IAEA 60 Years
Atoms for Peace and Development

# IAEA-CIELO Covariance Evaluation for U-235 and U-238

A.Trkov, R. Capote and CIELO collaboration
IAEA, Vienna, Austria

# Overview

- General covariance evaluation approach
- Nuclide-specific features:
  - Resonance region
  - Fast energy region
  - Average number of neutrons per fission

# General covariance evaluation approach

Applicable above the resonance range:

- Model calculations with input parameters are chosen to represent the bulk of experimental data
- “Generous” uncertainties are assigned to model parameters
- By Monte Carlo sampling ~n.1000 EMPIRE runs are made (→~n.1000 ENDF files). More details are given in the NDS paper.

# General covariance evaluation approach (Cont.)

Applicable above the resonance range:

- All reaction channels are accounted for, some are lumped together (e.g. MT52-91, MT600-849)
- This allows the total to be the sum of all the partials (consistent with ENDF philosophy)
- Scattering moments are included
- Relative covariance matrix prior is assembled, including all cross-correlations

# General covariance evaluation approach (Cont.)

Applicable above the resonance range:

- A 3% statistical uncertainty is added to all reactions to account for model deficiencies (increment to diagonal terms, softens the stiffness of the correlations)
- Additionally, 20% uncertainty is added to reactions that are Standards (making the prior for these reactions non-informative)

# General covariance evaluation approach (Cont.)

GANDR fitting:

- Experimental data for the total cross section are carefully chosen and fed to GANDR, together with the covariance prior.
- On next round, the Standard reactions (each separately) with the associated covariances are fed as input to GANDR
- Finally, experimental data for other reactions are carefully chosen and fed to GANDR one-by one.
- Additional uncertainties to account for unrecognised sources, recommended by Standards-2017:
  - Capture: 1.7% below fission threshold, 2.4% above
  - Fission: 1.2%

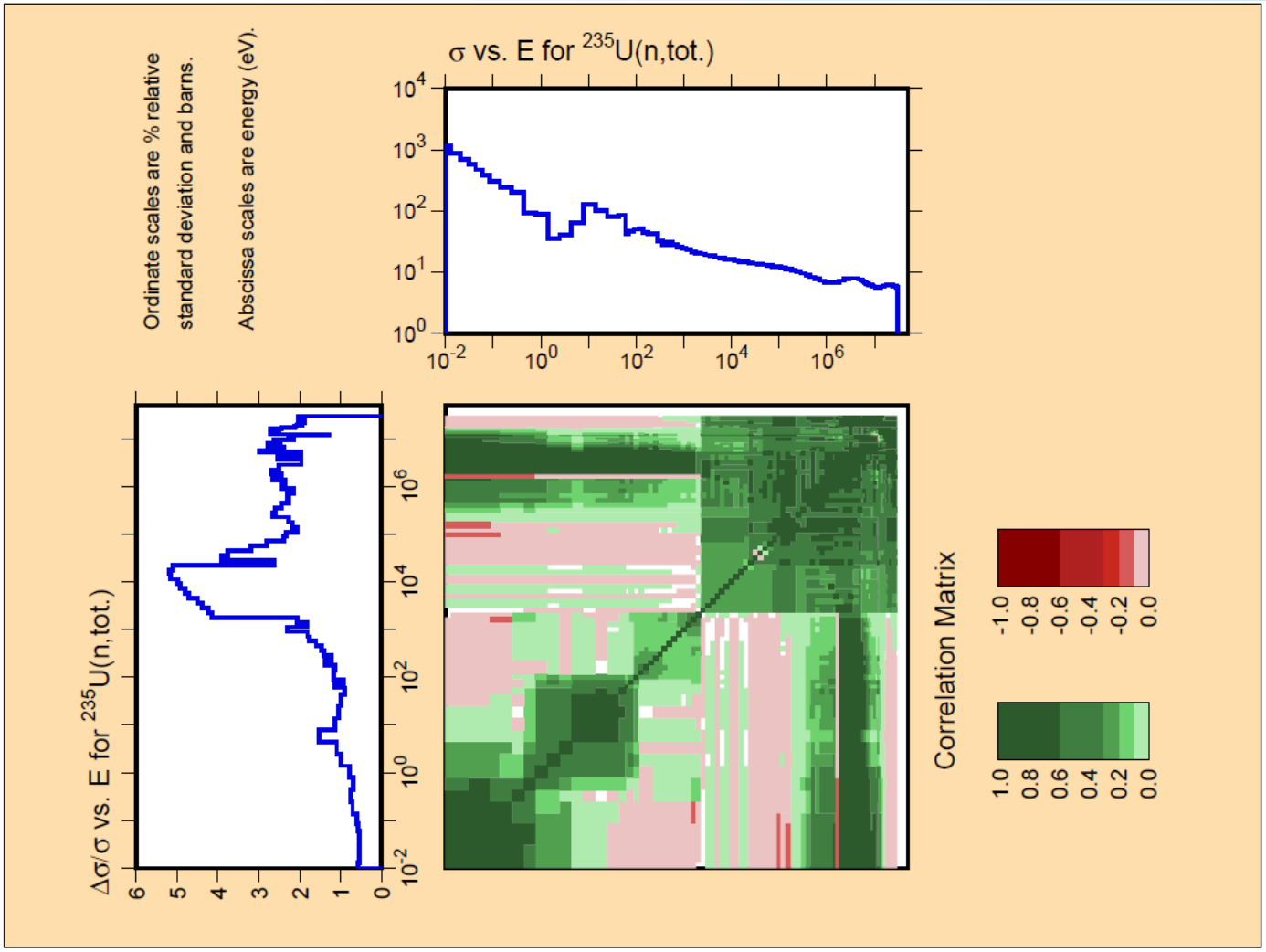
# General covariance evaluation approach (Cont.)

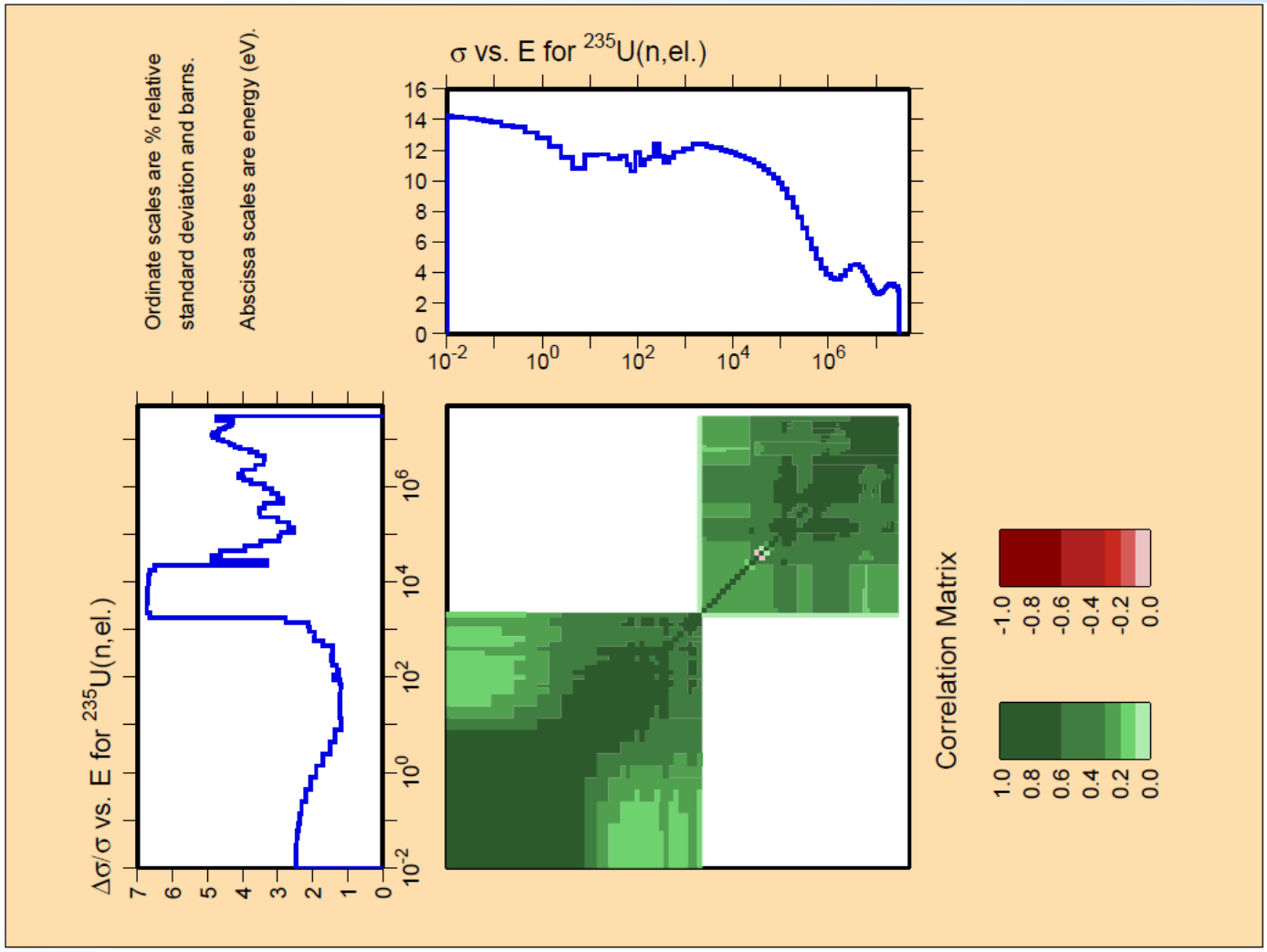
Interpretation of GANDR results:

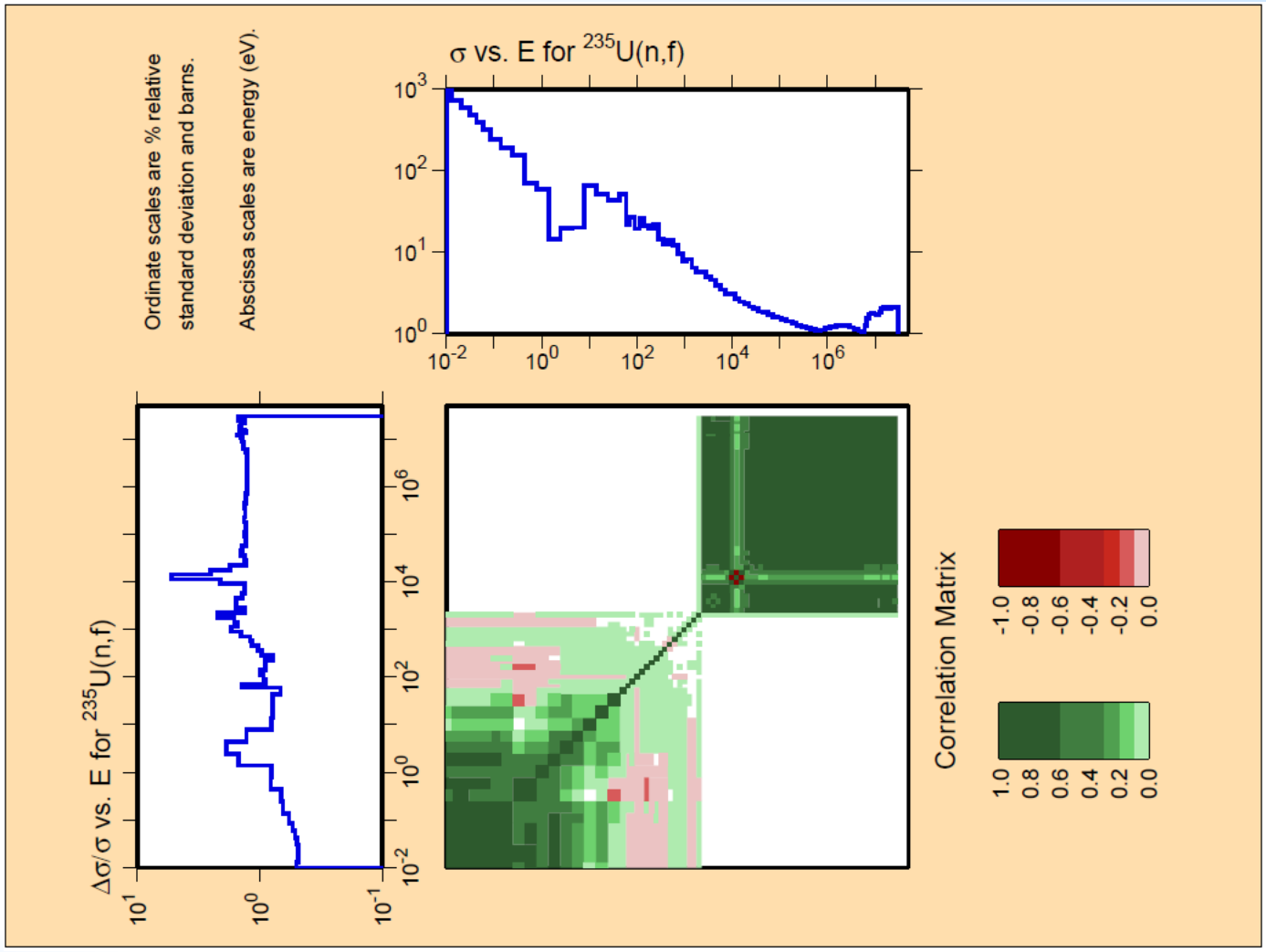
- Explicit and lumped reactions are coded in ENDF MF33 format.
- The total is defined as the sum of the partials (valid, since all cross-correlations are given)
- Covariances of the angular distributions ($P_L$ Legendre coefficients in the LAB coordinates) are reconstructed from the scattering moments
- For U-235 and U-238 terms up to $P_2$ are given
- Cross correlations between $P_L$ must be included to correctly reconstruct scattering moments (→ format representation currently not supported by NJOY)

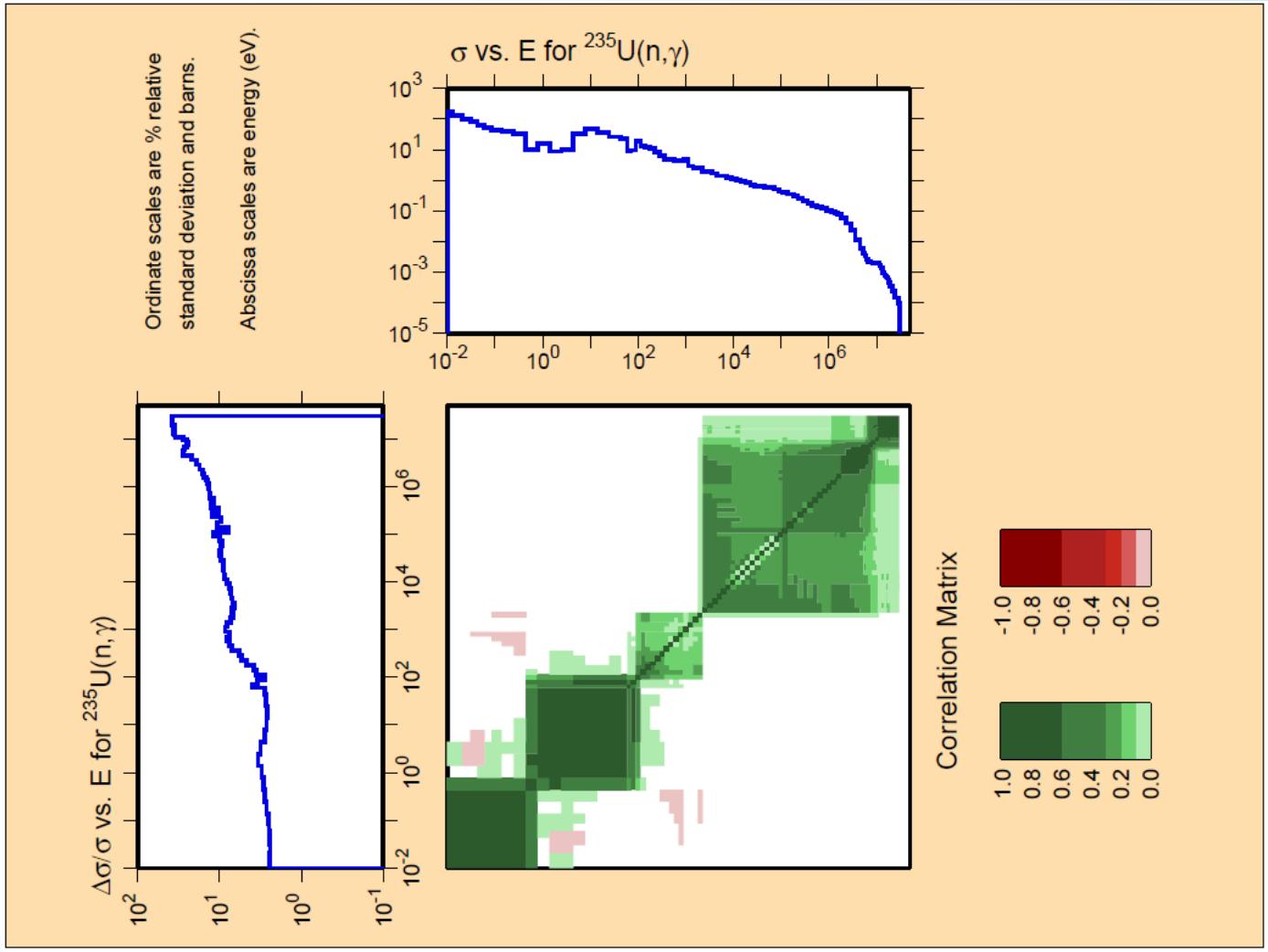
# Resonance region of U-235

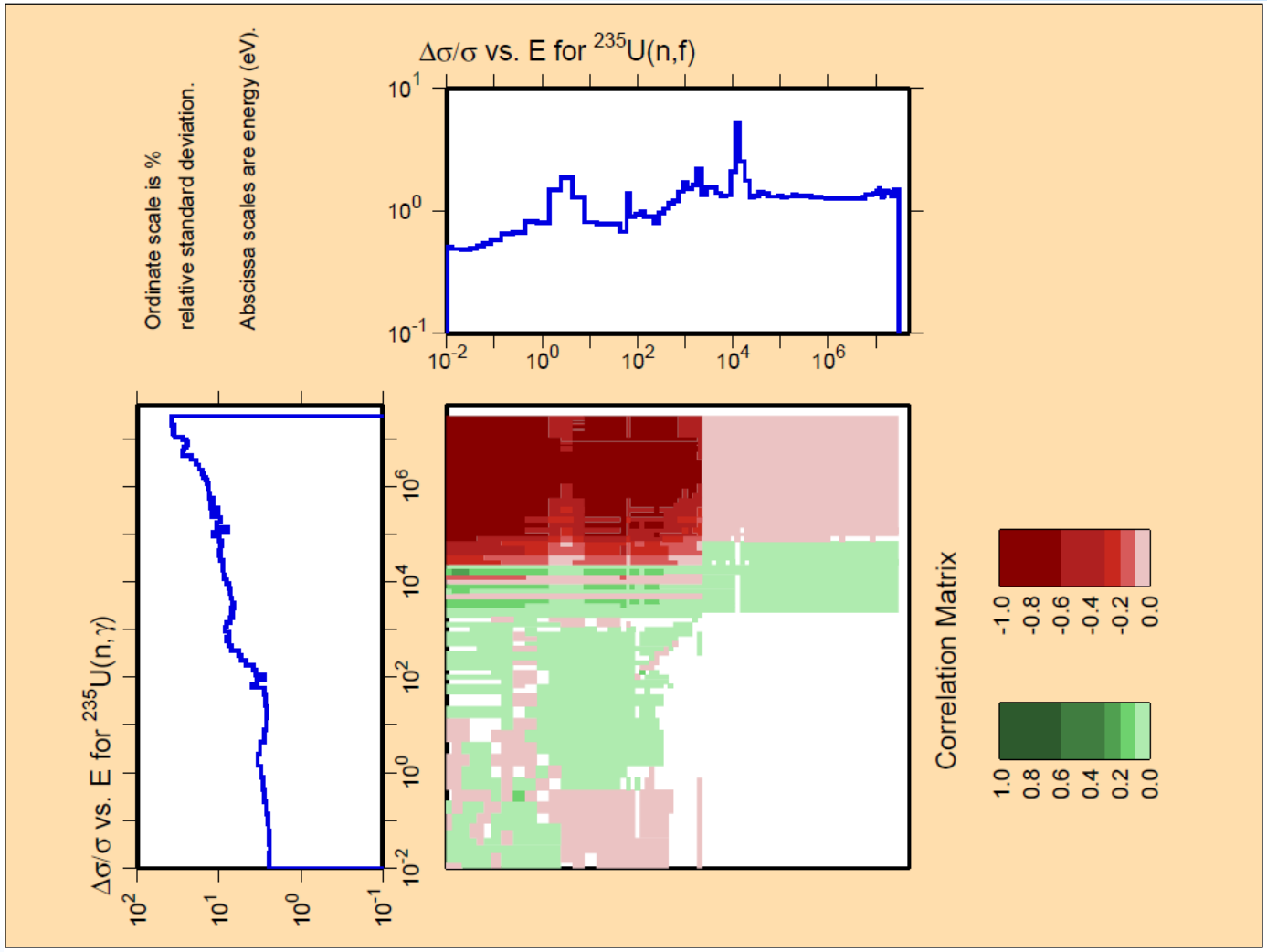
- ORNL analysis with SAMMY (M. Pigni)
- Full resonance covariance matrix too bulky to be of practical use for evaluated data file
- Covariance matrix with cross-reaction correlations was provided by M. Pigni in a fine-group structure.
- The resonance covariance matrix was merged with the fast one in MF33 representation for all resonant reactions


σ vs. E for 235U(n,tot.)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 235U(n,tot.)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0


σ vs. E for 235U(n,el.)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 235U(n,el.)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

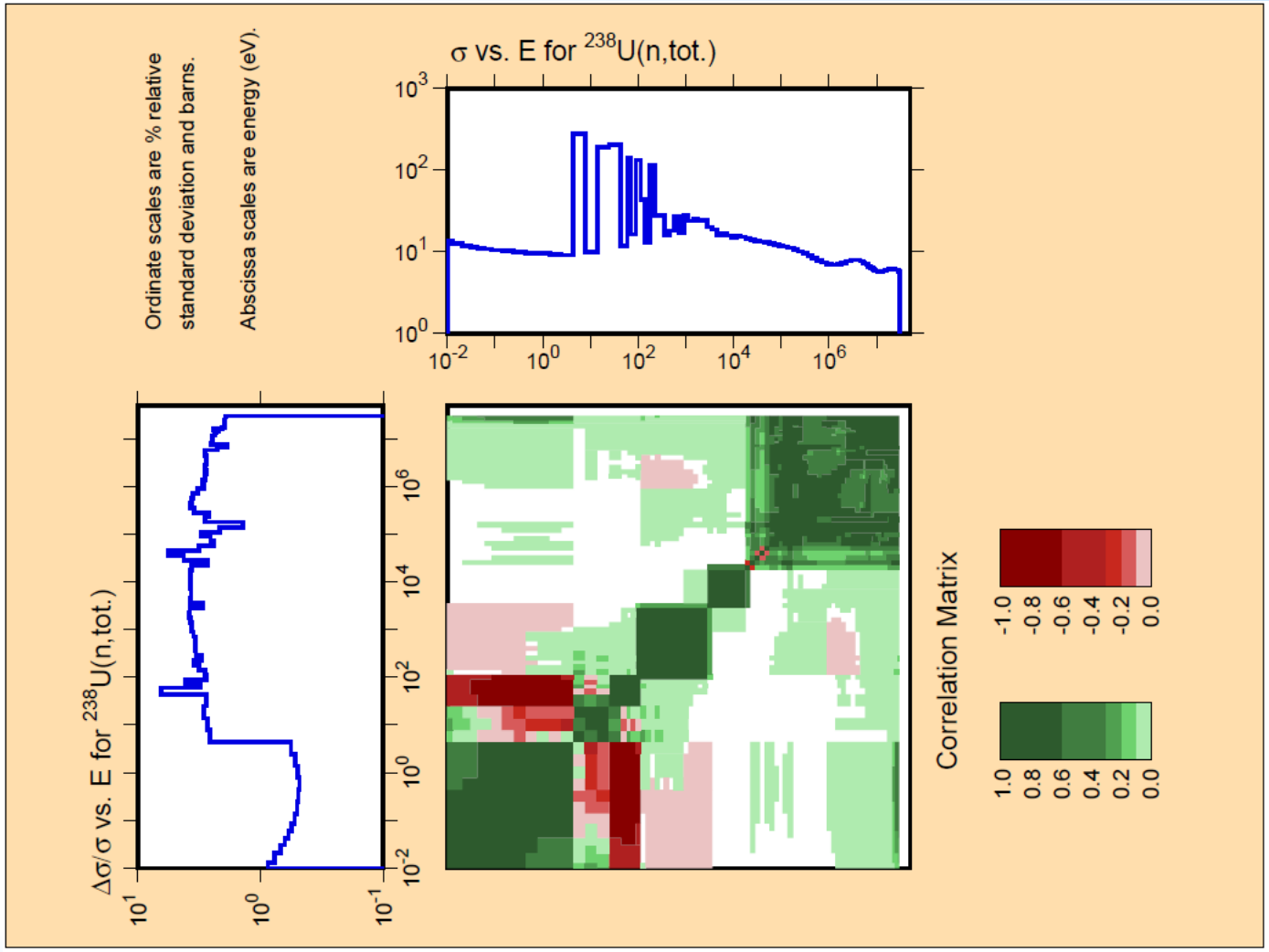

Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
σ vs. E for 235U(n,f)
Δσ/σ vs. E for 235U(n,f)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

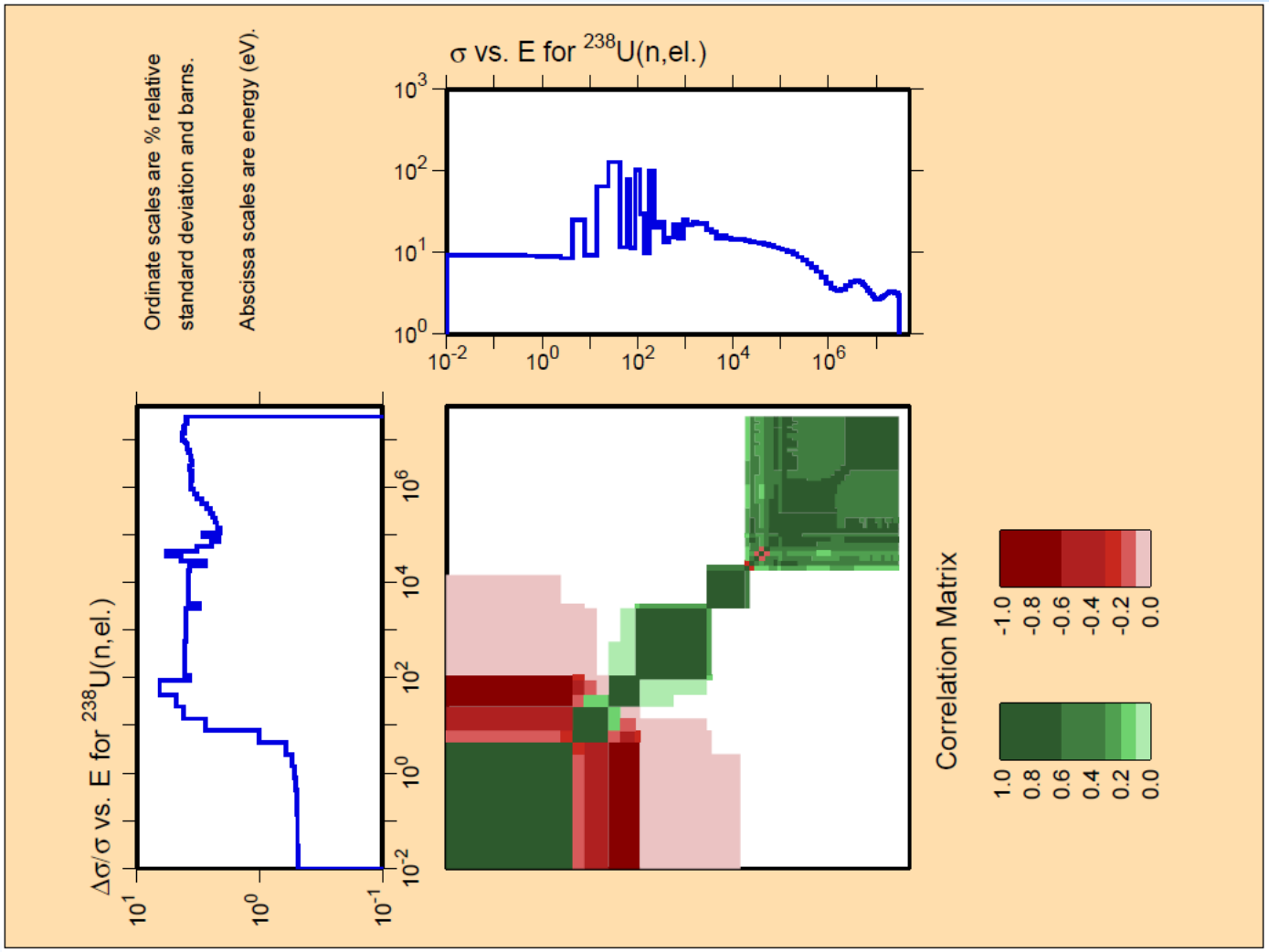

σ vs. E for 235U(n,γ)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 235U(n,γ)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

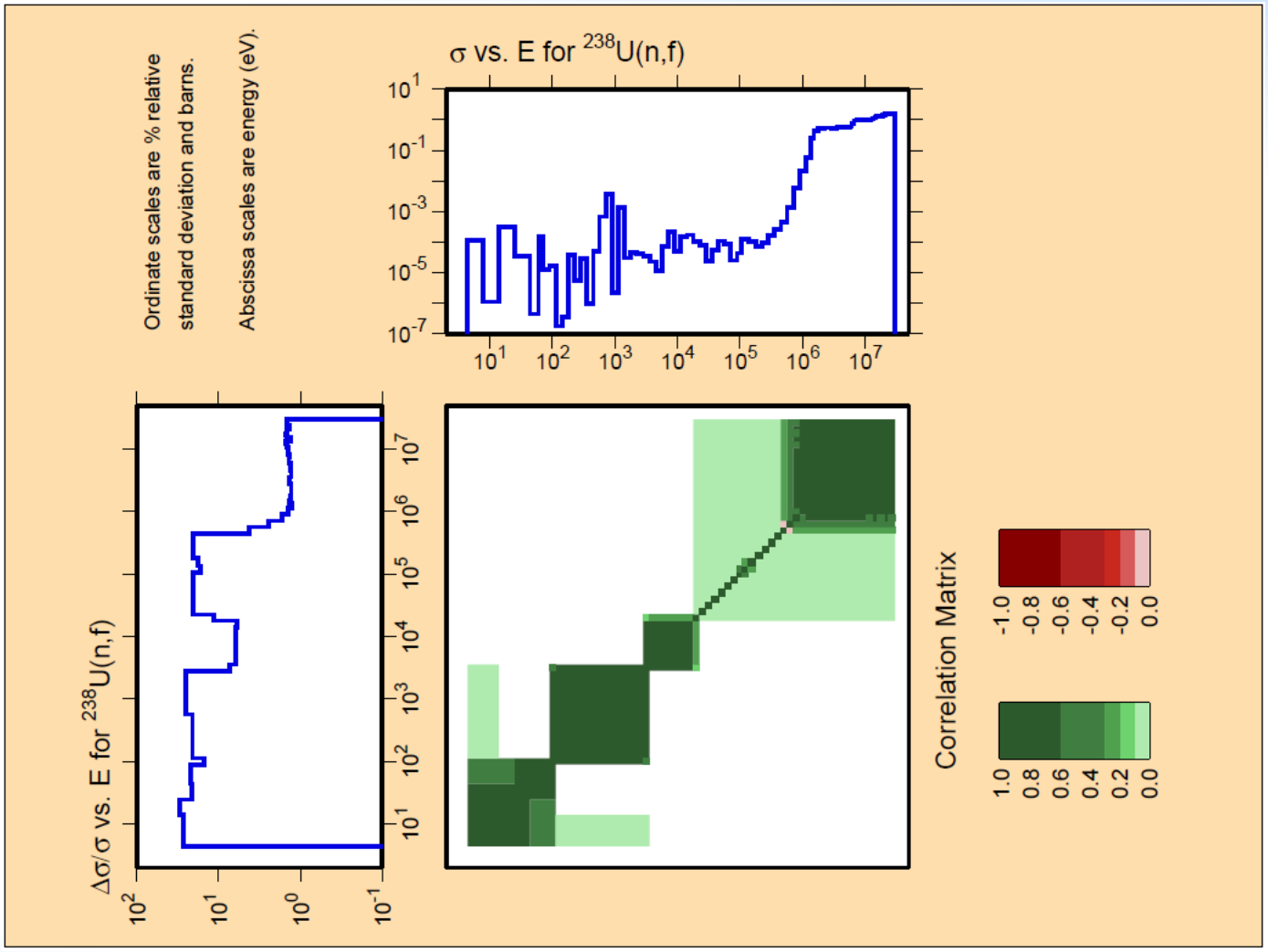

Δσ/σ vs. E for 235U(n,f)
Ordinate scale is % relative standard deviation.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 235U(n,γ)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

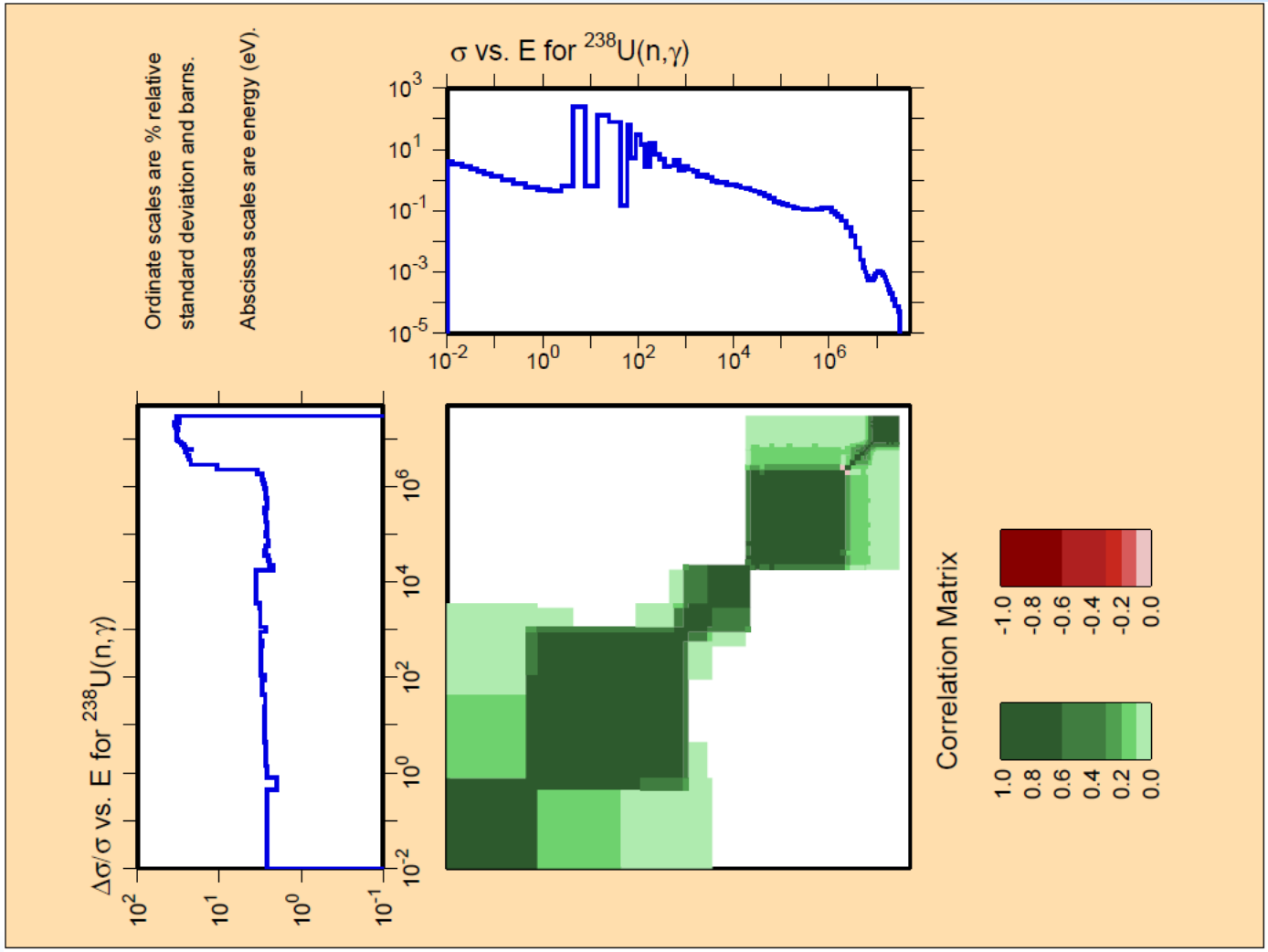
# Resonance region of U-238

- Adopted from IRMM/CEA resonance analysis for JEFF-3.3
- The variance in the elastic had a “hole” in the energy range 100-1000 eV.
- A 4% (fully correlated) uncertainty was added to fill the hole
- Additional 2.4% uncertainty was added to the diagonal elements for capture to account for unrecognised sources of uncertainty


σ vs. E for 238U(n,tot.)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 238U(n,tot.)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

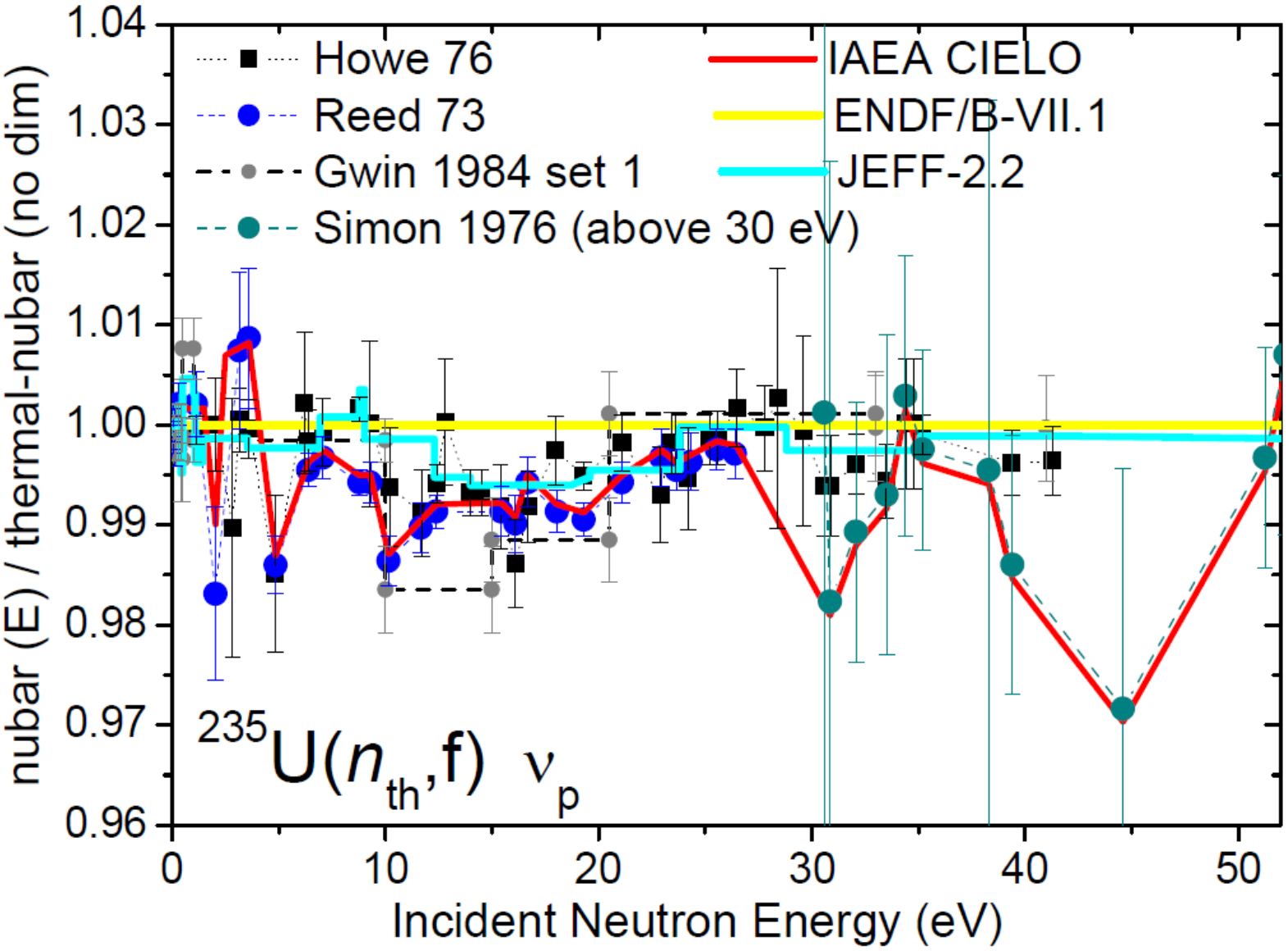

σ vs. E for 238U(n,el.)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 238U(n,el.)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

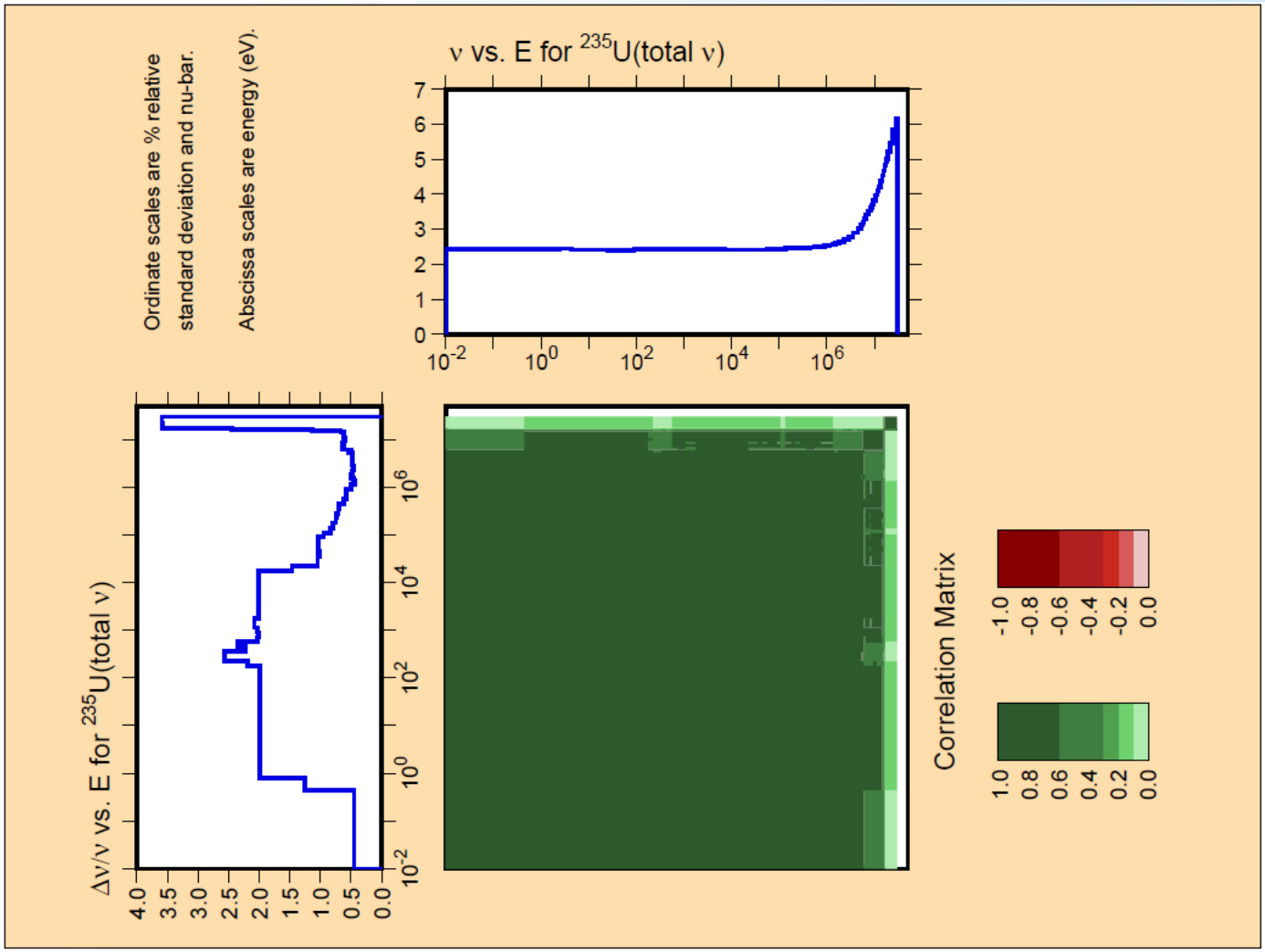

σ vs. E for 238U(n,f)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 238U(n,f)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0


σ vs. E for 238U(n,γ)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
Δσ/σ vs. E for 238U(n,γ)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

# Nu-bar of U-235

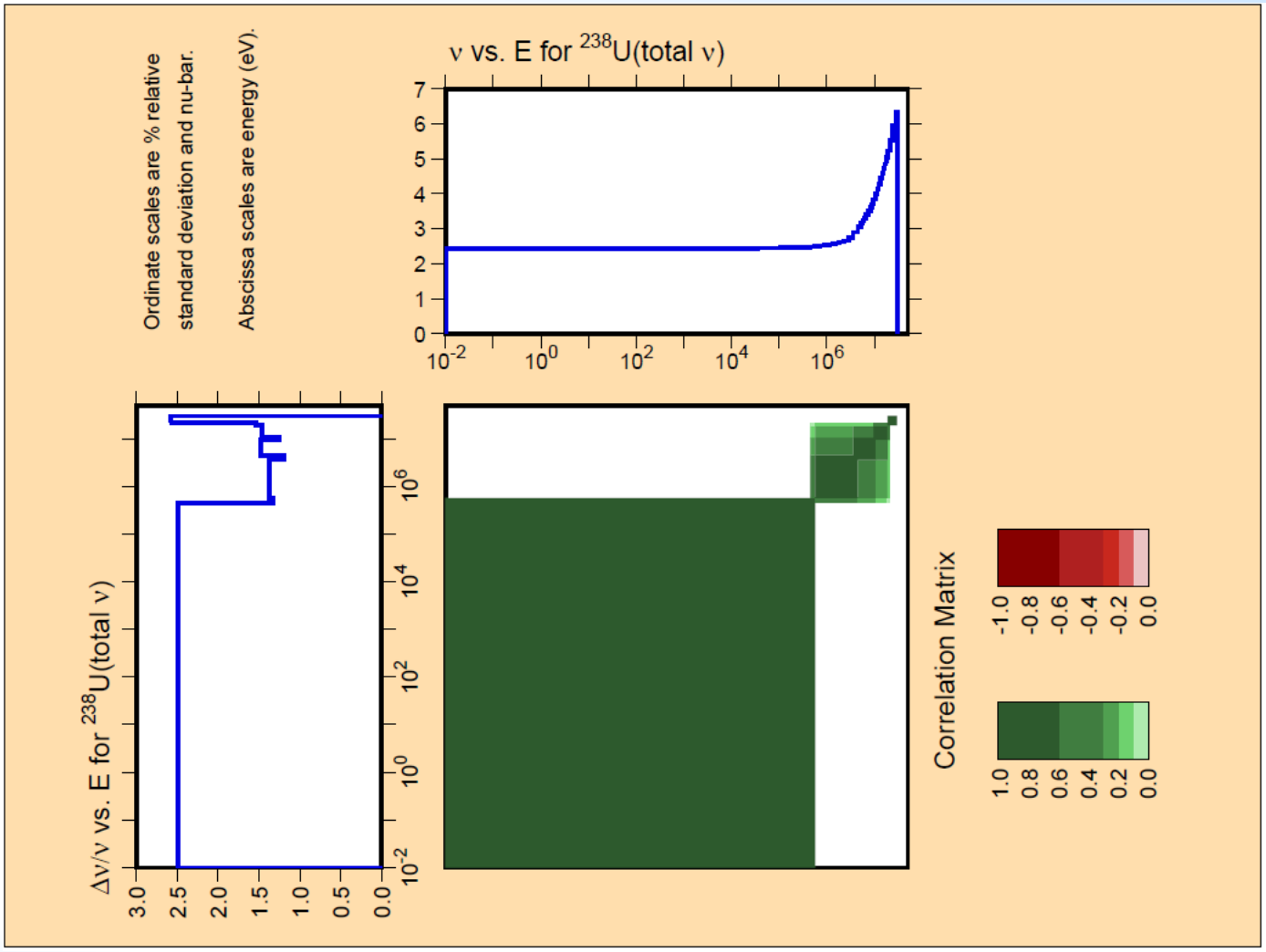
- Covariances Essentially adopted from ENDF/B-VII.1
- Variance of nu_p at thermal was modified for consistency with Standards-2017
- In the region of fluctuations (up to 200 eV) a 2% uncertainty was assigned (could not use LB=9 because it is not supported by NJOY)
- In the range 200 eV – 20 keV a 2% uncertainty was assumed (no experimental data)
- Above 20 keV: 1%; above 100 keV: 0.76%; above 200 keV: 0.56% added (transition to region where data are available)
- Above 1 MeV a 0.4% uncertainty was added to account for unrecognised uncertainties (recommended by Standards-2017)
- nu_d uncertainties taken from Tuttle(1975)
- nu_tot is defined as the sum of prompt+delayed


Howe 76
Reed 73
Gwin 1984 set 1
Simon 1976 (above 30 eV)
IAEA CIELO
ENDF/B-VII.1
JEFF-2.2
$^{235}U(n_{th},f)$ $\nu_p$
nubar (E) / thermal-nubar (no dim)
Incident Neutron Energy (eV)
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0
10
20
30
40
50


Ordinate scales are % relative standard deviation and nu-bar.
Abscissa scales are energy (eV).
ν vs. E for 235U(total ν)
Δν/ν vs. E for 235U(total ν)
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

# Nu-bar of U-238

- Covariances Essentially adopted from ENDF/B-VII.1
- Additional uncertainty of 0.4% was added
- nu_d covariances adopted from ENDF/B-VII.1
- nu_tot is defined as the sum of prompt+delayed

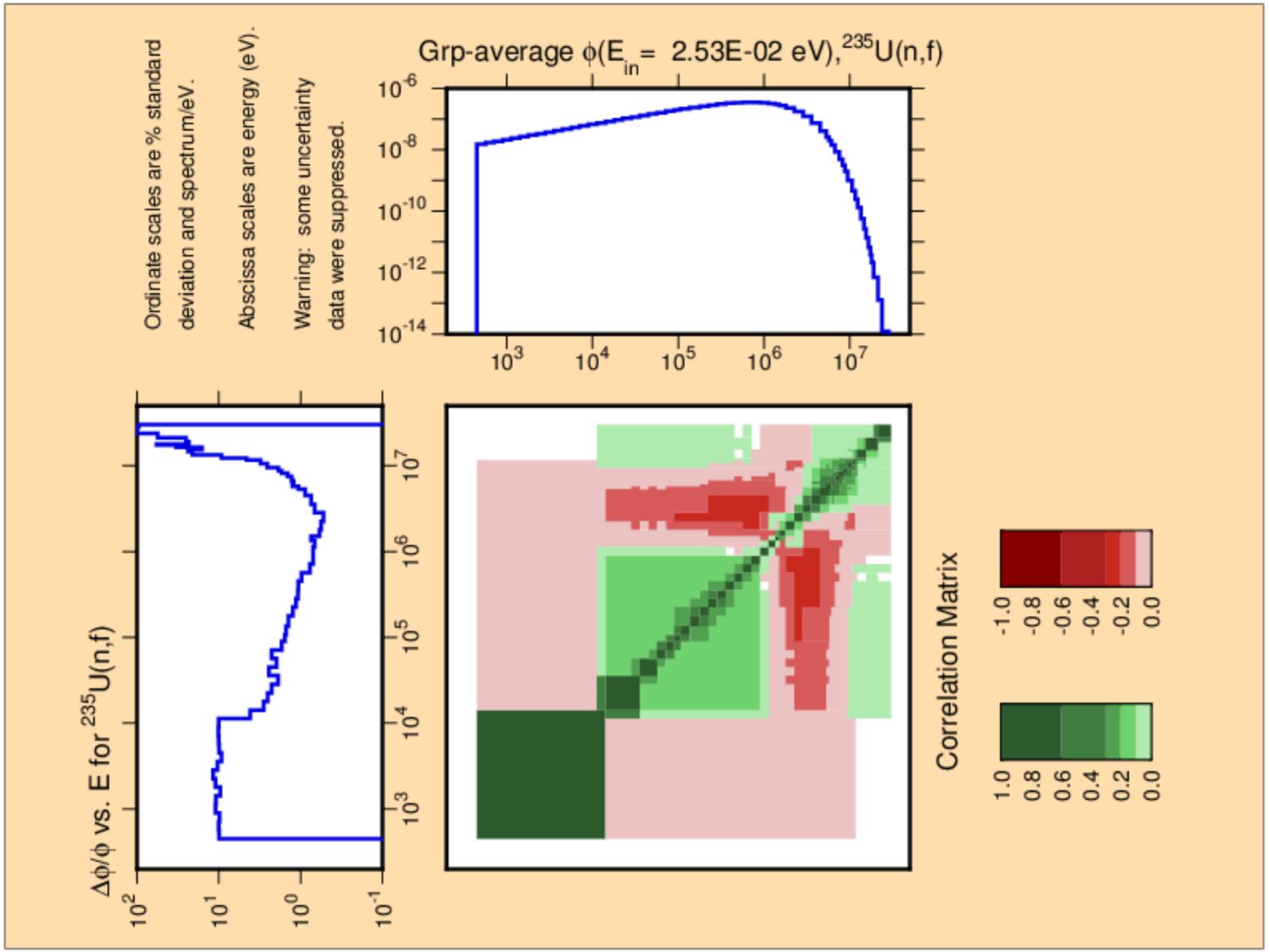

Ordinate scales are % relative standard deviation and nu-bar.
Abscissa scales are energy (eV).
ν vs. E for 238U(total ν)
Δν/ν vs. E for 238U(total ν)
Correlation Matrix
-1.0 -0.8 -0.6 -0.4 -0.2 0.0
1.0 0.8 0.6 0.4 0.2 0.0

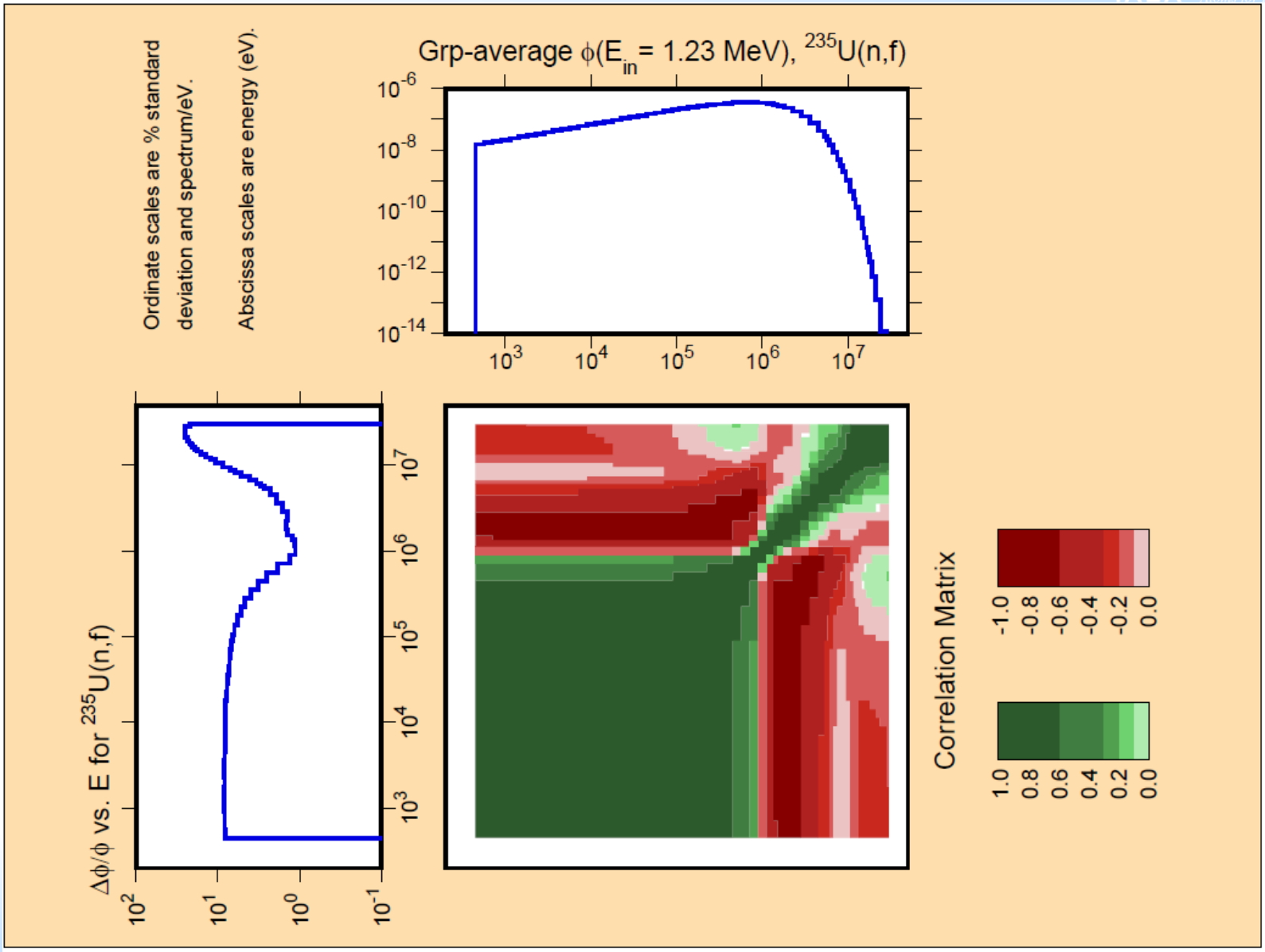
# PFNS

- For incident thermal neutrons the covariance matrix was taken from the Standards-2017
- Covariance matrices at higher energies were provided by D. Neudecker (LANL)

# PFNS (thermal)

- GMA fit of measured ratios to Cf-252
- At low energies the spectrum was extrapolated by a Maxwellian; 20% uncertainty was assigned
- Above 10 MeV, the spectrum was extrapolated with assigned uncertainties:
  - 12% in the range 12-15 Mev
  - 20% in the range 15-20 MeV
  - 50% in the range 20-30 MeV


Grp-average φ(E_in = 2.53E-02 eV), ^235U(n,f)
Ordinate scales are % standard deviation and spectrum/eV.
Abscissa scales are energy (eV).
Warning: some uncertainty data were suppressed.
Δφ/φ vs. E for ^235U(n,f)
Correlation Matrix


Ordinate scales are % standard deviation and spectrum/eV.
Abscissa scales are energy (eV).
Grp-average ϕ(E_in = 1.23 MeV), 235U(n,f)
10-6
10-8
10-10
10-12
10-14
103
104
105
106
107
Δϕ/ϕ vs. E for 235U(n,f)
102
101
100
10-1
Correlation Matrix
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
1.0
0.8
0.6
0.4
0.2
0.0

# Conclusions

- Covariance information was generated for ith IAEA-CIELO evaluations of U-235 and U-238
- More accurate data representation required the use of (legal) format options, which are not yet supported by NJOY, or external codes
- Needs the proof of time…

Full set of ENDF/B-VIII.b5 covariance plots is on

https://www-nds.iaea.org/CIELO/e80b5_list.html