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Investigation and Compensation of Detector Time Delays caused by Receive Signal Intensity Fluctuations

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Introduction

Accuracy of a measurement:

Single Shot Precision:

Uncertainty of the measurement, increased repetition rate leads to high Normal Point Precision

Trueness (range bias):

Deviation of the measurement to the „real" value, e. g. asymmetric return signal distribution leads to biases

Error sources in SLR:

- Atmospheric contribution
- Satellite Signature
- Laser stability and pulse length
- Intensity dependent detector time delays, ...

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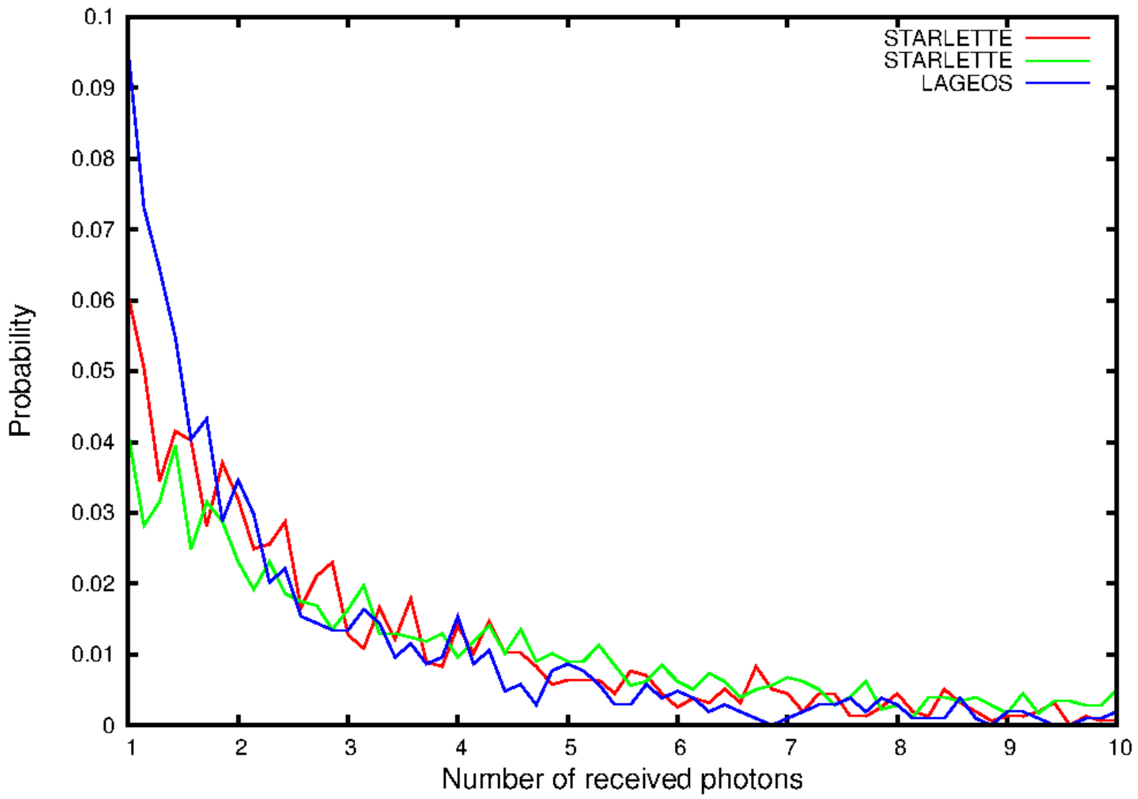
Intensity Fluctuations
- Experimental Characterisation-

Investigation of quantity and distribution of intensity fluctuations by means of a linear photodetector (MCP)

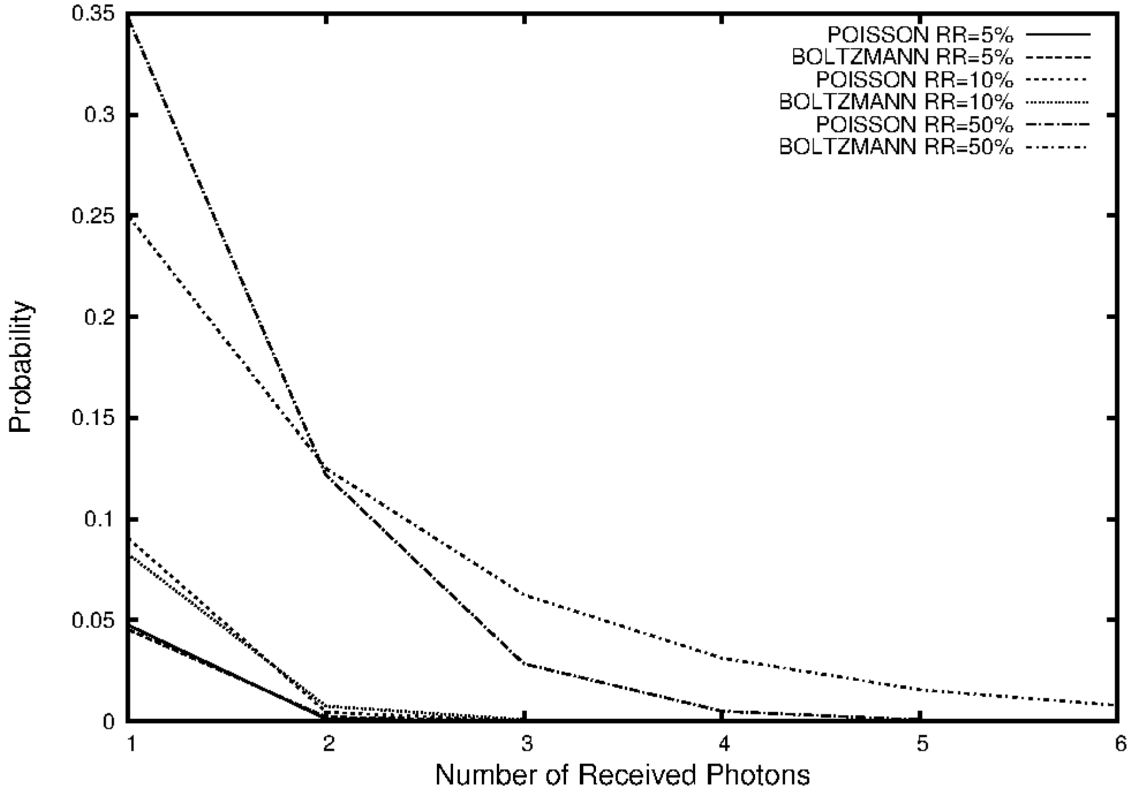
→ Return Signal Intensity is Boltzmann-distributed



Intensity Fluctuations - Theoretical -

Laboratory: During the calibration of an SLR-System the signal is Poisson-distributed (ideal Laser)

=> Similar return rate may lead to different mean signal level



Intensity Fluctuations
- Summary & Problems -

Good: return rate < 10%
=> intensity distributions comparable even for small variations, however: no single photons

Problems: How to ensure a true Return Rate < 10%, consider e. g.: daylight noise, dark noise, small clouds, plane trails, telescope pointing
- In our measurements both did never match! -

Approach: Find a dependency of the intensity dependent detection delays on the output pulse-shape (peak-voltage, rise-time) for an InGaAs/InP-SPAD @ 1064nm and compensate the intensity dependent delays via postprocessing

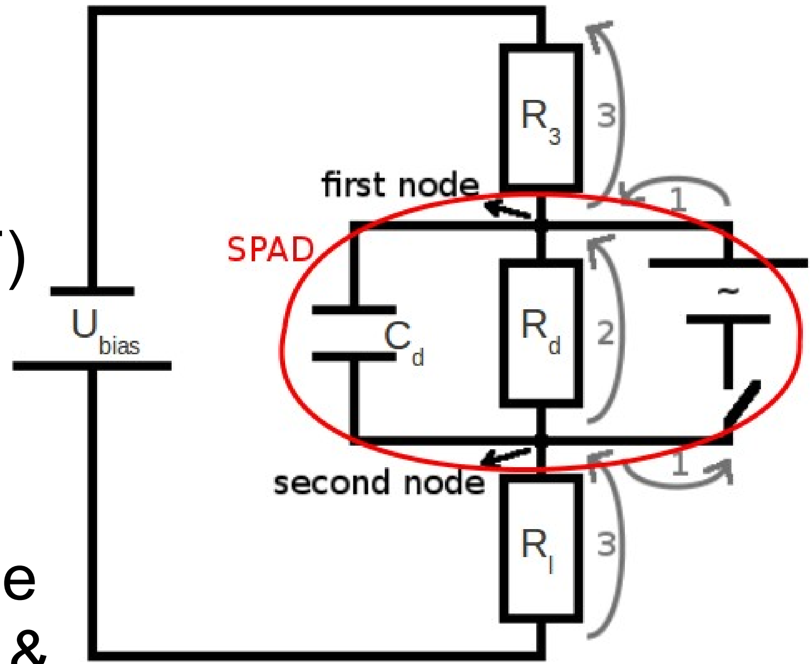
Intensity Dependent Delays - electrical circuit -

Add resistor (R_3) to bias circuit:

=> Diodes Anode decoupled from current source

=> Capacity of SPAD (few pF) drives avalanche breakthrough

=> Small variations in current through ionized parts of the diode reduce bias voltage & gain (the longer an avalanche lasts [Timewalk], the wider it spreads laterally on the chip)

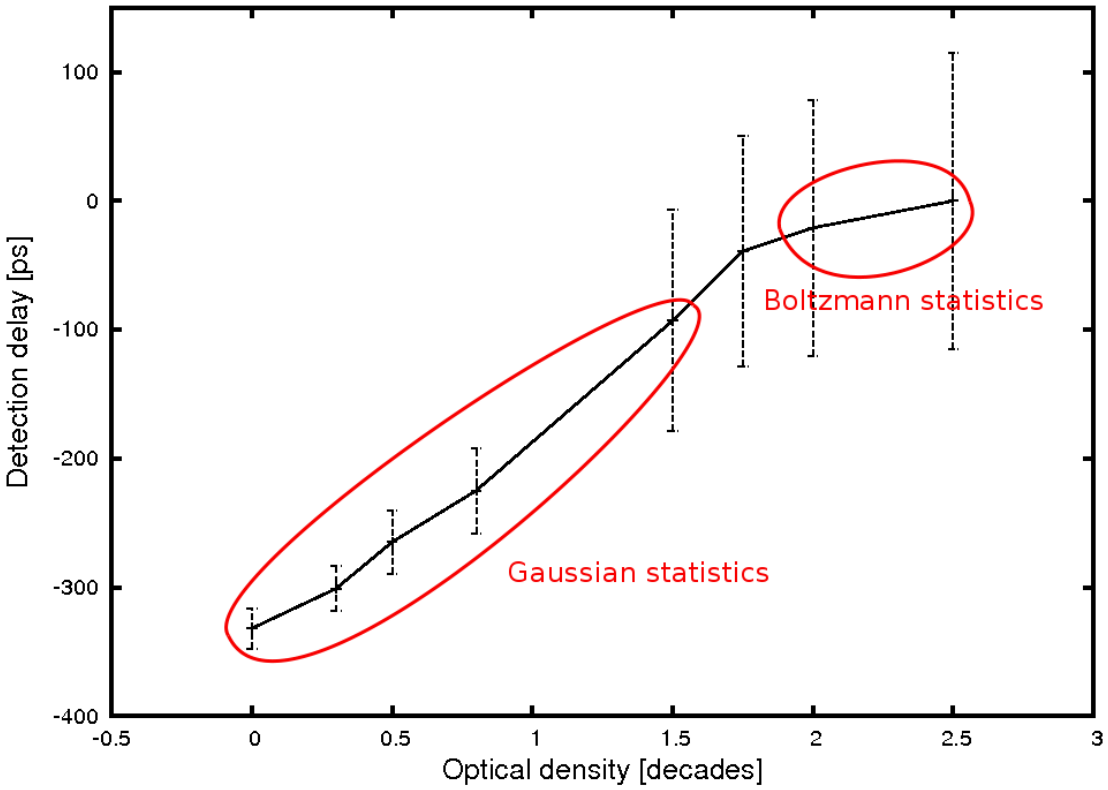


Intensity dependent delays - Quantity -

Measure a constant distance (Calibration)

Simulate Boltzmann distribution (Multi Mode Fibre)

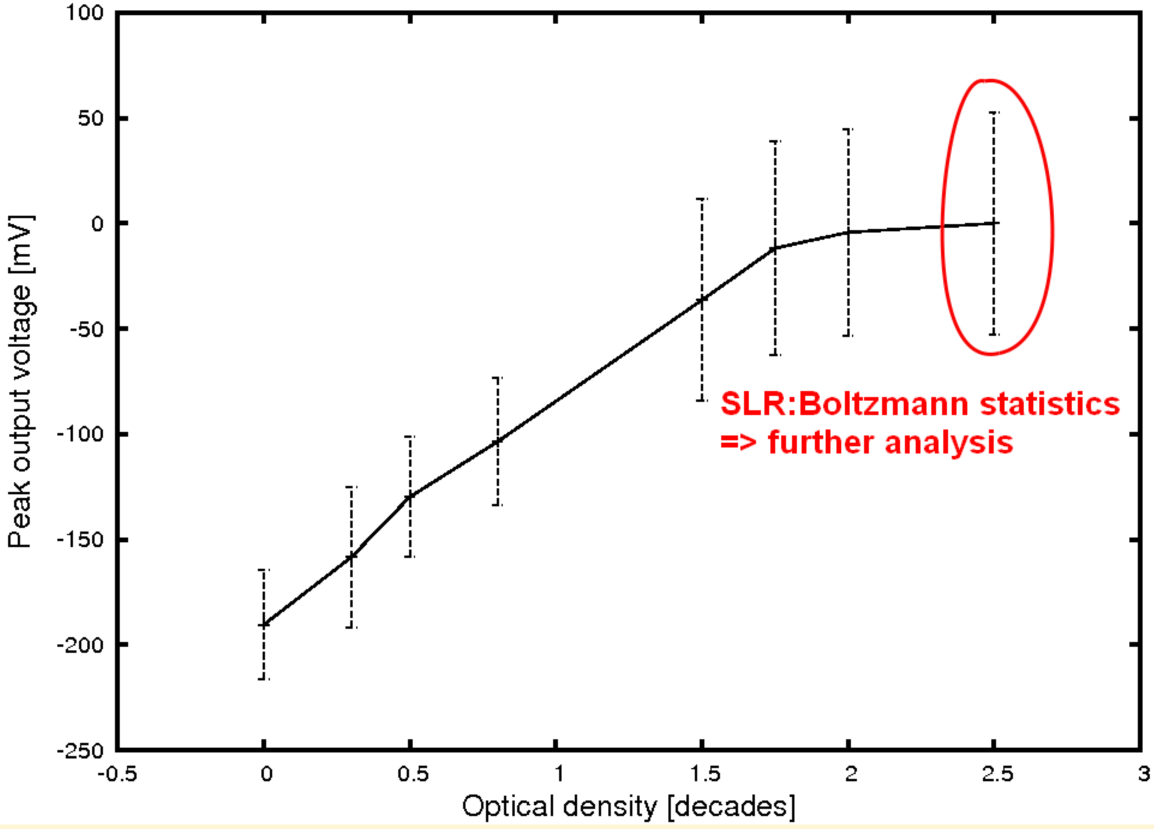
Use neutral density filters to adjust signal level



Intensity dependent delays - Dependencies -

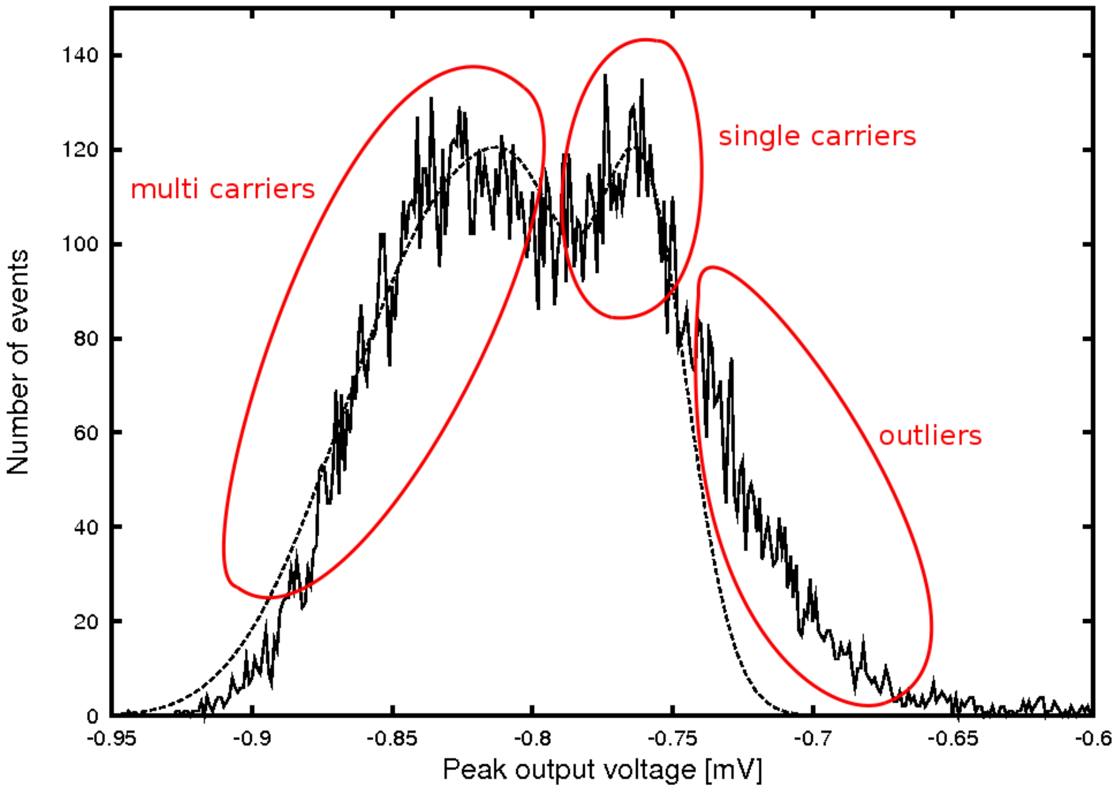
Simultanously the peak output voltage was measured

Same characteristics



Intensity Dependent Delays
- Peak Distribution -

Peak distribution:	- distinct single carrier multiplication peak
(@21% count rate)	- broad multi carrier multiplication peak
Reason:	logarithmic dependence ⟶ modelling



Intensity Dependent Delays
- Modelling -

- 20 Gaussian distributed functions, each representing a specific carrier number
- Boltzmann statistics (multi mode fiber at low light level)

scale factor

carrier number

logarithmic dependence

$$f(x) = d \cdot \sum_{n=1}^{20} \exp(n \cdot f) \cdot \exp\left(\frac{(x + c + e \cdot \log(n))^2}{-2 \cdot b^2}\right)$$

mean carrier number

peak jitter of single carrier number

Compensation
- Strategies -

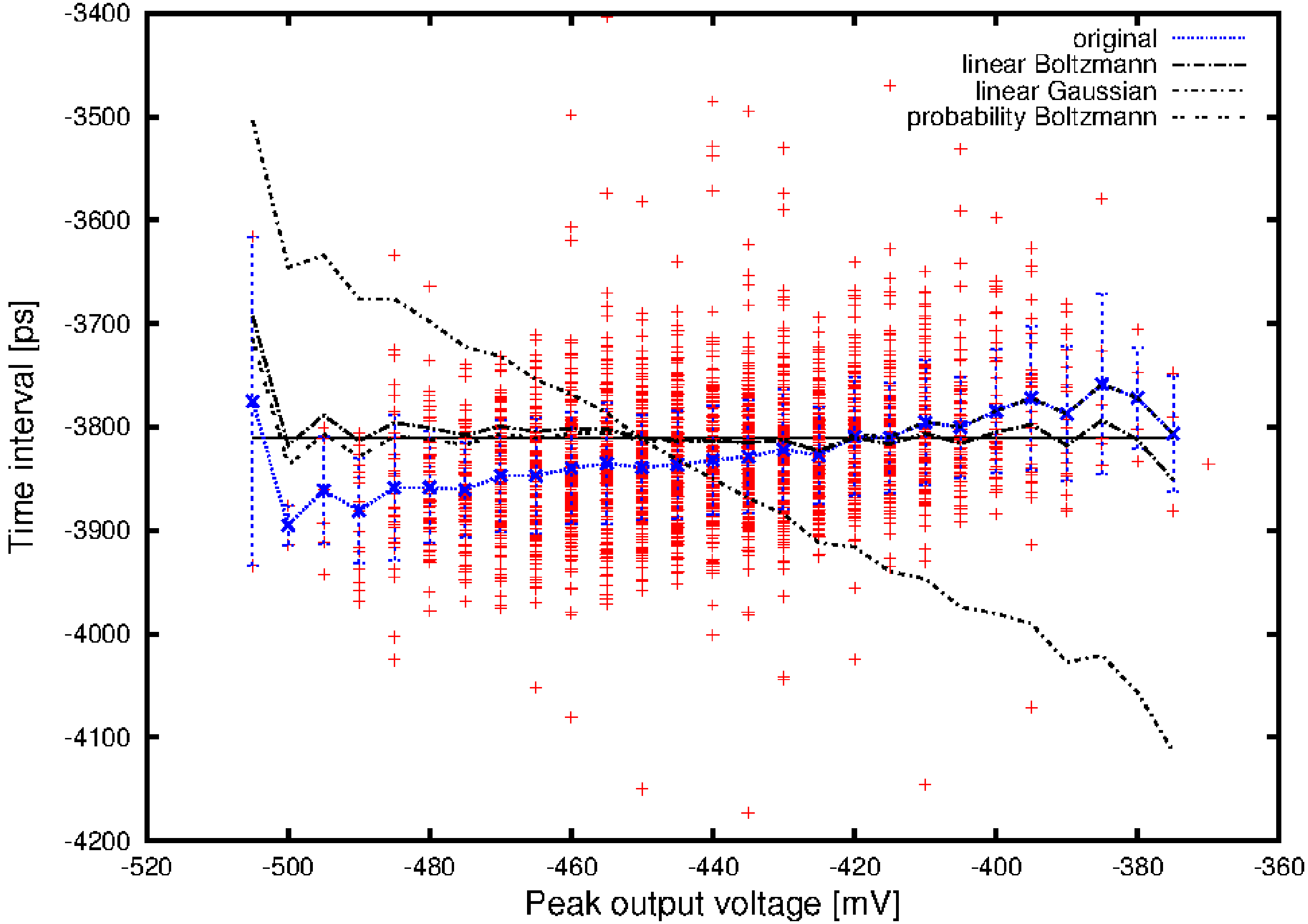
Intension: Find mean carrier number to get probabilities of each carrier number & compensate intensity dependent delays based on these probabilities

Investigation of three compensation strategies by recording each single event:

1) linear approach based on symmetric Gauß-Statistics (Slope at high light intensities)
2) linear approach based on fitting the distribution (not possible during SLR measurement, no fixed distance)
3) approach based on the mean photon number (derived from modelling with Boltzmann-statistics)

Compensation
- Results Strategies -

Ideal: get a constant time interval for any peak voltage



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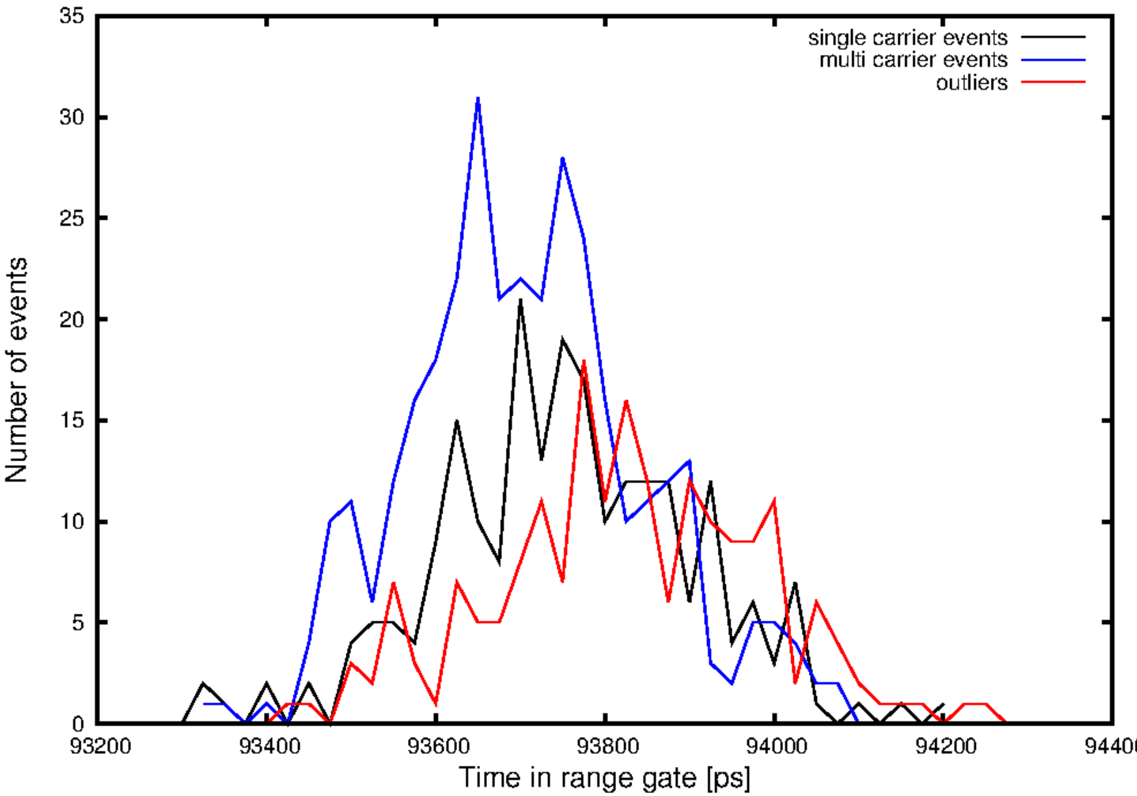
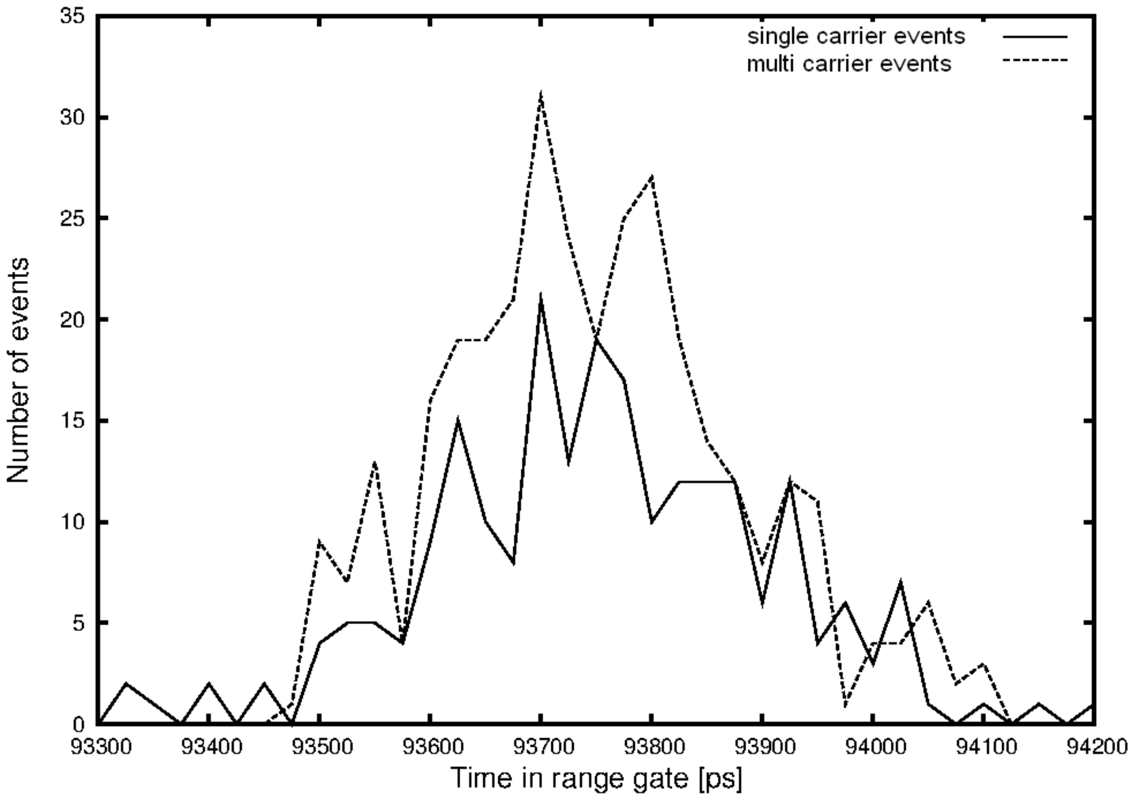
Compensation
- Return Signal Distribution -

- Distributions of the return signal in range gate for different regions of the peak voltage
- Shift in mean value for single and multi-carrier signals, outliers in peak voltage are also outliers in the ToF measurement



Compensation
- Compensated Distribution -

- Compensation approach matches the distributions
- Satellite signature of GLONASS visible to some extend



Conclusion & Outlook

- The return signal distribution seems to follow Boltzmann-Statistics for a high dynamic range
- An approach was developed to find the mean return signal level
- This information was successfully used for compensation of intensity dependent detection delays

- Physics for silicon is the same => apply to Si SPADs
- Still pending: Orbit determination based on the results
- Maybe: analysis of satellite signature for single/multi photon returns