LED calibration systems for CALICE hadron calorimeter

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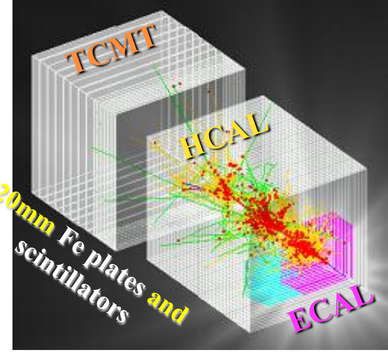
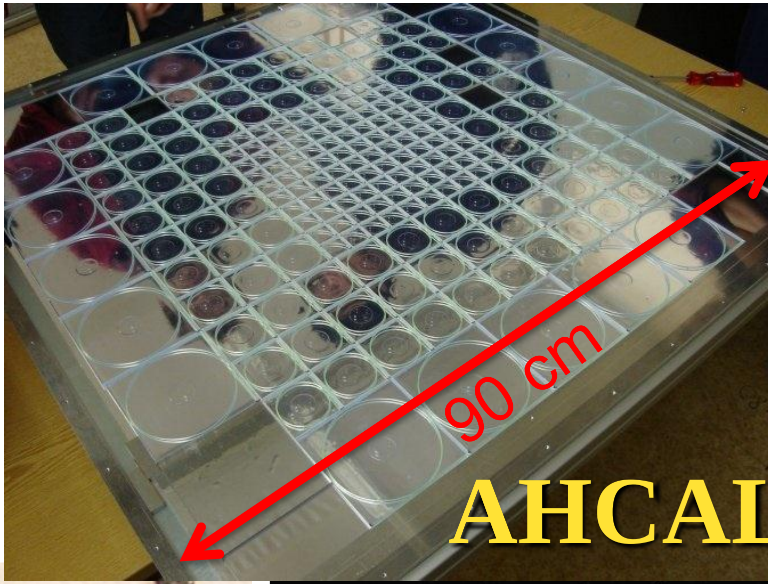
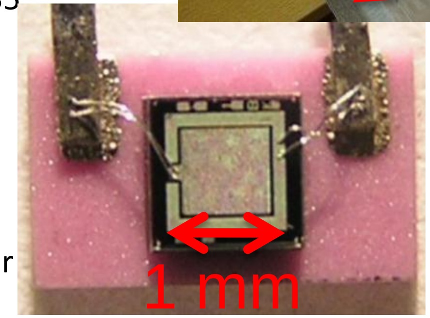
- The CALICE 1m^3 HCAL prototype
- Calibration solution for CALICE AHCAL (DESY, FZU)
- Embedded calibration solution (DESY, Wuppertal)
- Quasi-resonant LED driver (FZU)
- Optical fiber light distribution (FZU)

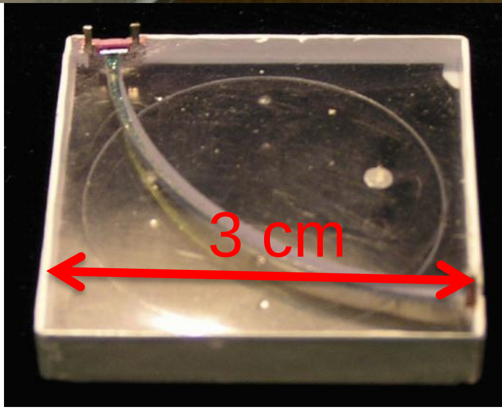
AHCAL 1m^3 Physics prototype

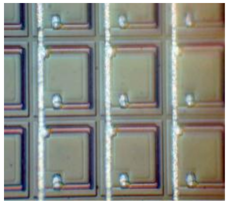


- The AHCAL 1m^3 - CALICE collaboration
  - built in 2005
  - Testbeams 2006-2011 at CERN and FNAL.
  - Now in CERN as **WHCAL** with tungsten absorber
  - Tested together with ECAL (electromagnetic calorimeter) and TCMT (Tail Catcher and Muon Tracker)
- 38 layers, 2cm Fe absorbers
- 7608 photo detectors (SiPM) in total
- **One layer**
  - 216 scintillator tiles with SiPMs, 3x3, 6x6, 12 x 12 cm2
  - **Calibrating system** (CMB) with 12 LEDs monitored by PIN-Photo Diodes
  - **Optical flash** is distributed by fiber bundle **individually** to each scintillator
  - 5 temperature sensors per layer - integrated circuits LM35
- **Scintillating tile**
  - 5mm thick Scintillator
  - WLS (wavelength shifting fiber), ~380nm→~500nm)
  - SiPM photodetector attached to the WLS fiber + mirror
- **SiPM** (silicone photomultiplier)
  - 1156 pixels (avalanche photodiode), each works in Geiger mode
  - Fixed charge per pixel
  - Gain of SiPM has large spread ~$0.5 \cdot 10^6$ to $2 \cdot 10^6$

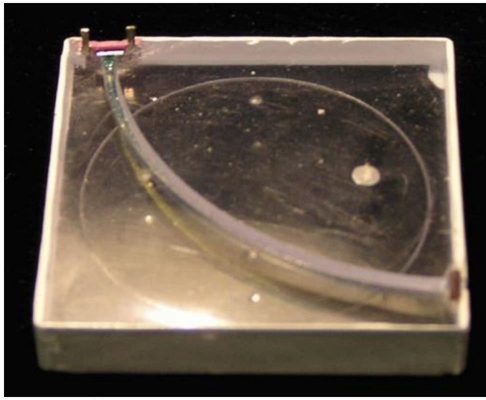








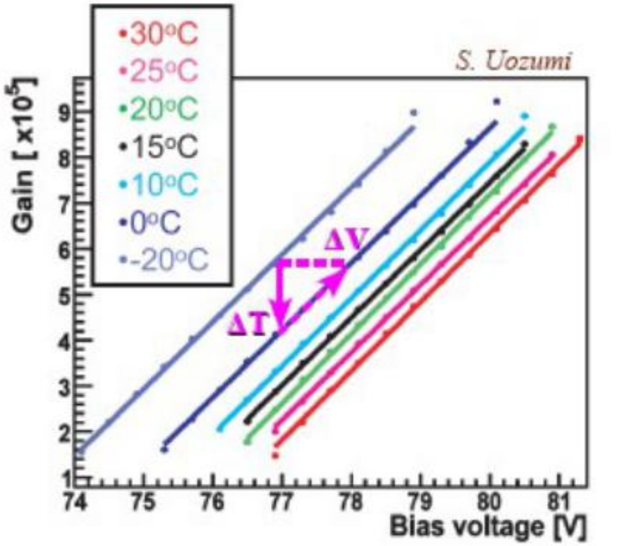
Calibration Chain: ADC to MIP

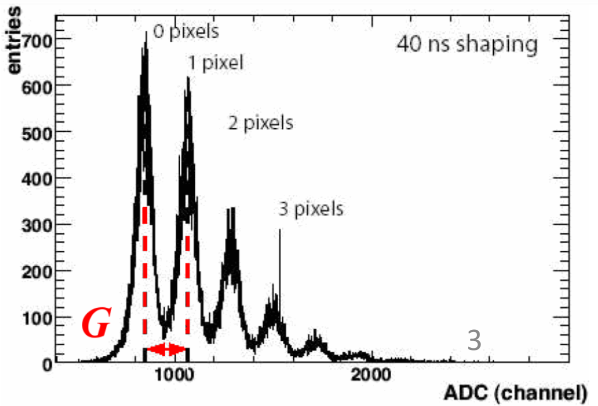


- AHCAL signal chain:

  Particle → MIPs → Scintillating tile → photons (UV) → Wavelength-shifting fiber → photons (green) → SiPM → Photo-electrons → ASIC readout
- Calibration task:

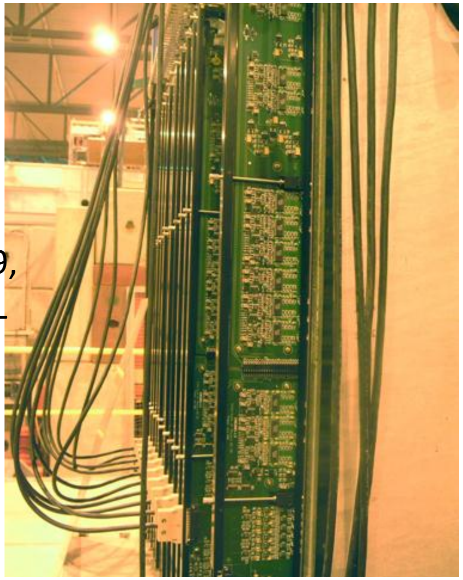
  Convert the detector signal to a number of MIP deposited by the particle
- Calibration possibilities:
  - **LED light**
  - Charge injection (ASIC ADC calibration)
  - Cosmic muons
  - Other means, not used: laser, radioactive source
- Key parameters factors of SiPM:
  - SiPM gain (from Single Photon Spectrum)
  - Temperature (gain factor ~-2% per 1K)
  - Voltage applied
  - Saturation function



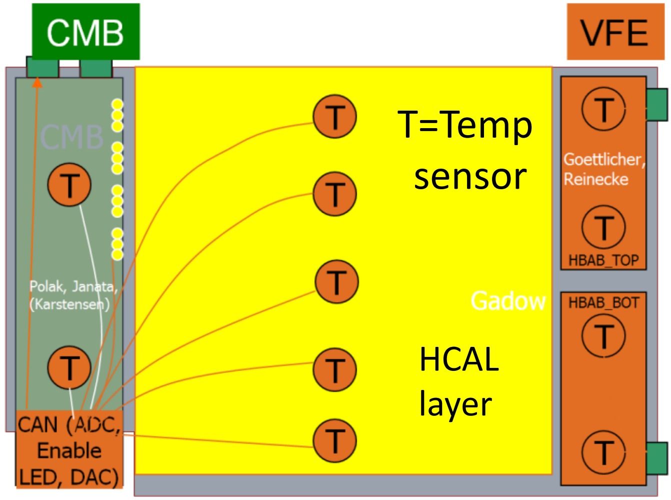


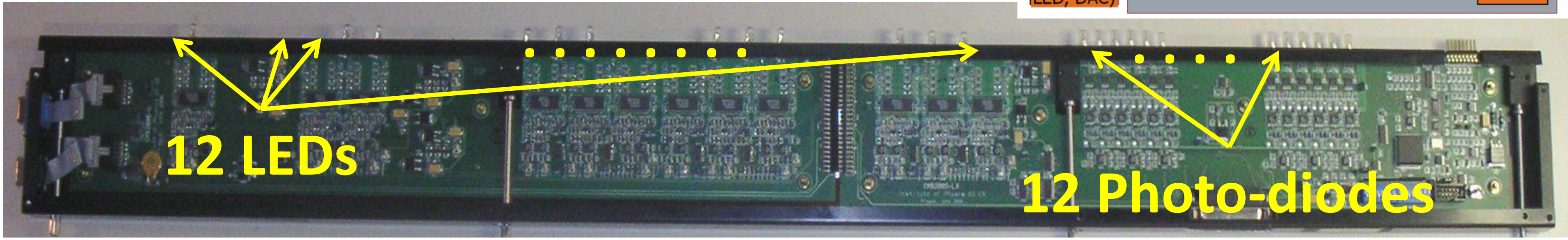
Calibration and Monitoring Board (CMB)

HCAL 1m²
BT 2006-2009,
now WHCAL



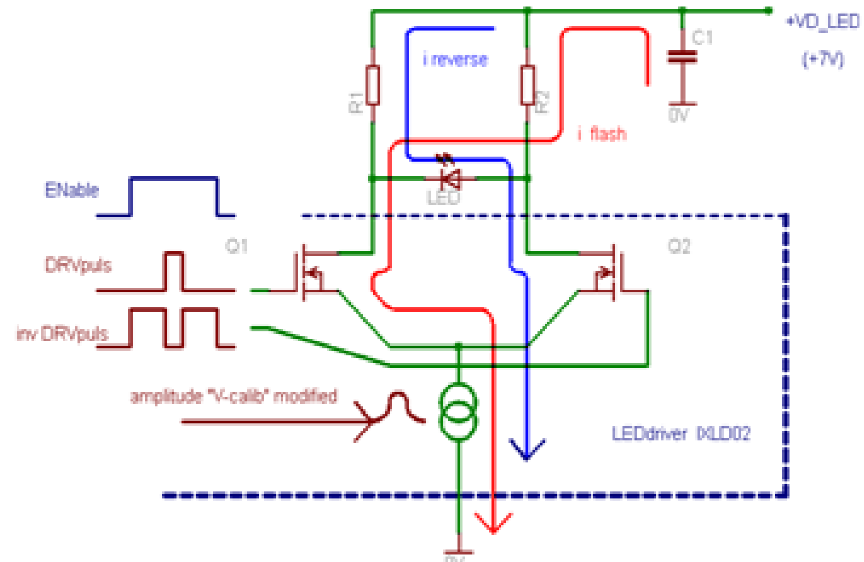
- Developed by **DESY** and **FZU** for the CALICE AHCAL 1m^3 prototype
- CMB consists of:
  - 12 UV LEDs, each LED illuminates 18 Scintillating tiles
  - 12 pin-photodiodes preamplifier (LED feedback)
  - Light flash is steerable in width (2~100 ns) and amplitude
  - Controlled externally by CANbus, T-calib (LVDS trigger) and V-calib (differential analog signal)
  - Temperature readout, sensors all over the module
- Used both for gain and saturation corrections

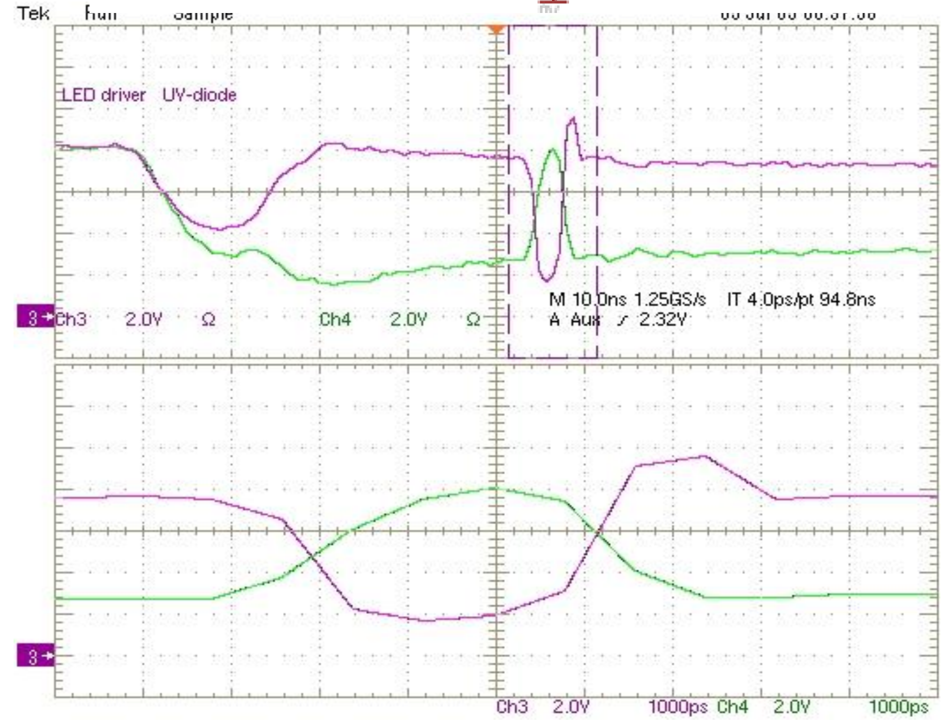




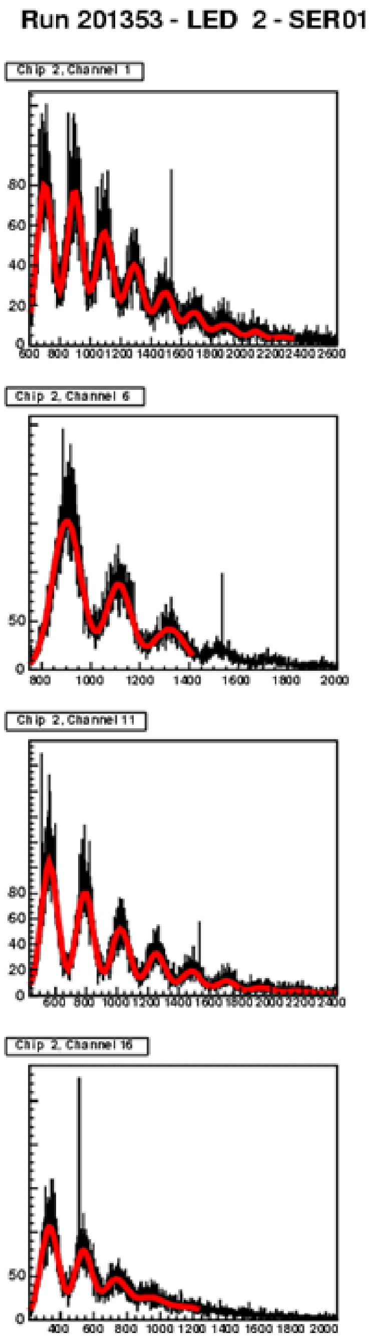
LED driver on CMB

- The LED is driven **differentially**
- The key component is an IC IXLD02, a LED driver from IXIS company
- Reverse voltage is applied right after the pulse → LED stops to shine immediately
- Disadvantage: RFI (radio frequency interference) due to the sharp edges

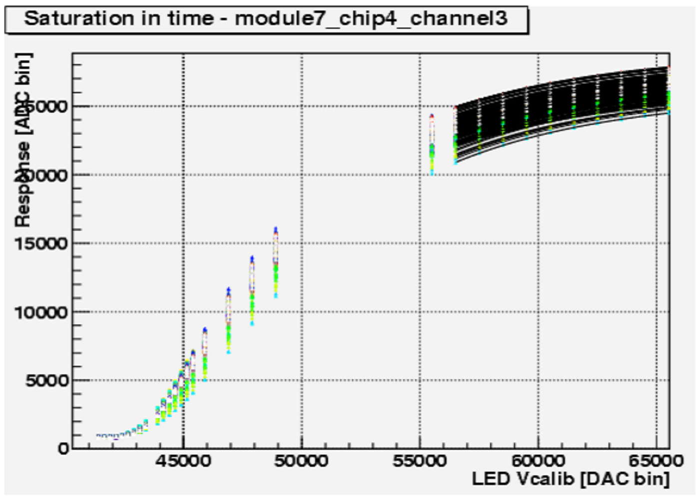


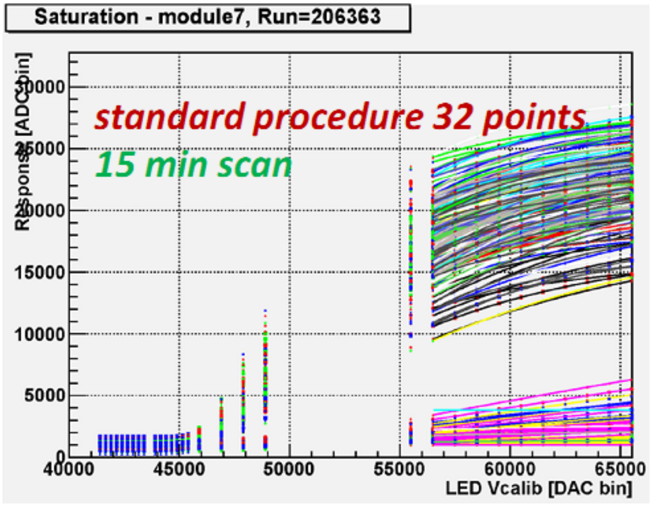


CMB results



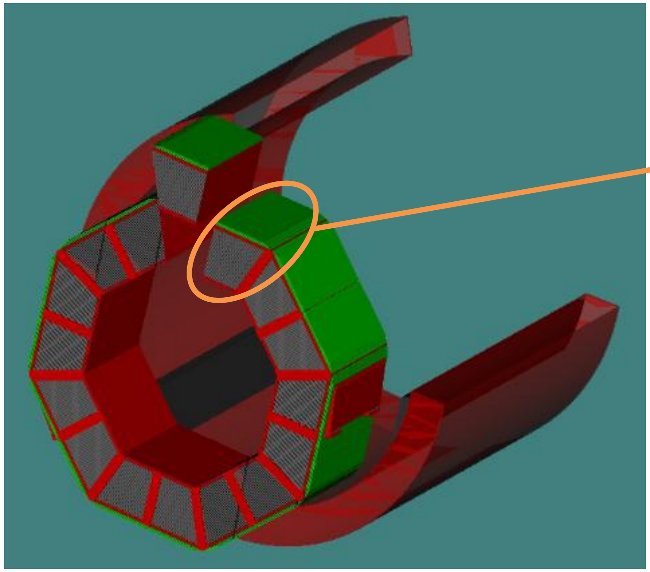
- CMB worked well for the 1m3 HCAL phys. prototype (2005-2011, from 2010 with Tungsten: WHCAL)
- Used for
  - Low intensity: the Single Photon Spectrum (gain calibration)
  - High intensity: SiPM saturation
  - Temperature measurements (for corrections)

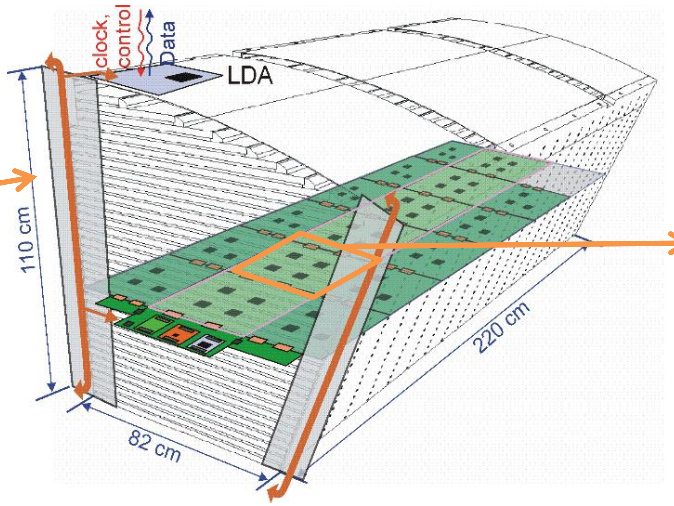


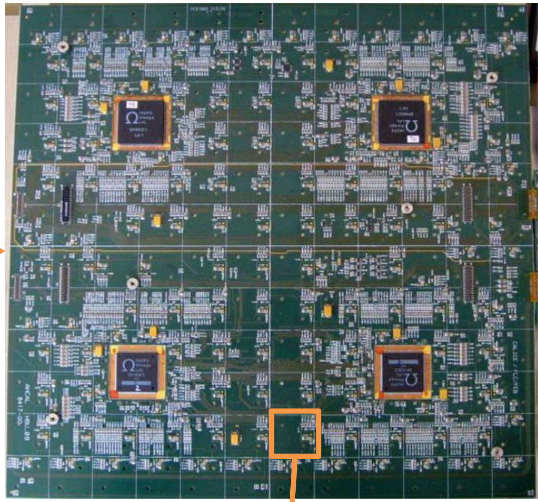


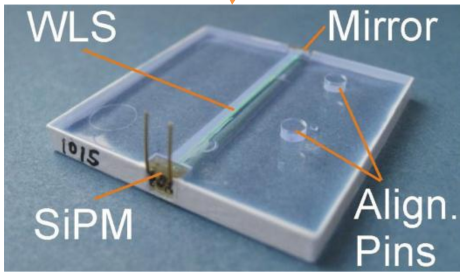
The engineering AHCAL prototype

The Engineering prototype aims to find solution for hadron calorimeter in real ILD detector









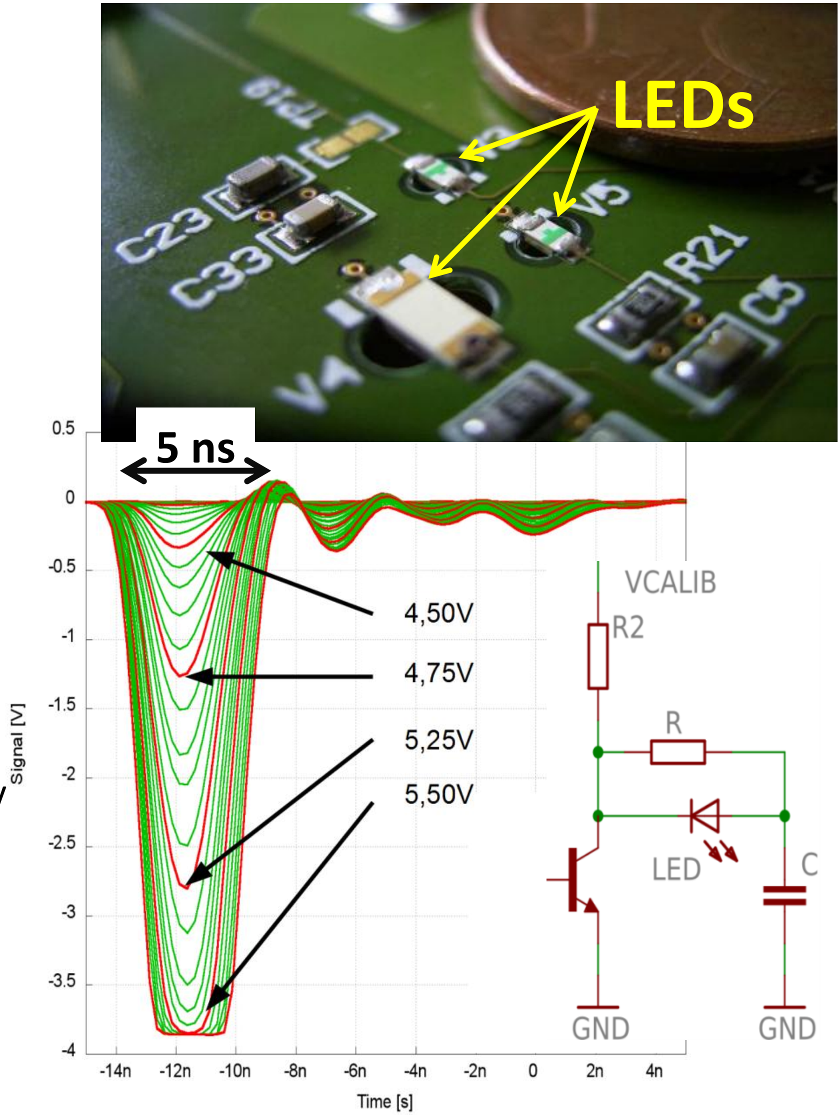
HBU: PCB 36x36 cm
144 scintillating tiles with **SiPM**
4 ASICs for **integrated readout**

Octagonal structure,
16 equivalent wedges,
2 barrels attached subsequently
~$8 \cdot 10^6$ channels in total

2 calibration systems:
- Integrated (distributed)
- External via optical fiber

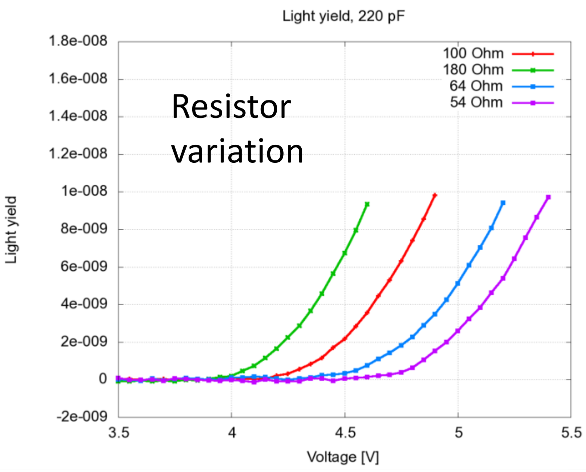
Integrated LED system

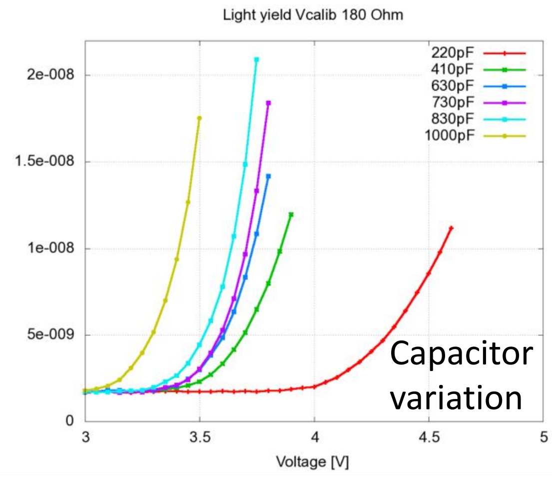
- Developed by **DESY** and **Uni Wuppertal** (Mathias Goetze, Julian Sauer, Sebastian Weber)
- Each tile has its through-hole mounted LED with its own driver.
  - Compact circuitry
  - **Operation**: The current pulse though the LED is generated by discharging of the Capacitor by a fast transistor
  - V-calib signal range: 3–10 V covering both Single Photon Spectrum and saturation
- Choice of the LED is critical for this driver
  - Several different LED types were tested
  - The **internal capacitance** of the LED is most important
    - Only Single-quantum-well LEDs work well (usually UV-LED)
    - Usual (multi-quantum-well) LEDs have too big capacitance and produce longer optical pulse. On the other hand, they are very bright

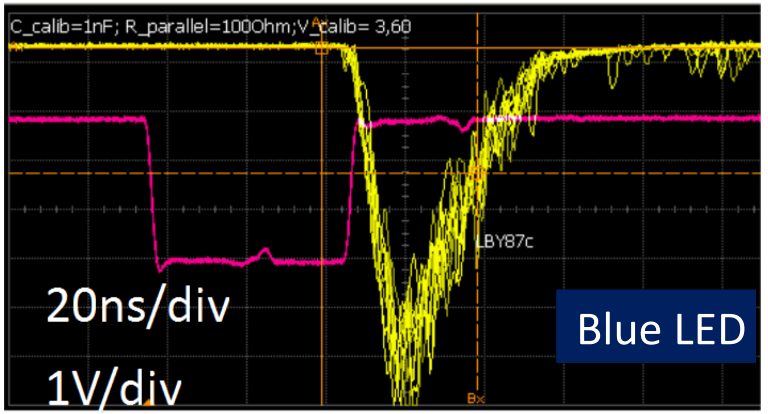


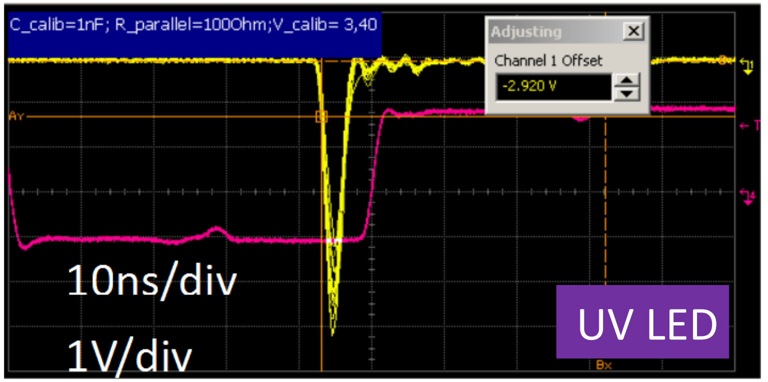
Integrated LED system – Optimization

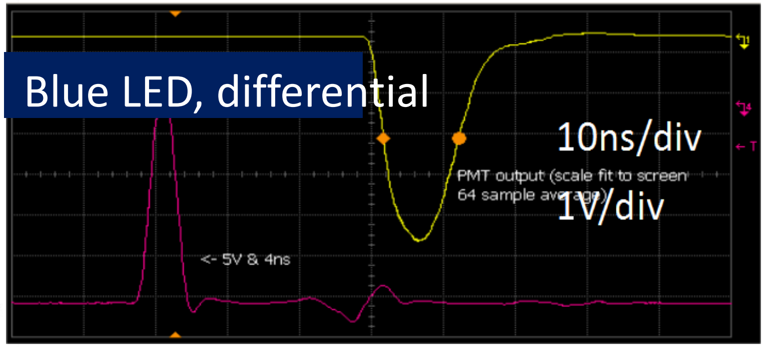
- Pulse of the Blue LED (~40 ns) and the UV LED (~5 ns) with the current circuit on HBU0
- Proof of the capacitance dependency: Light pulse width re-measured with a **differential driver**
  - In this mode: LED is reverse biased, then for a short pulse forward biased and directly reverse biased again
  - The reverse voltage helps to discharge the LED
  - Blue LED stops shining much faster in differential mode
- Optimization process: measurements with key components variation





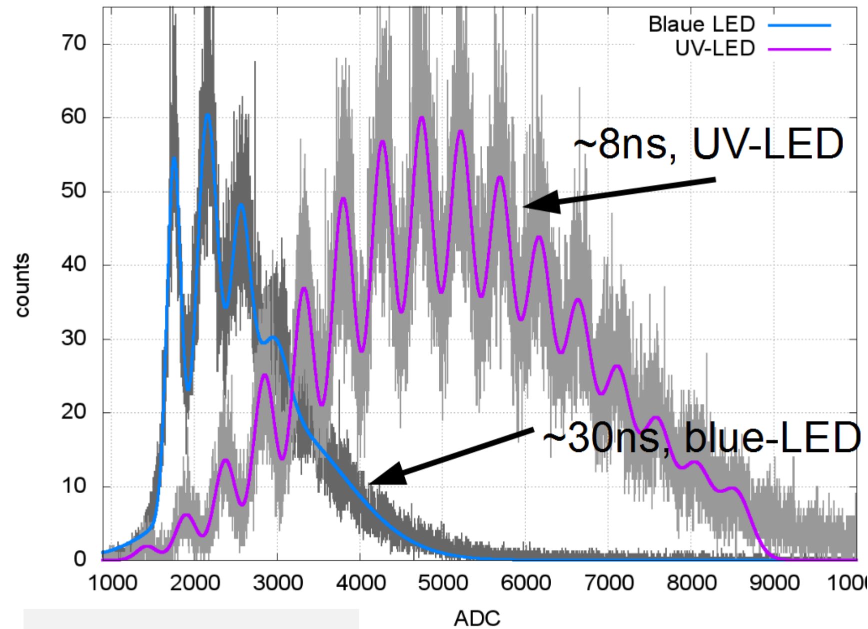


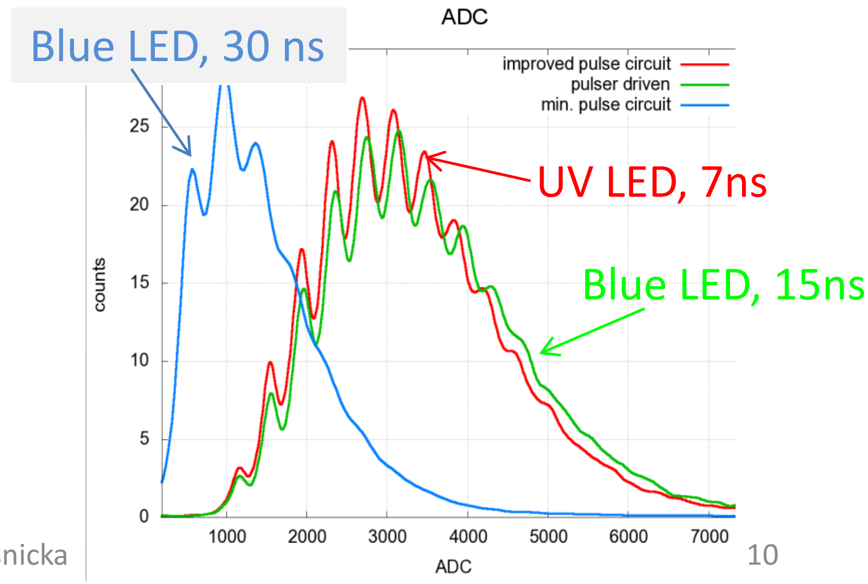




Integrated LED system – SPS

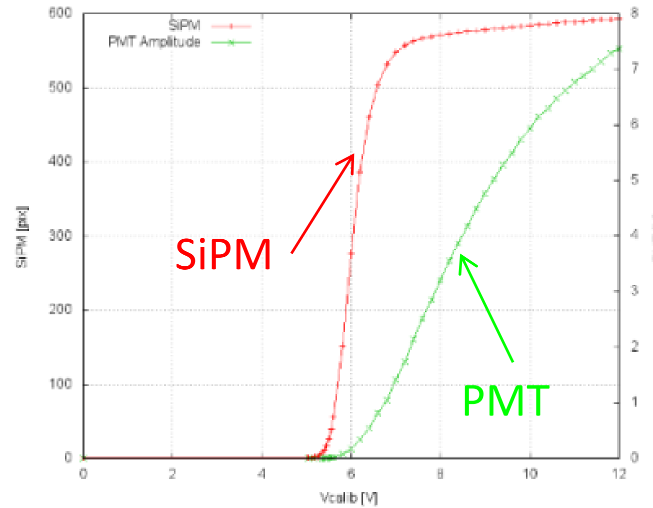
- For longer (>30 ns) pulses, both UV and Blue LEDs produce equal optical pulses
- Question: is short pulse necessary?
  - Answer: Yes, only 15 ns pulses and faster produce decent Single Photon Spectra
- **Single Photon Spectrum (SPS)**
  - The number of visible (fittable) peaks is a key indicator of the quality
  - The more peaks are visible, the easier is the system task to generate SPS for all channels (different LEDs and SiPMs)
  - Quality spectrum → less statistics required
  - Short pulse -> improvement of the quality
  - Nice spectrum with UV-LED
  - Spectrum is more smeared with 30 ns blue-LED
- Driver circuitry is now **optimized** and being manufactured on the new HBU for the technological prototype

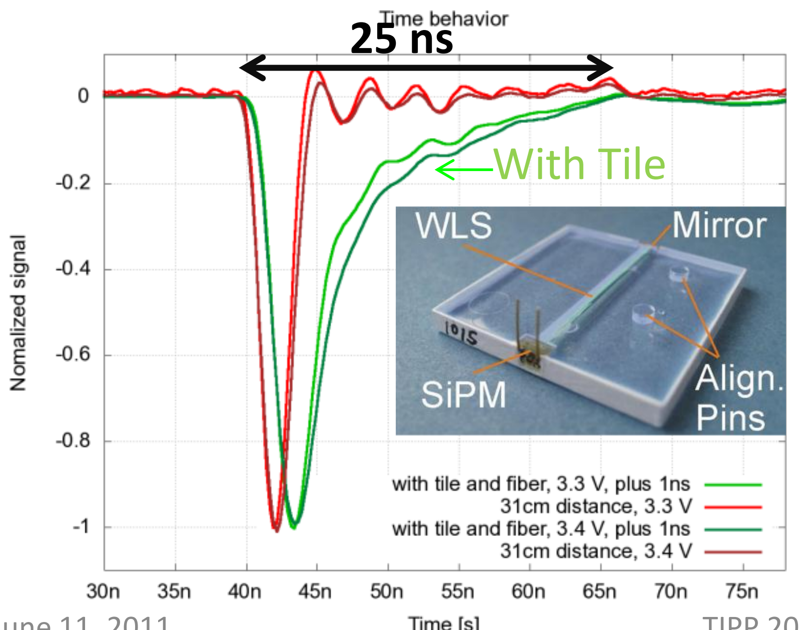


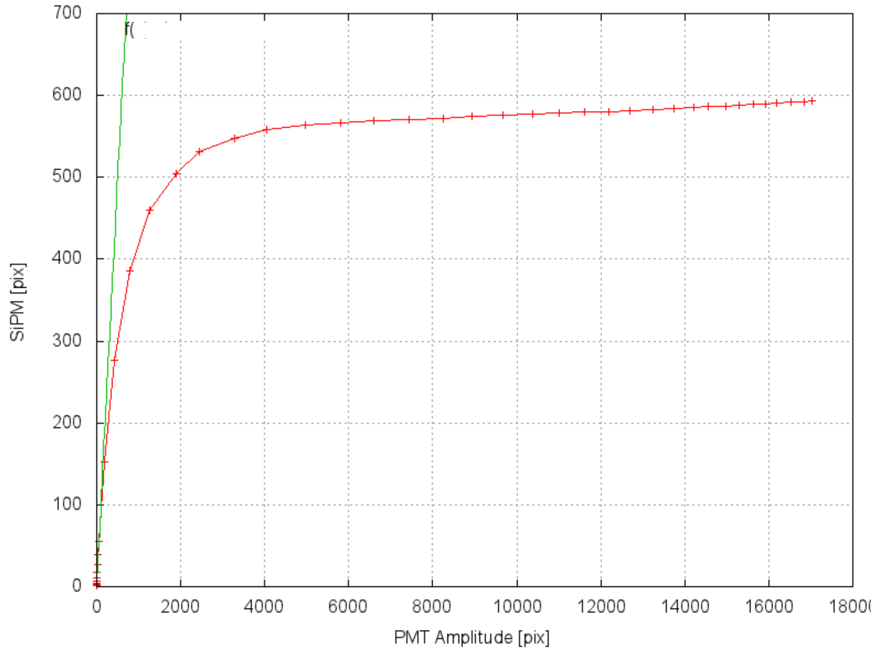


Integrated LED system – Light Yield

- The saturation curve is not an pure $f(x) = N\left(1 - e^{-\frac{x}{N}}\right)$ function. The reason could be the light distribution and coverage from the WLS fiber.
- Circuitry was finally tuned to deliver up to 17K effective pixels in saturation mode
  - Light referenced to PMT signal
  - Light pulse gets wider with increasing intensity (>20ns)
- Time behavior of Scintillation tile
  - Measured with PMT
  - Without tile: sharp pulse
  - With tile (and Wavelength shifting fiber) → long tail

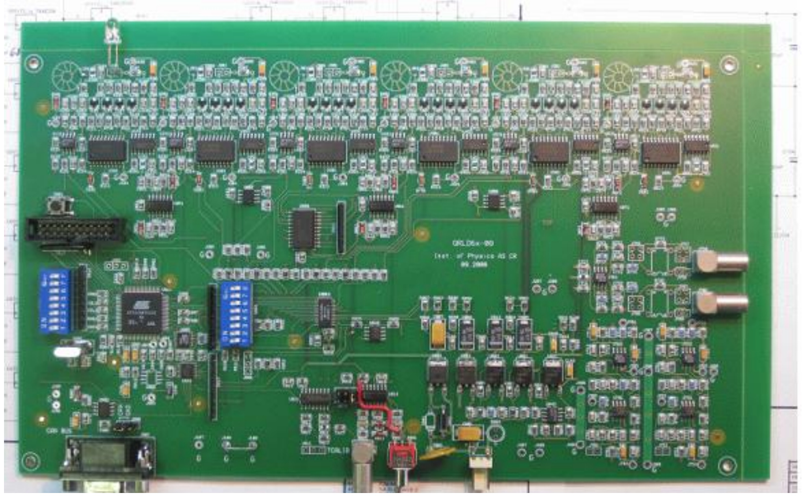


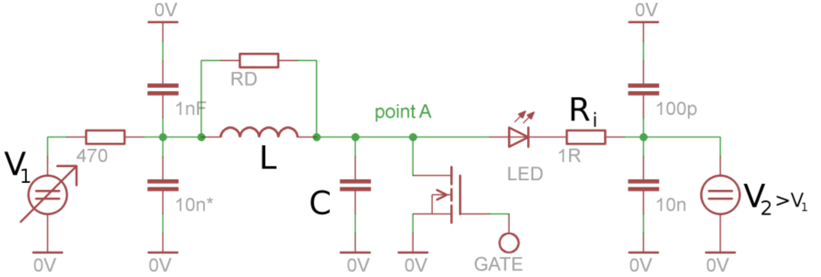


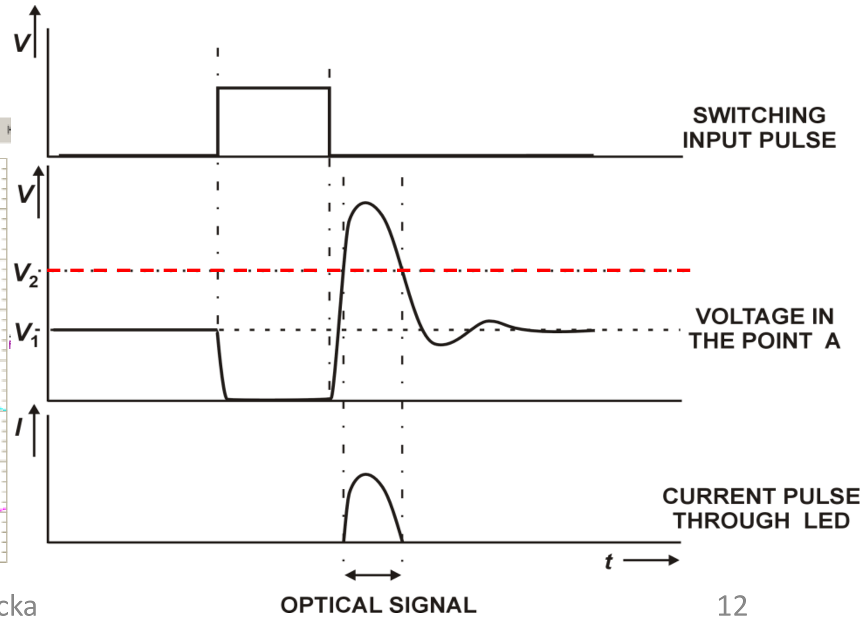


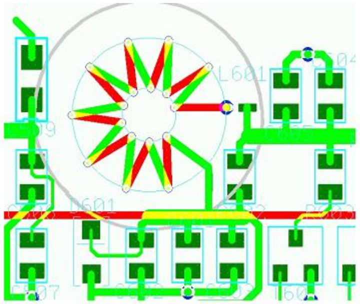
External calibration system - QMB6

- New idea of driving the LED by a quasi-sine wave
- The board has 6 Quasi-resonant LED drivers, developed in 2008/2009
- Microcontroller with CANbus control
- Voltage and temperature monitoring
- **Operation**: the transistor shorts the coil to ground → energy is stored in coil → transistor go off → the current still go through the coil → Voltage (point A) flies up and the energy is transferred to the capacitor
- The resonance of the capacitor and coil is heavily dumped by a resistor (RD) → only the first wave overcomes the control voltage V2, which forces the current to flow through the LED

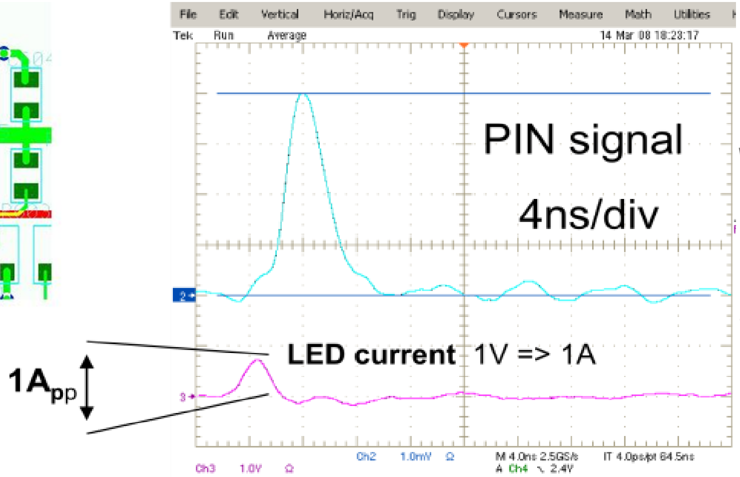






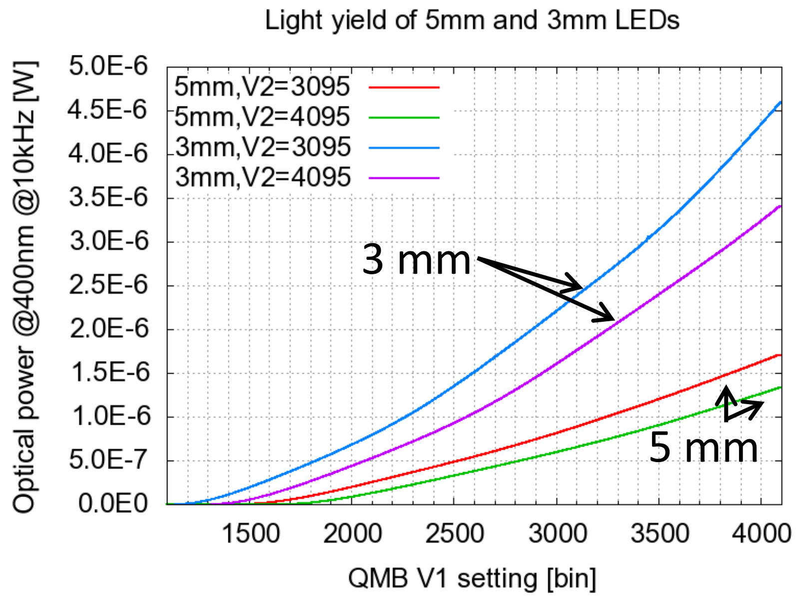


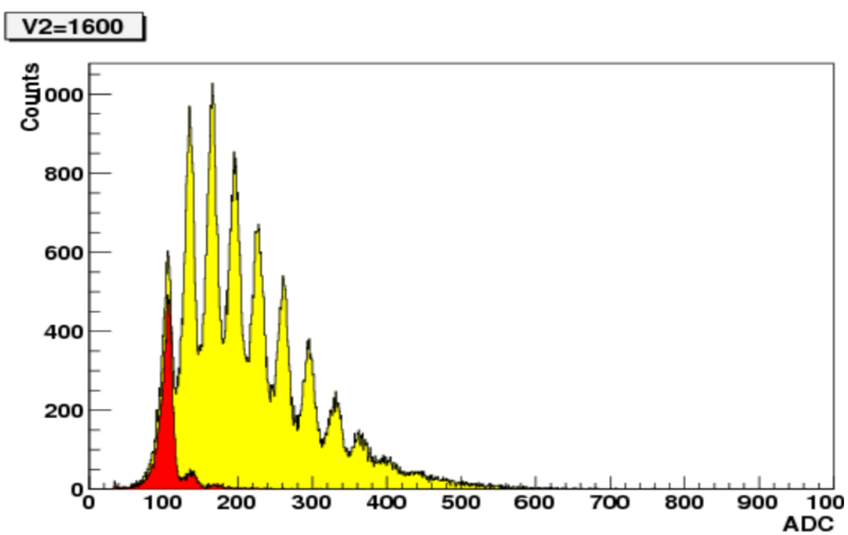
Special PCB toroidal inductors for low RFI (~35nH)

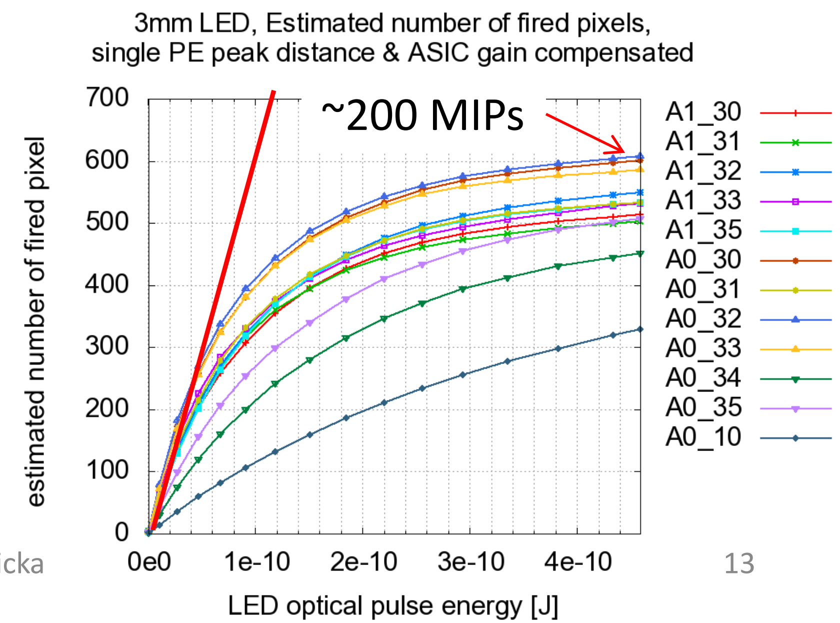


QMB6 performance

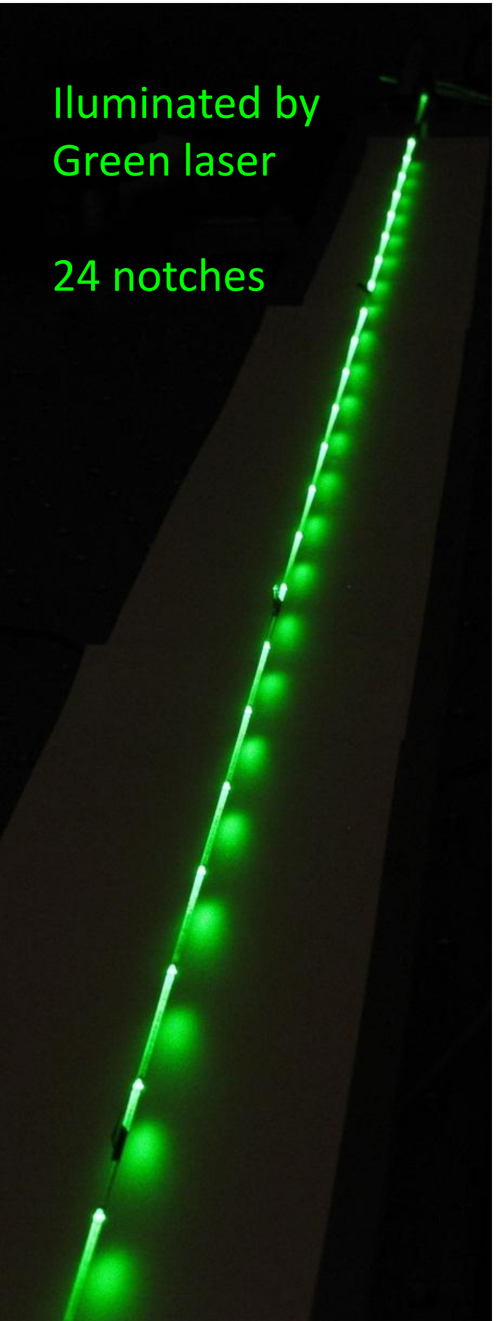
- Very nice single photon spectrum (due to <3.5 ns pulse)
- Nice saturation curves (all 12 SiPMs illuminated by 1 LED)
- We did a test in 4T magnetic field with a minimal effect (<1%) on operation
- Dynamic range up to 200 MIPs per position
- LED optical power up to 0.4 nJ per pulse



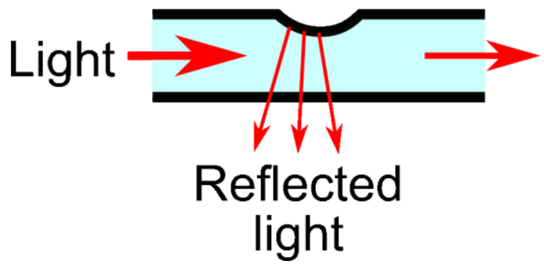




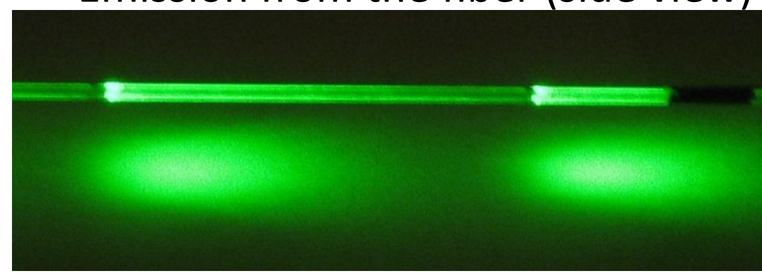
Distribution of light: Notched Fiber



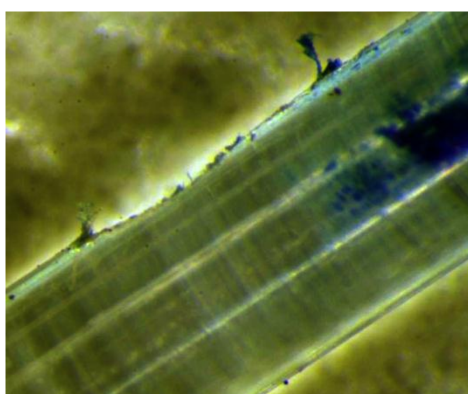
- Light is emitted from the **notches**
- The **notch** is a special scratch to the fiber, which reflects the light to the opposite direction
- The size of the notch varies from the beginning to the end of the fiber to maintain homogeneity of the light, which comes from notches



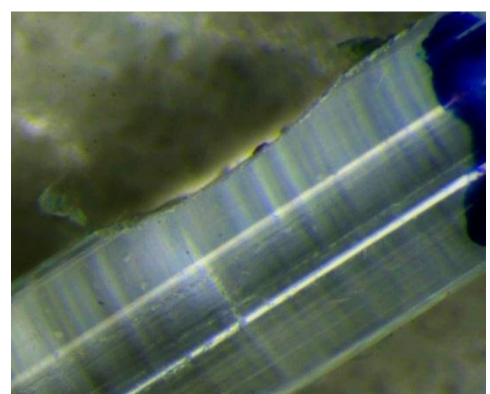
Emission from the fiber (side view)



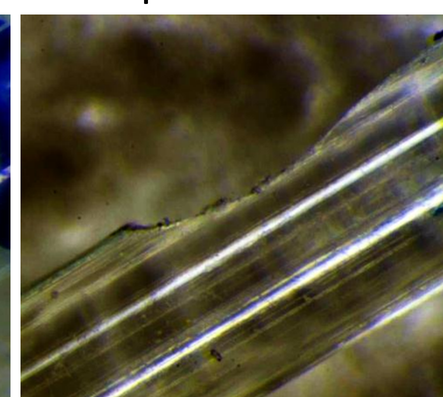
First notch



Middle notch

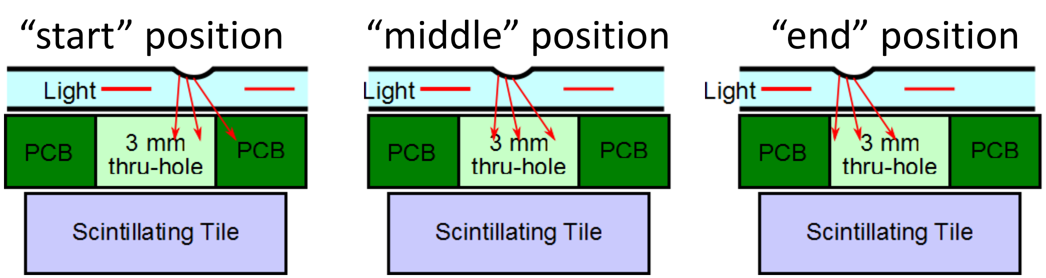


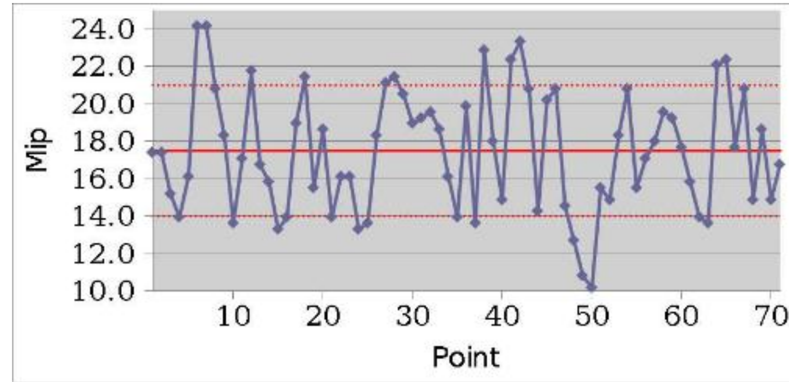
End position notch

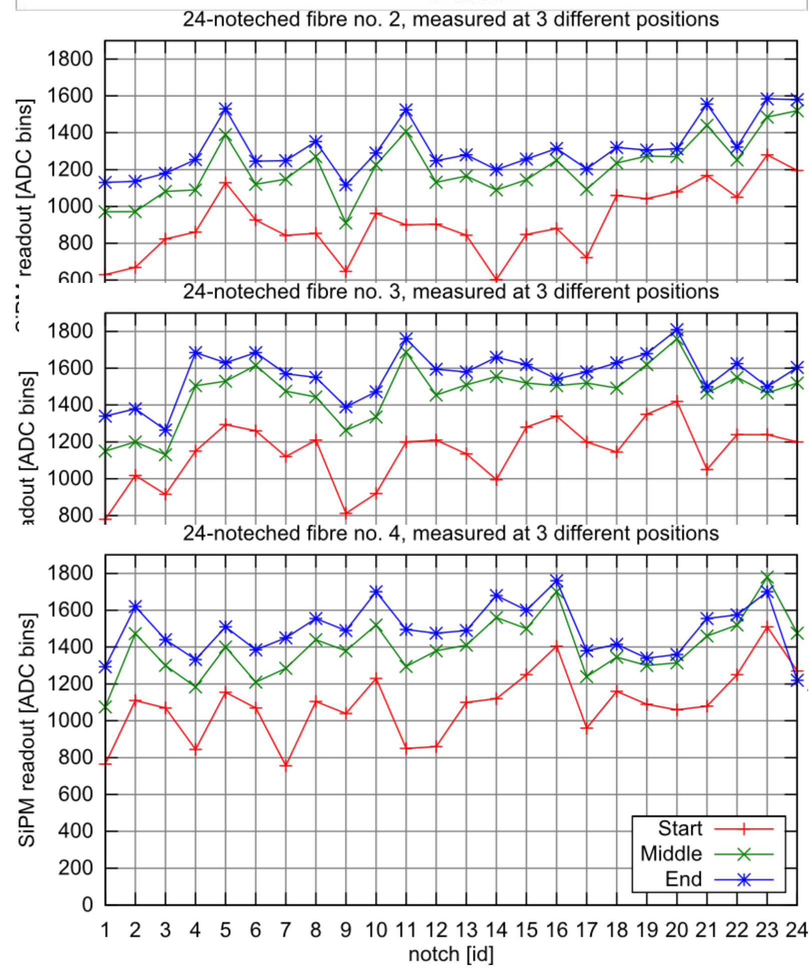


Optical fiber: performance

- We have measured several hand-made notched fiber:
  - 72 notches: tolerance within 20%
  - 24 notches: tolerance within 15%
  - 12 notches: tolerance within 10%
- We had a measurement mismatch with a fiber producer → We discovered, that the measurement methodology is crucial
- Latest measurements of the light yield
  - Through the 3mm hole on the PCB (FR4 with filled inner layer)
  - 3 positions of the notch according to the PCB thru-hole

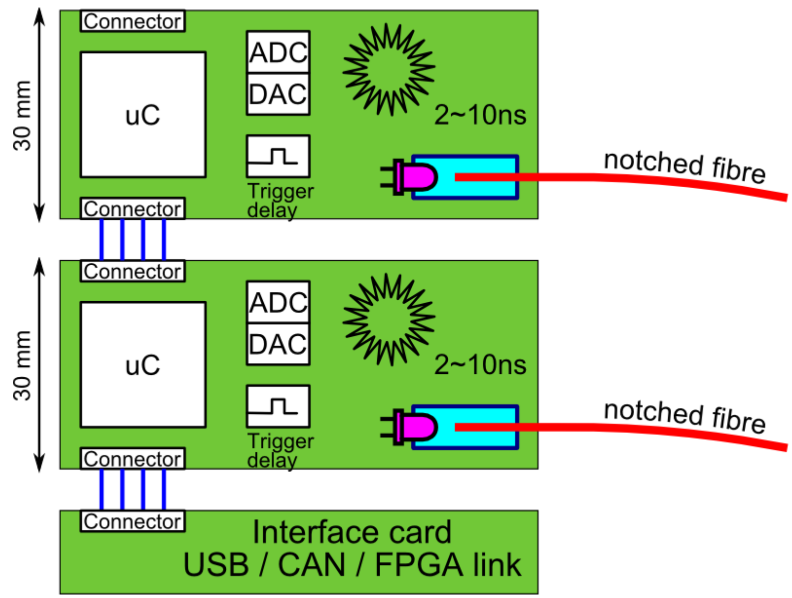


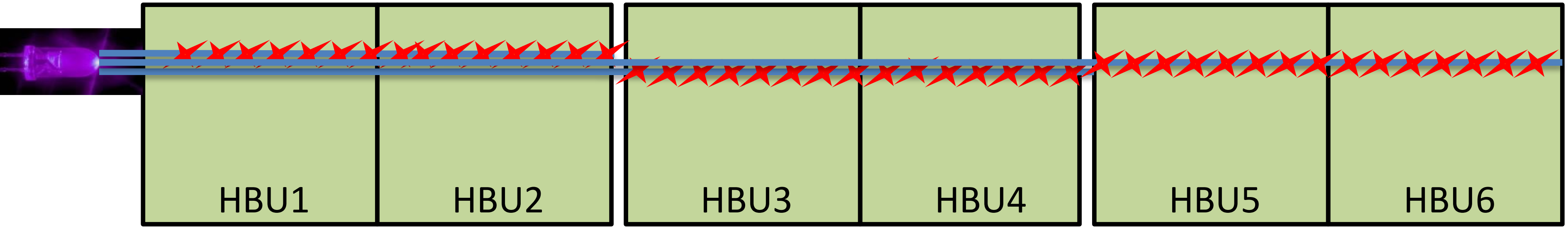




Development of new Quasi-resonant LED driver (QMB1)

- QMB1 (1-chanel LED driver):
  - Status: PCB layout
- Semi-automatic notch-fiber machine under development
- Set: 3*fiber with 24 notches, creating a line of 72 notches. The set is illuminated by a single LED





Conclusions

- Calibration and monitoring is very important for calorimeters based on SiPMs
- CALICE HCAL physics prototype – experience with SiPM calibration (CMB boards)
- Integrated LEDs and drivers are now being produced in a new version.
  - Pulse length was shortened to ~8ns
  - New SMD UV LED incorporated
- Quasi-resonant LED driver was tested on 6-channel board (QMB6)
  - Produce very short pulses ~3.5 ns
  - Enough power to saturate a row of 12 SiPMs
- New Quasi resonant driver is being developed
  - Pulse length extended to ~5ns
- Test with notched fiber and different fiber configuration
  - Proven, that it is possible to manufacture a 72-notched fiber with 20% tolerance

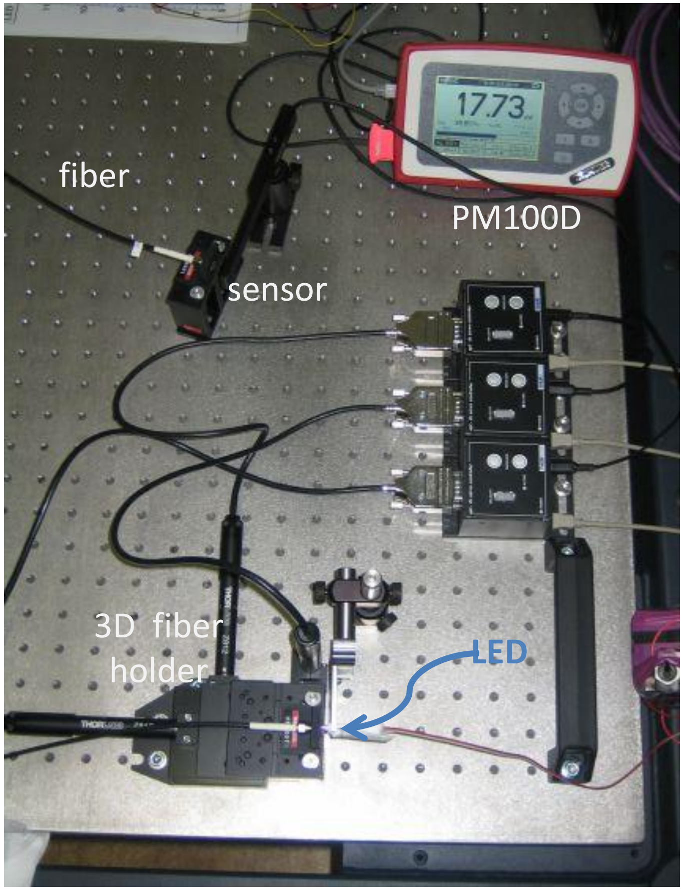
Backup

Outline

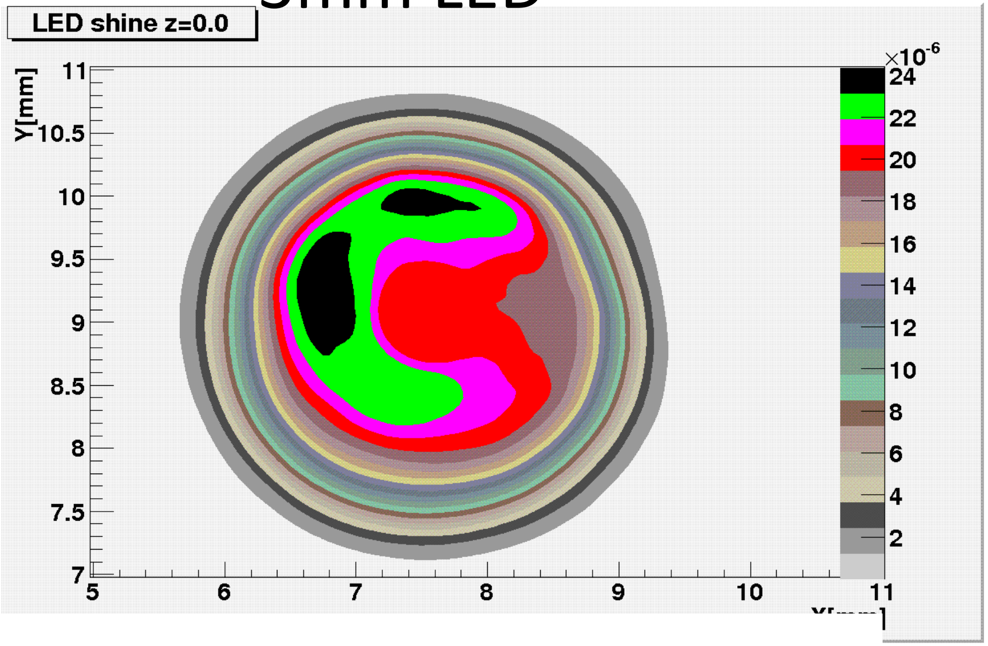
- CALICE prototype
- SiPM motivation (SiPM issues, temperature drift..)
- AHCAL $1m^3$ calibration solution (DESY, FZU)
  - Electronics solution
  - performance
- Embedded calibration solution (DESY, Wuppertal)
  - Electronics solution
  - Performance
- Quasi-resonant LED driver (FZU)
  - Electronics solution
  - Performance
- Optical fiber light distribution
- Conclusion

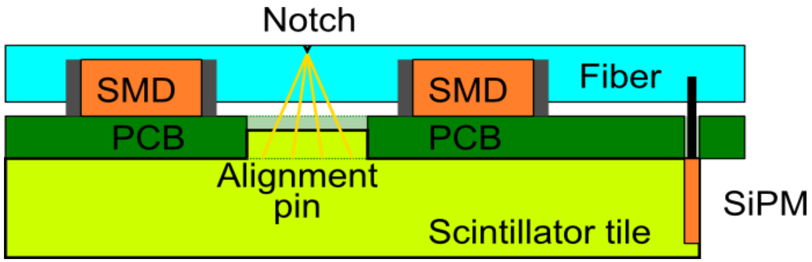
Light coupling

Test setup

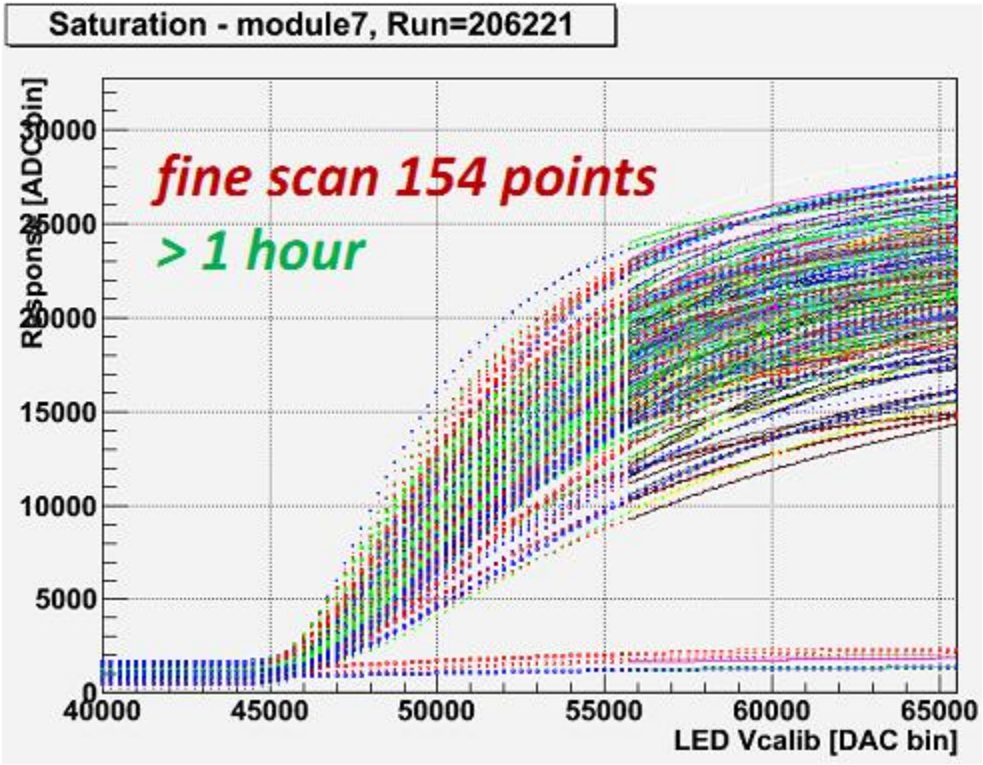


3mm LED



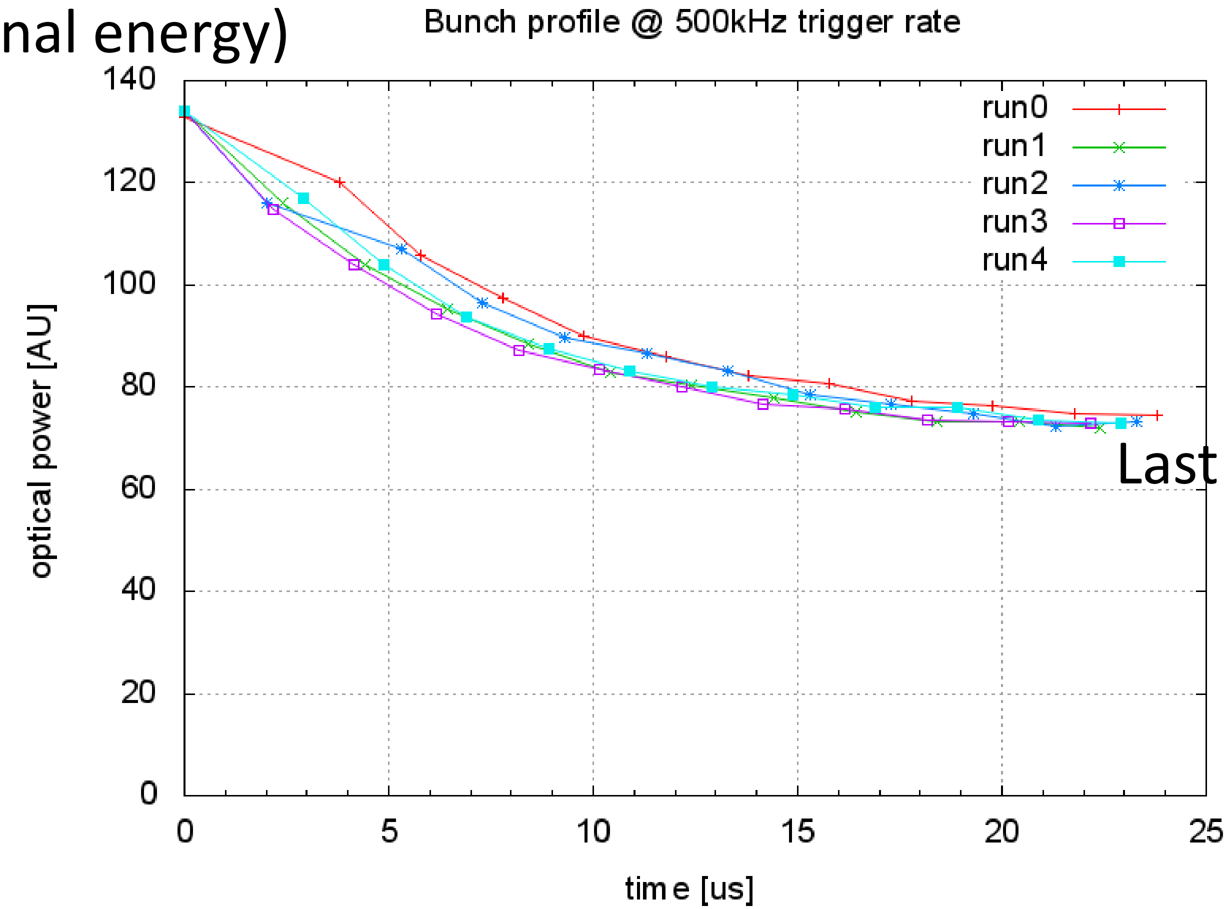


Full saturation and gain scan



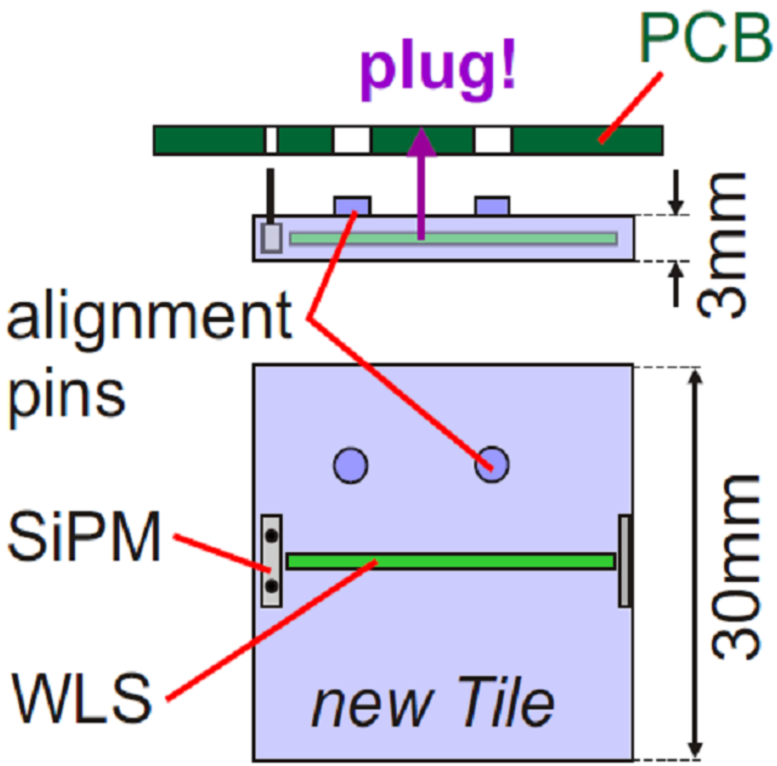
Flashing at 500kHz frequency

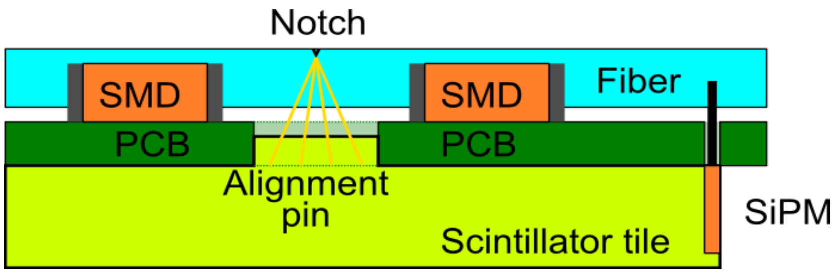
First pulse
(nominal energy)



Last pulse

Illumination through the alignment pins of the tile





Light yield over V1 and V2 variation