Propagation of nuclear data uncertainties with a Monte Carlo method

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PSI, Switzerland, July 2012

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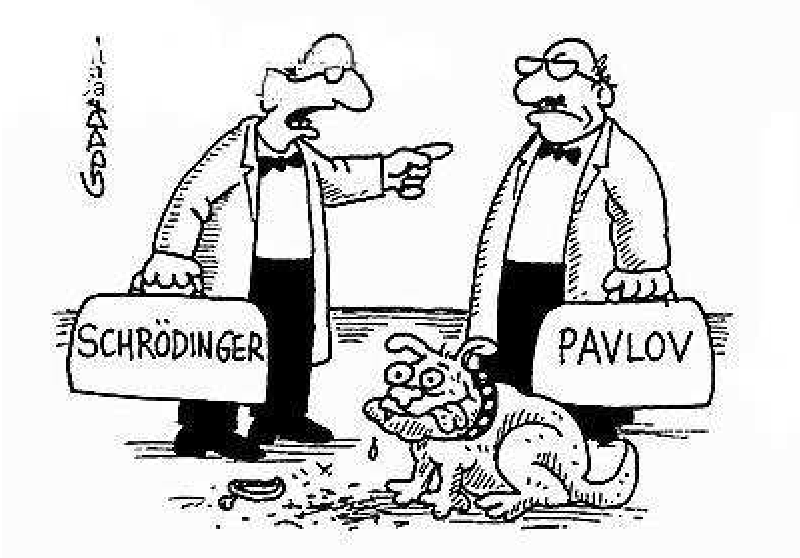
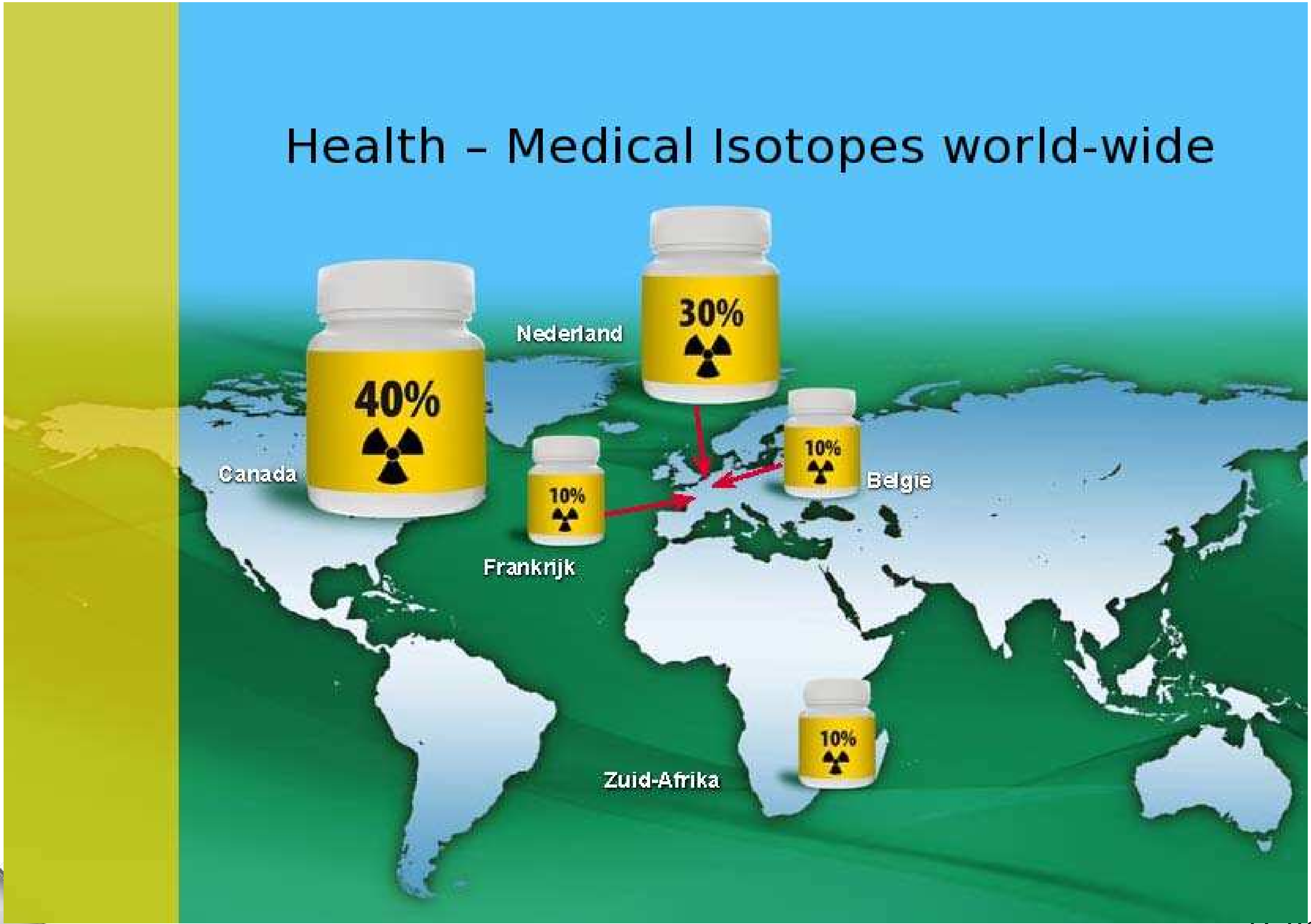


Pavlov’s dog eating Schrodinger’s cat
(deterministic vs. Monte carlo approach)

Who are we ?

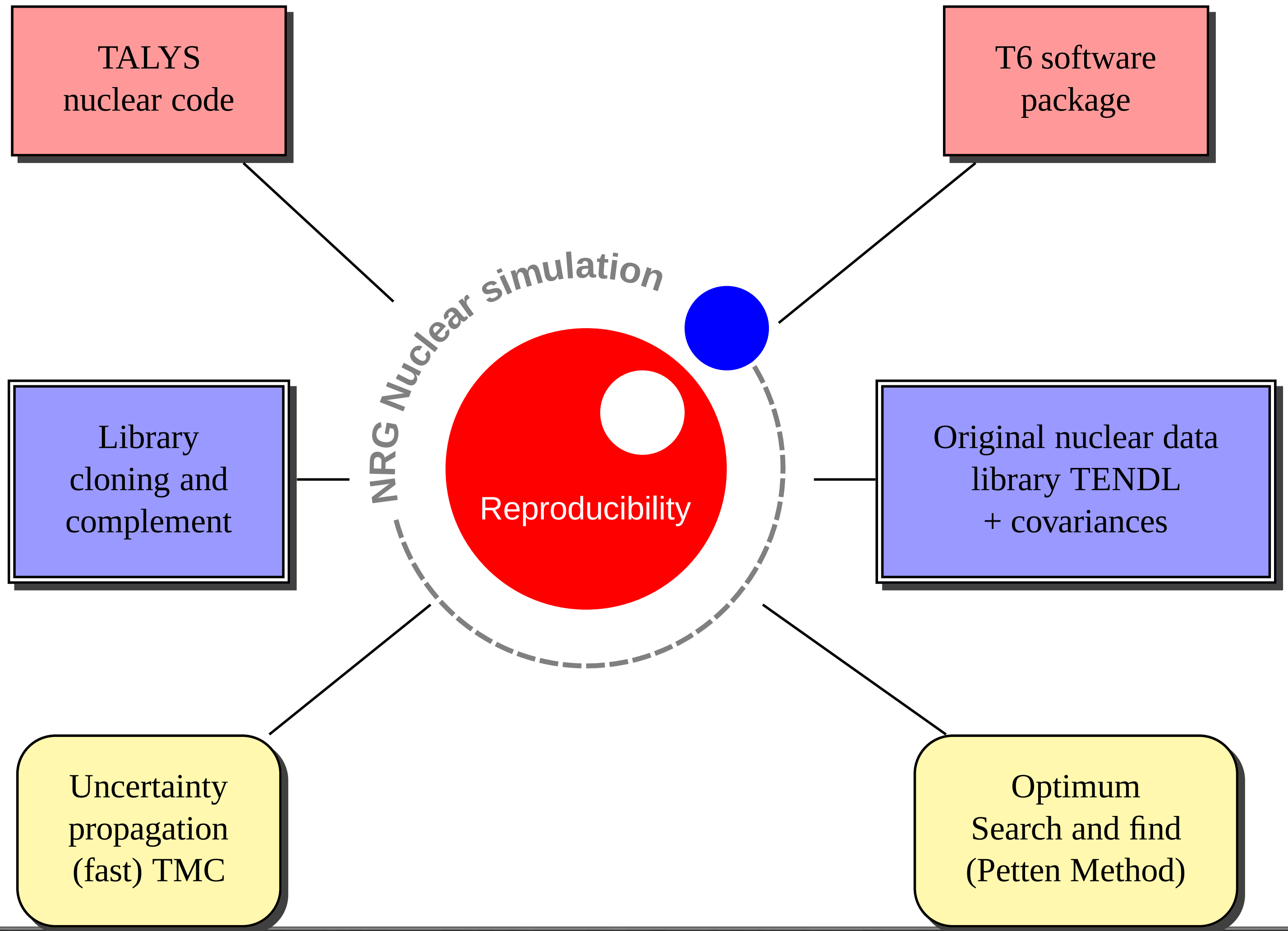
- NRG: a leading nuclear sector service provider
- Over 50 years experience in nuclear technology
- Over 400 employees (10 in R&D reactor physics and simulations)
- Turnover approximately Meuros 60 / per year
- High Flux Reactor, Hot Cell Laboratories and Radiological labs

Who are we ?


Health – Medical Isotopes world-wide
40%
Canada
Nederland
30%
10%
Belgie
10%
Frankrijk
Zuid-Afrika
10%

Mission and objective

Our mission: improve nuclear simulations



Introduction: Motivations for a change

Usual procedures in uncertainty propagation imply:

- rigid format, fixed libraries of cross sections, simplification of covariances,
- need for processing, sensitivity and perturbation codes, group scheme,
- necessity of linearizing inherently nonlinear relationships, and so on...

> *"Researchers should cease trying to be clever in devising refinements to old methods that were developed when computational resources were limited.*

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"Researchers should cease trying to be clever in devising refinements to old methods that were developed when computational resources were limited. Instead, their creative instincts should be redirected to unleashing the full potential of computers for **brute** *force analysis"*

D. Smith, Santa Fe 2004

$\Longrightarrow$ Most straightforward way: Total Monte Carlo Approach !

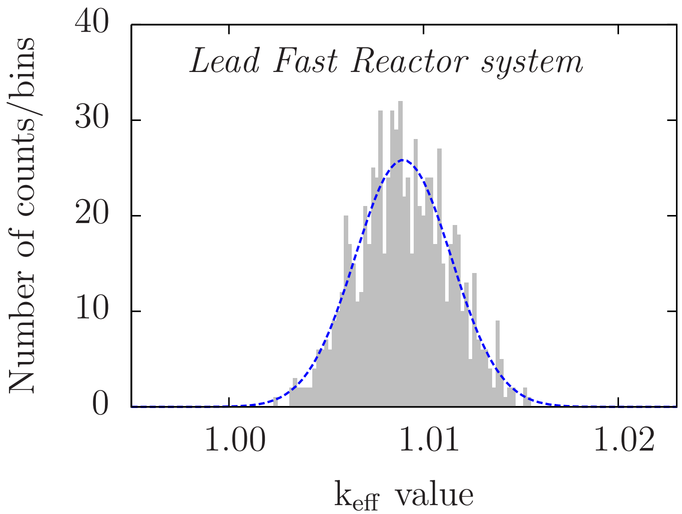
Method: Total Monte Carlo (TMC)

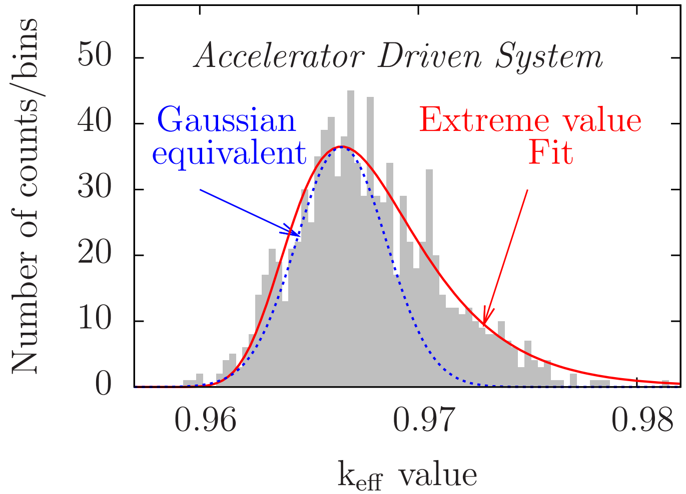
Control of nuclear data (TALYS system)
+ processing (NJOY)
+ system simulation (MCNP/ERANOS/CASMO...)

1000 times

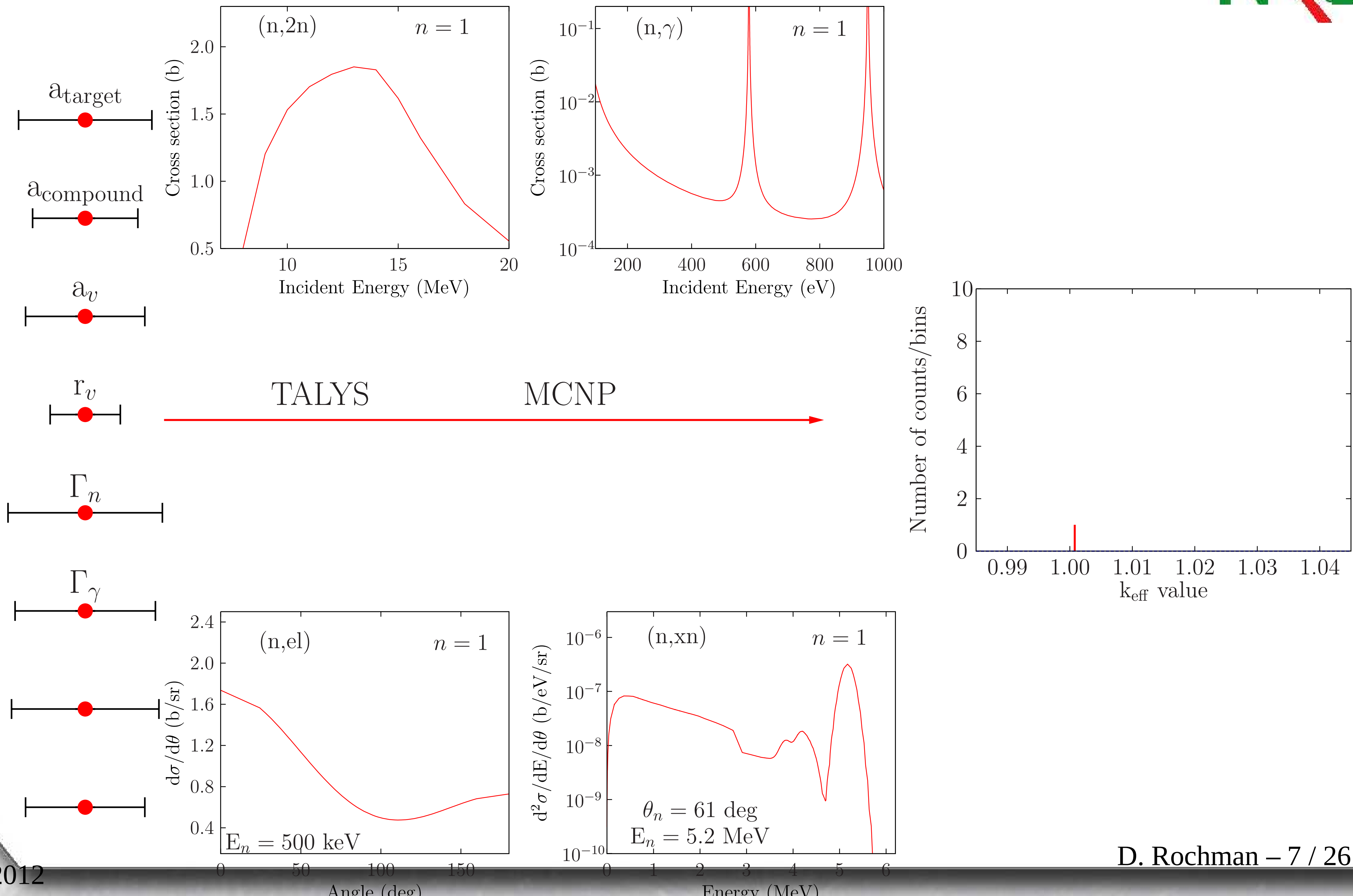
For each random ENDF file, the benchmark calculation is performed with MCNP. At the end of the n calculations, n different k_{eff} values are obtained. In the obtained probability distribution of k_{eff}, the standard deviation σ_{total} reflects two different effects:

$$\sigma^2_{total} = \sigma^2_{statistics} + \sigma^2_{nuclear\ data}.$$





Hands on “1000 $\times$(Talys + ENDF + NJOY + MCNP) calculations”



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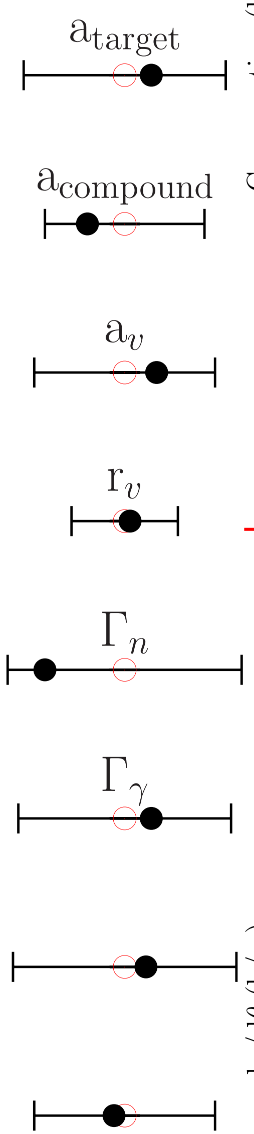
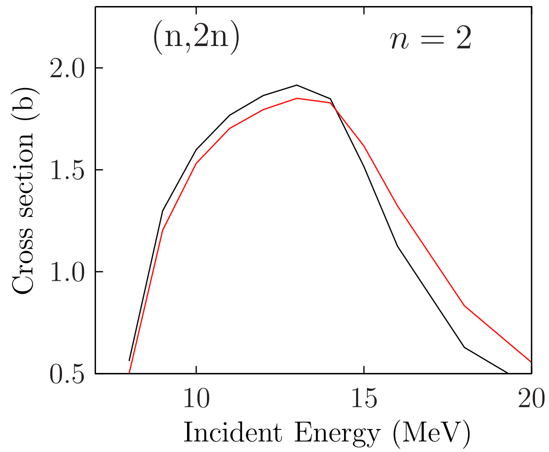
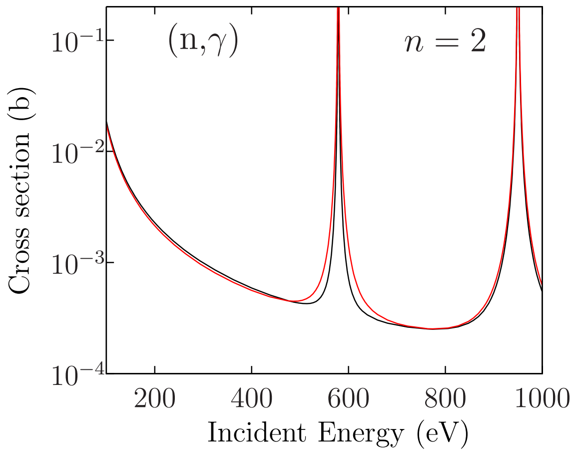
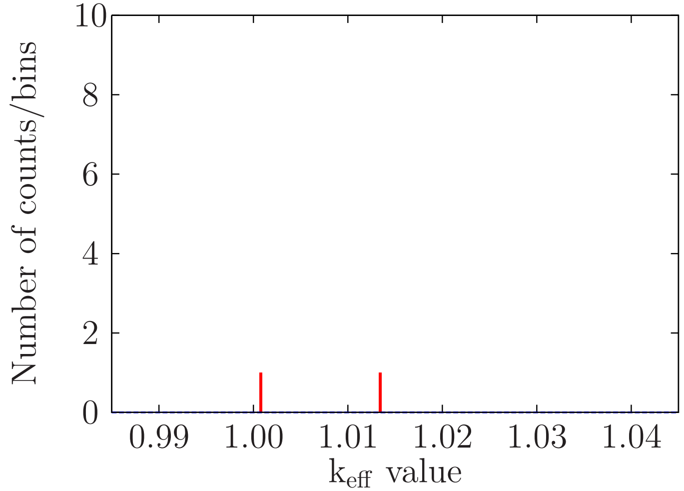
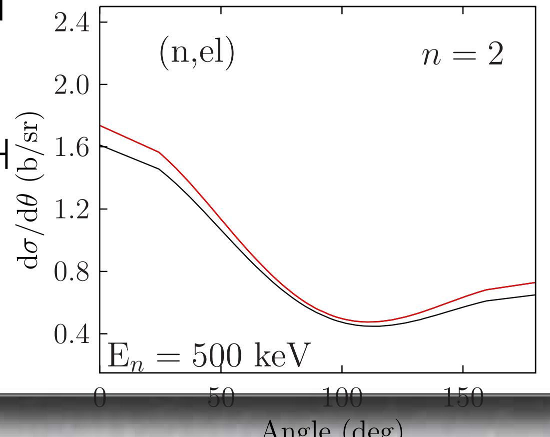


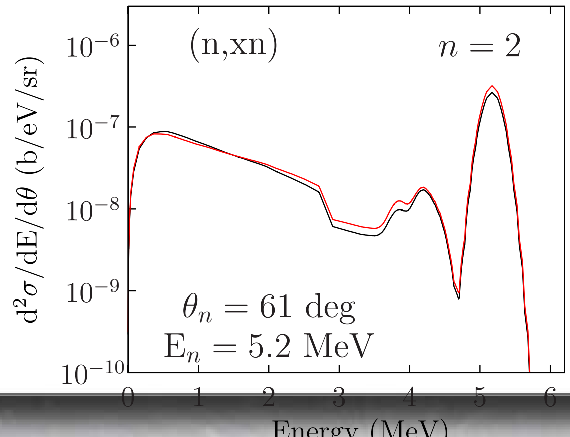




TALYS MCNP







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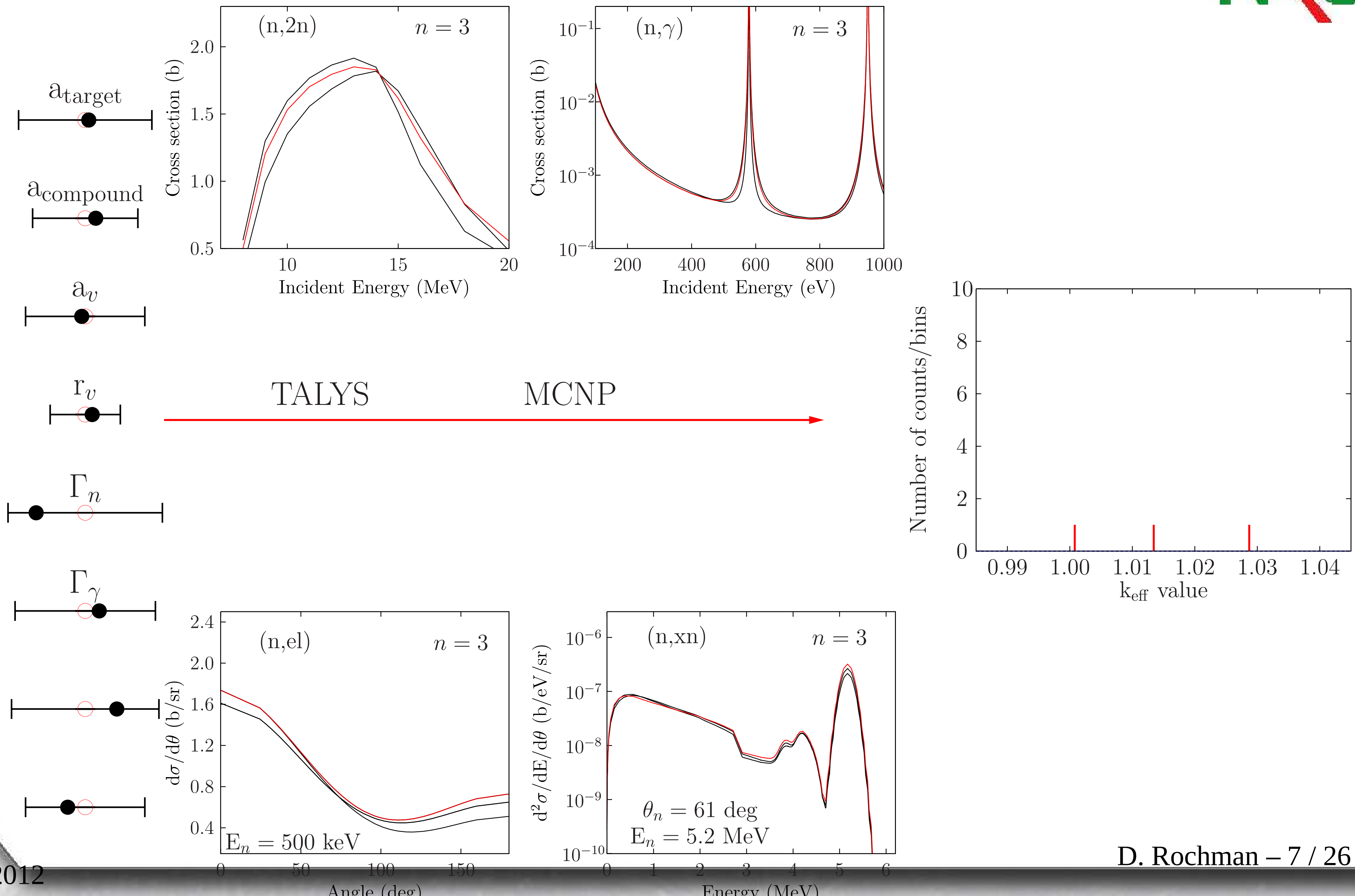

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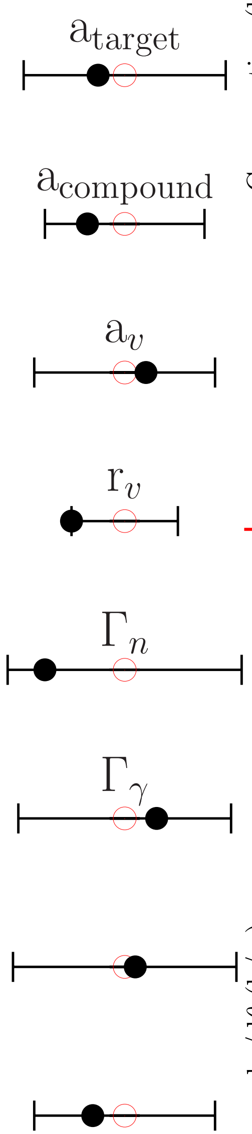

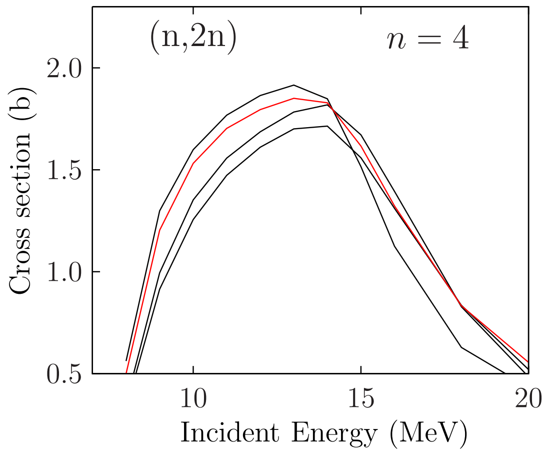

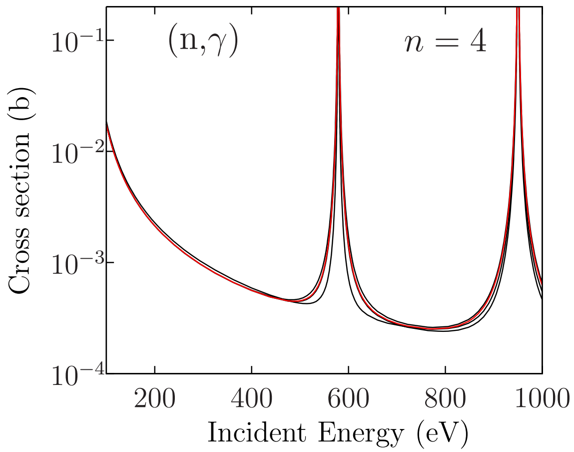

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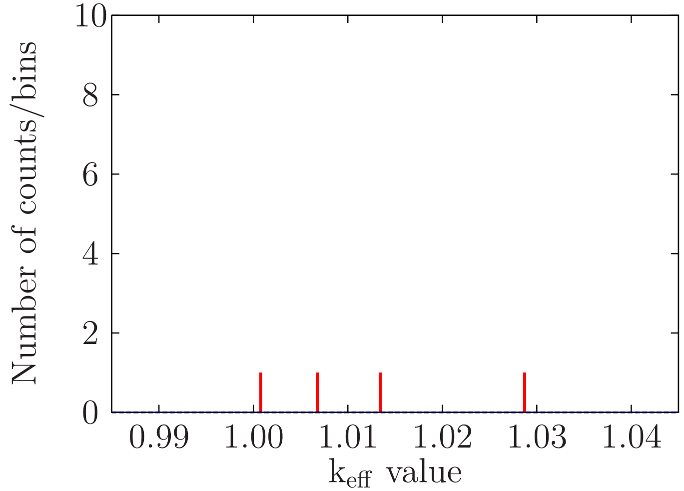

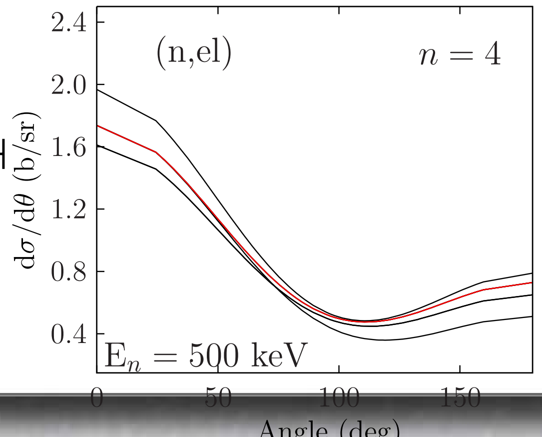

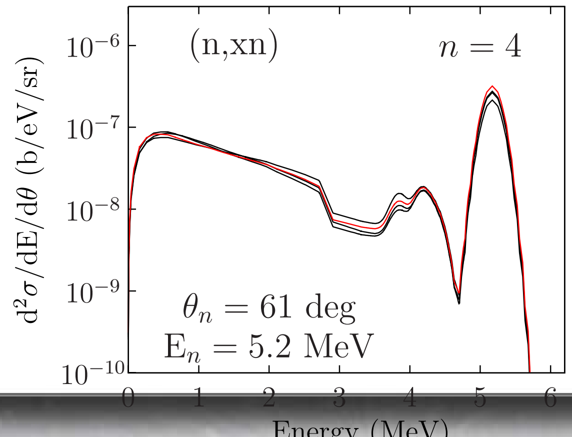

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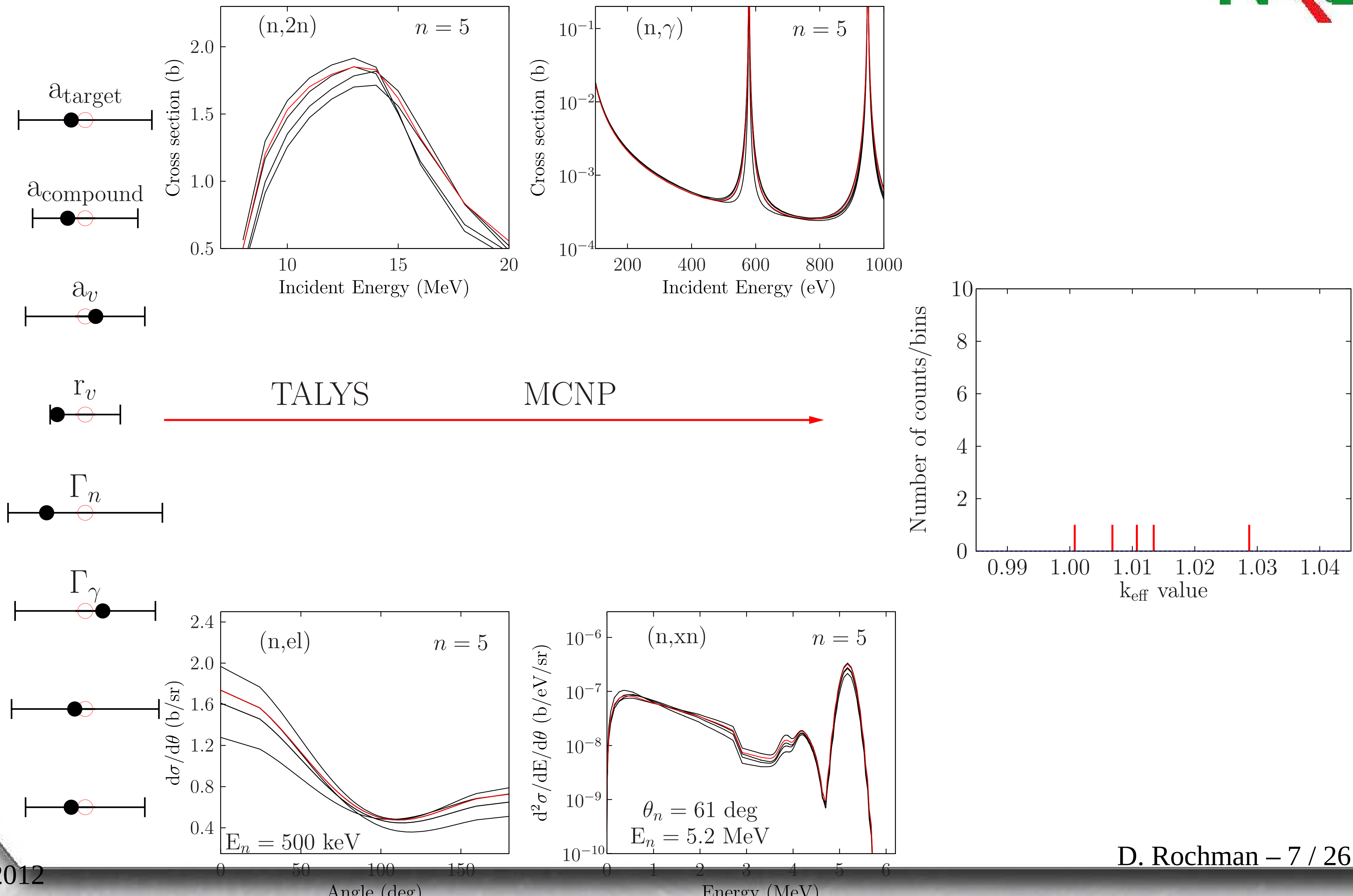

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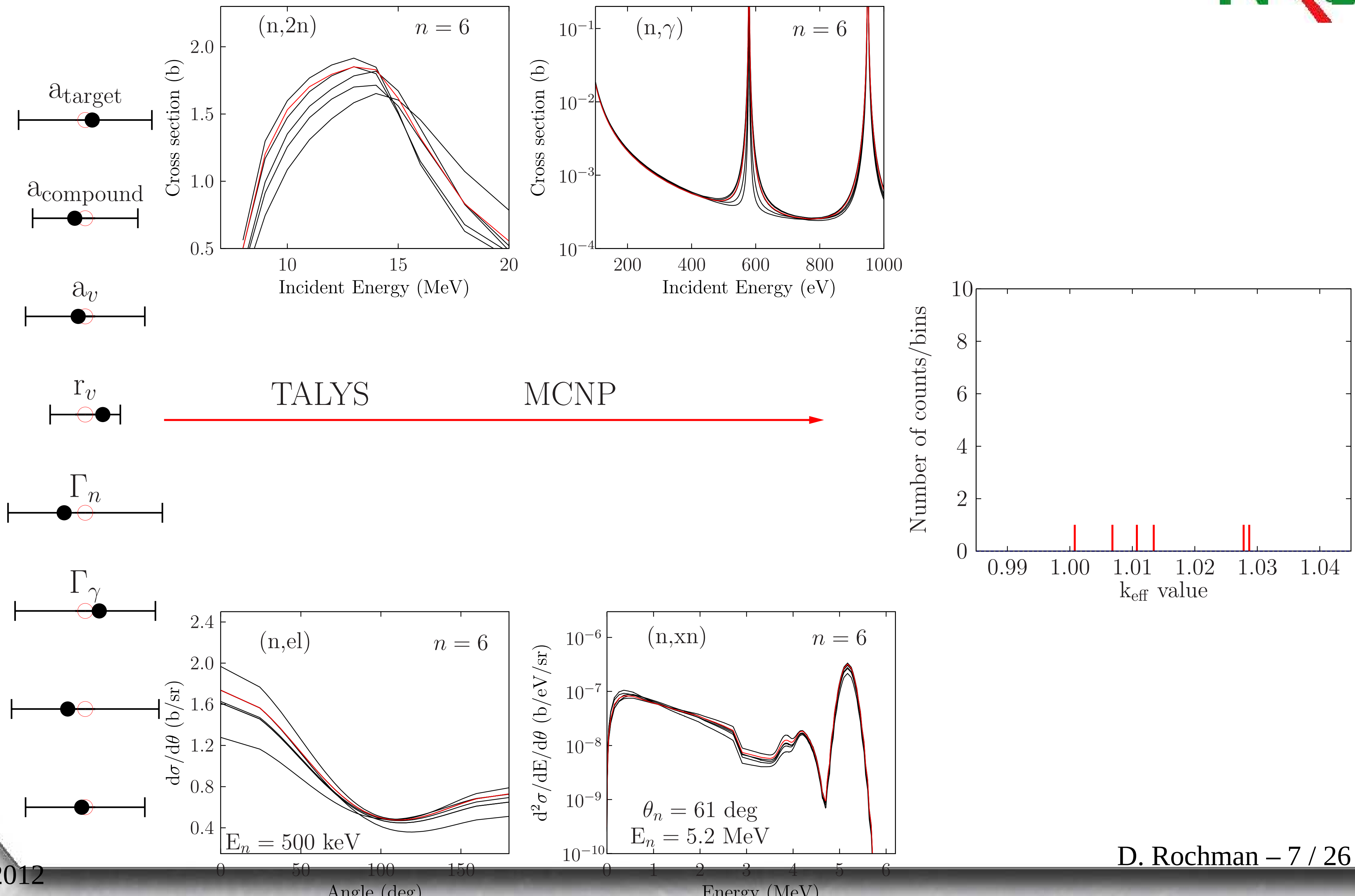

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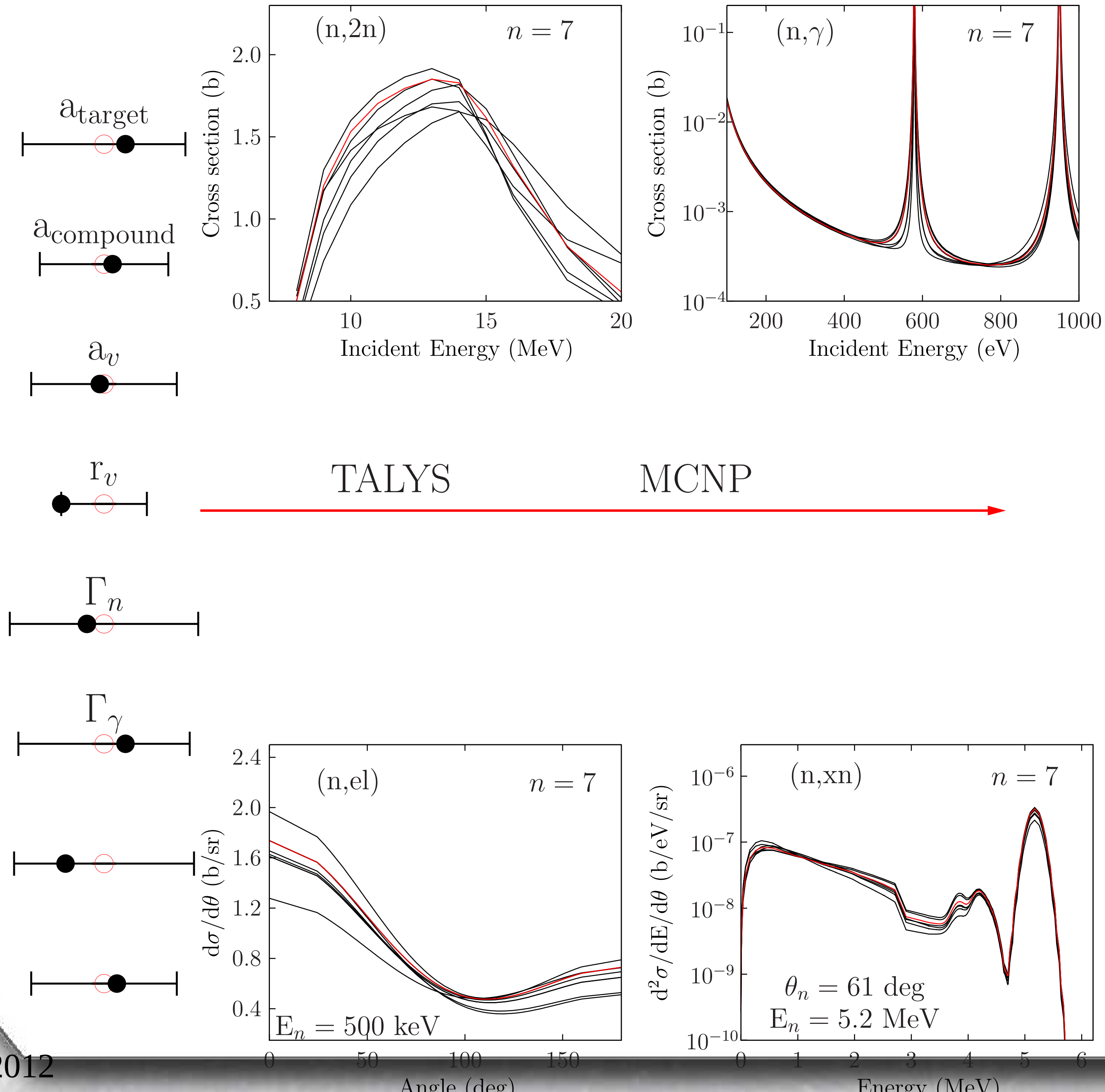

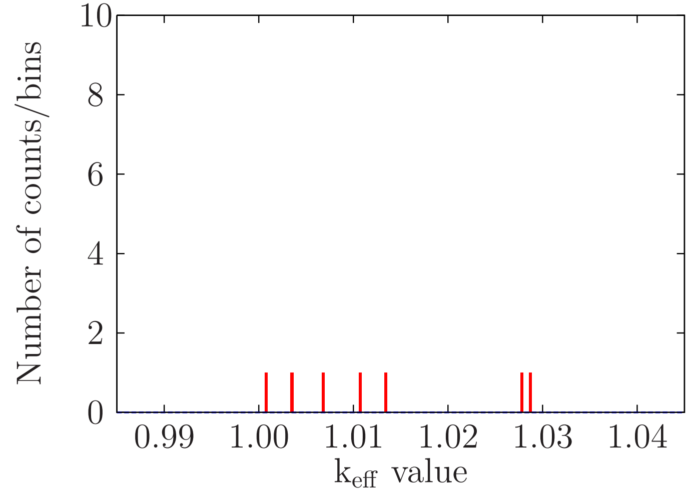

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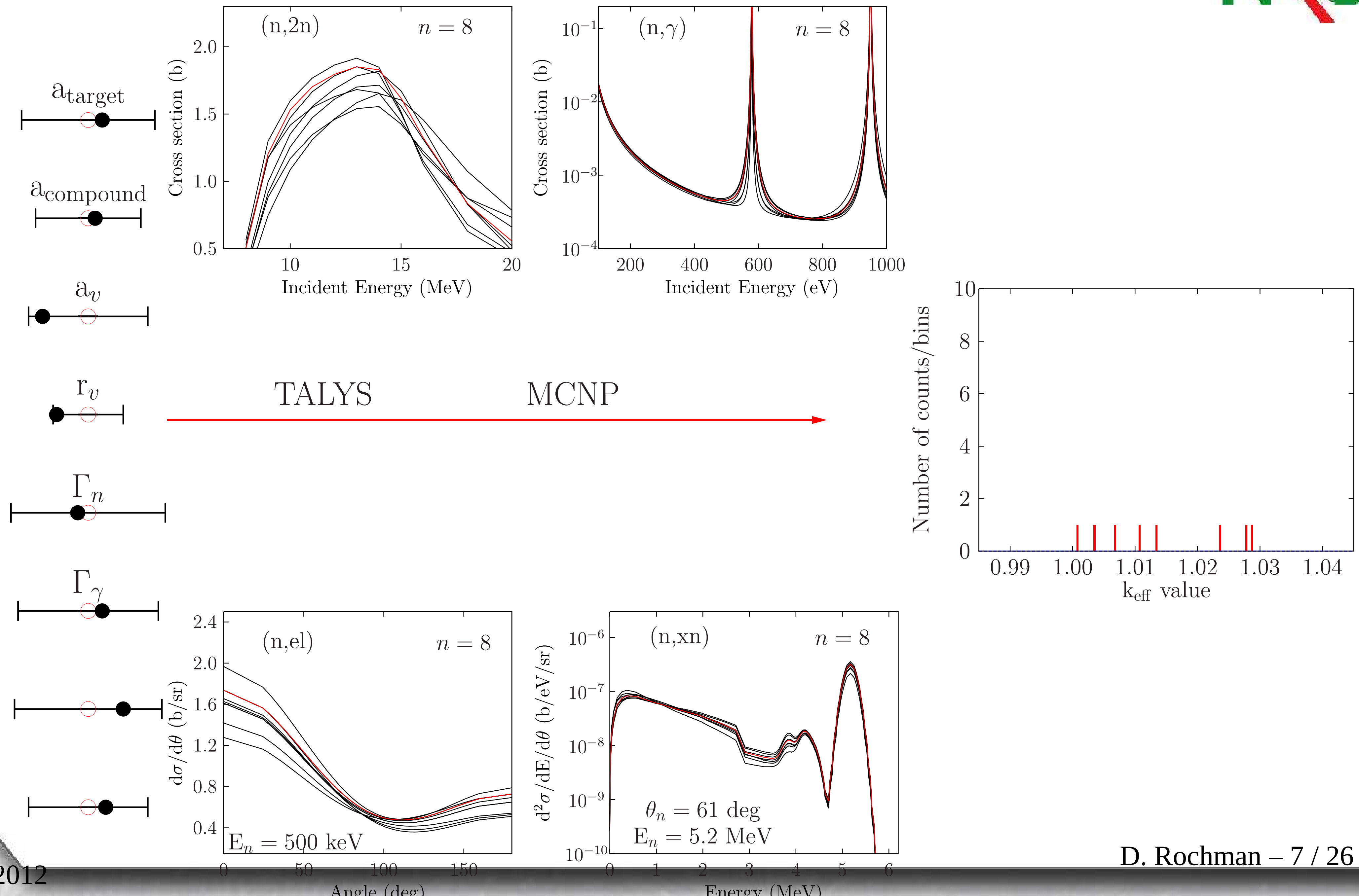

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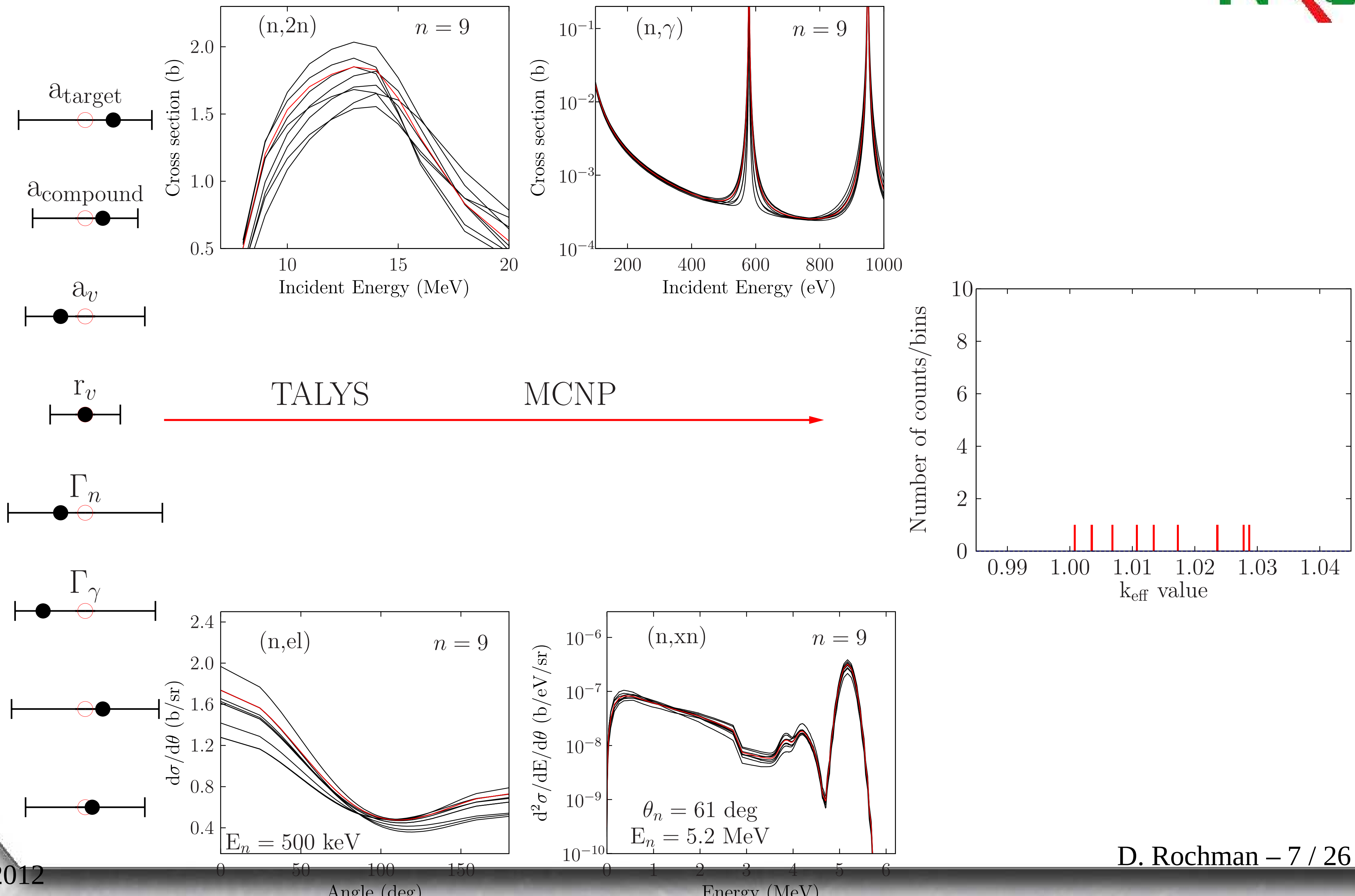

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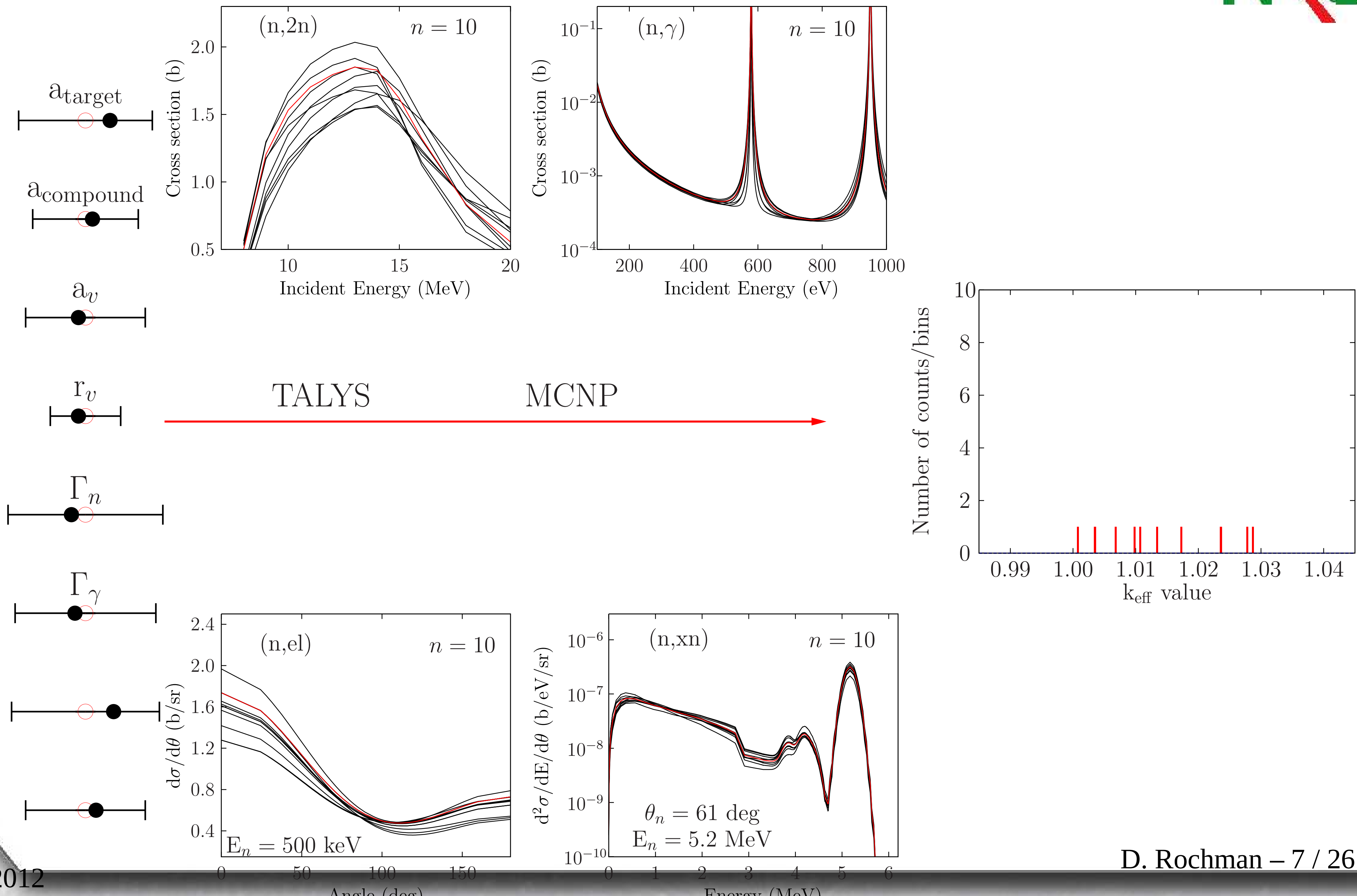

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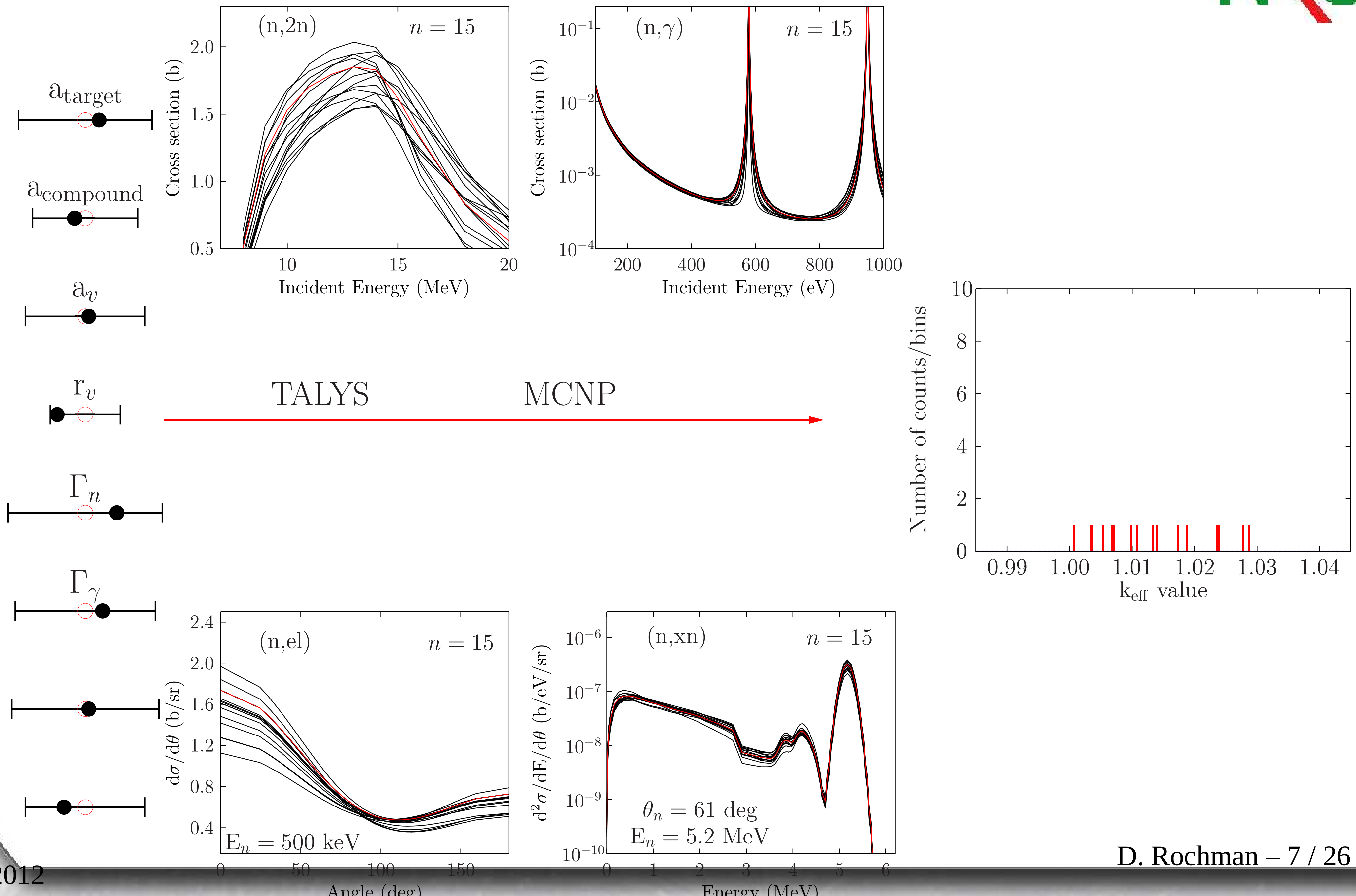

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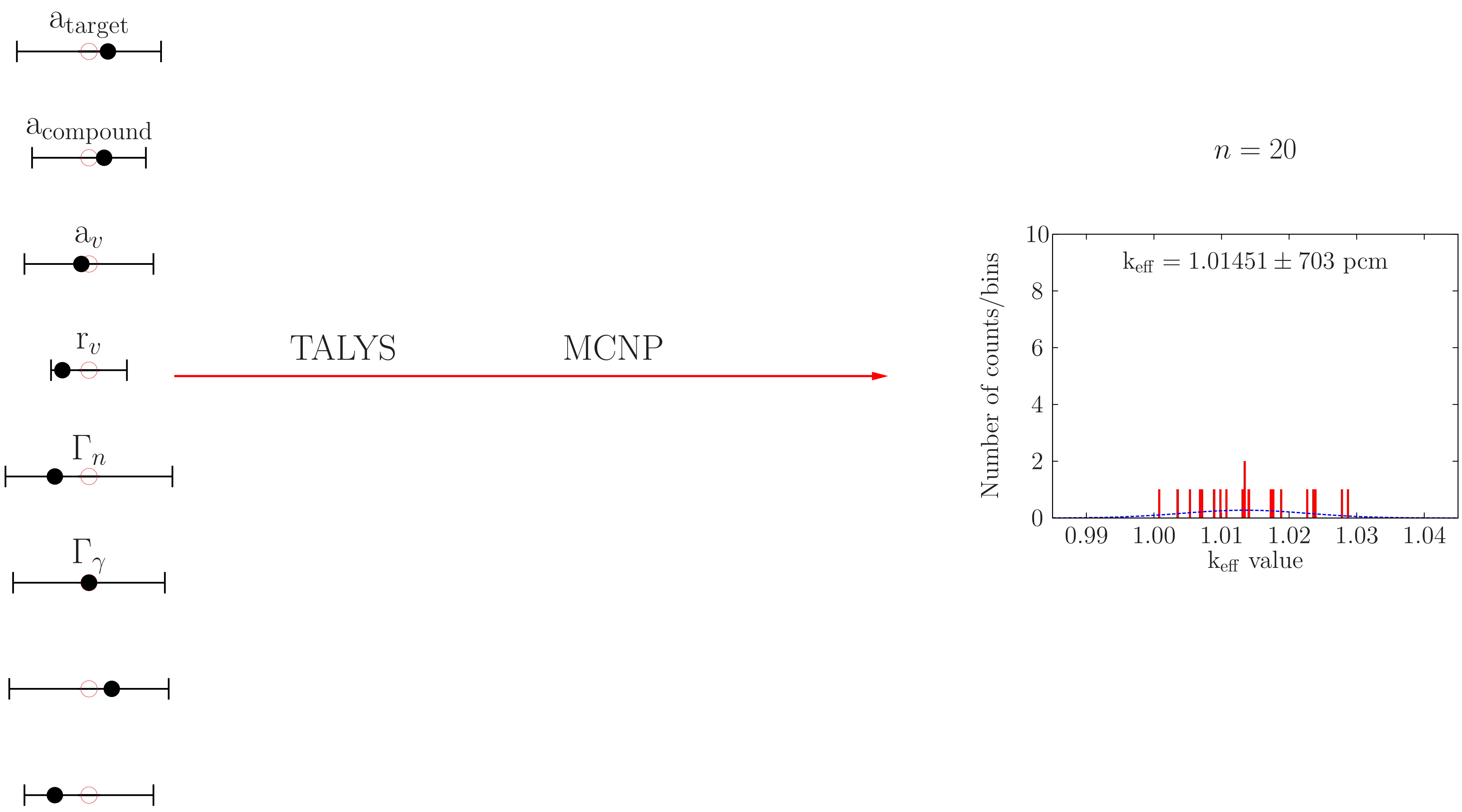

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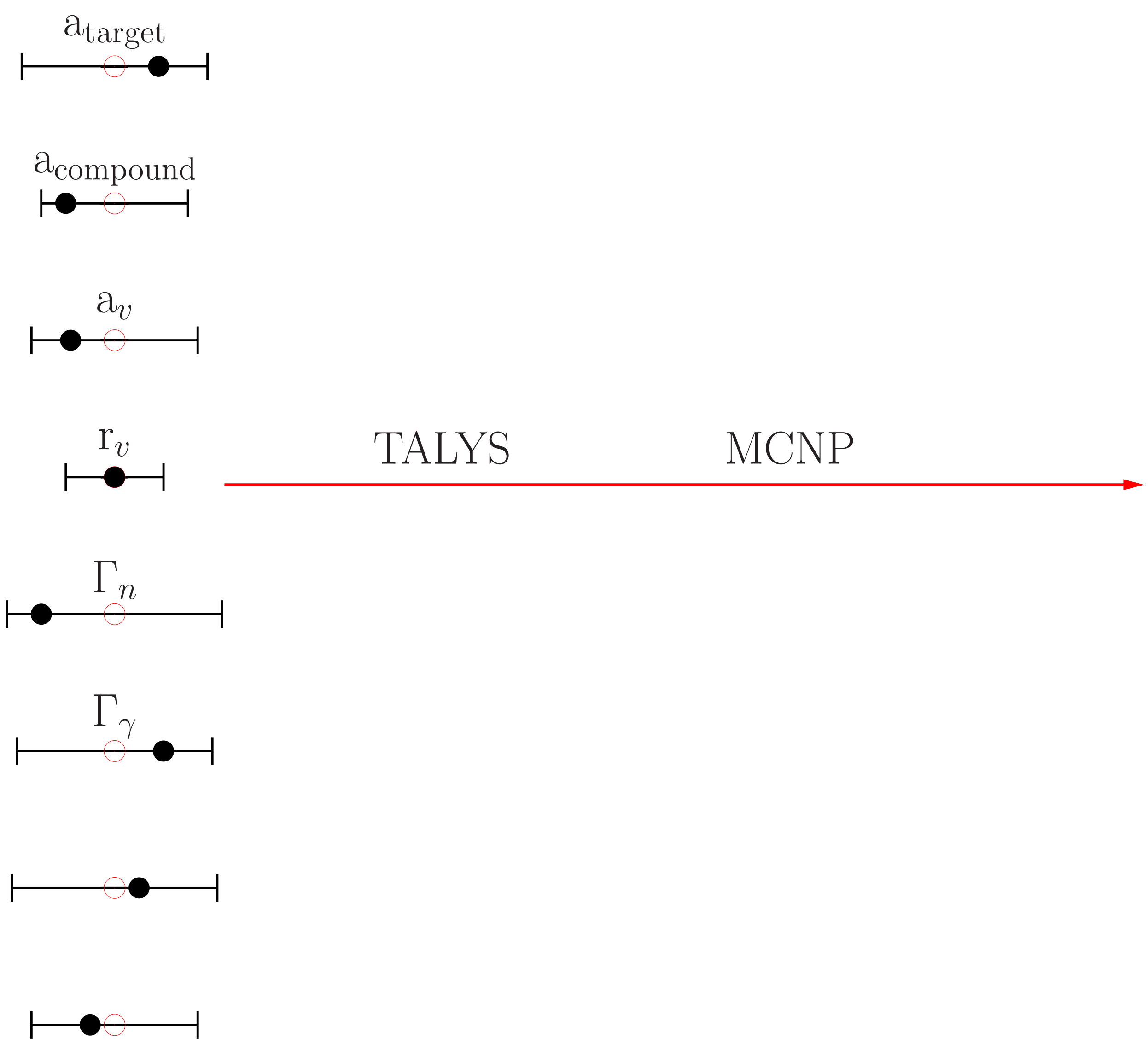
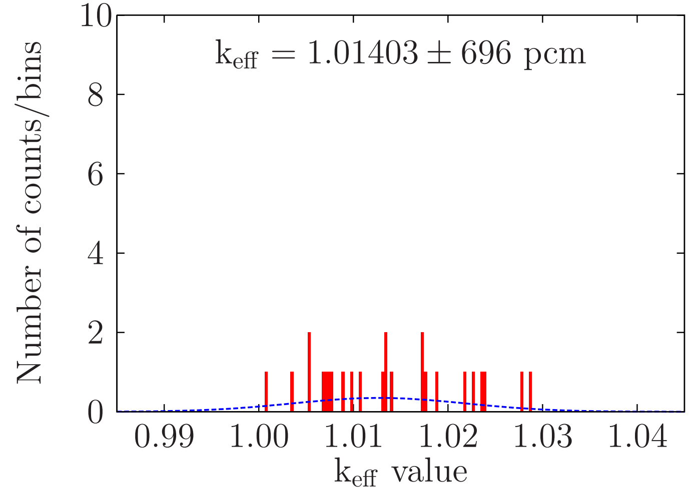


$n = 25$



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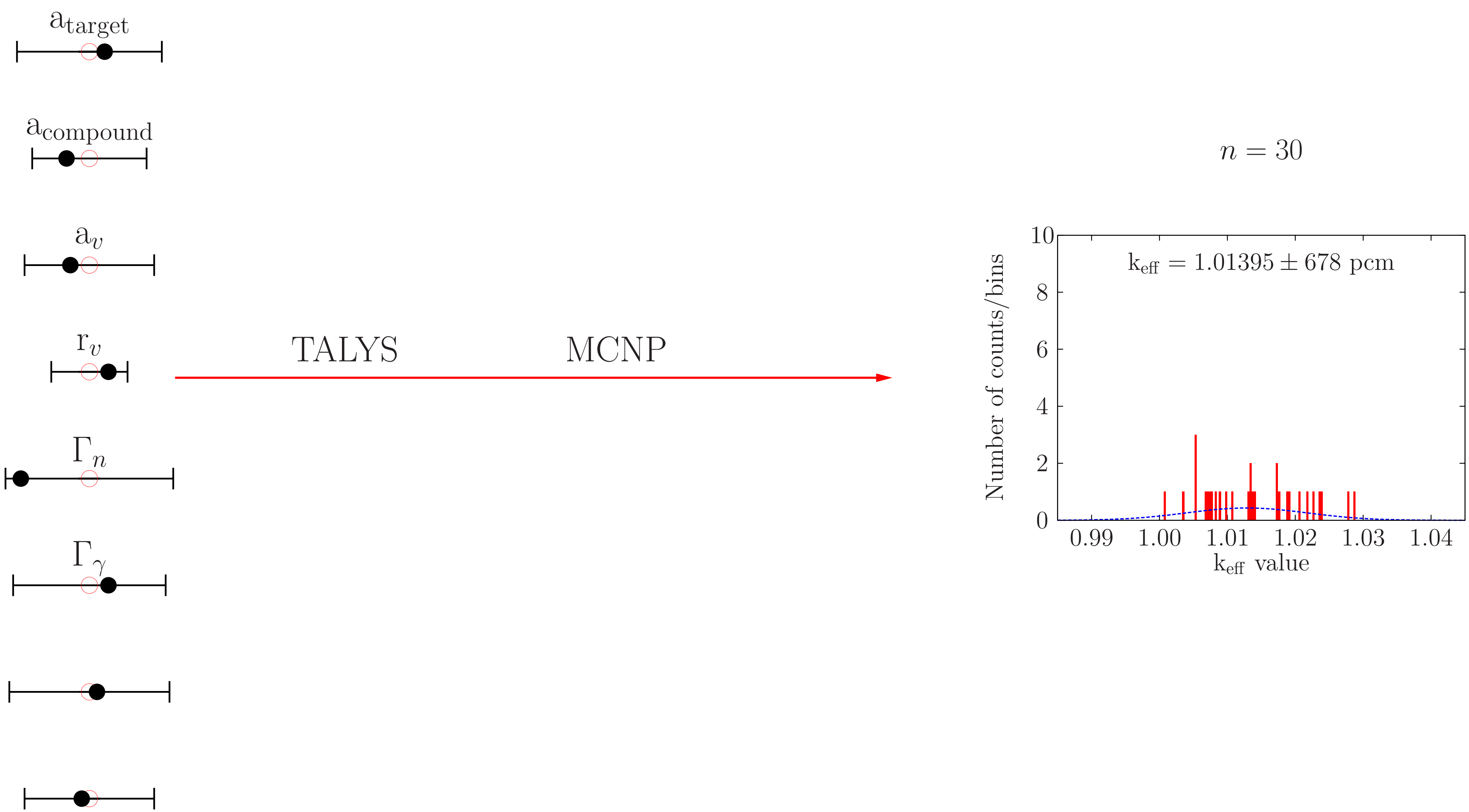

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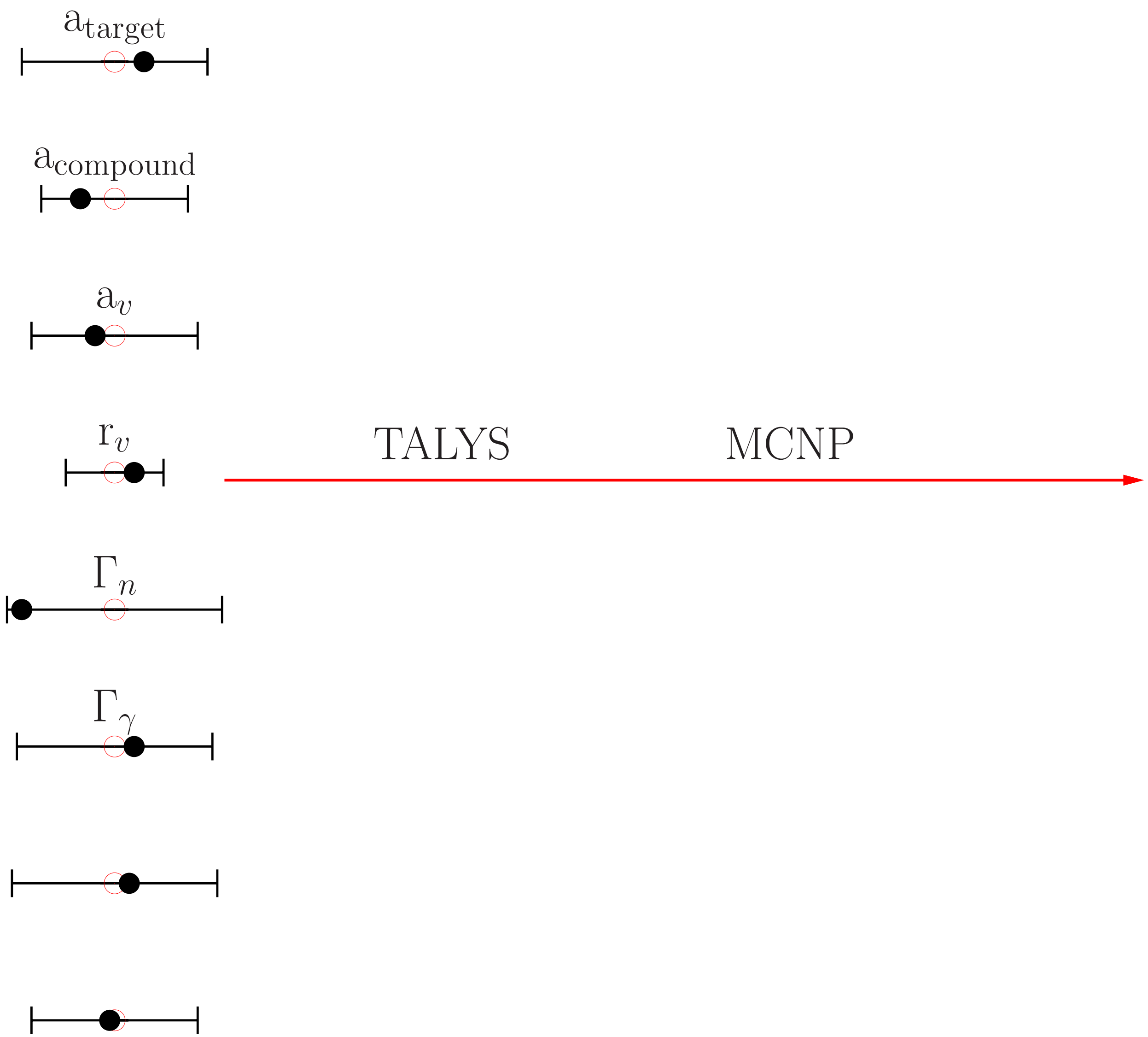

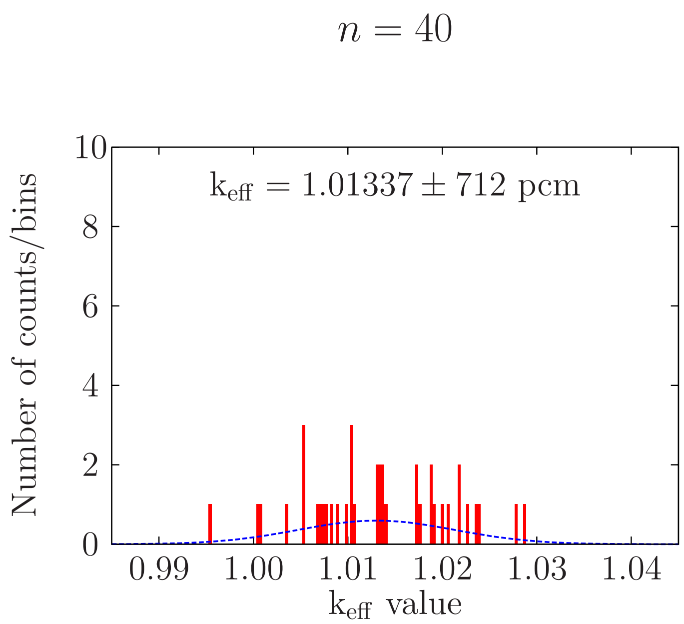

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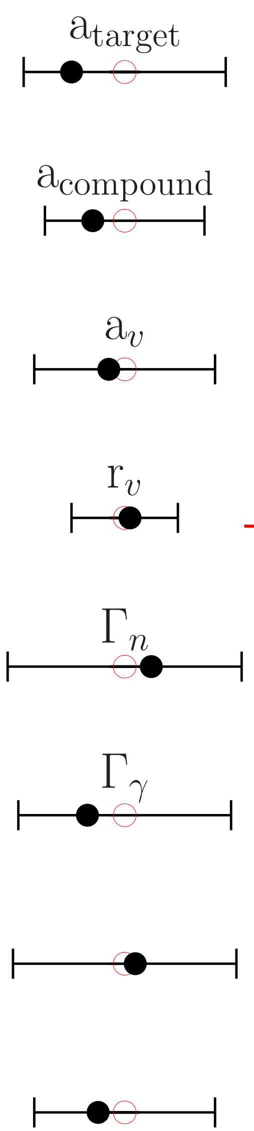
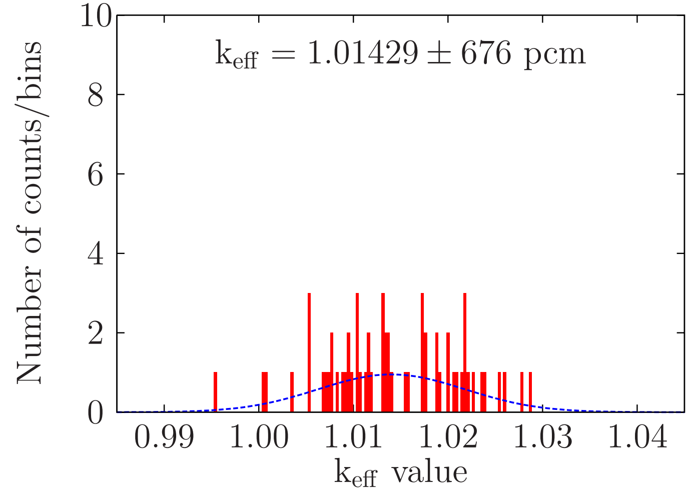


TALYS MCNP

$n = 60$



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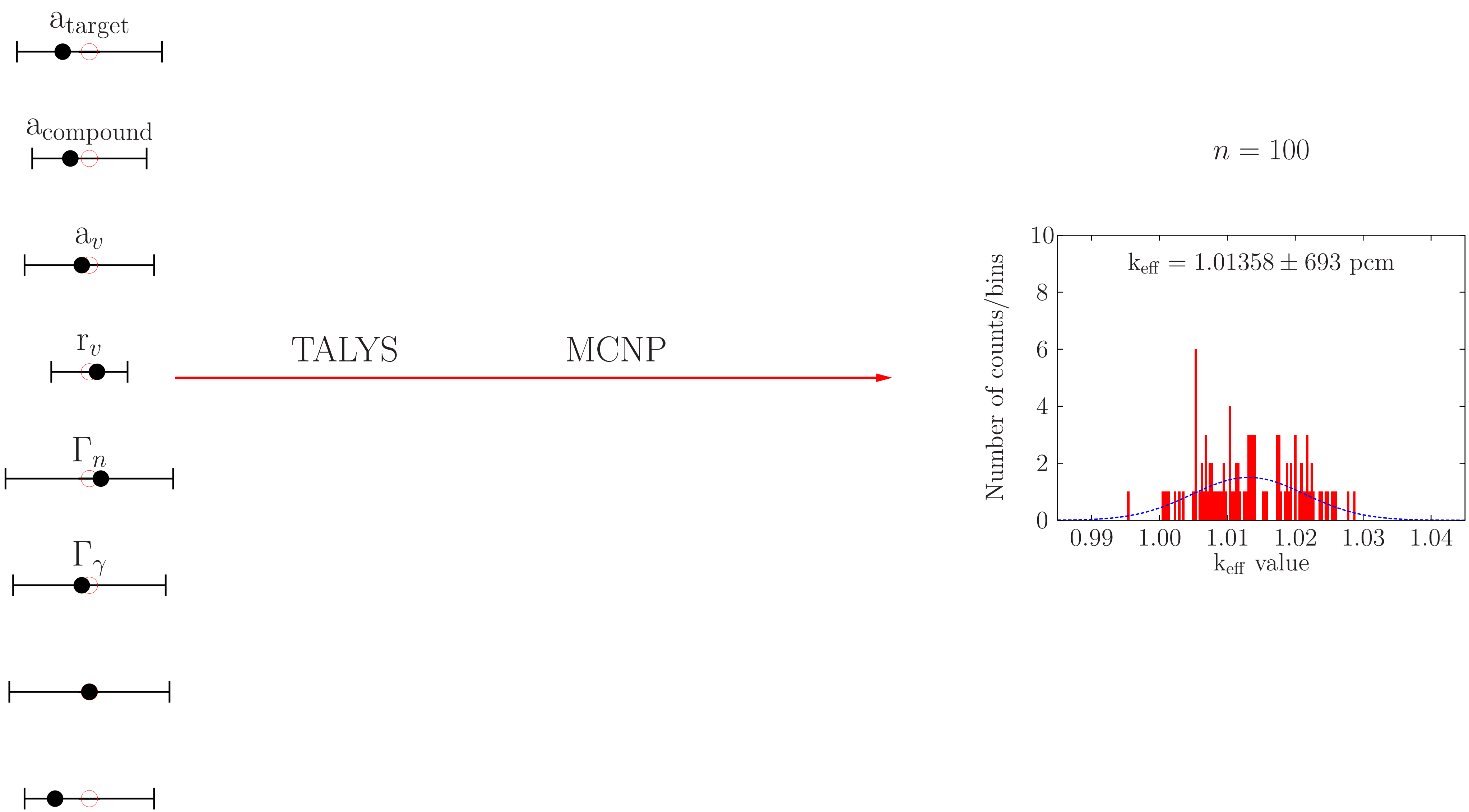

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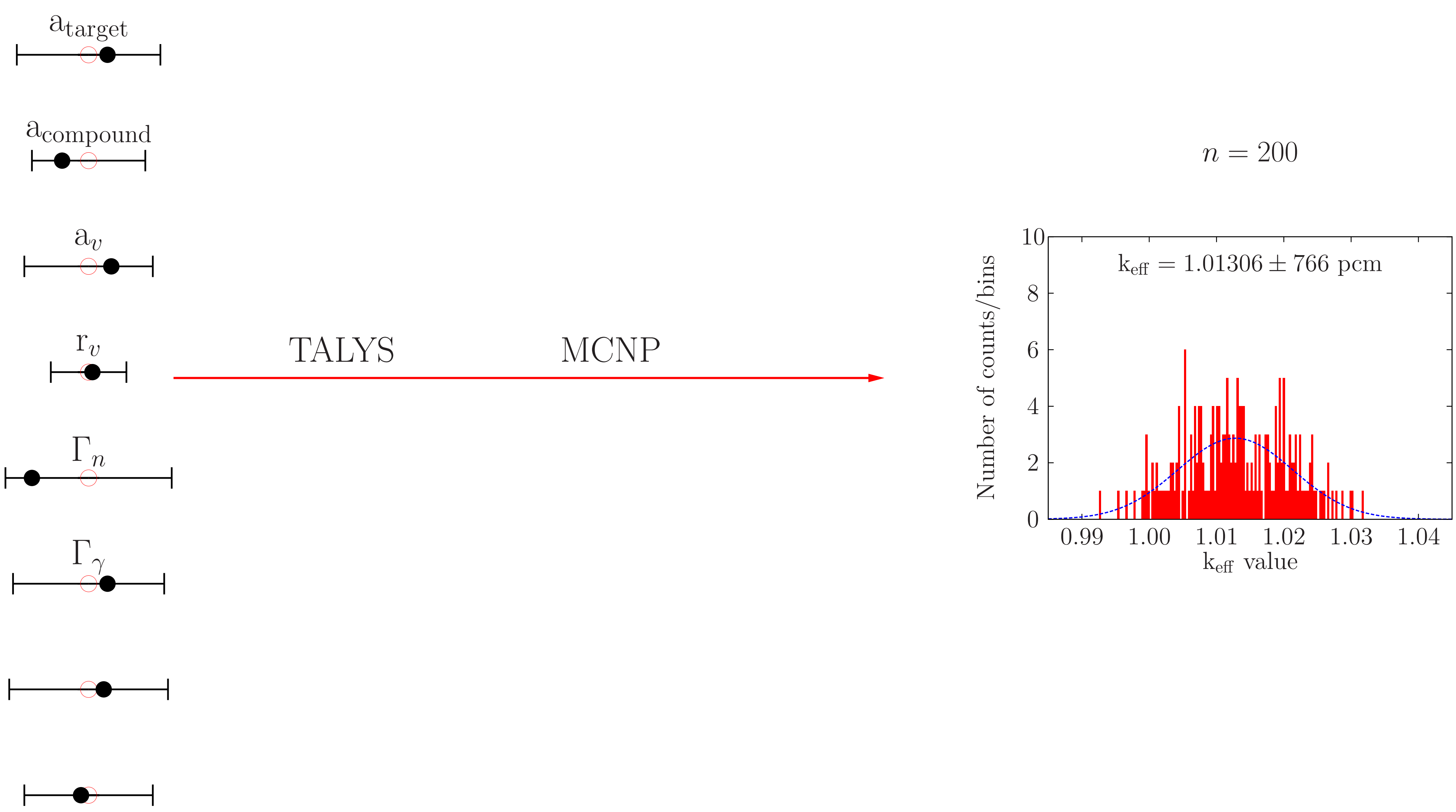

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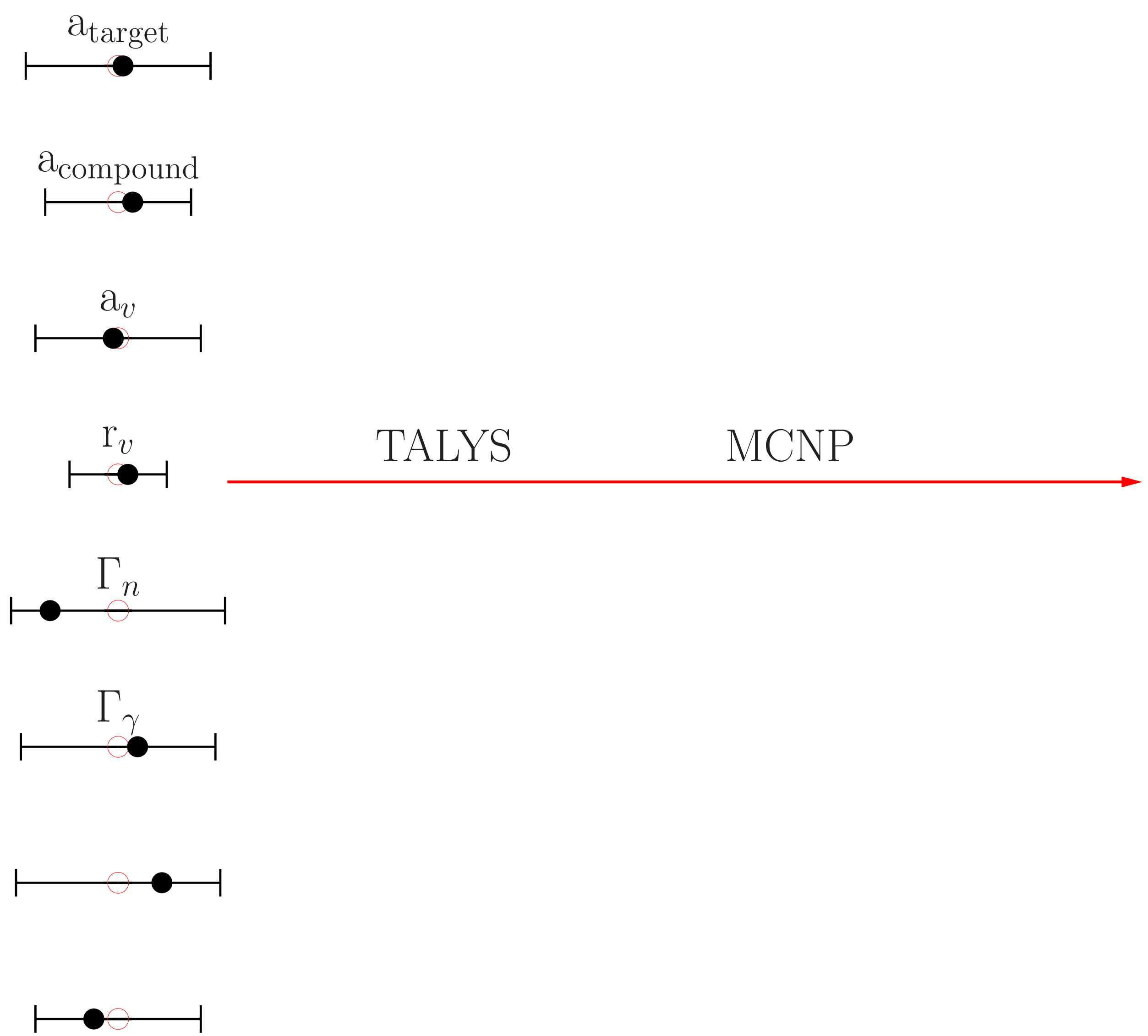
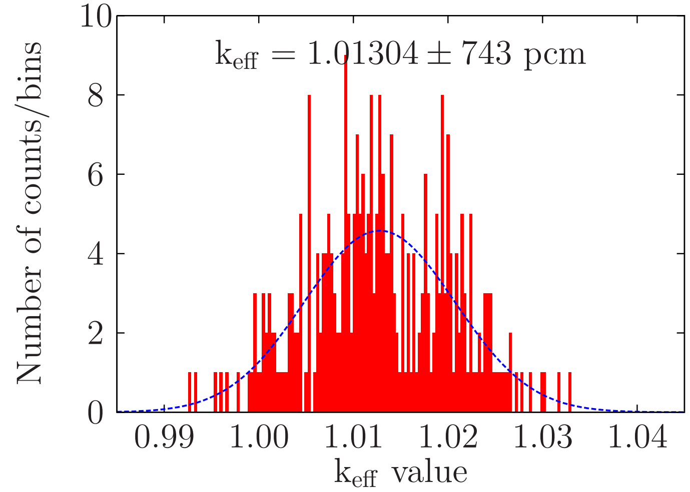


$n = 300$



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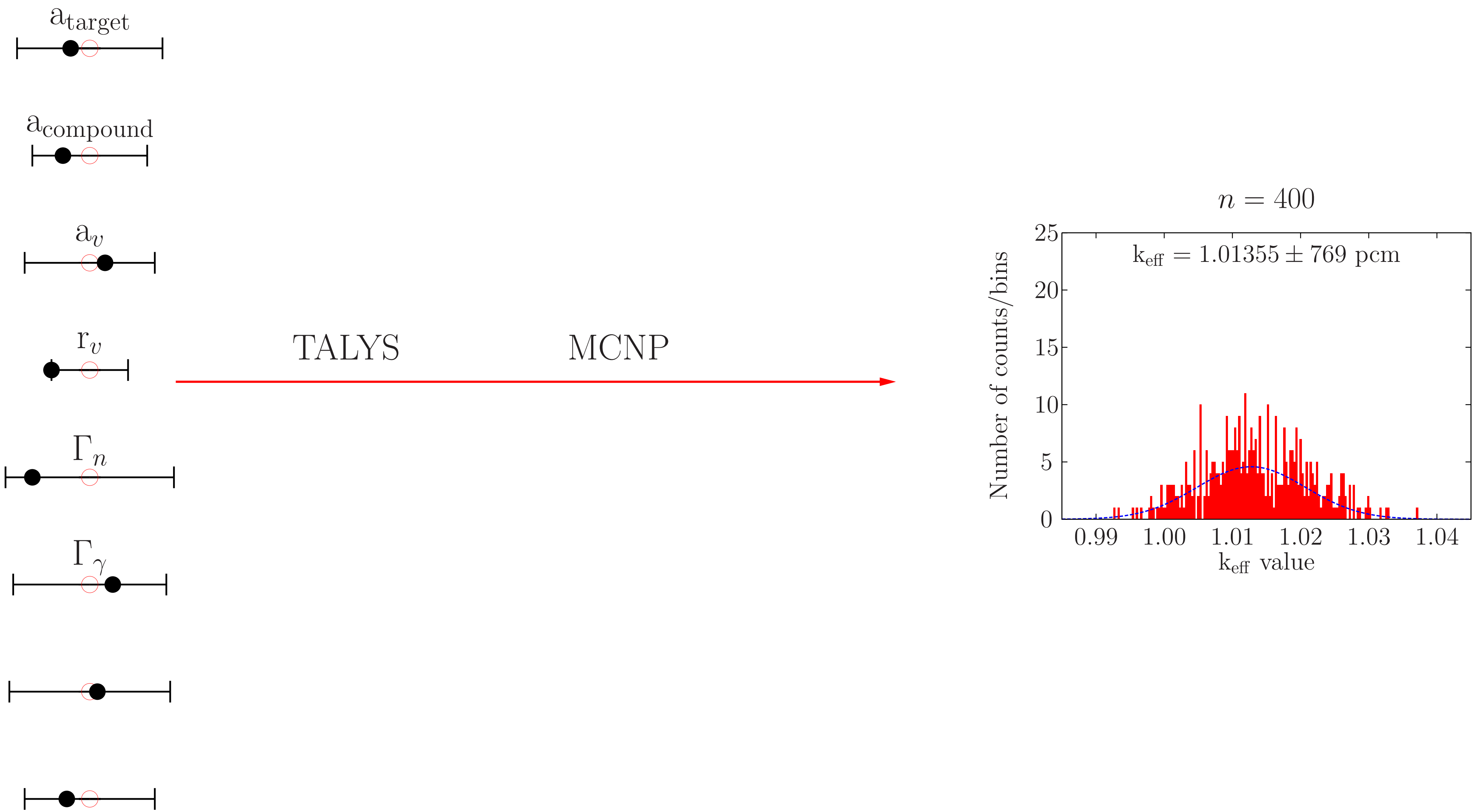

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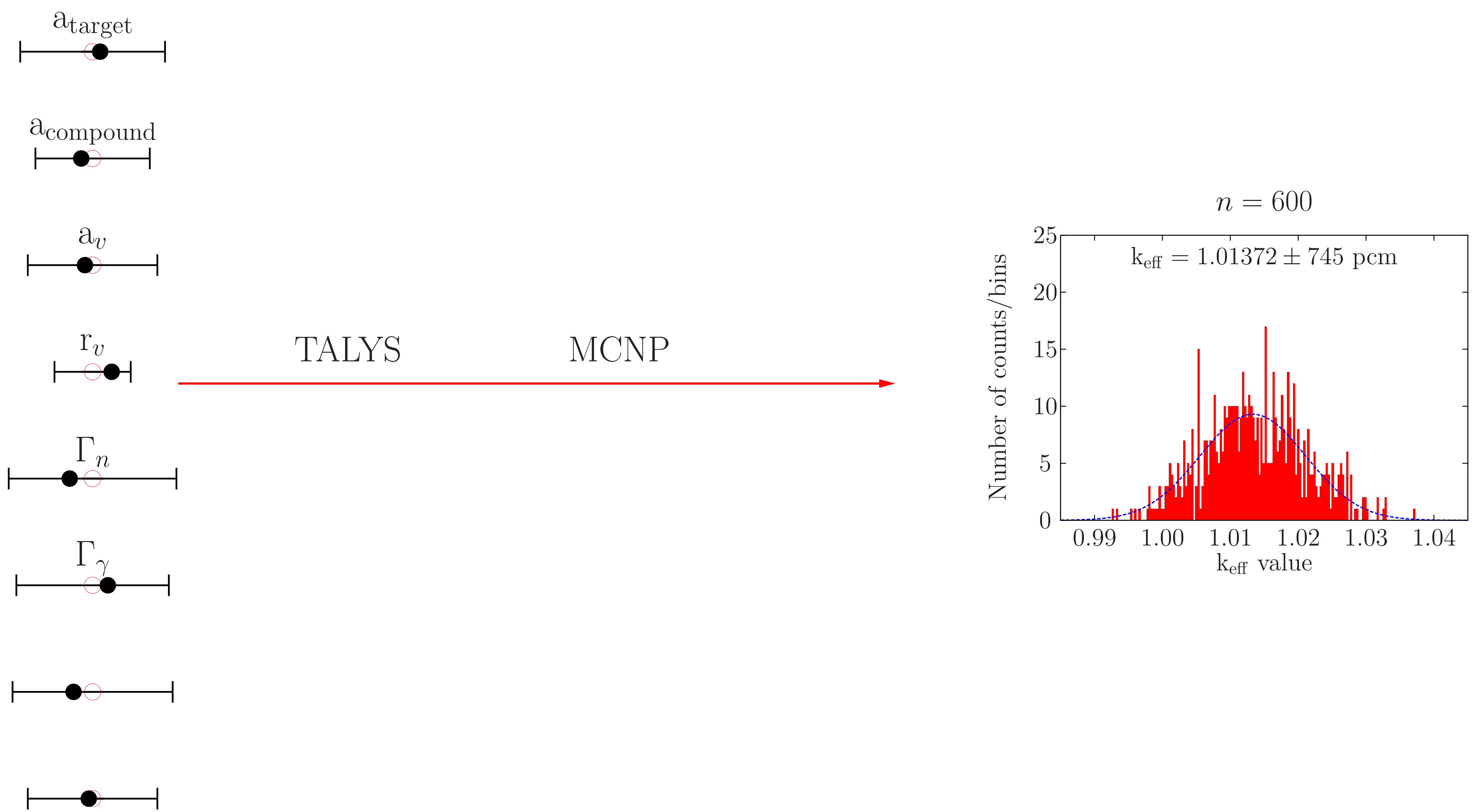

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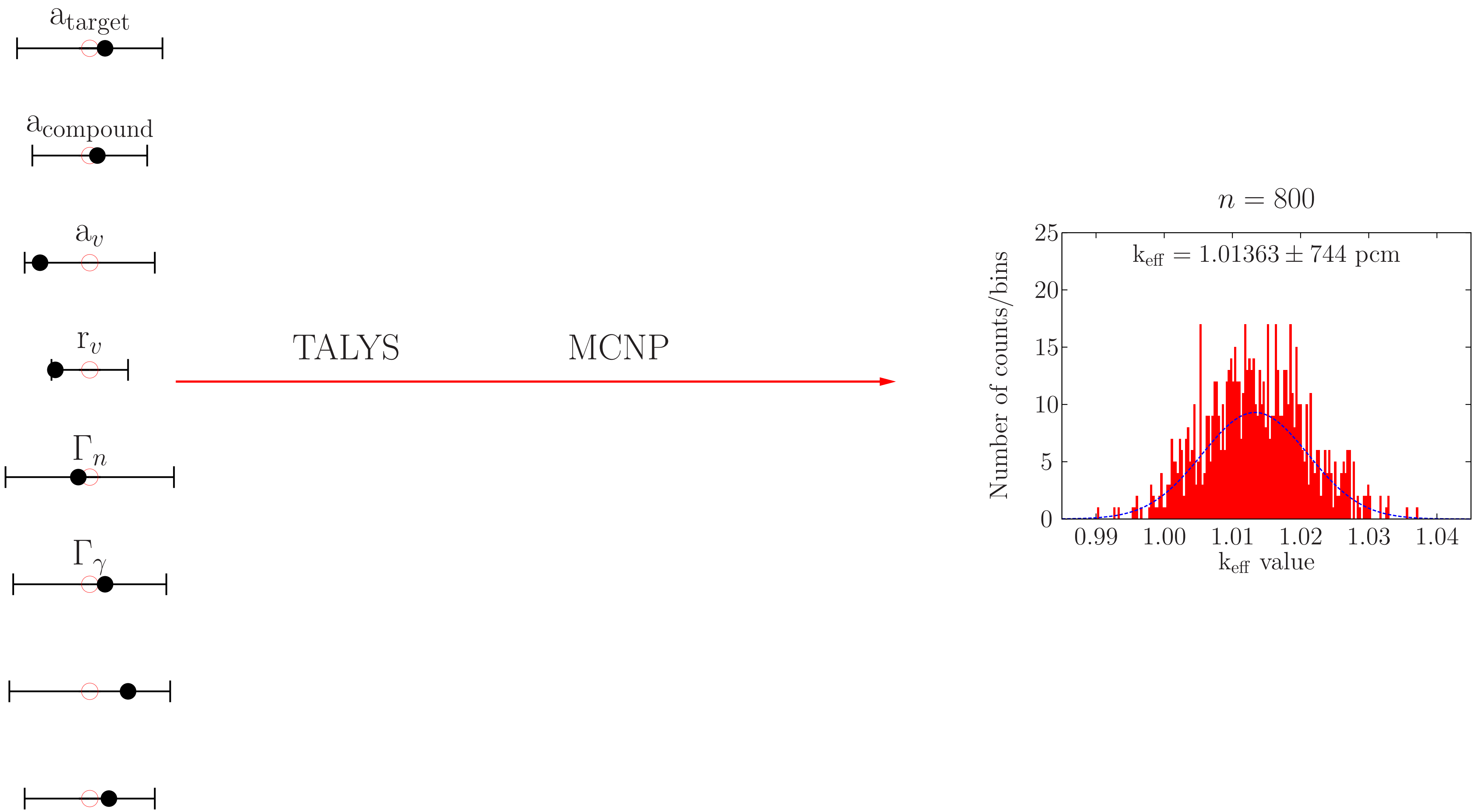

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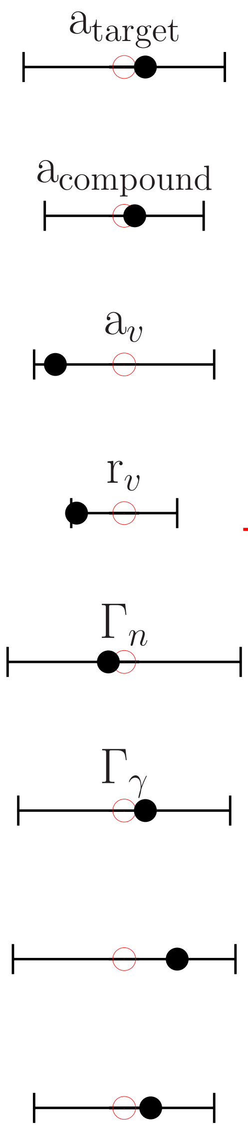
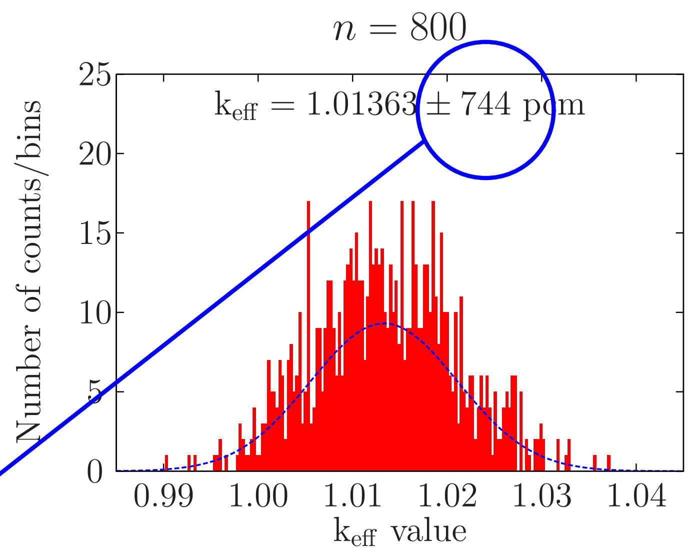


TALYS MCNP



Statistical uncertainty $\simeq$ 68 pcm

$\Longrightarrow$ uncertainty due to nuclear data $\simeq$ 740 pcm

New (and most simple) path

5000 random Talys parameter sets 5000 random resonance parameter sets

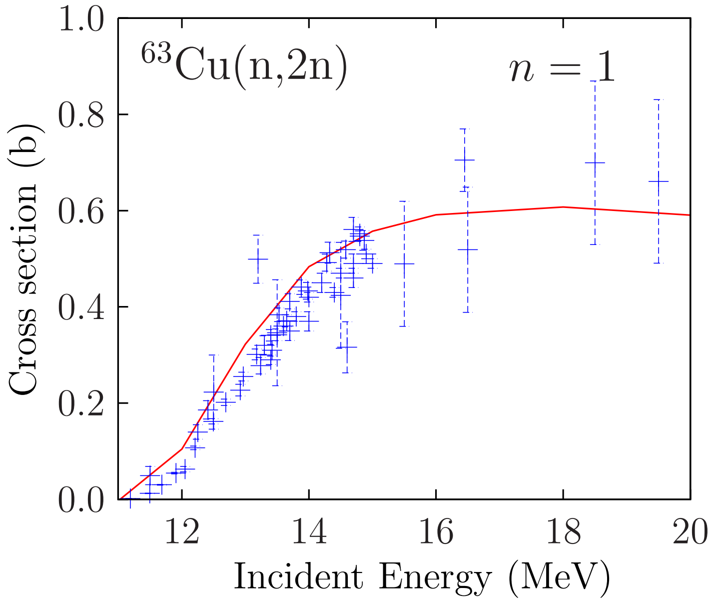
Average to get full covariance matrix MF-31,32,33,34,35

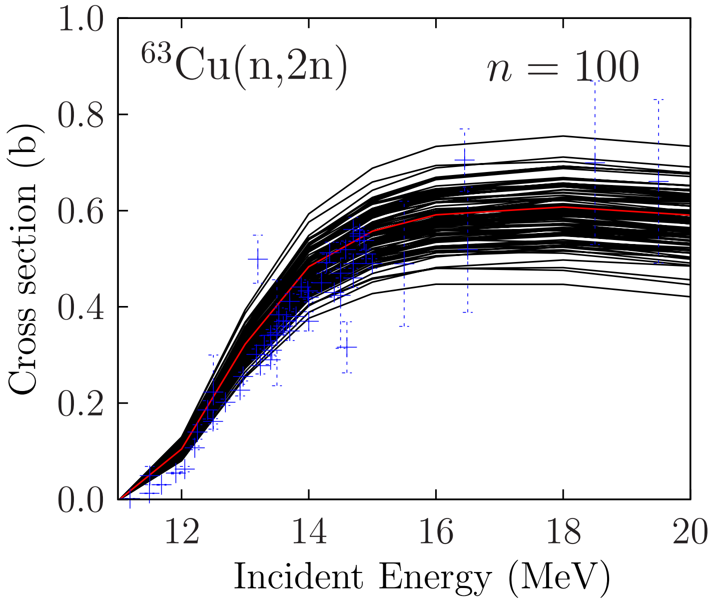
5000 random ENDF-6 files
NJOY $\longrightarrow$ 5000 ACE files
5000 MCNP calcs for the same case

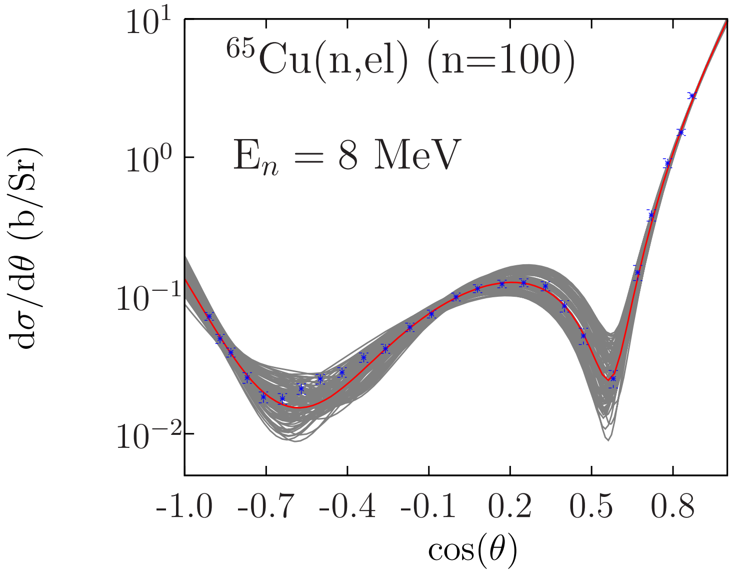
Other groups have developed variants: AREVA (NUDUNA), GRS (XSUSA), CIEMAT (ACAB) and PSI, based on covariance files.

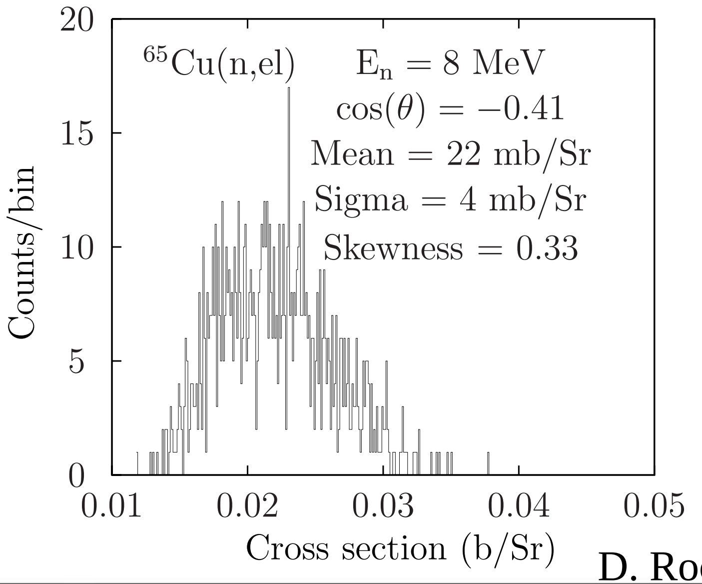
No covariances for fission yields, thermal scattering, pseudo-fission products, branching ratios, DDX, γ-production ...

Examples with ^{63}Cu(n,2n) and ^{65}Cu(n,el)

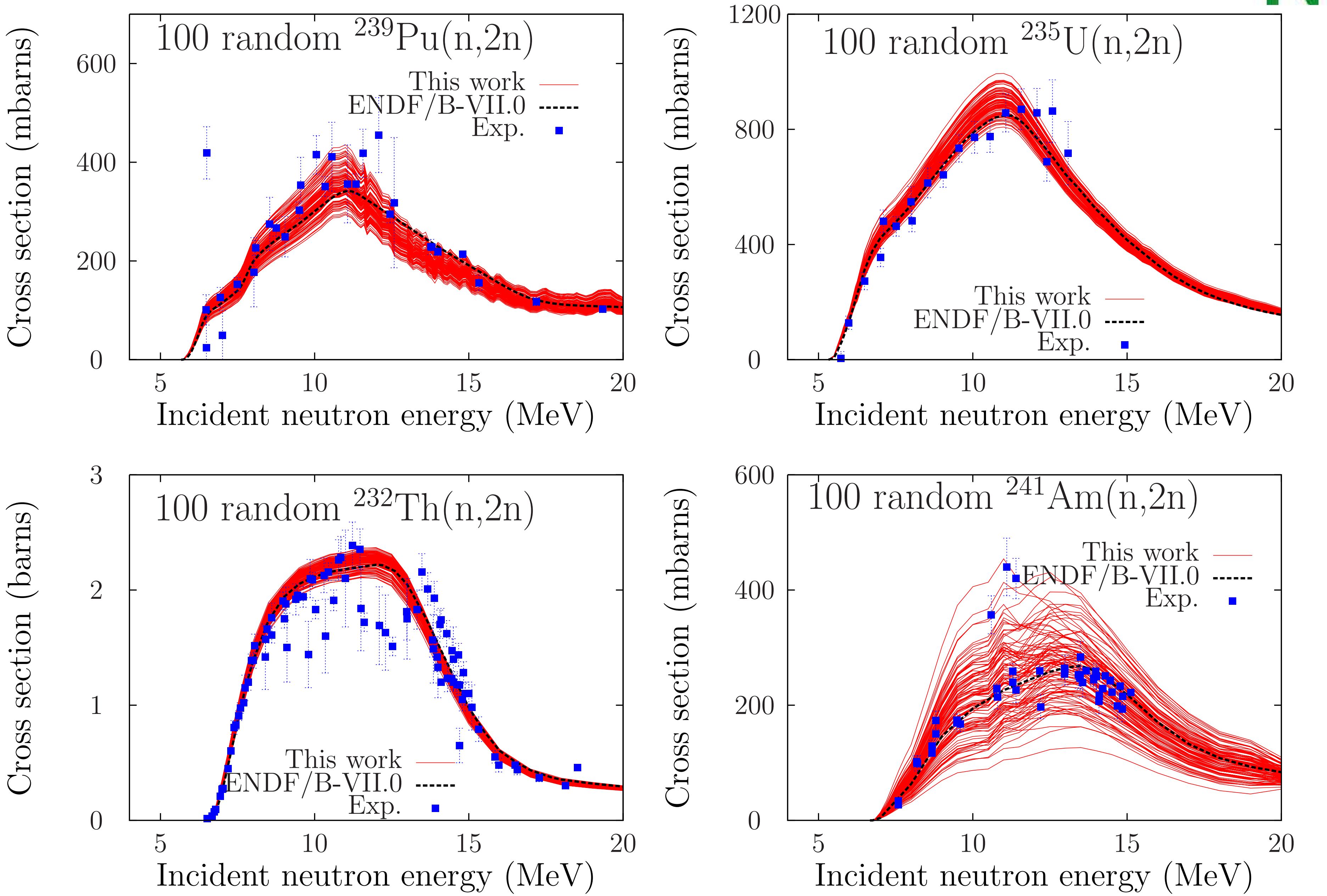




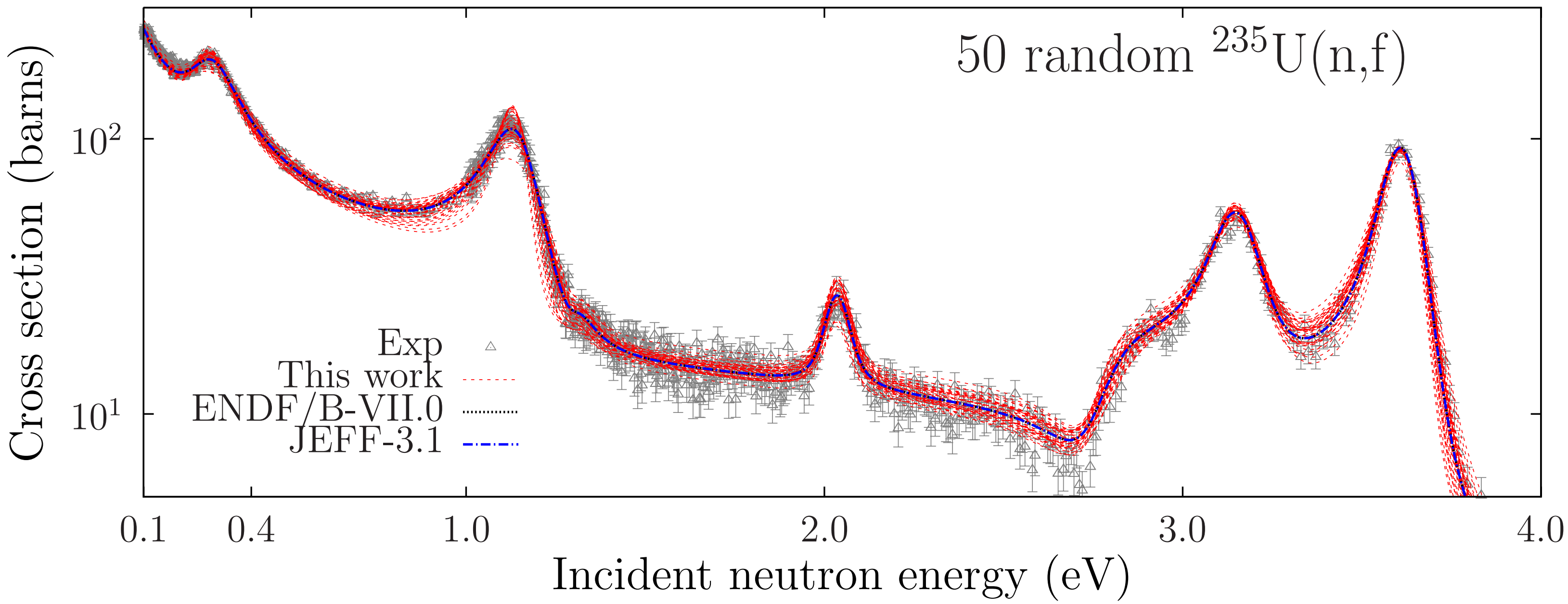


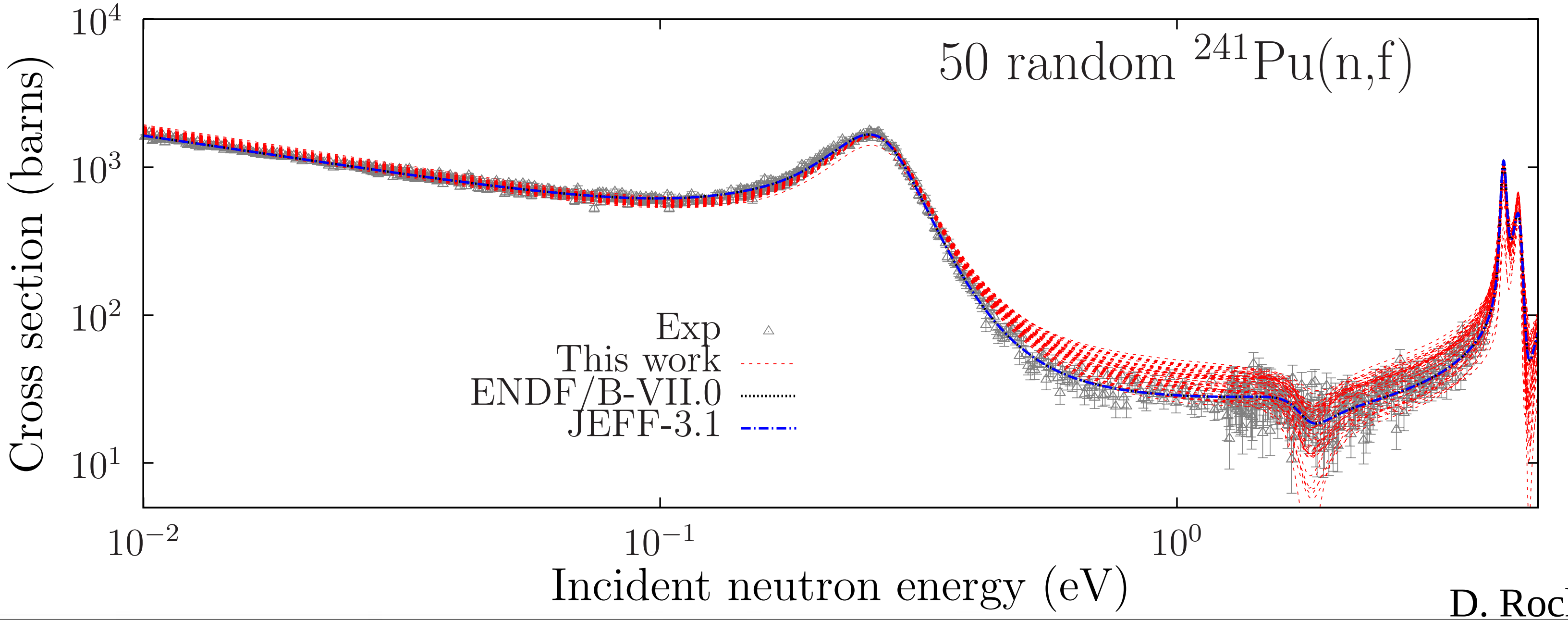


Nuclear data: examples on (n,2n) cross sections

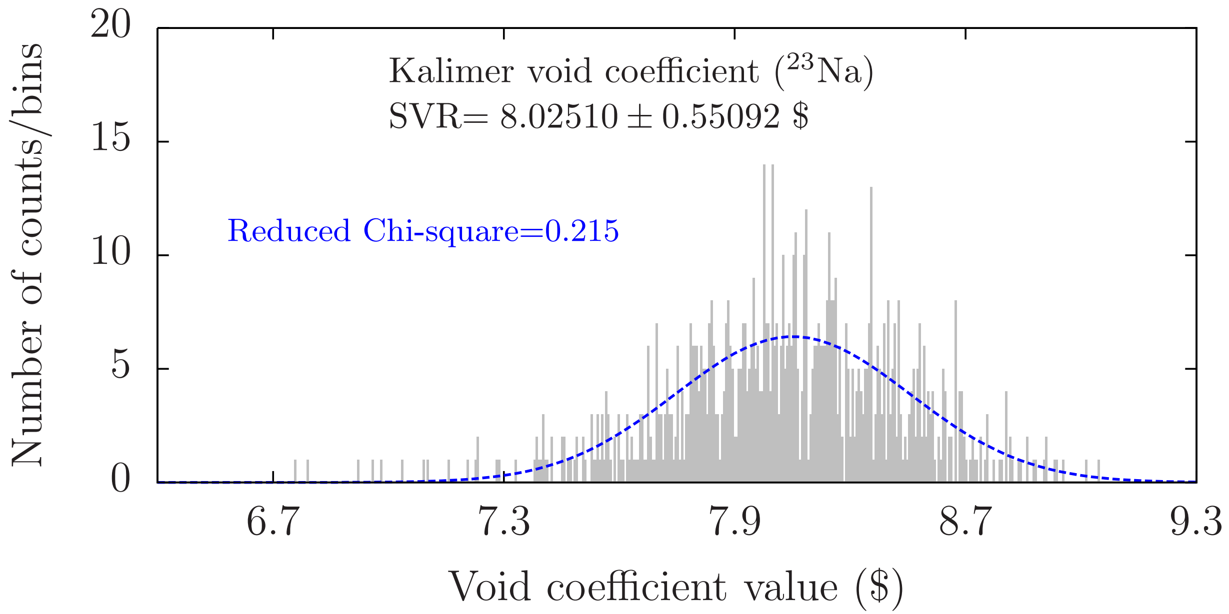


Nuclear data: examples in the resonance region



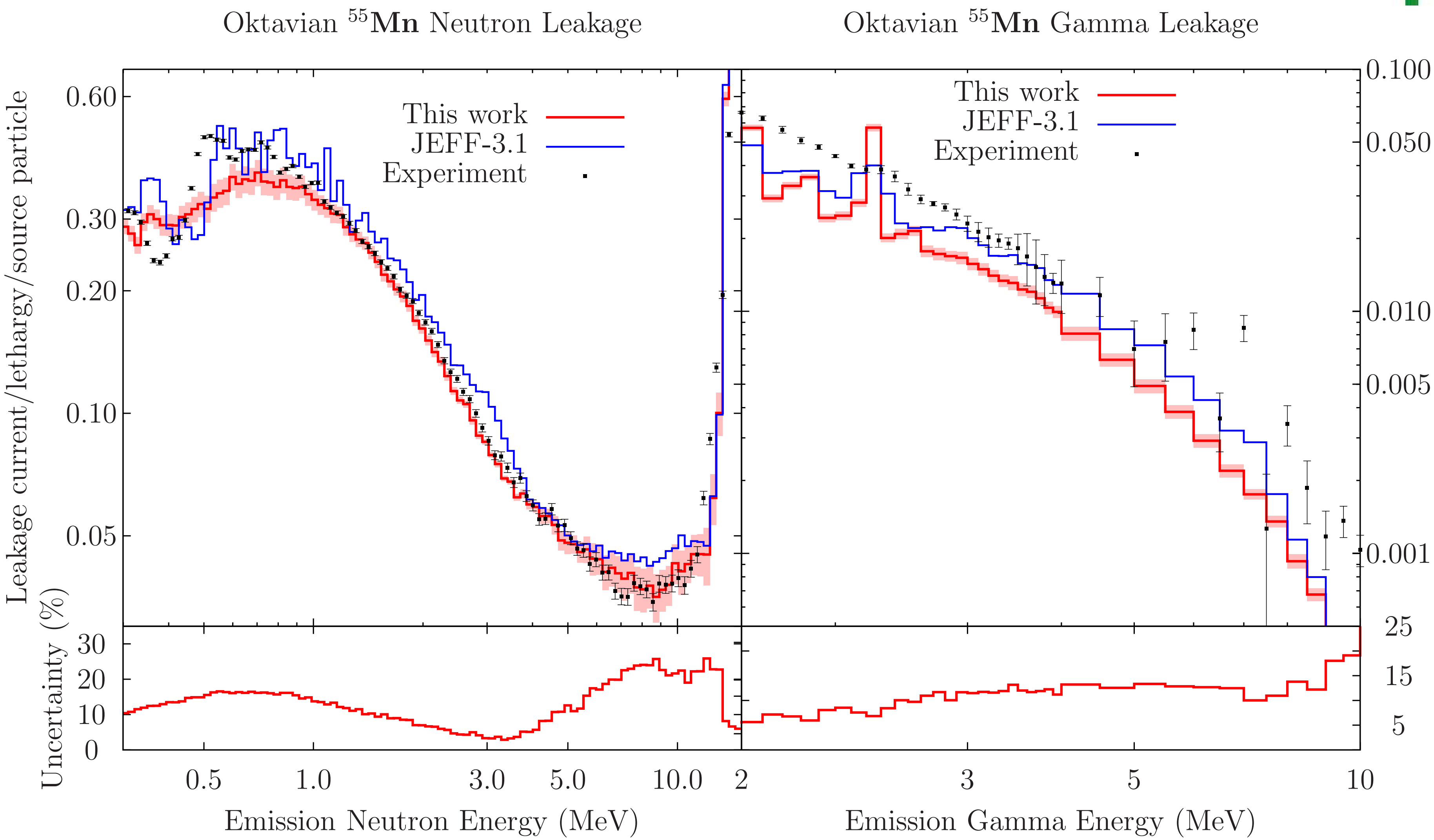


Application: TMC applied to a SFR void coefficient

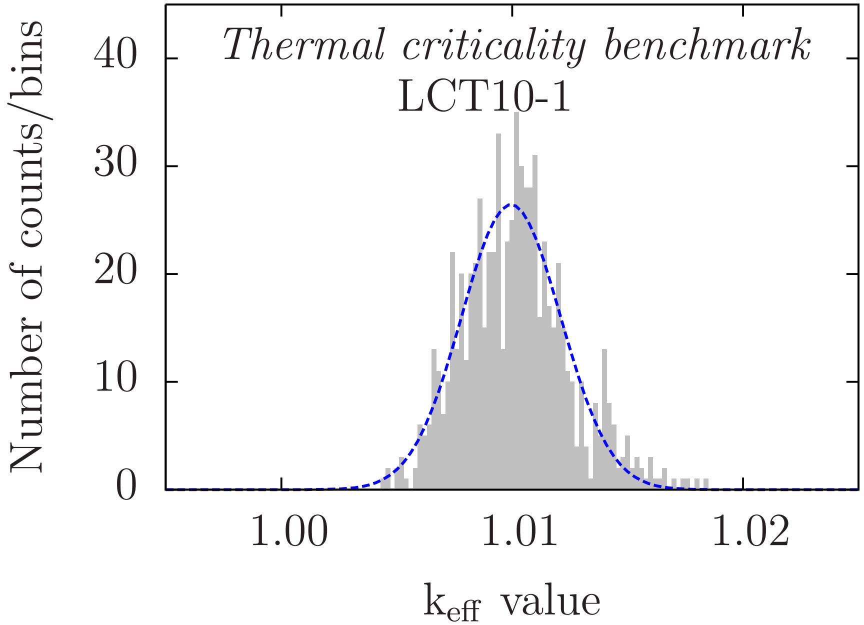


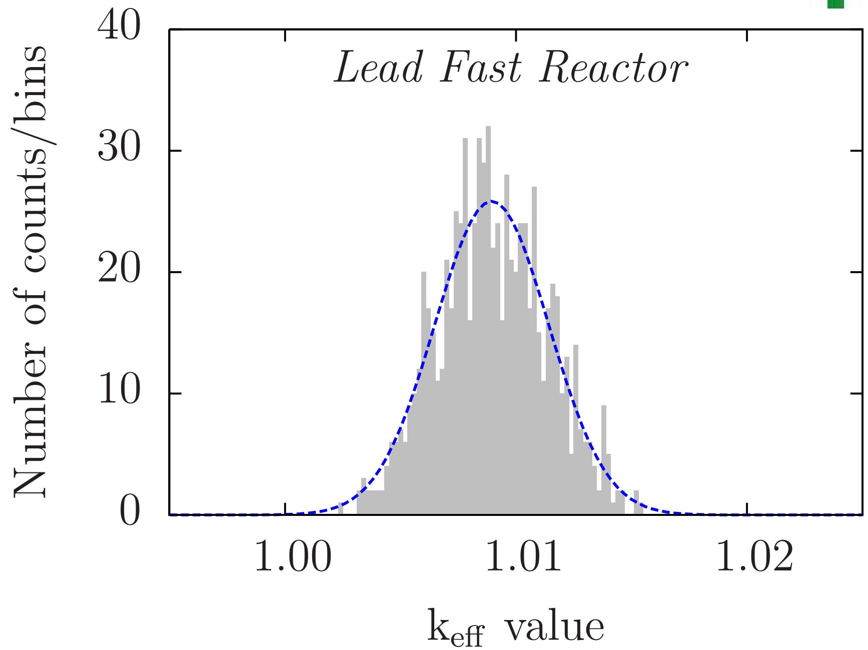
Coefficient	value	Uncertainty due to nuclear data ^{23}Na, $^{239-242}$Pu and ^{238}U
SVR	8.02 $	$\simeq$ 7 %
Non Voided k_{eff}	0.98298	$\simeq$ 100 pcm
Voided k_{eff}	1.00481	$\simeq$ 15 pcm
β_{eff}	371 pcm	$<$ 1 pcm
Doppler	-0.60 pcm/C	$\simeq$ 7-13 %

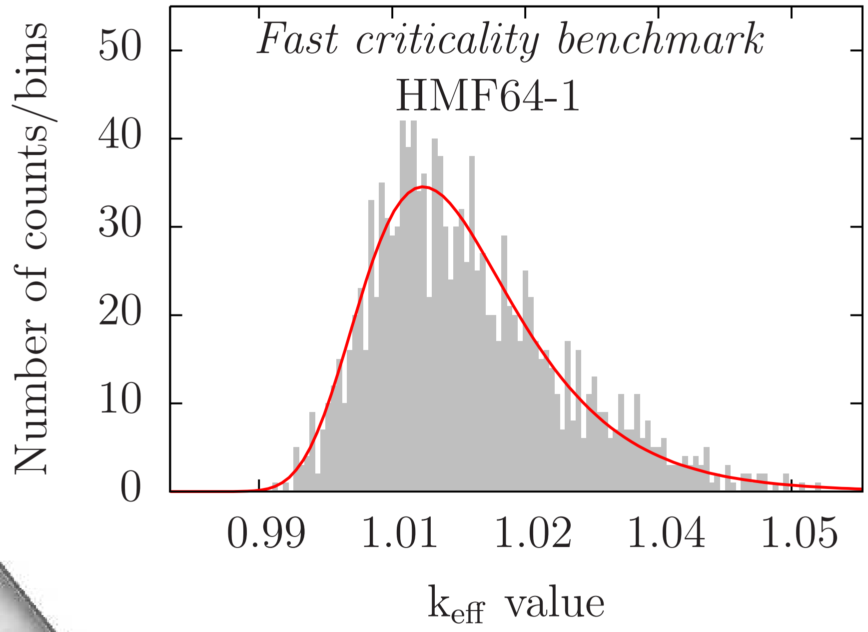
Application: TMC applied to shielding benchmark (Mn Oktavian benchmark)

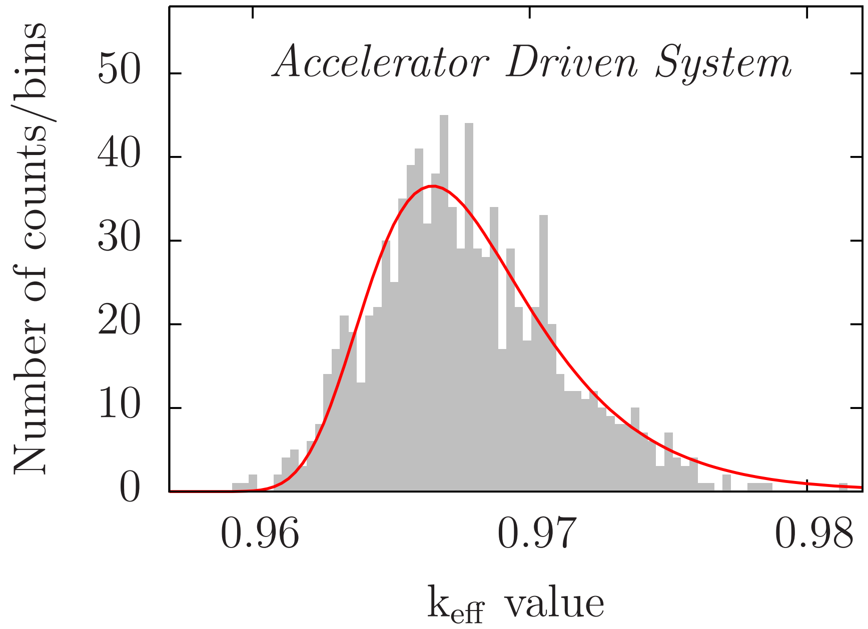


Application: Pb criticality and reactor systems

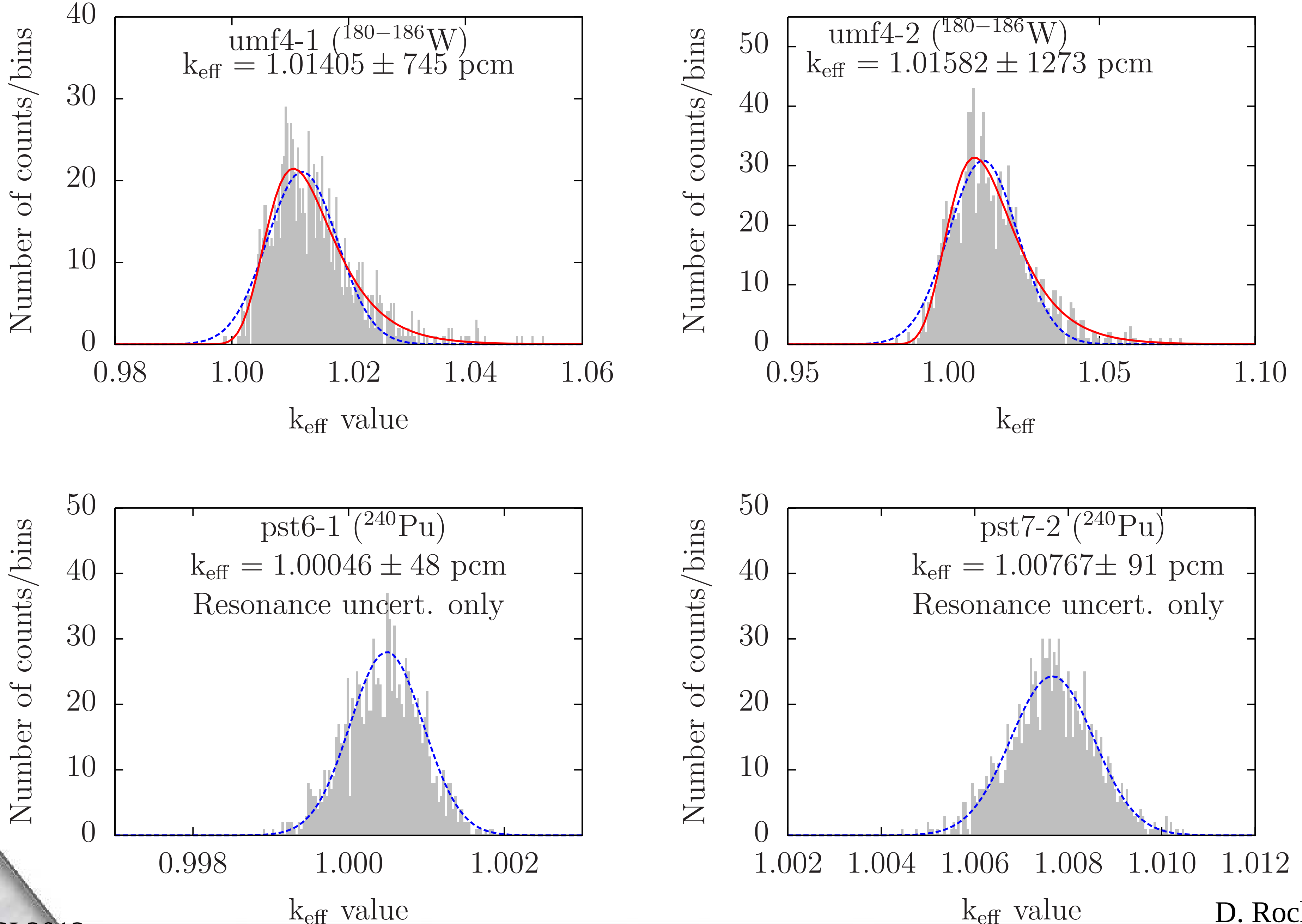






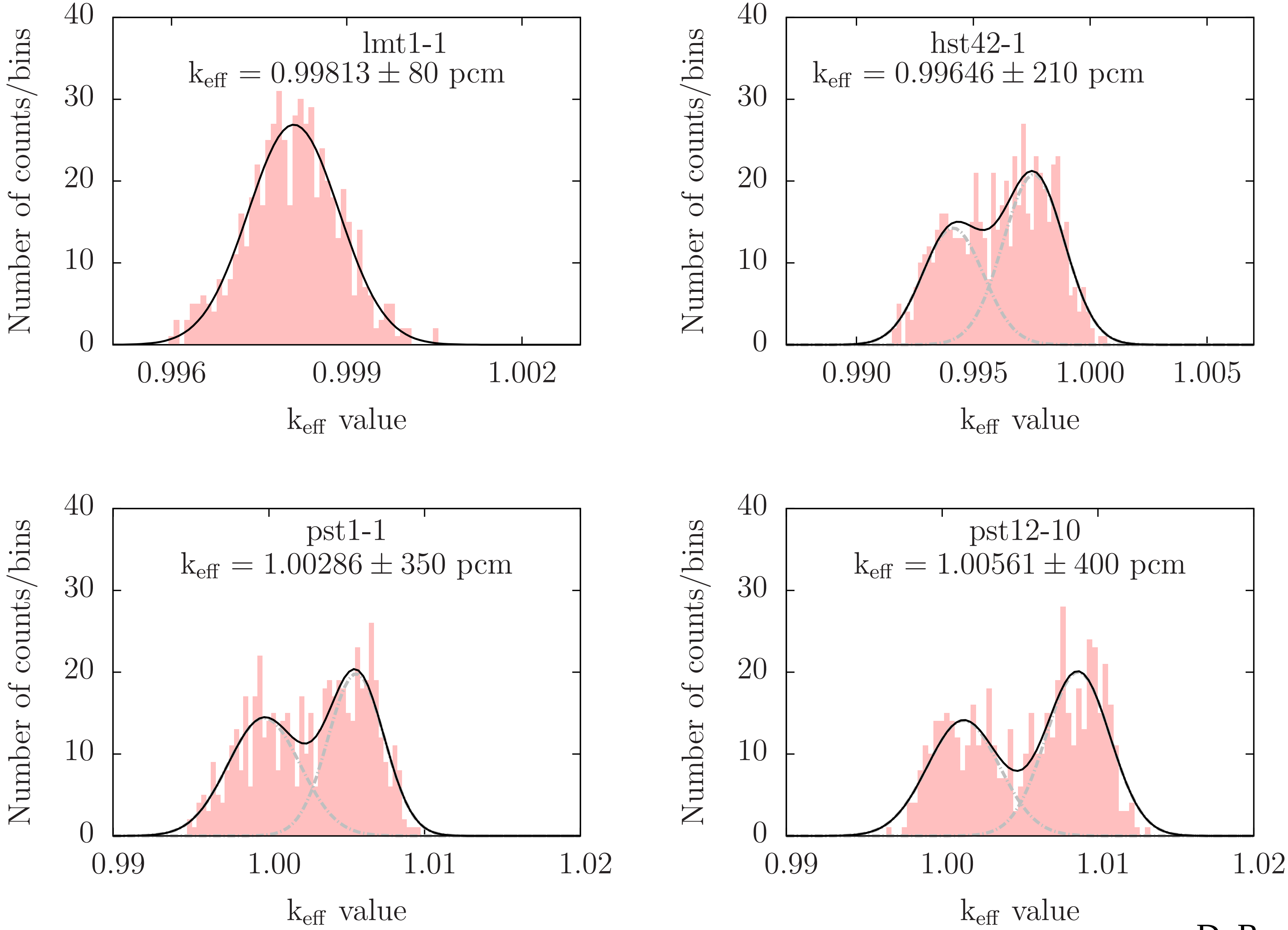


Application: k_{eff} benchmarks for $^{180-186}$W and ^{240}Pu (with MCNP)



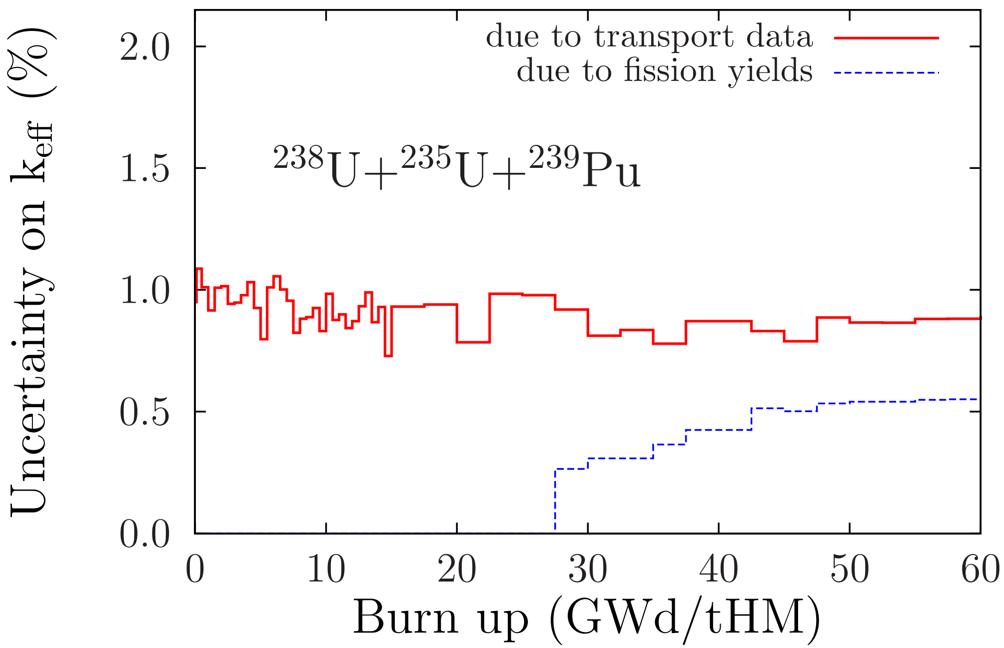
Application: thermal scattering for H in H_2O or $S(\alpha,\beta)$ tables (with MCNP)

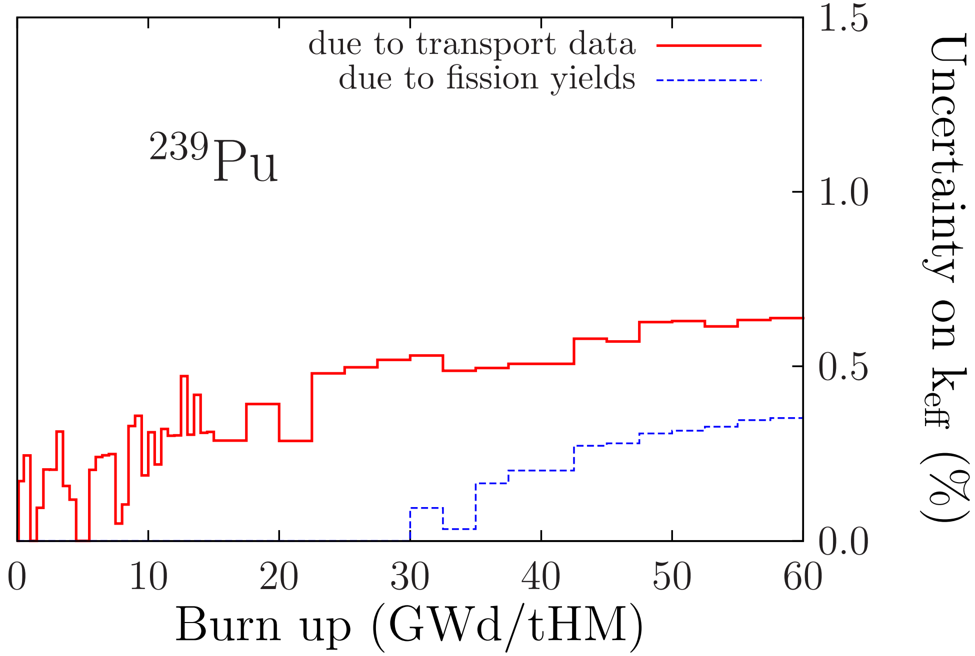
Random parameters of the $S(\alpha,\beta)$ for inelastic scattering



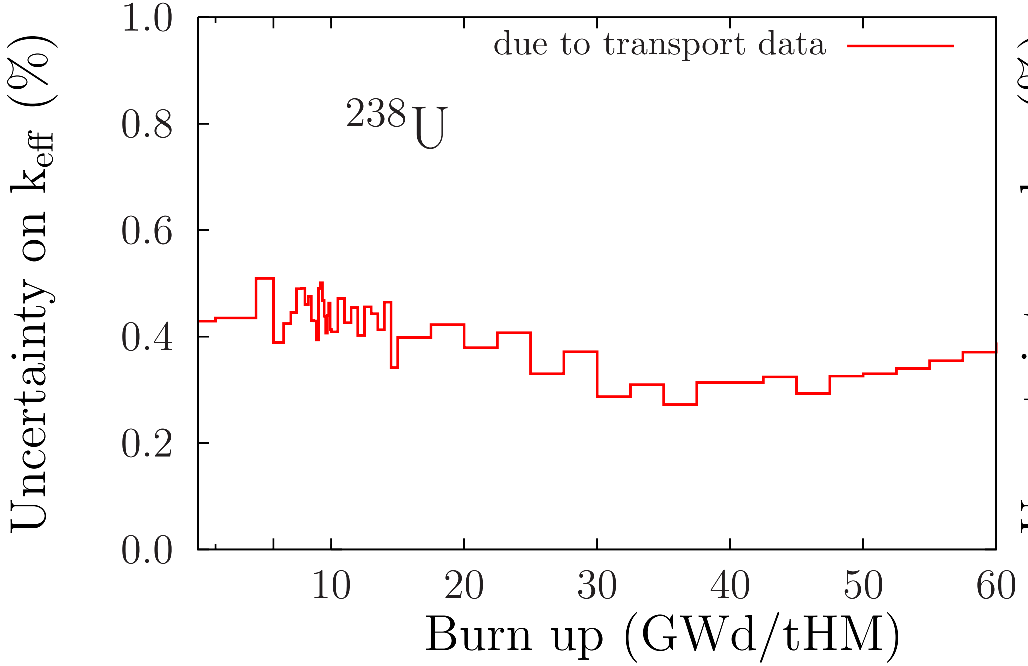
TMC applied to burn-up calculations with SERPENT

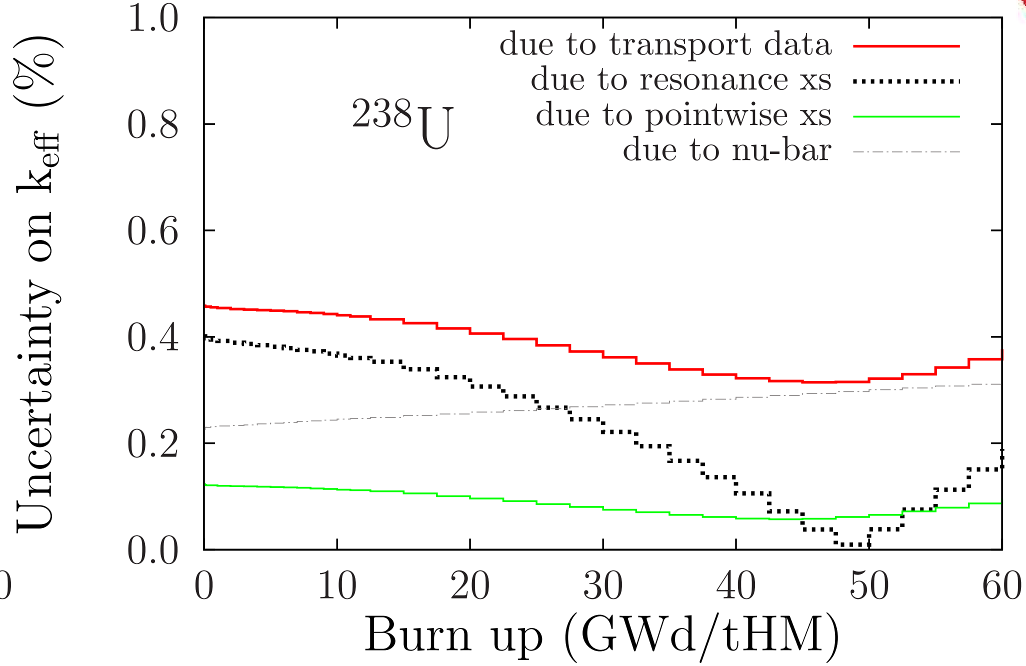
PWR fuel element based on a Westinghouse 3-loop PWR design (array of 17x17), 4 m in length, 21.5 cm in width, 400-500 kg of enriched uranium (4.8 % in ^{235}U)





TMC applied to burn-up calculations with DRAGON





SERPENT (Monte Carlo)

DRAGON (deterministic)

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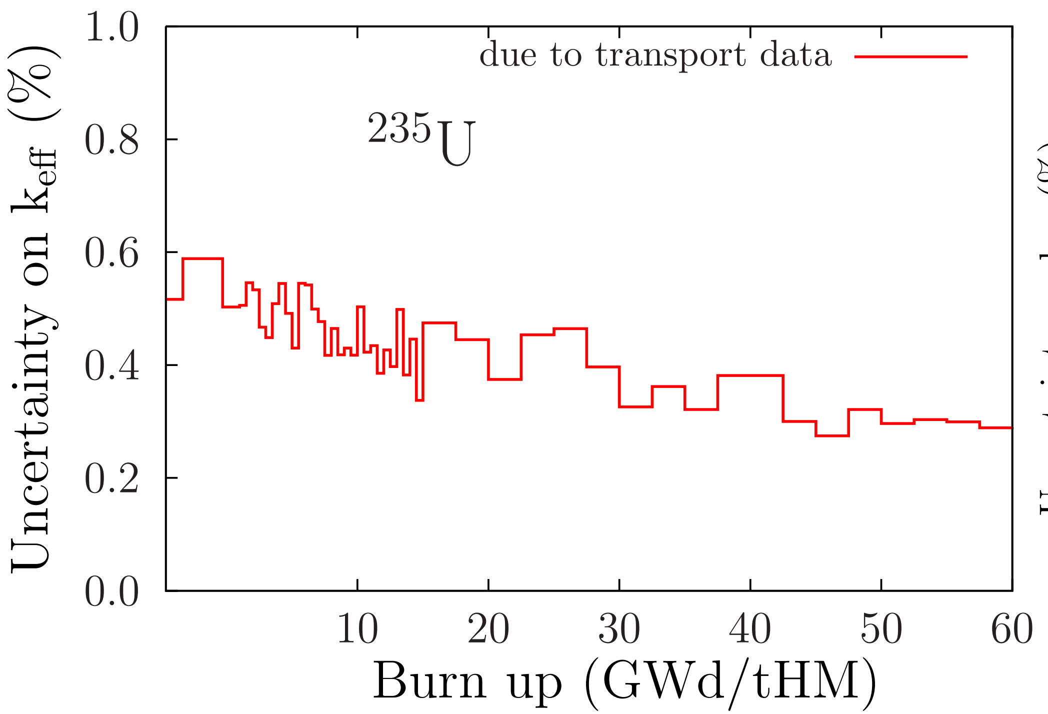
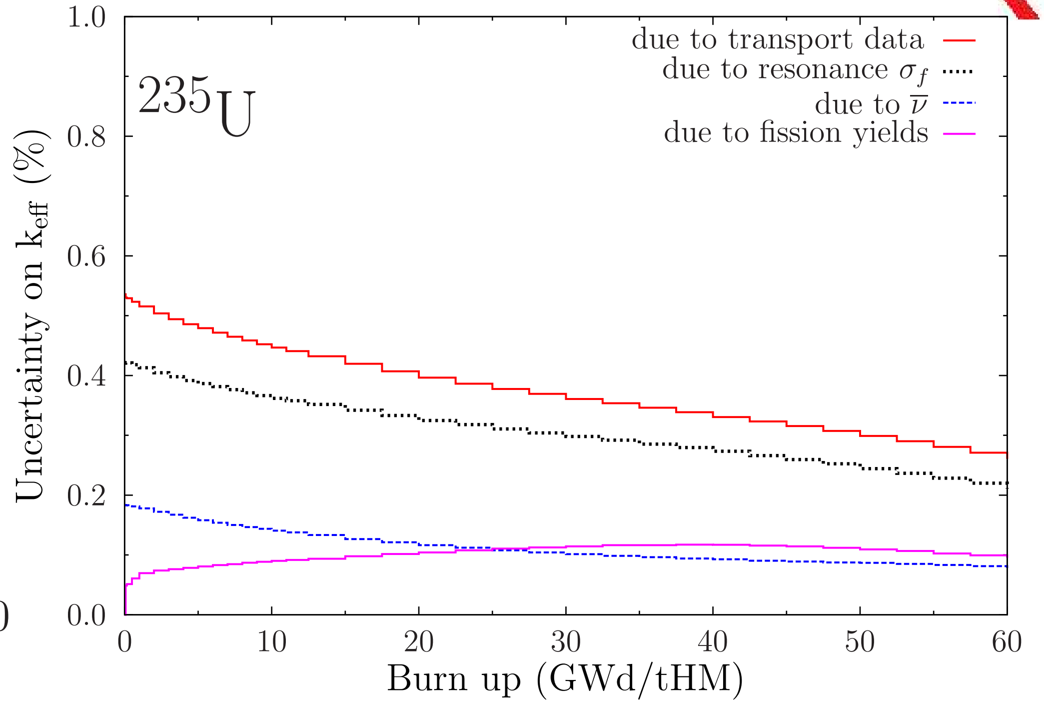
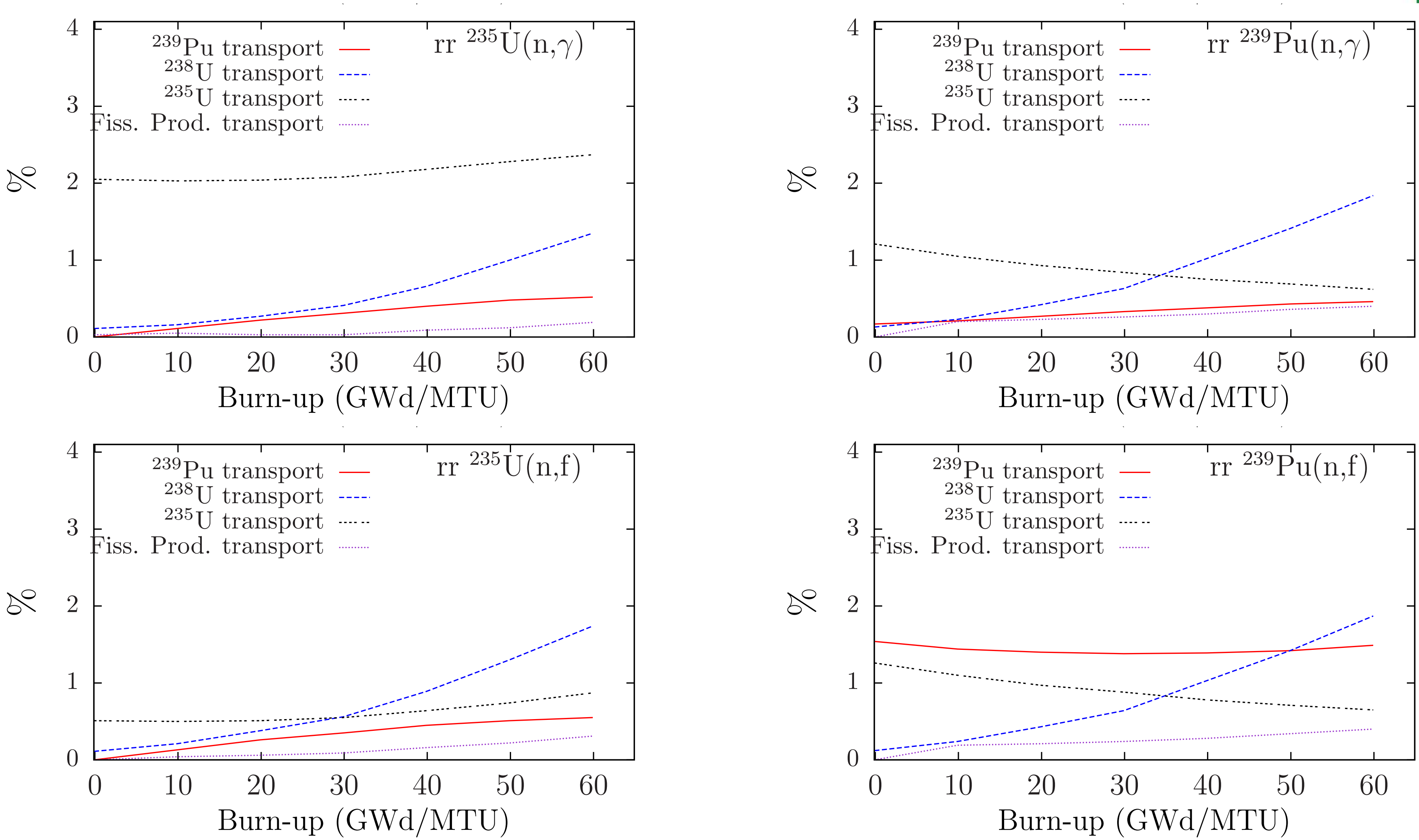




SERPENT (Monte Carlo)

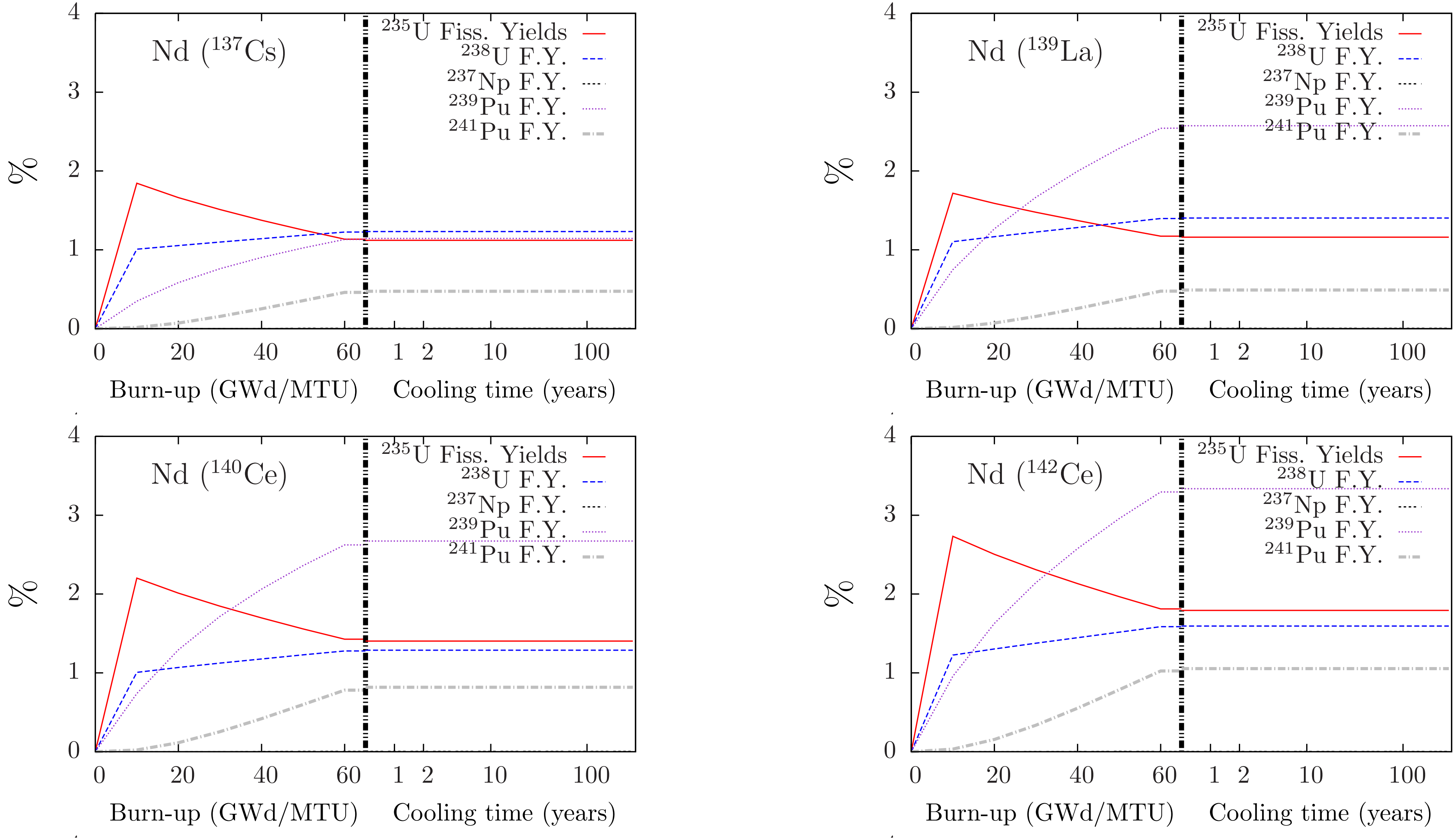
DRAGON (deterministic)

TMC applied to PWR burn-up calculations: reaction rates with SERPENT



There are 138 fission products included in this study: from ^{72}Ge to ^{167}Er.

TMC applied to PWR burn-up calculations: reaction rates with SERPENT



Under development: fast TMC

In TMC:

If we can do a calculation once, we can also do it a 1000 times, each time with a varying data library.

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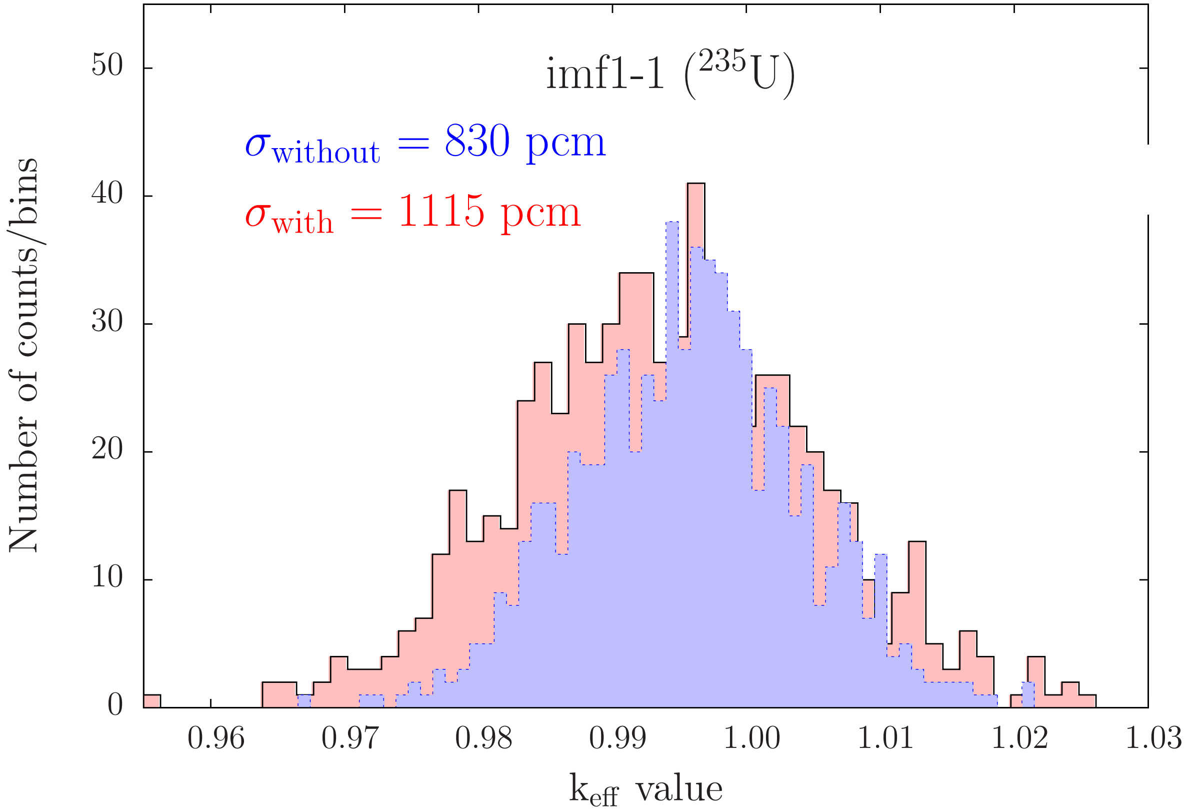
There is a solution with Monte Carlo codes (in fact 2 solutions):

- GRS method,
- and fast TMC.

Under development: fast TMC

In TMC with MCNP, a single run i takes long so that $\sigma^{(i)}_{\text{statistics}} << \sigma^{(i)}_{\text{nuclear data}}$.
What if we perform:

- a 1000 short runs (equivalent in time to one long run) with each time different nuclear data and different seeds ($\sigma^{(i)}_{\text{statistics}} >> \sigma^{(i)}_{\text{nuclear data}}$),
- and 1000 short runs with each time different seeds ?



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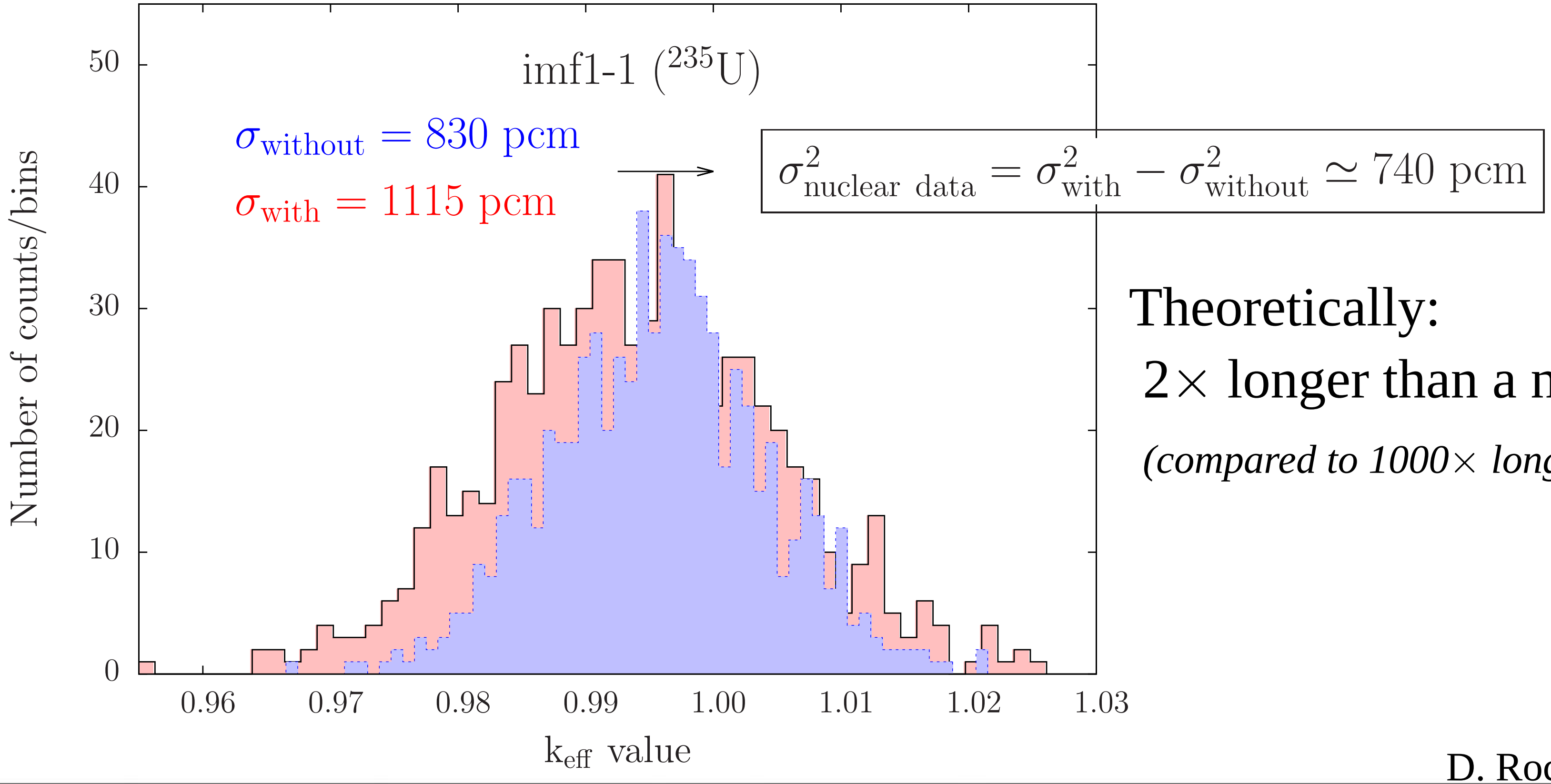
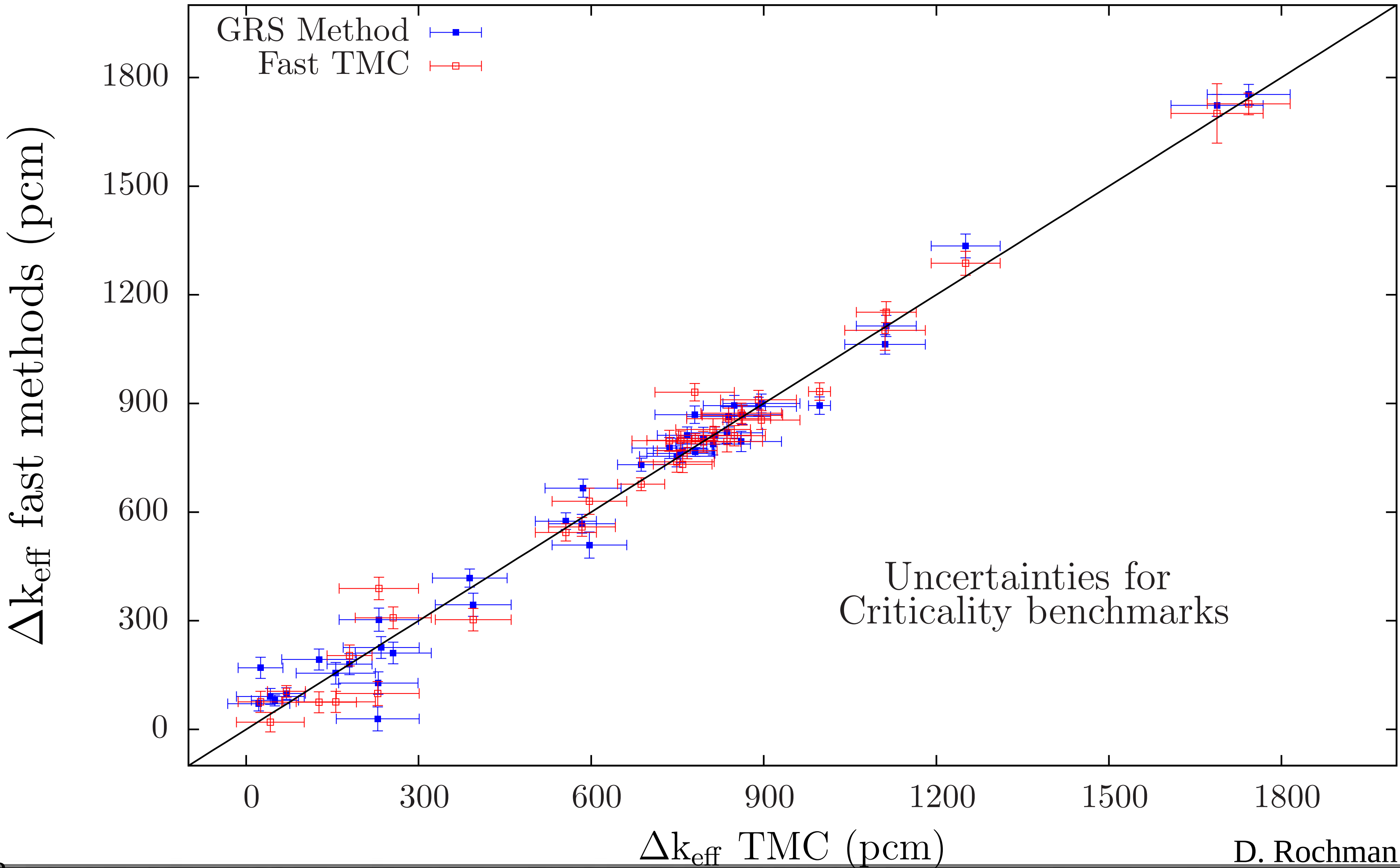


Theoretically:
$2\times$ longer than a normal run
(compared to 1000$\times$ longer for TMC)

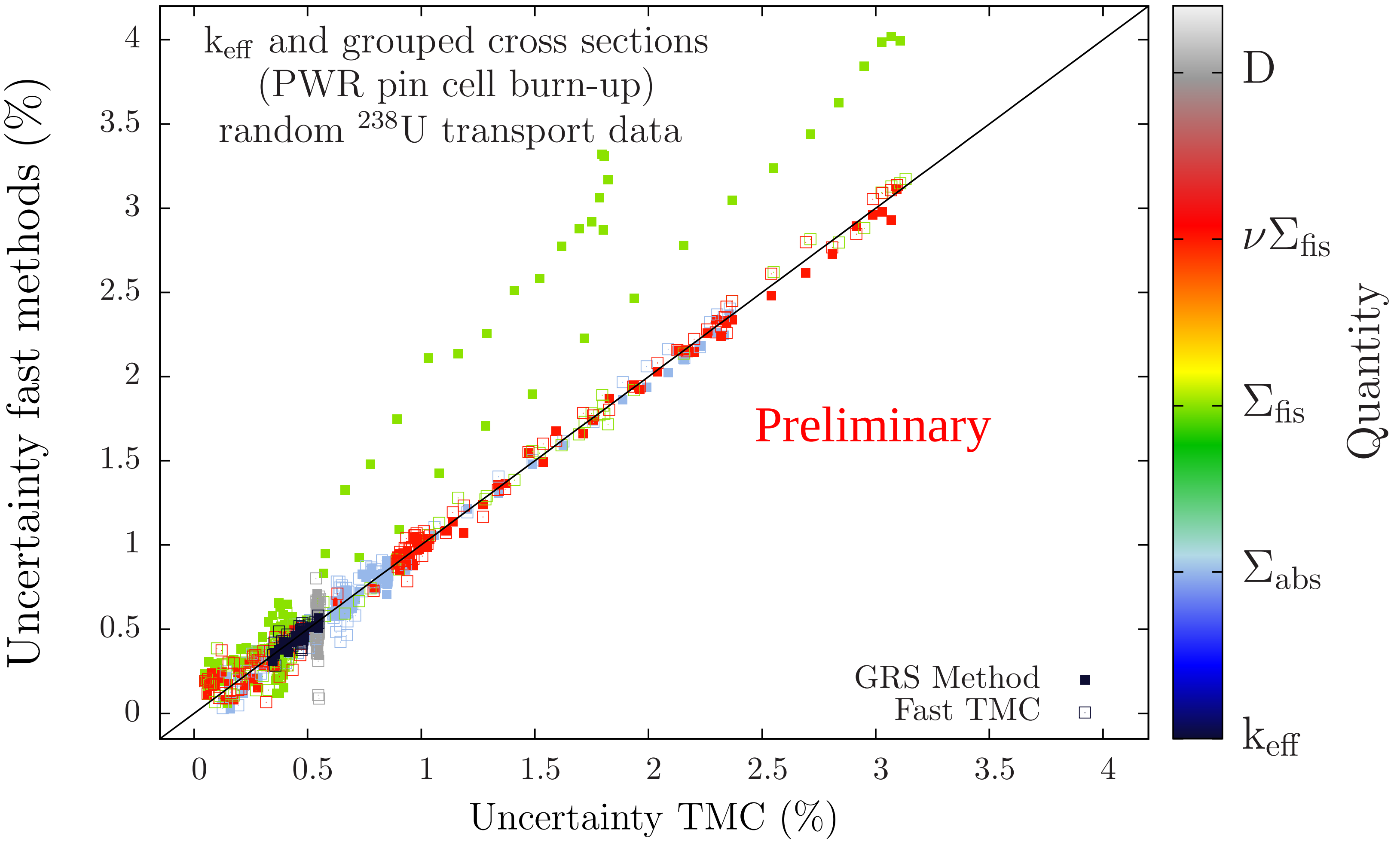
fast TMC: test on k_{eff} criticality benchmarks

Comparison between TMC (considered as reference), fast TMC and the GRS method with 44 benchmarks, changing $^{235,238}U$, $^{239,240}Pu$ and ^{56}Fe.

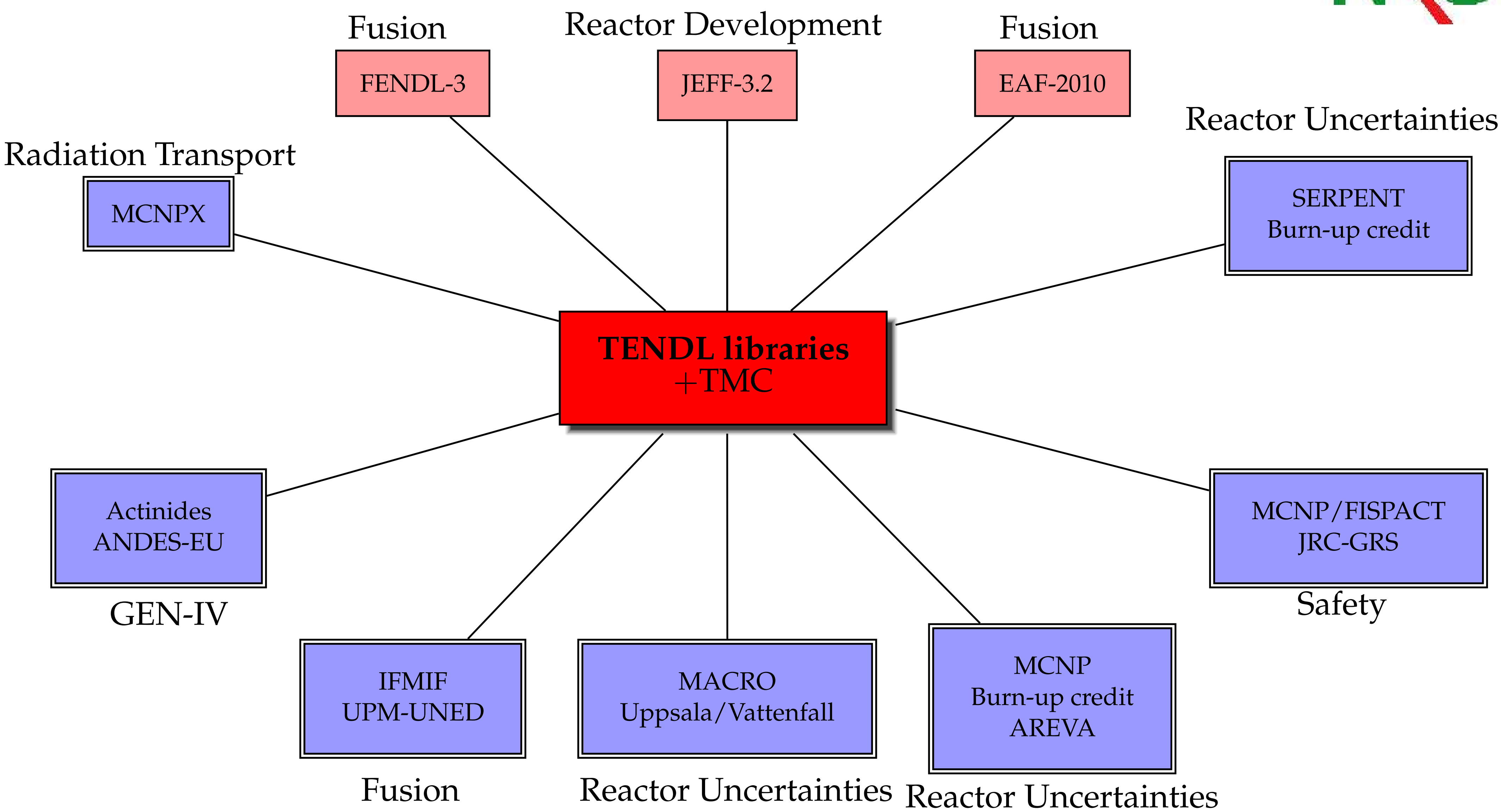


fast TMC: test on burn-up quantities

Comparison between TMC (considered as reference), fast TMC and the GRS method with UAM pin cell model of a PWR, changing ^{235,238}U transport data and ^{239,240}Pu fission yields.



Current and future (next year) partnerships



Future work

- Continue with TMC (more reactor calculations, applied to current and future reactors),
- Go where covariance methods (perturbation) can not be applied (TMC applied to thermo-hydraulic and transient calculations),
- Continue partnerships to expand the application of TMC methods,

- Improve the quality of the TENDL library (baseline for TMC, TMC^{-1}),
- Create the world best nuclear data library (NRG, CCFE, CEA).

☺And finally nuclear data world domination (and world peace).