Photo-Fission Product Yields of Special Nuclear Materials

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Research Program: Photo-fission measurements

1. **Photo-fission cross-section ratio: $\sigma(^{235}U(\gamma,f))/\sigma(^{239}Pu(\gamma,f))$**

   Measure ratio of cross sections with mono-energetic γ-ray beam

   - Ratio can be made to high precision, e.g., better than ±3%
   - Enables high precision comparisons to theoretical predictions
   - (γ,f) cross sections measured relative to a standard; reducing uncertainty in standard improves accuracy of many cross sections

   Energy range: E_γ = 9 to 17 MeV

2. **Fission product yields of $^{235,238}U$, ^{239}Pu and ^{240}Pu**
   - **Provide first FPY for monoenergetic γ-rays**
   - Determine whether the fission product yields (FPY) depend on the attributes of the particle inducing the reaction, e.g., n or γ
   - Is energy dependence of FPY similar for γ-rays and n?

   Energy range: E_γ = 13 MeV for $^{235,238}U$, ^{239}Pu and 11.1 MeV for ^{240}Pu

   Technique: activation counting

3. **Fission product yields of ^{134m}Te and ^{136m}Xe Isomers**

   - Development of technology for remote detection of special nuclear materials

   Isotopes: ^{233}U, ^{235}U, ^{238}U, ^{239}Pu

   Technique: direct real-time detection and spectroscopy of delayed γ-rays

   Energy range: 8 – 14 MeV

Team: Physics Department, Duke University and TUNL

Faculty

Calvin Howell, PI

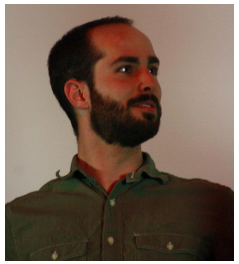
Werner Tornow, Co-PI

Graduate Students

Brent Fallin
Measurements

Postdocs

Megha Bhike
Measurements and Analysis



Sean Finch
Measurements

Krishichayan
Measurements and Analysis

Team: National Laboratory Collaborators

Los Alamos National Laboratory

Todd Bredeweg

Matthew Gooden

David Vieira

Jerry Wilhelmy

Lawrence Livermore National Laboratory

Mark Stoyer

Anton Tonchev

Research Schedule: Photo-fission measurements

1. **Year 1: Oct. 2015 - Sept. 2016**
   - *Measure of photo-fission cross-section ratio of* $\sigma(^{235}U(\gamma,f))/\sigma(^{239}Pu(\gamma,f))$ at E_γ = 9 - 17 MeV
   - Measure fission product yields of $^{235,238}U$ and ^{239}Pu at E_γ = 13.0 MeV

2. **Year 2: Oct. 2016 – Sept. 2017**
   - Measure fission product yields of ^{240}Pu at E_γ = 11.1 MeV
   - *R&D of* ^{134m}Te *and* ^{136m}Xe *Isomer FPY at* E_γ *= 15 MeV on* ^{238}U

3. **Year 2: Oct. 2017 – Sept. 2018**
   - *Measure FPY of* ^{134m}Te *and* ^{136m}Xe *Isomer on* $^{235,238}U$ and ^{239}Pu at E_γ = 8 – 14 MeV

Photo-Fission Cross-section ratio measurement: Experiment Technique

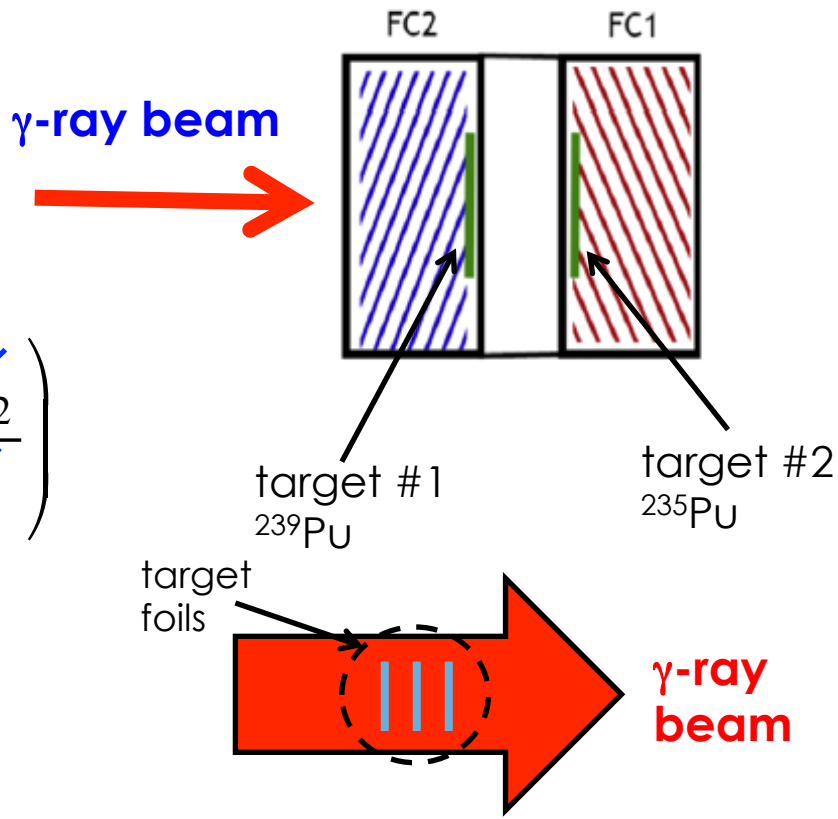
$$\sigma_{fi} = \left(\frac{N_{fi}}{\phi_{\gamma i} n_{ti} \varepsilon_i (\Omega_i / 4\pi)} \right)$$

σ_{fi} = photo-fission cross section for nucleus ***i***
N_{fi} = number of fission fragments counted in detector from nucleus ***i*** during measuring period
$\phi_{\gamma i}$ = integrated g-ray beam flux (γ/cm^2)
n_{ti} = number of nuclei in target ***i***
ε_i = efficiency of detector for counting fission from nucleus ***I***
Ω_i = solid angle of detector for fragments from nucleus ***i***

Dual fission chamber ➔ Concurrent measurements with identical detectors

$$R = \frac{\sigma_{f1}}{\sigma_{f2}} = \left(\frac{N_{f1}}{N_{f2}} \right) \left(\frac{\cancel{\phi_{\gamma 2}} n_{t2} \cancel{\varepsilon_2} \cancel{\Omega_2}}{\cancel{\phi_{\gamma 1}} n_{t1} \cancel{\varepsilon_1} \cancel{\Omega_1}} \right)$$

$$R = \frac{\sigma_{f1}}{\sigma_{f2}} = \left(\frac{N_{f1}}{N_{f2}} \right) \left(\frac{n_{t2}}{n_{t1}} \right)$$

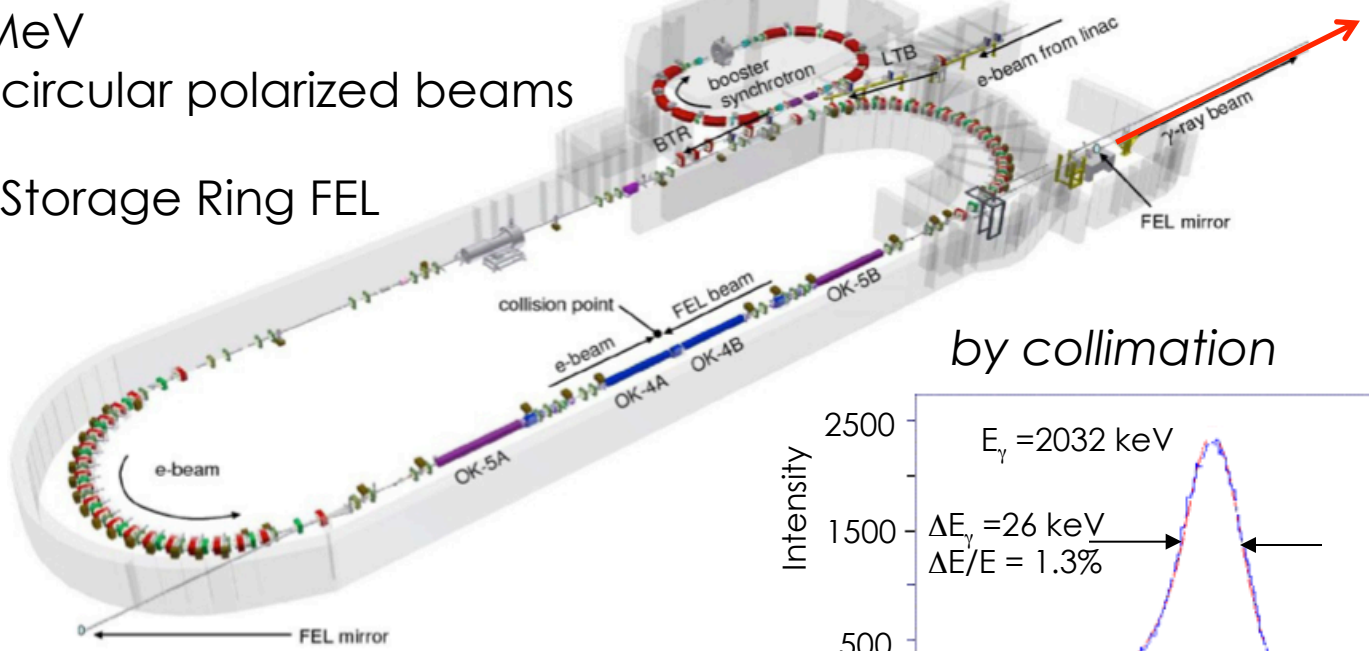


High Intensity Gamma-ray Source (HIγS)

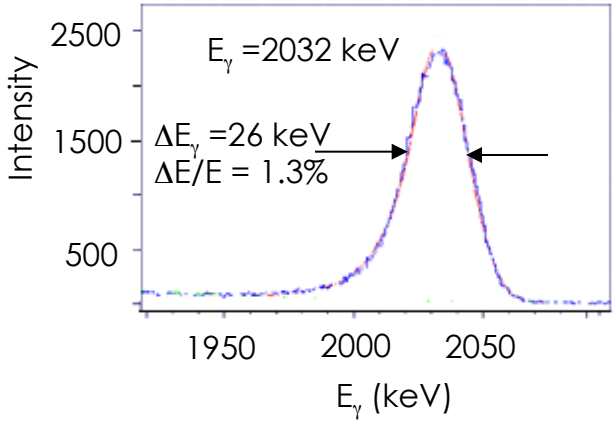
HIγS is the most intense Compton γ -ray source in the world

Produces γ-rays by Compton backscattering
Intensity = 10^3 γ /s/eV on target
E_γ = 1 – 80 MeV
Linear and circular polarized beams

1.2 GeV Storage Ring FEL



by collimation

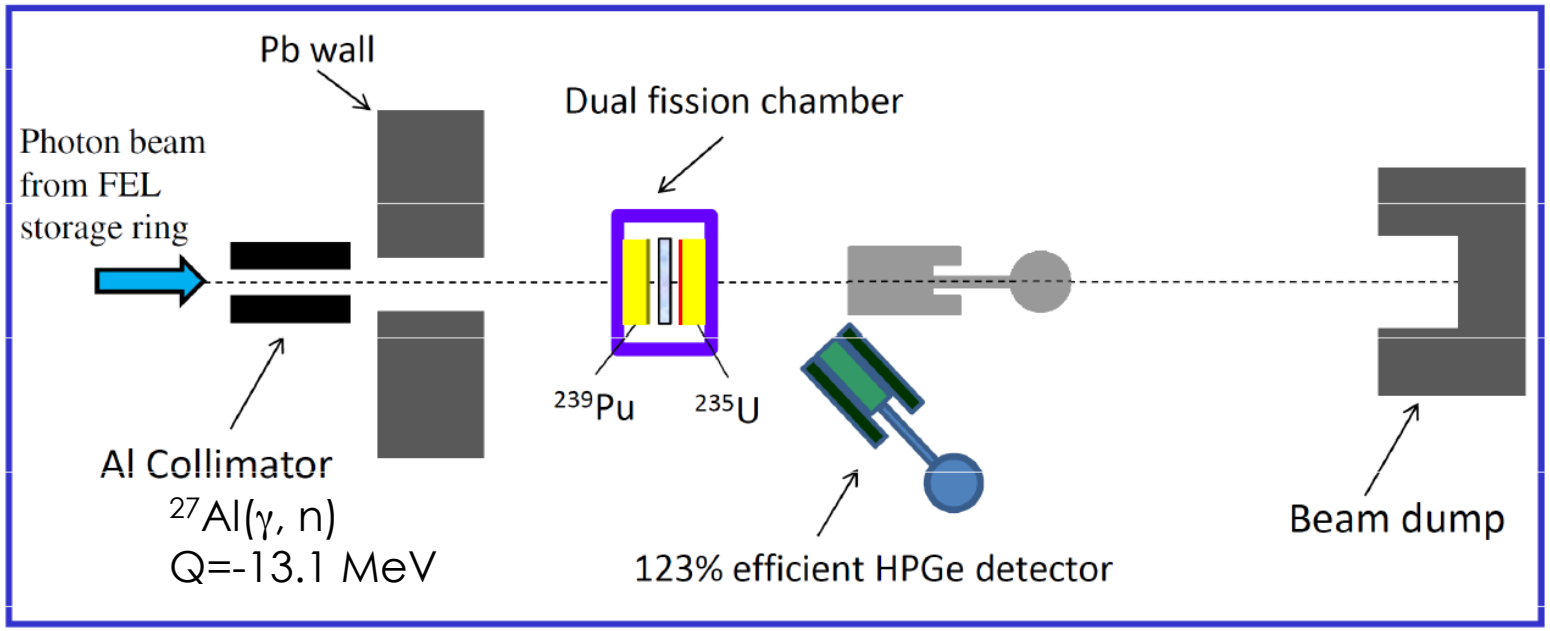


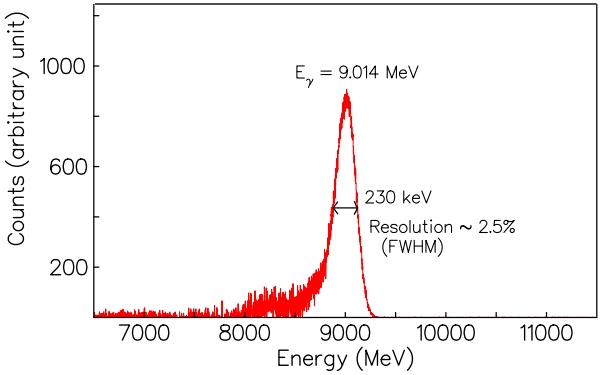
Beam time structure: Rep rate = 5.58 MHz (T = 180 ns) and Δt = 100 ps

Photo-Fission Cross-section ratio measurement: Experiment Setup

Measurements conducted in the Upstream Target Room at HIγS

$\sigma(^{235}U(\gamma,f))/\sigma(^{239}Pu(\gamma,f))$

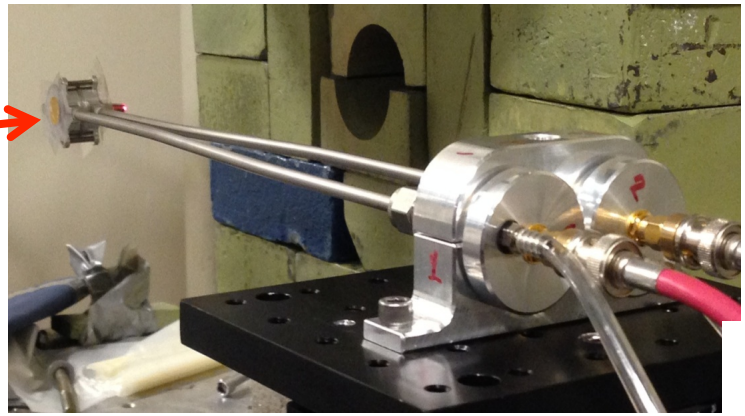


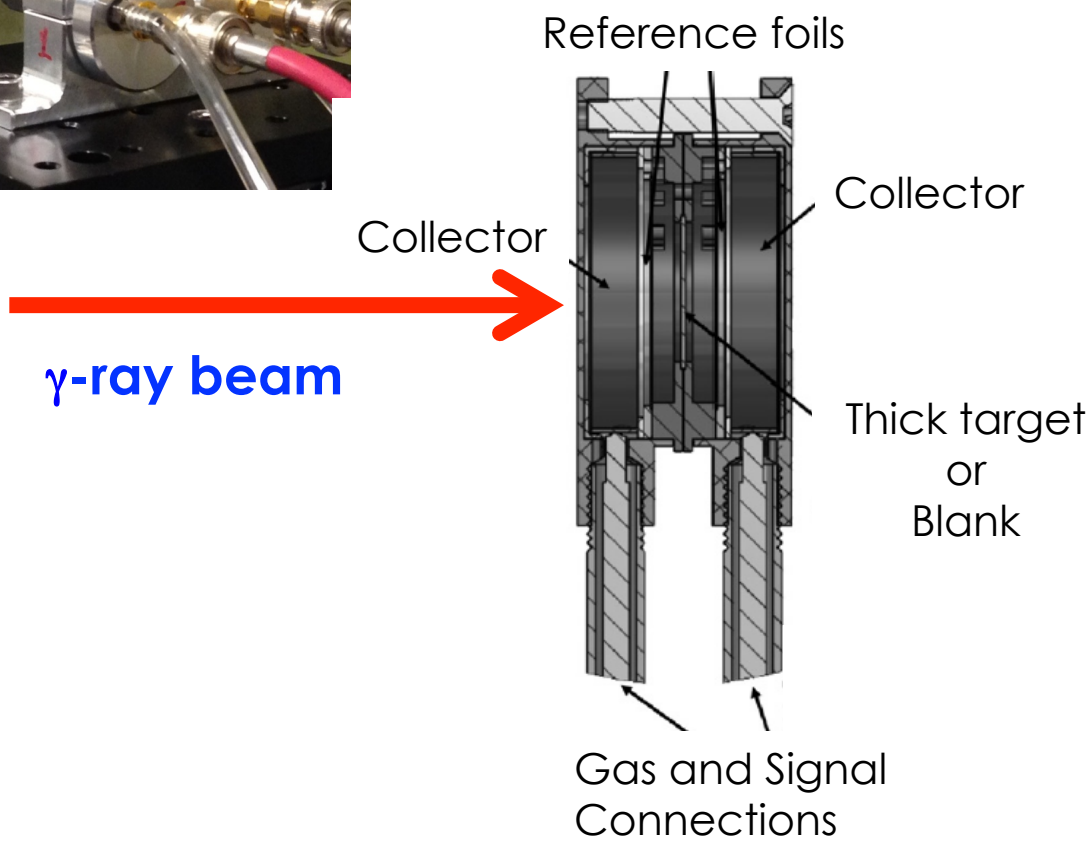


E_γ = 9.0 – 17.0 MeV
I_γ = 2 x 10^6 γ/s
Counting time = 60 hours

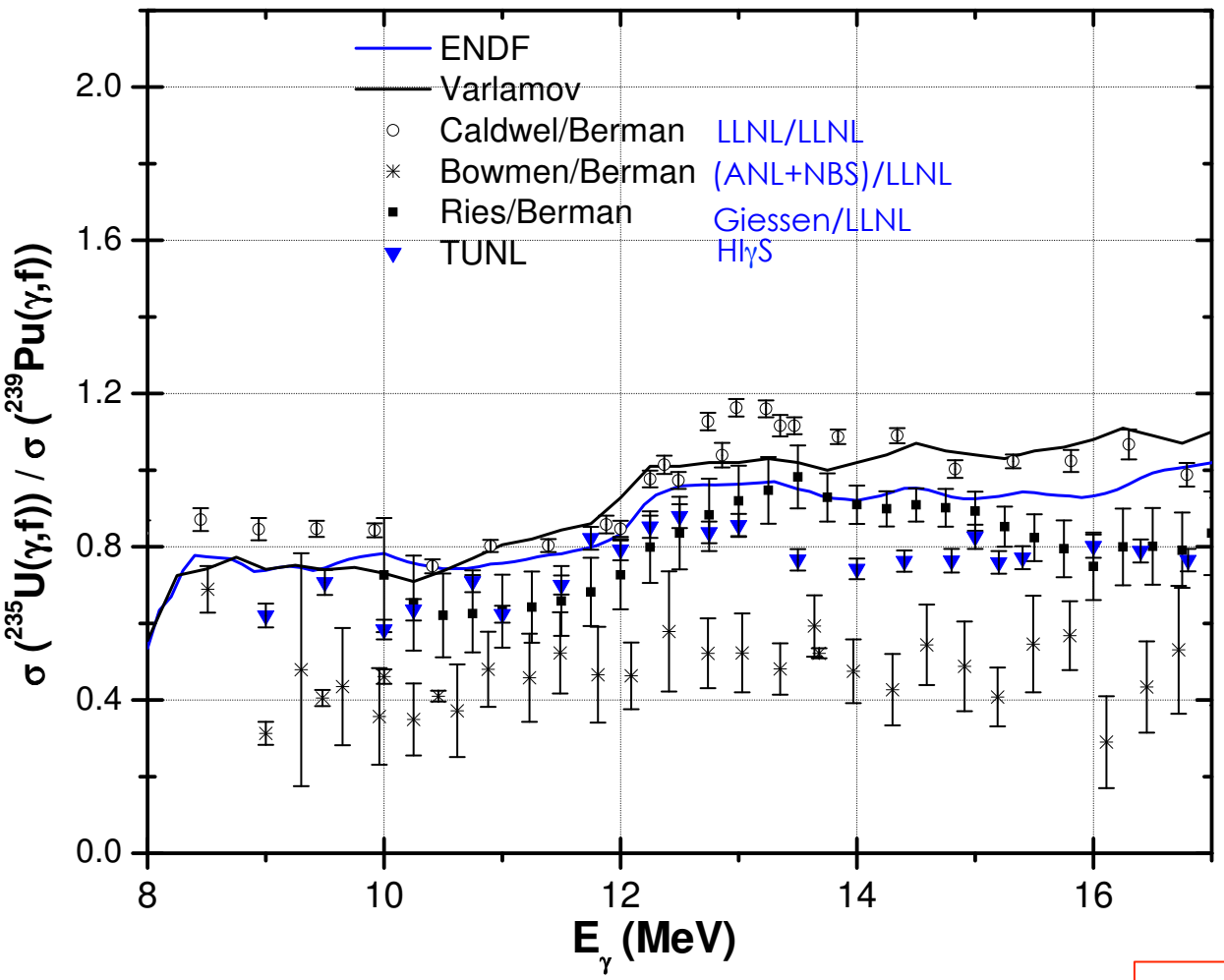
Photo-Fission Cross-section ratio: Setup Diagrams

γ-ray beam





Fission Cross-section ratio measurement: Results



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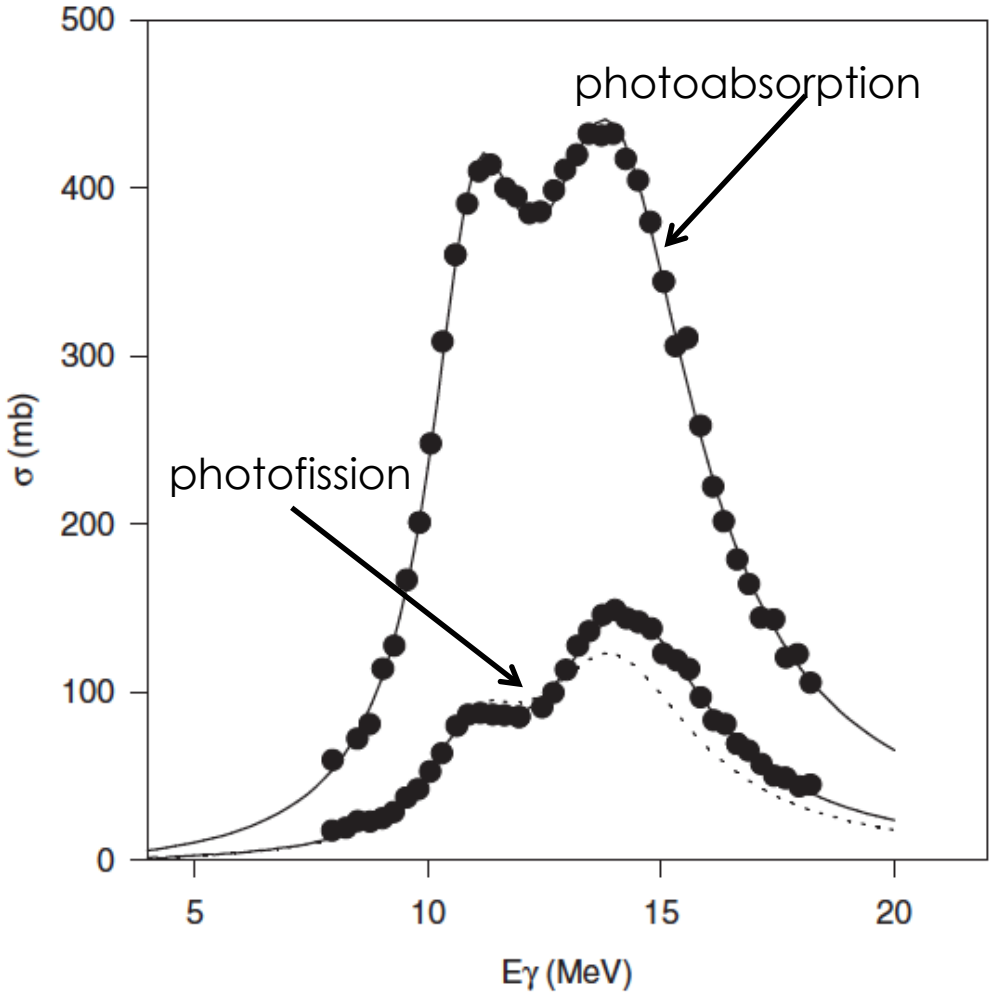
B.L. Berman *et al.*, PRC **34**, 2201 (1986)
C.D. Bowman *et al.*, PRC**17**, 1086 (1978)
H. Ries *et al.*, PRC **29**, 2346 (1984)

Lead postdoc: Krishichayan
Paper under preparation

Why about E_γ = 13 MeV?

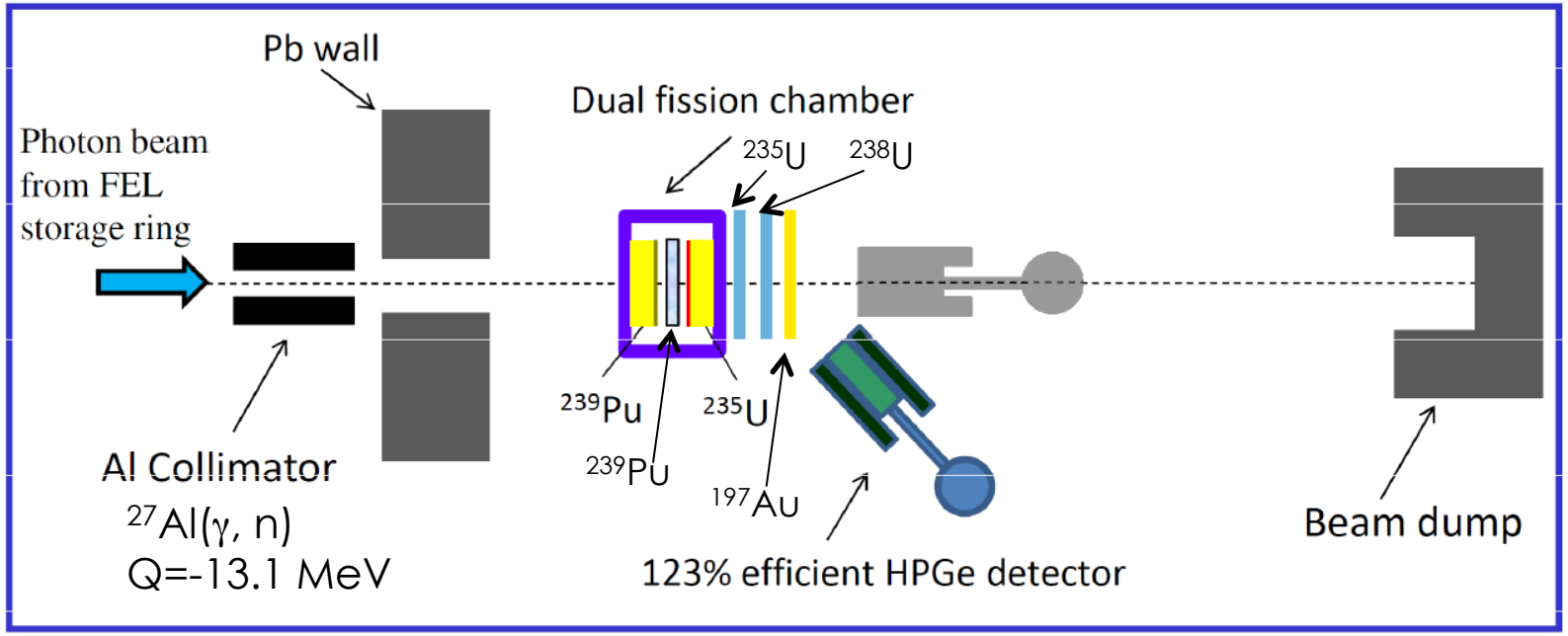


Fission cross section enhancement due to the GDR

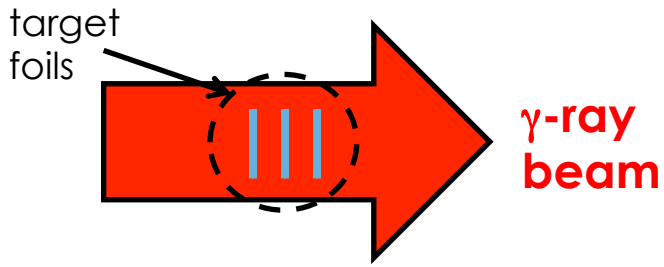
D. Bhowmick et al., Phys. Rev. C. **91**, 044611 (2015)

FPY from ^{235},^{238}U and ^{239}Pu by photon-induced fission: Experiment Technique, part 1

(1) γ-ray beam irradiation of foils



E_γ = 13.0 MeV
I_γ = 2 x 10^6 γ/s
Irradiation time = 63 hours



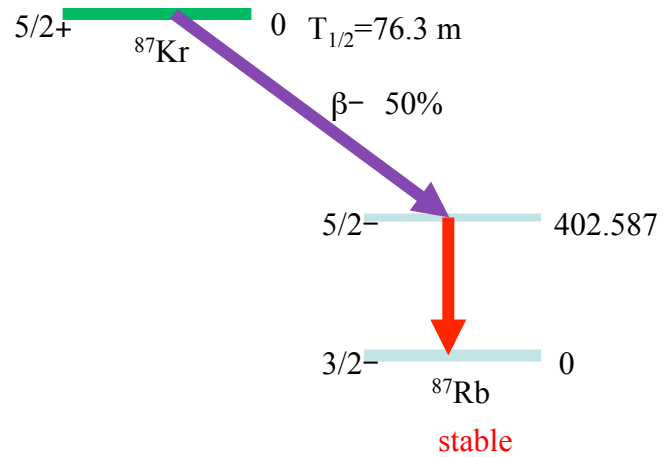
See poster by Krishichayan

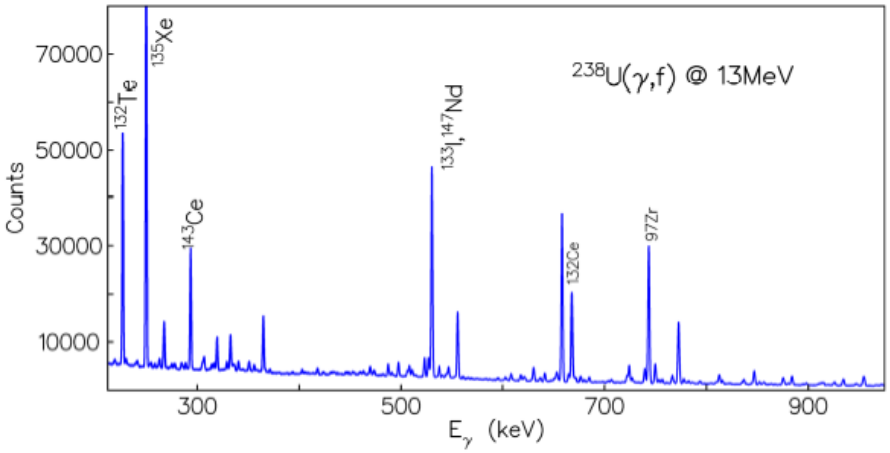
FPY from ^{235},^{238}U and ^{239}Pu by photon-induced fission: Experiment Technique, part 2

(2) Fission fragment analysis via γ-ray energy spectroscopy and lifetime counting measurements

Low-background γ-ray Counting Facility at TUNL

See poster by Krishichayan





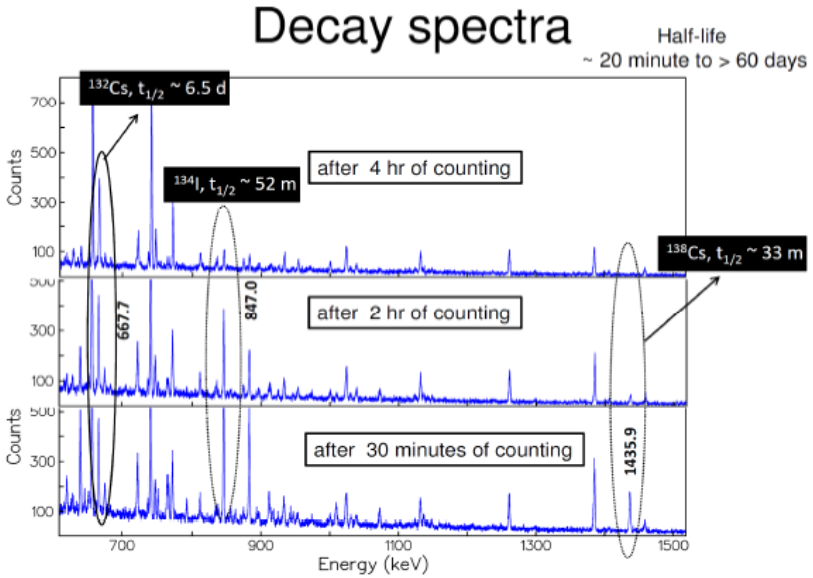
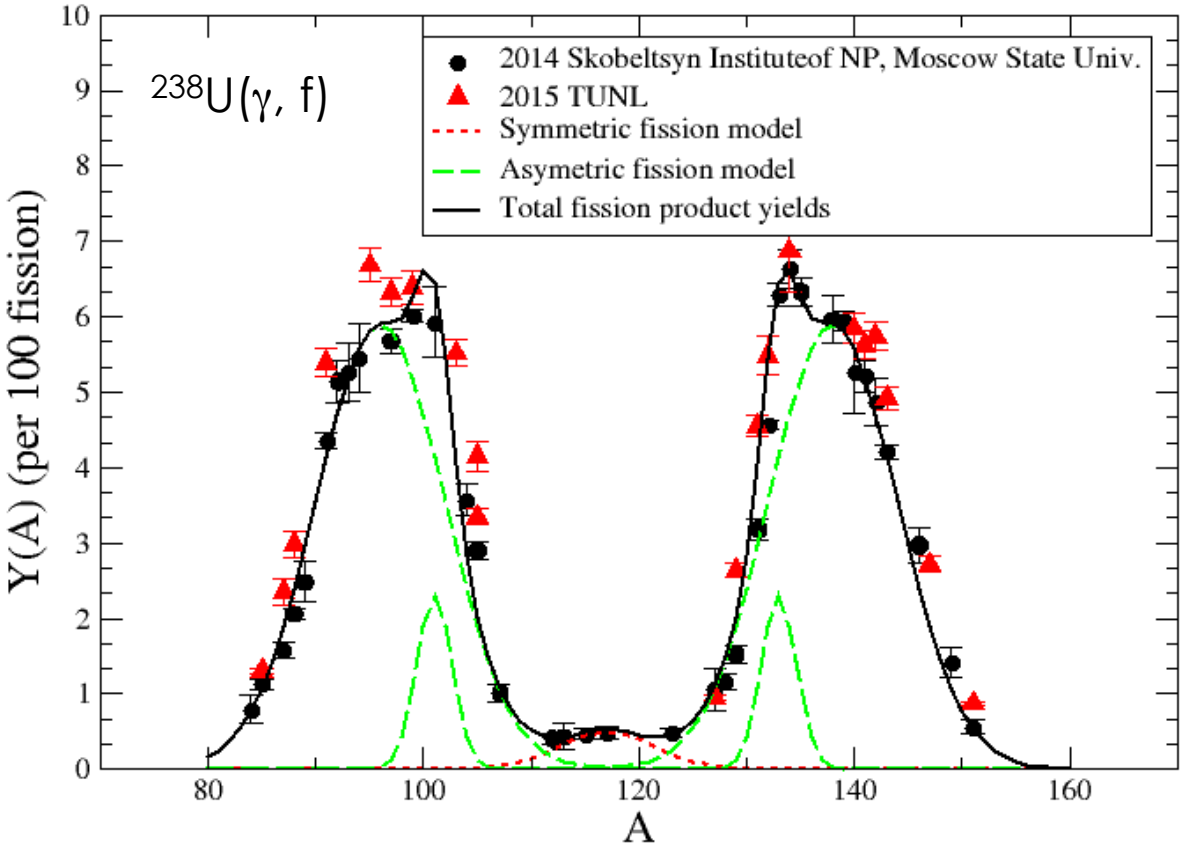


Photo-Fission of ^{235,238}U FPY: Preliminary Results



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FPY calculations: D. Bhowmick et al., Phys. Rev. C. **91**, 044611 (2015)

What's next

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   - *Measure of photo-fission cross-section ratio of* $\sigma(^{235}U(\gamma,f))/\sigma(^{239}Pu(\gamma,f))$ at E_γ = 9 - 17 MeV

   → **Publish results**

   - Measure fission product yields of $^{235,238}U$ and ^{239}Pu at E_γ = 13.0 MeV

   → **Complete data analysis**

   → **Publish results**

2. **Year 2: Oct. 2016 – Sept. 2017**
   - Measure fission product yields of ^{240}Pu at E_γ = 11.1 MeV
   - *R&D of* ^{134m}Te *and* ^{136m}Xe *Isomer FPY at* E_γ *= 15 MeV on* ^{238}U

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