Understanding the temperature and humidity dependence of the SiPM characteristics

Gobinda Majumder, Mandar Saraf, Raj Shah, Mamta Jangra

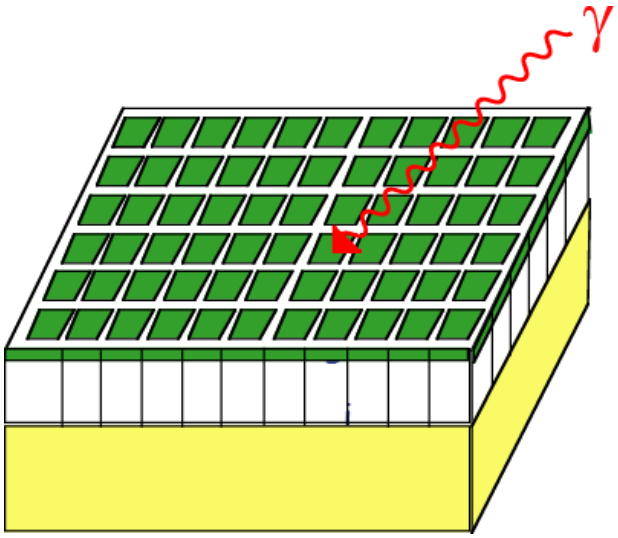
TIFR, Mumbai, India

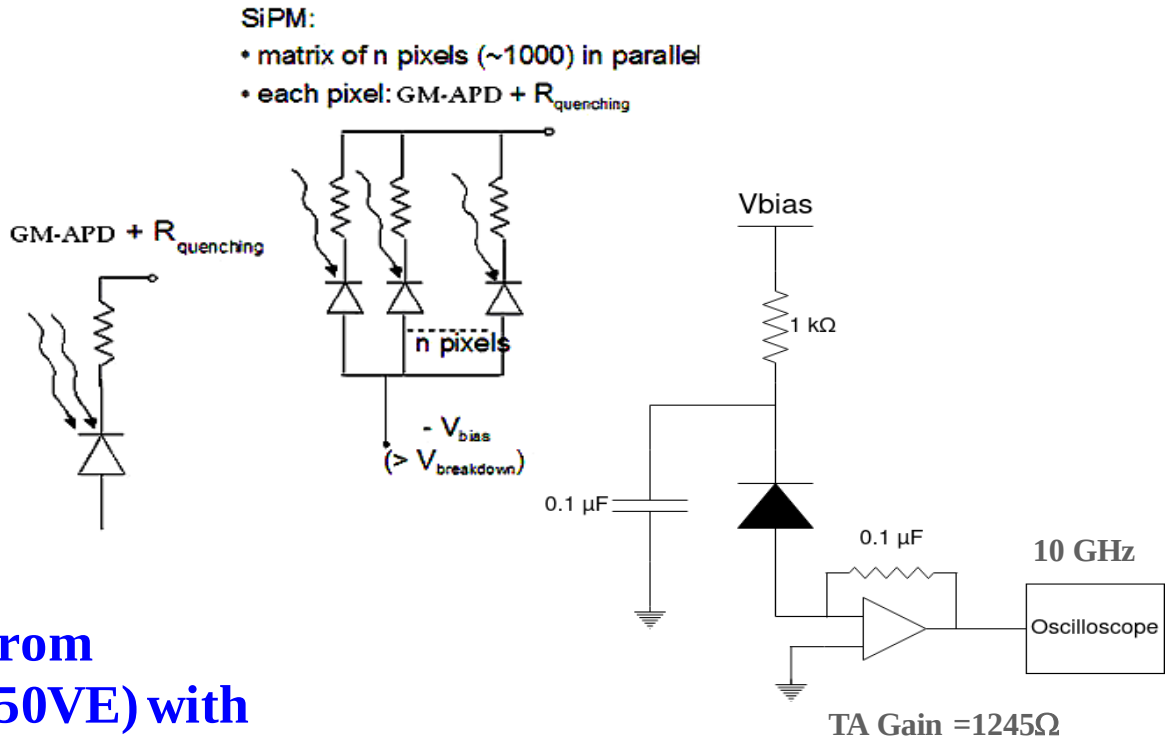
- **Introduction to SiPM signal and noise**
- **Effect of humidity**
- **Signal shape and fit to extract falling slope**
- **Recovery time**
- **Fraction of prompt Cross talk events**
- **Ratio of After Pulse + Delayed Cross talk**
- **Conclusion**

Most of the results are based on only noise signals of SiPM, though similar studies were done with LED sources also.

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

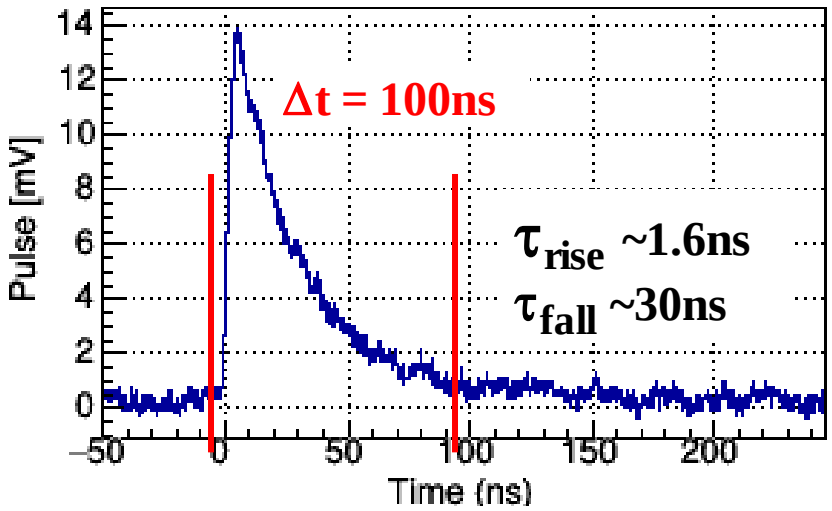
Introduction



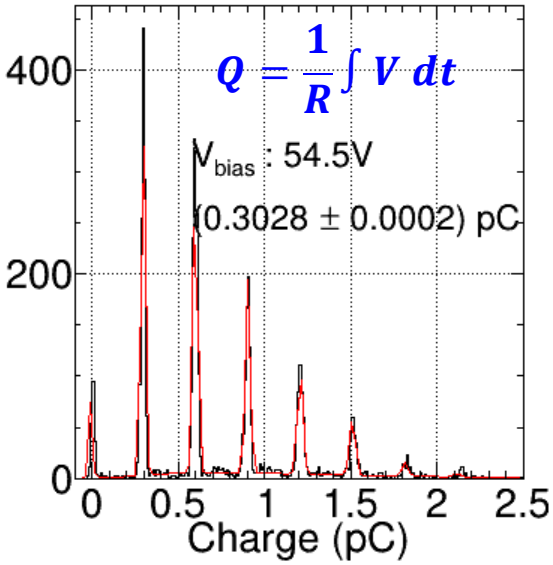


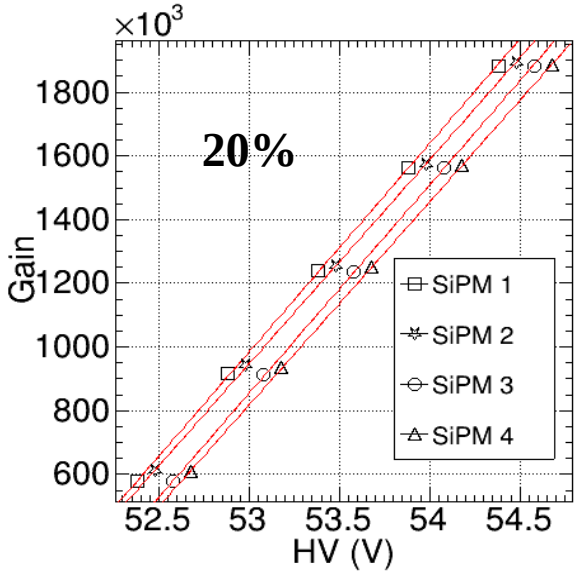
- **The SiPM under test is from Hamamatsu (S13360-2050VE) with**
  - **Photosensitive area of 2 mm×2 mm and a pixel pitch of 50 μm**
  - **Breakdown voltage of (53 ± 5) V**
  - **dG/dV ~ 6.5×10^5**
  - **dV_{th}/dT ~55mV/°C**
  - **dG/dT ~ –2%**

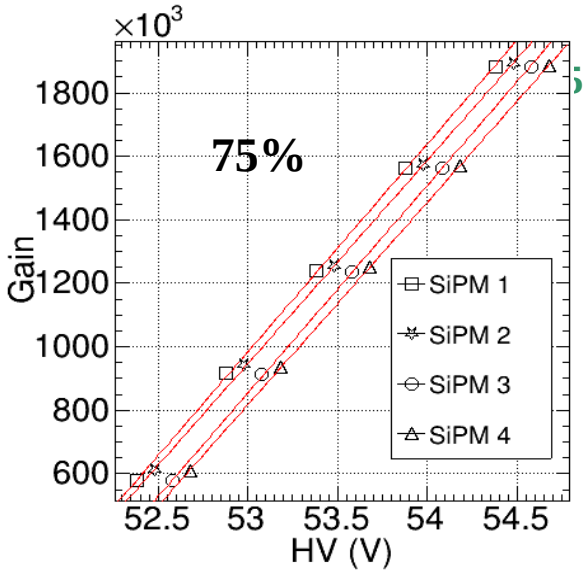
$$Q = \frac{1}{R}\int V\,dt$$



Any effect of Humidity ?





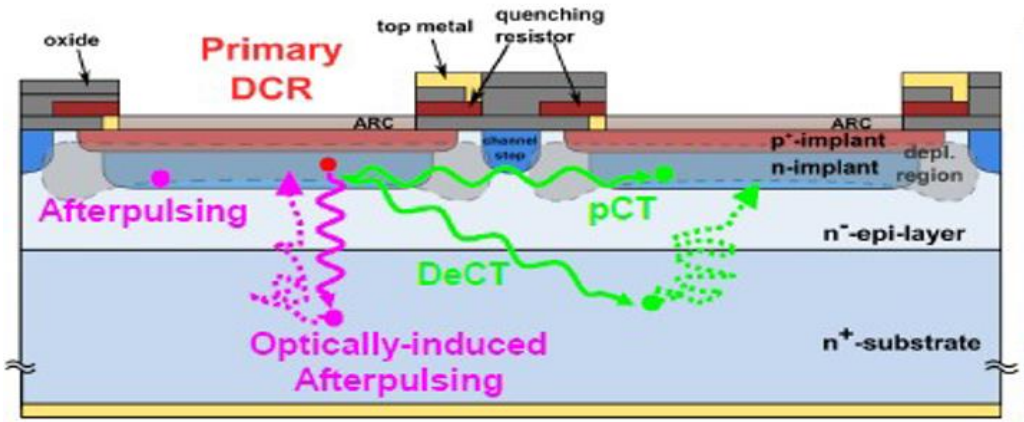


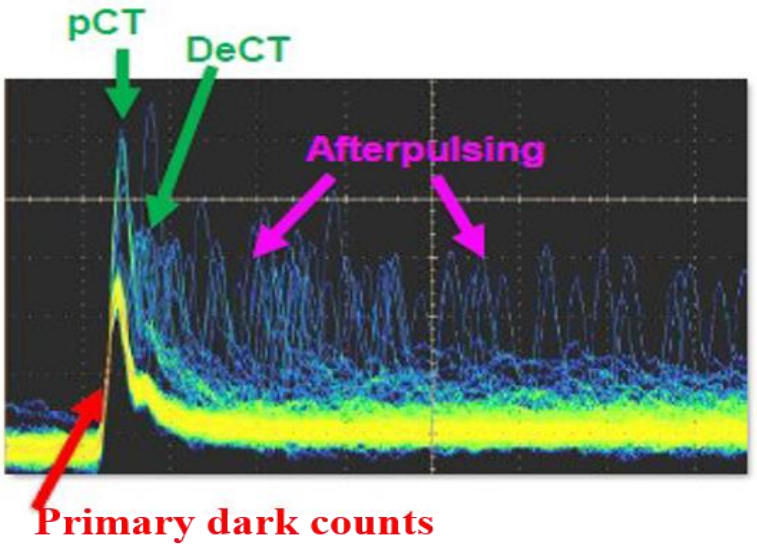
Thermal chamber is used to maintain the temperature (21.2°C) and Humidity (20%)

SiPM	dG/dV (1/V) × 10^3		V_{bd}	
	Humidity (20%)	Humidity (75%)	Humidity (20%)	Humidity (75%)
1	655 ± 0.4	654 ± 0.5	51.496 ± 0.001	51.496 ± 0.001
2	641 ± 0.5	640 ± 0.6	51.421 ± 0.001	51.424 ± 0.001
3	654 ± 0.5	653 ± 0.7	51.493 ± 0.001	51.493 ± 0.001
4	638 ± 0.7	635 ± 0.8	51.418 ± 0.002	51.412 ± 0.002

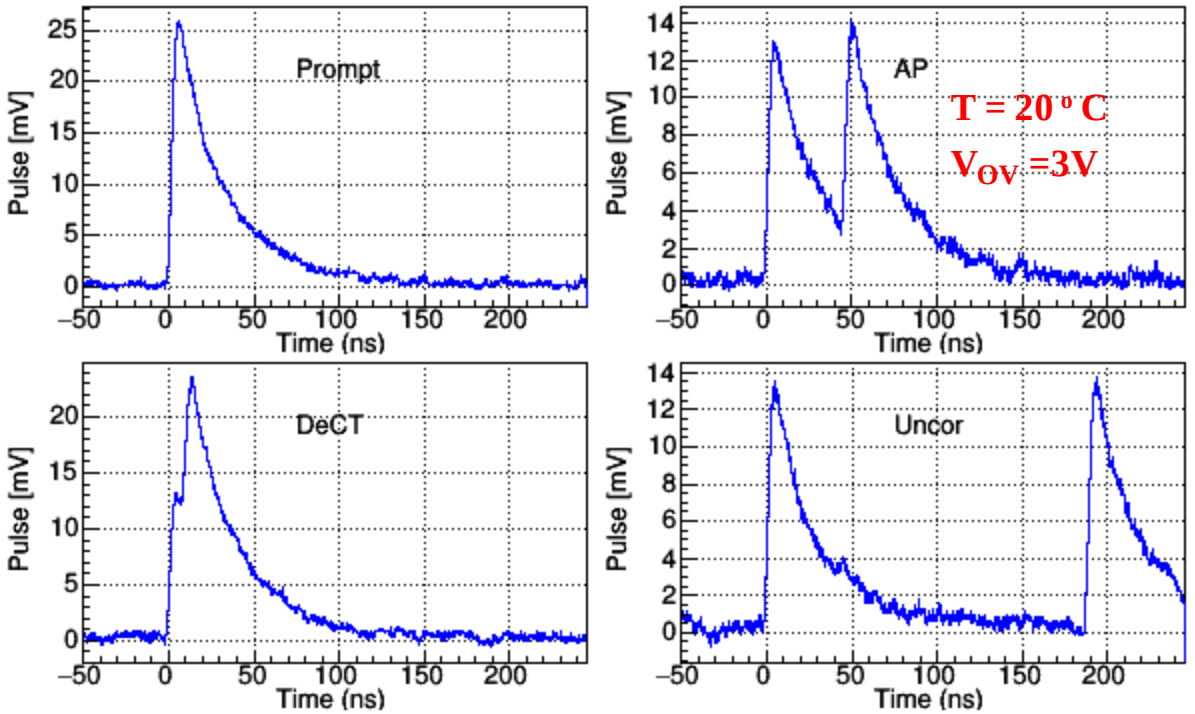
- V_{bd} and Gain does not change with humidity, which is expected
- But, yet to test a long term effect of humidity on SiPM

Signal shape and Correlated noises in SiPM





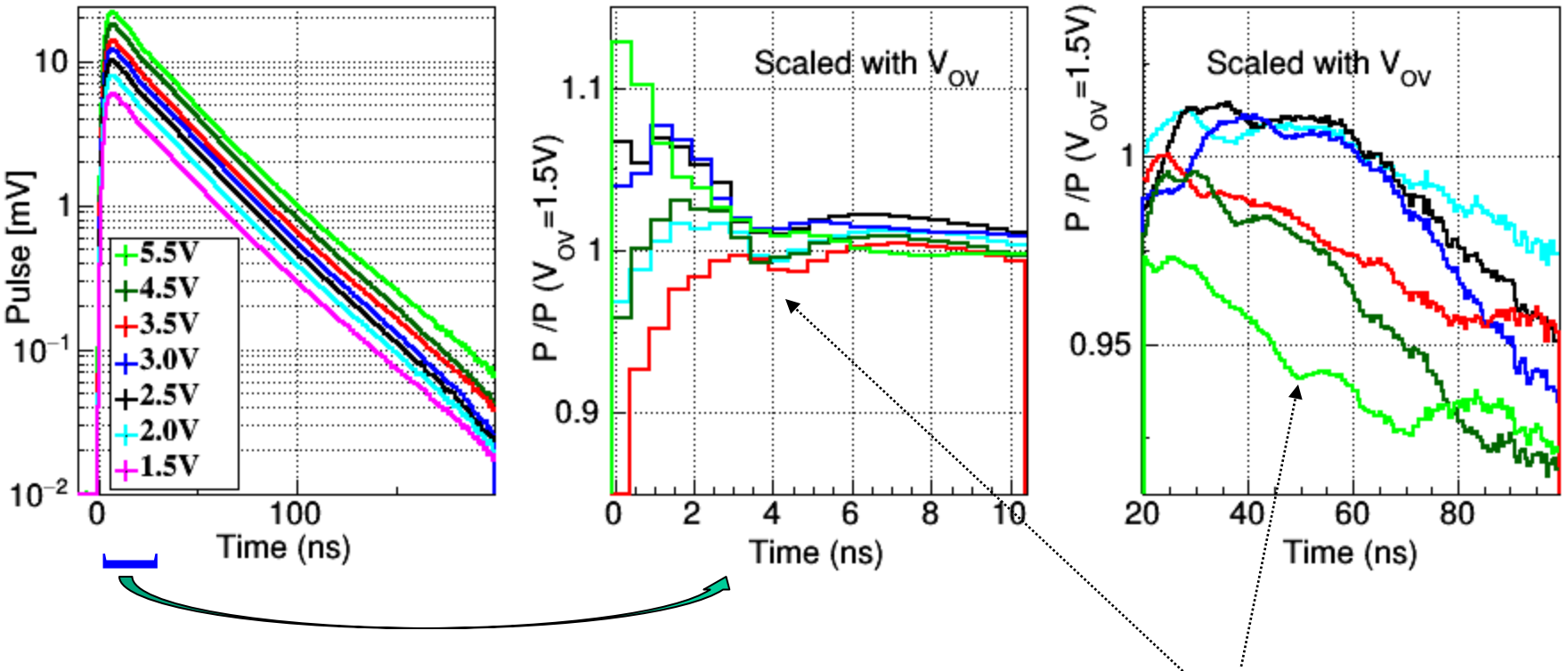
Note : Vertical scales are different



Signal shapes at various overvoltage @T=20°C

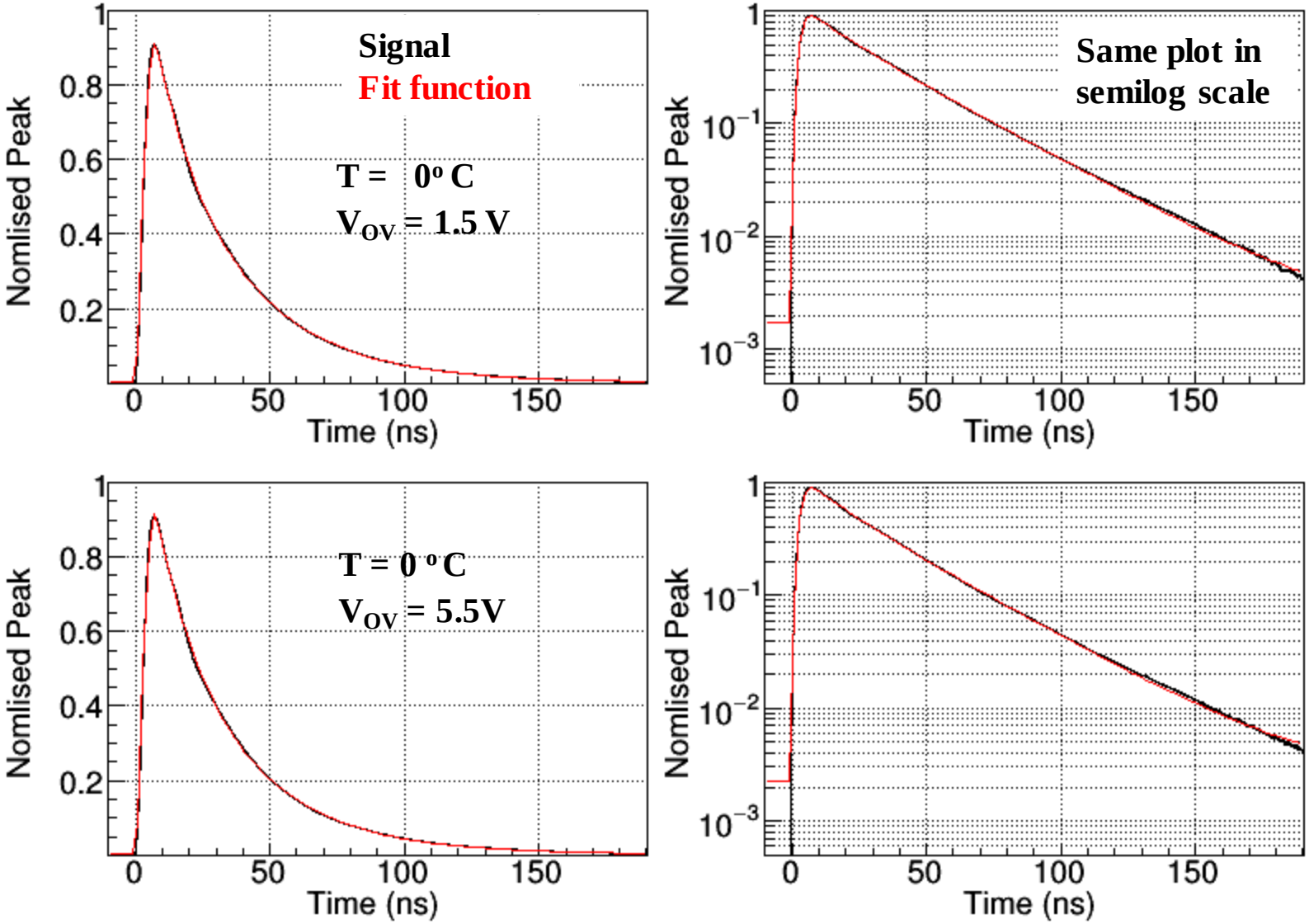
- It is well known that the recovery time depends on the temperature
  - Is there any effect variation due to V_{OV} ?

Superimpose many data by adjusting the starting time, use χ^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}

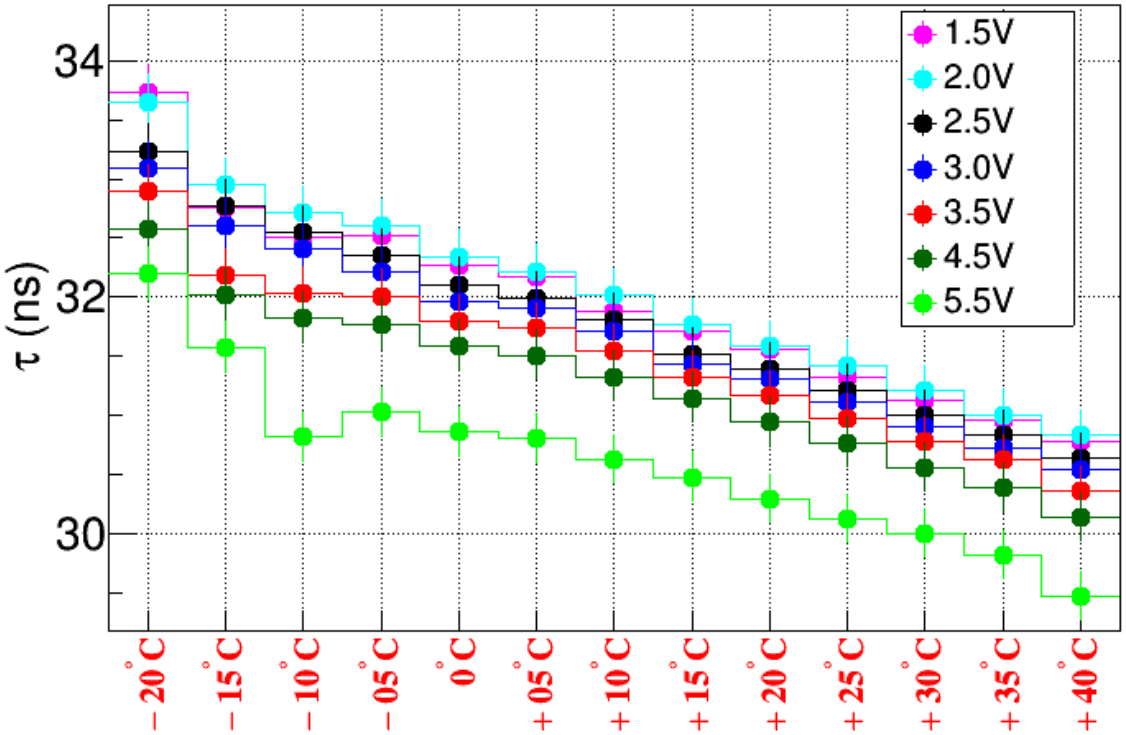


Signals are fitted with a function which includes growth of signal and two exponential falling curves.

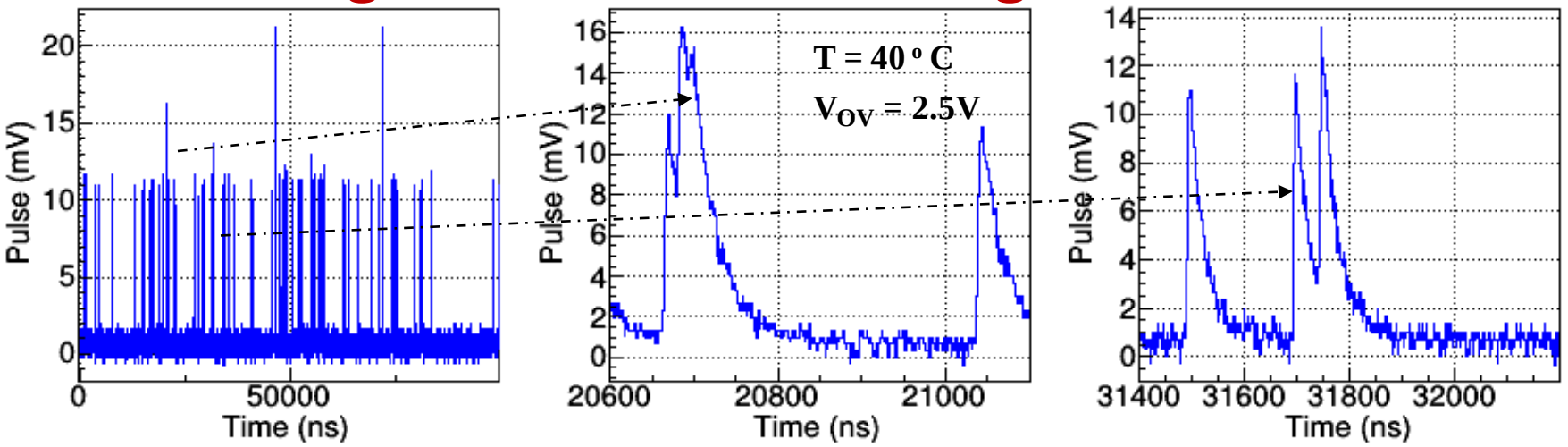
Variation of falling components with V_{OV}

- 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

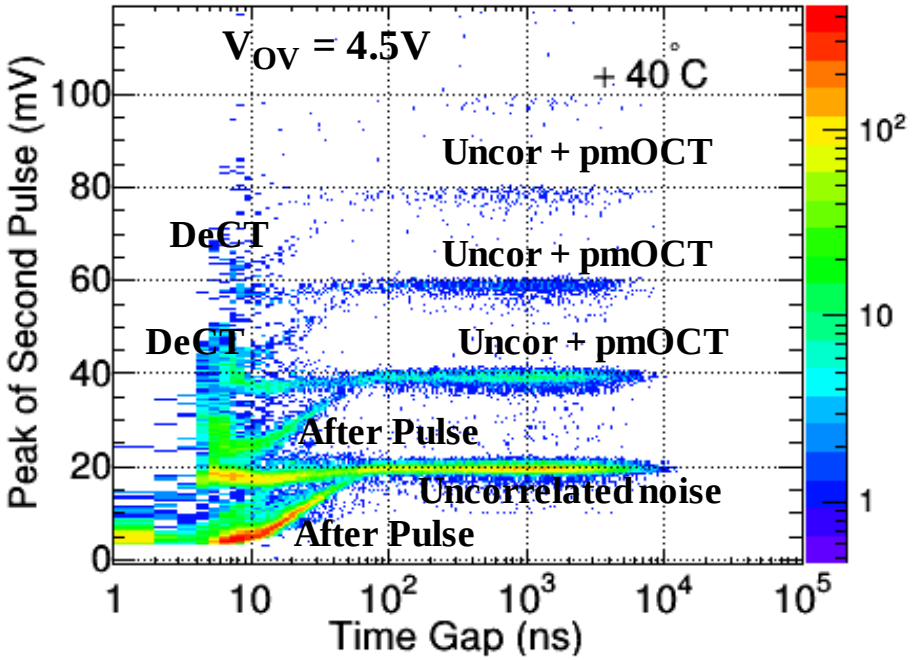
- Variation of τ with temperature is well known
- But also observe a variation with V_{OV}
  - A possible explanation is that the removal of large number of hole for high gain takes longer time

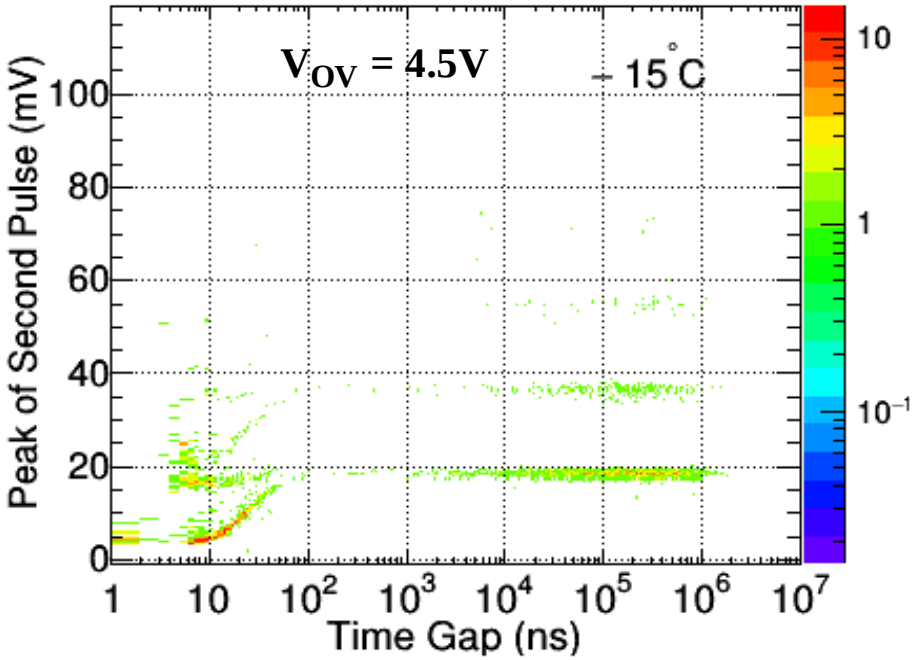


Signal of SiPM in the large time scale



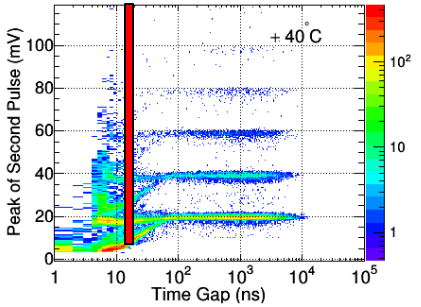
Find out all these peaks and get a correlation of the pulse height of second peak and time gap

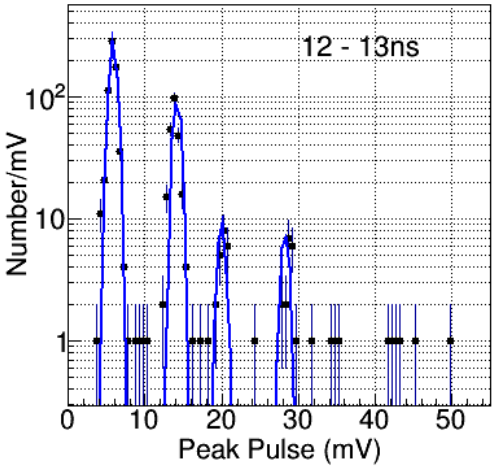


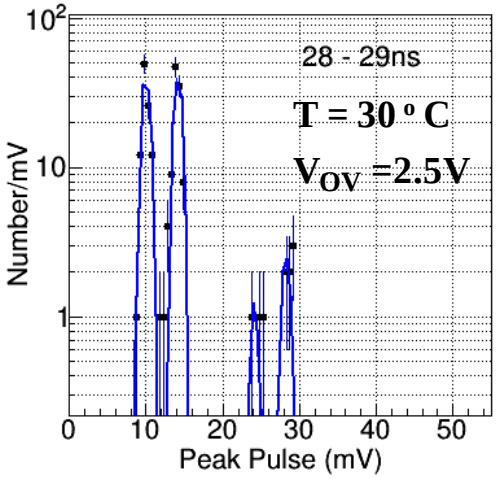


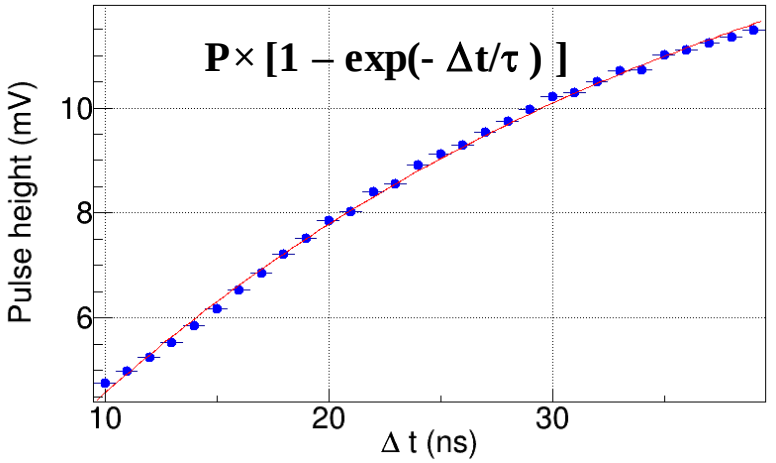
Recovery time

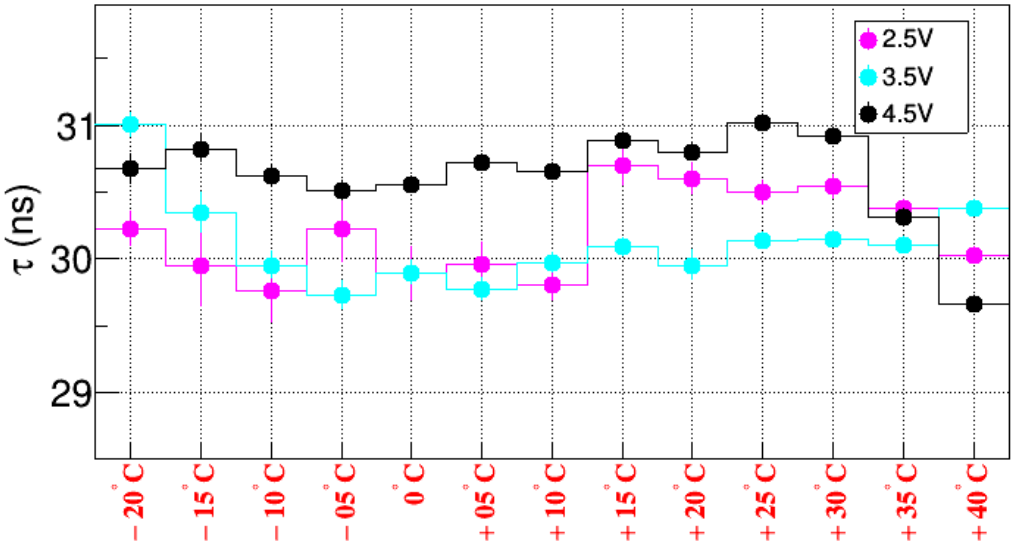
- Fitted signals in Δt time window with four Gaussian functions to find the peaks of AP signals
- Fit the peak position vs Δt to get recovery time







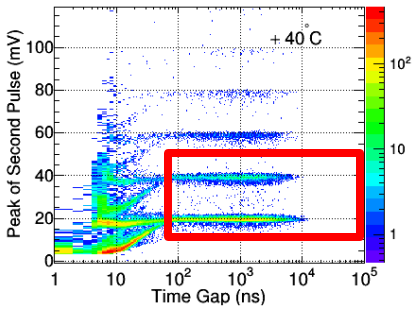


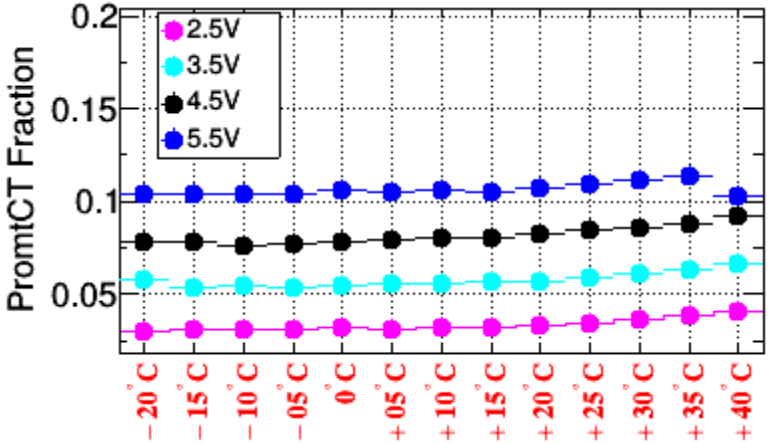


- Range of Δt is very small as well as number of event to have accurate numbers, but
  - There is no clear trends of variation in Recovery time with temperature, V_{OV}
  - Need more data and better algorithm to have data with larger range of Δt

Prompt cross-talk

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

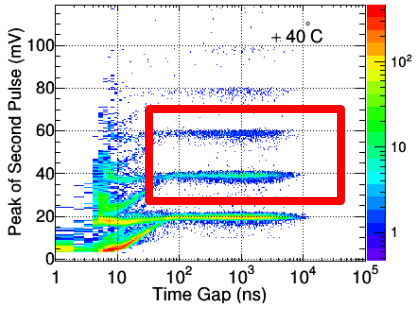


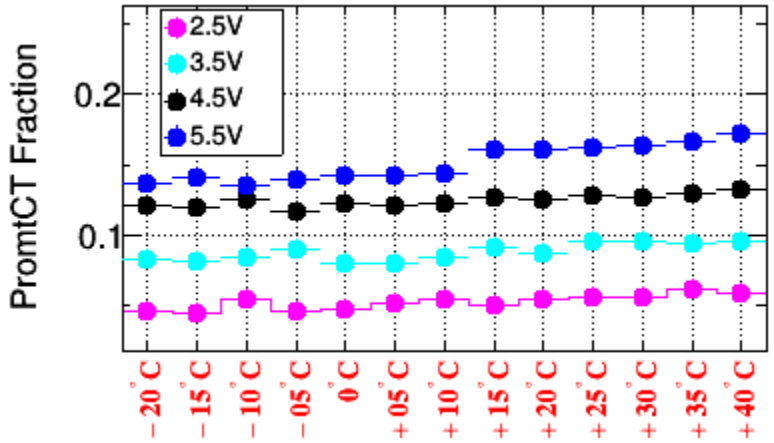


Also a small variation with temperature!!!!

A linear increase of PromptCT fraction with V_{OV}

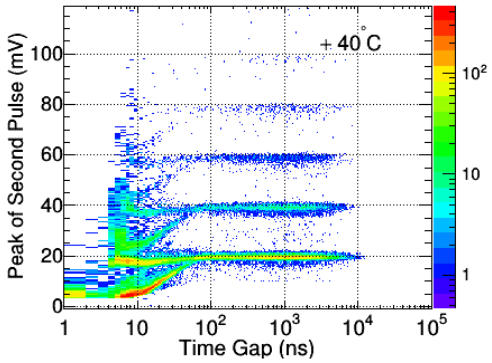
- **Ratio of 3rd and 2nd band**
  - **Expect to have large ratio (~2) wrt 2nd/1st band, but observation does not agree with factor 2**





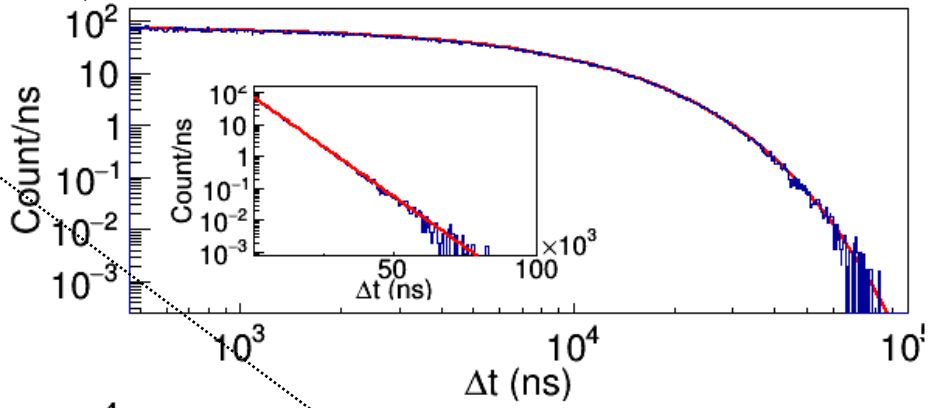
DeCT + AfterPulse

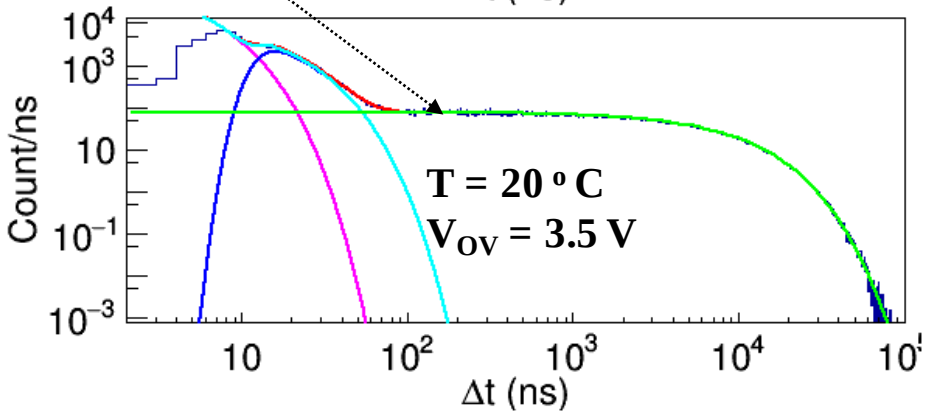
- **Fit the tail part with simple exponential function to get the uncorrelated noise rate**
- **Combined fit :**
  - **Exponential for Delayed CT**
  - **Exponential with threshold due to pulse height selection criteria as well as resolution for AP**
  - **Fixed parameters of Uncorrelated noise**
  -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



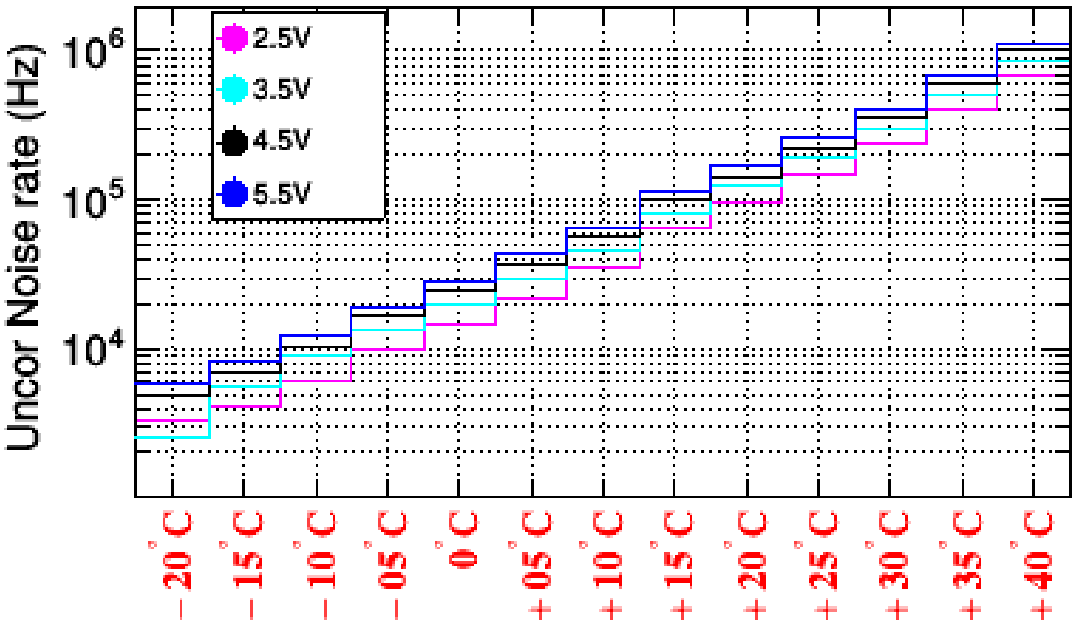
Take projection on X-axis (Δt)

Difficult to separate out DeCT & AP



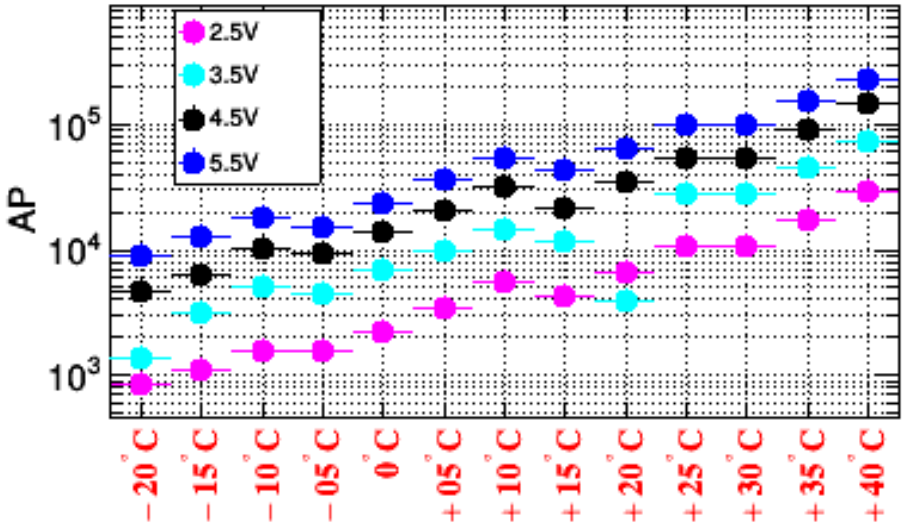


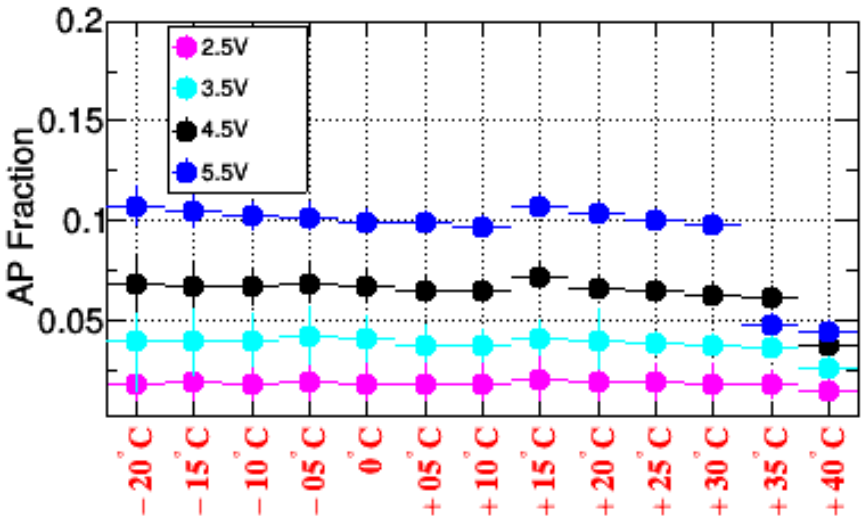
Uncorrelated noise rate : V_{th} = 0.5p.e.



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

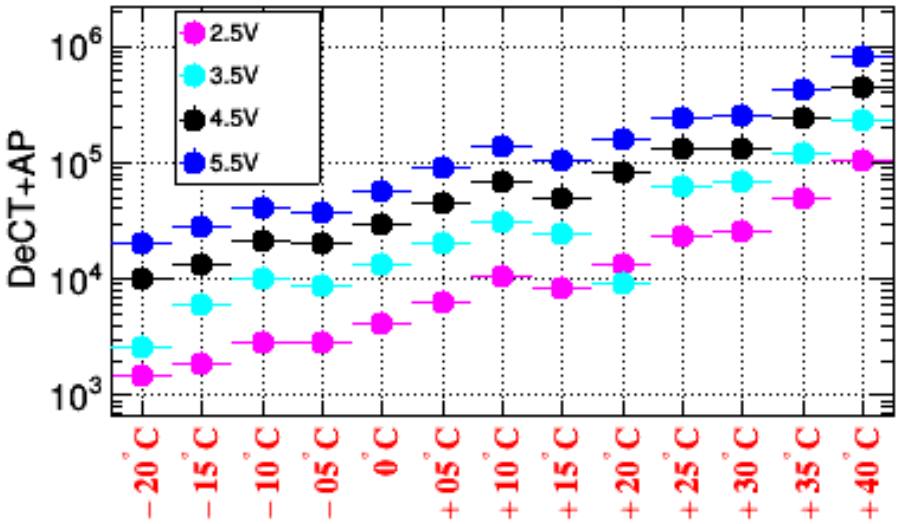
Fraction of After Pulse (from fit parameters)

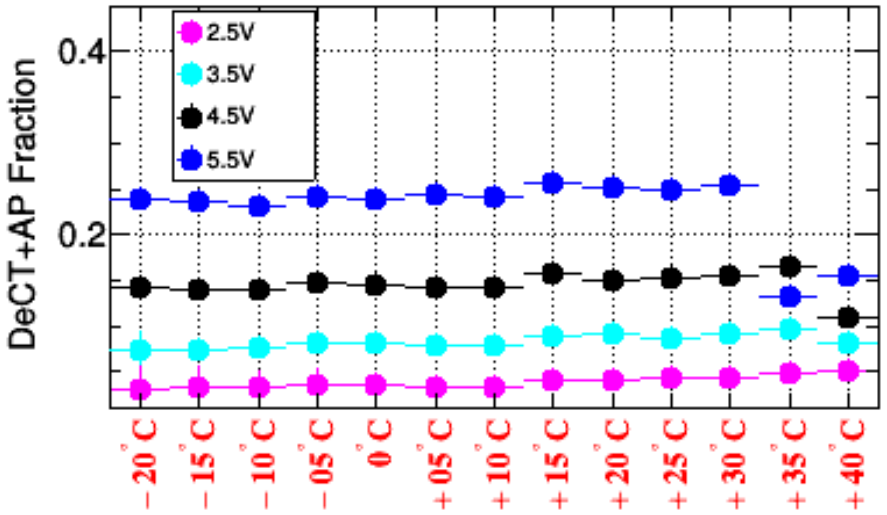




- A non-linear (~exponential) increase of AP fraction with V_{OV}
- Change in Time scale at 15°C has a systematic shifts
- Readings of High Temp + high V_{OV} (Need to tune algorithm for very high noise)
- No increase of fraction with temperature (opposite to PromptOCT)
  - Extraction of AP from DeCT may be a possible source, or this is the feature

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





- A non-linear (~exponential) increase of fraction with V_{OV} - Similar to AP
- Problem with few V_{OV} at high Temperature (Need to tune algorithm for very high noise)
- Nearly same trends of increase with temperature, what was observed in Prompt OCT

Conclusion

- No short term effect of humidity
- Variation of signal shapes and 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 rise and 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 algorithm to distinguish DeCT and AP and if required improve the hardware configurations