Concept and status of the LED calibration system

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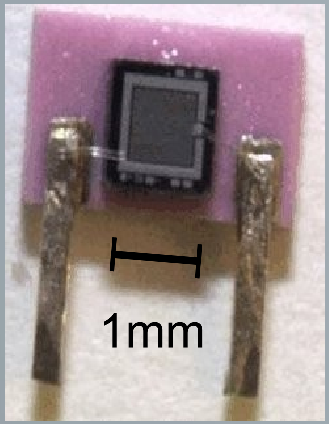
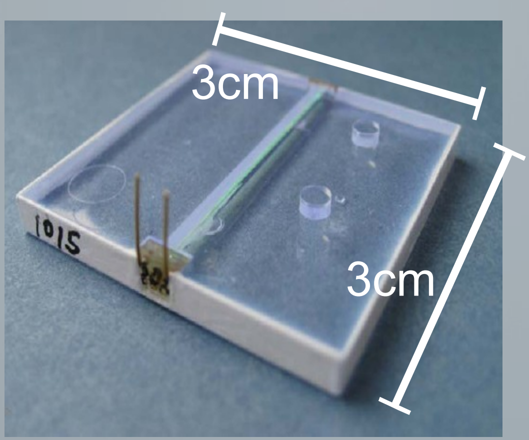
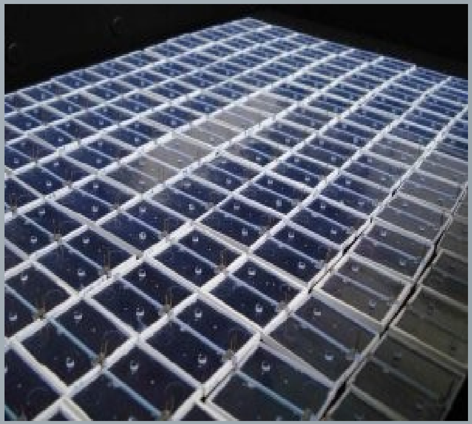
Short reminder on the analog HCAL

Design is driven by particle flow requirements, minimal dead space and high granularity

- Placed inside the tracker's magnetic field, self-supporting sampling structure of 2cm steel + 3mm scintillator + embedded readout
- $8 \cdot 10^6$ scintillator tiles, each with silicon photomultiplier (SiPM)







- SiPM: insensitive to magnetic fields, highly miniaturized, high gain (10^5), low supply voltage (40V), plain wiring

SiPM structure and signal

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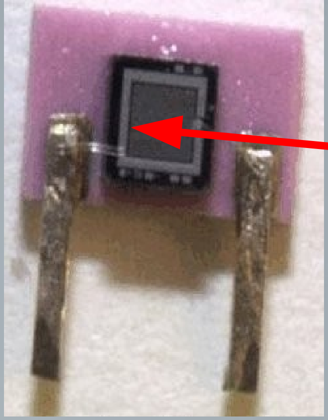
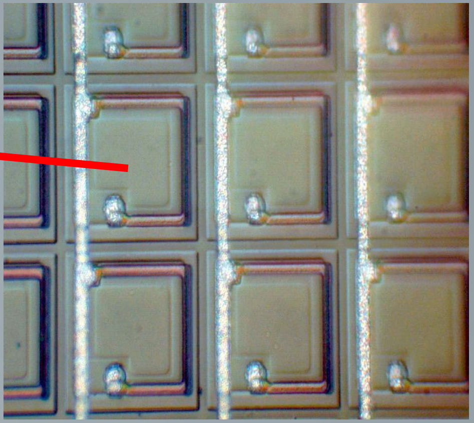
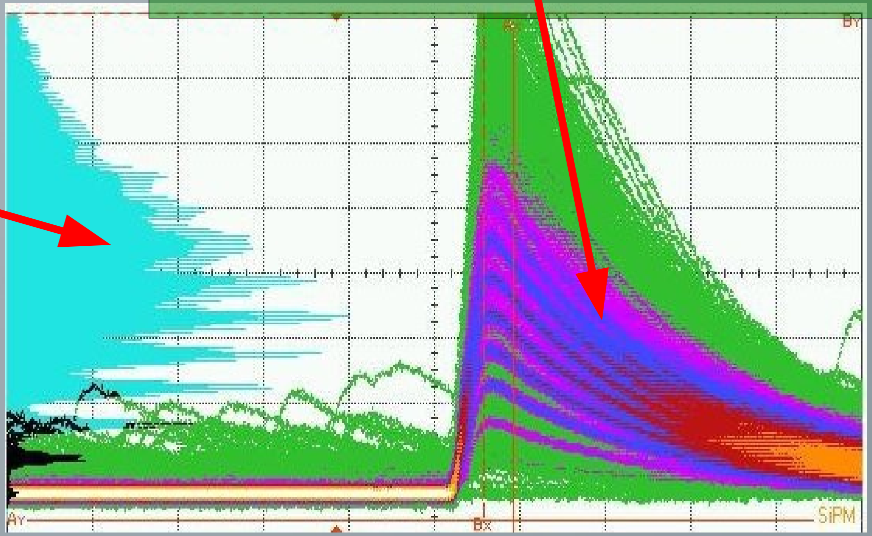
- SiPM are arrays of ~10^3 avalanche photo diodes ('Pixels'), wired in parallel
- Pixels are single photon sensitive
- Operated in Geiger mode: fixed charge per avalanche → analog signal quantized by pixel discharge
- Single photon spectrum (SPS): histogram of the SiPM signal for small light pulses shows quantization



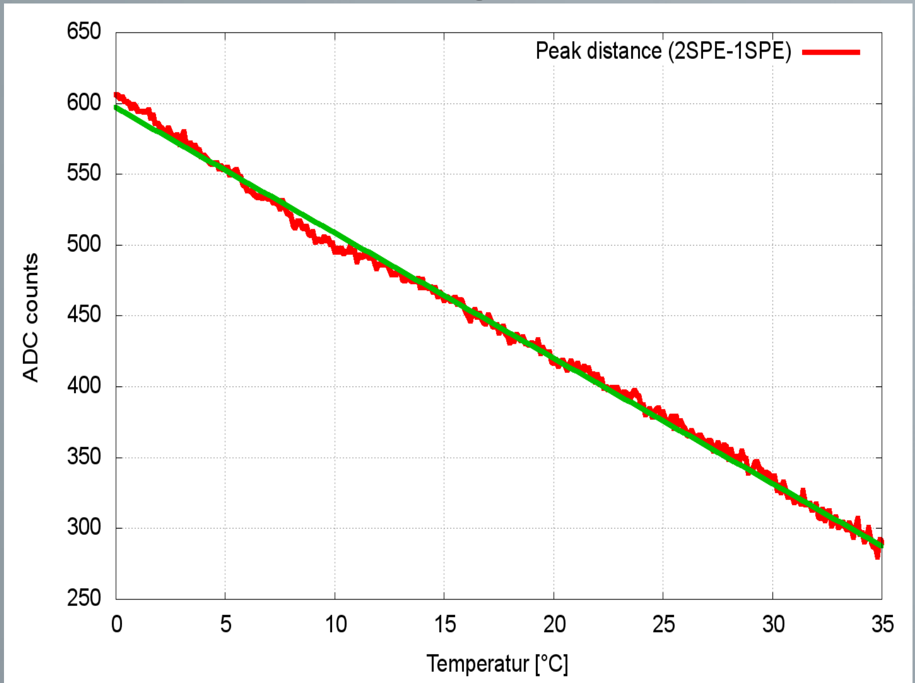


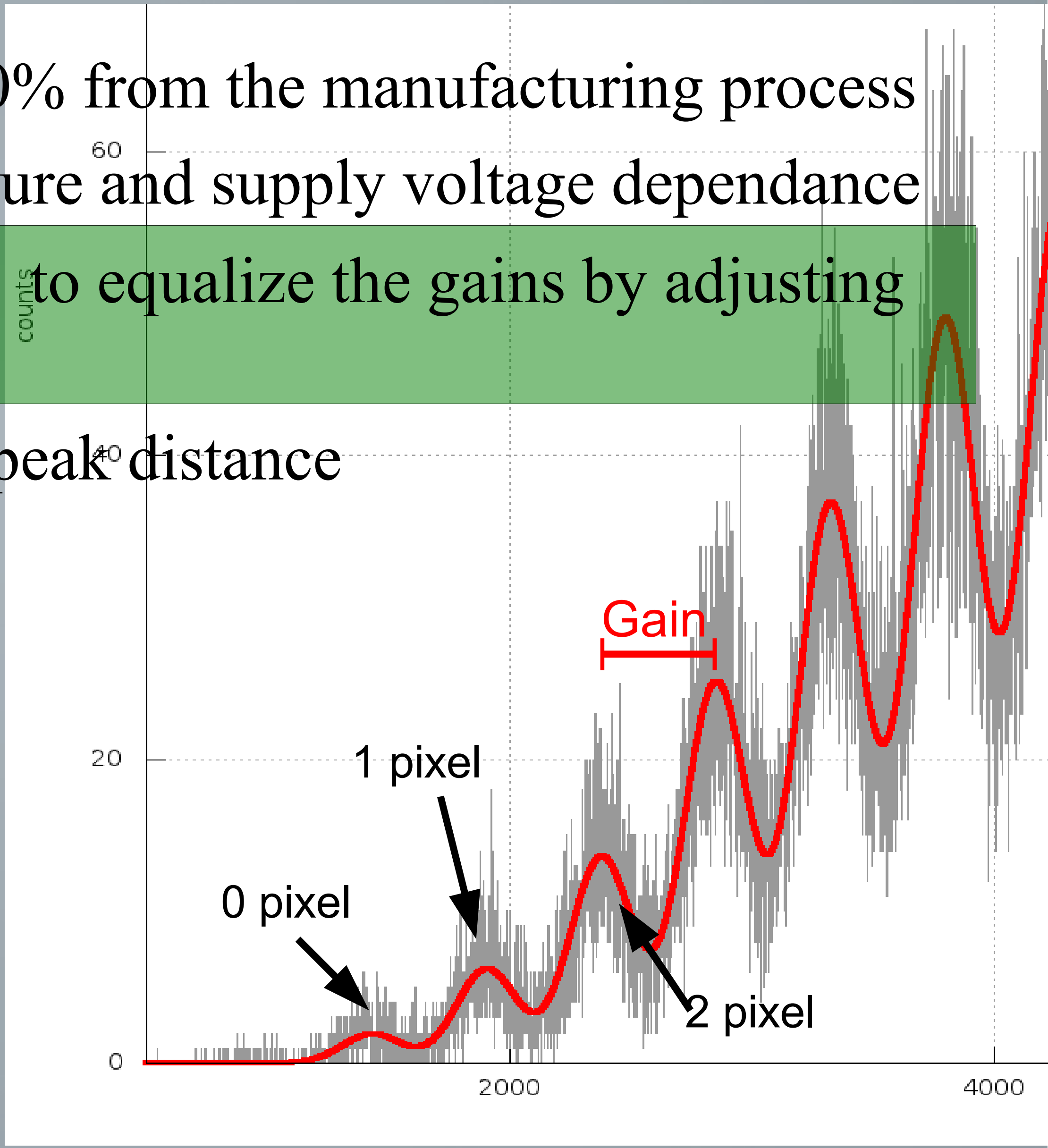
Overlaying SiPM signals cluster around 'integer' pixel discharges



SiPM gain calibration

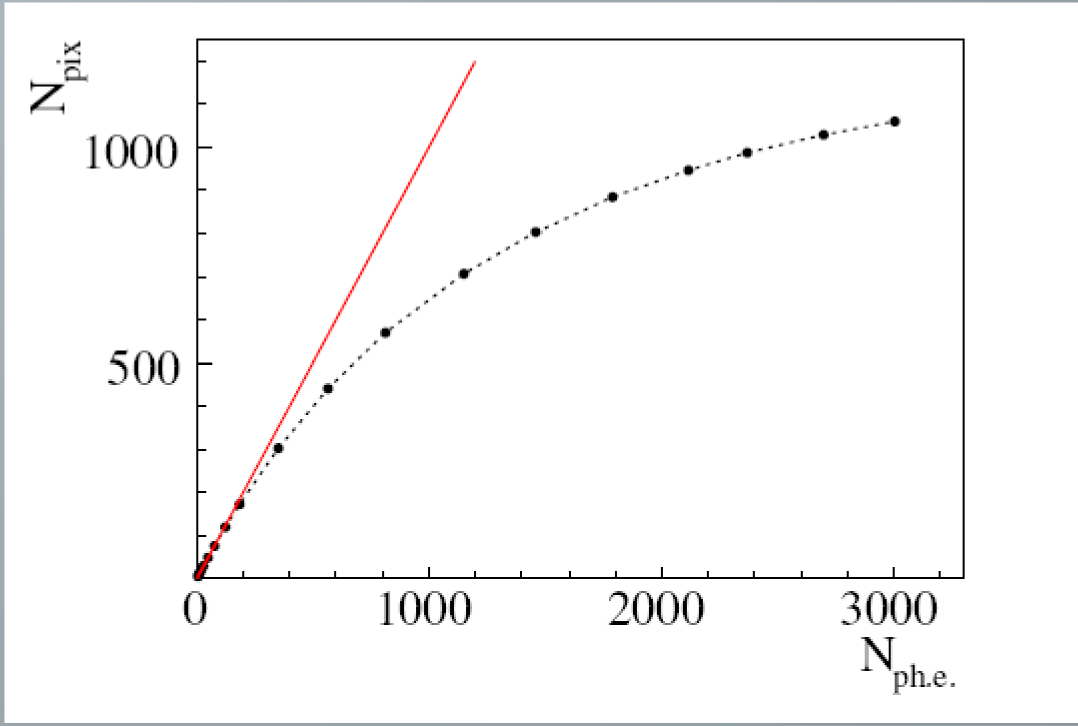
- SiPM disadvantages:
  - SiPM gain varies up to 300% from the manufacturing process
  - SiPM gain shows temperature and supply voltage dependance
  - → use the latter characteristic to equalize the gains by adjusting the SiPM supply voltages
- Extract the gain from SPS as peak distance





Saturation correction

- Once fired, a pixel has a dead time, finite number of pixels
  → exponential SiPM response for large photon numbers
- Coupling of tile to SiPM can change the number of effective pixels
  → strong but short light pulses can saturate the SiPM
- Pulses must be short to avoid re-firing



Embedded calibration system

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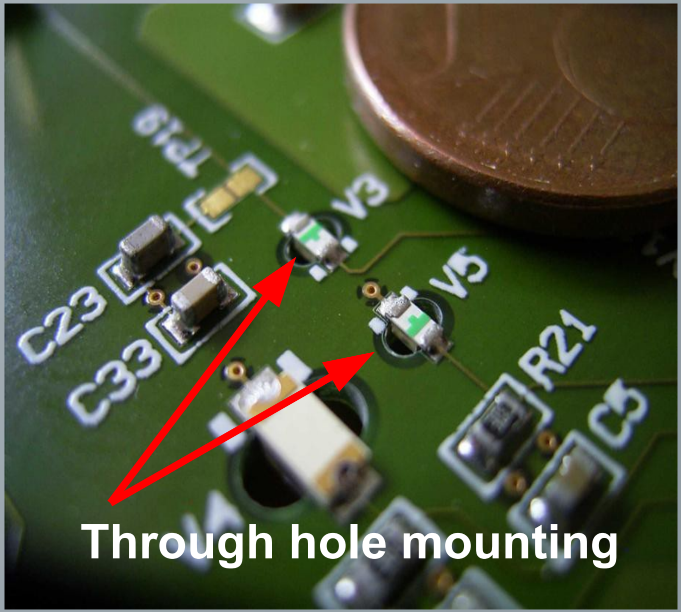
- SPS creation with short light pulses for gain calibration
- Saturation correction with large but short pulses
  → wide dynamic range
- System must be scalable to millions of channels (mechanically, financial)

Approach:

- Calibration system as part of the embedded readout electronics (one LED + pulse circuit per tile)
  → Optimal scalability

- Developed by DESY & Uni Wuppertal



Embedded calibration system II

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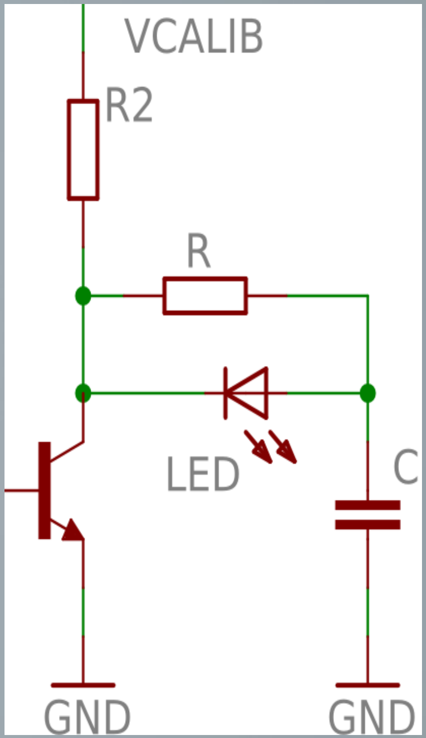
Choice of LED and pulse circuit are essential for the calibration performance: optimized for shortest pulses

- Pulse circuit idea:
  - Capacitor discharge via fast transistor through LED, V_calib steers light yield
- Several different LED types tested
  - Lowest internal capacitance necessary
  - Single-quantum-well LEDs are good (usually UV-LEDs)

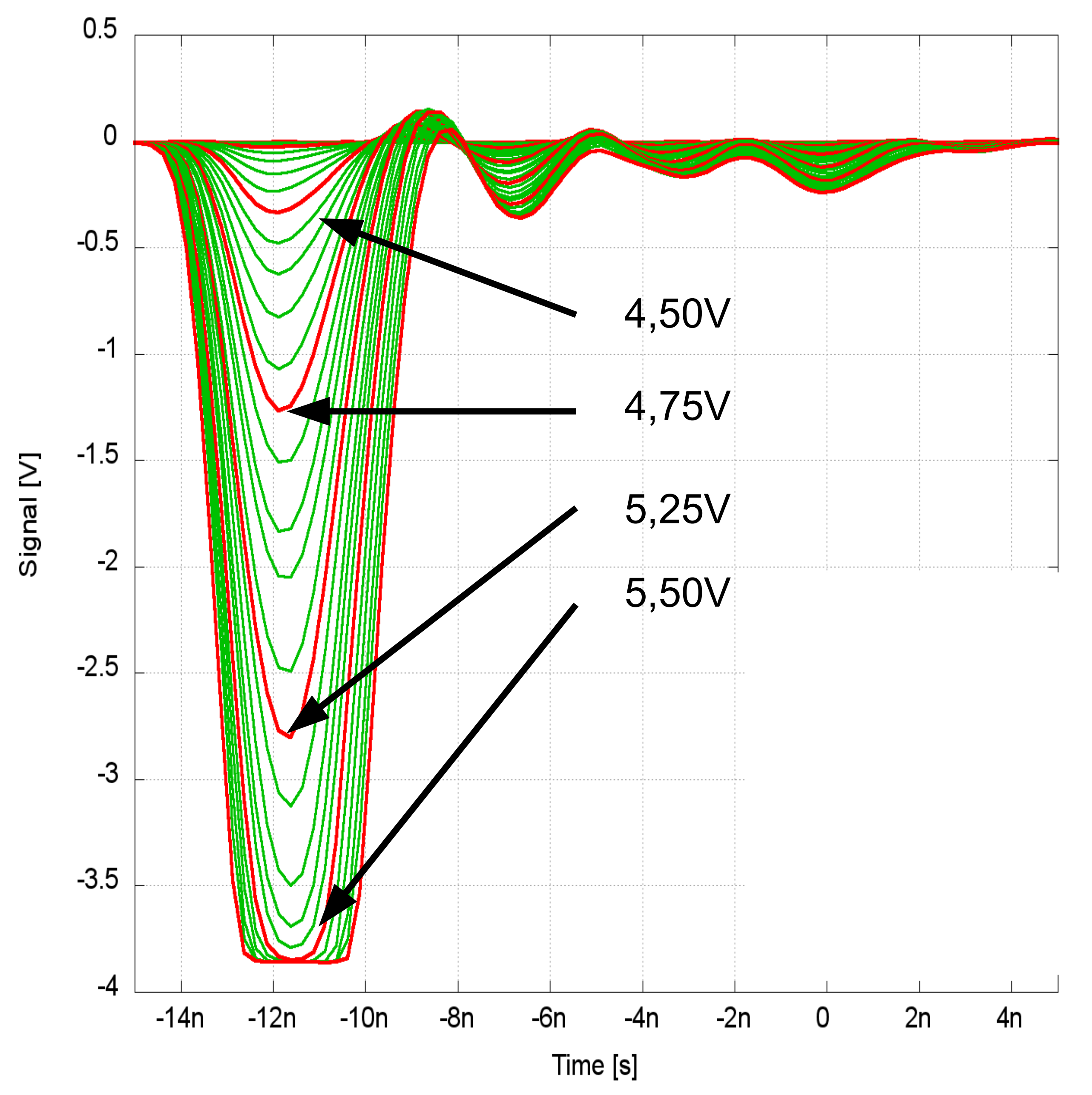


- Pulse length could be fixed at around 8ns for reasonable V_calib (3-10V) → see next slide

Pulse length

- Pulse length should be comparable to the light pulse of a traversing particle

  (time constant of tile is about 10ns)
- Measurement with fast PMT
- V_calib steers the light yield
- Low light yield dependence



Pulse length and SPS quality

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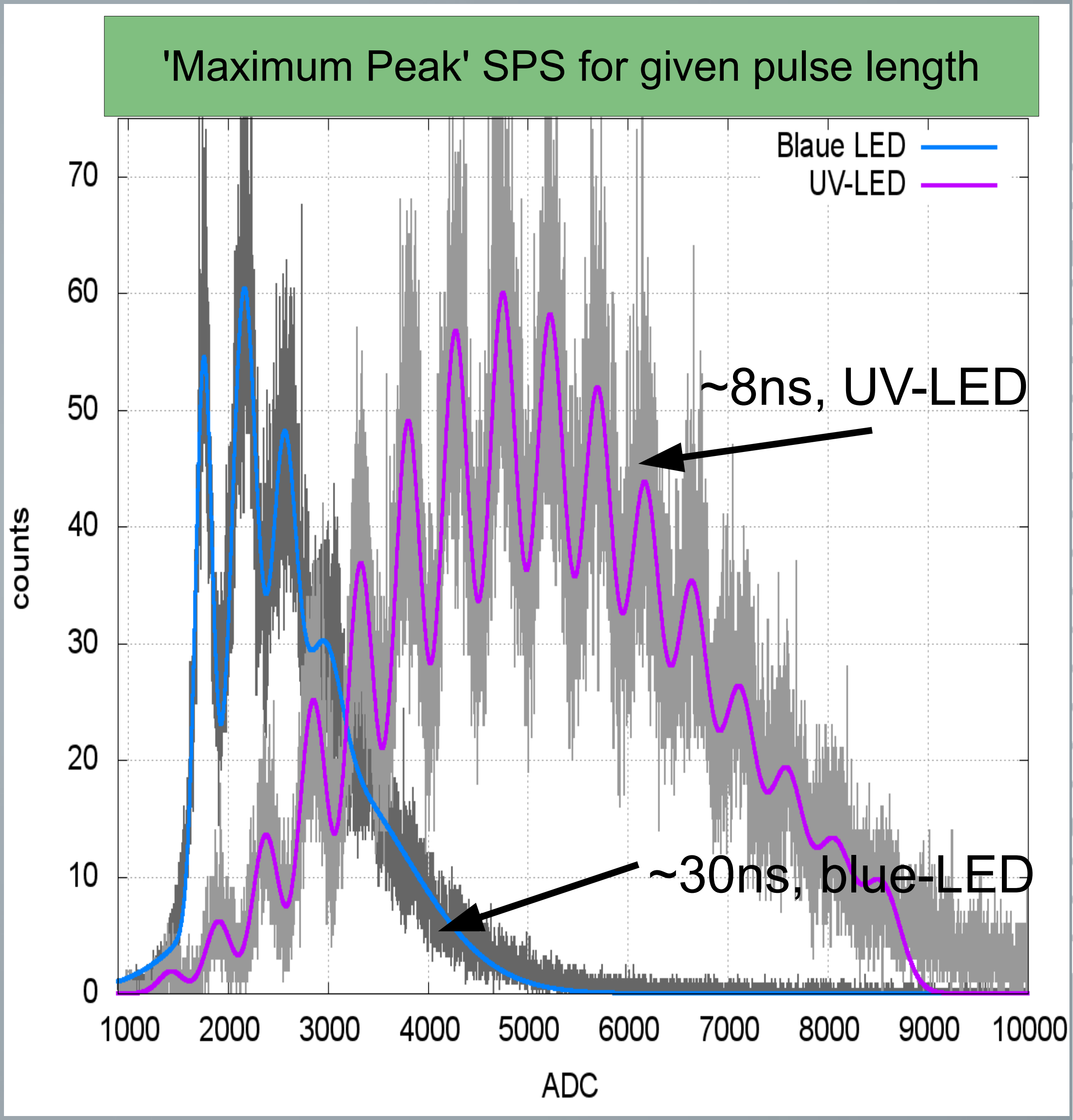
- V_calib range, that yields SPS is limited

  → shorter pulses allow for more peaks, before SPS gets diffuse

  → better overall quality
- Mean of the SPS corresponds to light yield

  → possible to create SPS for much higher photon counts per pulse
- Important for multi SiPM systems



Calibration of multi SiPM systems

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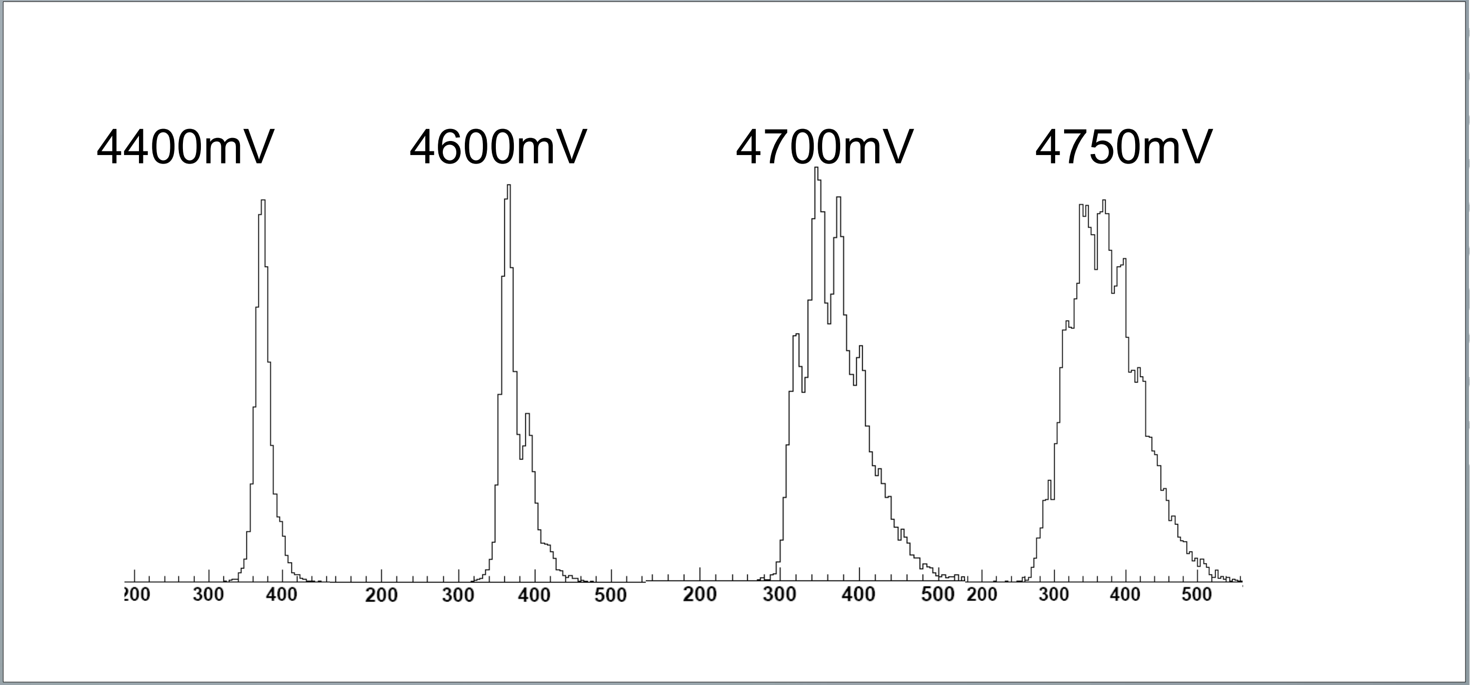
- More parameters to be taken into account:
  - LED Spread in light yield, collection efficiency of the tiles

  → Changes the received photon count for a given V_calib
- Problem: disjunct V_calib ranges for SPS between SiPM if the V_calib range is to small
- Example for >30ns pulses from an electronic prototype (HBU0)

for 39 SiPM 5 V_calib settings needed



Multi SiPM calibration

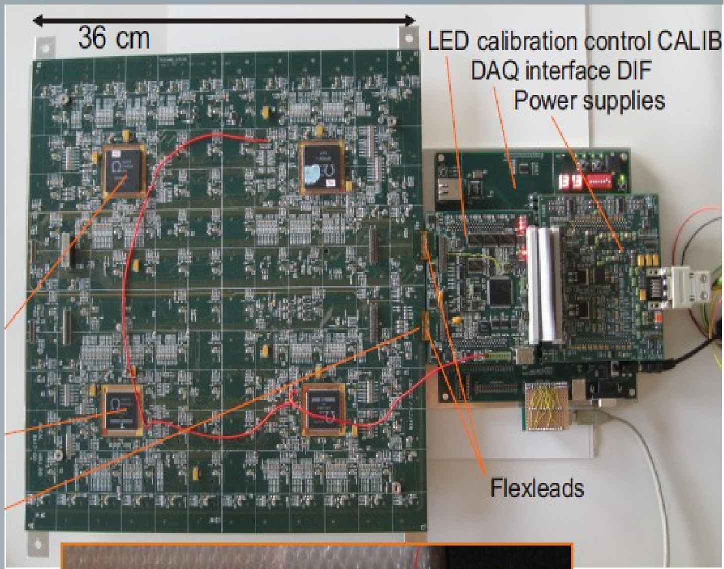
More benchmarks: Calibration speed, low failure rate (no SPS creation), optional: optical crosstalk measurements

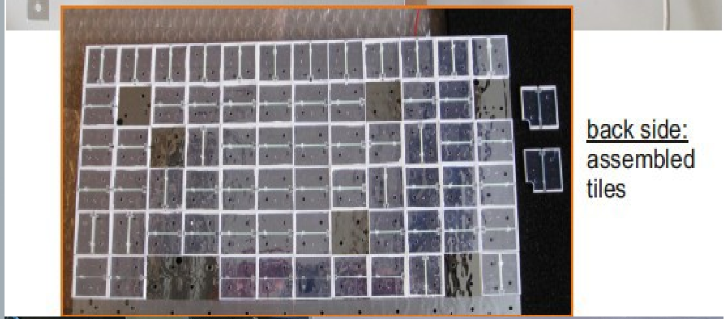
Keep system simple: common V_calib for all channels (no programmable V_calib supply per channel)

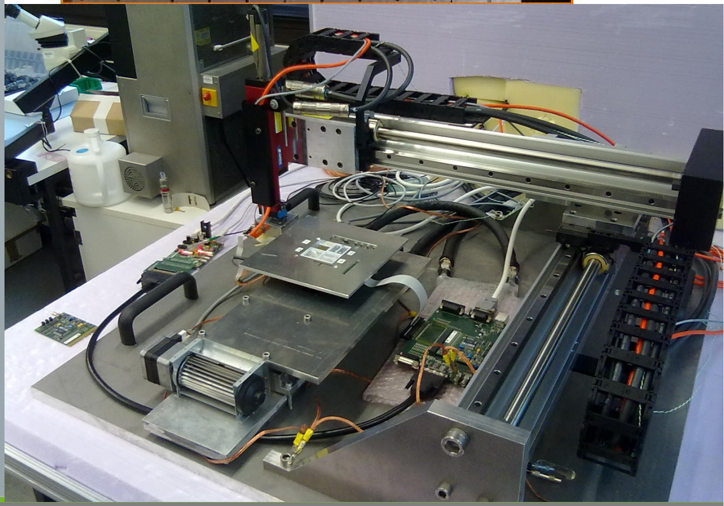
- Importance of SPS quality:
  → broader spectra allow bigger overlap (ideal: no disjunction)
  → clear spectra require less statistic
  → more tolerance for long SiPM signal tails (to be shown)
- Minimize the spread in light yield and collection efficiency
  → parallel capacitors to unify LED light yield
  → LED preselection (vendor or CALICE)
  - Mechanical realization challenging!

Current studies:

- Repeat calibration of HBU0 (65 SiPM channels) with optimized pulse circuit
  - Former calibration took 5 different V_calib sets, 22 SiPM showed smeared spectra (no SPS possible)
- Use calib. environment (light-proof, temperature controlled XYZ table) to bring same pulse circuit to each tile of the setup
  - repeat measurement and compare: how many V_calib settings needed? Possible to recover smeared spectra?
  - Saturation comparison







Saturation

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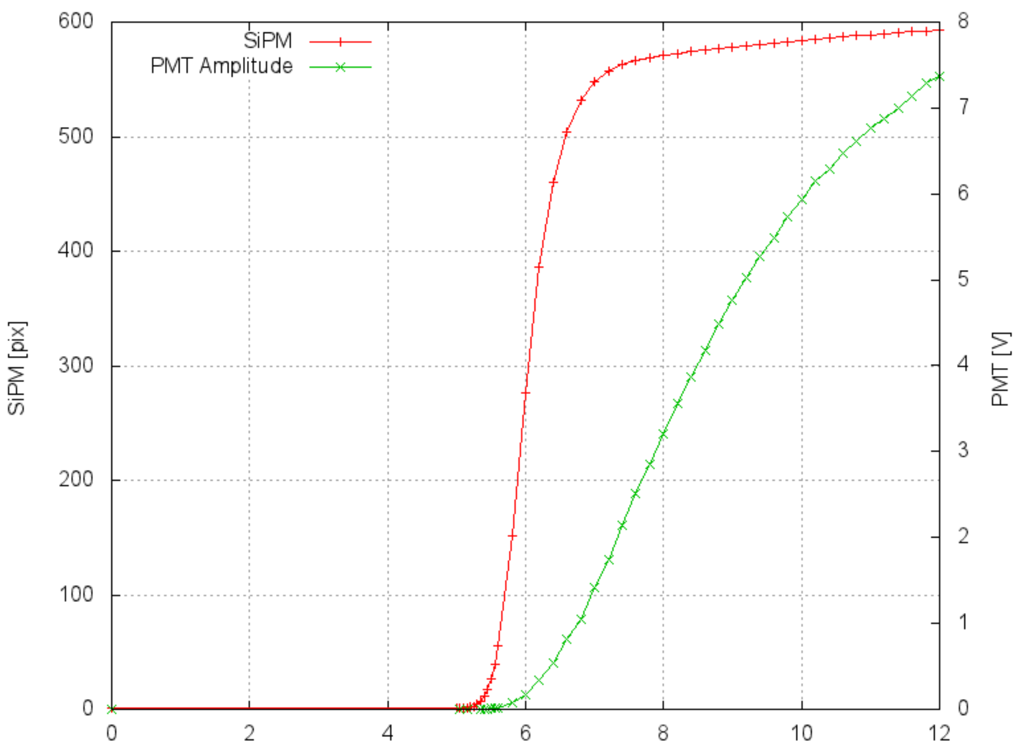
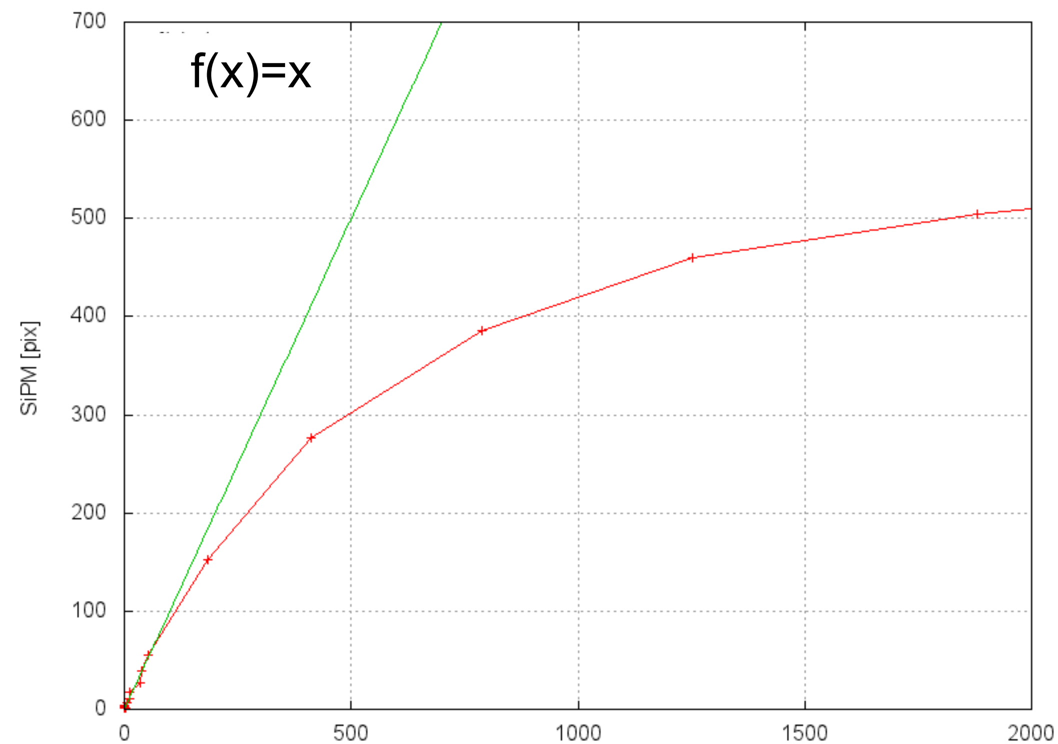
- High V_calib pulses into tile, PMT scans LED backside
  - Measuring partially the same light pulse at fixed ratio
    → Distinguish SiPM and PMT or LED saturation



V_calib in mV (not proportional to photon count)



PMT single in pixel-equivalents (approx.)
Full dynamic range: 12V ~ 15k pixels

Outlook

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- First multi SiPM setup in Wuppertal:
  - Calibration studies with new pulser about to begin
  - Compare pulser performances for swift and complete calib. for all SiPM → duration full HCAL calibration
  - Develop a calib. procedure, optimize fits etc.
- Crosstalk measurements: using the XYZ table to pulse single tiles; implement pulse pattern option for the calib. system → determine crosstalk matrix for each cell of setup
- New electronic prototype: new HBU using a 'state of the art pulser', 72 SiPM setup
  - Use for inter-pulser comparison (refit XYZ table, bring tile to pulser)