Timing performance of large area SiPMs coupled to LYSO using noise compensation methods

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Motivation

Goal: To optimize Time-of-Flight capability of FBK SiPMs coupled to “slow” scintillators (e.g. LYSO)

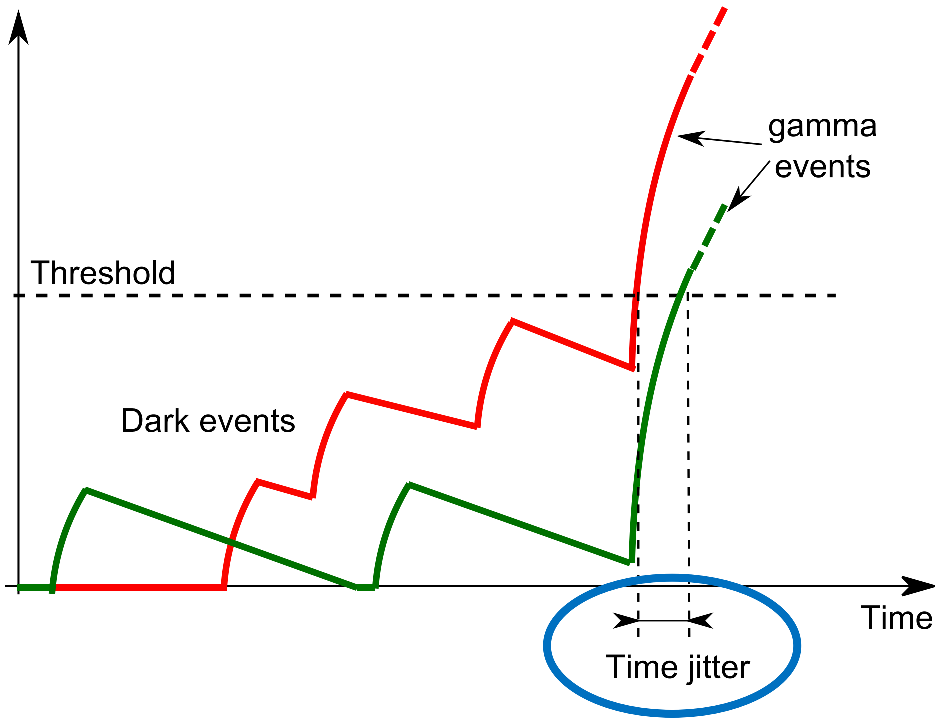
Main concerns for large area SiPMs were/are:
the high dark noise,
the signal shape,
the capacitance…

In the past year we have worked on **a method, implementable in an ASIC, which minimizes the effect of dark noise** on the timing performance.

In this contribution we will show some (quite good) results obtained with FBK large area SiPMs.

Effect of dark noise in LED

Leading Edge Discriminator (LED) is commonly used for time pick-off with PMTs.



long tail of the dark events

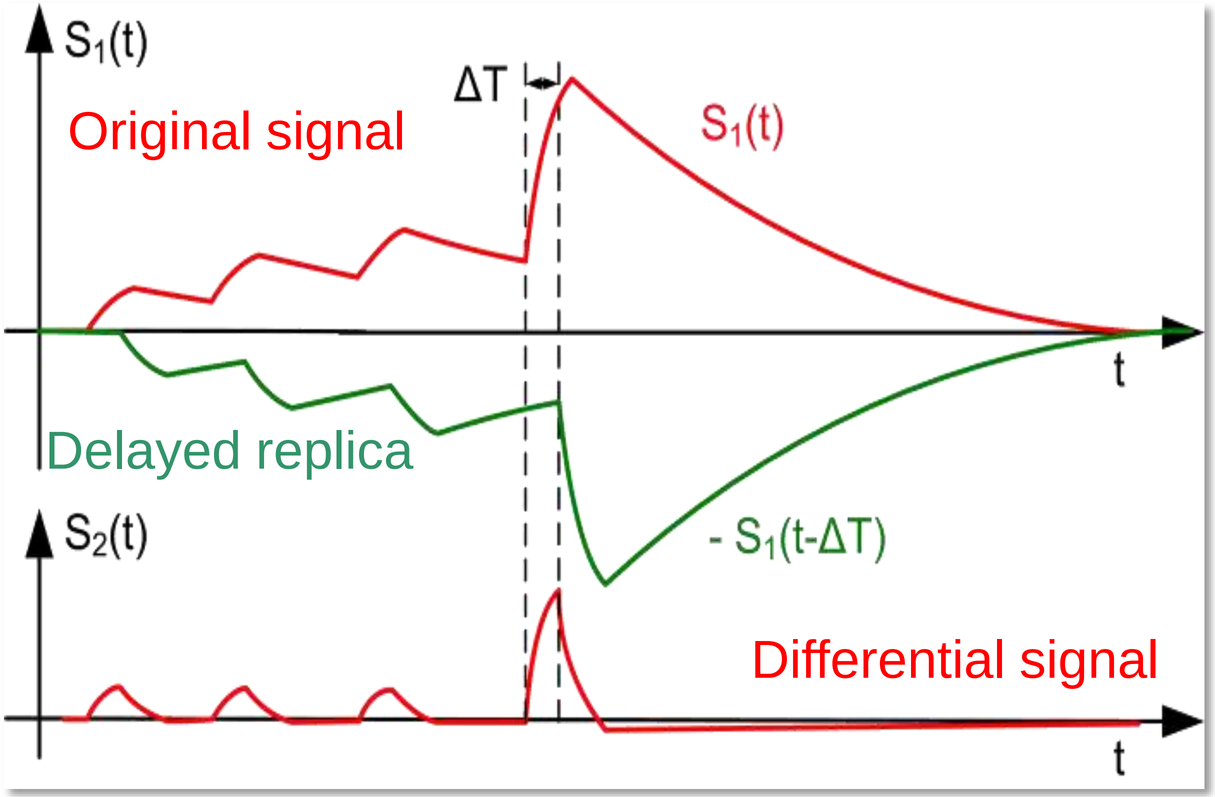
high dark rate

baseline fluctuation ➔ time jitter

high LED threshold ➔ worse photon stat.

In large area SiPMs the dark rate can be quite high and consequently also the effect described above.

SiPM Signal filtering: DLED



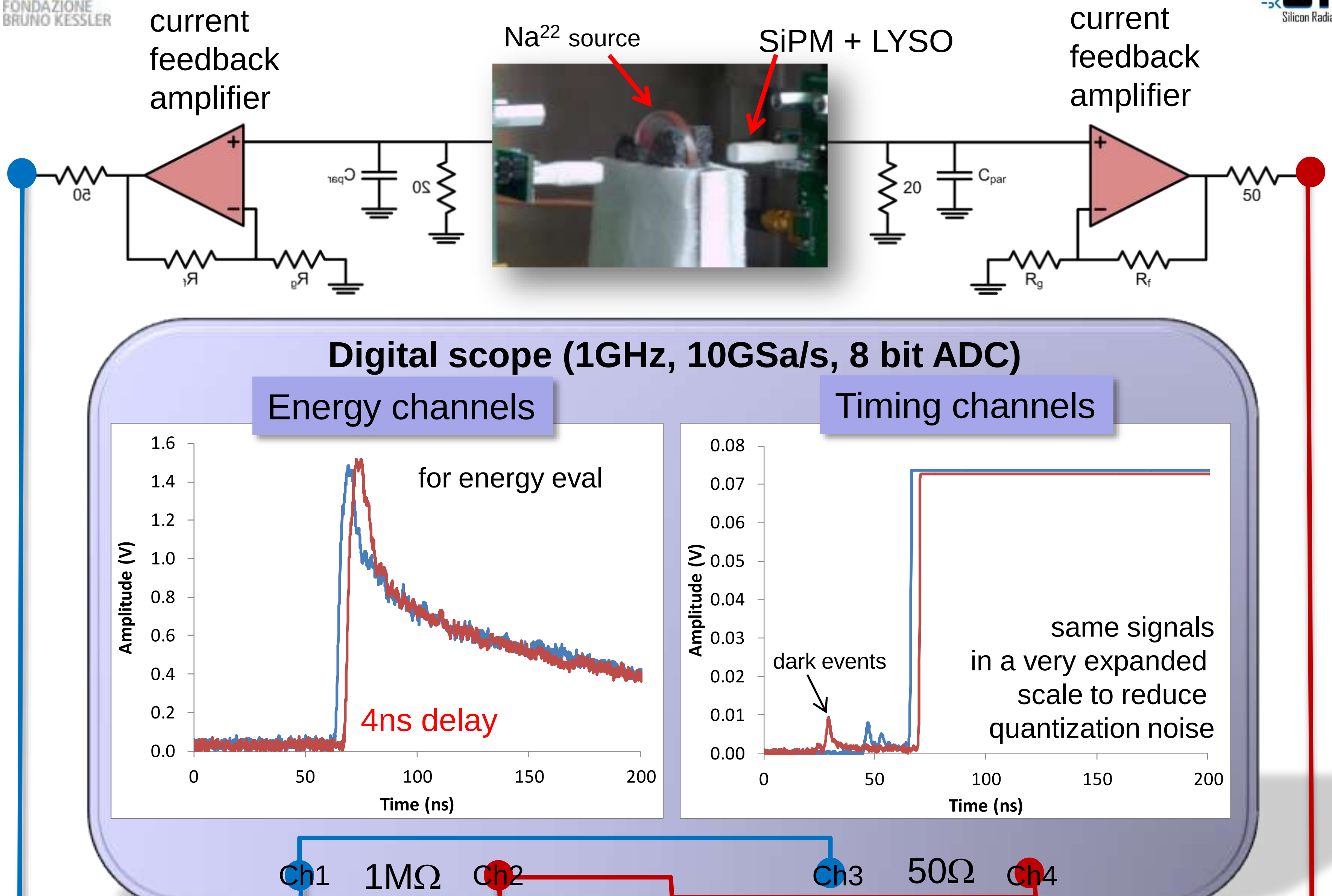
We exploit the difference between rise time and decay time to obtain a signal:

- **"free" from baseline fluctuations**
- **identical initial part of the gamma signal**

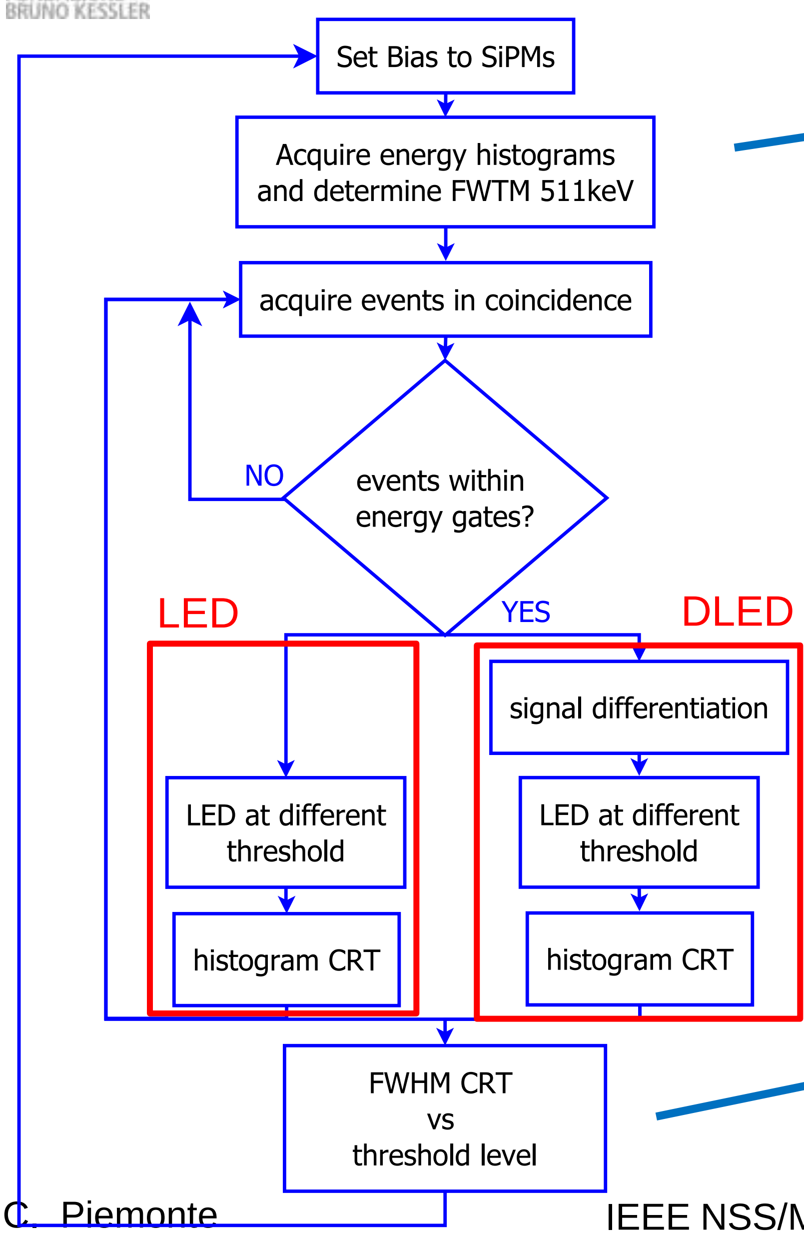
Then, we use the LED on the differential signal $s_2(t)$.

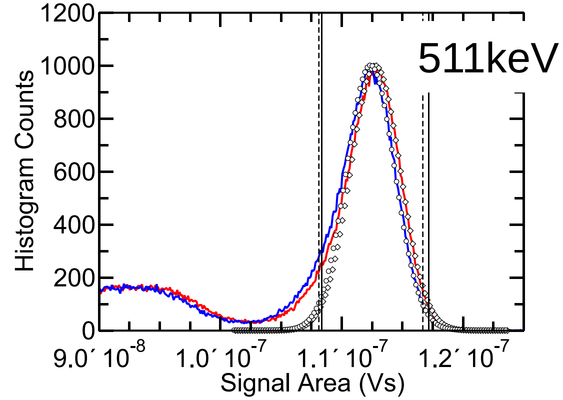
Important: electronic noise is ~ √2 higher in differential signal so its effect must be negligible for DLED to be effective

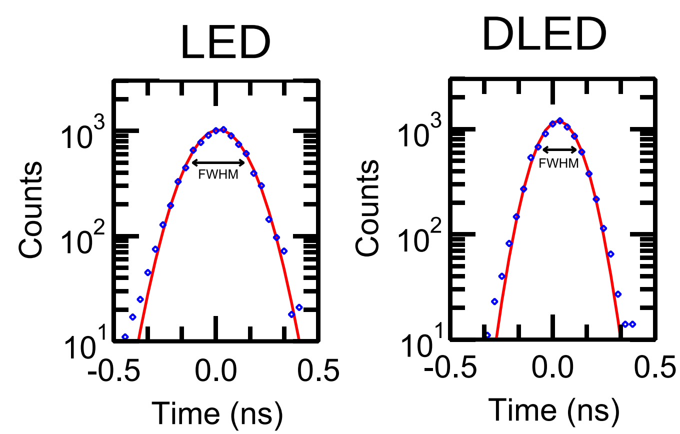
Experimental set-up

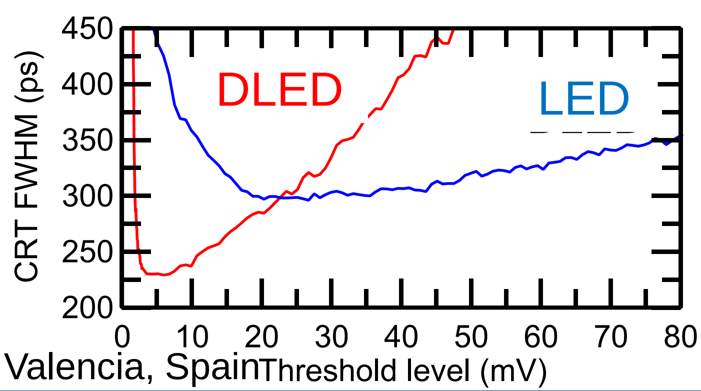


Measurement procedure



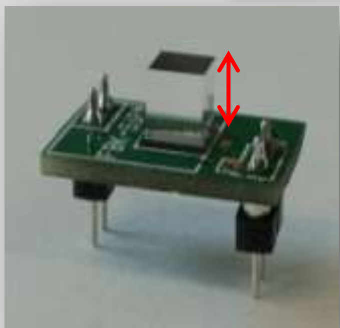






Detectors tested

Detector "cube"

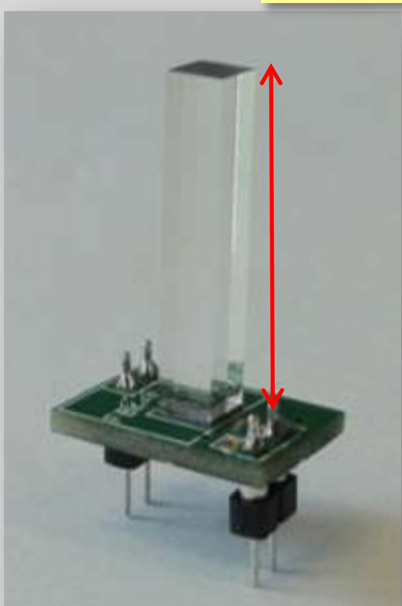


LYSO crystal 3x3x5mm^3

height ~ side

to test ultimate SiPM performance

Detector "PET"



LYSO crystal 3x3x15mm^3

height ~ 5 x side

real PET configuration (timing affected by light propagation in crystal)

SiPMs used

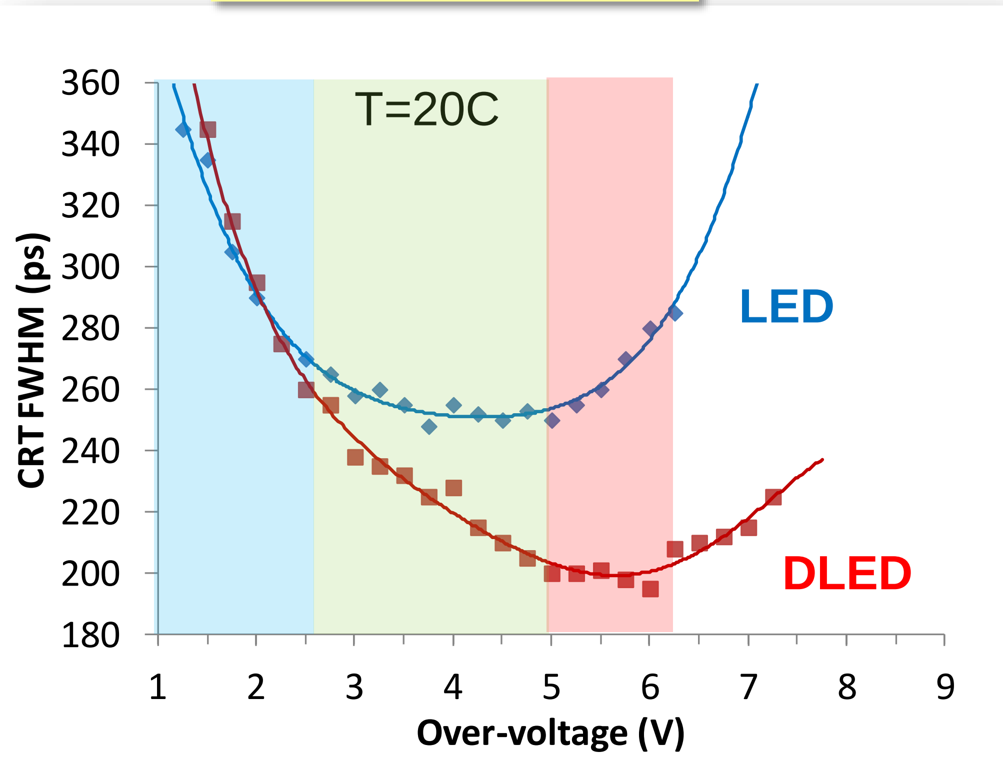
- **3x3mm^2**
- **4x4mm^2**

67um cell-size

produced by FBK, Trento

DLED vs LED performance

Detector cube, 3x3mm^2 SiPM



DLED ΔT=500ps good up to 1ns

Low over-voltage:
low gain, low dark rate
➔ electronic noise dominates
➔ DLED slightly worse than LED

Medium over-voltage:
gain increases
dark noise ampl. > elect. noise
➔LED is flat (increase of PDE is compensated by increase of noise)
➔ DLED improves following PDE

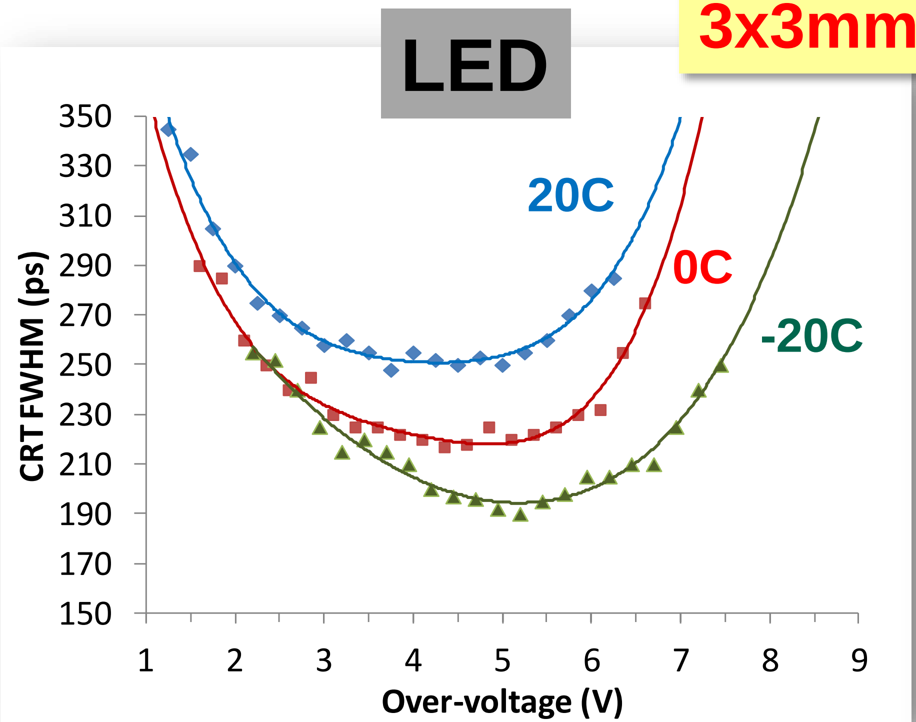
High over-voltage:
high dark noise/rate
➔ LED starts deteriorating
➔ DLED still improves for high PDE and good noise compensation

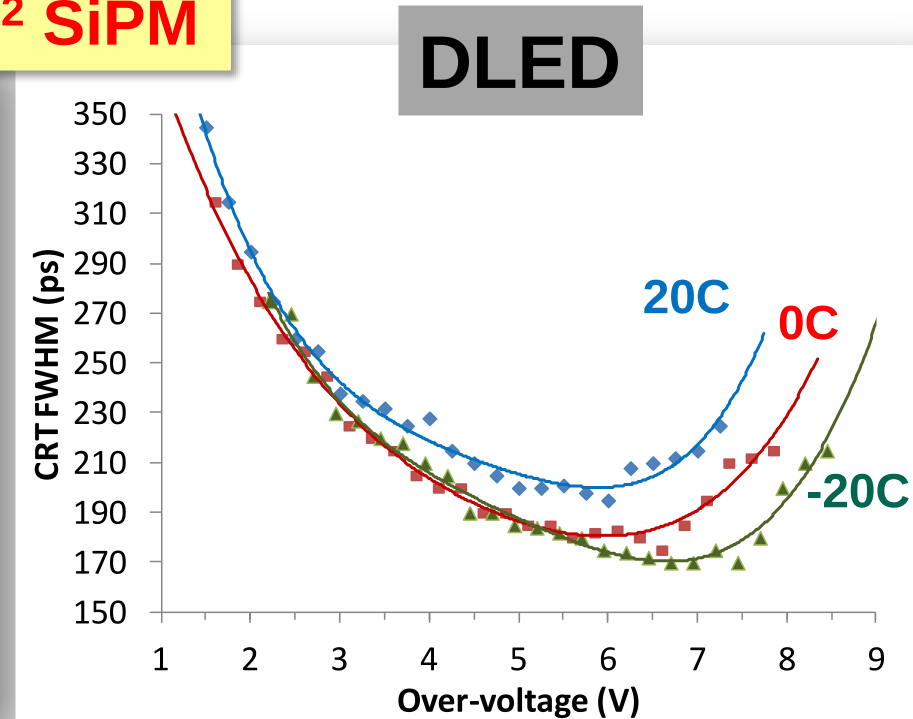
In the next slides:

- CRT vs Temperature
- Threshold level
- crystal height
- SiPM size

CRT vs Temperature

Detector cube 3x3mm² SiPM





LED strongly improves with temperature because of noise reduction.

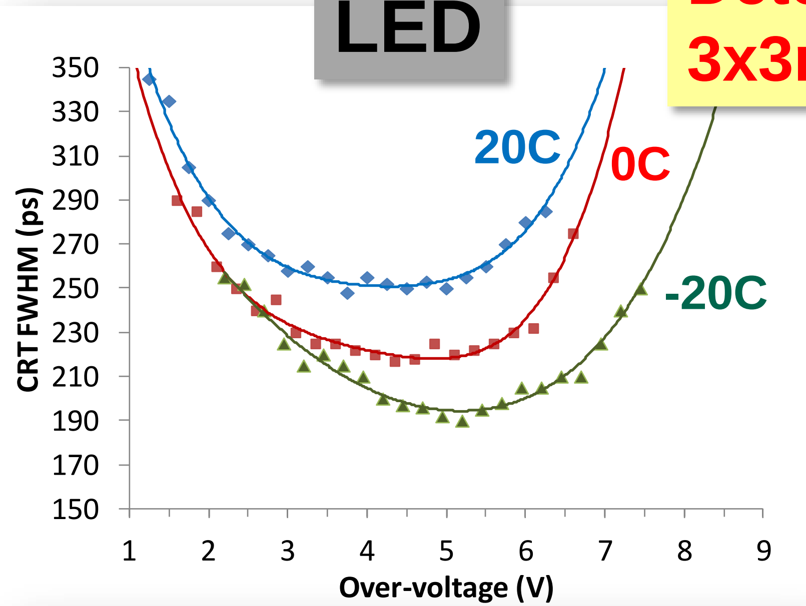
DLED improves less with temperature and only at high over-voltages.

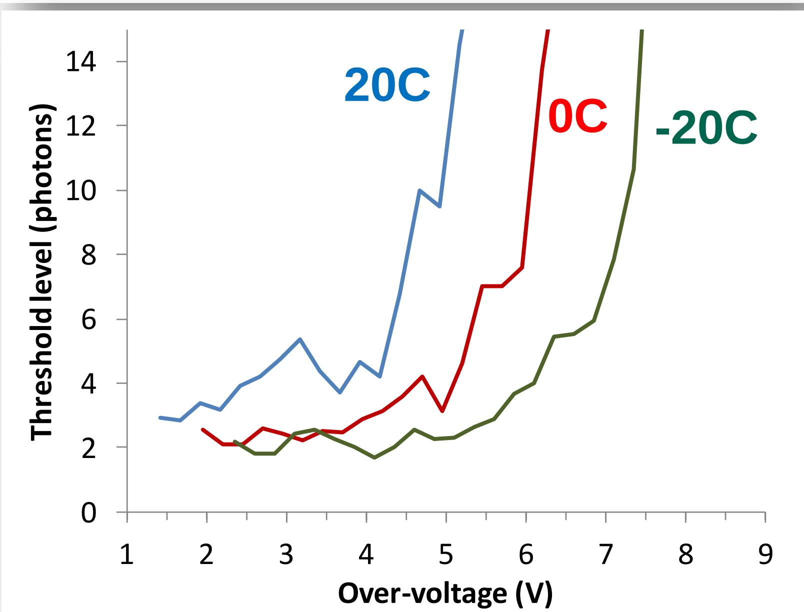
LED@ -20C is nearly equivalent to DLED@20C

Optimum Threshold level

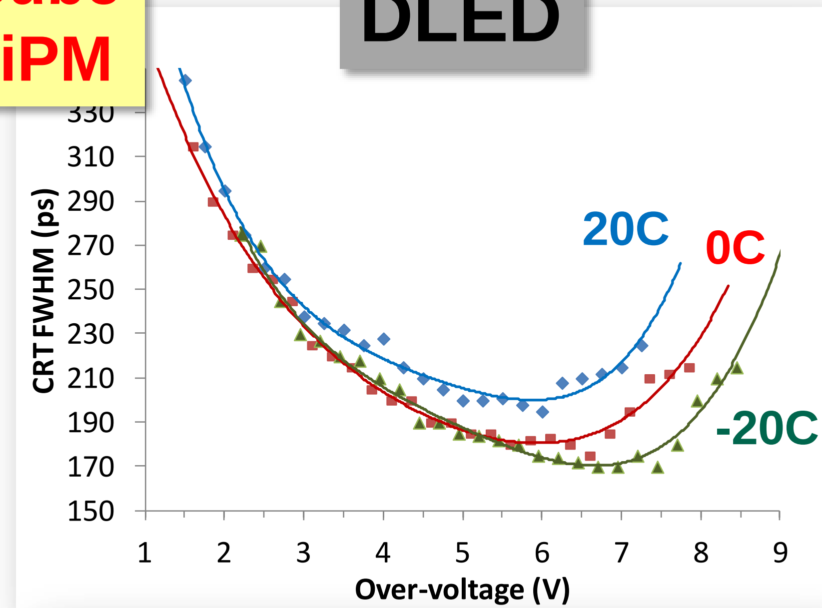
Detector cube 3x3mm² SiPM

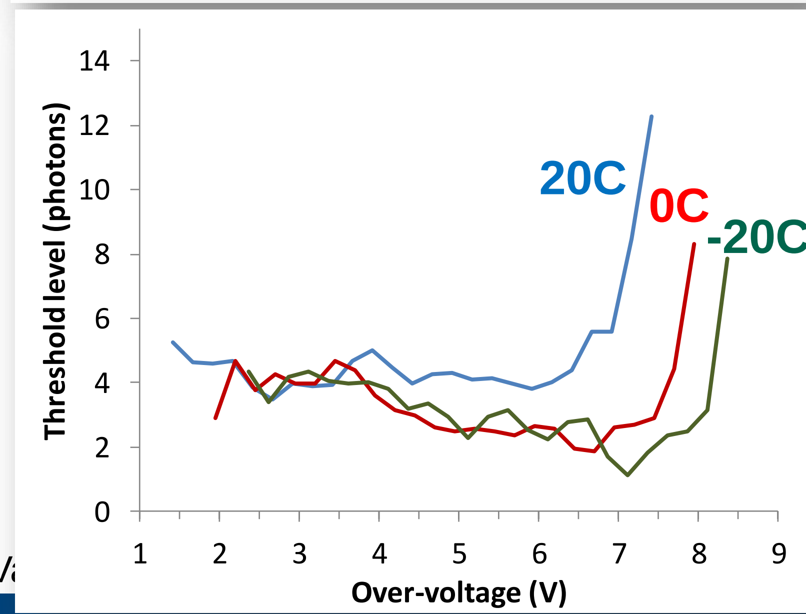
LED



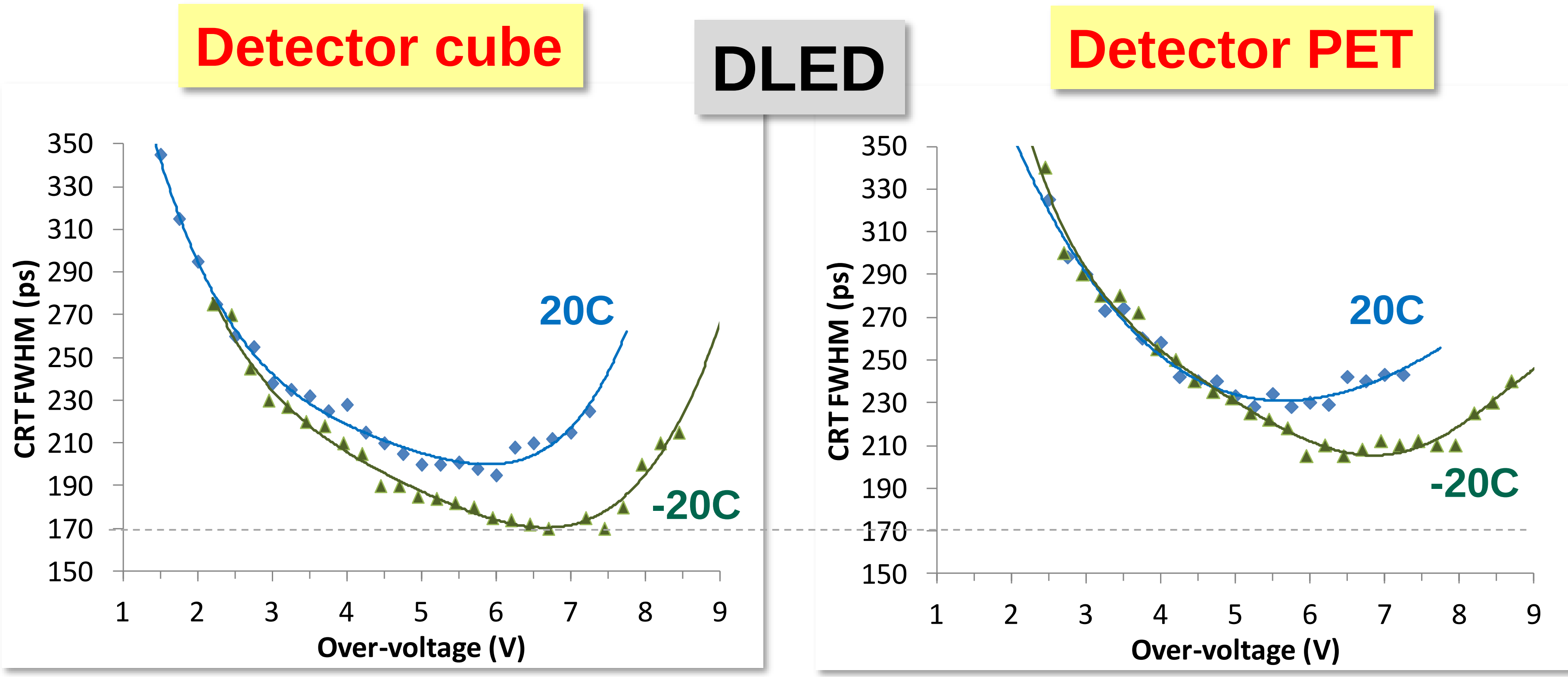


DLED





DLED – crystal thickness



As expected, with thicker crystal the timing performance degrades, still reaching 230ps at 20C.

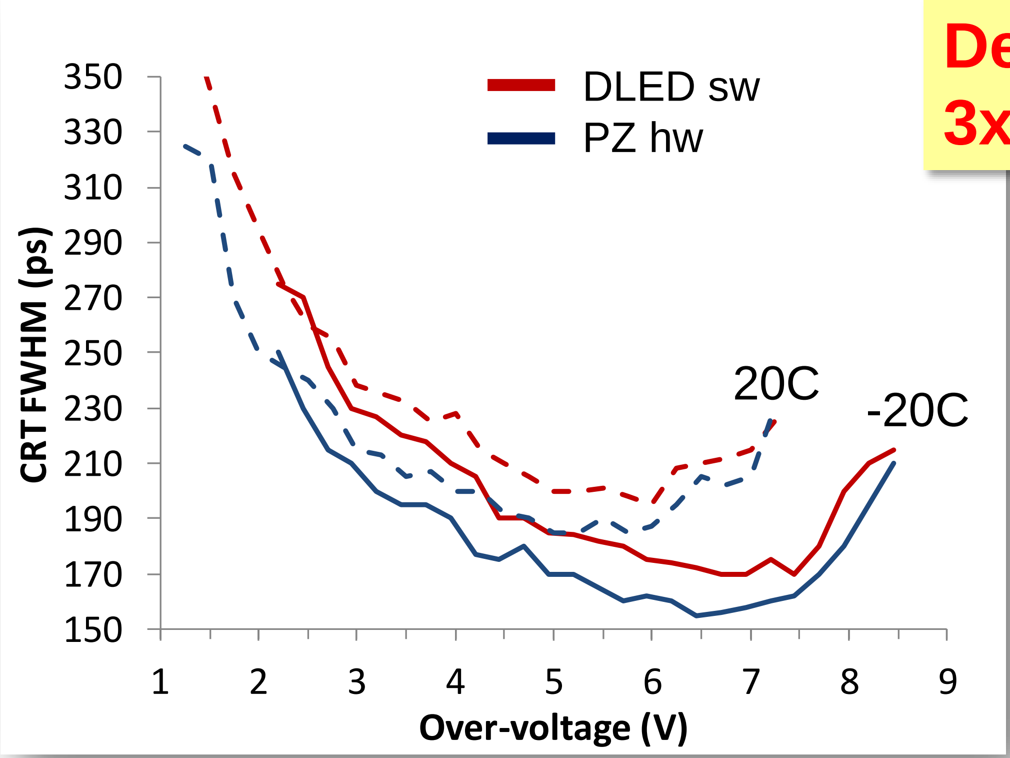
Summary of results with DLED

CRT FWHM (ps)

	T = 20C		T = -20C	
	$3x3mm^2$ SiPM	$4x4mm^2$ SiPM	$3x3mm^2$ SiPM	$4x4mm^2$ SiPM
Cube **($3x3x5mm^3$ LYSO)**	200	190	170	165
PET **($3x3x15mm^3$ LYSO)**	230	230	210	210

Hardware implementation

We implemented a simple hardware baseline compensation to be implemented eventually in an ASIC. Results are very promising, even better than DLED sw.



Detector cube $3x3mm^2$ SiPM

Details in poster n. NP2.S-51

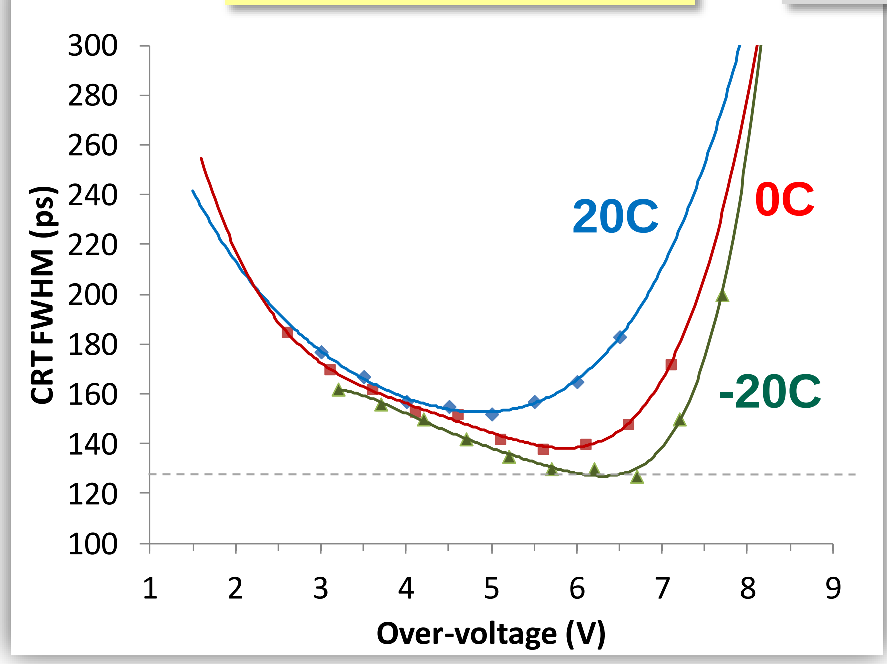
Latest timing results

preliminary

New 2.2x2.2mm^2 SiPM with enhanced fill factor has been produced by FBK: ~65% on a 50x50um^2 cell.

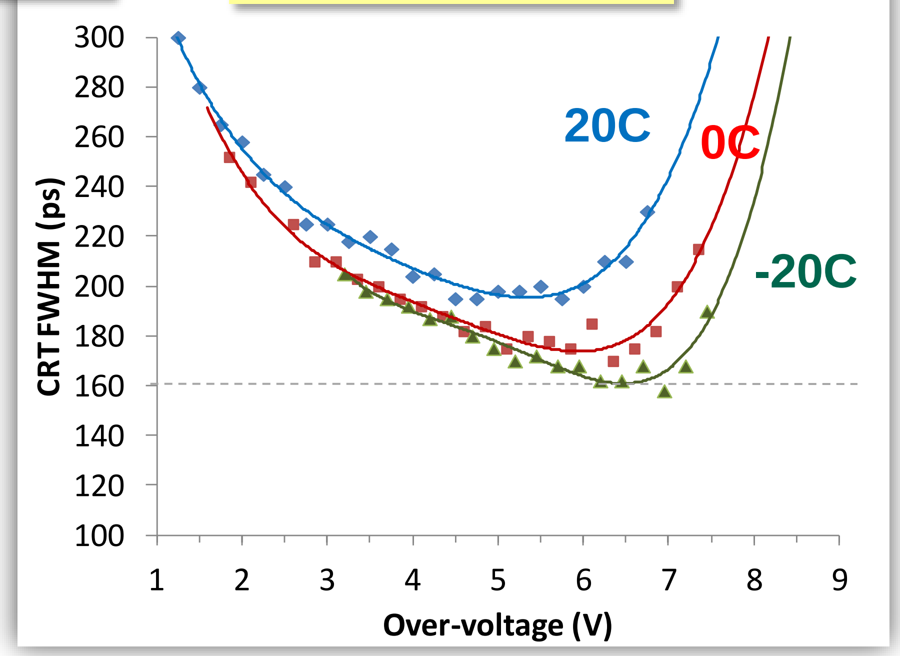
DLED

Detector cube



LYSO: 1.8x1.8x2mm^3

Detector PET



LYSO: 1.8x1.8x10mm^3

Quite impressive results!!

Conclusion

We demonstrated that the **effect of dark noise** on timing measurements with SiPM coupled to LYSO crystal **can be largely compensated**.

FBK technology allows a very competitive TOF performance that can lead to strong improvements in TOF-PET compared to present systems

In poster **NP2.S-51** we show that a **simple hardware noise compensation can be implemented in an ASIC**

New developments are on-going to reach even better values…

Acknowledgments

HyperImage project

SUBLIMA project

FBK-INFN MEMS2 agreement