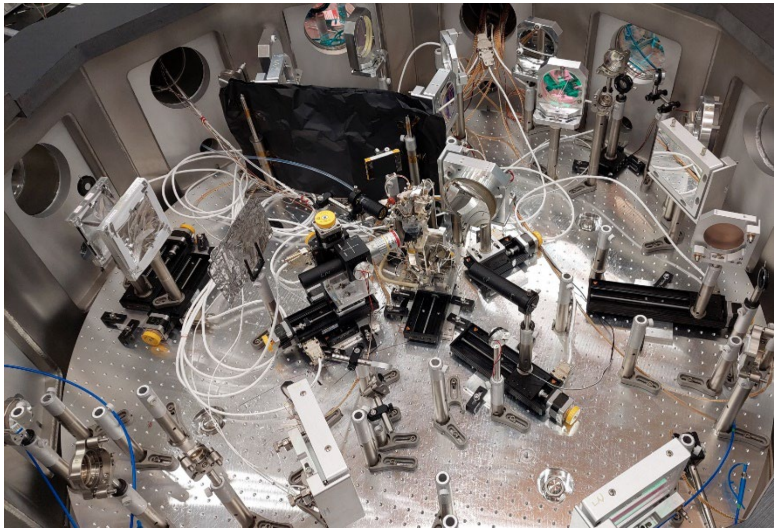
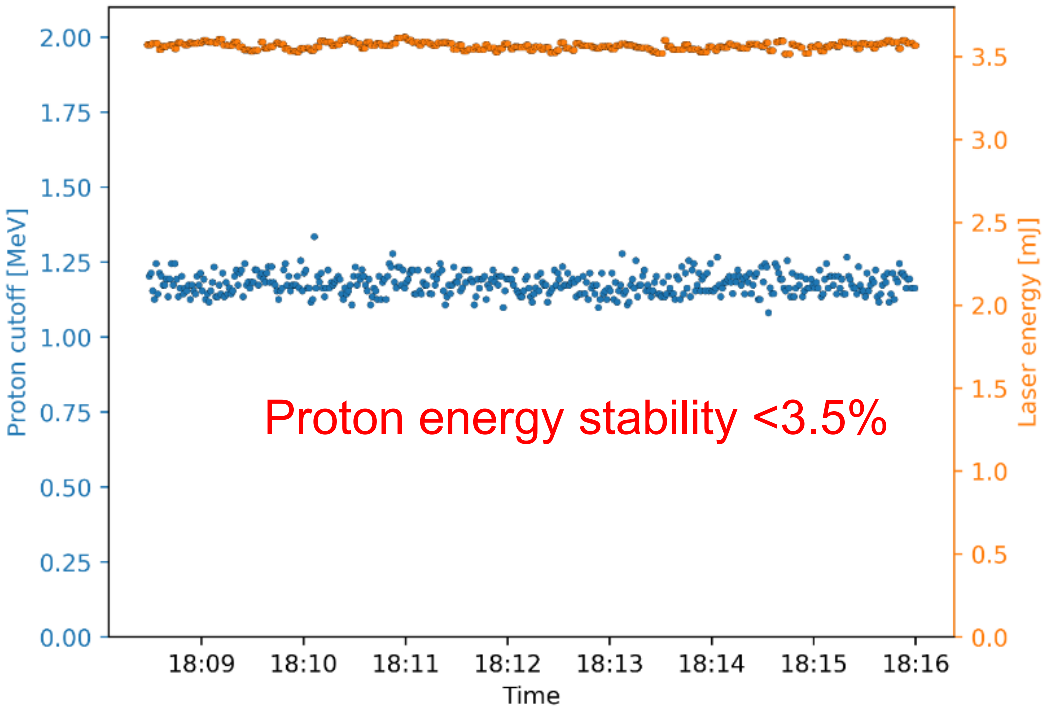


Laser "interaction" energy
3.56 mJ ± 0.02 mJ

Proton cut-off energy:
1.19 MeV± 0.04 MeV



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Deuterion acceleration at 10 Hz repetition rate

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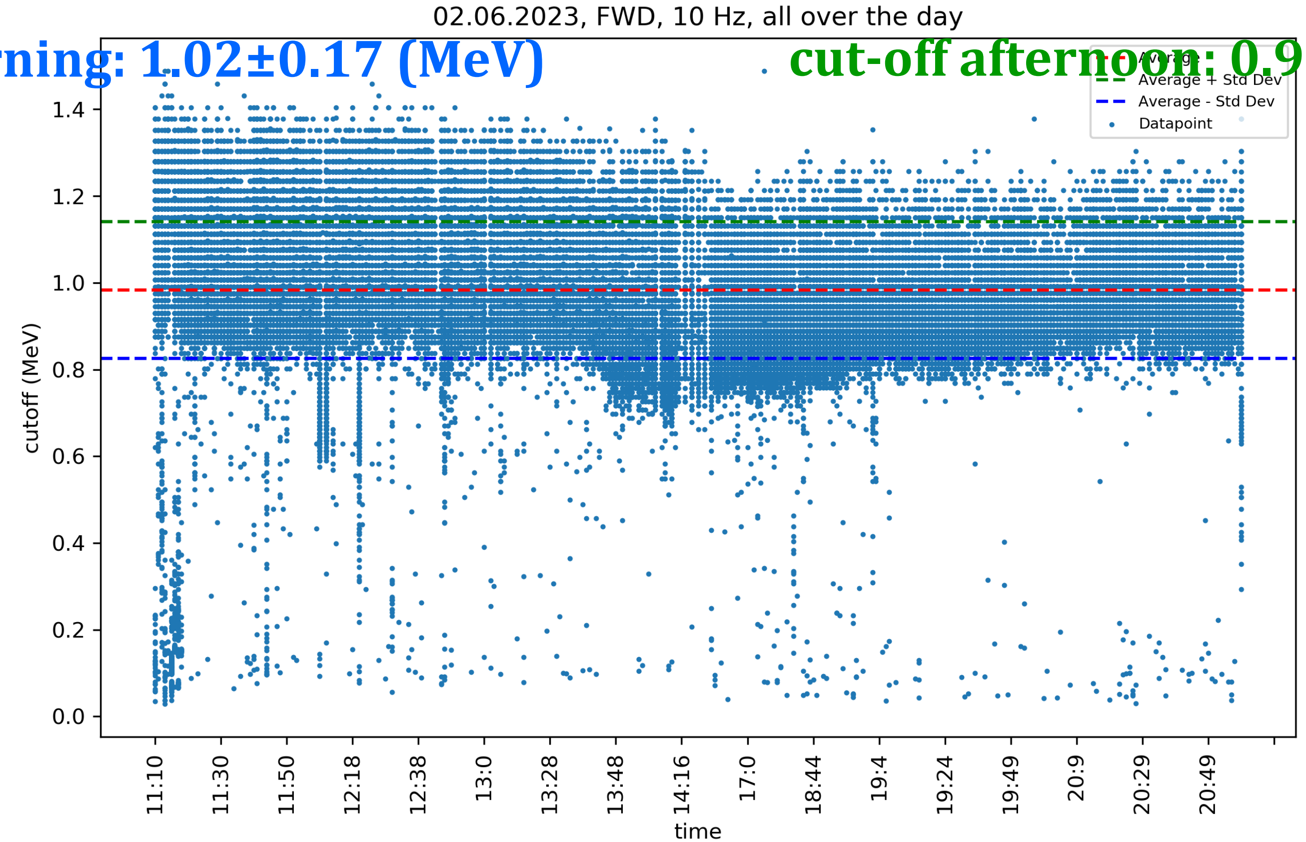
One of the four days
On 2nd June, number of shots: 73422

cut-off for the day: 0.98±0.16 (MeV)

cut-off morning: 1.02±0.17 (MeV)

cut-off afternoon: 0.96±0.11 (Me



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Deuterion acceleration at 10 Hz repetition rate

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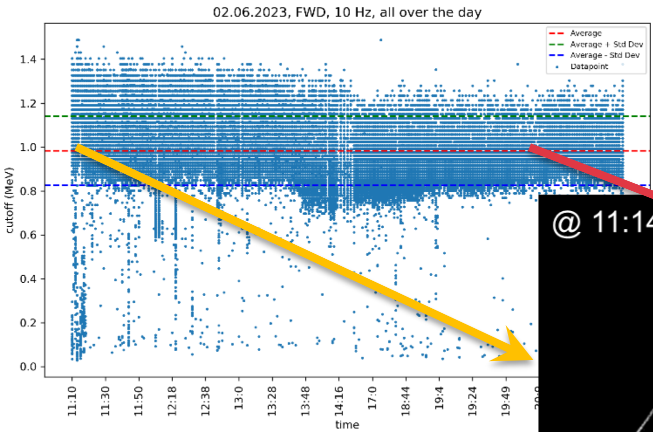
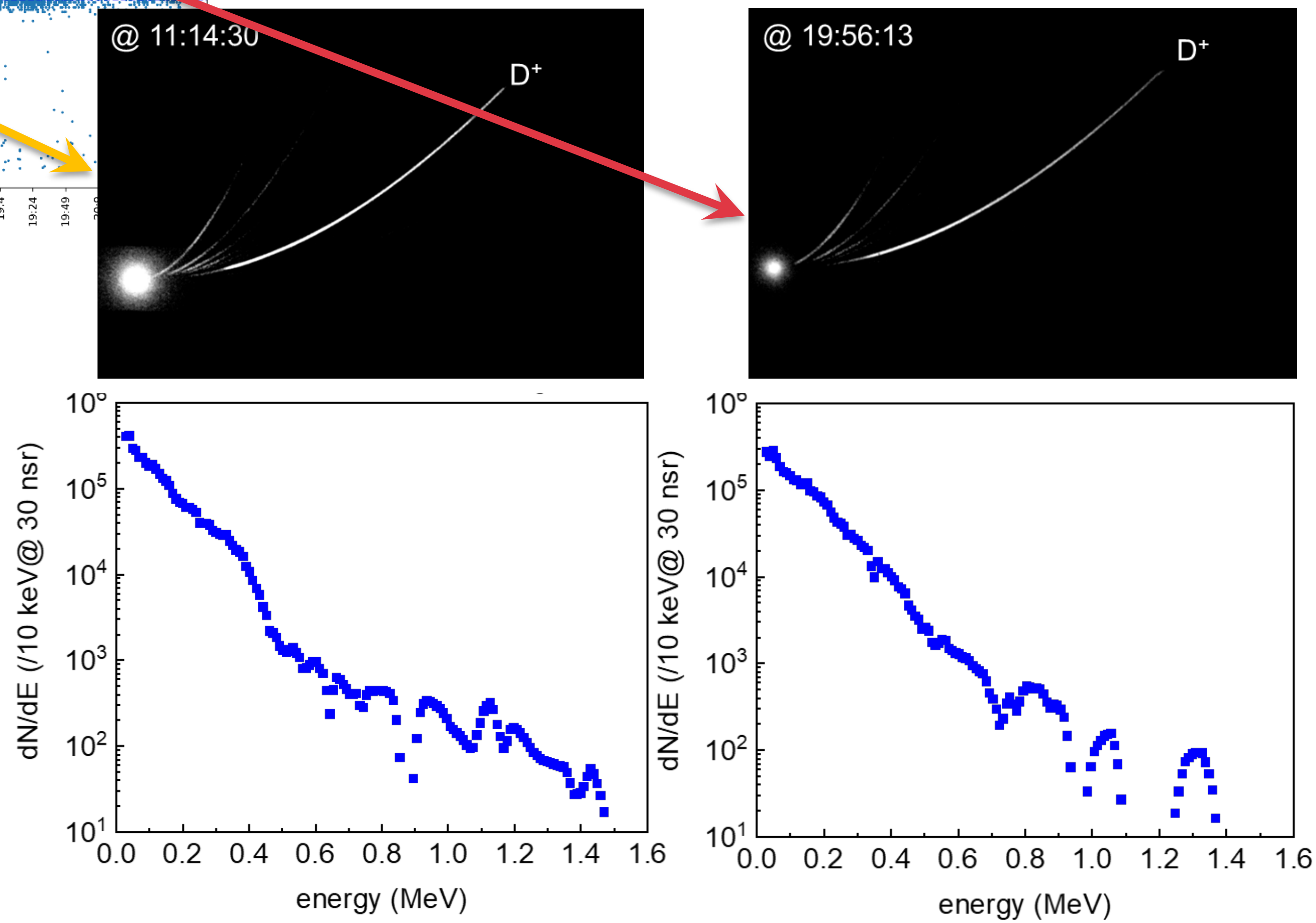
Spectral stability





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DIAGNOSTICS – neutron

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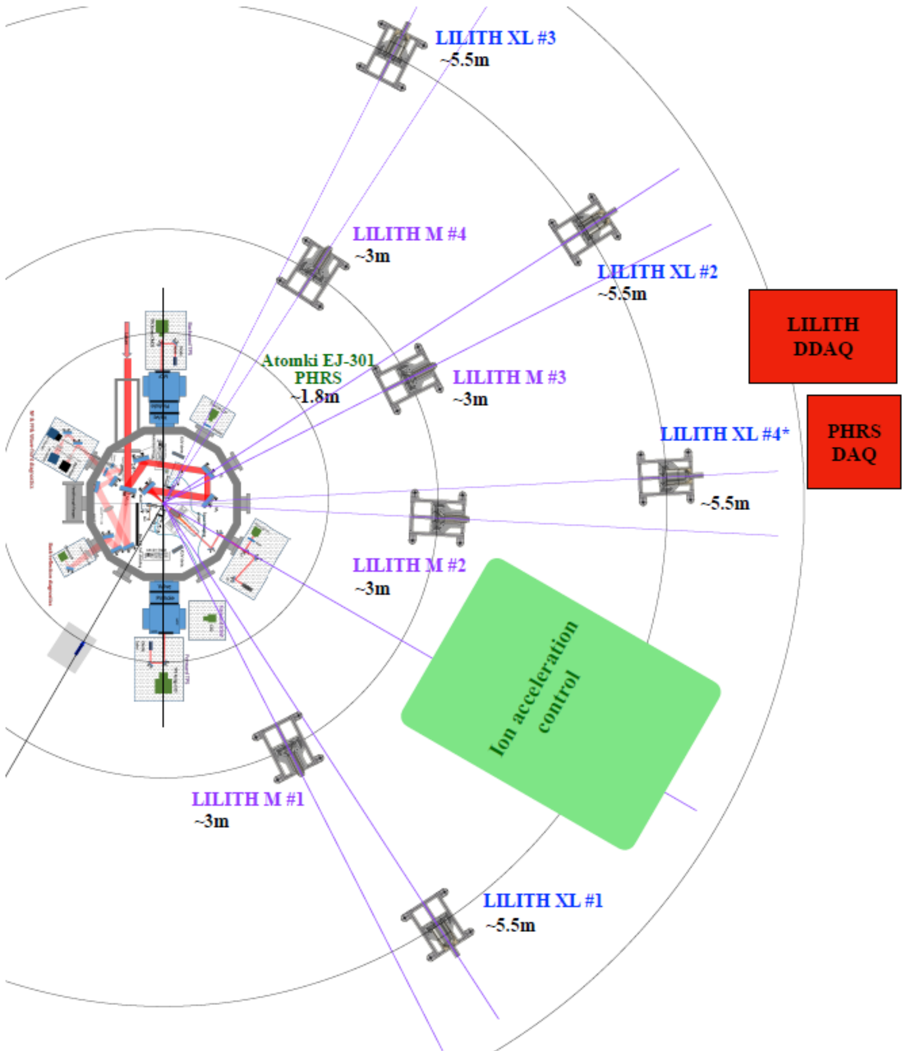

Three independent systems

Outside the chamber

Plastic scintillators: LILITH M, XL systems

Liquid scintillator: PHRS system

Inside the chamber

Bubble Neutron Detector Spectrometer

Neutron measurements
LILITH system, neutron spectra

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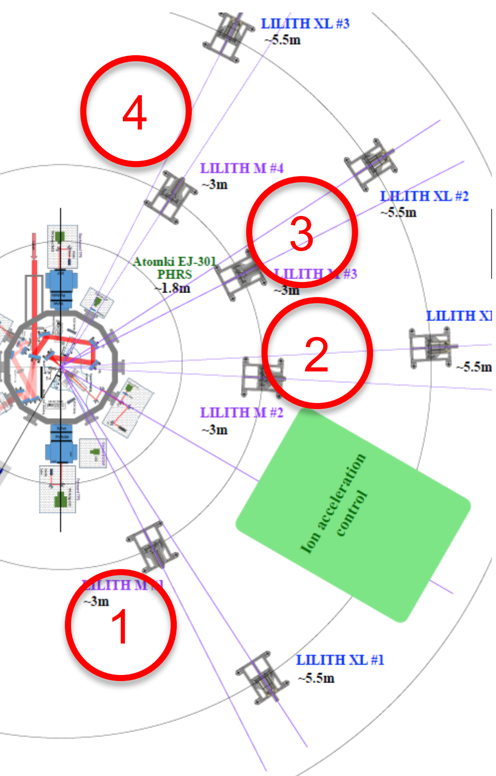

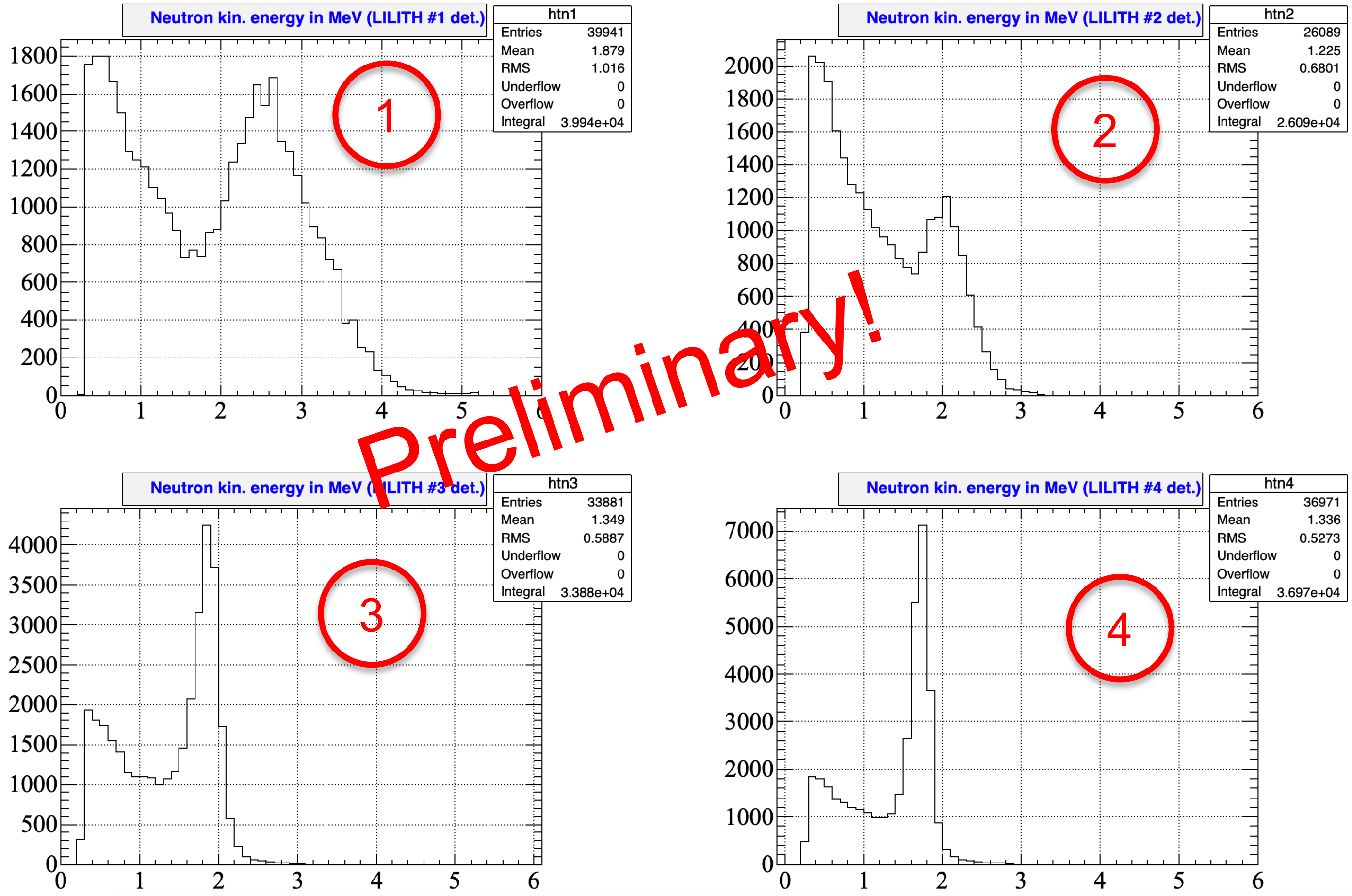

Neutron measurements
Pulse Height Response System (PHRS)

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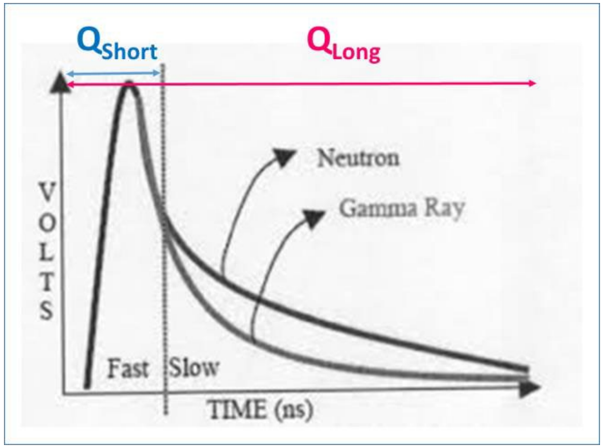

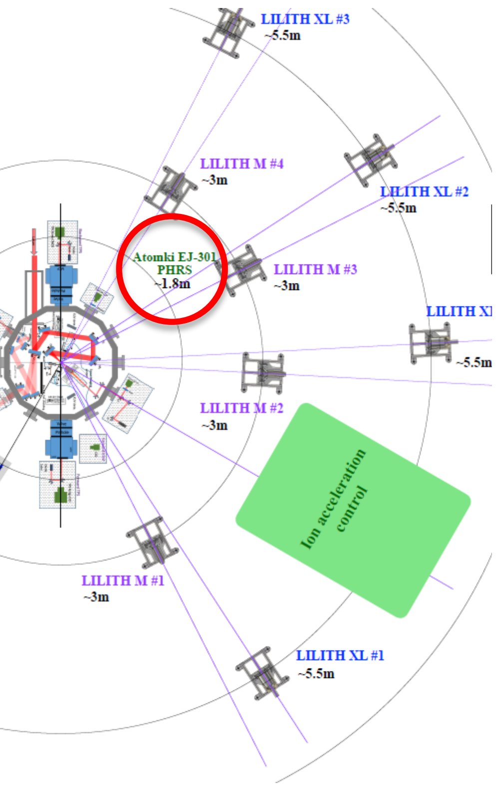

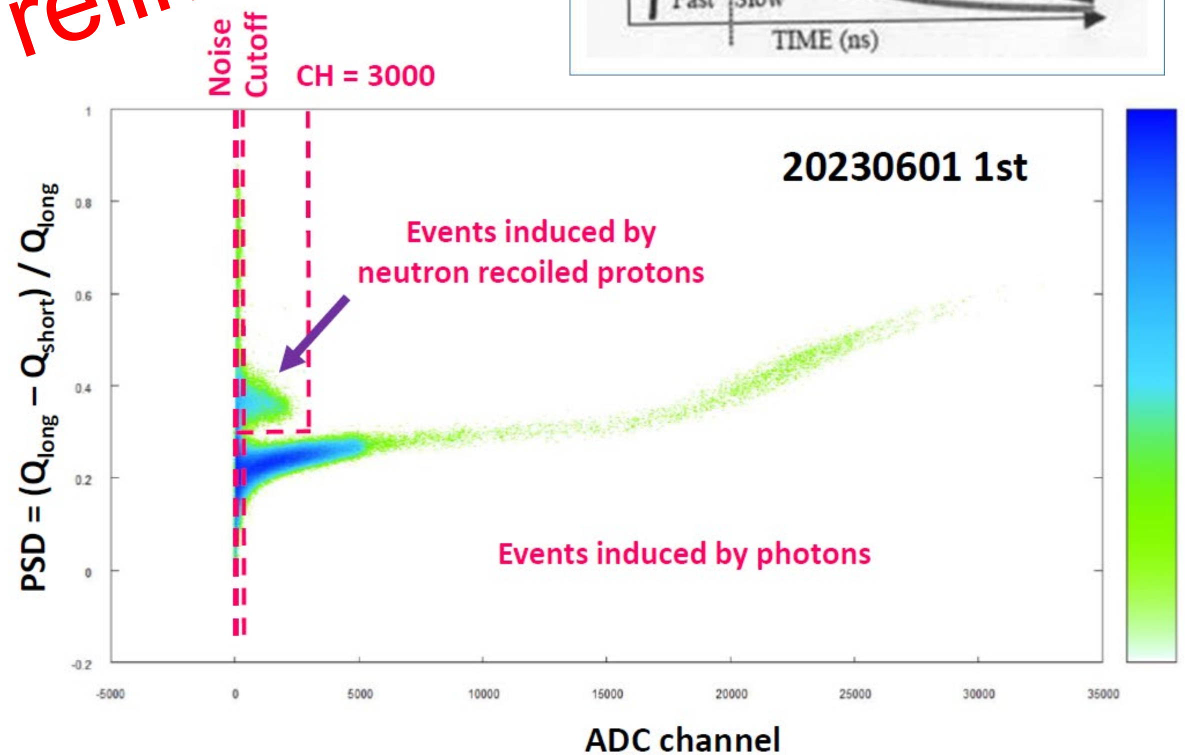

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Neutron measurements

Bubble neutron detector spectrometer
FWD, BWD

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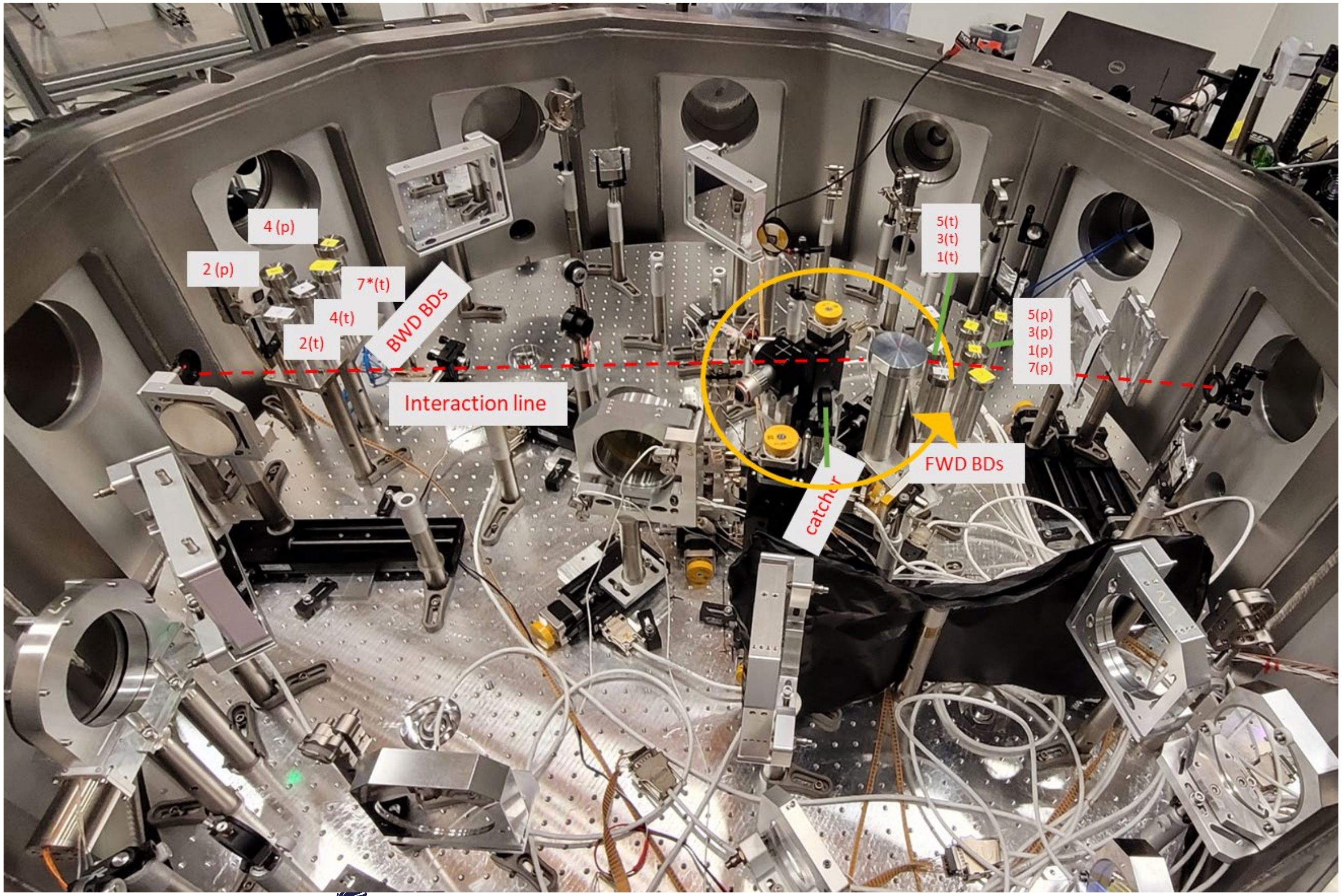

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Neutron yield / shot

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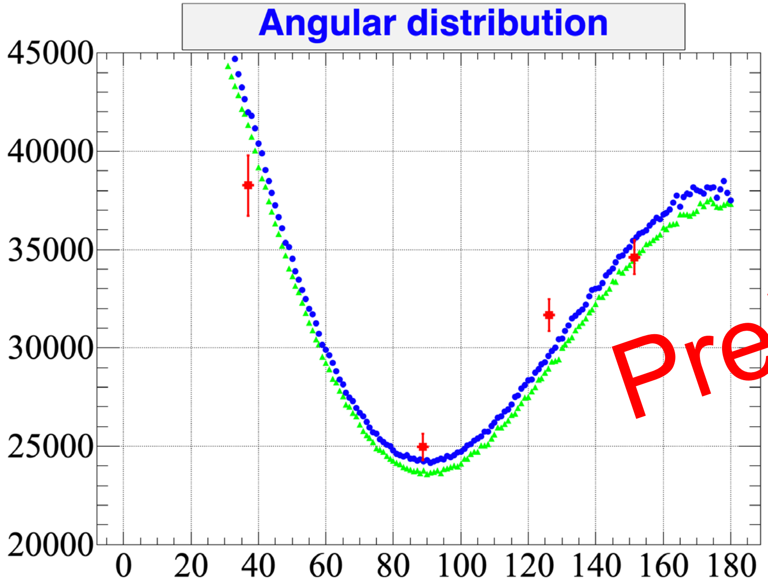
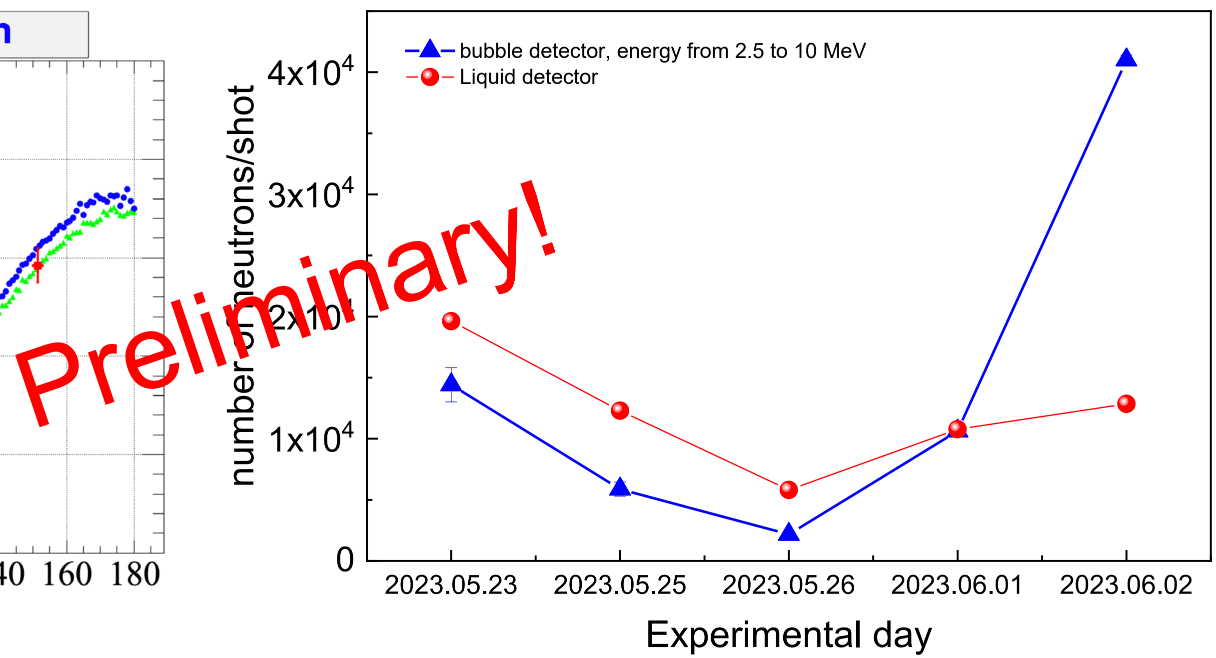
LILITH, vs angle



PHRS and BNDS, anisotropic distr.



Laser energy on the target: 23mJ
Laser energy within FWHM focal spot: 8mJ

~1.5×10^5 n/J

~1.5×10^5 n/s

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Summary

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State of the art neutron generation from foil

- at 1 Hz (burst)
- at 21mW *(3.5mW)* average power
- 200nm C_2D_4 foil + 0.1mm C_2D_4 tablet

1200 n/shot

~4×10^4 n/J

~1.2×10^3 n/s

State of the art neutron generation from liquid

- at 10 Hz (continous)
- at *230mW (80mW)* average power
- 200nm D_2O leaf + 0.1mm C_2D_4

15000 n/shot

~1.5×10^5 n/J

~1.5×10^5 n/s

If scaleable, then @ 1kW laser → **~10^{10} n/s**

Achievable by end 2023 at 1kHz: **~ 10^8 n/s**

- at *100W (?50W?)* average power

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Thank you for your attention

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