HP FE-B ATLAS PIXEL DEMONSTRATOR ELECTRONICS

Laboratory and Testbeam Results

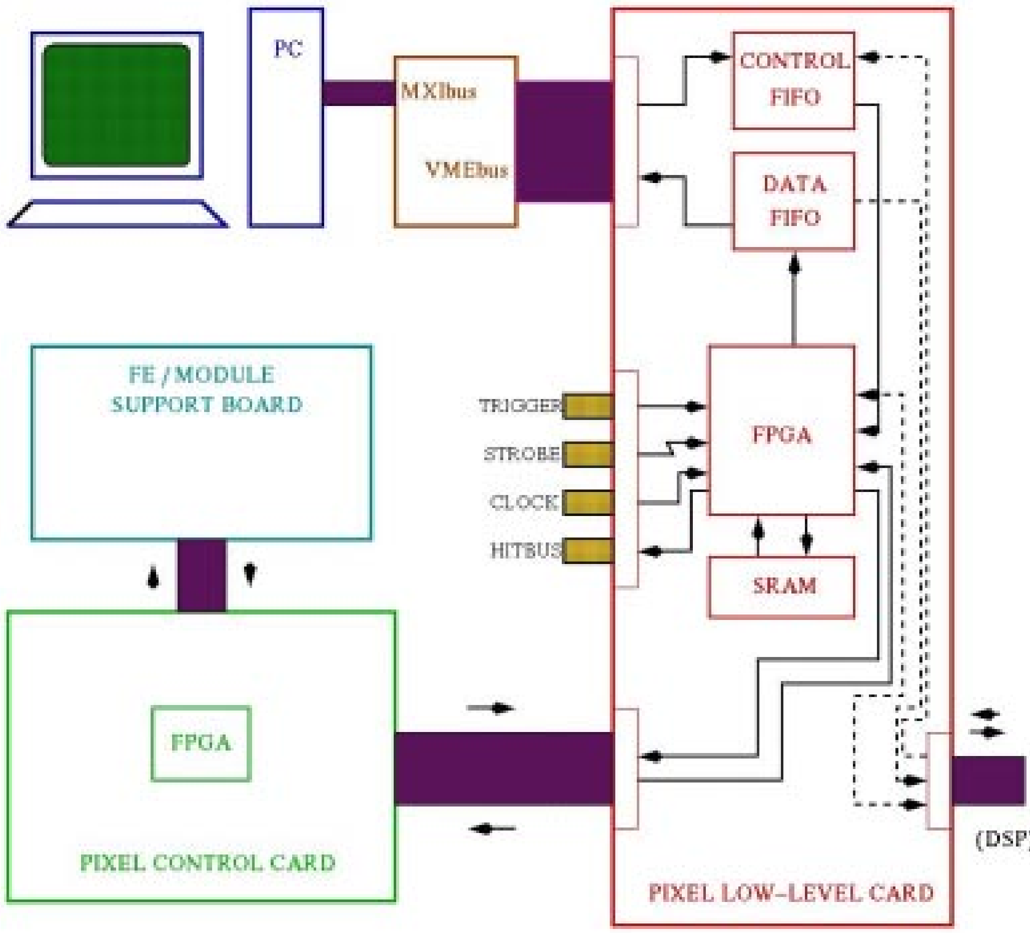
- Overview of laboratory test system
- Wafer probing results
- Laboratory results from single-chip assemblies
- 1998 Testbeam results

John Richardson LBNL

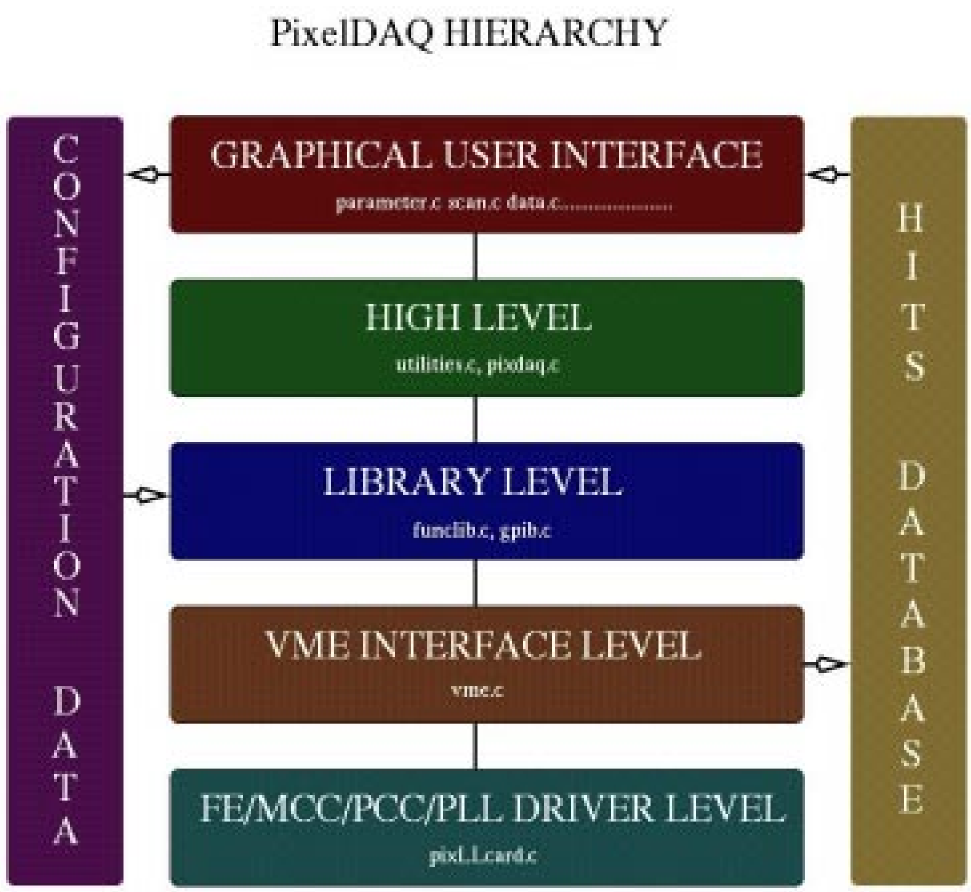
U.S. ATLAS Pixel Review
Berkeley
11th March 1999

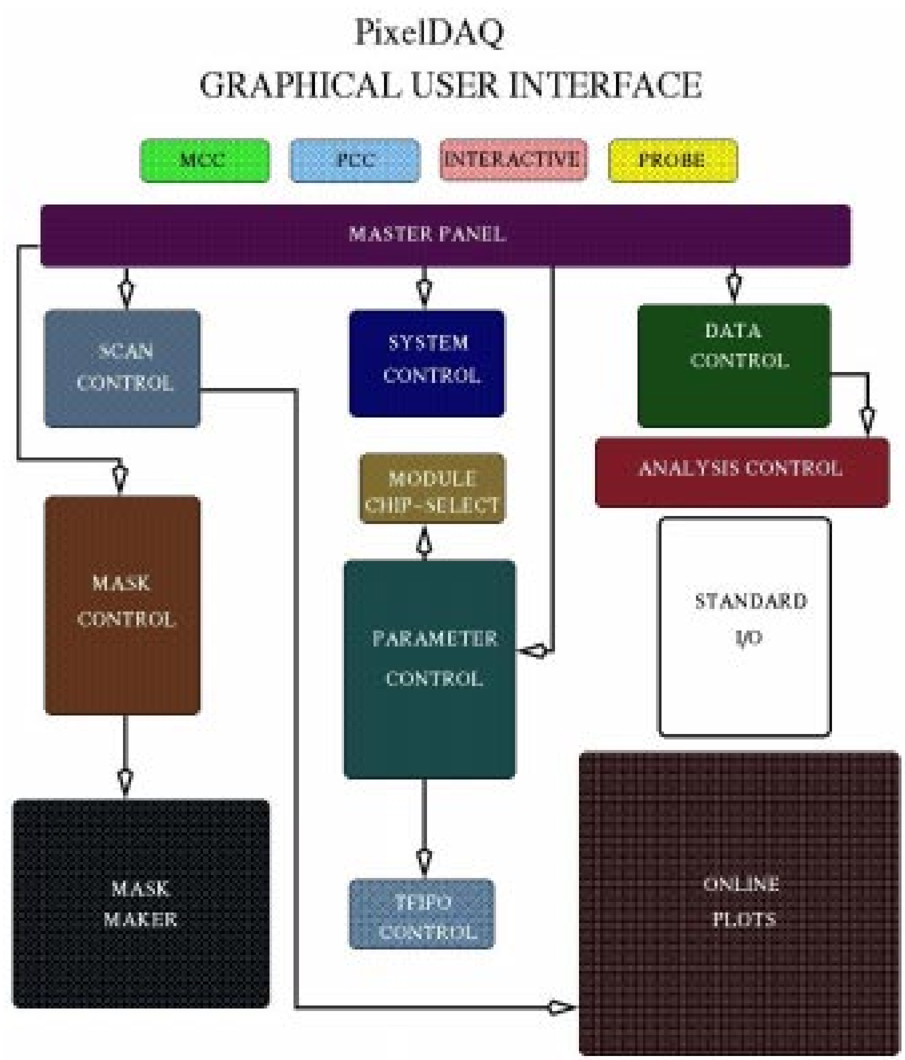
John Richardson 3/11/99

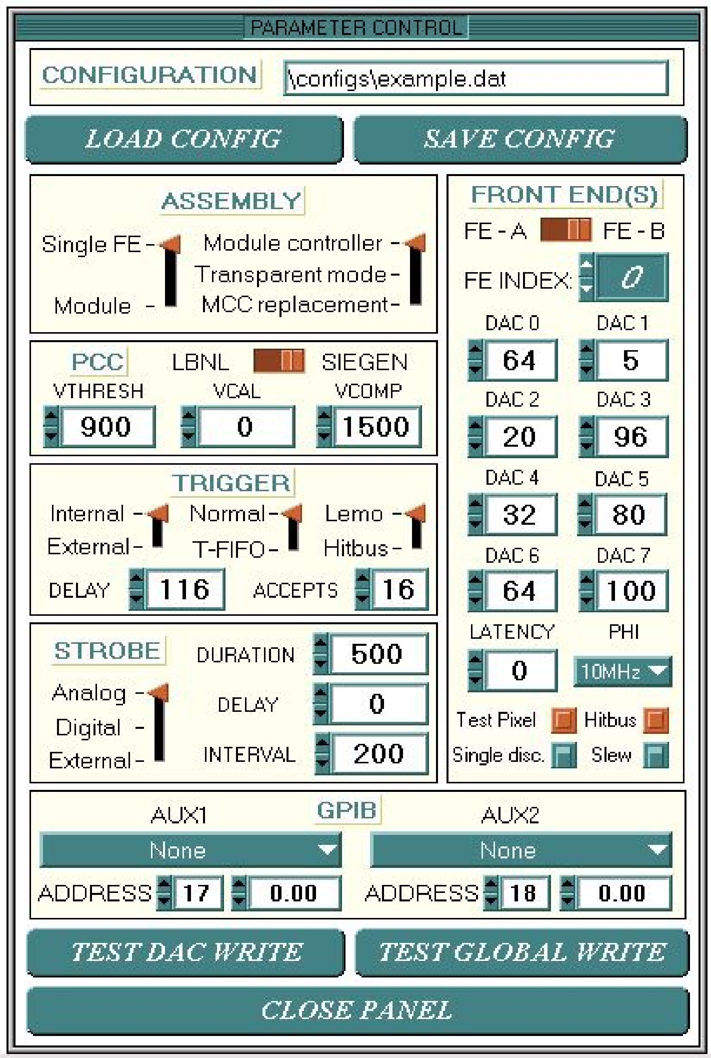
The Demonstrator Test System

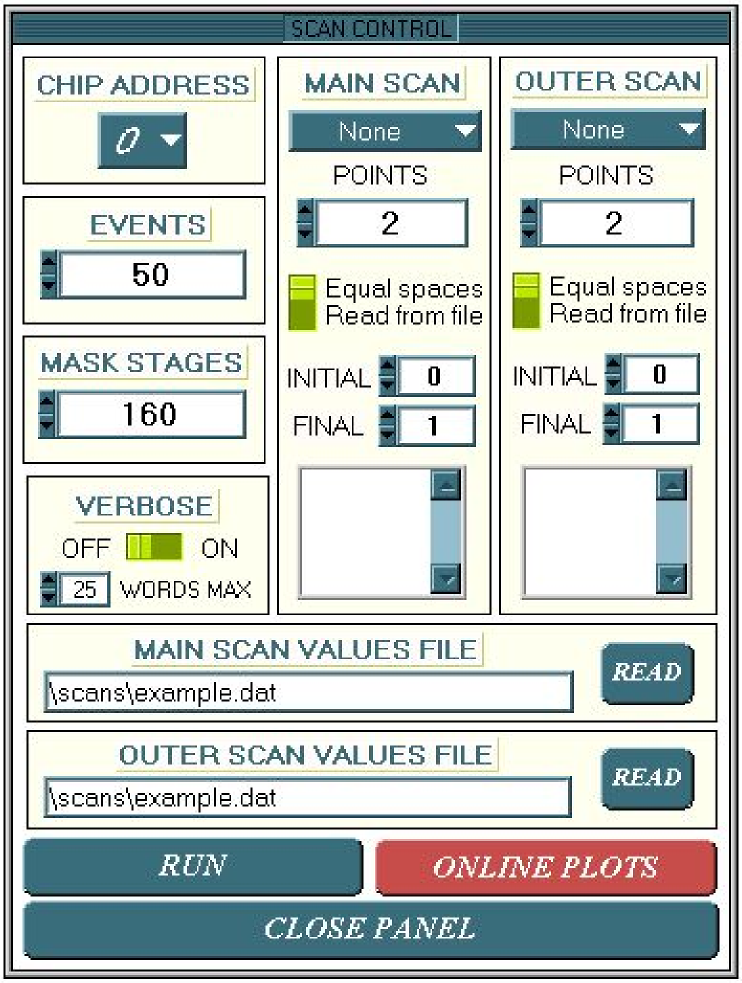


John Richardson 3/11/99




PixelDAQ
GRAPHICAL USER INTERFACE
MCC
PCC
INTERACTIVE
PROBE
MASTER PANEL
SCAN CONTROL
SYSTEM CONTROL
DATA CONTROL
ANALYSIS CONTROL
MODULE CHIP-SELECT
MASK CONTROL
PARAMETER CONTROL
STANDARD I/O
MASK MAKER
TFIFO CONTROL
ONLINE PLOTS


PARAMETER CONTROL
CONFIGURATION
\configs\example.dat
LOAD CONFIG
SAVE CONFIG
ASSEMBLY
Single FE
Module
Module controller
Transparent mode
MCC replacement
FRONT END(S)
FE - A
FE - B
FE INDEX
0
PCC
LBNL
SIEGEN
VTHRESH
VCAL
VCOMP
900
0
1500
DAC 0
DAC 1
64
5
DAC 2
DAC 3
20
96
TRIGGER
Internal
External
Normal
T-FIFO
Lemo
Hitbus
DELAY
116
ACCEPTS
16
DAC 4
DAC 5
32
80
DAC 6
DAC 7
64
100
STROBE
Analog
Digital
External
DURATION
500
DELAY
0
INTERVAL
200
LATENCY
0
PHI
10MHz
Test Pixel
Hitbus
Single disc.
Slew
GPIB
AUX1
None
ADDRESS
17
0.00
AUX2
None
ADDRESS
18
0.00
TEST DAC WRITE
TEST GLOBAL WRITE
CLOSE PANEL


SCAN CONTROL
CHIP ADDRESS
0
MAIN SCAN
None
POINTS
2
Equal spaces
Read from file
INITIAL
0
FINAL
1
OUTER SCAN
None
POINTS
2
Equal spaces
Read from file
INITIAL
0
FINAL
1
EVENTS
50
MASK STAGES
160
VERBOSE
OFF
ON
25
WORDS MAX
MAIN SCAN VALUES FILE
\scans\example.dat
READ
OUTER SCAN VALUES FILE
\scans\example.dat
READ
RUN
ONLINE PLOTS
CLOSE PANEL

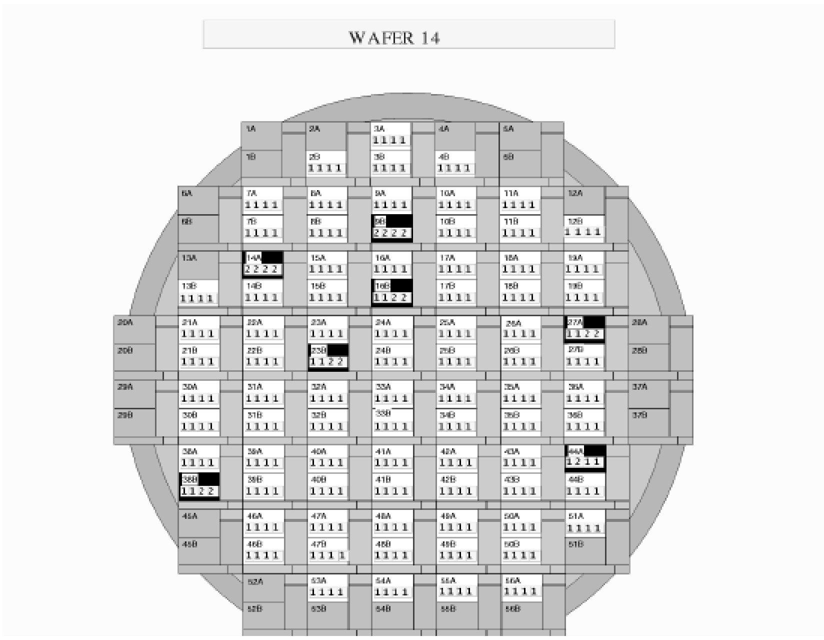
Wafer Probing

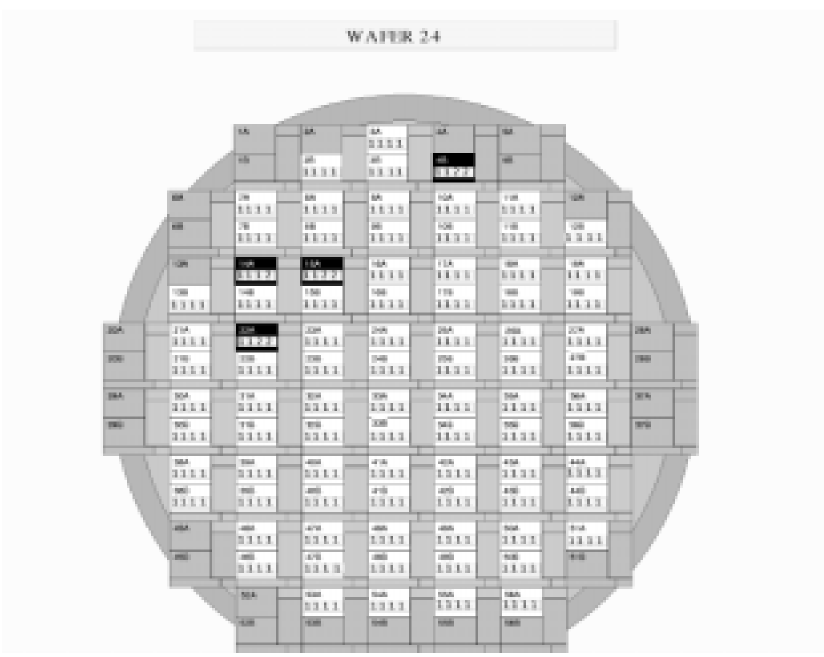
Procedure:

- Power consumption check, $I_{AVDD} \approx 40mA$, $I_{AVCC} \approx 17mA$, $I_{DVDD} \approx 48mA$.
- Writing and reading of DAC, global and pixel registers.
- Serial data check.
- Check for presence of time and level hitbus' along with test-pixel preamp output.
- Test digital injection $\forall$ channels.
- Test all channels with analogue charge injection, evaluating $\overline{\text{threshold}}$ and $\sigma_{\text{threshold}}$.
- $\approx$ 70 seconds/chip, 85 chips/wafer.

Results:

- $6\frac{1}{2}$ wafers probed.
- Out of 552 dice probed ($>1.5\times10^{6}$ channels), 39 failed to pass all tests.


WAFER 14


WAFER 24

'Single-Chip' Sensor Assemblies

• Tile-1-type (e.g. ST1): Individual p-stops providing isolation.

• Tile-2-type (e.g. ST2, SSG): N-side isolation provided by means of p-spray coverage, atoll n-ring for charge division enhancement on ST2.

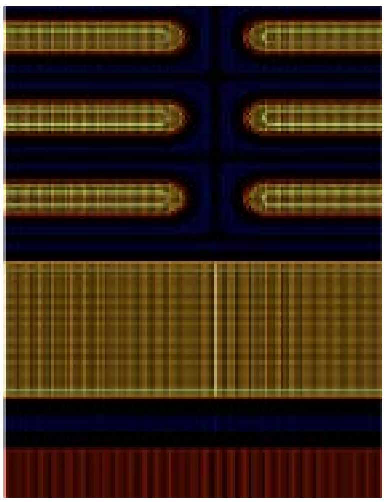
Assemblies evaluated to date: (*H8 testbeam also)

• CIS ST1-01.*
• CIS ST2-02.*
• CIS SSG-01.*
• CIS S7O-01.*
• CIS S8O-01.*
• CIS SBR-01.*
• CIS ST1 irradiated to 5×10^{14}.*
• CIS ST1 irradiated to 1×10^{15}.*
• CIS ST2 irradiated to 5×10^{14}.*
• CIS ST2 irradiated to 1×10^{15}.*
• CIS ST2-01 SiON.
• CIS ST2-02 SiON.
• CIS ST2-03 SiON.
• CIS ST1-01 SiON.
• CIS ST1-02 SiON.
• CIS ST1-03 SiON.
• CIS 11D S8O-01.
• CIS 01S S7O-01.
• CIS 01S SSG-01.
• CIS 01S SXT-02.
• CIS 11D S8O-01.
• CIS MCMD ST1.
• CIS MCMD ST2.

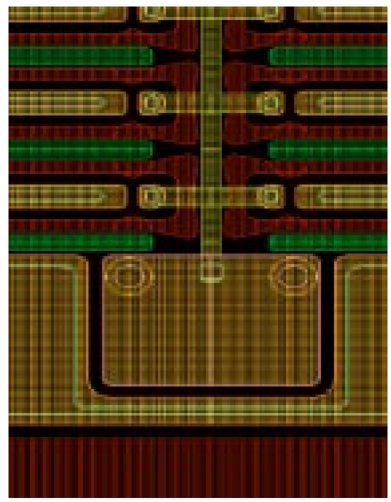
Fluences are 1MeV ncm^{-2} NIEL equivalent

Principal prototype design philosophies

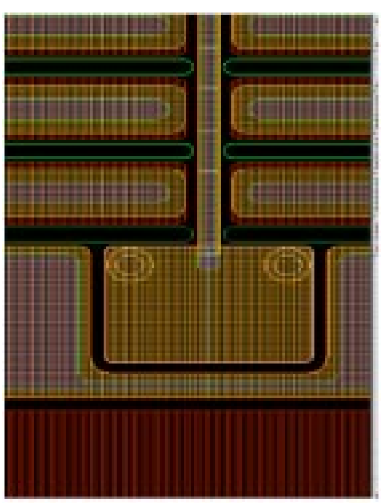
p-stop



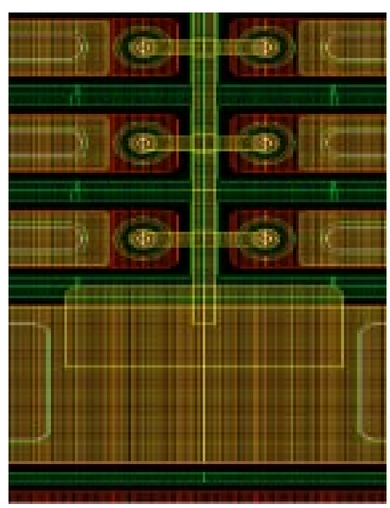
p-spray



small-gap



medium-gap



Single-Chip Parameterisation Procedures

For all assemblies:

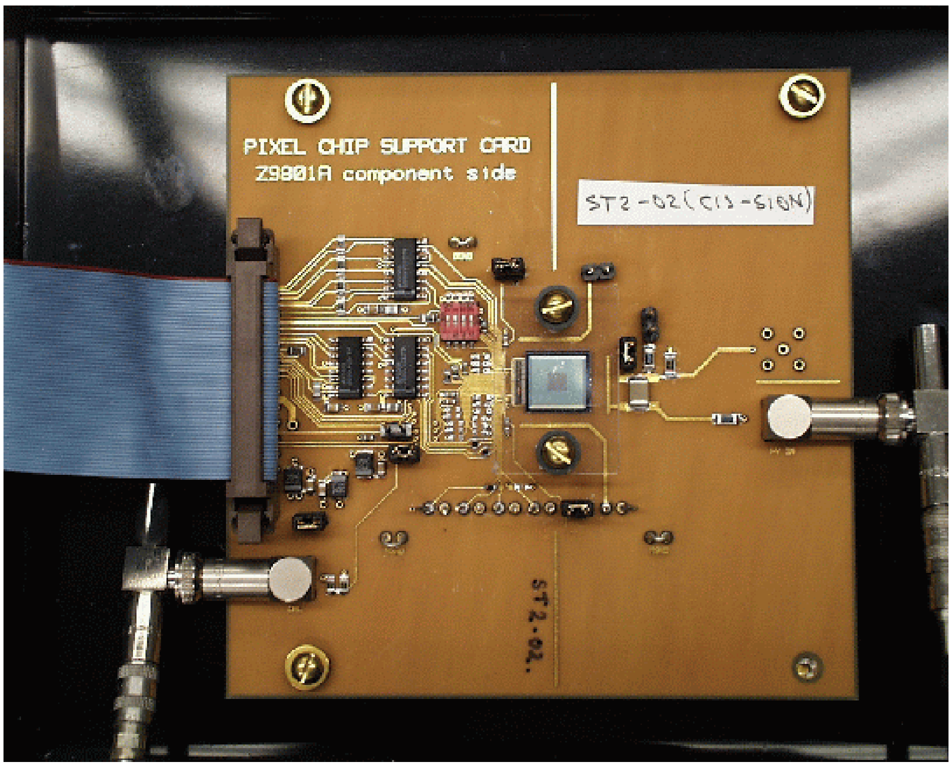
- Threshold and noise evaluation $\forall$ channels.
- Determination of optimal trim-DAC settings.
- Re-evaluation of threshold dispersion post-tune.
- Time-over-Threshold measurement calibration using charge injection $\forall$ channels.
- Creation of bad-channel database.
- Collection of 15,000,000 source events using Cd109 to determine bump-bonding success (fast-OR from all channels (hitbus) used as trigger).
- Evaluation of sensor bulk behaviour (leakage current through preamps/guard and approximate depletion voltage).
- Determine absolute charge calibration using $\mathbf{Cd}_{109}$ X-ray source and $\mathbf{Am}_{241}$ γ source.

Also investigate:

- Crosstalk behaviour and timewalk performance.

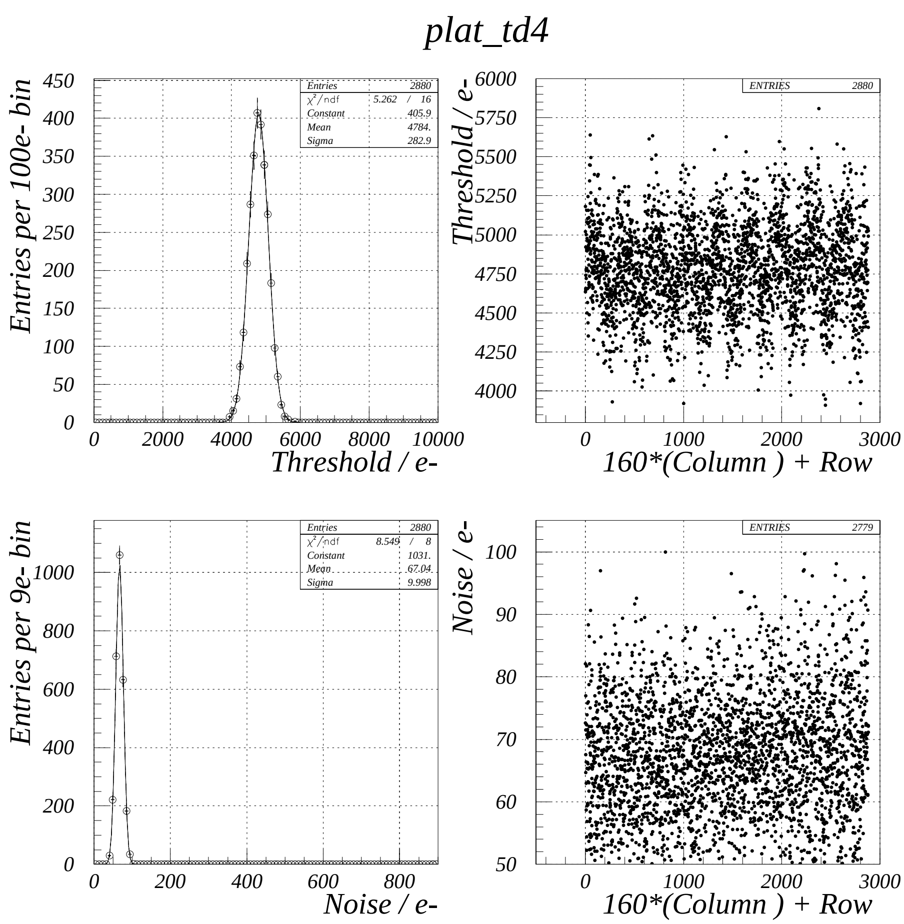
John Richardson 3/11/99

Single-Chip Assembly on Support Card



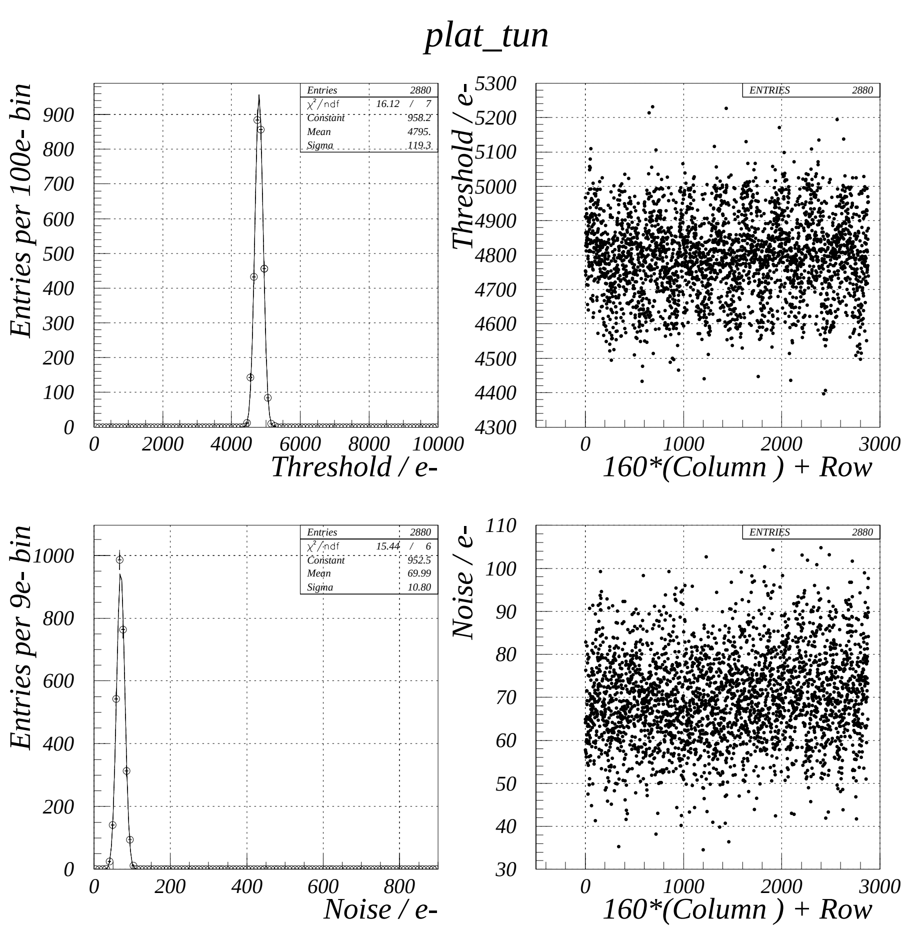
Bare FE-B Chip: Untuned Configuration

$\sigma_{Thresholds}$ = 283e-, ENC = 67e-



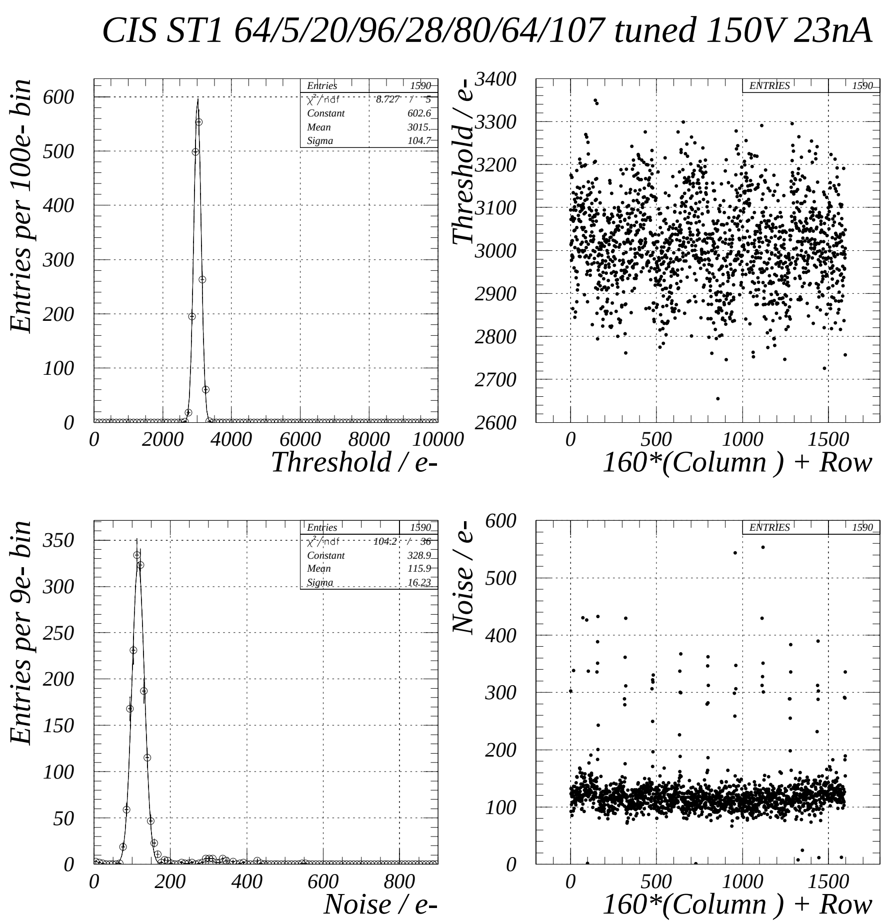
Bare FE-B Chip: Tuned Configuration

$\sigma_{Thresholds}$ = 119e-, ENC = 70e-



ST1 Assembly: Tuned Configuration

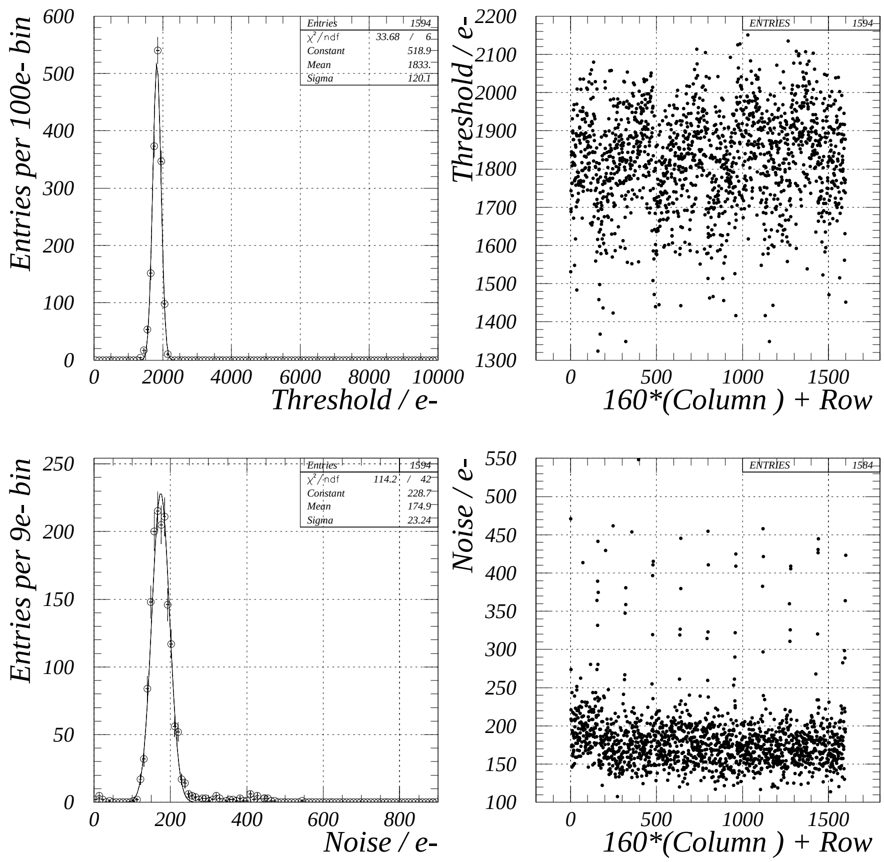
$\sigma_{Thresholds}$ = 105e-, ENC = 116e-



SSG Assembly: Tuned Configuration

$\sigma_{Thresholds}$ = 120e-, ENC = 175e-

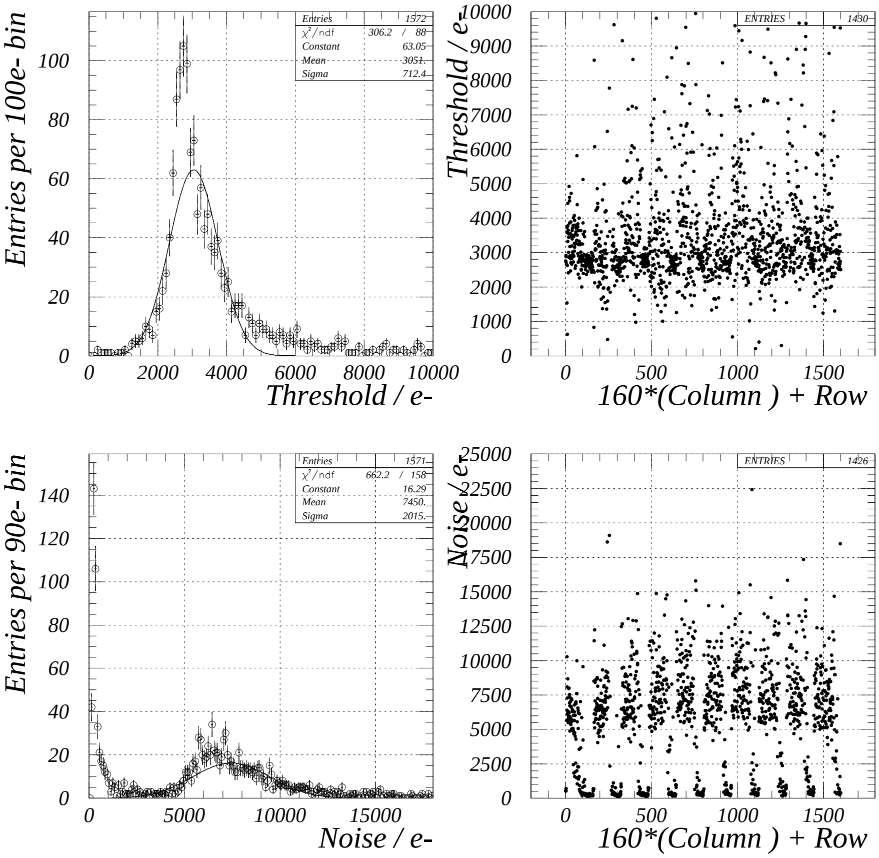
CIS SSG 64/5/20/96/100/80/64/107 tuned 150V 129nA



Irradiated ST1 Assembly: Tuned Config.

250V, I_{leak}=121μA, ENC $\rightarrow$ 15000e-!

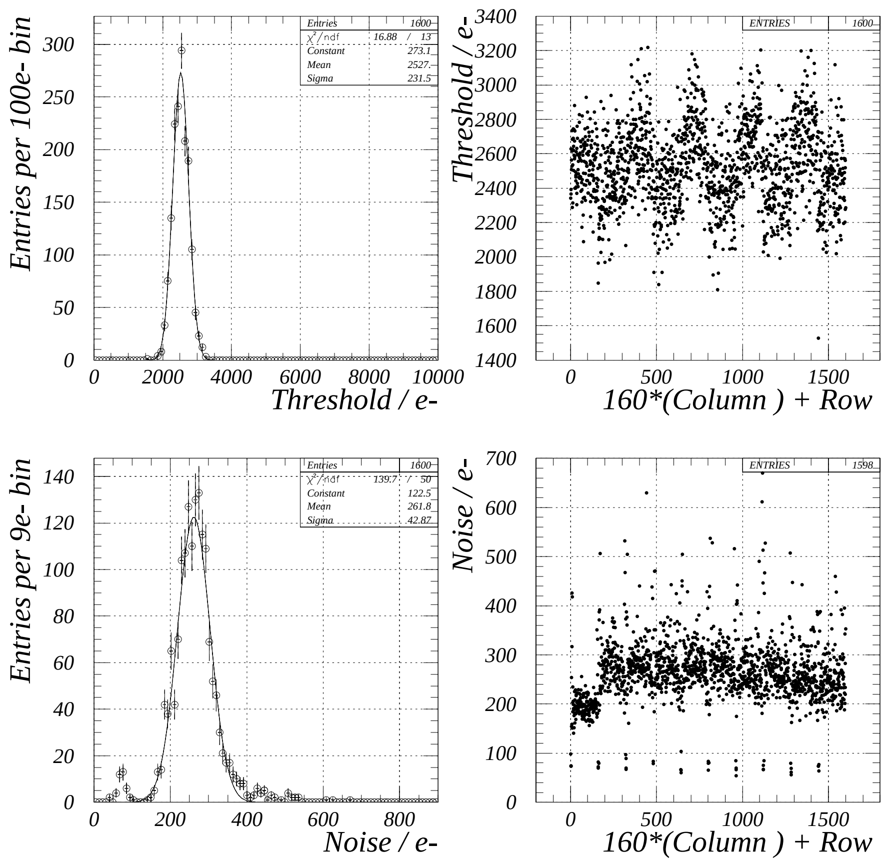
CIS Irrad2 ST1 64/1/20/96/32/80/64/120 tuned2 -7.0C 250V 121.0uA



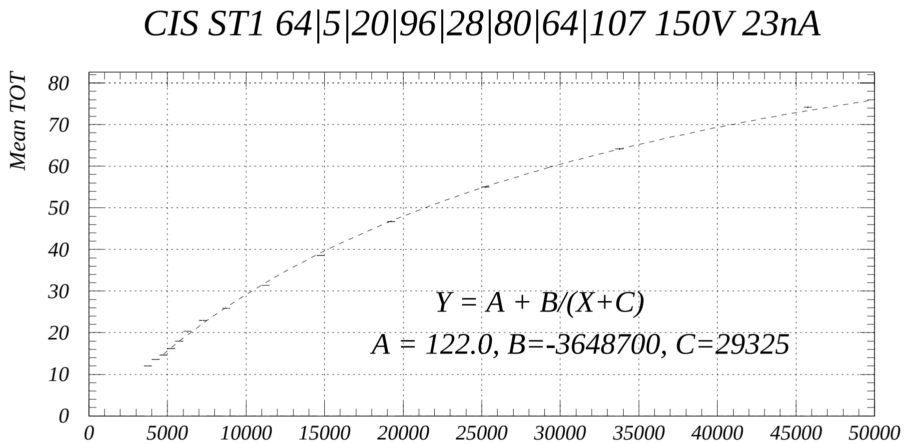
Irradiated ST2 Assembly: Tuned Config.

600V, I_{leak}=63μA, ENC = 262e-

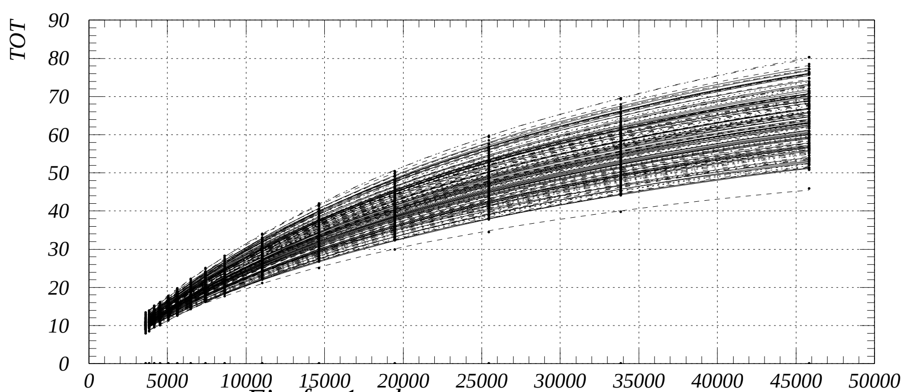
CIS ST2 Irrad 1E15 64/1/20/96/65/80/64/84 tuned -8.8C 600V 63uA



Time-Over-Threshold Calibration Example



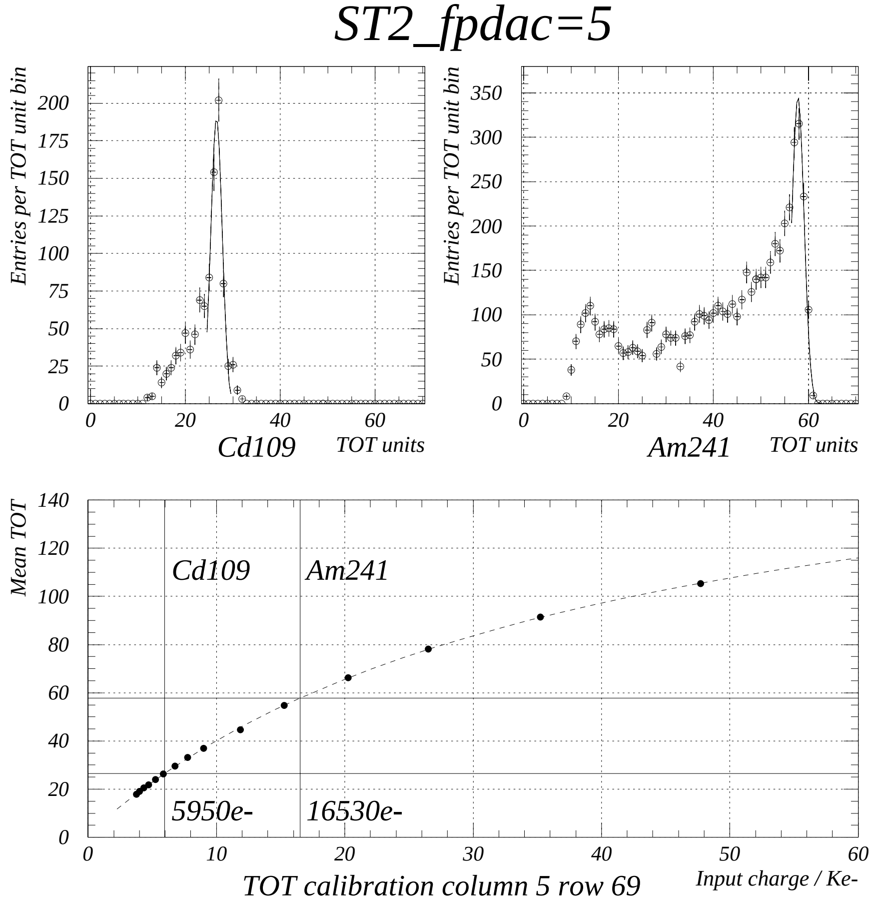
Mean calibration - first 10 columns



Fits for 1 column

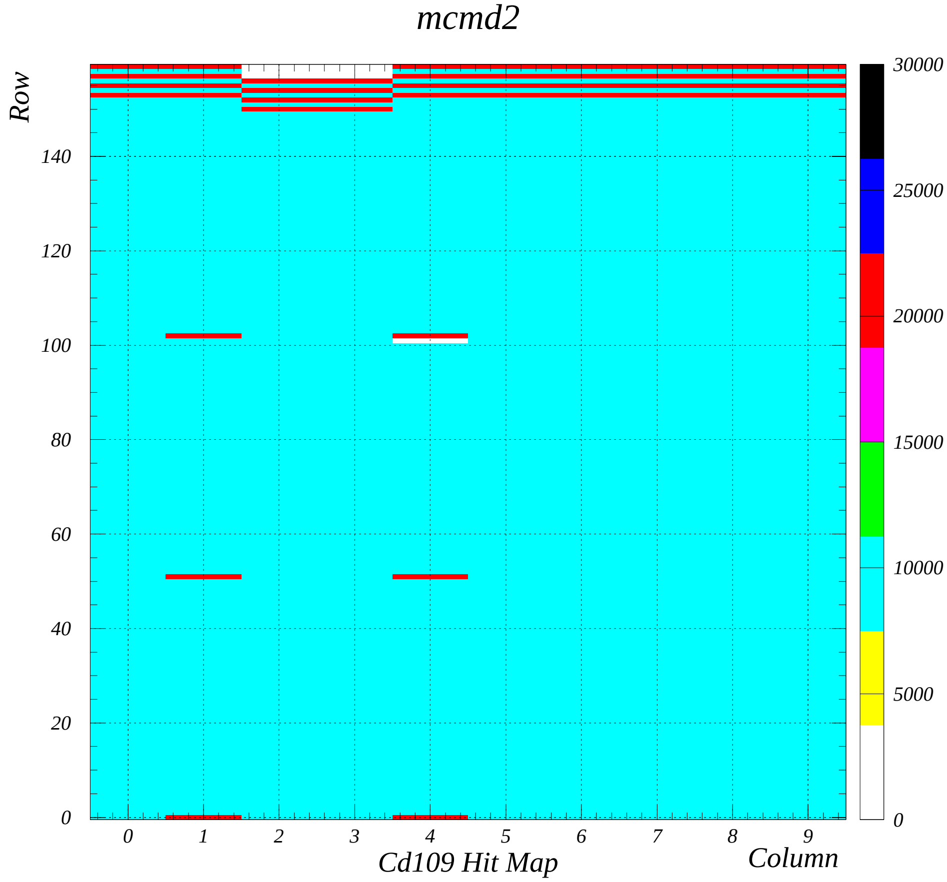
Absolute Calibration Example

5% agreement here with Cd_{109} and Am_{241}



Bump-Bond Evaluation: Cd109 Hitmaps

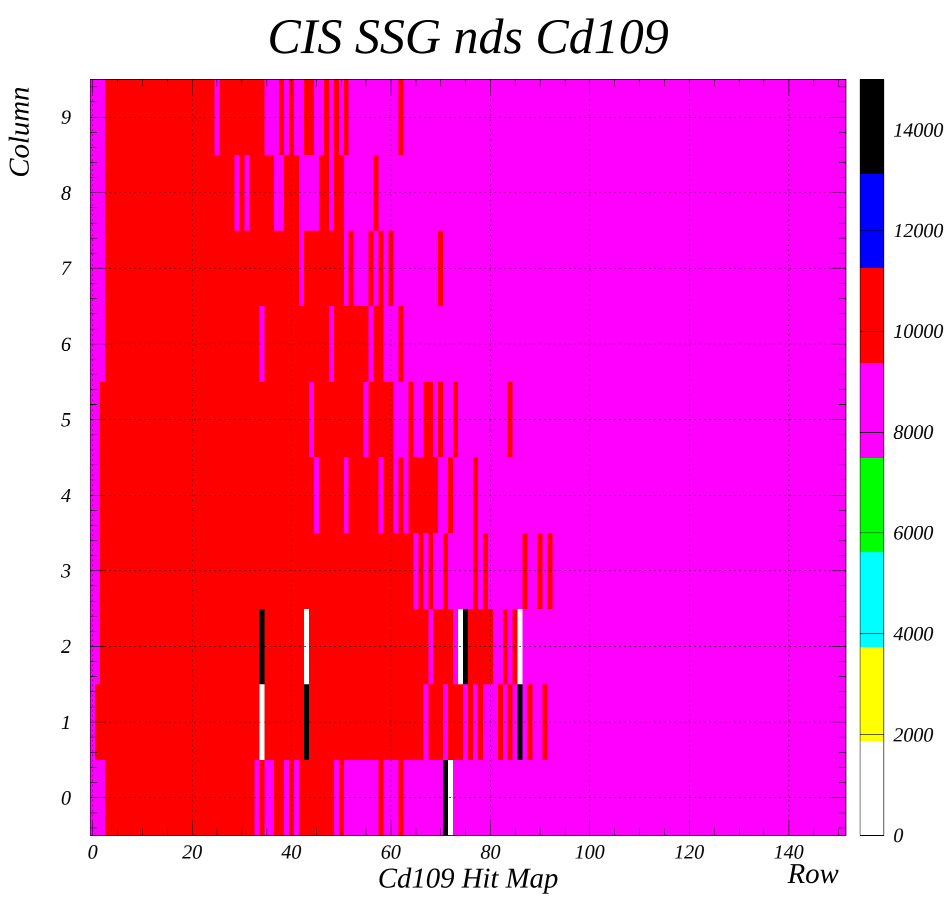
Only 1 'dead' channel on this MCMD example → missing bump



John Richardson 3/11/99

Bump-Bond Evaluation: SSG Example

5 instances of merged bumps



Crosstalk examination: Methodology

- For nearest-neighbour study, define strobe-enable mask which illuminates one pixel per column pair.

- Disable the strobed pixel for readout and enable the two nearest neighbours.

- Step this mask configuration along the shift register 320 times so that all channels have been fired.

- For each mask step scan the charge input from 0 - 250,000e- and fit s-curves to each channel.

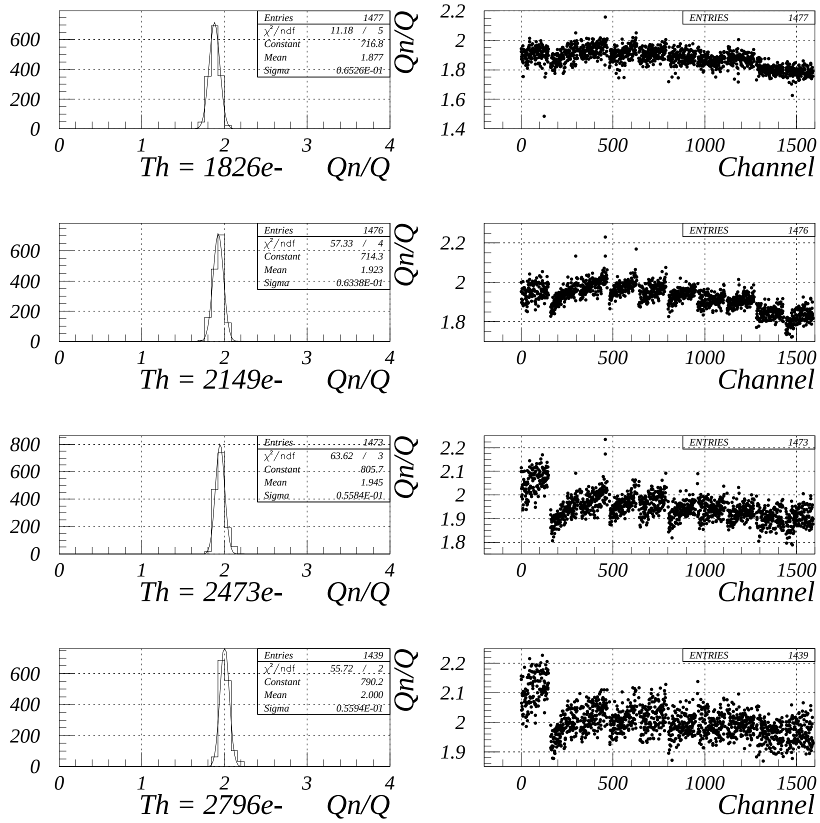
- For each channel the quotient of it's individual threshold (derived earlier) and the s-curve median indicates the percentage of charge loss.

- For ganged-pixel study, inject one pixel at a time and enable all other channels in the ganged region for readout.

Crosstalk Evaluation: ST1 Sensor Design

Crosstalk ≈ 2%

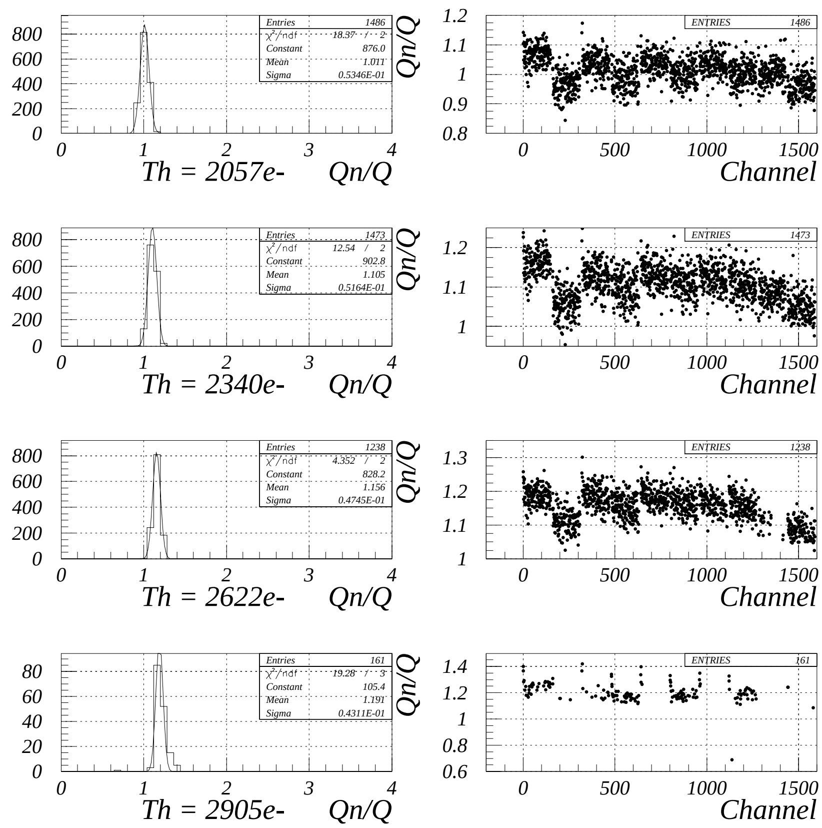
CIS ST1_01 %Q loss to neighbour in column



Crosstalk Evaluation: ST2 Sensor Design

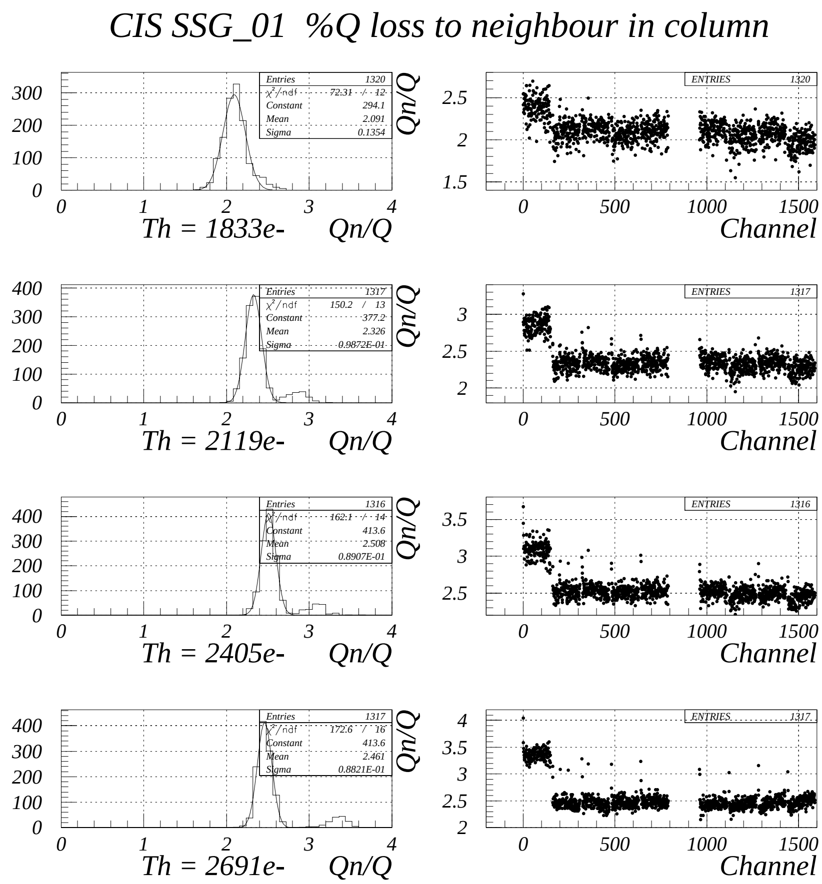
Crosstalk ≈ 1%

CIS ST2_03 %Q loss to neighbour in column



Crosstalk Evaluation: SSG Sensor Design

Crosstalk ≈ 2.3%



Timewalk study: Methodology

- Define a 2D scan in PixelDAQ.

- Scan the entire range of strobe-delay (256 steps of 250ps) as the inner scan.

- In the outer loop scan the input charge, beginning on threshold. Take many points at low values and sparsify towards the maximum input charge (18 steps total).

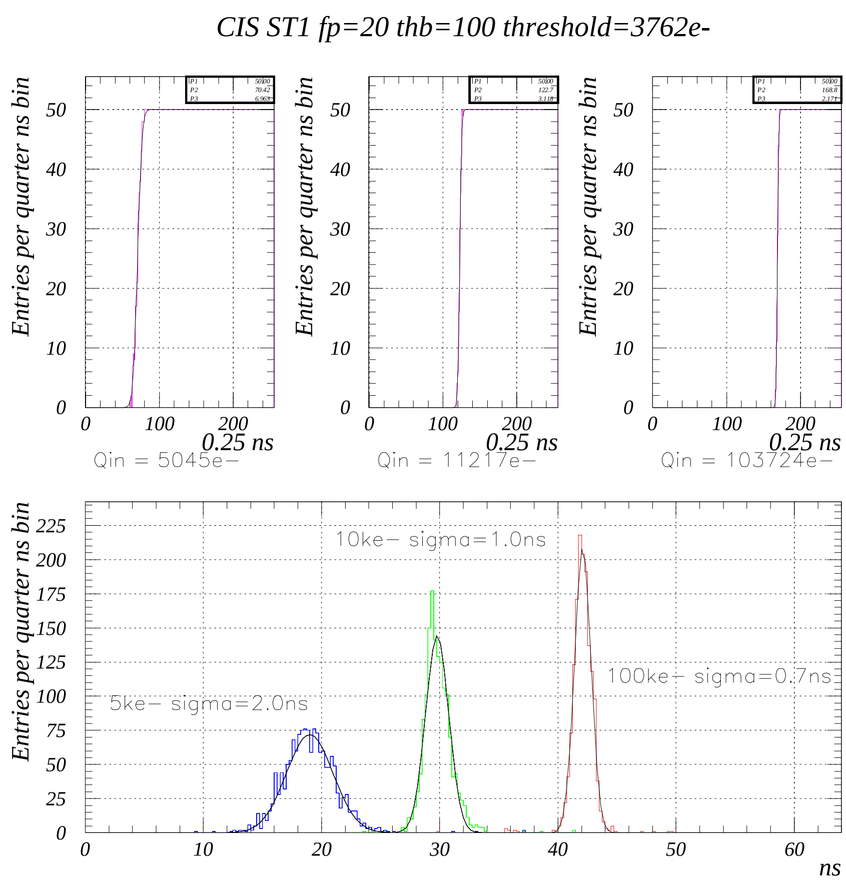
- Issue several accepts in order to obtain a single s-curve (of efficiency vs. time) per channel per charge value.

- For each channel, fit the s-curves and plot their medians vs. the overdrive, i.e. the charge above threshold calculated individually.

- Fit the timewalk function ∀ channels.

Timewalk

ST1-01 with fast shaping (i.e. FPDAC=20)
mean threshold = 3762e-.

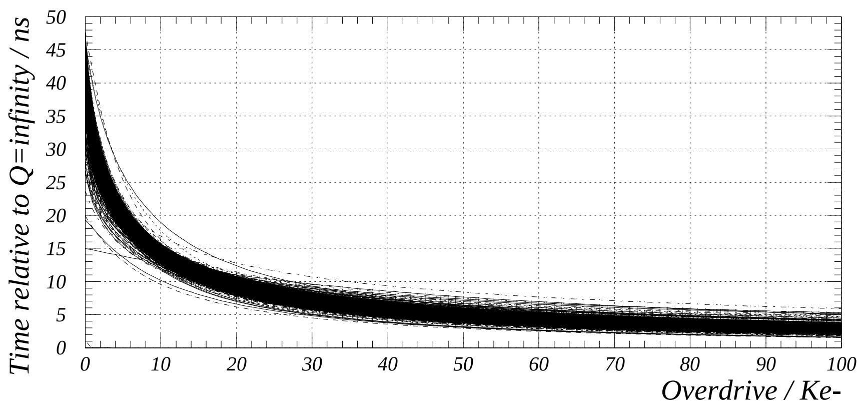


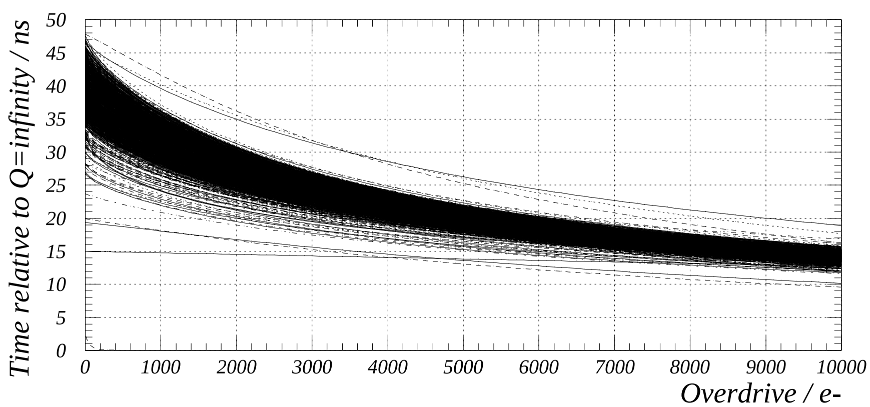
Timewalk SSG Example

$$t = f(Q) = A + \frac{B}{(CQ^E - D)}$$

A = assymptotic time as Q→ ∞ which has been subtracted here.

CIS SSG_01 FPDAC=20 THBDAC=100

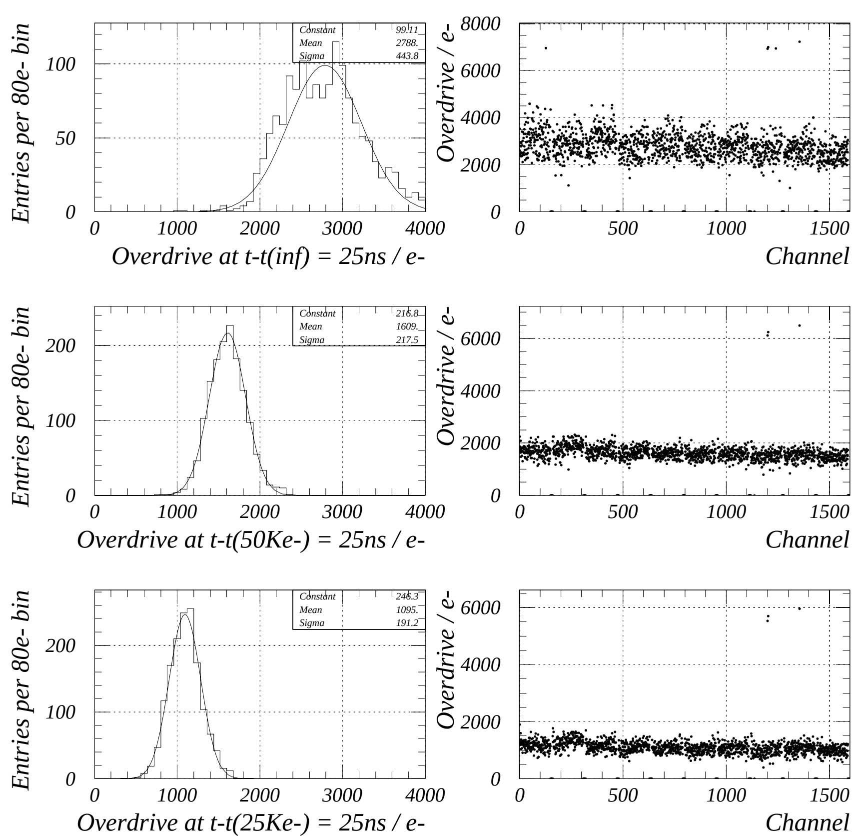




Timewalk ST2 Example

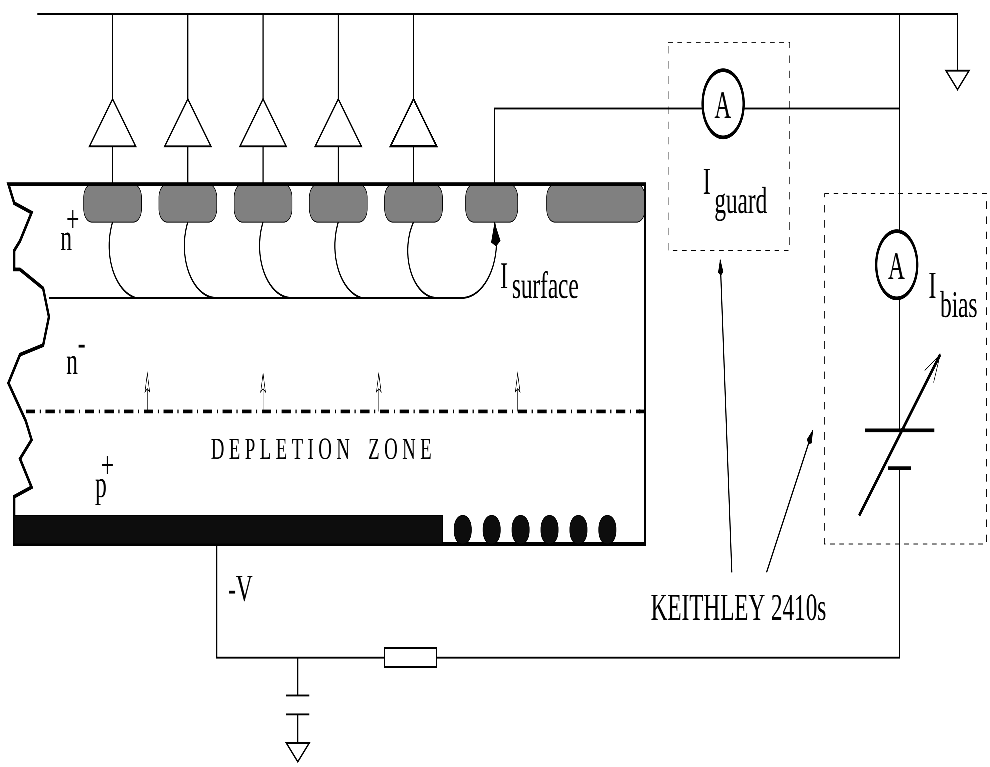
ST2-03 SiON with fast shaping (i.e. FPDAC=20) mean overdrive for timewalk relative to 50ke- = 25ns is 1609e-.

CIS ST2-03 SiON FPDAC=20 THBDAC=83



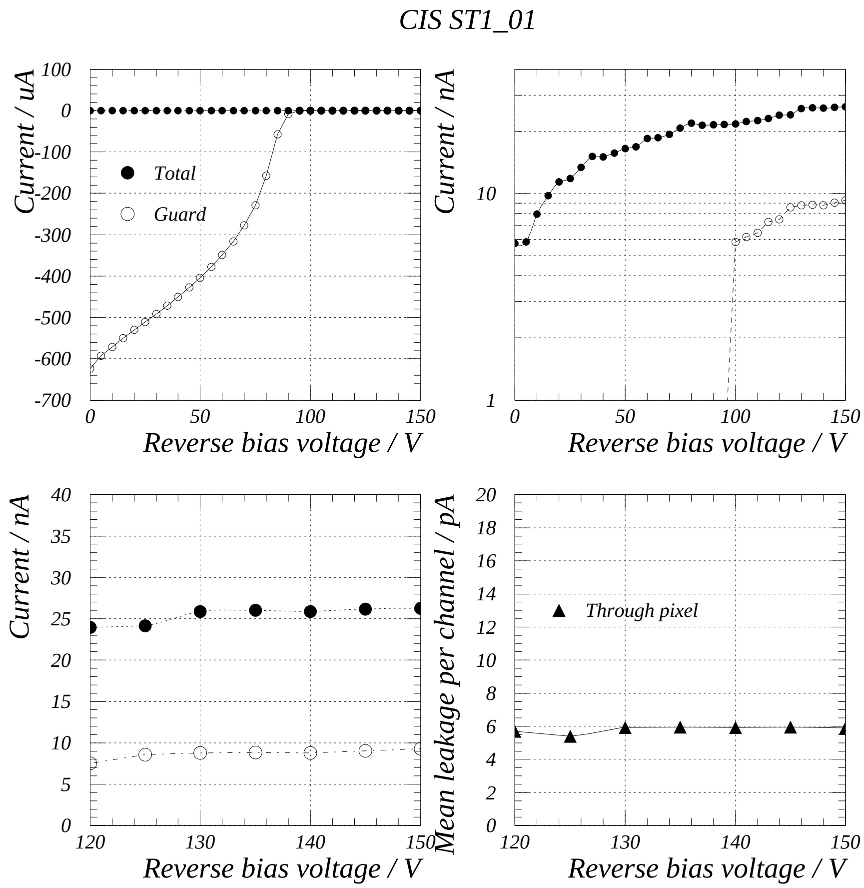
John Richardson 3/11/99

Sensor I-V Characterisation Technique



Sensor I-V Characterisation

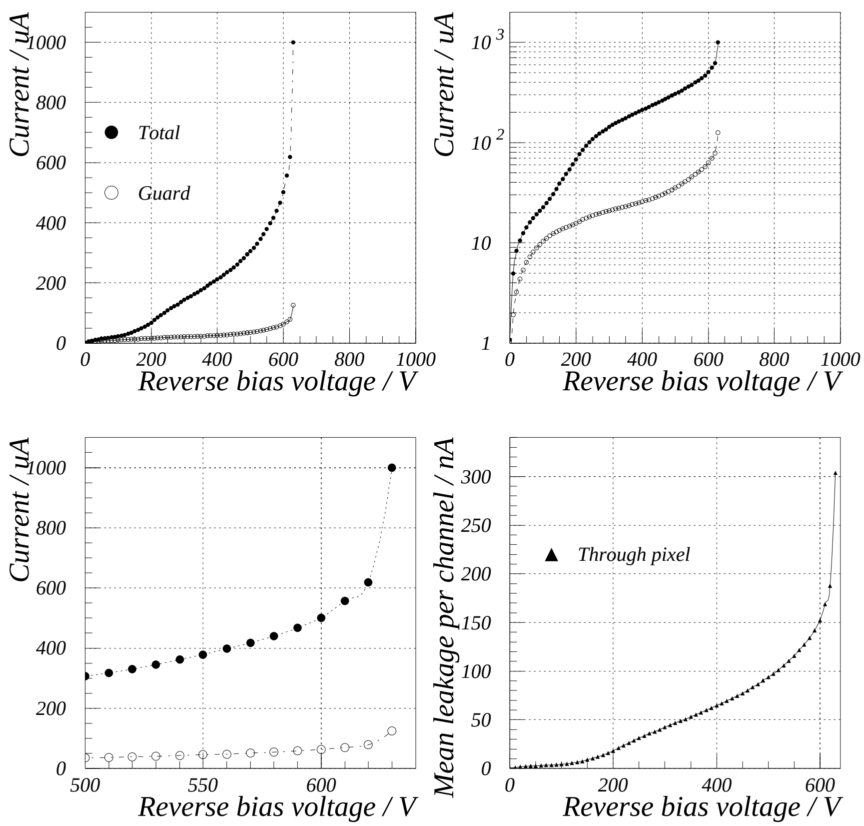
ST1-01 draws 17nA @ 150V → 6pA per channel.



Sensor I-V Characterisation

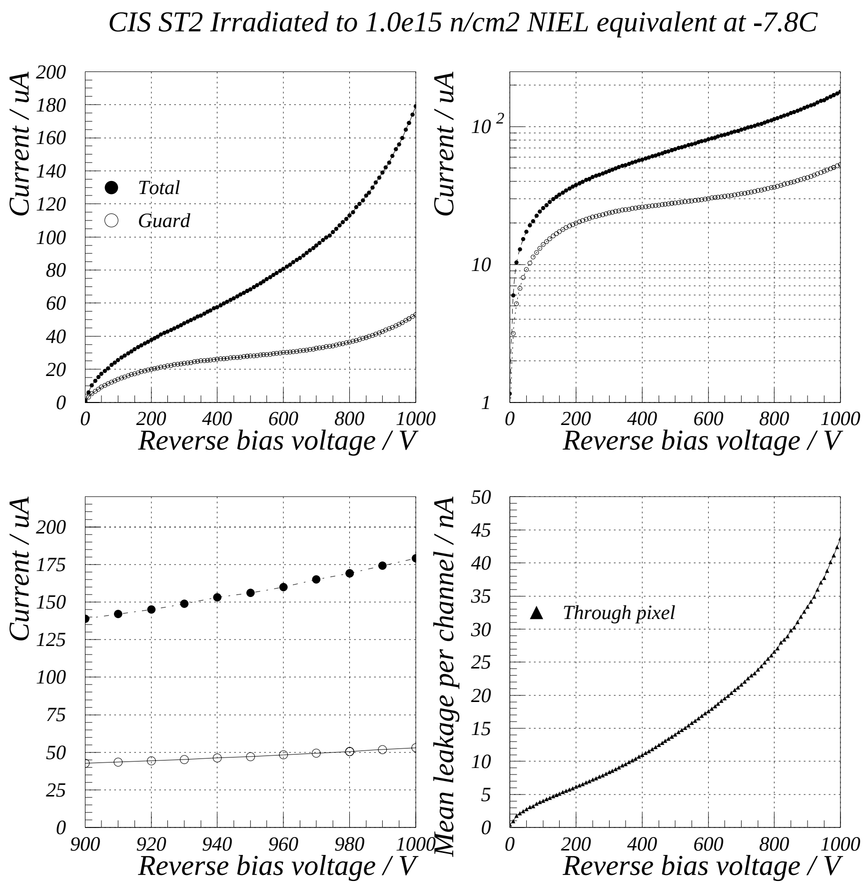
ST1 irradiated to 1×10^{15}ncm^{-2} draws 450μA @ 600V $\rightarrow$ 150nA per channel (-8^{o}C). Breakdown at 630V.

CIS ST1 Irradiated to 1.0e15 n/cm2 NIEL equivalent at -7.8C

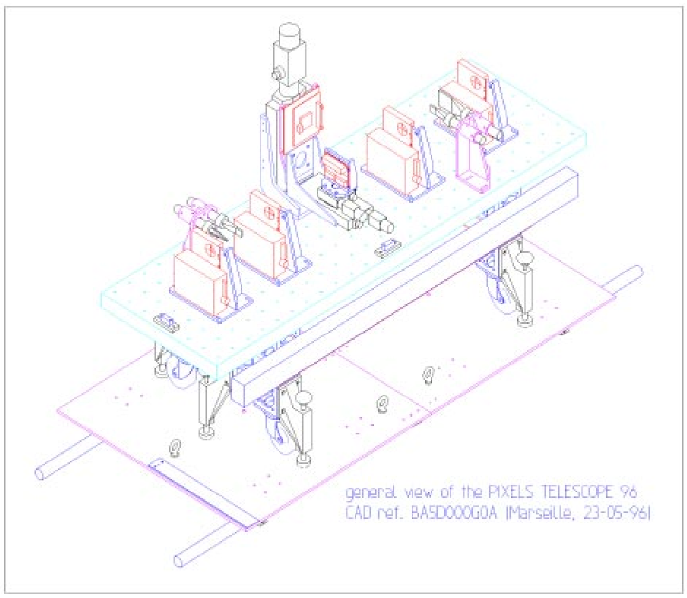


Sensor I-V Characterisation

ST2 irradiated to $1 \times 10^{15} \mathrm{ncm}^{-2}$ draws 125μA @ 1000V $\rightarrow$ 45nA per channel (-8^{o}C). No breakdown.



Test Beam Setup



Data Collected

4 Data Taking Periods

- April, June, August, September

Data Collected

- Different read-out architectures

  FE A, FE B, FE C, Marebo

- Different Sensor Designs

  Tile 1 (p-stop insulation)

  Tile 2 (p-spray insulation)

  Small Gap

  Common p-stop

  Cross talk optimised

  Several pixel geometries options

Data Collected

Data Collected

- ***Different conditions***
  - *normal beam incidence*
  - *various θ and ϕ angles*
  - *magnetic field*
  - *different thresholds*
  - *different operating voltages*

- ***Radiation hardness***
  - *T2 design irradiated*
  - *T1 design Irradiated*
  - *SG design Irradiated*
  - *Analog F.E. irradiated*

Efficiency

Build Pixel Clusters:

- *Contigous Pixel*
- *Digital Algorithm for Position*

Sample Definition :

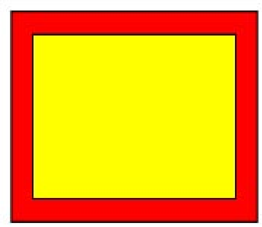
- *Tracking quality:*

  χ^2 probability > 0.2 in x and y views

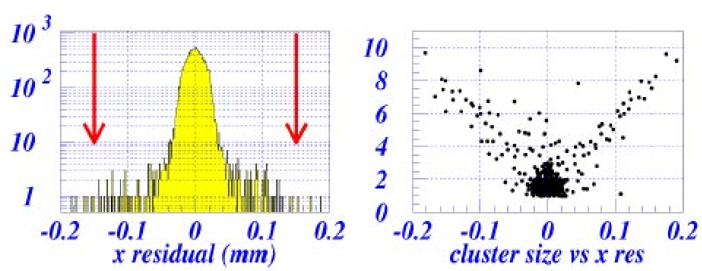
- *fiducial cuts:*

  remove edge of the detector

  to avoid resolution effects



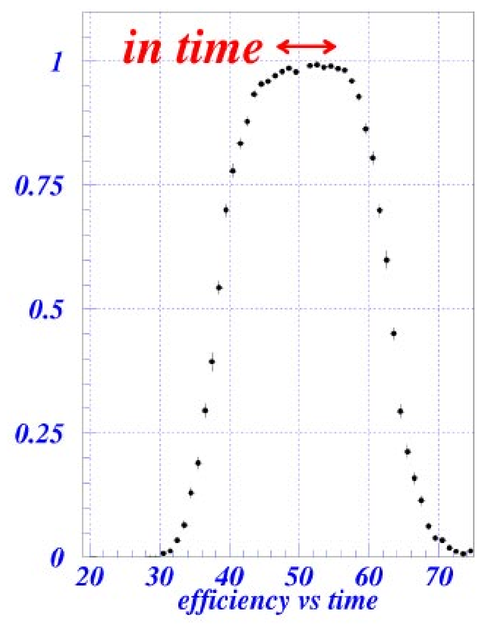
Cluster - Track Matching:



Efficiency vs Time

Efficiency 'in time'

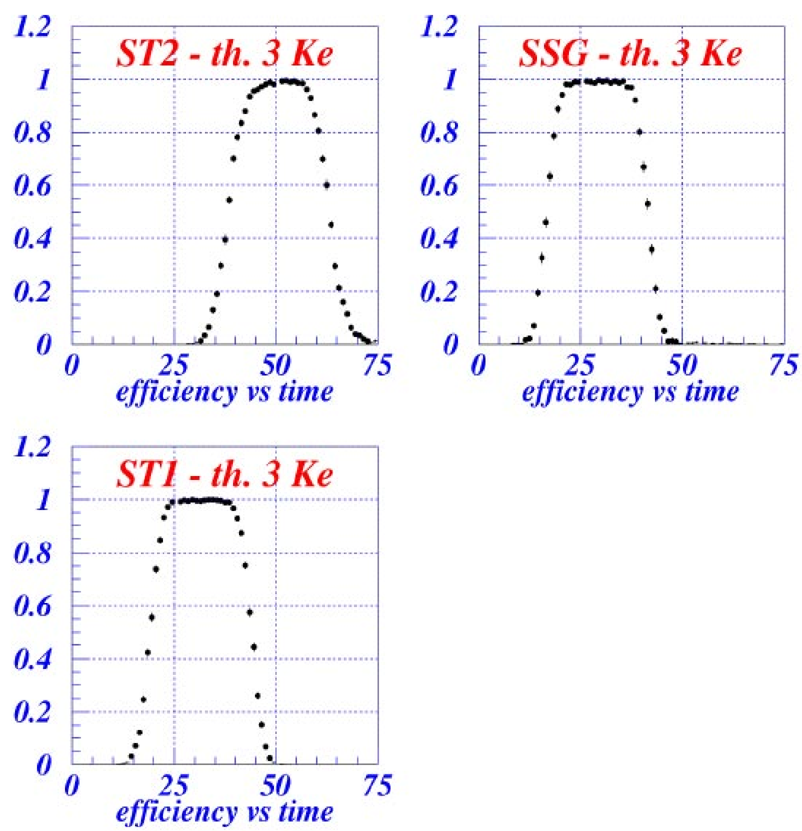
efficiency	***98.8***	***Losses***	***1.2***
1 hit	*82.0*	*0 hits*	*0.4*
2 hits	*14.6*	*not match*	*0.2*
>2 hits	*2.2*	*not in time*	*0.6*



Detector ST2 - no Fluence - Thr. 3 Ke

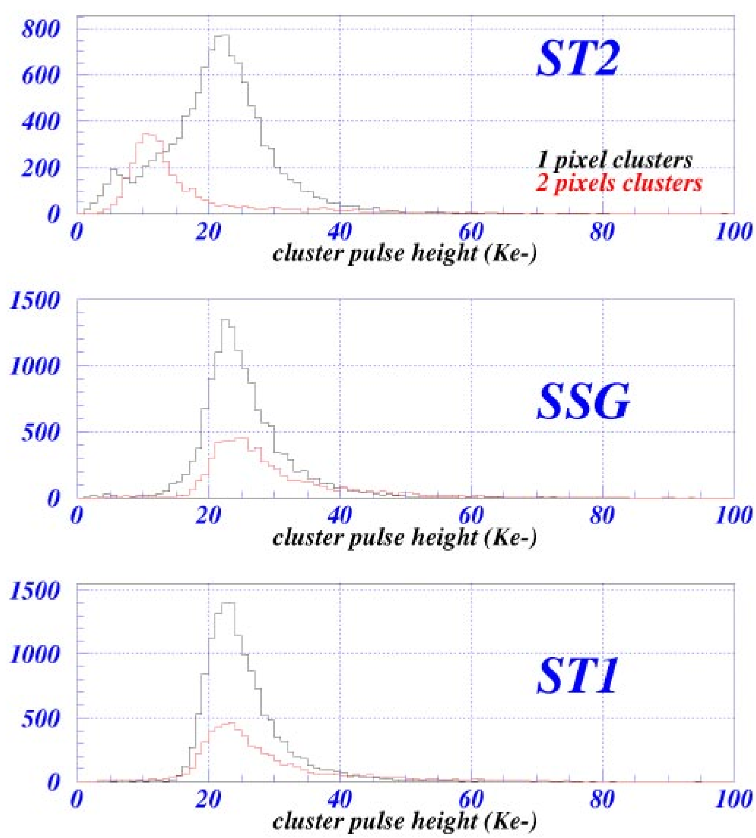
Efficiency

Comparison of the Efficiencies for different Designs



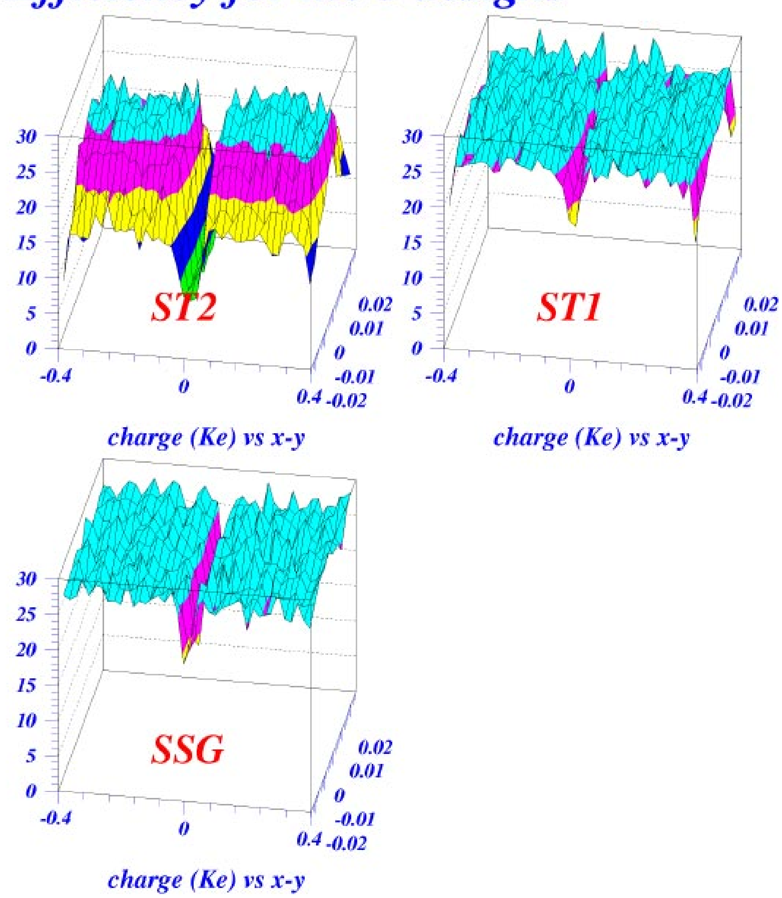
Charge Collection

The Landau Distribution for the Tile 2 design shows a problem



Charge Collection

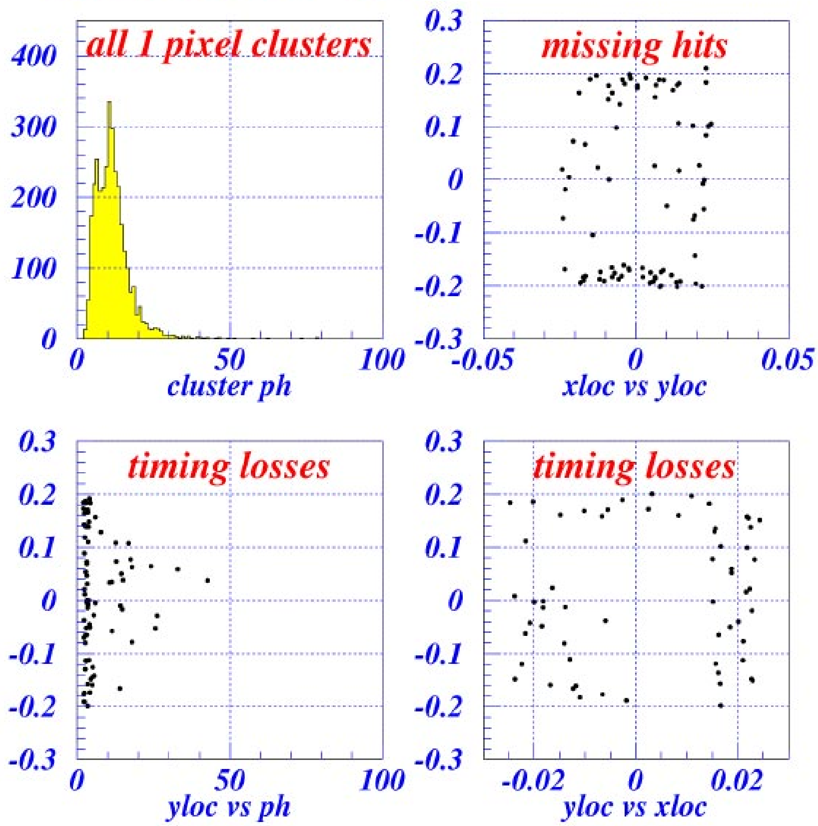
Comparison of the Charge Collection Efficiency for the 3 designs



Irradiated Detectors

Irradiated Detectors Efficiency:

- T2 design -600 V bias
- Fluence 1 x 10^{15} n /cm^2



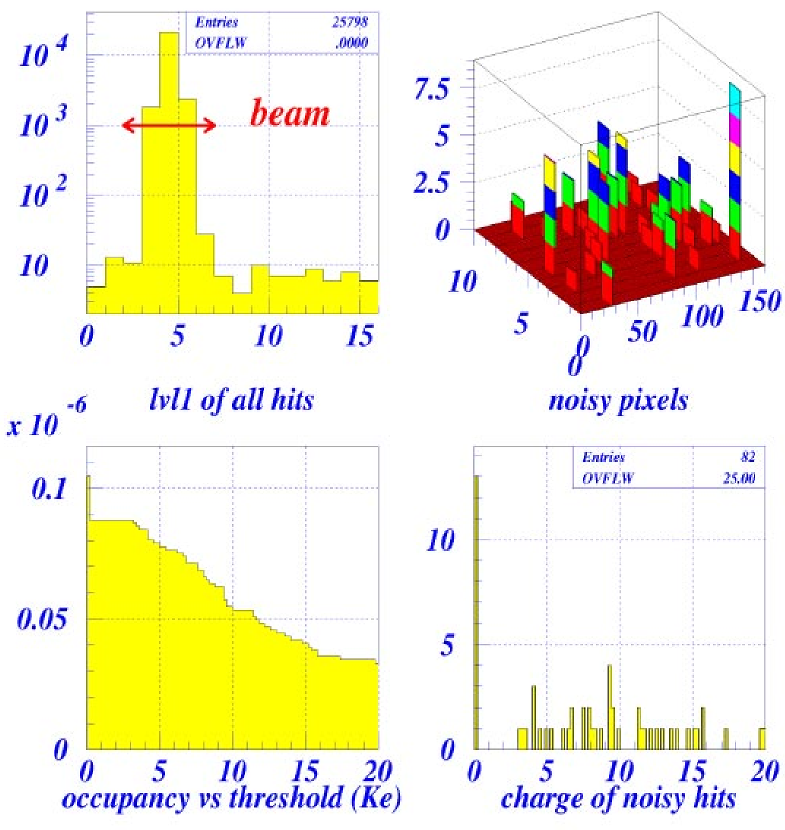
	CIS Tile 2		Small Gap		CIS Tile 1		
	ST2 2 Ke ndsl	ST2 3 Ke nds	SSG 2 Ke ndsl	SSG 3 Ke nds	ST1 2 Ke ndsl	ST1 3 Ke nds	ST1 3 Ke fp20
1 hit	74.7	82.0	65.7	71.7	67.2	72.0	75.9
2 hits	21.9	14.6	30.7	25.6	29.8	25.3	21.3
≥3 hits	2.4	2.2	2.6	2.0	2.7	2.4	2.3
Efficiency	99.0	98.8	99.0	99.3	99.7	99.7	99.5
Losses	1.0	1.2	1.0	0.7	0.3	0.3	0.5
0 Hits	0.3	0.4	0.3	0.2	0.0	0.1	0.3
Not matched	0.1	0.2	0.2	0.2	0.2	0.1	0.1
Not in time	0.6	0.6	0.5	0.3	0.1	0.1	0.1
1 hit not in time	0.5	0.5	0.3	0.2	0.0	0.1	0.1

	Dose: 1×10^{15} n				Dose: 0.5×10^{15} n			
	ST2 2.8 Ke 600 V	ST2 |ylocl<.15 |xlocl<.015	ST2 2.2 Ke 300 V	ST2 2.2 Ke 150 V	ST2 2.4 Ke 600 V			
1 hit	86.3	92.2	84.1	71.0	71.0			
2 hits	7.6	4.5	3.1	1.6	20.6			
≥3 hits	1.4	1.5	0.7	0.2	5.9			
Efficiency	95.3	98.2	87.9	72.8	97.5			
Losses	4.7	1.8	12.1	27.2	2.5			
0 Hits	2.2	0.5	6.1	19.8	1.3			
Not matched	0.1	0.1	0.1	0.4	0.4			
Not in time	2.4	1.2	5.9	7.0	0.8			
1 hit not in time	2.1	1.2	5.7	6.9	0.6			

Occupancy

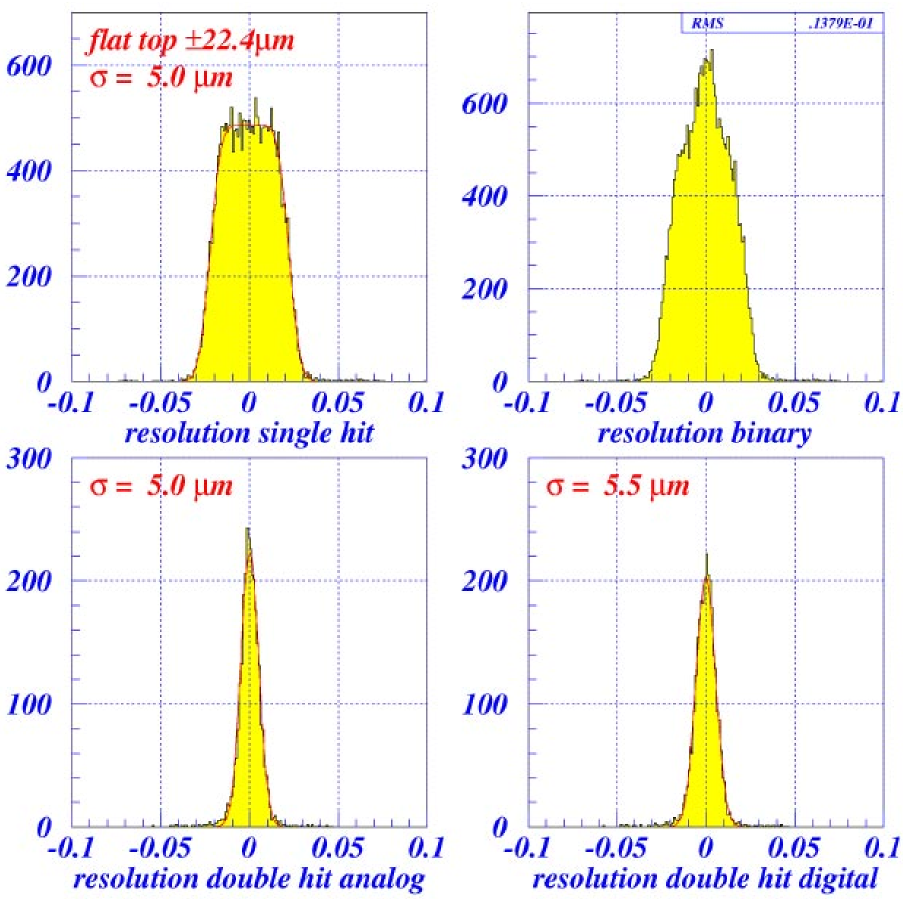
Tile 2 (p-spray) design

- Fluence 1 x 10^{15} n/cm^2
- occupancy = 0.9 x 10^{-7}



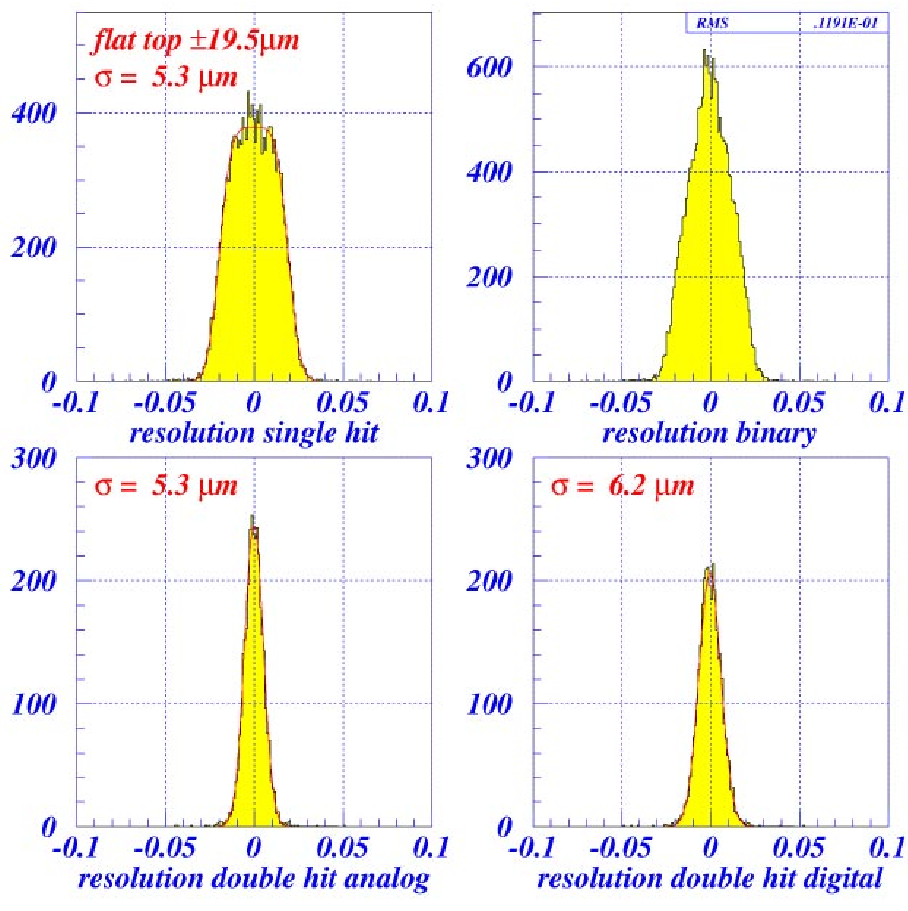
Resolution

Tile 2 Design



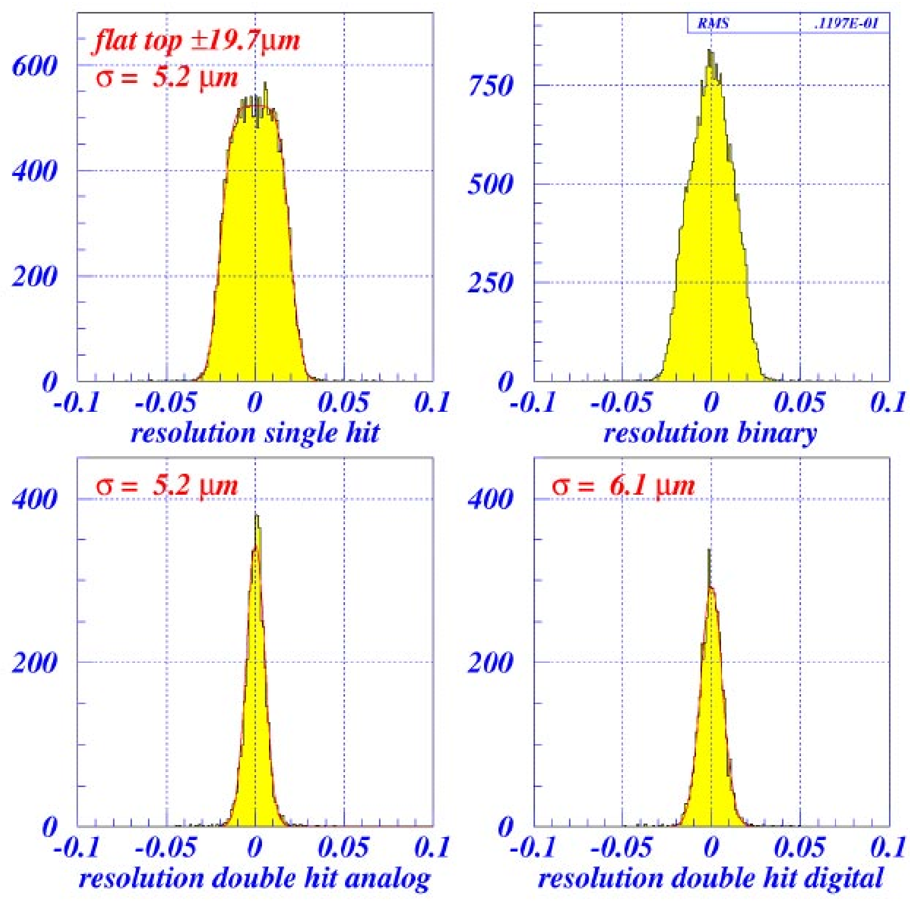
Resolution

Small Gap Design



Resolution

Tile 1 Design



Pixel Detector Test Beam Results
Atlas Week - September 1998

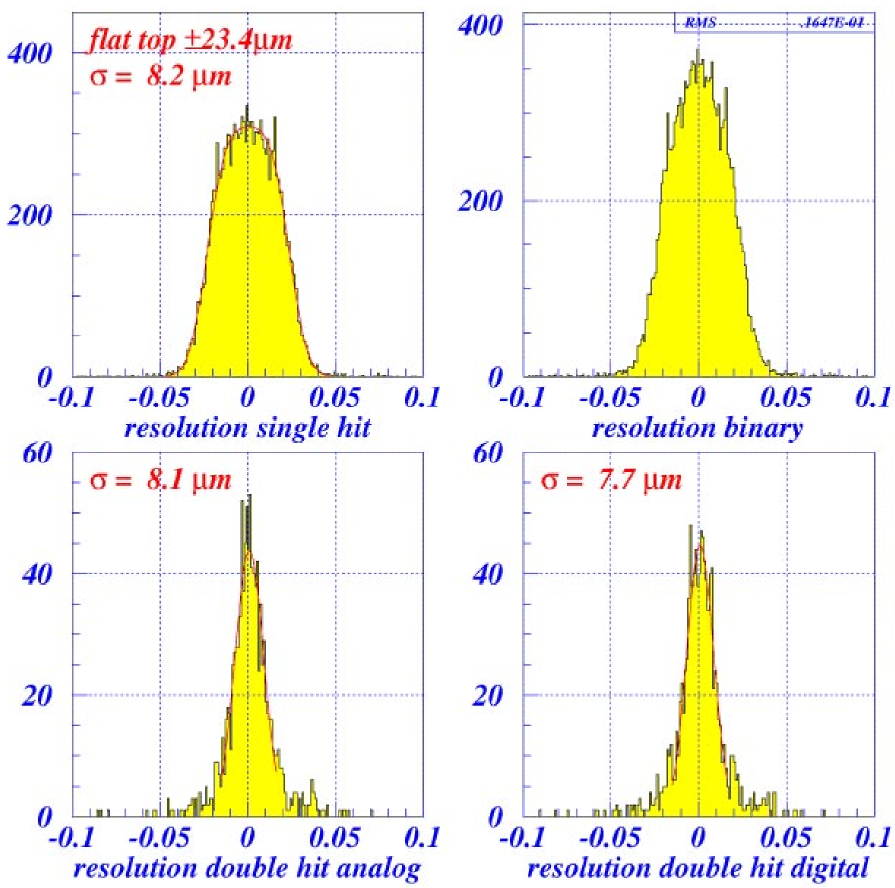
F. Ragusa - Milano

34

Resolution

Irradiated Tile 2 Design

- ***Fluence 10^{15} n /cm^2***



Conclusions

- Demonstrator test system proven in lab and testbeam environments. Now running at several institutes in Europe and North America

- Yield of H.P. process for FE-B = 93% .

- FE-B FE performance very encouraging, meeting the specs in terms of threshold dispersion (after tuning), noise, crosstalk, occupancy, efficiency and leakage-current tolerence etc.

- Time-over-Threshold information has proven extremely useful in evaluating proposed sensor designs pre and post-irradiation. FE-B has been instrumental in this process.

- Testbeam data yields efficiencies in excess of 99% for non-irradiated assemblies and resolutions as expected.

Conclusions Continued

• The ST2 design suffers serious charge-loss in the region of the intermediate n^+ ring.

• The ST1 design has good charge-collection efficiency pre-irradiation but becomes inoperable after irradiation due to breakdown phenomena.

• The ST2 design performs very well even after the 10-year equivalent hadronic damage... no breakdown apparent in I-V characteristic and 98% efficency recorded in testbeam.

• Next prototype sensor design reflects these observations.