Innovative low material vertexing and tracking technologies

David Quirion, G. Pellegrini, S. Hidalgo, P. Fernández,
M. Baselga, D. Bassignana, M. Lozano (IMB-CNM)
I. Vila, F.J. Muñoz, M. Fernández, R. Jaramillo (IFCA)

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IMB-CNM facilities - Spanish research center for microelectronic

Clean Room

- 1.500 m2, class 100 to 10.000
- Micro- and Nano-fabrication technologies.

Processes

- 4'' complete
- 6'' partial

Available technologies:

- CMOS, BiCMOS, MCM-D,MEMS/NEMS,
- power devices
- Bump bonding packaging

Silicon micromachining

Laboratories

- Characterization and test
- Reverse engineering
- Simulation/CAD
- Mechanical workshop

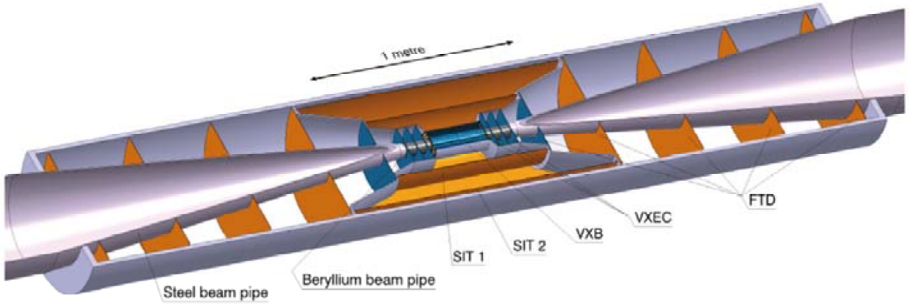
Research groups

- Power electronics
- Chemical sensors
- Bio-sensors
- Optical sensors
- Radiation sensors

CLIC requirements

Low material budget is key

Vertex and Tracker must be ultra-light



Strategy: To obtain the same (information) with less (material)

Two routes:

- Silicon sensors with low gain multiplication

Thinner sensor with same S/N

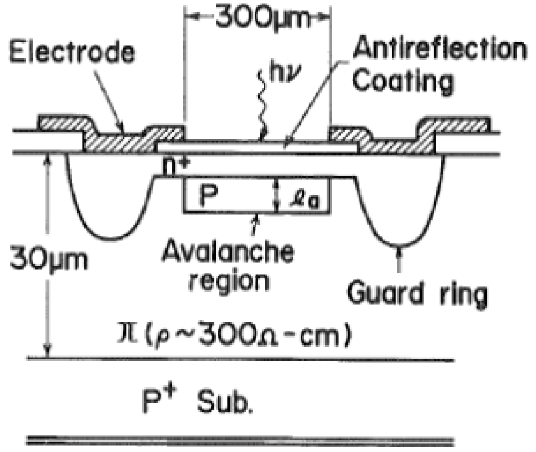
- Silicon microstrip sensors with resistive electrodes

2D positioning with low material budget

Low Gain Avalanche Detectors (LGAD)

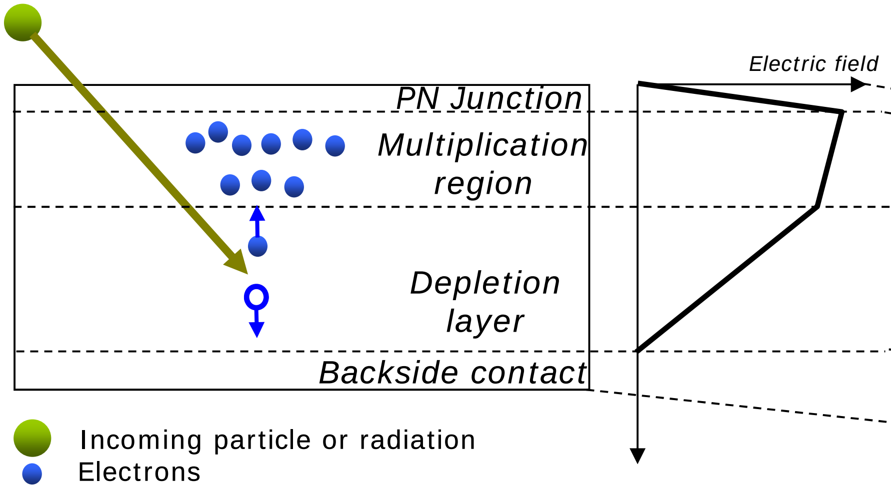
Thin sensors with multiplication:

- Low material budget
- Same S/N



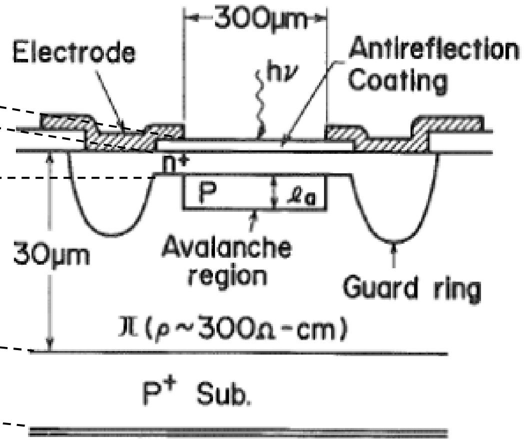
Charge multiplication in silicon detectors

Basic principle of charge multiplication



● Incoming particle or radiation
● Electrons
○ Holes

Structure of a silicon reach-through avalanche photodiode



T. Kaneda, Semicond. Semimetals 22D (1985) 247

Idea: Use multiplication to compensate for low signal due to thin sensor
(Sensors also with good time resolution)

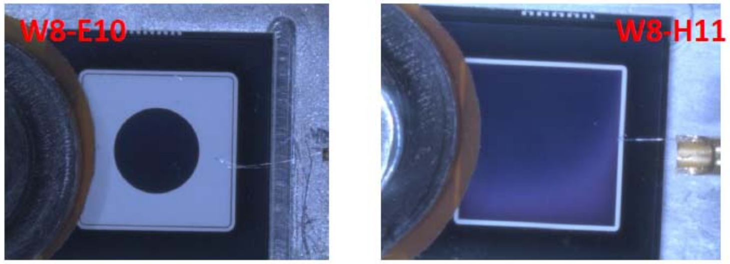
Signal = (depletion layer thickness) x (multiplication factor)

⇒ A 3-6 gain is enough to compensate for 50-100um sensors (standard: 300um)

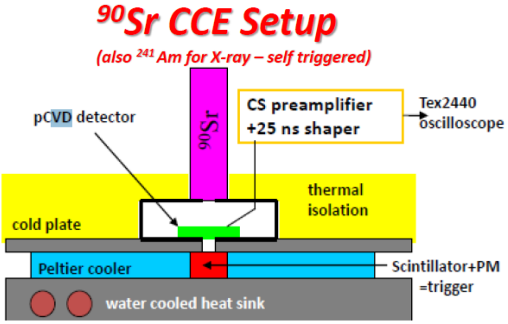
⇒ Low Gain Avalanche Detectors (LGAD)

- ⇒ Linear mode (proportional response)

Proof of principle: low gain avalanche pads detectors



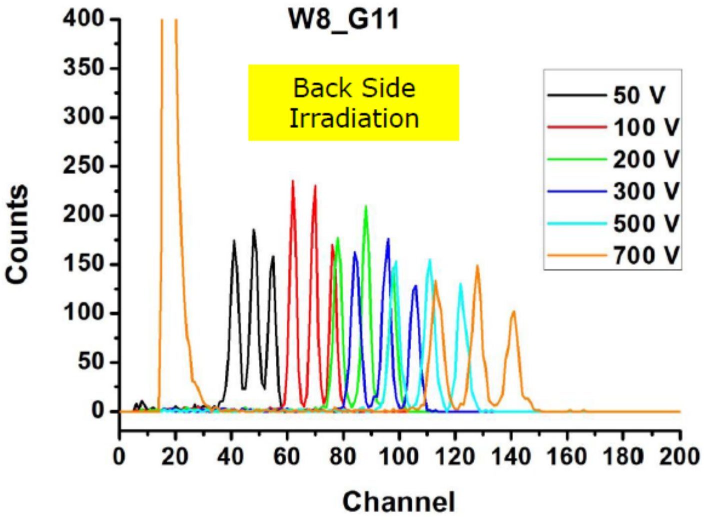
0.5x0.5mm^2, 300um thick pads

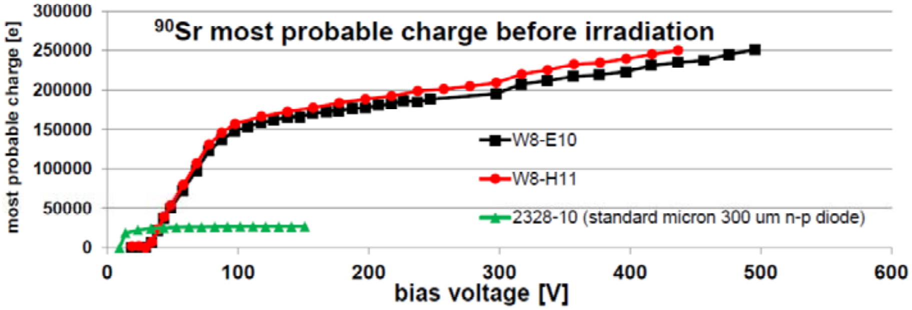

^{90}Sr CCE Setup

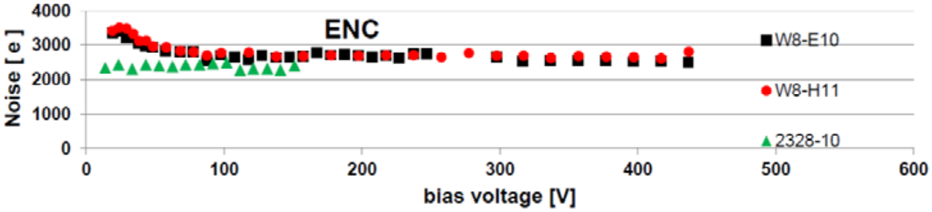
(also ^{241}Am for X-ray – self triggered)

CCE measurements performed by G. Kramberger (J. Stefan Institute)

Tri-alpha (^{239}Pu/^{241}Am/^{244}Cm) spectra







- ➢ Improvement of signal for a factor 8 at 300 V before irradiation
- ➢ No significant increase of noise – dominated by series noise

See S. Hidalgo’s and G: Kramberger’s talks at RD50 meeting at Albuquerque (2013)

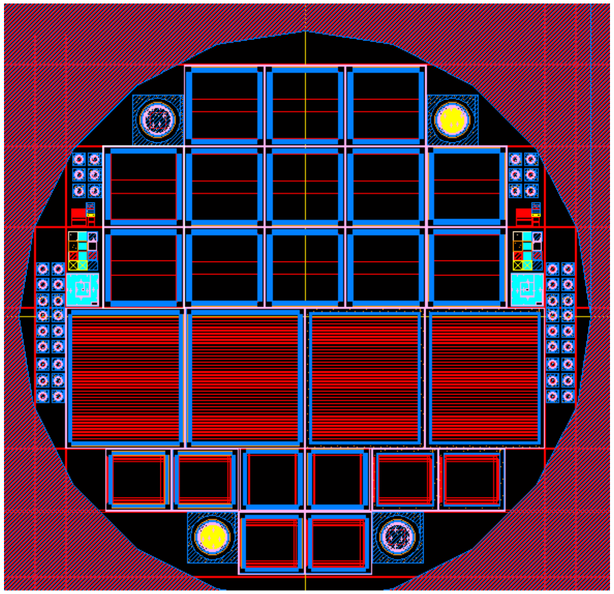
Low Gain Avalanche Detectors (LGAD)

RD50 project:

Fabrication of new p-type pixel detectors with enhanced multiplication effect in the n-type electrodes

Institutes participating in this project:

G. Pellegrini (IMB-CNM), G. Casse (Liverpool University), H. Sadrozinki (UCSC), S. Grinstein (IFAE), W. de Boer (KIT), I. Vila (IFCA), R. Bates (University Glasgow), M. Bruzzi (INFN Florence) M. Moll (CERN)

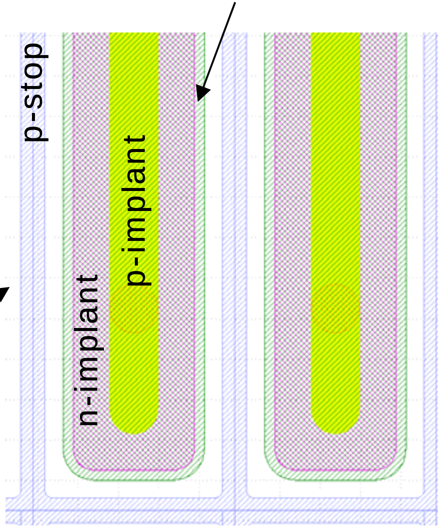


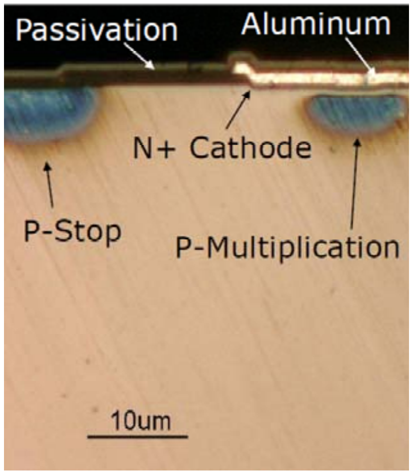
AC Microstrips

FE-I4 pixels

FE-I3 and CMS pixels

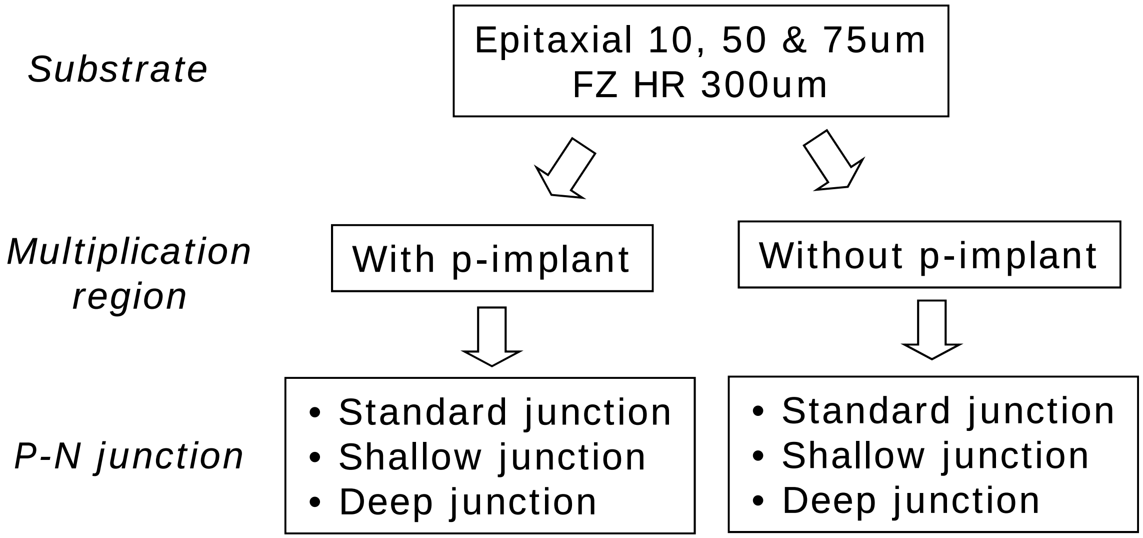
Metal overlap: 2.5um





See G. Pellegrini's talk at CLIC January meeting, S. Hidalgo's talk at RD50 meeting at Albuquerque (2013) and H. Sadrozinski, "Exploring charge multiplication for fast timing with silicon sensors" 20th RD50 Workshop, Bari (2012)

Low Gain Avalanche Detectors (LGAD): run



Substrate

Epitaxial 10, 50 & 75um
FZ HR 300um

Multiplication region

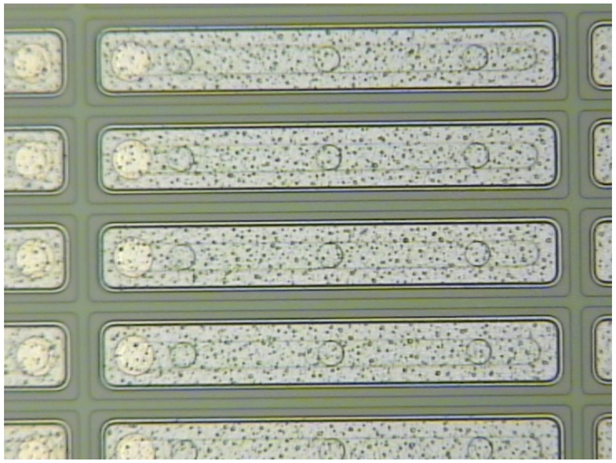
With p-implant

Without p-implant

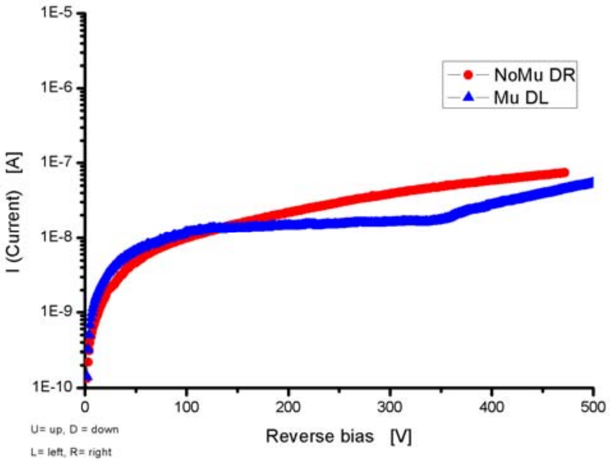
P-N junction

- Standard junction
- Shallow junction
- Deep junction

- Standard junction
- Shallow junction
- Deep junction



FE-I4 pixel sensor



AC Microstrip Epi 50um deep junction

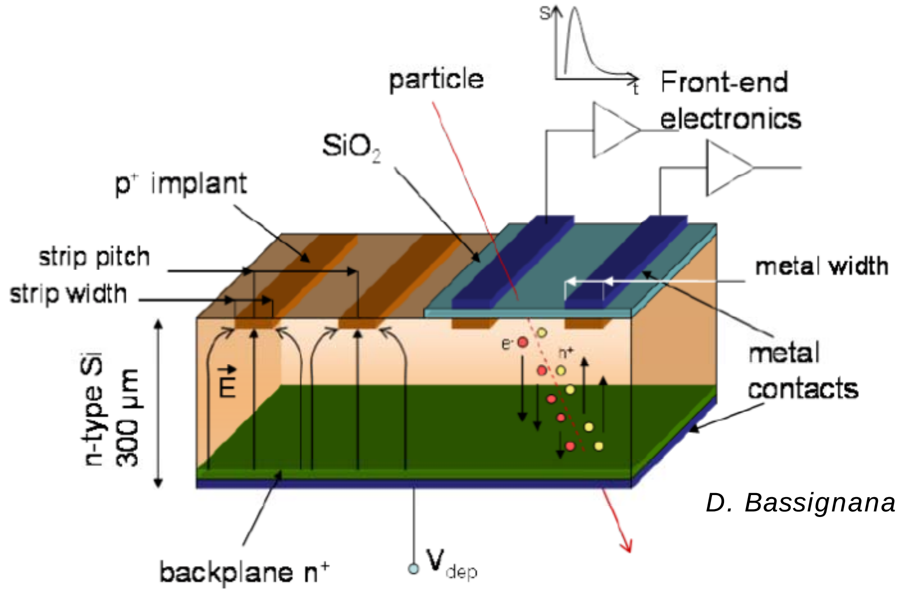
Run finished this summer.
Sensors currently characterized at UC Santa Cruz by M. Baselga (Ph.D. student – IMB-CNM)

See G. Pellegrini's talk at CLIC January meeting and
H. Sadrozinski, "Exploring charge multiplication for fast timing with silicon sensors" 20th RD50 Workshop, Bari (2012)

Polysilicon resistive detectors

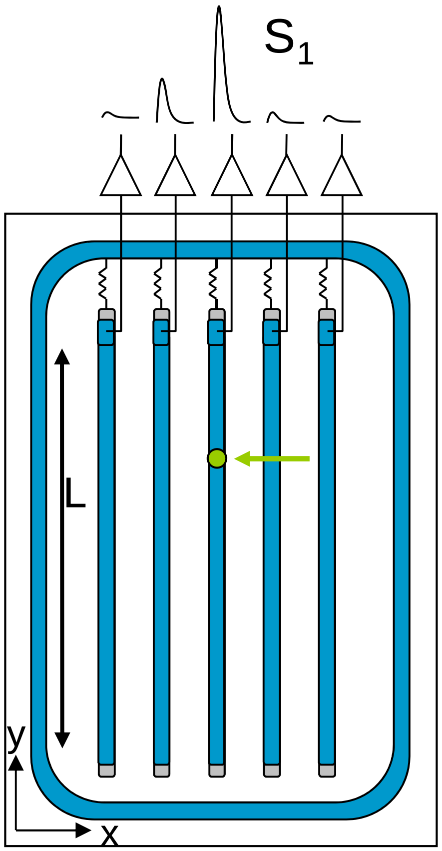
2D positioning with microstrip sensors:

- Low cost
- Low material budget



D. Bassignana

Polysilicon resistive detectors: concept

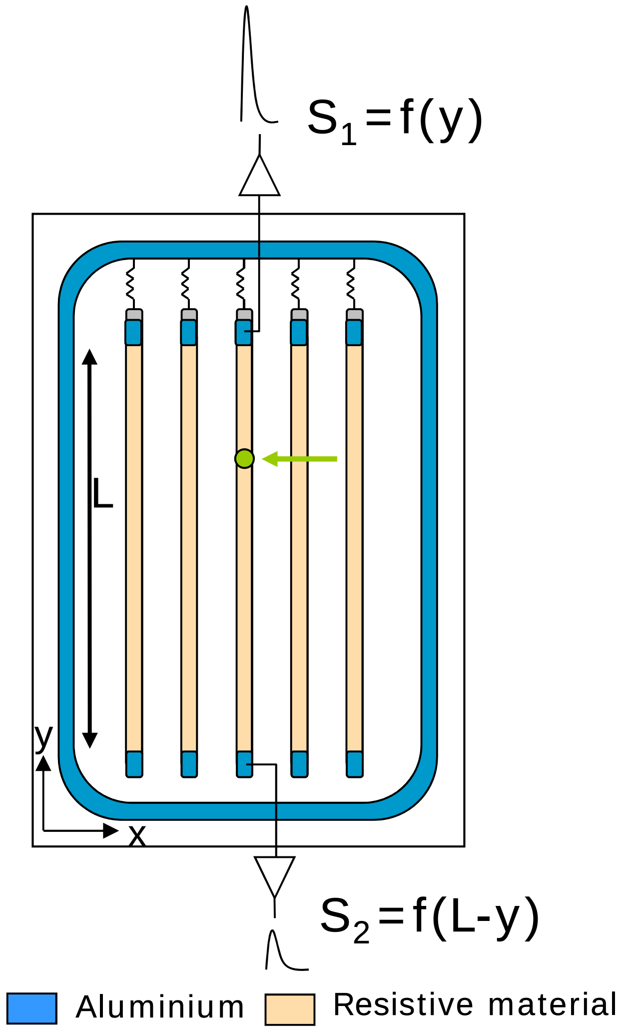


Simple single-side AC-coupled microstrip detectors

X-coordinate: cluster-finding algorithms for strip detectors

🟦 Aluminium

Polysilicon resistive detectors: concept



Simple single-side AC-coupled microstrip detectors
with resistive coupling electrodes

X-coordinate: cluster-finding algorithms for strip detectors

Y-coordinate: resistive charge division method

$$\frac{y}{L} = \frac{A_2}{A_1 + A_2}$$

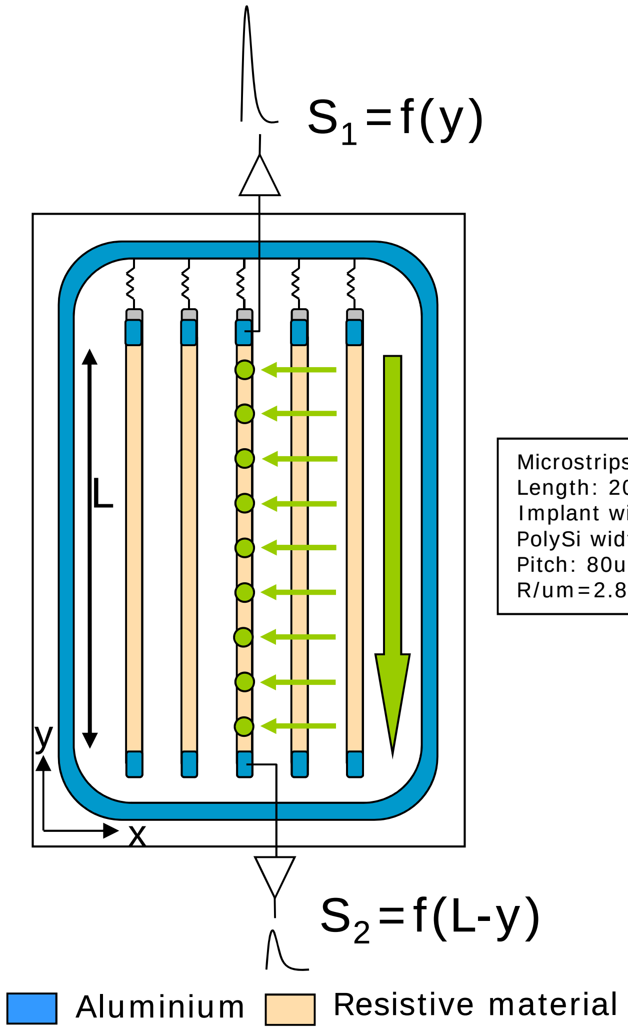
** Electrode resistance >> preamplifier impedance.
** Optimal shaping time (to reduce the ballistic deficit effect).

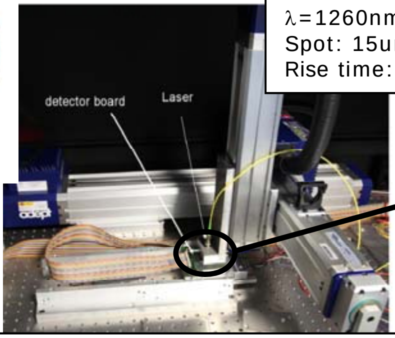
V. Radeka, IEEE Transaction on Nuclear Science NS-21 (1974) 51

Resistive material: highly doped polysilicon

Process:
- Standard single-side microstrip process (fully compatible with standard sensors – see below)
- No need for extra mask level (no extra cost)

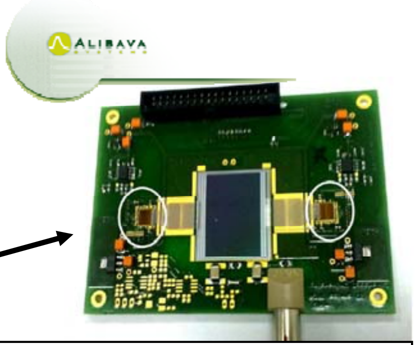
Polysilicon resistive detectors: Measurements





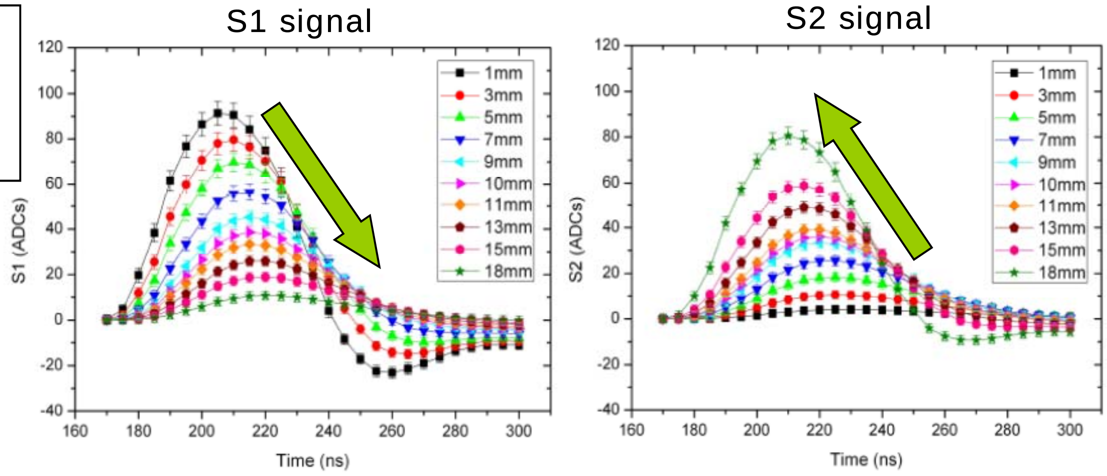
Pulsed DFB laser:
λ=1260nm
Spot: 15um
Rise time: 2ns

3D stage with 10um displacement accuracy



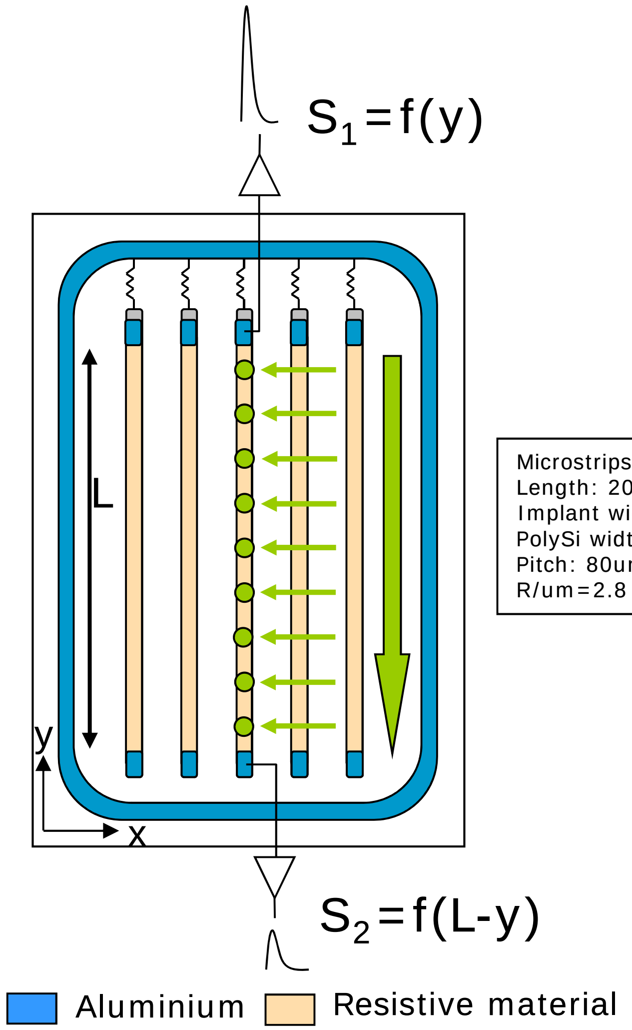
ALIBAVA DAQ system based on
Beetle analog readout:
256 channels
Peaking time: 25ns

Microstrips:
Length: 20mm
Implant width: 20um
PolySi width: 30um
Pitch: 80um
R/um=2.8 & 12.2Ω/um



D. Bassignana et al., J. Inst. 7 (2012) P02005 and D. Bassignana's talk at PSD9 (2011)

Polysilicon resistive detectors: Measurements



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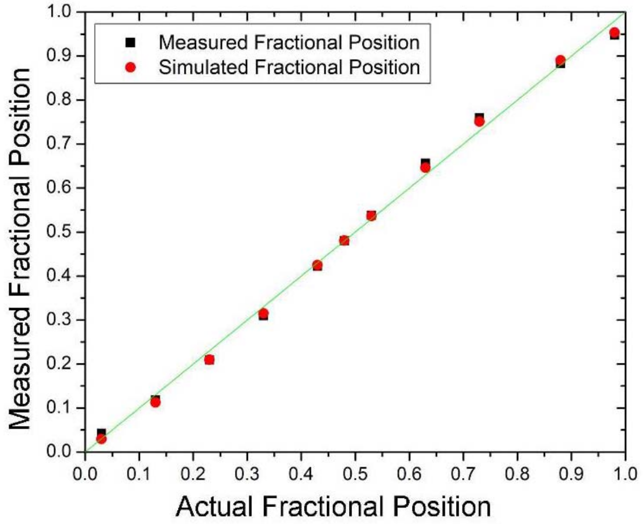


$$\frac{y}{L} = \frac{A_2}{A_1 + A_2}$$

Good linearity and agreement with Spice simulation

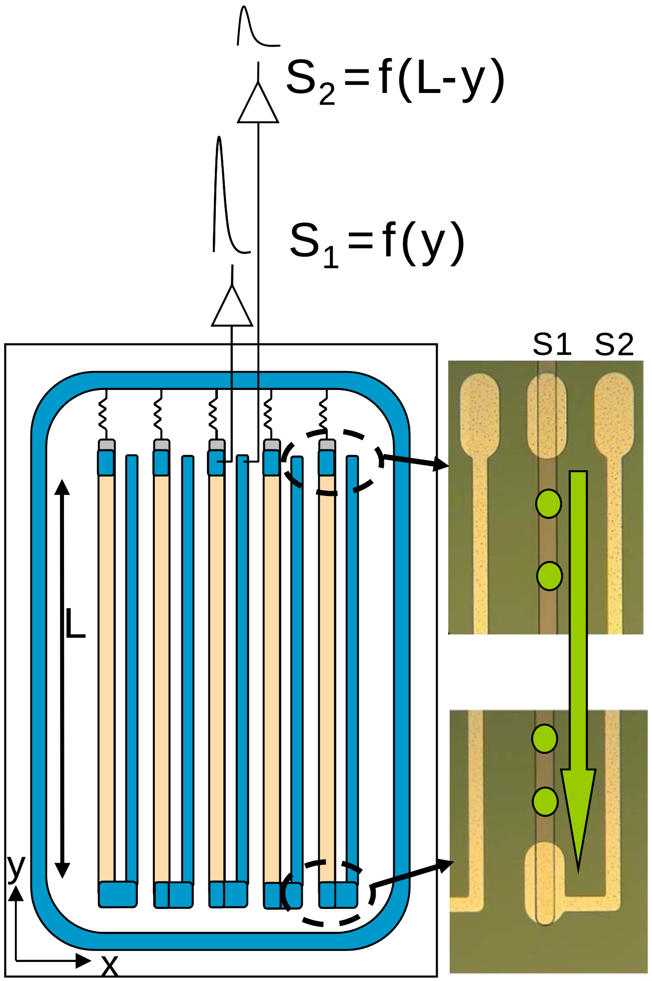
Longitudinal spatial resolution for 6 MIPs signal
1,1-1,2% L ⇒ 220-240um
(Dependence on R/um also)

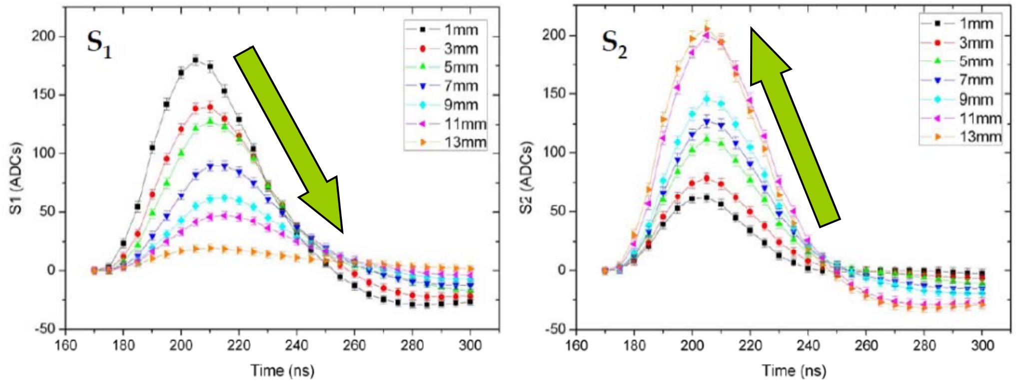
D. Bassignana et al., J. Inst. 7 (2012) P02005 and D. Bassignana's talk at PSD9 (2011)
See also See G. Pellegrini's talk at CLIC January meeting

Polysilicon resistive detectors: integrated routing

Integrated routing to facilitate connection to electronics

Possibility of both signal processing on same electronics



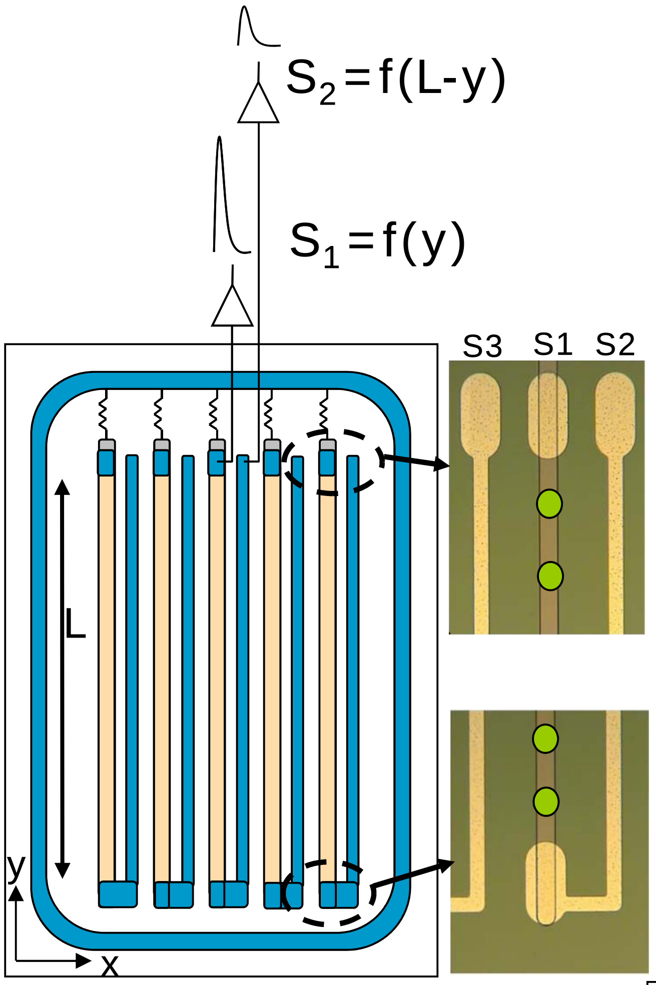


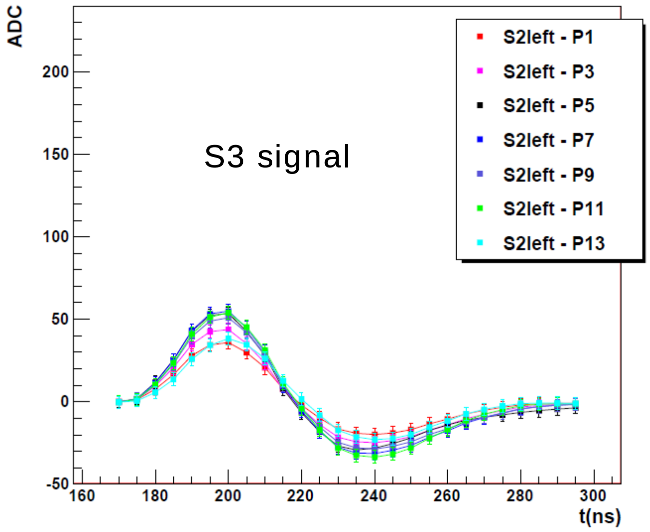
D. Bassignana et al., J. Inst. 7 (2012) C04008

Microstrips:
Length: 14mm
Width: 20um
Pitch: 160um
R/um=20Ω/um

🟦 Aluminium 🟨 Resistive material

Polysilicon resistive detectors: integrated routing





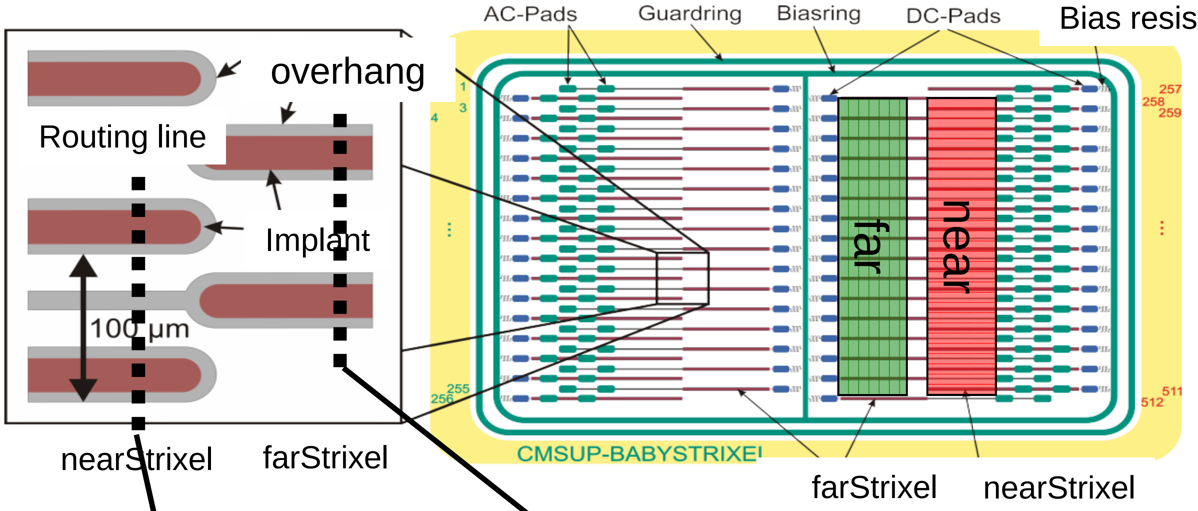
- Observation of an induced (bipolar) signal on metallic routing NOT connected to the "illuminated" strip.
- It superposes to "direct signal" propagated through polysilicon electrode and metal routing.

Microstrips:
Length: 14mm
Width: 20um
Pitch: 160um
R/um=20Ω/um

🟦 Aluminium 🟧 Resistive material

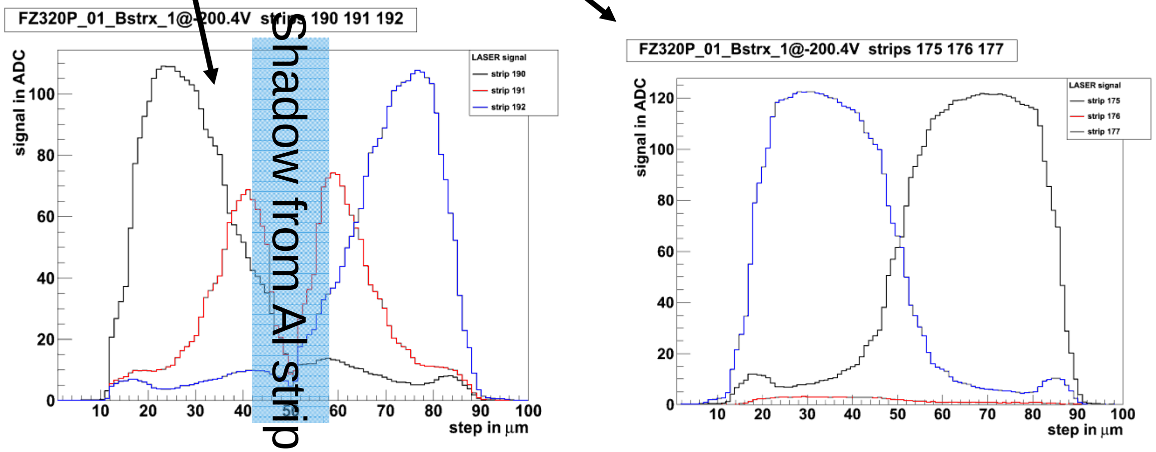
Polysilicon resistive detectors: FOSTER common issues

FOSTER sensors – A. Dierlamm, M. Strelzyk, M. Printz



FOur-fold segmented **ST**rip sensors with **E**dge **R**eadout (FOSTER)

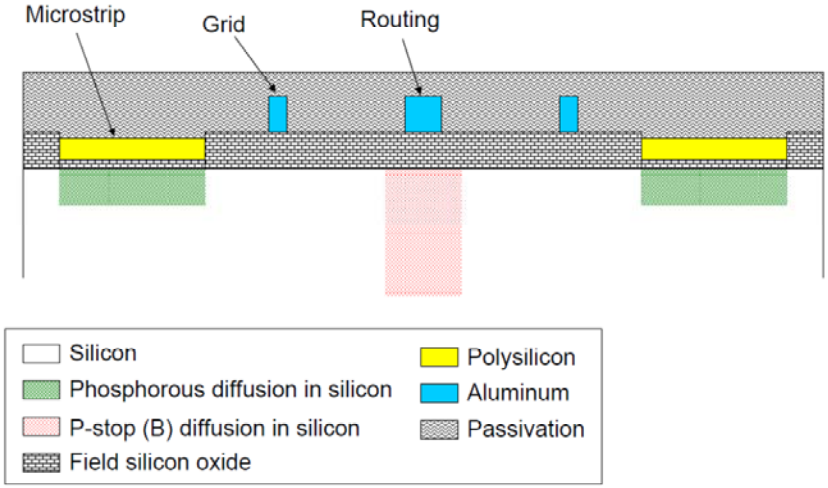
High granularity for HL-LHC upgrade



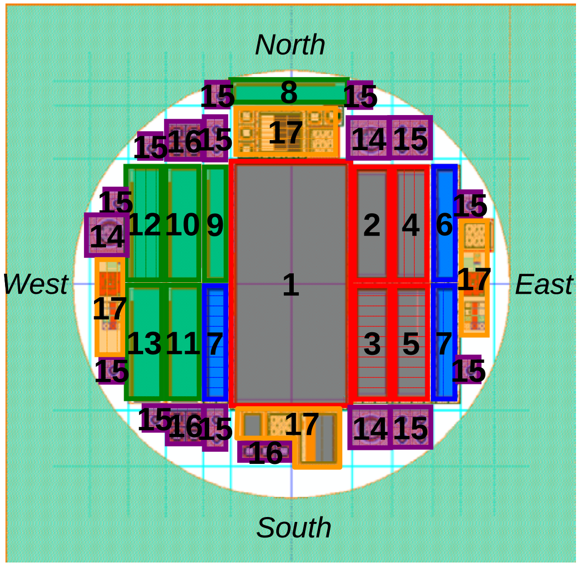
Observation of an induced signal on metal routing line

Polysilicon resistive detectors and FOSTER common run

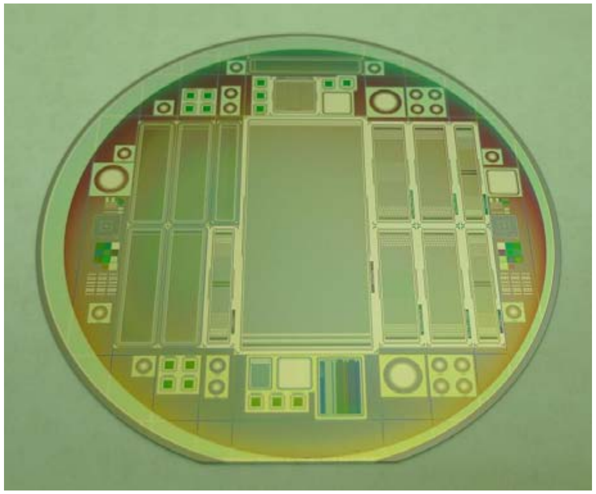
Idea: to implement a metal grid line to close the electric field lines and limit the crosstalk between polysilicon contact and routing line



Run parameters:
- Common mask
- n-on-p technology with p-stop
- ONO coupling



Ref.	Name	Qty
1	**Big CMS sensor**	**1**
2-5	**Small CMS sensors**	**4**
6-7	FOSTER	3
8-13	New polySi sensors	6
14-16	Pads	34
17	Test structures	-



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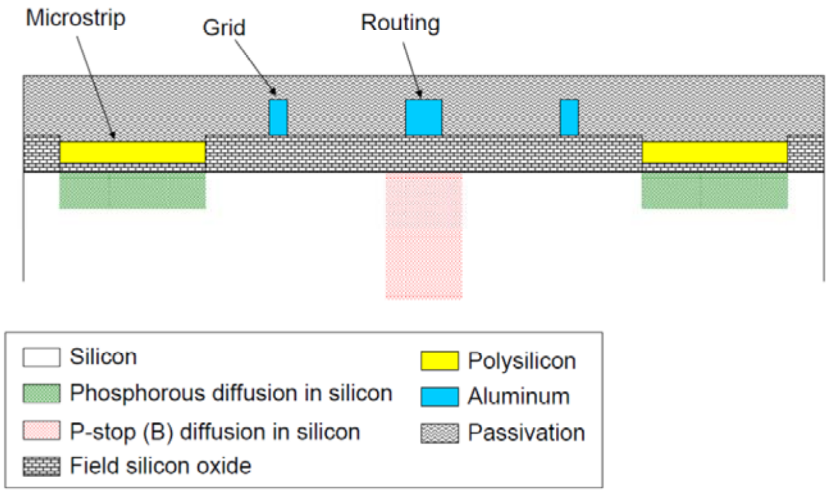
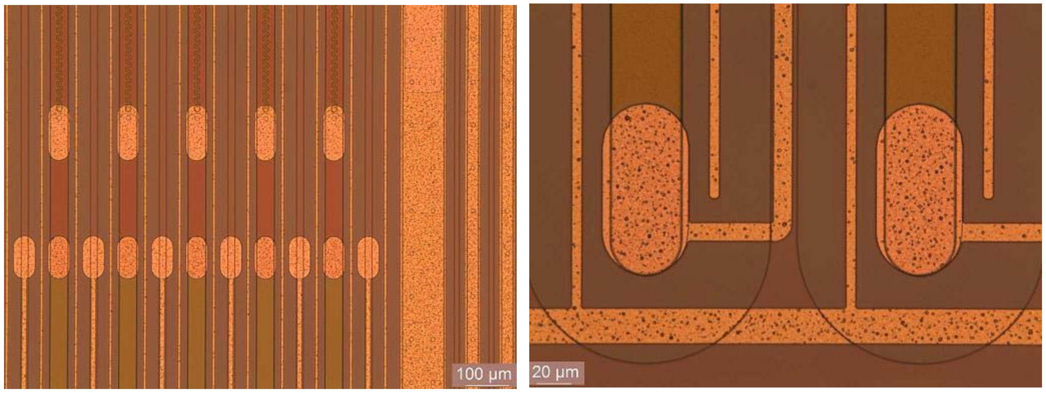
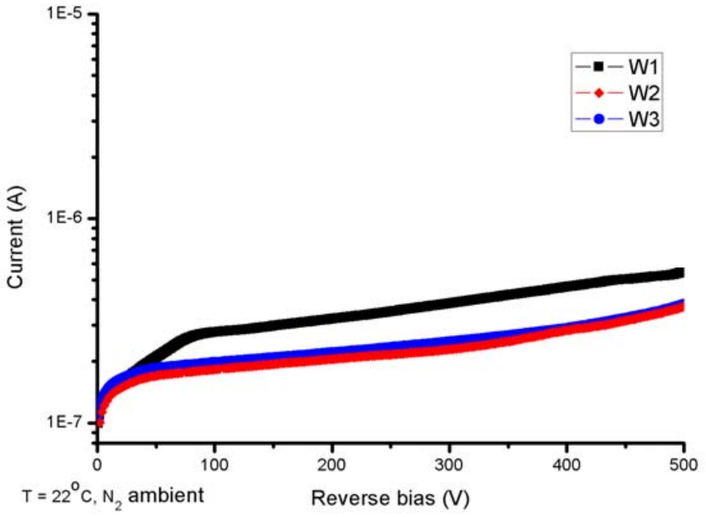


Microstrips:
Length: 22mm
Width: 20um
Pitch: 80um





Run finished this summer
Measurements to come…

Conclusion

In order to fulfill CLIC requirements for ultra-light Si sensors, we are developing and studying:

- Sensors with charge multiplication with moderate gain (within RD50 collaboration)
- Single side microstrip detector 2D position-sensitive with AC coupled resistive electrodes and integrated routing

Combining different technologies we aim at the ideal detectors: thin, ultra fast, high S/N and 2D with a low material budget