Consistent Data Adjustment

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a passion for discovery

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Cecil Lubitz' Opinions about Evaluation

- You can't ***measure*** cross sections well enough for reactor design purposes.
- You can't ***calculate*** cross sections well enough for reactor design purposes.
- When you do measure them, or do calculate them, you have no ***objective*** way of determining their accuracy.
- The only ***objective*** of quality is the agreement between differential and integral data.

Thoughts on evaluation, cont.

- ***They could both be wrong*** ... but even when they are, it's still the best you can do ... and for most purposes it's good enough.

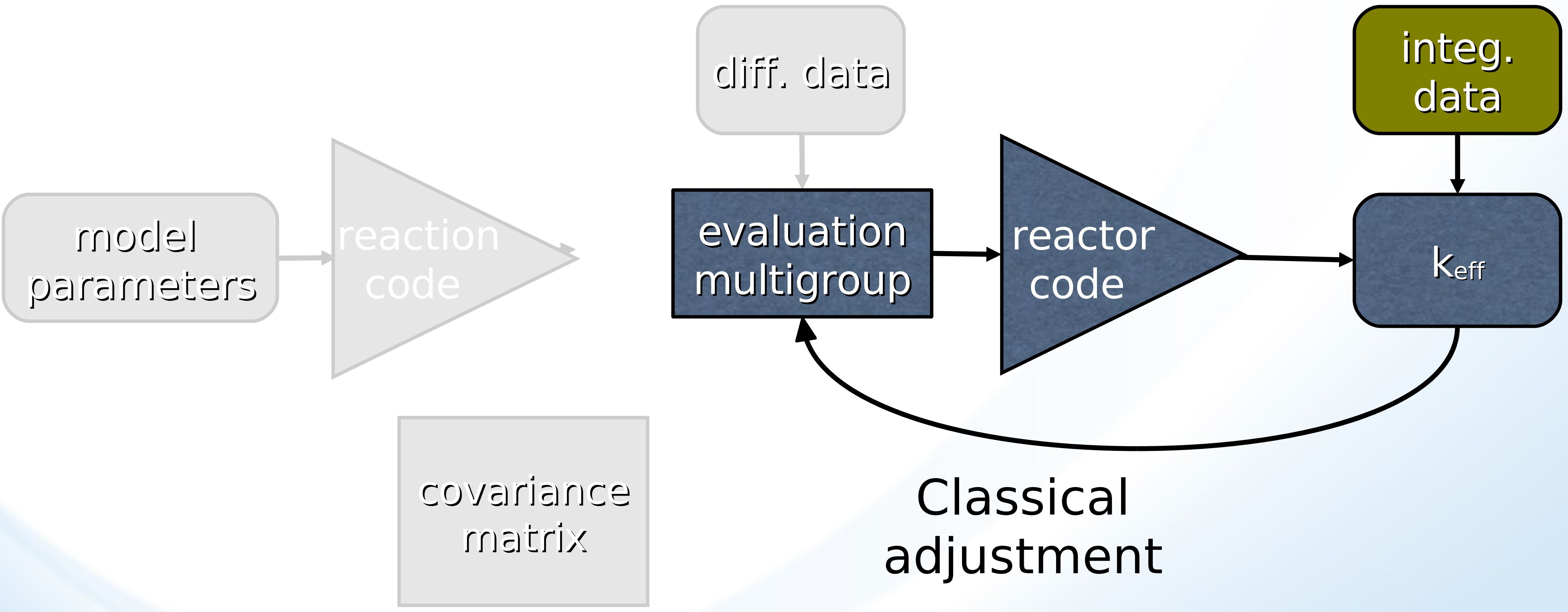
- Experimental (differential) measurements establish a "volume", not a "value" ... and the evaluator is free to move about inside that "volume" to optimize ***the integral agreement***. It is "never" where the ***experimental average*** is.

Consistent adjustment (assimilation)

linking reaction theory and integral experiments

INL + BNL

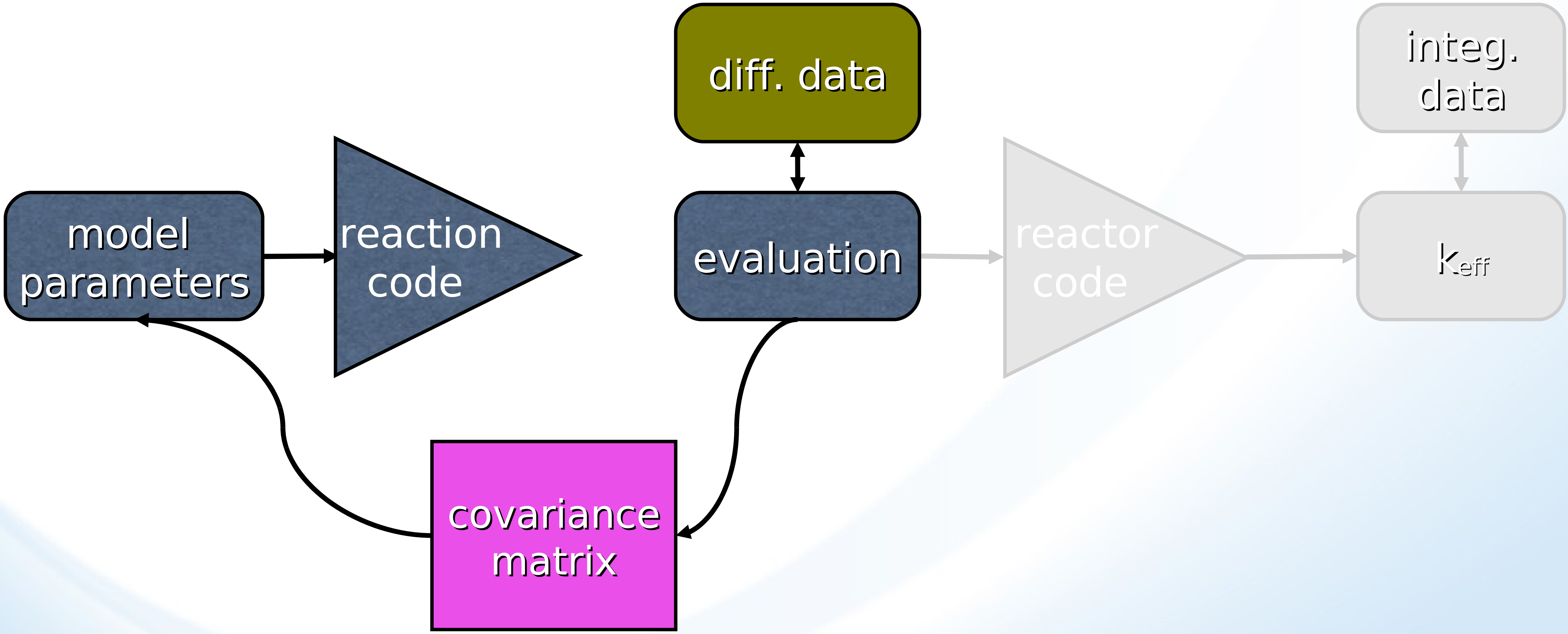
- Users often tune multi-group evaluated files to a certain type of integral experiments
- Such adjusted file is only valid for a specific application



Consistent adjustment (assimilation)

linking reaction theory and integral experiments

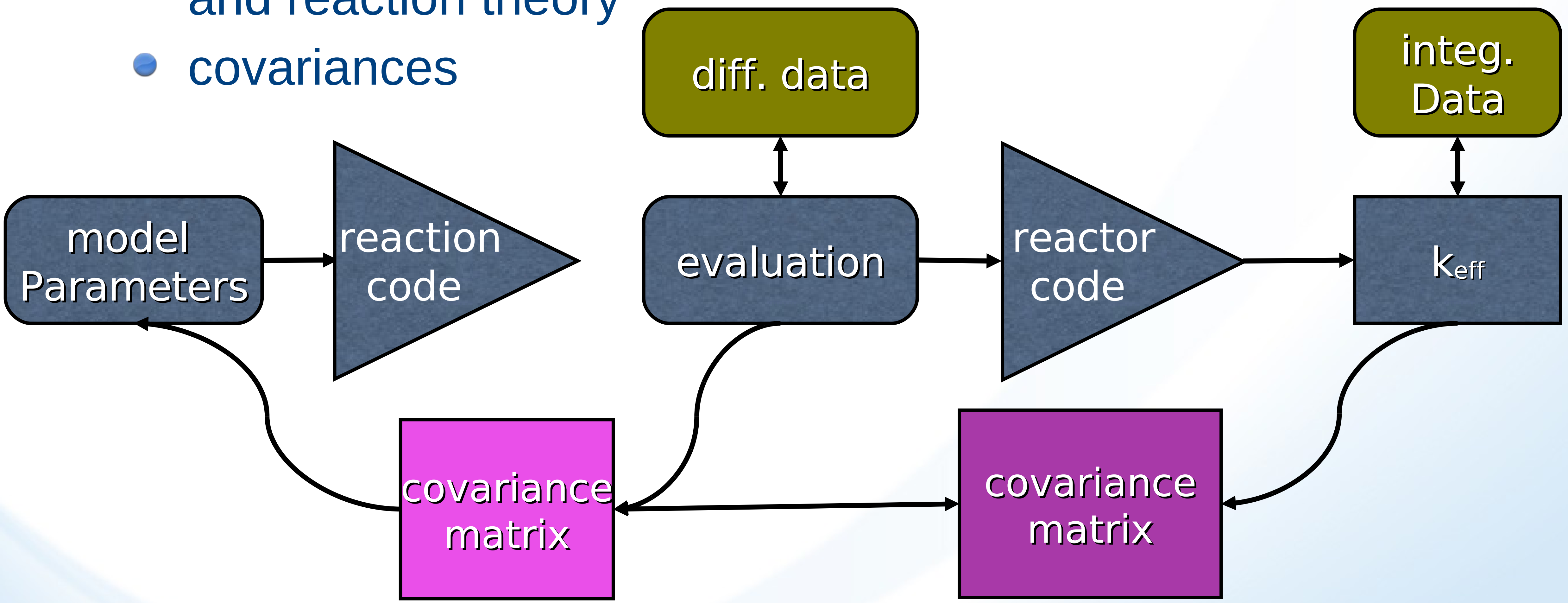
- Modern practice is to use nuclear reaction code constrained by experimental data to produce evaluation and covariances



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



Assimilation

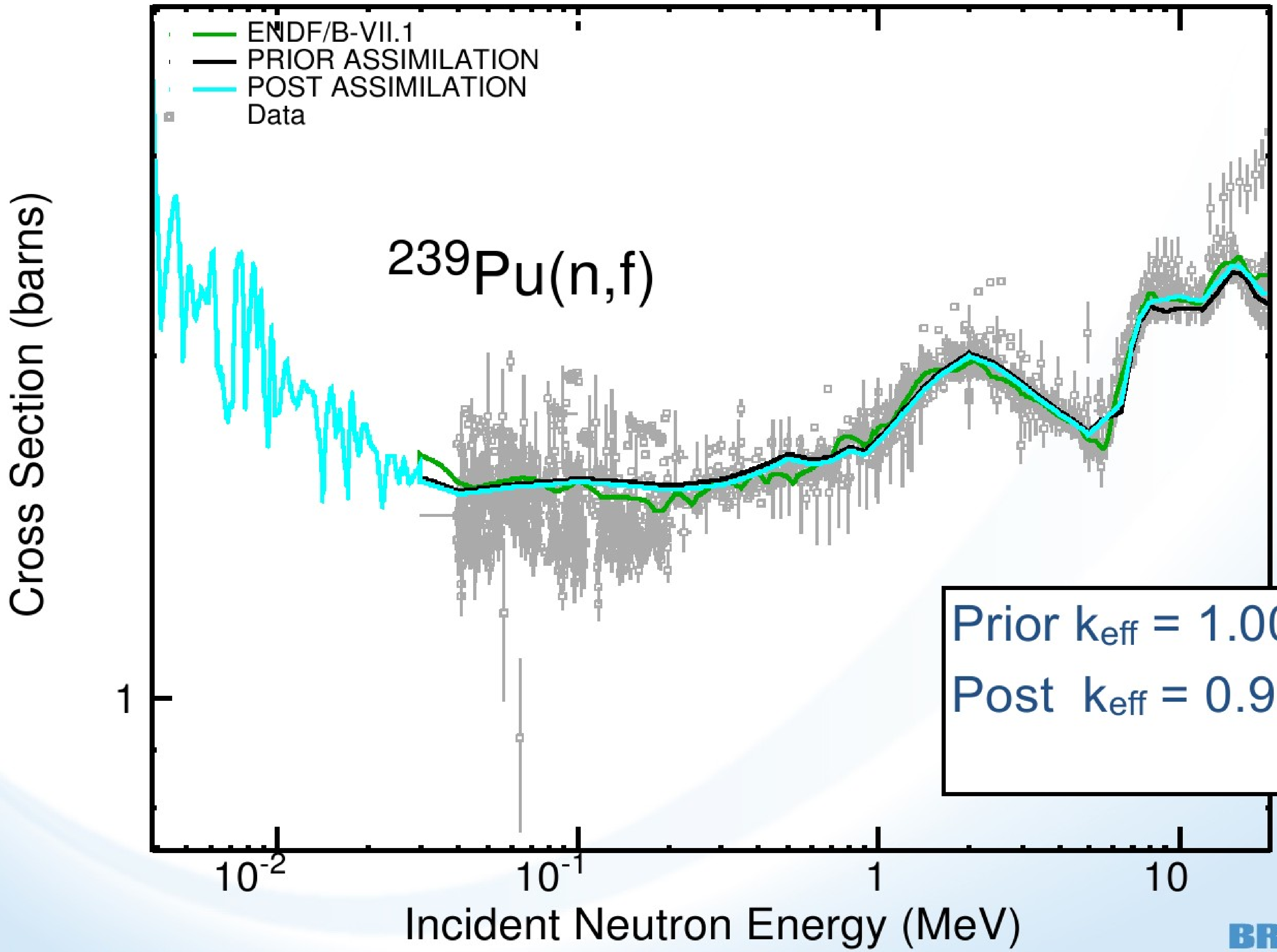
Assimilation - consistent adjustment

- Benefits
  - Application independent (or less dependent) adjustment (no multi-group structure)
  - Reduced target uncertainties
  - Correlations (x-experiment, x-materials, x-reactions)
  - Cohesion of integral and differential experiments and nuclear reaction theory
    - Better model parameters
    - More reliable (physics constrained) data

Assimilation for ^{239}Pu (2nd round)

- EMPIRE-3.1 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.

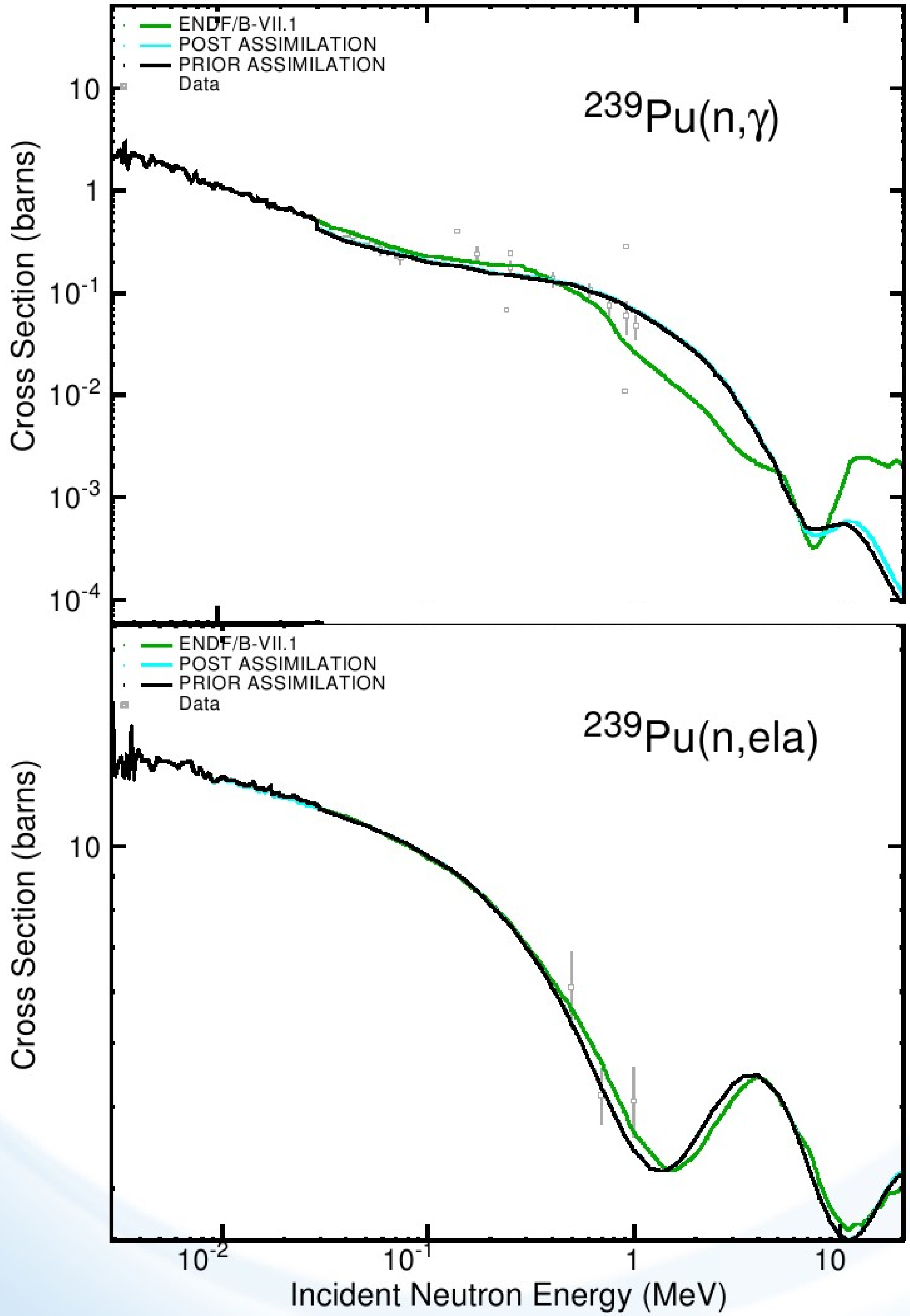
^{239}Pu assimilated fission

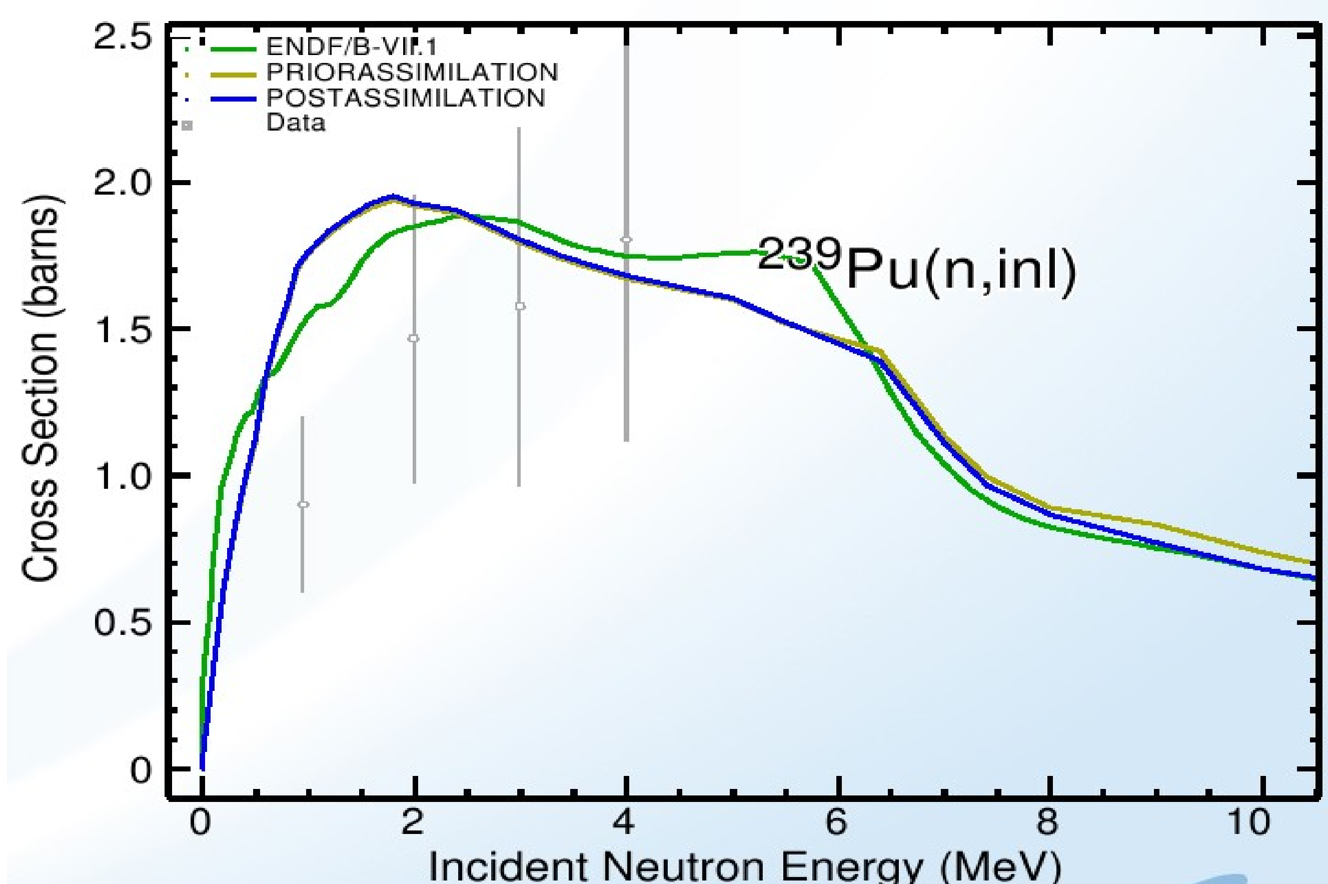


Prior k_{eff} = 1.00516 (8)

Post k_{eff} = 0.99959 (8)

Assimilated cross sections vs VII.1





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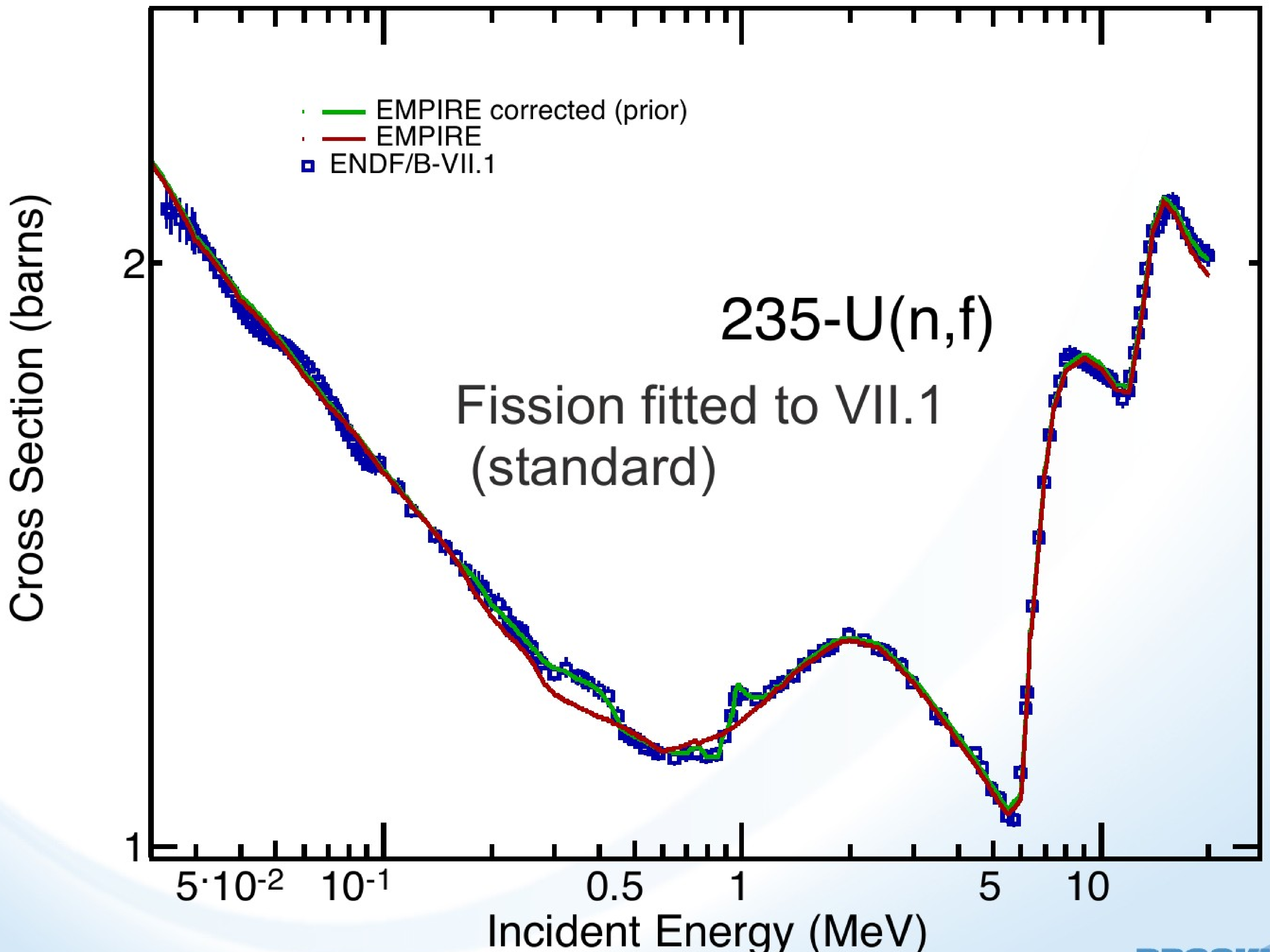
^{239}Pu - assimilated parameters

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

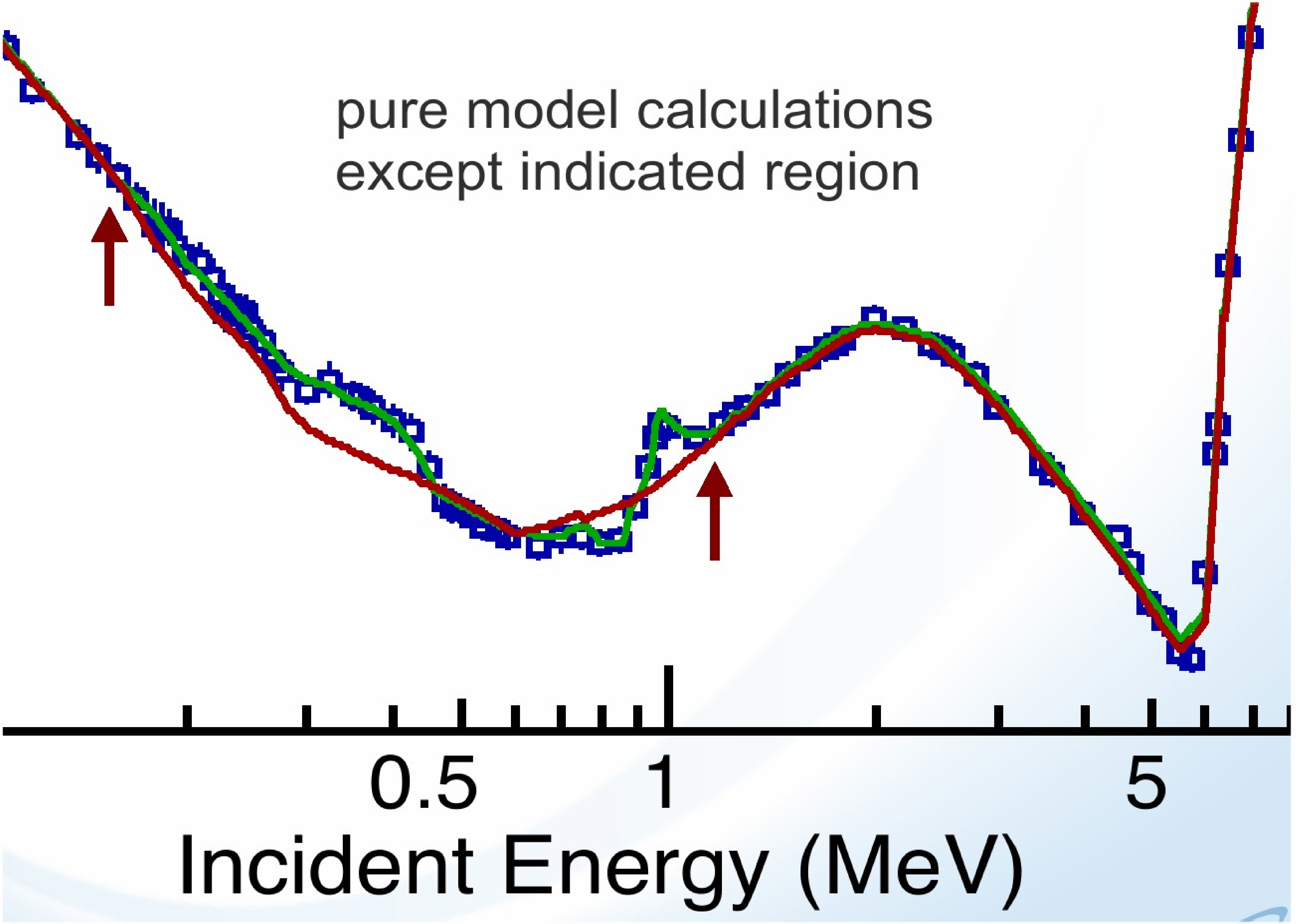
- Changes required for assimilation are very small compared to experimental uncertainties.
- Changes in the parameters even smaller.
- Impossible to determine with such precision from differential data only!

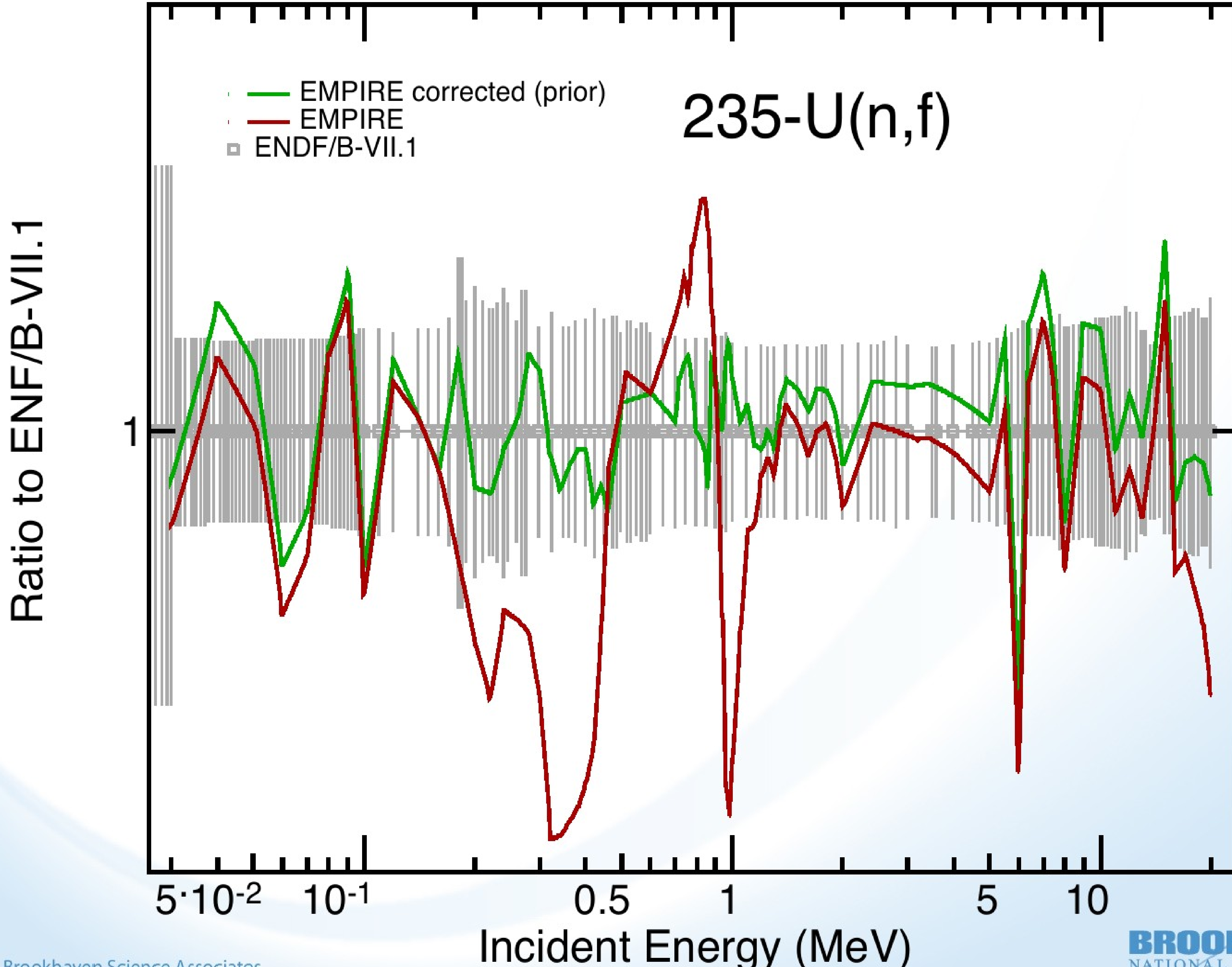
Assimilation for ^{235}U (3rd round)

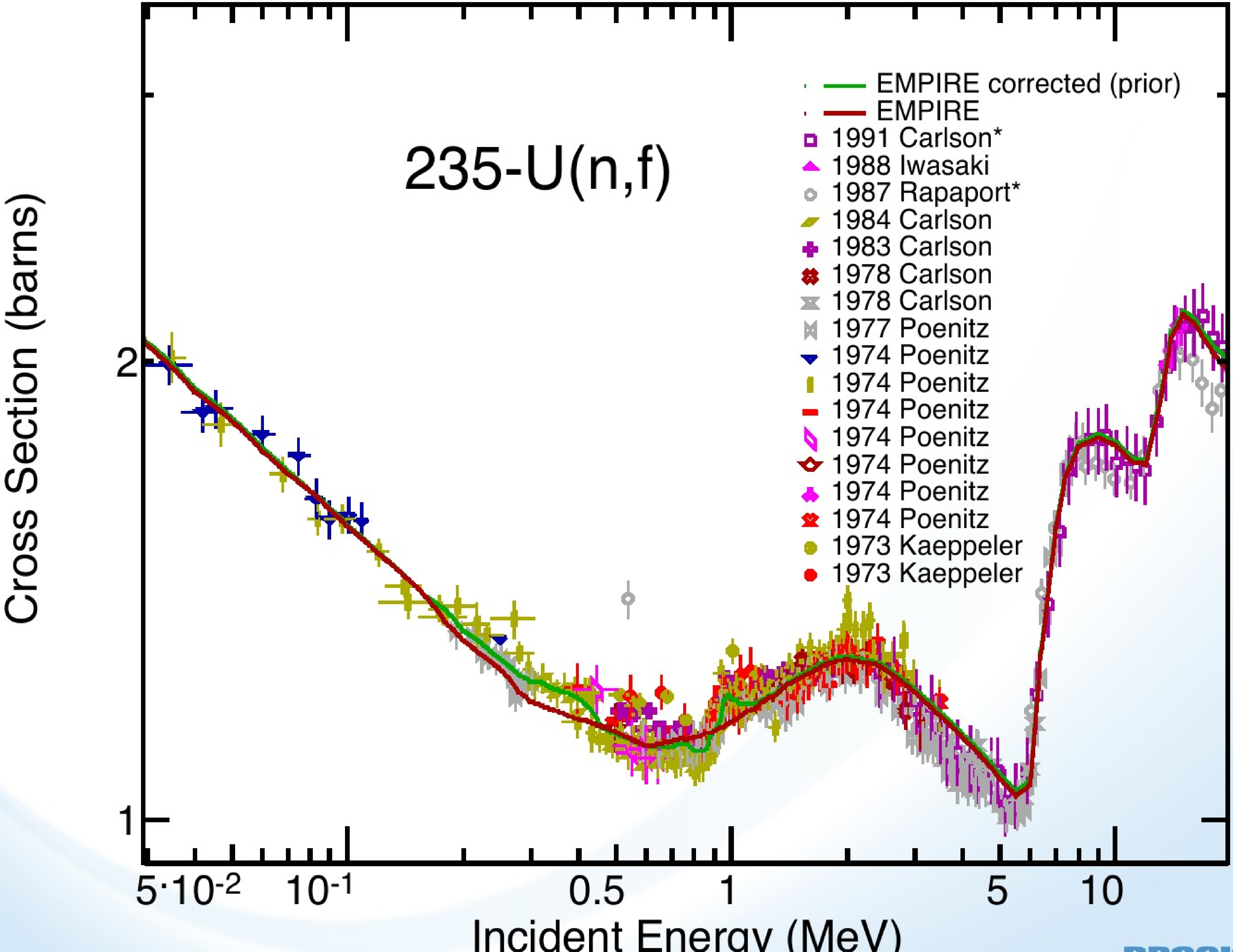
- EMPIRE-3.1 with improved fission parametrization
- Overall very good prior
- EMPIRE calculated PFNS included in assimilation
- Direct assimilation using MCNP
- Anisotropic CN elastic
- nu-bar included in assimilation
- Multi-experiment:
  - BIGTEN, FLATTOP U-235, GODIVA HEU
  - k_{eff} and spectral indices.

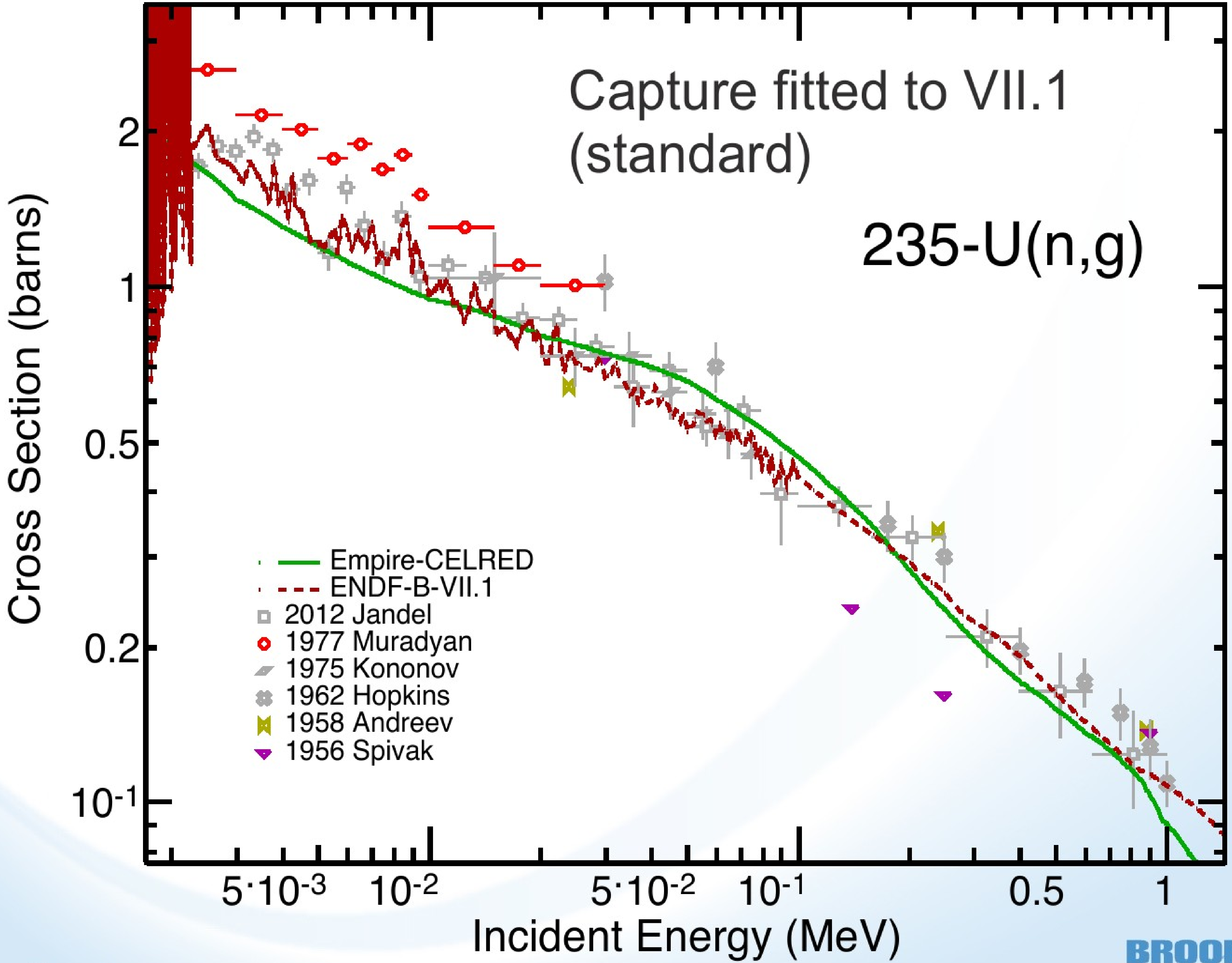


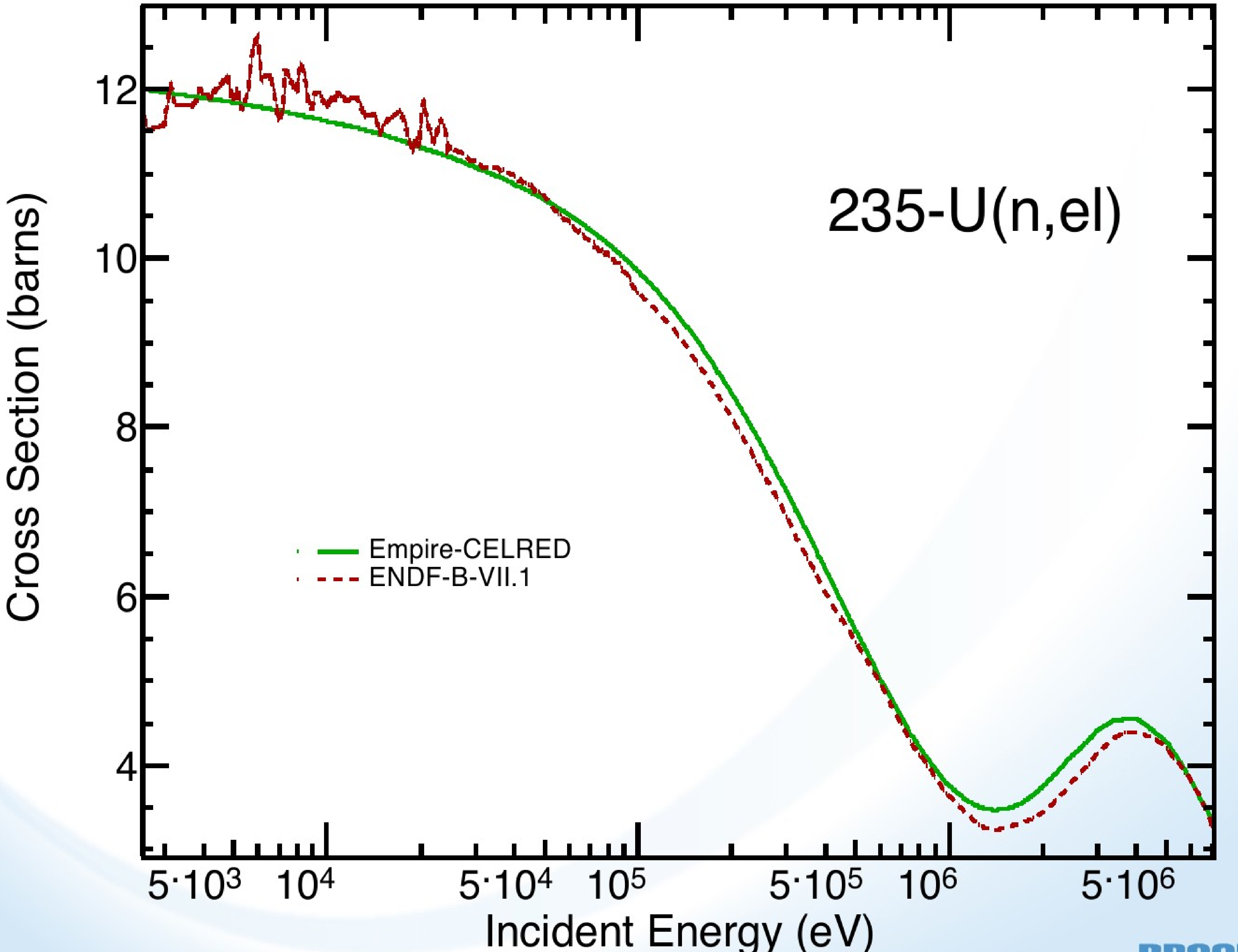
EMPIRE corrected (prior)
EMPIRE
ENDF/B-VII.1
235-U(n,f)
Fission fitted to VII.1
(standard)
Cross Section (barns)
2
1
5·10-2
10-1
0.5
1
5
10
Incident Energy (MeV)

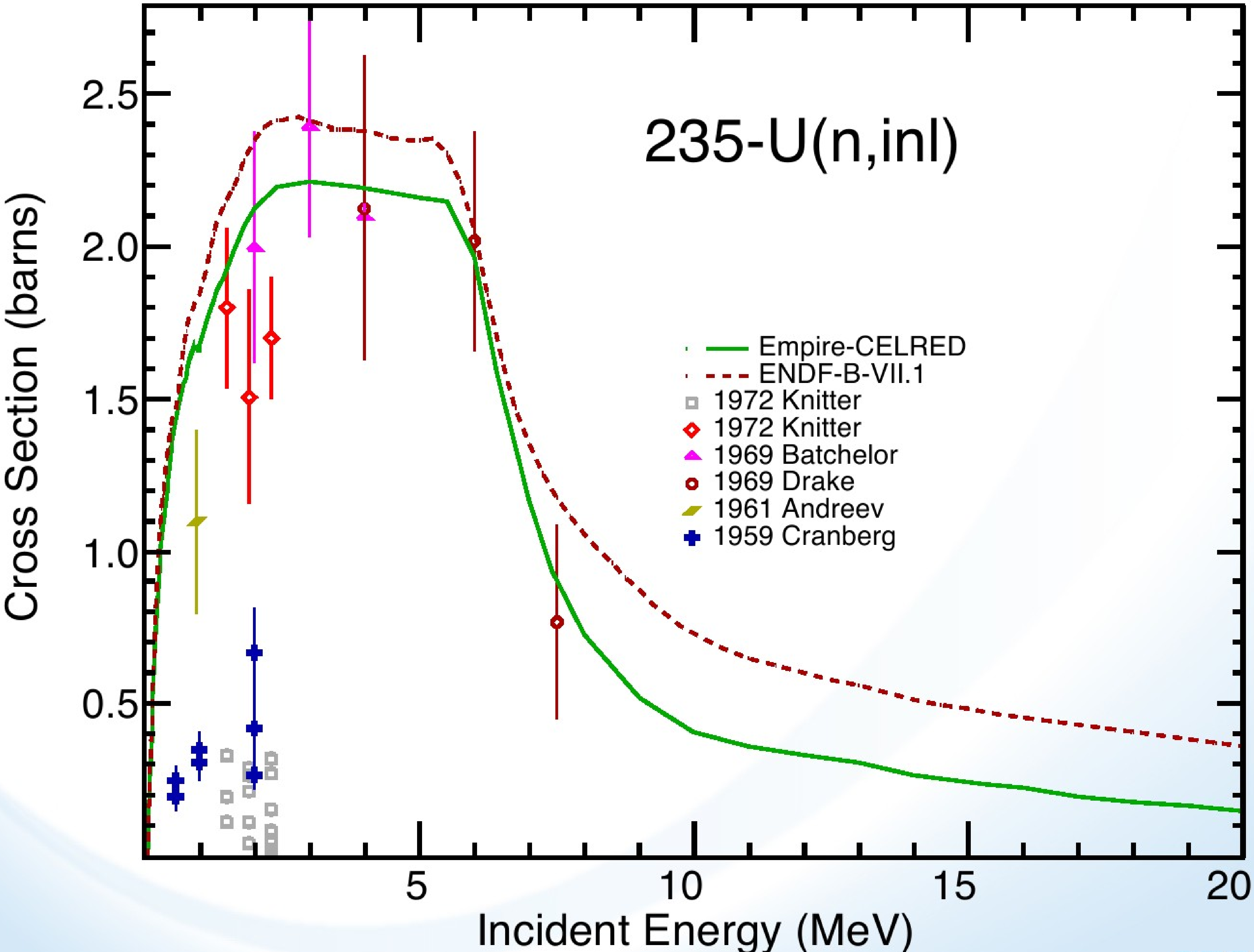

pure model calculations
except indicated region
0.5
1
5
Incident Energy (MeV)

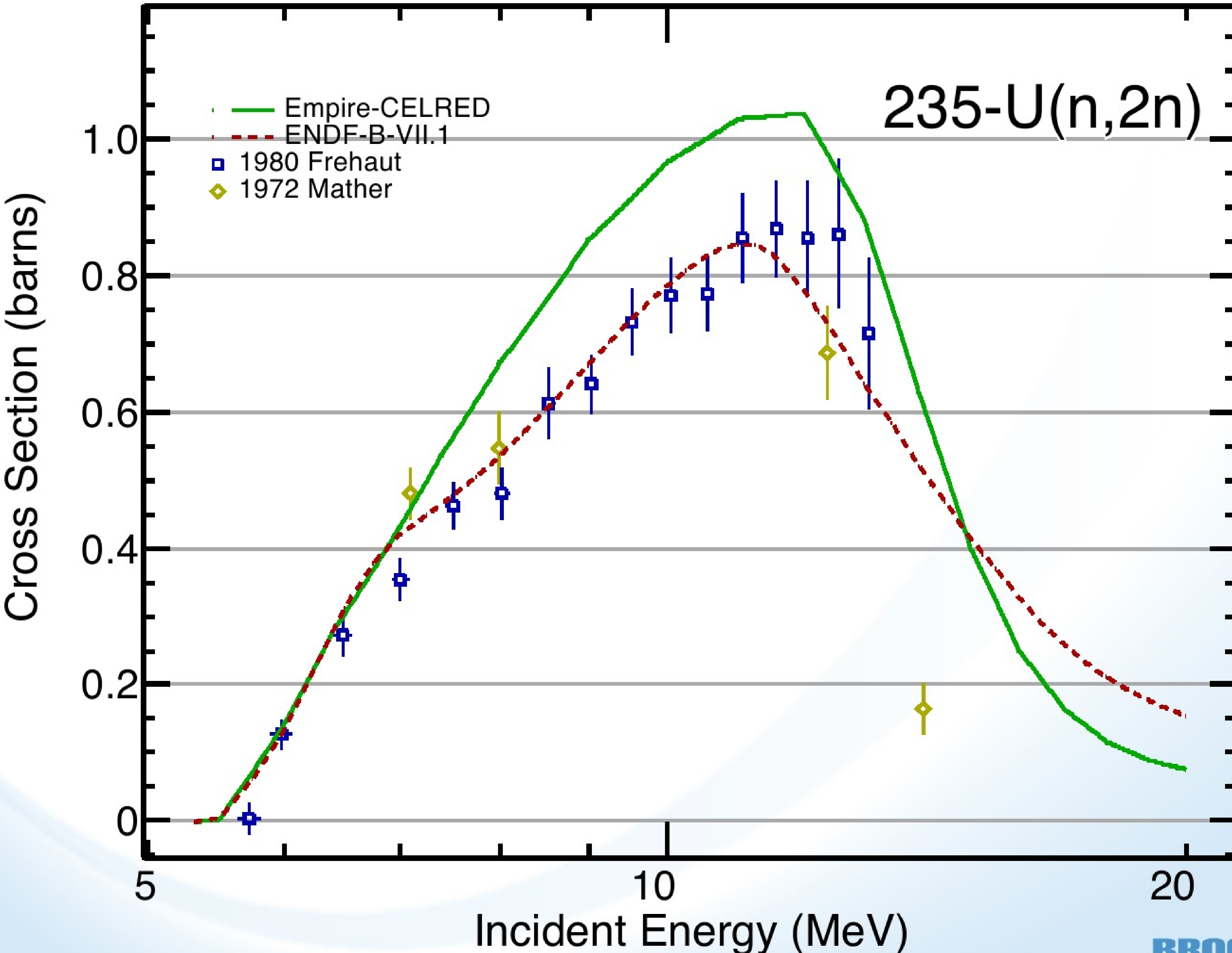

EMPIRE corrected (prior)
EMPIRE
ENDF/B-VII.1
235-U(n,f)
Ratio to ENF/B-VII.1
1
5·10-2
10-1
0.5
1
5
10
Incident Energy (MeV)


235-U(n,f)
EMPIRE corrected (prior)
EMPIRE
1991 Carlson*
1988 Iwasaki
1987 Rapaport*
1984 Carlson
1983 Carlson
1978 Carlson
1978 Carlson
1977 Poenitz
1974 Poenitz
1974 Poenitz
1974 Poenitz
1974 Poenitz
1974 Poenitz
1974 Poenitz
1974 Poenitz
1973 Kaeppeler
1973 Kaeppeler
Cross Section (barns)
2
1
5·10-2
10-1
0.5
1
5
10
Incident Energy (MeV)


Capture fitted to VII.1
(standard)
235-U(n,g)
Cross Section (barns)
Incident Energy (MeV)
Empire-CELRED
ENDF-B-VII.1
2012 Jandel
1977 Muradyan
1975 Kononov
1962 Hopkins
1958 Andreev
1956 Spivak
2
1
0.5
0.2
10-1
5·10-3
10-2
5·10-2
10-1
0.5
1


235-U(n,el)
Cross Section (barns)
12
10
8
6
4
Empire-CELRED
ENDF-B-VII.1
5·10^3
10^4
5·10^4
10^5
5·10^5
10^6
5·10^6
Incident Energy (eV)

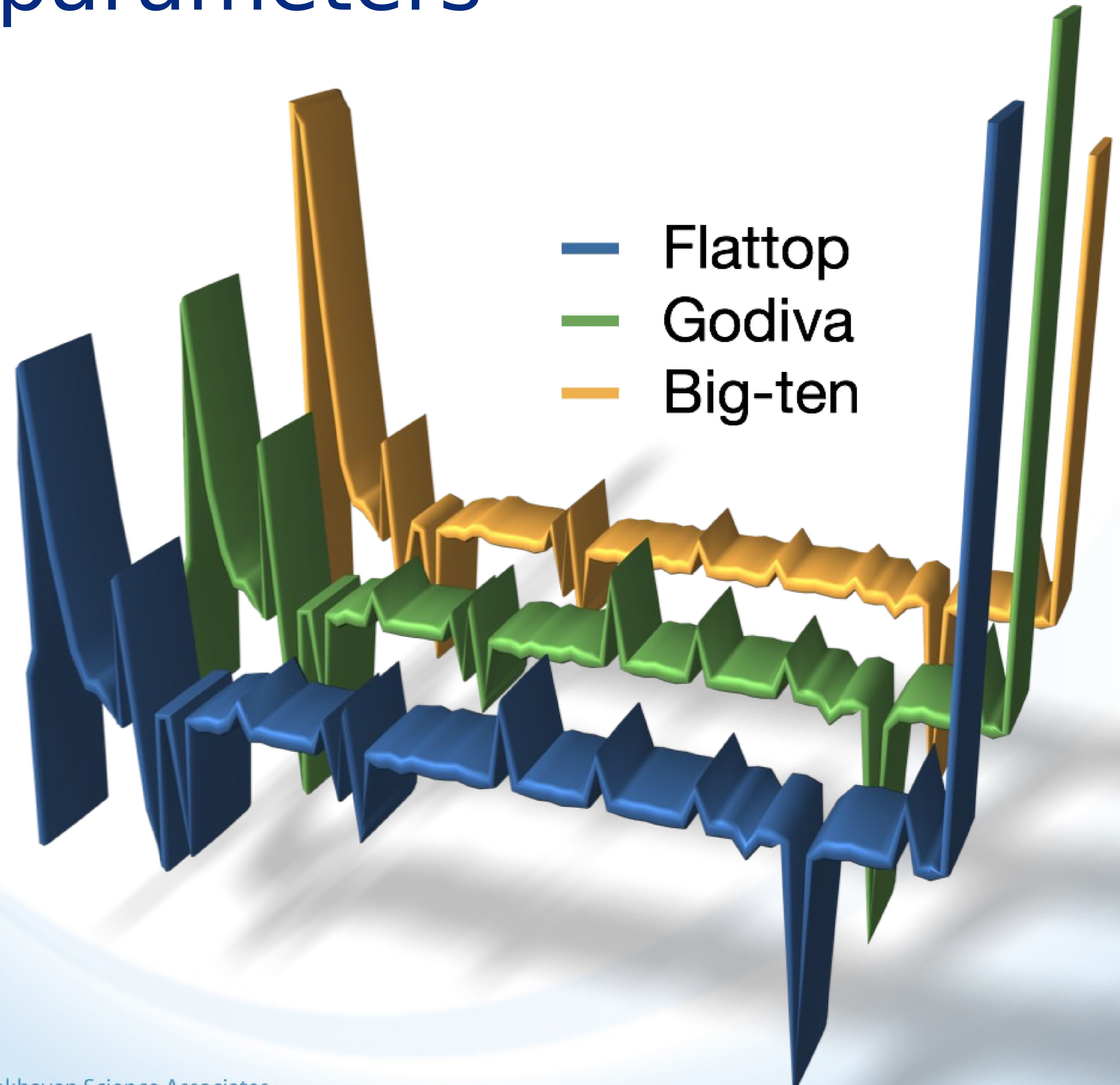

235-U(n,inl)
Cross Section (barns)
Incident Energy (MeV)
2.5
2.0
1.5
1.0
0.5
5
10
15
20
Empire-CELRED
ENDF-B-VII.1
1972 Knitter
1972 Knitter
1969 Batchelor
1969 Drake
1961 Andreev
1959 Cranberg



235-U(n,2n)
Empire-CELRED
ENDF-B-VII.1
1980 Frehaut
1972 Mather
Cross Section (barns)
1.0
0.8
0.6
0.4
0.2
0
5
10
20
Incident Energy (MeV)

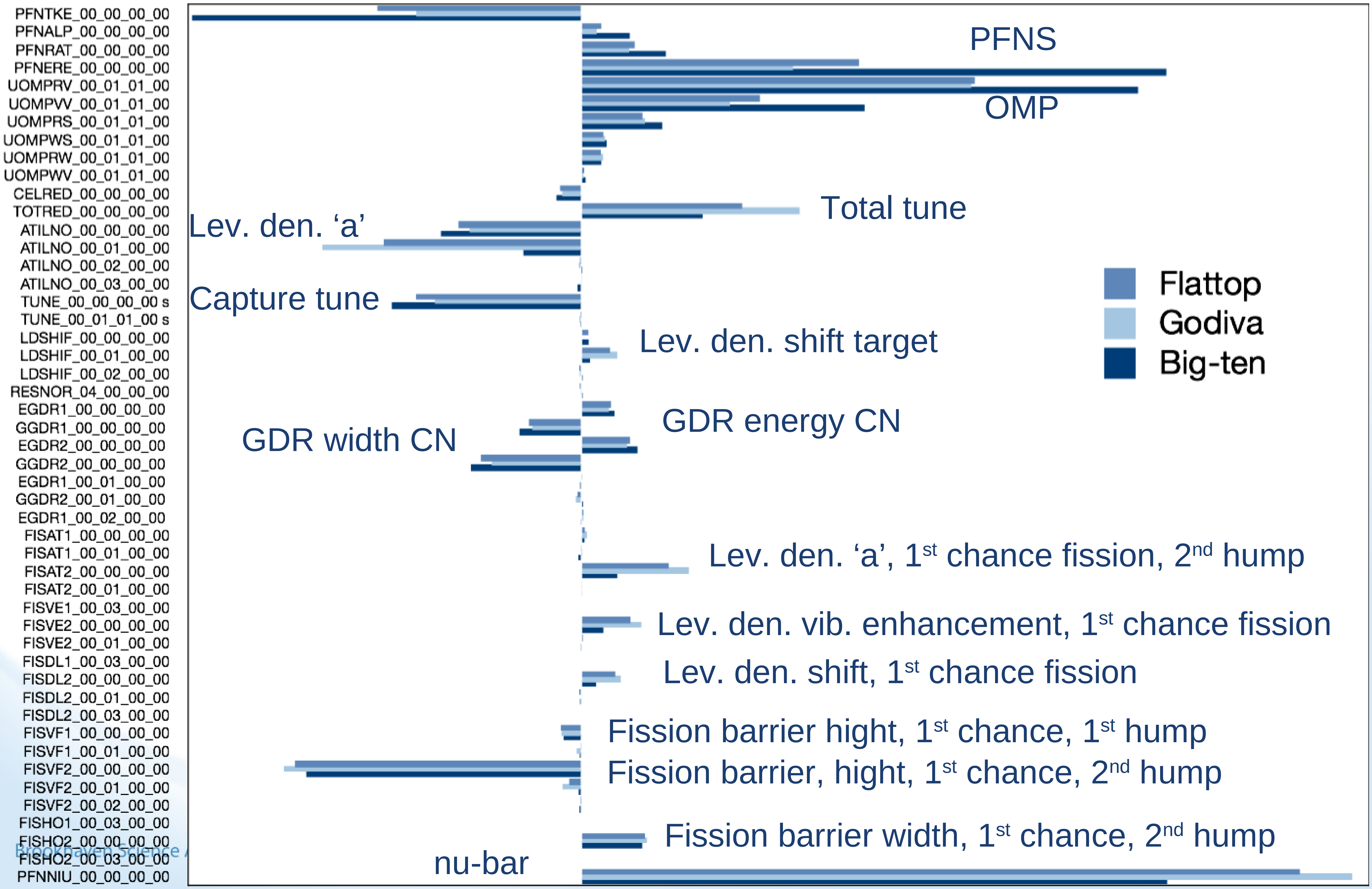
Experiment	Prior	Kalman	Posterior	Exp
FLATTOP U-235				
k_{eff}	1.00397	1.00119	1.00469	1.00000
F28/F25	0.14254	0.14415	0.14296	0.14920
F49/F25	1.35948	1.36531	1.36479	1.38470
GODIVA HEU				
k_{eff}	1.00316	0.99984	1.00385	1.00000
F28/F25	0.15549	0.15799	0.15631	0.16500
F49/F25	1.38195	1.38993	1.38729	1.40200
BIGTEN				
k_{eff}	1.00262	1.00329	1.00279	1.00450
F28/F25	0.03572	0.03723	0.03495	0.03739
F49/F25	1.16304	1.17139	1.16655	1.19360

^{235}U - k_{eff} sensitivities to model parameters

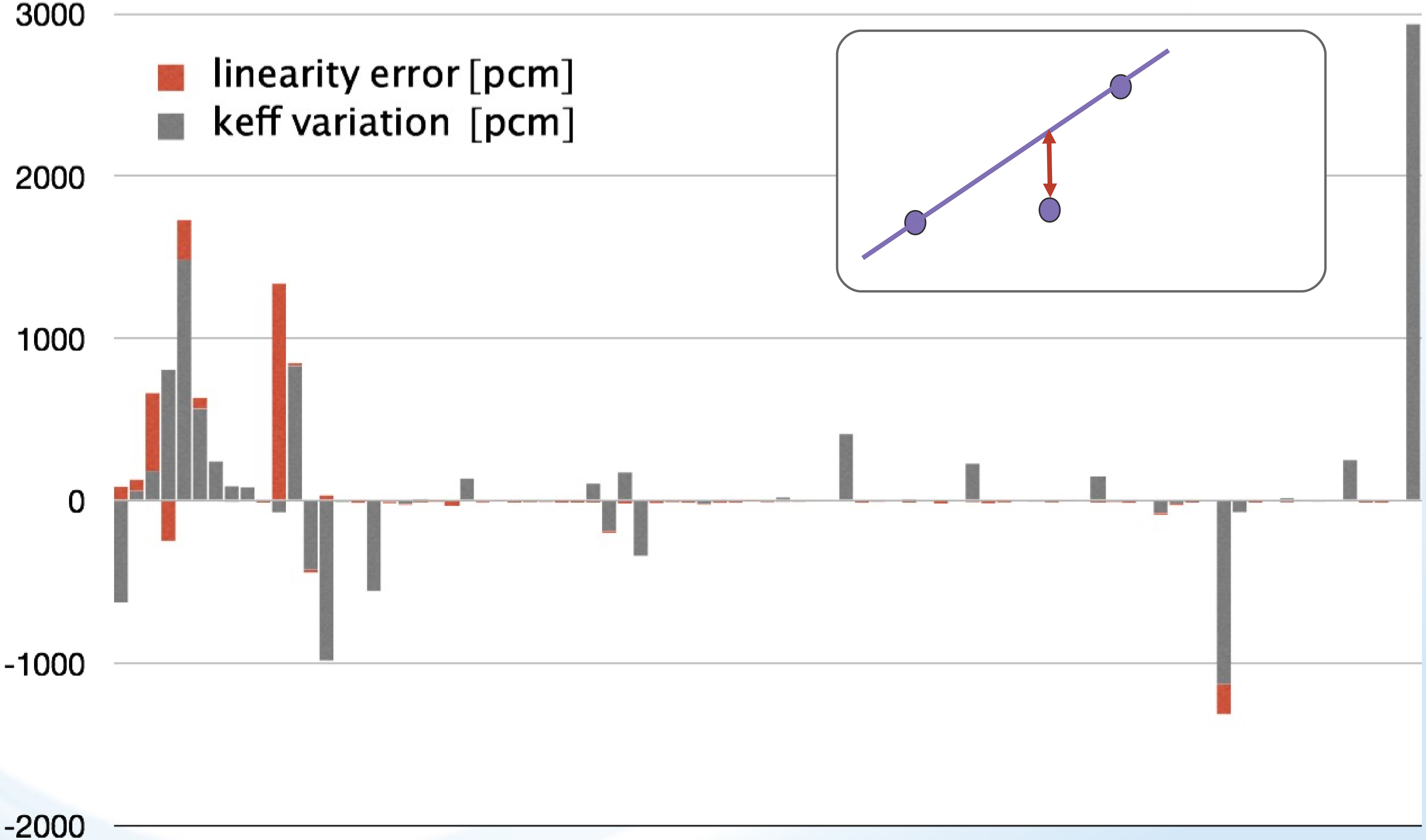


- Flattop & Godiva very similar
- Big-ten follows the same pattern but amplitudes differ

^{235}U - k_{eff} sensitivities to parameters



Godiva k_{eff} sensitivities & linearity test



Lesson learned from sensitivities

- Similarity among Godiva, Flattop, and Big-ten
- About 70% of model parameters can be eliminated
- nu-bar sensitivity ~80% and perfectly linear
- PFNS parameters tend to be nonlinear and strongly correlated - high risk combination!
- Adjustment of OMP parameters dangerous
- CN elastic tuning dramatically nonlinear (needs further study)

Conclusions

- Good reaction modeling and flexible code are prerequisites for assimilation
- No assimilation will fix a bad prior
- Adjustment to one k_{eff} is trivial, adjustment to several ones may not
- Non-linearities need to be properly treated
- Precision required to fit k_{eff} is so demanding that there is no chance to achieve it through differential measurements

Extras

Experiment	Prior	Kalman	Posterior	Exp
FLATTOP U-235				
k_{eff}	1.00397	1.00119		1.00000
F28/F25	0.14254	0.14415		0.14920
F49/F25	1.35948	1.36531		1.38470
GODIVA HEU				
k_{eff}	1.00316	0.99984		1.00000
F28/F25	0.15549	0.15799		0.16500
F49/F25	1.38195	1.38993		1.40200
BIGTEN				
k_{eff}	1.00262	1.00329		1.00450
F28/F25	0.03572	0.03723		0.03739
F49/F25	1.16304	1.17139		1.19360