Detector development for the instruments in the forward region of future linear colliders

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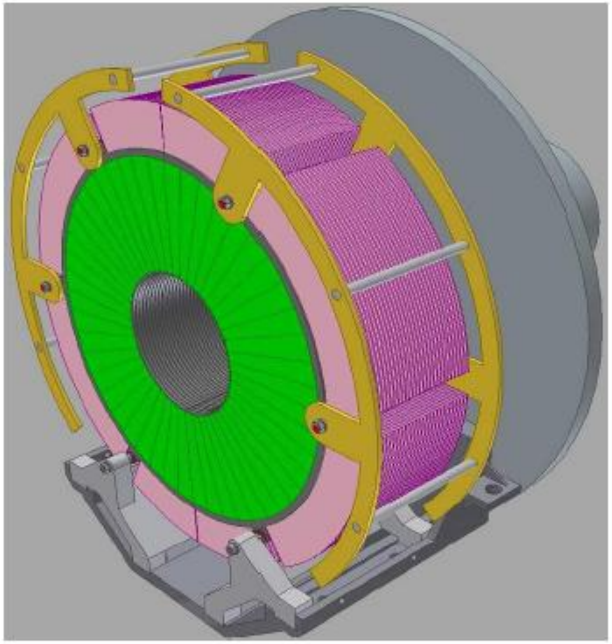
Introduction

This presentation summarizes results from my thesis work, on the lab measurement and 2010 beam test of the LumiCal silicon-sensor prototype, and includes:

- Capacitance measurement.
- Spectrum analysis.
- Cross-talk.
- Uniformity and Charge sharing.



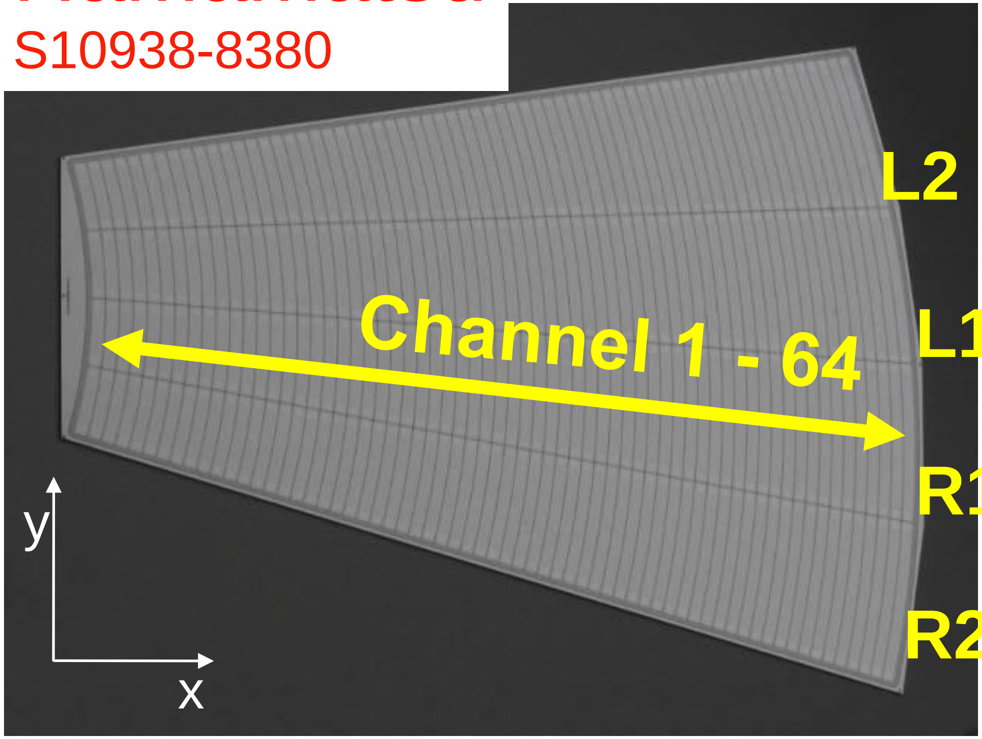
Silicon-sensor prototype

MC simulation studies led to the design and production of a silicon-sensor prototype for the luminosity calorimeter :

- 0.32 mm thickness from 6” wafer.
- high resistivity n-type Silicon.
- 1,7 mm p+ - strips
  with an Al-metallization.
- Backplane: n+ implant and an Al-metallization.
- 3 guard rings
- 4 sectores
- 64 pads in a sector

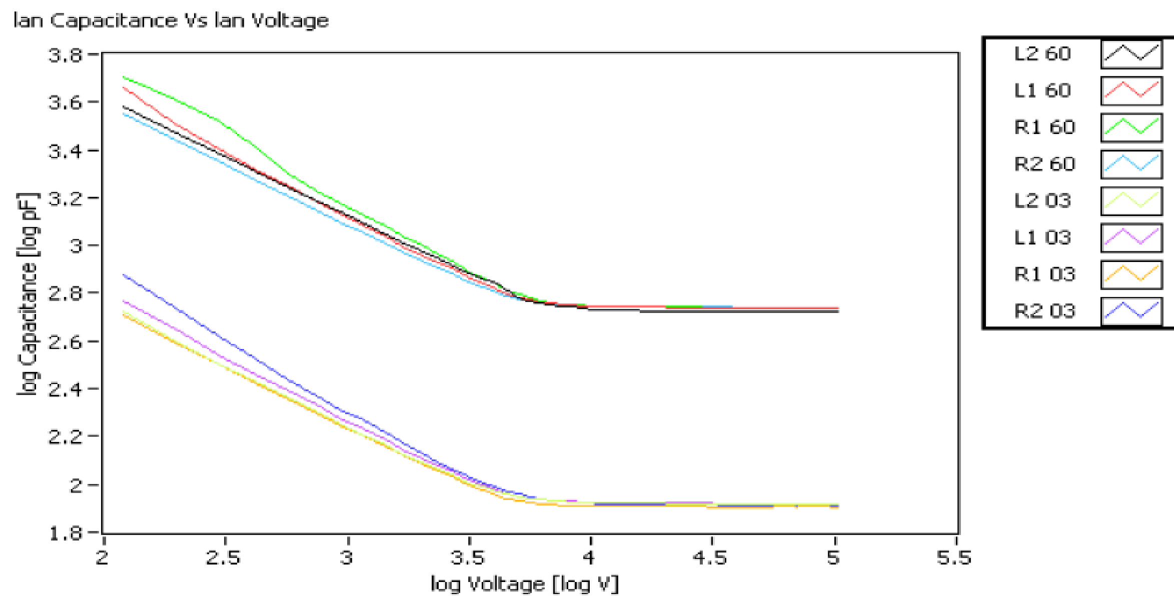
Hamamatsu

S10938-8380



Capacitance measurement

Past presentations discussed the lab measurement of sensor characteristics. For better understanding sensor behavior number of calculations were made.



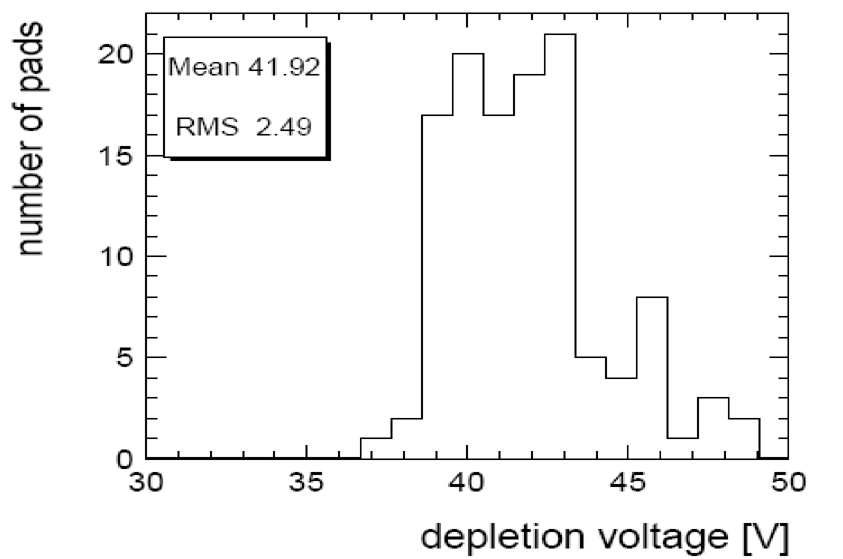
As the pad area is relatively large the capacitance is mostly a geometrical property :

$$C_g = A\frac{\varepsilon_{Si}\varepsilon_0}{w} = \begin{cases} A\sqrt{\frac{\varepsilon_{Si}\varepsilon_0 e N_d}{2V}} & \text{for } V < V_d \\ A\frac{\varepsilon_{Si}\varepsilon_0}{w_m} & \text{for } V > V_d, \end{cases}$$

It is easier to determine the depletion voltage from the log(C) - log(V) plot.

depletion voltage determined as the crossing point between two linear fits, V <30V & V > 80V

•Average depletion voltage of 42 V.



Capacitance measurement

Another way to present this relationship is,

$$\frac{1}{C^2} = \frac{2}{\varepsilon e N_d A^2} V.$$

From it one can extract the donor density in the n-type silicon-bulk or the resistivity. In the order of $1 \times 10^{12} \, \frac{e}{cm^3}$.

In text books, an estimate of the full depletion-layer width in the n-type silicon bulk is

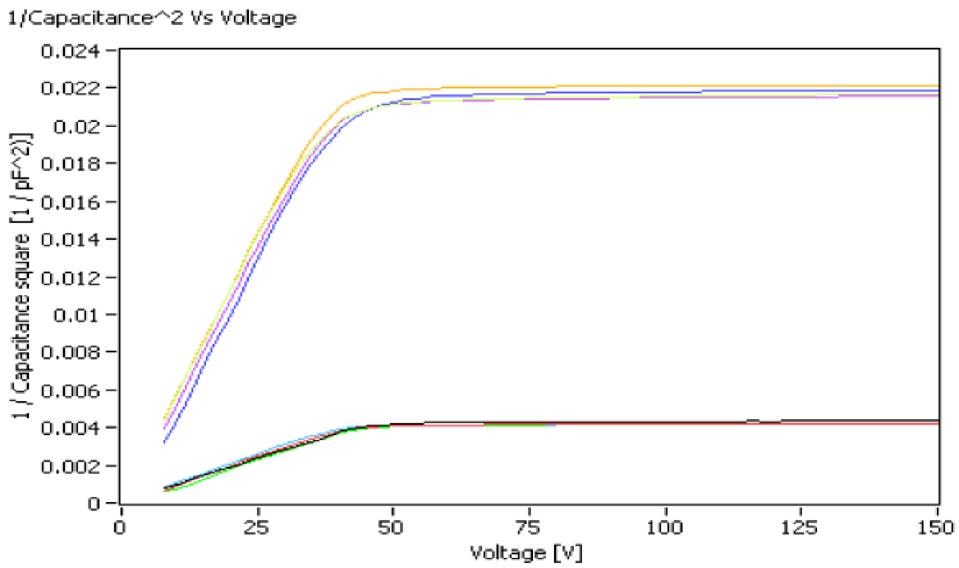
$$w_m = 0.5[\,\mu\text{m}] \times \sqrt{V_d \rho}.$$

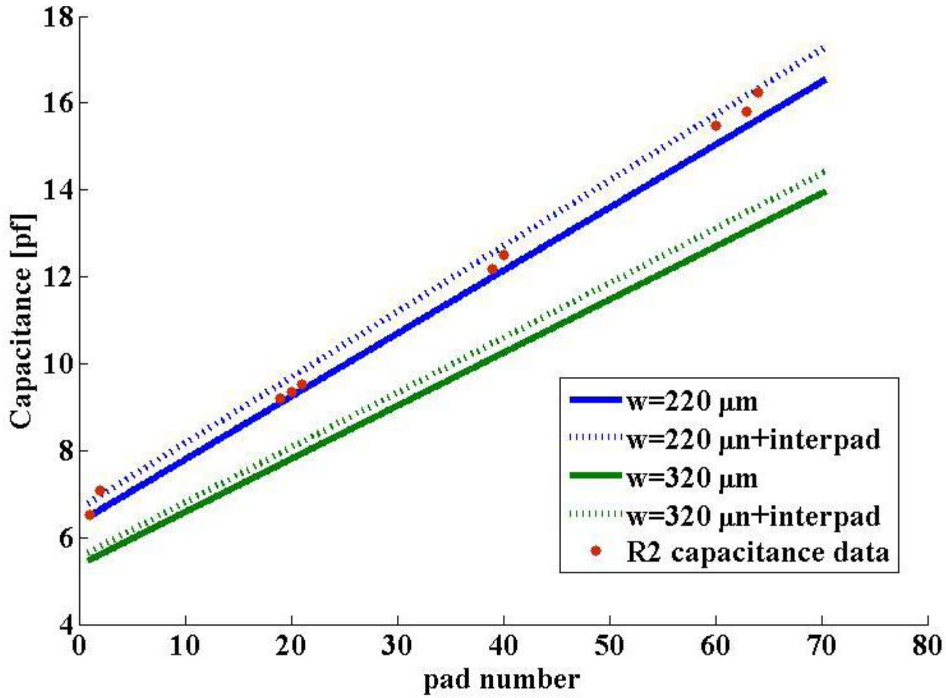
From that the full depletion-layer width can be determined as 220 µm.

It is possible to express the inter-pad capacitance by

$$C_i = \left[0.03 + 1.62\frac{(d - w_d) + 20\,\mu\text{m}}{p}\right] \text{pF/cm},$$

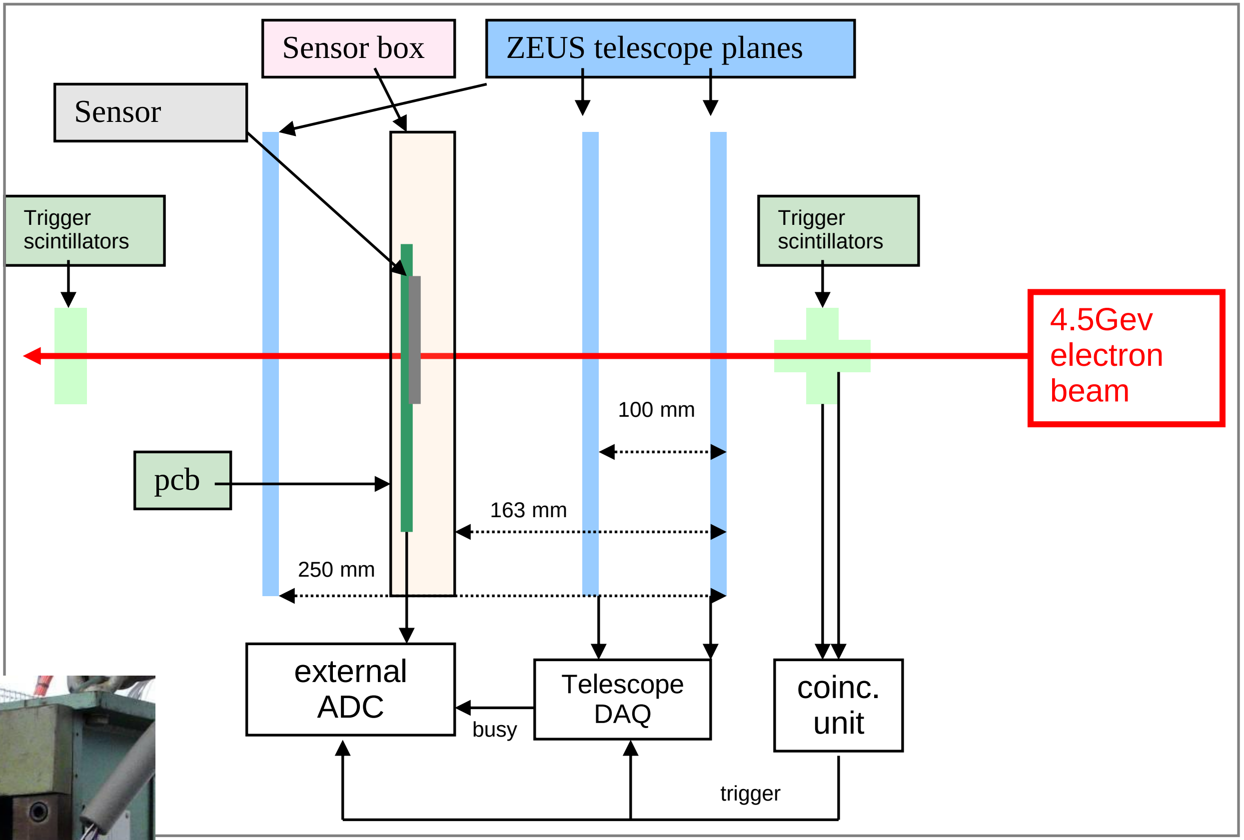
And in around 4% of the capacitance





Test Beam Set Up

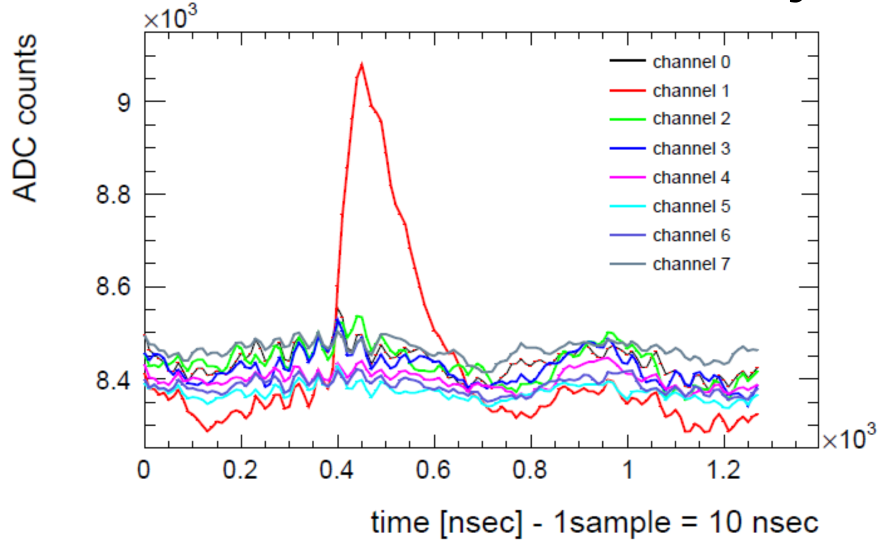
In the summer of 2010 the FCAL collaboration had the first test beam measurement of the Lumical silicon prototype, and of the BeamCal GaAs. In these measurements the full readout chain including silicon sensors, kapton fan-out and front-end electronics were tested.

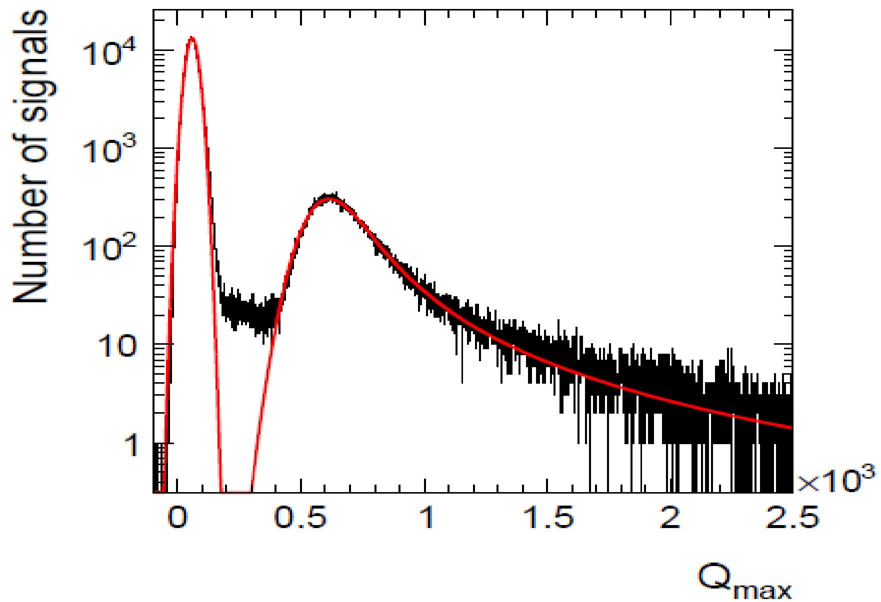


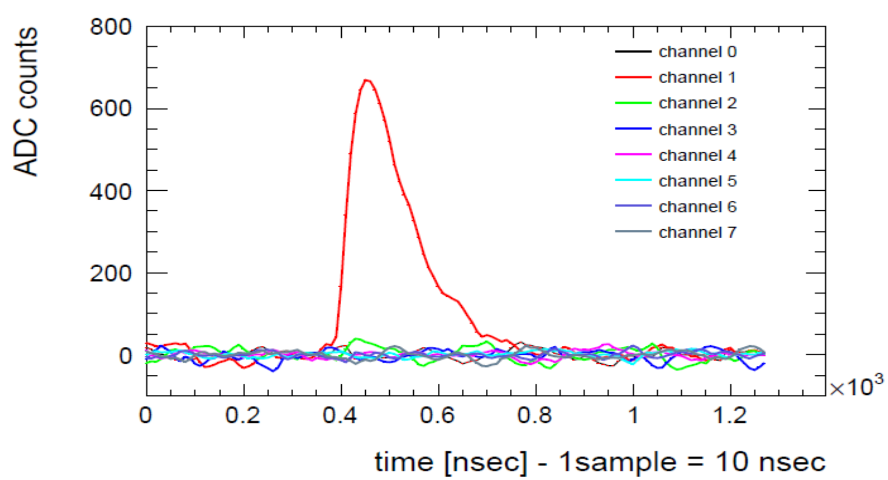
Test beam took place in beam line 22 of DESY II ring in Hamburg with 4.5 GeV electron beam. Measurements are the combination of our sensors, ZEUS telescope for position reconstruction and temperature monitoring.

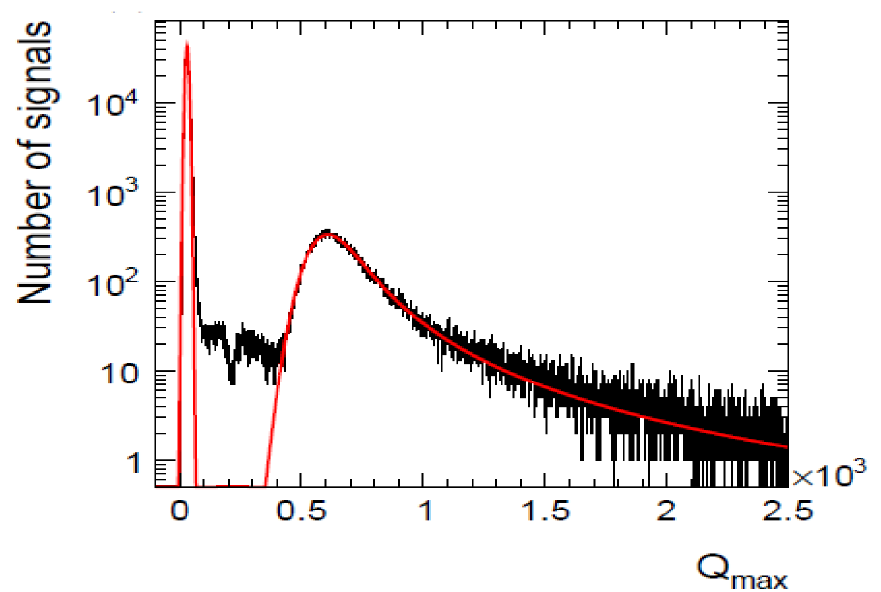
Spectrum analysis

As discussed in the previous meeting first the common mode noise has to by removed







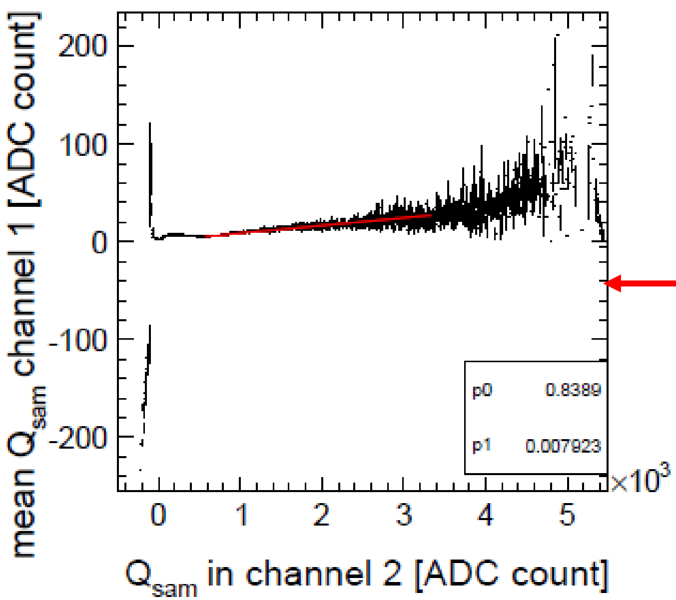


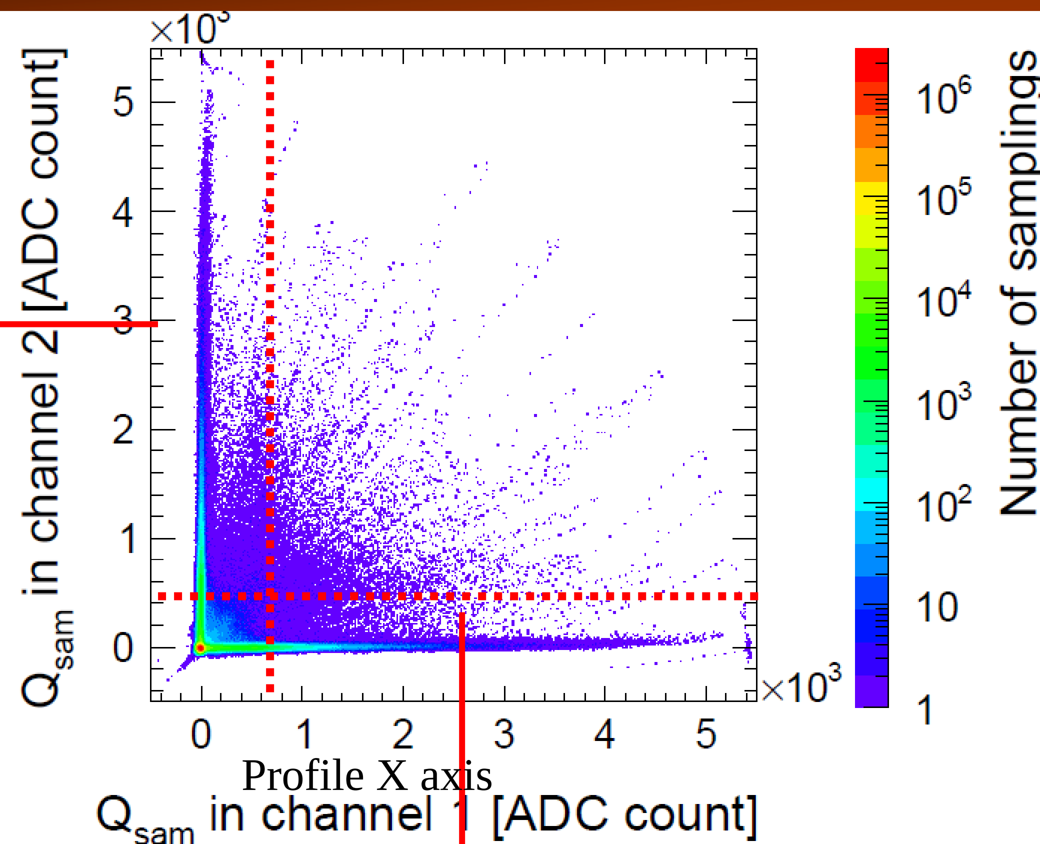
Spectrum analysis

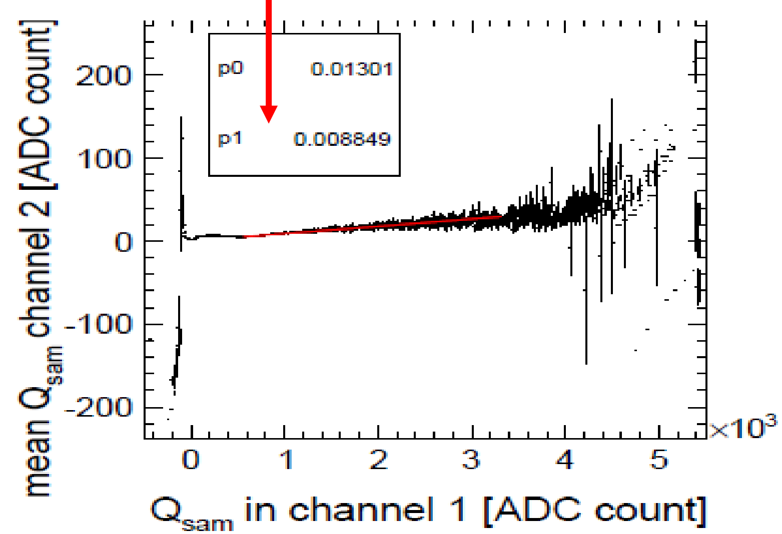
		before filter				after filter			
Area	Channel	$\tilde{Q}_{int}$	S/N	$\tilde{Q}_{max}$	S/N	$\tilde{Q}_{int}$	S/N	$\tilde{Q}_{max}$	S/N
1	0	8758	7.4	529	20	9237	43	562	74
	1	8790	8.0	527	21	9095	48	554	79
	2	8619	7.7	529	21	9015	47	557	77
	3	8708	7.9	527	21	9102	48	557	78
	4	4368	7.5	268	21	4619	28	279	50
	5	4432	7.5	272	21	4701	30	283	52
	6	4405	7.4	269	20	4668	30	282	52
	7	4404	6.9	267	19	4623	32	283	56
2	0	8634	7.1	524	19	8879	43	542	83
	1	8129	7.2	515	20	8535	38	519	73
	2	8354	7.5	515	21	8545	38	523	75
	3	8282	7.6	512	21	8530	39	522	75
	4	4336	7.5	265	20	4514	31	271	63
	5	4321	7.6	265	21	4504	33	271	65
	6	4355	7.5	266	20	4527	33	272	65
	7	4362	6.4	266	17	4546	33	275	64

Where Q_{max} – maximum amplitude , Q_{int} - integration

Cross-talk





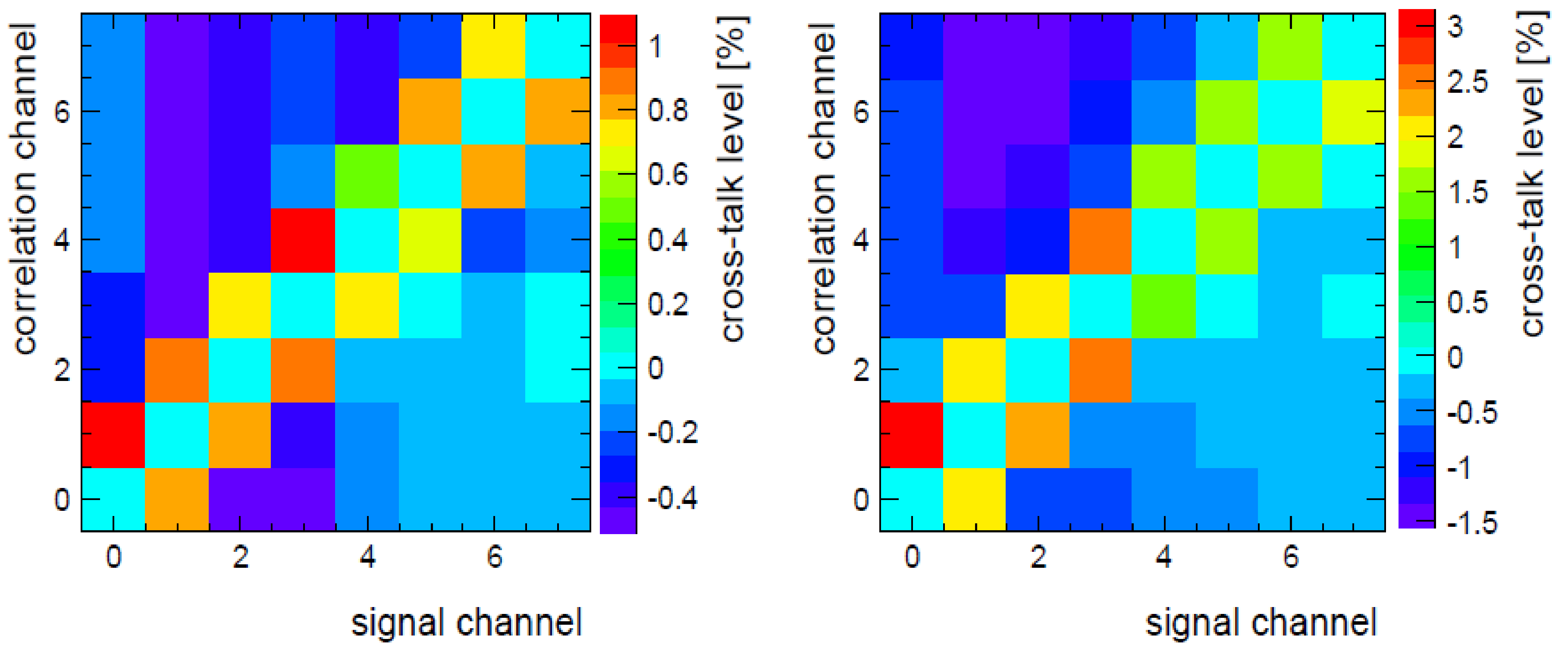


In order to investigate the cross-talk between channels, the correlation between the responses of every pair of channels was investigated. The correlation was studied for the full data set, and for all samplings in the response. The magnitude of each sampling response was corrected (Q_{sam}).

After calibrating all channels through their MPVs, the cross-talk coefficient can be defined as the slope of the dependence of the mean pedestal value of one channel on the response in the other channel

Cross-talk

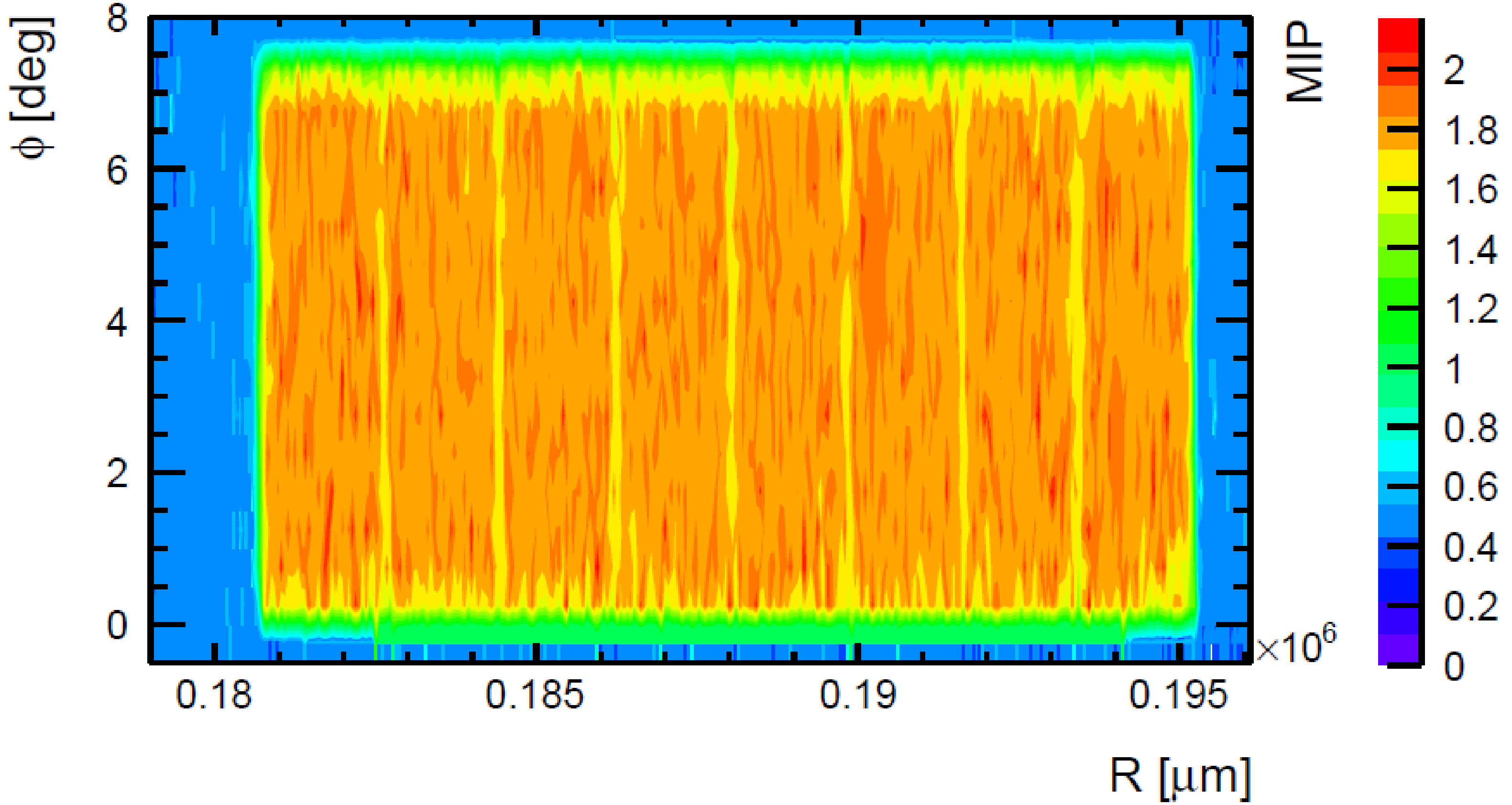
As expected the cross-talk is small, at the percentage level, and is significant in neighboring channels. The observed cross-talk coefficient for the pads in area 2 (3%) is more than twice the value of the coefficient for the pads of area 1 (1%). This is probably due to the longer transition-lines from pads in area 2 to the ASICs than those from pads in area 1.



Uniformity

The response of the sensor was studied as a function of hit position, for area 1 in the sensor coordinate.

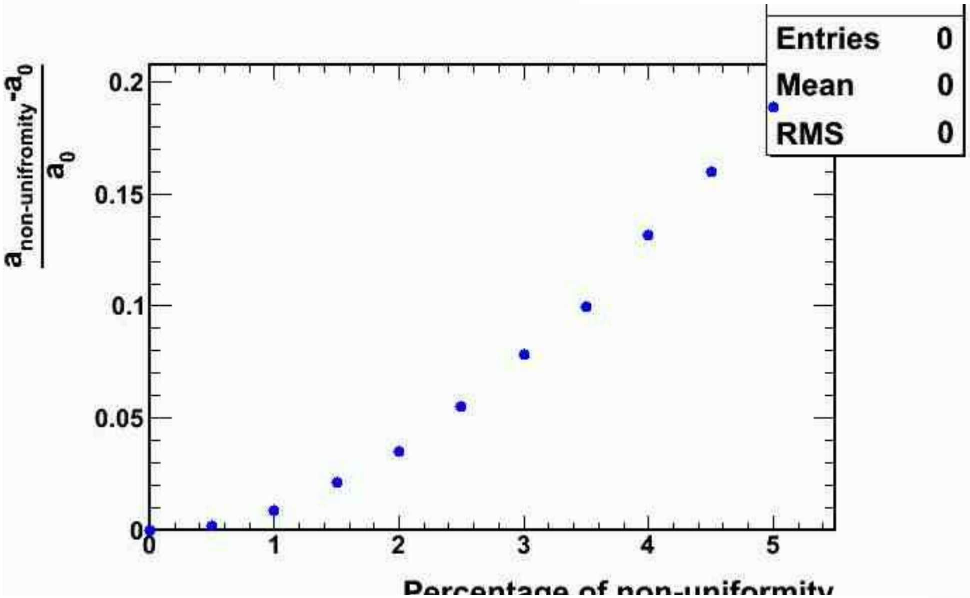
A 10% decrease in the total charge collection is observed around the 0.1mm gap between pads and the region extends through about 0.2 mm.

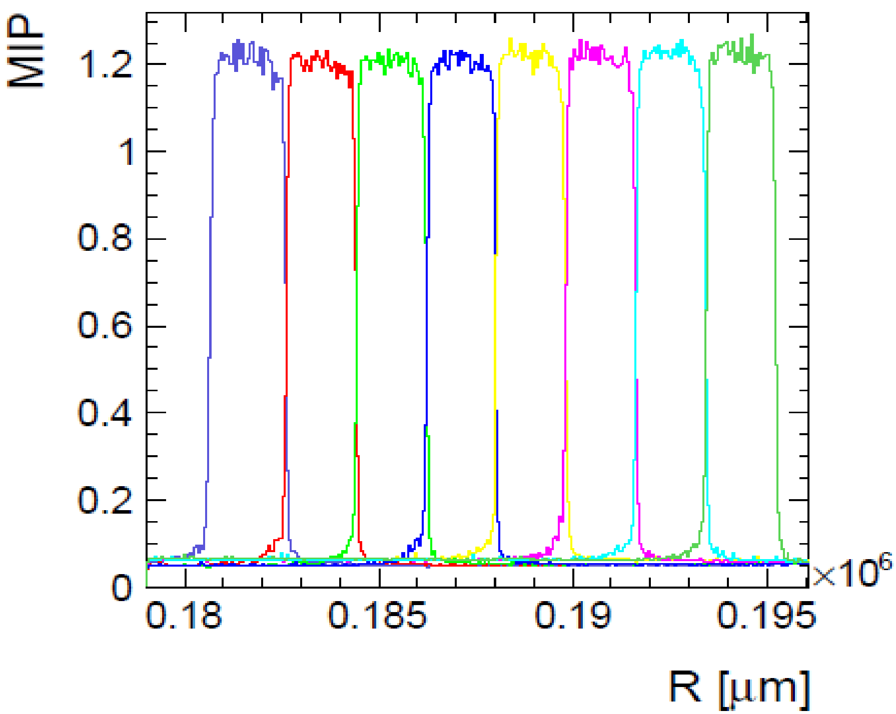


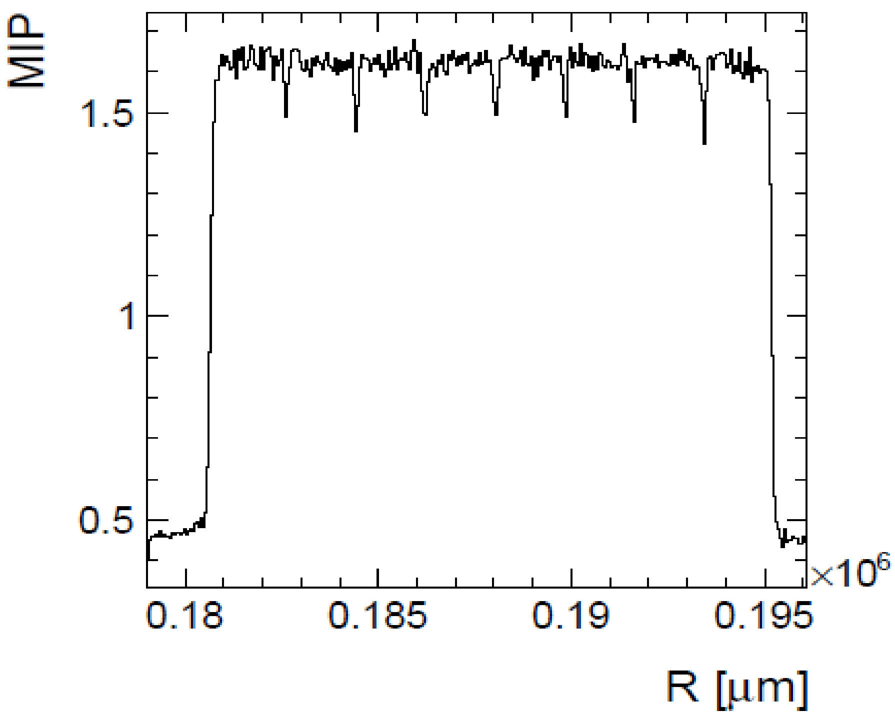
Uniformity

The non-uniformity is at the level of < 1.5%, to be compared tolerance of the sensor depth $\sim \frac{15\mu m}{320\mu m}$

A degree of non-uniformity was introduced on the result of MC simulation of the CLIC detector (MOKA at 3 TeV). In order to estimate the effect of non-uniformity on uncertainty level of the energy resolution. Since the allowed uncertainty is 10%, its seems that the non-uniformity is not a concern.



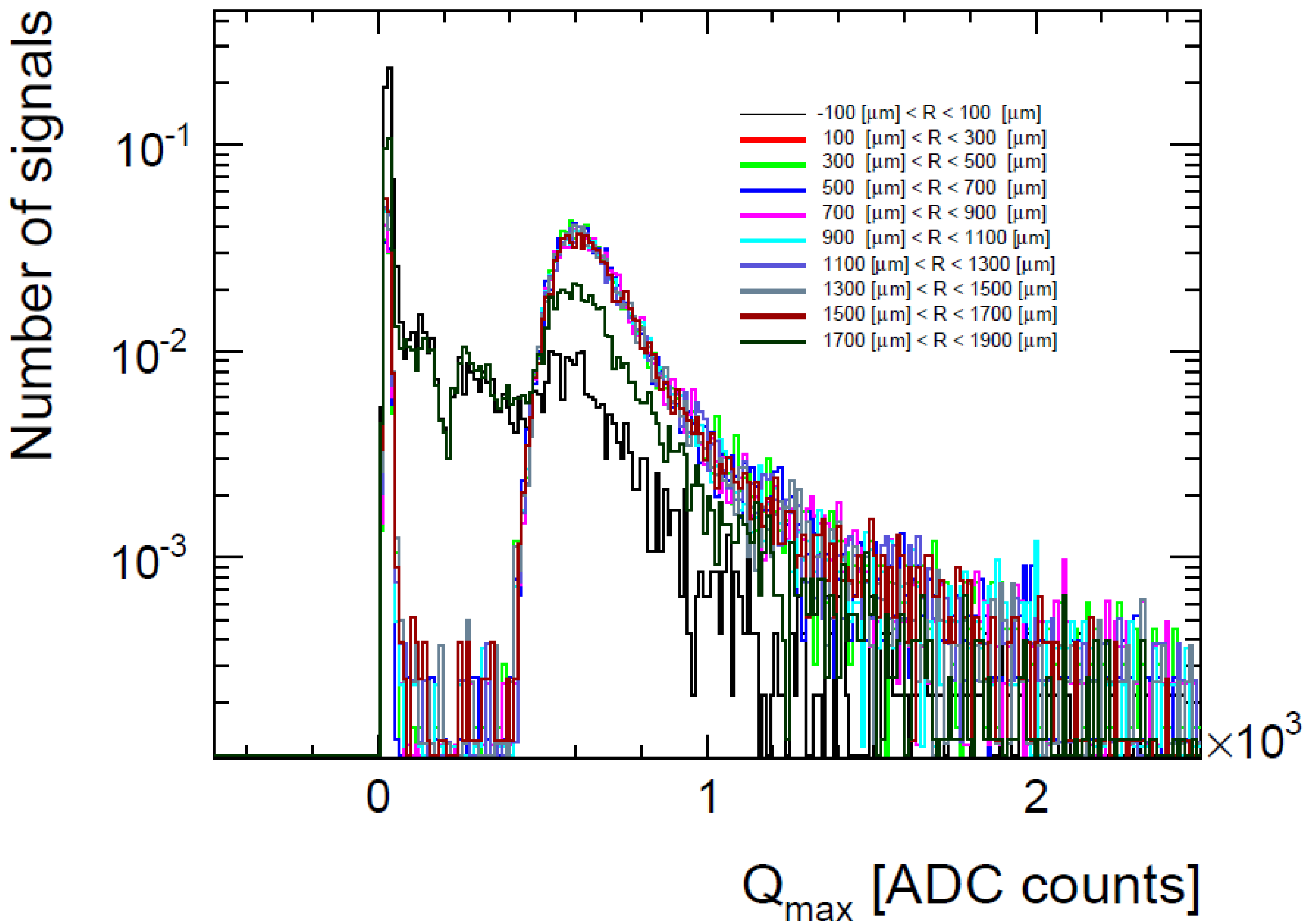




Uniformity and Charge sharing

To further investigate uniformity, pad was subdivided into radial bins and the corresponding spectrum was investigated.

The charge sharing observed in 5% of events is a result of a track that induces charge generation in two (or more) pads.



Summary

We showed here some new results from the testing of the silicon-sensor prototype.

- Sensor characteristics - Average depletion voltage of 42 V, high resistivity and a full depletion-layer width of 220 μm.
- Common mode subtraction and its effect on the S/N ratio.
- low levels of cross-talk.
- A non-uniformity <1.5% in the charge collection in pads and a 10% decline between pads, that seems adequate with uncertainty level of the energy resolution.
- Charge sharing effect in the pad gap.

I would like to use this opportunity to thank all of the colleagues and friends from the FCAL collaboration and test beams, for the help, time and patience, in person and from over the sea, in all of the work here.

Additional slides

Luminosity measurement

The luminosity determined by counting the number of small angle Bhabha events scattering, since the Bhabha scattering is a well-known and theoretically controlled process.

$$L = \frac{N_B}{\sigma_B}$$

The design luminosity precision is $\frac{\Delta L}{L} \sim 10^{-4}$

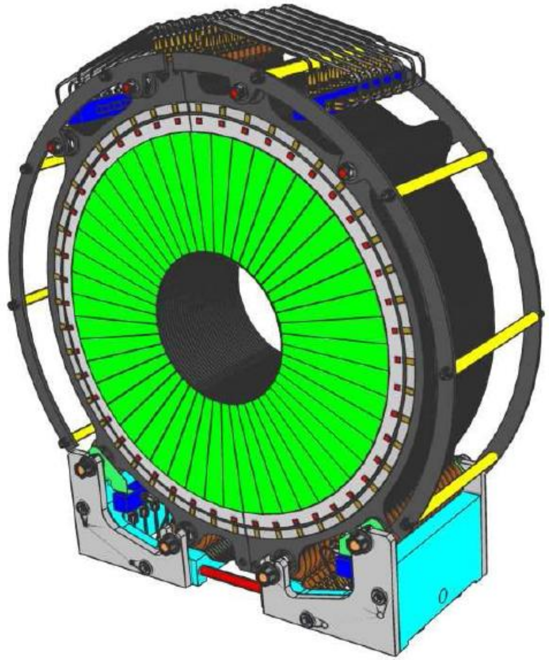
Requirements:

Energy resolution $20\% / \sqrt{E(GeV)} \pm 2\%$

Position precision $R_{in} \sim 1 \mu m$

$D_{arms} \sim 300 \mu m$

Fine granularity : 64 pads and 48 sectors



LumiCal

I/V and C/V Measurements scheme