UK Research and Innovation

Recent developments and future applications of laser-driven neutron sources

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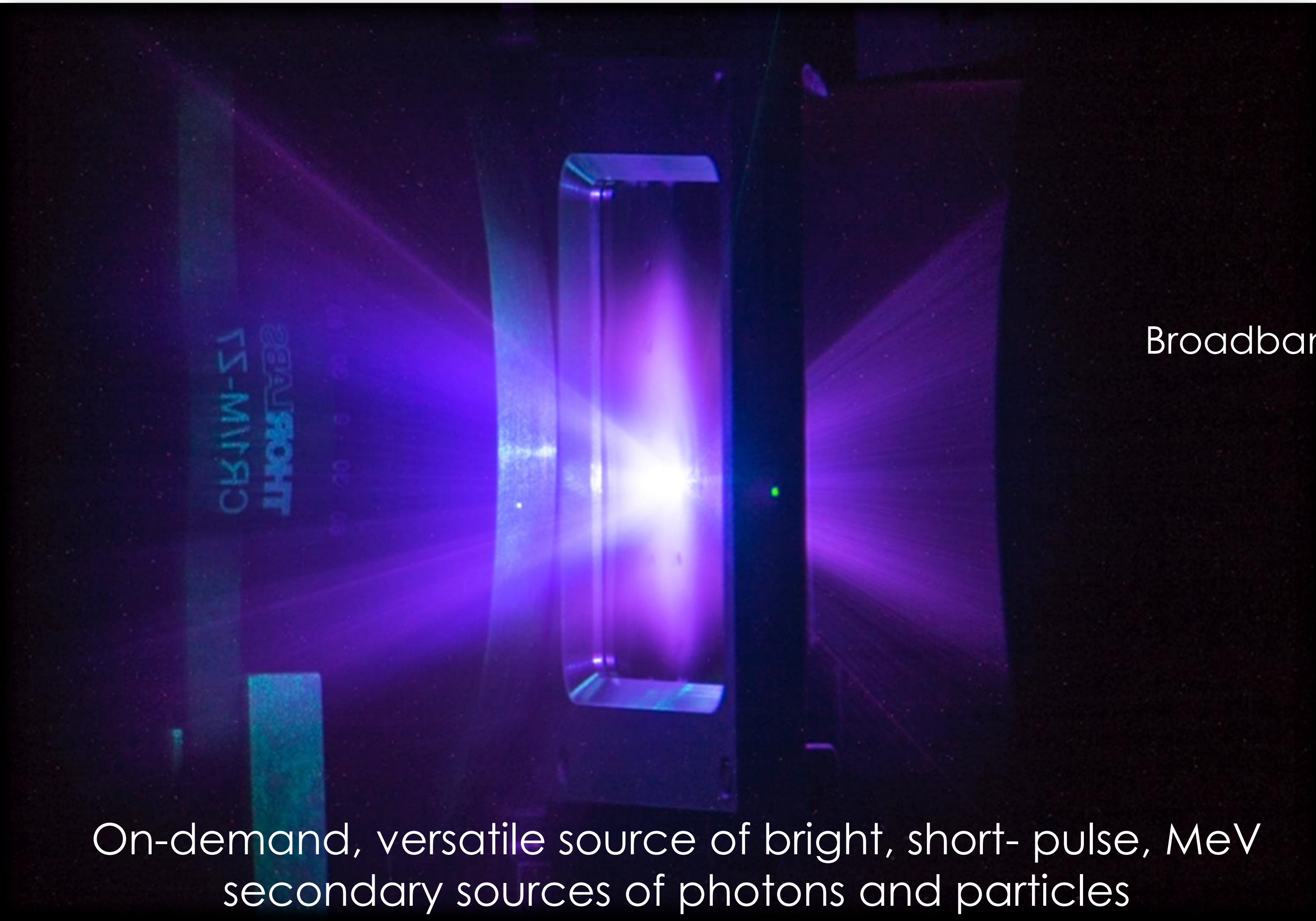
EAAC 2019, Elba Island, Italy

Laser-driven sources from lasers > 10^{18} W/cm^2 focused onto solid targets



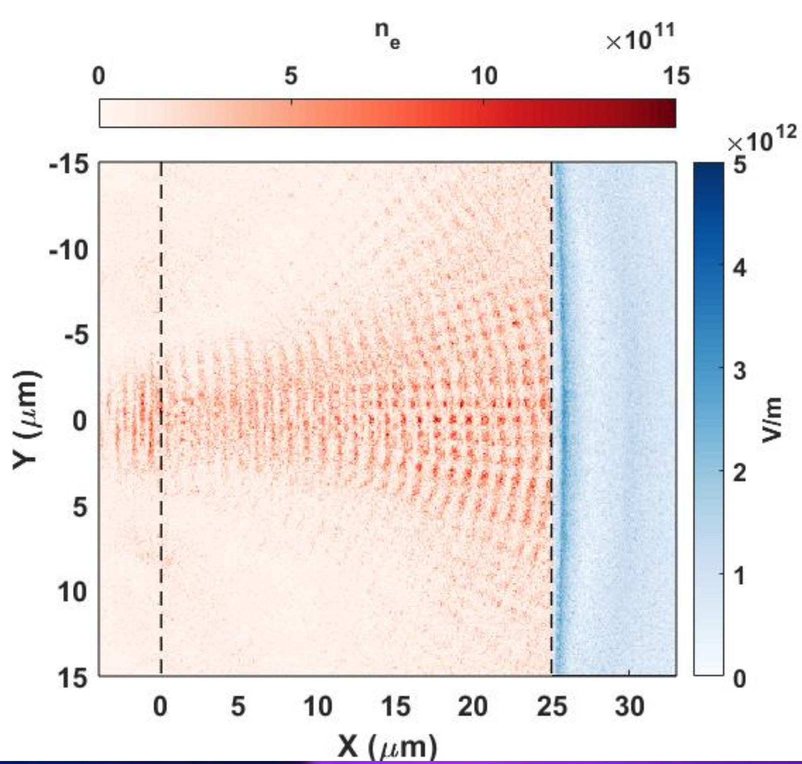
Broadband, beamed emission:

Electrons

X-rays

Ions

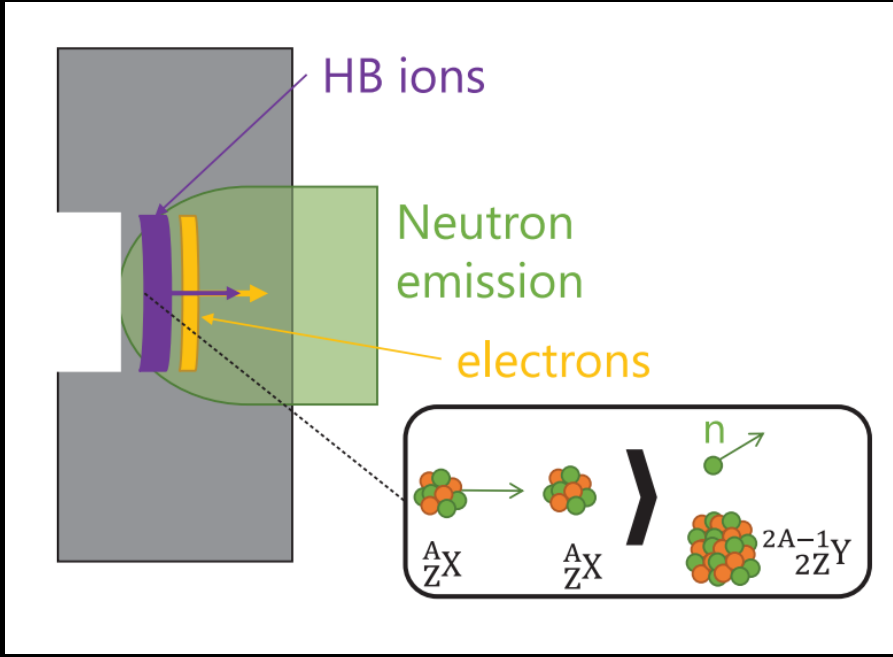
On-demand, versatile source of bright, short- pulse, MeV secondary sources of photons and particles



EPOCH 2D simulation, with thanks to C. Armstrong

Neutron emission with laser accelerators

P. Norreys *et al,* Plasma Phys. Control. Fusion 40 (1998) 175–182

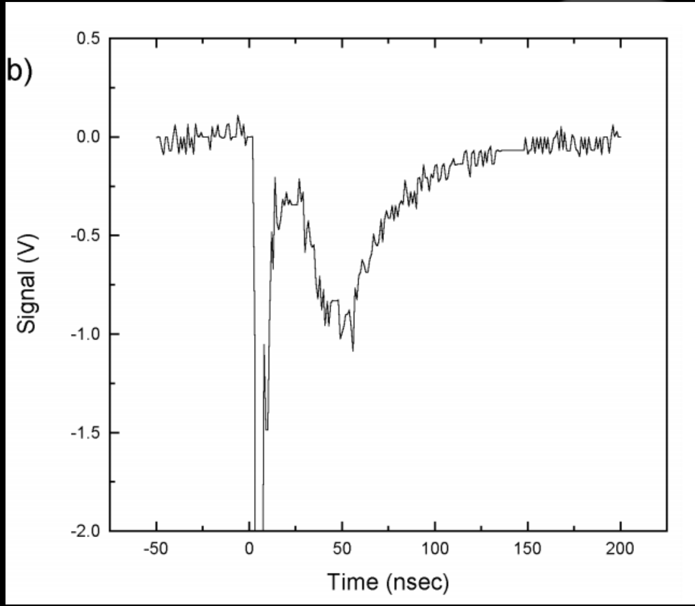


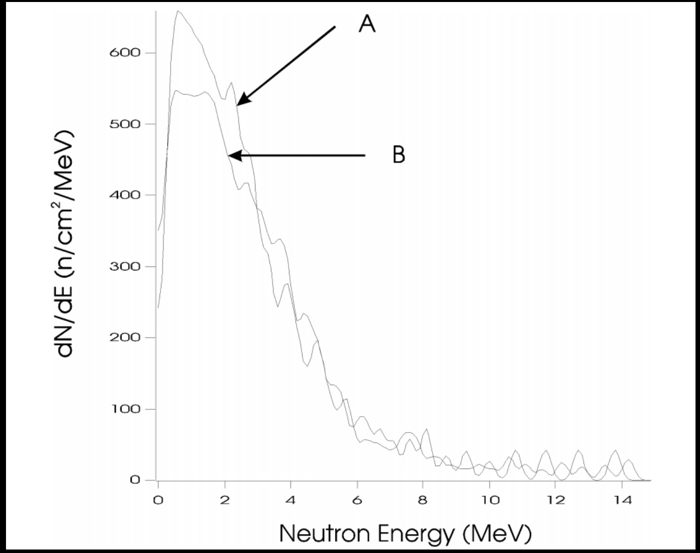
A. Alejo, *et al*., Nuovo Cimento C 38 (2016): 188.

~ 7 x 10^7 n/sr

120 μm thick CD targets

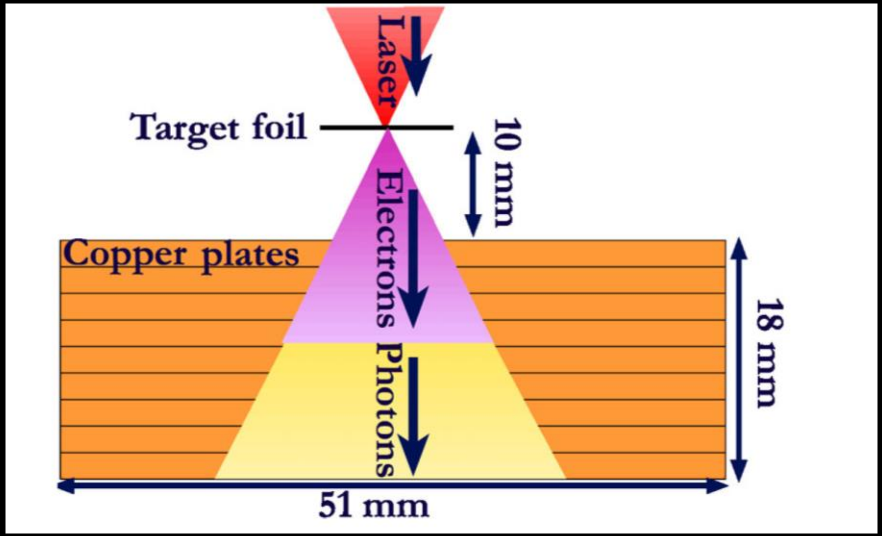
20 J, 1.3 ps, 5 x 10^{18} W/cm^2





Neutron emission with laser accelerators

I. Pomerantz *et al*, Physical Review Letters, 113, 184801 (2014)

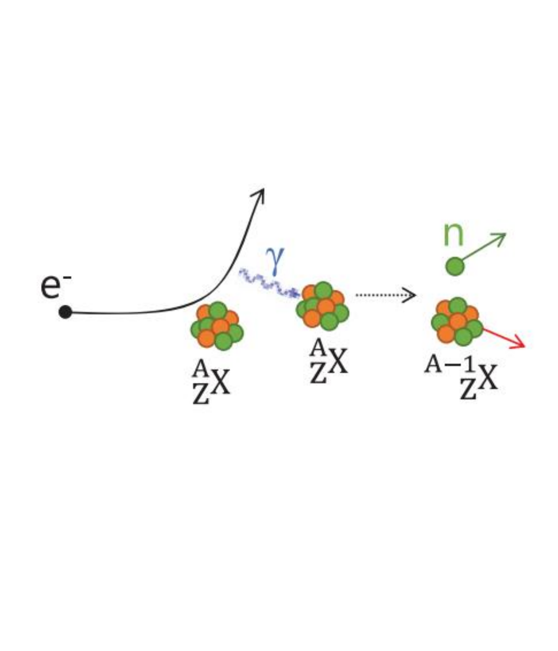


150 fs, 90 J

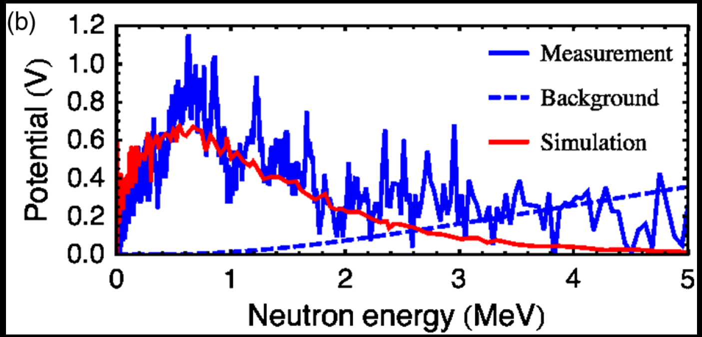
~ 8 x 10^7 n/sr

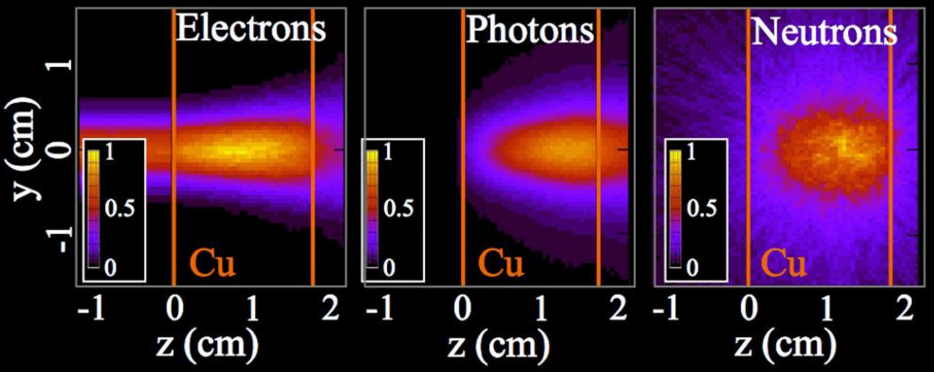
Pulse duration determined to be ~ 50 ps

$^{65}Cu(\gamma,n)^{64}Cu$ $^{63}Cu(\gamma,n)^{62}Cu$

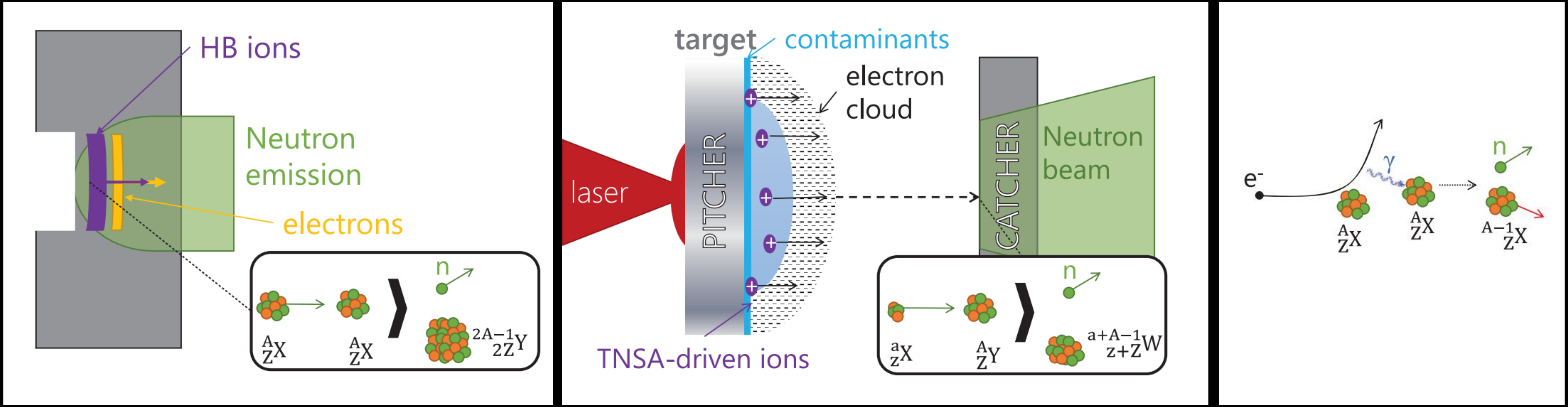


A. Alejo, *et al.*, Nuovo Cimento C 38 (2016): 188.



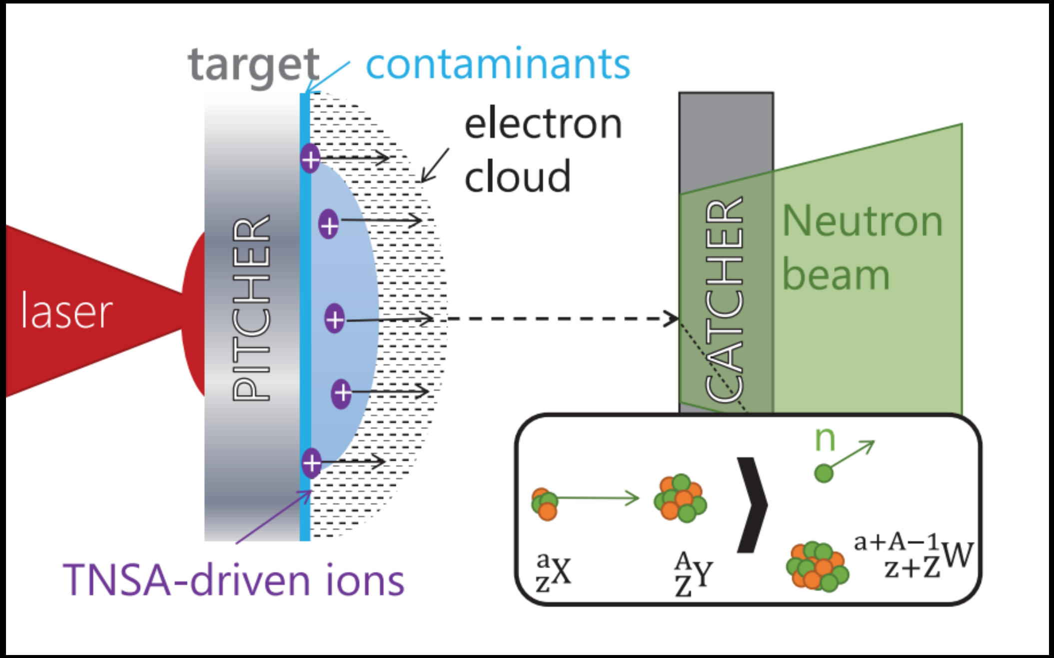


Neutron emission with laser accelerators



A. Alejo, *et al.*, Nuovo Cimento C 38 (2016): 188.

Neutron emission with laser accelerators



A. Alejo, *et al.*, Nuovo Cimento C 38 (2016): 188.

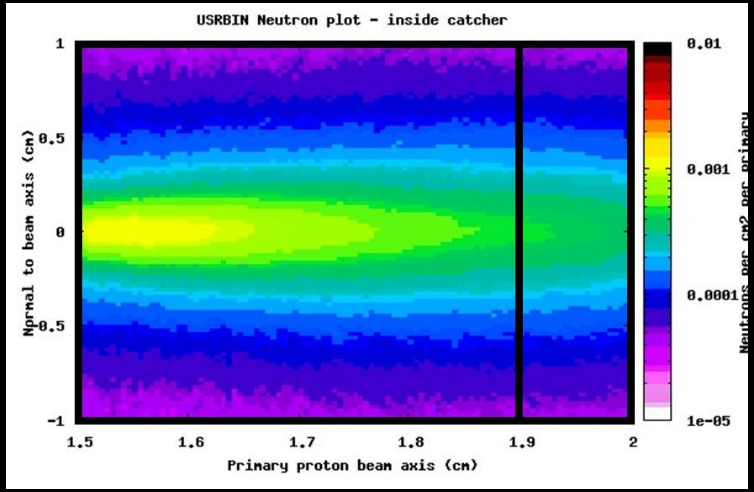
Beam fusion

(p,n) and (d,n) reactions in Li, CD, Be, Cu

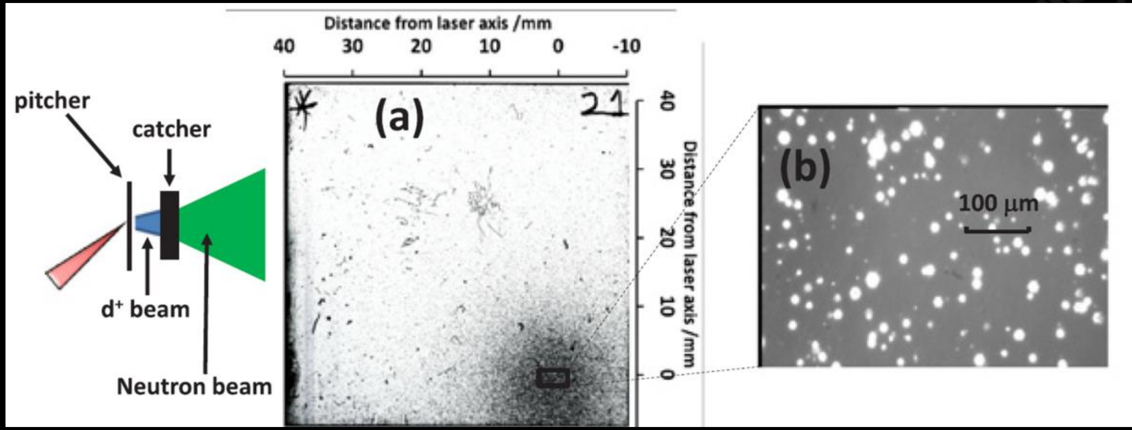
Pre-equilibrium emission where neutron is emitted before the energy of the proton is fully transferred to all degrees of freedom of the compound nucleus

Deuteron breakup with > 2.2 MeV D ions

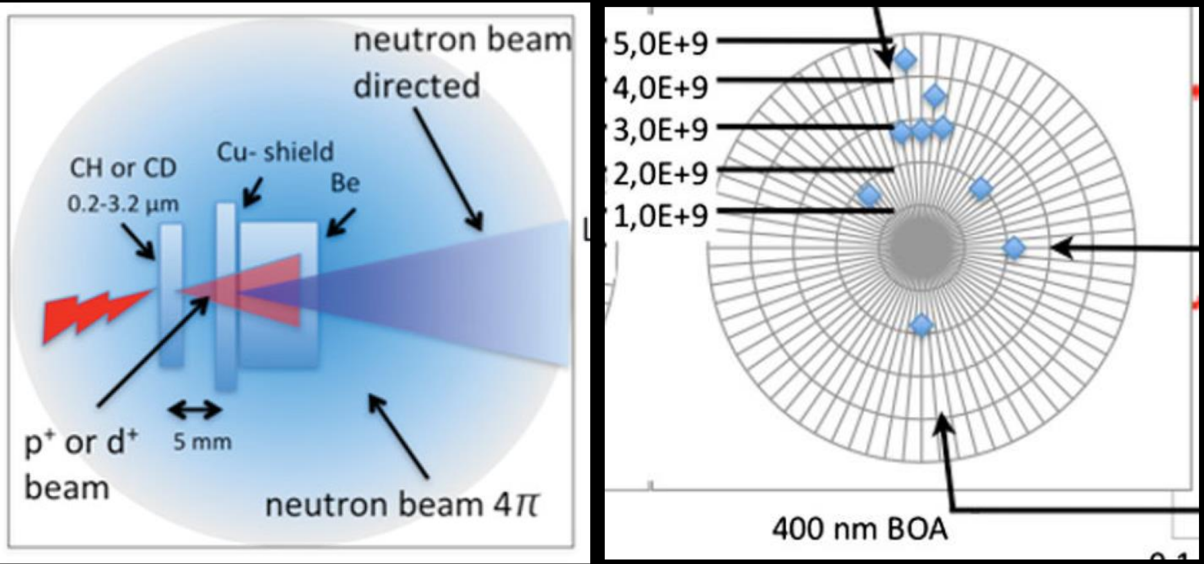
Forward peaked emission neutron beams



FLUKA simulation, with thanks to J. McKinney

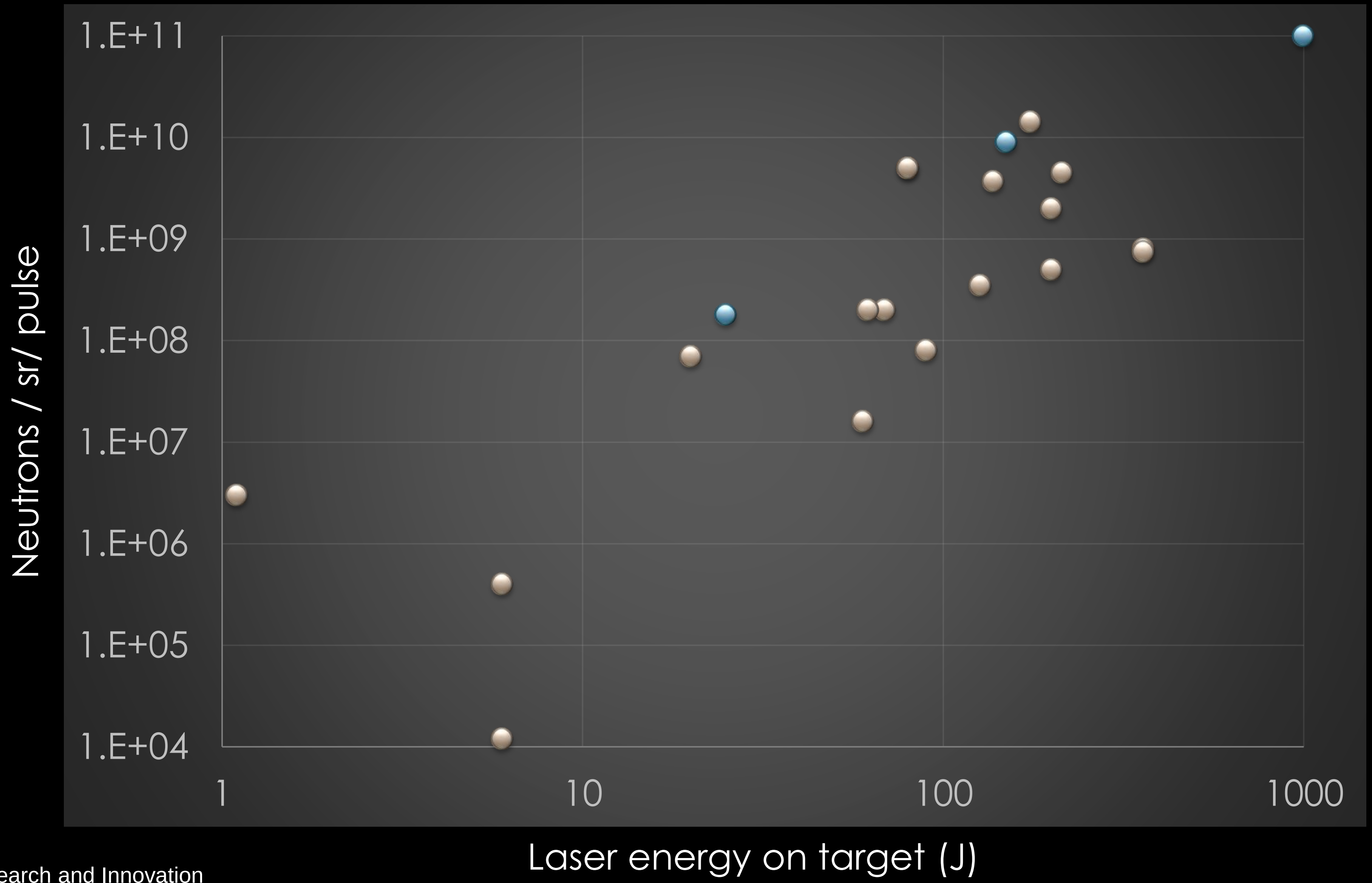


S. Kar, A. Green *et al*, NJP 18 053002 (2016)

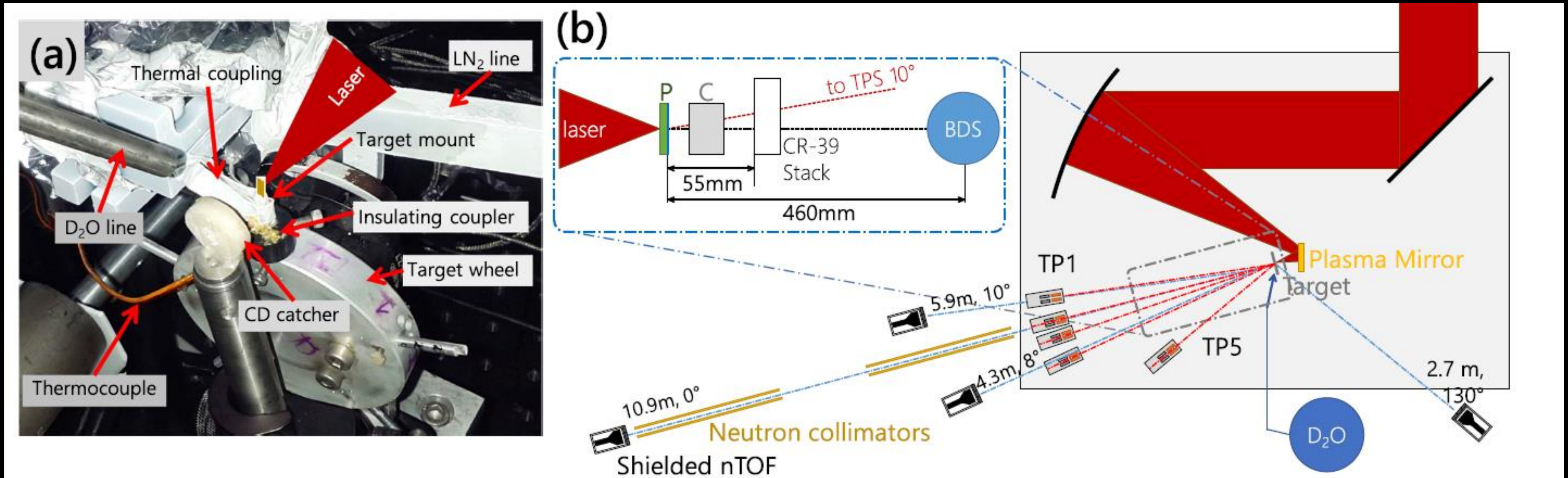


M. Roth *et al*, Physical Review Letters, 110, 044802 (2013)

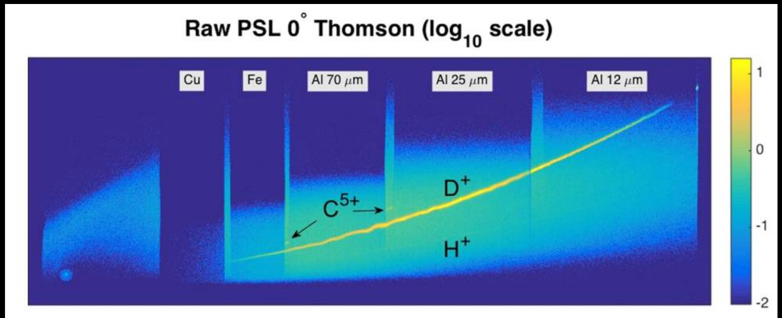
On axis neutron emission review



Cryogenic targetry for enhanced emission

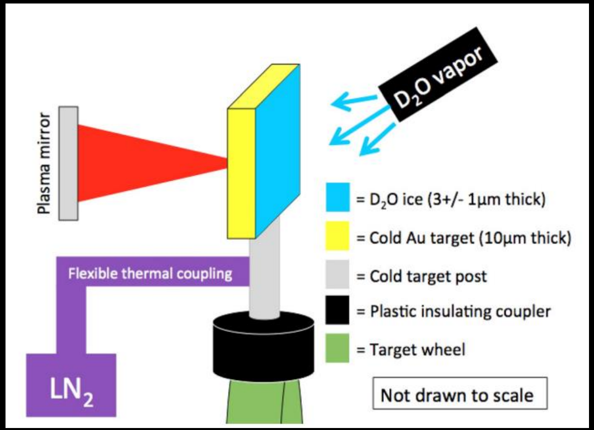


9.4 % laser–to-deuterium energy observed



$\Rightarrow$ 18.8 J carried in proton pulse

2×10^9 n/sr from (d,n) reactions

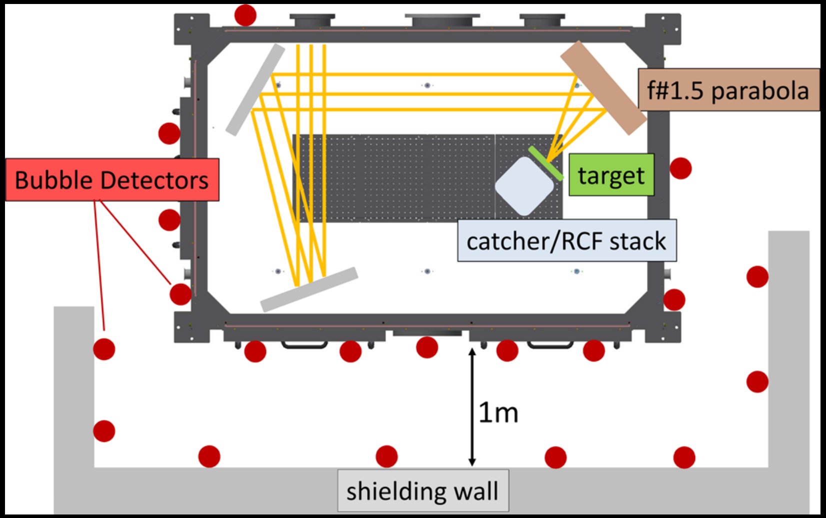


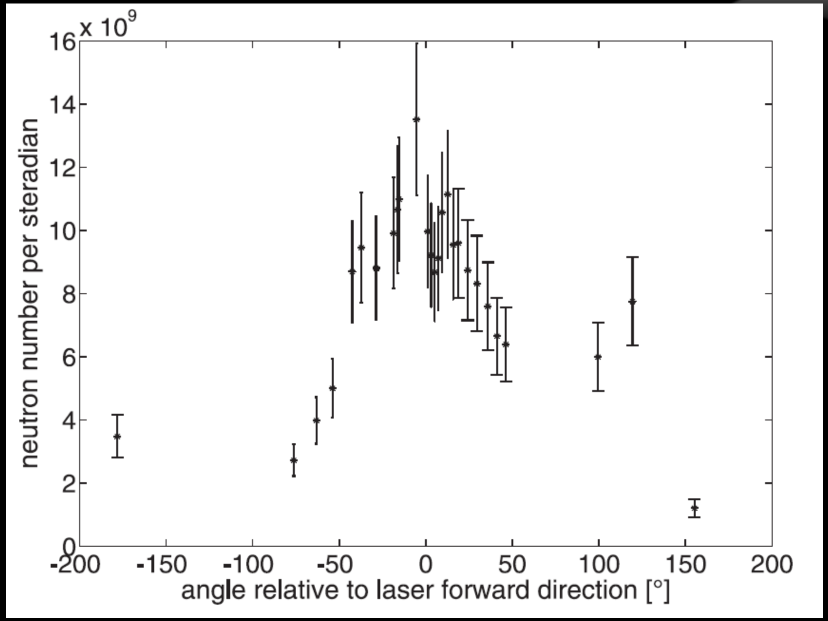
A. G. Krygier *et al*, PoP, **22**, 053102, (2015)

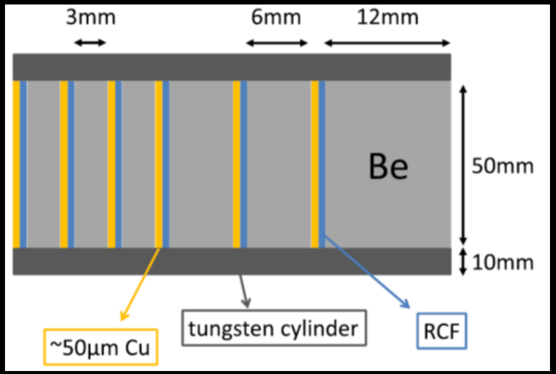
A. Alejo, A. G. Krygier *et al*, PPCF 59 064004 (2017)

High flux and reproducible beams

A. Kleinschmidt *et al*, Physics of Plasmas, 25, 053101 (2018)



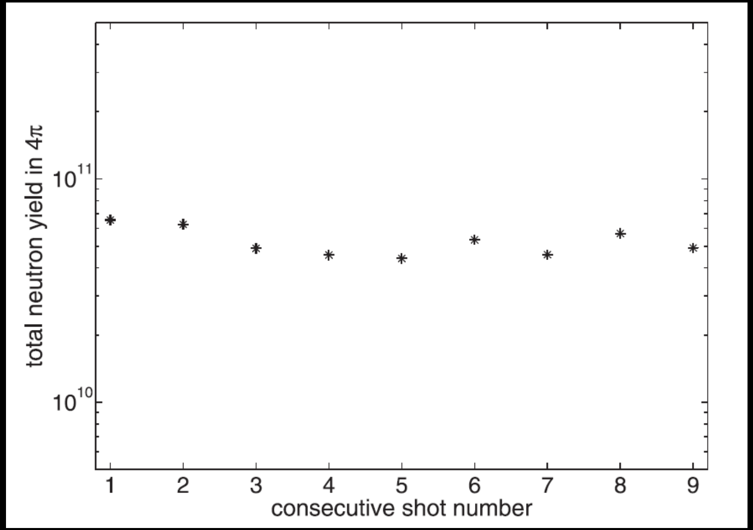




175 J, 500 fs, 2 x 10^{20} W/cm^2

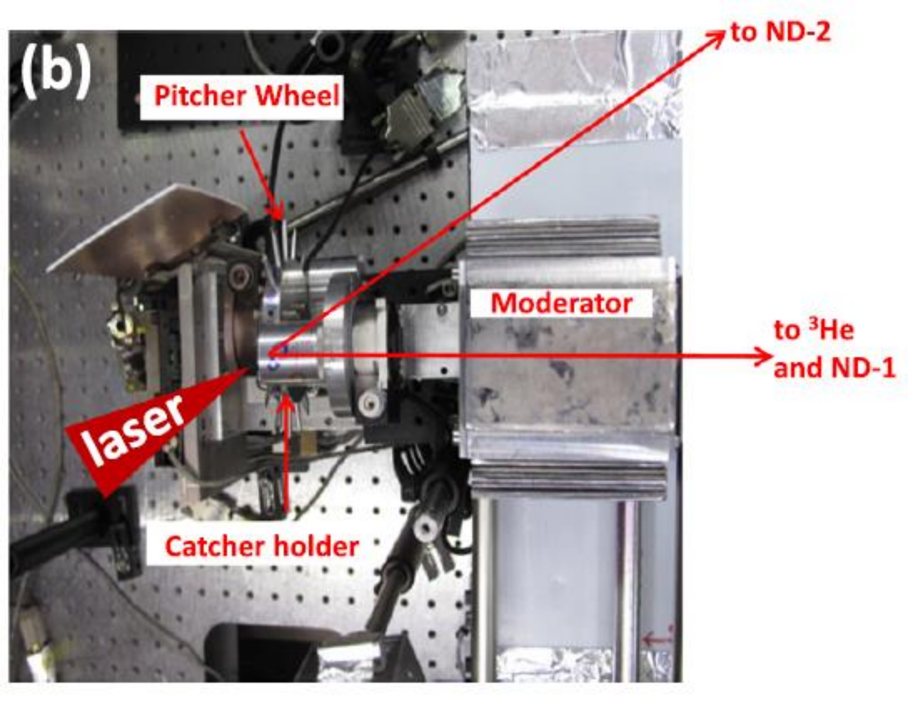
800 nm CD pitcher
Be catcher

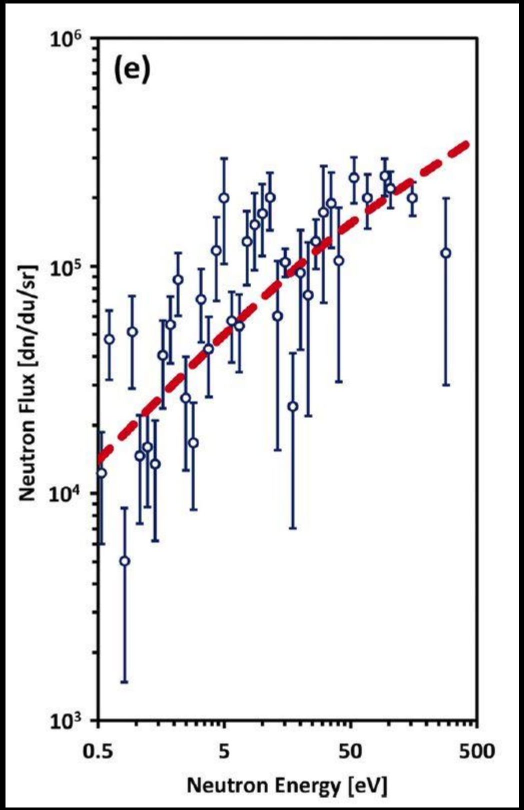
1.4 x 10^{10} n/sr/pulse



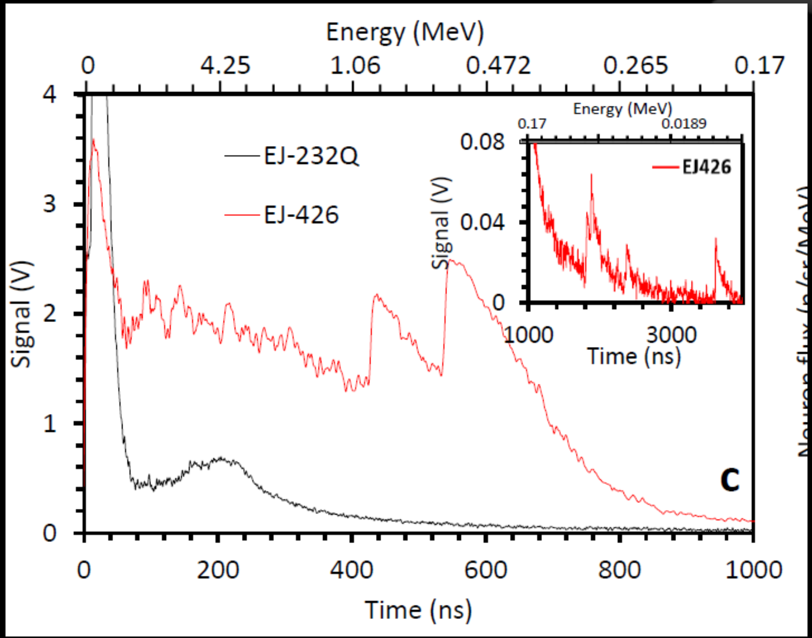
Generation of slow(er) neutron beams

S. R. Mirfayzi, *et al*, Applied Physics Letters 111 044101 (2017)





Using moderator
10^5 n/sr/pulse
0.5 – 300 eV
50 J on target, Au pitcher, Li catcher



Using near threshold endothermic

$^7Li(d,n)^8Be$
10^7 n/sr/pulse

20 – 200 keV with 100s ps duration

30 J on target, Au pitcher onto Li

S. R. Mirfayzi, *et al*, Applied Physics Letters, in press (2019)

Demonstration and development of laser-driven acceleration mechanisms and production of x-rays and neutrons

Development of sources and enabling technology for applications

Delivering laser-driven sources for applications

RESEARCH

The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions

INNOVATION

Make changes in something established, especially by introducing new methods, ideas, or products

Optimisation of parameters for applications

Applications: Imaging

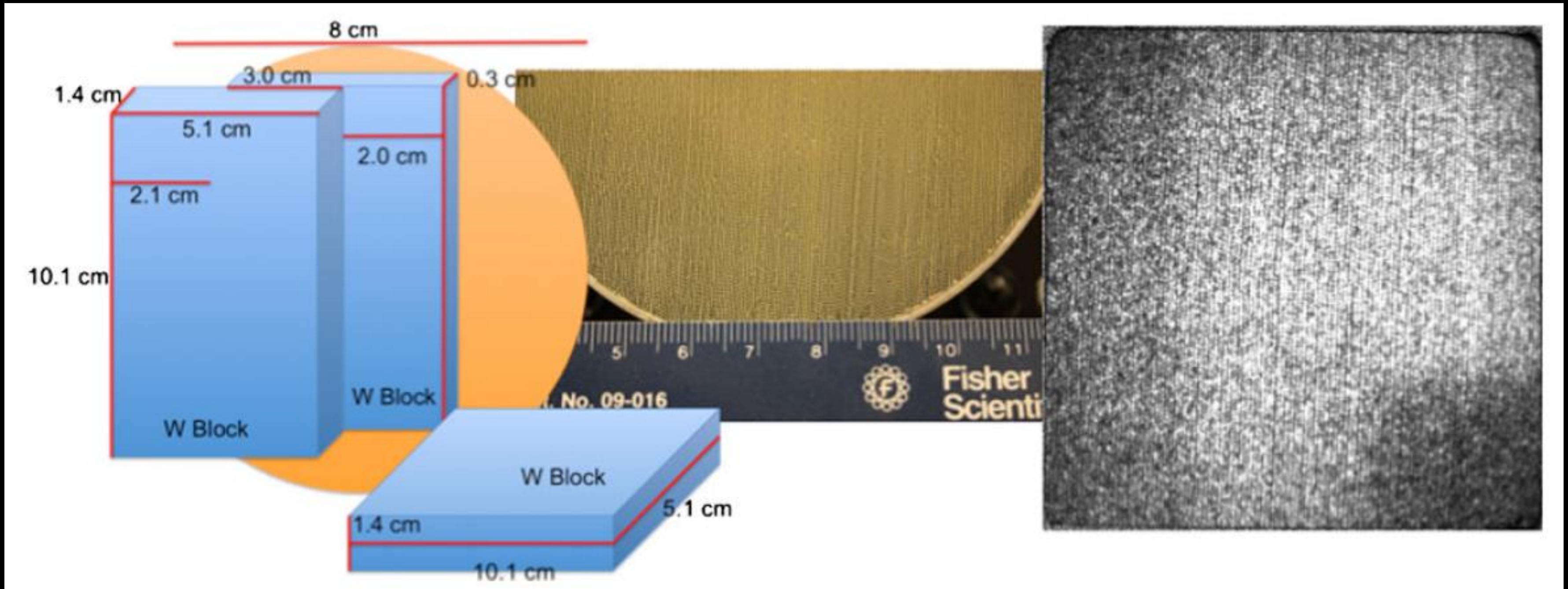
Not just for guns and roses….

High value engineering and manufacturing (oil flow, plastic, air gaps)

Infrastructure inspection (corrosion, water)

Applications: Imaging

M. Roth *et al*, Physical Review Letters, 110, 044802 (2013)



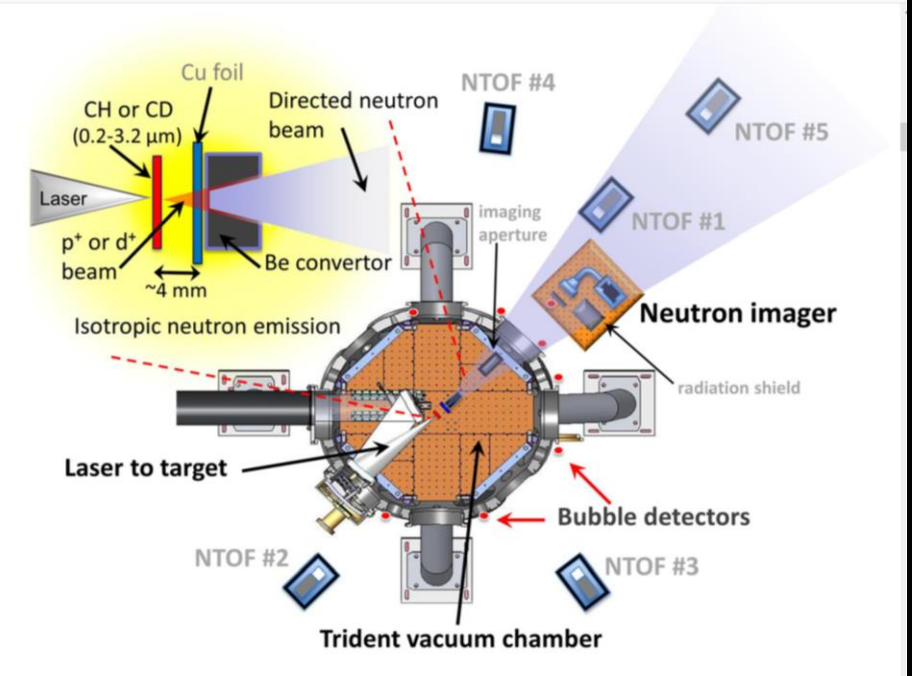
2 pulse acquisition, 75 J, 800 fs, CD pitcher with Be convertor, ~ 5 x 10^9 n/sr/pulse

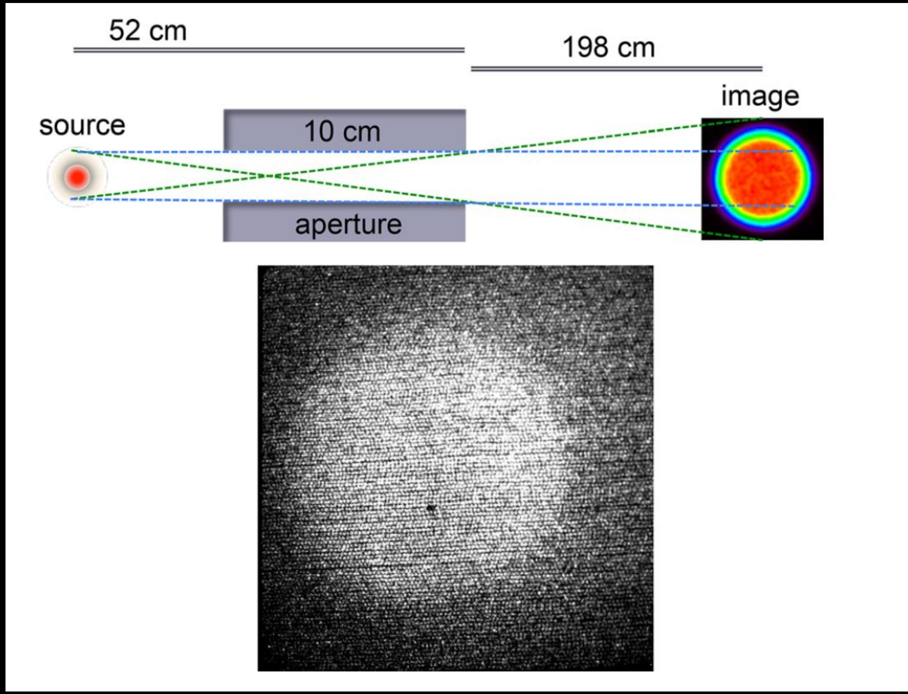
Gated ToF scintillator detector

2. 5 – 15 MeV used

Applications: Imaging

N. Guler *et al*, Journal of Applied Physics, 120, 154901, (2016)





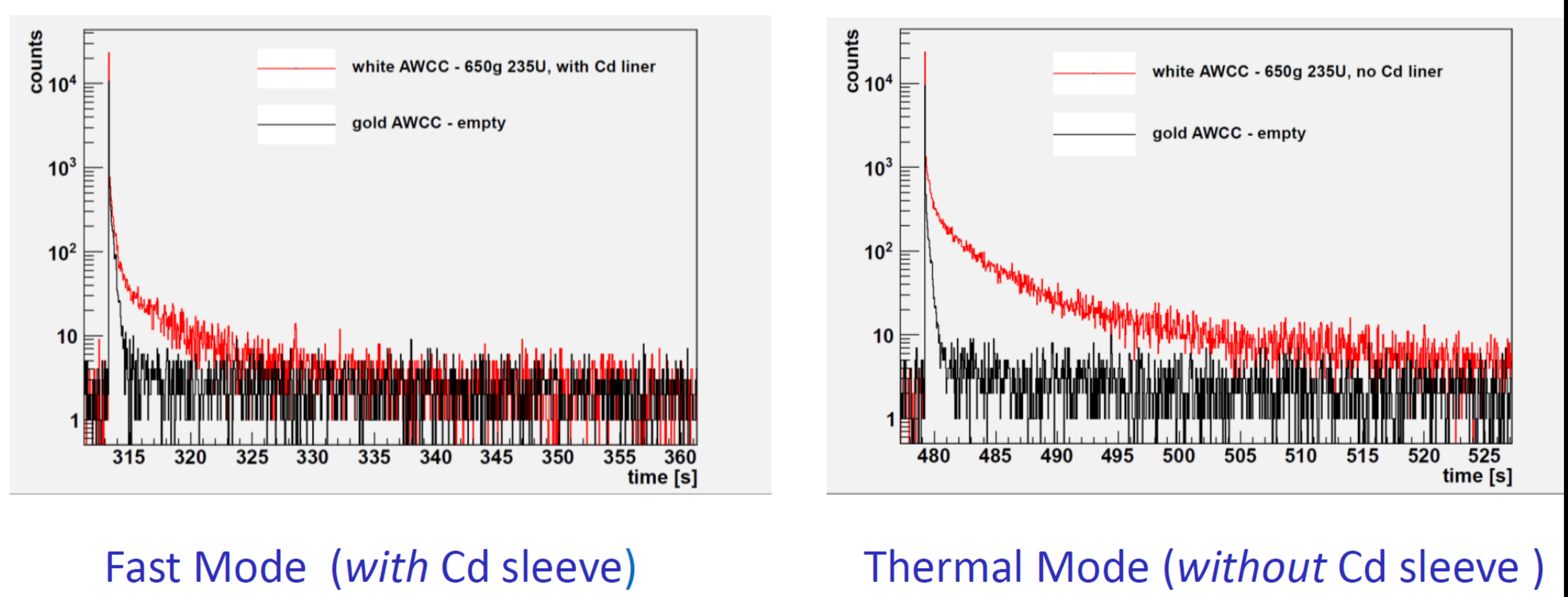
Source size measurement of 1.2 mm

Imaged using gated fibre scintillator detector

Sampled neutrons with energy 2.5 – 15 MeV

Applications: Inspection
Laser-driven neutrons for active interrogation

A. Favalli *et al*, IEEE Nuclear Sympoisum, (2014)



Highly enriched Uranium (650 g ^{235}U)

Single pulse acquisition

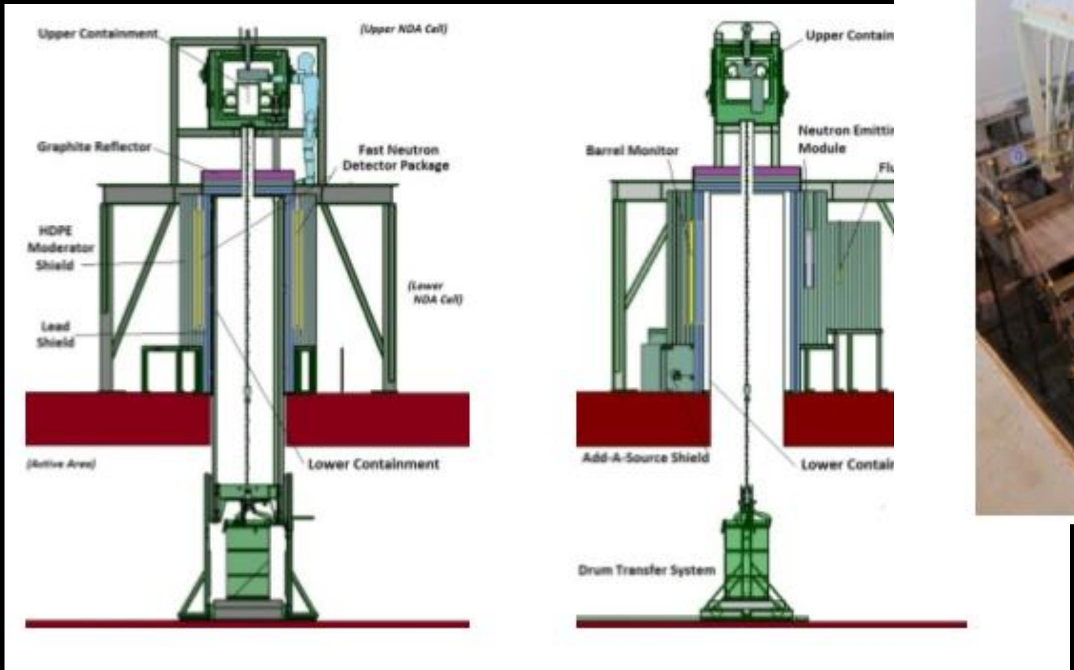
Fission emission gives delayed neutron signature

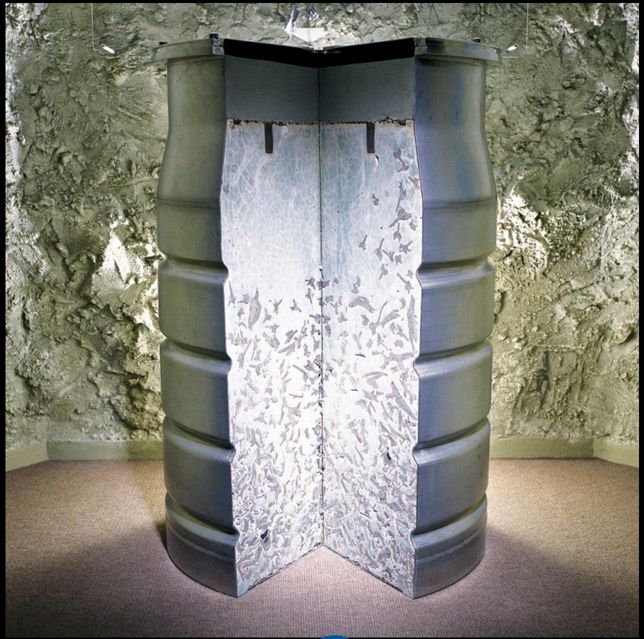
Applications: Inspection
Nuclear waste management assay

Active and passive neutron measurement as well as segmented high resolution gamma spectrometry (HRGS)

40 mins per drum

For Dounreay Site Restoration Limited



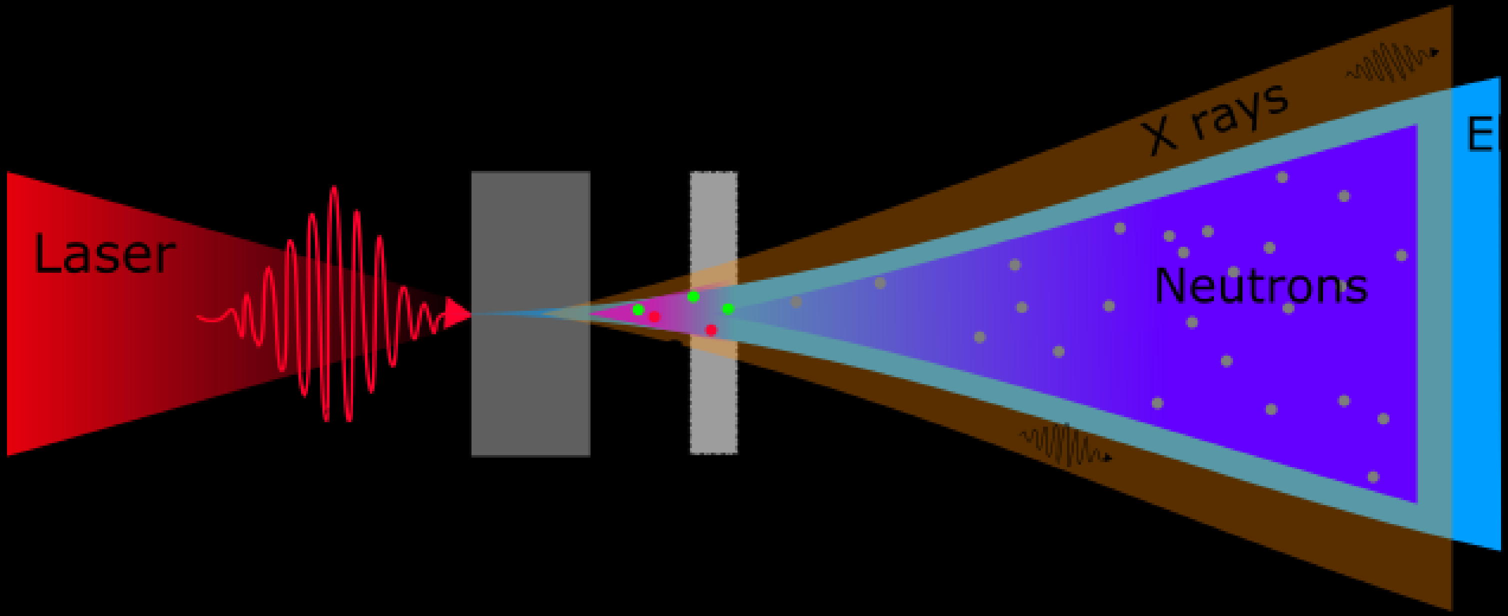


Sellafield Ltd

MIRION TECHNOLOGIES

J. Singh *et al*, Combined Assay Systems for the Characterisation of Historical ILW at of the Dounreay Shaft and Silo-18140, Waste Management Symposia, 2018

Applications: Inspection
Nuclear waste management assay



Laser-driven sources, USP:

1) Fast throughput, high-resolution projection imaging through thick, dense objects
2) Multi-modal inspection with in-line x-ray and neutron generation

Applications: Inspection
Nuclear waste management assay

PLATINUM

Pulsed Laser Accelerators for The Inspection of NUclear Materials

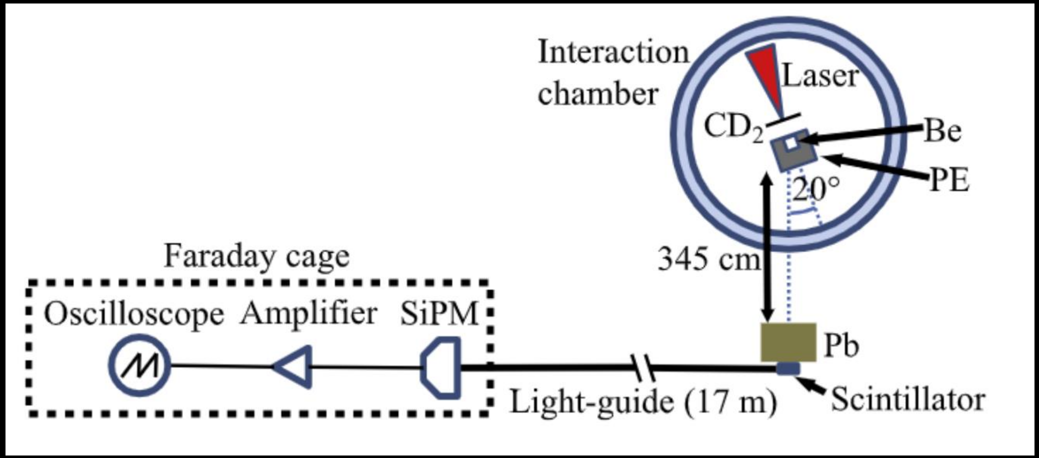
University of Bristol	Queen's University Belfast	central laser facility	Sellafield Ltd
T. B. Scott C. P. Jones	S. Kar S. R. Mirfayzi	C. Brenner R. Allott C. Armstrong D. Neely	J. Jowsey A. Adamska

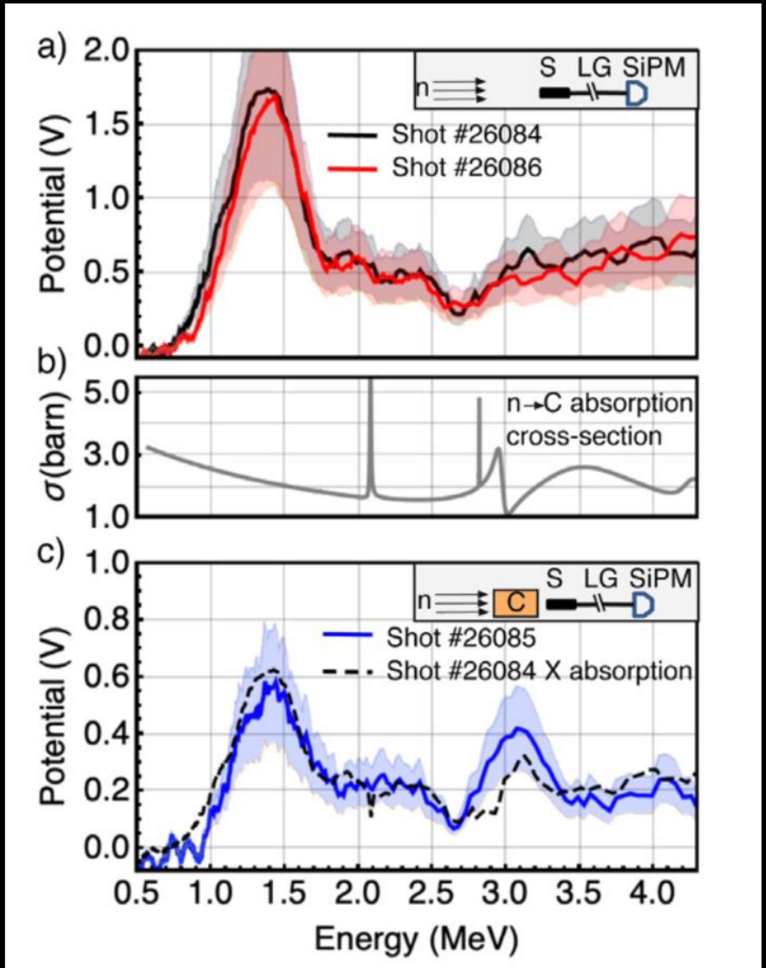
The principle concern regarding intermediate level waste (ILW) containers is the internal volumetric expansion due to the formation of corrosion products.

C. P. Jones, C. M. Brenner, *et al* , Journal of Hazardous Materials 318 (2016) 694 - 791

Applications: Inspection
Laser driven fast neutron absorption spectroscopy

I. Kishon, *et al* , Nuclear Instruments and Methods in Physics Research A 932 (2019) 27 - 30





Single pulse acquisition, with 67 – 86 J, 550 -607 fs, CD foils with Be convertor, ~ 1 x 10^{10} n/sr/pulse

New detector for eliminating EM noise

21 cm graphite absorber

Applicable for fast neutron resonance radiography for element mapping

Neutron resonance spectroscopy for time resolved temperature measurements

Applications: Insight
Laser-driven neutron probing of extreme states

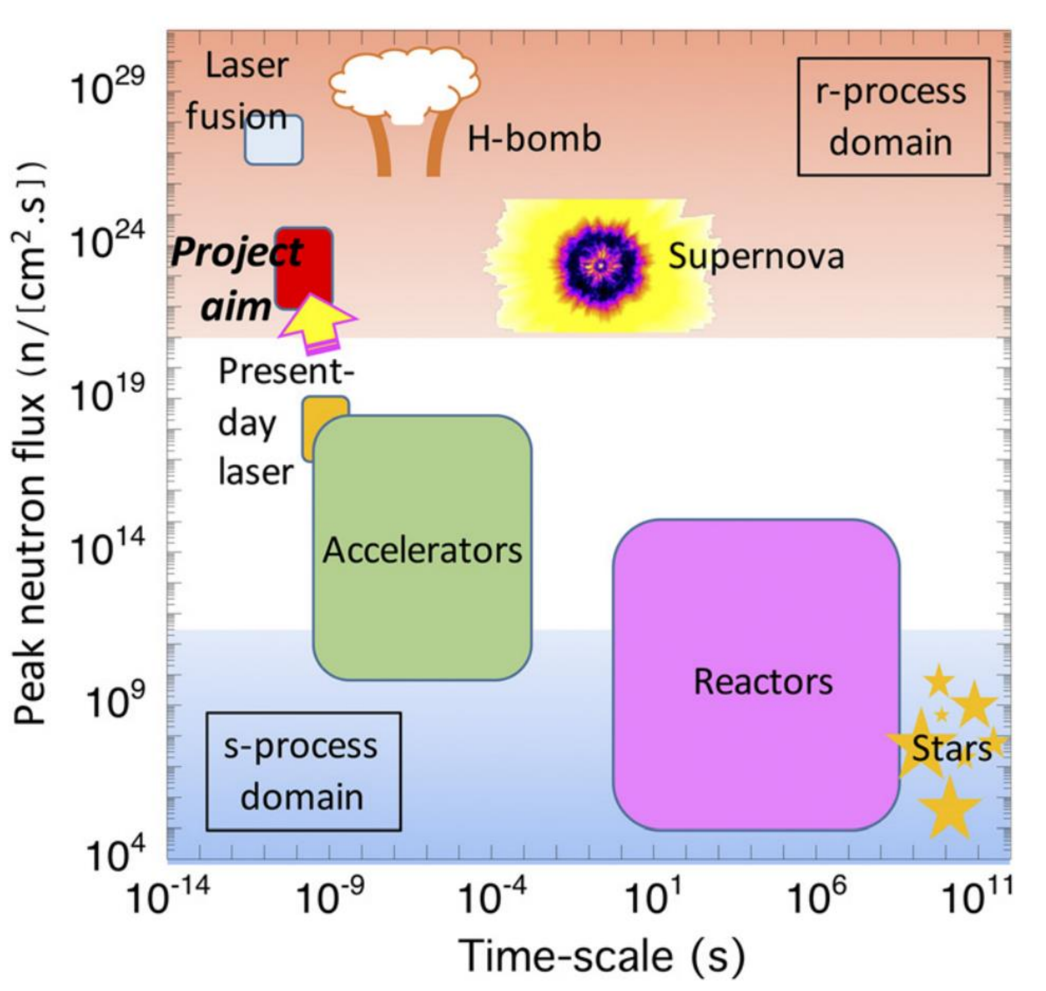
S. N. Chen *et al*, Matter and Radiation at Extremes, 4, 054402 (2019)

peak flux of up to $10^{22\text{-}24}$ n/(cm^2 s) expected from Apollon and ELI-NP

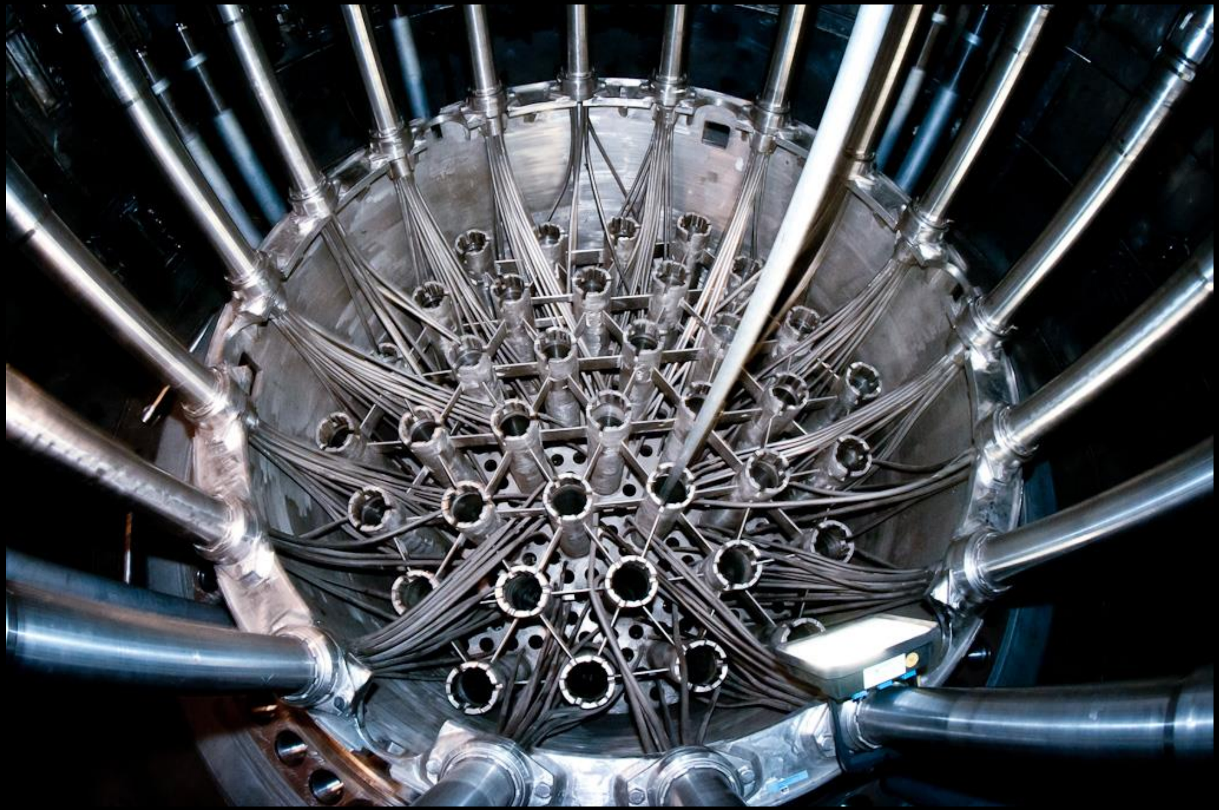
direct measurements of neutron capture and β-decay rates related to the r-process of nucleosynthesis of heavy elements

nuclear measurements in a hot plasma environment

astrophysically relevant conditions



Applications: Irradiation



Very little access available worldwide for testing materials under extreme radiation environments

An industry nuclear materials scientist wants to be able to irradiate 25 mm^2 metal alloys with 10^{22} 1 MeV neutrons/m^2 fluence for mechanical testing

Can we generate 10^{12} neutrons/pulse/steradian source??

So that with a 10 Hz system the irradiation can be completed with 2-3 hours exposure time

Demonstration and development of laser-driven acceleration mechanisms and production of x-rays and neutrons

Development of sources and enabling technology for applications

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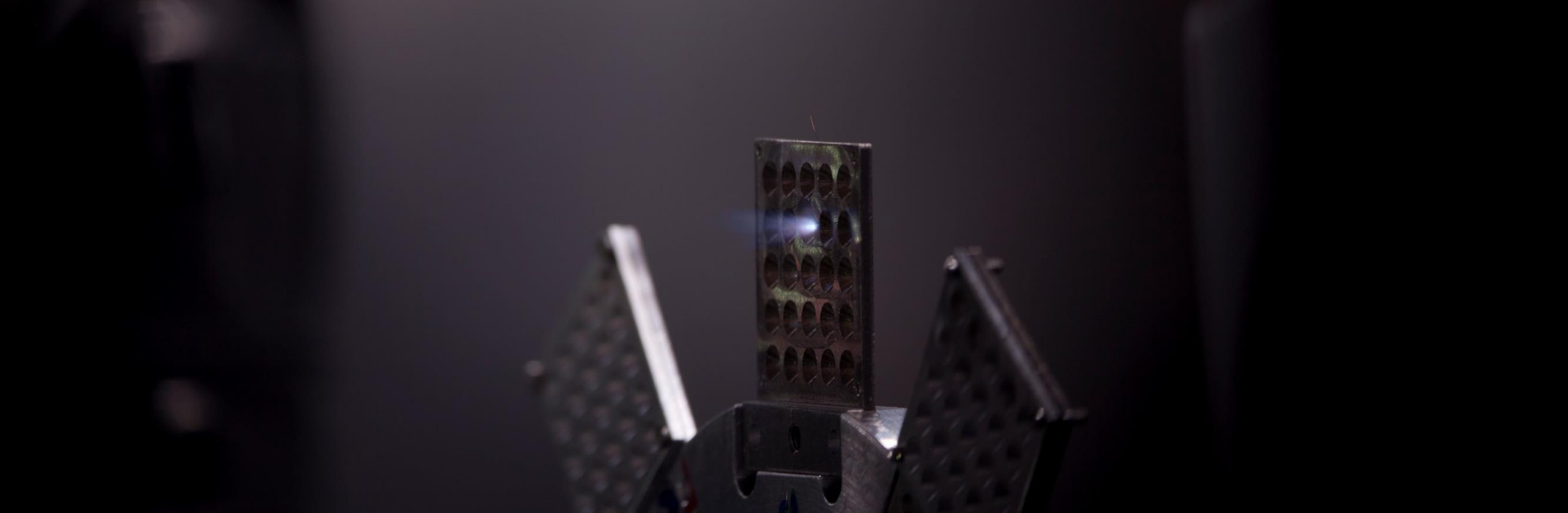
IBM
Data Processing
Division
IBM 5 MB hard drive
1956



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Laser-driven neutron sources provide:

Additional capacity to existing fleet of sources

Deployable technology with reduced infrastructure so can be installed in challenging environments and industrial settings

Ultra-short pulse for increasing spectral resolution and speed up acquisition