Nuclear Physics Mid Term Plan in Italy

LNS – Session

Catania, April 4th-5th 2022

Nuclear Physics
Mid Term Plan in Italy

Laser-driven applications

G A Pablo Cirrone and Giuliana Milluzzo
Laboratori Nazionali del Sud, INFN, Catania, Italy

INFN
Istituto Nazionale di Fisica Nucleare

Laser beam-lines and secondary laser-driven beams @ LNS

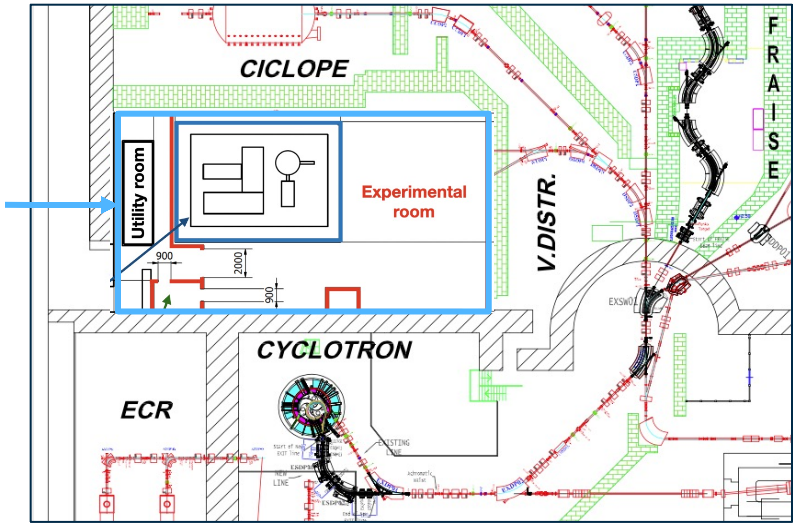
First phase (BCT project)

- Two laser beamlines: Low Energy (LE) and High Energy (HE)
  - Proton beams: max energy 5 MeV; Fluence: 10^9 cm^{-2} @ 1 MeV
  - Electron beams up to 200 MeV
  - X-Rays, neutrons

Second phase

- High energy laser beamline will reach a laser power of 250 TW
  - Proton beams: max energy 30 MeV; Fluence: 10^9 @ 15 MeV
  - Electron beams up to 500 MeV and corresponding bremsstrahlung x-Rays
  - X rays and neutrons

I-LUCE



Courtesy of S. Passarello and A. Russo

Low-Energy (LE) laser beamline

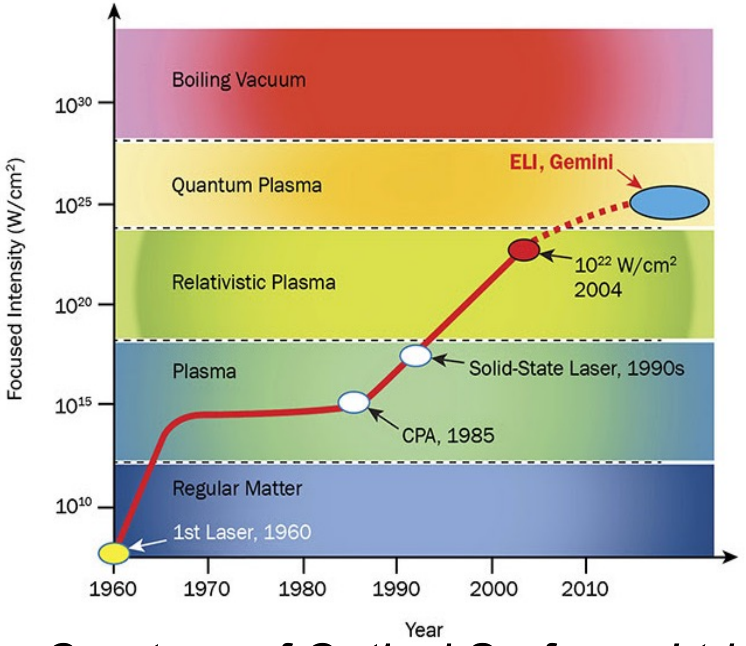
Laser Power	~ 1 TW
Energy per pulse	>25 mJ
Pulse duration	≤ 30 fs
Contrast ratio ns	< $1*10^{-8}$
Contrast ratio @5 ps	> 10^6
Contrast ratio @100 ps (ASE)	> 10^{10}
Repetition rate	10 Hz

High-Energy (HE) laser beamline

Laser Power	45-50 TW
Energy per pulse	≥ 1 J
Pulse duration	≤ 25 fs
Contrast ratio ns	< $1*10^{-8}$
Contrast ratio @5 ps	> 10^6
Contrast ratio @100 ps (ASE)	> 10^{10}
Repetition rate	5 Hz

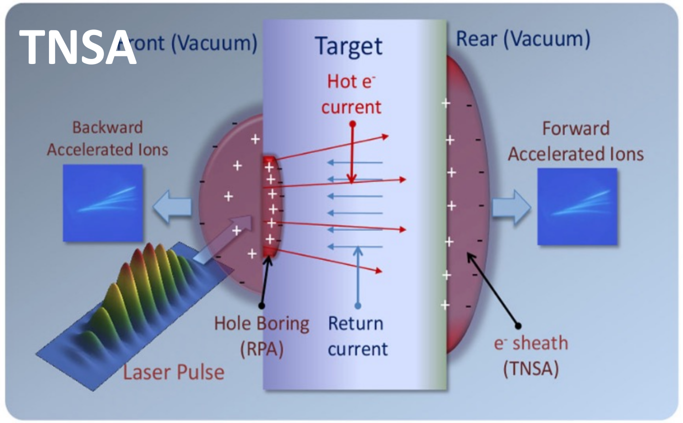
Laser-matter interaction mechanisms

Laser classes	High energy CPA systems	Ultrashort CPA systems
Technology	Nd: Glass	Ti:Sa
Energy	100's J	10's J
Pulse duration	>100's fs	10s fs
Intensity [W/cm2]	10^{21} Wcm2	10^{21} Wcm2
Rep rate	1 shot/hours	1-10 Hz



Courtesy of Optical Surfaces Ltd.

Laser-solid target interaction for protons, ions acceleration

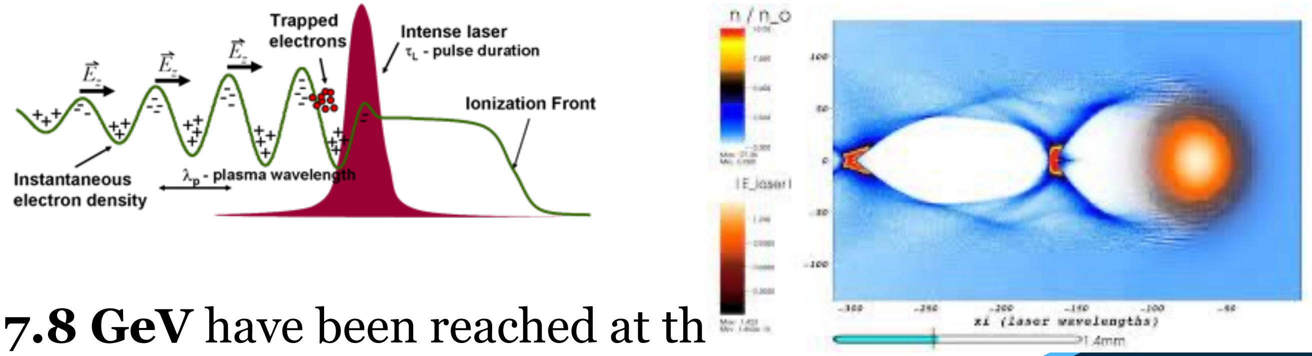


- Multi species production: g, e-, p, ions
- **E_{max} ~ 10 TV/m**
- Short distance (~µm)

Proton characteristics

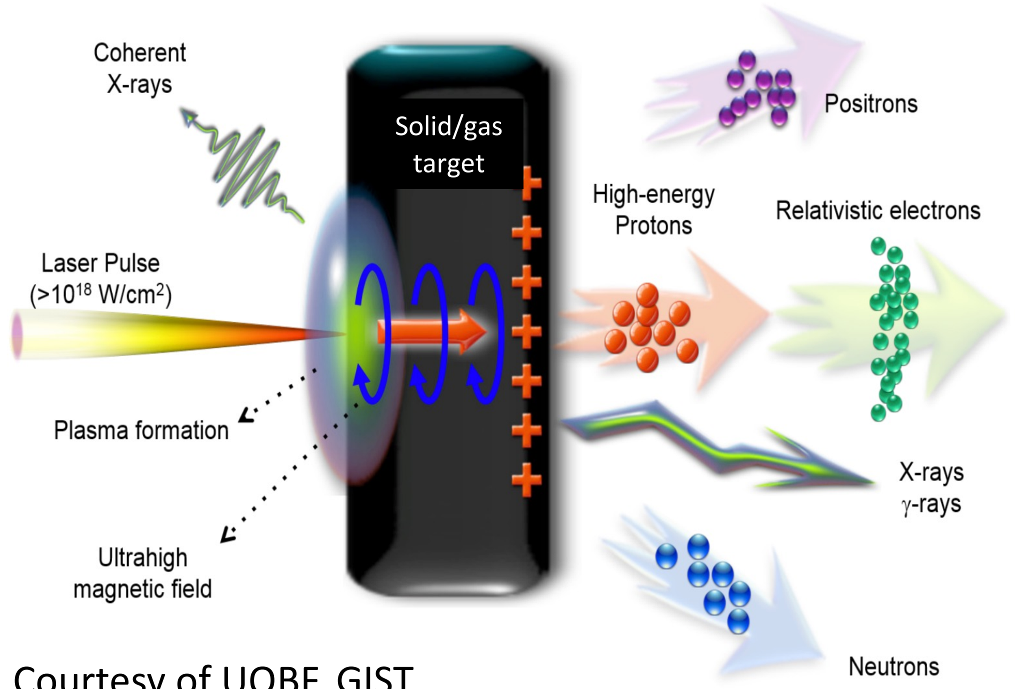
High energy: up to ~ **98 MeV Articolo**
Pulse duration ≈ 10s fs - 100s ps
ppb ≈ 10^{8}-10^{11}
Broad energy spectra (100%)
Wide angular divergence (≈ 10° -20°)

Laser Wake Field Acceleration (LWFA) for electrons



7.8 GeV have been reached at th BELLA (Berkeley Lab) in 2019 using two lasers

Contributions outline



Courtesy of UQBF, GIST

I Protons and electrons acceleration

- **M. Borghesi, S.Kar, D. Margarone**
  Centre for Plasma Physics, Queen's University Belfast (UK)
- **L. Labate, L. Gizzi** CNR-INO, Pisa (I)

II Positron, photon and neutron beams

- **G. Sarri**
  Centre for Plasma Physics, Queen's University Belfast (UK)
- **S. Kar**
  Centre for Plasma Physics, Queen's University Belfast (UK)

III Fusion, fission, nuclear reaction schemes for applications

- **D. Margarone**
  Centre for Plasma Physics, Queen's University Belfast
- **D. Batani**, CELIA Laboratory, University of Bordeaux, France
- **L. Volpe** CLPU, Salamanca (Spain)
- **P. Thirolf** LMU Univ, Munchen (Germany)
- **Kierzkowska-Pawlak** Lodz University of Technology, Lodz (PL)

I Proton and electron acceleration: The BCT related activities

Contributions

- **M. Borghesi, S.Kar, D. Margarone**
  Centre for Plasma Physics, Queen's University Belfast
- **L. Labate, L. Gizzi**
  CNR-INO

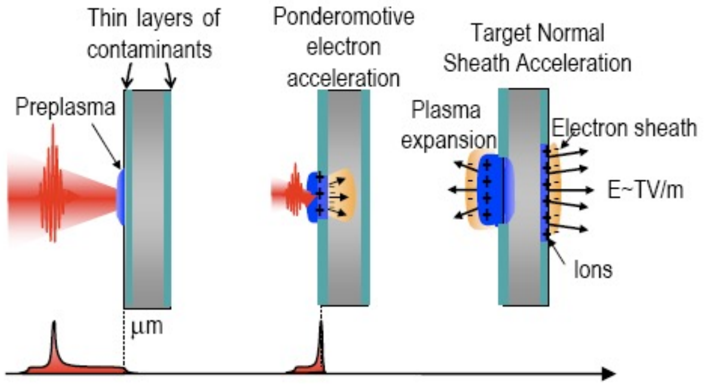
LNS contributions

G.A.P. Cirrone, G. Cuttone, R. Catalano, G. Milluzzo, G. Petringa, S. Tudisco, C. Guarrera, B. Cagni, A. Kurmanova

Ions laser-acceleration – state of the art

M. Borghesi, S.Kar, D. Margarone
Centre for Plasma Physics, Queen's University Belfast
QUEEN'S UNIVERSITY BELFAST

Proton acceleration : Target Normal Sheath Acceleration (TNSA)



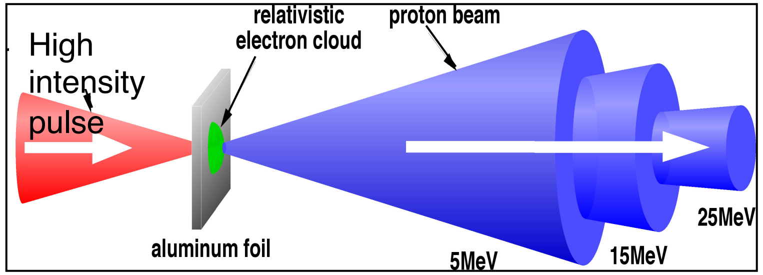
- Surface process,
- Mostly acting on proton contaminants

Scaling: $E_p \sim I^{0.5-1}$

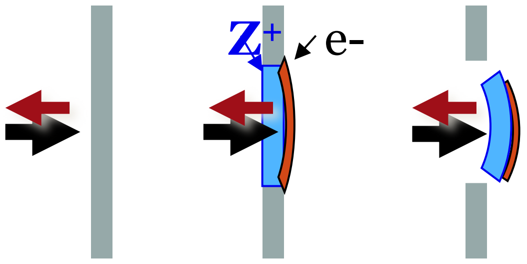
Indicative values:

Laser power	Cut-off energies
1 PW	40-70 MeV
250 TW	20-30 MeV
50 TW	3-5 MeV

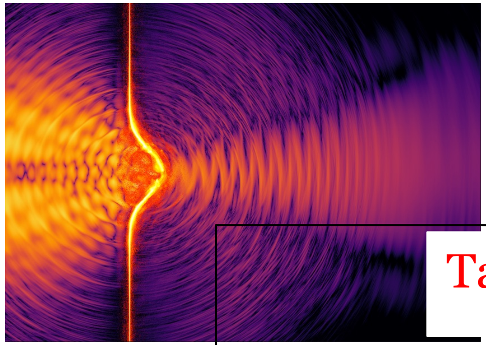
Divergent beam, broadband, exponential spectrum



Carbon acceleration: Radiation Pressure Acceleration (RPA)



- Accelerating field sustained by light pressure
- Acts on target bulk
- Requires ultrathin foils and high-contrast pulses



Requires target to stay opaque

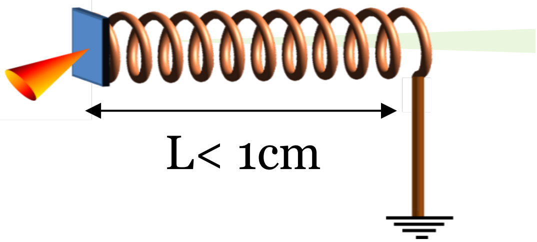
Scaling: $E_p \sim I^2$

Target **must stay opaque**:

Potential issues → Electron heating
Target disassembly
Transverse instabilities

Ions laser-acceleration – recent achievements

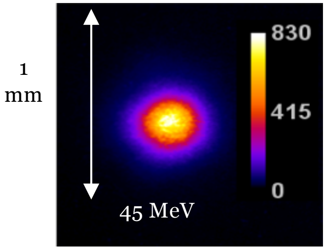
Production of collimated, narrow-band beamlets of high energy protons

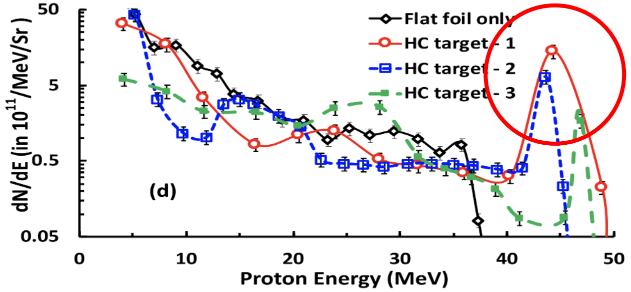


S. Kar *et al*, Nature Comm. (2016)
H. Ahmed *et al*, Sci. Report (2021)

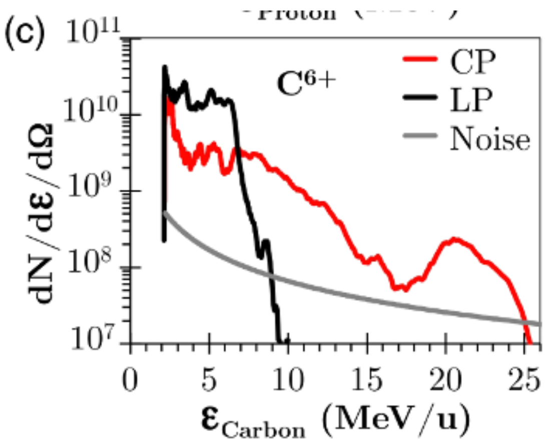
- Use of **miniature accelerating structures**
- **EM pulse** travelling along coil affects TNSA protons through radial confinement and reacceleration
- Process is energy-selective due to sync between EMP and a proton group within TNSA spectrum

Data from VULCAN PW



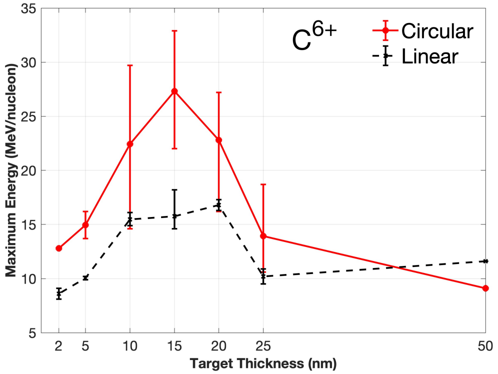


Production of *proton-free* high-energy carbon beams from ultrathin foils



Efficient RPA carbon acceleration from 10 nm foils using Circularly Polarized (CP) pulses

Data from GEMINI (350TW)



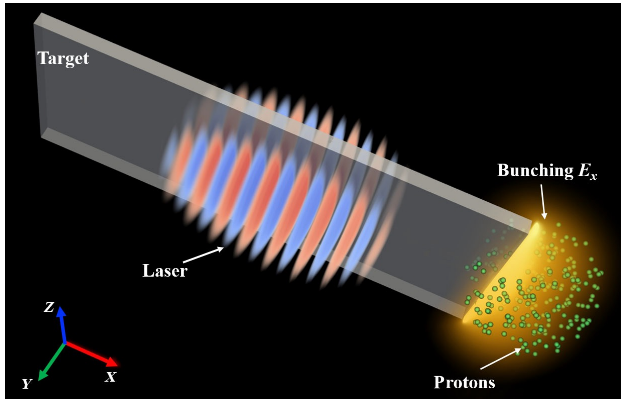
Optimum target thickness for Carbon acceleration

Proton-free carbon beams under optimized conditions

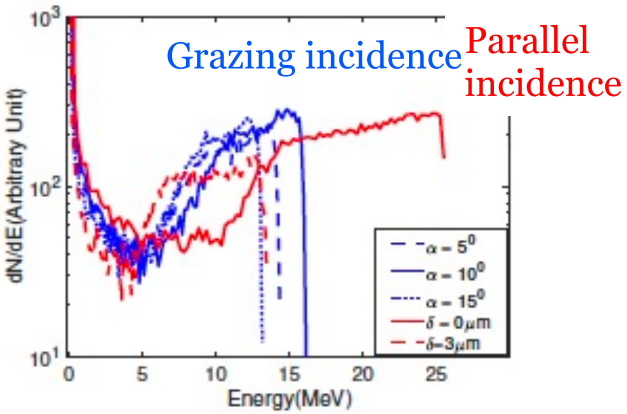
C. Scullion et al, PRL, **119**, 054801 (2018)
A. McIlvenny et al, PRL, **127**, 194801 (2021)

Ions laser-acceleration – proposed activities @ LNS

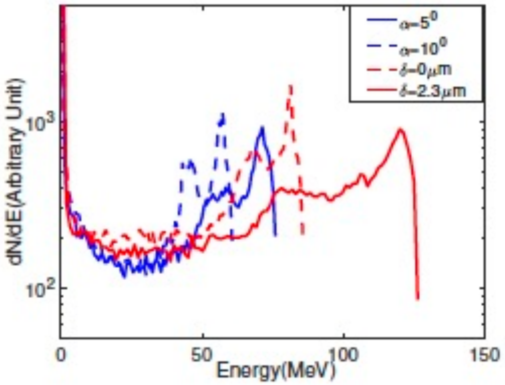
New acceleration processes through high-field plasmonics



- Laser propagates along the target surface (or grazing incidence)
- Drives a surface plasma wave, accelerating electrons
- Strong sheath field formed at target edge
- Proton energies >> TNSA

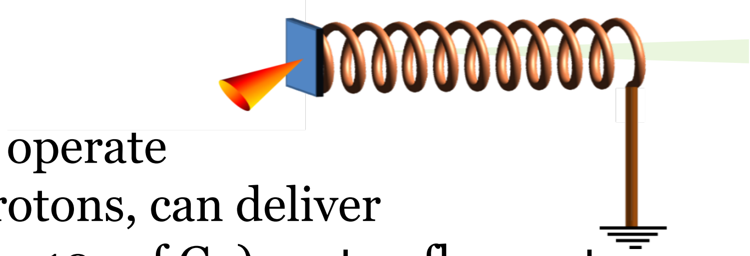


Proton spectra for ~**50 TW** pulses (I~3 10^{19} W/cm²)

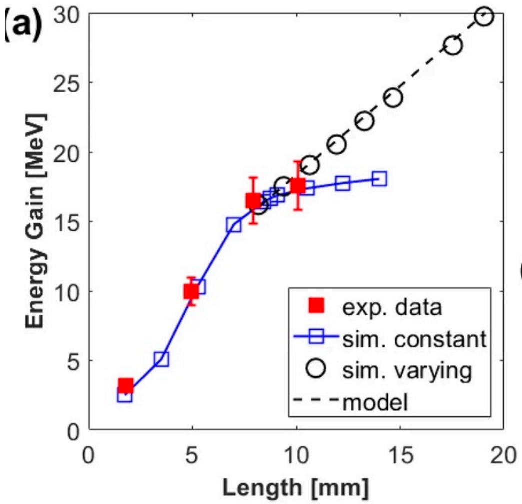


Proton spectra for ~300 TW pulses (I~6 10^{20} W/cm²)

Provision of high flux, multi-MeV ions



Tuning coil to operate on 3-5 MeV protons, can deliver multi-Gy (up to 10s of Gy) proton fluxes at energies of 5-10 MeV protons (Phase 1), >30 MeV in Phase 2

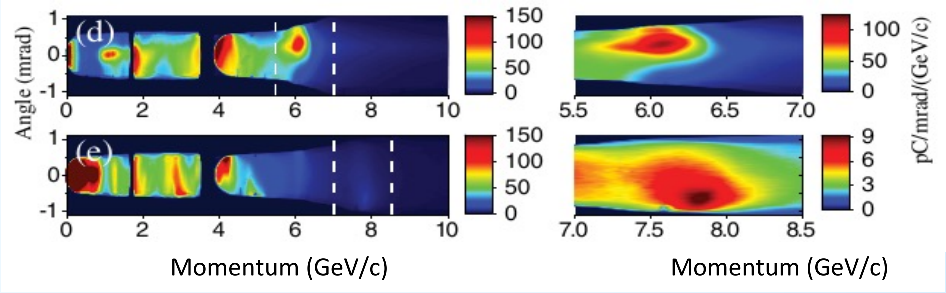


To extend acceleration length at high energies and overcome proton-EMP phasing, we will test variable pitch coils, which will lead to higher energy gains in Phase 2

State of the art of Laser WakeField Acceleration (LWFA) accelerators & perspectives @LNS

L. Gizzi, L. Labate CNR Istituto Nazionale di Ottica (CNR-INO)

Current record e- energy: 8 GeV (Bella 850 TW laser) (recent 10 GeV milestone reached at Texas PW)

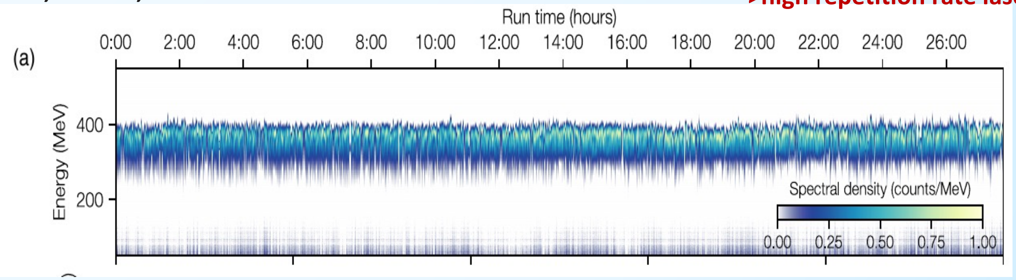


A.J.Gonsalves *et al.* (LBNL) PHYSICAL REVIEW LETTERS **122**, 084801 (2019)

Peak energy, charge and spectral width stability <10% achieved over 24h operation

2 J, 42 fs, 48 TW, 1 Hz

High statistics required
->high repetition rate lasers

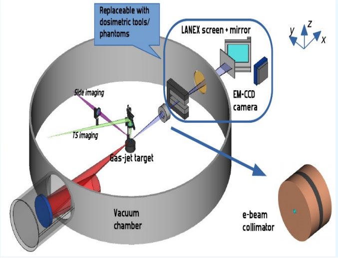


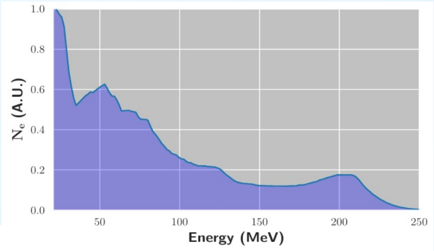
A. Maier *et al.* (CFEL/DESY Hamburg)
PHYSICAL REVIEW X **10**, 031039 (2020)

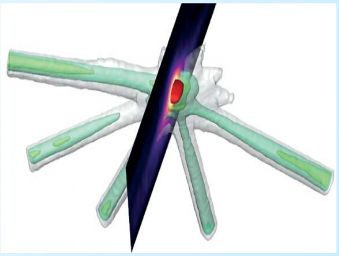
Activities @ CNR-INO

The Intense Laser Irradiation Laboratory of CNR-INO in Pisa is equipped with a 220 TW ultrashort laser system.

Mimicking IMRT and multi-field irradiation with laser-driven VHEE pencil beams







Scientific Reports | (2020) 10:17307

What next?

Perspectives for electron acceleration @LNS

LWFA is reaching high TRL for societal applications of high impact (biomedical/radiotherapy and diagnostics, remote inspection, secondary nuclear sources.

I-LUCE related activities

Applications with the VHEE in radiobiology and medical applications for flash radiotherapy studies

I phase-> preliminary studies

II phase -> VHEE flash radiotherapy preclinical studies

II Positron, photon and neutron beams

Contributions

- **G. Sarri**
  Centre for Plasma Physics, Queen’s University Belfast
- **S. Kar**
  Centre for Plasma Physics, Queen’s University Belfast

Positron beams

G. Sarri
Centre for Plasma Physics, Queen's University Belfast

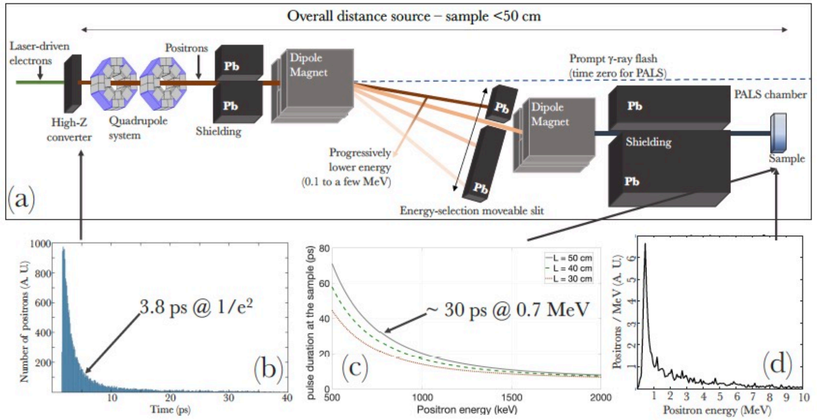
UKRI Science and Technology Facilities Council · EPSRC · Queen's University Belfast · Central Laser Facility · EuPRAXIA

T. Audet et al., Phys. Rev. Acc. Beams (2021)

MeV-scale positron beams

G. Sarri et al., Plasma Phys. Contr. F. (2022)

Positron beams of this kind to be used for volumetric material inspection with nm-resolution down to cm-scale depths



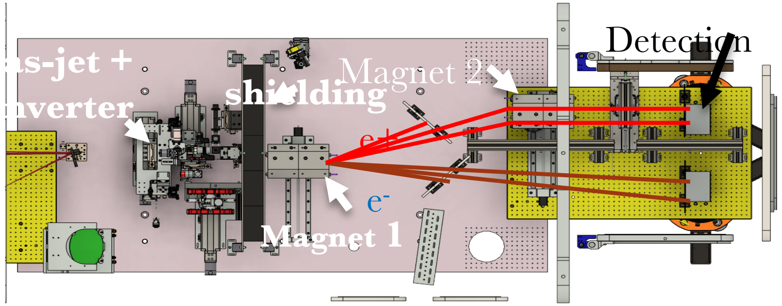
- High-flux, ultra-short (~ps) positron beams demonstrated at low repetition rate.
- Ultra-short and MeV-scale positron beams will allow, for the first time, for volumetric material inspection at unprecedented resolution (Positron annihilation lifetime spectroscopy PALS)

1 Phase: 1-50 TW laser
MeV positron beams at high repetition rate (1-10 Hz)
Study of materials with high resolution

G. Sarri et al., Nat. Comm. (2015)

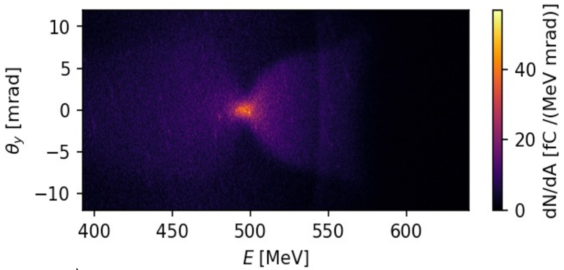
GeV-scale positron beams

Positron beams of this kind to be used for laboratory astrophysics, detector testing, and as a test-facility for plasma-based accelerators.



- Expected ~ mm-scale normalized emittance positron beams with a ~200 – 300 TW laser system :

- **E ~ 0.5 GeV**
- **ΔE/E = 4.5%**
- $\mathbf{N_{max} = 10^6}$



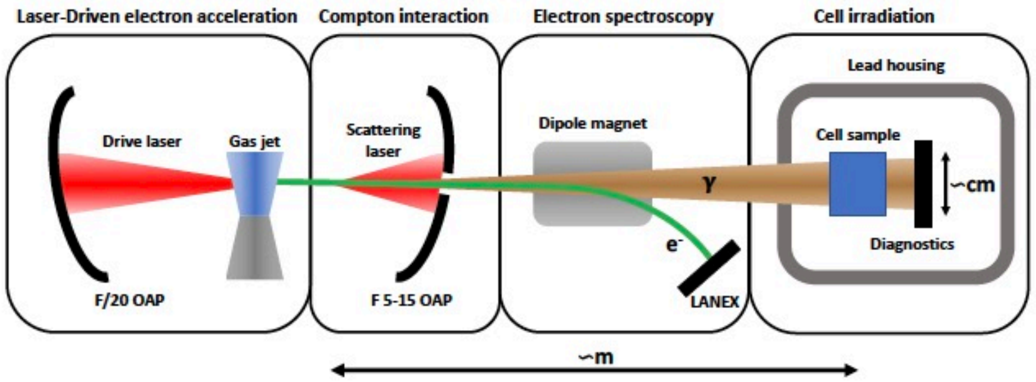
2 Phase: upgrade up to 250 TW
GeV positron beams with reduced energy and emittance spread
Plasma-based accelerator

A. Alejo et al., PPCF (2020)
M. Streeter at al., *submitted* (2022)
J. Warwick et al., Phys. Rev. Lett. (2017)
A. Alejo at al., Sci. Rep. (2019)

Photon beams and applications- Inverse compton

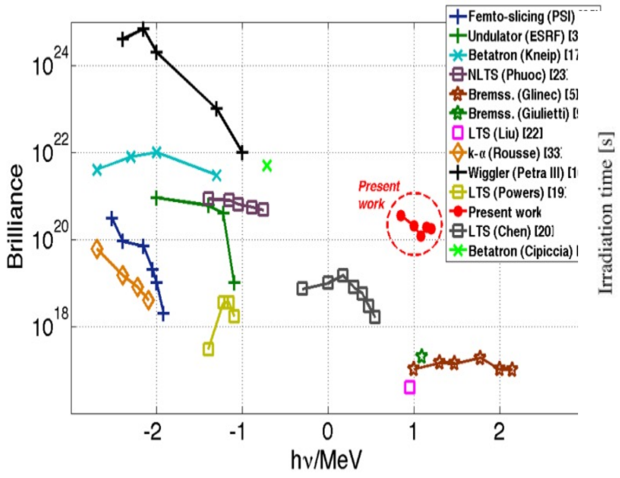
G. Sarri
Centre for Plasma Physics, Queen's University Belfast

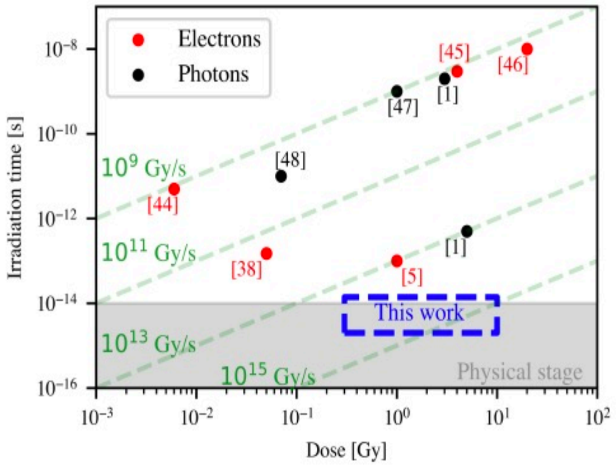
- Ultra-high brilliance, MeV-scale femtosecond photon beams can provide Gy-scale irradiation at the femtosecond level (dose rates >1014 Gy/s)



Photon beam characteristics

- Demonstrated peak brilliance > 10^{20} s^{-1} mm^{-2} $mrad^{-2}$ 0.1 % BW
- Highest brilliance ever achieved in the multi-MeV range
- Photon beam duration ~ 10 - 20 fs, allowing for time-resolved imaging and scanning
- Interest from industry and for bio-medical applications





Bio-medical applications

- Numerical work demonstrates up to 2 – 3 Gy per irradiation on a timescale of 10 – 30 fs
- Plans to reach FLASH regime (> 10 Gy) to be tested at CLF in June 2022

G. Sarri et al., Phys. Rev. Lett. (2014)

G. Sarri et al., Frontiers Physics (2017)

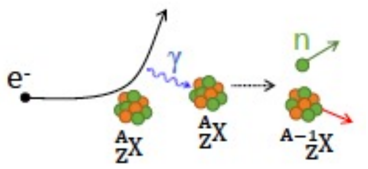
C. McAnespie et al,, Phys. Med. Biol. (2022)

Laser-driven neutrons: current state-of-art

S.Kar
Centre for Plasma Physics, Queen's University Belfast
QUEEN'S UNIVERSITY BELFAST

Using electrons

Photo-electron

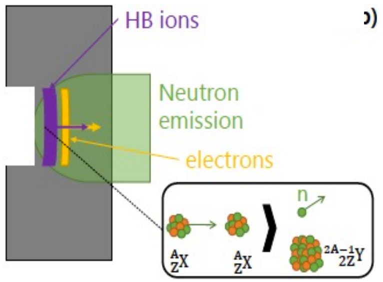


Hot electrons from laser interaction produce MeV gamma via Bremsstrahlung process, which produce neutrons by (g,n) reaction

Phys. Rev. Lett., 113, 184801 (2014)

Using ions

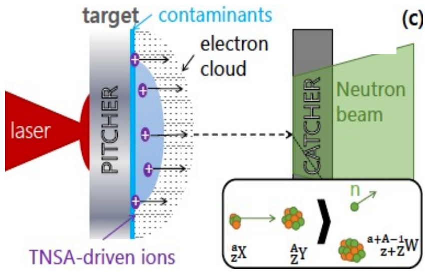
In-target



Laser driven ions trigger nuclear reaction in the target bulk

Plasma Phys. Controll. Fusion, 40, 175 (1998); New J. Phys., 18, 053002 (2016)

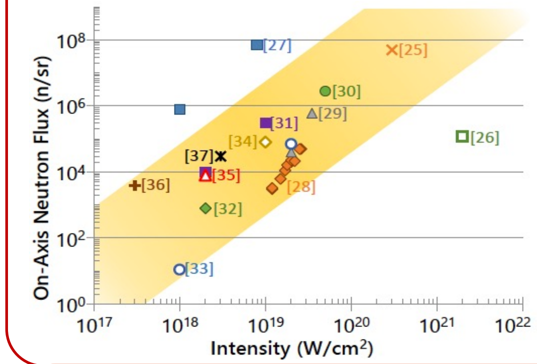
Pitcher-catcher



Laser driven ions trigger nuclear reaction in a secondary target (catcher)

Phys. Rev. Lett., 110 044802 (2013); New J. Phys., 18, 053002 (2016)

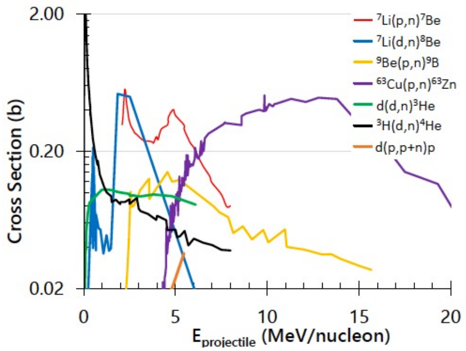
Neutron flux scale



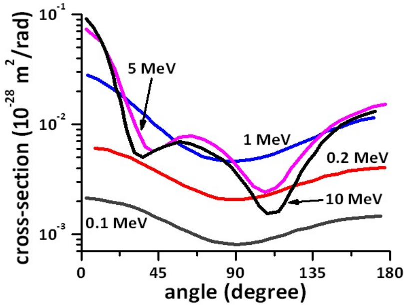
Fairly promising scaling, but rather slow.
Would need another 2 order increase in laser intensity to achieve what we have with pitcher-catcher [~ 10^{10} n/sr]

Pitcher-catcher : a wider choices available

High cross-section



Beamed emission

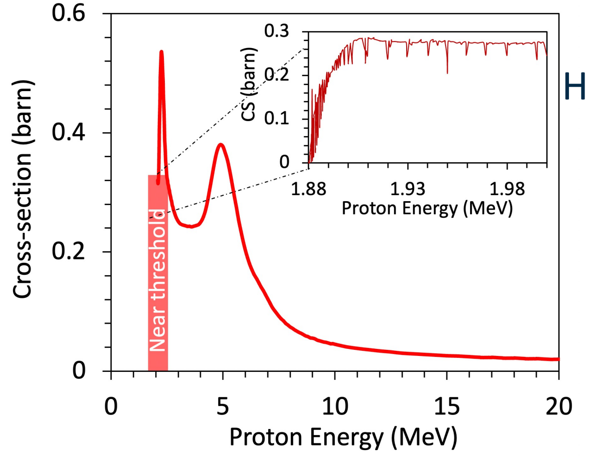


What do we need? High energy Low Z projectile
=> deeper penetrations in catcher => higher yield
=> beamed emission => higher on-axis flux

Efficient moderations to epithermal, (Appl. Phys. Lett. 111, 044101, 2017) thermal : (Appl. Phys. Lett. 116, 174102, 2020) and cold regimes : (Sci. Report, 10, 20157, 2020)

Efficient neutron generation using moderate power lasers@ LNS

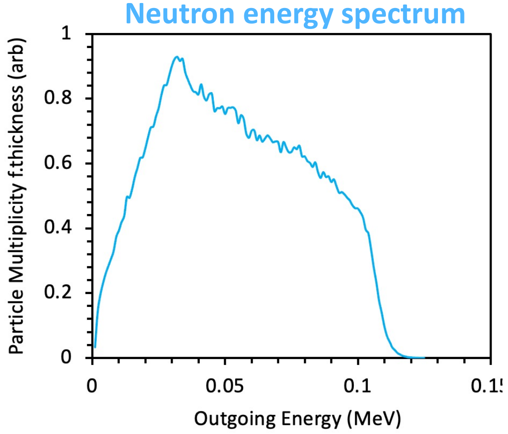
(p,Li) reactions near-threshold reaction

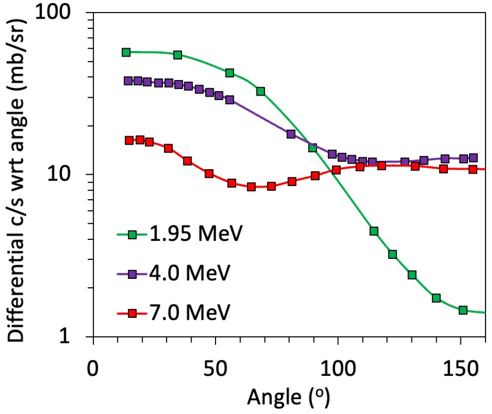


High Cross-section, and needs only 2 MeV protons

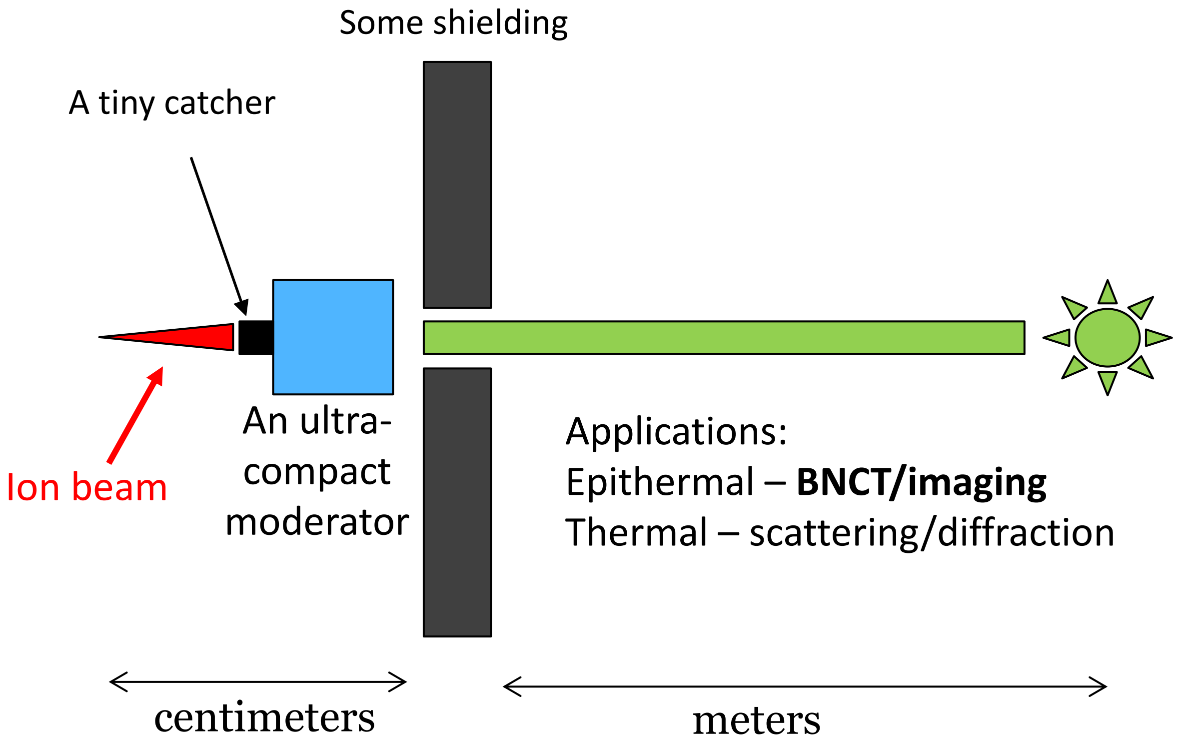
=> perfect for TNSA

Intrinsic beamed emission of those keV neutrons





Beamline setup (schematic, not to scale)



With high repetition lasers, it can provide a university-scale, ultra-compact neutron sources

III Fusion, fission, nuclear reaction schemes for applications

Contributions

D Batani, Philippe Nicolai, Didier Raffestin
CELIA Laboratory, University of Bordeaux, France
P.E. Masson-Laborde (CEA)
D. Margarone
Centre for Plasma Physics, Queen's University Belfast
L. Giuffrida
Eli-Beamlines (CZ)
A. Picciotto
Fondazione Bruno Kessler (FBK), Italy
P. Thirolf (LMU)
L Roso (CPLU)
L Volpe (CPLU)

Table-top intense ion sources;
Radioisotopes production;
Energy

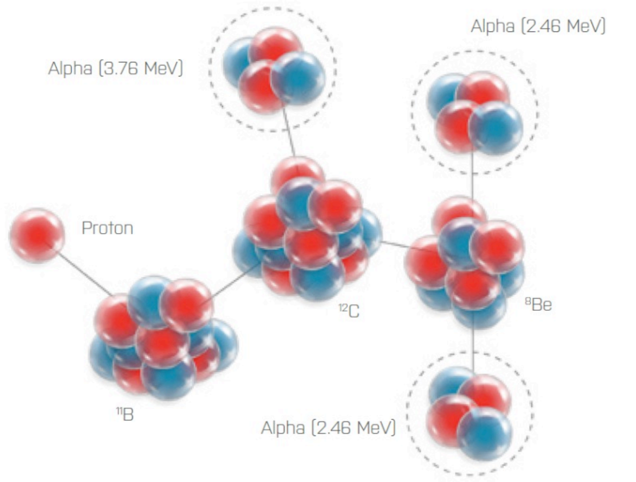
LNS contributions

P. Cirrone, G. Milluzzo, G. Petringa, S. Tudisco, L. Guardo, S. Romano

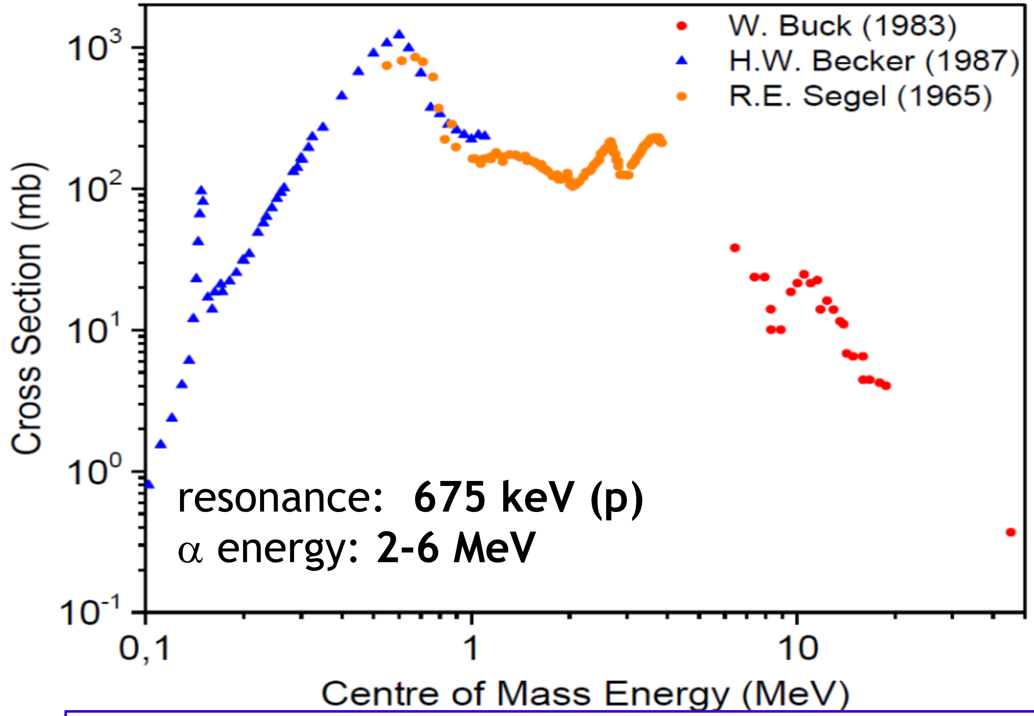
p-B Nuclear Fusion in laser-plasma for energy and health

D Batani, Philippe Nicolai, Didier Raffestin. CELIA Laboratory, University of Bordeaux,
L. Giuffrida Eli-Beamlines (CZ)
A. Picciotto Fondazione Bruno Kessler (FBK), Italy
D. Margarone Centre for Plasma Physics, Queen's University Belfast

$p + {}^{11}B \rightarrow 3\alpha + 8.7$ MeV



Oliphant & Rutherford (1933)



$$p + 11B \rightarrow \alpha_0 + {}^8Be + 8.59\ MeV \rightarrow \alpha_0 + \alpha_{01} + \alpha_{02}$$

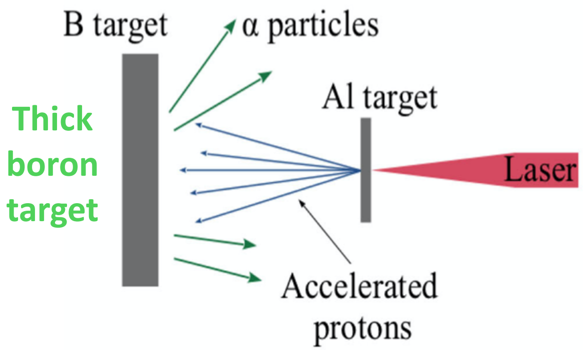
$$p + 11B \rightarrow \alpha_1 + {}^8Be * + 5.65\ MeV \rightarrow \alpha_1 + \alpha_{11} + \alpha_{12}$$

$$p + 11B \rightarrow 12C * \rightarrow 3\alpha + 8.68\ MeV$$

- ✓ Low-energy nuclear resonances: **675 keV** (main); **160 keV** (secondary)
- ✓ Ultraclean: **no neutron** production
- ✓ Efficient particle production: **3 alpha-particles**

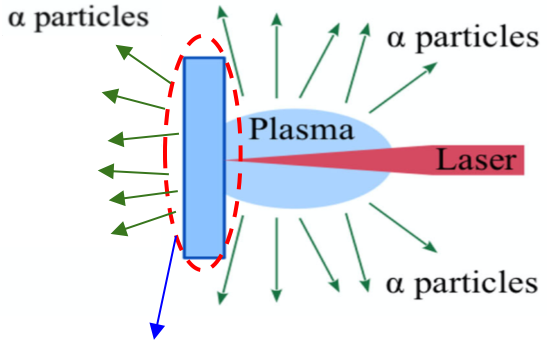
Laser-induced p-^{11}B fusion reaction- PB experimental progress

Pitcher-catcher scheme

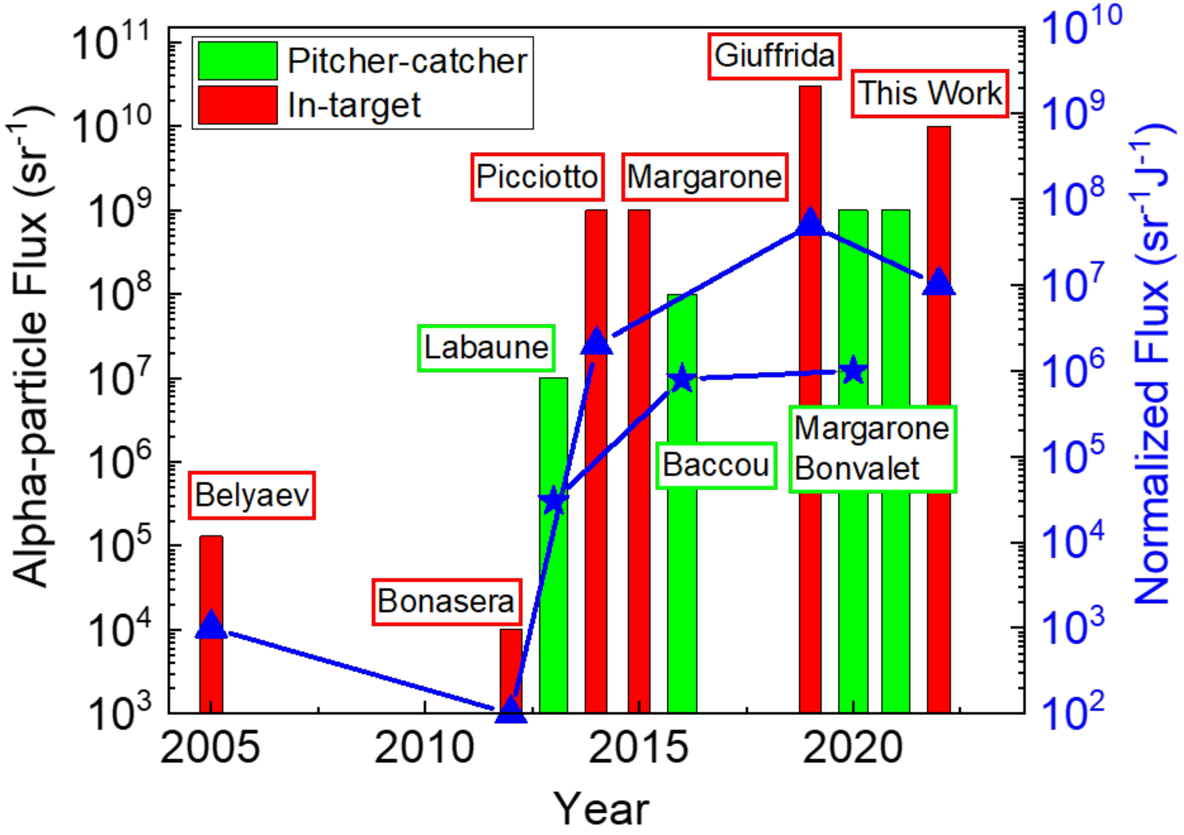


Consoli F et al., (2020) Front. Phys. 8:561492

In-target scheme



Boron (natural or B11) enriched target on silicon substrates
NB targets

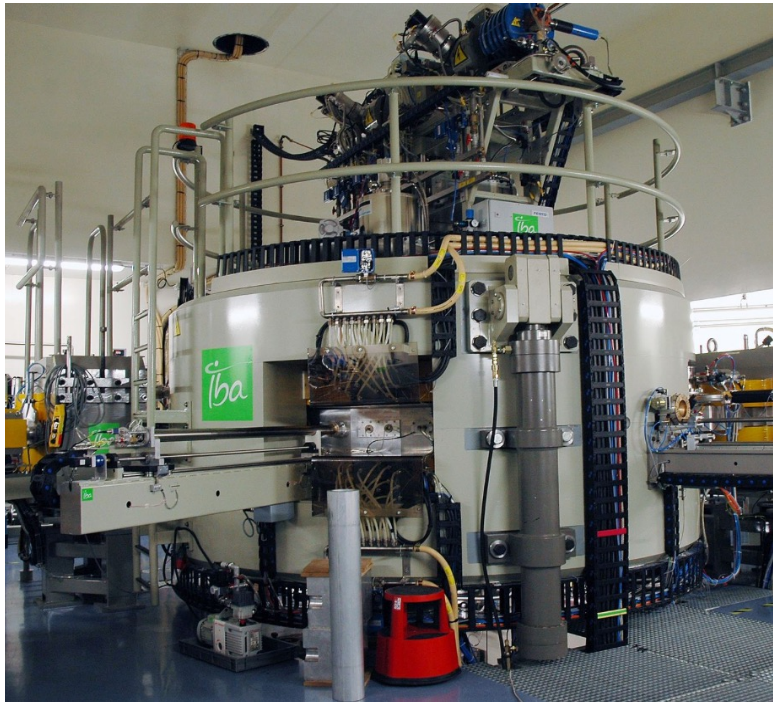


Transversal interest with the ASFIN research group @ LNS for nuclear astrophysics research

- Belyaev, PRE 72 (2005) 026406
- Labaune, Nat. Comm. 4 (2013) 2506
- Picciotto, PRX 4 (2014) 031030
- Margarone, PPCF 57 (2015) 014030
- Giuffrida, PRE 101 (2020) 013204
- Margarone, Front. Phys. 8 (2020) 343
- Bonvalet, PRE 103 (2021) 053202
- Margarone, Appl. Sci. (2022)

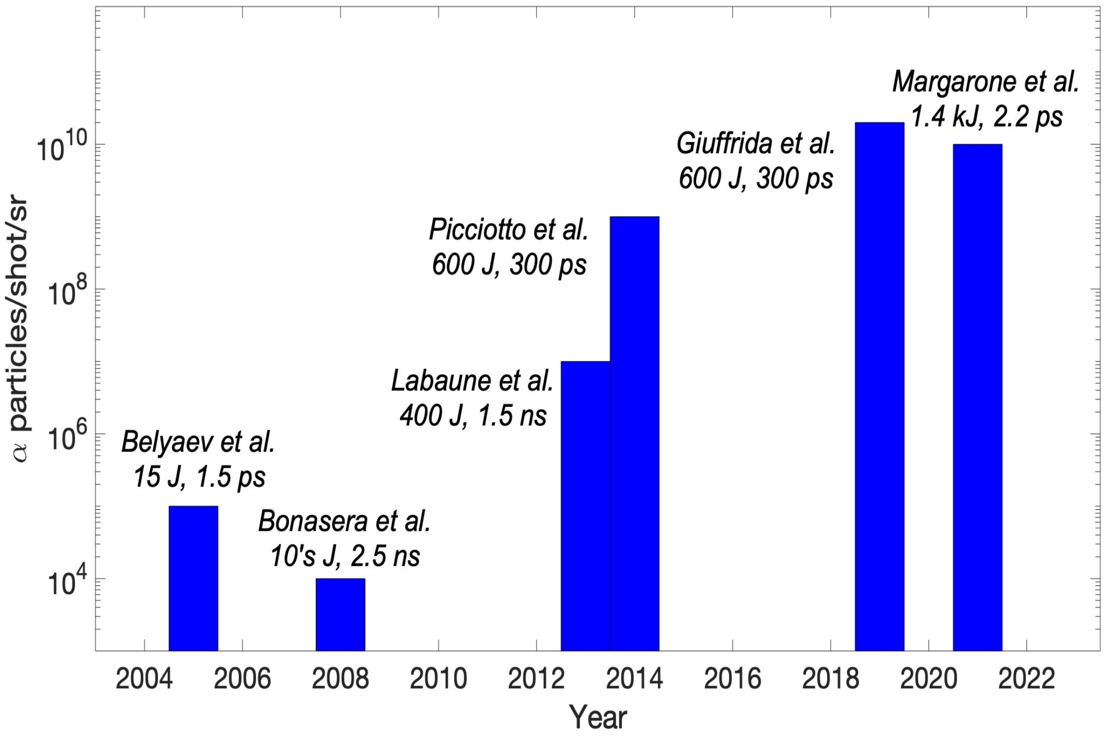
Status of the art and recent achievements in alpha production

Cyclotron ARRONAX for radioisotopes



10 µA of α-particles ≈ 10^{14} α/s (for instance ARRONAX produces 2×375 µA protons but only 70 µA of a-particles)

α-yield from laser experiments



Laser experiments show a maximum of 10^{11} a/shot.

In order to be competitive, we need:

i) use a new generation of 100 Hz laser systems

ii) increase the α-yield of at least 1 order of magnitude

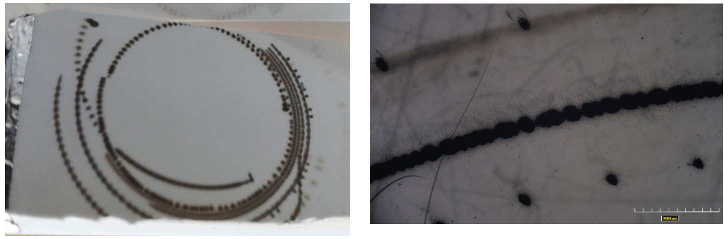
Perspectives to improve alpha particle yield

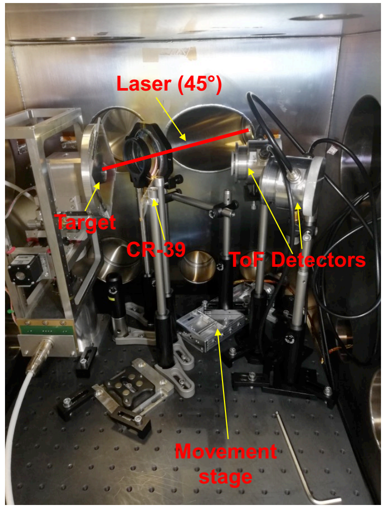
Table-top multi-MeV a-accelerator @ kHz

PERLA-B laser system
- ✓ central wavelength: **1.03 µm**
- ✓ pulse energy: **20 mJ**
- ✓ pulse length: **~1 ps**
- ✓ rep. rate: **1 kHz**
- ✓ Beam quality (M^2): **<1.15**

LaserLab Europe beamtime ***@HiLASE***

Target craters





- ✓ Intensity: ~2x10^{16} W/cm^2
- ✓ Peak Power: **10 GW** (only!)
- ✓ Rep. rate: 1, 10, 100, 1000 Hz

!!!Preliminary!!!
- ➢ a-particle flux: ~10^3/sr/shot (**3-7 MeV**)
- → **~5x10^6/sr/s (@kHz)** using **10 GW** laser

I-LUCE laser @ LNS

I phase
LE Beamline: 1 TW, 25 mJ, 25 fs, **10 Hz**
HE Beamline: 45-50 TW, 1.2 J, 25 fs, **5 Hz**
II phase
250-300 TW, 1 Hz

- The available high repetition rate **(10 Hz)** will allow exploring the parameters space and optimizing target and laser parameters, which is not possible with high-energy PW laser system which provides only a few shots per day.
- The high power will allow to accelerate protons up to the energy of interest and improve the alpha particle yield
- Possibility to investigate the p-11B with high rep-rate femtosecond laser at different laser powers
- New target structure enriched in hydrogen and boron and new diagnostics approaches

Submitted PRIN 2022
Next Project proposed in COM 5
Discussions on going INFN-E

Perspectives for high power laser applications in Nuclear Physics

P.G. Thirolf, LMU Munich

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Basic idea: Exploit the unique properties of dense laser-driven ion beams for nuclear astrophysics

→ Complement rather than compete with conventional accelerators
→ Focus on unique properties of laser-driven ion bunches
→ In particular: uniquely high density of ion bunches

→ Exploit this property to establish novel nuclear reaction scheme to produce extremely neutron rich isotopes
→ Isotopic region in vicinity of r-process nuclei near Waiting Point at N=126 comes into reach

→ 'Fission-Fusion' scheme requires: - laser-driven acceleration of (fissile) heavy ions to beyond fission barrier energies
  → demonstration of laser-accelerated ion induced nuclear fission
  → optimized (rep-rated) targetry for control of acceleration mechanism and optimum yield
  → separation and spectroscopic identification of fission fragments and potential fusion products

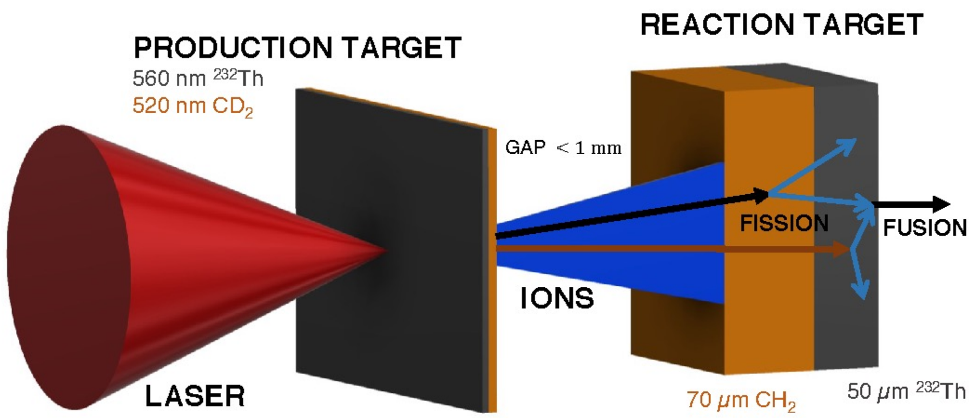
→ High ion density may also result in new **collective effects modifying the stopping behavior** in solid media

Fission-fusion nuclear reaction scheme

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

- **2-stage process, requiring 2 closely spaced targets:**

1. accelerate fissile ion species (e.g. ^{232}Th from 'production target') to beyond its fission barrier energy (ca. 7 MeV/u)
   impinge onto fissile fission in both beam-like second target species ('reaction target')
   induce and target-like nuclei
2. high density enables re-fusion of, e.g., 2 light (neutron-rich) fragments
   fusion products will be extremely neutron rich



1. Fission stage:

Beam: **(~ 7 MeV/u):** d, C, ^{232}Th
target: p, C, ^{232}Th

^{232}Th + p, C → $F_L + F_H$: beam-like fission fragments
d, C + ^{232}Th → $F_L + F_H$: target-like fission fragments

light species in sandwich-targets to optimize fission yield

2. Fusion stage: light fission fragments of beam + light fission fragments of target

- $F_L + F_L$ → $\langle^{A}Z\rangle \approx {}^{182}75$:
  → nuclei close to N=126 Waiting Point

D. Habs, PT et al., Appl. Phys. B 103, 471 (2011)

Potential collective effects on stopping power in solid and fluid media with high-dense ion bunch

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Bethe-Bloch equation for individual ions

$$-\frac{dE}{dx} = 4\pi n_e \frac{Z_{\mathrm{eff}}^2 e^4}{m_e v^2}\left(\ln\left(\frac{m_e v^2}{e^2 k_D}\right) + \ln\left(\frac{k_D v}{\omega_p}\right)\right)$$

Solid-state high density ion bunches into a solid target

binary collisions
k_D = Debye wave number

long-range collective interaction
ω_p = plasma frequency

Reduction of atomic stopping power for ultra-dense ion bunches:

- plasma wavelength (~ 5 nm) << bunch length (< 1mm):

  → collective effects cancel: only binary collisions contribute

- Dense ion bunch consisting of ~103 atomic layers with a distance between the Th ions of about 3.2 Å as obtained from the bulk density of metallic thorium (11.7 g/cm3).

- *"snowplough effect"*: first layers of ion bunch remove electrons of target foil

- predominant part of bunch: screened from electrons (n_e reduced)

Consequencies of reduction of dE/dx:

→ would allow for thicker reaction targets for fusion reactions

→ theoretical calculations & experimental data needed: evaluate (counteracting) impact of plasma instabilities

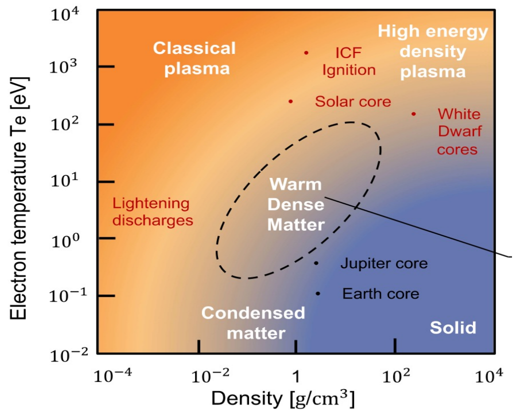
INFN

Ion Stopping Power in Warm Dense Matter (WDM) driven by laser

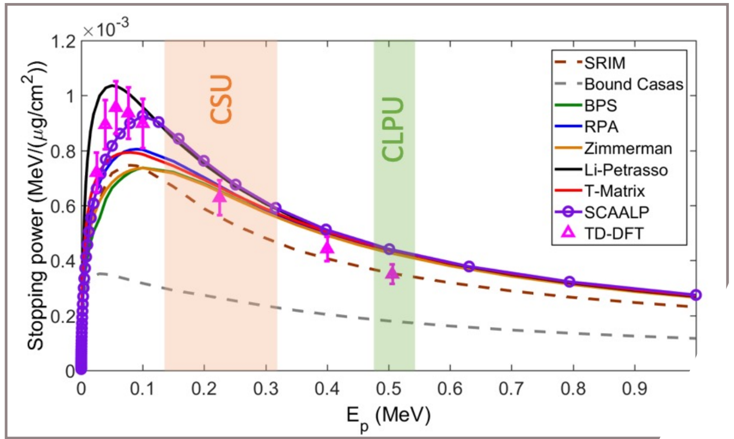
L. Volpe
Centre de Laseres Pulsados (CLPU)

STATE OF THE ART

Warm Dense Matter definition



Stopping power models@ low energy

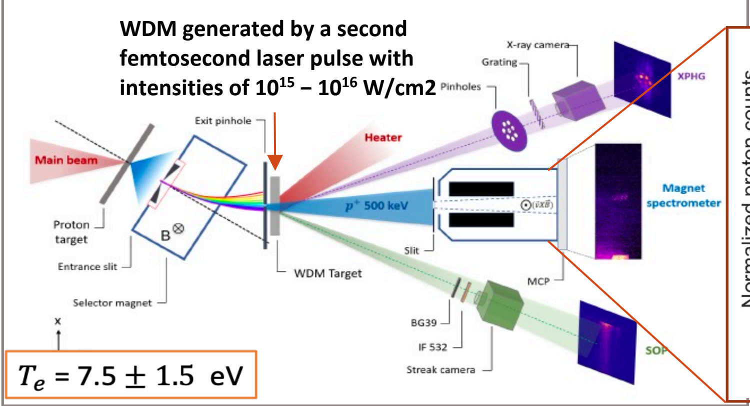


Theoretical modelling is challenging!

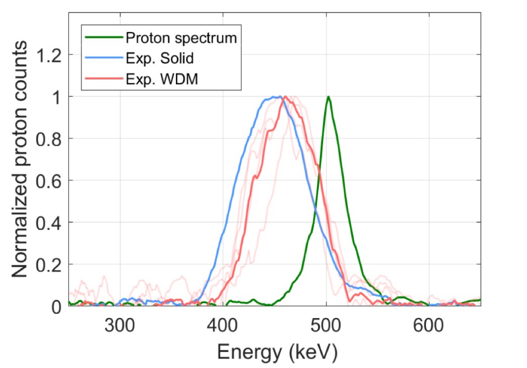
- Free + Bound electron stopping [1,2,3,4]
- Density Functional Theory (DFT) TD OF DFT [5]
- Average atom approach [6,7]

[1] *Zimmerman, G. Report no. ucrl-jc-105616. LLNL.(1990)*
[2] *Gericke, D. O. et al., Physical Review E, **65** (2003)*
[3] *Zylstra A. et al., Physics of Plasmas **26**, 122703 (2019)*
[4] *Casas D. et al., Phys. Review E **88**, (2013)*
[5] *Ding Y. et al., Phys. Rev. Lett. **121**, 145001 (2018)*
[6] *Faussurier G., et al., Physics of Plasmas **17**, 052707 (2010)*
[7] *Wang P. et al., Phys. Plasmas **5**, 2977 (1998)*
[8] *Zylstra A. et al., Phys. Rev. Lett. **114**, 2015002 (2015)*
…alko S., PhD Thesis (2020)
… et al., in submission to Nature Communications (2021)

Experiment @ CLPU with VEGA II (30 fs, 200 TW system)



T_e = 7.5 ± 1.5 eV



Ol…

- …
- Ene…

Possible interpr…

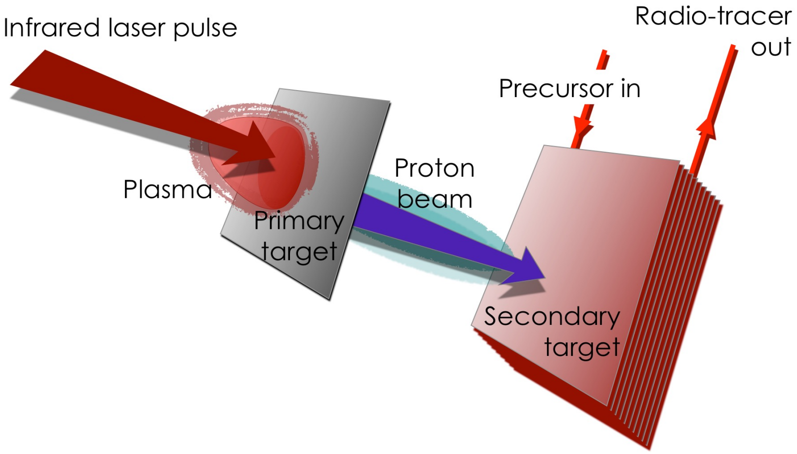
- TD-OF-DFT model, w… stopping power in WDM is be… interaction regime

Possibility to measures the stopping power using both protons accelerated by laser and conventionally by Tandem and Cyclotron @ LNS

S. Malko, W. Cayzac, V. Ospina-Bohorquez et al. in submission to Nature Communications (2021)

New scheme for radioisotopes production

- Intense protons/ions beams 10E11 shot-1 (up to 100 Hz)
- Collective effects reduce the stopping powers increasing the interaction probability
- Ions heavier than protons available
- Nuclear reactions in plasma may:
  - Improve the reaction cross-sections (ex p(11B, a)2a)
  - Completely change the "target" philosophy



- Primary and secondary targets must be very close in space to optimize accelerated protons features. Even that could be the same eventually.
- Liquid water target (able for high rep rate)
  Substitute normal water by Oxigen- 18 water
  -> No need of secondary target

Luis Roso
Centre de Laseres Pulsados (CLPU)

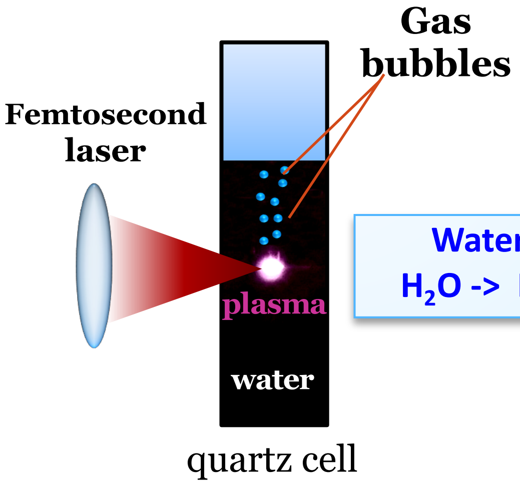
Discussion for future collaboration on going with the colleagues of LNL-INFN (Gaia Pupillo, Juan Esposito)

Water splitting by focused femtosecond laser pulses *
- novel approach to hydrogen production

Kierzkowska-Pawlak H.[a], Tyczkowski J.[a], Jarota A.[b], Abramczyk H.[b]

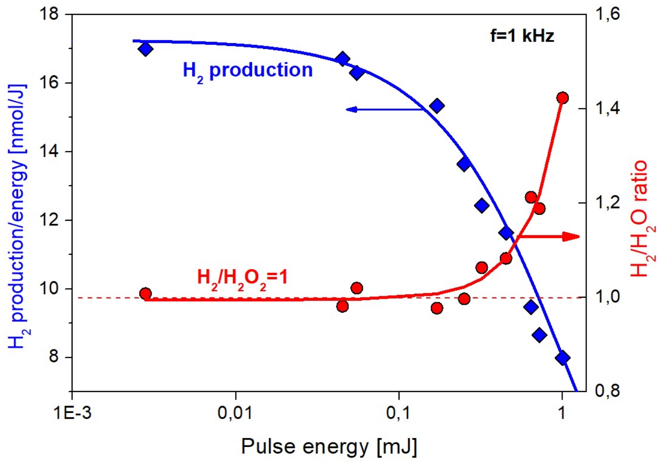
a Department of Molecular Engineering
b Institute of Applied Radiation Chemistry

Lodz University of Technology



Water splitting:
H_2O -> H_2, O_2, H_2O_2

H_2 production and H_2/H_2O_2 ratio vs. pulse energy



@ LNS

Working at low laser energy to improve the production of H2 pure hydrogen

Irradiation conditions

- Wavelength = 800 nm
- Pulse duration 100 fs
- Repetition rate f=(0.1-1) kHz
- Pulse energy E=(0.01-1) mJ

✓ At low pulse energies, water splitting follows the stoichiometry:

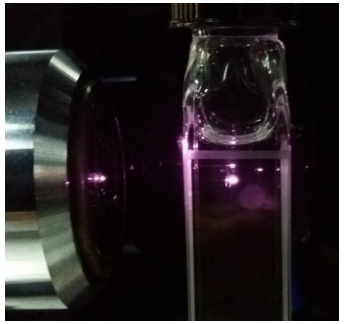
$2 H_2O$ -> $H_2 + H_2O_2$ no oxygen!

Pure hydrogen in the gas phase

✓ At higher pulse energies, H_2O_2 decomposition occurs:

H_2O_2 -> $H_2O + 0.5 O_2$

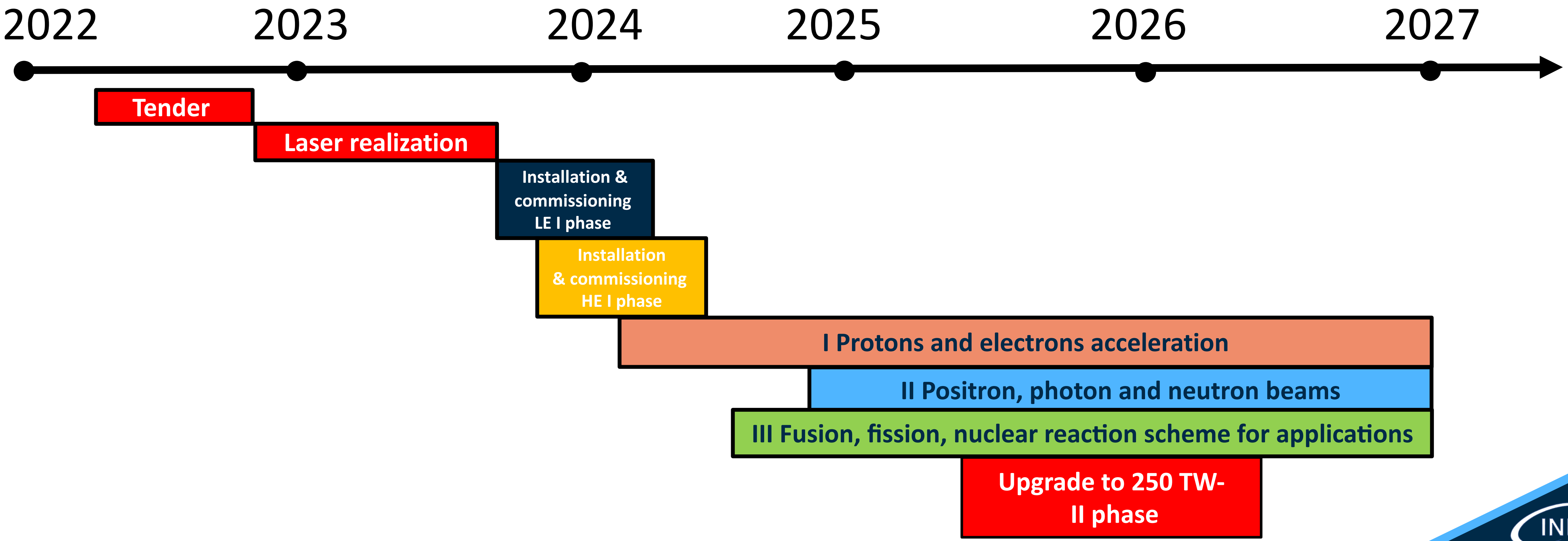
✓ A practical approach to process intensification is proposed



*) *Kierzkowska-Pawlak, H., Tyczkowski, J., Jarota, A., & Abramczyk, H. (2019). Hydrogen production in liquid water by femtosecond laser-induced plasma.* ***Applied Energy****, 247, 24-31.*

When?

I-LUCE Timescale



Thank you

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Université Mohammed V de Rabat

GSI

Institut za nuklearne nauke Vinča

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Lodz University of Technolog

MTA atomki DEBRECEN

GHANA ATOMIC ENERGY COMMISSION

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