Cross-Calibration of the XMM-Newton EPIC pn & MOS On-Axis Effective Areas Using 2XMM Sources

XMM
EPIC

Andy Read (amr30@le.ac.uk)
IACHEC #9 – Effective Area X-Cal of XMM-Newton MOS & pn
Airlie Center, Warrenton, Virginia, USA, 12-15/05/14

University *of* Leicester

Cross-Calibration: Some Different Samples & Methods

- Galaxy Clusters (GC)
  - Pros : Constant, Spectrally simple
  - Cons : Extended, diffuse
- Very Bright AGN (XCAL)
  - Pros : Bright, point-source
  - Cons : Piled-up, core-excised, variable
- Bright clean point sources (2XMM)
  - Pros : Point-source, non-piled-up
  - Cons : Spectrally complex/different, variable

2XMM Sample Selection

- 2XMM DR3 source catalogue (up to Rev1600, Sep 2008)
- Full-Frame (FF) mode and thin or medium filter in all of M1, M2 & pn
- Point sources (zero extent)
- Near on-axis (EP_OFFAX<2')
- Low column (|b|<15deg)
- Large numbers of counts (>5000 in each MOS, 15000 in pn)
- Below FF pile-up limit (rate<0.7 c/s [MOS], <6 c/s [pn])
- 87 sources
- BG-flare cleaned, common GTIs applied, and visually inspected
- Removed sources where:
  - at least one instrument had ~zero time/counts
  - confused sources close to other bright sources
  - appearing extended, or point source within extended emission
  - quadrant/chip loss
  - bright sources in the BG(/src) extraction region(s)
- 46 sources

2XMM Data Reduction

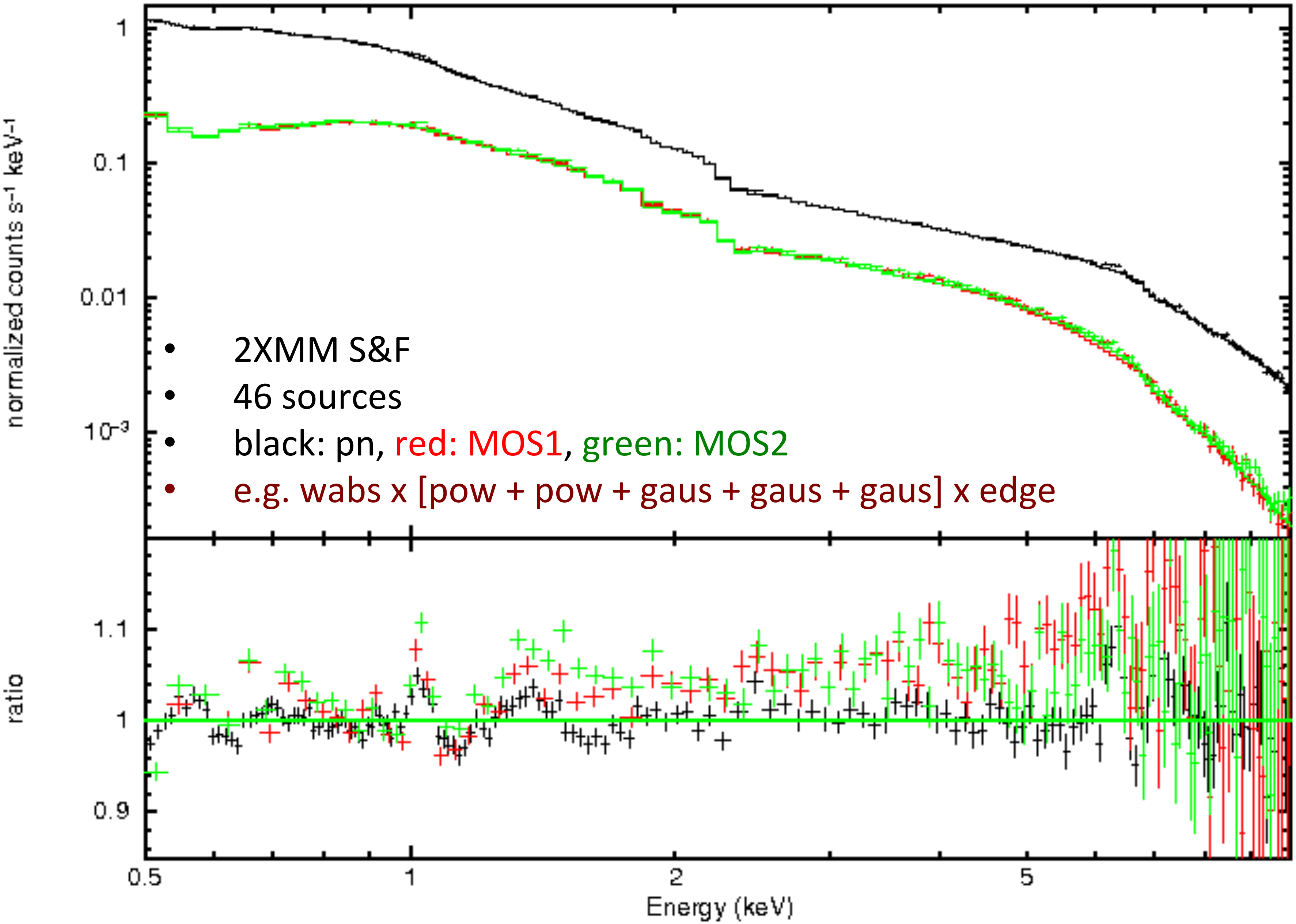
- Public SASv12, standard data-reduction meta-tasks e[mp]proc/e[mp]chain, default parameters
- Calibration up-to-date at time of analysis (end 2012)
- Use data screening criteria as recommended to users:
  - PATTERN(grade)<=12 for MOS, PATTERN<=4 for pn
  - FLAG #XMMEA_EM (MOS), FLAG==0 (pn)
  - spectralbinsize=5 in evselect
- Common Good-Time-Intervals - GTIs (combining M1, M2, pn) for each source separately

2XMM Spectral Reduction

- For each source and each instrument, produced:
  - Source spectra 0-40” (full circle, free from other sources)
  - BG spectra 90-180” (full annulus, free from sources)
  - rmfs and arfs
- For each instrument:
  - Source spectra stacked together, summing counts (exposure-weighting BACKSCAL)
  - BG spectra stacked together, summing counts (exposure-weighting BACKSCAL)
  - Average exposure-weighted arf calculated
  - Average exposure-weighted rmf calculated (addrmf; ensuring sum of exposure weights is unity)
- Output is (for each of M1, M2 & pn) one source spectrum, one BG spectrum, one arf & one rmf

2XMM Spectral Analysis

- Having stacked the data, we now fit:
  'Stack & Fit' – S&F
- Multi-component (phenomenological) model constructed to closely fit the pn data
- pn chosen as 'anchor'/baseline –
  - pn mainly drives multi-EPIC fit
  - pn appears stable (though not necessarily 'correct')
- Final results insensitive to 'goodness' of model, so long as it is adequate
- How M1/M2 varies wrt pn can then be inspected



- 2XMM S&F
- 46 sources
- black: pn, red: MOS1, green: MOS2
- e.g. wabs x [pow + pow + gaus + gaus + gaus] x edge

XMM EPIC

Andy Read (amr30@le.ac.uk)
IACHEC #9 – Effective Area X-Cal of XMM-Newton MOS & pn
Airlie Center, Warrenton, Virginia, USA, 12-15/05/14

University of Leicester

2XMM Residuals Analysis

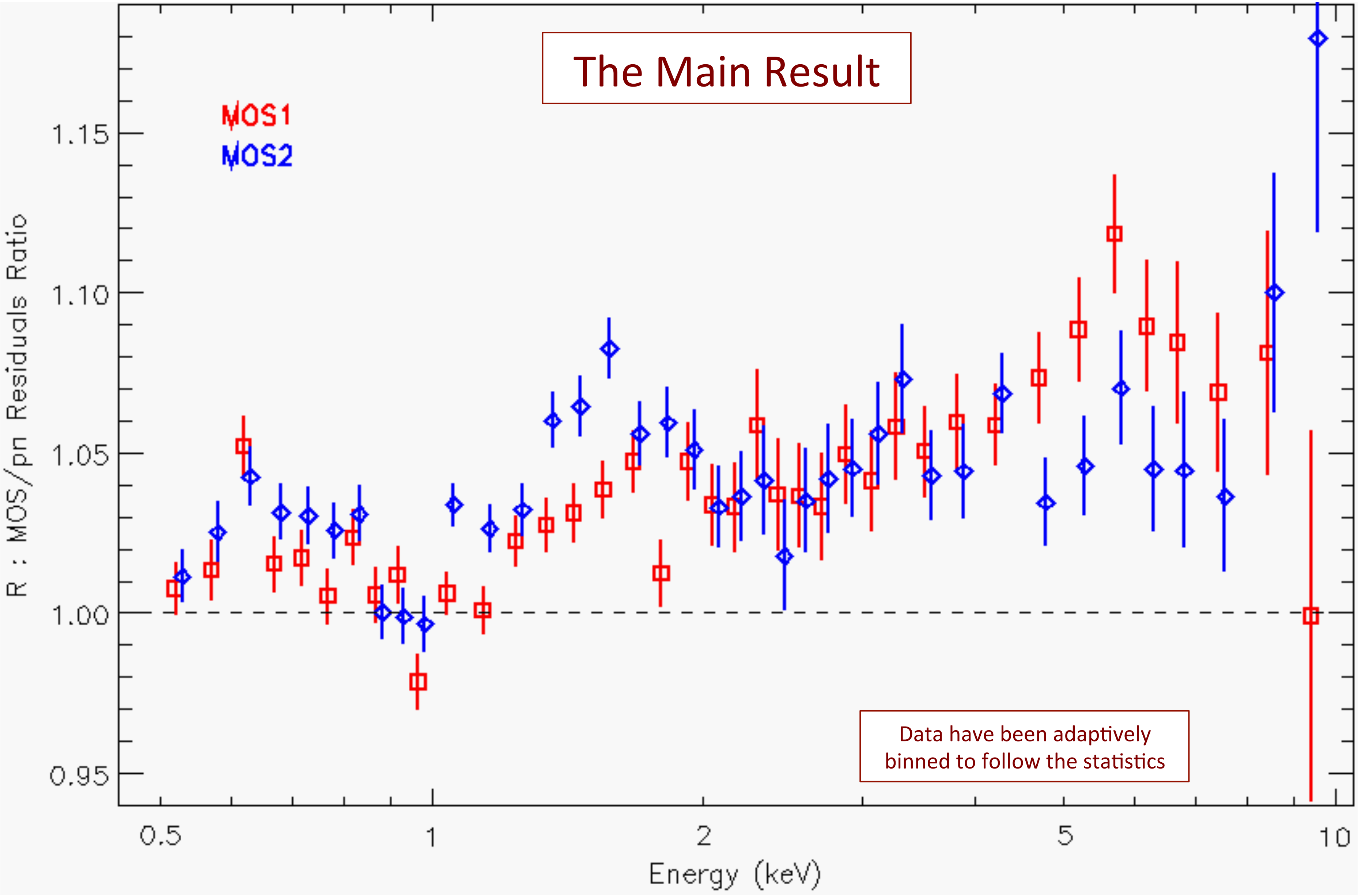
- Calculate and plot the residuals ratio :

  [MOS-data/(pn-)model] / [pn-data/pn-model]

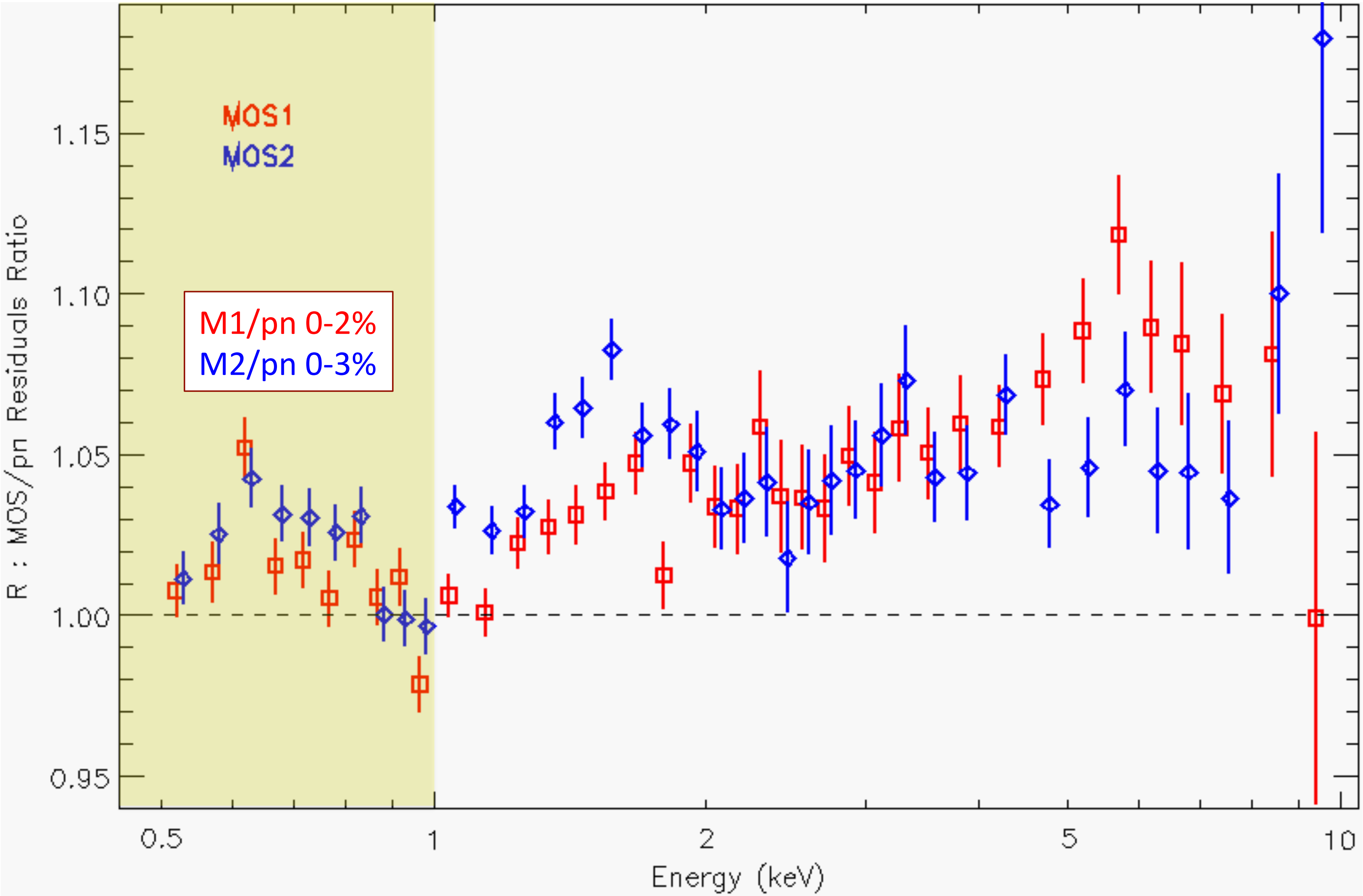
$$\alpha = \frac{\mathrm{data}_{\mathrm{MOS}}}{\mathrm{model}_{\mathrm{MOS|pn}} \otimes \mathrm{resp}_{\mathrm{MOS}}} \times \frac{\mathrm{model}_{\mathrm{pn}} \otimes \mathrm{resp}_{\mathrm{pn}}}{\mathrm{data}_{\mathrm{pn}}}$$

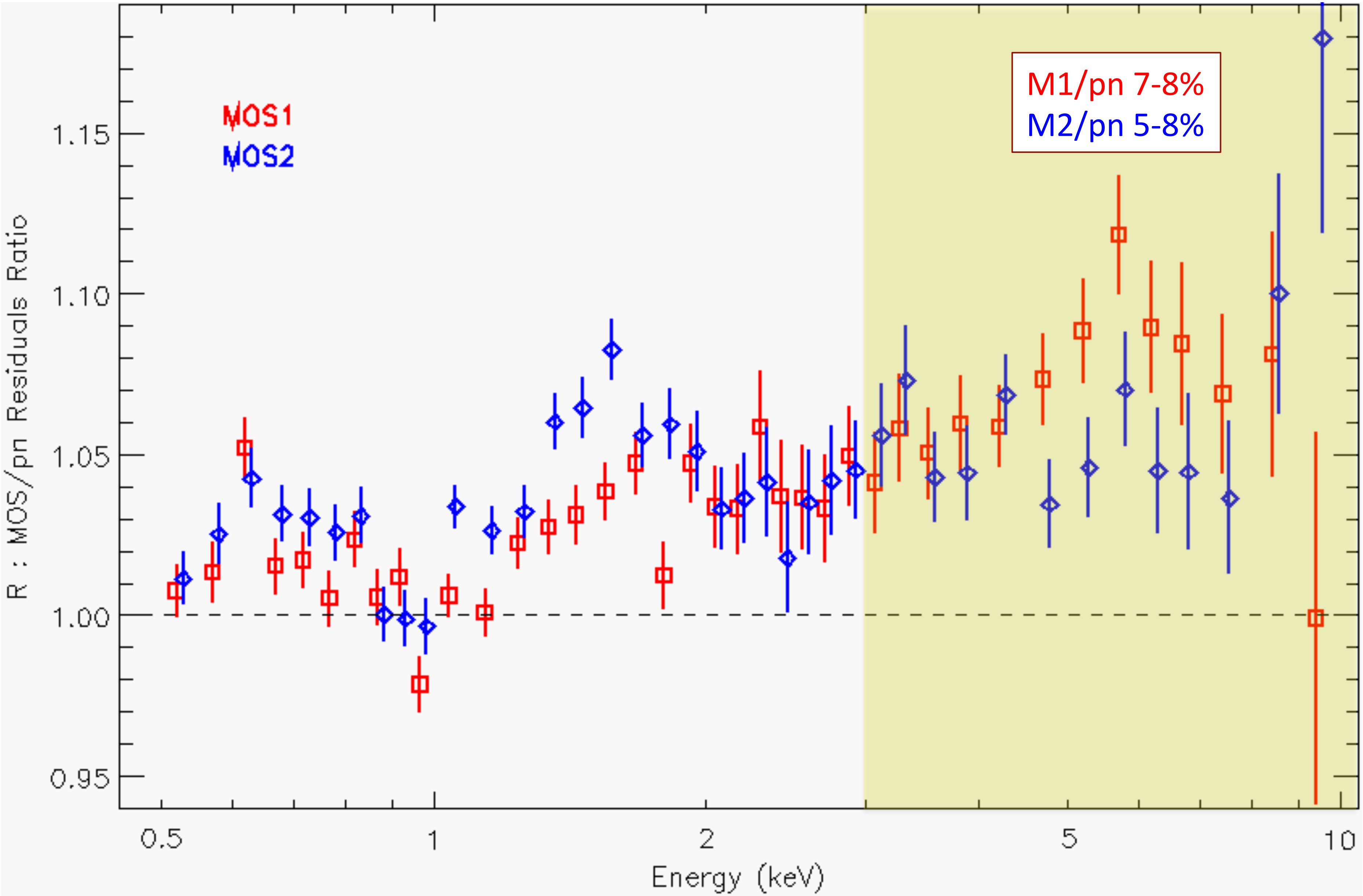
- This removes any differences between the pn data and the pn model prediction (tests using ‘good’ models of varying ‘goodness’ resulted in zero/negligible changes to the ratio)
- Most/all sources of possible error removed/minimized:
  - Variability – Common GTIs used
  - PSF – non-piled up sources and large extraction radius + full ‘un-cheesed’ circles and BG annuli
  - Complex/different spectra – stack into one spectrum, fit, calculate residuals ratio

Andy Read (amr30@le.ac.uk)

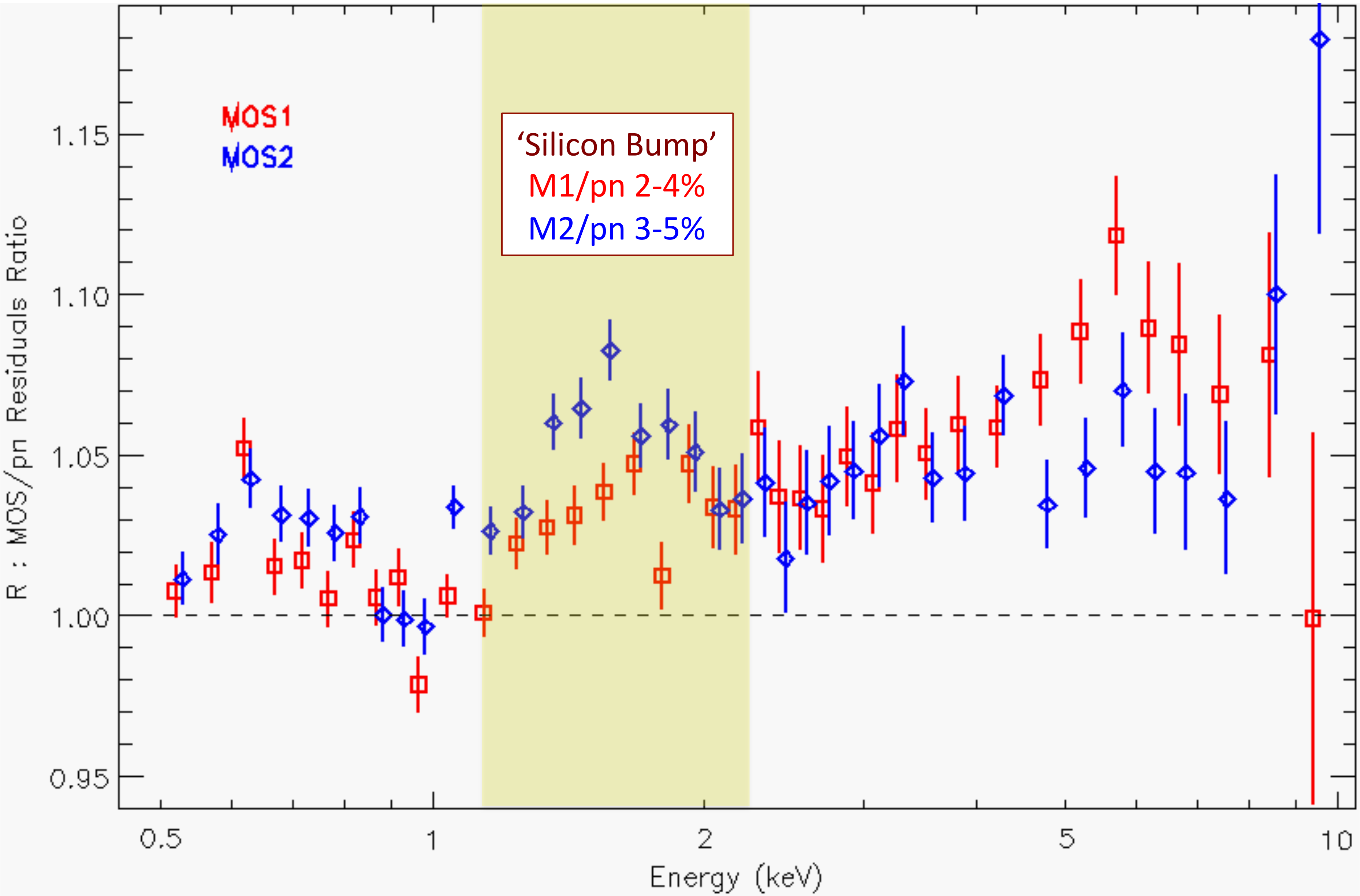


The Main Result
MOS1
MOS2
Data have been adaptively binned to follow the statistics
R : MOS/pn Residuals Ratio
1.15
1.10
1.05
1.00
0.95
0.5
1
2
5
10
Energy (keV)

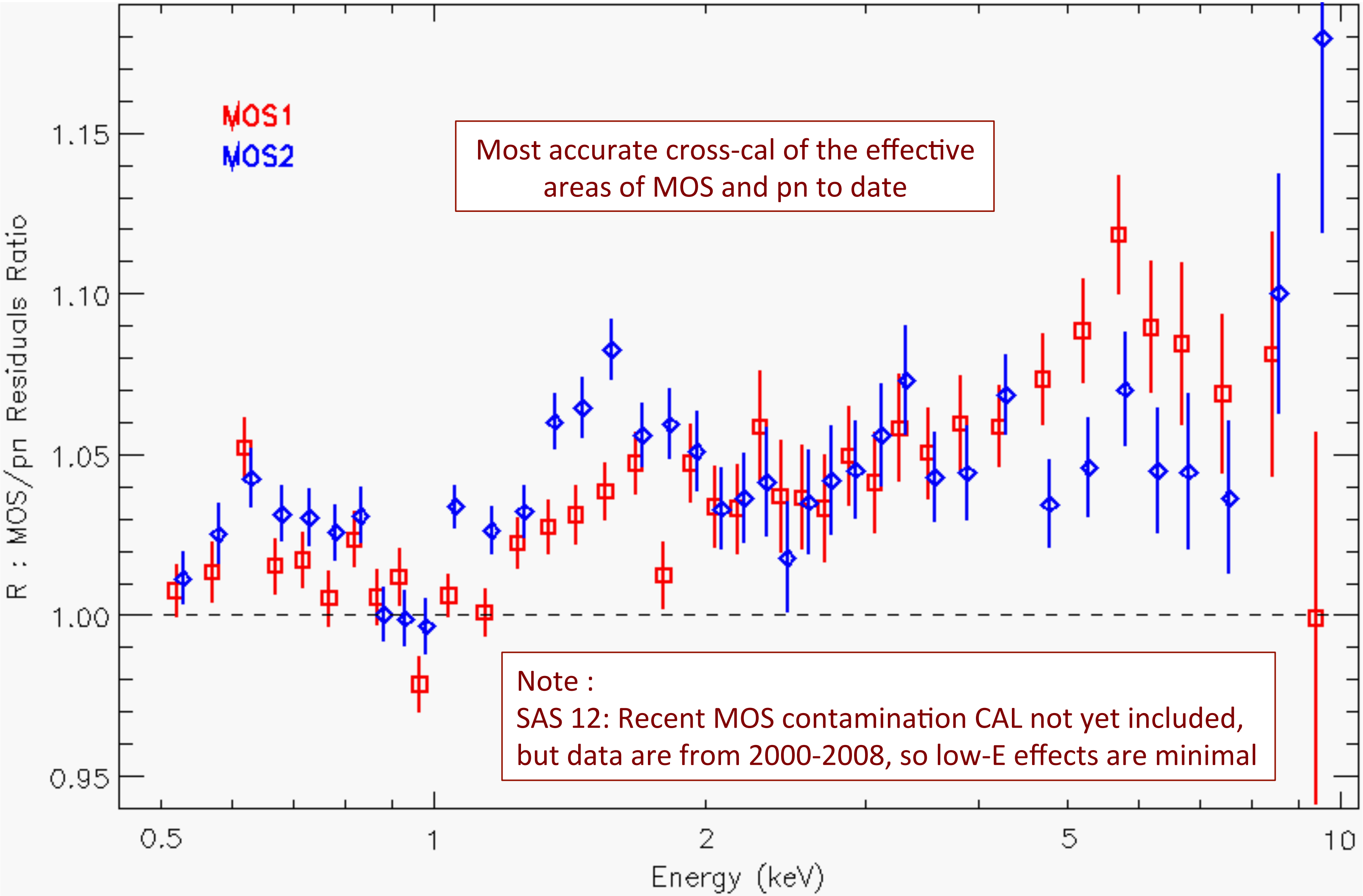

MOS1
MOS2
M1/pn 0-2%
M2/pn 0-3%
R : MOS/pn Residuals Ratio
1.15
1.10
1.05
1.00
0.95
0.5
1
2
5
10
Energy (keV)



MOS1
MOS2
M1/pn 7-8%
M2/pn 5-8%
1.15
1.10
1.05
1.00
0.95
R : MOS/pn Residuals Ratio
0.5
1
2
5
10
Energy (keV)



MOS1
MOS2
'Silicon Bump'
M1/pn 2-4%
M2/pn 3-5%
R : MOS/pn Residuals Ratio
0.95
1.00
1.05
1.10
1.15
0.5
1
2
5
10
Energy (keV)



MOS1
MOS2
Most accurate cross-cal of the effective areas of MOS and pn to date
Note :
SAS 12: Recent MOS contamination CAL not yet included, but data are from 2000-2008, so low-E effects are minimal
R : MOS/pn Residuals Ratio
1.15
1.10
1.05
1.00
0.95
0.5
1
2
5
10
Energy (keV)

Cross-Calibration of the XMM-Newton EPIC pn & MOS On-Axis Effective Areas Using 2XMM Sources

A. M. Read[1], M. Guainazzi[2], S. Sembay[1]

[1]Dept. of Physics and Astronomy, Leicester University, Leicester LE1 7RH, U.K.
e-mail: amr30@star.le.ac.uk
[2]XMM-Newton Science Operations Centre, ESAC, Apartado 78, 28691 Villanueva de la Cañada, Madrid, Spain

A&A 564, A75 (2014) DOI: 10.1051/0004-6361/201423422

ABSTRACT

Aims. We aim to examine the relative cross-calibration accuracy of the on-axis effective areas of the XMM-Newton EPIC pn and MOS instruments.

Methods. Spectra from a sample of 46 bright, high-count, non-piled-up isolated on-axis point sources are stacked together, and model residuals are examined to characterize the EPIC MOS-to-pn inter-calibration.

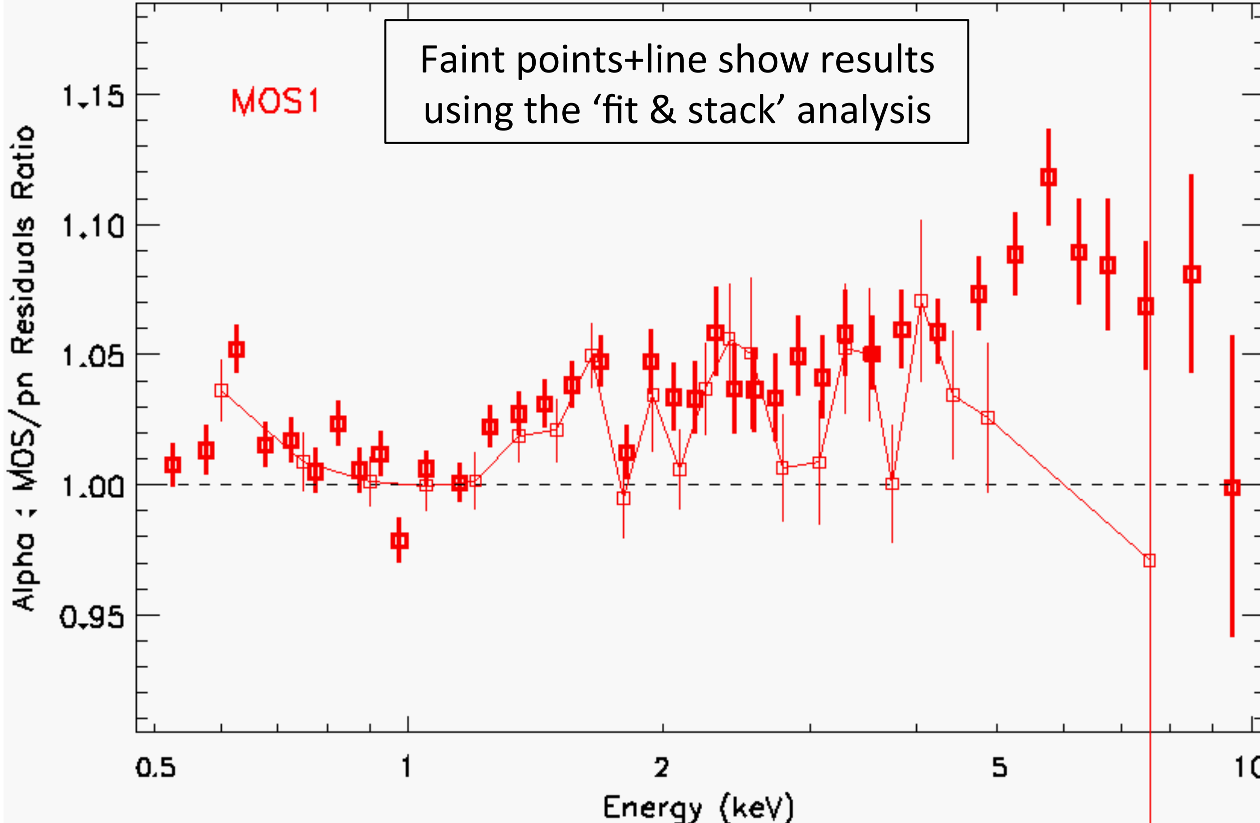
Results. The MOS1-to-pn and MOS2-to-pn results are broadly very similar. The cameras show the closest agreement below 1 keV, with MOS excesses over pn of 0-2% (MOS1/pn) and 0-3% (MOS2/pn). Above 3 keV, the MOS/pn ratio is consistent with energy-independent (or only mildly increasing) excesses of 7-8% (MOS1/pn) and 5-8% (MOS2/pn). In addition, between 1-2 keV there is a 'silicon bump' – an enhancement at a level of 2-4% (MOS1/pn) and 3-5% (MOS2/pn). Tests suggest that the methods employed here are stable and robust.

Conclusions. The results presented here provide the most accurate cross-calibration of the effective areas of the XMM-Newton EPIC pn and MOS instruments to date. They suggest areas of further research where causes of the MOS-to-pn differences might be found, and allow the potential for corrections to and possible rectification of the EPIC cameras to be made in the future.

Key words. Instrumentation: detectors - Instrumentation: miscellaneous - Telescopes - X-rays: general

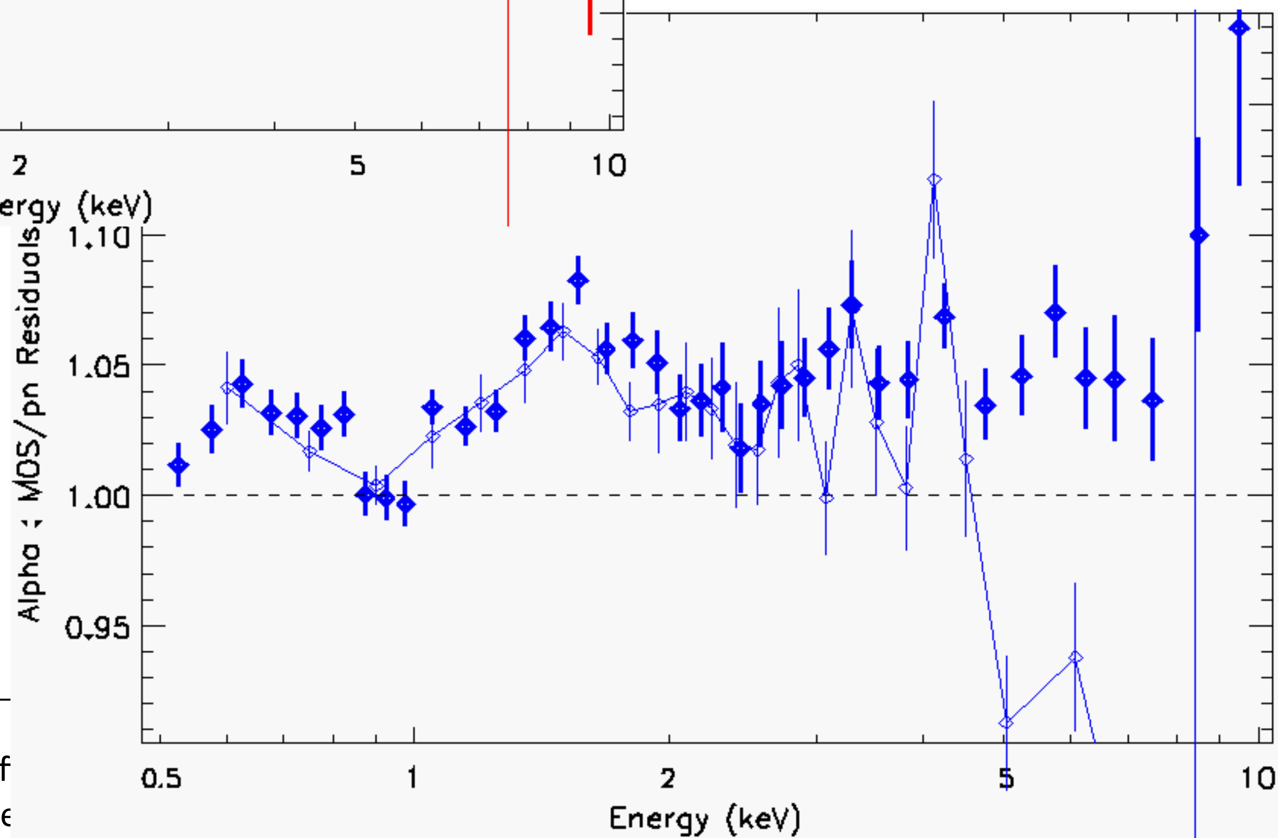
Alternative Stacked Residuals Method – 'Fit & Stack' (F&S), used e.g. in GC/RLAGN

- For each source, pn spectrum is fit
- Calculated model applied to spectrum of each camera – residuals (data/model) calculated and stored
- For each camera, residuals obtained on all sources are averaged (median) together
- Each MOS average residual spectrum divided by the pn average residual spectrum (as for S&F) – removes features due to uncertainties in pn calibration
- Possibly addresses remaining 'con' to the 2XMM sample/method – that the sources are spectrally very different & complex…



- F&S/S&F agreement very good below 4 keV.
- Above 7 keV (MOS1) / 5 keV (MOS2), deficit seen in F&S
- BG subtraction problem involving error bars on negative spectral bins that can sometimes occur in individual source spectra

- S&F gives better results over all E ranges
- S&F is the more robust of the two.



- End