Status and perspectives of IFR R&D in Ferrara

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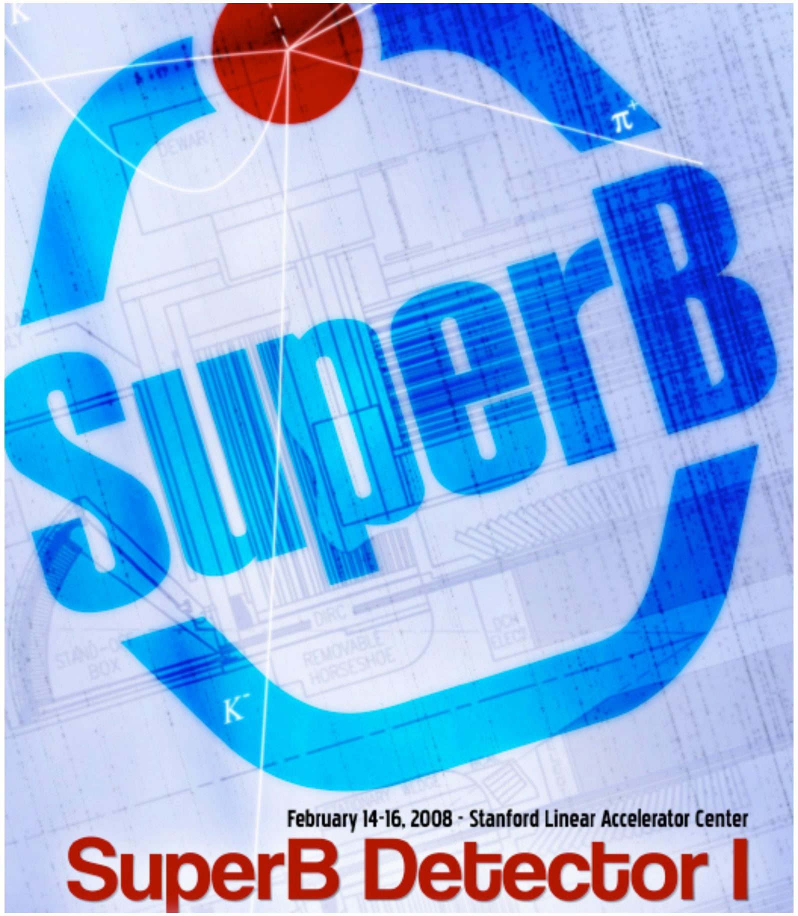
SuperB Detector R&D Workshop

SLAC Feb 14-16, 2008

Outline

- The R&D program
- The Geiger mode APDs
- What has been done so far
  - Charge distributions
  - Efficiency study
  - Time resolution
- Future plans and conclusions



The R&D program

- SCINTILLATOR:
  - Minimumum number of fibers to collect enough light (1- 4 fibers per scintillator bar)
  - different shapes (rectangular with surface grooves or co-extruded inner holes)
  - time response
  - Coating efficiency (TiO_2 , reflecting tape.. ..)
- WLS FIBERS:
  - performances/cost effective combination of diameter (0.8, 1.0, 1.2) and dopant concentration (150, 175, 200 ppm)
  - Round/square fibers comparison (for baseline type: 1.0 mm – 175 ppm)
  - Faster fibers (bicron BCF-92) time resolution
- APD vs geiger mode devices
  - performances/cost most effective device
  - Ratio S/N, time resolution, Gain stability vs Voltage and Temperature, spread among channels, etc.…
- SCINT + FIBERS + PHOTODETECTORS combined tests:
  - Detection efficiency
  - time/space resolution
  - …..

The Geiger mode APDs

- A silicon photo-multiplier consists in a matrix of Single Photon Avalanche Diodes (SPAD) i.e. avalanche diodes operated a few volts above the breakdown voltage (Geiger Mode APD).

- Pioneering work in the 90's by russian institutes:
  - JINR (Dubna), Obninsk/CPTA (Moscow) and Mephi (Moscow)

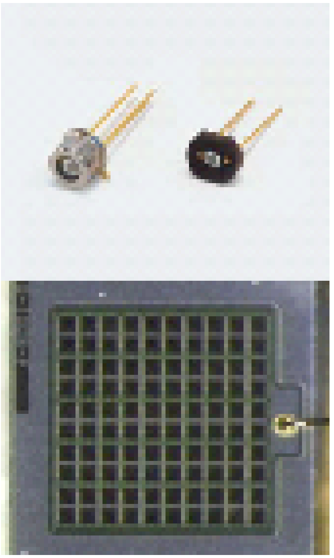
- Today more institutes/companies involved in SiPM production:
  - Hamamatsu, Japan
  - SensL, Ireland
  - FBK-IRST, Italy MEMS project with INFN
  - MPI, Germany

Hamamatsu MPPC

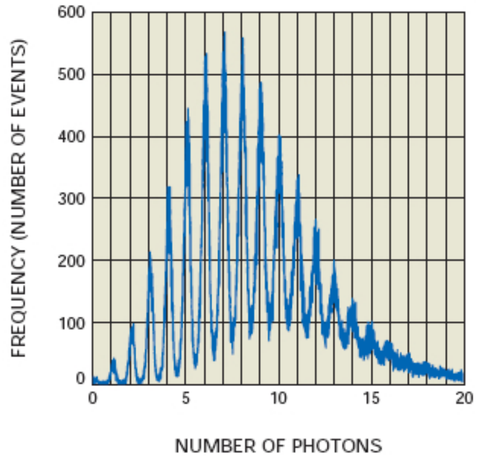
- Hamamatsu MPPC is a well established technology
  - Low dark counts
  - 70V bias voltage

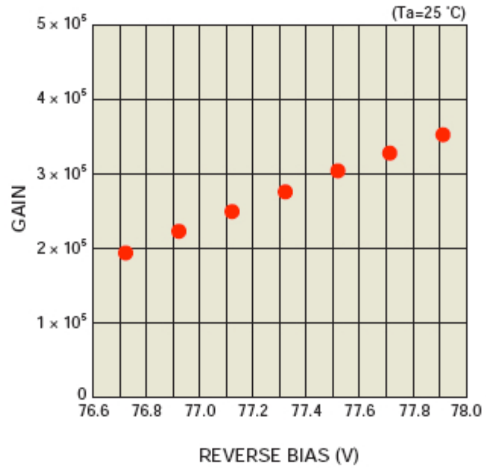
Specifications (Ta=25 °C)

Parameter	Symbol	S10362-11 series			Unit
		-025U, -025C	-050U, -050C	-100U, -100C	
Chip size	-	1.5 × 1.5			mm
Effective active area	-	1 × 1			mm
Number of pixels	-	1600	400	100	-
Pixel size	-	25 × 25	50 × 50	100 × 100	µm
Fill factor *1	-	30.8	61.5	78.5	%
Spectral response range	λ	270 to 900			nm
Peak sensitivity wavelength	λp	400			nm
Quantum efficiency (λ=λp)	QE	70 Min.			%
Photon detection efficiency *2 (λ=λp)	PDE	25	50	65	%
Operating voltage	-	77 ± 10	70 ± 10	70 ± 10	V
Dark count	-	100	270	400	kcps
Terminal capacitance	Ct	35			pF
Time resolution (FWHM)	-	250	220	250	ps
Temperature coefficient of reverse bias	-	50			mV/°C
Gain	M	2.75×10^5	7.5×10^5	2.4×10^6	-



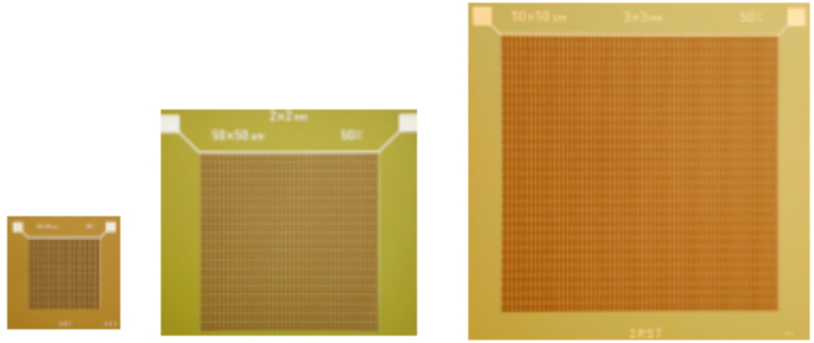
Pulse height spectrum when using charge amplifier (S10362-11-025U, M=2.75 × 10^5)



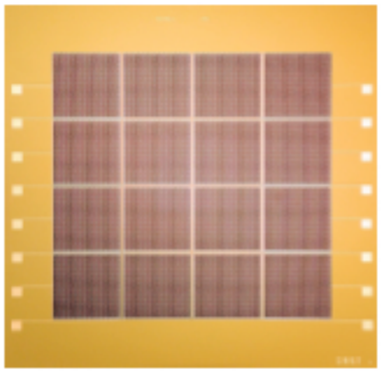


FBK-IRST SiPM

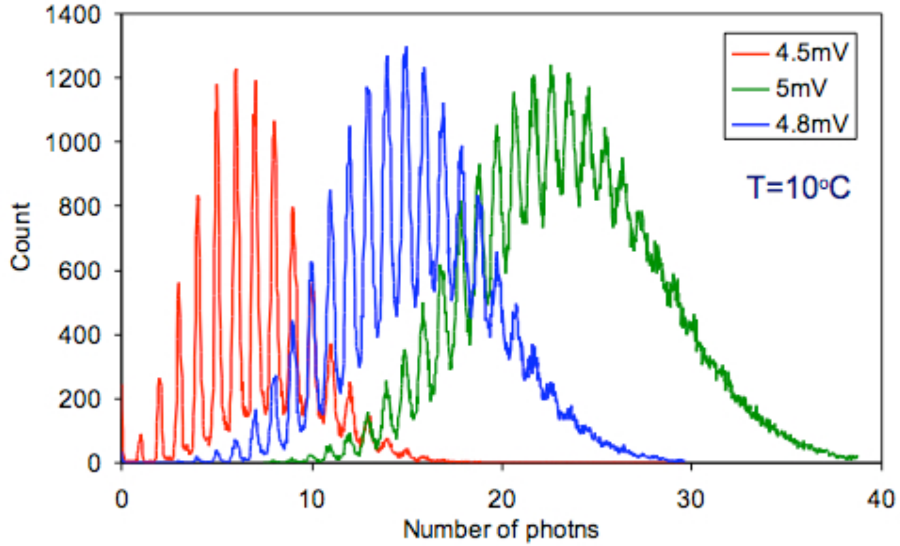
- FBK-IRST devices:
  - Cheaper
  - better time resolution
  - Higher noise
  - More design flexibility
  - 35V bias voltage



1x1mm^2 2x2mm^2 3x3mm^2

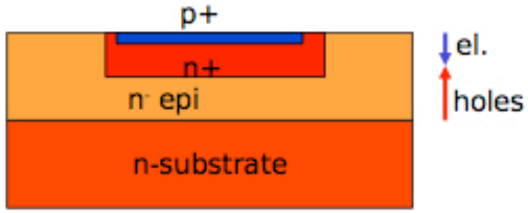
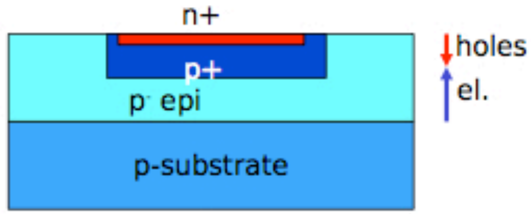


8x8 SiPM array



C.Piemonte, workshop on "Photon Detection" - Perugia 13-14/6/2007

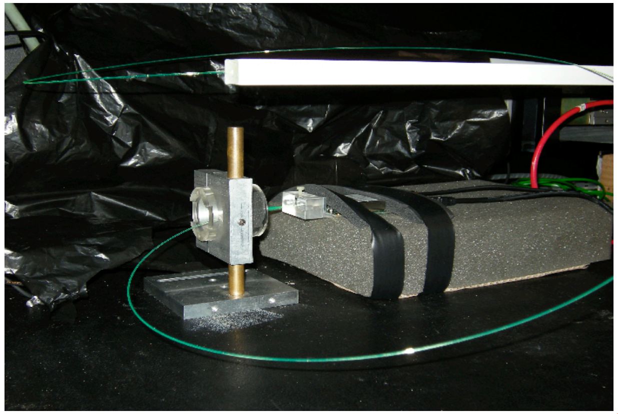
Hamamatsu vs FBK-IRST

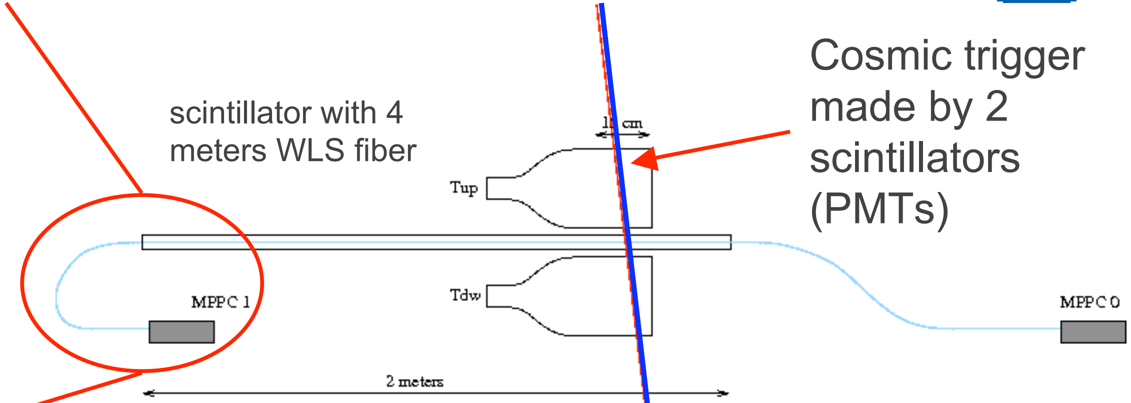
Product.	Hamamatsu	IRST
Type		
Gain	10^5 - 10^6	10^5 - 10^6
PDE	30-70% (UV)-blue-green	30-70% (blue)-green-IR
Noise	200kHz - 1MHz	~ HPK x 2
After-pulse	~ 10%	~ 1%
Cross-talk	~ 10%	~ 1%
Timing	~ 100 ps	~ 50 ps

NOTE: working V_{bias} range

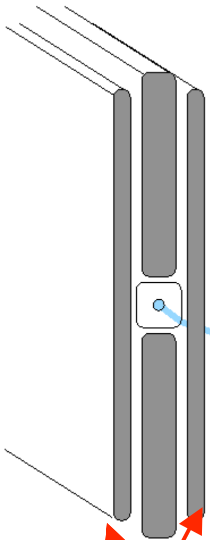
Gianmaria Collazuol - Padova, Jul 3rd 2007

The test stand in Ferrara





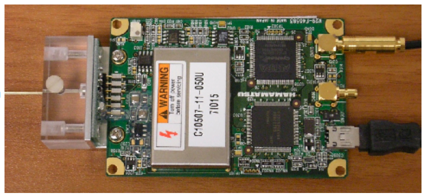
Cosmic trigger made by 2 scintillators (PMTs)

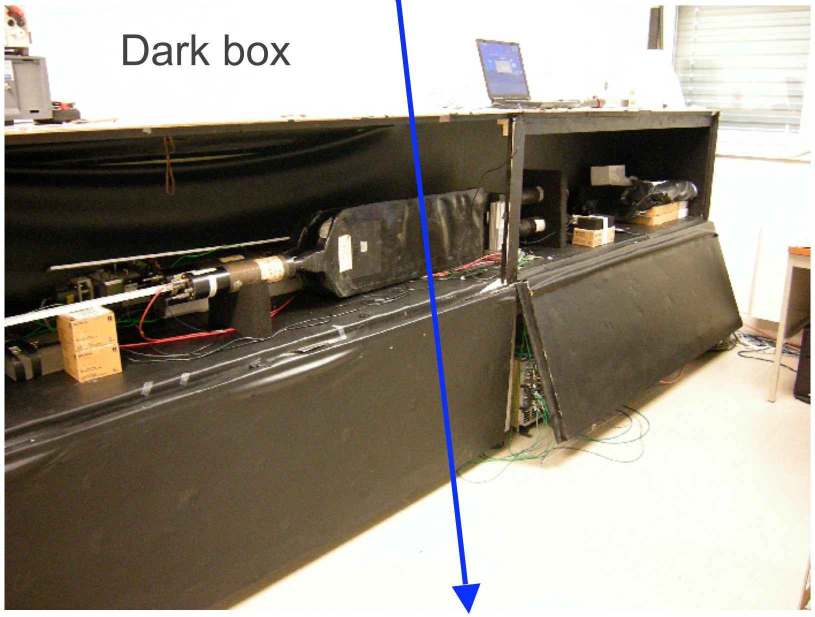


Veto scintillators

Scintillators have been added on the side as veto for showers

MPPC module

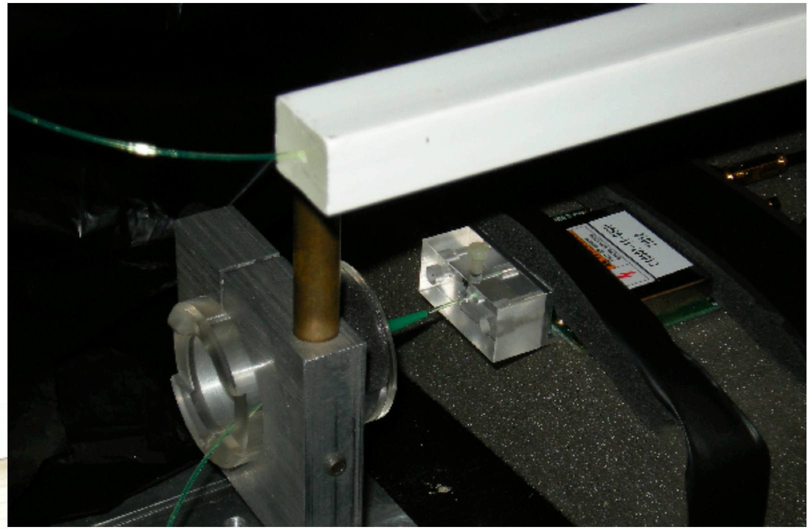


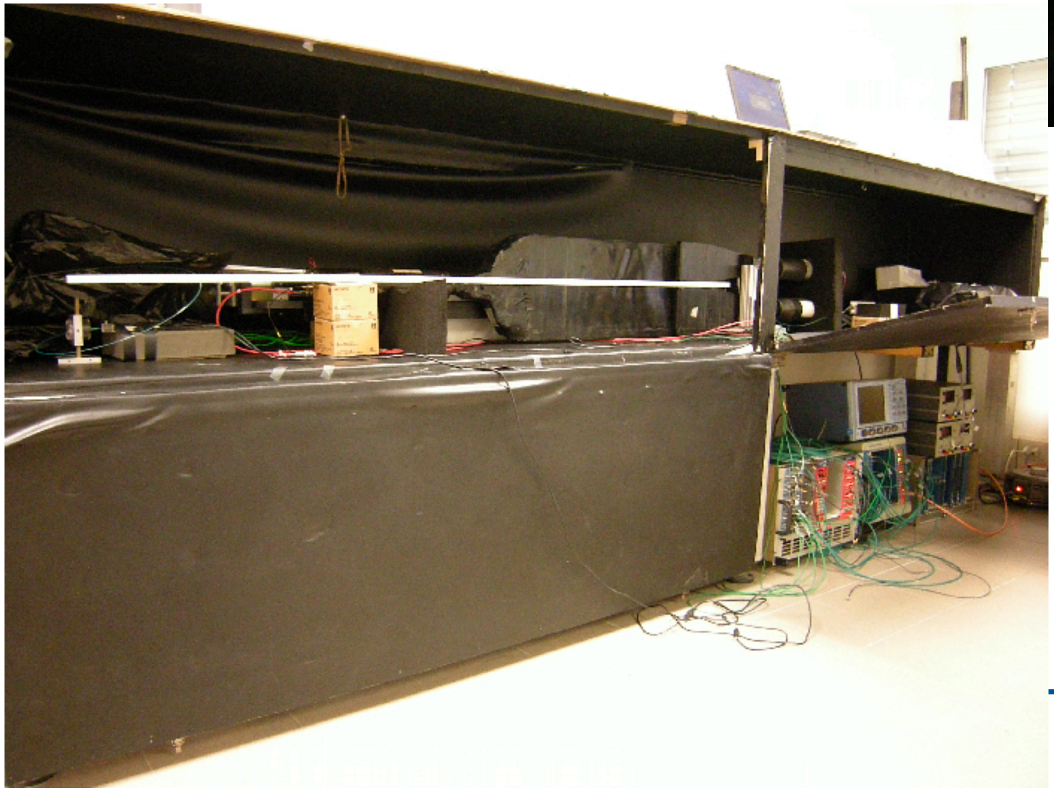


Dark box

Some more pictures

- So far tested one combination:
  - Square scintillator 2m long 2x2cm2 with hole in the center
  - WLS fiber: bicron: BCF-92 fibers (round multiclad)





- Used optical grease to improve light transmission

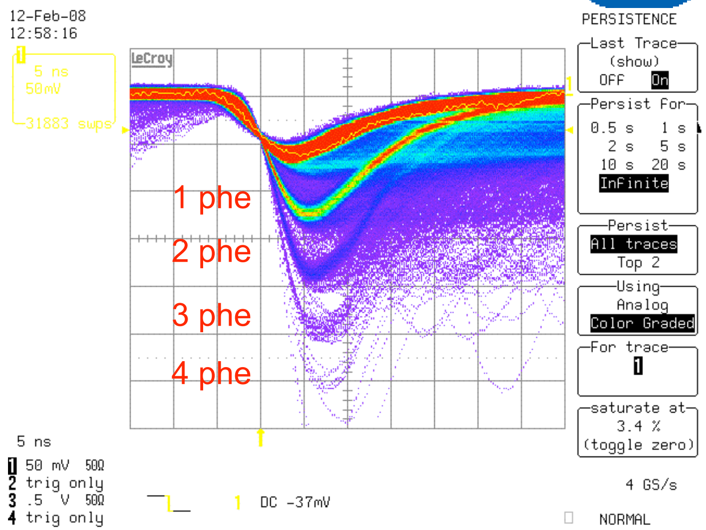
- Tested with both MPPC and SiPM

Test with MPPC readout

- Hamamatsu MPPC (S10362-11-050U)
  - 400 pixels (1mmx1mm)
  - Gain ~7.5 x105
  - Time resolution 220 ps

Specifications (Ta=25 °C)

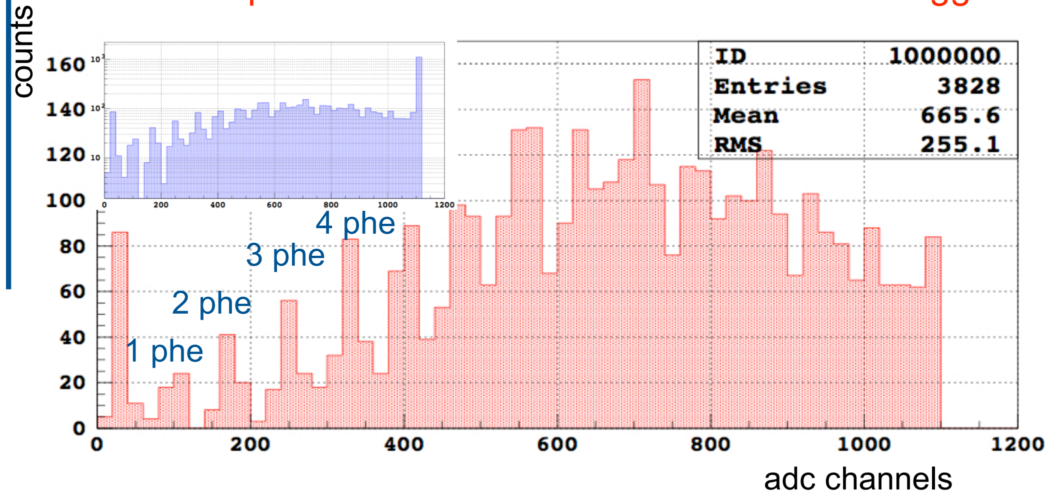
Parameter	Symbol	S10362-11 series -050U, -050C	Unit
Chip size	-	1.5 × 1.5	mm
Effective active area	-	1 × 1	mm
Number of pixels	-	400	-
Pixel size	-	50 × 50	µm
Fill factor *1	-	61.5	%
Spectral response range	λ	270 to 900	nm
Peak sensitivity wavelength	λp	400	nm
Quantum efficiency (λ=λp)	QE	70 Min.	%
Photon detection efficiency *2 (λ=λp)	PDE	50	%
Operating voltage	-	70 ± 10	V
Dark count	-	270	kcps
Terminal capacitance	Ct	35	pF
Time resolution (FWHM)	-	220	ps
Temperature coefficient of reverse bias	-	50	mV/°C
Gain	M	7.5×10^5	-



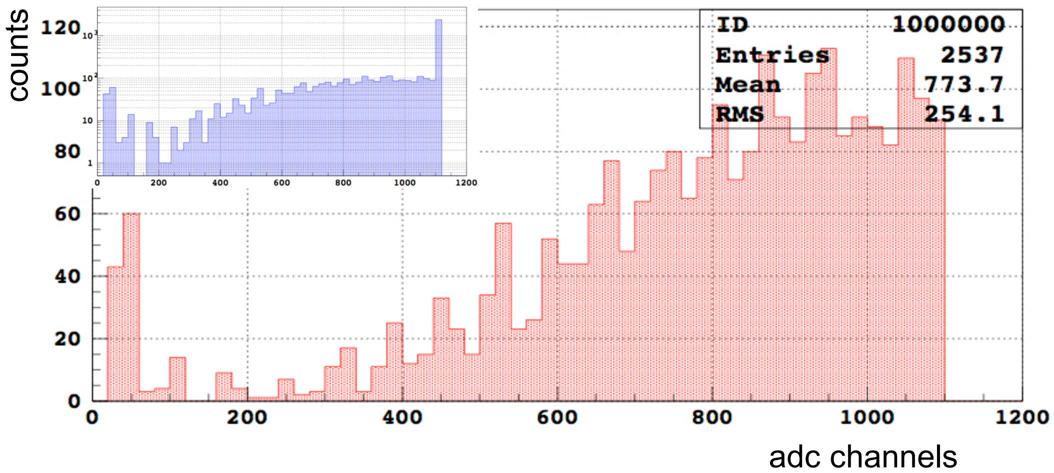
- Used MPPC modules which provides:
  - Bias voltage
  - Current to voltage conversion amplifier
  - Signal decoupling
  - Temperature correction
- Disadvantage of the module: bias voltage not settable
  - Less flexibility

ADC spectra

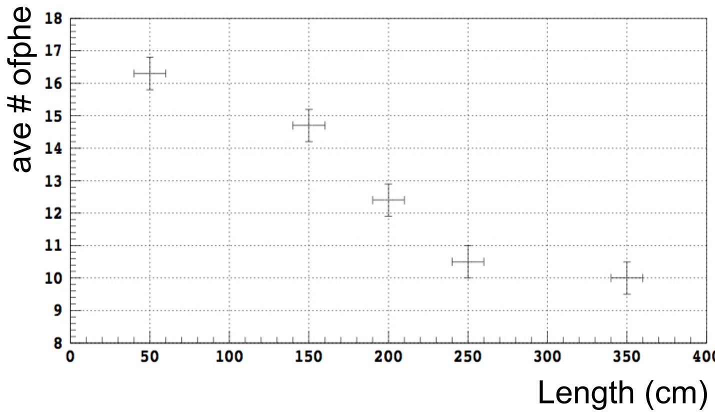
ADC spectrum for MPPC 350 cm far from the trigger



ADC spectrum for MPPC 50 cm far from the trigger

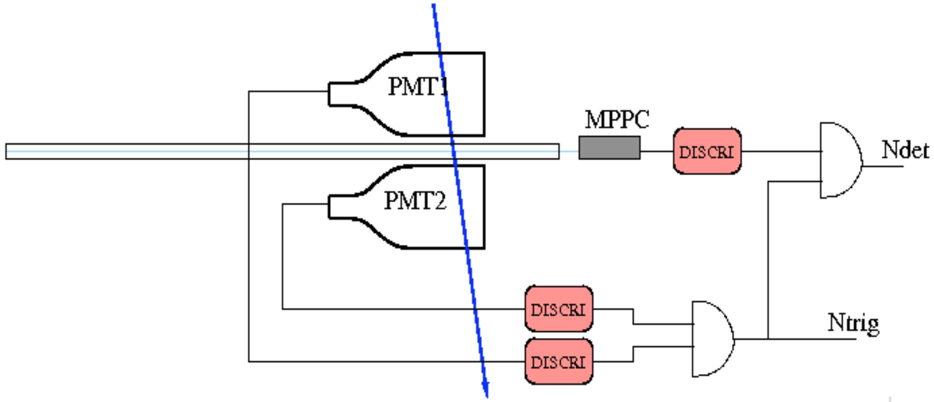


- Single photons are clearly visible in the ADC spectra
- The light yield depends on the distance.



- This doesn't affect the efficiency.
- But it's quite significant for the signal rise-time and play and important role in the time resolution.

Efficiency measurements



Sandwich efficiency has been calculated as the ratio between number of events detected by the MPPC (N_{det}) and the number of triggers (N_{trig}) at different distances.

A cut at 1.5phe has been applied on the ADC signal from the MPPC

- Efficiency is almost independent by the distance.
- The average value is ~93% because the trigger system is not yet properly optimized.

	EFFICIENCY %	
distance (cm)	**MPPC 0**	**MPPC1**
50	92.8	-
150	93.1	-
200	93.2	93.2
250	-	92.9
350	-	92.5

- In fact adding in the trigger one of the two MPPC and doing an independent measurement of the efficiency of the MPPC on the other side we found

$$\varepsilon > 99\%$$

meaning that once the light is produced we detect it.

Efficiency vs dark counts

- With a cut at 1.5 phe MPPC devices have a dark counts rate around 60kHz.
- Rising the threshold to 2.5 phe the noise will be cut of an order of magnitude with no significant loss of efficiency:

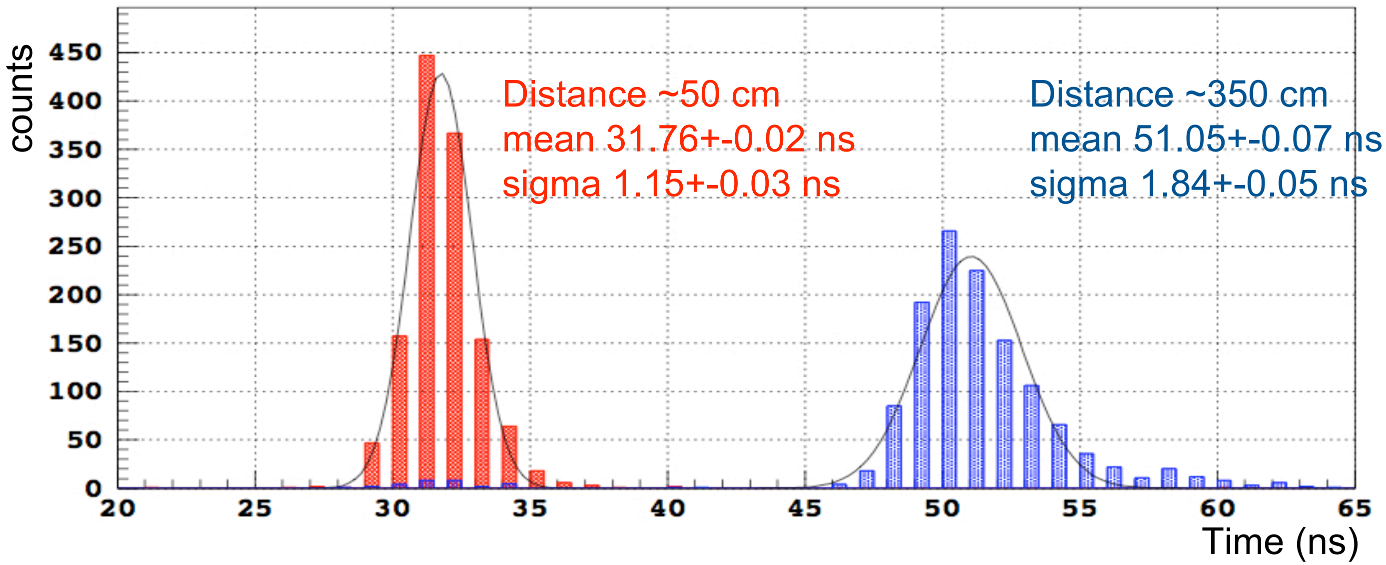
	EFFICIENCY %			
distance (cm)	MPPC 0		MPPC1	
	1.5 phe	2.5 phe	1.5 phe	2.5 phe
50	92.8	92.3	-	-
150	93.1	92.2	-	-
200	93.2	92.7	93.2	91.9
250	-		92.9	91.1
350	-		92.5	90.4

- The efficiency of one side as respect to the other remains ~99%

Time resolution (I)

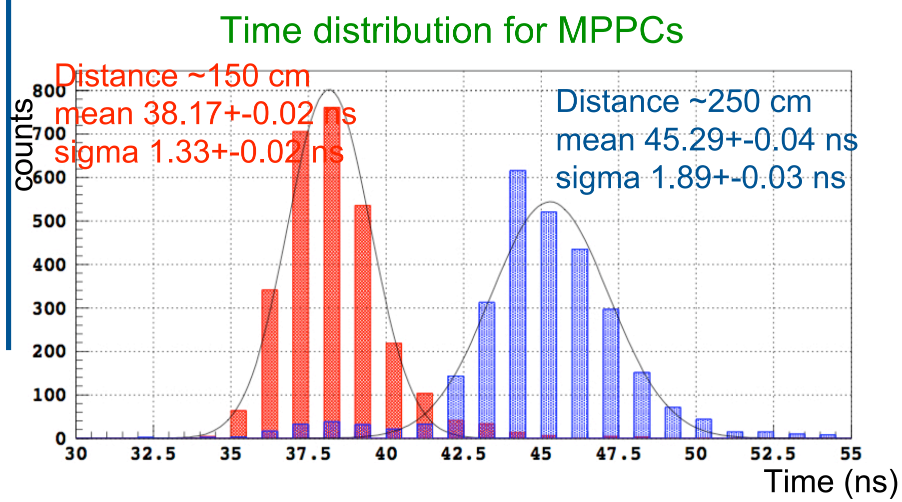
- Time resolution has been measured with a common start TDC.
- TDC distribution represent the time between the trigger signal and the MPPC signal (+ delay).
- The trigger is 15 cm wide so we expect about 0.8 ns contribution to the resolution from that.

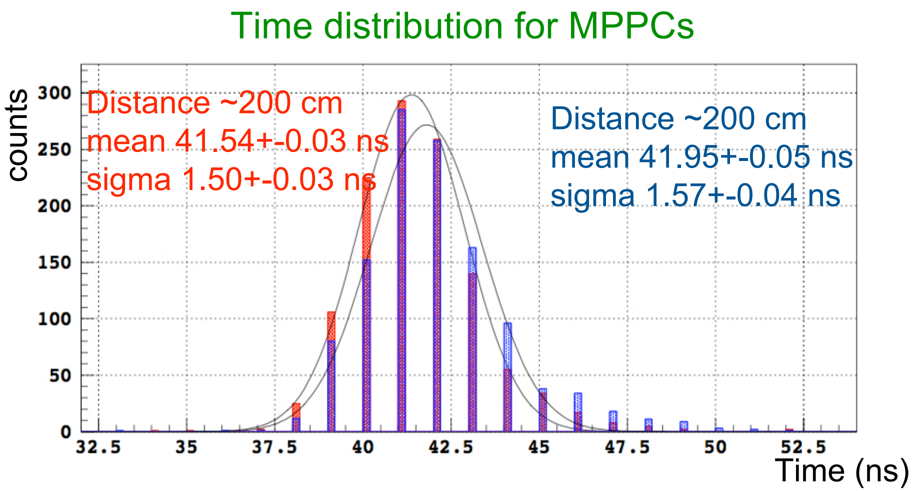
Time distribution for MPPCs at the two side of the fiber



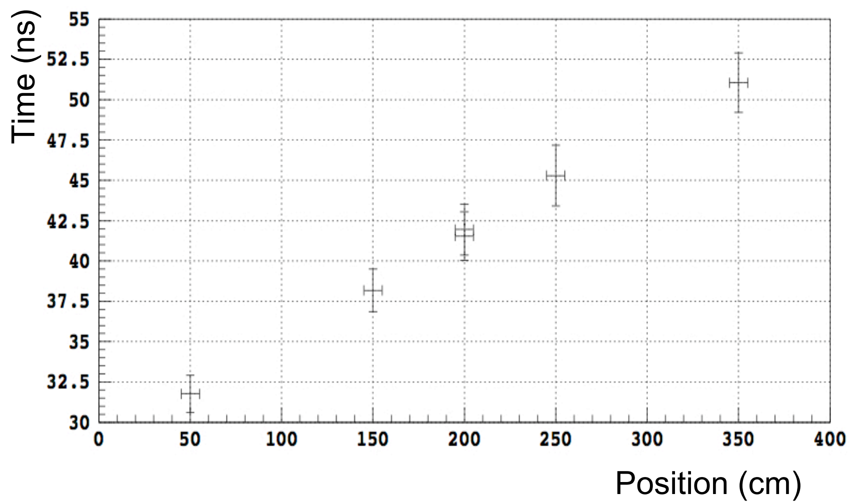
- The resolution depends on the distance (i.e. light yield).
- The resolution ranges between 1 and 2 ns.
- That's not bad considering that we are using a threshold discriminator (1.5phe)

Time resolution (II)



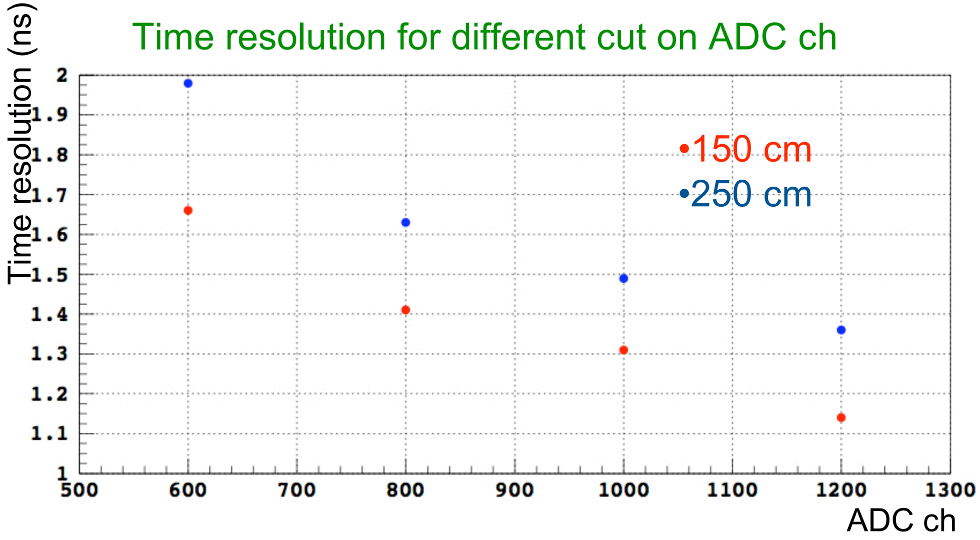


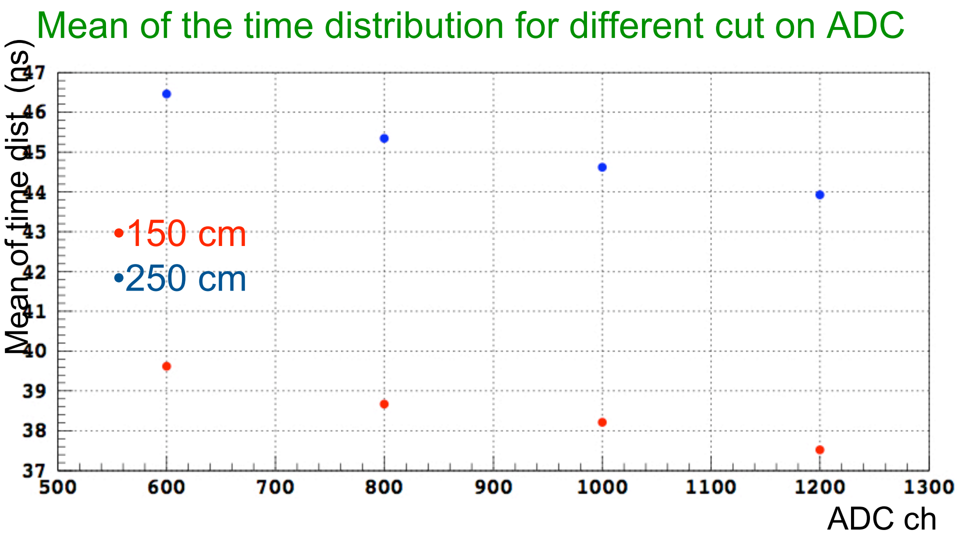
- The test has been repeated at different position moving the fiber with respect to the trigger



- Measured the linearity of the mean of the time distribution with the position.

Time resolution (III)

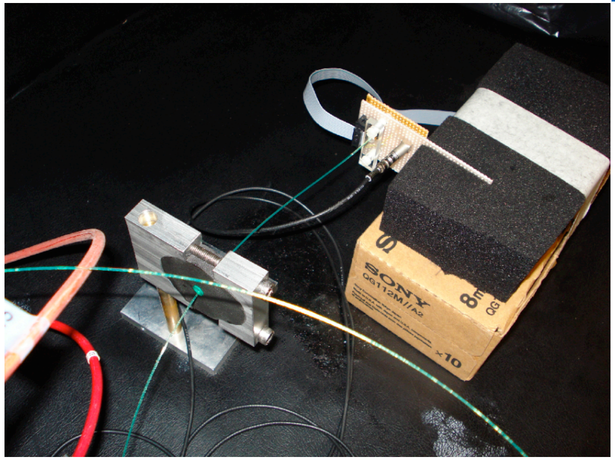


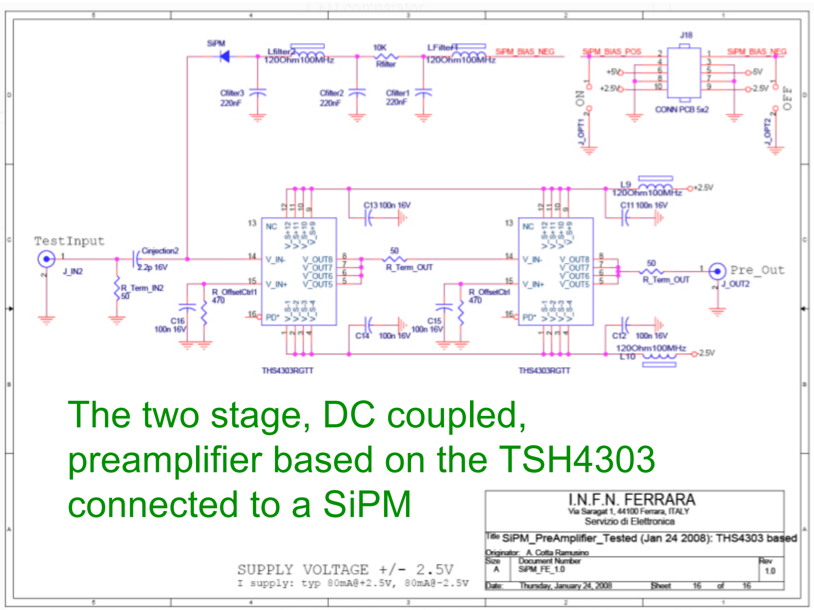


- Time resolution and mean of the time distribution with different cut on the signal yield.
- Increasing the number of ADC channels (i.e. number of photons detected) per event, the time resolution largely improves and the signals are anticipated of ~2 of ns.
- Having a device that take into account the rise time of the signal, like a constant fraction discriminator, will certainly improve the time resolution.

Test with SiPM readout

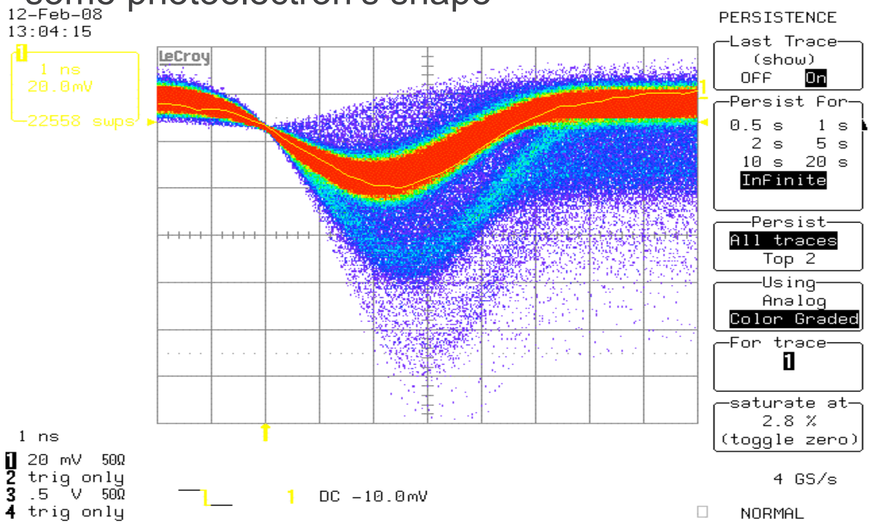
- SiPMs from FBK-IRST come with very raw package, no amplification and no power supply.
- Used custom amplifier designed by Angelo Cotta Ramusino (INFN Ferrara).





The two stage, DC coupled, preamplifier based on the TSH4303 connected to a SiPM

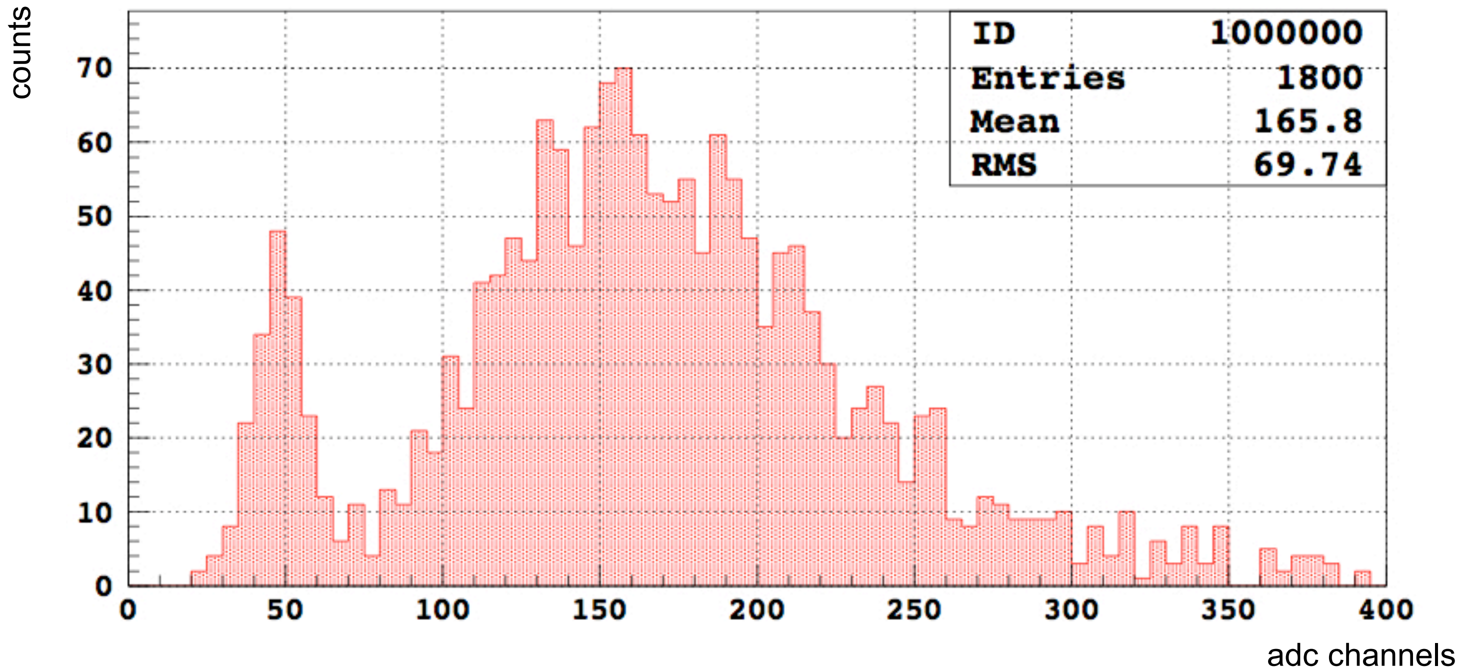
SiPM are more noisier but you can distinguish some photoelectron's shape



ADC spectra

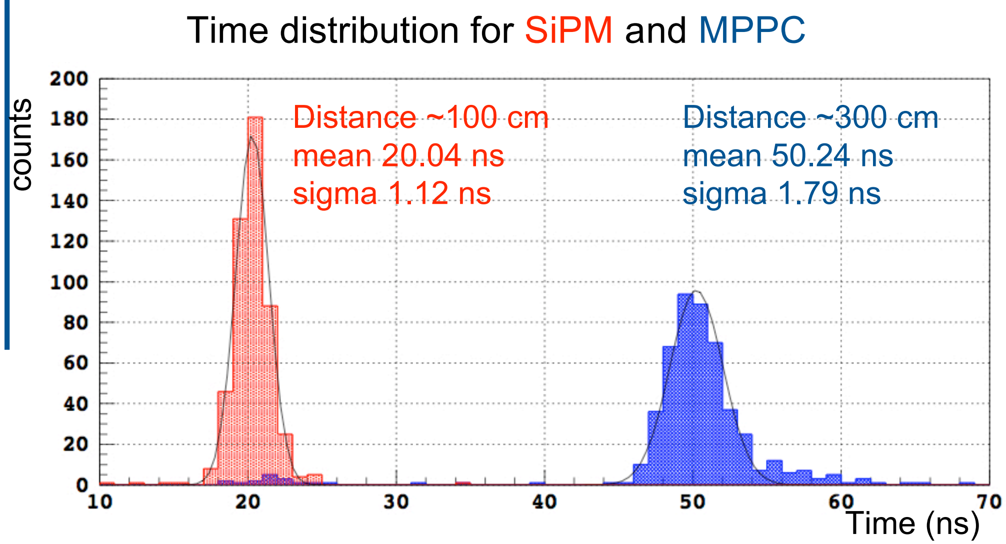
- More difficult to see the photoelectron peaks in the ADC spectra.
- The amplification is lower than for the MPPC, no temperature correction and grounding not optimized.

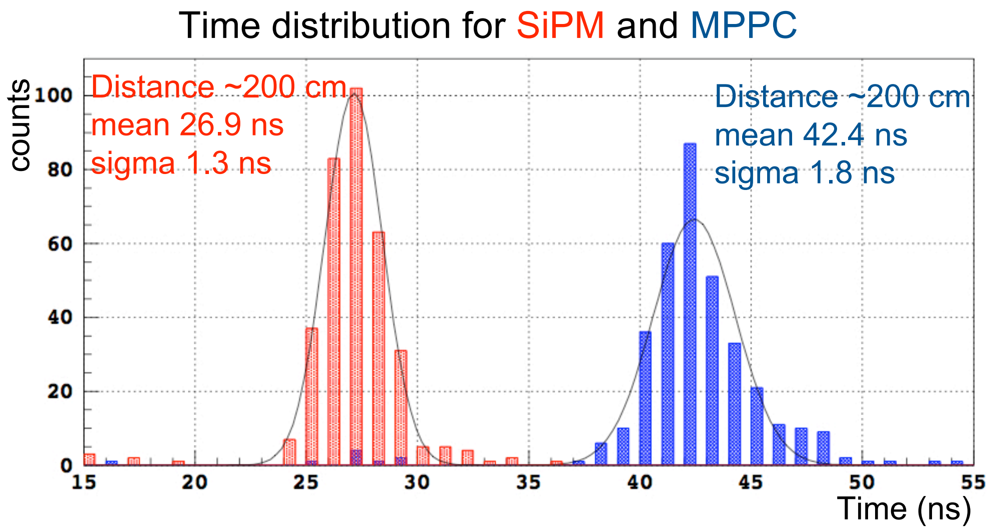
ADC spectrum for SiPM 200 cm far from the trigger



- Efficiencies are around 90% calculated respect to the external trigger.
- Including the opposite side of the fiber into the trigger gives ~97% efficiency

Time resolution (SiPM vs MPPC)





- The time resolution for SiPM is better than for MPPC, consistently with what reported by other studies.
- Considering the 15 cm of trigger width and using a constant fraction discriminator, a time resolution around 1ns could be achieved.

Future plans

- Improve our experimental setup:
  - Build a larger dark box
  - Optimize the trigger
- Use a constant fraction discriminator to improve the time resolution.
- Add more statistics and repeat the tests with different:
  - Scintillator bars
  - WLS fibers
  - SiPMs/MPPCs
- Help developing the electronics

Outlook and conclusions

- Complete R&D program mainly based on the Geiger Mode APDs.

- Preliminary results from cosmic run tests have been presented:
  - GM-APDs operation
  - Light yield and ADC spectra
  - Efficiency measurements: 93% - 99%
  - Time resolution: 1 to 2 ns (need feedback from simulation)

- Results are very encouraging
  - large improvements are possible