FRONTIER DETECTORS FOR FRONTIER PHYSICS

20-26 May 2012

La Biodola, Isola d'Elba, Italy

Accurate modeling

POLITECNICO DI BARI
I Facoltà di Ingegneria

# of SiPM detectors coupled to timing performance analysis

F. Ciciriello°, F. Corsi°, F. Licciulli°, C. Marzocca°, G. Matarrese°,
A. Del Guerra*, M. G. Bisogni*

°DEE – Politecnico di Bari and INFN Sezione di Bari, Italy
**Università di Pisa and INFN Sezione di Pisa, Italy*

FE electronics for

Abstract

- The shape of the current pulse produced by a SiPM in response to an incident photon is sensibly affected by the characteristics of the FE used to read out the detector.

- An accurate modeling of the SiPM is thus mandatory to identify the best solutions and design parameters of the FE.

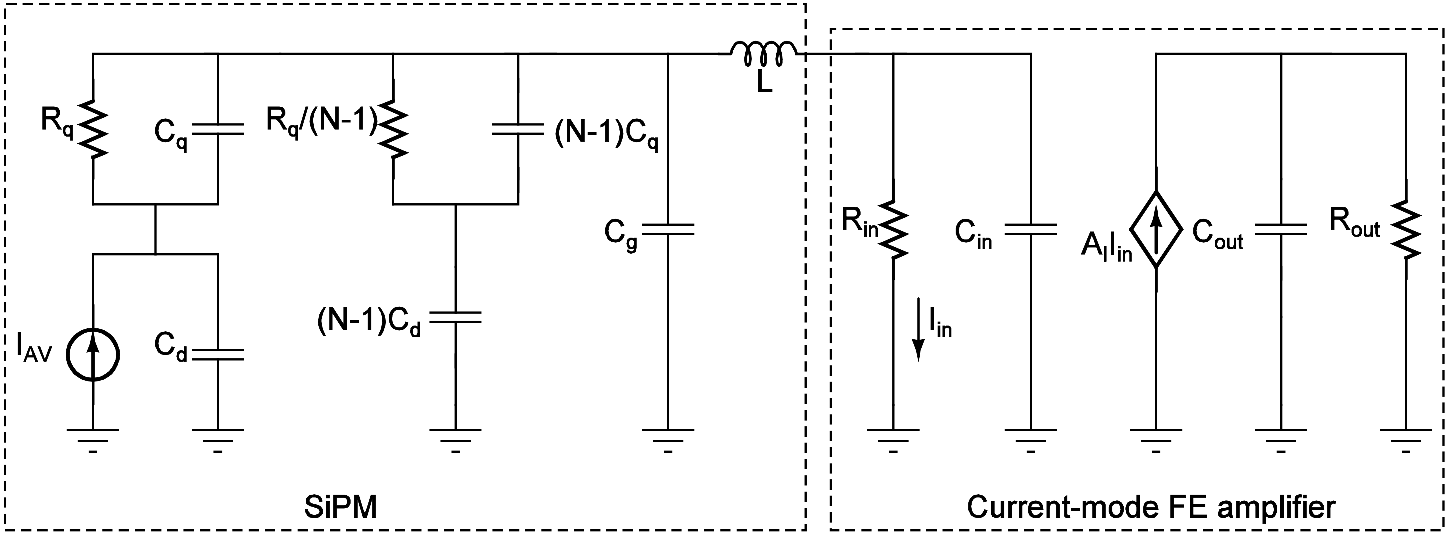
- To approach the best theoretical time performance of the detection system, the influence of all the parasitics associated to the coupling SiPM – FE must be adequately modeled.

- In this contribution, we extend the validity of a previously presented SiPM model to account for the parasitic inductance of the wiring connection between SiPM and FE.

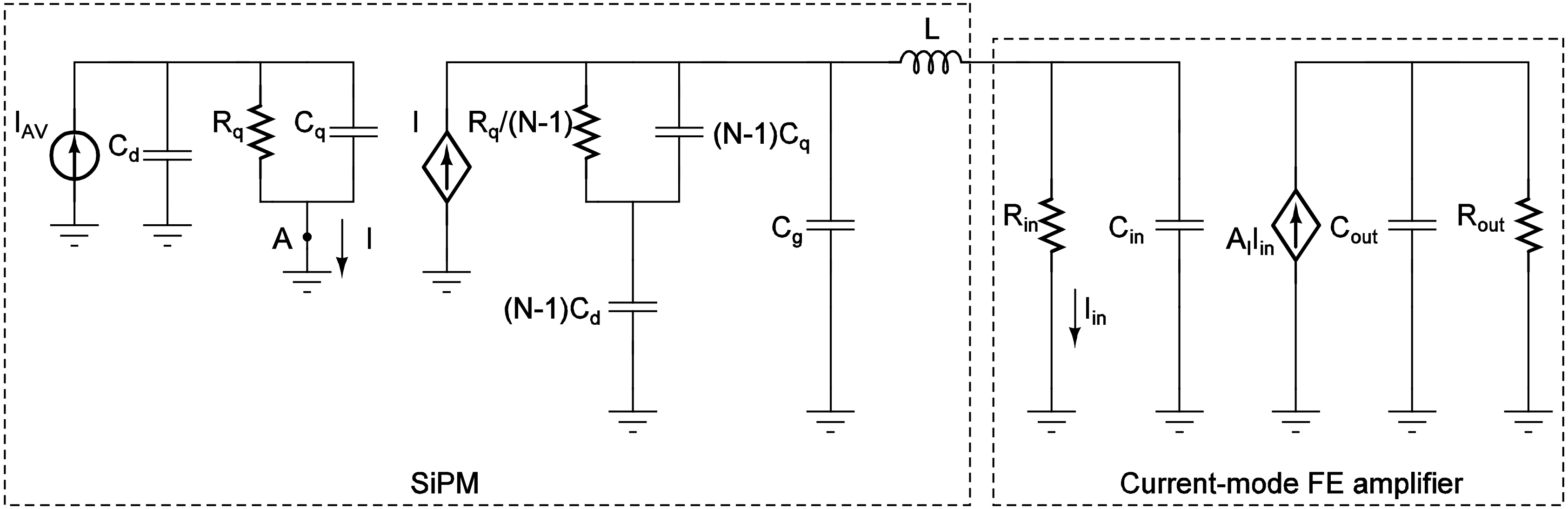
- Monte Carlo simulations have been employed to evaluate a number of realistic sets of arrival times for the first scintillating photons on the SiPM.

- Various combinations of the main performance parameters of the FE (input resistance R_{in} and bandwidth BW) have been simulated to evaluate their influence on the time accuracy of the detection system, when the time pick-off of each single event is extracted by means of a Leading Edge Discriminator.

Modeling the SiPM coupled to the FE



Complete model



Simplified model

Model parameters

R_q: quenching resistor (hundreds of kΩ)

C_d: photodiode capacitance (few tens of fF)

C_q: parasitic capacitance in parallel to R_q (smaller than C_d)

I_{AV}: short current pulse modeling the total charge delivered by a micro-cell during the avalanche

C_g: parasitic capacitance, due to the large metal grid used for routing the N micro-cells to V_{BIAS} (few tens of pF)

L: parasitic wiring inductance (from few nH to tens of nH)

Model parameters

- Extraction procedure applied to a 3 X 3 mm^2 SiPM with 3600 micro-cells from Hamamatsu
- The table summarizes the main features of the device and the results obtained

Model Parameter	SiPM HAMAMATSU N=3600, V_{bias}=73V
R_q	182.6 kΩ
V_{br}	70.68 V
Q	216.9 fC
C_d	75.2 fF
C_q	17.7 fF
C_g	36.9 pF

L 3 nH ÷ 15 nH

High level description of the system: transfer function

$$I_{in}(s) = Q_{tot} \cdot \frac{1 + s\tau_q}{a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0}$$

Analytical expression of the response to a single fired μ-cell

$$a_4 = L\tau_{in}\left[\left(C_g + NC_d\right)\tau_q + R_q C_d C_g\right]$$

$$a_3 = L\left[\left(C_g + NC_d\right)\left(\tau_{in} + \tau_q\right) + R_q C_d C_g\right]$$

$$a_2 = \tau_{in}\tau_r + C_g\left(R_{in}\tau_r + L\right) + NC_d\left(R_{in}\tau_q + L\right)$$

$$a_1 = \tau_{in} + \tau_r + R_{in}\left(C_g + NC_d\right)$$

$$a_0 = 1$$

$$Q_{tot} = \left(V_{bias} - V_{br}\right)\left(C_d - C_q\right)$$

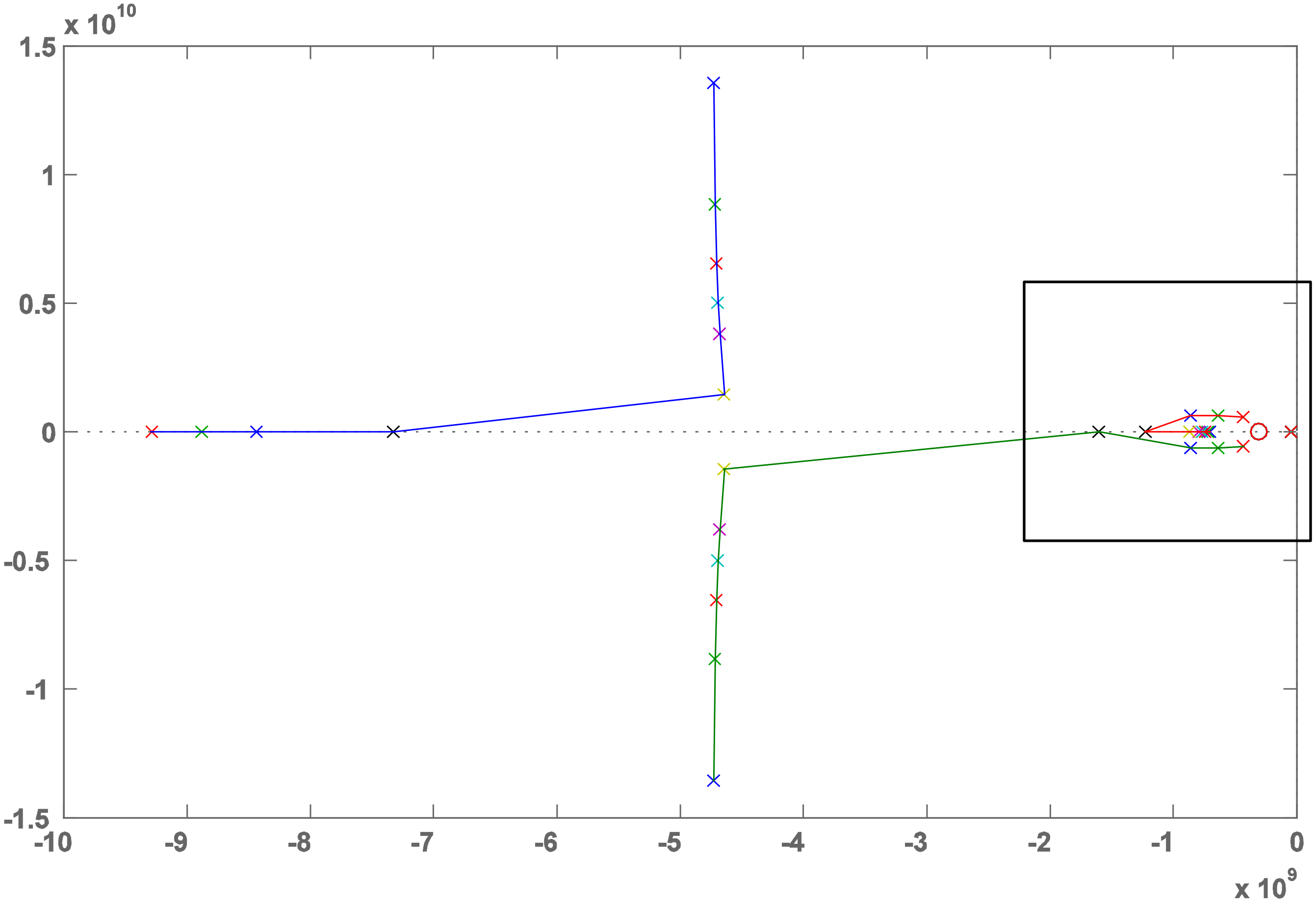
$$\tau_{in} = R_{in} C_{in}$$

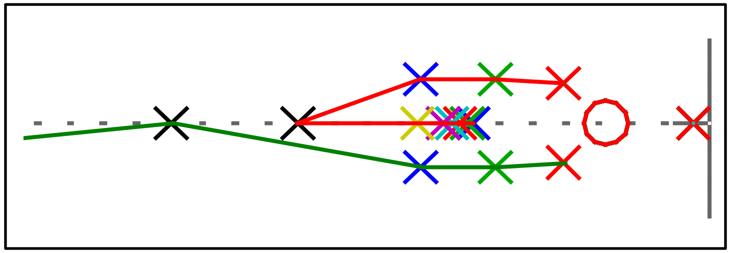
$$\tau_q = R_q C_q$$

$$\tau_r = R_q\left(C_d + C_q\right)$$

Very good agreement between MATLAB and Pspice simulations!

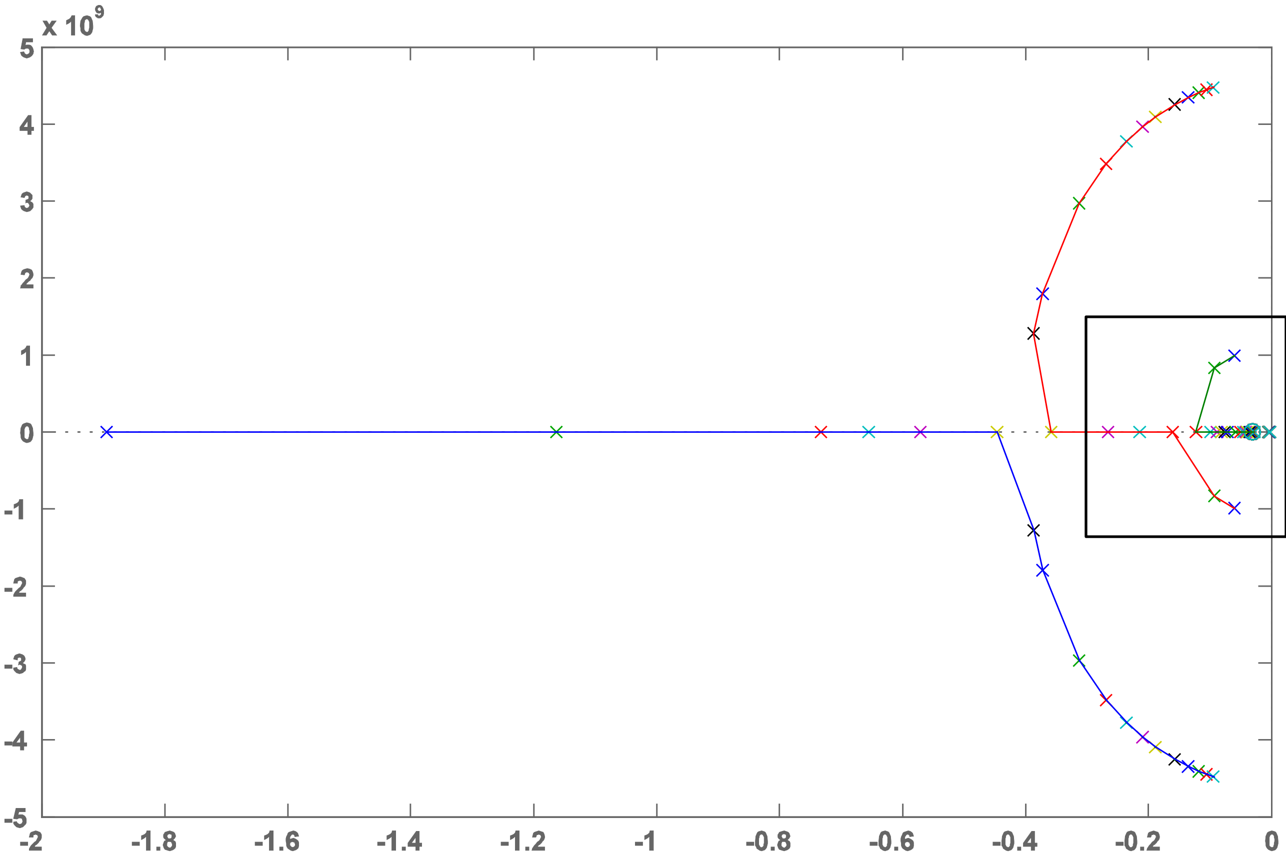
Poles and zeroes evaluation

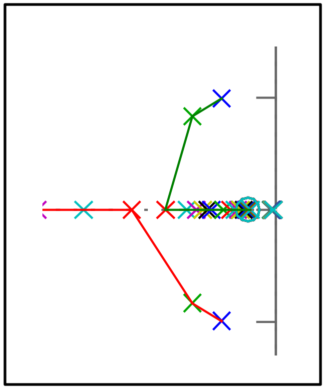




Root contour for BW = 300 MHz, R_{in} = 20 Ω and L = 1 nH ÷ 30 nH

Poles and zeroes evaluation

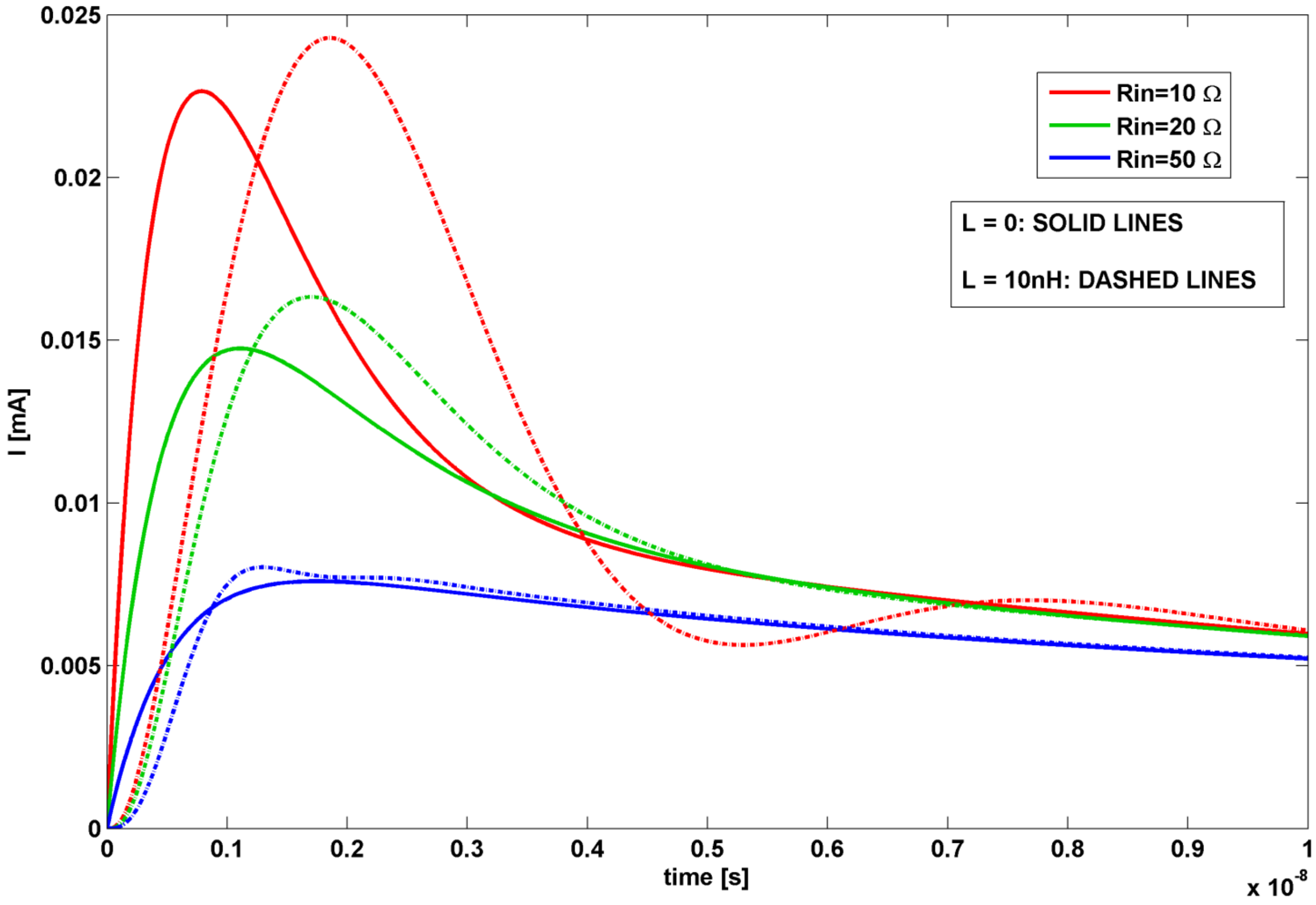




Root contour for BW = 300 MHz,
L = 10 nH and R_{in} = 10 Ω ÷ 100 Ω

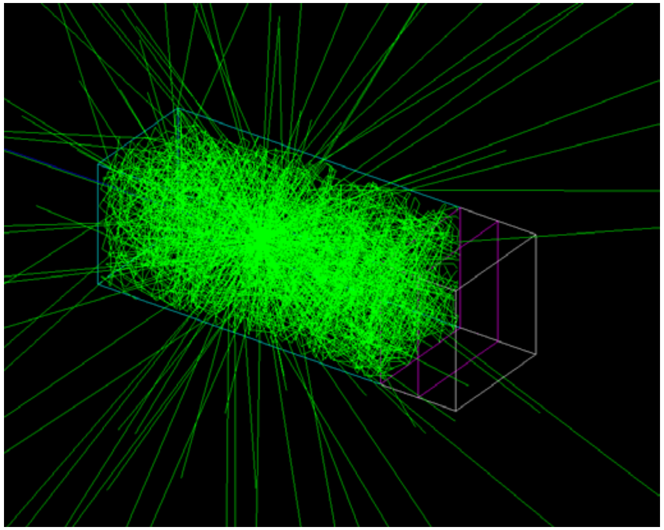
Influence of L on the waveform of the elementary current pulses

Elementary current pulses produced by the SiPM for BW = 300 MHz and different values of R_{in} and L



Evaluation of realistic arrival times

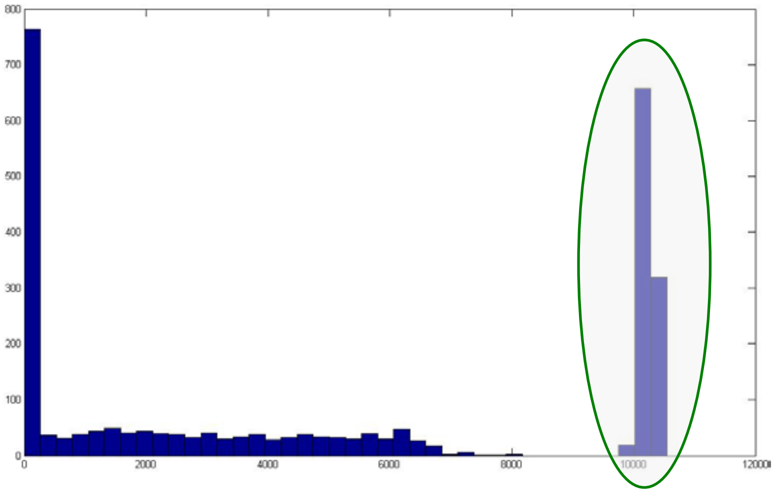
The Geant4 simulator has been used for the MC simulations



Example of Geant4 simulation

Parameters of the scintillator

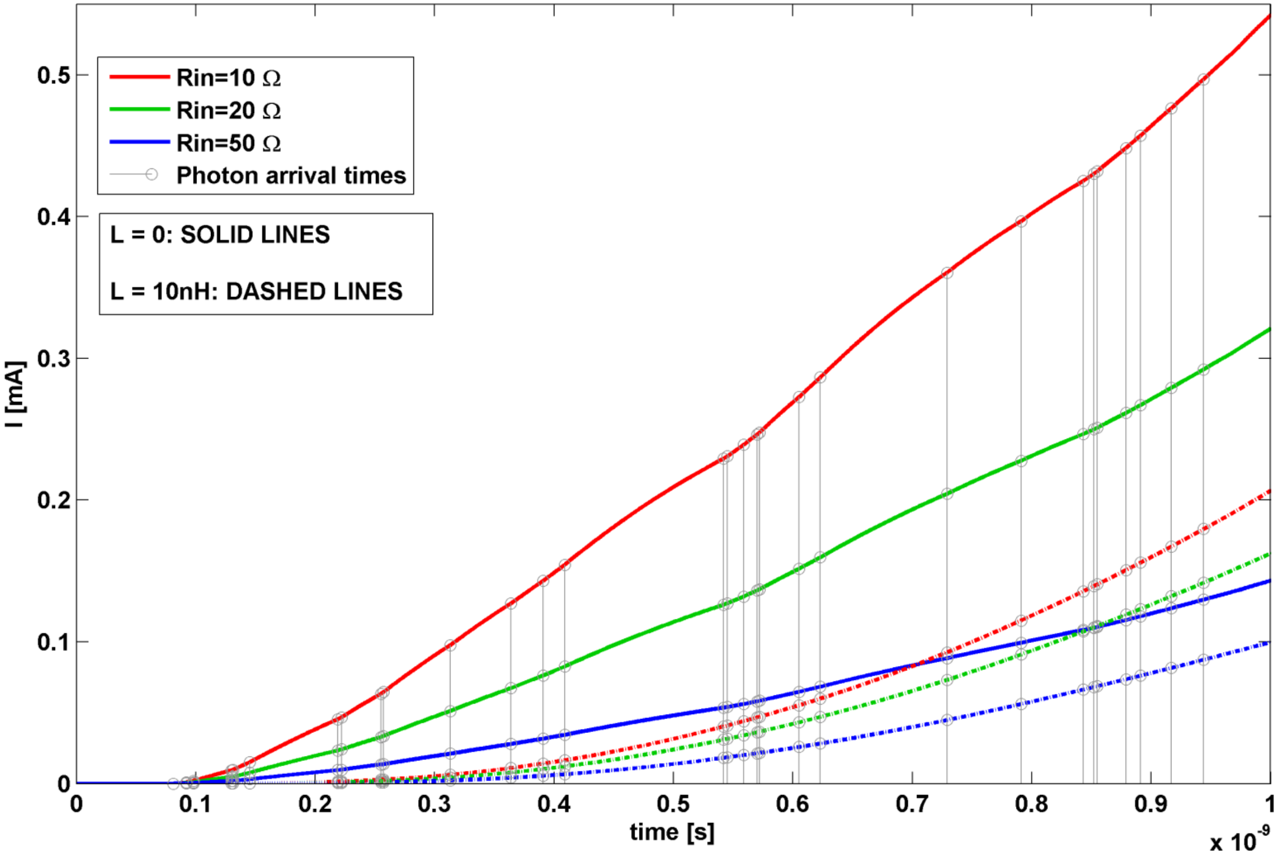
- **LSO, non-wrapped**
- **Size: 3 x 3 x 15 mm^3;**
- **Refraction index = 1.82;**
- **Light yield = 20000 ph/MeV;**
- **Decay time constant τ_{DEC} = 40 ns.**



Distribution of the no. of generated photons
(only the highlighted events have been considered)

SiPM 3x3 mm^2
PDE = 20%

Composition of elementary current pulses



Waveforms of the SiPM current pulse produced by the first 20-30 photons for different values of R_{in} and L.

Evaluation of the time resolution

CRT for different values of R_{in}, L and BW for a $3X3X15mm^3$ LSO crystal coupled to a 3600μ-cells SiPM

CRT [ps]	**R_{in}=10Ω BW=80MHz**	**R_{in} =10Ω BW=300MHz**	**R_{in} =20Ω BW=80MHz**	**R_{in} =20Ω BW=300MHz**	**R_{in} =50Ω BW=80MHz**	**R_{in} =50Ω BW=300MHz**
L=0	197	176	211	184	227	192
L=1nH	193	176	199	174	213	174
L=5nH	219	204	216	197	216	191
L=10nH	237	218	231	211	227	203

Conclusions

- **A simulation environment has been devised and implemented to account for the effects of the coupling inductance between the SiPM and the FE.**

- **The parasitic inductance of the wire connecting the SiPM to the FE sensibly affects the shape of the elementary current pulses produced by the device.**

- **The combination of the electrical parameters of the equivalent circuit including the SiPM, the FE and the coupling inductance between them may give rise to pairs complex conjugate poles, thus producing ringing in the shape of the elementary pulses.**

- **The knowledge of the value of this inductance would allow the FE designer to choose the FE parameters (R_{in}, BW) for optimal timing performance.**

- **It appears that a careful choice of the LED threshold is needed to achieve the best time resolution.**

References

[1] F. Corsi, C. Marzocca et al.: "Modelling a Silicon Photomultiplier (Sipm) as a Signal Source For Optimum Front-End Design", Nuclear Instruments and Methods in Physics Research A, vol. A572, pag. 416-418, 2007.

[2] J. Huizenga, S.Seifert et al.: "A fast preamplifier concept for SiPM-based time-of-flight PET detectors", Nucl. Instr. and Met. in Phys. Res. A, (2011), doi:10.1016/ j.nima.2011.11.012.

[3] F. Ciciriello, F. Corsi, F. Licciulli, C. Marzocca, G. Matarrese:"Assessing the time resolution of an integrated front-end for solid state radiation detectors" , IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2011, pp. 1678- 1682..

[4] F.Powolny et al., "Time Based Readout of a Silicon Photomultiplier (SiPM) for Time of Flight Positron Emission Tomography (TOF-PET)" IEEE Trans. on Nuclear Science,vol. 58,n.3, pp. 597-604, 2011.