University of Liverpool

Development of p-type detectors for present LHC and luminosity upgrades

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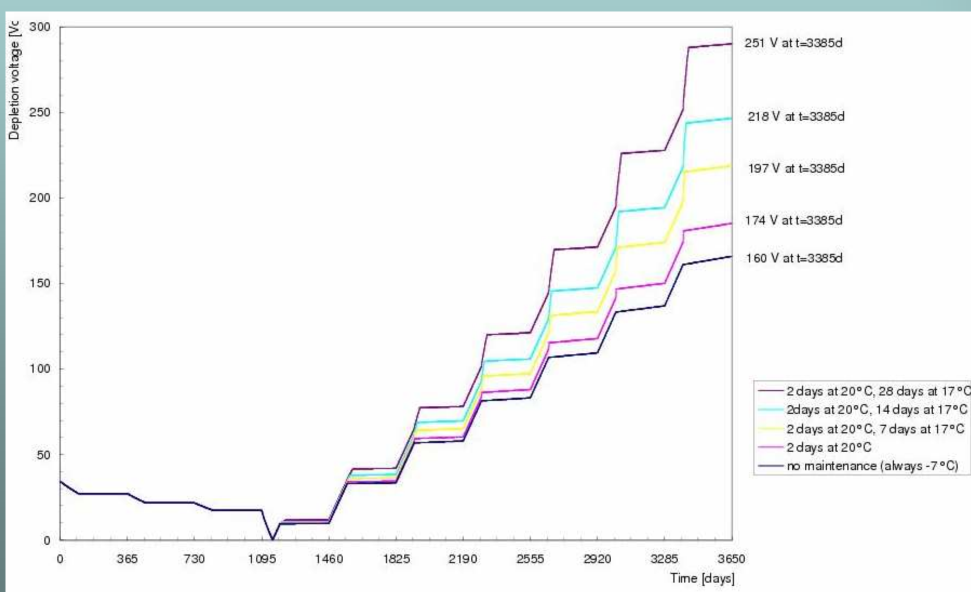
OUTLINE

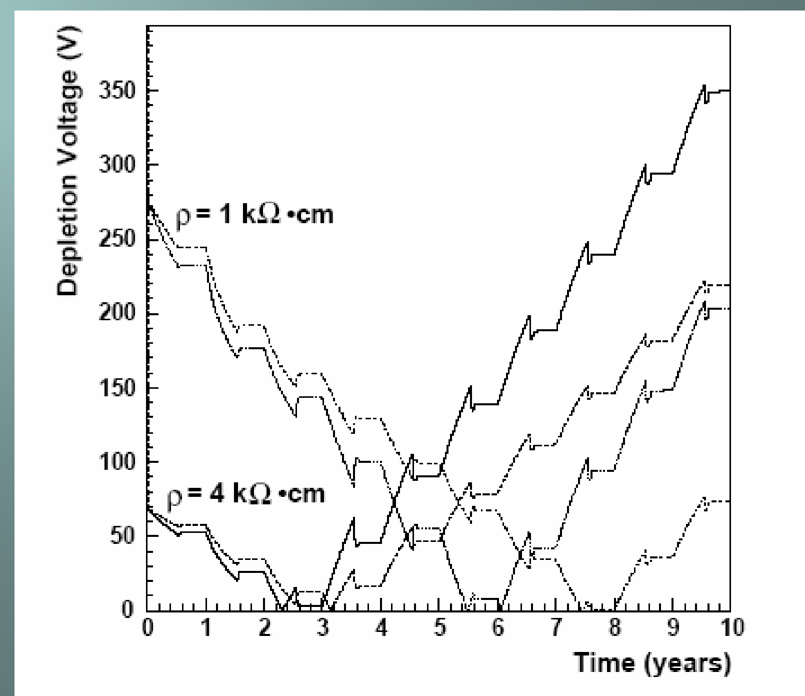
- Full depletion voltage (V_{FD}) vs Charge Collection Efficiency (CCE)
- Optimisation of the CCE after radiation damage
- Large area detectors for high radiation doses
- Conclusions

The present (LHC silicon trackers):

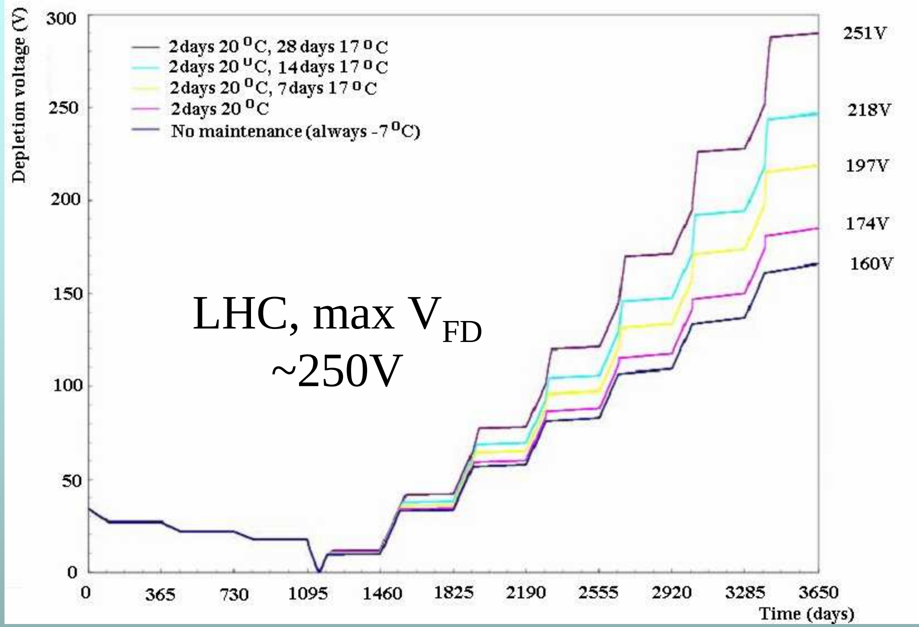
The majority of the silicon detectors for the current (LHC) tracker devices are "standard" p-in-n devices made with high purity high resistivity FZ silicon, and they achieve beautiful pre-irrad characteristic (low V_{fd}, extremely low reverse currents, high CCE)

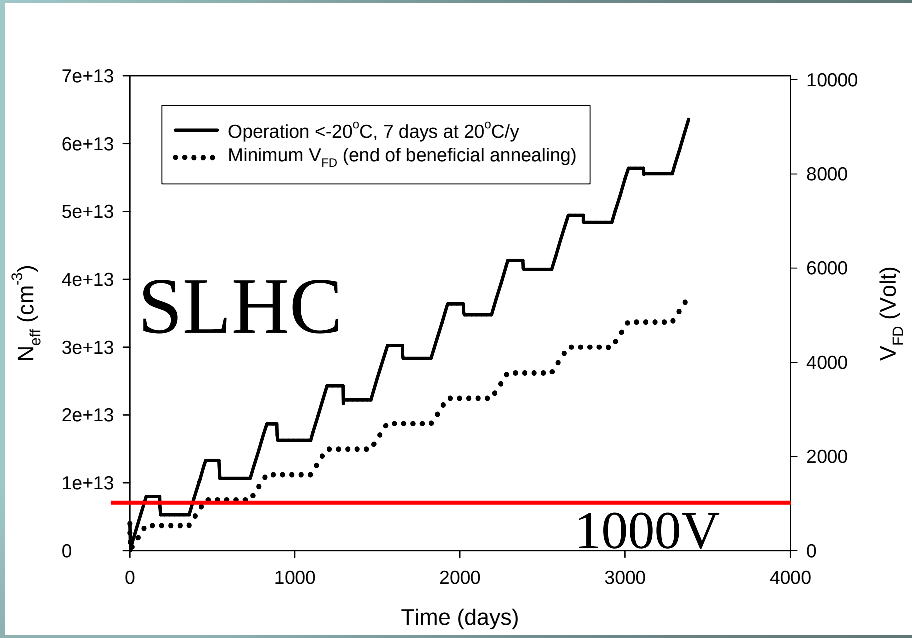
The failure mode after irradiation is usually estimated using the concept of full depletion (V_{FD}). V_{FD} + some overdepletion (50%) is considered adequate for detector operation. When this value matches the maximum bias voltage allowed by the system, the detector starts to fail.





Future upgrades (Super-LHC silicon trackers):

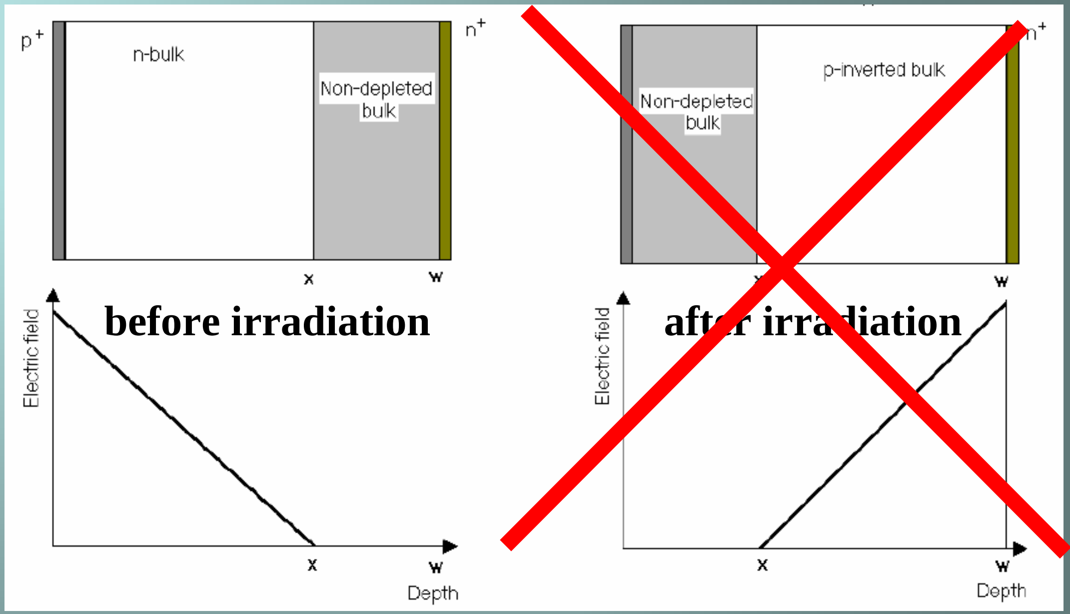




According to this scenario the V_{FD} in the SLHC middle pixel layer (right) exceeds 1000V already in the first year. This voltage can be considered the very maximum achievable for a large silicon detector system. The prediction based on V_{FD} would lead to the conclusion that a Si-tracker in the upgraded machine is unfeasible.

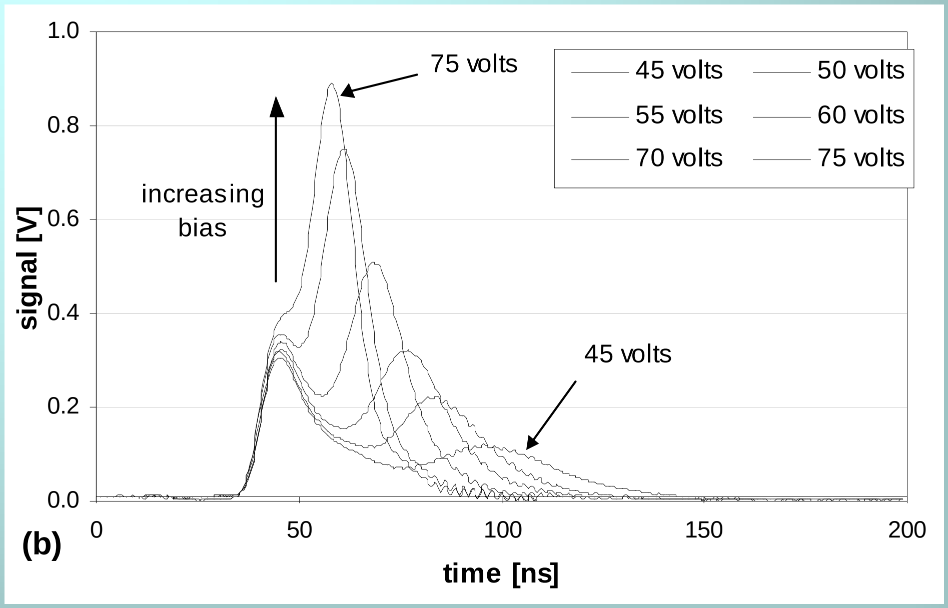
Future upgrades (Super-LHC silicon trackers): how to proceed?

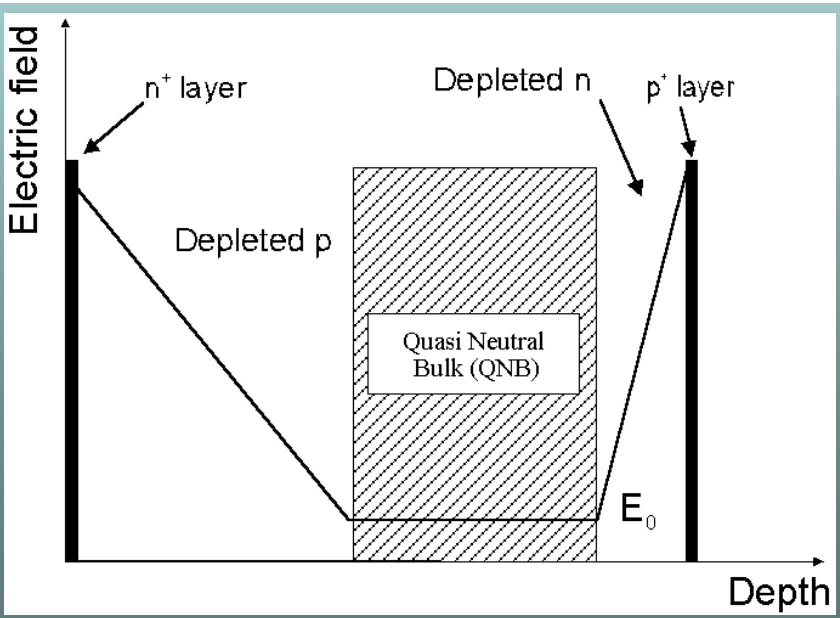
Ignore V_{fd}, maximise CCE as a function of fluence

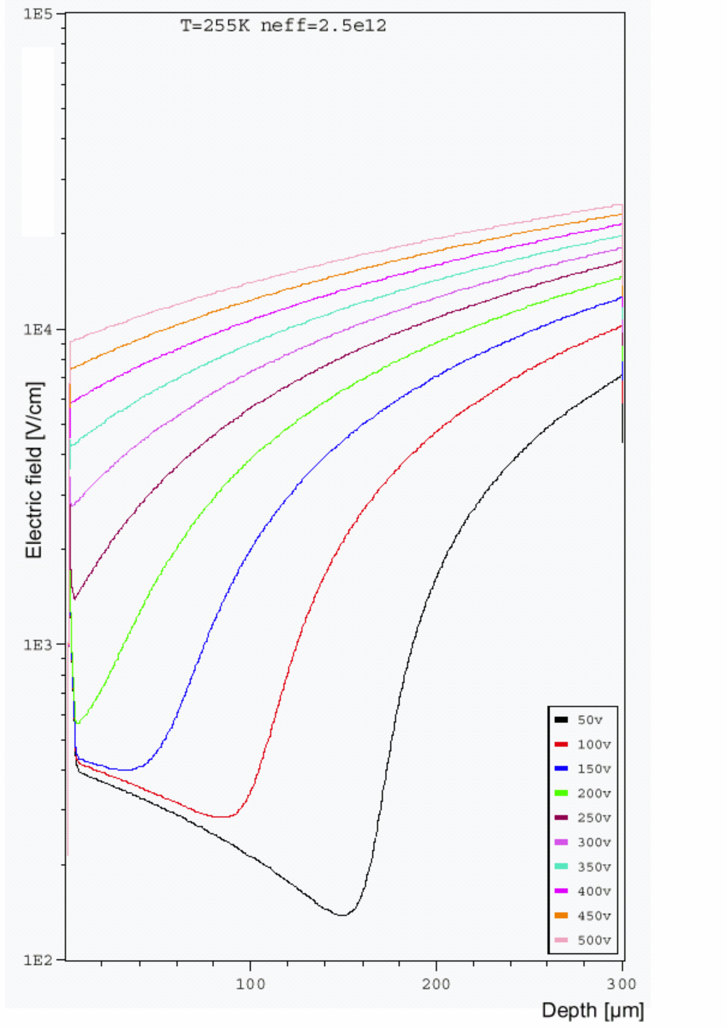


There is evidence that a more structured E develops after irradiation

More realistic electric field after irradiation



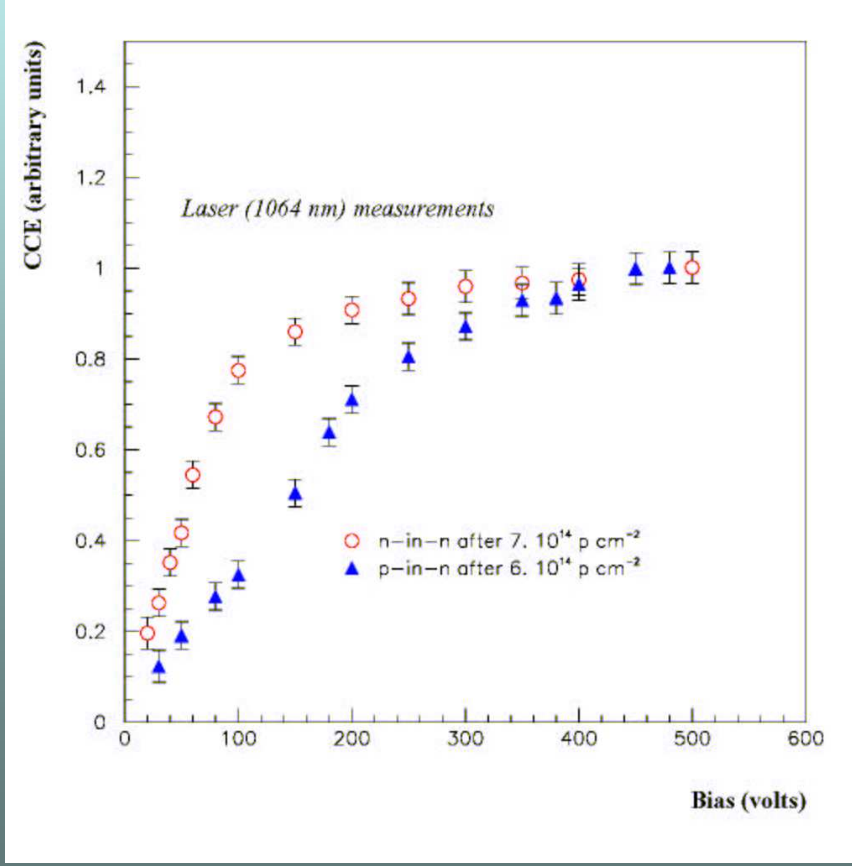




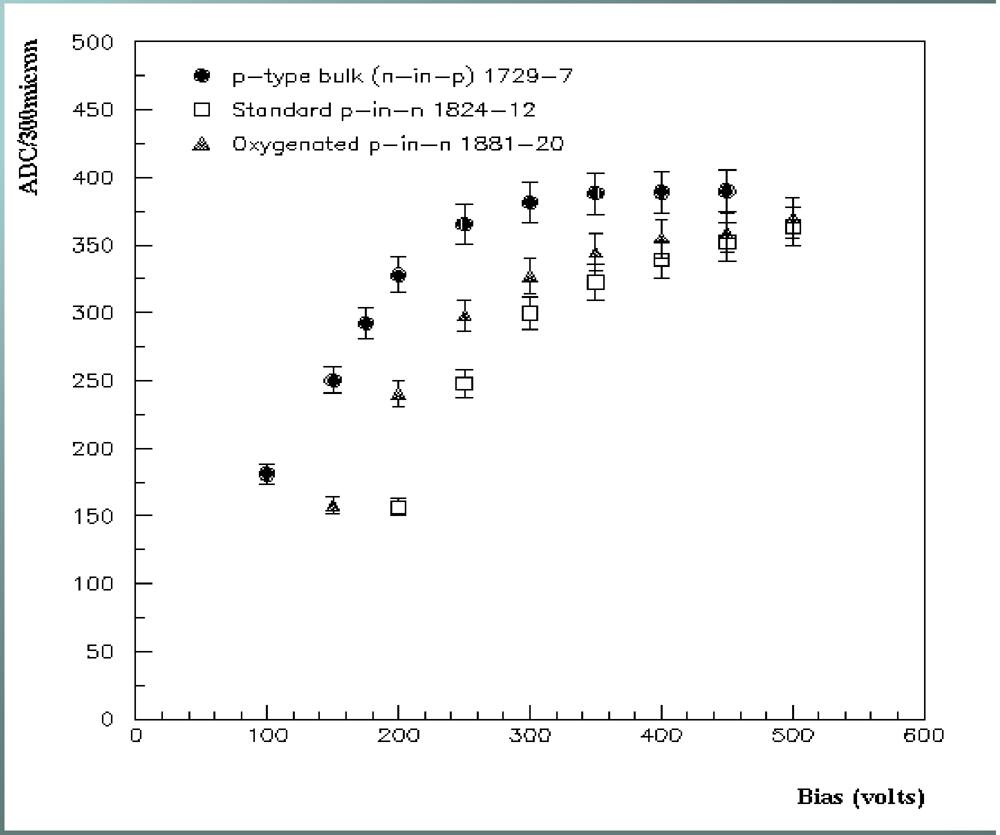
ISE-TCAD simulation after $6.\ 10^{14}$ p cm^{-2}

How to better exploit the properties of Ē after irradiation? With n-strip read-out.

On n-type substrate



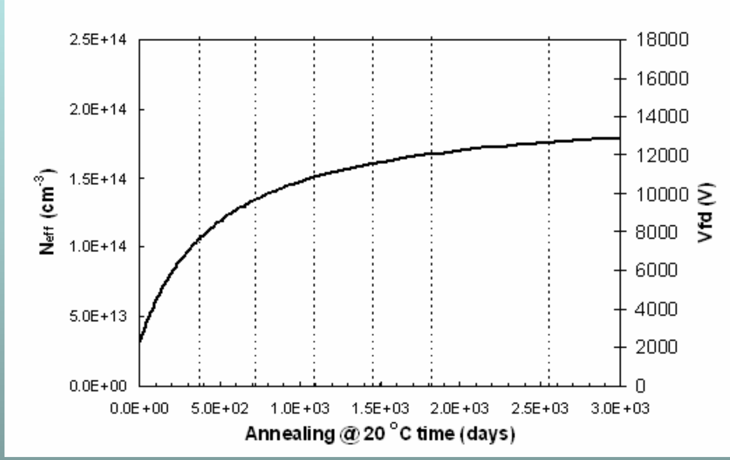
On p-type substrate



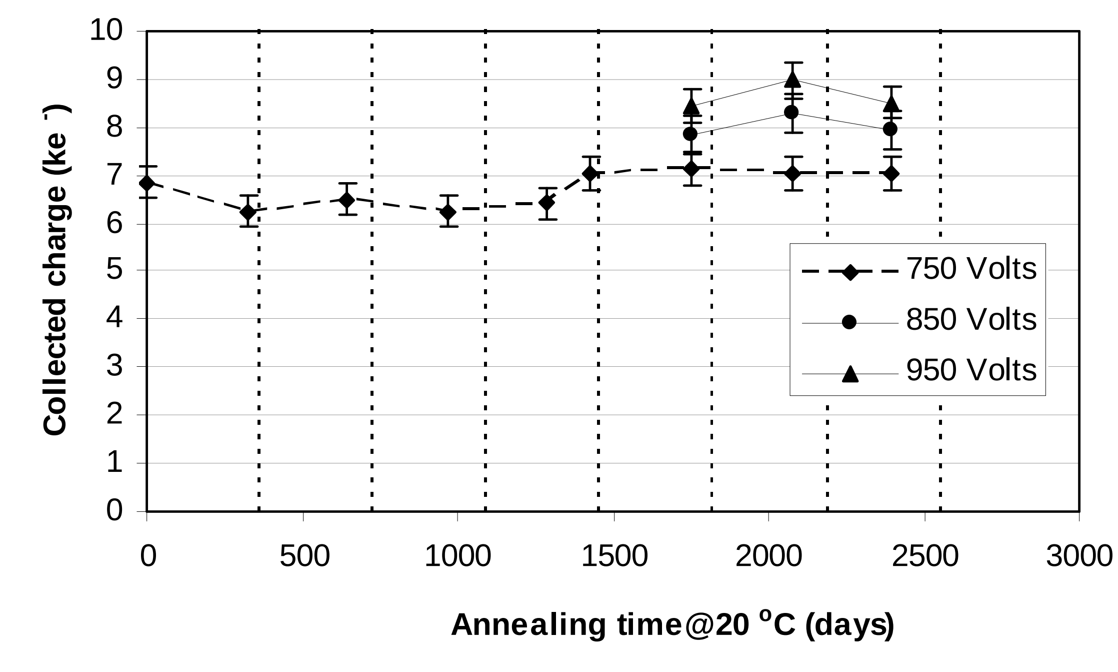
Annealing of n-strip read out sensors: how does actually change the relevant parameter (CCE) with time?

P-type detector irradiated to 7.5 10^{15} p cm^{-2}

Initial V_{FD} ~ 2800V



Predictions from RD48 parameters for Oxygen enriched devices (best scenario: after 7 RT annealing years the V_{fd} goes from ~2800V to ~12000 V!

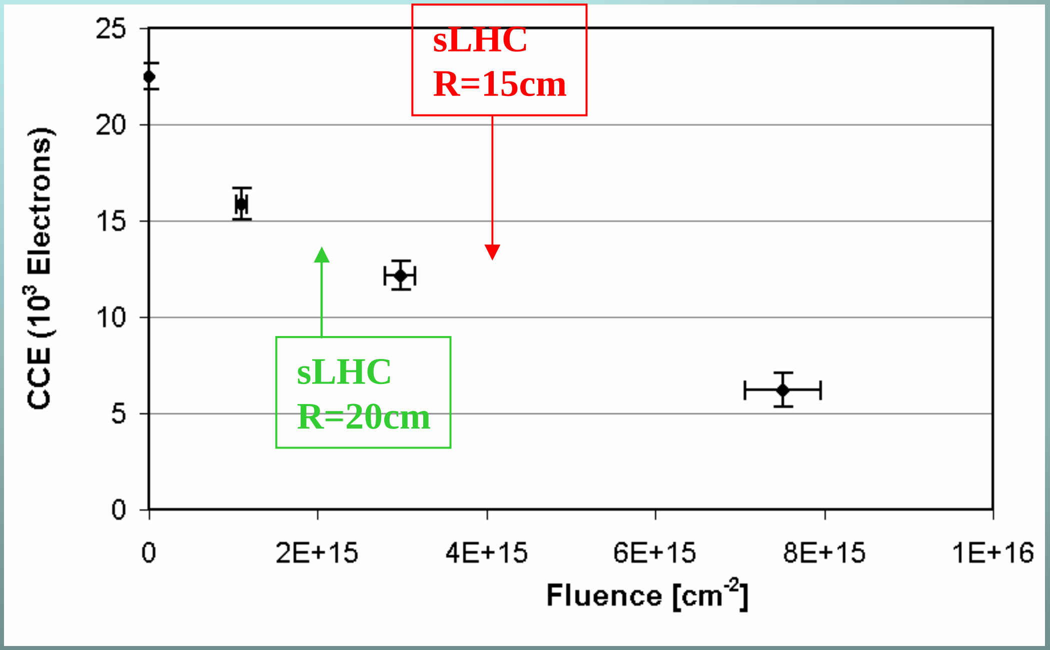


With n-side read-out, no effect of reverse annealing on the CCE is observed!

Charged Trapping in Si

Efficiency of Charge Collection in 280 um thick p-type SSD

After 7.5 $*10^{15}$ p/cm^2, charge collected is > 6,500 e^-



No adverse effects of anti- annealing observed!

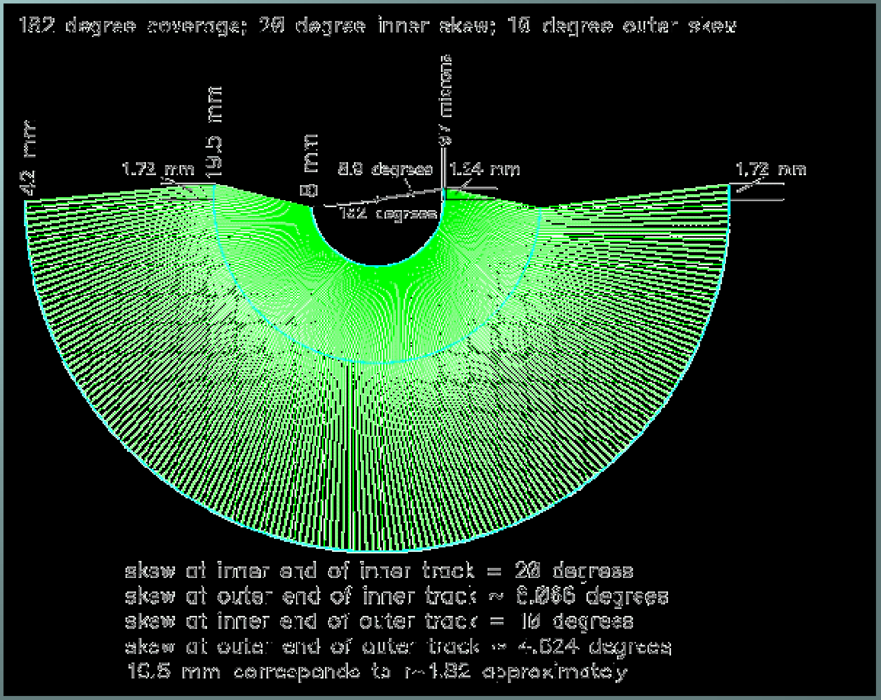
In the present LHC, the sub-detectors most exposed to the higher radiation levels are the ATLAS and CMS pixels and the LHCb-VELO microstrips.

They are all n-in-n design.

We proposed and prototyped with Micron Semiconductor, the n-in-p version of the VELO microstrip detectors, to prove the feasibility of a large area, complex double metal detector with p-spray interstrip insulation on high resistivity (low initial Vfd) p-type substrates.

A tough test for large area p-type sensors: the LHCb-VELO detectors

2048 strips each, routed with double metal

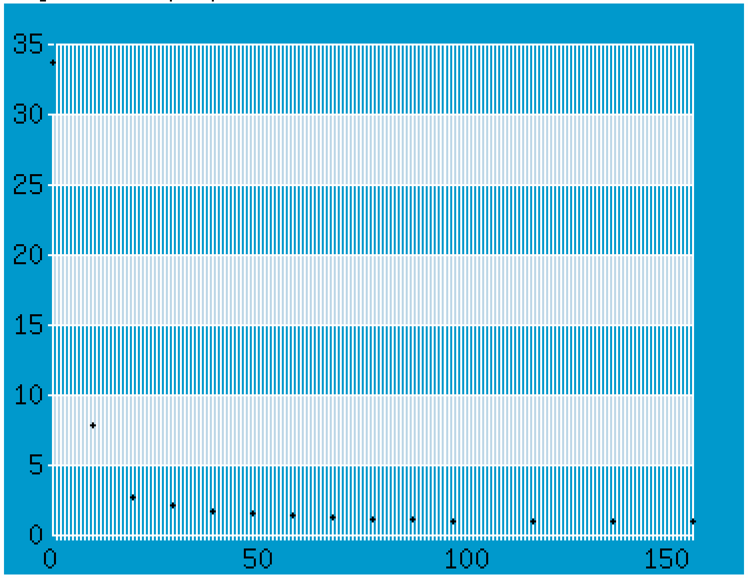


LHCb Velo - CV data for 2433-01D

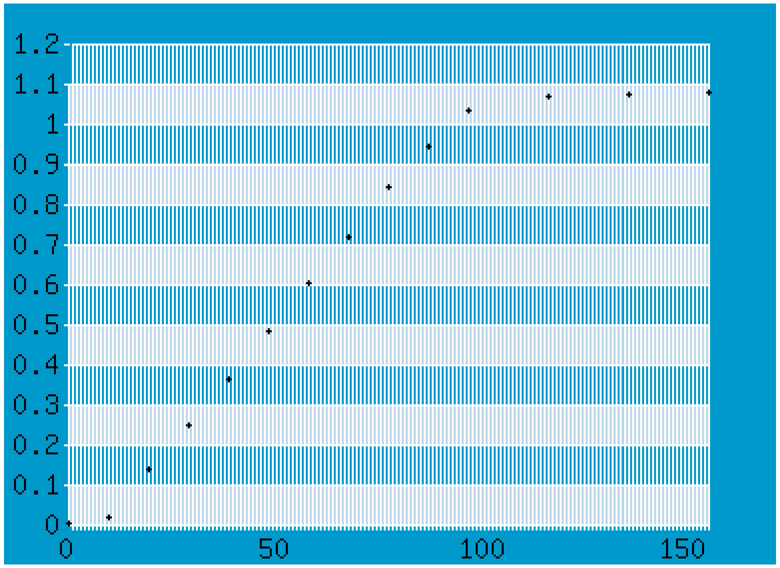
Data from file 2433-01D.Lvpool.CV.504.txt

2433-01D Sensor CV Measurements. 20.8C 38.8%

Capacitance (nF)



1/nF **2



Turn over at 100 Volts.
Plateau 0.96 nF

LHCb Velo - IV data for 2433-01D

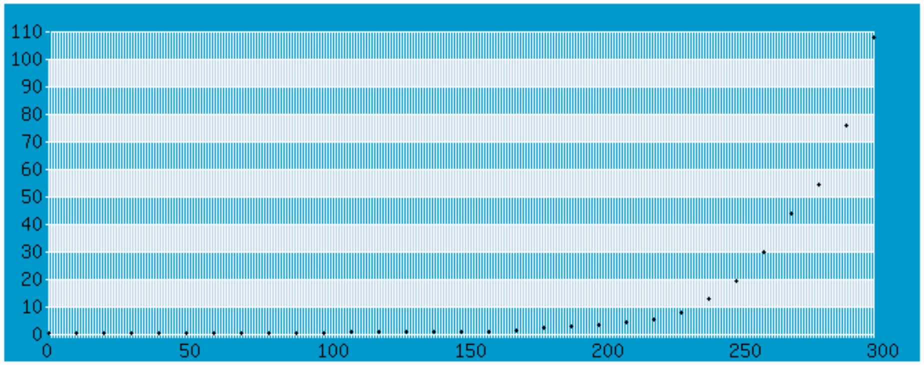
Data from file 2433-01D.Lvpool.IV.503.txt

2433-01D IV measurements after CV 20.8C 38.8%

Current at 350V not measured

Initial current at 0V = 0.02 µA
Final current at 0V = 107.54 µA

µA vs. V 0 < x < 300 0.01622436 < y < 107.5416 y scale factor 1



... - IV data for 2433-10A

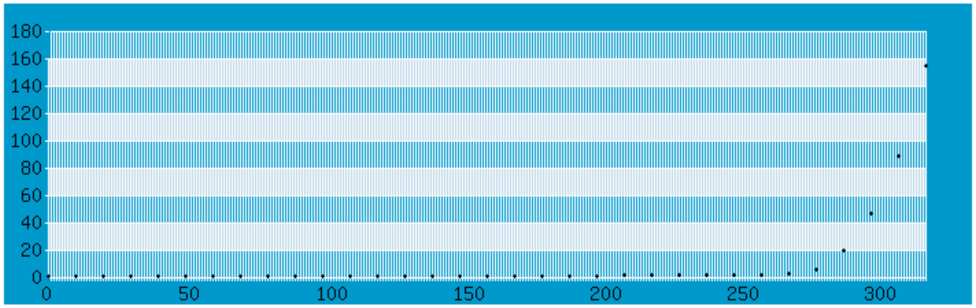
...Lvpool.IV.1164.txt

2433-10A IV measurements after cv 20.5C 45.3%

Current at 350V not measured

Initial current at 0V = 0.06 µA
Final current at 0V = 154.54 µA

µA vs. V 0 < x < 320 0.0557022 < y < 154.5382 y scale factor 1



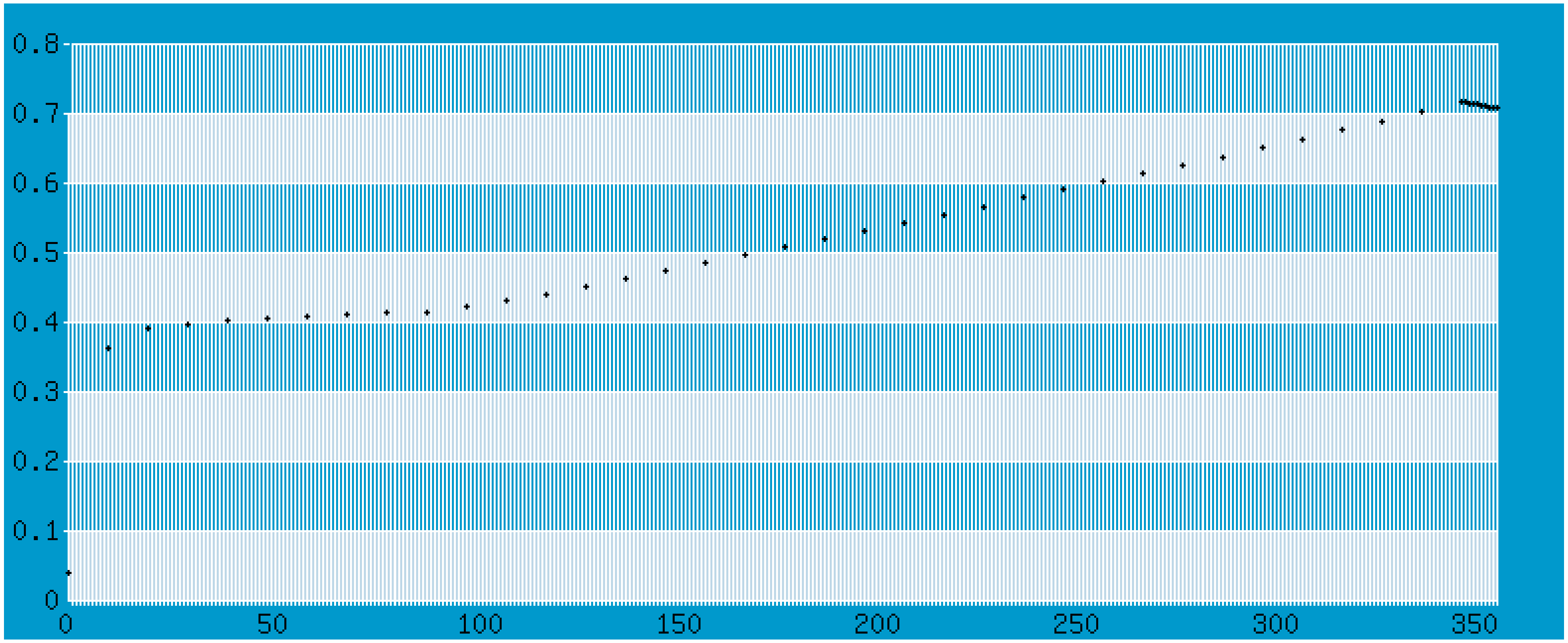
LHCb Velo - IV data for 2433-05D

Data from file 2433-05D.Lvpool.IV.1129.txt

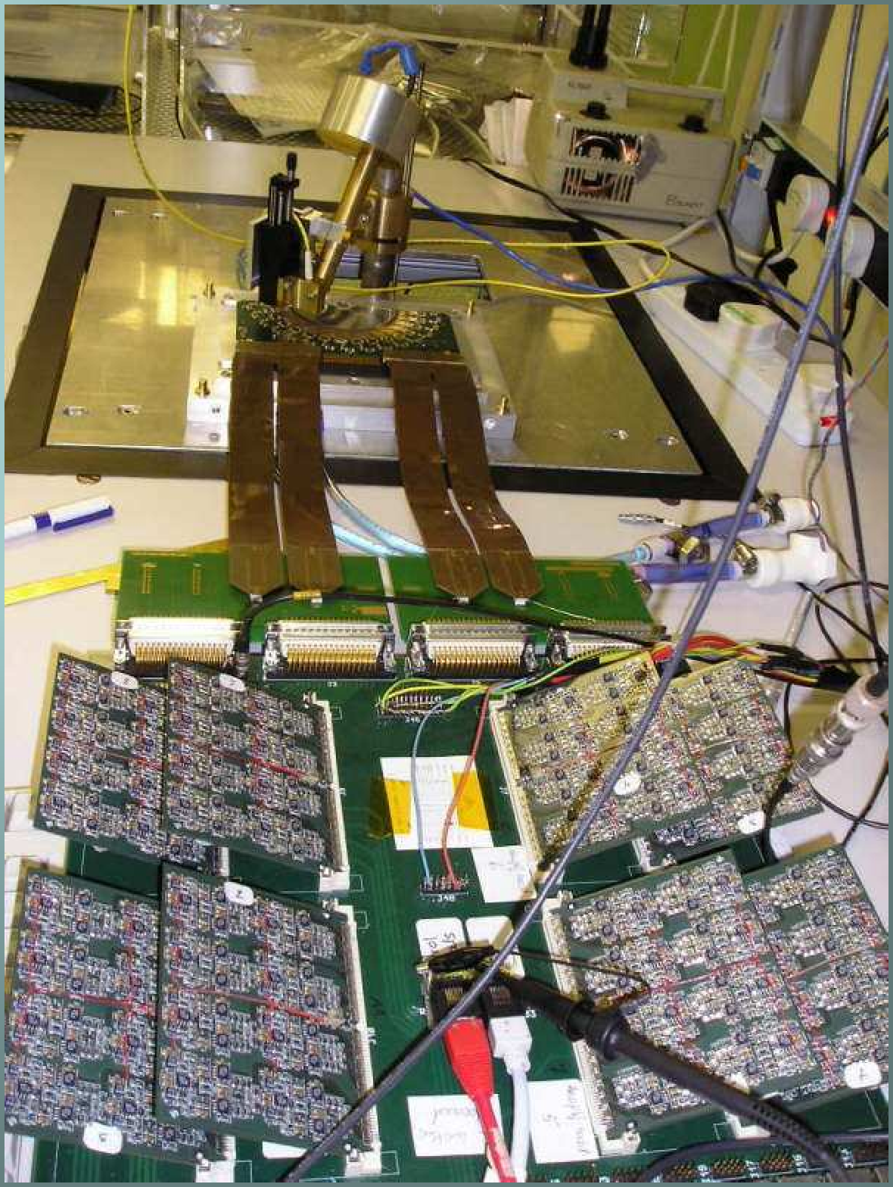
2433-05D IV measurements after current scan 20.5C 40.9%

Current at 150V = 0.47 µA
Current at 280V = 0.62 µA
Current at 350V = 0.72 µA
Initial current at 350V = 0.72 µA
Final current at 350V = 0.71 µA

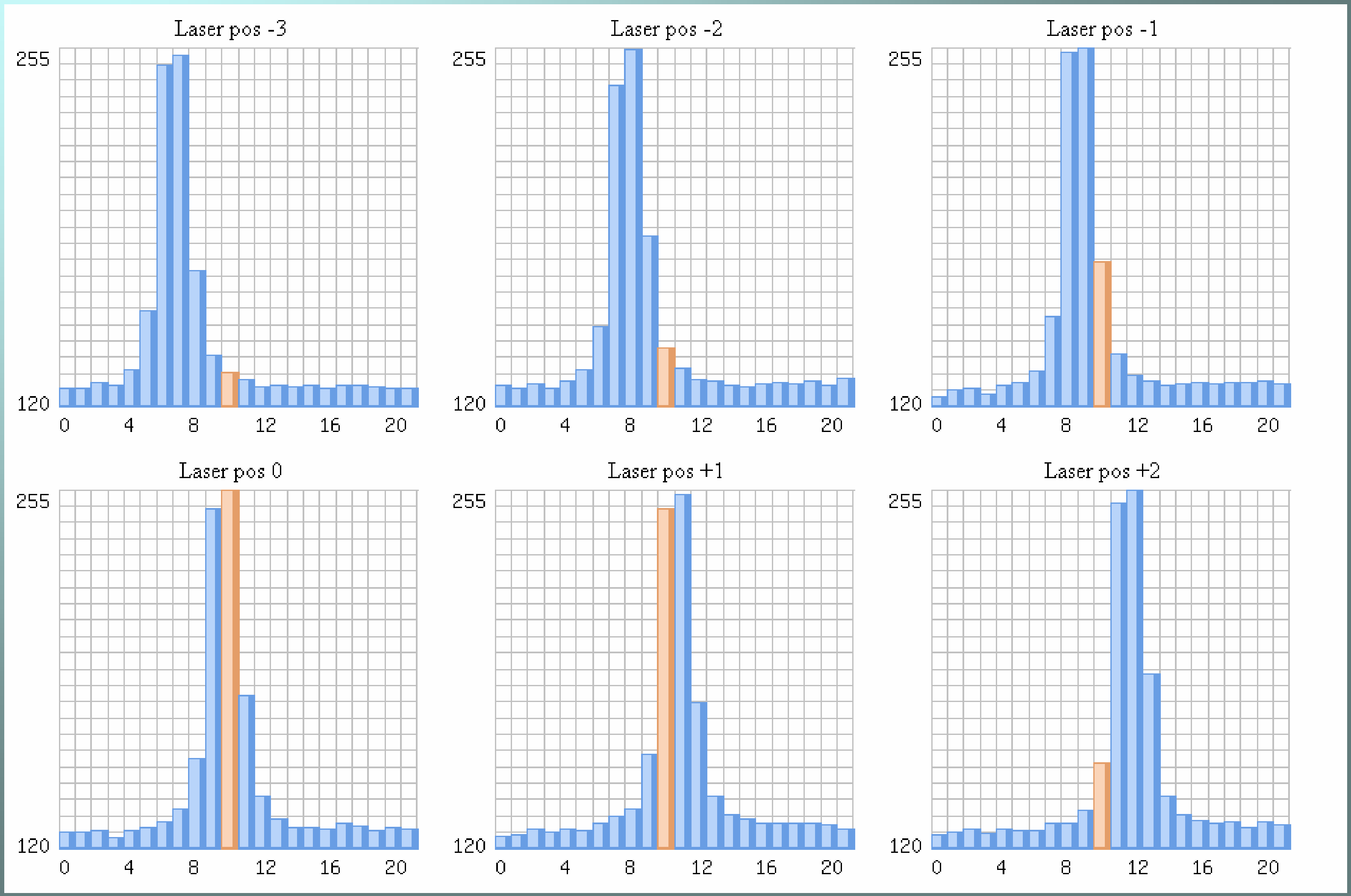
µA vs. V   0 < x < 359   0.0376554 < y < 0.715828   y scale factor 1



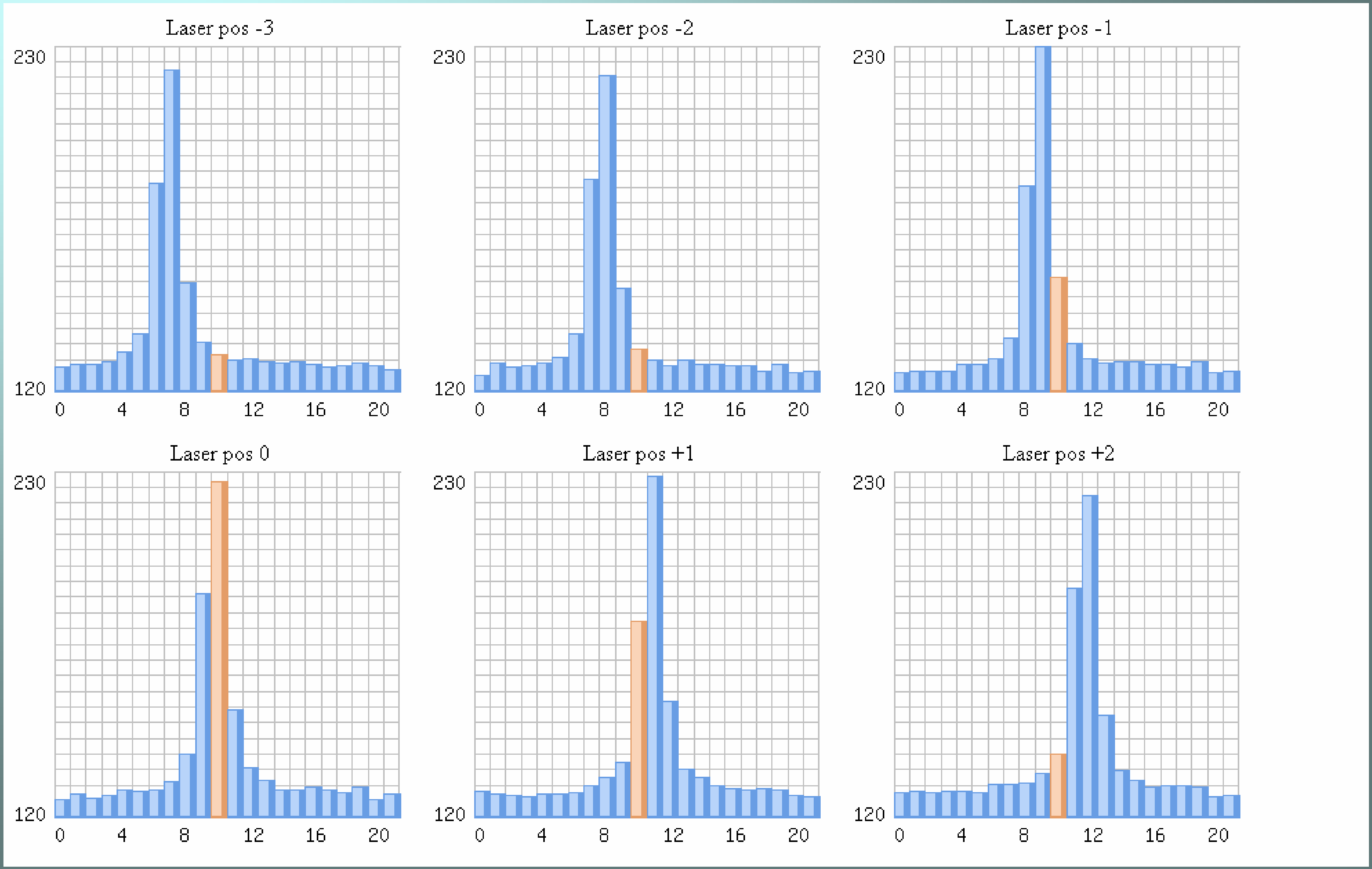
Individual strip test of modules. 16 Beetle chips are reading out the 2048 strips of each side. Narrow focus laser is moved over individual strips by a precise x-y stage.



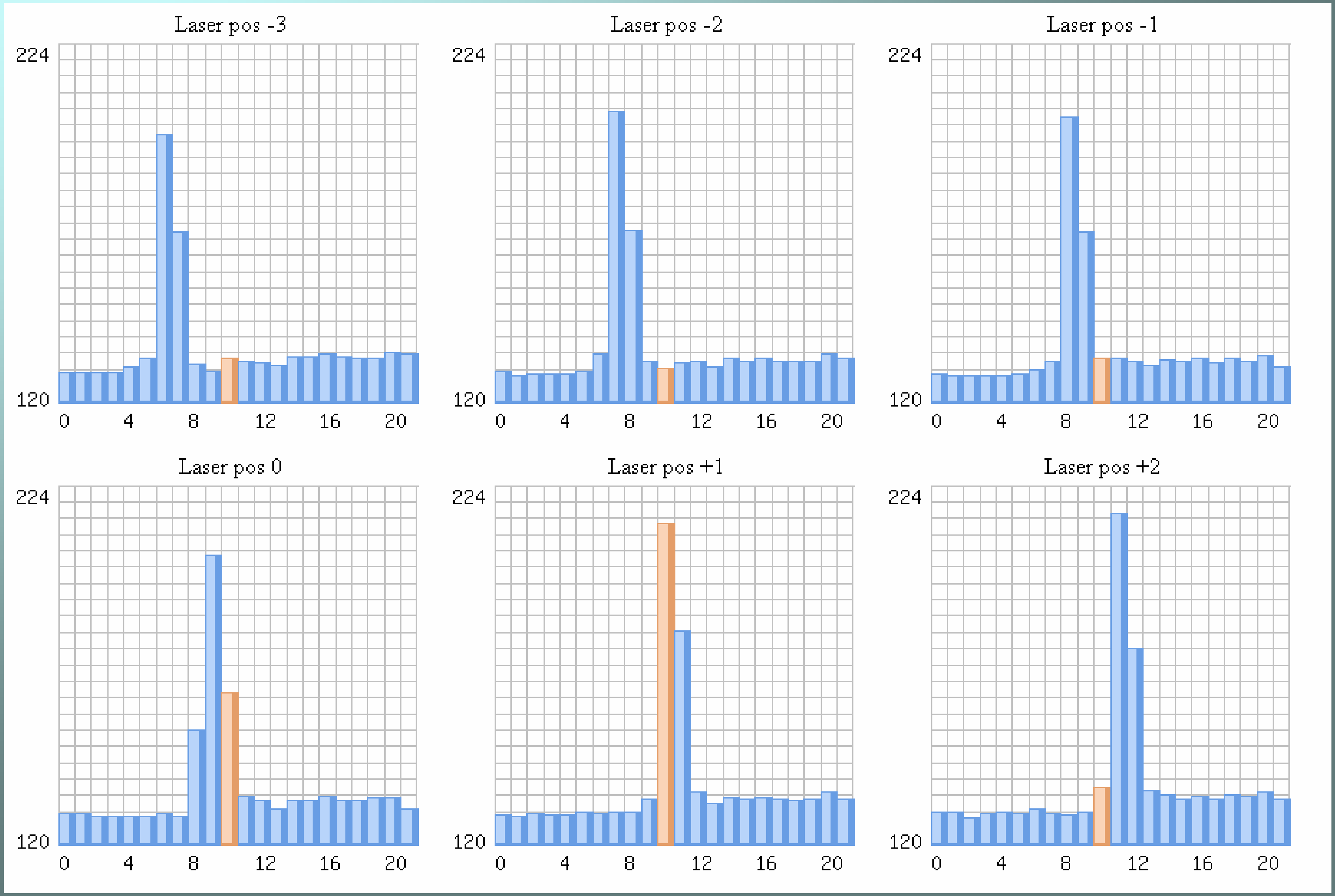
Example of laser scan across a few strips on a n-in-n VELO R detector



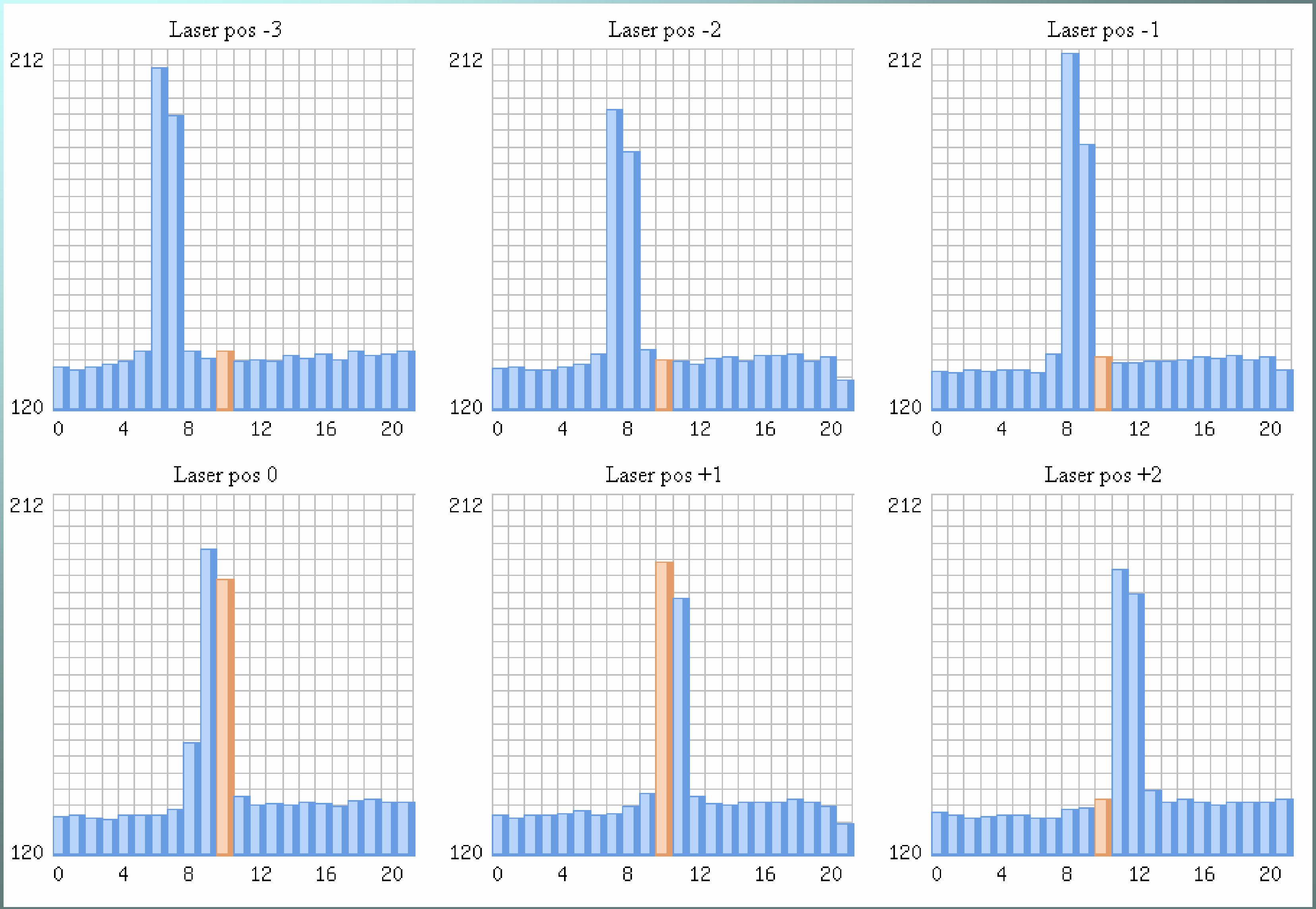
Example of laser scan across a few strips on a n-in-p VELO R detector



Example of laser scan across a few strips on a n-in-n VELO Phi detector



Example of laser scan across a few strips on a n-in-p VELO Phi detector



Strip inefficiency after full module production and tests (2048 channels/detector)

LHCb Velo - Problem Channels - Mozilla Firefox

http://velodb.ph.liv.ac.uk/lhcb/ShowProbChan.php?label=60&modID=49&type=p&hybID=98

Module 26 Hybrid 60 - Problem Channels

R side problem channels

Strip	chip	chan	Spad	FEB	SEB	Laser	Noise	Verified	Lstrip
1039	4	15	1521	0	-2	-1	-4	Open	1039
1477	5	58	1351	0	-2	-3	-2	Open	1477

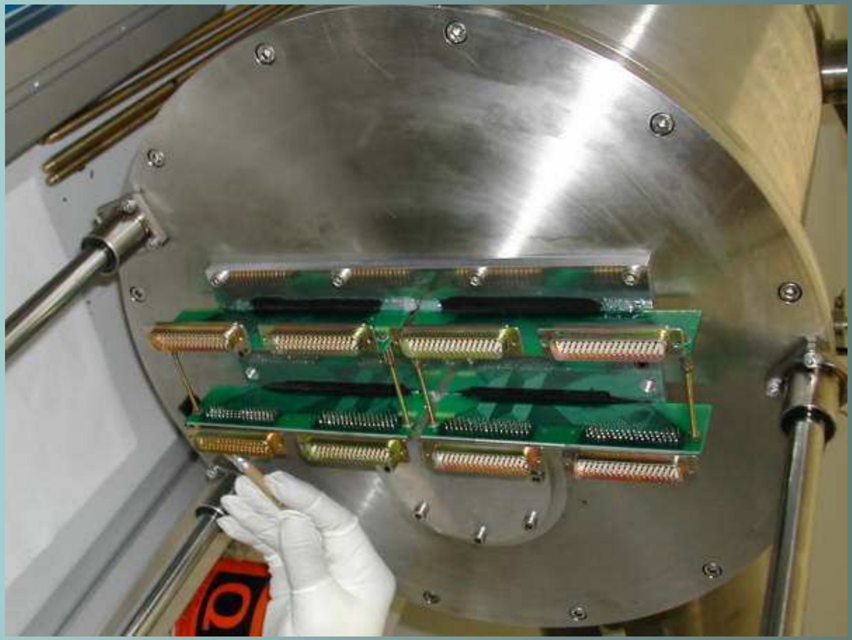
Total problem R channels 2 (**2 dead** / 0 problematic)

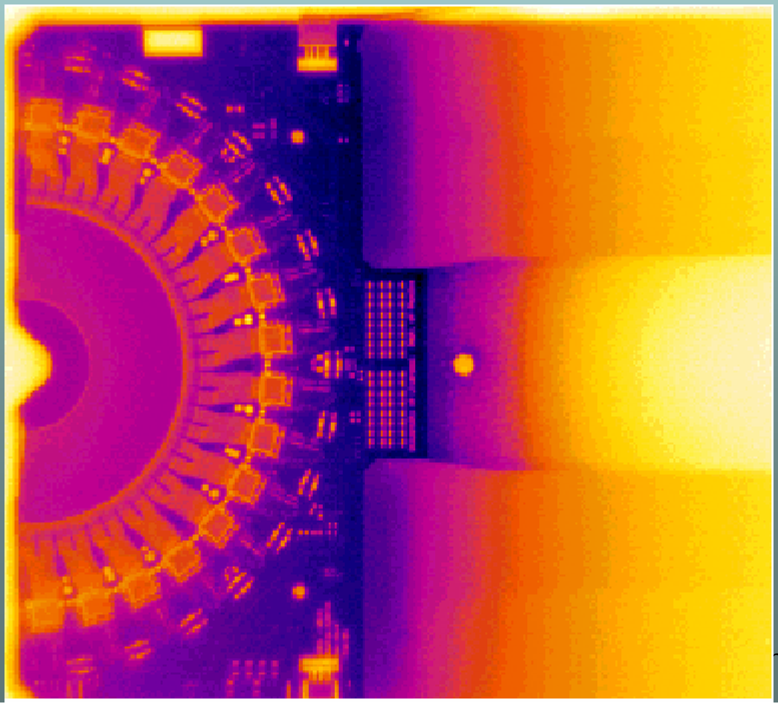
P side problem channels

Strip	chip	chan	Spad	FEB	SEB	Laser	Noise	Verified	Lstrip
82	14	8	248	0	-2	-1	-2	Open	82
505	4	20	1516	0	0	0	-1	Noisy	505
587	2	29	1762	0	-2	-1	-2	Open	587
634	1	16	1904	0	0	0	-2	Dead	634
658	0	72	1976	0	0	0	-1	Short	658
1694	4	17	1518	0	0	-3	0	Dead	1694
1957	1	7	1913	0	0	-1	-2	Dead	1957
1998	0	73	1974	0	1	0	-1	Short	1998

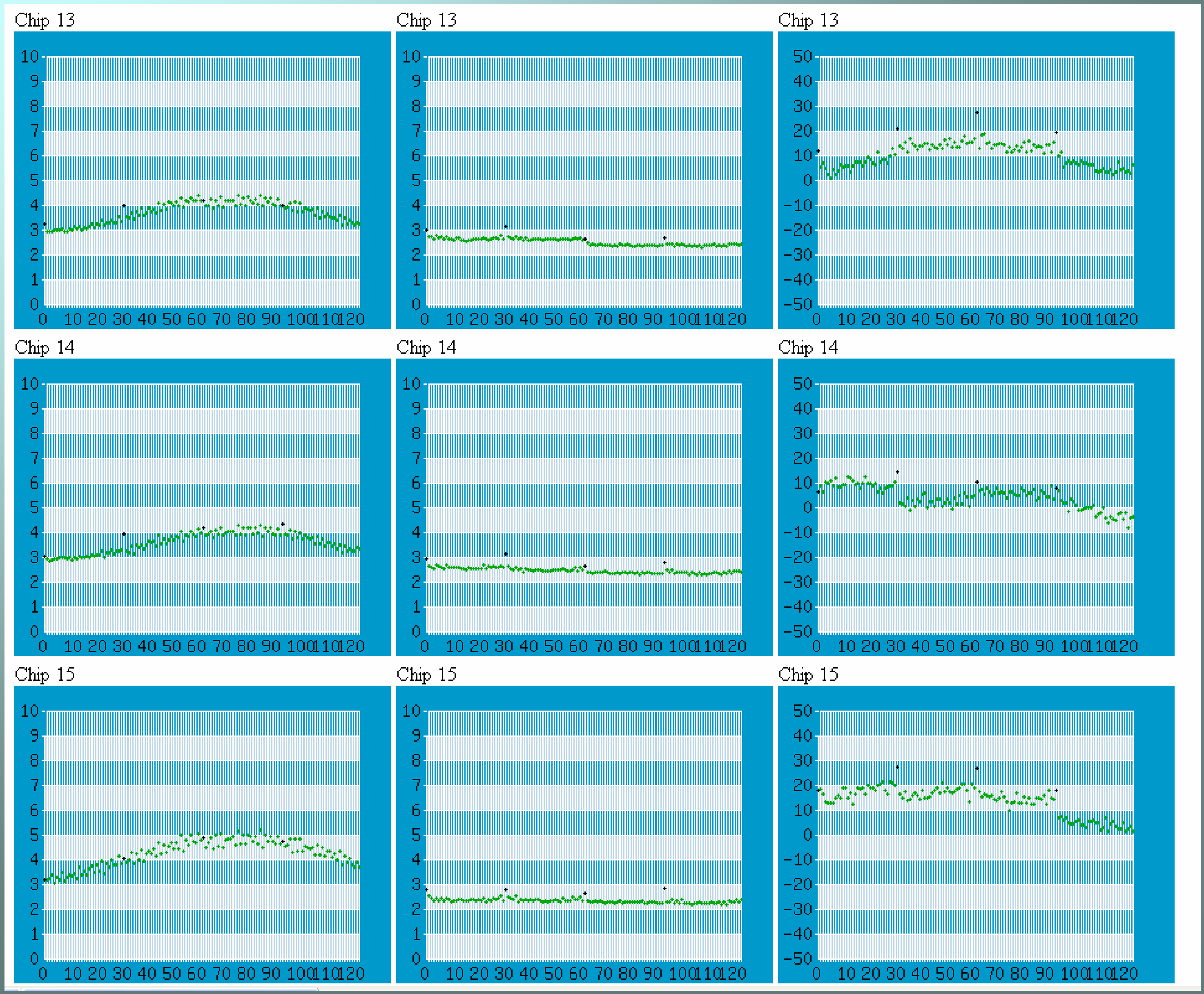
Total problem P channels 8 (**7 dead** / 1 problematic)

Confirmation tests, after hybrids are glued on the paddle (module) are performed in real conditions of cooling and vacuum in the vacuum tank. Read out of the Beetle chips is performed by the Tell1-DAQ system developed by LHCb.

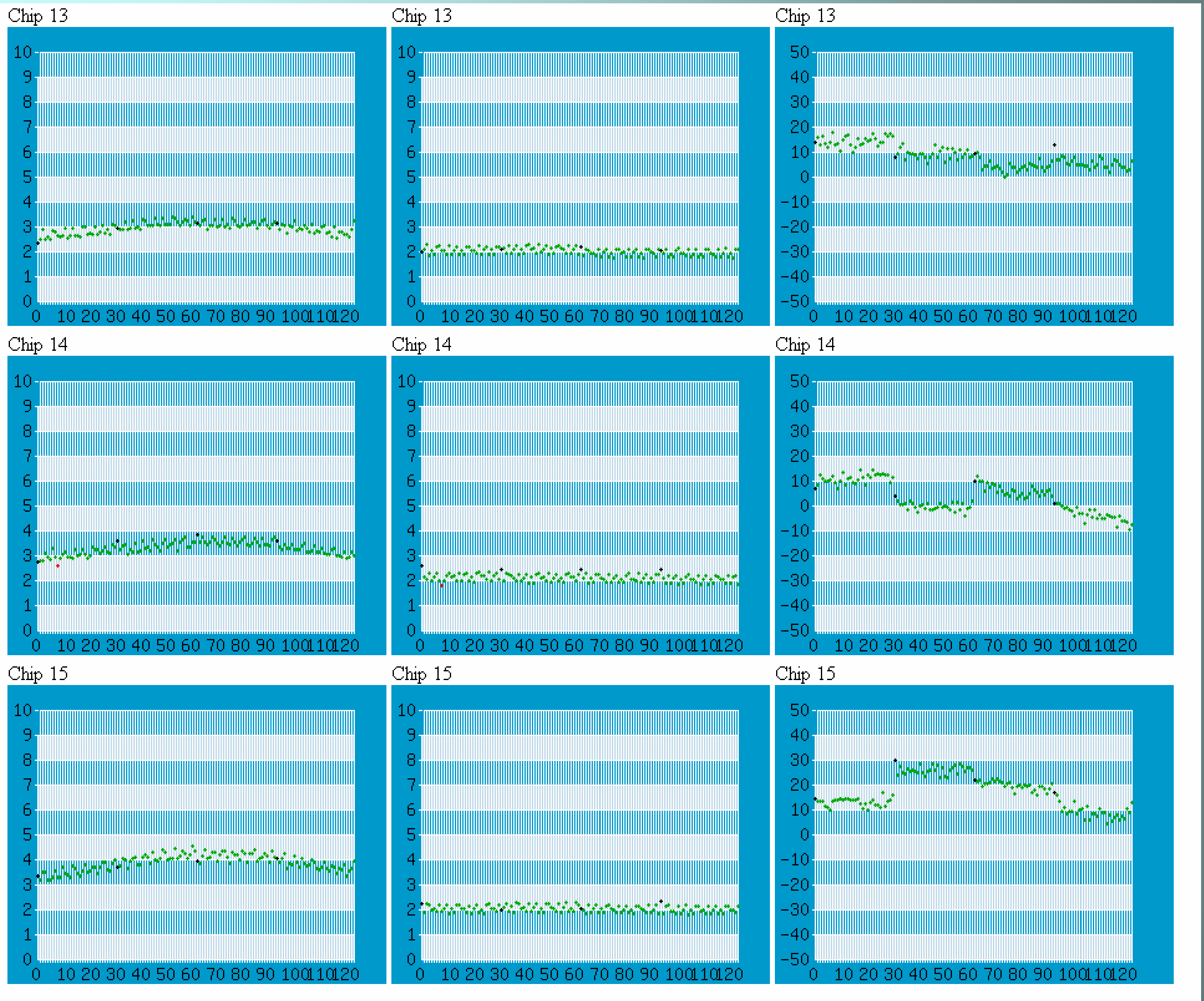




Noise of p-type VELO R- detector

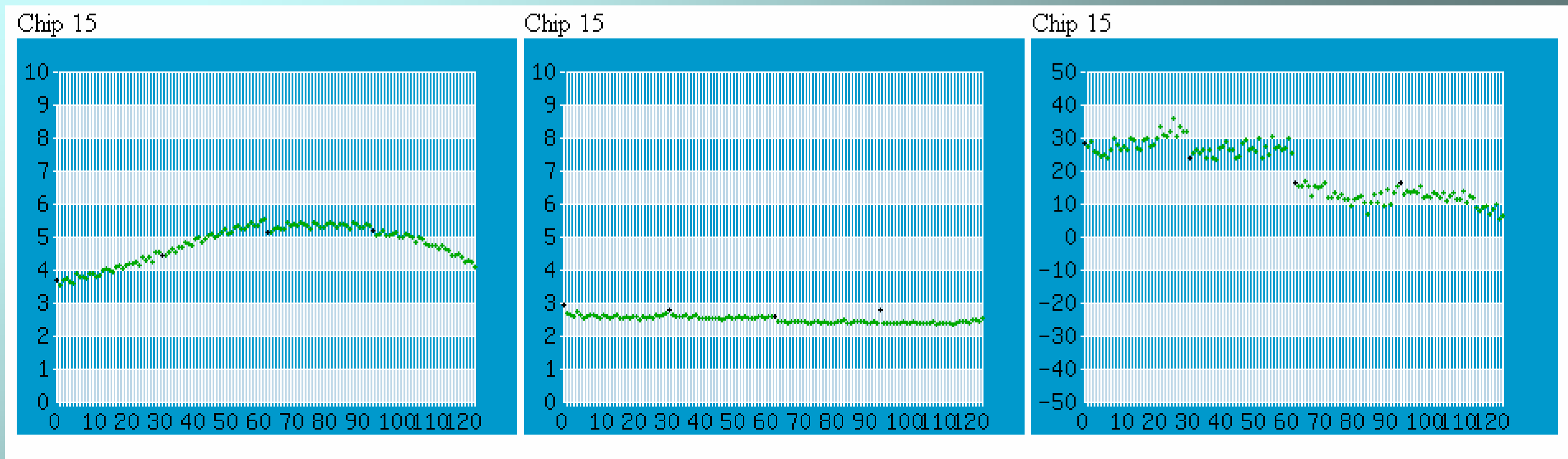


Noise of p-type VELO Phi - detector

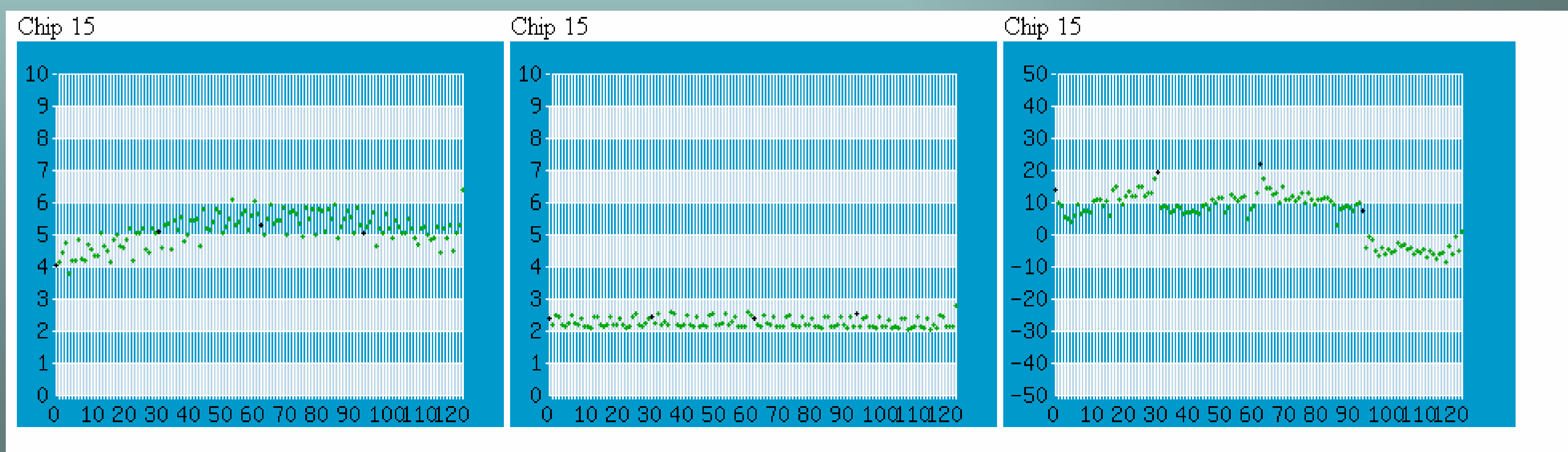


Noise of n-type VELO Phi - detector

R-sensor

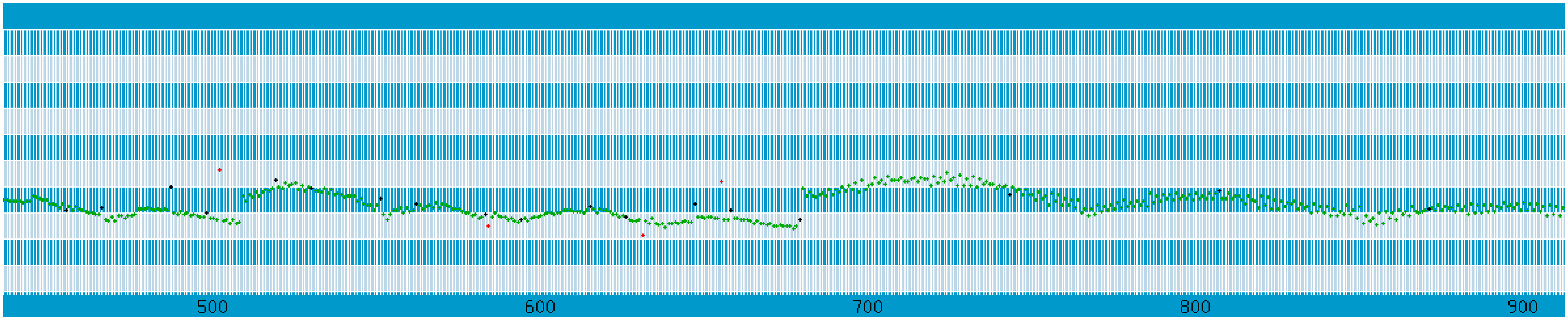


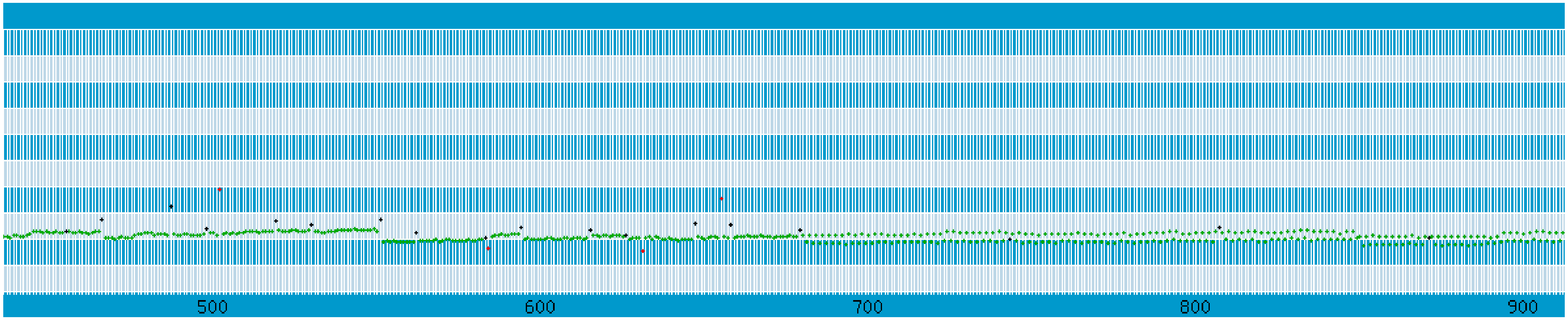
Phi-sensor



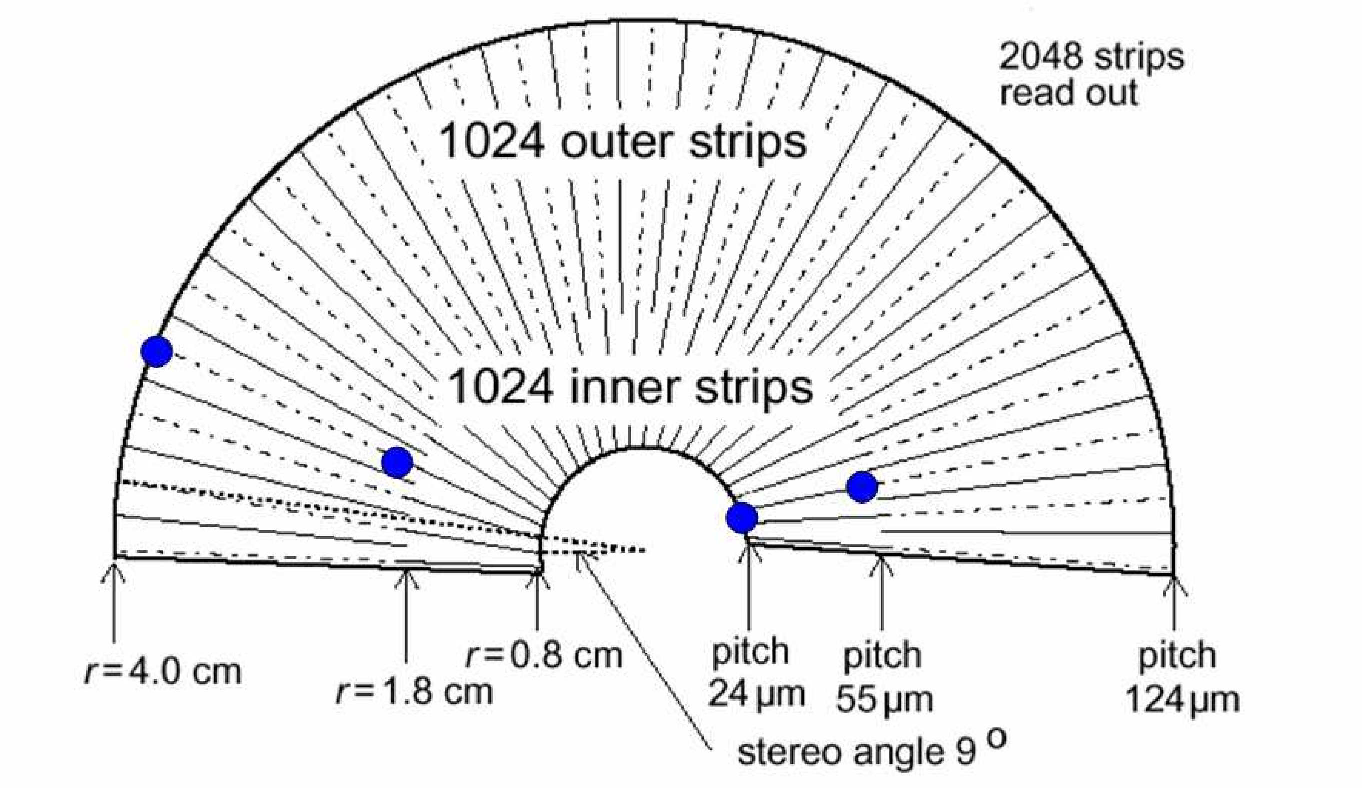
Noise of VELO Phi – detector

3 different 'flavours' of strips





Inner strip length(cm)	0.9952
Outer strip length(cm)	2.2108
Routing line(cm)	2.1981



$$C_{inner} = 6.7 \pm 0.4\ \text{pf}$$
$$C_{outer} = 7.6 \pm 0.4\text{pf}$$

		Inner Section	Outer Section
Smallest Radius	Strip	4.00pf/cm	2.74pf/cm
	Routing Line	-	-
Largest Radius	Strip	3.48pf/cm	3.41pf/cm
	Routing Line	1.54pf/cm	1.51pf/cm

Capacitance (pf/cm) calculated

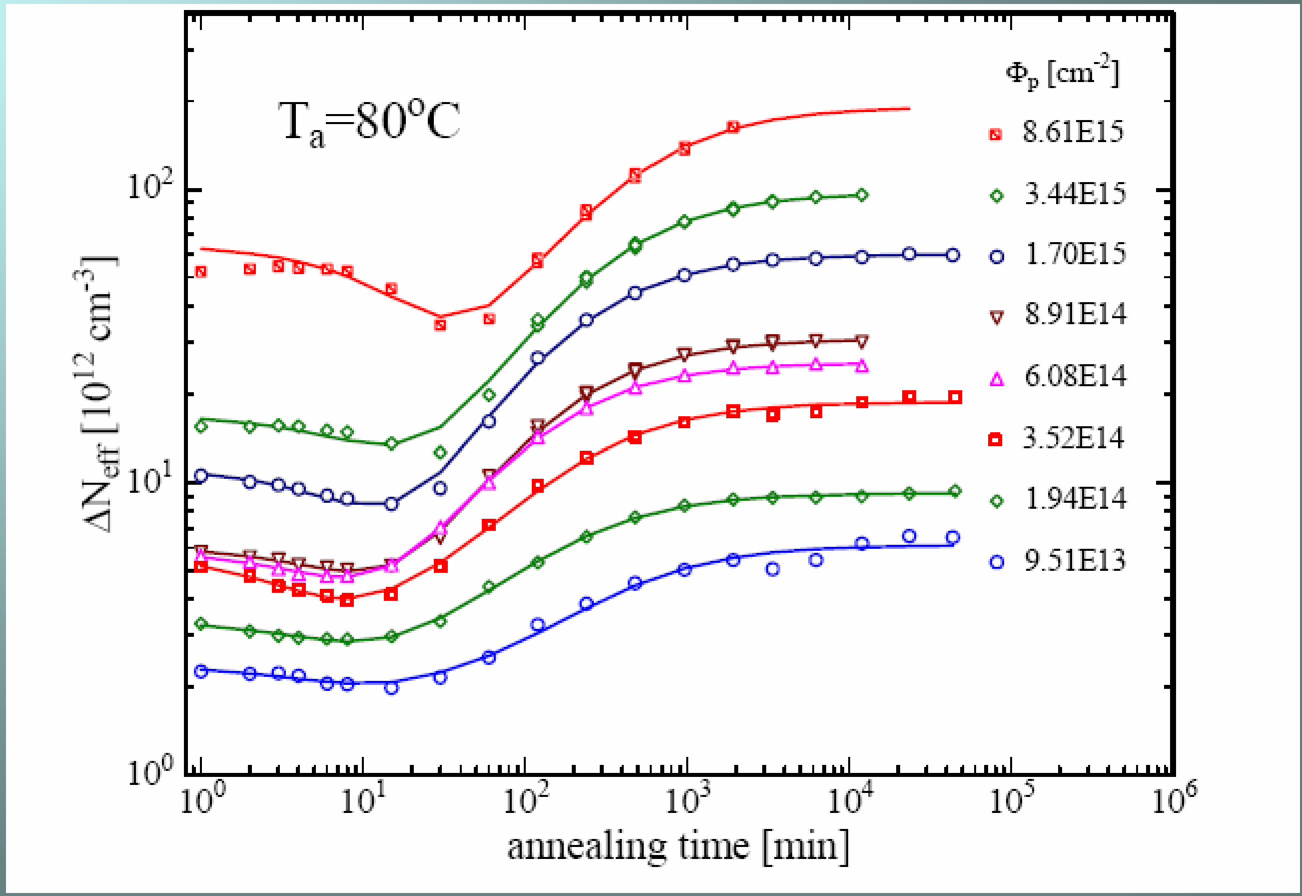
CONCLUSIONS:

The concept of using the S/N ratio to evaluate the performances of silicon sensors to be used in high radiation environment is now well in place. This has substituted the V_{fd} (that can't, e.g., predict the differences in the performances of n-strip or p-strip read out) and lead to the conclusion that only n-strip read out is usable to operate silicon sensors after high fluences.

In this optic, p-type substrates offer a valid alternative to n-type for their easier litography and reduced processing cost. Large area p-type sensor for the VELO sub-detector at LHC have already been prototyped and tested and exhibit pre-irradiation performances perfectly in line with the n-in-n devices in term of all the electrical characterisations (I-V, C-V, laser test, noise).

The LHC scenario always includes the well known evolution of V_{FD} with maintenance time at temperature above operation temperature (17 – 20 ^{o}C).

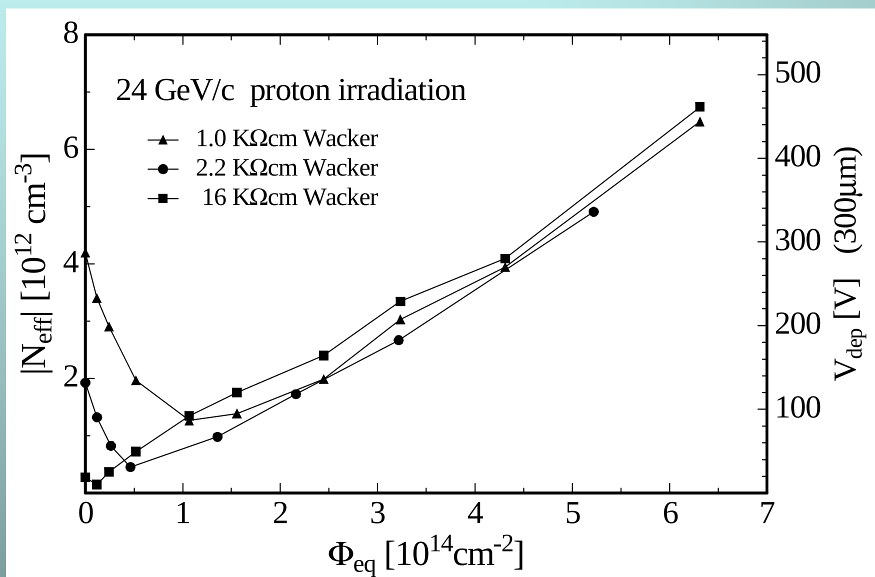
Presented by E. Fretwurst at the 4th RD50 workshop, CERN 5th-7th May 2004.



The initial resistivity has an effect only for irradiation with neutrons, while no benefit is seen with proton irradiation.

3RD RD48 STATUS REPORT

CERN/LHCC 2000-009
LEB Status Report/RD48
31 December 1999



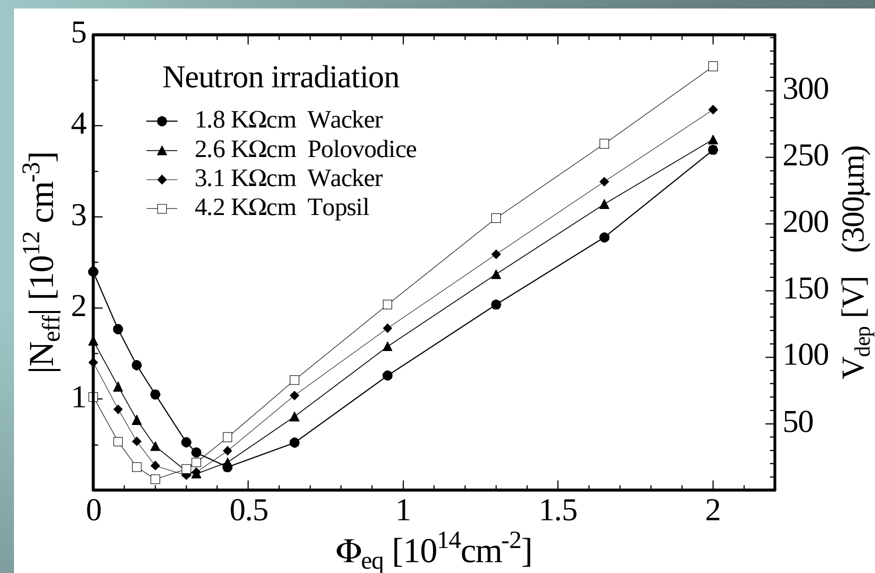


Fig. 11.: 24 GeV/c proton irradiation of O-rich diodes with different resistivity.

Fig.12: Reactor neutron irradiation of O-rich diodes with different resistivity.

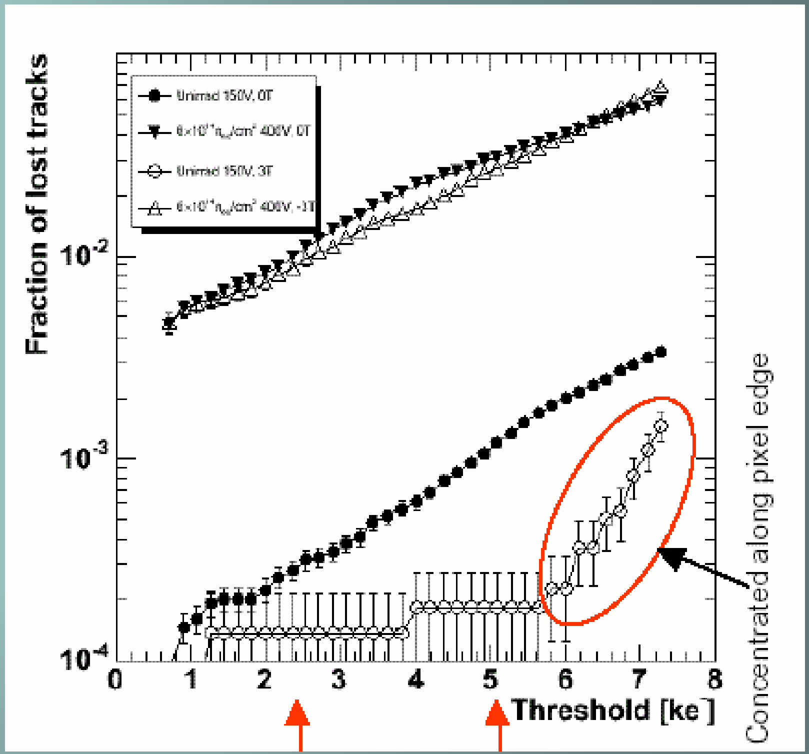
Signal / Threshold S/T : Expected Performance

Efficiency in CMS Pixels

(T. Rohe, RESMDD04)

After radiation damage from a fluence of $6*10^{14}\ n_{eq}/cm^{-2}$, inefficiency vs. the signal-to-threshold ratio S/T:

S/T	Inefficiency [%]
6	1
4	2
3	3
2	9



Efficiency in Pixels
(depends on B-field, pixel size etc, but serves as a guide even for larger fluences):

Need S/T > 4 - 5

The n-side read-out segmented Si-detectors are the state-of-the-art rad hard devices for tracking in hep experiments. How to estimate the maximum survival dose?

Signal-to-noise ratio S/N is essential for performance of the tracking system.

RMS noise σ [electrons]
depends mainly on shaping time and size (input C) of the detector channel

Threshold Thr
need to suppress false hits Thr = n* σ + threshold dispersion δThr

Examples:
SCT: $\sigma \approx$ 600+C*40 $\approx$ 1500e-, n = 4 --> Thr $\approx$ 6,000e-
Pixels: σ = 260e- , δThr = 40 e-, n = 5 --> Thr $\approx$ 1,300e-