First Results on biased CMOS MAPS-On-DIAMOND devices

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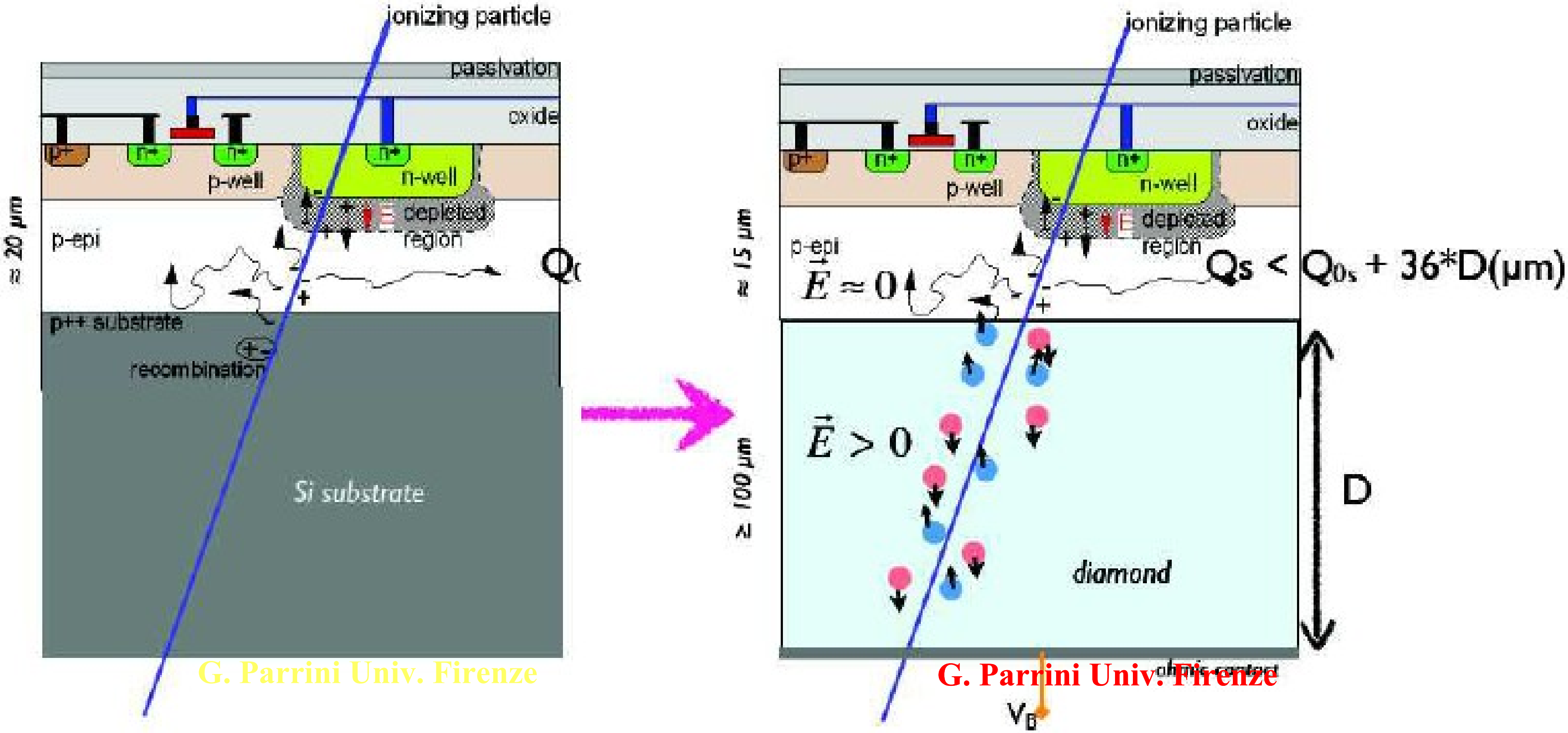
Outline

- ✓ Motivation and aim.
- ✓ MAPS-On-Diamond device.
- ✓ MAPS characterization (noise, calibration)
- ✓ Test with charged particles (MIP)
- ✓ Conclusions.

Motivation and Aim

- ✓ Diamond sensors have several advantages:
- → radiation hardness; → small leakage current;
- → room temperature operation; → fast signal;
- ✓ Also problems......
  - → small dimensions; → few suppliers; → high cost; ...
  - → small signal for a MIP; need low noise readout;
  - → readout granularity;
- ✓ Goal: connect a full CMOS readout chip to a diamond substrate to obtain a highly segmented device for charged particle detection.

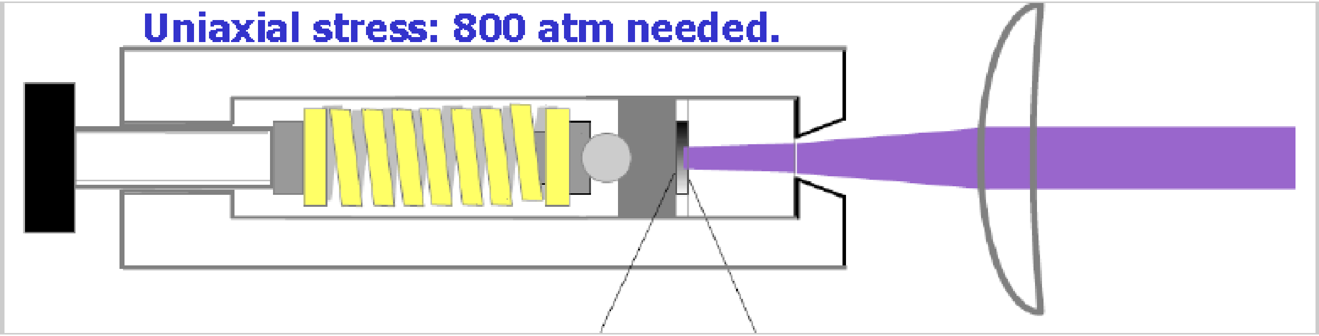
MAPS-On-Diamond Concept



Aim: to collect the charge generated in the diamond substrate using MAPS photodiodes.

We want to prove that charges conveyed by HV bias to the Silicon / Diamond interface cross it and are collected by MAPS photodiodes.

Laser Bonding Process



- The silicon layer is pushed to the diamond surface with a pressure of 800 atm. (roughness ~ few nm).

- A pulsed laser (355 nm, 20 ps), entering from the diamond side is focused onto the Silicon - Diamond surface, to deliver the energy needed to form a Silicon-Carbon interface (~100 nm)

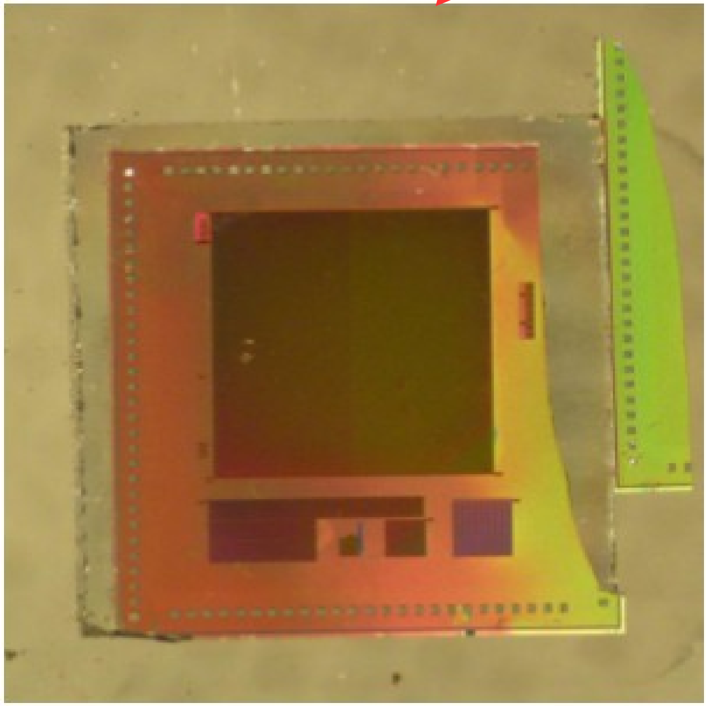
- The beam spot is then moved using micrometric precision stages to paint uniformly all the contact surface.

MAPS-On-Diamond devices

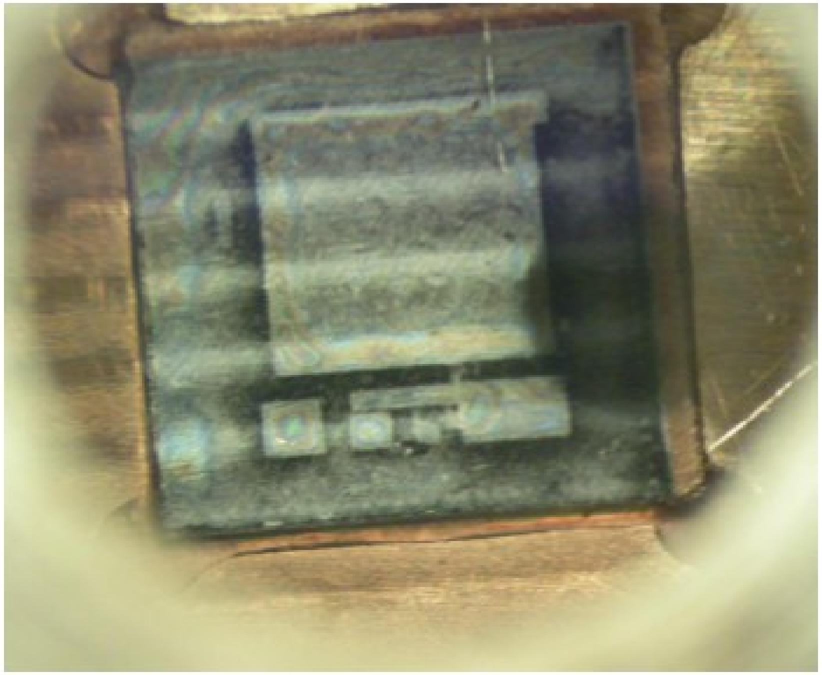
- ✓ The new concept of Silicon-on-Diamond (SoD) bonding has been adopted to couple the CMOS RAPS03 chip with a diamond substrate.

BAD!!

GOOD!!

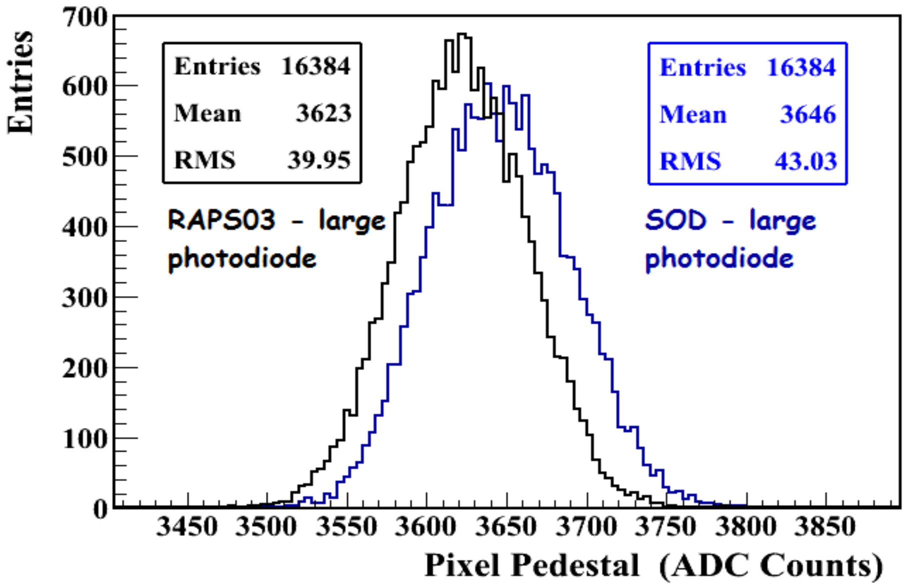


Top view (silicon side) after the bonding **(broken sample).**



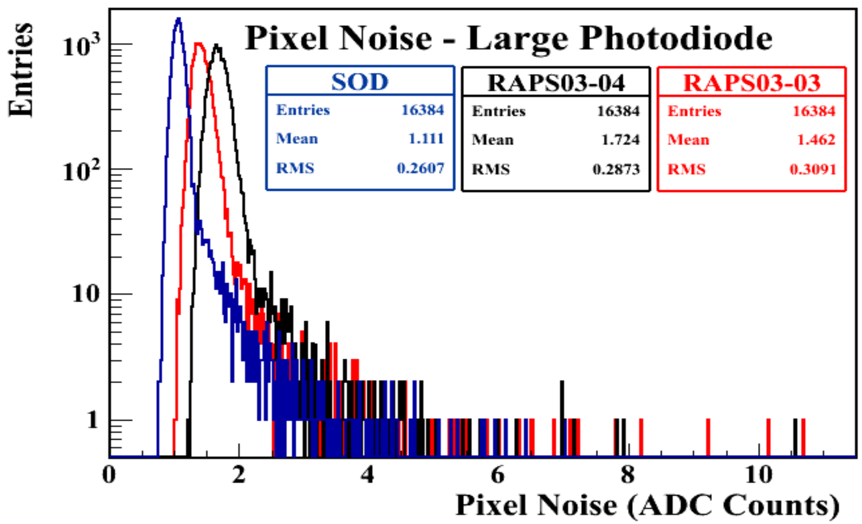
Bottom view (through the diamond and the quarz windows) after the bonding.

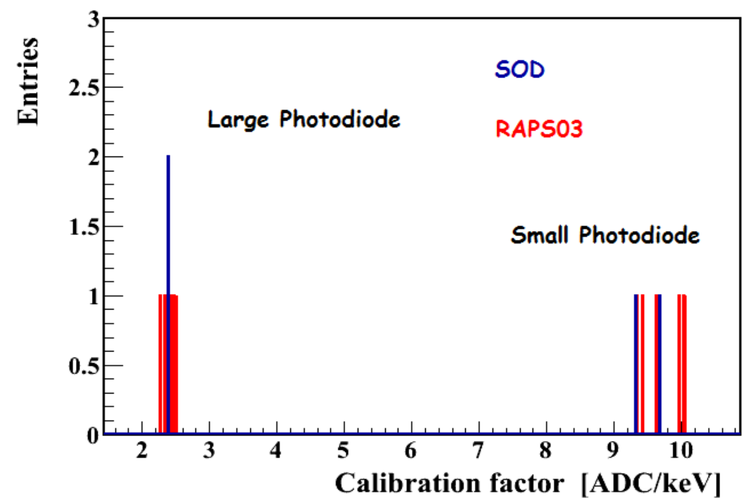
MAPS-On-Diamond



Bonding procedure does not destroy CMOS electronic.

Comparable characteristics for non thinned RAPS03 (black, red) and thinned RAPS03 laser bonded to 500 µm pCDV (blue).



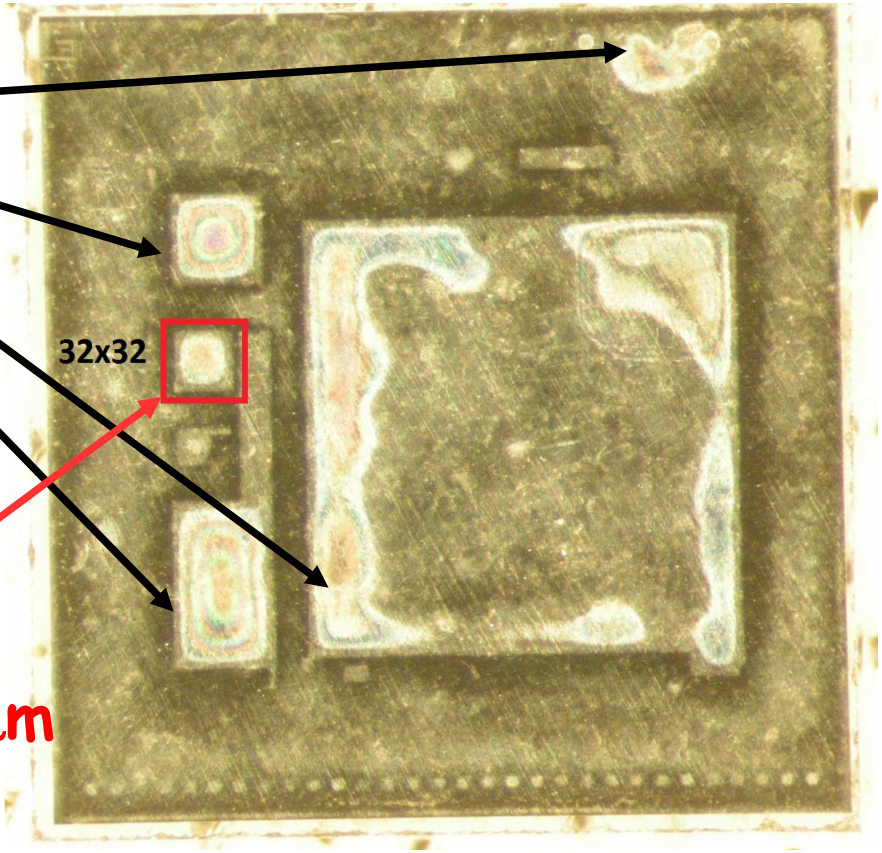


MAPS-On-Diamond

Device SOD-40 (25 µm silicon, 500 µm pCVD)

Interference regions (white light)

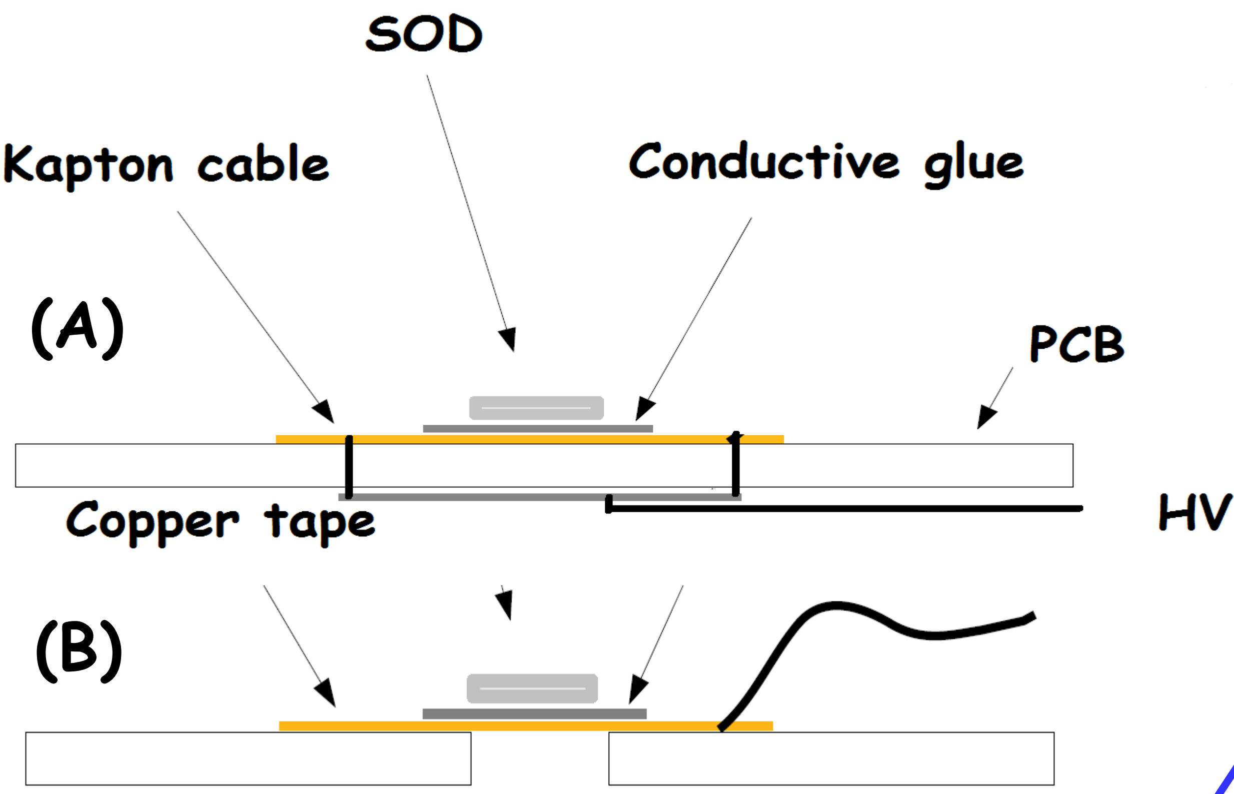
→ Non perfect Silicon/Diamond adhesion

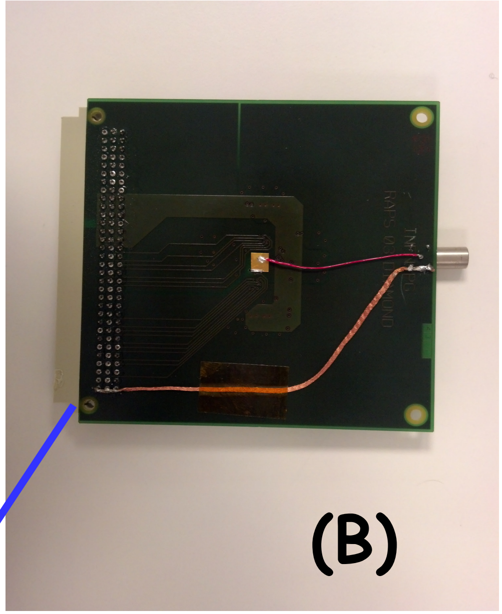


Read-out matrix
32x32 pixels 10x10 µm single pixel size.

MAPS-On-Diamond

Device polarization schemes:





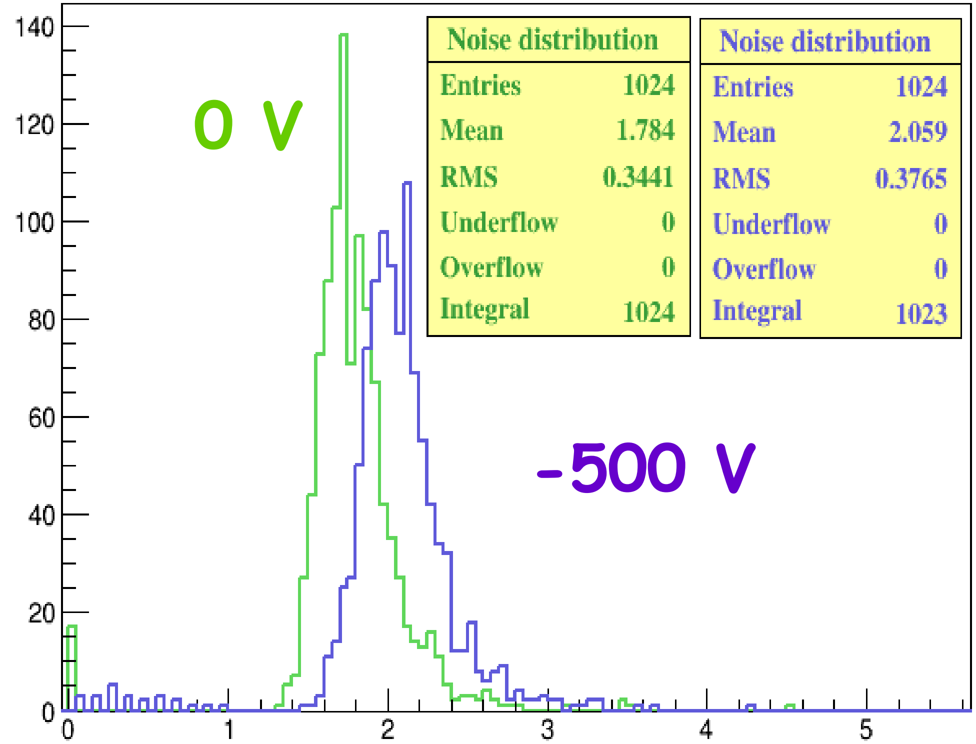
Sensor Board

MAPS-On-Diamond

Effect of polarization on noise:

~ 0.2 ADC average increase.

Negligible on signal reconstruction.

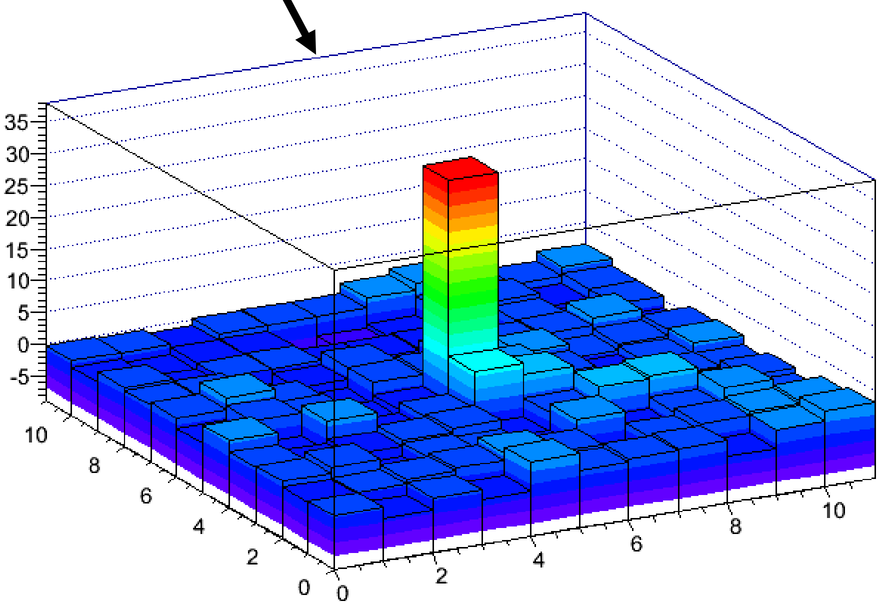


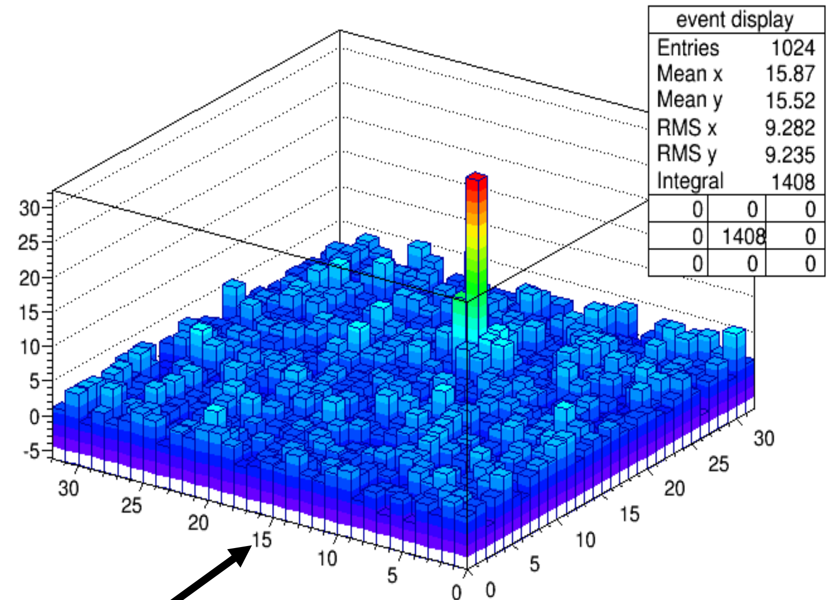
MAPS-On-Diamond

Event Display $^{90}Sr/^{90}Y$ source

Single trigger event displays

@ 0 V polarization

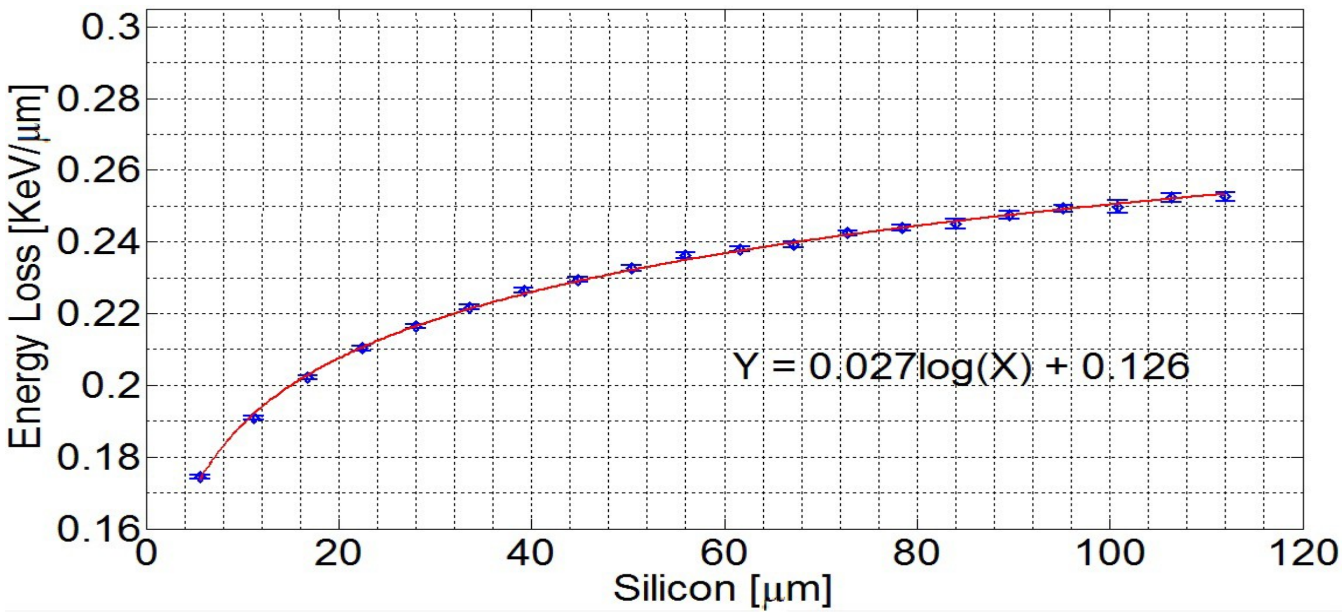




@ -500 V polarization

Limited number of pixels involved, mostly inside 5x5 matrix around maximum signal pixel.

Charge Collection: Silicon Contribution

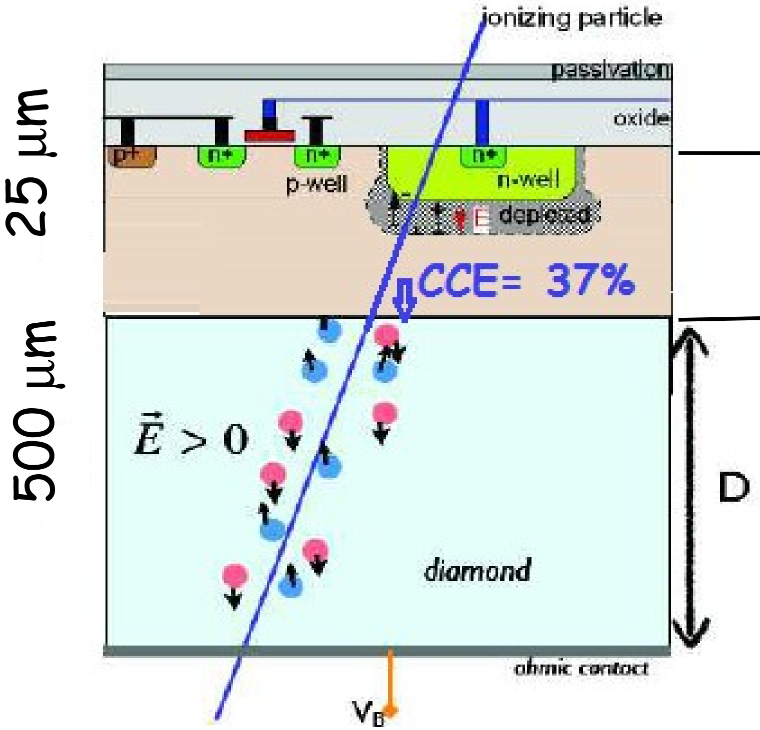


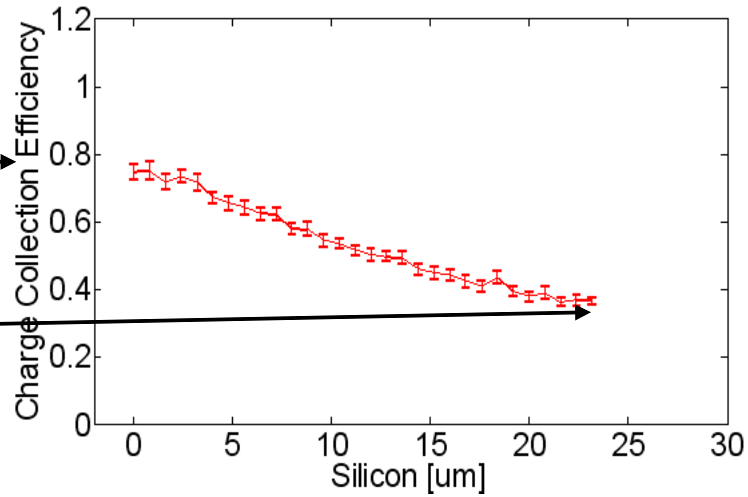
@ 25 μm thickness, the MPV of MIP energy loss in silicon is:

0.213 keV/μm = 1479 e-h pairs

S. Meroli, D. Passeri, L. Servoli. **Energy loss measurement for charged particles in very thin silicon layers.** *Journ. of Instr. (2011) 06 P06013*

Charge Collection: Diamond contribution





The charges crossing the interface would be collected by MAPS @ interface efficiency, i.e. 37% @ 25 µm

The **MPV** of diamond contribution for a PolyCVD, 500 µm thickness, @ full collection efficiency is ~ 7000 e-h pairs (at most). For the diamond we used, full collection was reached at -500 V.

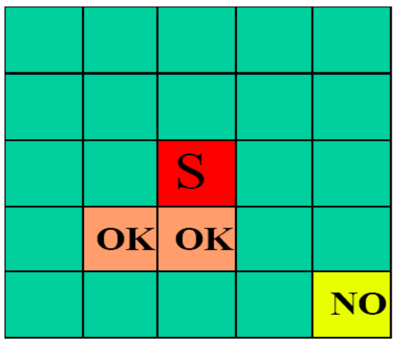
Max Diamond Charge Collected by MAPS →

$S_{diamond}$ = 7000 e * 0.37 = 2590 e-h pairs

MAPS-On-Diamond: SOD-40

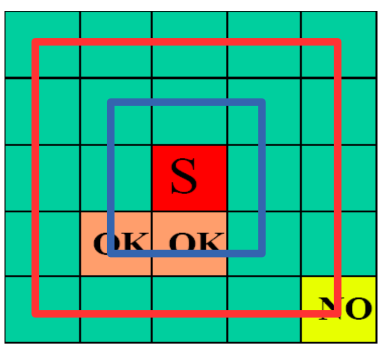
Clustering Algorithm:

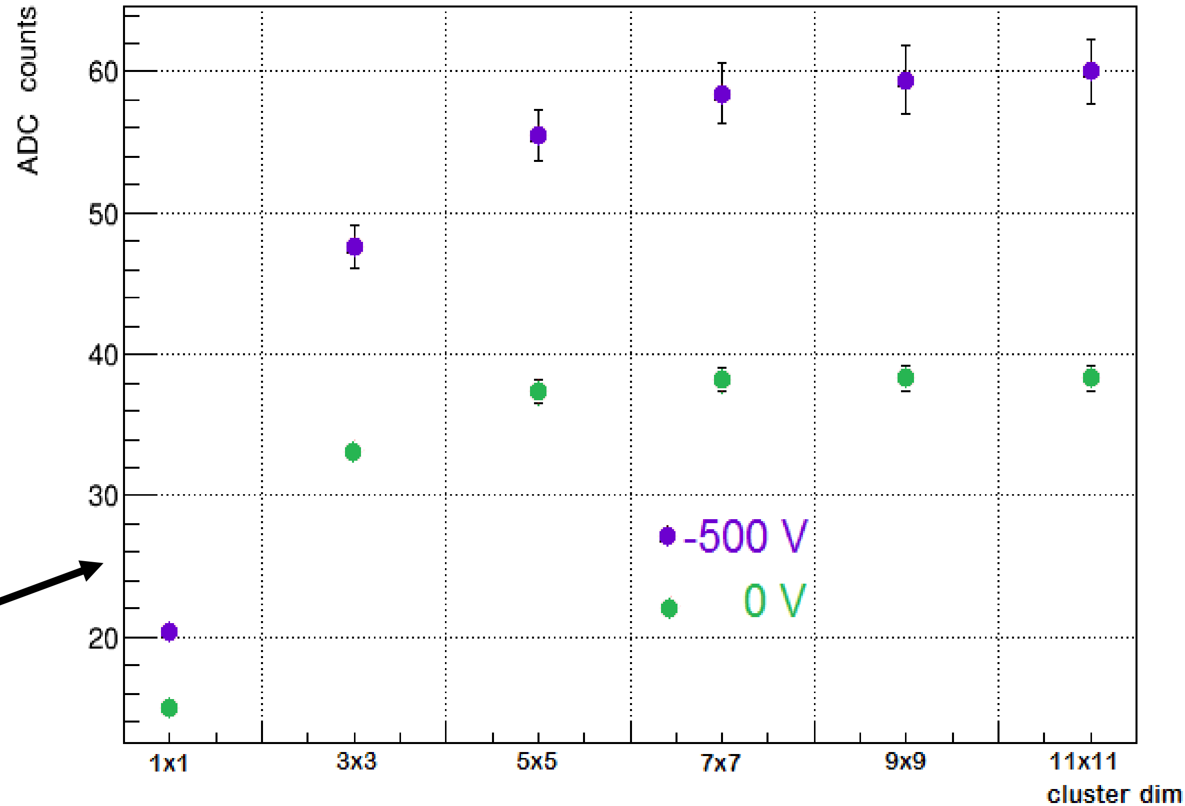
1) double threshold



2) symmetric

1x1
3x3
5x5
...





Reconstructed cluster charge vs submatrix dimension:
in 5x5 matrix we collect almost everything for both 0 and -500 V

MAPS-On-Diamond: SOD-40

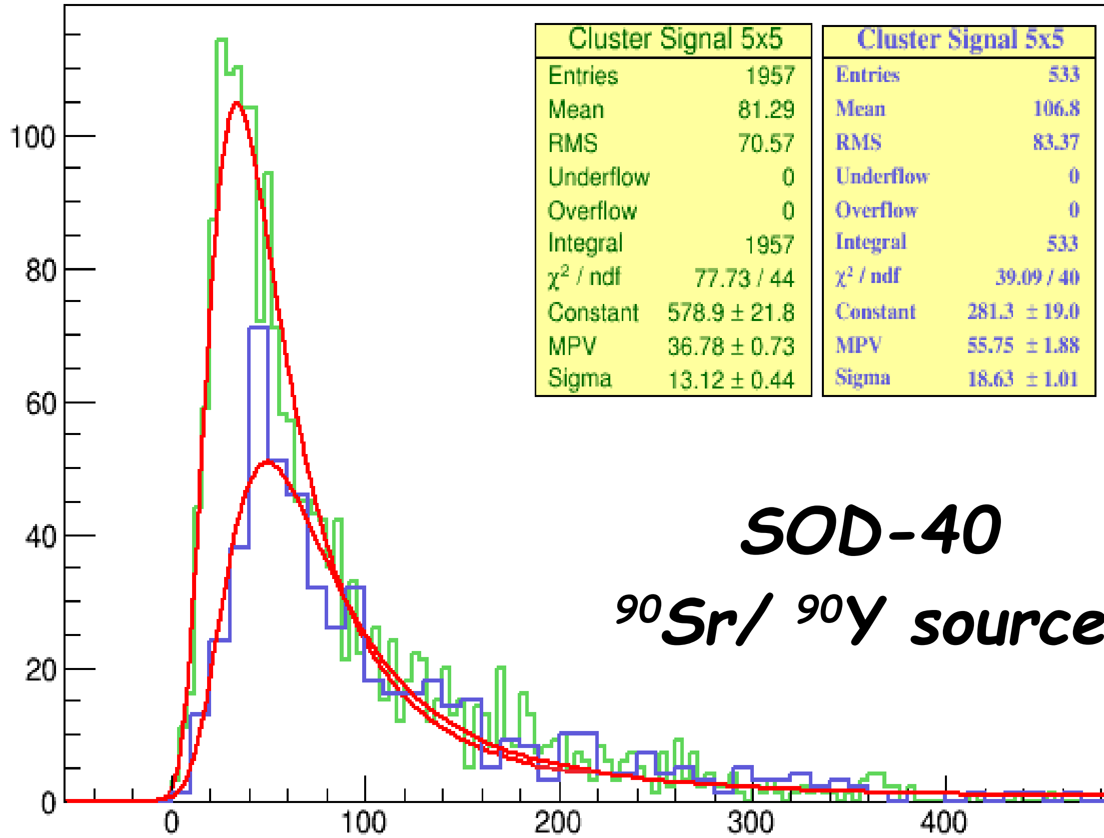
What we see:

$MPV_{0\ V} = 37\ ADC$

$MPV_{-500\ V} = 56\ ADC$

$\Delta_{MPV} = 19\ ADC$

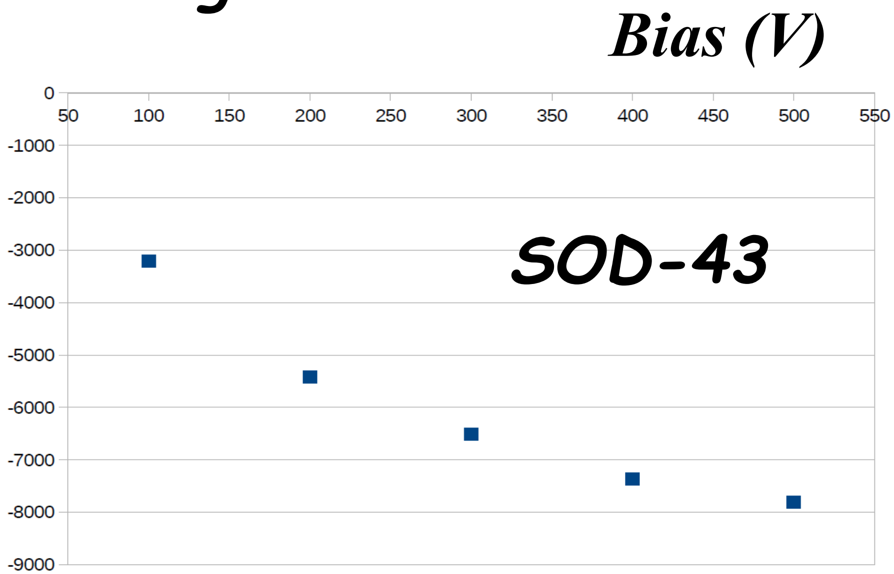
$\rightarrow\ \Delta_{MPV} = 515\ e^-$

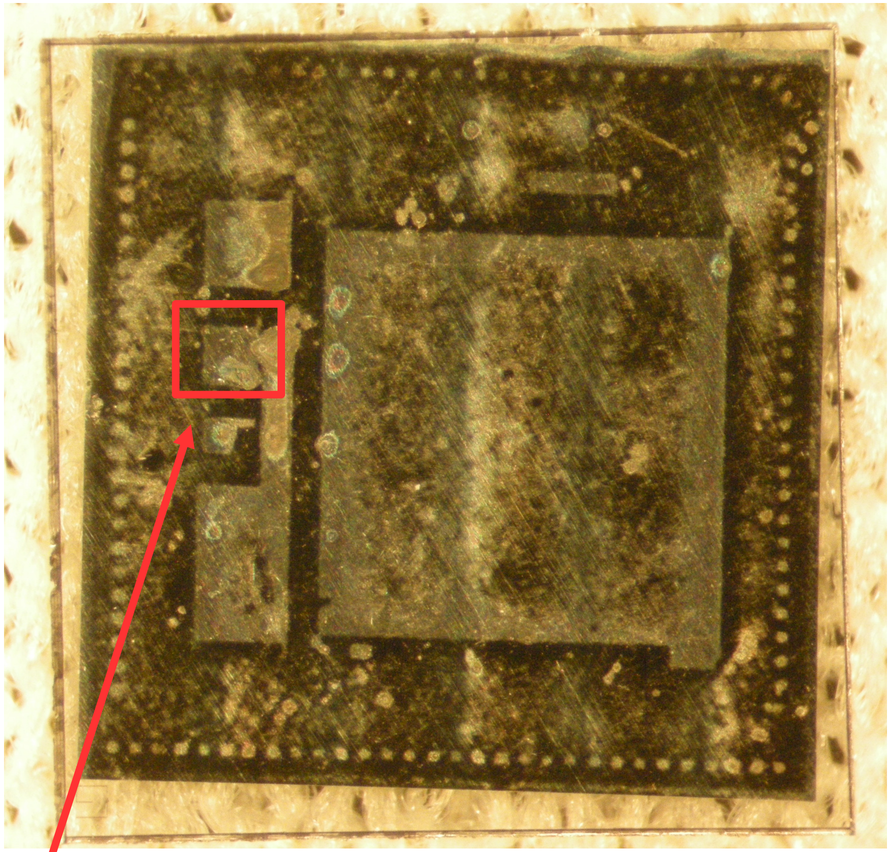


$\eta = \Delta_{MPV} / S_{diamond} = 515/2590 \sim 20\ \%$

MAPS-On-Diamond: SOD-43

Diamond CCE vs bias before bonding.





SOD-43 from diamond side: better adhesion than SOD-40

MAPS-On-Diamond: SOD-43

SOD-43 not fully polarized.

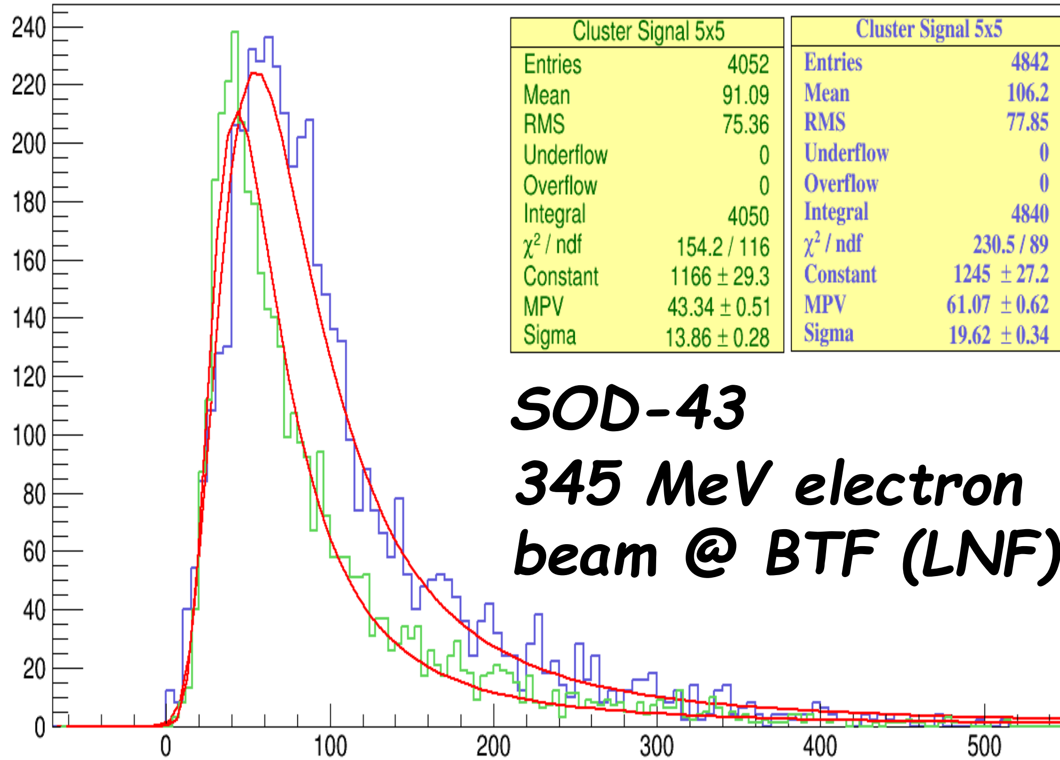
What we see:

$MPV_{0\ V} = 43\ ADC$

$MPV_{-500\ V} = 61\ ADC$

$\Delta_{MPV} = 22\ ADC$

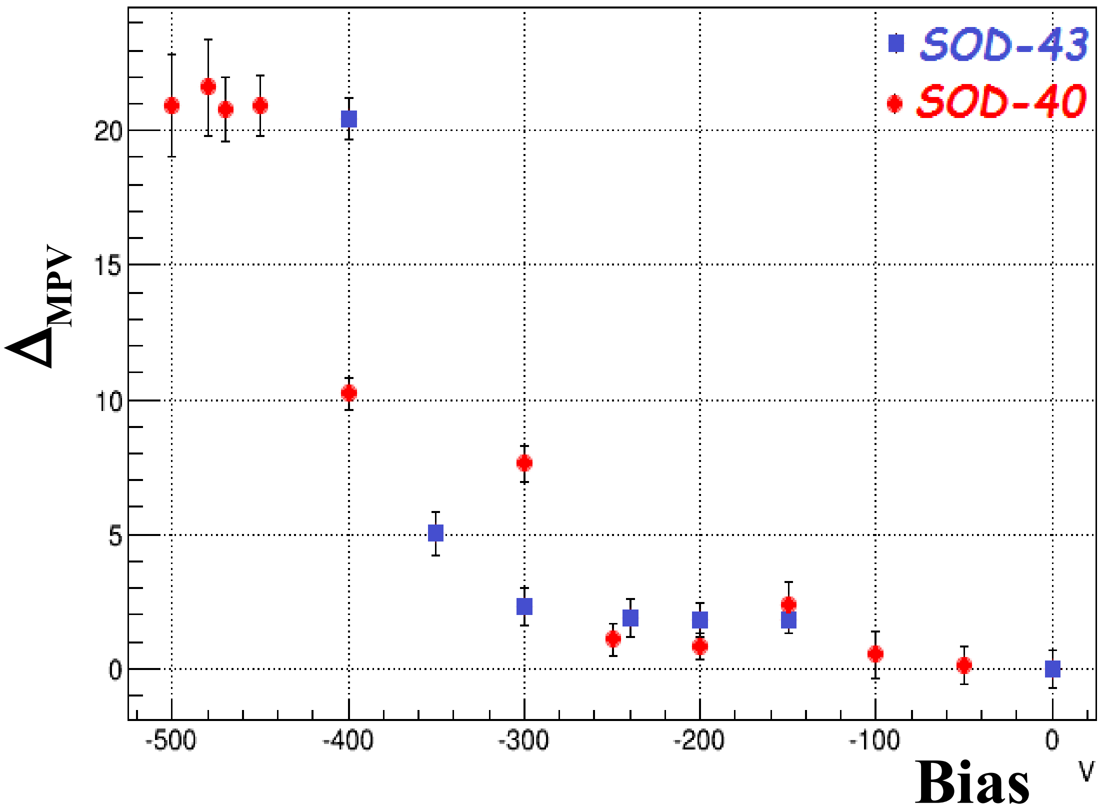
$\rightarrow\ \Delta_{MPV} = 597\ e^-$



$\eta = \Delta_{MPV} / S_{diamond} = 597/2590 \sim 23\ \%$

Full polarization value

MAPS-On-Diamond: bias scan



SOD-43 not fully polarized (max -400 V)

- *It seems onset for collecting diamond signal @-250 V.*
- *SOD-43 collects potentially more signal than SOD-40 (better adhesion?)*

Warning: all results with not-pumped diamond substrate

Conclusions (1)

- ✓ Two MAPS-On-Diamond devices have been built using thinned RAPS03 non-epitaxial MAPS and 500 mm pCVD diamond substrate.

- ✓ The CMOS properties of the devices have not changed from the standard MAPS behaviour.

- ✓ A biasing scheme for the diamond substrate has been implemented using the CMOS reference as reference also for the HV negative bias.

- ✓ When diamond bias is on the CMOS properties remain essentially the same of the unbiased case.

Conclusions (2)

✓ The devices have been tested with electrons both in laboratory ($^{90}Sr/^{90}Y$) than in a beam test (500 MeV).

✓ For all devices an increase of the signal during a bias scan has been observed.

✓ The estimated additional signal corresponds to 20% of the expected signal generated in the diamond.

✓ An estimated signal of 40% is possible if full biasing could be reached in SOD-43.

It is whortwhile to notice that the amount of signal generated in the diamond is more than 150% of what is generated in the silicon.