LA-UR-16-28728

Gamma-ray production for ^{235,238}U and ^{239}Pu

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Motivation for new evaluation of prompt fission gammas

- New experimental data available (better resolution) for ^{235}U
- ENDF-B/VII.1 (and previous) for $^{235}U(n,f)$ and $^{239}Pu(n,f)$:
  - Below 1.09 MeV gamma production evaluations for different reaction channels provided
  - Above 1.09 MeV, only the total gamma production available (running different models for fission would over produce gammas)
- ENDF-B/VIII.0 beta2 (starting evaluation files):
  - Individual reaction channels evaluated (IAEA and TK)
  - Prompt fission production not updated
- Possibility to use MCNP w/ other fission models

Theoretical tool: CGMF simulations

- CGM
  - Monte-Carlo implementation of the de-excitation of compound nuclei using the Hauser-Feshbach model
  - Full treatment of neutron-gamma competition
  - Phenomenological approach, many parameters from experiment or systematics

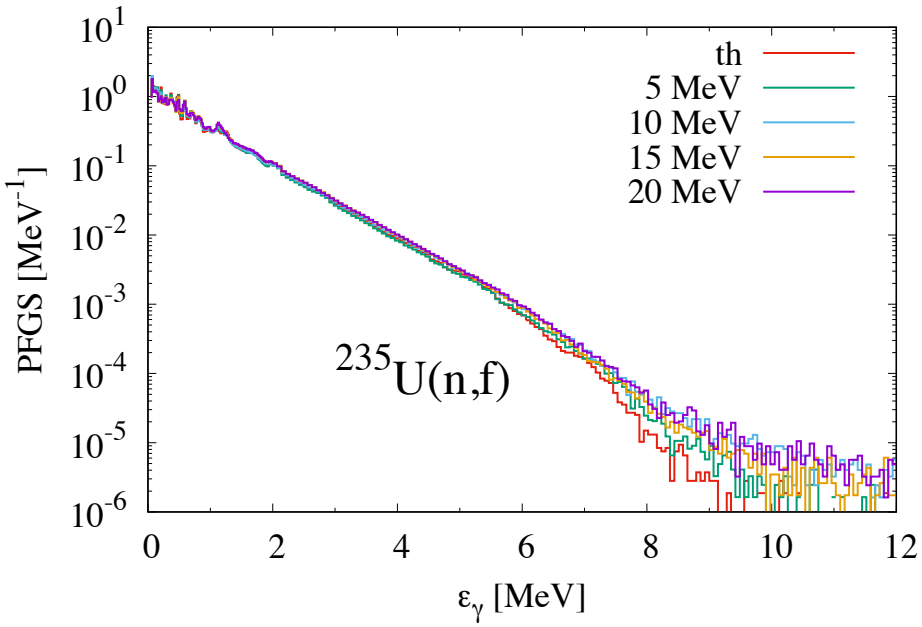
- F
  - Monte-Carlo sampling of fission fragment yields
  - (Monte-Carlo sampling of pre-fission neutrons)
  - Parameterization of
    1. fission yields (mass, charge, TKE)
    2. TXE sharing between FFs
    3. FF angular momenta

- Output:
  History file with emitted particles (prompt fission neutrons and gamma rays) from each fragment

New evaluations for prompt fission gammas: summary

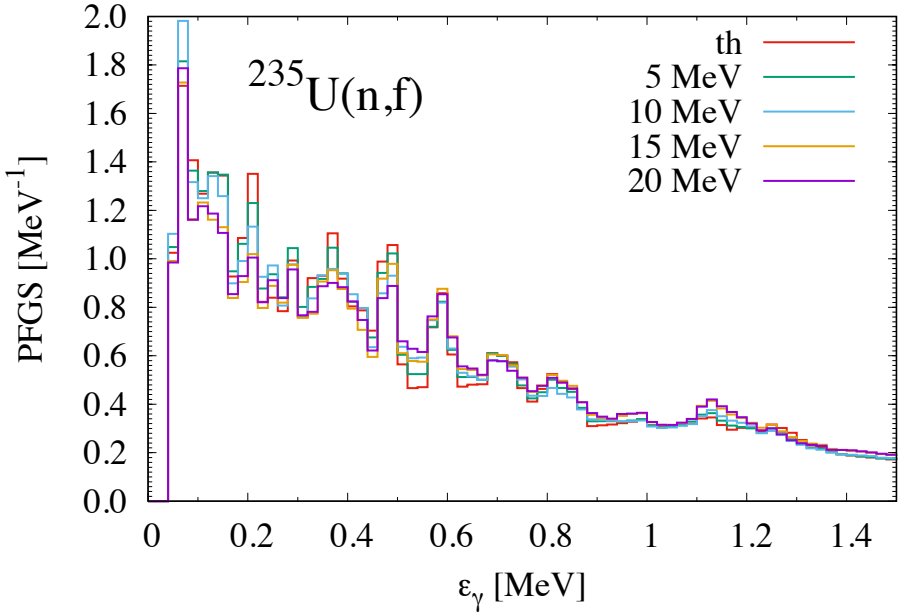
- 235U:
  - Spectrum: based on Oberstedt data between 100 keV and 2 MeV
  - Spectrum: based on CGMF simulations for 0 to 100 keV and 3 MeV+
  - Spectrum: assume no incident neutron energy dependence
  - Multiplicity: CGMF calculations
- 238U:
  - Spectrum and Multiplicity: based on CGMF calculations
  - Spectrum: assume no incident neutron energy dependence
- 239Pu:
  - Spectrum and Multiplicity: based on CGMF calculations
  - Spectrum: assume no incident neutron energy dependence

^{235}U(n,f) CGMF energy dependence

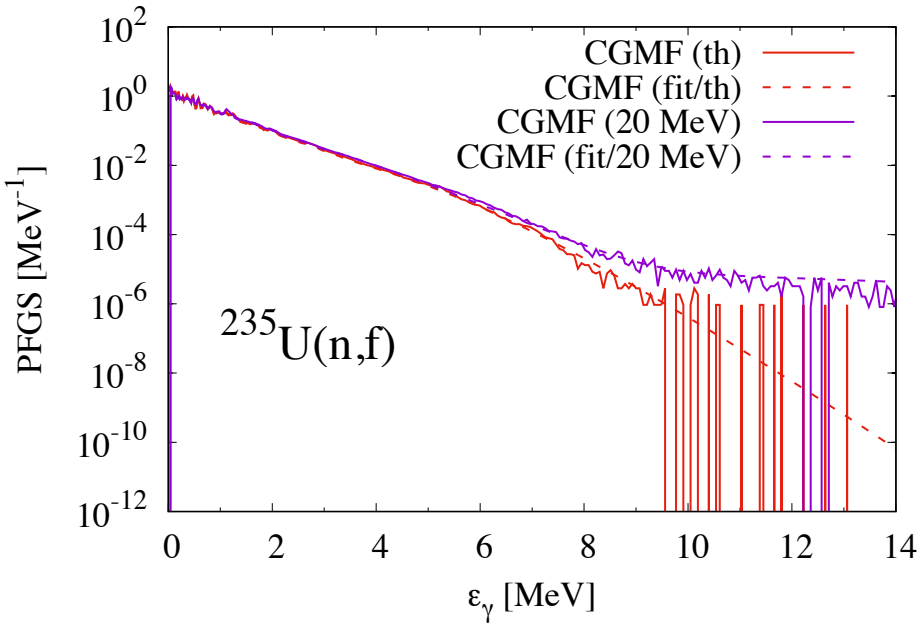


- Similar spectra up to ~ 4 MeV
- Differences in the tail, but no experimental data available

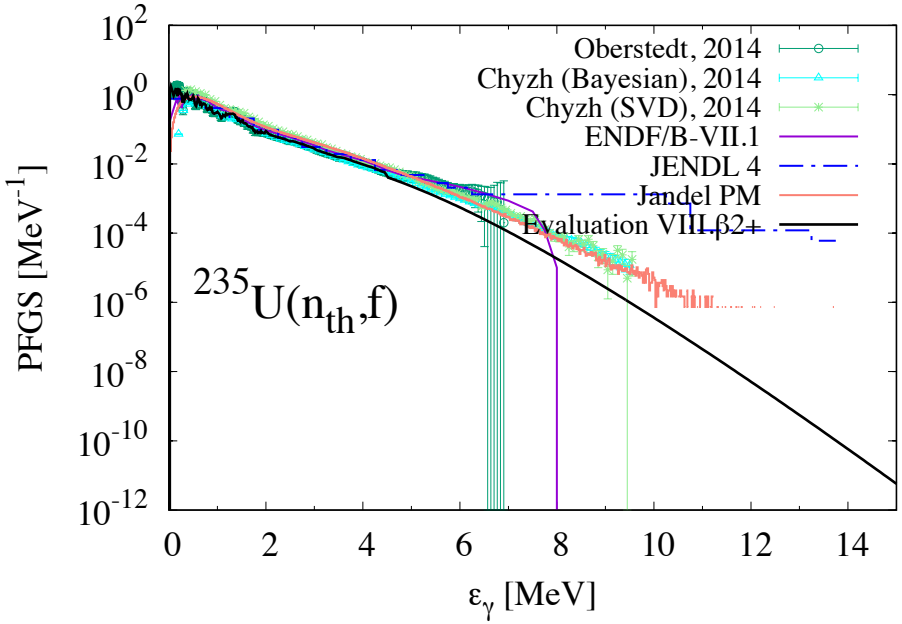
Evaluation
no incident neutron dependence of the PFGS



^{235}U(n,f): high-energy tail

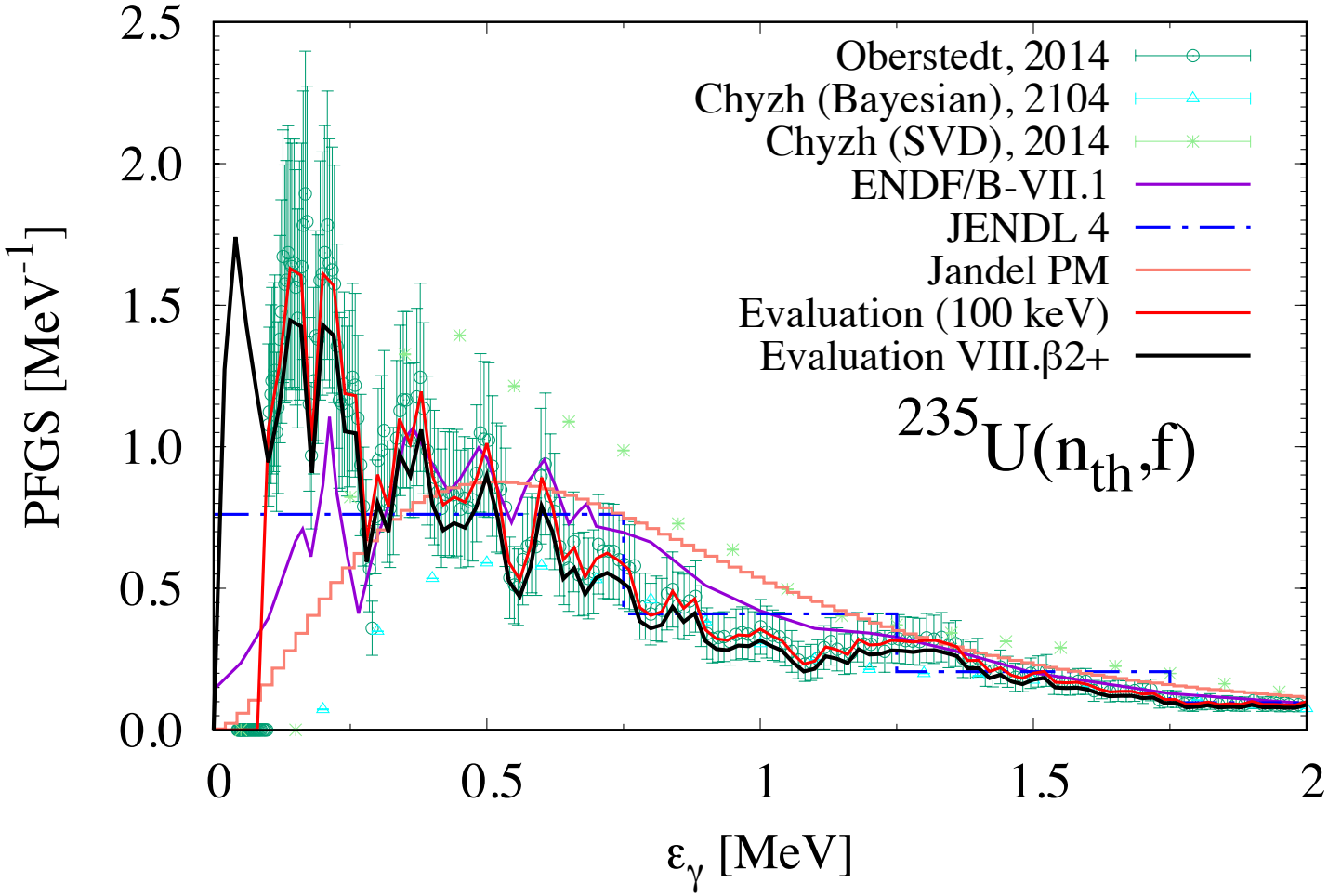


- Change in slope at high energies



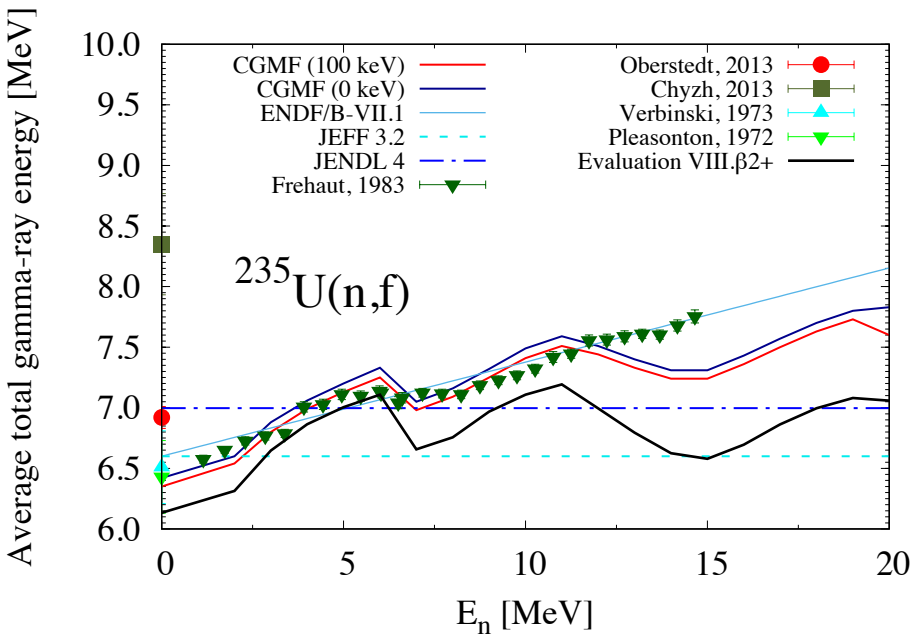
- ENDF-B/VIII.beta4: Will have to correct the high energy tail to reproduce available data

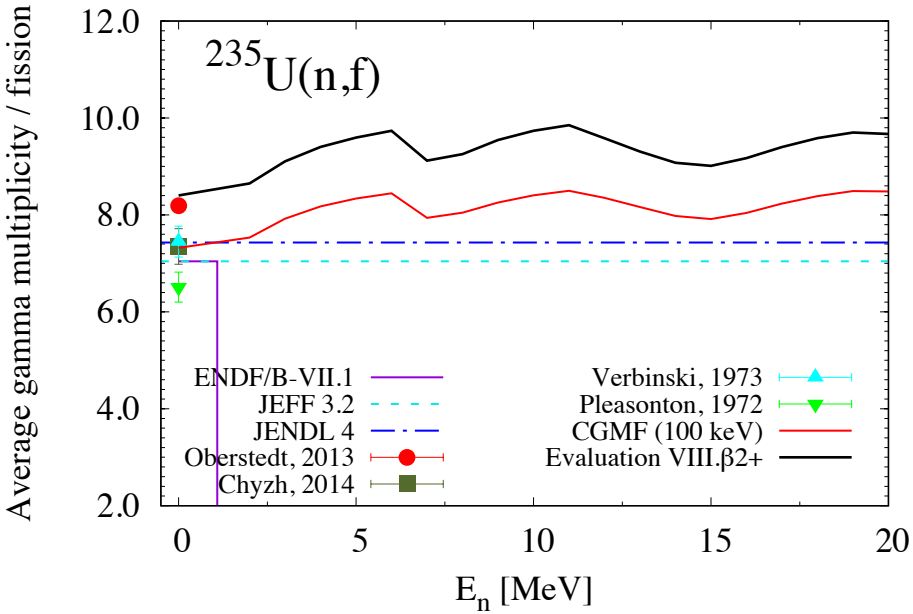
^{235}U(n,f): low-energy gamma rays



- New evaluation adjusted to reproduce the PFGS measured by Oberstedt at low energies
- ENDF-B/VII.1, JEFF 4.0 and JEFF 3.2: based on Verbinski

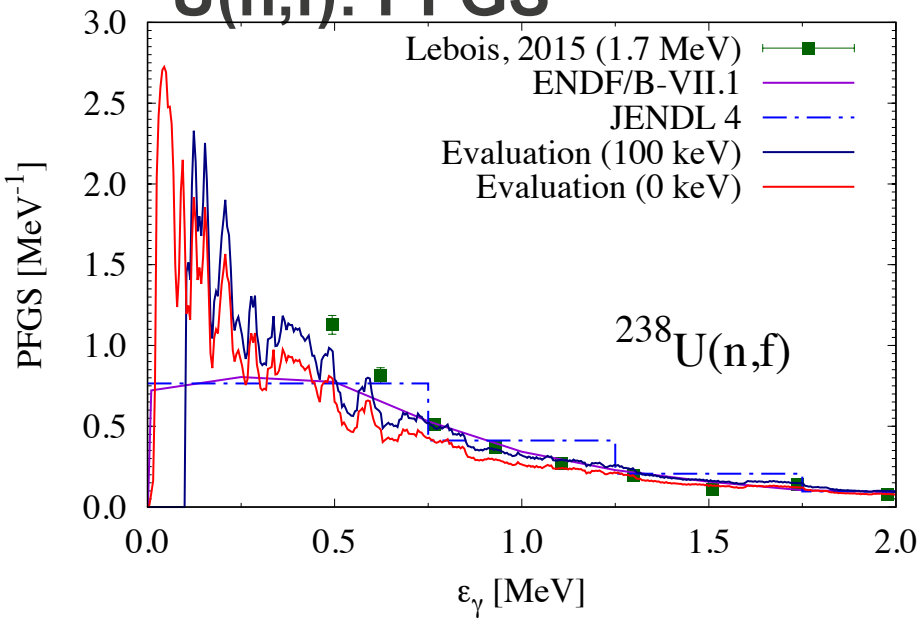
^{235}U(n,f): average total gamma ray and multiplicity

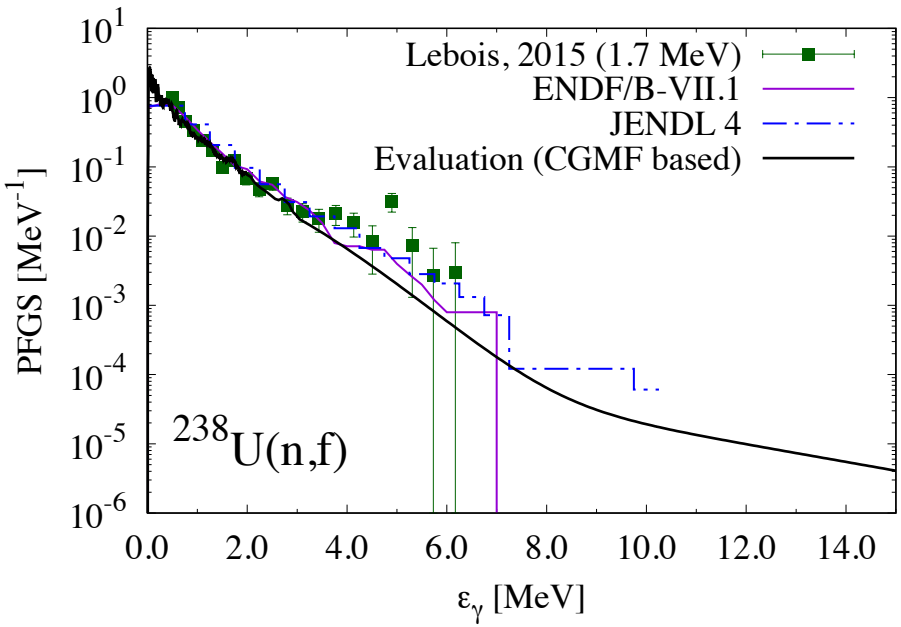




- For beta4: make the average gamma energy, PFGS and multiplicity consistent

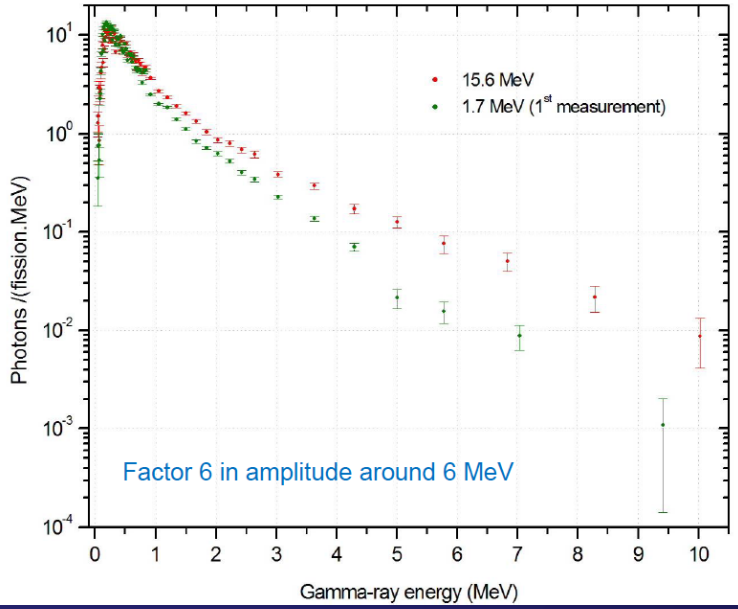
^{238}U(n,f): PFGS



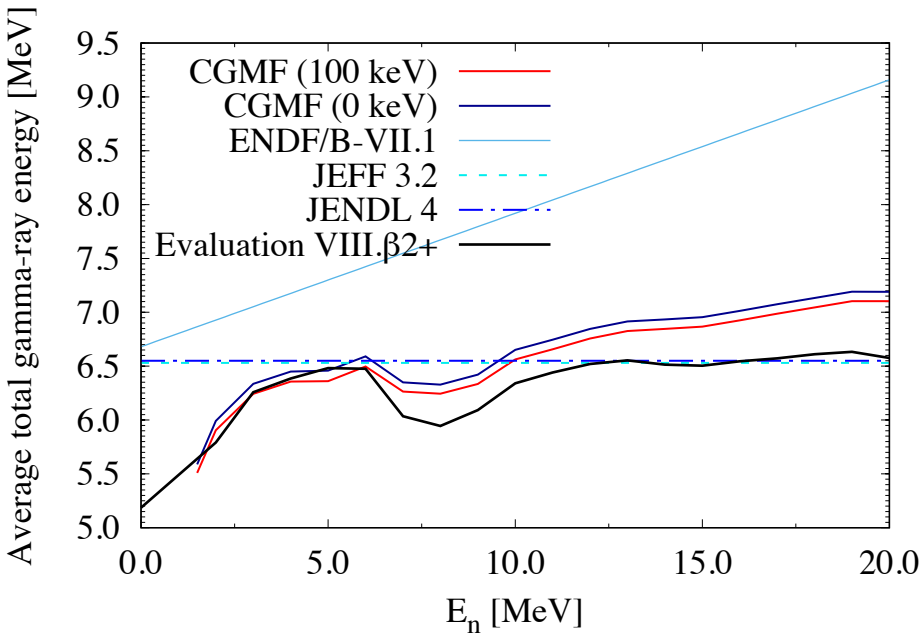


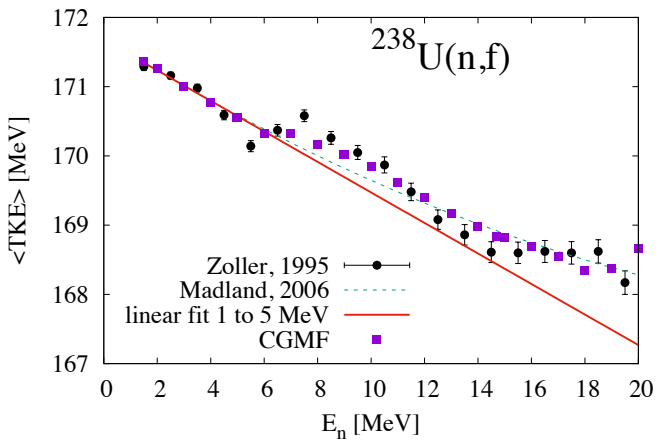
- (unpublished) data suggest incident neutron energy dependence for PFGS
- VIII.0beta4: high-energy tail to be corrected
- Evaluated data from ENDF-B/V.2
- JENDL 4.0: Verbinski's data for 235U(n,f)
- JEFF 3.2: ENDF-B/VII

J-M Laboire, talk at NFS Workshop 2014



^{238}U(n,f): average total energy released and multiplicity

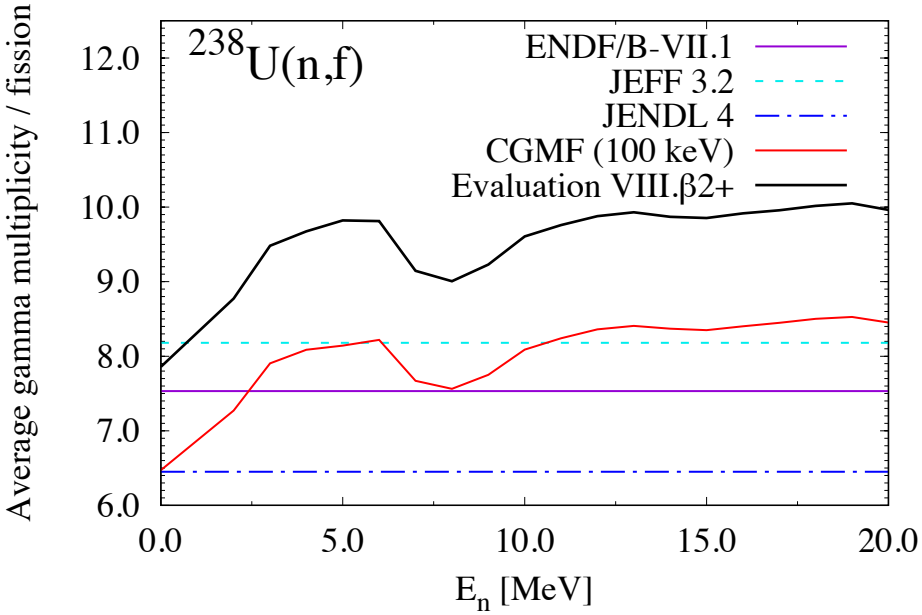




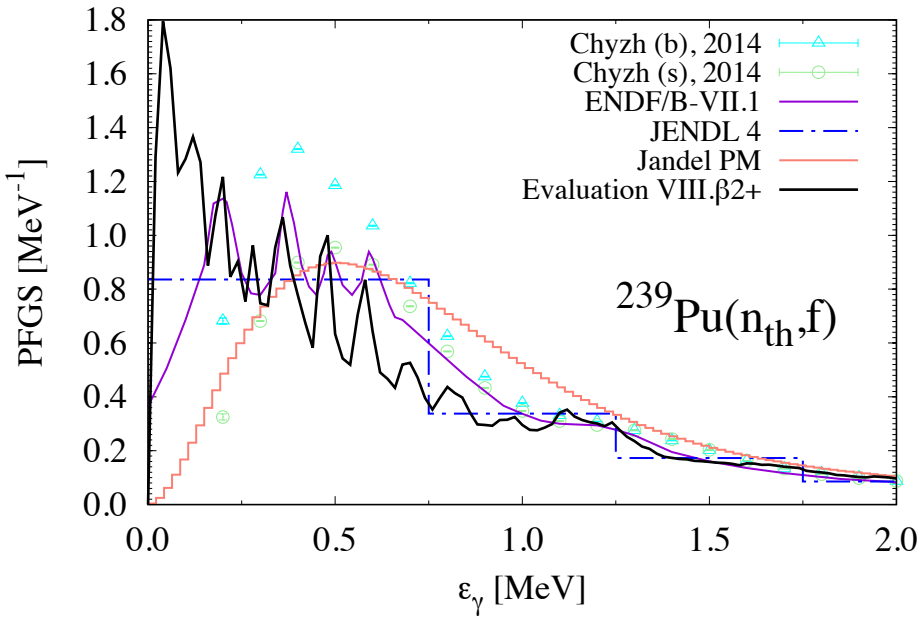
Total gamma energy: U8/U5=1.003(70) at 1.7 MeV (Lebois, 2015)

Problem w/ total gamma energy released:

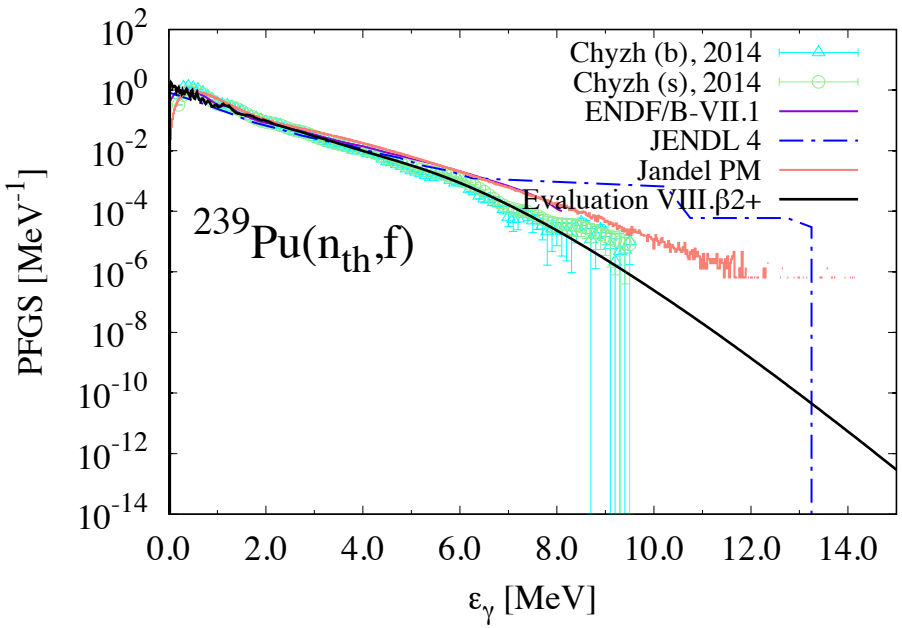
- Suggests that a too low spin was used (multiplicity will be higher)
- Work in progress



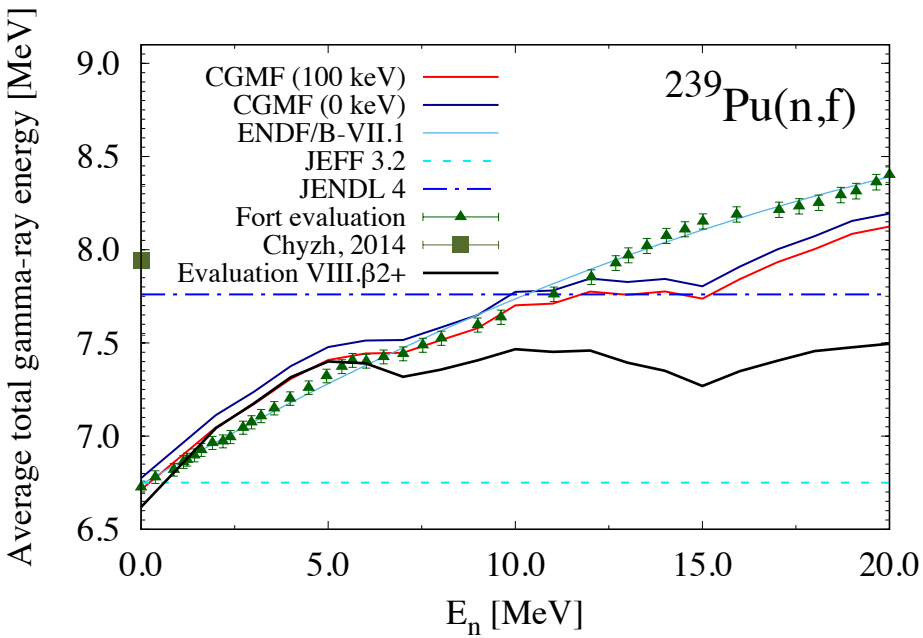
^{239}Pu(n,f): PFGS

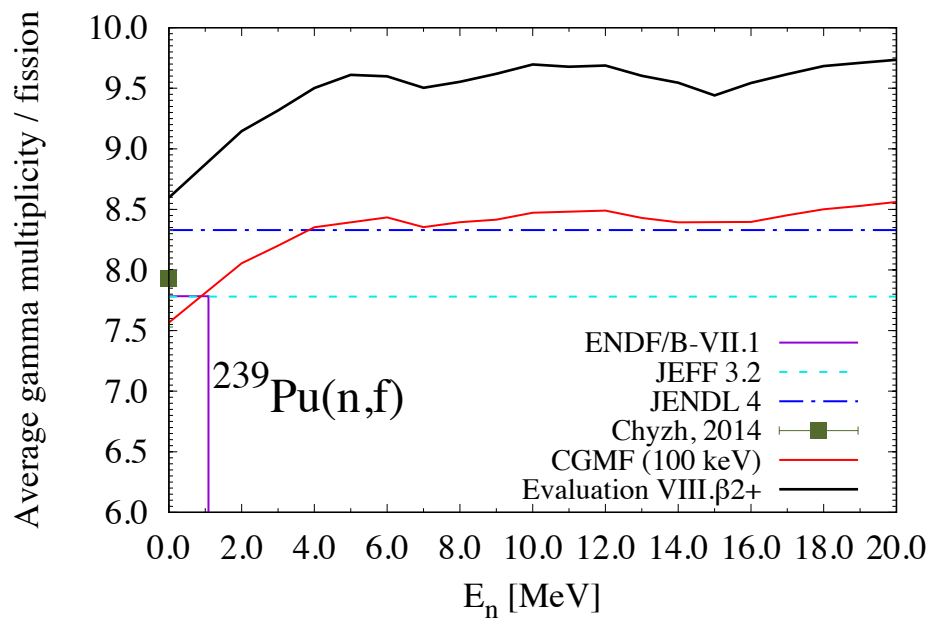


- Calculations agree well w/ Chyzh data at high energies
- Calculations agree with Verbinski (ENDF-B/VII.1) at low energies



^{239}Pu(n,f): average total gamma ray energy and multiplicity





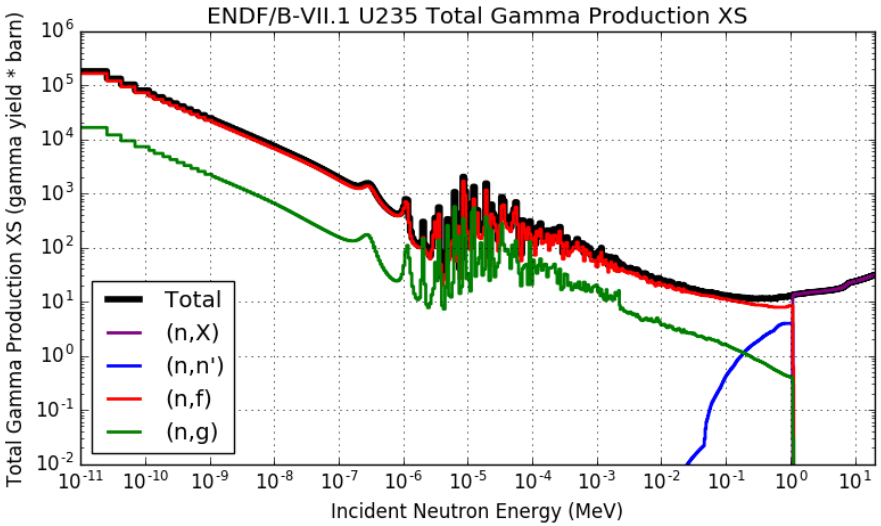
"Fort evaluation": not published, not documented

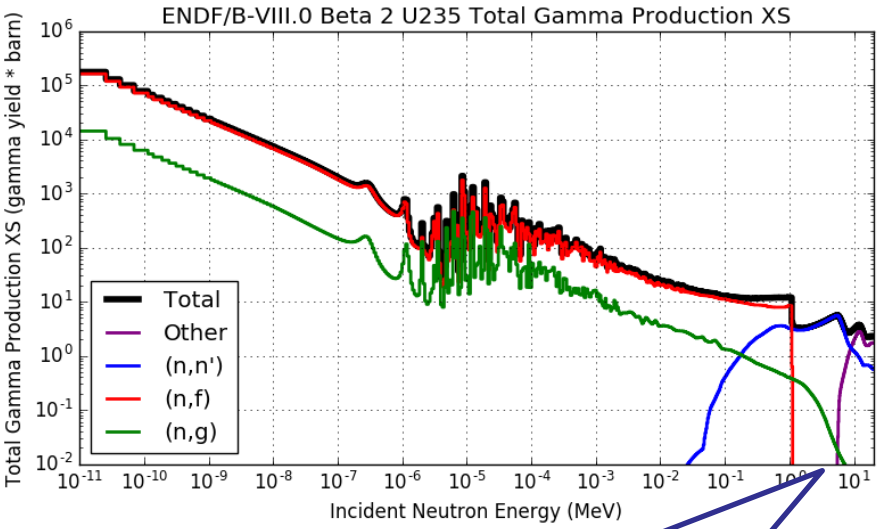
Average photon energy, multiplicity, and total gamma energy released

	$^{235}U(n_{th},f)$			$^{238}U(n_{5MeV},f)$			$^{239}Pu(n_{th},f)$		
	$<M_\gamma>$	$<\varepsilon_\gamma>$[MeV]	$<E_\gamma>$[MeV]	$<M_\gamma>$	$<\varepsilon_\gamma>$	$<E_\gamma>$[MeV]	$<M_\gamma>$	$<\varepsilon_\gamma>$[MeV]	$<E_\gamma>$[MeV]
ENDF/B-VII.1	7.04	0.94	6.60	7.53	0.76	7.30	7.78	0.87	6.74
JEFF 3.2	7.04	0.94	6.60	8.18	0.76	6.53	7.78	0.87	6.75
JENDL 4	7.43	0.94	6.997	6.45	0.97	6.55	8.34	0.89	7.75
CGMF (100keV)	7.31	0.82	6.35	8.14	0.78	6.36	7.56	0.89	7.41
CGMF (0keV)	8.39	0.73	6.42	9.80	0.66	6.46	8.60	0.77	7.48
Verbinski	6.70(30)	0.97(5)	6.51(3)				7.23(30)	0.94	6.81
Oberstedt	8.19(11)	0.84(2)	6.92(9)						
Chyzh	7.35	(1.14)	8.35				7.93	(1.00)	7.94
Peele	7.45(35)	0.99(7)	7.18(26)						
Pleasonton	6.51(30)	0.99(7)	6.43(30)						
Lebois (1.7MeV)		0.76(4)			0.77(6)				
VIII.beta2+	**8.39**	**0.73**	**6.12**	**9.80**	**0.66**	**6.47**	**8.6**	**0.77**	**6.62**

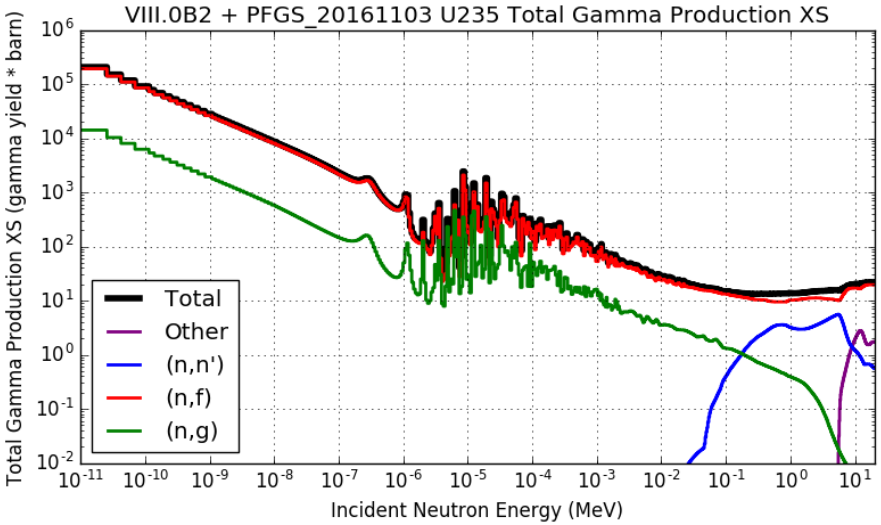
*Most experiments have 100 keVgamma-detection threshold

Gamma Production Comparison: VII.1 and VIII.0 beta2+





Lack of fission gammas



- Comparable gamma production with previous evaluation
- Similar results for ^{238}U and ^{239}Pu

Questions

- Energy grid for PFGS: how fine?
- Time-coincidence window: how do we add this information?