PADI – new models

Mircea Ciobanu for the CBM - ToF group

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Introduction

The planned time-of-flight wall of the CBM experiment at the future FAIR facility requires a full-system time resolution (σ) better than 80 ps – with more than 100,000 channels and event rates of up to 300 kHz per channel. The planned detectors are Resistive-Plate Chambers (RPCs) with electrodes either as strips (read out at both ends) or in pad form.

RPCs deliver very fast pulses when an ionizing particle passes through them. Typical signal parameters of the 50 Ω narrow strip electrodes (2.54 mm pitch) are: rise time ~ 0.3 ns, FWHM ~ 1 - 2 ns, fall time ~ 0.3 ns.

We started the design of a customized ASIC (in UMC 180 nm technology) named PADI after testing and analyzing the first chip specialized in time measurements NINO [1], an 8-channel ASIC amplifier-discriminator chip, developed for the ALICE experiment at CERN. PADI was designed to be coupled with the GET-4 time-to-digital converter (TDC) [2], whose design began at the same time. The evolution of the PADI project from PADI-1 to PADI-8 is described in detail in [3], [4] and [5], with the presentation of the block diagram and the detailed schematic of important cells together with obtained performances both at cell and at whole ensemble level.

[1] F.Anghinolfi et al.," NINO: An Ultrafast Low-Power Front-End Amplifier Discriminator for the Time-of-Flight Detector in the ALICE Experiment", *IEEE Trans. on NS*, Volume 51, Issue 5, pp. 1974 – 1978, Oct. **2004**.

[2] H.Flemming and H.Deppe, "The GSI Event-Driven TDC with 4 Channels GET-4", *IEEE N**SS** – conference record*, pp. 295-298. Published: **2009**

[3] M.Ciobanu et al.,"PADI, a fast Preamplifier – Discriminator for Time-of-Flight Measurements", *IEEE NSS Conference 2008, IEEE N**SS** – conference record*, pp. 1293-1299, Published: **2009**.

[4] M.Ciobanu et al., "PADI-2,-3 and -4: The second iteration of the Fast Preamplifier – Discriminator for Time-of-Flight Measurements at CBM", *IEEE NSS Conference 2009 record*, pp: 1300-1303, Published: **2009.**

[5] M.Ciobanu et al., "PADI, an Ultrafast Preamplifier - Discriminator ASIC for Time-of-Flight Measurements", IEEE TNS, Vol.61, No. 2, pp.1015-1023, **2014.**

[6] M.Ciobanu et al., "New Models of PADI, an Ultrafast Preamplifier - Discriminator ASIC for Time-of-Flight Measurements", IEEE TNS, DOI: 10.1109/TNS.2021.3073487, 15 April **2021.**

PADI - X

The PADI-X model is identical with PADI-8 [5] but it is encapsulated in QFN-64 package.

The main parameters are:

- 8 channels per chip, preamplifier (PA)
- PA Bandwidth ~ 411 MHz
- PA voltage gain ~ 250
- PA conversion gain ~ 30 mV/fC
- PA noise ~ 5.5 mVrms
- Threshold dynamics ~ +/- 750 mV
- Input impedance 50 – 400 Ω
- Power consumption ~ 17 mW/channel
- Output LVDS compatible

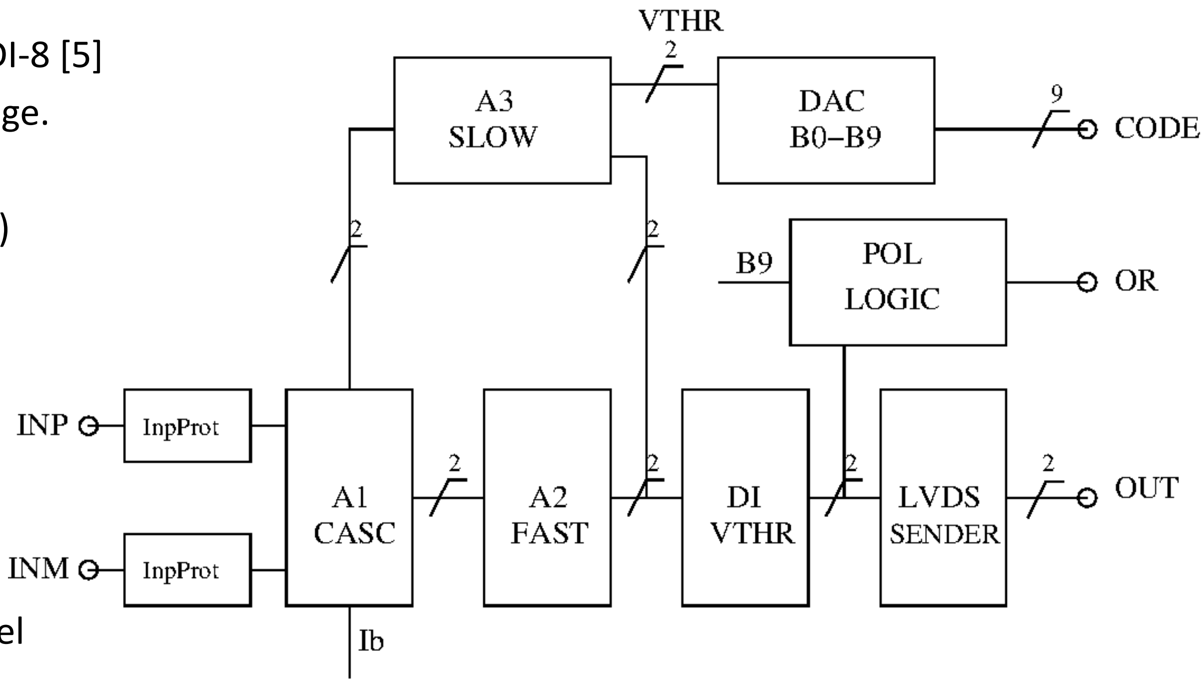


Fig. 1. Simplified block diagram of one PADI-X channel.

PADI – X simulation

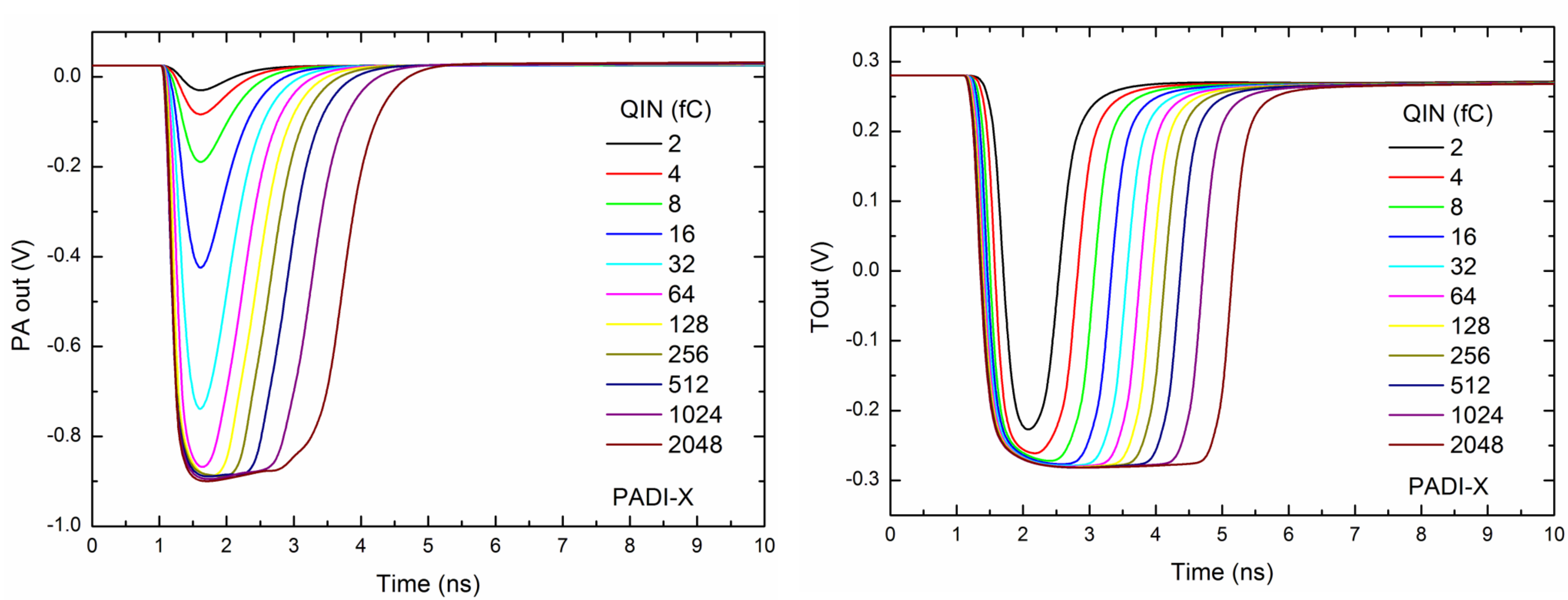


Fig. 3. The PA out and TOut response for input charge QIN swept from 2 fC to 2048 fC, threshold voltage VTHR = 25 mV.

PADI prototypes were used in the development of RPC detectors and very good results were obtained with detectors powered by two high voltage (+/- HV) sources. But economic considerations required the use of a single high voltage source to power the detectors, which led to the "folding" of the detectors. The final detectors have strips with characteristic impedance of around 25 Ohms. To adapt this impedance to the input impedance of the PADI, the FEE had to be placed close to the end of the detection strip, inside the metal box of the detector.

PADI - XI

PADI-XI had to fulfill two new objectives: halving the minimum input impedance (~ 50 Ω differential, for impedance match with the new RPC detectors) and introducing a stretcher to extend the width of the discriminated pulse, to increase the maximum cable length to the TDCs and allow the use of old TDCs.

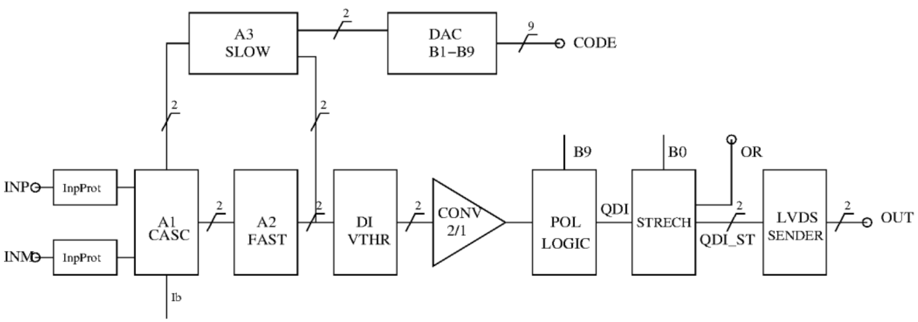


Fig. 3, Simplified block diagram of one PADI-XI channel.

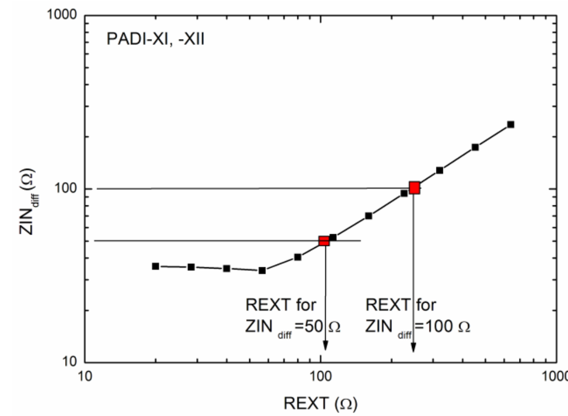
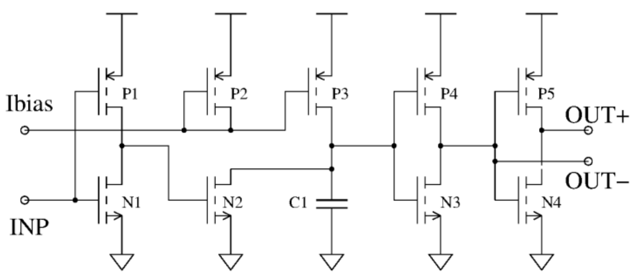


Fig. 5, The input differential impedance versus REXT.



	W (um)	L (um)	fin./val.	II No.
P1,4,5	2.88	0.18	2	1
P2	2.88	0.18	1	10
P3	2.88	0.18	1	1
N1,3,4	1.44	0.18	1	1
N2	1.44	0.18	3	1
C1	4.5	4.5	21.6 fF	1

Fig. 4, The diagram of STRECH cell.

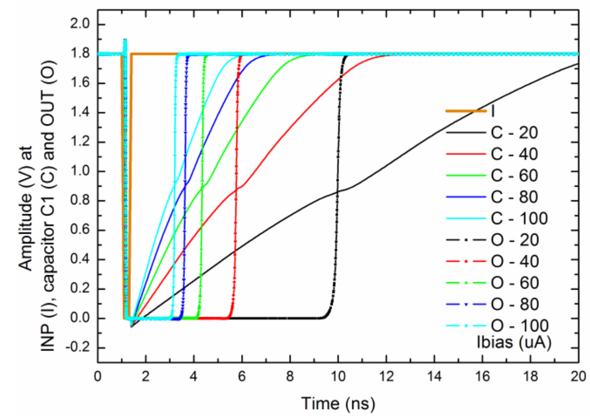
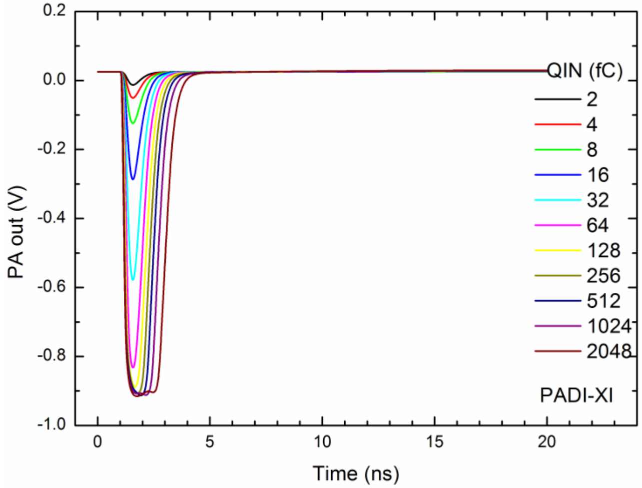


Fig. 6, STRECH cell: simulation.

PADI - XI



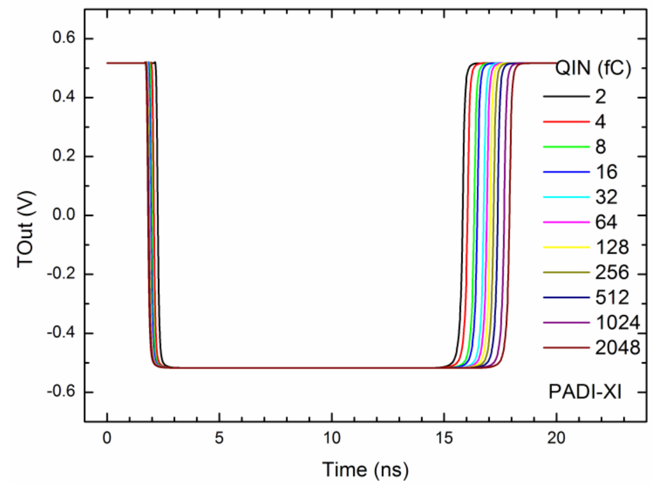


Fig. 7, Simulated response of PA out and Tout for QIN swept from 2 fC to 2048 fC; VTHR=25 mV, the stretched time is set to about 15 ns.

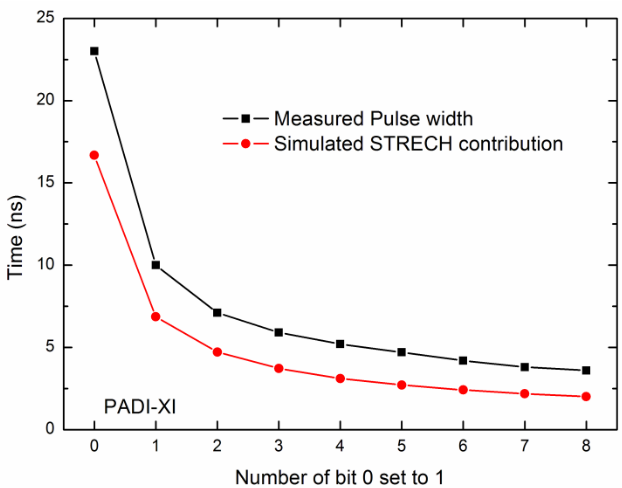


Fig. 8, The output pulse width depends on the number of bits B0 connected to 1 (at VDD).

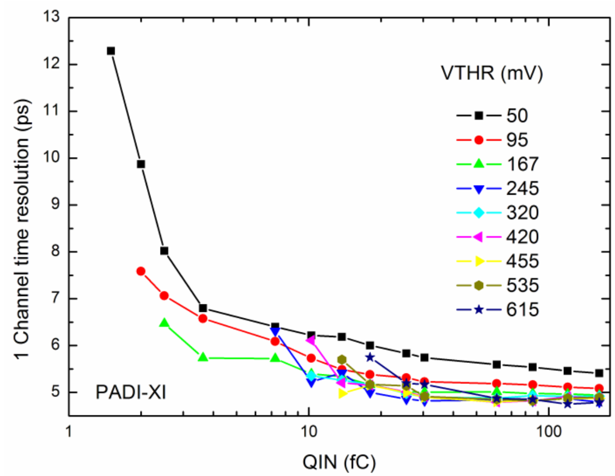
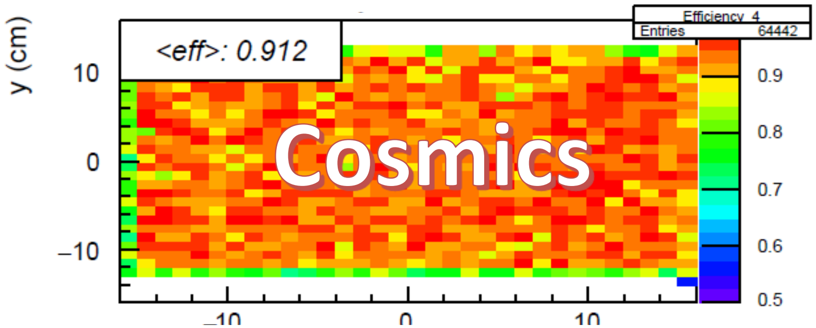
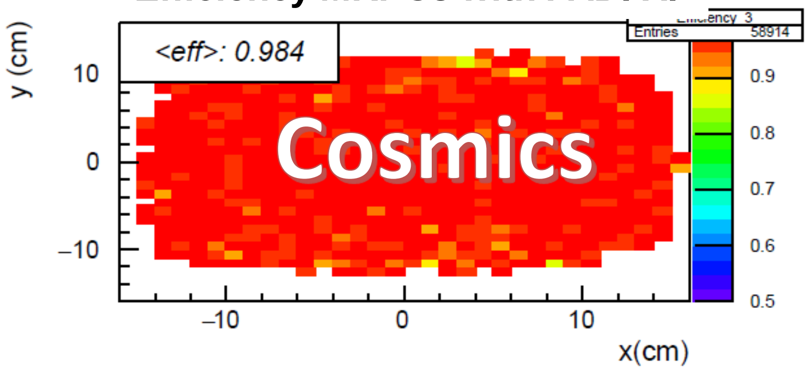


Fig. 9, 1 Channel PADI-XI and TDC time resolution.

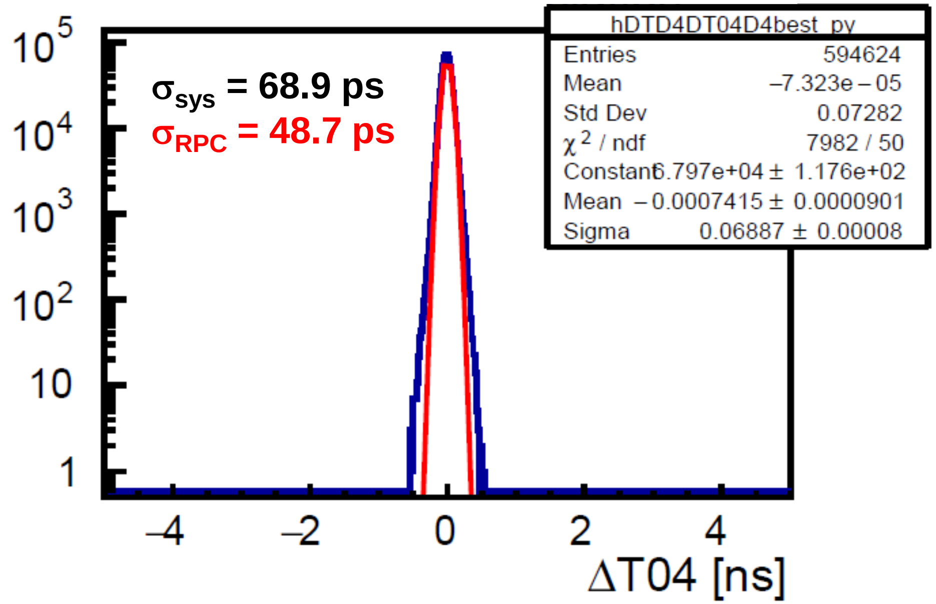
Efficiency MRPC3 with PADI X

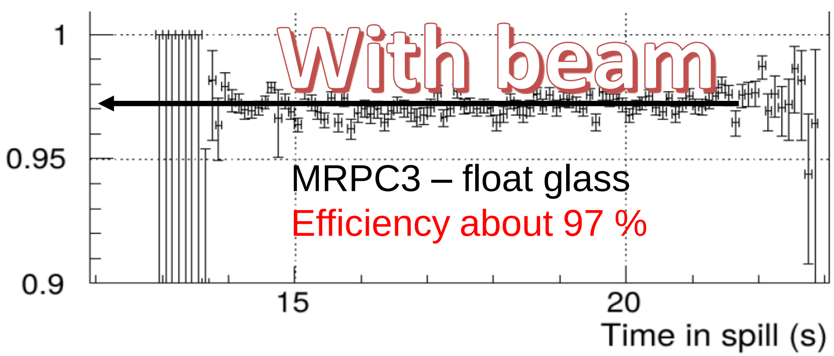


Efficiency MRPC3 with PADI XI



Time resolution of MRPC2 with PADI XI





Efficiency Bucharest counter

Efficiency	Gap 140 µm	Gap 200 µm
PADI X	81 %	93 %
PAD XI	92 %	98 %

Preliminary

PADI - XII

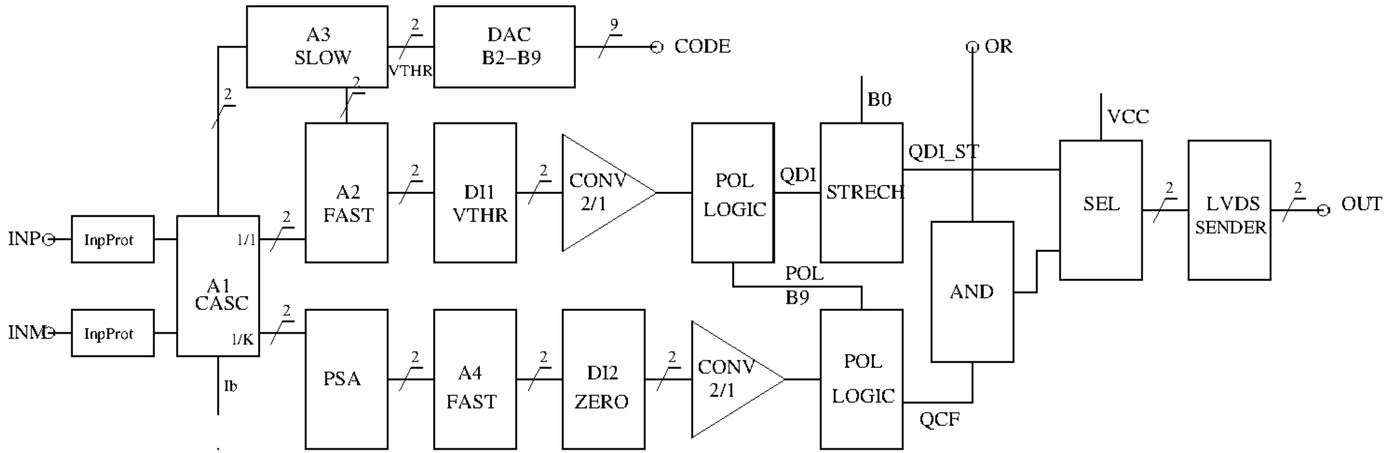


Fig. 10, Simplified block diagram of one PADI-XII channel.

PADI-XII was designed to allow the hardware selection of the number of channels used, 4 or 8, and the working mode, leading edge detection (LED) or pulse shape analysis (PSA). For this, the supply voltages of the two groups of channels (1-4, 5-8) as well as of the additional cells involved only in the PSA modes were mapped separately.

The input A1 cell is modified by adding a current dividing element to enable two outputs: the normal output (1/1) and the divided output (1/K). Due to the 1/K current division, the active elements in A4 amplifier remain in linear regime for the full input charge range.

The 1/K output is applied to PSA, a cell using resistors and capacitors elements (see Fig. 14). In the PSA cell, the bipolar output signal is obtained by subtracting the differentiation from the integration of the 1 / K output of the cascode.

PADI - XII

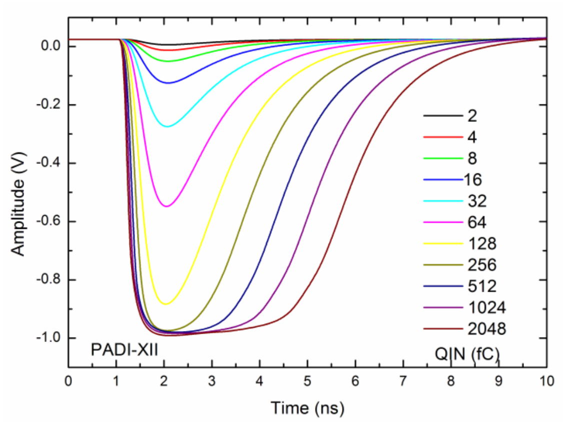


Fig. 11, PADI-XII , PA 1/1 out, QIN swept from 2 to 2048 fC

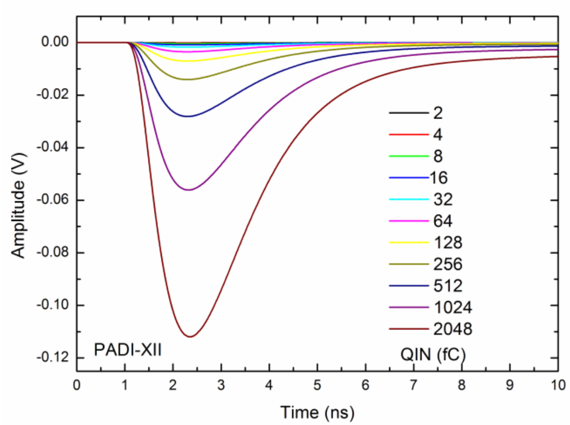


Fig. 12, PADI-XII , PA 1/K out, QIN swept from 2 to 2048 fC

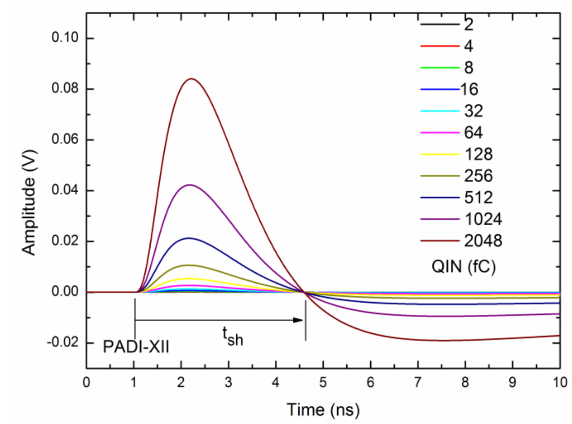
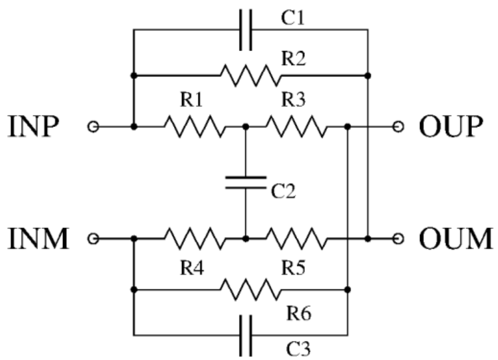


Fig. 13, PADI-XII , PSA out, QIN swept from 2 to 2048 fC



	W (um)	L (um)	val.
C1,3	20	22,2	0.45p
C2	20	13.8	0.281p
R1,3,4,5	1.6	15.15	10k
R2,6	0.86	3x15.08	60K

Fig. 14 PADI-XII , PSA schematic

As shown in Fig. 11, the 1/1 output signal has a brutal change of shape. The 1/K output is smooth and more convenient to be processed further (see Fig. 12).

In Fig. 13, the input charge is swept from 2 fC to 2048 fC. The delay of zero crossing, t_{sh} is independent of the signal amplitude but depends on the signal shape (see Fig.17).

PADI - XII

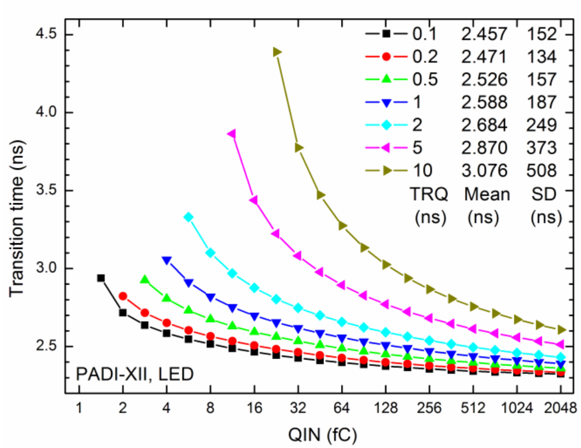


Fig. 15, PADI-XII in LED mode. TOut for QIN swept from 1 fC to 2048 fC, for 7 TRQ parameters.

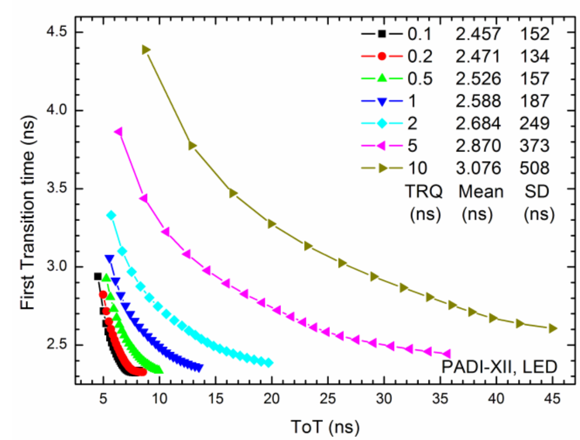


Fig. 16, PADI-XII in LED mode. TOut versus ToT with same QIN and TRQ parameters

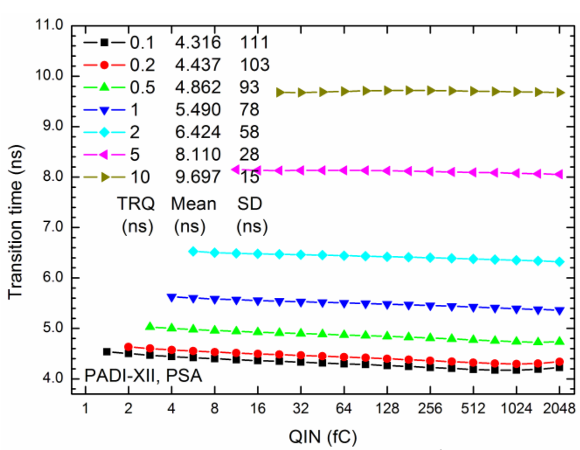


Fig. 17, PADI-XII in PSA mode. TOut versus QIN with same QIN and TRQ parameters

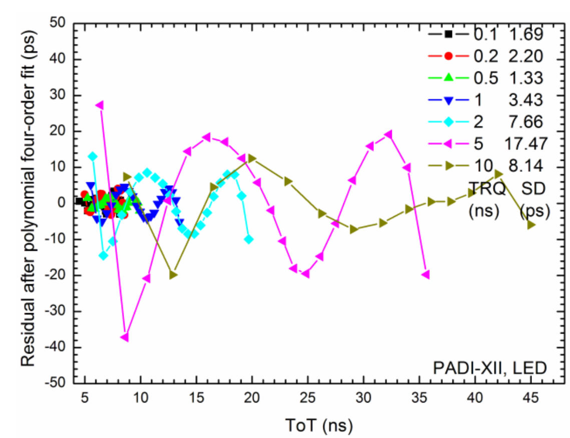


Fig. 18, PADI-XII in LED mode. Residual after polynomial four – order fit of data from Fig. 16.

Summary

• PADI-X was used in a very important application, namely the upgrade with the eTOF detector of the STAR experiment (Brookhaven National Laboratory)._More recently, PADI-X has been identified, selected and qualified as FEE for the PEP/JDC instrument of the JUICE mission.

• PADI-X and -XI were included in a set-up for long-term cosmic ray tests. The mCBM assembly was tested in several beam instances that confirmed the ability to meet the final requirements of the CBM experiment.

• The design stage of the PADI-XII project is concluded and the prototype batch is currently under production. It represents a new attempt to integrate all cells in a multichannel ASIC: preamplifier, discriminator and the Pulse Shape Analysis.

Table 1 summarizes the power consumption simulations for PADI-X, PADI-XI and PADI-XII configured hardware for 4 or 8 channels, in mode leading edge detection (LED) or pulse shape analysis (PSA).

Power cons./ PADI type (mode)	PADI - X	PADI - XI	PADI – XI (LED)	PADI – XI (PSA)
Power cons. (mW) For 4 channels	-	-	122.7	160.5
Power cons. (mW) For 8 channels	135	174.8	192.1	253.5

• Part of this work was supported by the Core Program of the Romanian Ministry of Research and by ESA's – PRODEX program through the PADI project, contract 4000128741.