# *PTP and the inter-strip capacitance and resistance for irradiated ATLAS07 mini-sensors.*

**Jan Bohm, Institute of Physics ASCR, Prague**

**Peter Kodys, Zdenek Dolezal, Jan Scheirich,**
**Charles University in Prague**

**Petr Masek, Michael Solar, Institute of Experimental and Applied Physics of Czech Technical University in Prague**

The performance of the sample of 75 ***n*-in-*p* ATLAS07 HPK** miniature 1cm*1cm sensors developed by ATLAS Collaboration for LHC upgrade [**Y. Unno, et.al., Nucl. Inst. Meth. A636 (2011) S24-30**] with different punch through structures, BZ4A-D, and with three different **ion concentrations of 2E12, 4E12 and 1E13 ion/cm^2** of the P-stop and P-stop + P-spray separation is studied before and after irradiation with the aim to select the P-stop ion concentration and punch through structure as the most effective protection against beam splashes

1. Introduction
2. IV characteristics of heavily irradiated sensors
3. Interstrip capacitance and bias dependence
4. Time evolution of interstrip and bulk capacitances
5. Interstrip resistance
6. Characteristics of punch through structures
7. Summary and conclusions

# *Sample of HPK miniature sensors*

| | ATLAS07-pre-series-3rd | | | | | | | | ATLAS07-series2 | | | | | | | | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pspray(2E12)+Pstop(2E12) | | | | Pstop(2E12) | | | | Pstop(1E13) STD | | | | Pstop(1E13) HPK_ex | | | | |
| | W4 | W5 | W6 | W10 | W14 | W17 | W19 | W31 | W75 | W78 | W80 | W81 | W89 | W91 | W93 | W97 | |
| BZ4A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| BZ4B | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| BZ4C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| BZ4D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| total | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 63 |

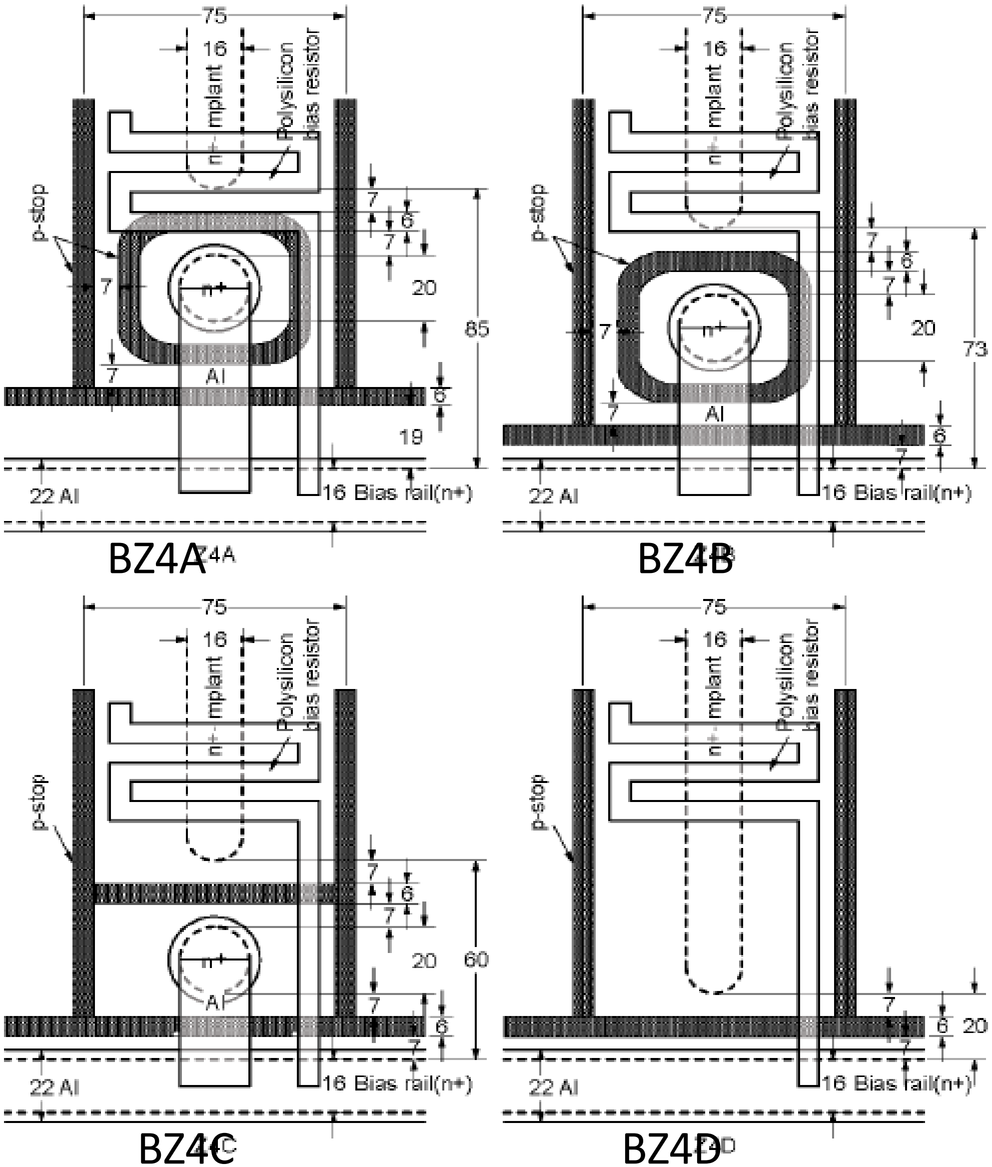
From Hamburg we received next 12 sensors BZ4A-D of **Series 3** (wafers 264,278 and 281) with P-stop ion concentration **4E12 ion/cm^2**. **Many thanks to colleagues from DESY**.

## Irradiation of sensors BZ4A, B, C and D for each wafer

| Wafer | Isolation | Ion/cm^2 | Fluency neq/cm^2 | Particles | Where | Annealing |
|---|---|---|---|---|---|---|
| W06 | Pspr+Pstp | 2E+12 | 4E+14 | neutrons | Ljubljana | 80min/60degC |
| W10 | Pspr+Pstp | 2E+12 | 2E+15 | neutrons | Ljubljana | 80minn/60degC |
| W17 | Pstop | 2E+12 | 4E+14 | neutrons | Ljubljana | 80min/60degC |
| W19 | Pstop | 2E+12 | 2E+15 | neutrons | Ljubljana | 80min/60degC |
| W278 | Pstop | 4E+12 | 4E+14 | neutrons | Ljubljana | 80min/60degC |
| W281 | Pstop | 4E+12 | 2E+15 | neutrons | Ljubljana | 80min/60degC |
| W31 | Pstop | 2E+12 | 4E+14 | p 23GeV/c | CERN | 80min/60degC |
| W91 | Pstop | 1E+13 | 4E+14 | neutrons | Rez Prague | 80min/60degC |
| W93 | Pstop | 1E+13 | 2E+15 | neutrons | Rez Prague | 80min/60degC |
| W97 | Pstop | 1E+13 | 1E+16 | neutrons | Rez Prague | 80min/60degC |

Many thanks to Vlado Cindro , Morris Glaser and Jan Kucera for irradiation

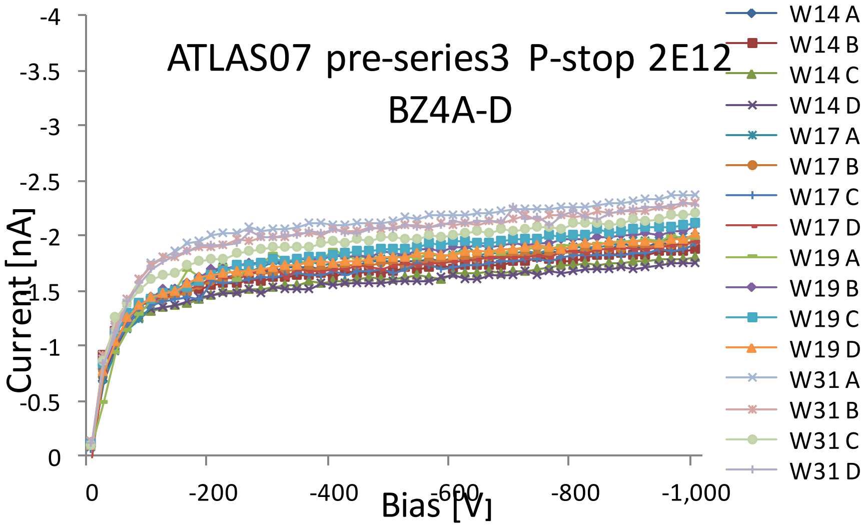
# *Punch Through Protection Structures for ATLAS07*

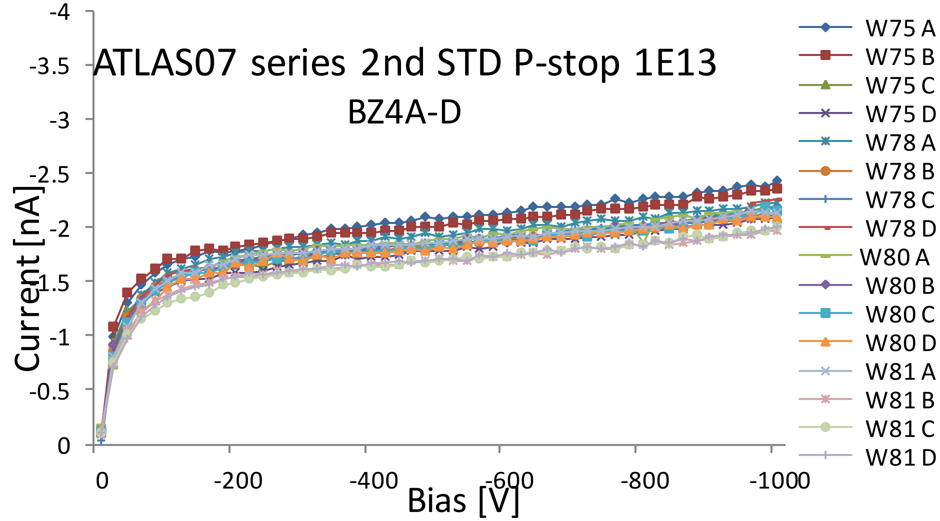


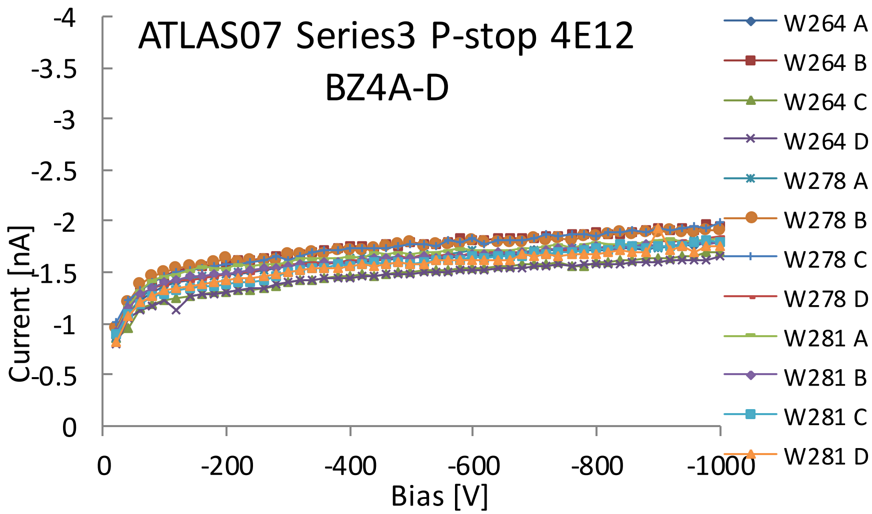

A protection of AC coupling capacitors against the beam splashes should ensure special structures, BZ4A,B,C on the HPK ATLAS07 mini-sensors.
A beam splash generates a spike of voltage across the AC coupling insulator. When the distance between the bias rail and the n-strip implants is appropriate, this voltage between the bias rail and the n-strip implant ends can be limited. This distance is 20 μ and is used in all special structures BZ4A,B,C and sensor BZ4D

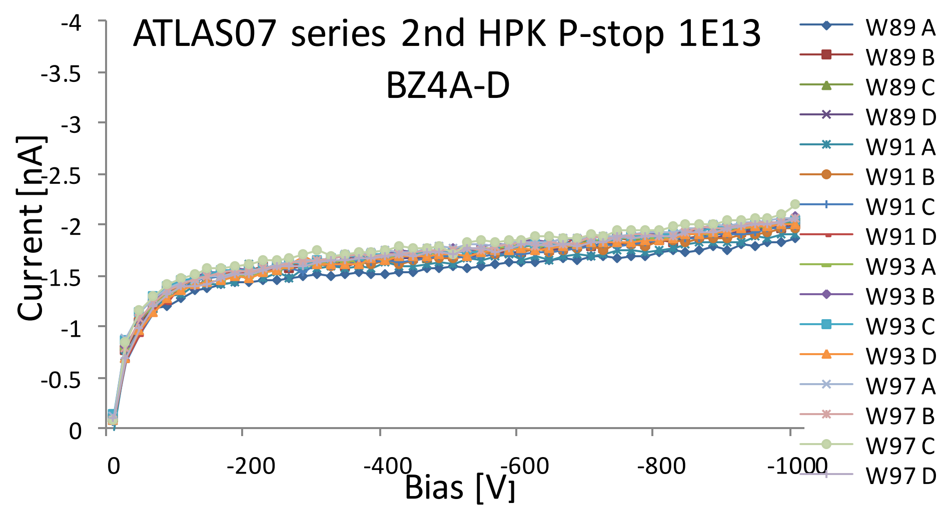
Sensor BZ4D has no special structure and it is used for comparison with structures BZ4A, B and C.

# *IV characteristics of non-irradiated ATLAS07 sensors*



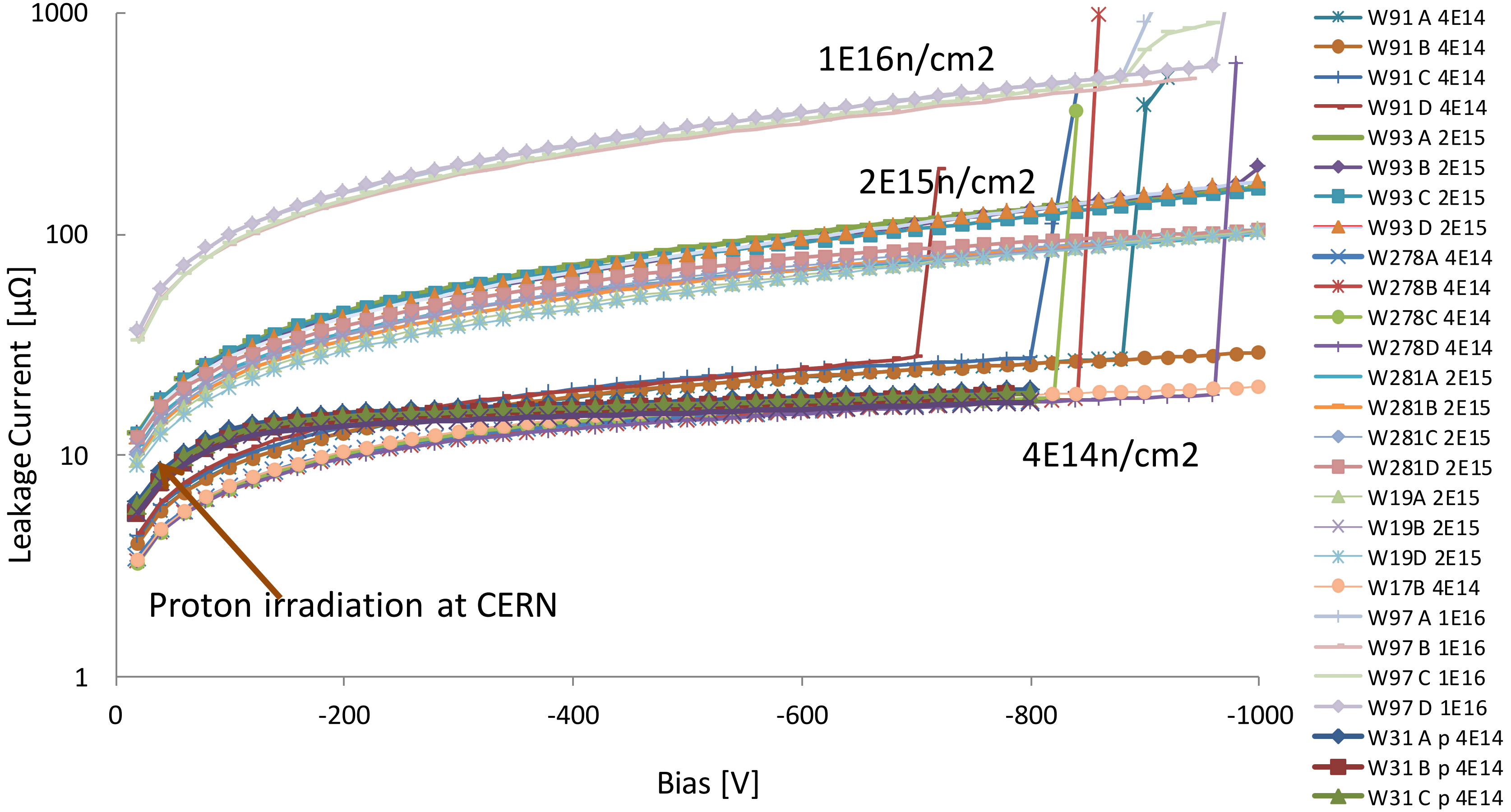



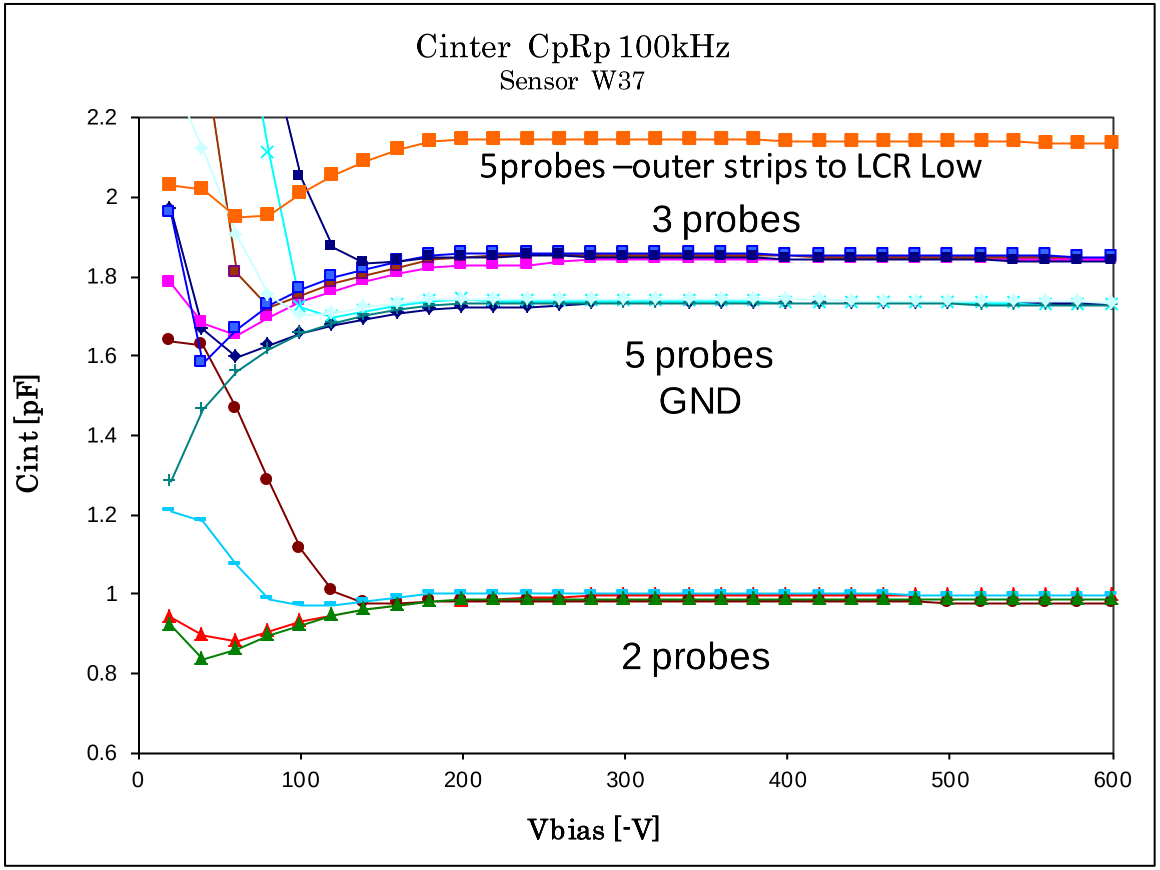

Measured sensors were placed on the table without vacuum chuck jig to avoid possible strong stresses which could cause breakdowns.

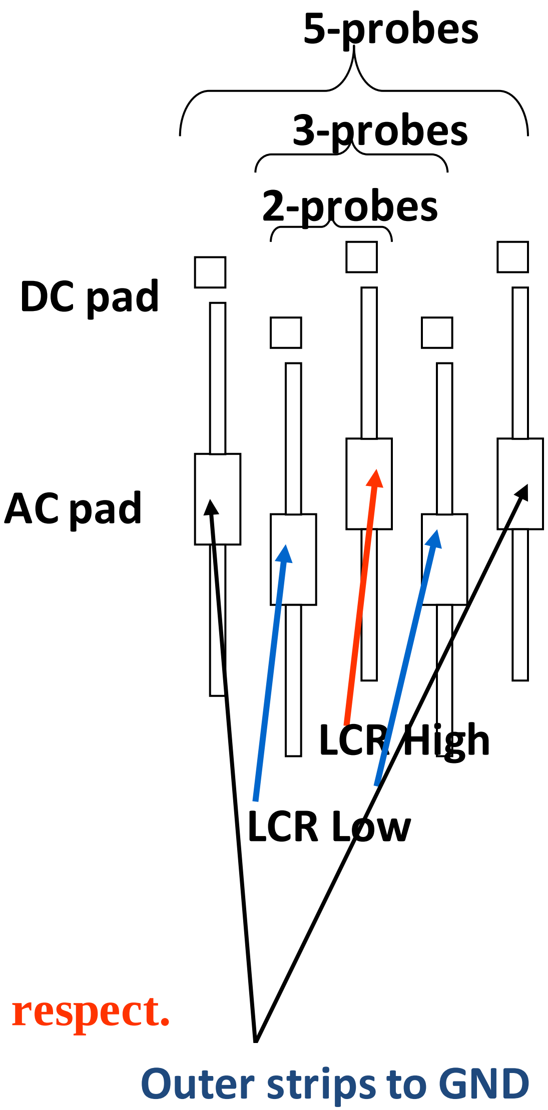
# *IV Characteristics of irradiated ATLAS07 sensors*




The heavily irradiated sensors (≥ 2E15n/cm2) with p-stop isolation of different ion concentrations were successfully operating up to 1000V with the exception of fluency 4E14n/cm2 where an onset of micro-discharges was observed above ~700V

# *Interstrip Capacitance - Method of measurement*

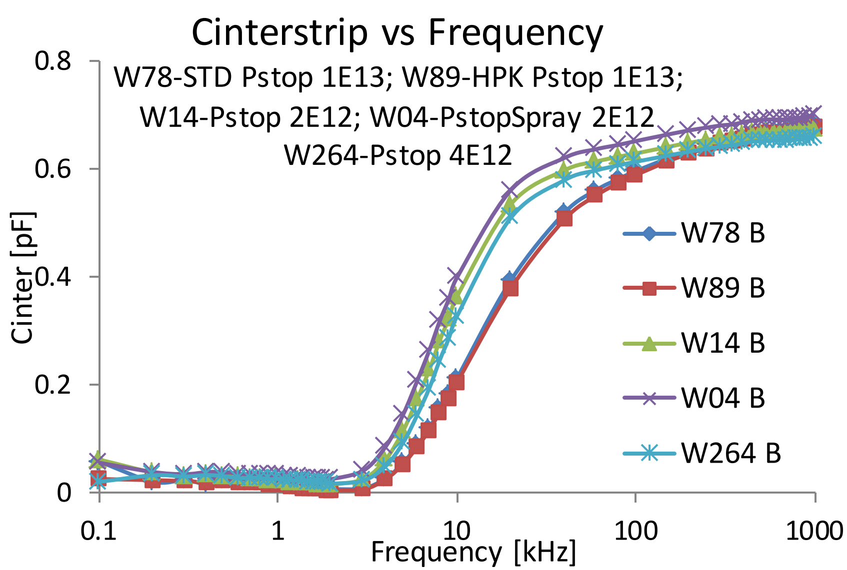


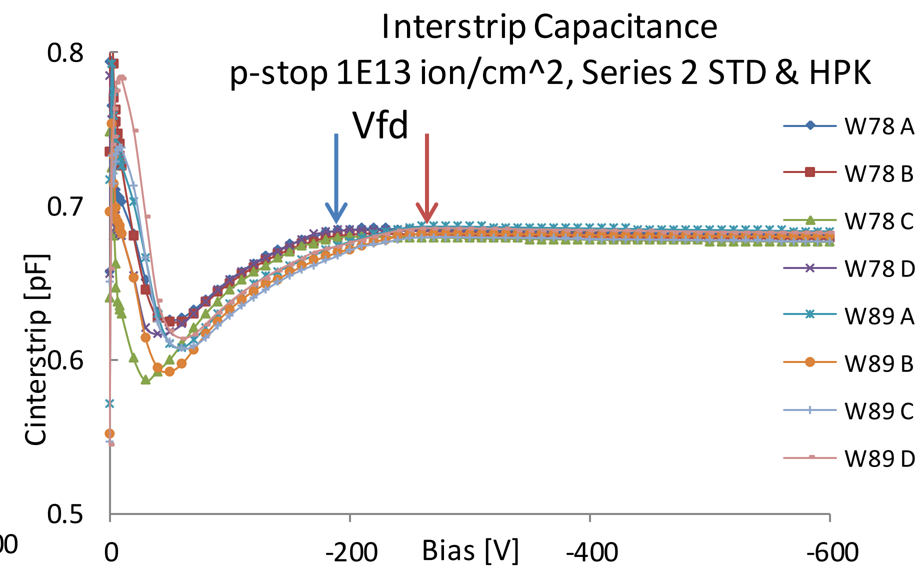



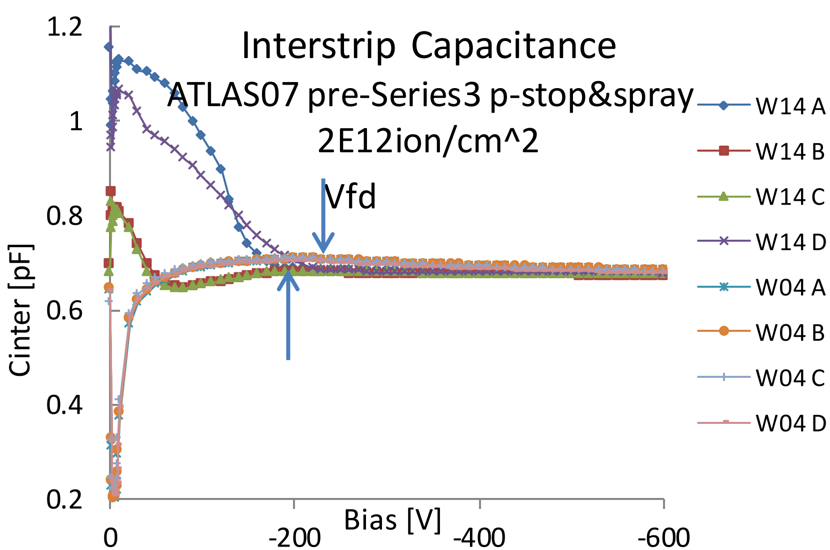

**Cint(5-pr)/Cint(3-pr)=0.939 and 0.913 for 100kHz and 1MHz, respect.**
**Cint(2-pr)/Cint(5-pr)=0.57**

J.Bohm, M.Mikestikova et.al, NIM A636 (2011)S104-S110

# *Interstrip Capacitance – non-irradiated*



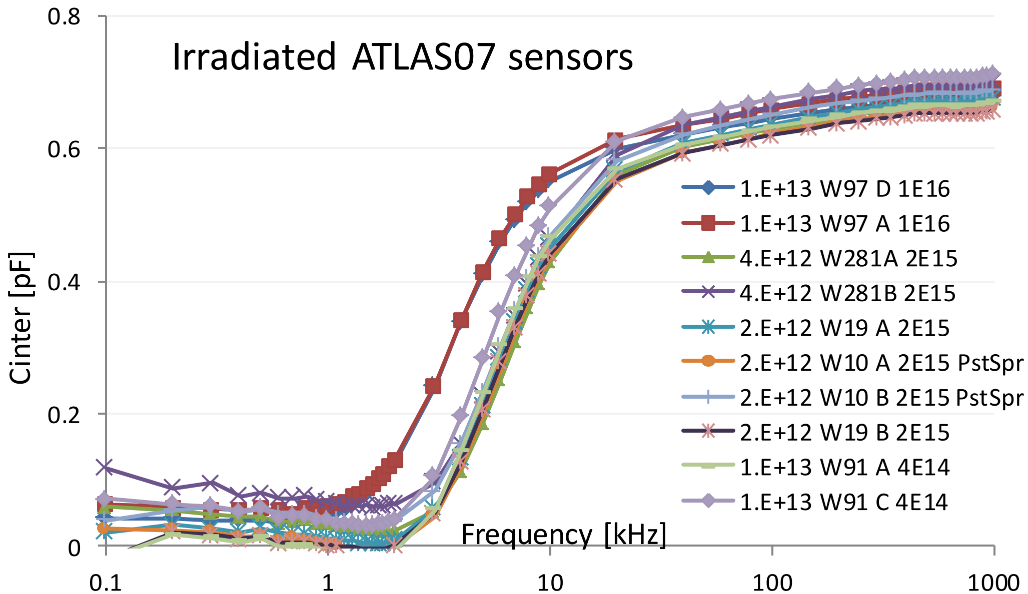

Interstrip capacitance is measured by 3 probes at 1 MHz and CpRp

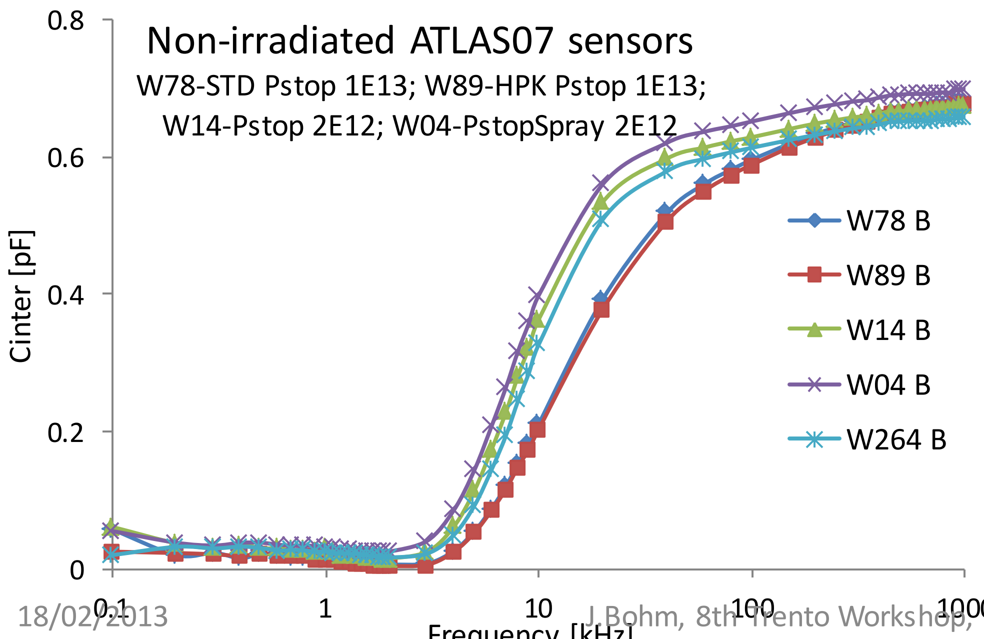
C interstrip for frequency above 100kHz is slowly increasing up to 1MHz.

For Vbias<Vfd the values of C interstrip depend on the P-stop & P-spray ion concentration but above Vfd the Cinter is constant and the same for all p-stop doses.

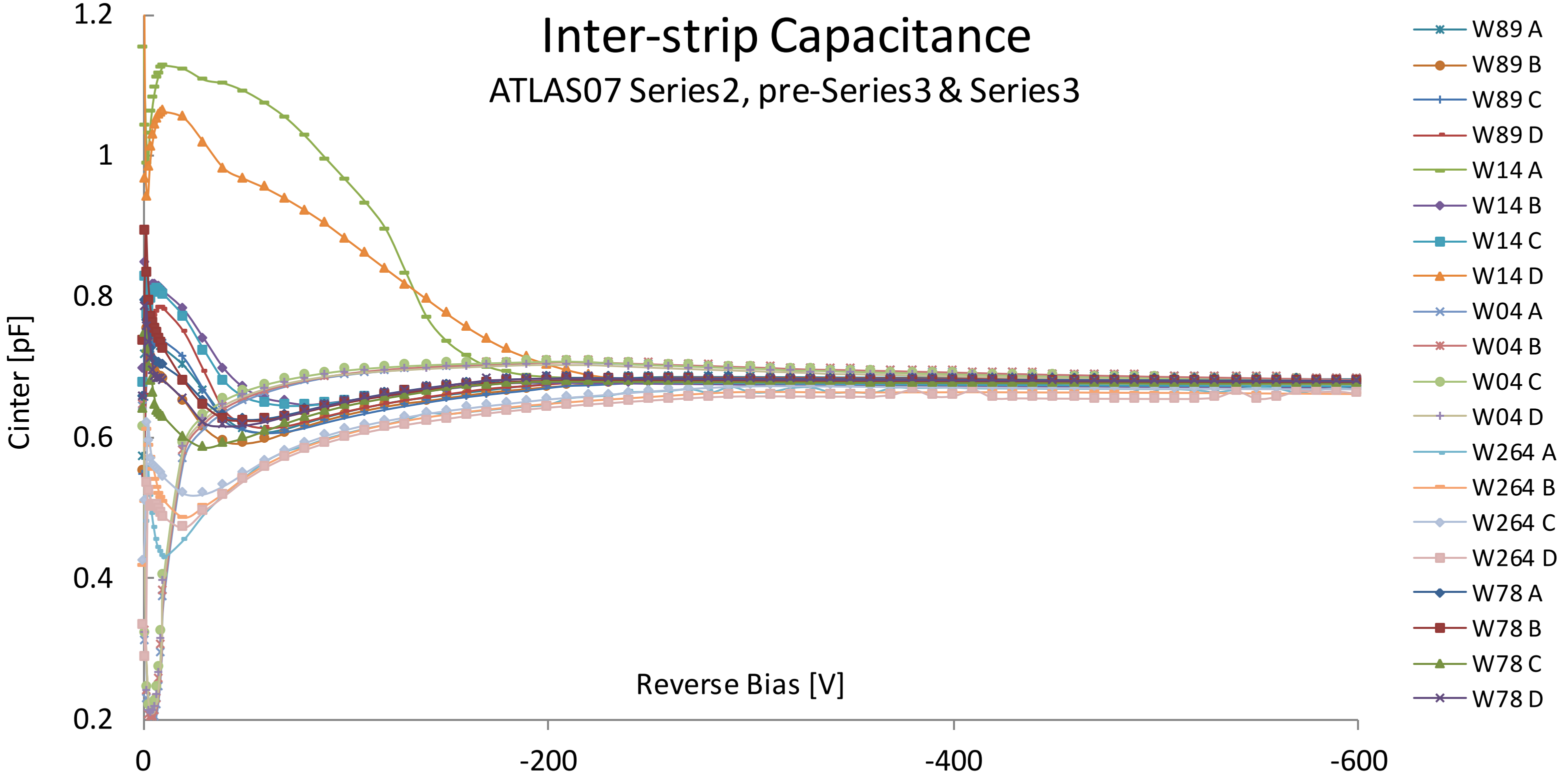
There is narrow deep minimum of Cint at Vbias =-4V for P-stop+P-spray isolation.

# *Interstrip Capacitance Dependence on Frequency*



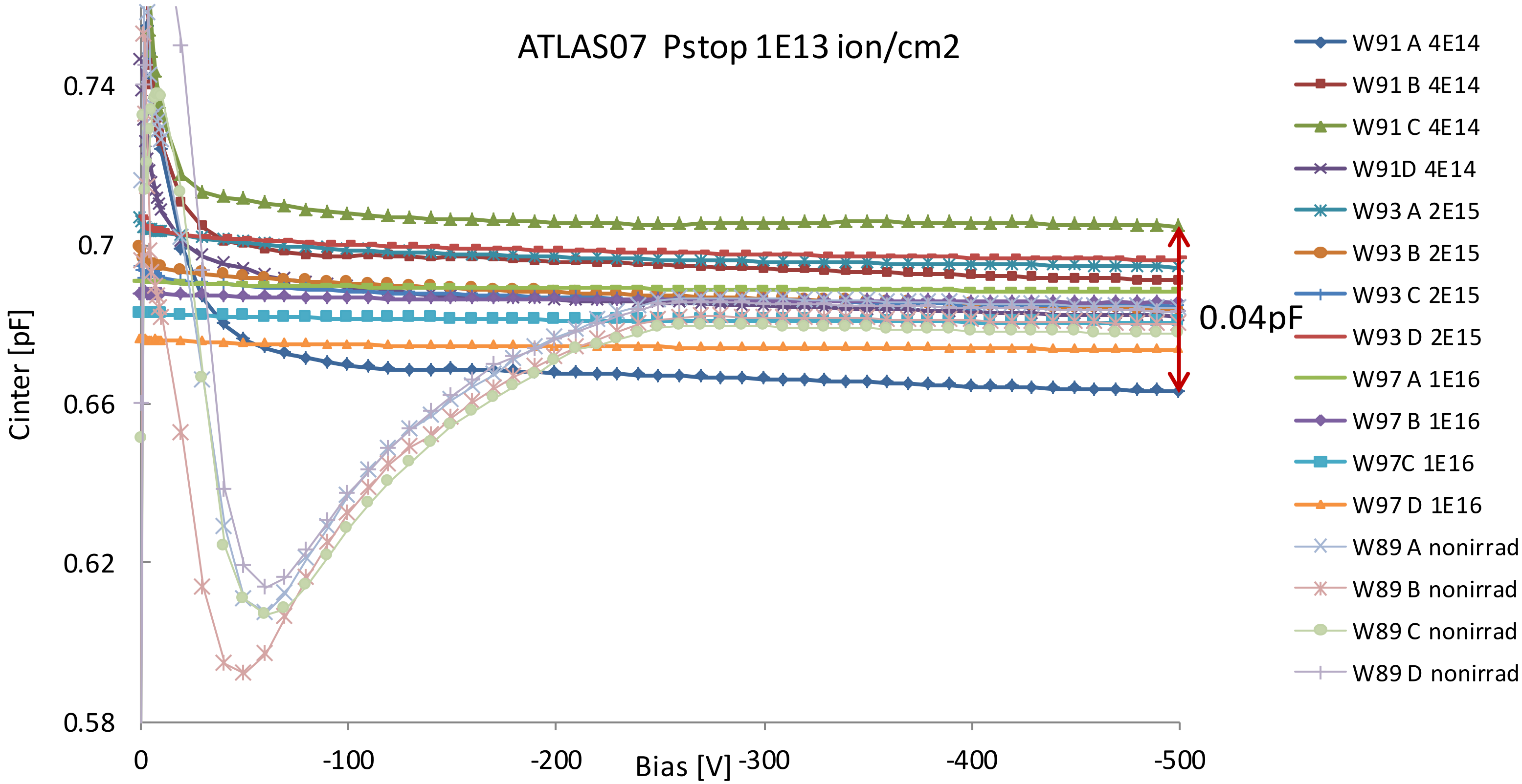



# *Interstrip Capacitance – non-irradiated*




The inter-strip capacitance, Cint, is constant for bias voltages higher than respective full depletion voltages and Cint does not depend in this region on an ion concentration and the punch through protection structures within measuring error of ±0.02pF.

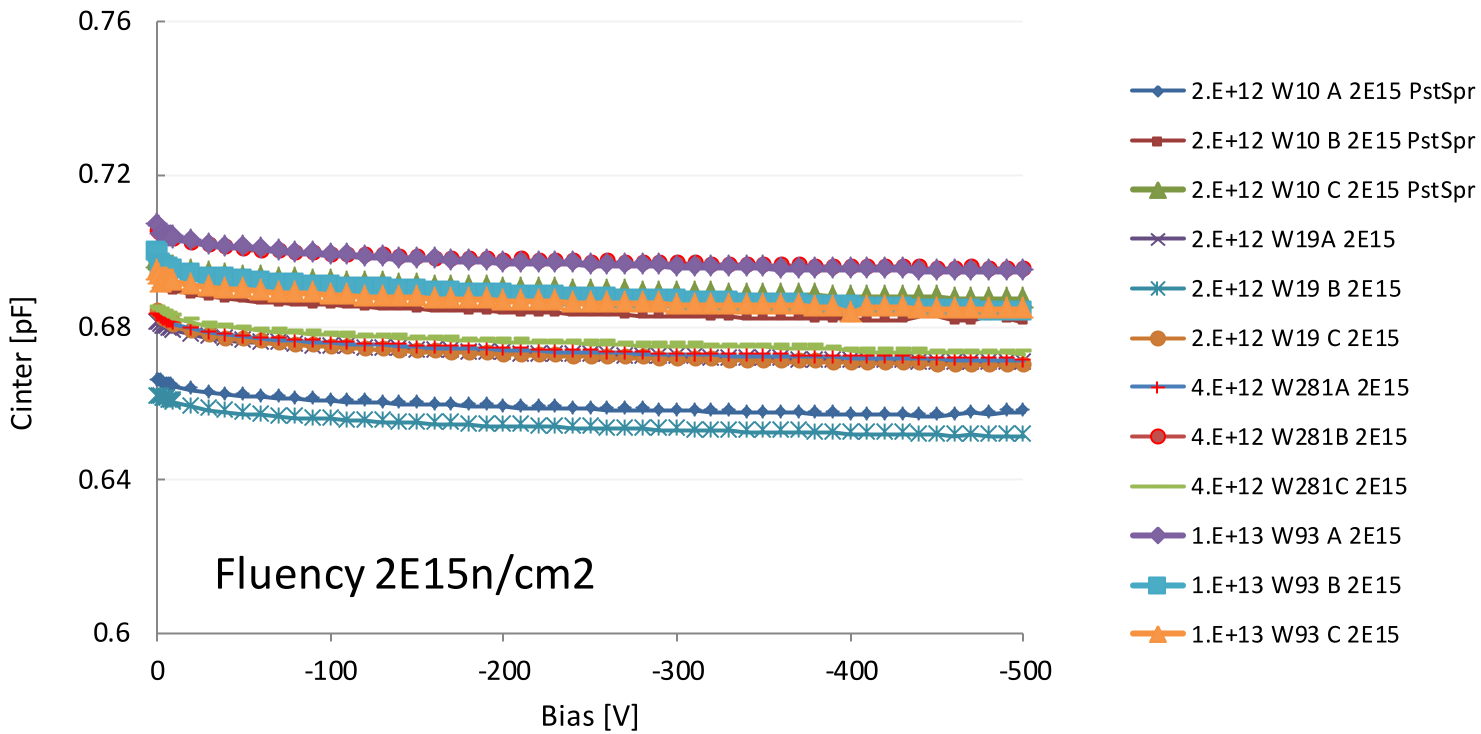
# *Interstrip Capacitance of Heavily Irradiated Sensors*




Cinter before irradiation for p-stop dose 1E13ion/cm2 is also shown. Cinter is not changed by irradiation up to 1E16n/cm2.

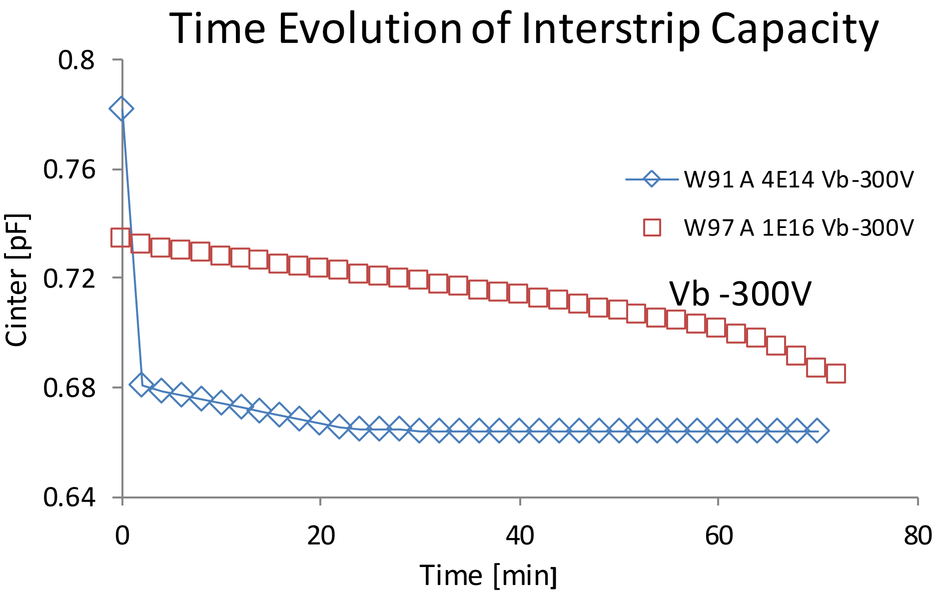
A slow decrease is observed with growing bias voltage which is more pronounced for fluency 4E14n/cm2 than for higher doses.

# *Interstrip Capacity and p-stop ion concentration*




Interstrip capacitance does not depend on ion concentration of p-stop implant within measuring error of ~0.02pF.
A decrease of Cinter with bias voltage is the same for all p-stop and p-stop+p-spray implant doses. It is supposed that this decrease of Cinter is due to small contribution of Cg, capacitance between strip and the backplane. Cg is decreasing function of bias voltage.

# Time Evolution of Interstrip and Bulk Capacitances




Total strip capacitance

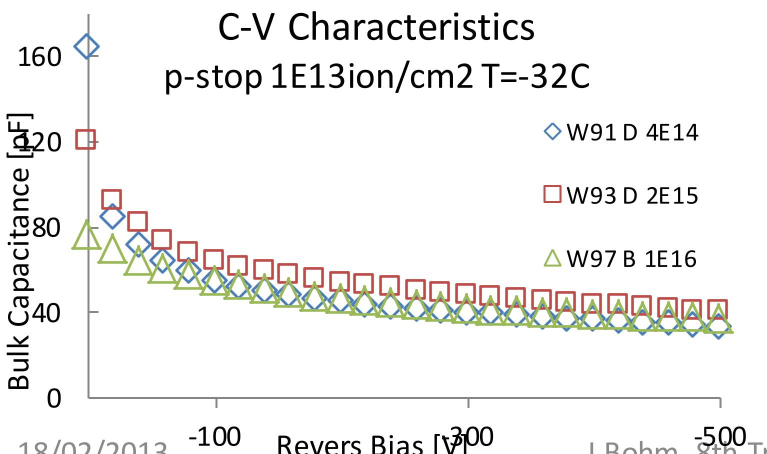
Cint=Cg + 2Cs in the first approximation.

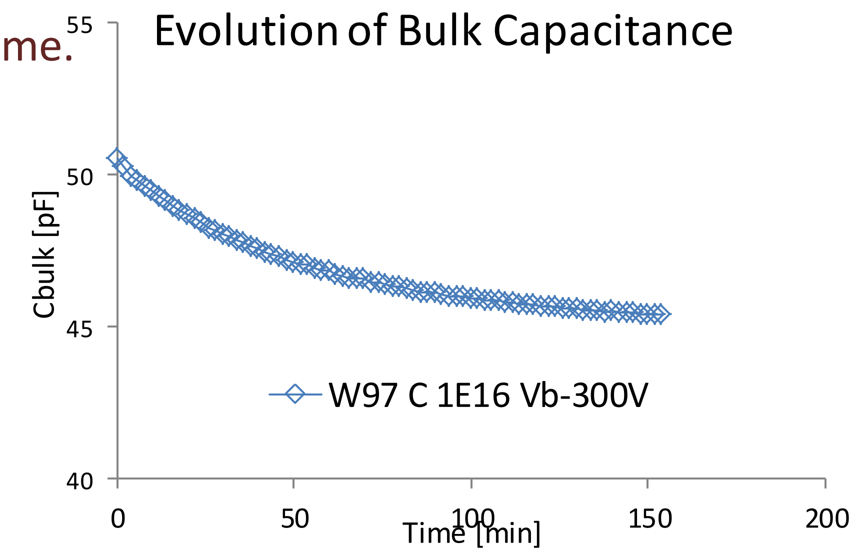
Here Cs is capacitance between 2 strips and Cg between the strip and backplane, Cs>>Cg.

Cg one can estimate as Cbulk/n strips.

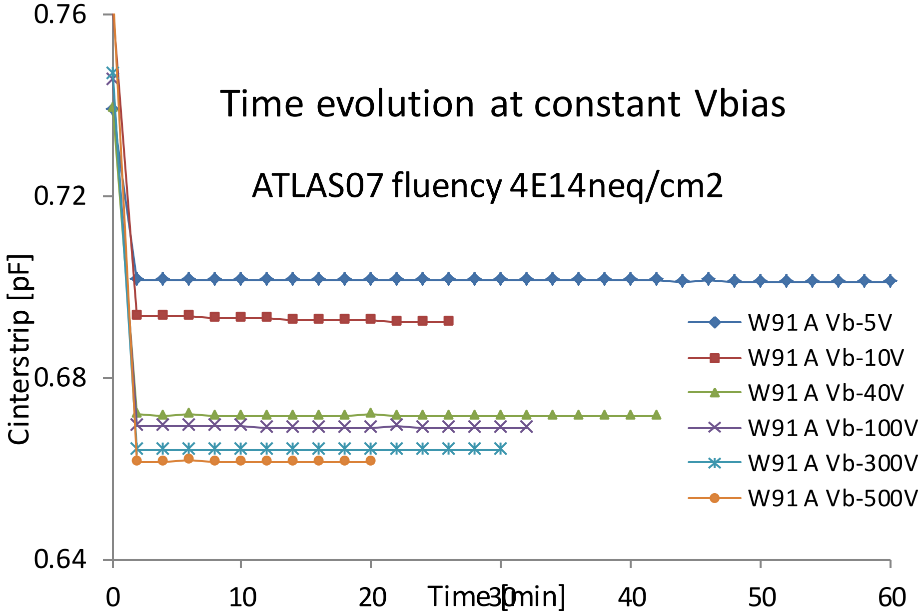
Ruther long time is needed to rearrange charge carriers in the un-depleted region so as to bring the electric field back to zero.

A decrease of Cinter with time at constant bias voltage could be due to decrease of Cbulk with time.



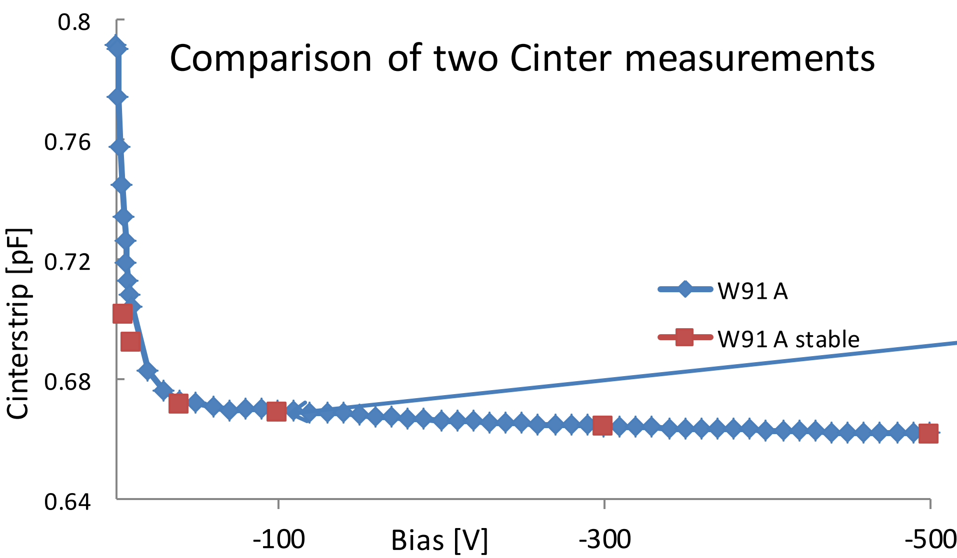



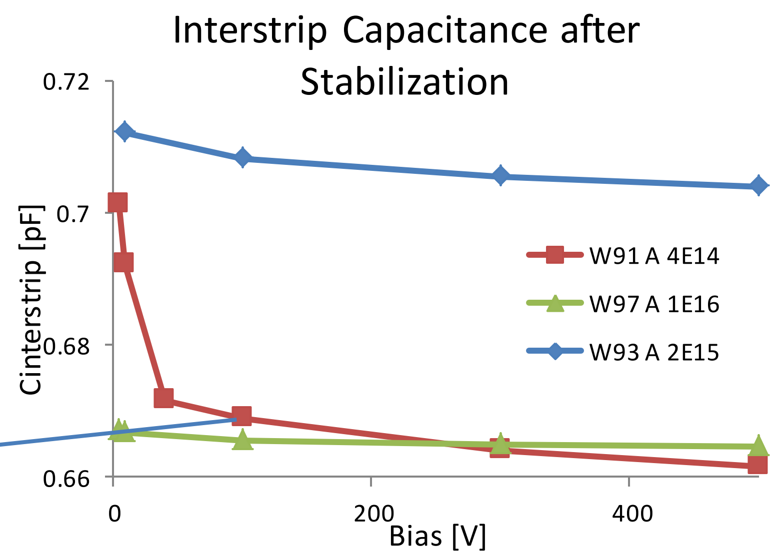
# Time Evolution of Interstrip Capacitance



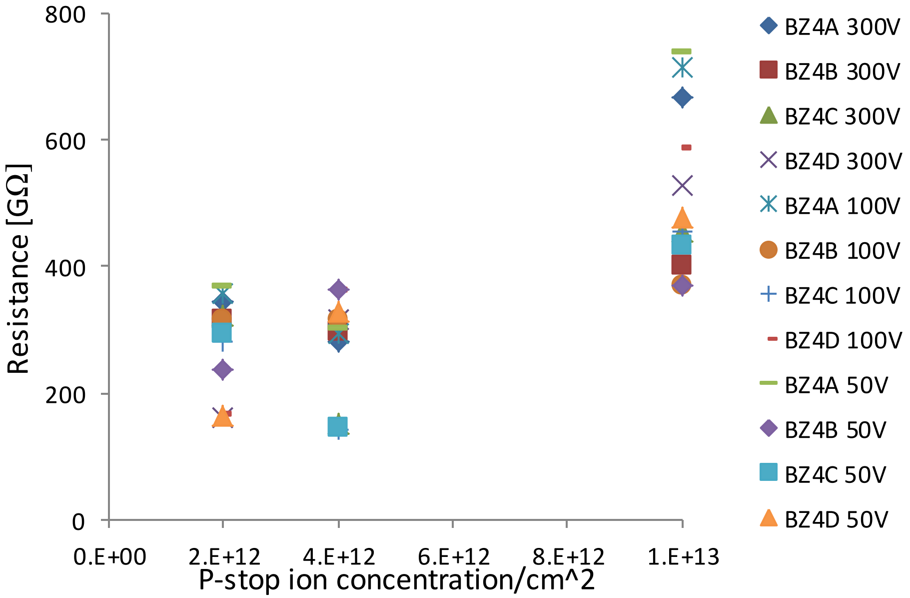

Measurement of Cinter must be done with appropriate time delay between consecutive steps.

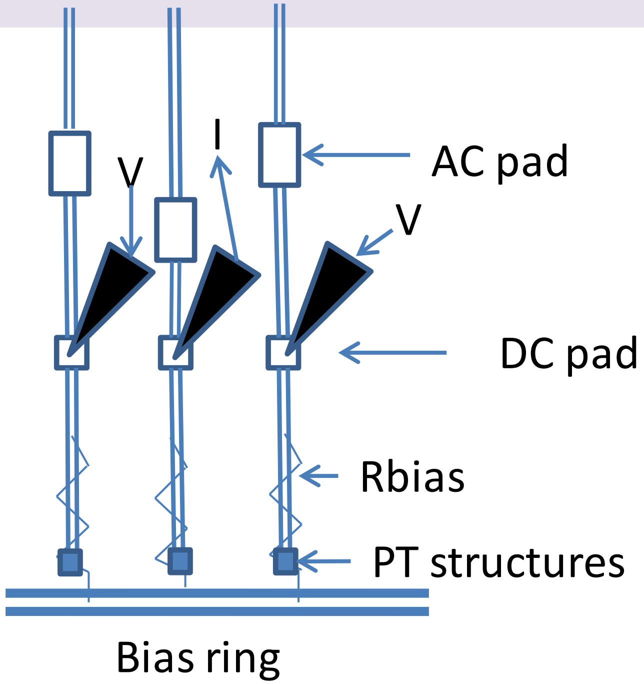
Cinter data taken after stabilization period agree well with Cinter results measured by the program



# *Interstrip Resistance - non-irradiated*

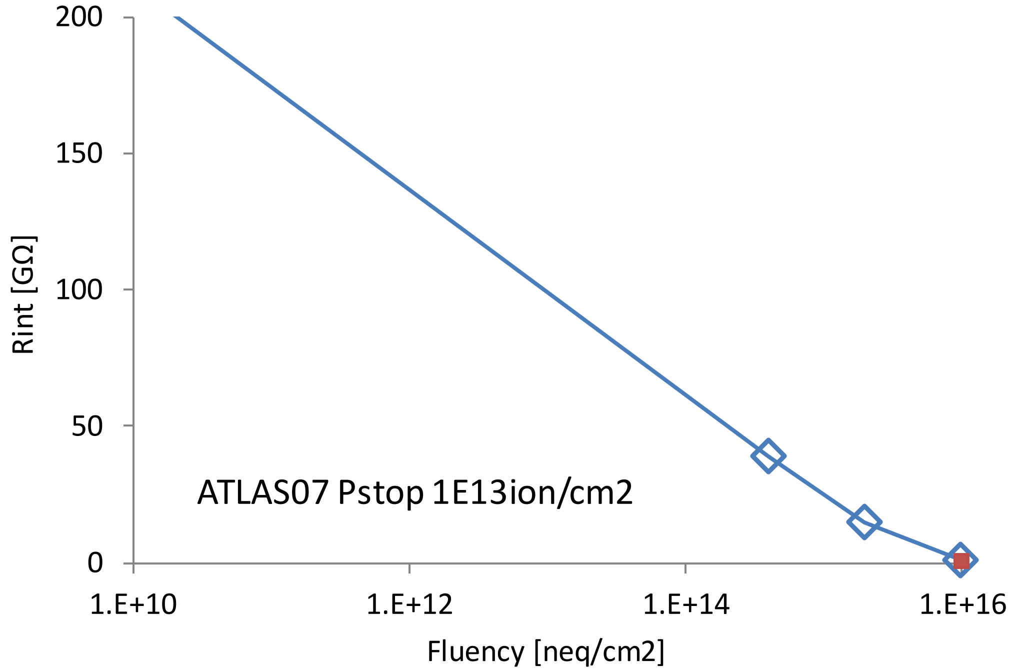



Rint = 2*dV/dI measured at Vbias=-50V, -100V and -300V

Interstrip resistance increases with P-stop ion concentration from 4E12ion/cm^2 up to 1E13 ion/cm^2

# *Interstrip Resistance – heavily irradiated*




Interstrip resistance is decreasing with increasing fluency
K.Hara et al: Nucl.Instrum.Meth. A636 (2011) S83-S89

Resistance for fluency 1E16n/cm2 is about 0.7 GΩ which is many times higher than bias resistor ~1.5MΩ.

Resistance before irradiation Rint=587 GΩ

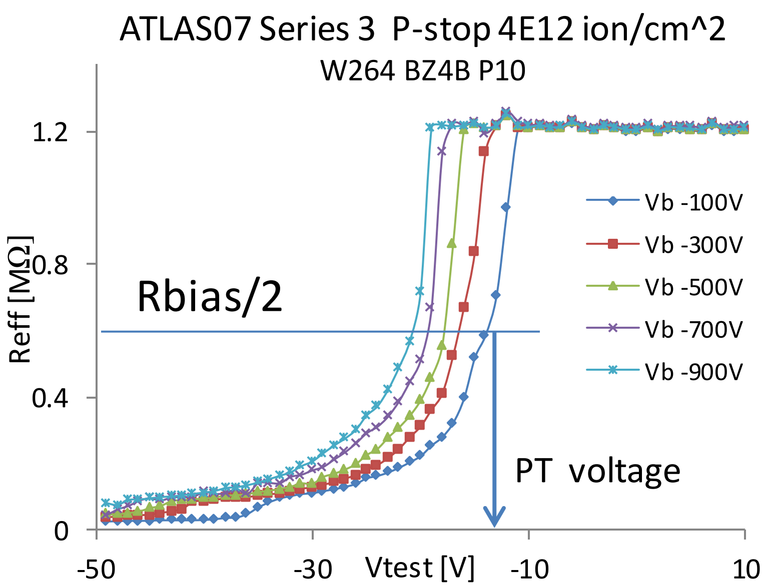
# *Punch Through Protection Structures for ATLAS07*

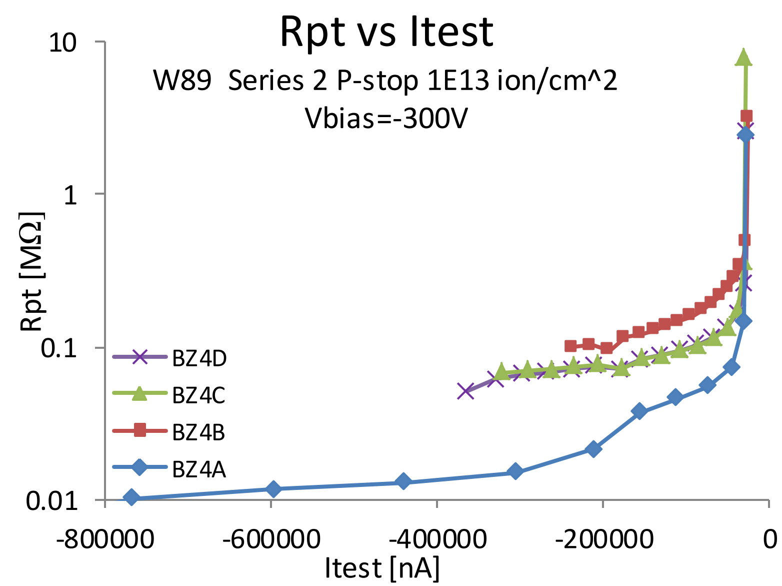
The punch-through (PT) develops via 20µm gap between the strip implant edge and the bias rail . The gap is the same for all three structures and also for case of no structure.
Characteristics of punch through structures are studied by **DC method**:
Negative **Vtest** is an applied voltage to DC pad and **Itest** is current between DC pad and the bias ring**.** DC method S.Lindgren et.al NIM A636(2011)S111-S11&
The effective resistance **Reff=dVtest/dItest** which is constant and equal to bias resistor **Rbias** for low values of Vtest and is rapidly decreasing when PT is developed.

Then **Rpt** is supposed to be parallel to **Rbias: 1/Reff=1/Rbias+1/Rpt.**

**Punch-Through Voltage** is the Test Voltage for **Rbias=Rpt**, i.e. for **Reff=Rbias/2.**

**PT voltage** is evaluated at bias voltages -100, -300, -500, -700 and -900V .

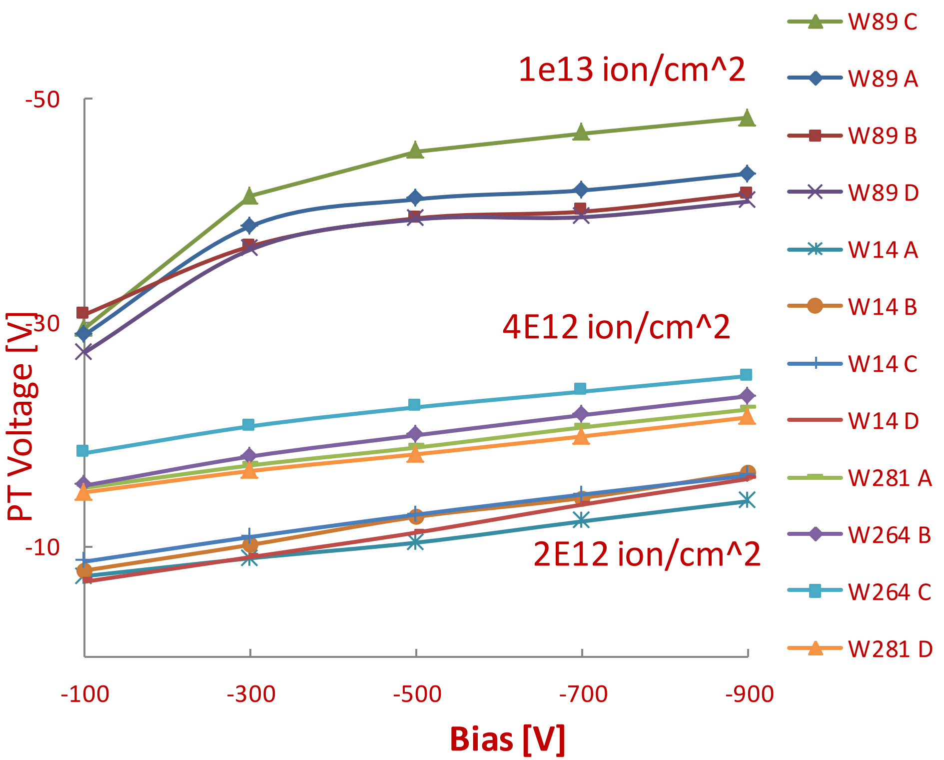


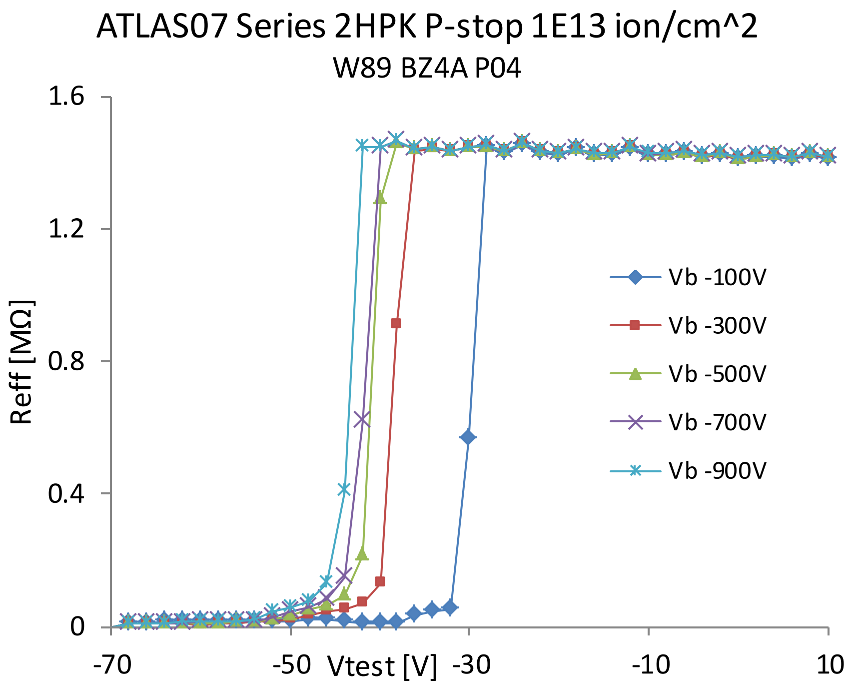






Laser method: C.Betancourt at al. IEEE Vol. 59, No3, June 2012

# Punch Through Voltage
# non-irradiated



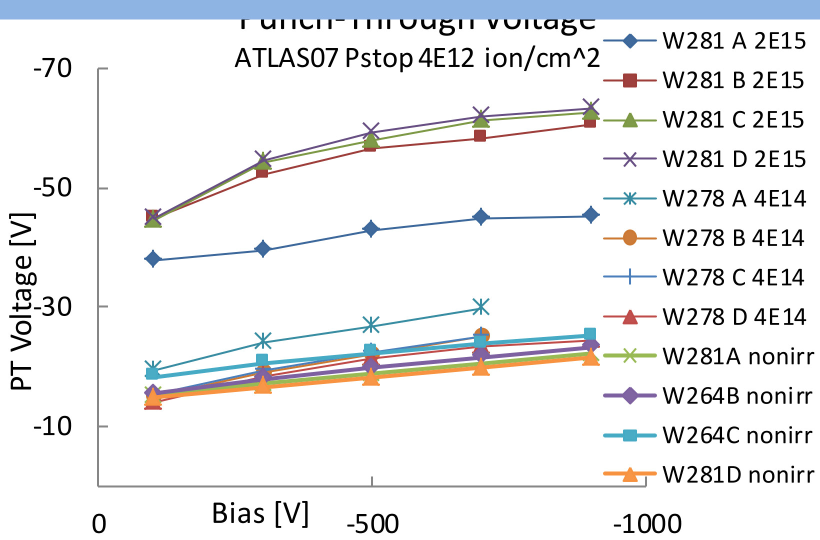

-Punch through voltage dominantly depends on P-stop ion concentration for all punch through structures.

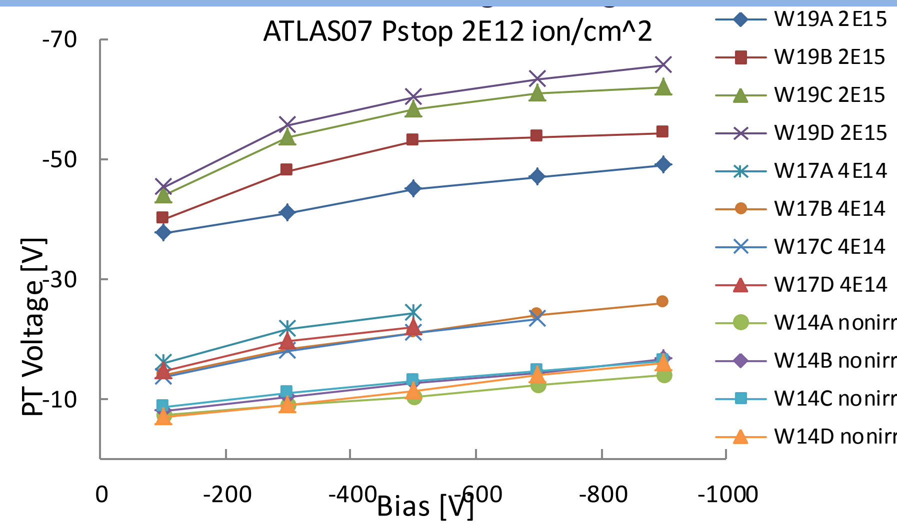
-Differences among PT voltages for structures BZ4A-D are small for all concentrations, several volts only

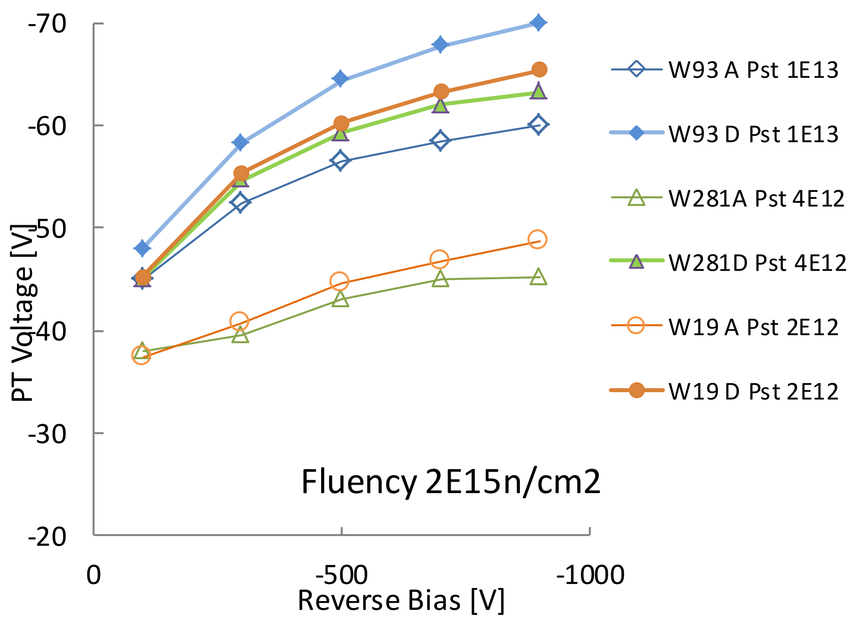
-PT voltage increases with applied bias, for concentration 1E13 ion/cm^2 is observed nearly saturation for Vb>500V.

-PT voltages are smaller than 50V, i.e. they are significantly below the hold-off voltages of the coupling capacitor which are typically tested to 100V.

# *Punch Through Voltage*
## *irradiated*



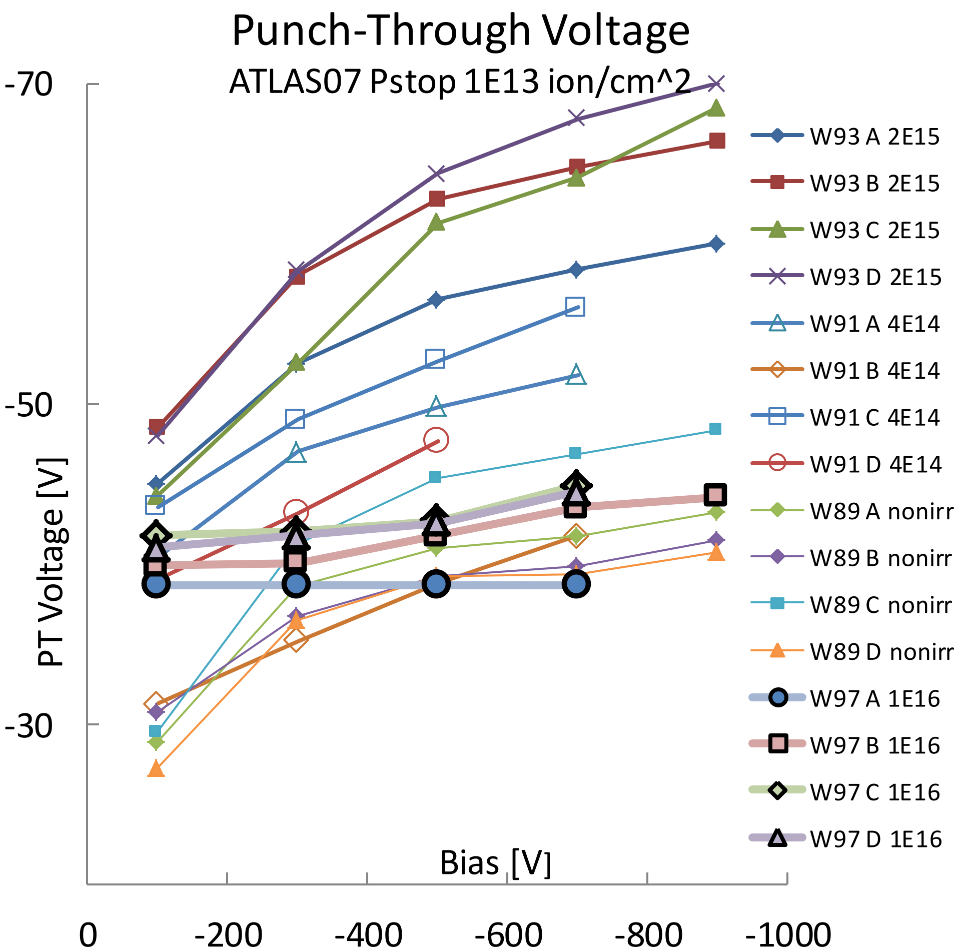



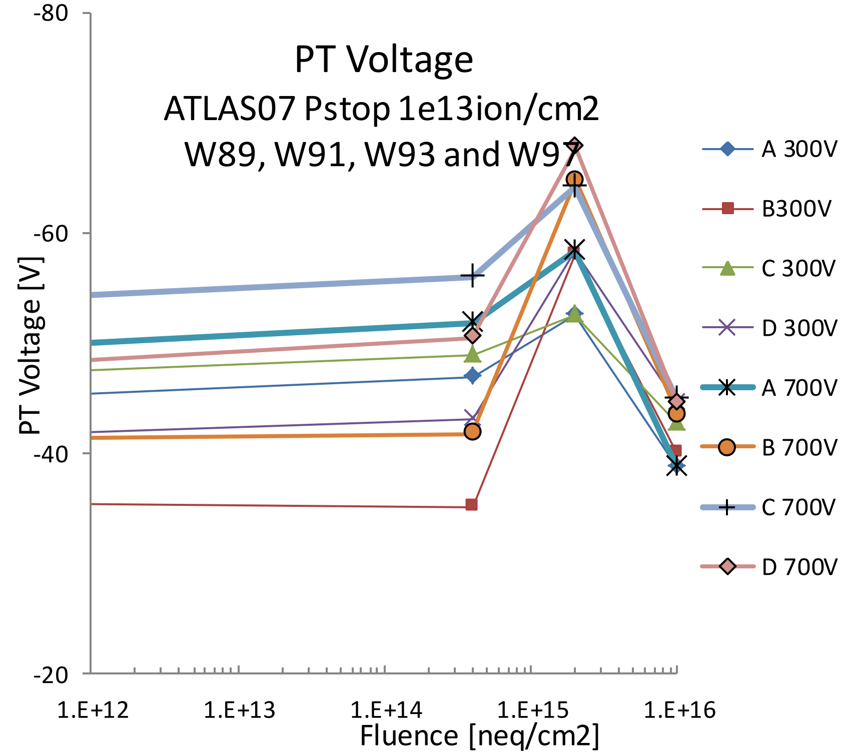

-PT voltage increases predominantly with fluency and very slowly with ion concentration

-At fluency 2E15 n/cm^2 and for all tested ion concentrations the PT voltage for structure BZ4A reaches minimum value and BZ4D without any special structure –the maximum.

The same behaviour of structure BZ4A is observed also for p-stop doses 4E12 and 2E12 ion/cm2.

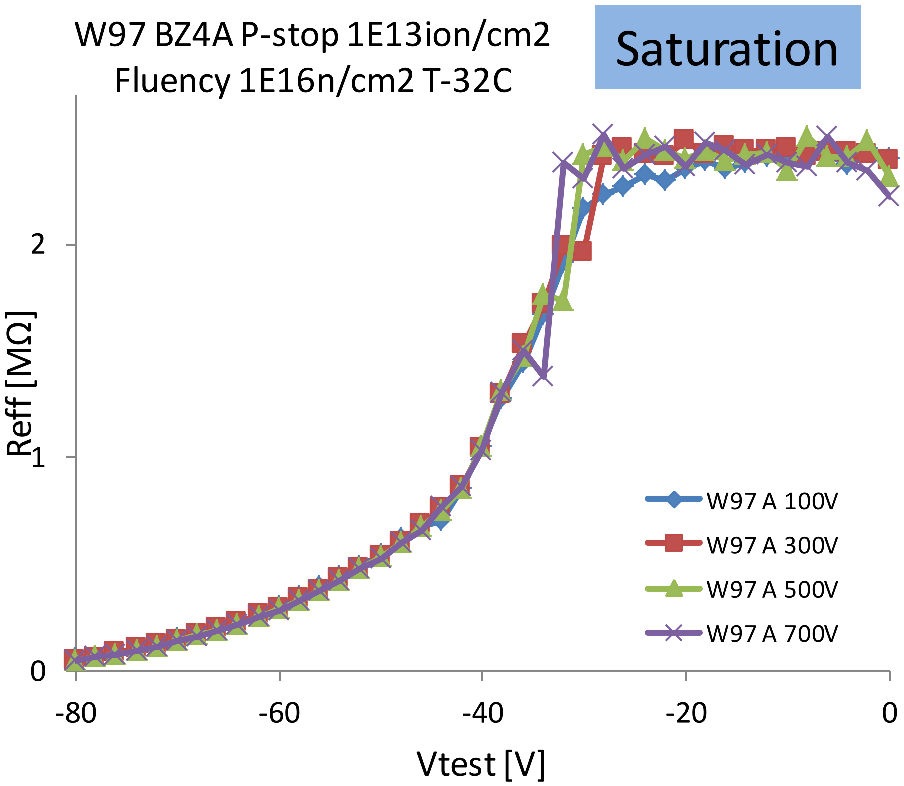
# Punch Through Protection Structures for ATLAS07



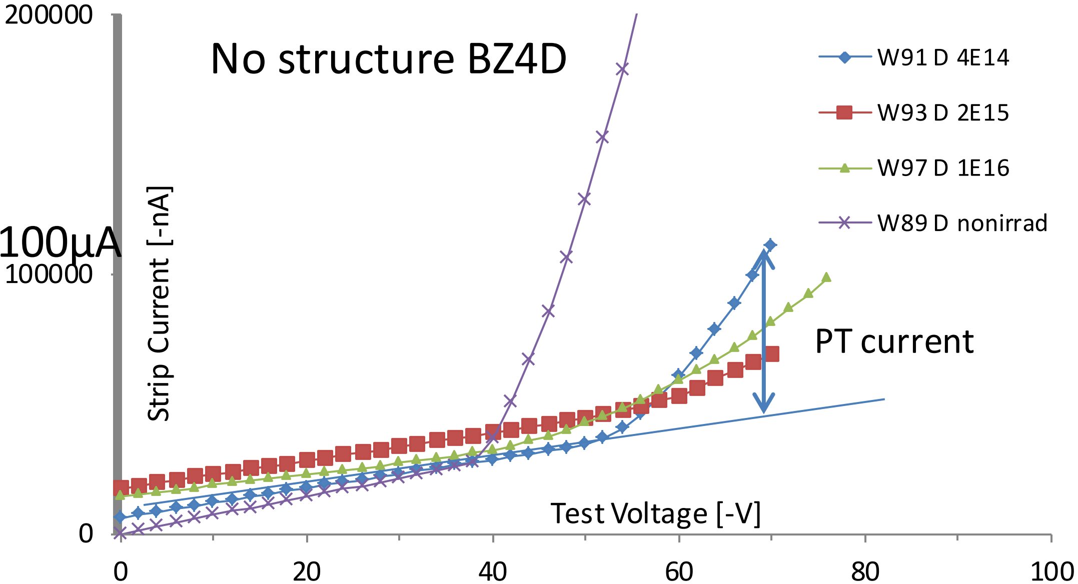



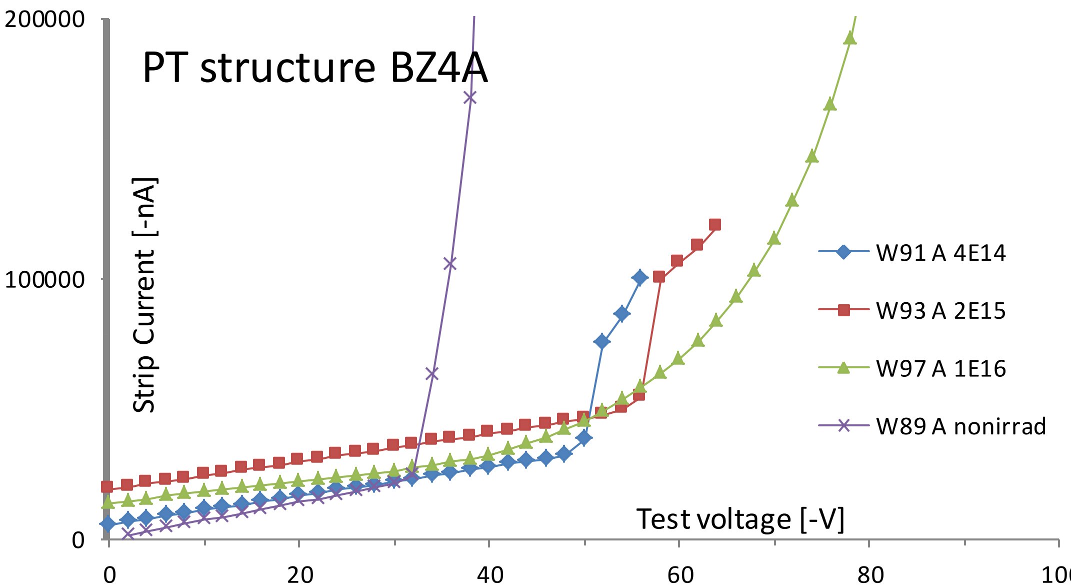

-PT voltages for P-stop ion concentration 1E13 ion/cm^2 and fluency 1E16n/cm2 are surprisingly below the PTV for lower fluency and even smaller than safety level of 50V and do not depend on the bias voltage (saturation)

# *Punch Through Voltage*
## *irradiated*



# Punch-Through Current for ATLAS07



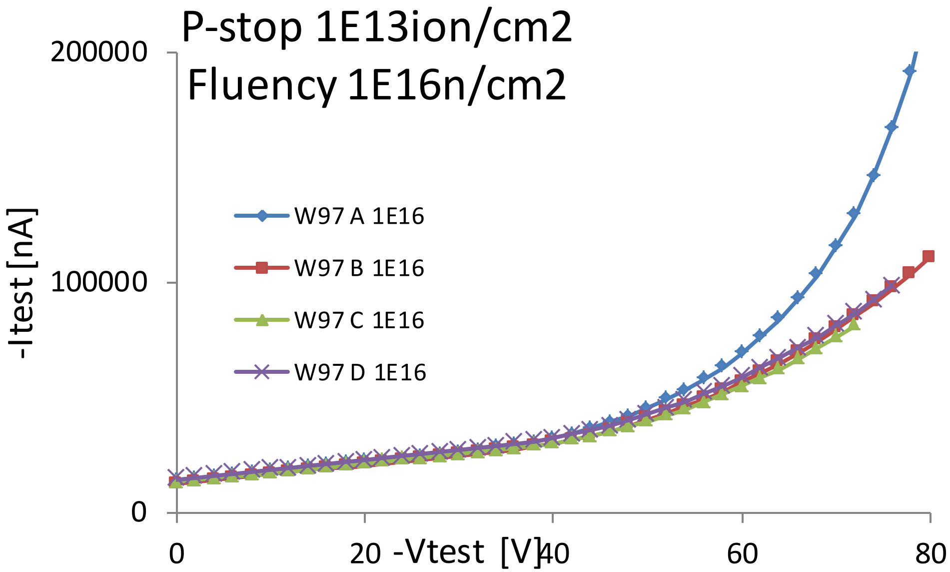



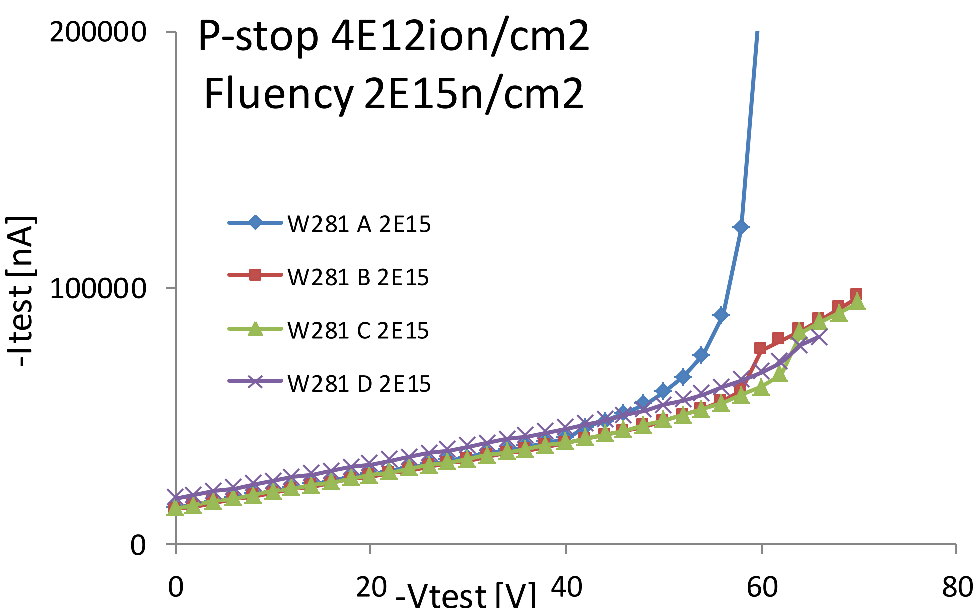

At low volts the current flows to BR only through the bias resistor and grows linearly with voltage. At higher volts the PT current appears as a component additional to the linear rise.

Typically the PT current grows very steeply with voltage above the onset value thus preventing the sensor.

**A.Chilingarov: Report on 21st RD50 Workshop, 15.11.2012, CERN**

# Comparison of PT structures




Punch-through current grows rapidly for structure BZ4A only .

A difference among structures BZ4B, BZ4C and no-structure BZ4D is negligible.

The better performance of zone BZ4A would be due to the **gate effect** since larger portion of the channel length is covered by the bias resistor (conformation of previous results).

Radiation damage reduces the effectiveness of PTP structures. It is the question to what extent the effectiveness depends on p-stop implant dose.
It will be tested with new irradiated
In Ljubljana sensors up to 1E16n/cm2
and with several p-implant doses.

# Summary and Conclusions

1 The heavily irradiated sensors (≥ 2E15n/cm2) with p-stop isolation of different ion concentrations were successfully operating up to 1000V but not for fluency 4E14n/cm2 where an onset of micro-discharges was observed above 700V.

2 Interstrip capacitance is the same within measuring error of ~0.02pF for irradiated (4E14, 2E15 and 1E16n/cm2) and non-irradiated sensors as well as for all tested p-stop ion concentrations (2E12, 4E12 and 1E13ion/cm2).

3 An observed decrease of interstrip capacitance after irradiation with growing bias voltage could be qualitatively explained by the contribution of the bulk capacitance.

4 Time evolution measurement has shown a slow decrease of the bulk and interstrip capacitances of irradiated sensors before the plateau is reached.

5 Interstrip resistance is decreasing with increasing fluency ; Resistance for fluency of 1E16n/cm2 is still ~0.7 GΩ which is significantly higher than Rbias ~ 1.5MΩ.

6 Punch-through protection was characterized by parameters of DC method: Effective resistance, PT voltage and PT resistance as a function of bias voltage.

7 An investigation of punch-through current allowed to estimate PT structure BZ4A as the most effective protection against beam splashes

8 Next 16 sensors were already irradiated in Ljubljana as the last step of investigation.

*Thank you for your attention*