Development of a novel 2D position-sensitive semiconductor detector concept

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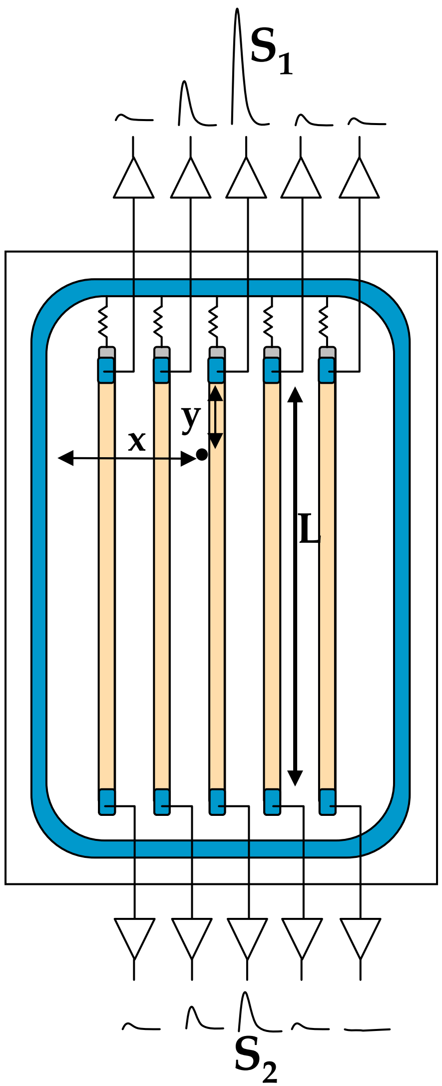
Outline

- New detectors concept
- Simulation Models and results
- First prototypes
- Second prototypes
- Conclusions

New detectors concept

Simple single-sided AC-coupled microstrip detectors with resistive coupling electrodes.



- X-coordinate: charge sharing between neighbouring strips*.
- Y-coordinate: Resistive charge division method.

Resistive material

Aluminum

✓ Electrode resistance >> preamplifier impedance.

✓ Optimal shaping time (to reduce the ballistic deficit effect).

$S_1=f(y)$

$S_2=f(L-y)$

$$\frac{y}{L} = \frac{S_2}{S_1+S_2}$$

Resistive electrodes uncoupled from the diode structures of the detector.

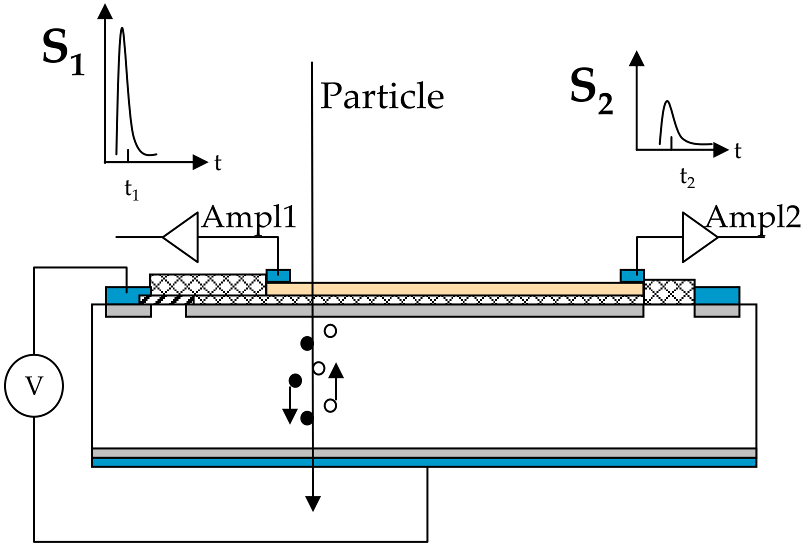
** V. Radeka, IEEE Transaction on Nuclear Science NS-21 (1974) 51

Resistive charge division in microstrip detectors

Resistive electrodes represent diffusive RC lines.

- Signal amplitude attenuation during propagation towards the preamplifier.
  - $R_{electrode}$ fixed: longer propagation ➡ smaller signal amplitude.
  - Electrodes length fixed: higher $R_{electrode}$ ➡ smaller signal amplitude.

- Rise time of the propagating signal increases the further the pulse travels.
  - Non constant ballistic deficit effects (propagation length, $R_{electrode}$, shaping time).



We investigated the feasibility of this method by means of simulations and characterization of real proof-of-concept prototypes.

Simulation Models

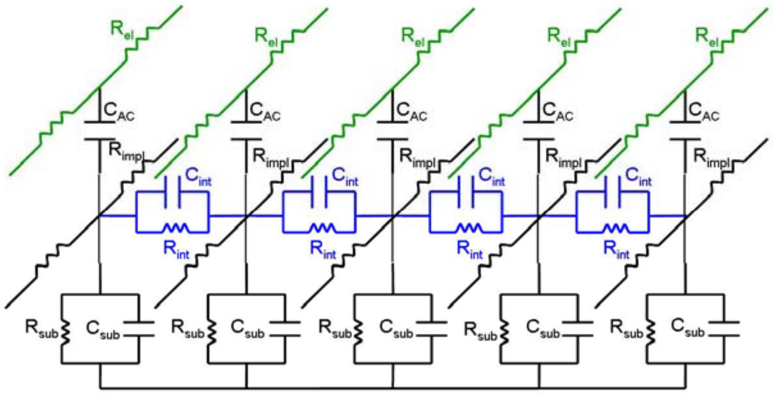
Framework: Virtuoso Spectre by Cadence.

(2009) Detector (p^+-on-n) ***

***N. Bacchetta et al. , IEEE Transaction on Nuclear Science, VOL. 43, NO. 3, JUNE 1996.

56 (or 80) cells 250 μm long

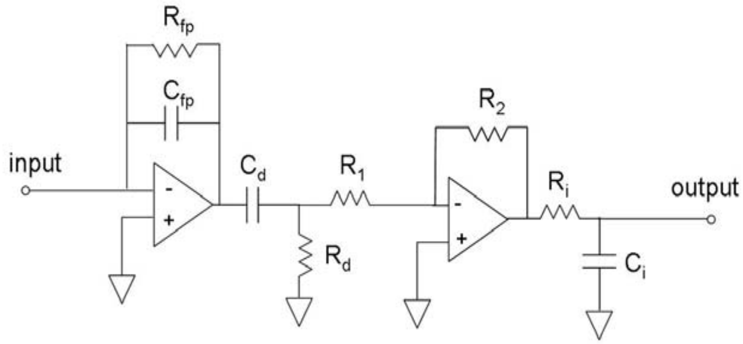
- five strips 14 (or 20) mm long (R_{impl}, C_{AC}, R_{el}),
- C_{int}, R_{int},
- bulk (300 μm thick) representation (R_{sub}, C_{sub}).



The parameters values, as well as the number of cells, have been adapted to the results of the electrical characterization of the real prototypes.

(2011) Readout electronics

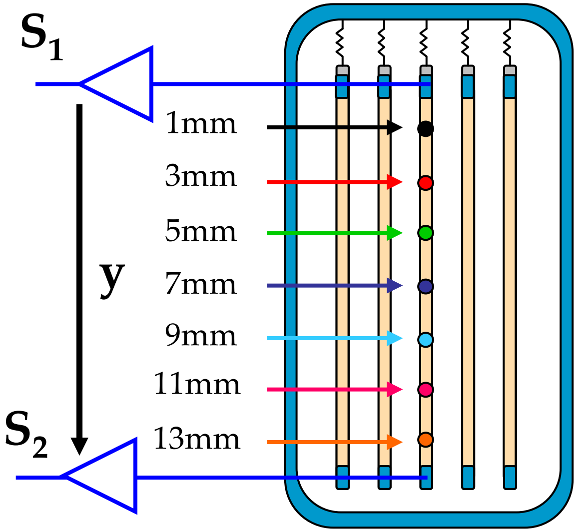
- ideal charge sensitive preamplifiers,
- 1ºorder CR-RC band-pass filter,
- Peaking time 25ns (Beetle chip- ALIBAVA DAQ system).

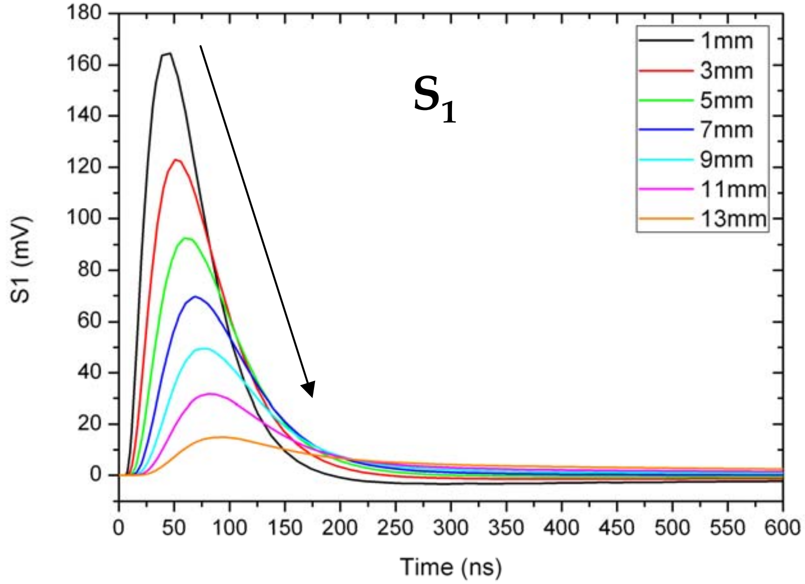


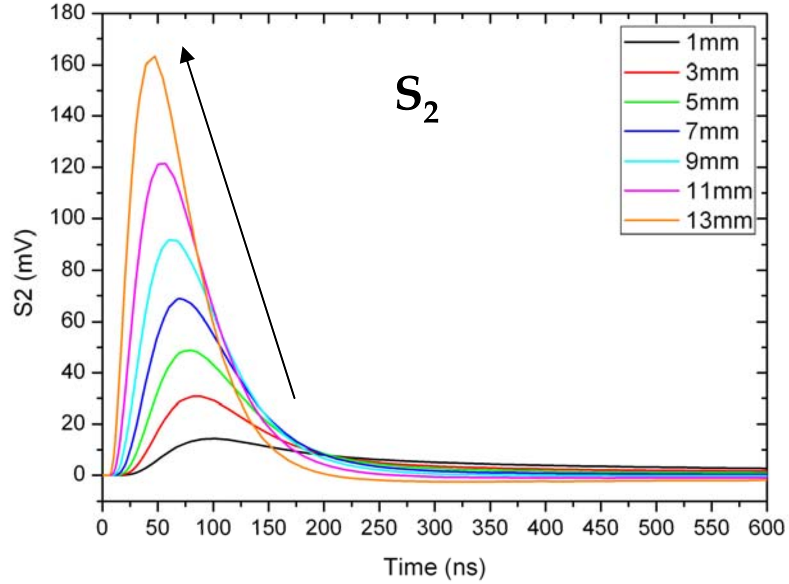
First prototypes: Simulation results

- Strips length 14mm (width 20 μm)
- Electrode resistance **$R_{electrode}$/μm =20 Ω/μm**

Current pulse injected by a pulse generator: shape and integrated charge equivalent to a MIP in 300 μm thick bulk (≈ 3.5 fC).

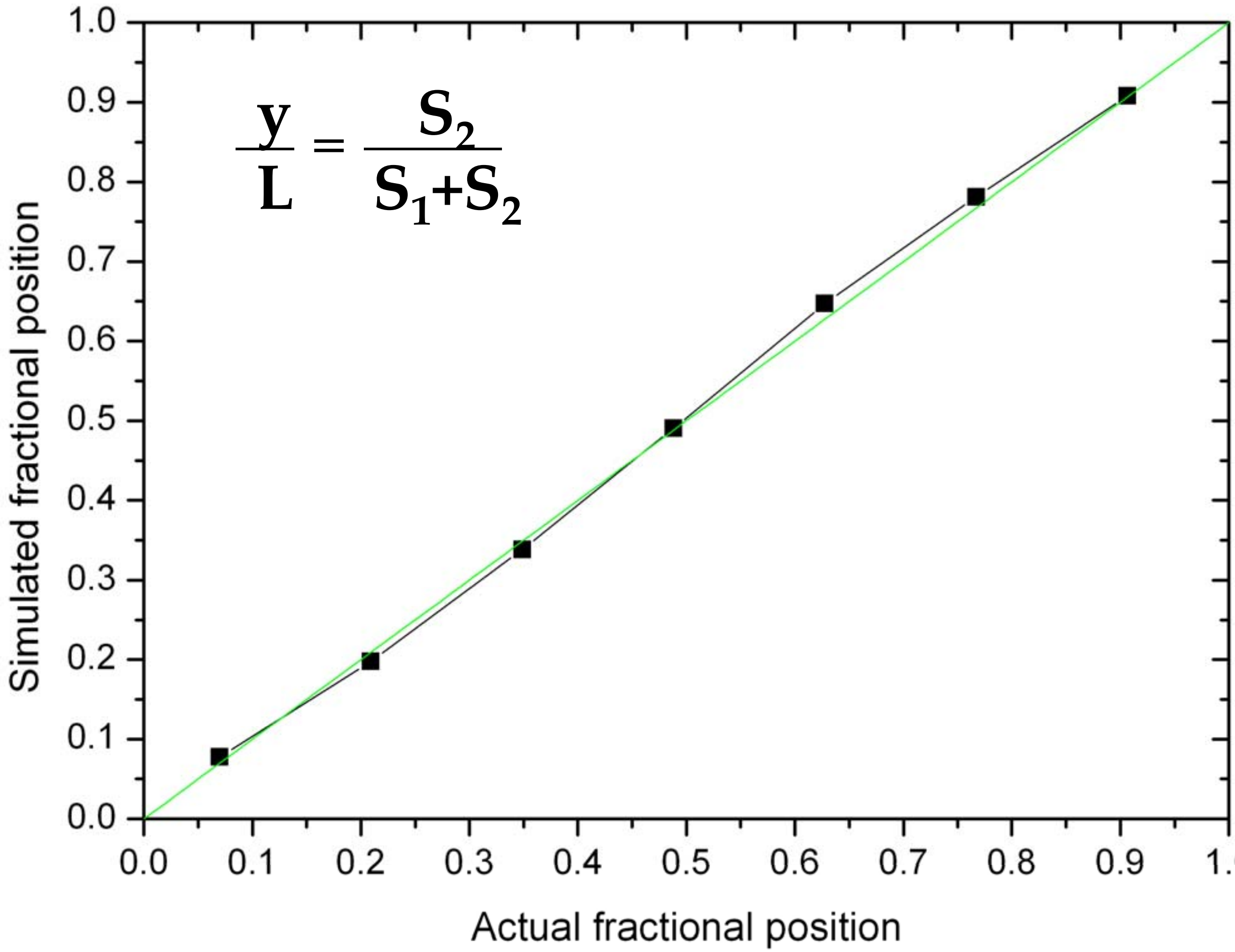






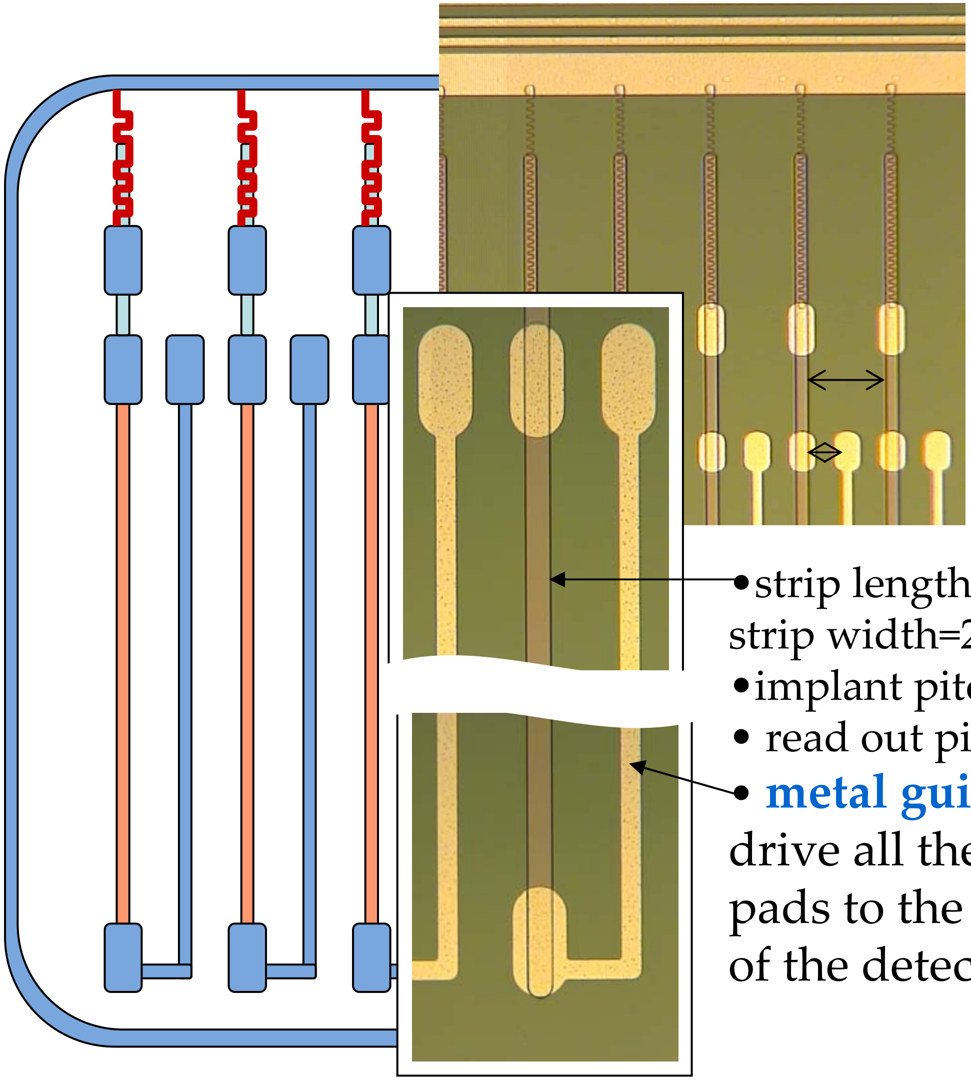
First prototypes: Simulation results (2)

Simulated fractional position (**S_2/S_1+S_2**) vs the actual one (**y/L**)
Ballistic deficit effects due to a non optimal shaping time.



First prototypes: design and fabrication

IMB-CNM facilities of Barcelona (2009-2010).



Fabrication run: standard technology for single-sided p⁺-on-n silicon microstrip detectors.

- strip length= 14 mm, strip width=20 μm.
- implant pitch= 160 μm
- read out pitch= 80 μm
- **metal guides** to drive all the contact pads to the same edge of the detector.

Resistive material = highly doped polysilicon.

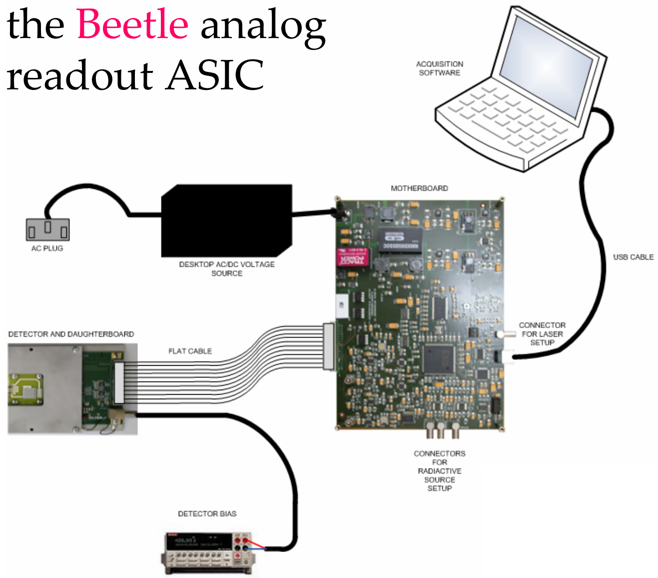
$R_{electrode}/\mu m = 20\ \Omega/\mu m$

Only one chip to read out the detector.

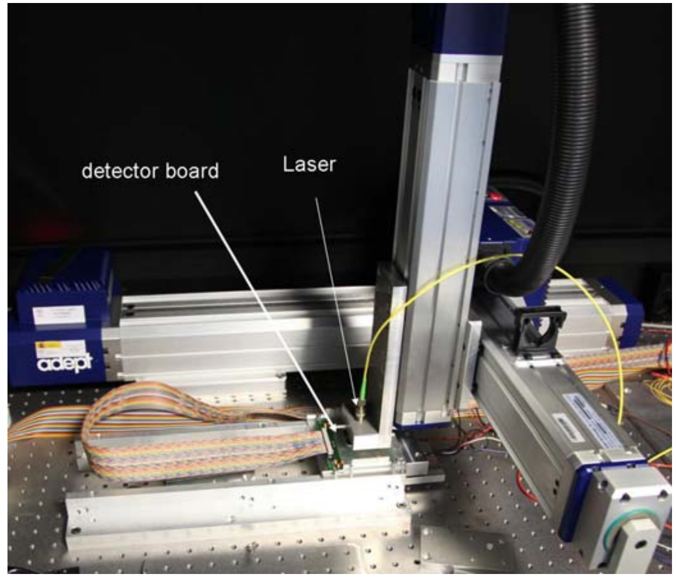
Experimental arrangement

Detectors have been characterized in the IFCA clean room in Santander

ALIBAVA DAQ system for microstrip detectors, based on the Beetle analog readout ASIC



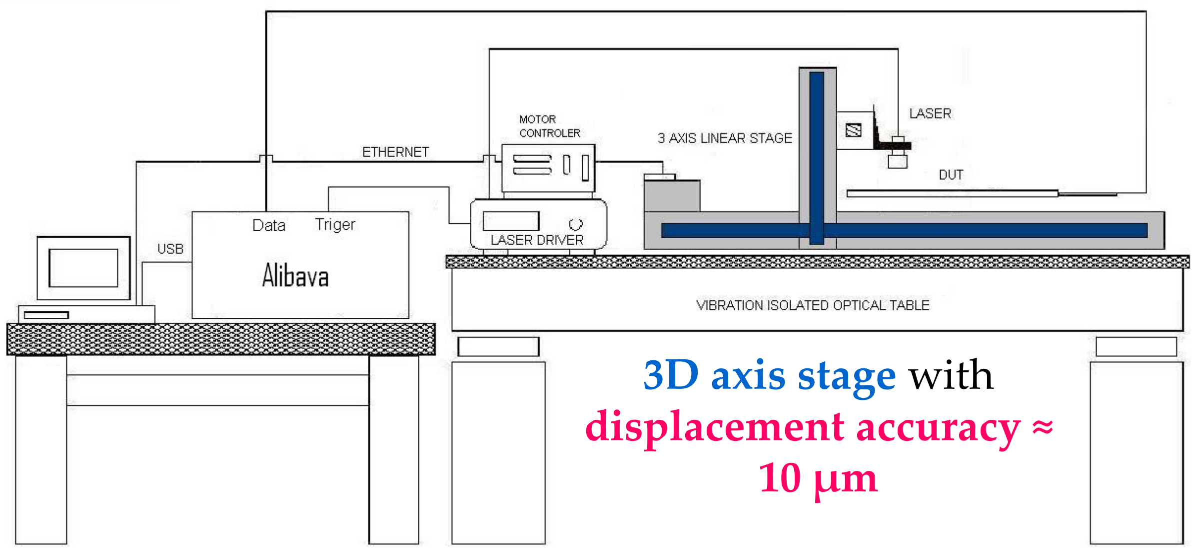
- 256 channels
- **peaking time = 25ns**
- S/N≈20 for standard no irradiated detectors



Pulsed DFB laser

λ=1060nm

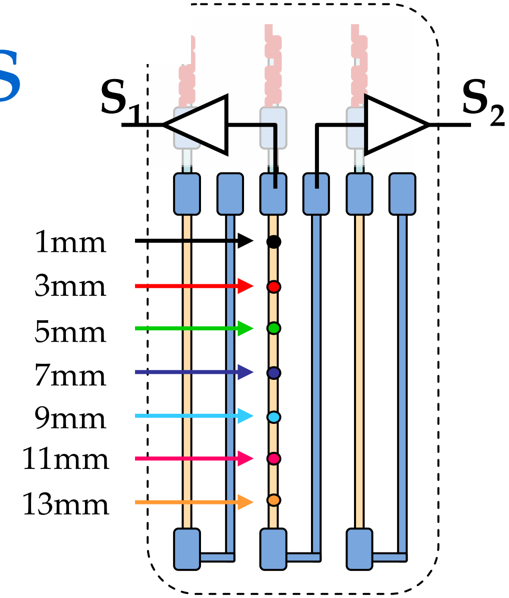
- gaussian beam spot width ≈ 15 µm
- rise time 2ns
- amplitude 1mV
- **total charge ≈ 10MIPs**



3D axis stage with **displacement accuracy ≈ 10 µm**

First prototypes: experimental results

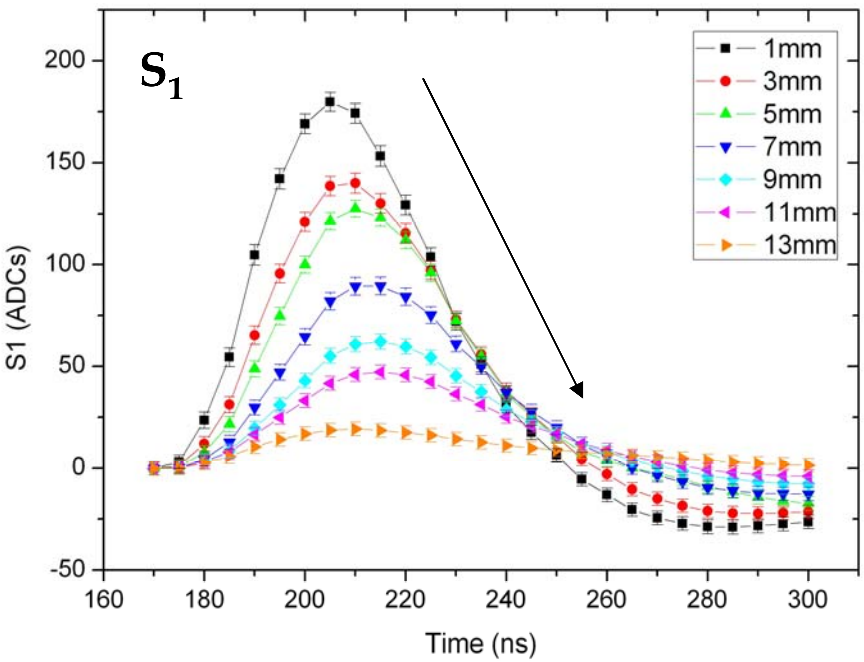
(2010)

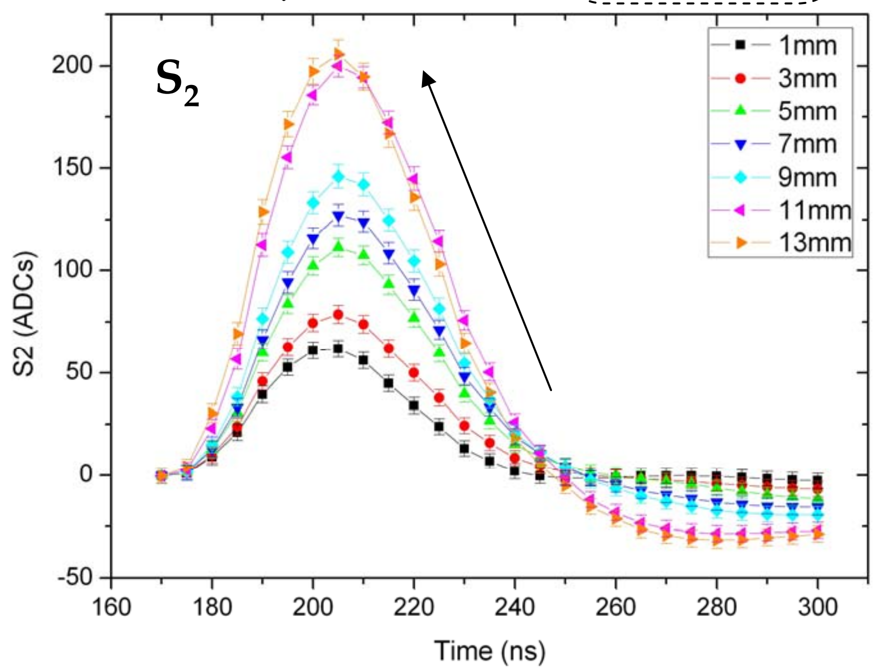


Asymmetry in the detector response:

Metal guides capacitively coupled with the neighbouring strips.

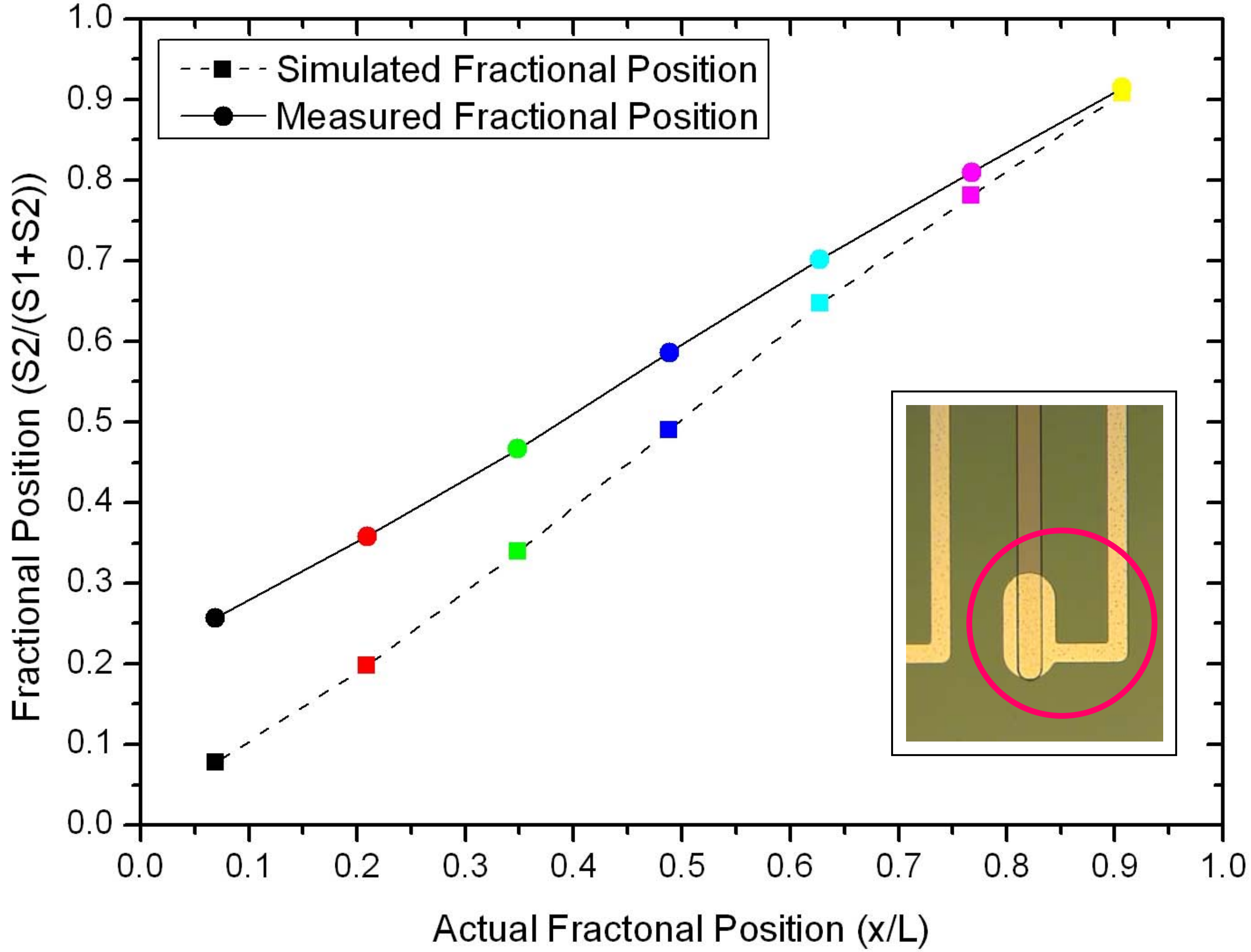
Induced signal components contribute to signal S_2 changing its shape (amplitude and peaking time).

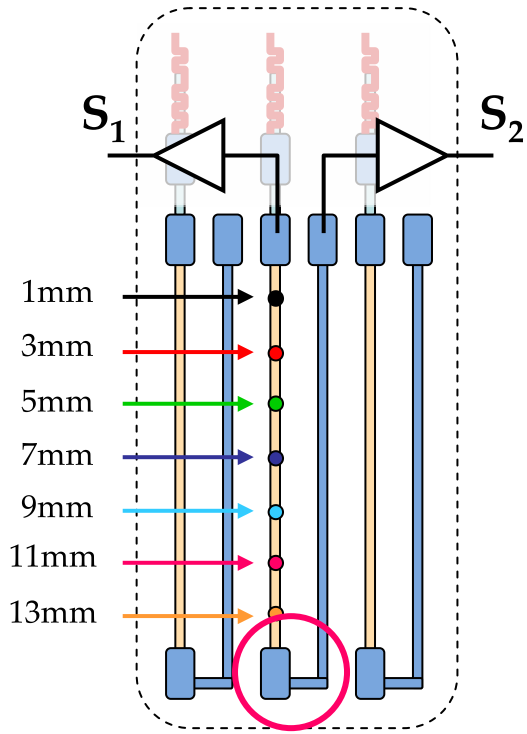




Experimental results (2)

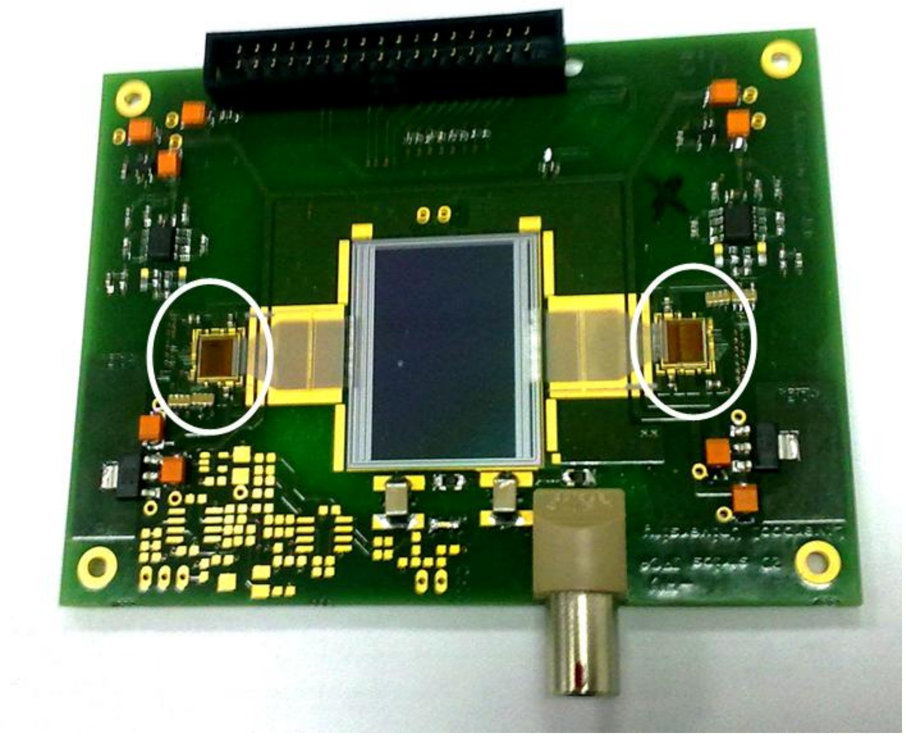
Experimental fractional position (S_2/S_1+S_2) versus the simulation.
Contribution of induced signal decreases when the laser is placed close to the connection between the resistive electrode and the metal line.





Second prototypes

Produced at the IMB-CNM facilities of Barcelona (2010).



Fabrication run:
standard technology for single-sided p^+-in-n silicon microstrip detectors.

Resistive material = highly doped poly silicon.
Different concentration of Boron
➡ **different values of the electrodes resistance.**

$R_{electrode}/\mu m = 2.8\ \Omega/\mu m$ or $12.2\ \Omega/\mu m$

No metal guides

- strip length= 20 mm, strip width=20 µm
- Electrode width= 30µm
- pitch= 80 µm

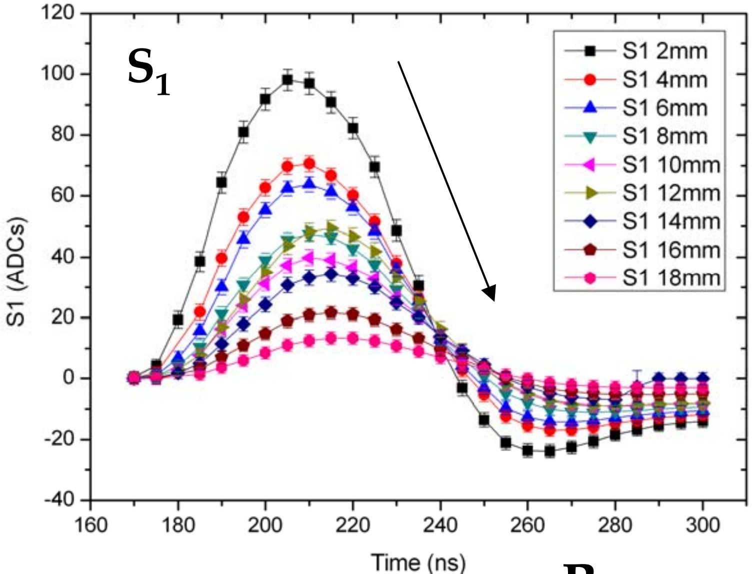
Two chips to read out the detector.

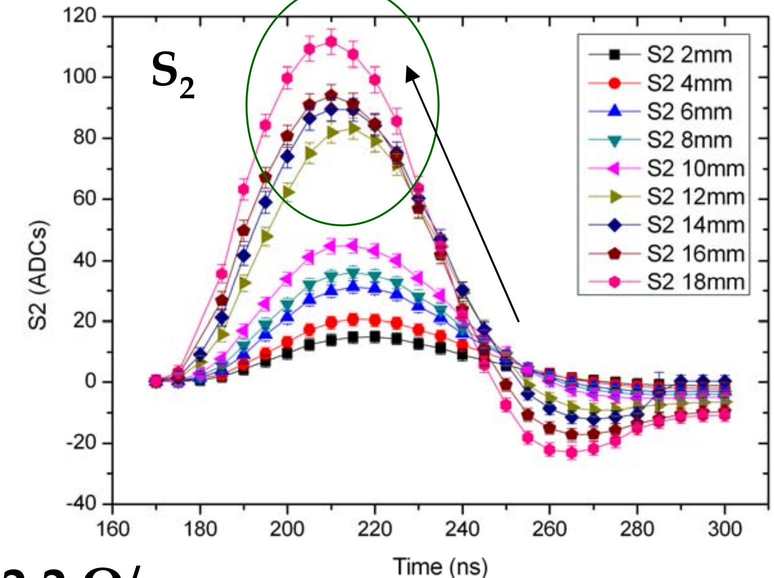
Thanks to Marko Dragicevic (HEPHY institute, Vienna) for his contribution to the mask design and to Gianluigi Casse (University of Liverpool) for the wire bonding.

(2011) Experimental results

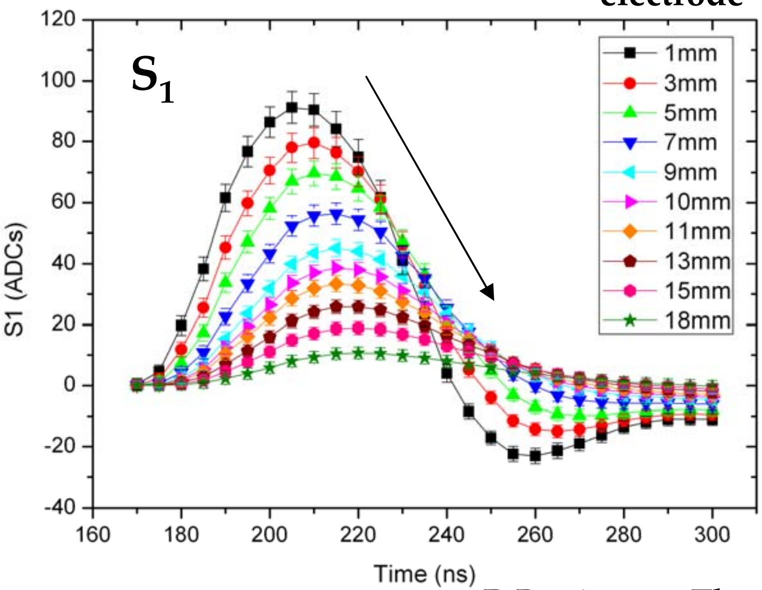
$R_{electrode}/\mu m = 2.8\ \Omega/\mu m$

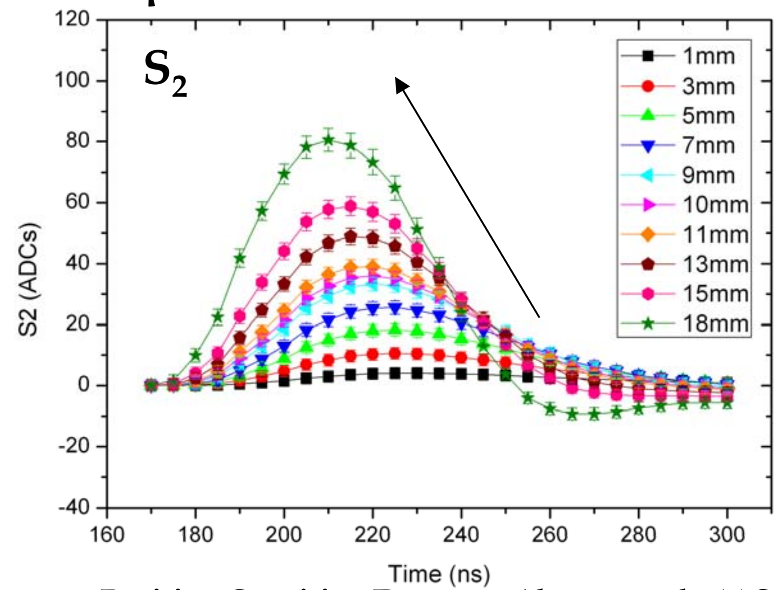
Laser misalignment





$R_{electrode}/\mu m = 12.2\ \Omega/\mu m$

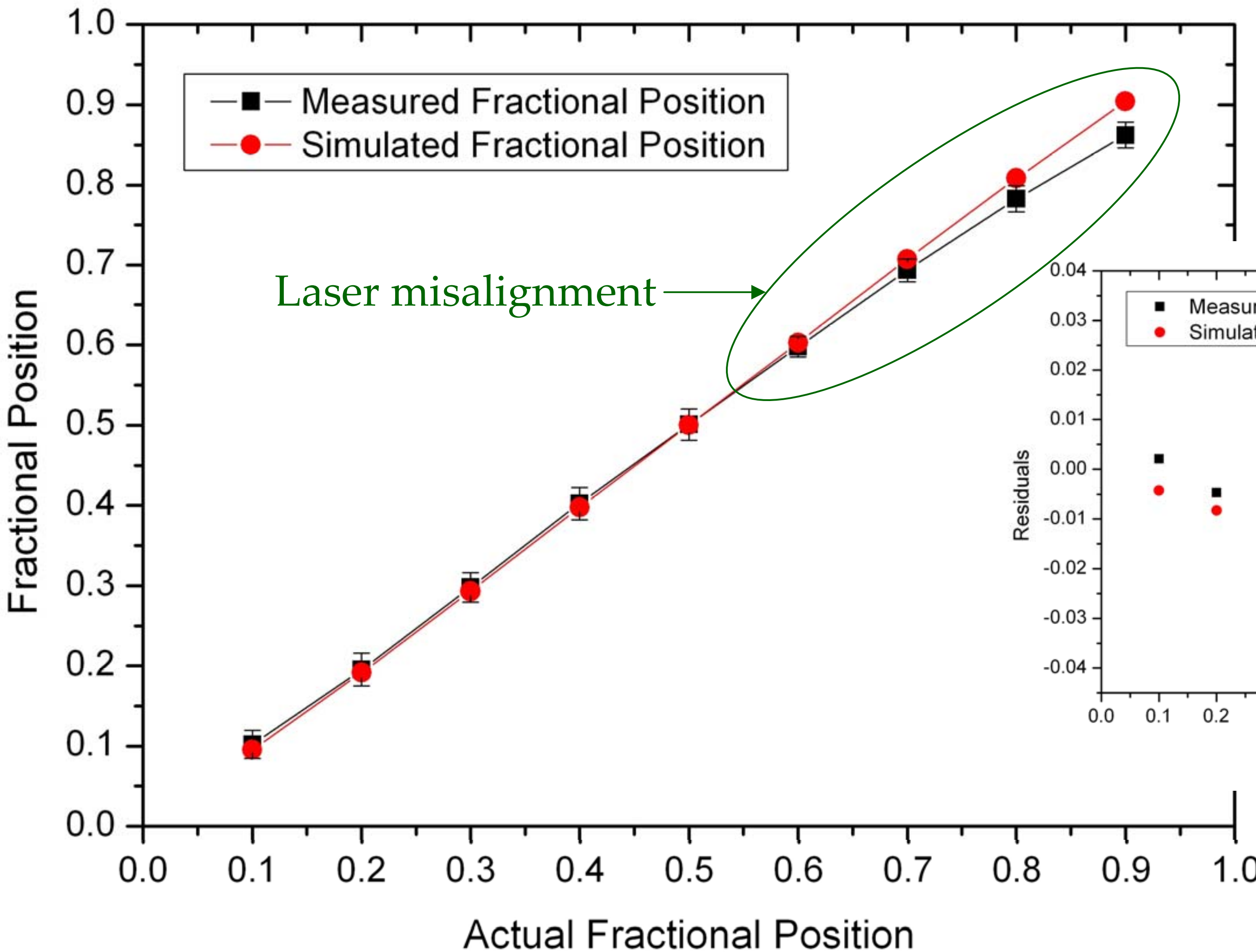




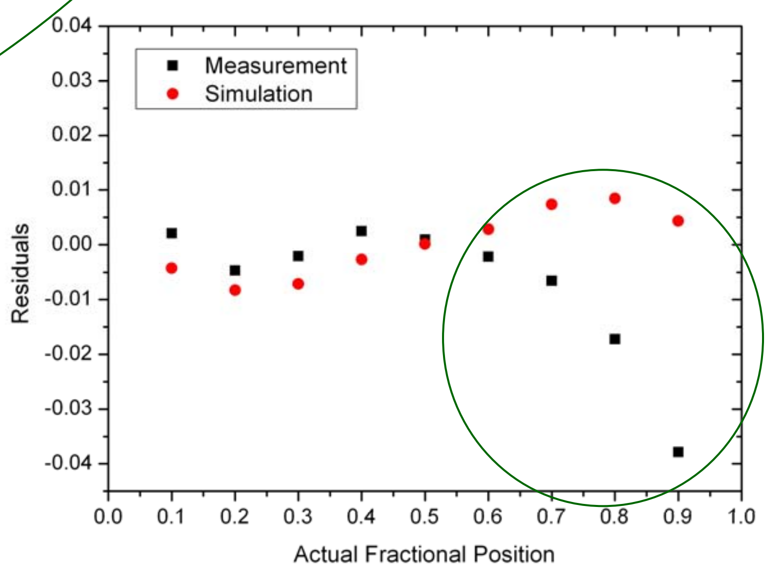
Fractional Position

$R_{electrode}$/μm = 2.8 Ω/μm **RC ≈ 100ns** **total charge collected ≈35fC**

Calculated **fractional position resolution ≈ 2%** 400 μm over 20 mm



$$\frac{y}{L} = \frac{S2}{S1+S2}$$

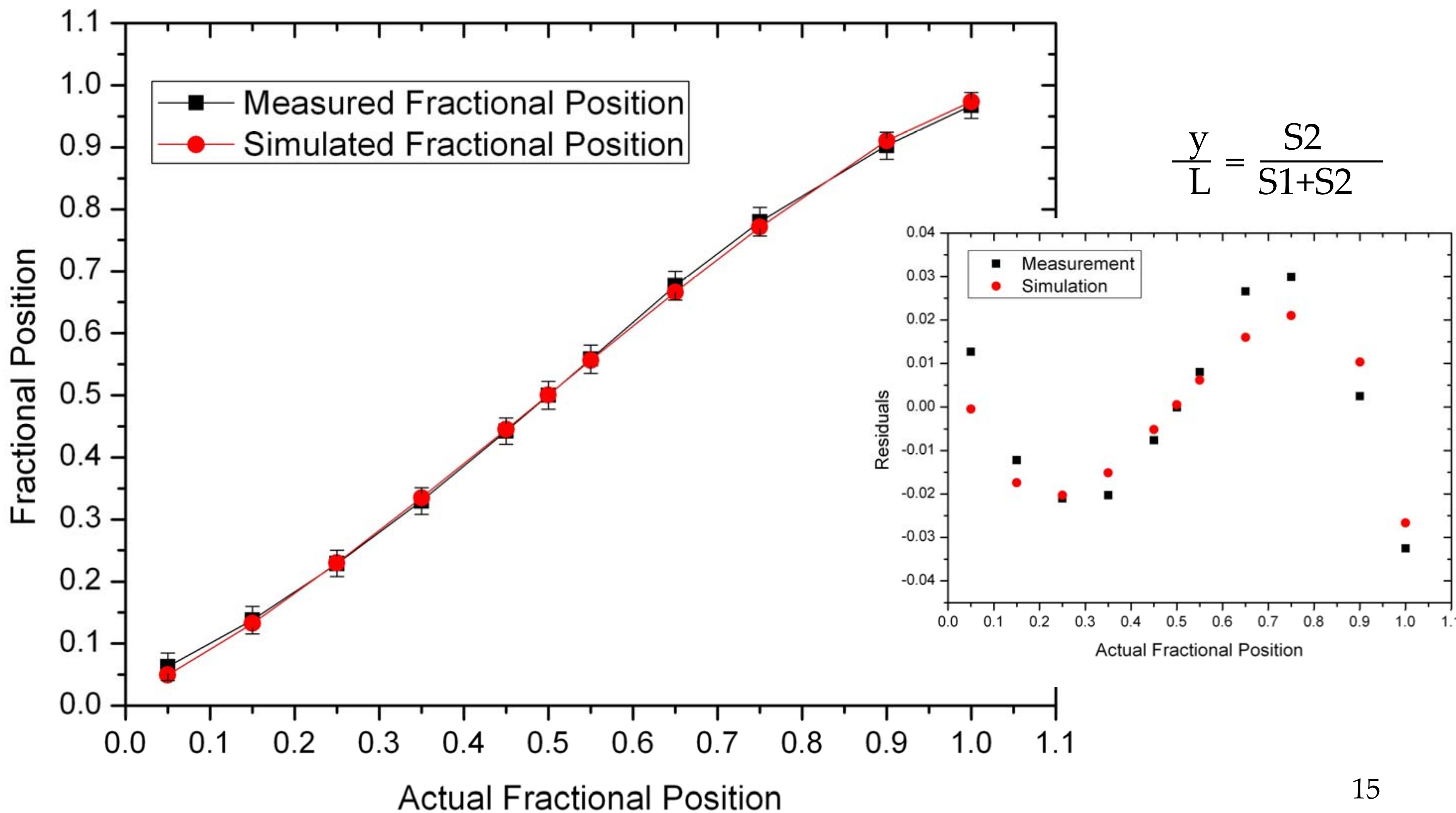


Fractional Position (2)

$R_{electrode}/\mu m = 12.2\ \Omega/\mu m$ RC ≈ 100ns total charge collected ≈35fC

Calculated **fractional position resolution ≈ 2.2%** **440 µm** over 20 mm

$$\frac{y}{L} = \frac{S2}{S1+S2}$$



Conclusion

Novel 2D position-sensitive semiconductor detector concept based on the standard technology of AC coupled microstrip detectors.

We have demonstrated the feasibility of resistive charge-division method in microstrip detectors to obtain longitudinal coordinate.

✓ **Different proof-of-concept prototypes** characterized with the use of a NIR laser and the ALIBAVA DAQ system.

Spatial resolution (in the best case) = 400 μm over 20 mm for a total charge collected ≈ 35fC.

✓ **Resistive electrodes** uncoupled from the diode structures of the detector.

✓ **A SPICE-like model** of the detectors and analog front-end electronics for future prototype optimization.

Applications in nuclear or particle physics tracking, laser-based position sensitive devices, heavy ion and other highly-ionizing particle detection, medical imaging, etc.

Currently the new prototypes are being tested at SPS pion beam at CERN.

Aiming to technological transfer Pat. **PCT/ES2011/070088**

Thank you for your attention!