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Experimental results using large area picosecond photodetectors

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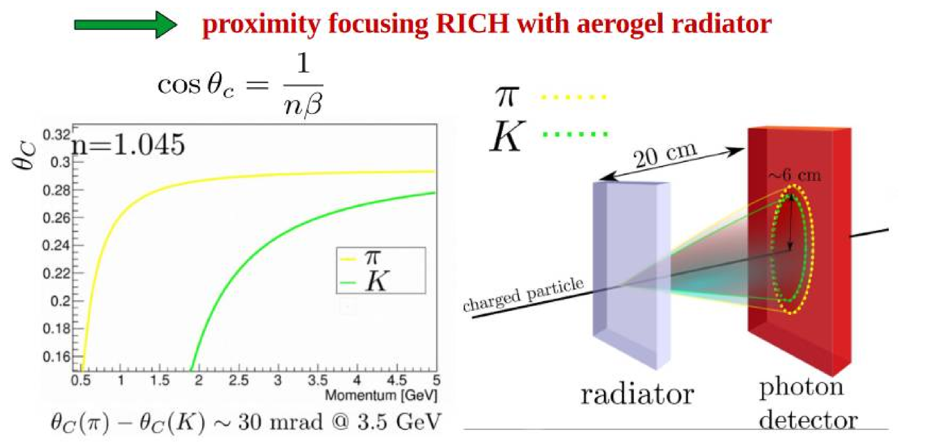
1. Abstract

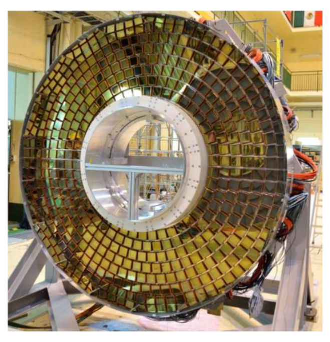
For the planned future upgrades of several high energy physics experiments, highly performing position sensitive photodetectors are needed. In ring imaging Cherenkov counters, planned for the upgrades of LHCb and Belle II experiments, detection of single photons with position resolutions a good as 1 mm will be required, with timing resolution on the order of 100 ps and surface coverage of m². In addition, the photodetector has to operate in high magnetic field and neutron radiation background, representing very high requirements for photodetectors. One promising development is the picosecond photodetector (LAPPD), a large area of 200 mm x 200 mm microchannel plate photomultiplier tube (MCP PMT). In this contribution, experimental results obtained with the generation I LAPPD produced by INCOM company are presented. Using custom designed PCBs, capacitive couplings to the anode with different segmentation, and therefore, spatial resolution capabilities, were explored. As the photodetector readout, PETsys TOFPET 2, as well as FastIC ASICs were used. Reported results include characterization of spatial response, using precision scanning of focused laser light, and temporal response to picosecond illumination at single photon level.

2. Background

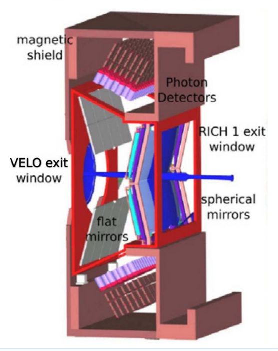
Future **RICH detectors**, upgrades for Belle II ARICH[1] or LHCb[2] at CERN, will require single photon sensitive imaging detectors with **a few mm pixel pitch**, and timing ability **100ps**. These detectors are very large in size, usually an area of few m² needs to be covered.



Belle II ARICH

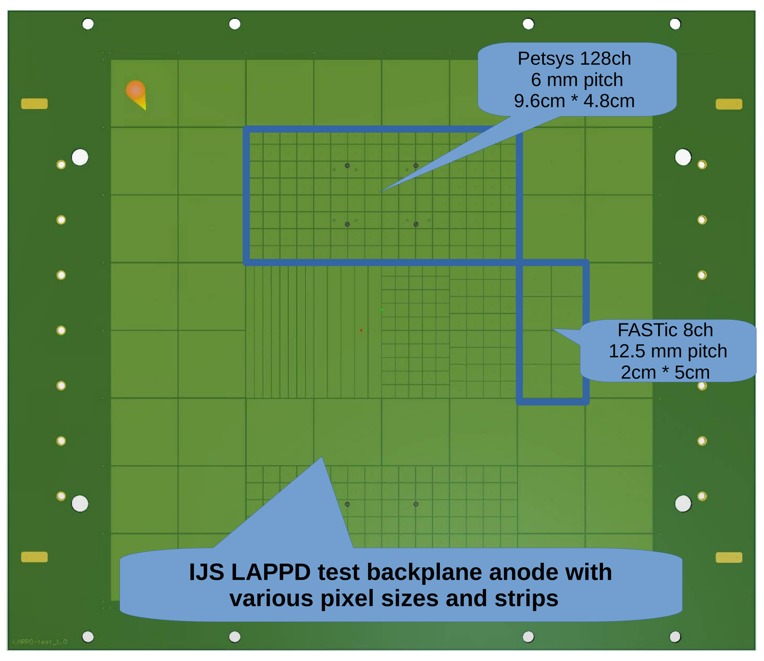


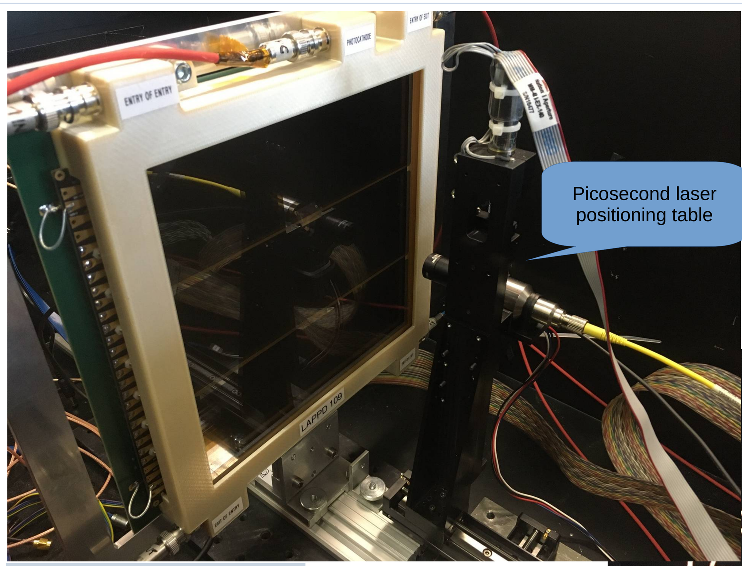
LHCb RICH1



3. Experimental setup

Large area picosecond photo-detector (LAPPD) Generation II
→ Large area 200 mm x 200 mm
→ Quantum Efficiency > 20% (90% uniformity)
→ 20 µm micro channel plate pores
→ Gain > 1 x 10⁷
→ Dark count rate less than 150 Hz/s/cm²
→ Capacitively coupled anode with custom pattern





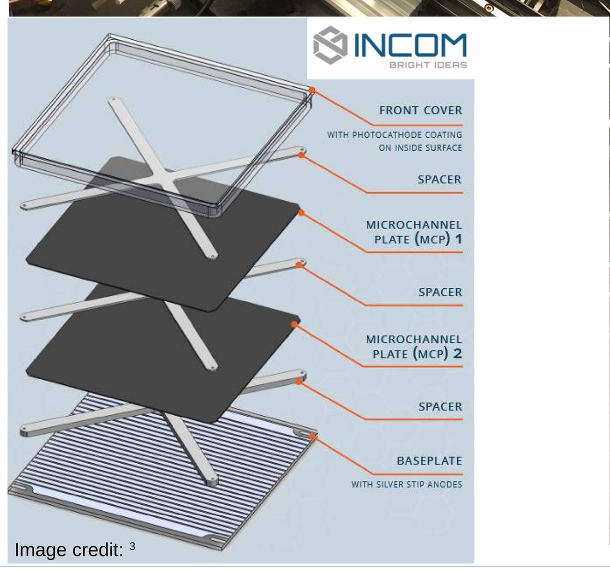
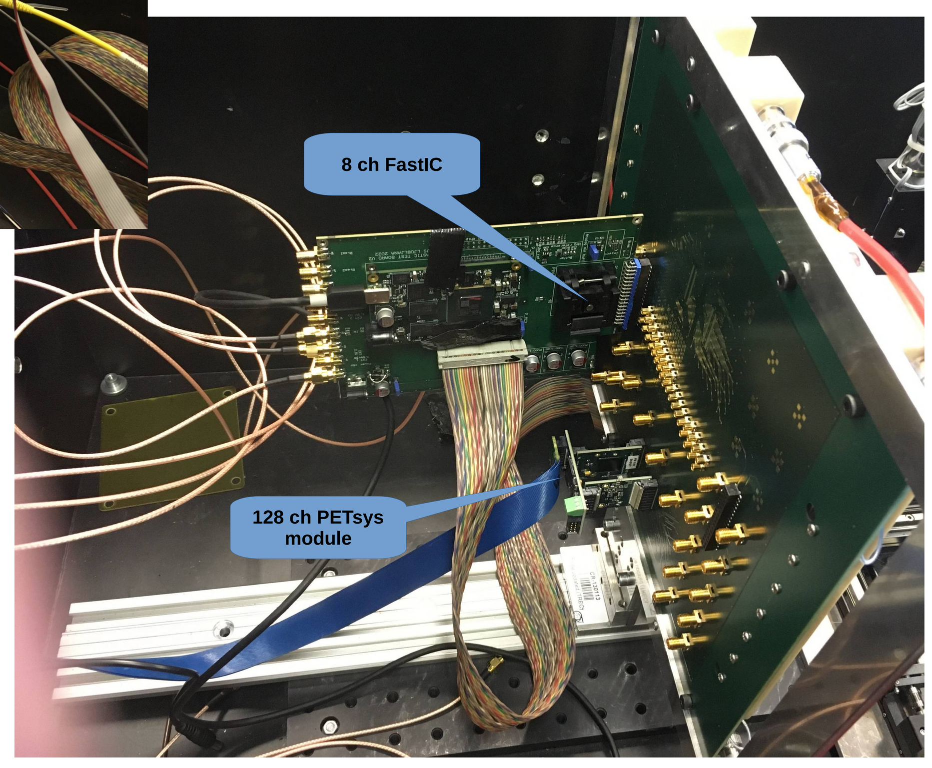


Image credit: [3]

Experimental setup
→ Alphalas PICOPOWER-LD-405 laser (~20 ps FWHM) on positioning arm for X,Y scanning,beam spot in sub mm dimension, single photon level
→CAEN V1295, 25ps bin size TDC used to read the FastIC ASIC

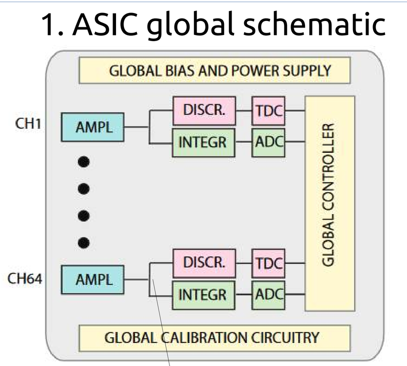


4. ASICs

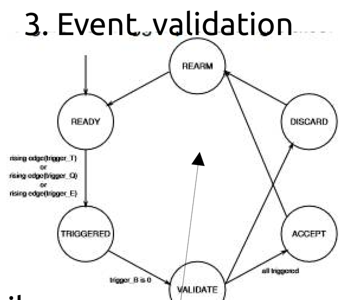
PETSYS TOFPET 2 ASIC

→ Signal amplification and discrimination
→ Gain adjustment per channel: 1, 1/2, 1/4, 1/8
→ Dual branch quad-buffered analogue interpolation TDCs
→ Quad-buffered charge integration for each channel
→ Dynamic range: 1500 pC
→ TDC time binning: 30 ps
→ positive input signal polarity
→ Max channel hit rate: 600 kHz
→ Configurable timing, trigger and time-over-threshold (ToT) thresholds
→ Fully digital output

1. ASIC global schematic



3. Event validation



2. Channel details

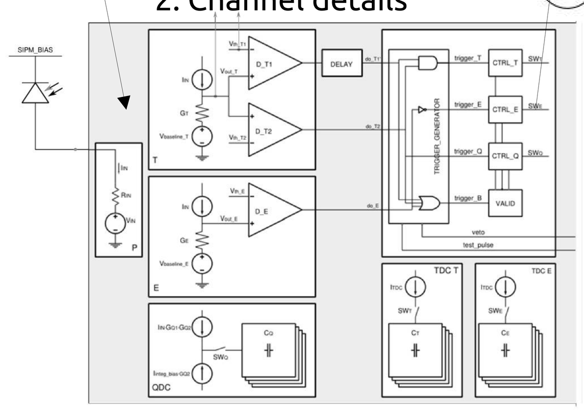


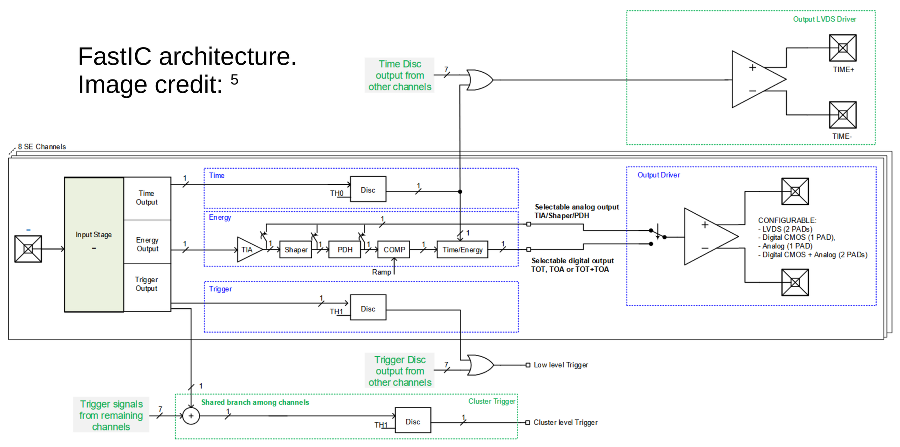
Image credit: [4]

FastIC ASIC*

→ 8 CH ASIC
→ 65 nm CMOS technology
→ ~ 6 mW/ch
→ Number of channels: 8 SE / 4 DIFF
→ Connection Type Configurable SE (Pos/Neg polarity)DIFF,
Sum of 4 (Pos/Neg polarity)
→ Electronics Time Jitter ~ 25 ps rms
→ Energy Resolution Linear (~ 2.5 % Linearity error)
→ Dynamic Range 5 uA - 20 mA
→ Maximum Rate ~ 2 MHz (Linear Time-over-Threshold (ToT) readout)
→ Interface I2C (compatible with picoTDC)
→ Configurable Digital
(single-ended CMOS or differential or SLVS)
→ The chip was set to provide ToT information only

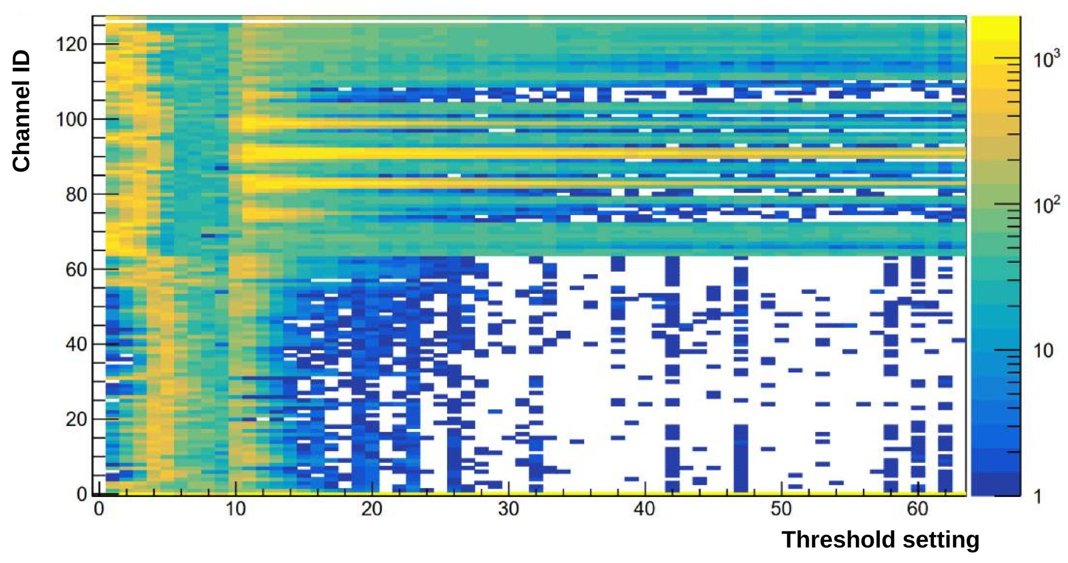
* We thank David Gascon and Rafael Ballabriga Sune for making it possible for us to test the FastIC ASIC.

FastIC architecture.
Image credit: [5]

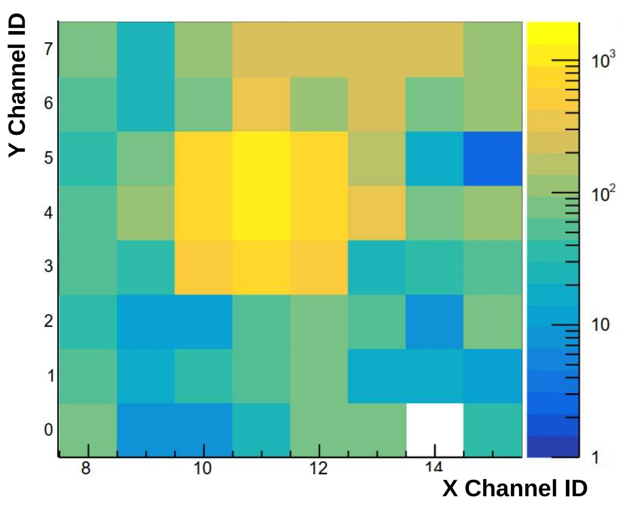


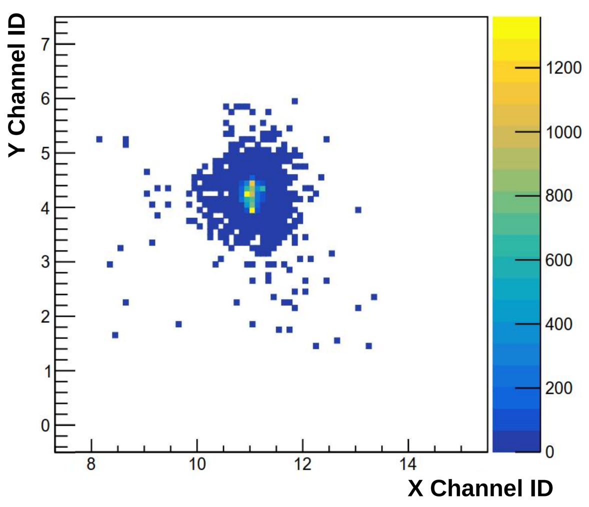
The output of the ASIC was sent into an Artix 7 FPGA which switched SLVS FastIC standard output to an LVDS level appropriate for the external CAEN TDC. We measured the TDC and FPGA contribution to be around 40 ps sigma. The laser contribution is quantified around 10 ps.

5. Results



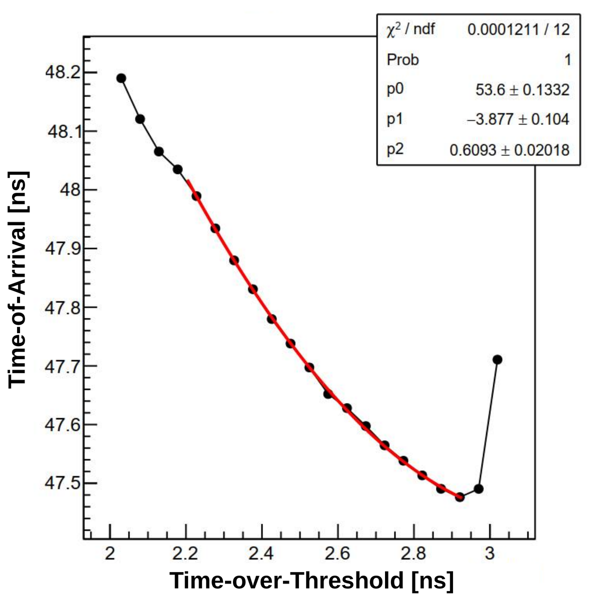
Threshold scan of the calibrated system: response of instrumented channels to single photons in dependence of PETsys threshold setting, showing noise level around threshold setting of 8, and LAPPD single photon illumination level signal height distribution for the illuminated channels. Each horizontal slice is a threshold scan of a single channel.

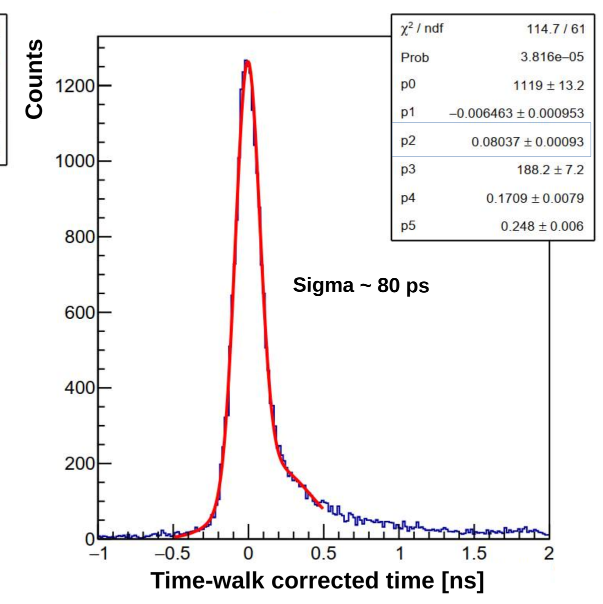




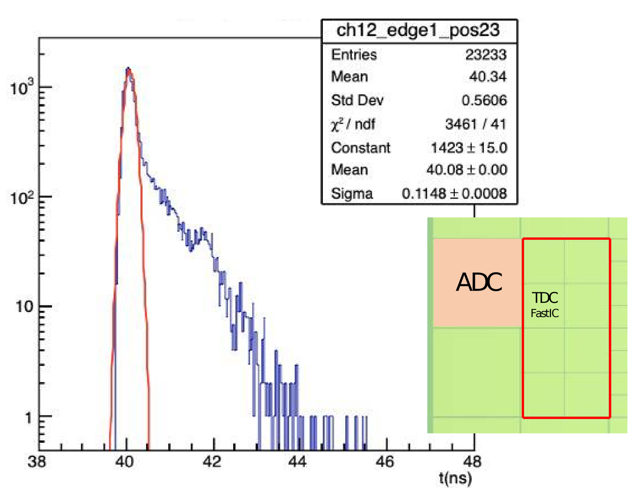
Spatial resolution:
The hit count map (left) was produced by histograming events in all pixels, while illuminating a single pixel in the center of the pad, and having set a fixed threshold.

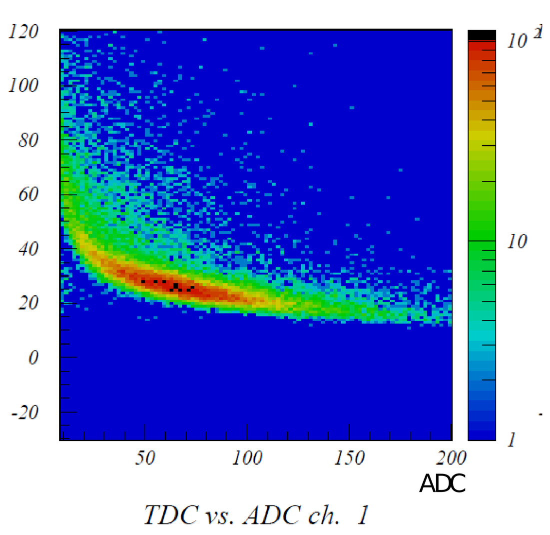
We used the ToT information of the ASIC to extract an estimate of the charge. Using the same data, we reconstruct the position by calculating the center of gravity of the charge for every event. In this way, we found the **spatial resolution to be in mm range**.

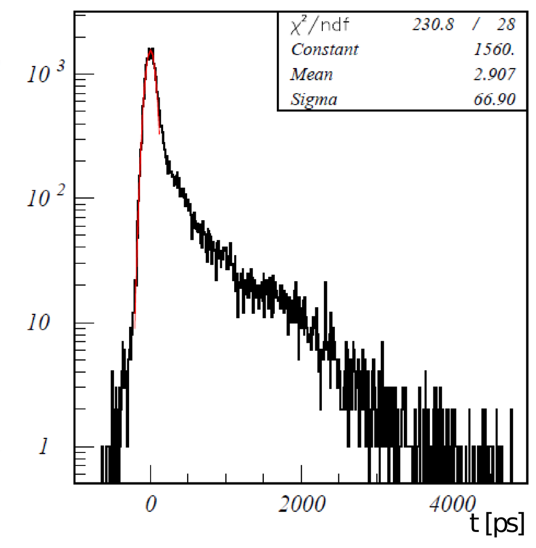




Timing resolution with LAPPD and PETsys: **(left)** distribution of time-of-arrival vs. time-over-threshold (proportional to signal amplitude), clearly showing **time-walk effect**, with the fit used for time-walk correction; **(right)** single photon timing resolution with **sigma around 80 ps** is obtained with after time-walk correction.







A single channel the size of 1/2'' was illuminated at the center with a picosecond laser pulses. We measured the timing spread between the laser trigger and time-of-arrival (ToA) to be **115 ps without time walk correction** (left). While signal was too short for ToT detection, we used induced signal on the neighboring pad, measured by VME ADC, for time-walk correction (middle). **After time-walk correction the timing spread of the prompt signal was ~ 70 ps** (right).

6. Conclusions

LAPPD

A very large device with the flexibility of making custom pads and readout system. During tests we noticed that due to charge spread in the enclosure back-plane the minimal anode pad pitch is around 6 mm. By using information on amount of charge induced on different pixels, one can achieve much better spatial resolution (mm range).

Petsys - ToFPET2

This is a commercially available ASIC, which seems to work quite well with the LAPPD. Using some careful tuning it is possible to achieve a mm size physical pixels with a timing blow 100 ps. **Furthermore, the system already has 1024 channels which, using a pad size of 0.9cm, can handle the entire LAPPD surface.**

FastIC

This chip is performing very well on timing, although we couldn't get a direct measurement for the amount of charge, to improve its timing ability by means of time-walk correction. The new FastRICH ASIC[2], will encapsulate 16 channels along with an internal high precision TDC. The addition of a rudimentary charge measurement at single photon level would be an asset for MCP detectors.

SCAN ME

Article

References:

[1] Belle II Technical Design Report, https://doi.org/10.48550/arXiv.1011.0352
[2] Framework TDR for the LHCb Upgrade II, CERN-LHCC-2021-012, LHCB-TDR-023.
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[4] PETsys, https://www.petsyselectronics.com/ (accessed October 2022).
[5] S. Gómez et al., "FastIC: A Highly Configurable ASIC for Fast Timing Applications," 2021 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Piscataway, NJ, USA, 2021, pp. 1-4, doi: 10.1109/NSS/MIC44867.2021.9875546.