SiPms at MTest. SiPms timing properties.

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Fermilab

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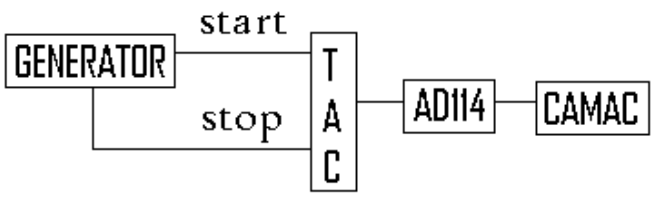
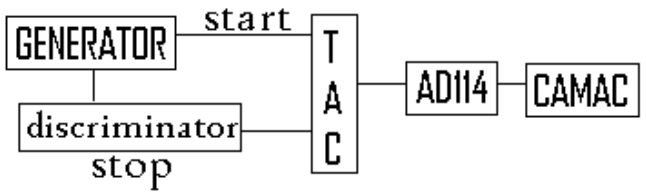
The goal of the SiPms timing study

- To measure Single Photoelectron Time Resolution (SPTR) of different Silicon Photomultipliers (SiPms) in dependence on overvoltage, readout electronics, wavelength of the illuminated light, temperature. PiLas laser used as light source. (14-17 ps of the light pulse rms, 2.3 ps time jitter, rms)
- To study fast new Ortec electronics with the SiPms
- To approve consistency of the data obtained with the PiLas laser and beam. This allows to develop and study the planned time of flight system (TOF) in details without beam. The beam will be used only to test final system.
- To build TOF system for the MT with the few tens picosecond time resolution based on SiPms.

Examples of used SiPms readout

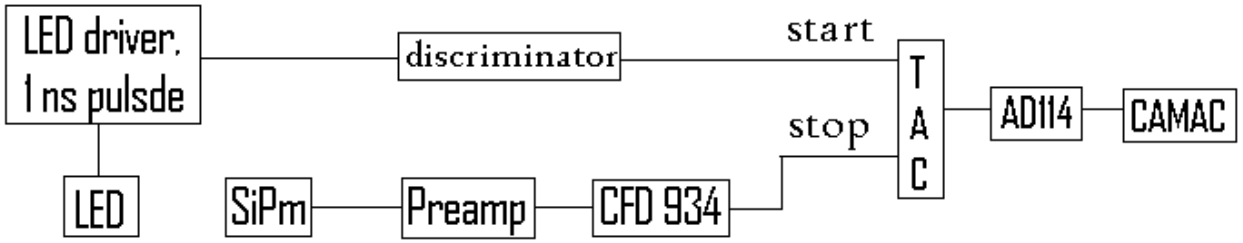


"Electrical" time resolution - 2 ps

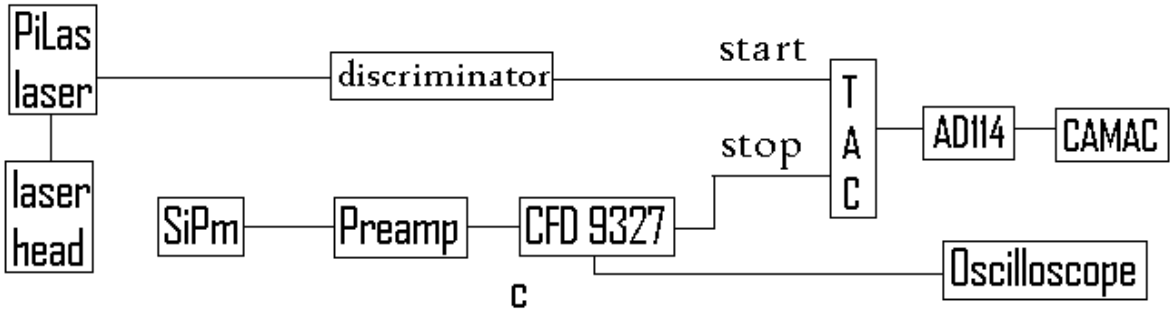


"Electrical" time resolution - 3 ps

a



b

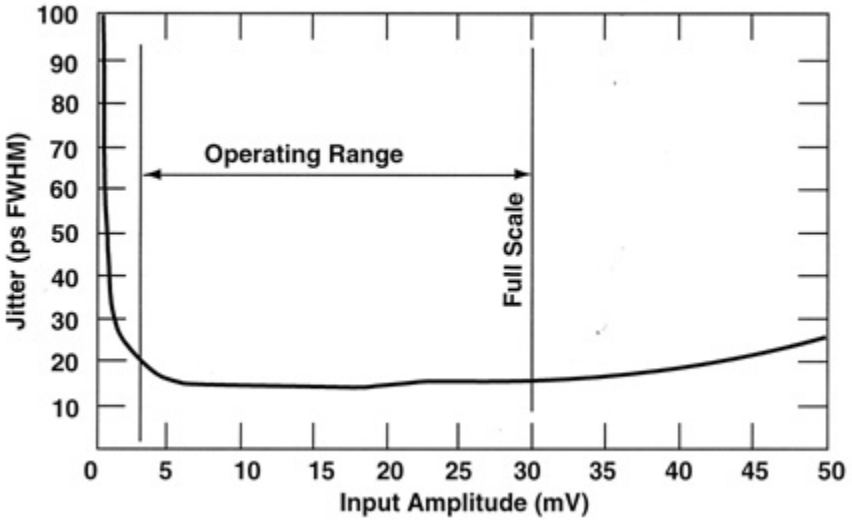


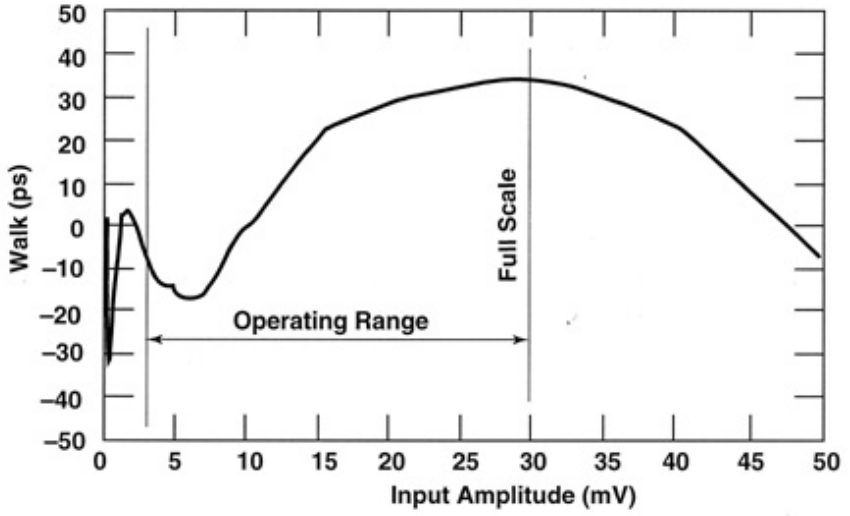
c

9327 requirements to input signals

9327 1-GHz Amplifier and Timing Discriminator

- For picosecond timing with mV signals from: Microchannel Plate Detectors
  Microchannel Plate PMTs
  Fast Photodiodes
  Fast Photomultiplier Tubes
- 1-GHz Amplifier and Timing Discriminator are internally matched for minimum walk and timing jitter
- Walk typically <±40 ps over the top 90% of full scale
- Jitter <20 ps FWHM at 50% of full scale
- Optimized for pulse widths from 250 ps to 1 ns; accepts pulse widths up to 5 ns
- Selectable input pulse height range: 0 to −30 mV, or 0 to −150 mV full scale
- 2:1 Fine Gain control
- Over-Range LED for precise gain adjustment without an oscilloscope

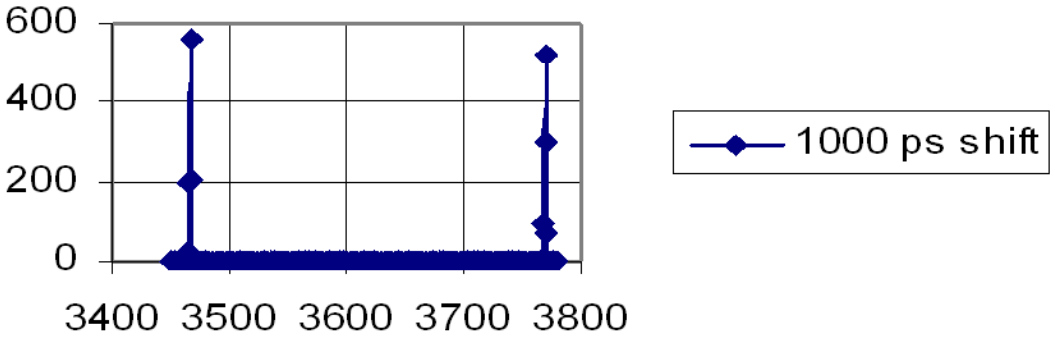


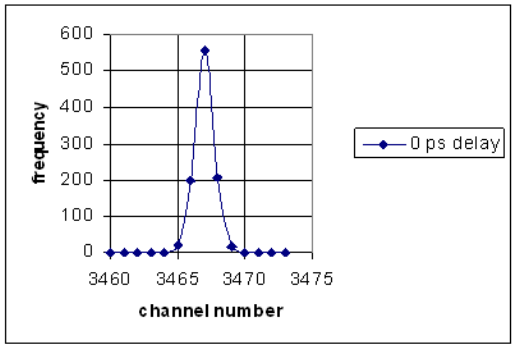


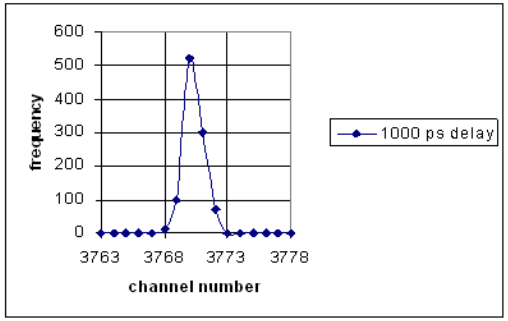
The “electrical” time resolution of the setup is 2 picosecond

TAC567+AD114. 2 ps “electrical” time res.

TAC567+AD114. Start, stop - generator. "Electrical" time resolution = 2 ps. 50 ns of dynamic range, 16,128 chs, 3.1 ps/ch





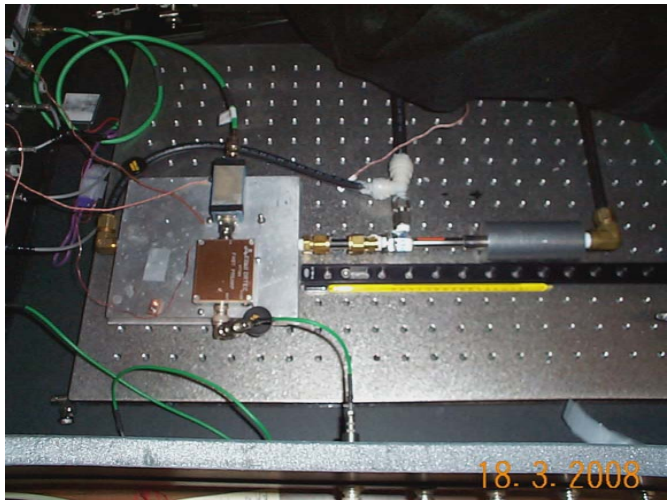


Linearity of the TAC567 is in accordance with specs.

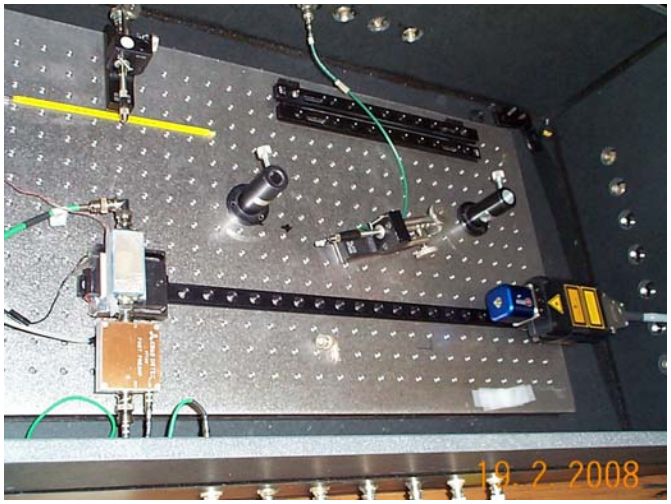
mean 1 = 3467, rms = 0.6945; mean 2 = 3770, rms = 0.6614

Fig. 3

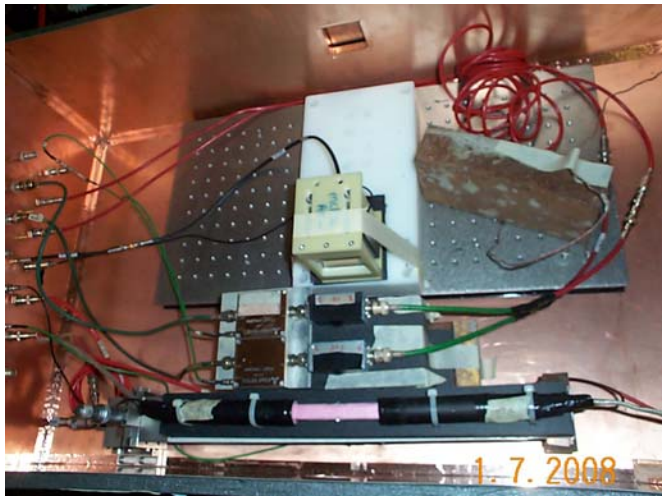
Parts of setups for SiPms study, SiDet, MT



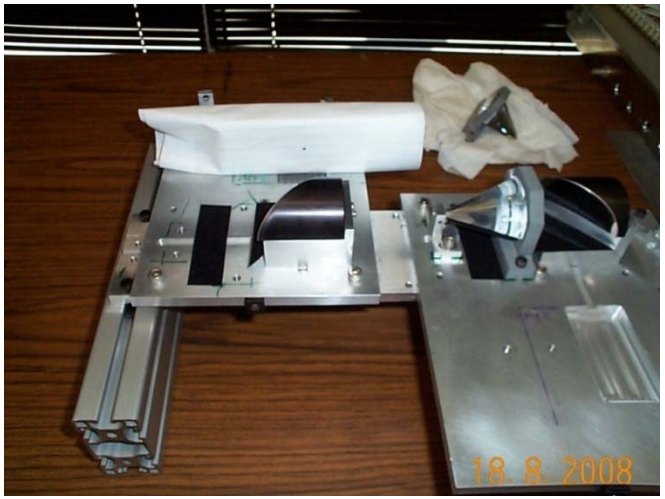
SiPm, Ortec preamp, placed on cooling plate



SiPm, Ortec preamp, PiLas head (635 nm)



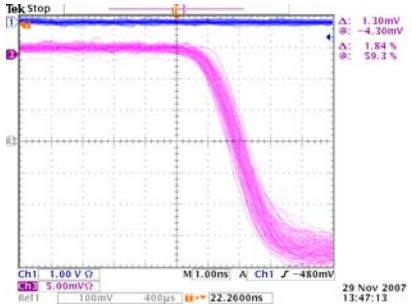
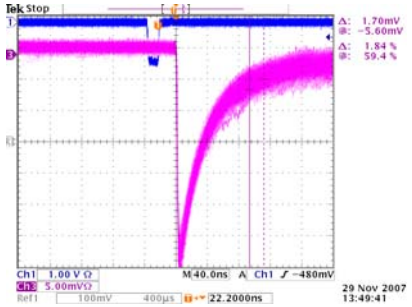
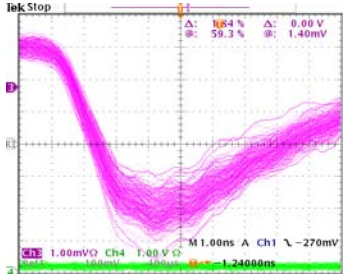
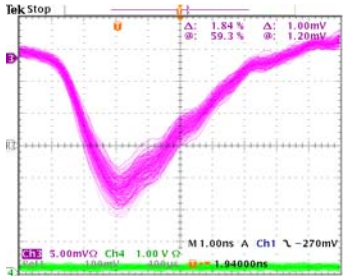
Test beam setup: 2 SiPms with preamps, trigger counters, micro channel plate PMT downstream inside of Faraday cage box.



Mike Albrow, TOF counters at SiDet, prototype of the TOF for FP420, CERN

500 MHz TEK, 1ns, 40 ns – raw signals, 1 ns – differ. Signals and 9327 out

HAM-100U-10

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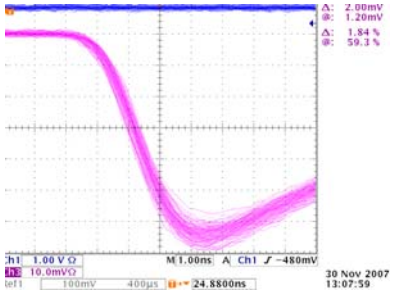
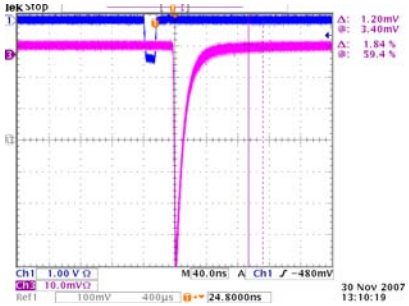
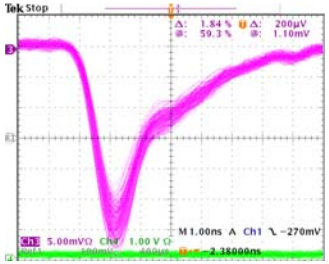
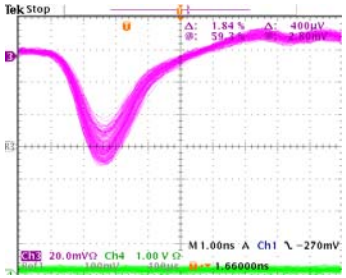
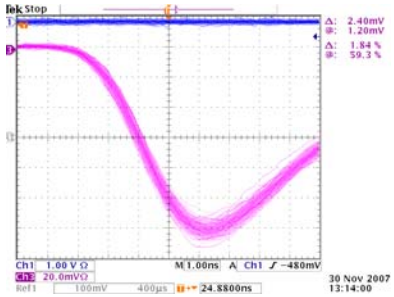
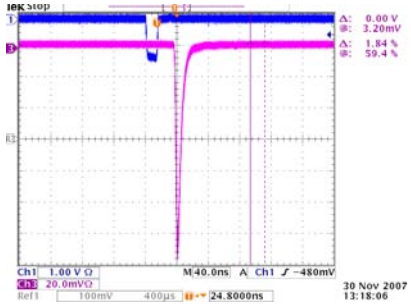
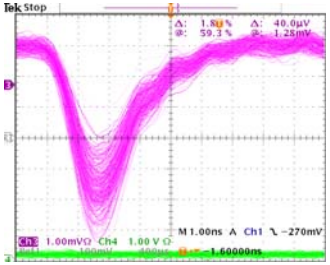
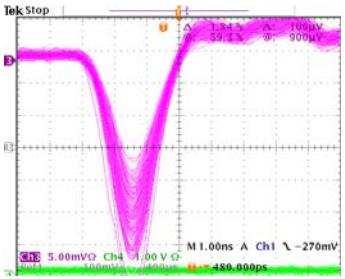
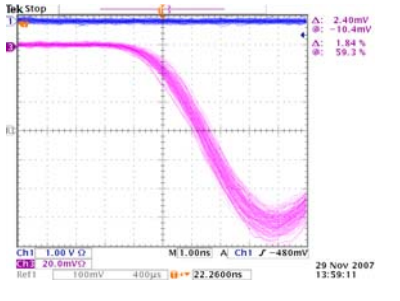
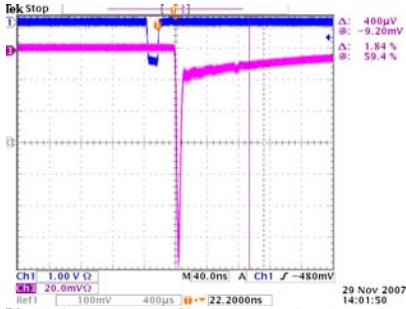
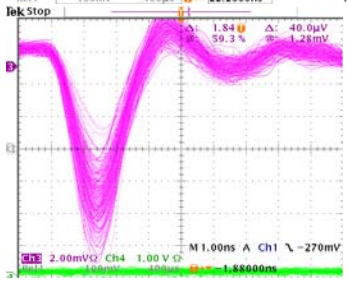
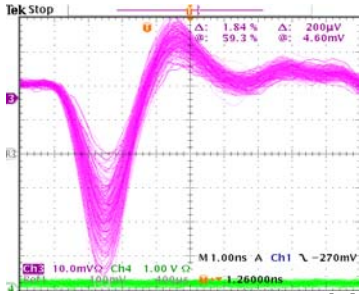





HAM-025U-10

MRS

One of the schematics to clip SiPm signal

SiPm's schematics

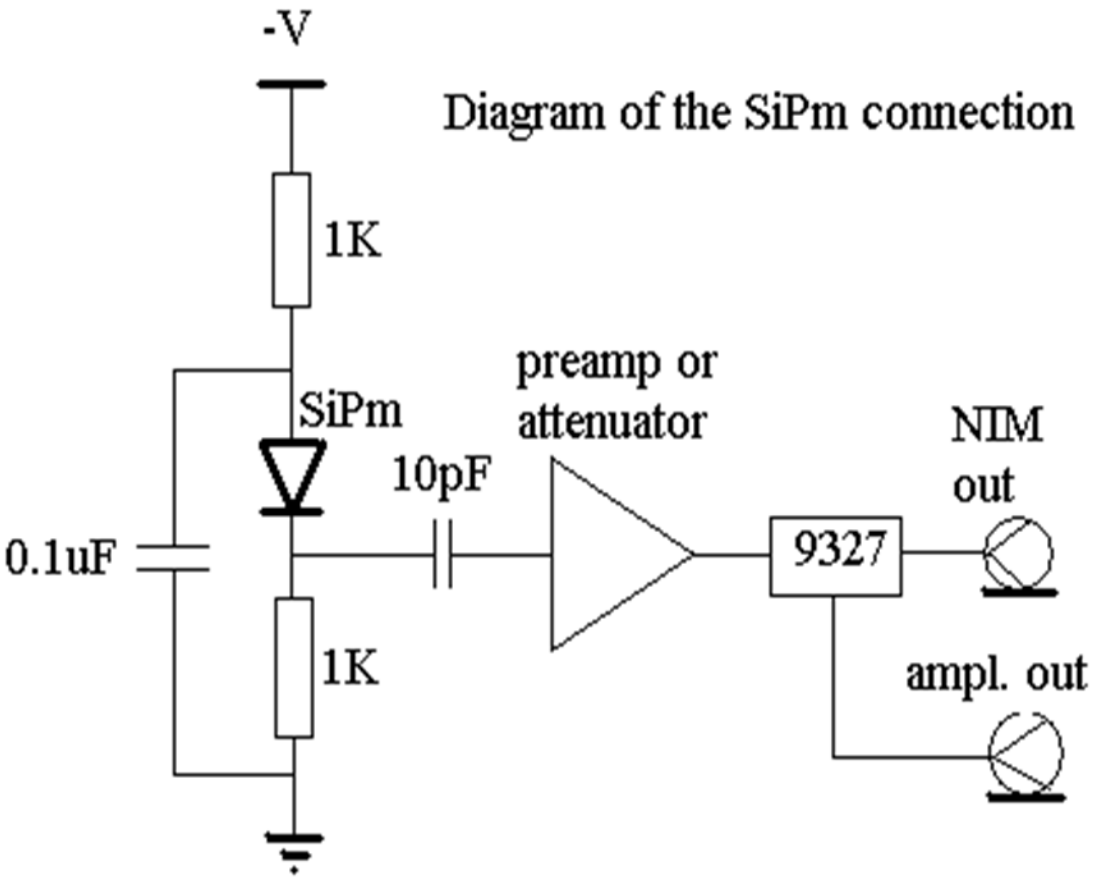
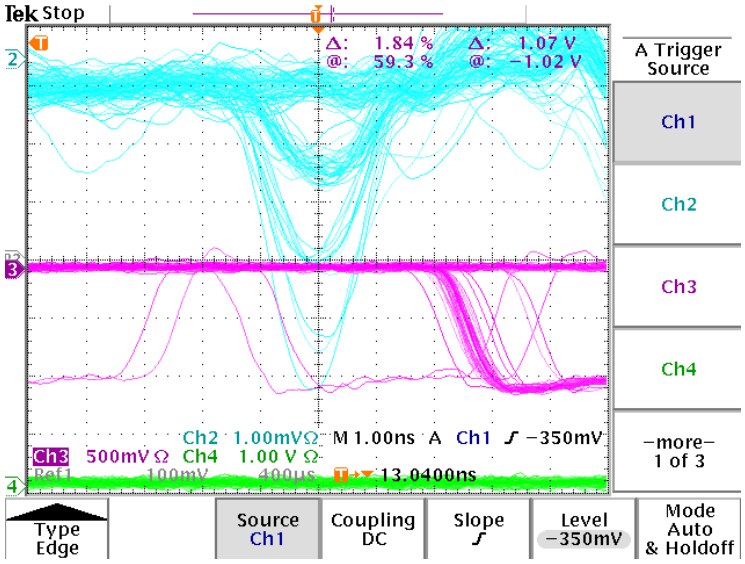
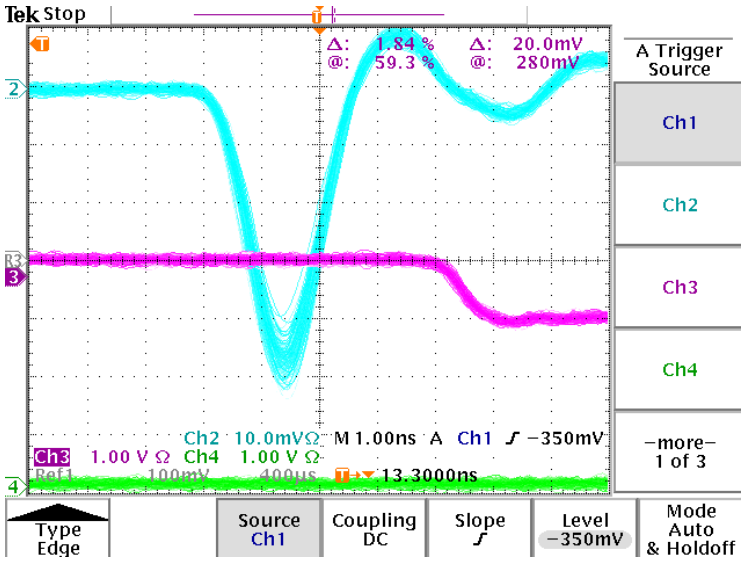
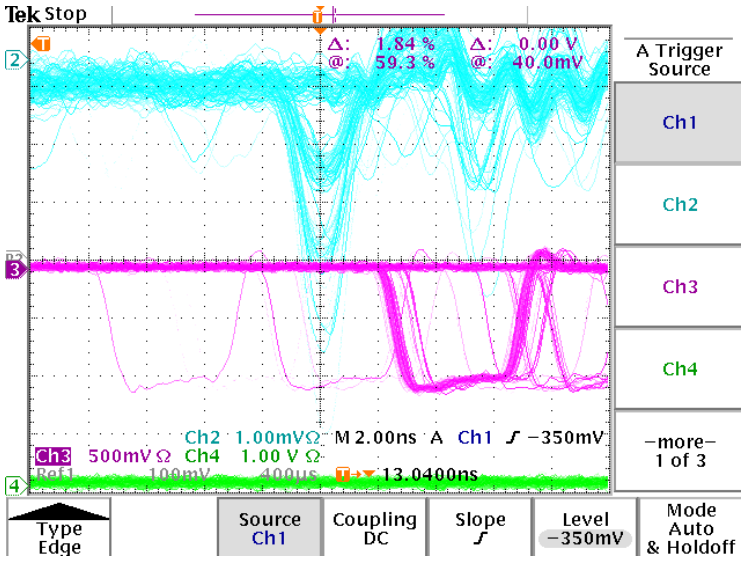


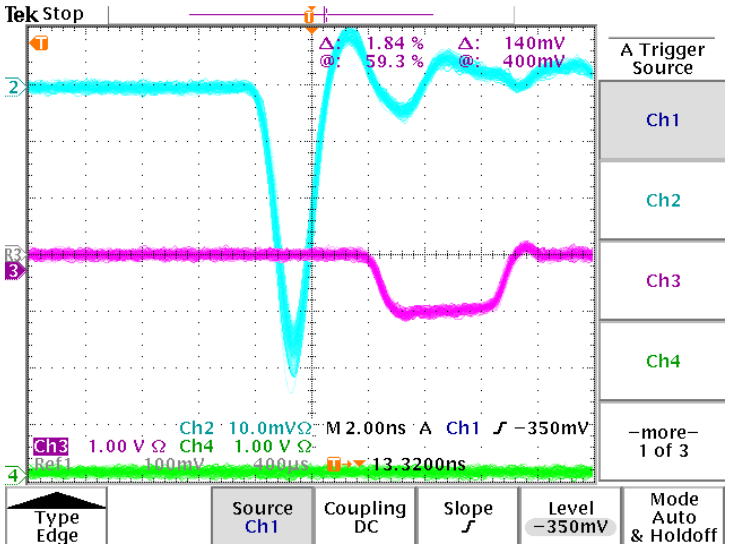
Fig. 5

IRST, 1x1mm2, differential SiPm out.

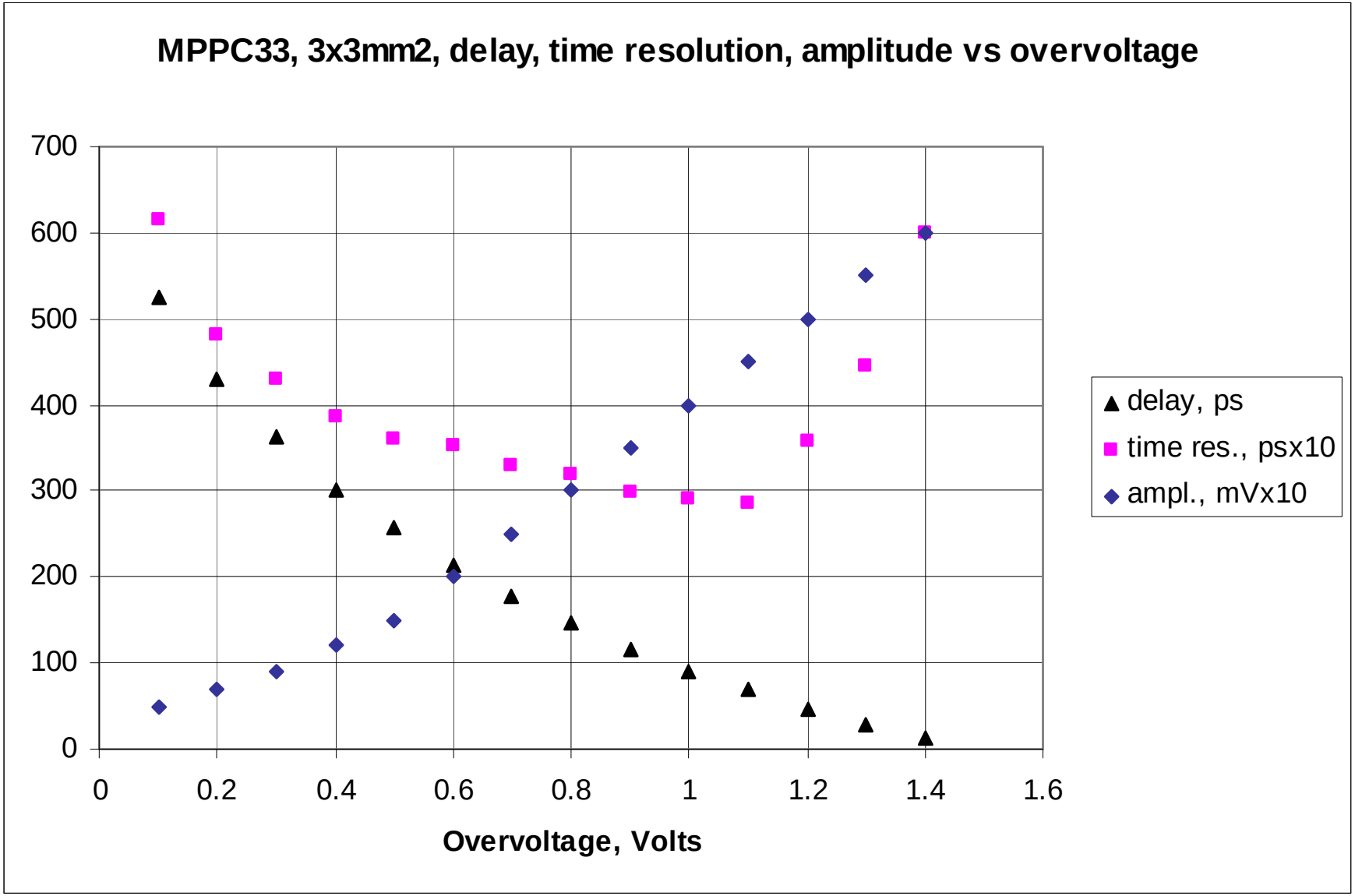




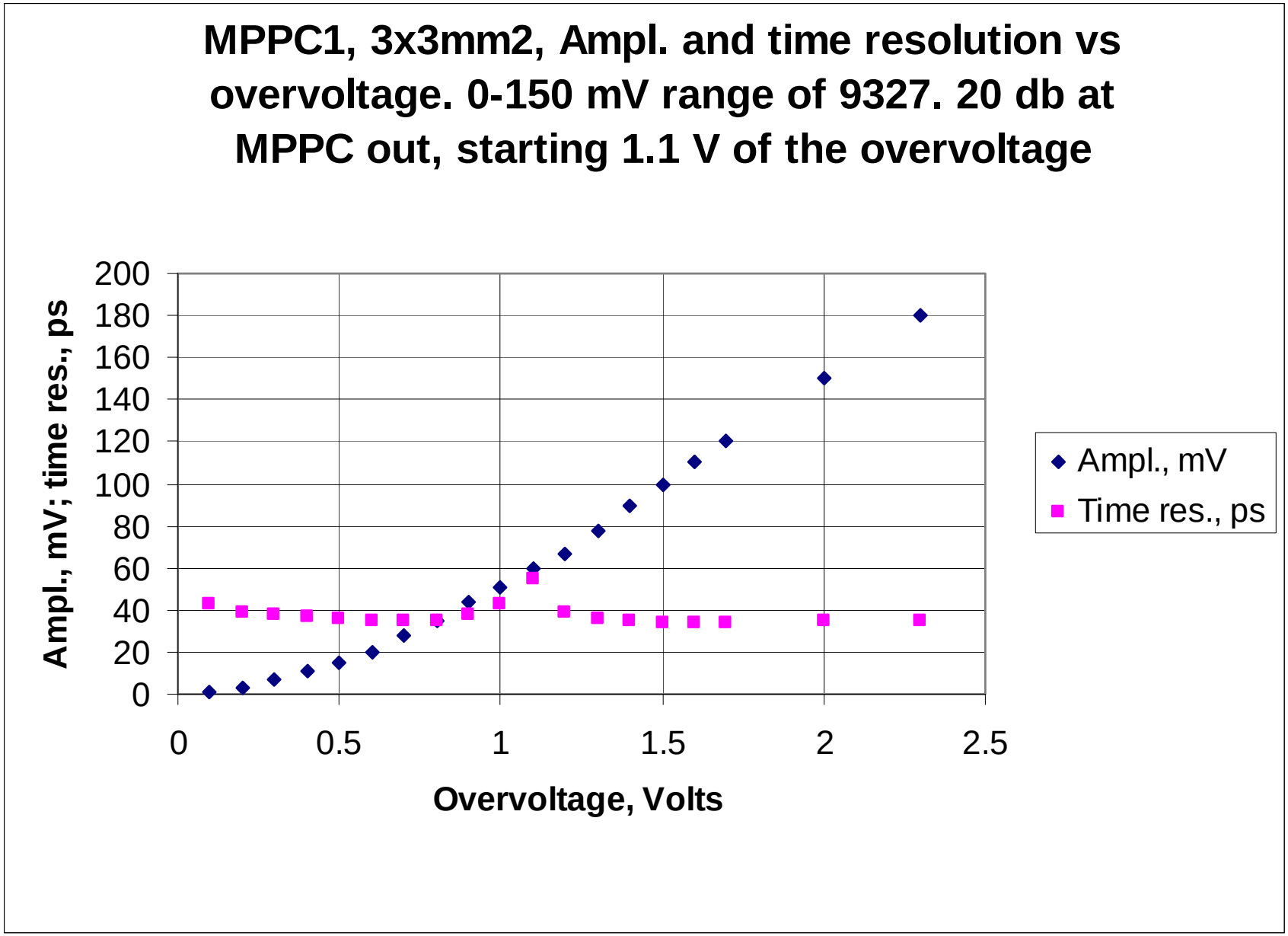




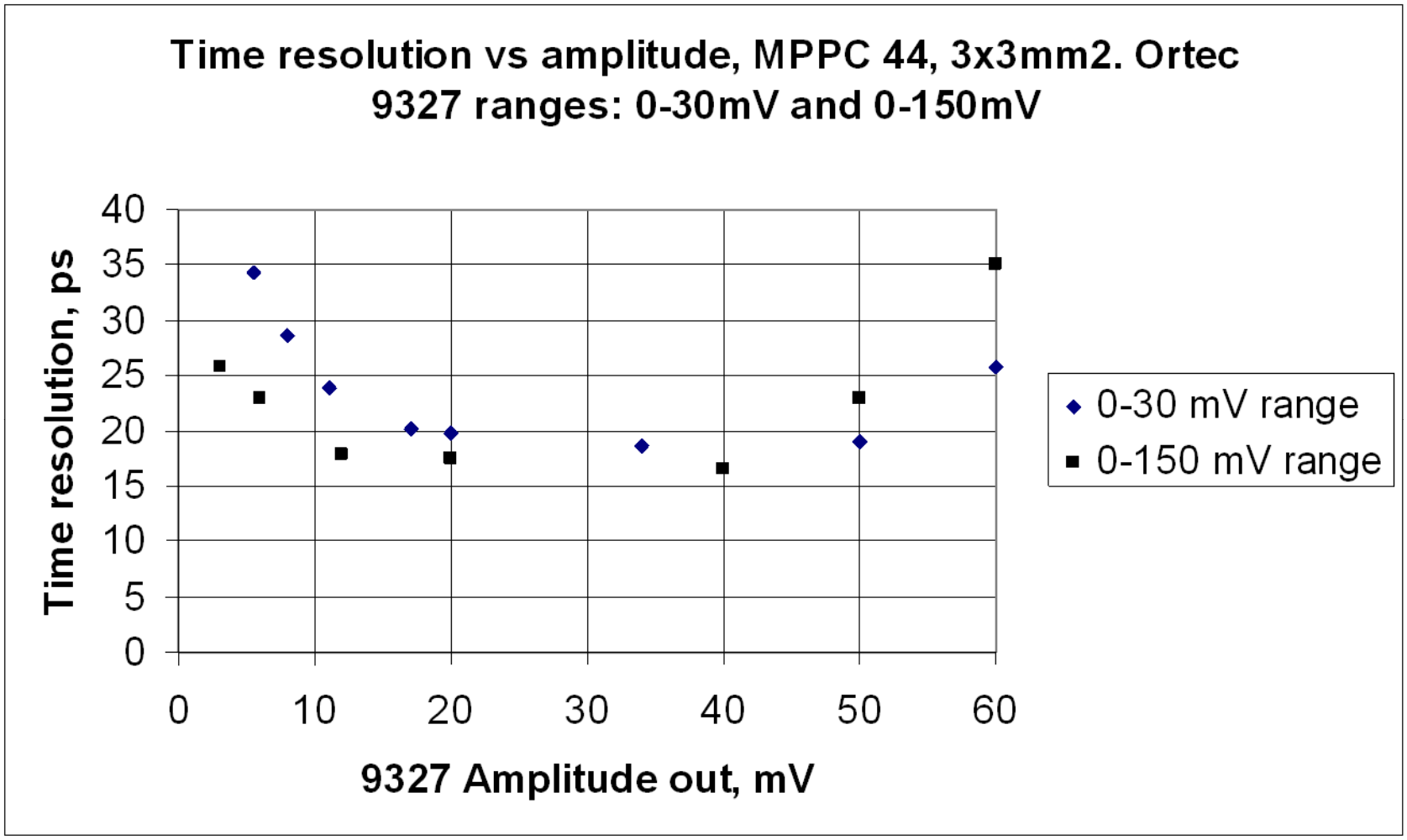
MPPC33, 3x3mm2, 0-30 mV range of 9327



MPPC1, 3x3mm2, 0-150 mV range of 9327 Ortec

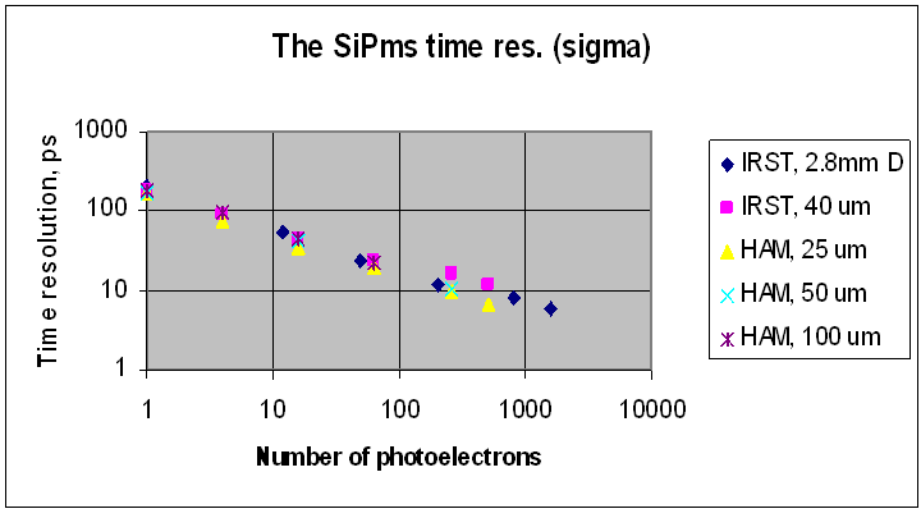


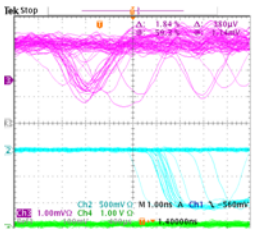
MPPC 44, 3x3mm2, signal changed by attenuator



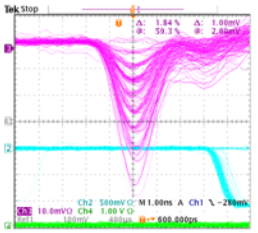
Dependence of the time resolution on the number of the photoelectrons, 1 Volt of the overvoltage, PiLas red light head (635 nm), clipping, 9327

Dependence of the SPTR on number of photoelectrons

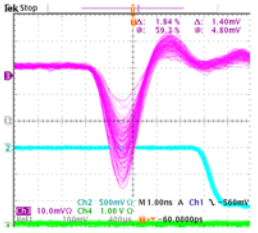




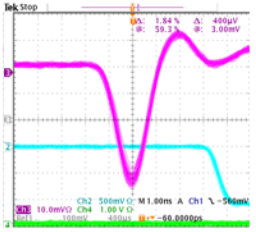
1 phe



4 phes



32 phes



256 phes

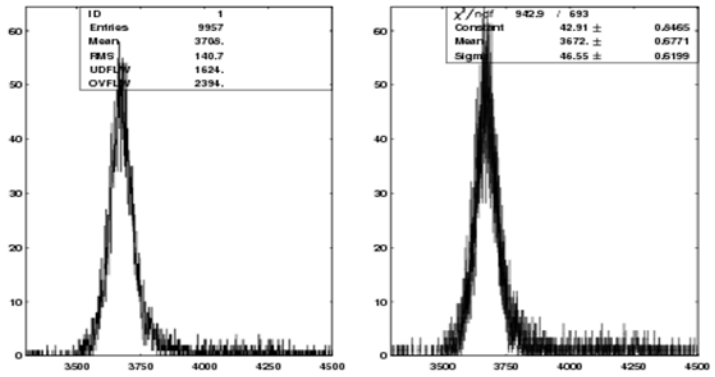
N phes	IRST 2.8 diam	IRST1mm2	HAM-025U-10	HAM-050U-9	HAM-100U-10
	50mk, 2500 pixs	40mk, 625 pixs	25mk, 1600 pixs	50mk, 400 pixs	100mk, 100 pixs
1	210	178	164.6	171.4	182.2
3					
4		89	72.3		93.3
12	53.7				
16		44.6	35.1	42.5	45.8
50	24.2				
64		23.6	19.5	22	22.7
200	12				
256		16.1	9.9	10.2	
512		11.9	6.8		
800	7.9				
1600	5.9				

Fig. 6

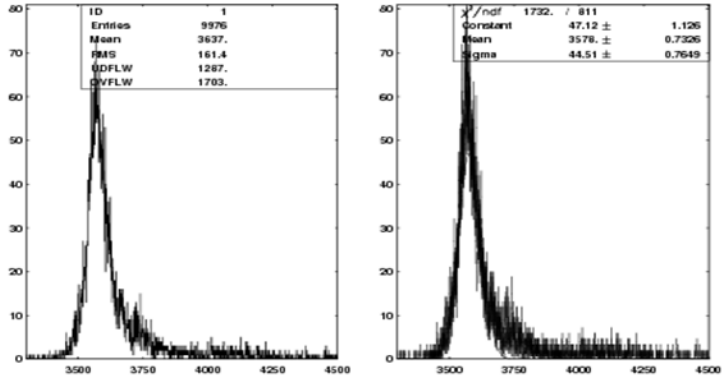
Typical SPTR spectra, PiLas, 635 nm

Hamamatsu, sample 41, 0.5 and 1.5 phes. thresh.

hamv1_1pe0db692.out



hamv1_1pe0db697.out



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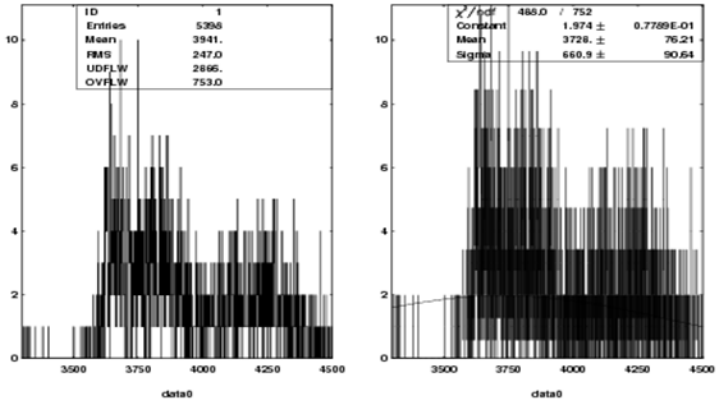

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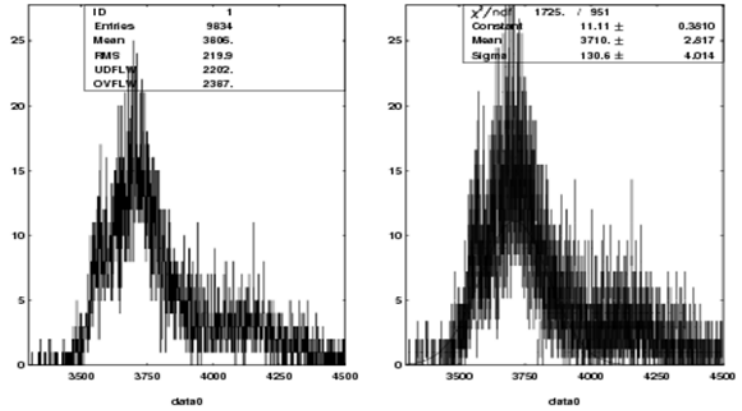


Fig. 7

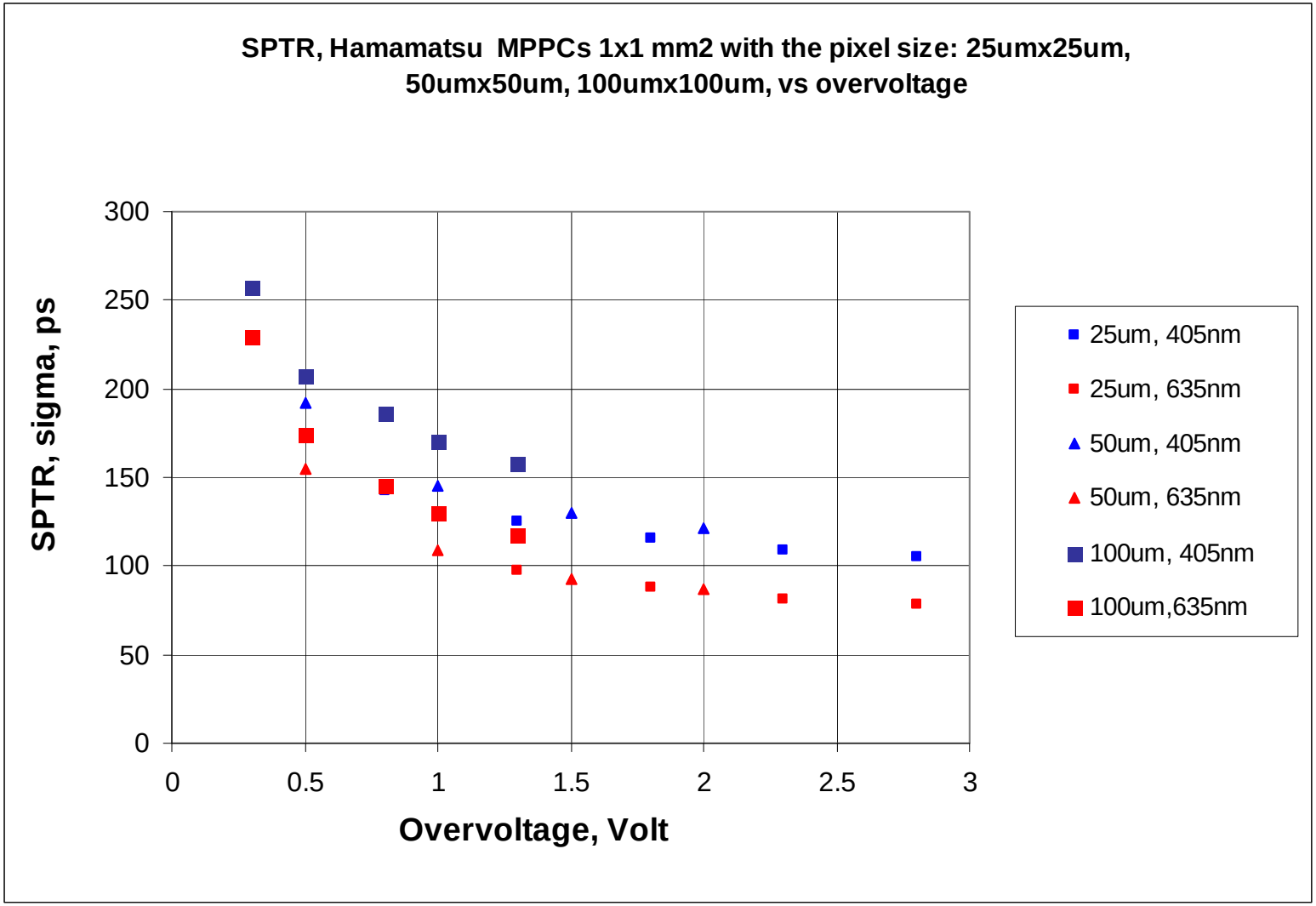
Slide 12

Results of the preliminary tests

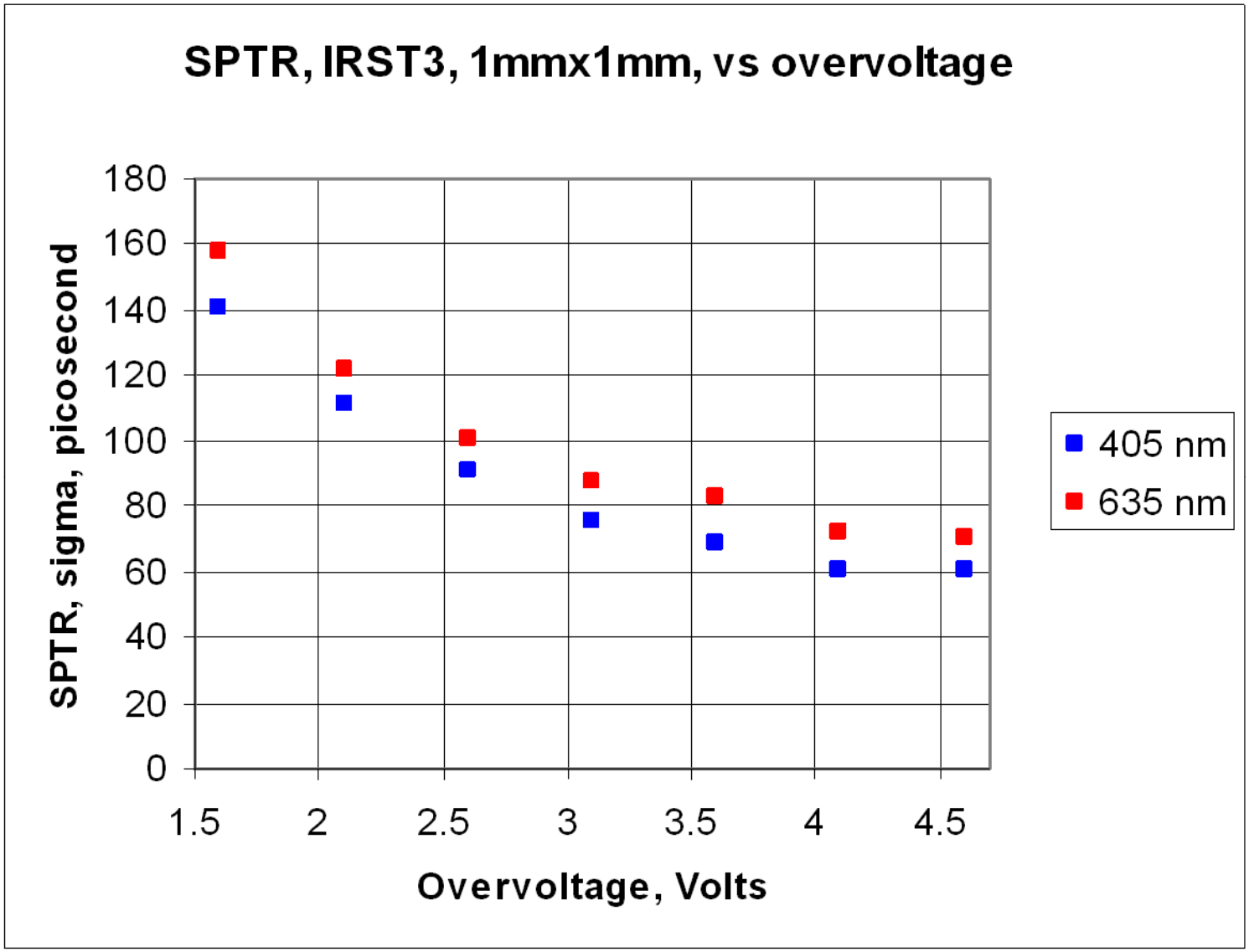
Few SiPms properties were observed during the test.

- **The single photoelectron time resolution (SPTR) depends on:**
  1. applied overvoltage. SPTR improved with overvoltage increase.
  2. used set of parameters of the 9327 CFD. (Optimal dynamic range is only 15-45 mV)
  3. used clipping schematics
  4. wavelength of the PiLas light.
- **Weak SPTR dependence on temperature observed in the range -20 +20 degrees C.**
- **Inverse square root dependence of the time resolution vs amount of the photoelectrons was clearly observed.**
- **For some SiPms SPTR spectra has bump/tail which is likely due to optical crosstalk.**

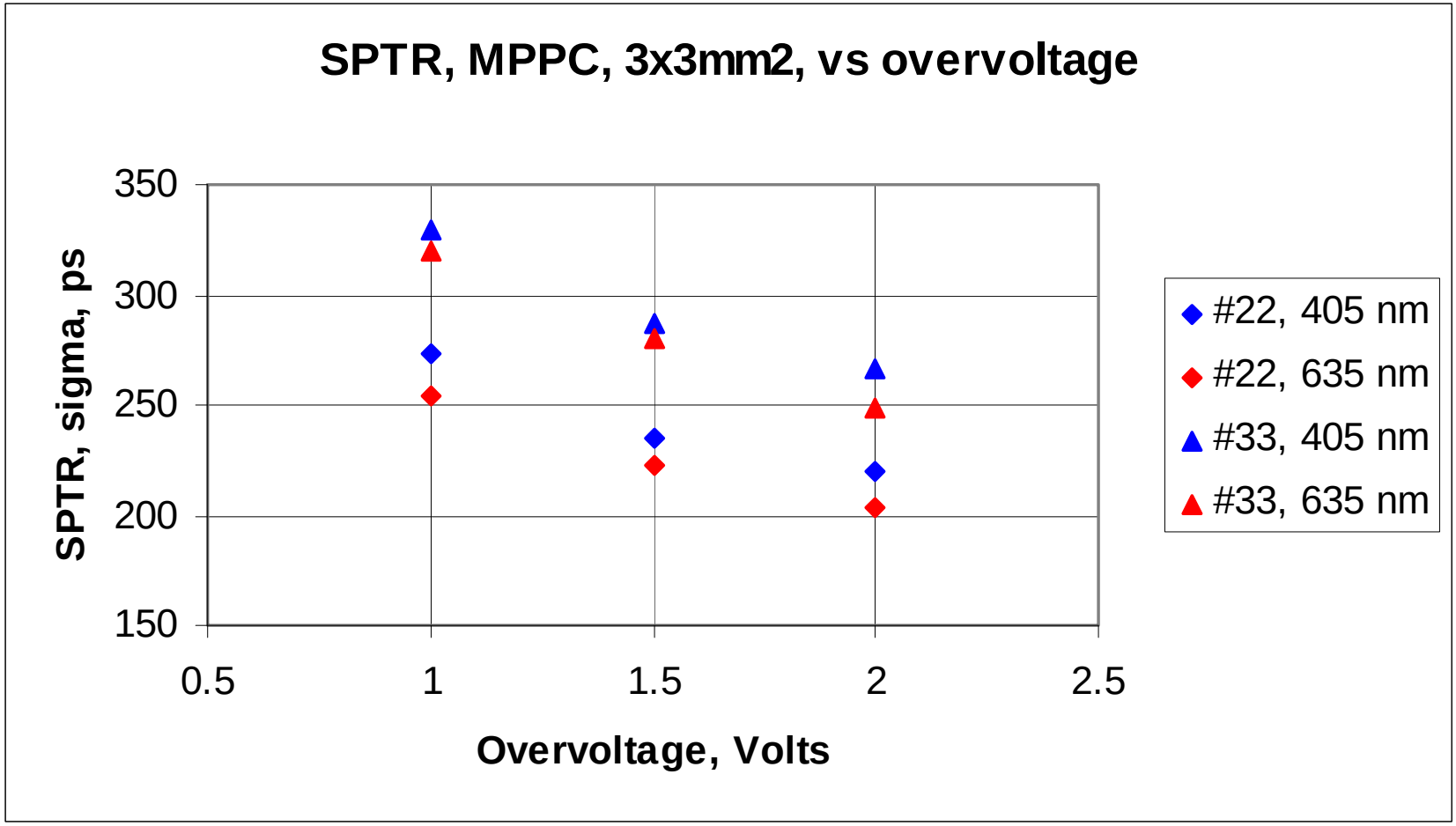
SPTR of Hamamatsu MPPCs, 1x1mm2, 405 nm and 635 nm



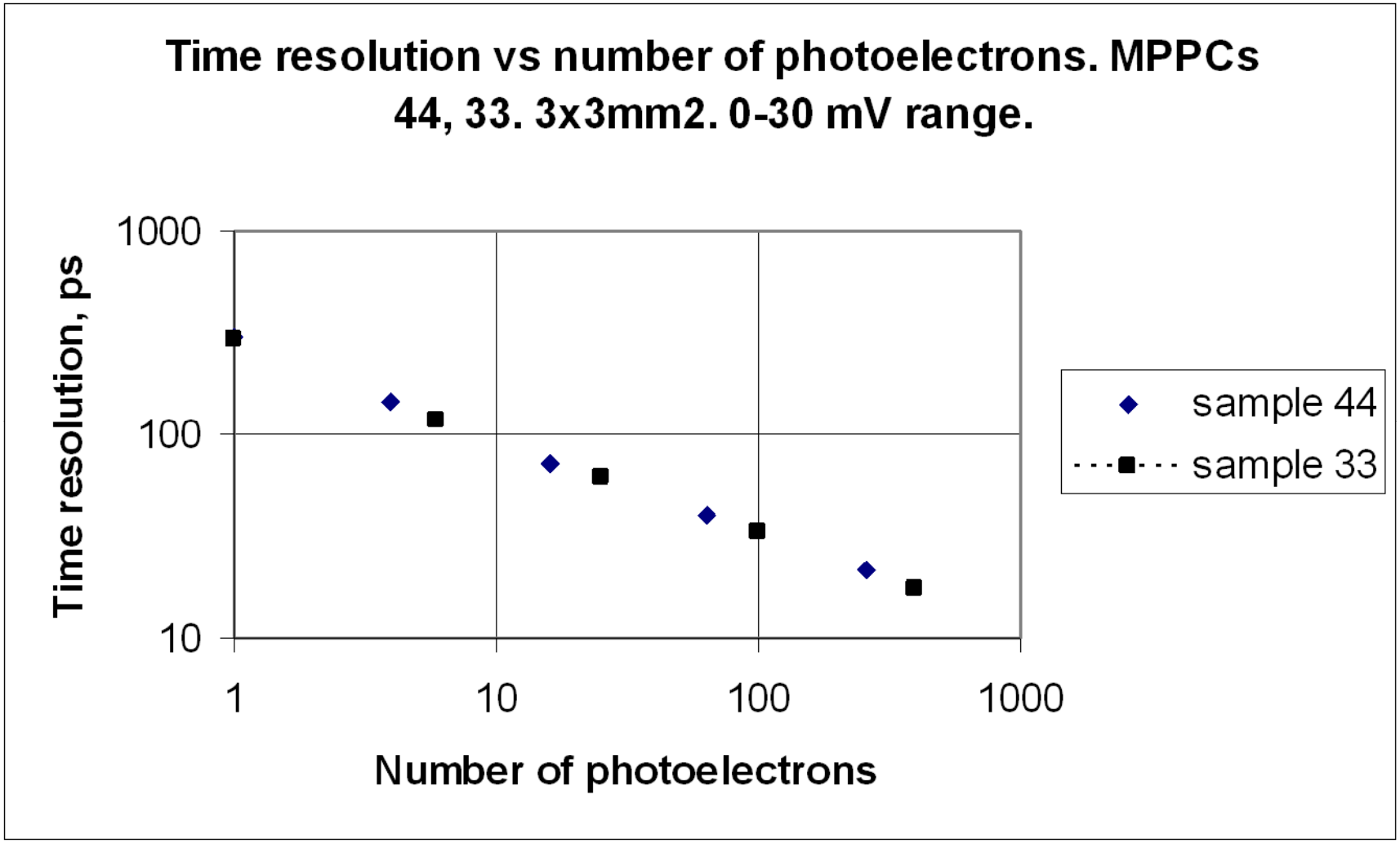
SPTR of IRST, 1x1mm2, 405 nm and 635 nm



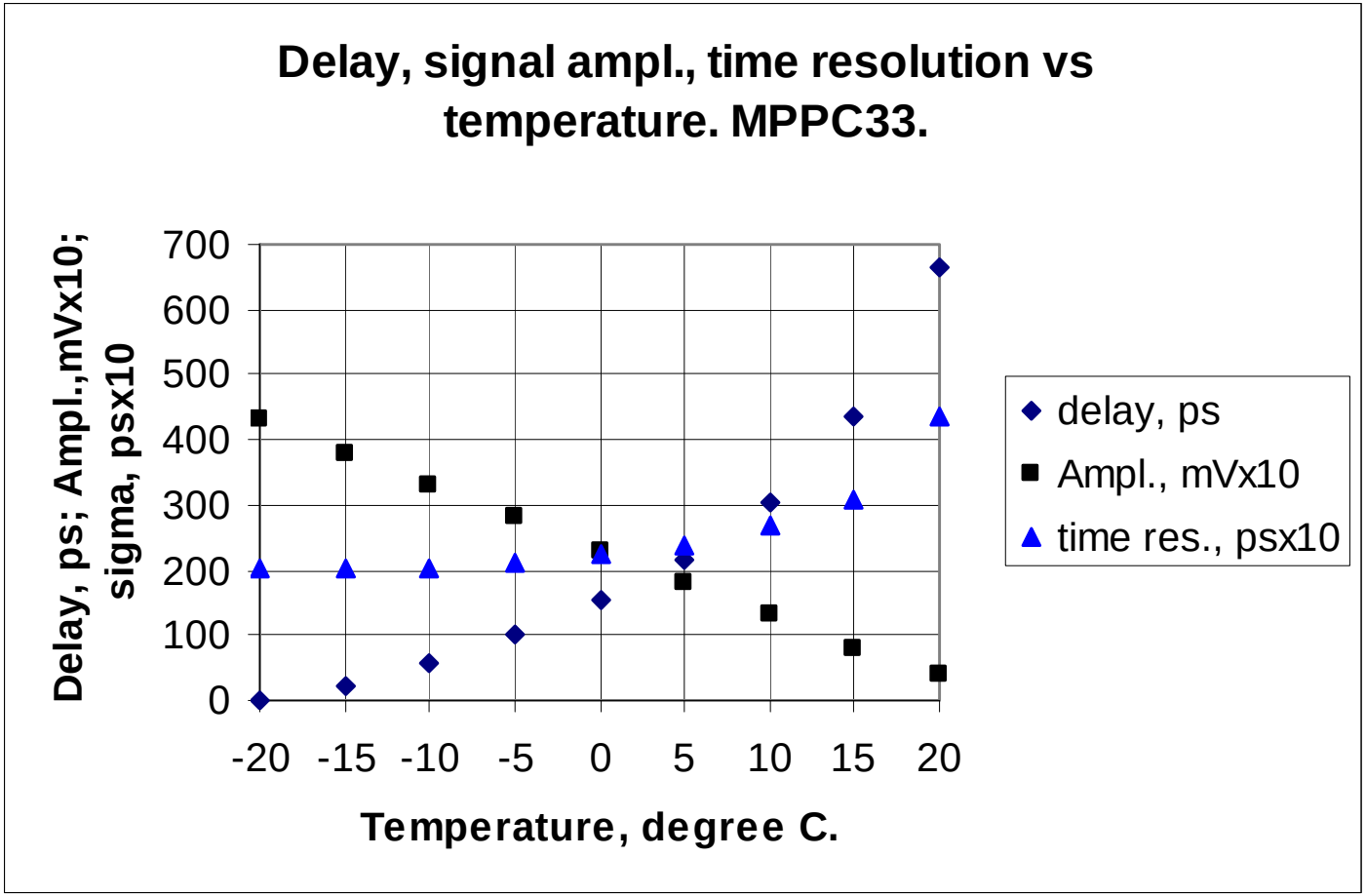
SPTR, MPPCs, 3x3mm2, 405 nm and 635 nm



MPPCs, 3x3mm2, 405 nm



MPPC33, temperature effects



Note: worsen of the time resolution is due to the overvoltage decrease with the temperature (1C of the temperature increase corresponds about 0.05 V of the overvoltage decrease).

Light absorption in Silicon*

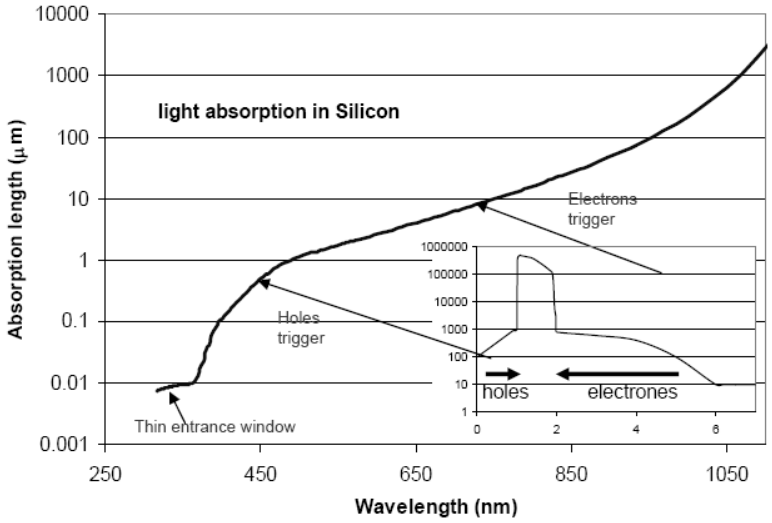


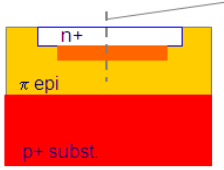
FIGURE 4. Light absorption in Silicon. The insert indicates the field configuration in a SiPM (see Fig. 1) and the drift direction of electrons and holes.

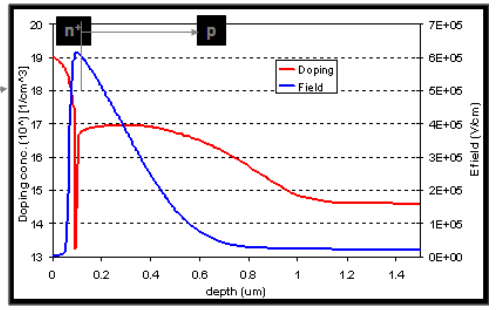
IRST technology

We developed 2 technologies. In this talk only one is reported.
(the first production of the second technology is in its final stages)

[C. Piemonte "A new Silicon Photomultiplier structure for blue light detection" in press on NIMA (see ScienceDirect)]

Shallow-Junction SiPM





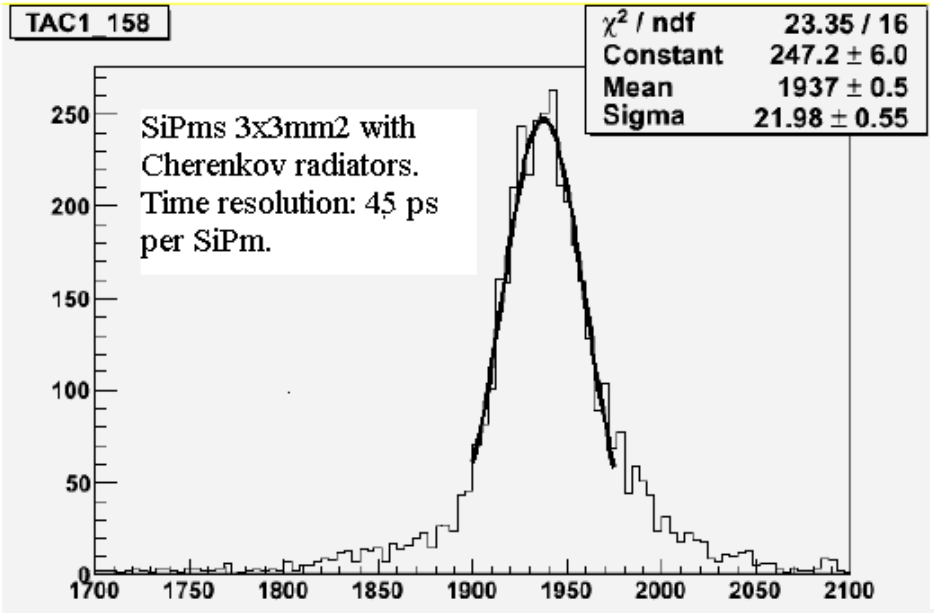
1) Substrate: p-type epitaxial
2) Very thin n+ layer
3) Quenching resistance made of doped polysilicon
4) Anti-reflective coating optimized for λ~420nm

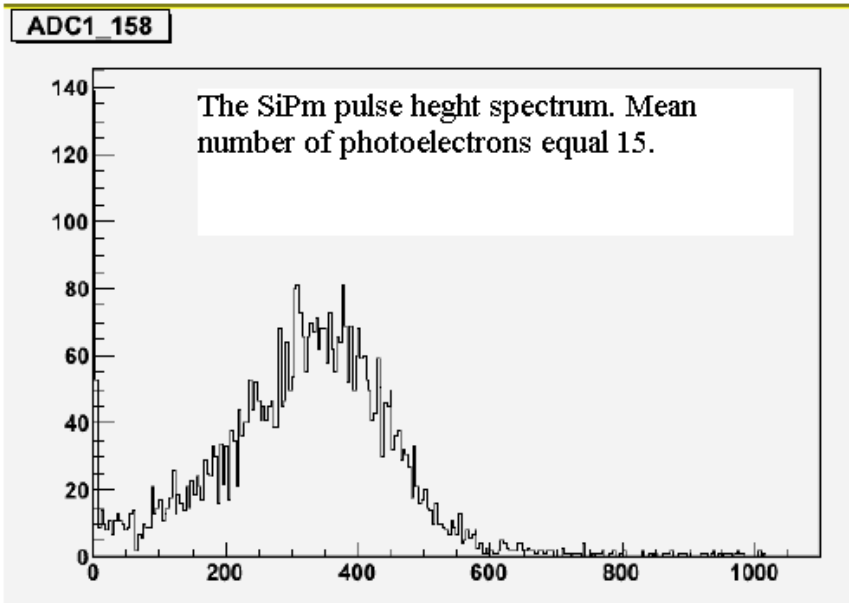
If p+ side of a silicon photomultiplier faced to the illuminating light (MPPC case) the carriers will be mostly electrons for the 405 nm light and holes for the 635 nm due to different absorption length of the light into silicon. This could make difference in the single photoelectron time resolution (SPTR) for the blue and red light . Experimentally some difference observed for the MPPCs.

If n+ side of the silicon photomultiplier faced to the light the carriers will be mostly holes for the blue (405 nm) light and electrons for the red (635 nm) one. Because the corresponding absorption lengths are 100 nm and 4000 nm. This is the case of the IRST (Italy) SiPms (see top right corner of the slide). The SPTR difference for the 405 nm and 635 nm experimentally observed.

Test beam results with MPPCs, 3x3 mm2

- The beam data (120 GeV protons) obtained for two identical TOF counter. The distance between counters is about 50 mm. Each counter consists of Hamamatsu MPPC with 3x3 mm2 of the sensitive area and with Cherenkov quartz radiator, 3x3 mm2 of the transverse size. The radiator is optically coupled with the MPPC by optical grease. The “effective thickness” of the radiator along the beam is 1.5 mm. The obtained time resolution is 48 ps/single counter. As the result of the postmortem study of the TOF counters was found that we can improve the obtained time resolution.





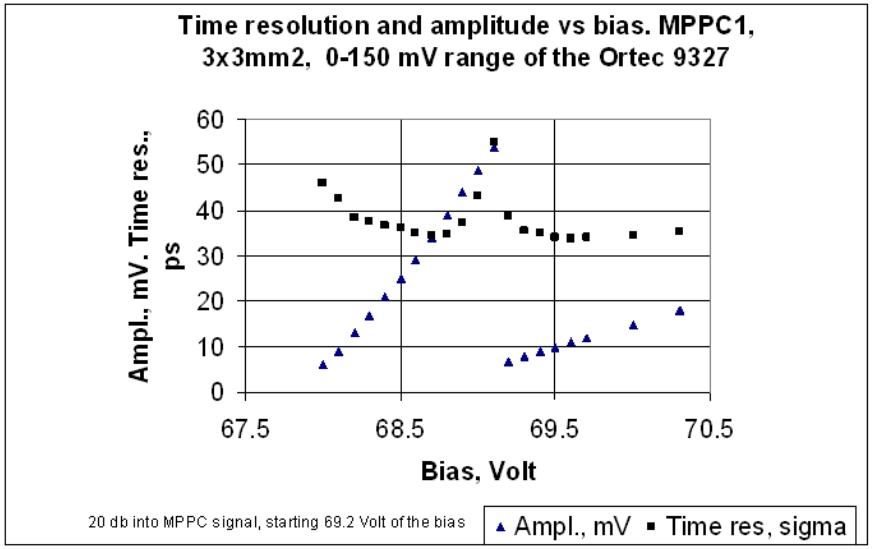
Results, what we need

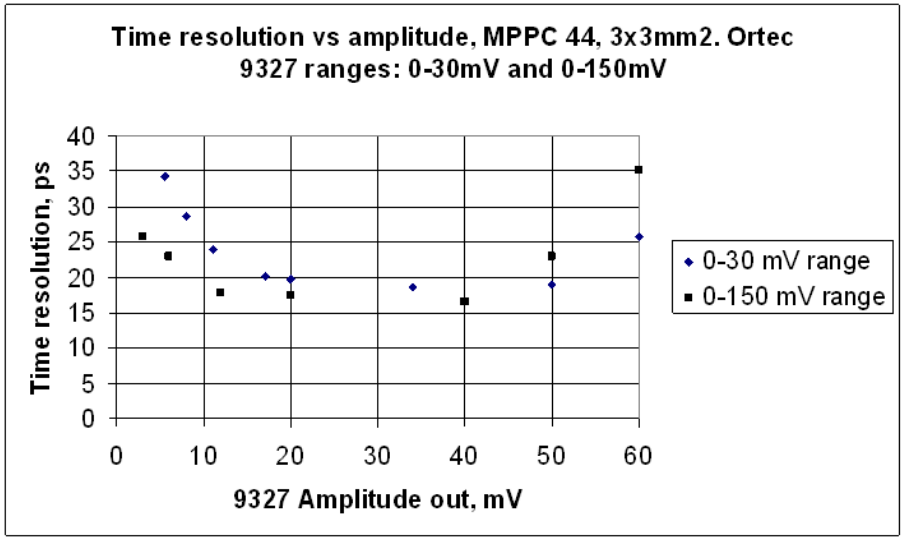
- The new setups were arranged at SiDet and MT to study SiPms time resolution at the picosecond level. The part of the system is PiLas laser. The TAC 567 + AD114 Ortec units show up 2 picosecond (rms) of the “electrical” time resolution.
- We have explored timing properties of the different type of SiPms with different type of front end electronics. The best results obtained with Ortec 9327 CFD. The used readout looks like optimal with our current stage of the SiPm’s time properties understanding.
- We performed the study of the time of flight (TOF) system based on Hamamatsu MPPCs with Cherenkov radiators (3x3 mm2 of the transverse size) with 120 GeV proton beam. The obtained time resolution is 48 ps/single counter The test beam data are in good agreement with PiLas data (405 nm).
- The next step is to complete MT TOF with about 50x50 mm2 of transverse size and time resolution of 30 ps of the time resolution. All needed resources are already allocated.

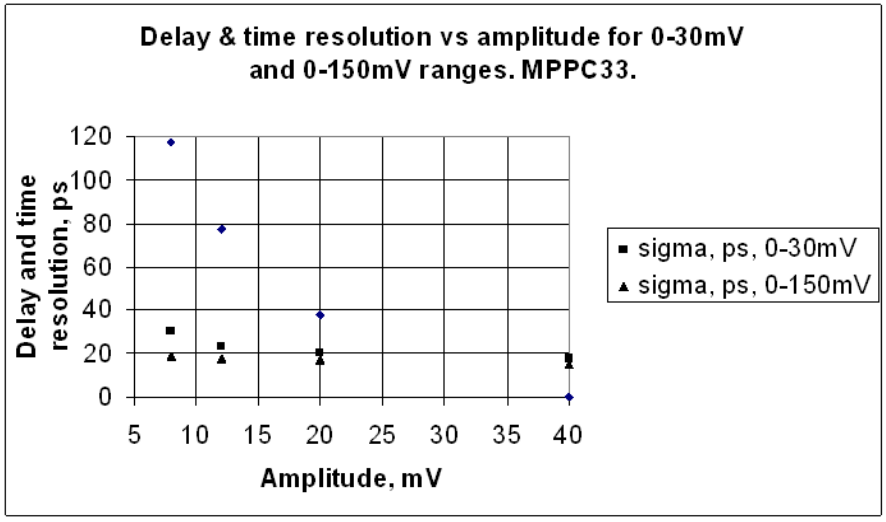
Below is appendix

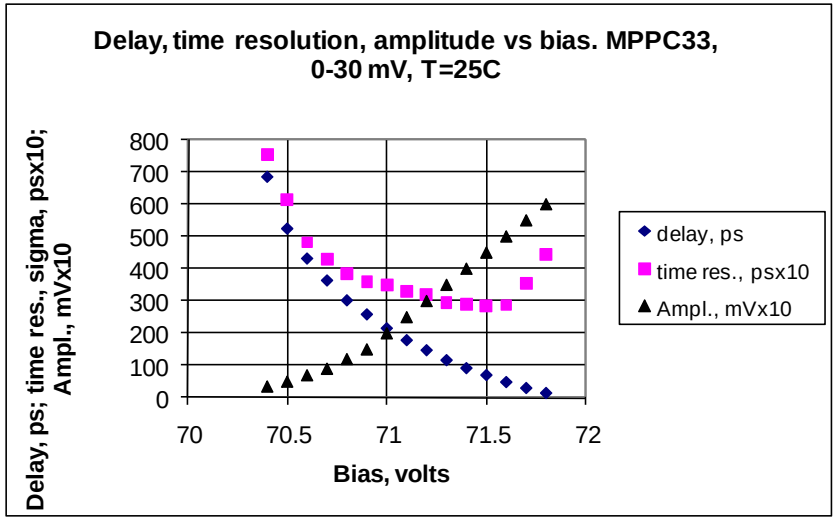
- **APPENDIX is below**

Time resolutions and delays of the 9327 in dependence on MPPC's amplitude

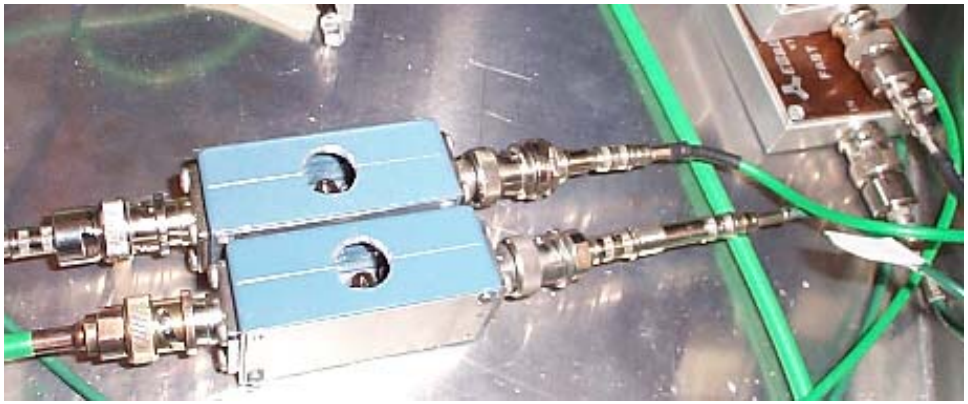




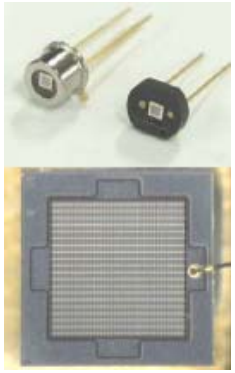




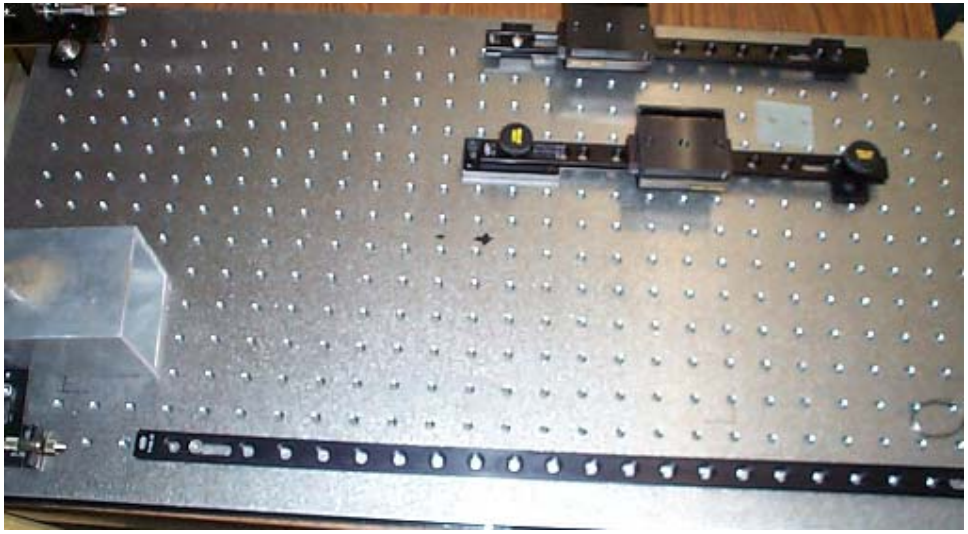
Parts of new TOF setup at SiDet



The SiPms for testing



Constant impedance trombone picosecond line

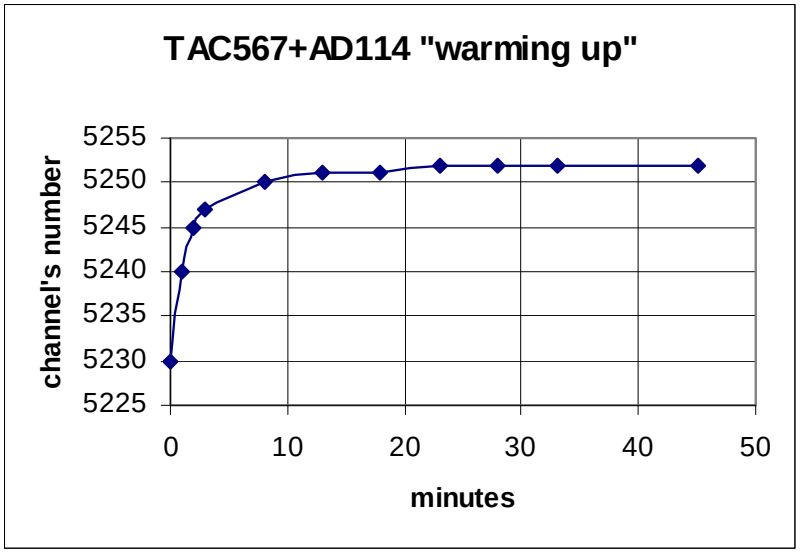


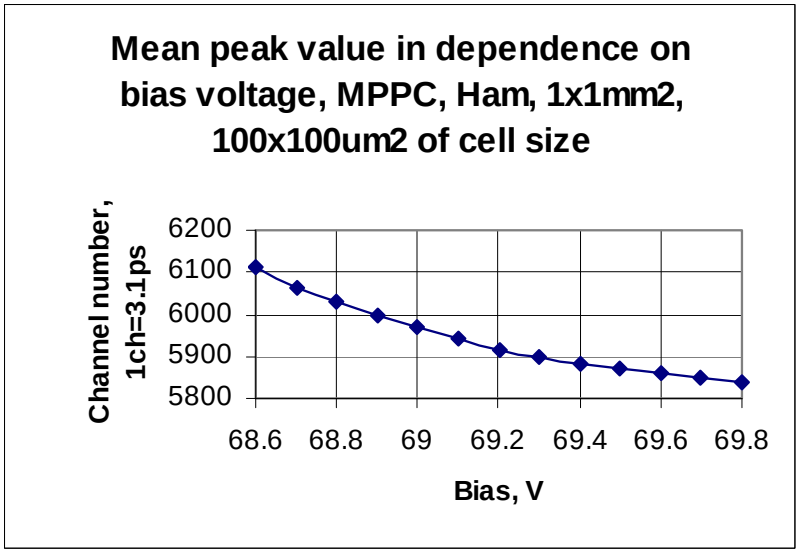
Parts of new movable table for SiPms timing test at SiDet

AD114+TAC567 (3 ps/ch),

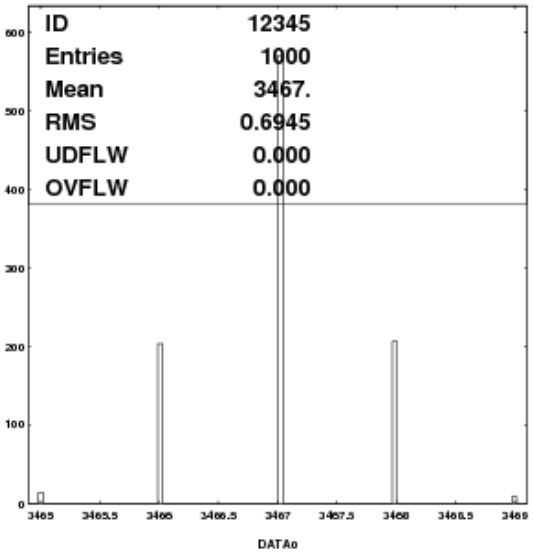
borrowed PiLas (40 ps light pulse), different SiPms in hands

TAC567+AD114, MPPC “warming up”, 1ch=3.1ps, temp. in the box is 73 +/- 1F

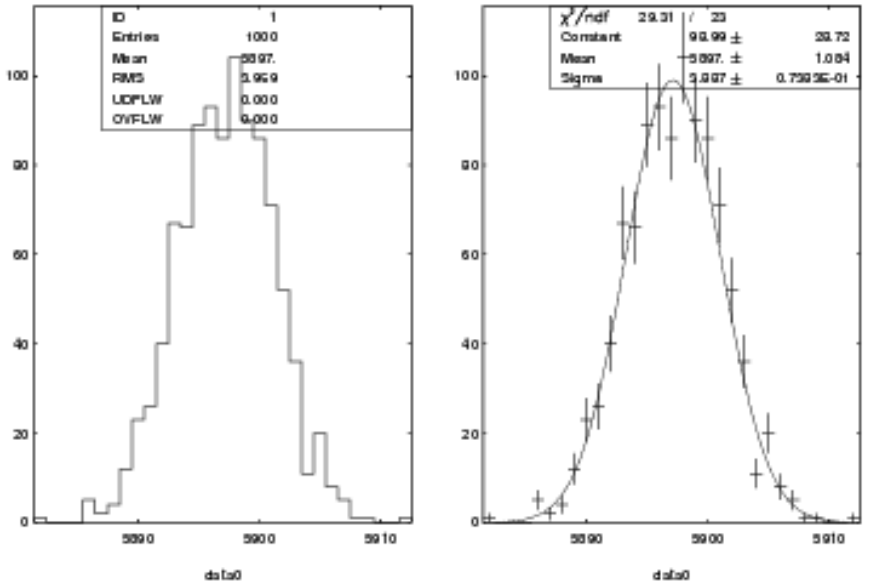




ham_plus_0ps.out



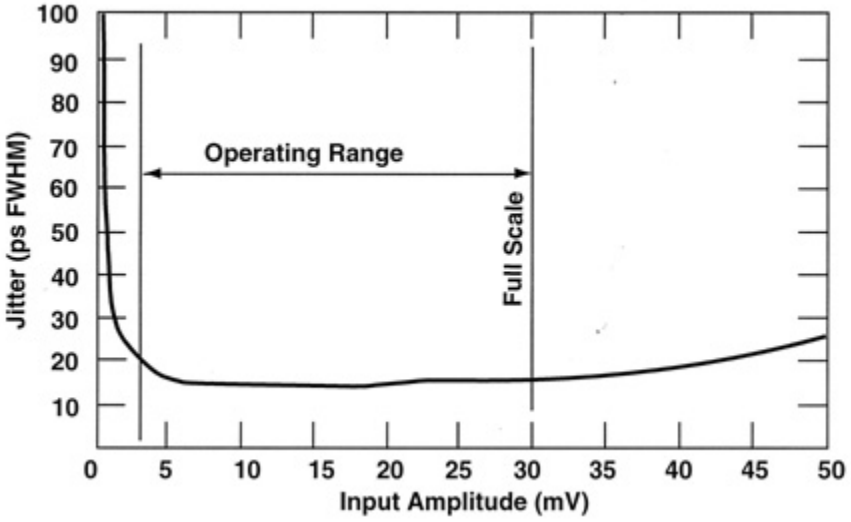
gtemp82.out

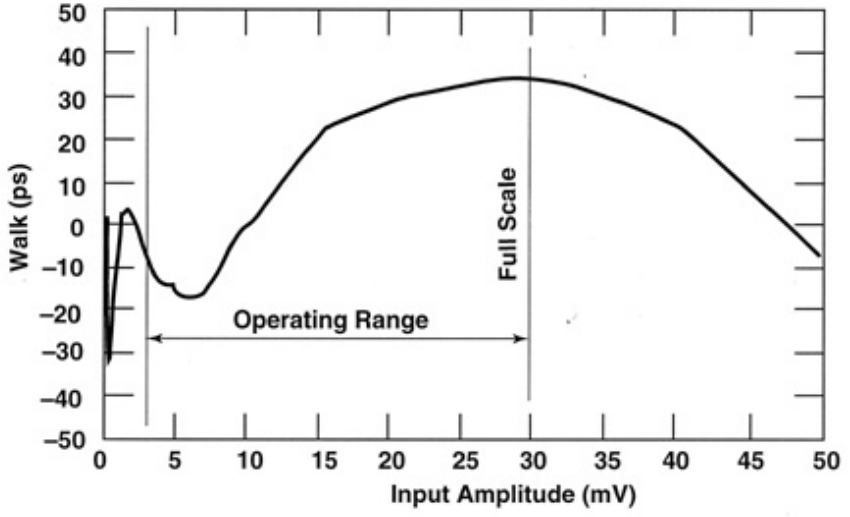


9327 requirements to input signals

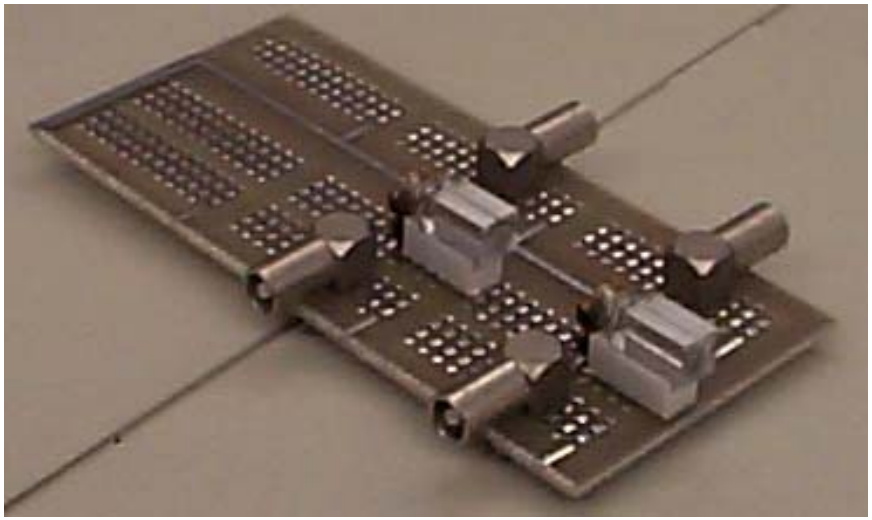
9327 1-GHz Amplifier and Timing Discriminator

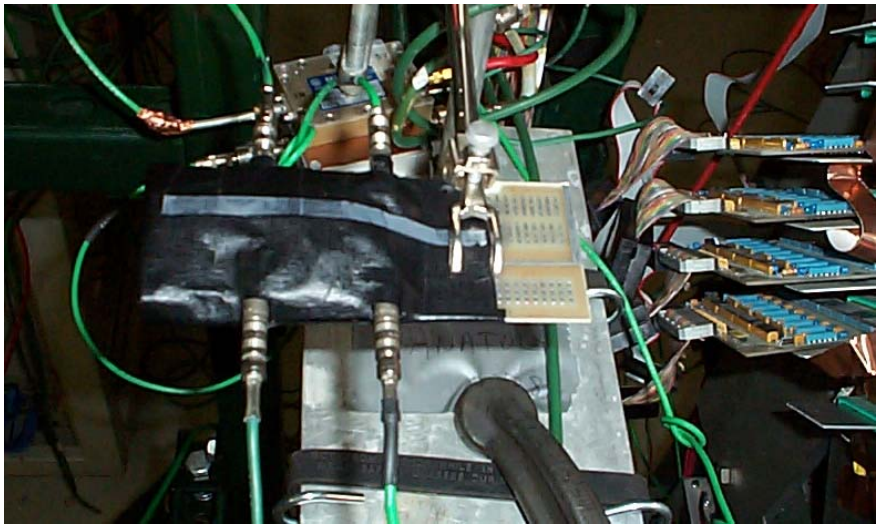
- For picosecond timing with mV signals from: Microchannel Plate Detectors
  Microchannel Plate PMTs
  Fast Photodiodes
  Fast Photomultiplier Tubes
- 1-GHz Amplifier and Timing Discriminator are internally matched for minimum walk and timing jitter
- Walk typically <±40 ps over the top 90% of full scale
- Jitter <20 ps FWHM at 50% of full scale
- Optimized for pulse widths from 250 ps to 1 ns; accepts pulse widths up to 5 ns
- Selectable input pulse height range: 0 to –30 mV, or 0 to –150 mV full scale
- 2:1 Fine Gain control
- Over-Range LED for precise gain adjustment without an oscilloscope

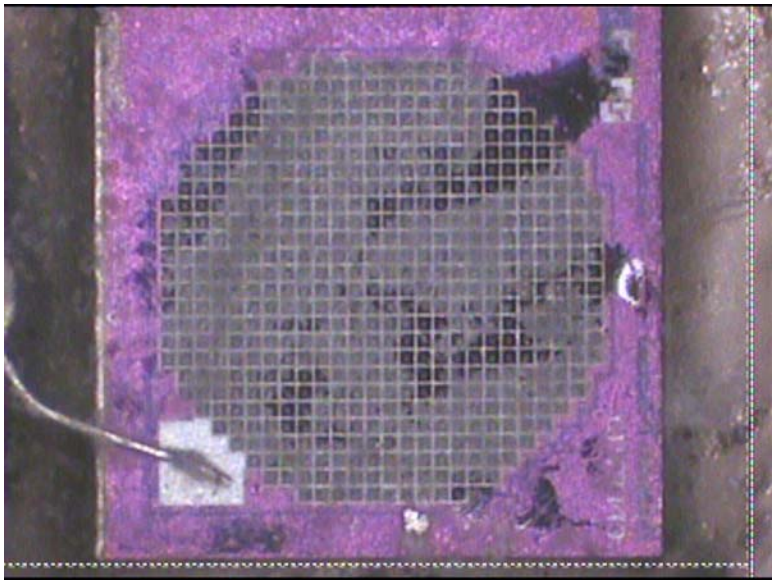


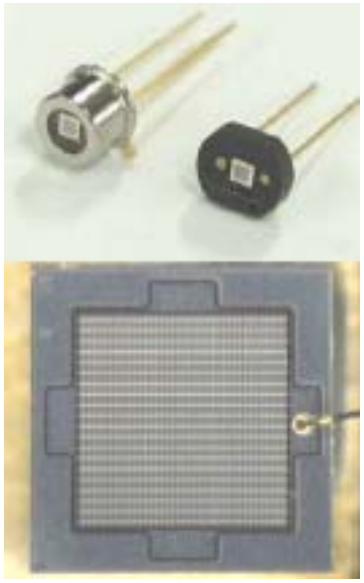


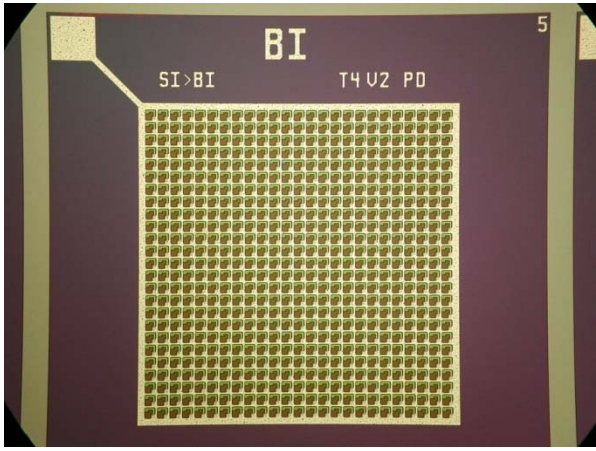
TOF, SiPms front face pictures



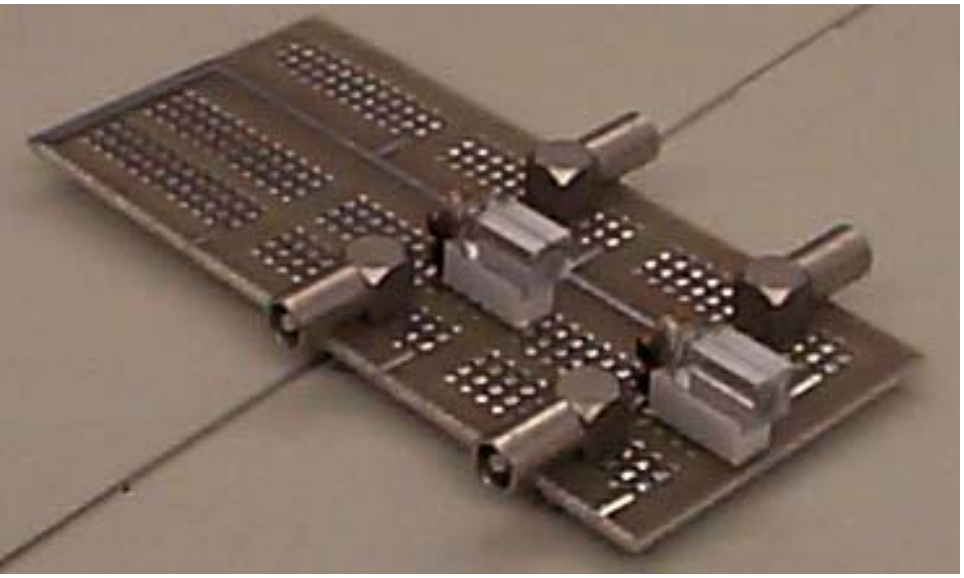


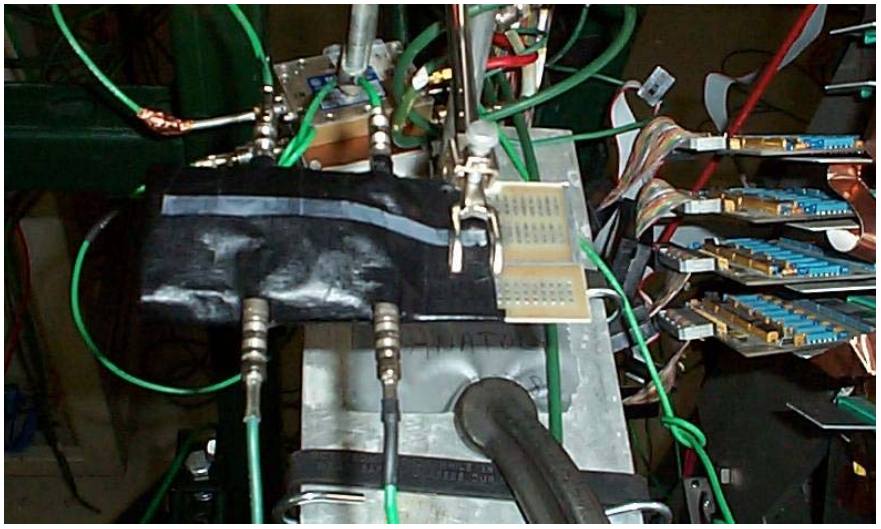


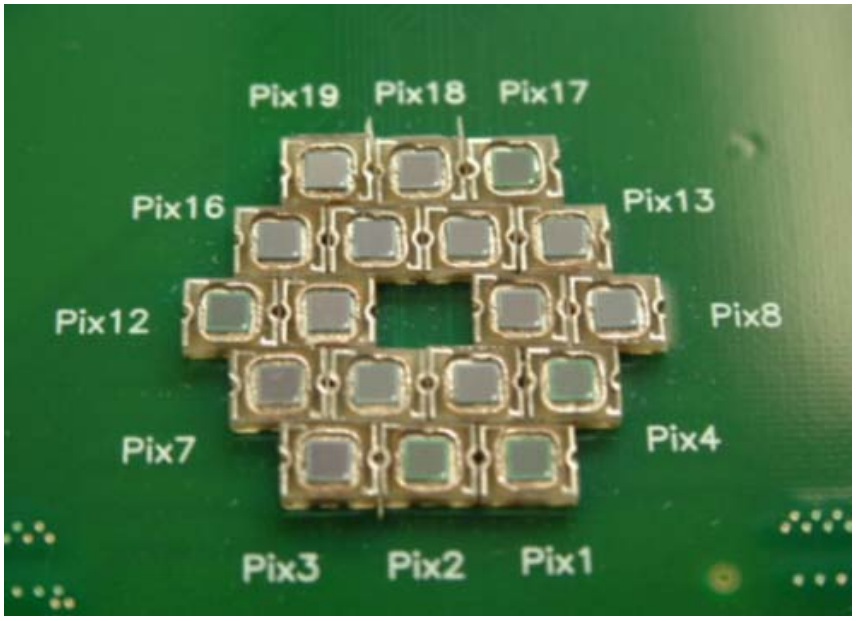


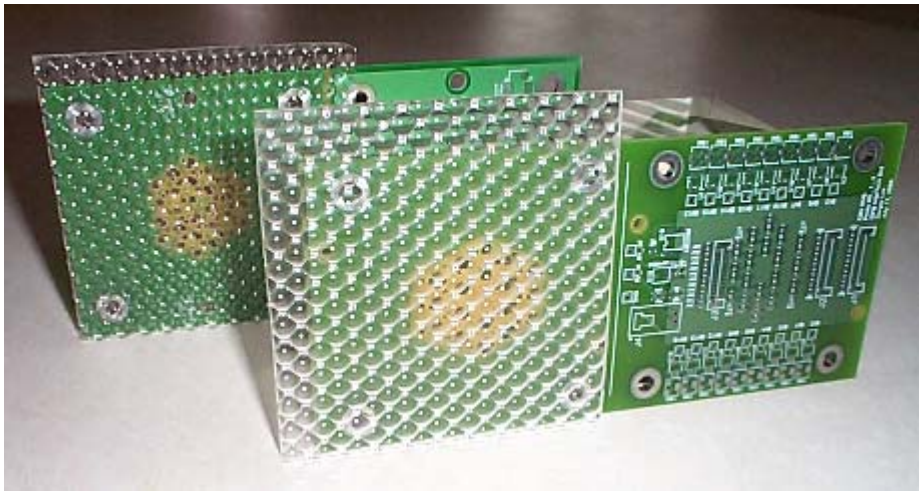


TOF SiPms tested on a beam. Samples of SiPms plane matrix, CMS HCAL (S.Los design, FNAL)









MPPC (IRST) single photoelectron time resolution vs overvoltage