Laser Driven Nuclear Physics (LDNP): a Bridge Between ELI-NP and Apollon

Andi S. Cucoanes, ELI-NP/IFIN-HH Romania
on behalf of the ELI-NP team and Laser-TDR1 WG

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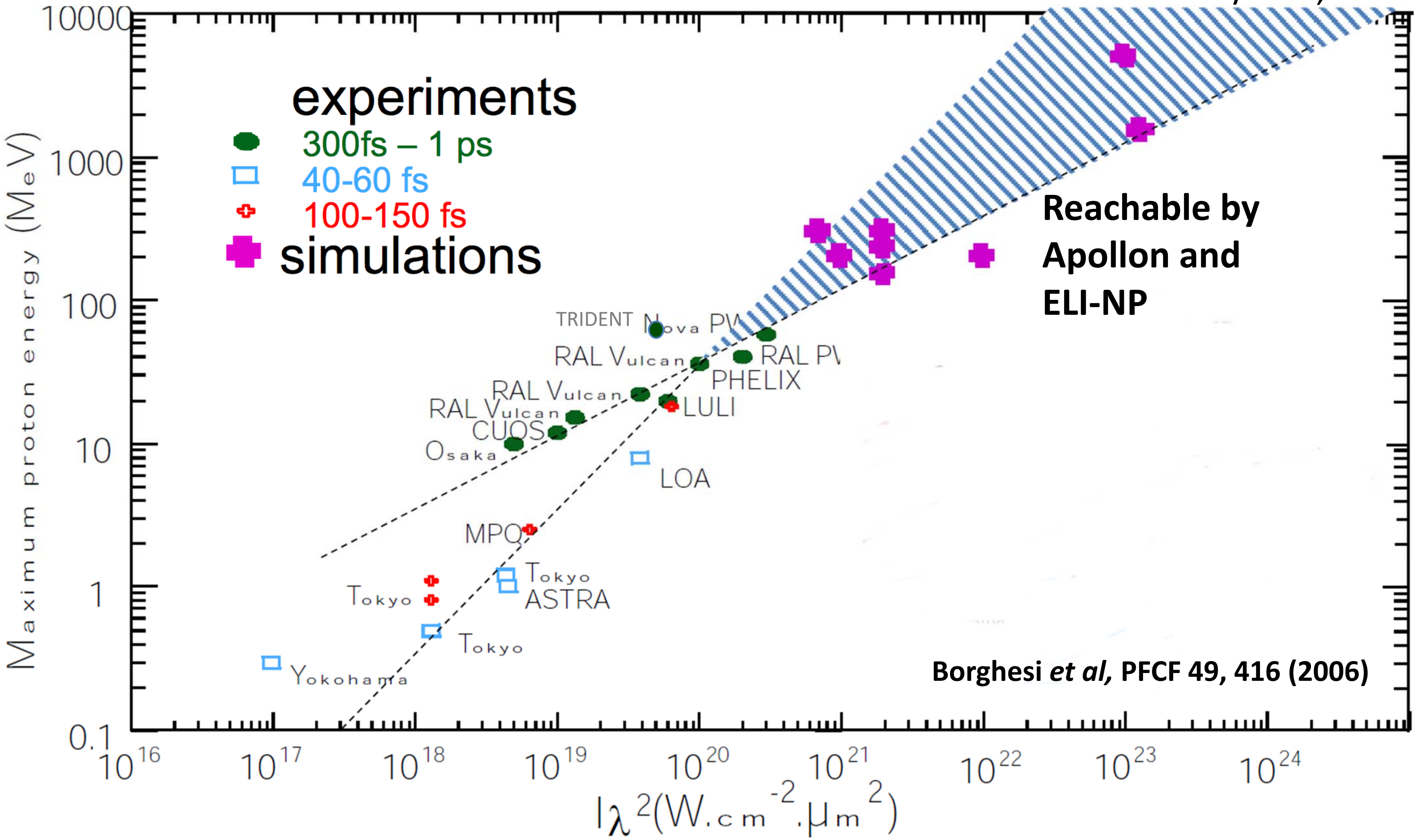
2 Laser giants in EU: ELI-NP & Apollon

ELI Nuclear Physics / IFIN-HH	CILEX Apollon
• Ultra-short pulse (~30 fs) high power system 2*10PW@0.02 Hz, 2*1PW@1Hz, 2*0.1PW@10Hz • High intensity gamma beam, tunable energy up to 20MeV, produced by Compton scattering of a laser beam on a 700MeV e^- beam from a LINAC • 8 areas for laser, gamma and gamma-laser experiments. Total build: $3.3*10^4 m^2$	• Ultra-short pulse (15 fs) high power system 10PW, ns beam at 200J uncompressed, ultra short (15 fs) pulse @1PW, probe beam @0.25J • 2 experimental areas. Total build $3.5*10^2 m^2$
• Building will be ready in 2016. The facility expected to be commissioned in 2018. • A full 10PW laser is “in the boxes” waiting the building construction, progress on the gamma source, too.	• Building delivered since march 2015 • Progress with laser components (compressor chamber, amplifier, etc.)

As the present overview: Apollon will start before ELI-NP; how this situation could help LDNP@ELI-NP ?

Appetizer: proton acceleration @ ELI-NP & Apollon

RPA simulations 10^{23}W/cm2, 15 fs



Maximum energy scales with laser beam intensity as approx. $I^{0.5}$

LDNP@ELI-NP: a general perspective

- Very challenging field with broad inter-disciplinarity: nuclear physics, plasma physics, QED, laser physics, etc.

- More than 50 contributors (physicists, engineers) from 8 countries to the “TDR1” containing the proposed experiments.
  - Convener of the group: M.Roth (TUD)
  - F.Negoita (IFIN-HH/ELI-NP) as liaison with ELI-NP.

- Beyond state of the art experiments proposed:
  - Nuclear fusion reactions induced by laser-accelerated fissile ion beams
  - Nuclear (de)excitation processes induced by lasers
  - Reactions in laser plasma for nuclear astrophysics
  - Laser driven neutron production and applications

Could Apollon help LDNP@ELI-NP via exploratory experiments ?

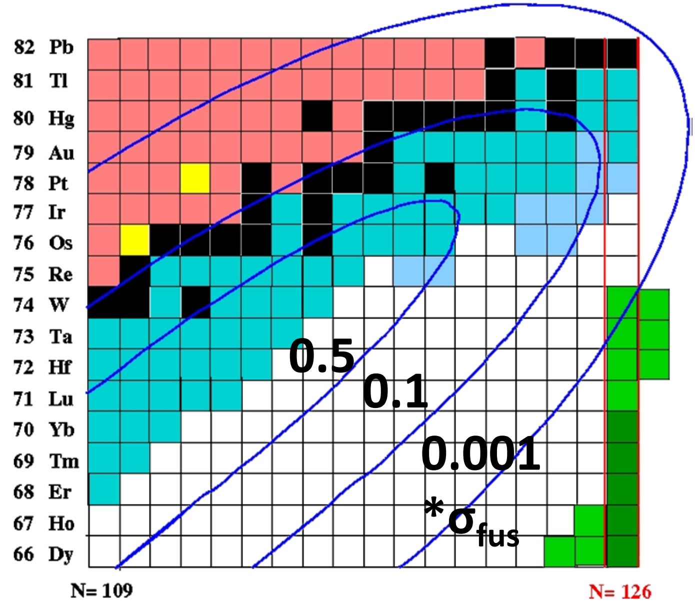
Nuclear fusion reactions induced by laser-accelerated fissile ion beam

- **Proposed by: P. Thirolf (LMU) and collaborators.**
- **Goal: Study of exotic (n-rich) nuclei of astrophysical interest, around N=126 produced from high-density ion bunches: fission-fussion reactions.**

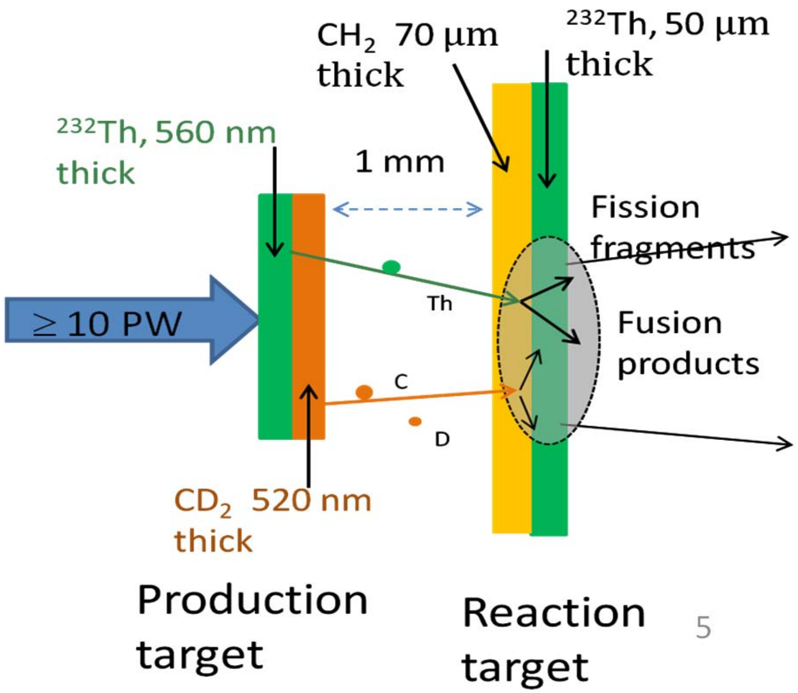
RPA for heavy ions with circularly polarized laser pulses: need very thin optimized targets (5-10 nm) and ultra high contrast (~10^8) to avoid pre-heating and expansion of the target, repetition rate capability, etc.

Dense ion beams characterization in free space (components, energies angular and temporal distributions) **and study of the changes induced by passing through different materials** (deceleration study).

Measurements of the yields of the fusion products and the optimization of the kinetic energy of the beam-like fission products.

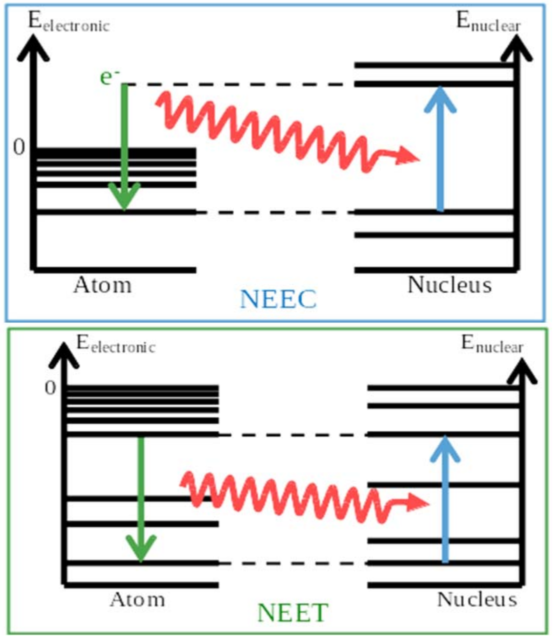


D.Habs, P.Thirolf et al., Appl.Phys. B103, (2011)



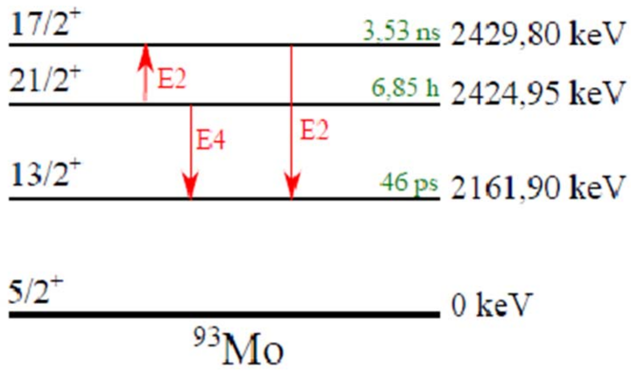
Nuclear (de)excitation processes induced by lasers

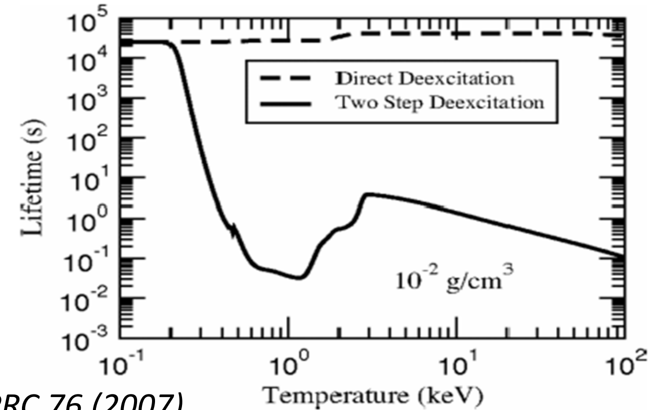
- **Proposed by: F.Hannachi (CENBG) and collaborators.**
- **Goal: Observation of NEET/NEEC/BIC processes in laser induced plasmas**



NEET was observed in cold targets, never observed in plasmas.
NEEC was never observed

Significant changes in lifetimes predicted in plasma conditions.





^{93}Nb(p,n)^{93}Mo^{m} *Gosselin,Meot, Morel, PRC 76 (2007)*

The isotopic states could be studied with 2 laser beams, for ex. 1PW laser for particle acceleration and isomeric state production in a solid target, and another one, uncompressed for plasma formation and heating.

The production mechanism need to be studied and tuned for each isomer: ion acceleration, e- to gamma conversion in high Z targets, etc.

Isomeric production yields and gamma detection from short live isomers are problematic and need further study & development.

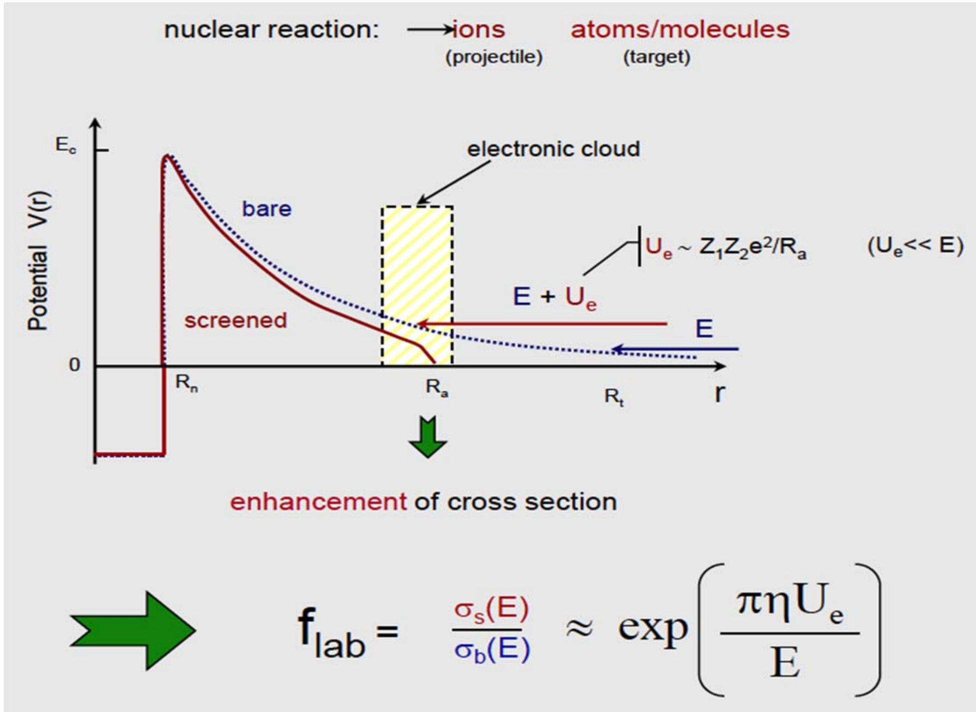
Reactions in laser plasma for nuclear astrophysics

- **Proposed by: S.Tudisco (INFN-LNS) and collaborators.**
- **Goal: Study of screening effect in plasma conditions.**

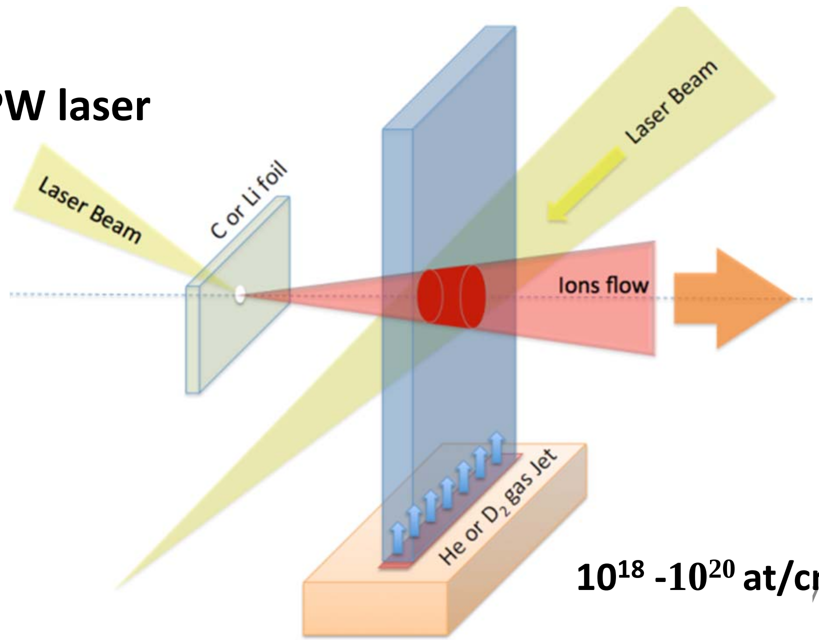
Proposed reactions:

$^{13}C(^{4}He,n)^{16}O$
$^{7}Li(d,n)^{4}He$

It requires methods for measurement of high energetic neutrons. Need tuning of the laser (incident angle, polarization), target (thickness, structure, composition) for a large flux of ions with low energy cut-off.



PW laser

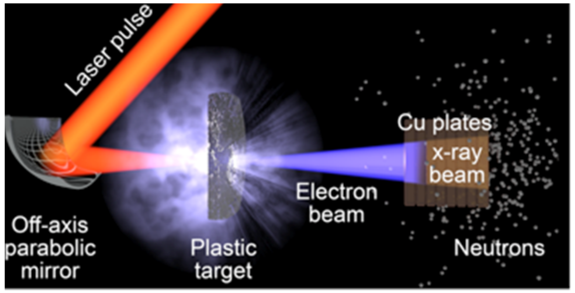


10^{18} -10^{20} at/cm^3

Laser driven neutron production and applications

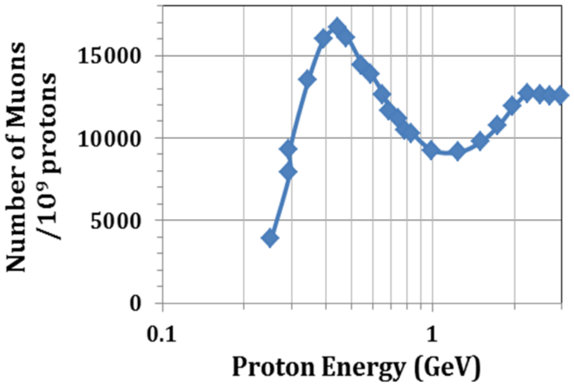
Neutron production via (p,n) and (γ,n) reactions with solid targets

Goal: Study of the neutron production mechanisms via BOA and RPA ion acceleration at high (>10^{22}W/cm^2) laser intensities.



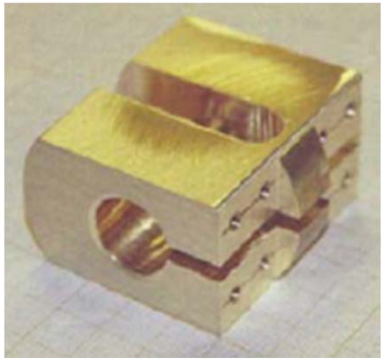
Muon catalysed fusion (μCF) study, by Mirfayzi (QUC) et al.

Goal: Study of the muon production via laser accelerated proton scattering on low Z targets (such as ^{7}Li or graphite). Study of the μCF: formation of the dμ atoms and ddμ molecules which improves the probability of fussion.



Compact Magnetic Photo-Fusion device, by S Moustaizis (UC) et al.

Goal: High neutron flux production and study of the burning processes of fission fuels such as D-D, D-T and p-^{11}B. Enhanced neutron production is based on trapping of high density (10^{18}cm^{-3} – 10^{19}cm^{-3}) and high temp. (tens of keV) magnetized plasmas (~120T) for duration of order of microsecond.



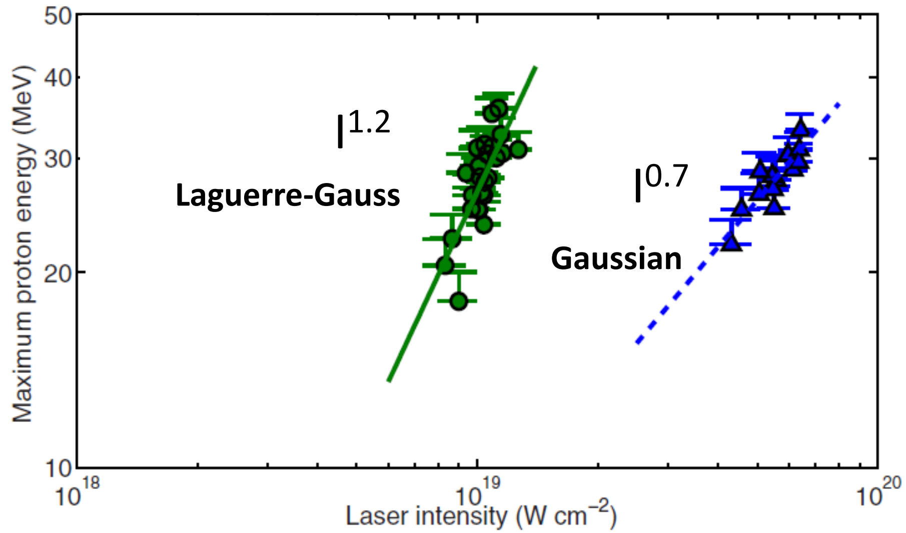
The neutron production could be studied and optimized in a two step approach, at lower laser intensities via TNSA ion acceleration and then via BOA and RPA at higher intensities.

Ion acceleration needs of LDNP@ELI-NP

- **Nuclear physics experiment needs:**
  - heavy ions: Li, C, …, Th
  - moderate energies: up to ~ 10 MeV/n
  - high flux (per shot and also for several shots per day)
  - high bunch density
  - low divergence
- **High energy protons requested only for neutron production**

Possible ion acceleration development at Apollon for LDNP@ELI-NP (a non-exhaustive list)

Brabetz et al. Phys. Plasmas 22, (2015)



- Laguerre-Gauss (helical phase) beams

- Near critical density targets for heavy ions acceleration

- Testing high repetition rate targetry

Conclusions

- **ELI-NP and Apollon are two extremely challenging projects, placed at the state of the art.**

- **Many exploratory experiments are needed for the proposed LDNP@ELI-NP. A long range of opening opportunities.**

- **At least of part of these experiments could be implemented at Apollon by collaboration teams with ELI-NP participation. The experience gained could be extremely usefull for ELI-NP development.**