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Present and future research at DANCE

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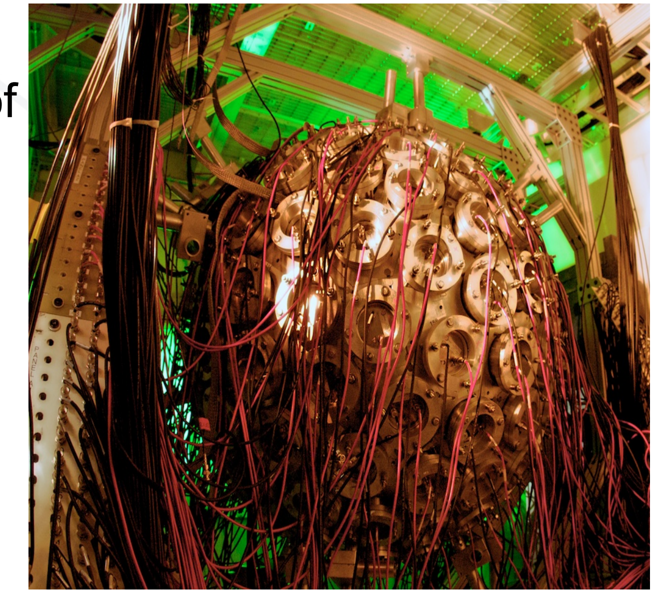
UNCLASSIFIED

Introduction – capture and fission at DANCE

- The Detector for Advanced Neutron Capture Experiments (DANCE) was developed for studies of neutron capture:
  - High precision cross sections
  - Photon strengths and level densities
  - Resonance J^{π} assignments
- Located at the Lujan Center at the LANSCE
- 160 x BaF2 crystals in 4π geometry
- Fast (6ns), high efficiency calorimeter for γ-rays
- Digital DAQ – 324 channels
- Recently, focus on neutron-induced fission:
  - Prompt fission gamma-ray (PFG) studies
  - Correlations between PFG and other fission observables
  - Cross sections

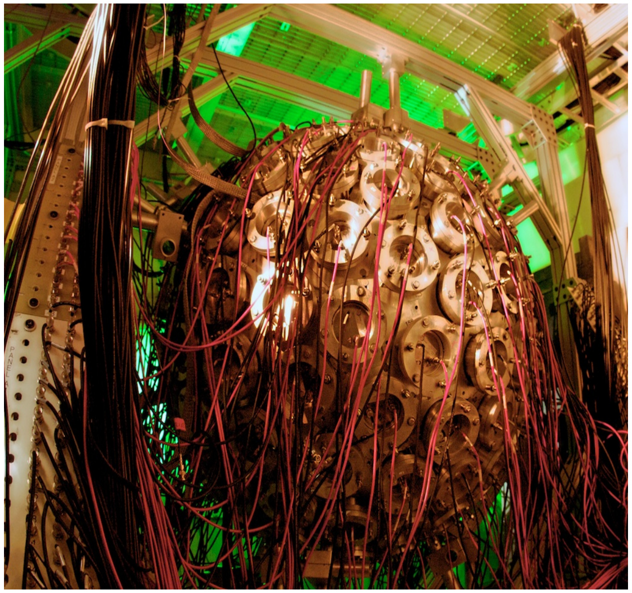


DANCE - 160 x BaF_2 gamma-ray calorimeter

- *20.24 m long flight path*
- *Water moderator*

Motivations

- Basic Nuclear Science
- Applications
- Nuclear Energy
- Stockpile Stewardship
- Non-proliferation
- Nuclear Forensics
- New High Precision Data on NC and NF



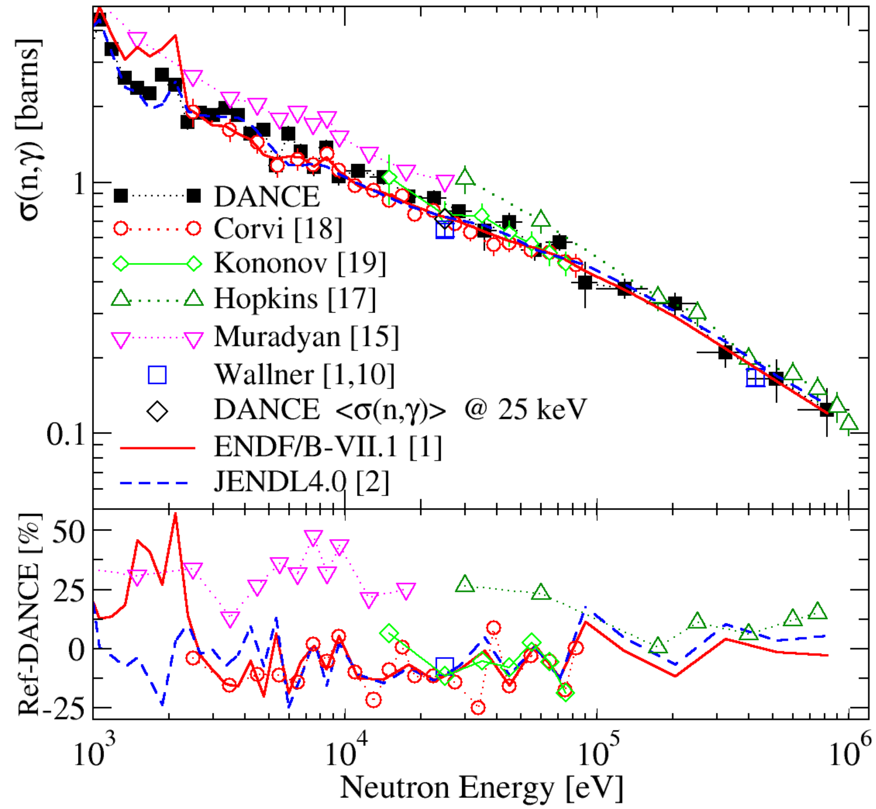
DANCE - 160 x BaF_2 gamma-ray calorimeter

Research Programs

- A) High fidelity neutron capture measurements at DANCE
  - Five year long experimental program: U-234,236,238(n,g)
  - Reduce the uncertainties below 3%
  - Funded by DOE, Office of Science, Nuclear Physics
- B) Short-lived Actinide Isomers
  - Three year long, major R&D program
  - New capability at DANCE – NEUANCE 4π neutron detection
  - Funded by LDRD/DR (LANL)
- C) Studies of prompt fission gamma-rays correlations with FF
  - Three years long experimental program: Cf-252, U-235
  - Funded by NA22, Office of Detection and Non-proliferation, DOE

Capture XS: high precision U235 and Pu239

- Ratio method developed for ^{235}U(n,g)
- Precision <3% was achieved using simultaneous rate determination;
  - Rates of U5(n,g) and U5(n,f)
  - The same target → same neutron flux for both reactions

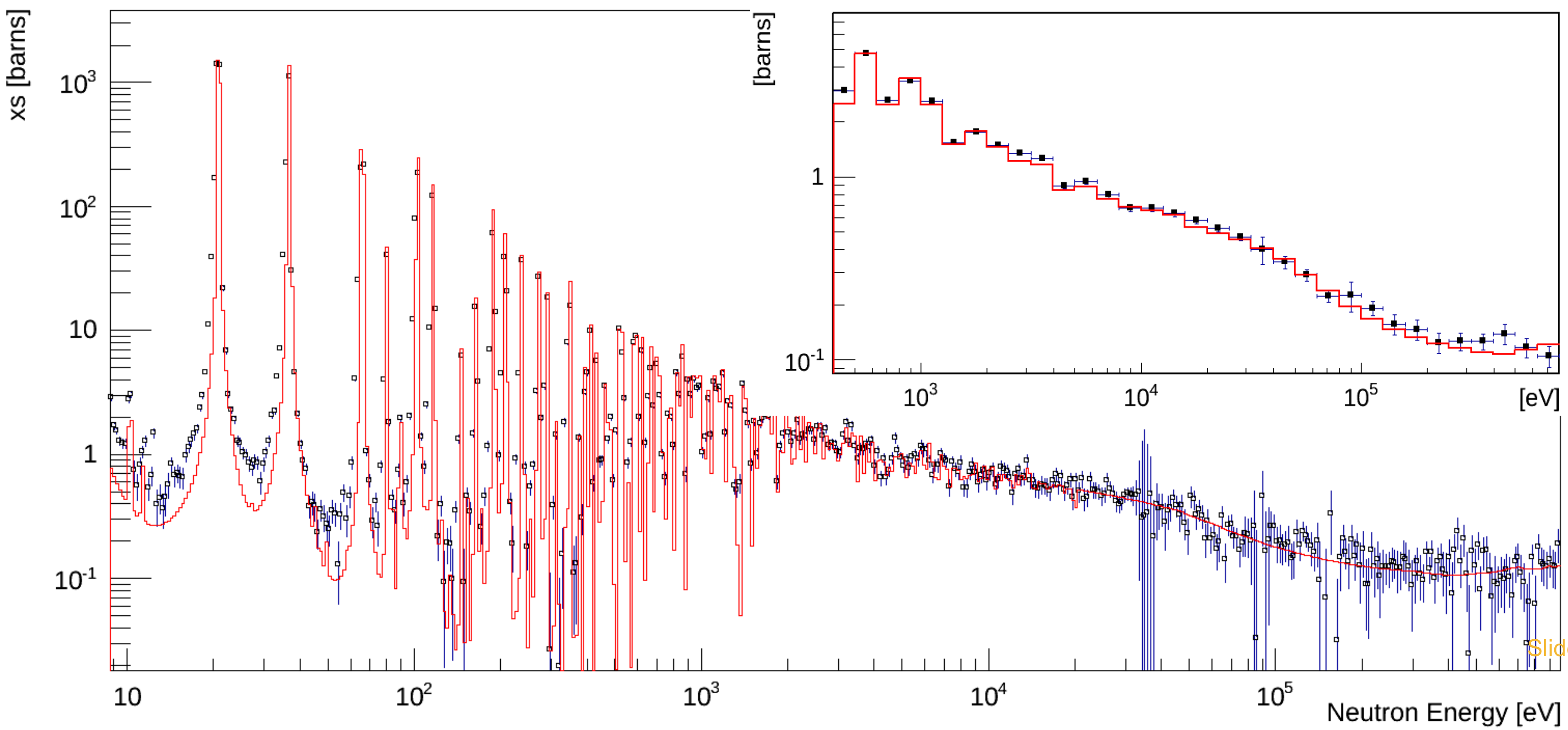


M. Jandel et al., Phys Rev Lett 109, (2012)

- Successfully implemented for ^{239}Pu (*S. Mosby et al., PRC 89, 034610, see the next talk*)

A) Capture XS: U238 / U235 from independent measurements

- Can Ratio method be applied to developed for ^{236}U(n,g) and other isotopes ?
- Results of region of two independent measurements on thick U236, U-238 and U-235 foils are promising



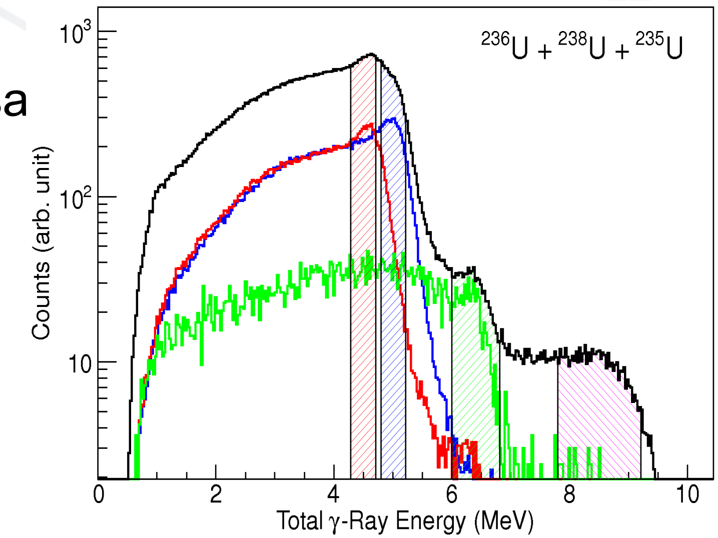
Capture XS: U236 and U238 mixed targets

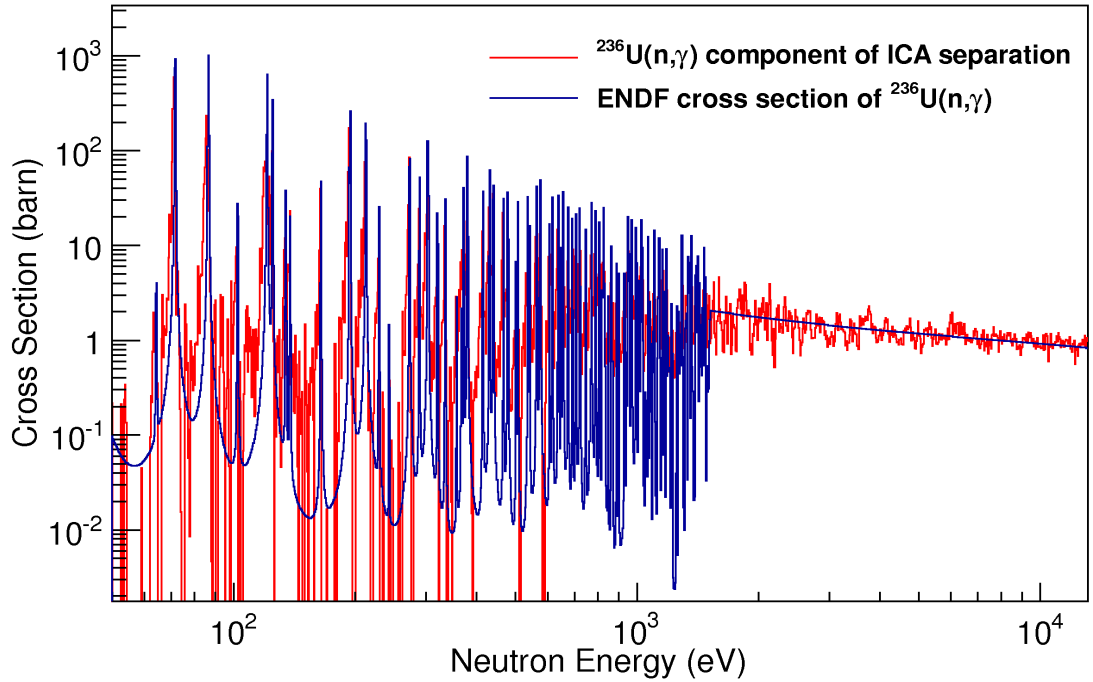
- Can Ratio method be applied to developed for $^{236}U(n,g)$ and other isotopes ?
- Results of region of two independent measurements on thick U236, U-238 and U-235 foils are promising

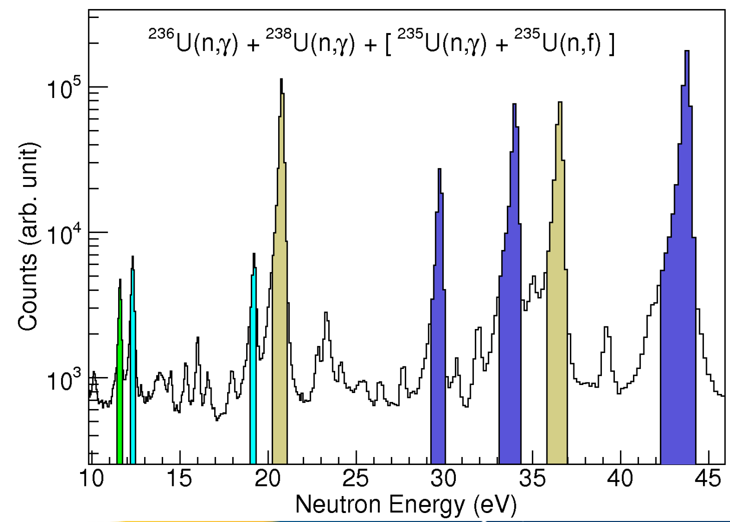
- New measurements with mixed targets to cancel out n flux:
  - $^{236}U+^{235}U$ (Nov 2013)
  - $^{238}U+^{235}U$ (Fall, 2014)

Capture XS: U236 and U238 – applied math

- ICA analysis – work in progress by B. Baramsai
- Last year measurements
  - U235+U236+U238 mixed target







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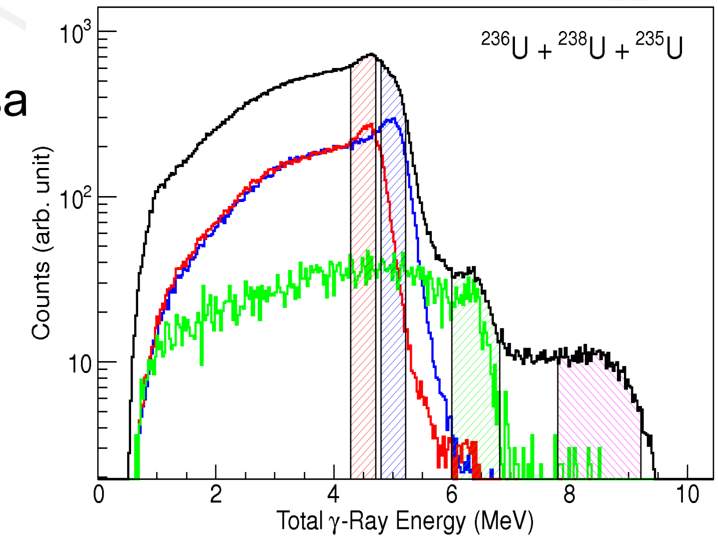
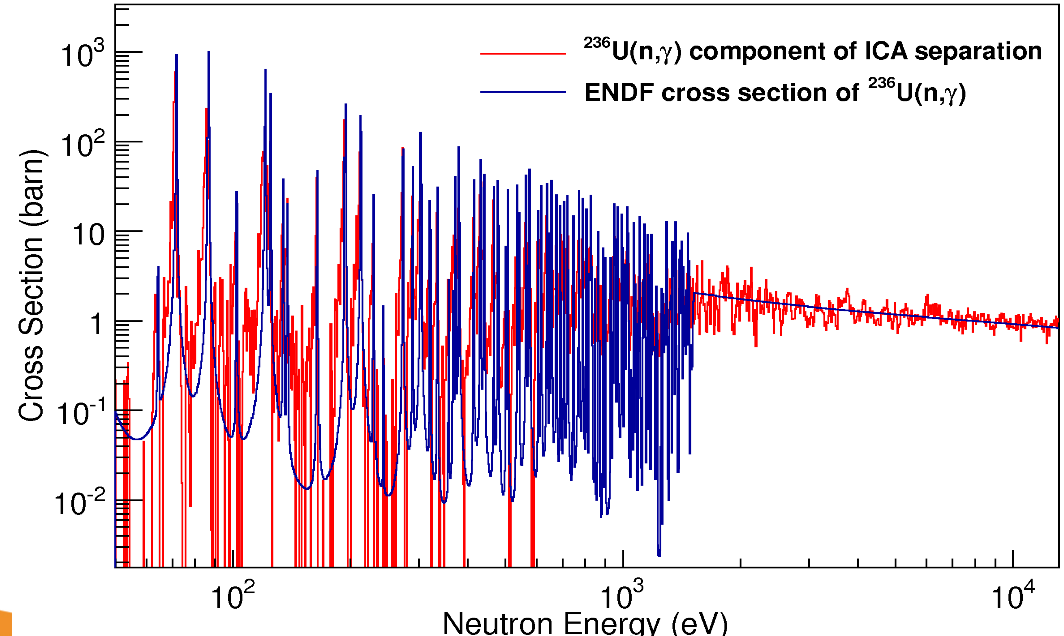
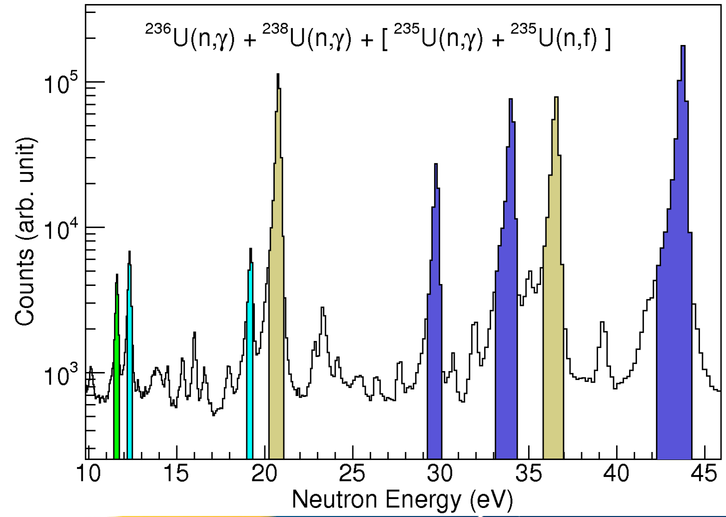




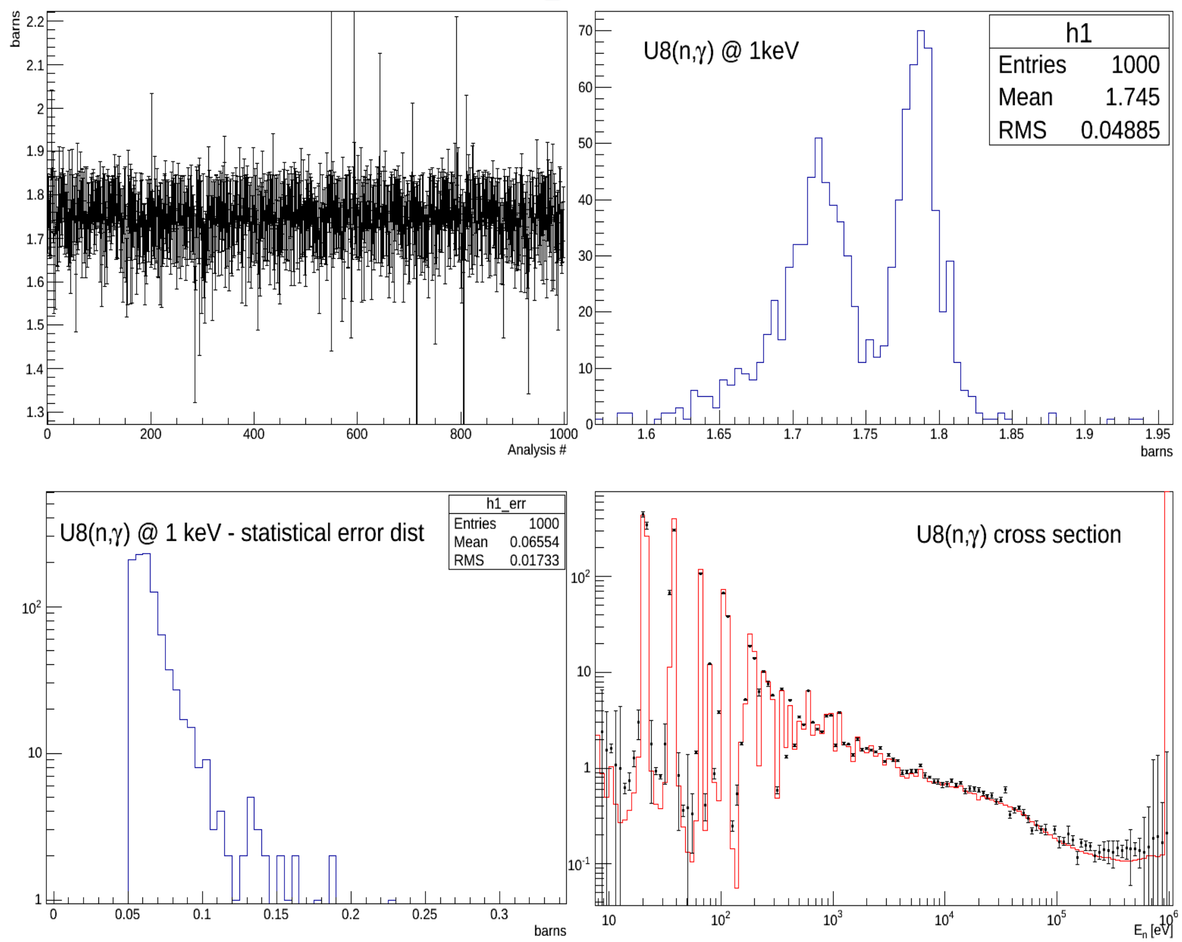


Capture XS: uncertainties – Monte Carlo

- Many Sources:
  - Detector set-up, reference nuclear data, analysis, data reduction
- Data Reduction
  - What happens if 1000 people analyze the same dataset ?
  - Sample over all parameters of data reduction using Monte-Carlo

Capture XS: U238 - uncertainties – Monte Carlo

- Gates: M=(p(M1),p(M2)), E1=(p(Q1),p(Q2)), E2=(p(B1),p(B2))
- P is a distribution to sample from (Gaussian, uniform)
- U238 – En=1 keV
- 1.745 (0.05) barns
- Average statistical error ~ 0.066
- Systematical/analysis error ~ 0.05



Capture Gamma-rays

- Studies of photon strengths and level densities in actinides
- De-excitation codes: DICEBOX (M. Krticka), CGM (T. Kawano)
- Detector Response: DANCE-Geant4

- We will use forward methods: trial & error approach
- Under development is also multidimensional decomposition
  - See G. Rusev talk
  - Very promising results on this new technique

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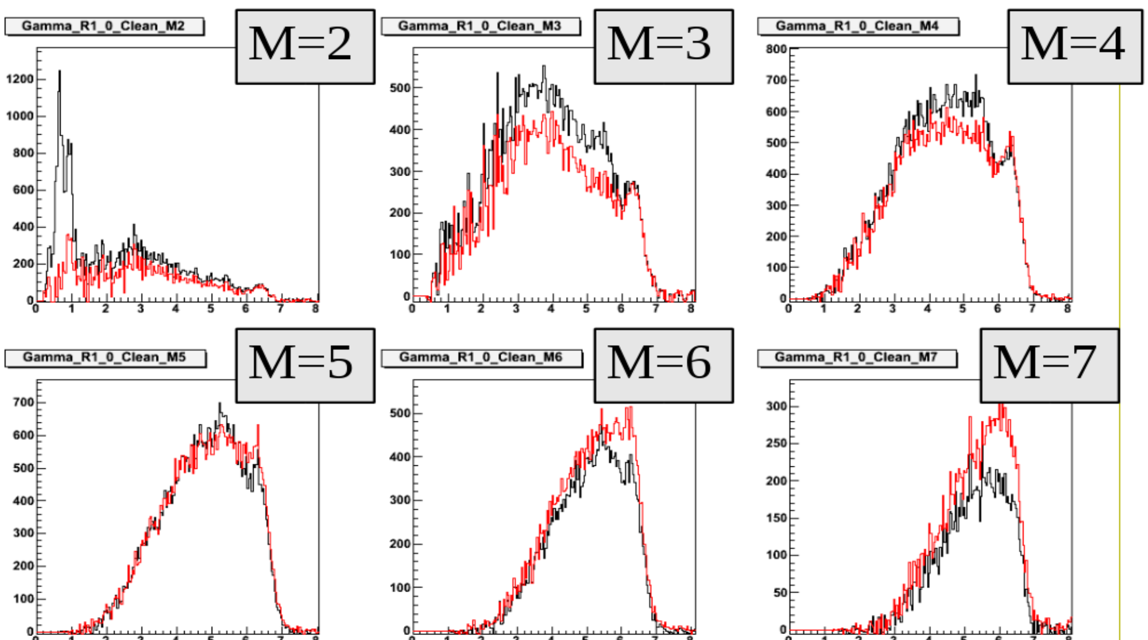
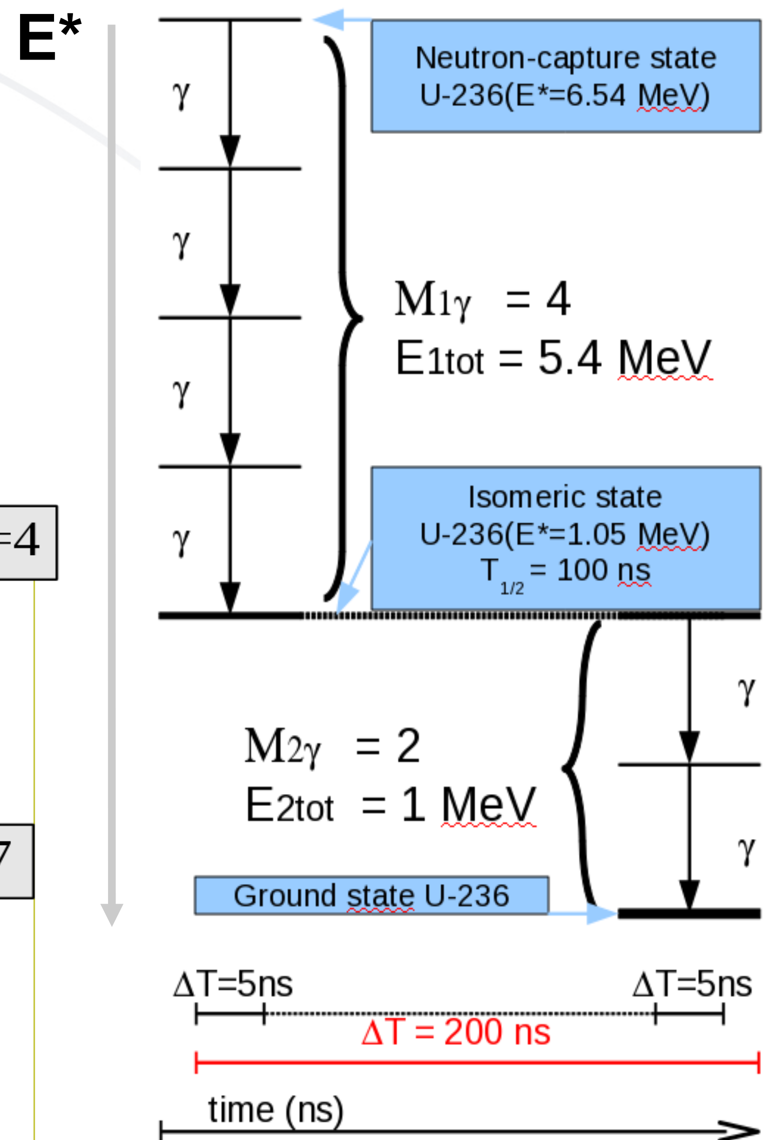
Isomeric states after U235+n

- During analysis of ^{235}U(n,γ) cross section we have found structure in the total gamma-ray energy E_{tot} spectra

M. Jandel et al., Phys Rev Lett 109, (2012)

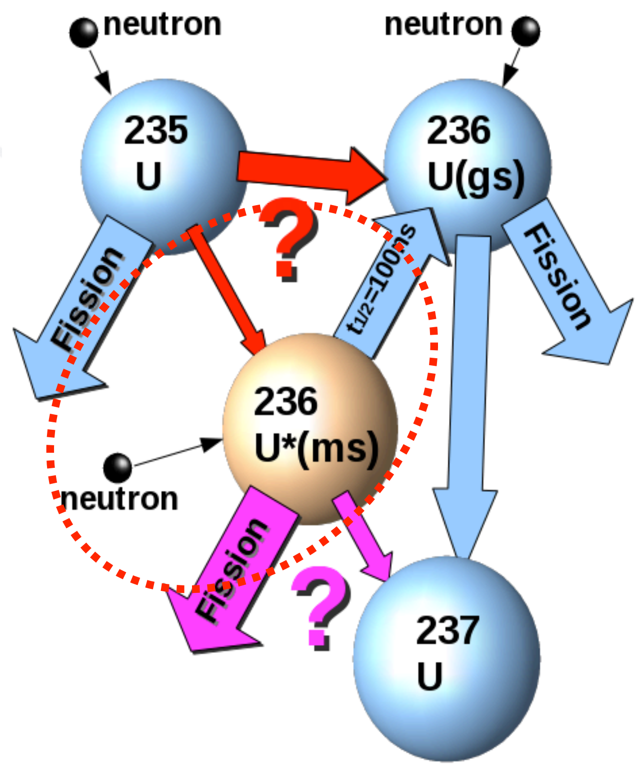
- E_{tot} variations with ΔT and number of gamma-rays detected in a ΔT window



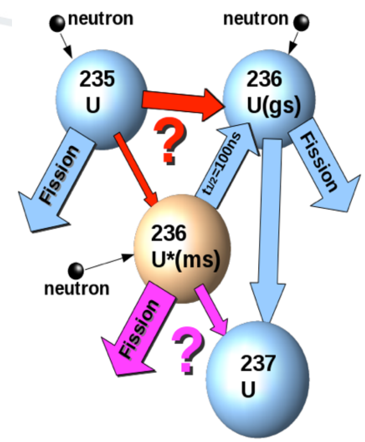


Isomeric states after U235+n

- In high neutron fluence the secondary reactions can occur
- $^{236}U^*$: 1024 keV (4-) $T_{1/2}$ = 100 ns
- $^{236}U^*$: 678 keV (1-) $T_{1/2}$ = 3.7 ns



- What is the population of these states after ^{235}U+n ?
- What are the n-reaction cross sections on these states ?

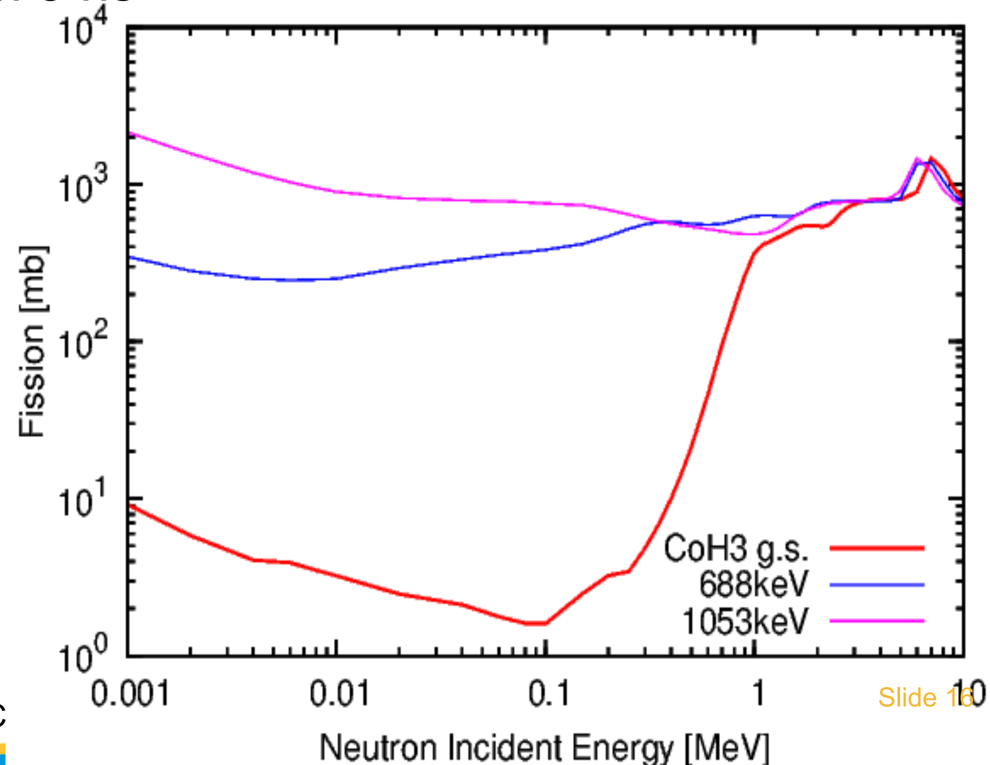


Isomeric states after U235+n

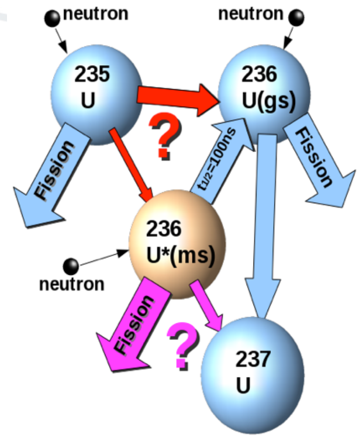
- In high neutron fluence the secondary reactions can occur
- $^{236}U^*$: 1052.5 keV (4-) $T_{1/2}$ = 100 ns
- $^{236}U^*$: 687.59 keV (1-) $T_{1/2}$ = 3.78 ns

- What are the n-reaction cross sections on these states ?

- Preliminary calculations show **50-100 x larger** cross section for (n,f) reactions on isomers compared to ground state - *T. Kawano et al.*



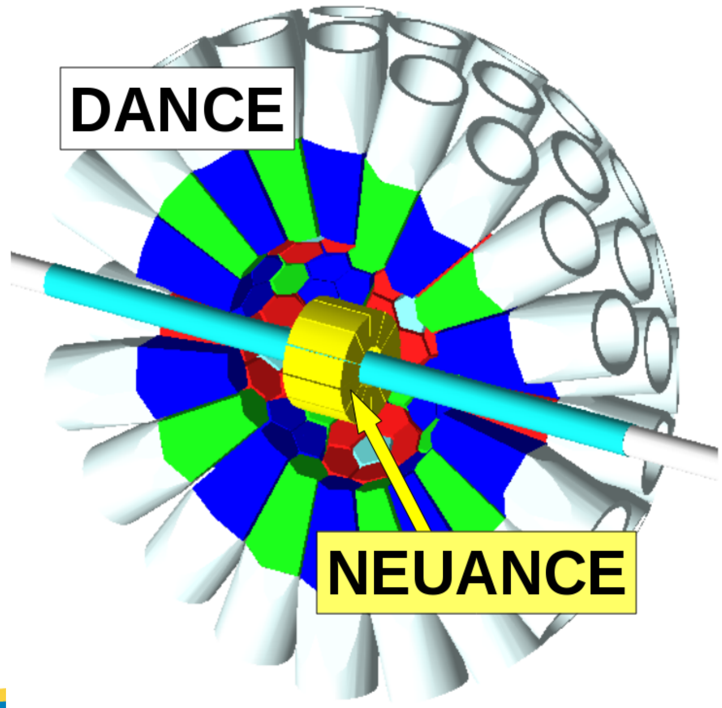
NEUANCE - NEUtron Array at daNCE



- We need to improve counting statistics on fission and capture of U235
- For all gamma multiplicities !
- This is very difficult with FF detectors because of thin targets

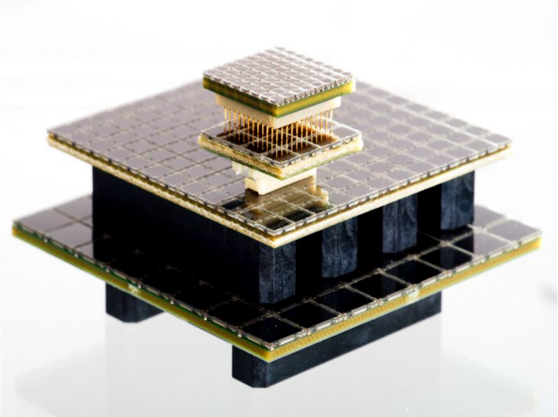
- What is the population of these states after ^{235}U+n ?

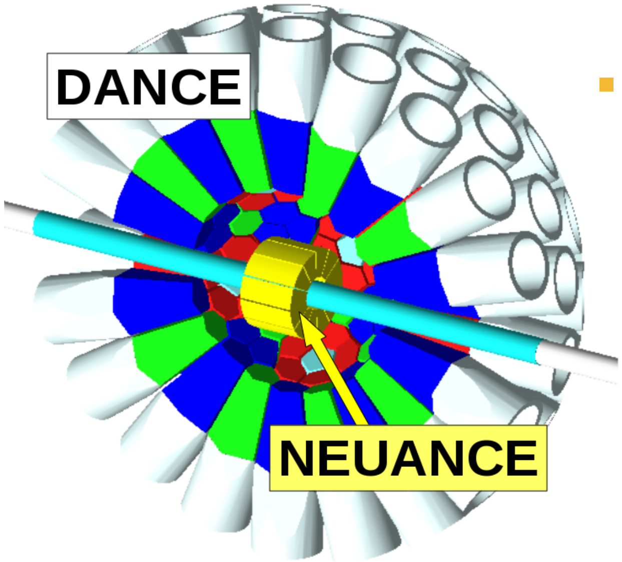
- NEUANCE: 8-12 segments of liquid scintillators in the center of DANCE
- NEUANCE will be sensitive only to neutrons above 200 keV --> only from fission



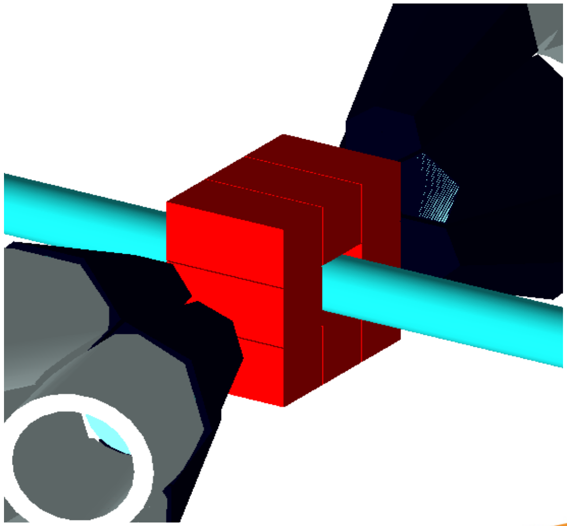
NEUANCE - NEUtron Array at daNCE

- Challanges in NEUANCE design
  - Small cavity (17 cm diameter) - need small PMTs or alternative SiPM
  - Loss of 6LiH shell - larger backgrounds
  - Close geometry - pileups, pulse shape discrimination efficiency





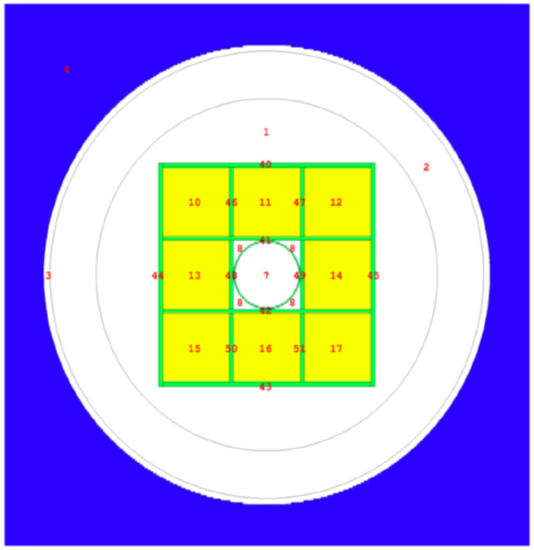
- NEUANCE - 12 or 8 segments of liquid scintillators
  - Geant4 and MCNP-Polimi simulations

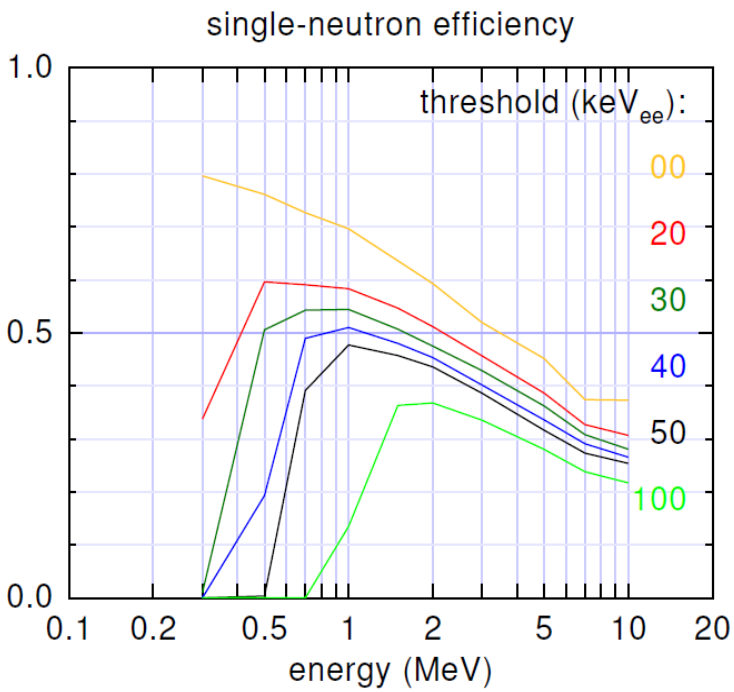


NEUANCE - NEUtron Array at daNCE

- MCNP-Polimi: NEUANCE - 12 or 8 segments of liquid scintillators
- thanks to T. Taddeucci

MNCPX-PoliMi was used to calculate the efficiency of a square detector array





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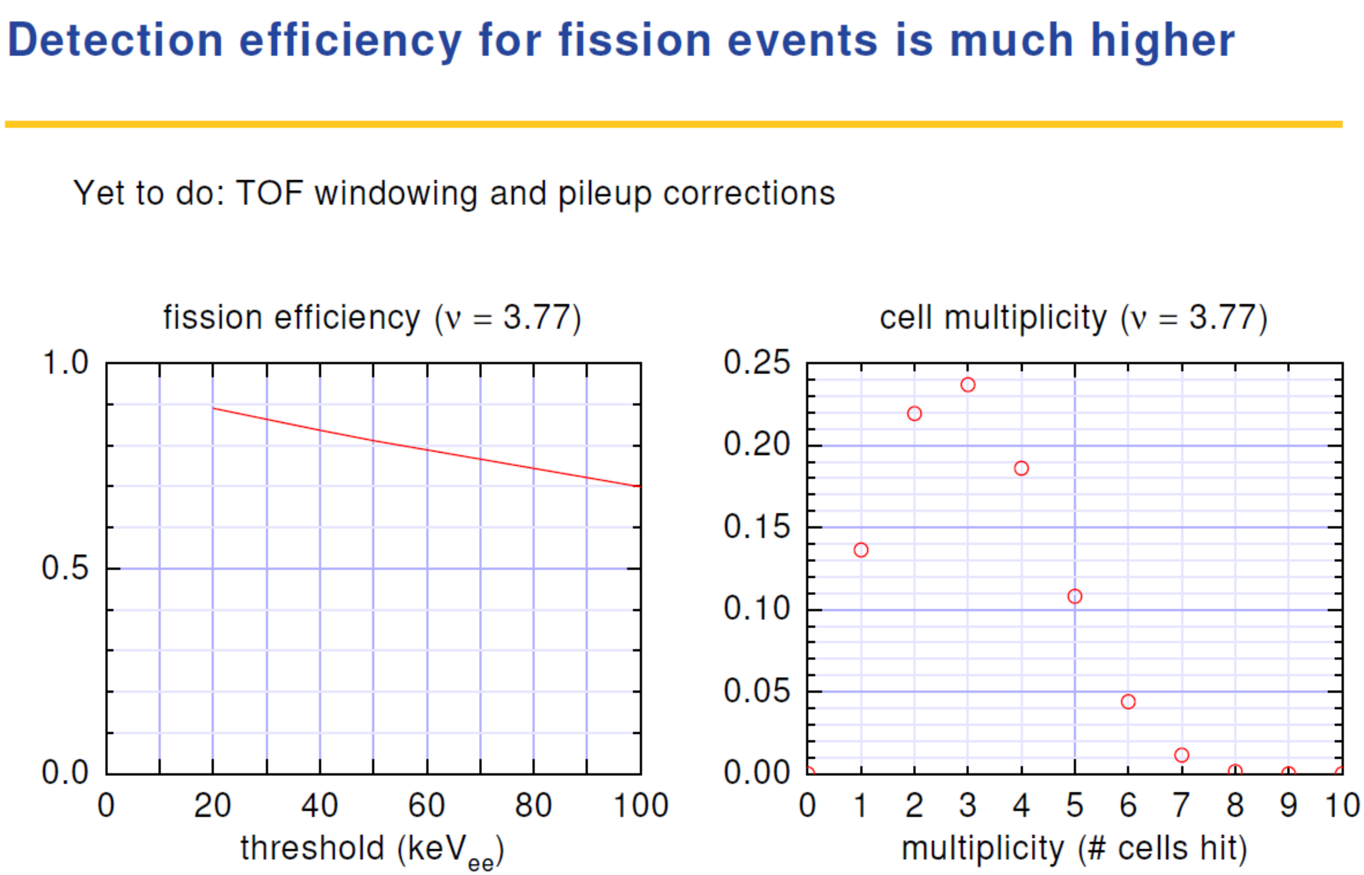
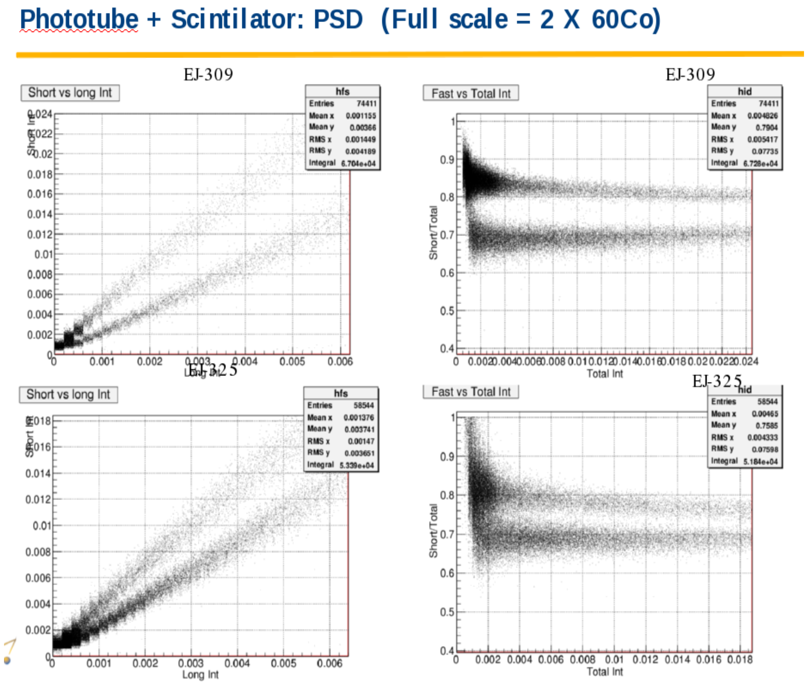


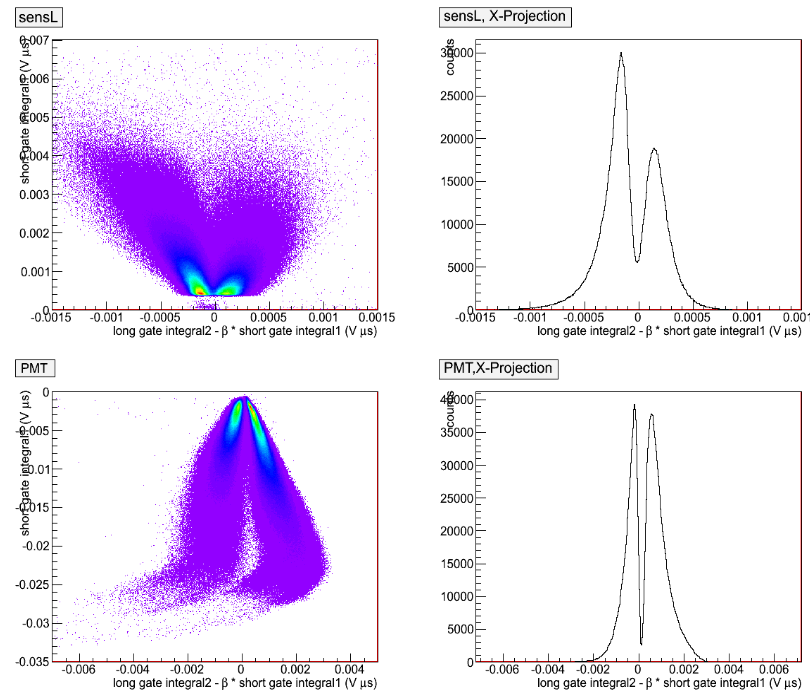
NEUANCE - NEUtron Array at daNCE

- Detector tests are under way - prototype cells
- Hammamatsu PMT vs SiPM - PSD efficiency tests

Liquid Scintillator + PMT

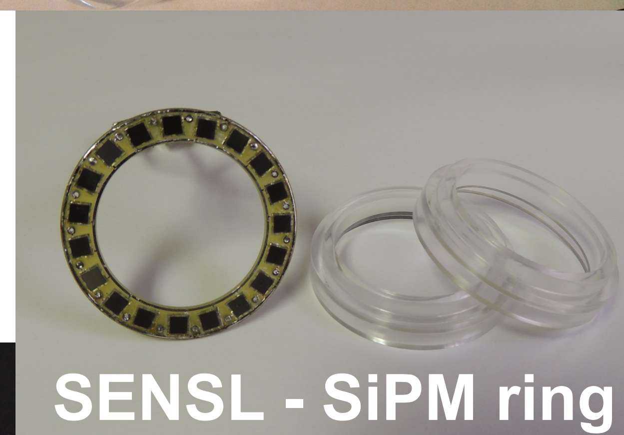


Stilbene + SiPM(6x6mm)



Fission fragment detectors R&D

- A) Multifoil PPACs
- B) Thin scintillator foils - multifoil design allows to put many foils per 1mg/cm2 in beam
  - Thin sc foils 10x between the rings
  - Acrylic rings are painted from inside by sc paint
  - Light collected at the end by SiPM ring
  - Initial tests with Cf-252 are promising
  - design/work by G. Rusev



New data acquisition for DANCE

- 14 bit 500 MHz digitizers
- FPGA onboard zero suppression processing

- Significant investment
- New hardware will arrive in Sep 2014
- Next beam cycle will be used to implement it

- See talk by A. Couture

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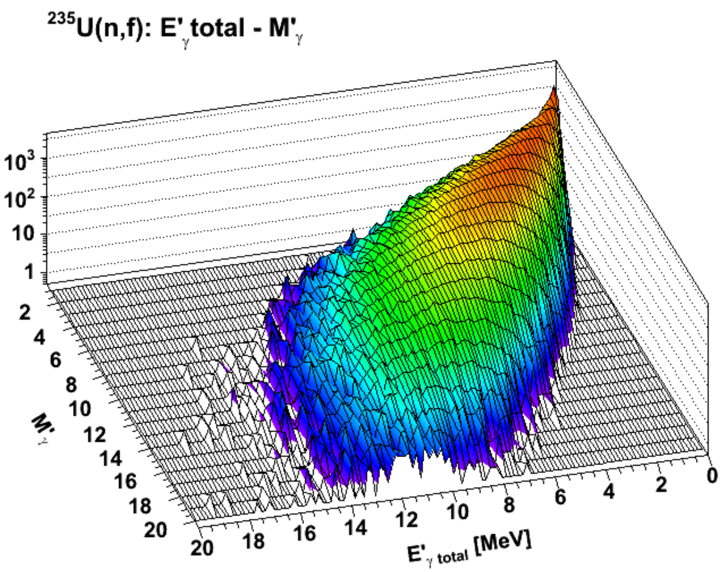
DANCE – efficient gamma-ray calorimeter

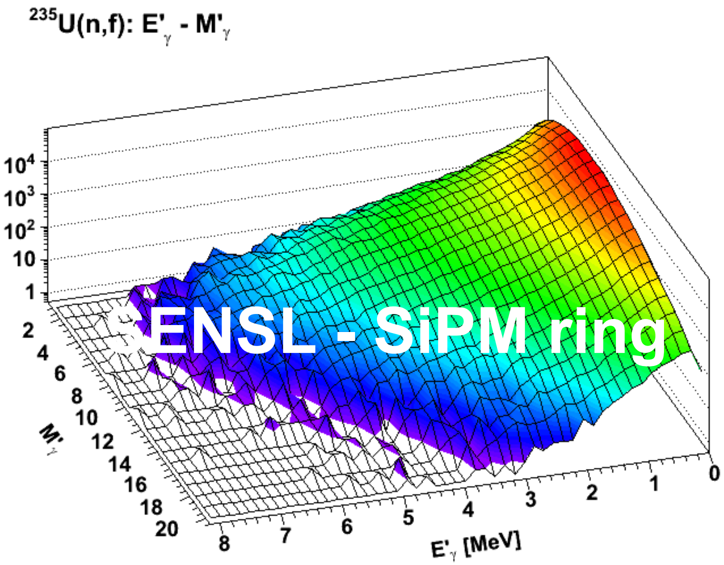
- With high efficiency and 4p solid angle DANCE is ideal for prompt-fission gamma-rays studies
- We measure correlated events of Mγ, Eγ and $E_{\gamma tot}$
- So far we have studied integral properties
- *M. Jandel et al., to be published in Physics Procedia, conf. proceedings of GAMMA-2, Sremski Karlovci, Serbia, 2013*

$$p(M_{1,2})=(2M_{1,2}+1)\,e^{-M_{1,2}(M_{1,2}+1)/2c_{12}^2}$$
$$p_1(E_\gamma)\propto E_\gamma^2 e^{-t_1 E_\gamma}$$
$$p_2(E_\gamma)\propto E_\gamma^3 e^{-t_2 E_\gamma}$$

$$M_\gamma=M_1+M_2$$
$$t_{1,2}=a_{1,2}+b_{1,2}M_\gamma$$

	c_1	c_2	a_1	b_1	a_2	b_2
^{235}U	6.2	2.06	3.610	0.0453	1.620	0.0458
^{233}U	6.53	2.22	3.376	0.0449	1.575	0.0461
^{239}Pu	7.11	2.14	3.618	0.0454	1.403	0.0438
^{242m}Am	7.17(5)	2.02(2)	3.80(3)	0.0467(3)	1.371(5)	0.0450(7)
^{252}Cf	7.73(8)	2.57(3)	5.03(6)	0.0098(2)	1.65(2)	0.0406(7)





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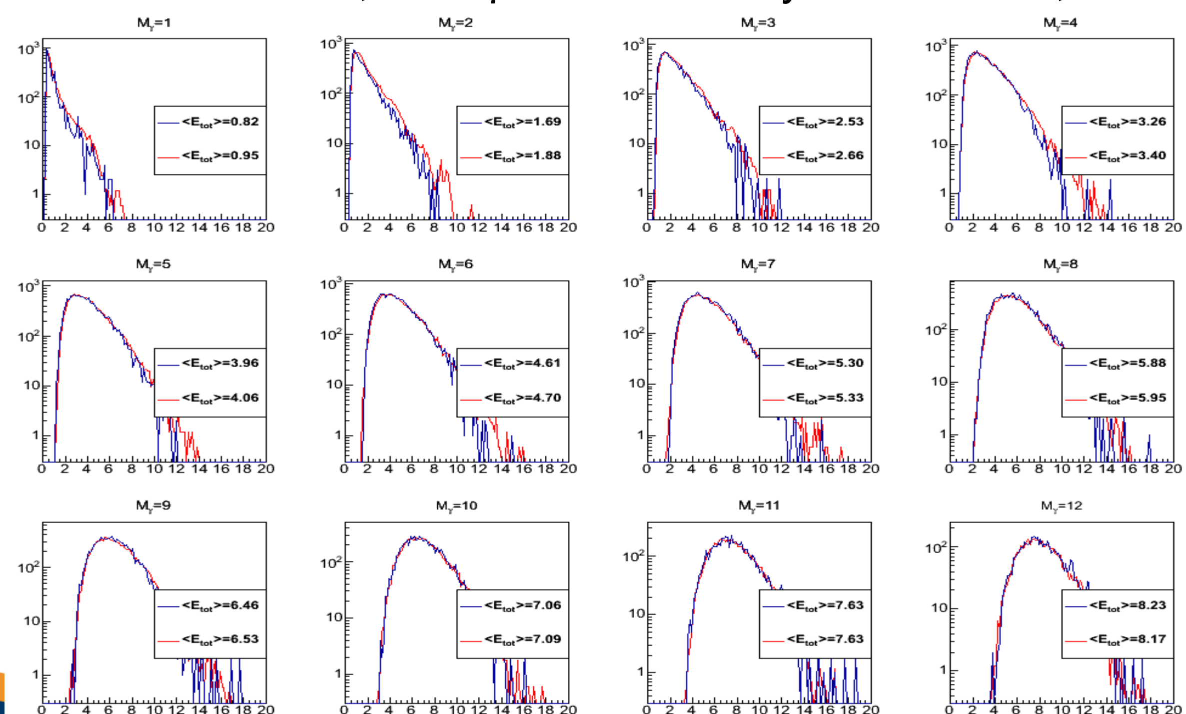

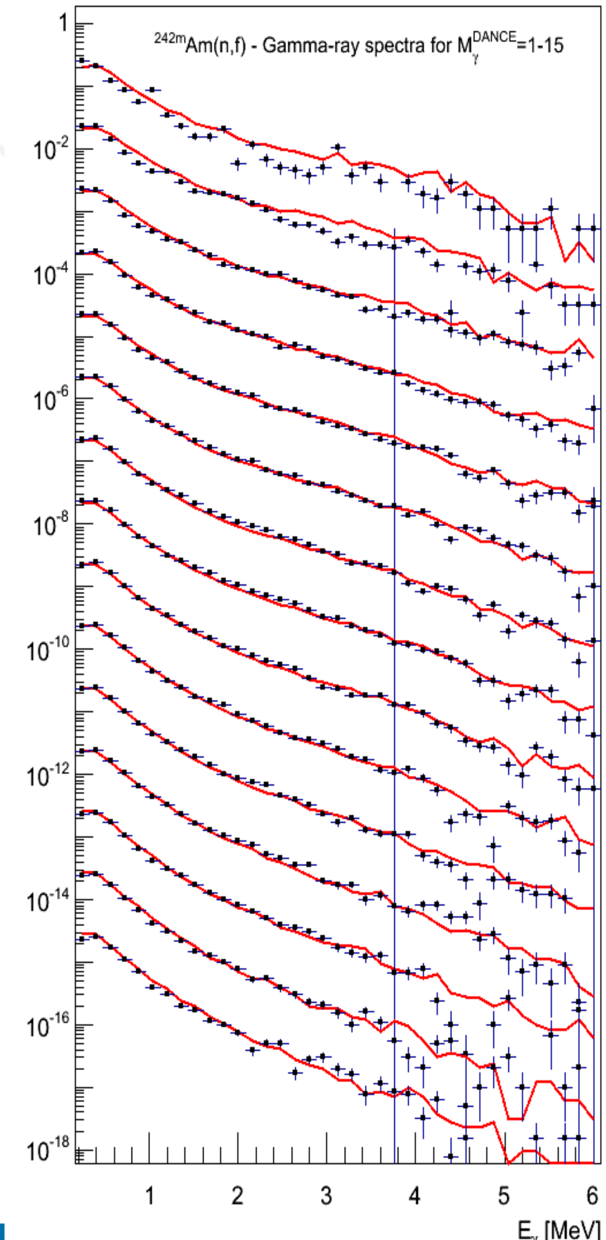

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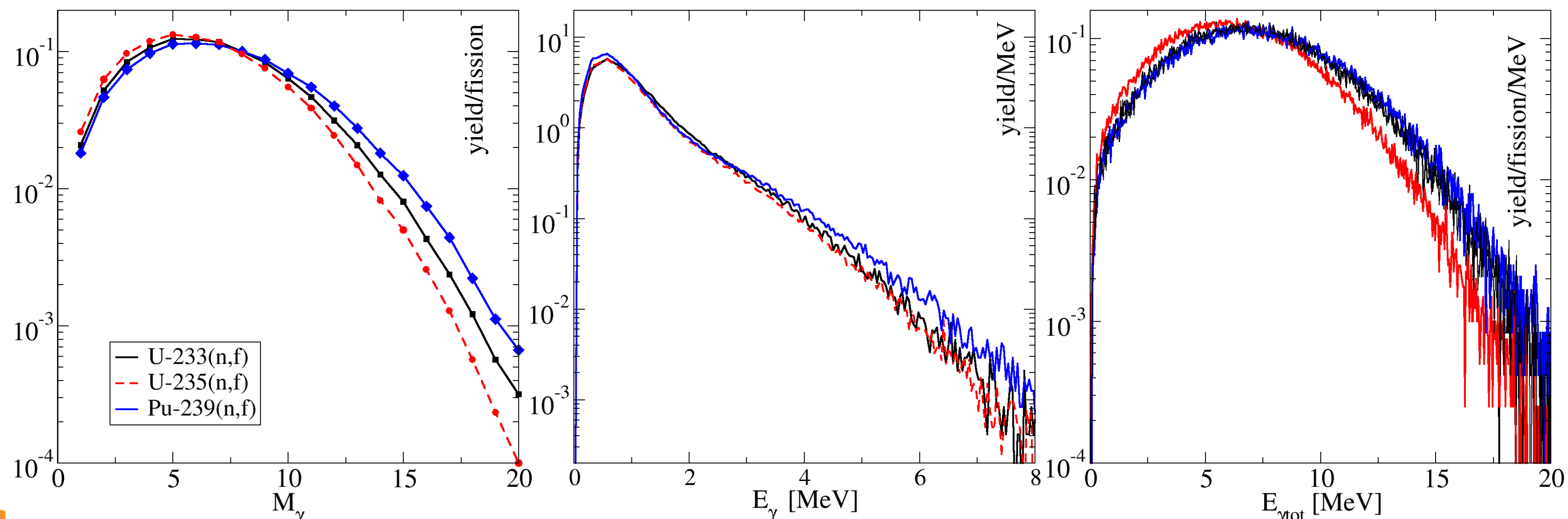
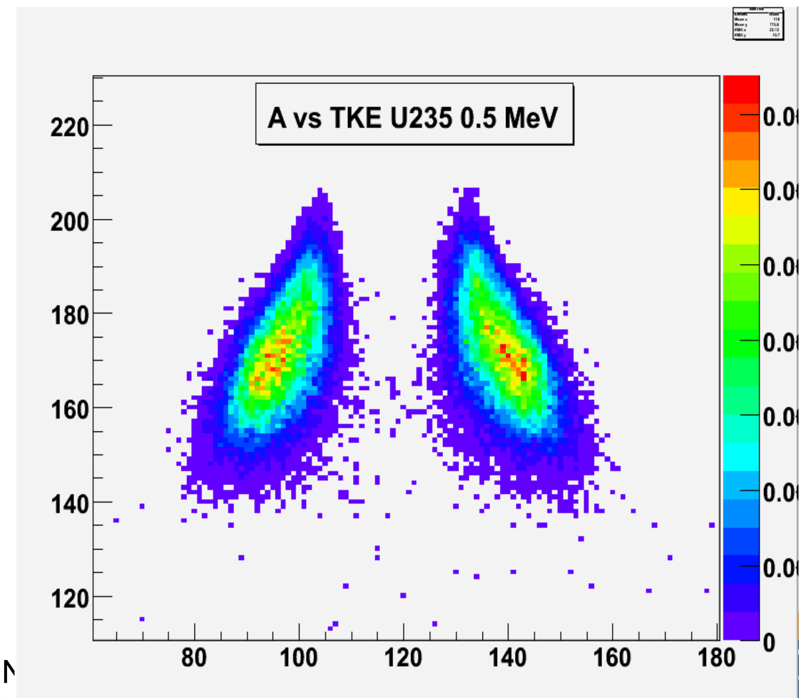
	Mg	sig	E g	sig	E g,tot	sig
^{235}U	6.31	3.02	1.025	0.8100	6.480	3.0700
^{233}U	6.76	3.15	1.077	0.8300	7.240	3.3200
^{239}Pu	7.21	3.42	1.036	0.8800	7.430	3.4300
^{242m}Am	7.14(5)	3.45(4)	0.999(5)	0.88(1)	7.13(6)	3.32(3)
^{252}Cf	8.11(7)	3.77(4)	0.891(9)	0.807(9)	7.22(6)	3.33(3)



DANCE – efficient gamma-ray calorimeter

- Next step – adding measurements of kinetic energies and masses of fission fragments with PFG
- Benchmarking the evaporation and fission codes – CGMF (P. Talou, I. Stetcu, T. Kawano)
- MCNP6 development – de-excitation modules (gamma/neutrons in correlation)



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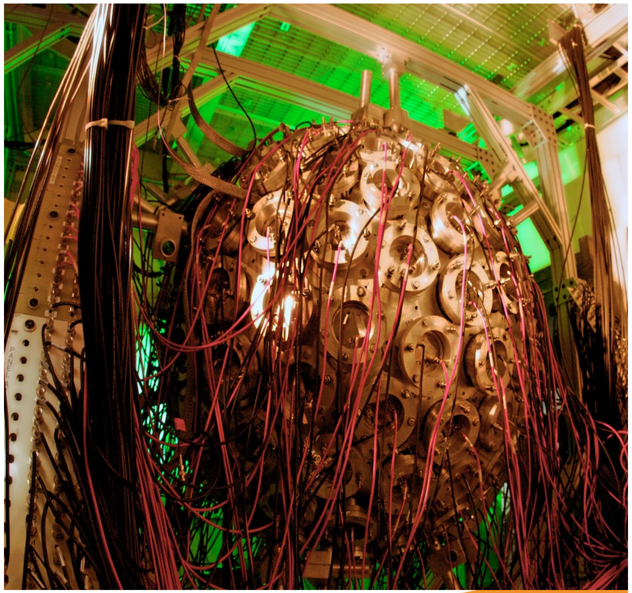
Summary

- Very exciting times for DANCE research
- Well funded for next five years and new opportunities will open up with all upgrades and new detection capabilities
- Cross sections: U, Pu isotopes, …
- Fission properties: complete measurements of prompt neutrons and gammas and fission fragments in full correlation CoFIE (complete fission experiments)
- Fundamental studies, de-excitation physics
- Applied physics: reactor heat, delayed gamma-rays



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- T-division: A. Hayes, P. Talou, T. Kawano, I. Stetcu
- X-division