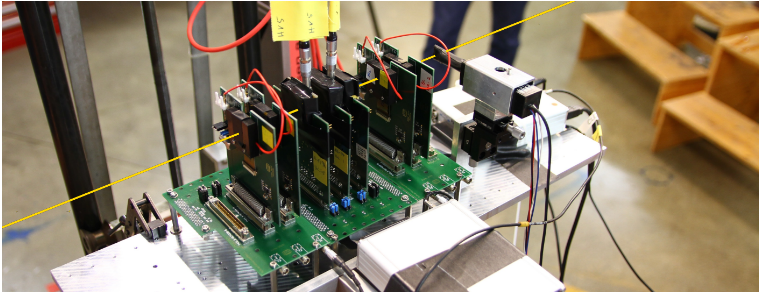


ETH High Rate Beam Telescope

presented by: Michael Reichmann
coauthors: Felix Bachmair, Dmitry Hits

Table of contents

Motivation

Goal:

- testing of different types of diamond sensors for rate dependence (up to fluxes of 10 MHz/cm^2)

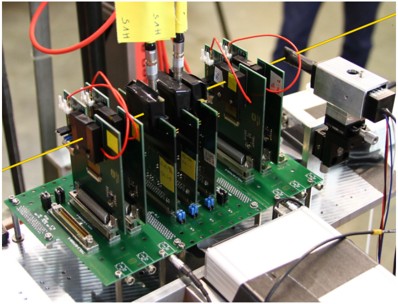
Conditions:

- beam line PIM1 at PSI (Paul Scherrer institute)
- continous pion beam with a flux of up to 10 MHz/cm^2 and momenta of 100-500 MeV/c

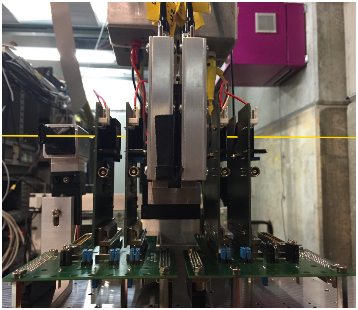
Requirements:

- small, flexible and modular system
  - reduce effects of multiple scattering
  - fast setup, easy to tear down,
- high rate continuous data taking
- scalable trigger area
  - high efficiency in the DUT
- precise trigger timing

The Telescope

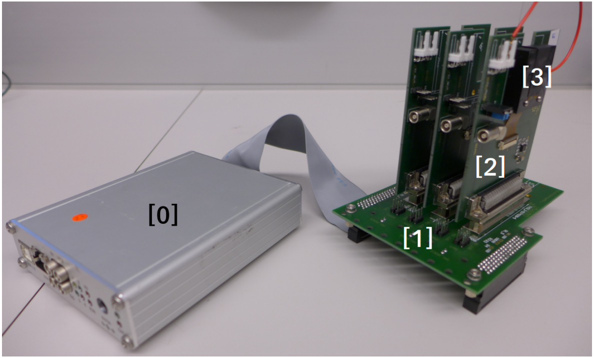


Pixel Setup



Pad Setup

Telescope Module



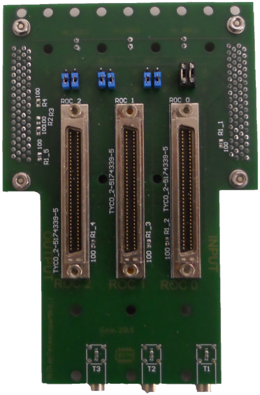
- [0] DTB (Digital Test Board): interface to a computer
- [1] Motherboard: main frame of the telescope
- [2] Adapter Planes: interface to the single pixel chips
- [3] CMS Pixel Chip (analogue or digital)

CMS Pixel Chips

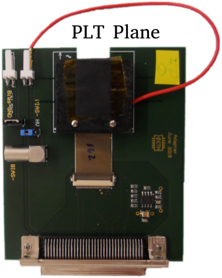
	PSI46v2	PSI46dig	PROC600
Chip size		$\approx 8 \times 10\,\mathrm{mm}^2$	
Pixel size		$150 \times 100\,\mu\mathrm{m}^2$	
Pixel array		52×80	
Pixel charge readout	**analogue**	**digitised**	**digitised**
Readout	multi level 40 MHz	160 MBit/sec	160 MBit/sec
Hit rate	$80\,\mathrm{MHz/cm}^2$	$120\,\mathrm{MHz/cm}^2$	$600\,\mathrm{MHz/cm}^2$
Radiation Tolerance	200 kGy	1 MGy	6 MGy (exp.)
In-time threshold	**3500 e**	**$\approx$ 1500 e**	**$\approx$ 1500 e**
Fast-OR trigger	**yes**	**no**	**yes**

Parts

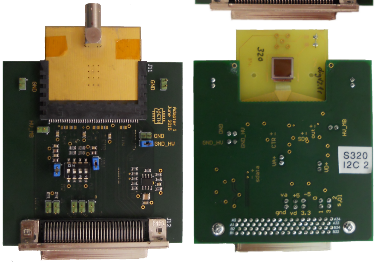
Motherboard



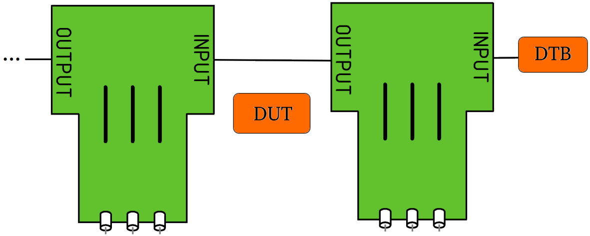
PLT Plane



DTB Planes

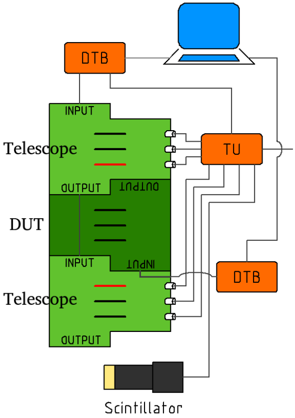


Schematic Setup



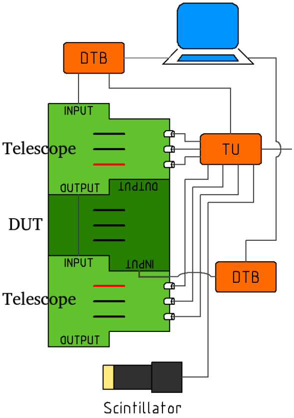
- chain several motherboards together into a single big telescope
- can only chain one chip type (analogue or digital)
- number of planes per motherboard is also variable $(1-3)$

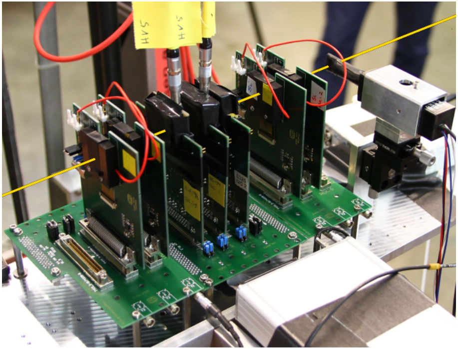
Diamond Pixel Setup



- telescope: two motherboards
  - analogue chips
- DUT: single motherboard
  - diamonds sensors on digital chips
- scintillator: precise trigger timing (fast-OR depends on clock, usually 40 MHz)
- trigger: coincidence of the two planes closest to the DUT (red) and the scintillator

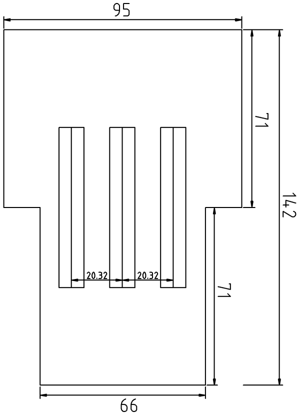
Diamond Pixel Setup





Pixel Setup

Specification



Spec	Value
Number of planes	variable
Interplane distance	20.32 mm
Module length	9.5 cm
Height	$\approx$ 12 cm
Width	14.5 cm
Maximum trigger area	$7.8 \times 8\,\mathrm{mm}^2$
Y-Resolution at PSI	$\approx$ 50 µm for pads
	$\approx$ 100 µm for pixel

Datataking

EUDAQ

Software:

- portable, modular and cross-platform DAQ framework
- developed for the EUDET Telescope
- can combine data streams from several different devices into an event based data stream
- utilises pXar to communicate with the telescope
  - pXar-core libraries: programming and readout of the the CMS pixel chips

Extension: (with guidance from DESY)

- readout of the analogue chip with pXar and the DTB (thanks to Simon Spannagel!)
- readout of diamond pad sensors with DRS4 Evaluation Board
- adding new class to save whole waveforms

Trigger

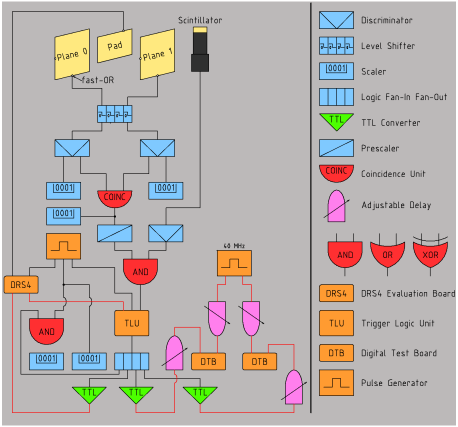
Requirements:

- guarantee DUT hit
  - use coincidence of the fast-ORs from the planes directly before and after the DUT
- scalable trigger
  - mask pixels of correspondent trigger planes
- exact timing
  - coincidence with a fast scintillator
- event alignment
  - EUDAQ Trigger Logic Unit (TLU)

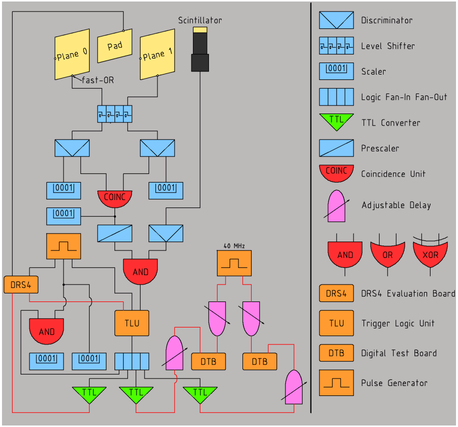
Addition for pads:

- constant low frequency pulser as stable reference signal
  - OR with pulser and particle trigger

Trigger Logic

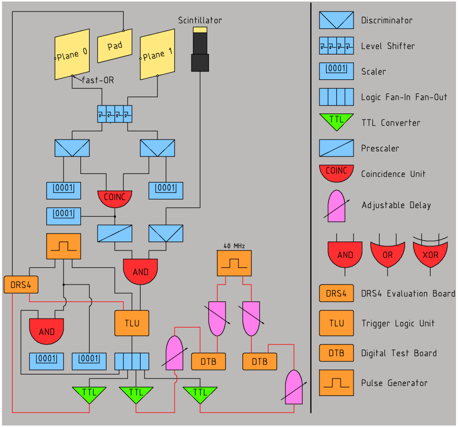


Trigger Logic



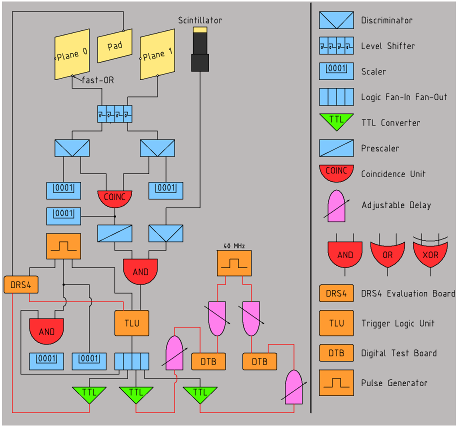
- fast-OR coincidence

Trigger Logic



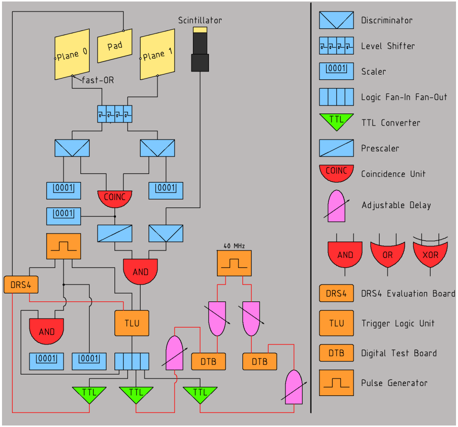
- fast-OR coincidence
- coincidence with scintillator

Trigger Logic



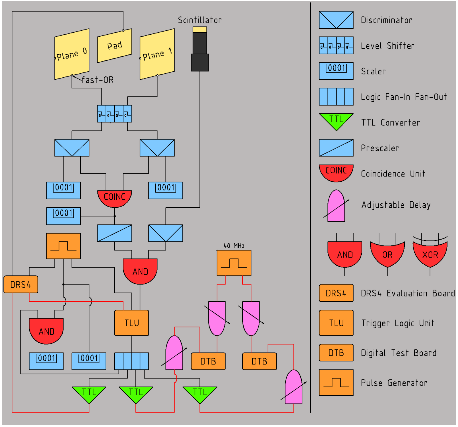
- fast-OR coincidence
- coincidence with scintillator
- OR with pulser

Trigger Logic



- fast-OR coincidence
- coincidence with scintillator
- OR with pulser
- global external clock with adjustable delays

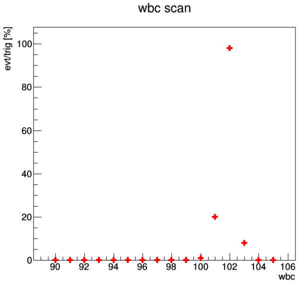
Trigger Logic



- fast-OR coincidence
- coincidence with scintillator
- OR with pulser
- global external clock with adjustable delays
- busy signal after each trigger to avoid event misalignment
    - useful for events with many pixels hit

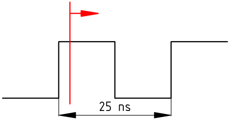
Commissioning

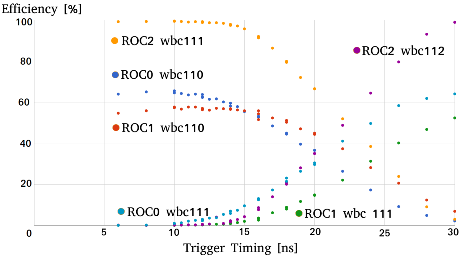
WBC scan



- ROC saves bunch crossing when particle hits the sensor
- programmable setting called wbc (wait bunch crossing)
- trigger only validates if time the trigger takes back to the ROC matches the wbc setting
- automated wbc scan using the pXar CLI

Efficiency Optimisation



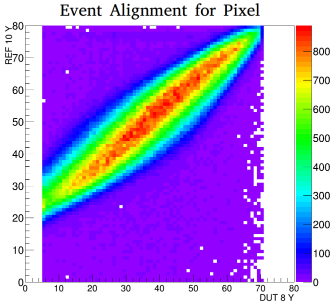


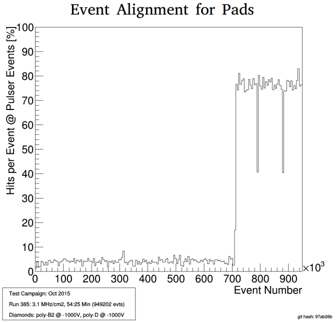
- wbc scan also yields:
  - detailed information about the hit yield for every connected ROC
  - information of the trigger phase (relative timing of the trigger compared to the clock)
- first use trigger delay to shift the the trigger in the middle of the clock
- shift trigger and external clock delay together
  - leaves trigger phase constant
  - find optimal efficiency relative to the telescope clock

Event alignment

- two event streams (telescope and DUT)
- event alignment has to be guaranteed to make use of tracking
- DRS4 board has no event counter
- using busy signal of the DRS4 as handshake for the TLU
- no handshake for the DTB yet (but in progress)
- control event alignment in online analysis

Analysis

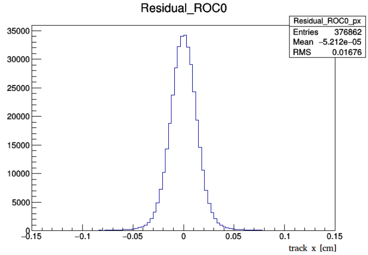


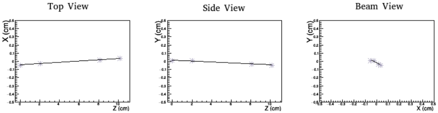


- compare x and y position of telescope and DUT

- use constant frequency pulser signal as reference
- expect less pixel hits at pulser events

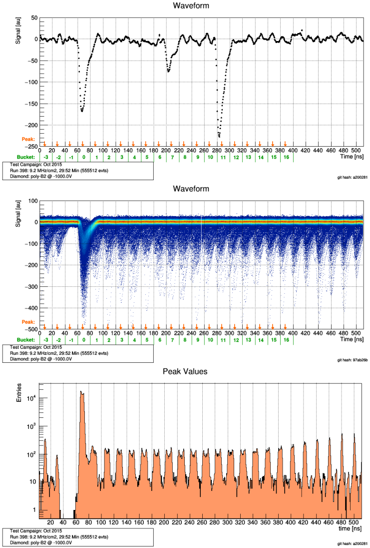
Plane alignment

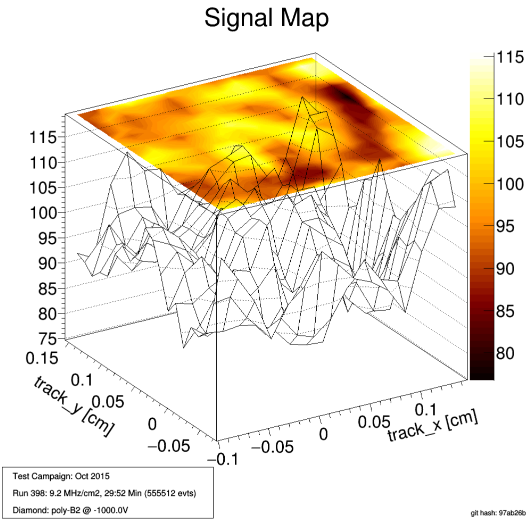




- iterative procedure written by Gregor Kasieczka using the PLT framework
- moving track residuals to zero
- first rotation around beam axis
- translation in x-y plane perpendicular to the beam axis

Miscellaneous




Signal Map
115
110
105
100
95
90
85
80
75
0.15
0.1
0.05
0
−0.05
track_y [cm]
−0.1
−0.05
0
0.05
0.1
track_x [cm]
115
110
105
100
95
90
85
80
Test Campaign: Oct 2015
Run 398: 9.2 MHz/cm2, 29:52 Min (555512 evts)
Diamond: poly-B2 @ -1000.0V
git hash: 97ab26b

Conclusion

- overcoming problems in the beginning
  - finding a good design and testing the single components
  - readout of the analogue chip by the DTB
  - extending the softwares pXar and EUDAQ
- great working telescope for our purposes
  - reliable tracking and alignment
  - a few runs still have event misalignment (can be fixed offline)
- setup time currently about half a day
- still room for improvement

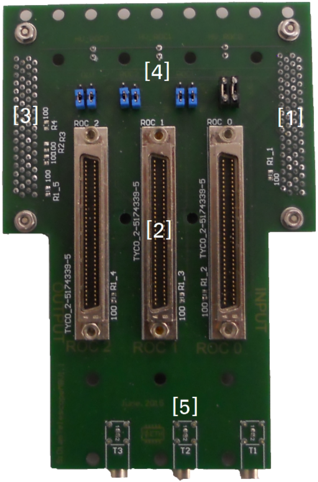
Outlook

- merge trigger logic into single device (Trigger Unit)
  - currently testing a TU from OSU
- two preinstalled setups for pad and pixel tests
- synchronise DTB clock with the beam clock at PSI ($40 \rightarrow 50\,\mathrm{MHz}$)
- save scintillator signal with the DRS4
  - more precise trigger timing
  - particle identification by time of flight
- increasing resolution
  - try tilting the planes (more charge sharing)
  - reduce material
- testing PROC600 as telescope chip with trigger as well as DUT
- testing PSI-ROC4SENS (chip without threshold) as DUT

Special Thanks to:

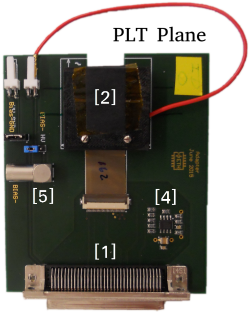
- the DESY people for helping us with the the EUDAQ framework
- Simon Spannagel for the insights in pXar and its analogue extension as well as immediate help during beam tests
- the Horisberger group at PSI for advice concerning the pixel chips
- David ... for the information about the PSI facilities
- ...

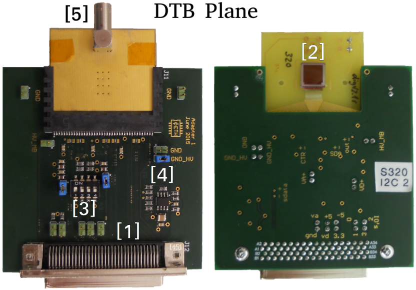
Motherboard



- [1] input: SCSI connector to the DTB
- [2] sockets for the adapter planes
- [3] output (optional): SCSI connector to another motherboard
  - daisy-chainable
- [4] token jumpers:
  - blue = plane used
  - black = plane skipped
- [5] output of the fast-OR trigger signal

Adapter Planes

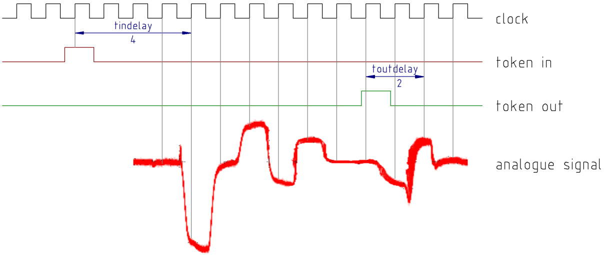




- [1] SCSI connector to MB
- [2] CMS pixel chip
- [3] bit switch for I^2C address
- [4] fast-OR amplifying circuit
- [5] sensor bias input

Inclusion of the analogue pixel chip

- analogue chips were read out with an Analogue Test Board (ATB)
  - limited buffer size ($\rightarrow$ limited run time)
- adapting pXar to use the DTB for the readout (thanks to Simon Spannagel)
- need to adjust DTB timings:
  - token delays to find the begin and the end of the waveform
  - clock offset to sample at the center of each peak of the waveform



The Digital Test-Board

- FPGA including soft Token Bit Manager (TBM) emulator
- clock and external trigger inputs
- connectors: USB, low voltage and scsi
- LEMO high voltage input for biasing the sensors
- internal ADC

Figure : DTB inside

Figure : DTB front and back