Electrical and optical characterization of SiPMs at Aachen

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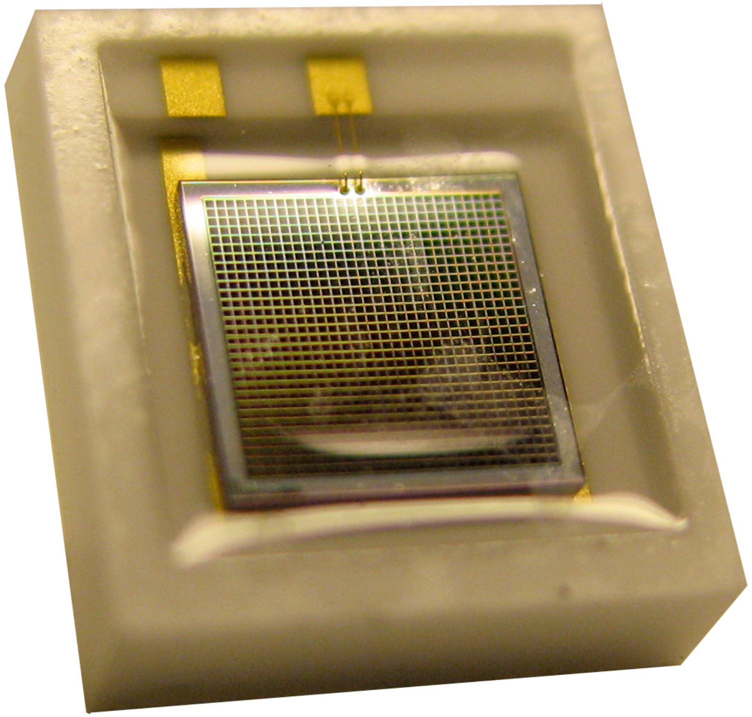
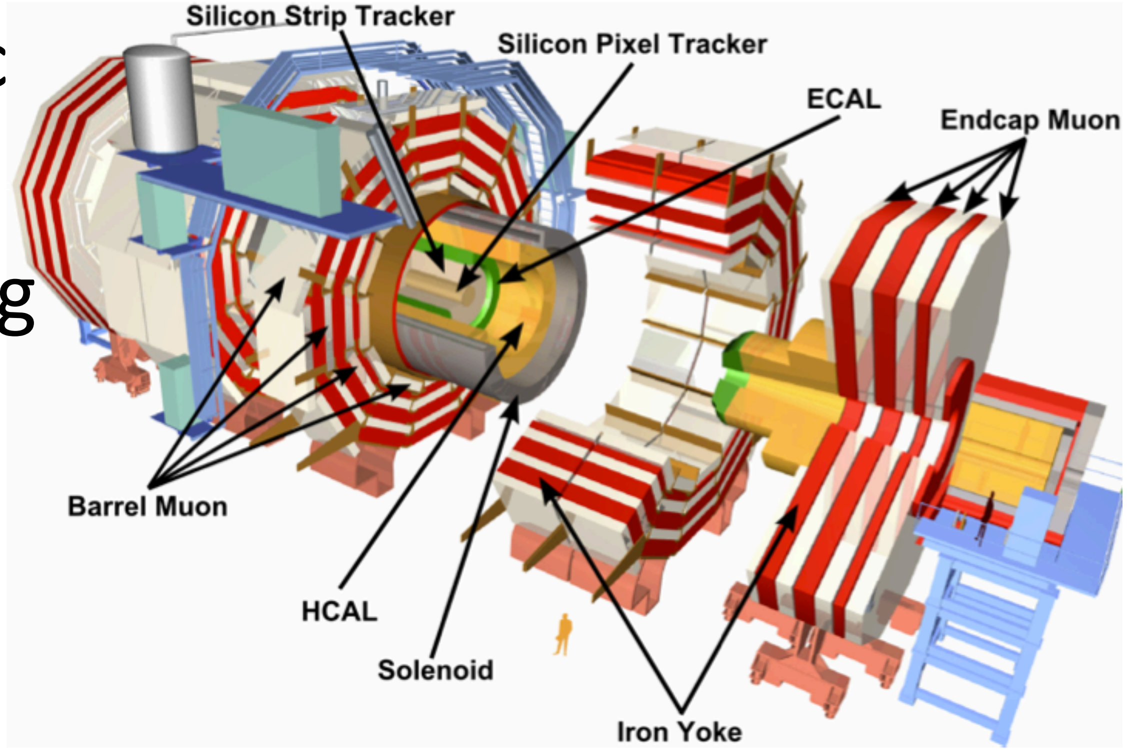
Outline

- Possible SiPM applications at CMS
- Electrical characterization
  - Electrical model
  - Impedance measurements
  - SPICE simulation
- Optical characterization
  - Optical test stand
  - Signal train analysis
- Summary and outlook



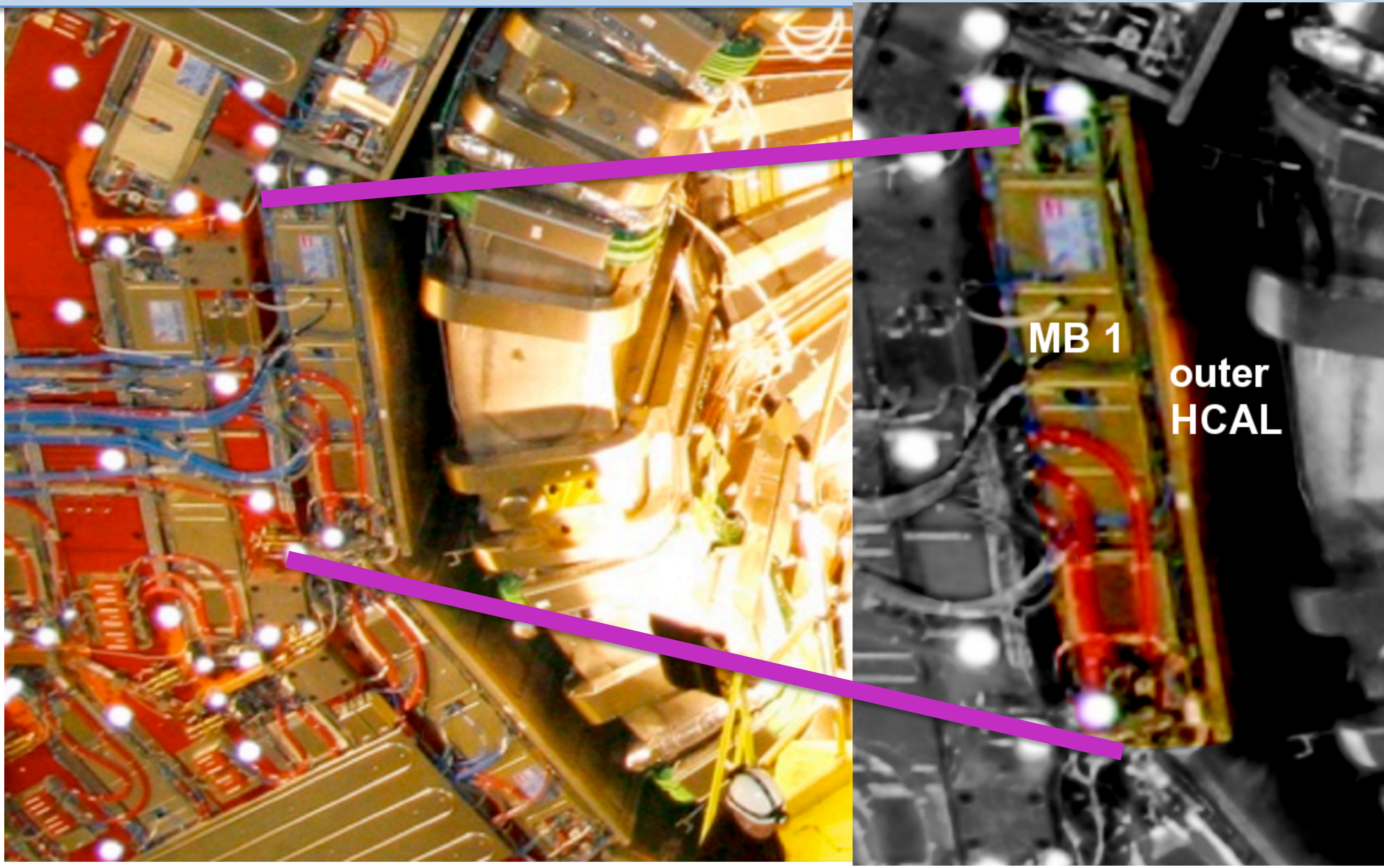
Motivation

- CMS: Compact detector, 4T magnetic field
- MTT – Muon Track Tag for S-LHC after 2020
  - Fast muon tag for L1 track triggering
- SiPMs are used by outer hadronic calorimeter



The CMS experiment at the CERN LHC. IOPscience, August 2008

MTT



- Fast readout needed at limited space (~cm)

SiPM Properties

- Advantages:
  - High light detection efficiency
  - Low bias voltage
  - Small dimensions
  - Insensitive to magnetic field

→ Excellent understanding of all SiPM aspects needed

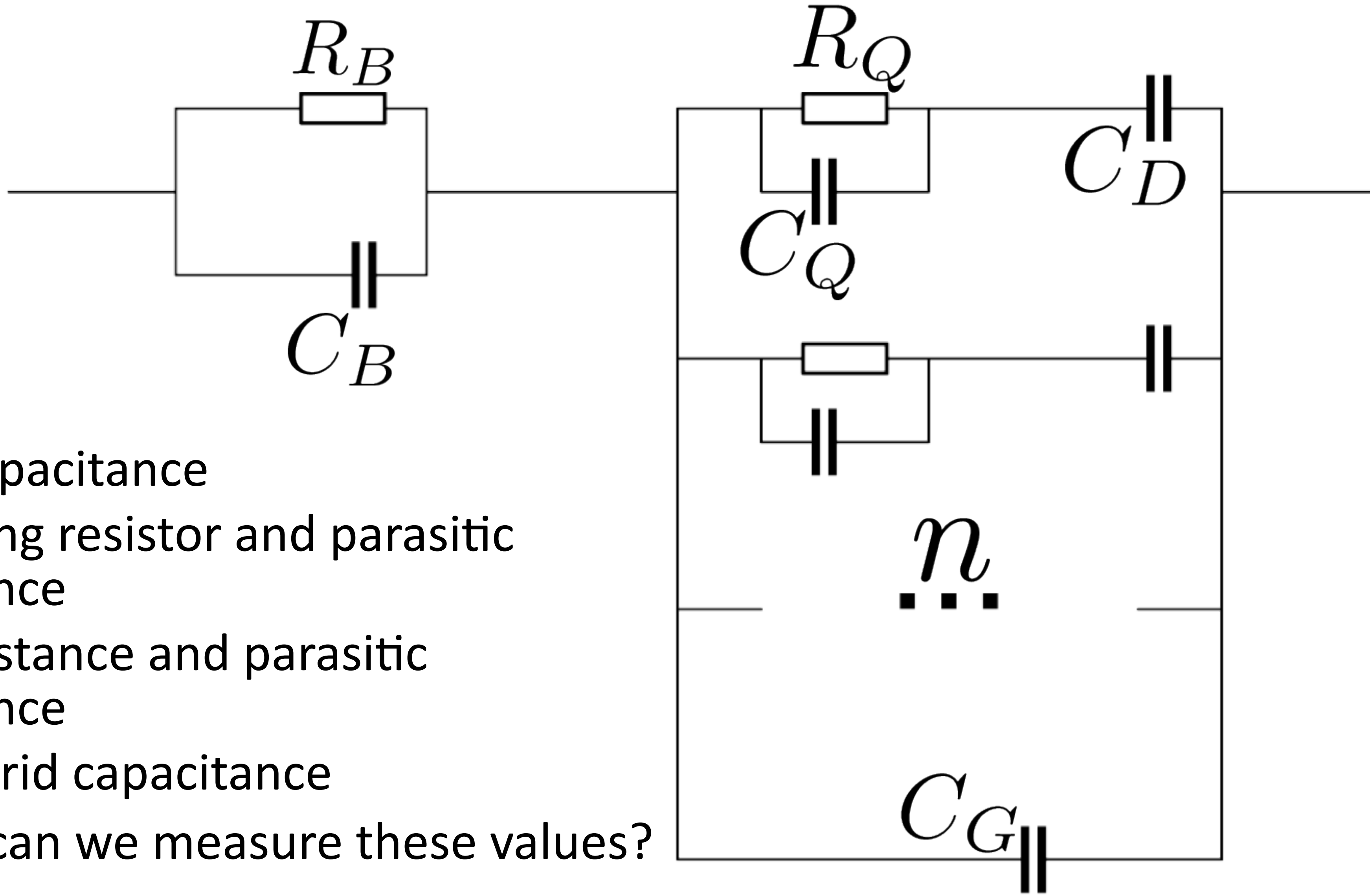
- Challenges:
  - Thermal and correlated noise (up to ~MHz for whole SiPM)
  - Substantial temperature dependency of operating voltage

→ Important for front-end electronic design

→ Fast recovery of SiPM

→ Full use of dynamic range

Electrical model



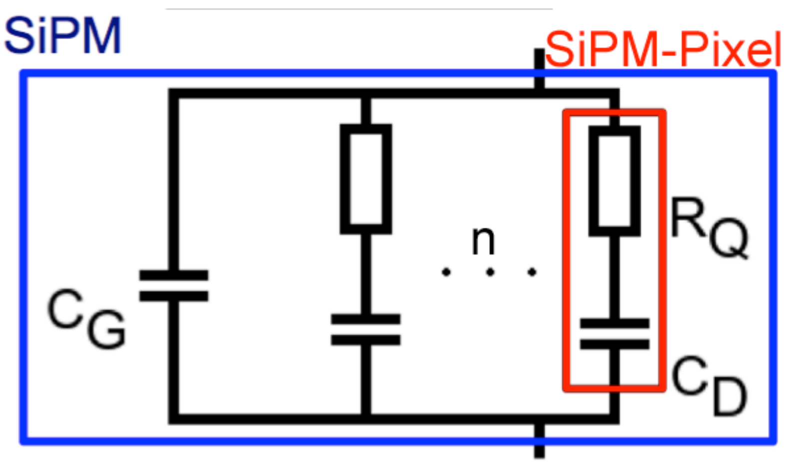
- Diode capacitance
- Quenching resistor and parasitic capacitance
- Bulk resistance and parasitic capacitance
- Overall grid capacitance

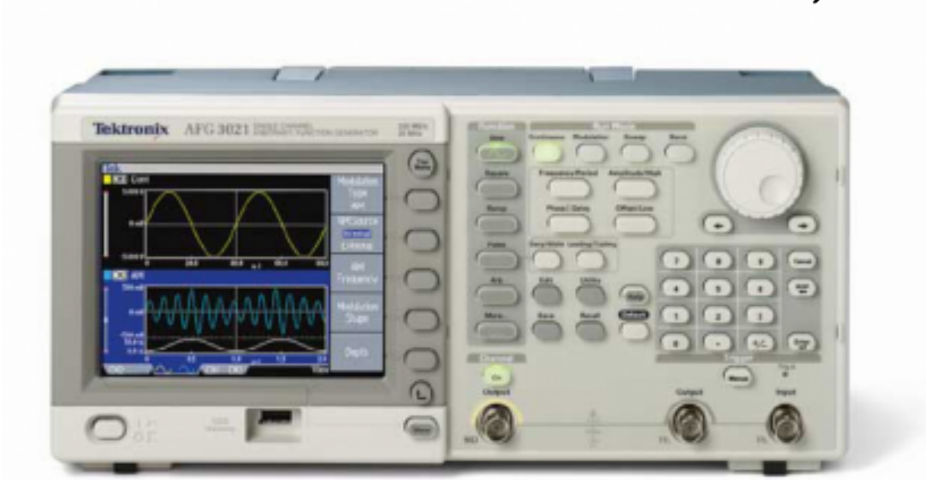
→ How can we measure these values?

Impedance measurements

- Measure SiPM answer to sine signal
- Fit electrical model to measured impedance
  → Extract electrical parameters (C_D, R_Q, C_G)
  → Reduced model: C_B, R_B, C_Q ~ 0 (within errors)

$$Z = \frac{1}{\sqrt{n^2 {R_q}^2 \left({R_q}^2 + \frac{1}{\omega^2 {C_d}^2}\right)^{-2} + \left(n\omega^{-1} {C_d}^{-1} \left({R_q}^2 + \frac{1}{\omega^2 {C_d}^2}\right)^{-1} + \omega C_g\right)^2}}$$





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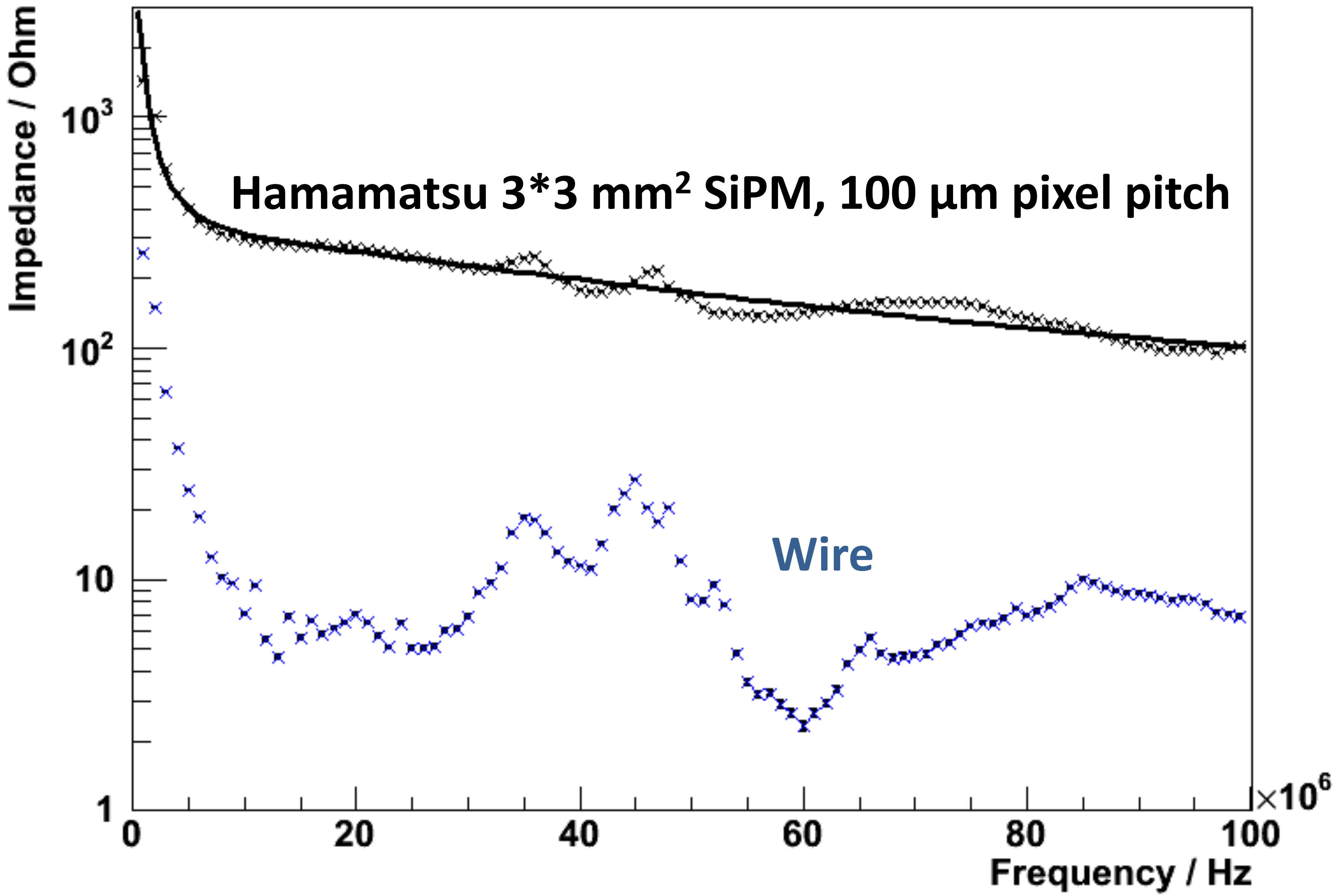
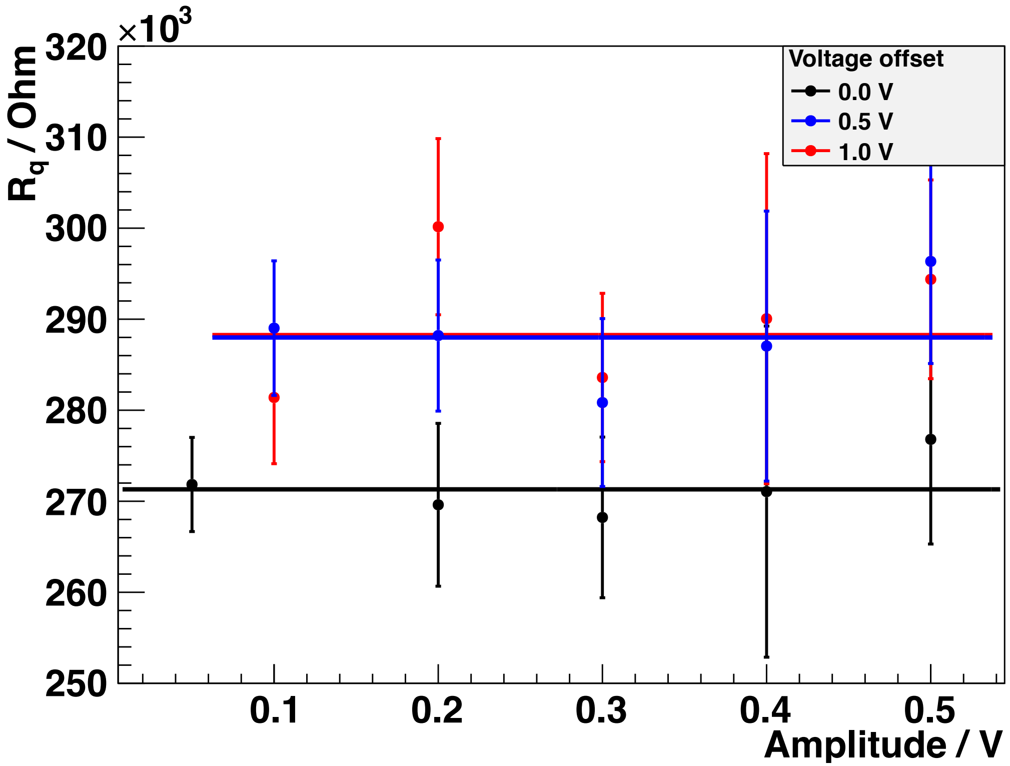
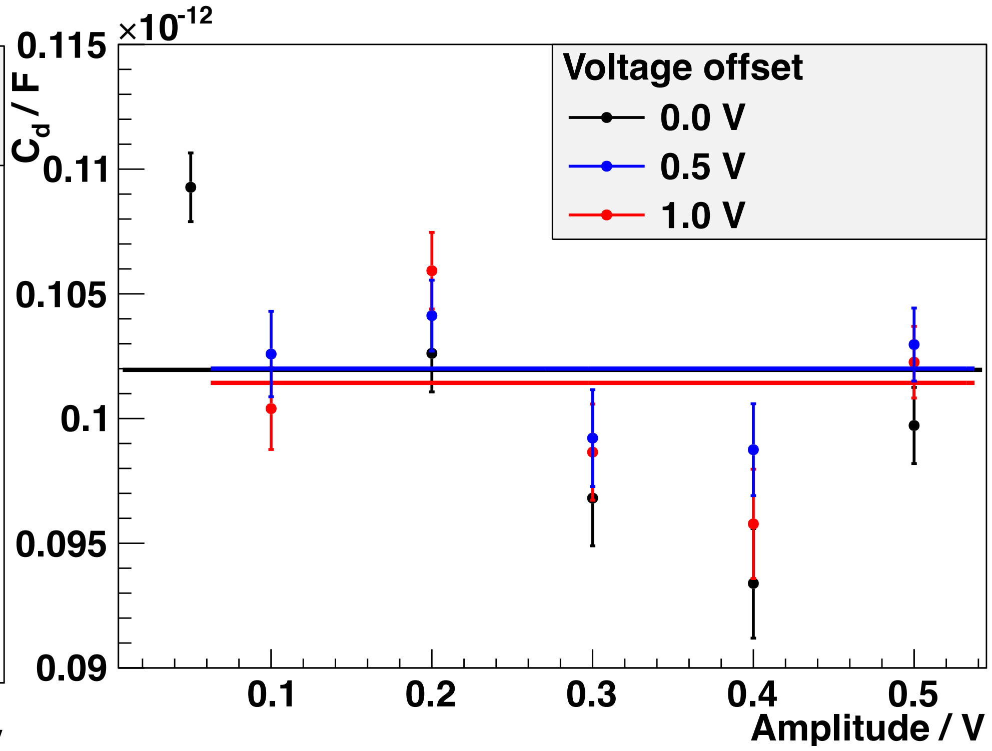

Hamamatsu 3*3 mm² SiPM, 100 µm pixel pitch
Wire
Impedance / Ohm
10³
10²
10
1
0
20
40
60
80
100
×10⁶
Frequency / Hz

Impedance measurements





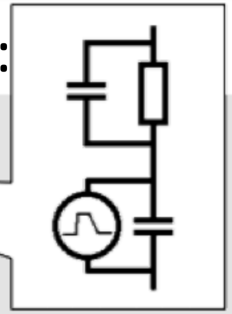
R_q ~ 280kΩ, C_d~ 0.1pF → Recovery time ~ 30ns

C_g ~ 14 pF

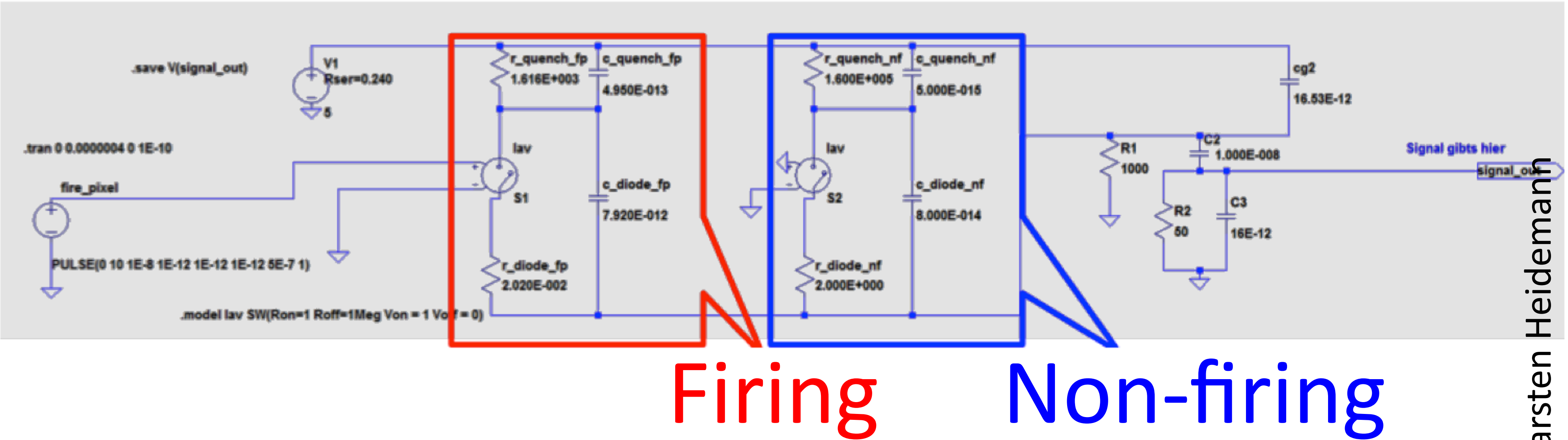
Next: Measurements with LCR-Meter at 2Hz – 2MHz and bias voltage up to 40 V

SPICE - Simulations

Single pixel model (computing time increases by number of pixels):



Fast model (computing time constant):



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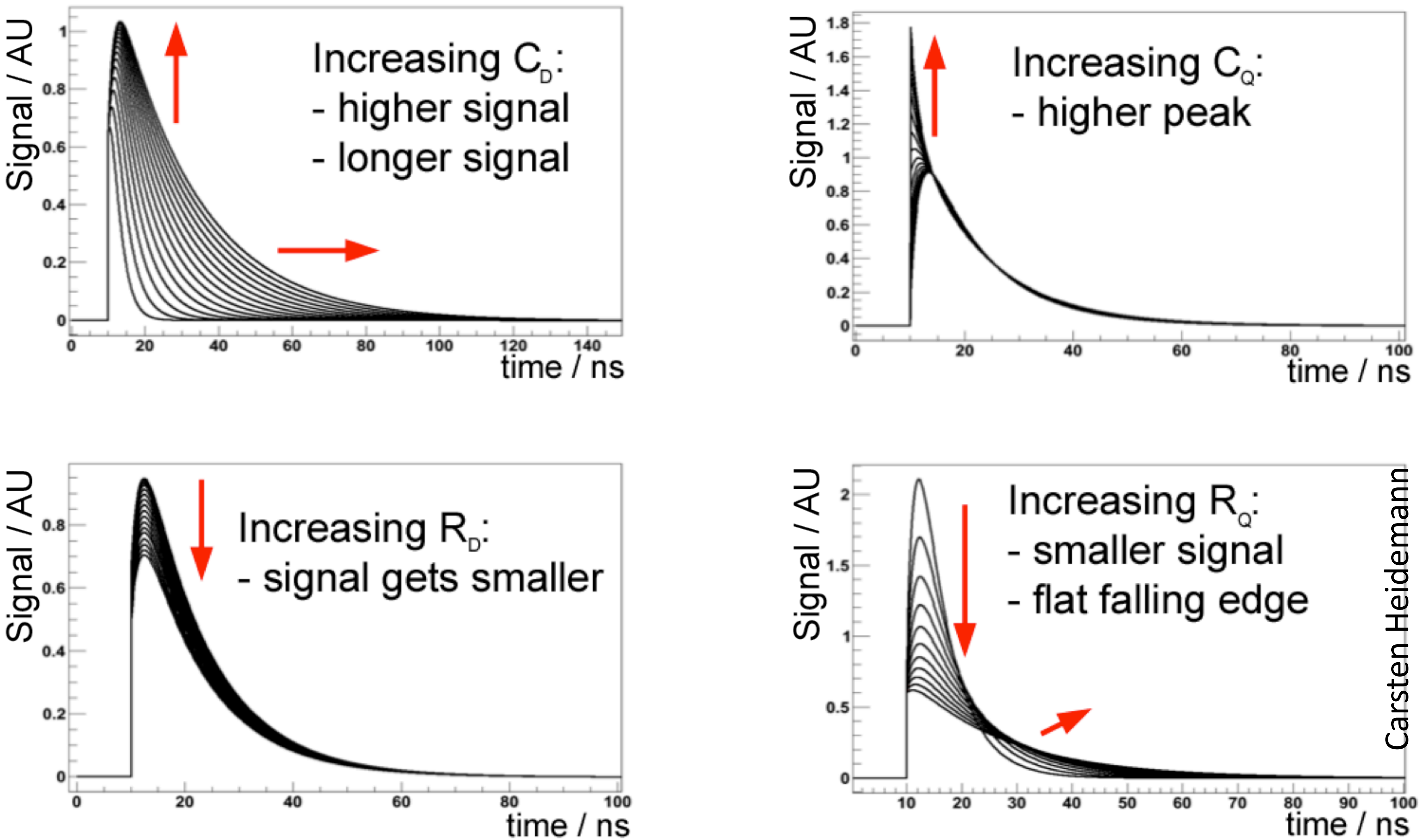
SPICE = Simulation Program with Integrated Circuit Emphasis

Parameter variation - SPICE



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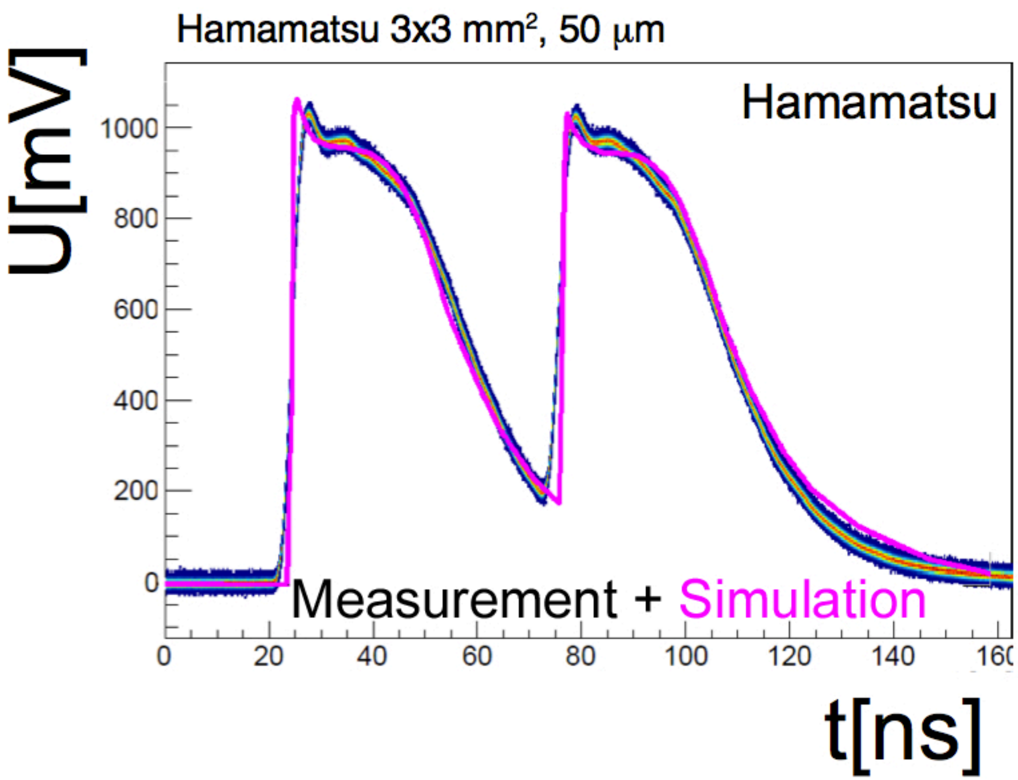
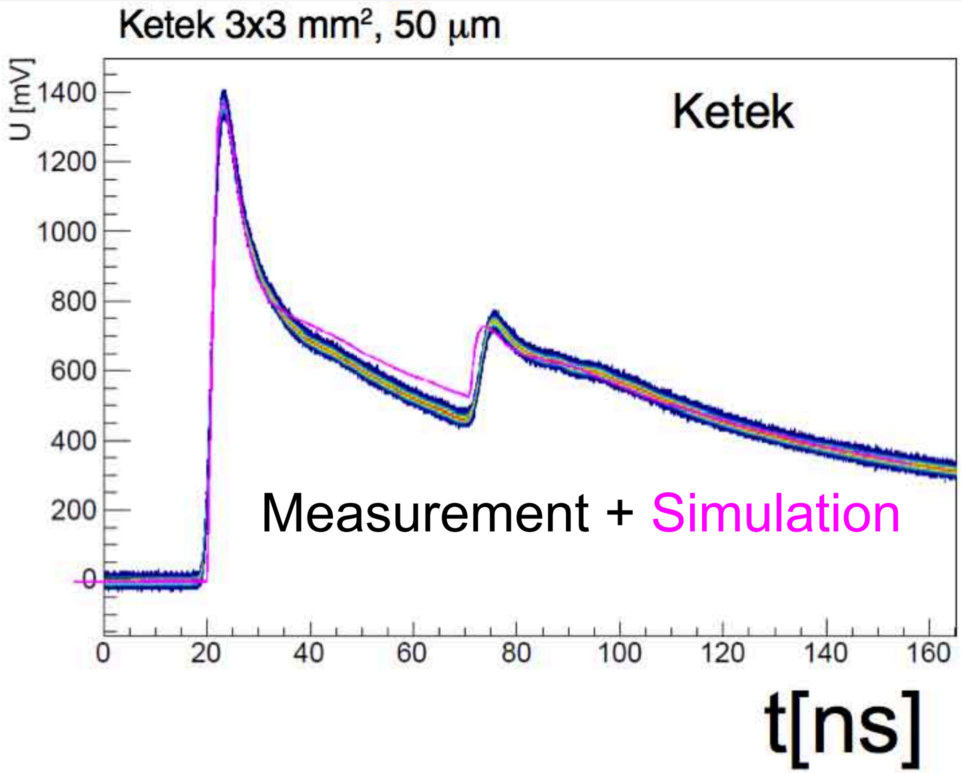
Double Pulses - SPICE





- Modeling of single pulses yields also shape for double pulses
- Good agreement of data and simulation
- Hamamatsu: Signal is mainly produced by pixel capacitance small peak component -> fast recovery time
- Ketek: High signal by quenching capacitance tall peak component -> slow recovery time

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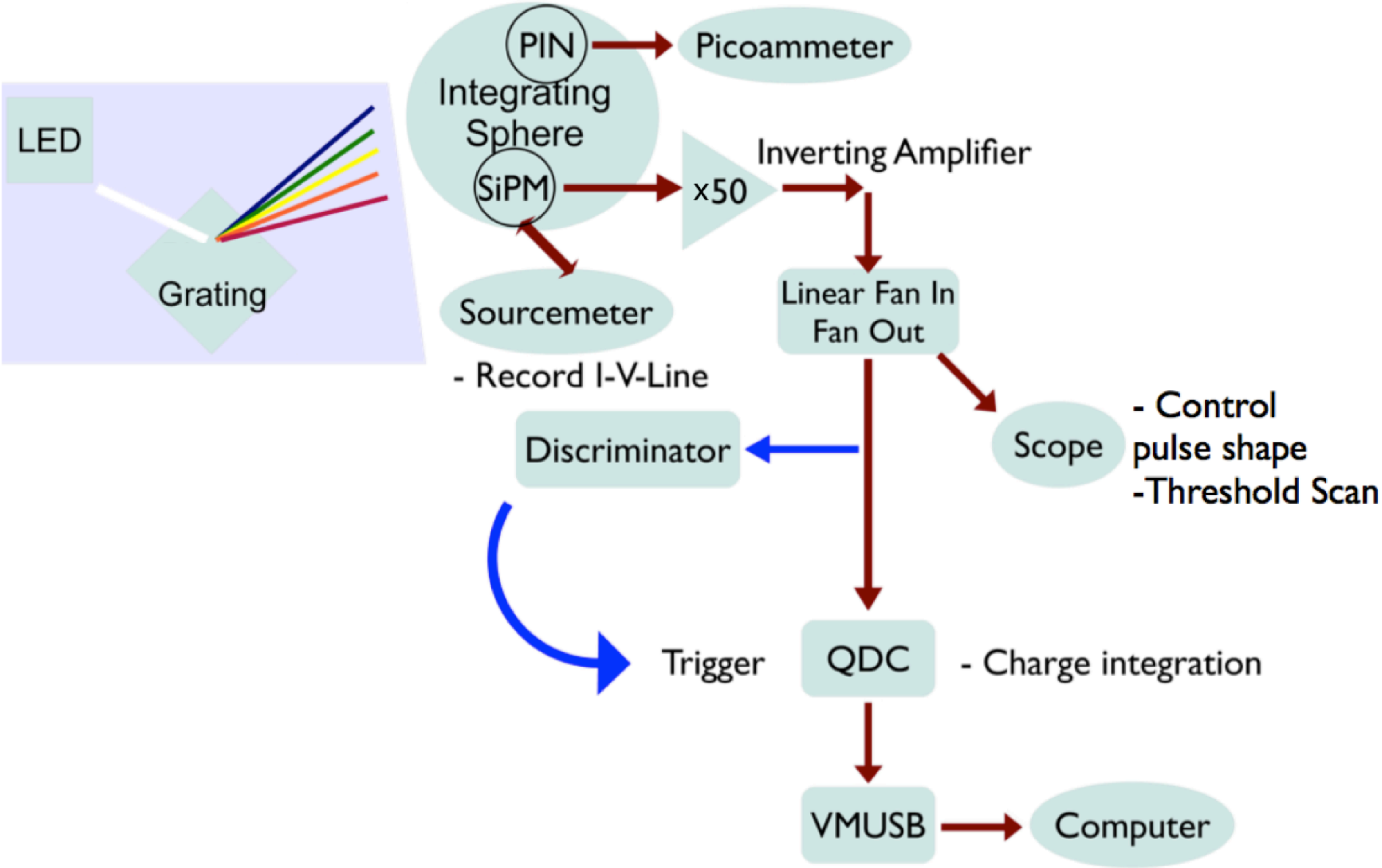
Optical characterization

- Teststand for automatic characterization of SiPMs



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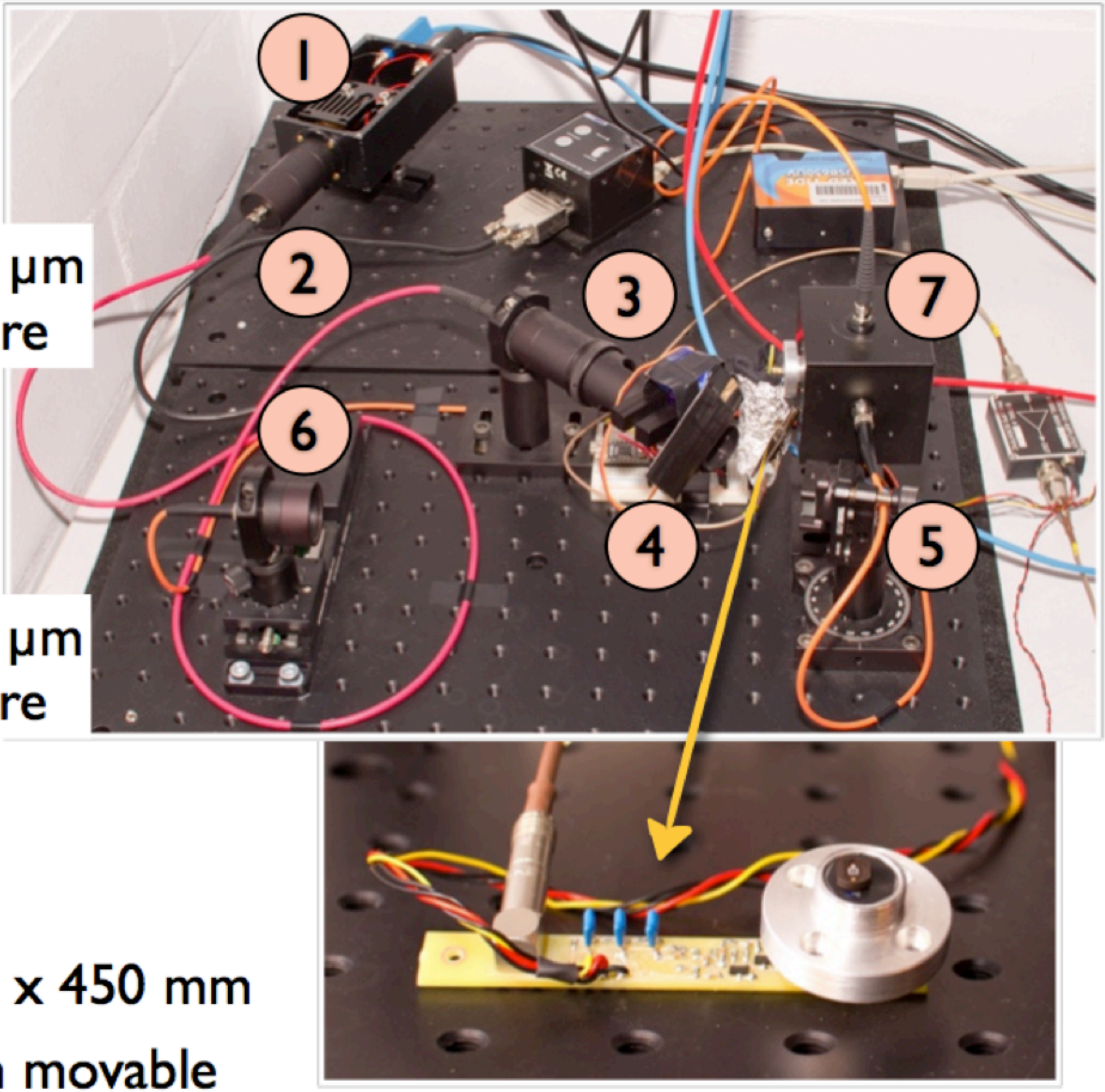
Optical teststand

1. LED
2. Cone
3. Collimator
4. Shutter
5. Grating
6. Light pickup
7. Integrating sphere +detectors

(2–3) 500 µm fibre

(6–7) 200 µm fibre



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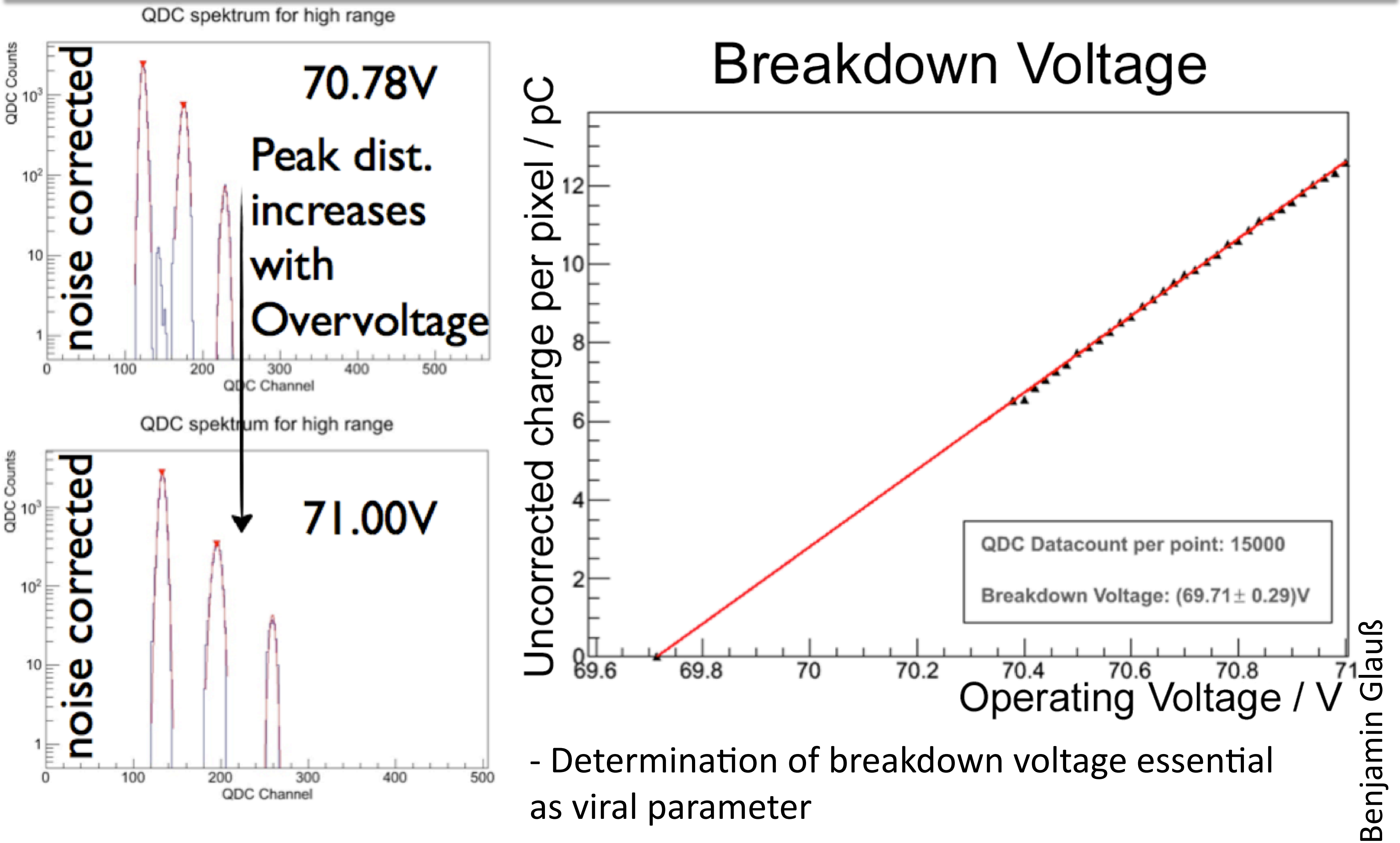
Dimensions:

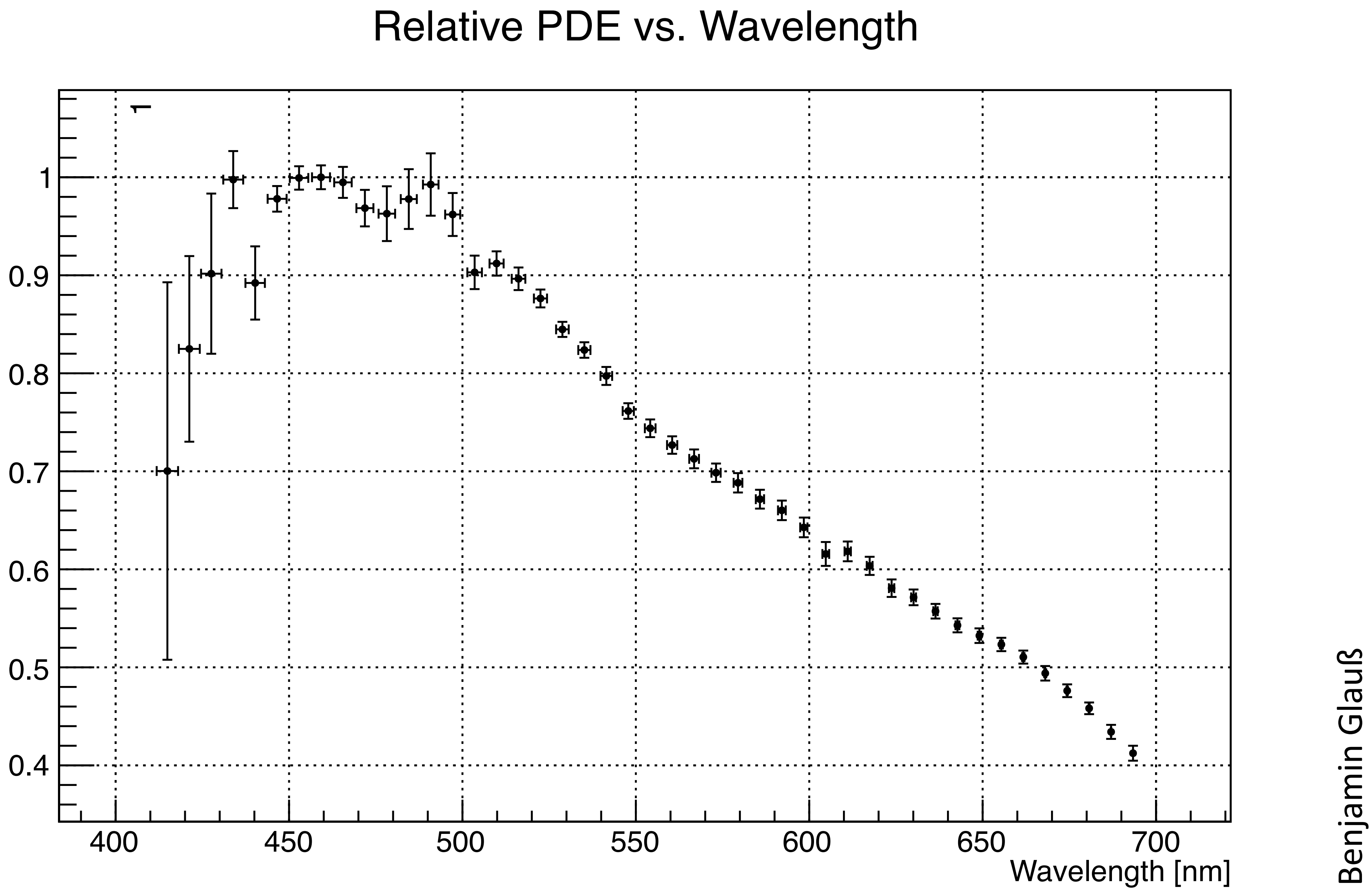
- Table: Twice 300 mm x 450 mm
- step motor: ~54 mm movable

Breakdown Voltage



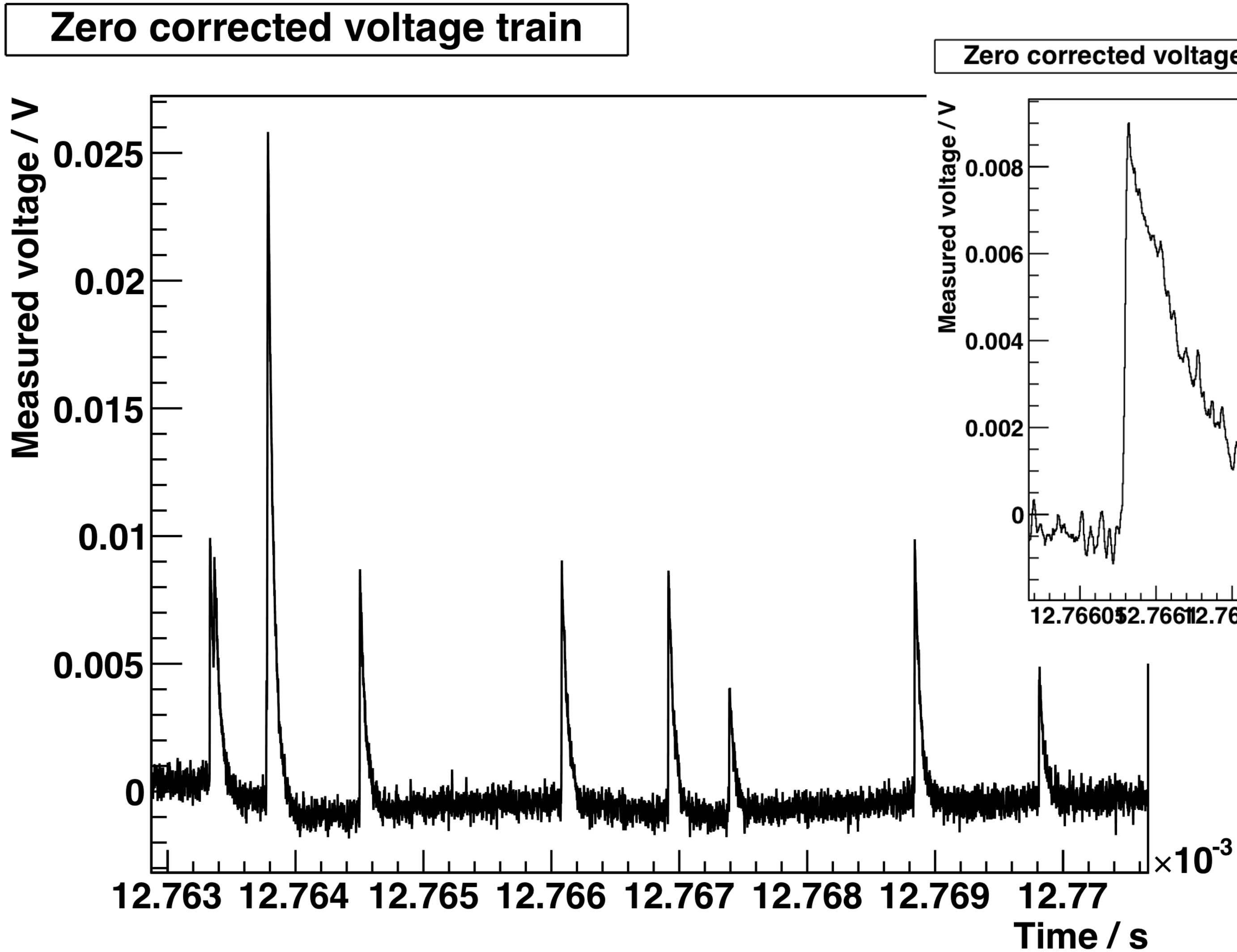
- Determination of breakdown voltage essential as viral parameter

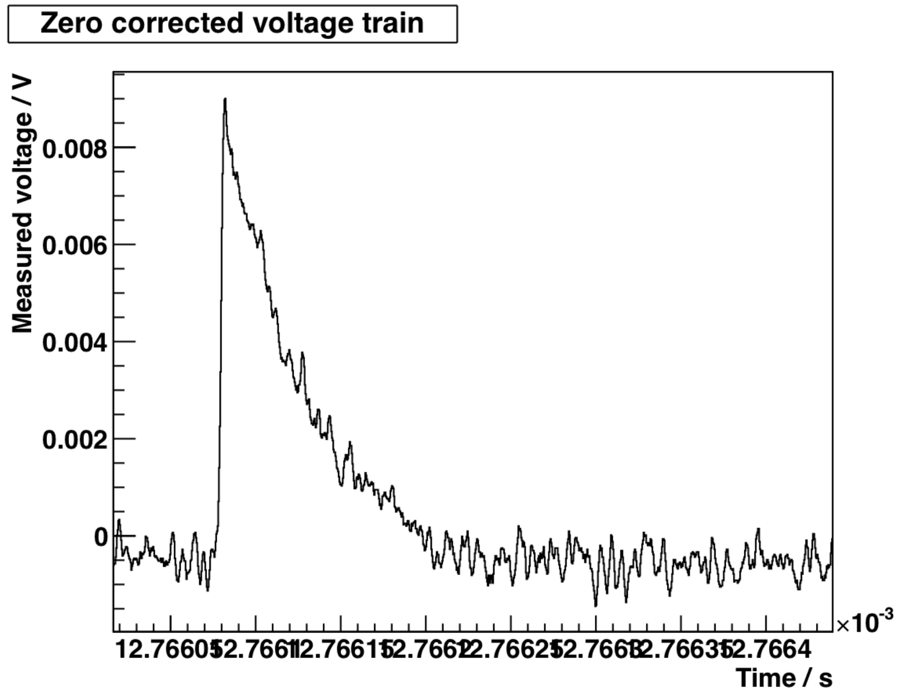
PDE-Measurements



Signal train analysis

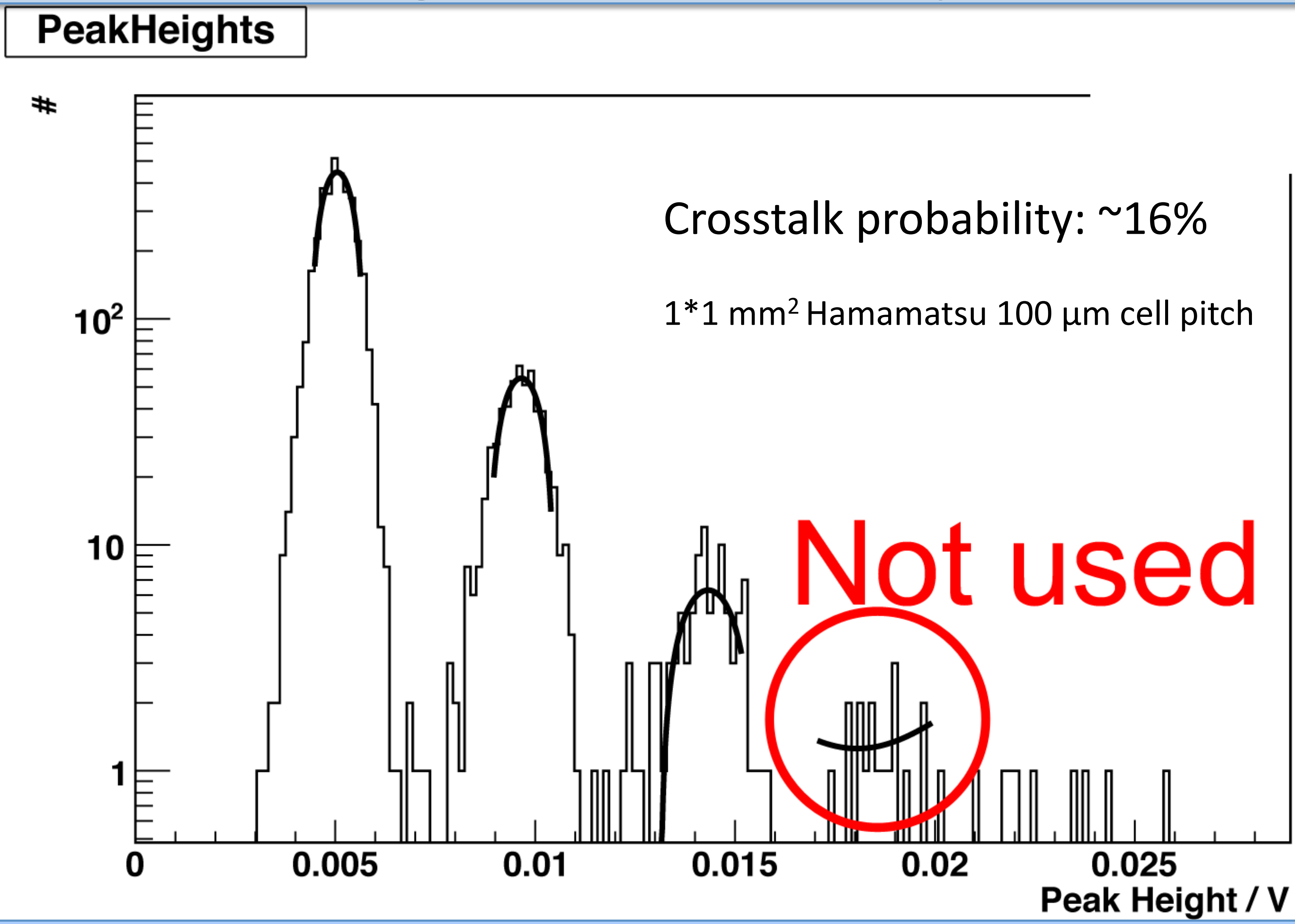
- 20ms data with 50M data points recorded



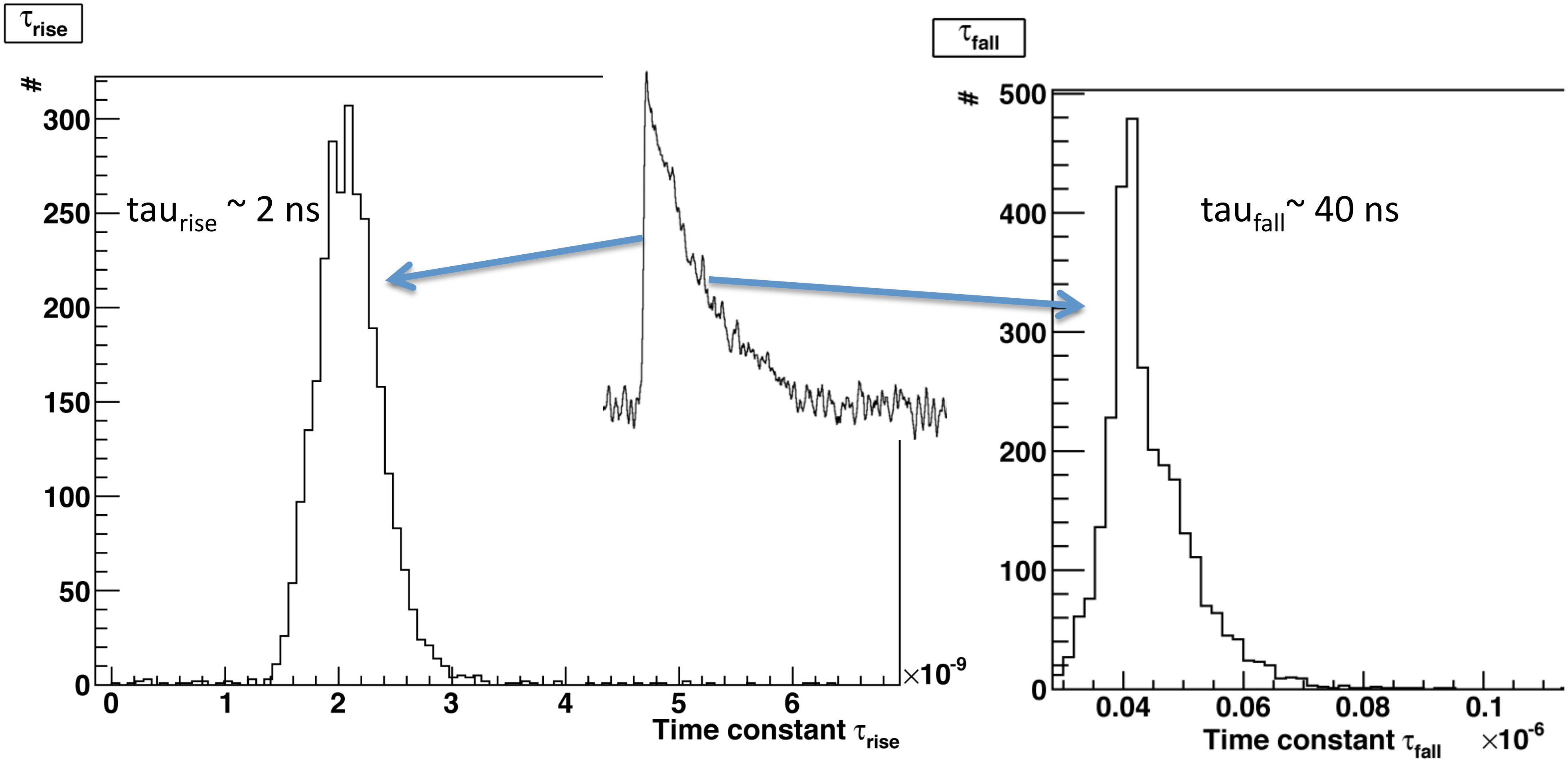


400 ps sample time

Signal train analysis



Signal train analysis – Signal shape



$$U(t) = A \cdot \exp\left(\frac{-(t - t_{rise})}{\tau_{rise}}\right) \cdot \left(1 - \exp\left(\frac{-(t - t_{fall})}{\tau_{fall}}\right)\right)$$

Summary and outlook

- Various methods for SiPM characterization:
  - Determination of electrical parameter
  - Determination of optical parameter
  - → Model of SiPM
  - → Input for electronic design
- Next steps:
  - Impedance measurements at 2 Hz – 2 MHz (LCR-Meter)
  - Implement measurement results in SPICE
  - Complete, fast and automated SiPM characterization procedure