High intensity γ-ray and neutron generation by ultra intense laser

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American Chemical Society, “From NIF to the Stars”

Collaborator

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Summary

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- Laser driven γ-ray or neutron generation can open stellar nuclear science.

- LFEX laser demonstrated 10^9 neutron/ shot by photo-nuclear reaction. and will be improved more.

- The γ-ray and neutron peak intensity exceeds 10^{27} /cm^2 s and 10^{21} /cm^2 s.

- Plasma mirror was demonstrated on LFEX sub-kJ shot.

World highest energy PW laser LFEX in ILE Osaka

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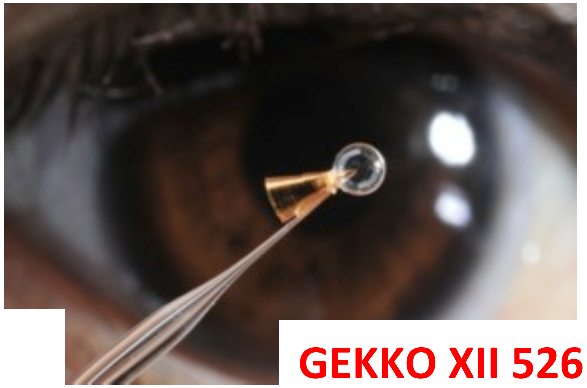

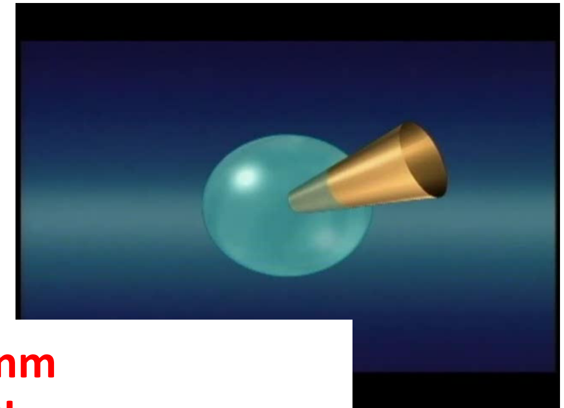

LFEX 1053 nm
1~10 kJ/1~10ps
started from 2009
increasing energy
to be ~3 kJ in 2014

GEKKO XII 526 nm
300J/1.2ns x 12beams
since 1983

LFEX is now completed!

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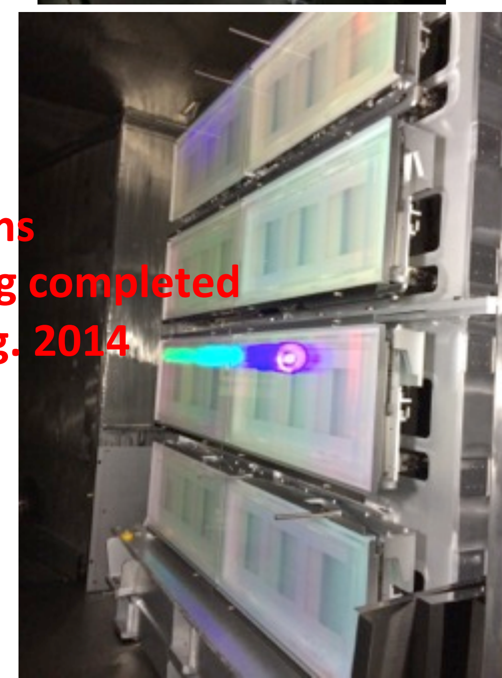
- **FY 2009.7~9** Completed 1-beam.
  1^{st} FI exp't with 1 beam ~500J (at Amp)
- **FY 2010.11~12** 2^{nd} FI exp't with 2 beam ~1000J
- **FY 2011.3** e^--e^+ generation exp't with 2 beam ~ 2000J
- **FY 2012.7~8** 3^{rd} FI exp't with 2 beam ~1000 J
  New diagnostics installed
  Improved laser pre-pulse
- **FY 2013.11** 4^{th} FI basic exp't with 3 beam ~1200 J
  Pulse monitors installed
  (pulse duration, prepulse, spot size)
- **FY 2014** 4-beams completion.
  5^{th} FI exp't with 4 beam ~ 3000 J

3-beams
Grating Sep. 2013



4-beams
Grating completed
on Aug. 2014

Laser driven neutron generation

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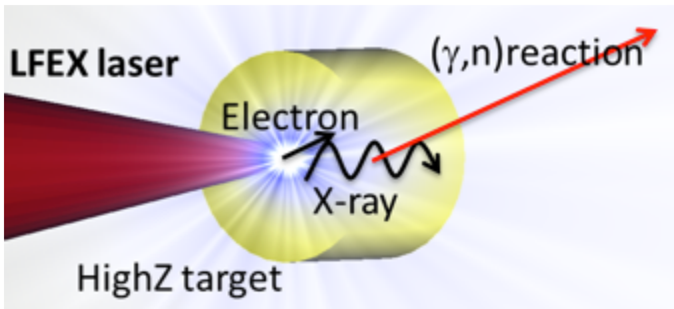
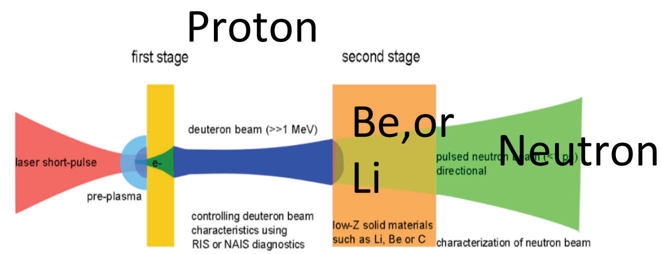
Photonuclear



Neutron yield ~10^{10} /shot. 1ps
Laser 2000 J

Proton assist



Neutron yield 2×10^{10} /shot
Laser 80J
(M. Roth, Nature, 2012)

Laser driven neutron generation opens the steller nuclear science

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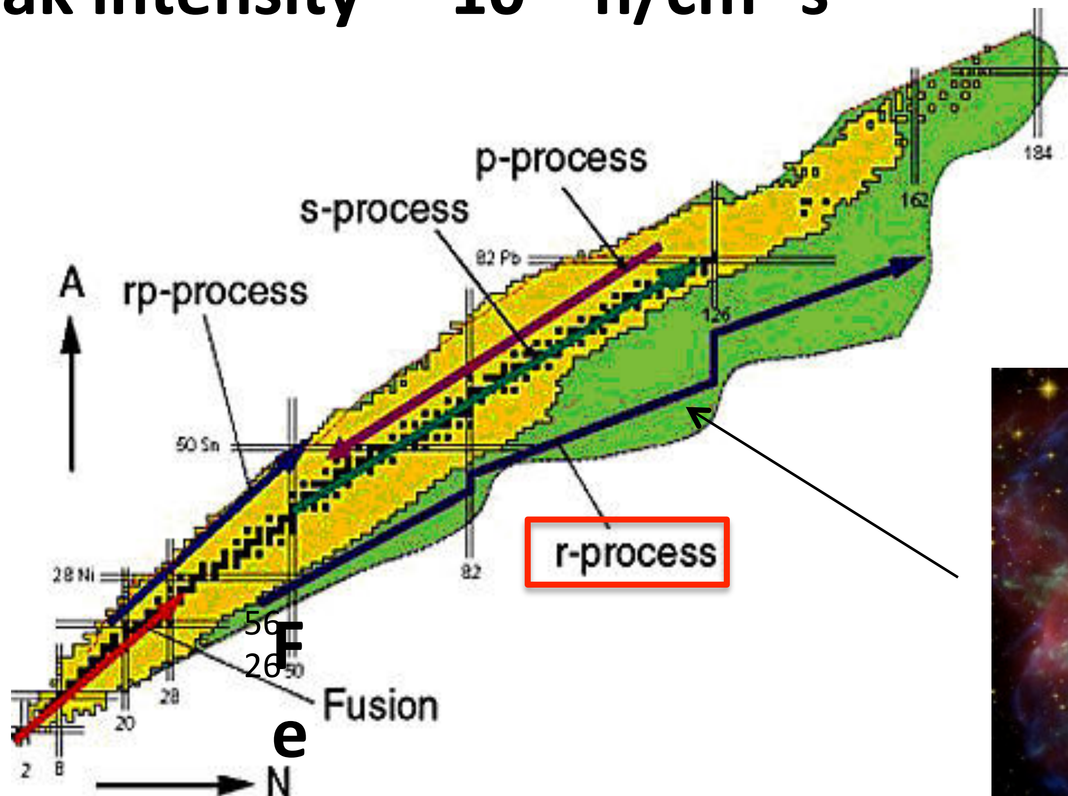
Laser neutron peak intensity ~10^{24} n/cm^2 s

Ultra-short pulse
Very small spot size
→Ultra high-intense, short lifetime nuclear reaction



S-process (slow process) N flux～10^{10} n/cm^2/s 1000 years ←Easily archived.
S-process from the excited nucleus N flux ~10^{20} ncm^2/s 1 ns ←Possible!
R-process (rapid process) N flux～10^{22} n/cm^2/s 1s ←Might be possible!

Laser driven neutron can create short pulse, small spot size

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	neutron yield per pulse	rep rate	pulse width	Source size Accessible	neutron flux /1 sec	Neutron "local peak intensity" (/s・cm^2)
LFEX (photonuclear) eV〜MeV	10^{10}	1shot/3h	1 ps Laser pulse width	1 mm^2 Target size	10^{10}	10^{24}
NIF (fusion) ev〜14 MeV	10^{16}	1shot/day	100 ps Confinement time	1 cm^2 Target outer surface	10^{16}	10^{26}
J-PARC thermal〜	5x10^{15}	25 Hz	500 ms	100 cm^2 Hg target surface	10^{17}	10^{17}
FNS (DT fusion) 14MeV	4x10^{6}	2.5 MHz	3 ns	10 cm^2 T-doped target surface	10^{12}	10^{14}

Laser driven neutron has an advantage in the short lifetime nuclear reaction

*estimated by using typical values

Laser driven neutron generation

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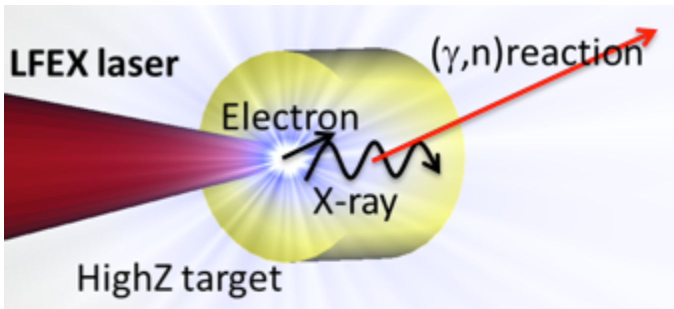
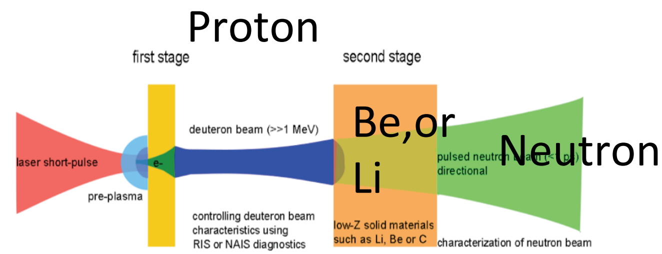
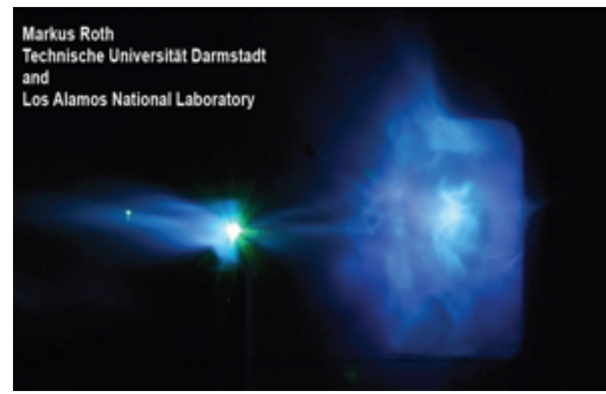
Photonuclear



Neutron yield ~10^{10} /shot. 1ps
Laser 2000 J

Proton assist





Neutron yield 2×10^{10} /shot
Laser 80J
(M. Roth, Nature, 2012)

Laser driven photonuclear reaction

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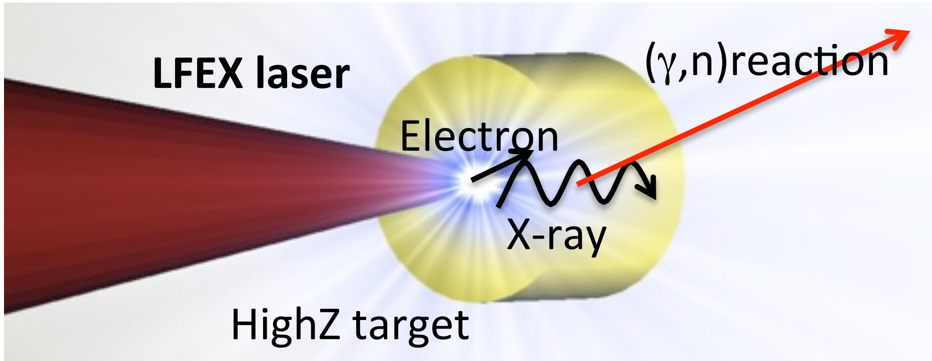
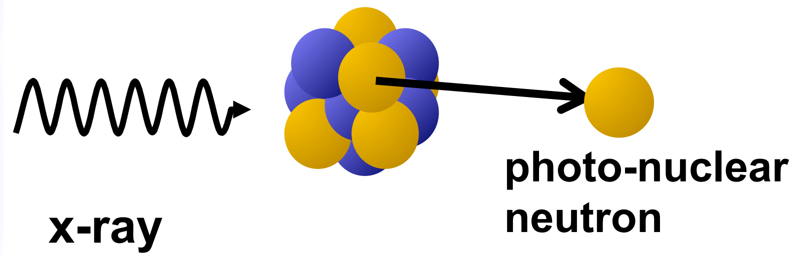
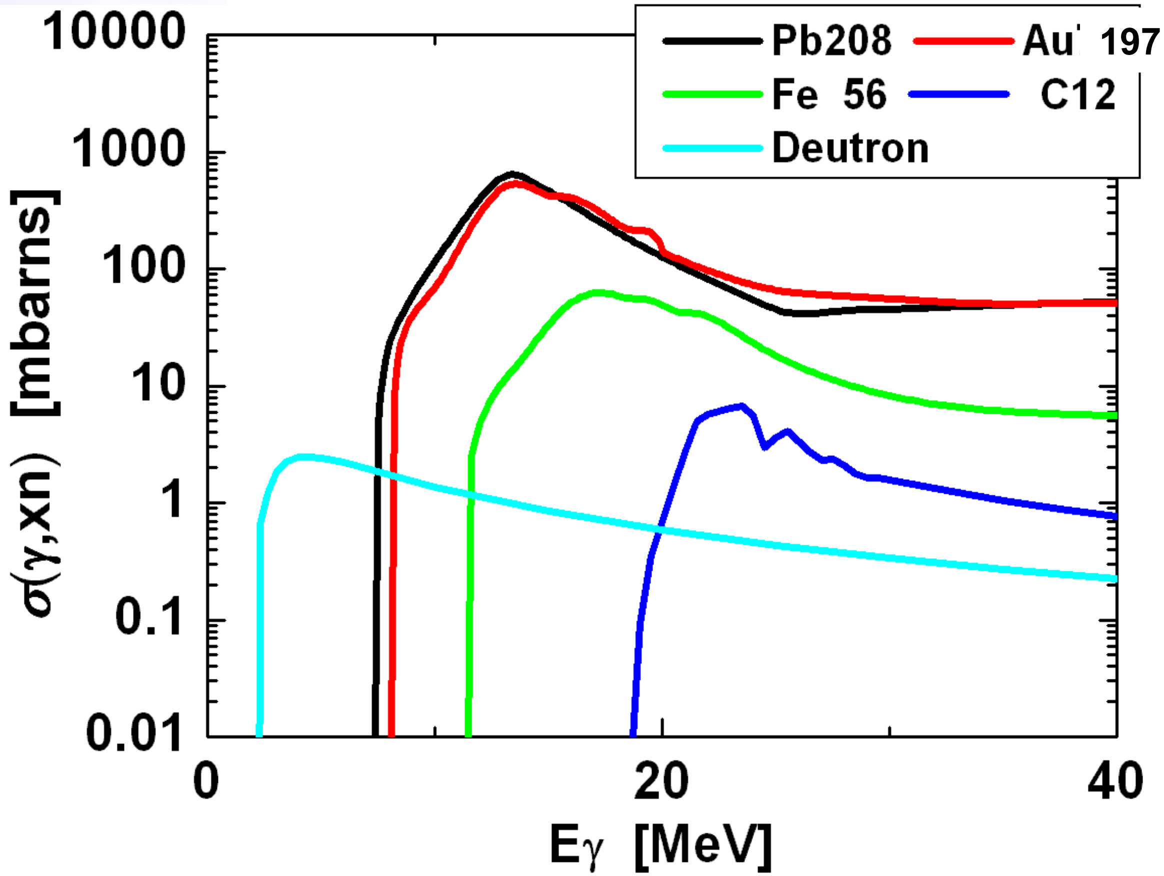
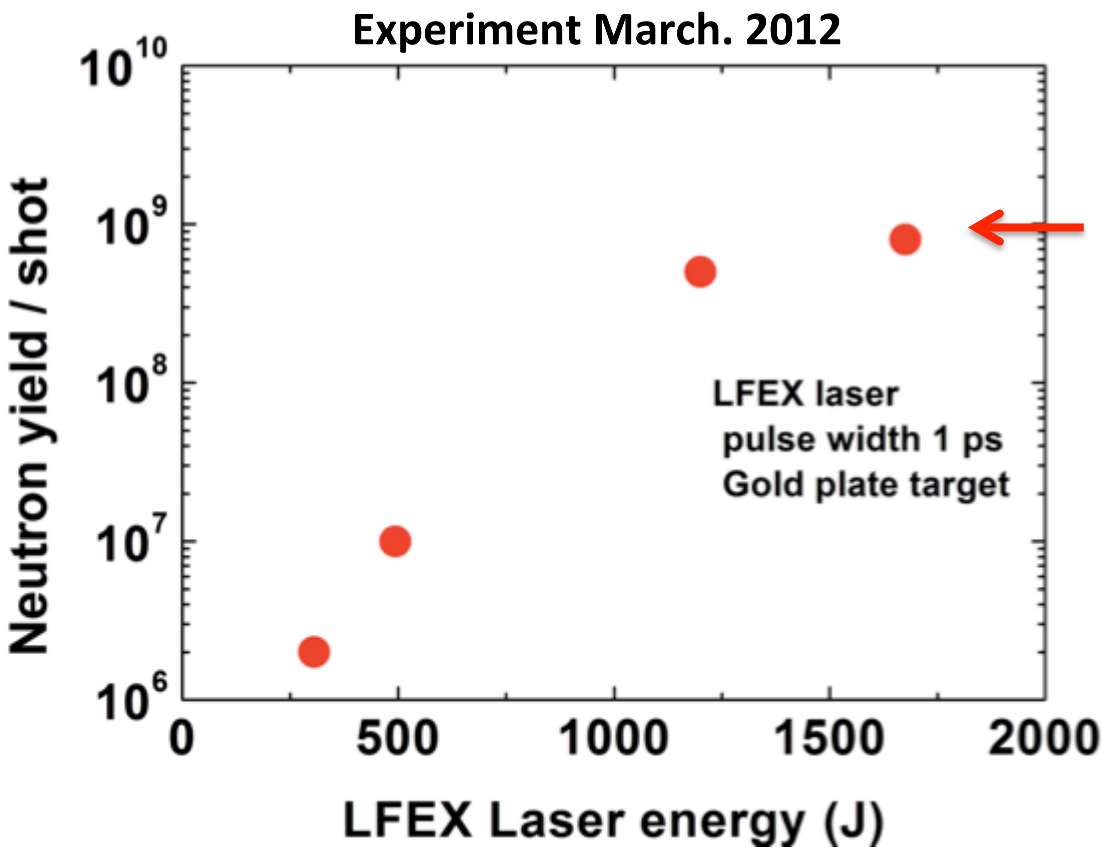


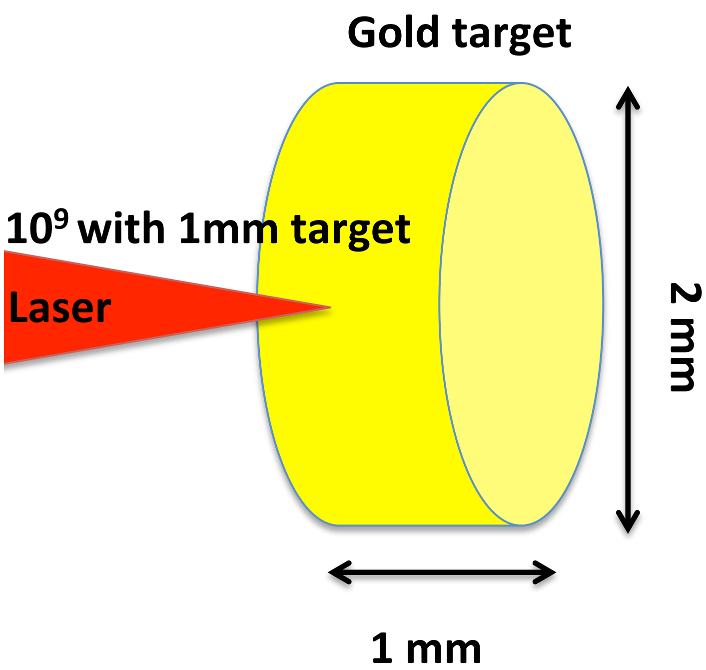


- **Simple physics**
- **Neutron source inside the target**
- **Simultaneous irradiation with γ-ray**



~10^9 neutrons / shot was demonstrated with LFEX





Yn~10^{10} can be archived with 1 cm target

By ~3 kJ LFEX laser in this year 10^{11} or more can be expected.

Broad spectrum neutron, attractive for nuclear synthesis

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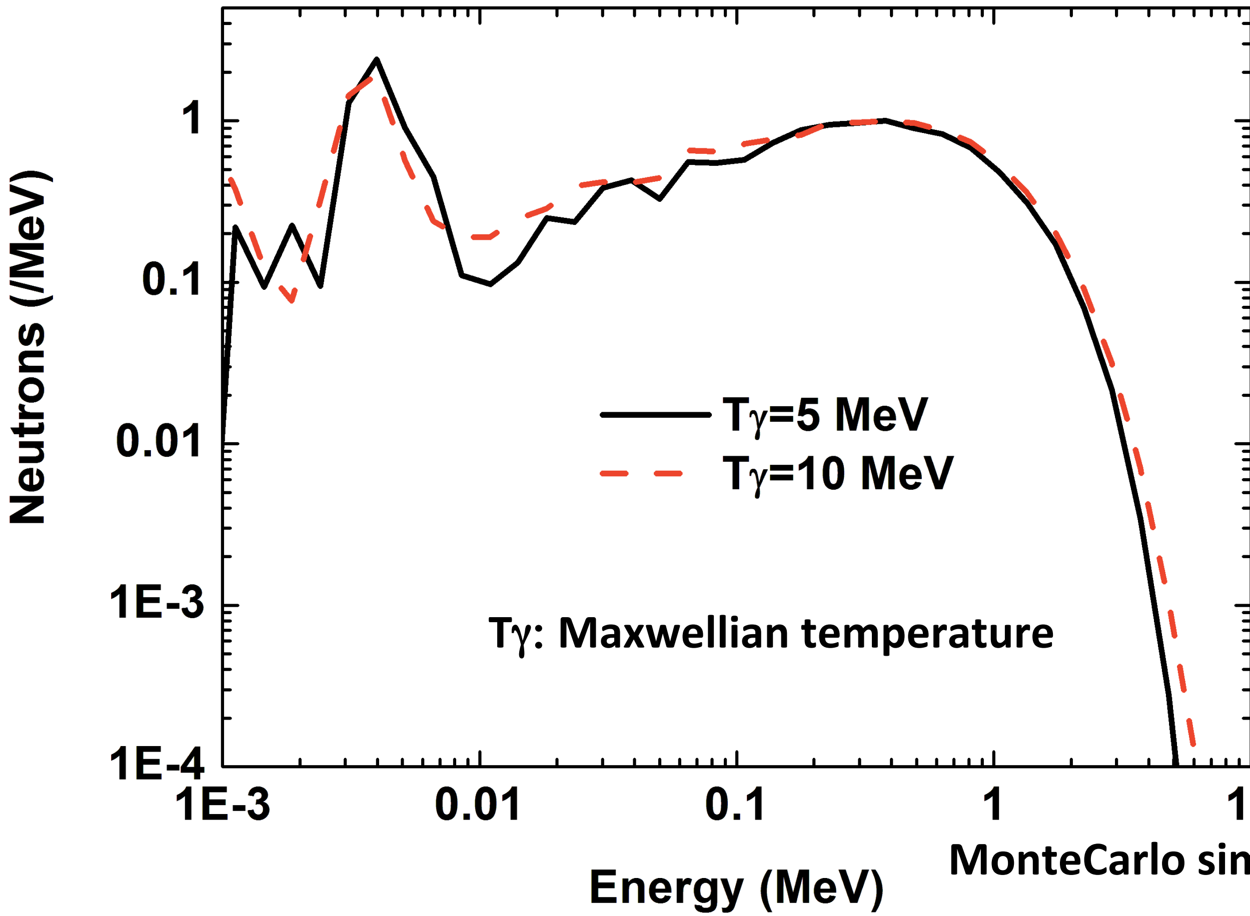

MonteCarlo simulation PHITS

Neutron spectrum is not affected by γ-ray spectrum, thus stable neutron source can be achieved.

Focused point neutron source

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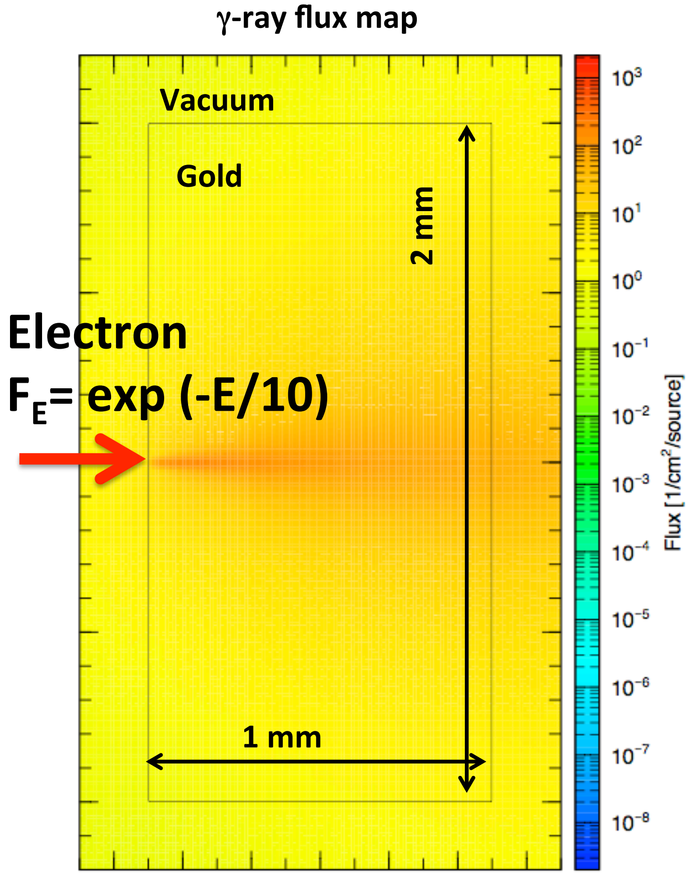

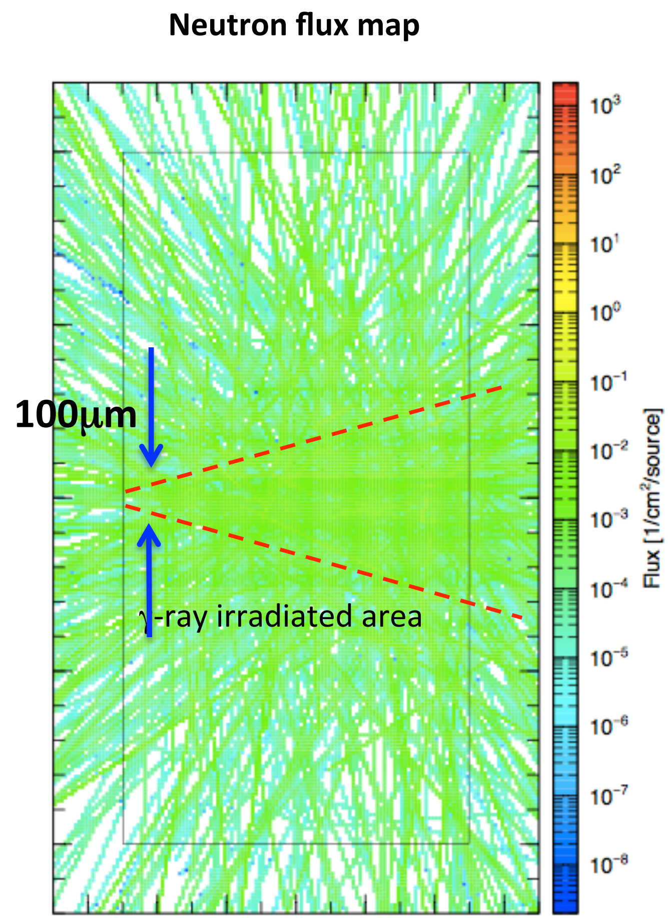

MonteCarlo simulation PHITS

γ-ray is collimated, neutron is isotropic.
There is very intense neutron spot inside the target.

Ultra short pulsed γ-ray + neutron source

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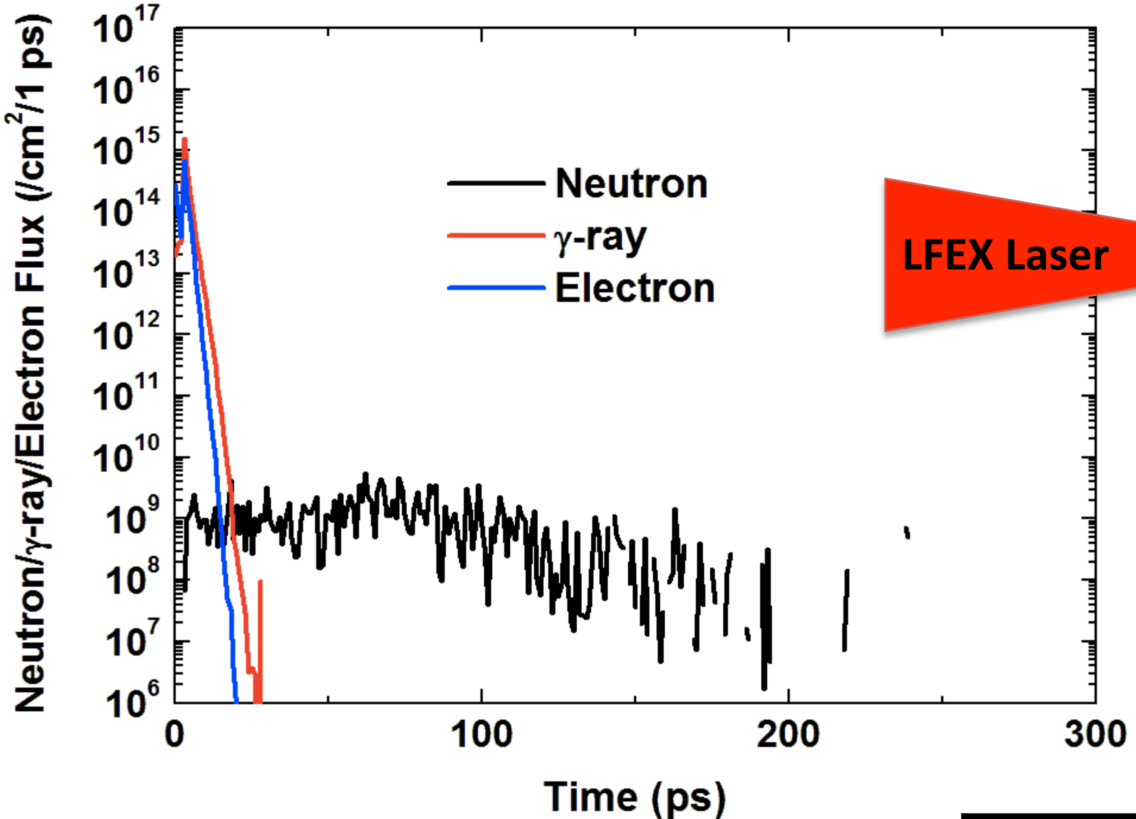
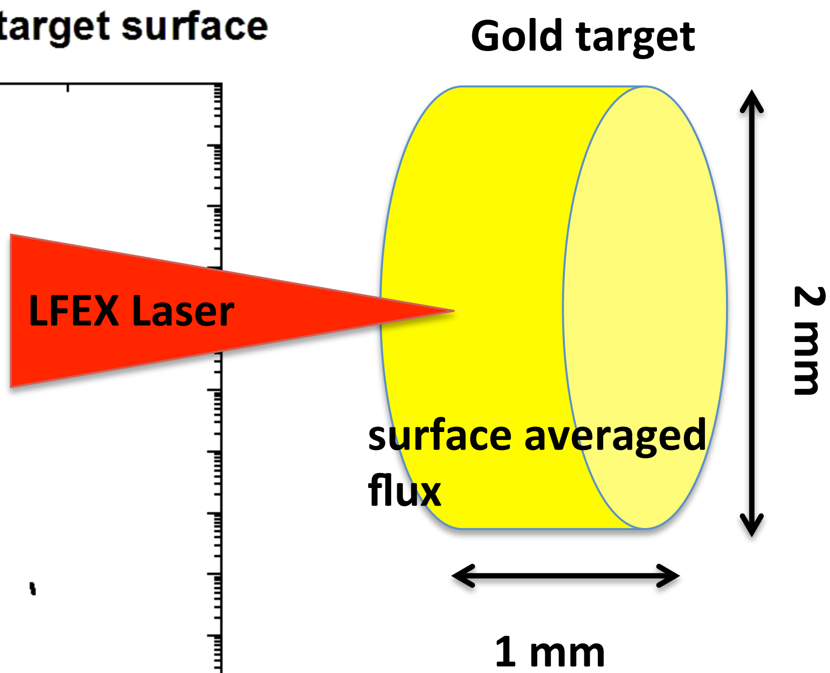
Neutron/γ-ray/Electron fluxes at the target surface





MonteCarlo simulation PHITS

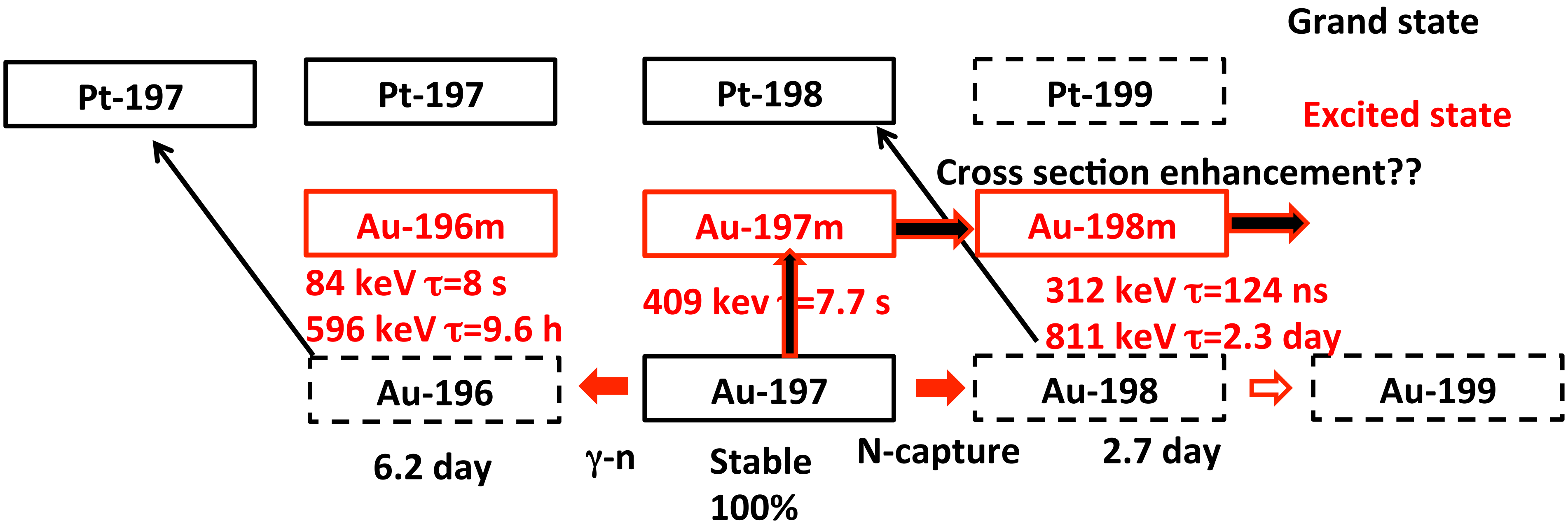
	$/cm^2$ /1ps	$/cm^2$ /1s
γ-ray	10^{15}	10^{27}
Neutron	10^{9}	10^{21}

Example of the gold neutron capturing

Gold

- R-process nucleus
- Important in a "Astro-clock"[1]
- Pure Au-197 is available
- Many isomer are existing but not benchmarked

[1] S. Wanajo, et. al., "The r-process in the neutrino winds of core-collapse supernovae and U-Th cosmochronology "The Astrophysical Journal. 577. 853-865 (2002)



Neutron capture of Au-197m pre-excited by γ-ray

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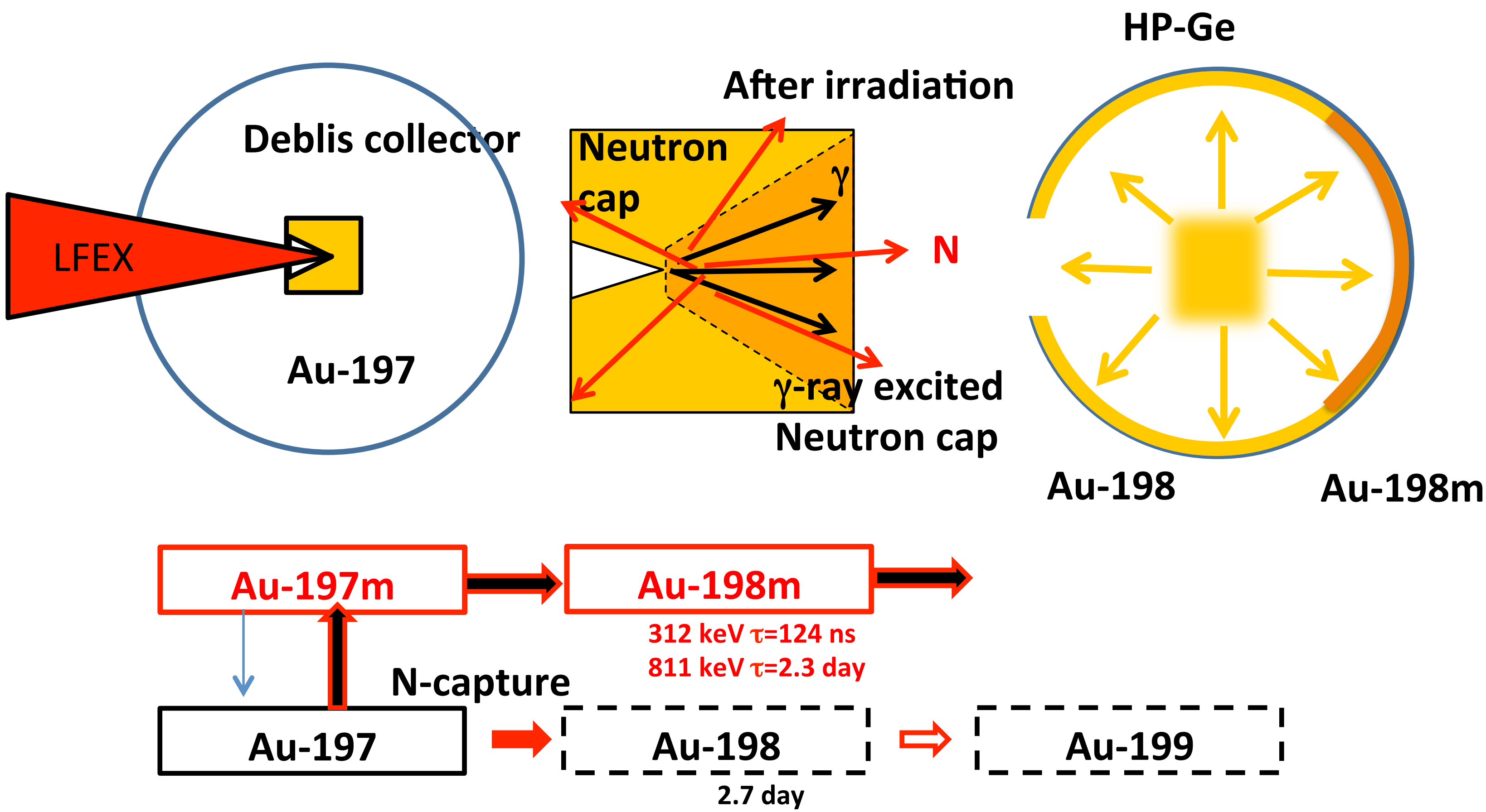

This experiment will be conducted 17-21. Nov. 2014.
(Ride along with the H. Chen e^+ generation.)

A shot can create detectable created nucleuus.

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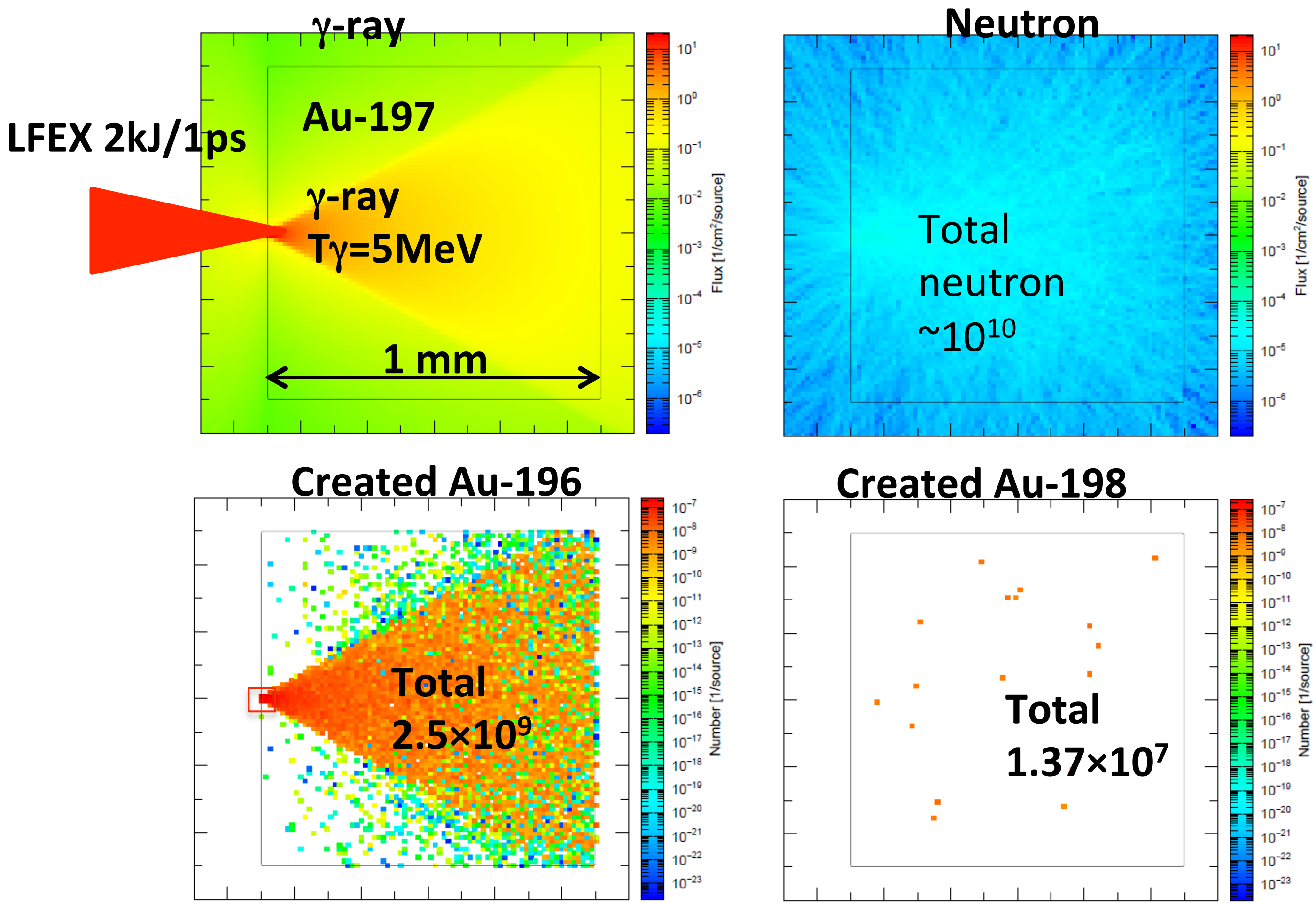

With LFEX 2 kJ shot (10^{14}photons, Tγ=5MeV),

Au-196	2.5×10^9	(196keV, β decay τ=6.2 day)
Au-198	1.37×10^7	(198keV, β decay τ=2.7 day)

Detectable!

Laser driven neutron generation

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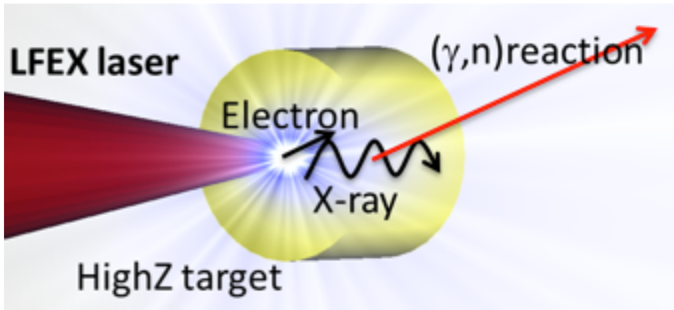
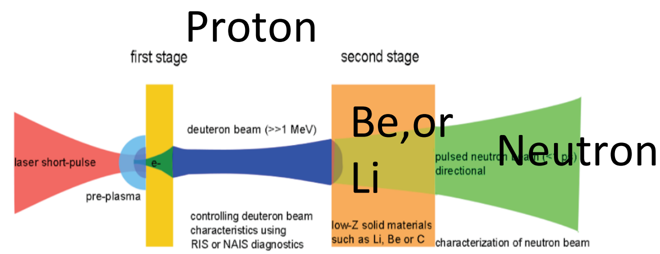
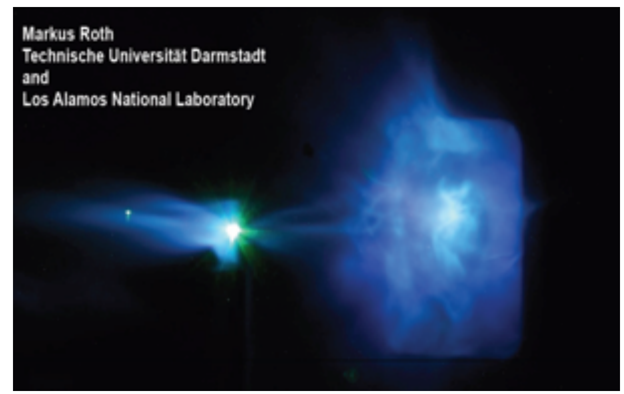
Photonuclear



Neutron yield ~10^{10} /shot. 1ps
Laser 2000 J

Proton assist

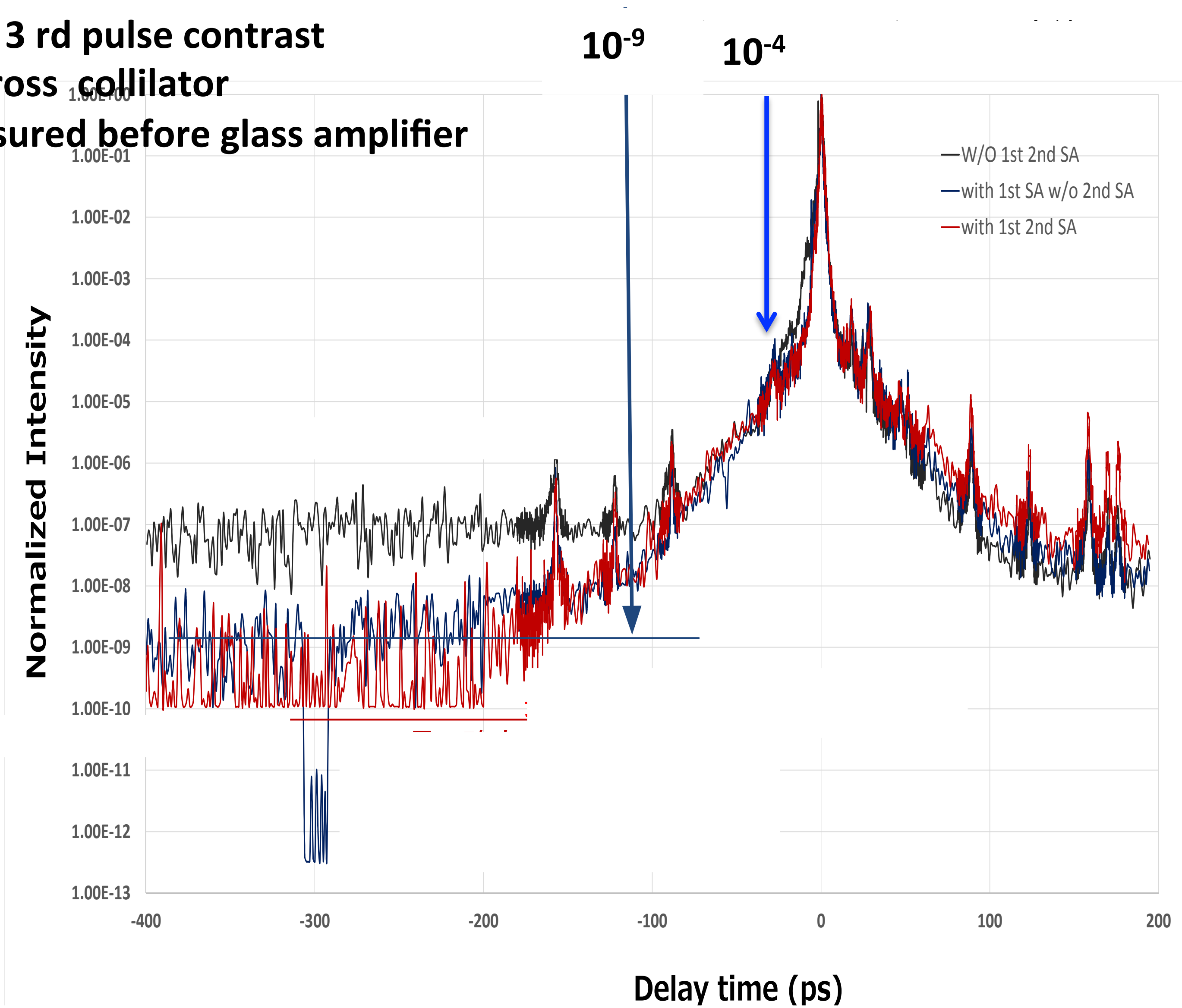




Neutron yield 2×10^{10} /shot
Laser 80J
(M. Roth, Nature, 2012)

Ultra clean pulse is indispensable

LFEX 3 rd pulse contrast
3rd cross collilator
measured before glass amplifier



Plasma mirror will improve preplasma

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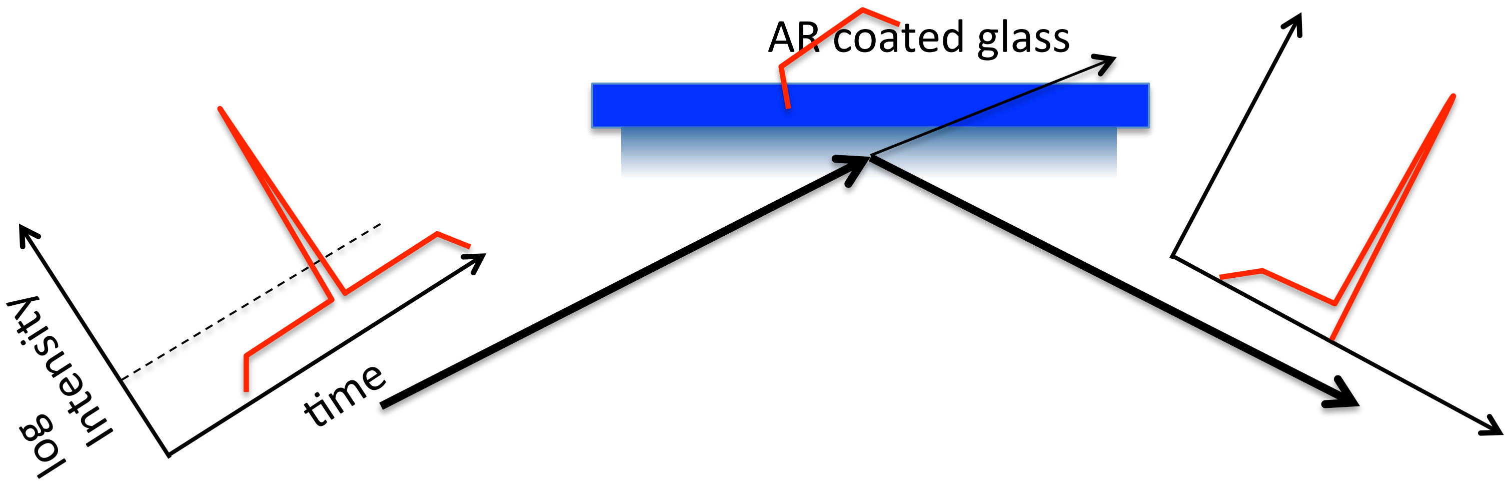
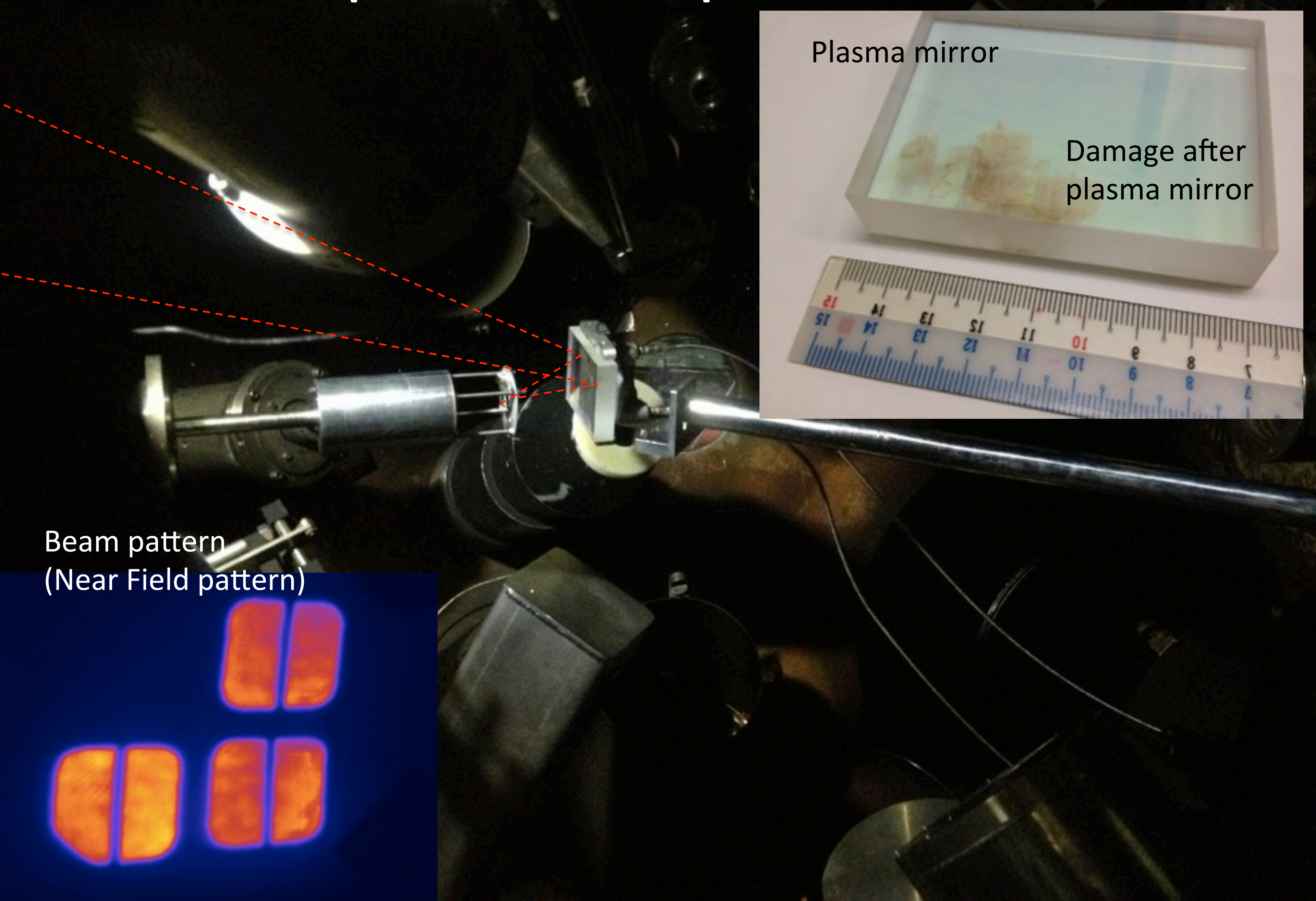


Plasma mirror was demonstrated only with the ~ 100fs pulse duration and small size laser so far.

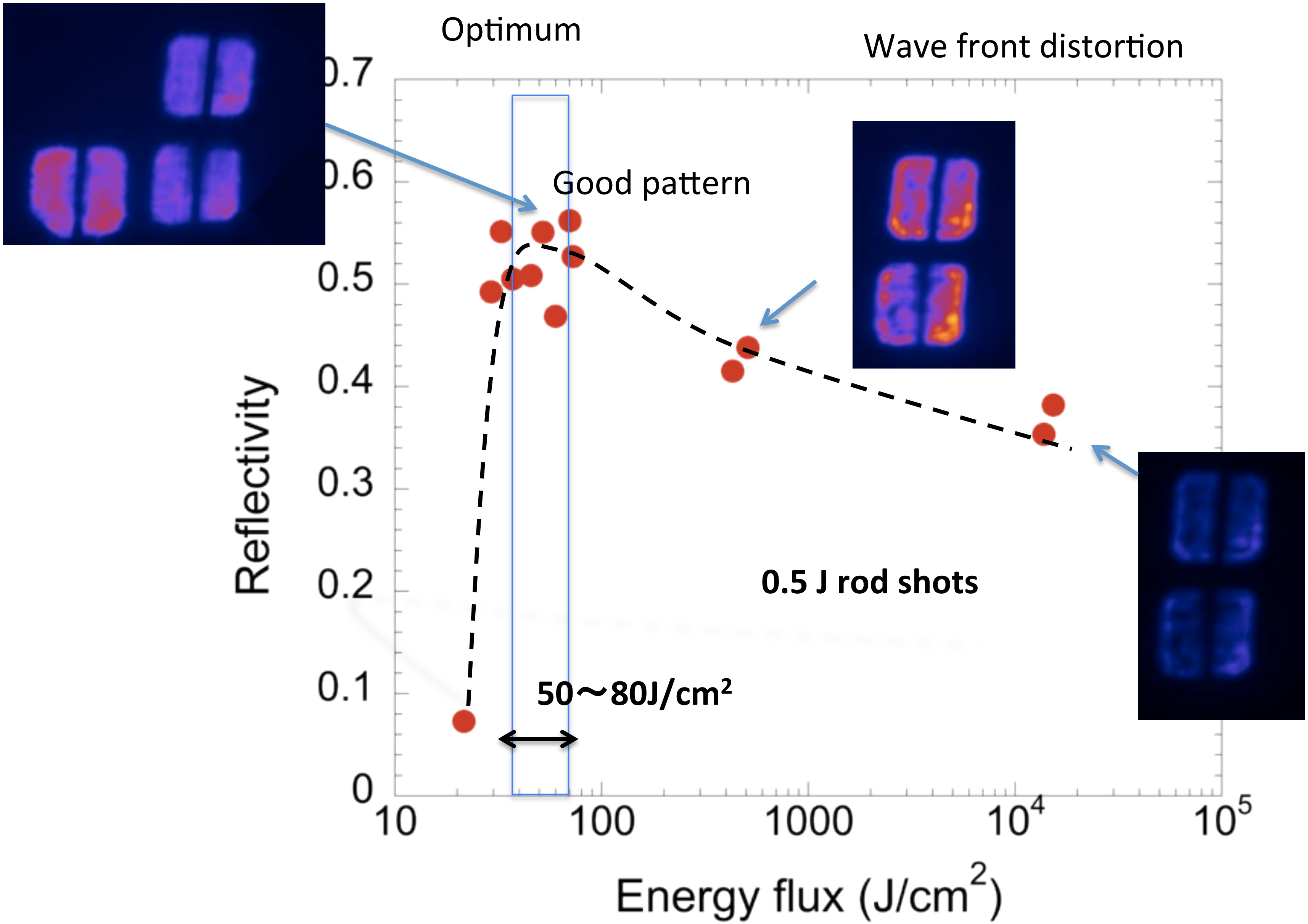
PROBLEM

- **The beam size of LFEX is too large.**
- **The pulse duration is too long.**

First experiment with a plasma mirror on LFEX



Reflectivity 56% was demonstrated



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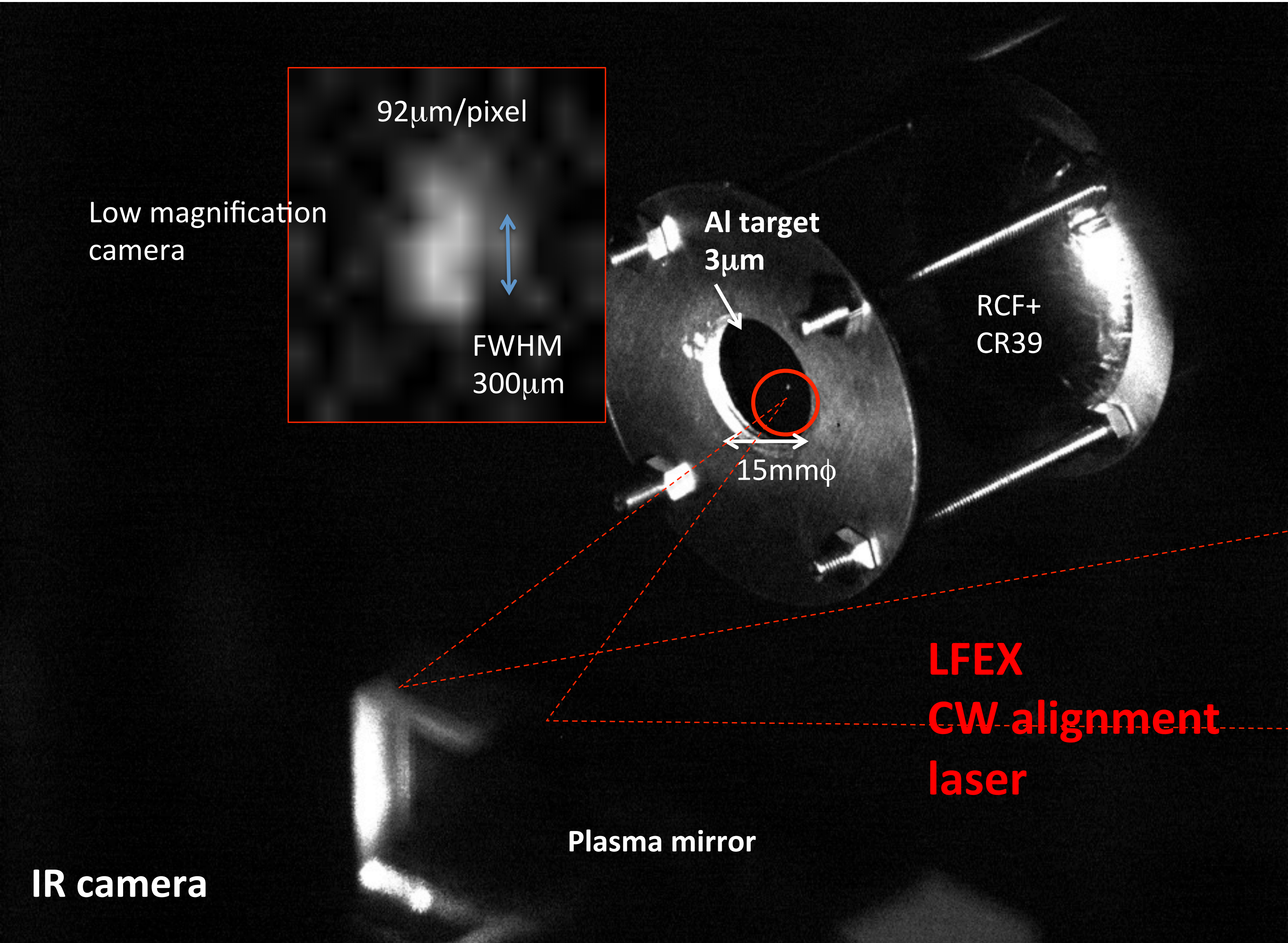
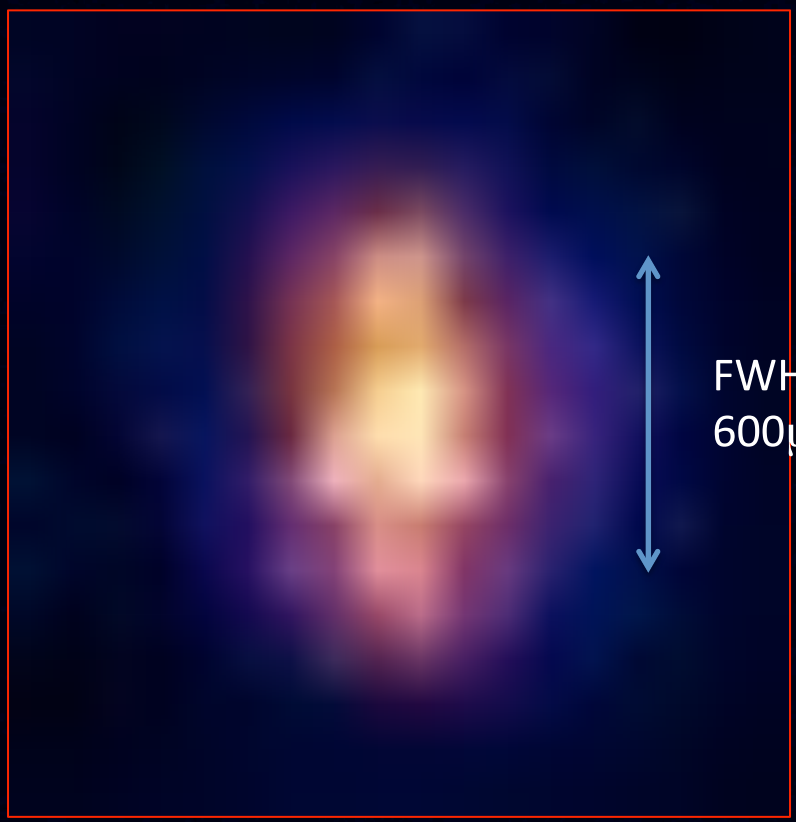

92μm/pixel
Low magnification camera
FWHM 300μm
Al target 3μm
RCF+ CR39
15mmϕ
LFEX CW alignment laser
Plasma mirror
IR camera

Over 500 J shot with a plasma mirror was demonstrated

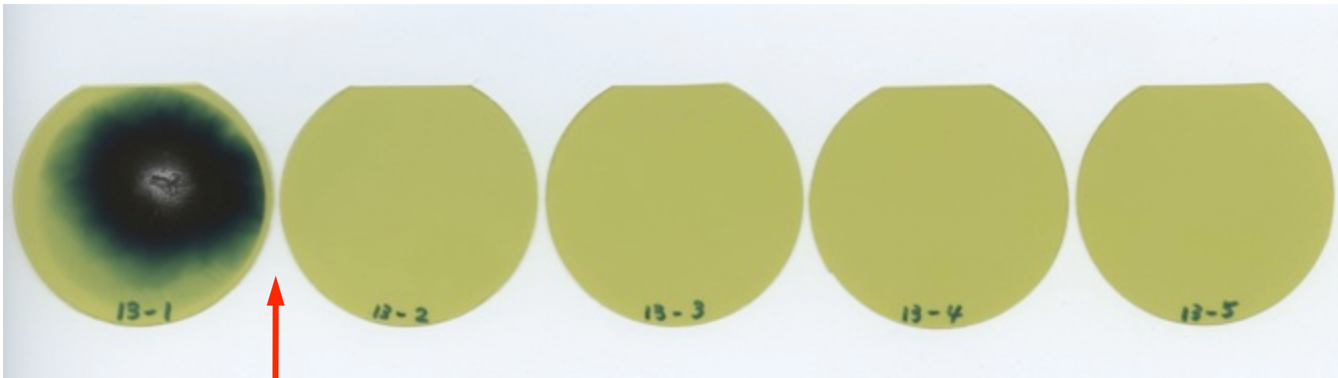
92μm/pixel



FWHM
600μm

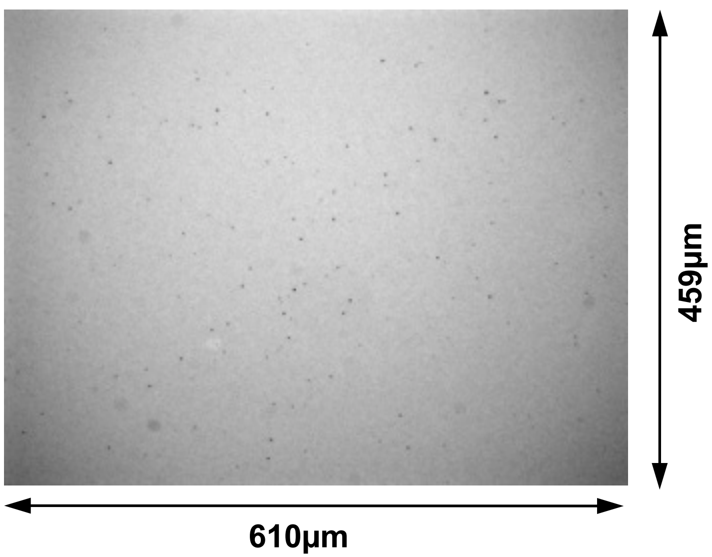
On –shot photo
IR + ND filter
2013/11/29
L2085
Disk amp shot
H2 237.3 J
H3 82.9 J
H4 247.7 J

Proton was successfully accelerated



CR-39
13-1

~3MeV



Even though the proton energy was not so good, we firstly succeeded to realize world largest plasma mirror on LFEX.

Data from Dr. Sagisaka,

Plasma mirror will be utilized in this year

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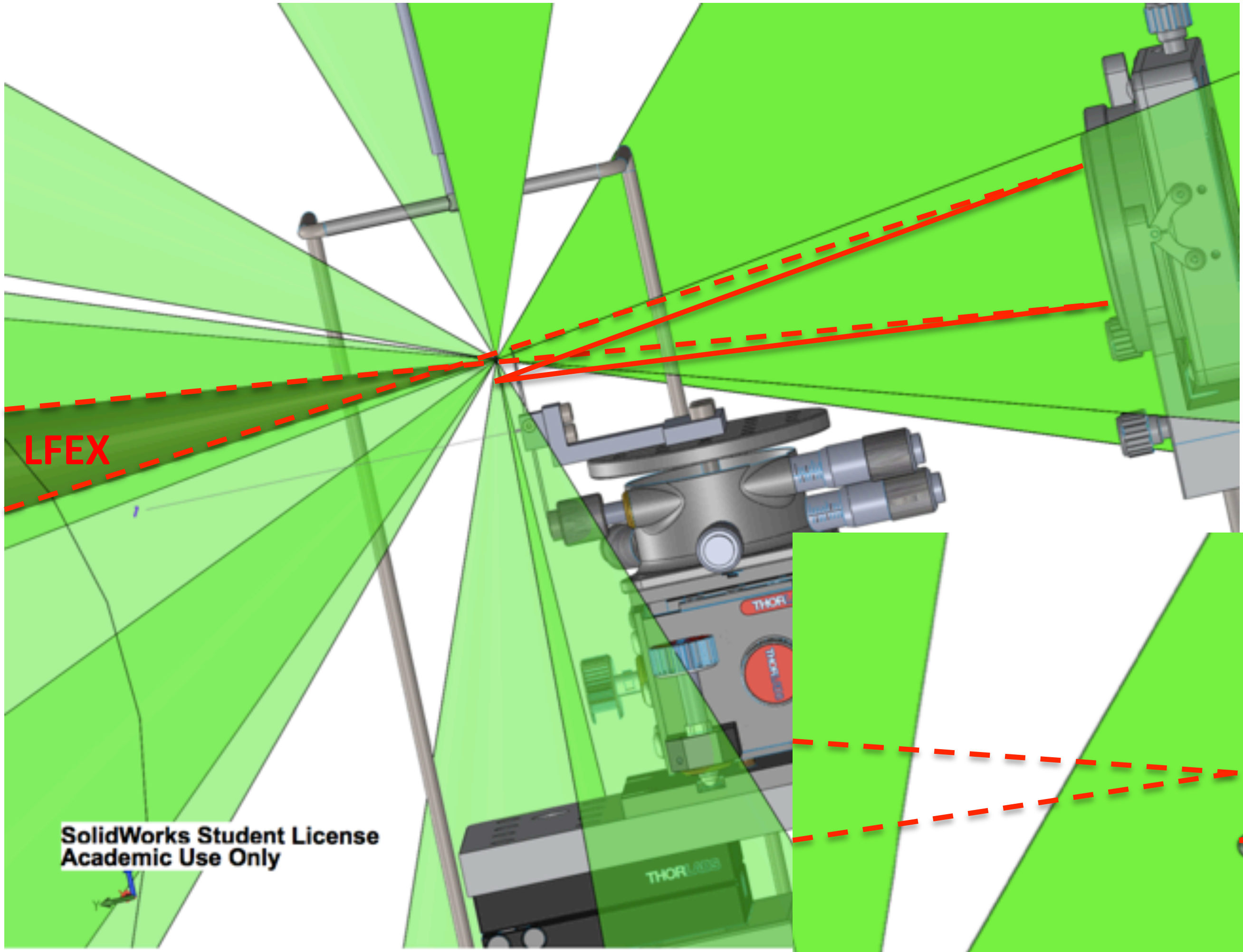
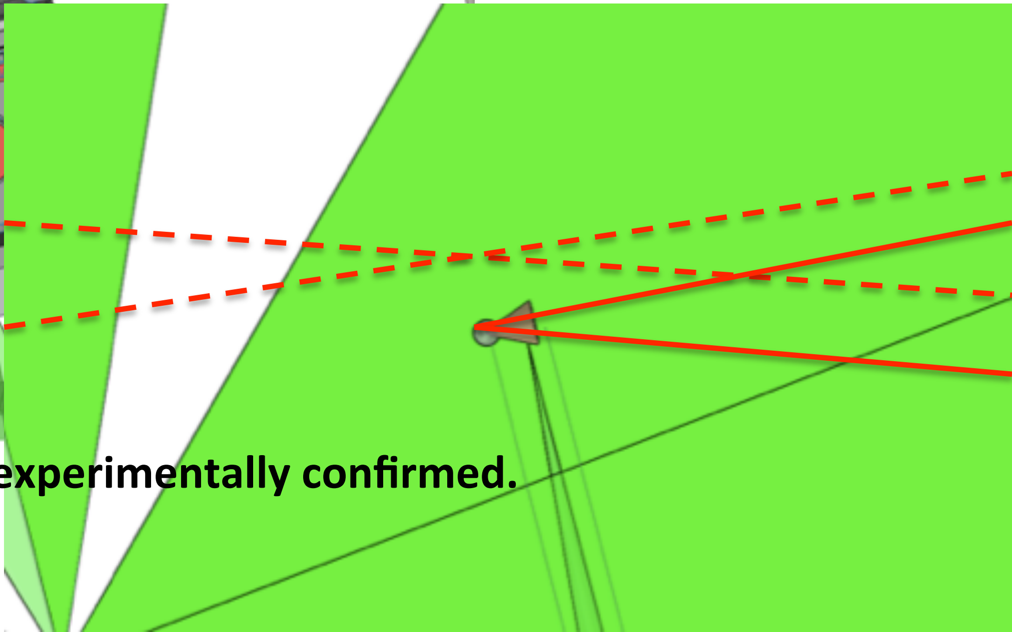


Spherical
Plasma mirror



The focusebility, pedestal reduction, will be experimentally confirmed.

How can we measure ?

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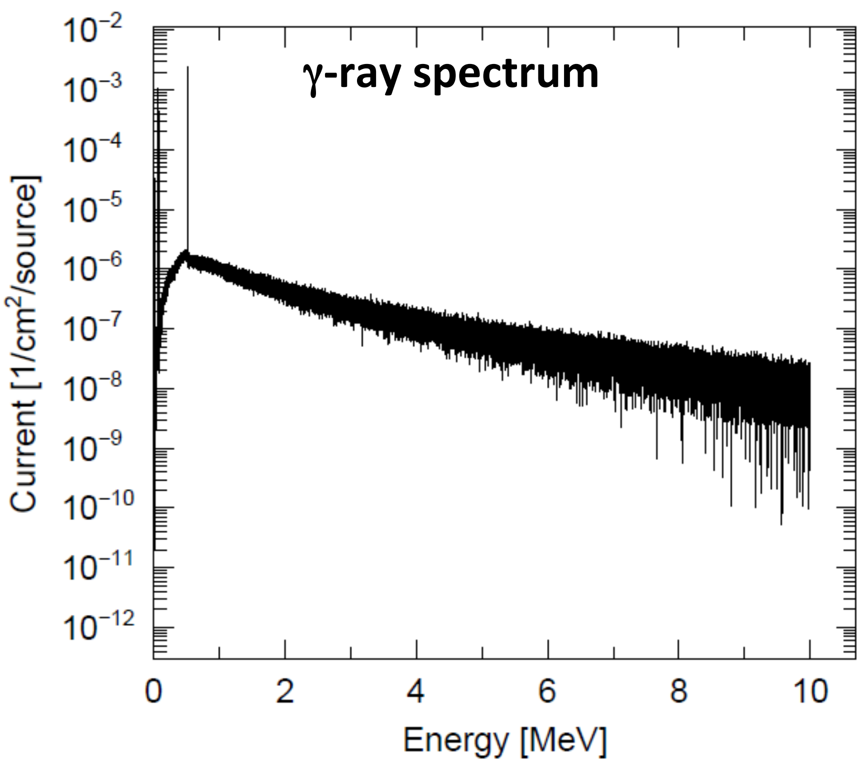
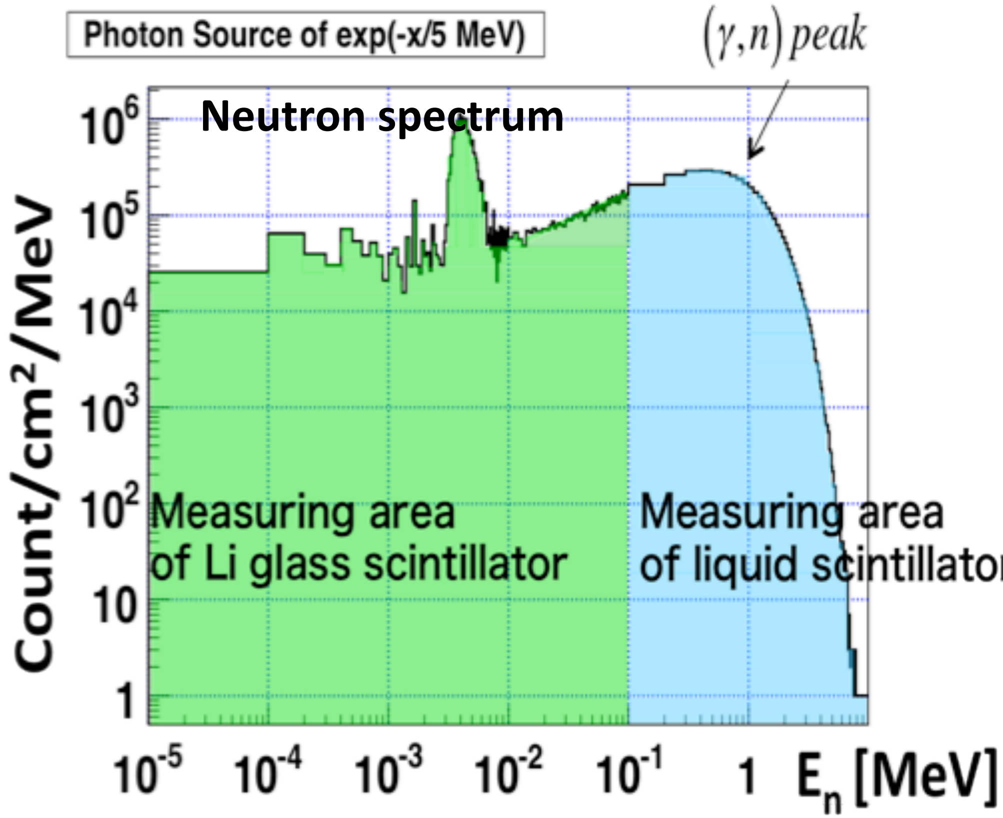
- γ-ray spectrum : keV ~ 100 MeV γ-ray
- Neutron spectrum: thermal ~ 10 MeV neutron
- β-decay from isomers: ~μs time scale β-ray





Wide range X-ray spectrometers have been developed

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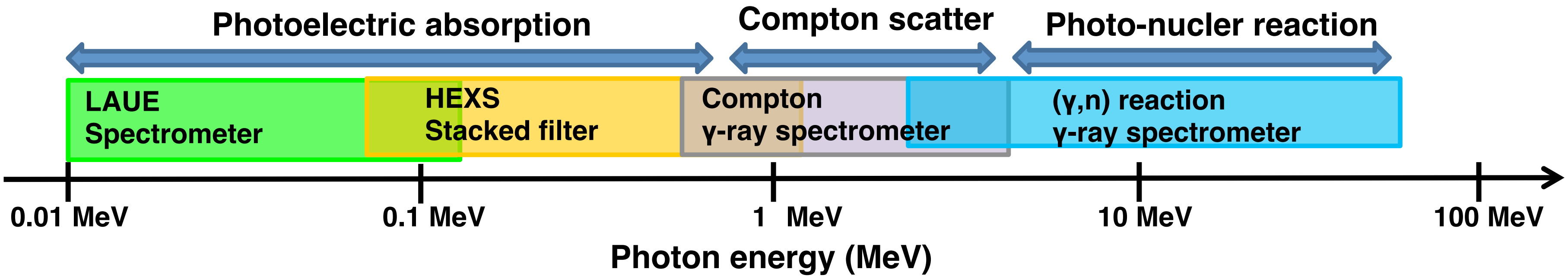
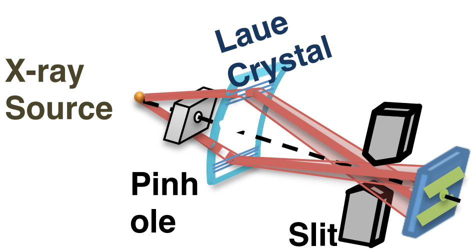
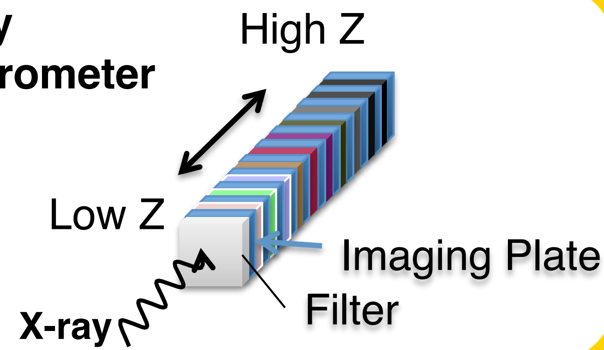


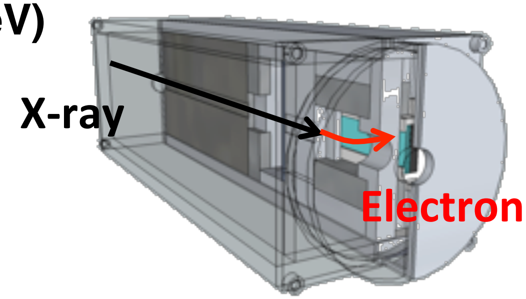
LAUE Spectrometer (<0.1 MeV)



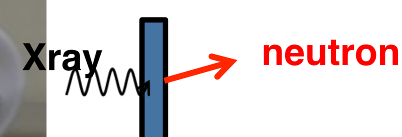
High Energy X-ray Spectrometer (< 1 MeV)



Compton γ-ray spectrometer (0.5 - 5 MeV)



(γ,n) reaction γ-ray spectrometer (3 - 30 MeV)



Wide range X-ray spectrum detection was demonstrated

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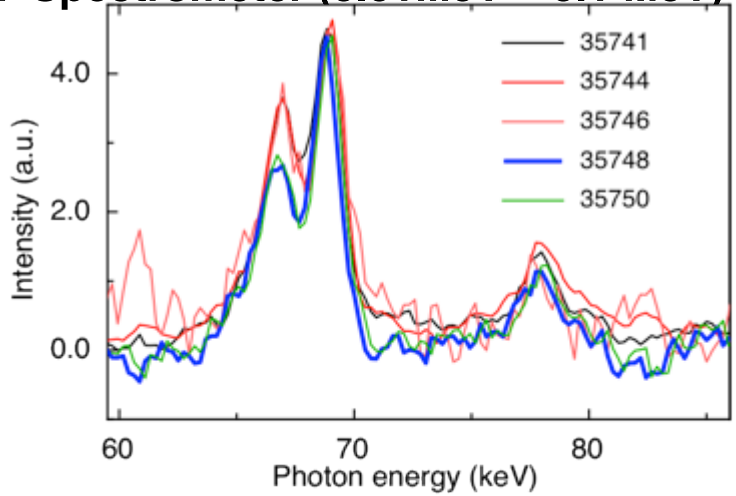
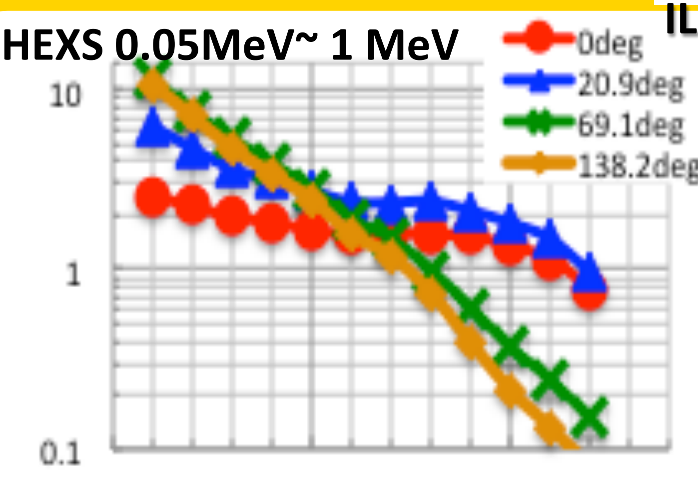
LAUE Spectrometer (0.01MeV ~ 0.1 MeV)

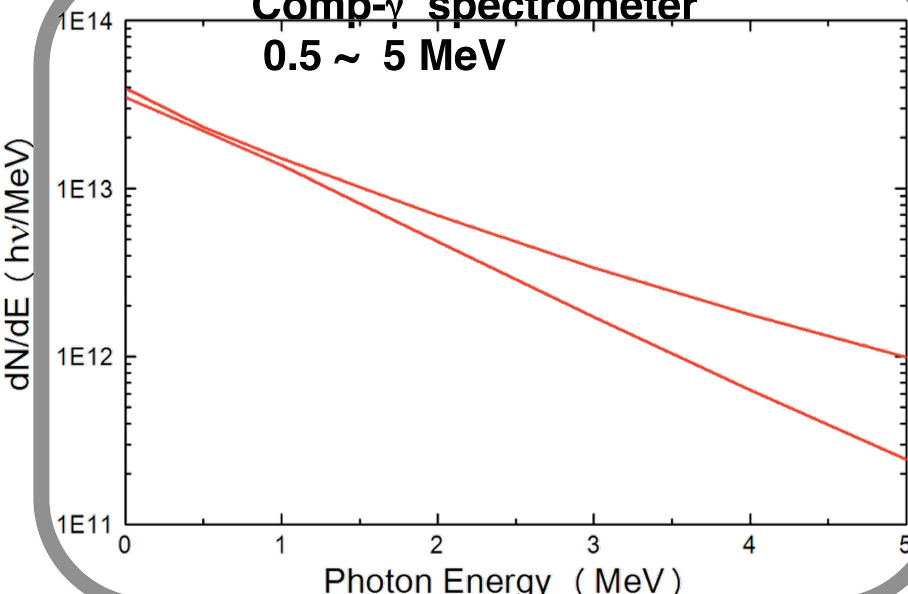


HEXS 0.05MeV~ 1 MeV

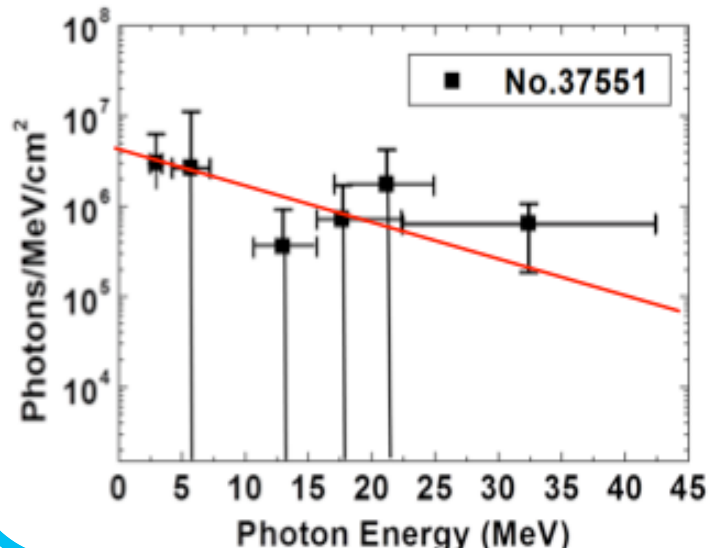


~0.05MeV ~0.1 MeV ~0.3 MeV

Comp-γ spectrometer
0.5 ~ 5 MeV



γ-Bubble 3 ~ 40 MeV



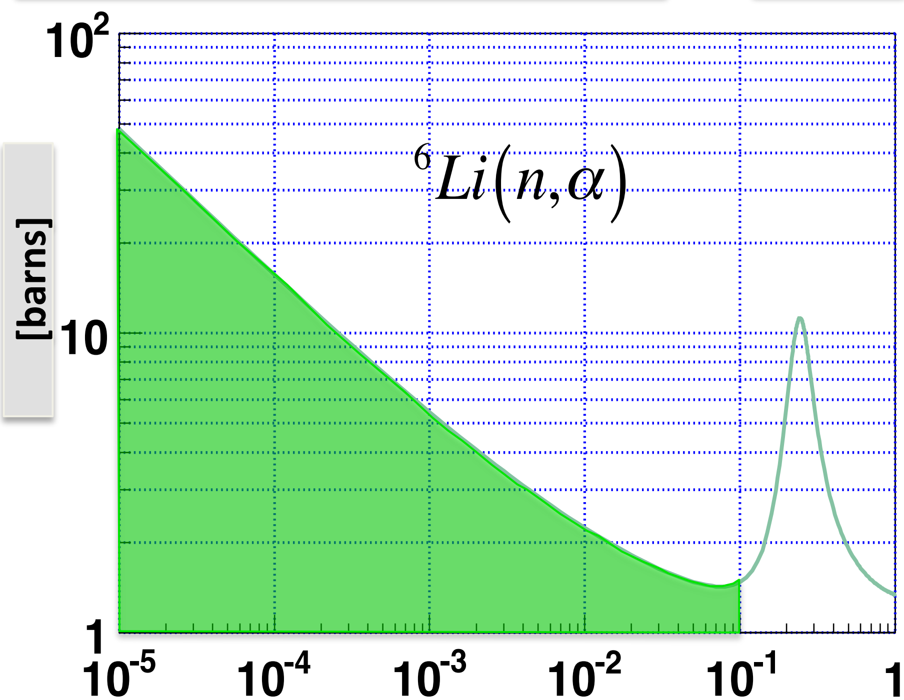
Organic/Li-6 scintillator combine provides wide energy range

Fast response Li-6 glass sci.

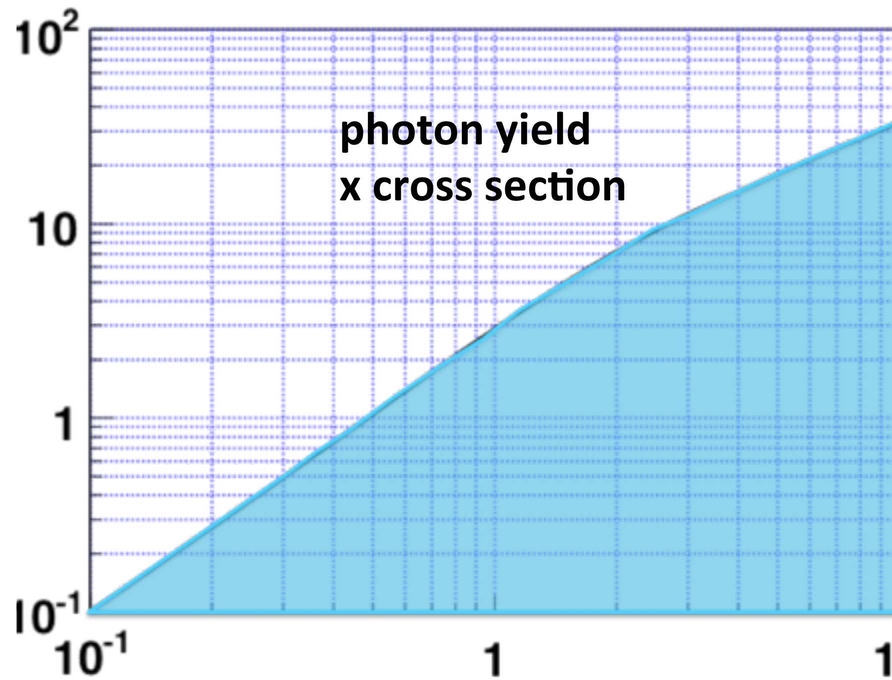
Fast response liquid sci.

Neutron cross section

^{6}Li



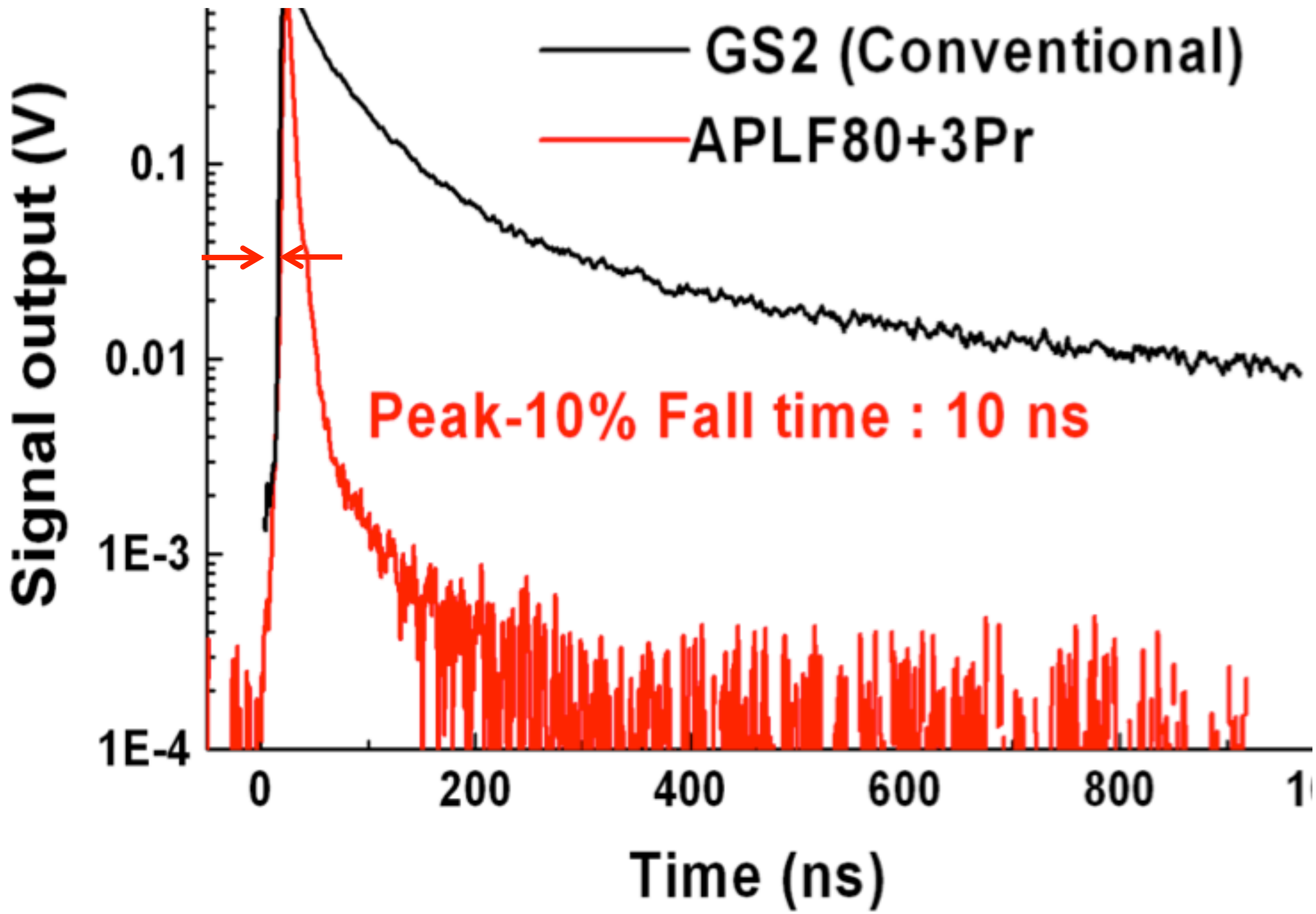
^{2}H



Neutron energy[MeV]

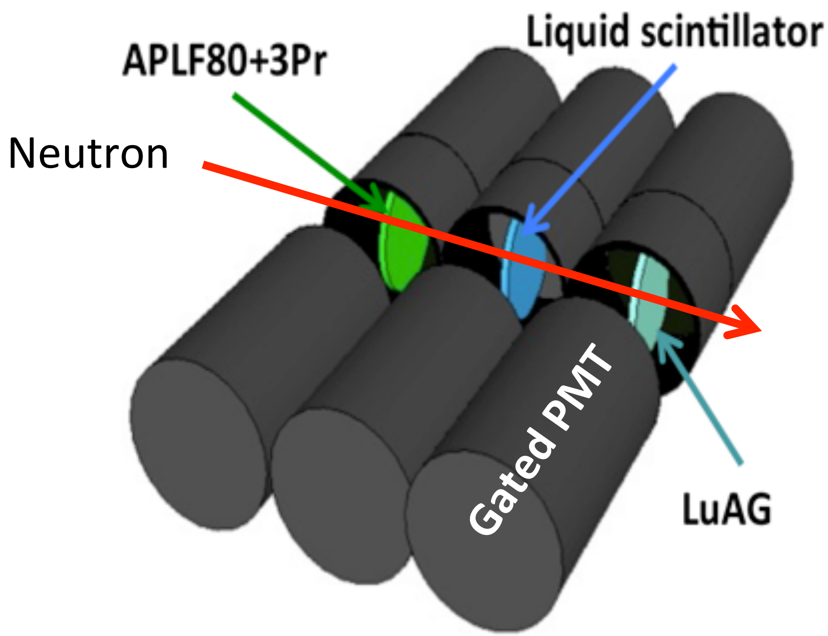
Fast response ^{6}Li scintillator APLF 80+3Pr

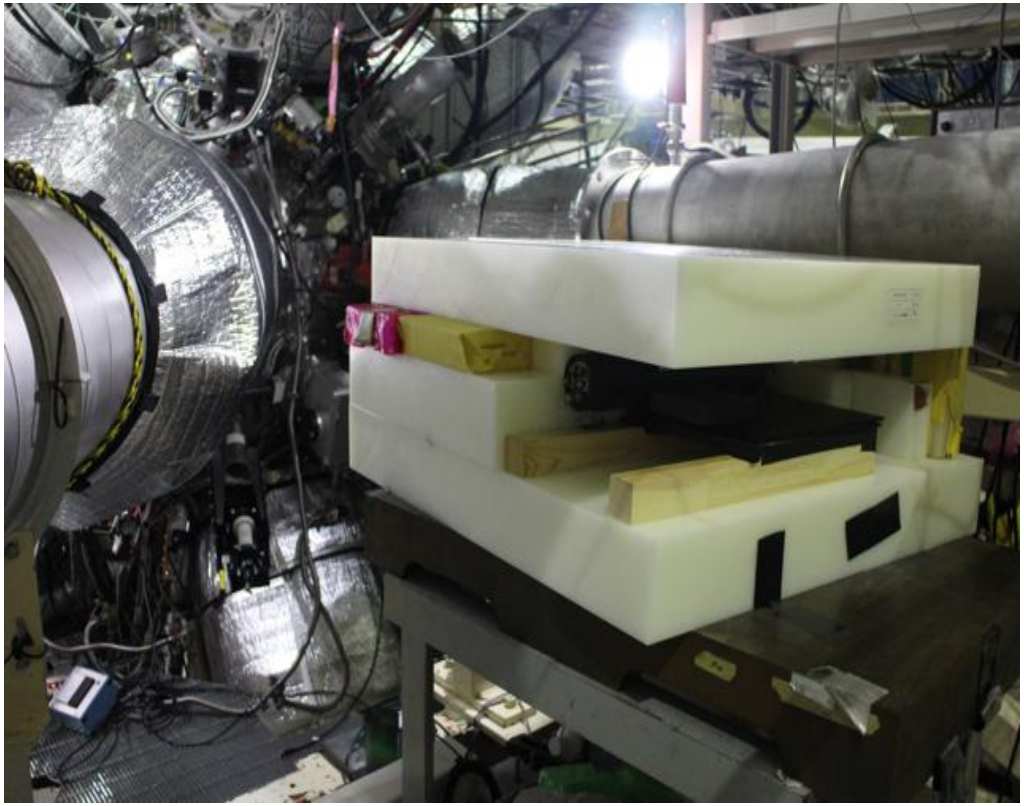
Sealed neutron source



Y. Arikawa et al., *Rev. Sci. Inst.* 80, 113504 (2009),

N-TOF detector with three different scintillators.





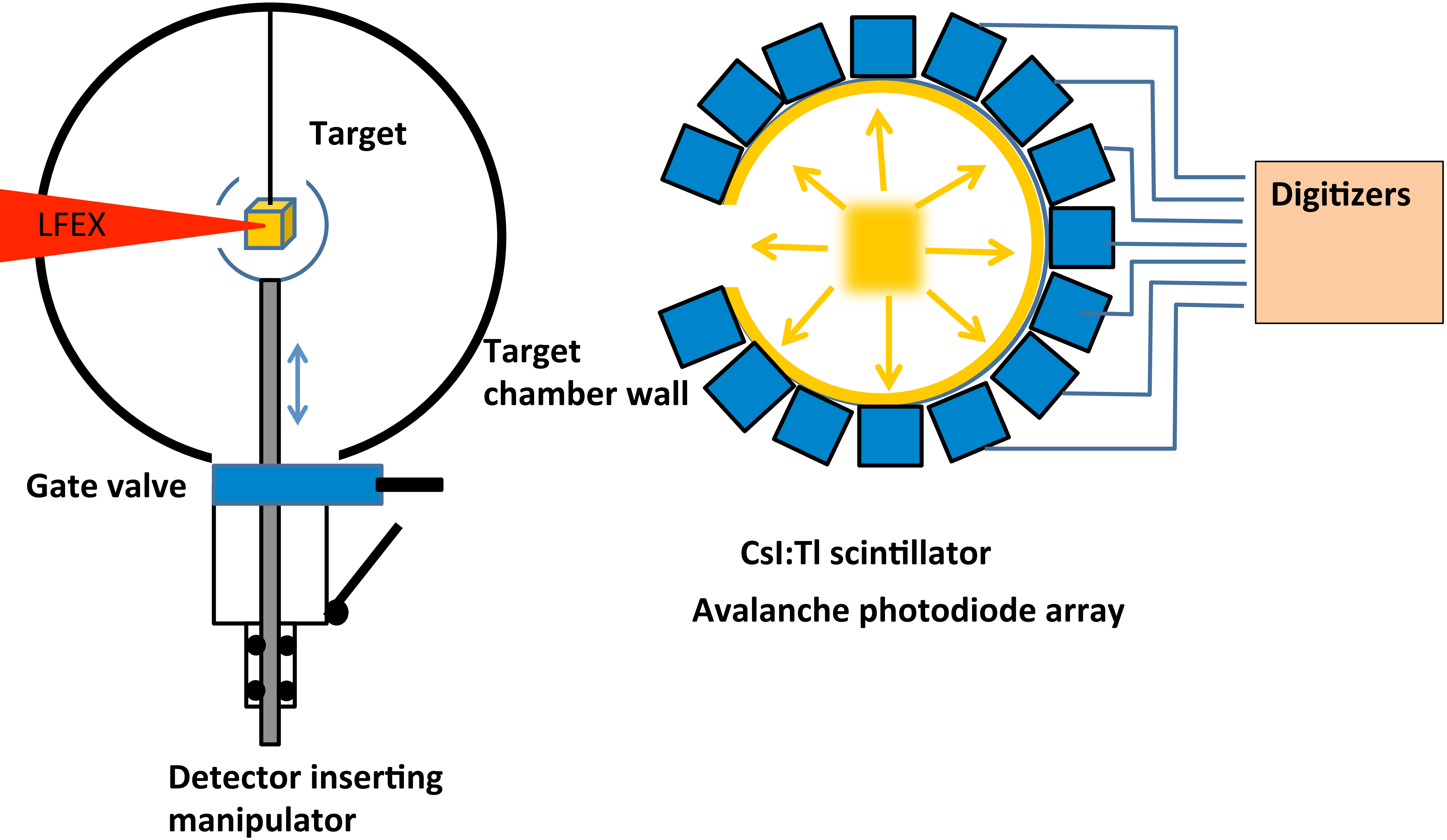
APLF80+3Pr : low energy neutron sensitive

Liquid : fast neutron sensitive

LuAG:Pr : γ-ray sensitive

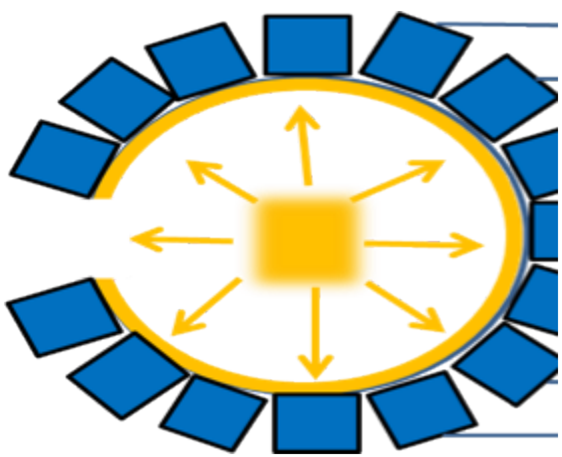
Double PMT: large dynamic range

μs- time resolution β-decay counter



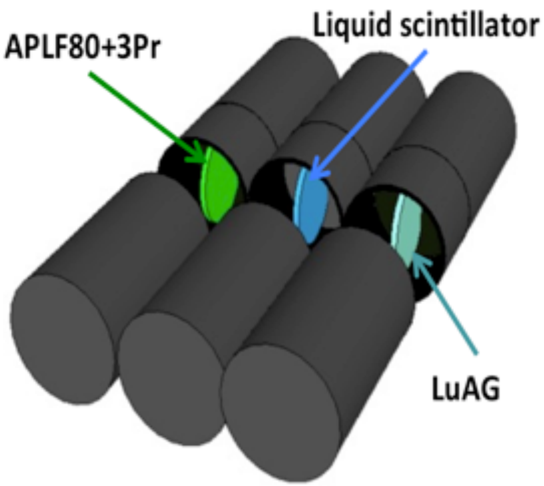
neutron/ γ-ray spectrum are ready.

- B-decay from isomer ･･･Fast multi chanel β-ray counter
- kev ~ 100 MeV γ-ray ･･･ comp γ-ray, etc.
- eV ~ 10 MeV neutron･･･Gated N-TOFs,



Under designing

Demonstrated, working



Tested,
under modification

Summary

ILE Osaka

▪Laser driven γ-ray or neutron generation can open stellar nuclear science.

▪LFEX laser demonstrated 10^9 neutron/ shot by photo-nuclear reaction. and will be improved more.

▪The γ-ray and neutron peak intensity exceeds 10^{27} /cm^2 s and 10^{21} /cm^2 s.

▪Plasma mirror was demonstrated on LFEX sub-kJ shot.

We need your ideas for pushing the nuclear science by using LFEX. Why don't you join us!

Thank you for your attention!

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