Complementary

A compact laser based neutron source

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Worldwide situation

- High-power accelerator-driven spallation neutron sources have already established themselves as the flagship facilities, eventually targeted to replace the high-flux reactors
- Accelerator-driven neutron sources based on low-energy neutron-producing reactions, which are less expensive to build and operate have become an attractive alternative for some experiments
- However small labs or Universities that have to develop and test new instrumentations, to teach students, to make particular experiments, need compact sources, cheap, easy to manage and to maintain, better if they have not to use RF!

Anderson, I. S., et al. "Research opportunities with compact accelerator-driven neutron sources." *Physics Reports* 654 (2016): 1-58.

High power lasers

- High power lasers are now studied as a source of charged particles
- However both the electron and proton beams are still quite far for the required quality for many application
- But neutrons generation <u>does not require</u> small energy spread or accurate pointing stability due to the moderation process
- One of the most reliable application in a short term for high power laser could be neutron production

Compact portable sources

- Conventional portable source, based for instance on ^{241}Am/Be, ^{252}Cf, ^{241}Am/B are in the order of 10^8-10^9 n/s.
- The backdrop of these sources, e.g. ^{252}Cf, is that they cannot be turned off and may be a burden in decommissioning of industrial and research equipment.
- Due to the limited half-life (e.g. about 2.6 years for ^{252}Cf), the availability of radioisotope sources is limited compared to other neutron sources.

Several possible applications

- Data mining and code testing
- Neutron radiography/tomography
  - Most applications of do not depend on a particularly high neutron flux. More important is a well-collimated, widely open neutron beam in a low background environment.
- Reflectometry
  - Reflectivities down to 10^{-6} are accessible with about 10^5–10^6n/cm^2/s peak flux
- Neutronic engineering
  - Small neutron flux, due to limited activation, can give very good opportunities for neutronic engineering research, neutron instrument component development, and testing of new instrument ideas and new devices.

Integration with other radiation sources

- Complementary to other radiation sources, like FEL, Compton, THz, etc.
- Great interest in having at the same place all of these radiation sources

Cultural heritage studies

- Usually a series of many techniques are used to study the objects in this field, like THz, IR, X-ray, -ray radiation and neutron based techniques
- Neutron radiography requires parallel beam or divergent beam of low energy neutrons having intensity in the range of only 10^4 -10^6 n/cm^2/s to avoid formation of significant amount of long-lived radioactive isotope from neutron absorption within the specimen.
- PGAA are less demanding, giving flux on the sample in the order of 10^3 -10^4 n/cm^2/s.

Three possible scenarios

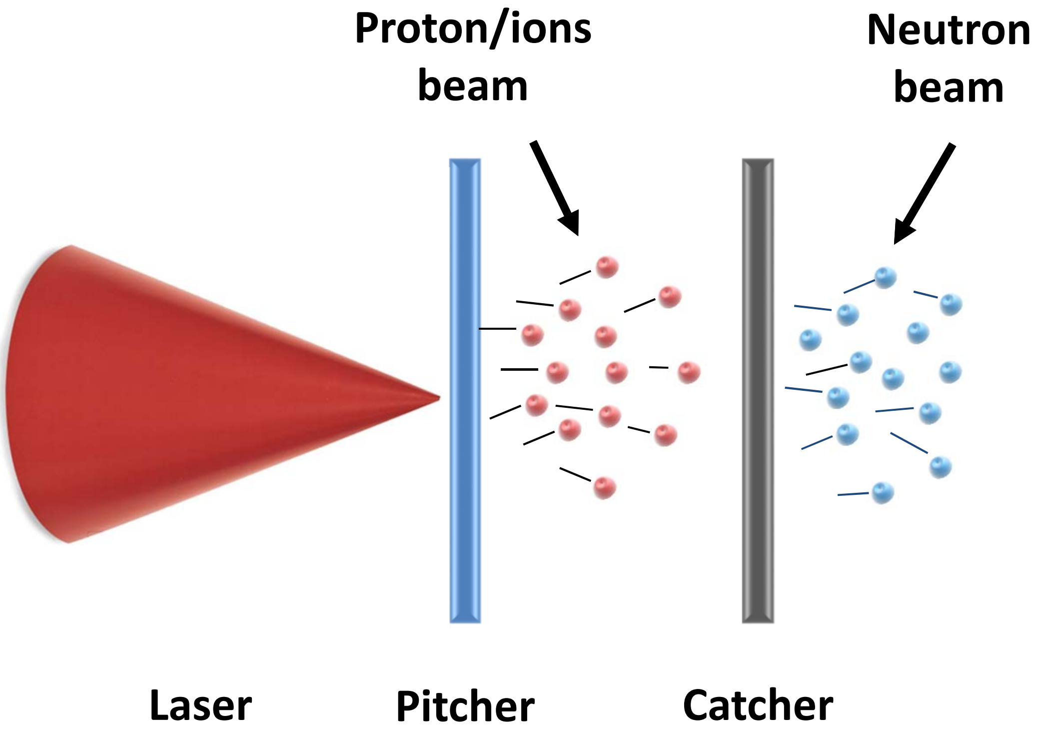
- Neutrons from electron bremsstrahlung by main linac
- Neutrons from proton produces via TNSA o similar interaction by laser
- Neutrons from electron bremsstrahlung produced by self-injection

Conventional Sources

- We use as a master reference the parameter of the Eupraxia collaboration
- We have considered a tungsten target of 5x5xL cm^3.
- The maximum yield is at L about 8-9 cm, where we can obtain about 0.4 neutrons for primary electron.
- With the values in we can have about 2.5 10^9 neutrons /s. This number sets the lower limit of any laser based neutron compact source that can be consider interesting at such a facility.

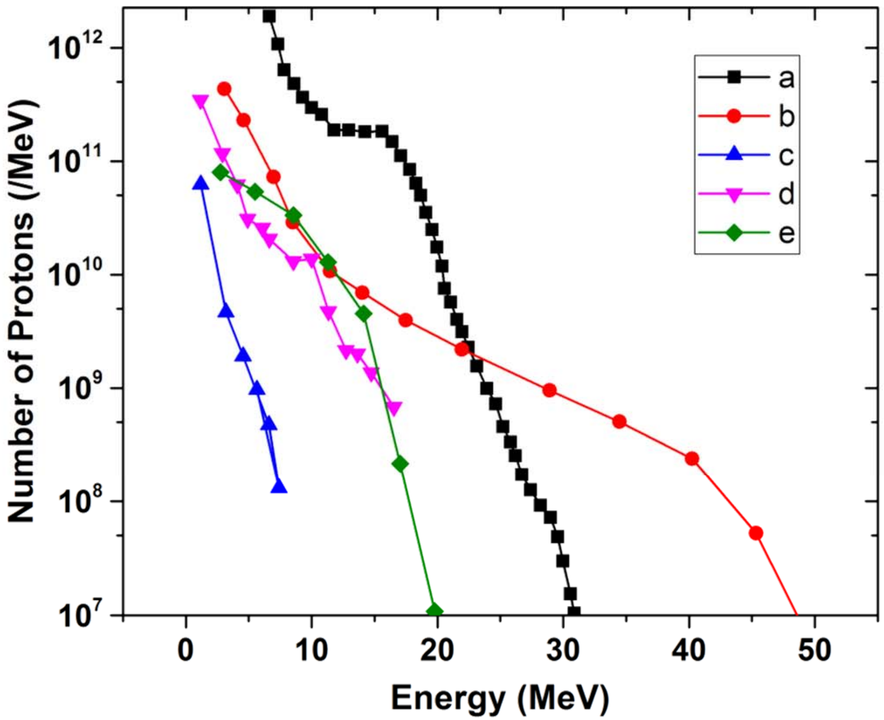
Parameter	Value
Beam energy	1 GeV
Bunch charge	100 pC
Repetition rate	10 Hz
Average current	1 nA

Neutron production by Protons



- Neutrons can be produced by converting primary particles (electrons, protons, deuterons or other ions) on dedicated targets.
- A scheme called “pitcher-catcher” is frequently adopted to convert primary particles into neutrons. Reactions as (p,n) on LiF or (d,n) on Be are used.

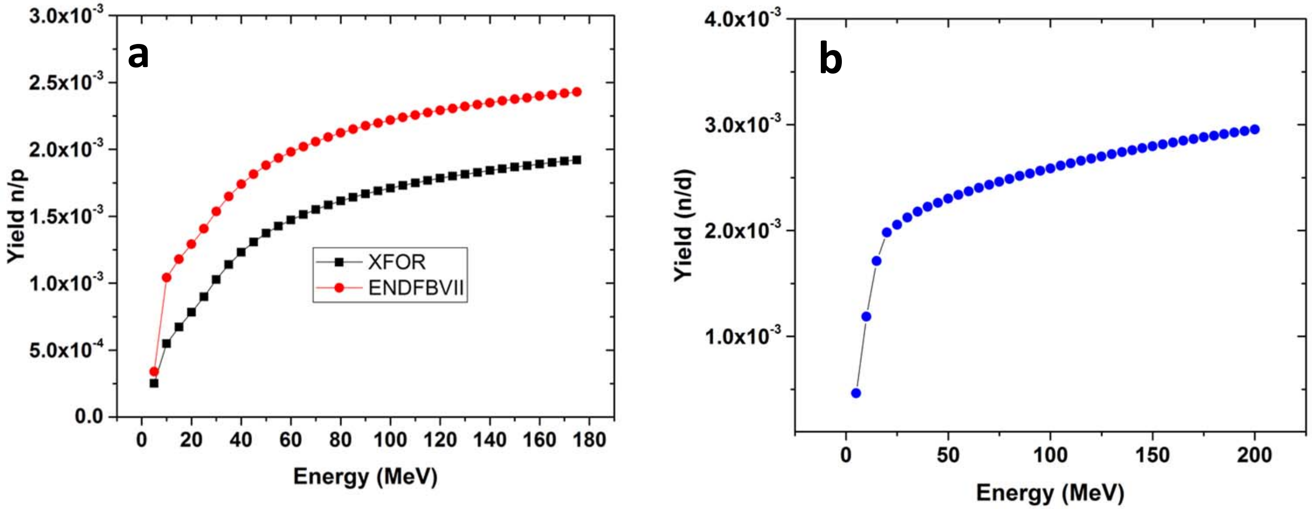
Typical proton spectra



Label	Name	Intensity(W/cm^{-2})	Energy(J)
a)	Vulcan	2.0 10^{20}	200
b)	Trident	1.5 10^{20}	80
c)	Arcturus	1.0 10^{20}	3
d)	Vulcan	1.0 10^{20}	42
e)	Astra Gemini	1.0 10^{21}	10

- Increasing the laser energy increases both proton fluence and average energy.
- However this dependence is not followed very strictly, being dependent mainly on particular experimental arrangement of the target, in order to increase the proton number and improve their transport, as wells as the use of different kind of targets triggering mechanisms different from TNSA for instance.

Neutron Yield



a) protons on LiF
b) deuteron on Be.

- Increasing particle energy above 25 MeV is not really convenient, because the higher laser energy required, at expense of the repetition rate is not compensated by the increasing in the number of particles.

Charge scaling law for self-injection

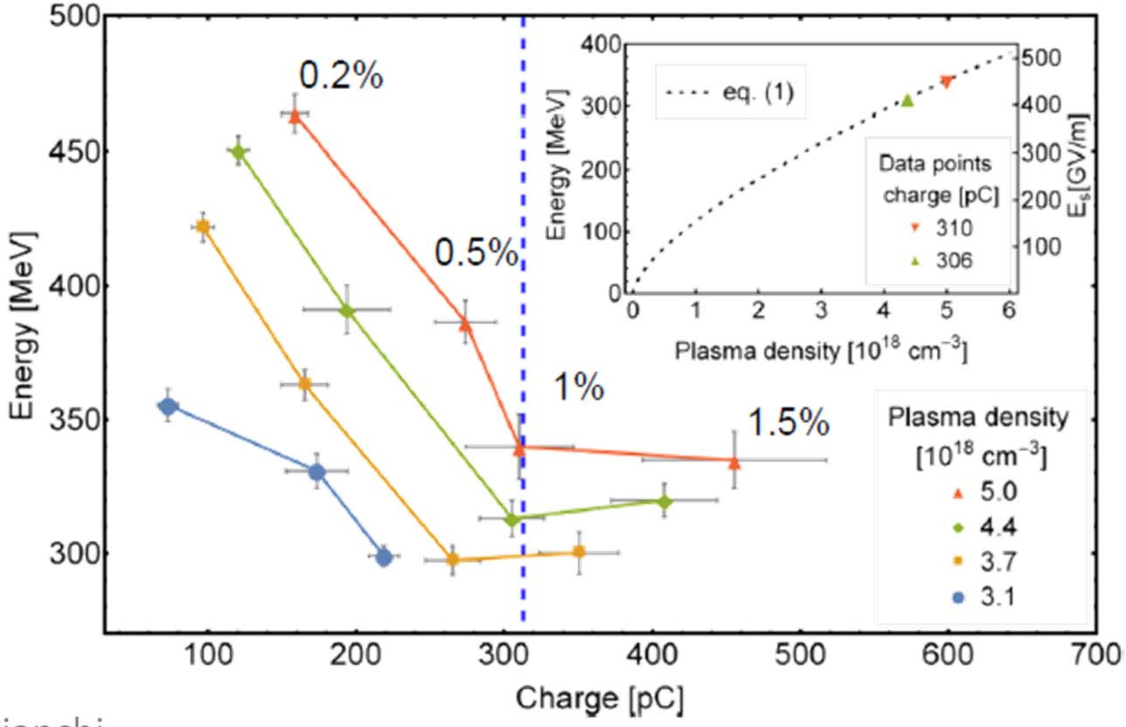
$$N \sim 2.5 \cdot 10^9 \frac{\lambda_0[\mu m]}{0.8}\sqrt{\frac{P[TW]}{100}}$$

- About 625 TW are needed for 1 nC but only about 160 TW for 0.5 nC

-] Lu, Wei, et al. "Generating multi-GeV electron bunches using single stage laser wakefield acceleration in a 3D nonlinear regime." Physical Review Special Topics-Accelerators and Beams 10.6 (2007): 061301

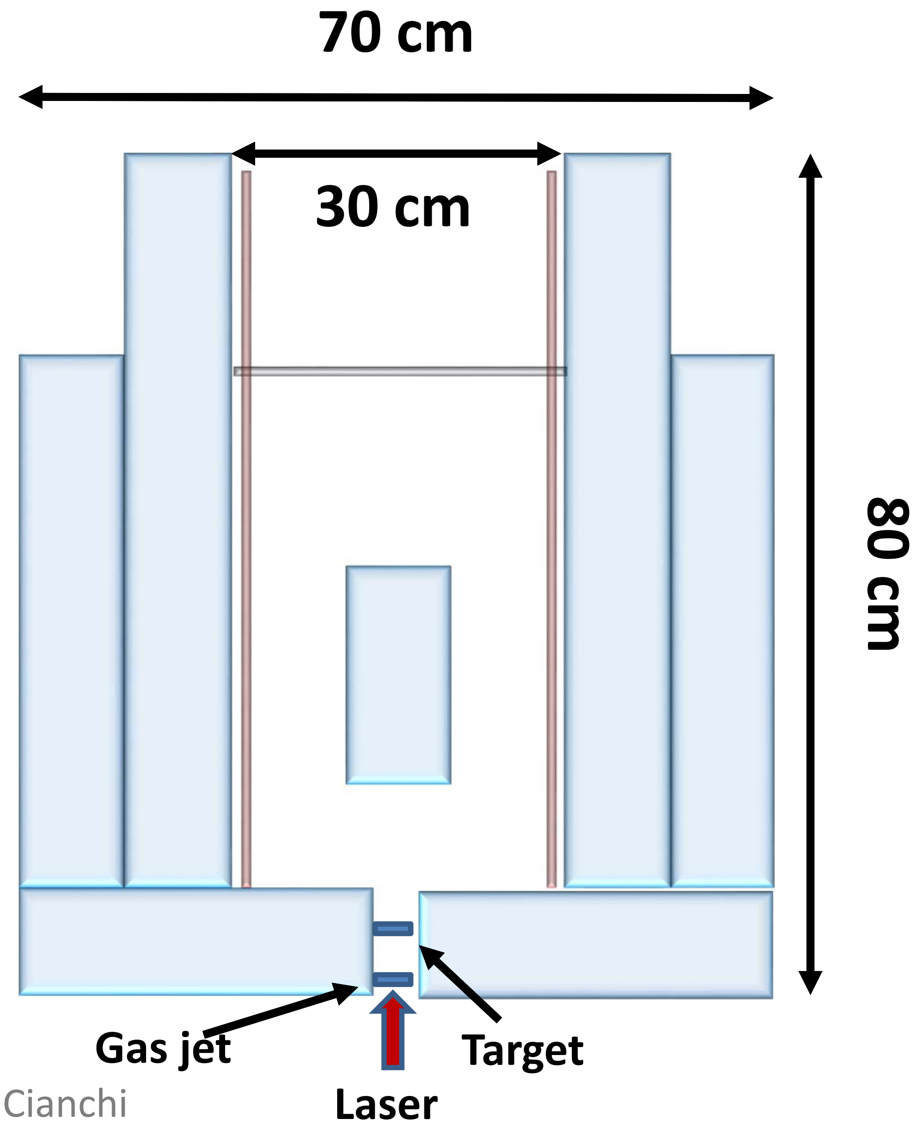
However…

- Li et al. Physics of Plasmas **24**, 023108 (2017); doi: 10.1063/1.4975613 reported 625 with only 80 TW with energy between 0.2 and 0.6 GeV with 3 cm of He gas jet
- Schramm, Ulrich, et al. "First results with the novel peta-watt laser acceleration facility in Dresden." 8th Int. Particle Accelerator Conf.(IPAC'17), Copenhagen, Denmark, 2017.



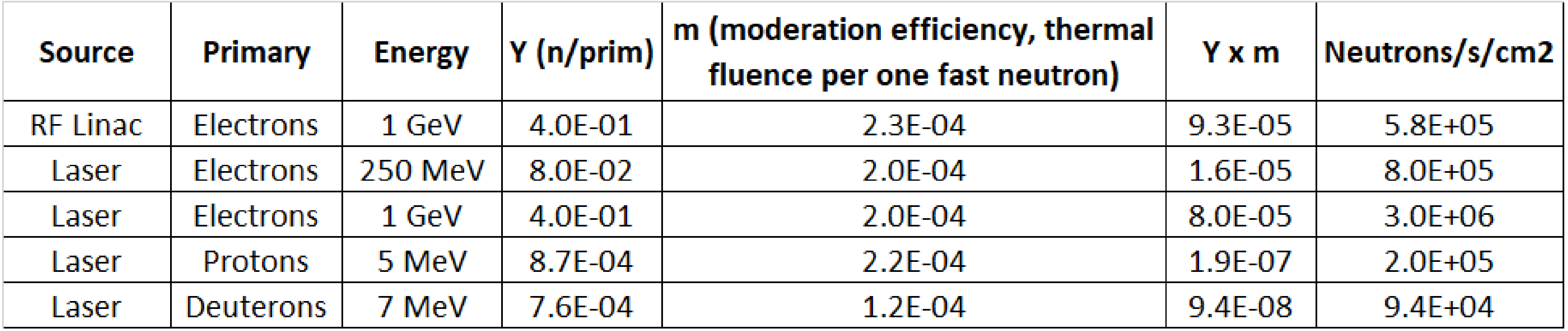
2.5 J
30 fs
plasma density
3.1×10^{18} cm^{-3}
mixed He + 1% N_2

Moderator



- A compact moderator can be achieved using the Bedogni design
- A neutron source is located on bottom of a large cylindrical cavity delimited by polyethylene walls.
- Owing on a polyethylene shadow-bar, only multiple-scattered neutrons can reach the irradiation volume.
- The resulting neutron spectrum is highly thermalized.
- Irradiation planes are disks (30 cm in diameters) showing very uniform thermal field (1-2%) over their whole surface.
- The moderating efficiency (thermal fluence per primary neutron) is about 2 10^{-4} cm^{-2}.

Numbers



Source	Primary	Energy	Y (n/prim)	m (moderation efficiency, thermal fluence per one fast neutron)	Y x m	Neutrons/s/cm2
RF Linac	Electrons	1 GeV	4.0E-01	2.3E-04	9.3E-05	5.8E+05
Laser	Electrons	250 MeV	8.0E-02	2.0E-04	1.6E-05	8.0E+05
Laser	Electrons	1 GeV	4.0E-01	2.0E-04	8.0E-05	3.0E+06
Laser	Protons	5 MeV	8.7E-04	2.2E-04	1.9E-07	2.0E+05
Laser	Deuterons	7 MeV	7.6E-04	1.2E-04	9.4E-08	9.4E+04

Uncollimated thermal neutron fluence rate expected from different fast neutron sources. For Proton and Deuterons we assume 10^{11} particles per second at 10 Hz, for laser electron 0.5 nC at 10 Hz for the 250 MeV case, while 1.2 nC at 5 Hz for 1 GeV case.

- All of these solutions are compatible with a large number of applications

Conclusions

- There is a lot of room for complementary neutron sources laser based on the sites of larger radiation facilities
- Both TNSA (or BOA or similar) techniques and electron from self injection can be considered for such applications
- The flux are comparable with several compact neutron sources accelerator based
- A wide range of application is possible