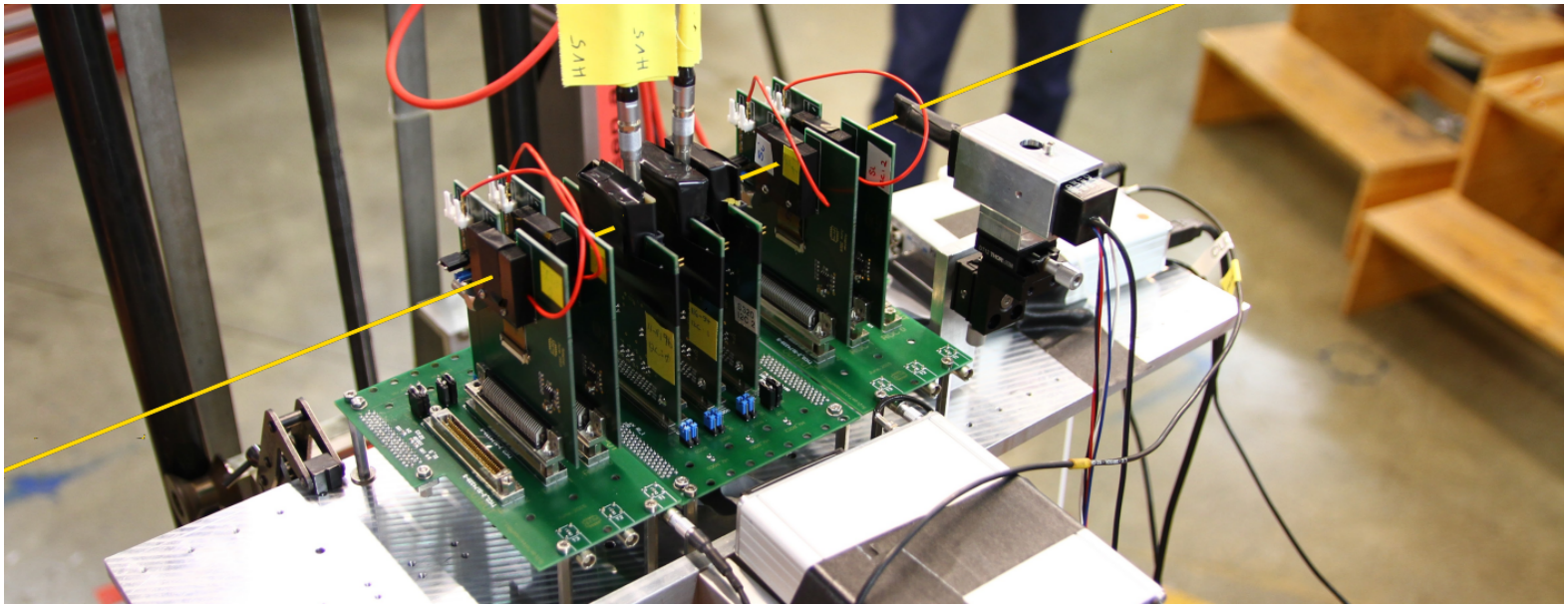

ETH High Rate Beam Telescope

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

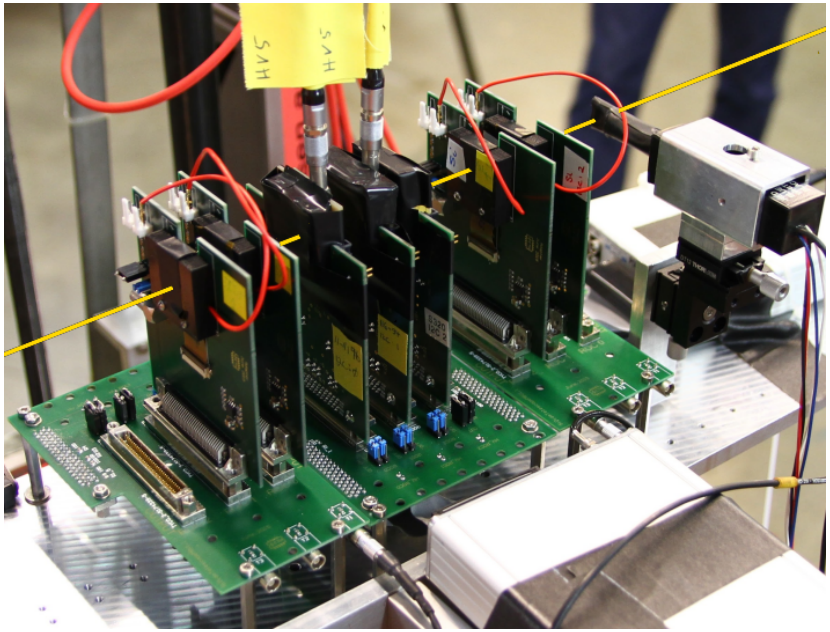
Conditions:

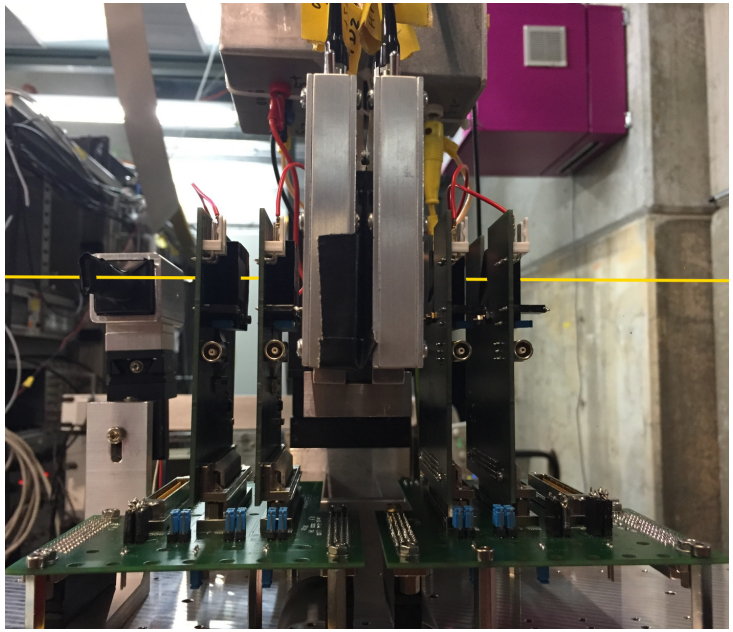
- beam line PIM1 at PSI (Paul Scherrer institute)
- continous pion beam with a flux of up to $10\,\mathrm{MHz/cm^2}$ and momenta of 100-500 MeV/c

Requirements:

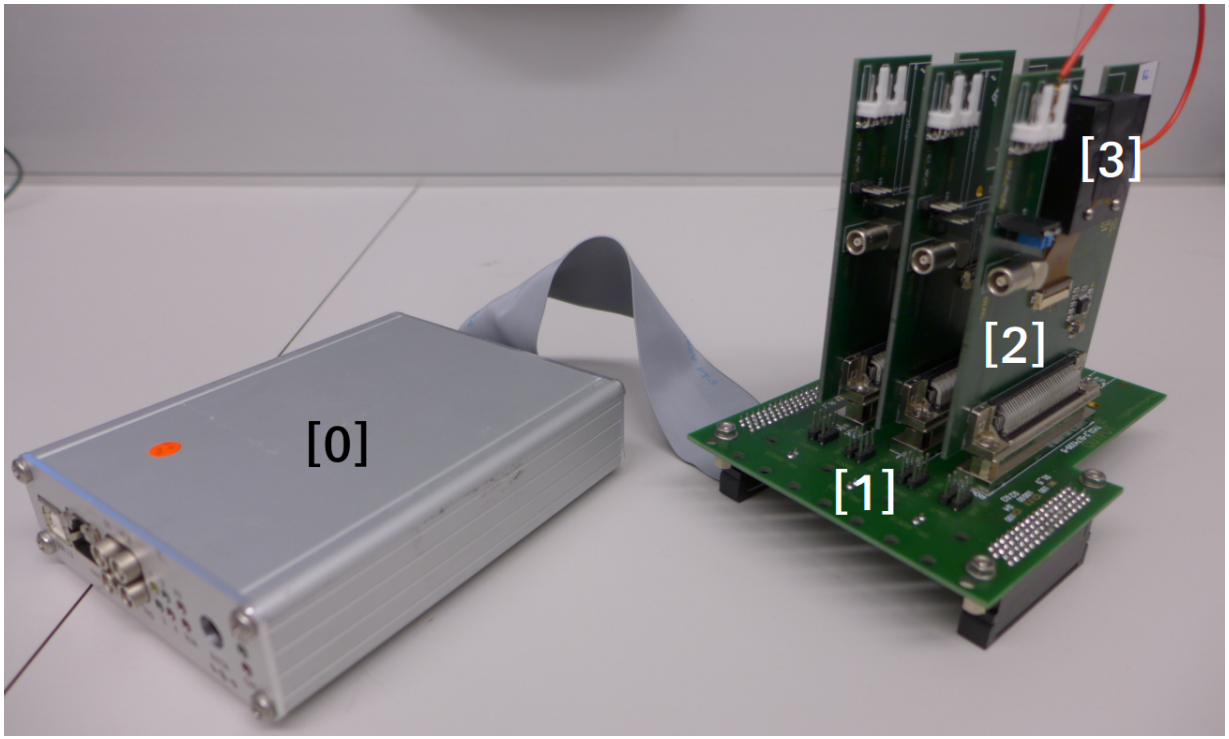
- small, flexible and modular system
  - reduce effects of multiple scattering
  - fast setup, easy to tear down,
- high rate continuous data taking
- scalable trigger area
  - high efficiency in the DUT
- precise trigger timing

The Telescope





Telescope Module

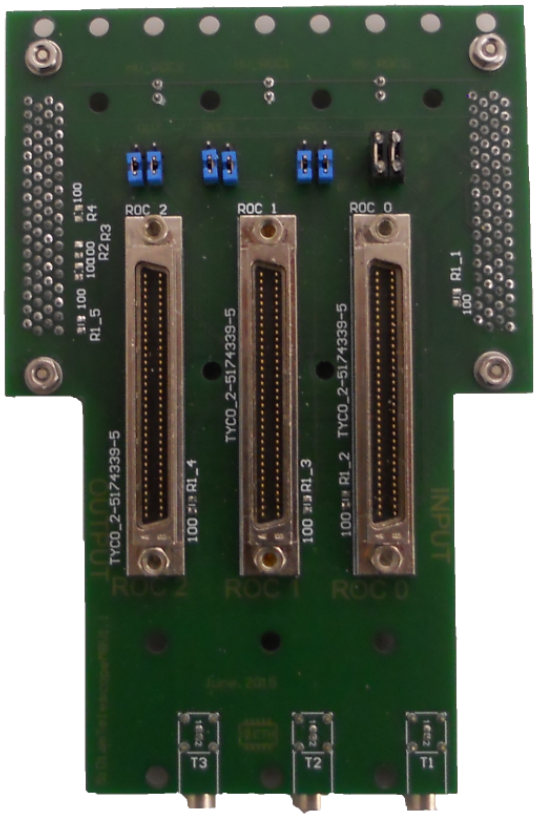


- [0] DTB (Digital Test Board): interface to a computer
- [1] Motherboard: main frame of the telescope
- [2] Adapter Planes: interface to the single pixel chips
- [3] CMS Pixel Chip (analogue or digital)

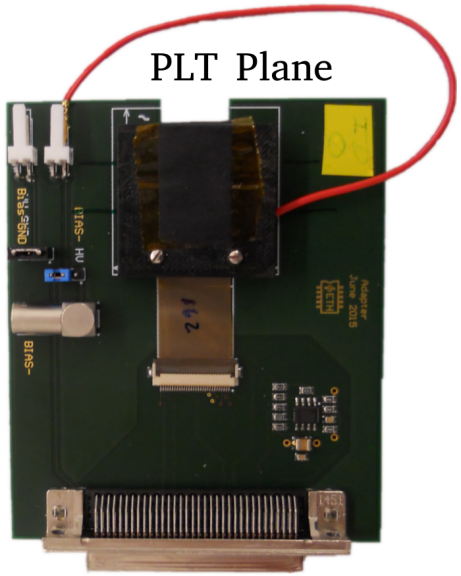
CMS Pixel Chips

	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**

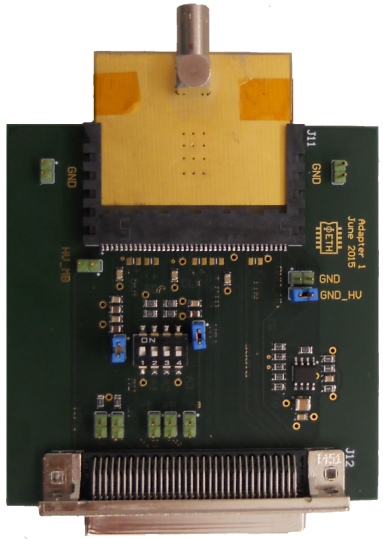
Motherboard

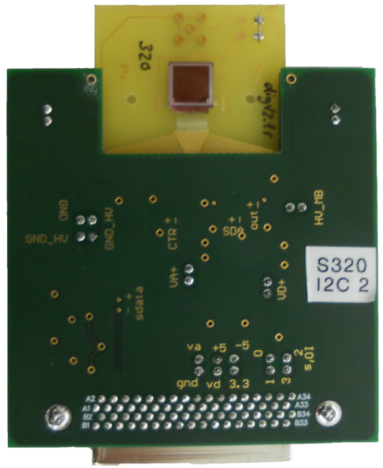


PLT Plane

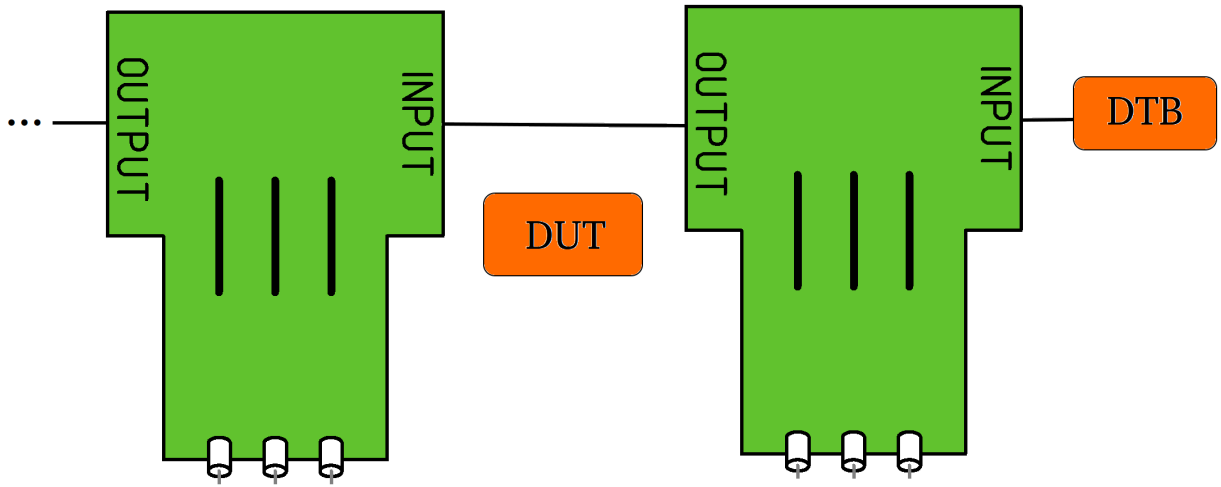


DTB Planes



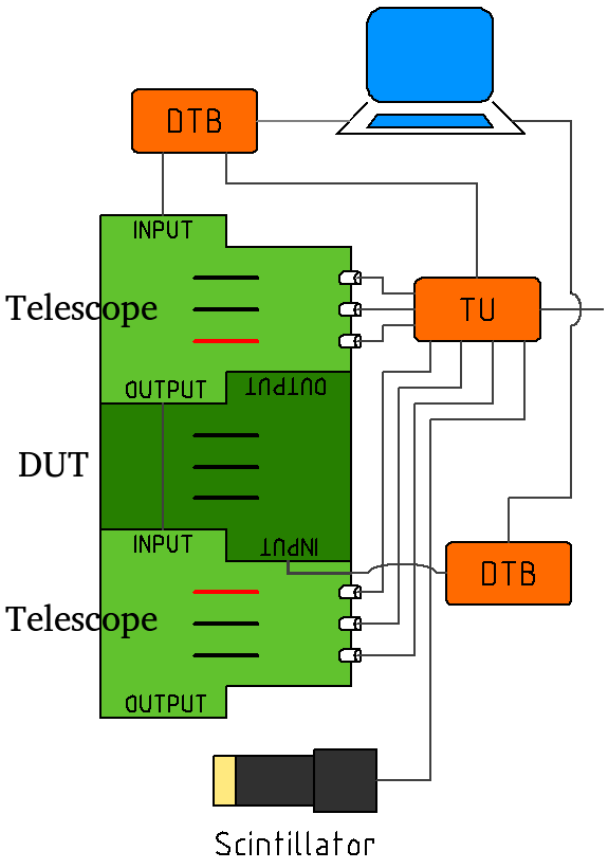


Schematic Setup



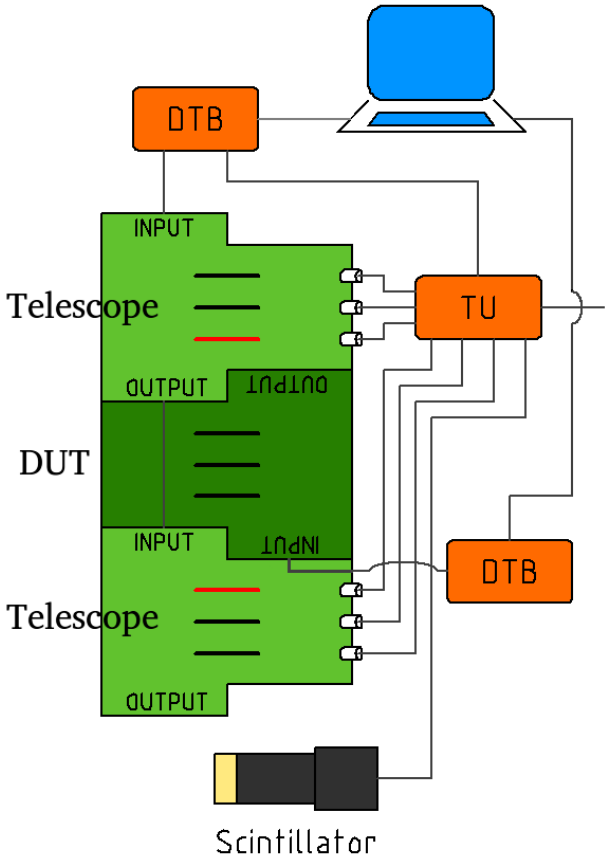
- chain several motherboards together into a single big telescope
- can only chain one chip type (analogue or digital)
- number of planes per motherboard is also variable $(1 - 3)$

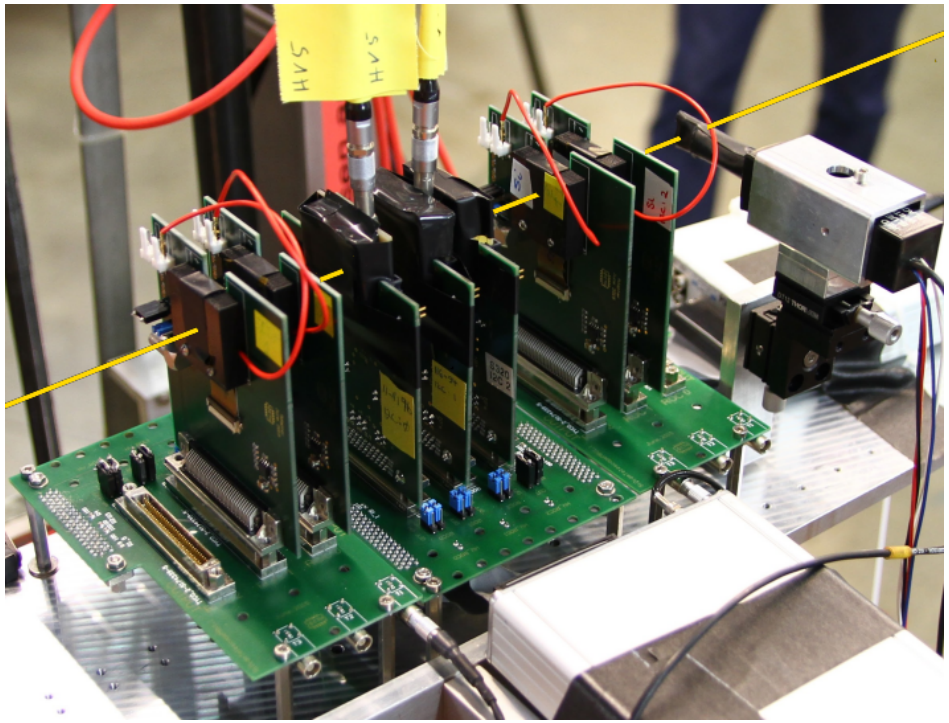
Diamond Pixel Setup



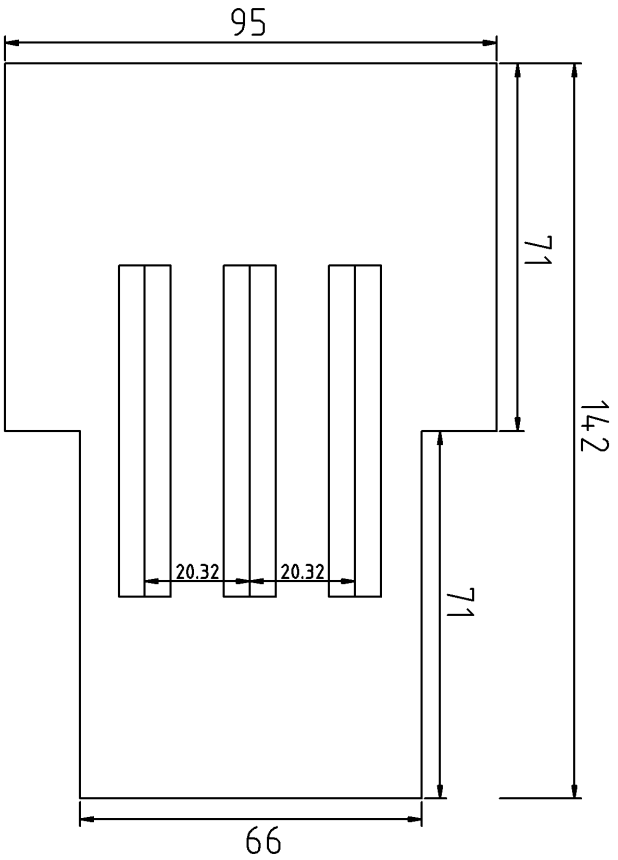
- telescope: two motherboards
  - analogue chips
- DUT: single motherboard
  - diamonds sensors on digital chips
- scintillator: precise trigger timing (fast-OR depends on clock, usually 40 MHz)
- trigger: coincidence of the two planes closest to the DUT (red) and the scintillator

Diamond Pixel Setup





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 µm for pads
	$\approx$ 100 µm for pixel

Datataking

EUDAQ

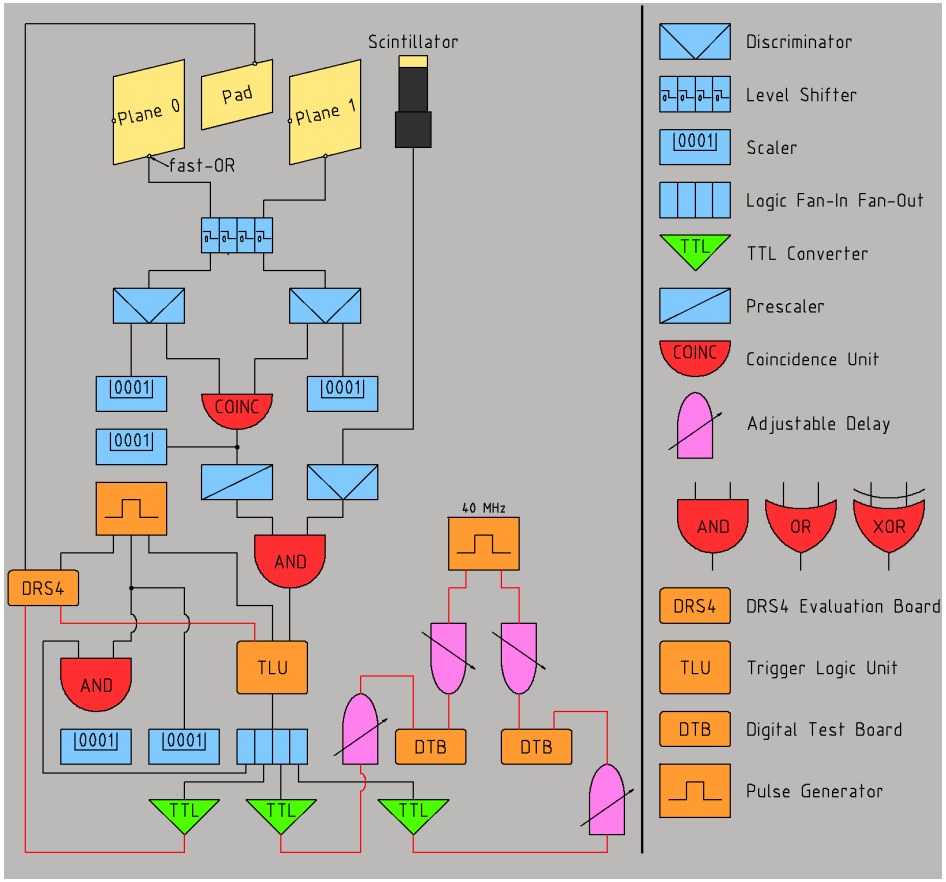
Software:

- 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 logic

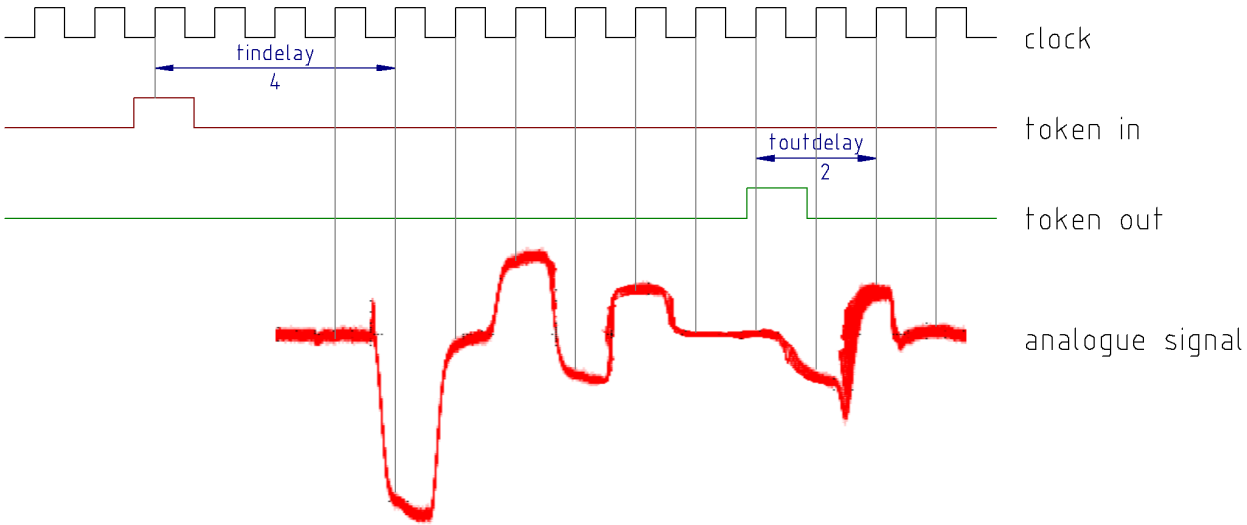


- coincidence between a fast-OR of planes before and after the DUT
- AND of scintillator and fast-OR coincidence as trigger
- OR with a low frequency pulser
- global external clock with adjustable delays
- busy signal after each trigger to avoid event misalignment
  - useful for events with many pixels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



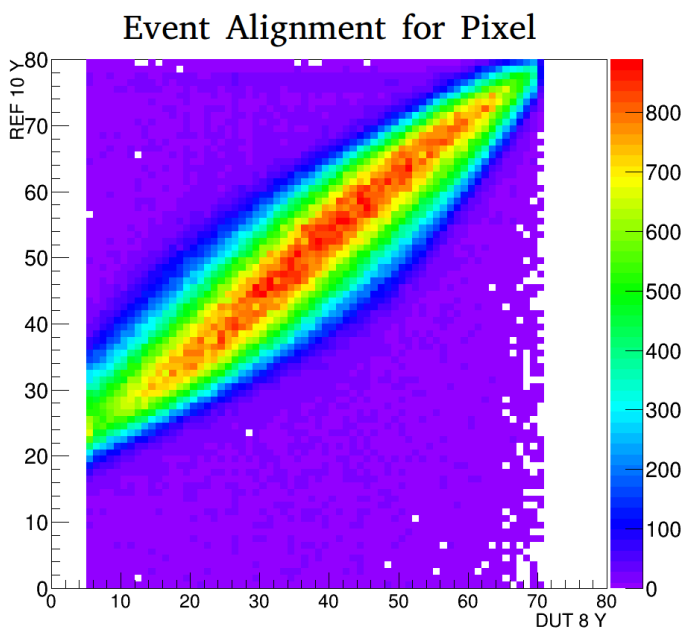
WBC scan

```
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%
```

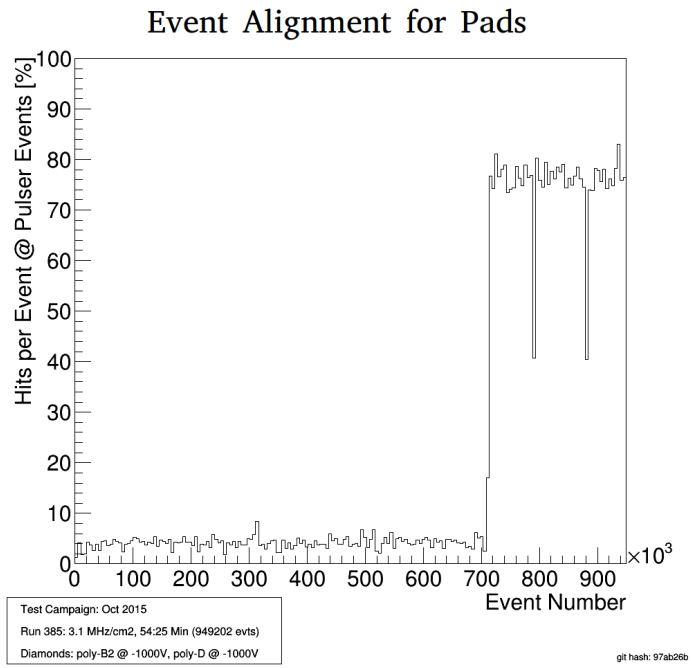
- ROC saves bunch crossing when particle hits the sensor
- programmable setting called wbc (wait bunch crossing)
- trigger only validates if time the trigger takes back to the ROC matches the wbc setting
- automated wbc scan using the pXar CLI
- detailed information about the hit yield (event has at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

Analysis

Event alignment



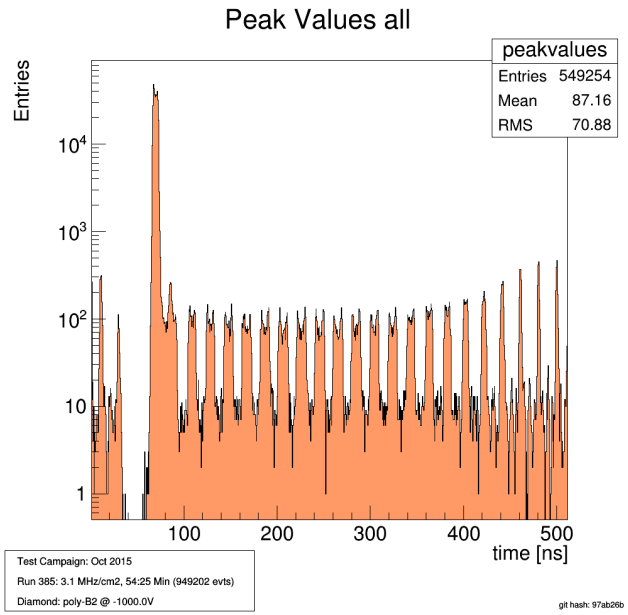
- compare x and y position of telescope and DUT

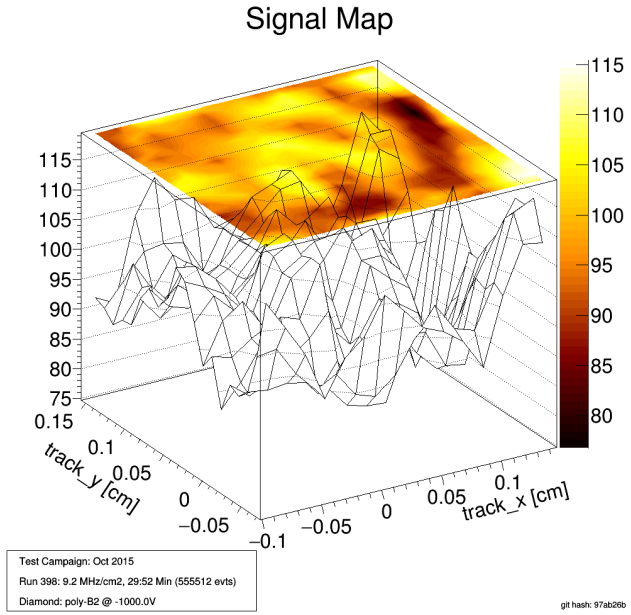


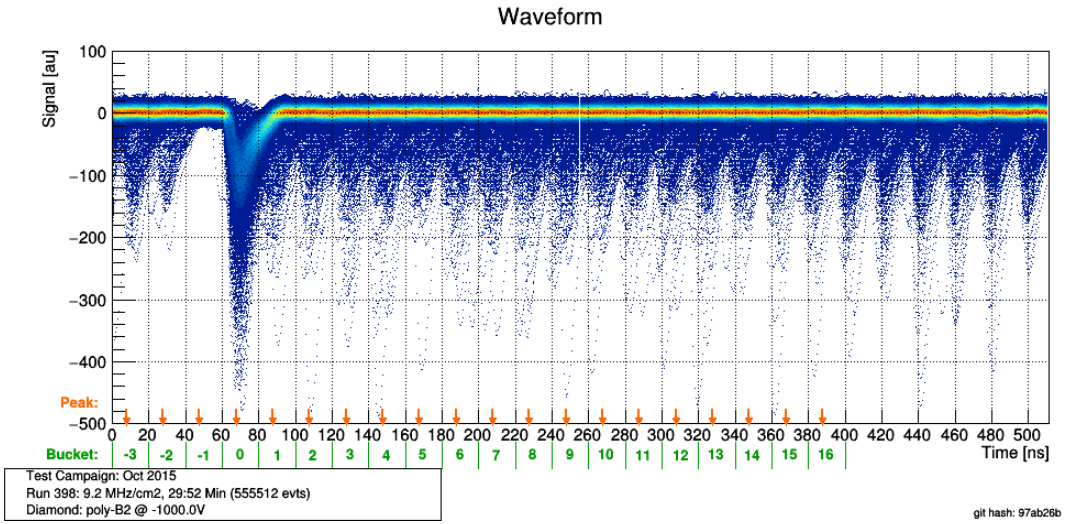
- use constant frequency pulser signal as reference
- expect less pixel hits at pulser events

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


Peak Values all
peakvalues
Entries 549254
Mean 87.16
RMS 70.88
Entries
time [ns]
Test Campaign: Oct 2015
Run 385: 3.1 MHz/cm2, 54:25 Min (949202 evts)
Diamond: poly-B2 @ -1000.0V
git hash: 97ab26b


Signal Map
track_y [cm]
track_x [cm]
Test Campaign: Oct 2015
Run 398: 9.2 MHz/cm2, 29:52 Min (555512 evts)
Diamond: poly-B2 @ -1000.0V
git hash: 97ab26b


Waveform
Signal [au]
Peak:
Bucket:
Time [ns]
Test Campaign: Oct 2015
Run 398: 9.2 MHz/cm2, 29:52 Min (555512 evts)
Diamond: poly-B2 @ -1000.0V
git hash: 97ab26b

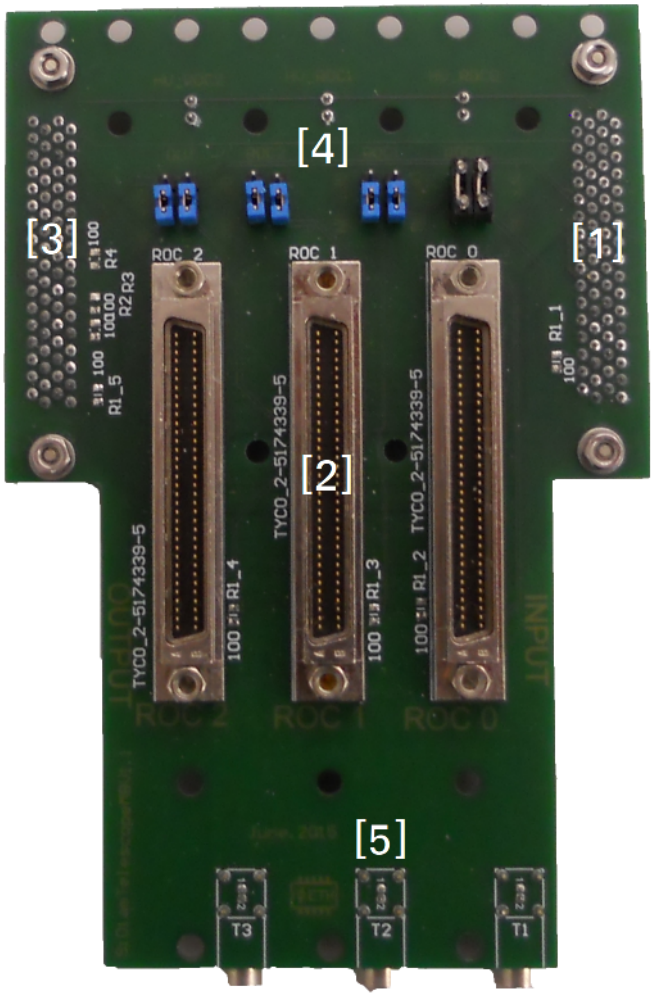
Conclusion

- overcoming problems in the beginning
  - finding a good design and testing the single components
  - readout of the analogue chip by the DTB
  - 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

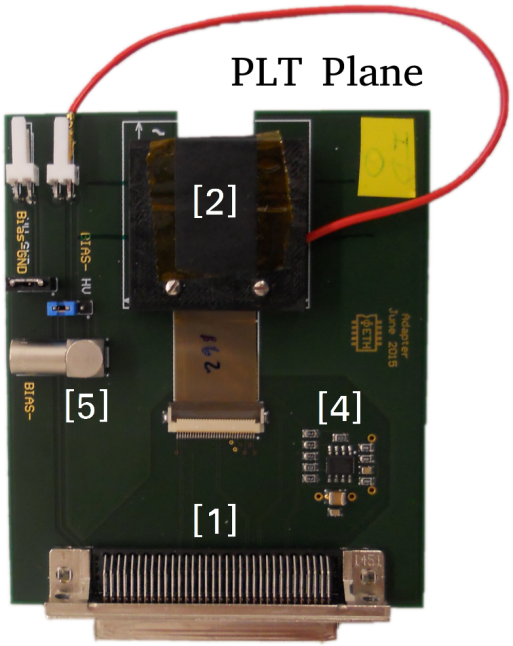
- use the OSU TU (Trigger Unit) as single device to process all triggers
- two preinstalled setups for pad and pixel tests
- synchronise DTB clock with the beam clock at PSI (40 $\rightarrow$ 50 MHz)
- save scintillator signal with the DRS4
  - particle identification by time of flight
- increase resolution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

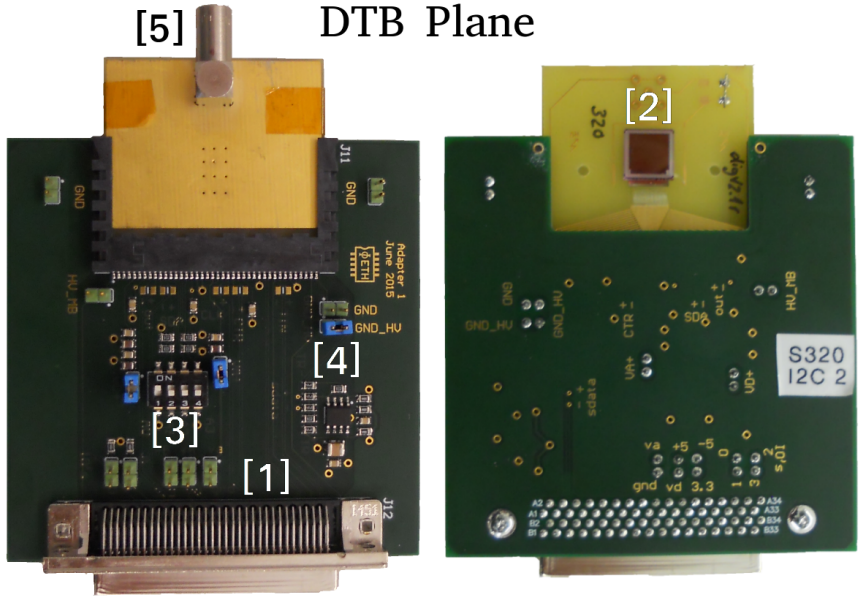
Motherboard



- [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

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