Characteristics of SiPM at various Temperature

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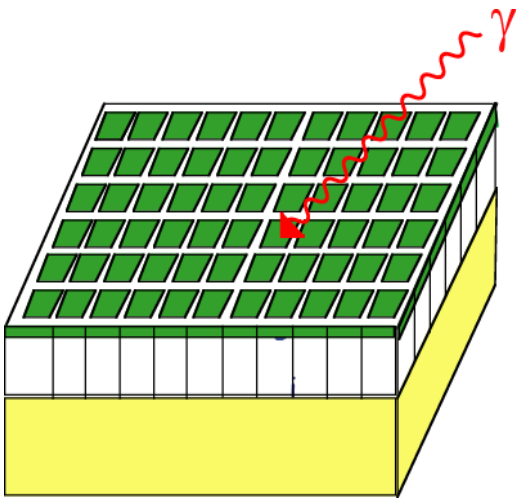
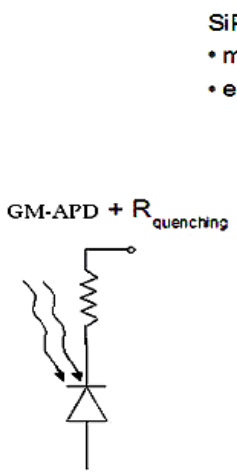
- **Introduction to SiPM signal and noise**
- **Fit to extract slope**
- **Recovery time**
- **Fraction of prompt Cross talk events**
- **Ratio of After Pulse + Delayed Cross talk**
- **Conclusion**

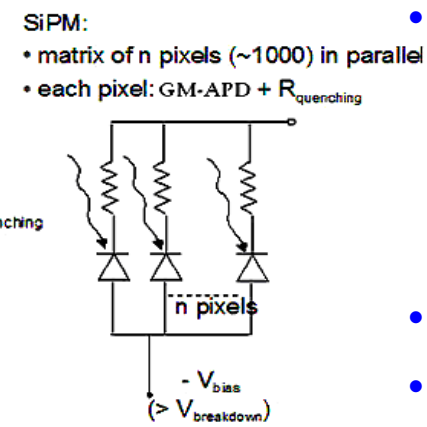
These results are based on only noise signal of SiPM, though similar study were done with LED source also.

Disclaimer : No systematic uncertainty on the results, only statistical error from number counting and/or fit.

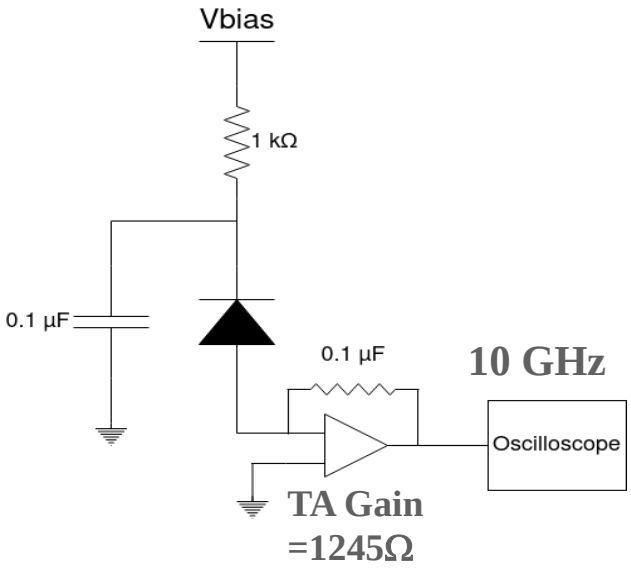
Signal shape and noises in SiPM

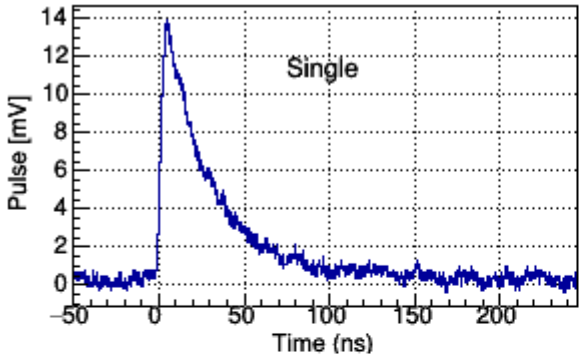


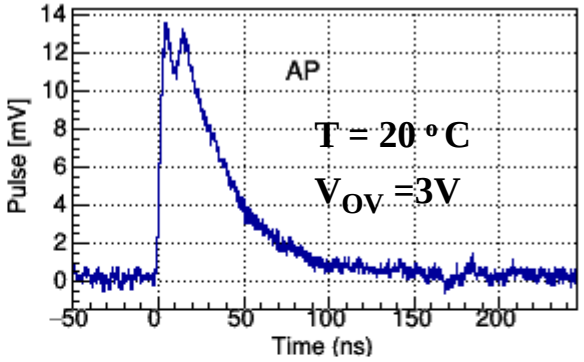


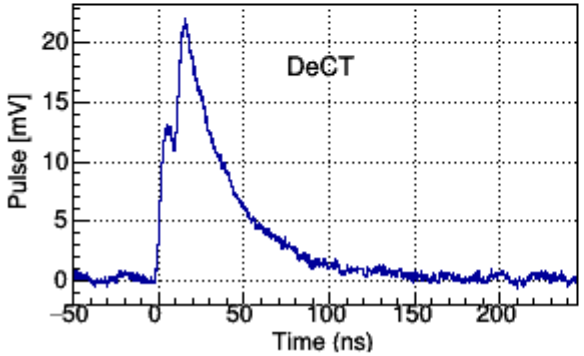


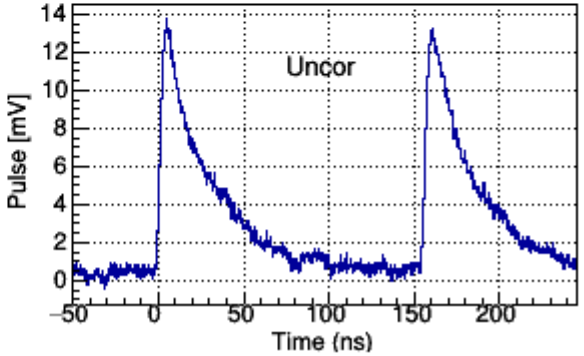
- The SiPM under test is from Hamamatsu (S13360-2050VE) with photosensitive area of 2 mm×2 mm and a pixel pitch of 50 μm,
- breakdown voltage of (53 ± 5)V,
- $dG/dV \sim 0.7 \times 10^6$
- $dV_{th}/dT \sim 55 mV/^oC$ and
- $-dG/dT = 2\%$







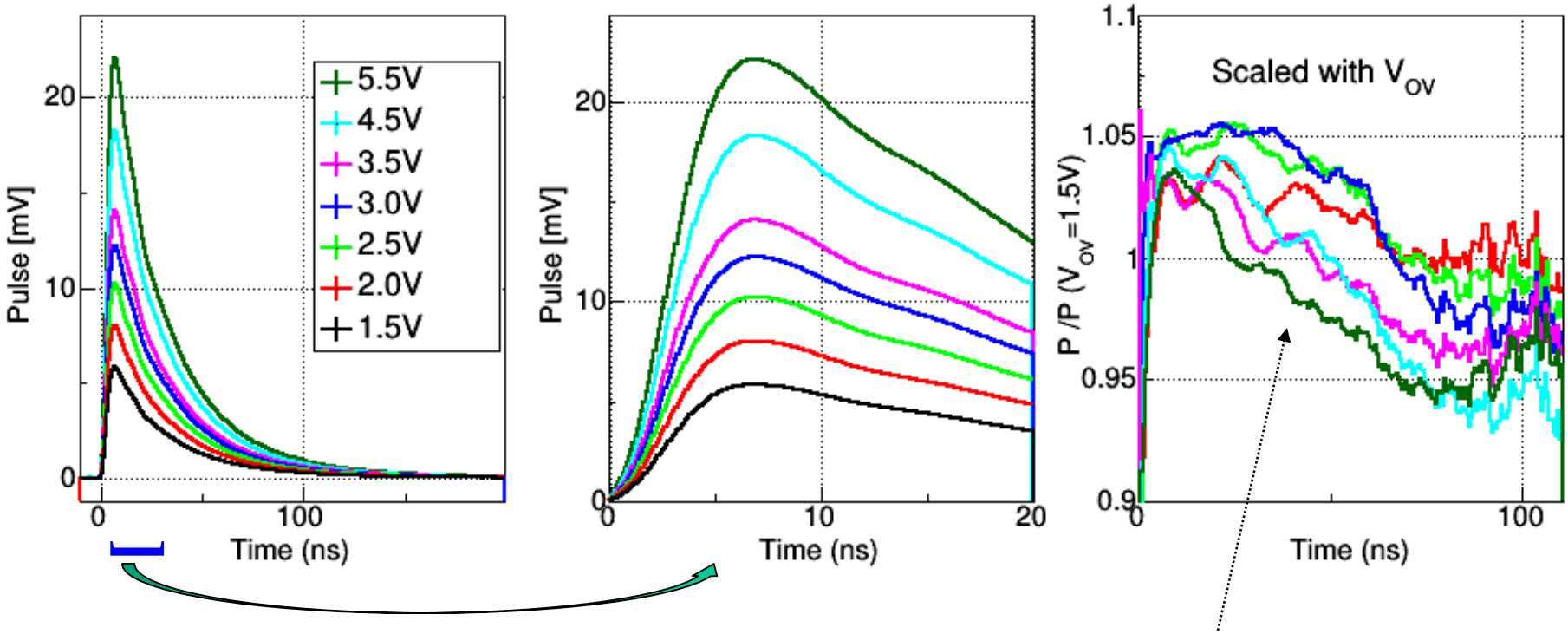




Signal shapes at various overvoltage @T=20°C

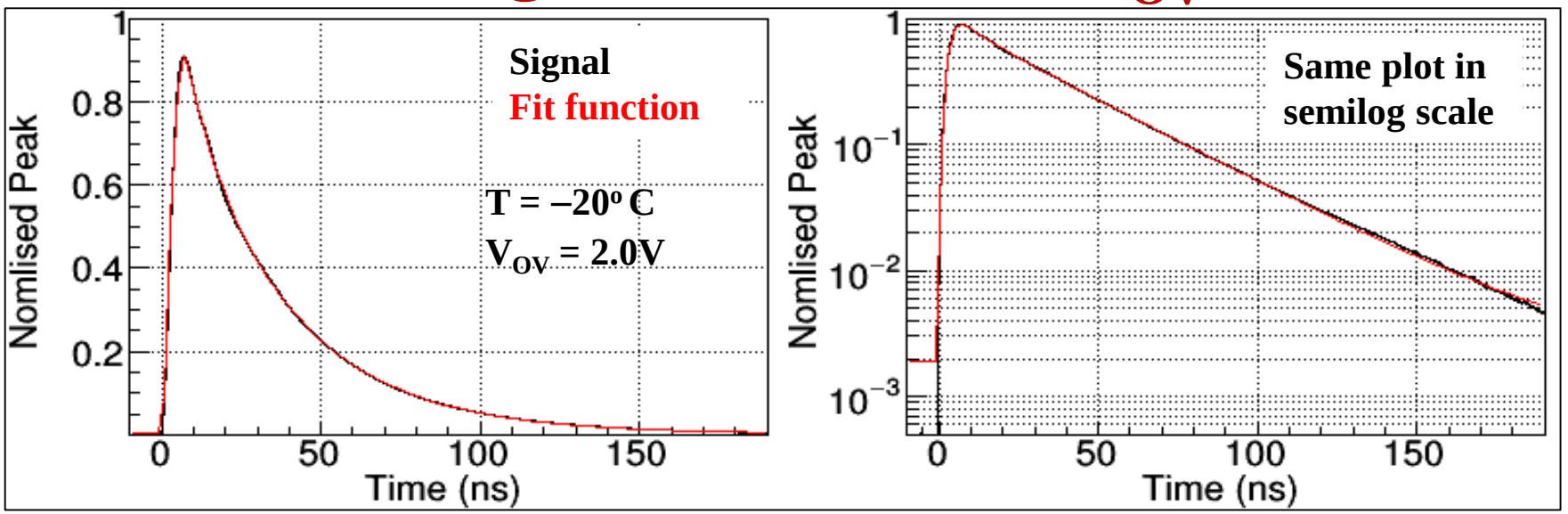
- It is well known that the recovery time depends on the temperature
  - Is there any variation due to V_{OV} ?

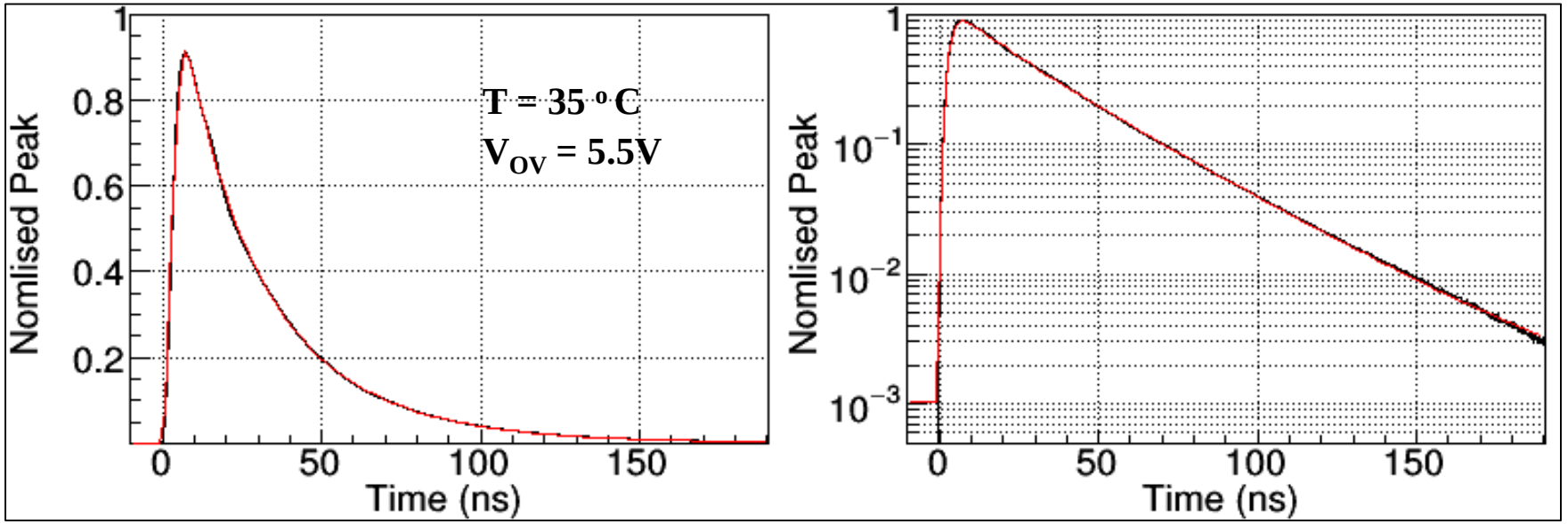
Superimpose many data by adjusting the starting time, use $\chi 2$ criteria to remove events with correlated noises → Reduce the fluctuation of individual signal



- Normalised wrt to V_{OV} and take ratio with respect to data at V_{OV} = 1.5V
- There are fluctuations, possible noise in electronics,….
  - But a clear trend that the shape (both raising and falling parts) depends on V_{OV}

Signals at different V_{OV}

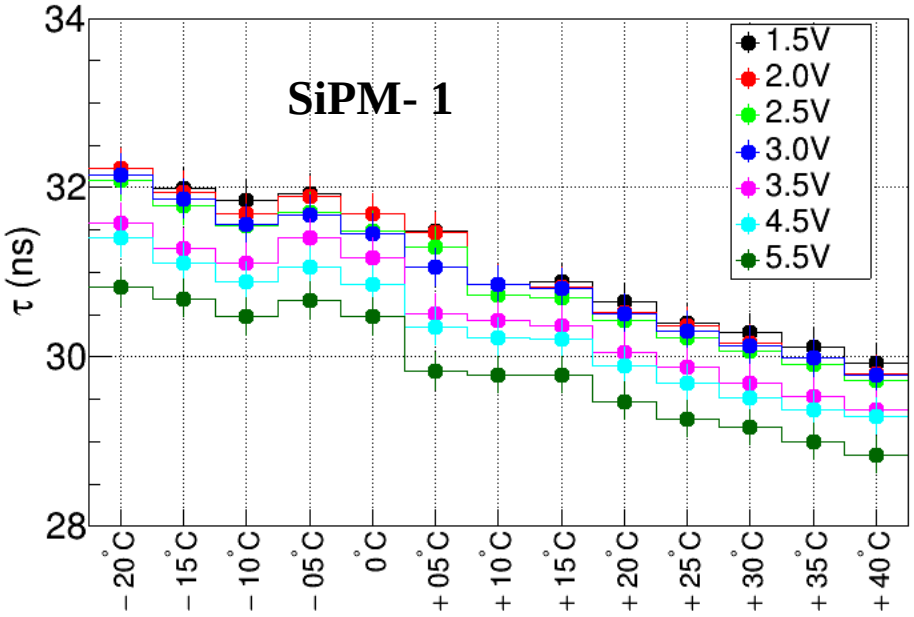


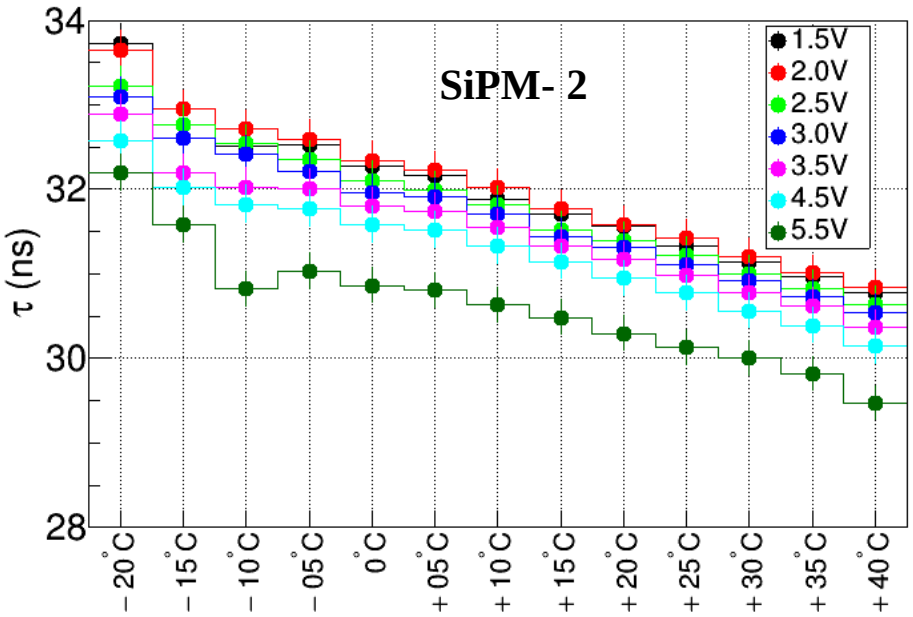


Signal are fitted with a function which includes growth of signal and two exponential falling curves.

Variation of falling components with V_{OV}

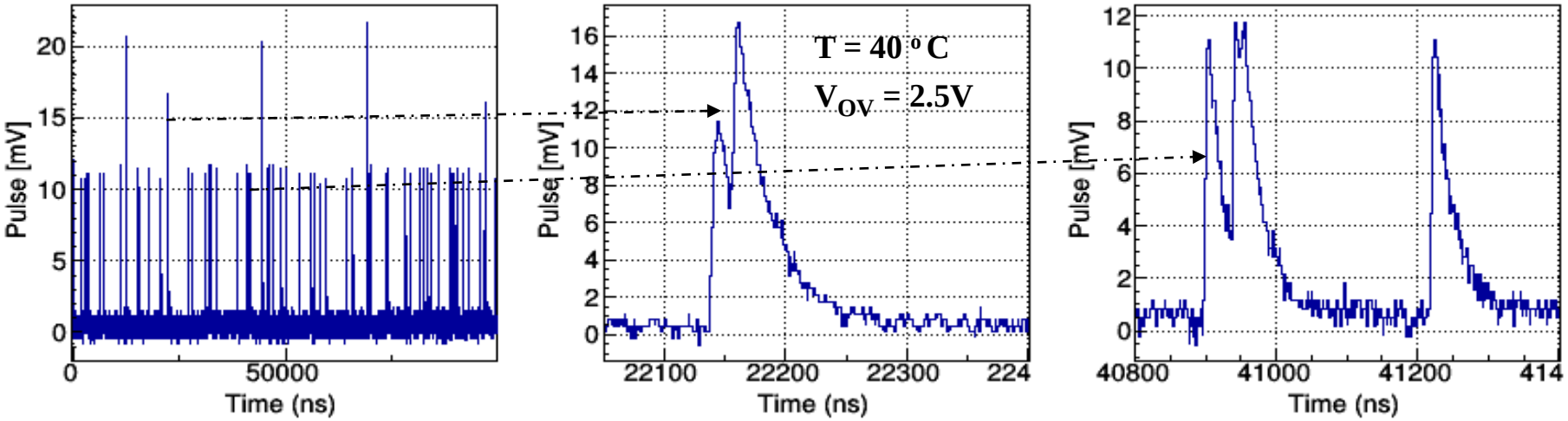
- Fit the signal shape, where the area and relative slope of the second component are fixed
- Similarly, parameters of rising components.
- There are correlations among all these



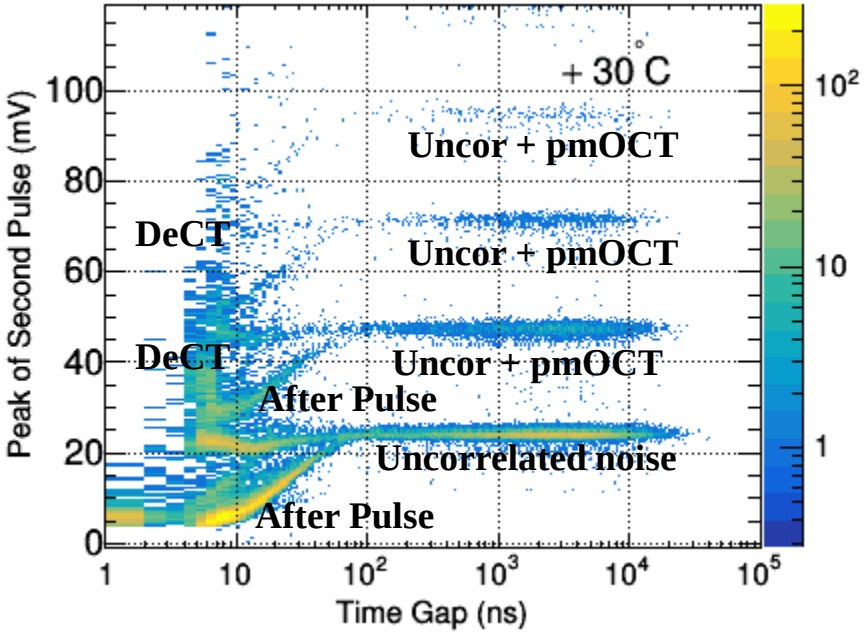


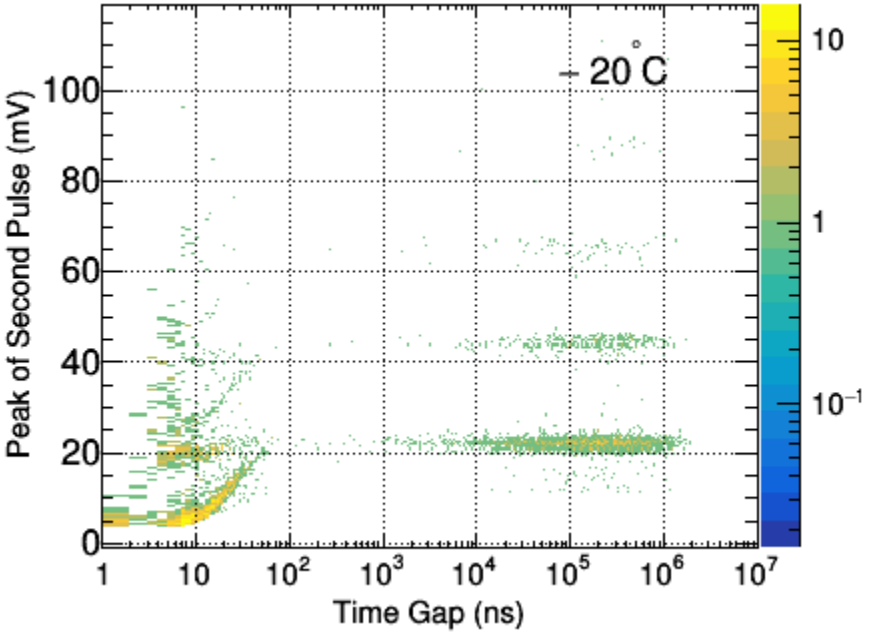
- Variation of τ with temperature is well known
- But also observe a variation with V_{OV}
  - A possible explanation is that the removal of large number of hole for high gain takes longer time

Signal of SiPM with a large time scale



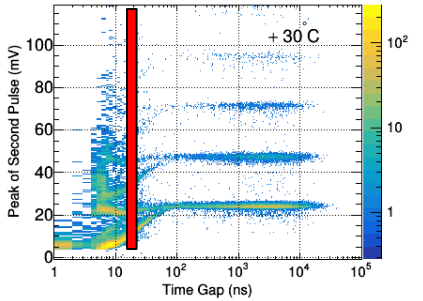
- **Find out all these peaks and get a correlation of the pulse height of second peak and time gap**

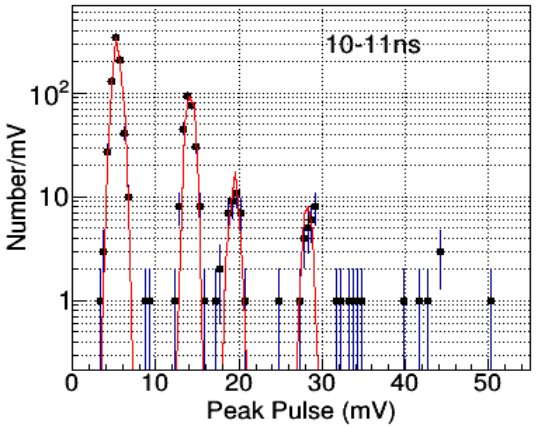


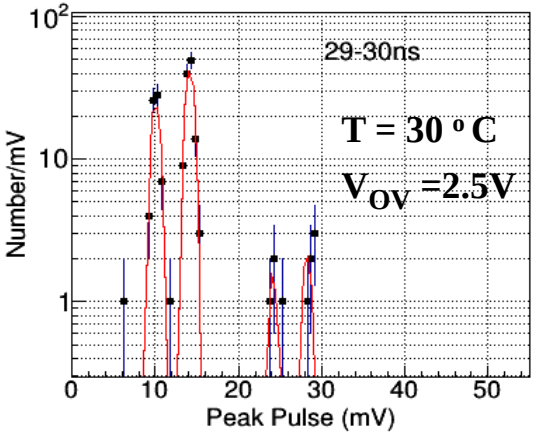


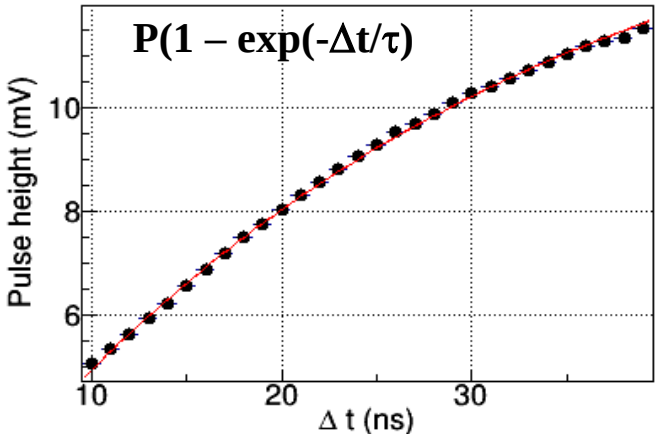
Recovery time

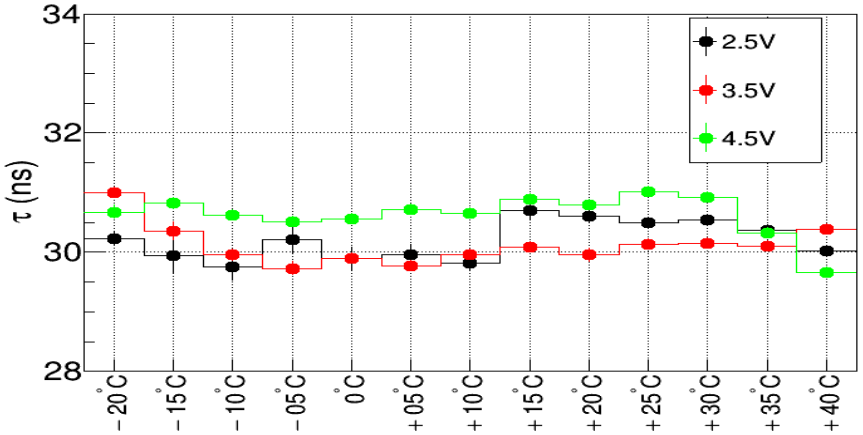
- Fitted signals in Δt time window with four Gaussian functions to find the peaks of AP signals
- Fit the peak position vs Δt to get recovery time

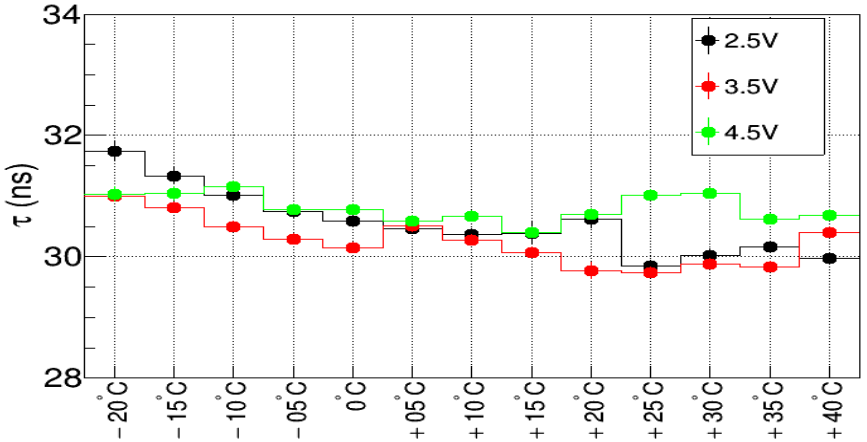








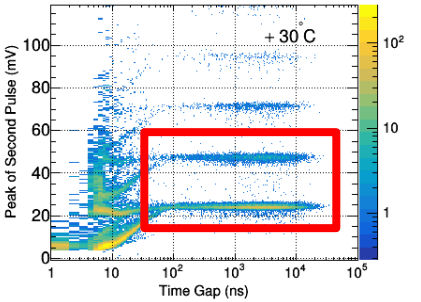


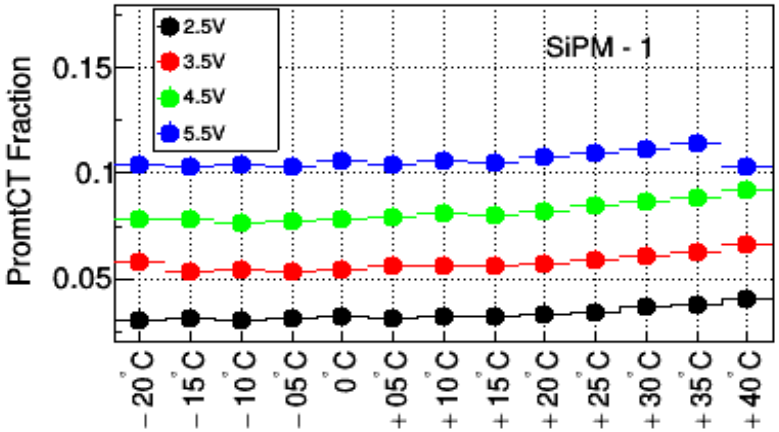


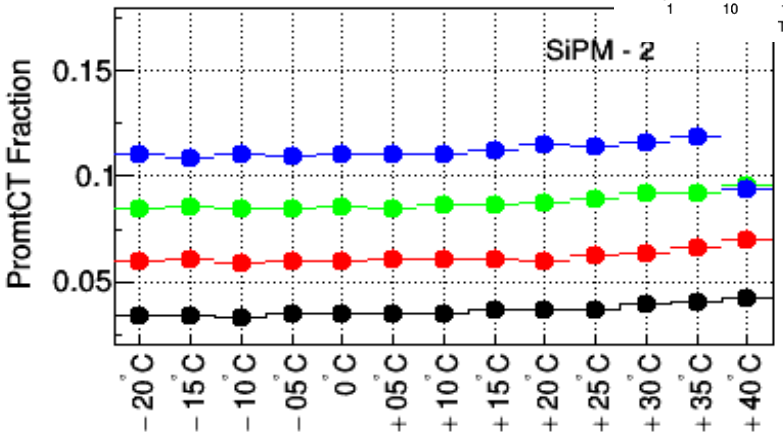
- Range of Δt is very small as well as number of event to have accurate numbers, but
  - There is no clear trends of variation in Recovery time with temperature, V_{OV}
  - Need more data and better algorithm to have data with larger range of Δt

Prompt cross-talk

- **Ratio of 2nd and 1st band**
  - **Expect to have dependency on the gain/V_{OV} of SiPM**

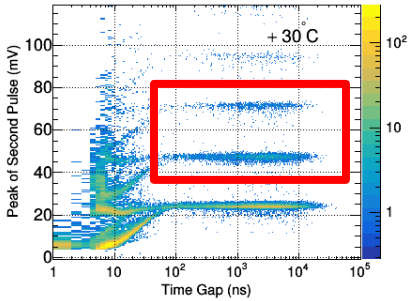


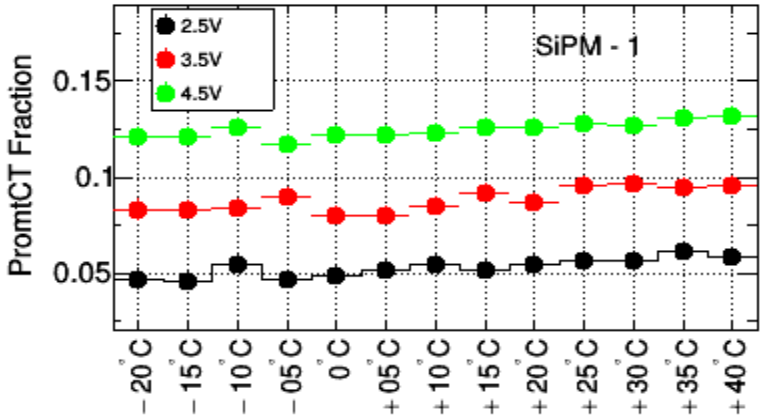


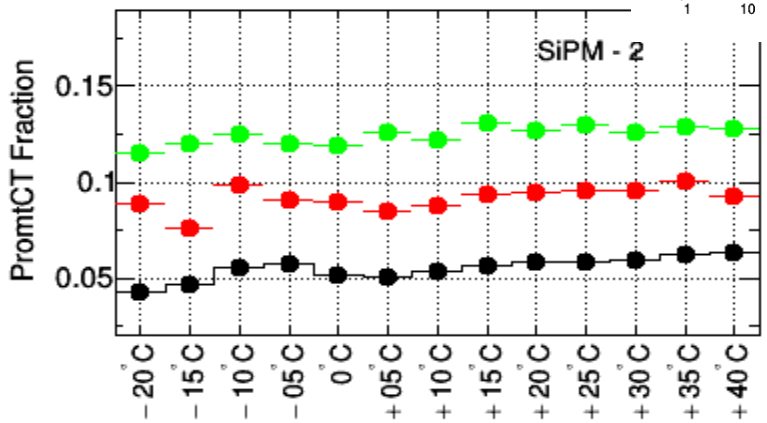


Also a small variation with temperature,

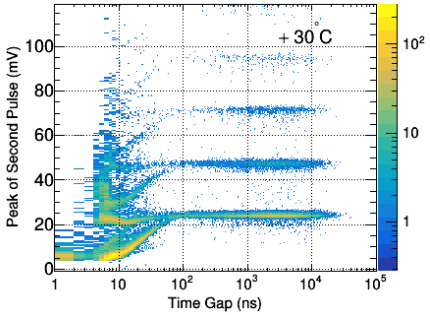
- **Ratio of 3rd and 2nd band**
  - **Expect to have large ratio wrt 2nd/1st band**







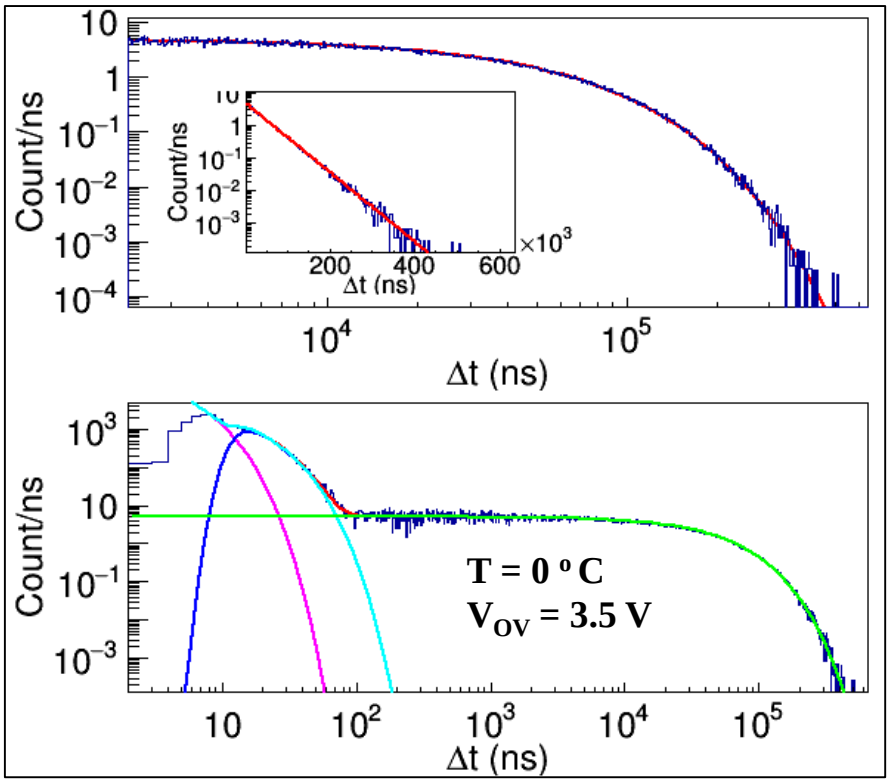
DeCT + AfterPulse

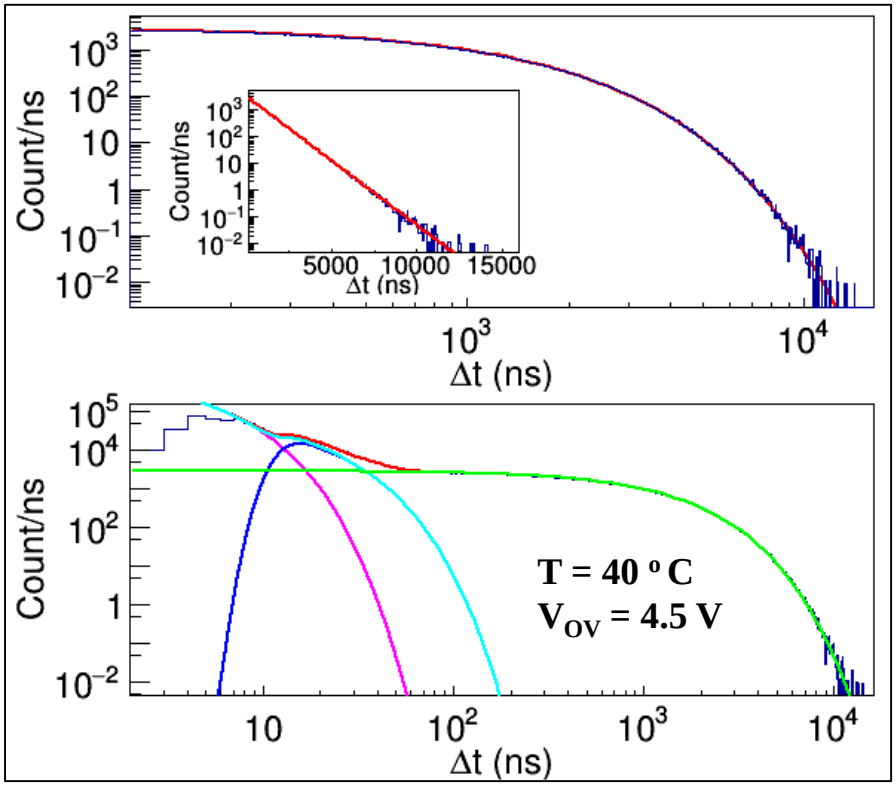


Take projection on X-axis (Δt)

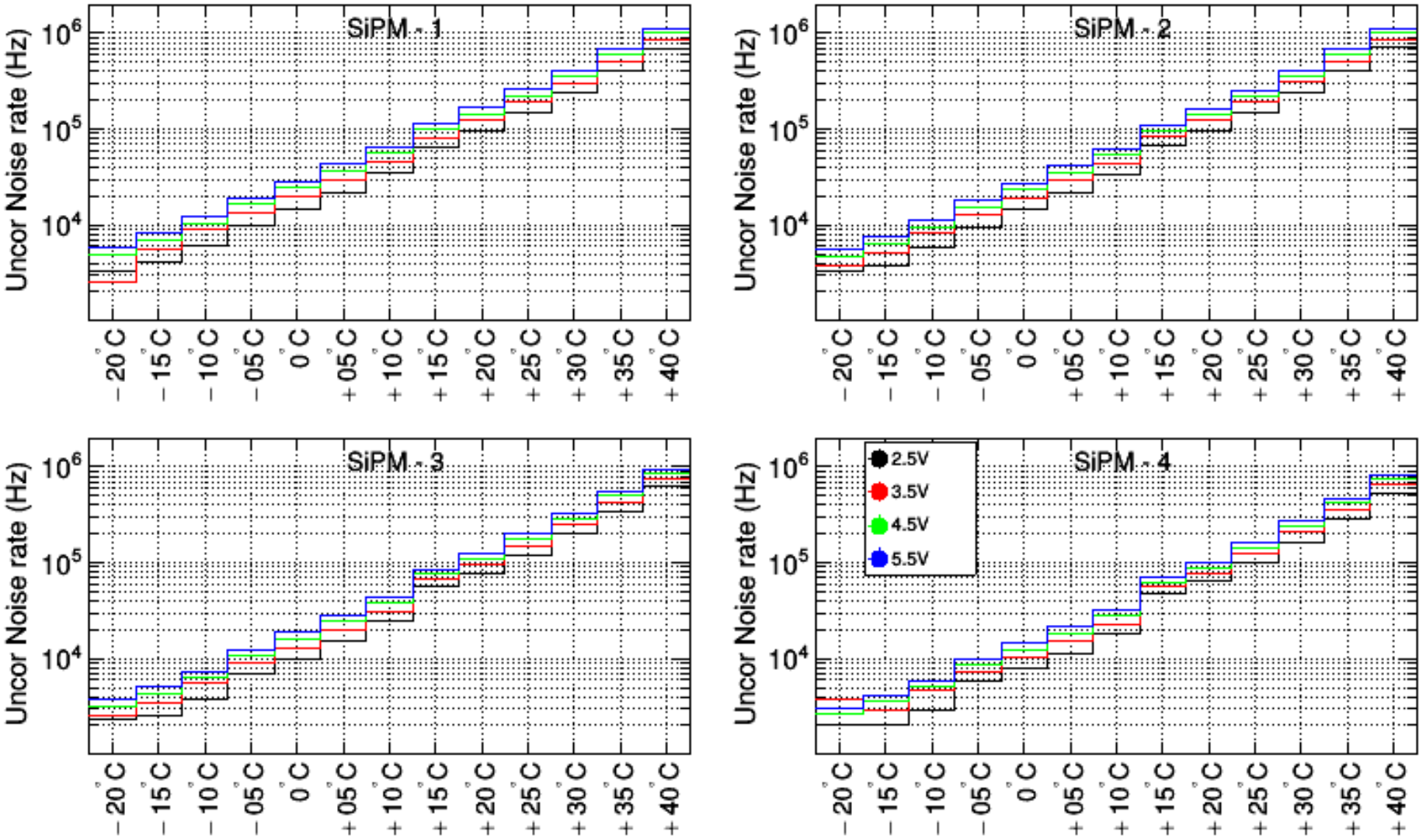
Difficult to separate out DeCT & AP

- **Fit the tail part with simple exponential function to get the uncorrelated noise rate**
- **Combined fit :**
  - **Exponential for Delayed CT**
  - **Exponential with threshold due to pulse height selection criteria as well as resolution for AP**
  - **Fixed parameters of Uncorrelated noise**
  - **Exclude area of low statistics**



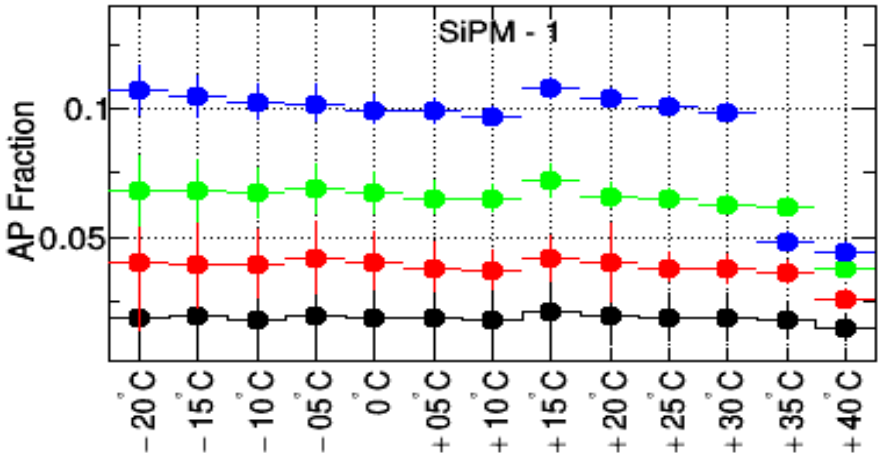


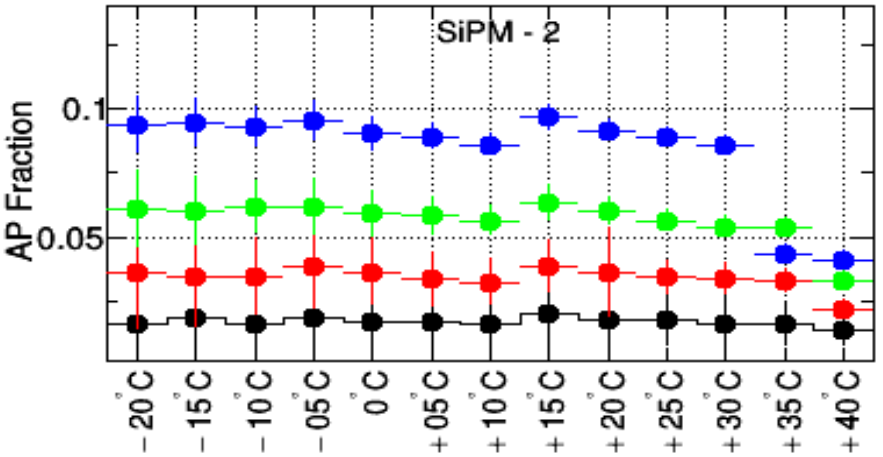
Uncorrelated noise rate : V_{th} = 0.5p.e.

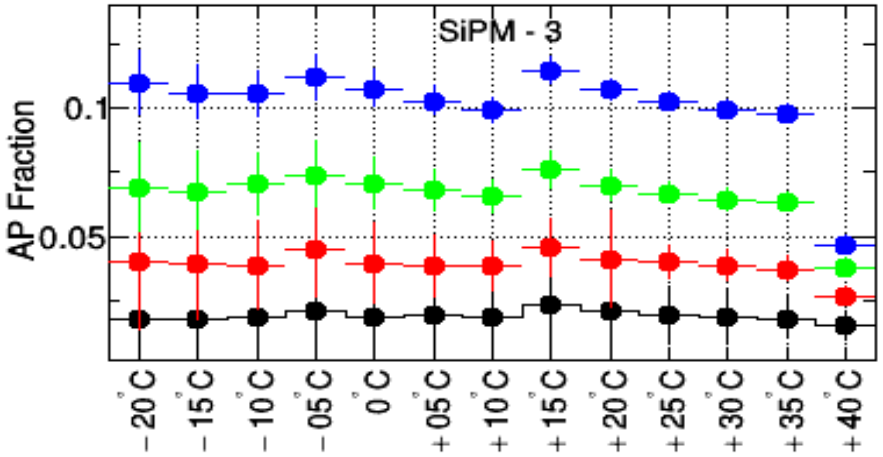


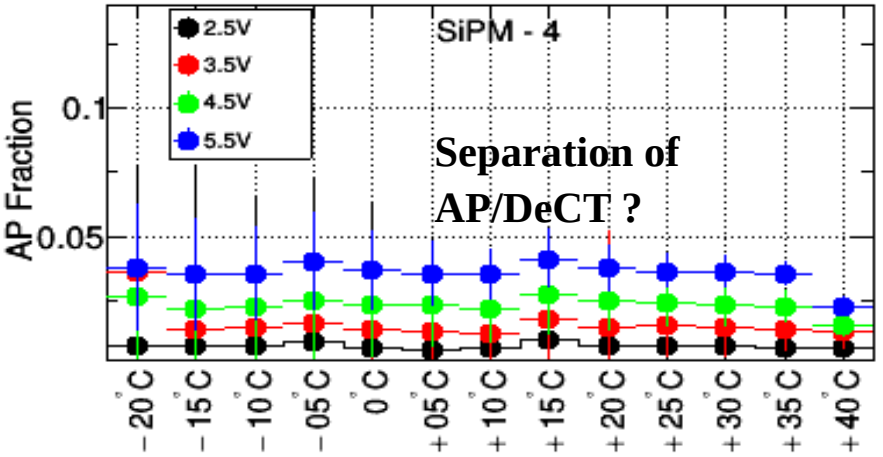
- **As expected**
  - **Increase with Temperature as well as with V_{OV}**

Fraction of After Pulse (from fit parameters)



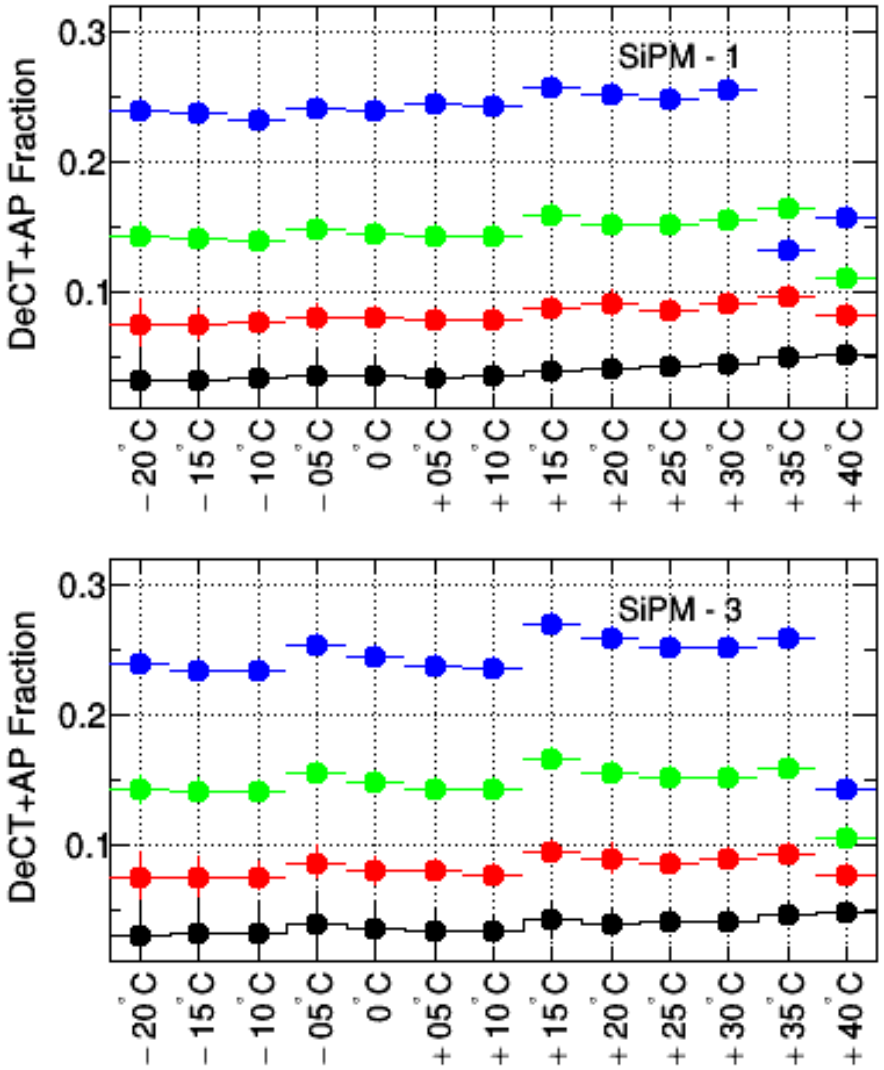


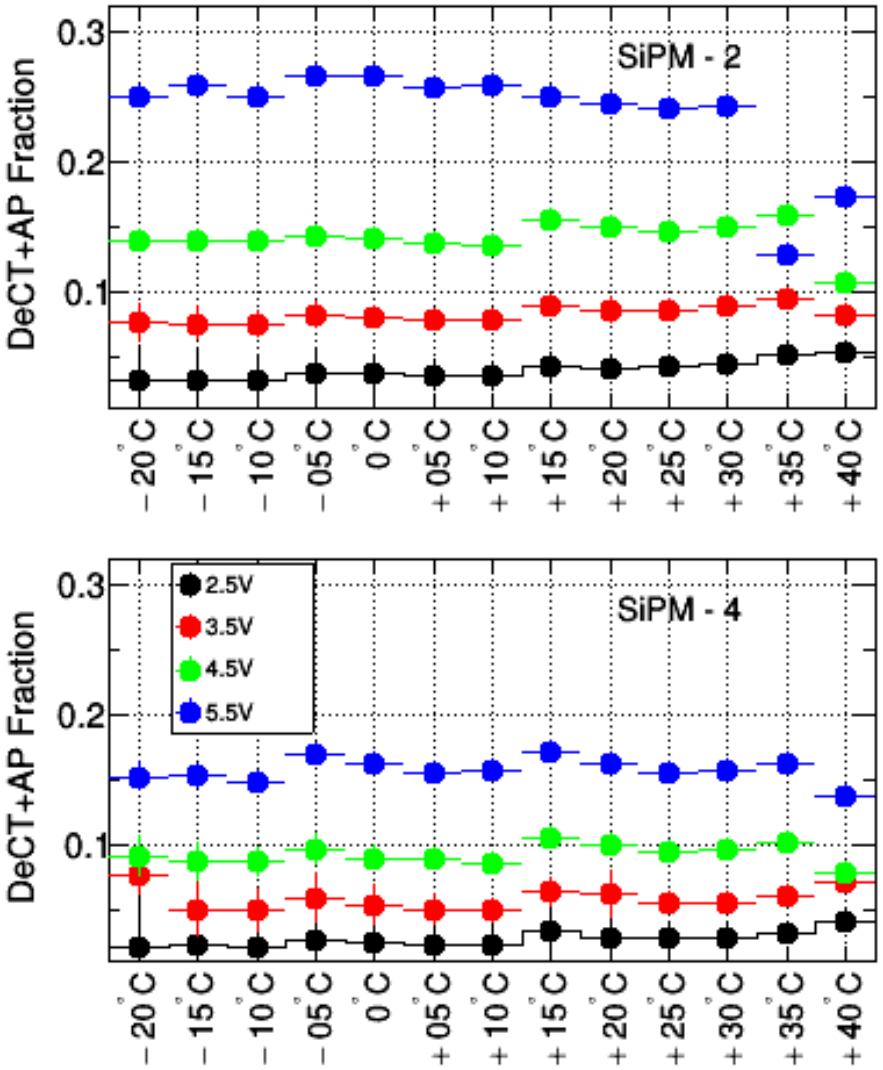




- **Change in Time scale at 15°C has a systematic shifts**
- **Behaviour of 4th SiPM is different than others !!**
- **Readings of High Temp + high V_{OV} (need to look in details)**
- **No increase of fraction with temperature (opposite to PromptOCT)**
  - **Extraction of AP from DeCT may be a possible source, or this is the feature**

Fraction of DeCT+AP (Number count + Fit of Uncor noise)

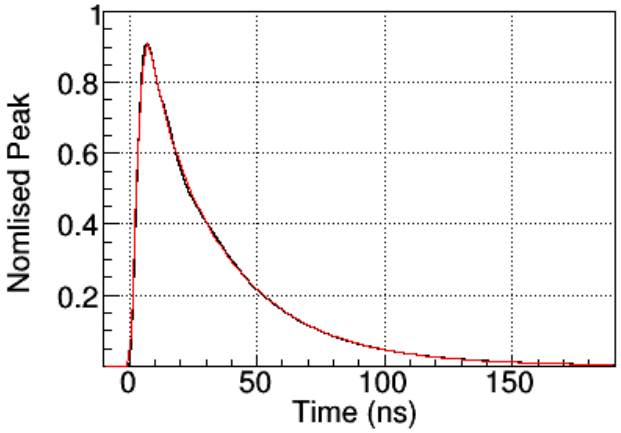


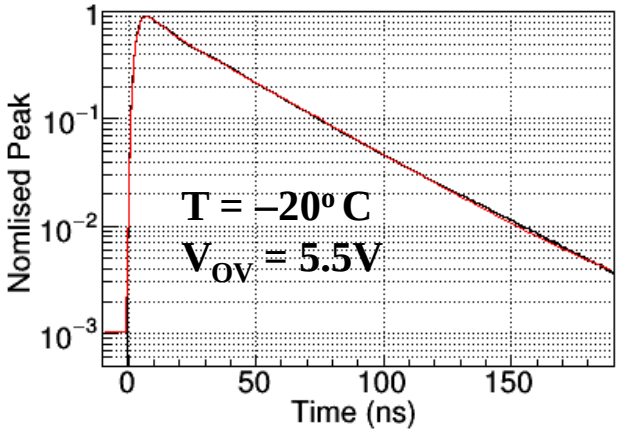


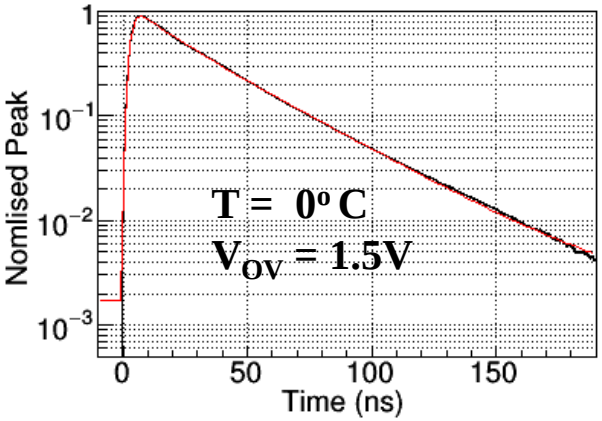
- **Problem with few V_{OV} at high Temperature (need to tune the algorithm)**
- **Nearly same trends of increase with temperature, what was observed in Prompt OCT**

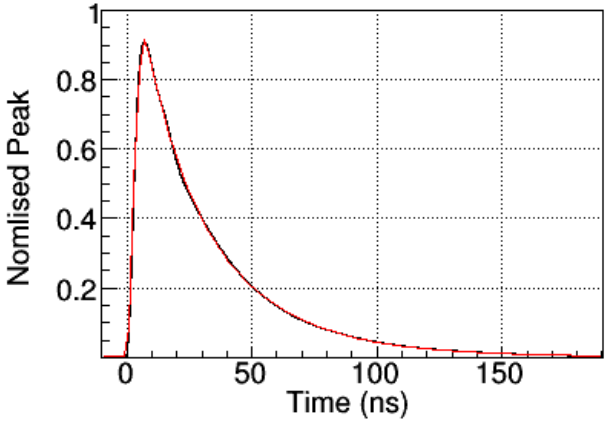
Conclusion

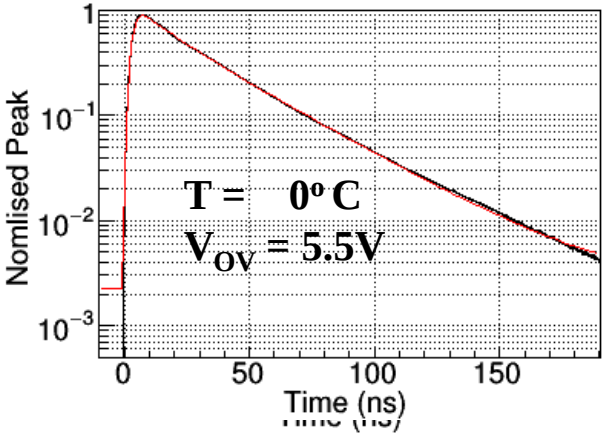
- **Variation of different noise properties have been studied as a function of temperature and V_{OV}**
- **Some qualitative features of those without any strong interpretations are**
  - **Both rise time and fall time of the spectrum varies with temperature as well as $V_{OV,}$**
  - **Did not find any variation on recovery time due to limited statistics (but, does not look like the trends, what was observed for fall time),**
  - **Prompt cross talk increases with temperature and depends on the initial pulse,**
  - **AP does not vary with Temp and**
  - **Combination of DeCT+AP follows the same trends of PromptOCT**
- **Need more data to confirm all these properties**
- **Need to improve the readout to distinguish DeCT and AP as well as algorithms**

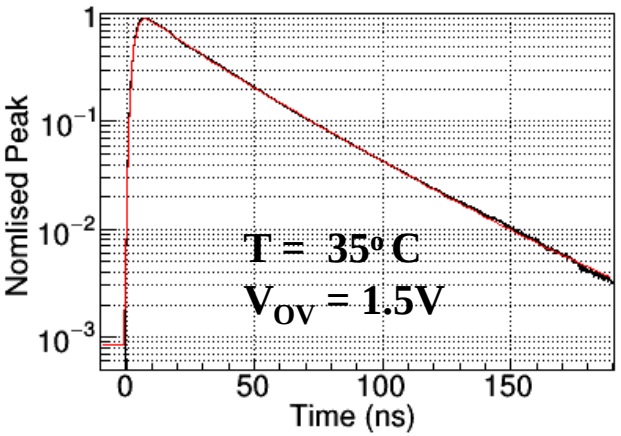

Nomlised Peak
Time (ns)


T = –20° C
V_{OV} = 5.5V
Nomlised Peak
Time (ns)


T = 0° C
V_{OV} = 1.5V
Nomlised Peak
Time (ns)


Nomlised Peak
Time (ns)

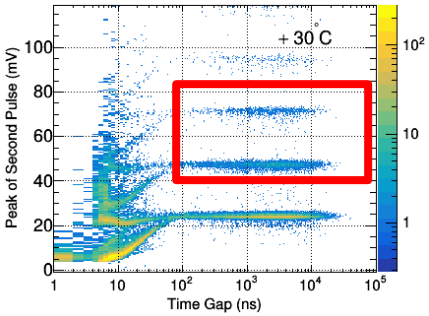

T = 0° C
V_{OV} = 5.5V
Nomlised Peak
Time (ns)

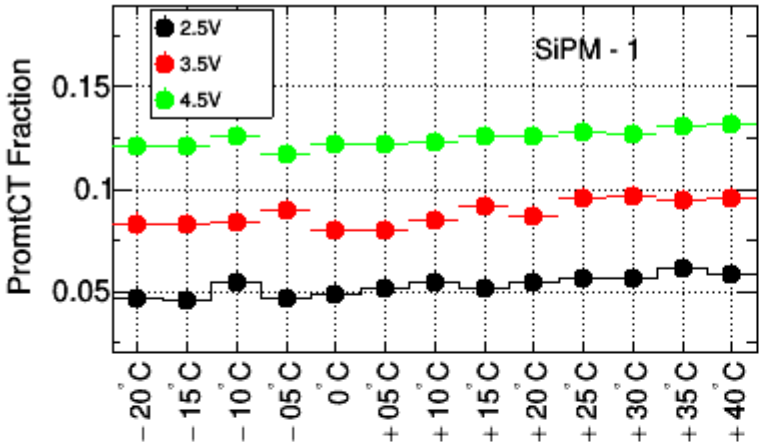

T = 35° C
V_{OV} = 1.5V
Nomlised Peak
Time (ns)

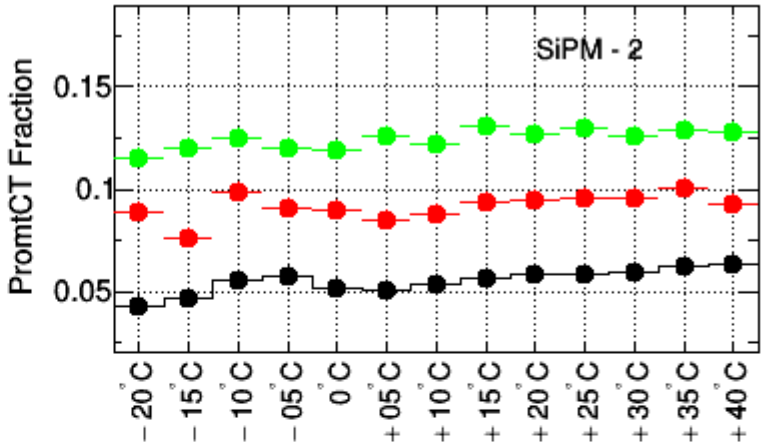
Prompt cross-talk

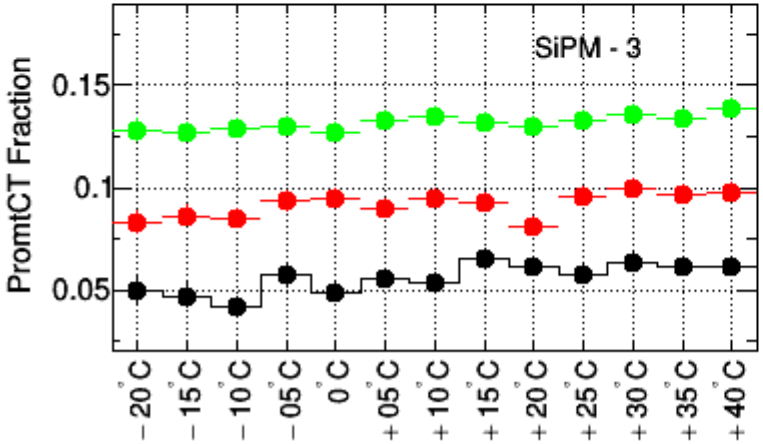
(Ratio of 3rd and 2nd band)

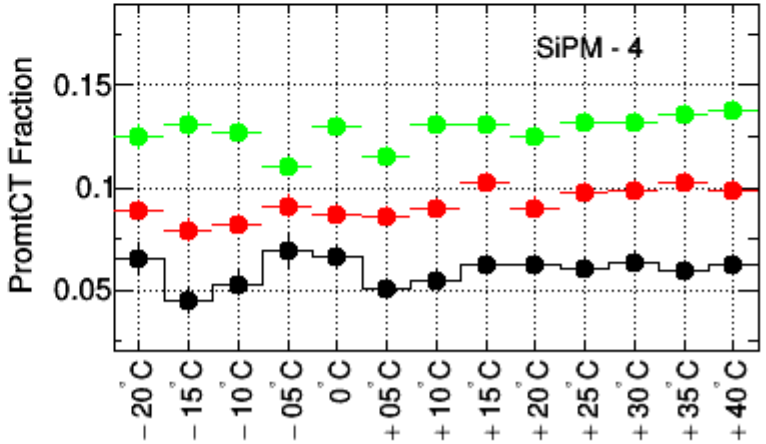
- Expect to have large ratio wrt 2nd/1st band







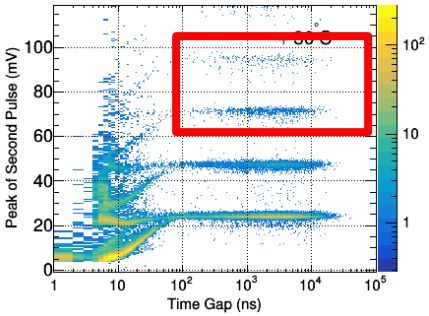




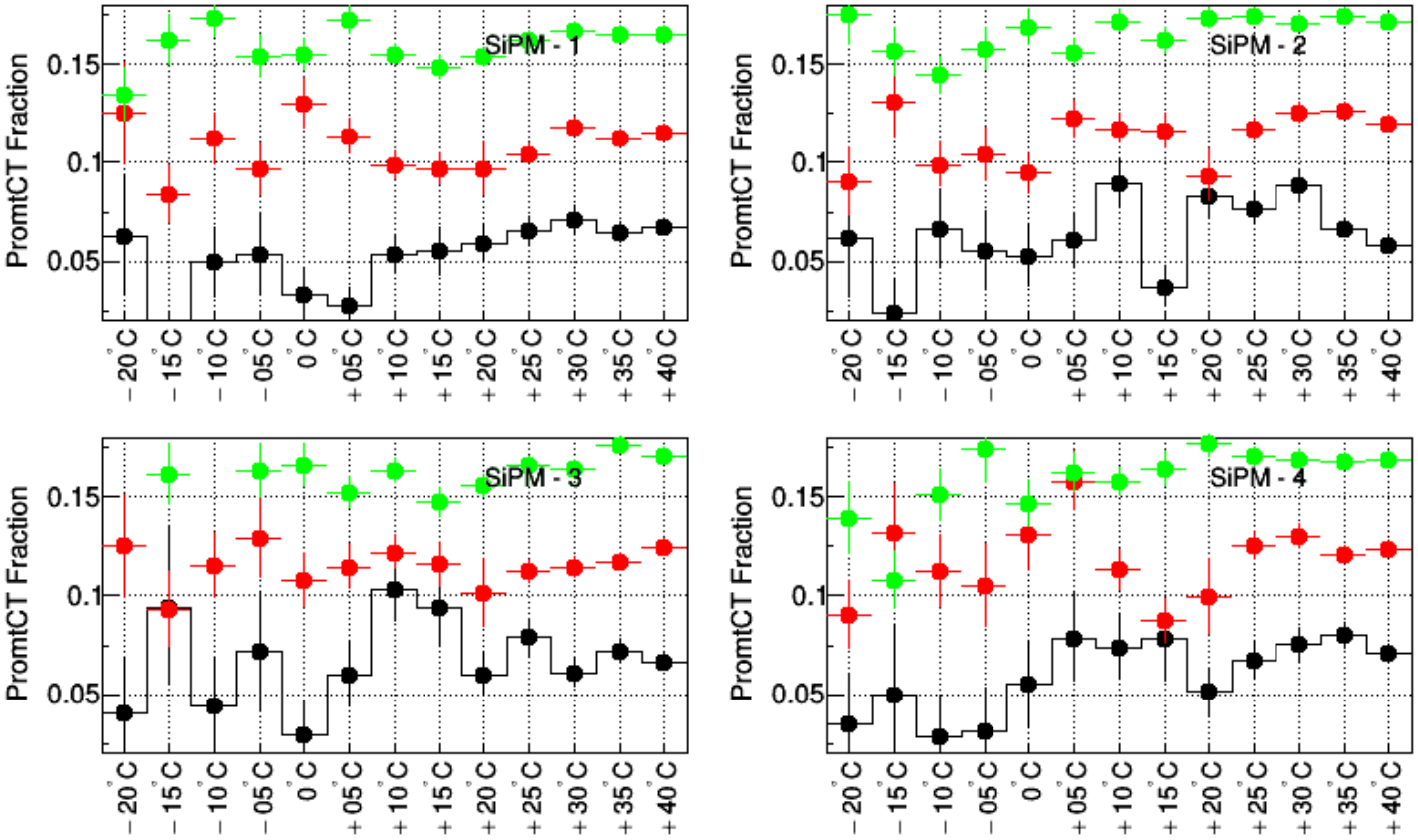
- Also a small variation with temperature,

Prompt cross-talk

(Ratio of 4th and 3rd band)

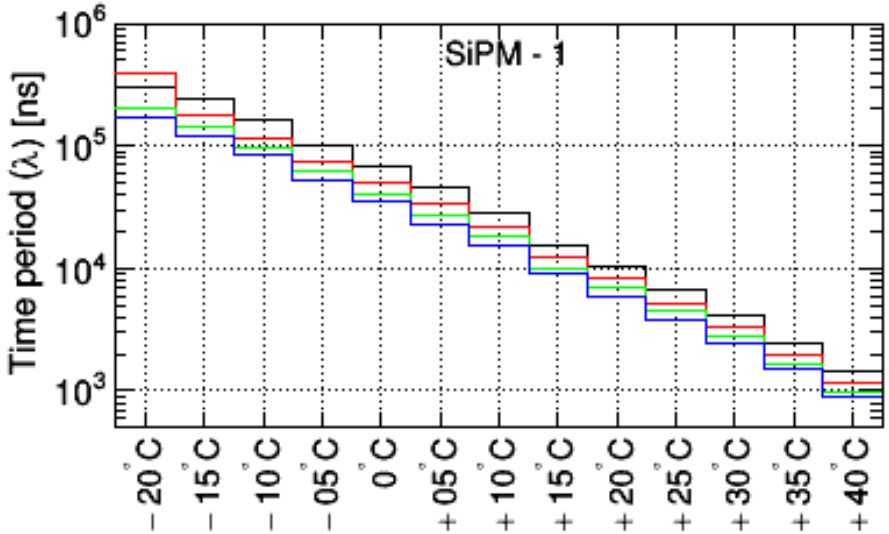


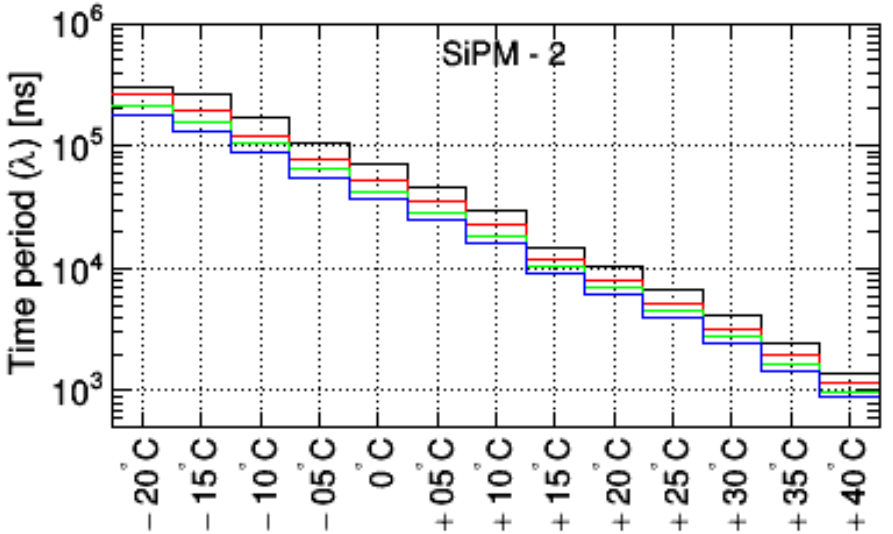
- **Expect to have larger ratio wrt to earlier**

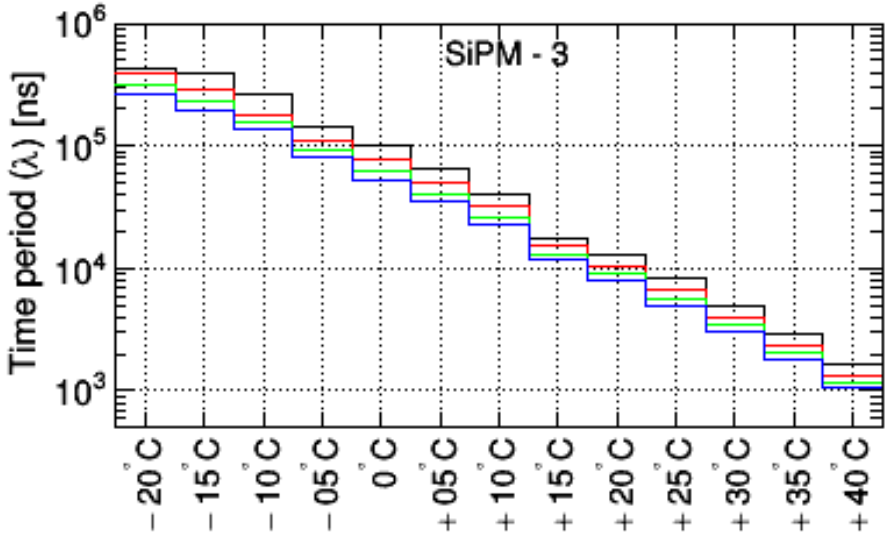


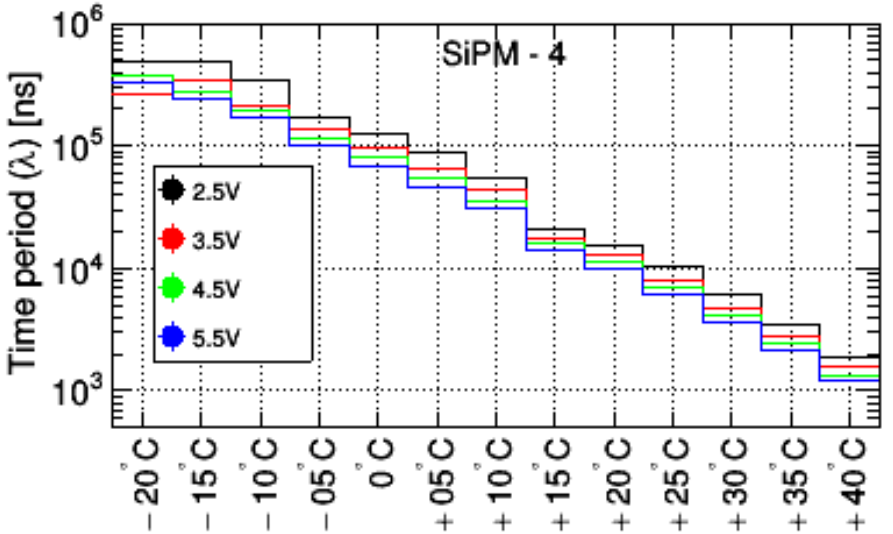
- **Overall ratios are larger, but due low larger statistical uncertainty, can not make any judgement on its trends or proportionality wrt to earlier two**

Time period for Uncorrelated noise

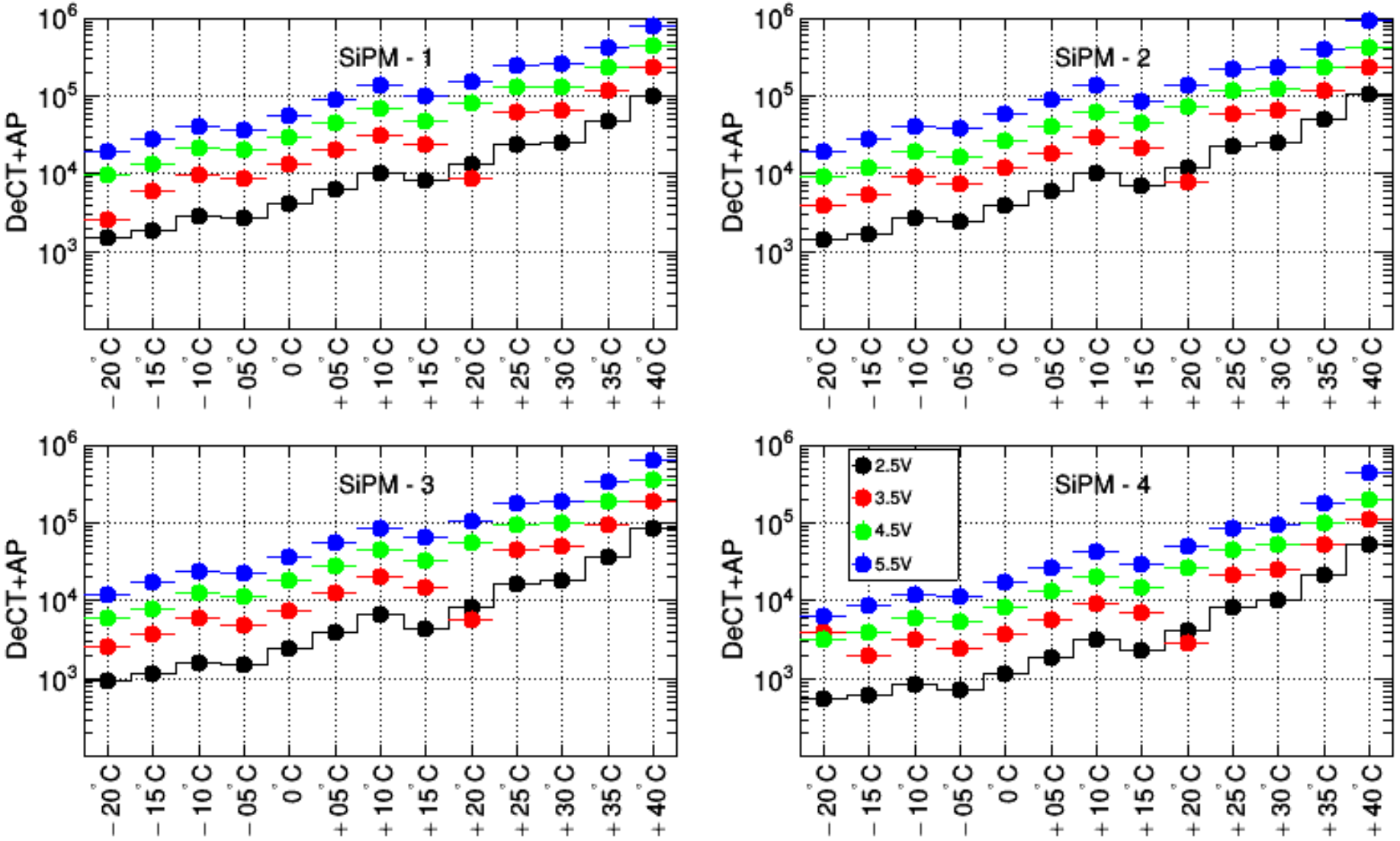




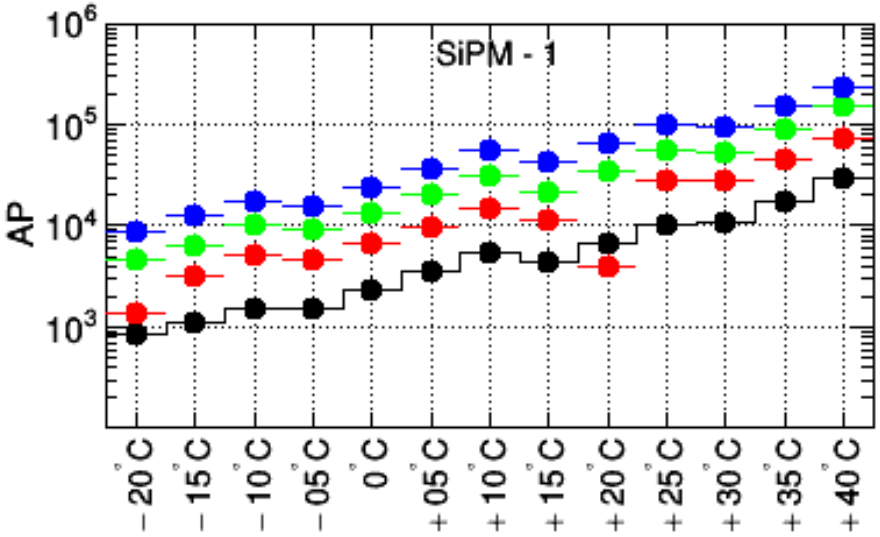


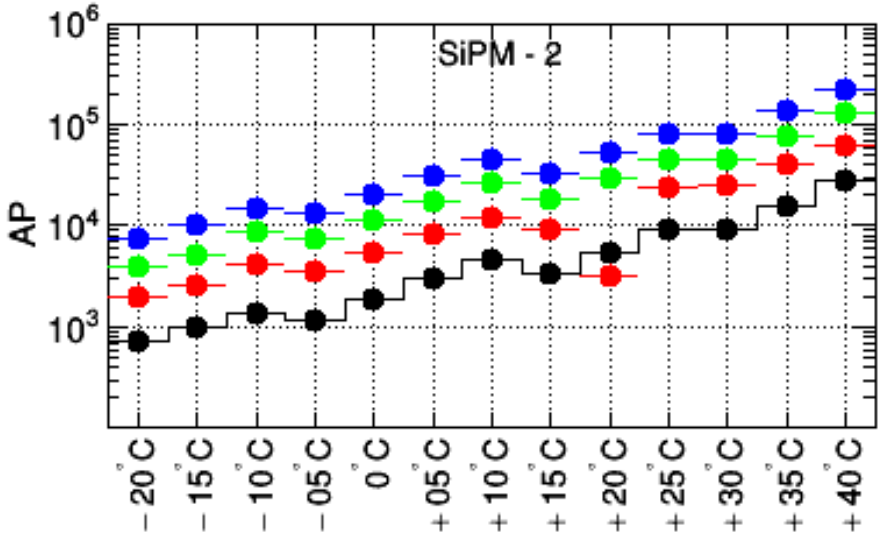


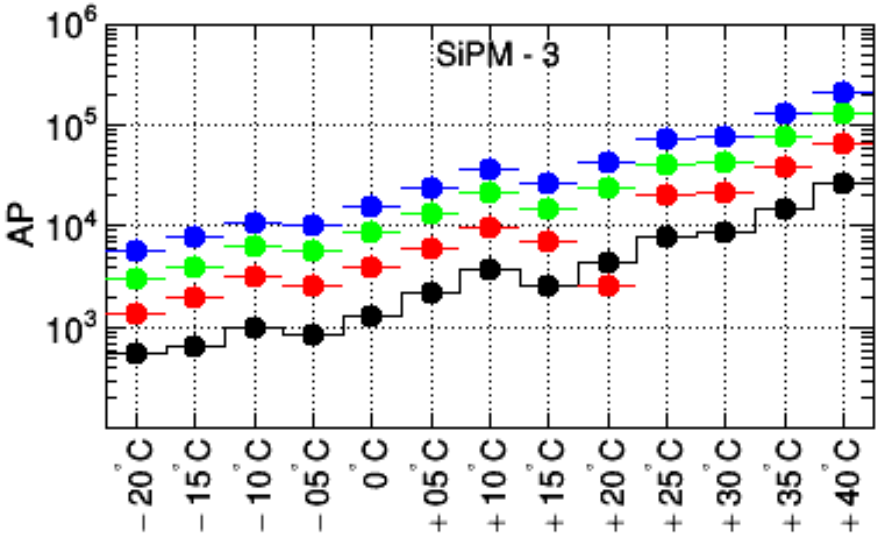
DeCT+AP (Arbitrary scale)

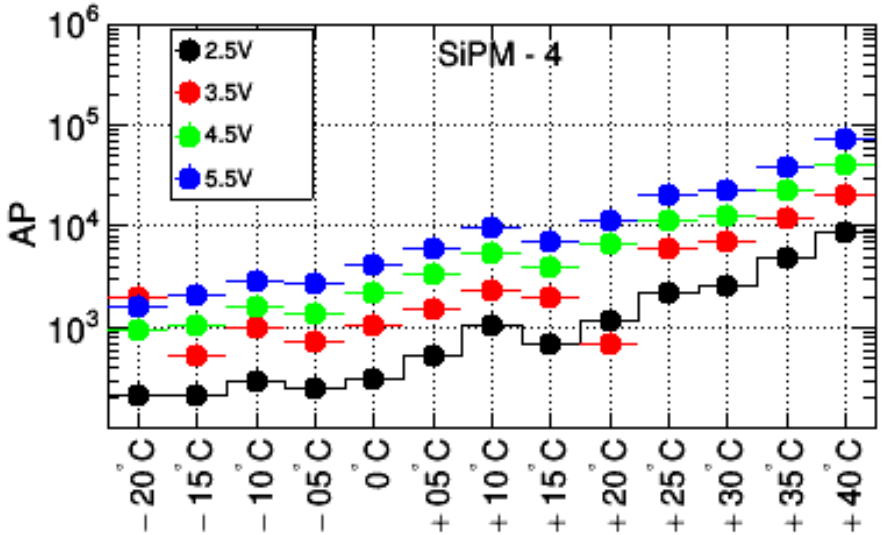


After pulse rate (arbitrary unit)

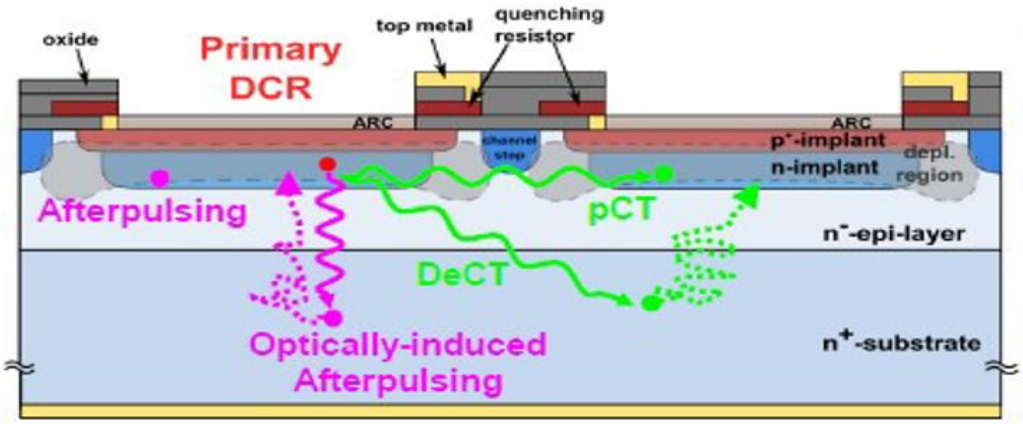


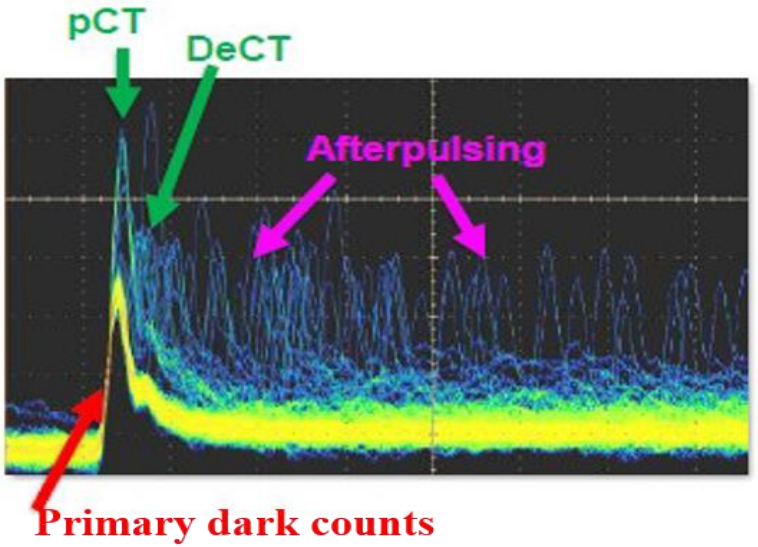
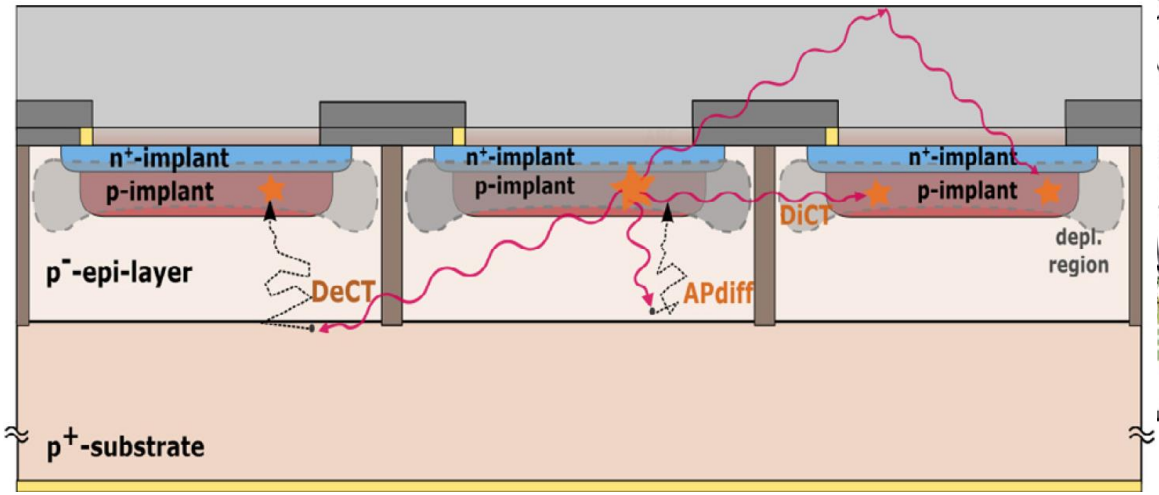
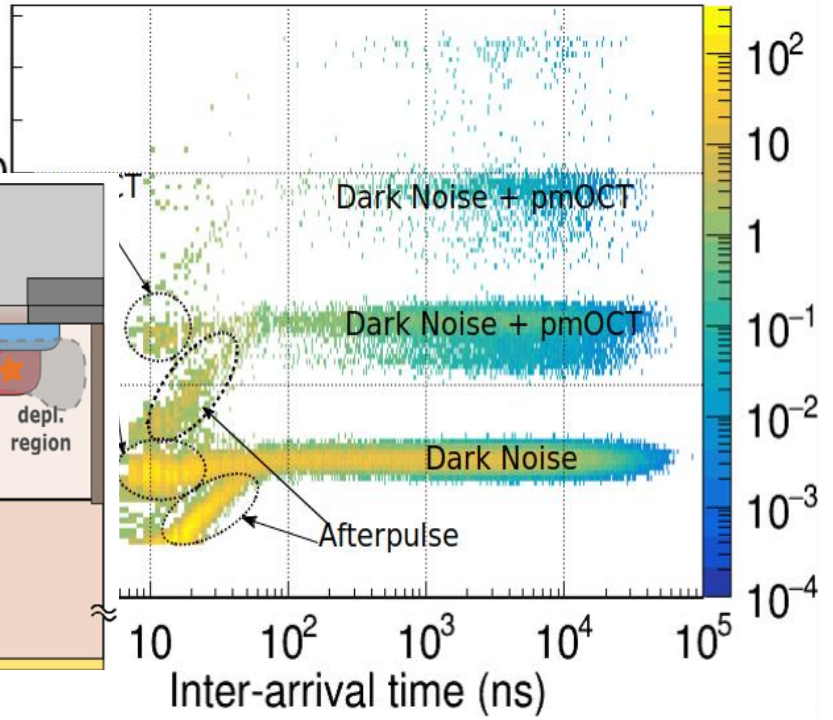






Explanation of different noise rate





- **Own plots**