Forward RICH FEE & DAQ

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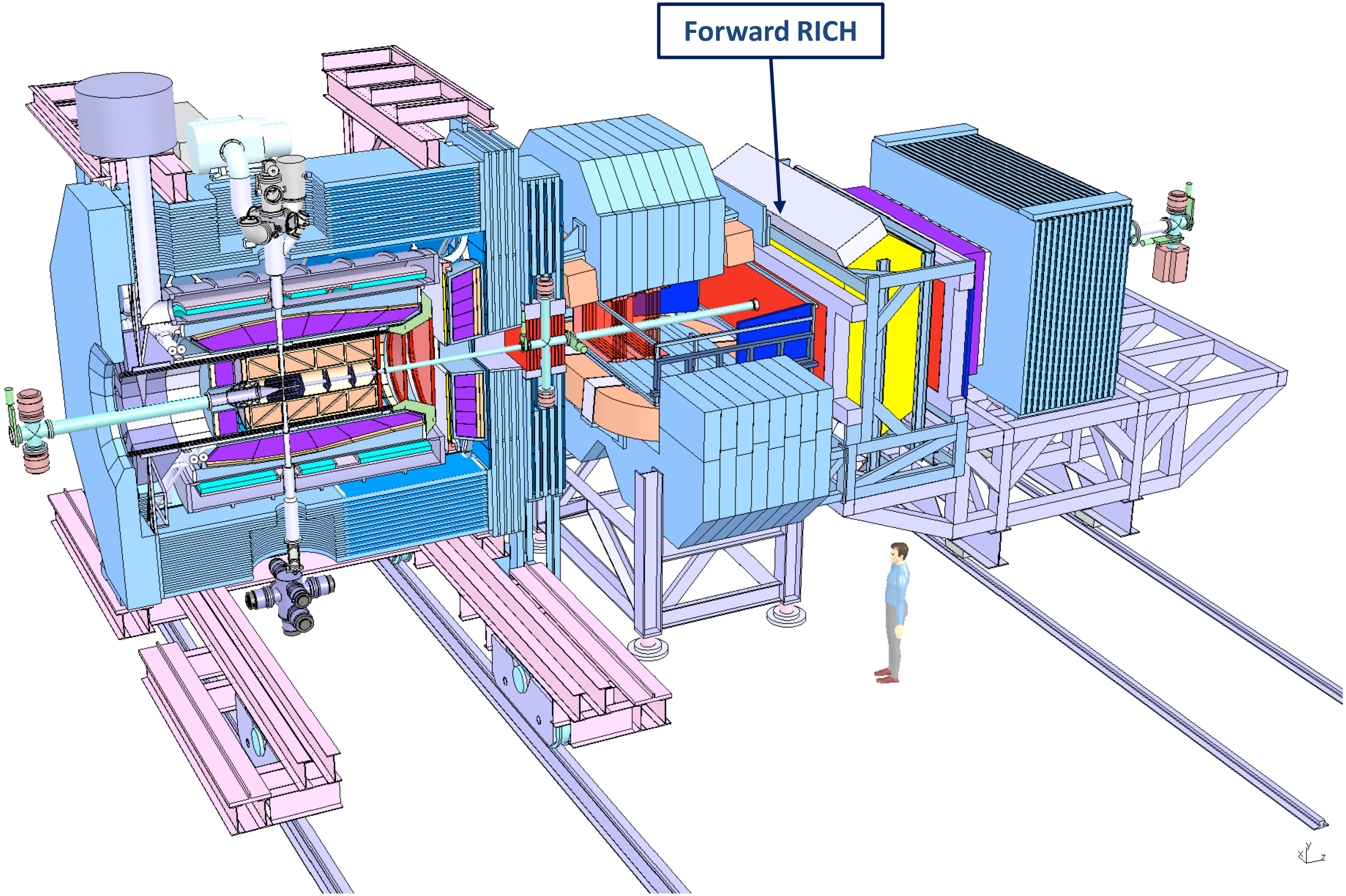
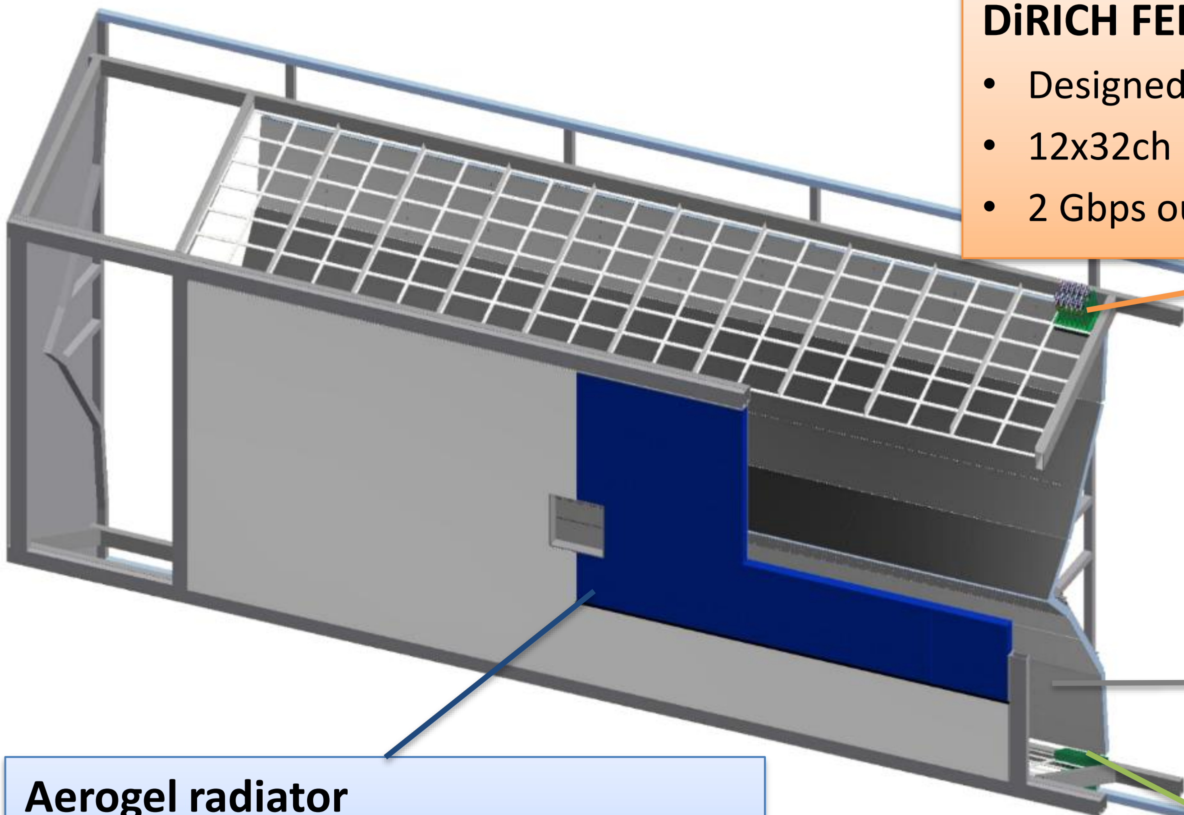
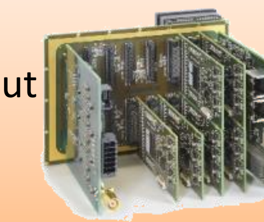
PANDA detector



Baseline design



DiRICH FEE (GSI)
- Designed for H12700 readout
- 12x32ch preamp+disc+TDC
- 2 Gbps output link



Mirrors
- 2 mm float glass
- Al+SiO_2 coating

Aerogel radiator
- Focusing 2- or 3-layer aerogel
- n=1.05
- 40 mm thick

Photon Detector

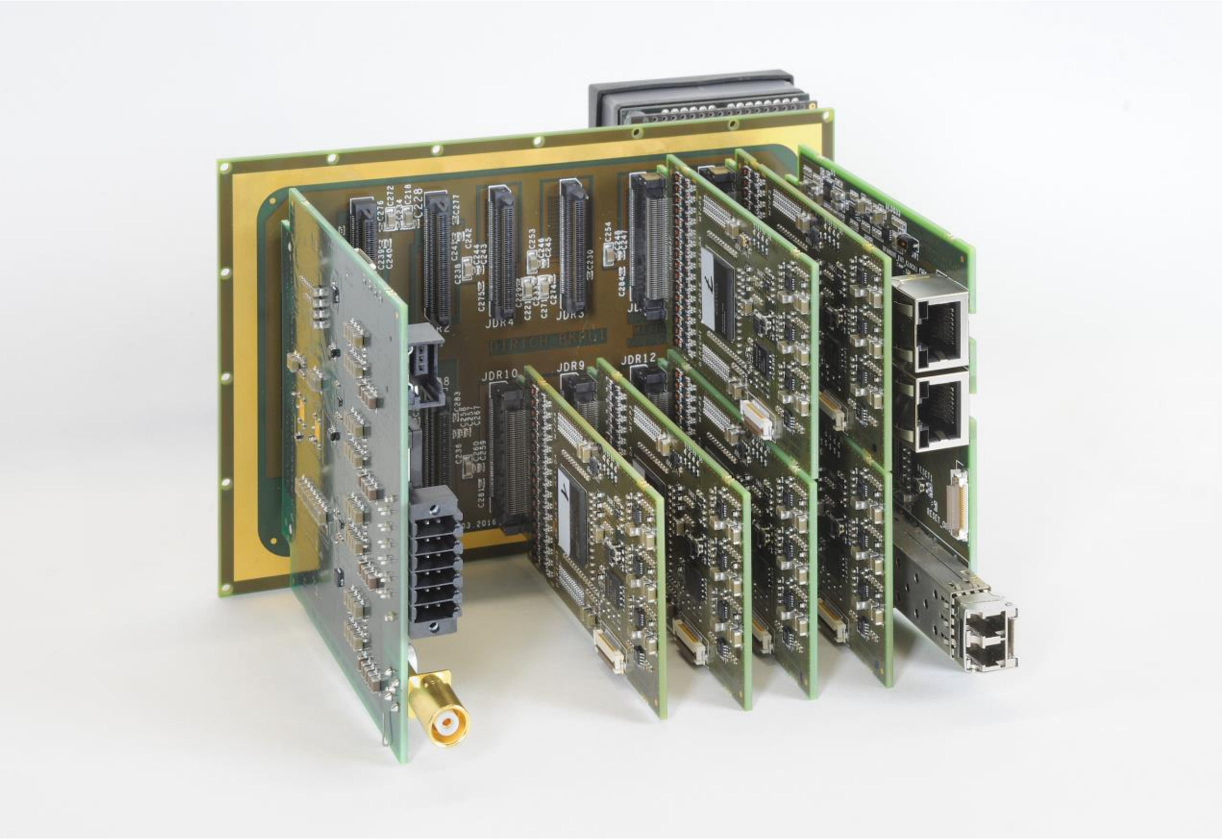
H12700 MaPMTs (Hamamatsu)
- flat panel
- 8x8 anode pixels of 6mm size

Requirements for front-end electronics

- Readout of single photoelectron signals from H12700 MaPMTs: Q≈300 fC
- Timing measurement with moderate resolution ≤1ns, amplitude measurement with time-over-threshold
- 6x6 mm^2/ch footprint with high geometric efficiency
- 92k channels in total (very high)
- Tolerant to $2\cdot10^{11}$ cm^{-2} of 1 MeV neutron equivalent of total dose for 10 years of operation
- High voltage distribution to MaPMTs (U=1000 V)
- Compliance with general PANDA requirements

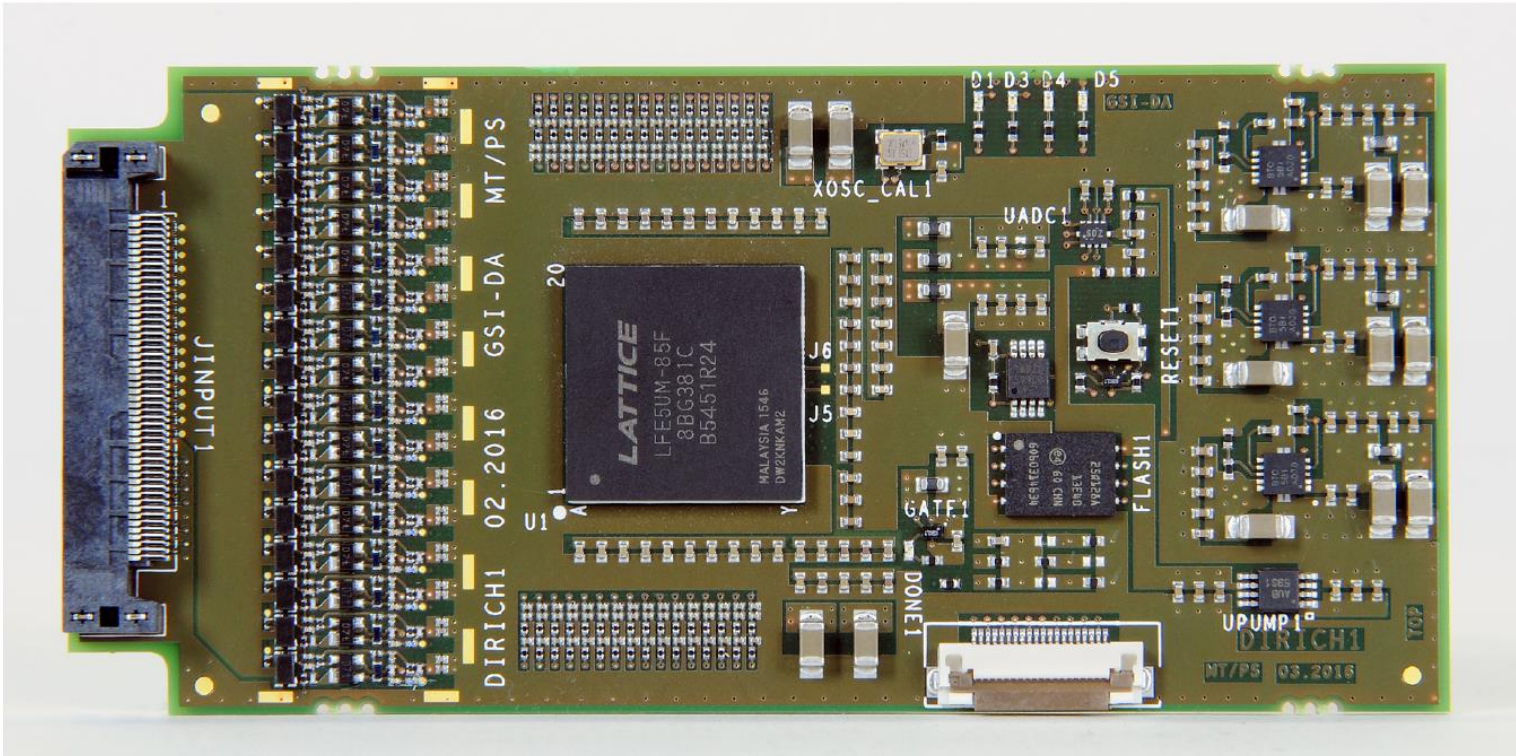
DiRICH electronics

- Based on successful PADIWA and TRB3 designs
- Developed for MaPMT H8500/H12700 readout
- ~10 ps TDC resolution
- Hosts 6 MaPMTs, 384 channels in total
- Power Module distributes external LV to electronics and HV to MaPMTs
- DCM concentrates data from 12 DiRICH cards by TRBNet 2-Gbit/s links
- 2 Gbit/s output optical link via SFP transceiver



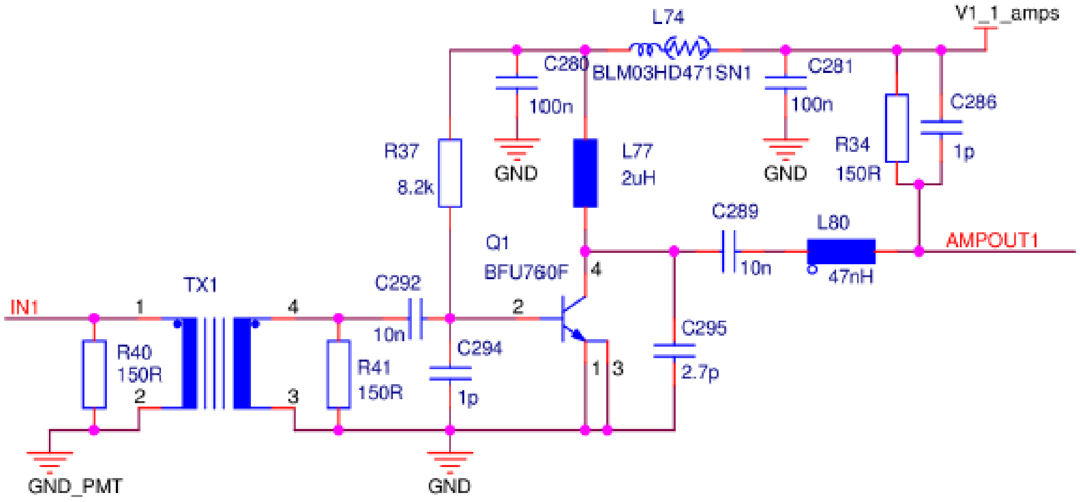
Further info: trb.gsi.de, M. Traxler talk @ DIRC17 workshop

DiRICH: In Real Life



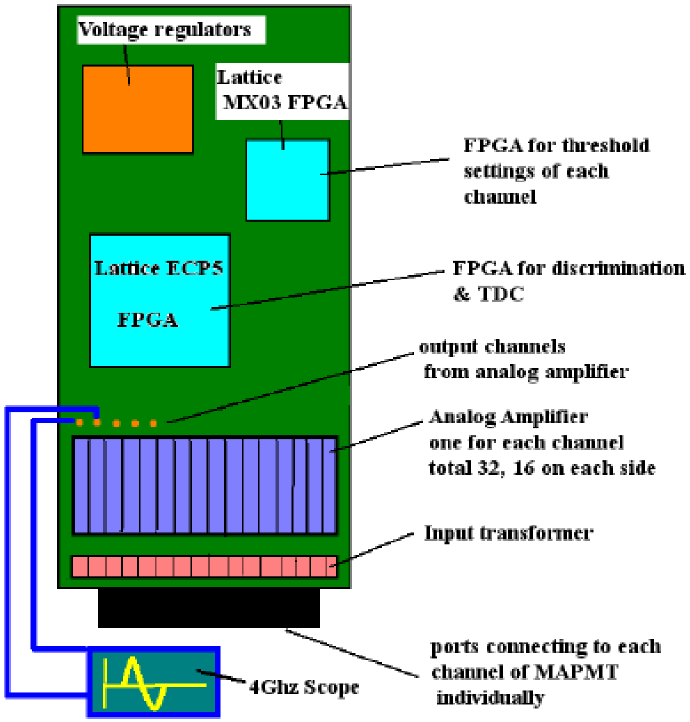
- 47mm x 100mm area, 300μm x 600μm components, 0201 (imperial)
- transformer, gain 30 amps, 16bit-DAC, discriminator, high precision TDC, DAQ + TrbNet (2Gbit/s SERDES), slow-control and voltage-regulation

DiRICH amplifier (1 ch)



Crosstalk issue

V. Patel, M. Traxler, Journal of Instrumentation, 13 (3) (2018) C03038



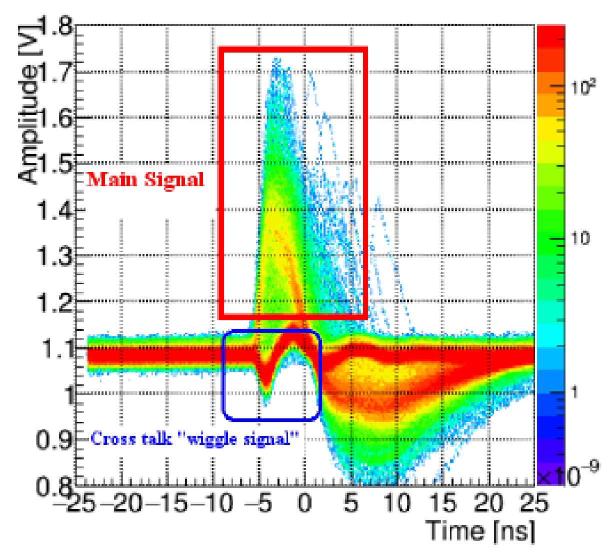
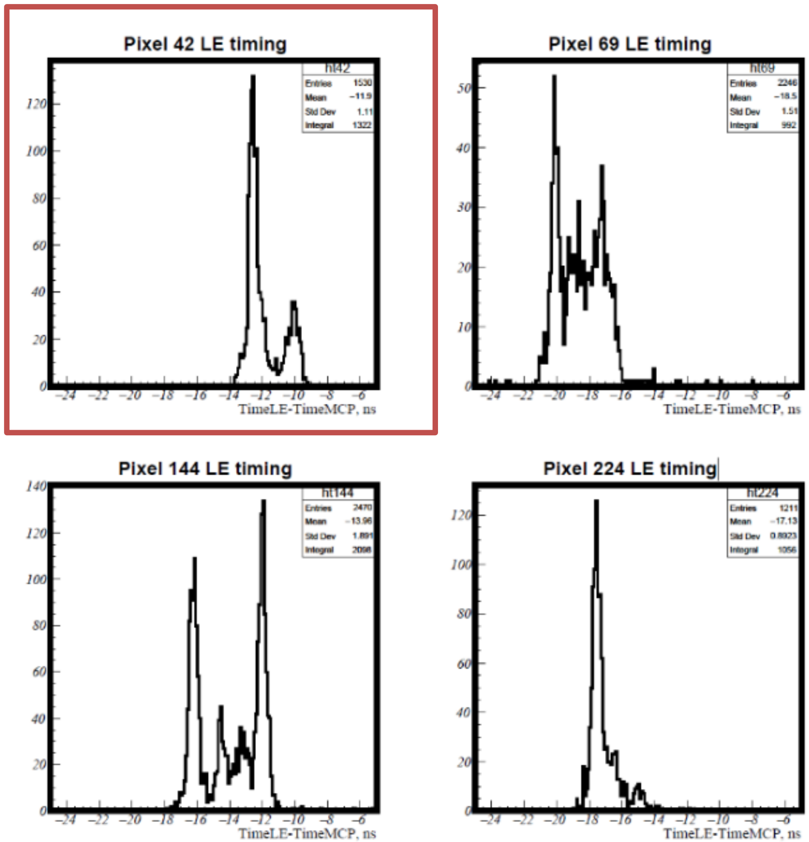


Figure 5. (i) Sketch of a DiRICH front-end module with schematic representation of the oscilloscope probes connected to two channels after preamplification.
(ii) Typical MAPMT single photon signals after preamplification.

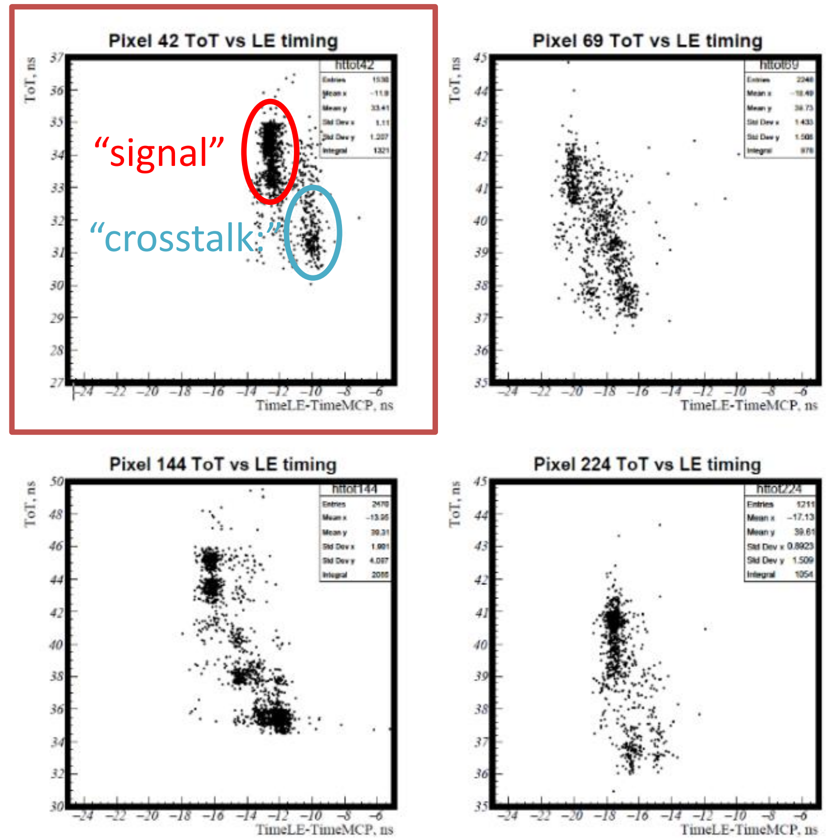
Time + ToT plots for MaPMTs

3 June 2018

Leading edge timing distributions for 4 random anodes of different MaPMTs measured w.r.t. MCP detector



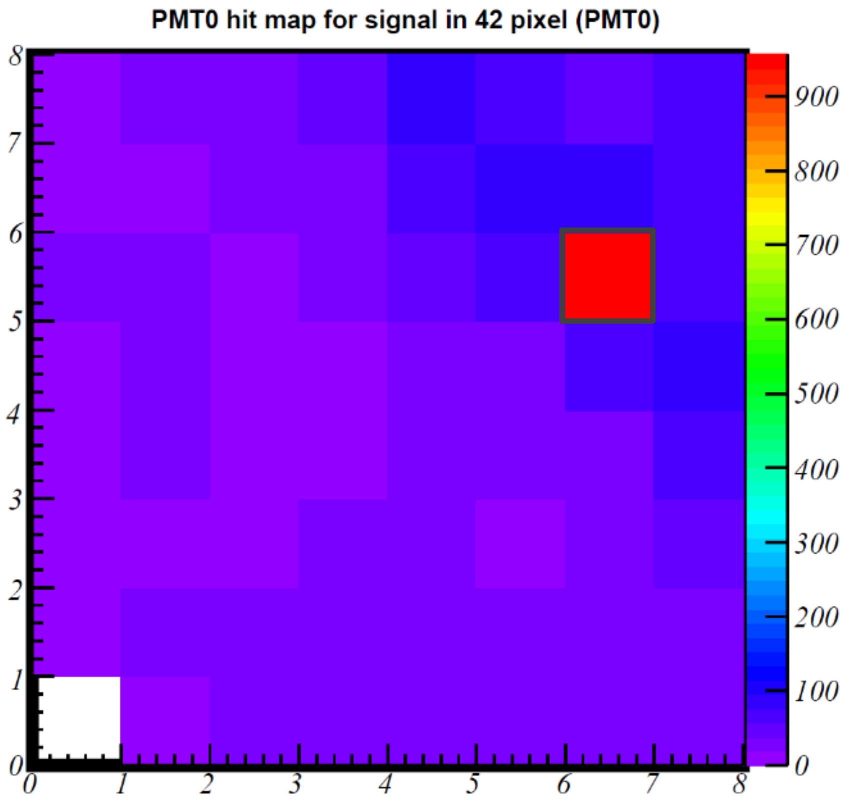
Corresponding timing vs ToT scatter plots



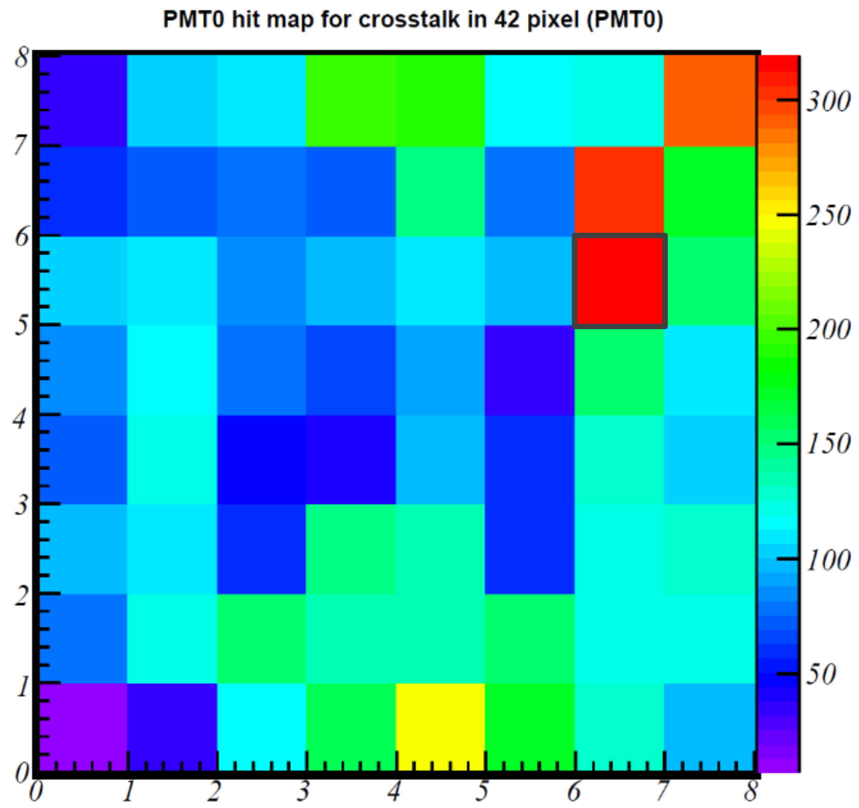
NB: 2-4 ns separation between peaks. Earlier one has largest ToT (amplitude). Looks like crosstalks between anodes or common crosstalk.

Signal and crosstalks hit patterns

Events with signal hits in anode 42

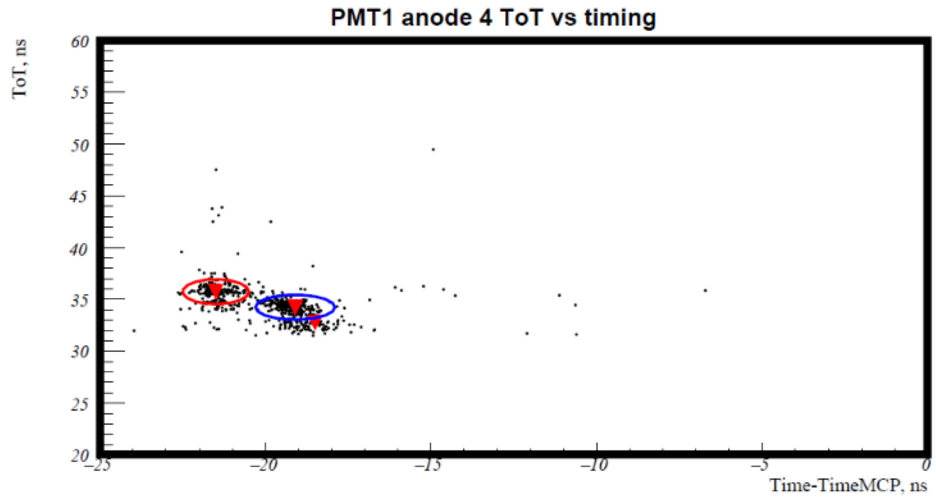


Events with crosstalk hits in anode 42

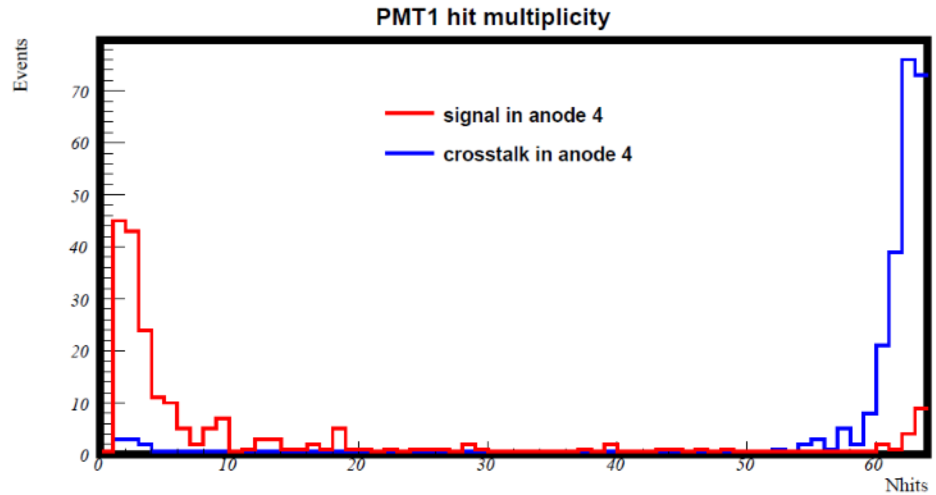


NB: No typical pattern of neighboring anodes

Hit multiplicity for signal and CT

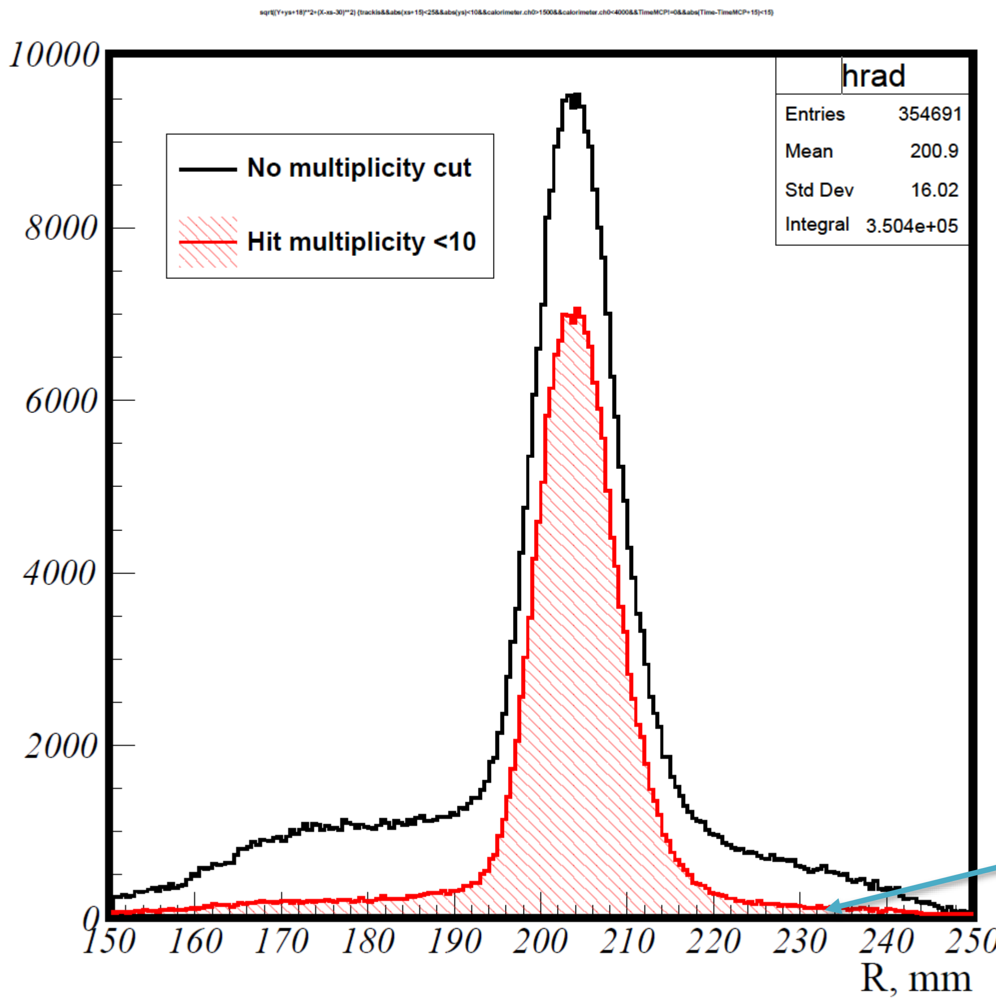


- Signal and CT hits are determined by ROOT::TSpectrum2 class.
- Cut regions – ellipses.



NB: Almost all anodes of the MaPMT fire when we observe “crosstalk” in one anode.

Hit radius distribution with multiplicity cut



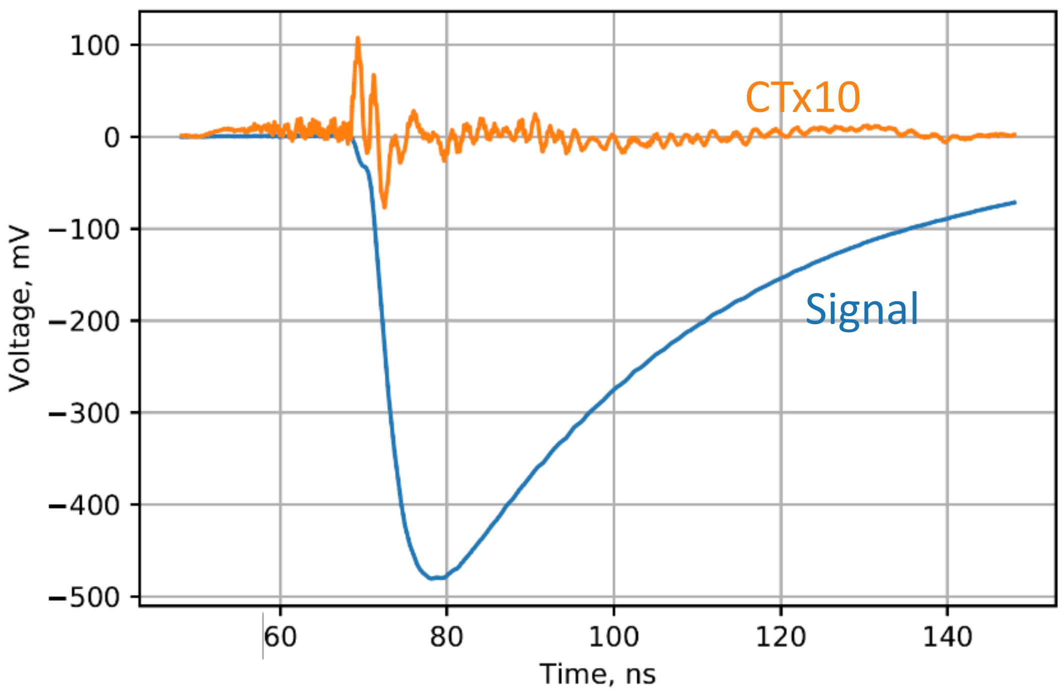
Apply per-event cut for number of hits in 30-ns window

5x S/B increase

NB: still non-negligible background remains

Signal and crosstalk waveforms from PADIWA preamplifier

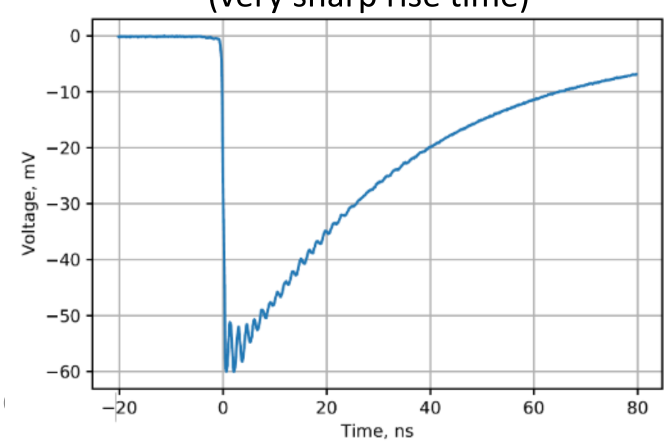
Pulsed illumination from a laser



- Light source: PiLas PiL051x, 510nm, Δt<140 ps
- Oscilloscope: Keysight MSOX6004A, 6 GHz BW with differential active probe N2752A, 6 GHz BW
- Signal viewed directly on illuminated anode, CT viewed on a distant anode
- All anodes connected to PADIWA

Single photon pulse

(very sharp rise time)

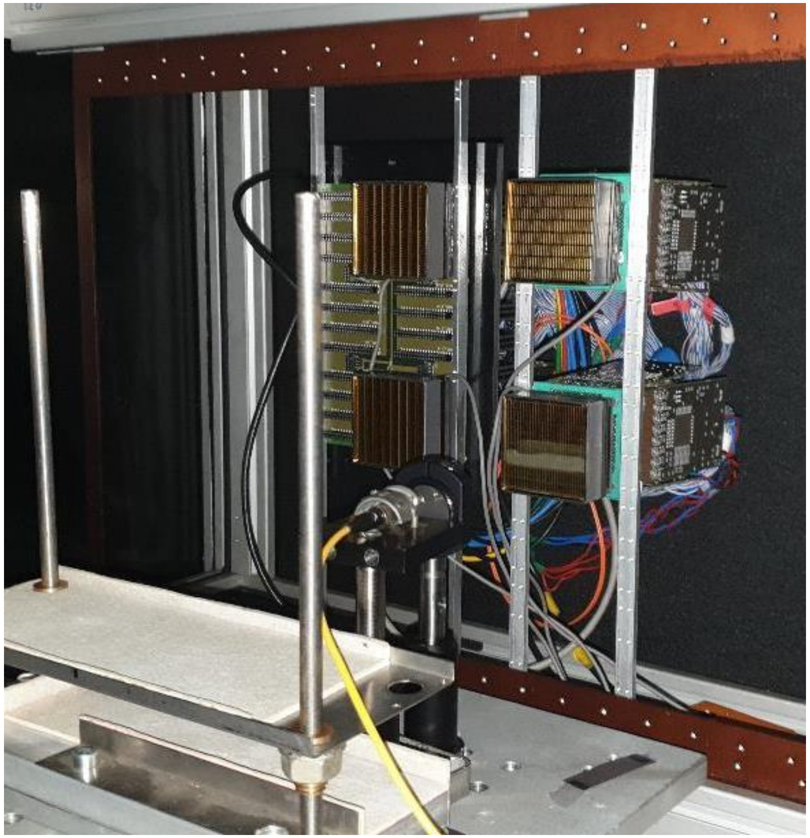


- Signal amplitude is ~9 p.e.
- CT amplitude is about 2% of signal
- CT negative swing is delayed by a few ns w.r.t. signal at the same voltage level.

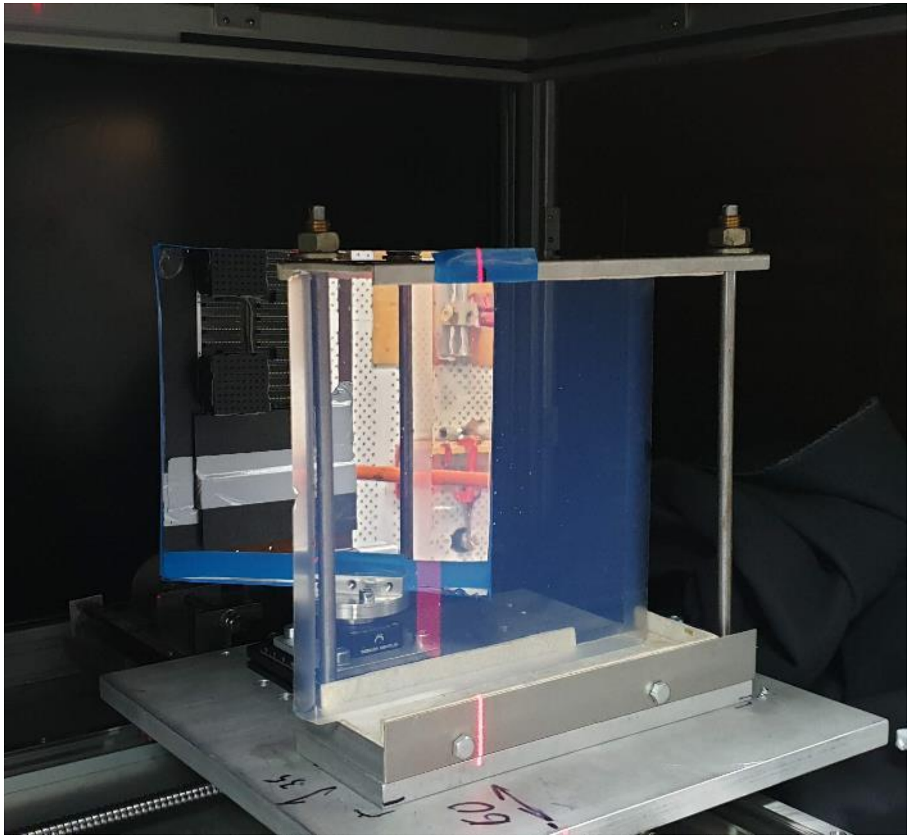
On the origin of crosstalks in the beam data

- Studies with pulsed laser illumination show that a single photon signal can not cause CT to exceed standard calibrated PADIWA thresholds. It should be a many photon signal.
- A relativistic particle produces about 20 Cherenkov photoelectrons in 1.5 mm window of MaPMT.
- BINP electron test beam is not essentially collimated and originates from 5-cm bunches in the accelarator. All particles from an acc. bunch come very close in time.
- Electrons and positrons scattered far from the beam may directly hit MaPMTs causing large signals and CT on all anodes.
- Probably origin of CT inside MaPMT: parasitic capacitive coupling between the last dynode and anodes.
- This effect is shown to be event rate dependent. The higher event rate the higher particle multiplicity.
- May be an issue in PANDA. Precise signal timing and ToT calibration with a laser is needed for each channel to suppress this effect.
- Another approach: suppress crosstalks by setting higher thresholds at the cost of single photon efficiency

FRICH prototype with DiRICH&PADIWA&TRB3 readout in 2019



4 MaPMTs readout in half by PADIWA and DiRICH. 256 channels in total.

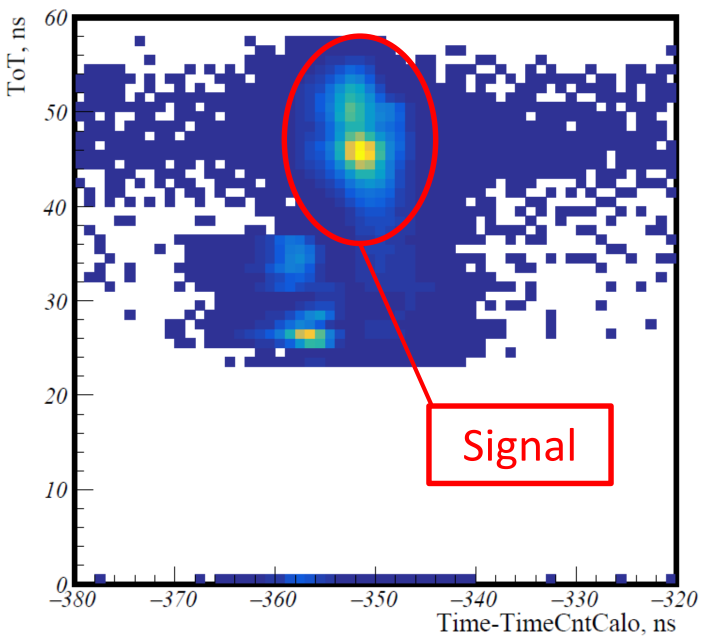


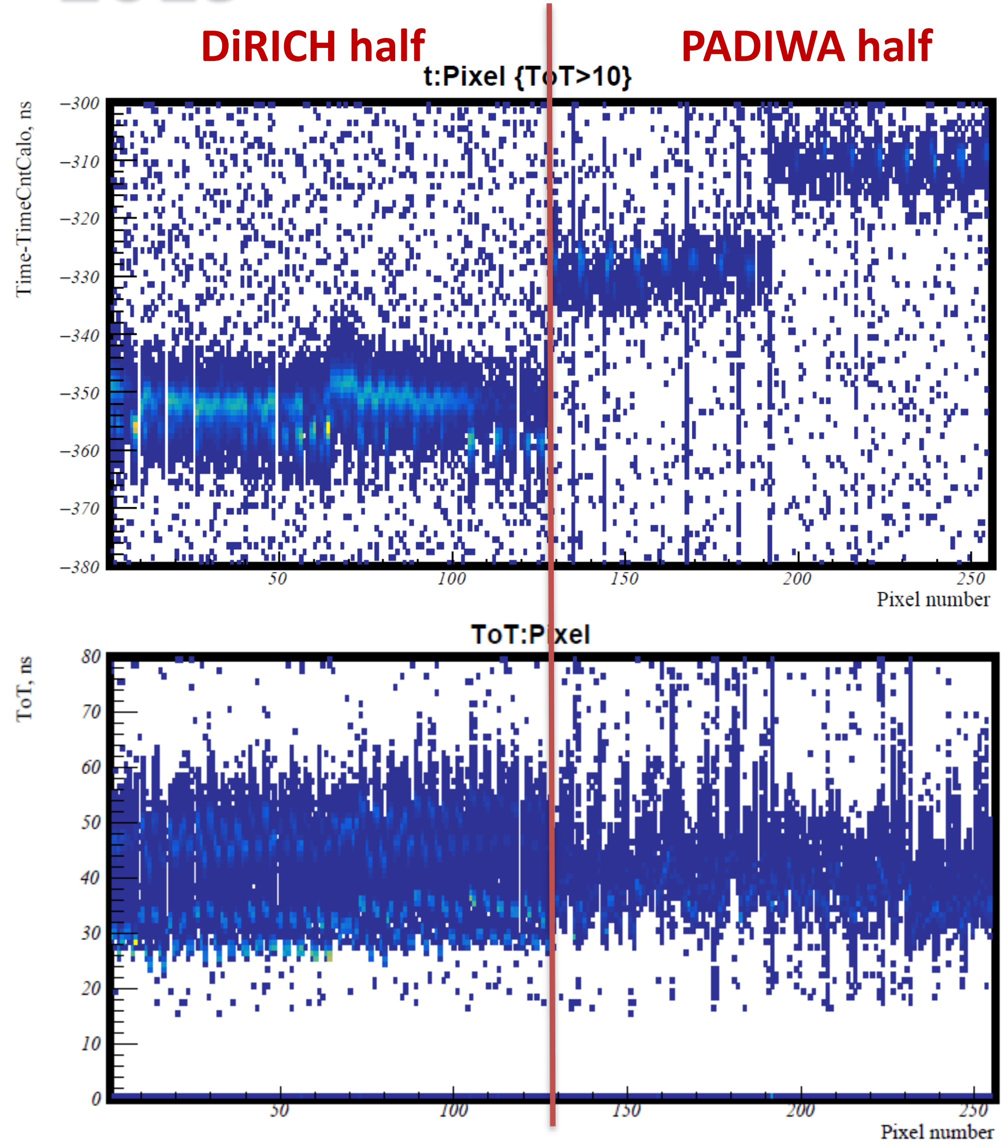
Aerogel sample with a flat mirror installed at 45° w.r.t. the PD and aerogel.

Time and ToT vs channel 2019

Timing is measured w.r.t. a scint. counter (~few ns resolution)

ToT vs Timing for DiRICH channels

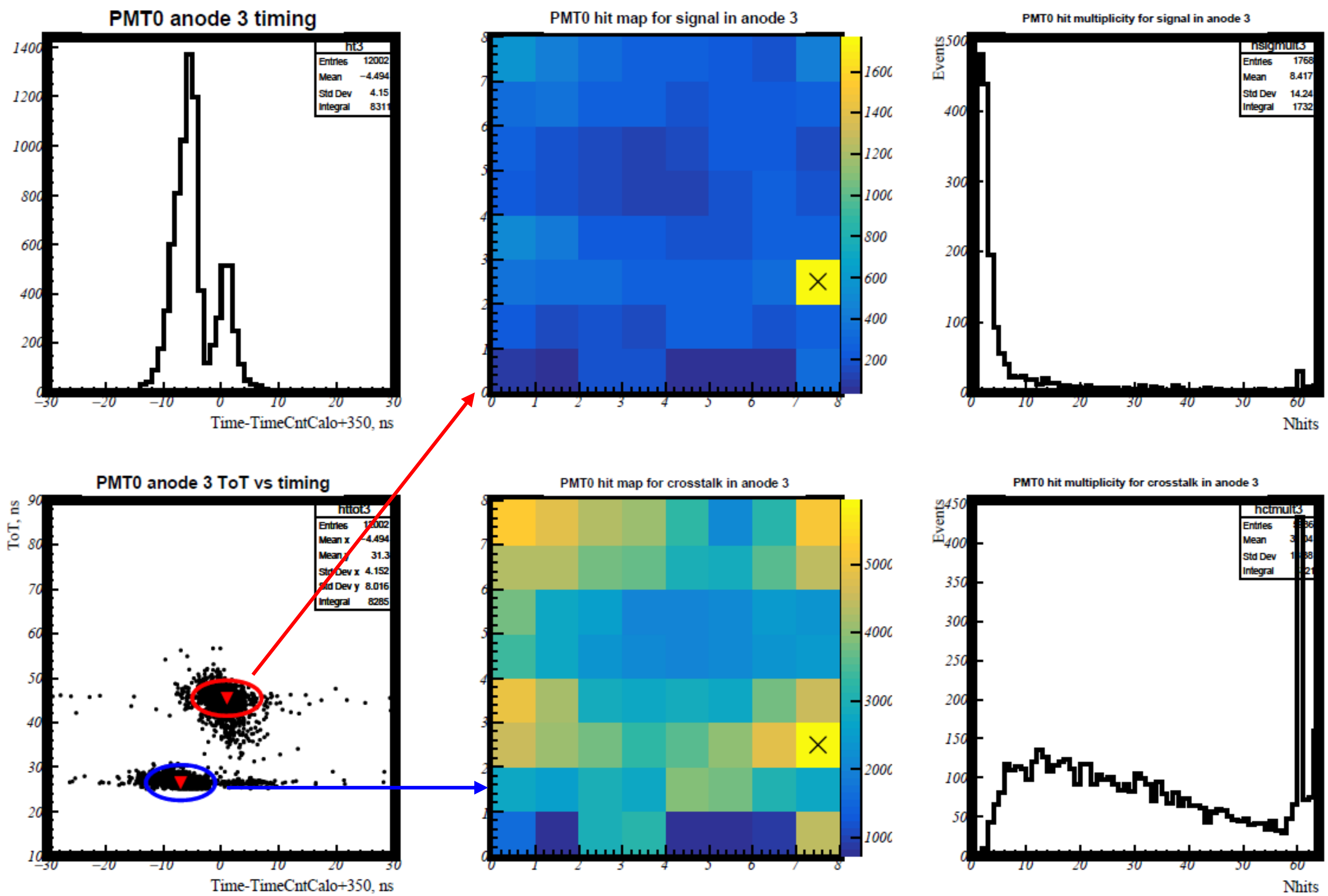




Cross talk issue in 2019

Signal coming later in time and have higher ToT

Crosstalk coming earlier in time and have lower ToT



Conclusion & outlook for FEE

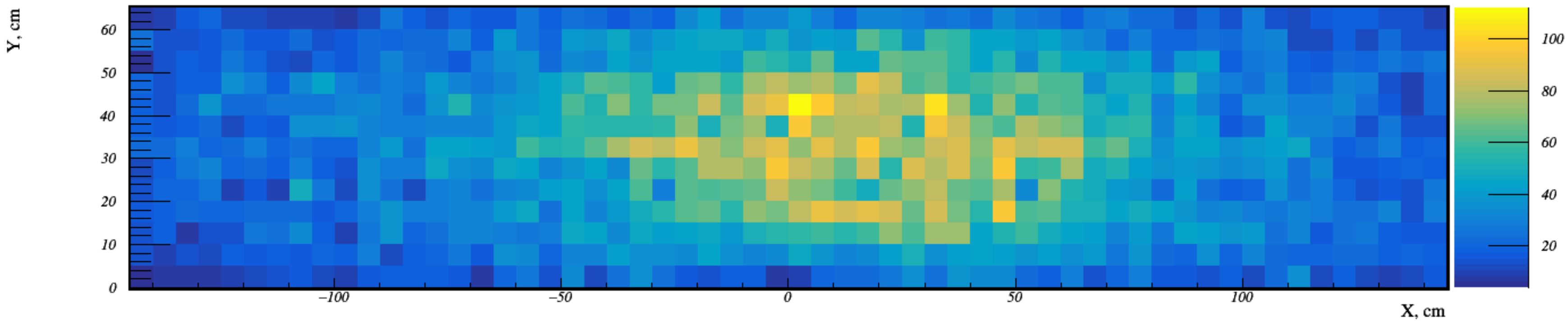
- DiRICH front-end electronics based on TRB3 platform was selected for the PANDA Forward RICH readout
- Previously tested PADIWA preamplifier-discriminators previously with TRB3 digitization. Applicability for MaPMT single photon readout was proven.
- In 2018 we got one DiRICH module equipped for readout of 6 MaPMTs. DiRICH was tested in the beam test. Results are positive.
- Timing and ToT calibration for each channel are necessary to cope with direct particle hits that produces small signals in all MaPMT anode

DAQ FOR THE FORWARD RICH

Simulated distribution of hits over the photon detector

1000 $p\bar{p}$ events were simulated in PandaRoot for the full PANDA setup

Number of hits per 5x5 cm^2 per 1000 events



Average hit rate: 0.02 hits/PMT area/event
Maximum hit rate: 0.05 hits/PMT area/event

Hit and data rate estimations (1)

Input from full sim (PandaRoot) & datasheets

- 0.8 effective charged particle multiplicity (Cherenkov radiation intensity weighting) per $\bar{p}p$ collision for 10 GeV/c beam momentum
- $2 \cdot 10^7$ average collision rate in PANDA
- 28 photon hits per particle
- Direct particle hits: 200 hits/s/ch
- H12700 MaPMT dark current: 80 counts/s/ch
- Timestamp size: 4 bytes
- Leading+trailing timestamps: 8 bytes
- Epoch counter (for every frame of 10 μs): 4 bytes

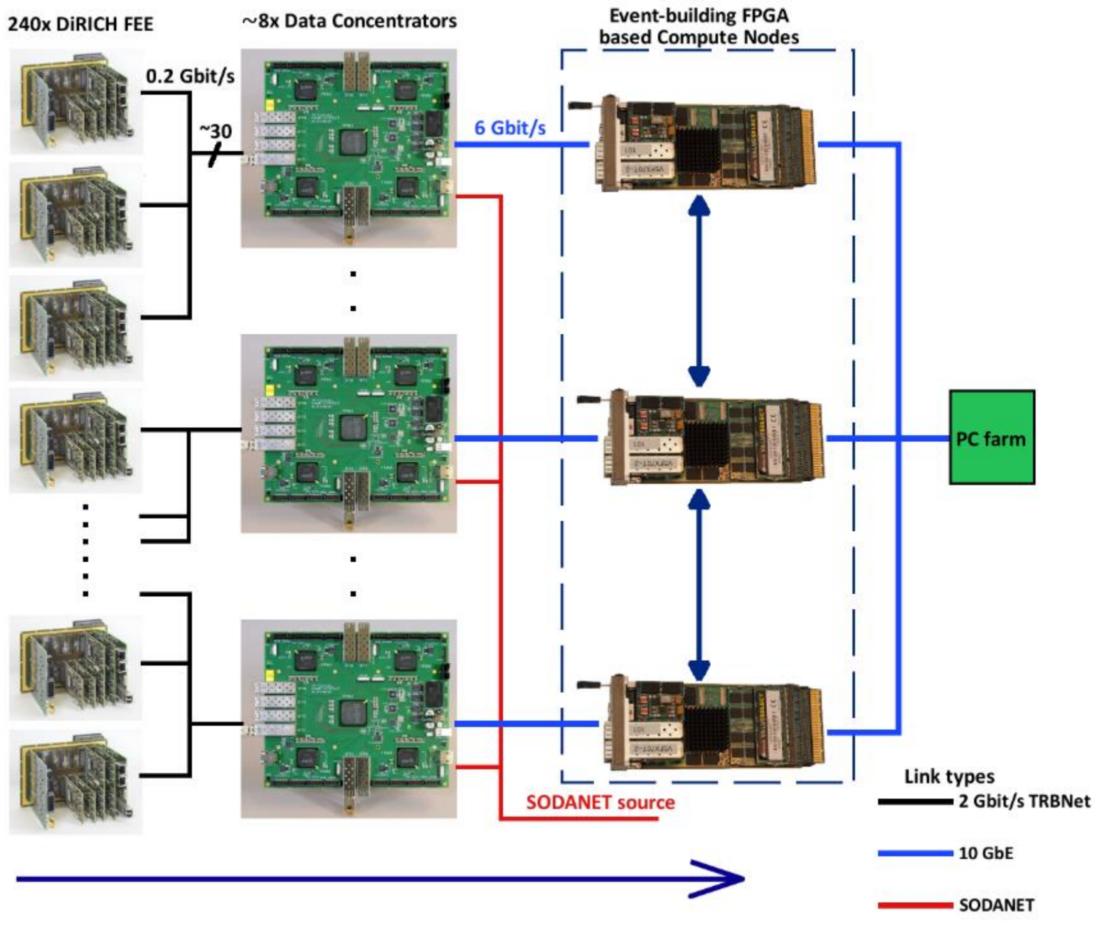
Hit and data rate estimations (2)

Source	Per channel	Per DiRICH board (32 ch)	DiRICH module (6 PMTs)	Per system (240 DiRICH modules)
Cherenkov photons	5.2 kcps	170 kcps	2 Mcps	480 Mcps
Direct particle hits	200 cps	6 kcps	77 kcps	18 Mcps
Dark current	80 cps	2.6 kcps	30 kcps	7.2 Mcps
Total hit rate	5.5 kcps	180 kcps	2.1 Mcps	500 Mcps
Raw data flow	**0.53 Mbps**	**17.3 Mbps**	**200 Mbps**	**48 Gbps**

Maximum data rate per DiRICH module in the hot area ~500 Mbps, well below the data throughput of the 2-Gbps link.

8x 10 Gbps links should be enough to readout data from DCBs

Forward RICH readout concept



Event selection by timing in presence of uncorrelated background

Toy simulation studies (Python with numpy)

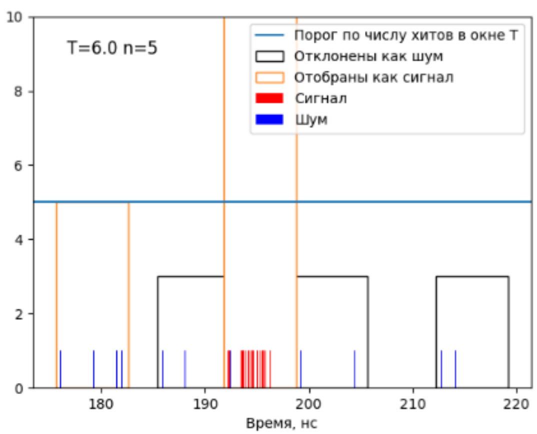
- Simulate data as time series of hits
- Signal events – uniformly distributed in time with $2 \cdot 10^7$ s^{-1} rate
  - Number of hits of an event are distributed by Poisson law with $\langle N_{pe} \rangle = 20$
  - Hits of an event are distributed by gaussian w.r.t. mean event time with $\sigma_t = 1$ ns
- Background hits (dark counts) are uniformly distributed in time with 10^8 s^{-1} rate

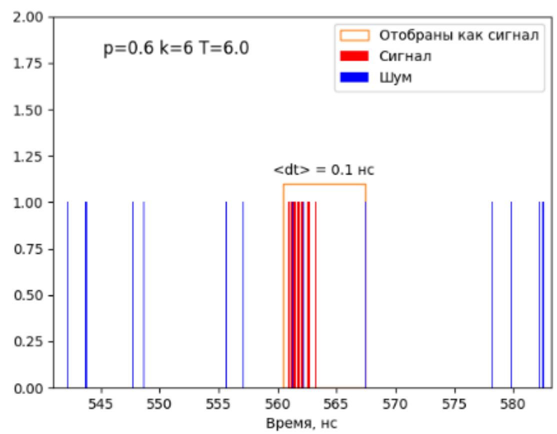
Event filters algorithms

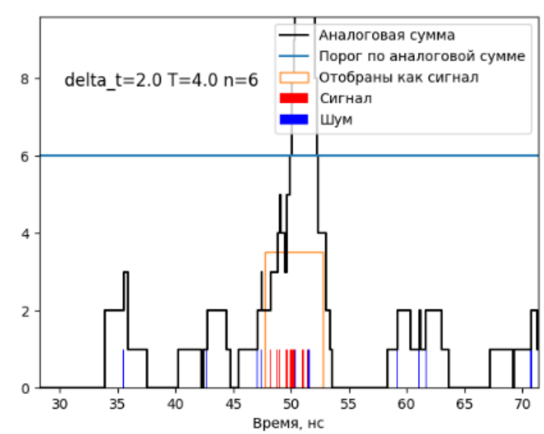
Filter #1
Select by min. number of hits in a fixed window

Filter #2
Select by max. mean interval between successive hits

Filter #3
Select by min. analog sum of rectangular signals

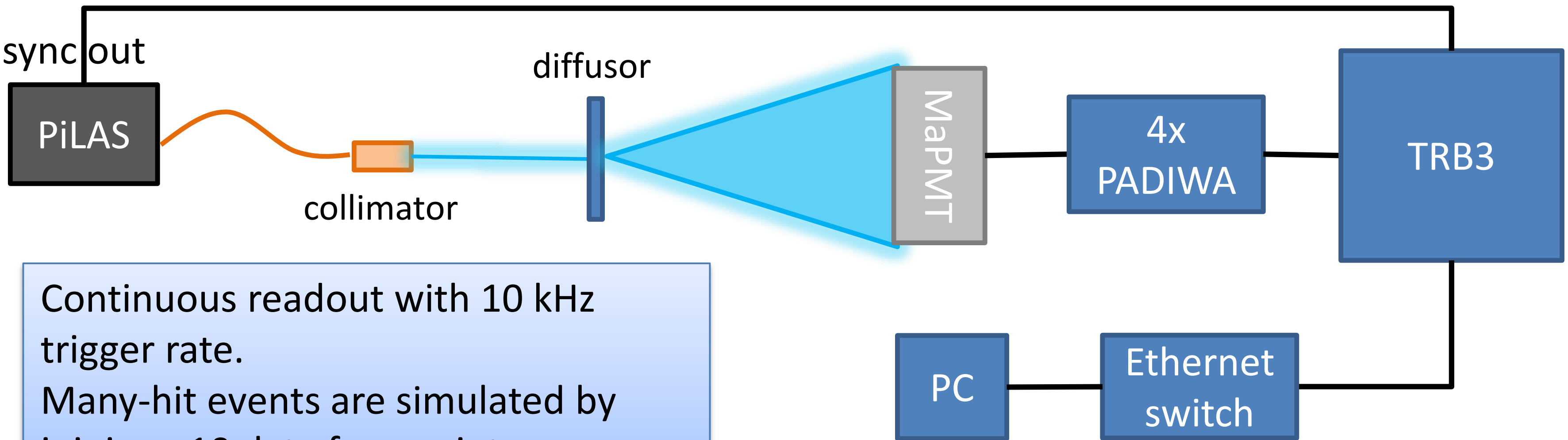




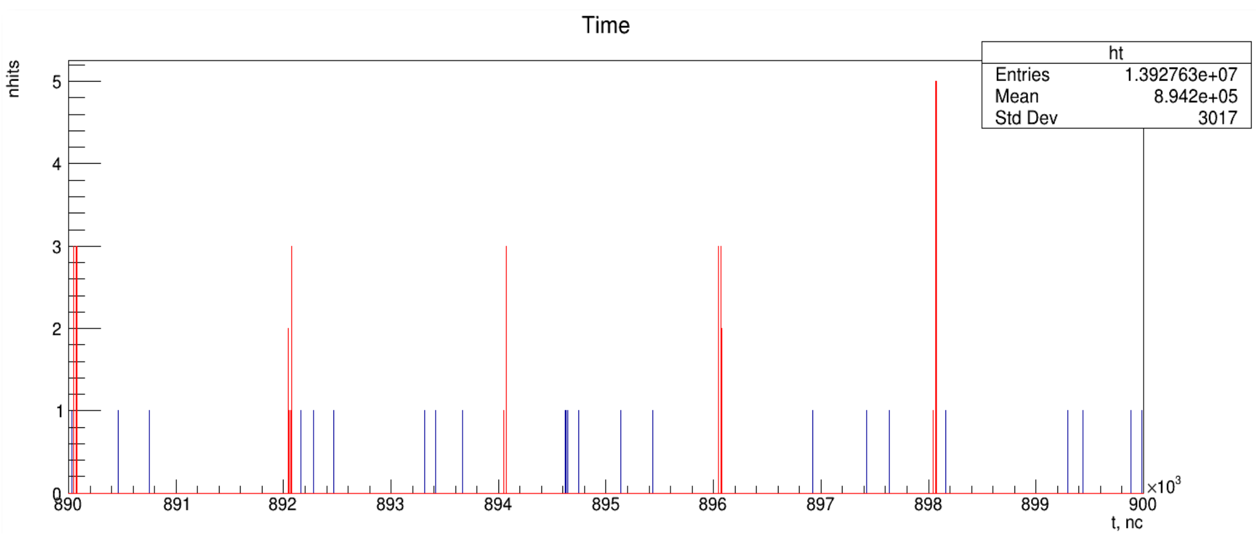


	Filter #1	Filter #2	Filter #3
Optimal filter parameters	T = 6 ns n = 5	p = 0.6 ns k = 6 T = 6 ns	delta_t = 2 ns T = 4 ns n = 6
Max. background suppression @ 99% signal event efficiency	4.2	7.1	9.1

Application of the filter #3 to the data from a test bench



Continuous readout with 10 kHz trigger rate.
Many-hit events are simulated by joining ~10 data frames into one.



Red histogram – hits selected by filter as signal

Blue histogram – hits rejected by filter

Conclusion & outlook for DAQ

- Data rate value and uniformity is estimated from the PandaRoot full simulation with the DPM generator
- General readout concept for the Forward RICH subdetector is drawn
- Three different event selection software algorithms tested in a time data stream on the toy sim. data
- Tried the most optimal selection SW algorithm on the experimental data from the test bench
- Envisage algorithm for event building based on 2D information (θ, t)
- Implement event building in an FPGA