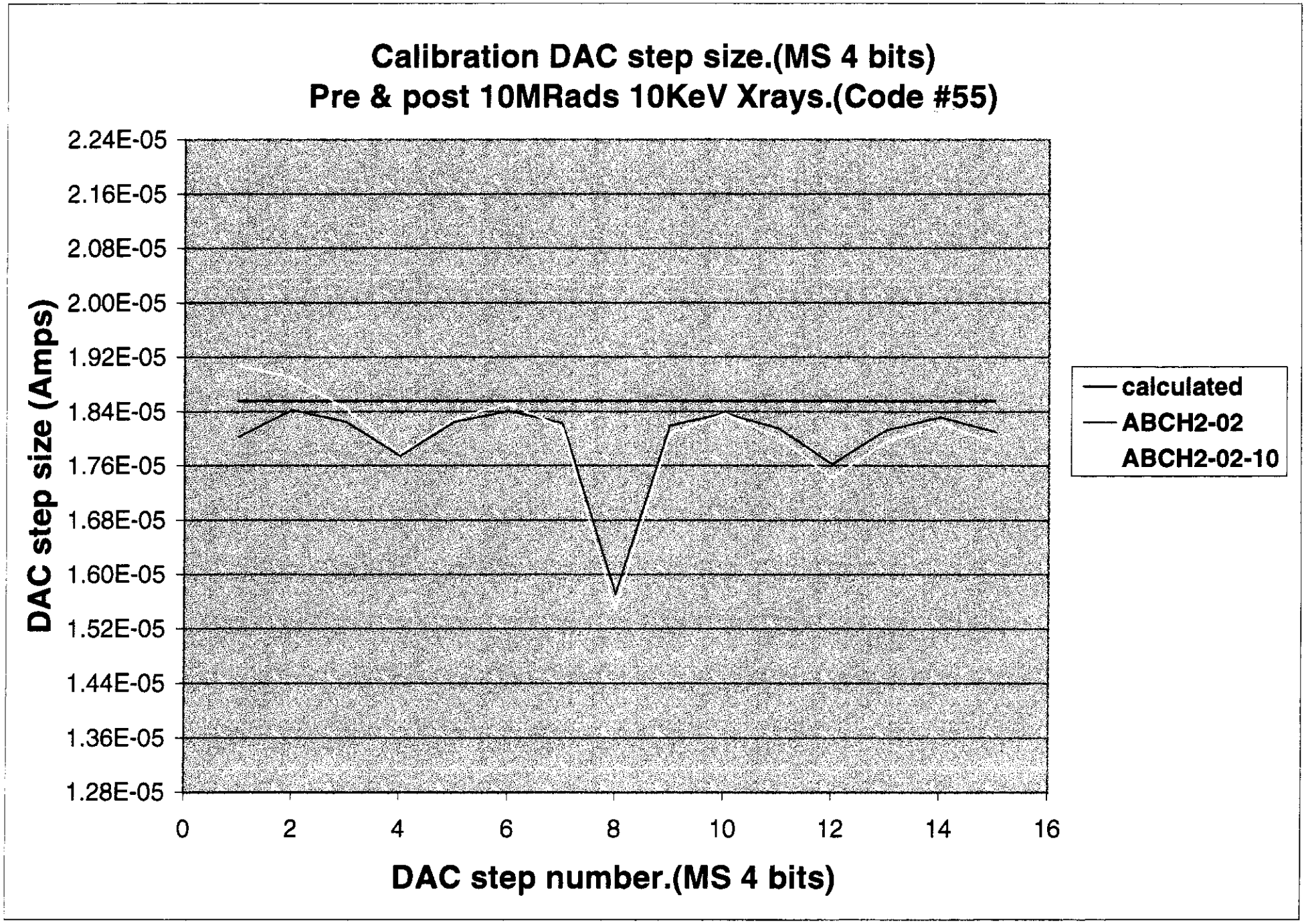
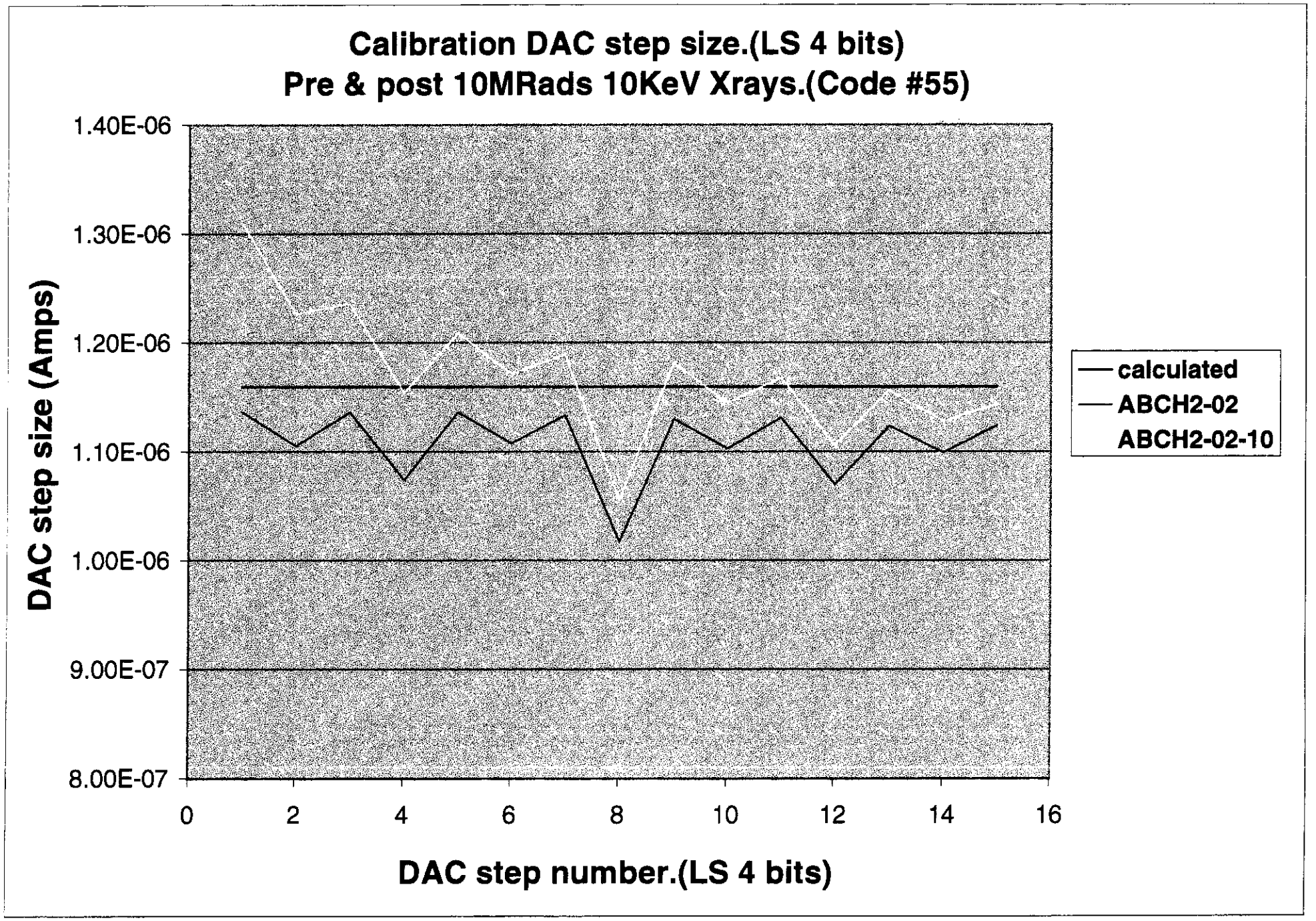
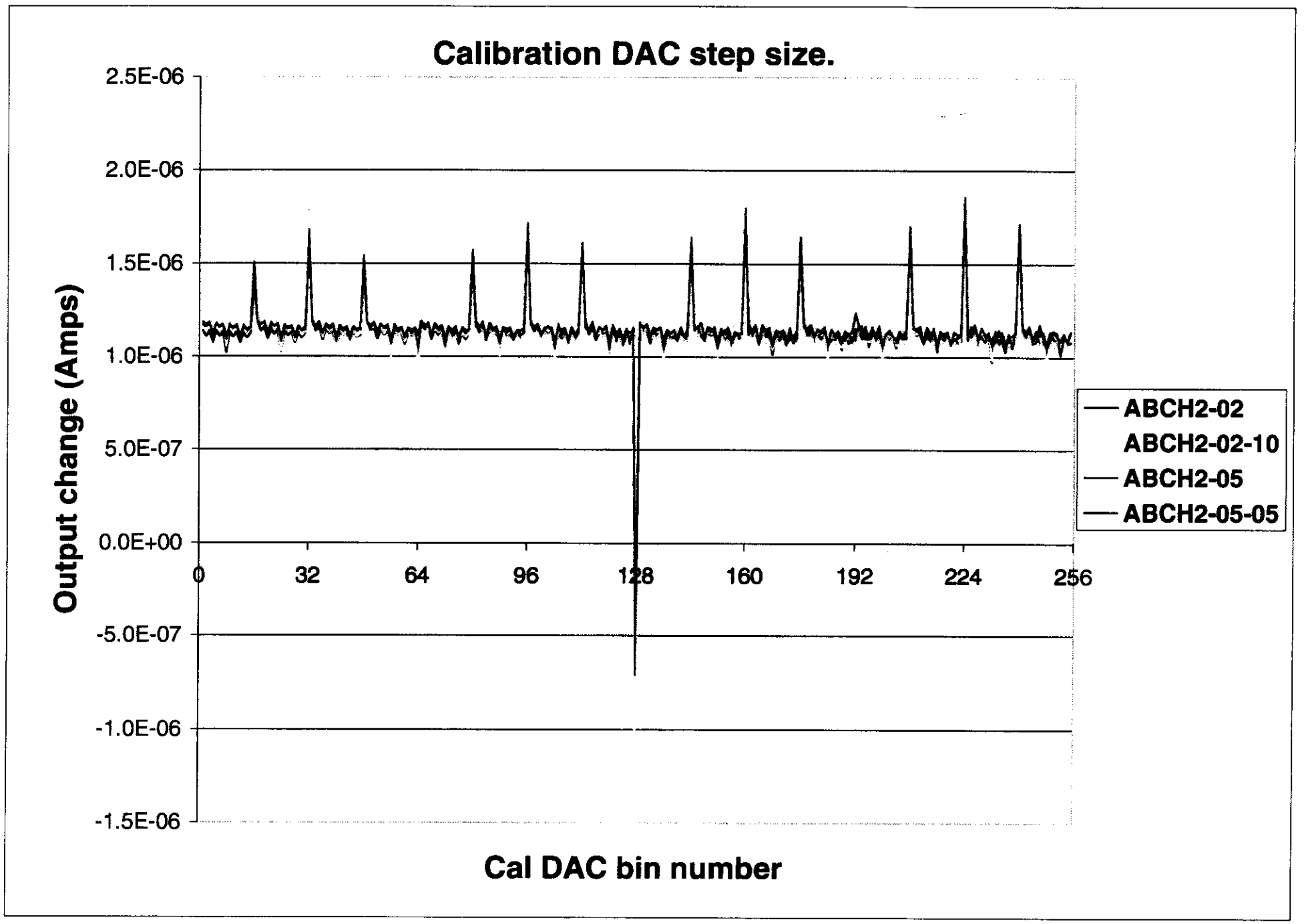
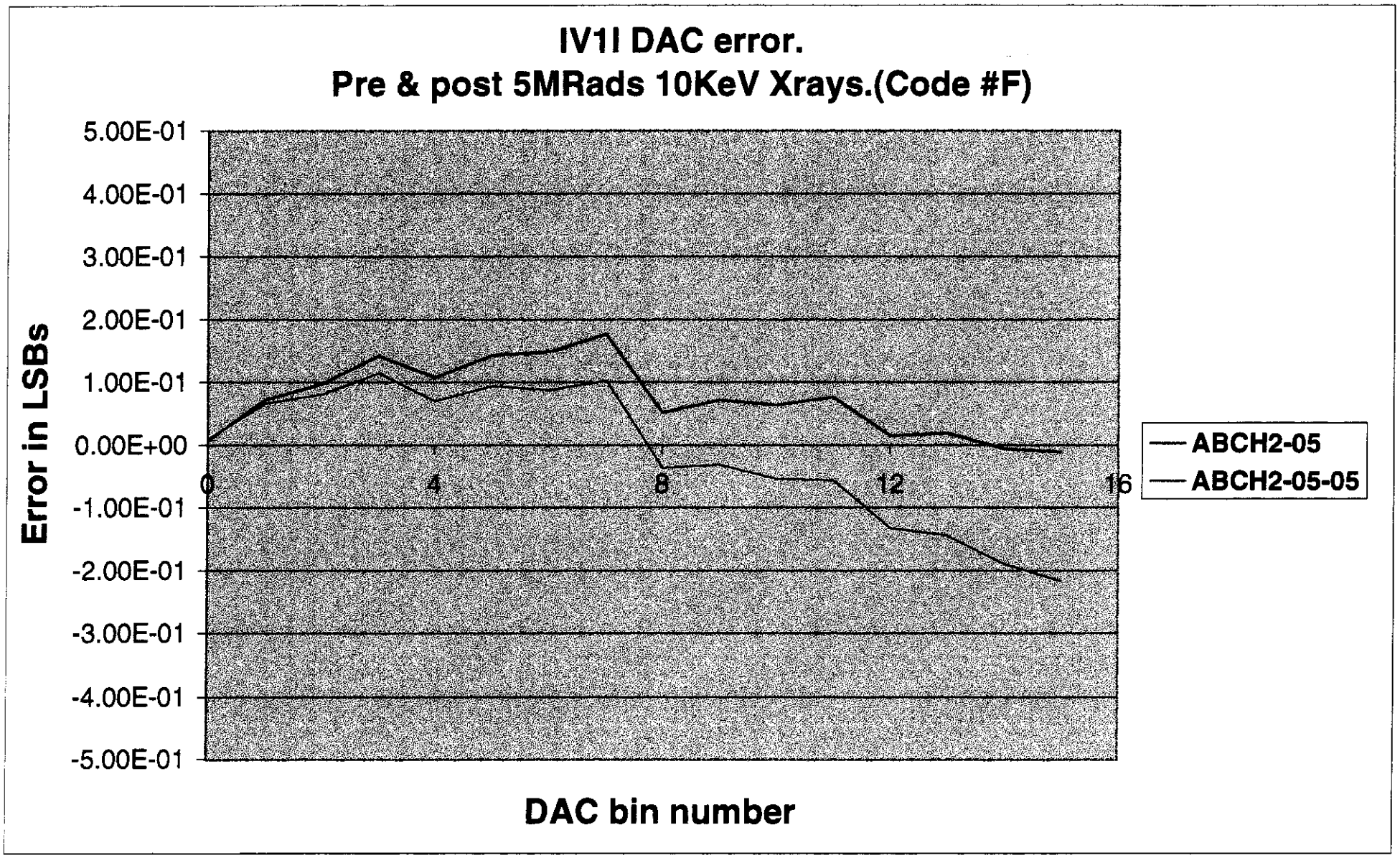
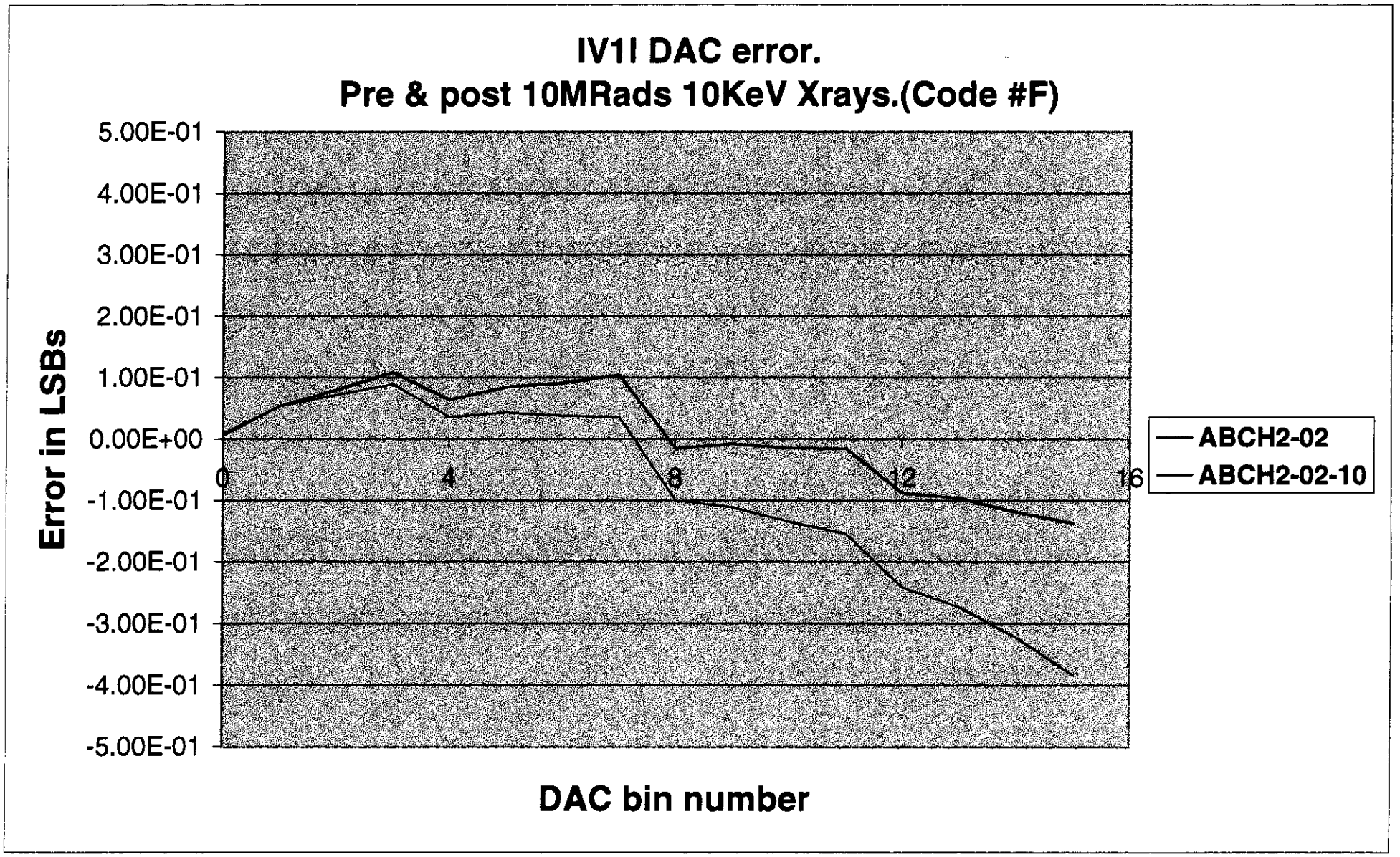

Calibration DAC step size.(MS 4 bits)
Pre & post 10MRads 10KeV Xrays.(Code #55)
DAC step size (Amps)
2.24E-05
2.16E-05
2.08E-05
2.00E-05
1.92E-05
1.84E-05
1.76E-05
1.68E-05
1.60E-05
1.52E-05
1.44E-05
1.36E-05
1.28E-05
0
2
4
6
8
10
12
14
16
DAC step number.(MS 4 bits)
calculated
ABCH2-02
ABCH2-02-10

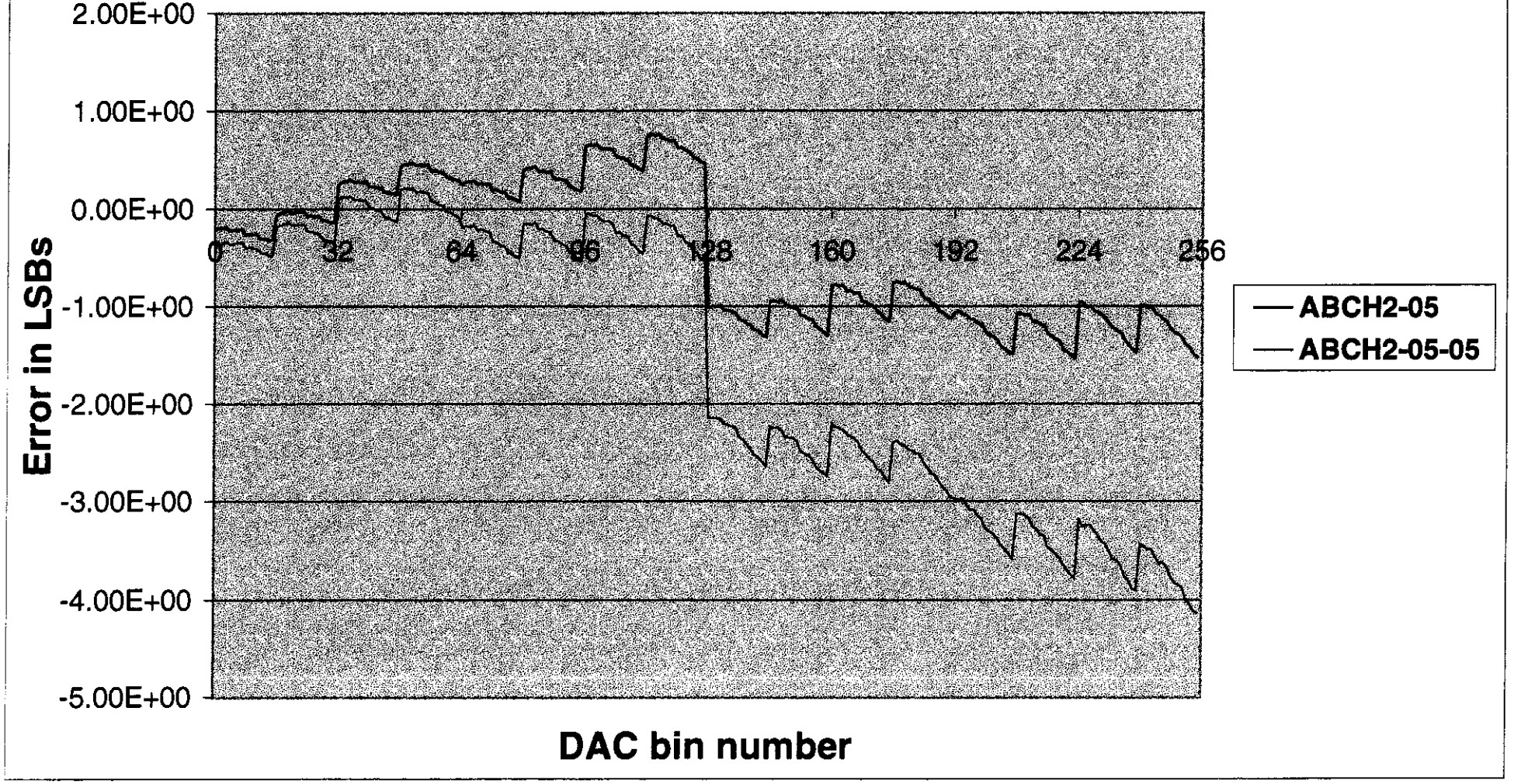

Calibration DAC step size.(LS 4 bits)
Pre & post 10MRads 10KeV Xrays.(Code #55)
DAC step size (Amps)
1.40E-06
1.30E-06
1.20E-06
1.10E-06
1.00E-06
9.00E-07
8.00E-07
0
2
4
6
8
10
12
14
16
DAC step number.(LS 4 bits)
calculated
ABCH2-02
ABCH2-02-10

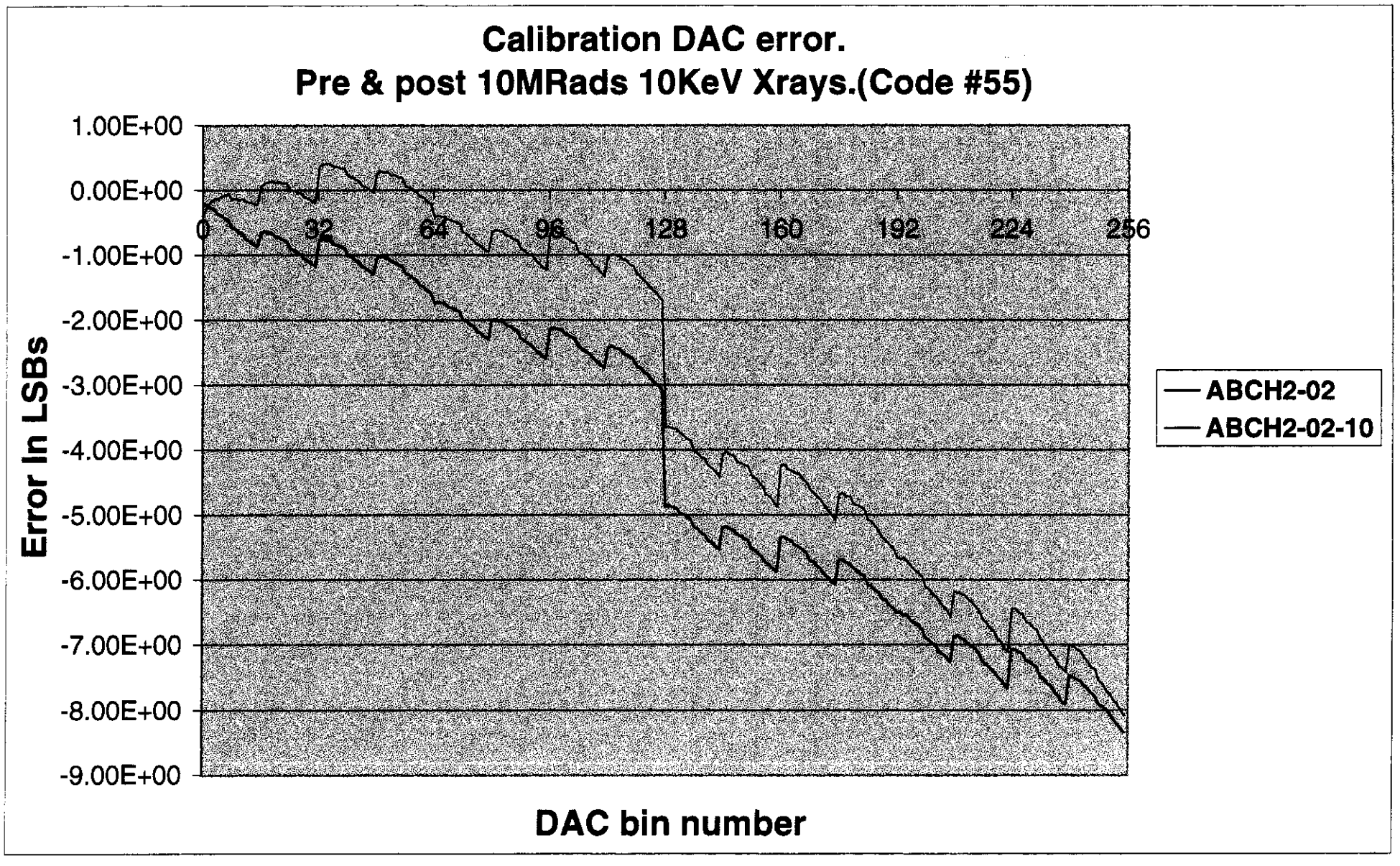

Calibration DAC step size.
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
-5.0E-07
-1.0E-06
-1.5E-06
Output change (Amps)
0
32
64
96
128
160
192
224
256
Cal DAC bin number
ABCH2-02
ABCH2-02-10
ABCH2-05
ABCH2-05-05

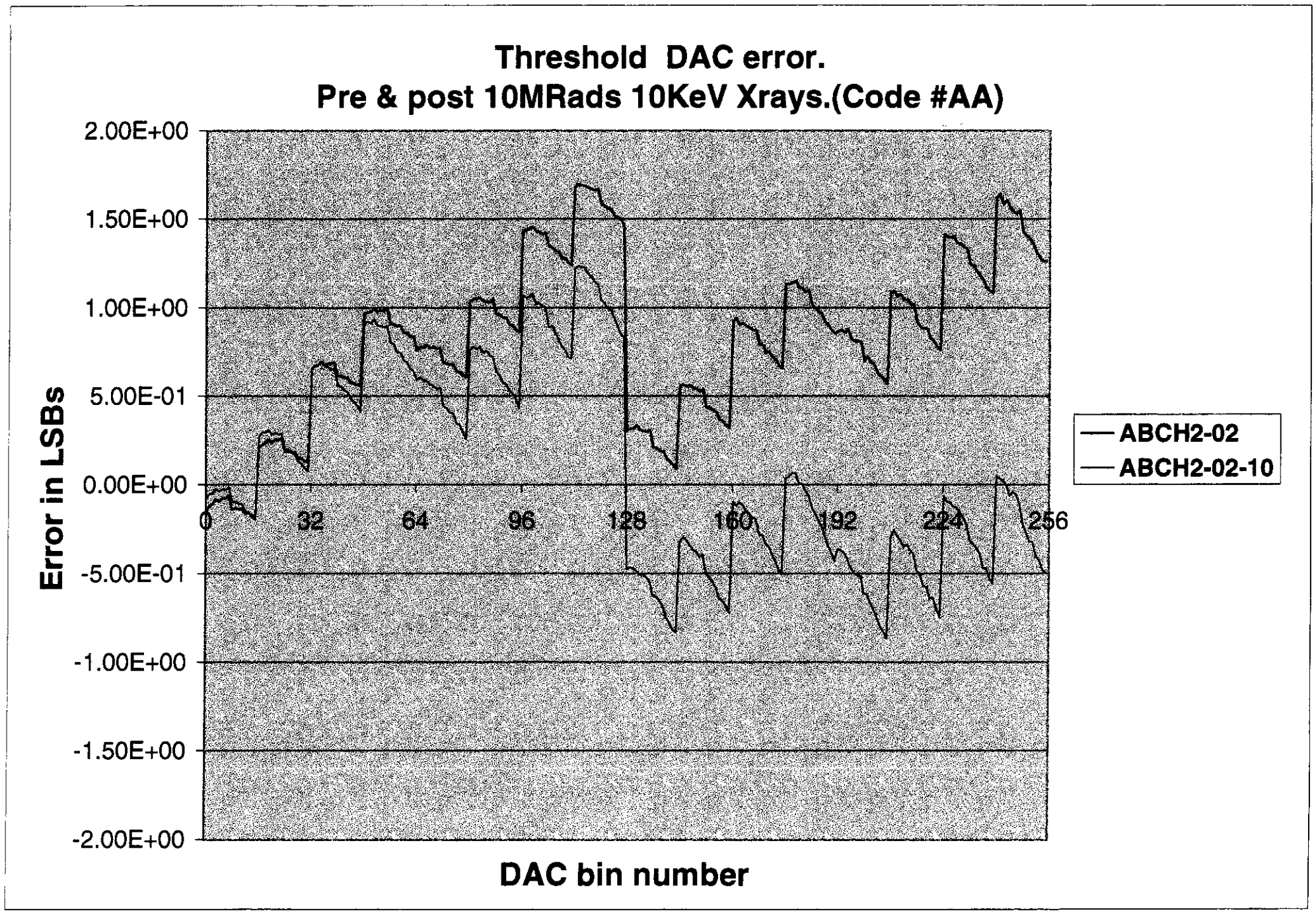

IV1I DAC error.
Pre & post 5MRads 10KeV Xrays.(Code #F)
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
-2.00E-01
-3.00E-01
-4.00E-01
-5.00E-01
Error in LSBs
0
4
8
12
16
DAC bin number
ABCH2-05
ABCH2-05-05

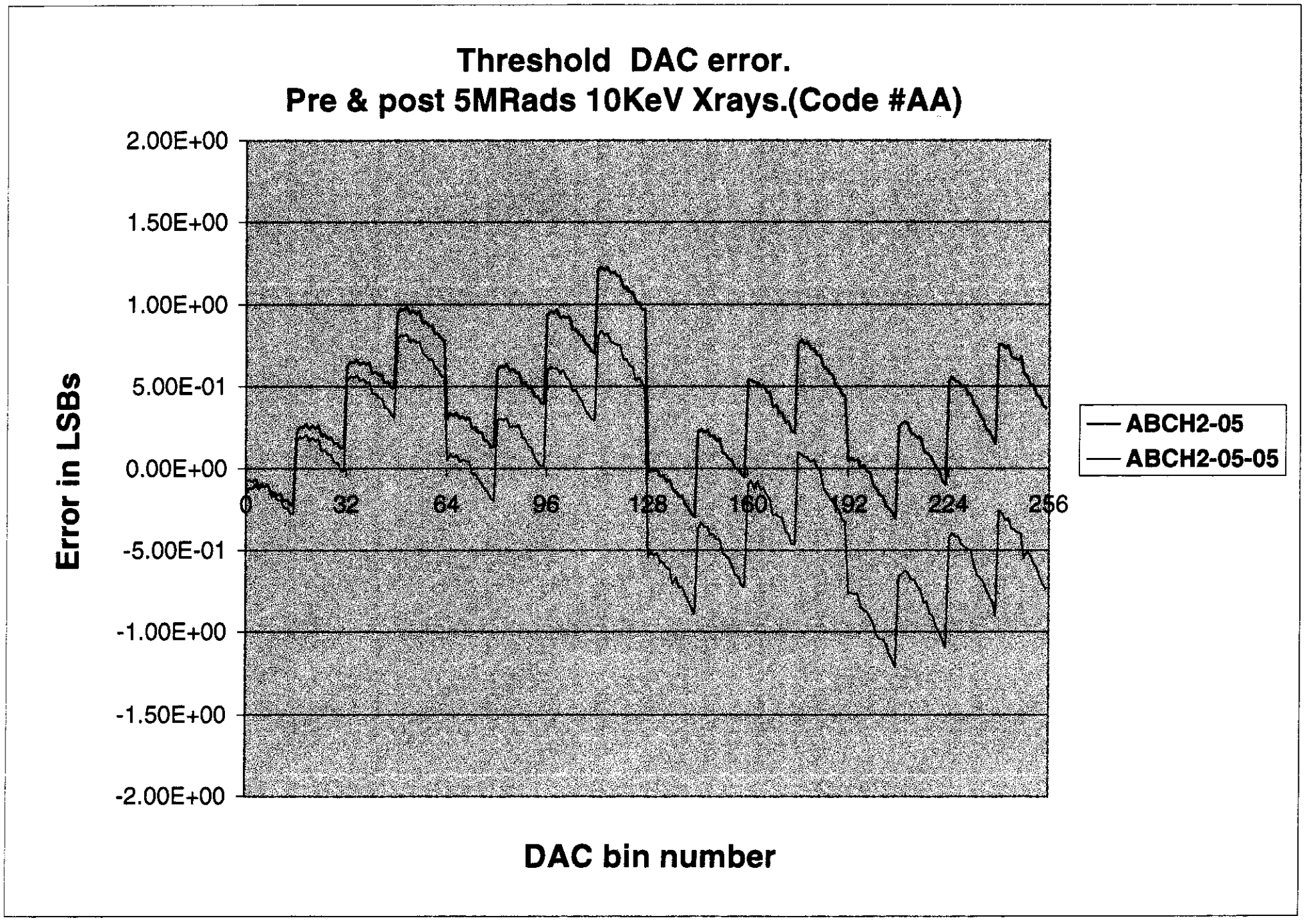

IV1I DAC error.
Pre & post 10MRads 10KeV Xrays.(Code #F)
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
-2.00E-01
-3.00E-01
-4.00E-01
-5.00E-01
Error in LSBs
0
4
8
12
16
DAC bin number
ABCH2-02
ABCH2-02-10

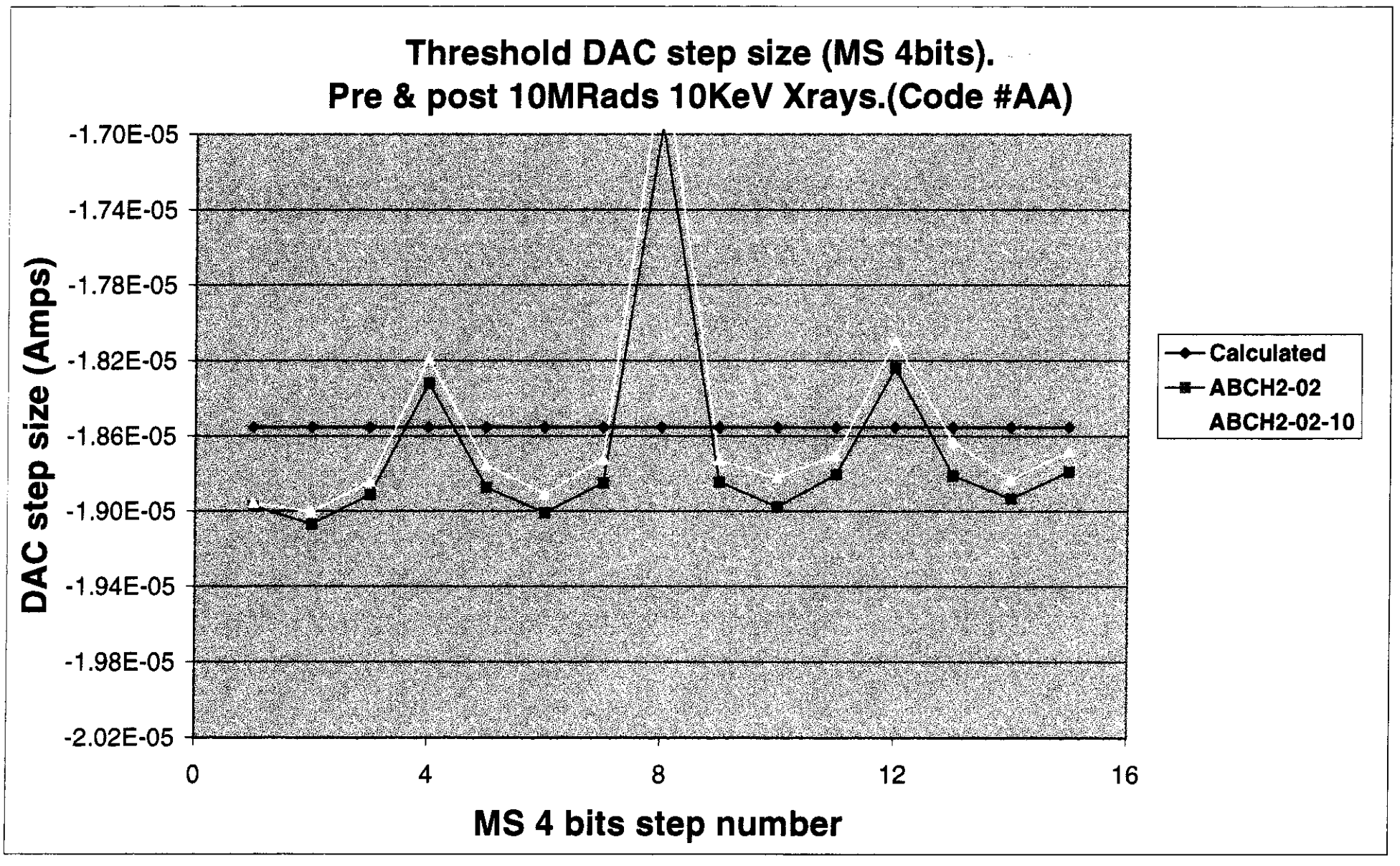
Calibration DAC error.
Pre & post 5MRads 10 KeV Xrays.(Code #55)

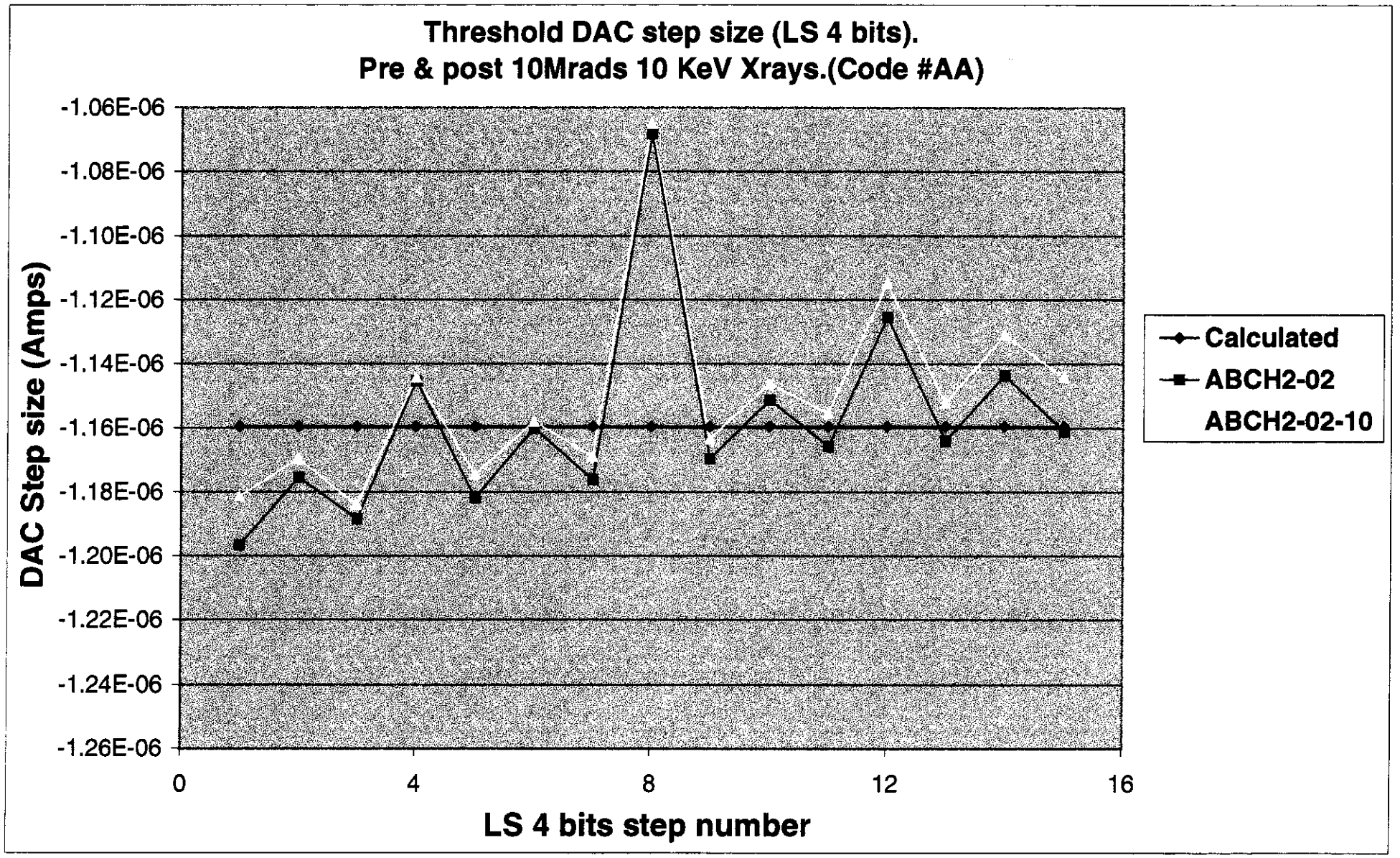


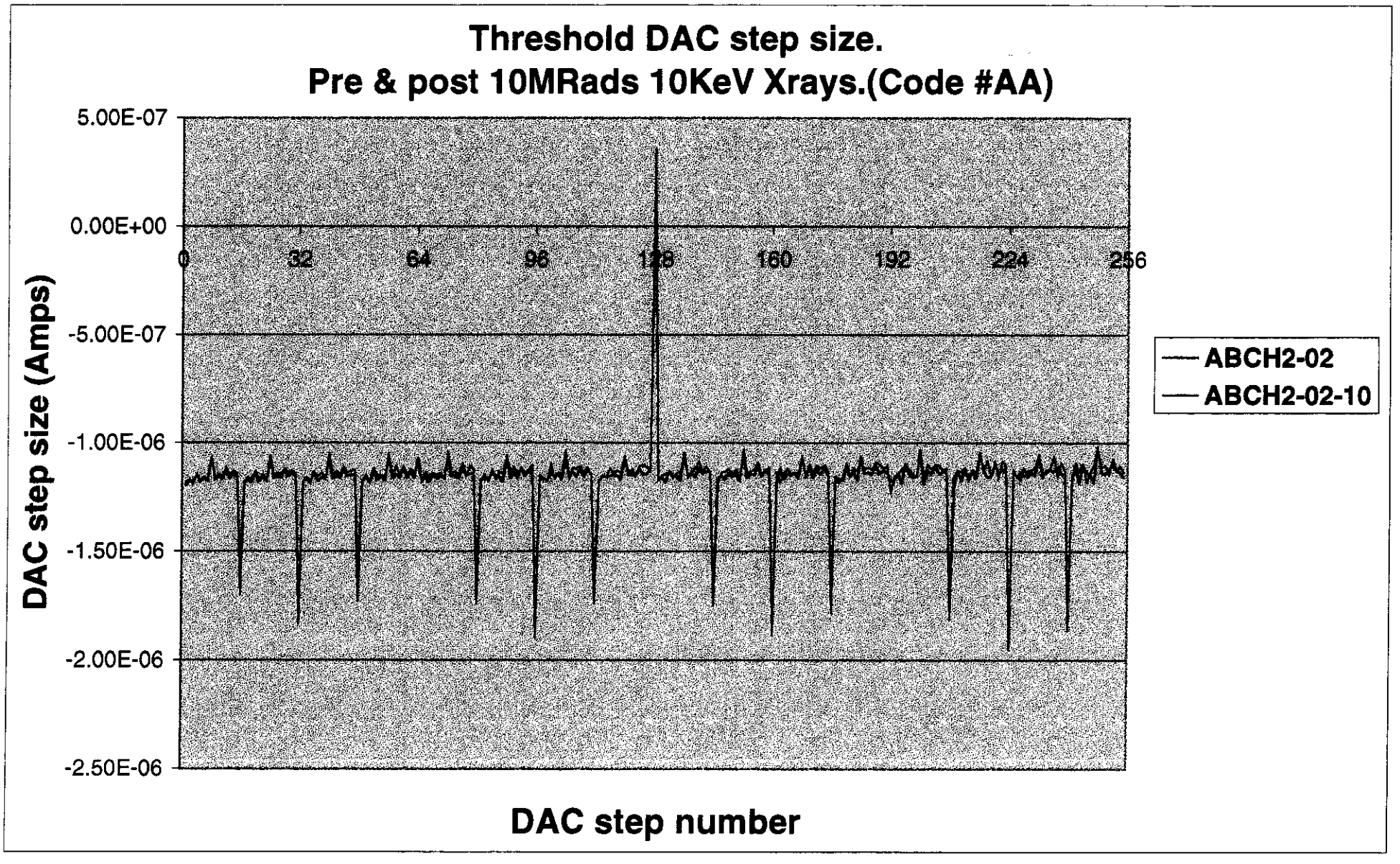

Calibration DAC error.
Pre & post 10MRads 10KeV Xrays.(Code #55)
1.00E+00
0.00E+00
-1.00E+00
-2.00E+00
-3.00E+00
-4.00E+00
-5.00E+00
-6.00E+00
-7.00E+00
-8.00E+00
-9.00E+00
0
32
64
96
128
160
192
224
256
Error In LSBs
DAC bin number
ABCH2-02
ABCH2-02-10

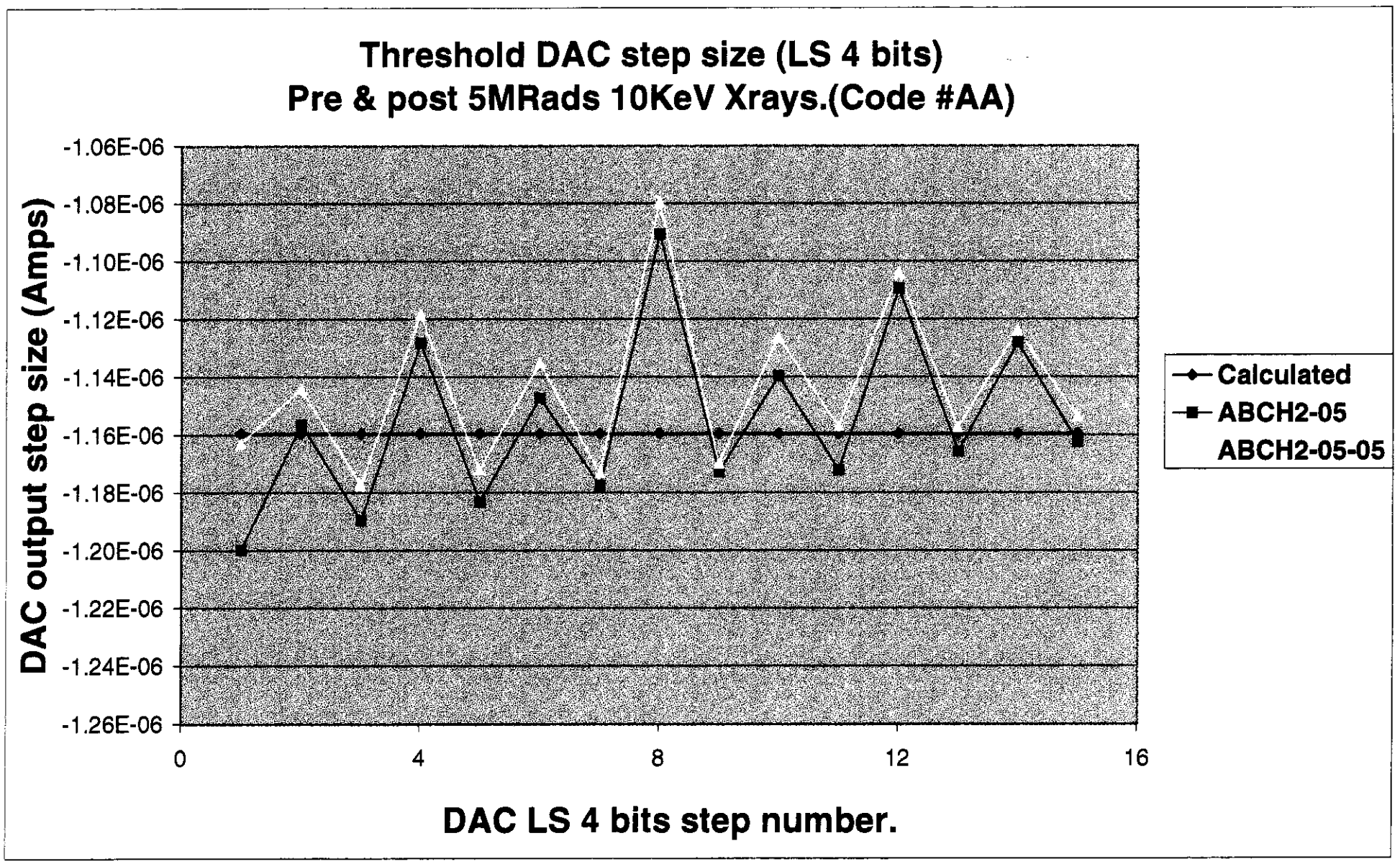

Threshold DAC error.
Pre & post 10MRads 10KeV Xrays.(Code #AA)
2.00E+00
1.50E+00
1.00E+00
5.00E-01
0.00E+00
-5.00E-01
-1.00E+00
-1.50E+00
-2.00E+00
Error in LSBs
0
32
64
96
128
160
192
224
256
DAC bin number
ABCH2-02
ABCH2-02-10

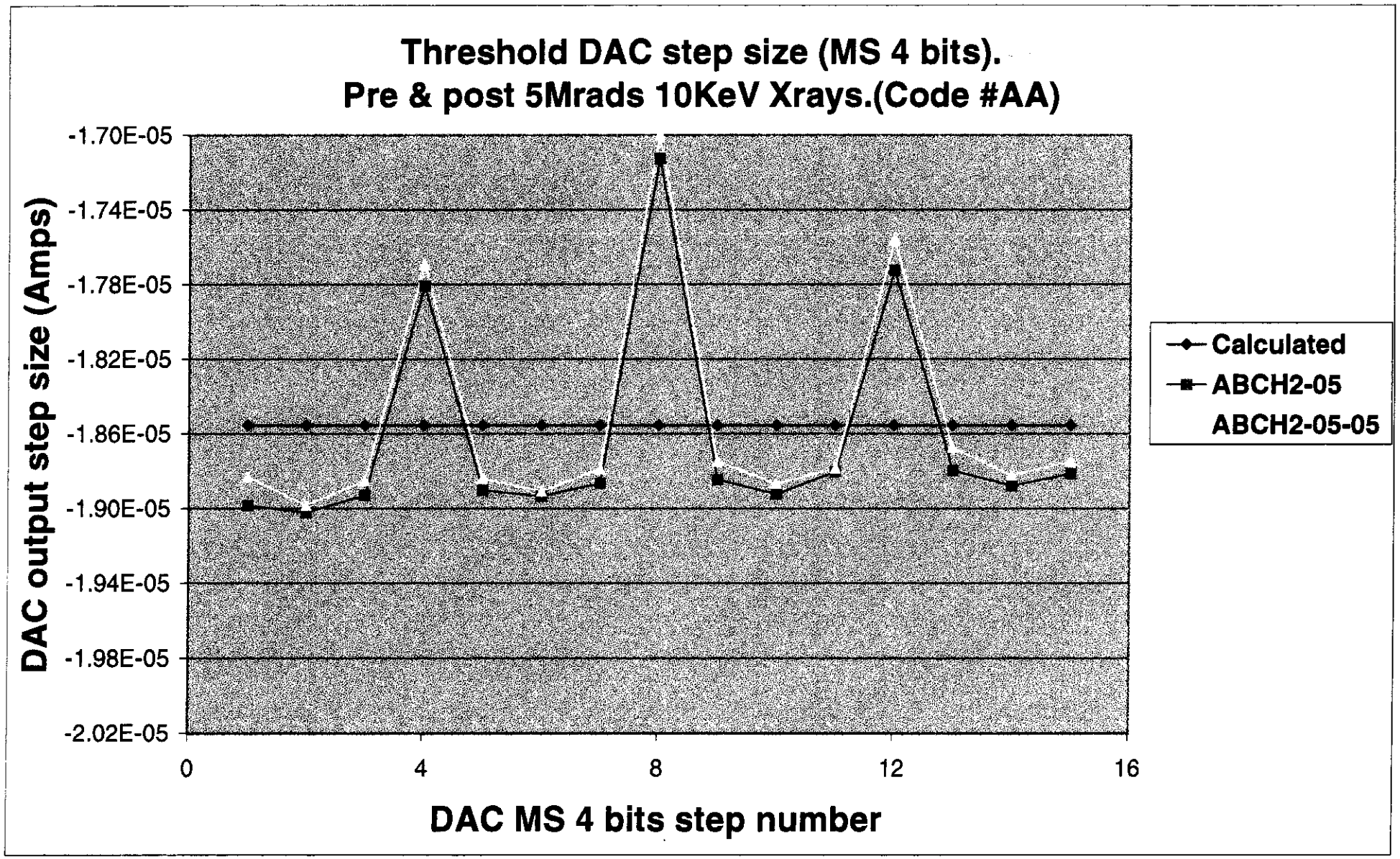

Threshold DAC error.
Pre & post 5MRads 10KeV Xrays.(Code #AA)
2.00E+00
1.50E+00
1.00E+00
5.00E-01
0.00E+00
-5.00E-01
-1.00E+00
-1.50E+00
-2.00E+00
Error in LSBs
0
32
64
96
128
160
192
224
256
DAC bin number
ABCH2-05
ABCH2-05-05

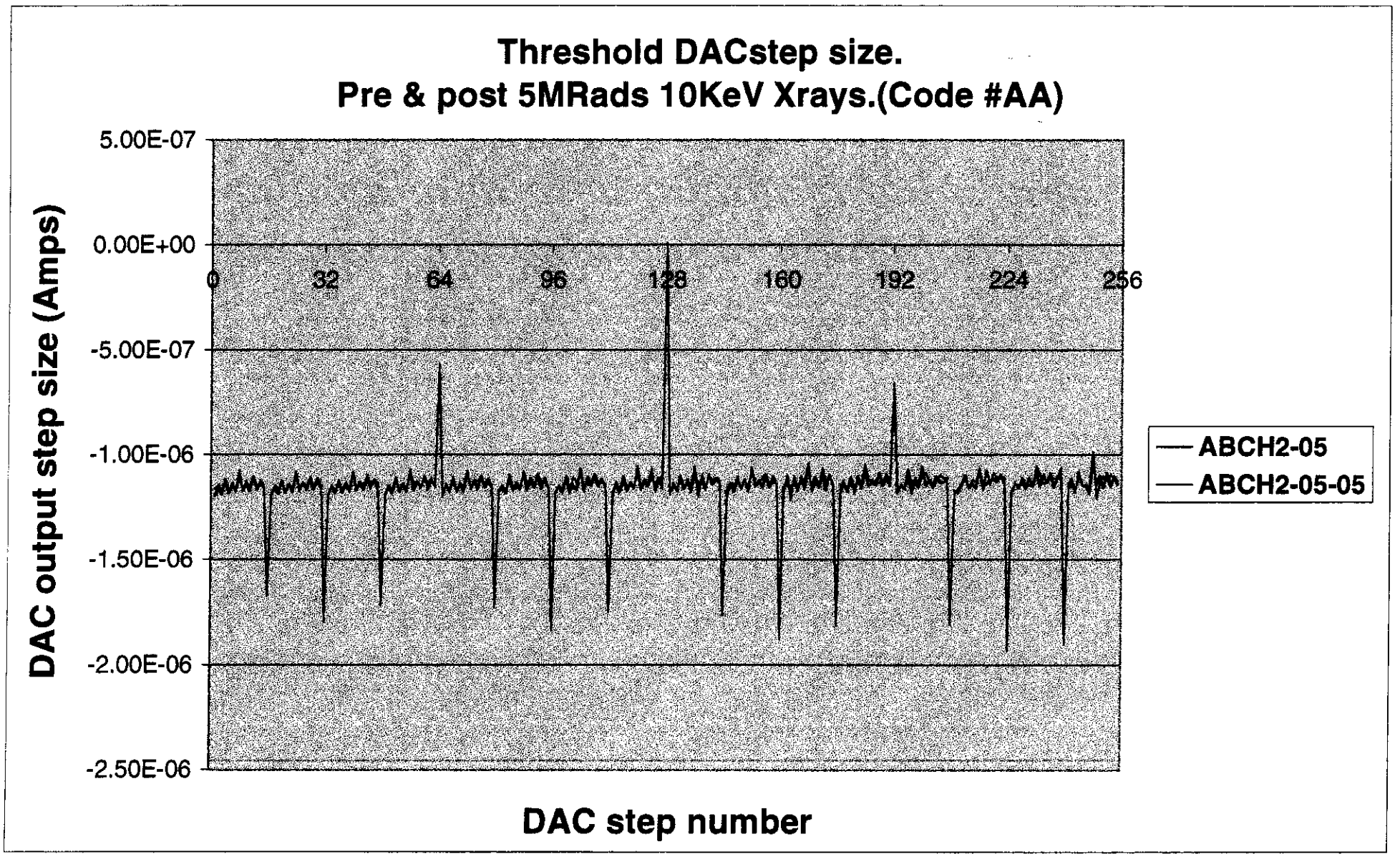

Threshold DAC step size (MS 4bits).
Pre & post 10MRads 10KeV Xrays.(Code #AA)
DAC step size (Amps)
-1.70E-05
-1.74E-05
-1.78E-05
-1.82E-05
-1.86E-05
-1.90E-05
-1.94E-05
-1.98E-05
-2.02E-05
0
4
8
12
16
MS 4 bits step number
Calculated
ABCH2-02
ABCH2-02-10

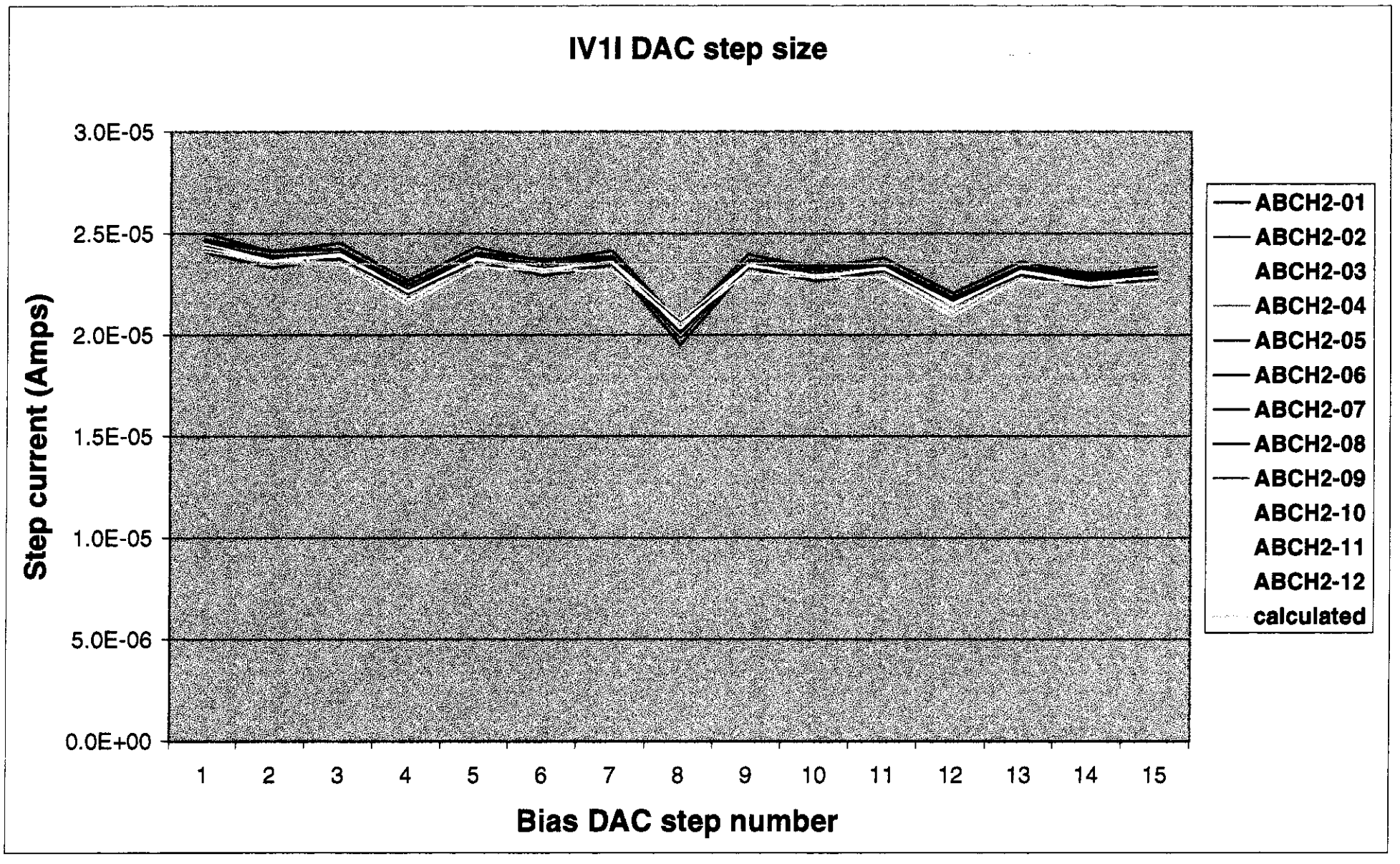

Threshold DAC step size (LS 4 bits).
Pre & post 10Mrads 10 KeV Xrays.(Code #AA)
-1.06E-06
-1.08E-06
-1.10E-06
-1.12E-06
-1.14E-06
-1.16E-06
-1.18E-06
-1.20E-06
-1.22E-06
-1.24E-06
-1.26E-06
DAC Step size (Amps)
0
4
8
12
16
LS 4 bits step number
Calculated
ABCH2-02
ABCH2-02-10


Threshold DAC step size.
Pre & post 10MRads 10KeV Xrays.(Code #AA)
5.00E-07
0.00E+00
-5.00E-07
-1.00E-06
-1.50E-06
-2.00E-06
-2.50E-06
0
32
64
96
128
160
192
224
256
DAC step size (Amps)
DAC step number
ABCH2-02
ABCH2-02-10


Threshold DAC step size (LS 4 bits)
Pre & post 5MRads 10KeV Xrays.(Code #AA)
DAC output step size (Amps)
-1.06E-06
-1.08E-06
-1.10E-06
-1.12E-06
-1.14E-06
-1.16E-06
-1.18E-06
-1.20E-06
-1.22E-06
-1.24E-06
-1.26E-06
0
4
8
12
16
DAC LS 4 bits step number.
Calculated
ABCH2-05
ABCH2-05-05


Threshold DAC step size (MS 4 bits).
Pre & post 5Mrads 10KeV Xrays.(Code #AA)
DAC output step size (Amps)
-1.70E-05
-1.74E-05
-1.78E-05
-1.82E-05
-1.86E-05
-1.90E-05
-1.94E-05
-1.98E-05
-2.02E-05
0
4
8
12
16
DAC MS 4 bits step number
Calculated
ABCH2-05
ABCH2-05-05


Threshold DACstep size.
Pre & post 5MRads 10KeV Xrays.(Code #AA)
5.00E-07
0.00E+00
-5.00E-07
-1.00E-06
-1.50E-06
-2.00E-06
-2.50E-06
0
32
64
96
128
160
192
224
256
DAC output step size (Amps)
DAC step number
ABCH2-05
ABCH2-05-05


IV1I DAC step size
3.0E-05
2.5E-05
2.0E-05
1.5E-05
1.0E-05
5.0E-06
0.0E+00
Step current (Amps)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Bias DAC step number
ABCH2-01
ABCH2-02
ABCH2-03
ABCH2-04
ABCH2-05
ABCH2-06
ABCH2-07
ABCH2-08
ABCH2-09
ABCH2-10
ABCH2-11
ABCH2-12
calculated

ABC Test Results

- Design Verification
- Speed Degradation vs. Radiation Dose
- Single Event Effects with 55 MeV Protons
- Implications for Production Testing and Yield Estimate

H. Niggli, N. Busek, A. Ciocio,
M. Gilchriese, C. Haber, H. Spieler, F. Zetti

Testvectors

- Complete set of 45 Verilog testvectors* was used for
  - Verifying specified functionality in simulation
  - Irradiation Tests
  - Wafer Probing
  - Total length of testvectors is over 500'000 words
- Testvectors designed for 100% test coverage of digital circuitry:
  - Pipeline, Readout buffer and FIFOs scanned
  - All possible addresses, commands, counter values etc. tested
  - Master/Slave/End Mode tested, redundant I/O tested
- NOT routinely tested:
  - DAC's
  - Test Strobe to CAFE-P

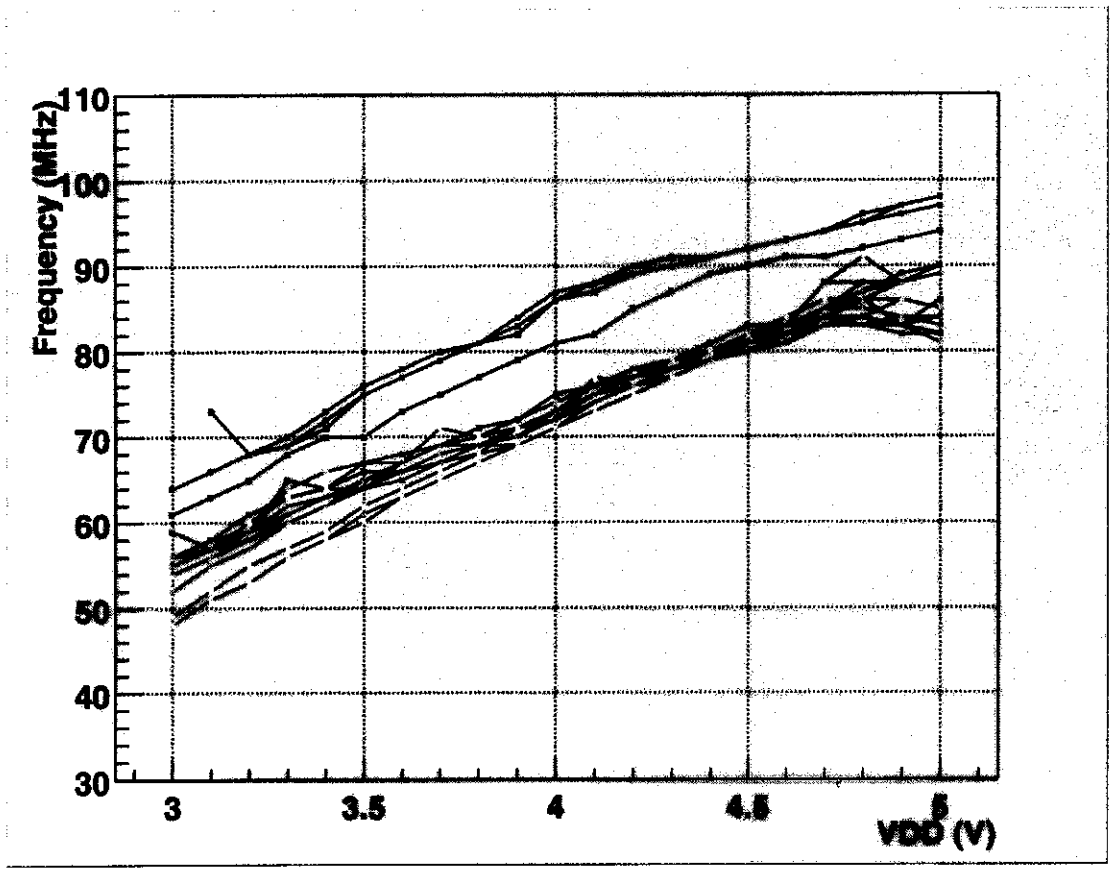
*Detailed description available

Test Equipment

Custom 133 MHz State Logic Analyzer/Pattern Generator

- 6-u VME board (LA/PG and Frequency Synthesizer)
- 22.5 foot cables (length important for irradiations)
- Chip glued/bonded on chip carrier card (only passive components)
- Chip carrier card plugs into support card which has line drivers/receivers for long cable, registers, LVDS drivers/receivers for ABC chip, PLL zero delay clock buffer. Clock is routed back to the VME board.
- Control Software: MS Visual C++. Data display in OpenGL. WindowsNT.
- "Support Card" with possibility to set signal levels and skew all output channels independently is in development.
- Same test equipment for wafer probing, single chip tests and irradiation testing.

Example



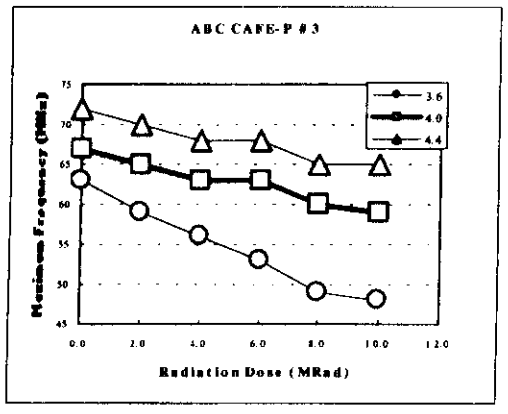
- Each curve corresponds to one testvector
- Data points are maximum frequency at which results agree with Verilog simulation at 40 MHz
- Fastest TV's are those involving only the command decoder
- Slowest are those using the strobe input register command

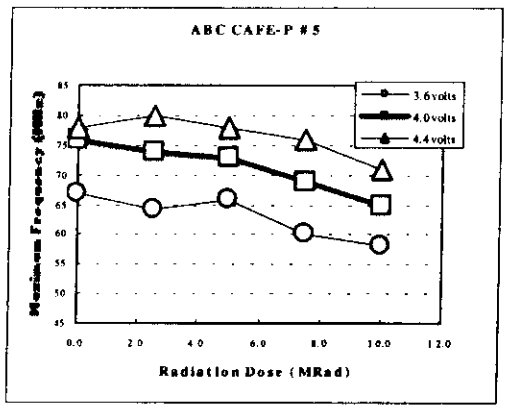
Known Problems

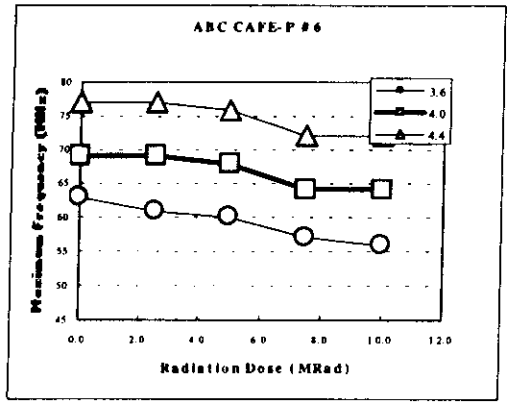
- Test pulse and test dc level for input level translators flaky if ABC gets it's OUTRH/OUTRL currents from CAFE-P. Problem not existent if current level on OUTRH is set by resistor to GND and OUTRL is floating. Occured on one die during irradiation and on 2 dies already before. Tuning CA does NOT fix the problem - why? Lowering VCC on the CAFE-P down to 3.2 volt reduces the number of errors but does not fix the problem either.
- Data format error in header. (known since a long time, listed for completeness)
- 8-bit DAC's not monotone or not very linear at transition from x0f to x10

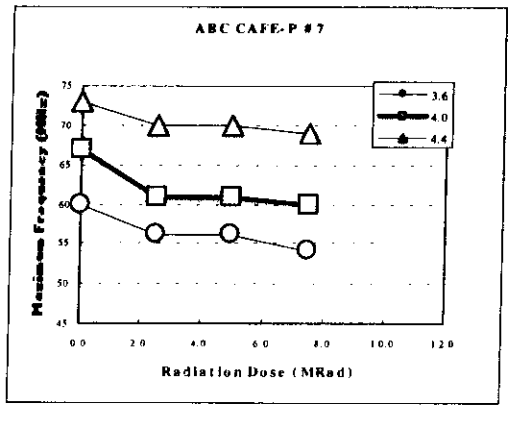
→ problems are small and fixable

Speed Degradation vs Radiation Dose



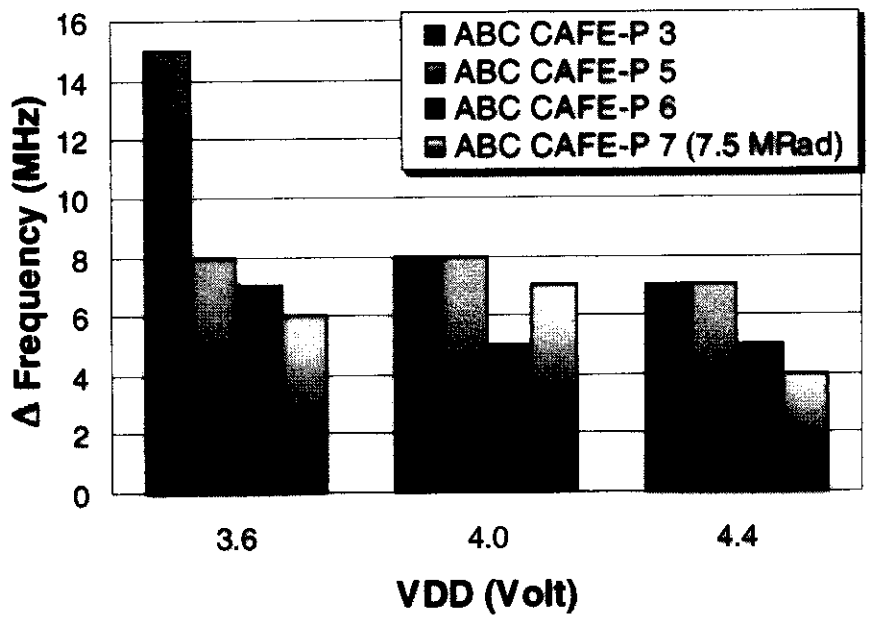






- 55 MeV Protons
- Fluence of $6 \cdot 10^{13}$ p/cm^2 corresponds to a dose of 10 MRad. Fluence rate was $5 \cdot 10^{10}$ p/cm^2/s.
- Samples cooled down to 0-3° C during irradiation and stored in freezer afterwards.
- Curves show maximum frequency at which the slowest TV passed as a function of the dose.
- Upper curves: VDD=4.4 V, middle curves: VDD=4.0 V, lower curves: VDD=3.6V

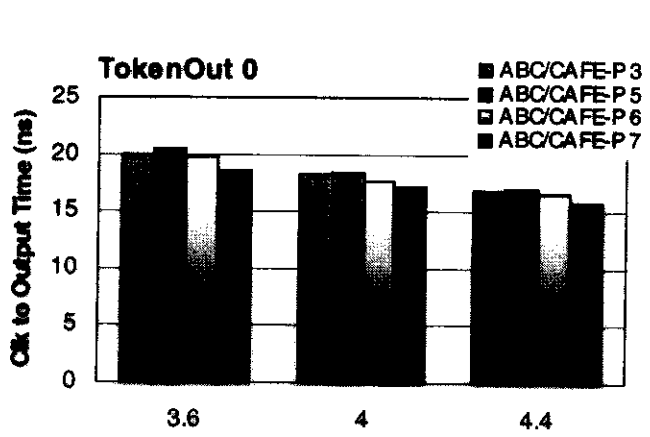
Speed Degradation after 10 MRad

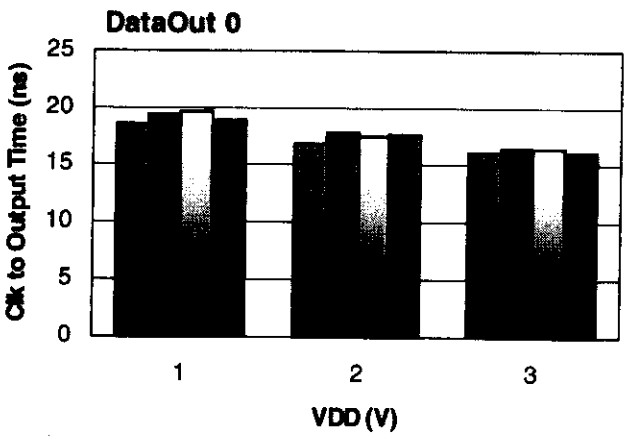


- Speed loss after 10 MRad is around 5-8 MHz at 4.0 V.
- It is planned to watch the samples for annealing effects in the next months.

→ Plenty of headroom in frequency/VDD for this particular wafer/batch.

Clk to Output Times for TokenOut/DataOut





Token/Data Clk-> Output Delay:

- shown left is post-rad data. Load= 6 pF for each trace
- difference between pre- and post-rad is below 2 ns, typical value 1 ns

Token/Data/LED signal amplitudes:

- no measurable change in current due to radiation
- termination resistor changes around 1%
- Typ. Amplitudes across 100 Ω:

	3.6 V	4.0 V	4.4 V
LED	440 mV	490 mV	550 mV
Token/Data	308 mV	345 mV	380 mV

→ Plenty of margin for this particular wafer/batch.

Temperature Test, LED Drive, Wafer Screening at higher Frequencies

- Temperature: ABC tested at -20° C, 0° C, +20 ° C, +50 ° C: Few MHz variation in speed seen. Works at all temperatures. But: Only 1 chip tested yet.
- LED output drives at least 22.5 foot cable after Irradiation at (at least) 70 MHz.
- Wafer Screen: Results from testing 30 dies on wafer indicates that the chips chosen for the irradiation are representative for this particular wafer/batch. Wafer screening continues. Main questions:
  - What is the spread in the maximum operating frequency? Prel. Answer: Few MHz.
  - Are there particular failure modes which could be fixed with a design change? Prel. answer is NO.
  - What is the yield versus VDD and frequency?

→ no surprises yet...

Single Event Effects with 55 MeV Protons

- Sample: Single ABC/CAFE-P pair on test board
- Test: Run one 37kWords testvector which writes data to the mask register, stores it in the pipeline/fifo and activates the DCL/readout controller. Test vector is run until readout disagrees with simulation data. Then the readout data is transferred to PC and saved for off-line analysis.
- Conditions: 40MHz and VDD=4.0 V
- How to distinguish errors in the tester from SEE's in the ABC?
  - Test for errors in ABC readout and readout system by running TV for 0.5 10^6 times with beam off $\rightarrow$ 0 Errors.
  - Test for SEE on support card by running TV 0.5 10^6 times in situ when beam is on but replacing ABC chip with loopback wires $\rightarrow$ 0 Errors.
- Result: 32 SEE spotted in a time interval with a fluence of 4.64 10^{11} p/cm^2 . Thereof
  - 27 times just a bit flip in the pipeline or the readout buffer
  - 4 times readout controller/data compression logic shows errors in the data format which would lead to the loss of one event at most.
  - 1 event not understood, most probable also error on ROC/DCL
  - No hard errors or functional interrupts found

Takes fluence of 1.45 10^{10} p/cm^2 on average for 1 SEE with 55 MeV with this specific TV. Would need to measure SEE cross section versus LET, use a realistic data taking mode and fold in the particle spectrum to obtain an estimate of the SEE Rate for SCT conditions. Doable, but necessary?

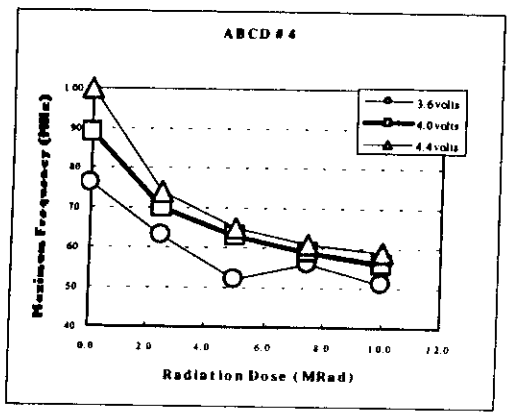
Implications on Production Testing and Yield

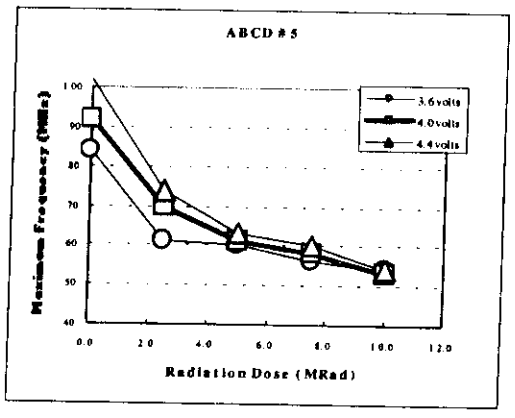
- Wafer probing at around 55 MHz / 4.0 V should give enough margin. More irradiations with other types of particles and other dose rates are needed.
- Yield measurement from lower frequency wafer probing are expected to be accurate for this batch.
- Extrapolating from the 30 dies tested: Typical frequency is 65 to 70 MHz.

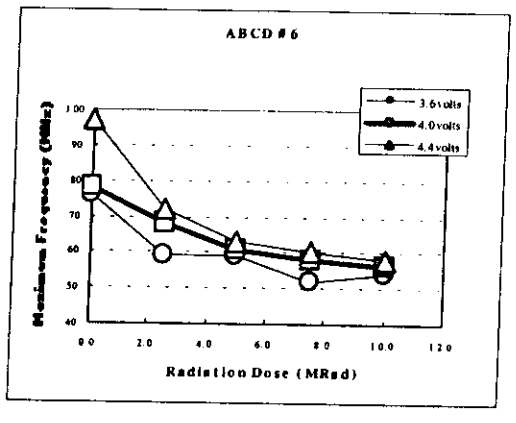
→ This batch is about 10 MHz faster than necessary for good yield at 55 MHz / 4.0 V

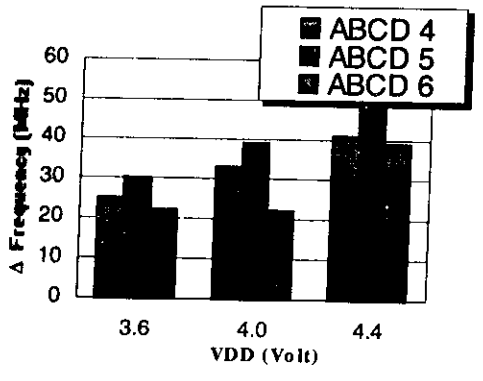
→ Really need to know where this batch is within the production window.

ABC2T Speed Degradation vs Radiation Dose









- Data from newer batch which is much faster than first one
- Testvectors only test the Cmd Decoder, Mask Register, DCL and ROC, but not the timing in the pipeline ("strobe input reg command" not used)
- Slows down by 30-45 MHz.
- TokenOut/DataOut Clk to Output time changes from 17-18 ns to 22-23 ns at 4 V.
- TokenOut/DataOut current amplitude drops by 20-23%.

PS Irradiation

Irradiation of a ABC/CAFE hybrid, October 1999.

Richard Bates, Lars Eklund, Jerzy Kudlaty, Joleen Pater, Andras Zsenei, et al.

General Performance

- All chips responding digitally throughout the irradiation.
- Some chips were giving zeros from the analogue part for high preamplifier currents at high dose. All chips fully functional for preamplifier 100 and 150 uA @ $3*10^{14}$ p/cm^2.

Dose (10^{14})	200 uA	250uA
2.43	All OK	1 chip >> zeros
2.78	1 chip >> zeros	2 chip >> zeros
3.0	2 chip >> zeros	5 chip >> zeros

Power Consumption

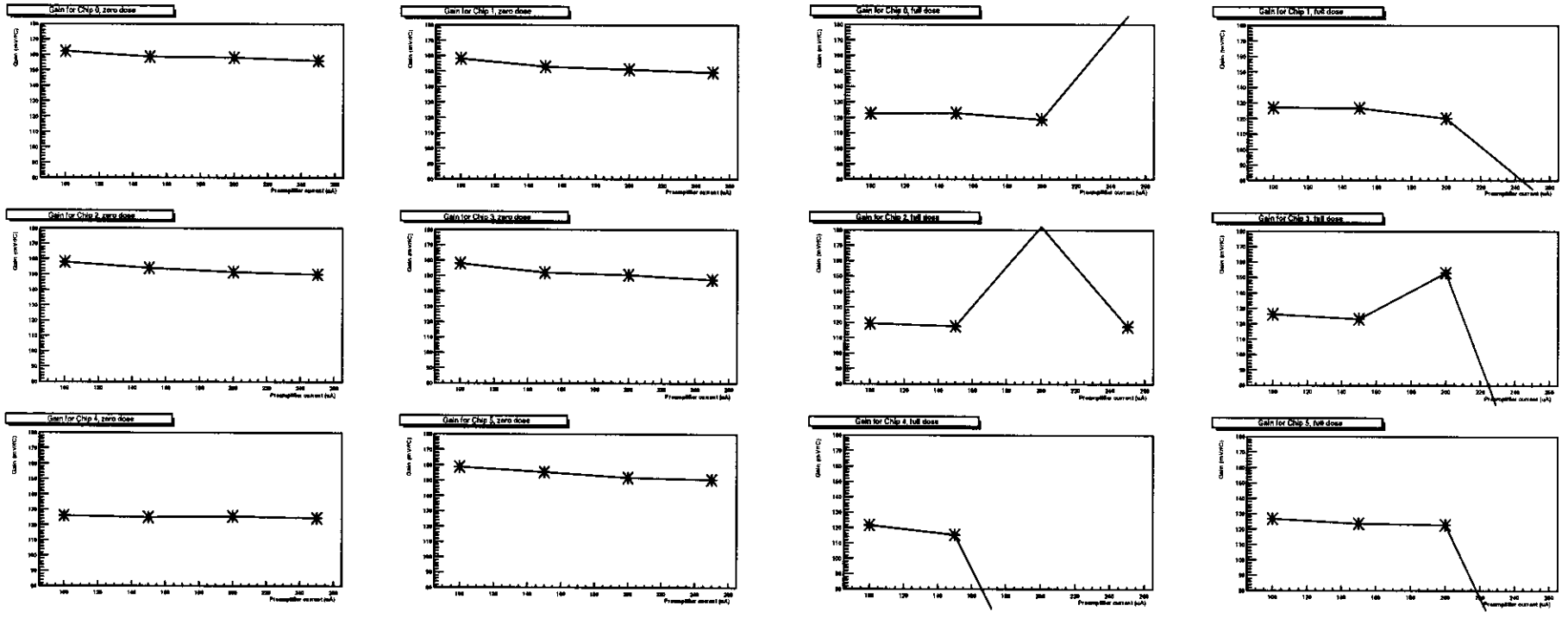
Idd includes 40-50mA consumed by the support card.
Icc is taken with arbitrary DAC settings.

	Vdd	Idd	Vcc	Icc
Before Irradiation	4.0	315mA	3.5	350mA
After Irradiation.	4.0	270mA	3.5	335mA
After Irradiation, + 4 weeks.	4.0	230mA	3.5	400mA
After Irradiation, + 4 weeks. No clock.	4.0	120mA	3.5	310mA

Lars Eklund

PS irradiation, October 1999

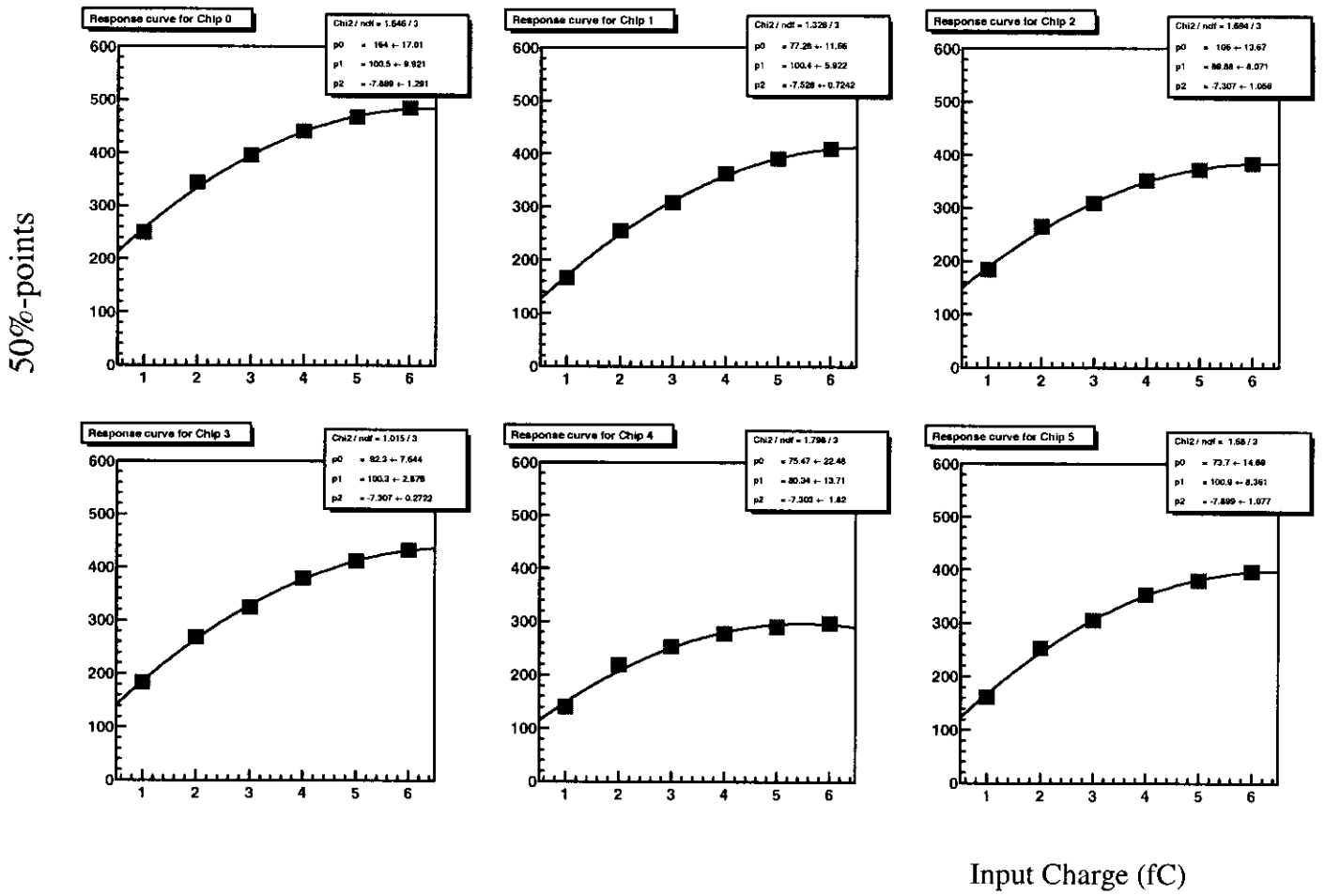
Gain vs Preamplifier bias.



Lars Eklund

PS irradiation, October 1999

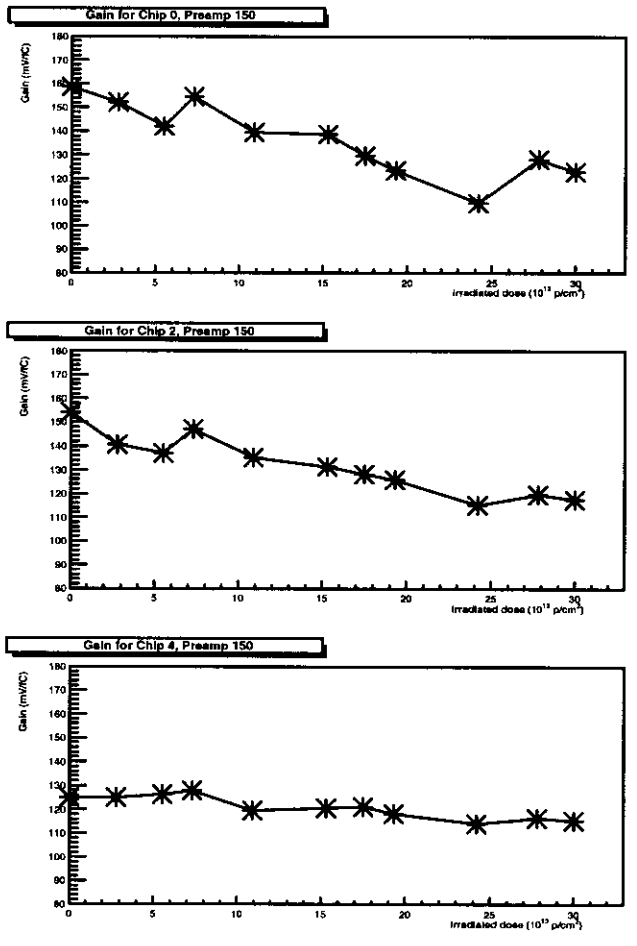
Response curve



Lars Eklund

PS irradiation, October 1999

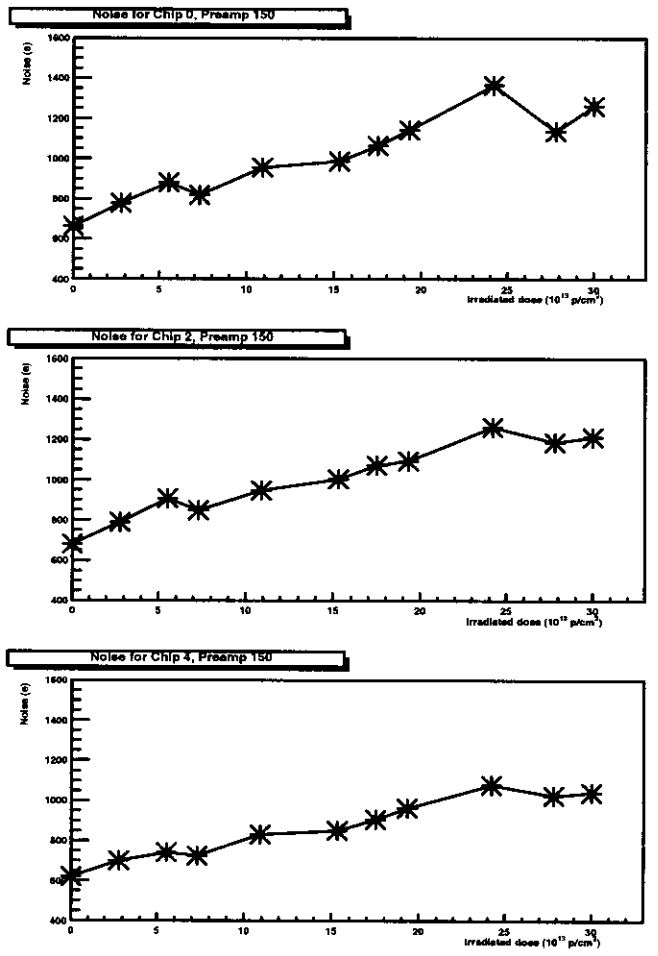
Gain Evolution



Lars Eklund

PS irradiation, October 1999

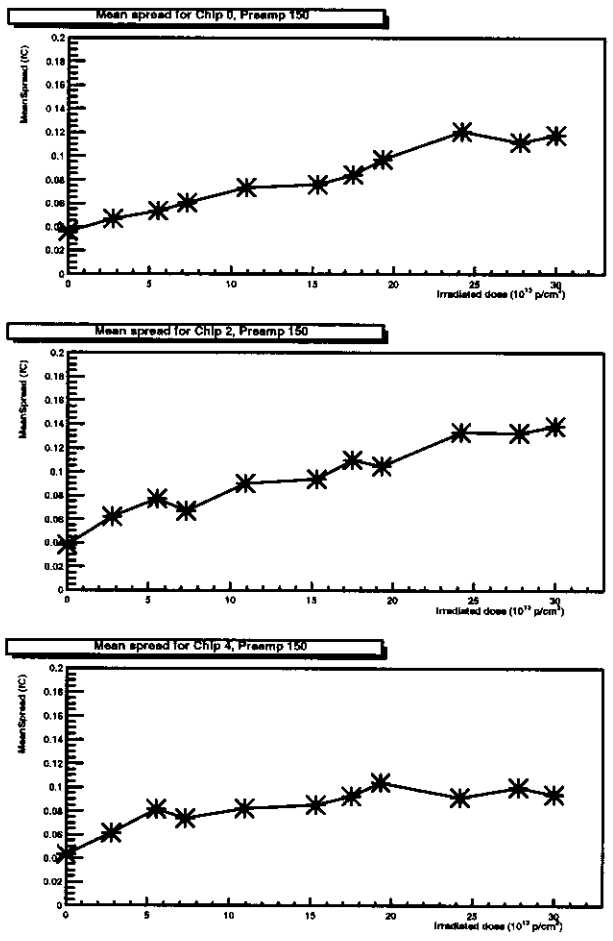
Noise Evolution



Lars Eklund

PS irradiation, October 1999

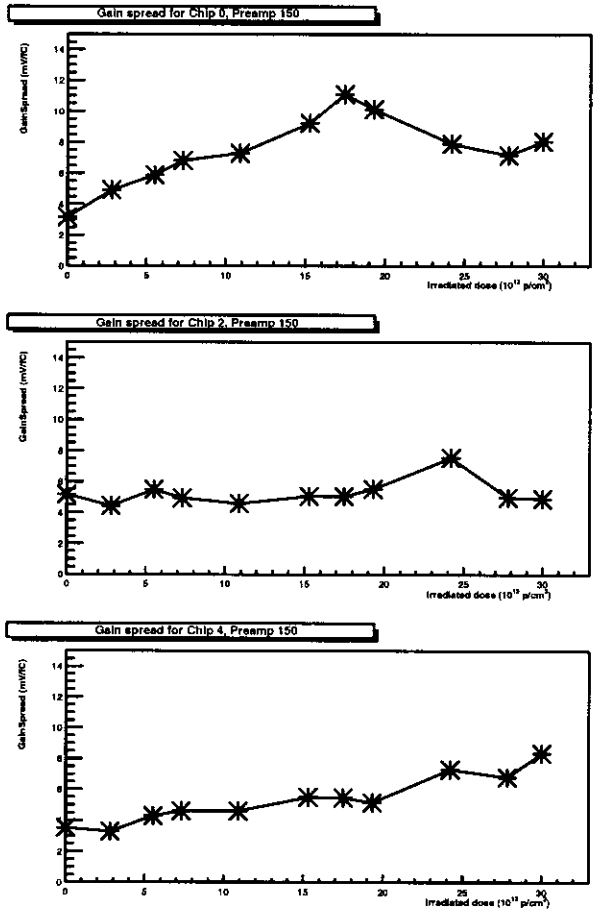
Mean Spread Evolution



Lars Eklund

PS irradiation, October 1999

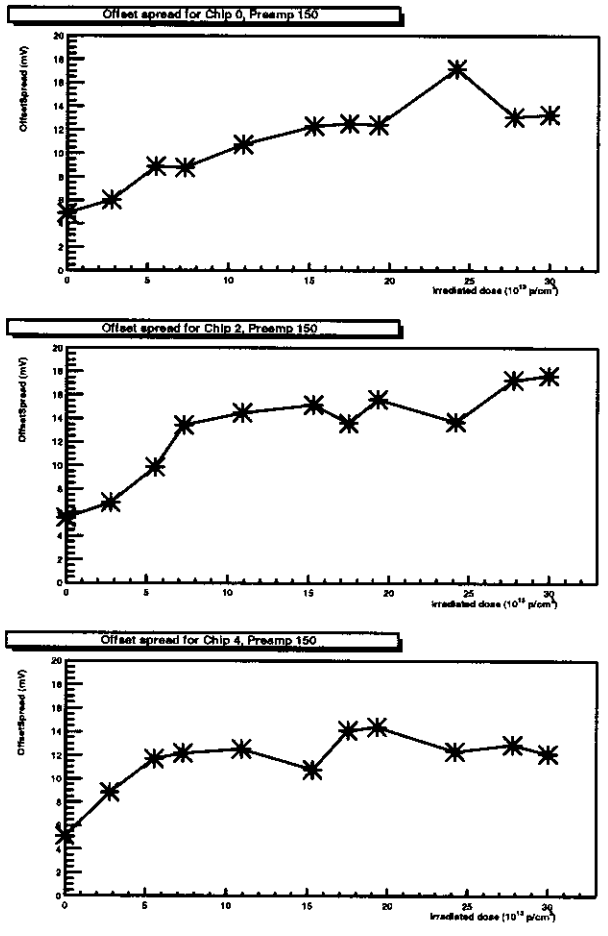
Gain Spread Evolution



Lars Eklund

PS irradiation, October 1999

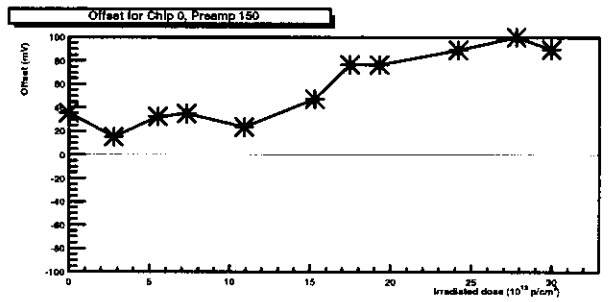
Offset Spread Evolution

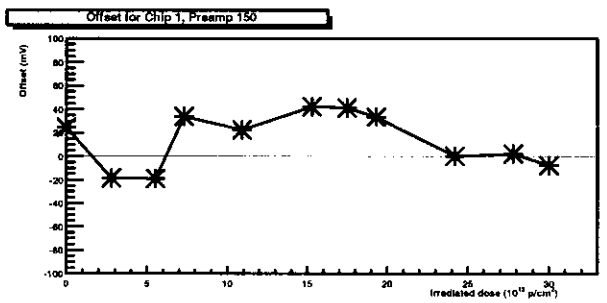


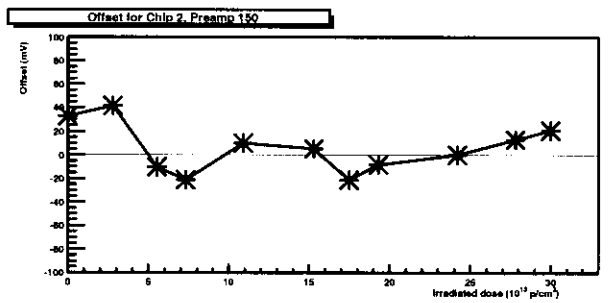
Lars Eklund

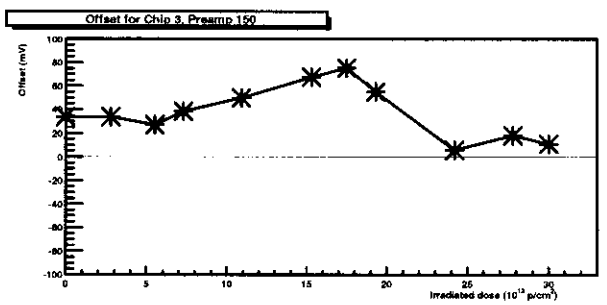
PS irradiation, October 1999

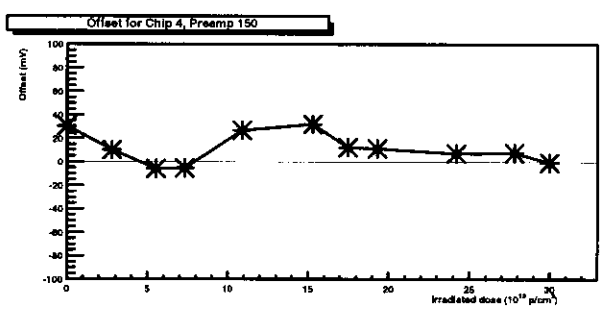
Offset Evolution

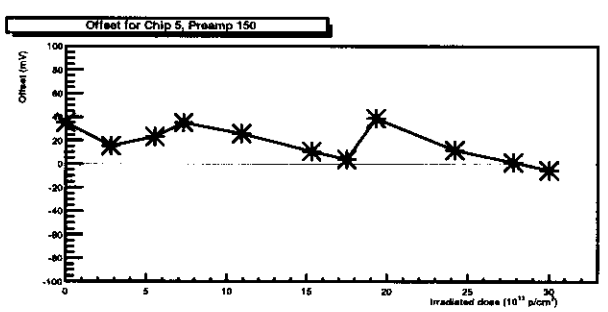












Lars Eklund

PS irradiation, October 1999

Conclusions ABC/CAFE

- All chips digitally functional throughout the irradiation.
- Problems with analogue performance for high preamplifier bias at high dose.
- Gain drops from 155 to 123 mV/fC (20 %).
- Noise increases from 690 to 1275 electrons (85%).
- Mean spread goes from 0.045 to 0.13 fC.

ABC/CAFE-P Irradiation at the LBNL Cyclotron

J.Bernabeu (IFIC-Valencia)
A.Ciocio, M.Gilchriese, C.Haber, H.Niggli, H.Spieler, F. Zetti (LBNL)

ABC/CAFE-P Irradiation

- Sample in a cooled box: $\sim 2 - 3^{o}$C during irradiation.
- Hybrid Temperature: $\sim 8 - 13^{o}$C during irradiation.
- Sample stored in the freezer after irradiation.
- Measurements done at room temperature.

ABC/CAFE-P Irradiation

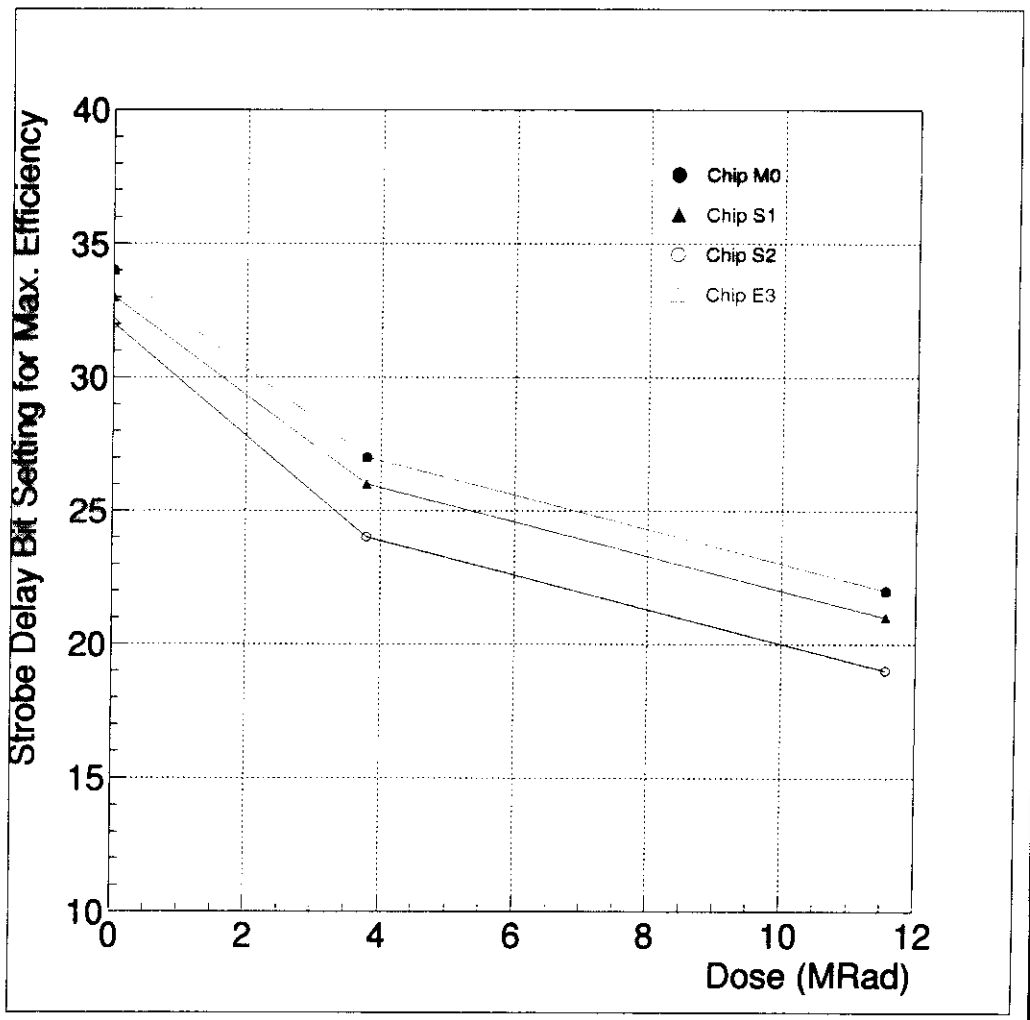
- Sample
  - 1 Hybrid with 4 ABC/CAFE-P
- 2 Runs: - First Run: Fluence $2.25 * 10^{13}$ protons/cm^2 (55MeV)
  Dose 3.8 MRad
  Rate $\sim 1.1 * 10^{10}$ p cm^{-2} min^{-1}
  - Second Run: Fluence $4.65 * 10^{13}$ protons/cm^2 (55MeV)
  Dose 7.75 MRad
  Rate $\sim 1.1 * 10^{10}$ p cm^{-2} min^{-1}
  - Total fluence and dose after both runs:

  Fluence $6.9 * 10^{13}$ protons/cm^2 (55MeV)

  Dose 11.55 MRad

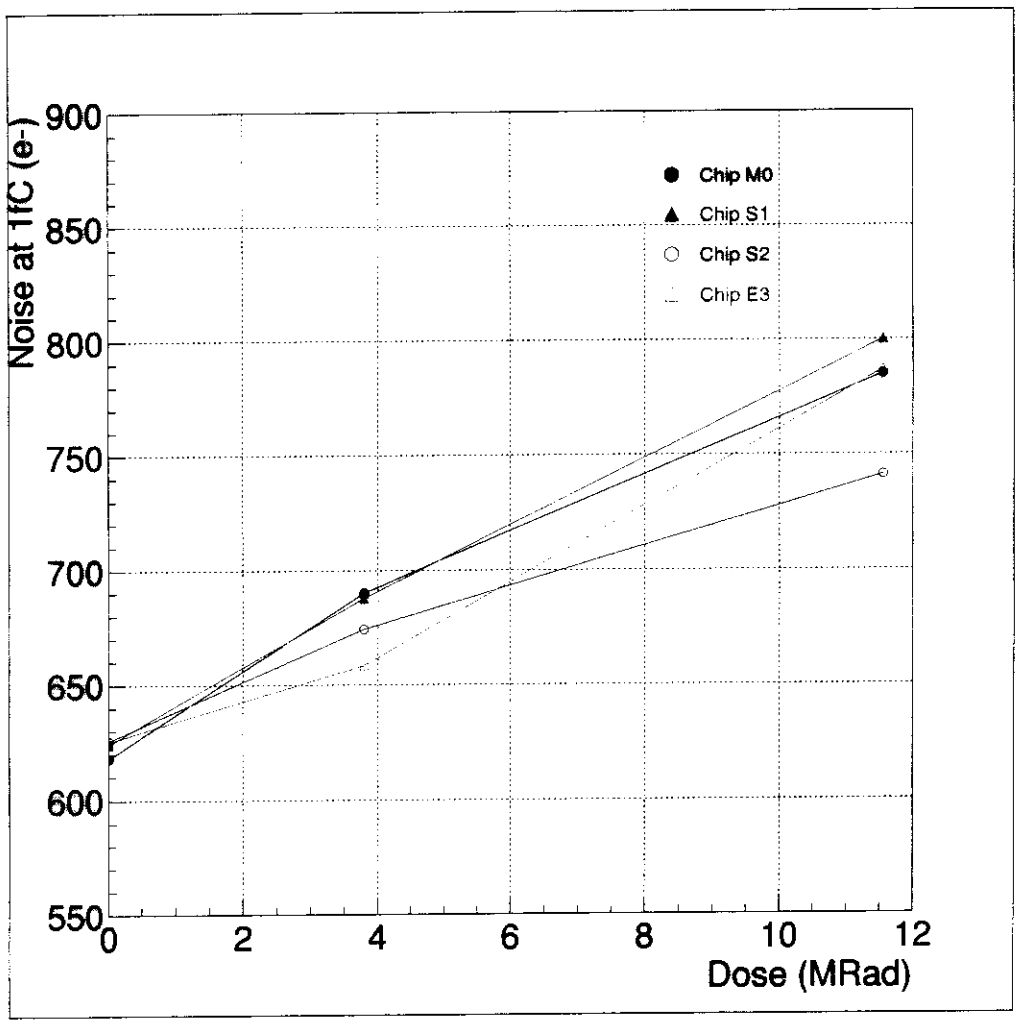
ABC/CAFE-P Timing

- Strobe Delay Bit Setting per chip for maximum efficiency
- Strobe Delay Step (pre-rad) = 1.4ns
- Setting decreases with radiation
  - Longer peaking time
  - Increase of Strobe Delay Step



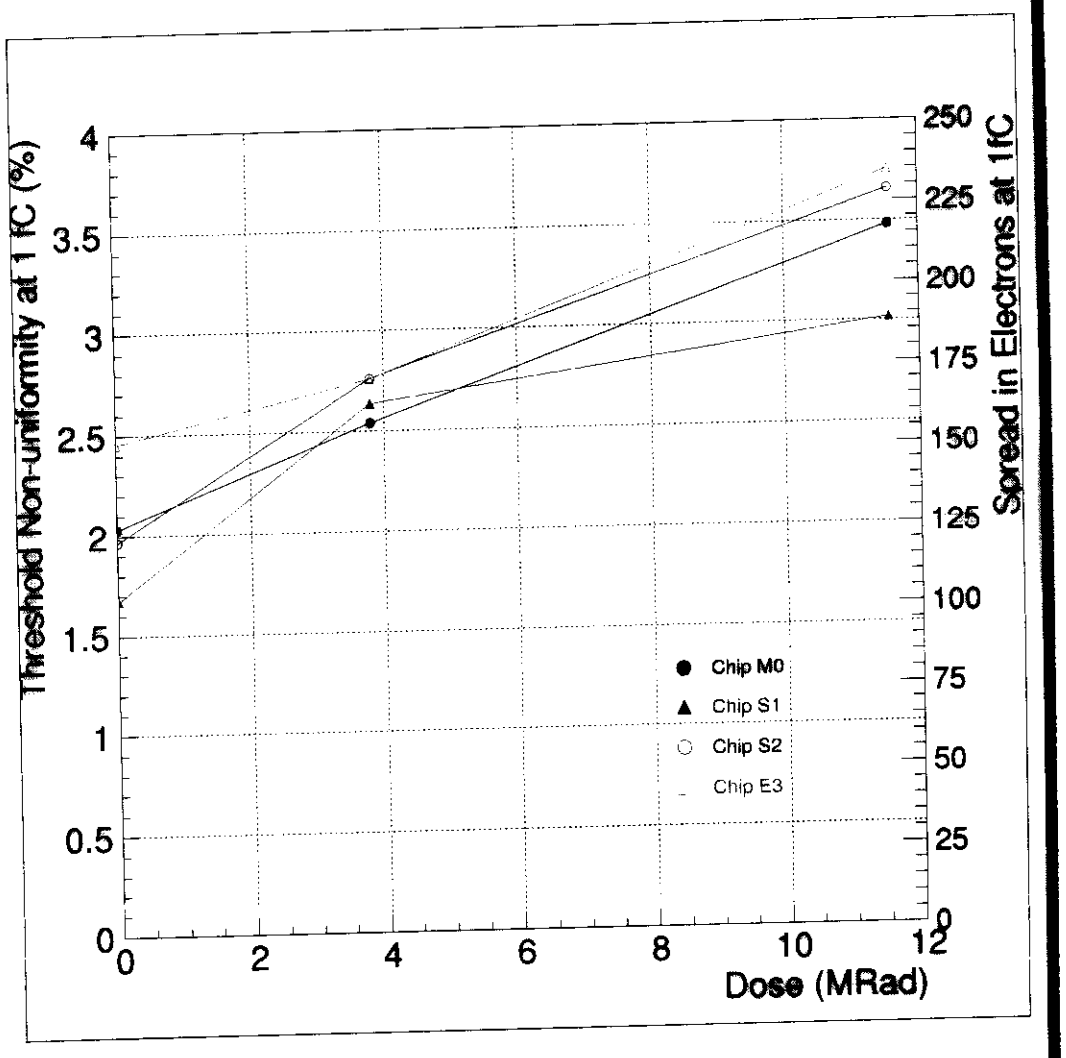
CAFE-P Noise

- All channels
  (0 bad channels)
- $I_{preamp} = 218\ \mu A$
- From VCal Scan
- Mean from gaussian fit to distribution of 128 channels



CAFE-P Threshold Spread 1fC

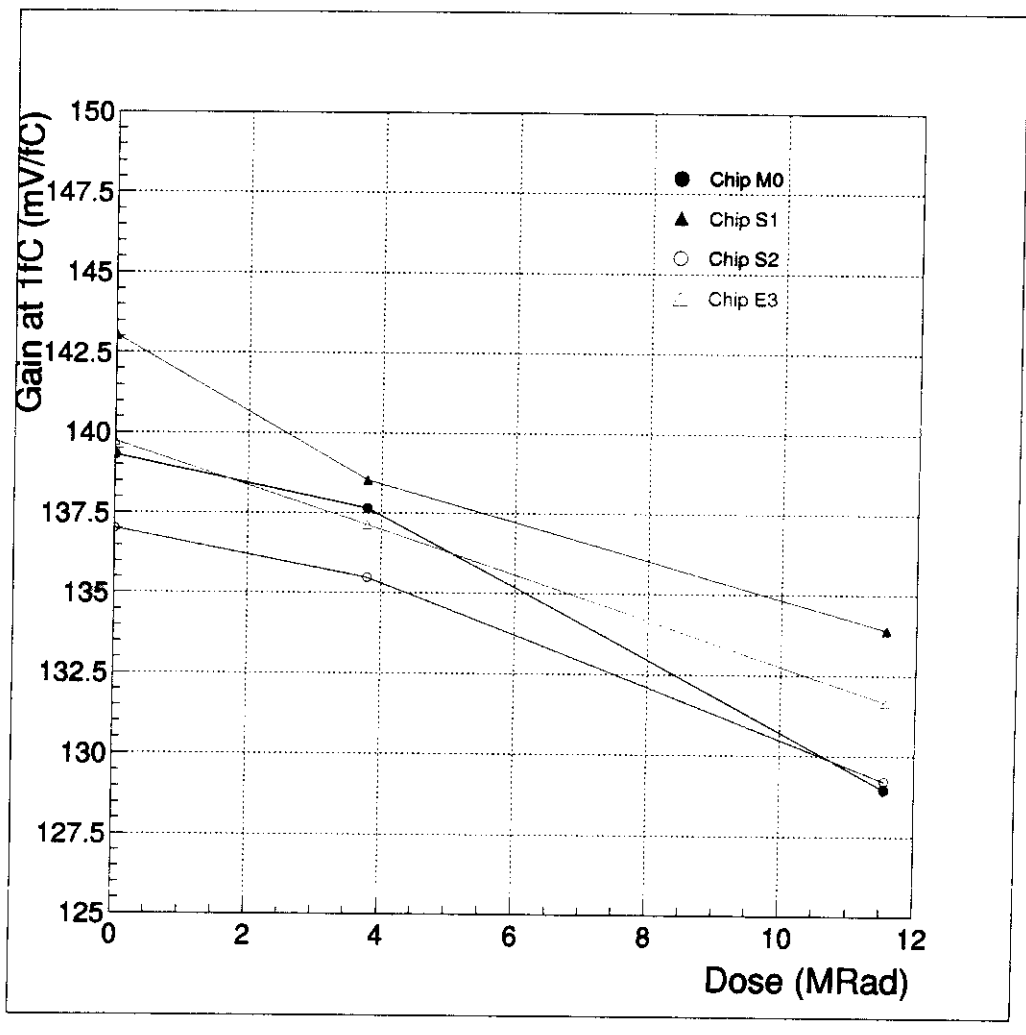
- All channels
  (0 bad channels)
- $I_{preamp} = 218\ \mu A$
- From Threshold Scan at Qin=1fC
- Spread (mV) from gaussian fit to threshold distribution divided by the $Gain_{1fC} \Rightarrow$ Spread (fC)
- Results checked with Vcal Scan



CAFE-P Gain at 1fC

- All channels
  (0 bad channels)
- $I_{preamp} = 218\ \mu A$
- Response curve calculated per channel
- Fit function:

  $Thr = A + \frac{B}{(1+e^{-Qin/C})}$
- Gain curve per channel obtained as the derivative of the response curve
- Shown is the mean of the 128 channels/chip



Summary

- ABC/CAFE-P working at nominal pre-rad conditions after $6.9 * 10^{13}$ protons/cm^2 at a dose rate of $\sim 1.1 * 10^{10}$ p cm^{-2} min^{-1}.
- Threshold Spread within specification after irradiation ($< 4\%$).
- Noise increase without detector reasonable.
- Results in:

$$\boxed{http://www-physics.lbl.gov/\sim pberna/rad_88}$$

$$\boxed{http://ific.uv.es/\sim pberna/rad_88}$$