Future Application of NRF NDA using LCS gamma-rays to Detection of Nuclear Material with Heavy Shield in Cargo Containers

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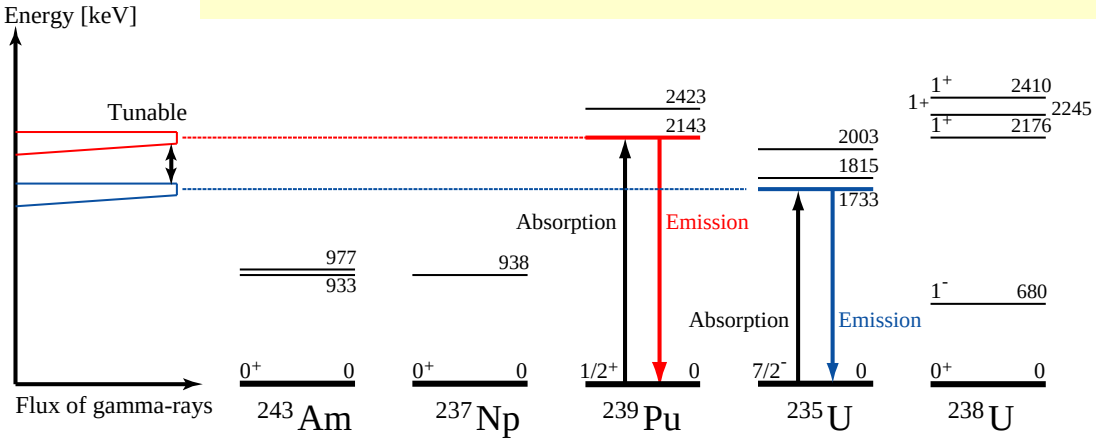
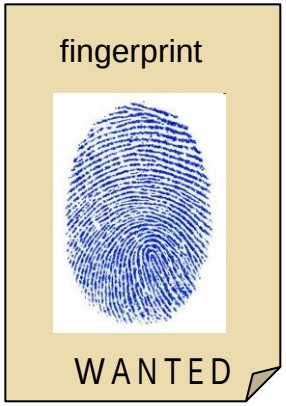
Nondestructive Detection of Nuclear Material

NRF=Nuclear Resonance Fluorescence





Nondestructive Detection

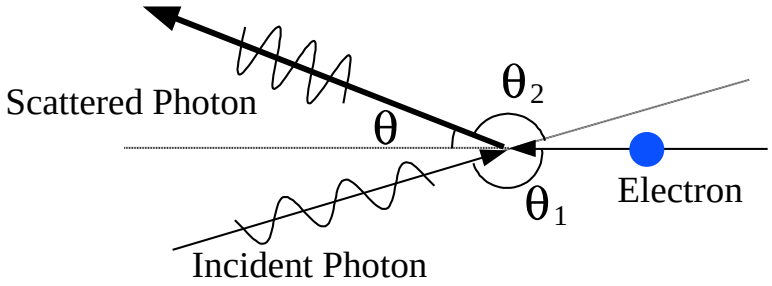
Nuclear material ?

- ✓ Strong penetration of γ-ray
- ✓ Isotope specific detection
- ✓ No further radioactivation

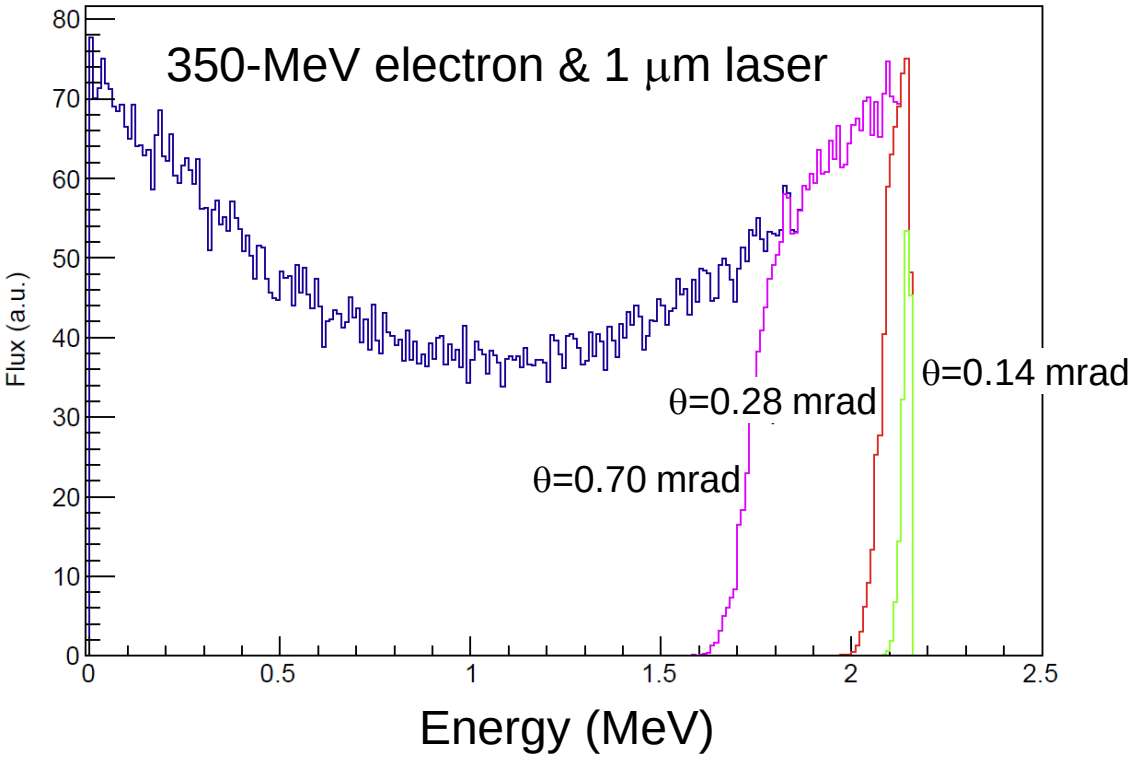
R. Hajima et al., J. Nucl. Sci. Tech. 45, 441 (2008)
J. Pruet et al., J. App. Phys. 99, 123102 (2006)

Laser Compton Scattering (LCS)

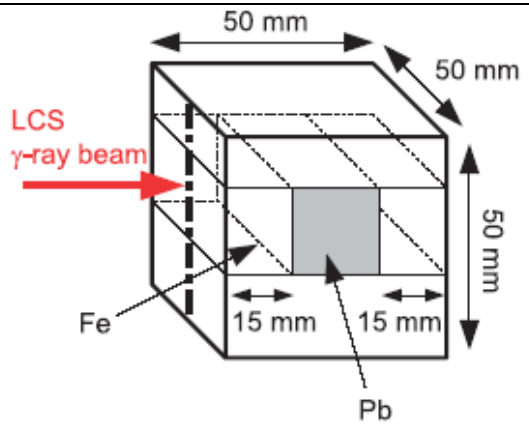
γ-ray generation by collision of electron and laser beams



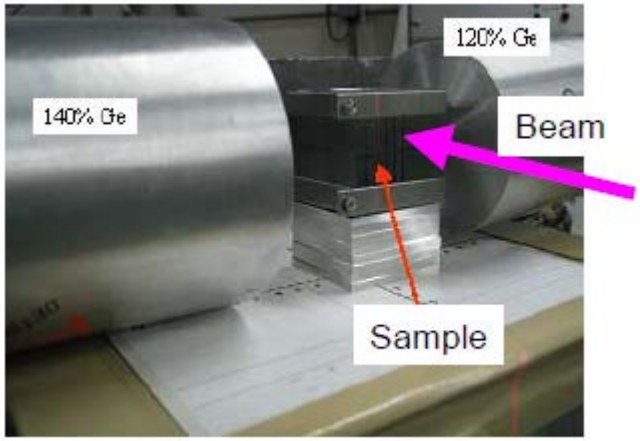
- ✓ Pencil like beam
- ✓ Energy Tunable
- ✓ Quasi-monochromatic with collimators

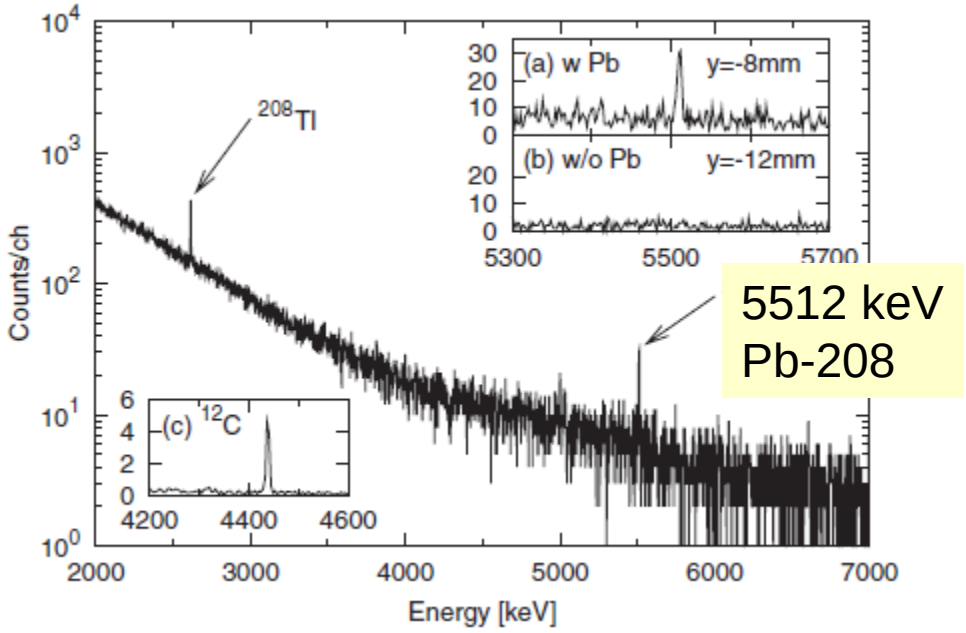


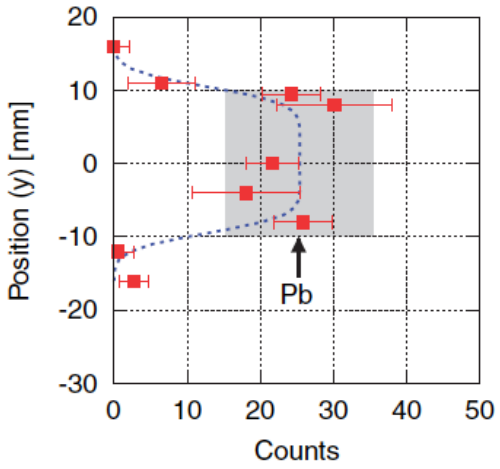
Experimental Demonstration – nondestructive detection of isotope



Pb block shielded by 15mm-thick iron box







Position and shape of the Pb block were clearly identified.

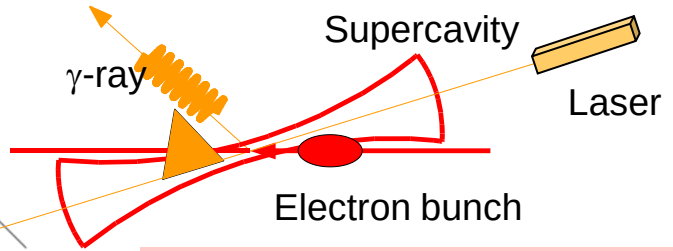
N. Kikuzawa et al., Applied Physics Express 2, 036502 (2009).

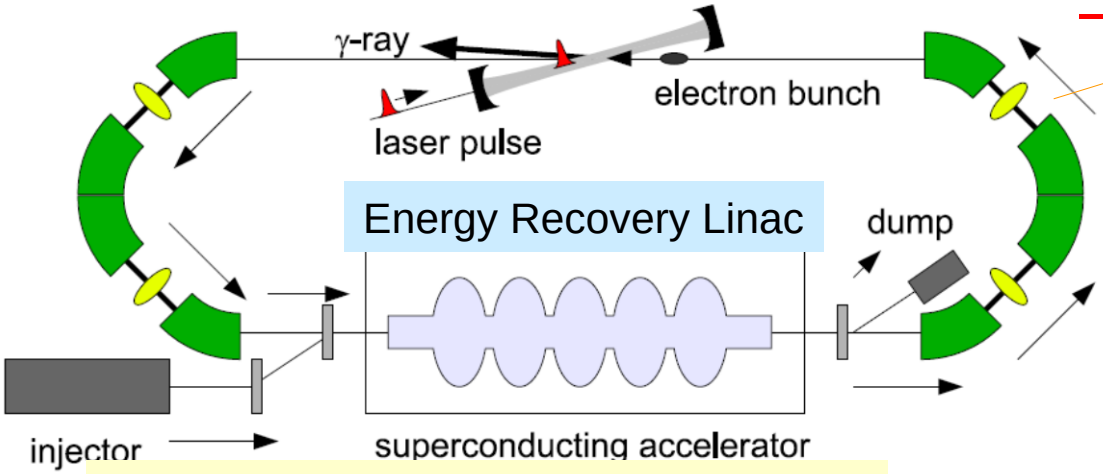
~ 10 hours @ AIST

Proposal of ERL-based LCS source

collision at a small spot
collision at a high repetition
→ Low emittance & high-average current

laser enhancement cavity

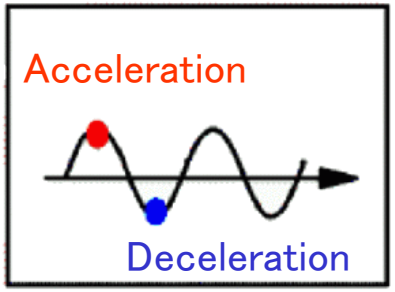




laser photons are recycled

high-flux γ-ray

electron energy is recycled



- Electron beam = 350 MeV, 13 mA
- Laser intracavity = 700 kW
- **LCS ~2MeV, 1x10^{13} ph/s**

0.1 ph/eV/s → 10^7 ph/eV/s

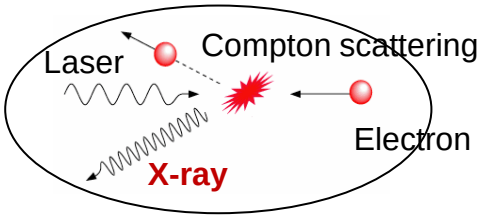
AIST
(1st-generation LCS)

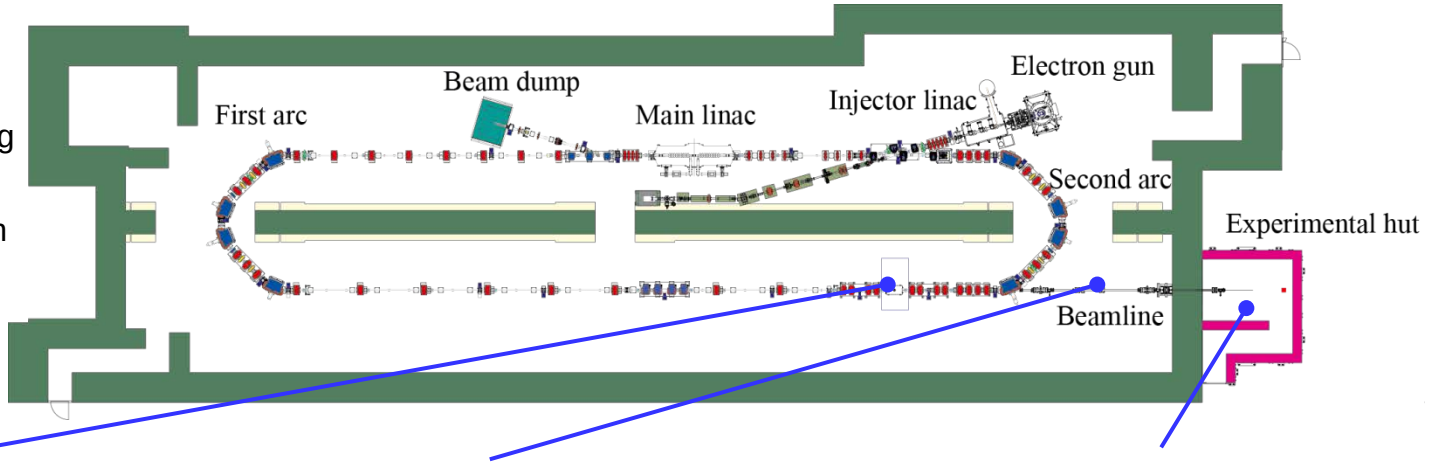
ERL

R. Hajima et al., NIM-A608 (2009)

LCS Experiment at Compact ERL

Demonstration of technologies relevant to future ERL-based LCS sources

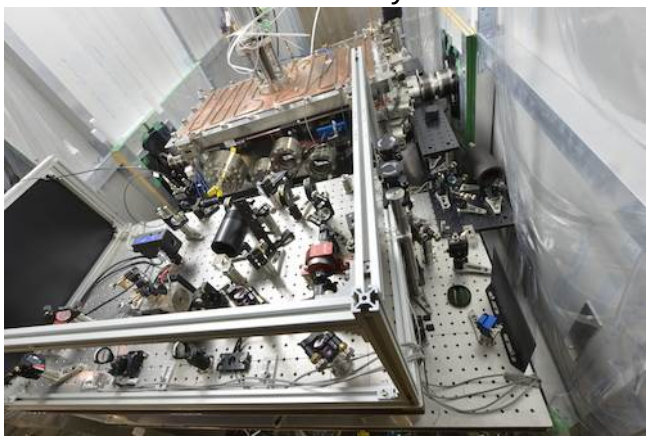




Laser enhancement cavity and 45W laser

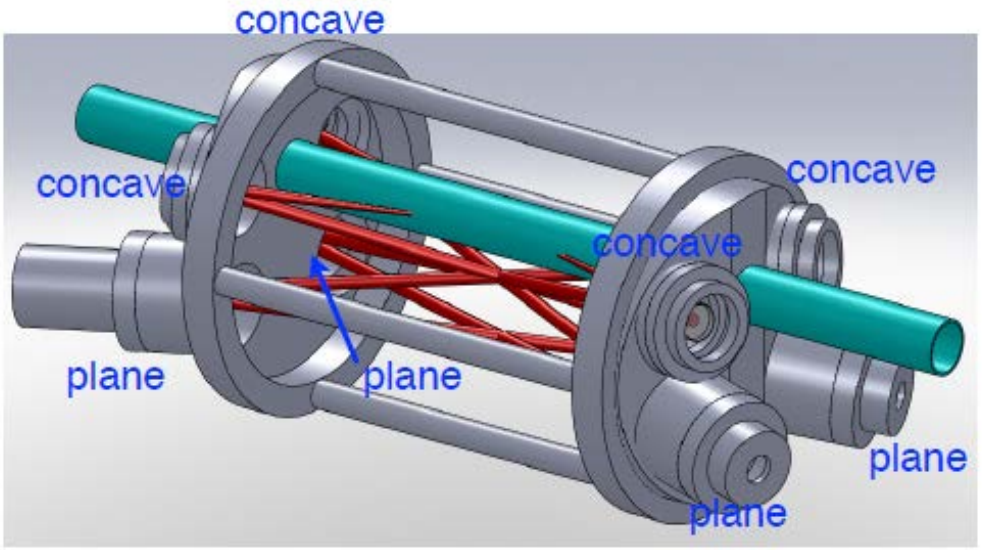
Beam line

Experimental hut



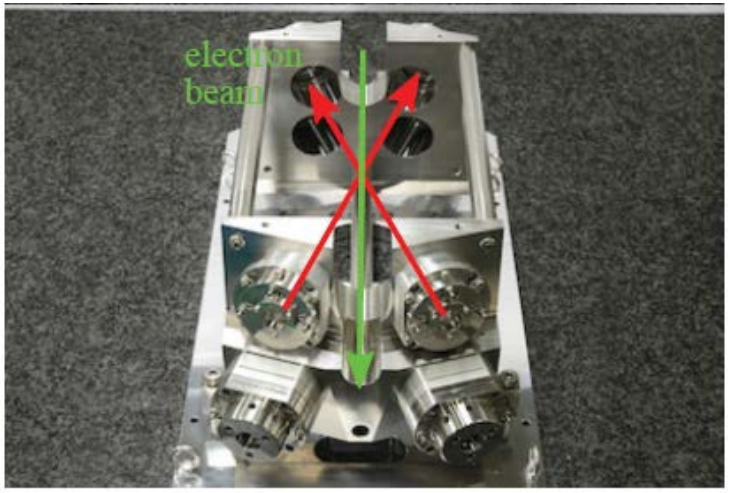
Work supported by:
A government (MEXT) subsidy for strengthening nuclear security (R. Hajima, JAEA), and
Photon and Quantum Basic Research Coordinated Development Program from the MEXT (N. Terunuma, KEK)

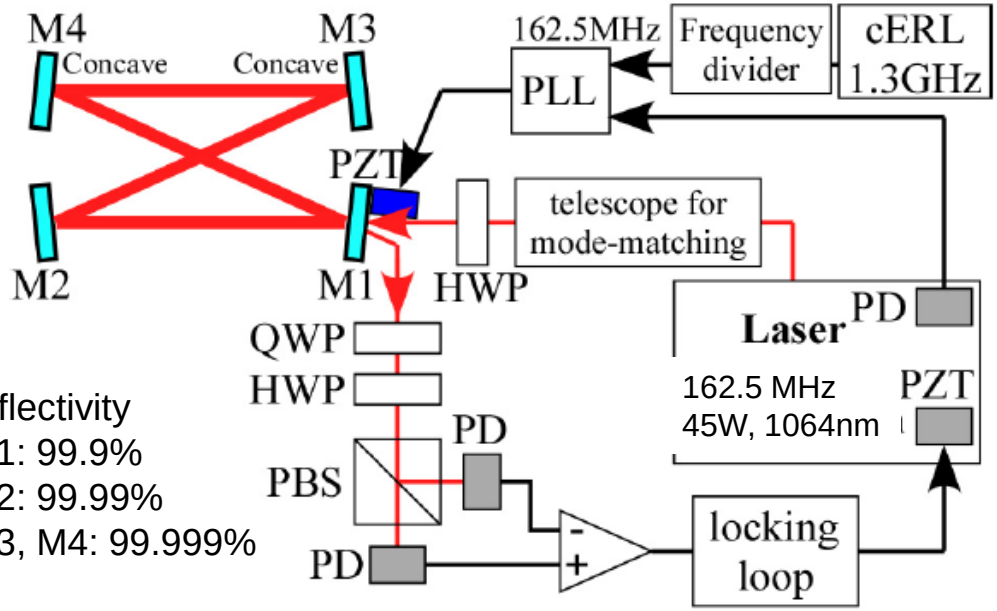
Laser Enhancement Cavity



Developed by T. Akagi (KEK)

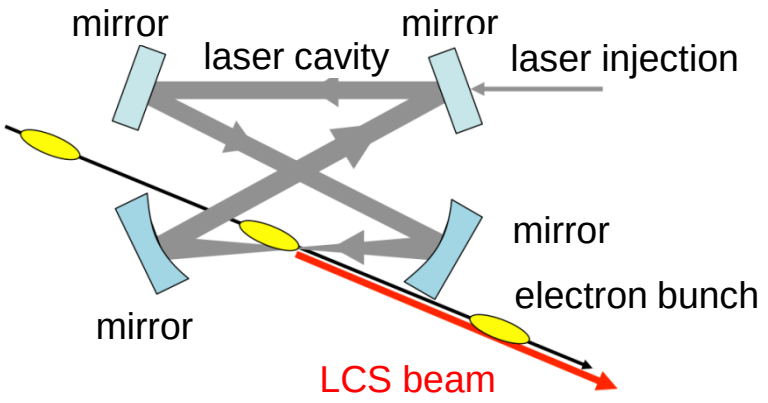
T. Akagi et al., Proc. IPAC-2014, p.2072
A. Kosuge et al., Proc. IPAC-2015, TUPWA-66





reflectivity
M1: 99.9%
M2: 99.99%
M3, M4: 99.999%

Spot size: σ=30μm



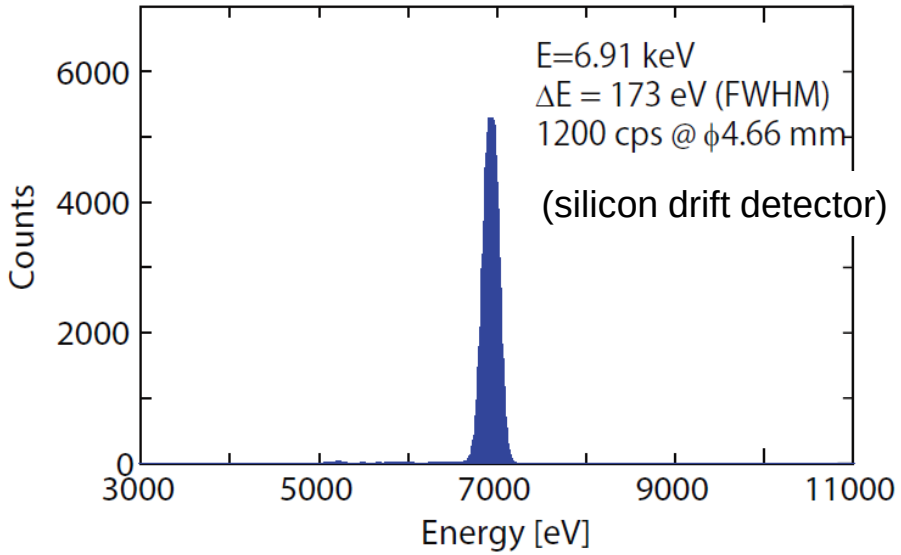
X-ray Produced by LCS

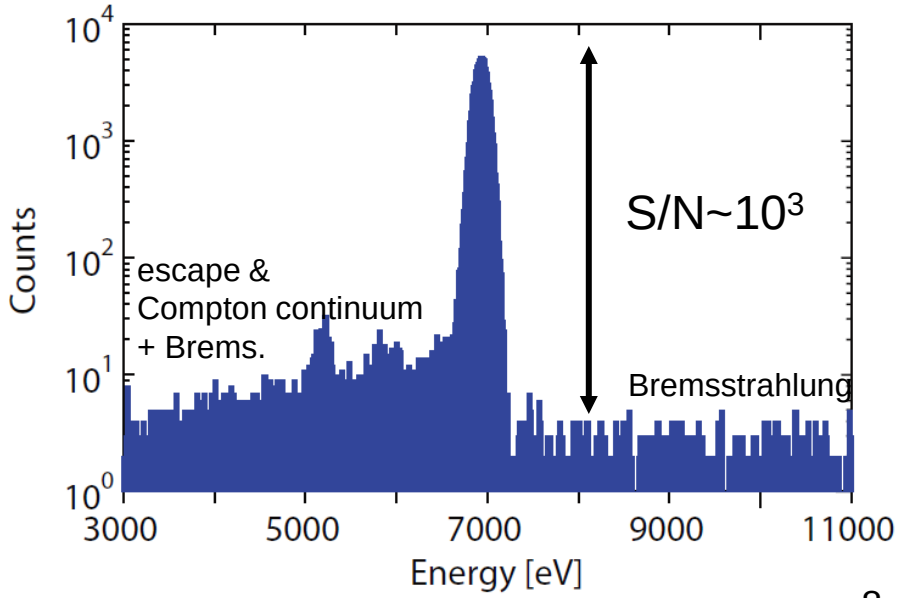
Parameters of electron beams:

Energy [MeV]	20
Bunch charge [pC]	0.36
Bunch length [ps, rms]	2
Spot size [μm, rms]	30
Emittance [mm mrad, rms]	0.4
Repetition Rate [MHz]	162.5
Beam current [μA]	58

Parameters of laser (enhanced by cavity):

Center wavelength [nm]	1064
Pulse energy [μJ]	64
Pulse length [ps, rms]	5.65
Spot size [μm, rms]	30
Collision angle [deg]	18
Repetition rate [MHz]	162.5
Intracavity power [kW]	10





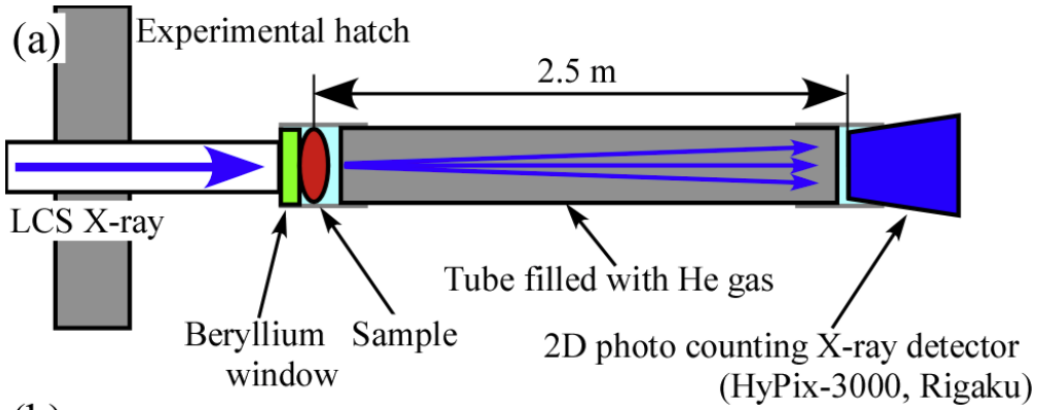
Results:

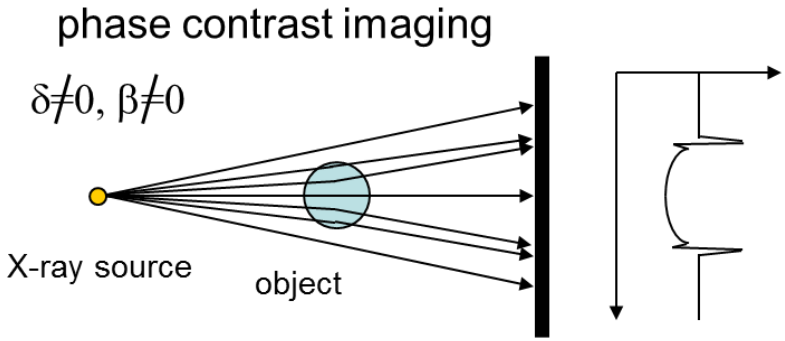
Photon energy = 6.9 keV
Detector count rate = 1200 cps @ϕ4.66mm (*)
Source flux = 4.3 x 10^7 ph/s (**)

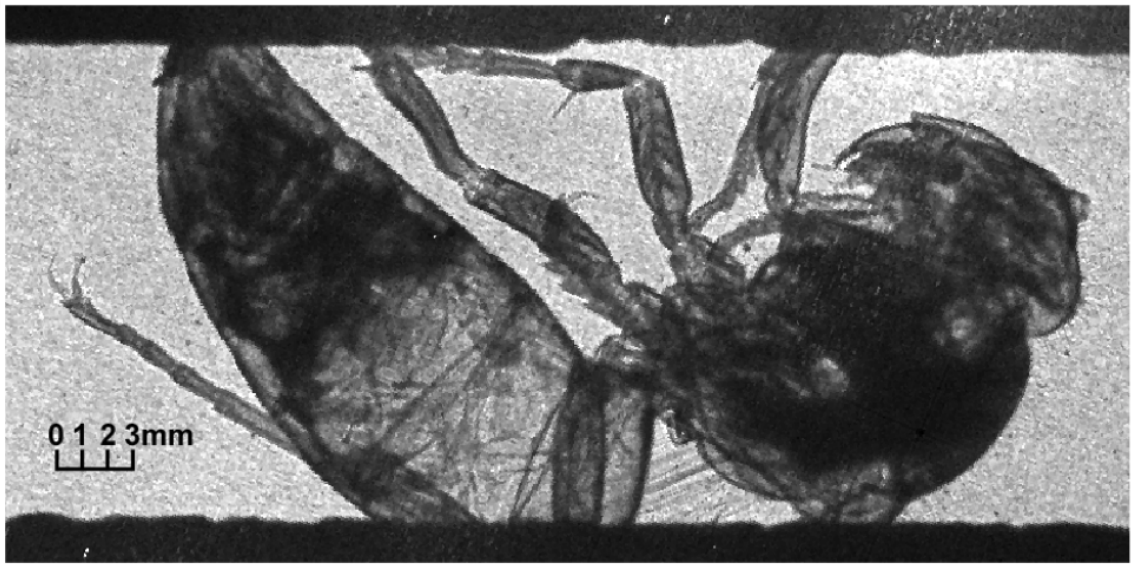
(*) Detector collecting angle is 4.66mm/16.6m = 0.281 mrad
(**) CAIN/EGS simulations with the detector count rate

R. Nagai et al., Proc. IPAC-2015, TUPJE002

X-ray imaging with a LCS beam





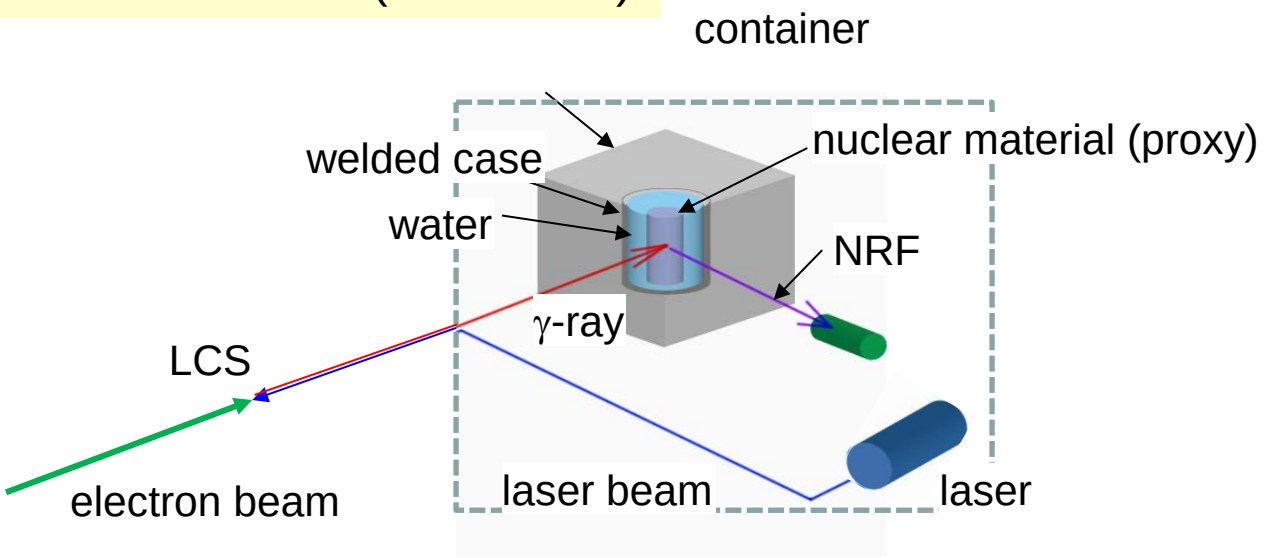


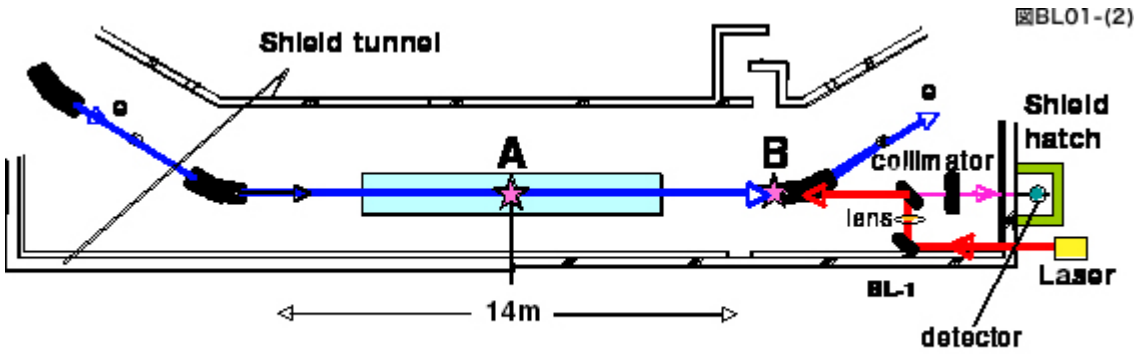
An X-ray image of a hornet taken with LCS-produced X-ray.
Detector: HyPix-3000 from RIGAKU. Detector was apart from the sample by approx. 2.5 m.

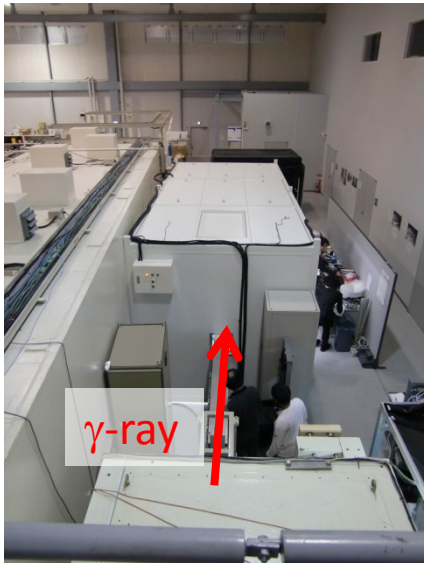
A. Kosuge et al., Proc. IPAC-2015, TUPWA066

NDA experiment with a heavy shield

Planned at NewSUBARU (2015-2019)



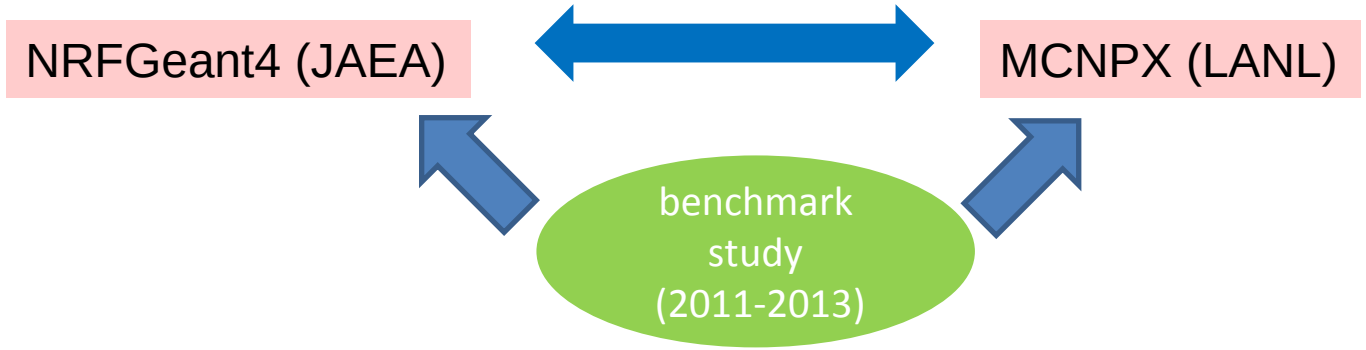


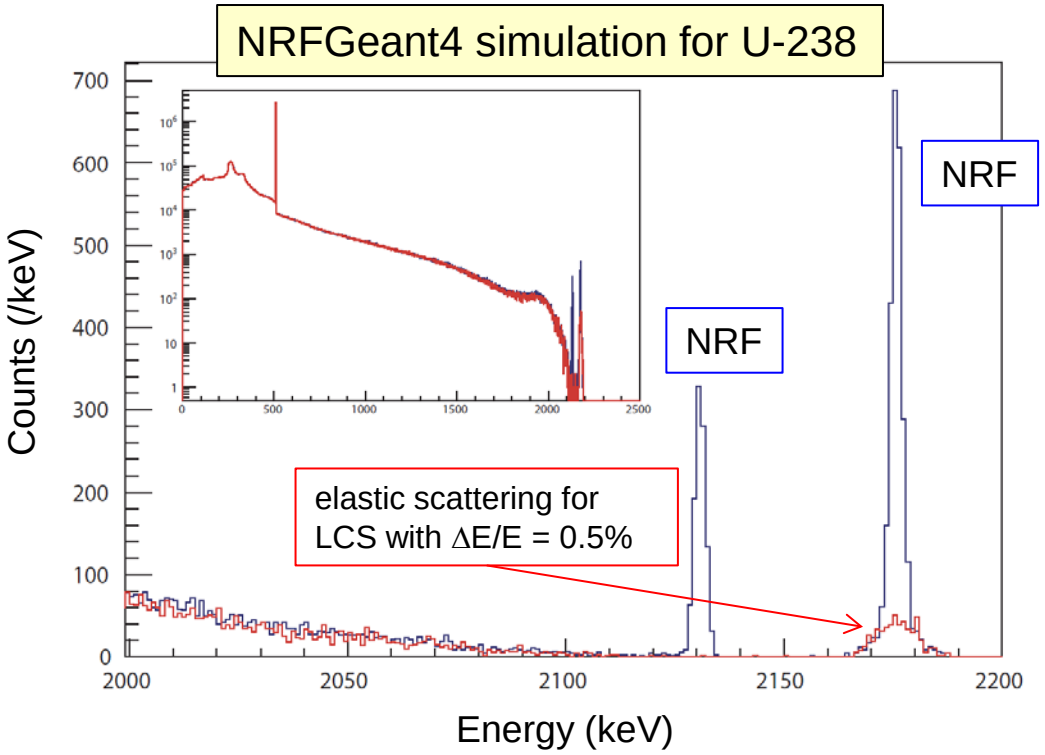


A: collision point for Nd laser (1.064 μm)
B: collision point for CO_2 laser (10.52 μm)

http://www.lasti.u-hyogo.ac.jp/NS/facility/bl01/

Monte Carlo code for NRF





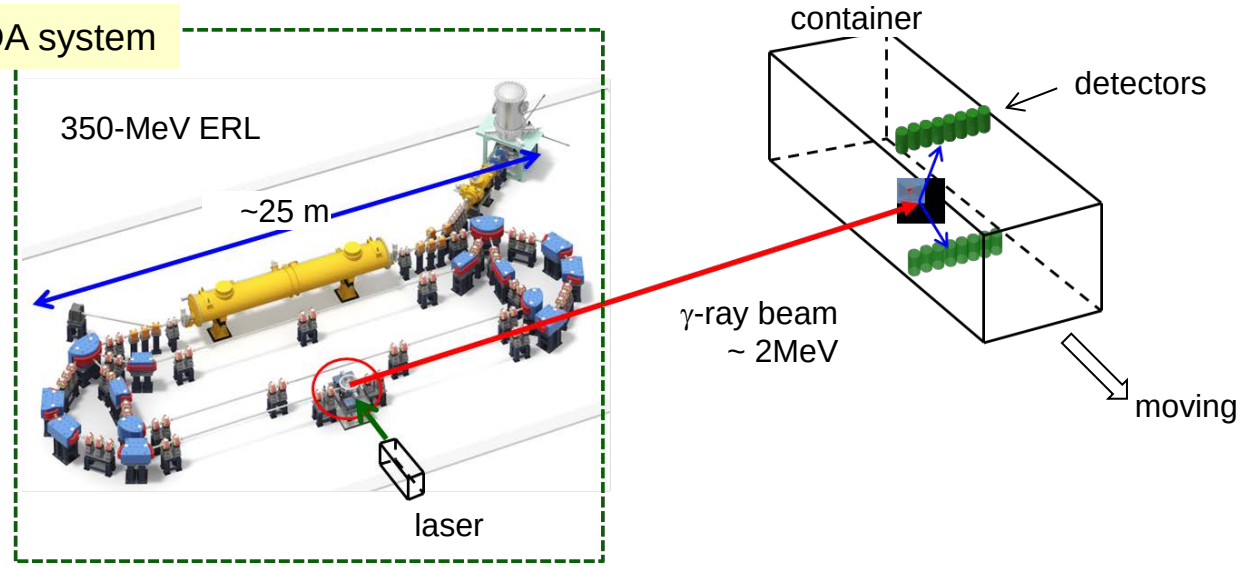
Further improvement is underway

- ✓ Implement of elastic scattering
  - Rayleigh scattering
  - Nuclear Thomson scattering
  - Delbrück scattering
- ✓ Benchmarking with experiments
  - U-238 exp. at Duke University

Summary

- NRF is a promising process to realize NDA of nuclear material
  - ✓ isotope-specific NDA
  - ✓ 2-MeV γ –rays penetrate through a thick shield
  - ✓ no radioactivatoin
- R&D's on NRF-NDA have been carried out and still continue
  - ✓ demo-exp. for high-flux LCS generation
  - ✓ development of a Monte Carlo code
  - ✓ demo-exp. for NDA of heavily shielded material

Future NRF-NDA system



Collaborators

- Quantum Beam Science Center, JAEA
  - Laser Compton Scattered Gamma-ray Research Group
    T. Hayakawa, T. Shizuma, C.T. Angell,
    M. Sawamura, R. Nagai, N. Nishimori, M. Omer
  - Advanced Laser Development Group
    M. Mori
- Integrated Support Center for Nuclear Nonproliferation and Nuclear Security, JAEA
  - M. Seya, M. Koizumi
- High Energy Accelerator Research Organization, KEK
  - H. Kawata, Y. Kobayashi and cERL team
  - J. Urakawa, H. Terunuma, A. Kosuge, T. Akagi
- Kyoto Univ.
  - H. Ohgaki
- Osaka Univ.
  - M. Fujiwara

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