Time resolution studies with TOFPET ASIC

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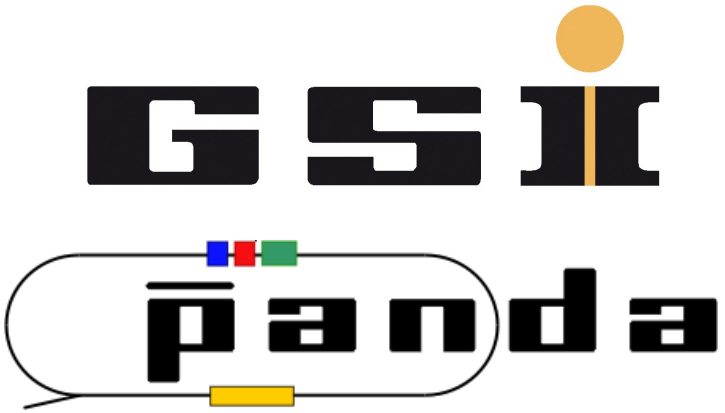
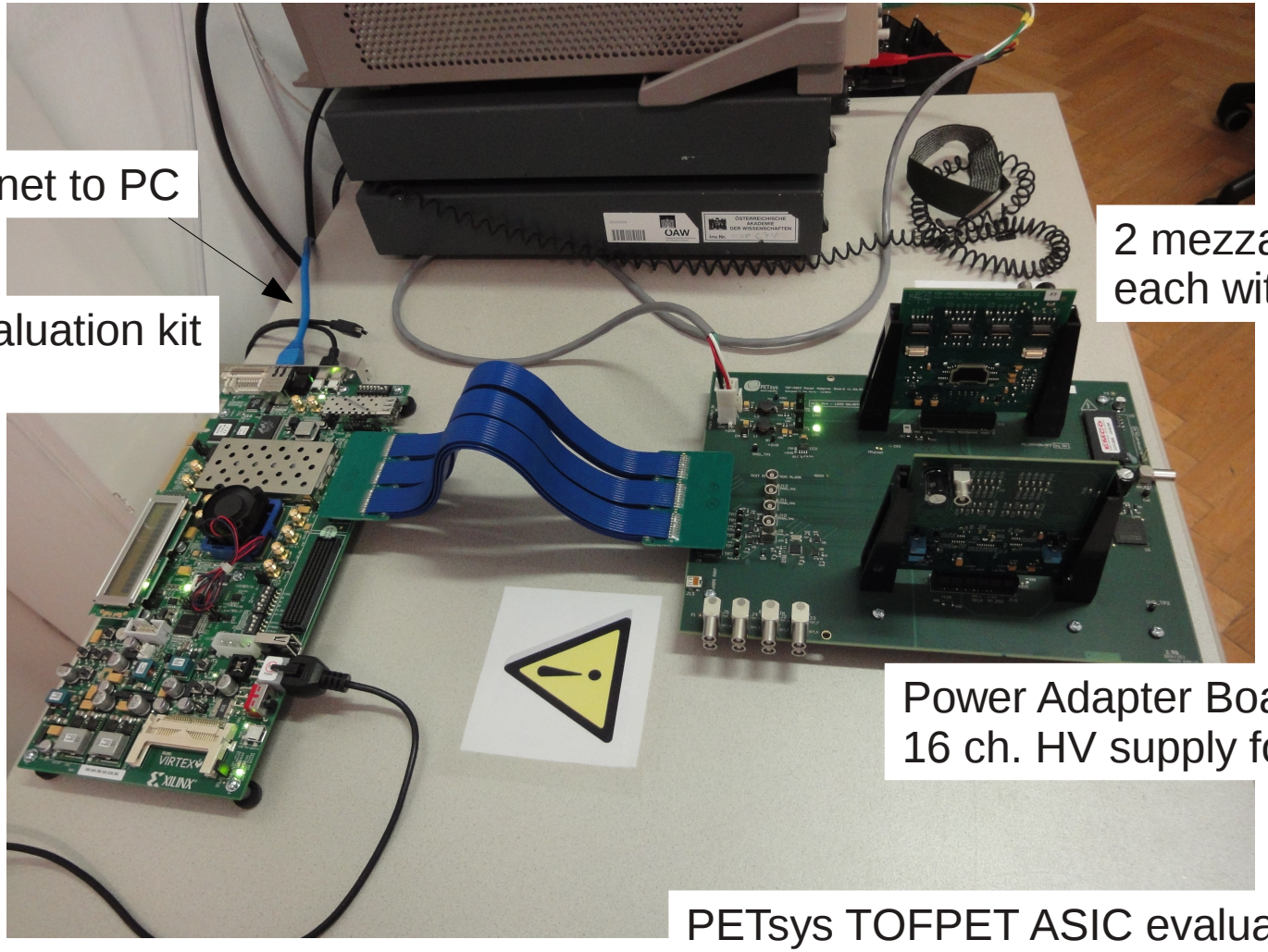


Outline

- TOFPET evaluation kit
- First steps (clock, HV, connections, threshold)
- Dark count measurements
- Timing with test pulses
- Timing with laser
- Timing with scintillator and source
- Summary and outlook

Evaluation kit



First steps

- Documentation, firmware, demo programs, etc. provided by PETsys (GoogleDrive)
- Getting started with test routines and calibration
- Test functionality of ML605 board running a Build-In System Test
- Check the communication between the two boards (FPGA and TOFPET) by testing clock and HV

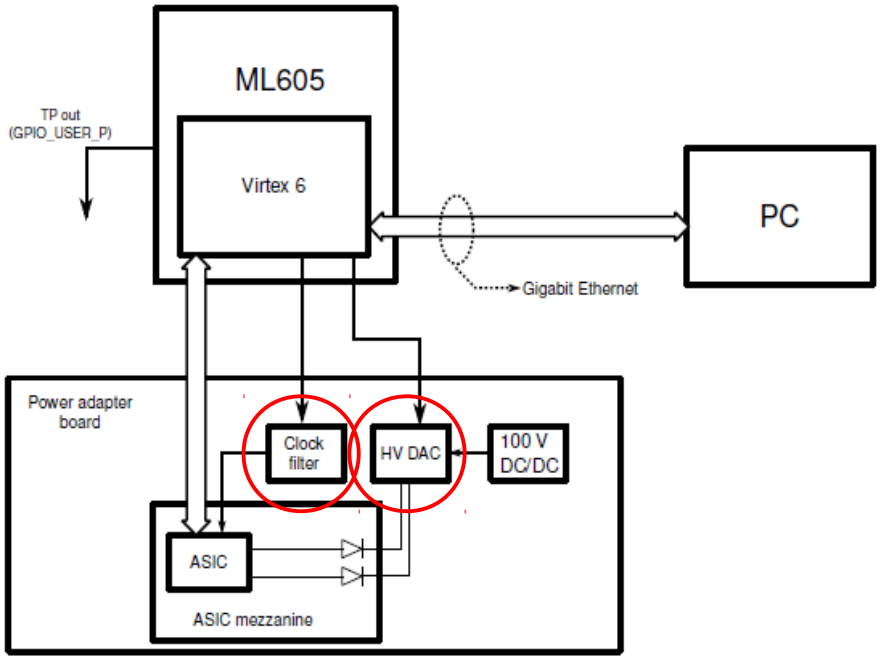


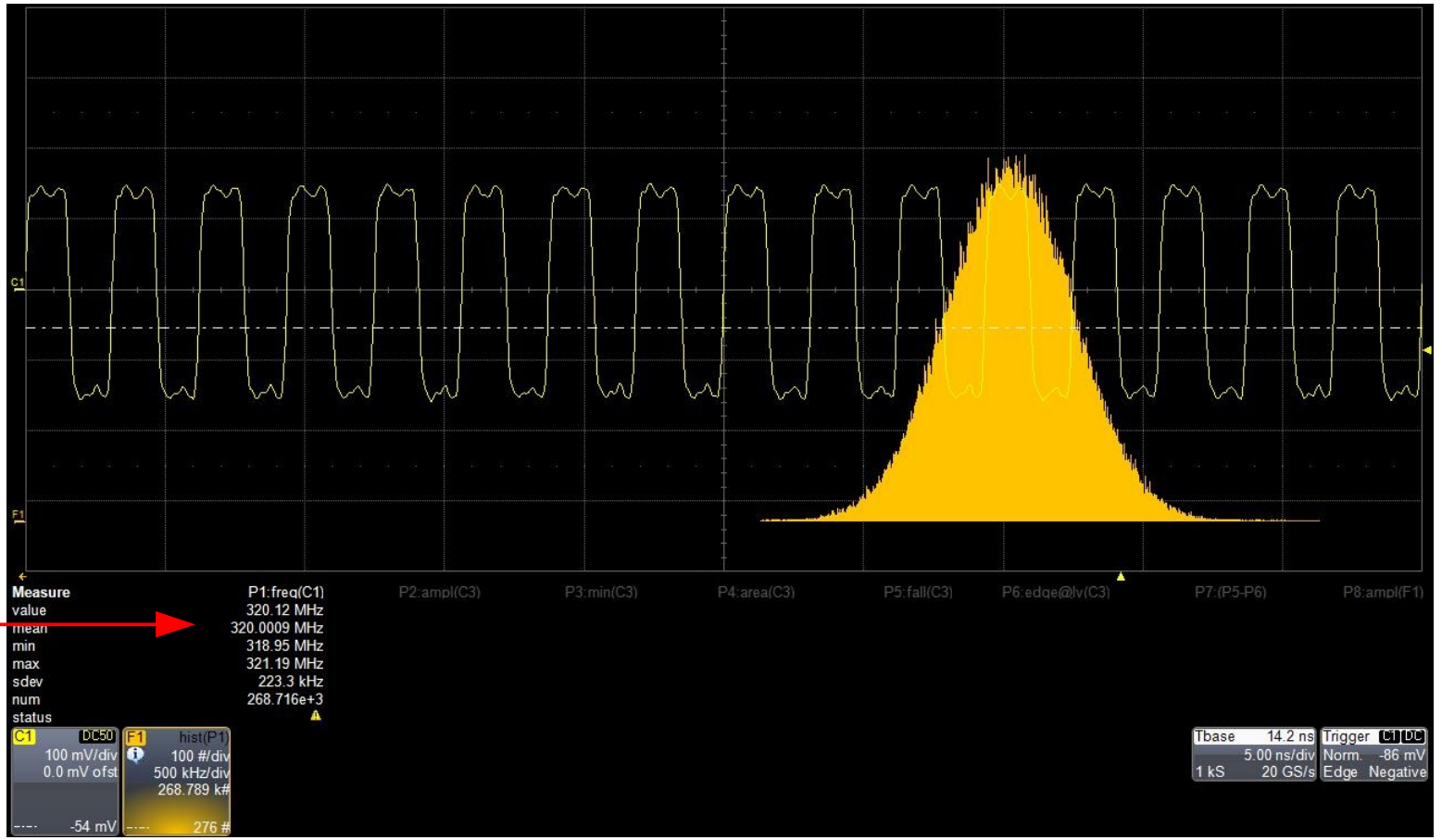
Figure 1.1: System diagram

TOFPET ASIC evaluation kit software user guide v3.1,
PETsys, March 2015

320 MHz clock

The PAB should receive a 320 MHz clock from the FPGA

Clock signal measured at the PAB:

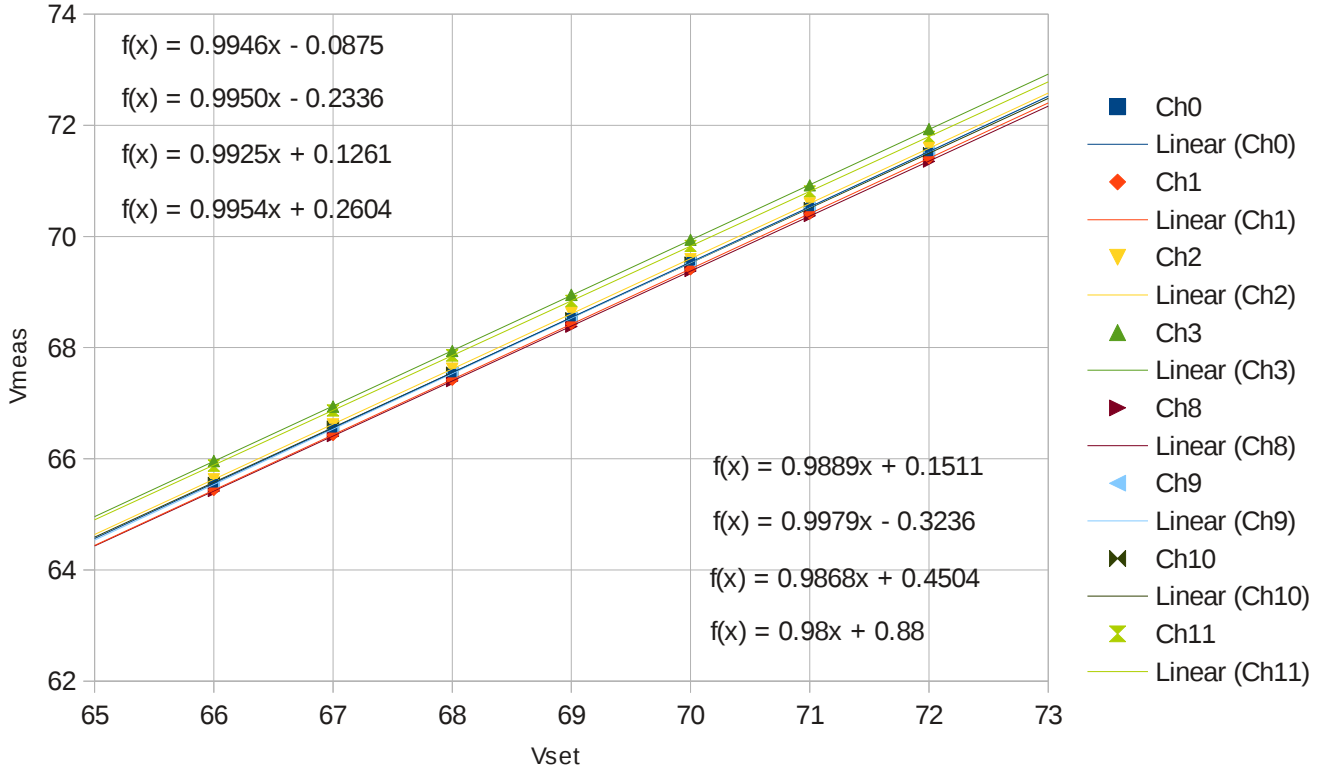


320 MHz

→ **Communication between FPGA and TOFPET works**

HV supply

- The PAB has an internal HV supply module which can be controlled via the FPGA
- The HV DAC has to be calibrated by comparing the set voltage (V_{set}) and the actual voltage (V_{meas}) at the output of the mezzanine bords
- Shows again that communication works



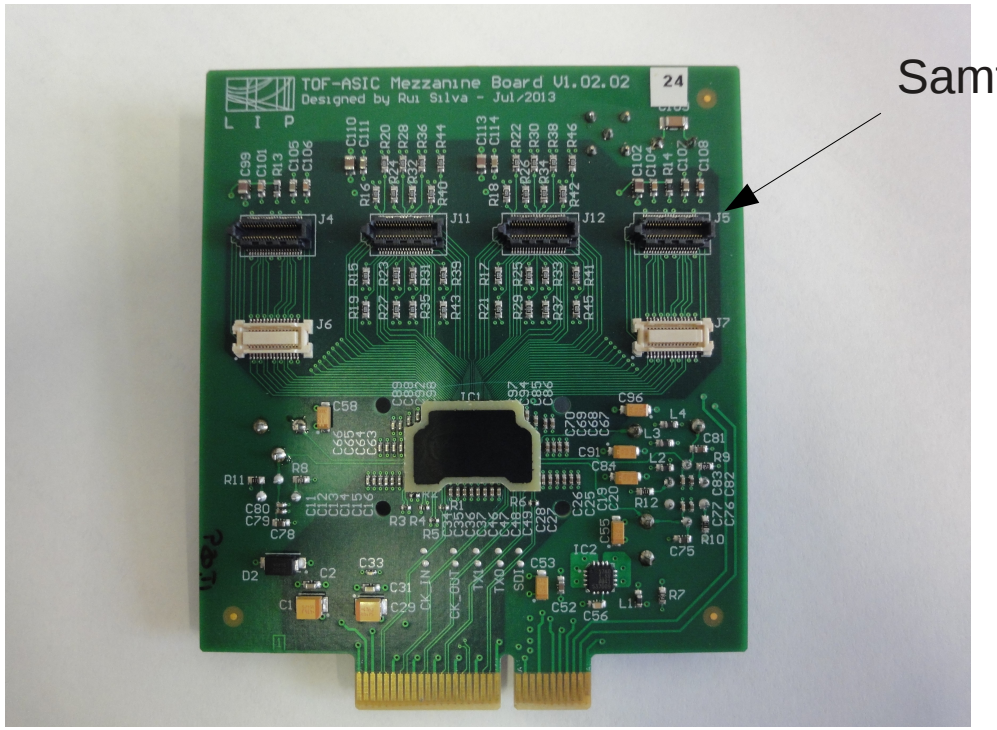
Simple linear regression:

$$V_{meas} = m \times V_{set} + b$$

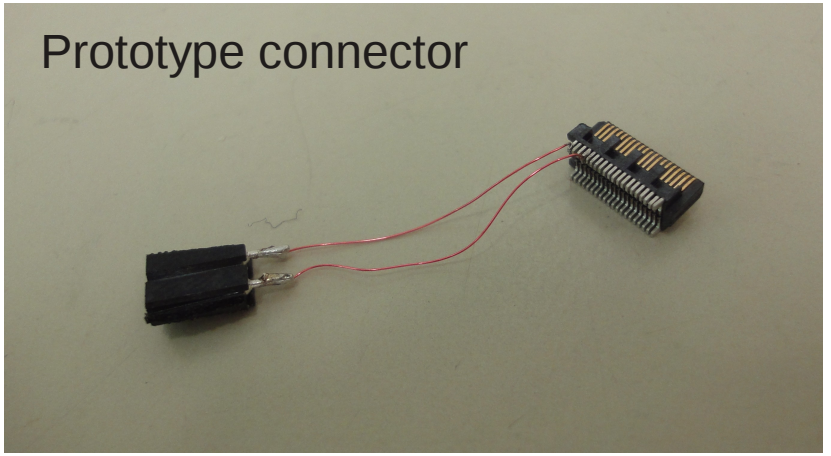
Parameters m,b are used to produce a calibration file and calibrate the HV DAC.

SiPM connection

- The mezzanine board connects to 4 Hamamatsu 16 channel arrays
- We need an adapter to connect single SiPMs



Samtec SS4 connector fits to ST4



We will prepare a print board with ST4 on one side and connectors for SiPMs on the other side.

Threshold setting

- Two thresholds: vth_T (time) and vth_E (energy, validation)
- Time over threshold (ToT) is defined by rising edge of vth_T and falling edge of vth_E
- 6-bit DAC: threshold ranges from 0 to 63 with an inverted scale
- Each unit increase corresponds to a step of about 10 mV at the amplifier output
- Amplifier output baseline has some offset (rel. to DAC) which has to be determined
- The amplifier produces a ~ 20 mV signal for 1 p.e. for a Hamamatsu SiPM with G = 1.25E6

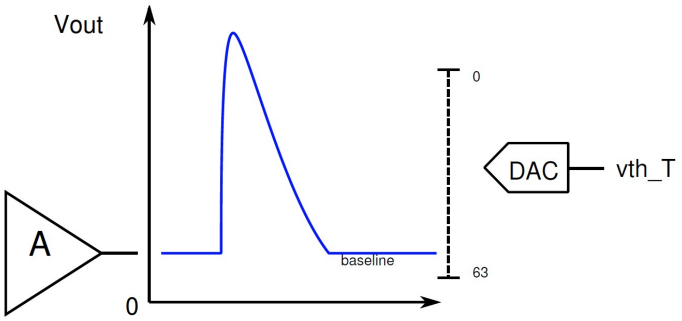
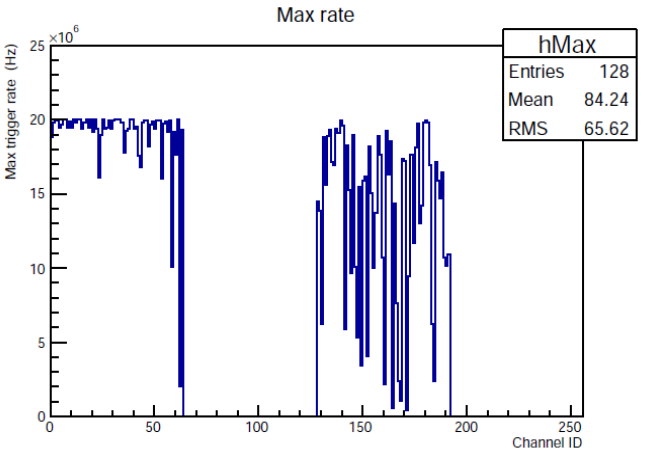
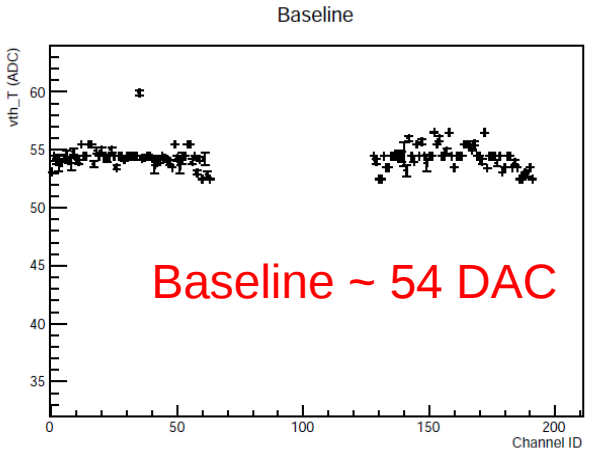
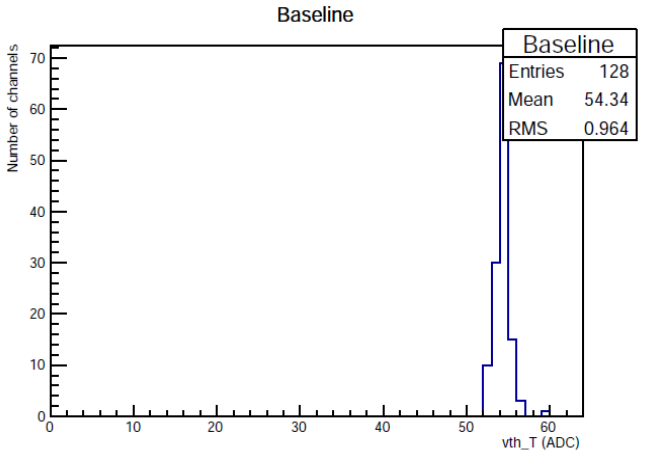
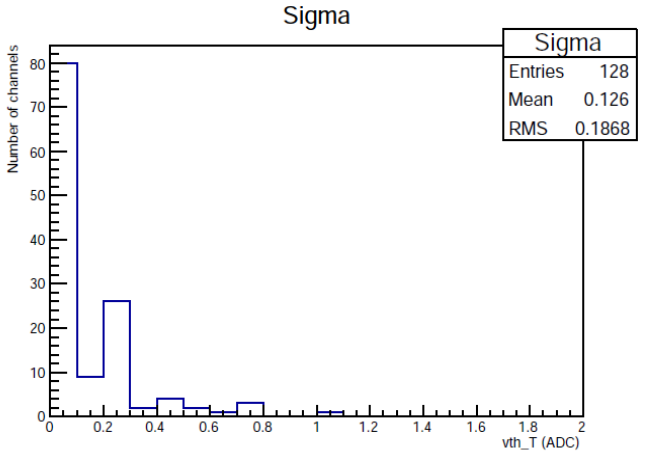


Figure 3.2: Amplifier output and threshold DAC.

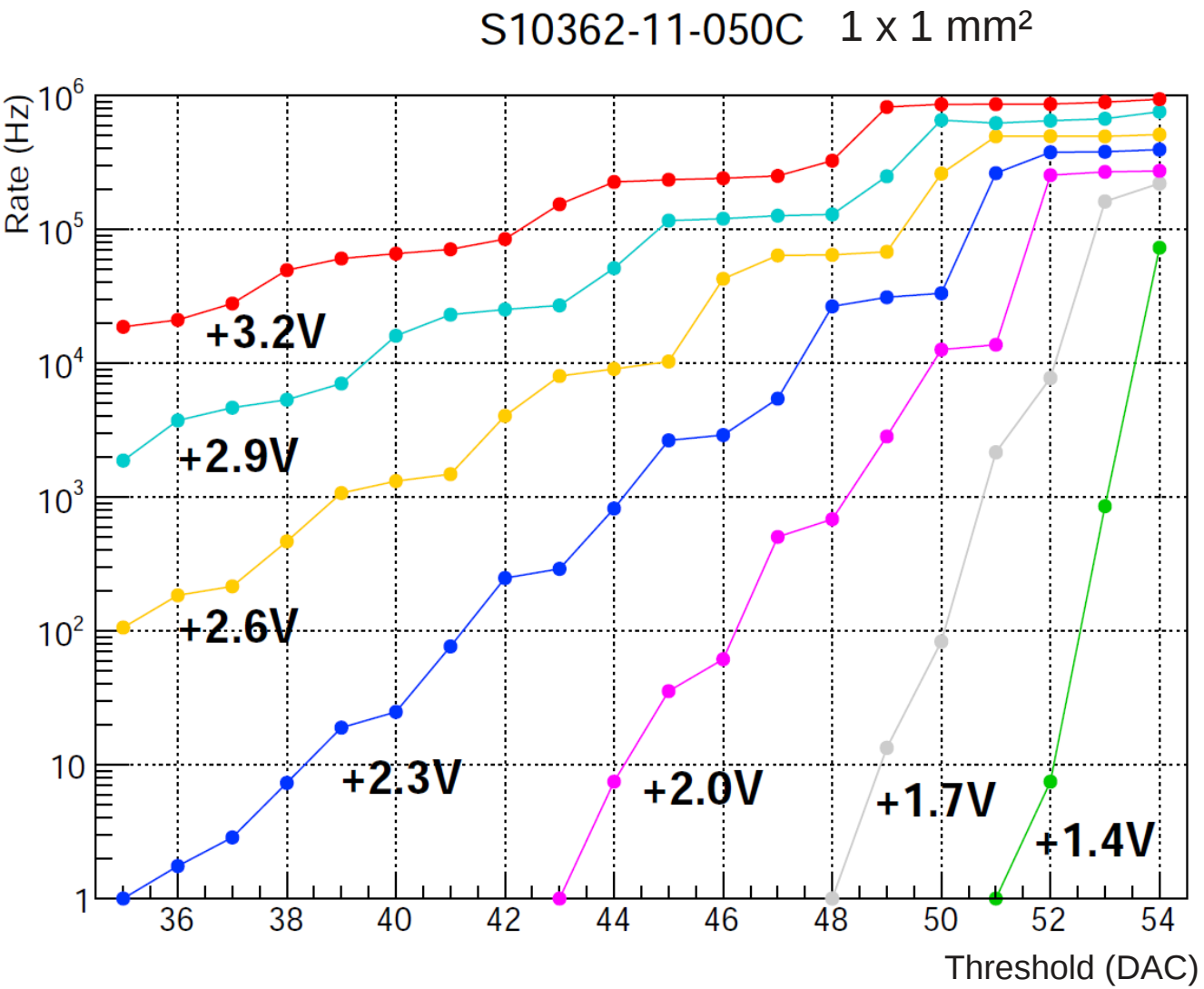








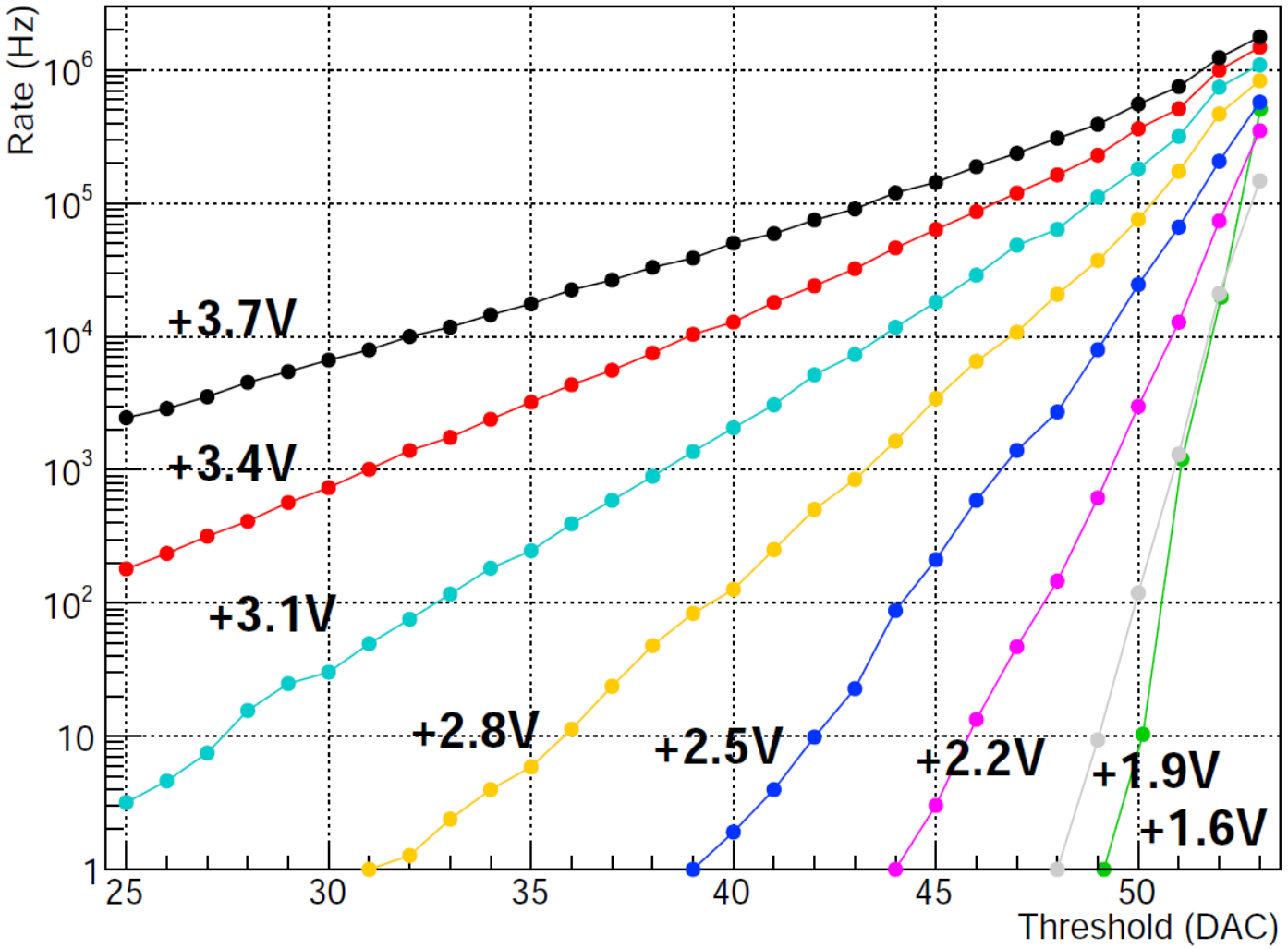
Dark counts



Nice steps (1 p.e., 2 p.e.,...)
Reasonable rates.

Dark counts

S12572-050P 3 x 3 mm²



No steps?
No photon separation?

Timing with test pulses

Two pulse modes:

1. tdca
2. fetp

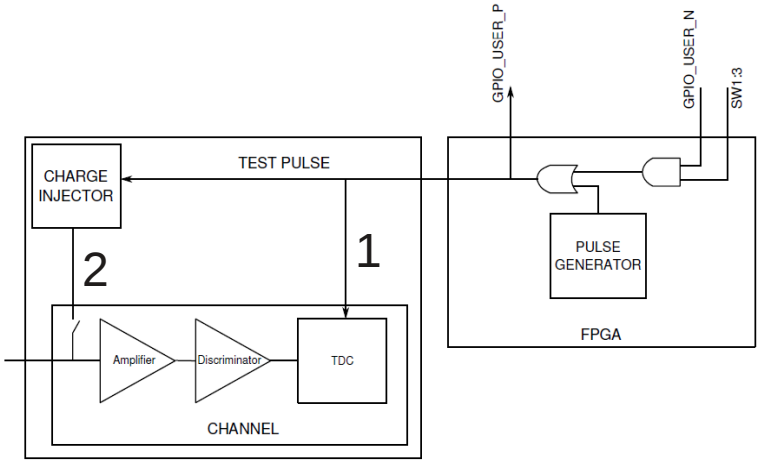
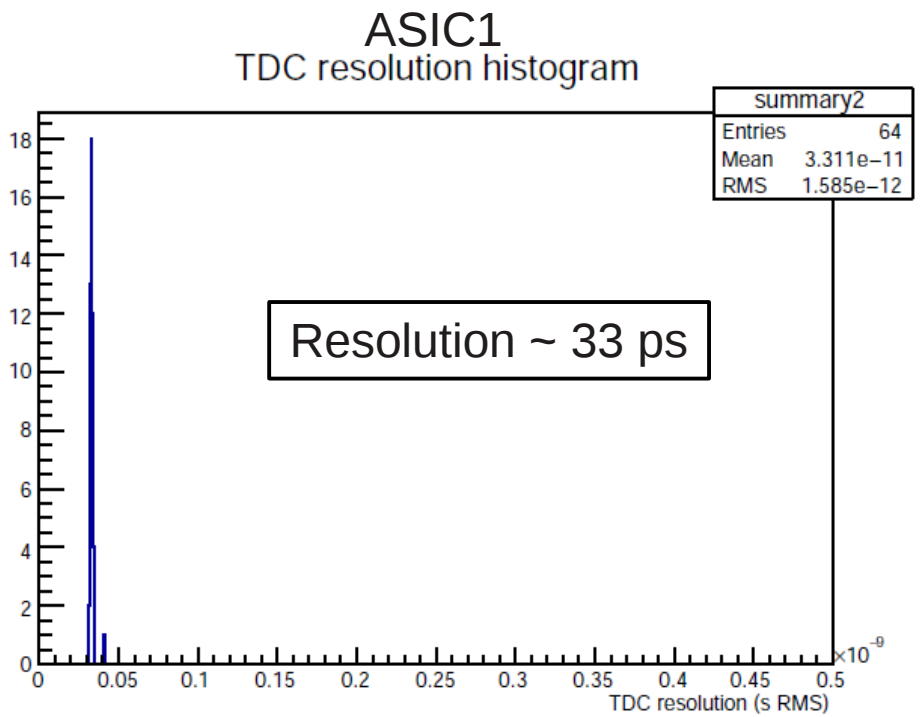
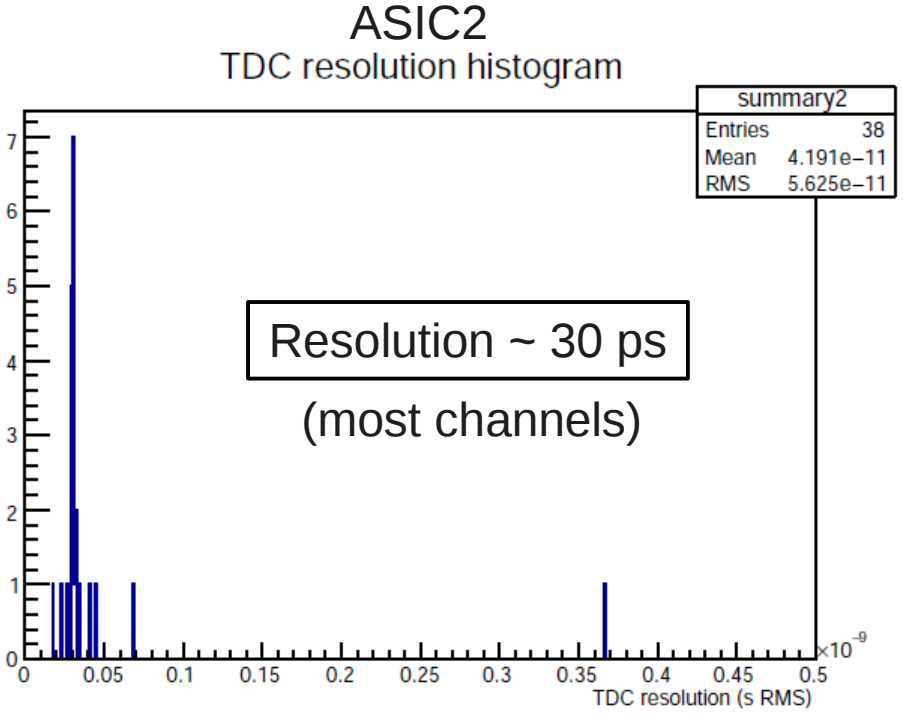


Figure 4.1: Test pulse paths





Timing with laser + SiPM

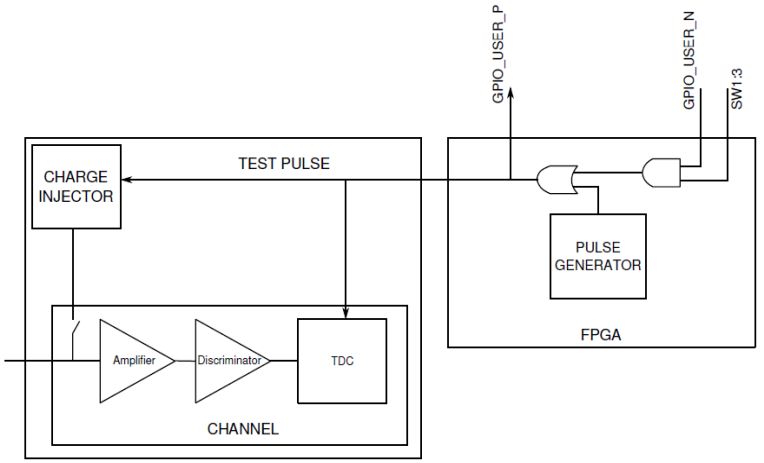
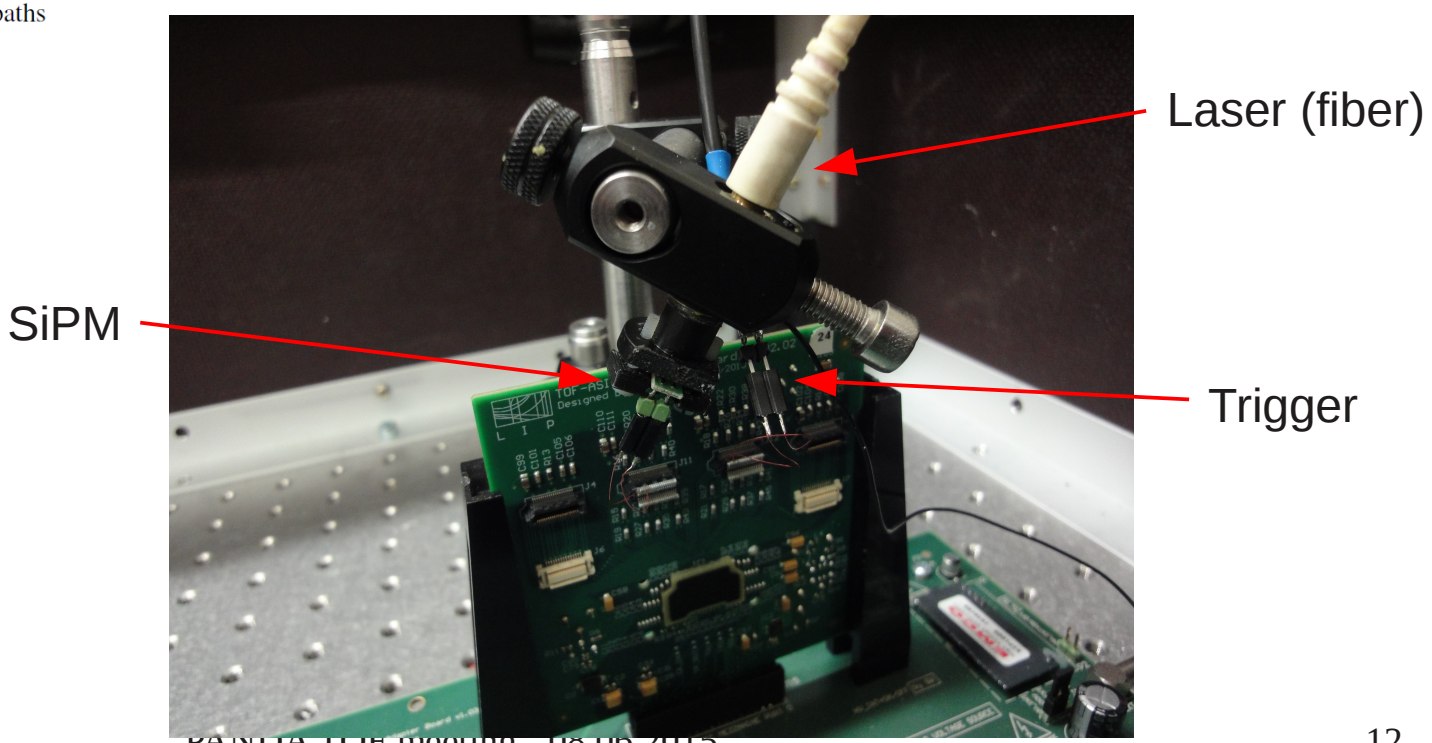


Figure 4.1: Test pulse paths

- Use GPIO_USER_P to trigger laser
- Insert GPIO_USER_P also to TOFPET → **start**
- Illuminate SiPM with laser
- Use SiPM signal as **stop**
- Determine time resolution by measuring the delay between trigger and SiPM signal



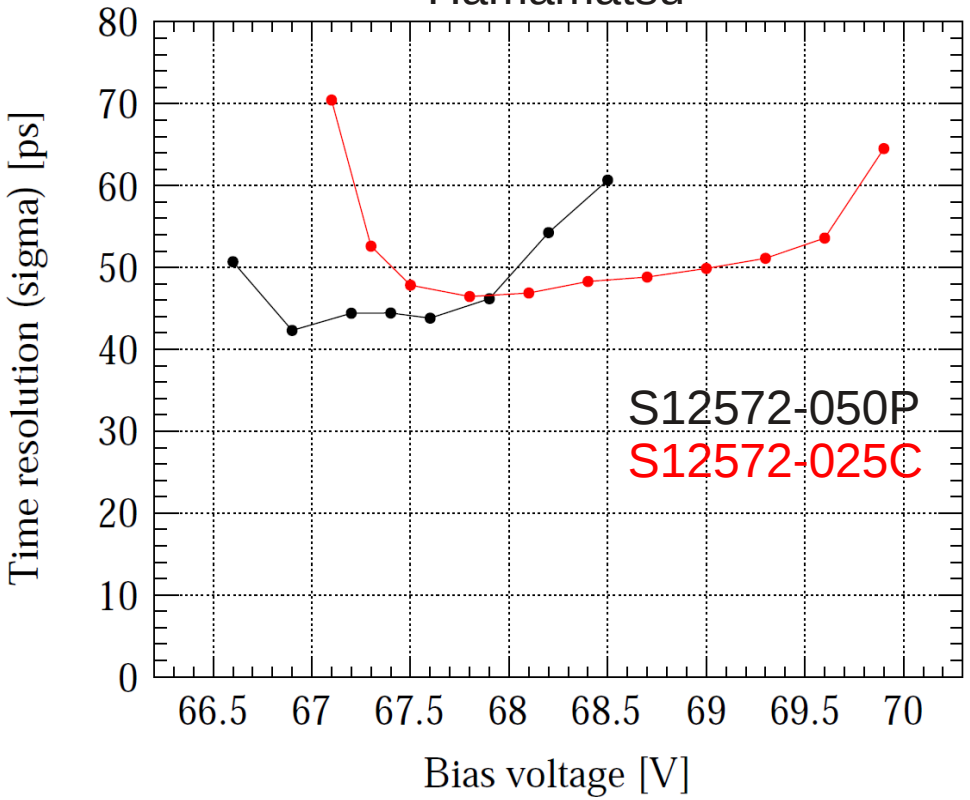
Timing with laser + SiPM

Many photons (~ 100 photons)

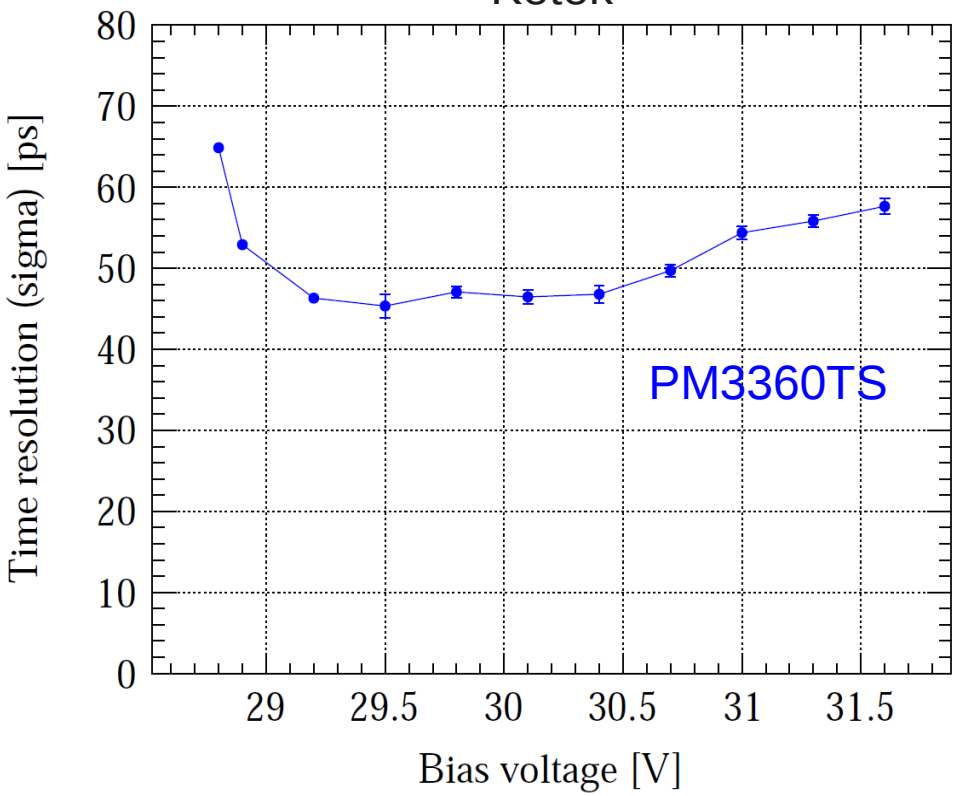
vth_T = 5 DAC above baseline
vth_E = 30 DAC above baseline

+ time walk correction

Hamamatsu



Ketek



Time resolution σ ~ 45 ps dominated by electronics (laser, trigger, TDC).
SiPM time resolution is negligible due to high photon number.

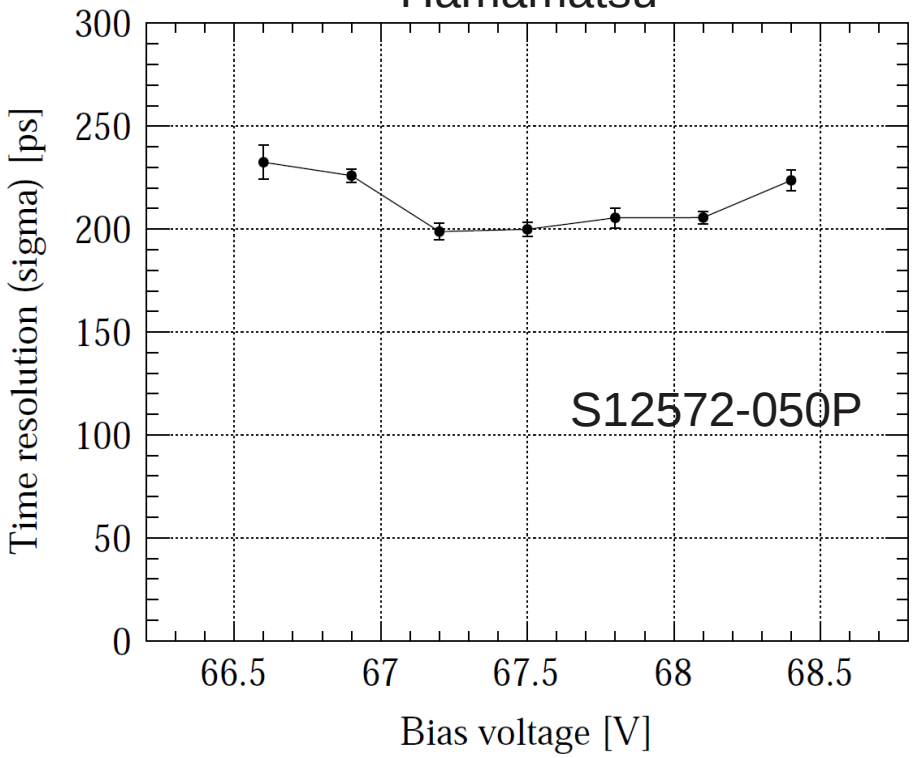
σ_{laser} ~ 30 ps
σ_{TOFPET} ~ 33 ps
σ_{SiPM} ~ 10 ps

Timing with laser + SiPM

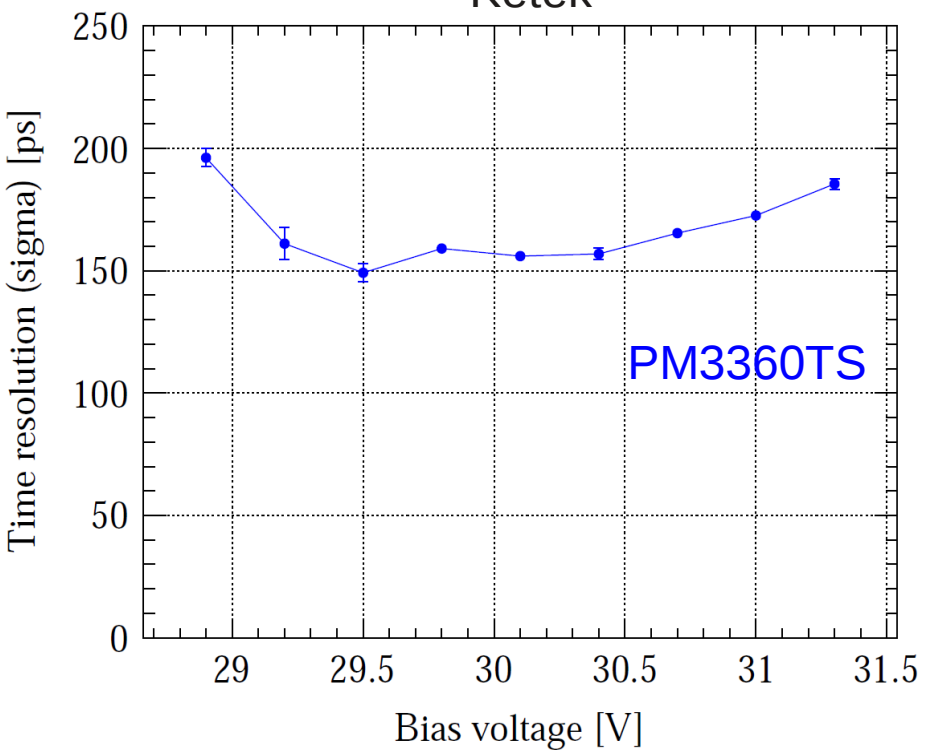
"Single" (few) photons

vth_T = 2 DAC above baseline
vth_E = 6 – 10 DAC above baseline

Hamamatsu



Ketek

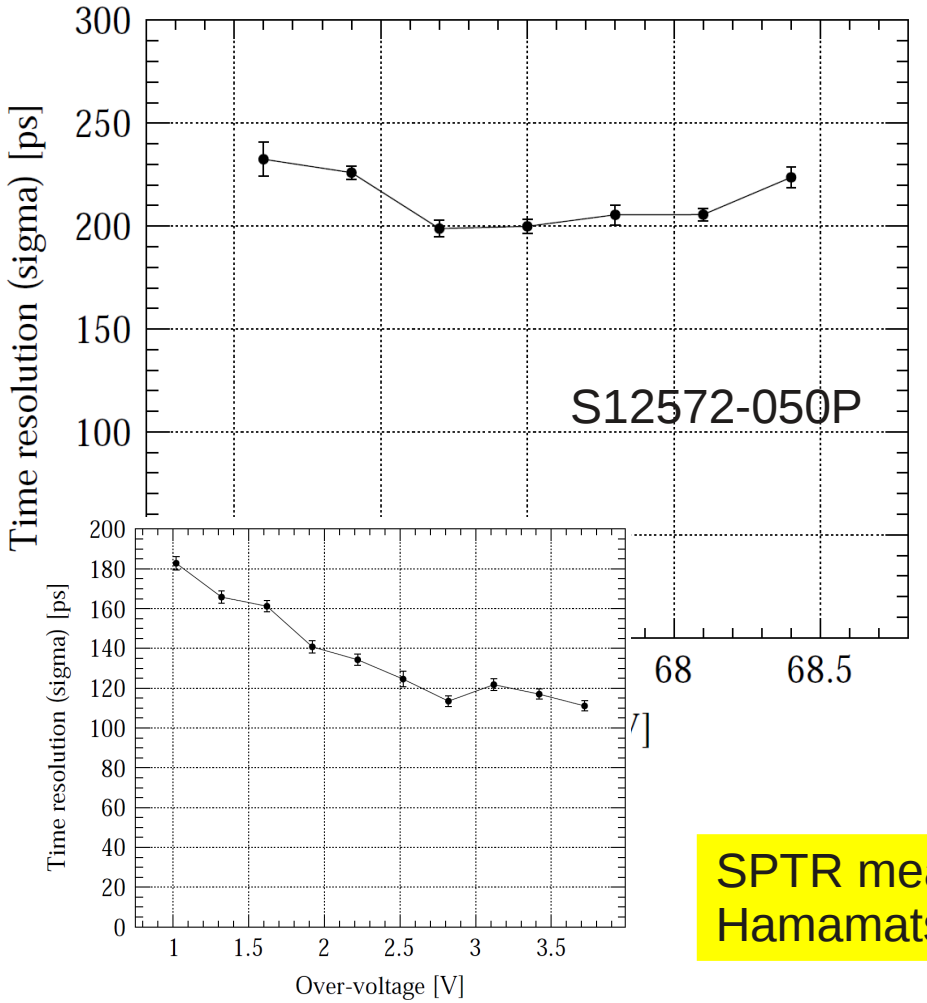


Not possible to count and select photons from ToT spectrum.
Broadening of timing spectrum.
No knowledge about exact number of detected photons.

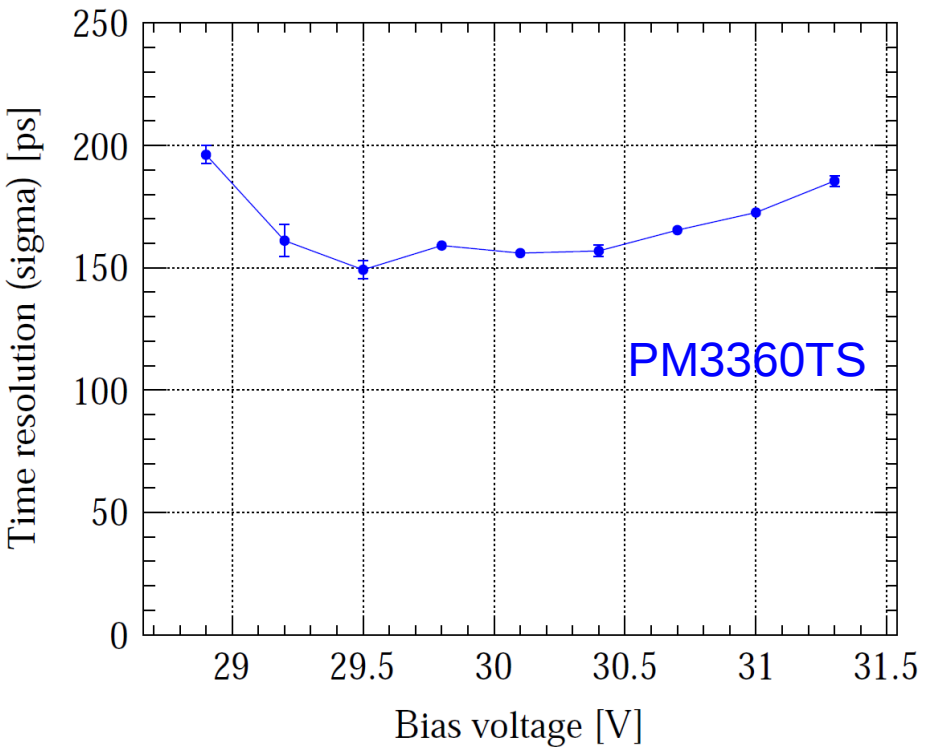
Timing with laser + SiPM

"Single" (few) photons

Hamamatsu



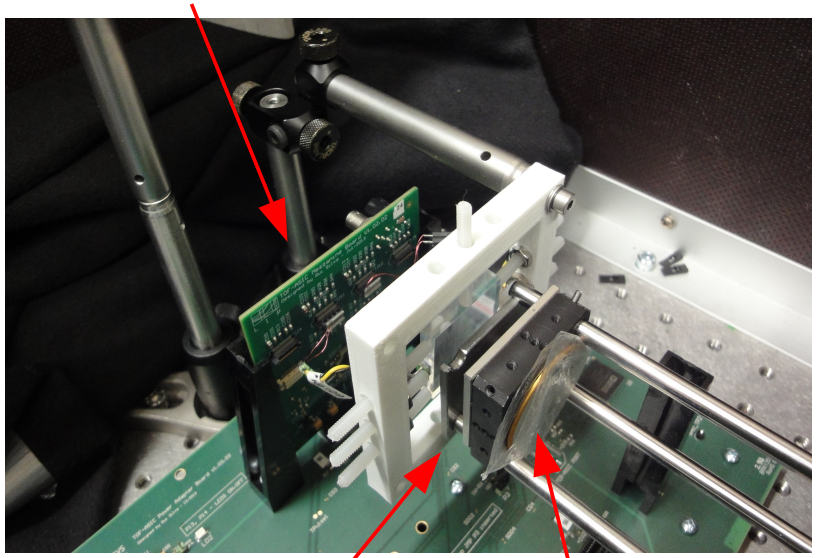
Ketek



SPTR measured with Oscilloscope about 110 ps (sigma).
Hamamatsu states SPTR 250 ps (FWHM).

Timing with scintillator + SiPM

TOFPET board

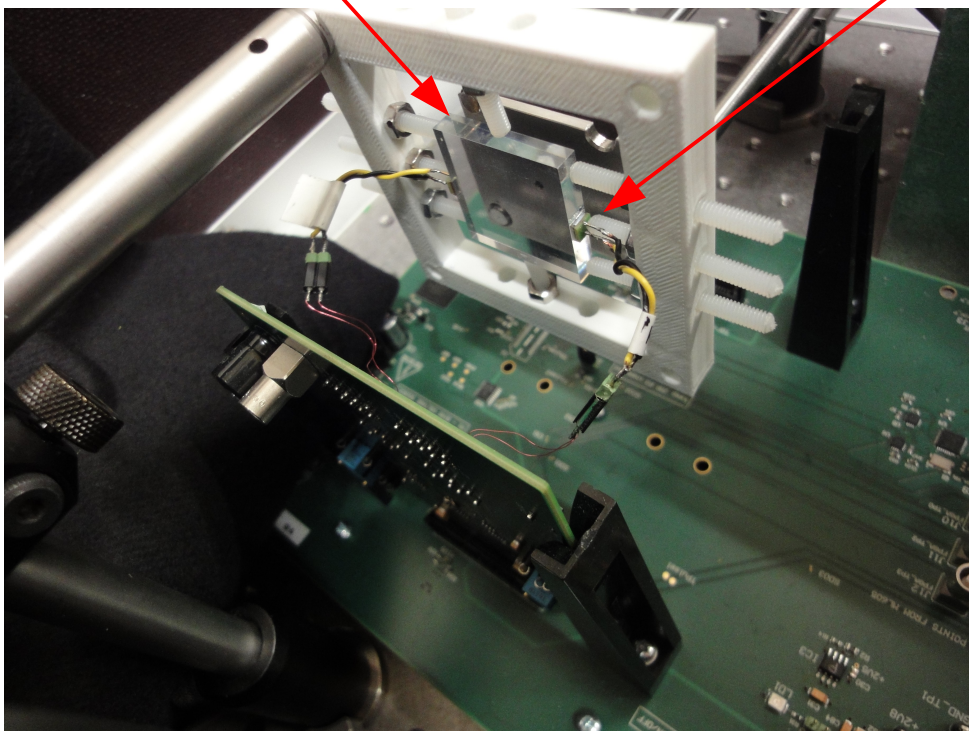


Collimator

Sr90 source

SiPMs

Scintillator (EJ-228 30 mm x 30 mm)



Time resolution (σ_{tile}) estimated by time difference between the two SiPM signals:

$\sigma_{tile} \sim \sigma_{diff} / 2$

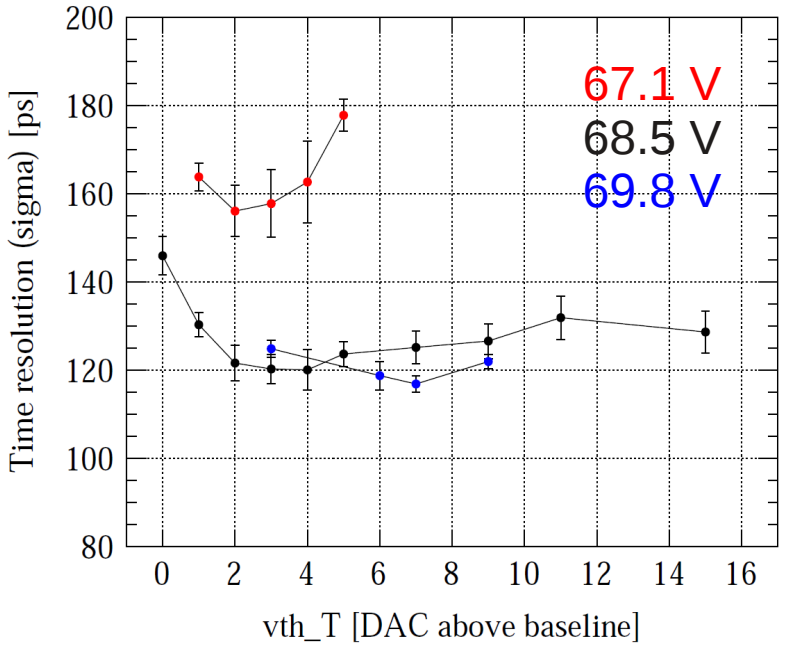
Timing with scintillator + SiPM

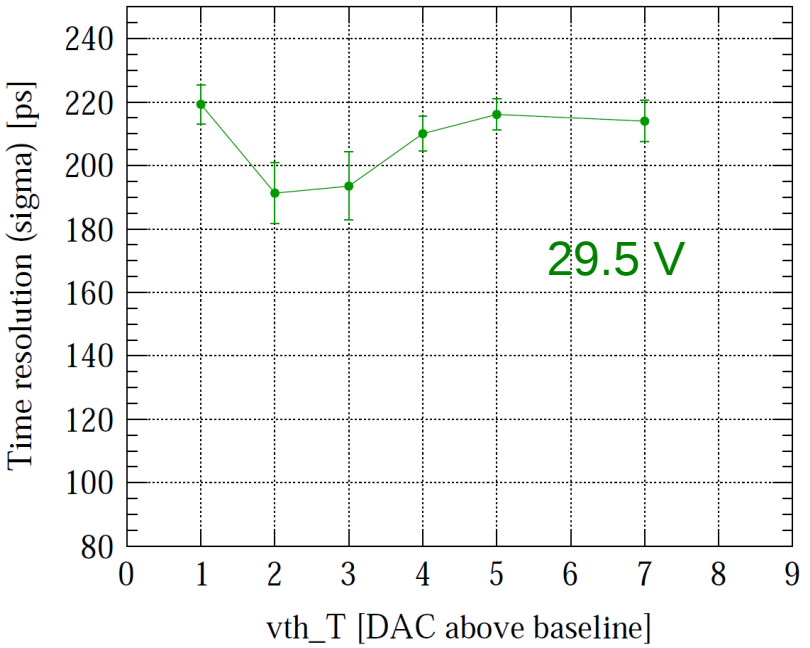
vth_T set to low values for timing (depending on HV – see below)
vth_E = 5 – 35 DAC above baseline
vth_E set to higher values so that there is no noise and few dark counts (depending on HV)
+ additional cut on ToT spectrum (ΔE > 0.8 MeV)

E.g.: **HPK S12572-025C**
vth_E = 5 for 67.1 V
vth_E = 34 for 69.5 V

E.g.: **Ketek PM3360**
vth_E = 4 for 28.6 V
vth_E = 18 for 31.0 V

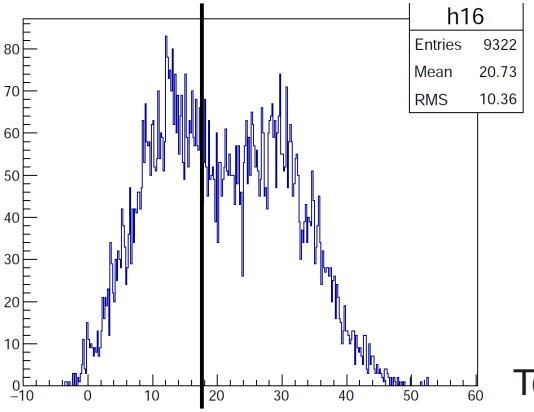
Optimal vth_T depends on bias voltage.



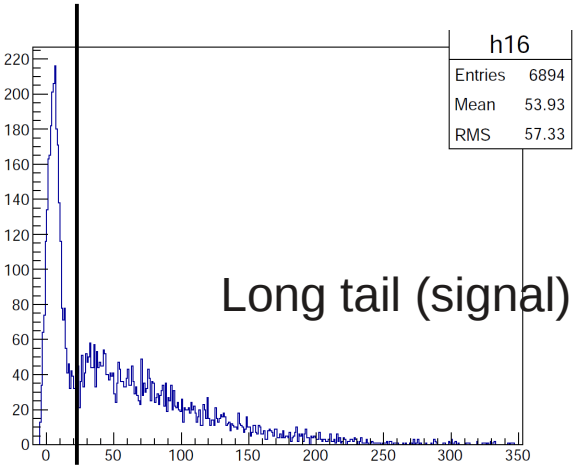


Timing with scintillator + SiPM

vth_T = 5 DAC above baseline
vth_E = 5 – 35 DAC above baseline (depending on HV)
+ additional cut on ToT spectrum (ΔE > 0.8 MeV)

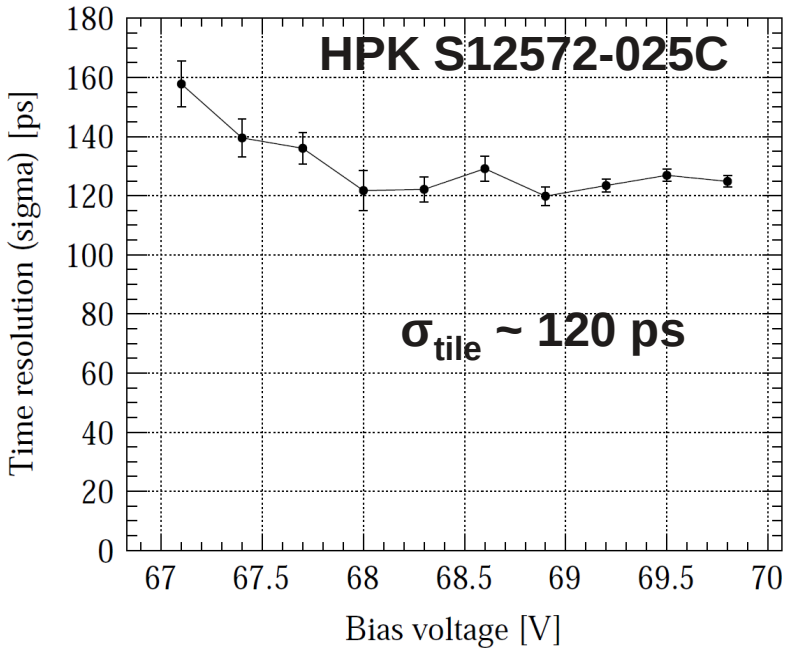


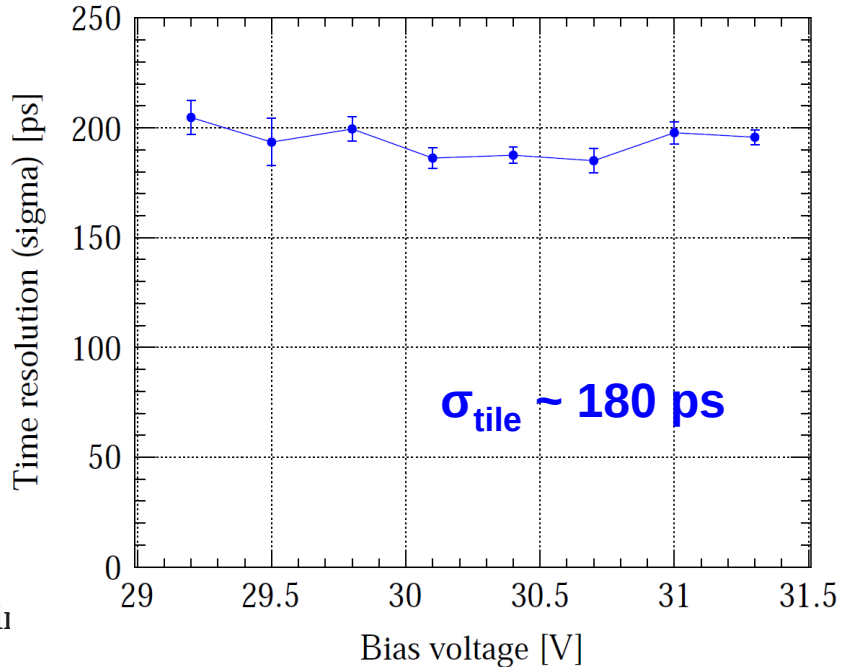
ToT [ns]



Long tail (signal)

ToT [ns]





Summary and outlook

- Results are very preliminary
- Time resolution of about 30 – 35 ps using test pulses
- Time resolution of about 45 ps with laser and SiPM
- Time resolution of about 120 ps with Hamamatsu 050C and EJ-228
- Time resolution of about 180 ps with Ketek 3360TS and EJ-228

To do:

- Update firmware and software (new release available)
- Redo calibration (TDC, amplifier) – some channels show worse resolution?
- More systematic measurements needed
- Some results not yet fully understood (timing, ToT spectra, coincidences, ...)
- Improve SiPM connection (Samtec connector)
- Use new SiPMs (current SiPMs have been used at test beam)
- Noise on signal? Connection? (high vth_E needed)

Thank you !