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# Measurements of $^{233}$U(n,$\gamma$) with DANCE

## NCSP Technical Program Review

**LANL ND3 (Unresolved and Fast Measurements of $^{233}$U (n,$\gamma$))**

Esther Leal Cidoncha, Aaron Couture and
Gencho Rusev

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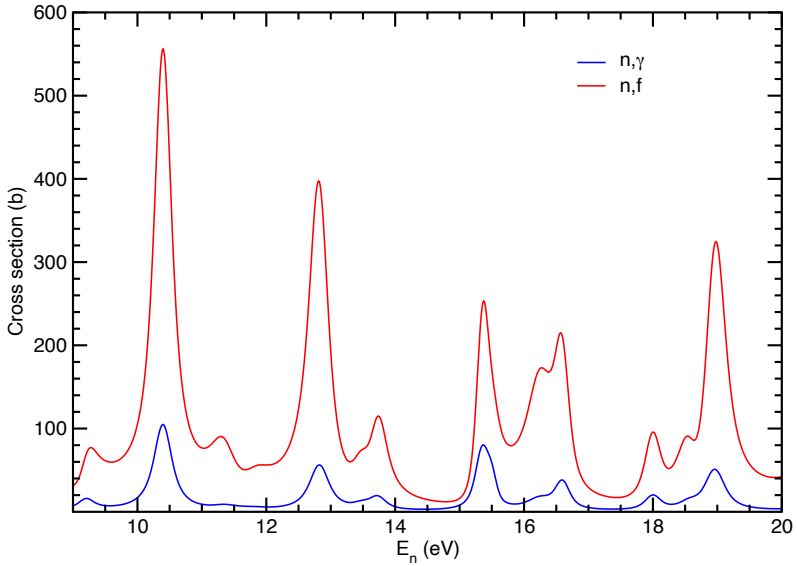
# Motivation

- Th-U alternative to U-Pu fuel cycle due to its reduced amount of transuranium elements.
- Experimental $^{233}$U(n,$\gamma$) cross section data in the literature are scarce and were measured decades ago.
- Previous 2008 measurement at LANL combining the “fowler” PPAC with DANCE.
- For $^{233}$U fission is around one order of magnitude more likely than capture.
  - Good discrimination between gammas coming from capture and fission is required.
  - New measurement proposed at LANL combining NEUANCE and DANCE.




$^{233}$U(n,g) and $^{233}$U(n,f) cross sections from ENDF/B-VIII.



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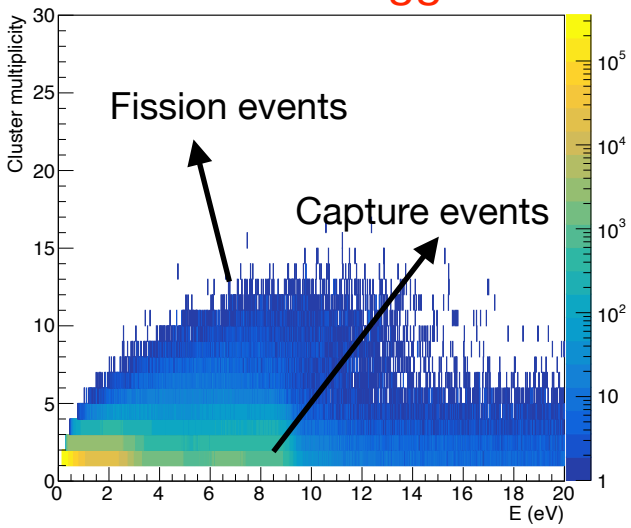
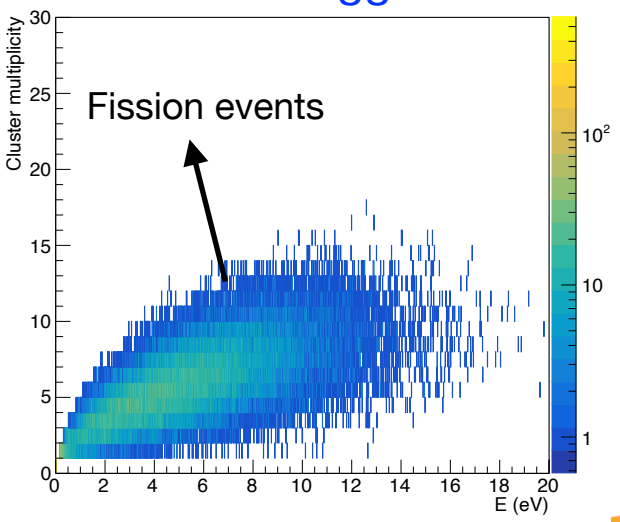
# LANL 2008 experiment

- Previous 2008 measurement at LANL combining the “fowler” PPAC with DANCE.
  - Two $^{233}U$ samples placed back to back were electrodeposited in a thick backing.
  - Analysis method consisted in tagging the coincidence signals between DANCE and the PPAC as fission. Then a second coincidence method between the two PPAC anodes was used to identify the cases in with the two FF or just one FF are detected in the PPAC.
  - The PPAC efficiency was around 37%, lower than expected (80%). Hence the statistics in the keV region were inadequate to calculate the cross section up to 100 keV.

AntiPPAC tagged

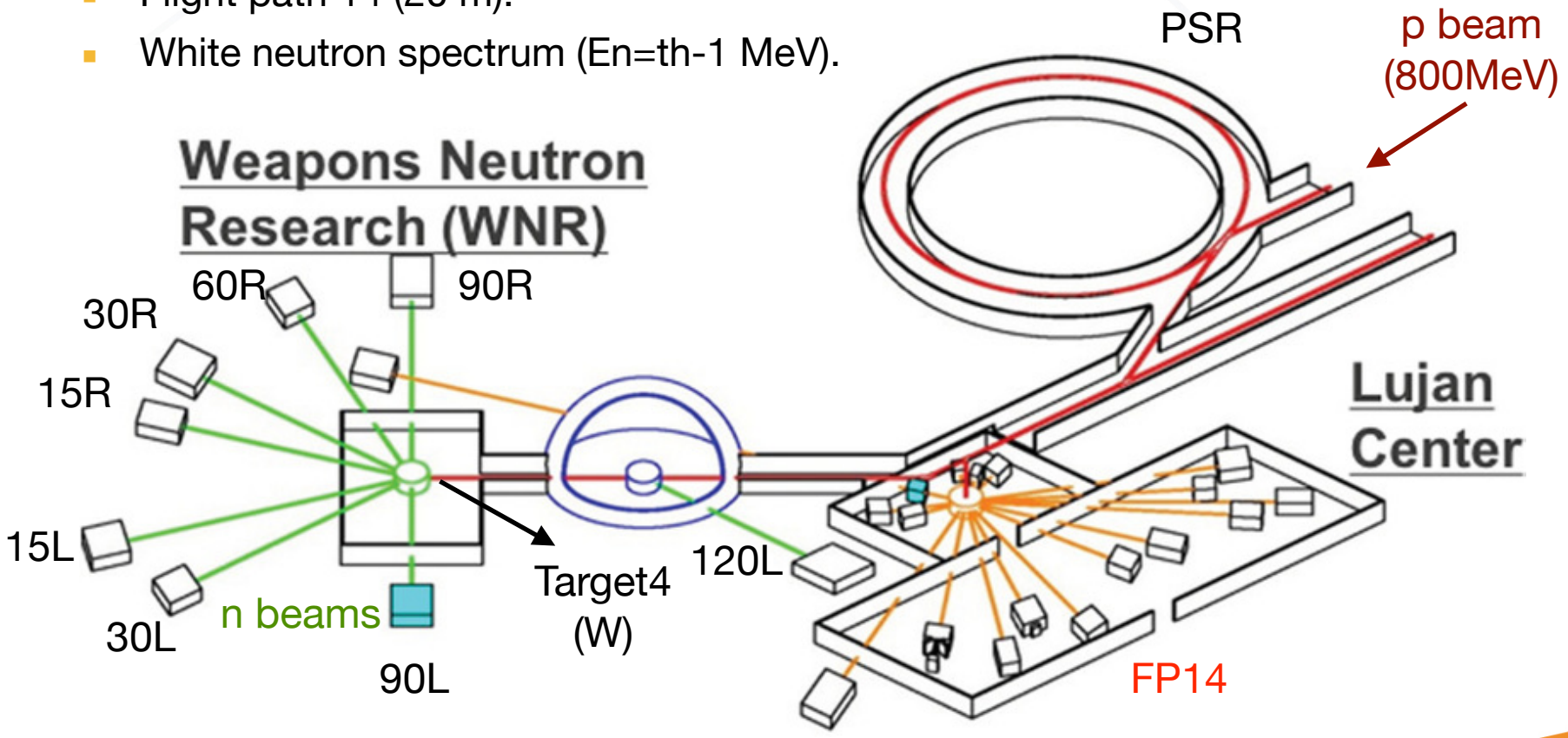



PPAC tagged



# LANSCE facility

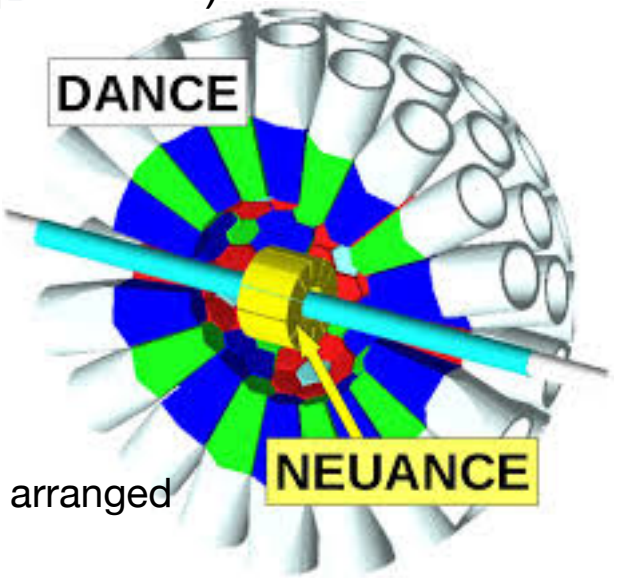
- Neutrons produced by proton spallation on a W target.
- Flight path 14 (20 m).
- White neutron spectrum (En=th-1 MeV).



# DANCE and NEUANCE

**DANCE** (**D**etector for **A**dvanced **N**eutron **C**apture **E**xperiments)

- $4PiBaF_2$ gamma-ray calorimeter composed by 160 crystals with an inner cavity of 17 cm [1].
- Used to measure neutron capture cross section data on small quantities of radioactive isotopes.
- We can measure En, Esum, Ecl, and Mcl, providing more information than with C6D6 detectors.




**NEUANCE** (**NEU**tron detector array at d**ANCE**)

- Neutron detector array that consists in 21 stilbene crystals arranged in a cylindrical geometry around the beam pipe [2].
- Possibility to use a thick target.
- Used to detect neutrons coming from fission and determine by coincidence with DANCE, the gammas coming from fission.
- Those events are suppressed with a fission tag, and then the fission gamma shape is characterized with fission events to subtract the remaining fission background.

[1] Heil et al. NIMA (2001).
[2] M. Jandel et al. NIM 00 (2017) 1-27.



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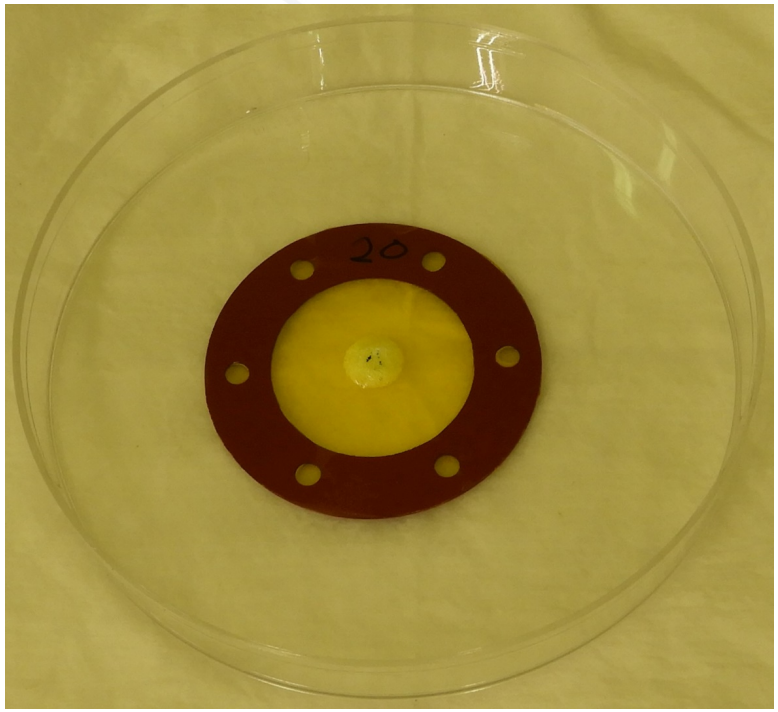
# $^{233}$U targets

- The 30 mg of $^{233}$U were supplied from Oak Ridge National Laboratory (ORNL).
- Material composition:

| Isotope | Atom (%) |
|---|---|
| $^{233}$U | 99.9843 |
| $^{234}$U | <0.0002 |
| $^{235}$U | 0.0017 |
| $^{236}$U | 0.0004 |
| $^{238}$U | 0.0134 |




- Two samples have been prepared by Evelyn M. Bond at LANL.
  - 20 mg
  - 10 mg



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# $^{233}$U experiment (nov.-dec. 2020)

- **DANCE & NEUANCE:**
  - 10 days of data taking with the 20 mg $^{233}$U sample.
  - 1 day of data taking with the 10 mg $^{233}$U sample.
  - 2 days of radioactive gamma sources for calibration (before and after the $^{233}$U measurements).
  - Measurements with a $^{235}$U sample to cross-check the performance and the systematics.
  - Measurements with a $^{208}$Pb sample to set a trigger to select fission neutrons and reject scattered neutrons.

- **Neutron beam monitors:**
  - <u>Fission chamber:</u>
    - In parallel to measure $^{235}$U(n,f) reactions during the whole data taking to calculate the neutron flux.
  - <u>Si detectors:</u>
    - In parallel to measure $^{6}$Li(n,t) reactions to calculate the neutron flux.



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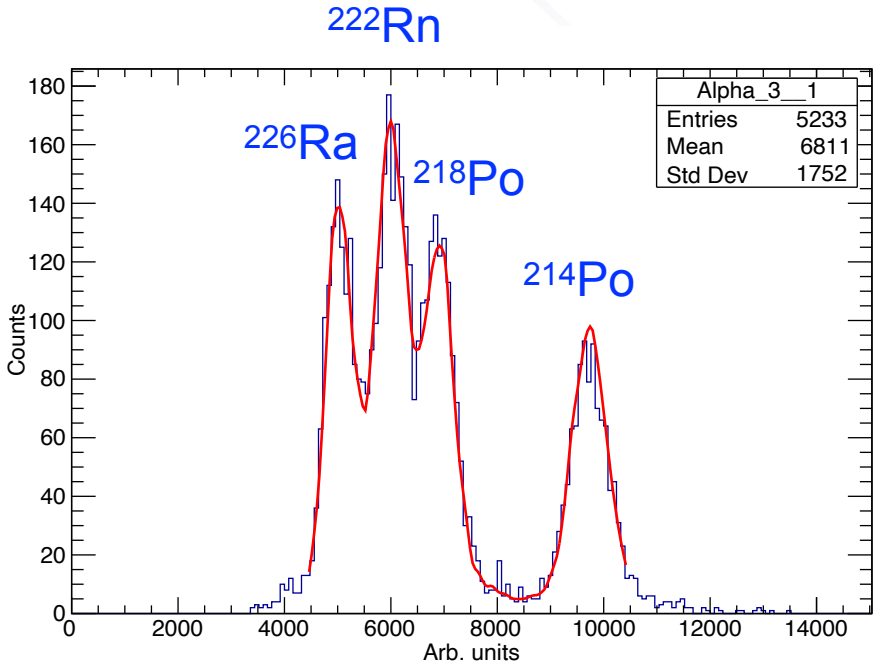
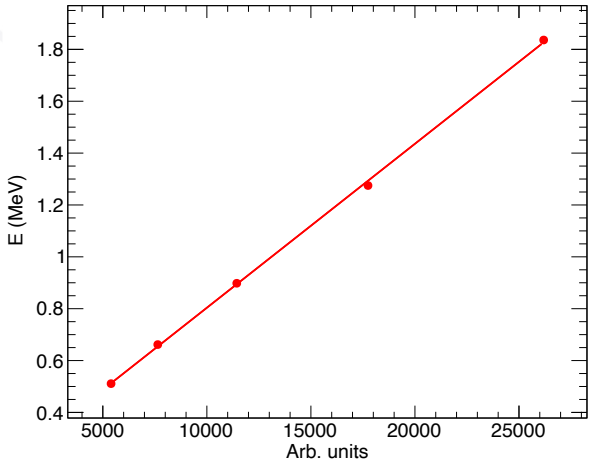
# DANCE calibrations

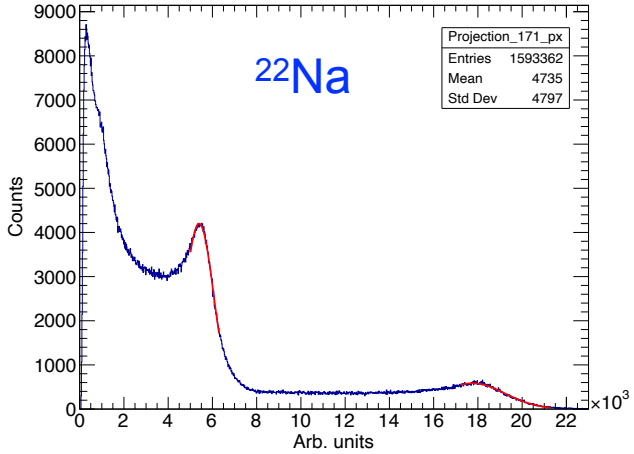
- Intrinsic radioactivity of $BaF_2$ used to calibrate the DANCE crystals.
- Using the Alpha-decay chain of the $^{226}Ra$ present in the $BaF_2$.
  - $^{226}Ra$ (4.8 MeV)
  - $^{222}Rn$ (5.5 MeV)
  - $^{218}Po$ (6.0 MeV)
  - $^{214}Po$ (7.7 MeV)

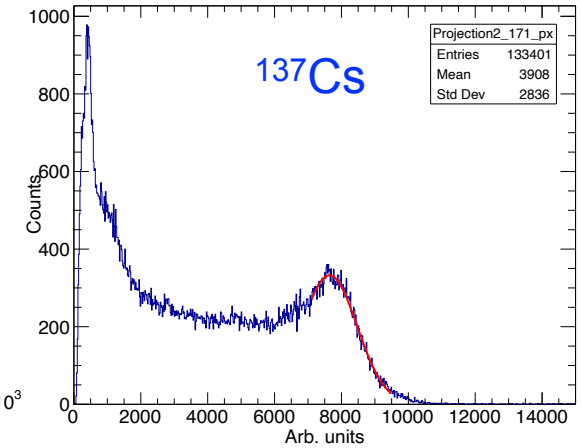


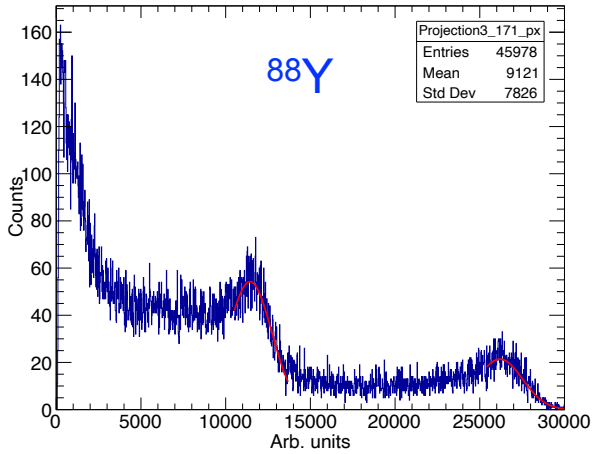
# NEUANCE calibrations

- Calibration using gamma sources:
  - $^{22}$Na (511 keV and 1274.537 keV).
  - $^{137}$Cs (661.657 keV).
  - $^{88}$Y (898.047 keV and 1836.090 keV).



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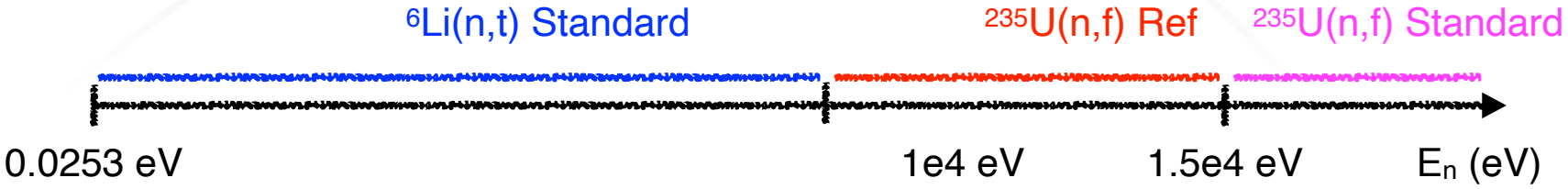
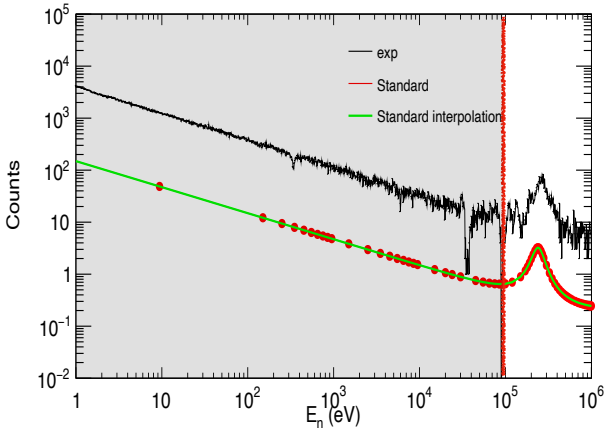
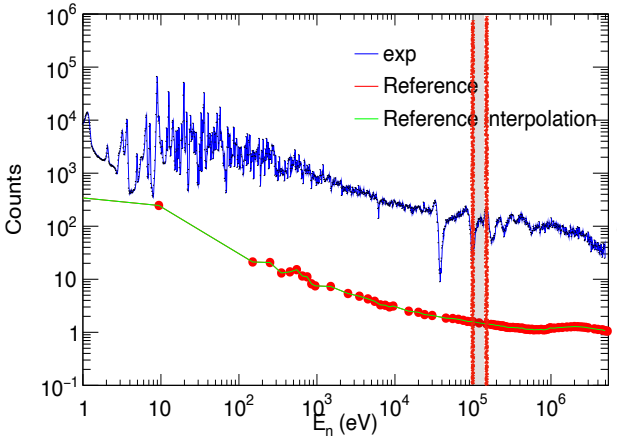
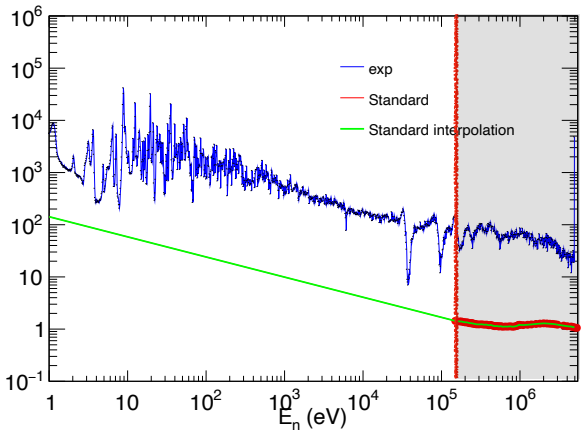
# Flux calculation

- Flux shape:




- Normalization:
  - To the $^{235}$U(n,f) second Standard (7.8-11 eV).



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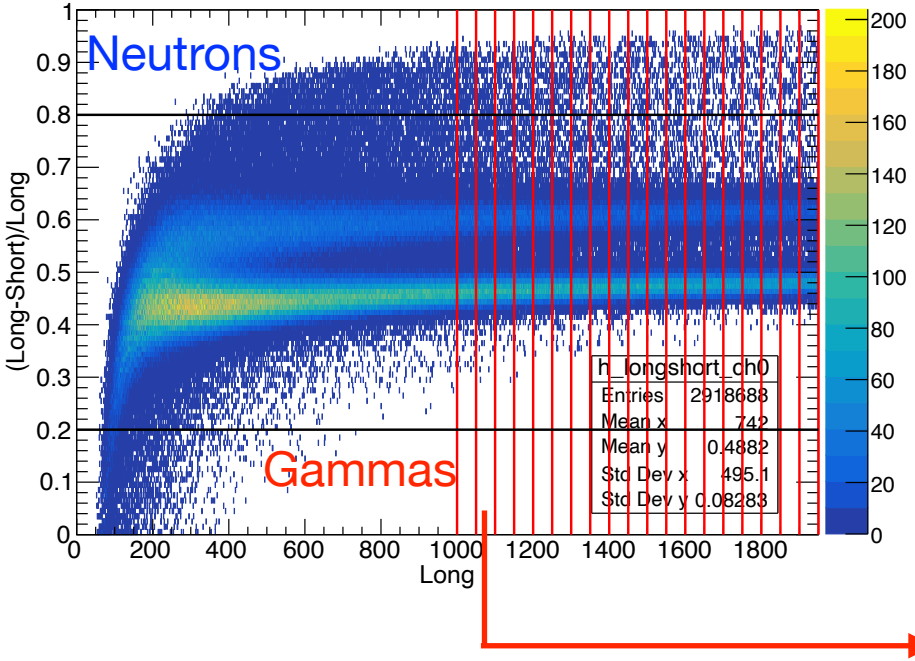
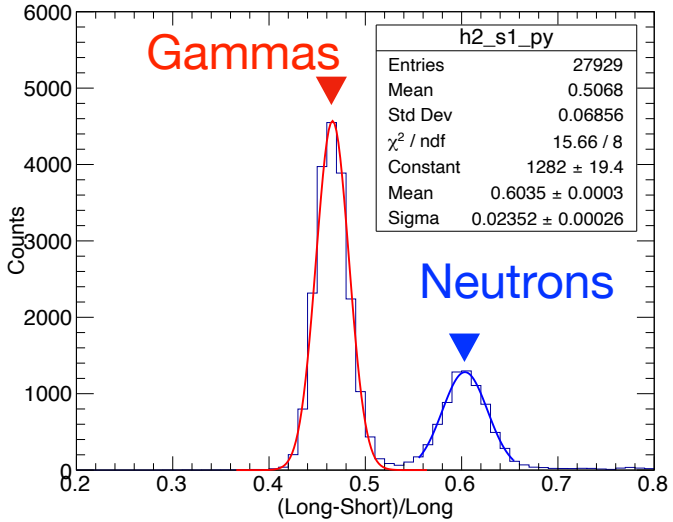
# PSD NEUANCE

- Neutrons & gammas separation using the plot (long-short)/long vs long.




- Clear discrimination between fission neutrons and gamma-rays.



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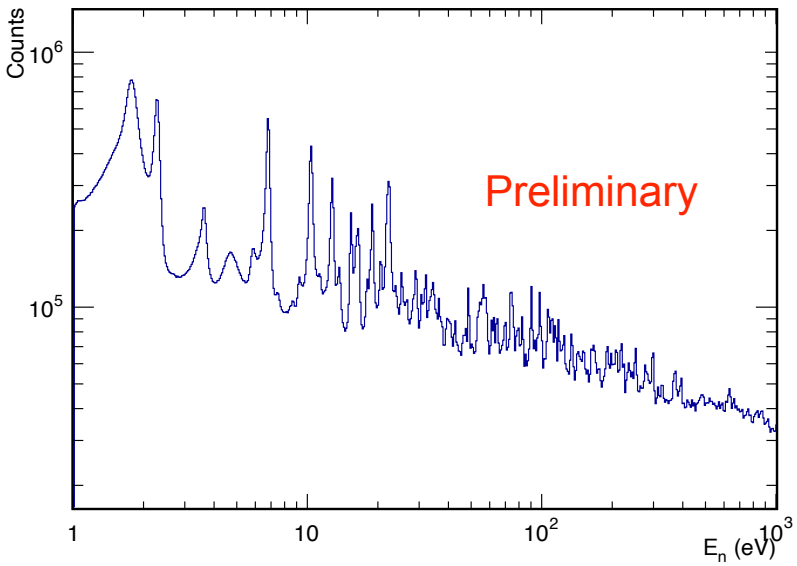
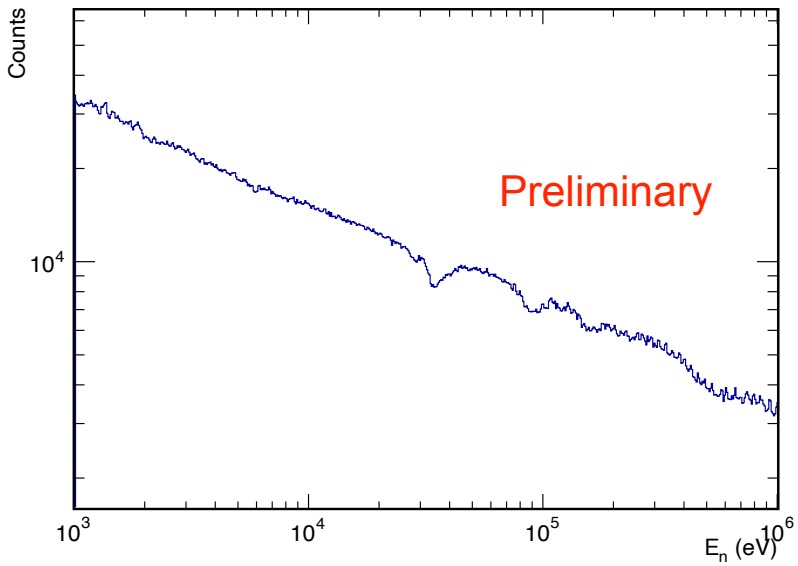
# $^{233}$U (n,γ) DANCE spectrum

- Raw counts of the $^{233}$U(n,γ) reaction measured with DANCE, before fission tagging.

Resonance Region




keV Region



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# Conclusions and next steps

- Previous measurement of the $^{233}$U(n,$\gamma$) reaction measured in 2008 using DANCE combined with the “Fowler” PPAC at LANSCE: poor statistics in the keV region.
- New measurement at LANSCE combining DANCE and NEUANCE at the end of 2020.
- There was a delay on the $^{233}$U target production due to COVID issues with transportation.
- The $^{233}$U material was provided by Oak Ridge National Laboratory (December 2020).
- Two samples of 10 mg and 20 mg of $^{233}$U have been prepared at LANL by Evelyn M. Bond (December 2020).
- The 20 mg sample has been measured during 10 days of data taking (December 2020).
- Data analysis in process (2021 - 2022).
- Continue data taking in 2021 to increase the statistics.


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# Acknowledgements

The $^{233}U$ was supplied by DOE/SC Isotope Program.
Thanks to our collaborators John Ullmann (P-3), Catherine Fry (P-3) and Todd A. Bredeweg (C-NR), to Oak-Ridge National Laboratory for providing the $^{233}U$ material and to Evelyn M. Bond for preparing it.



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