Irradiation of Fz and MCz mini-sensors of n and p-type with 24 GeV/c and 26 MeV/c protons up to fluences of 3 10^{15} 1MeV n/cm^2

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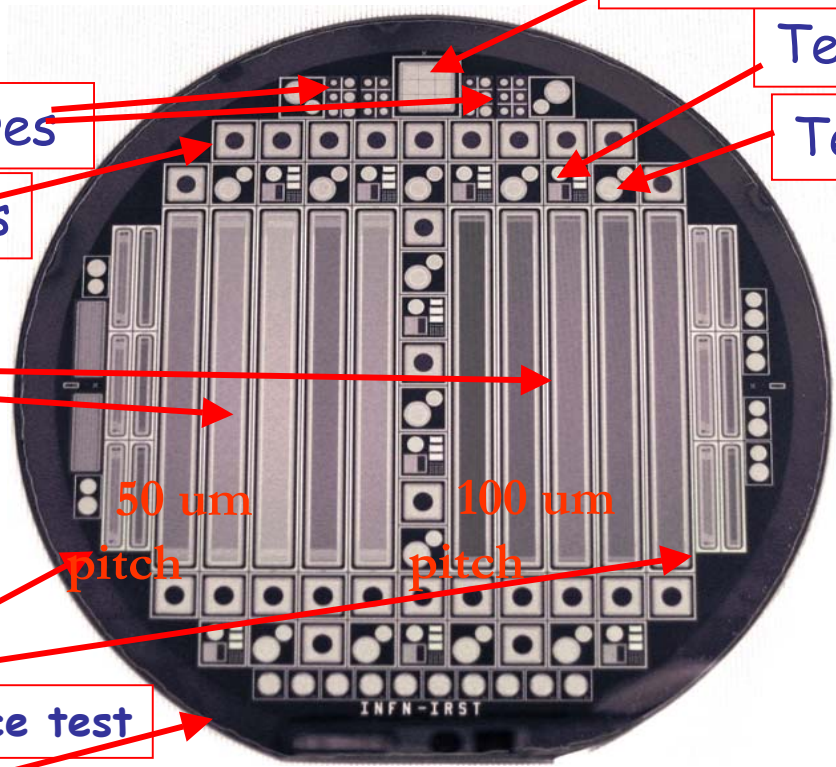
SMART Collaboration

Thanks to: M.Glaser (CERN) & A.Furgeri (Karlsruhe)

Talk outline

- The SMART RUN I & II
  - **Layout and materials**
- Process and Pre-irradiation qualification
- Irradiation
- Studies on mini-sensors
  - **Preliminary results on**
    - **Electrical performances**
    - **Detector properties**
- Conclusion

Wafer layout - SMART



RUN I p-on-n

22 wafers Fz, MCz, Cz, Epi

March 04

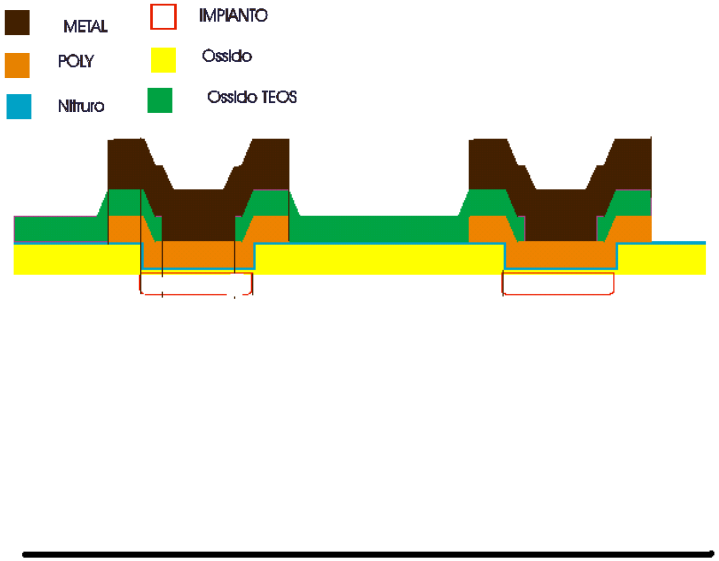
RUN II n-on-p

24 wafers Fz, MCz

September 04

- ✓RD50 common wafers procurement
- ✓Wafer Layout designed by SMART collaboration
- ✓Masks and process by ITC-IRST

Mini-sensors design features



μ-strip #	pitch (μm)	p+ width (μm)	Poly width (μm)	Metal width (μm)
S1	50	15	10	23
S2	50	20	15	28
S3	50	25	20	33
S4	50	15	10	19
S5	50	15	10	27
S6	100	15	10	23
S7	100	25	20	33
S8	100	35	30	43
S9	100	25	20	37
S10	100	25	20	41

Mini-sensor active area=0.32 x 4.5 cm^2

a) Pitches 50, 100 μm to match active thickness (EPI) and for a low occupancy level
b) Strips length ~45 mm to exploit tracking detector performances (noise)
c) Implants geometry to investigate leakage current level, breakdown performances and capacitance effects

Material under investigation

- p-on-n MCz <100> ρ> 500 Ω cm RUN I

standard process	W364
no LTO, sintering @ 380 °C	W115,W130,W164,W91
no LTO, sintering @ 350 °C	W179
no LTO, sintering @ 380 °C + TD killing	W160,W127

- n-on-p MCz, no OG <100> ρ> 1.8 KΩ cm RUN II

low dose p-spray 3E+12 cm $^{-2}$	W66,W9,W102,W14
high-dose p-spray 5E+12 cm $^{-2}$	W182,W64,W130,W84, W6,W253,W248

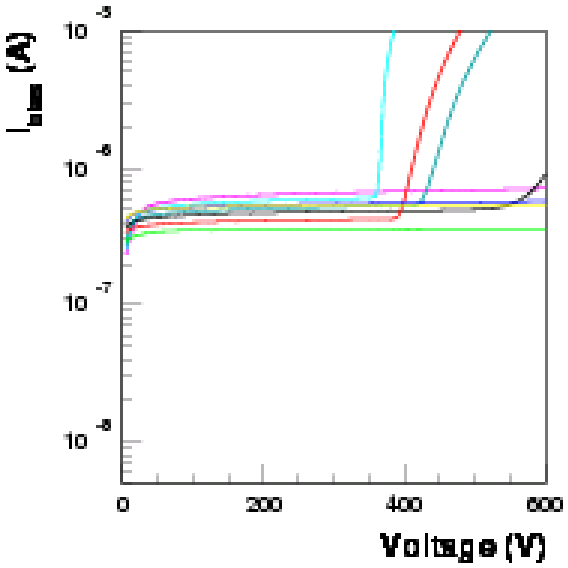
- Fz reference samples

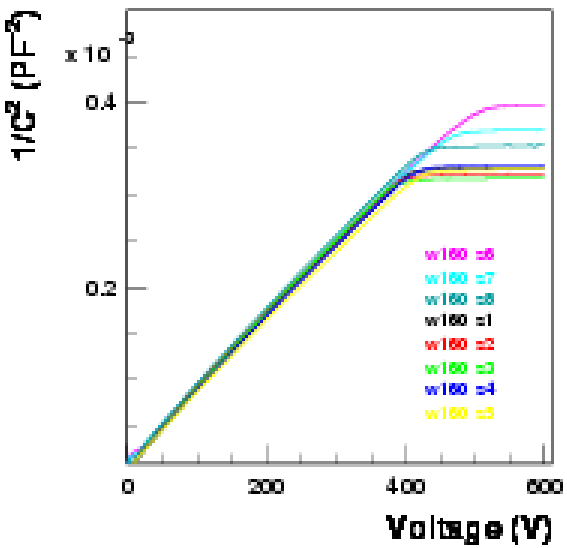
n-type <111> RUN I	W1253,W1254 (std) , W1255 (T=380 C)
p-type (passivated) RUN II	W14 (low dose p-spray), W37 (high dose p-spray)

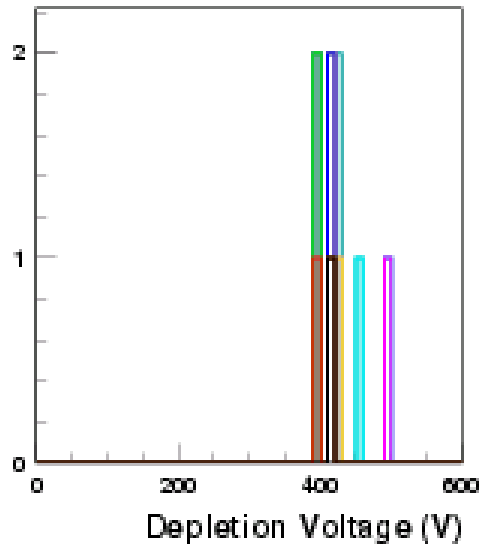
Pre irradiation measurement

- **Bulk current & Depletion voltage**
  - **Diodes & Mini-sensors**
- **Strip capacitive load**
  - **Capts & Mini-sensors**
- **Surface current**
  - **GCD (Metal, Poly)**
- **Oxide trapped charge**
  - **MOS**

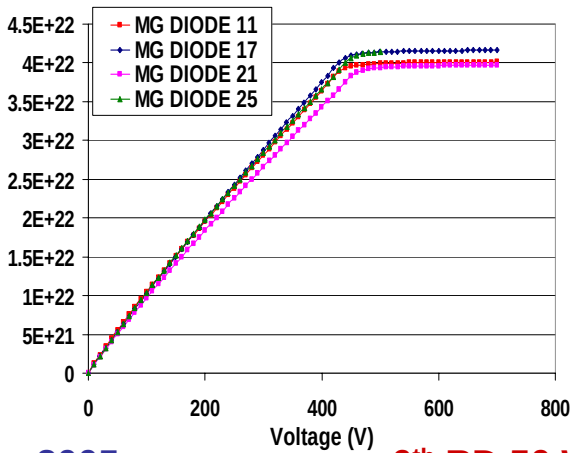
Wafer MCz *n-type* pre-irr: typical performance

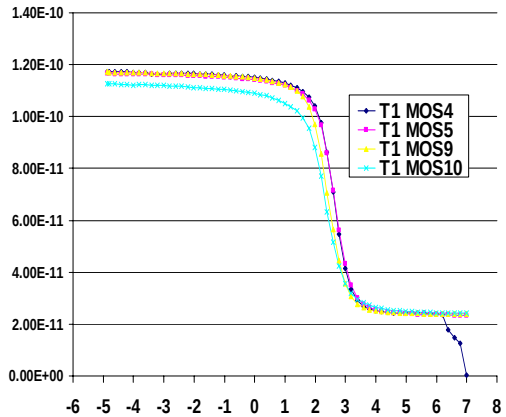






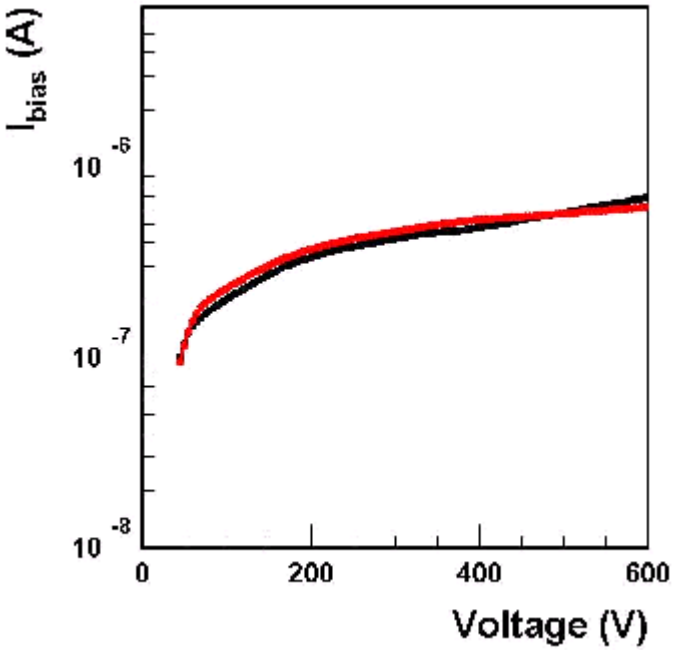
Measurement on test structures in agreement with sensors properties



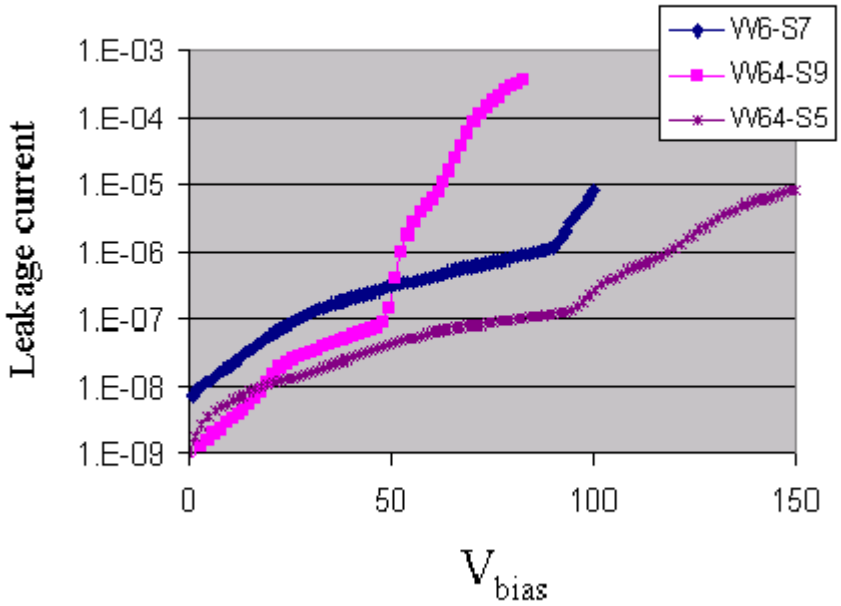


Wafer MCz *p-type* pre-irr

Mini-sensors (W66) 50 μm pitch



Mini-sensors 50/100 μm pitch



MCz and Fz p-type mini-sensors of 100 μm pitch may show an early breakdown before irradiation:

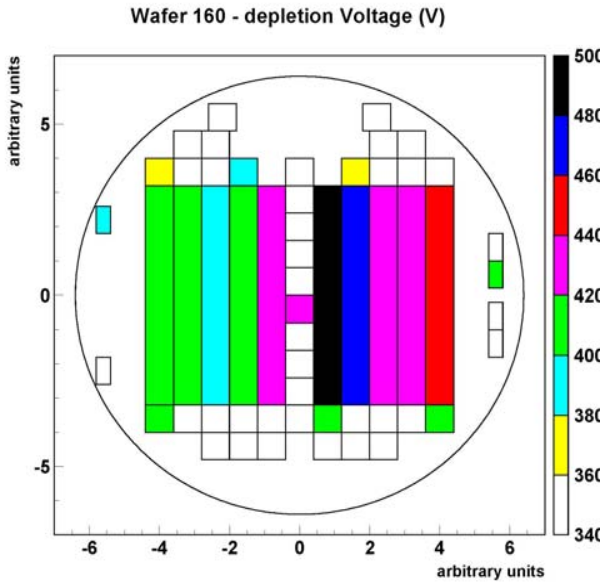
Preliminary investigations suggest that the problem can be related with p-spray deposition: no special mask has been used to diffuse it

Wafer resistivity

Diode CV measurements show a variation of the bulk resistivity both in n- and p-type MCz wafers with a depletion voltage spread for the mini-sensors.

MCz n-type – no LTO -

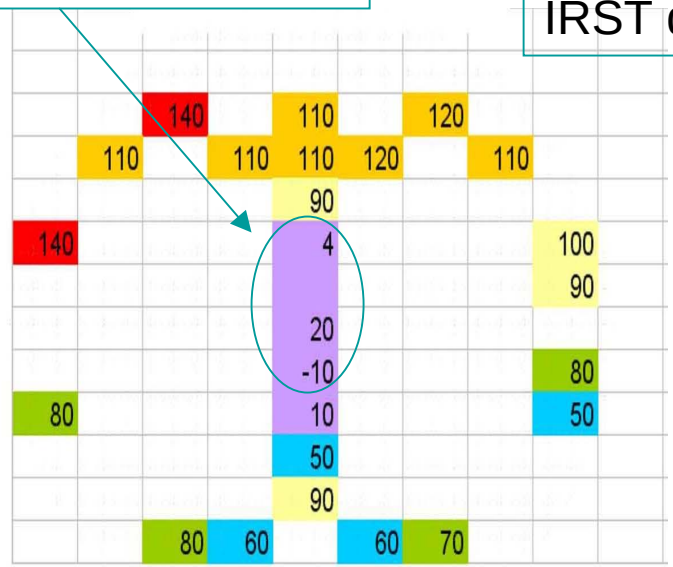
W164	430 < Vdepl < 520 V	(19 %)
W115	520 < Vdepl < 580 V	(11 %)
W130	400 < Vdepl < 460 V	(15 %)
W160	380 < Vdepl < 500 V	(27 %)



Larger variation for Wafer MCz p-type

Type inverted region ?

IRST data



Thermal Donor activation , see talk of D.Menichelli

Irradiation campaign

- CERN OCT 04 : 24 GeV/c Protons
  - **K factor ~ 0.62**
- Karlsruhe May 05 : 26 MeV/c Protons
  - **K factor ~ 3.0**

- Irradiation performed on diodes & test structures* and Mini-sensors

*(result reported on the D.Creanza Talk this workshop)

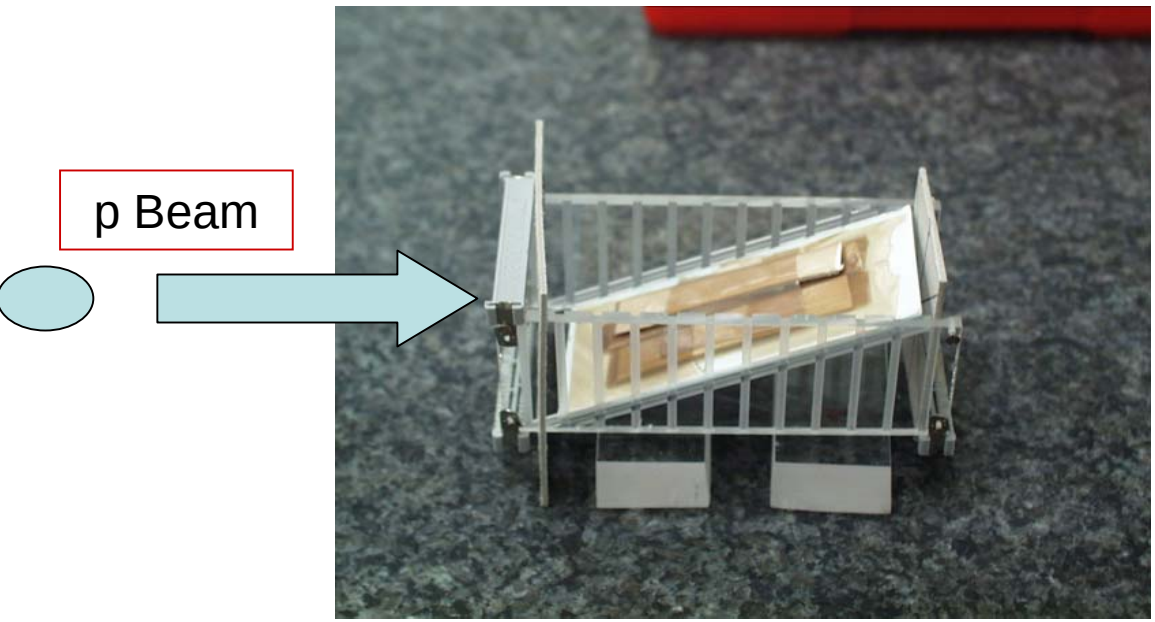
Cern Irradiation (Oct04)

	FZ	MCz 380 noLTO				MCz	MCz		FZ	
fluence (p)		TD killing				low p-spra	gh p-spra	w p-spra	gh p-spra	
			160	130	164		364		182		
5.56E+15			*S10,S5*	*S9*	*S4,S10*		S5		*S4,S2*		
	1255		160	130	164	115	364	66		14	37
4.43E+14	*S3*		*S9*	*S7*	*S5,S6*	*S3*	*S1*	*S1*		*S1*	*S1*
	1255	1254	160	130	164	115	364	66			37
9.63E+13	*S1*	*S9*	*S1*	*S2*	*S3*	*S4*	*S2*	*S2*			*S4*

75 % n-type
25 % p-type

- About **90 diodes** and a few test structures irradiated
- Fluences range : **6 10^{13} - 3.4 10^{15} 1 MeV neutr. eq./cm^2**

CERN Irradiation set-up



Diodes and test-structures T1, T2 and T3 have been placed orthogonally to the beam direction

Mini-sensors have been placed with an inclination of about 26° to be irradiated uniformely by the beam (section = 2x2 cm^2)

active area=0.32 x 4.5 cm^2

Non uniform damage on mini-sensors , effect seen at the strips level

Irradiation in Karlsruhe (May05)

n-type Fz n-type MCz p-type MCz

Fi2 = 6*10^13	Fi3 = 1*10^14	Fi4 = 2*10^14	Fi5 = 3*10^14	Fi6 = 4*10^14	Fi7 = 6*10^14	Fi8 = 8*10^14	Fi9 = 1*10^15
5.6 10e13	1.04 10e14	1.76 10e14	3.09 10e14	3.87 10e14	5.9 10e14	7.92 10e14	1 10e15
W1253 -s1	W1253 -s2	W1253 - s3	W84 - s2	W1253 - s7	W1253 - s7	W127 - s9	W127 - s10
W127 - s1	W127 - s2	W127 - s3		W91 - s7	W91 - s7	W91 - s9	W64 - s6
W91 - s1	W91 - s2	w179 - s3		w64 - s8	w64 - s8	w64 - s10	w6 - s9
w179 - s1	w179 - s2	W64 - s3		W9 - s8	W9 - s8	W9 - s10	W9 - s9
W64 - s1	W64 - s2	W6 - s3		W130 - s8	W130 - s8	W24 - s3	W130 - s9
W9 -s1	W64 - s9	W9 - s3		W248 - s3	W102 - s2	W160 - s2	W102 - s3
W130 - s2	W9 - s2	W130 - s4		W84 - s3	W14 - s4	W84 - s6	W66 - s4
W84 - s1	W130 - s3				W160 - s3		W160 - s4
	W248 - s1	W102 - s4			W248 - s5		W84 - s7
		W1255 - s8			W84 - s4		
		W160 - s8					
		W248 - s2					
		W84 - s1					
		W187 - s2					
		W187 - s4					
		W253 - s2					
		W253 - s4					

38 % n-type
62 % p-type

- About **100 diodes** and a few test structures irradiated
- Fluences range : **1.8 10^{14} - 3 10^{15} 1 MeV neutr. eq./cm^2**

Karlsruhe

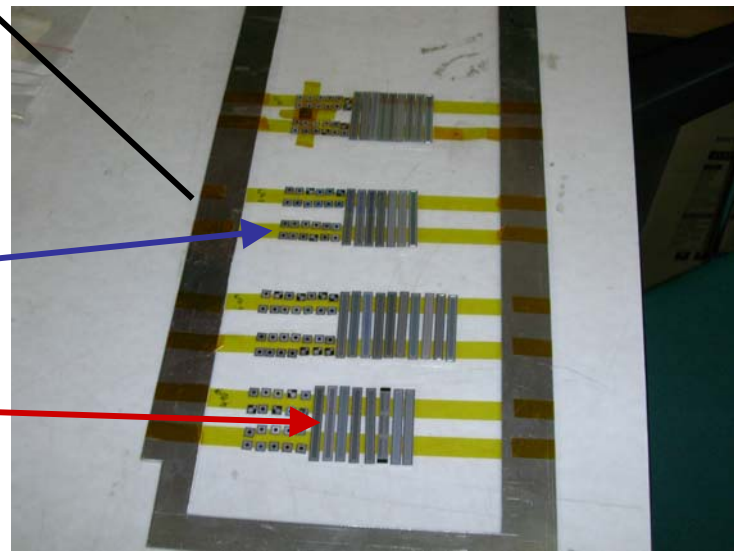
Irradiation set-up

Box is moving to scan the whole relevant area

Low energy protons : uncovered devices exposed to the beam

Diodes

Mini-sensors



Preliminary results on mini-sensors

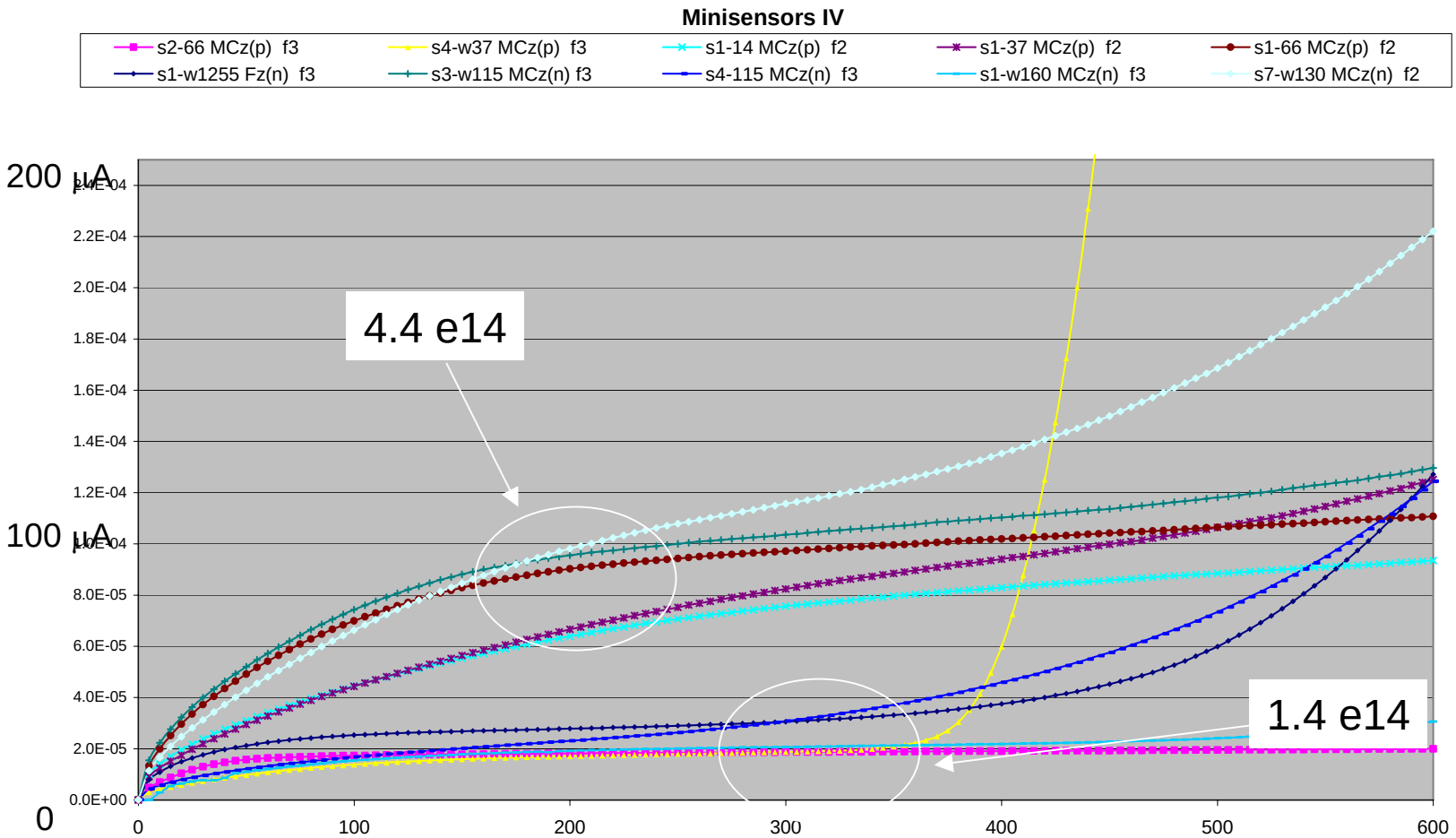
1. Leakage current
2. Neff annealing
3. Inter-strip capacitance

- Device Measurements performed in:
  - **Firenze & Pisa at low temperature**
  - **Bari at room temperature**
- All laboratories have a set of dedicated instruments for semiconductor measurements

(Vbias up to 1 KV, LCR 20Hz – 1 MHz , Pico Ammeter)

CERN Irradiation: leakage current

IV of n-type and p-type, measured at 0 °C, no annealing performed

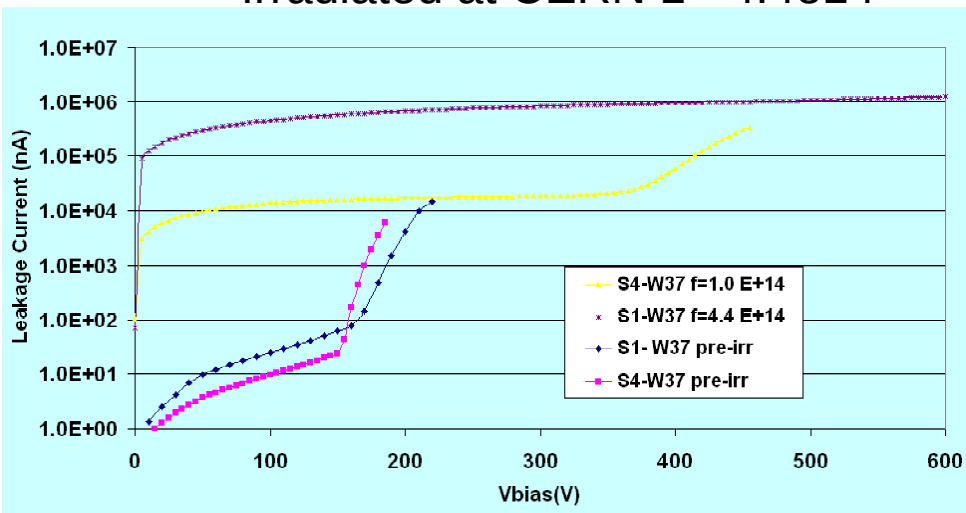


CERN Irradiation: breakdown performance

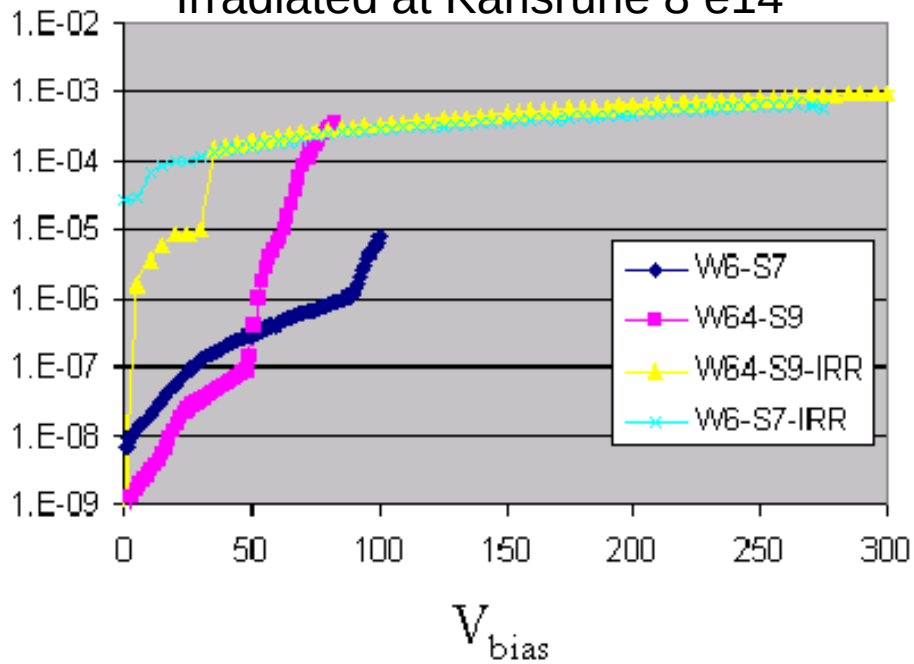
n-on-p mini-sensors with High p-spray 3e15/cm2

After irradiation Breakdown voltage improves

Irradiated at CERN 1 - 4.4e14

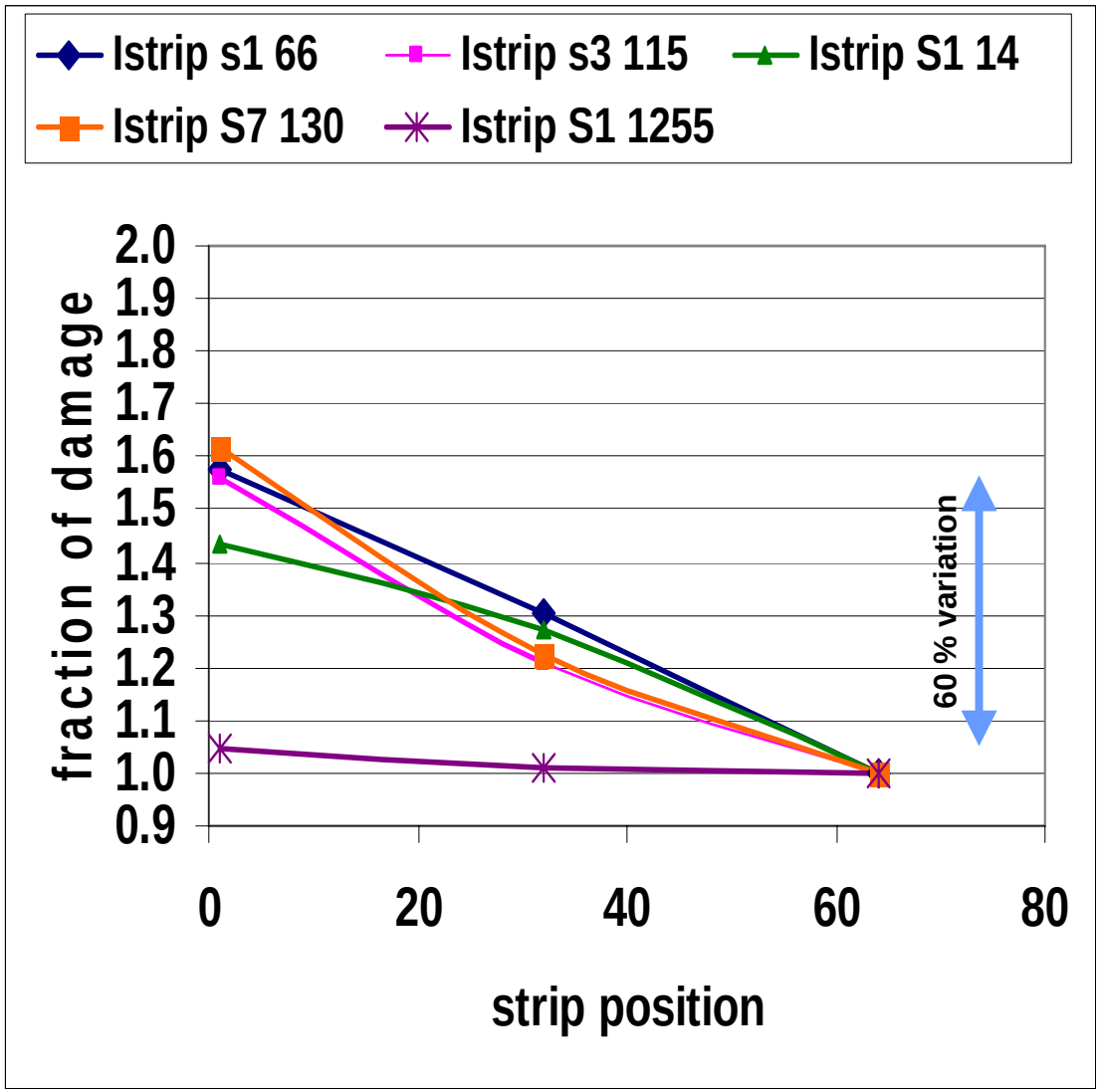


Irradiated at Karlsruhe 8 e14



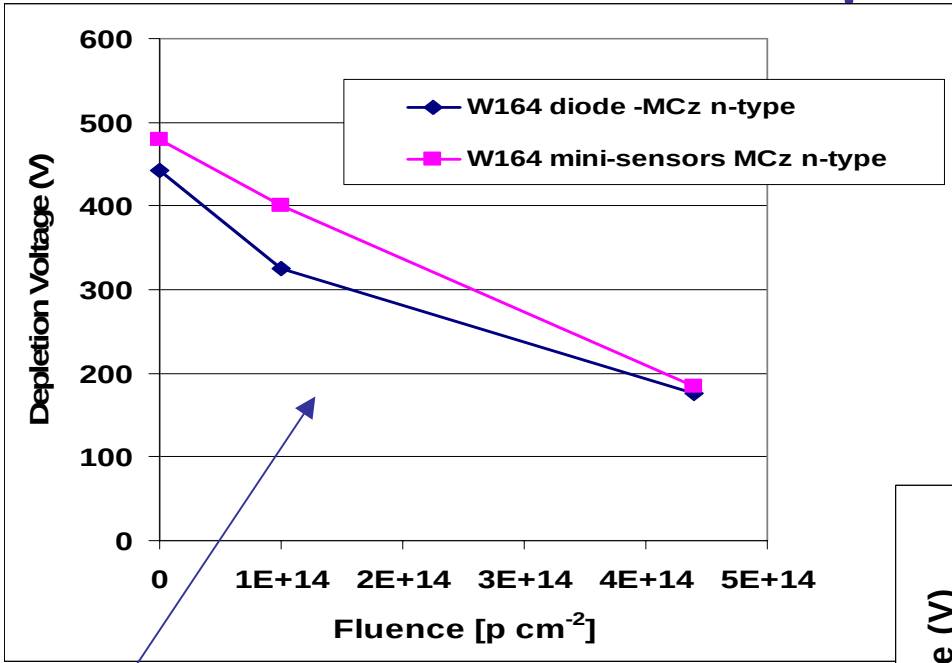
Oxide trapped charge induced by radiation damage modifies the electrical field at surface

CERN irradiation: mini-sensors strip leakage current



Non uniform beam spot produces a position dependent damage !

Variation of the depletion voltage with fluence



CERN irradiation

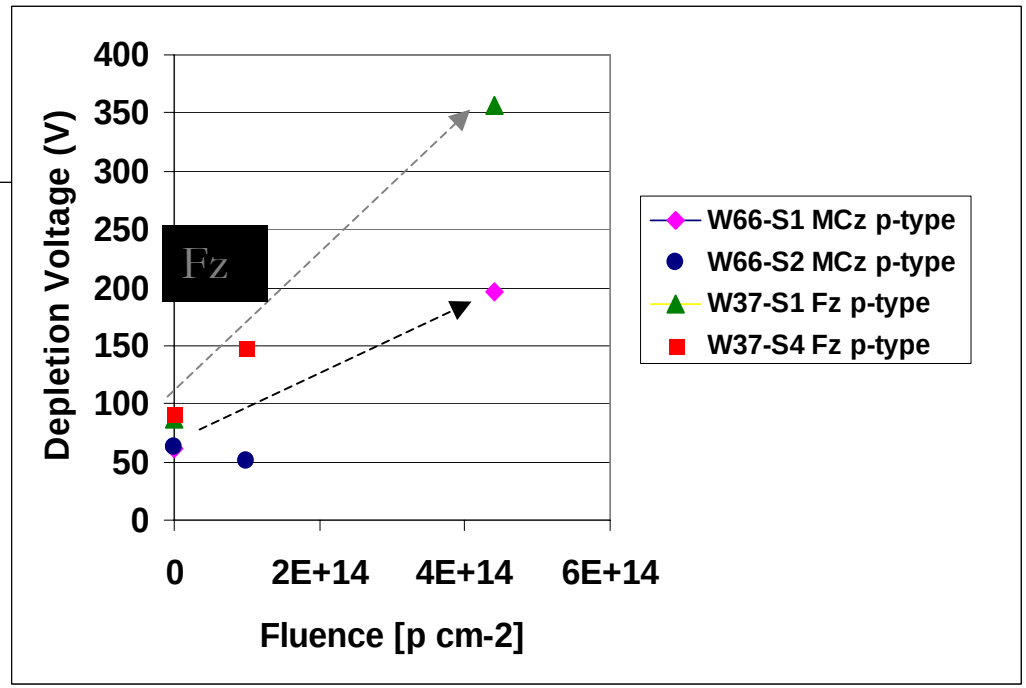
MCz p-type

Mini-sensors

MCz n-type

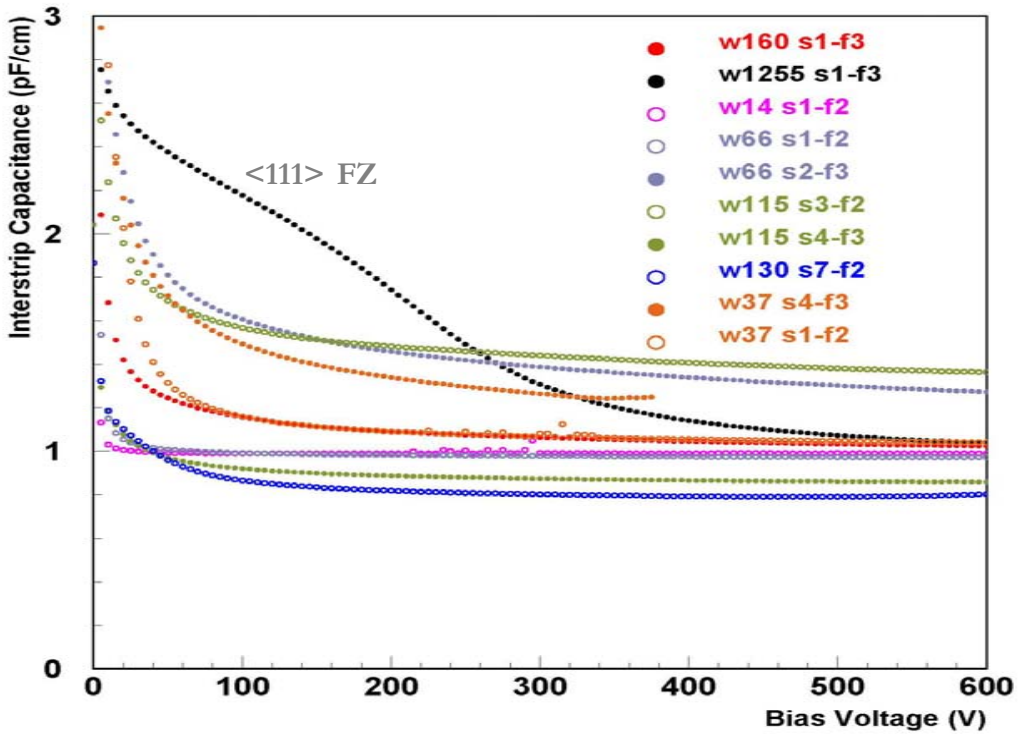
Diodes and mini-sensors agree

Detailed fluence study is under investigation on Karlsruhe irradiated sample



Inter-strip capacitance on mini-sensors

		50 μm pitch	100 μm pitch
Pre-irradiated	n-type	~ 0.8 pF/cm	0.6 pF/cm
MCZ p and n-type	ϕ= 1-4.4 E+14 p cm^{-2}	~ 1.5-1.7 pF/cm	0.9-1.2 pF/cm



f3= 1.0 E+14 p cm^{-2}

f2= 4.4 E+14 p cm^{-2}

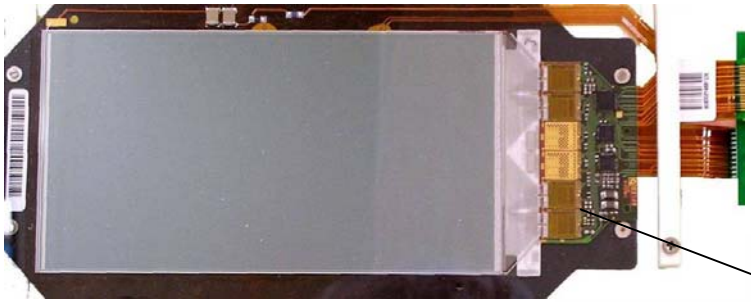
C-int decreases for the p-type sensors at increasing fluences.

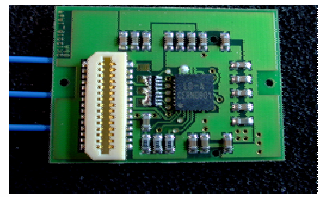
The opposite behavior for the n-type sensors.

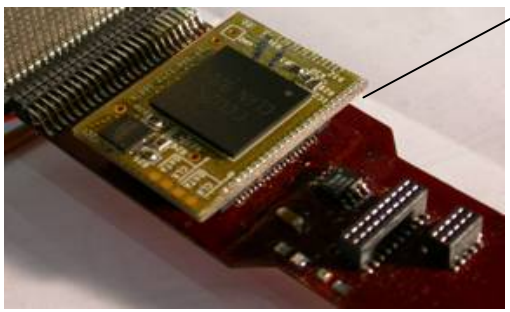
Measurement on detectors

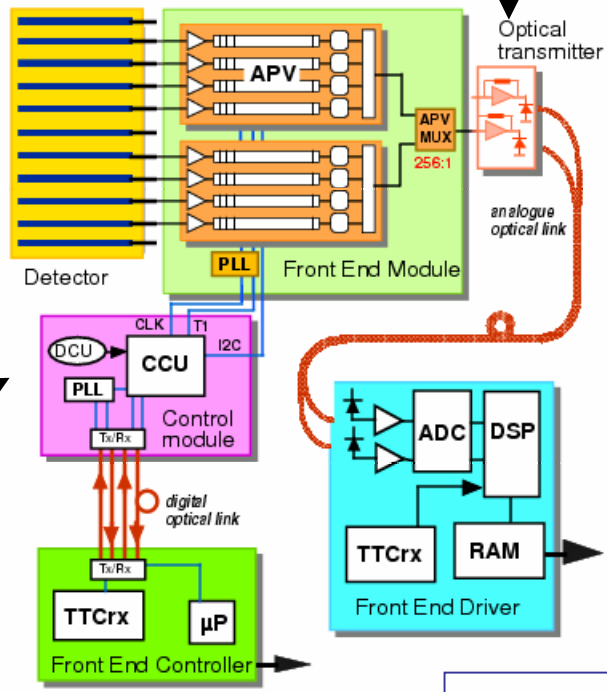
- A few mini sensors assembled in detector unit
  - **Main facility from CMS tracker (Pisa)**
    - **Front end electronics**
    - **DAQ system LHC like**
- Detector performance with laser system
- Single particle detection study with β source

CMS DAQ system



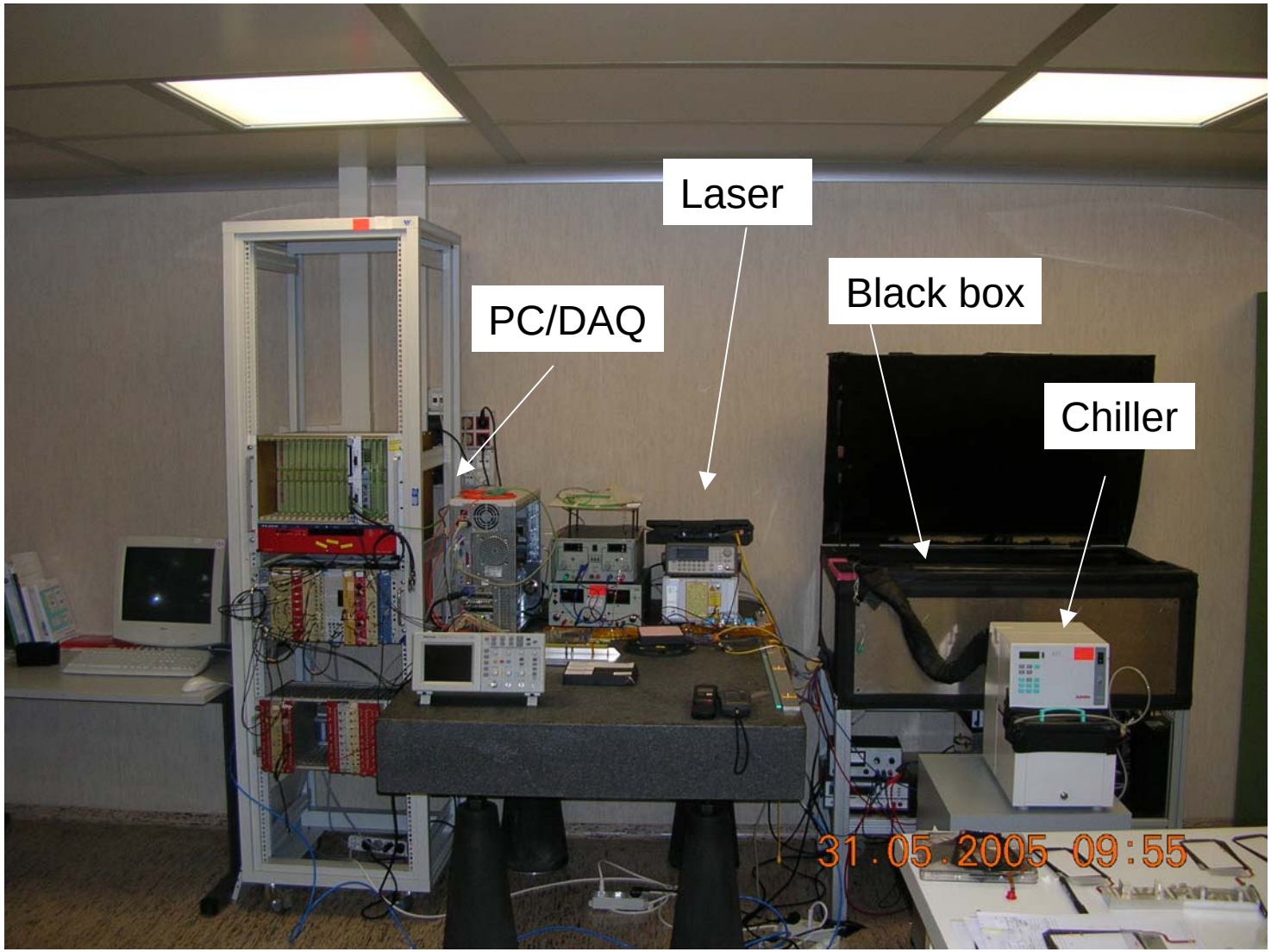






Test in realistic LHC-like conditions

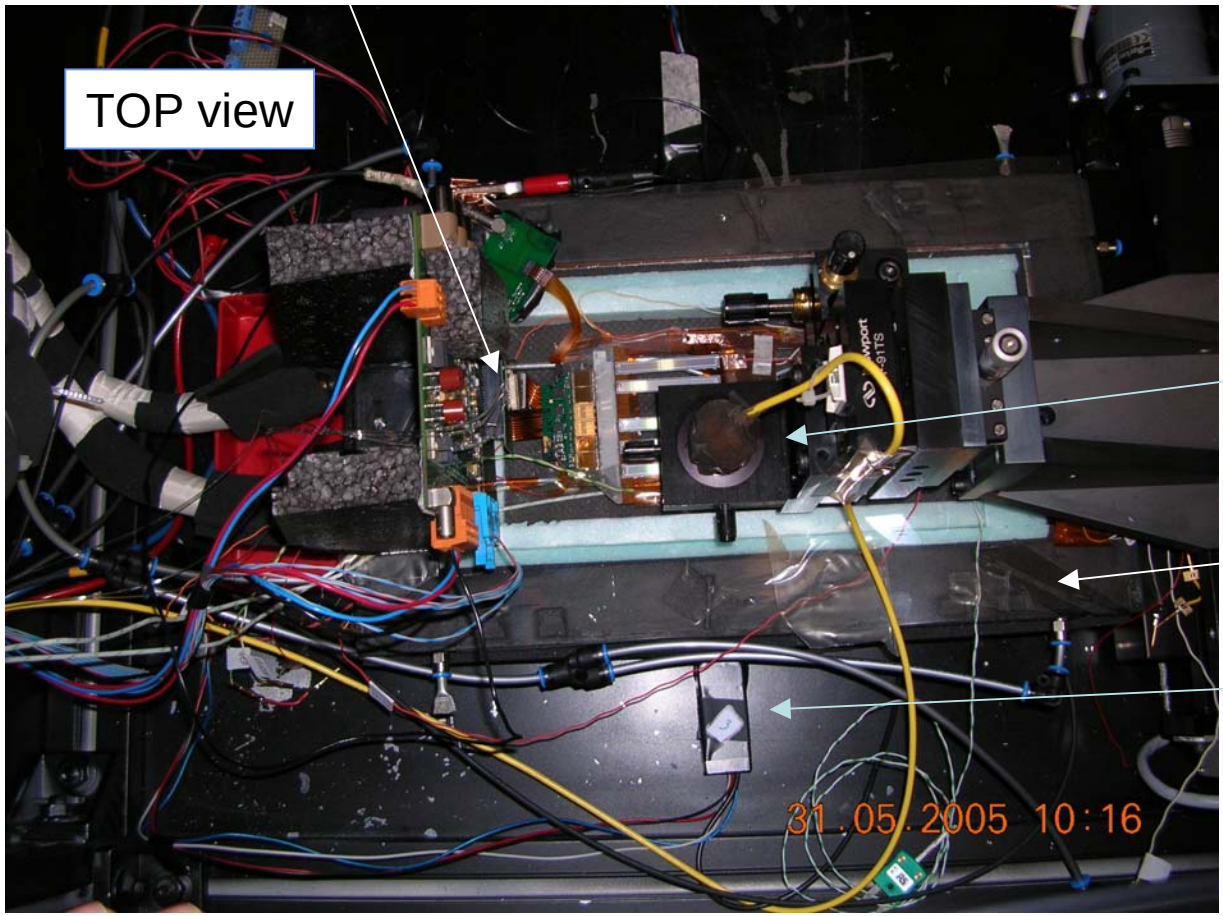
Test stand with Laser and β source



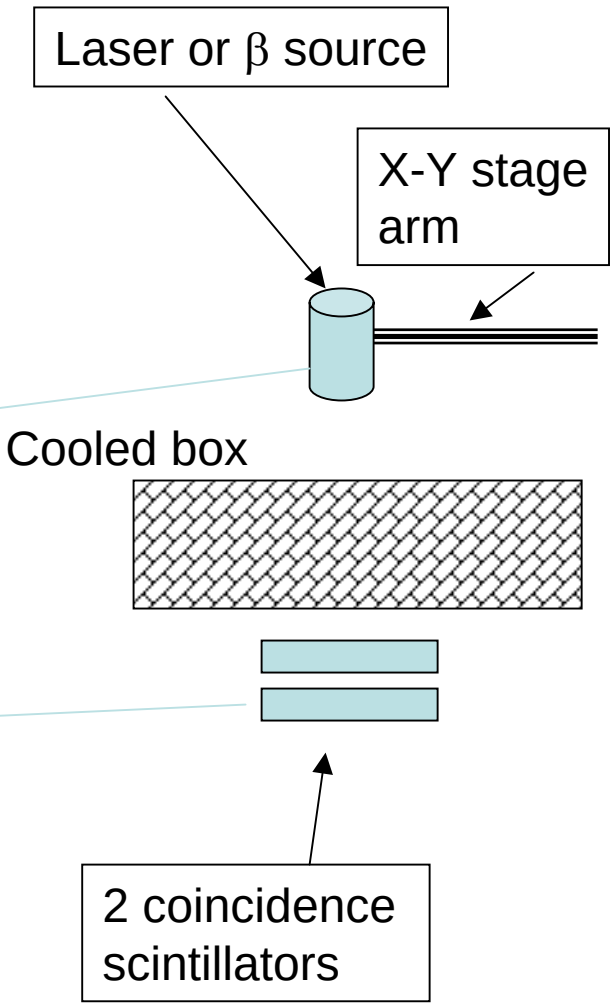
Detector set-up

FE + read-out elect.

TOP view



Cross-section view



Mini-Sensors assembled

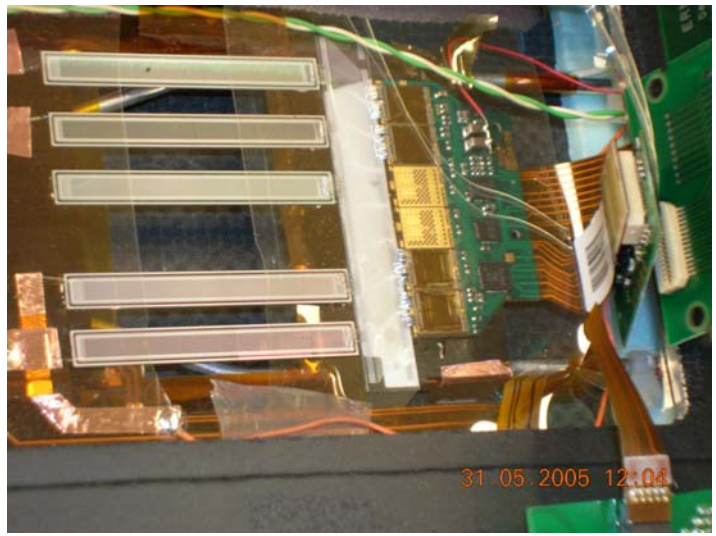
MCz (n-type)

130 s7 irradiated at 4.4e14 at CERN

α_0 ~ 6.3E-17 (no annealing)

V_{depl} pre-irr. 441 V

V_{depl} after irr. 230 V



MCz(n-type)

130 s5

V_{depl} pre-irr. 405 V

160 s7

V_{depl} pre-irr. 441 V

Reference Fz (n-type)

1255 s4

V_{depl} pre-irr. 43V

Laser test set-up

- RD50 Laser 1060 nm **(Maurice)**
- Beam splitter **(reduces 1/3 + db attenuation)**

- Pulsed with **Agilent Waveform Generator 33250A(80 MHz)** 1V Vpp with an output of ~4 ns laser pulse
- Laser spot focused on the detector

- **DAQ**:
  - 1 Laser event followed by 10 random trigger
  - DAQ average rate 1.1KHz

β test set-up

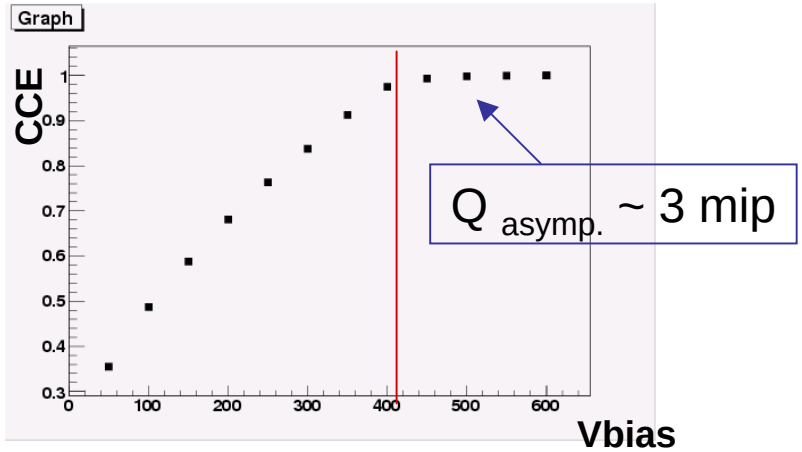
- DAQ system configured in *peak mode* :
  - sensitive to the maximum charge and with a lower noise level
- Measurement performed:
  - at over-depletion for not irradiated detectors
  - up to V_{depl} for the irradiated one
- Conditions:
  - not irradiated detectors at room T
  - irradiated detectors at low T (3 ^{o}C)

MCz(n) Laser spectra results

MCz(n) 130 s5 not irradiated

V_{depl} ~405 V

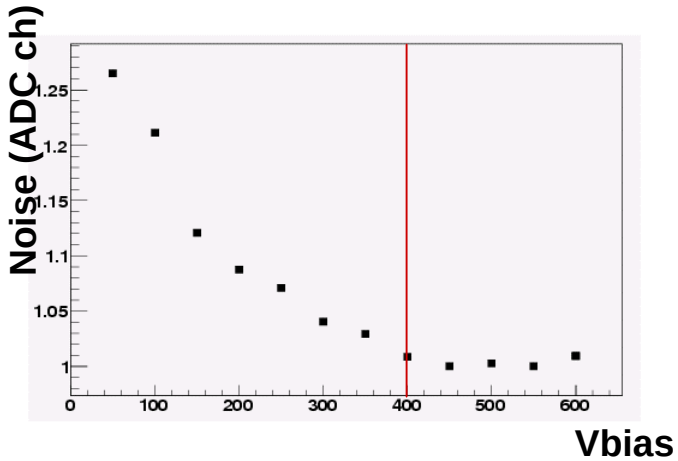
- **Laser point to the mid gap between strips**
- **Reconstructed cluster with, in average, 2 strips involved**



Full collected Charge at depletion voltage

Similar conclusion for Fz ref. sample

Good Noise figure:
Cluster noise ~1



MCz(n) β spectra results

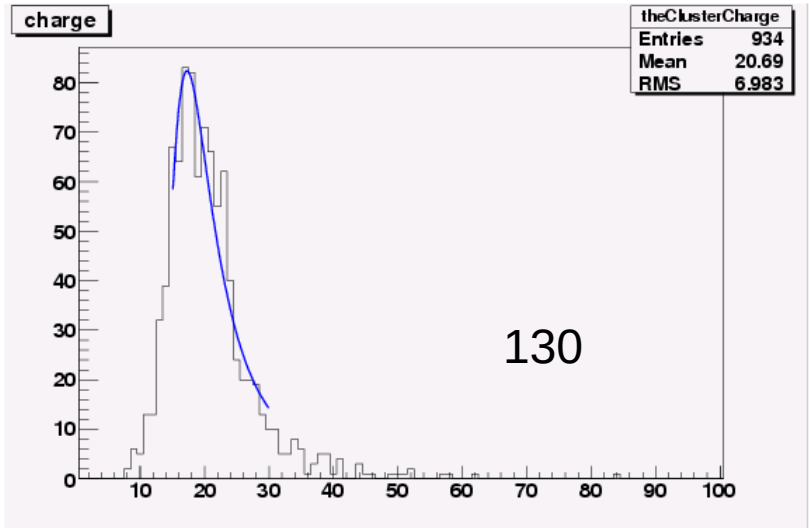
Not irradiated sensors
130 MCz(n) 1255 Fz(n)

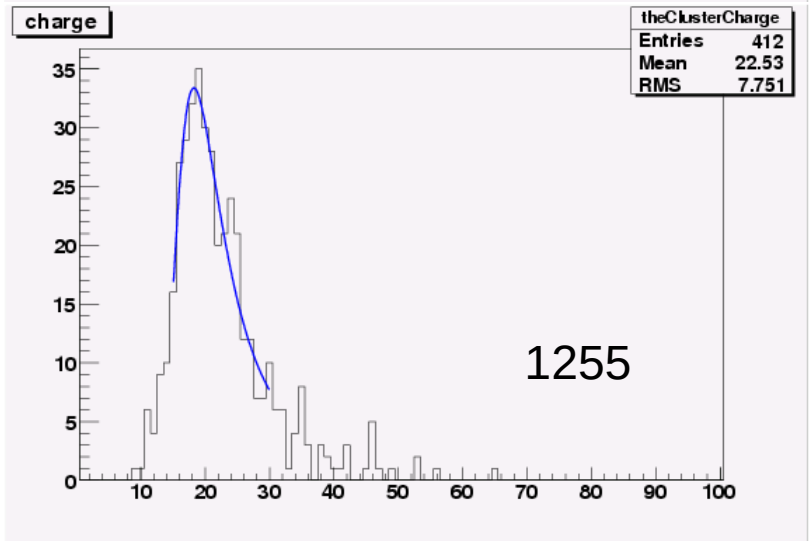
Landau plots show good performance of mini-sensors as particle detectors

130-s5 500 V Q 17.8 ± 0.2
noise 1.02

1255-s4 200 V Q 18.8 ± 0.3
noise 0.98

Noise is a bit higher that expected s/n at level of 17-19

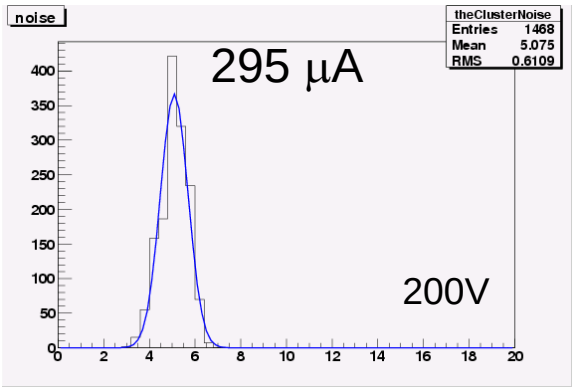


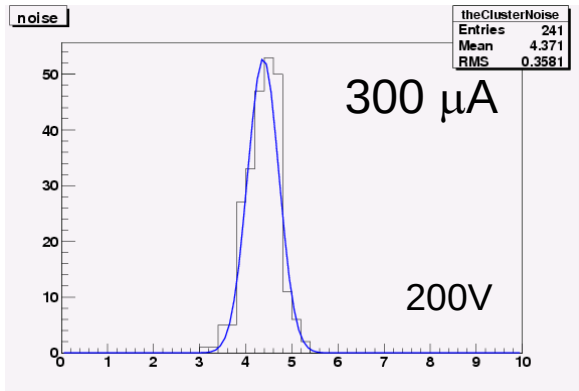


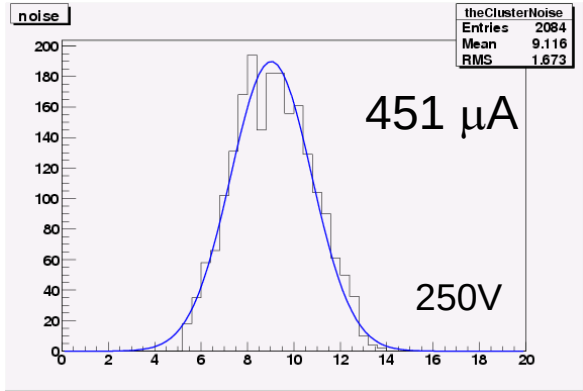
Irradiated sensors

- Cooling system with low efficiency
  - **Measurement performed in dry atmosphere at 3ºC**
- Sensors irradiated at 4.4 e14 CERN protons
- Measurement performed up to V_{depl}
  - **High current affects charge and noise figure**

Noise study results



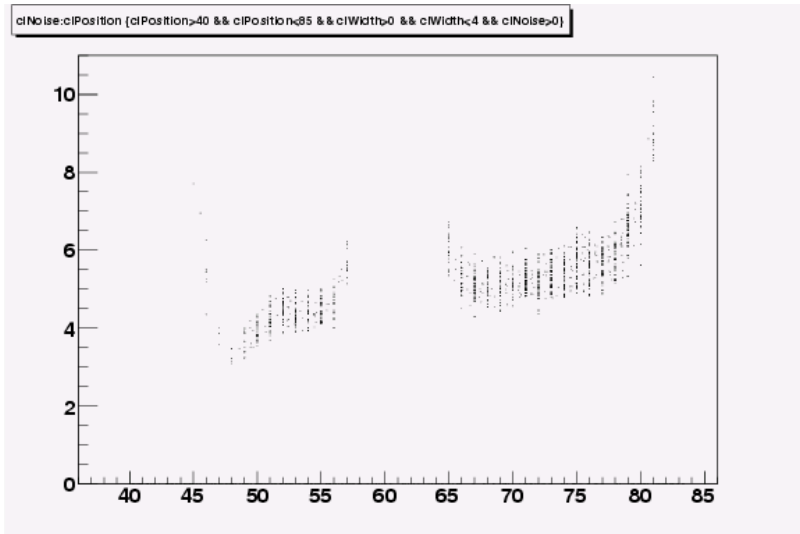




Current □A	Nose (ADC ch)
295	4.371
300	5.073
451	9.116

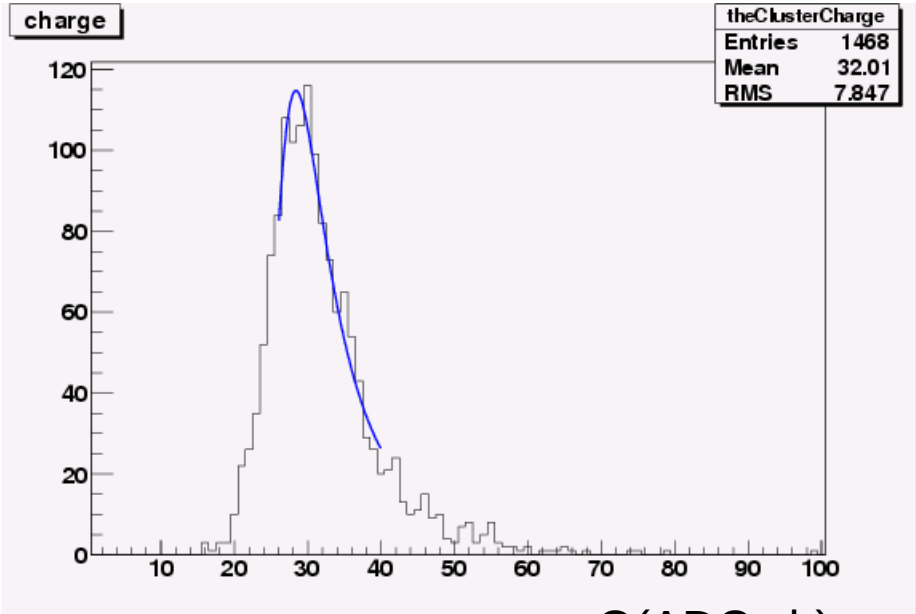
Noise grows with dark current: main contribution

Noise vs strip damage: non uniform Irradiation beam spot (CERN)



130-s7 irradiated 200 V

- V_{bias} = 200 V
- Charge distribution show Landau shape but noise plays a relevant role :
  - **lower T needed**
  - **clustering algorithm should be optimized**
  - **tuning of analysis tools**



Cluster Q	28.9 + 0.2
Cluster noise	5.1

Conclusion

- Pre-irradiation

1. MCz p-type wafers have a large resistivity spread: critical feature for detector processing.
2. The performance of p-type mini-sensors need additional masks to implant the p-stop.
3. The n-type MCz mini-sensors perform comparably to the Fz ones.

- After-irradiation

1. p-type mini-sensors with high p-spray show an improved IV after irradiation.
2. Fairly good overall performance of irradiated mini-sensors with good inter-strip capacitance.

Conclusion

- **Detector measurement**

1. Laser & β source system equipped and operational
   i. Preliminary results are satisfactory
   ii. Not irradiated MCz(n) detectors showed good performance, similar to reference sample

2. Irradiated detector shows understood figure on noise
3. Acceptable charge collection at V_{depl}
4. Technical improvements and systematic study are needed

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