Nuclear resonant scattering with high-brilliance X-ray for ^{229}Th isomer studies

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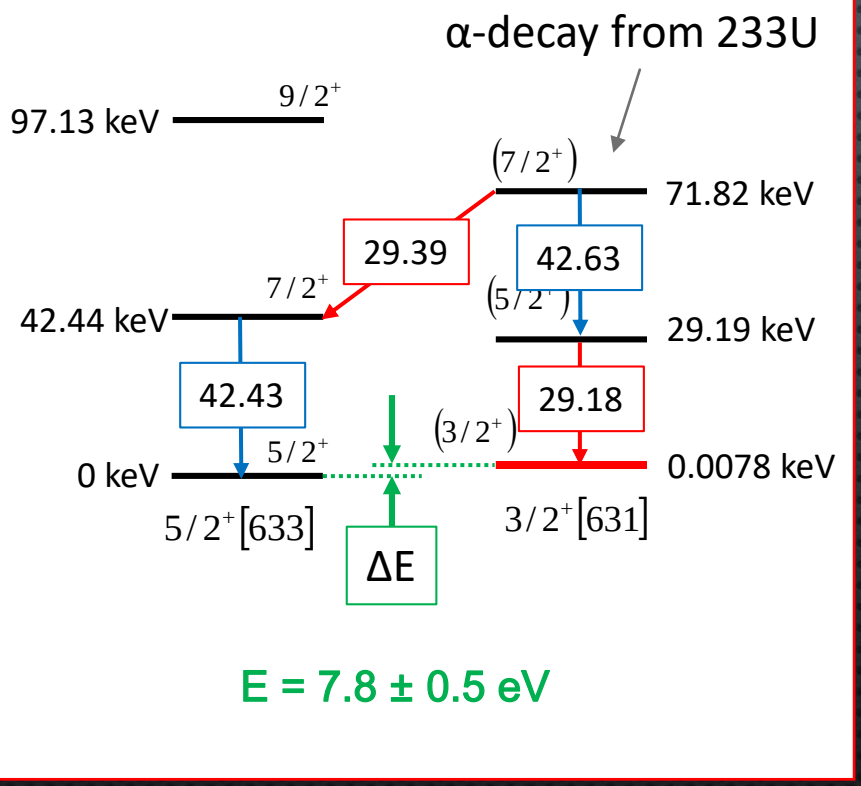
Ultra-low energy nuclear excited state of ^{229}Th

Precise γ-decay spectroscopy experiment
Beck et al., PRL **98,** 142501 (2007)



Detection of Internal conversion electrons from isomer state

6.3 eV < E < 18.3 eV

L.Wense et al., Nature 533 (2016) 437.
PRL 118, 042501 (2017) .

Excitation experiments at SR-facility (**no signal** at present)

Synchrotron radiation at Metrology Light Source (MLS); Germany

E = 3.54 - 9.54 eV — A. Yamaguchi et al., New J. Phys. 17 (2015) 053053

USA
Advanced Light Source (ALS) synchrotron

E = 7.29 – 8.86 eV — J. Jeet et al., PRL 114, 253001 (2015)

> Isomer energy is out of these ranges ?
> Excitation rate is smaller than expected?

Energy / half-life measurement of isomer state at Okayama-Gr.

[1] Excitation to upper excited state

Use the well known leve
ΔE/E ~ 10^-13

[2] Observation of de-excitation to the isomer state

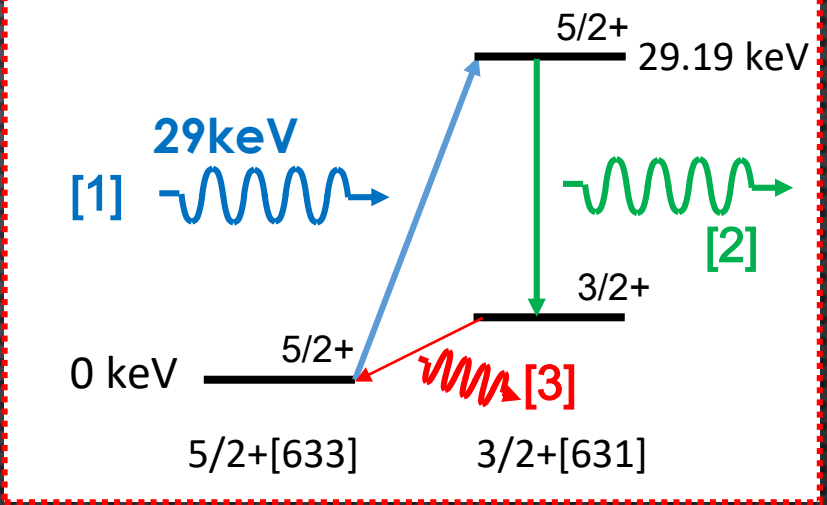
Confirm the isomer-population

[3] Observation of VUV isomeric transition

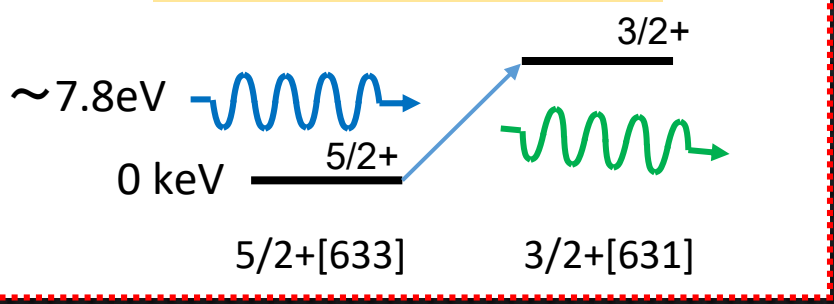
VUV-Monochromator → Δλ~0.1 nm (meV)

- Reliably populating Isomer state (not need precise isomer energy/life)
- Isomer spectroscopy possible during Xray-irradiation

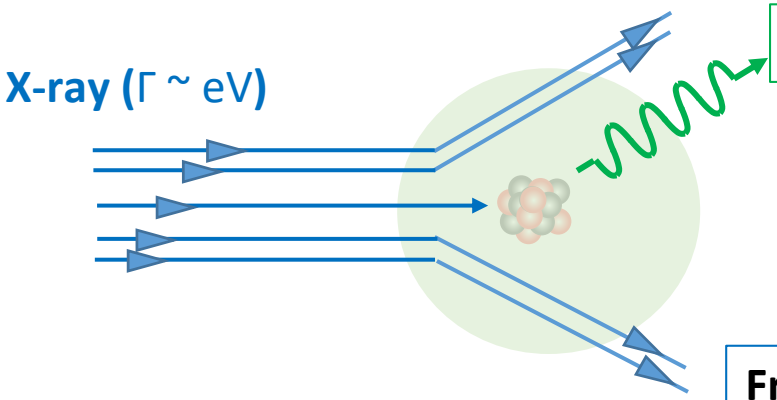
Isomer population through 29-keV level



Direct isomer excitation



Nuclear Resonant Scattering



From nuclear excitation

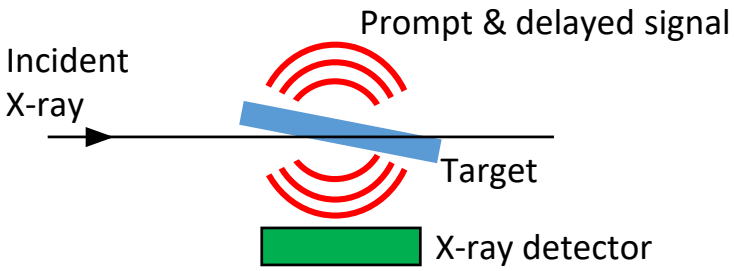
Nuclear excitation (Γ ~ neV)

σ ~ mb Delayed signal

From photoelectric process

σ ~ 10kb Prompt signal

Detection of NRS



^{127}I - NRS time spectrum
Hyperfine Interact. 5 (2003) 17.

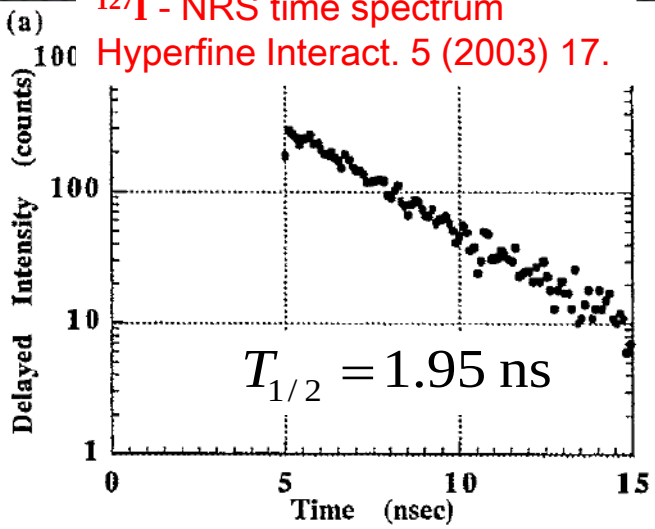
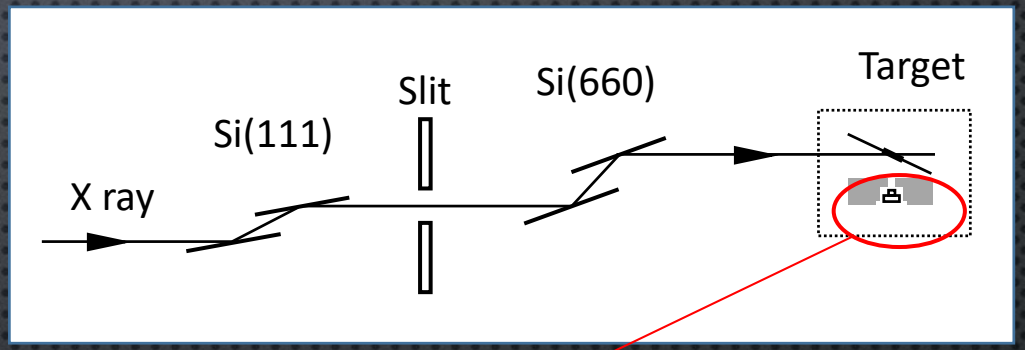


Figure 3. Time spectra from Na^{127}I detected by the

High-brilliance X-ray and fast X-ray detector

SPring-8 ; Synchrotron Radiation facility

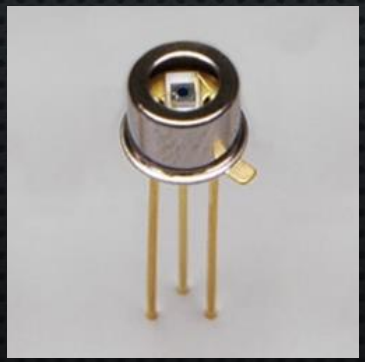
Beam line (BL09XU) for
Nuclear Resonant Scattering



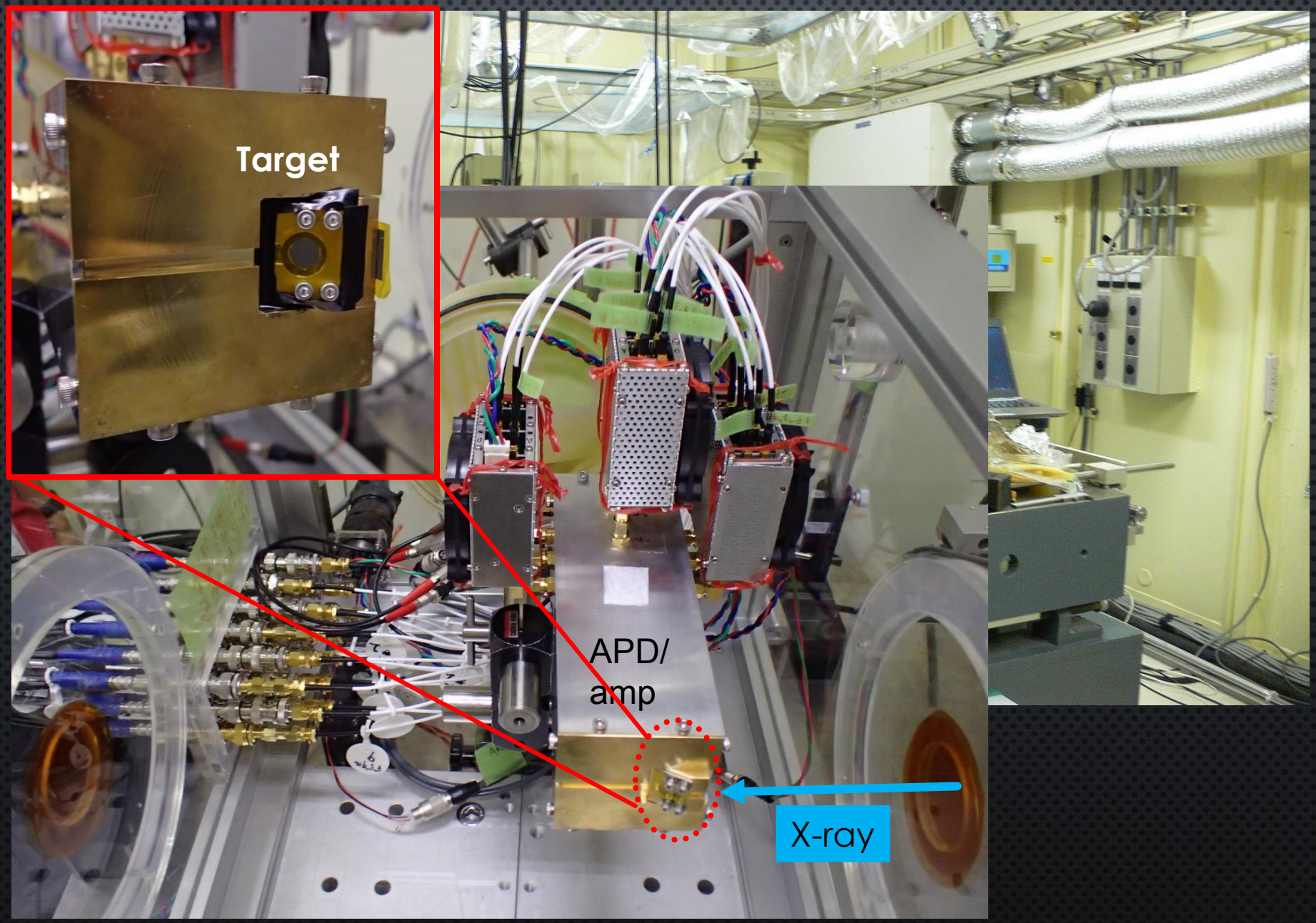
APD (Avalanche Photo Diode)

- Fast response
- Low background

Photon flux: **4 x 10^11 photons/s** @ 29 keV
Energy band width: **0.15 eV** (ΔE/E = 10^-5)
Beam spot : **1.2 mm x 0.6 mm**
※ with double-monochromators setting:
Si(111) + Si(660)



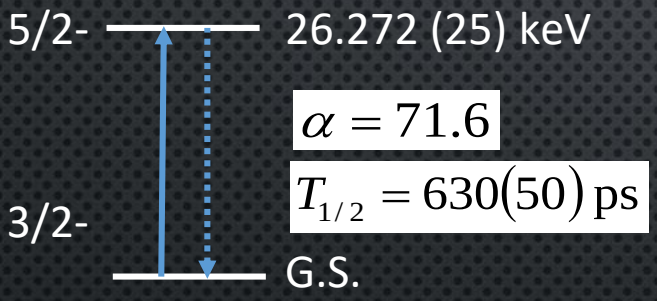
Small diameter :
φ 0.5mm
Thin depletion layer :
～10μm

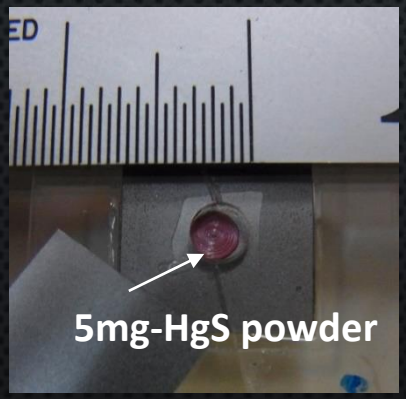

Target
APD/
amp
X-ray

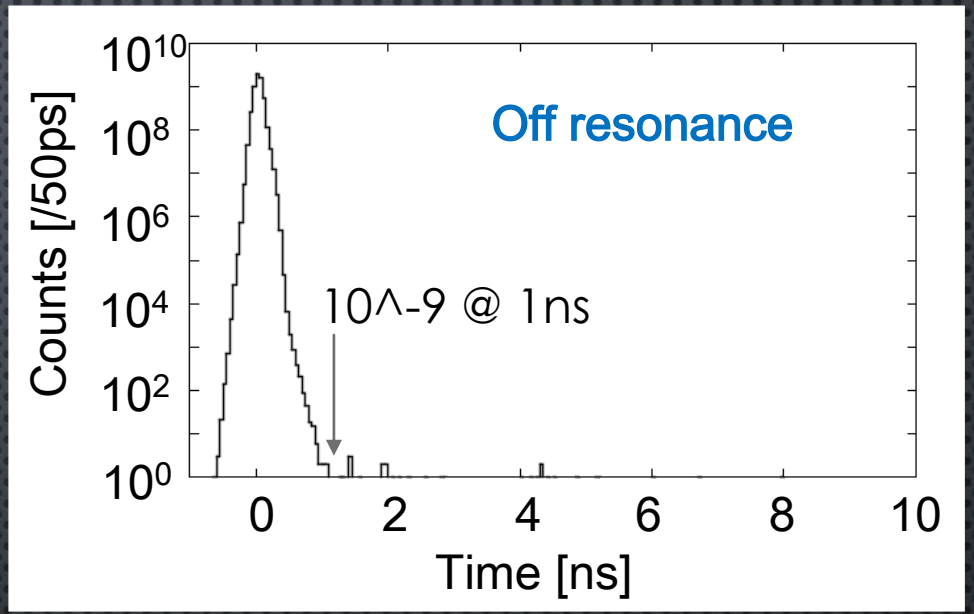
Nuclear resonant signal with test nuclide

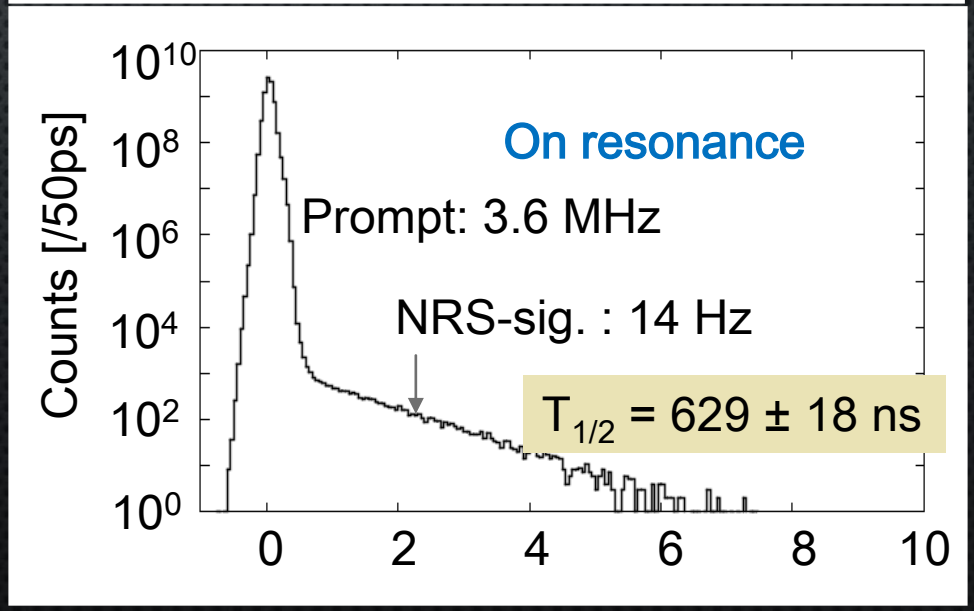
^{201}Hg; 26.27keV-level

Similar properties to ^{299}Th
- Same energy level
- Large IC coefficient
- Short half-life







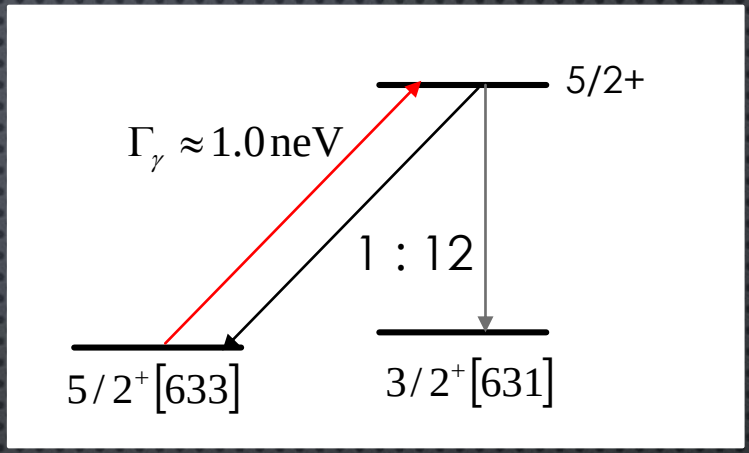


For NRS experiment with 229Th

- Unknown half-life (probably shorter)

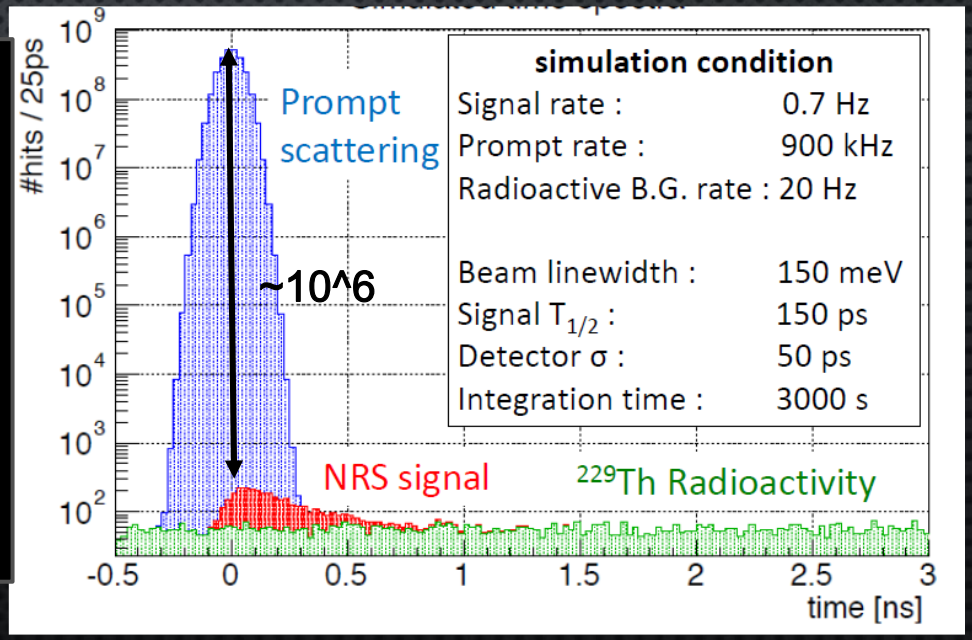
  Rough estimation from M1-transition probability within [631] band

$$T_{1/2} \approx \frac{\ln 2}{\Gamma_{\gamma M1}(\alpha+1)} \cdot \frac{12}{13} \approx 0.15\ \text{ns}$$



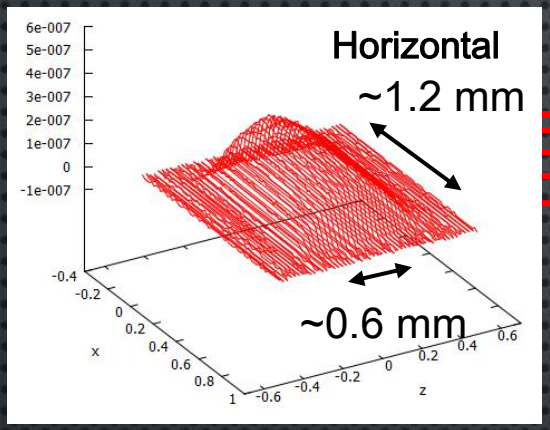
- Smaller excitation rate

	Γ_{rad}	σ_{NRS}	σ_{prompt}
^{199}Hg	10.0 neV	350mb	15.4kb
^{229}Th	~ 1.0 neV	~ 20mb	12.7kb



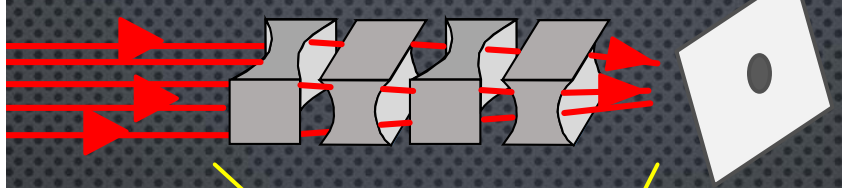
Focused X-rays and high-density ^{229}Th in small area

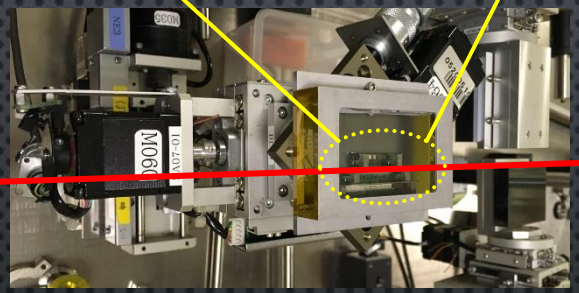
Transmission ~ 60%

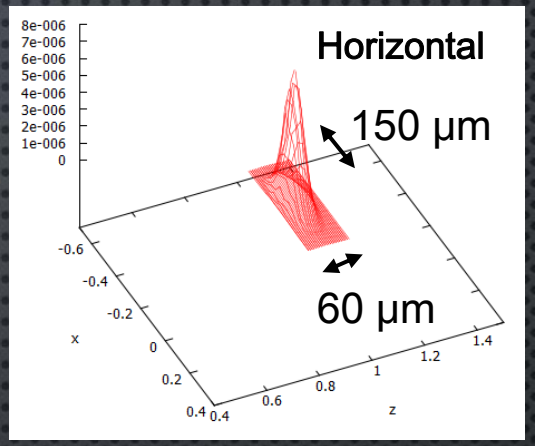


$\sim 7 \times 10^{11}$ photons/s/mm^2

X-ray focusing lens

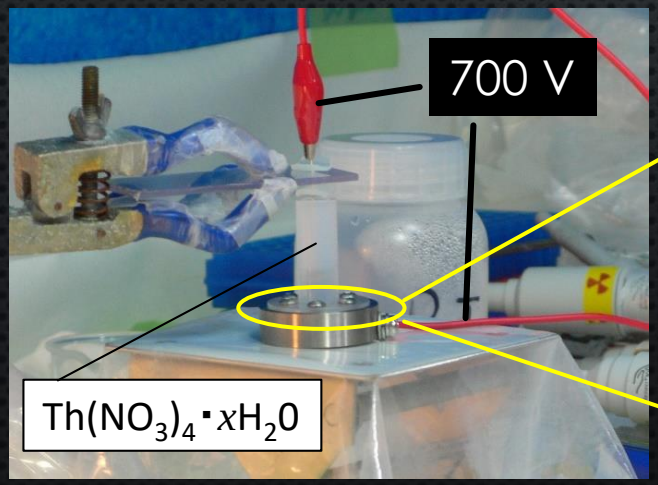




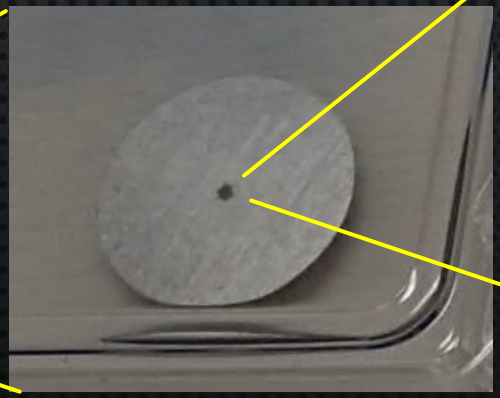


$\sim 3 \times 10^{13}$ photons/s/mm^2

Electrodeposition of 229Th

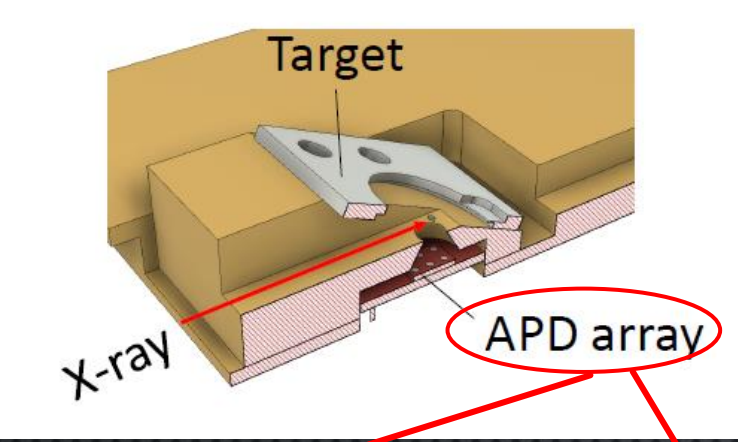


^{229}Th on Be sheet

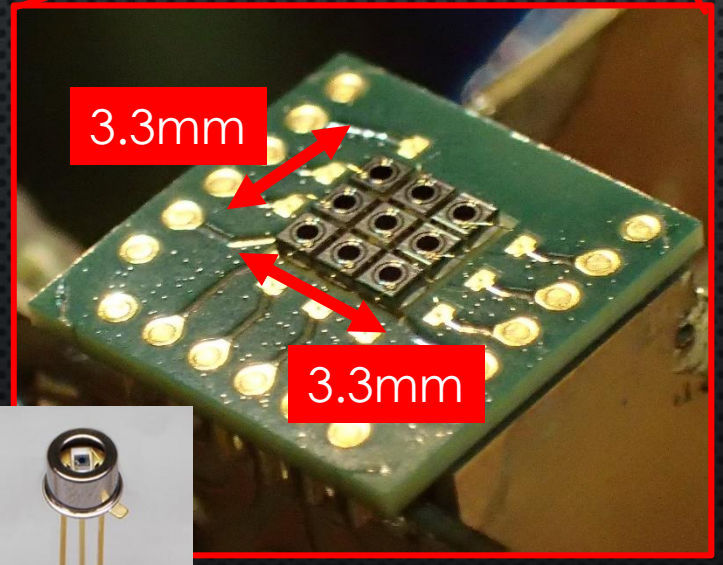


0.6 ug (4.4 kBq)

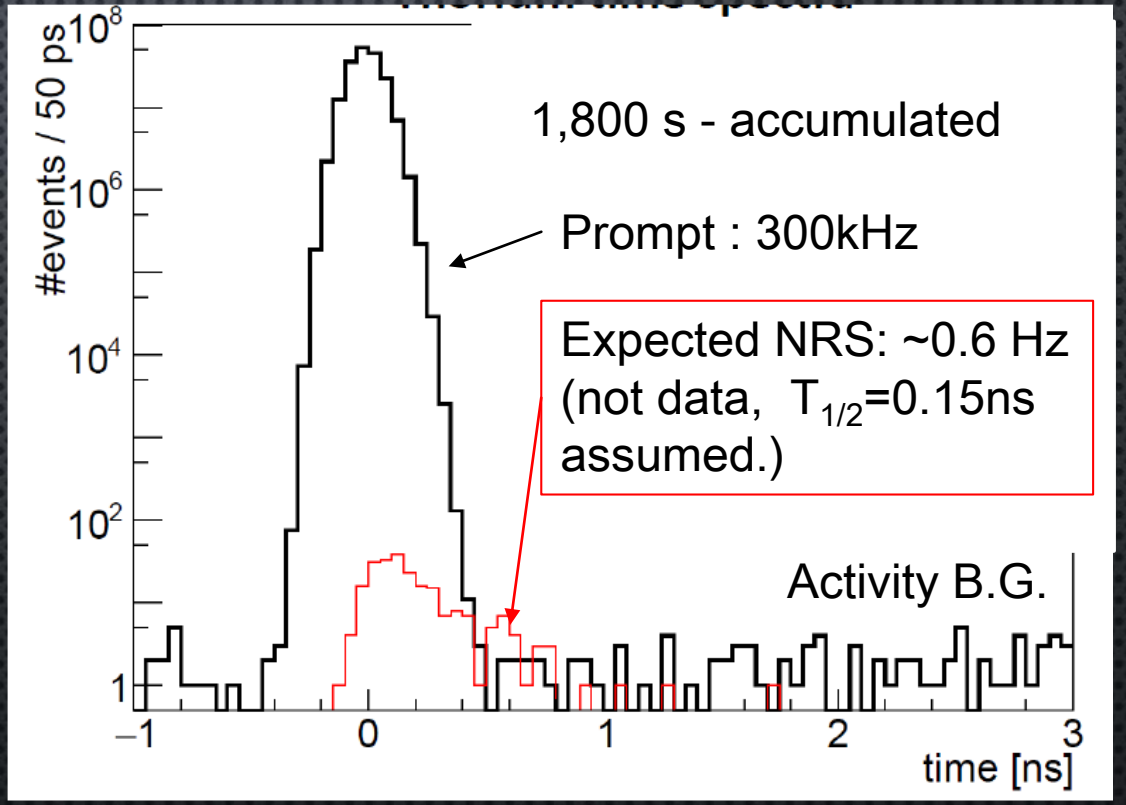
Present status of 229Th-NRS experiment



9-APD chip array



Trial measurement of ^{229}Th-NRS



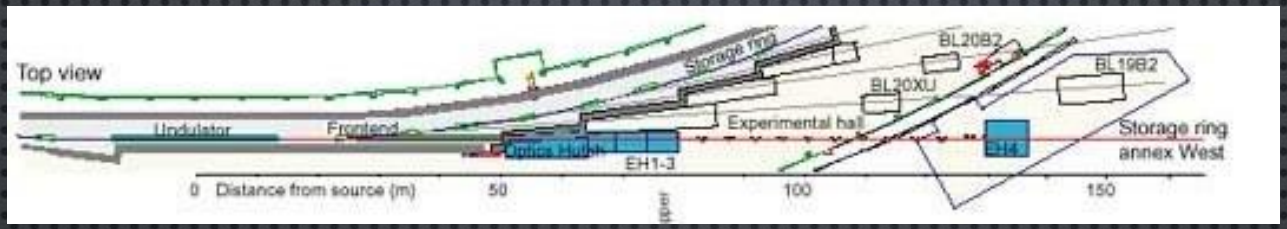
Trial scanned E-region: (29.191 ~ 29.196) keV

NRS rate estimated from $\frac{R_{\mathrm{NRS}}}{R_{\mathrm{prompt}}} \approx 2\times10^{-6}$

On-going improvements / experiments

Higher X-ray flux

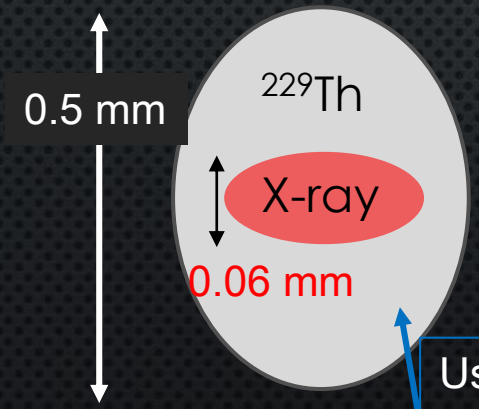
Specified beam-line with 27m-long undulator



$\sim 5\times10^{13}$ photons/s → $\sim 2\times10^{14}$ photons/s

Beam-target matching

View from beam-axis



Useless 229Th only producing activity background

Lifetime measurement of 29keV-level with independent method

γ-γ coincidence with LaBr3 scintillators

Purified 233U (30MBq)

Collaborators

RIIS, Okayama University
S.Okubo, H.Hara, T.Hiraki, T. Masuda, Y.Miyamoto, K.Okai, R. Ozaki, N.Sasao, K. Suzuki, O. Sato, K. Imamura, S. Uetake, A.Yoshimi, K.Yoshimura, M.Yoshimura

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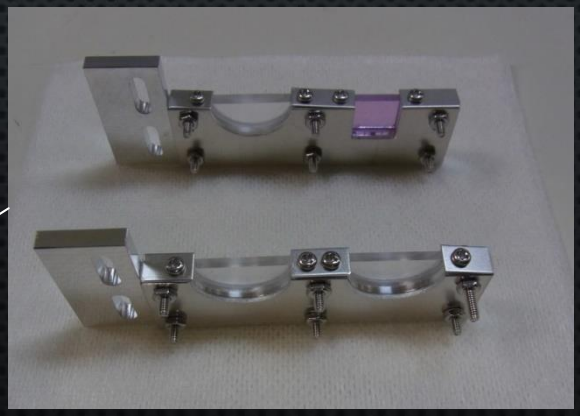
IMR, Tohoku University
K.Konashi, M.Watanabe

Osaka University
Y.Kasamatsu, Y.Yasuda, y.Shigekawa

Vienna Univerty of Technology Institute
T. Schumm, S.Stellmer

229Th – doped CaF2 / MgF2 crystal



Summary

- Experiments on low-energy isomer of Th-229 have been extensively conducted, especially in this decade.
- New method using high intense x-ray beam has been developed.

T. Masuda et al., Rev. Sci. Inst. **88**, 063105 (2017).
A. Yoshimi et al., Phys. Rev. C (in press).

- We are now preparing the Beam-time for 229Th-NRS detection.

For detailed information, please visit the poster presentations:

No. 17: S. Okubo : Detection system of NRS-experiment
No. 18: R. Ozaki : X-ray focusing
No. 22: K. Suzuki : On-going lifetime measurements of 29keV-state