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Enhancing of deuteron acceleration with spectral phase modulation of few-cycle laser pulses

Károly Osvay

AAC’24

Naperville, IL
23th July, 2024

National Laser-Initiated Transmutation Laboratory University of Szeged

P. Varmazyar, E. Buzas, M. Füle, T. Gilinger, M. Karnok, A.P. Kovács, B. Nagy

Zs. Lécz, A. Börzsönyi, J. Csontos, P.P. Geetha, A. Mohácsi, T. Somoskői, Sz. Tóth

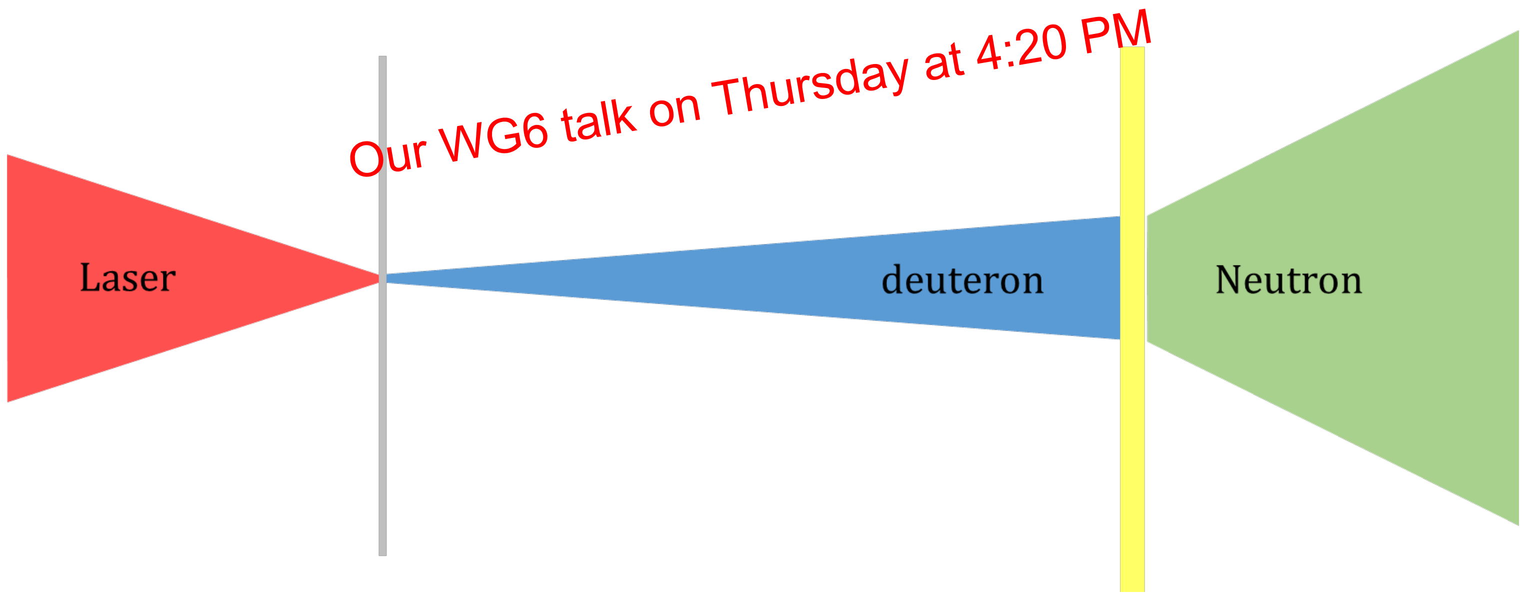
S. Figul, G.Marowski

- 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

Motivation I
– increase the neutron yield of a laser based high average power neutron source

D$^+$ acceleration

d(D,n)3He fusion



Primary target (pitcher)

Secondary target (cathcer)

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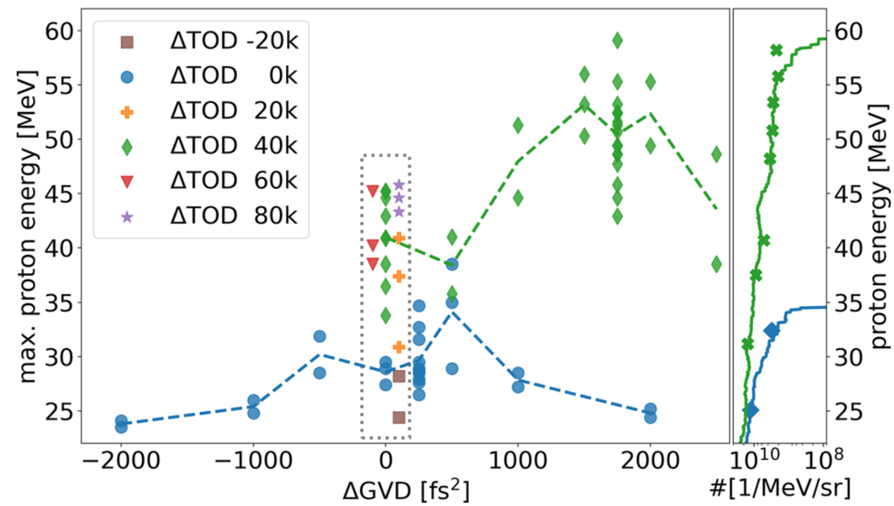
Previous experimental works on the effect of chirp

For TNSA, linear polarisation

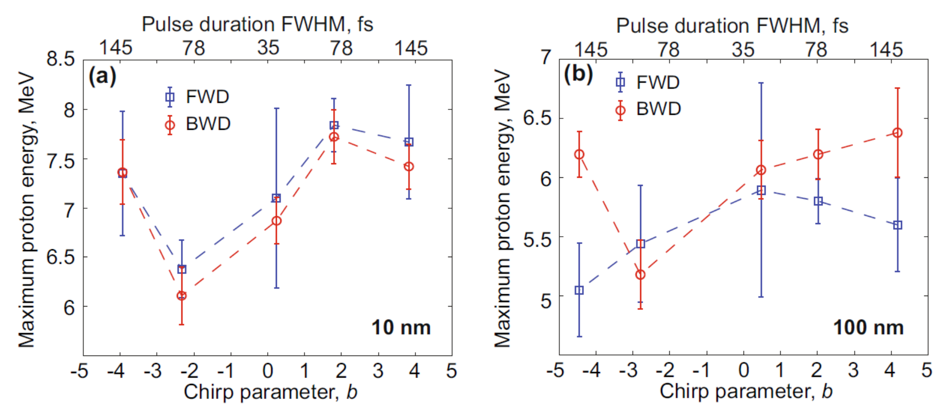
- GDD effect: enhancement of cut-off by 15%
- Positive TOD: enhancment of cutoff by 100%
- Effect is larger for thinner foils (400nm)

Ziegler *et al.,* Sci.Rep. **11** (2021) 7338



- GDD effect: enhancement of cut-off by 10%

Permogorov *et al.,* Sci.Rep. **12** (2022) 3031



Previous theoretical works on the effect of chirp

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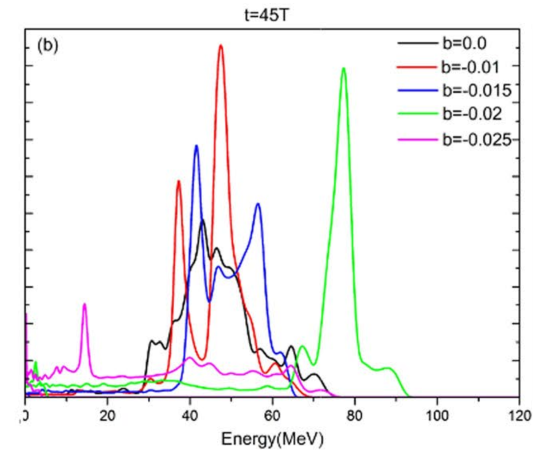
For RPA and (light sail), circular polarisation

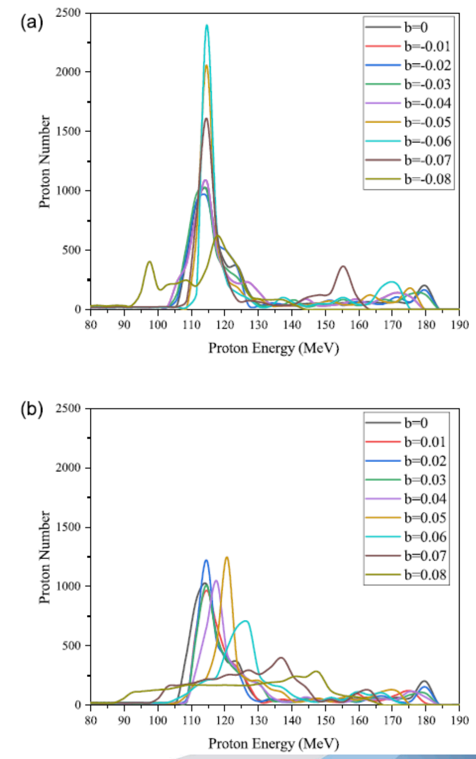
- GDD effect: an optimum (+) chirp, enhancement of cut-off by 15%

Vosoughian *et al.,* Phys.Plasmas **22** (2015) 073110



- GDD effect: cut-off is enhanced by both signs;
- Negative chirp may be more advantageous

Souri *et al.,* Phys.Plasmas **24** (2017) 053108



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Effect of spectral phase modulation on the temporal shape of fs pulses

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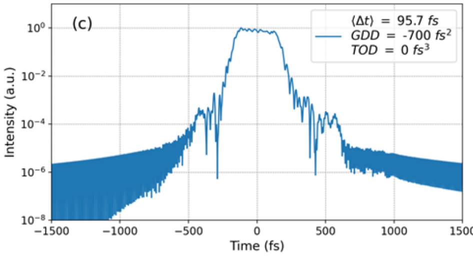
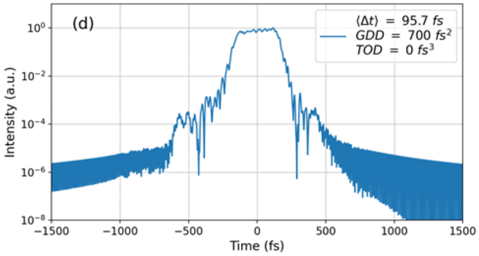
GDD – linear re-distribution of spectral energy

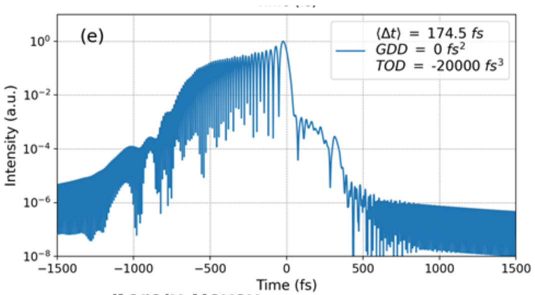
- Quasi-”symmetrical” lengthening from the intensity peak
- Effect of sign: high(-) or low (+) frequency components first
- Asyimmetrical spectrum -> asyimmetrical temporal shape
- Lower temporal intensity contrast

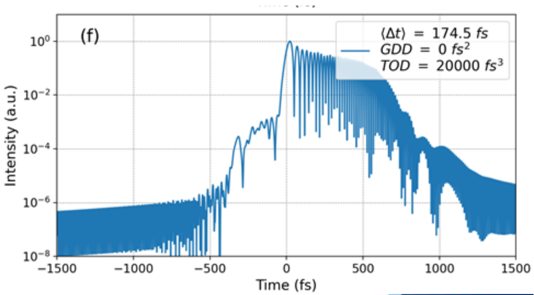




TOD – nonlinear re-distribution

- Some (asymmetrical) lengthening of the major peak
- Series of pre- (post) pulses appear
- Effect of sign I: post (+) or pre (-) pulses
- Effect of sign II: faster (+) or slower (-) rising edge of the major peak
- Lower temporal intensity contrast





Interplay also with the effect of "rising edge"

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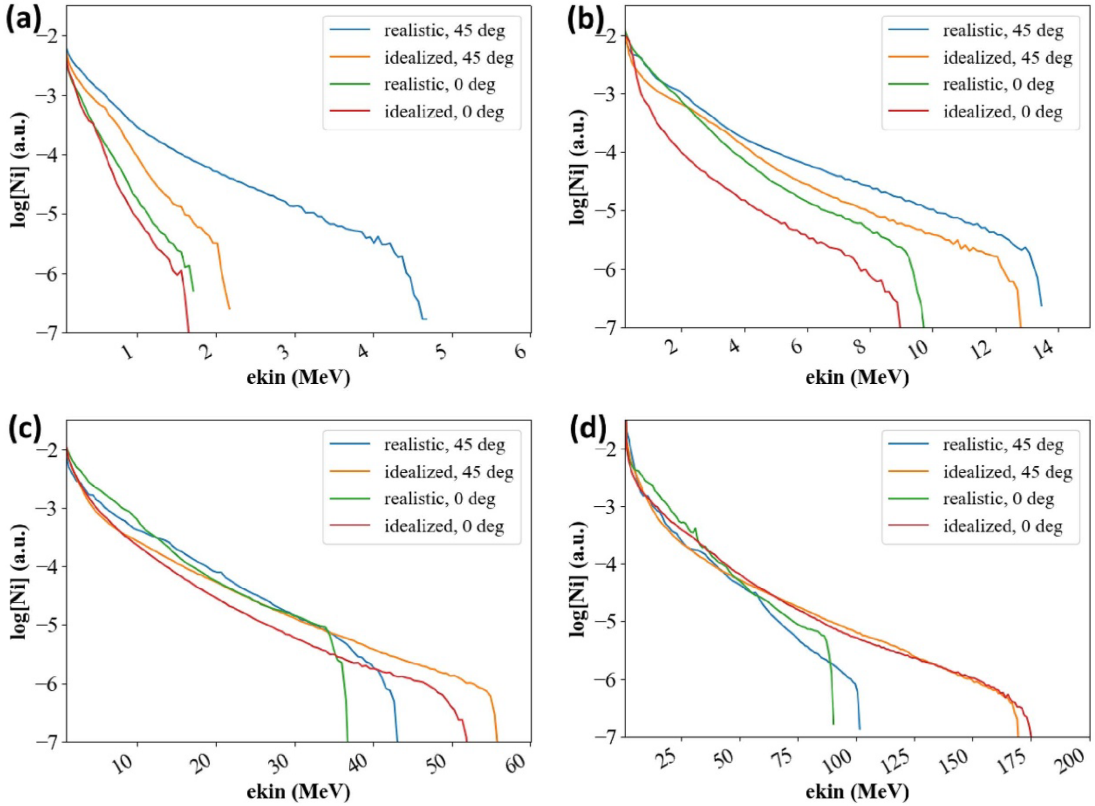
Effect of rising edge

- "ideal" and "realistic" cases
- Depends on the peak intensity

J. Psikal, PPCF **66** (2024) 045007



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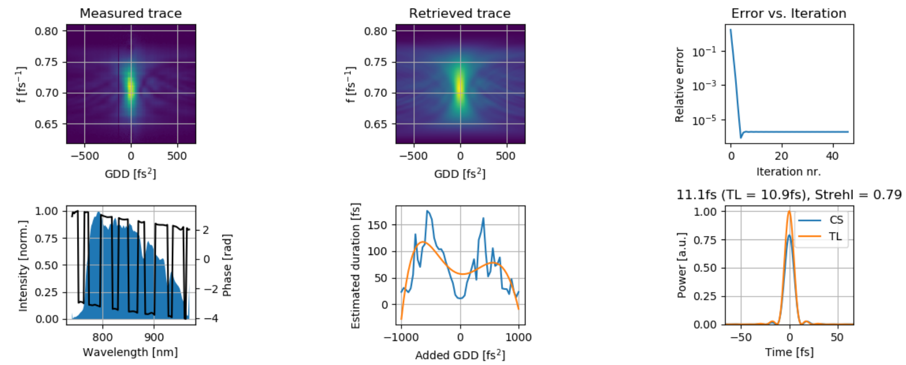
SEA laser (10Hz, OPCPA) of ELI-ALPS parameters *on target*

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

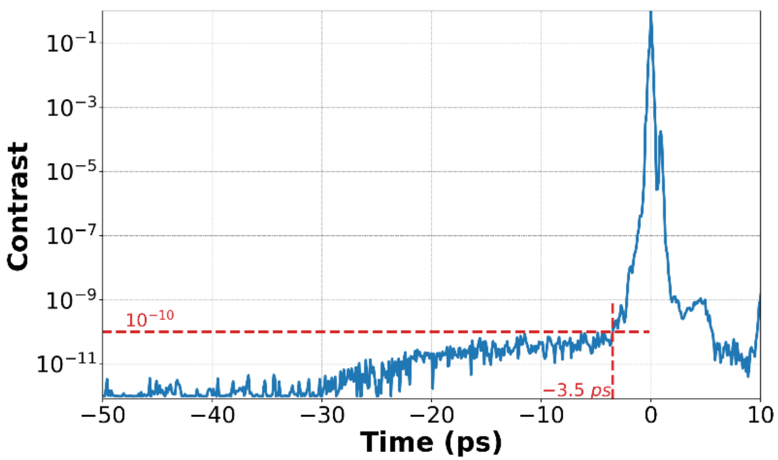
Laser pulse duration: *12.3 fs*
Measured in vacuum, after OAP, with disp scan

Focal spot FWHM: 3.2×3.8 μm^2

Peak intensity in focus: **4×10^{18} W/cm^2** (a_0~1)



Temporal contrast



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

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Motivation II

Investigate the effect of chirp with an almost Dirac-delta type, few-cycle laser pulse, which has

- **negligible pedestal**
- **broad enough bandwidth,**

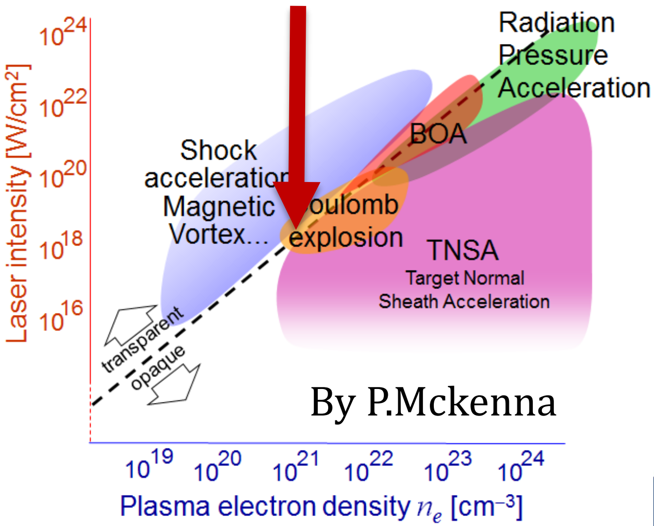
... on the acceleration scheme of

- **Coulomb explosion / RPA (light sail) situation**

Ter-Avetisyan *et al.*, PPCF **65** (2023) 085012

- **also for benchmarking simulations**

See also M. Rehwald talk on Monday.



By P.Mckenna

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Ion acceleration at 10 Hz repetition rate from D_2O liquid target

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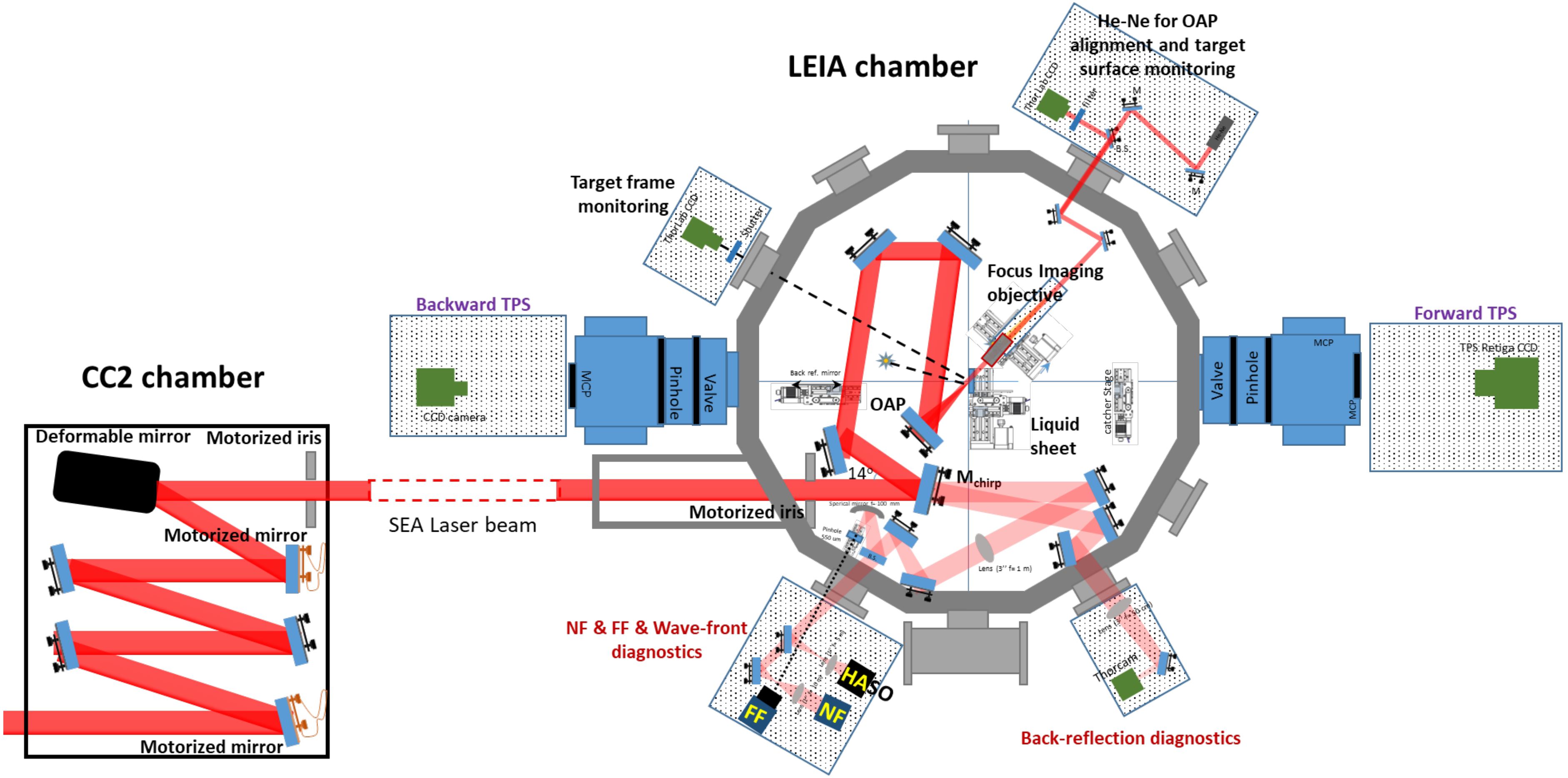

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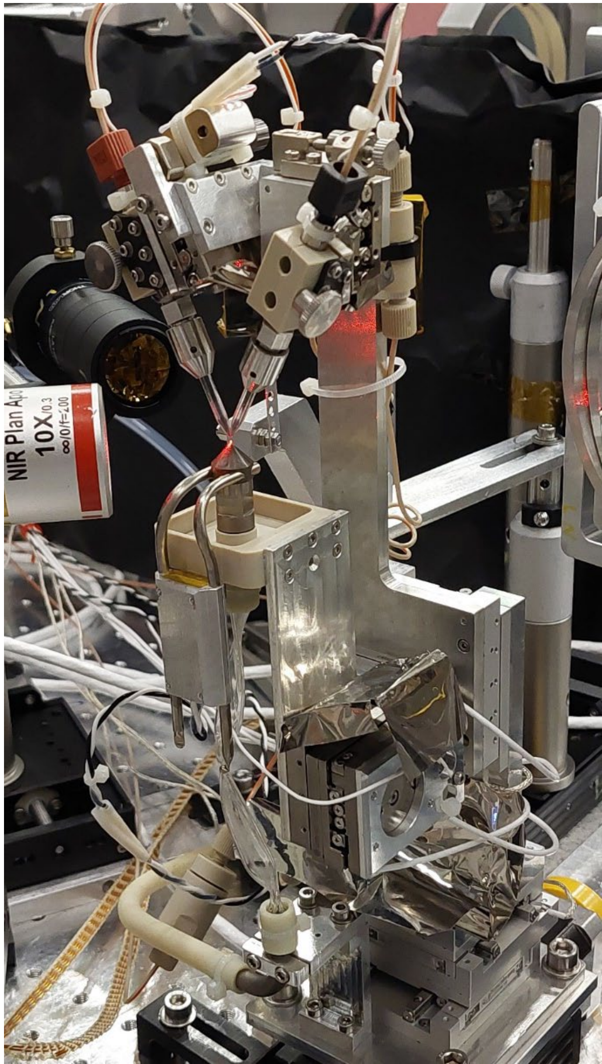
Development of a sub-200nm liquid leaf target

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

Füle et al., *HPLSE **12** (2024) e37*



Füle et al, HPLSE (2024) *in print*

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Advanced Microfluidic Systems GmbH

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

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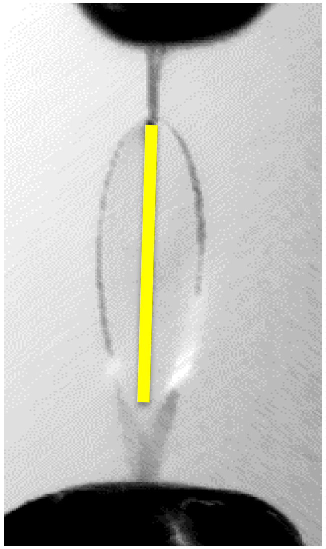

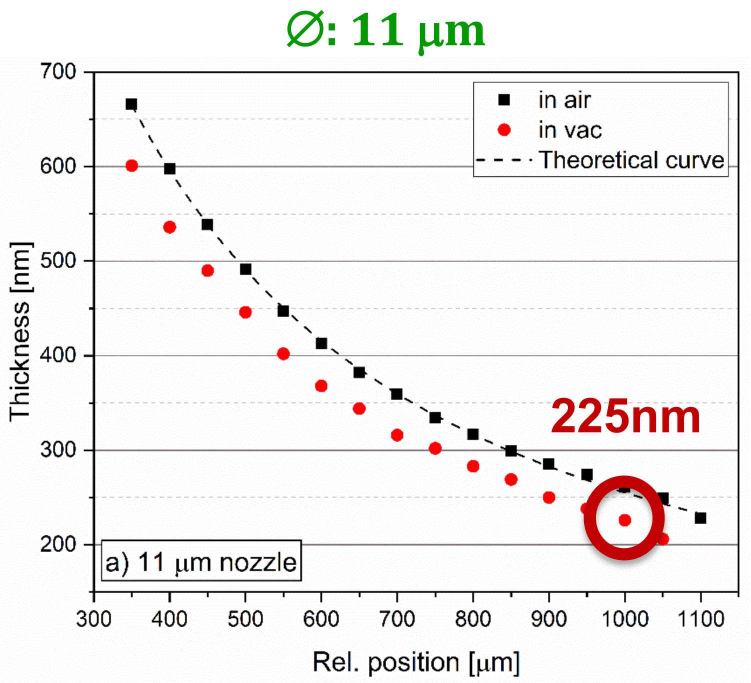

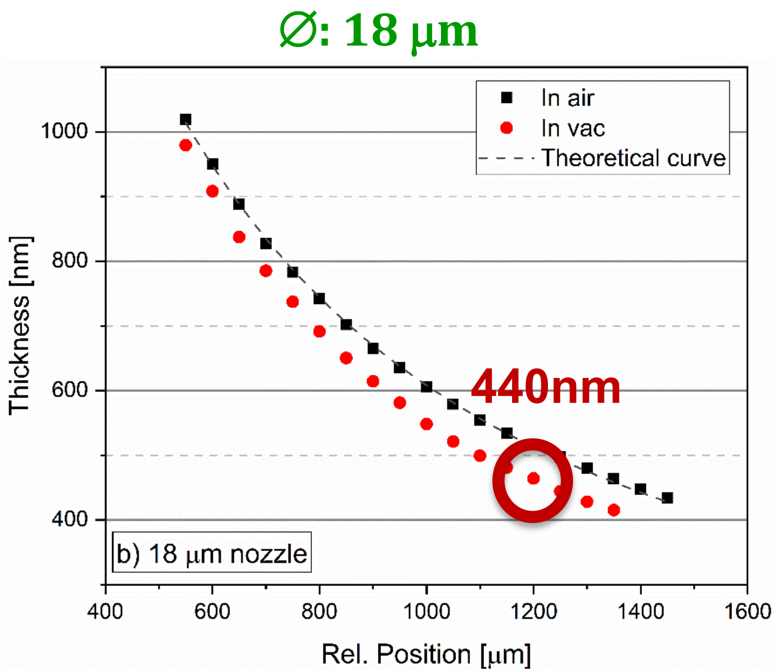

Thickness of the liquid sheet

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

Vacuum: <10^{-4} mbar

Füle et al., *HPLSE* ***12*** *(2024) e37*

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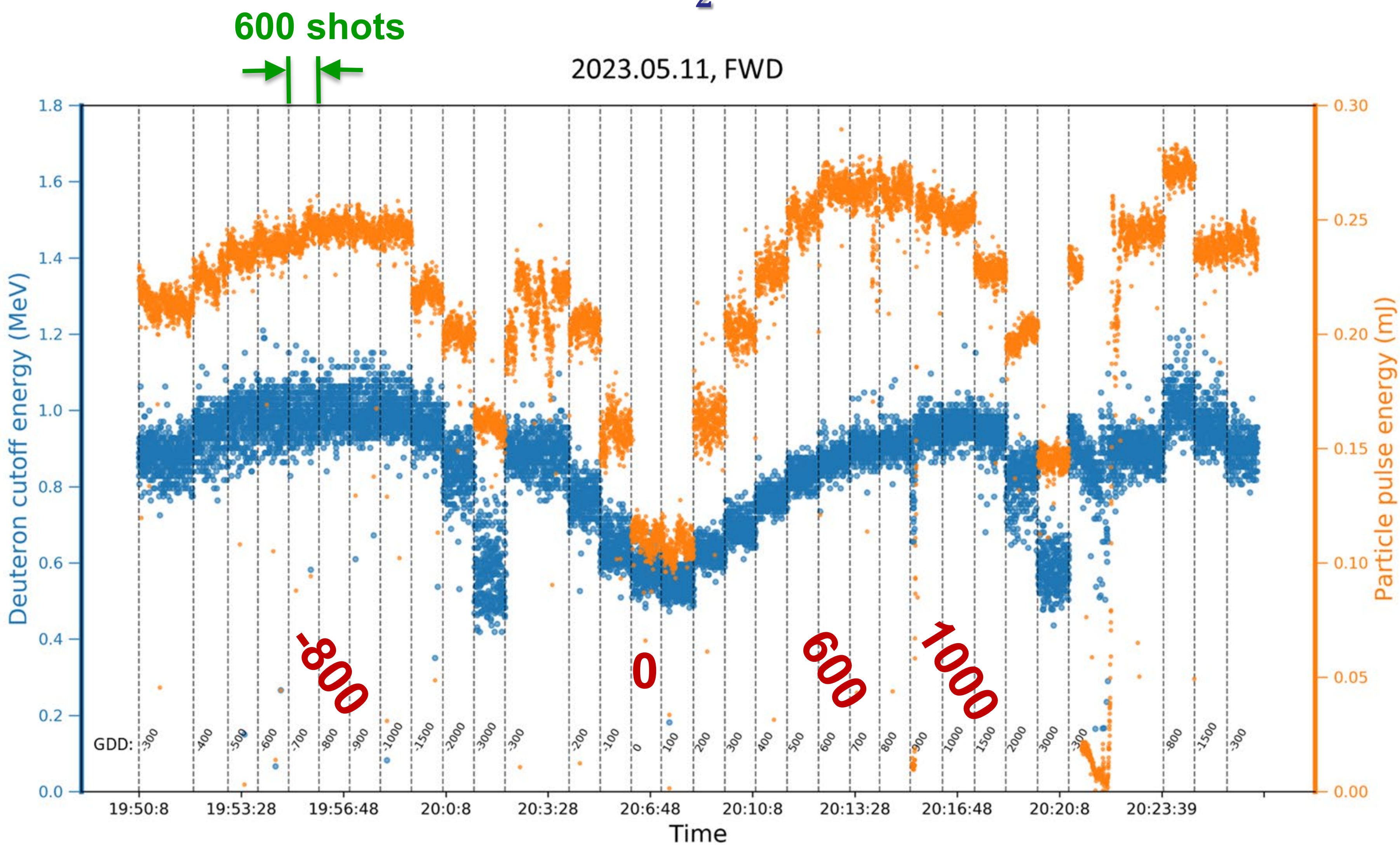
Tuning of GDD
220nm D_2O leaf



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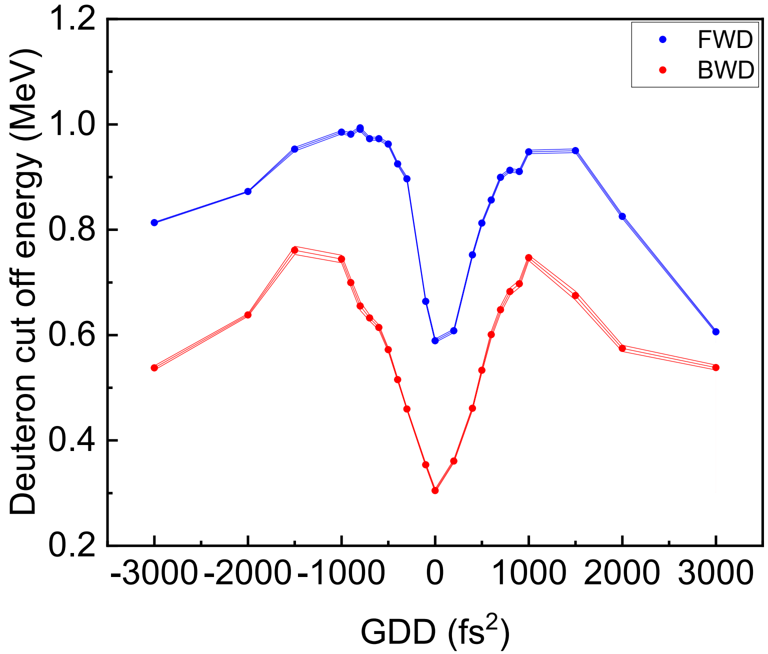
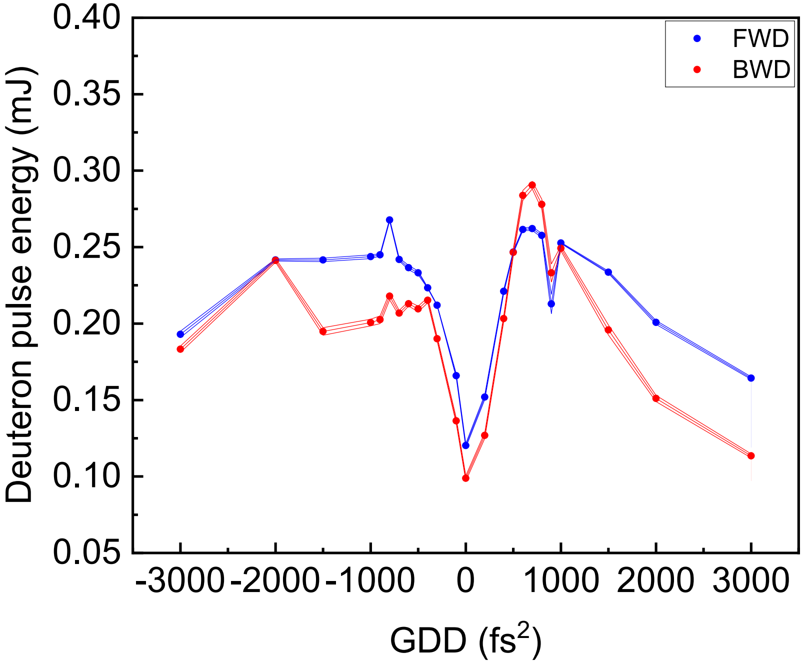
220nm D_2O leaf





Increase of cut-off energy by ~70%

Increase of energy of deuteron bunch by ~100%

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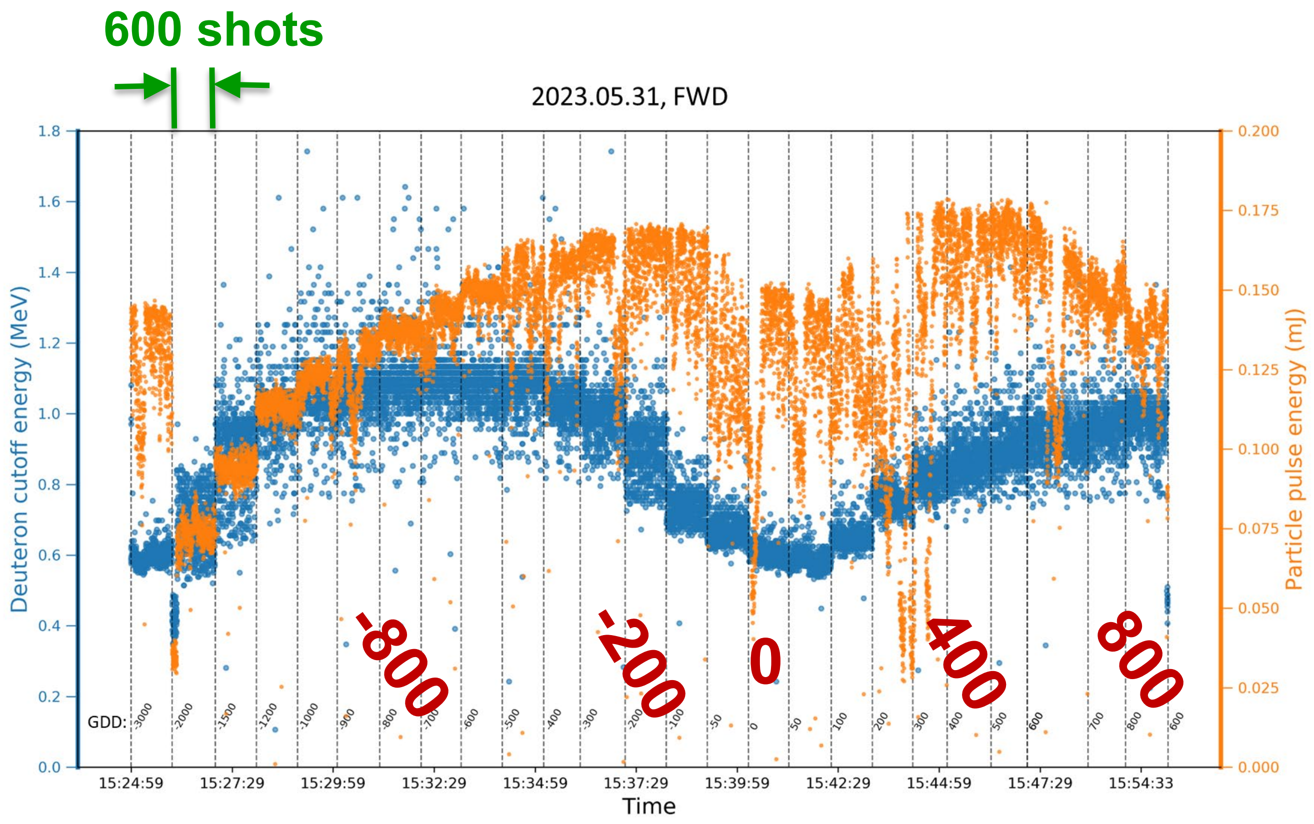
Scan of GDD
440nm D_2O leaf



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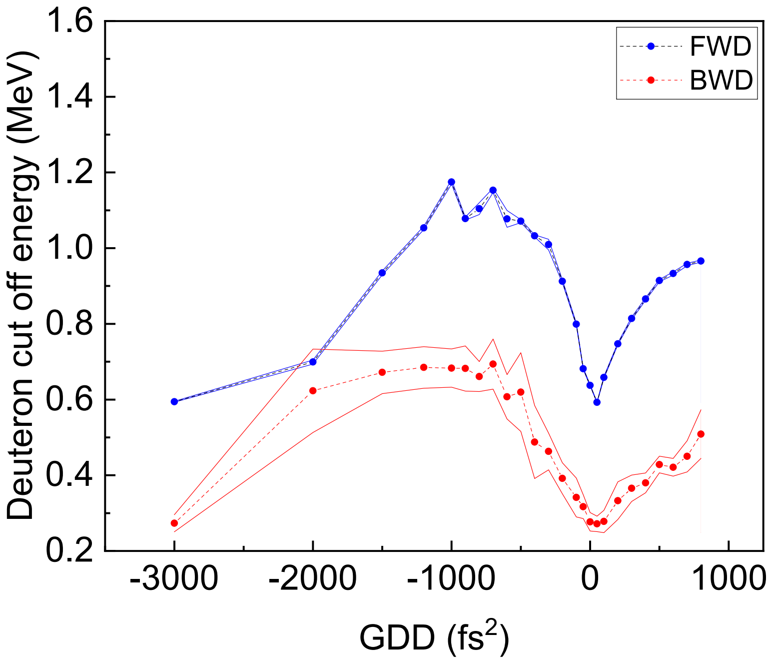
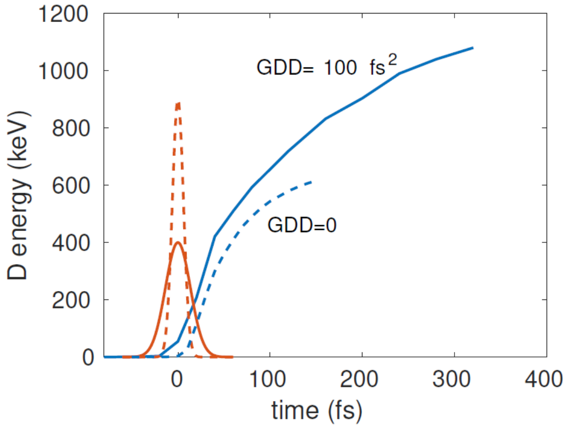
Tuning of GDD
440nm D_2O leaf

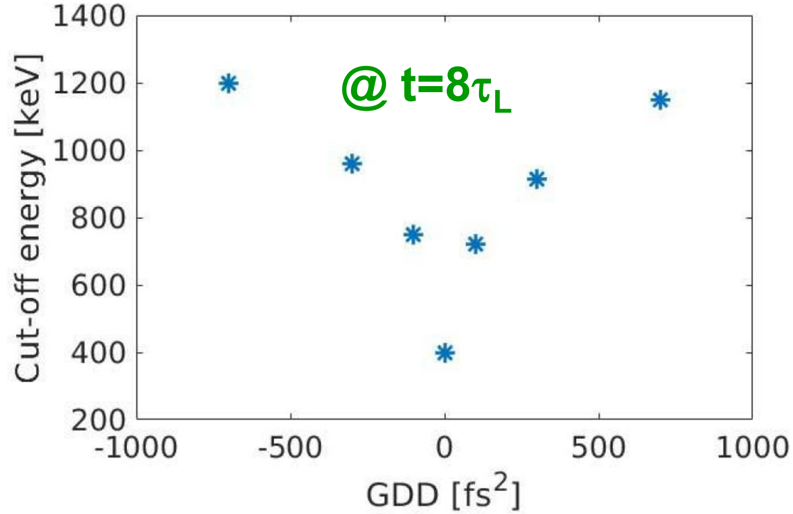


Increase of cut-off energy by ~100%

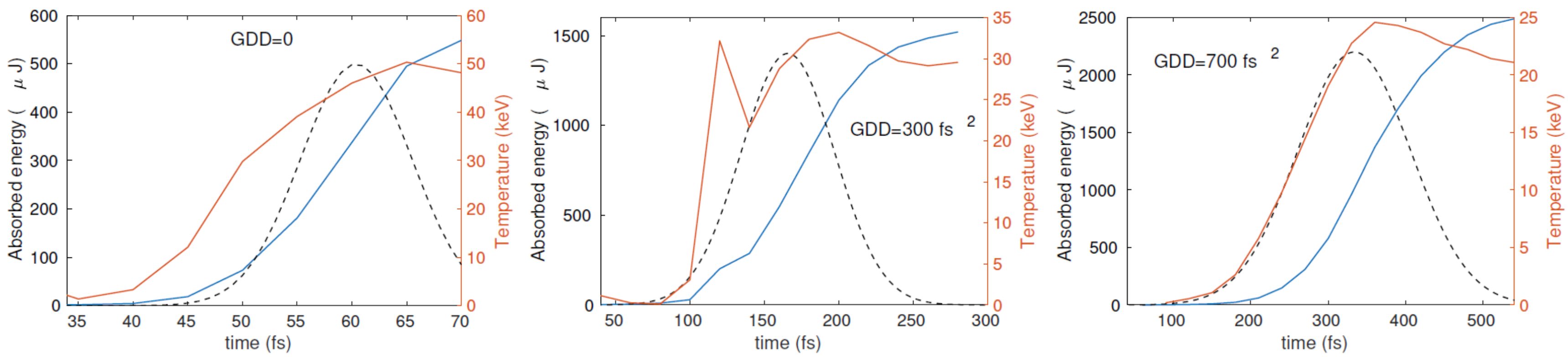
Simulation of GDD
200nm D_2O leaf

2D PIC *(EPOCH)*





Electron heating   Absorbed energy



Yogo et al., PPCF ***58*** *(2016) 025003*
Bulanov et al., PoP ***22*** *(2015) 063108*
Lecz et al., NIMA ***774*** *(2015) 42*

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TOD scan at 10 Hz repetition rate
440nm D_2O leaf

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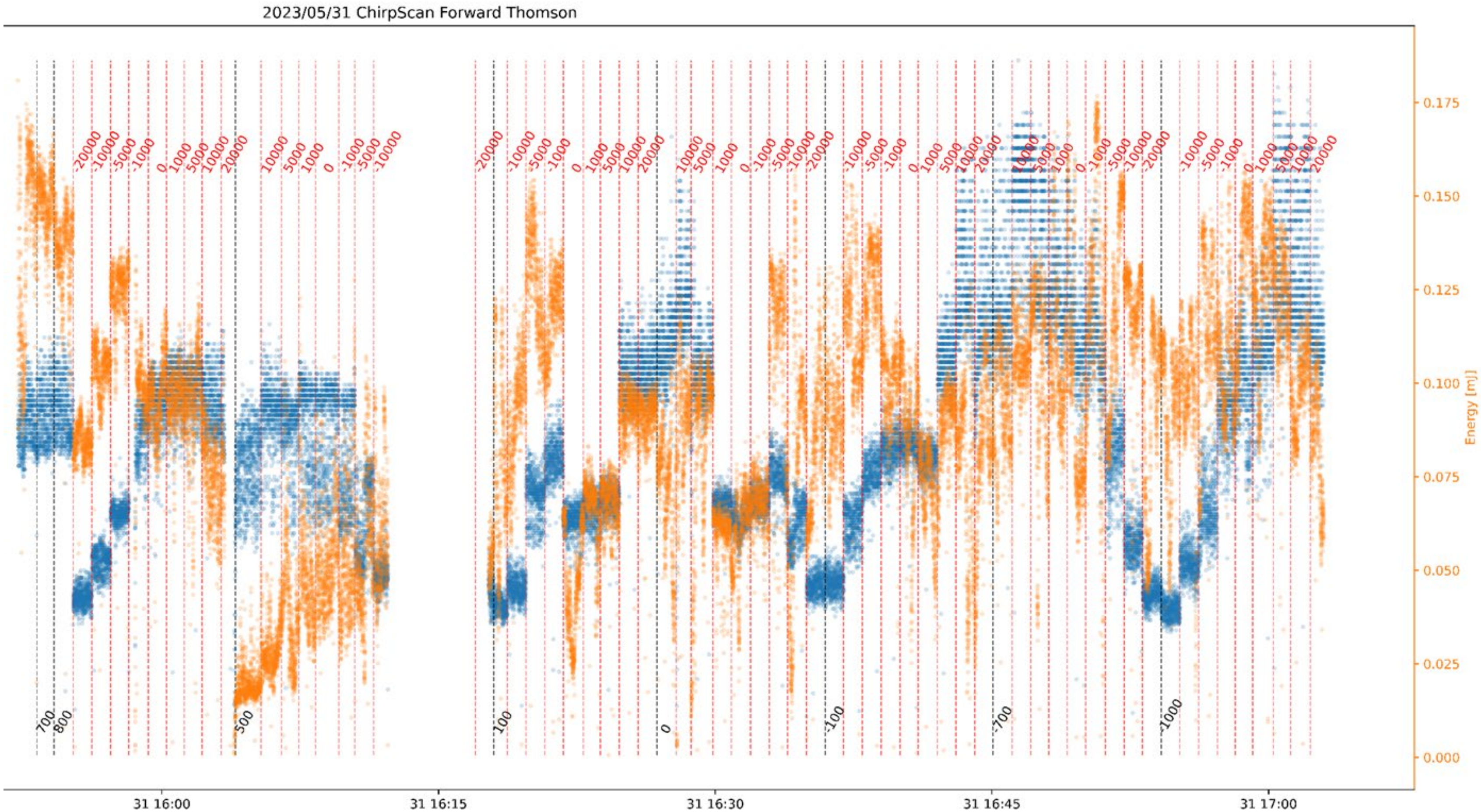
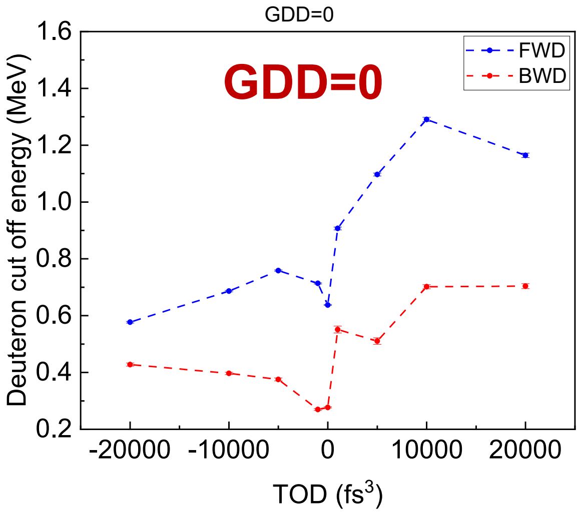
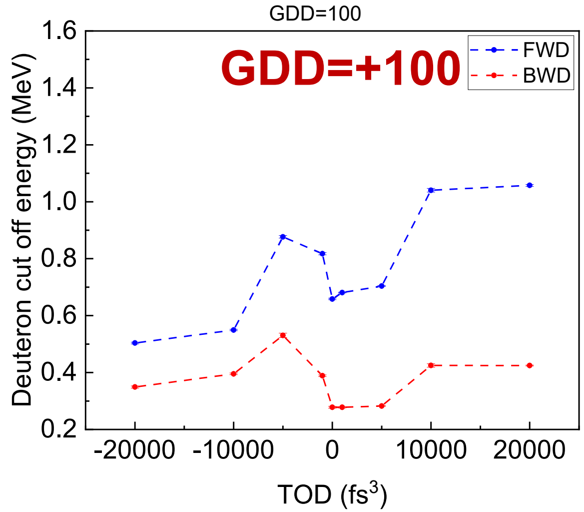
At various GDDs

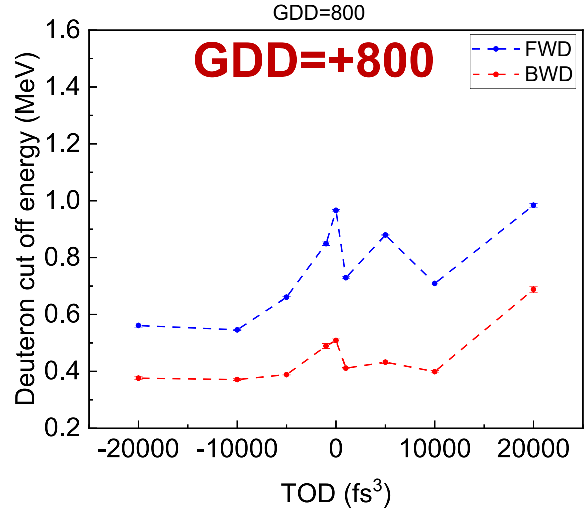
Cut-off energy: 0.4 MeV – 1.4 MeV **Deuteron bunch energy: 0.01 mJ – 0.175 mJ**

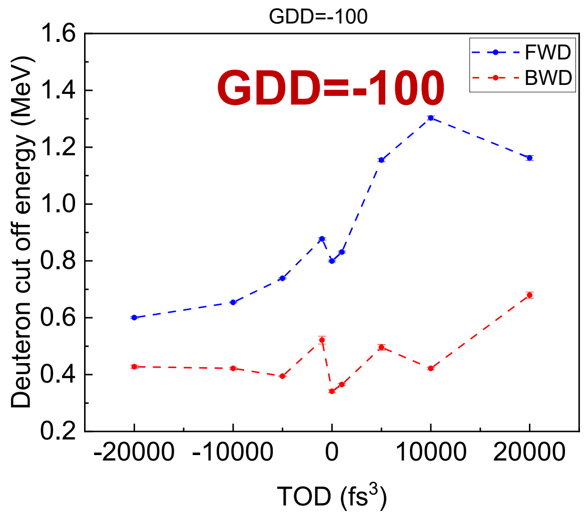


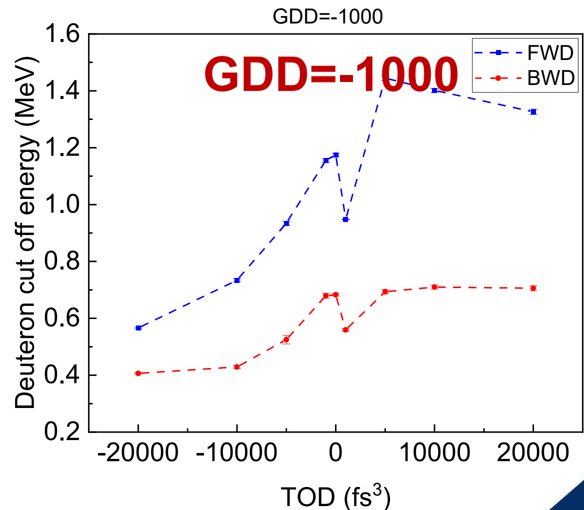
Scan of TOD
440nm D_2O leaf











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Scan of TOD

440nm D_2O leaf

At various GDDs

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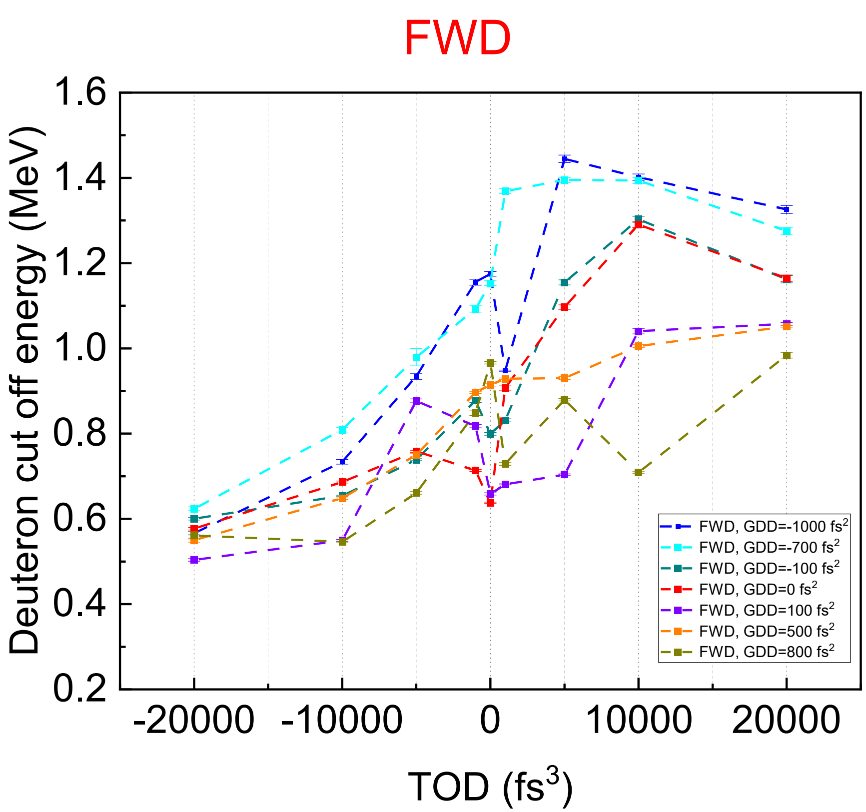

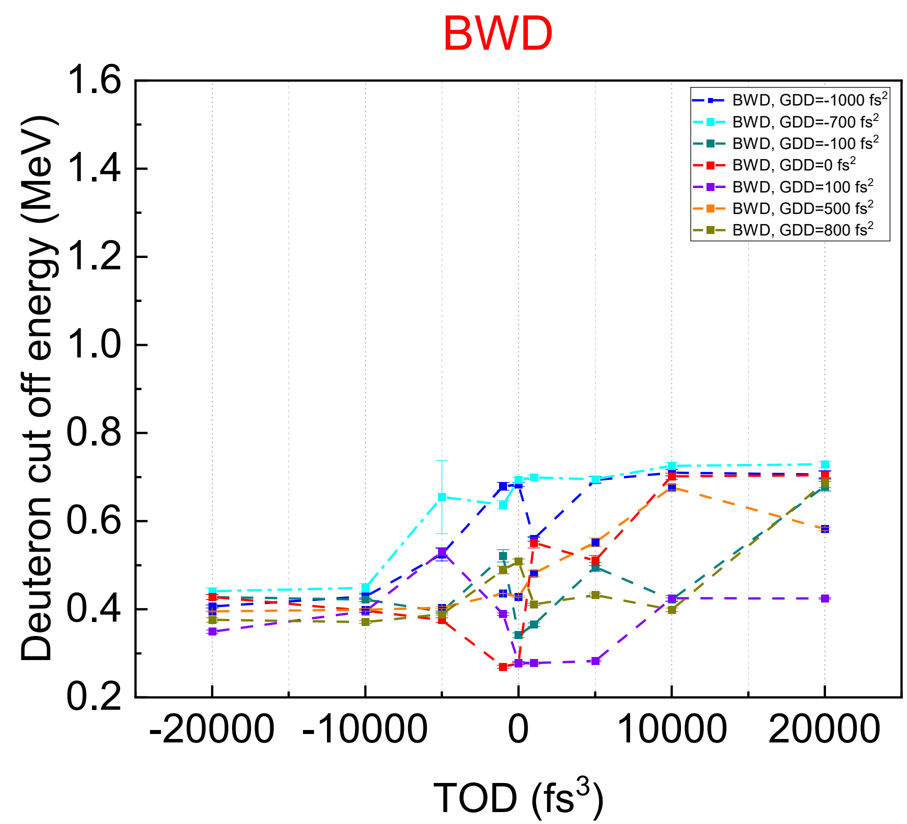

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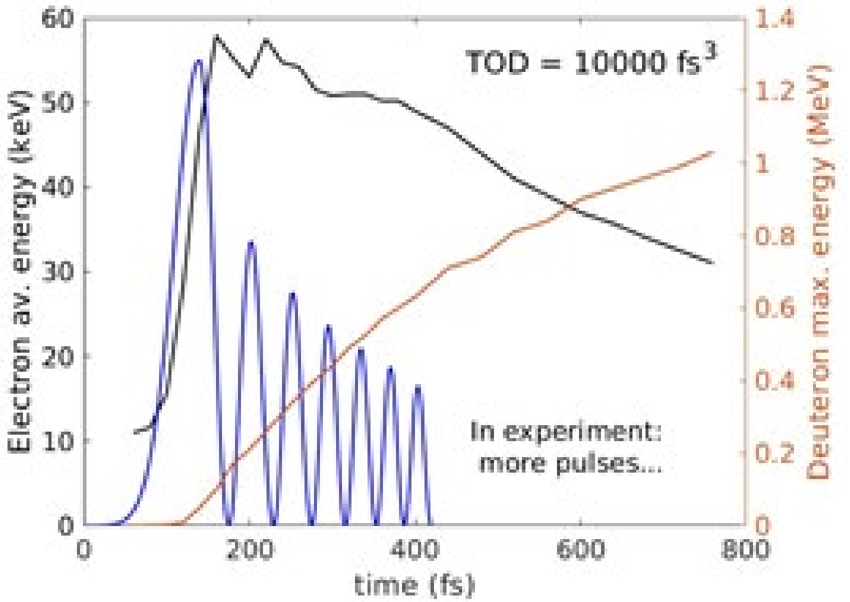
Simulation of TOD

200nm D_2O leaf

2D PIC *(EPOCH)*

Electron heating **Deuteron energy**



Positive TOD:
- fast rising edge
- nonlinear Brunnel effect – electron heating
- Subsequent pulses keep accelerating the electrons

Negative TOD:
- Low intensity pulses expand the plasma
- It becomes transparent at the arrival of the main pulse

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Summary

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The effect of chirp on deuterons accelerated via Coulomb / RPA mechanism:

Osvay, Lecz, Varmazyar et al., *in prep*.

GDD:

- The increase of the cut-off energy and the full energy of the ions depends on liquid sheet thickness, and can reach 100%.
- The sweet points are NOT at the same GDD values – either one.

TOD:

- Positive TOD is always more beneficial;
- The increase of the cut-off energy and the full energy of the ions can reach 120% and 135% (GDD=0)
- At other GDDs, the increase can be higher by 10%-20% points.
- The TOD sweet points are close to each other.

Simulations:

- Support findings, more-or-less understood.

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eli 5th Joint ELI Call for Users

- **ELI Facilities:**
  - **ELI ALPS,** Szeged, Hungary
  - **ELI Beamlines,** Dolní Břežany, Czech Republic
  - **ELI NP,** Magurele, Romania
- **5th Call period: 25 September - 29 October 2024**
- **Unique scientific opportunities provided by access to a wide range of complementary instruments**
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- **Access is free** based on a **peer-reviewed** evaluation of **scientific excellence**
- Contact Integrated **ELI User Office**
  user-office@eli-laser.eu
  or **technical contacts** listed on **User Portal.** 1

The instrument run by NLTL of University of Szeged is "LEIA".

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Károly Osvay
AAC 2024, Naperville, IL
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Thank you for your attention

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