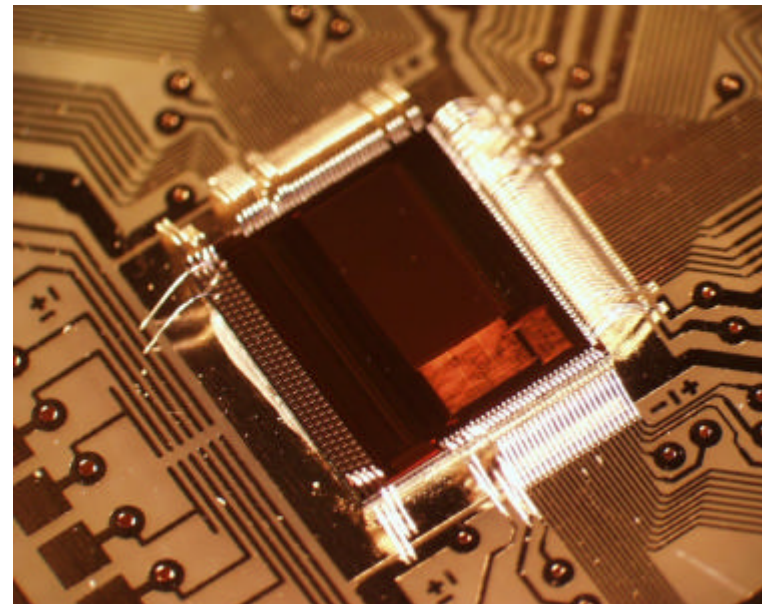




Lab measurements with the Beetle 1.3

Sven Löchner

(Max-Planck-Institute for Nuclear Physics, Heidelberg)



Beetle 1.3 on a test PCB





Motivation for Beetle 1.3

in descending order of priority:

- **Sticky Charge Effect**
- **Comparator Offset Variation**
- **80 MHz Crosstalk**
- **Output Driver Performance**
- **Sagging Readout Baseline**
- **5V tolerant I²C pads**
- ...





Modifications in Beetle 1.3

• Design changes (on schematic level)

- analog delay of MuxTrack signal (sticky charge)
- improved comparator (5 bit threshold / channel)
- Current Output Buffer (inc. gain / diff. output)
- Multiplexer (reduction of switching spikes)
- Control Logic (bug fixes, daisy chain, low-Rclk)
- new I²C-Pads (5V compatible)
- modified Testpulse pattern (“+1/-1” pattern)

• Layout and Power Routing

- modified front-end power pads
- improved front-end routing / bias
- separation of comparator core power / LVDS
- improved pipeamp power routing
- on-chip power blocking / additional pads

• Crosstalk measures

- reduced no. of FF in MUX
- reduced no. of clock buffers
- on-chip power blocking

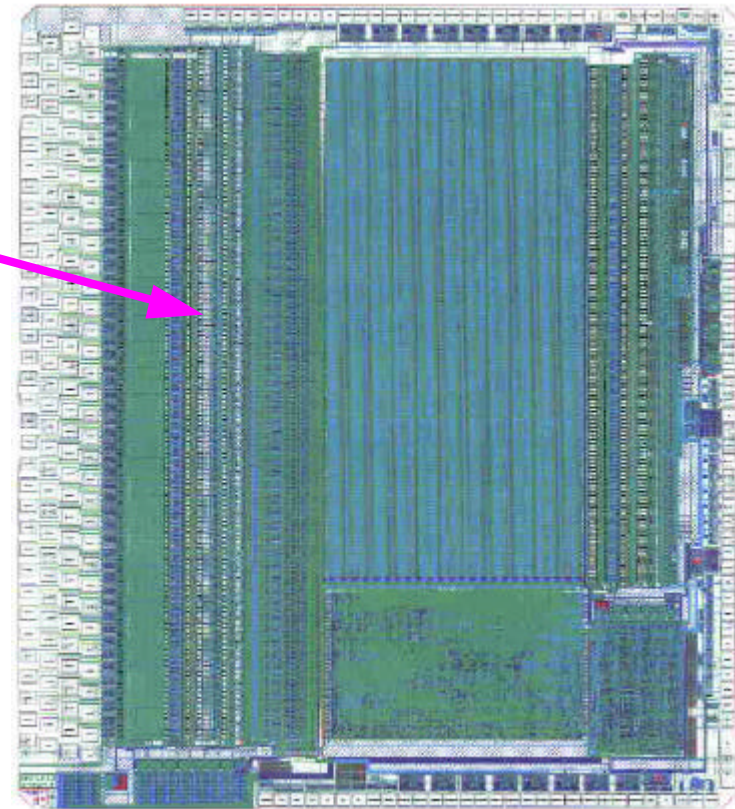




Motivation for Beetle 1.3

Result of hard design work

- 30.06.2003 Submission of Beetle 1.3
- 22.09.2003 Beetle arrived in Heidelberg

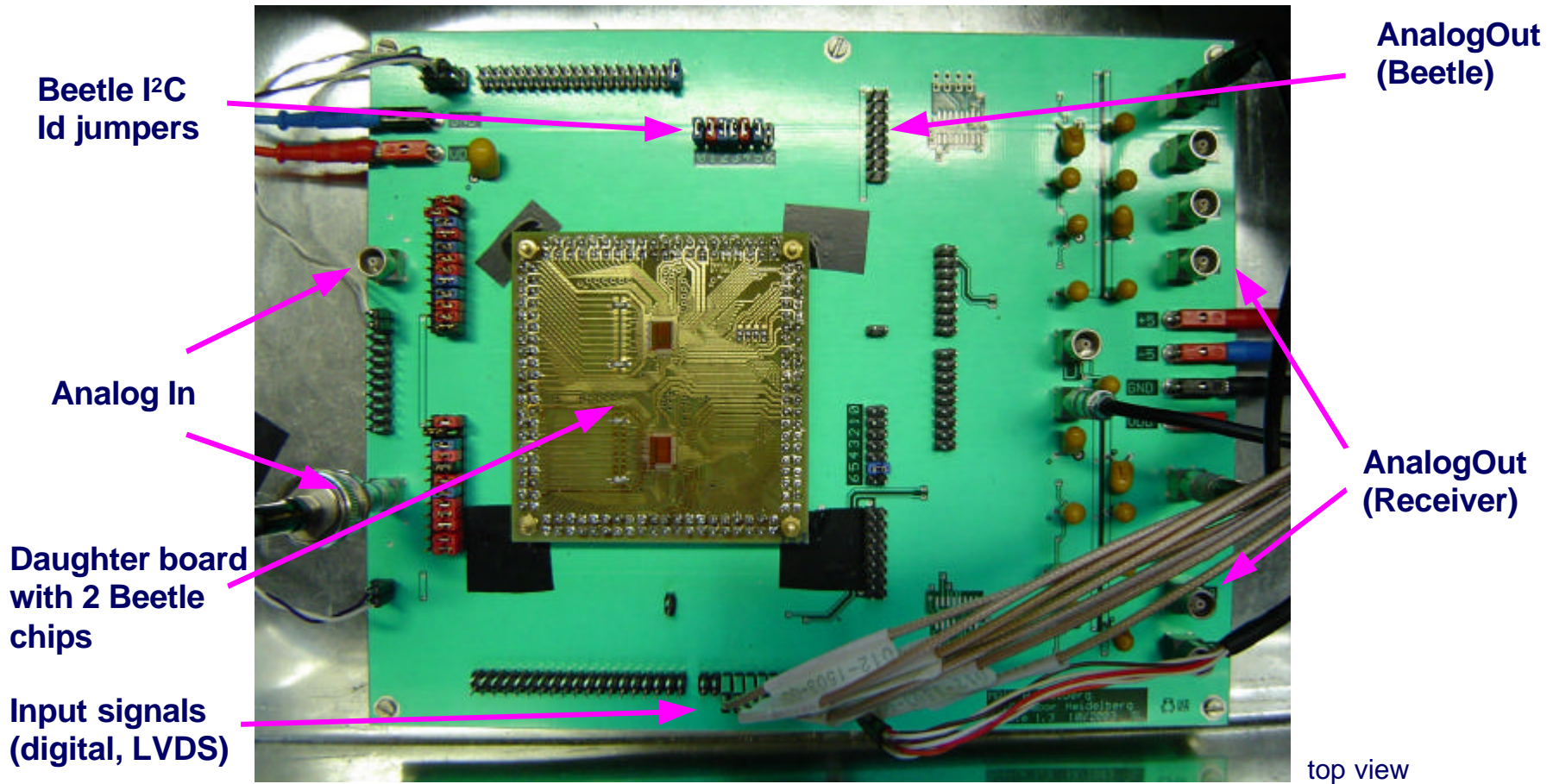


Beetle 1.3 layout





Beetle 1.3 Lab Setup (1)

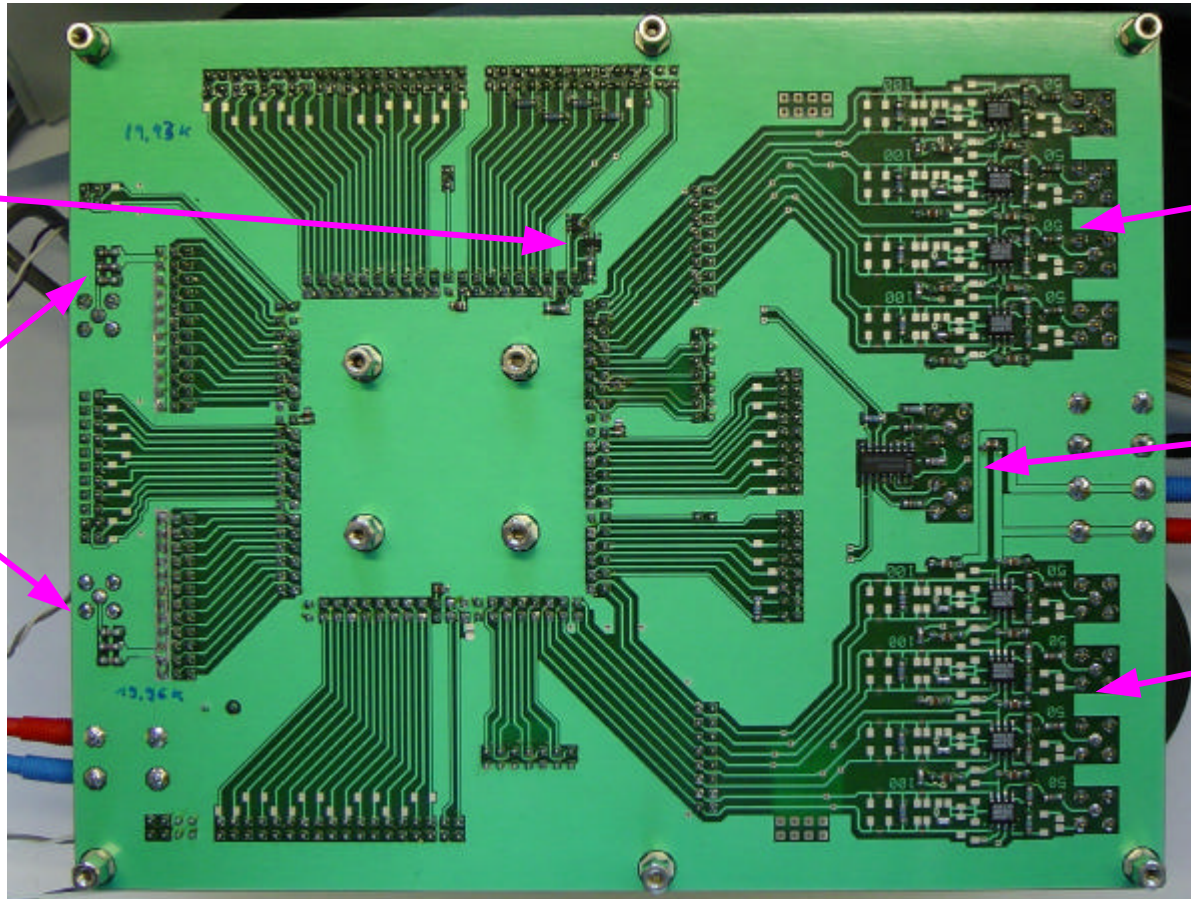




Beetle 1.3 Lab Setup (2)

I²C level shifter
(unnecessary for Beetle 1.3)

Analog In
Voltage divider



4 Analog Receiver for 2nd Beetle
(AD8130)

LVDS receiver
(DS90C032)

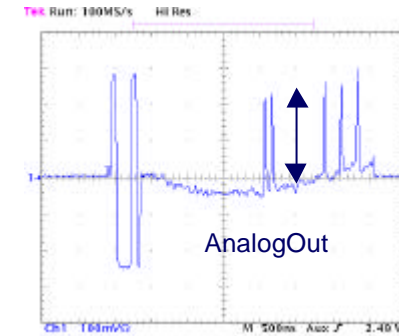
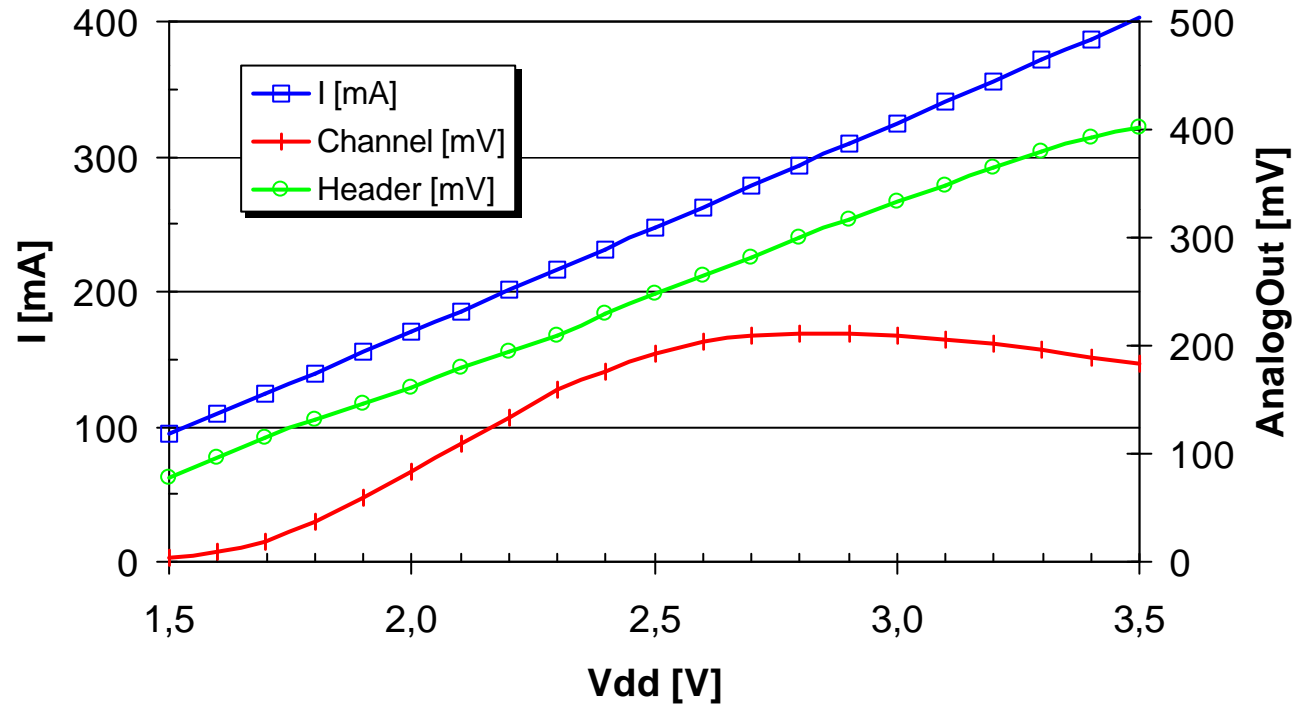
4 Analog receiver for 1st Beetle
(AD8130)

bottom view





Power Supply Operation



- Analog / Digital: 1.5V to 3.5V





Total Power Consumption (1)

Power consumption [mW/ch.] #AO drivers	Minimal	Nominal			Max. operation			Max. DAC
	0	0	1	4	0	1	4	4
without clock	0,48	3,49	3,68	4,25	4,76	5,02	5,83	14,21
only 40 MHz clock	1,26	4,28	4,46	5,03	5,54	5,81	6,61	14,95
clocked + 1.1 MHz trigger	1,26	4,36	4,56	5,14	5,62	5,90	6,70	15,12





Total Power Consumption (2)

I²C DAC Settings

minimal

nominal

max. reasonable values

Register (minimal)	Register (nominal)	Register (max. operation)
Itp (#0) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Ithmain (#8) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>	Itp (#0) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Ithmain (#8) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>	Itp (#0) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Ithmain (#8) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>
Ipre (#1) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Vrc (#9) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/>	Ipre (#1) <input type="text" value="x4C"/> <input type="text" value="596"/> <input type="text" value="uA"/> Vrc (#9) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/>	Ipre (#1) <input type="text" value="x80"/> <input type="text" value="1004"/> <input type="text" value="uA"/> Vrc (#9) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/>
Isha (#2) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Ipipe (#10) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>	Isha (#2) <input type="text" value="xA"/> <input type="text" value="78"/> <input type="text" value="uA"/> Ipipe (#10) <input type="text" value="xD"/> <input type="text" value="102"/> <input type="text" value="uA"/>	Isha (#2) <input type="text" value="xA"/> <input type="text" value="78"/> <input type="text" value="uA"/> Ipipe (#10) <input type="text" value="x1A"/> <input type="text" value="204"/> <input type="text" value="uA"/>
Ibuf (#3) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Vd (#11) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/>	Ibuf (#3) <input type="text" value="xA"/> <input type="text" value="78"/> <input type="text" value="uA"/> Vd (#11) <input type="text" value="x8E"/> <input type="text" value="1392"/> <input type="text" value="mV"/>	Ibuf (#3) <input type="text" value="x1A"/> <input type="text" value="204"/> <input type="text" value="uA"/> Vd (#11) <input type="text" value="x8E"/> <input type="text" value="1392"/> <input type="text" value="mV"/>
Vfp (#4) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/> Vdcl (#12) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/>	Vfp (#4) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/> Vdcl (#12) <input type="text" value="x63"/> <input type="text" value="971"/> <input type="text" value="mV"/>	Vfp (#4) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/> Vdcl (#12) <input type="text" value="x63"/> <input type="text" value="971"/> <input type="text" value="mV"/>
Vfs (#5) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/> Ivoltbuf (#13) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>	Vfs (#5) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/> Ivoltbuf (#13) <input type="text" value="x1A"/> <input type="text" value="204"/> <input type="text" value="uA"/>	Vfs (#5) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="mV"/> Ivoltbuf (#13) <input type="text" value="x2D"/> <input type="text" value="353"/> <input type="text" value="uA"/>
Icomp (#6) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Isf (#14) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>	Icomp (#6) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Isf (#14) <input type="text" value="x1A"/> <input type="text" value="204"/> <input type="text" value="uA"/>	Icomp (#6) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Isf (#14) <input type="text" value="x1A"/> <input type="text" value="204"/> <input type="text" value="uA"/>
Ithdelta (#7) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Icurrbuf (#15) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/>	Ithdelta (#7) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Icurrbuf (#15) <input type="text" value="x66"/> <input type="text" value="800"/> <input type="text" value="uA"/>	Ithdelta (#7) <input type="text" value="x0"/> <input type="text" value="0"/> <input type="text" value="uA"/> Icurrbuf (#15) <input type="text" value="x99"/> <input type="text" value="1200"/> <input type="text" value="uA"/>
Latency (#16) <input type="text" value="d0"/> RclkDivider (#18) <input type="text" value="d0"/>	Latency (#16) <input type="text" value="d160"/> RclkDivider (#18) <input type="text" value="d0"/>	Latency (#16) <input type="text" value="d160"/> RclkDivider (#18) <input type="text" value="d0"/>
ROCtrl (#17) <input type="text" value="b0"/> CompControl (#19) <input type="text" value="b0"/>	ROCtrl (#17) <input type="text" value="b11100"/> CompControl (#19) <input type="text" value="b1001"/>	ROCtrl (#17) <input type="text" value="b11100"/> CompControl (#19) <input type="text" value="b1001"/>
ROCtrl <input type="checkbox"/> OFF binary (2 ports) CompControl <input type="checkbox"/> OFF DisableLVDSout	ROCtrl <input type="checkbox"/> OFF binary (2 ports) CompControl <input checked="" type="checkbox"/> ON DisableLVDSout	ROCtrl <input type="checkbox"/> OFF binary (2 ports) CompControl <input checked="" type="checkbox"/> ON DisableLVDSout
<input type="checkbox"/> OFF analog (1 port) <input type="checkbox"/> OFF CompPolarity	<input type="checkbox"/> OFF analog (1 port) <input type="checkbox"/> OFF CompPolarity	<input type="checkbox"/> OFF analog (1 port) <input type="checkbox"/> OFF CompPolarity
<input type="checkbox"/> OFF analog (4 ports) <input type="checkbox"/> OFF CompOutMode	<input checked="" type="checkbox"/> ON analog (4 ports) <input type="checkbox"/> OFF CompOutMode	<input checked="" type="checkbox"/> ON analog (4 ports) <input type="checkbox"/> OFF CompOutMode
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<input type="checkbox"/> OFF ProbeEnable	<input type="checkbox"/> OFF ProbeEnable	<input type="checkbox"/> OFF ProbeEnable





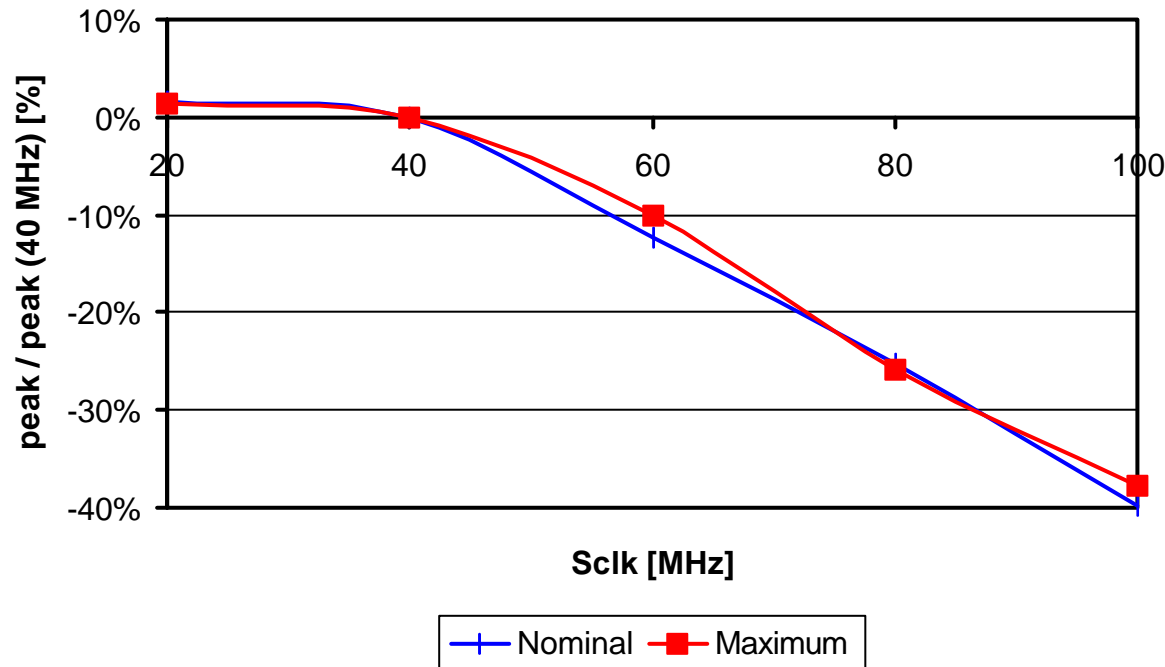
Temperature Test

- **Start-up tests (~ 15 times each chip):**
 - 2 Beetle 1.3
 - @ $T = -44^{\circ}\text{C}, 60^{\circ}\text{C}, 75^{\circ}\text{C}$ (facility temperature)
 - Programming (I²C)
 - 1.1 MHz trigger + analog readout
- **Longtime operating tests (~3 days):**
 - 1 Beetle 1.3
 - @ $T = -44^{\circ}\text{C}, 60^{\circ}\text{C}, 75^{\circ}\text{C}$ ($T_{\text{surface}} = -4^{\circ}\text{C}, 94^{\circ}\text{C}, 107^{\circ}\text{C}$)
 - 1.1 MHz + analog readout
- **Max. stress test:**
 - 1 Beetle 1.3
 - max. DAC settings
 - @ $T = 60^{\circ}\text{C}$ ($T_{\text{surface}} = 126^{\circ}\text{C}$)
 - Operating over ~ 12 hour





Overclocking Test



frequency test

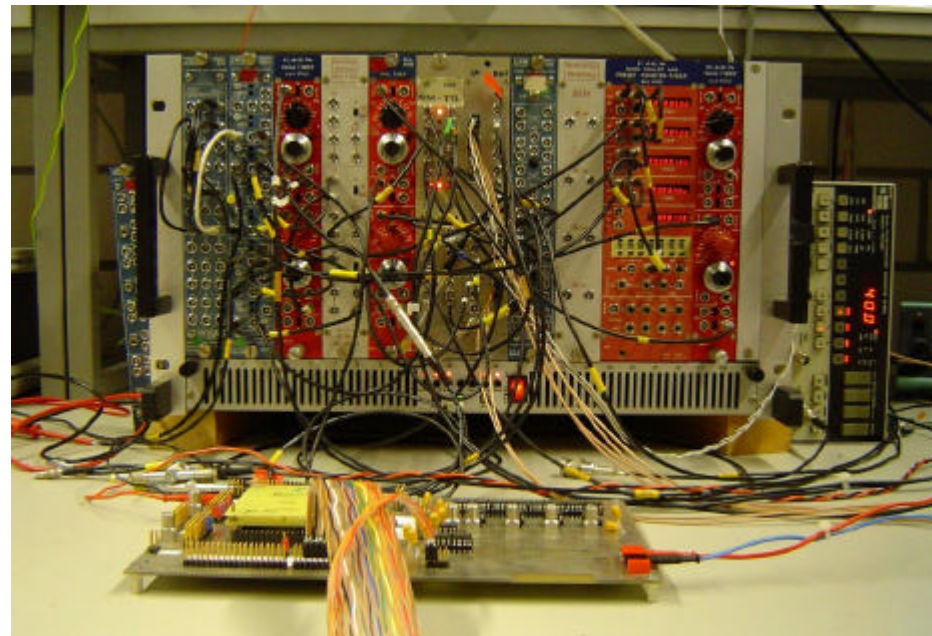
- Digital: perfect operation up to 100 MHz
- Analog: nearly 40% gain loss @ 100 MHz





Random Trigger Test

- 2 Beetle 1.3 @ 40 MHz
- 2 x $2.34 \cdot 10^{12}$ random triggers
 - 172h ($1.778 \cdot 10^{12}$, \bar{P} 2.87 MHz)
 - 75h ($3.039 \cdot 10^{11}$, \bar{P} 1.12 MHz)
 - 92h ($2.550 \cdot 10^{11}$, \bar{P} 0.77 MHz)
- no triggers lost

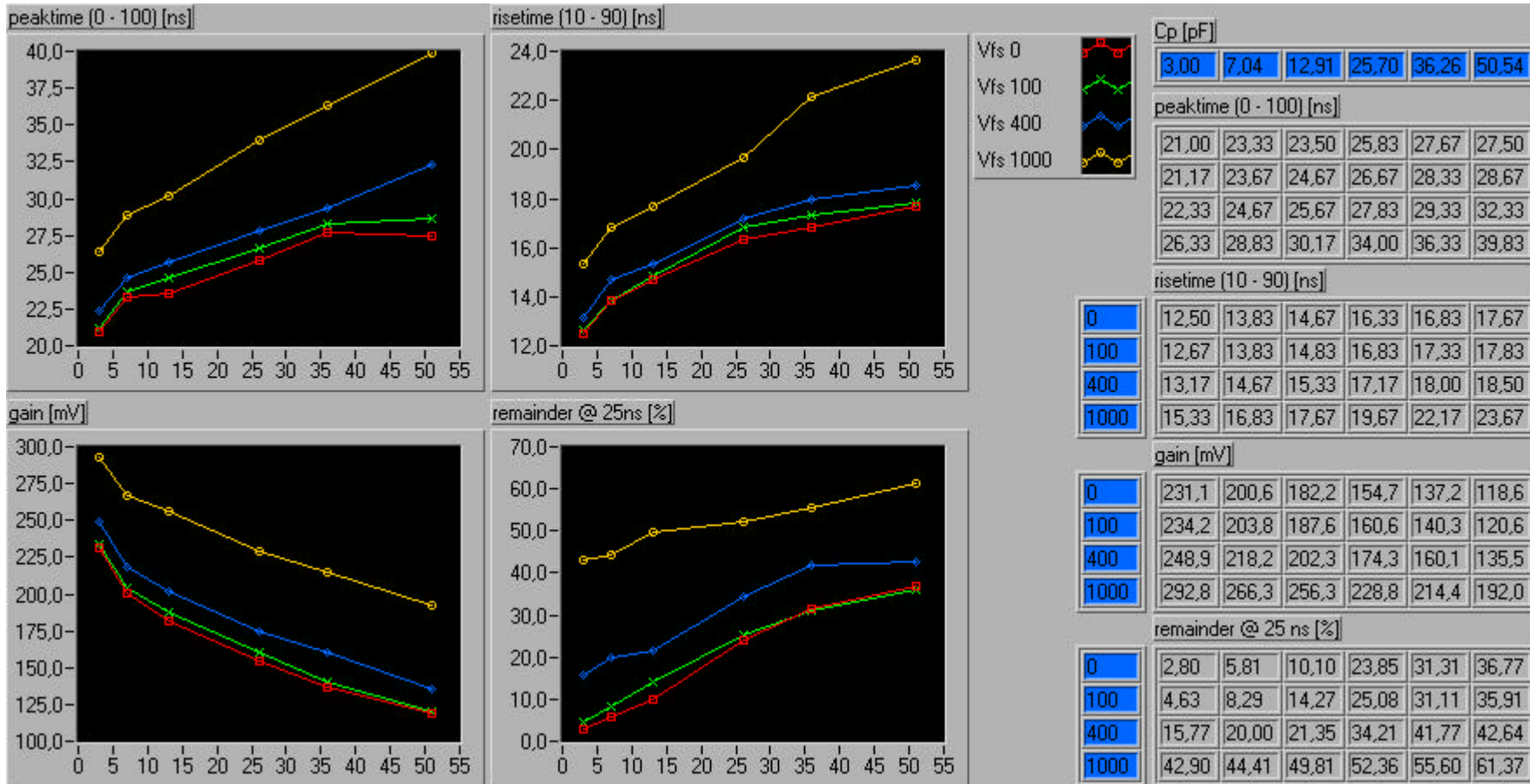


Beetle 1.3 random trigger test setup



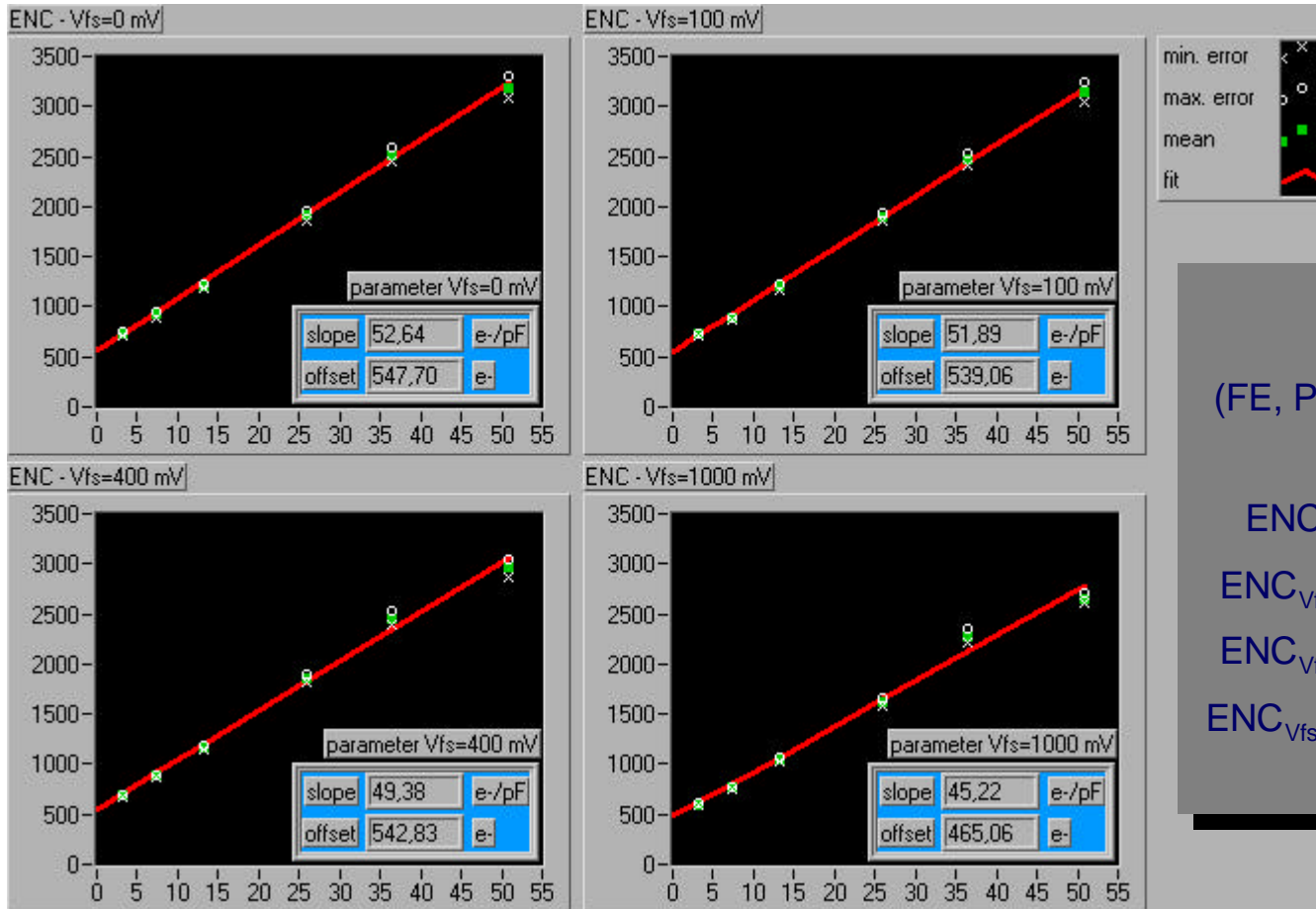


Front end: Pulse-Parameter





Front end: ENC - Beetle 1.3



min. error

max. error

mean

fit

Beetle 1.3 ENC

(FE, Pipeline, Pipeamp, Readout)

ENC_{V_{fs}=0}: 547.7 e⁻ + 52.6 e⁻/pF

ENC_{V_{fs}=100}: 539.1 e⁻ + 51.9 e⁻/pF

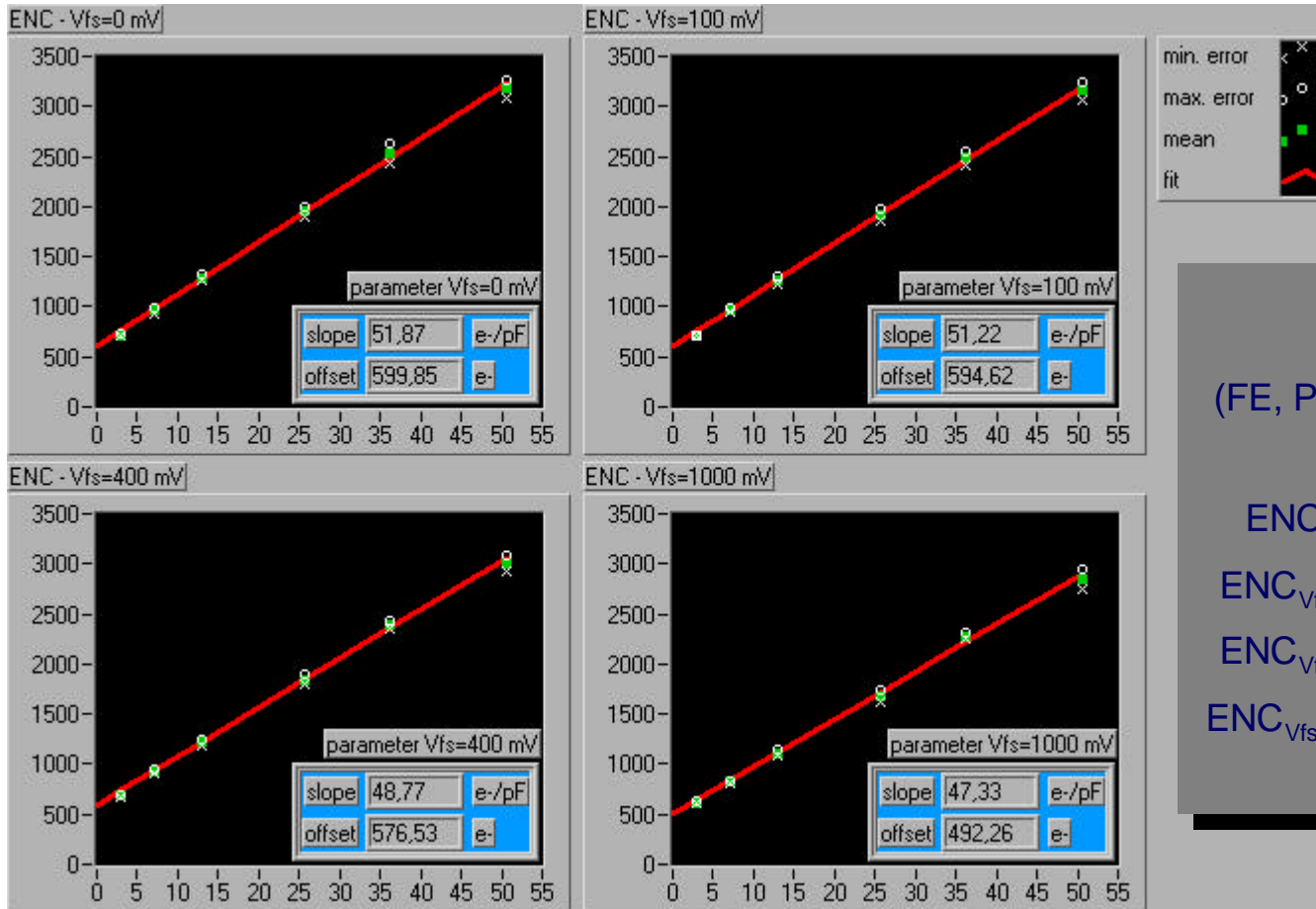
ENC_{V_{fs}=400}: 542.8 e⁻ + 49.9 e⁻/pF

ENC_{V_{fs}=1000}: 465.1 e⁻ + 45.2 e⁻/pF





Front end: ENC - Beetle 1.2



min. error x

max. error o

mean ■

fit —

Beetle 1.2 ENC

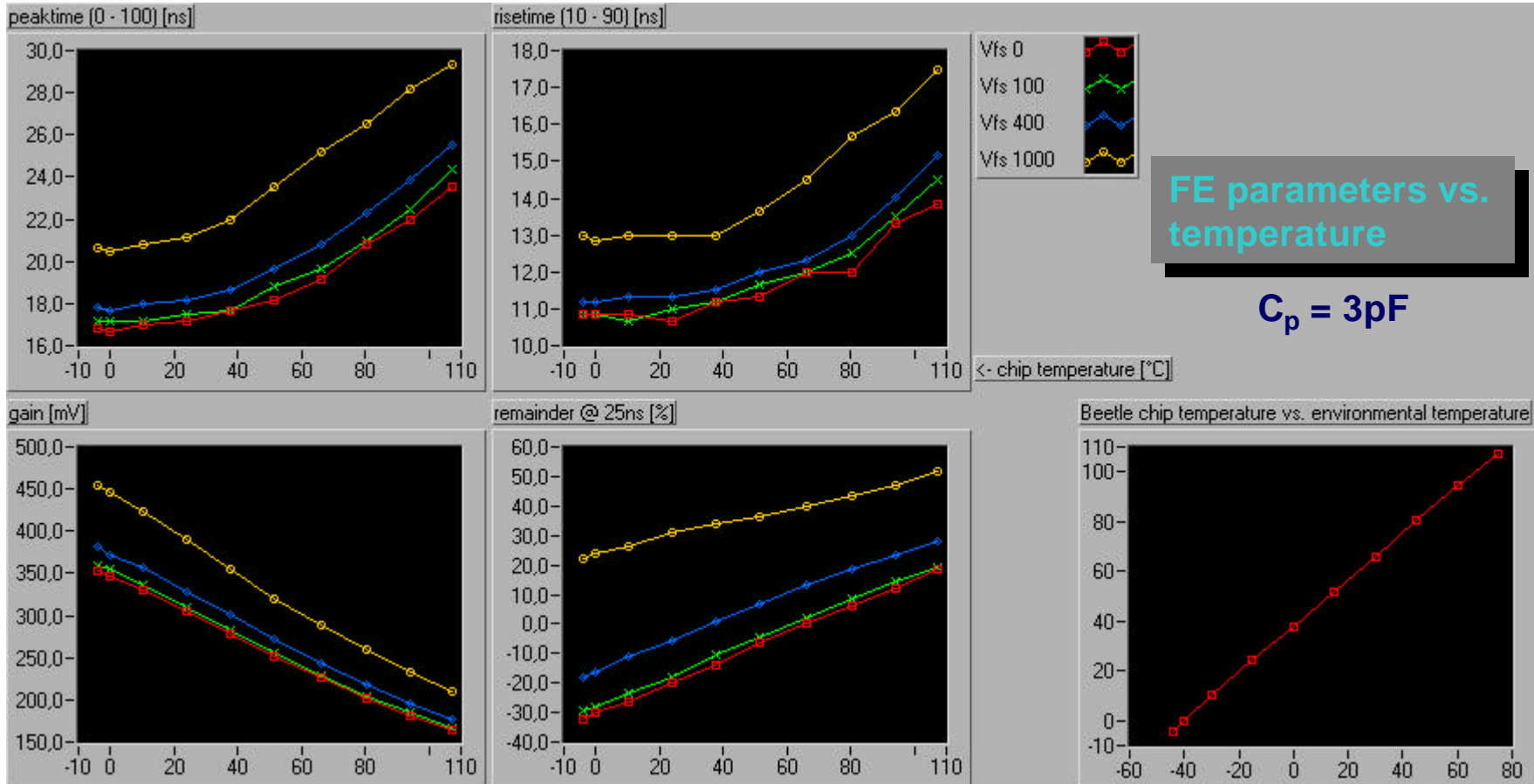
(FE, Pipeline, Pipeamp, Readout)

$ENC_{V_{fs}=0} : 599.9 e^- + 51.9 e^-/pF$
 $ENC_{V_{fs}=100} : 594.6 e^- + 51.2 e^-/pF$
 $ENC_{V_{fs}=400} : 576.5 e^- + 48.8 e^-/pF$
 $ENC_{V_{fs}=1000} : 492.3 e^- + 47.3 e^-/pF$





Front end: Temperature (1)





I²C - Input Pads

New 5V tolerant I²C-Pads for Beetle 1.3

- **SCL / SDA input level tested:**
 - min. HIGH: 1.5V**
 - max. HIGH: 7.0V** (only tested up to 7.0V)

 - min. LOW: -0.7V**
 - max. LOW: 1.1V @ 2.5V HIGH level**
 - 1.2V @ 3.3V**
 - 1.3V @ 5.0V**

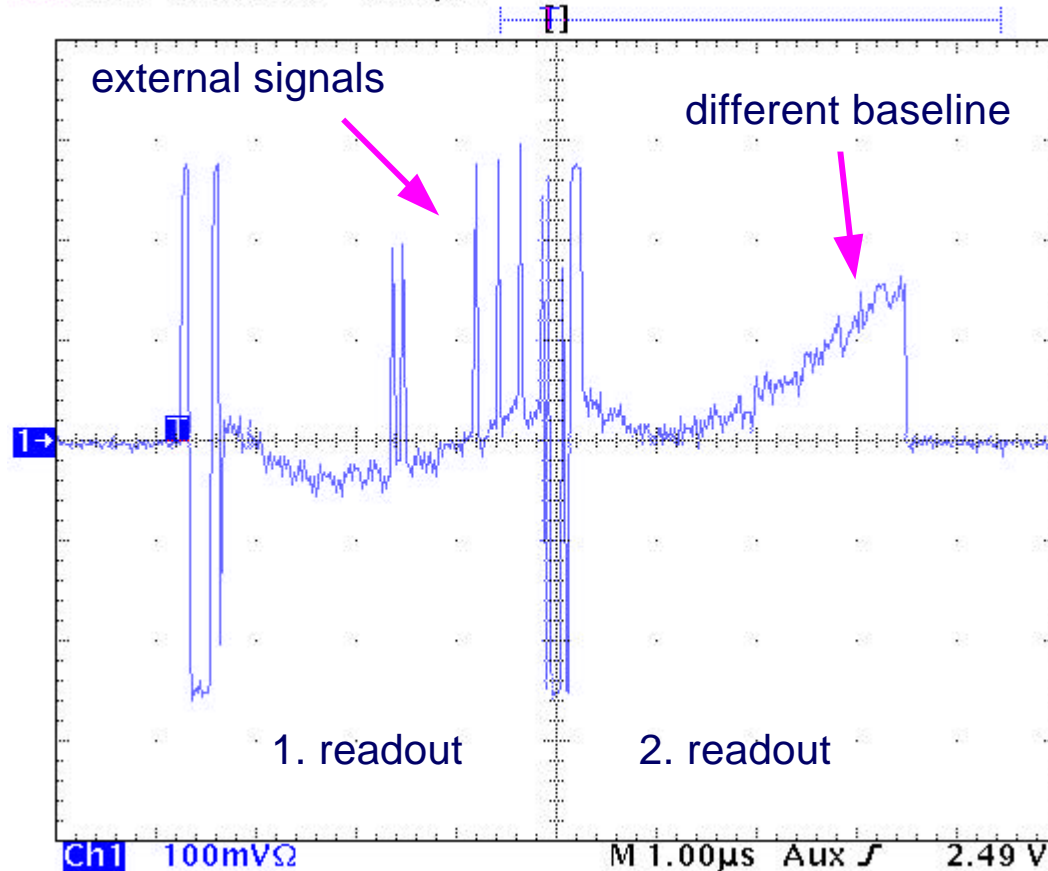
- **SDA output delay (ACK): 500ns** (I²C specification: delay > 300ns)





Sticky Charge

Tek Run: 50.0MS/s Sample



Consecutive readout

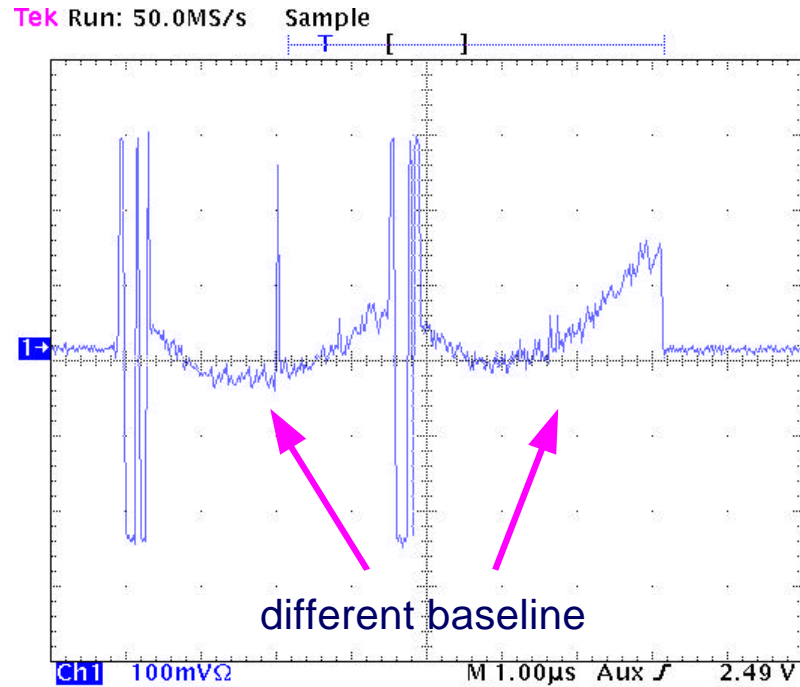
- External signals on 5 channel in 1st readout frame
- No sticky charge in 2nd readout frame

but still a different baseline

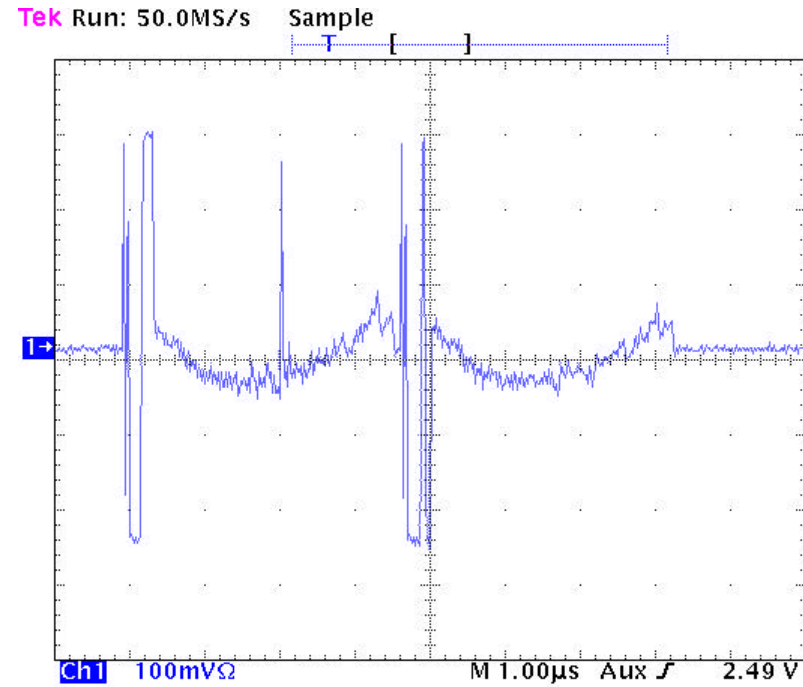




Readout



consecutive readout



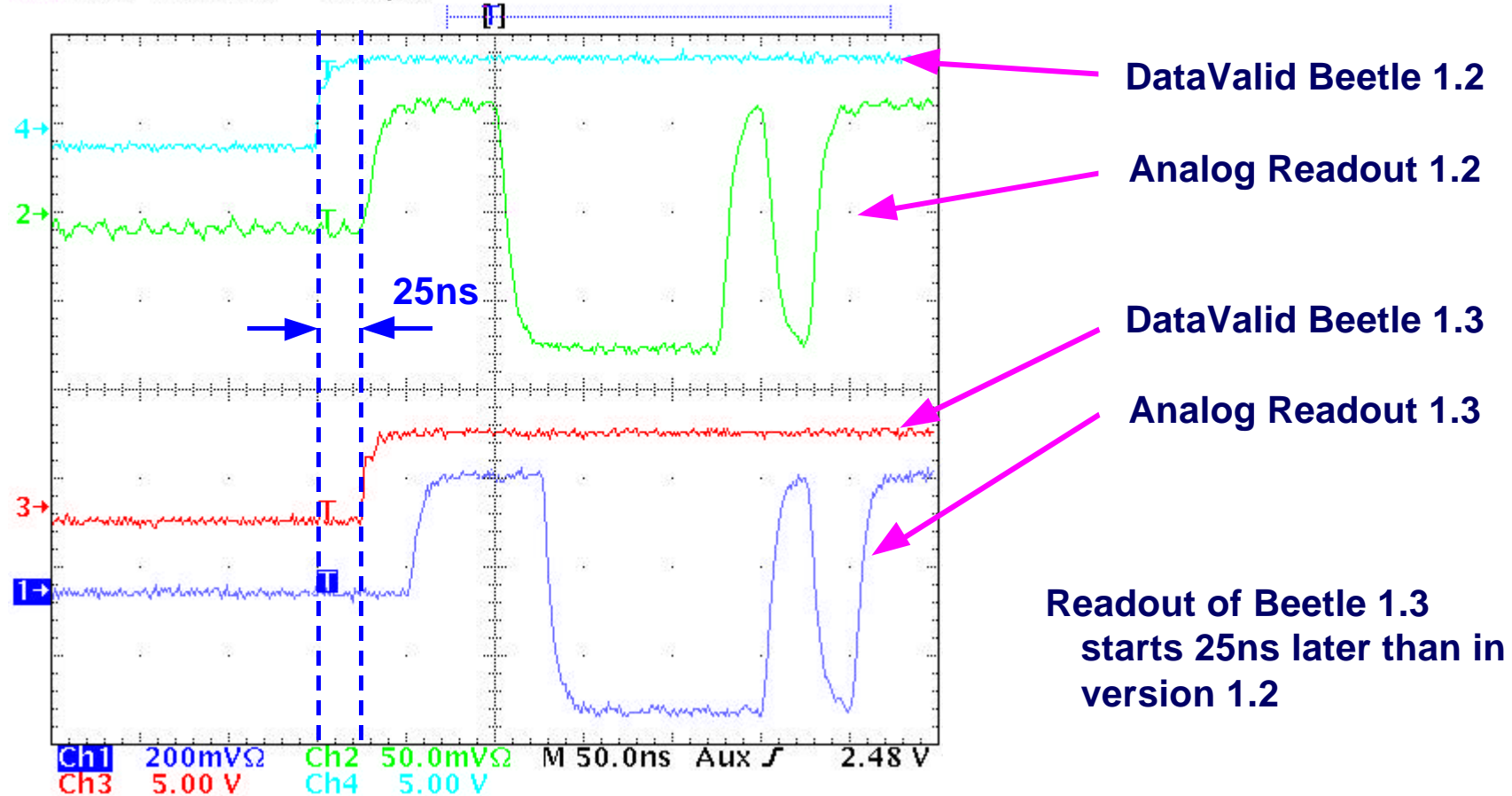
non-consecutive readout





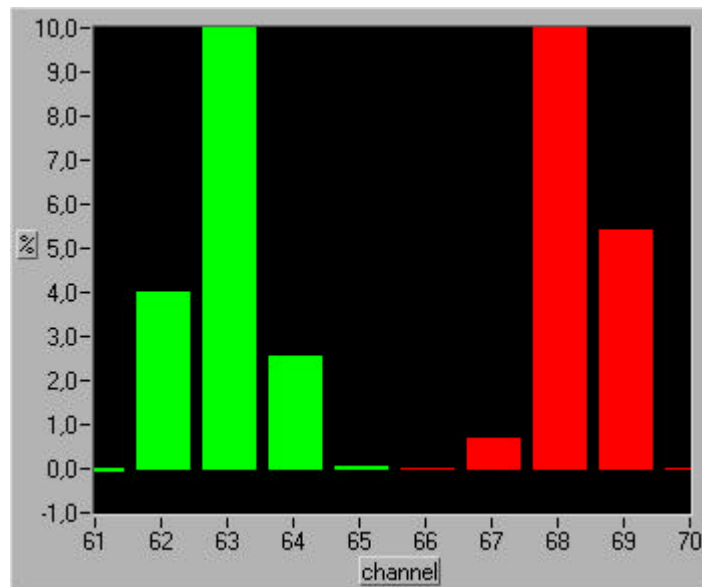
Readout Beetle 1.2 <-> 1.3

Tek Run: 1.00GS/s Sample





Channel Crosstalk



Testpulse (63. & 68) is standardised to 100%

Channel crosstalk

- measured a even/odd dependency
- up to now the reason is not understood, but this effect is also present in 1.2

Clarification of crosstalk:

typical Testpulse for a odd channel (e.g. 63):
crosstalk into predecessor channel is larger than into successor channel

typical Testpulse for a even channel (e.g. 68):
crosstalk into successor channel is larger than into predecessor channel





Future work

- Analyse recorded noise data vs. temperature
- Analyse the Pipeline homogeneity of Beetle 1.3
- Closer investigation of different readout behaviour (consecutive/non-consecutive)
- Measuring of the analog output driving capability
- Completion of front end parameters:
 - response to heavy ionizing particles
 - max. charge rate @ 22ke⁻
- Investigation of even/odd crosstalk
- ...

