MONTE CARLO CALIBRATION UNCERTAINTIES: XMM-NEWTON EPIC-PN

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MC APPROACH

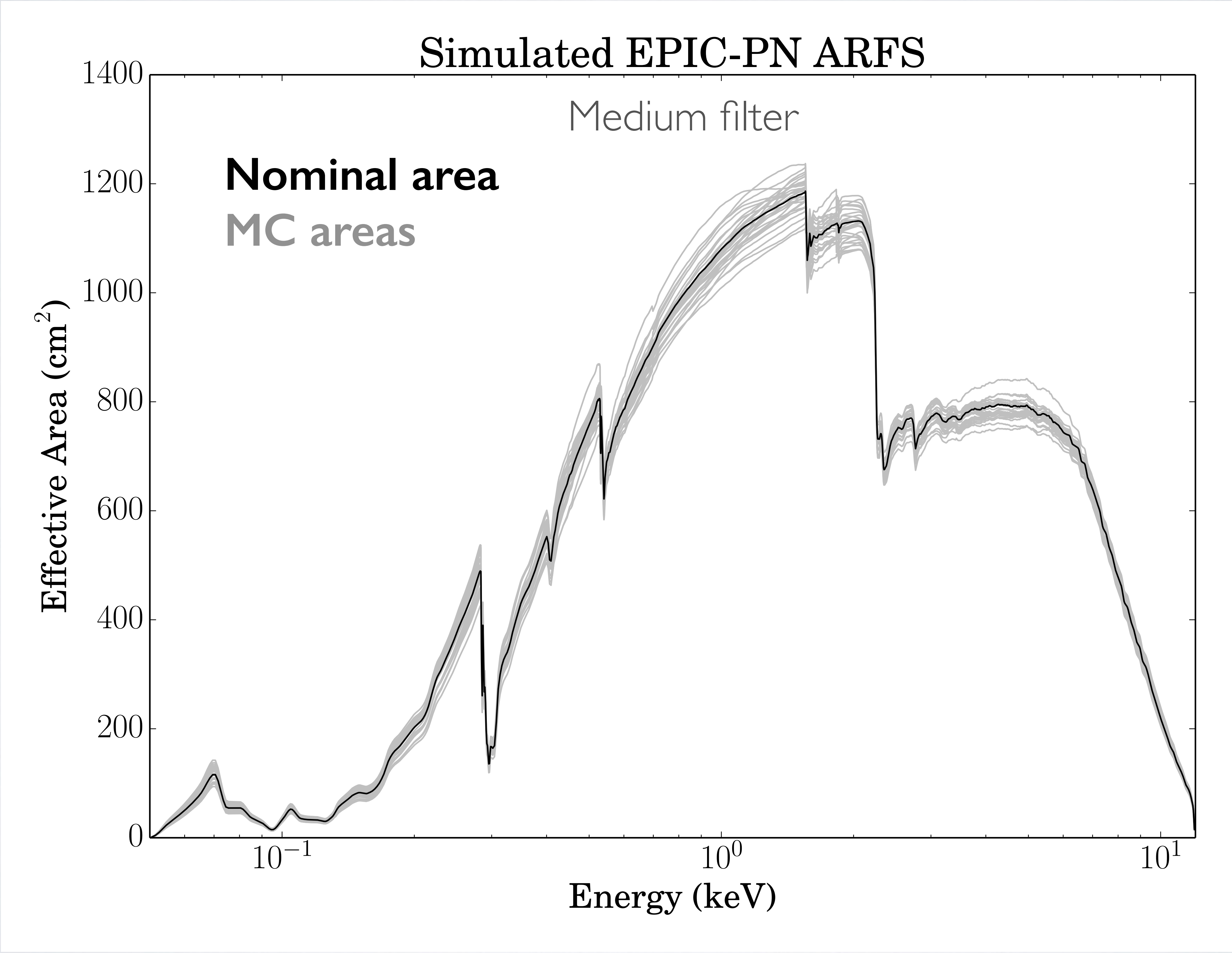
- Adopt same approach as for Chandra, realized in XSPEC MC and PyBLoCXS methods
- Currently just including inter-edge "perturbation function" method - see Appendix
- Input uncertainties currently pure JJD guesswork - can work with XMM team to include improved guesses, and any instrument numerical/analytical model info available
- In this example we use the "Medium" EPIC-pn filter

INPUT FILE

- File consists of uncertainty data for each instrument subassembly (MM=multi-mirror, OBFM=optical blocking filter medium, etc)
- Each line refers to an energy range (in keV) bounded by instrument edges
- Format: Emin,Emindev,Emax,Emaxdev,Edgeveto, maxdiff (see Appendix for details)

```
MM
0.05 0.04 2.291 0.04 0.03 0.04
2.291 0.03 3.425 0.03 0.01 0.03
3.425 0.03 7.000 0.03 0.005 0.03
7.000 0.05 12.0 0.10 0.10
CONTAM
0.05 0.10 0.2838 0.02 0.02 0.10
0.2838 0.02 0.4099 0.02 0.02 0.02
0.4099 0.02 0.532 0.02 0.01 0.02
0.532 0.02 0.6967 0.02 0.02
OBFTN
0.05 0.15 0.297 0.07 0.03 0.15
0.297 0.05 0.540 0.03 0.02 0.05
0.540 0.02 1.567 0.02 0.02 0.02
1.567 0.02 12.0 0.02 0.02
OBFM
0.05 0.15 0.297 0.07 0.04 0.15
0.297 0.06 0.540 0.03 0.02 0.06
0.540 0.02 1.567 0.02 0.02 0.02
1.567 0.02 12.0 0.02 0.02
OBFTK
0.05 0.15 0.297 0.07 0.05 0.15
0.297 0.07 0.540 0.03 0.02 0.07
0.540 0.02 1.567 0.02 0.02 0.02
1.567 0.02 12.0 0.02 0.02
EPICPN
0.05 0.20 0.132 0.10 0.11 0.20
0.132 0.15 0.539 0.05 0.03 0.15
0.539 0.04 1.827 0.04 0.03 0.04
1.827 0.04 12.0 0.03 0.04
EPICMOS
0.05 0.30 0.132 0.20 0.11 0.30
0.132 0.15 0.539 0.07 0.04 0.15
0.539 0.05 1.827 0.05 0.04 0.05
1.827 0.05 12.0 0.04 0.05
```

SAMPLE AREAS

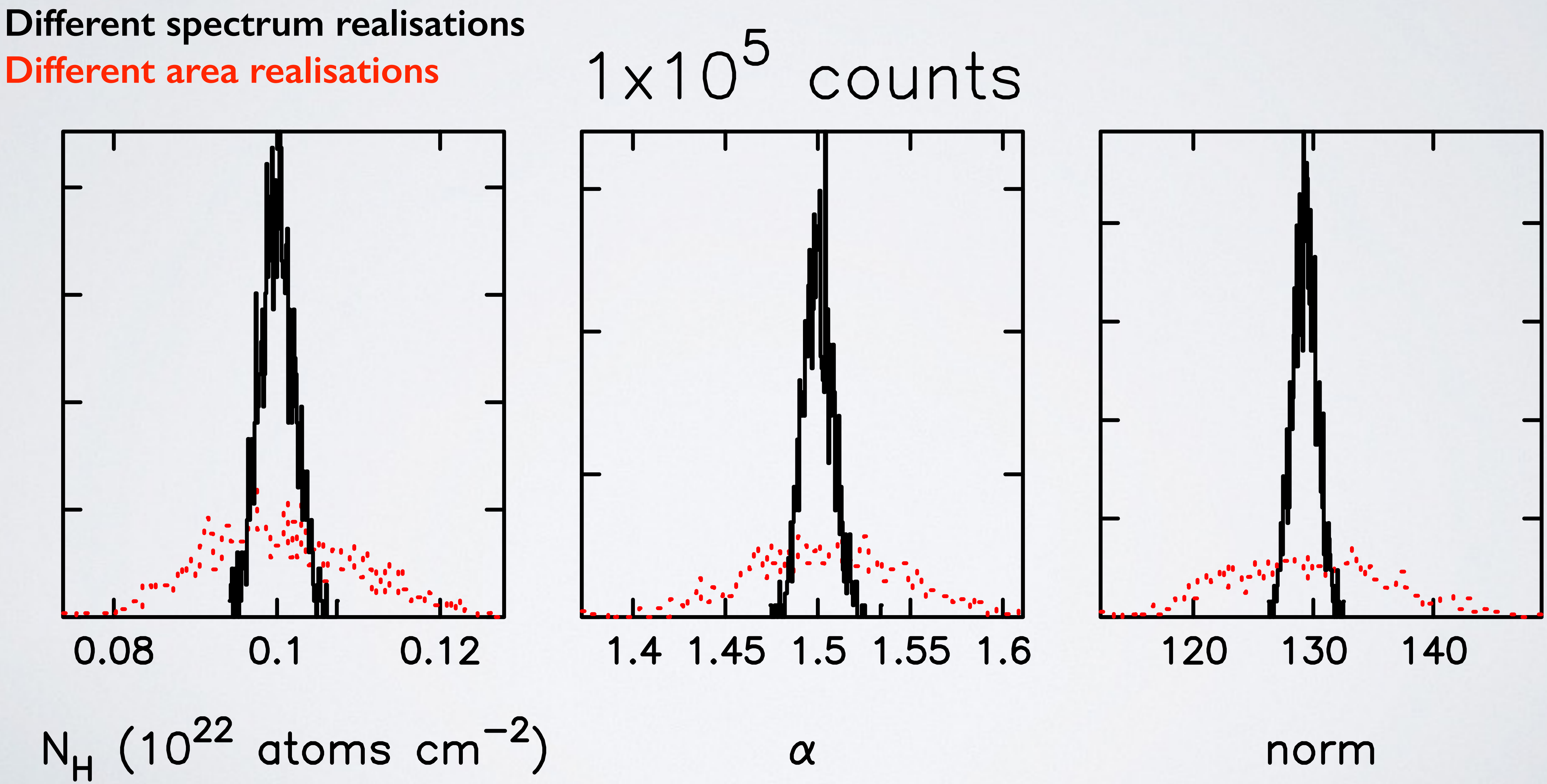


EXERCISE: LIMITING ACCURACY OF EPIC-PN

- Same approach as previously applied to Chandra ACIS-S:
- Simulate spectrum ("fakeit")
- Fit using different effective area realisations a lot of (e.g. 1000) times
  - Sherpa driven by Python
  - Models: blackbody, MEKAL, power-law; all with ISM absorption
- Compare with fits to 1000 different "fakeits" using nominal area to probe uncertainties from only counting statistics

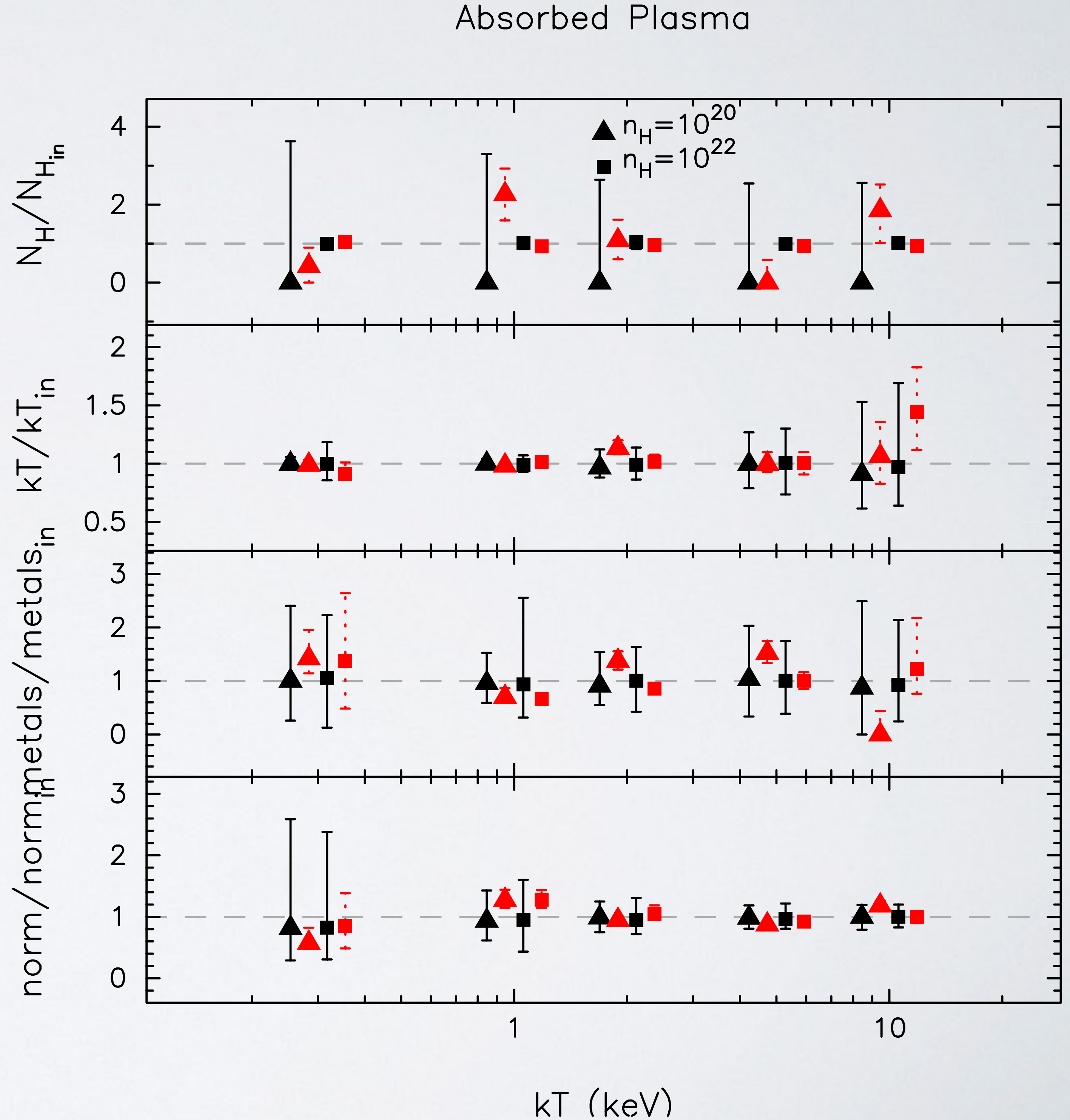
FITTED PARAMETER DISTRIBUTIONS

Absorbed Power Law : $\alpha=1.5$, $n_H=10^{21}$



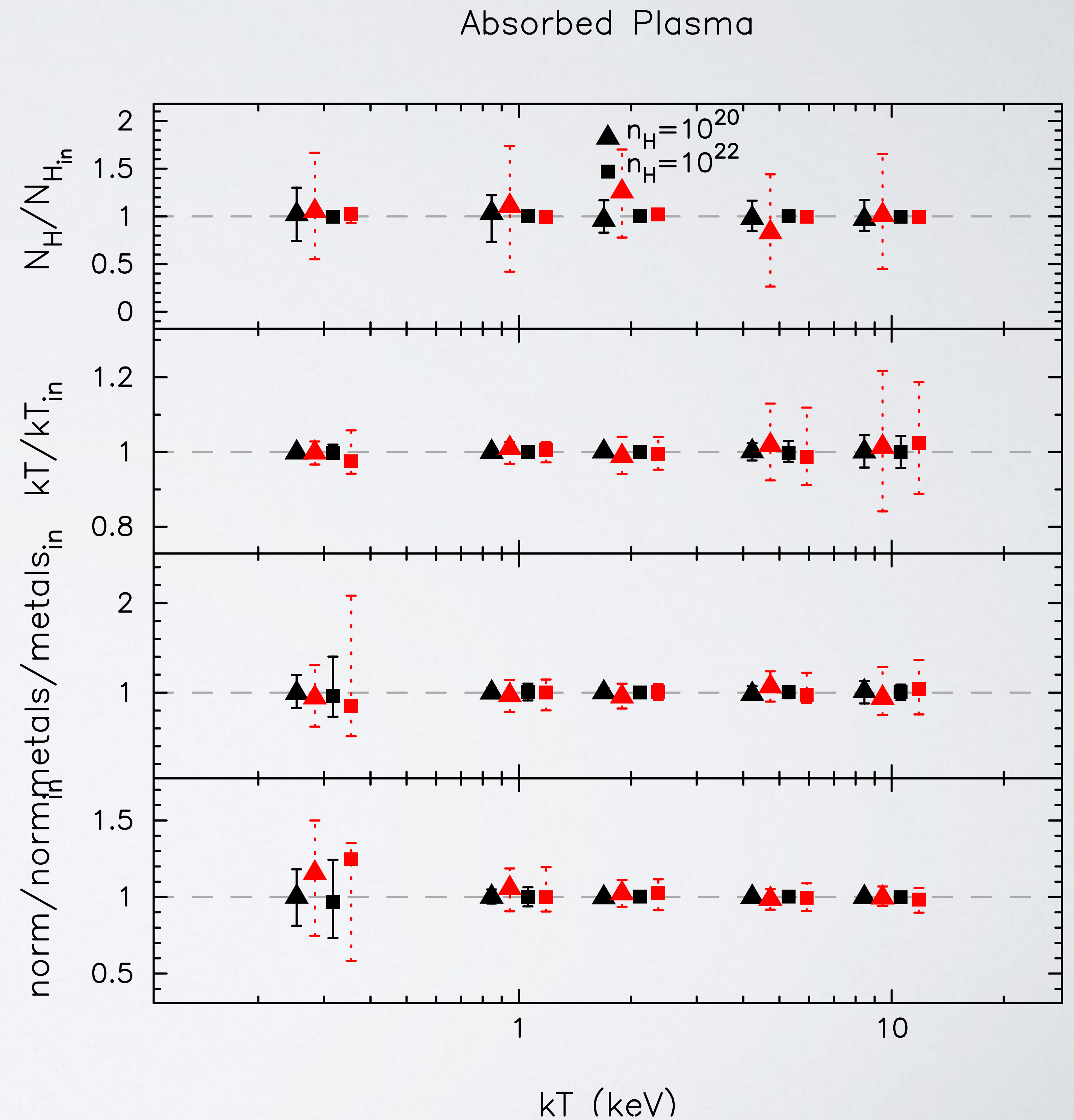
FITTED PARAMETER DISTRIBUTIONS

- 10^3 counts: **Poisson noise** dominates **calibration uncertainties**

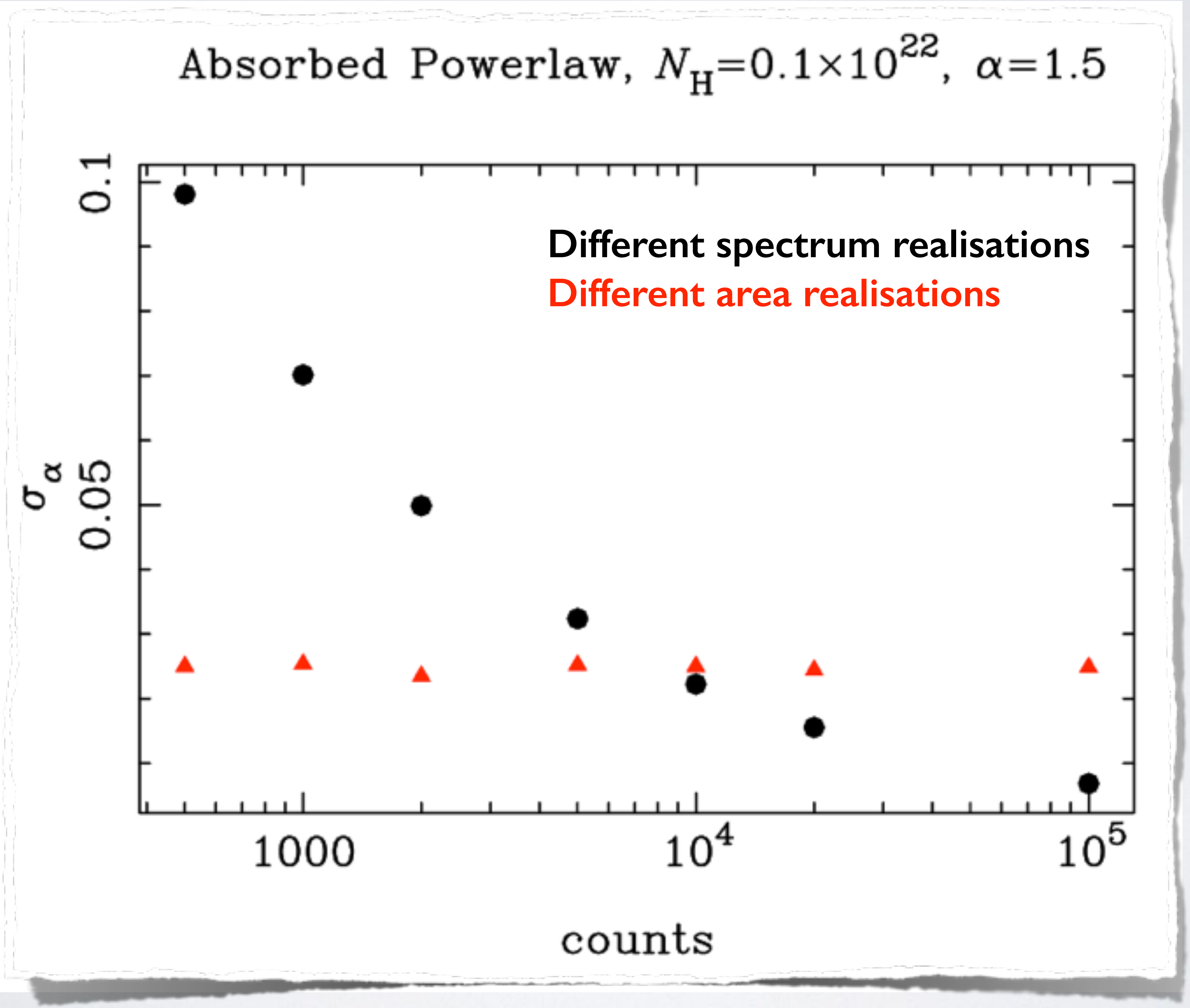


FITTED PARAMETER DISTRIBUTIONS

- 10^5 counts: **calibration uncertainties** dominate **Poisson noise**



XMM EPIC-PN PRECISION



SUMMARY

- A fairly simple MC analysis using JJD-invented uncertainties for XMM-Newton EPIC-pn finds that the limiting precision is reached for about 10,000 counts; ie increasing exposure time to get more counts does not help the accuracy of the fit

- Analysis can be repeated for “real” uncertainty data

APPENDIX: NOTES ON METHODOLOGY

MONTE CARLO APPROACH

Analytical solutions difficult....

- Moore's law: since initial thoughts and ideas, computer power sufficiently advanced to allow brute-force Monte Carlo methods:
  - Simulate 100's-1000s of response functions that sample nominal response and its uncertainties
  - Repeat parameter estimation and examine distributions of "best-fit" parameters

METHOD APPLIED TO ACIS-S3

- Parameterised instrument models where available; vary parameters, re-compute response, eg:
  - Mirror trial models
  - CCD QE, contamination, RMF models
- Use a "perturbation function" - a perturbation vs E by which to change subassembly responses between edges

METHOD APPLIED TO ACIS-S3

Uncertainties in Photon Path

↓

HRMA: geometry, obscuration, reflectivity, scattering

↓

ACIS OBF: transmittance, contamination

↓

ACIS QE: (CTI, dead time, cosmic rays, electronics…)
ACIS RMF: (gain distribution, escape peaks...)

METHOD APPLIED TO EPIC-PN

Uncertainties in Photon Path

↓

MM: perturbation function for reflectivity, obscuration etc

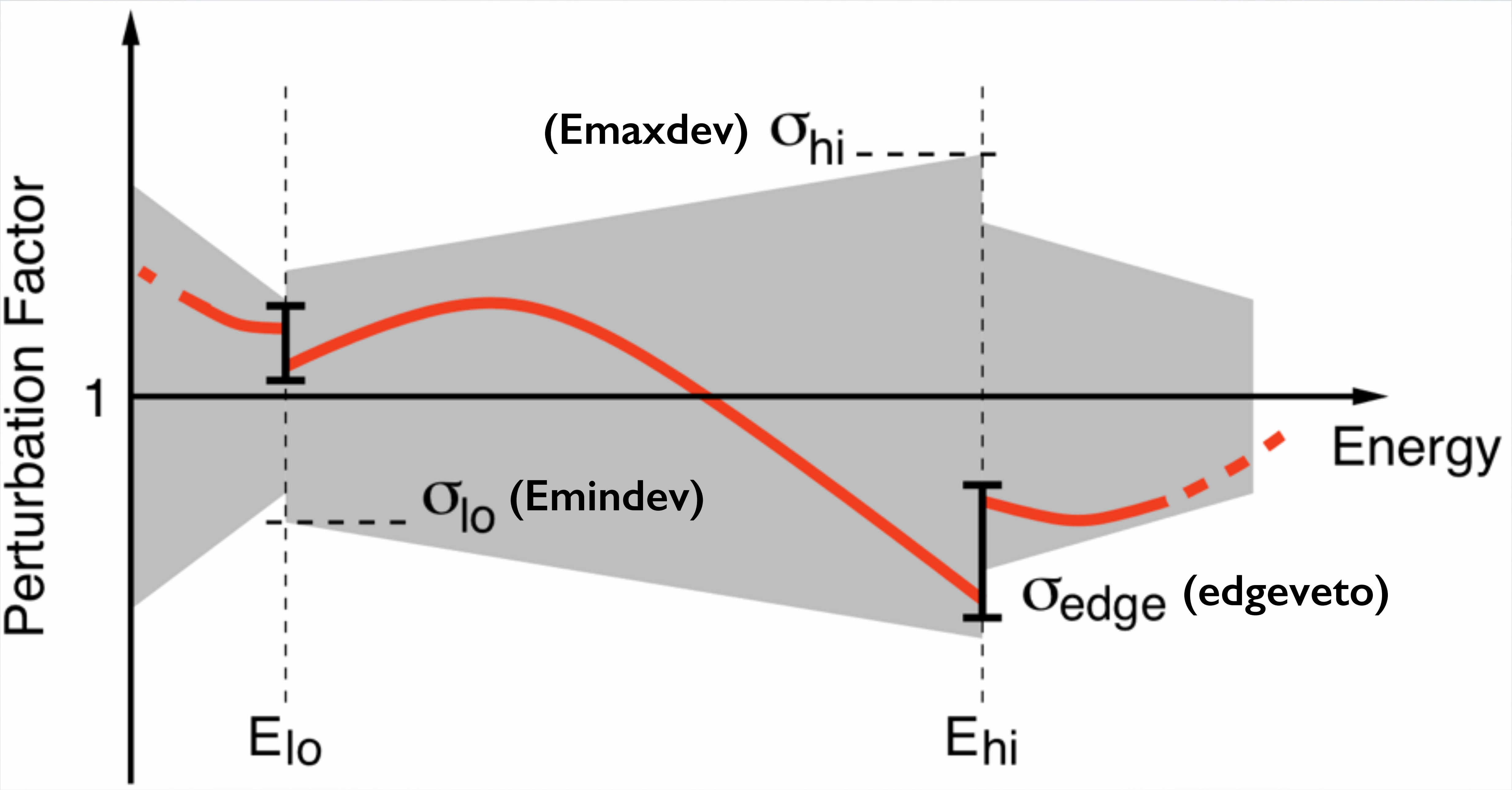
↓

OBF: perturbation function for transmittance, contamination

↓

EPIC QE: perturbation functions
RMF: not yet included

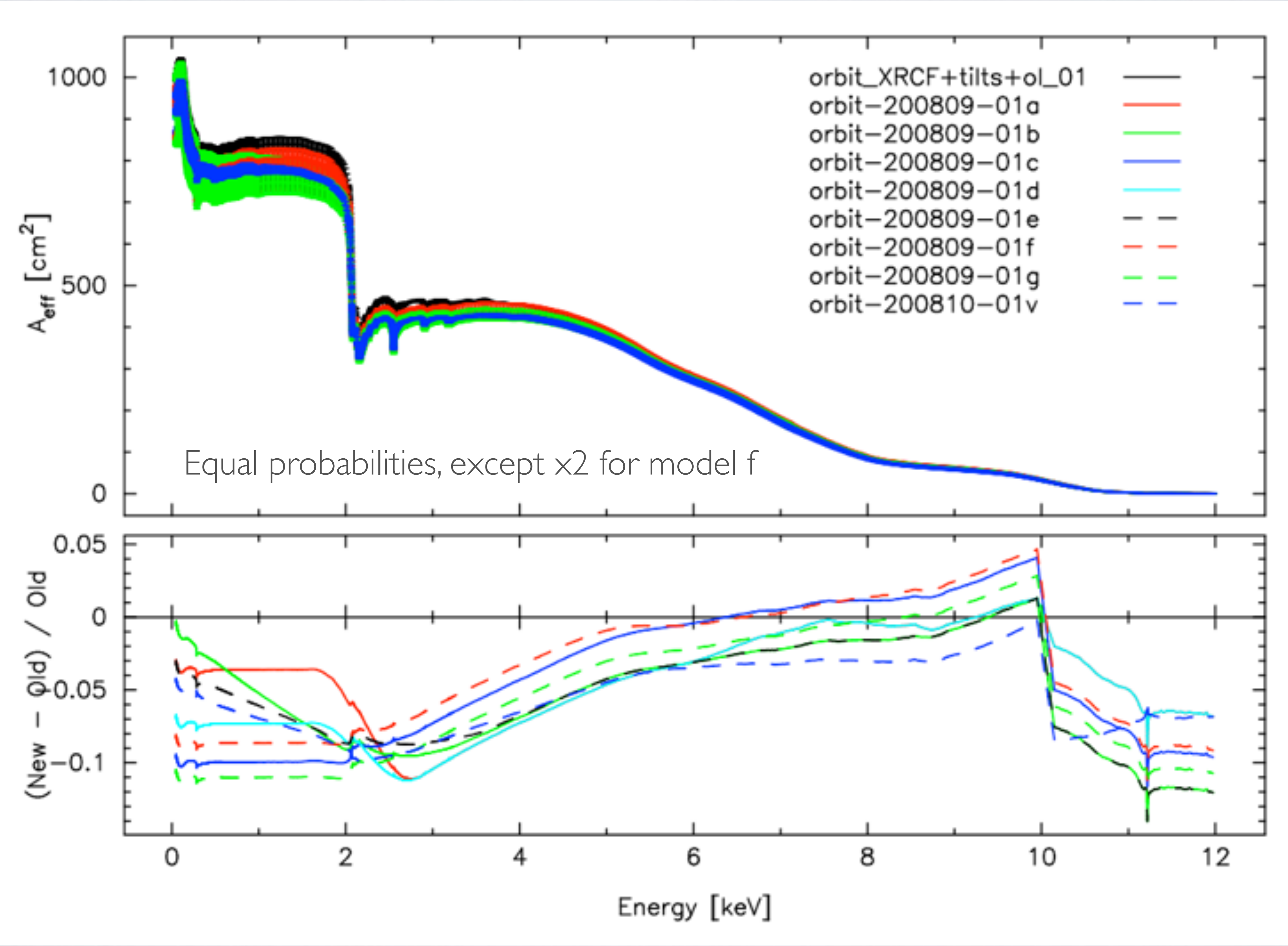
PERTUBATION FUNCTION



2014: Added "maxdiff" - the maximum difference allowed between nominal (=1) and perturbed area.

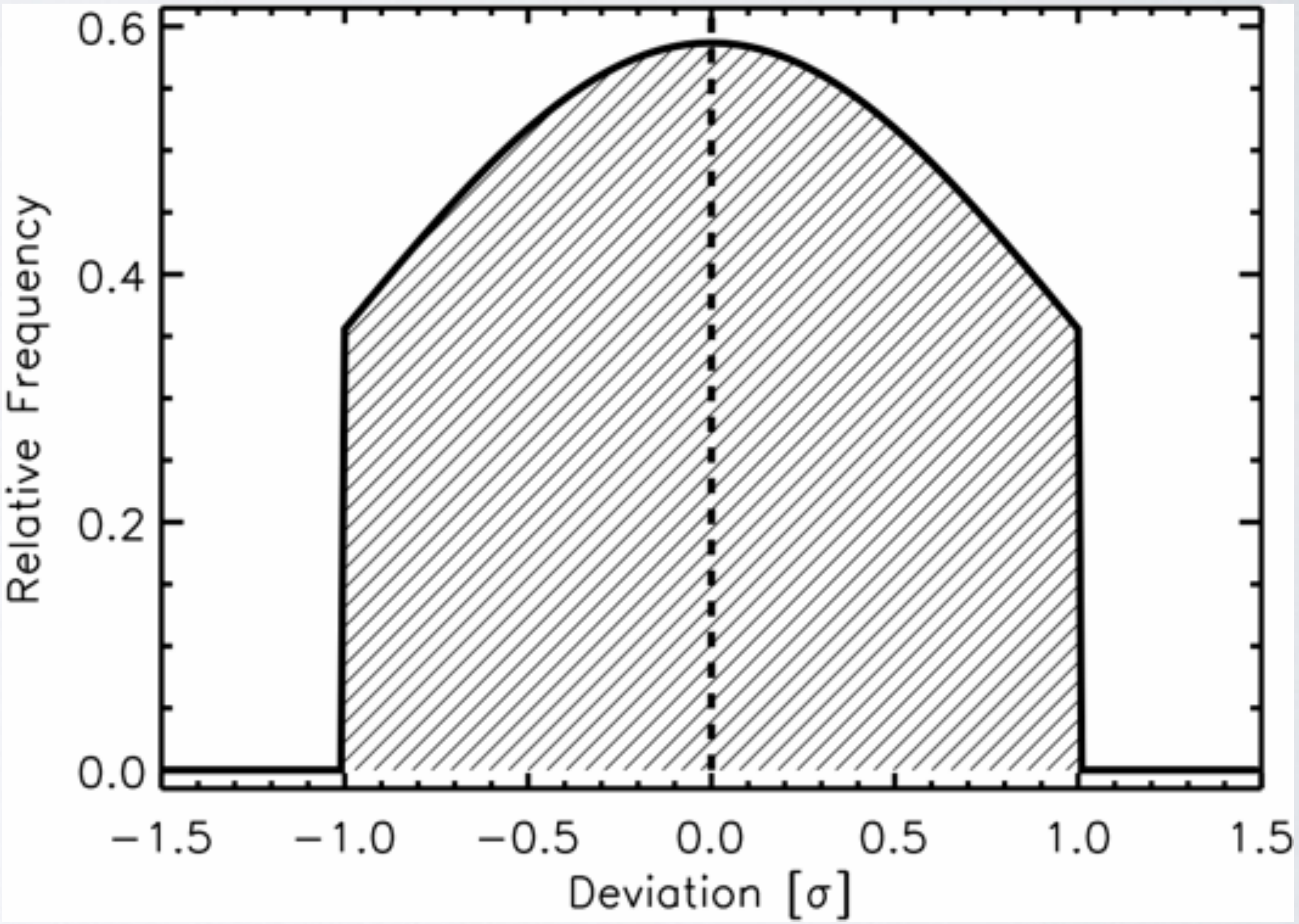
- controls curvature in function, prevents unrealistic deviations

FOR HRMA WE ALSO USE RAY-TRACE MODEL AREAS



HOW ARE CALIBRATION UNCERTAINTIES DISTRIBUTED?

- Rigorous treatment requires knowledge of how uncertainties are distributed
  - Unknown!
- Assume a truncated normal distribution -1σ to +1σ
  - Peaked at preferred value
  - Includes gut feeling!



RESULTING ACIS-S3 AREAS