# US Nuclear Data Program

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BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

U.S. DEPARTMENT OF ENERGY | Office of Science

# ARRA project (2009-2012)

**Use of Covariances in a Consistent Data Assimilation for Improvement of Basic Nuclear Parameters in Nuclear Reactor Applications: From Meters to Femtometers**

**BNL** - EMPIRE prior calculations, covariances for model parameters, group-wise sensitivity matrices

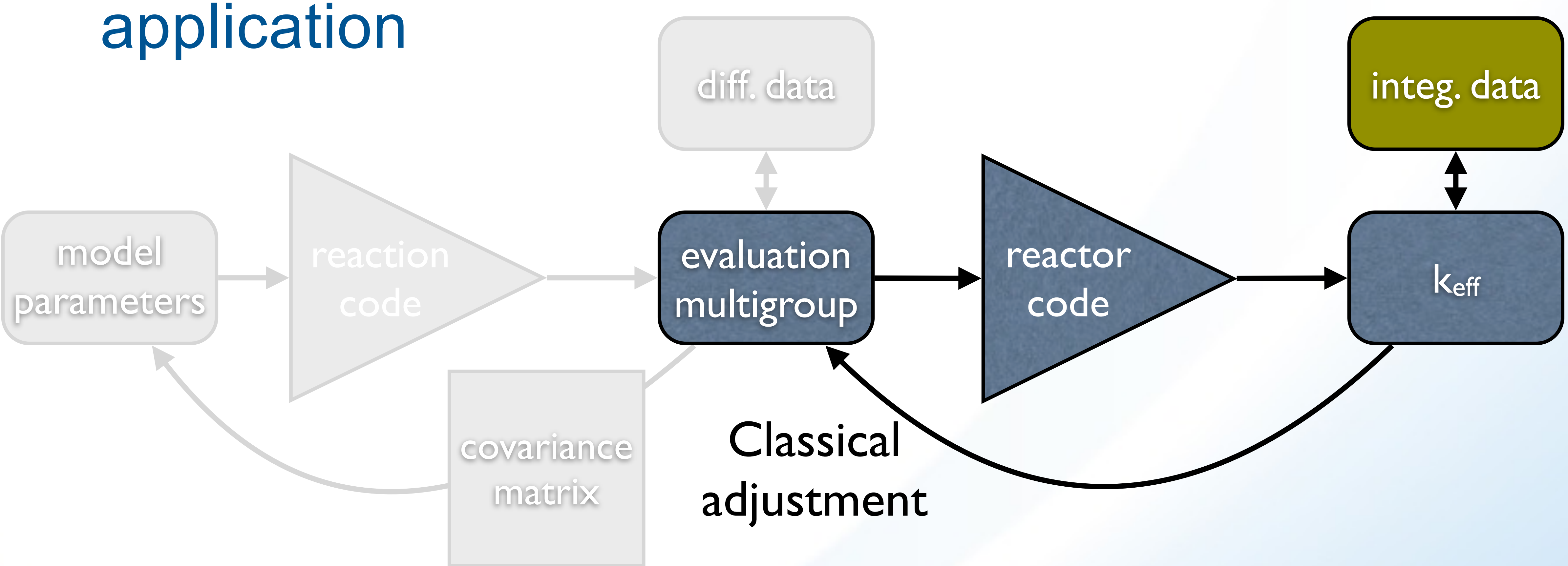
**INL** - integral experiment sensitivities to group-wise cross sections, assimilation

*"It has been a bit forgotten that in all really creative thinking in reactor design, a working knowledge of nuclear reaction theory is required."*

*E. Wigner*

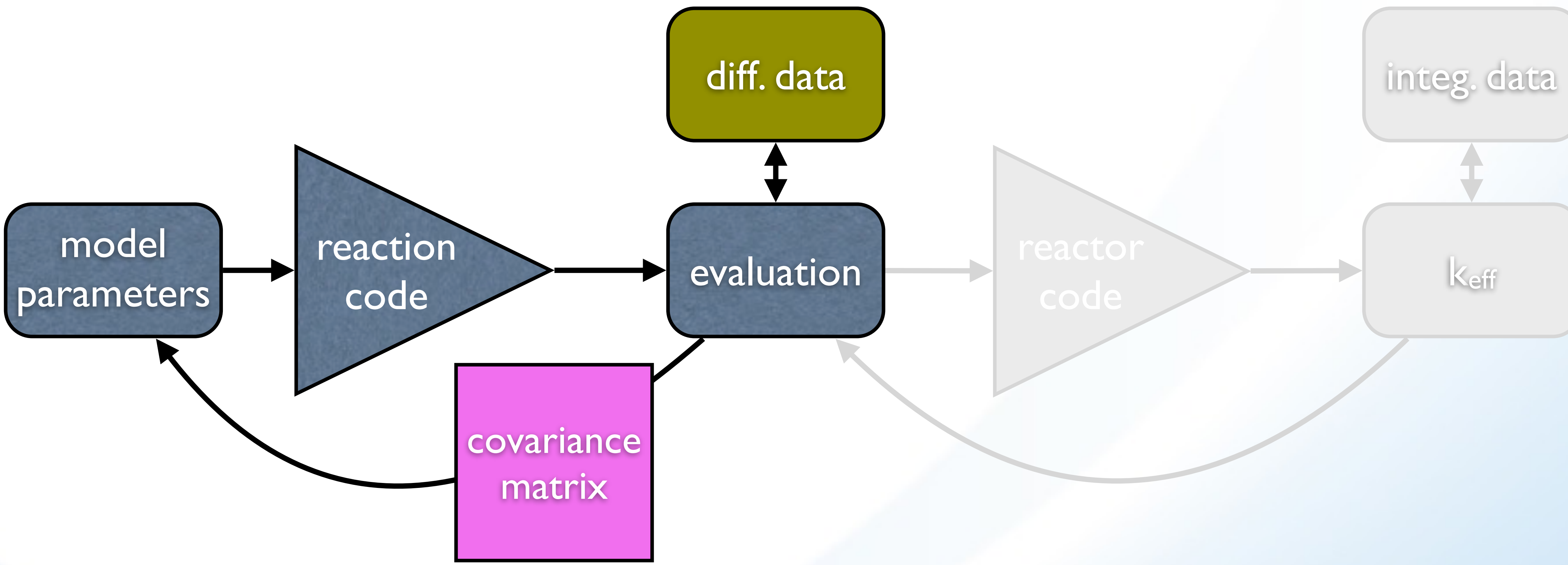
# Consistent adjustment (assimilation)
## linking reaction theory and integral experiments

- Users often tune multi-group evaluated files to a certain type of integral experiments
- Such adjusted file is only valid for a specific application



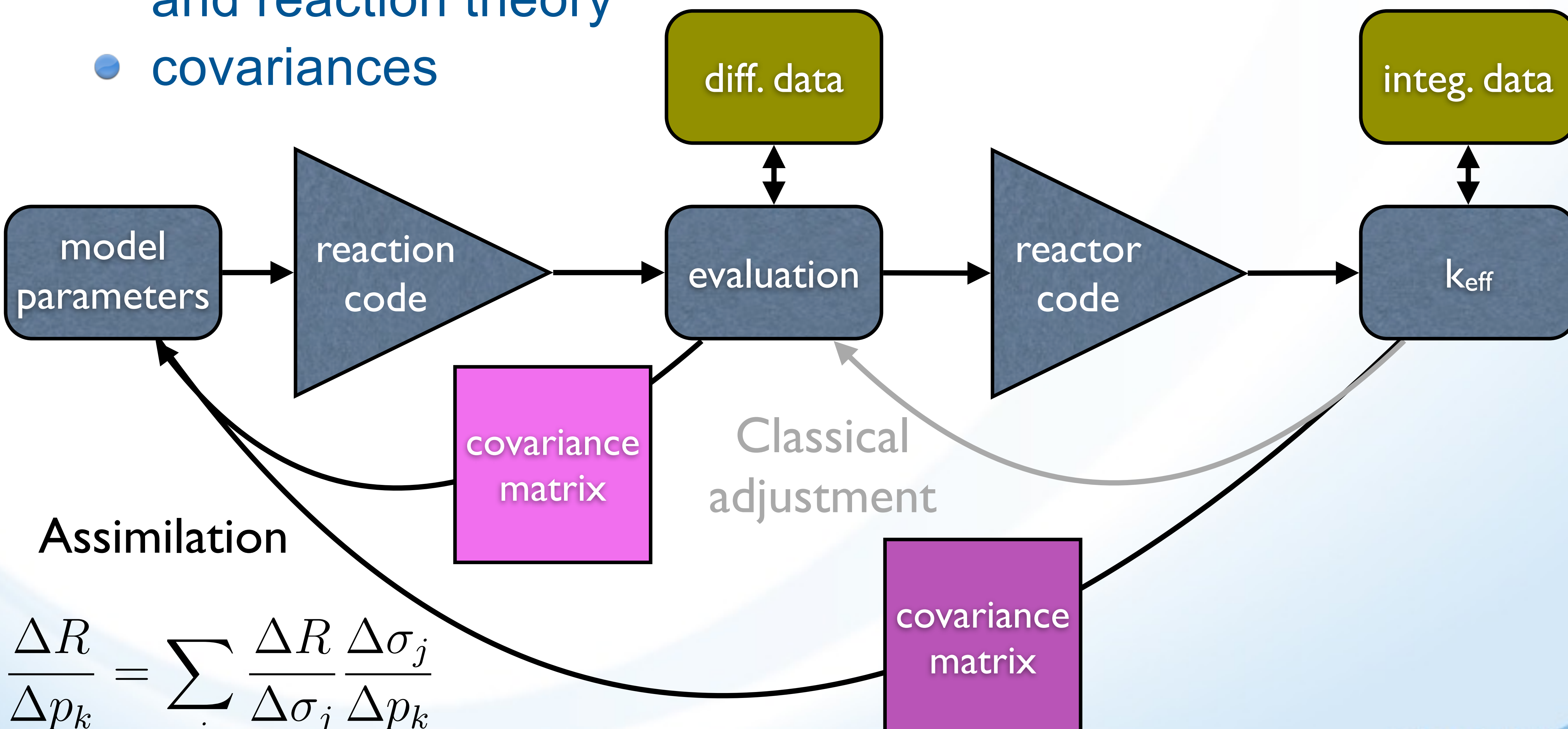
# Consistent adjustment (assimilation)
## linking reaction theory and integral experiments

- Modern practice is to use nuclear reaction code constrained by experimental data to produce evaluation and covariances



# Consistent adjustment (assimilation)
## linking reaction theory and integral experiments

- Tuning is moved from multi-group file to reaction model parameters providing
  - evaluation constrained by differential and integral data and reaction theory
  - covariances




$$\frac{\Delta R}{\Delta p_k} = \sum_j \frac{\Delta R}{\Delta \sigma_j} \frac{\Delta \sigma_j}{\Delta p_k}$$

# Scope of the project

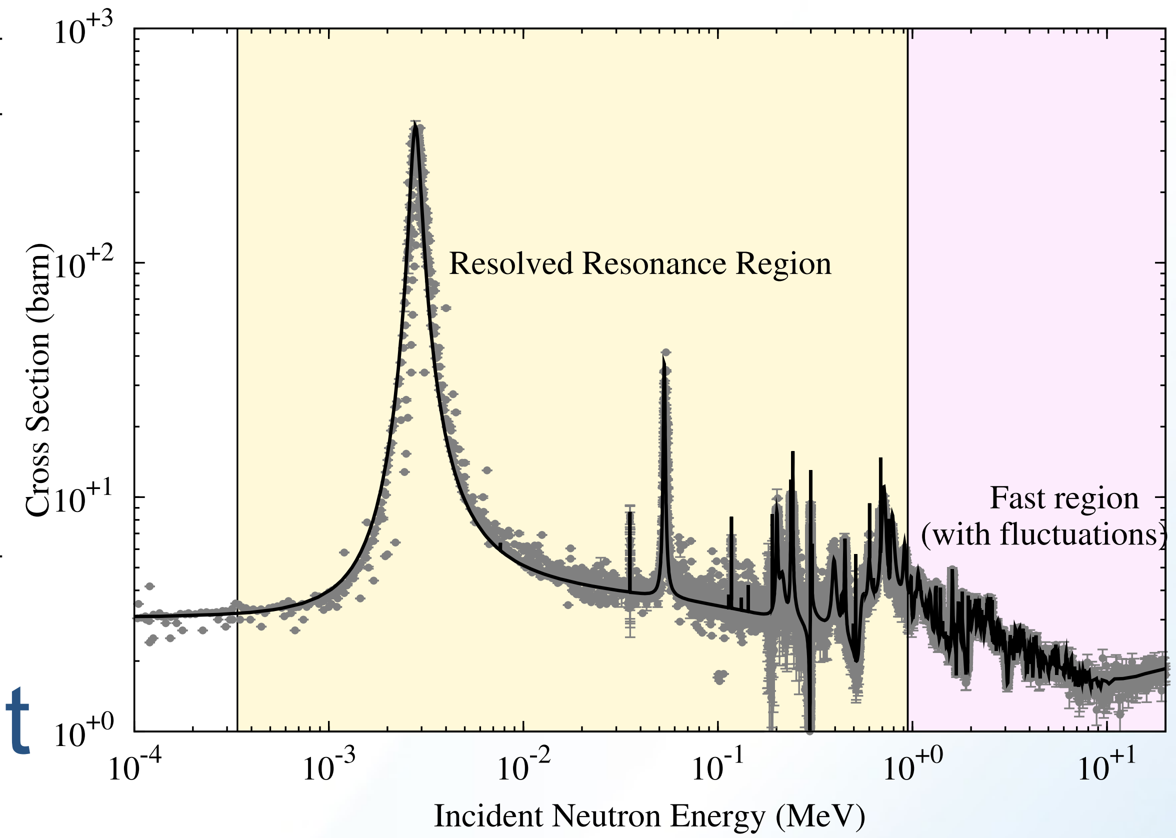
Investigate feasibility of the assimilation concept for priority materials

- $^{23}$**Na** - coolant
- $^{56}$**Fe** - structure material
- $^{105}$**Pd** - fission product
- $^{235,238}$**U**, $^{239}$**Pu** - major actinides
- $^{242}$**Pu** - minor actinide

Clean integral experiments available

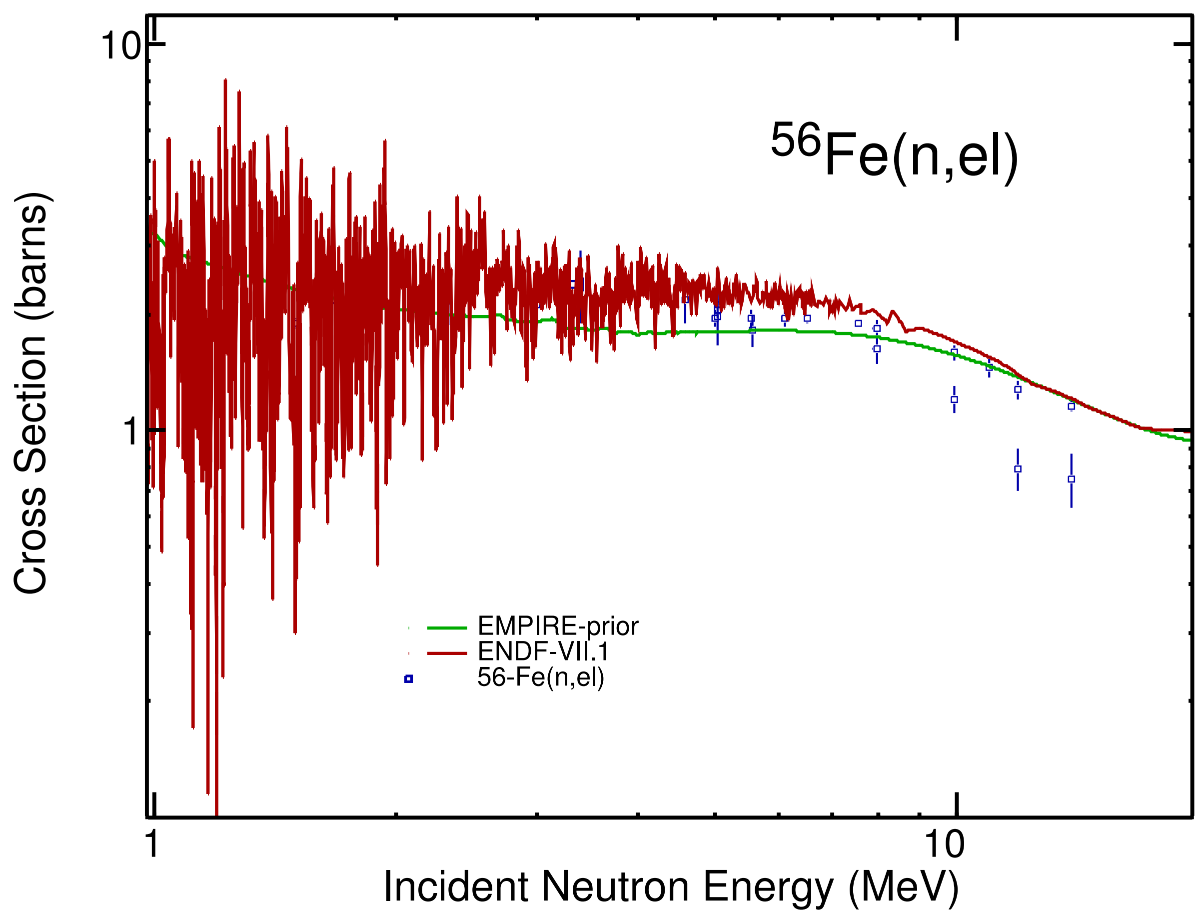
# Assimilation of $^{23}$Na

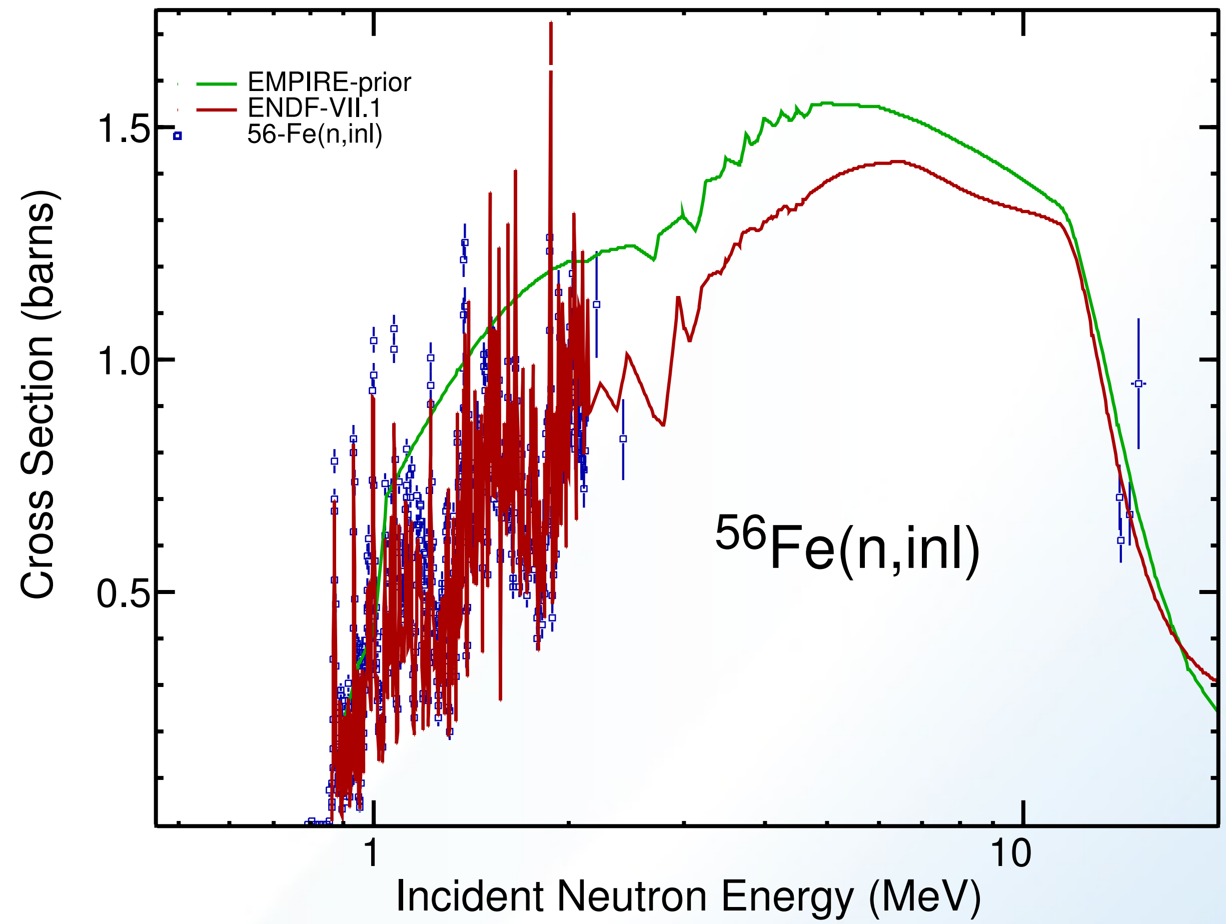
| Detector | prior C/E | posterior C/E |
|---|---|---|
| EURACOS $^{32}$S | $0.770 \pm 0.085$ | $0.997 \pm 0.057$ |
| EURACOS $^{197}$Au | $0.954 \pm 0.102$ | $0.946 \pm 0.010$ |
| JANUS-8 $^{32}$S | $0.538 \pm 0.022$ | $1.000 \pm 0.022$ |
| JANUS-8 $^{197}$Au | $1.010 \pm 0.033$ | $0.959 \pm 0.028$ |
| JANUS-8 $^{55}$Mn | $1.158 \pm 0.025$ | $1.028 \pm 0.023$ |
| JANUS-8 $^{103}$Rh | $0.960 \pm 0.106$ | $0.976 \pm 0.047$ |




- Apparently excellent result but failed 'retrofitting test'
- Lesson learned
  - non-linearity effects may distort the assimilation procedure and must be kept under control.
  - cross section fluctuations represent a challenge (in $^{23}$Na treated via energy dependent scaling factor)

# Assimilation of $^{56}$Fe




- Hopeless resonance-like structure up to 8 MeV
- Poor prior - better CC omp needed

# C/E after assimilation of $^{56}$Fe

| Experiment | | C/E ± (before) | C/E ± (after) |
|---|---|---|---|
| $^{10}$B(n, ) slope | ZPR3-54 | 0.853 ± 0.030 | 1.012 ± 0.022 |
| $^{235}$U(n,f) slope | ZPR3-54 | 0.907 ± 0.030 | 1.015 ± 0.013 |
| $^{239}$Pu(n,f) slope | ZPR3-54 | 0.889 ± 0.030 | 0.996 ± 0.013 |
| $^{238}$U(n,f) slope | ZPR3-54 | 1.455 ± 0.030 | 1.284 ± 0.014 |
| $^{32}$S(n,p) slope | EURACOS | 0.879 ± 0.093 | 1.197 ± 0.055 |
| $^{197}$Au(n, ) slope | EURACOS | 1.288 ± 0.098 | 1.054 ± 0.032 |
| $^{115}$In(n,n') slope | EURACOS | 0.327 ± 0.156 | 0.455 ± 0.042 |
| $^{103}$Rh(n,n') slope | EURACOS | 0.478 ± 0.071 | 0.511 ± 0.010 |

- Certain improvement achieved but VII.0 performs better
- Poor prior - better CC omp needed

# $^{56}$Fe - posterior parameters

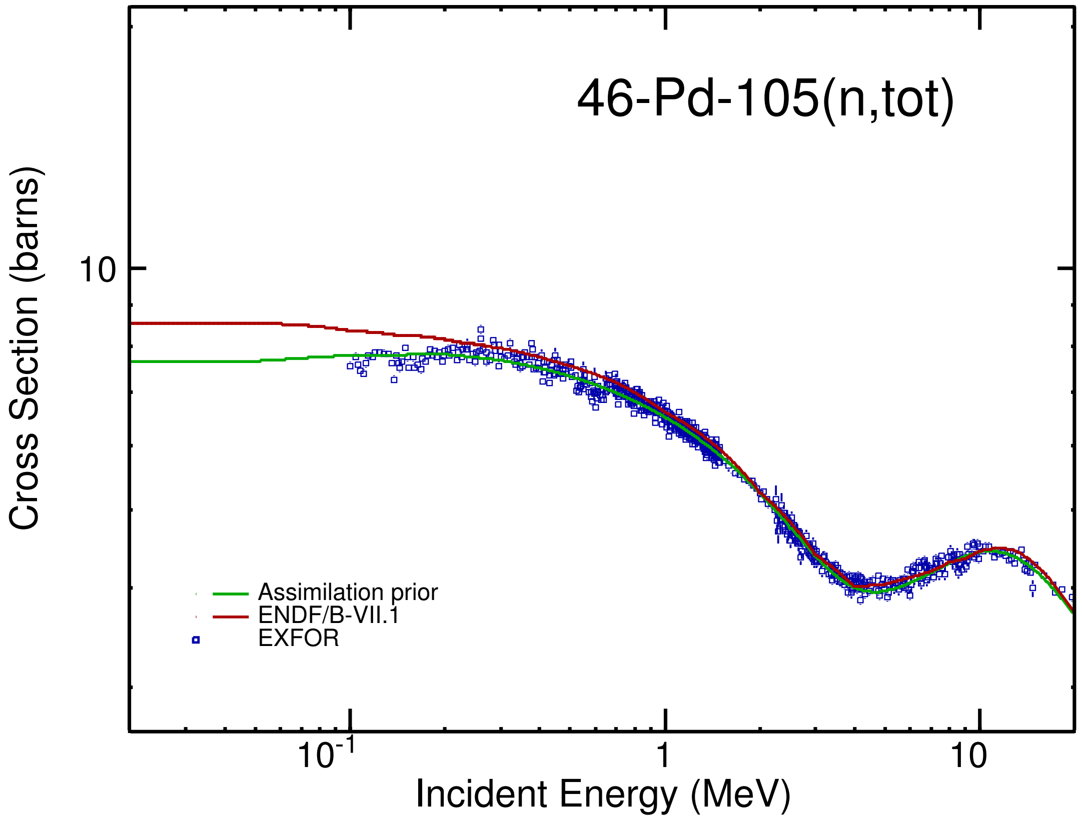
| Parameter | Variation (%) | Init. Std. Dev. (%) | Final Std. Dev. (%) |
|---|---|---|---|
| Scat. Rad.[a] | -13.25 | 5.1 | 2.1 |
| $\Gamma_n$ Bound Level[b] | 1.9 | 4.0 | 3.7 |
| $\Gamma_g$ Bound Level[b] | -2.1 | 5.0 | 4.8 |
| $\Gamma_n$ 277 keV[c] | -1.1 | 8.0 | 8.0 |
| $\Gamma_n$ 317 keV[c] | -2.2 | 8.0 | 8.0 |
| $\Gamma_n$ 361 keV[c] | -2.9 | 8.0 | 8.0 |
| $\Gamma_n$ 381 keV[c] | -3.0 | 8.0 | 8.0 |
| $\Gamma_n$ 665.6 keV[c] | 1.3 | 8.0 | 8.0 |
| Real well volume[d] | 15.1 | 3.0 | 2.2 |
| Nuclear radius Real Surf.[e] | 10.5 | 3.0 | 2.9 |
| Imag. & Real Surf.[f] | 10.8 | 5.0 | 4.9 |
| TOTRED[g] | -0.9 | 1.0 | 1.0 |
| FUSRED[h] | -2.0 | 1.3 | 1.2 |

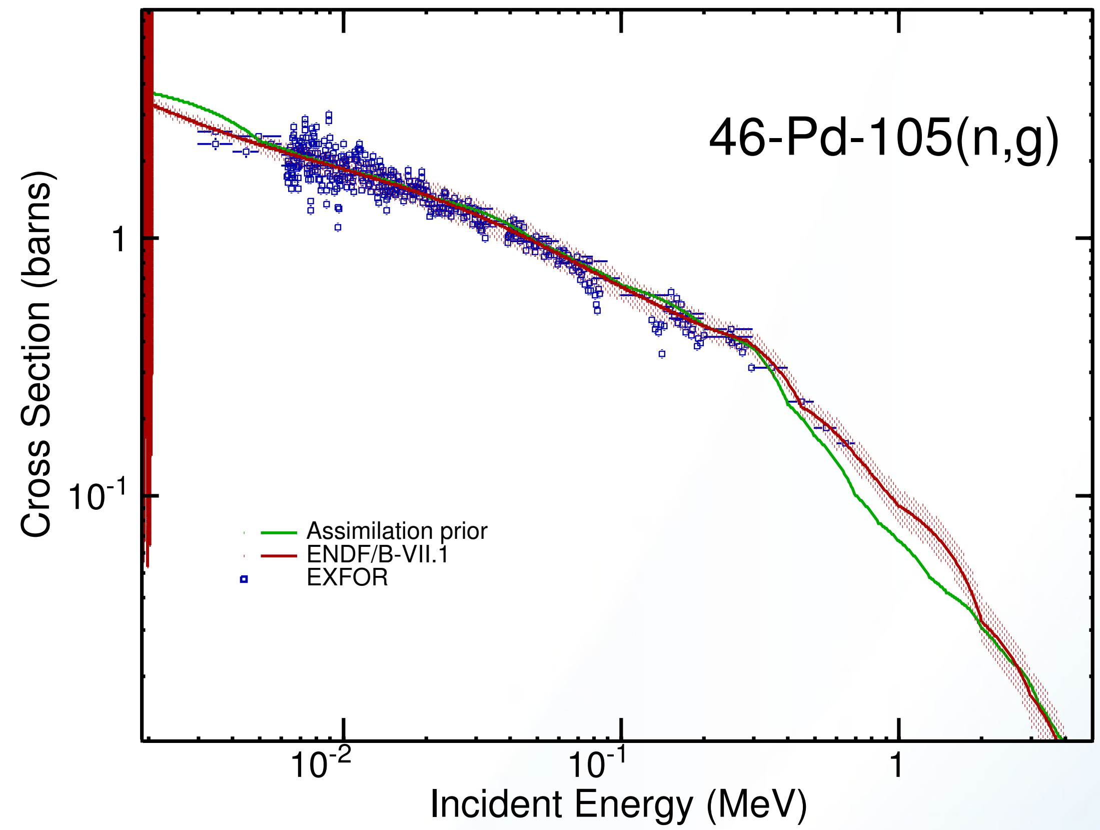
Unphysical changes
in the parameters

# $^{56}$Fe lesson learned

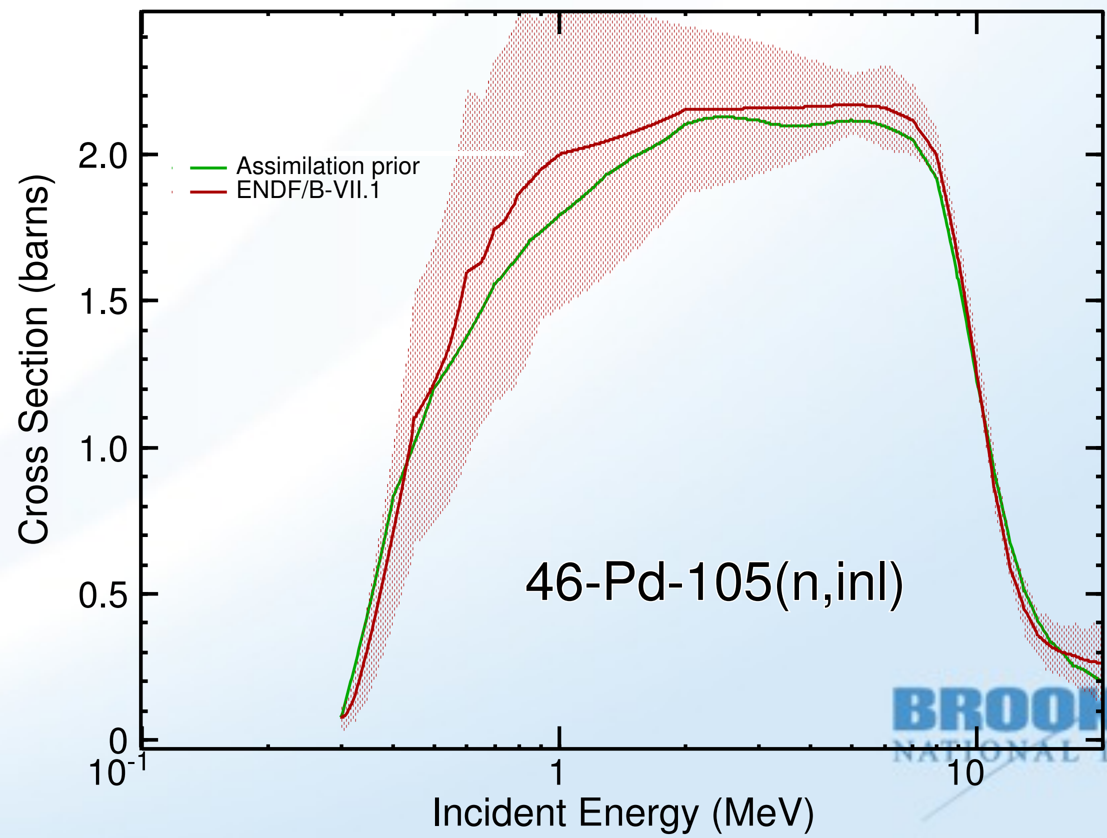
- Integral experiments alone do not ensure restoring agreement with differential data if the prior is of poor quality.
- A practical, necessarily approximative, method should be developed for treating fine energy fluctuations that can't be treated in terms of the reaction theory
- Possible discrepancies among differential and integral experiments might make consistent assimilation difficult or impossible.

# Assimilation of $^{105}$Pd




- Pretty good prior
- Integral experiment PROFIL-1 sensitive to capture <=> should be easy!



# $^{105}$Pd - prior parameter correlations

| | Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UOMPRV-011[a] | 100 | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | UOMPVV-011[a] | -99 | 100 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | UOMPRS-011[a] | -72 | 67 | 100 | | | | | | | | | | | | | | | | | | | | | |
| 4 | UOMPWS-011[a] | 89 | -89 | -78 | 100 | | | | | | | | | | | | | | | | | | | | |
| 5 | UOMPRW-011[a] | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | | | | | | | |
| 6 | UOMPWV-011[a] | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | | | | | | |
| 7 | TOTRED-000[b] | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | | | | | |
| 8 | FUSRED-000[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | | | | |
| 9 | ATILNO-000[c] | -4 | 4 | 2 | -5 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | | | |
| 10 | ATILNO-010[c] | -40 | 40 | 26 | -35 | 0 | 0 | 0 | 0 | 1 | 100 | | | | | | | | | | | | | | |
| 11 | ATILNO-020[c] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | |
| 12 | ATILNO-030[c] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | |
| 13 | GTILNO-000[d] | 30 | -30 | -20 | 26 | 0 | 0 | 0 | 0 | -1 | -38 | 0 | 0 | 100 | | | | | | | | | | | |
| 14 | GTILNO-010[d] | 2 | -2 | -1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | -5 | 100 | | | | | | | | | | |
| 15 | GTILNO-020[d] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | |
| 16 | GTILNO-030[d] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | |
| 17 | TUNEPE-100[e] | 4 | -4 | -3 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | -10 | -1 | 0 | 0 | 100 | | | | | | | |
| 18 | TUNE-000[f] | 6 | -6 | -4 | 7 | 0 | 0 | 0 | 0 | -99 | -2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 100 | | | | | | |
| 19 | TUNE-011[f] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | |
| 20 | TUNE-010[f] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | |
| 21 | PCROSS-000[g] | -25 | 25 | 17 | -23 | 0 | 0 | 0 | 0 | 1 | 68 | 0 | 0 | 36 | 2 | 0 | 0 | 5 | -1 | 0 | 0 | 100 | | | |
| 22 | RESNOR-100[h] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | |
| 23 | RESNOR-200[h] | -1 | 1 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | -24 | 0 | 0 | 5 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 100 | |
| 24 | RESNOR-300[h] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |

Strong anti-correlation between CN level density and gamma strength function

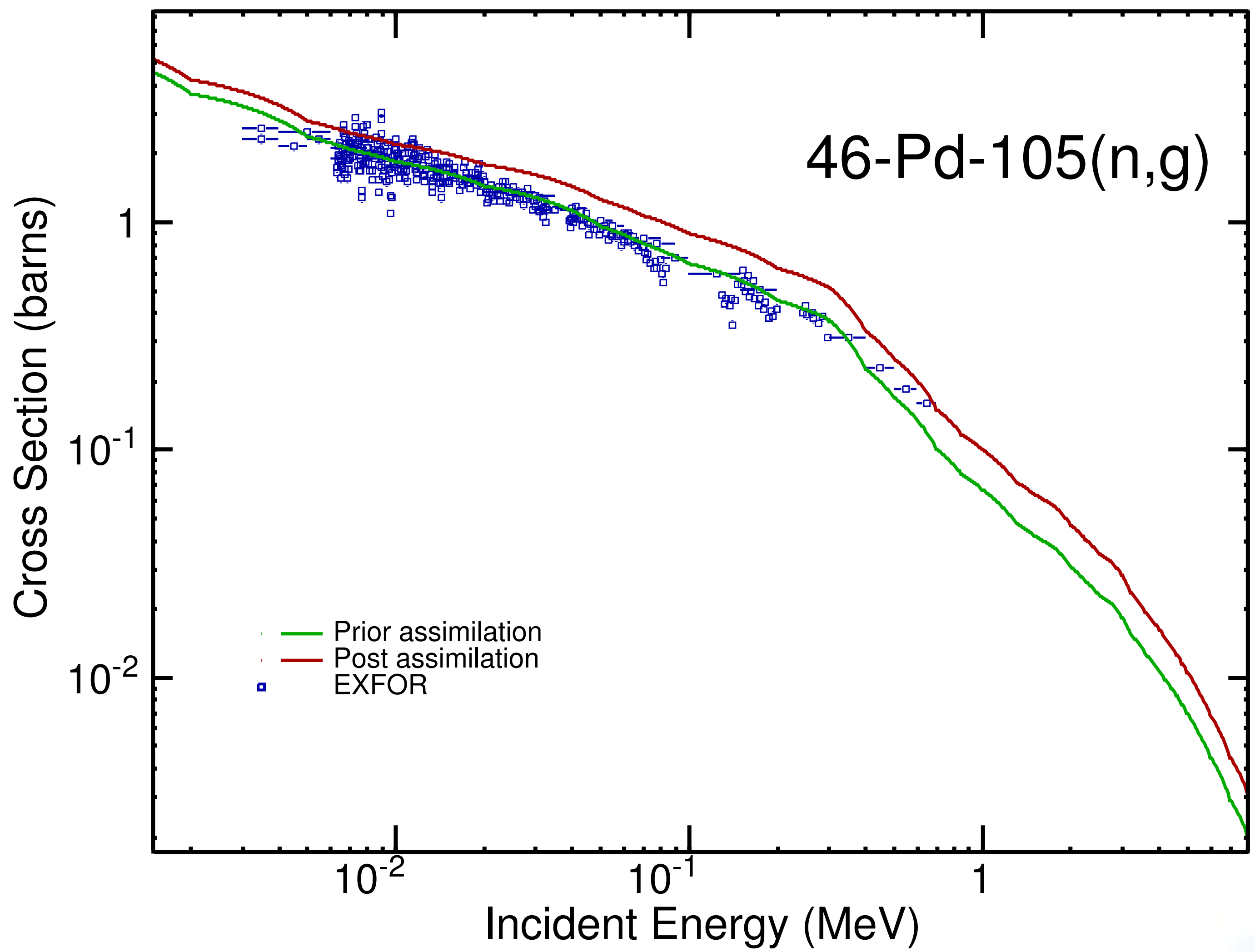
# $^{105}$Pd - assimilation results

| Experiment | old C/E $\pm\ \sigma$ | new C/E $\pm\ \sigma$ |
| --- | --- | --- |
| PROFIL-1 | $0.835 \pm 0.028$ | $0.990 \pm 0.027$ |

| Parameter | Variation (%) | Init. % Std. Dev. | Final % Std. Dev. |
| --- | --- | --- | --- |
| TUNE000[a] | 69.253 | 40.00 | 10.77 |
| ATILNO000[b] | -2.573 | 1.49 | 0.43 |
| FUSRED000[c] | 0.353 | 2.00 | 1.99 |

- TUNE-ATILNO anti-correlation keeps capture cross section constant!
- Assimilation required modification of the covariance matrix (increasing gamma-strength uncertainty keeping CN level density constrained)

# $^{105}$Pd - assimilation results (cont.)




- posterior disagrees with differential data
- differential and integral experiments discrepant

**Assimilation concept worked**! Violence had to be done to the differential covariance matrix to fit integral data.

# $^{105}$Pd - lesson learned

- If two parameters happen to be strongly anti-correlated assimilation may exploit this feature to drive both parameters out of the physical range.
- If assimilation is not possible without increasing properly defined prior uncertainties it either means that the model is not adequate or flexible enough, or that differential and integral experiments are inconsistent.

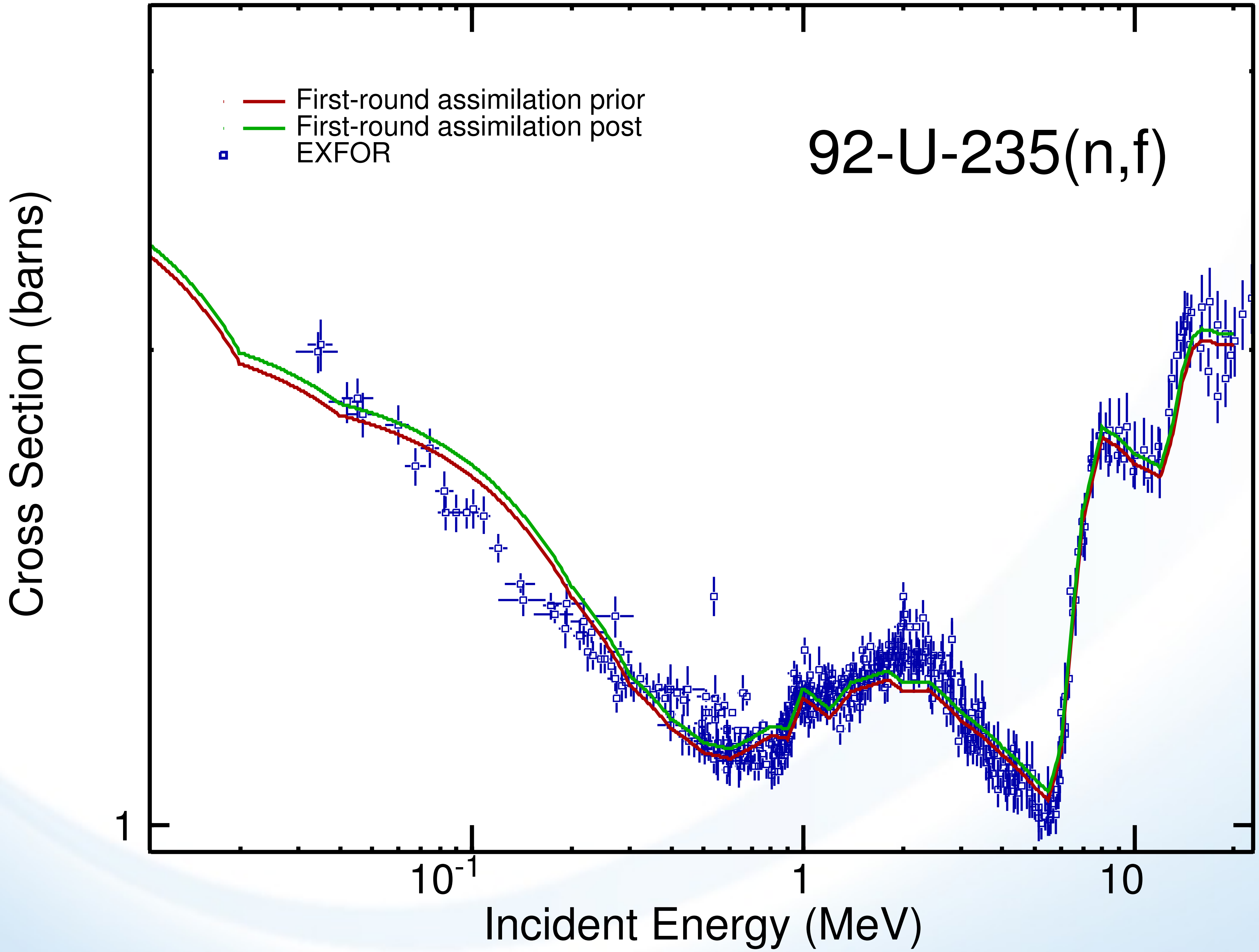
# Assimilation of $^{235}$U (1$^{st}$ round)

GODIVA

| Experiment | C/E ± σ (before) | C/E ± σ (after) |
|---|---|---|
| $k_{eff}$ | 0.9907 ± 0.002 | 1.0010 ± 0.002 |
| $^{238}$U(n,f)/$^{235}$U(n,f) | 1.0527 ± 0.013 | 1.0357 ± 0.004 |
| $^{239}$Pu(n,f)/$^{235}$U(n,f) | 0.9917 ± 0.018 | 0.9771 ± 0.003 |
| $^{237}$Np(n,f)/$^{235}$U(n,f) | 1.0703 ± 0.017 | 1.0536 ± 0.003 |
| $^{233}$U(n,f)/$^{235}$U(n,f) | 0.9964 ± 0.019 | 0.9820 ± 0.004 |

| Parameter | Variation (%) | Init. Std. Dev. (%) | Final Std. Dev. (%) |
|---|---|---|---|
| FUSRED000[a] | 1.402 | 1.257 | 0.878 |
| TOTRED000[b] | 0.461 | 0.966 | 0.917 |
| ATILNO000[c] | -0.236 | 0.950 | 0.946 |
| DELTAF000[d] | -0.025 | 0.649 | 0.621 |
| VB000[e] | -0.006 | 0.133 | 0.118 |
| UOMPVV011[f] | 0.033 | 0.116 | 0.116 |
| UOMPRS011[g] | 0.072 | 0.834 | 0.834 |
| UOMPWS011[h] | -0.110 | 2.023 | 2.022 |
| TUNE000[i] | -0.099 | 1.908 | 1.908 |

# $^{235}$U (1$^{st}$ round) - assimilated fission



# $^{235}U$ (1st round) - lesson learned

- A single integral experiment can be successfully assimilated even with a poor prior.
  Here, $k_{eff}$=1 was obtained by scaling fission (fusion) cross sections regardless of differential data.
- More integral experiments with diverse characteristics should help.

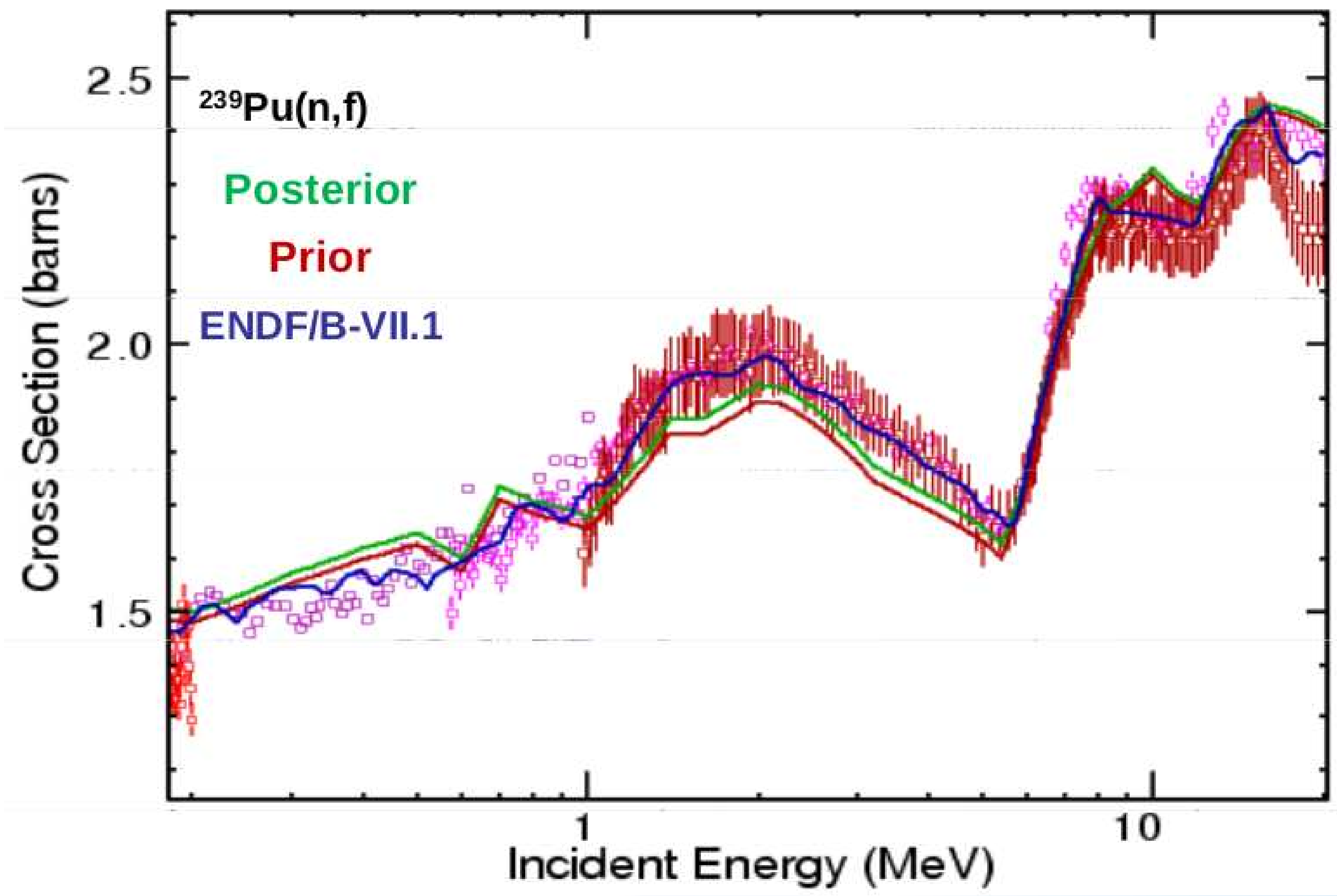
# Assimilation of $^{239}$Pu (1st round)

JEZEBEL

| Experiment | prior C/E $\pm\ \sigma$ | post C/E $\pm\ \sigma$ |
|---|---|---|
| $k_{\mathrm{eff}}$ | $0.9857 \pm 0.002$ | $0..9998 \pm 0.002$ |
| Fis.238U/Fis.235U | $0.9561 \pm 0.009$ | $0.9598 \pm 0.002$ |
| Fis.239Pu/Fis.235U | $0.9708 \pm 0.020$ | $0.9917 \pm 0.003$ |
| Fis.237Np/Fis.235U | $0.9988 \pm 0.017$ | $1.0010 \pm 0.001$ |
| Fis.233U/Fis.235U | $1.0003 \pm 0.017$ | $1.0002 \pm 0.001$ |

- Consistent improvement (except $^{238}$U/$^{235}$U)
- VII.1 and assimilated file equivalent on $k_{\mathrm{eff}}$ but...

# $^{239}$Pu (1st round) - assimilated fission




... NOT for differential experiments

# $^{239}$Pu (1st round) - assimilated parameters

| Parameter | Variation (%) | Prior Std. Dev. (%) | Posterior Std. Dev. (%) |
|---|---|---|---|
| VA000[a] | -0.141 | 0.134 | 0.121 |
| FUSRED000[b] | 0.432 | 0.951 | 0.612 |
| LDSHIF010[c] | 0.299 | 0.705 | 0.692 |
| DELTAF000[d] | -0.120 | 0.671 | 0.668 |
| ATILNO010[e] | -0.076 | 0.965 | 0.958 |
| VB000[f] | -0.079 | 0.480 | 0.479 |
| ATLATF000[g] | 0.128 | 1.240 | 1.239 |
| TOTRED000[h] | -0.0831 | 0.918 | 0.815 |
| HA000[i] | -0.155 | 0.474 | 0.471 |

Assimilation distributed over several parameters

# $^{239}$Pu (1st round) - lesson learned

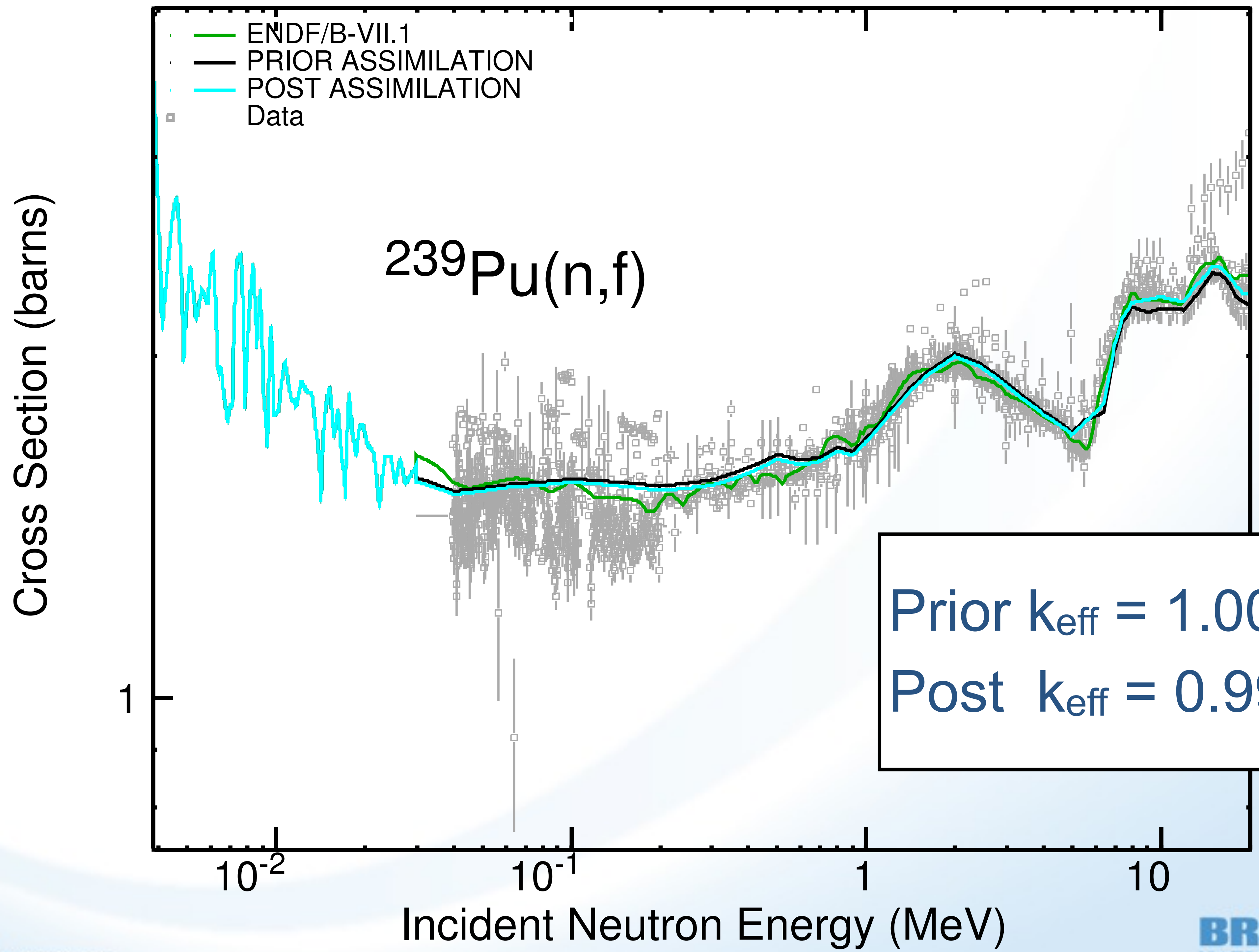
- Perfect agreement with integral parameter can be obtained without satisfactorily reproducing differential data.

**There is no substitute for a good prior!**

# Assimilation of $^{239}$Pu (2nd round)

- New version of EMPIRE with improved fission parametrization (M. Sin)
- Overall very good prior
- EMPIRE calculated PFNS included in assimilation
- Direct assimilation on JEZEBEL's $k_{eff}$ using MCNP performed at BNL.

# $^{239}$Pu (2nd round) assimilated fission




Prior $k_{eff}$ = 1.00516 (8)

Post $k_{eff}$ = 0.99959 (8)

# $^{239}$Pu (2nd round) - assimilated parameters

| Parameter Name | pre-assimilation | post-assimilation |
|---|---|---|
| ATILNO-000 | 1.083 | 1.0851 |
| ATILNO-001 | 0.907 | 0.9034 |
| ATILNO-020 | 0.938 | 0.9380 |
| ATILNO-030 | 0.988 | 0.9880 |
| TUNEFI-010 | 0.833 | 0.8327 |
| TUNE-000 | 2.228 | 2.2230 |
| FUSRED-000 | 0.970 | 0.9700 |
| RESNOR-000 | 1.320 | 1.3200 |
| FISVF1-000 | 1.000 | 0.9995 |
| FISVF1-010 | 1.000 | 1.0005 |
| FISVF2-000 | 1.000 | 1.0042 |
| FISVE1-000 | 1.000 | 0.9985 |
| FISVE2-000 | 1.000 | 0.9995 |
| FISHO1-000 | 1.000 | 0.9992 |
| FISHO2-000 | 1.000 | 0.9992 |
| FISAT1-000 | 0.917 | 0.9157 |
| FISAT2-000 | 0.971 | 0.9717 |
| FISAT2-010 | 0.981 | 0.9810 |
| FISDL1-000 | 1.000 | 0.9999 |
| FISDL2-000 | 1.000 | 0.9999 |
| LDSHIF-000 | 1.100 | 1.0990 |
| LDSHIF-010 | 1.063 | 1.0647 |
| LDSHIF-020 | 0.917 | 0.9170 |
| PFNALP-000 | 0.963 | 0.9613 |
| PFNRAT-000 | 0.928 | 0.9279 |
| PFNERE-000 | 0.999 | 1.0002 |
| PFNTKE-000 | 0.984 | 0.9853 |

- The change required for assimilation is very small in comparison to the uncertainties of the experimental data sets.
- Tiny changes in the parameters are well within the prior uncertainties of the parameters

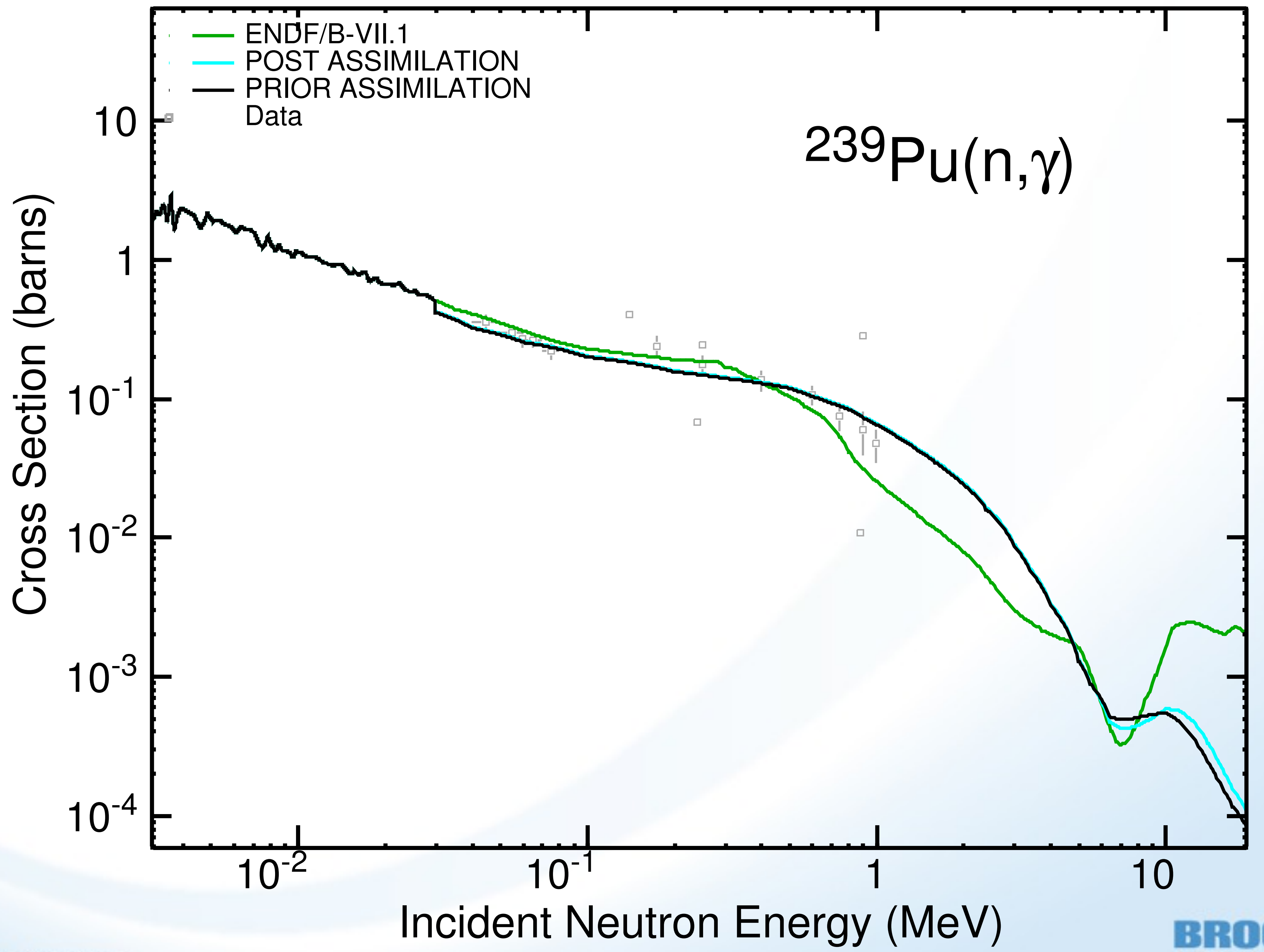
# $^{239}$Pu (2$^{nd}$ round) - post-assimilation covariance matrix

| | Parameter | 1 | 2 | 3 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 13 | 14 | 16 | 17 | 18 | 20 | 23 | 24 | 26 | 34 | 37 | 38 | 46 | 47 | 48 | 50 | 51 | 52 | 53 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ATILNO-000[a] | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | ATILNO-010[a] | 4 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | ATILNO-020[a] | -2 | 0 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | TUNEFI-010[b] | 0 | 1 | 4 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | TUNEFI-000[b] | -1 | 2 | -1 | 0 | 100 | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | TUNE-000[c] | -19 | -2 | 1 | 0 | -1 | 100 | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | TOTRED-000[d] | 0 | 0 | 0 | 0 | 0 | 0 | 100 | | | | | | | | | | | | | | | | | | | | | | |
| 10 | FUSRED-000[d] | 0 | 0 | 0 | 0 | 0 | 0 | -98 | 100 | | | | | | | | | | | | | | | | | | | | | |
| 11 | RESNOR-000[e] | -5 | 15 | -7 | 1 | 0 | 2 | 1 | 0 | 100 | | | | | | | | | | | | | | | | | | | | |
| 12 | FISVF1-000[f] | -3 | 47 | -12 | 2 | 8 | -3 | 0 | 0 | 17 | 100 | | | | | | | | | | | | | | | | | | | |
| 13 | FISVF1-010[f] | -2 | -13 | 22 | -2 | 0 | 1 | 0 | 0 | -47 | -7 | 100 | | | | | | | | | | | | | | | | | | |
| 14 | FISVF1-020[f] | 2 | 6 | -21 | -1 | 0 | -1 | 0 | 0 | 0 | 0 | -5 | 100 | | | | | | | | | | | | | | | | | |
| 16 | FISVF2-000[f] | -13 | -38 | 17 | -3 | 12 | 4 | 0 | 0 | -19 | -67 | 6 | 3 | 100 | | | | | | | | | | | | | | | | |
| 17 | FISVF2-010[f] | -2 | -5 | -21 | 19 | -1 | 0 | 0 | 0 | -2 | -16 | -26 | 2 | 22 | 100 | | | | | | | | | | | | | | | |
| 18 | FISVF2-020[f] | 0 | 3 | -24 | -1 | 0 | 0 | 0 | 0 | 0 | -2 | 1 | -29 | 4 | 6 | 100 | | | | | | | | | | | | | | |
| 20 | FISVE1-000[g] | -1 | -2 | 0 | 0 | -1 | -1 | 0 | 0 | 0 | 17 | 0 | 0 | 9 | 0 | 0 | 100 | | | | | | | | | | | | | |
| 23 | FISVE2-000[g] | -2 | 7 | -2 | 0 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | -2 | 0 | -1 | 100 | | | | | | | | | | | | |
| 24 | FISVE2-010[g] | 0 | 0 | 5 | -2 | 0 | 0 | 0 | 0 | 0 | 2 | -1 | 0 | -3 | 12 | 0 | 0 | 0 | 100 | | | | | | | | | | | |
| 26 | FISHO1-000[h] | 4 | 3 | 1 | 0 | 2 | 1 | -1 | 0 | 6 | 34 | 0 | -2 | 3 | 0 | 0 | 1 | 2 | 0 | 100 | | | | | | | | | | |
| 34 | FISAT1-000[i] | -1 | 10 | -3 | 1 | -1 | -1 | 0 | 0 | 1 | 3 | -3 | 1 | 20 | -4 | 0 | -1 | -2 | 0 | -1 | 100 | | | | | | | | | |
| 37 | FISAT2-000[i] | -2 | 67 | 21 | -3 | -2 | 0 | 0 | 0 | -4 | -2 | 10 | 7 | 20 | 20 | 8 | 0 | -4 | -3 | 3 | -3 | 100 | | | | | | | | |
| 38 | FISAT2-010[i] | 2 | -1 | 37 | -3 | 0 | -1 | 0 | 0 | 4 | 7 | -12 | 12 | -10 | 17 | 17 | 0 | 1 | -3 | -1 | 2 | -14 | 100 | | | | | | | |
| 46 | LDSHIF-000[j] | 21 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 2 | 3 | 0 | -1 | 2 | 0 | 0 | 0 | 1 | 0 | -4 | 0 | 1 | 0 | 100 | | | | | | |
| 47 | LDSHIF-010[j] | -9 | -18 | 5 | -1 | -7 | -1 | 1 | 0 | -17 | -13 | -15 | 7 | 50 | 7 | 3 | -10 | -6 | -1 | 11 | -6 | 8 | -2 | 2 | 100 | | | | | |
| 48 | LDSHIF-020[j] | 0 | 1 | 1 | -6 | 0 | 0 | 0 | 0 | 1 | 3 | -5 | -4 | -3 | 30 | -8 | 0 | 0 | -3 | 0 | 0 | -2 | -1 | 0 | -1 | 100 | | | | |
| 50 | PFNALP-000[k] | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | -1 | 1 | -1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 100 | | | |
| 51 | PFNRAT-000[k] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 65 | 100 | | |
| 52 | PFNERE-000[k] | -1 | 2 | -1 | 0 | 0 | 1 | 0 | 0 | -2 | 1 | -1 | 1 | -4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 | -65 | -1 | 100 | |
| 53 | PFNTKE-000[k] | -1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -2 | 1 | -1 | 1 | -4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 | -24 | 44 | 88 | 100 |

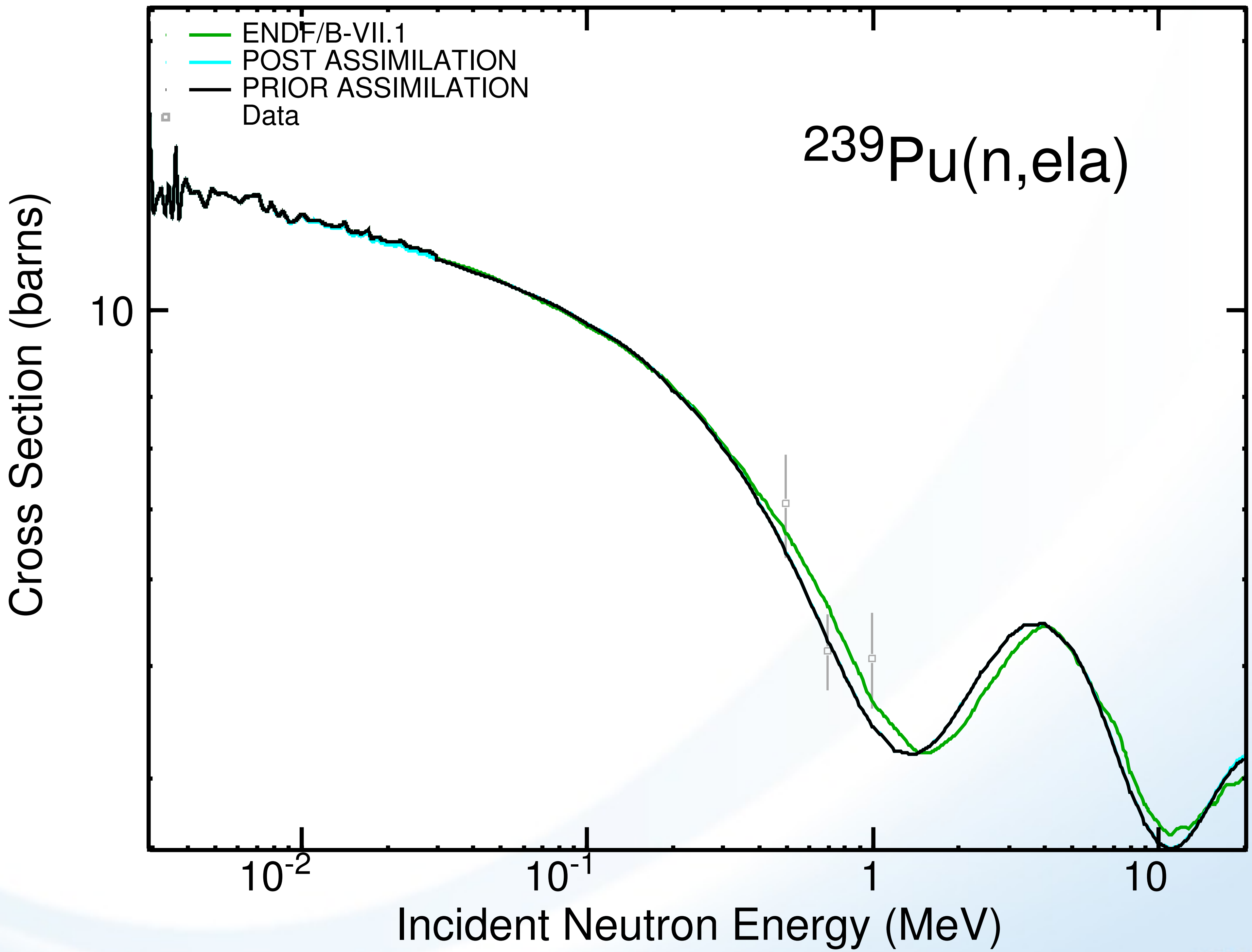
PFNS

Little correlations between PFNS and x-sec parameters

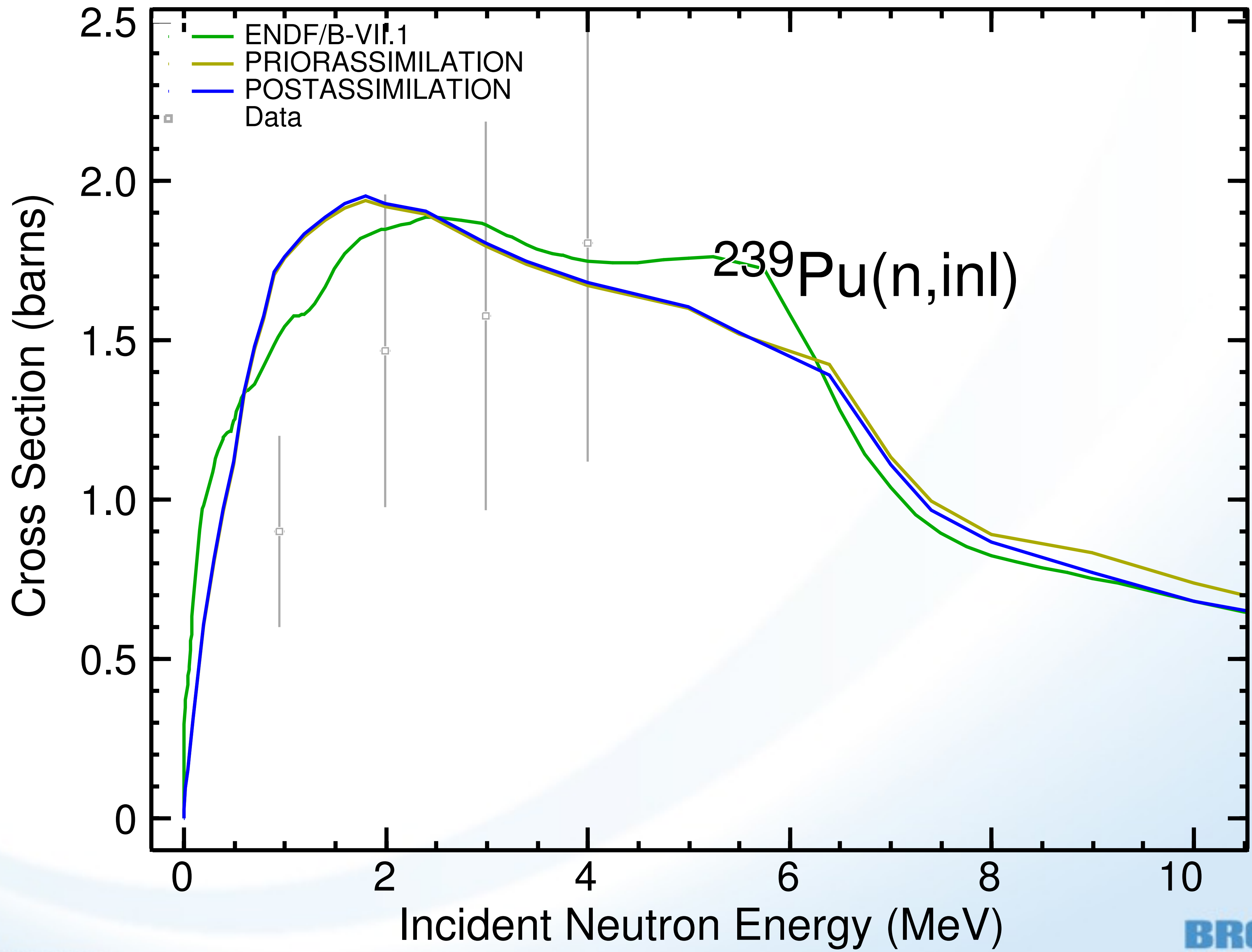
# $^{239}$Pu (2$^{nd}$ round) - assimilated capture



# $^{239}Pu$ ($2^{nd}$ round) - assimilated elastic



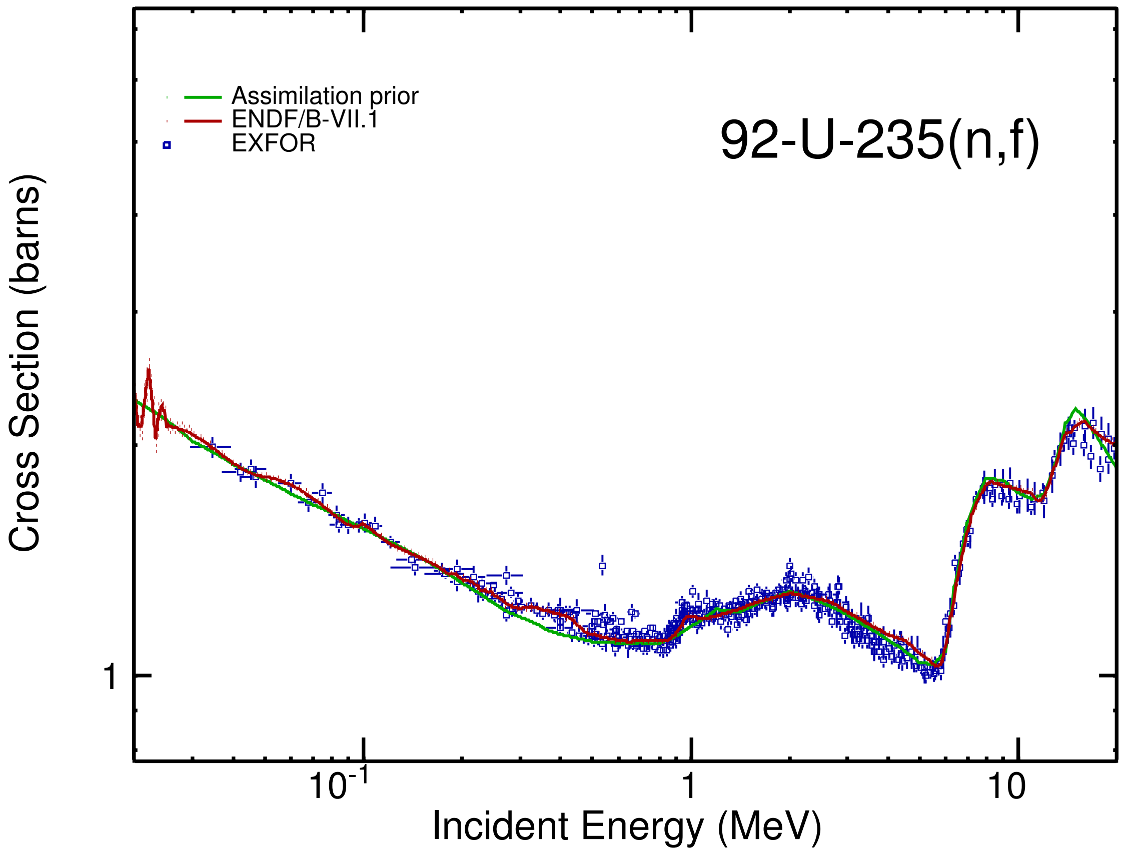
# $^{239}$Pu (2nd round) - assimilated inelastic

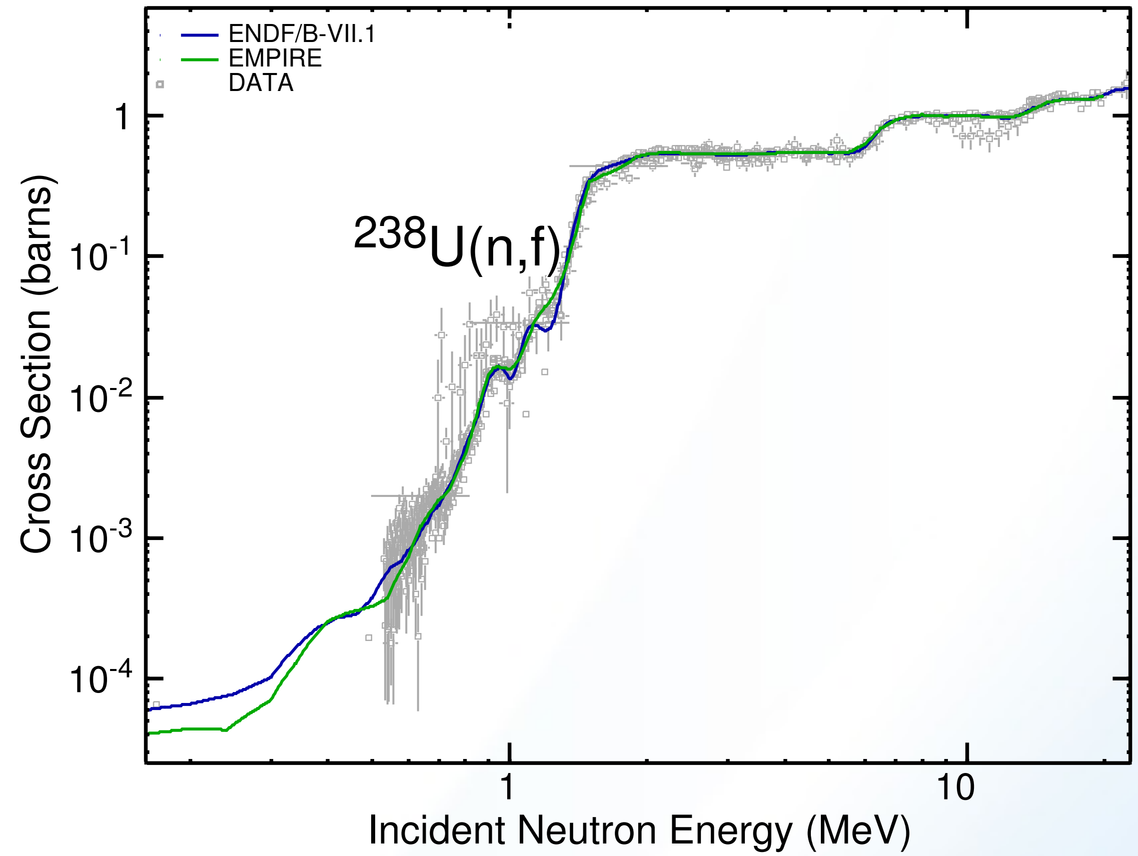


# $^{239}Pu$ (2nd round) - lesson learned

- Successful assimilations when starting with good prior
- Reduction of uncertainties in the model parameters and consequently also in the calculated integral result
- Little correlations among x-sec and PFNS parameters

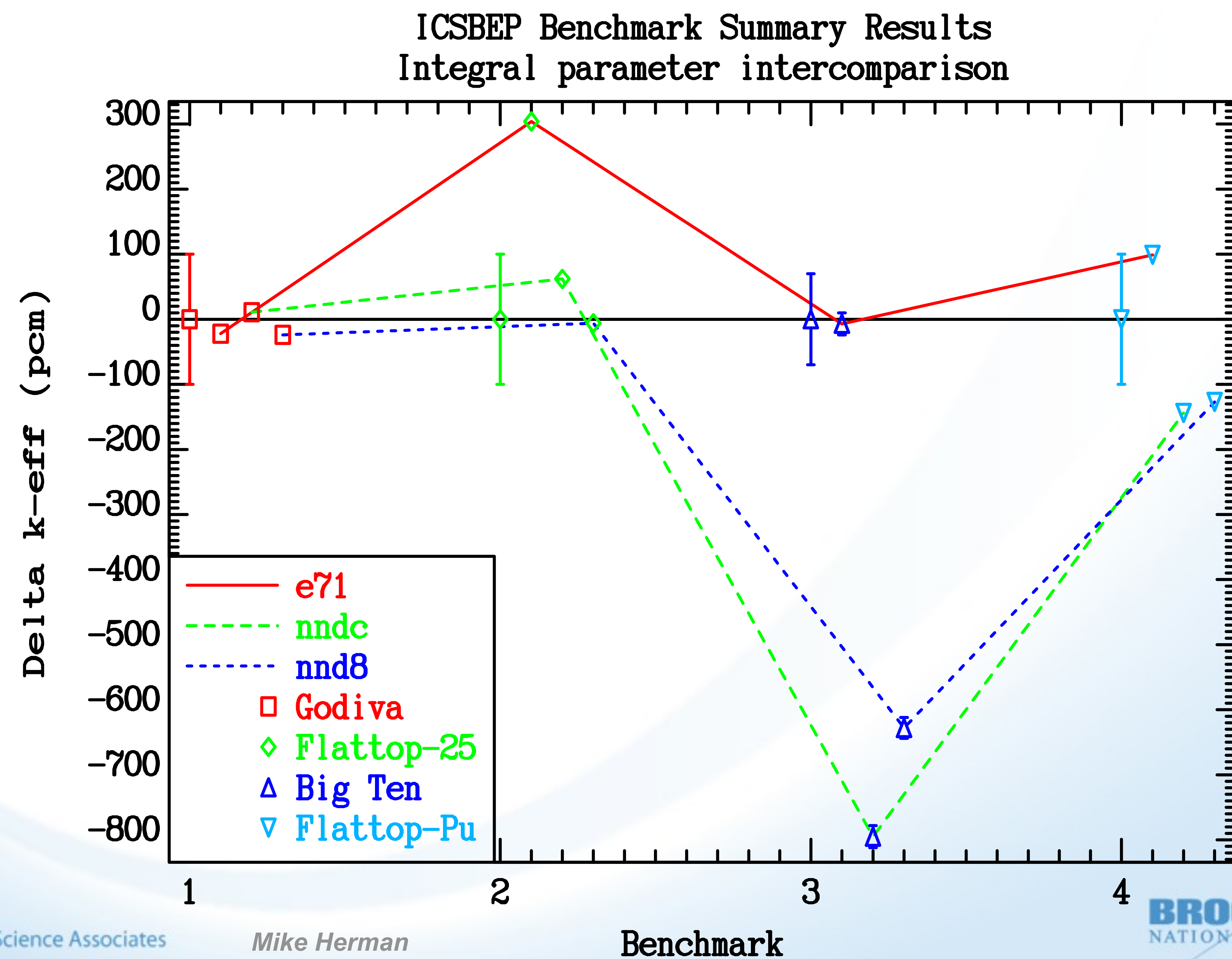
# Assimilation priors for $^{235}U$ and $^{238}U$ (2nd round)



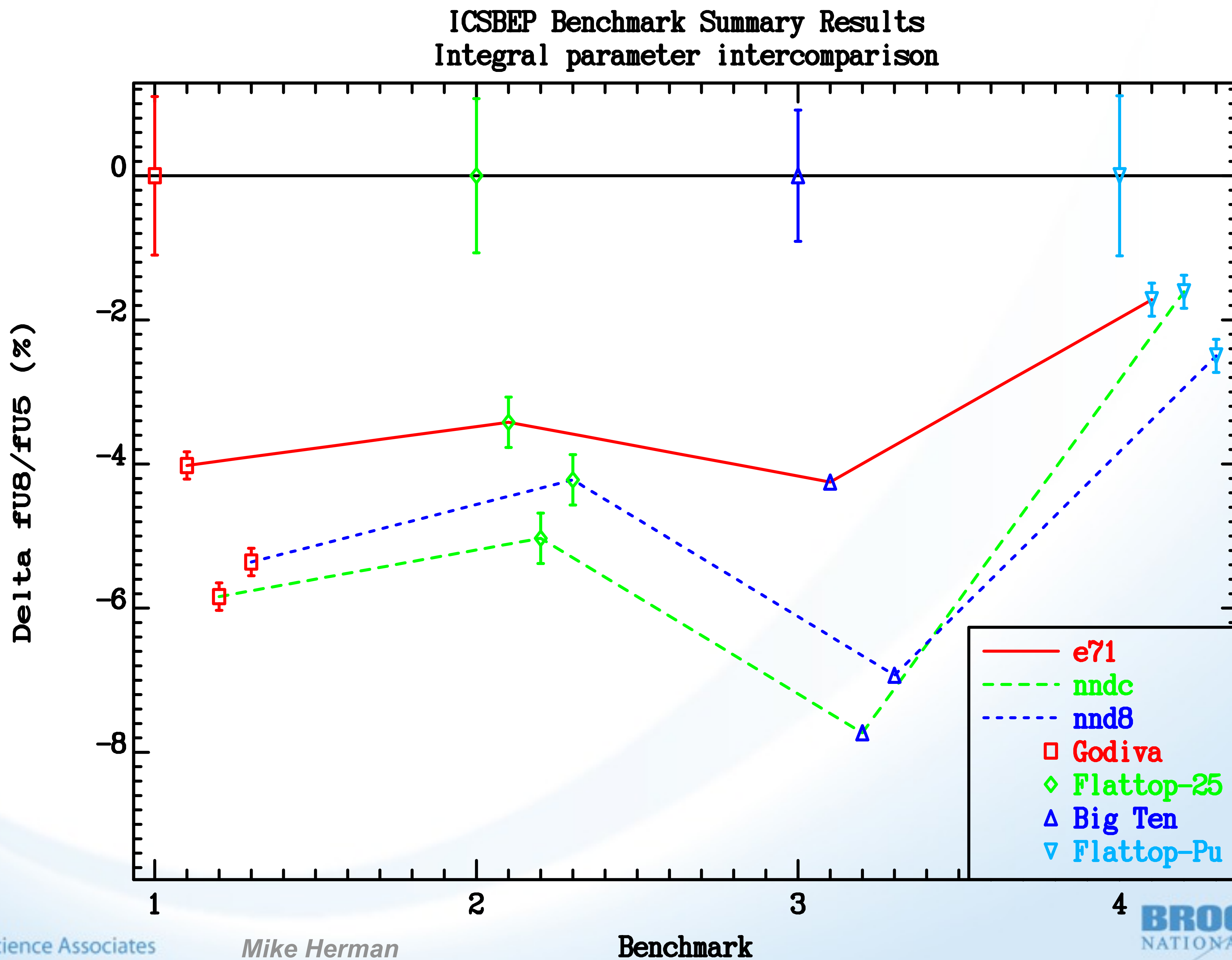




- Both standards and reproduced within about 2% (standards uncertainties)
- 14 levels coupled in $^{238}U$ calculations

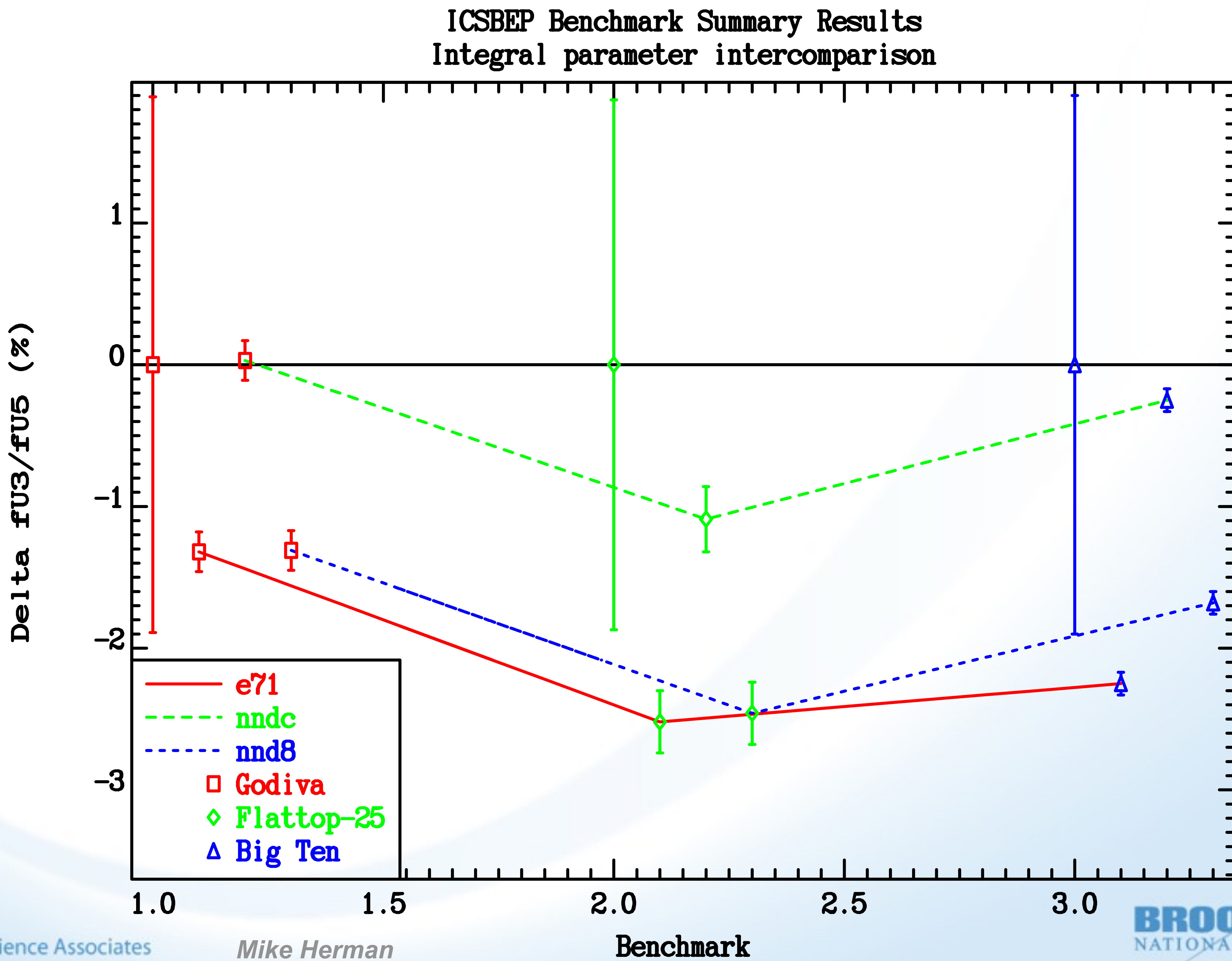
# Benchmarking new priors for $^{235}U$ and $^{238}U$



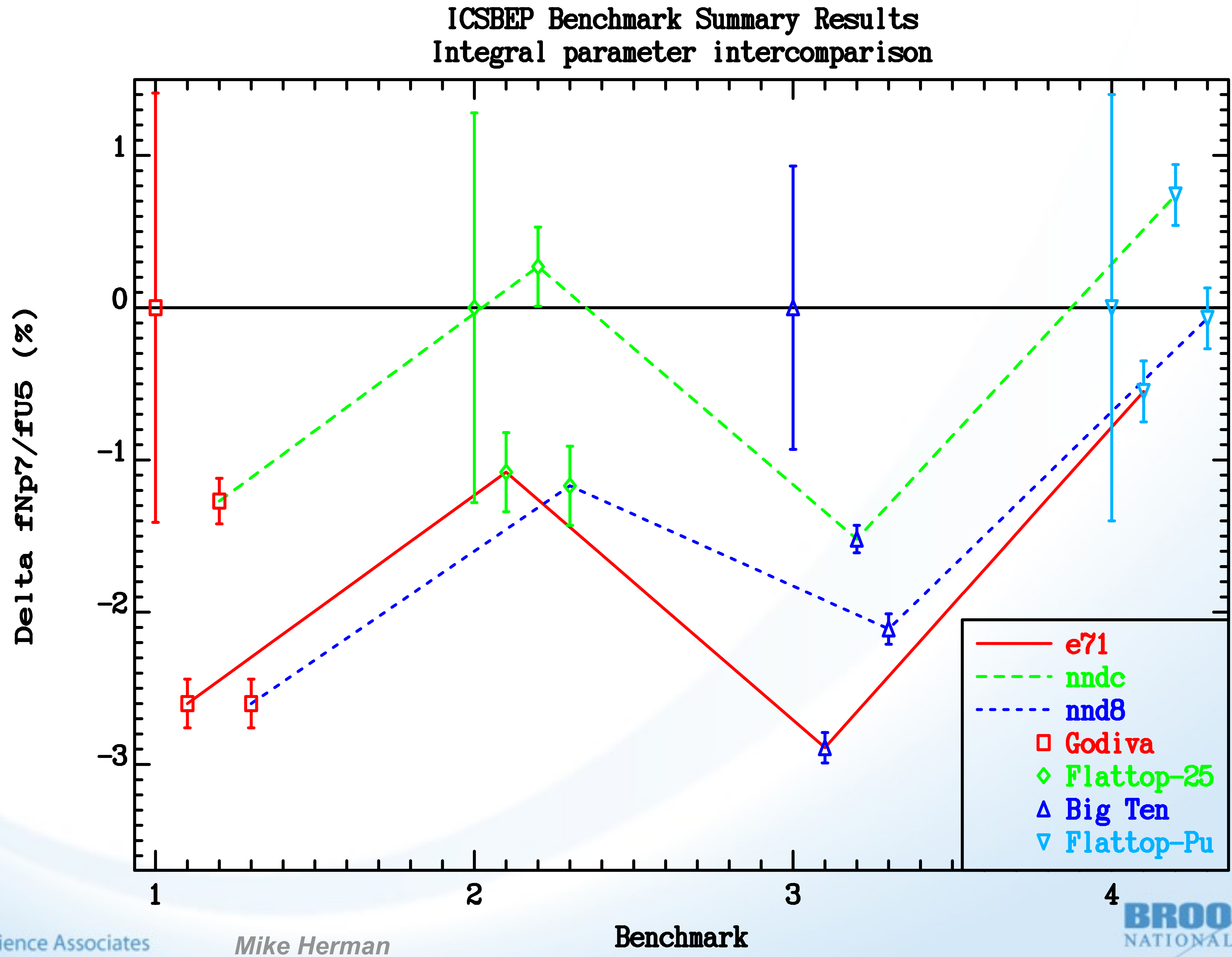
# Benchmarking new priors for $^{235}U$ and $^{238}U$



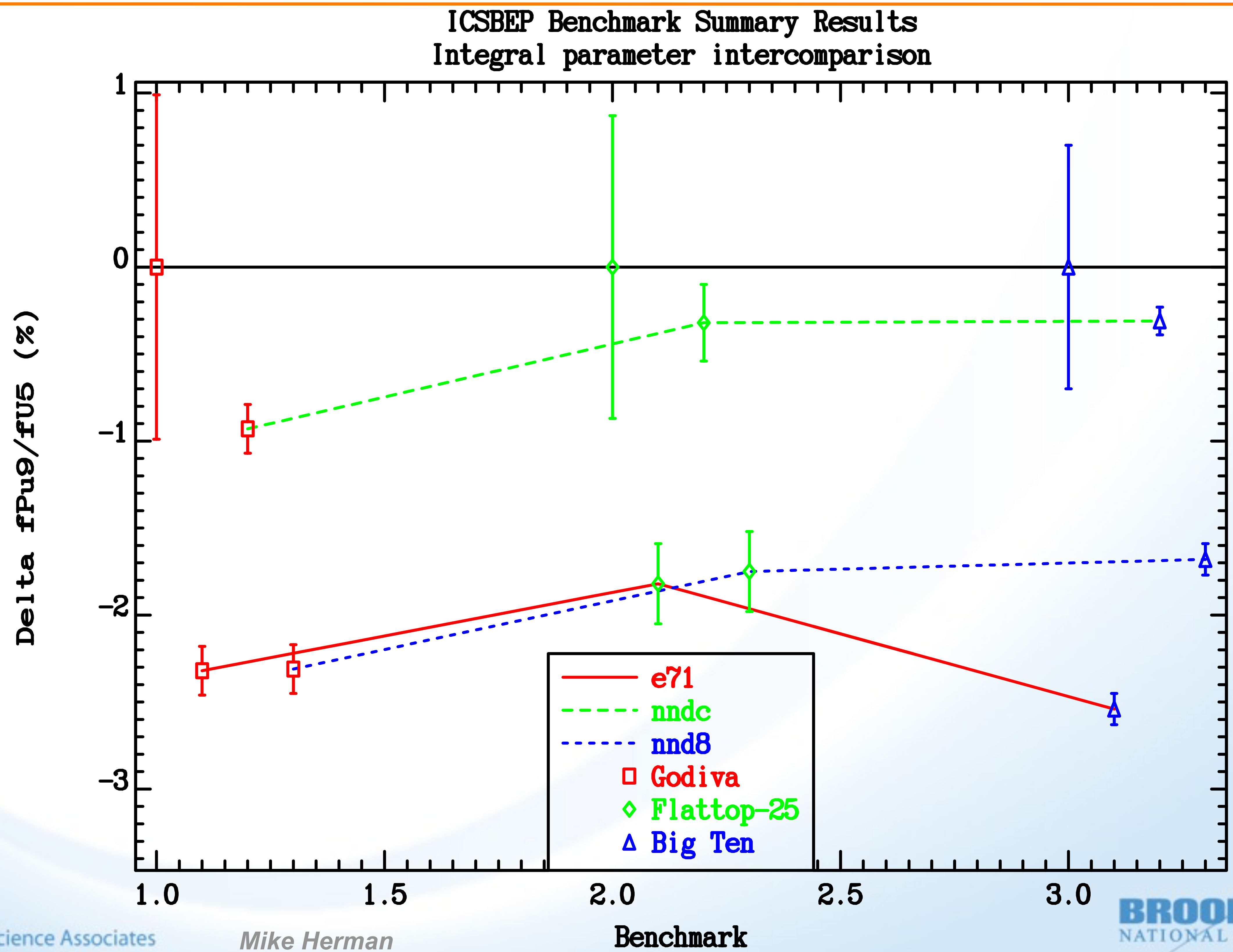
# Benchmarking new priors for $^{235}$U and $^{238}$U



# Benchmarking new priors for $^{235}U$ and $^{238}U$



# Benchmarking new priors for $^{235}U$ and $^{238}U$



# Assimilation priors for $^{235}U$ and $^{238}U$ - lesson learned

- Fully model based priors of a quality comparable to modern evaluations are possible!

# Conclusions

- **Assimilation pitfalls**
  - non-linearity
  - fluctuations in cross sections
  - selection of experimental data
  - PPP
  - anti-correlations driving parameters out of physical range
- **Assimilation prerequisites**
  - realistic covariances and correlations among measurements
  - good physics/modeling resulting in **good** prior
  - realistic weighting of differential and integral experiments
  - verity of experiments probing different aspects
- **Assimilation is feasible**

# Conclusions

Changes much smaller than experimental cross section or model uncertainties are sufficient for a good prior to reproduce integral measurements. Thus:

- differential data based evaluation is unlikely to predict integral experiment within its precision
- integral data are not sufficient to turn a bad prior into a good one
- only all experimental information combined with the state of the art modeling may provide a right answer