The PADI ASIC for Time of Flight (ToF) measurements.

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In this paper we recommend the PADI (preamplifier-discriminator) ASIC for future time of flight (ToF) measurements in space experiments.
We present our first trials in ToF measurements, the FEE1 and FEE5 PCB's developed for the upgrade of ToF measurements in FOPI detector (GSI-Darmstadt). We have obtained an excellent time resolution (at ~ ps level) but the power consumption was 1.8 W/Ch (for FEE1) and 0.5 W/Ch (for FEE5), totally unsatisfactory for large channel number applications. We decide to design a specialized ASIC and we present the main stages of the PADI ASIC development (present power consumption ~ 17mW/Ch).
This ASIC has been developed for large physics experiments: the future FAIR ensemble (at GSI-Darmstadt, Germany) will host the CBM experiment in which the ToF will be measured with Resistive Plates Counters in 150000 channels.
We present also the results of PADI when connected to several other detectors: Diamond, Straw Tubes, Silicon, Scintillation + PMT.
Following this development chain, PADI is now a mature product, tested in various configurations, and ready for use also in space research experiments.

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Time of flight (ToF) measurements with Resistive Plates Counters (RPC) detectors.

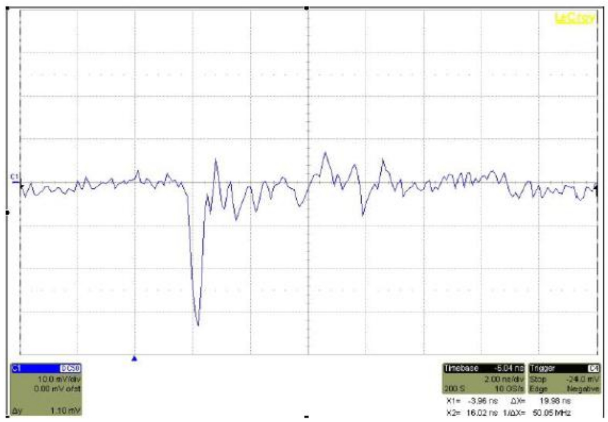

Figure 1: *Typical signal of an RPC detector (50 cm long, 1 cm wide strip electrodes, 80 Ω impedance, fully differential readout); rise/fall time 0.2 ns, FWHM 0.4 ns, amplitude 30mV.*

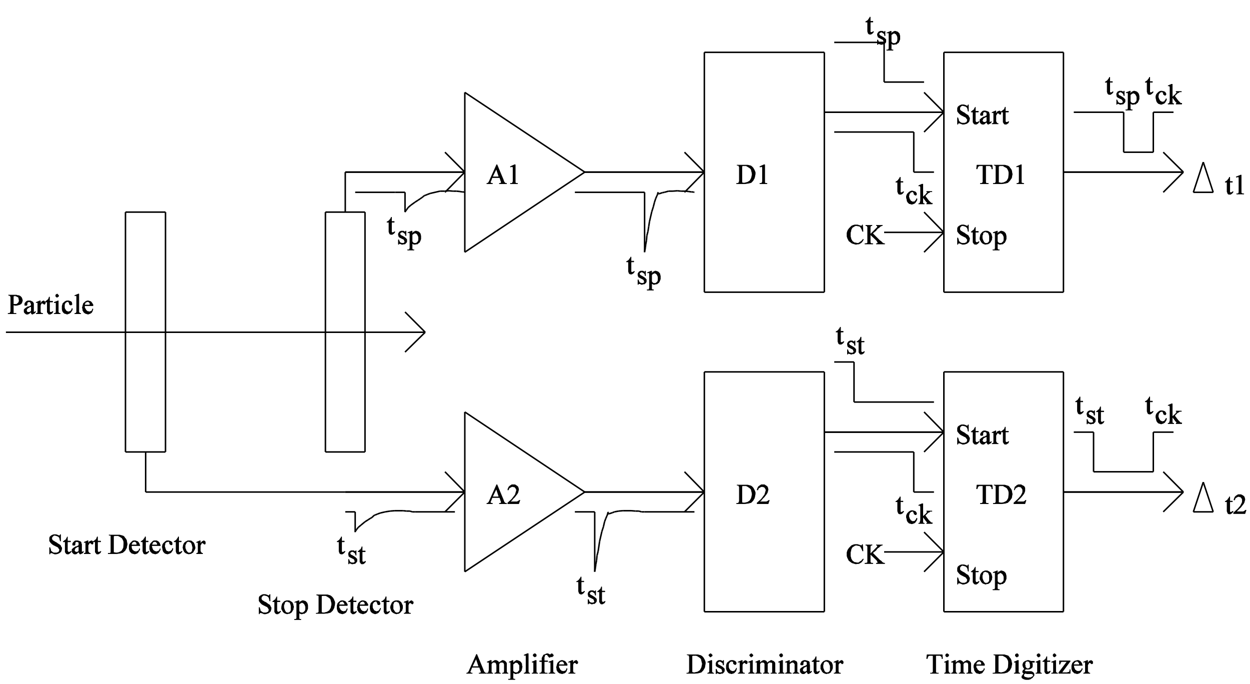

Figure 2: *Typical ToF block schematics.*

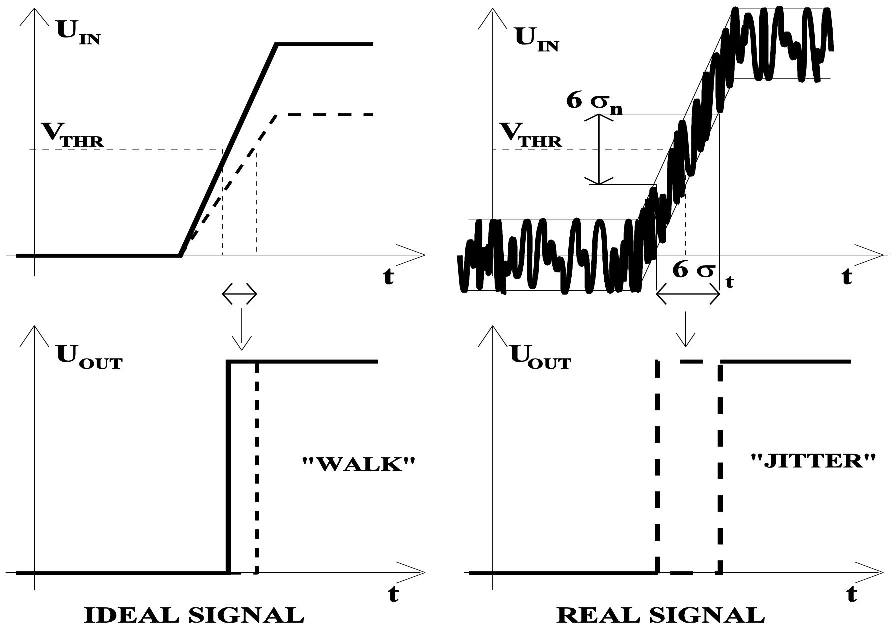

Figure 3: *Typical ToF errors in leading edge discrimination: Walk and Jitter*.

$$\sigma_{\mathrm{t}} = \frac{\sigma_{\mathrm{n}}}{\frac{\mathrm{dV}}{\mathrm{dt}}\Big|_{\mathrm{V_{THR}}}}$$

$$\sigma_{\mathrm{t}} = \frac{\sigma_{\mathrm{n}}}{\frac{\mathrm{dV}}{\mathrm{dt}}\Big|_{\mathrm{V_{THR}}}} + \delta\mathrm{t}$$

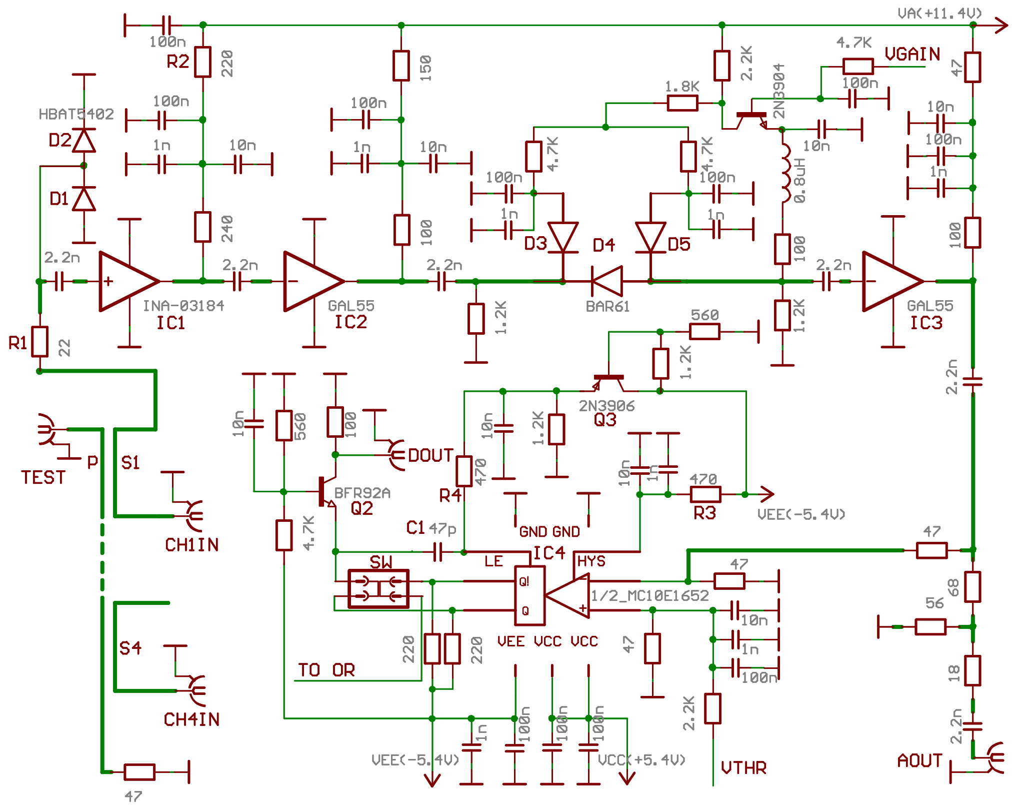

Figure 4: *The FEE1 schematics.*

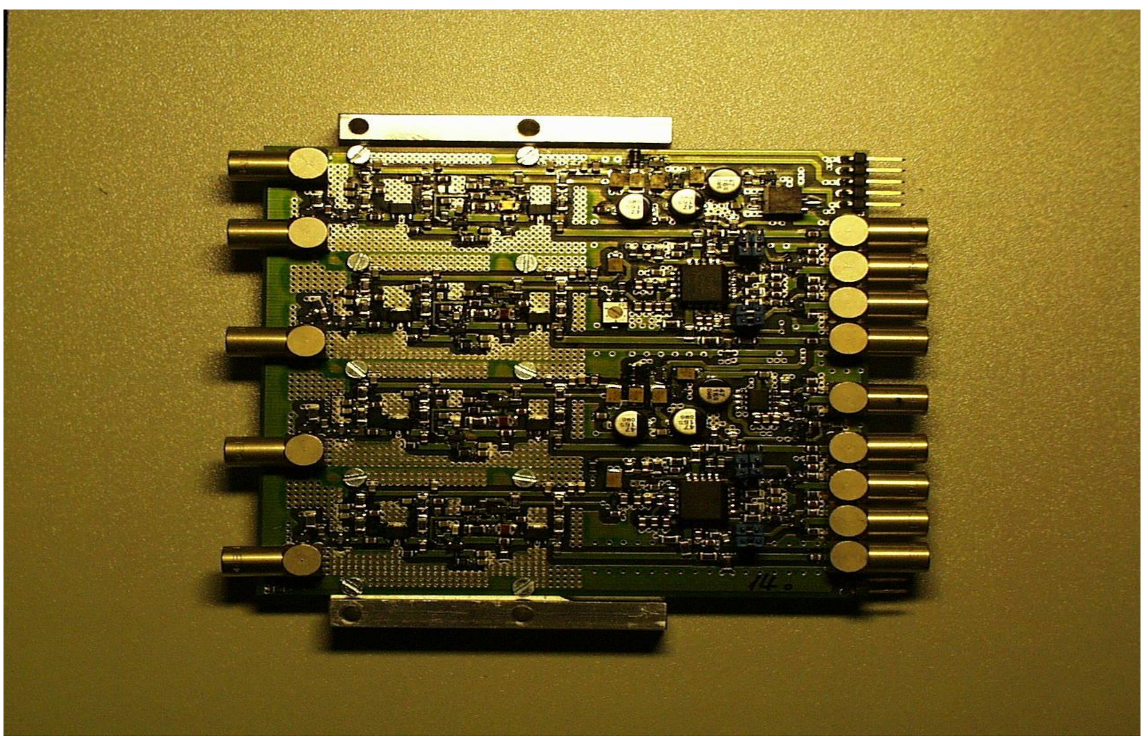

Figure 5: *The FEE1 picture.*

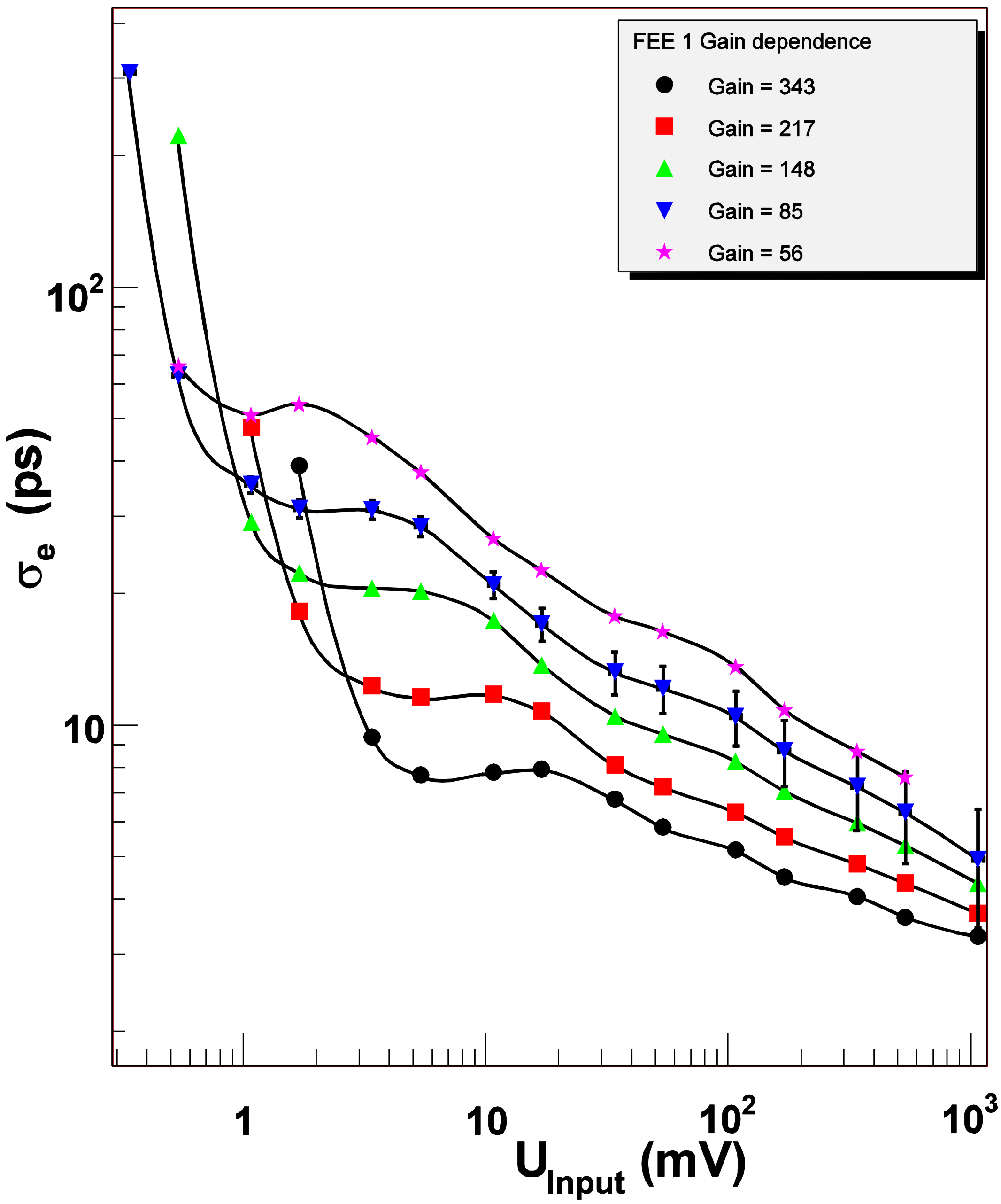

Figure 6: *The FEE1 time resolution dependence to GAIN values, at fixed threshold voltage.*

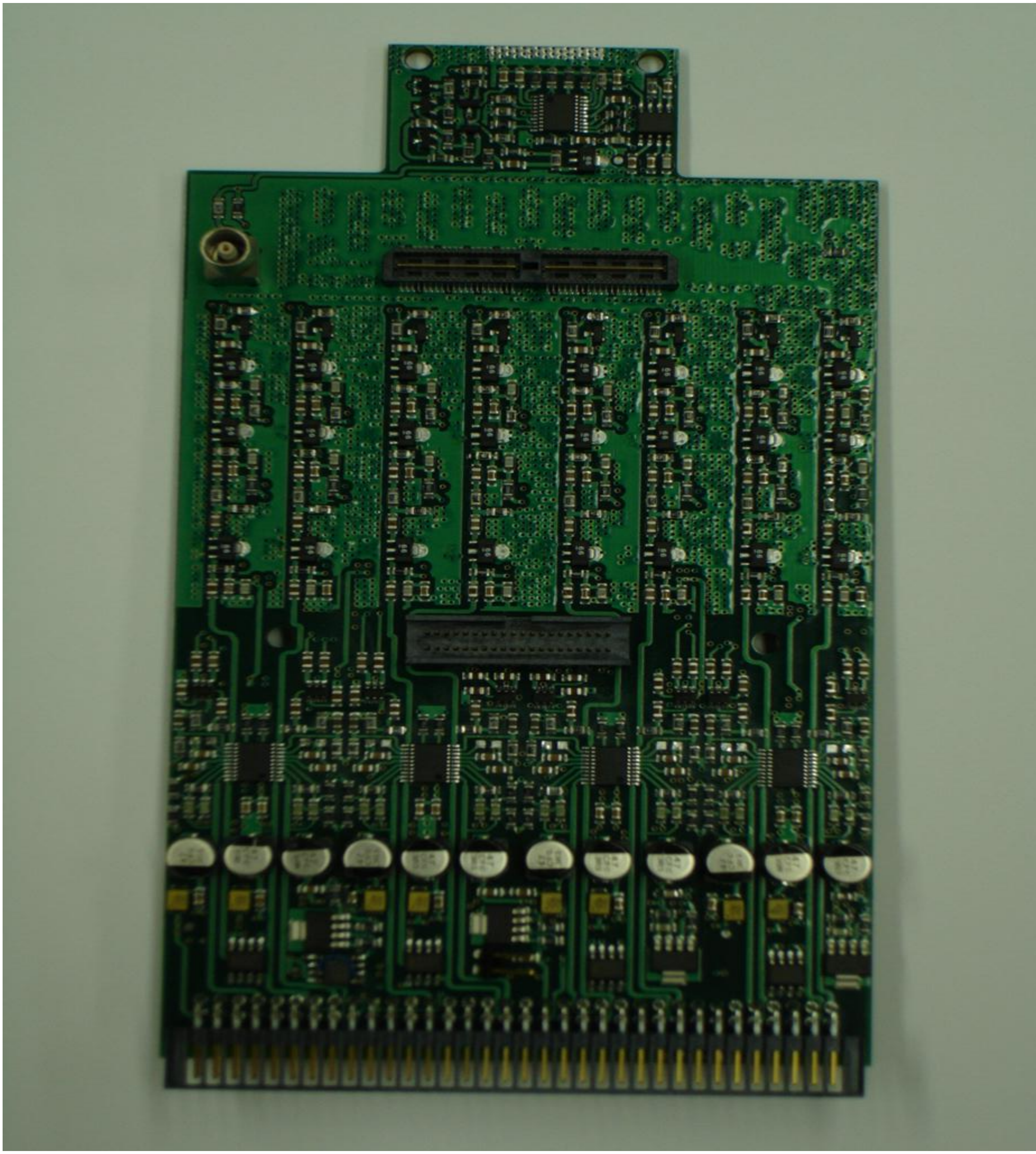

Figure 7: *The FEE5 picture.*

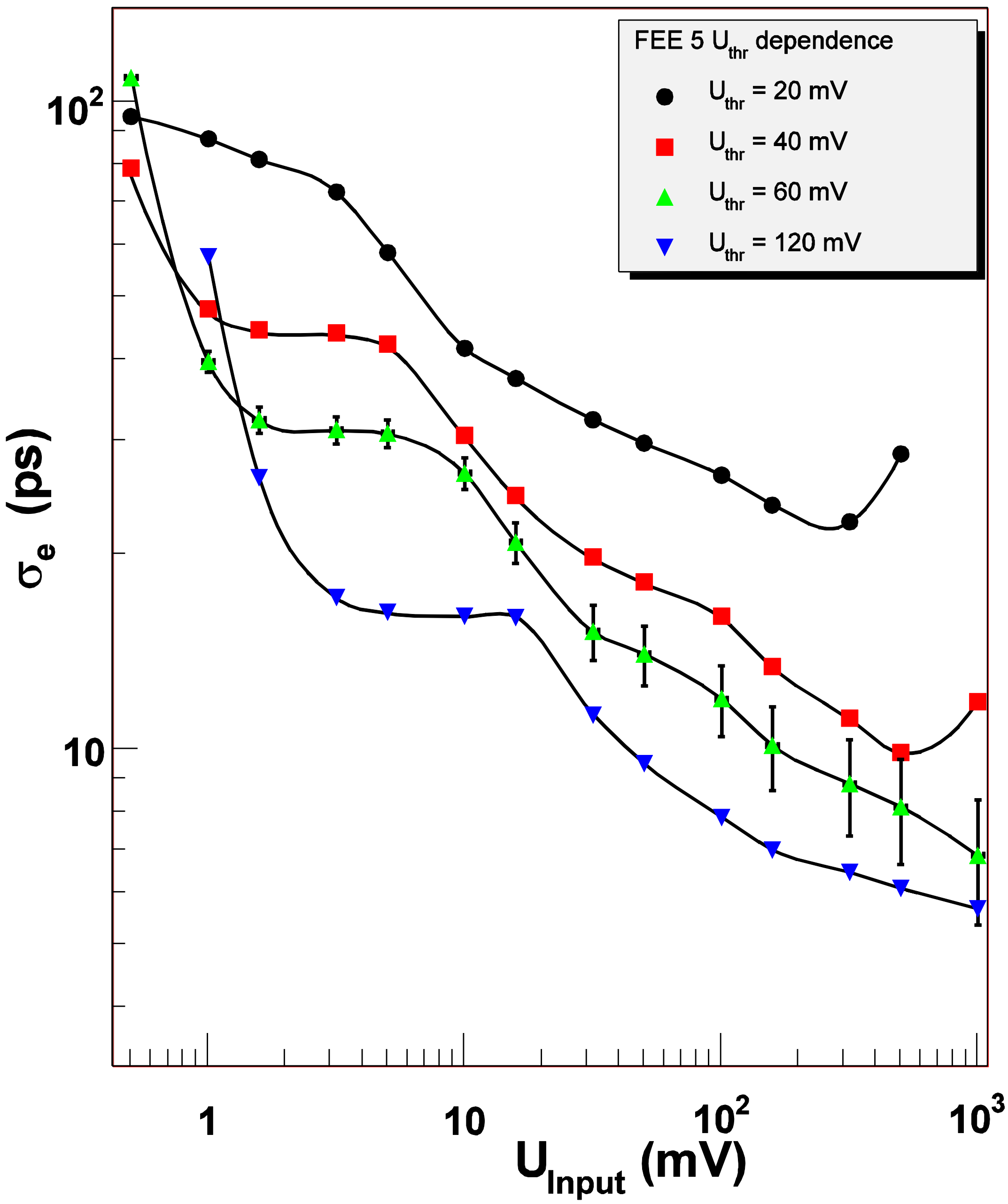

Figure 8: *The FEE5 time resolution dependence to threshold voltage.*

	FEE1	FEE5
Ch.Nr.:	4 channels AC amp., LE disc., 4*OR, THR and GAIN man. adj.	16 channels AC amp., LE disc., 16*OR, TEST gen., THR software
Bias :	+12V, +6V, -6V	+5.4V, -5V
Power:	1.85 W/ch.	0.51 W/ch.
Dim. :	110mm * 95mm	149 mm * 95 mm
INP. :	4Single Ended, Lemo 1 Lemo TEST	16 Single Ended, con. Mec1 ENA/DIS signals for TEST & threshold voltage
OUT. :	4 NIM for time 4 Lemo amplitude 1 Lemo OR	16 diff. PECL for time 16 diff. for amplitude 1 diff. PECL OR
GAIN. :	0 - ~600	~170
BW :	~ 1GHz	~1.5GHz
Noise :	~ 20μV	~25μV
t_r :	~ 350ps	~250ps
$\sigma_{t(FEE)}$:	<20 [ps] @(5mV)	<20 [ps] @(5mV)

Figure 9: *The comparison FEE1 - FEE5.*

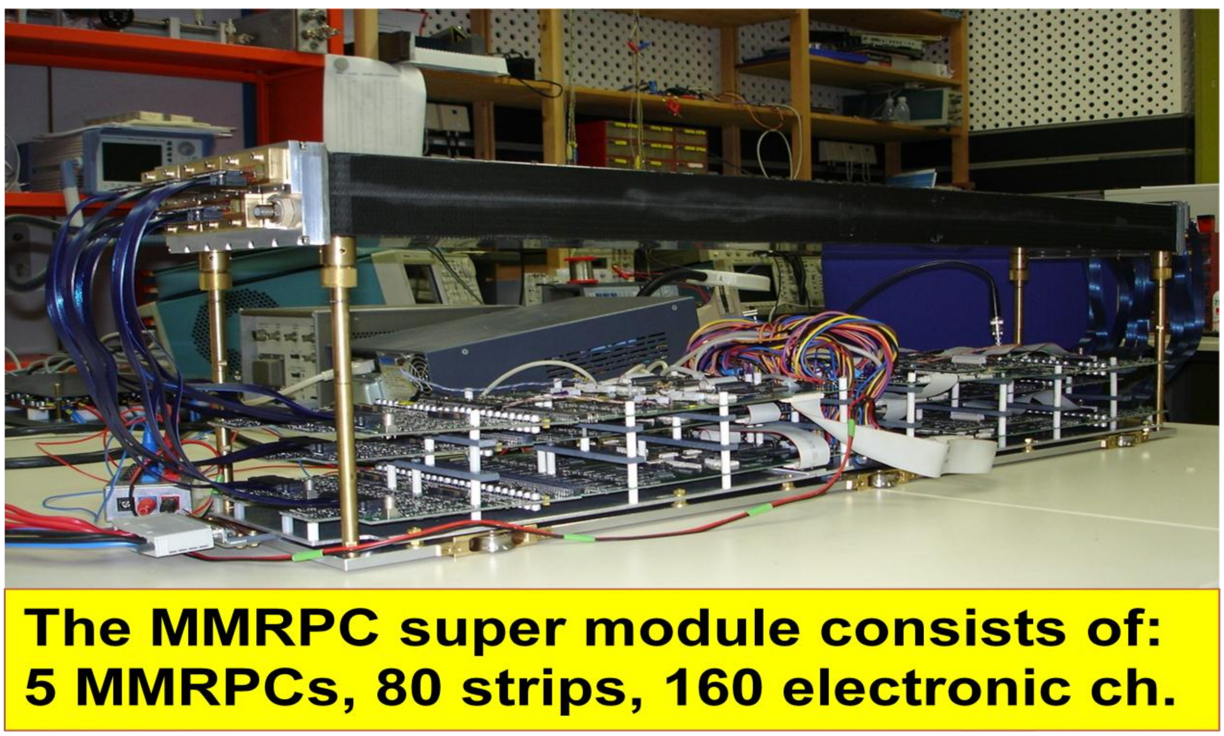

Figure 10: *The FOPI ToF upgrade: 4800 time channels and 2400 amplitude channels.*

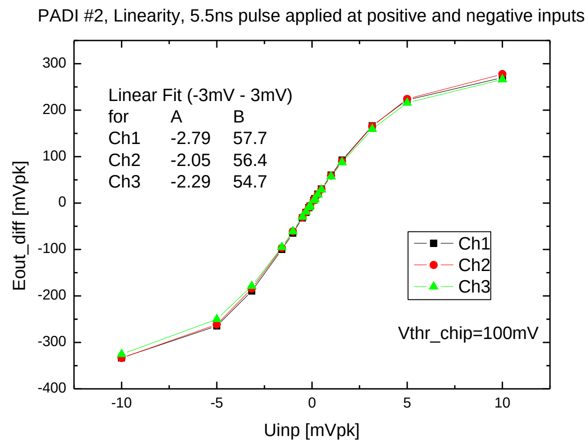

Figure 11: *PADI-1, Preamplifier linearity measurement: All three channels have a very similar sensitivity; the differential analogue output is almost linear within an input interval of* $3mV_{pk}$.

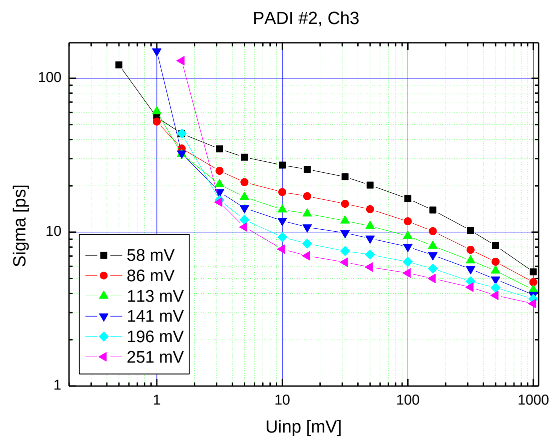

Figure 12: *PADI-1, The time resolution dependence on the input signal amplitude, for different discriminator thresholds.*

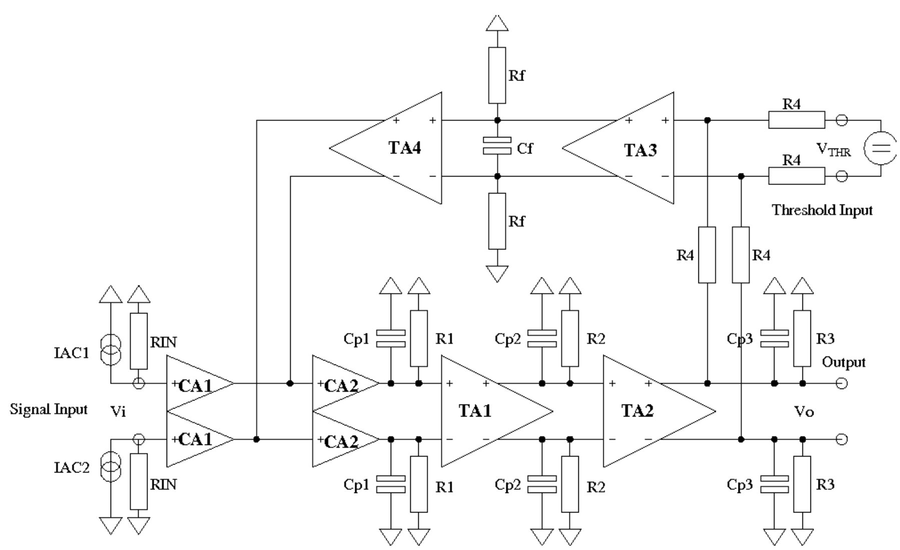

Figure 13: *Simplified AC scheme of the Preamplifier in PADI-6 and PADI-7.*

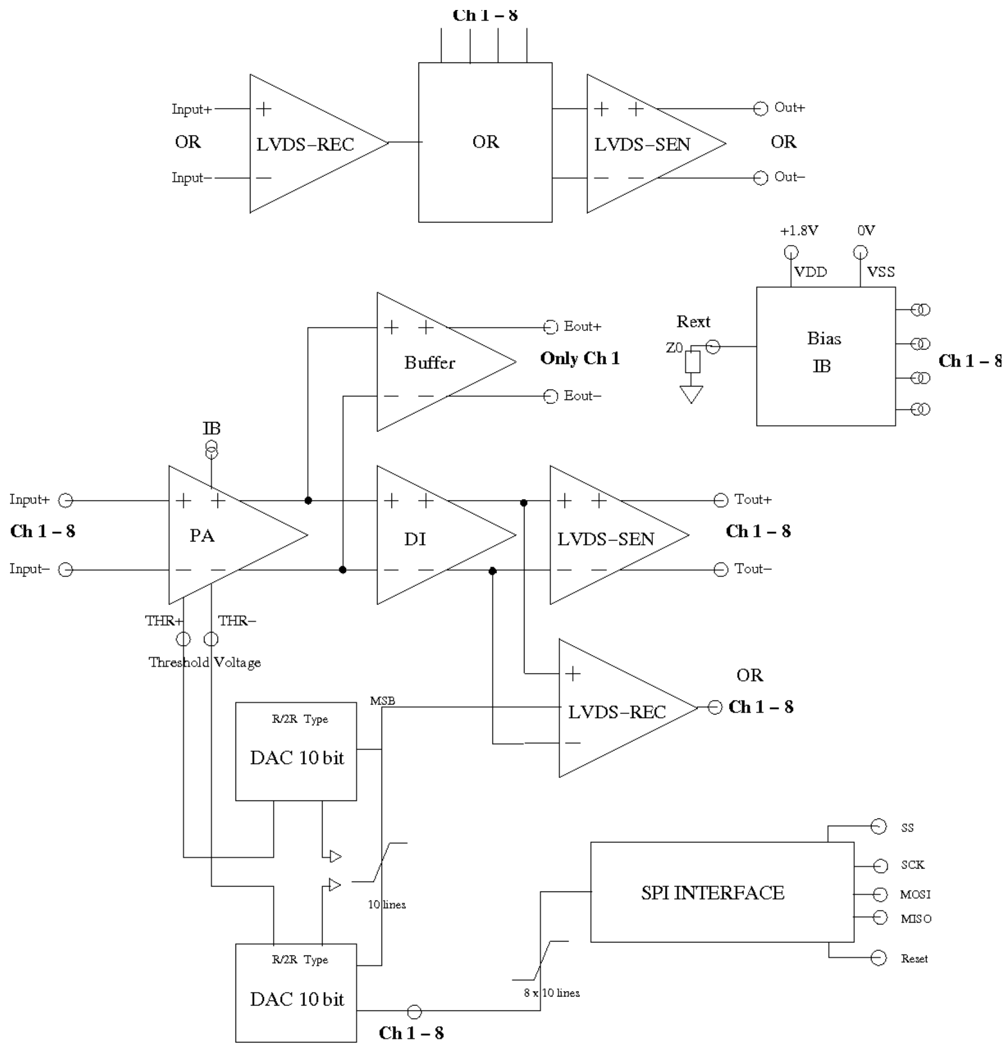

Figure 14: *PADI-8 and PADI-X Block scheme.*

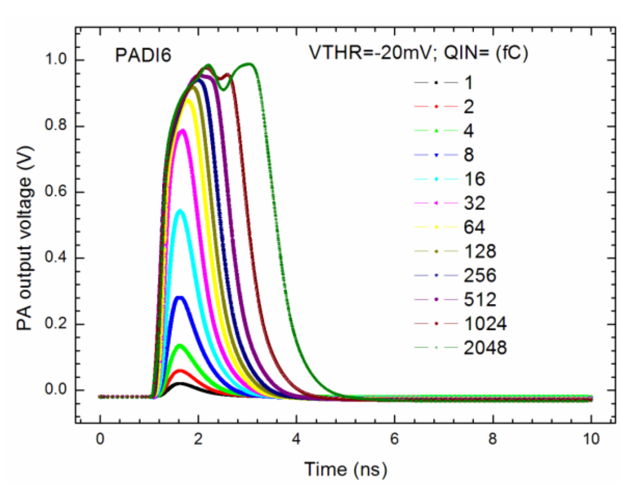

Figure 15: *Transient response at the Preamplifier output as function of QIN (simulation).*

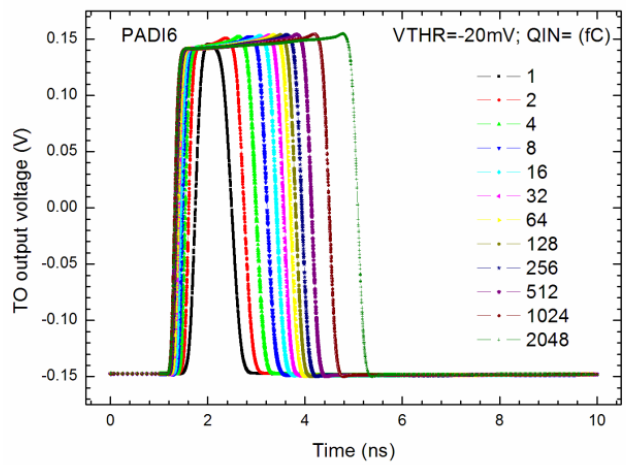

Figure 16: *Simulated transient response at the Time output as function of QIN.*

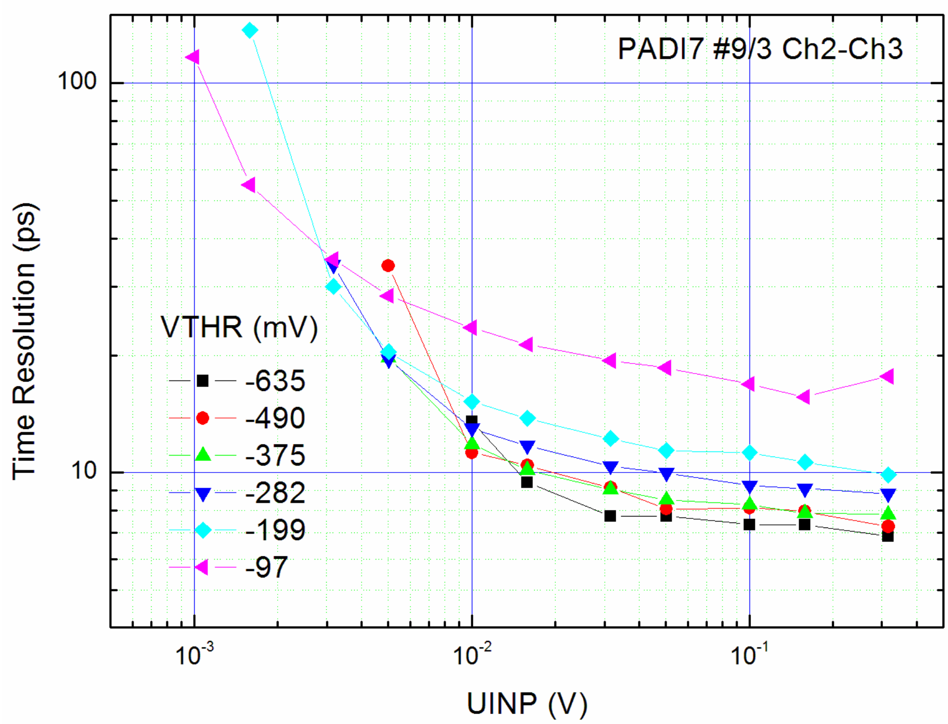

Figure 17: *Measured single-channel Time Resolution versus Input-Signal Amplitude for the specified threshold values.*

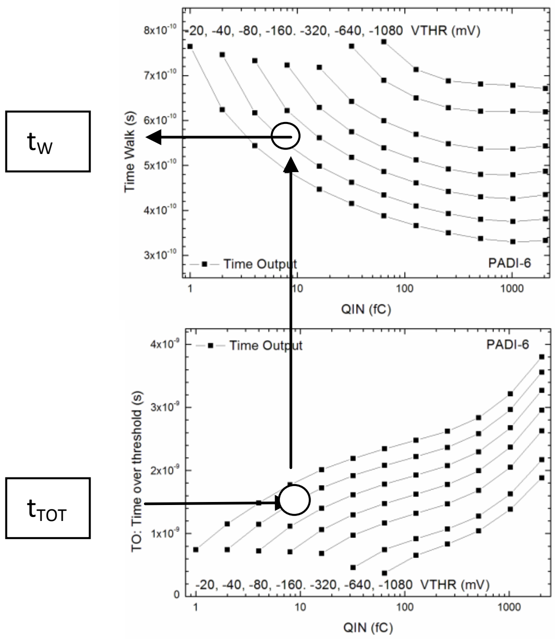

Figure 18*: Simulation: Time Walk (top) and Time over Threshold (bottom) as function of QIN and VTHR.*

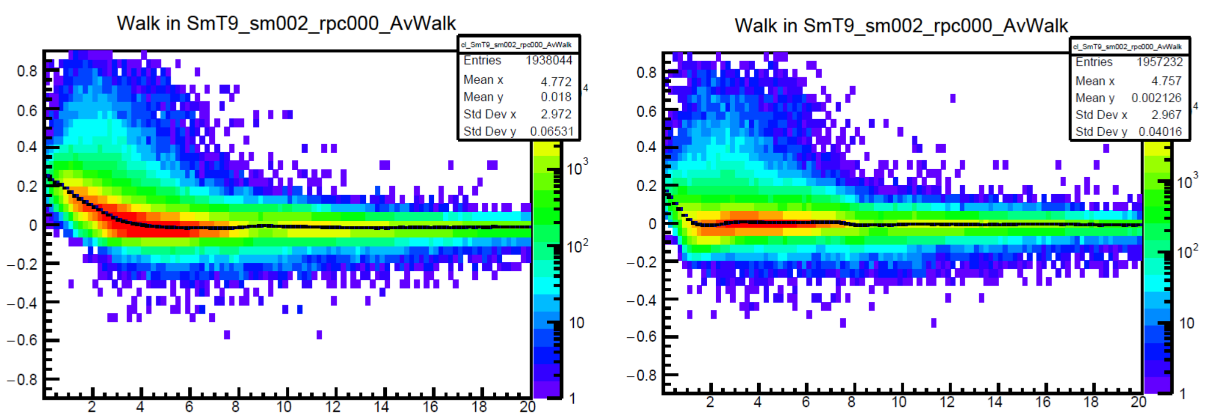

Figure 19: *Left: Time spectra, uncorrected data σ_t=65.3 ps; Right: walk corrected data σ_{tc}=40.16 ps.*

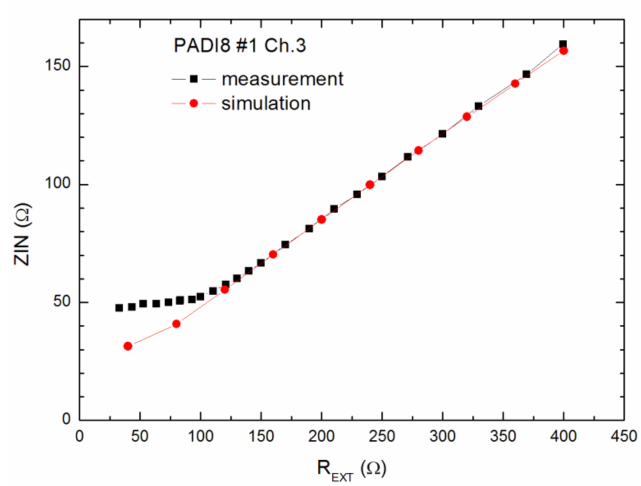

Figure 20: *Measured and simulated dependence of the input impedance on R_{EXT}.*

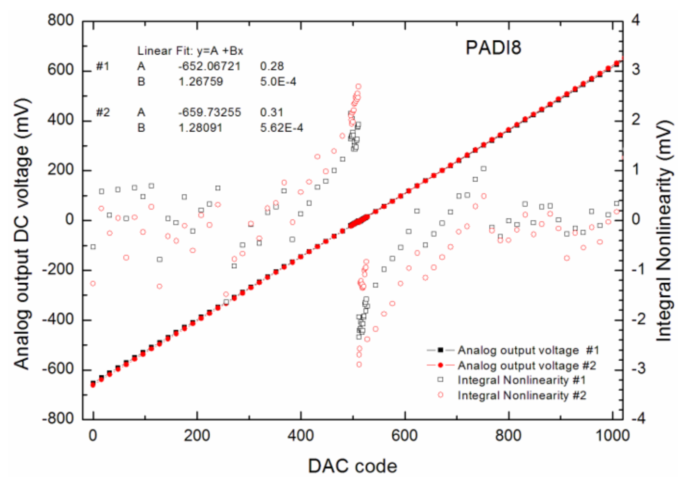

Figure 21: *Measured DC DAC Integral Non-Linearity for two PADI-8 channels (located on different chips).*

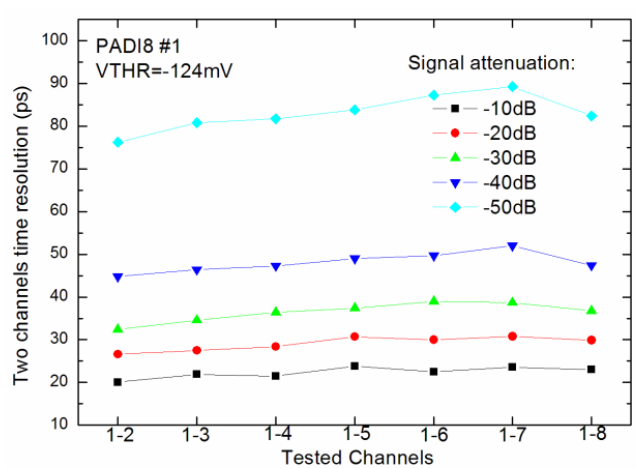

Figure 22: *Measured time resolution for different channel combinations on one chip (channel 1 against the others 7). The test pulse (0.25V amplitude and 3ns width) is attenuated by the specified values.*

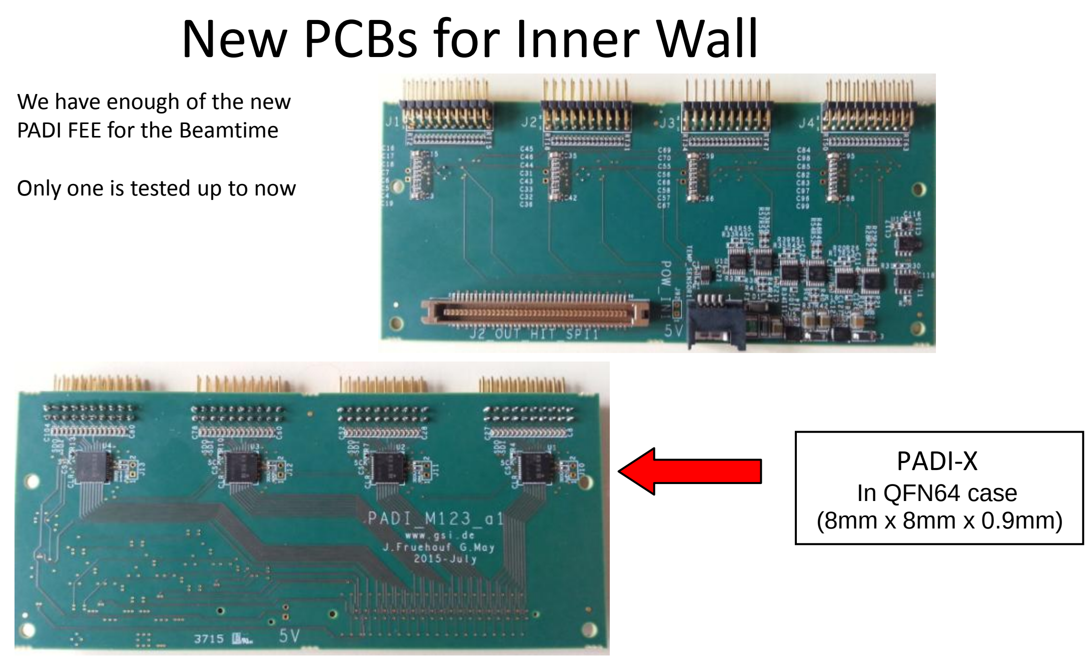

Figure 23: Jochen Frühauf, *Beamtime_Preperation_07.10_2015*

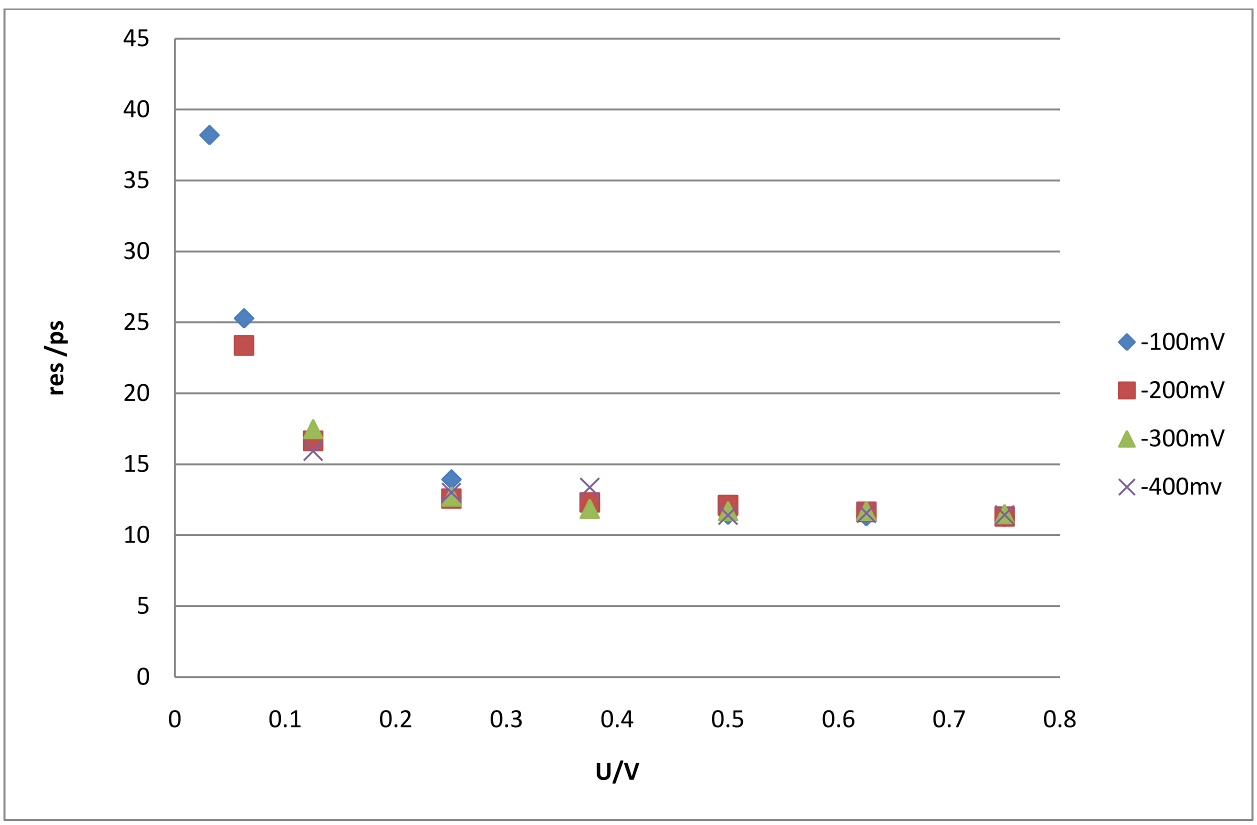

Figure 24: *Time resolution for two PADI-X channels measured with VFTX 10ps TDC.*

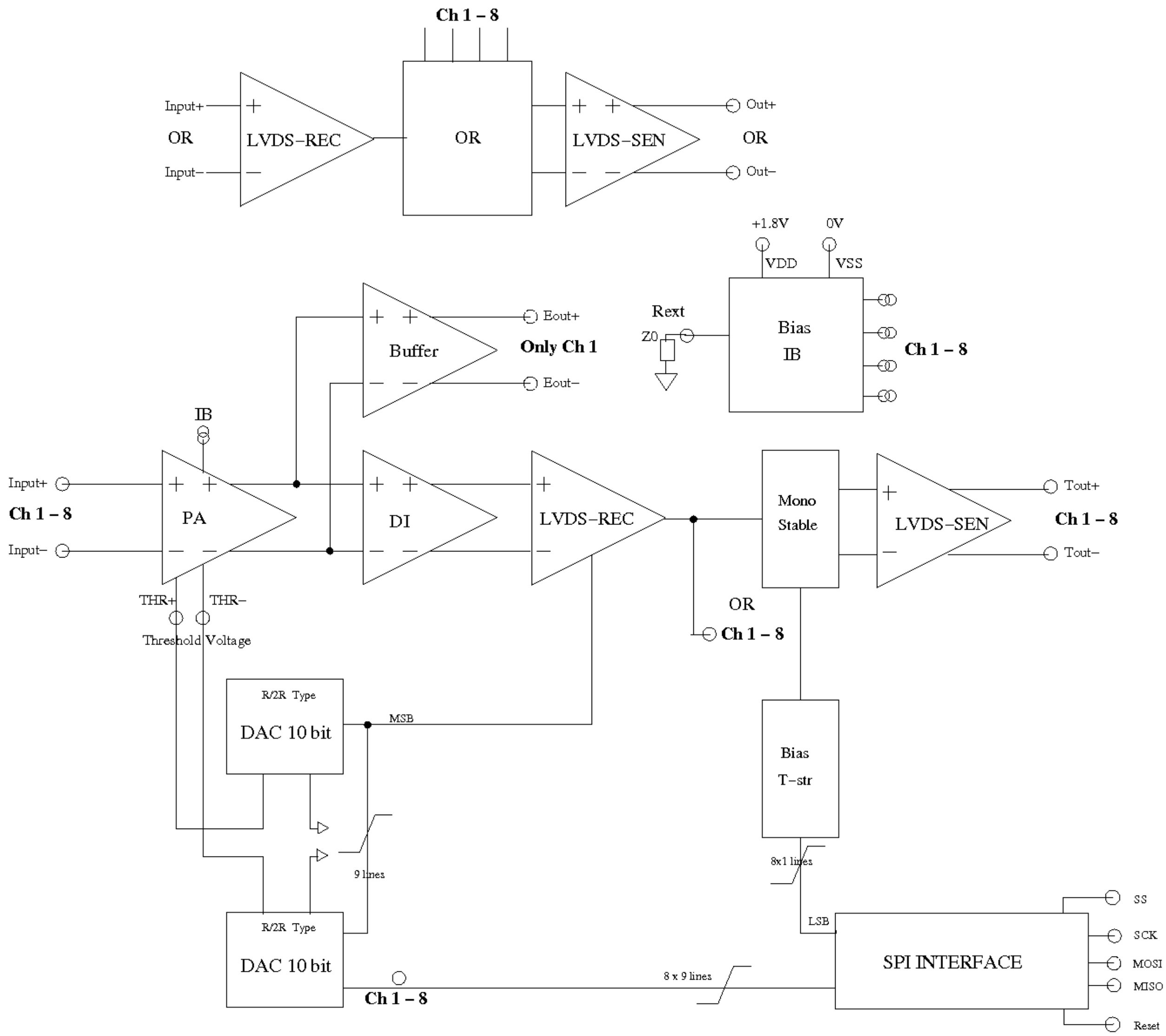

Figure 25: *PADI-XI, the Block scheme.*

The main changes of new PADI-XI design can be summarized as follows:

1) The input impedance is decreased in order to have a big reserve in the low limit of the range, 50 Ω differential.
2) The schematic of one channel is changed: is introduced a stretching time, starting with the trailing edge of the detected event pulse. This stretching time can be adjusted by software and can be accommodated for different TDC's (the old TDC's need a minimum pulse width of the order of a few ns).
3) The PADI-XI pin out is the same of PADI-X. We renounced to 1 bit of each DAC, the DAC information consists now of 9 bits used for threshold voltage control. The last bits collected from 8 channels are used for stretching time adjustment (all channels have the same stretching time) in 9 steps.

If you are interested in PADI, much information you can find at the ftp address:

http://gpsm.spacescience.ro/gpsm/ftp/om/padi/Murighiol/

You will find two directories containing following files,

PADI_PAPERS

- *Radiation Studies on the UMC 180 nm CMOS.pdf*
- *paper0_NSS-MIC_A FRONT END.pdf*
- *paper1_NSS-MIC08_PADI_v6_emb.pdf*
- *paper2_NSS-MIC09_PADI_v4.pdf*
- *paper3_NSS-MIC_TNS2014.pdf*
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PADI_APLICATIONS

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- *PADI for scintillation fibers.pdf*
- *PADI for RPC's the Time-Of-Flight System of the CBM Experiment_PADI2014.pdf*
- *Diamond_PADI.pdf*
- *Development of Diamond Detectors for ToF measurements at FRS-Super-FRS_PADI2014.pdf*

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