Spectroscopic Characterization of Novel Silicon Photomultipliers

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SiPMs

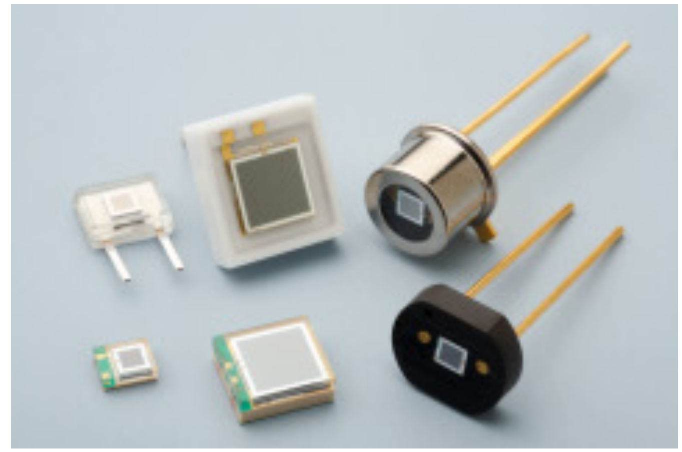
- Compact

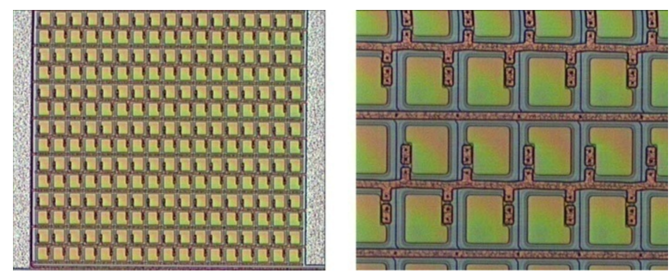
  from 1 to 3.5 mm^2
- Insensitive to magnetic fields
- Low operational voltage

  in the order of few tens of volts
- Versatile

  widely used in particle detection
- Cheap

  down to few hundreds dollars per detector



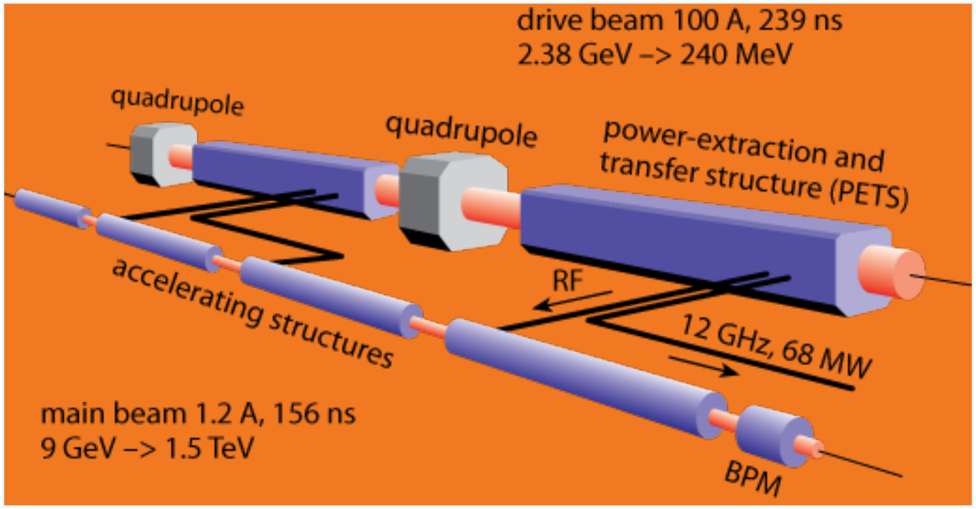


SPADs arrays and quenching resistors detail.

Courtesy of ST Microelectronics

Beam Loss Monitoring

- Critical for Large Facilities
  - (LHC, CLIC)
- Demanding requirements
  - dynamic range,
  - time resolution,
  - spatial resolution
- Economic dimension
  - Thousands of detectors

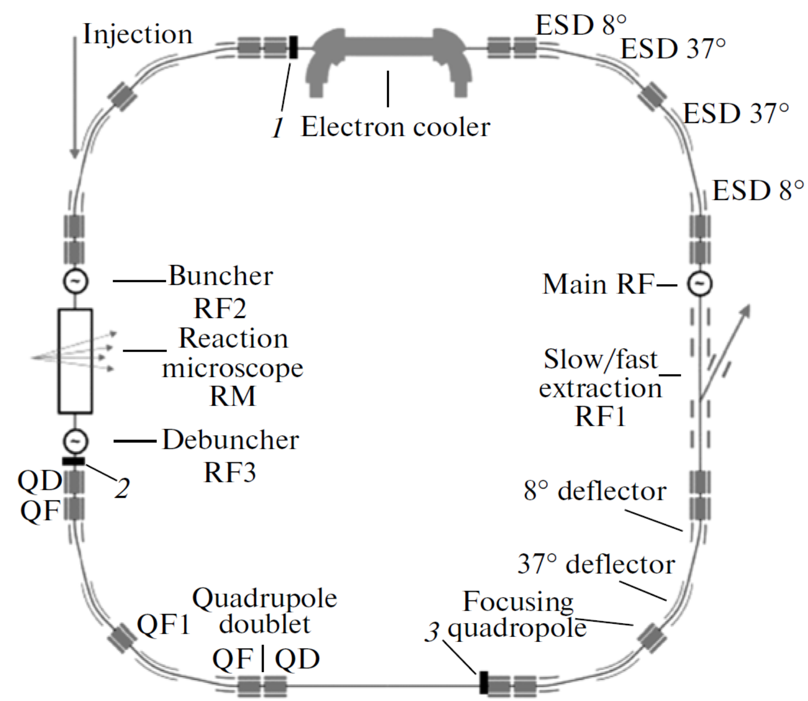


CLIC structure. clic-study.web.cern.ch

SiPMs have the potential to completely fulfill these requirements.

Additional Usage

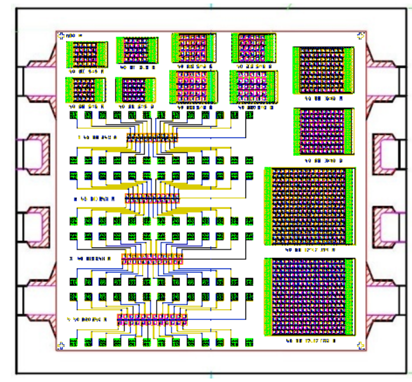
- Detection of low intensity beam losses/signals, e.g. USR @ FLAIR;
- Potential trigger for experiments and/or cross callibration
- Detection of annihilation signals
- Crucial to determine noise level, signal threshold, dynamic range, etc.



USR structure.

Prototypes under Test

SiPM	Array size	Number of cells	Cell Pitch	Fill Factor
ST (Mod. H)	1x1 mm²	17x17	58µm	45%
Hamamatsu S10362-11-100C	1x1 mm²	10x10	100µm	78.5%



ST Test prototype.

Courtesy of ST Microelectronics

- Quite different features
- Same wavelength sensitivity

Also studied:
Detector connected to a common multimodal optical fiber.

- Fiber radius chosen to match the active surface of the SiPM
- length depends on specific application needs.

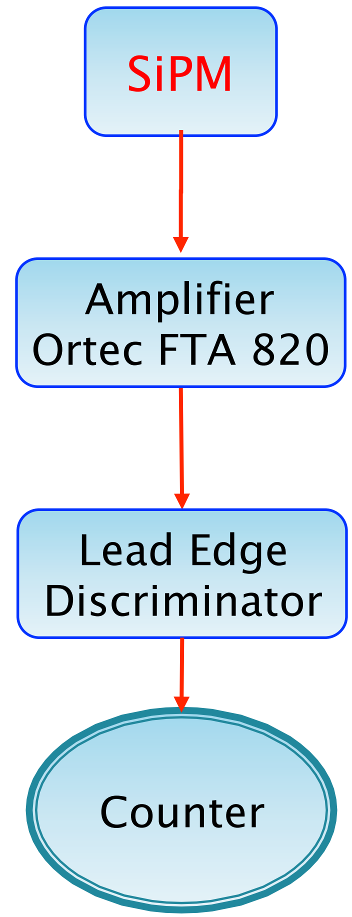
Investigated Parameters

- Total Noise
  - To define the count rate plateau and fluctuations
- Photons resolving power
  - To find the minimum/maximum number of detectable photons
- Time and spatial resolution
  - To benchmark detector limits

Noise Measurements

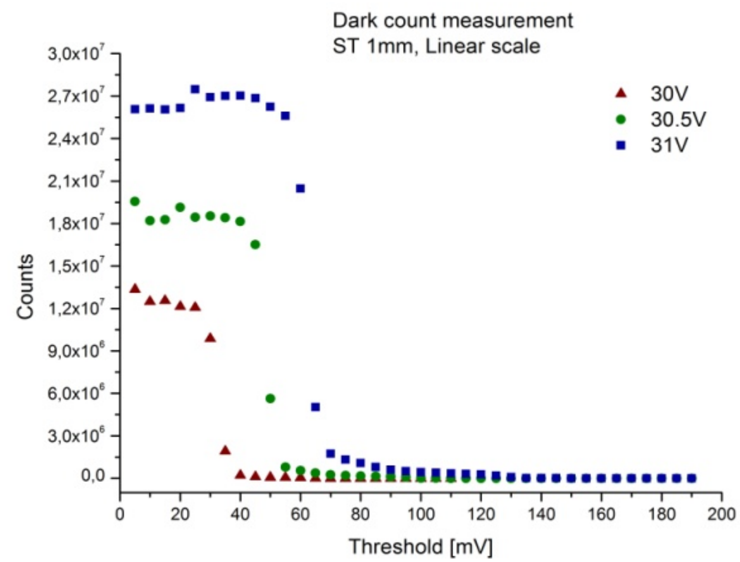
Superposition of correlated and uncorrelated events

- **Dark Count (statistical)**
  - Generated by thermal charge fluctuations
  - Minimized in coincidence regime
  - Main contribution to SiPM noise
- **Cross Talk (correlated)**
  - Triggered by photons generated by avalanches
  - Minimized using manufacturing remedies
  - Small contribution to modern SiPM noise
- **After Pulse (correlated)**
  - Generated by carriers trapped into Si defects
  - Minimized using manufacturing remedies
  - Little contribution to long dead time SiPMs

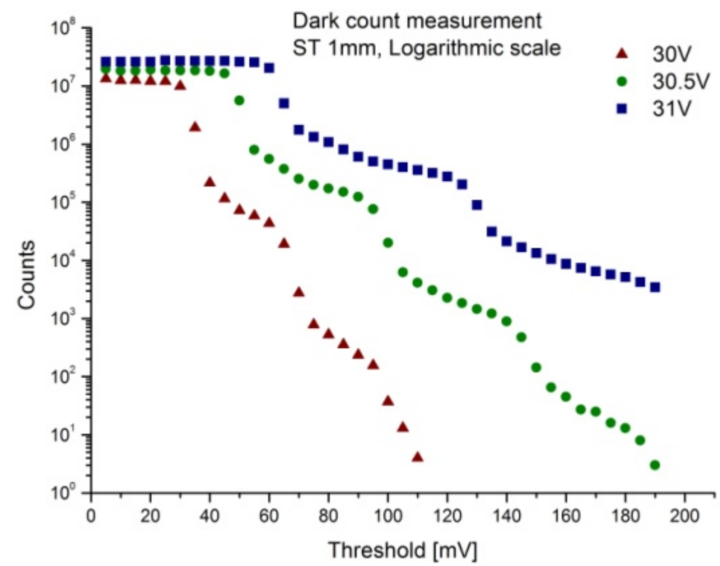


Noise Measurements

- Dark noise ∝ to bias voltage
- Rapid decay indicates single cell pulse amplitude;
- Negligible information lost until a threshold of more than 80% of a single cell amplitude

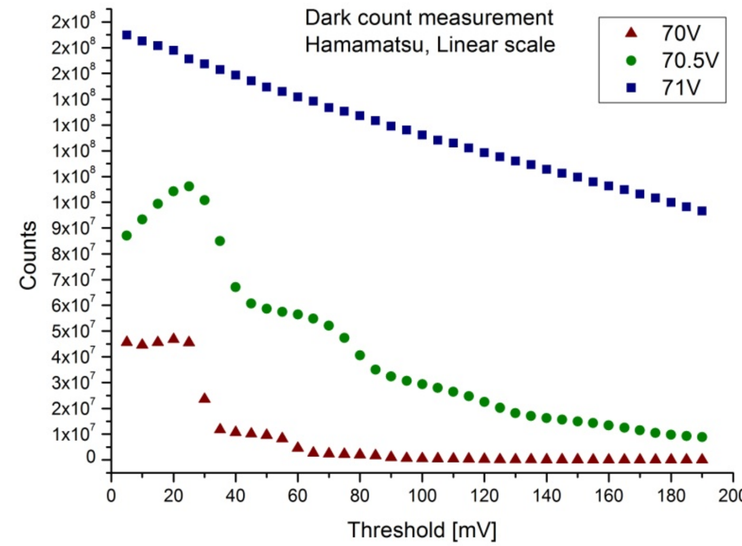


- Rapid decays indicate the number of simultaneously activated cells;
- The more the plateaus are flat, the less the SiPM is affected by partial cell activation.

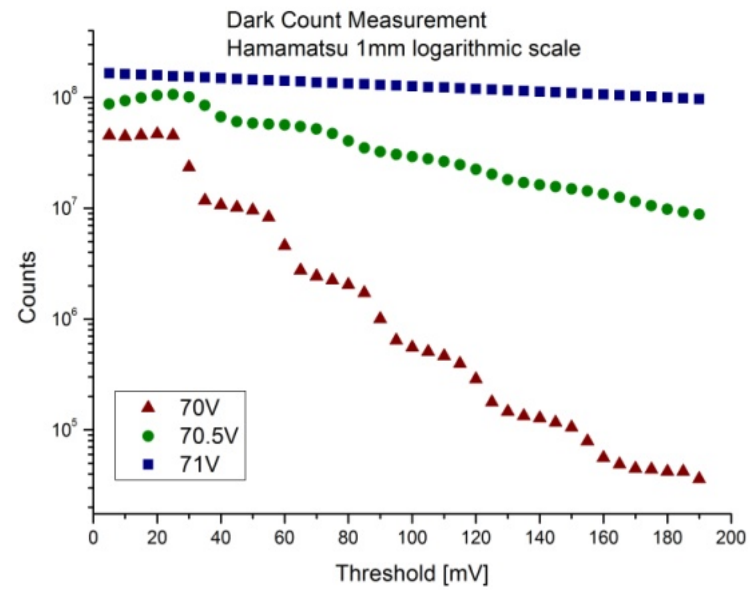


Noise Measurements

- Higher noise level, without clear separation between cells signals
- the partial activation seriously affects the output.



- Up to 6 cells signal are distinguishable;
- The Hamamatsu seems to suffer more from the effect of correlated noise



Noise Measurements

Start-stop uncertainty 0.8% plus the Poisson distribution variance.

Bias Voltage	Dark count rate [20 mV th.]
ST 30V	203 kHz ± 7%
ST 30.5V	317 kHz ± 6%
ST 31 V	435 kHz ± 5%
Hamamatsu 70 V	777 kHz ± 4%
Hamamatsu 70.5 V	1.733 MHz ± 3%
Hamamatsu 71 V	2.642 MHz ± 2%

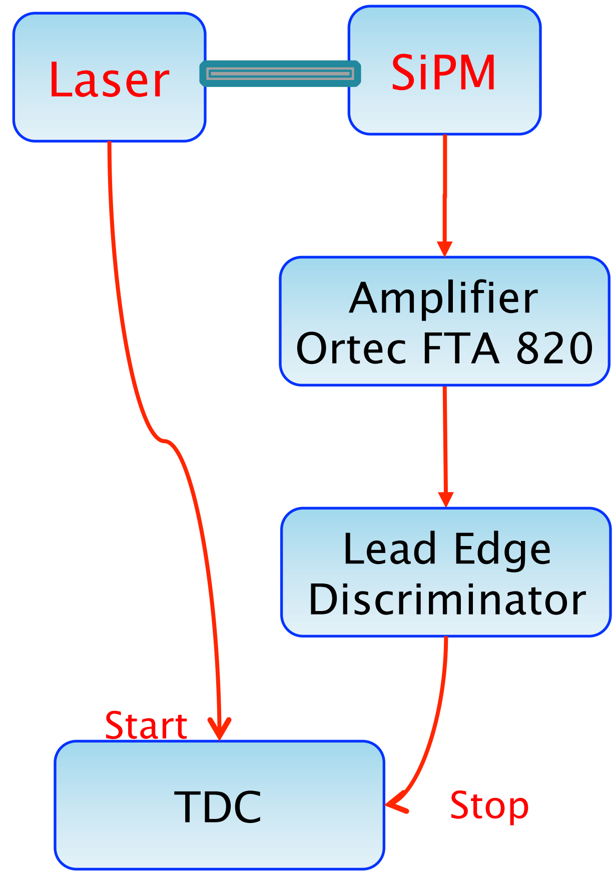
The threshold which allows a complete white noise cut off still guarantees 1 cell detection.

Finding:
ST SiPM seems to be more appropriate for low frequency events measurements.

Time & Spatial Resolution

The uncertainty shown by SiPM time distributions is referred to as its 'time resolution'.

- charge collection time carriers in the drift region. ~10 ps;
- The time of propagation of the avalanche. ~ tens of ps;
- The drift time of electrons through the depletion region. ~1 ps.

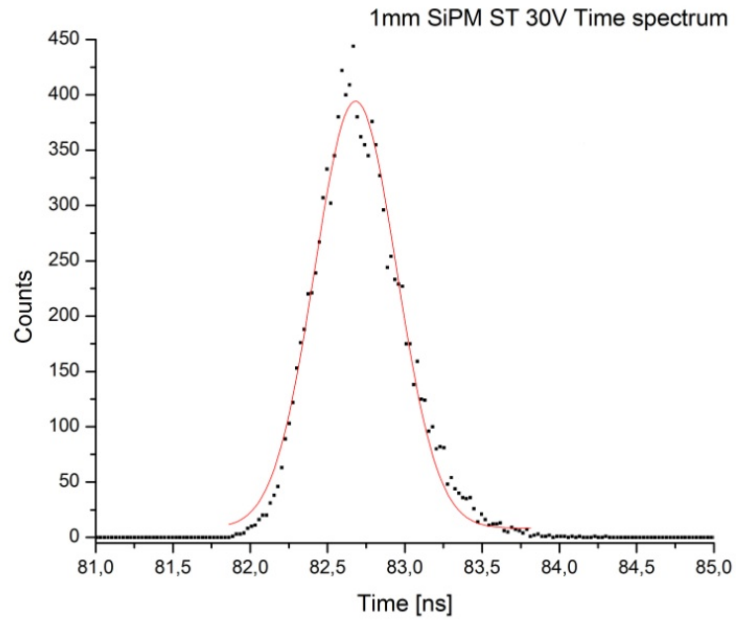


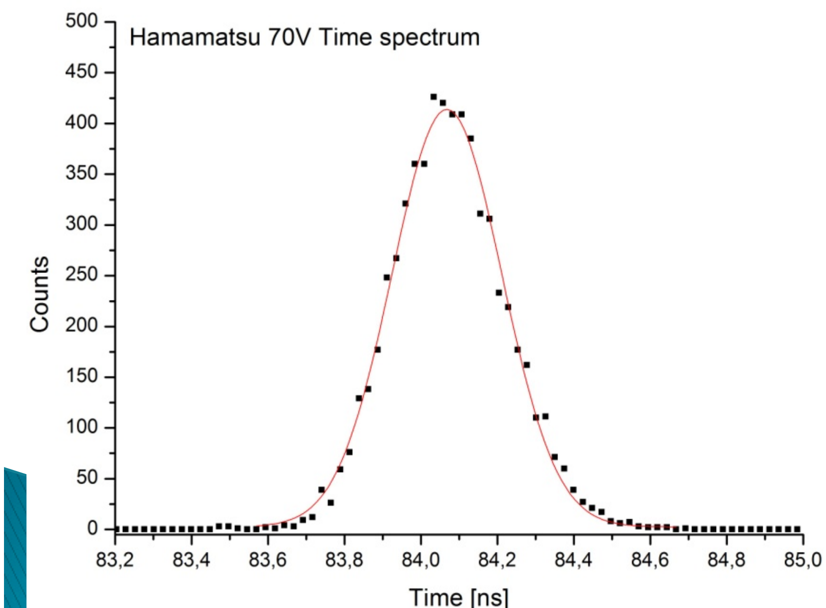
The only real limit is given by the readout electronics

Time & Spatial Resolution

The σ of the Gaussian indicates the temporal uncertainty.

The presence of the fiber deteriorates the SiPM performance proportionally to its length.





Linear spatial resolution depends on time resolution

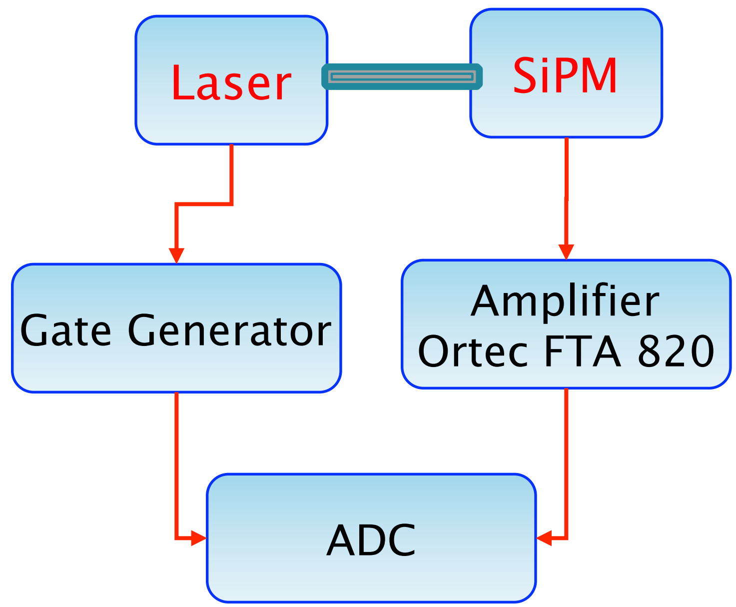
SiPM	Time Res. no fiber	Time Res. with fiber	Spatial Res. (d) [cm]; fib. (0-100)m
ST	264 ps	1,230 ps	7.9 < d <37
Hamamatsu	143 ps	903 ps	4.3 < d <27

Charge Spectrum

The ideal output should be an integer multiple of the elementary cell output, depending on the number of detected photons

The real output signal is affected by some unwanted contributions:

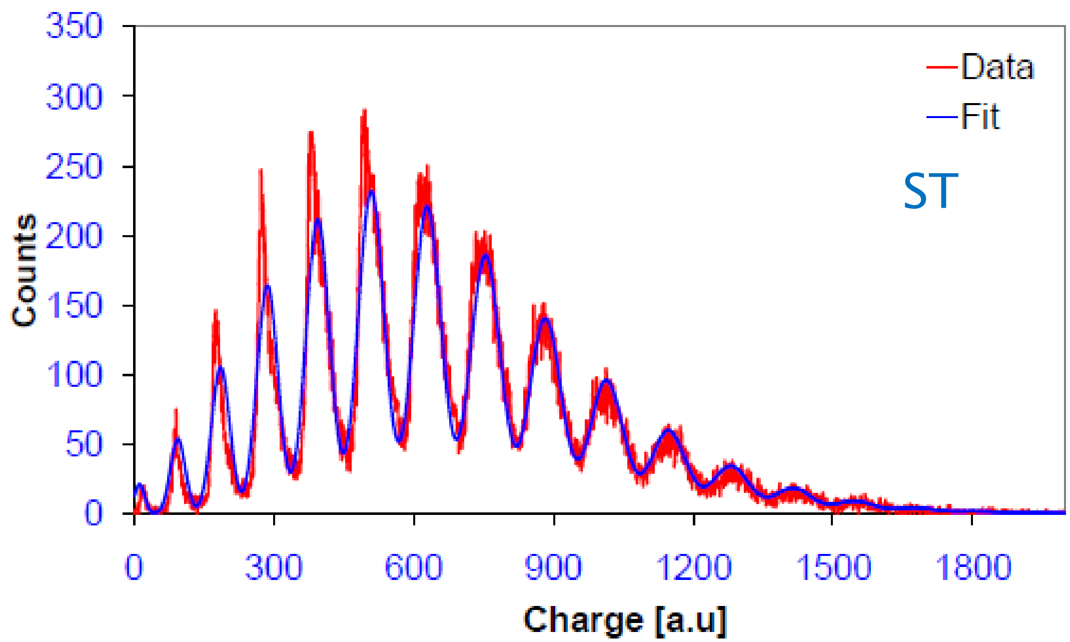
- Dark noise
- Uneven cells (major contribution)
- Electric noise (major contribution)

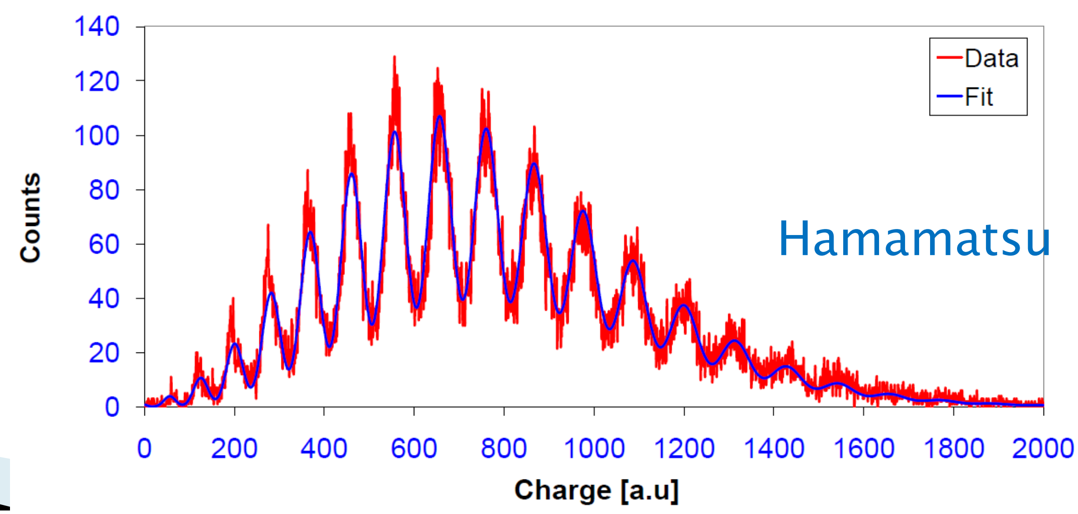


Measured Charge Spectra

Strongly affected by:

- Bias voltage
- Light source intensity

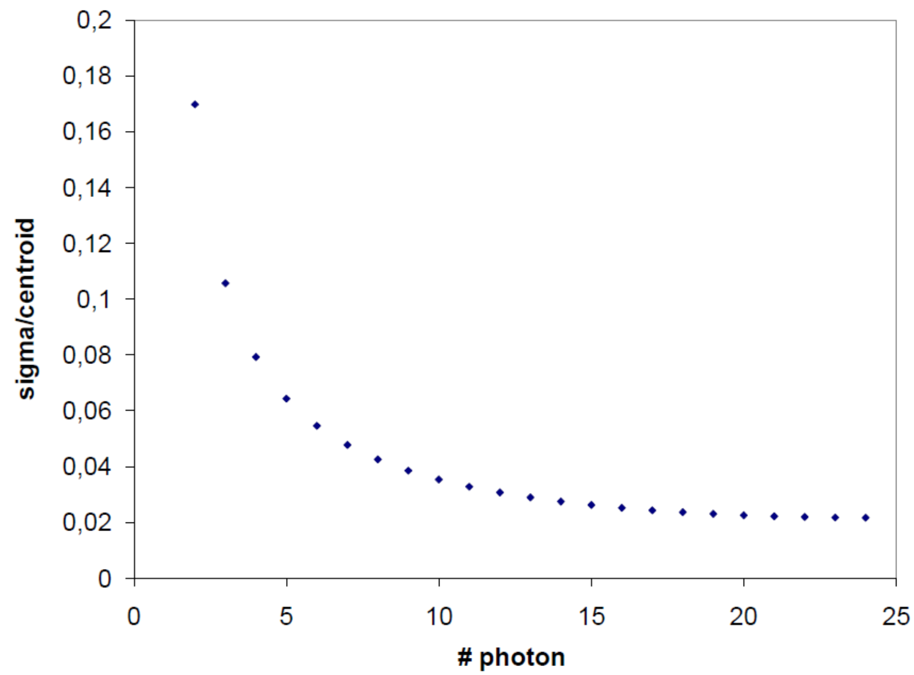




Charge Spectrum

The total variance of each single peak is given by:

$$\sigma_{tot}^2(n) = \sigma_e^2 + n\sigma_1^2$$



The relative sigma reaches a stable value at around 15 photons detected (2%).

Photon Resolving Power

The resolving power is the number of measured photons, where the separation between two consecutive peaks is three times the variance.

The peak resolution limit is two times the variance

SiPM	$R_{3\sigma}$	$R_{2\sigma}$
ST	13	29
ST 100 m fiber	5	11
Hamamatsu	14	31
Hamamatsu 100 m fiber	6	13

Future Plans

The presented data is the basis for:

- Accurate analysis for fiber coupling to different SiPMs with different configurations
- Detailed beam loss measurements on machines.

Furthermore, electronics improvements are planned to bring the time resolution closer to the theoretical limit.

Conclusion

- Comparison of the dark noise by two SiPMs
  - ✓ Understanding of the SiPMs architecture;
  - ✓ Determined the count rate plateau for any cell counts;
  - ✓ Determined the best configuration for the two SiPMs examinated.
- Time and spatial resolution in '(un)loaded' regime
  - ✓ Compared the time and spatial resolution for various configurations;
  - ✓ Verified the feasibility of a long distance detection for blue light;
  - ✓ Obtained a good time and spatial resolution even in worst-case scenarios.
- Photon resolving power in '(un)loaded' regime
  - ✓ Compared the charge resolution for various configurations
  - ✓ Determined a very good resolving power for both SiPMs
  - ✓ Obtained very good parameters for an extremely long detector

Thanks to:

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...you for your attention !!

Not everything that counts can be counted,

and not everything that can be counted counts.

A. Einstein