Interstrip Characteristics of ATLAS07 n-on-p FZ Silicon Detectors

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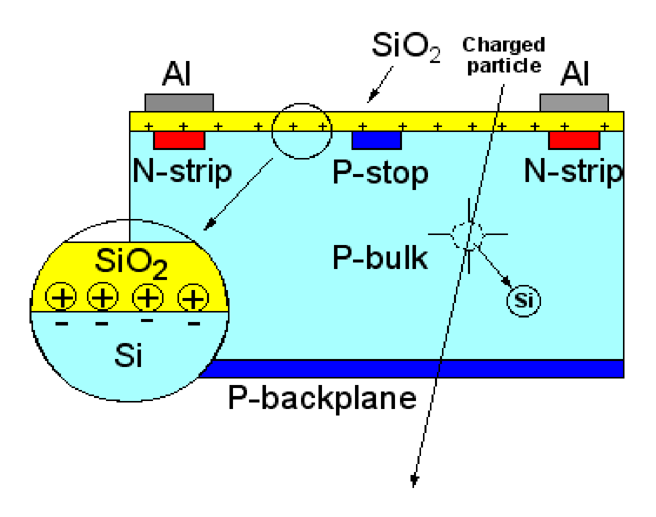
Need to start Large-Scale Production: HPK

- What are the operational characteristics of irradiated n-on-p FZ detectors?
  - Can adequate strip isolation be achieved after irradiation?
  - Does it depend on specific surface treatment? (p-spray, p-stop)
  - Do detectors with better strip isolation have lower breakdown?
  - Are complicated punch-through structures needed for adequate punch-through protection?

Silicon Detectors for the High Luminosity Upgrade



- Signal collection requires
  - High voltage operation
- Higher rate of particles requires
  - higher segmentation of detecting electrodes
  - acceptable data transfer rate
- N-strips in P-bulk wafer (n-in-p)
  - always depleting from strip side
  - lower cost
  - collecting electrons

History of ATLAS07 Submissions @ HPK

Batch	X1				
	Wafer No	P-spray (R)	P-stop (P)	Main sensors	BABY sensors
A	W1-22	2E+12	8E+12	W4,7,9 W14,15,16,20,21,22	W1,2,3,4,6,7,8,9,11 13,14,15,16,17
B	W23-36	----	1E+13	----	W23,24,26,27,28,29 31,34,35
			No. wafers	9	23

Batch	X2	Mask modified			
	Wafer No	P-spray (R)	P-stop (P)	Main sensors	BABY sensors
A	1-10	2E+12	2E+12	----	W1
B	11-13	---	1E+12	----	----
C	14-28	---	2E+12	----	W25
D	29-31	---	4E+12	----	W31
E	32-34	1E+12	---	----	----
F	35-40	2E+12	---	----	W35
G	41-43	4E+12	---	----	----
			No. wafers	0	4

Batch	X3				
	Wafer No	P-spray (R)	P-stop (P)	Main sensors	BABY sensors
A	1-11	2E+12	2E+12	----	W2,5,6,11
B	12-13	---	1E+12	W12	W12
C	14-31	---	2E+12	W25,26,27,28,30 W23	W23,25,W26,W27
D	32-39	---	4E+12	W32,33	W32,33
E	40-41	1E+12	---	W40, W41	W40
F	42-43	2E+12	---	W42	W42
G	44-45	4E+12	---	W44	W44, W43
H	46-47	2E+12	8E+12	W46	W46, W47
			No. wafers	14	17

Batch	S1				
	Wafer No	P-spray (R)	P-stop (P)	Main sensors	BABY sensors
A	1-41	---	4E+12	W9,11,12,13,15,16 W17,18,19,20,21,22,23,25,26,27,28 ,29,30,31,32,33,35,37,38,39,40,41	W9,10,11,12,13,15,16,1 7,18,19,20,21,22,29,30
B	42-45	---	1E+13	W42	W42,45
C	46-49	---	2E+13	W46	W46,49
			No. wafers	30	19

X1: p-stop,
p-spray+p-stop

↓

Weak spots identified
Mask modification

↓

X2 ~

with modified mask

↓

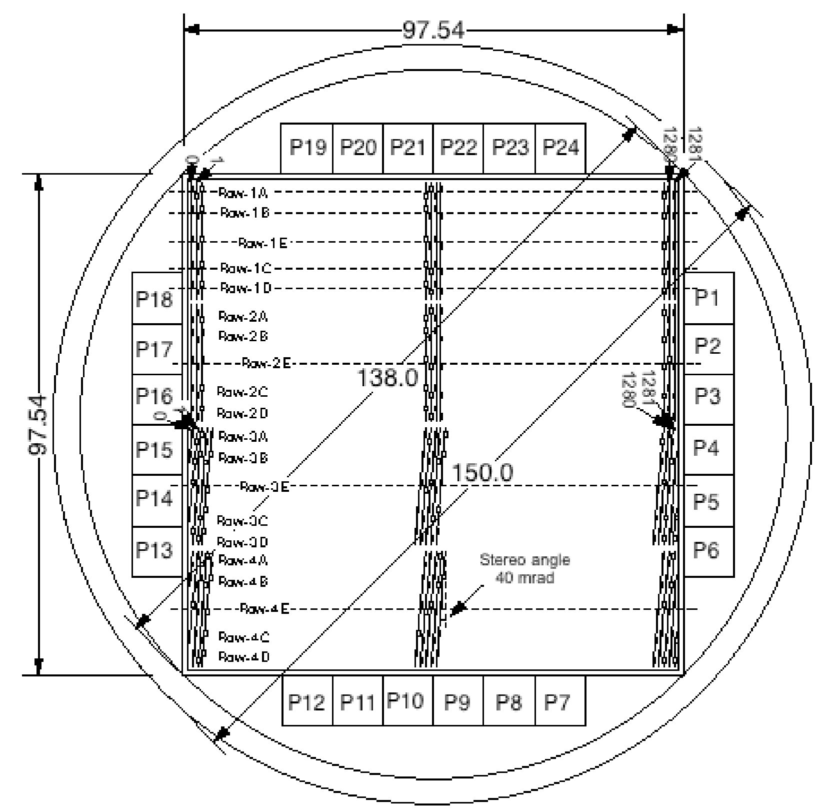
X3
many doping
densities

S1
p-stop, 30 wafers

S2
p-stop, p-spray
90 wafers

n-in-p Sensor

- Past Japanese studies
  - 4 inch (100 mm) wafers
    - FZ<111> (~6k Ωcm)
    - MCZ<100> (~900 Ωcm)
  - 6 inch (150 mm) wafers
    - FZ1<100>(~6.7k Ωcm)
    - FZ2<100>(~6.2k Ωcm)
    - MCZ<100>(~2.3k Ωcm)
  - FZ, MCZ available at HPK

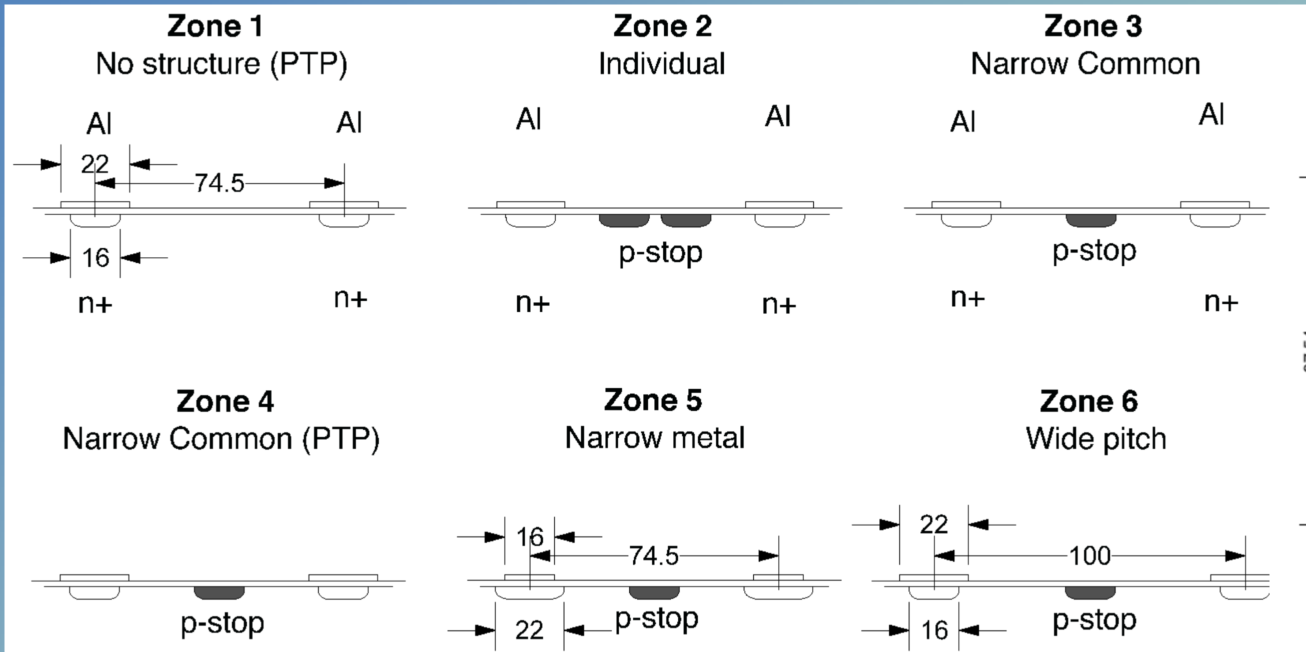


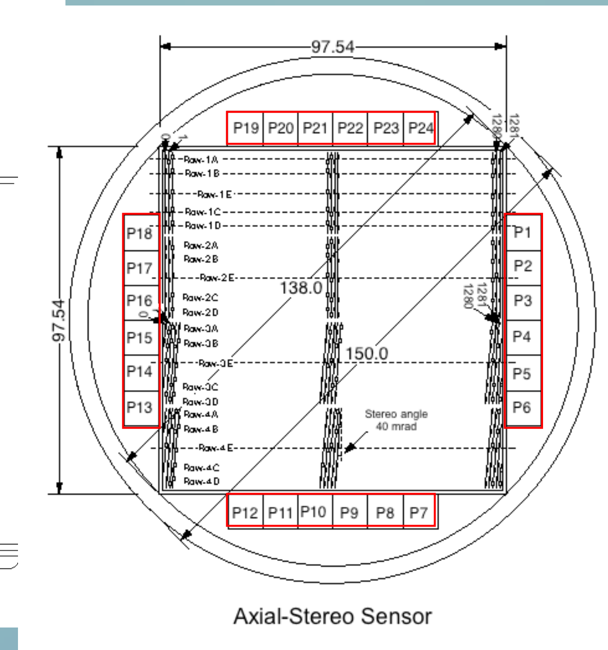
Axial-Stereo Sensor

- ATLAS07 submission
  - 6 inch (150 mm) wafers
    - FZ1<100>(~6.7k Ωcm)
    - (FZ2<100>(~6.2k Ωcm)

- Miniature sensors
  - 1cm x 1cm
    - Irradiation studies
- Full size prototype sensors for Stave program
  - 9.75 cm x 9.75 cm
    - 4 segments: two "axial" and two "stereo" (inclined) strips
    - Short strips

24 n-in-p Miniature Sensors





- Radiation damage study
  - Strip Isolation (Zone1, Zone2, Zone3)
    - Structure: p-stop, p-spray, p-stop+p-spray
    - Density: 1x, 2x, 4x, 10x10^{12} ions/cm^2, ...
  - "Punch-through Protection" structures (Zone4)
  - Narrow metal effect (Zone5)
  - Wide pitch effect (Zone6)

Evaluations

- Irradiations
  - 70 MeV protons at CYRIC (Tohoku Univ., Japan)
  - Reactor neutrons at Ljubljana (Slovenia)
- Measurements
  - Full-size sensors **(see J. Bohm's talk)**
    - C-V, i-V, single-strip measurements
  - Onset of Microdischarge
    - I-V
    - Hot electron

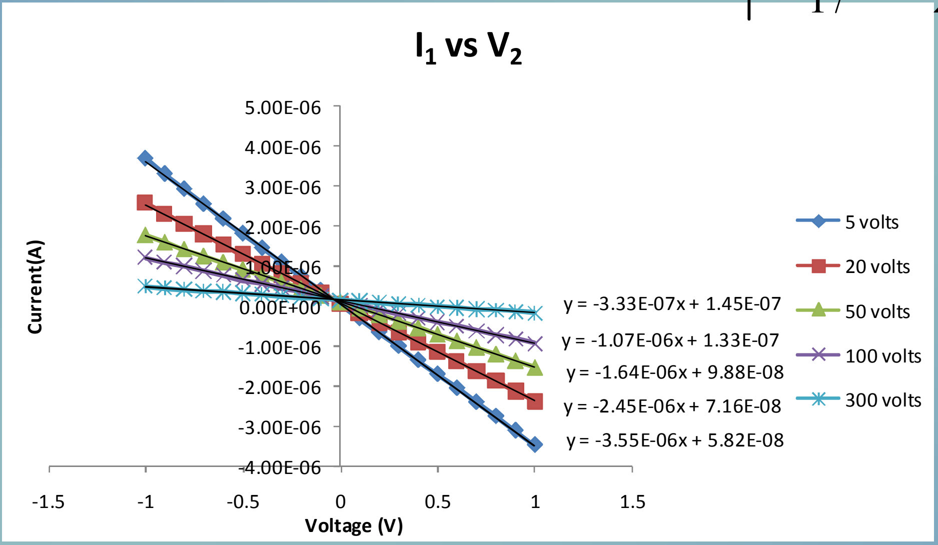
Interstrip resistance

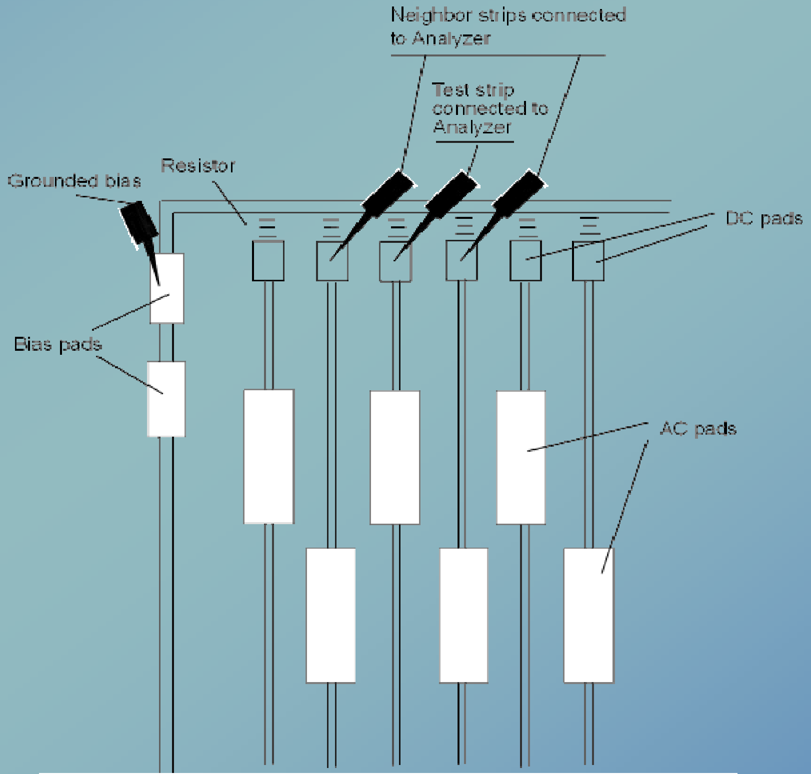
  - Charge collection efficiency (CCE) **(a few slides by A. Affolder)**
    - ^{90}Sr beta ray
  - Surface:
    - Interstrip resistance
    - Interstrip capacitance
  - Punch-through Protection
    - Dynamic resistance with a constant bias voltage to the backplane

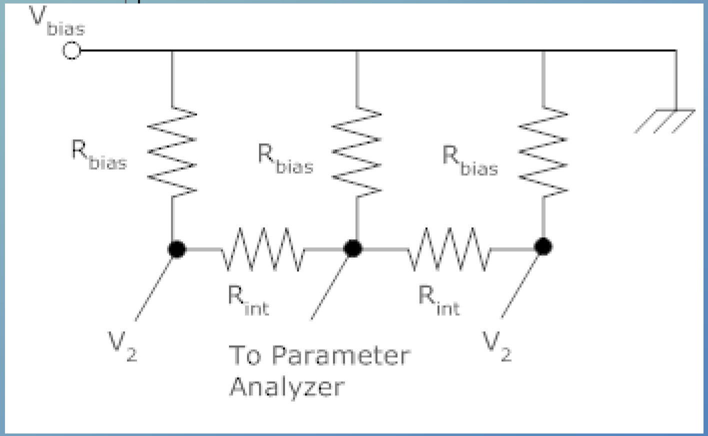
Interstrip Resistance Measurements

- Using the detectors DC-pads
- The setup purpose is to measure the current in the test strip due to the applied voltage on the neighbors using a parameter analyzer. Measurement was done at different bias voltages.
- Data taken is plotted as test current against the neighbor voltage

$$R_{\text{int}} = \frac{2}{\left| di_1 / dv_2 \right|}$$

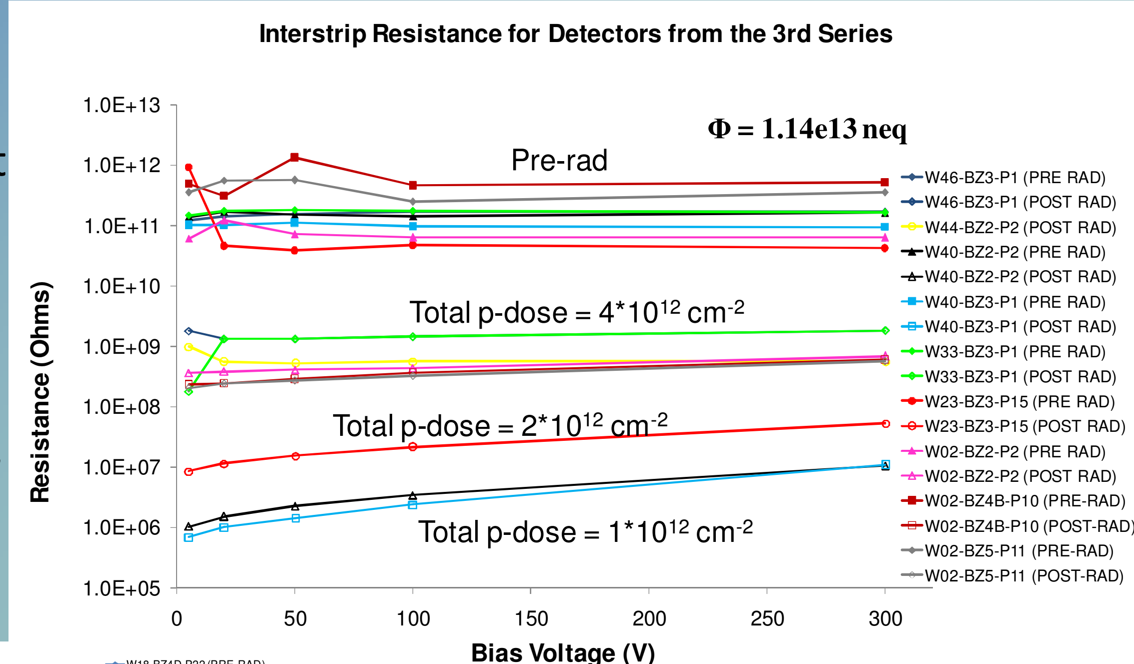


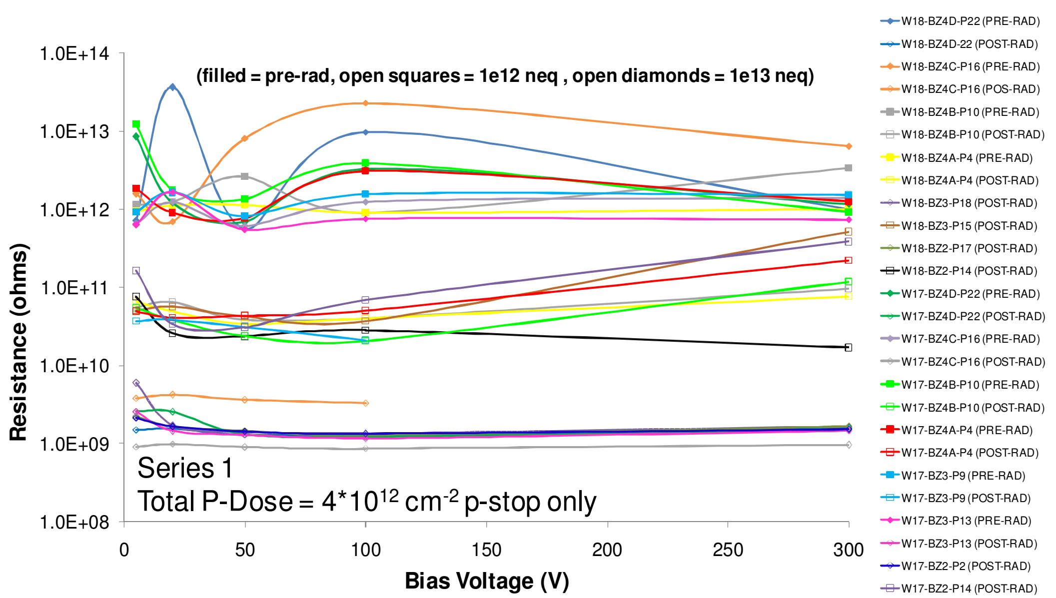


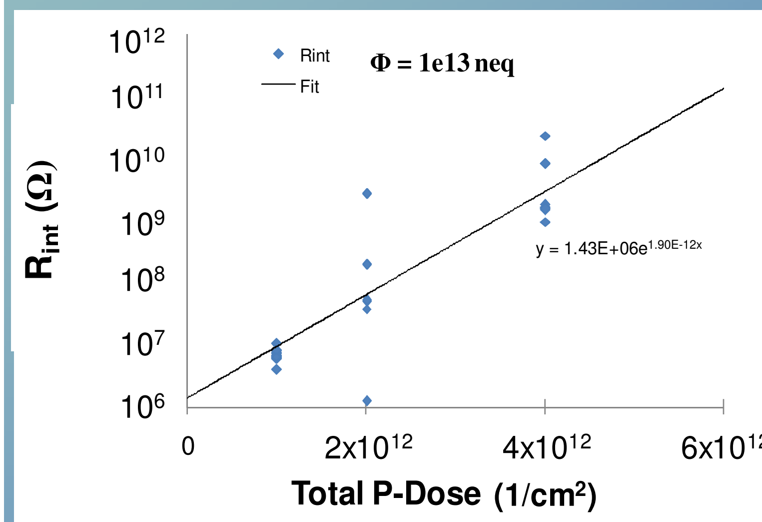


Interstrip Resistance Results

- To first order, interstrip resistance depends not on the specific zone, but depends on the total p-dose applied.
- Higher total p-dose means better strip isolation after irradiation.
- All Series 1 detectors exhibit a good post-rad Rint (>10^8 Ohms) behavior, even after being irradiated with protons up to 1e13 neq

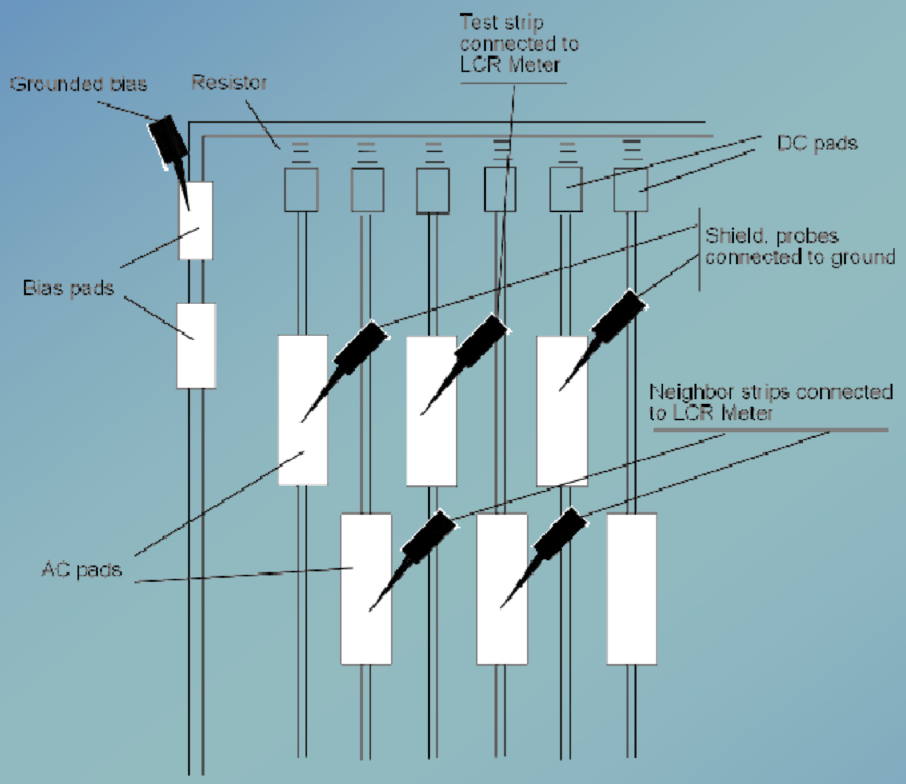


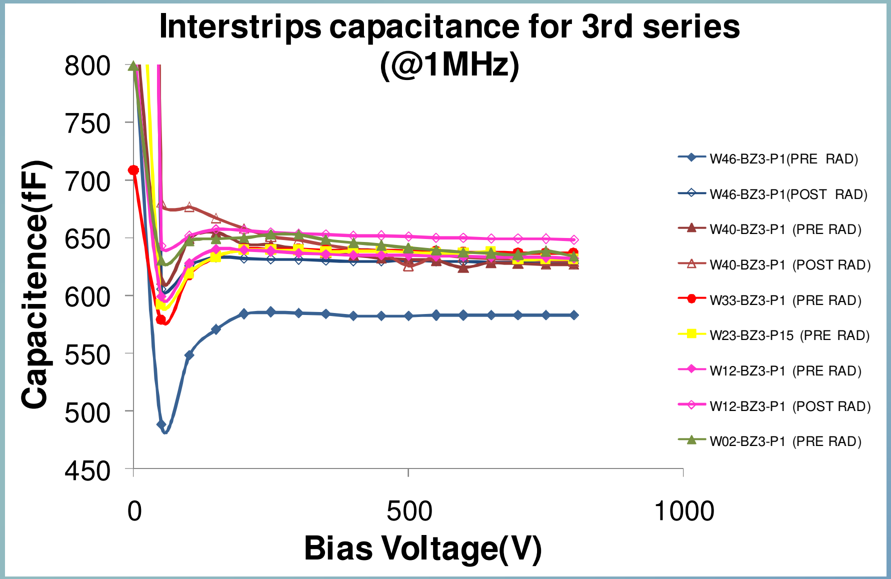


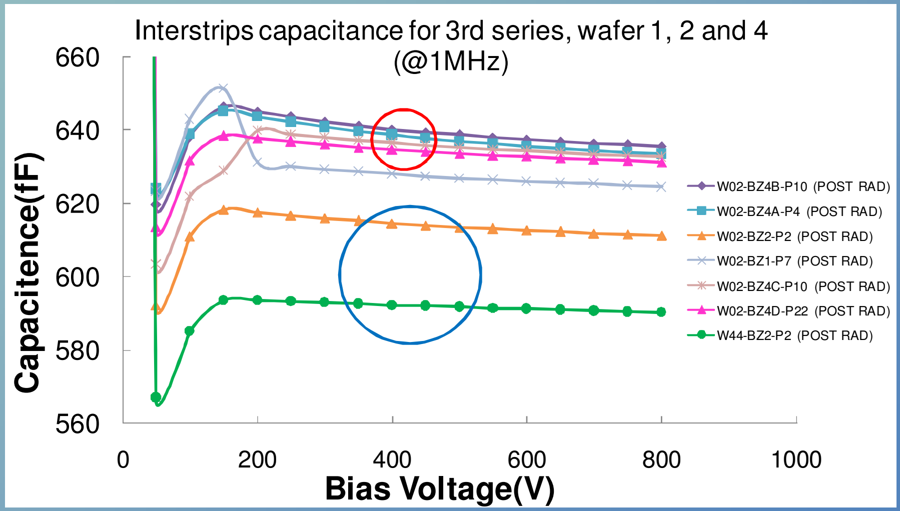


Interstrip Capacitance

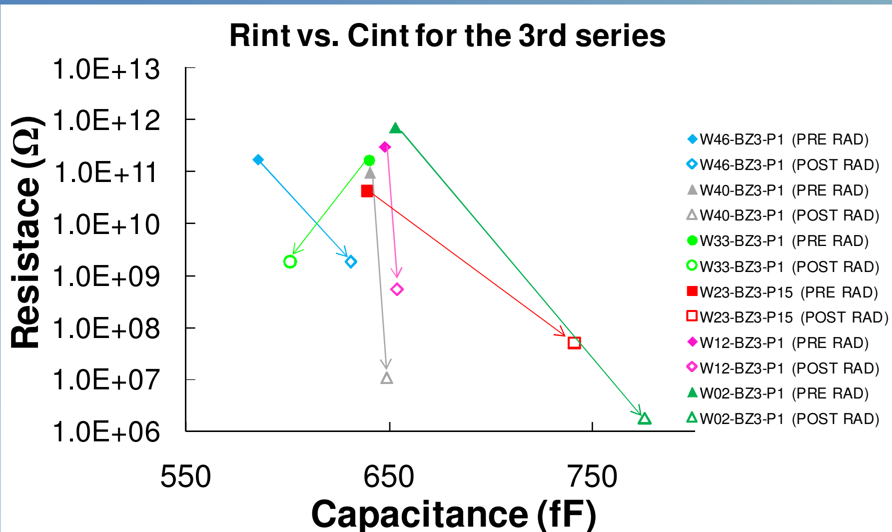
- AC pads are used.
- 5 probes are used; one on the test strip, one on each neighbor, and two more to ground the next neighbors.

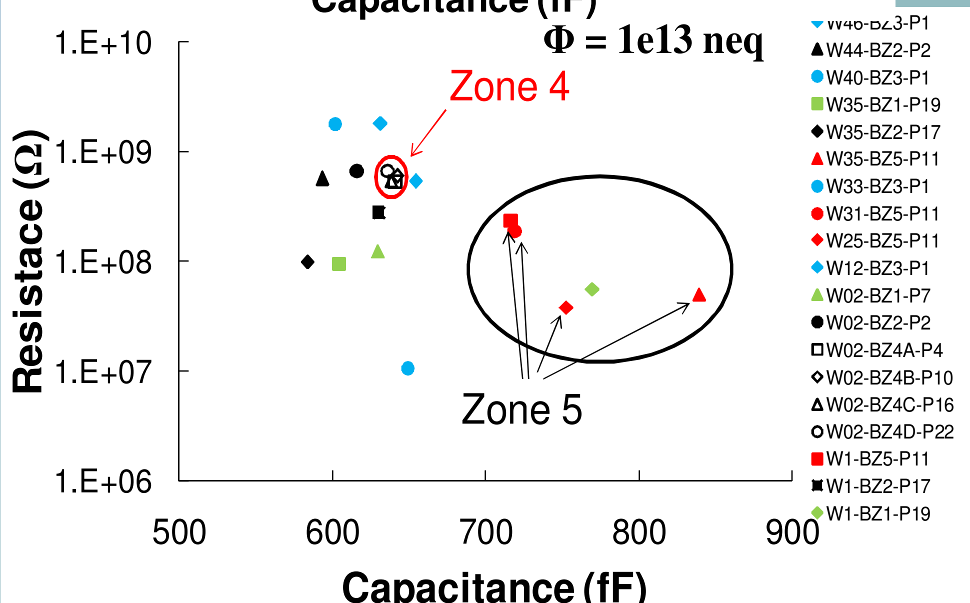




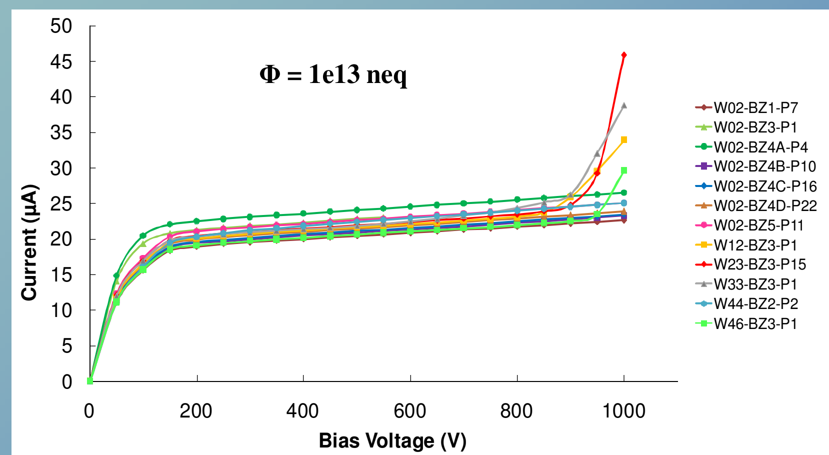


R_{int} vs. C_{int}





- Helpful to make scatter plot between R_{int} and C_{int}
- Strip isolation is best in the upper left corner, and worst in the lower right.
- Dependence of post-rad C_{int} on specific zone is seen.
- Zone 5 (narrow metal) has the highest Post-rad C_{int} without providing better breakdown performance.



Punch-Through Protection:
(against large strip voltages)

- Zone 4 detectors include an additional punch-through structures.
- Apply a voltage to DC pad and measure the induced current between DC pad and bias resistor.
- The effective resistance is then

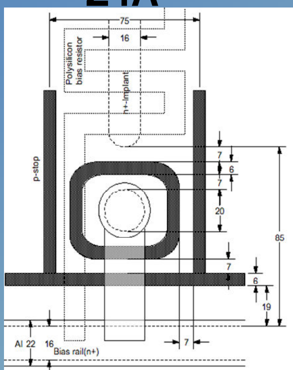
$$R_{eff} = dV_{test} / dI_{test}$$

- Punch-through resistance is defined as

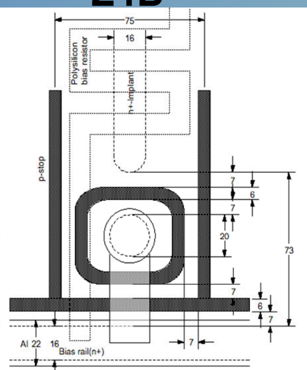
$$R_{PT} = (1/R_{eff} - 1/R_{bias})^{-1}$$

where R_{bias} is the resistance of the bias resistor.

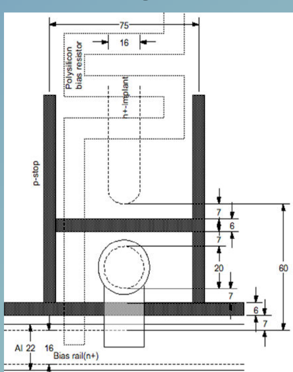
Z4A



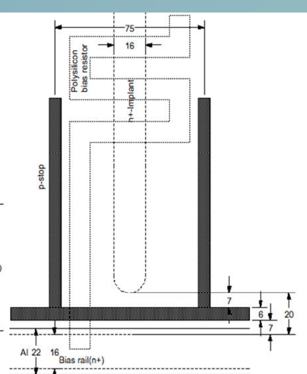
Z4B

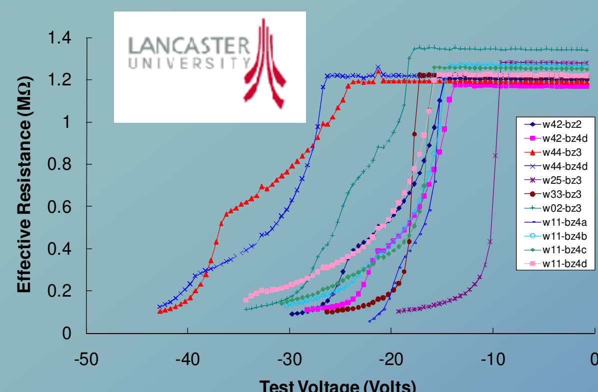


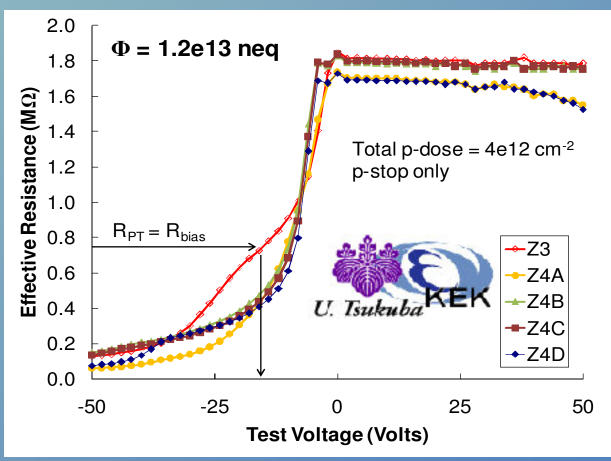
Z4C



Z4D

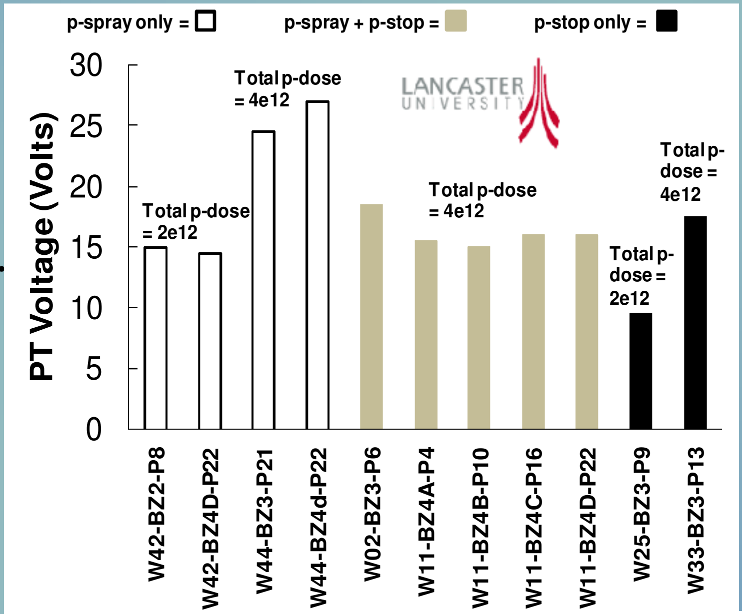


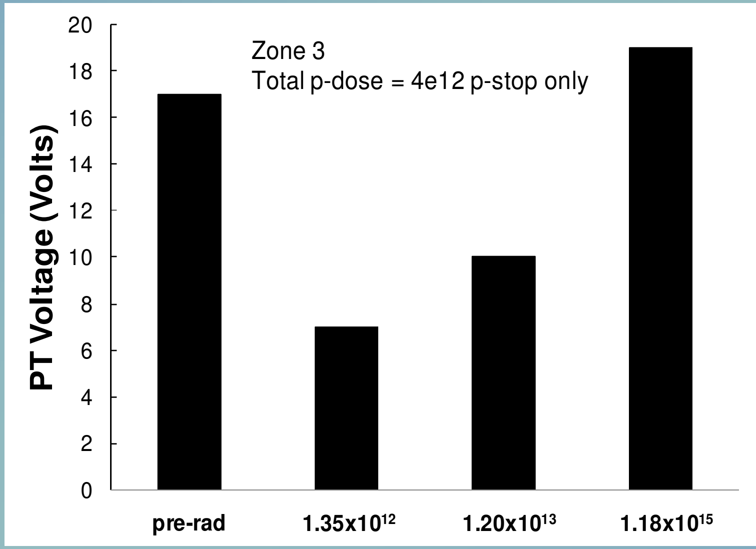


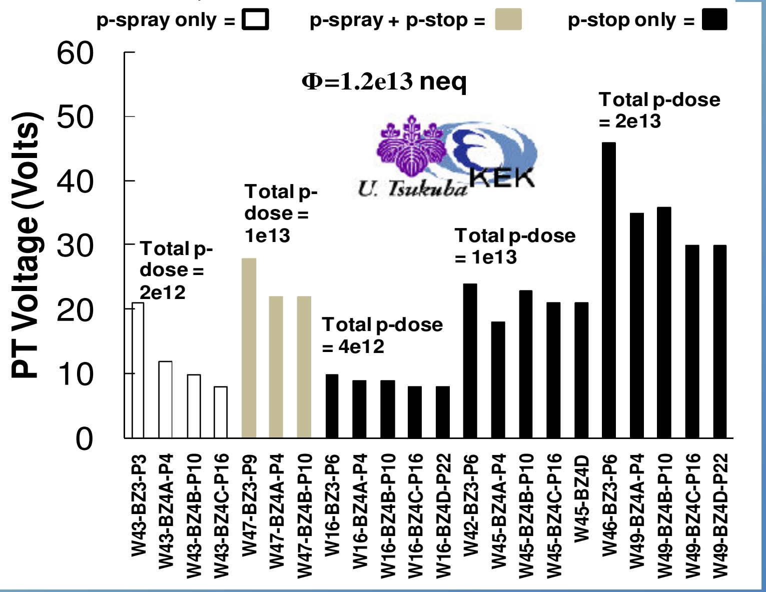


Punch-Through Voltage

- Punch-through Voltage is defined as the voltage where $R_{PT} = R_{bias}$
- For Pre-rad detectors, the punch-through voltage is dependent on the wafer number (i.e. the total p-dose).
- Dependence on the total p-dose is seen after irradiation, higher p-dose means lower PT Voltage.
- Zone 3 exhibits similar PT voltage to Zone 4, without the having a complicated PT structure.
- Further, Zone 3 shows adequate protection even at high fluences.

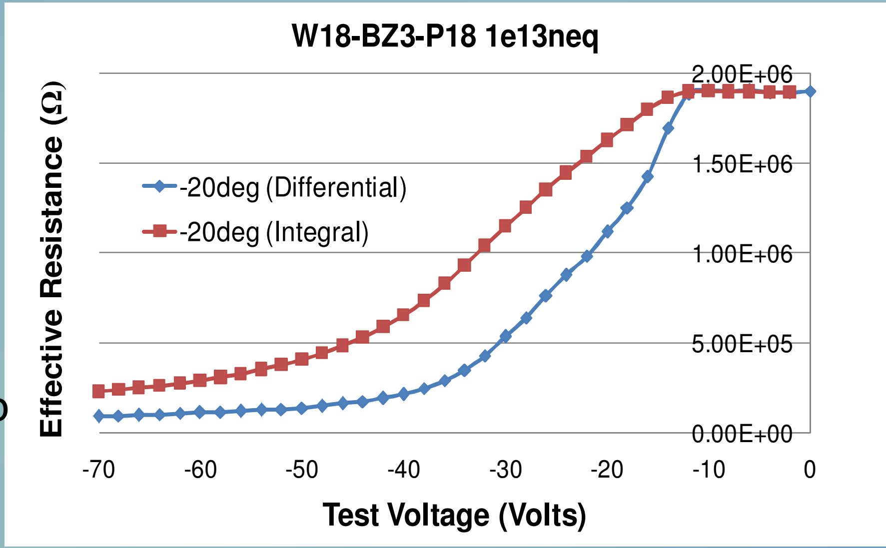


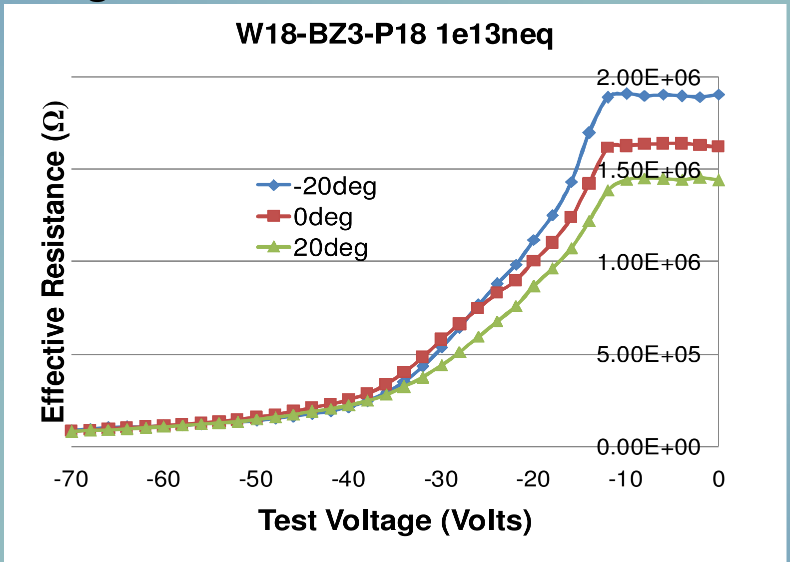




Comments on the Effective Resistance

- The effective resistance can also be defined by taking the integral form of the equation given earlier.
- This would have the advantage of incorporating the total current that can be drained from the strip to the bias rail and providing the effective resistance for charges to escape through.
- The disadvantage to the integral form is that it is less sensitive to the onset of punch-through, so it is less suitable for defining the punch-through voltage.





- Measurements at different temperatures reveal a clear temperature dependence on the effective resistance.
- The temperature dependence seems to come mainly from the polysilicon bias resistor.
- The value of the punch-through voltage does not depend on the temperature.

Charge Collection Studies with ATLAS07 n-on-p FZ Silicon Detectors
(compiled by A. Affolder)

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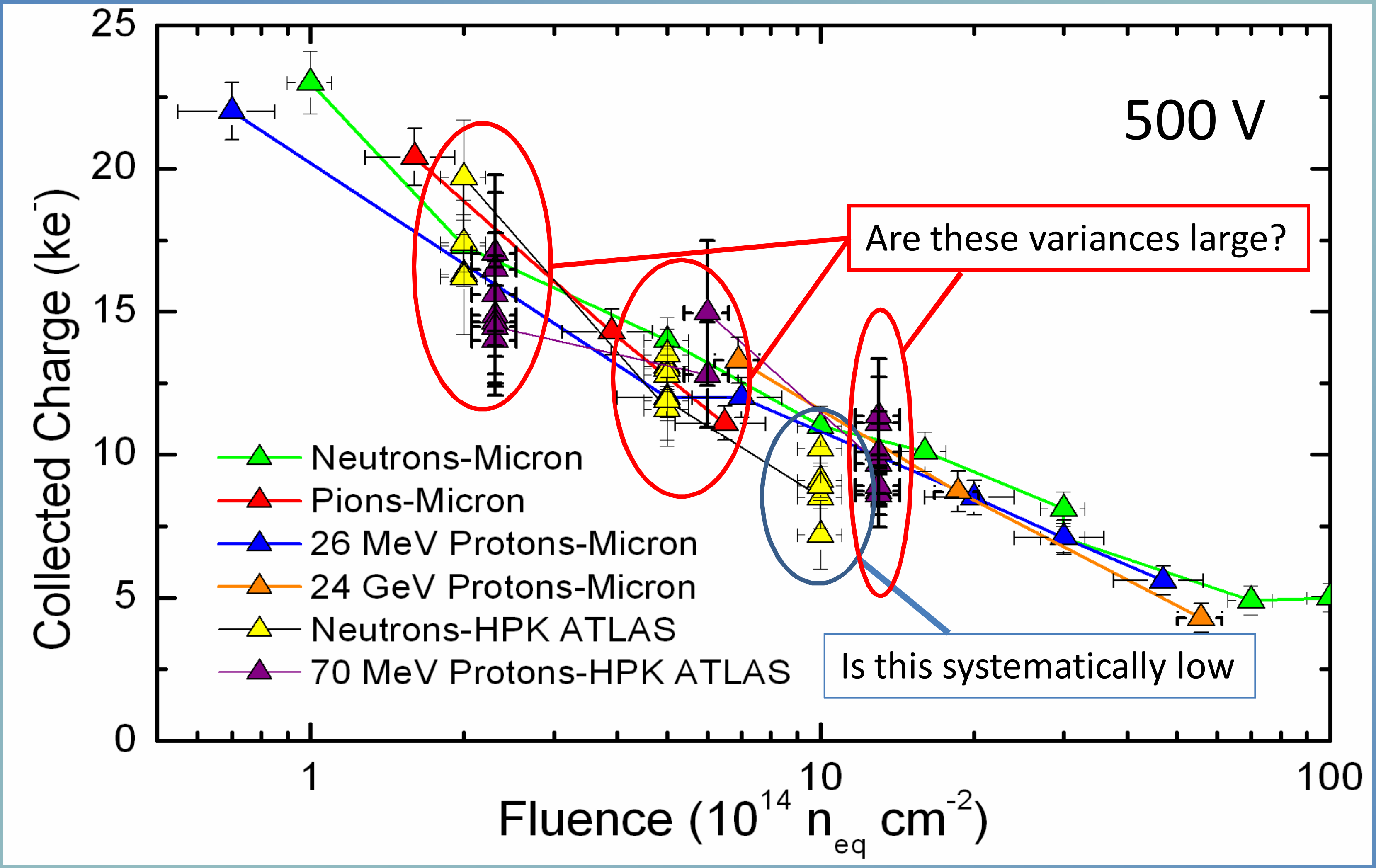
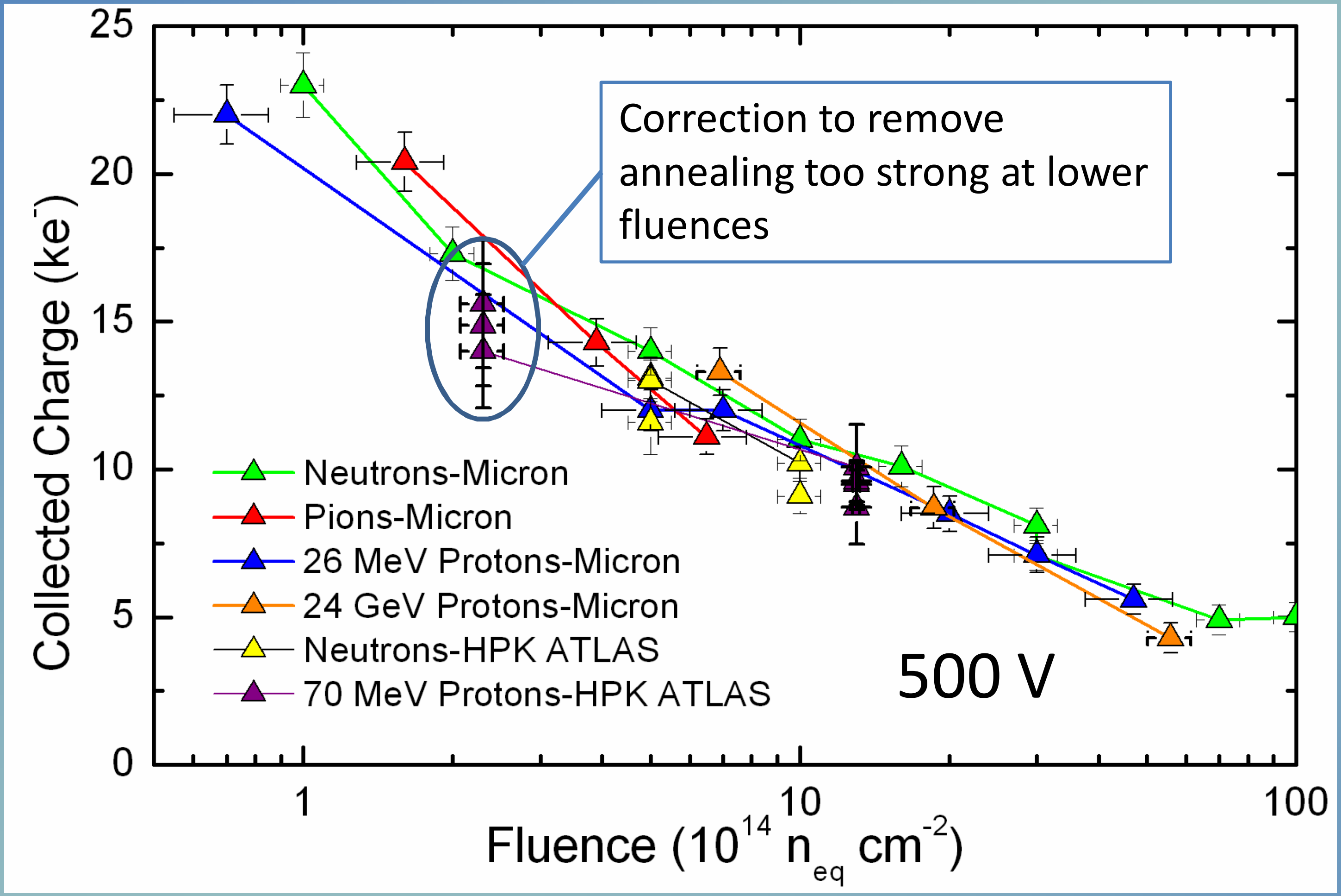
Summary of Results from Different Sources



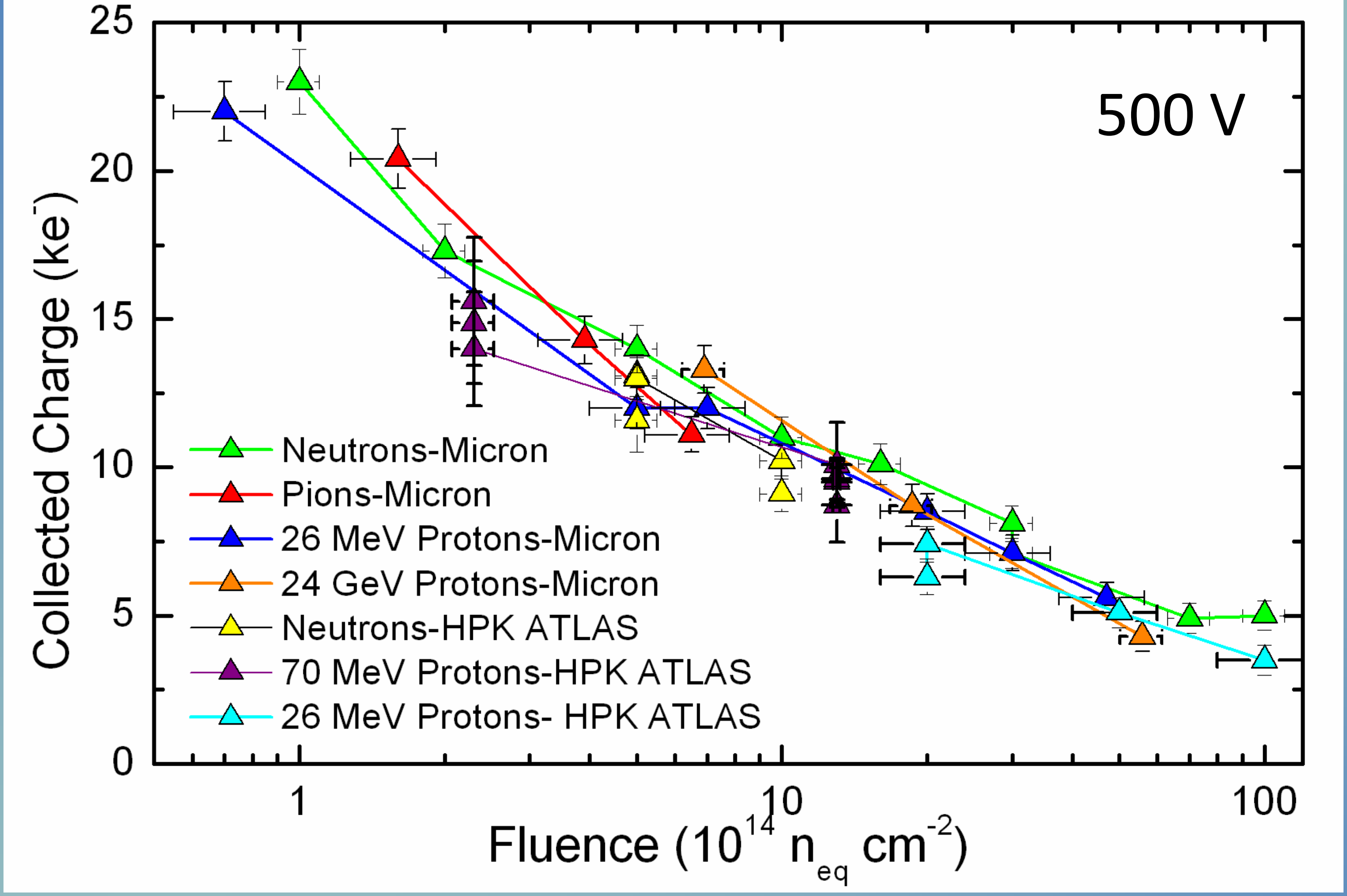
HPK data shown from all sites (with annealing corrections, i.e. CCE reduced by -20%+/-10%). Pion irradiation measurements corrected for annealing during run

Liverpool Only Data



- Remove normalization, annealing effects
- Results look consistent
  - Would assume variance due to slight systematic differences in normalizations/annealing corrections

Summary



- NIEL appears to work for charge collection with n-in-p FZ detectors
- Micron and HPK consistent over measure fluence range

Conclusions

- Good cooperation between ATLAS groups and HPK: 3 pre-series and 2 full series runs in about 2 years.
- All HPK detectors have a breakdown voltage that exceeds 900V, exceeding the specifications.
- To first order, the interstrip resistance does not depend on the specific zone, but instead depends on the total p-dose of p-impurities on the surface (p-stop + p-spray).
- The interstrip capacitance shows little change after irradiation and is dependent on the specific zones.
- Zone 5 (narrow metal) has the highest interstrip capacitance after irradiation (Don’t use narrow metal!).
- The punch-through voltage depends on the total p-dose in all configurations (p-stop only, p-stop+spray, p-spray only). Wafers with the highest total p-dose have a higher punch-through voltage, which holds true even after irradiation.
- After irradiation, Zone 3 detectors (Gap = 70 μm) have a similar punch-through voltage as Zone 4 detectors, which are made with a specific punch-through protection structure (Gap = 30 μm) . Needs explanation!
- The acceptable punch-through voltage of the Zone 3 sensors with p-stops of $4*10^{12}$ cm^{-2} extends to proton fluences beyond 10^{15} p/cm^2.

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ATLAS Upgrade Silicon Strip Detector Collaboration:
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A. Chilingarov, H. Fox, Lancaster University
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RD50 Bet Oct 17, 2006

“Will the "Kramberger effect" be traced to a temperature effect?”

Betting was heavily against (all in SFrs)

Against		For	
Moll	5	Hartmut	5
Vladimir Ci	1000	Thor	40 kr
Noman	2	Panja	3.75
Thor	5	Maurice	2
Gregor	5	Elena	10Kopek
VladPad	5	VladPad	2
Simon	5		
Alex?	10		
Uli	10		
	47		12.75
Sum	59.75		

Results shown at Vilnius makes it unlikely that temperature is the sole cause.

Proposal to pay off the bet in a communal way:

Bookie will forgo his usual proceeds (50% of total) and pay for drinks in the Bar tonight at 7 pm