Experience with 50um thick epi LGAD

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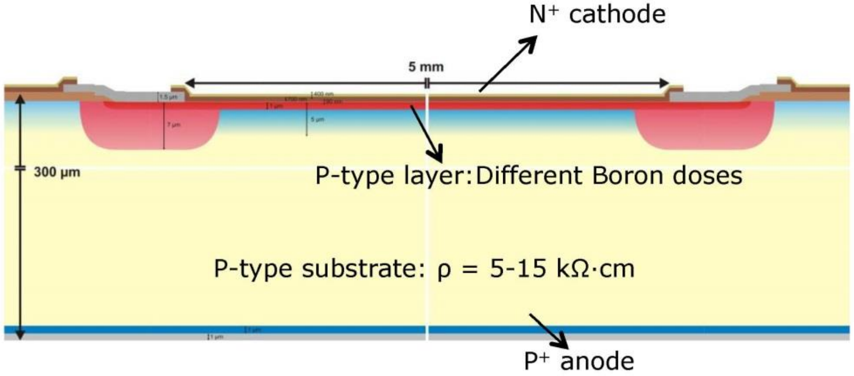
Why LGAD, why thin?
CCE (IR Laser, α top)
Gain thin-thick
Doping Profile

Low-Gain Avalanche Detector (LGAD)

Pads detectors with multiplication

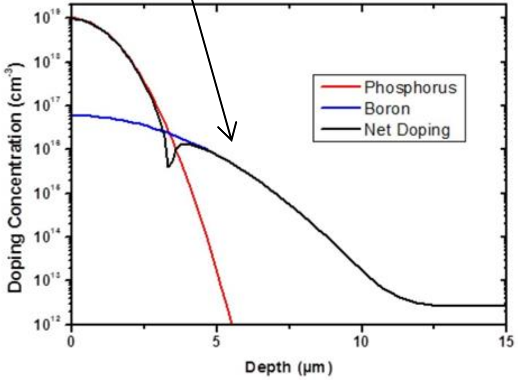
Low-Gain Avalanche Detector (LGAD)

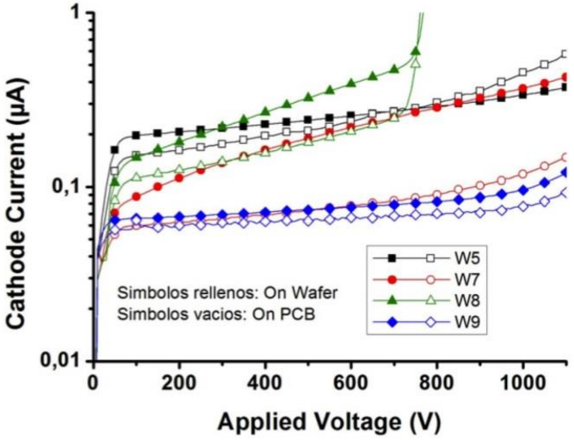
Marta Baselga,
Trento Workshop
Feb. 2013

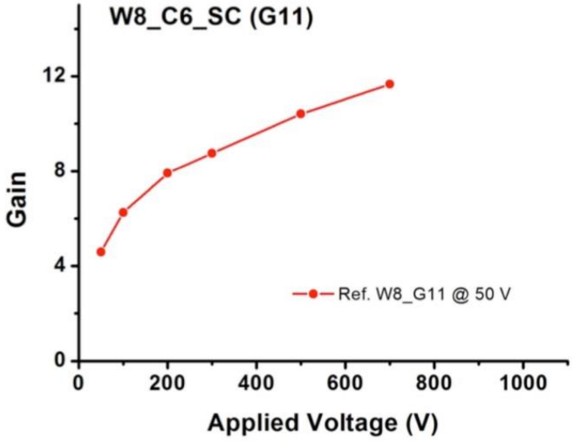


$V_{FD} < 30$ V
$V_{BD} > 1100$ V

High-Field: Gain





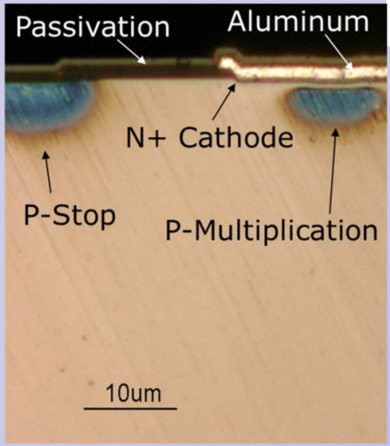


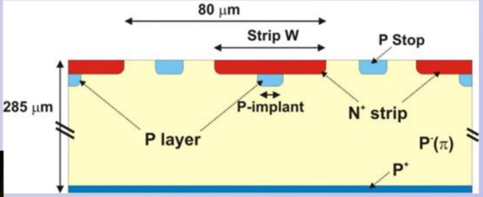
Fabrication of LGADs at CNM Barcelona

Run #	Geometries	
6474	Pads	1,4,7
6827	Pads, Strips, Pixels	2,4,5,6,7
7062	Pads	1,3,4,7,8

1. Edge of n+ and periphery variations
2. Wafers with different p-layer doping profiles
3. Shallow and deep n-diffusion profiles
4. High resistivity FZ 300 μm p-type substrate
5. Epi 100 Ω-cm p-type wafers,10-75 μm thick
6. Segmented detectors (strips, pixels)
7. Wafers contain reference PiN diodes
8. Backside metal grid allows red laser TCT

Run 6827 Diode Strip/Pixel Sensor

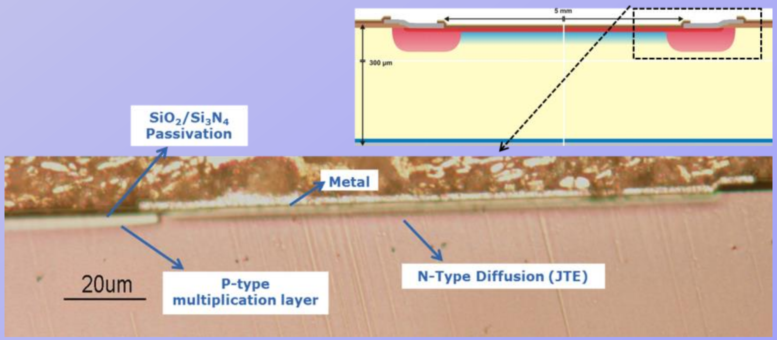




- Fixed pitch
- Vary n-strip width
- Vary p-implant width
- Vary bulk resistivity (10kΩ FZ, 100Ω Epi)
- Vary Epi thickness

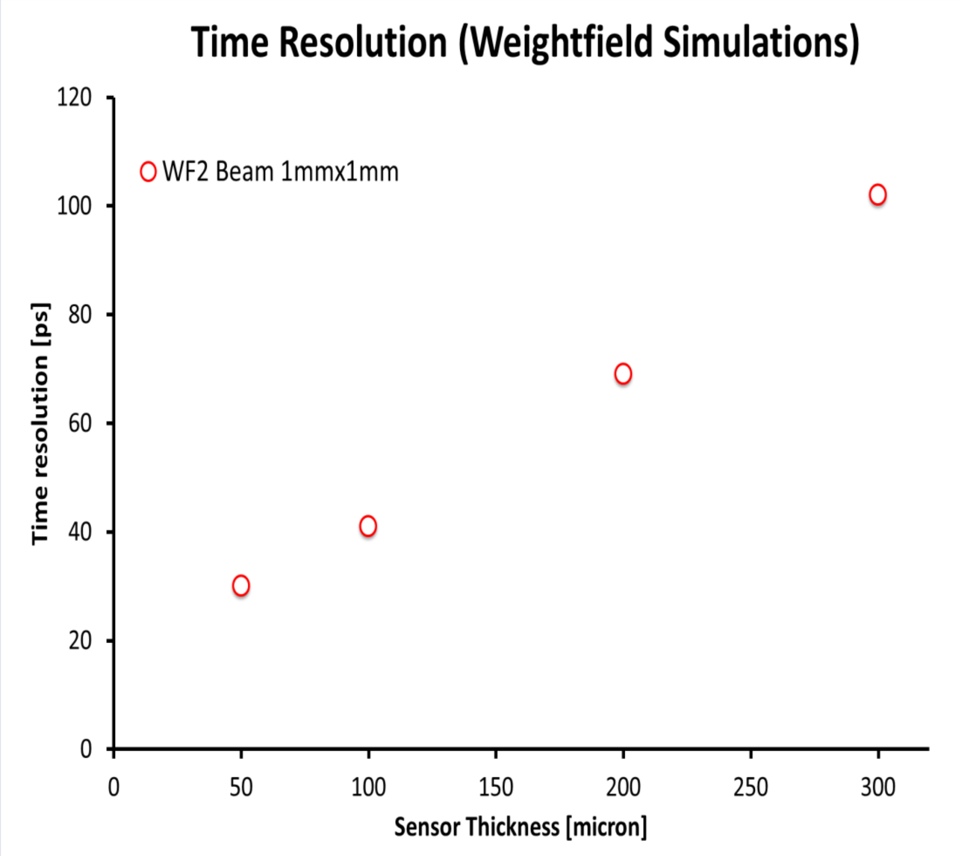
Run 6474 Diode

Periphery **Edge**



Time Resolution for thin LGAD

For the 300 µm thick large LGAD pads (C ≈ 10 pF), the time resolution measured in the beam test (BT) at Frascati, is predicted by the **Weightfield (WF2)** simulation –(see N. Cartiglia talk)



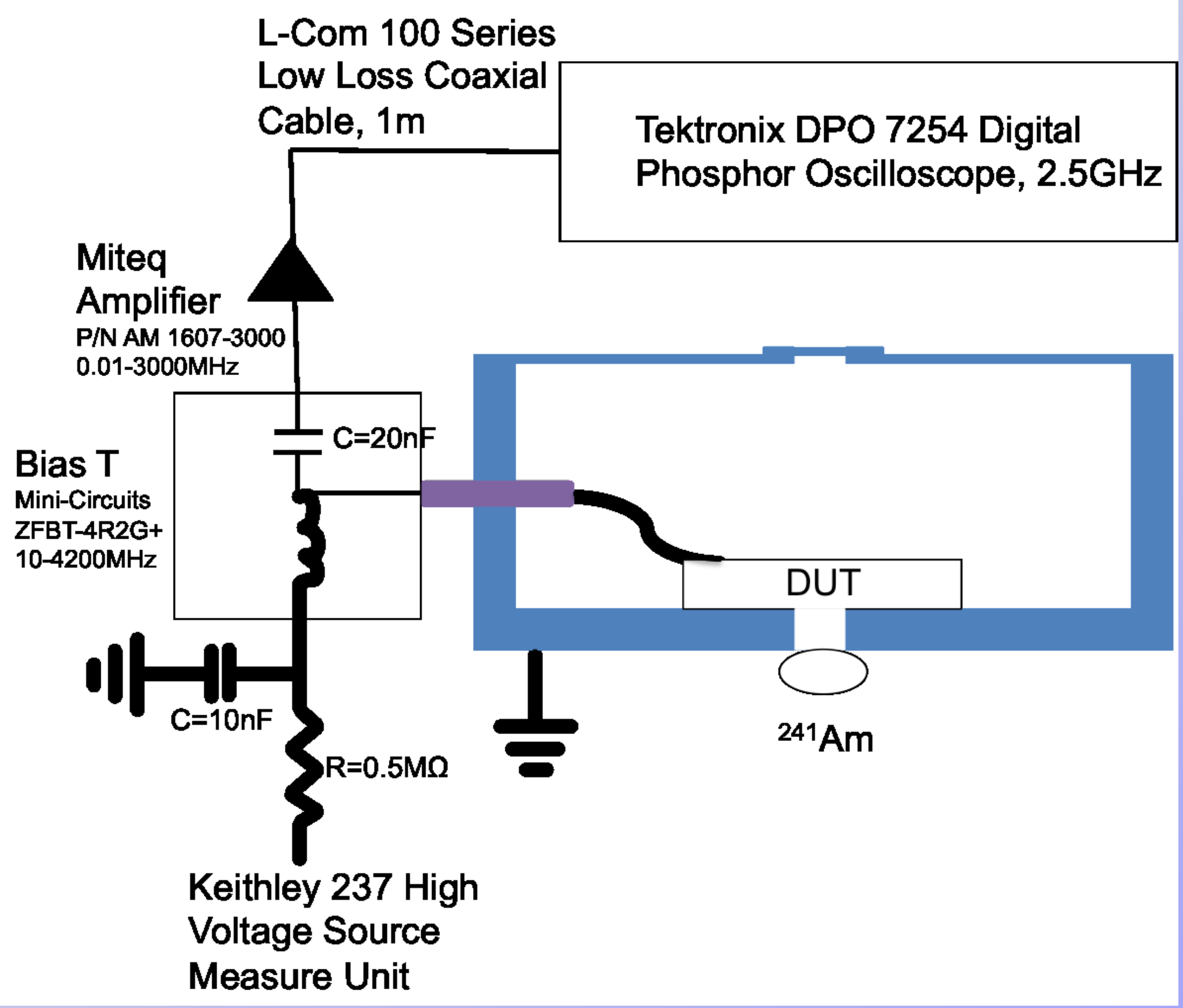
The time resolution is predicted to improve for smaller LGAD (1mmx1mm) and optimized electronics.
Reduced the thickness also improves the time resolution.

Expect for 50 µm thick LGAD (C~2pF):

σ_t = 30 ps (requires ASIC)

N. Cartiglia, F. Cenna et al. "Weightfield", 2014 IEEE NSS-MIC

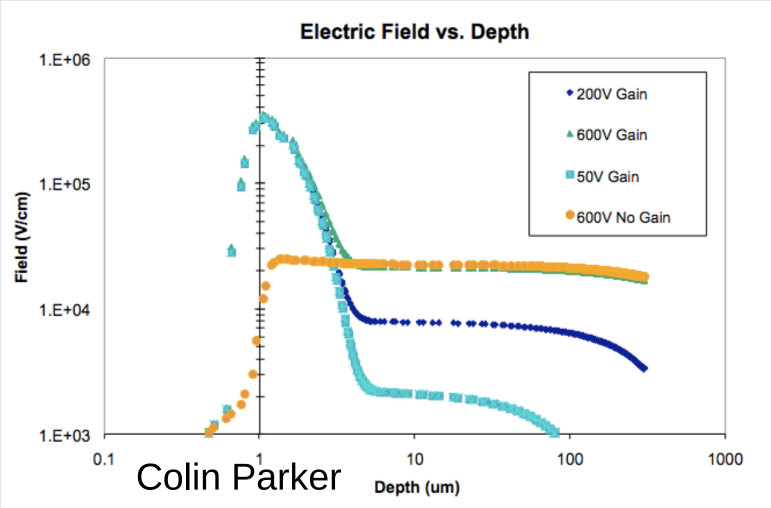
High BW Charge Collection Set-up



Charge Collection with α's from Am(241)

Front side illumination

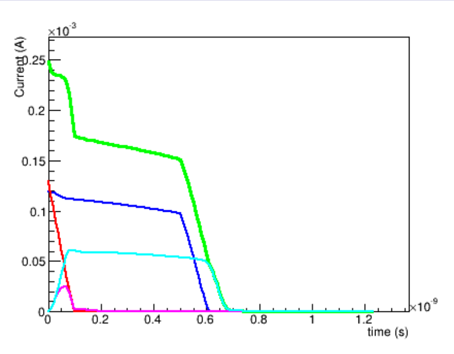
α's

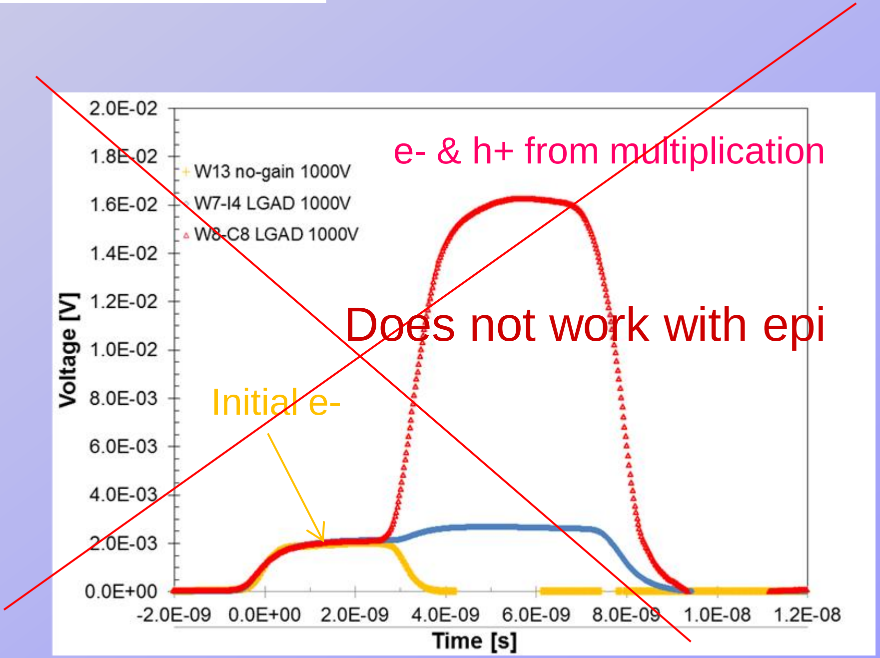


Colin Parker

Back side illumination

α's





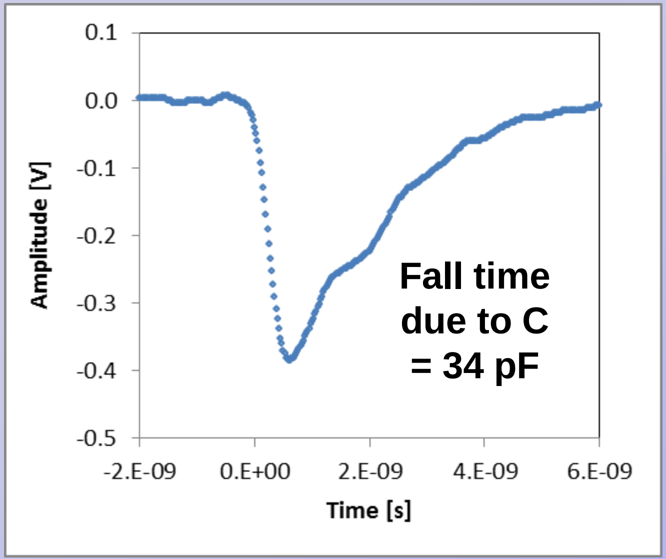
e- & h+ from multiplication

Does not work with epi

Initial e-

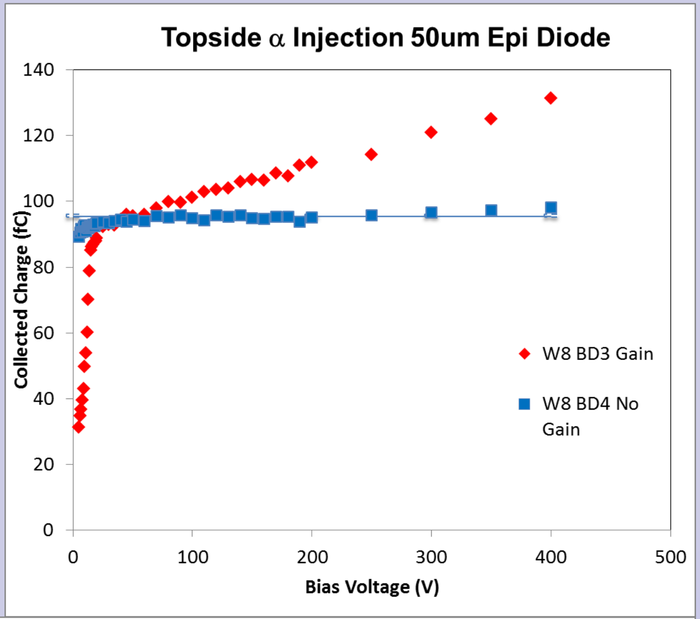
Rise time: 400ps

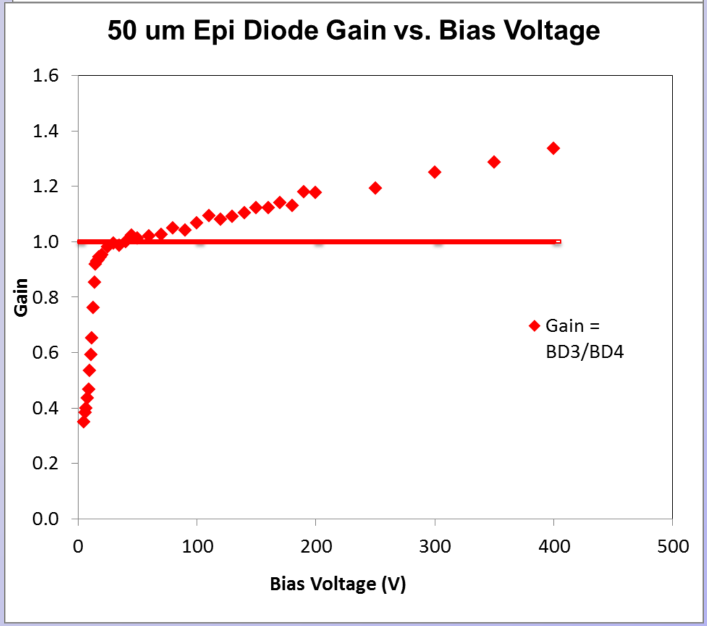
For MIP about 600ps



Fall time due to C = 34 pF

Gain in thin LGAD (Top-side α Injection)





The epi structure prevents electron injection through back-side α radiation.

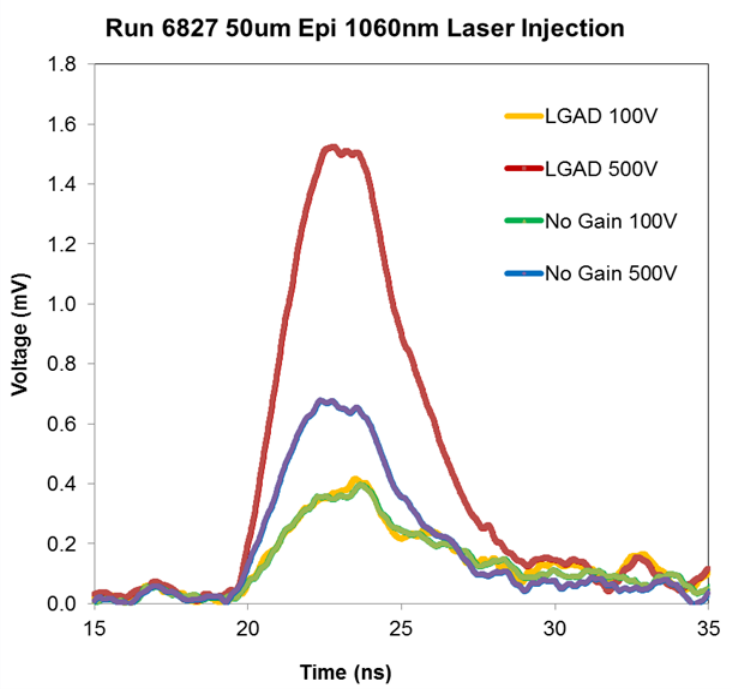
Using front-side α injection to compare LGAD and no-gain pads requires that the energy loss of the α's in the active region are the same (or are known well).

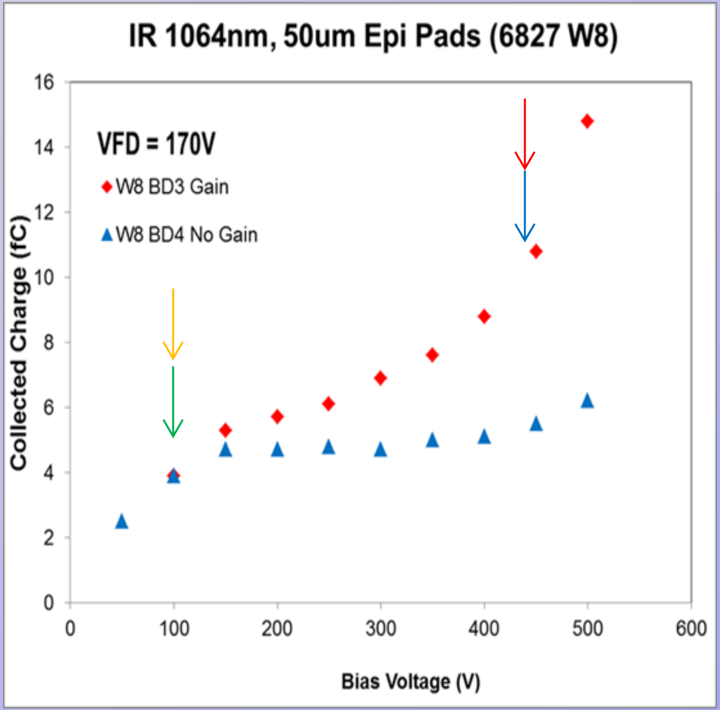
The α signal in the no-gain diode is constant as a function of the bias voltage.
While the α signal in the LGAD reaches the same level only after sufficient depth of the p+ implant is depleted (we estimate ~ 7 um) at a bias of ~ 25V. .

At higher bias, gain of about g = 1.4 is observed.

Gain in thin LGADs: IR Laser Injection

Gain in 50 µm 100 Ω-cm epi LGAD pad (6827)
IR (1064nm) laser injection from front shows characteristic LGAD voltage dependence of signal, while no-gain diode is constant above full-depletion voltage V_{FD} = 140 V. Gain of about 3 is observed.

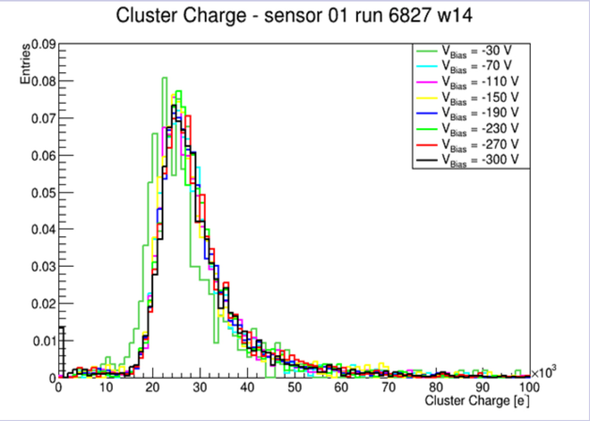


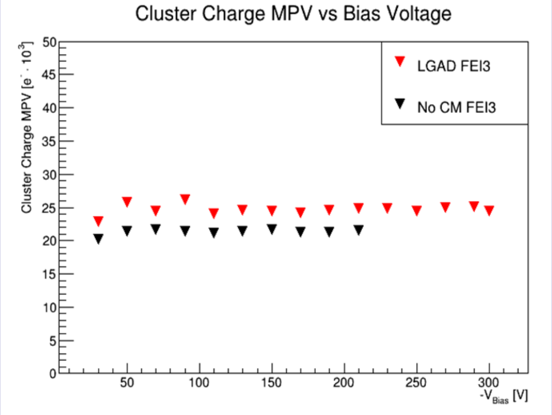


N.B. The 50 µm 100 Ω-cm epi LGAD strip and pixel sensors broke down before reaching their depletion voltage.
The difference of the measured gain factor
for top-side α Injection wrt laser (g=3) is predicted by the “Weightfield” program

Segmented LGADs (300um FZ)

300 μm FZ low p-dose run 6827

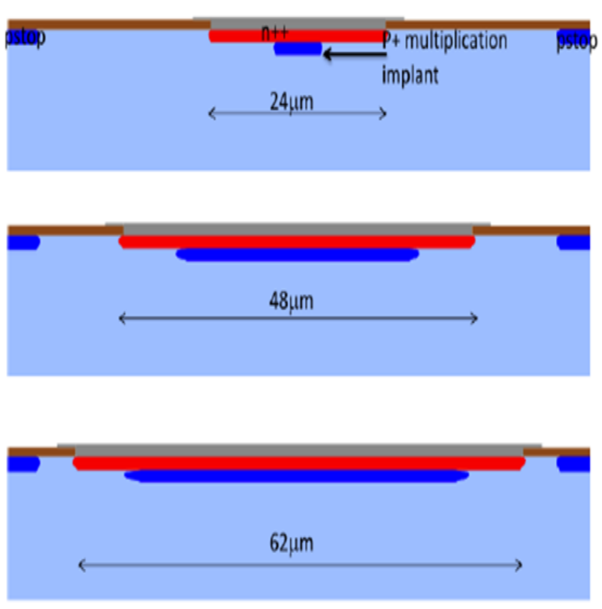


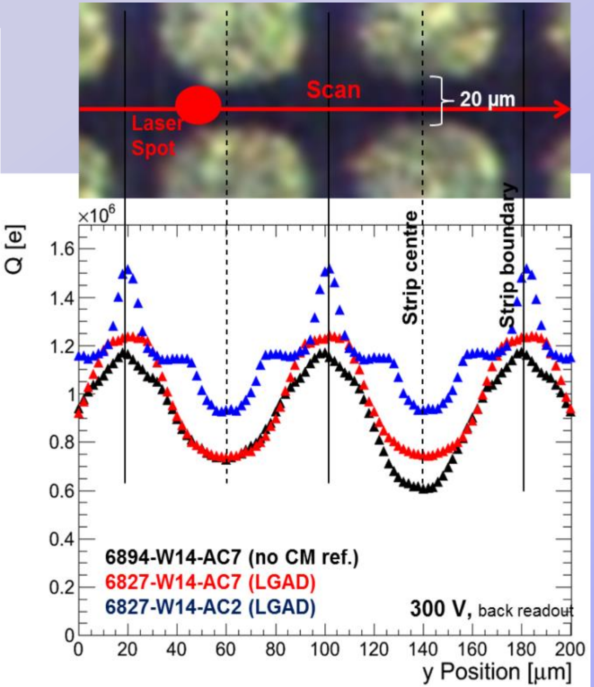


Pixels:

First measurement of LGAD pixels (FE-I3 and FE-I4). Collected charge with ^{90}Sr for LGAD and no-gain reference same up to 300V within calibration uncertainty.

No multiplication





Strips

Scan with focussed IR laser across strips with different p+ and n+ widths. Same charge measured (within laser intensity variations) for LGAD strips and no-gain reference up to 600 V.

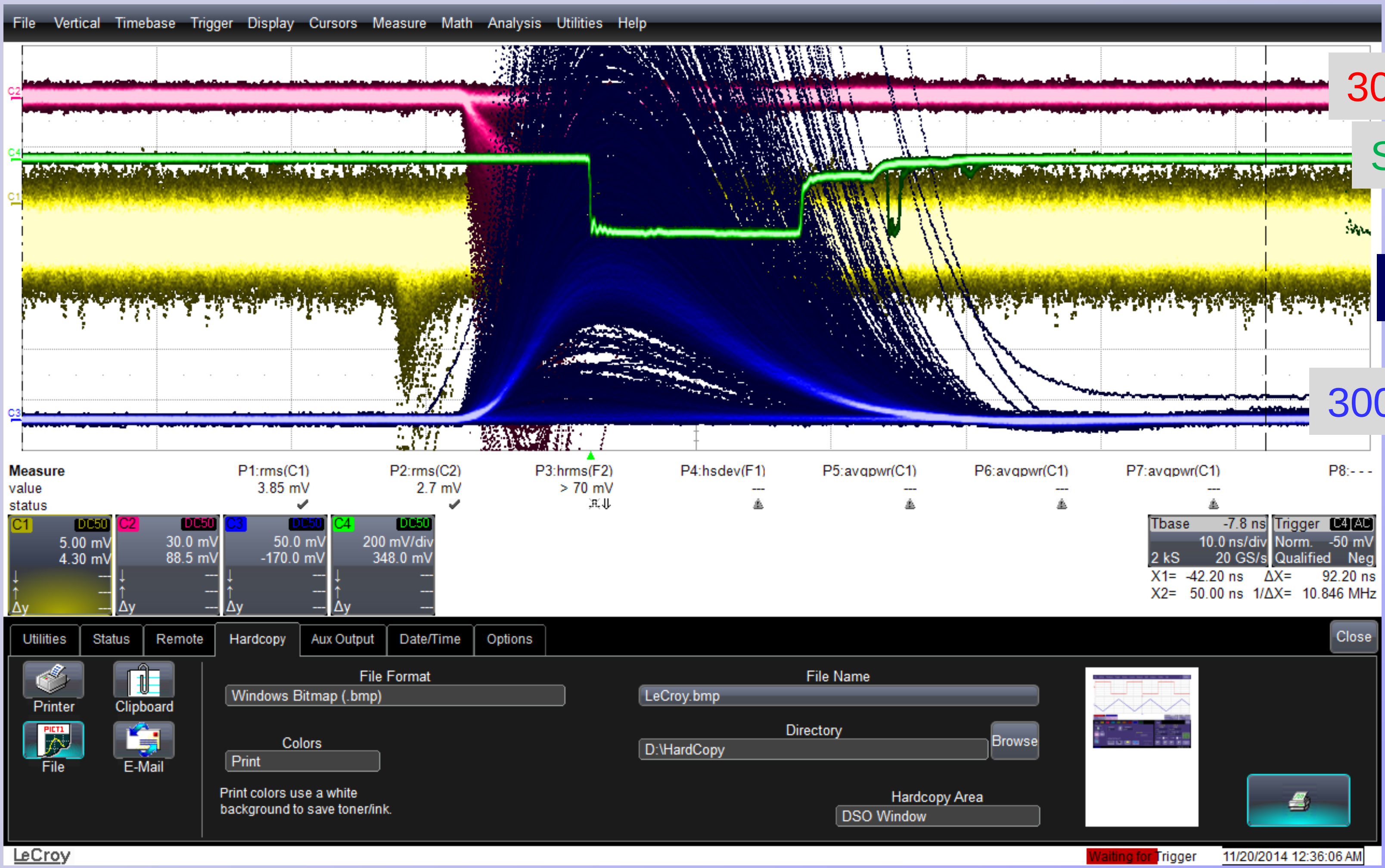
No multiplication observed in center of p+ layer, or at implant edges.

E. Cavallaro, et al., RESMDD14,
Florence (Italy), Oct. 2014

Last night in the H6 Beam Line….

2 300FZ LGAD (run 6474) with Broad Band (BB) amp & Charge Sensitive. Amp CSA

50um epi LGAD (run 6827) with BB



Measure: P1:rms(C1) value 3.85 mV; P2:rms(C2) value 2.7 mV; P3:hrms(F2) value > 70 mV; P4:hsdev(F1) ---; P5:avgpwr(C1) ---; P6:avgpwr(C1) ---; P7:avgpwr(C1) ---; P8:- - -

C1 DC50 5.00 mV 4.30 mV

C2 DC50 30.0 mV 88.5 mV

C3 DC50 50.0 mV -170.0 mV

C4 DC50 200 mV/div 348.0 mV

Tbase -7.8 ns 10.0 ns/div 2 kS 20 GS/s

Trigger C4 AC Norm. -50 mV Qualified Neg

X1= -42.20 ns ΔX= 92.20 ns

X2= 50.00 ns 1/ΔX= 10.846 MHz

File Format: Windows Bitmap (.bmp)

File Name: LeCroy.bmp

Colors: Print

Directory: D:\HardCopy

Print colors use a white background to save toner/ink.

Hardcopy Area: DSO Window

Waiting for Trigger 11/20/2014 12:36:06 AM

300 FZ BB

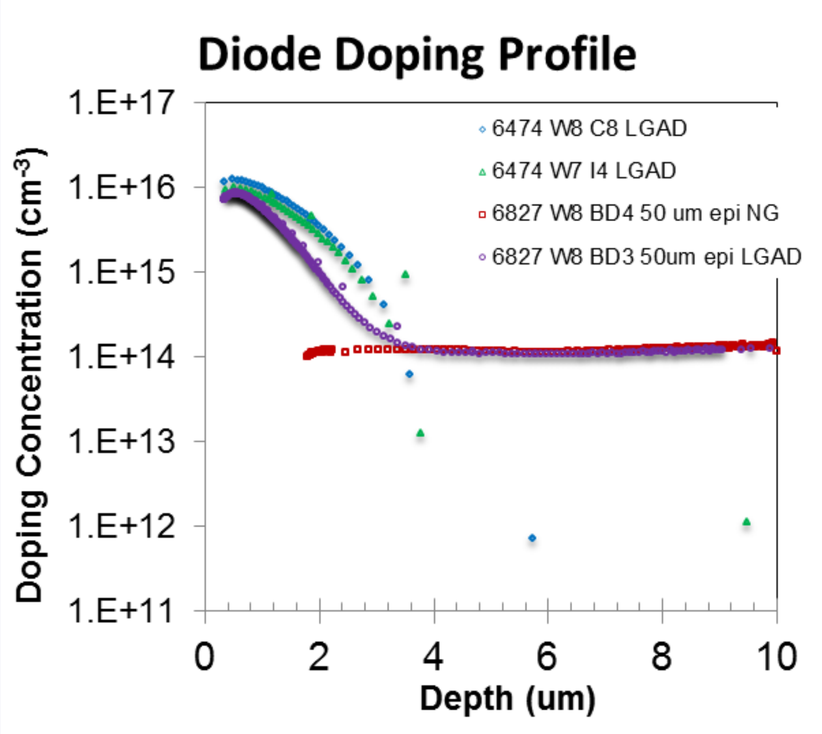
SiPM Trigger

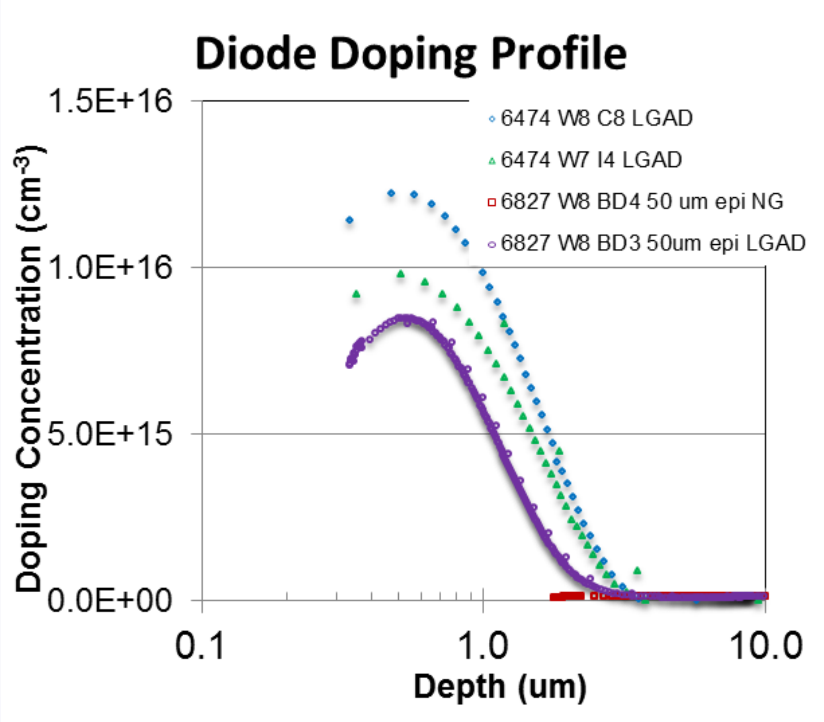
50um epi

300 FZ CSA

Hartmut F.-W. Sadrozinski, thin LGAD, 25th RD50, Nov 2014

Doping Density Profile (C-V)

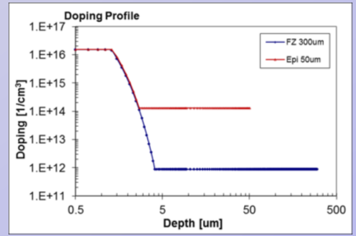


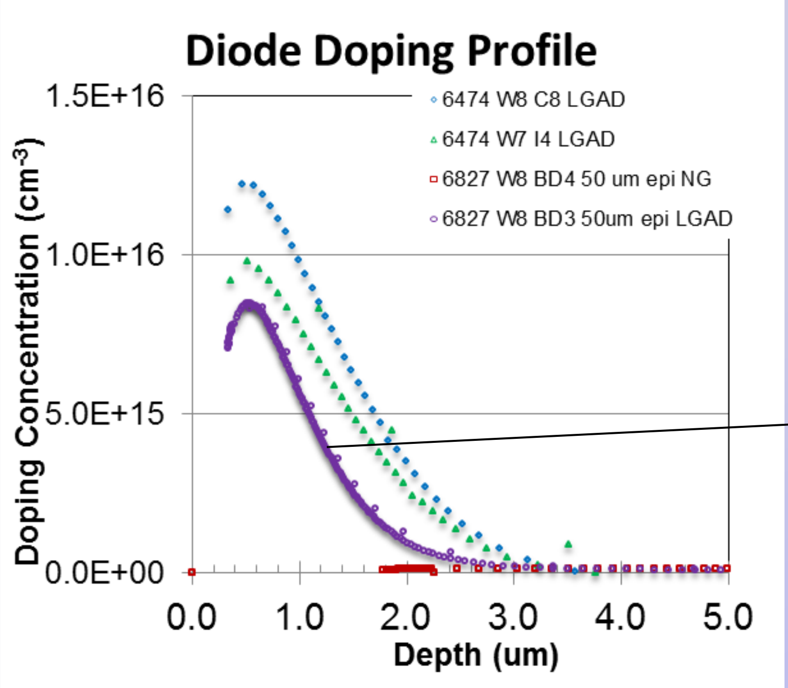


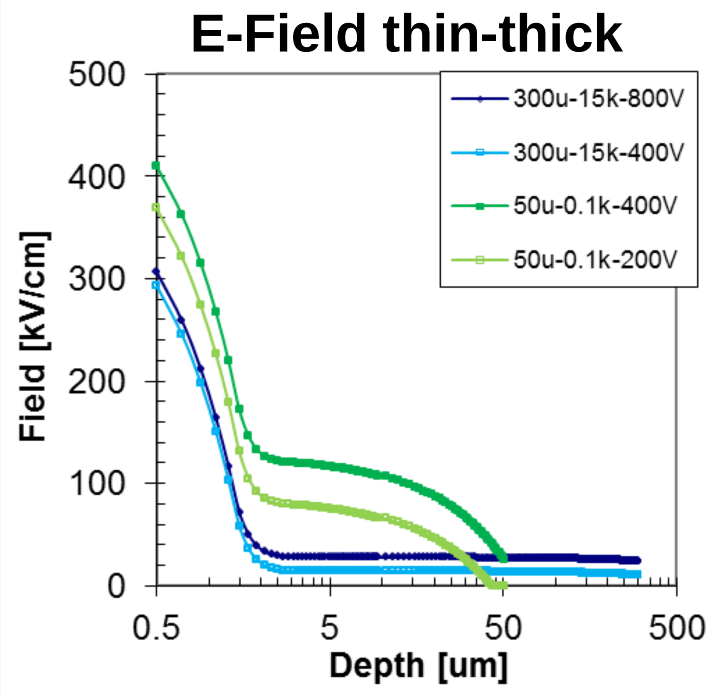
Device	Voltage Lag [V]	N_{max} [cm^{-3}]	N_{Bulk} [cm^{-3}]	Gain (400V)
6474 W8 C8 FZ	35	1.2e16	1 e12	8
6474 W7 I4 FZ	29	1.0e16	1.e12	2.5
6827 W13 300um FZ	14	0.8e16	1.e12	1
6827 W8 50um epi (gain)	14	0.8e16	1.1e14	1.4-2
6827 W8 50um epi (no-gain)	< 1	7e13	1.1e14	1

E-Field in thin LGAD

Run 6827 has 50um epi LGAD with gain, but 300um FZ LGAD with no gain with the same doping profile of the p-layer.
The evaluation of the electric field shows that the thin sensors have a much larger E-field and thus charge multiplication than thick detectors.



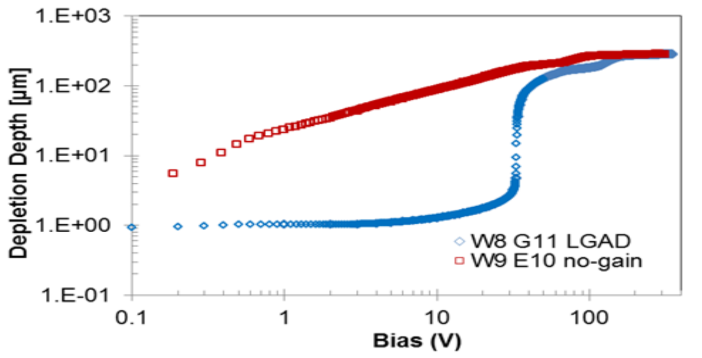




Thin sensors have a larger bias voltage dependence of the field, permitting the multiplication to be set largely by the bias voltage instead of mainly by the doping profile as in thick sensors.

Thin LGAD have more “compact” fields!

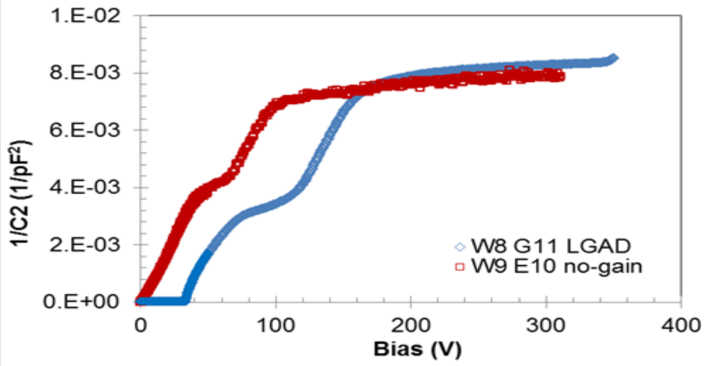
Doping Concentration from C-V



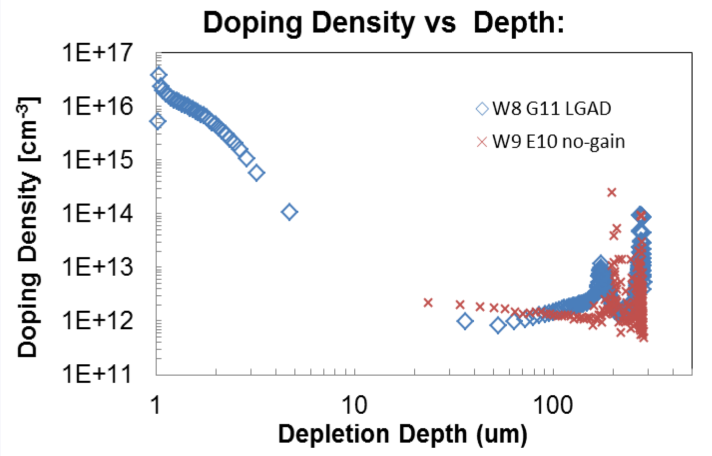
Depletion depth $x = A / C$

shows the voltage “lag” for the LGAD diode.

Voltage dependence of depletion depth x permits conversion of capacitance C(V) -> C(x)
doping density N(V) -> N(x)



$1/C^2$ shows a voltage “lag” for the depletion of the p+ layer responsible for multiplication.

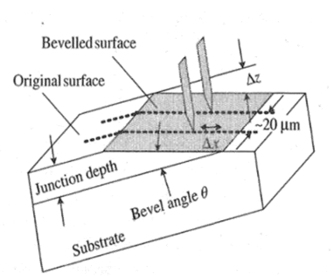


$$N = \frac{2}{\frac{d(1/C^2)}{dV}} \bullet \frac{1}{\varepsilon q A^2}$$

Doping density profile shows the p+ layer at shallow depth, and the ~10kΩ-cm FZ bulk.

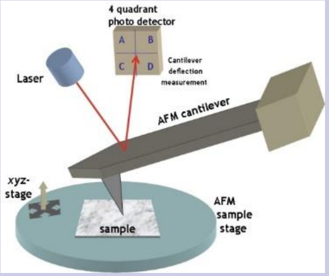
Doping Profile Measurements

Available methods

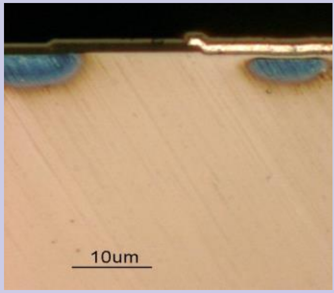


Spreading Resistance Profiling

LAL Pixel Group
Trento workshop 2014
(Vangelis talk)

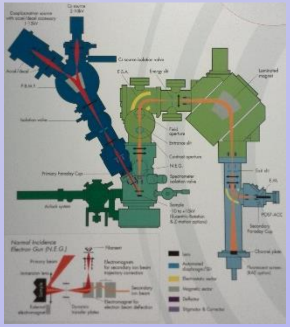


Conductive Atomic Force Microscopy



Micro-section + Etch
Salvador Hidalgo, 22nd RD50
see Marta's talk

SiMS
Secondary Ion Mass Spectroscopy



Terahertz Imaging
"Terahertz imaging of silicon wafers"
M. Herrmann at al,
JAP 91,3, 1 (2002)

XPS (ESCA)
X-ray photoelectron spectroscopy

C-V
(used here)

Question: Method applicable for our range :
$N = 10^{12} - 10^{17}\ cm^{-3}$?

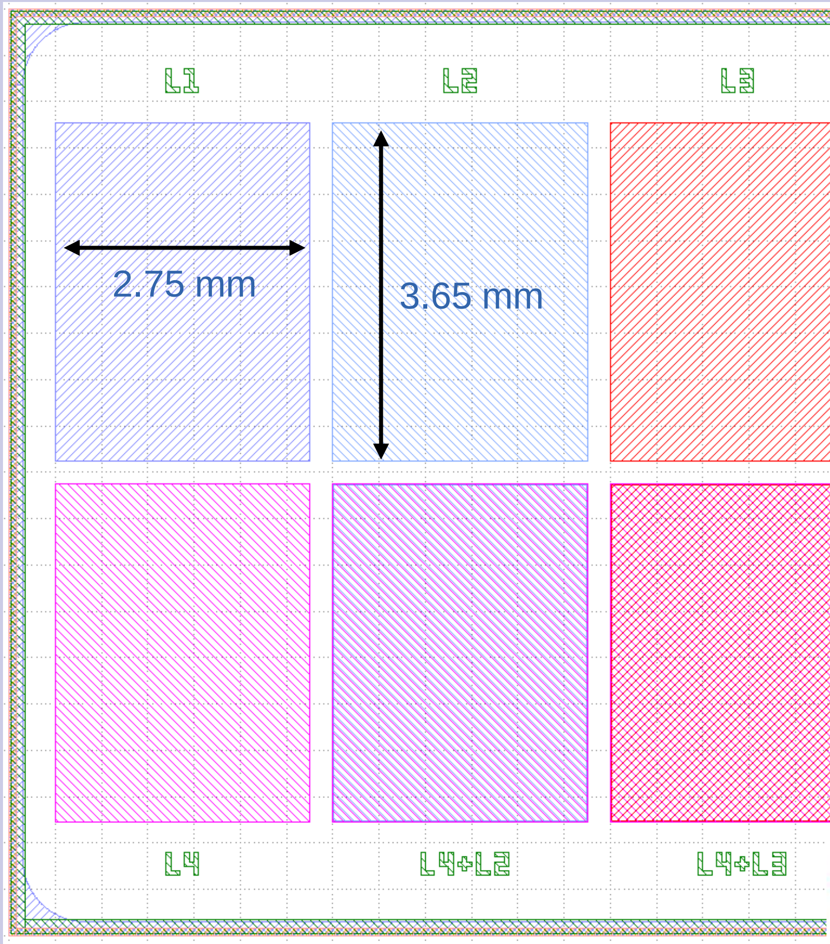
Measuring the Doping Profile in Low-Gain Avalanche Detectors LGAD

Methods envisioned:

1)	Capacitance – Voltage (C-V):	UC Santa Cruz, Hartmut Sadrozinski
2)	Mechanical micro-section + stain:	CNM Barcelona, Salvator Hidalgo
3)	Secondary Ion Mass Spectroscopy (SIM)::	LAL Orsay, Abdenour Lounis
4)	X-Ray Photoelectric Spectroscopy (XPS, ESCA):	LAL Orsay, Abdenour Lounis
5)	Spreading Resistance Profiling (SRP):	LAL Orsay, Abdenour Lounis
6)	Conductive Atomic Force Microscopy(CAFM):	LAL Orsay, Abdenour Lounis
7)	Terahertz Imaging:	Fraunhofer IPM, Georg v. Freymann

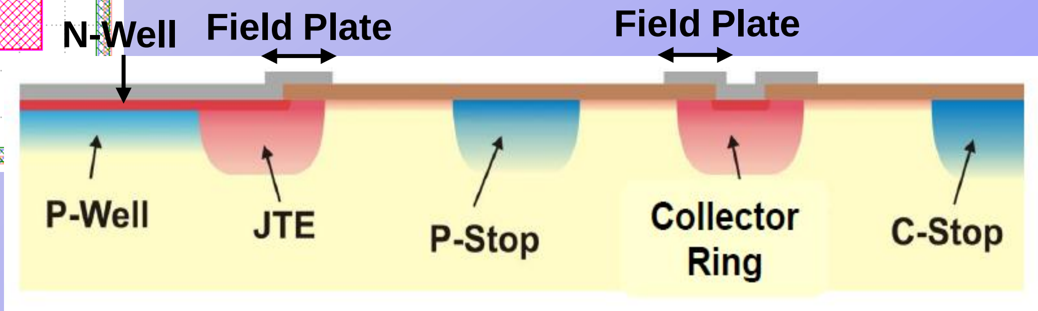
Preparation of RD50 Common Project;
LAL (Orsay), CNM (Barcelona), SCIPP (Santa Cruz), + ??

Test Structures in CNM RD50 Run



- L1 P-Stop, C-Stop Well
- L2 P-Well (P Multiplication)
- L3 JTE
- L4 N-Well
- L4 + L2 N-Well over P-Well
- L4 + L3 N-Well over JTE

The bevel angle α determines the depth d of probing:
α =1 deg d= 3mm*0.017 = 50 µm
α =4 deg d= 200 µm



Conclusions

- Thin LGAD promise to have good time resolution
- The low-resistance bulk of the thin epi LGAD in run 6827 works on pads, while segmented sensors brake down to early.
- The 300um FZ bulk in run 6827 allows high voltage on segmented LGAD, but no gain.
- Thin LGAD allow higher gain due to higher "compactness" of the electrical field.
- In addition, the E-field has a stronger bias dependence.
- Have started beam tests to evaluate time resolution

  (N. Cartiglia's talk ?)
- Simulation of gain depends on the knowledge of doping concentration: plan submission of a RD50 common project (LAL, CNM, UCSC: invitation to others to participate!