EUROPEAN UNION

Structural Instruments 2014-2020

Competitiveness Operational Programme (COP)

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) – Phase II

User Proposals from Japan and Their Scope in Future

KA Tanaka, S Gales, CA Ur, C Ivan,

I Dancus, C Matei, D Doria, D Balabanski,
O Tesileanu, S Ataman, C Chiochiu,
M Cuicuc, T Jitsuno, Y Nakamiya,
L Neagu, K Spohr

ELI-NP, Romania,

Examples of User Proposals at ELI-NP

01 Dark Matter Search (User Proposal and Commissioning Experiment)
On Going

02 X-ray Spectroscopy for Defining Focused Intensity of 10 PW Laser Beam
Planned as 10 PW Commissioning in 2023

03 Neutron Production for Resonance Spectroscopy
User Proposal

04 Laser Interaction with Nano wire targets
User Proposal

Authors of Proposals

【01】K Homma, Hiroshima U., S Tokita Kyoto U. Japan

【02】Yuji Fukuda, K Kondo, QST KPSI
SA Pikuz, HB11 Australia
A Martynenko GSI Germany

【03】A Yogo, Y Arikawa, K Mima, T Mori, Z Lan, T Wei, ILE, Osaka University
Y Abe, Y Kuramitsu Osaka Univ.
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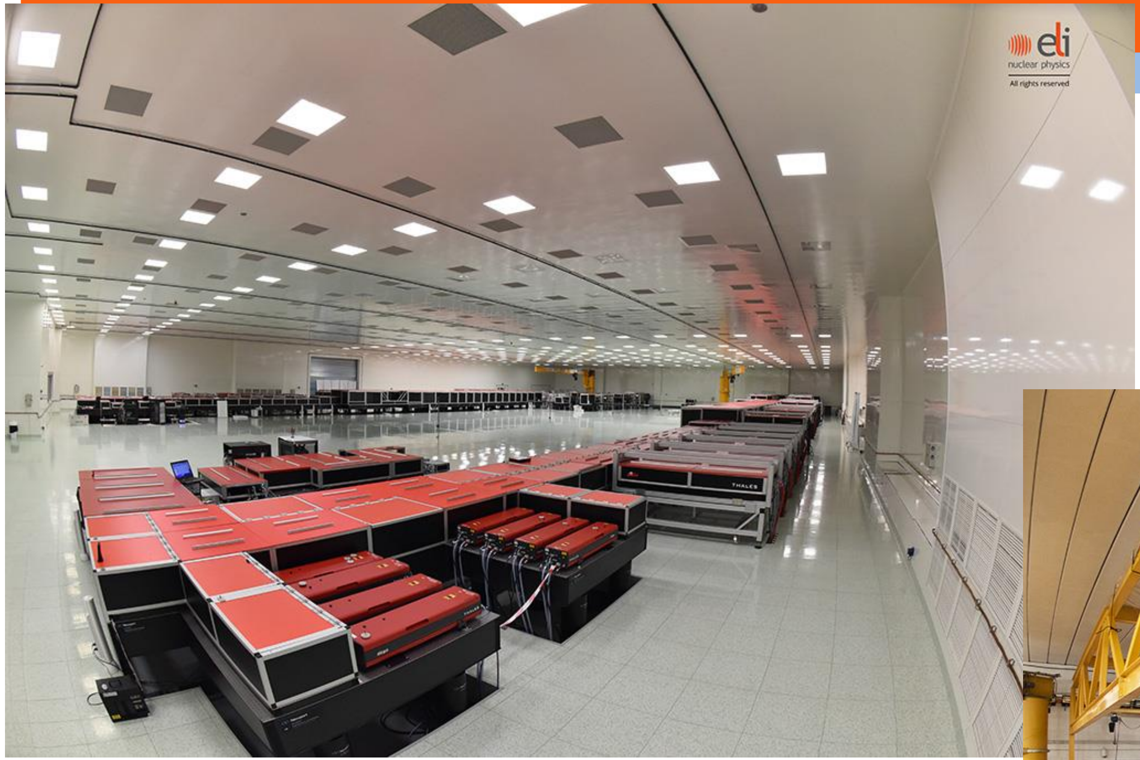
【04】GR Kumar, A Lad, R Palit, P Singh, TIFR India
A Adak IIT, India

H Habara, T Hanamoto, Y Kagawa, K Nishimura, Osaka University
K Nagai, Kanazawa University, Japan

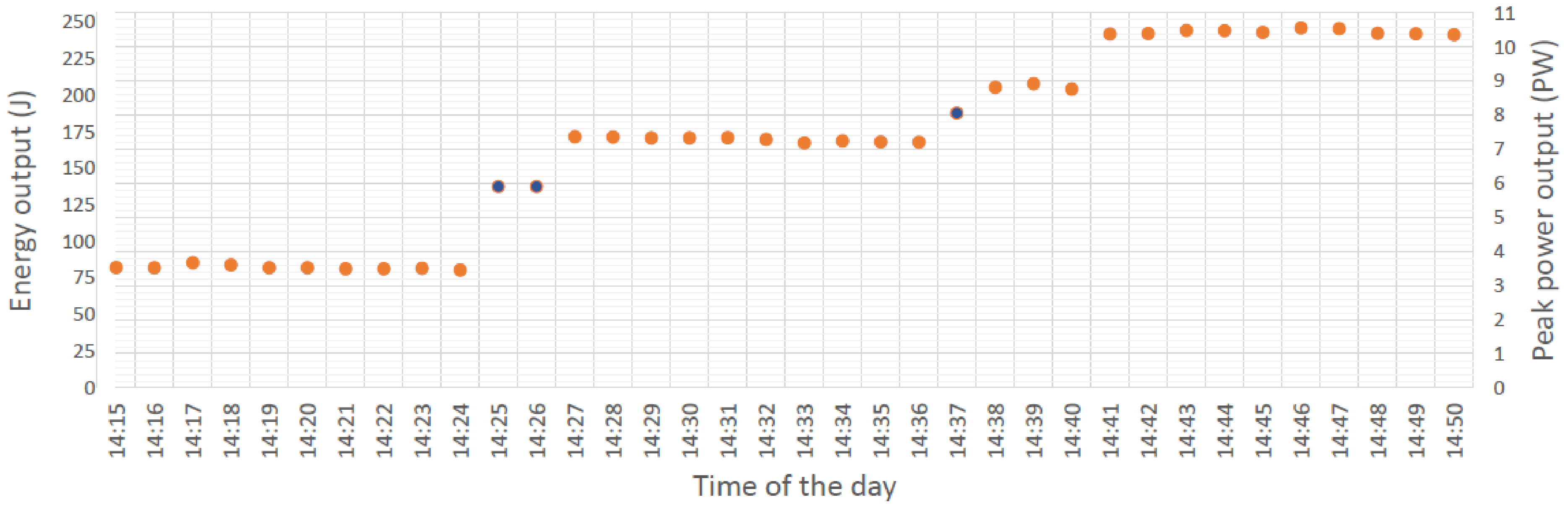
Laser System and Laser Beam Transport



High Power Laser System

	min	max	unit
Energy/pulse	150	225	J
Central wavelength	814	825	nm
Spectral bandwidth (FWHM)	55	65	nm
Spectral bandwidth (at nearly zero level of intensity)	120	130	nm
Pulse duration (FWHM)	15	22.5	fs
FWHM beam diameter/Full aperture beam diameter	450/550		mm
Repetition rate	1		pulse/min
Strehl ratio	0.8	0.95	
Pointing stability	2	5	µrad
Beam height to the floor	1500	1510	mm

10 PW pulse was shot every one minutes.



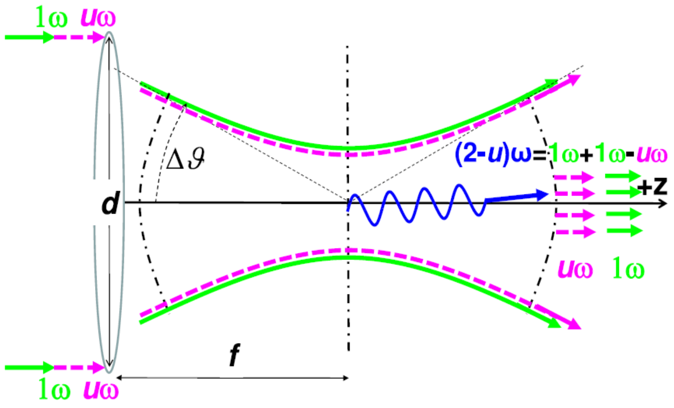
01 Dark Matter Search

- Y Nakamiya, O Tesileanu, L Neagu, M Cuiuc, S Ataman, C Chiochiu
  ELI-NP
- K Homma, Hiroshima University
- S Tokita ICR Kyoto University

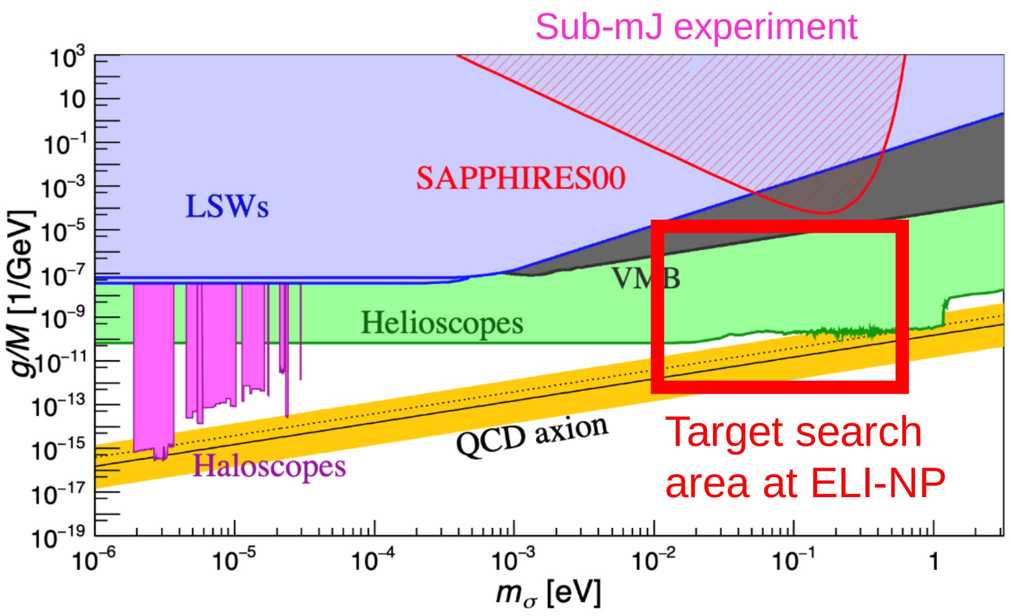
The proposal has been jointly performed by SAPPHIRES project and has been approved by ISAB.

ISAB: International Science Advisory Board

Dark Matter (Axion) Search at ELI-NP
The Commissioning Experiment in E4 area



Search for resonance states at very low energies. There are theoretical rationales to expect sub-eV particles.



- Quasi-parallel colliding system (QPS) between two incident photons
- Signature is produced via the four-wave mixing process
- mixing two-color waves with different frequencies 1ω and uω in advance of focus
- **SAPPHIRES** collaboration:
  - Japan: K. Homma (Univ. Hiroshima) & students, S. Tokita (ICR Kyoto)
  - Romania: LGED Experiments group, local PI Y. Nakamiya
- **Ongoing data analysis from the commissioning experiments in E4**

Search for sub-eV axion-like resonance states via stimulated quasi-parallel laser collisions with the parameterization including fully asymmetric collisional geometry

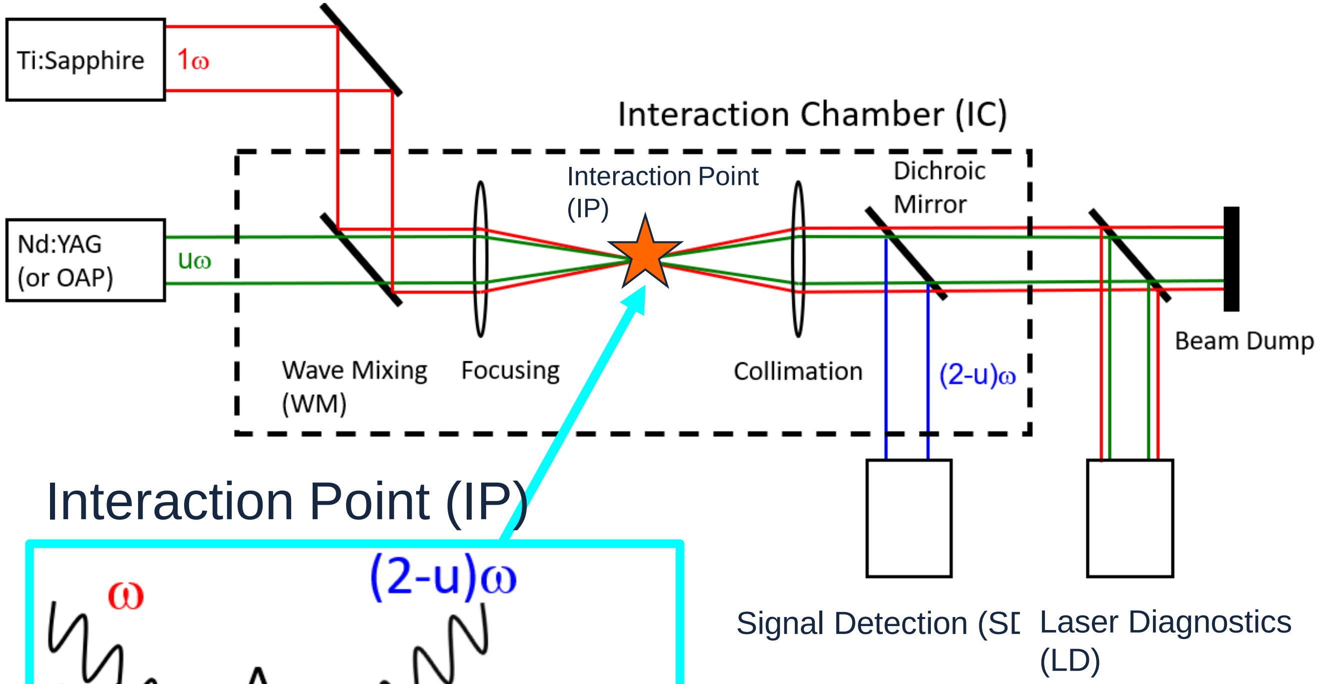
The SAPPHIRES collaboration

Kensuke Homma,[a,1,2] Yuri Kirita,[a,1] Masaki Hashida,[b,c,3] Yusuke Hirahara,[a] Shunsuke Inoue,[b,c] Fumiya Ishibashi,[a] Yoshihide Nakamiya,[b,d] Liviu Neagu,[d,e] Akihide Nobuhiro,[a] Takaya Ozaki,[a] Madalin-Mihai Rosu,[d] Shuji Sakabe[b,c] and Ovidiu Tesileanu[d]

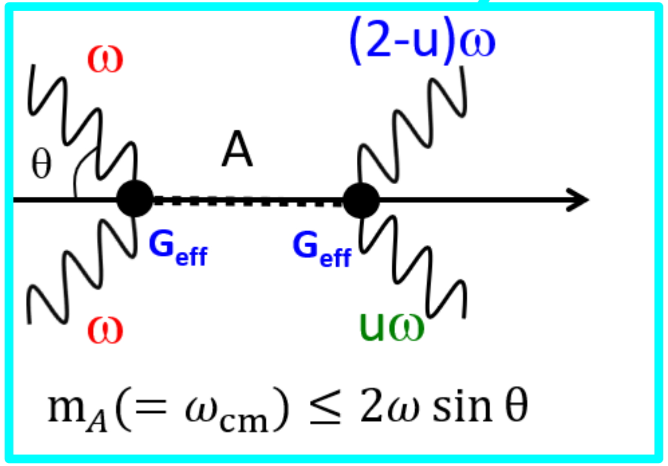
[a] *Graduate School of Advanced Science and Engineering, Hiroshima University, Kagamiyama, Higashi-Hiroshima 739-8526, Japan*
[b] *Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan*
[c] *Graduate School of Science, Kyoto University, Sakyouku, Kyoto 606-8502, Japan*
[d] *Extreme Light Infrastructure-Nuclear Physics (ELI-NP) and Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), 30 Reactorului St., P.O. Box MG-6, Bucharest-Magurele, Judetul Ilfov RO-077125, Romania*

JHEP12(2021)108

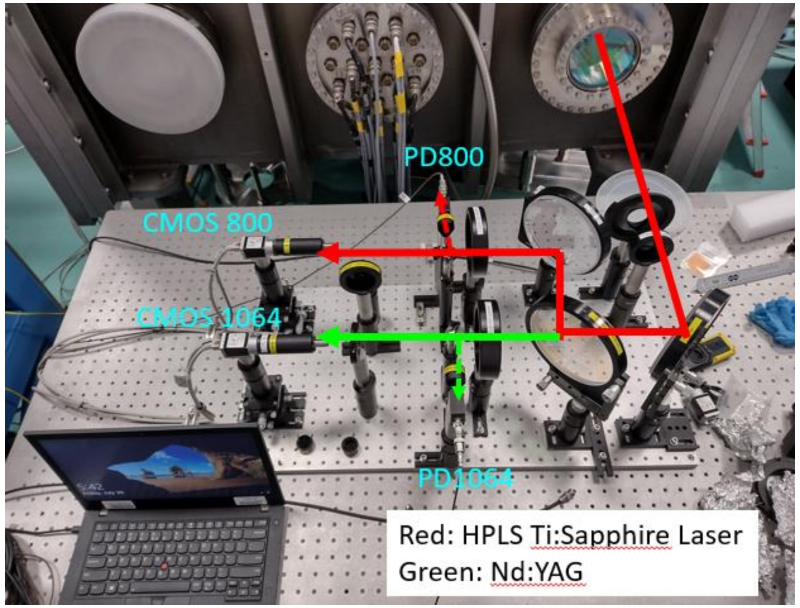
Dark matter detection with two-color high-intensity lasers: Four-wave mixing in “vacuum”



Interaction Point (IP)

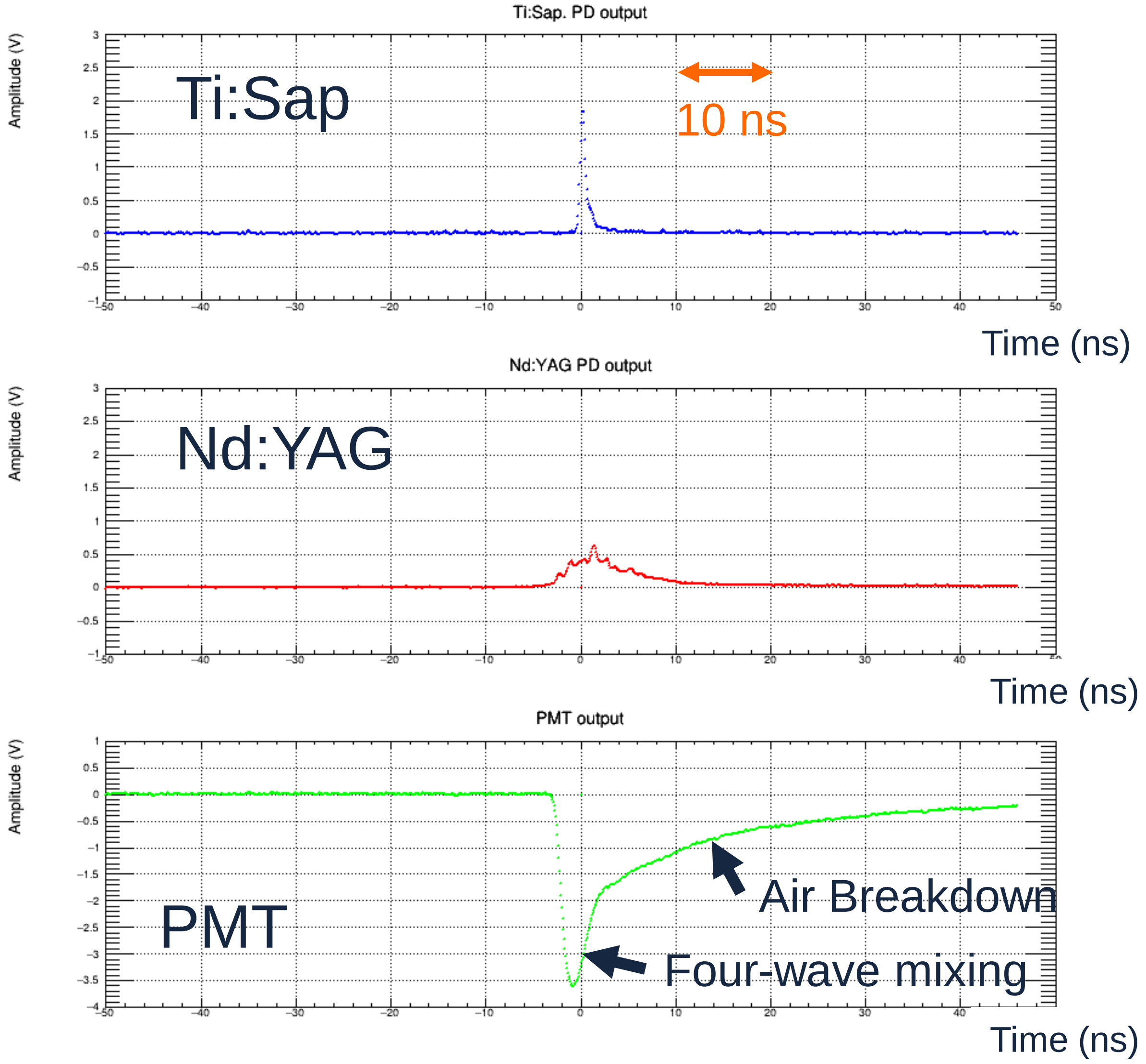


★ Interaction Point (IP)



A: Dark Matter

DM search: FWM signal in air



- Two decay components time structure
  - Fast component < 5ns -> FWM
  - Slow component > 30ns -> Air breakdown
- Slow component still visible when Nd:YAG turned off
- Fast component appears only when the laser pulses are synchronized

Full-Aperture Beam of 2mJ Ti:Sap.
Shortpass < 700 nm + Longpass > 550 nm on PMT

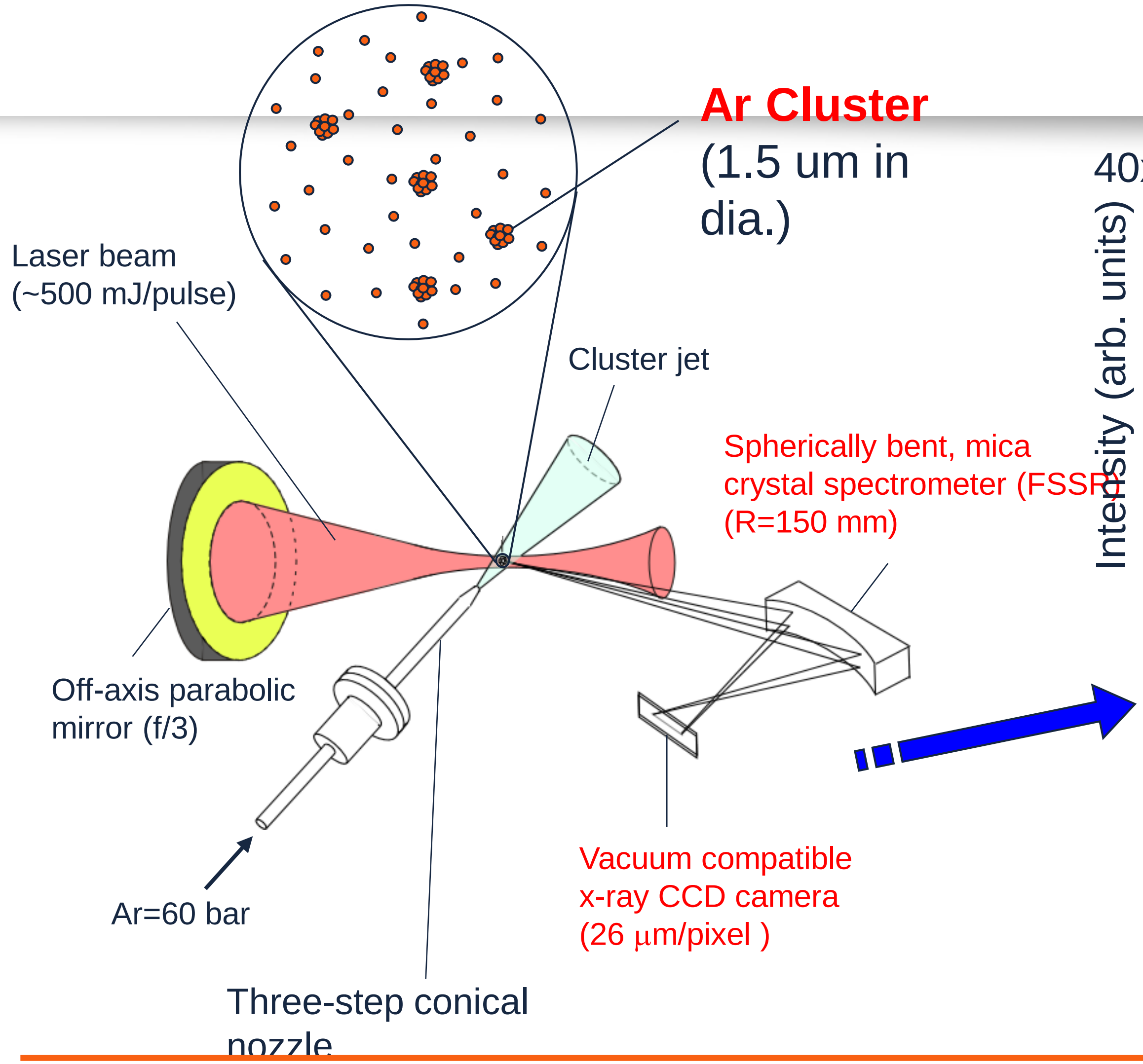
DM search: Progress and Perspectives

- First beamtime (July-Aug 2021): tuning of the system, first background measurements:
  - Background study with 1.6 mJ (Ti:Sap) + 1.8 mJ (Nd:YAG)
  - Test shots with 17.5 mJ (Ti:Sap) + 21.9 mJ (Nd:YAG)
- Second beamtime completed (September-October 2021): FWM background identified independent of vacuum level – search for ways of mitigation
- Third beamtime (Nov-Dec 2021): two mitigation methods for background implemented and tested: at 20mJ level there is still a background component persisting – discussion on possible sources
- Fourth beamtime (Mar-Apr 2022): background characterization at 2mJ and 20mJ level, DM search measurements at 20mJ pulses
- Last beamtime (June-July 2022): DM search measurements at 20mJ pulses, ongoing data analysis
- The **SAPPHIRES** collaboration will apply for continuation of the DM search experiments at the 100TW and then at 1PW areas at improved vacuum (UHV chamber in E4) / increased energy per pulse conditions

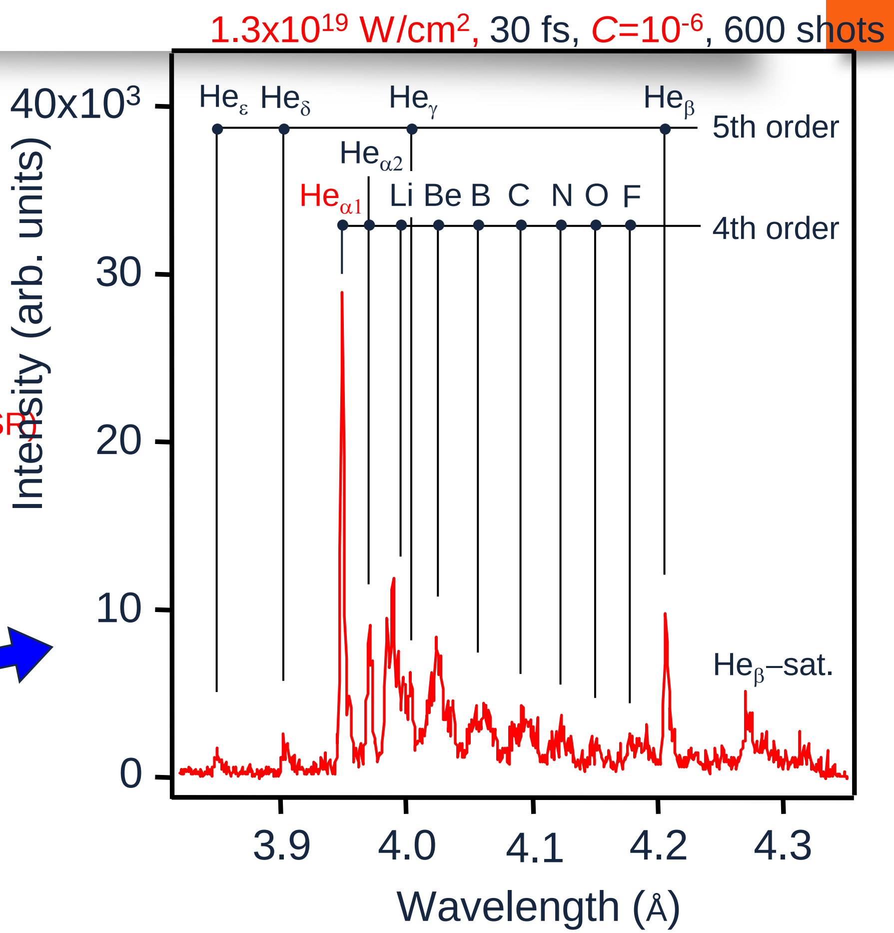
02 Diagnostics of Unexpected Plasma via X Ray Spectrometry with Cluster Targets

- Yuji Fukuda, QST-KPSI, Japan
- Kotaro Kondo, QST-KPSI, Japan
- Sergey A. Pikuz, HB11 Energy, Australia
- Artem Martynenko, GSI, Germany

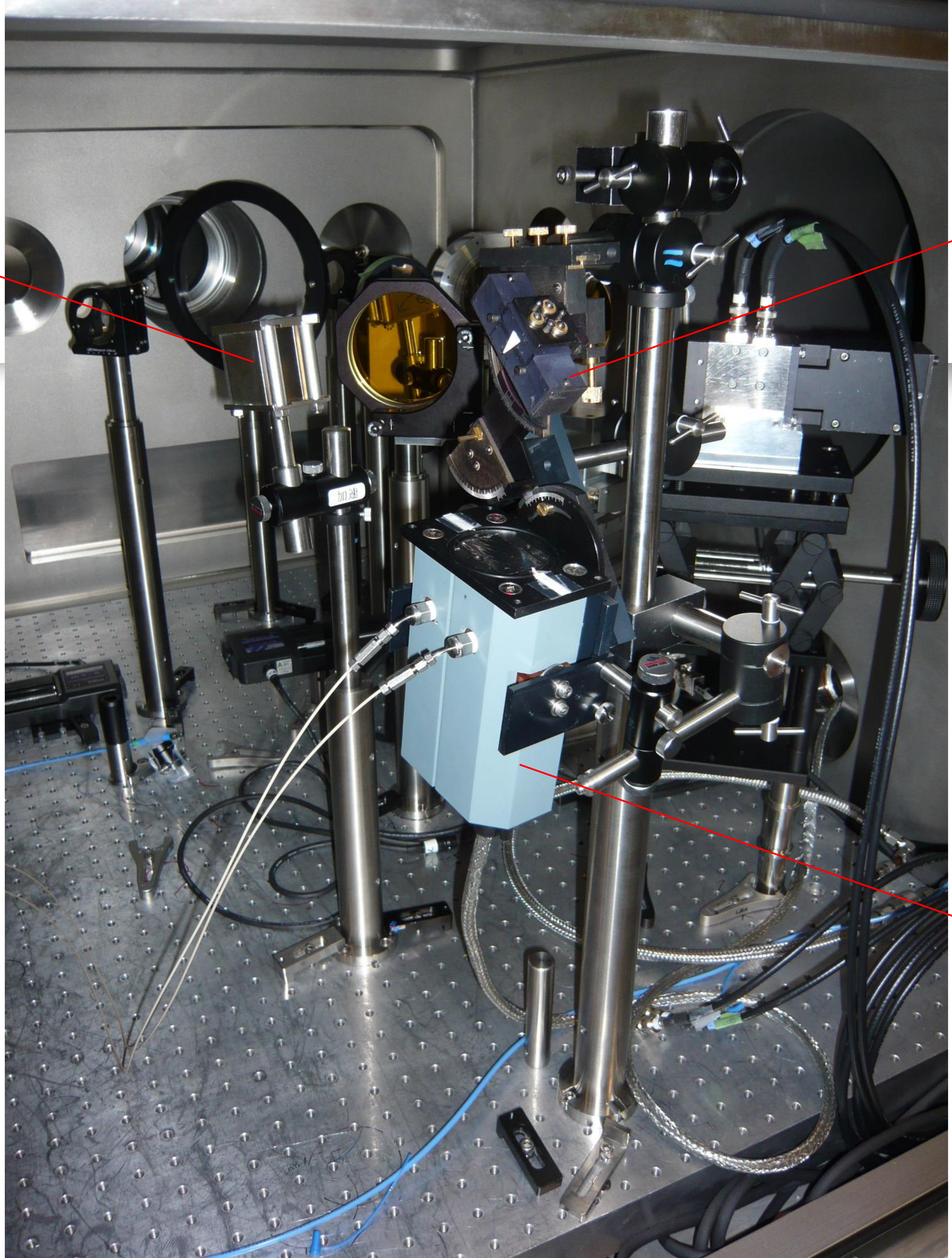
Experimental setup



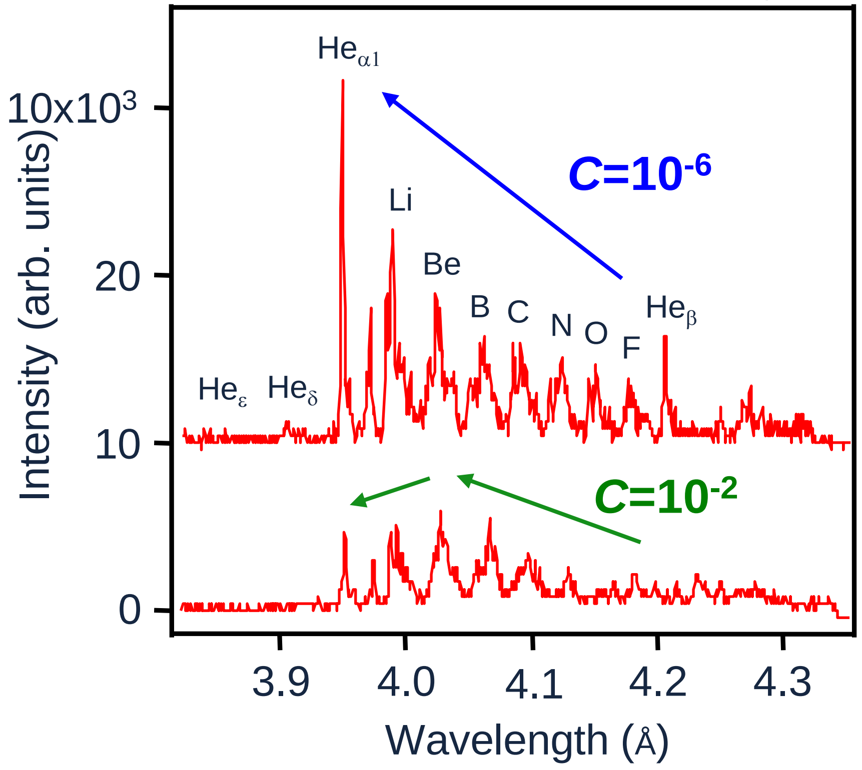
Ar K-shell spectrum



Y. Fukuda et al., JETP Lett (2003).

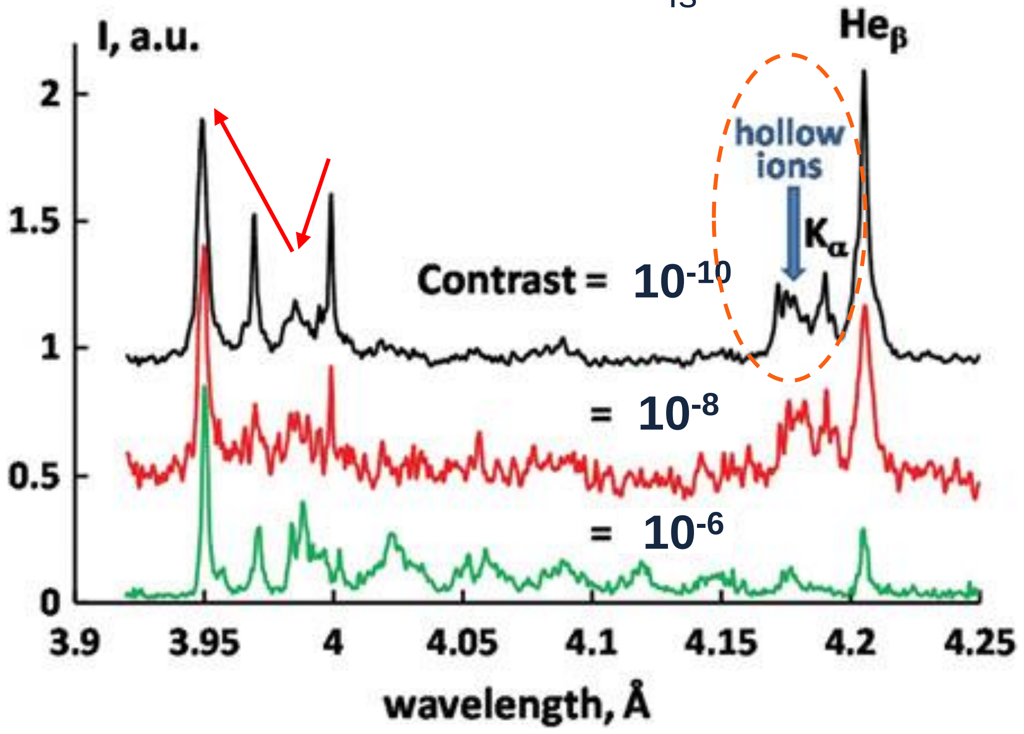

Magnet
Spherically bent, mica crystal spectrometer (FSSR)
Vacuum compatible CCD

3x10^18 W/cm^2, 30 fs



Y. Fukuda et al., LPB 22, 215 (2004).

3x10^18 W/cm^2, 40 fs



A. Faenov et al., LPB 30, 481 (2012).

1. **Spectra in the vicinity of He$_a$ line strongly depend on laser plasma conditions.**
2. **Signals from hollow ions appear only for extremely high laser intensity and contrast.**

Summary

What do we hope to gain from the cluster-based X ray emission experiments?

1. **Identification of the world's highest temperature (> keV) and density (> 10^{23} cm^{-3}) plasmas**

2. **Establishment of "hollow ion spectra-based plasma diagnostic techniques"**

   => Signals from "hollow ions" appear only for extremely high laser intensity and contrast.

3. **Evaluation of the world's highest laser intensity of 10^{23} W/cm^2**

   => We need to improve the existing method.

   Accuracy of "semi-empirical equations" relating electron temperature and laser intensity is not very high, because the equations were obtained long years ago for moderate laser intensities (< 10^{18} W/cm^2).

03 Neutron Production for Resonance Spectroscopy

- Akifumi Yogo, Yasunobu Arikawa, Kunioki Mima, Takato Mori, Zechen Lan, Tianyun Wei

  Institute of Laser Engineering, Osaka University, Japan
- Takehito Hayakawa

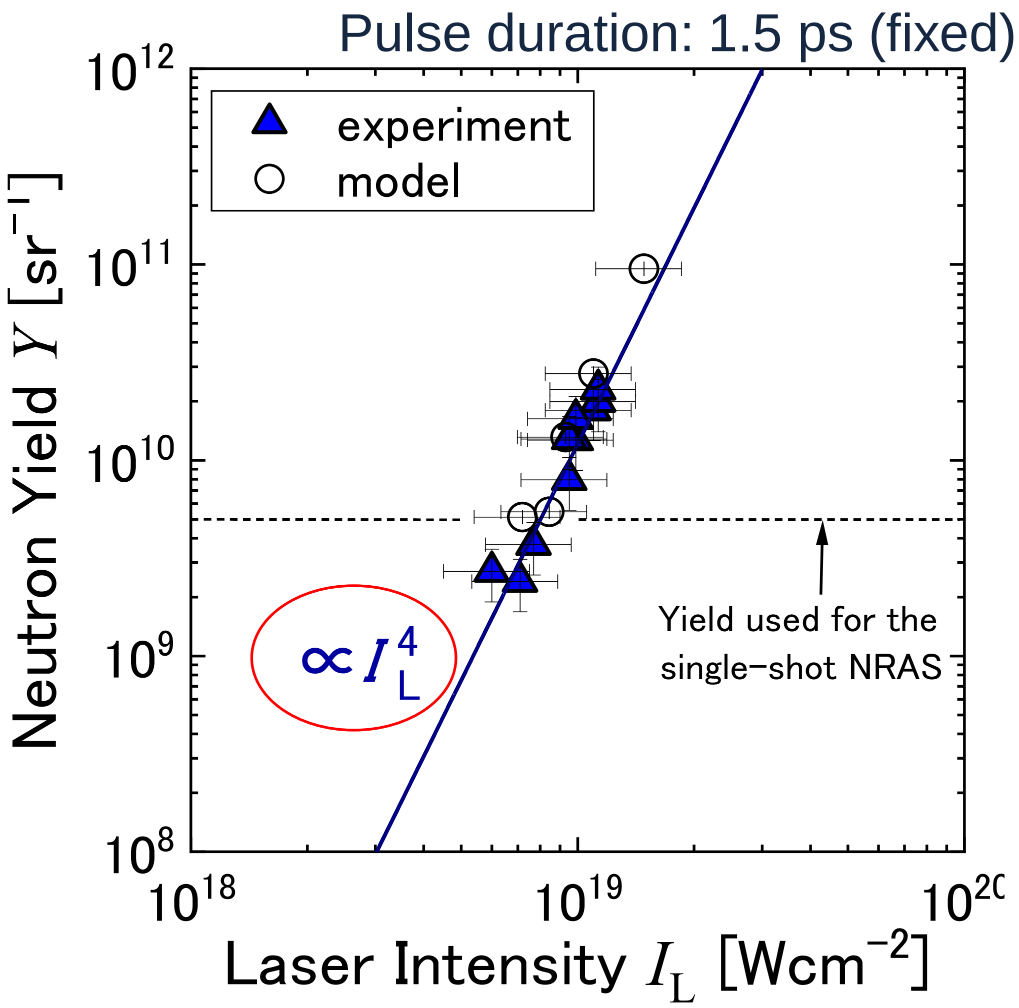
  National Institutes for Quantum and Radiological Science, and Technology, Japan
- Yuki Abe, Yasuhiro Kuramitsu

  Graduate School of Engineering, Osaka University, Japan
- Seyed Reza Mirfayzi

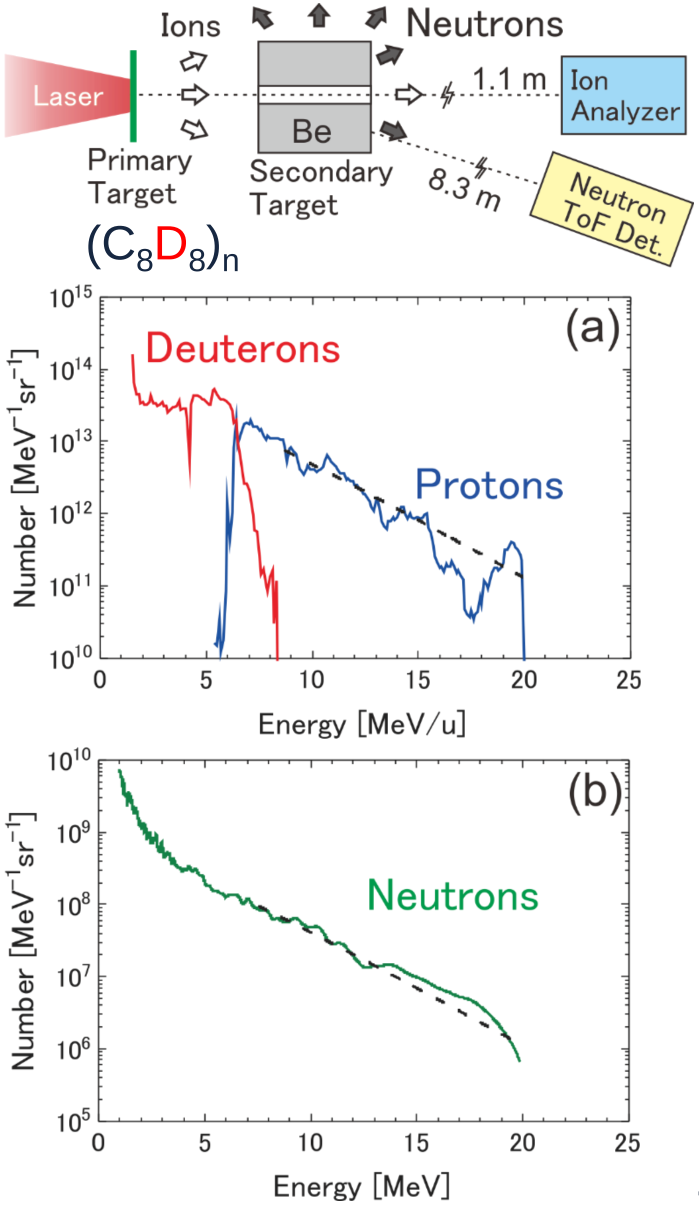
  Tokamak Energy ltd, UK
- Satyabrata Kar

  Queen's University Belfast, UK
- Klaus Spohr, Domenico Doria, Takahisa Jitsuno, Kazuo Tanaka

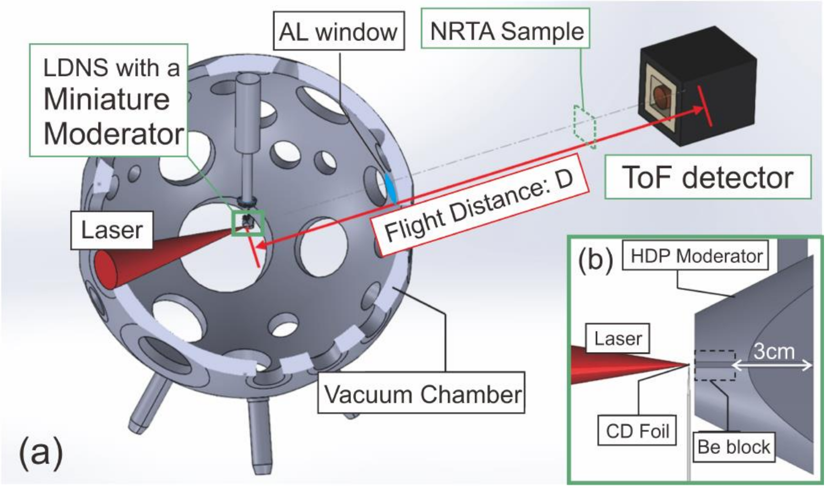
  ELI-NP, Romania

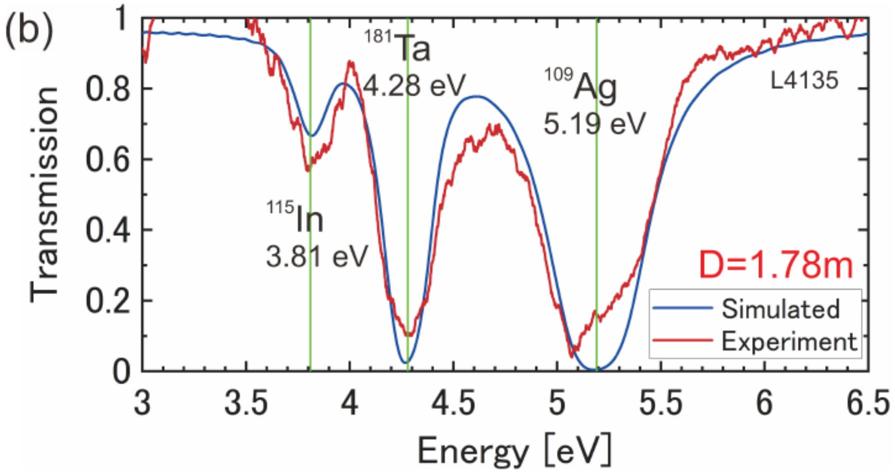


Pulse duration: 1.5 ps (fixed)
experiment
model
Neutron Yield Y [sr⁻¹]
Laser Intensity I_L [Wcm^{-2}]
$\propto I_L^4$
Yield used for the single-shot NRAS
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{18}
10^{19}
10^{20}



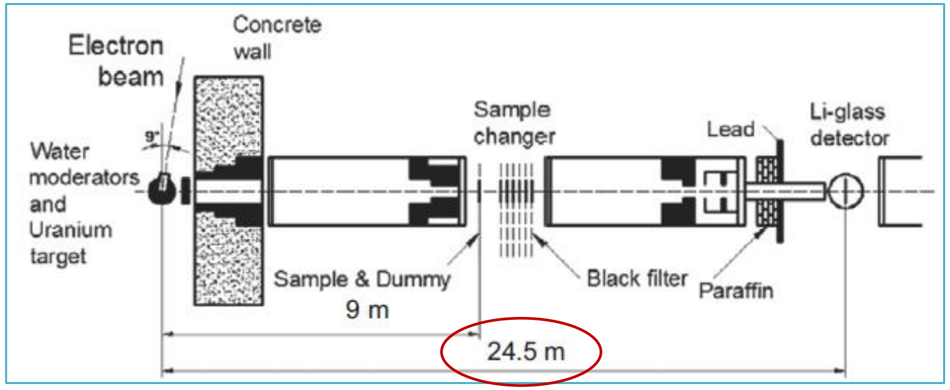
Laser
Ions
Neutrons
Primary Target
$(C_8D_8)_n$
Be
Secondary Target
1.1 m
Ion Analyzer
8.3 m
Neutron ToF Det.
(a)
Deuterons
Protons
Number [MeV^{-1}sr^{-1}]
Energy [MeV/u]
(b)
Neutrons
Number [MeV^{-1}sr^{-1}]
Energy [MeV]





2 m beamline, Single-shot analysis

20 m beamline, Time integration of 2-3 h



"Single-Shot" NRA result at LFEX, ILE

Isotope-sensitive non-destructive analysis
With high temporal resolution (~100 ns)
⇒Nuclear Fuels Inspection

Only **3 shots/day** at LFEX laser

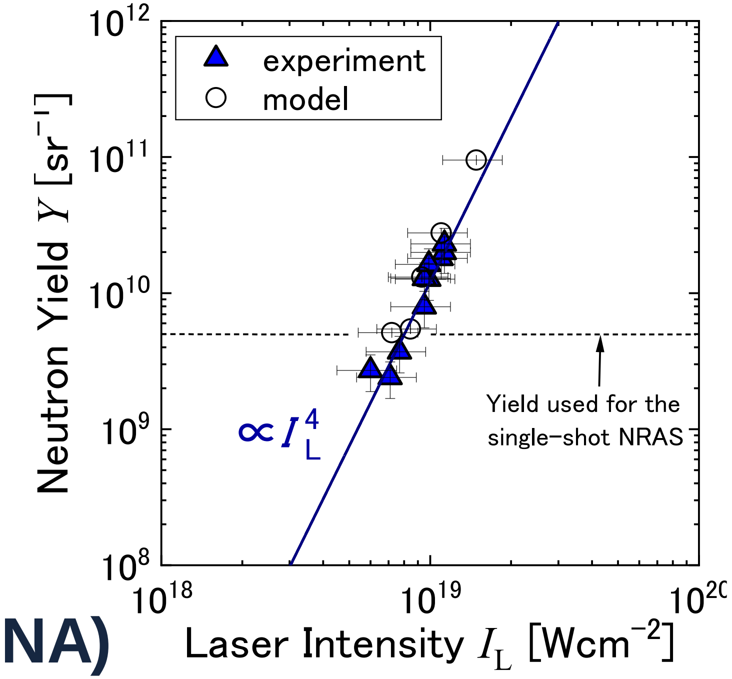
High-rep Laser system is desired!

Summary

I. Scaling on the neutron yield

$$\boxed{Y \propto I_L^{k+m+1}}$$

$E_{max,i} \propto I_l^{k}$, $CE \propto I_L^{m}$



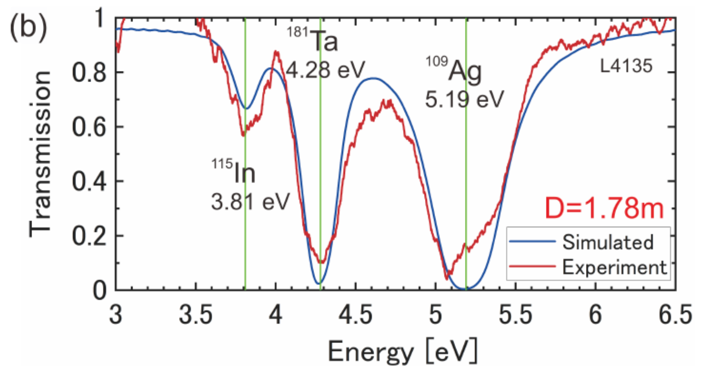
Problem

No sufficient data for fs pulses

Start the survey at 1PW ELI-NP!

II. Single shot neutron analysis (SSNA)

Neutron Resonance Spectroscopy achieved by 2 m beamline



The single-shot NRA can be achieved at 10 PW ELI-NP

04 Laser Interaction with Nano Wire Targets

- GR Kumar, A Lad, R Palit, P Singh, TIFR India
  A Adak IIT, India

- JF Ong, P Ghenuche, M Cernaianu, D Doria, K Spohr, O Tesileanu, KA Tanaka ELI-NP

- H Habara, T Hanamoto, Y Kagawa, K Nishimura, Osaka University
- K Nagai, Kanazawa University

Some more future look for 10 PW exp.

- Laser driven nanowires show high coupling efficiency by driving electron plasma wave in a solid. The following implosion of nano wires can produce pressured higher than 40 Tbar.

Electron transport in a nanowire irradiated by an intense laser pulse

J. F. Ong,[*] P. Ghenuche,[†] and K. A. Tanaka[‡]
Extreme Light Infrastructure-Nuclear Physics (ELI-NP), "Horia Hulubei" National Institute for Physics and Nuclear Engineering (IFIN-HH), 30 Reactorului Street, RO-077125 Bucharest-Măgurele, Romania

(Received 25 February 2021; accepted 31 August 2021; published 17 September 2021)

Electron transport in a nanowire exhibits a distinct behavior following the irradiation of intense laser pulse. Using particle-in-cell simulation, we observe a large-amplitude particle-driven wakefield excitation followed by electron acceleration in the solid density. Besides, we observed the quiver of the electrons across the nanowire under the action of the surrounding laser electric field facilitating deeper wakefield propagation in the nanowire with 2.5× energy gain over a flat target. These results open insights into the laser-energy coupling with nanostructure targets and radiation sources, and motivate the wakefield acceleration in solid density plasma.

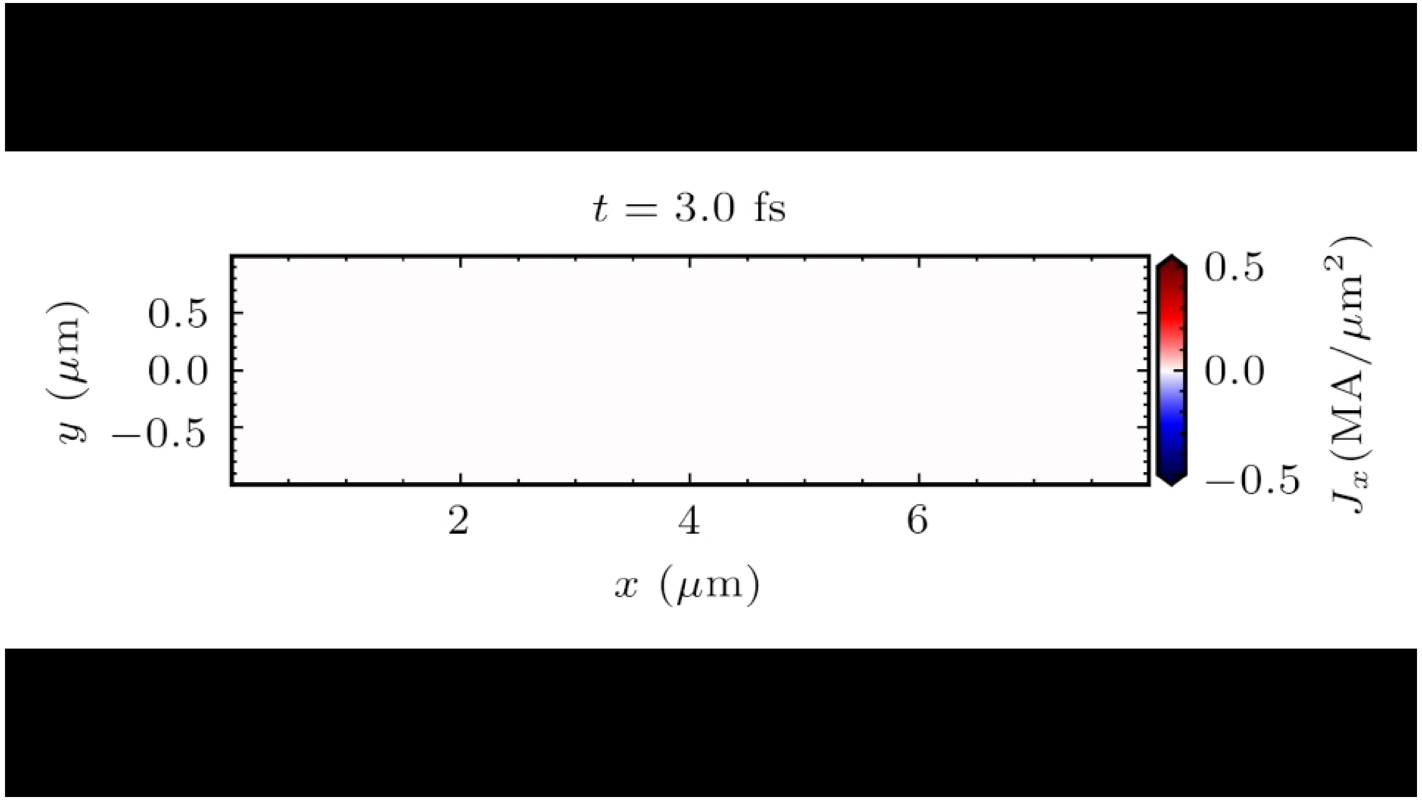
DOI: 10.1103/PhysRevResearch.3.033262

Phys. Rev. Res. 3, 033262 (2021) This Sept.

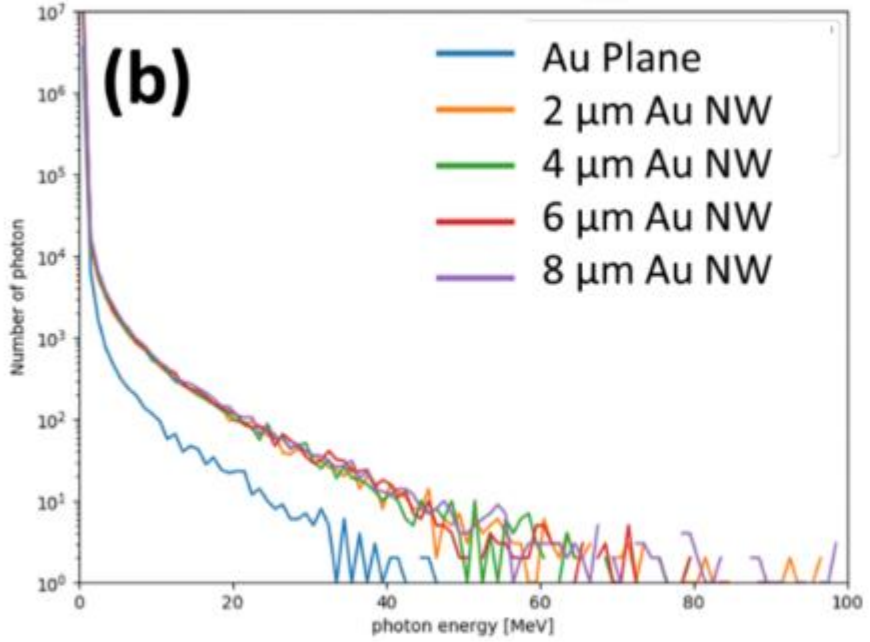
When we shoot carbon nano rod, electron wake field is excited.

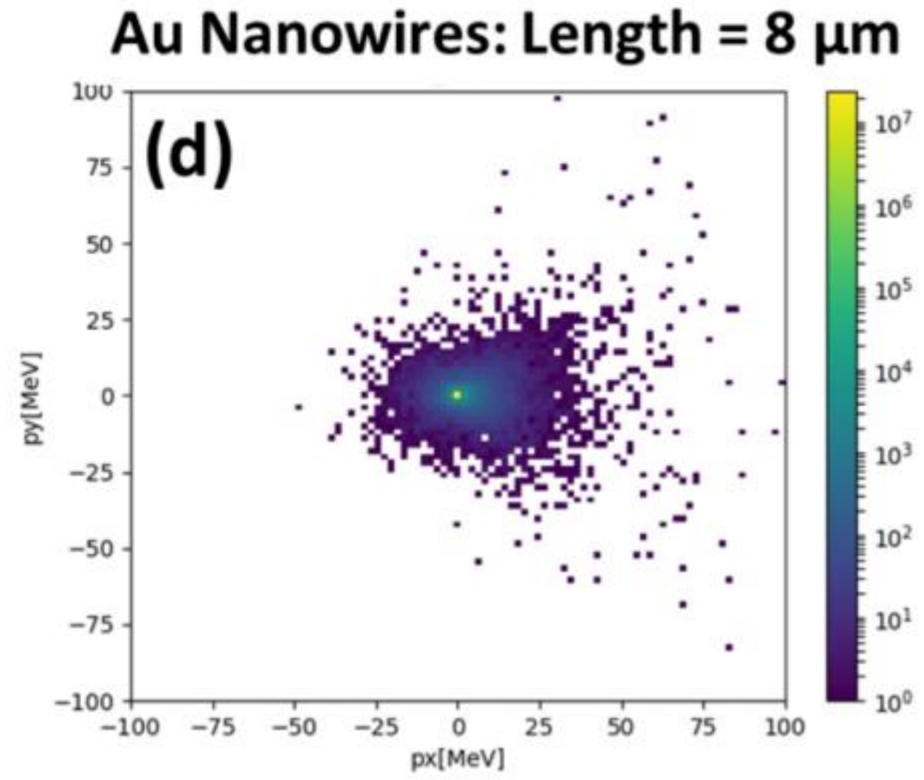
- Jian Fuh Ong (ELI-NP) used PIC simulation to show the laser wake field in solid density carbon nano rod resulting in 10 Tbar implosion pressure.

$I_L = 10^{23}$ W/cm^2
9 Nano-rods
3D PIC

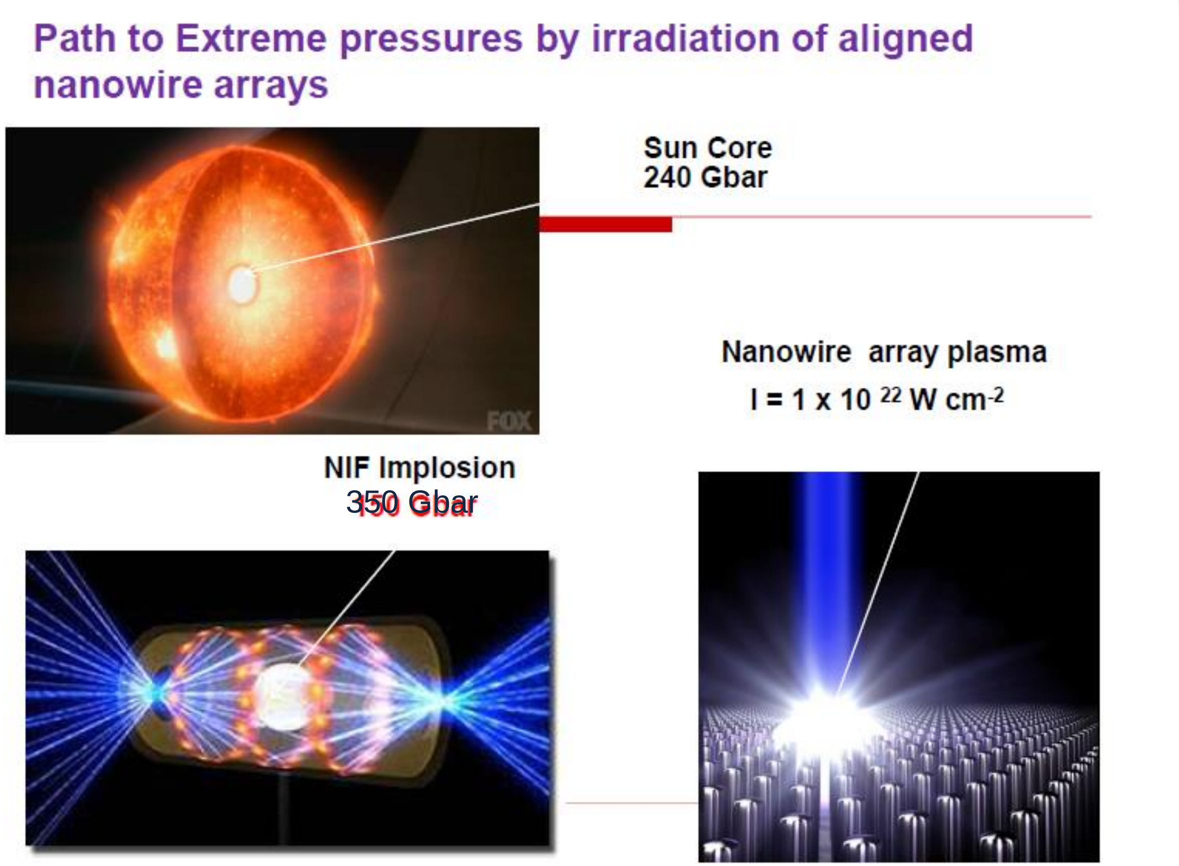


Nano wire target can emit gamma rays efficiently



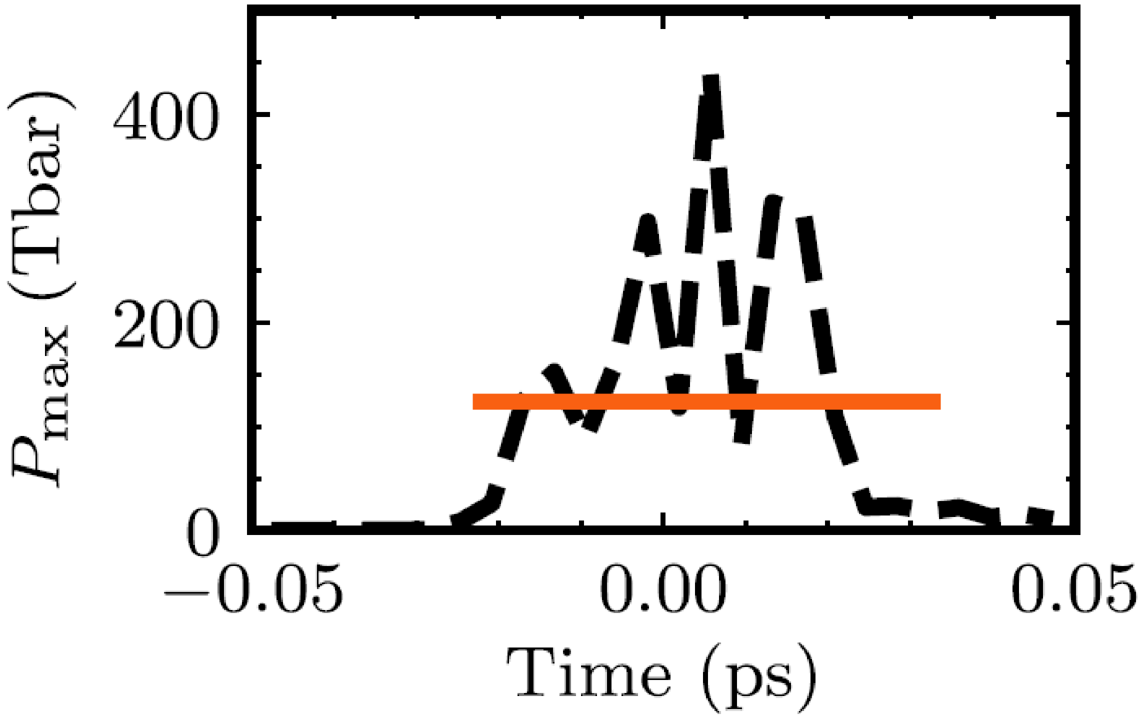


Tbar pressure may be possible at ELI-NP.



By Courtesy of A Pukhov, Henrich Heine U., Germany

Possiblity of highest pressure created on earth with 10 PW on nanowire



Summary

- All laser systems are up and running at ELI-NP.
- Expert users participated at 100TW and 1 PW experiments.
- Commissioning experiments continue this and next years with expert users.
- 10 PW full power target shot will start in 2023.
- User experiments have started in 2022.
- Unique and original proposals have been submitted.