Overview

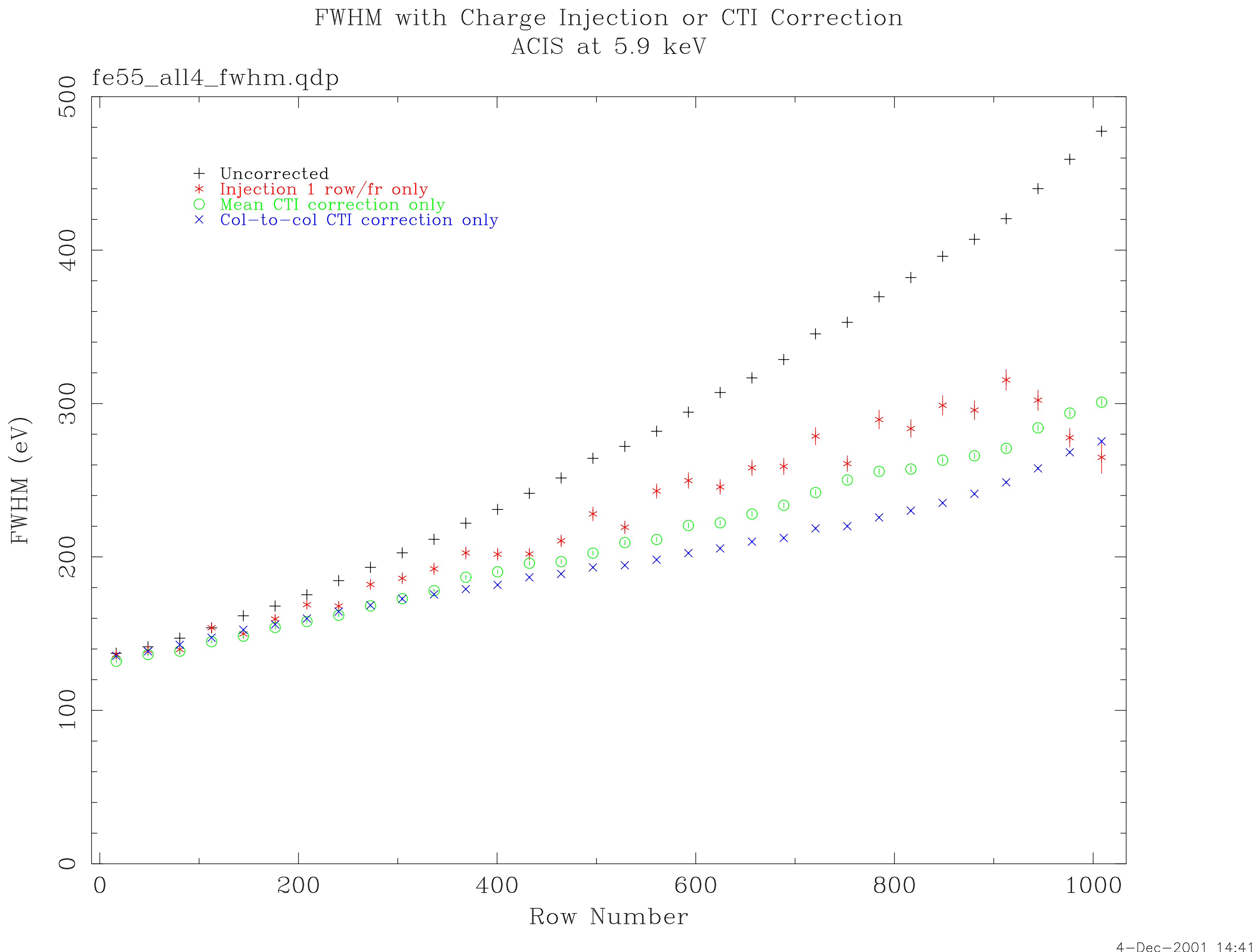
- Charge Injection
  - ⋆ Effects on XIS Performance: CTI Reduction and Knowledge vs. Resolution
  - ⋆ Proposed CCD Structure
  - ⋆ Risks
  - ⋆ Operational Scenarios
- Other CCD Design Changes
- Status/Schedule

Charge Injection: Motivation

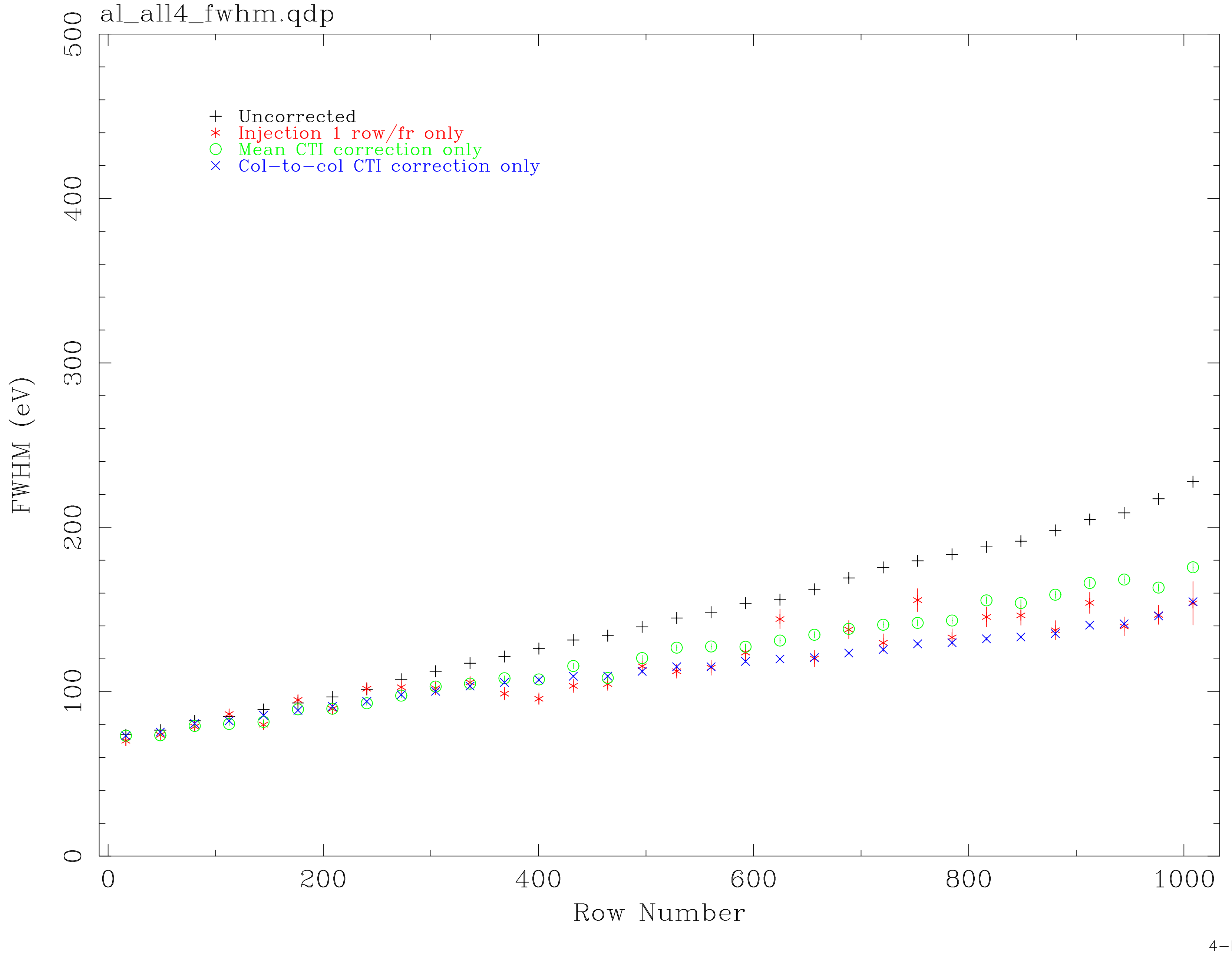
- XIS performance late in Astro-E2 mission is important
  - ⋆ Science driven by XRS in first two years
  - ⋆ XIS will be sole soft-X-ray instrument on Astro-E2 years 3-8
- Radiation-induced CTI increase for XIS will be comparable to SIS
  - ⋆ SIS: dCTI/dt $\sim 3 \times 10^{-5}$ yr^{-1} (Yamashita, Dotani et al. 1999 NIM-A 436 68)
  - ⋆ Lower XIS temperature makes modest ($\sim \times 2/3$) CTI improvement (for high energy protons!)
  - ⋆ Orbit and solar cycle phase similar to ASCA
  - ⋆ Shielding may be better for XIS, but XIS must transfer charge farther from aimpoint to readout (1.25 cm vs 1.0 cm)
- Laboratory and flight tests show charge injection can significantly reduce effective CTI (by $\sim \times 3 - 5$)
- Charge injection may signficantly improve XIS spectral resolution late in mission.

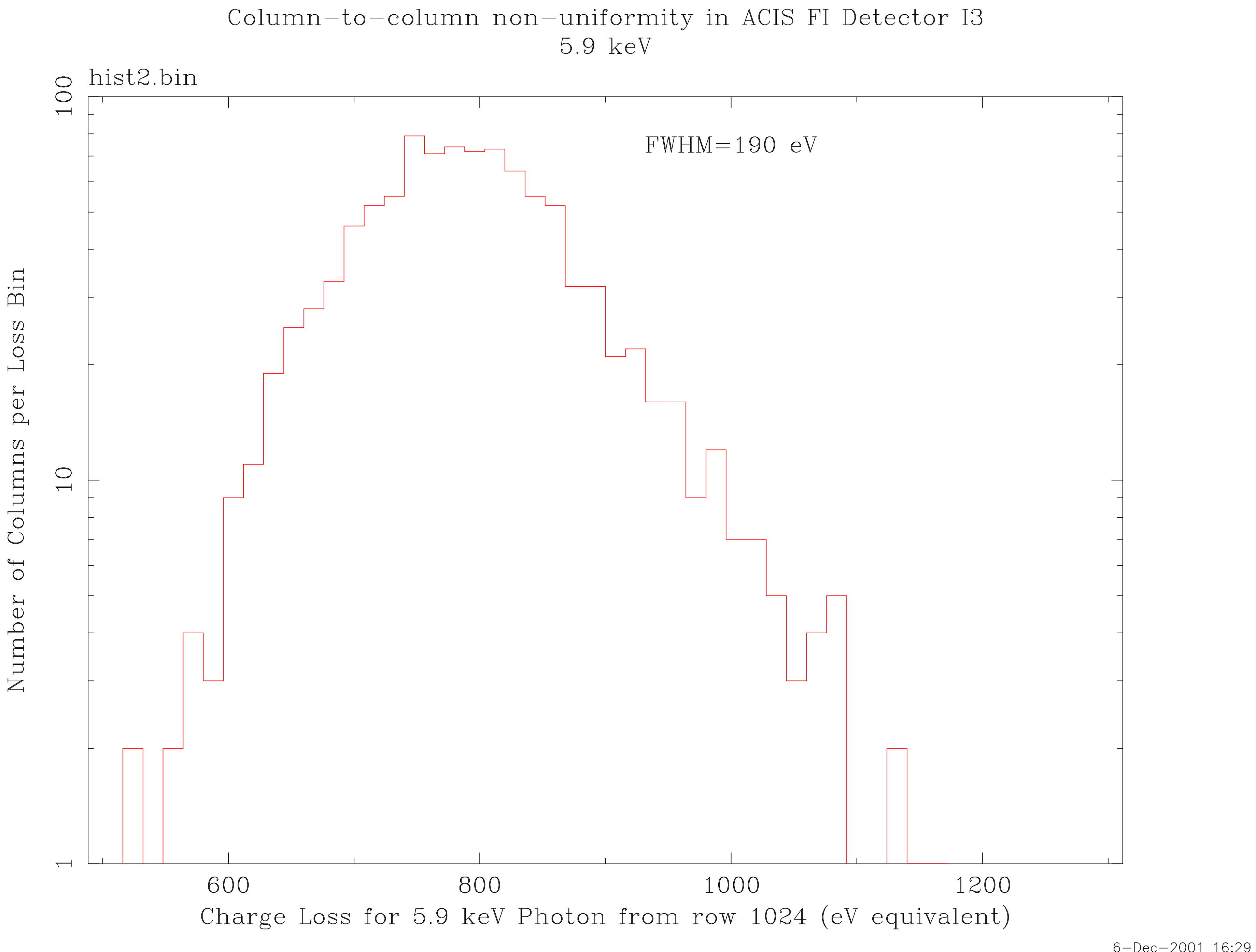
ACIS Experience with Charge Injection and CTI Measurement

- Charge injection can help performance two ways:
  - ⋆ "Sacrificial charge" effect reduces CTI and improves resolution.
  - ⋆ Accurate measurement of CTI (vs. energy and position) allows ground correction and leads to better resolution.
- ACIS Squeegee experience (sacrificial charge effect):
  - ⋆ Inject one bright line ($> 10^4\, e^-$ per 3.2s frame (T = -120C)
  - ⋆ Improves spectral resolution by $\times 1.7$ at 5.9 keV, by $\times 1.4$ at 1.5 keV.
  - ⋆ XIS results would probably not be this good with single injected line per frame, since XIS has higher detector temperature, longer frame time.
- ACIS experience with CTI measurement and ground correction:
  - ⋆ Charge loss varies significantly with charge-packet size ($\delta Q \sim Q^{0.53}$) so energy-dependent correction improves resolution for split events (helps high-energies most)
  - ⋆ CTI varies significantly with column (low-trap density statistical fluctuations) so column-by-column correction also helps.


FWHM with Charge Injection or CTI Correction
ACIS at 5.9 keV
fe55_all4_fwhm.qdp
Uncorrected
Injection 1 row/fr only
Mean CTI correction only
Col−to−col CTI correction only
FWHM (eV)
Row Number
0
100
200
300
400
500
0
200
400
600
800
1000
4−Dec−2001 14:41

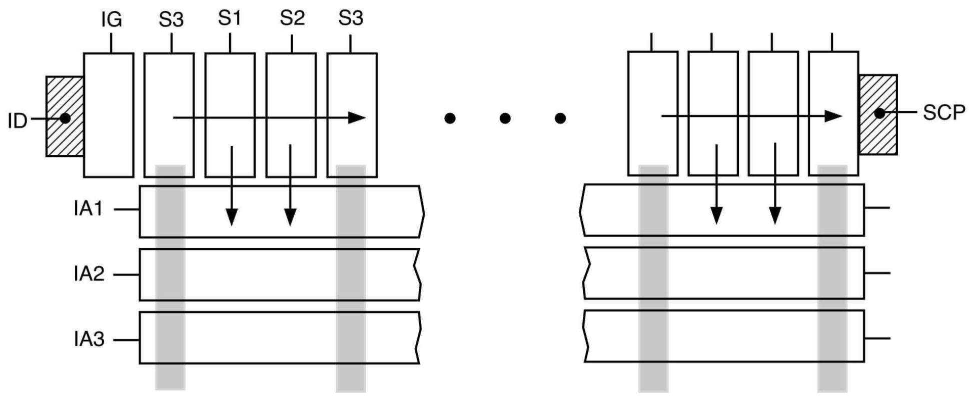
FWHM with Charge Injection or CTI Correction
ACIS at 1.49 keV



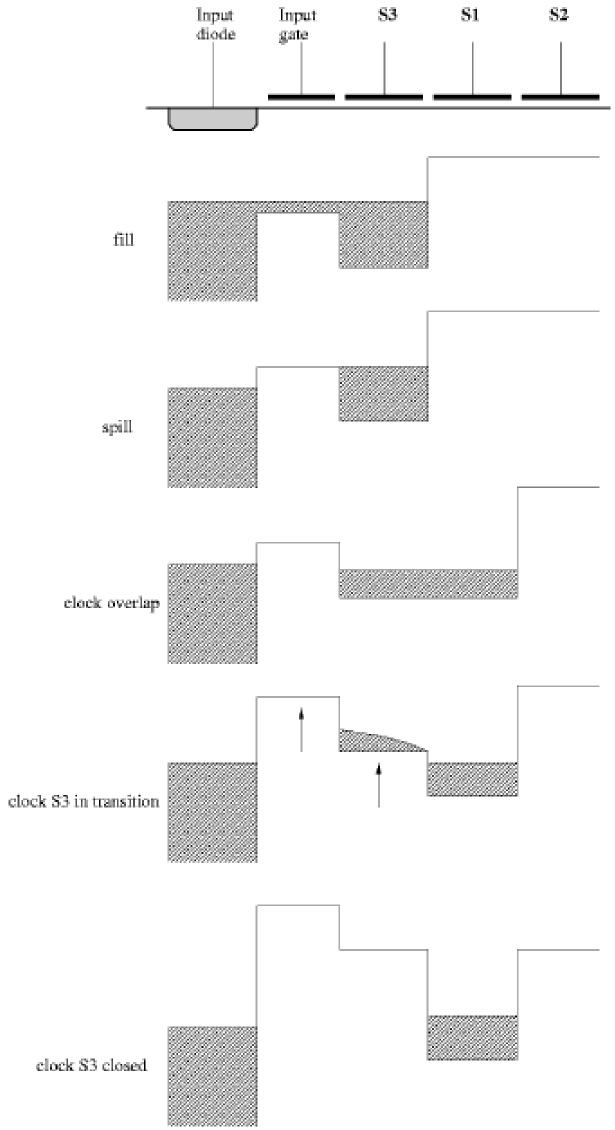


Column−to−column non−uniformity in ACIS FI Detector I3
5.9 keV
hist2.bin
FWHM=190 eV
Number of Columns per Loss Bin
1
10
100
600
800
1000
1200
Charge Loss for 5.9 keV Photon from row 1024 (eV equivalent)
6−Dec−2001 16:29

Proposed XIS Charge Injection Structure and Timing



- An input register is added “above” the imaging area (“row 1025”)
- During injection, input register is filled, pixel-by-pixel, from input diode, to create a line of charge which is then transferred through imaging area (IA)
- Adjustment of Input Gate (IG) to S3 potential allows precision control of quantity of injected charge: $\sigma_Q \sim 30\, e^-$, RMS



Input register timing during injection

Hardware vs. Software Charge Injection

- Hardware Charge Injection:
  - ⋆ Requires dedicated input structure on CCD.
  - ⋆ Allows multiple line/frame injection with minimal deadtime penalty.
  - ⋆ Good knowledge of injected charge quantity available even after radiation damage: should allow reliable CTI measurement.
  - ⋆ Has been demonstrated in-flight on XMM EPIC MOS (1 line/frame, fixed amplitude.)
- Software Charge Injection
  - ⋆ Relies on special-purpose microcode to inject charge.
  - ⋆ Single line/frame can be injected with minimal deadtime if background is high enough (ACIS squeegee).
  - ⋆ Injecting multiple lines/frame increases deadtime to $\sim 50\%$
  - ⋆ Quantity of injected charge sensitive to radiation damage: difficult to measure CTI reliably after damage.
  - ⋆ Multi-line injection demonstrated in lab tests with radiation-damaged CCDs (Steve Kissel)

Charge Injection: Summary

- Flight and ground tests show charge injection can significantly reduce the spatial variation of the energy scale in radiation-damaged CCDs (effective CTI reduced by $\sim \times 3 - 5$)
- ACIS flight experience shows that accurate knowledge of CTI (*vs.* column and energy) allows improved energy resolution through ground correction.
- XIS does not have multi-energy calibration source illuminating entire detector.
- Hardware charge injection will significantly improve XIS spectral resolution and calibration accuracy in the post-XRS phase of AstroE2.
- Risks have been considered and found to be modest compared to those inherent in fabrication of new mask. Backup masks (without charge injection) are being fabricated.
- Required modifications to AE have been identified and are feasible.
- Detailed plans for calibration and use of charge injection remain to be determined.

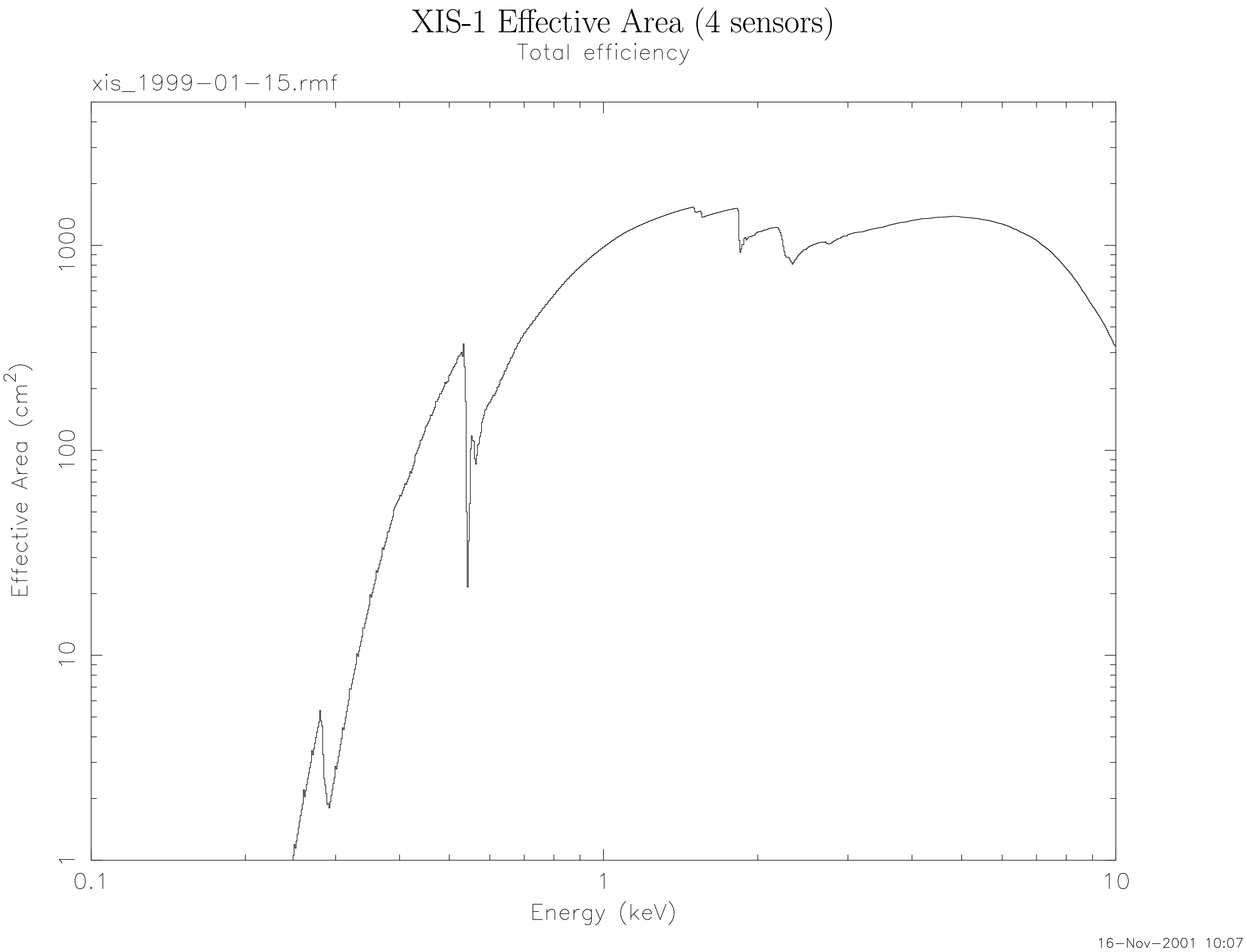
Other XIS CCD Design Changes

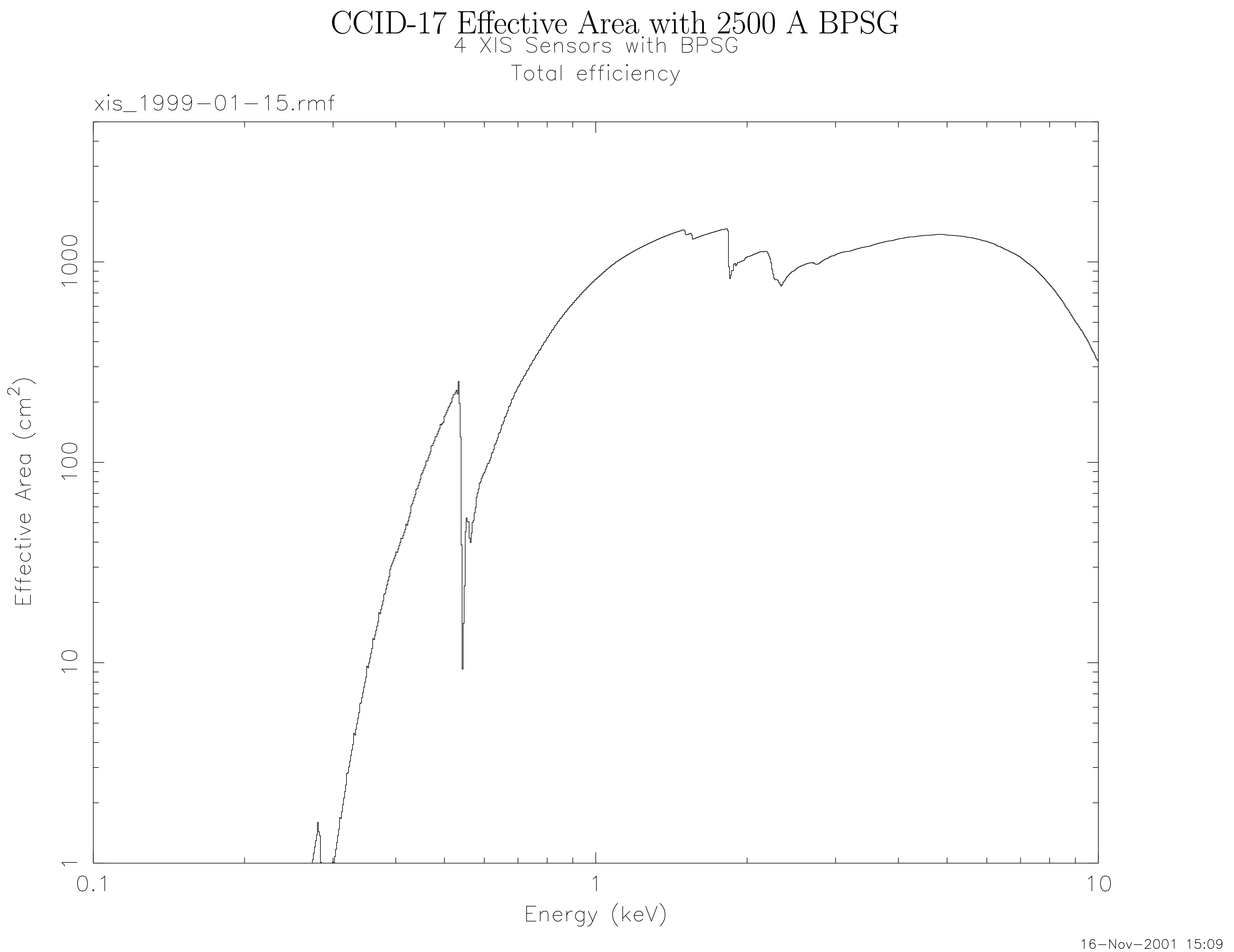
- New XIS CCD will be designated CCID41 (XIS-1 CCD was CCID17, as in ACIS.)
- Several changes will be made to accomodate current MIT Lincoln Lab design rules.
- These changes have each been demonstrated on at least one other MIT LL device.

Parameter	CCID17 (XIS-1)	CCID41 (XIS-2)	Remarks
Charge Injection Capability	S/W only	Input Register Available	
Channel Stop Width	4 μm	2 μm	Better low-energy QE Better high-energy QE
Gate Overlap	2 μm	1 μm	Better low-energy QE Lower capacitance
Undepleted Si	390μm	540μm	Larger dead-area Greater load on DE
Scratch Glass	PSG, removed from IA	$0.25 - 0.5\mu$m BPSG + PSG removed from IA	Better yield but significant loss of QE < 1 keV. Hope to reduce BPSG thickness.

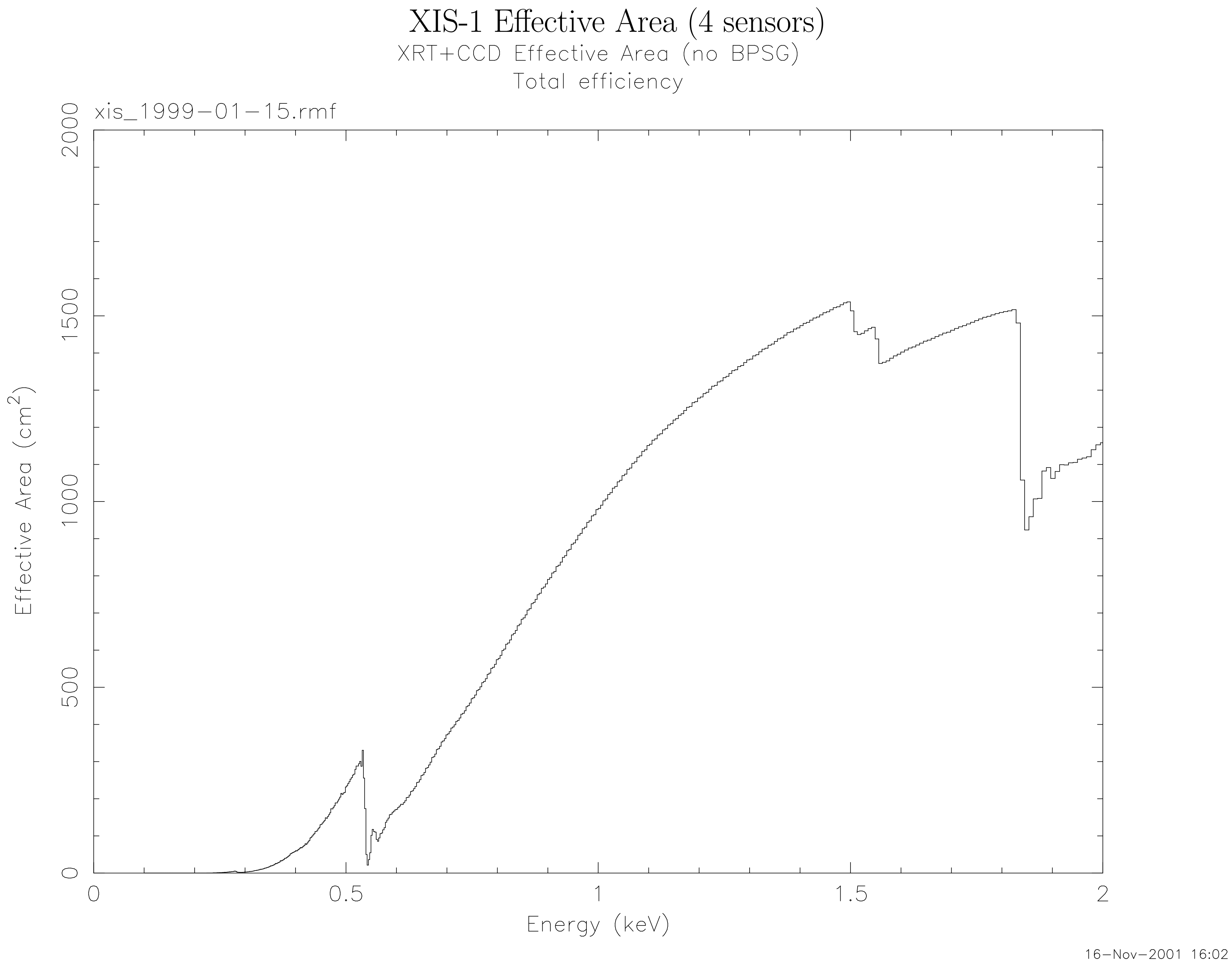
Borophoshosilicate Glass (BPSG)

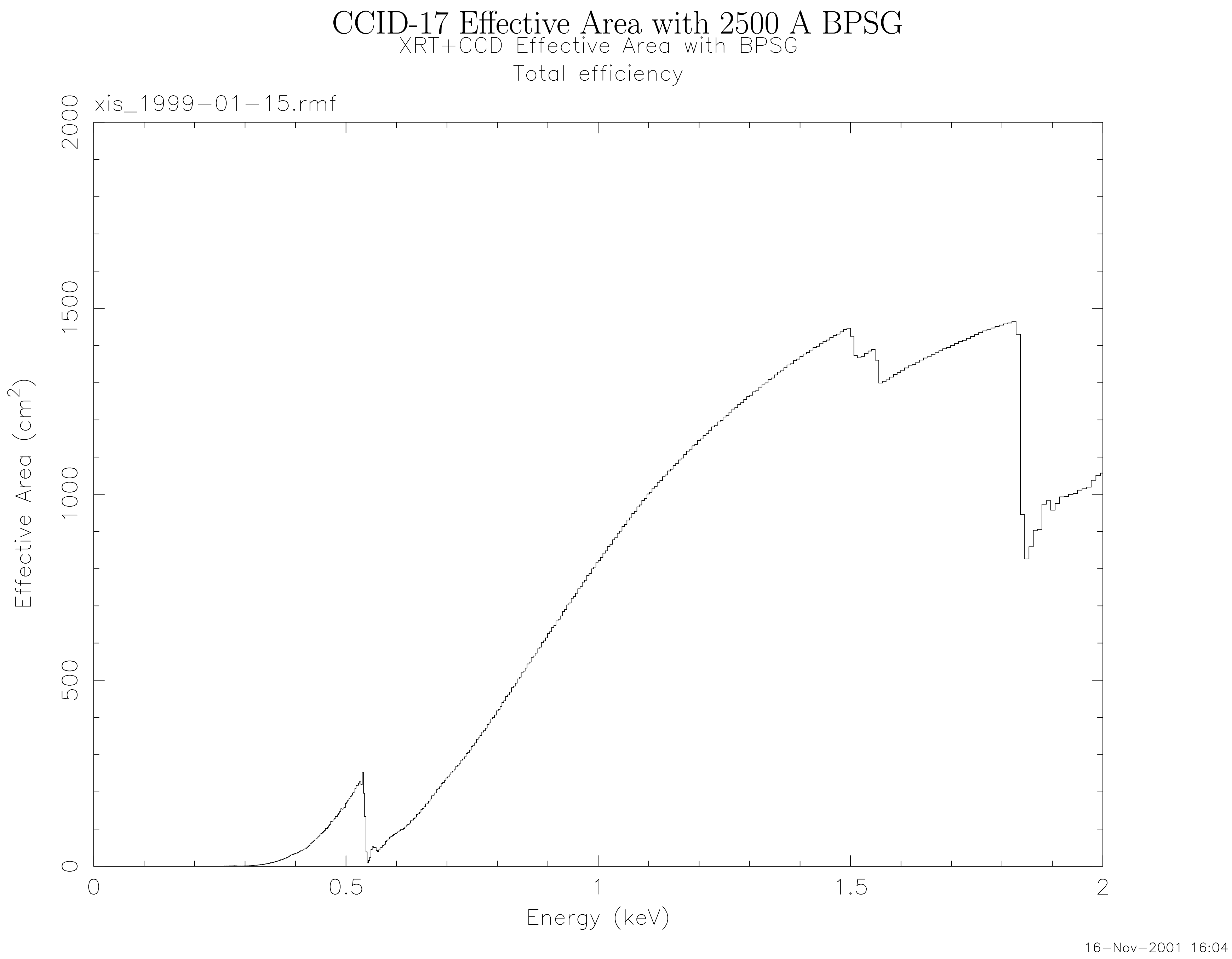
- Borophososilicate glass (BPSG) coating (0.25 - 0.50 μm) now part of standard MIT LL practice.
- BPSG smooths sharp edges from finer photolithography, reduces chance of discontinuities in aluminum traces, improves yield and reliability.
- BPSG causes significant reduction in low-energy QE.
- May be possible to reduce thickness of BPSG over imaging area.


XIS-1 Effective Area (4 sensors)
Total efficiency
xis_1999-01-15.rmf
Effective Area (cm^2)
1000
100
10
1
0.1
1
10
Energy (keV)
16-Nov-2001 10:07



CCID-17 Effective Area with 2500 A BPSG
4 XIS Sensors with BPSG
Total efficiency
xis_1999-01-15.rmf
Effective Area (cm2)
1
10
100
1000
0.1
1
10
Energy (keV)
16-Nov-2001 15:09


XIS-1 Effective Area (4 sensors)
XRT+CCD Effective Area (no BPSG)
Total efficiency
xis_1999-01-15.rmf
Effective Area (cm^2)
2000
1500
1000
500
0
0
0.5
1
1.5
2
Energy (keV)
16-Nov-2001 16:02


CCID-17 Effective Area with 2500 A BPSG
XRT+CCD Effective Area with BPSG
Total efficiency
xis_1999-01-15.rmf
Effective Area (cm^2)
0
500
1000
1500
2000
0
0.5
1
1.5
2
Energy (keV)
16-Nov-2001 16:04

Science Impact of BPSG

- Preliminary simulations performed with 2500 A BPSG, but CCID17 QE
- Actual CCID41 device may have thicker BPSG (up to 5000 A), but will have smaller gate overlaps and narrower channel stops than CCID17.
- Sample Counting rate ratios for low-column (4×10^{20} cm^{-2}) spectral models (counts ccid41/counts ccid17):

Spectrum	Count-rate ratio in Band (keV)		
	0.1 - 10	0.3 - 2	0.3 - 1
7 keV Thin Thermal	0.86	0.82	0.81
1 keV Thin Thermal	0.84	0.83	0.80
Power Law ($\Gamma = 1.7$)	0.88	0.86	0.75

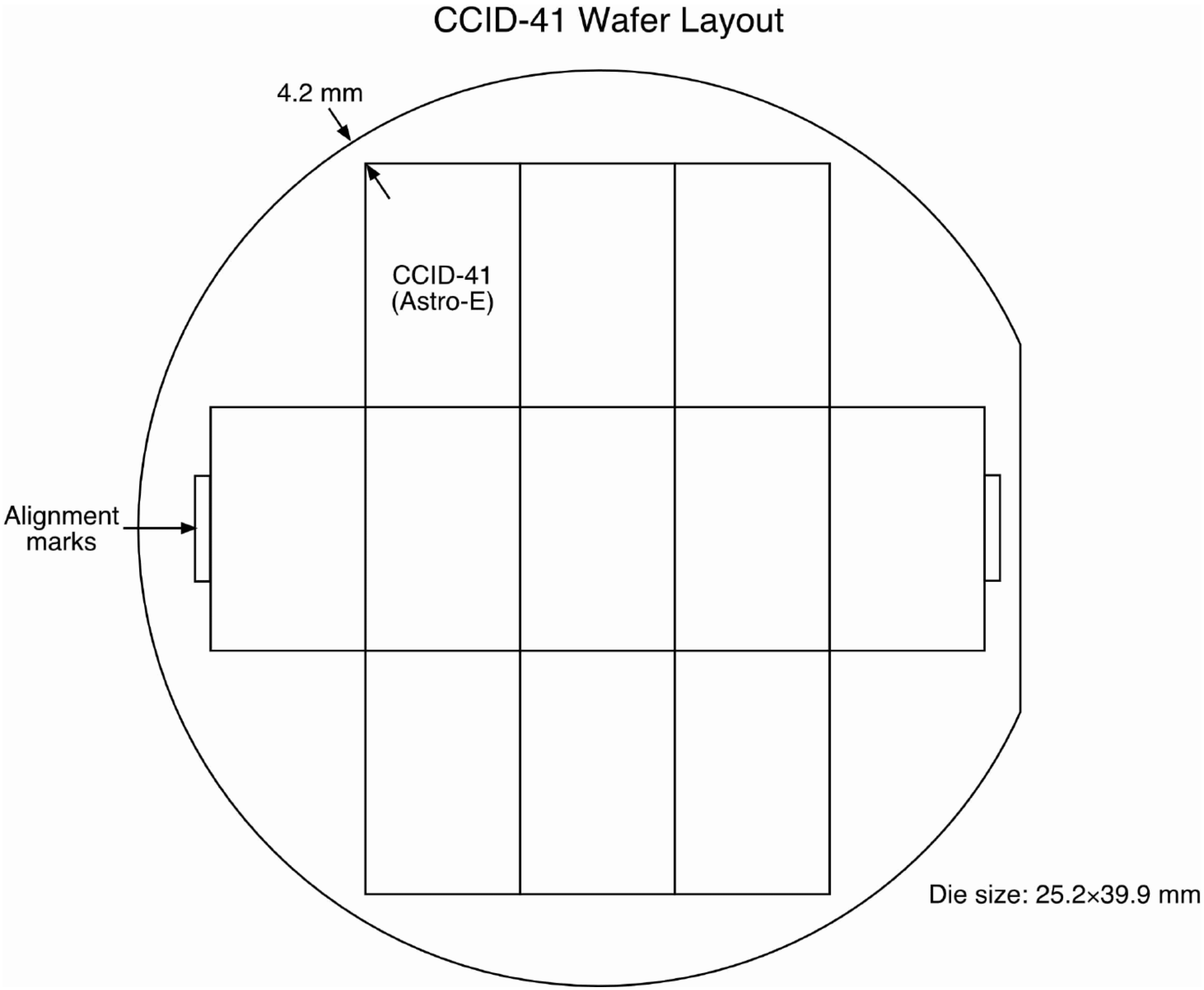
Status

Using "Phase-A" funding provided by ISAS directly to MIT CSR:

- CCID41 mask set (including non-injection version) has been designed
- Flexprint design is under review
- Design revisions for detector package/TEC interface in progress (A. Pillsbury)
- Frank LaRossa (digital designer) contract is being negotiated. (No word yet on FPGA revisions.)

Schedule

- Near-term milestones (2002):
  - ⋆ Mid-January: Masks fabricated
  - ⋆ April: Flexprints fabricated
  - ⋆ July/August: First flight detectors delivered to CSR from Lincoln.
- Long-term schedule: If NASA/ISAS agreement is signed very soon, can still maintain schedule proposed by Rick Foster in September, 2000.



11 XIS-2 CCID41 Devices per Wafer

Schedule Assumptions

- **July 2001 - Official (i.e funded) start at MIT**
  - Japanese FY starts April 1
    - *Gives some time to get the contract/money moved to MIT*
  - Funding of for atleast the CCD development required
    - *Contract for the actual flight build can come later, but we need to work on the detectors in this time frame.*
- **July 2002 - 1st Flight CCDs from Lincoln Laboratory**
  - Need early coordination/funding of contract with LL
- **Sept 2002 - Flight Build Start**
  - Engineering effort up to CDR completed
- **Sept 2003 - Flight units delivered to Japan**
  - Approximately 15 months prior to launch
  - System Calibration
  - Spacecraft Integration & Test
- **February 2005 - AstroE-II Launch date from Kagoshima**
  - Great Success !!