Random Telegraph Signals in CCDs and APS

(contract 17928/04/NL/PA)

Final Presentation

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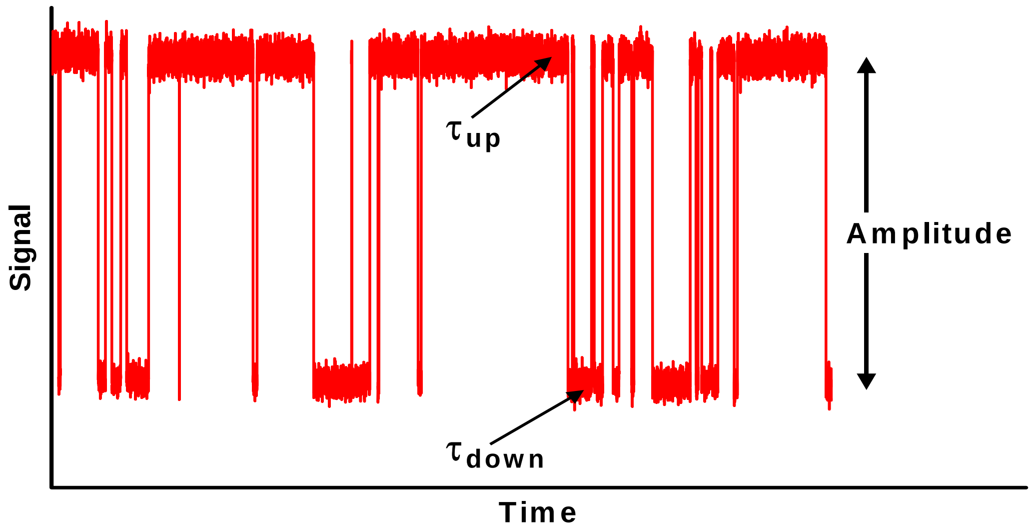
Introduction

- What is RTS ?
- Devices tested
- Irradiations
- Data analysis
- Results
- Conclusions (preliminary)

What is RTS ?

- Random telegraph signals (RTS) are seen in many electronic components
  - Occur when a defect can exist in two or more metastable states and switches between them at random time intervals

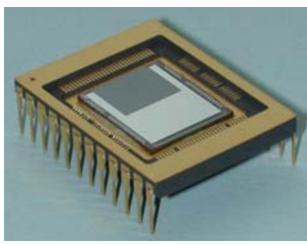


- Can occur in MOSFETS (conductance fluctuations), memories (leakage current), IR detectors (dark current)
- *& dark current in proton irradiated CCD and APS imagers*

Devices

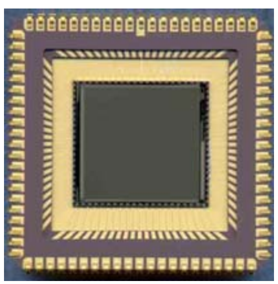
TH7890M CCD (e2v Grenoble)

- 512 x 512, 17 um x 17 um pixels
- frame transfer
- MPP



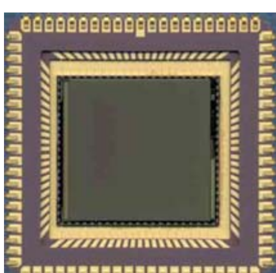
CCD57-10 (e2v technologies)

- 512 x 512, 13 um x 13 um pixels
- frame transfer
- AIMO



STAR250 (Cypress Semiconductor)

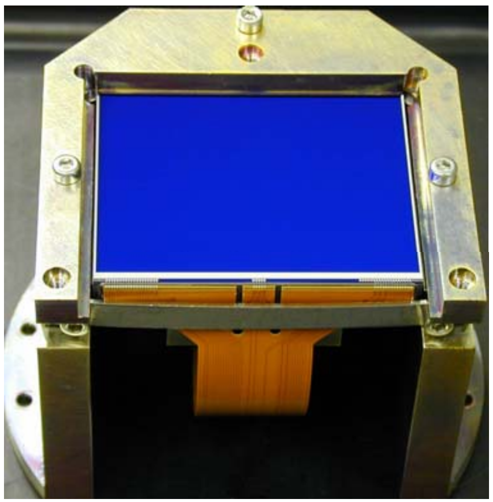
- 512 x 512, 25 um x 25 um pixels
- CMOS APS
- On-chip 10-bit ADC



STAR1000 (Cypress Semiconductor)

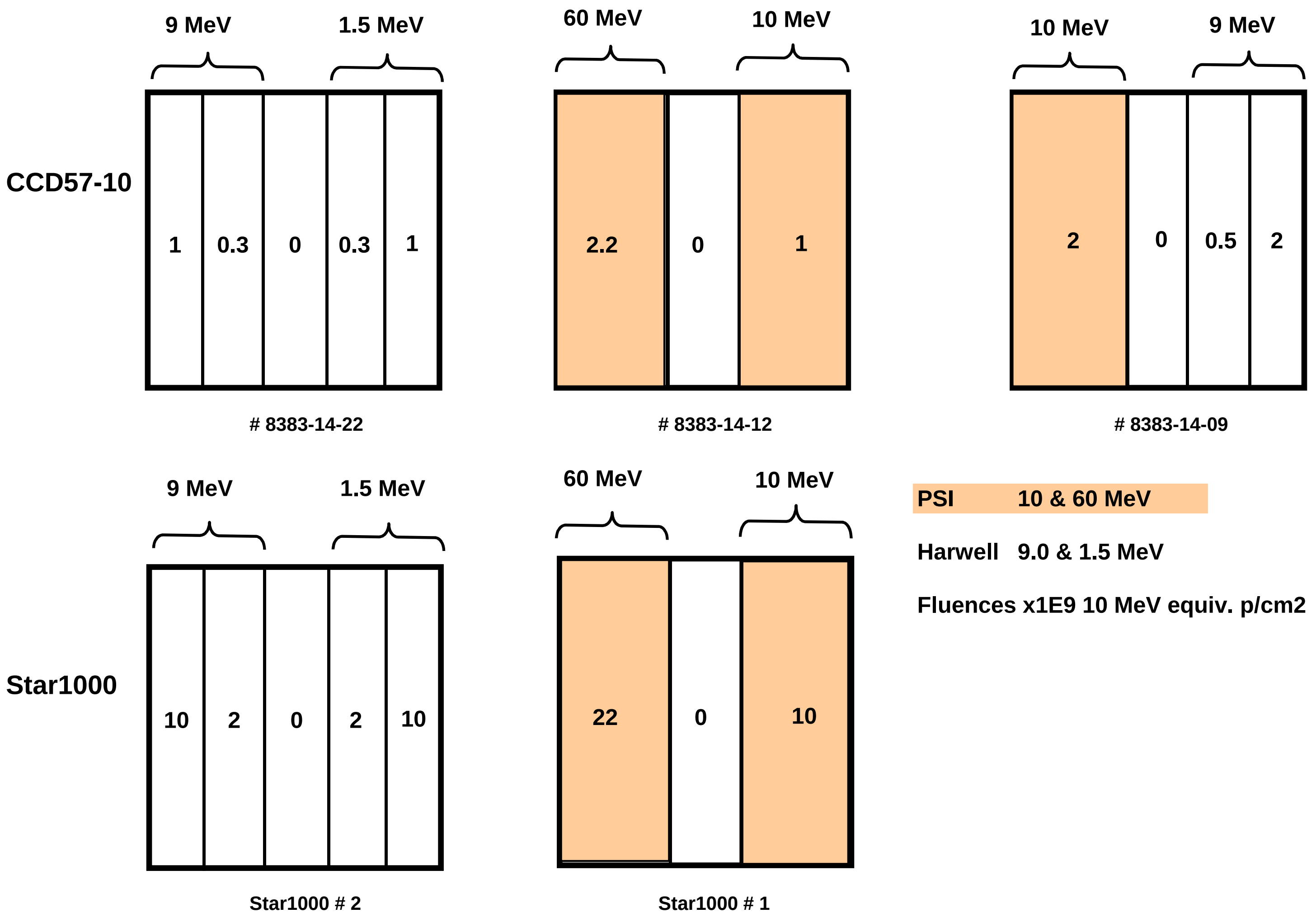
- 1024 x 1024, 15 um x 15 um pixels
- CMOS APS
- On-chip 10-bit ADC

Gaia AF device for alpha particle CTE damage



- Full frame CCD
- 4500 (vertical) x 1966 (horizontal) pixel
- n-buried channel.
- 4-phase parallel electrodes
- pixel width 30 µm and height 10 µm
- 2-phase readout register with single output
- Supplementary buried channel (SBC)
  - down each column of image area
  - small volume for charge packets < ~ 1000 e
- Back illuminated devices are thinned (to 16 µm),
- Front illuminated device for this study

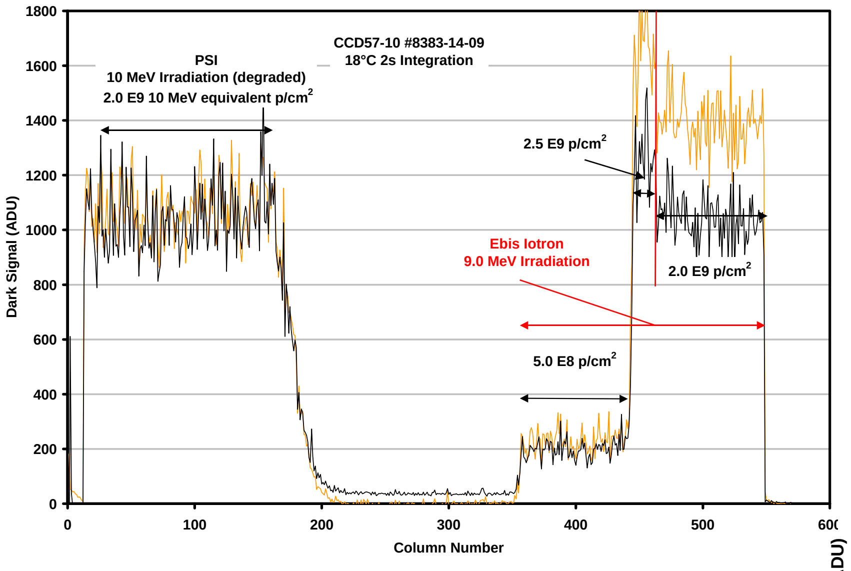
Irradiations

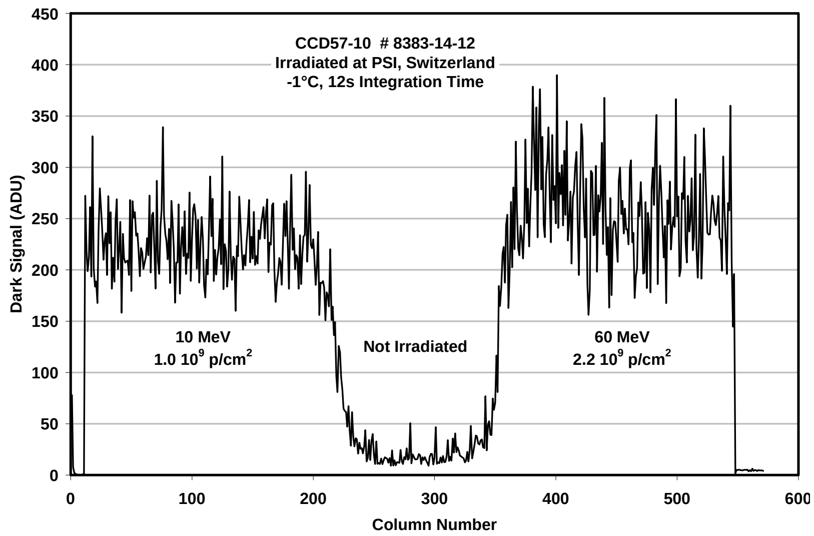


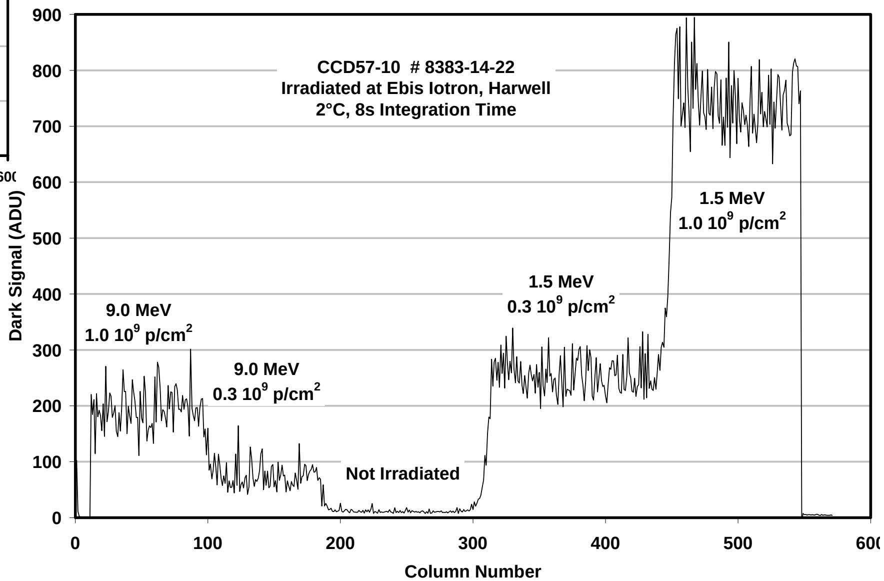
TH7890M & STAR250, Harwell, 9.5 MeV protons October 2002

~ $5\ 10^{8}$ $1.7\ 10^{10}$ and $1.7\ 10^{11}$ p/cm^2 10 MeV equivalent p/cm^2

CCD57-10 Irradiations







RTS Data Collection

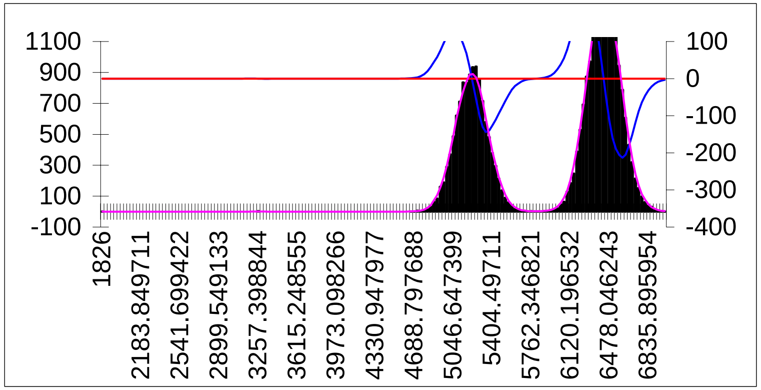
- Each device: data collected for selected pixels at several temps
- # of pixels selected in each image ~ 1000 - 2000
- Number of images ~ 20000 to ~ 30000
  - typical for TH7890M & STAR250 typical for CCD57 & STAR1000
- Integration time (hence time between each image) increased for lower operating temperatures
  - varied between 2 and 60s (minimum time between images = 6s)
  - so typical runs (30000 images) took 2-14 days.
- For each pixel the average & RMS values were calculated.
  - RTS pixels identified by anomalously high RMS value
- Occurrence probabilities: pixels selected at random
- Activation energies: brightest pixels
  - Analysis done for 30-50 pixels in each fluence region on each device for typically 4 temperatures in the range –4°C to 18°C
  - ~ 2500 analyses of 30000 data points
    - so > 75 million data points!

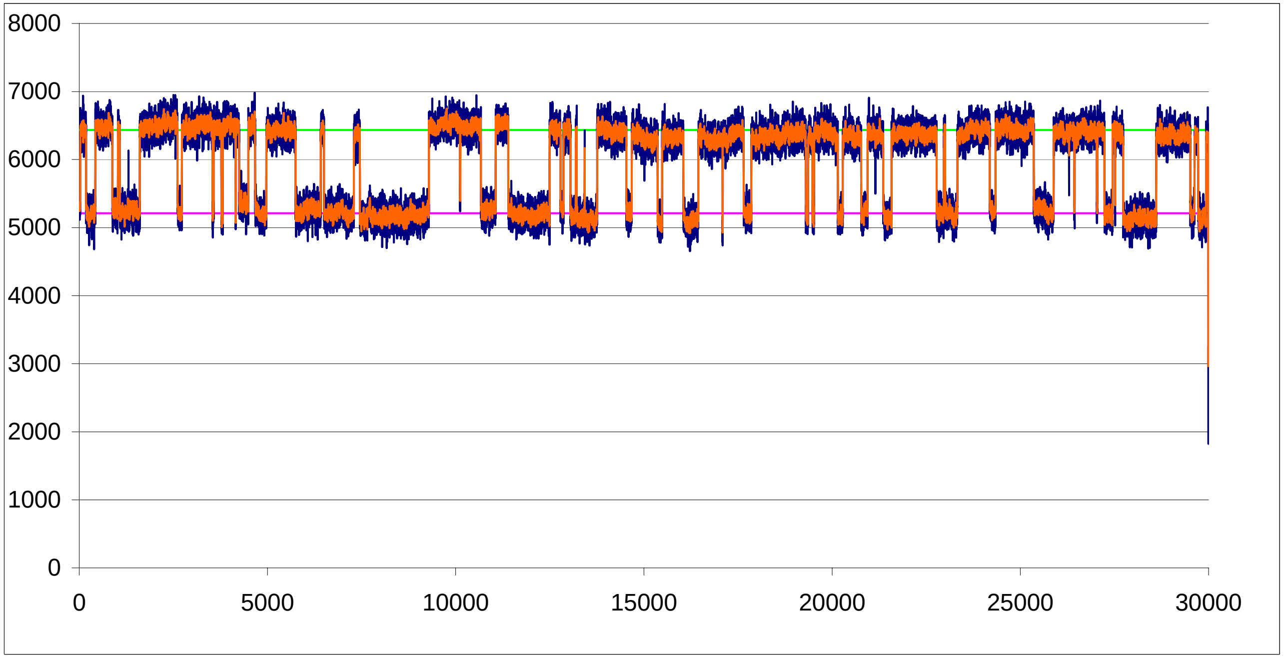
Data Analysis (1)

Levels	Amplitude
5211	1223
6433	
17140	
19203	
30574	
4923	
5960	

Main Results
UpState Time(s)
18607
Up/Down prob (%)
62.02%
Transitions
92

Intermediate results
Levels drawing
5211
5211
6433
6433
Treshold
5822

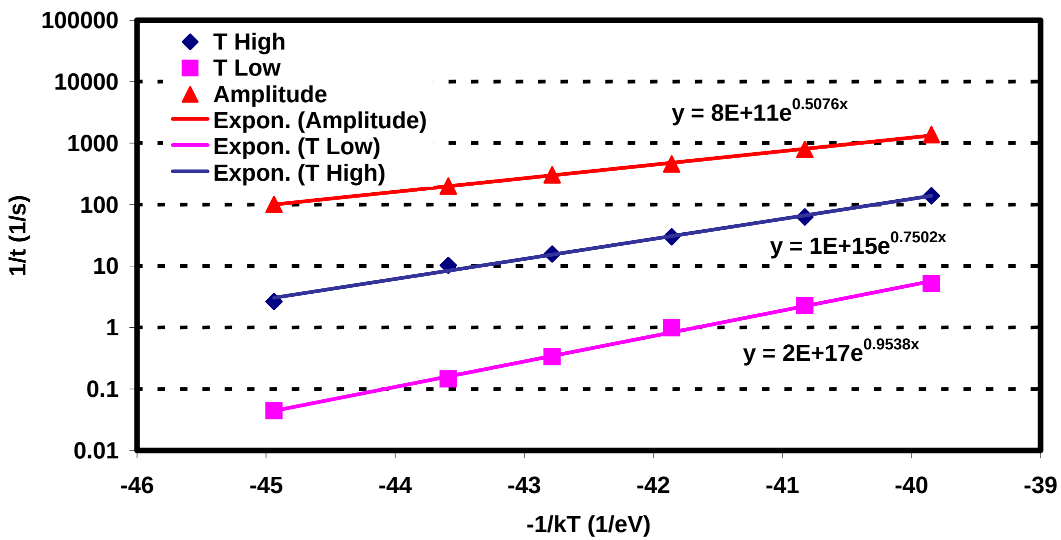




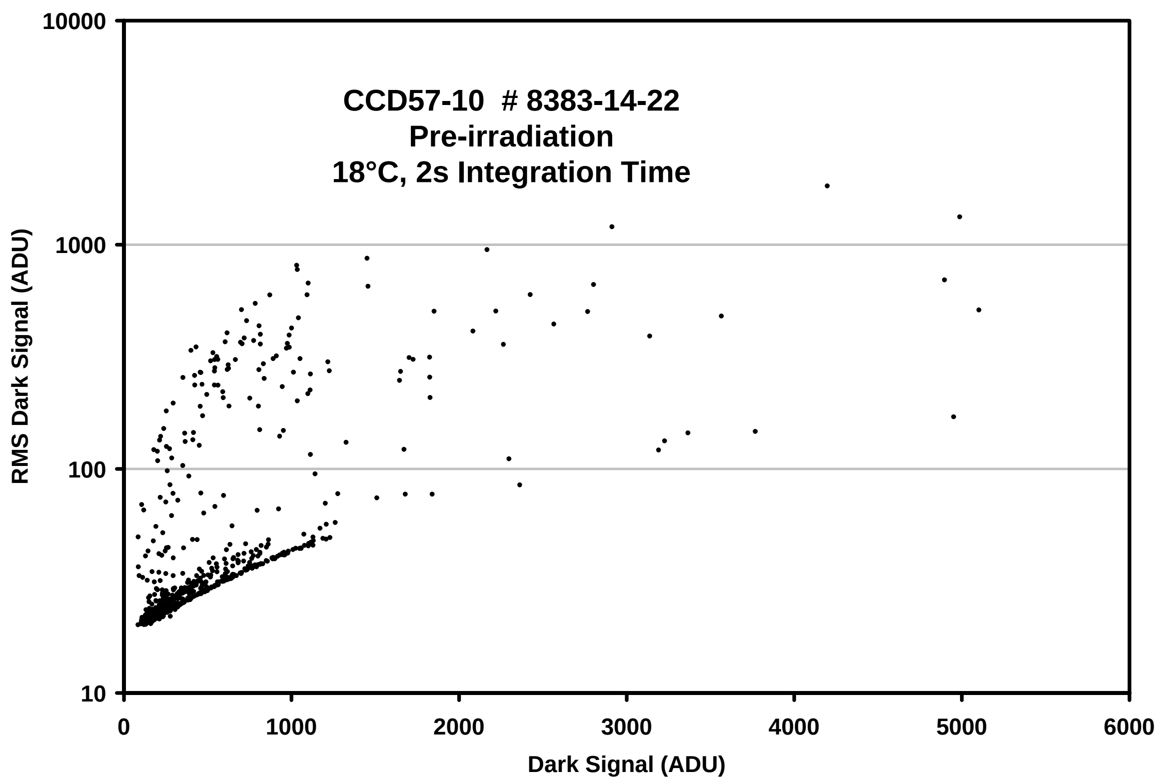
Data Analysis (2)

Temperature (deg)	-15	-7	-2	4	11	18
Temperature (K)	258.15	266.15	271.15	277.15	284.15	291.15
-1/kT (1/eV)	-4.49E+01	-4.36E+01	-4.28E+01	-4.19E+01	-4.08E+01	-3.98E+01
Nb of points	23370	30000	30000	30000	30000	30000
Gain (ADU/V)	1	1	1	1	1	1
Integration time (s)	60	30	20	12	6	2
Time interval (s)	60	30	20	12	6	6
Experiment duration (s)	1402140	899970	599980	359988	179994	179994
Up/DownProb (%)	1.7%	1.4%	2.1%	3.2%	3.5%	3.6%
Transitions	34	72	110	192	220	500
Amplitude (ADU)	6060	5998	6091	5508	4745	2754
Amplitude/Tint (V/s)	101	199.933333	304.55	459	790.833333	1377
τhigh	0.3780279	0.09721898	0.063634242	0.03333222	0.01590856	0.00719976
1/τhigh	2.6453071	10.2860572	15.71480954	30.001	62.8592382	138.893519
τlow	22.532756	6.84699398	2.966567778	1.00829972	0.43862174	0.19279357
1/τlow	0.0443798	0.14604949	0.337089888	0.9917686	2.27986874	5.18689489
τhigh / τlow	0.0167768	0.01419878	0.02145046	0.03305785	0.03626943	0.0373444

	Eact (eV)	C
τhigh	0.7501691	3.339E+13
τlow	0.9537716	1.9352E+18
Amplitude	0.5075846	4.2429E+11

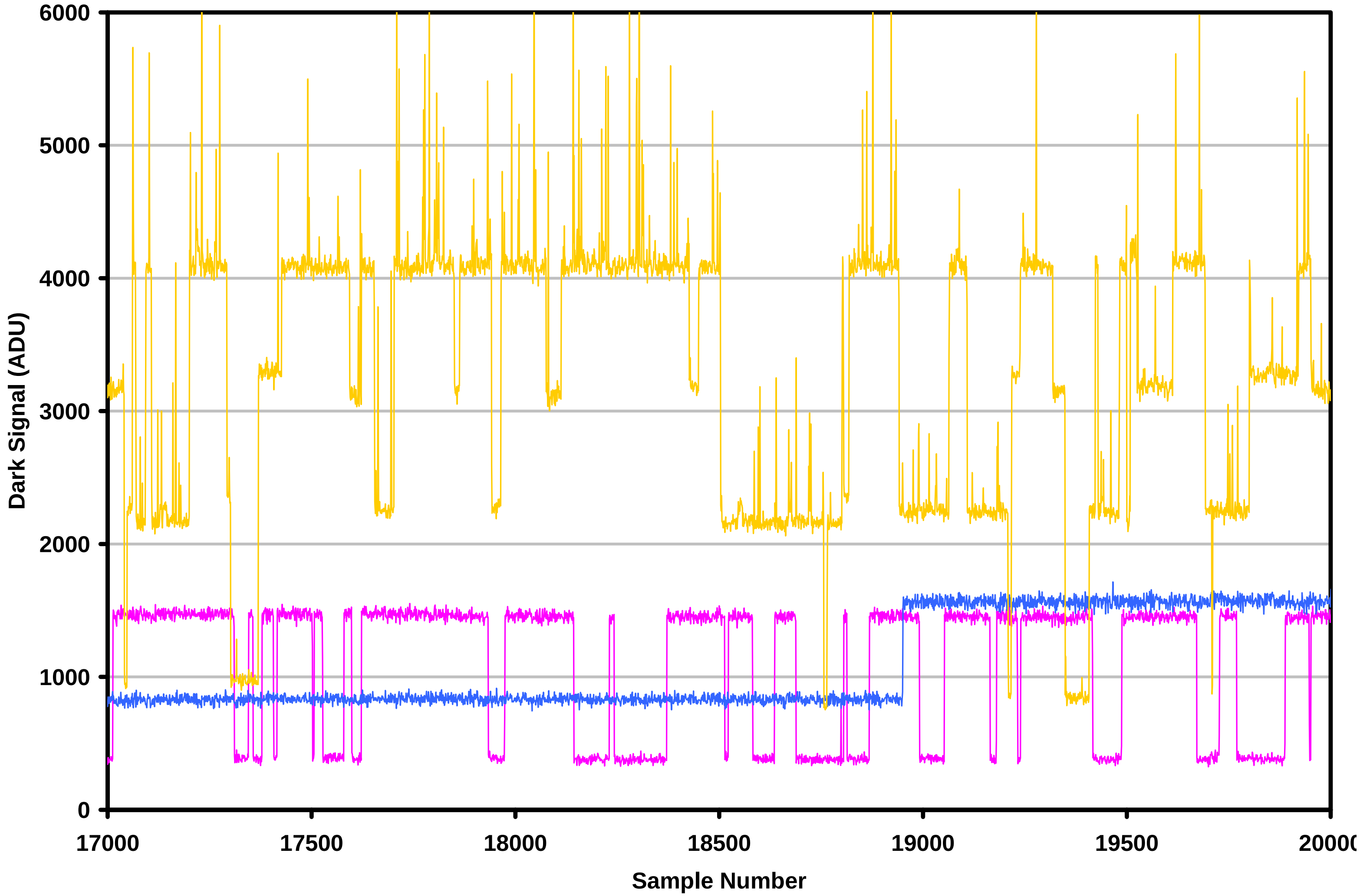


CCD57-10 Pre-rad RTS

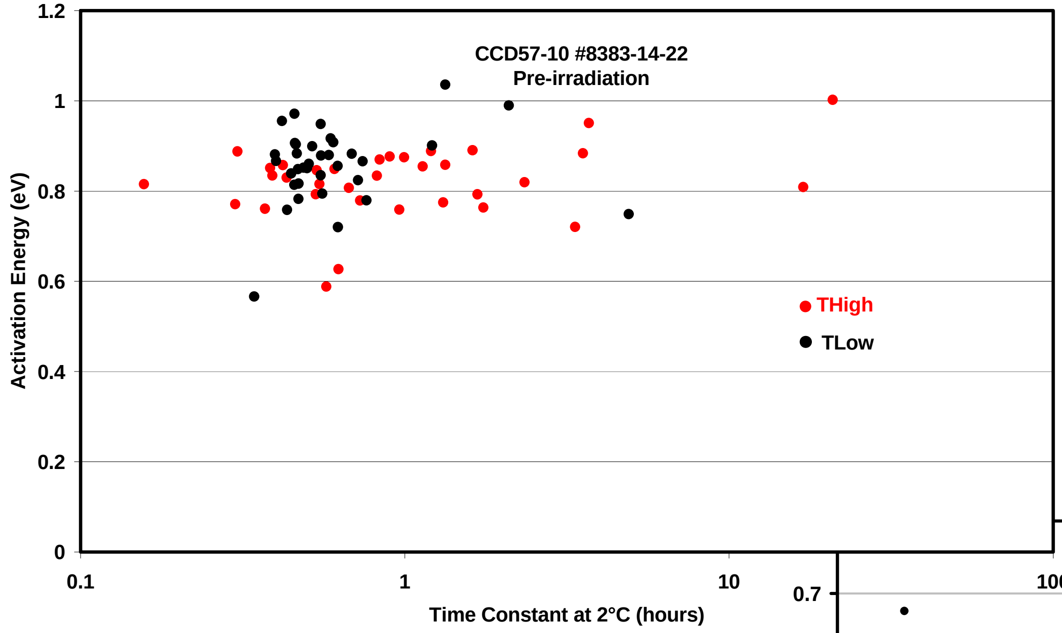


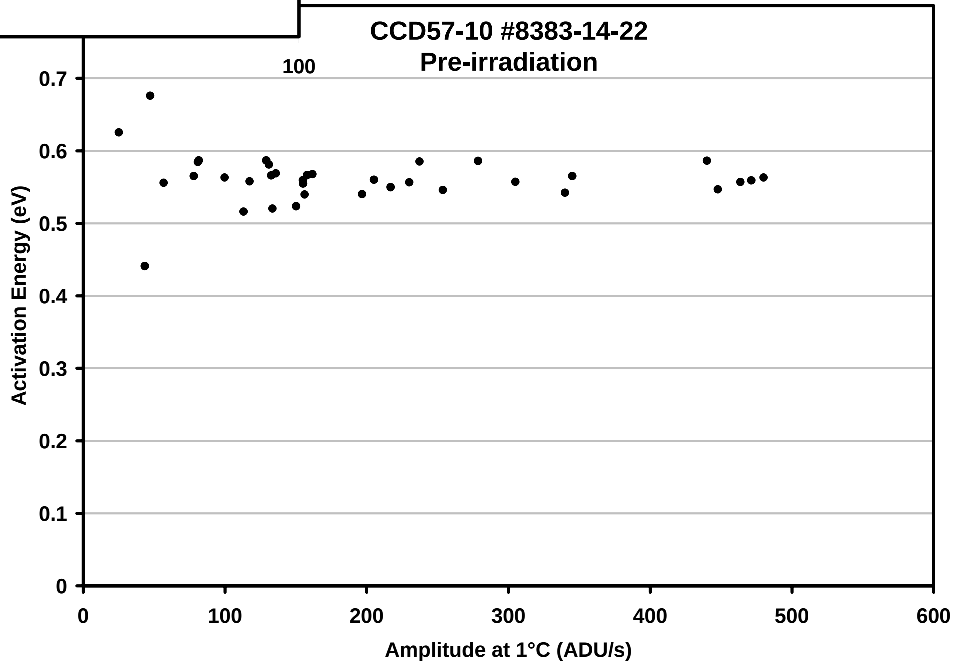
Device	Number of RTS pixels	% of RTS pixels that are 2-level	% of RTS pixels that are multi-level
8383-14-09	136	51%	46%
8383-14-12	81	47%	41%
8383-14-22	163	79%	21%

Pre-rad RTS

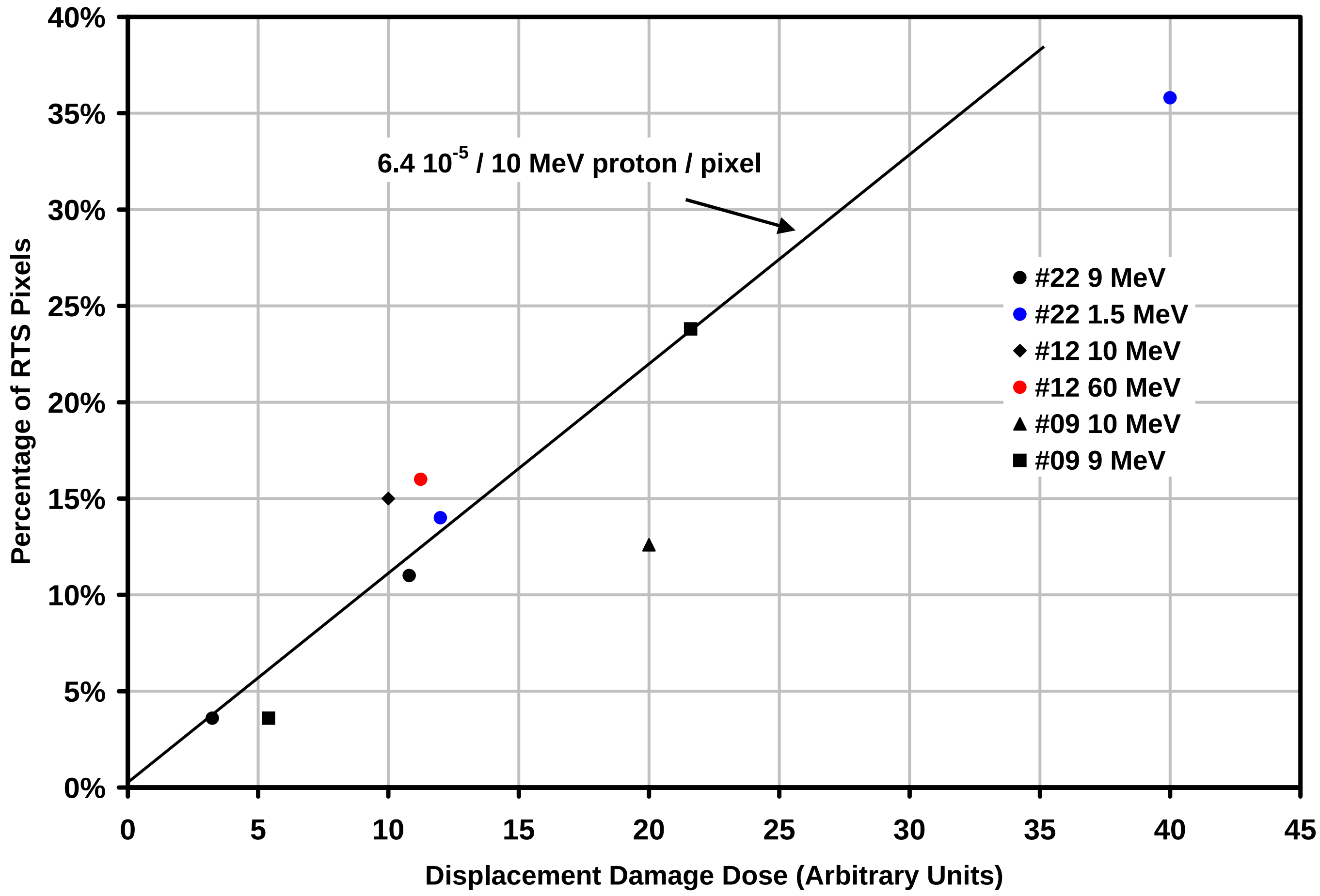

Dark Signal (ADU)
6000
5000
4000
3000
2000
1000
0
17000
17500
18000
18500
19000
19500
20000
Sample Number

Pre-rad RTS


CCD57-10 #8383-14-22
Pre-irradiation
THigh
TLow
Activation Energy (eV)
Time Constant at 2°C (hours)
1.2
1
0.8
0.6
0.4
0.2
0
0.1
1
10
100

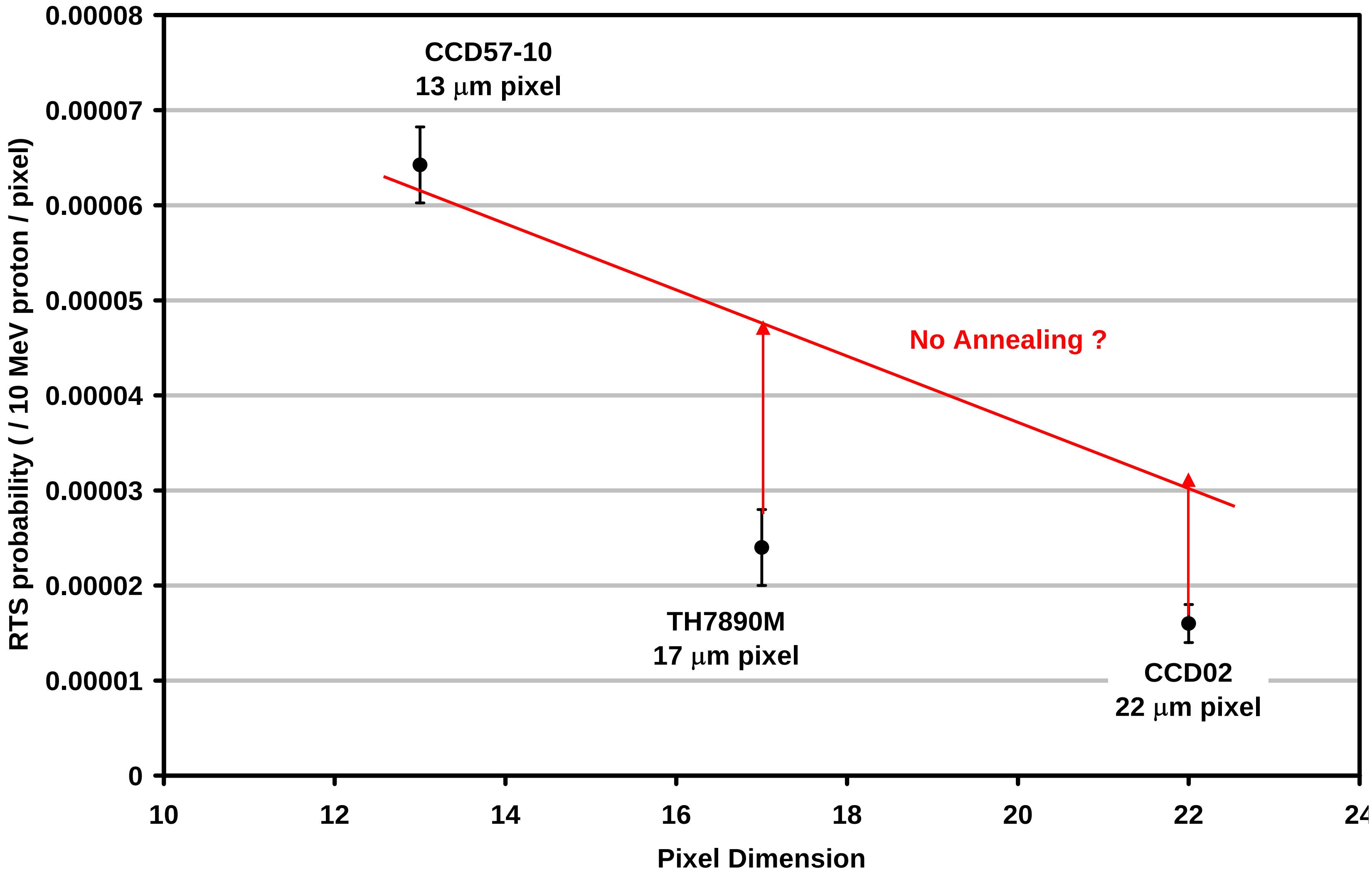

CCD57-10 #8383-14-22
Pre-irradiation
Activation Energy (eV)
Amplitude at 1°C (ADU/s)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600

Post-rad Ocurrence Probability



Random Pixels: ~ 50% of the RTS pixels were 2-level, regardless of fluence or proton energy

RTS Probability for CCDs

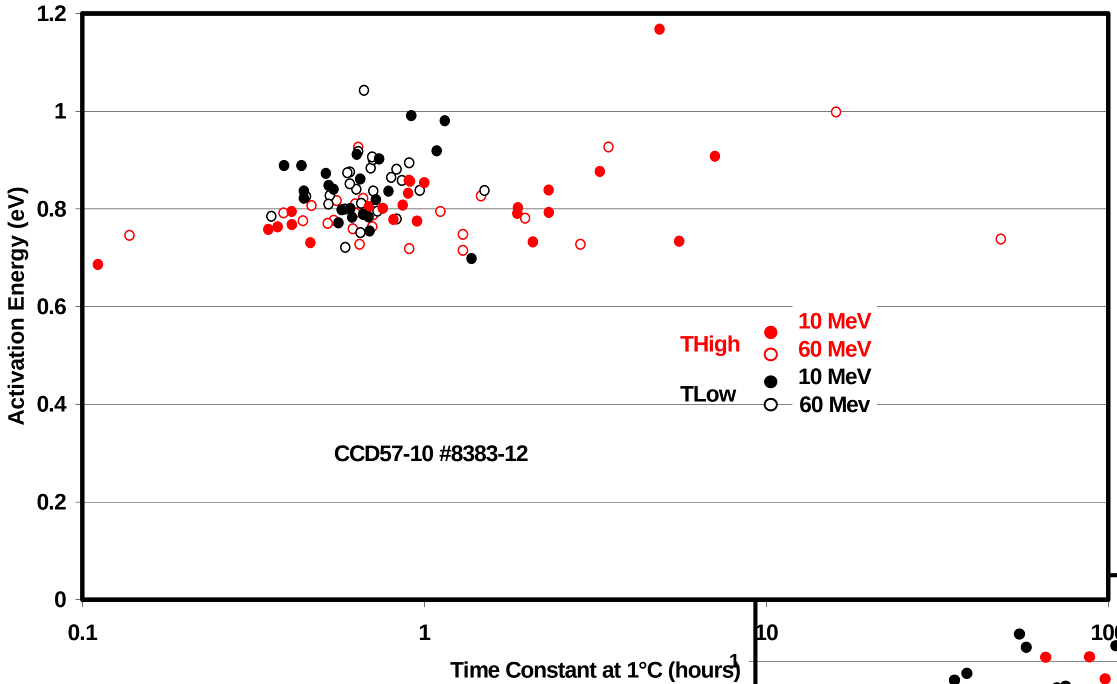


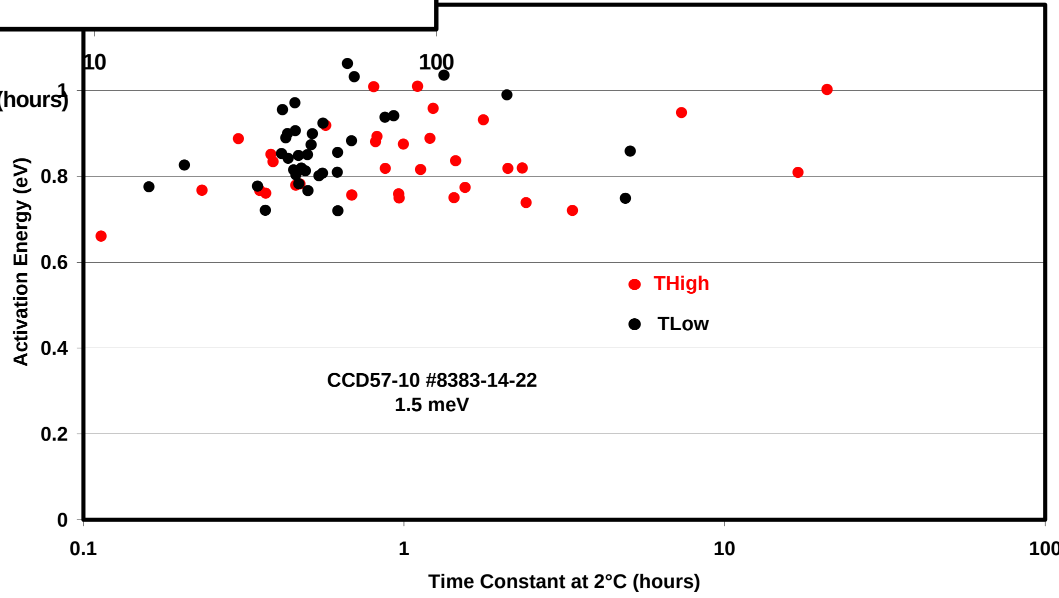
RTS probability ~ 10^{-10} / (10 MeV proton / cm^2)

CCD57-10 Bright Pixels

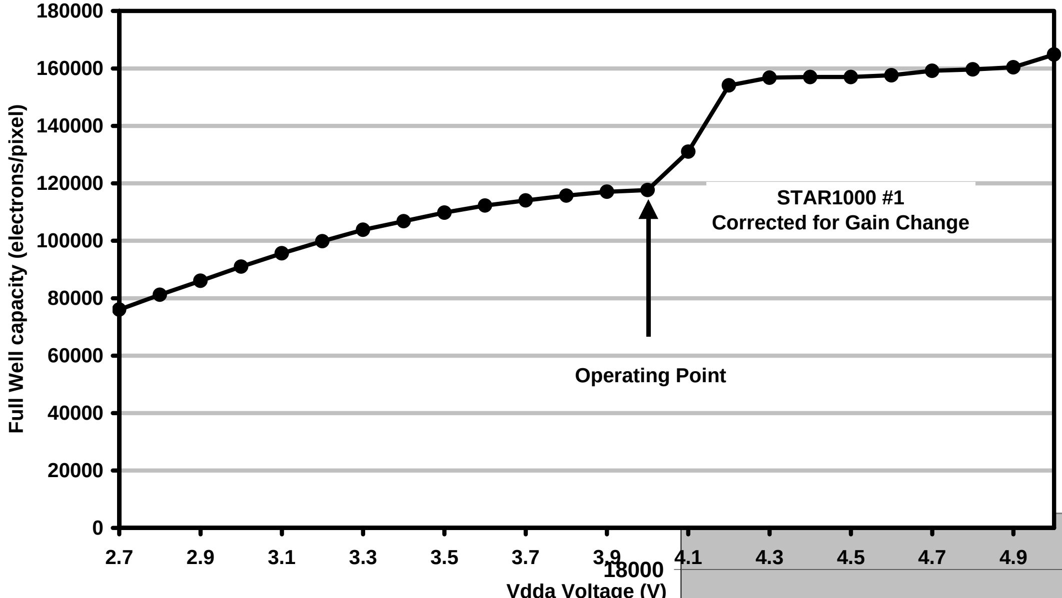
Device	Number of RTS pixels	% of bright pixels that are RTS	% of RTS pixels that are 2-level
8383-14-09 before anneal			
2 10^9 9 MeV p/cm^2, Harwell	977	98 %	9 %
5 10^8 9 MeV p/cm^2, Harwell	185	96 %	17 %
2 10^9 9 MeV p/cm^2, PSI	828	97 %	12 %
8383-14-09 after anneal			
2 10^9 9 MeV p/cm^2, Harwell	518	52 %	46 %
5 10^8 9 MeV p/cm^2, Harwell	83	43%	39 %
2 10^9 9 MeV p/cm^2, PSI	471	55 %	48 %
8383-14-12			
1 10^9 10 MeV p/cm^2, PSI	957	96 %	11 %
2.2 10^9 60 MeV p/cm^2, PSI	948	95 %	9 %
8383-14-22			
1 10^9 9 MeV p/cm^2, Harwell	454	91 %	17 %
3 10^8 9 MeV p/cm^2, Harwell	408	82 %	35 %
3 10^8 1.5 MeV p/cm^2, Harwell	456	91 %	18 %
1 10^9 1.5 MeV p/cm^2, Harwell	457	91 %	12 %

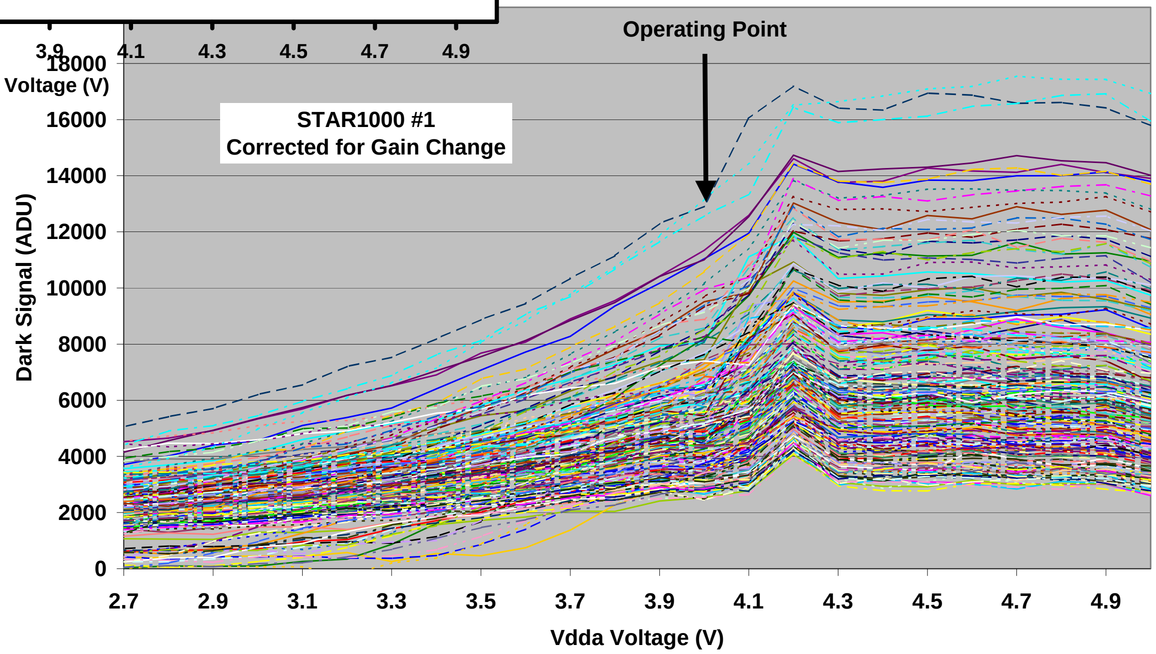
CCD57-10 Bright Pixels



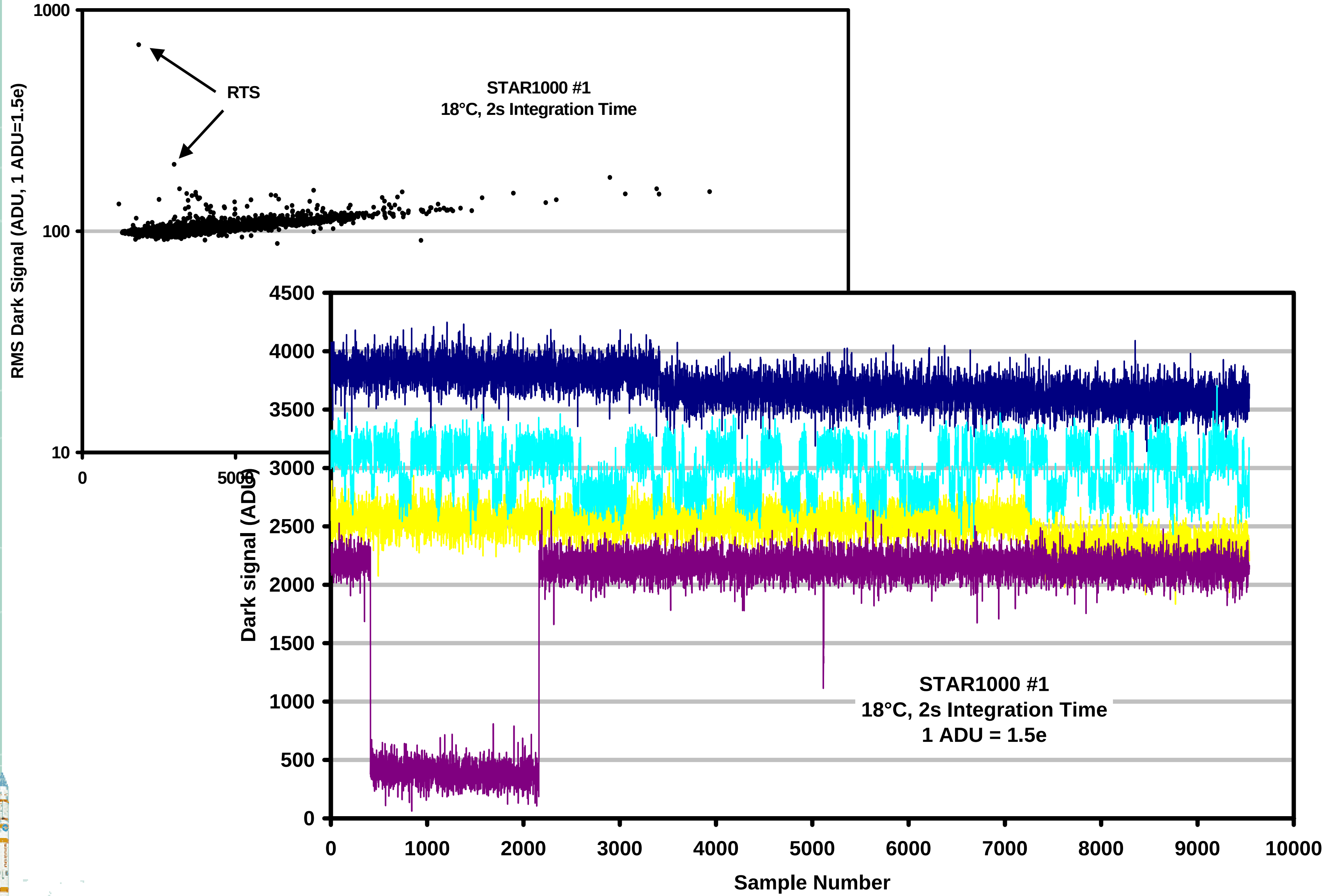


STAR1000: Hard Reset

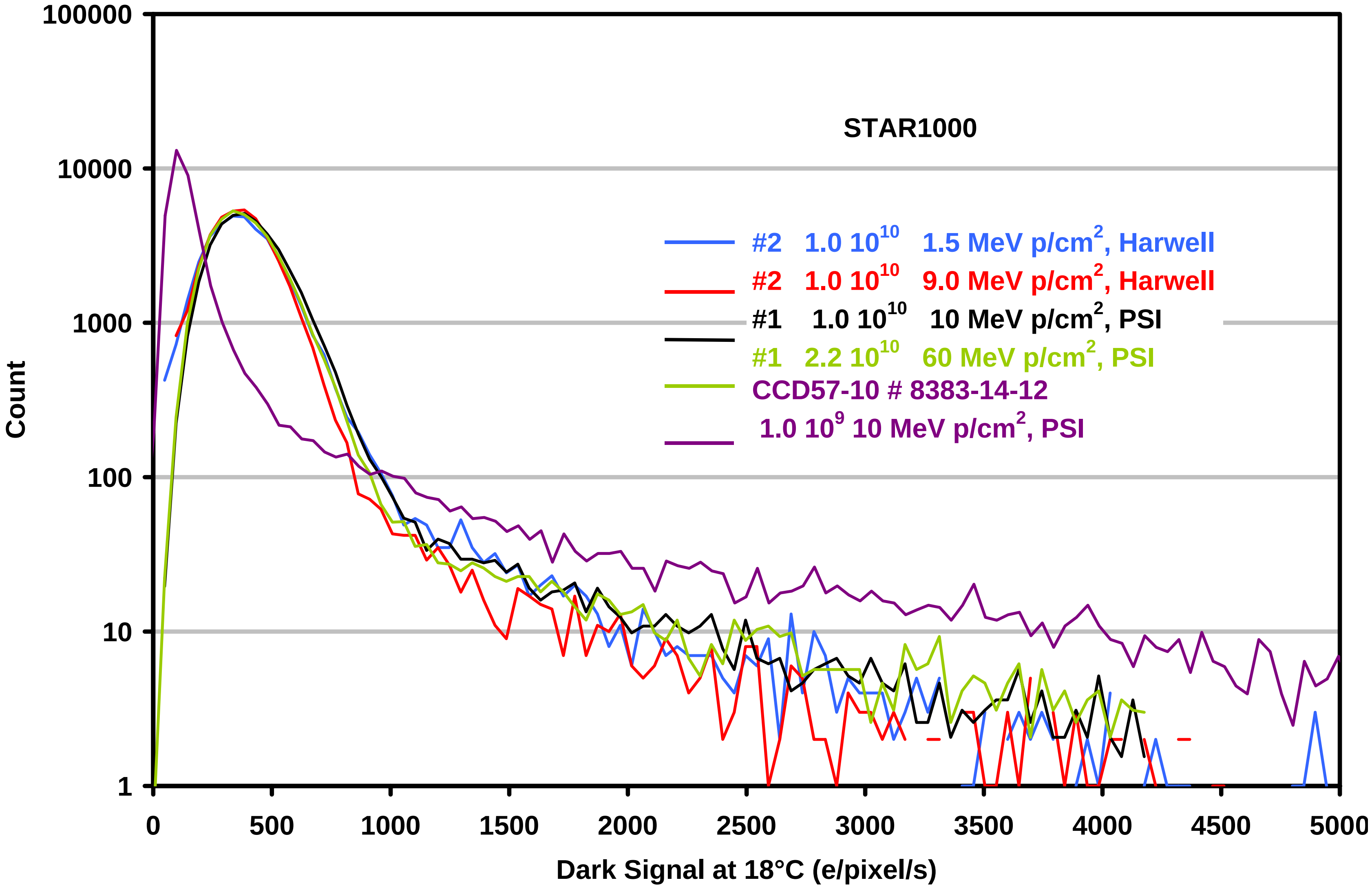




STAR1000 Pre-rad RTS



STAR1000: Dark Signal Histograms

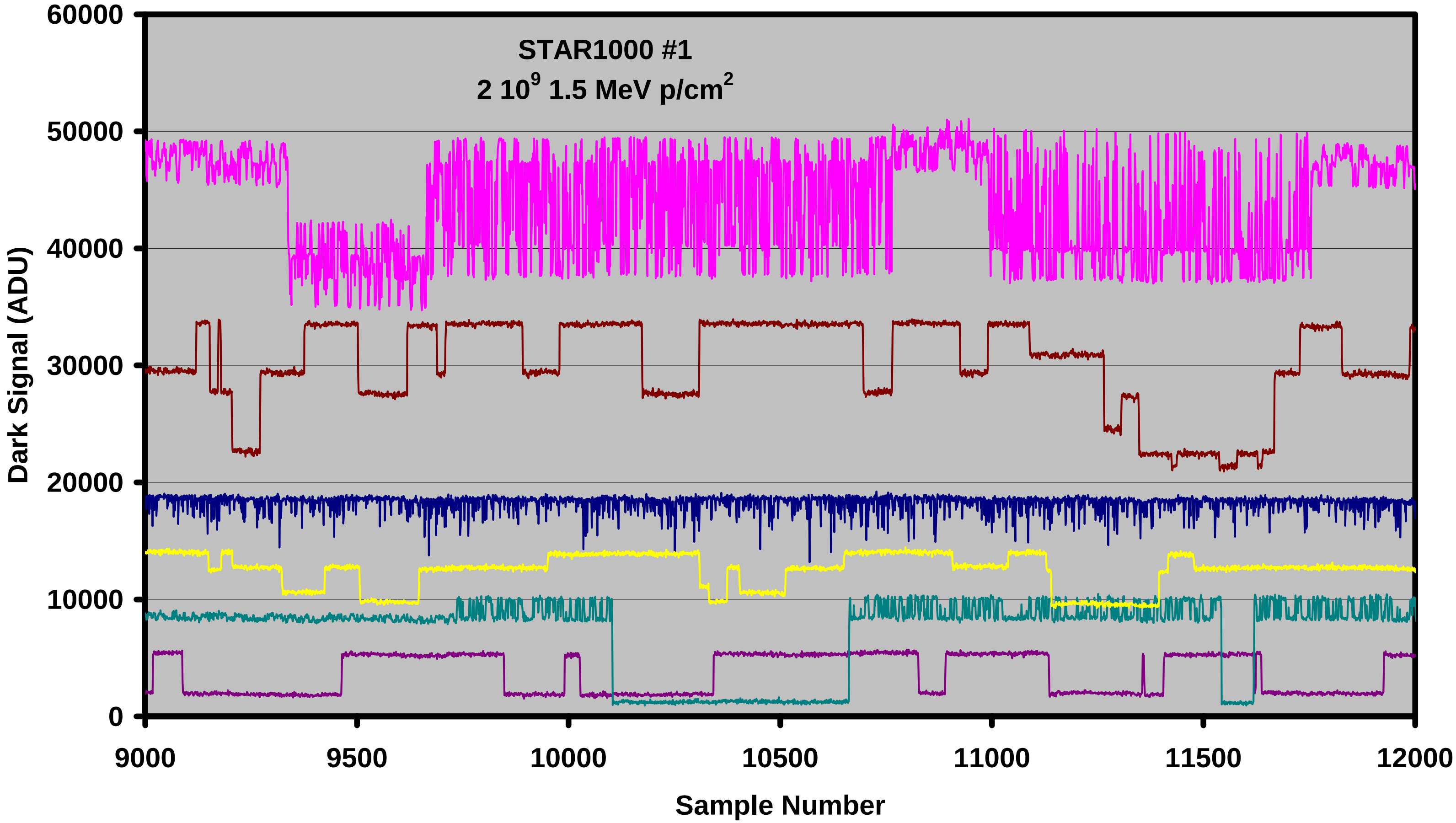


STAR1000 Occurrence Probabilities

Device	Number of RTS pixels in block of 500 pixels	% of pixels that are RTS	Number of RTS pixels that are multi-level
#1			
1 10^{10} 10 MeV p/cm^2, PSI	17	3.4 %	3
2.2 10^{10} 60 MeV p/cm^2, PSI	21	4.2 %	3
#2			
1 10^{10} 1.5 MeV p/cm^2, Harwell	11	2.2 %	1
2 10^{9} 1.5 MeV p/cm^2, Harwell	5	1 %	0
1 10^{10} 9 MeV p/cm^2, Harwell	8	1.6 %	3
2 10^{9} 9 MeV p/cm^2, Harwell	4	0.8 %	0

Random Pixels

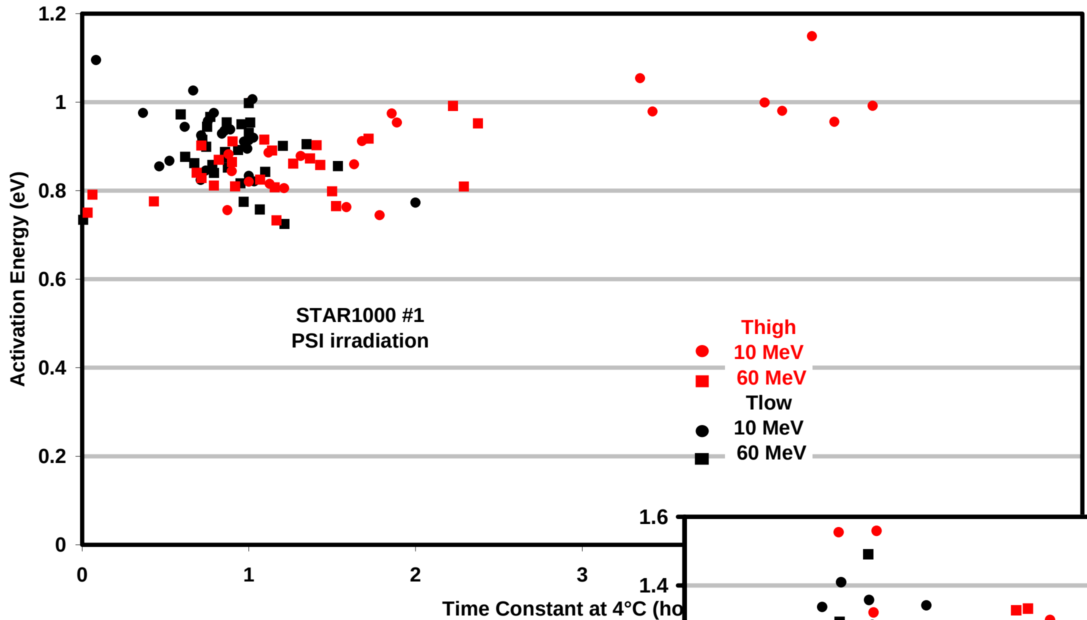
STAR1000 Brightest Pixels

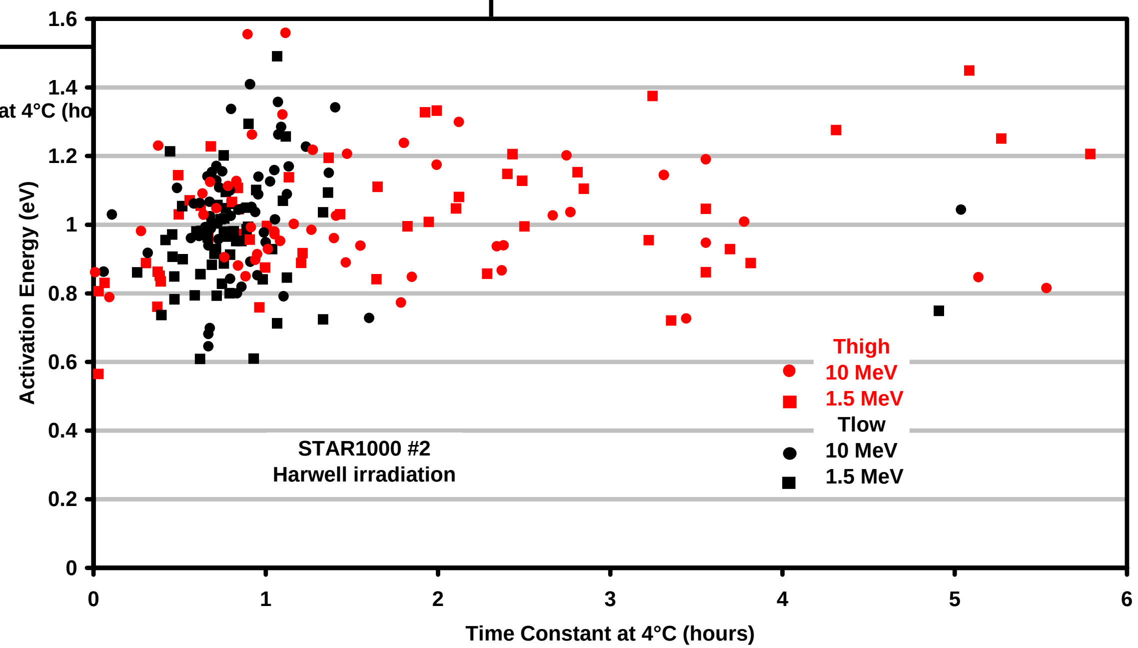


STAR1000 Brightest Pixels

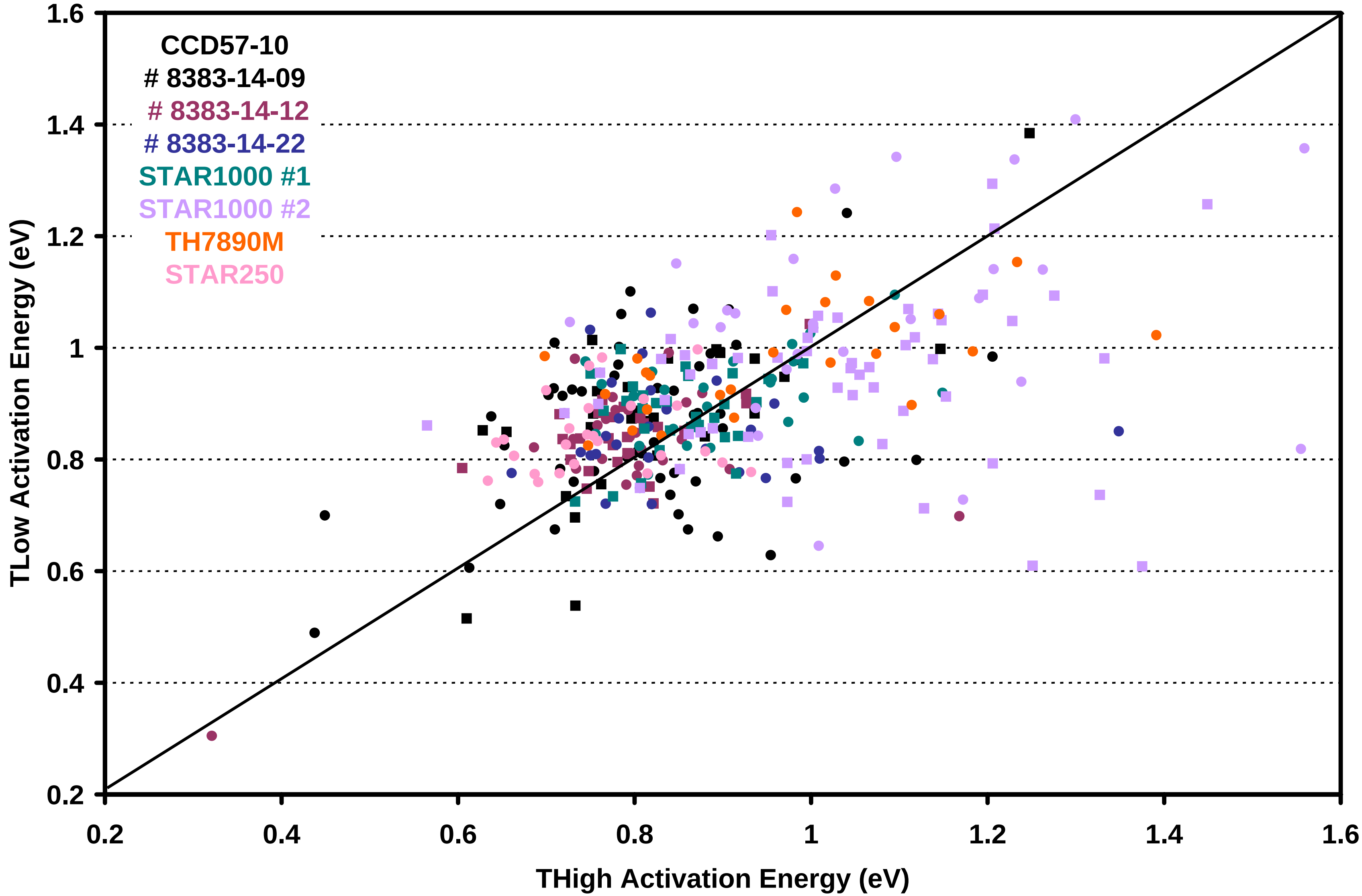
Device	Number of RTS pixels	% of pixels that are RTS	% of RTS pixels that are 2-level
#1			
1 10^{10} 10 MeV p/cm^2, PSI	449	65 %	29 %
2.2 10^{10} 60 MeV p/cm^2, PSI	722	72 %	31 %
#2			
1 10^{10} 1.5 MeV p/cm^2, Harwell	404	54 %	50 %
2 10^{9} 1.5 MeV p/cm^2, Harwell	123	59 %	39 %
1 10^{10} 9 MeV p/cm^2, Harwell	195	53 %	32 %
2 10^{9} 9 MeV p/cm^2, Harwell	128	51 %	30 %

STAR1000 Brightest Pixels





All Devices



CCD57-10
8383-14-09
8383-14-12
8383-14-22
STAR1000 #1
STAR1000 #2
TH7890M
STAR250
TLow Activation Energy (eV)
THigh Activation Energy (eV)
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

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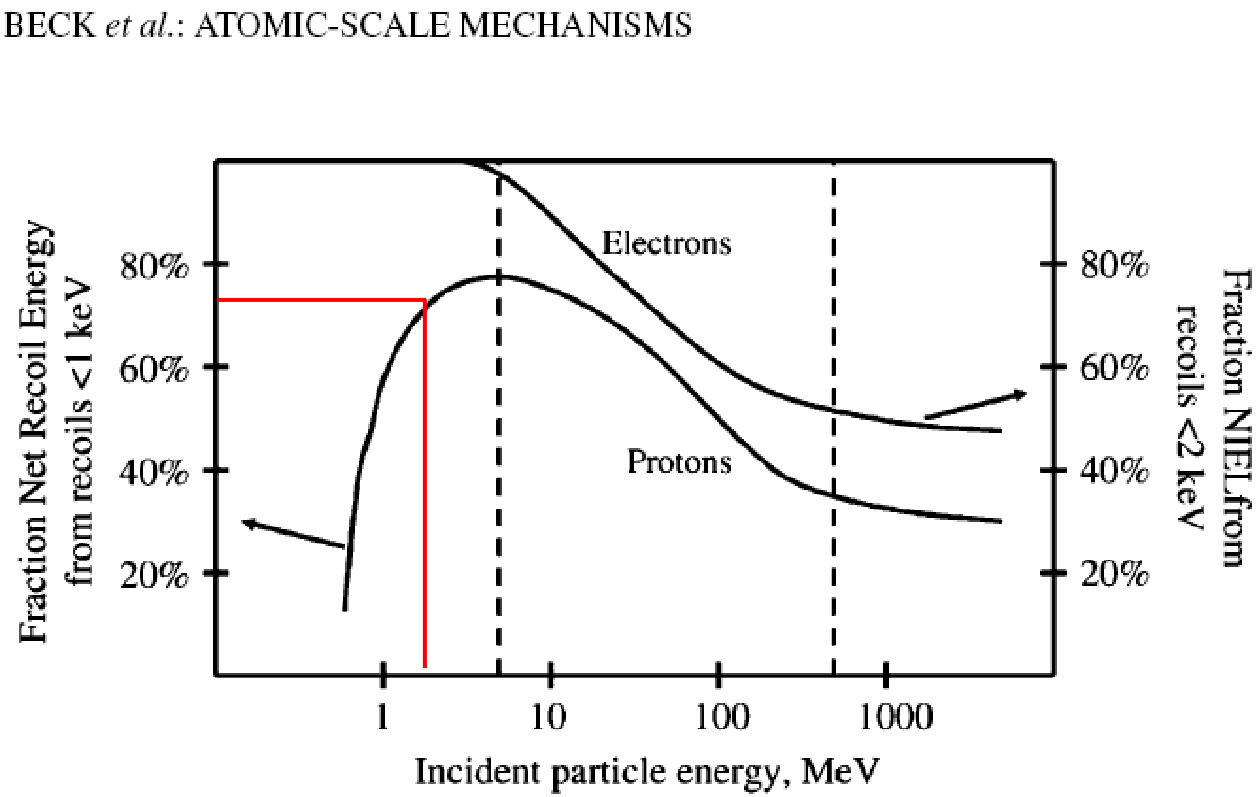
Conclusions (Preliminary)

- RTS behaviour is very similar for all devices and proton energies (including pre-rad) – after NIEL scaling
- With (random) occurrence probabilities of a few % still get a lot of multi-level defects
- Most of the brightest pixels (~ 1000 per chip) are multi-level
  - Cannot be explained by several independent collision events in a pixel
    - Also found by Thierry Nuns at ONERA
  - Either single RTS defects that are multi-level, or
  - Several defects (each 2-level) created by a collision – clusters (so intrinsic defects)
    - Even at 1.5 MeV, where expect mostly point defects

Cluster Production



Beck et al. NSREC 2006

SRIM Simulation: 1.5 MeV