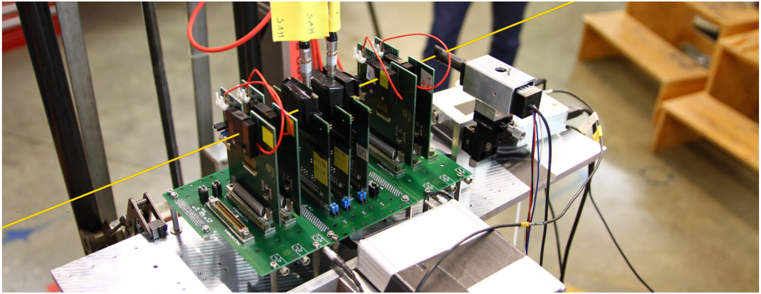

ETH High Rate Beam Telescope

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

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Motivation

Goal:

- testing of different types of diamond sensors for rate dependence (up to fluxes of $10\,\mathrm{MHz/cm^2}$)

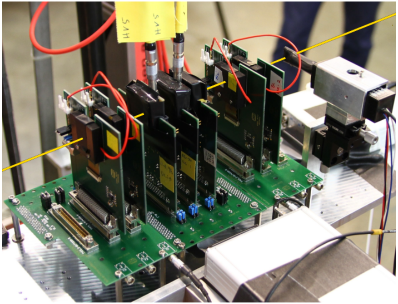
Conditions:

- beam line PIM1 at PSI (Paul Scherrer institute)
- continous pion beam with a flux of more than $10\,\mathrm{MHz/cm^2}$ and momenta of 100-500 MeV/c
  - running at 260 MeV/c and maximum $10\,\mathrm{MHz/cm^2}$

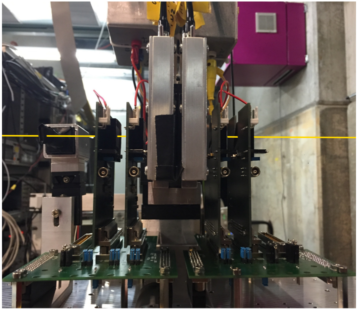
Requirements:

- 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

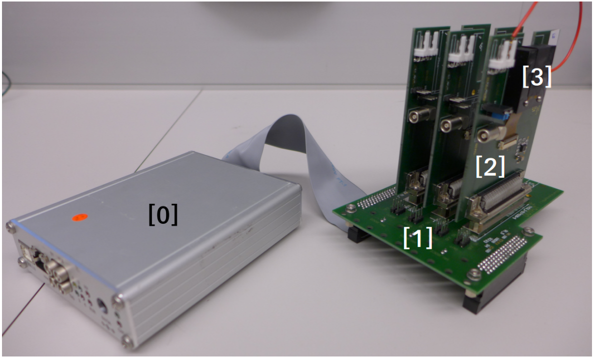


Pixel Setup



Pad Setup

Telescope Module



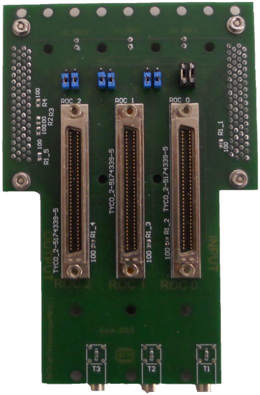
- [0] DTB (Digital Test Board): interface to a computer
- [1] Motherboard: main frame of the telescope
- [2] Adapter Planes: interface to the single pixel chips
- [3] CMS Pixel Chip (analogue or digital)

CMS Pixel Chips

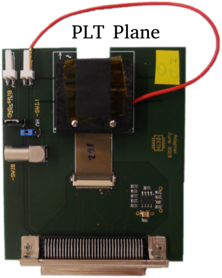
	PSI46v2	**PSI46dig**	**PROC600**
Chip size		$\approx 8 \times 10\,\mathrm{mm}^2$	
Pixel size		$150 \times 100\,\mu\mathrm{m}^2$	
Pixel array		52×80	
Pixel charge readout	**analogue**	**digitised**	**digitised**
Readout	multi level 40 MHz	160 MBit/sec	160 MBit/sec
Hit rate	$80\,\mathrm{MHz/cm}^2$	$120\,\mathrm{MHz/cm}^2$	$600\,\mathrm{MHz/cm}^2$
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

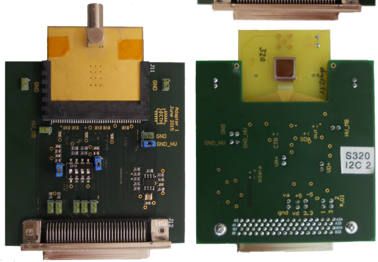
Motherboard



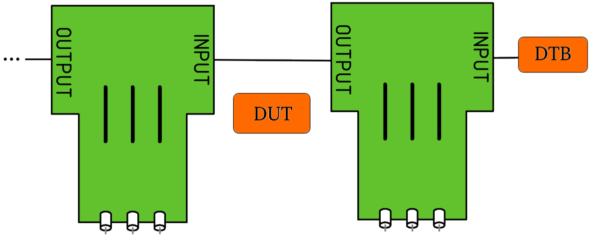
PLT Plane



DTB Planes

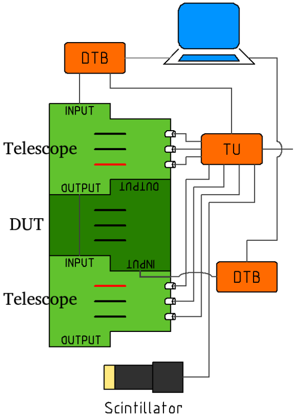


Schematic Setup



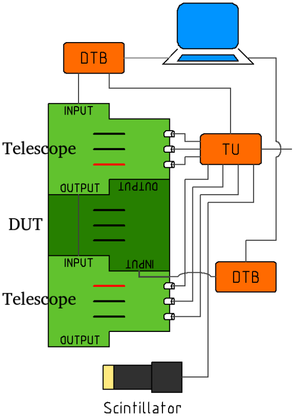
- chain several motherboards together into a single big telescope
- can only chain one chip type (analogue or digital)
- number of planes per module is also variable $(1-3)$

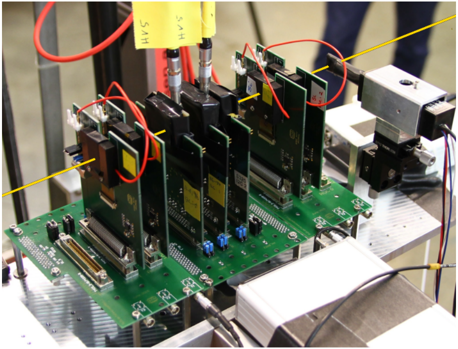
Diamond Pixel Setup



- 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

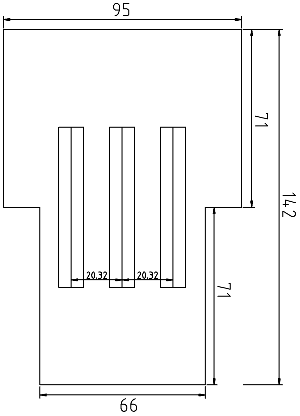
Diamond Pixel Setup





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	$7.8 \times 8\,\text{mm}^2$
Y-Resolution at PSI	$\approx 50\,\mu\text{m}$ for pads
	$\approx 100\,\mu\text{m}$ for pixel

Datataking

EUDAQ

Base 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!)
- a class to save whole waveforms
- readout of diamond pad sensors with DRS4 Evaluation Board

Trigger

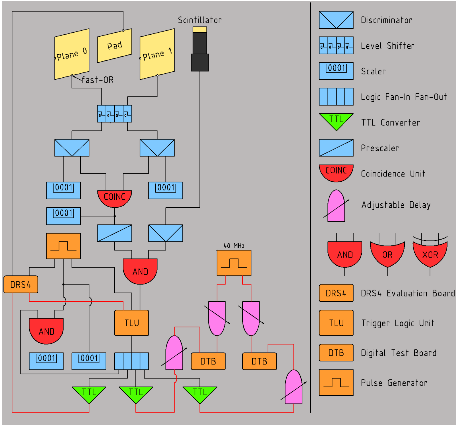
Requirements:

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

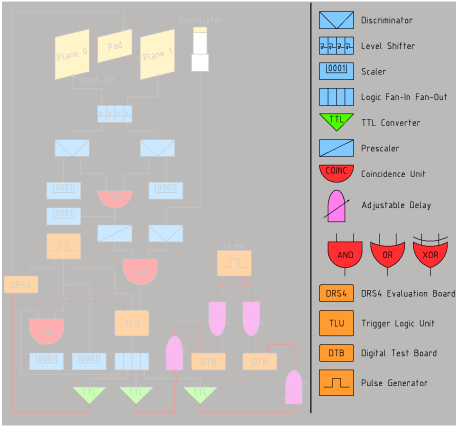
Addition for pads:

- mixing of a constant low frequency pulser as stable calibration signal
  - OR with pulser and particle trigger

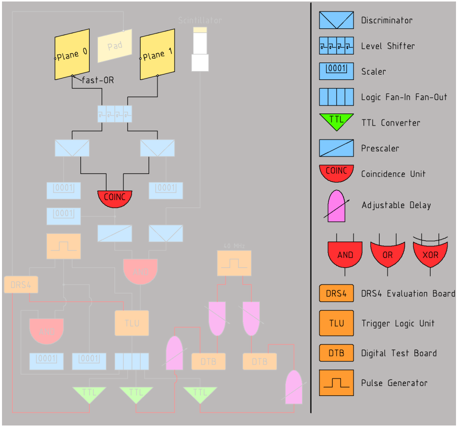
Trigger Logic



Trigger Logic

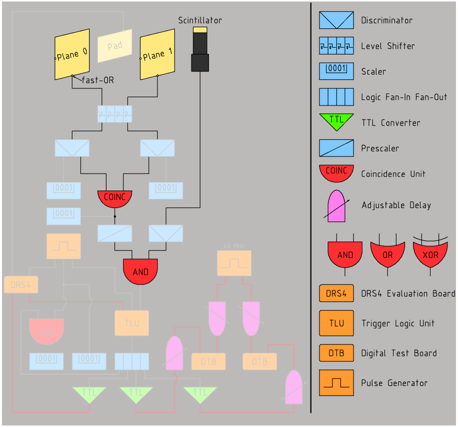


Trigger Logic



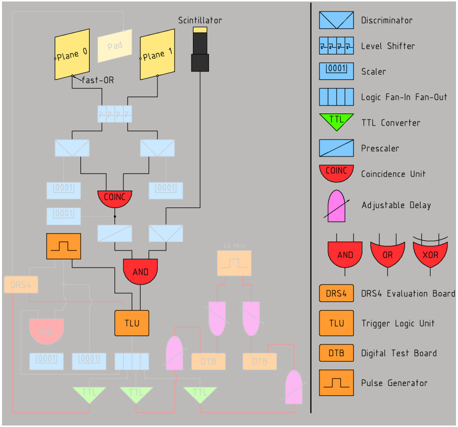
- fast-OR coincidence

Trigger Logic



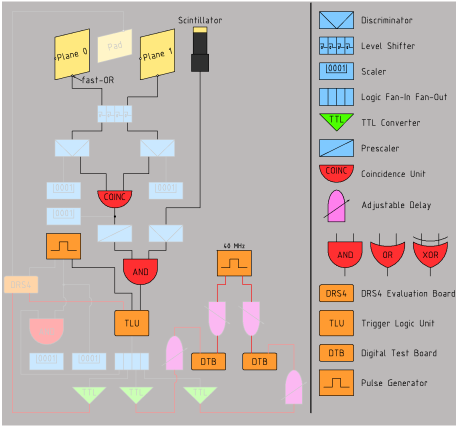
- fast-OR coincidence
- coincidence with scintillator

Trigger Logic



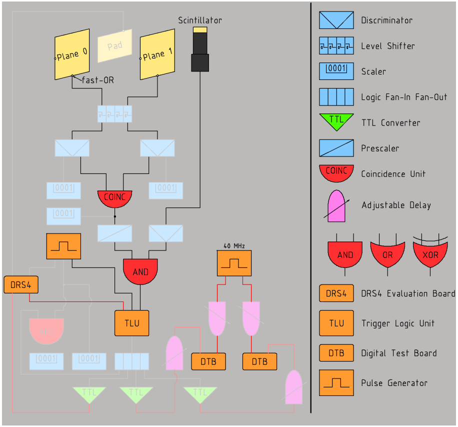
- fast-OR coincidence
- coincidence with scintillator
- OR with pulser

Trigger Logic



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

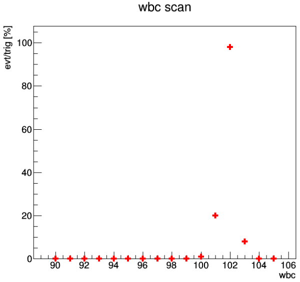
Trigger Logic



- 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

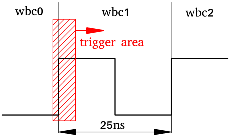
Commissioning

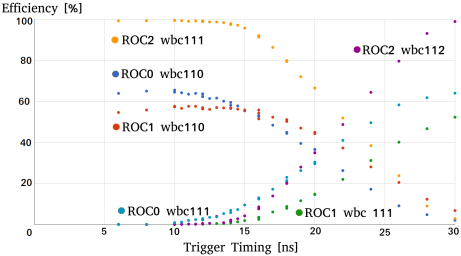
WBC scan



- ROC stores data of a hit with number of the bunch crossing counter
- programmable setting called wbc (wait bunch crossing)
- trigger only validates if wbc setting matches the number of bunchcrossings the trigger arrives at the ROC after the hit
- only one high efficient wbc setting
- automated wbc scan using the pXar CLI

Efficiency Optimisation



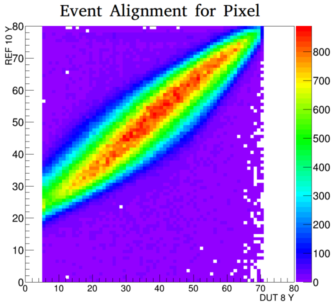


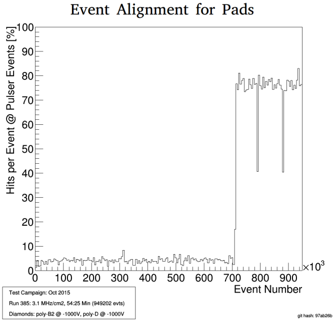
- need to optimise relative trigger phases for the telescope and DUT trigger (for pixel setup):
  - done by using information of the wbc scan:
  - hit yield of the ROCs
  - trigger phase with respect to the clock
- shifting triggers and external clock with additional delays

Event alignment

- two event streams (telescope and DUT)
- event alignment has to be guaranteed to make use of tracking
- our DRS4 readout 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

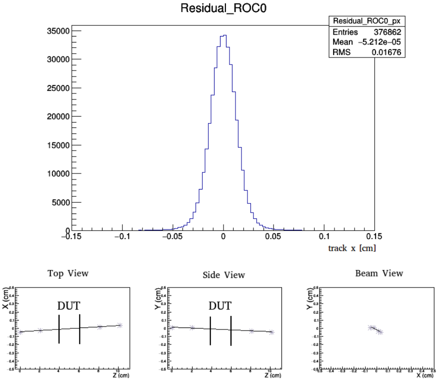




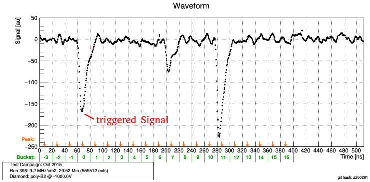
- compare x and y position of telescope and DUT

- use pulser calibration signal
  - expect less pixel hits

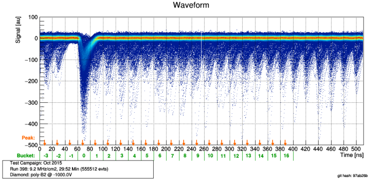
Plane alignment



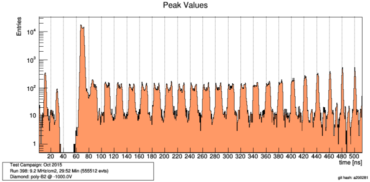
- iterative procedure
  - written by Gregor Kasieczka
- moving track residuals to zero
- first correct for rotation around beam axis
- second correct for translations in the plane perpendicular to the beam axis



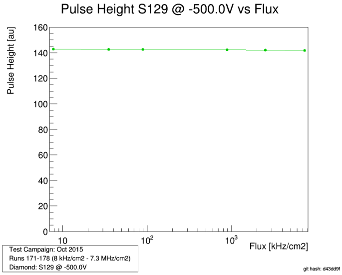
- sample pad DUT waveform

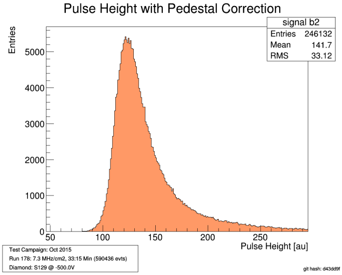


- overlay of 5000 waveforms
  - revealing beam structure of the PSI beam

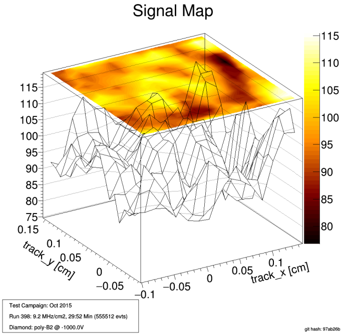


- highest peak pos of the whole waveform
  - also showing bunch structure





- left side: single chrystal diamond pad
  - expect no rate dependence
  - nice landau-shaped signal distribution
- right side: poly chrystalline diamond pad
  - variations of the signal in different regions
  - demonstration of working tracking



Conclusion

- Problems solved
  - found a good design and tested the single components
  - readout of the analogue chip by the DTB
  - extended the softwares pXar and EUDAQ
- great working telescope for our needs
  - reliable tracking and alignment
  - precise timing
  - a few runs still have event misalignment (can be fixed offline)
- setup time currently at least one day
- still room for improvement

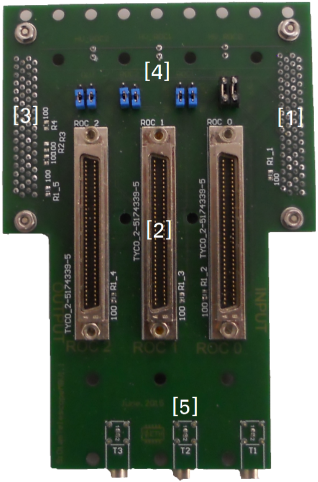
Outlook

- 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 ($40 \rightarrow 50\,\text{MHz}$)
- 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:

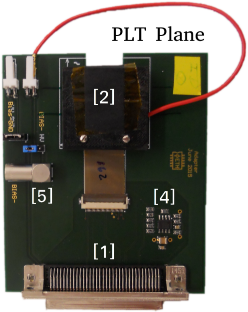
- the DESY EUDAQ group
  - especially Simon Spannagel
- the Horisberger group at PSI
- Konrad Deiters, Thomas Rauber, Davide Reggiane, Manuel Schwarz from the PSI beam facility

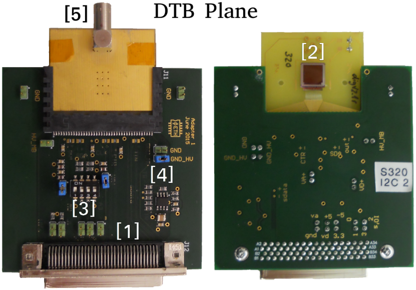
Motherboard



- [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

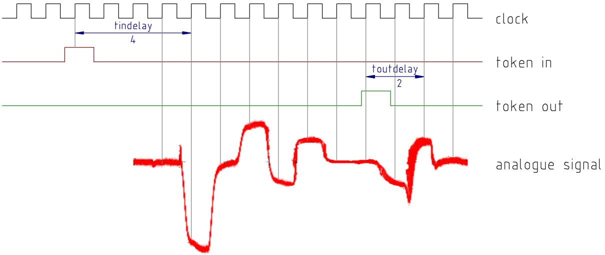




- [1] SCSI connector to MB
- [2] CMS pixel chip
- [3] bit switch for I^2C address
- [4] fast-OR amplifying circuit
- [5] sensor bias input

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