19th RD50 Workshop
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CERN

ATLAS Semi-Conductor Tracker (Strips)

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with input from
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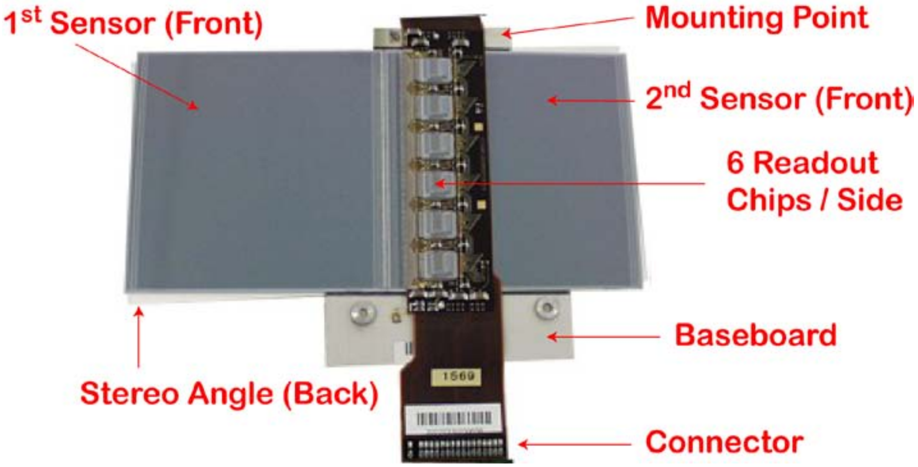
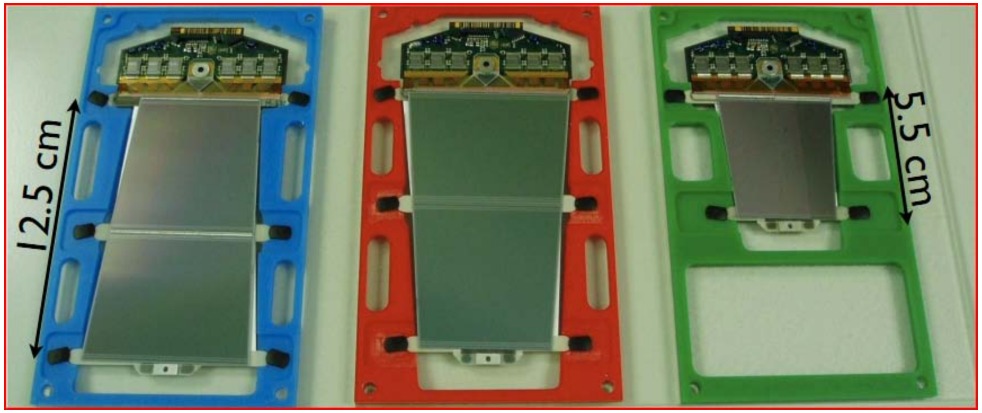
The SCT Modules (The basic detector unit)

- **Sensor Parameters**
  - Stand by Voltage = 50Volts
  - Operational Voltage =150Volts
  - Leakage current measured to 10nA
- **Temperature**
  - NTCs on Hybrid (2 BAR, 1 EC)
  - Difference Hybrid Si from FEA and measurement
  - Barrel Temp (Si) =-3°C End Caps =-7°C
  - Cooling by evaporation of C_3F_8
  - ***Barrel 6 operates at Thermal Shield (10°C warmer)***
- **Environment**
  - Volume is flushed with dry Nitrogen

- **Sensor Dimensions**
  - 12 (2x6) cm (B), 6-12 (1or2 x 6cm) cm (ECs)
  - See next slide for sensor details.
- **Baseboard**
  - Thermal Pyrolitic Graphite
  - Mechanical & thermal structure
- **Readout**
  - Rad-hard front-end readout chips (ABCD)
  - 6 chips/side, 128 channels/chip
  - 48 modules (96 optical links) served by 1 ROD
  - Mechanical & thermal structure
- **Resolutions**
  - ~17 μm(rφ, bending plane), ~580 μm (z)



Barrel Module



End Cap Modules

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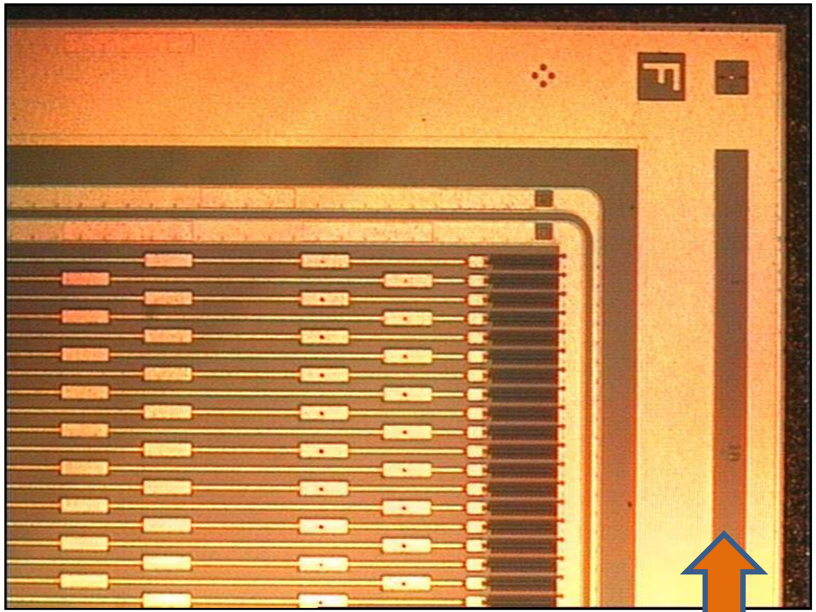
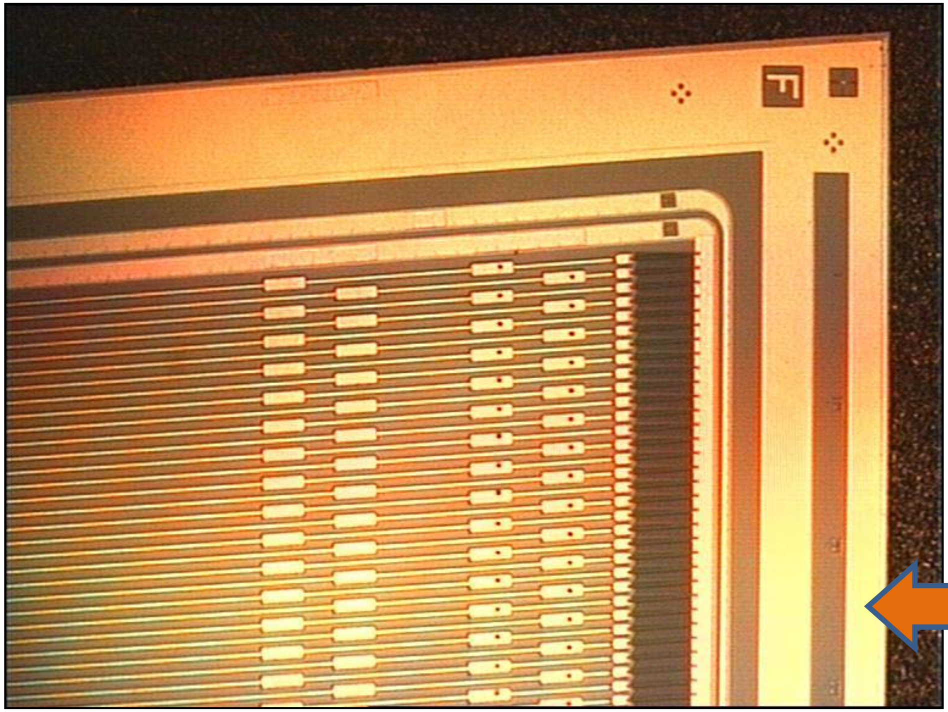
The SCT Sensors

- Single sided p-on-n
- <111> substrate, 285μm thick
- 768+2 AC-coupled strips
- Polysilicon (1.5MΩ) Bias
- Strips reach-through protection 5-10μm
- Strip metal/implant widths 20/16μm



- 8448 barrel sensors
- 64.0 x 63.6mm
- 80μm strip pitch
- All supplied by HPK



- 6944 wedge sensors
- 56.9-90.4μm strip pitch
- 5 flavours
- 82.8% HPK
- 17.2% CiS

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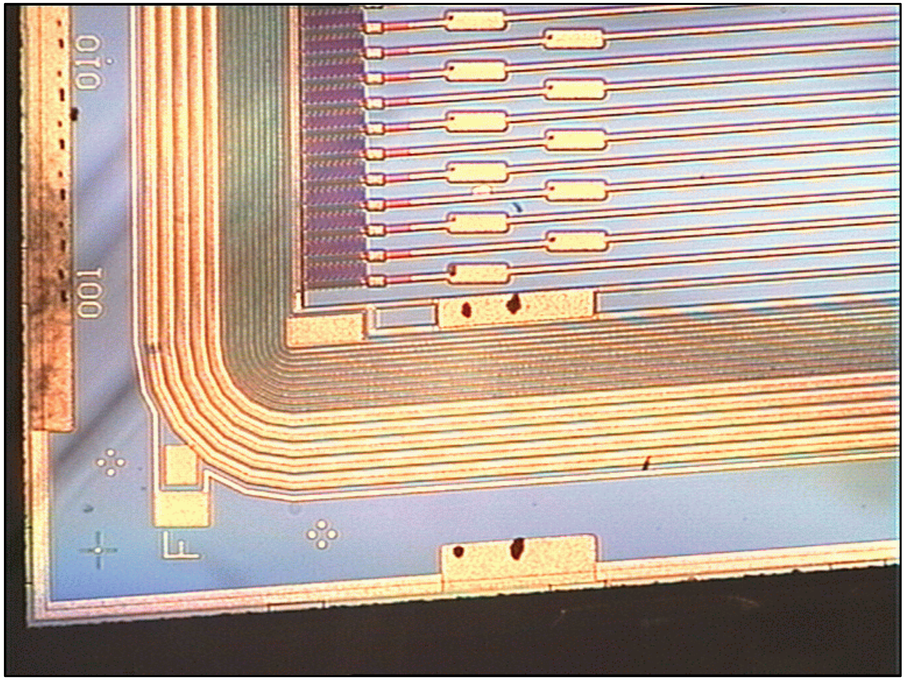
The SCT CiS Sensors – “Same spec, different species”



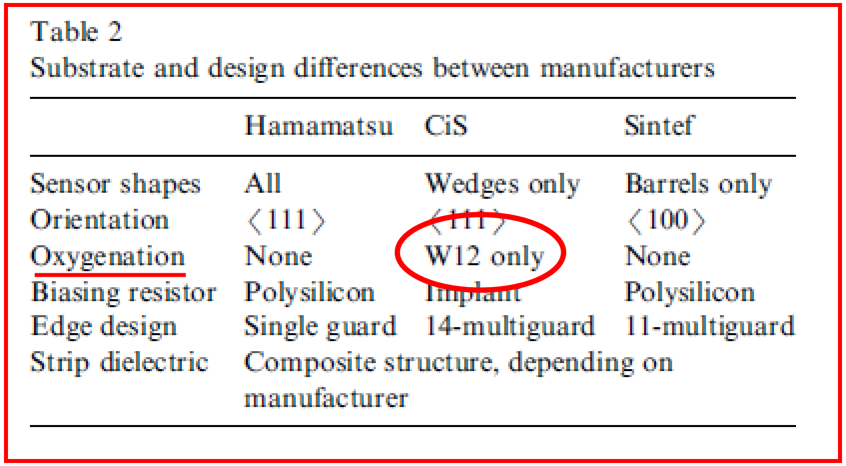


Table 2

Substrate and design differences between manufacturers

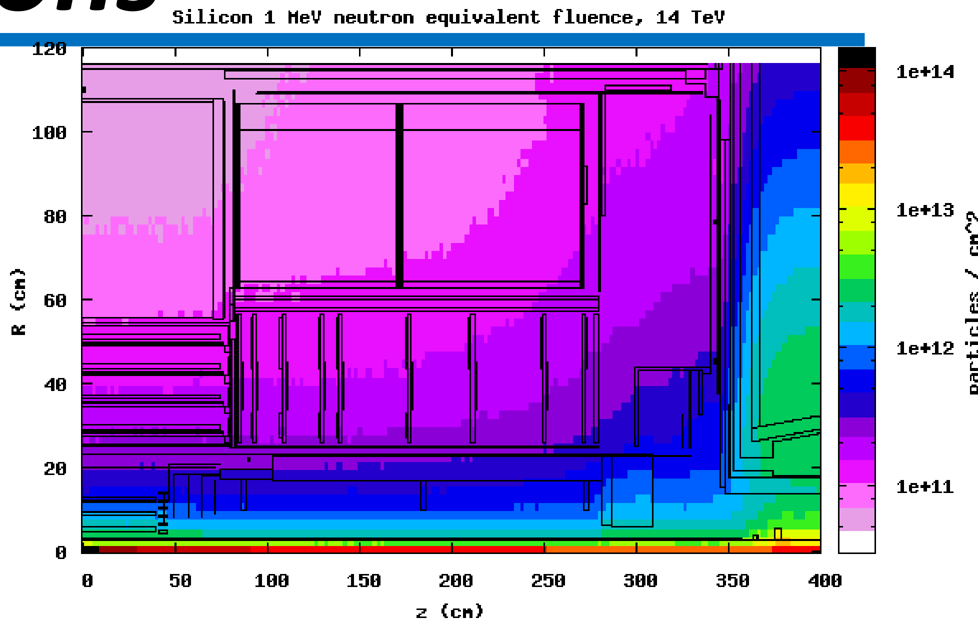
	Hamamatsu	CiS	Sintef
Sensor shapes	All	Wedges only	Barrels only
Orientation	⟨111⟩	⟨111⟩	⟨100⟩
Oxygenation	None	W12 only	None
Biasing resistor	Polysilicon	Implant	Polysilicon
Edge design	Single guard	14-multiguard	11-multiguard
Strip dielectric	Composite structure, depending on manufacturer		

	Hamamatsu	**CiS**
Bias Resistors (1.5MΩ)	Polysilicon	Implant
Strip metal/implant widths (μm)	20/16	16/20
Guard design	Single floating	Multi-guard
Barrels supplied	8448	0
Wedges supplied	6944	1196

Fluence Expectations

The silicon detectors SCT & PIX will be exposed to high a fluence of particles which will affect their performance.

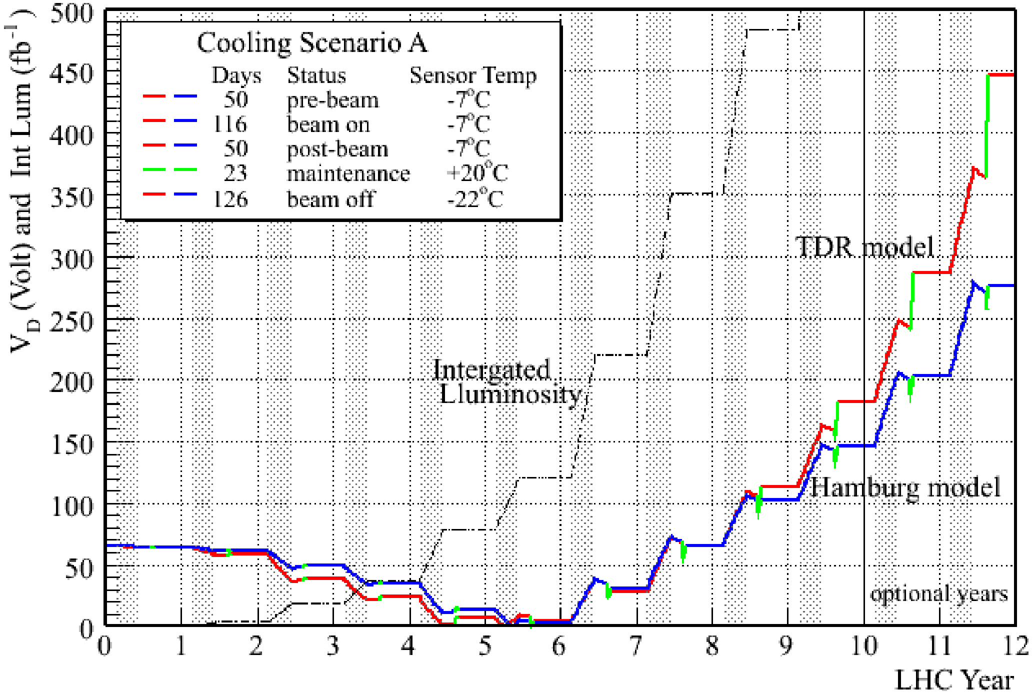
The PIXEL and SCT groups will monitor the affects of radiation on the leakage currents and depletion voltages



layer	R (cm)	Z(cm)	n_{eq} fluences (cm^{-2})/$100fb^{-1}$	n_{eq} fluences (cm^{-2}) /$730fb^{-1}$
Pixel B-layer	4.2	0-40.7	$267*10^{12}$	$1922*10^{12}$
Pixel B2	12.7	0-40.7	$46*10^{12}$	$335*10^{12}$
SCT B3	30	0-75	$16*10^{12}$	$130*10^{12}$
SCT B6	52	0-75	$8.9*10^{12}$	$65*10^{12}$
SCT D9	44-56	272	$14*10^{12}$	$102*10^{12}$

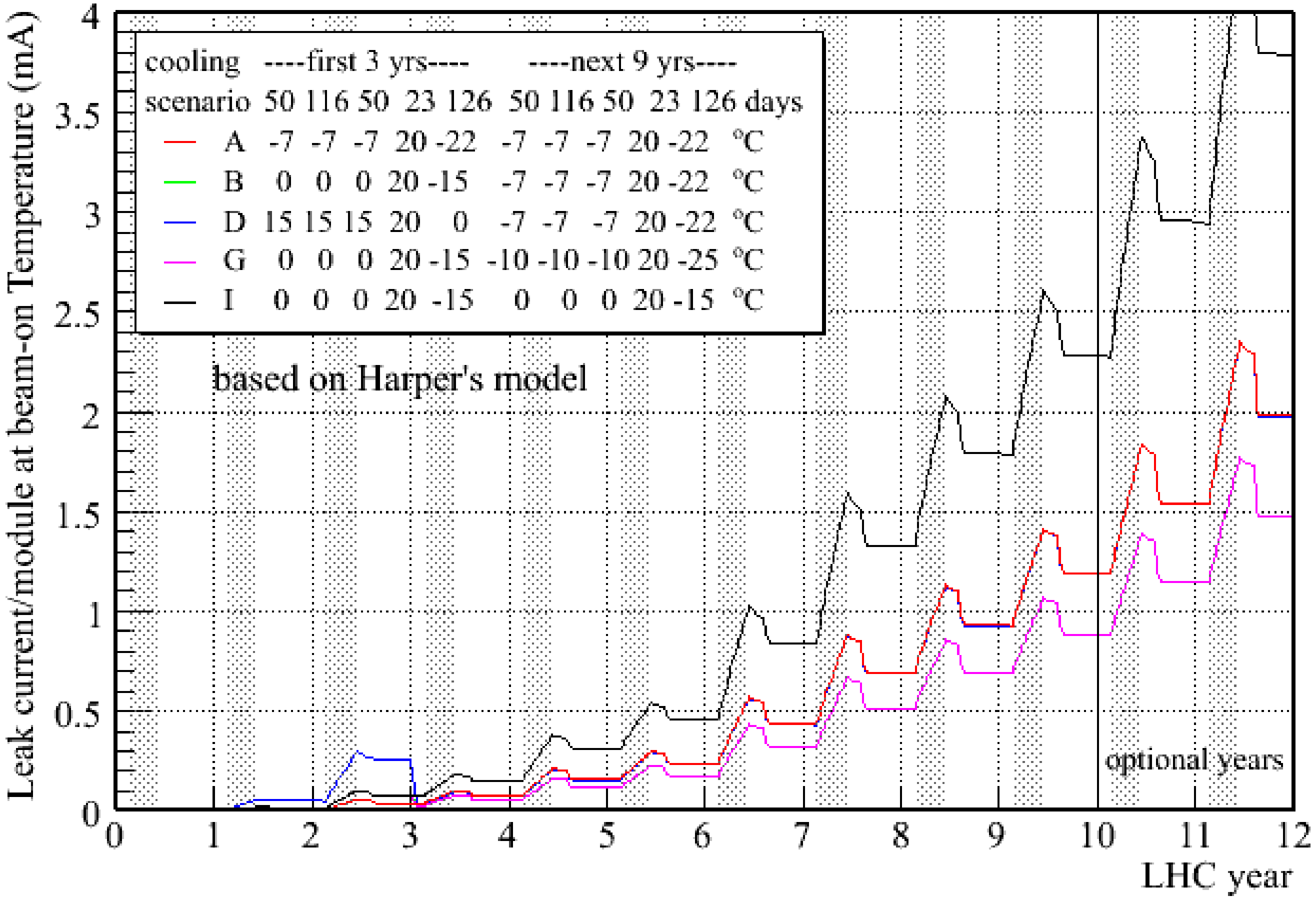
ATLAS-GEN-2005-001

Predictions (Depletion Voltage)



Prediction of LHC Luminosity profile (one particular profile with high(ish) integrated values)													
year	1 2010	2 2011	3 2012	4 2013	5 2014	6 2015	7 2016	8 2017	9 2018	10 2019	11 2020	12 2021	year
IL/year	0.5	3.3	15	19	41	42	99	132	132	145	193	242	fb^{-1}
Integ. L	0.5	***3.8***	19	38	79	121	220	352	484	**629**	822	**1064**	fb^{-1}

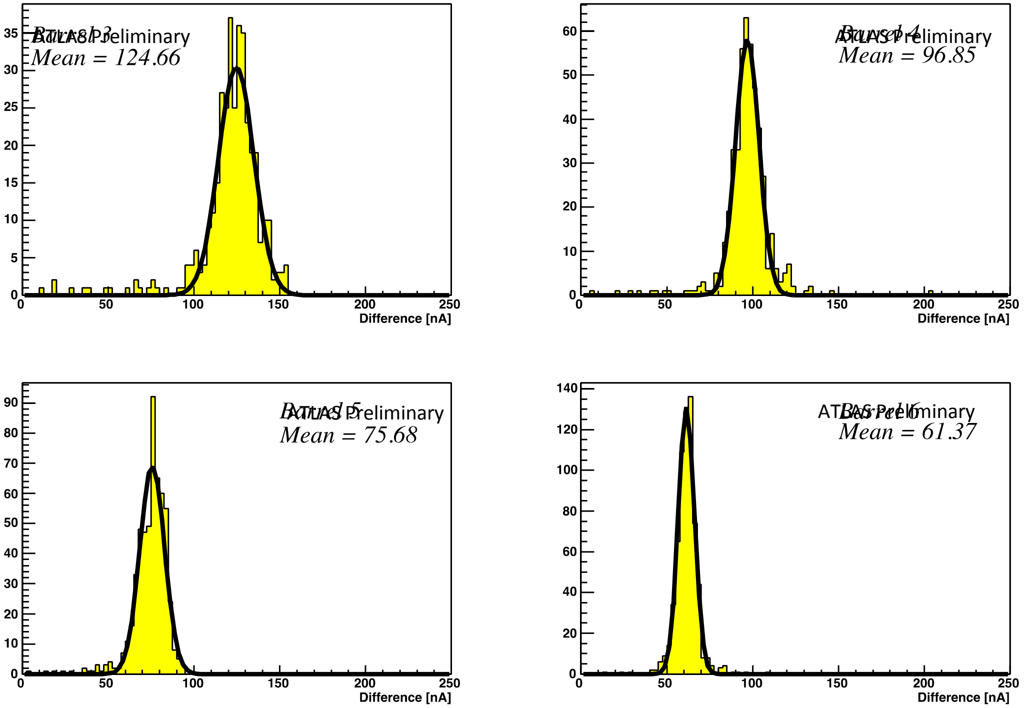
Predictions (Leakage current)



Barrel-3 for various cooling scenarios based on Harper's model (PhD Thesis, Sheffield). The integrated luminosity uses the same model as the previous slide.

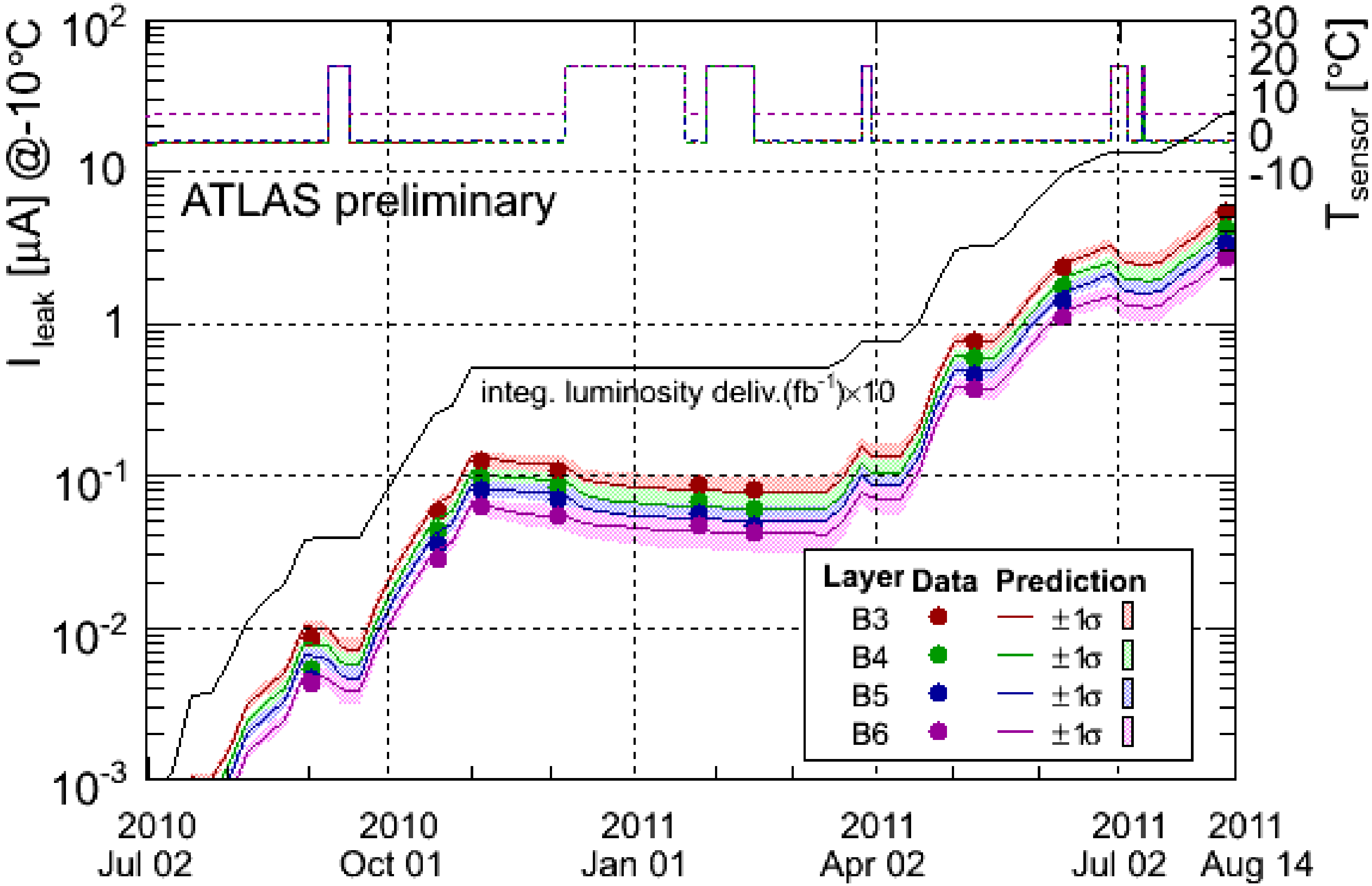
Leakage Current Measurements

- Measure current during Machine Development (FSI off)
  - *Current monitored constantly but make these special measurements during TS*
- Average over a period of time
- Correct current to -10^{o}C (temperature QA irradiations were performed at)
- Since first workshop now use 0^{o}C (but older results shown here)



A example of the measurements made in the barrel

Comparison of SCT measured leakage current and prediction



Excellent agreement between prediction and measurement through 2010 and 2011

The CIS Leakage Current Problem

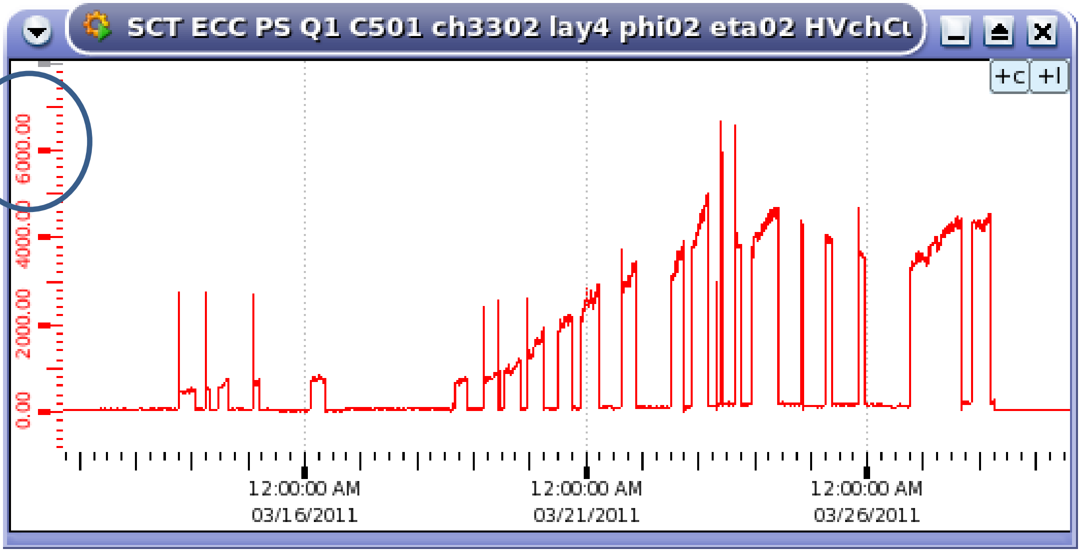
- During production become clear that the CIS SCT sensors were very sensitive to humidity
  - A significant subset displayed poor IV and early (<150V) breakdown in dry conditions
  - Need humidity to maintain a ‘healthy looking’ IV
  - Became more apparent during module tests which (unlike sensor QA) were typically conducted in nitrogen environment
  - Problem identified as micro-discharge from strips, due to lack of field plate (strip metal narrower than implant)
- As this became an issue rather late in the delivery program, SCT adopted a pragmatic strategy:
  - Only accept sensors with no sign of breakdown below 150V in dry air
  - OK for the short term, and then strip micro-discharge becomes less relevant after type inversion

CIS Leakage Current Problem

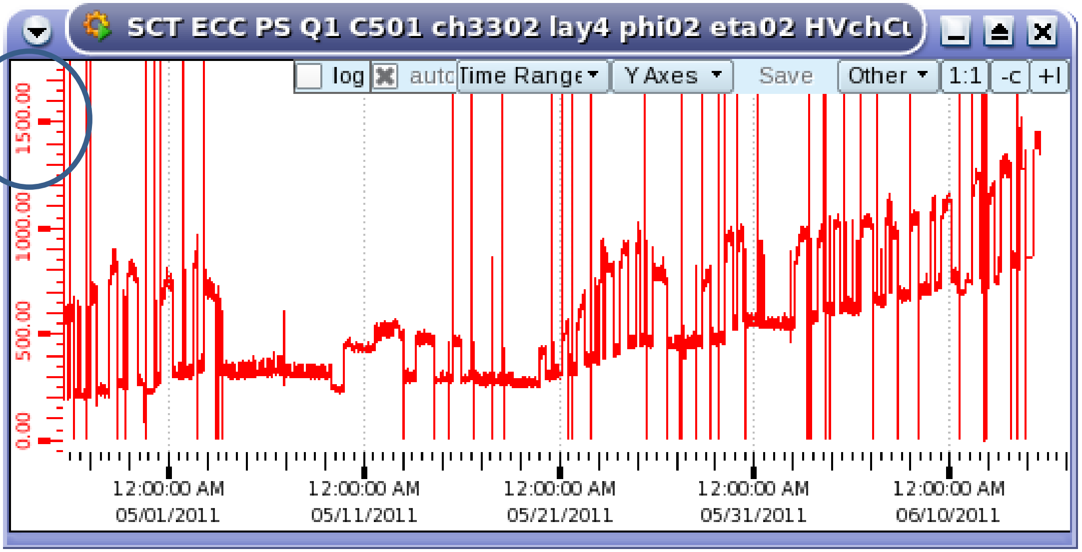
- We have had a small but significant (~30/4088) number of modules which have developed anomalously high leakage currents this year (2011)
- Almost all were constructed with CIS sensors, and all showed IV breakdown above 150V during production QA tests
- We believe that oxide charge buildup from ionising radiation is shifting the breakdown voltage downwards
  - *Decreasing HV and increasing current limits means we do keep operating these devices with full efficiency so far*

Example of leakage current deterioration from anomalous CIS-equipped modules

Note scales



Dramatic increase in current at 150V in April 2011 (but not for 50V) - breakdown



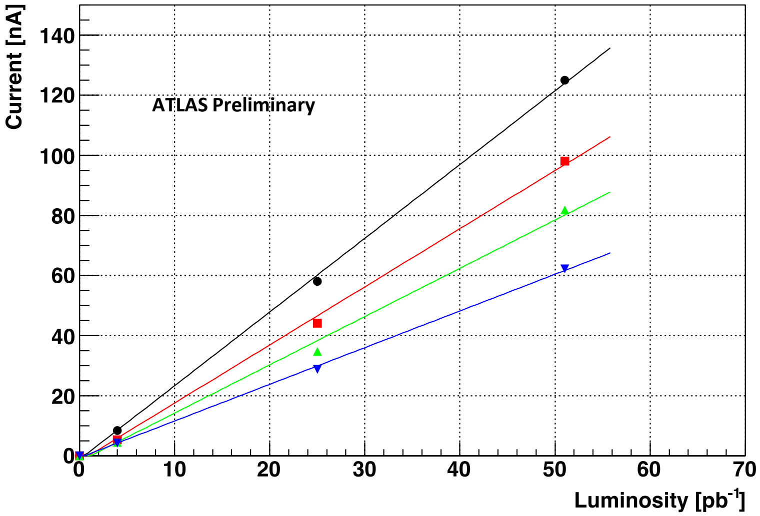
“Normal” behavior in June, albeit at 80V – bulk damage

Fluence extraction

1 MeV neutron equivalent fluences obtained from increased leakage currents

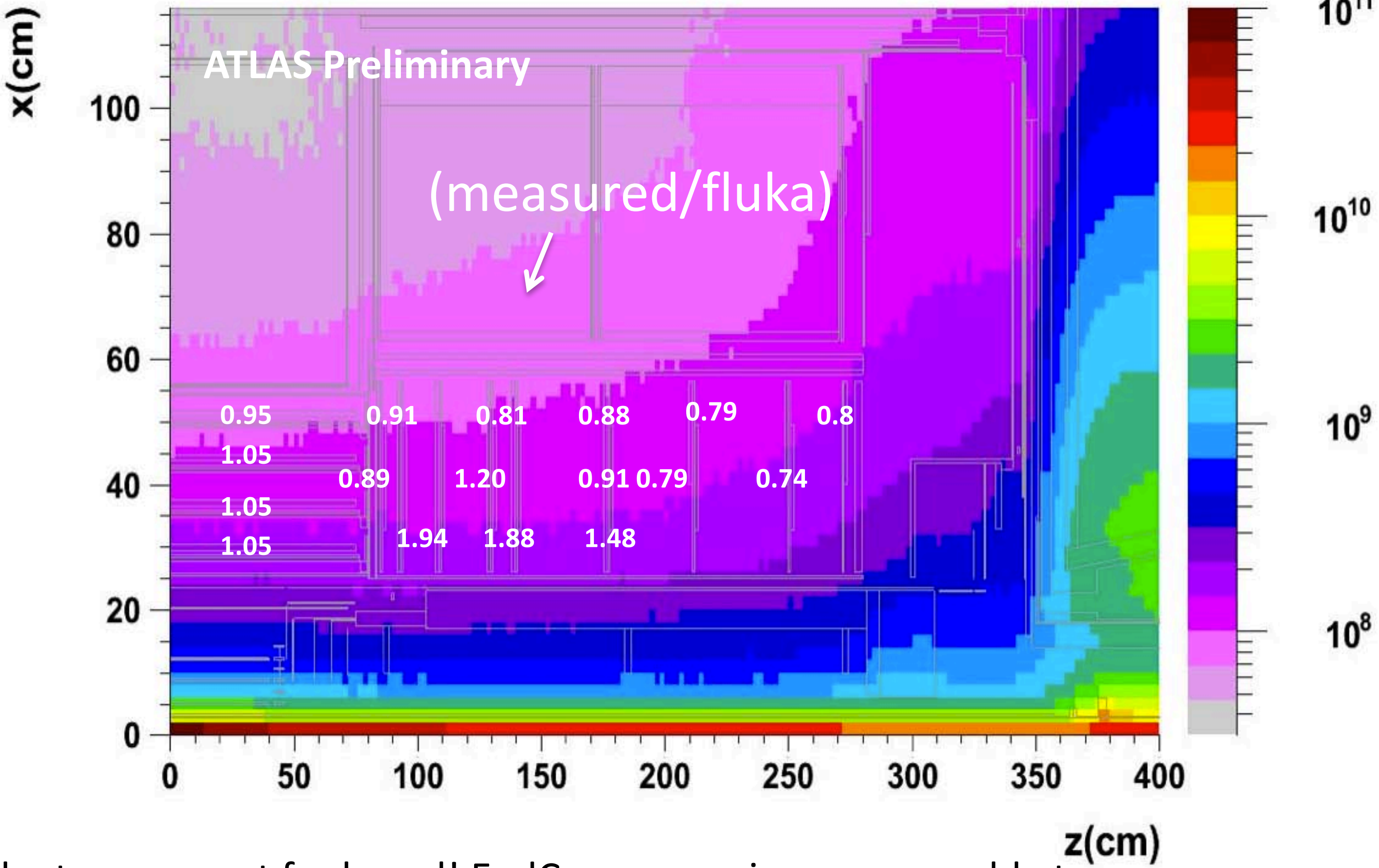
$$\Delta I = I_{Measured} - I_{Initial} = \alpha\phi V$$

I: leakage current	(measured)
α: damage parameter	(known)
V: active volume of detector	(known)
Φ: fluence	***(what we want)***



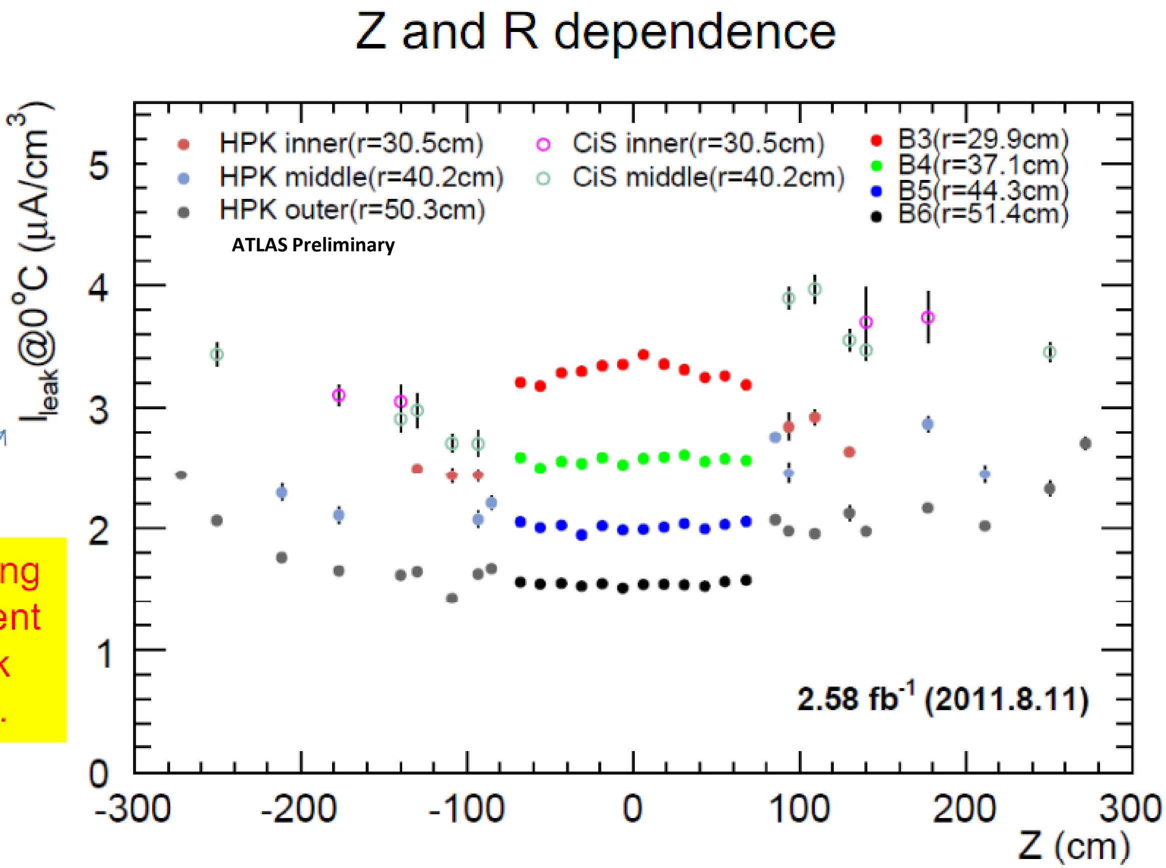
Linear increase in leakage currents with luminosity suggests fluences dominated by pp collisions (cf machine background.)

Comparison of 1MeV n-eq fluences determined from SCT leakage current measurements with simulated FLUKA predictions @ 7 TeV.



- Excellent agreement for barrel! EndCap comparisons reasonable too.
  - (Indicated are differences for EC-C.)
- For inner rings we measure consistently higher than predictions – why?

SCT Leakage Current



Assuming all current is bulk origin.

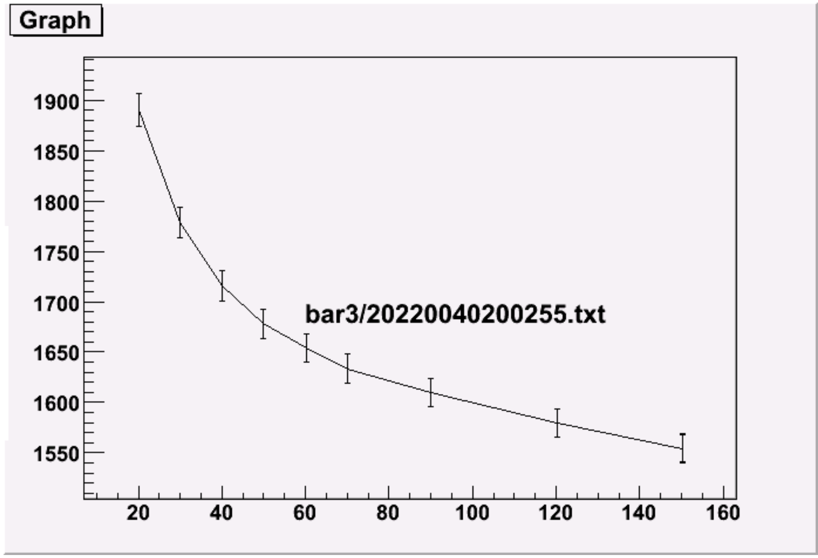
(1) CiS (○) shows higher current than HPK (●).
(2) A-side showes higher current .
(3) Large-z modules show higher current.

Shifting the “measured” temperature in the +Z end cap (2°C) removes discontinuity between the end of the barrel and end-caps (but right now we have no reason to do this)

Depletion Voltage

- Capacitance contributes to the noise
- When bias voltage reaches full depletion voltage in silicon sensors the strip to backplane capacitance becomes minimal as well as the noise due to this capacitance.
- Measurements were done in December 2008 at the start of LHC running, and were repeated on 8th November 2011.
- Analysis to track the changes since 2008 is now in progress
- However at for the current integrated lumi
  - Expect ΔV for large radius = 3V
  - Expect ΔV for small radius = 6V

$$ENC = \frac{e^3}{36q_e}\left\{\frac{3}{T_p}(C_{tot}+C_{stray}+C_a+C_f)^2\left(4kT_cR_{bb}+\frac{2k^2T_c^2}{q_eI_c}+4kT_sR_s\right)\right. \\ \left.+\frac{5T_p}{3}\left(\frac{2q_eI_c}{\beta}+\frac{4kT_c}{R_f}+2q_eI_l+\frac{4kT_s}{R_{bias}}\right)\right\}^{\frac{1}{2}} \qquad (3.2)$$



Summary (ATLAS-SCT)

- Predictions have been made for the evolution of the depletion voltage and leakage current
- Measurements of the leakage currents have been performed
  - Excellent agreement with Hamburg model predictions
- Fluence measurements have excellent agreement with FLUKA simulations
- Depletion voltage measurements (noise scans) will be performed at the end of the year and compared to predictions
- The effects of radiation will continue to be monitored

Bulk leakage current

references	Robert Harper’s Thesis (2001, University of Sheffield)

$$I = g(\Theta(T_A)t_{ir}, \Theta(T_A)t^{'})\alpha\phi V$$

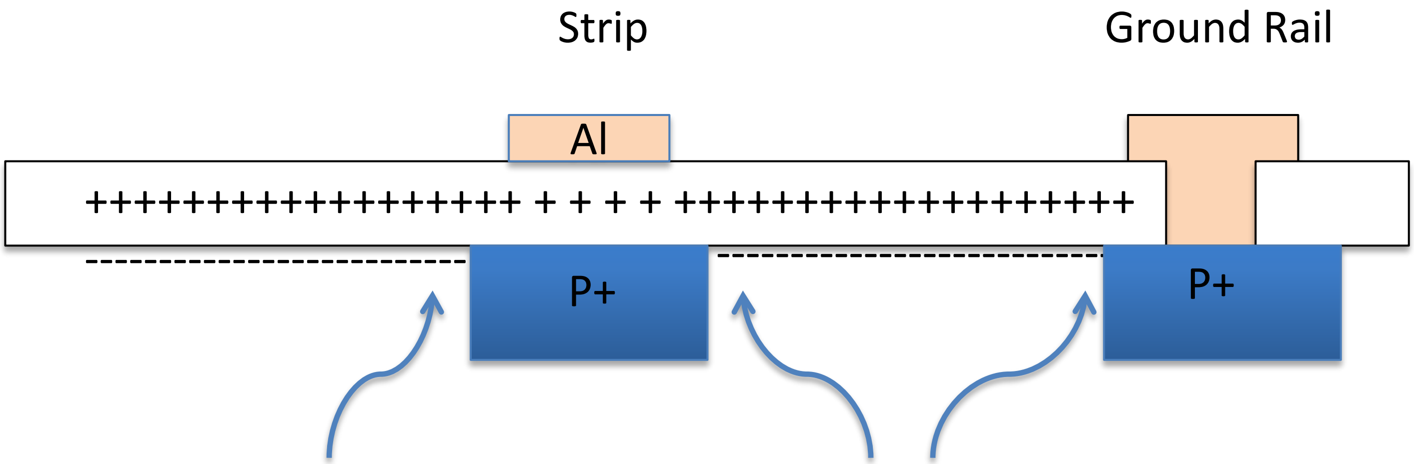
$$g(\Theta(T_A)t_{ir}, \Theta(T_A)t^{'}) = \sum_{i=1}^{n}\left\{A_i \frac{\tau_i}{\Theta(T_A)t_{ir}}\left[1-\exp\left(-\frac{\Theta(T_A)t_{ir}}{\tau_i}\right)\right]\exp\left(-\frac{\Theta(T_A)t^{'}}{\tau_i}\right)\right\}$$

$$\Theta(T_A) = \exp\left(\frac{E_I}{k_B}\left[\frac{1}{T_R}-\frac{1}{T_A}\right]\right)$$

$$\alpha_{eq}(-7^\circ C) = (6.90 \pm 0.20)\times 10^{-18}\ \mathrm{A \cdot cm^{-1}}$$

i	τ_i (min)	A_i
1	$(1.2 \pm 0.2)\times 10^{6}$	0.42 ± 0.11
2	$(4.1 \pm 0.6)\times 10^{4}$	0.10 ± 0.01
3	$(3.7 \pm 0.3)\times 10^{3}$	0.23 ± 0.02
4	124 ± 25	0.21 ± 0.02
5	8 ± 5	0.04 ± 0.03

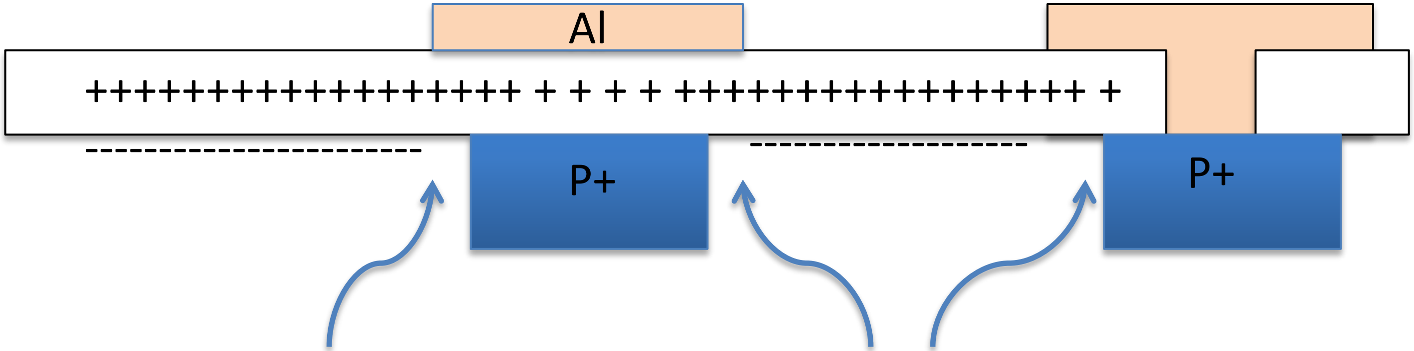
CiS Sensor strip schematic



High field regions lead to micro discharge

Build up of positive charge in oxide (which starts from a non-zero offset and steadily increases and eventually saturates with ionising radiation) leads to increasing electron accumulation layer at the Si-SiO interface, giving high field region at the edge of the implant. CiS sensors were known to have improved breakdown at high humidity because surface charge is always negative which suppresses the electron accumulation layer.

Hamamatsu Sensor strip schematic



Electron accumulation layer suppressed by field plate effect

Field plate effect suppresses electron accumulation layer (because strip metal is at negative potential wrt implant underneath it), lower field strength at edge of P+ implant, much less prone to micro discharge and less sensitive to humidity.