

# Uncertainties for criticality-safety benchmarks and consequences for nuclear data measurements

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May 14, 2009

- ① Motivations for a change:  
⇒ *a roadmap to consistent and state-of-the-art evaluations*
- ② Concept:  
⇒ *Monte Carlo from nuclear data evaluations to large-scale systems*
- ③ How does it work ?  
⇒ *TALYS + Monte Carlo*
- ④ Examples with  $^{235,238}\text{U}$ ,  $^{238,242}\text{Pu}$  and  $^{244}\text{Cm}$  isotopes:  
⇒  *$k_{\text{eff}}$  uncertainties and feedback to differential data for  $^{238,242}\text{Pu}$  and  $^{244}\text{Cm}$*
- ⑤ Conclusions

# Motivations: How to produce consistent (and reproducible) evaluations ?

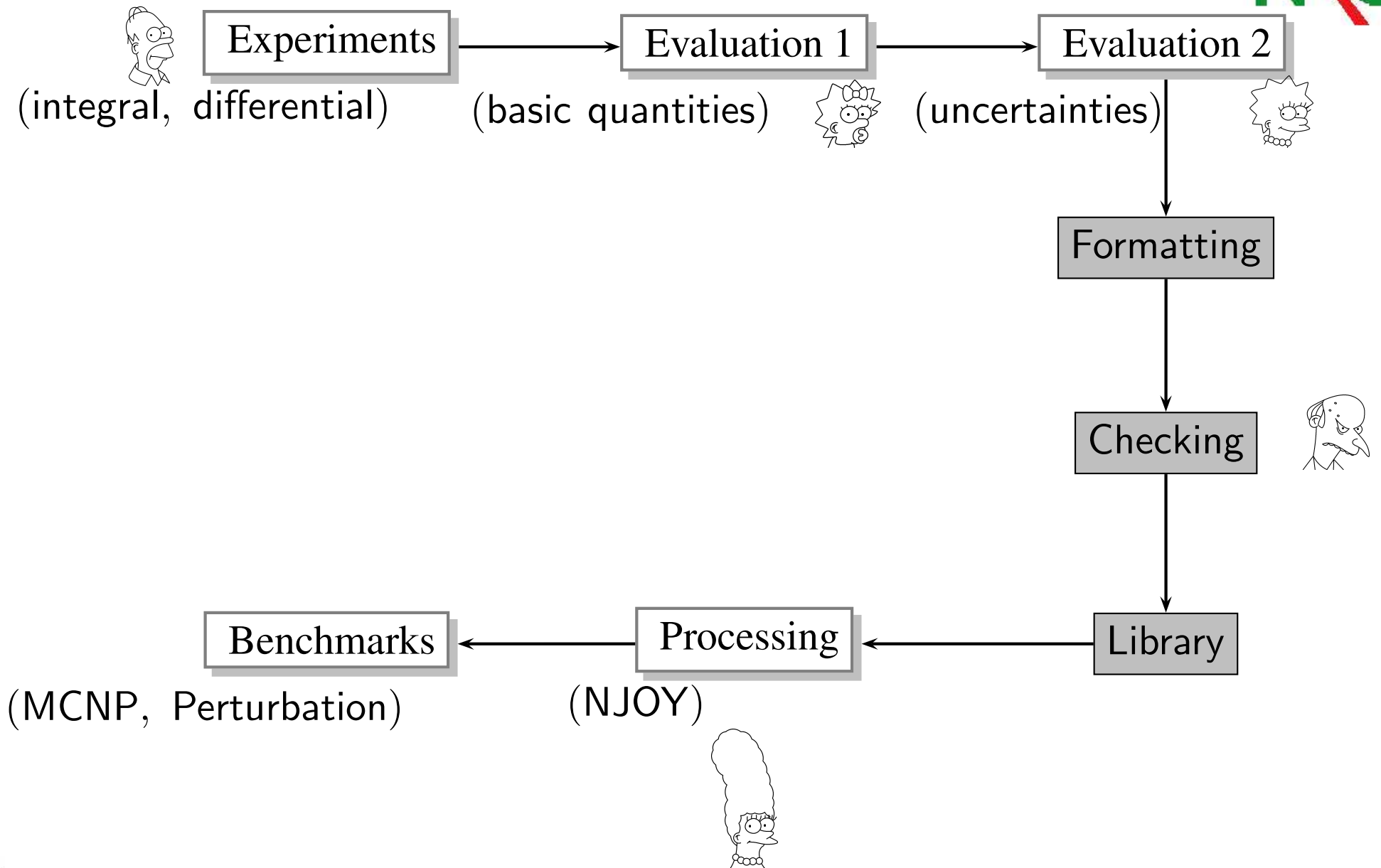


Usual procedures in evaluations imply

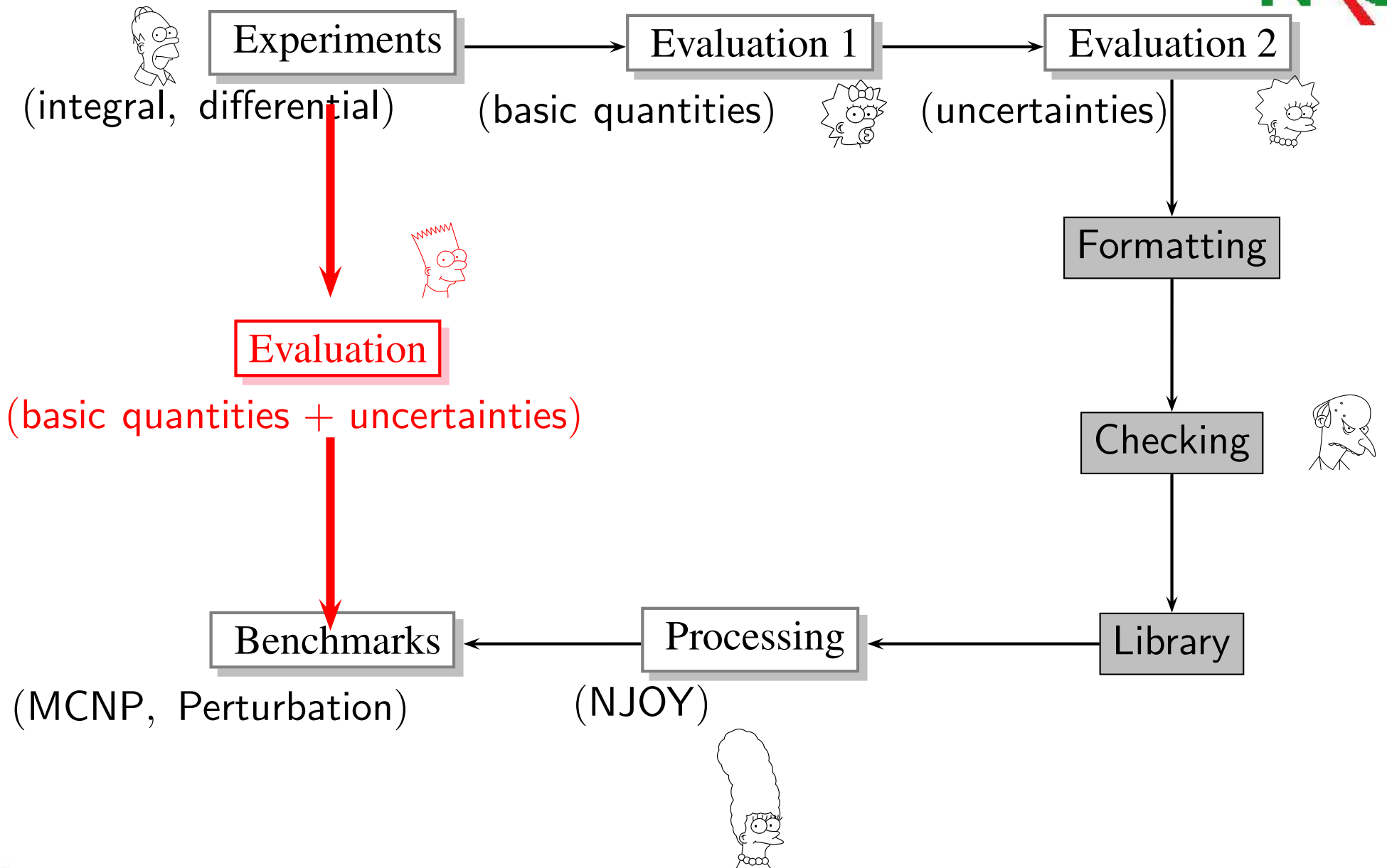
- ☞ **First**, there were measurements,
- ☞ **Then** nuclear reaction codes (TALYS, GNASH, EMPIRE...),
- ☞ Format the output semi-manually to ENDF file,
- ☞ Compare with experimental cross sections,
- ☞ Modify manually the ENDF file,
- ☞ Compare with integral tests,
- ☞ Modify manually the ENDF file, ENDF file ready,
- ☞ **At last**, "Industry can use evaluations", but...

➔ How include propagation of nuclear data uncertainties with a minimum number of approximation ?

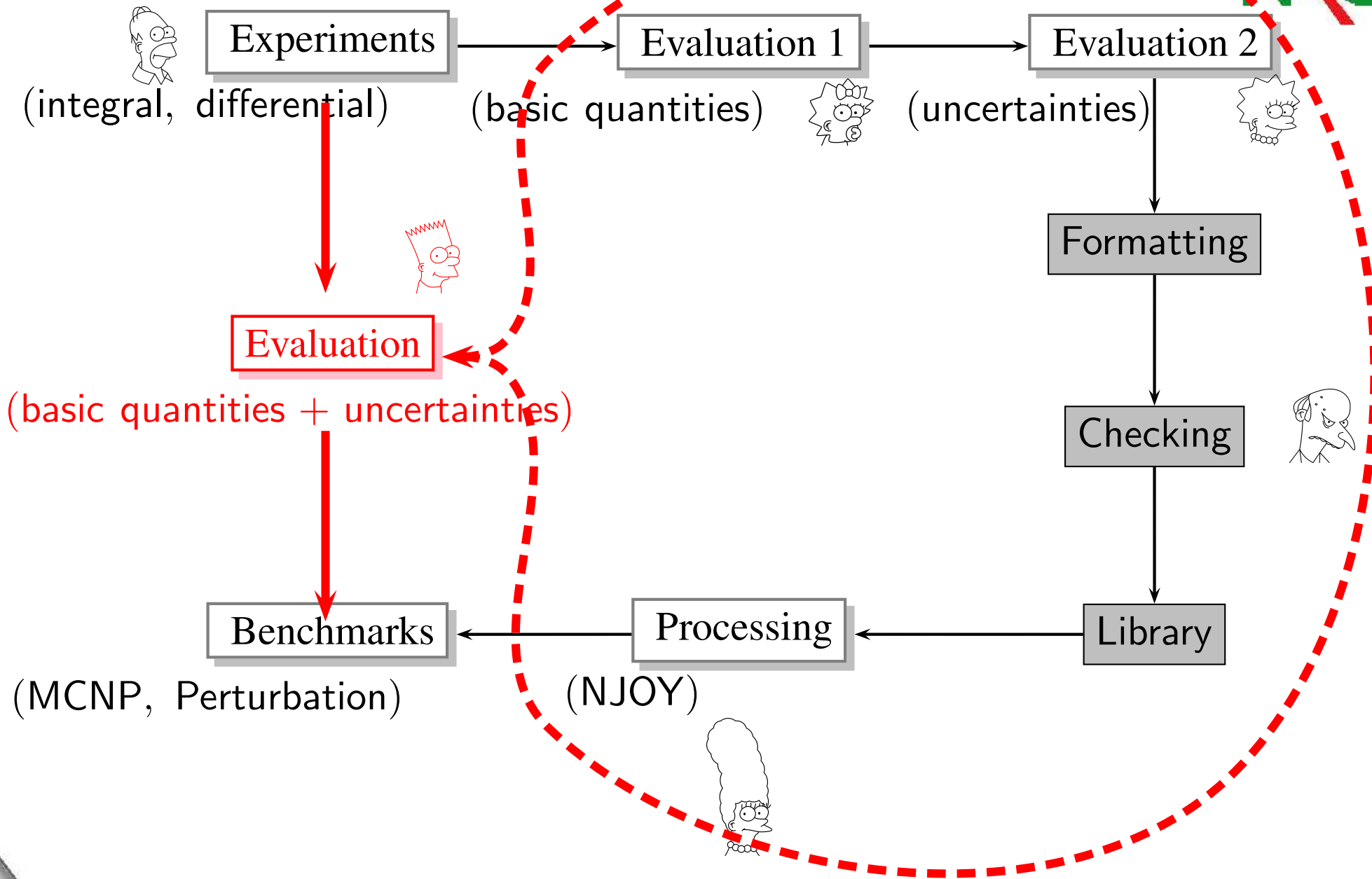
# Concept: No more delocalization



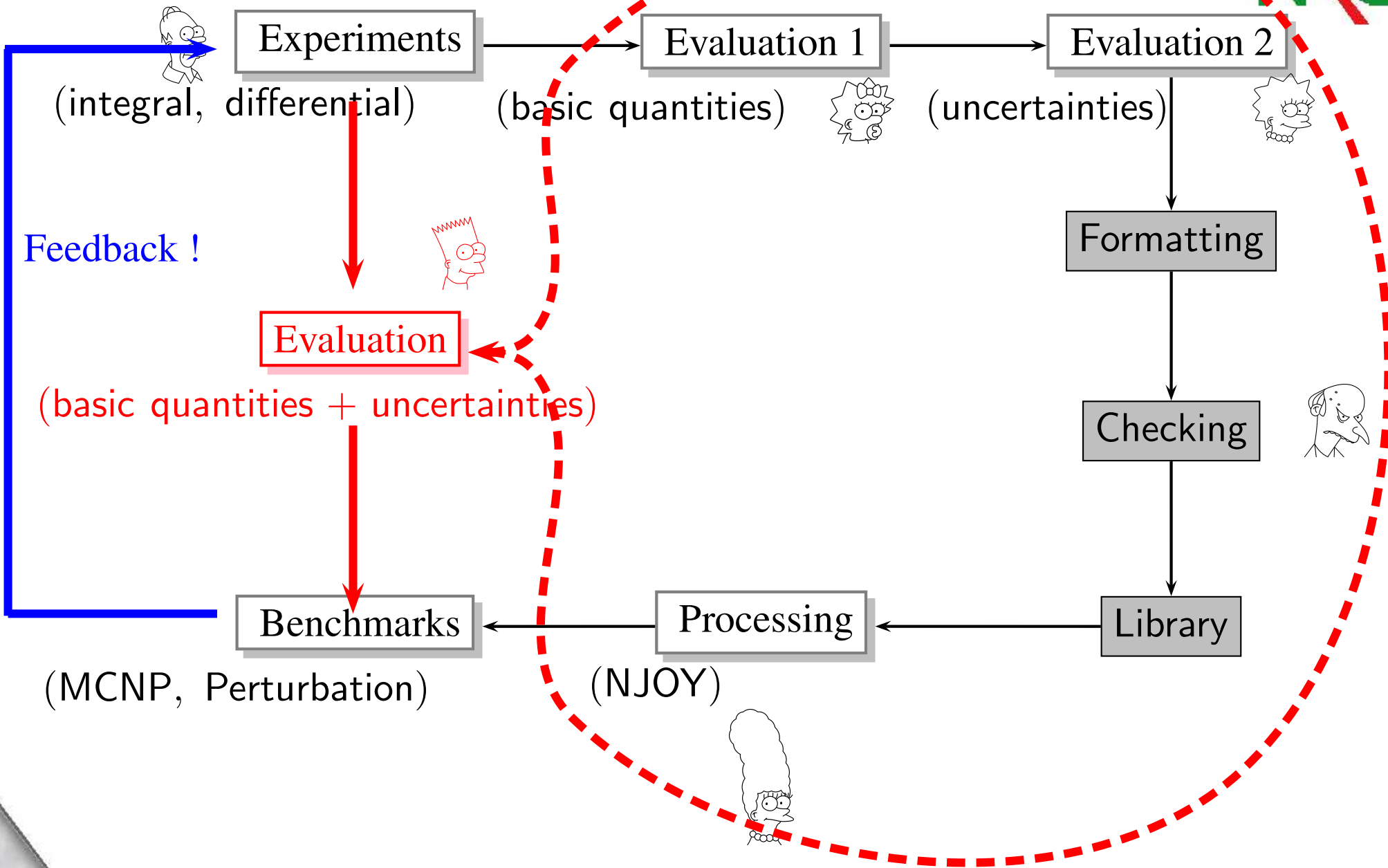
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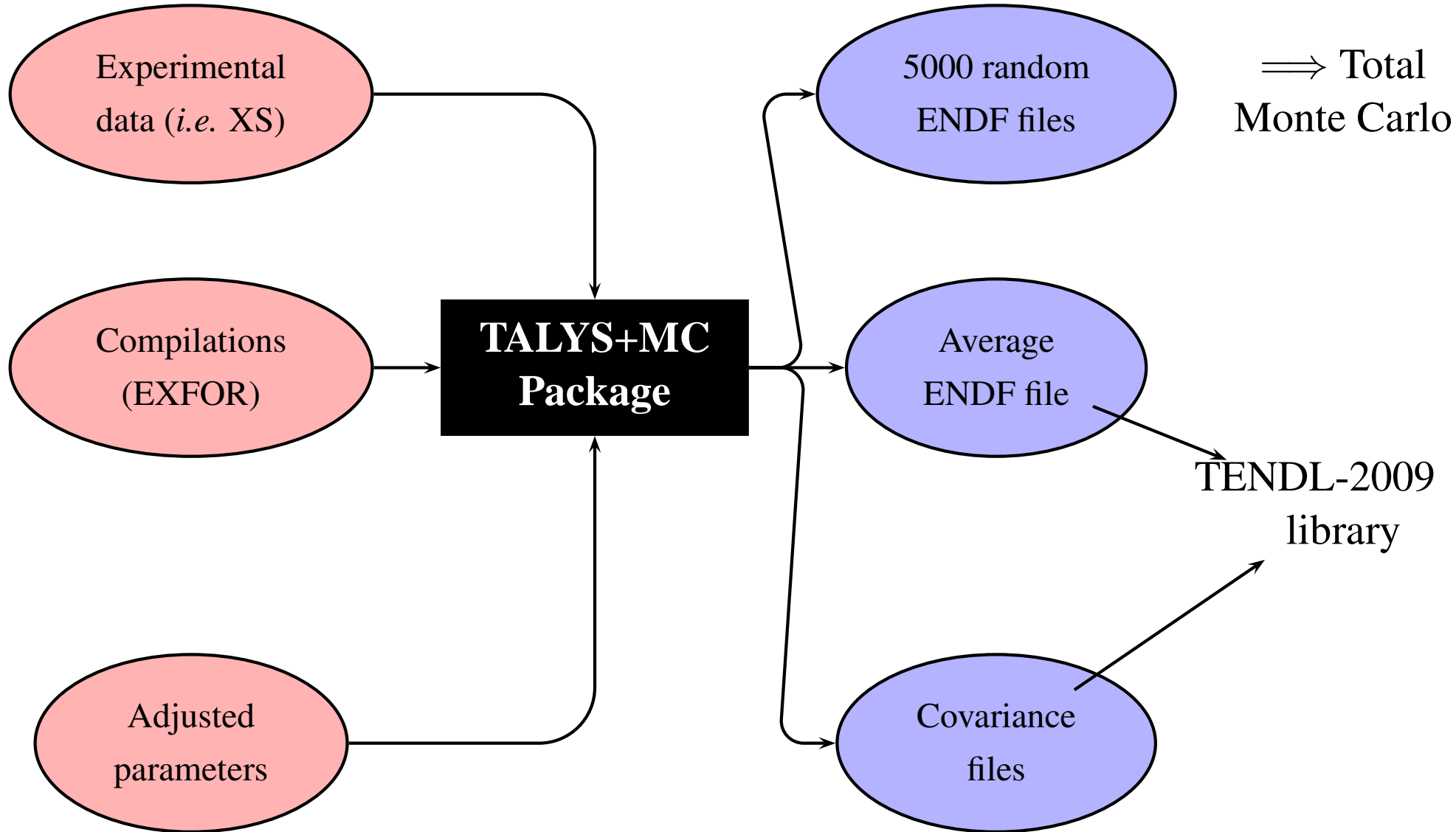
# Concept: No more delocalization



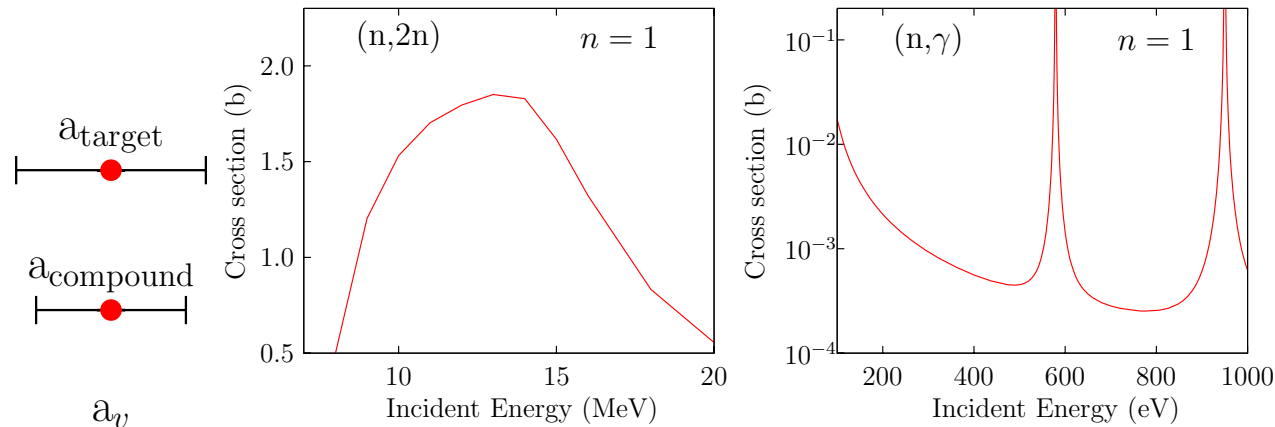
# Concept: TALYS + Monte Carlo



Possible answer to this problem: Maximization of automation



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”



$a_{\text{target}}$

$a_{\text{compound}}$

$a_v$

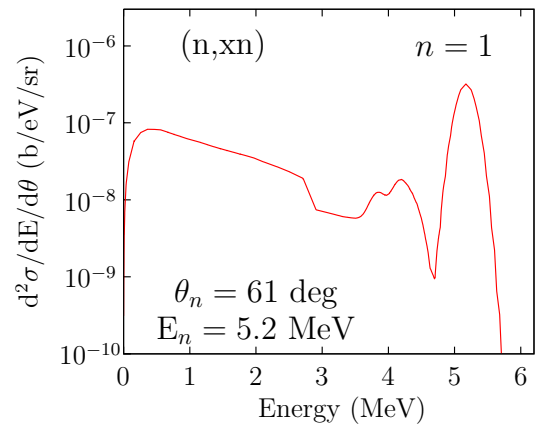
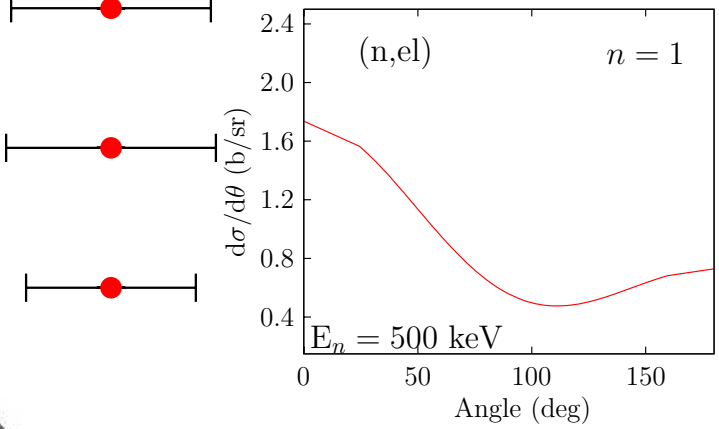
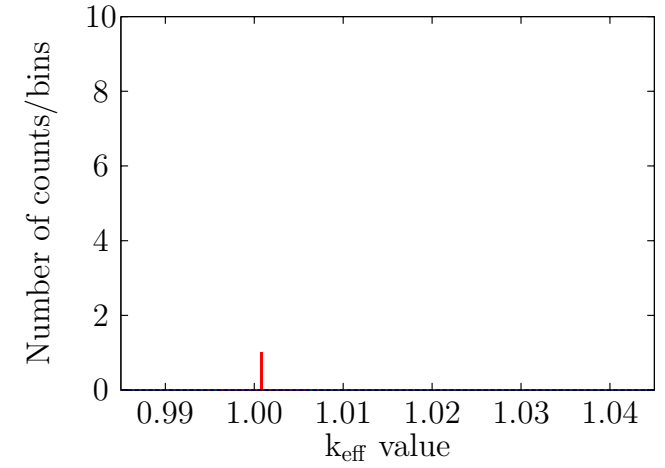
$r_v$

$\Gamma_n$

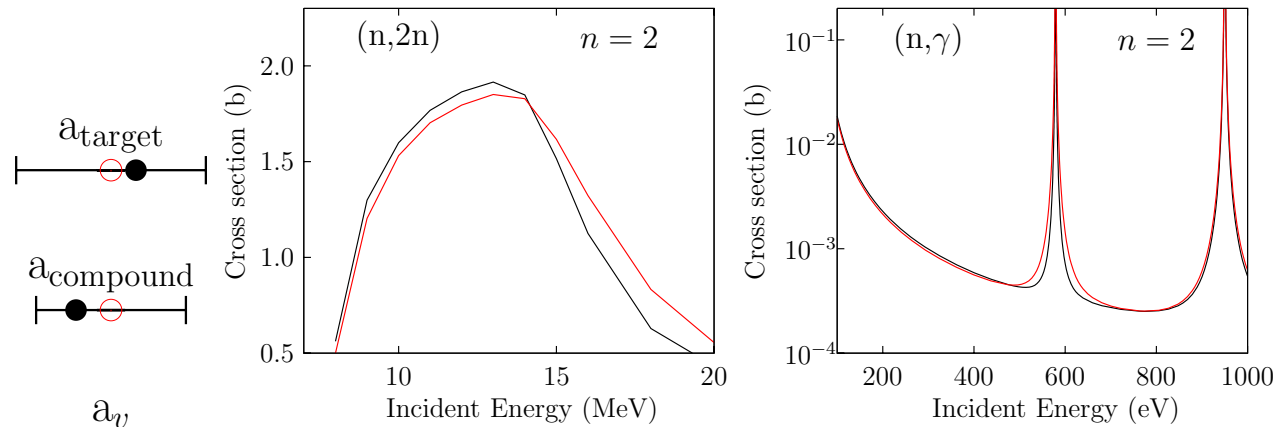
$\Gamma_\gamma$

TALYS

MCNP



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”



$a_{\text{target}}$

$a_{\text{compound}}$

$a_v$

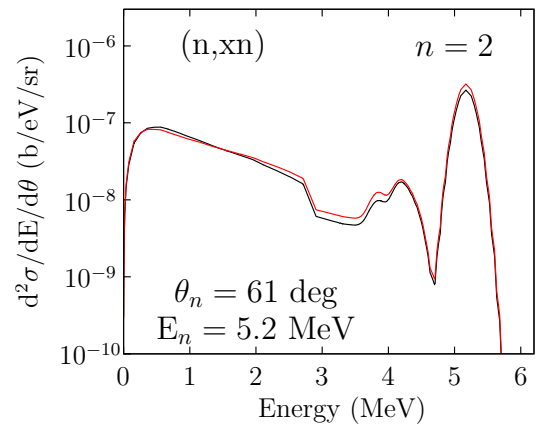
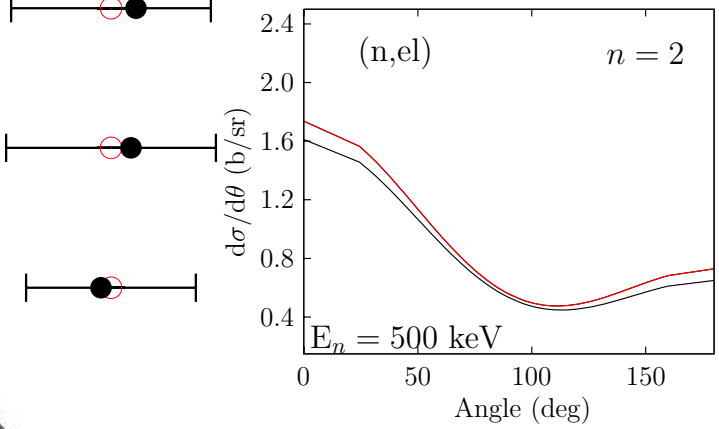
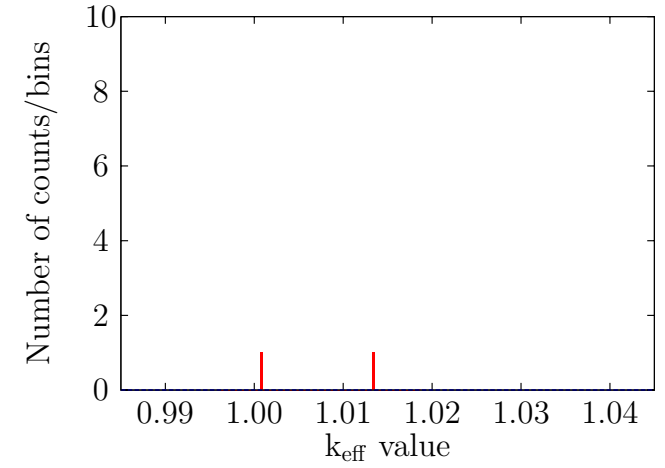
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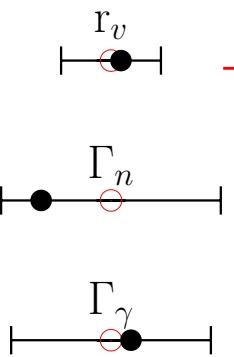
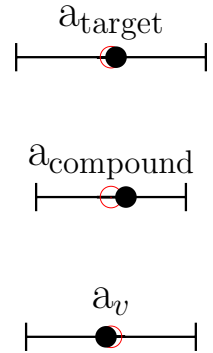
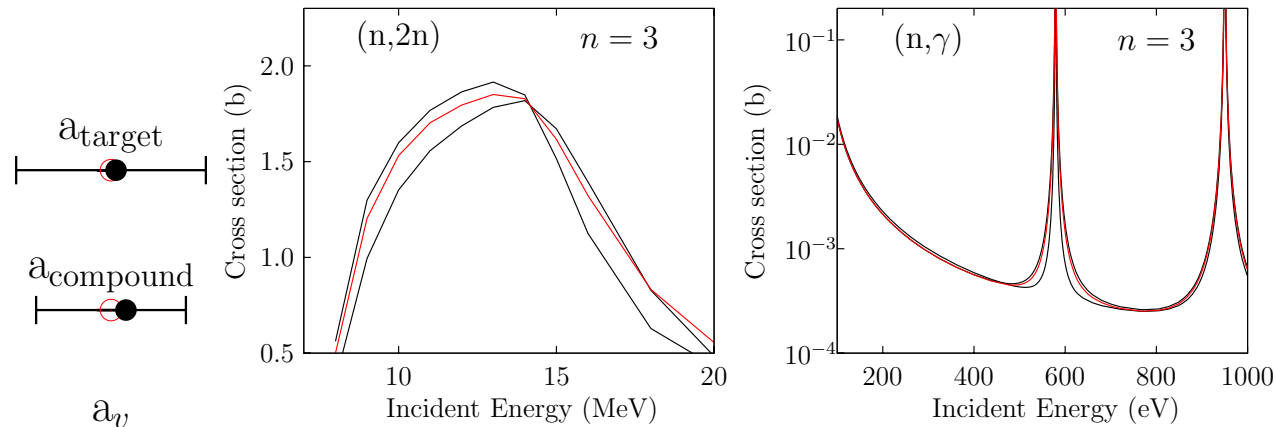
$\Gamma_\gamma$

TALYS

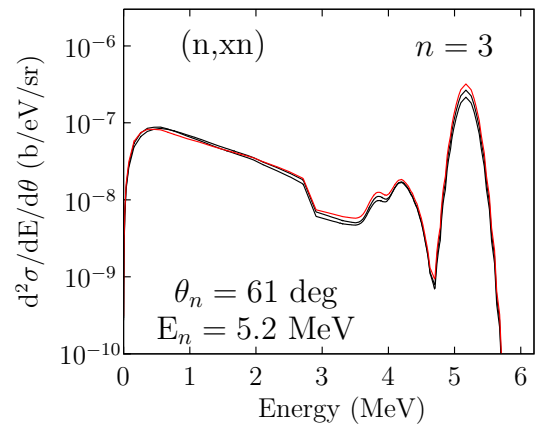
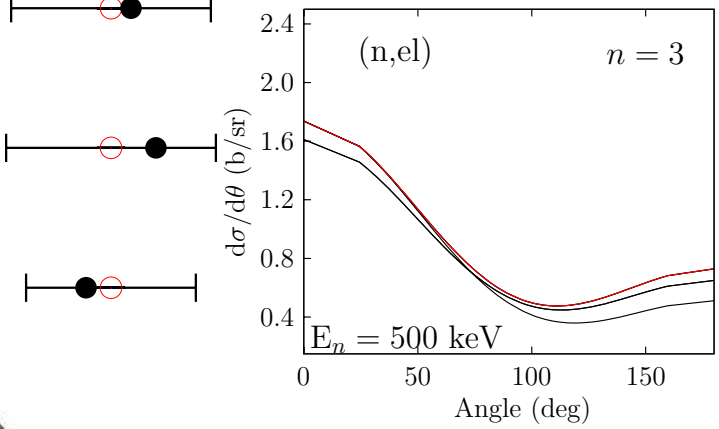
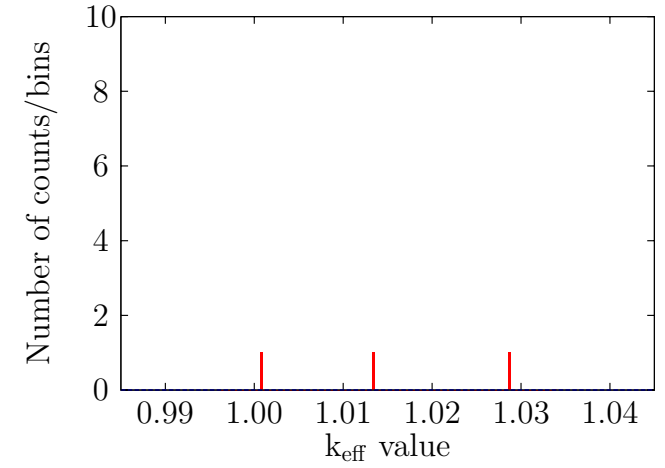
MCNP



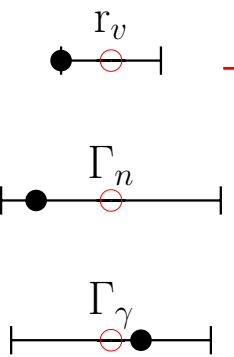
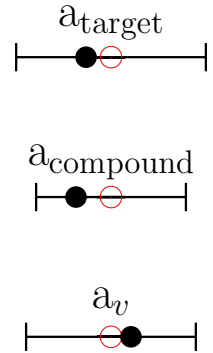
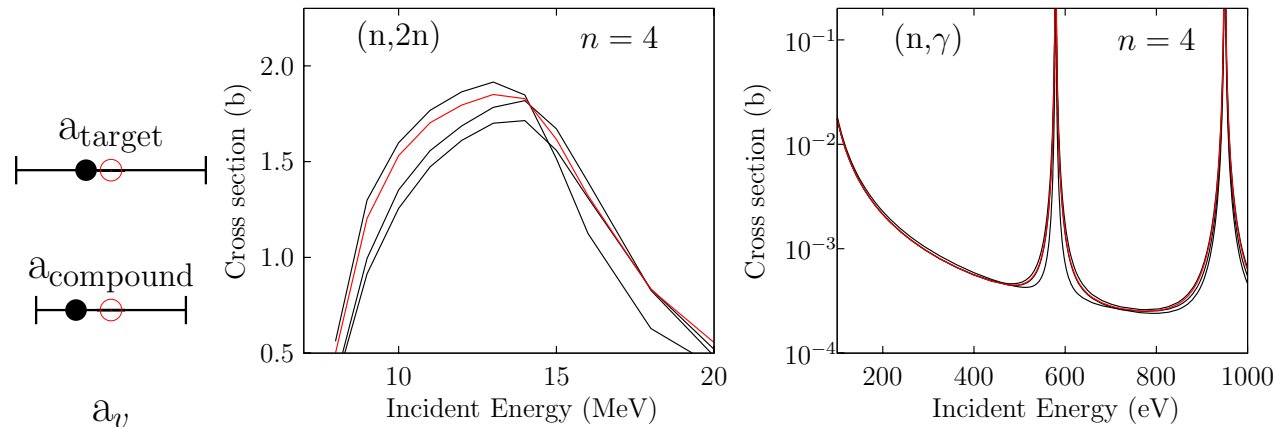
# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”



TALYS → MCNP

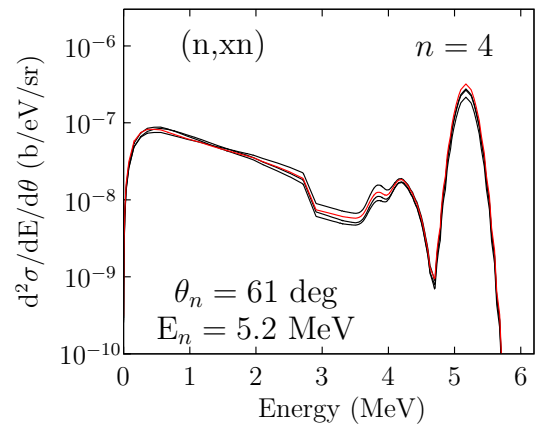
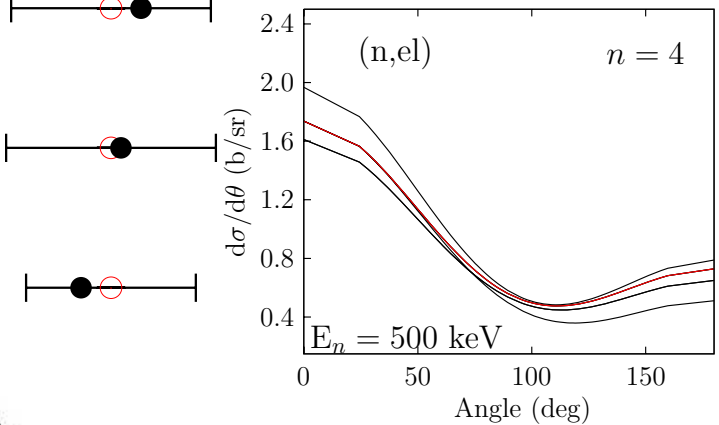
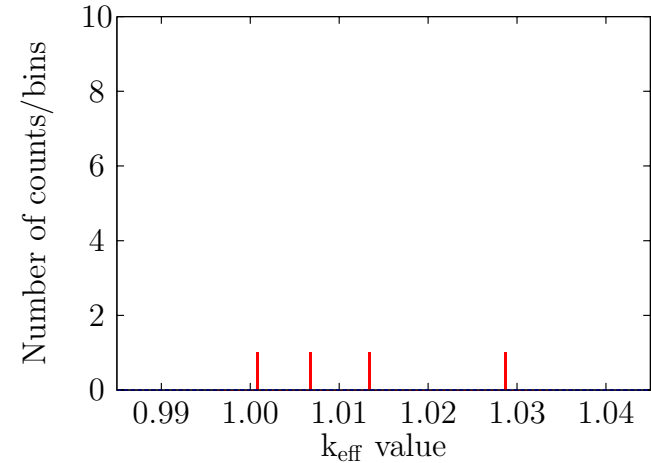


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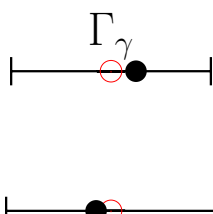
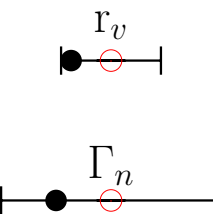
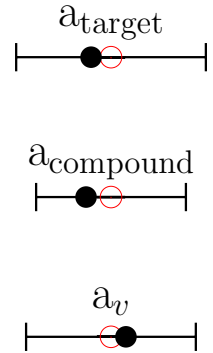
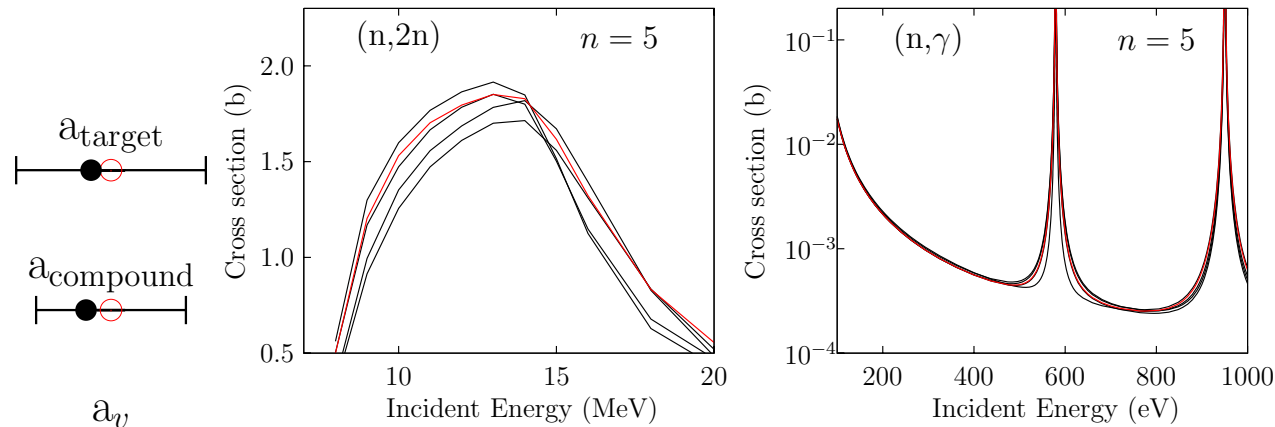


TALYS

MCNP

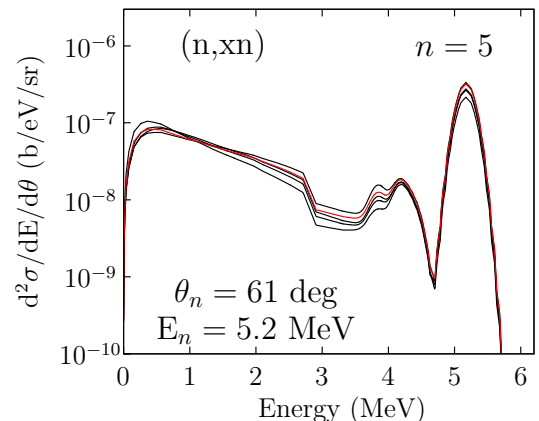
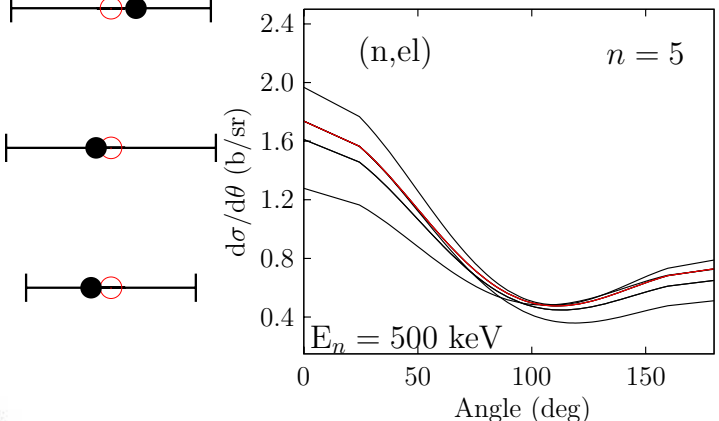
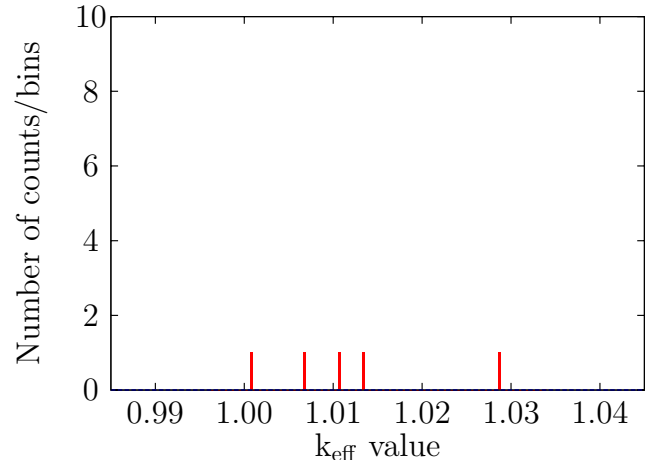


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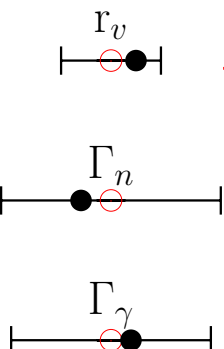
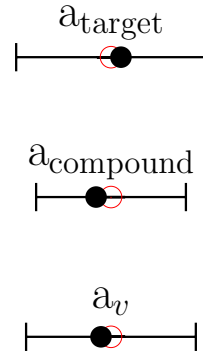
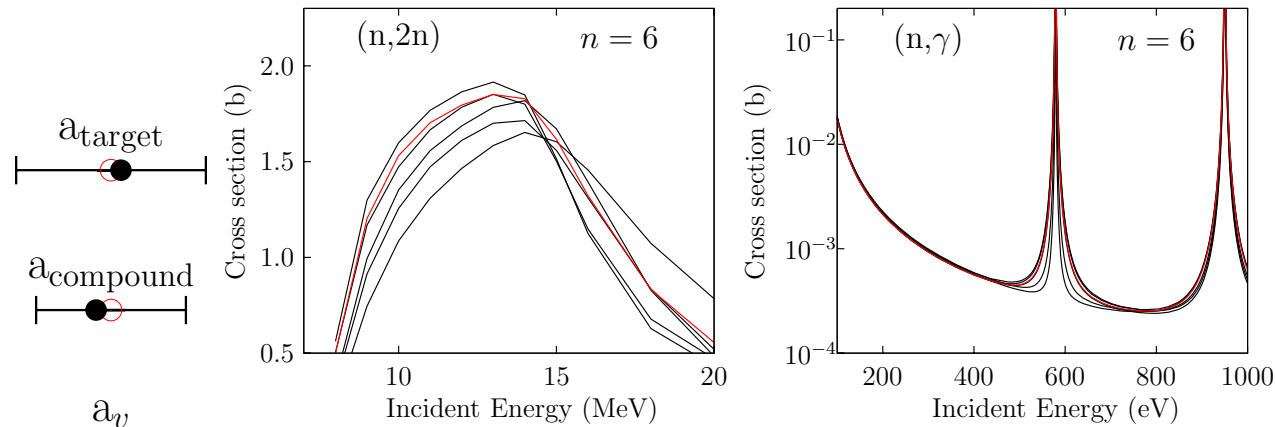


TALYS MCNP

→

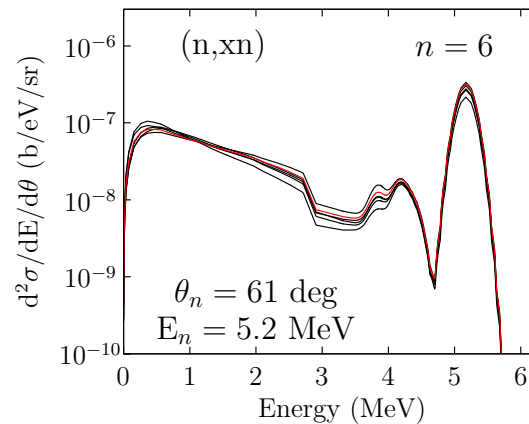
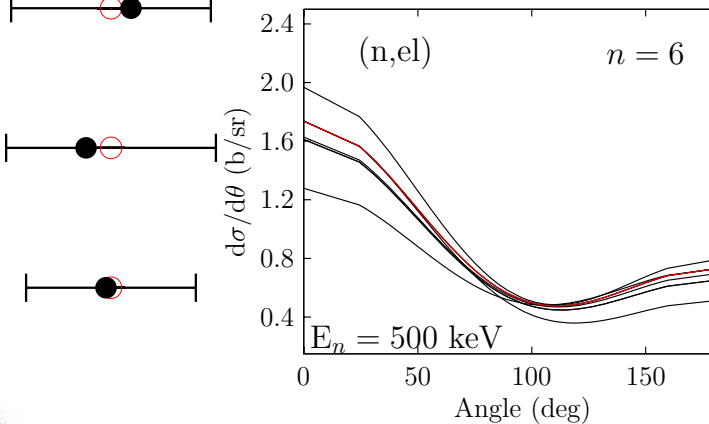
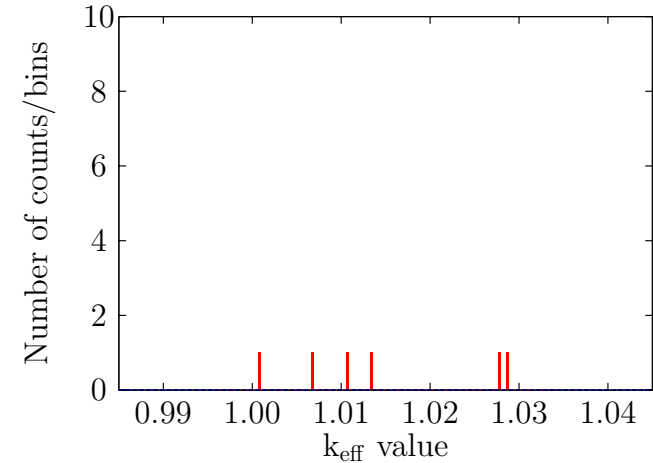


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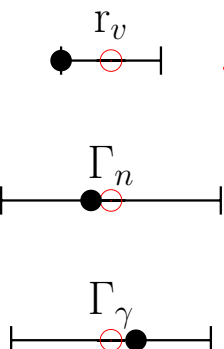
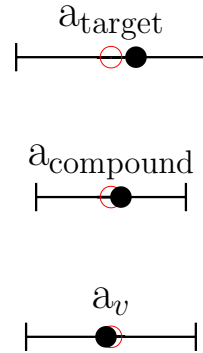
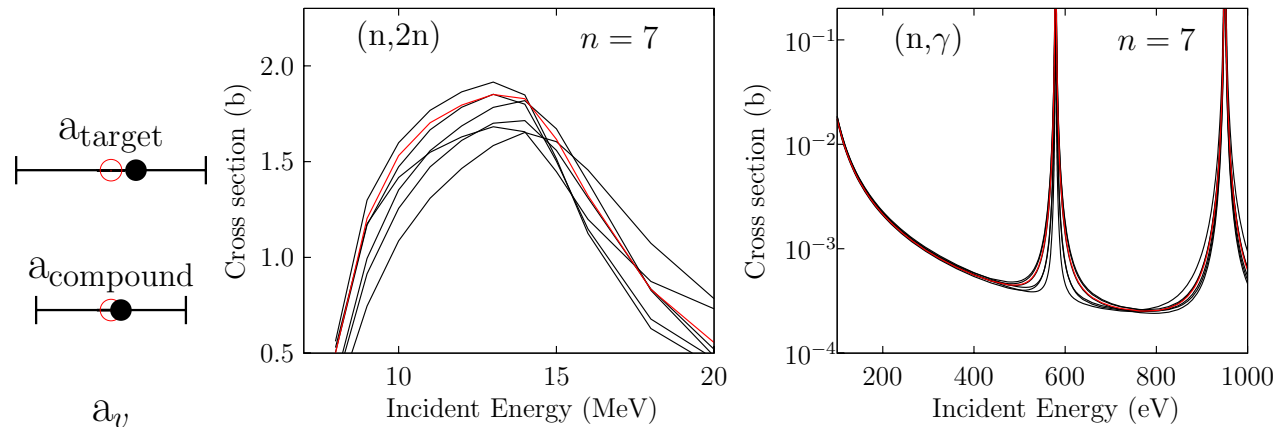


TALYS

MCNP

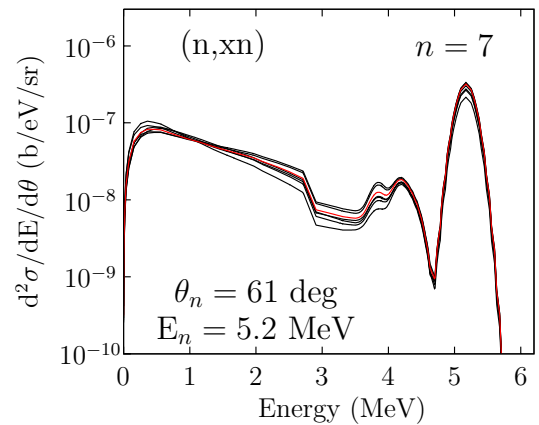
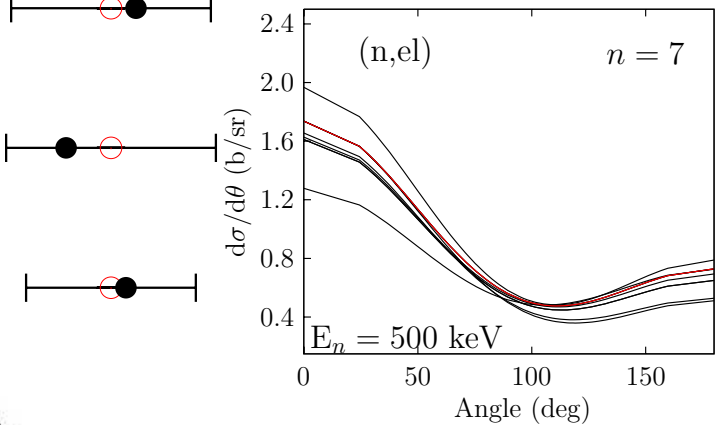
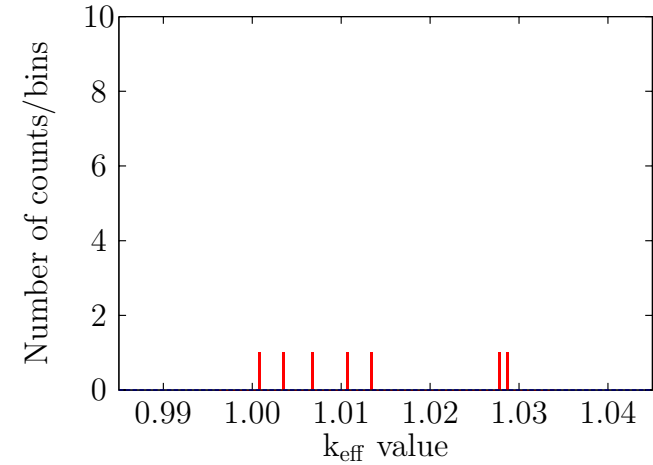


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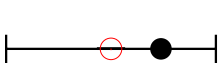
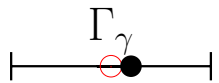
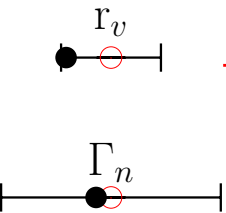
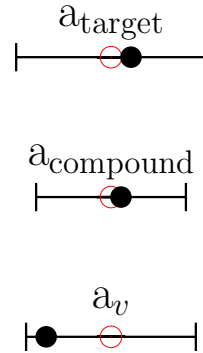
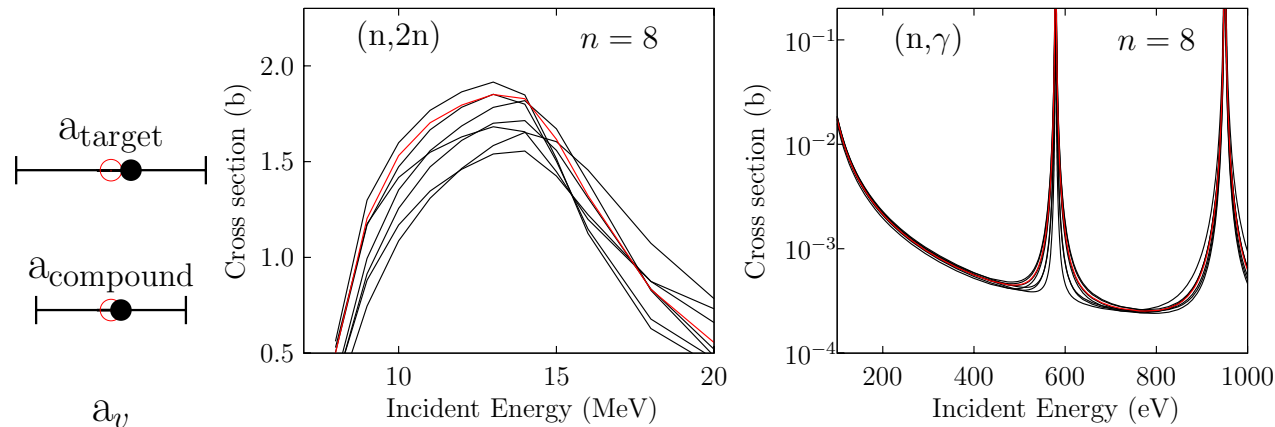


TALYS

MCNP

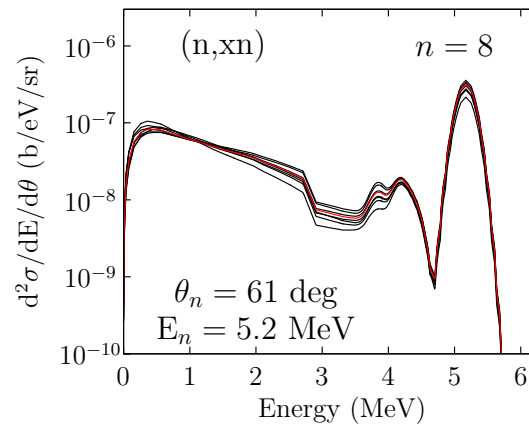
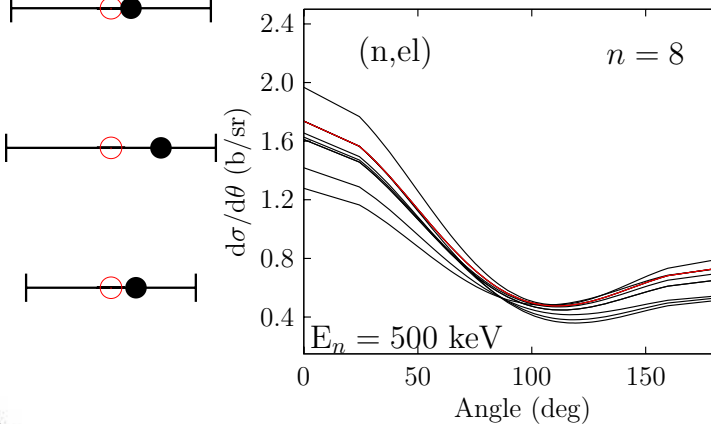
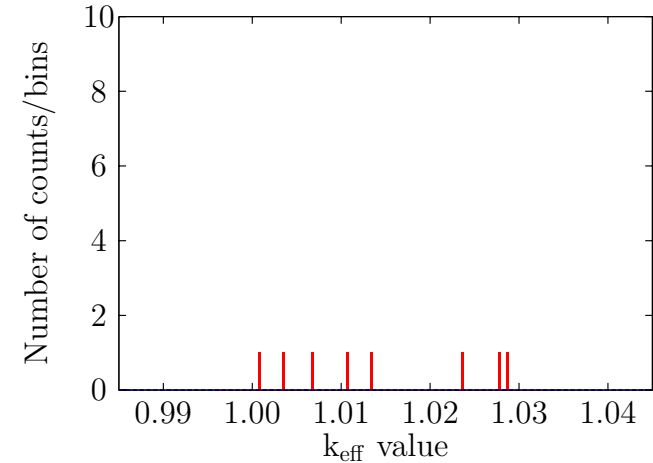


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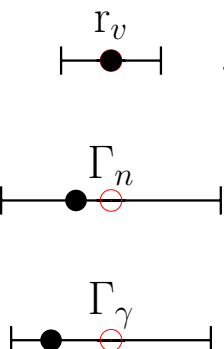
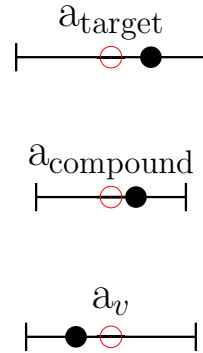
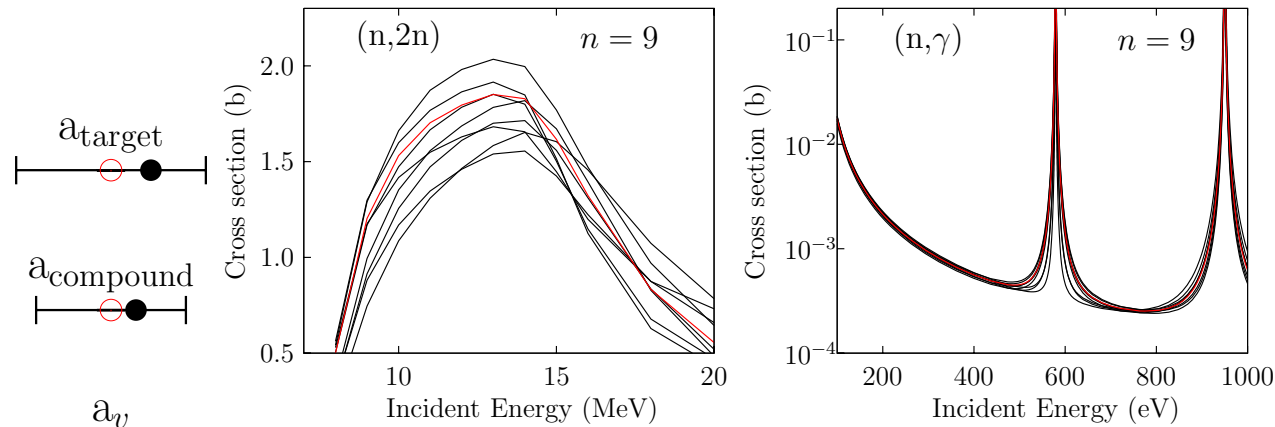


TALYS

MCNP

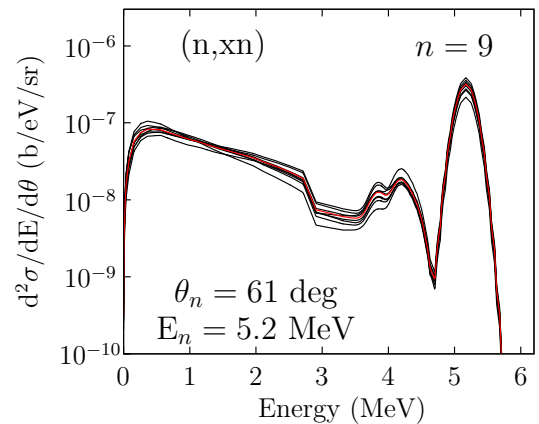
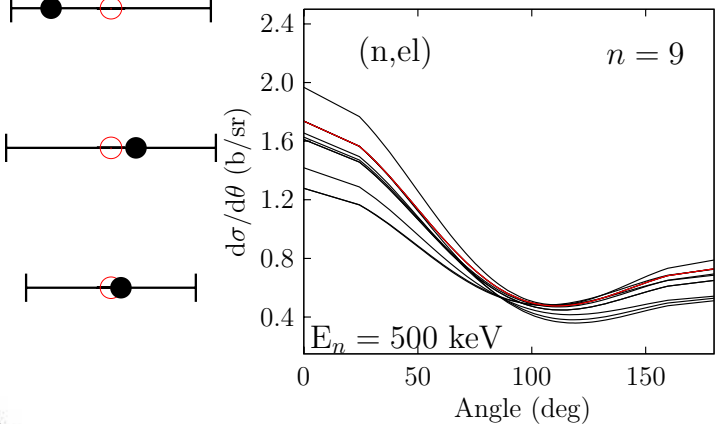
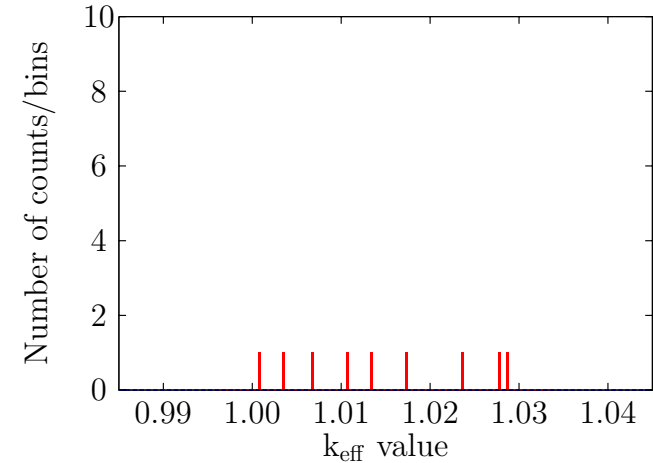


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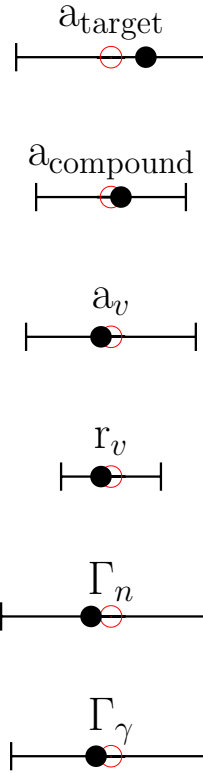
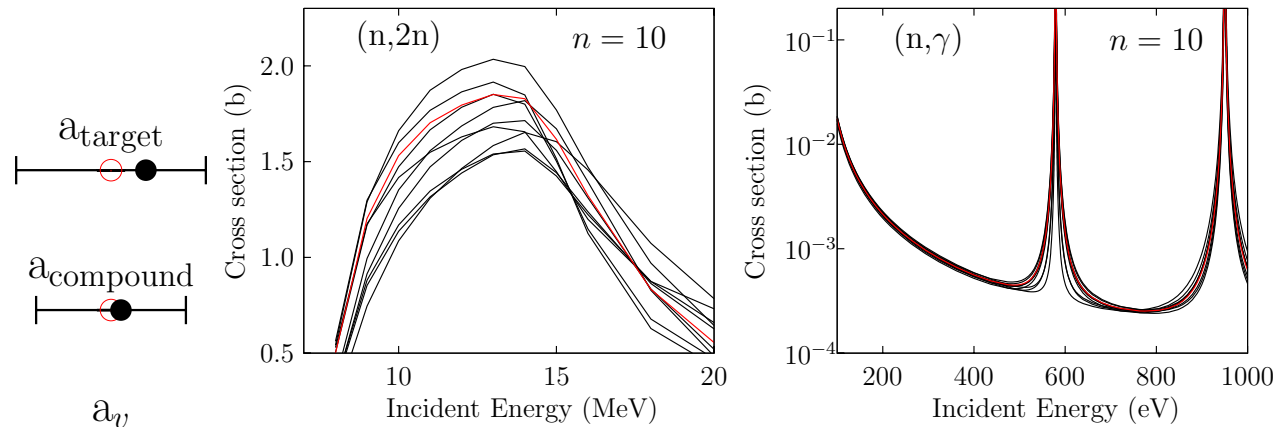


TALYS

MCNP

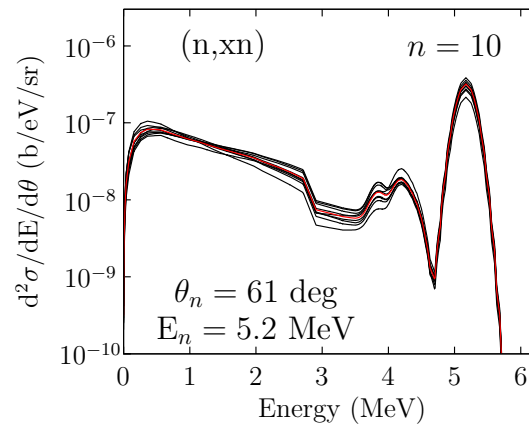
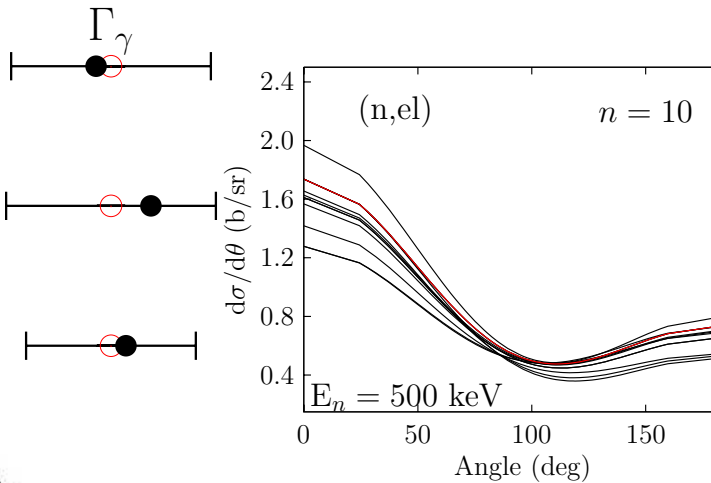
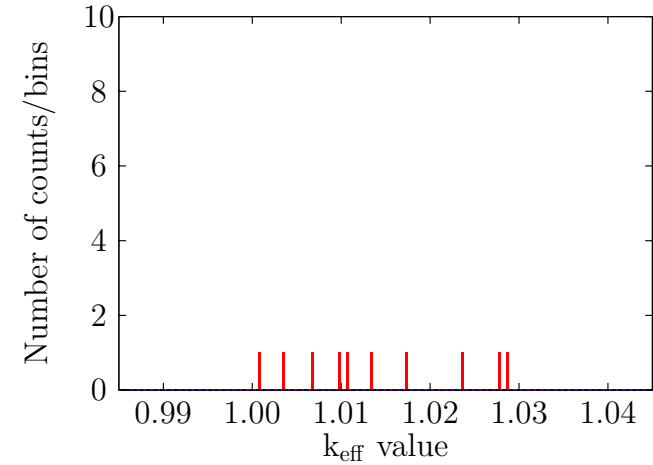


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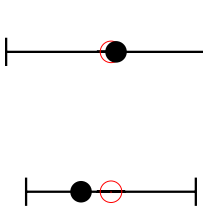
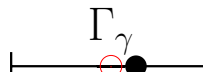
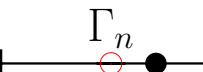
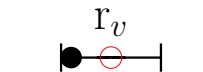
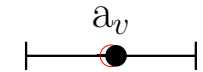
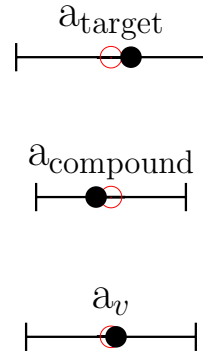
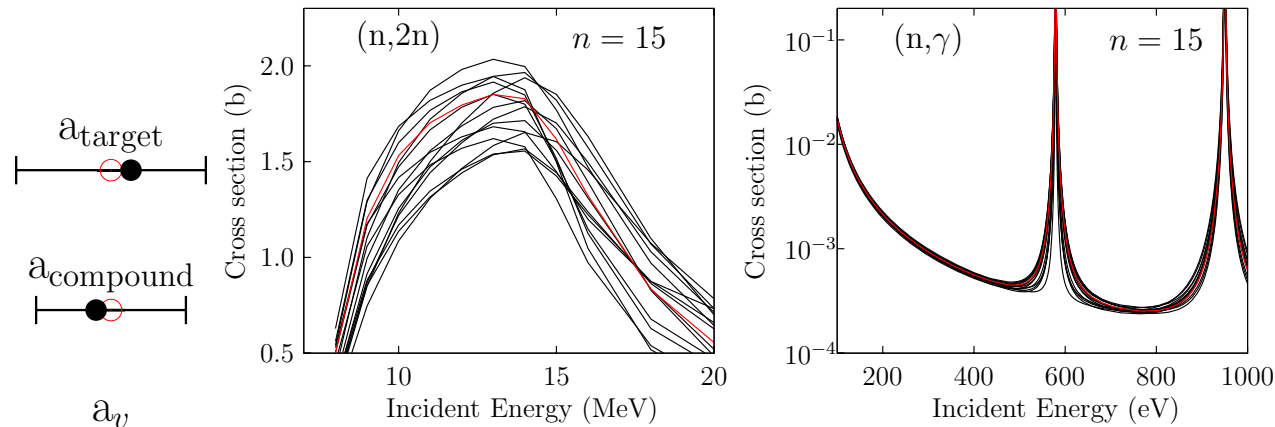


TALYS

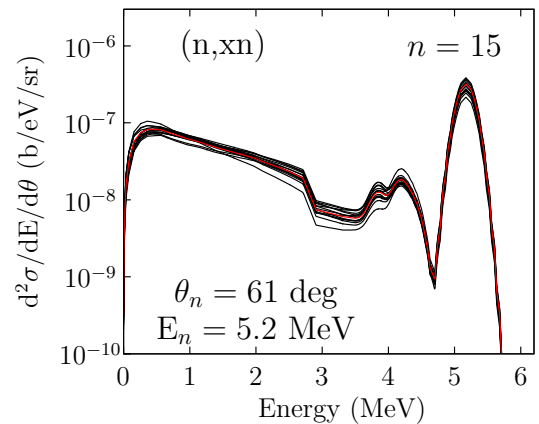
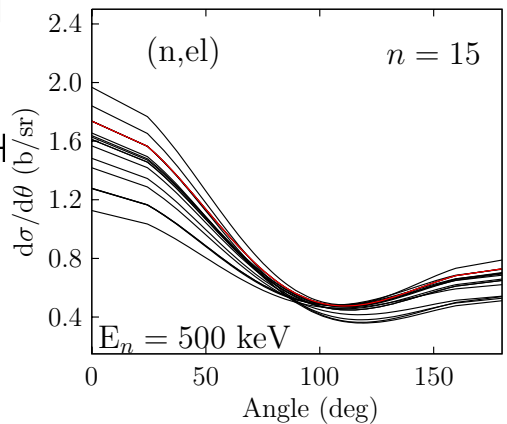
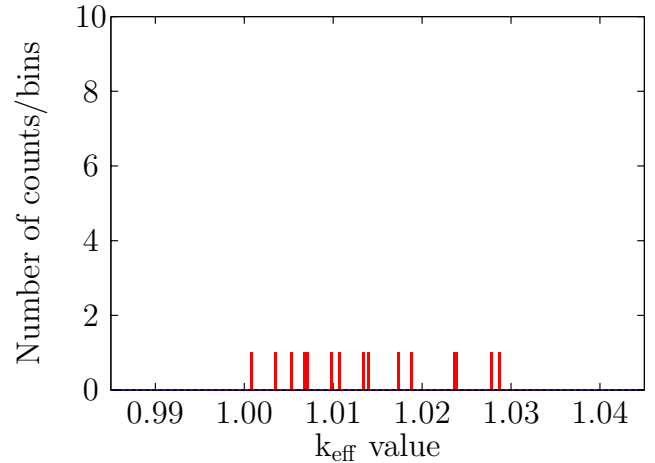
MCNP



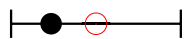
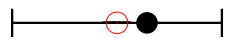
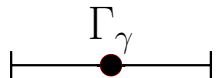
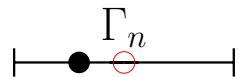
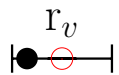
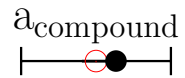
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TALYS  $\longrightarrow$  MCNP



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

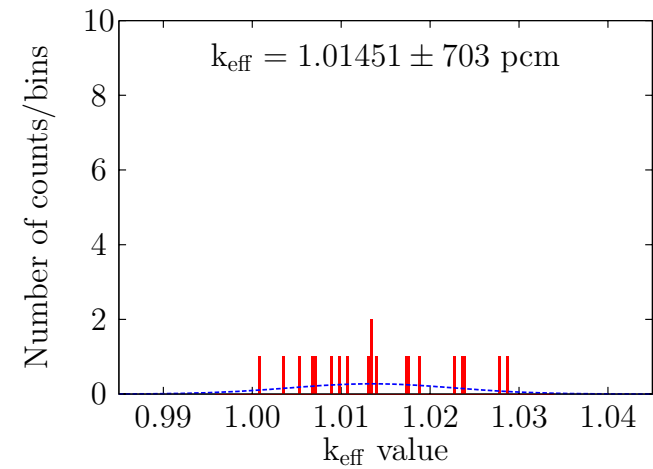


TALYS

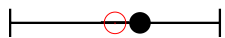
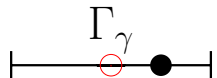
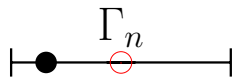
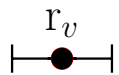
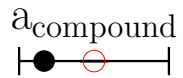
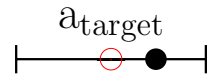
MCNP



$n = 20$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

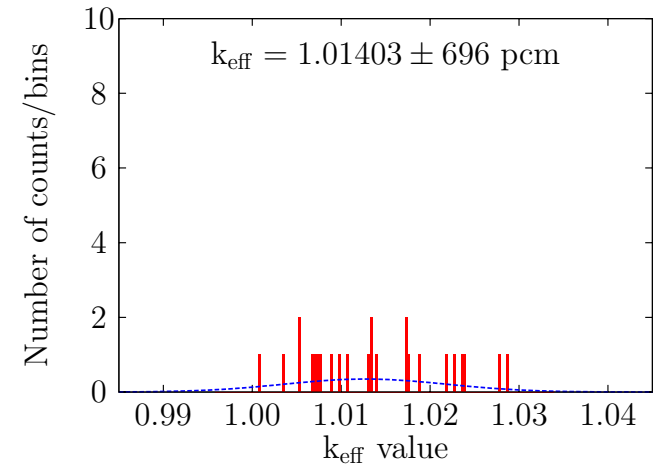


TALYS

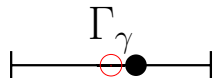
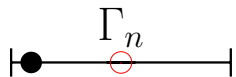
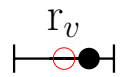
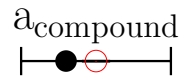
MCNP



$n = 25$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

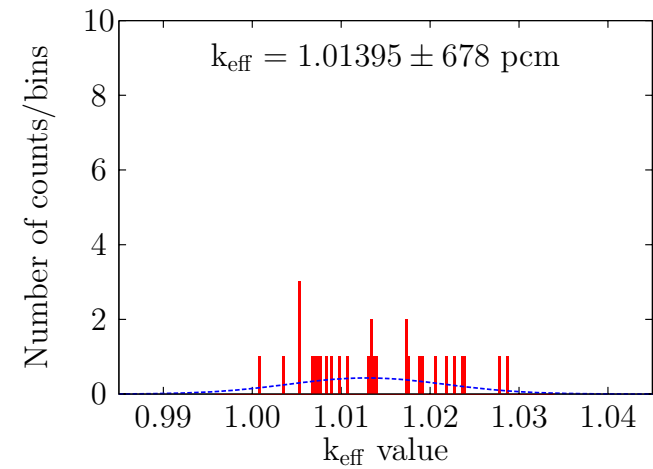


TALYS

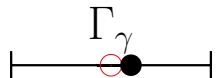
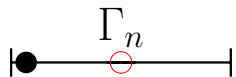
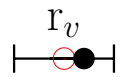
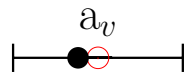
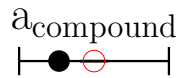
MCNP



$n = 30$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

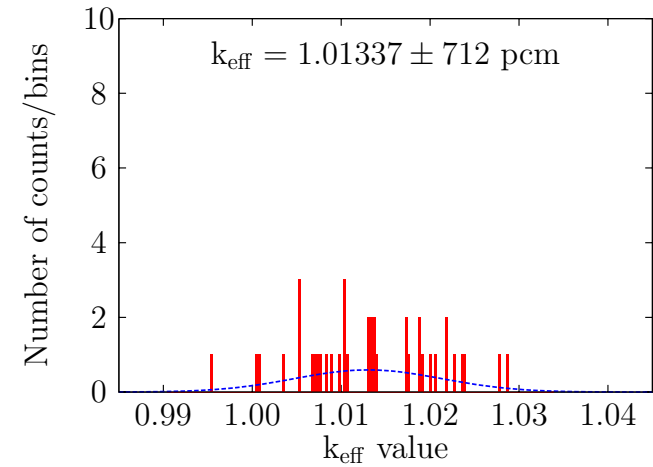


TALYS

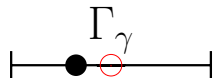
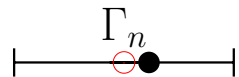
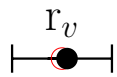
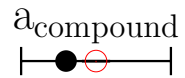
MCNP



$n = 40$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

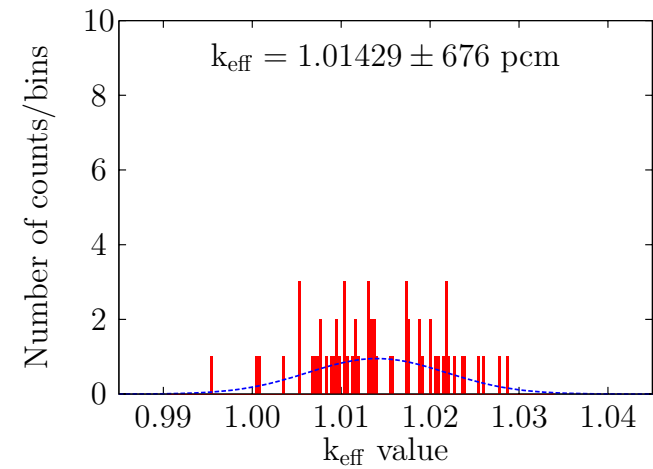


TALYS

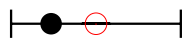
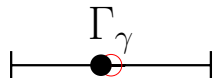
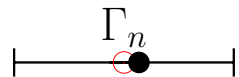
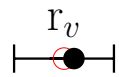
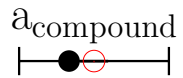
MCNP



$n = 60$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

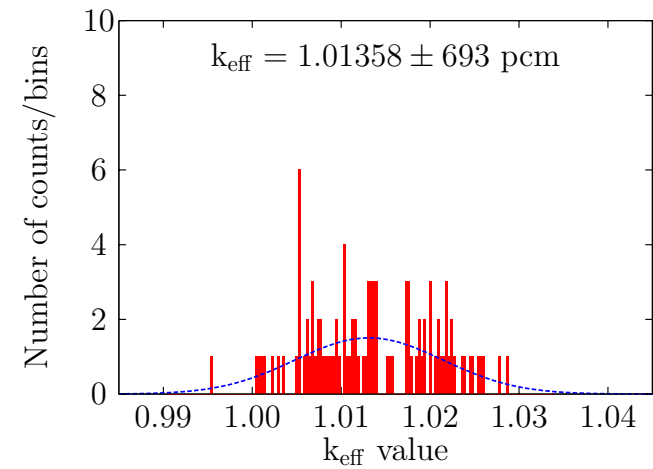


TALYS

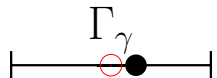
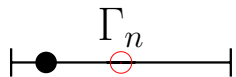
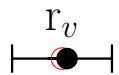
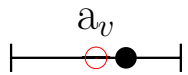
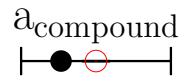
MCNP



$n = 100$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

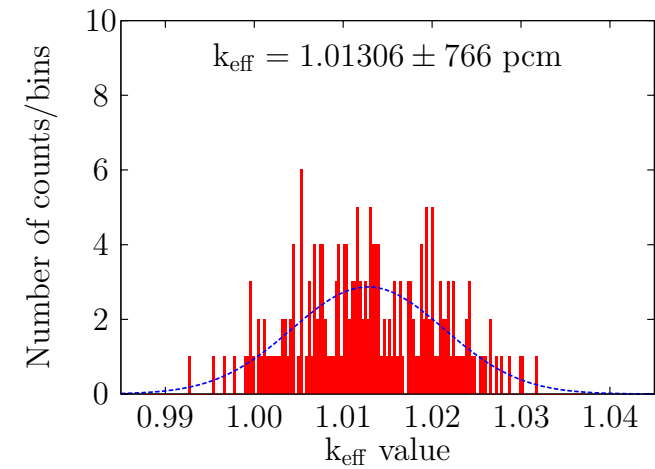


TALYS

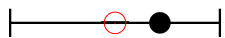
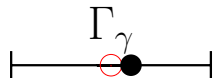
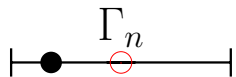
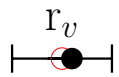
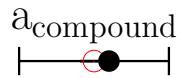
MCNP



$n = 200$



# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

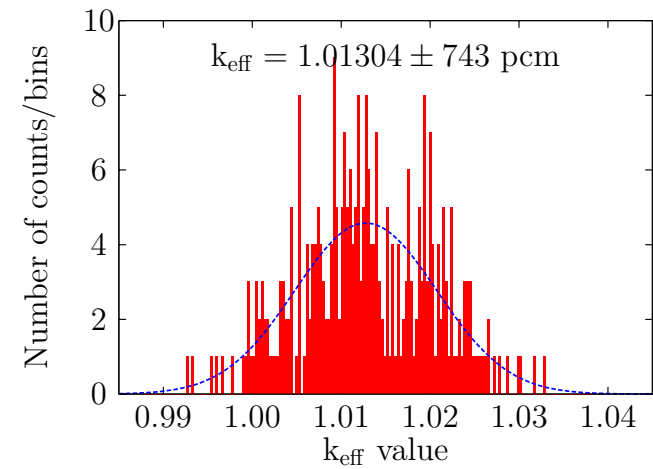


TALYS

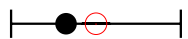
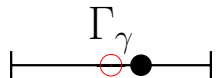
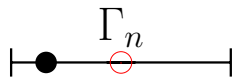
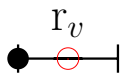
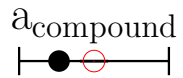
MCNP



$n = 300$

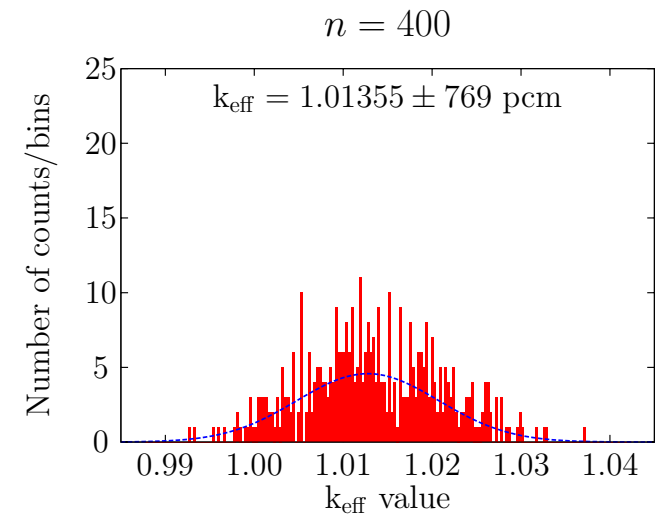


# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

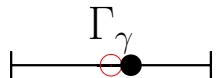
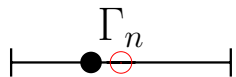
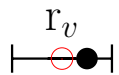
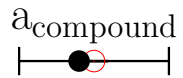


TALYS

MCNP

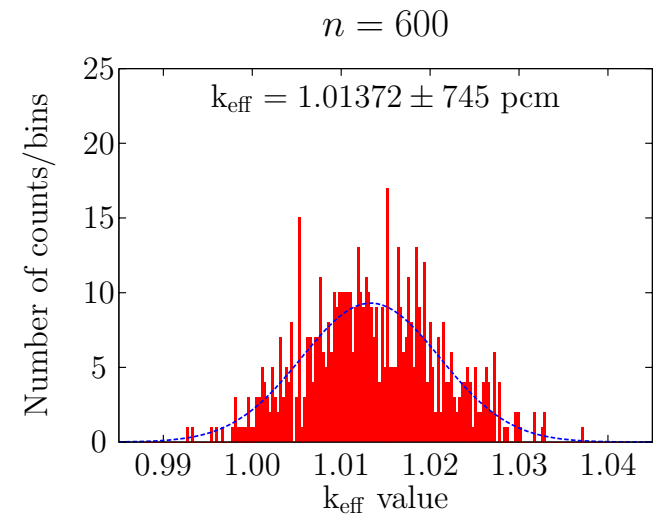


# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

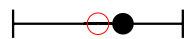
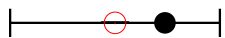
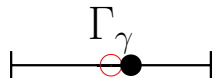
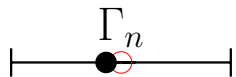
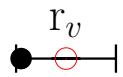
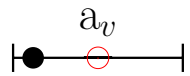
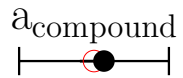


TALYS

MCNP

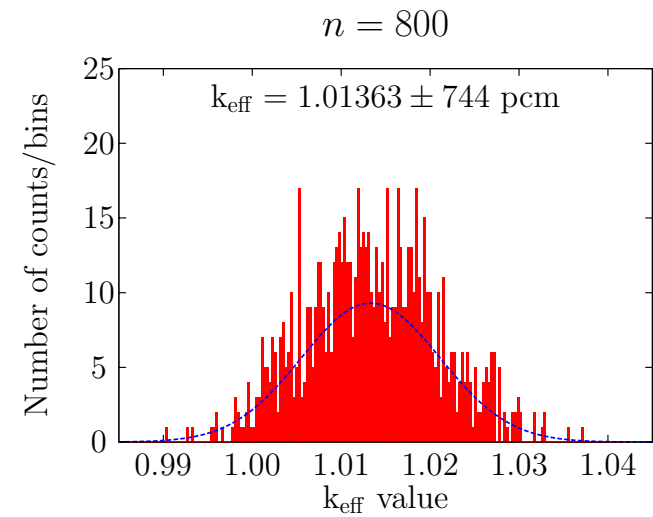


# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”

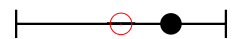
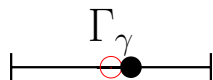
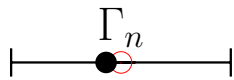
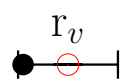
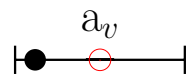
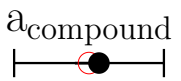


TALYS

MCNP

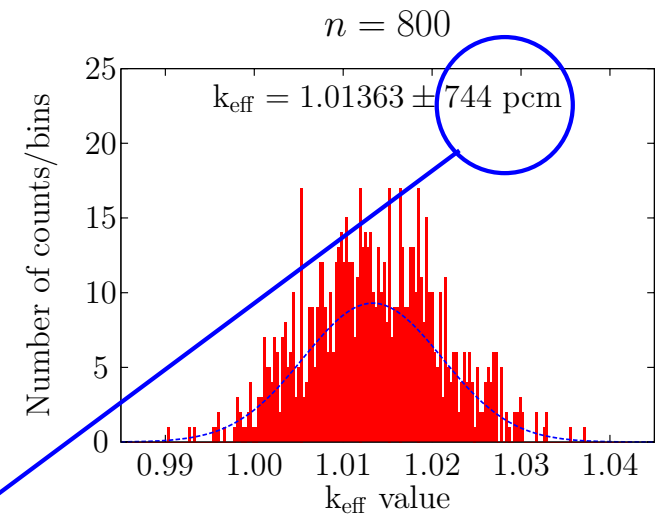


# Hands on “1000 × (Talys + ENDF + NJOY + MCNP) calculations”



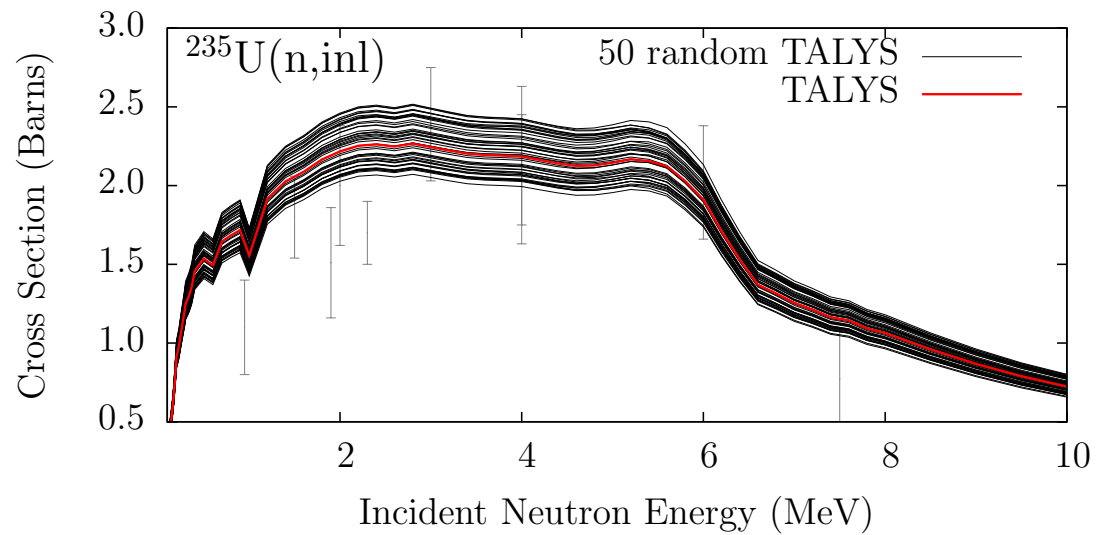
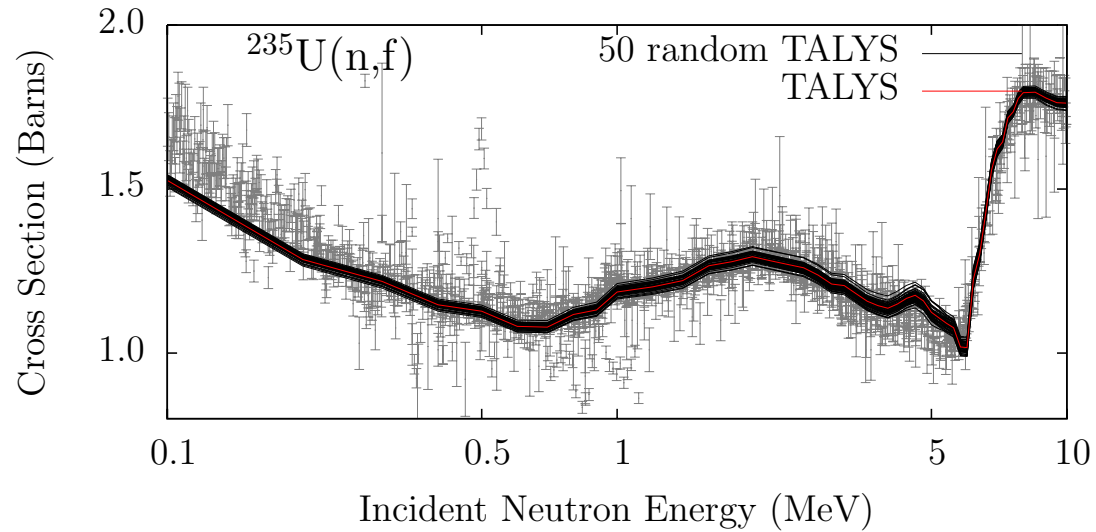
TALYS

MCNP

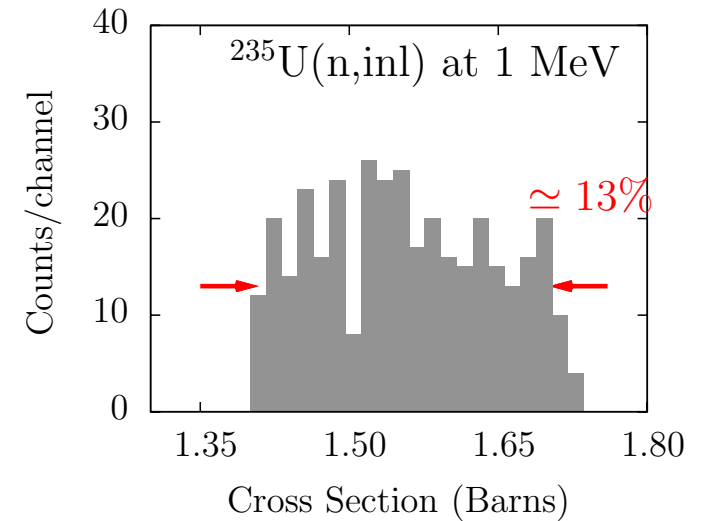
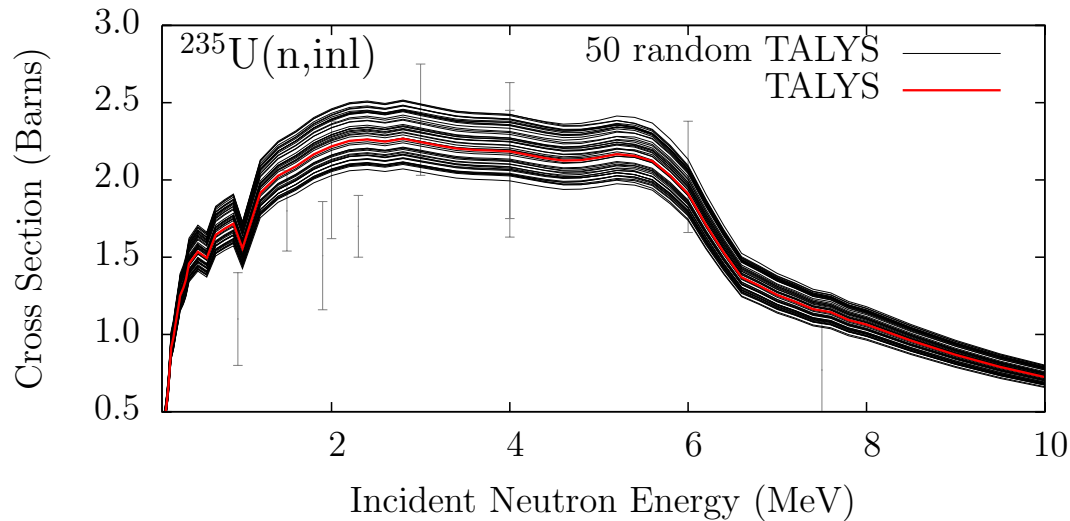
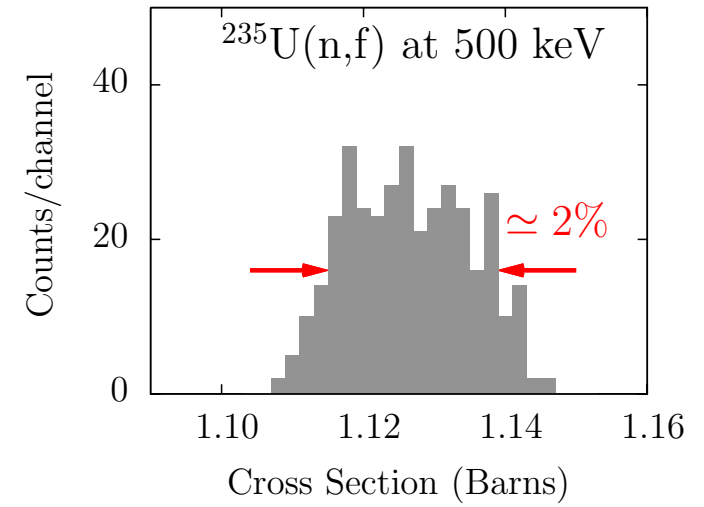
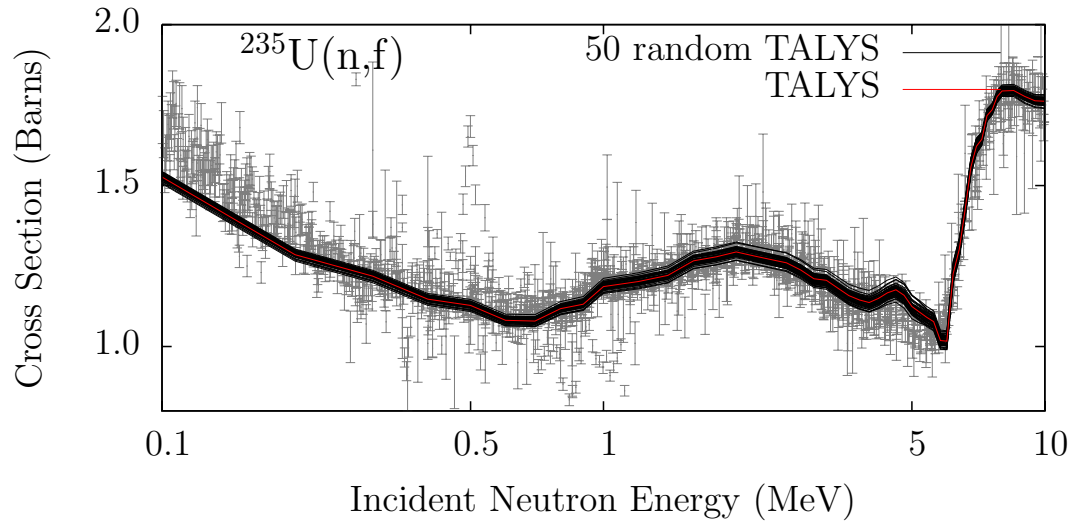


Statistical uncertainty  $\simeq 68$  pcm  
 $\implies$  uncertainty due to nuclear data  $\simeq 740$  pcm

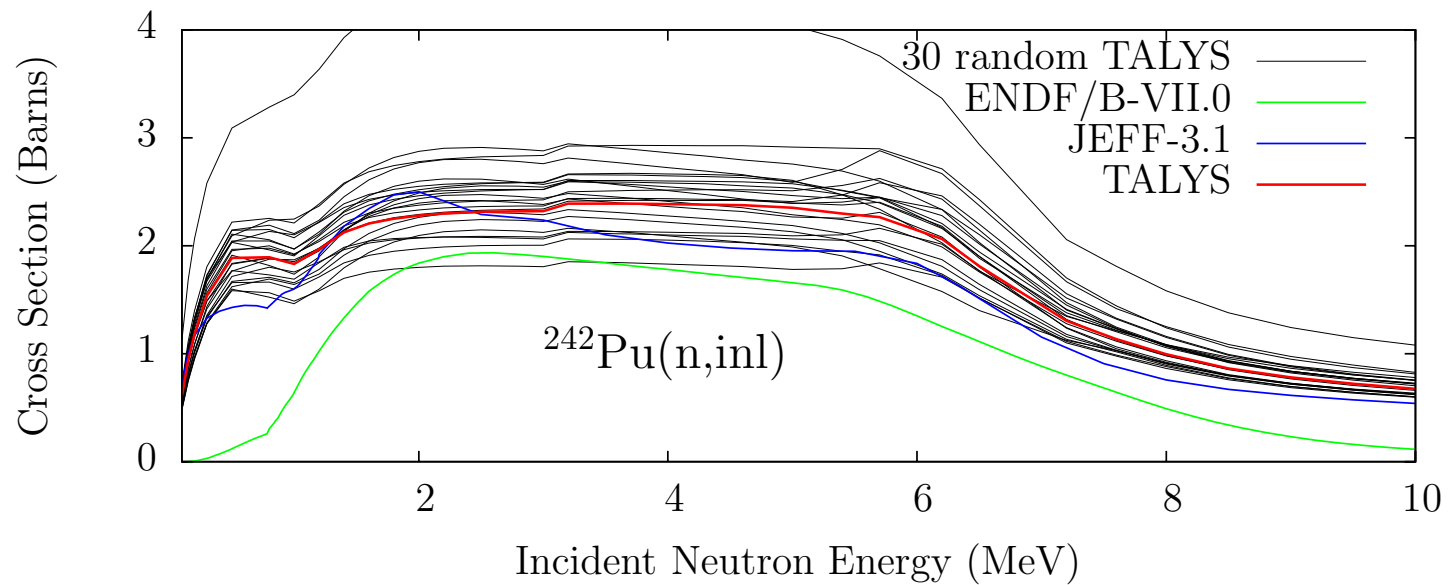
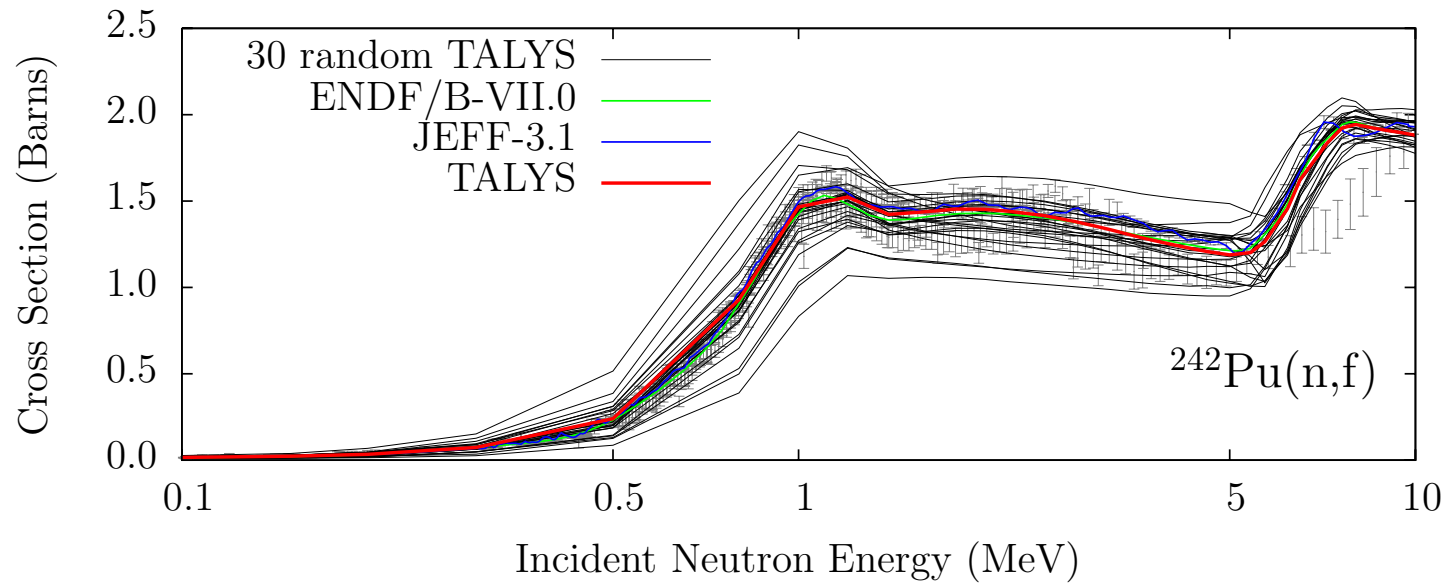
# Example with $^{235}\text{U}$ : Monte Carlo calculations



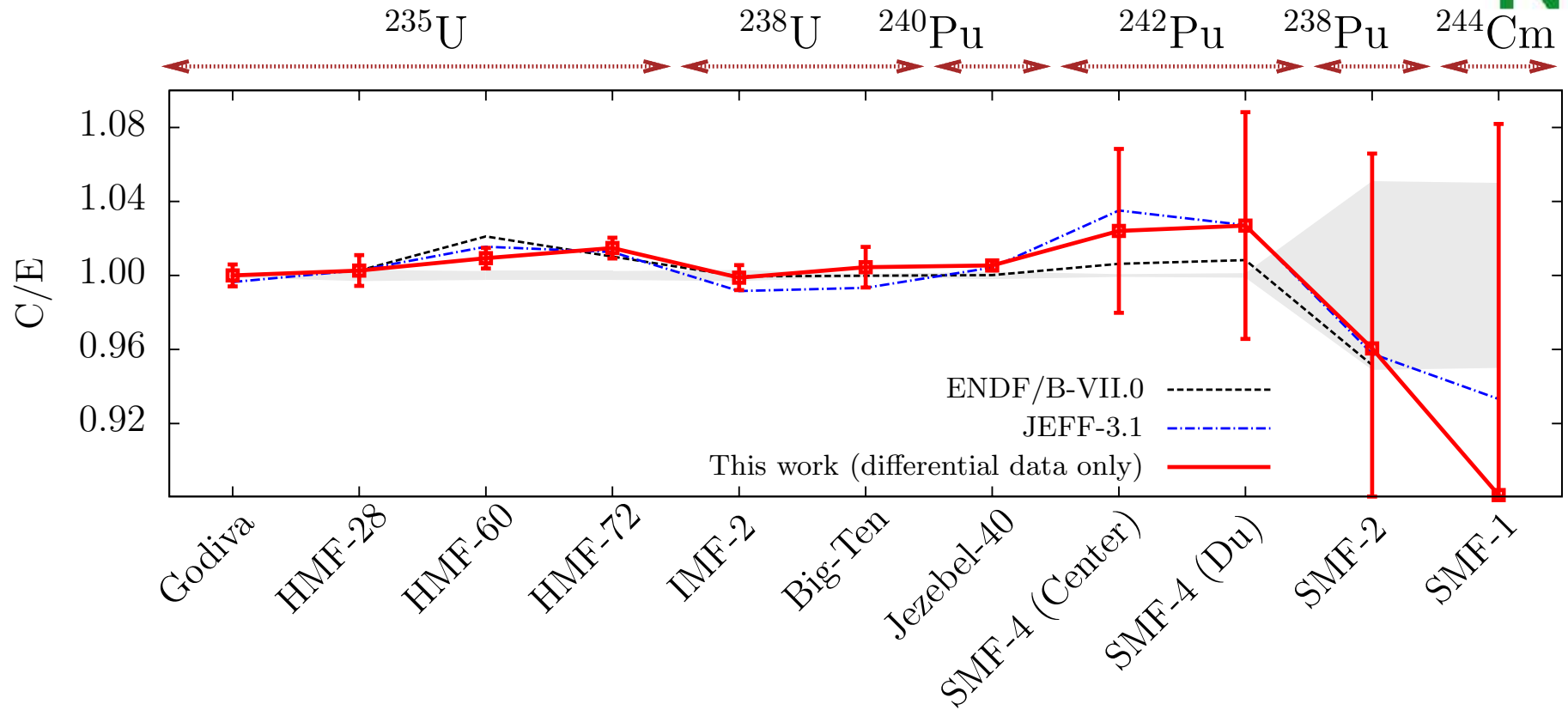
# Example with $^{235}\text{U}$ : Monte Carlo calculations



# Example with $^{242}\text{Pu}$ : Monte Carlo calculations

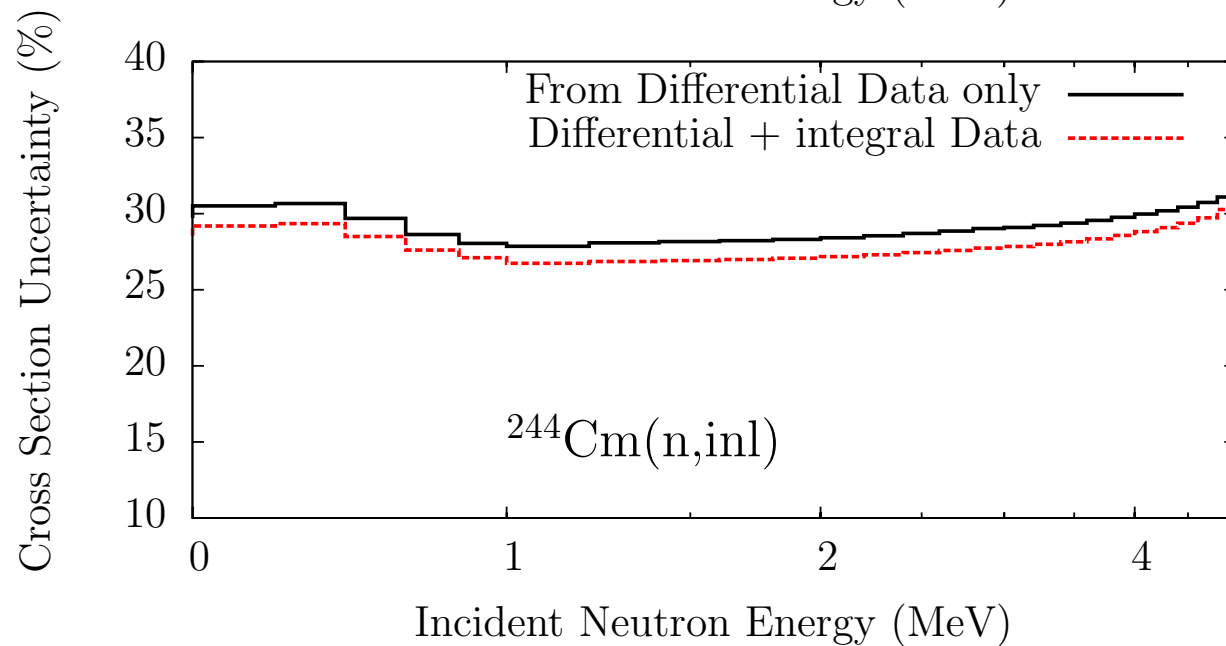
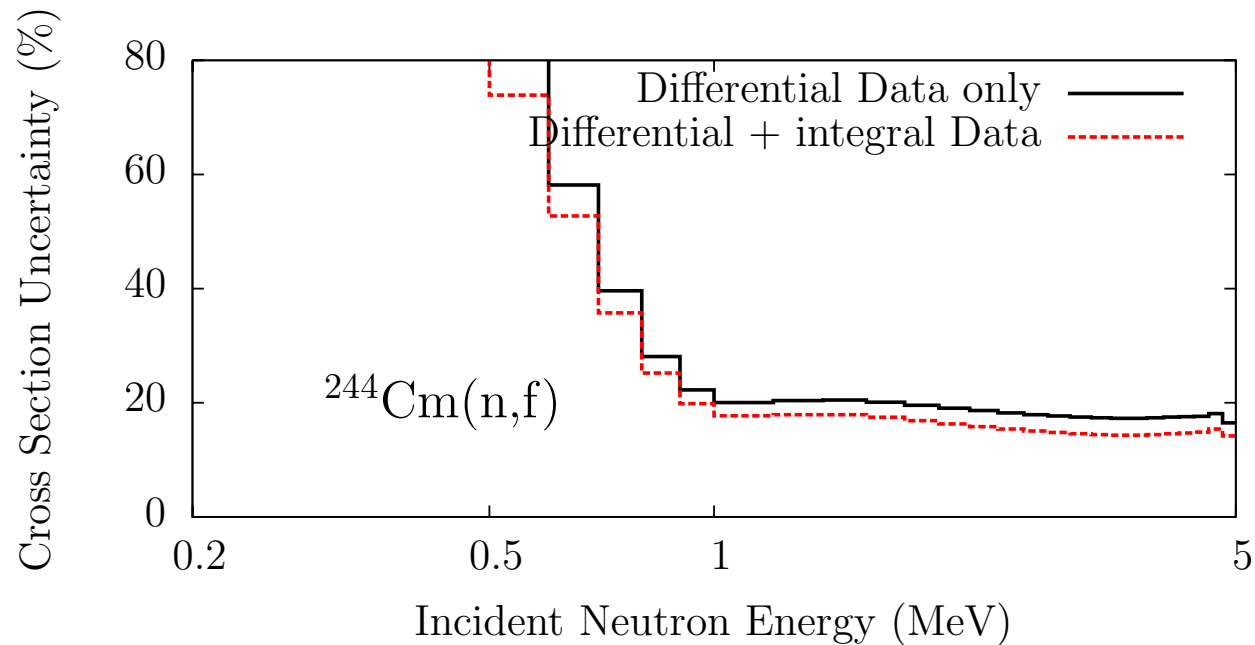


# Benchmark results using differential data only

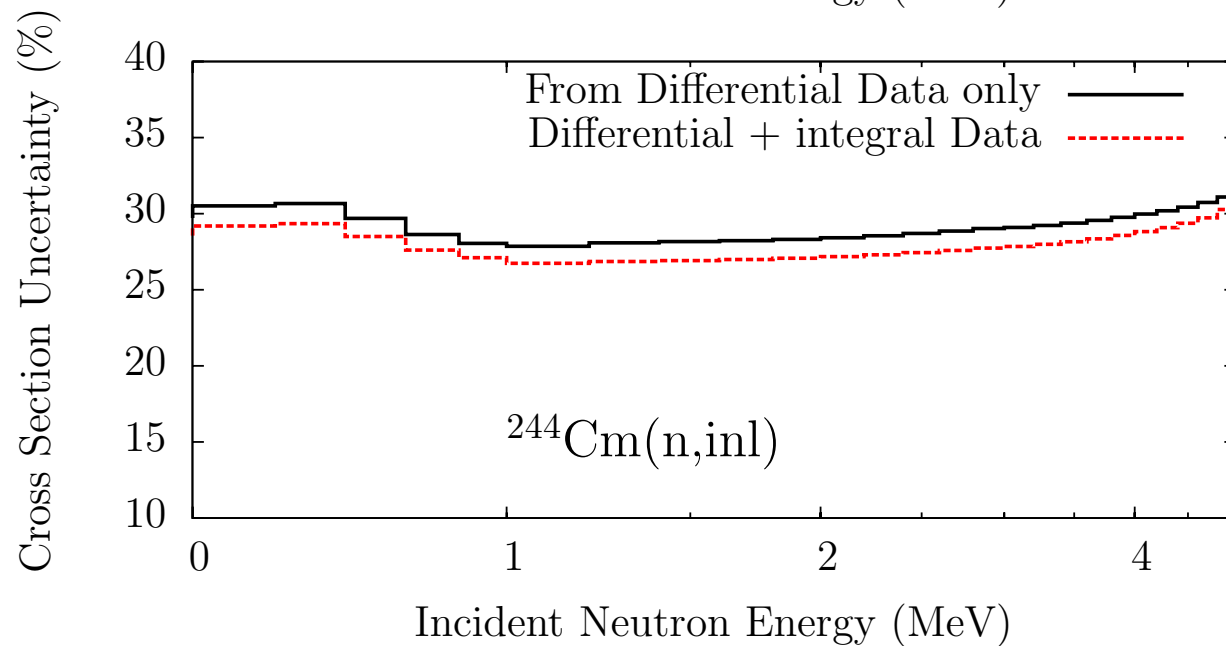
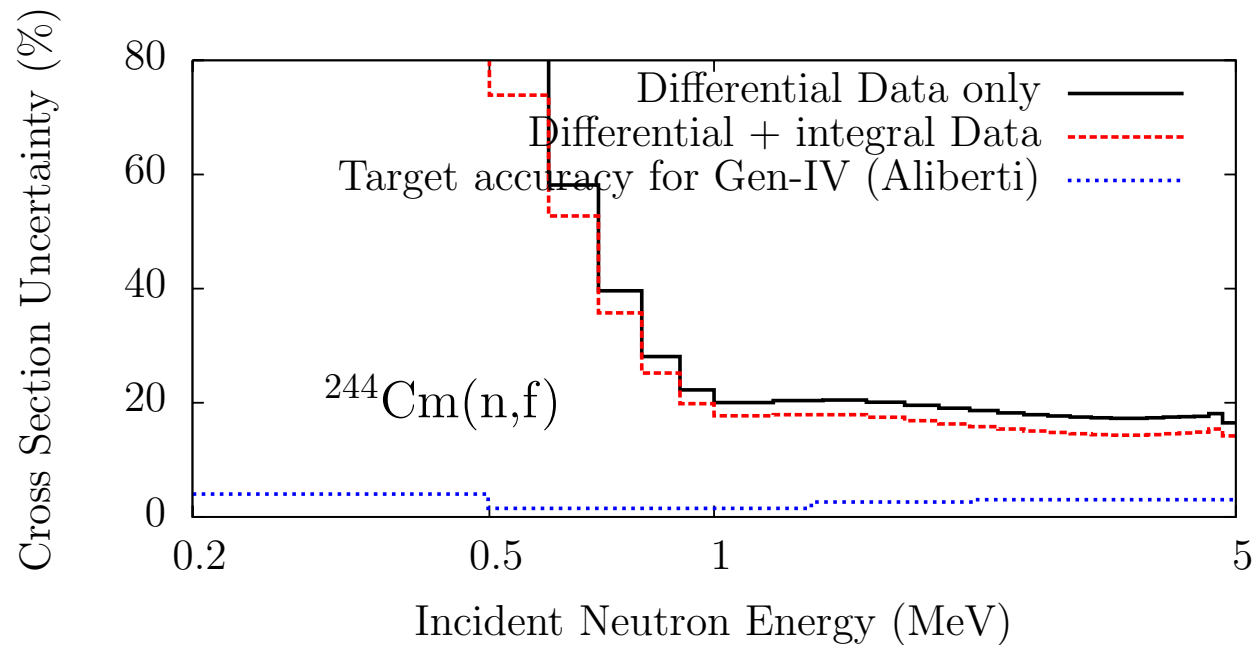


- Fast benchmarks
- SMF-1, -2 and -4: dedicated to minor actinides ( $^{238,242}\text{Pu}$  and  $^{244}\text{Cm}$ )
- SMF-1 and -2: Replacement measurements using Jezebel
- SMF-4: Plates of  $^{242}\text{Pu}$

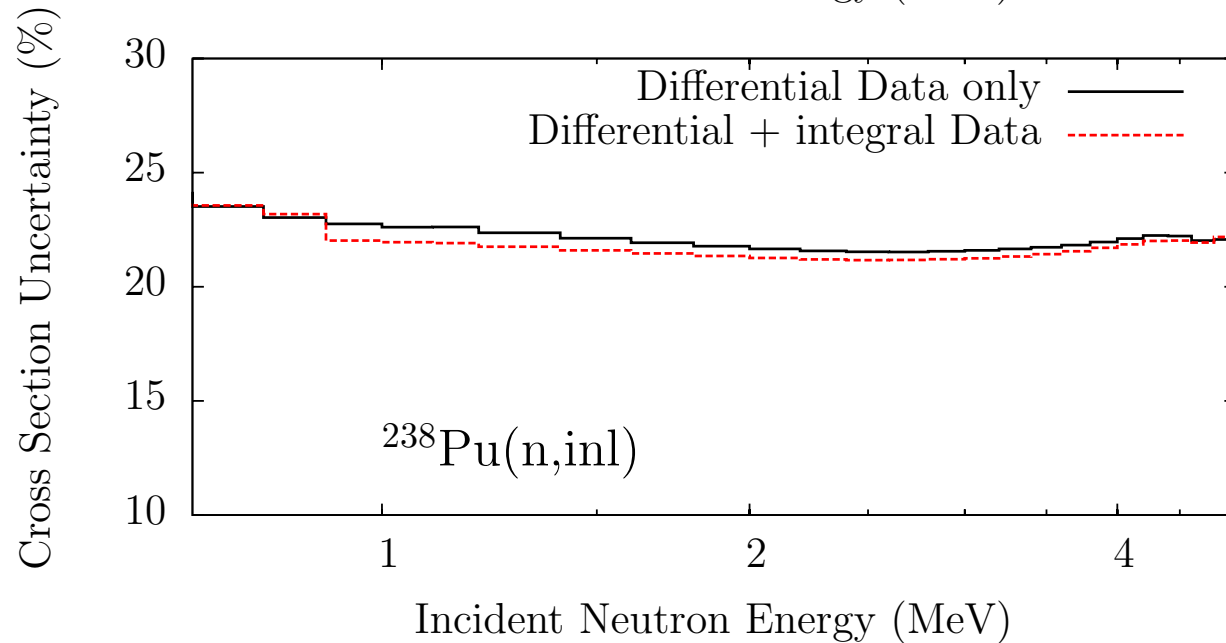
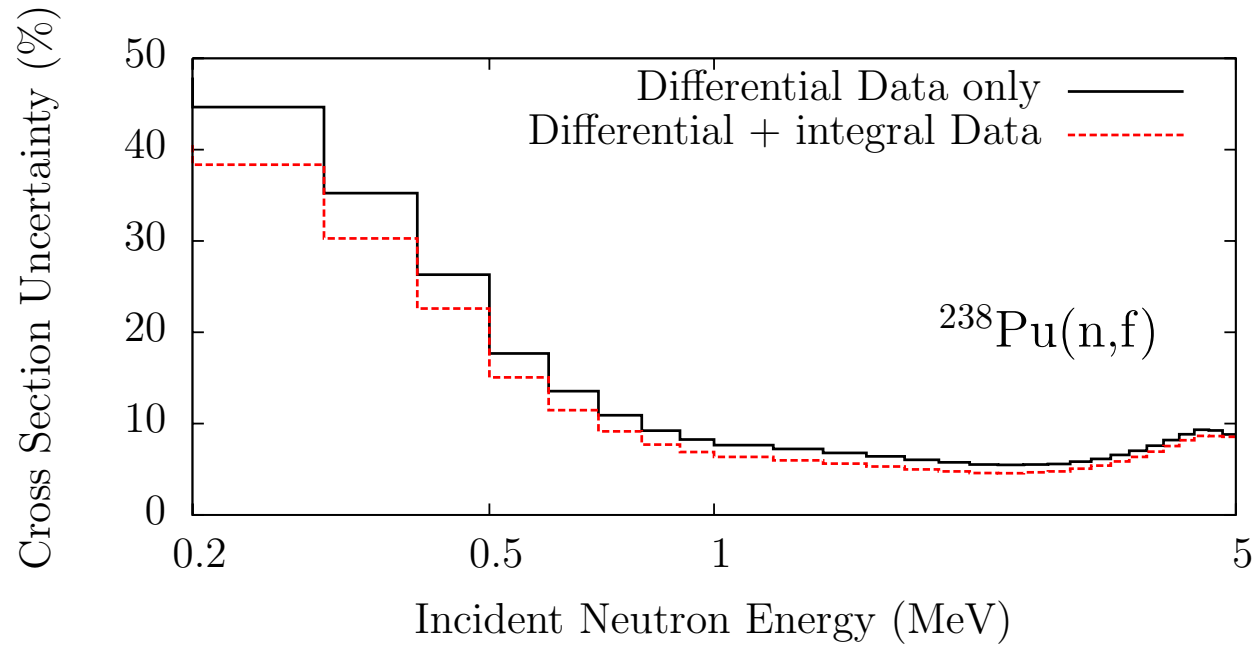
# Impact on $^{244}\text{Cm}(n,f)$ and $^{244}\text{Cm}(n,inl)$ uncertainties



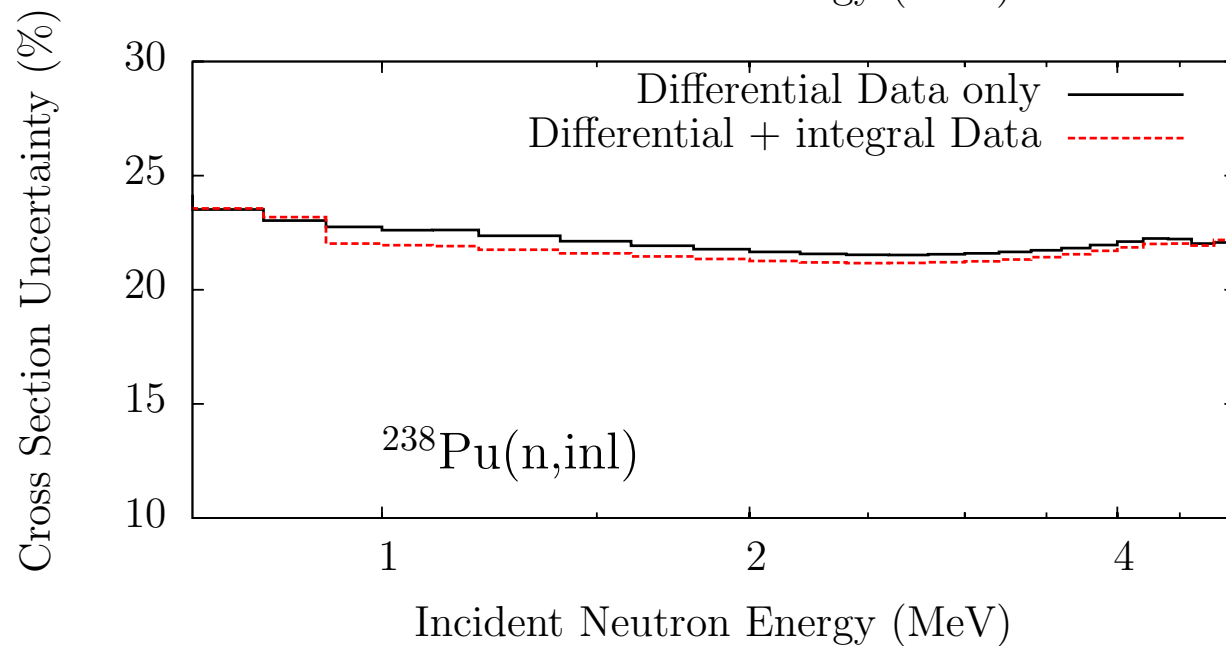
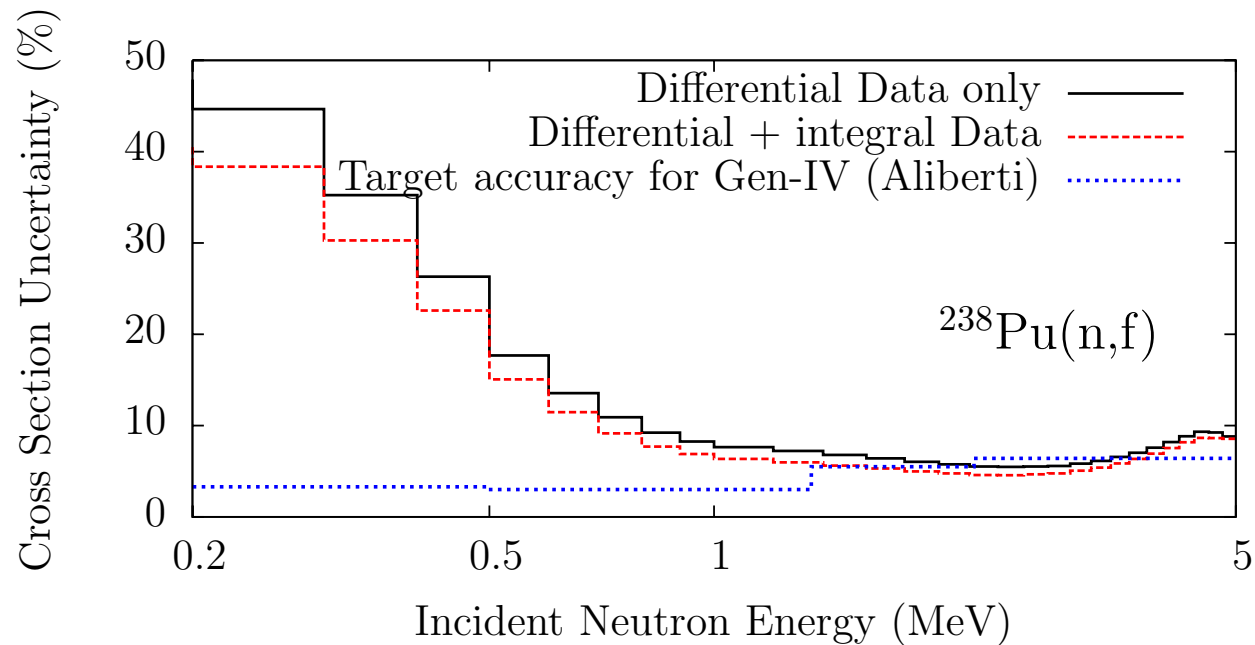
# Impact on $^{244}\text{Cm}(n,f)$ and $^{244}\text{Cm}(n,inl)$ uncertainties



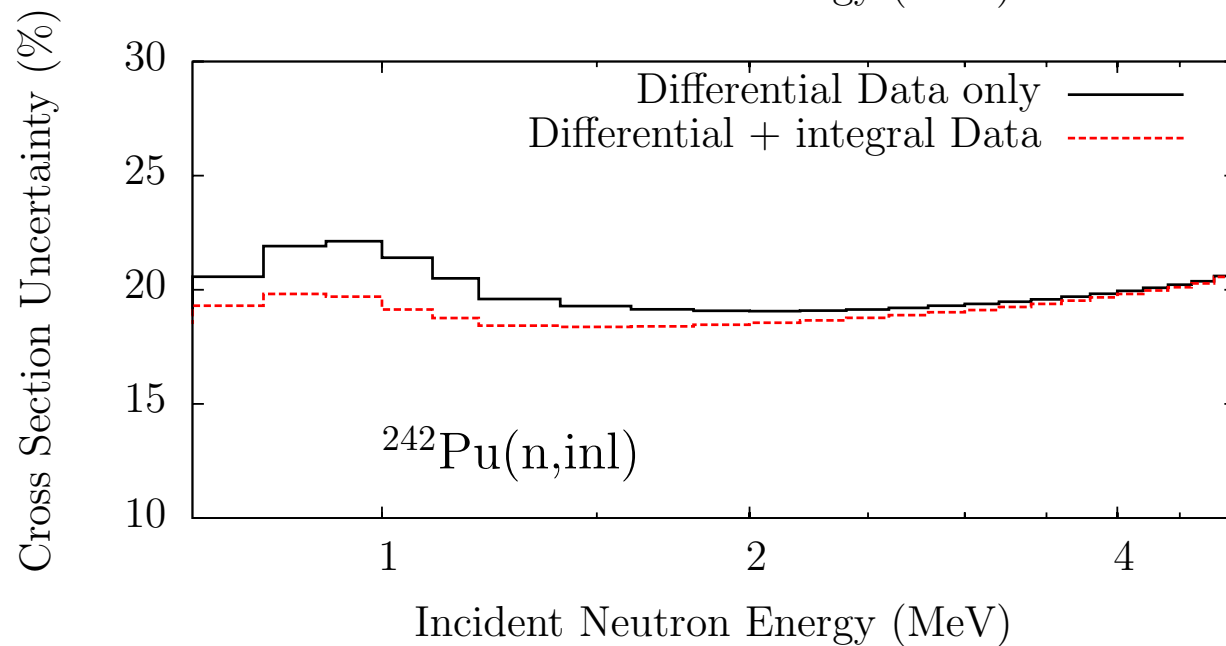
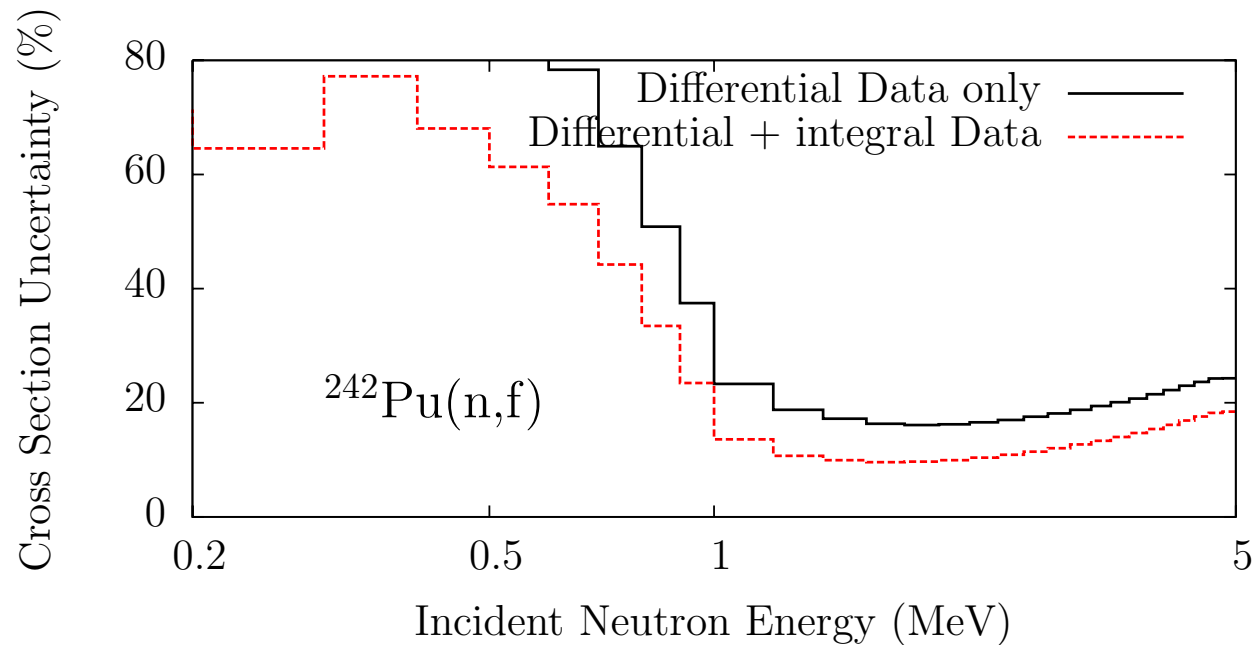
# Impact on $^{238}\text{Pu}(n,f)$ and $^{238}\text{Pu}(n,inl)$ uncertainties



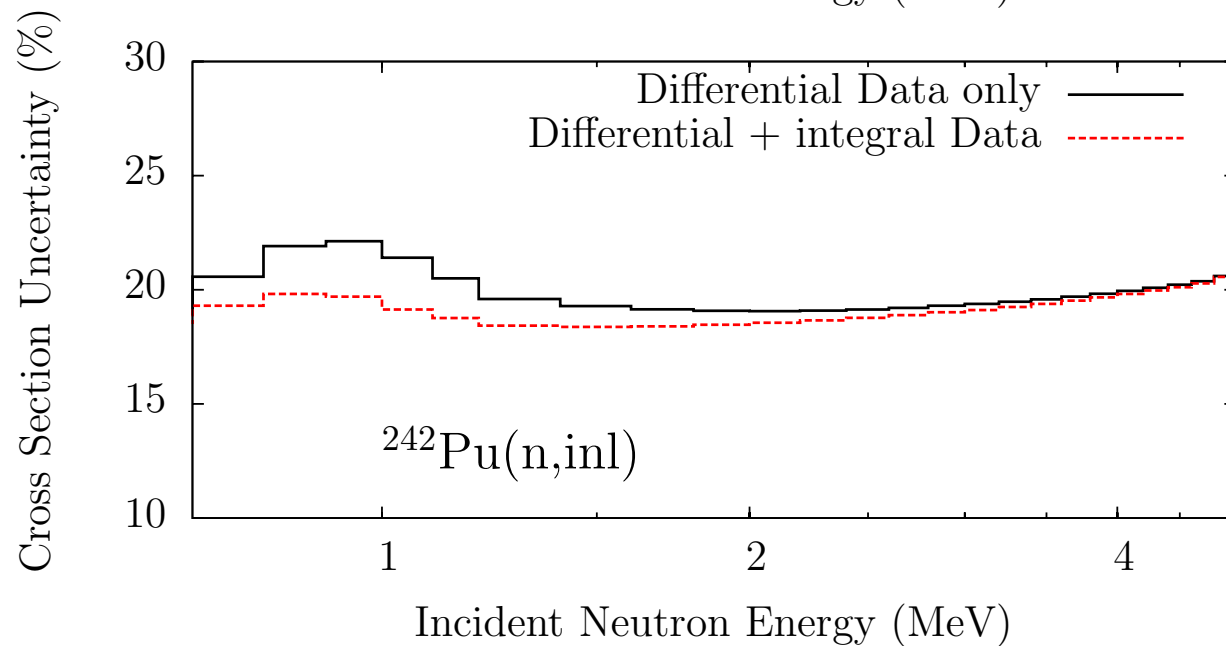
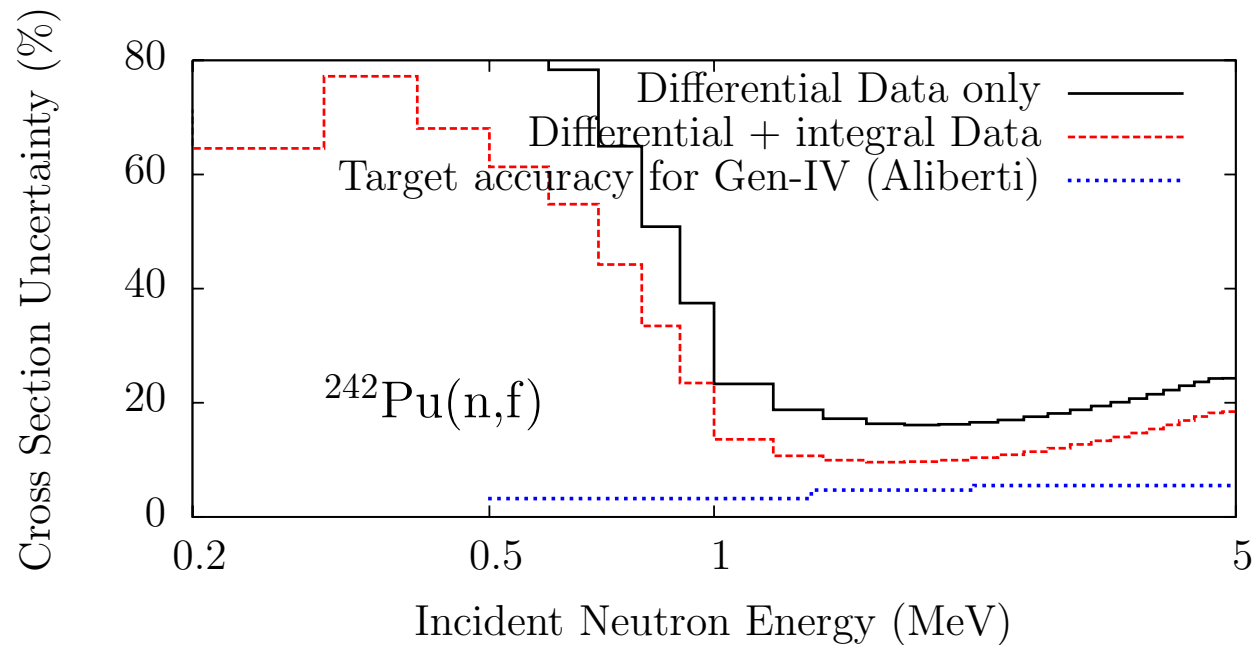
# Impact on $^{238}\text{Pu}(n,f)$ and $^{238}\text{Pu}(n,inl)$ uncertainties



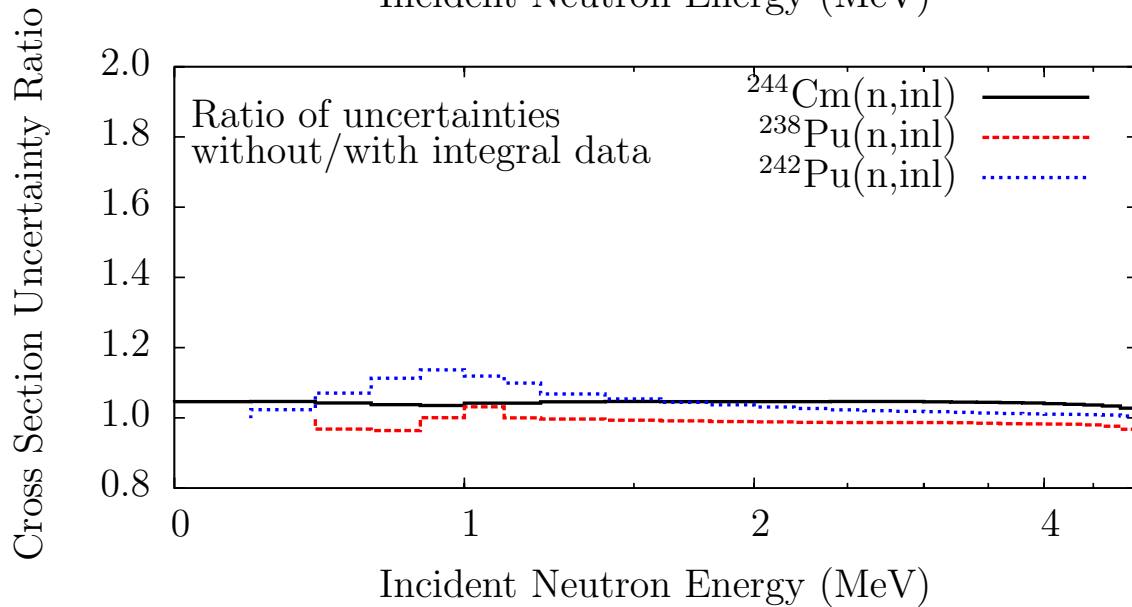
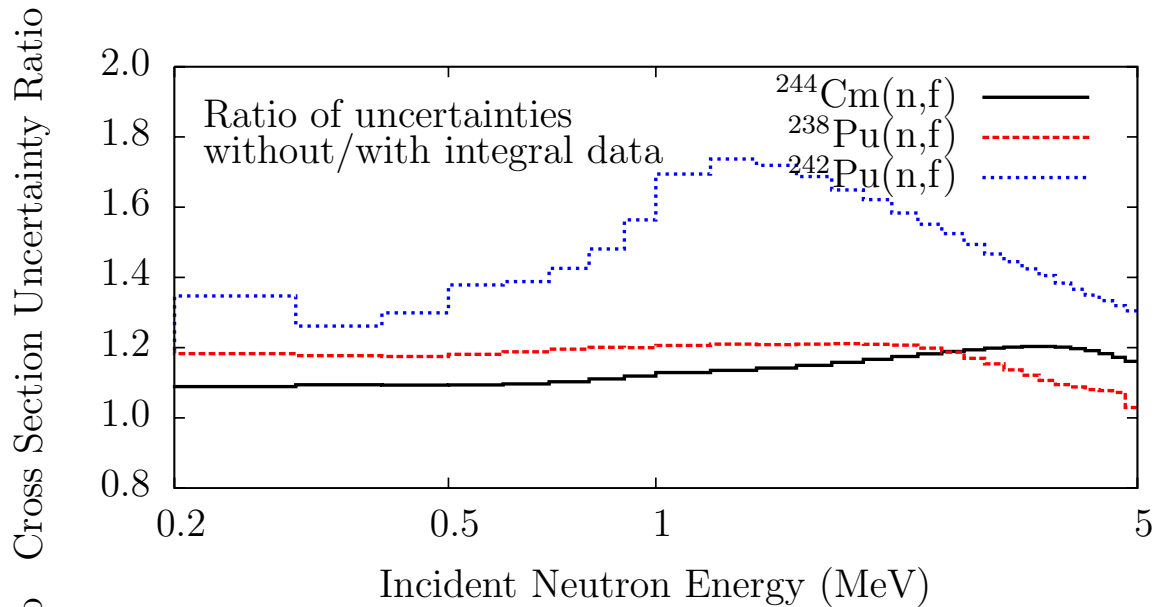
# Impact on $^{242}\text{Pu}(n,f)$ and $^{242}\text{Pu}(n,inl)$ uncertainties



# Impact on $^{242}\text{Pu}(n,f)$ and $^{242}\text{Pu}(n,inl)$ uncertainties



# Summary of the impact



## Conclusions and future improvements

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- ❑ New methodology to propagate nuclear data uncertainty to integral quantities ( $k_{\text{eff}}$  benchmarks, shielding benchmarks, reactivity swing, neutron flux for commercial reactor) via Monte Carlo
- ❑ Blending differential measurements, evaluations, and validation in one approach
- ❑ Proof of principle with minor actinides (and other isotopes)
- ❑ Mass production tested (new library TENDL-2008 and TENDL-2009 (see JEFF meeting in June))

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- ☒ Mass production tested (new library TENDL-2008 and TENDL-2009 (see JEFF meeting in June))
- ☐ Needs to develop best central-value evaluations (non-fissile and fissile) ?
- ☐ Compare with more benchmarks and more reaction channels (*e.g.* (n, $\gamma$ ))
- ☐ Need more clever sampling,
- ☐ At the end, experimentalists can tell about the feasibility of reaching smaller uncertainties.