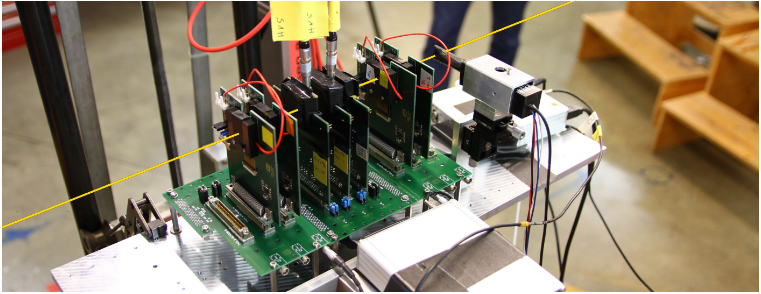


ETH High Rate Beam Telescope

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 $10\,\mathrm{MHz/cm^2}$)

Conditions:

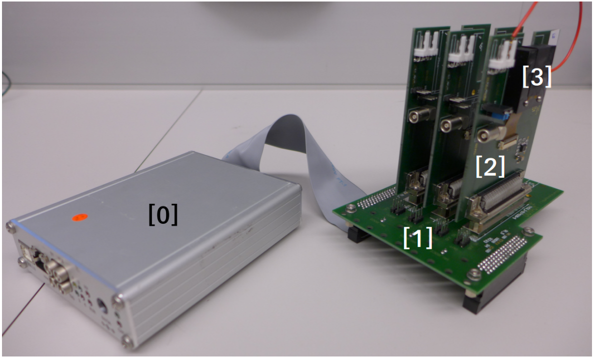
- beam line PIM1 at PSI (Paul Scherrer institute)
- continous pion beam with a flux of up to $10\,\mathrm{MHz/cm^2}$ and momenta of 100-500 MeV/c

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

General Setup

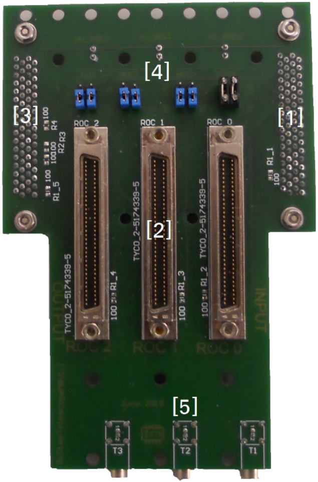


- [0] DTB (Digital Test Board): interface to a computer
- [1] Motherboard: main frame of the telescope
- [2] Adapter Planes: interface to the single pixel chips
- [3] CMS Pixel Chip (analogue or digital)

CMS Pixel Chips

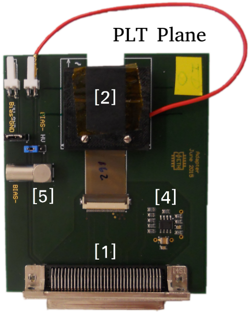
	PSI46v2	**PSI46dig**	**PROC600**
Chip size	$7.9 \times 10.0\,\text{mm}^2$	$7.9 \times 10.3\,\text{mm}^2$	$7.9 \times 10.6\,\text{mm}^2$
Pixel size	$150 \times 100\,\mu\text{m}^2$	$150 \times 100\,\mu\text{m}^2$	$150 \times 100\,\mu\text{m}^2$
Pixel array	52×80	52×80	52×80
Pixel charge readout	analogue	digitised	digitised
Readout	multi level 40 MHz	160 MBit/sec	160 MBit/sec
Hit rate	$80\,\text{MHz/cm}^2$	$120\,\text{MHz/cm}^2$	$600\,\text{MHz/cm}^2$
Radiation Tolerance	200 kGy	1 MGy	6 MGy
In-time threshold	3500 e	< 2000 e	< 2000 e
Fast-OR trigger	yes	no	yes

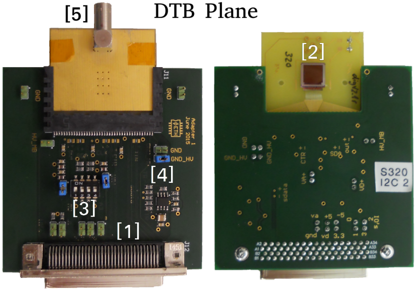
Motherboard



- [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

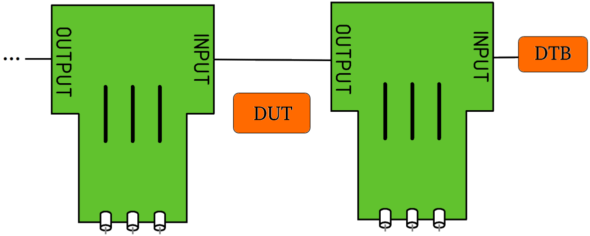
Adapter Planes





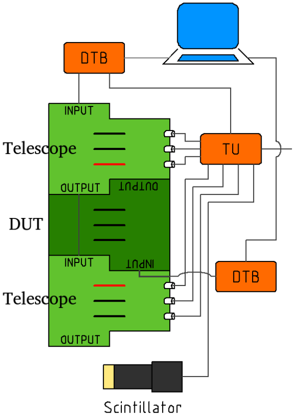
- [1] SCSI connector to MB
- [2] CMS pixel chip
- [3] bit switch for I^{2}C address
- [4] fast-OR amplifying circuit
- [5] sensor bias input

Modularity



- 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

Diamond Pixel Setup



- telescope: two motherboards with analogue chips
- DUT: single motherboard with 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

Specification

Spec	Value
Number of planes	variable
Unit length	9.5 cm
Height	$\approx$ 12 cm
Width	14.5 cm
Maximum trigger area	$150 \times 100\ \mu m^2$
X-Resolution at PSI	$\approx 50\ \mu m$ for pads
	$\approx 100\ \mu m$ for pixel

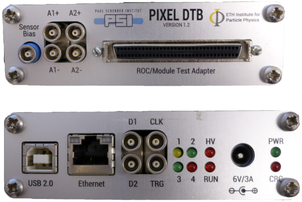
Datataking

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



pXar

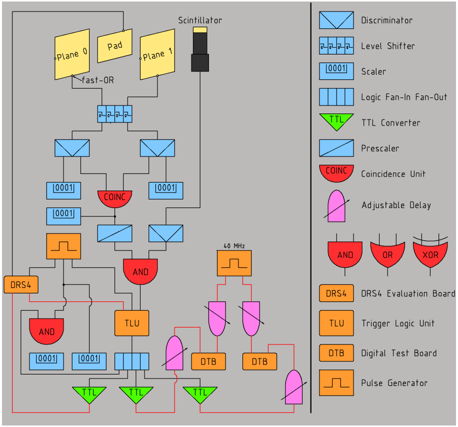
- short for Pixel eXpert Analysis Readout
- software for communication between the telescope and a computer
- pXar-core libraries: programming and readout information of the the CMS pixel chips
- python CLI (Command Line Interface) to perform simple tests

EUDAQ

- portable, modular and cross-platform DAQ framework
- developed for the EUDET Pixel Telescope
- can combine data streams from several different devices into an event based data stream
- using pXar core libraries
- adapting software to our purposes with help of DESY

- readout of diamond pad sensors with DRS4 Evalution Board
  - adding a producer for the DRS4 as extension to EUDAQ

Trigger logic

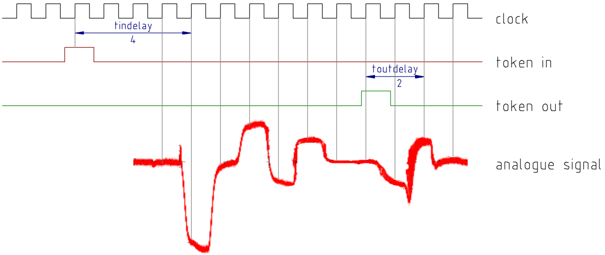


- coincidence between a fast-OR of planes before and after the DUT
- AND of scintillator and fast-OR coincidence as trigger
- OR with a low frequency pulser
- global external clock with adjustable delays
- busy signal after each trigger to avoid event misalignment
  - useful for events with many pixels hit

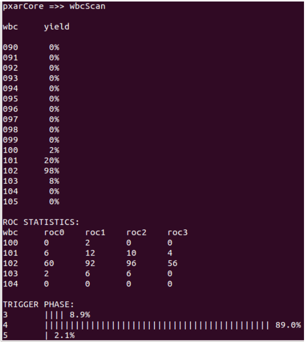
Commissioning

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



WBC scan

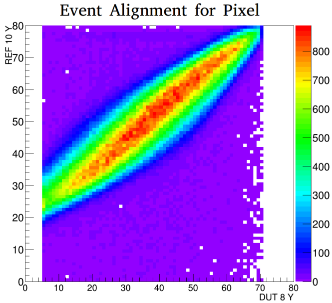


```
pxarCore =>> wbcScan

wbc     yield

090      0%
091      0%
092      0%
093      0%
094      0%
095      0%
096      0%
097      0%
098      0%
099      0%
100      2%
101     20%
102     98%
103      8%
104      0%
105      0%

ROC STATISTICS:
wbc     roc0    roc1    roc2    roc3
100     0       2       0       0
101     6       12      10      4
102     60      92      96      56
103     2       6       6       0
104     0       0       0       0

TRIGGER PHASE:
3       |||| 8.9%
4       |||||||||||||||||||||||||||||||||||||||||||| 89.0%
5       | 2.1%
```

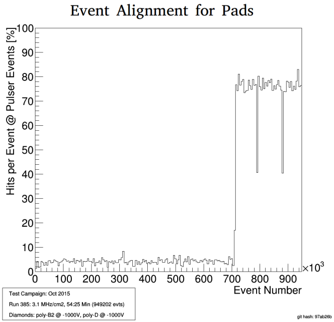
- ROC saves bunch crossing when particle hits the sensor
- programmable setting called wbc (wait bunch crossing)
- trigger only validates if time the trigger takes back to the ROC matches the wbc setting
- automated wbc scan using the pXar CLI
- detailed information about the hit yield (event has at least one hit) for every connected ROC
- information of the trigger phase (relative timing of the trigger compared to the clock)

Analysis

Event alignment



- compare x and y position of telescope and DUT

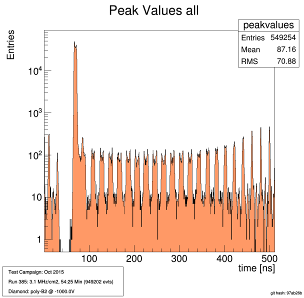


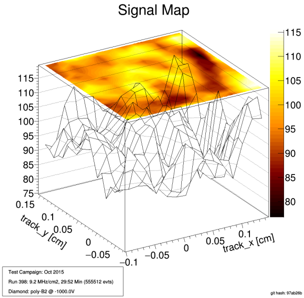
- use constant frequency pulser signal as reference
- expect less pixel hits at pulser events

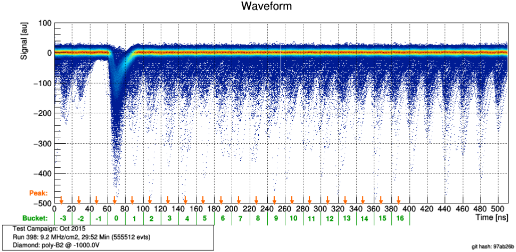
Plane alignment

- iterative procedure from the PLT
- moving track residuals to zero
- first rotation around beam axis
- translation in x-y plane perpendicular to the beam axis

Miscellaneous







Conclusion

- overcoming problems in the beginning
  - finding a good design and testing the single components
  - readout of the analogue chip by the DTB
  - adapting the softwares pXar and EUDAQ
- great working telescope for our purposes
  - reliable tracking and alignment
  - not fully working event alignment (can be fixed afterwards)
- setup time atm about half a day
- still room for improvement

Outlook

- use the OSU TU (Trigger Unit) as single device to process all triggers
- two preinstalled setups for pad and pixel tests
- synchronise DTB clock with the beam clock at PSI ($40 \rightarrow 50$ MHz)
- save scintillator signal with the DRS4
  - particle identification by time of flight
- increase resolution by tilting the telescope planes
- using PROC600 as chip for the telescope
- test PSI-ROC4SENS - a ROC without threshold