

# ATLAS SCT Module Production

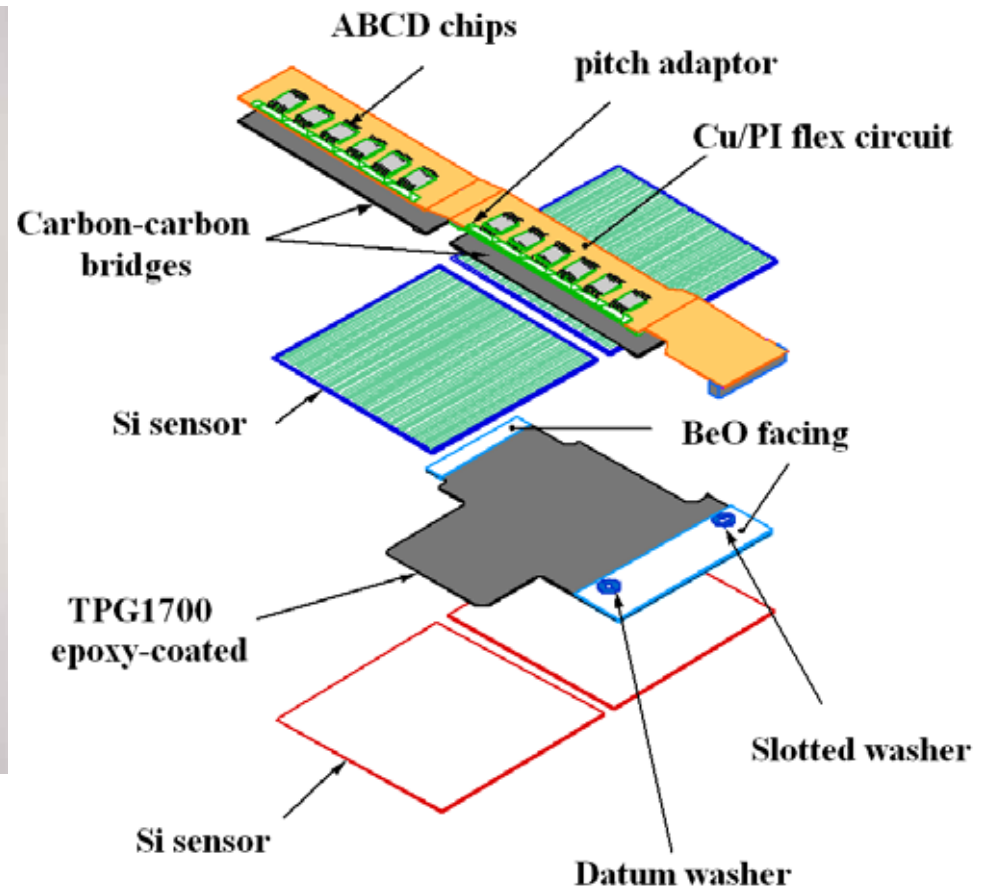
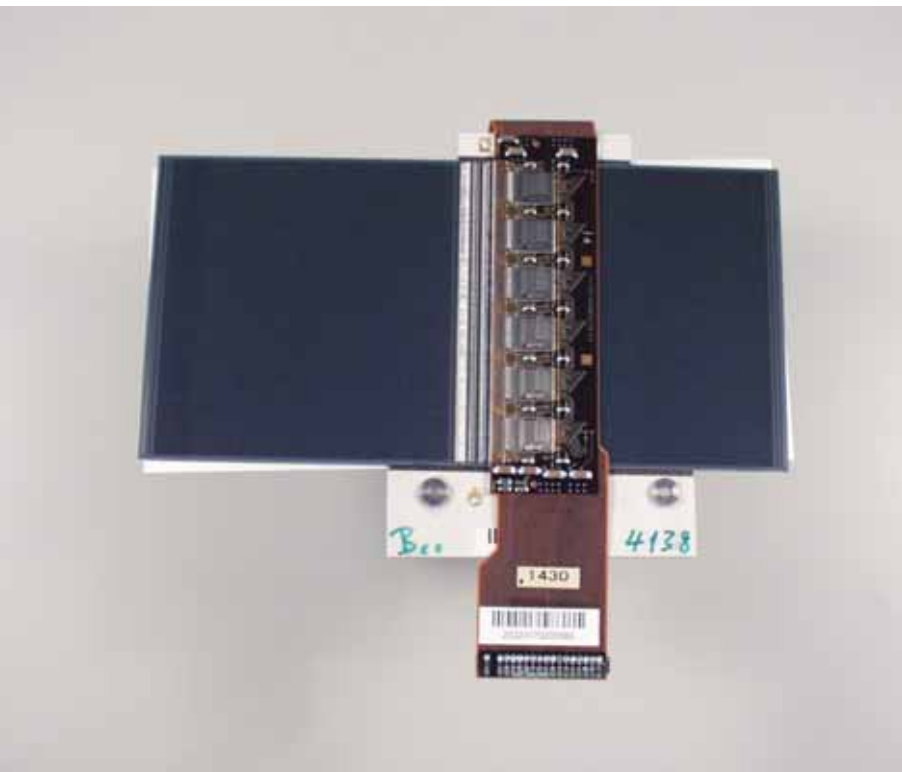
## Reference:

The Barrel Modules of the ATLAS SemiConductor Tracker,  
ATLAS Collaboration, NIM.A568 (2006) 642-671

The ATLAS semiconductor tracker end-cap module,  
ATLAS Collaboration, NIM.A575(2007)353-389

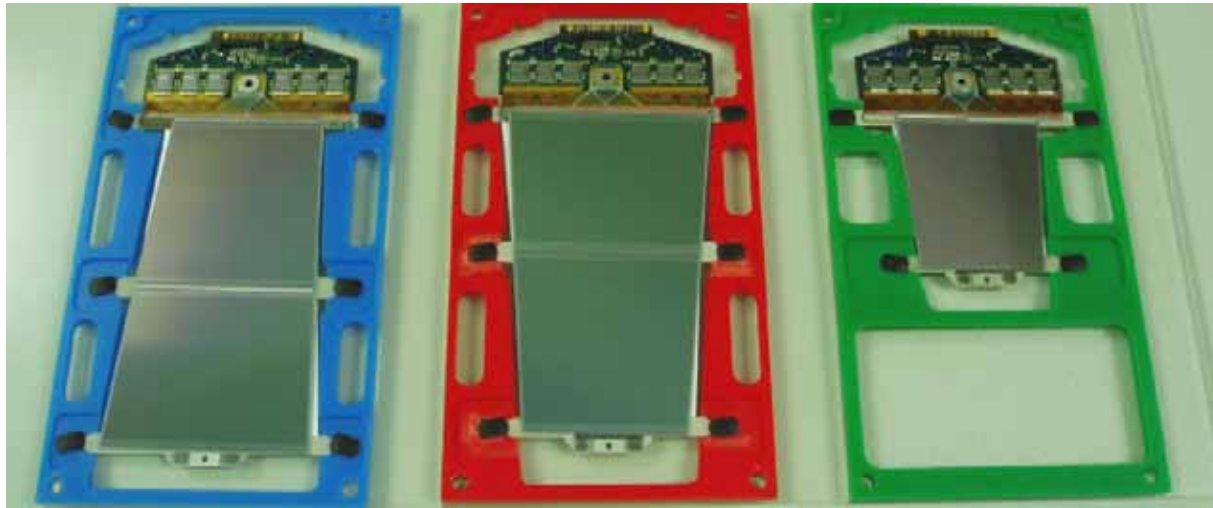
Yoichi Ikegami (KEK)

# ATLAS SCT barrel module



2112 modules assembled at 4 sites  
Double side module (40mrad strero)  
Module size 12cm x 6cm  
Strip length 12cm  
p-in-n 768 strips (80um pitch)

# ATLAS SCT end-cap module

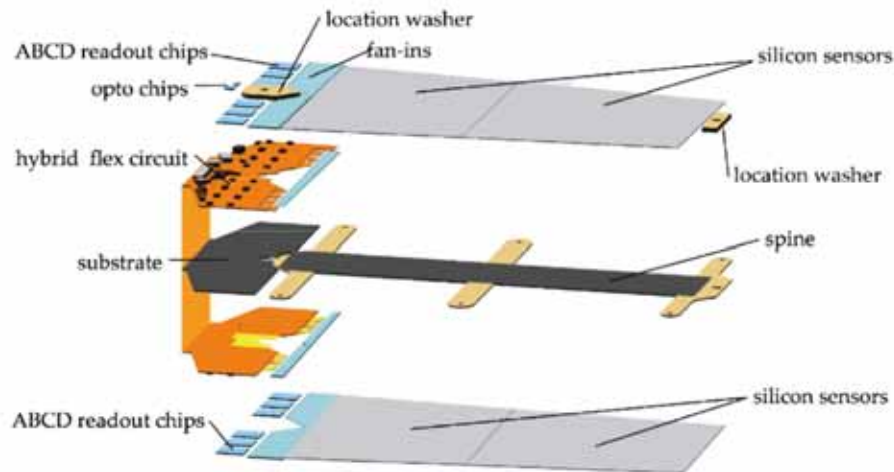


Outer

Middle  
Short-Middle

inner

1976 end-cap modules assembled  
at 7 SCT sites



# QA sequence

completed module assemblies (production site)

full characterization test

(reception test)

short characterization test

Thermal cycling

-25 ~+40 10times (~20hours)

short characterization test

Long term stability test

0 at least 24 hours

every 2 hours

short characterization test

Final full characterization test

Upload to the ATLAS-SCT database

characterization test

(1) Visual inspection

(2) Metrology measurements

(3) IV measurements

(4) Electrical performance tests



# Metrology

After the completed modules assemblies, modules were surveyed for mechanical precision. We have to measure each position with  $1\mu\text{m}$  accuracy.

- Tight module holding

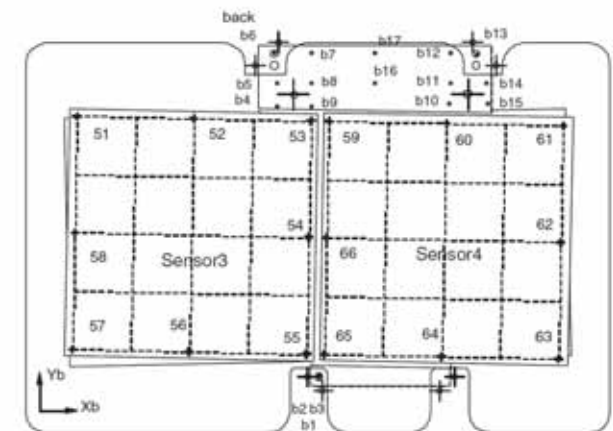
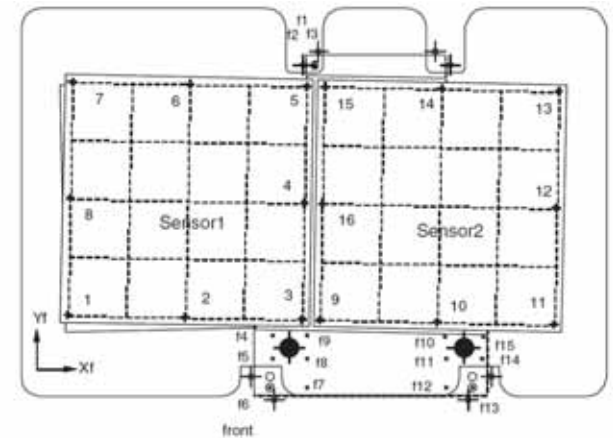
The module was held by vacuum in a measurement frame at three points.

- Transparent fiducial marks

We need transparent fiducial marks on the frame, or corner edges of the upper and lower sensors.

The precision was characterized by in-plane and out-of-plane parameters.

- in-plane survey: a well-defined set of fiducial marks on the sensors was used.
- out-of-plane survey: a matrix of points was measured on the surface of the sensors and the beryllia facings.



# mechanical parameters

Measured points are reduced in-plane and out-of-plane parameters.

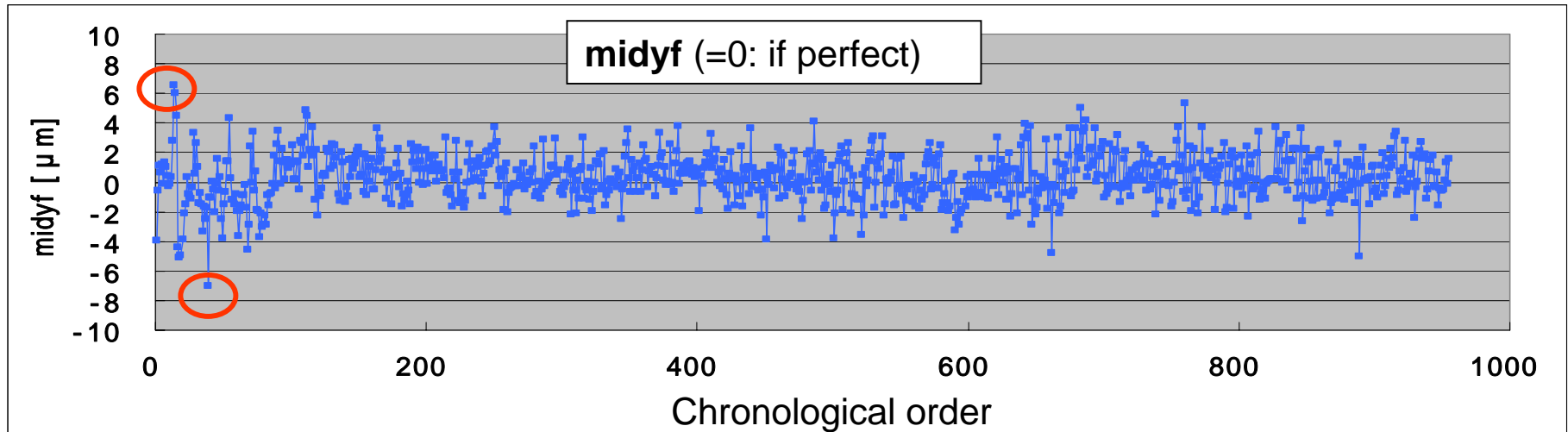
In-plane parameters of the SCT barrel module

Parameter	Design value	Specified tolerance
Dowel hole, mhx ( $\mu\text{m}$ )	-6500.0	40.0
Dowel hole, mhy ( $\mu\text{m}$ )	-6500.0	40.0
Dowel slot, msx ( $\mu\text{m}$ )	38,500.0	140.0
Dowel slot, msy ( $\mu\text{m}$ )	-37,000.0	40.0
Mid-point of front pair, midxf ( $\mu\text{m}$ )	0.0	20.0
Mid-point of front pair, midyf ( $\mu\text{m}$ )	0.0	8.0
Separation of front pair, sepf ( $\mu\text{m}$ )	64,090.0	20.0
Separation of back pair, sepb ( $\mu\text{m}$ )	64,090.0	20.0
Sensor1 angle, a1 (mrad)	0.00	0.13
Sensor2 angle, a2 (mrad)	0.00	0.13
Sensor3 angle, a3 (mrad)	0.00	0.13
Sensor4 angle, a4 (mrad)	0.00	0.13
Half stereo angle, half-stereo (mrad)	-20.00	0.13
Mid-point of front hybrid fiducial pair, hymxf ( $\mu\text{m}$ )	7698.5	200.0
Mid-point of front hybrid fiducial pair, hymyf ( $\mu\text{m}$ )	-154.0	200.0
Angle of front hybrid fiducial pair, hymaf (mrad)	-20.00	3.145
Mid-point of back hybrid fiducial pair, hymxb ( $\mu\text{m}$ )	7698.5	200.0
Mid-point of back hybrid fiducial pair, hymyb ( $\mu\text{m}$ )	154.0	200.0
Angle of back hybrid fiducial pair, hymab (mrad)	20.00	3.145
Connector pin #1, conplx ( $\mu\text{m}$ )	3611.8	480
Connector pin #1, conply ( $\mu\text{m}$ )	-69451.1	200

Z parameters of the SCT barrel module

Parameters	Nominal	Tolerance
maxZlower (mm)	0	abs < 0.2
maxZupper (mm)	0	abs < 0.2
moduleThickness (mm)	1.15	diff < 0.1
optimalMaxZerrorLower (mm)	0	abs < 0.07
optimalMaxZerrorUpper (mm)	0	abs < 0.07
optimalRmsZerrorLower (mm)	0	abs < 0.025
optimalRmsZerrorUpper (mm)	0	abs < 0.025
coolingTabThickness (mm)	0.93	< 1.0
farTabThickness (mm)	0.93	< 1.0
loCoolingFacing a (mrad)	0	abs < 0.5
loCoolingFacing b (mrad)	0	abs < 5
loCoolingFacingConcavity (mm)	0	abs < 0.03
hyb1NearH (mm)	1.18	0.25
hyb1FarH (mm)	1.18	0.25
hyb2NearH (mm)	1.18	0.25
hyb2FarH (mm)	1.18	0.25
hyb1Concavity (mm)	0	0.125
hyb2Concavity (mm)	0	0.125
hyb1CapMaxH (mm)	2.43	0.30
hyb2CapMaxH (mm)	2.43	0.30
hybridMaxThickness (mm)	3.28	0.44
capMaxThickness (mm)	5.78	0.66

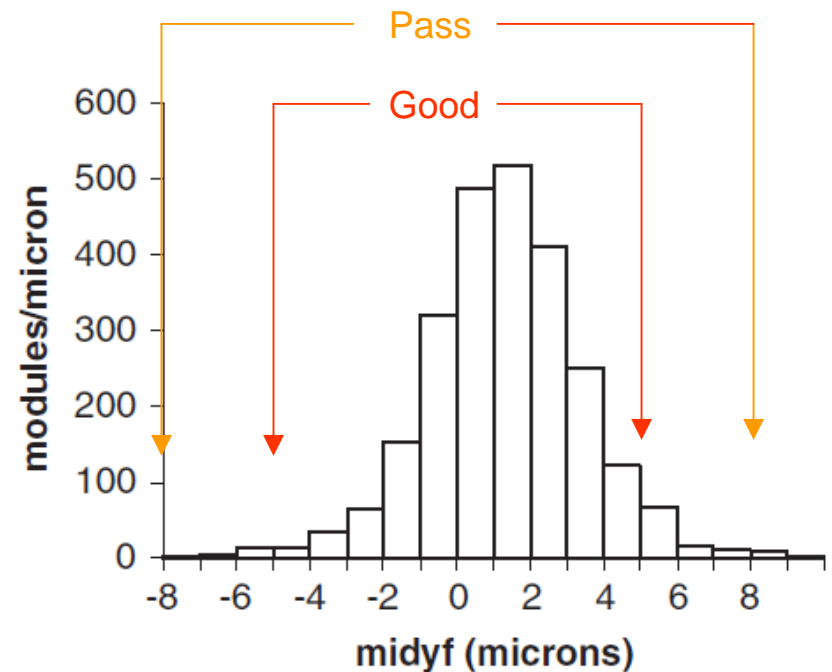
# Metrology results



The module is very rigid in-plane, and there is no measurable change in in-plane parameters, before and after thermal cycling and the long-term cold test.

Z deviations after thermal cycling are normally 10  $\mu\text{m}$ , and a further change of up to 20  $\mu\text{m}$  after the long-term test.

These are small in comparison with the tolerances.

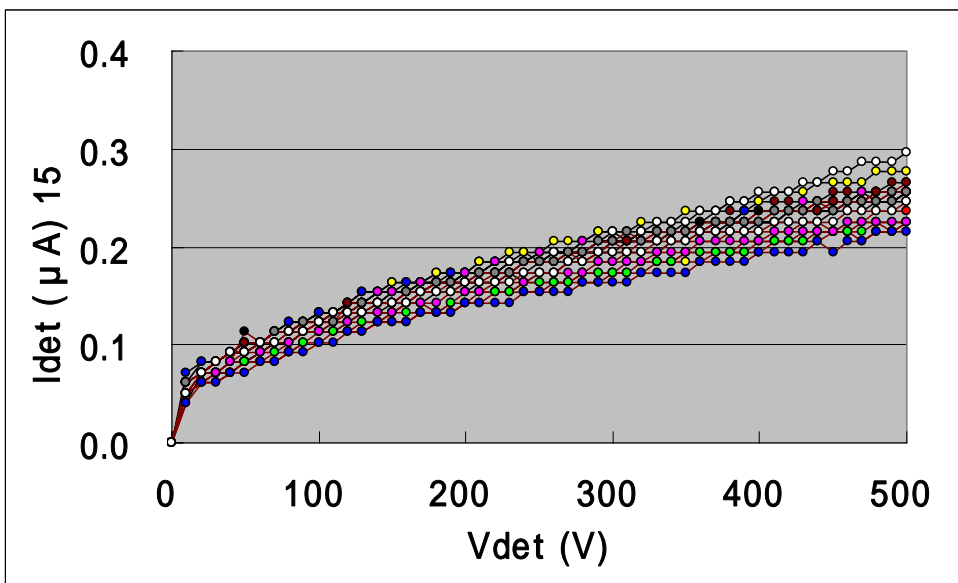


# Metrology classification

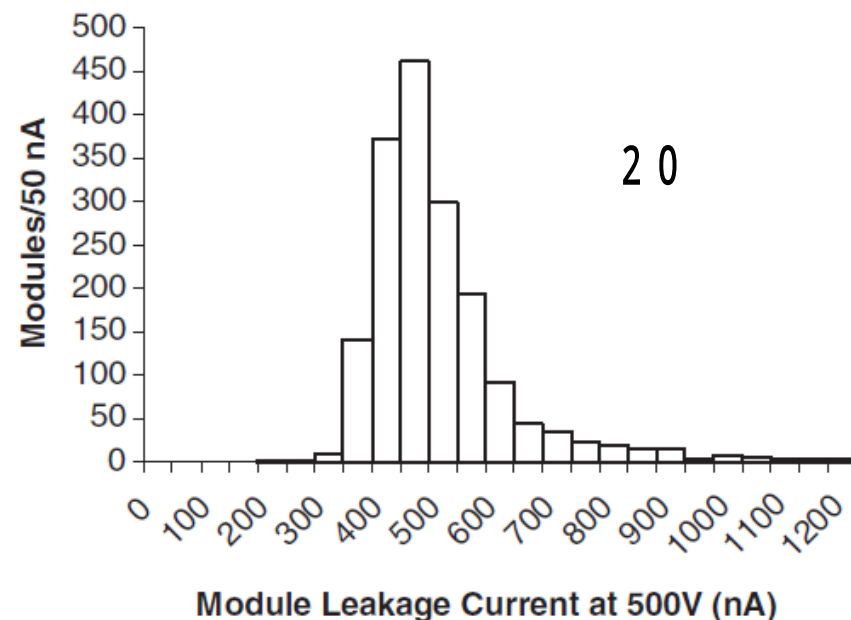
Metrology parameters		(Measurement values are rounded down for classification)				
	Parameter	GOOD	PASS	PASS2	SPARE	FAIL
in-plane	mhx [um]	+/-30	+/-40	+/-50	+/-60	> +/-60
	mhy [um]	+/-30	+/-40	+/-50	+/-60	> +/-60
	msx [um]	+/-100	+/-140	+/-170	+/-200	> +/-200
	msy [um]	+/-30	+/-40	+/-50	+/-60	> +/-60
	sepf [um]	+/-10	+/-20	+/-30	+/-40	> +/-40
	sepb [um]	+/-10	+/-20	+/-30	+/-40	> +/-40
	midxf [um]	+/-10	+/-20	+/-30	+/-40	> +/-40
	midyf [um]	+/-5	+/-8	+/-10	+/-15	> +/-15
	a1 [mrad]	+/-0.13	<-	+/-0.16	+/-0.24	> +/-0.24
	a2 [mrad]	+/-0.13	<-	+/-0.16	+/-0.24	> +/-0.24
	a3 [mrad]	+/-0.13	<-	+/-0.16	+/-0.24	> +/-0.24
	a4 [mrad]	+/-0.13	<-	+/-0.16	+/-0.24	> +/-0.24
	stereo [mrad]	+/-0.13	<-	+/-0.16	+/-0.24	> +/-0.24
	hymxf [um]	+/-100	+/-200	+/-500	<-	> +/-500
Out-of-plane	hymyf [um]	+/-100	+/-200	+/-500	<-	> +/-500
	hymaf [mrad]	+/-3.145	+/-3.145	+/-6.290	<-	> +/-6.290
	hymxb [um]	+/-100	+/-200	+/-500	<-	> +/-500
	hymyb [um]	+/-100	+/-200	+/-500	<-	> +/-500
	hymab [mrad]	+/-3.145	+/-3.145	+/-6.290	<-	> +/-6.290
	comp1x [um]	+/-320	+/-480	+/-640	<-	> +/-640
	comp1y [um]	+/-100	+/-200	+/-300	<-	> +/-300
	maxZlower [mm]	-0.2	<-	<-	<-	<-0.2
	maxZupper [mm]	0.2	<-	<-	<-	>0.2
	moduleThickness [mm]	0.1	<-	0.15	0.2	>0.2
	optimalMaxZerrorLower [mm]	0.05	0.07	0.09	0.11	>0.11
	optimalMaxZerrorUpper [mm]	0.05	0.07	0.09	0.11	>0.11
	optimalRMSZerrorLower [mm]	0.025	<-	0.03	0.03	>0.03
	optimalRMSZerrorUpper [mm]	0.025	<-	0.03	0.03	>0.03
	loCoolingFacing a [mrad]	+/-0.5	<-	+/-0.6	+/-0.6	> +/-0.6
	b [mrad]	+/-3	+/-5	+/-6	+/-7	> +/-7
	loCoolingFacingConcavity [mm]	+/-0.03	<-	+/-0.04	+/-0.05	> +/-0.05
	capMaxThickness [mm]	6.44	<-	<-	<-	>6.44
	hyb1NearH [mm]	+/-0.19	+/-0.25	+/-0.35	<-	> +/-0.35
	hyb1FarH [mm]	+/-0.19	+/-0.25	+/-0.35	<-	> +/-0.35
	hyb2NearH [mm]	+/-0.19	+/-0.25	+/-0.35	<-	> +/-0.35
	hyb2FarH [mm]	+/-0.19	+/-0.25	+/-0.35	<-	> +/-0.35
	hyb1Concavity [mm]	+/-0.15	+/-0.25	+/-0.35	<-	> +/-0.35
	hyb2Concavity [mm]	+/-0.15	+/-0.25	+/-0.35	<-	> +/-0.35
	hyb1CapMaxH [mm]	0.3	<-	<-	<-	>0.3
	hyb2CapMaxH [mm]	0.3	<-	<-	<-	>0.3
	hybridMaxThickness [mm]	0.44	<-	<-	<-	>0.44

Class of “Good” , “pass” and “pass2” modules are candidate for mounting cylinders and disks.

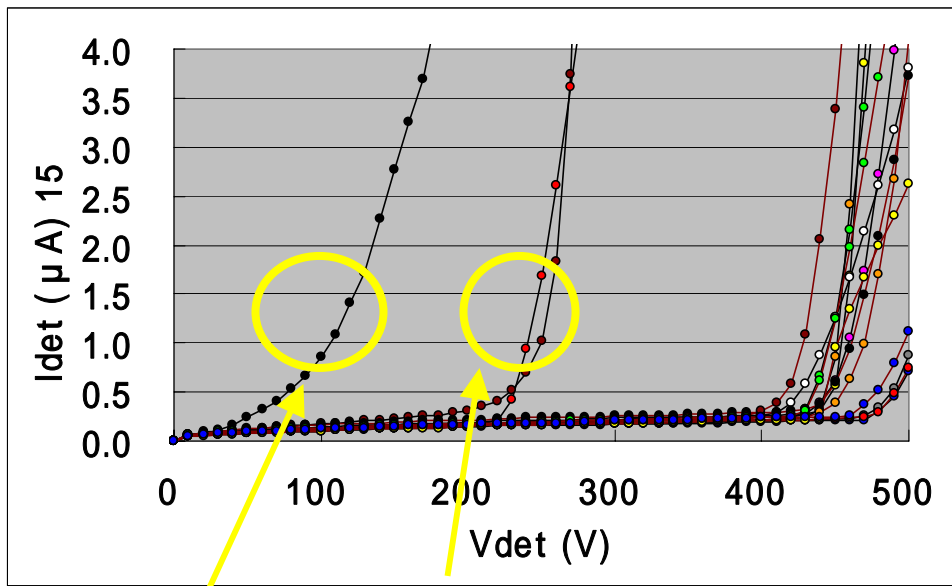
# Leakage current measurement



Good module 15  
w/o Micro-discharge  
~ 0.3  $\mu A$  @500V



# Leakage current classification



Fail

Spare

Parameter	GOOD	<-	PASS2	SPARE	FAIL
I-V [uA]	<=4@500V	<-	<-	<=4@350V	>4@350V
Microdischarge onset voltage [V]	>=350	<-	>=300	>=150	<150
Microdischarge decay time (MDM) [hr]	<=1	<-	<-	<=6	>6
Microdischarge decay plateau current [uA]	<=1	<-	<-	<=4	>4

	B3/B4	B5/B6	B6
Pre-series sensors	No	Yes	<-
MD>350V	>500V	>=350V	>=300V
Bad current behaviour	No	Yes	<-

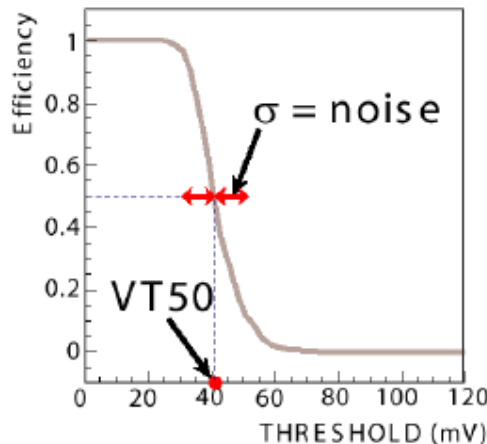
# Front-end readout chip :ABCD3T

## DMILL technology (BiCMOS)

- Binary architecture
- Gain                     $\sim 50\text{mV/fC}$
- ENC                     $\sim 1500\text{e}$  for an unirradiated module  
                              $\sim 1800\text{e}$  for an irradiated module
- peaking time    $\sim 20\text{nsec}$
- pipe line memory with 132 depth
- trimDAC            individual threshold correction in every channel  
                             using a 4-bit digital-to-analogue converter
- test pulse            Each channel has an internal Calibration Capacitor  
                             connected to its input for purposes of simulating a hit strip.

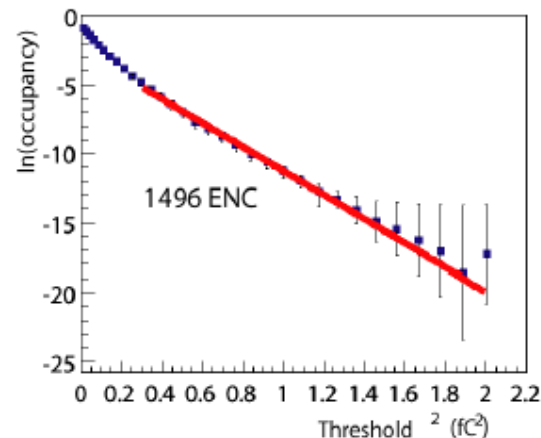
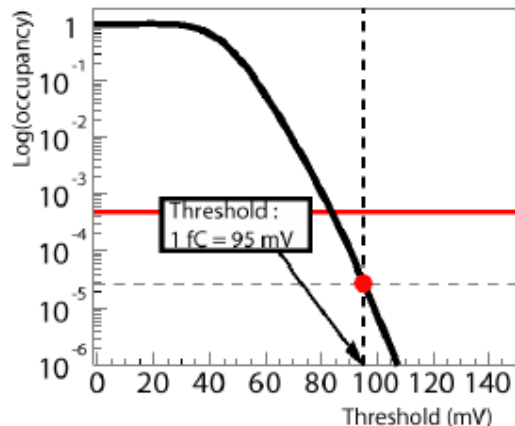
# Electrical tests

- digital function tests (pipe line memory, channel mask, ... )
- 3 point gain

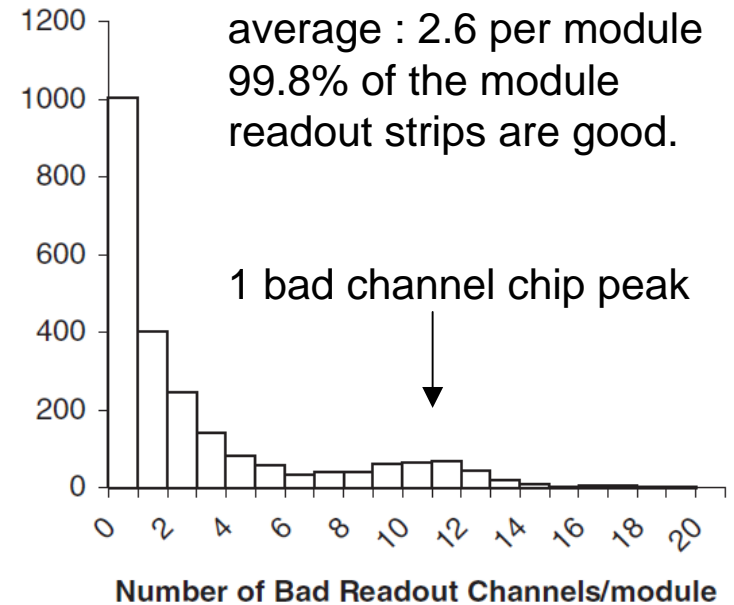
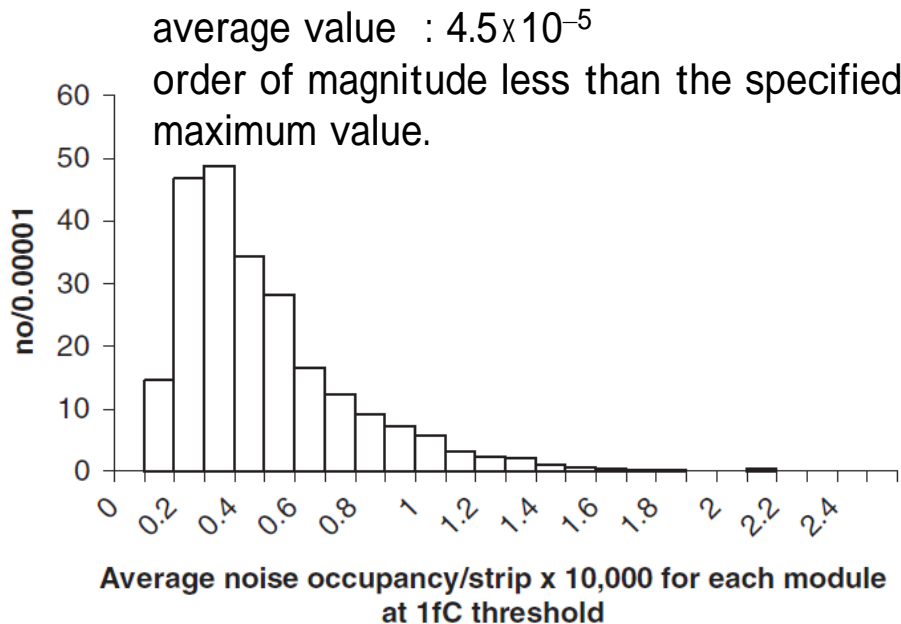
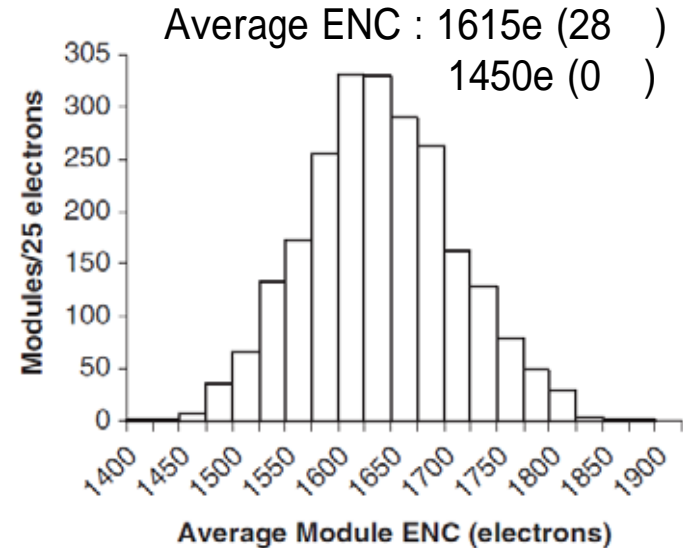
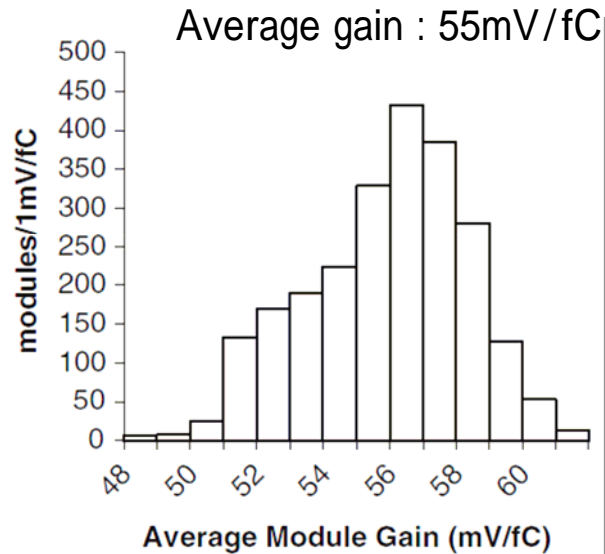


threshold scans for 3 different input charges  
From the error function fitting, the channel gain, discriminator offset and equivalent noise charge (ENC) at the discriminator input can be extracted.

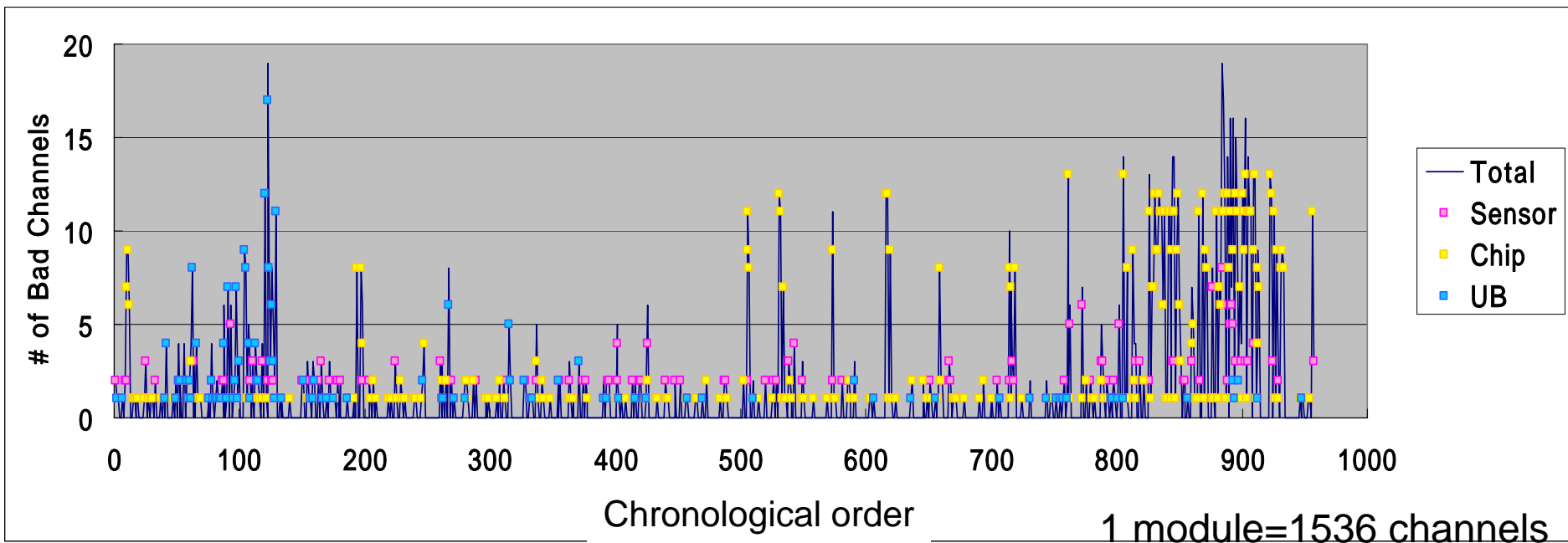
- trim scan : trim DAC tuning (do threshold scans with changing DAC)
- response curve scan (10 input charges)
- noise occupancy



# Electrical tests results



# Bad channel

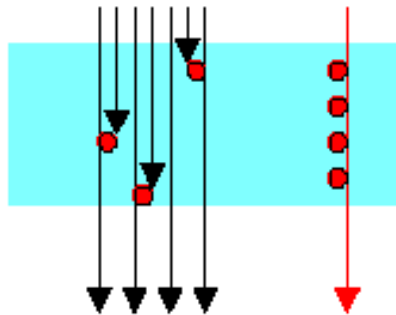


Bad channel/module = 1.8 ch (0.8 ch excl. 1bad ch chip)  
0.3 ch : sensor defects  
1.3 ch : chip defects (0.3 ch excl. 1bad ch chip)  
0.2 ch : WB defects (Unbonded)

# Barrel module production

Cumulative	GOOD+PASS+PASS2				YIELD	Rate						
Date	for any	for B5	for B6	total		GOOD	PASS	PASS2	(HOLD)	SPARE	FAIL	REWORK
030501	55	17	0	72	74.2%	69.1%	5.2%	0.0%	27.3%	0.0%	4.1%	6.2%
030601	74	24	0	98	76.6%	70.3%	6.3%	0.0%	25.7%	0.0%	3.9%	4.7%
030701	495	90	0	585	85.8%	79.2%	6.3%	0.3%	10.1%	0.3%	3.4%	3.2%
030801	530	98	0	628	85.8%	78.7%	6.8%	0.3%	10.8%	0.3%	3.4%	2.7%
030901	566	106	0	672	85.4%	78.3%	6.9%	0.3%	11.5%	0.3%	3.6%	2.5%
031001	627	130	0	757	86.0%	78.5%	7.3%	0.2%	10.0%	0.2%	4.1%	2.5%
031101	657	180	0	837	86.0%	78.2%	7.6%	0.2%	11.1%	0.2%	4.0%	2.3%
031201	721	198	0	919	86.0%	78.5%	7.3%	0.2%	10.8%	0.2%	4.6%	2.0%
040101	758	207	0	965	85.8%	78.5%	7.1%	0.2%	11.7%	0.2%	4.3%	1.9%
040201	806	248	0	1054	86.5%	79.3%	7.0%	0.2%	11.2%	0.2%	4.0%	2.0%
040301	937	281	0	1218	86.9%	79.8%	7.0%	0.1%	10.6%	0.1%	3.9%	1.9%
040401	1066	312	0	1378	86.8%	80.3%	6.4%	0.1%	11.0%	0.1%	3.7%	2.0%
040501	1210	321	0	1531	88.3%	80.2%	6.5%	1.6%	4.8%	1.6%	5.0%	1.8%
040601	1315	340	0	1655	89.1%	81.1%	6.4%	1.6%	1.7%	2.7%	5.2%	1.8%
040701	1450	365	32	1847	90.0%	80.0%	6.4%	3.5%	1.6%	2.6%	4.9%	1.4%
040801	1518	358	84	1960	90.4%	82.2%	5.7%	2.5%	0.9%	3.4%	4.8%	0.9%
040901	1609	390	96	2095	90.0%	81.7%	5.5%	2.8%	0.8%	3.3%	4.8%	1.4%
041001	1713	410	110	2233	90.1%	81.4%	5.5%	3.1%	0.8%	3.3%	4.7%	1.4%
041101	1730	465	119	2314	91.7%	82.2%	5.7%	3.8%	0.3%	3.2%	4.6%	0.2%
041201	1742	452	117	2311	90.9%	81.2%	5.9%	3.8%	0.3%	4.2%	4.5%	0.2%
050101	1742	452	117	2311	90.9%	81.2%	5.9%	3.8%	0.3%	4.2%	4.5%	0.2%
050201	1759	461	118	2338	90.5%	80.8%	5.9%	3.8%	0.3%	4.3%	4.8%	0.2%

# Electrical tests with Nd:YAG laser



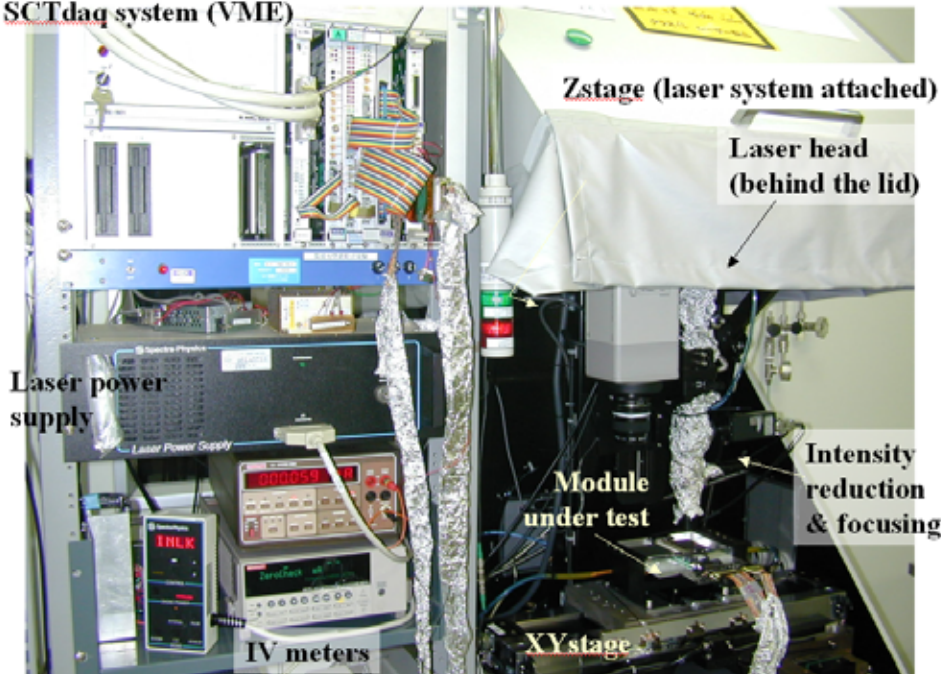
Laser m.i.p.

Since the energy of Nd:YAG laser 1.165 eV is just above the Si band gap energy of 1.12 eV, most of the laser light penetrates the Si sensor.

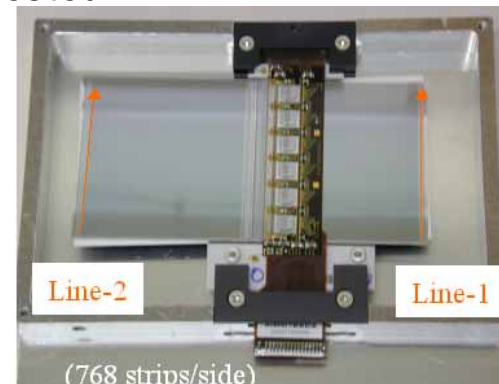
Thus the passage of charged particles can be simulated if the laser is collimated (2~3  $\mu\text{m}$  square spot) and its intensity properly adjusted.

## Nd:YAG Laser\* Test System

SCTdaq system (VME)



A total of 656 ATLAS SCT barrel modules were tested.



Number of channels 1,007,616

Defects not detected by electrical test 23

AI breaks identified by laser and HPK (16)

New sensor defects identified by laser only (4)

New defects, but reason not identified (3)

# Site qualification

All sites taking part in module production were subject to a thorough qualification procedure, where all aspects of production and testing were reviewed, including documentation, cleanliness, ESD safety, component traceability and accountability, etc.

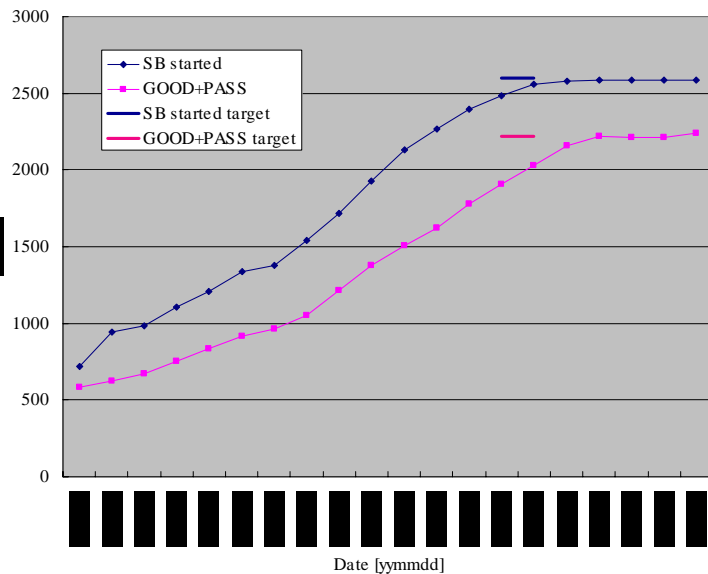
Each production line was required to produce at least five modules fully within specifications. Modules were exchanged between sites to ensure uniform quality and comparability of measurements.

# Summary

A total of 2582 for barrel and 2380 for end-cap modules have been constructed during a 2-year period of series production.

The overall yield of modules with satisfactory mechanical and electrical performance is 91% for barrel and 93% for end-cap, respectively.

## Barrel module production rate



## End-cap module production rate

