

# Optimal experiment utilization: **REWINDing PIA**

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# Outline

- Recall of **PIA** (**P**rogressive **I**ncremental **A**adjustment) and **REWIND** (**R**anking **E**xperiments by **W**eighting for **I**mproved **N**uclear **D**ata) methodology
- Incorporating REWIND in the PIA methodology: REWINDing PIA.
- Applying the new adjustment formulation to the case of the SG33 experiments and comparing results against those of standard formulation.
- Conclusions and considerations for future work.



# PIA (Progressive Incremental Adjustment)

- The proposed approach for avoiding compensations and give more reliable feedback to evaluator is to perform a progressive incremental adjustment.
- In PIA the starting point is giving priority to the utilization of experiments of elemental type (those sensitive to a specific cross section), following a definite hierarchy on which type of experiment to use (see next slide).
- Once the adjustment is performed, both the new adjusted data and the new covariance matrix are kept. This will limit the range of variability of the adjusted cross sections.
- In the final steps integral experiments that are sensitive to a large variety of cross sections (global type like critical mass) are added.



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# PIA Experiment Hierarchy

## ➤ For actinides:

1. **Fission spectral indices: sensitive to fission cross sections (but also to inelastic and fission spectrum, in the case of threshold fission cross sections)**
2. **Irradiation experiments: sensitive to capture cross sections (and second order to fission) and (n,2n)**
3. **Sample oscillation experiments and other experiment sensitive to inelastic (e. g. transmission, flat/steep adjoint as in STEK and SEG)**
4. **Critical masses**
5. **Reactivity variations (both reactivity coefficients and associated to fissile isotope variations in the same core geometry)**

## ➤ For structural materials:

1. **Propagation experiments (inelastic and elastic)**
2. **Sample oscillations (add capture)**
3. **Critical masses**
4. **Reactivity variations (e.g. k-infinity type experiments, sodium void, control rods)**



# Progressive Adjustment Issue

- The Kalman filtering technique is the algorithm at the base of the adjustment cross section adjustment. The original Kalman filter is applied separately to each measurement in a time series and it is naturally progressive, because time dictates the progressive adjustment.
- Evaluators make a massive use of Kalman filter, but it is not clear how they prioritize the measurements to be used in a successive way.
- The PIA (Progressive Incremental Adjustment) application has shown that the succession of experiments to be used in adjustment will impact significantly the final results both in terms of central values and a posteriori covariance. **This has been shown that is true only when there are correlations (experimental and/or calculational) among experiments.**
- The REWIND methodology was proposed in order to rank experiments by weight using a technique developed for optimizing portfolios of investment assets.



# Application to Integral Experiments: REWIND

- Let's consider the set of integral experiments we have as a “portfolio” of assets and calculate the optimal weights that maximize the portfolio “Sharpe Ratio” (similar to the “information ratio” in finance).
- First, let's define some attributes of the portfolio. The covariance of the portfolio is calculated as:

$$D_p = SD C_p SD^T$$

- Where  $SD$  is the experiment standard deviation and  $C_p$  is the correlation among experiments and are calculated using the usual formulation with sensitivity coefficients and cross section covariance:

$$C_{E'E} = \frac{(S_{E'} M_\sigma S_E)}{[(S_{E'} M_\sigma S_{E'}) (S_E M_\sigma S_E)]^{1/2}}$$

- The portfolio standard deviation and the internal portfolio correlation are:

$$SD_p = w D_p w^T$$

$$Cor_p = \frac{SD_p - SD_p^{cu}}{SD_p^{cc}}$$



# Application to Integral Experiments: REWIND

- Now let's define the Sharpe Ratio for the case we want to find the optimal experiment weights for improving the information we want on a set of isotopes like those of CIELO.
- In this case the return of each asset (experiment) is the potential gain an experiment can produce by reducing the uncertainty obtained by the usual sandwich formula limited to the isotopes under consideration. However, to this we have to subtract the experimental uncertainty  $U_i$  (both from measurement and calculation).
- Similarly, the portfolio standard deviations is calculated using only the sensitivity coefficients and covariance data of the isotopes under considerations.

$$SR_p = \frac{\sum_{i=1}^N w_i (SD_i - U_i)}{SD_p}$$



# Application to Integral Experiments: REWIND

- Note that the Sharpe Ratio for each experiment, defined in this way, is very similar to the Ishikawa factor.
- In fact the Sharpe Ratio equal to zero corresponds to the Ishikawa factor equal to 1. Positive Sharpe ratio is what we want from an experiment (corresponding to the Ishikawa factor greater than one).
- The optimization process maximizes this portfolio Sharpe Ratio in order to find the optimal weights, and, therefore we will obtain a ranking of the experiments.
- Subsequently we can use this ranking to apply a progressive adjustment like in PIA; it has to be noticed that the optimization process will reward experiments that are not correlated.
- If, instead, the adjustment is targeting a specific reactor design, the experiment return (gain) will be defined in the Sharpe Ratio as the reduction of uncertainty obtained using the representativity factor.



# REWINDing PIA

- In REWIND the ranking favors more global experiments than the elemental type one, and, therefore, it is not clear if compensations are avoided (the original aim of PIA).
- For coping with this problem, the REWIND procedure is applied to the hierarchic approach adopted in PIA. In other words, we consider a set of separate experiment portfolios following the PIA hierarchy and calculate the associate optimal weights inside each portfolio to determine the PIA sequence in the adjustment.
- The sequence of calculations is as it follows:
  - ❖ Start calculating the weights for each category of experiments (fission spectral indices, capture spectral indices,  $K_{\text{eff}}$ , reactivity coefficients) separately.
  - ❖ Perform adjustment in the first category of experiments (fission spectral indices) following the sequence established by the REWIND weights, and recalculate at each step new C/E, adjusted cross sections, and adjusted covariance.
  - ❖ Repeat the process in sequence for all other categories until all experiments are included.



# Application to the SG33 Experiments

- The methodology has been applied to the case of the 20 experiments of the SG33 exercise.
- Results are compared against the initial values (ENDF/B-VII.0 for cross sections and COMMARA 2.0 for standard deviations) and the results of the traditional (global) adjustments where all the experiments are considered at once.
- Results indicated:
  - ❖ In some cases there are differences on the central values of the cross sections.
  - ❖ Standard deviations tend to be systematically lower (except partially for one specific case) when the new methodology is applied.
  - ❖ One can expect a bigger impact if more experiments of elemental type are used (e. g. large ENDF/B-VII.0 adjustment).
  - ❖ The procedure is quite cumbersome (12 adjustments performed with several intermediate steps).



# REWINDing PIA applied to SG33 experiments and 5 Isotopes: $^{23}\text{Na}$ , $^{56}\text{Fe}$ , $^{235}\text{U}$ , $^{238}\text{U}$ , $^{239}\text{Pu}$

Experiment	Optimal weight %	Rank	Sharpe Ratio	C/E before adjust.	C/E after adjust.	Uncert. before adjust. %	Uncert. after adjust. %
JEZ_Pu239 F28/F25	67.4	1	0.61	0.9770	1.0025	3.75	0.59
JEZ_Pu239 F37/F25	0.0	3	0.39	0.9870	0.9963	2.38	0.42
JEZ_Pu239 F49/F25	0.0	3	-0.15	0.9753	0.9960	0.82	0.31
FLATTOP F28/F25	0.0	3	0.40	0.9822	0.9905	3.12	0.56
FLATTOP F37/F25	0.0	3	0.30	0.9956	1.0078	2.05	0.41
ZPR6/7 F28/F25	0.0	3	0.46	1.0045	1.0121	6.48	0.87
ZPR6/7 F49/F25	0.0	3	-2.07	0.9638	0.9786	0.84	0.41
ZPPR9 F28/F25	32.6	2	0.64	0.9710	0.9895	8.02	0.90
ZPPR9 F49/F25	0.0	3	-1.47	0.9808	0.9958	0.87	0.40
ZPR6/7 C28/F25	0.0	2	-0.78	1.0098	0.9985	1.51	0.51
ZPPR9 C28/F25	100.0	1	-0.29	1.0093	0.9999	1.55	0.51
JEZ_Pu239 KEFF	7.6	4	0.69	0.99986	1.00011	0.74	0.11
JEZ_Pu240 KEFF	0.0	5	0.59	0.99981	0.99999	0.73	0.13
FLATTOP KEFF	44.3	1	0.65	1.00097	1.00015	0.88	0.14
ZPR6/7 KEFF	0.0	5	0.77	1.00043	1.00038	1.00	0.09
ZPR6/7 PU40 KEFF	0.0	5	0.78	0.99937	0.99935	1.00	0.08
ZPPR9 KEFF	36.5	2	0.90	0.99922	1.00009	1.22	0.08
JOYO KEFF	11.7	3	0.79	0.99746	0.99991	0.90	0.14
ZPPR9 STEP3	0.0	2	-0.02	1.0192	1.0272	7.65	3.09
ZPPR9 STEP5	100.0	1	0.23	0.9732	0.9822	9.90	3.77

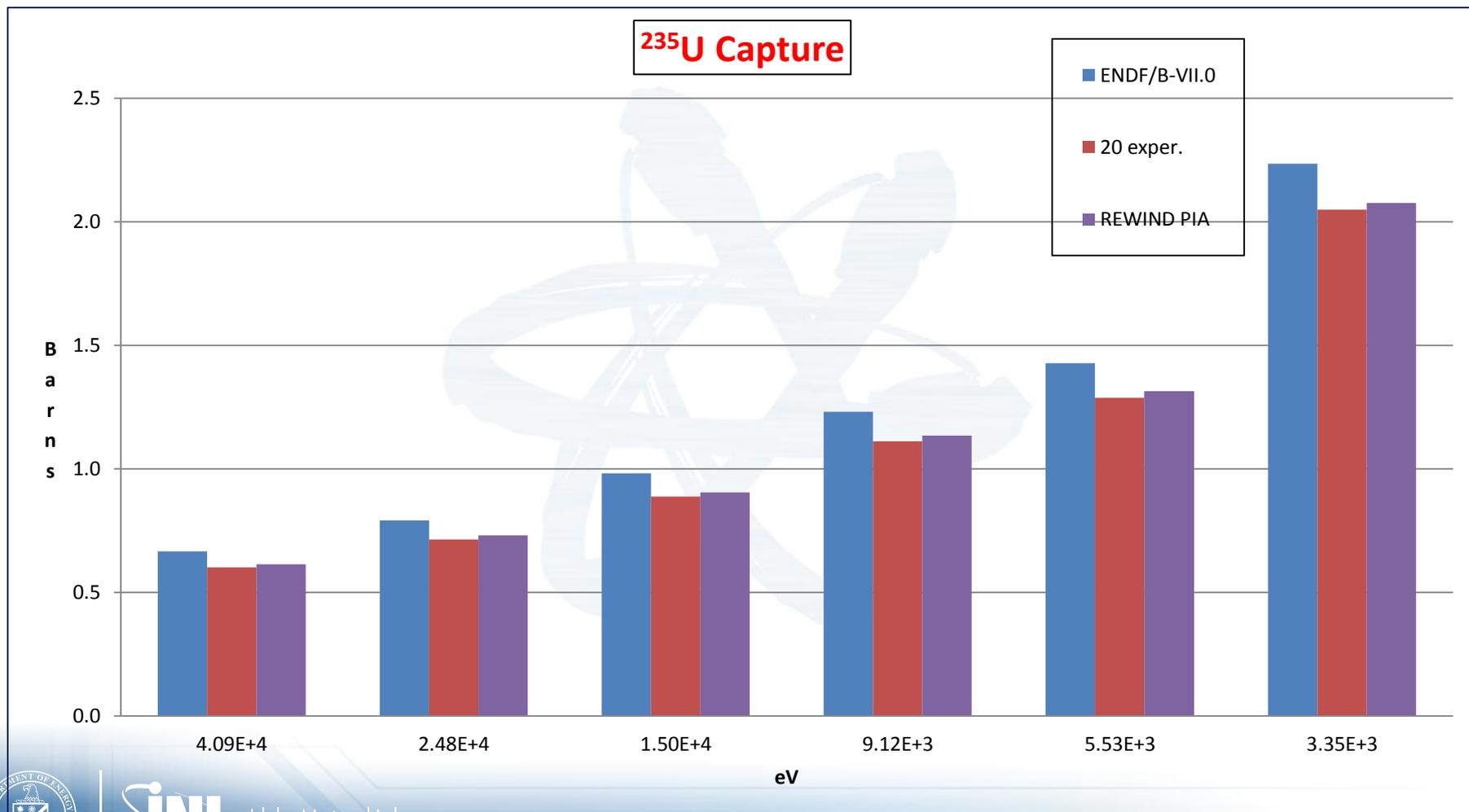
$\chi^2$  Before Adjust: 0.90 After Adjust.: 0.14



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# REWINDing PIA applied to SG33 experiments

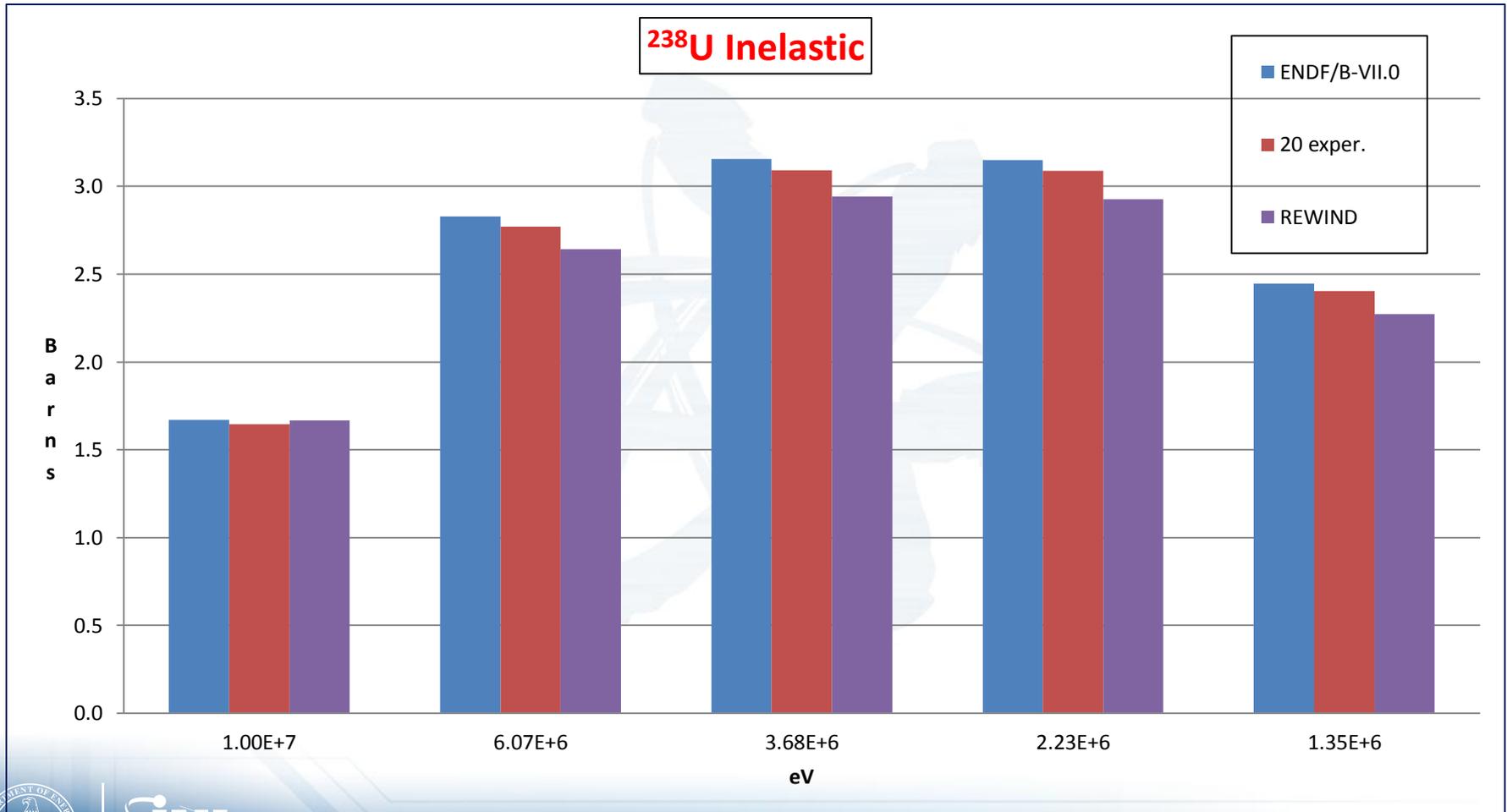
$\sigma$



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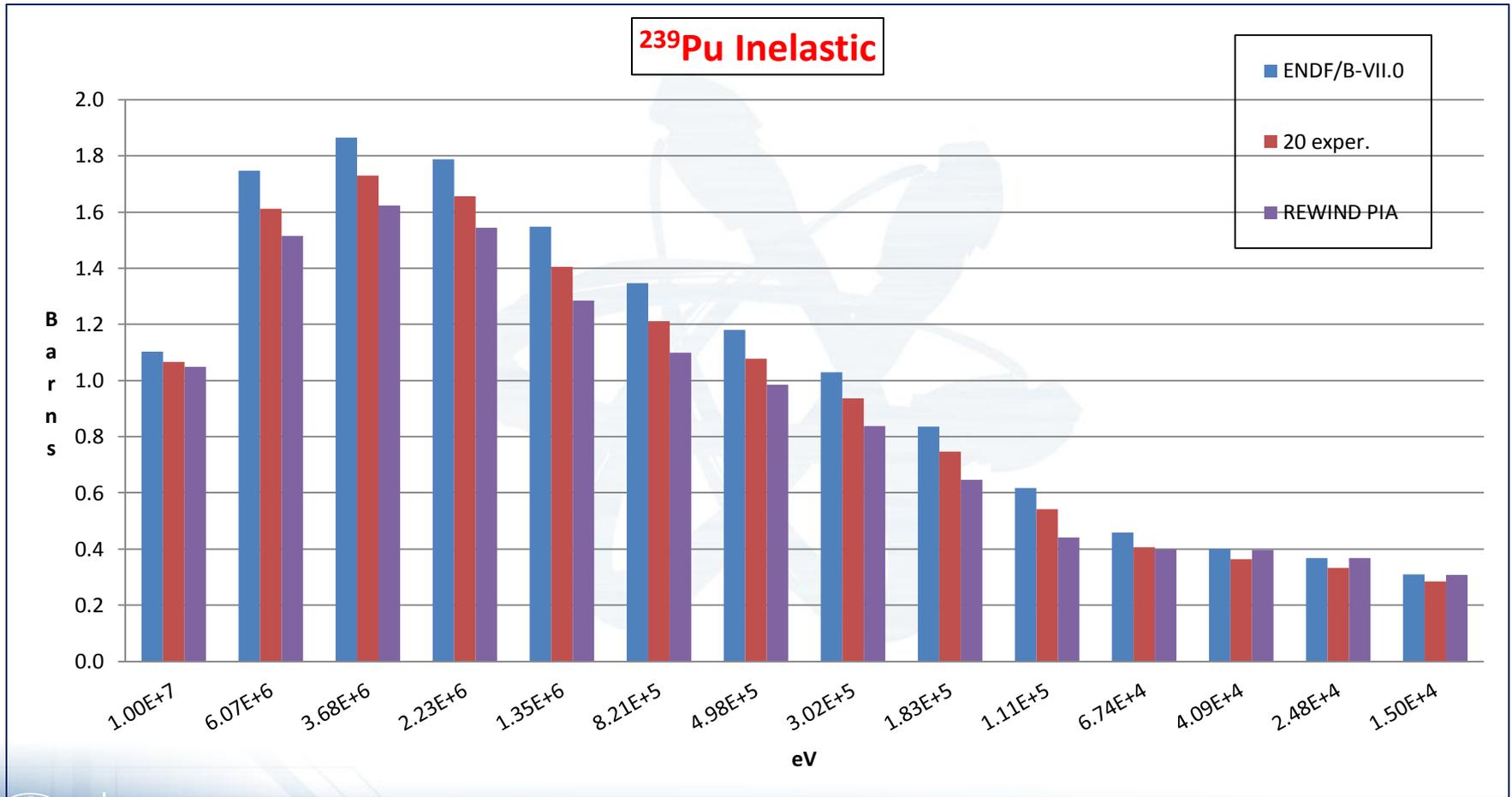
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$\sigma$

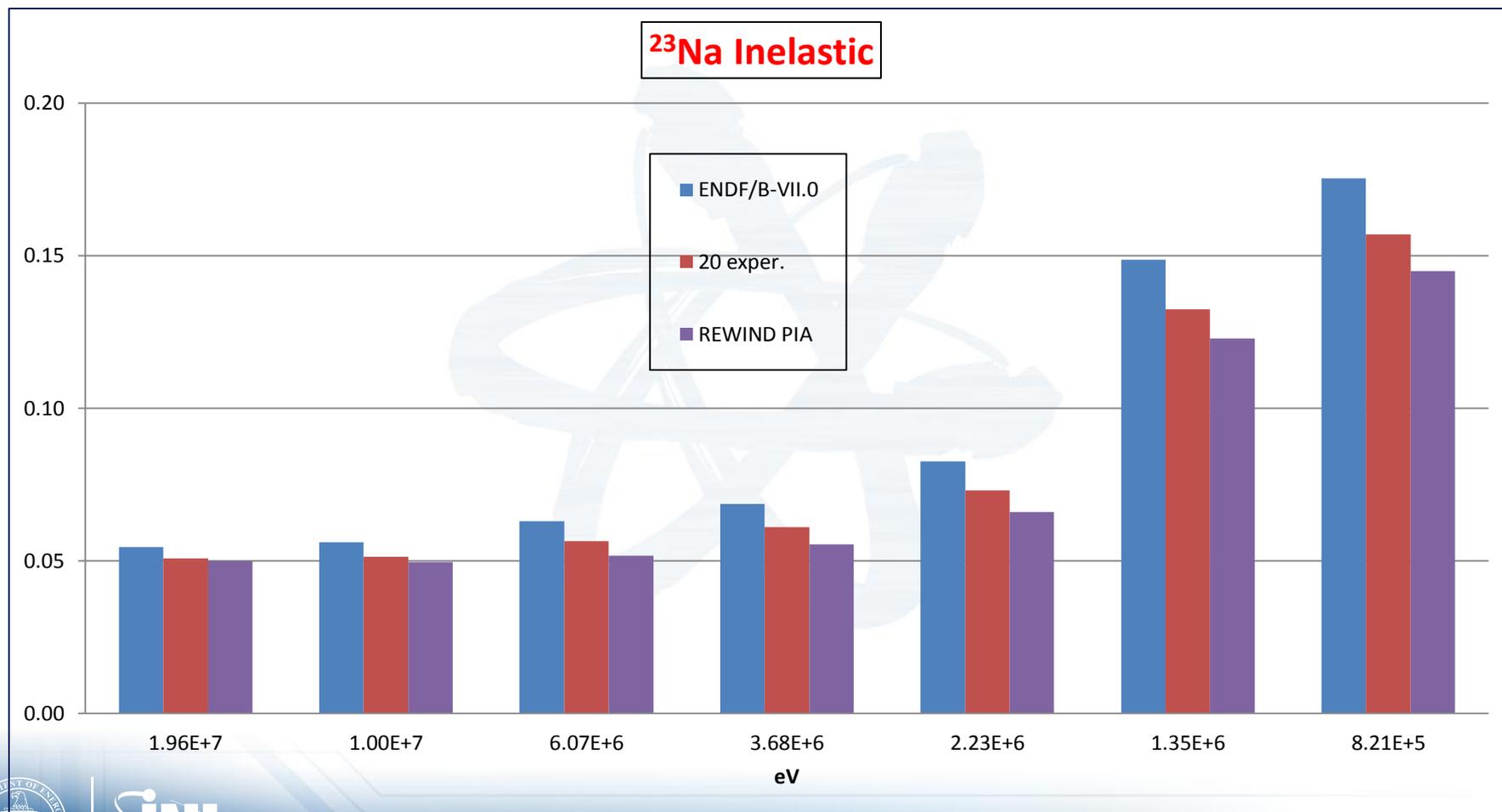


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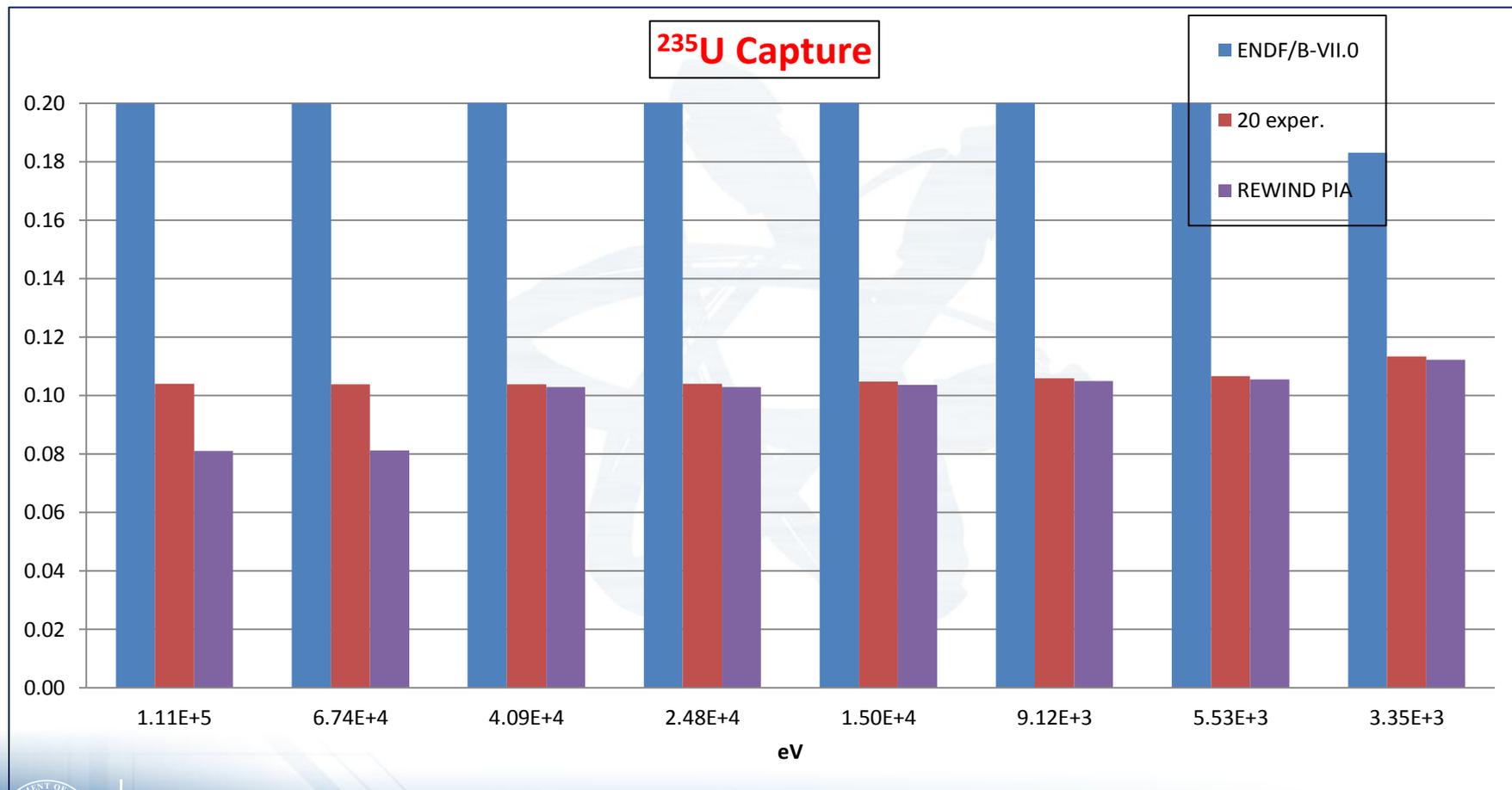
## $\sigma$



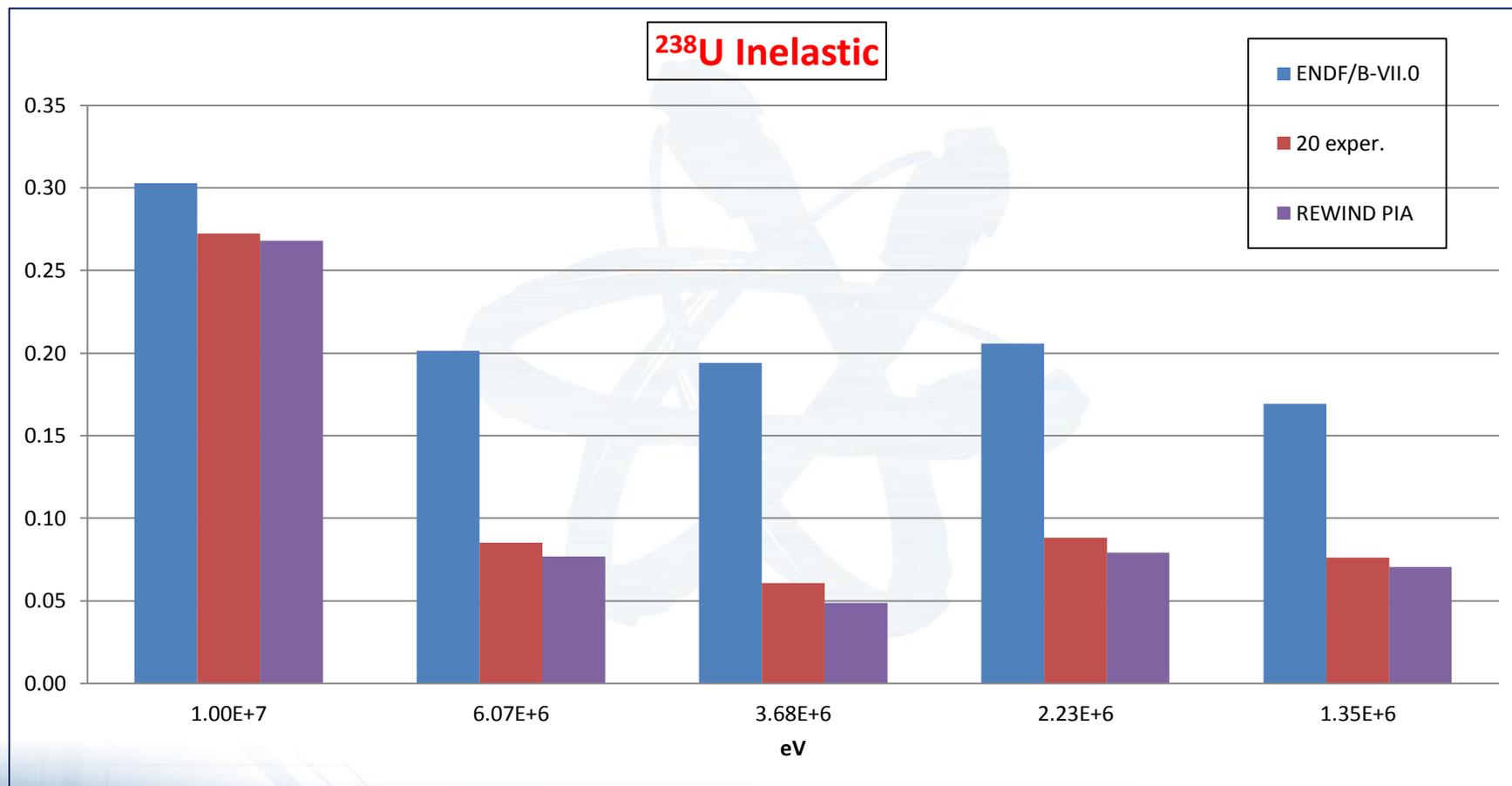
# REWINDing PIA applied to SG33 experiments Standard Deviation



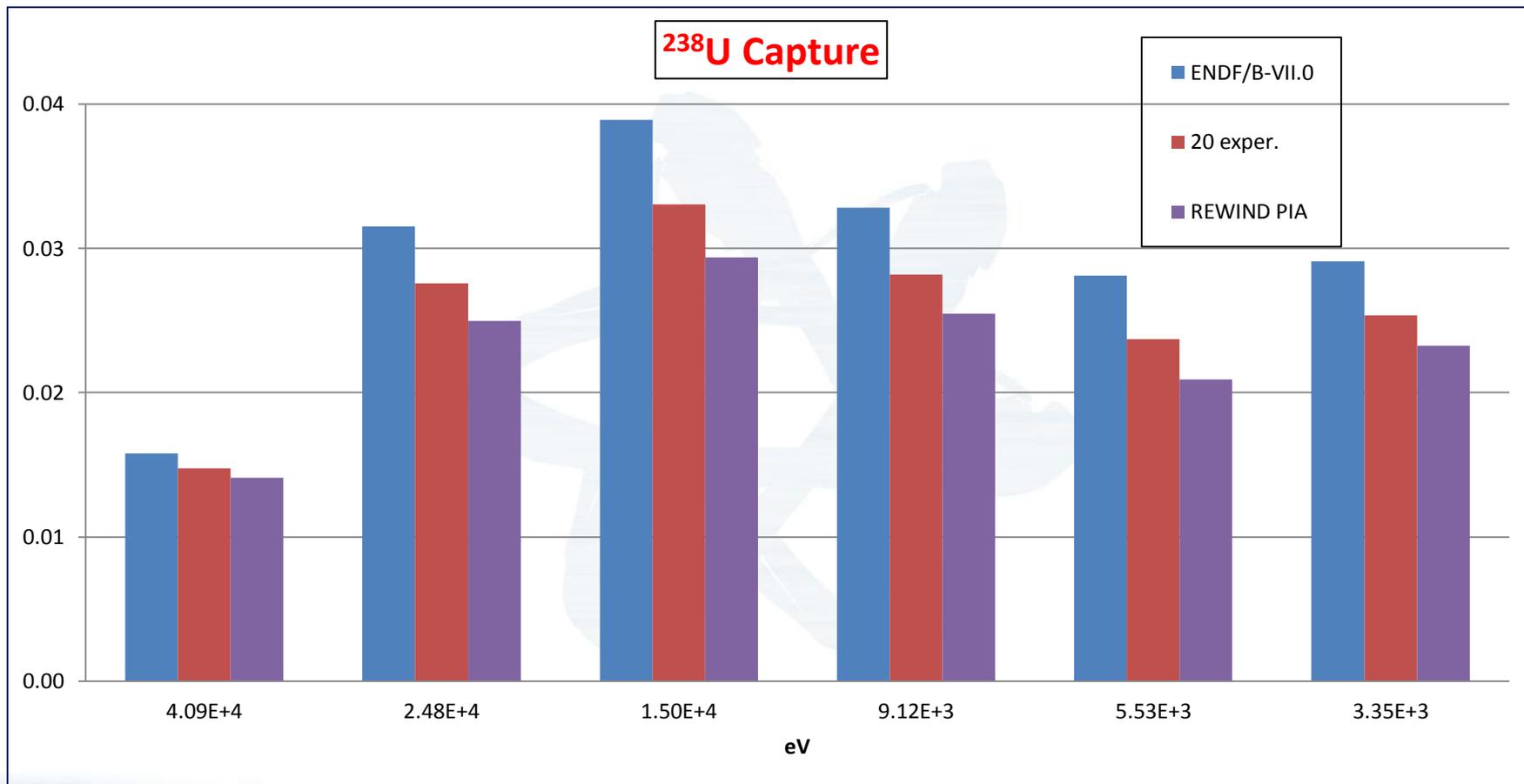
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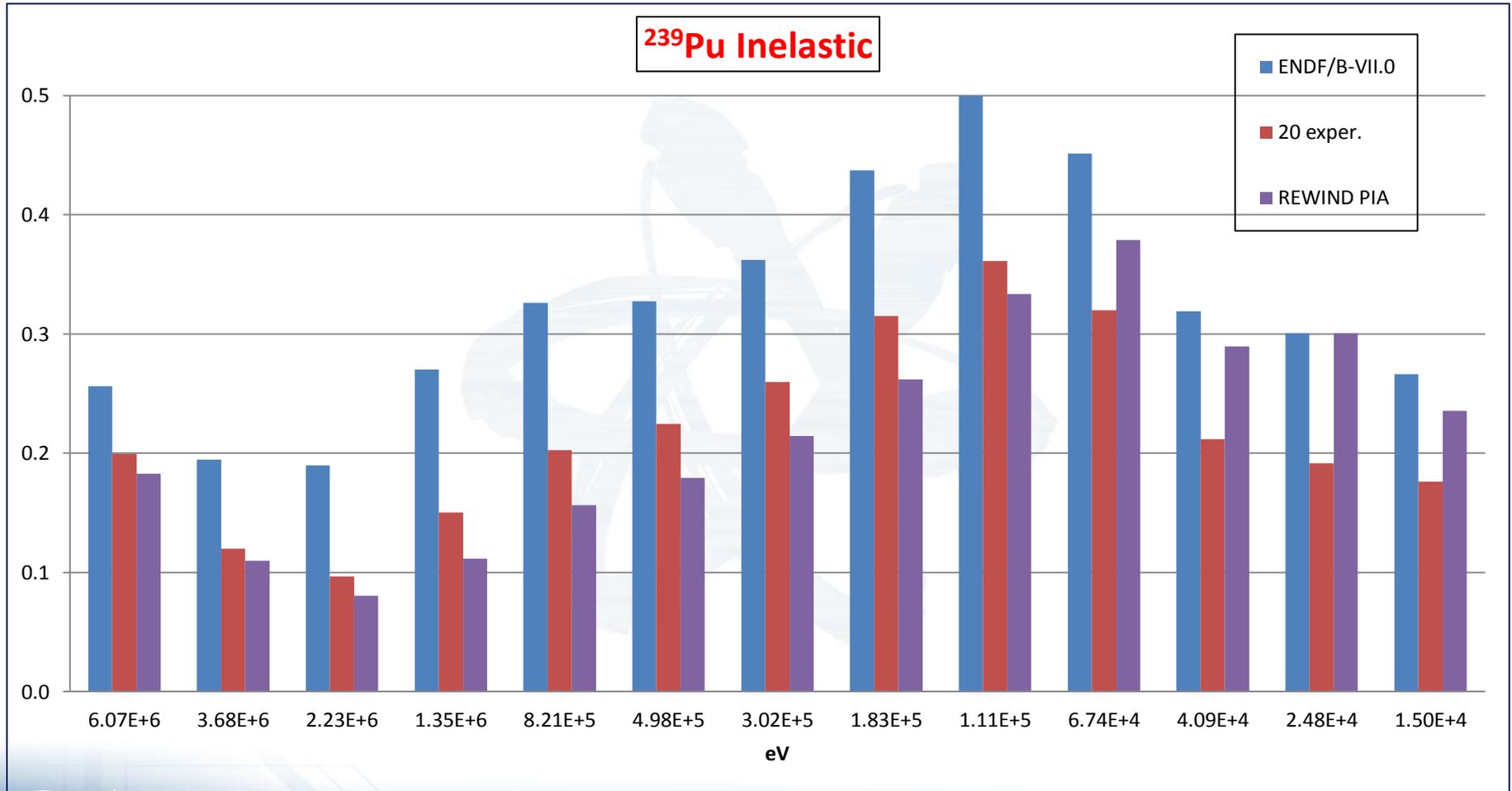


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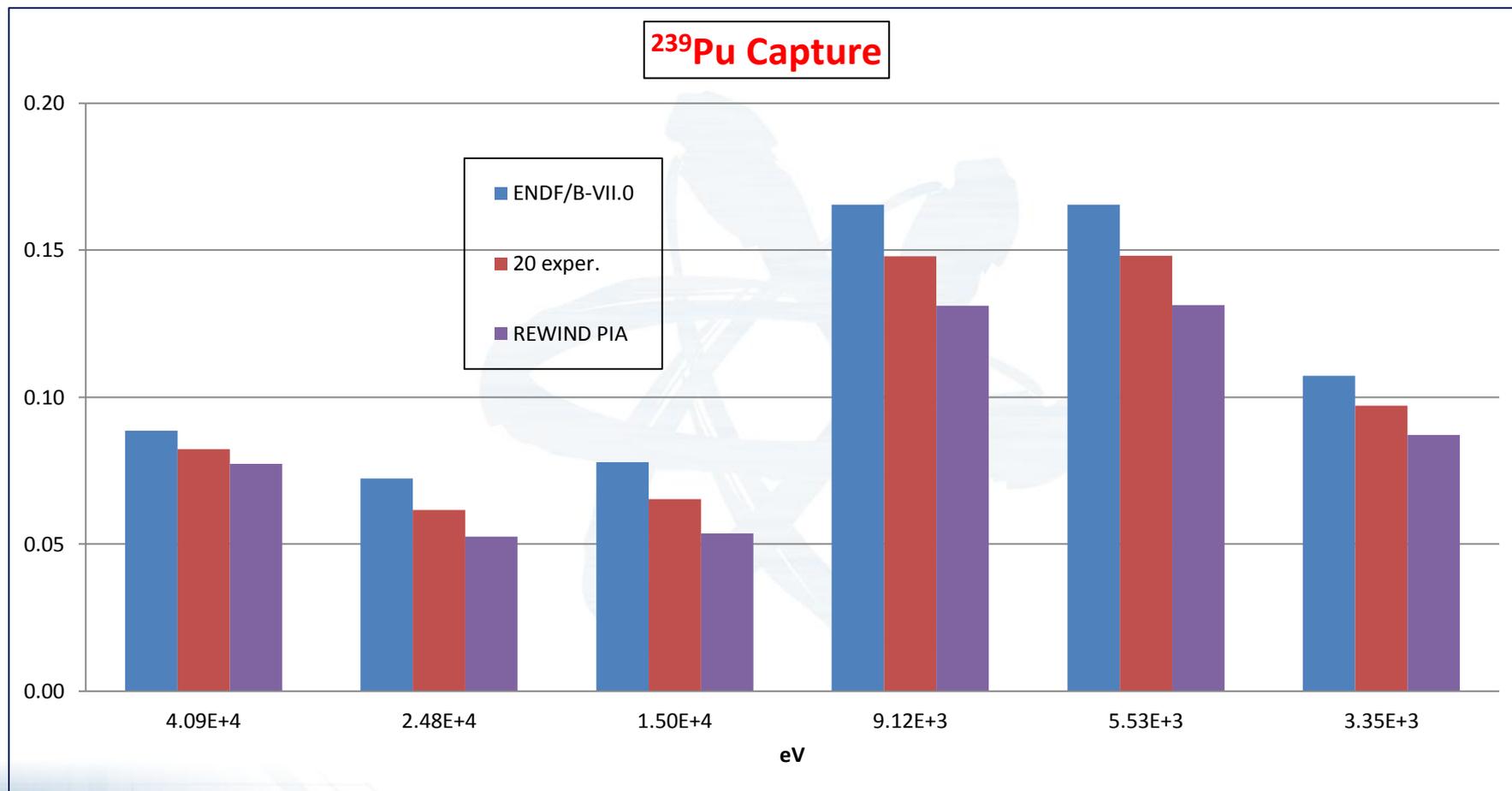


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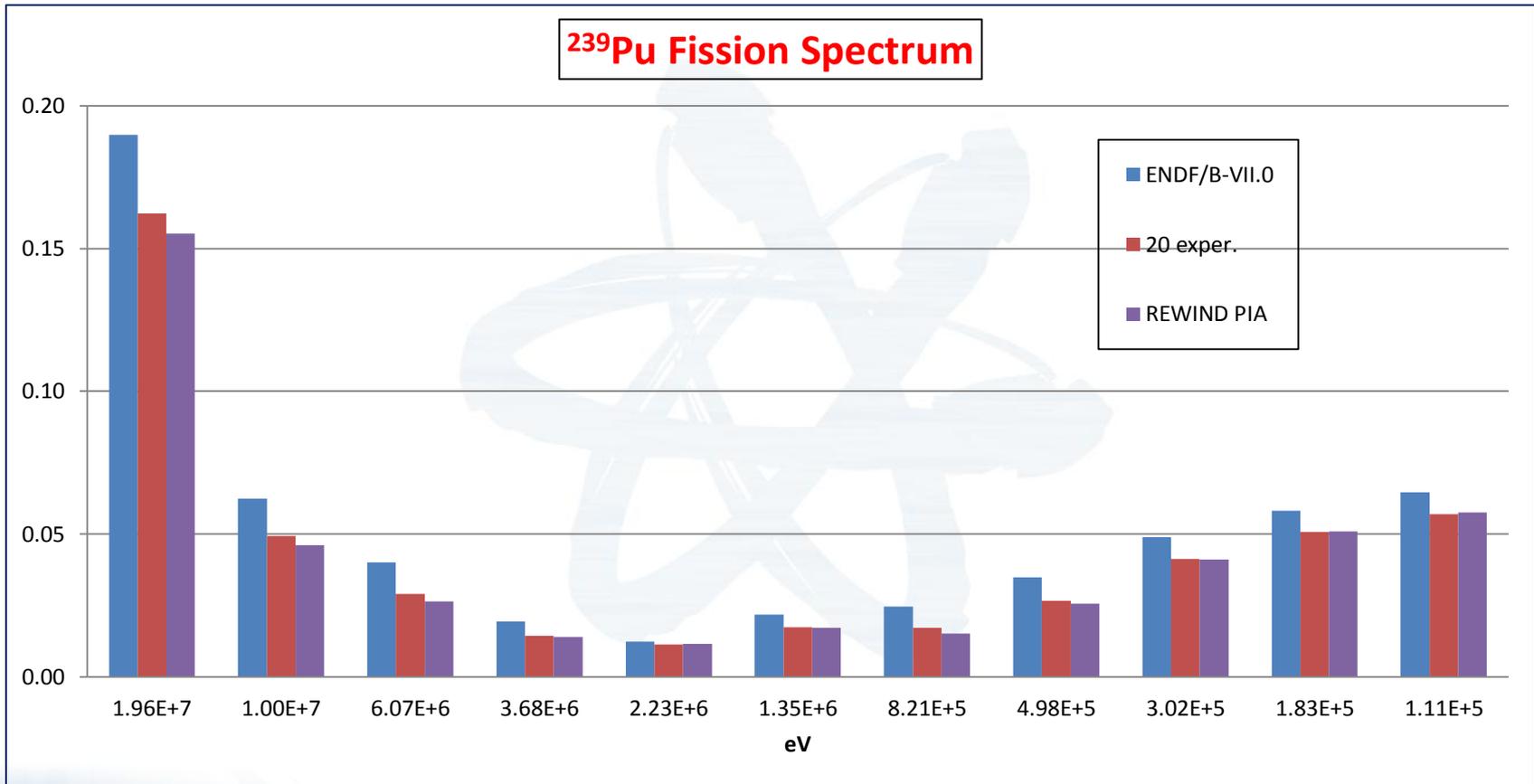
# REWINDing PIA applied to SG33 experiments Standard Deviation



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# REWINDing PIA applied to SG33 experiments Standard Deviation



# Conclusions

- **The REWINDing PIA methodology has been formulated and implemented.**
- **Results compared against the standard methodology shows that the new methodology tends to produce smaller standard deviations.**
- **In the future this new methodology can be applied to the set of the comprehensive adjustment of ENDF/B-VII.0 with ~ 100 experiments**
- **However, the implementation of the methodology is quite cumbersome and needs to be made more user friendly. Moreover, nonlinear effects are neglected.**
- **In the future, functionals, different from the Sharpe Ratio, can be considered for the optimization procedure in the REWIND methodology (e. g. Cook distance).**

