The HO upgrade at CMS

German/DESY Contributions

- Motivation
- The Outer Hadronic Calorimeter (HO)
- Light mixers
- Test stand / Test beam
- Conclusions

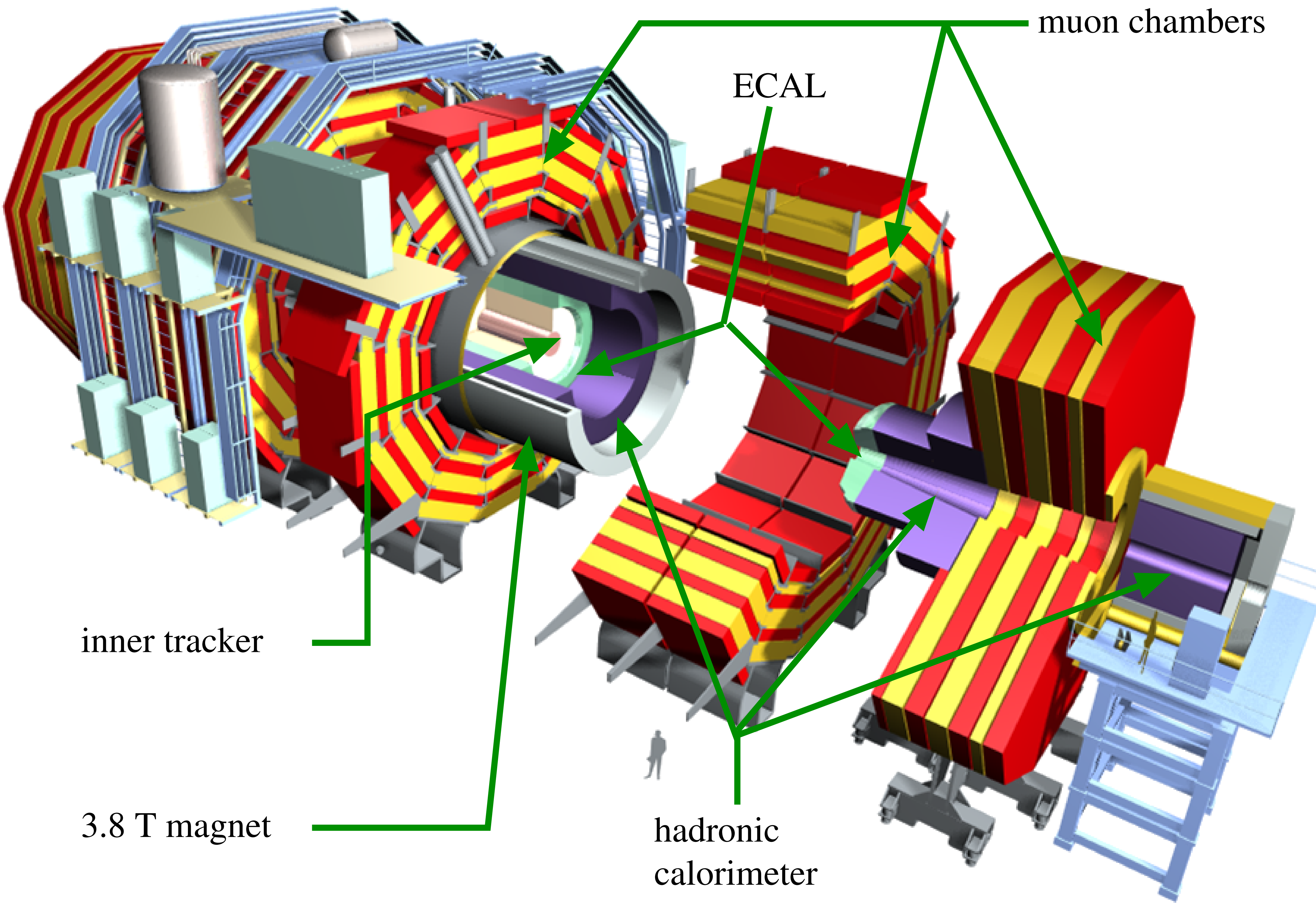
12 October 2012
Tyler Dorland
DESY

HELMHOLTZ
ASSOCIATION

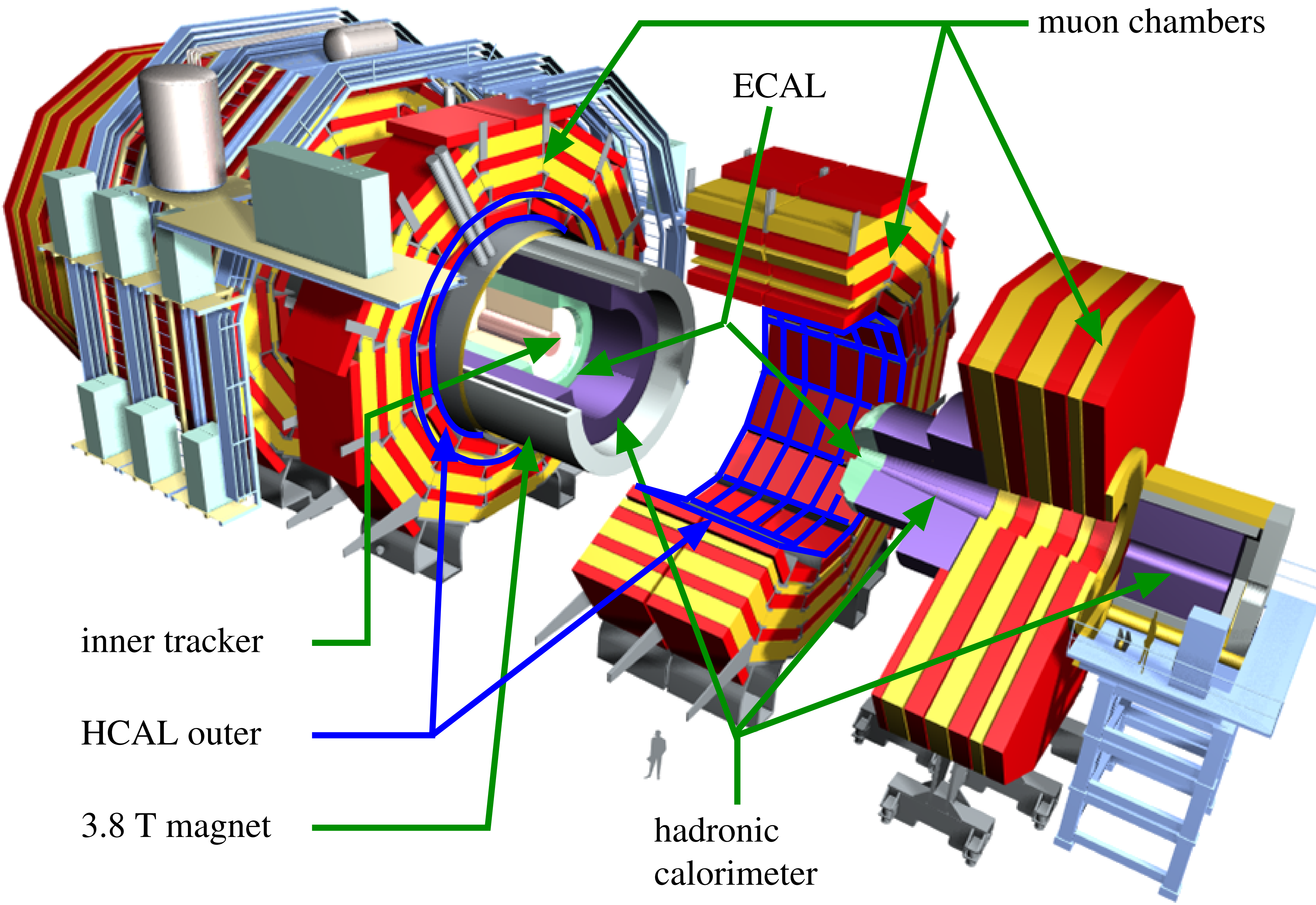
Motivation

- Hybrid Photo Diode (HPD) currently in use at CMS are not optimal for the conditions seen during running
  - Sparking due to fringe field of the CMS magnet
  - Low gain and photo detection efficiency
  - Aging
- Silicon Photomultiplier (SiPM) are now available and becoming more understood
  - Insensitive to magnetic fields
  - High photo-detection efficiency and gain
- CMS will replace HPDs in the Hadron Calorimeter (HCAL) with SiPMs
- The Outer Hadronic Calorimeter (HO) will be the first section of HCAL upgraded
  - We can show immediate performance upgrades
  - Serve as a testing/experience building ground for the rest of the upgrade

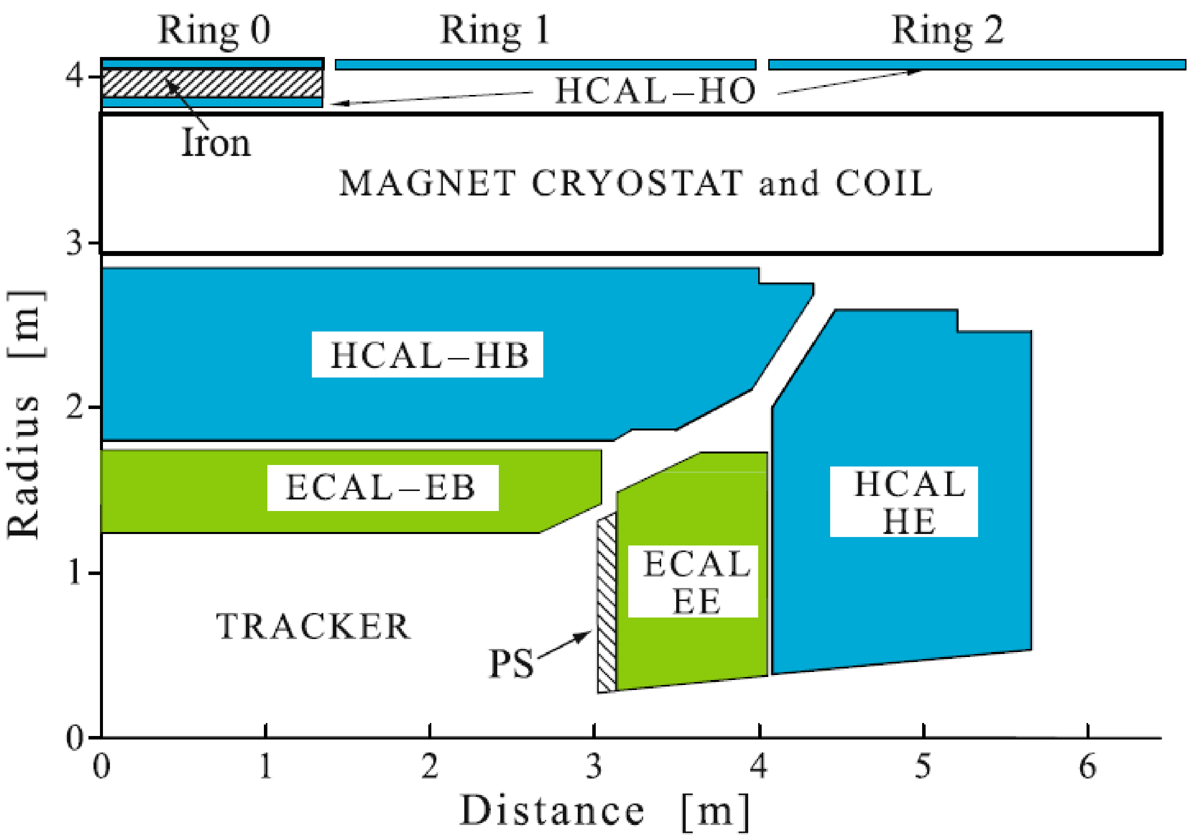
The CMS Detector



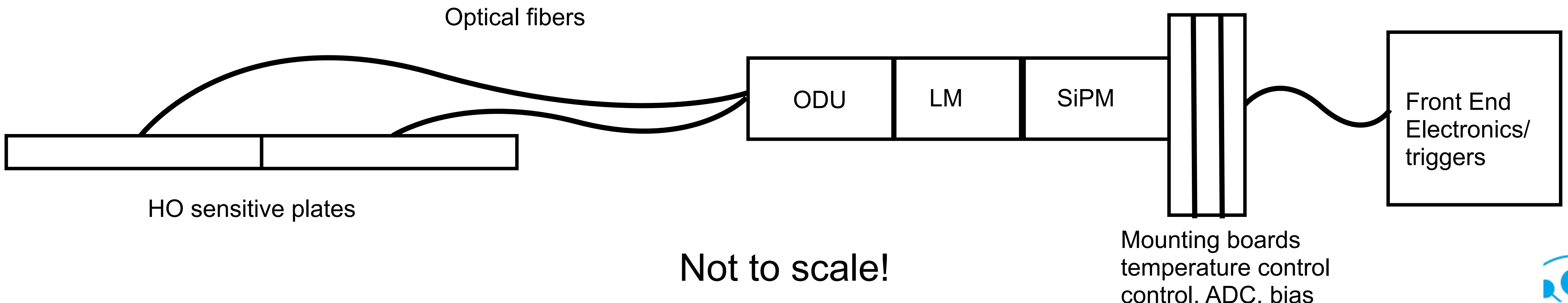
The CMS Detector



The HO



- Scintillator tiles with inlaid waveshifting fibers
  - two layers in ring 0
  - one layer in ring ±1,±2
- Placed directly after magnet cryostat
- “Tail-catcher” for punch-through jets in the barrel calorimeter
- Can be used to correct the MET and jets and improve both resolutions
- Use as another plane for muon detection



Not to scale!

Performance with Minimum Ionizing Particles (MIP)

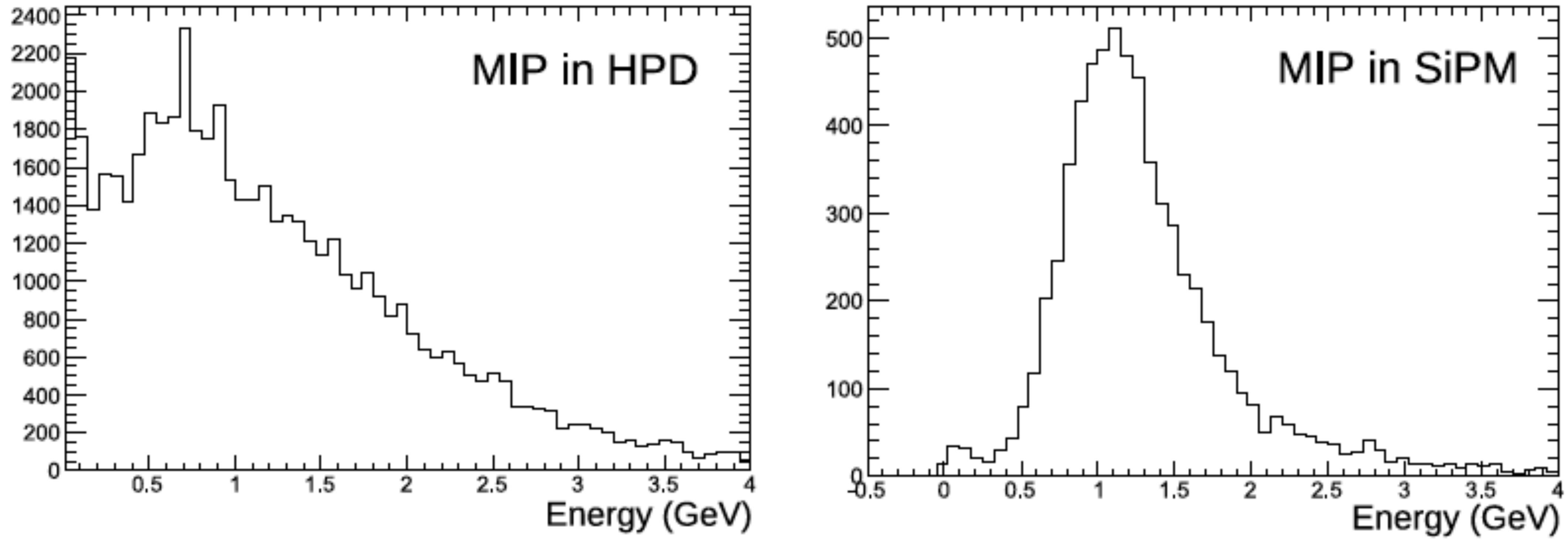
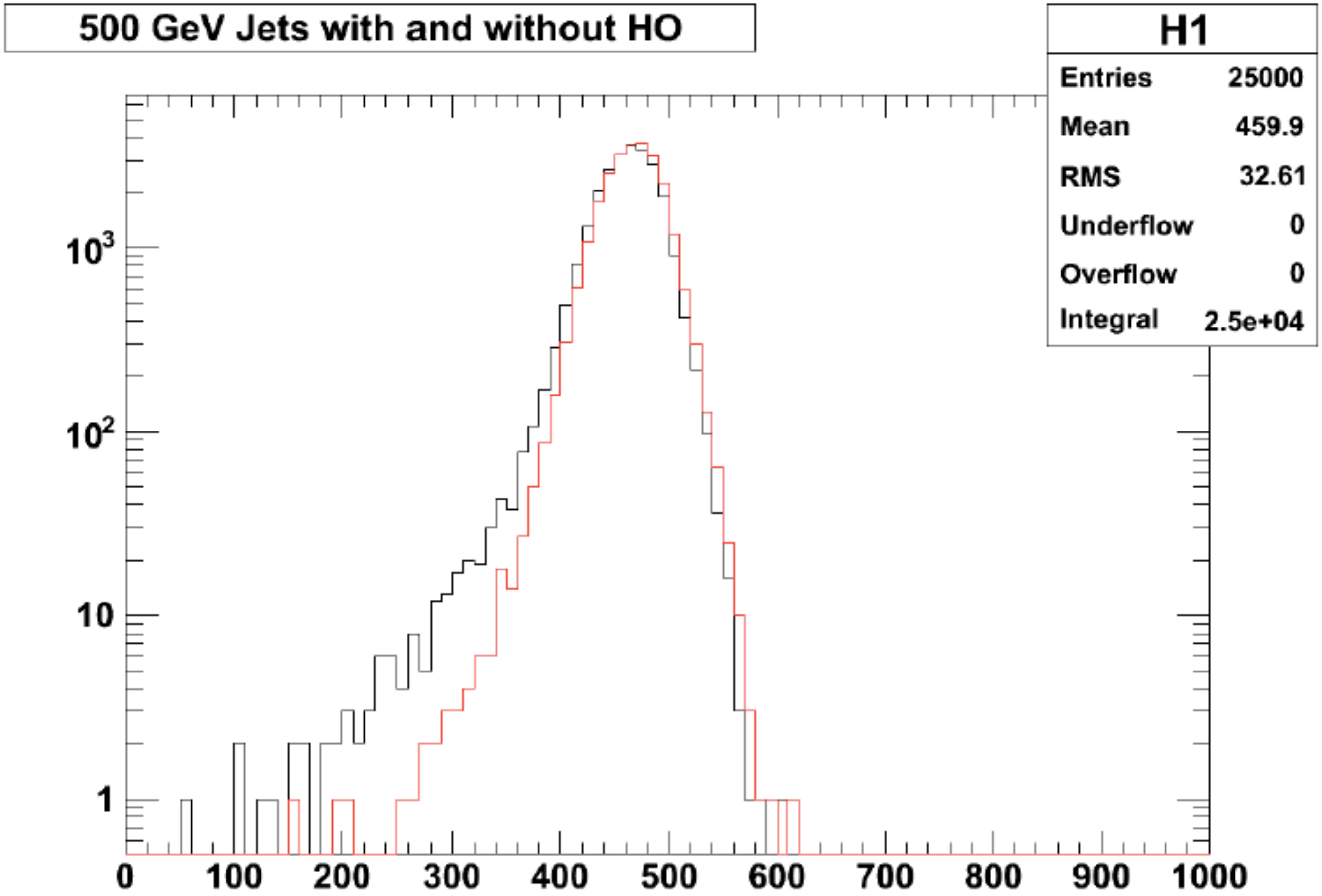


Figure 10(a) HO MIP signal from HPD channel.; (b)HO MIP signal for SIPM channel

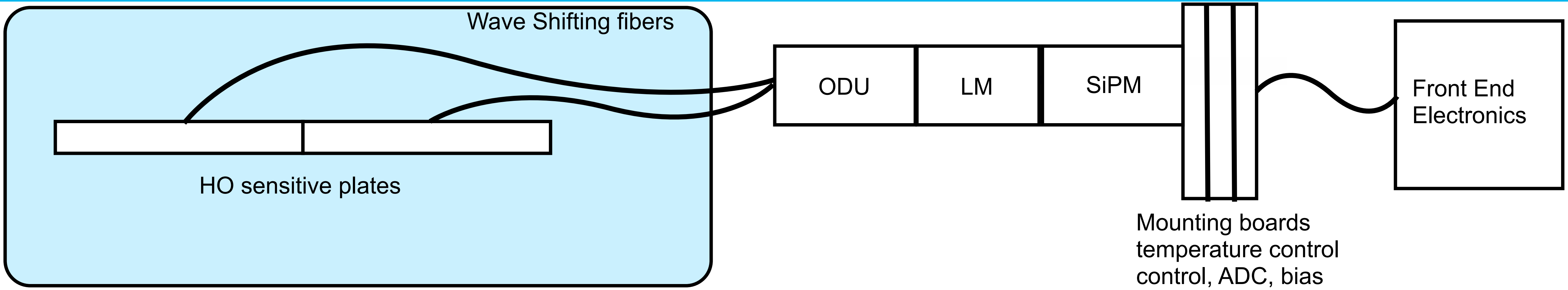
- SiPM already installed in sections of the HO for over two years
- Much better performance for MIPs
- Signal to background ratio of about 20/1

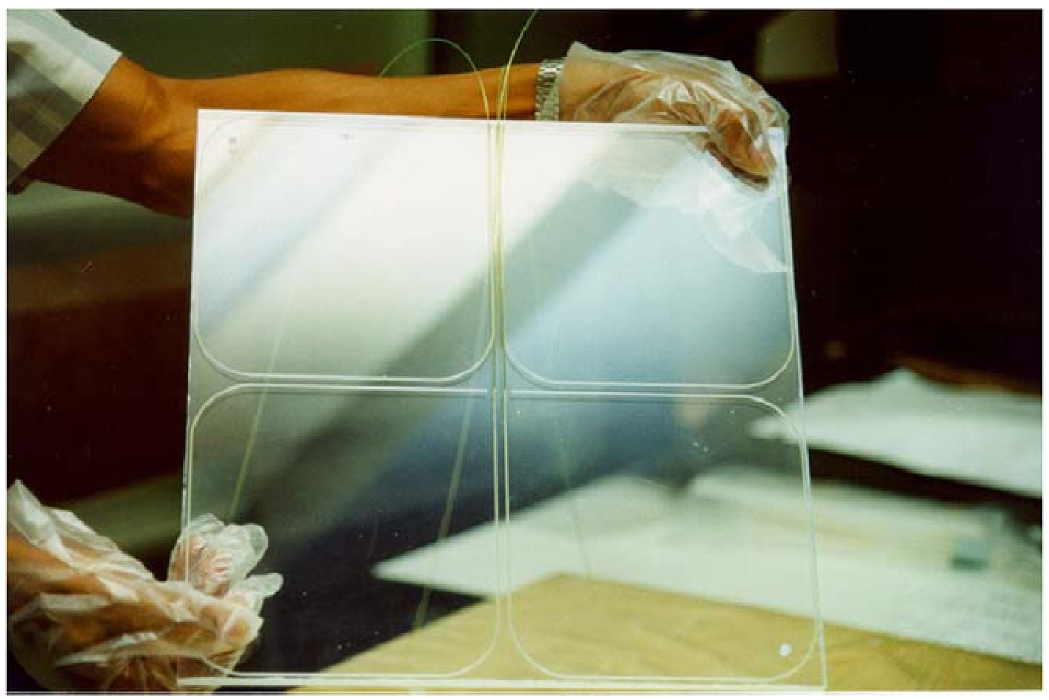
Physics - Improved Jet Energy Resolution

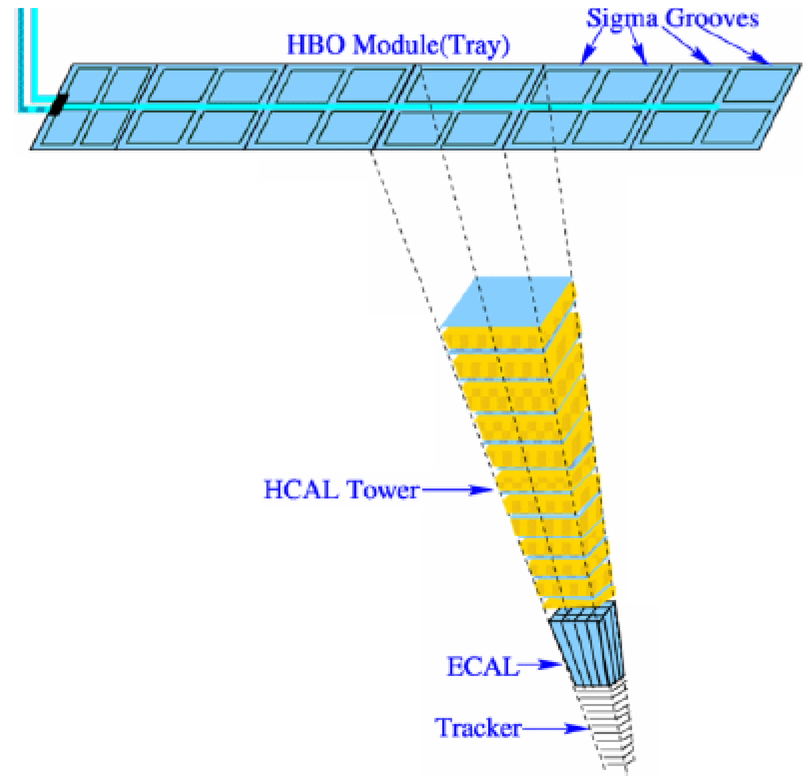


- HO significantly improves the low tail of the hadronic jets
- Ring 0 is most affected due to the “thin” barrel

The HO Sensitive Area

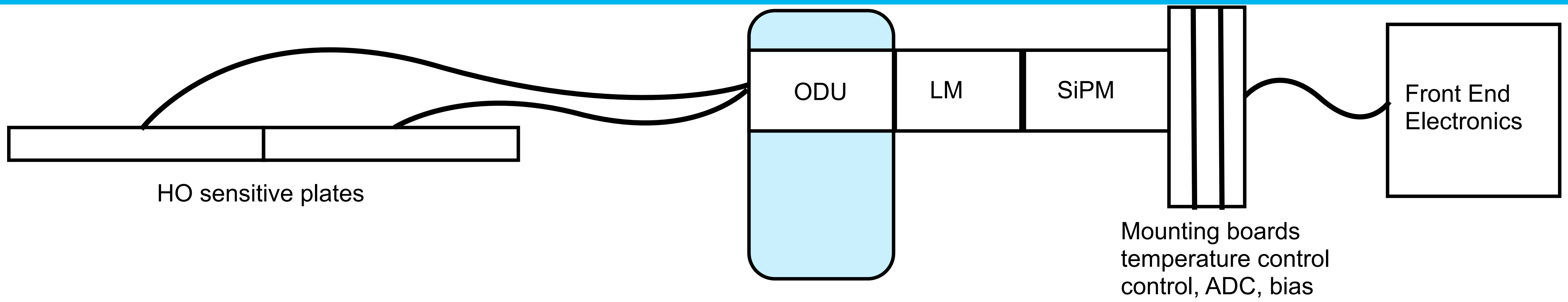


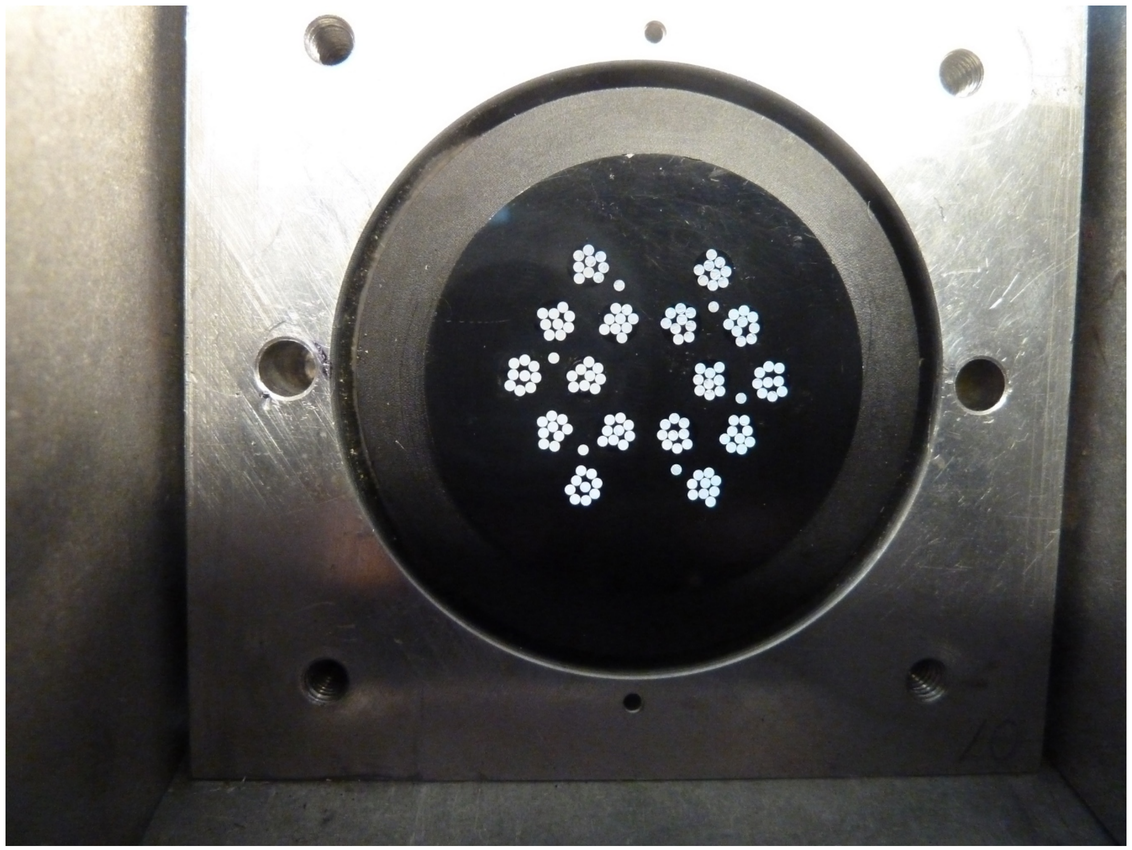




- Scintillating plates are sized to be approx. one calo tower in area
- provides additional calorimeter coverage with 3λ thickness
- signal collected with waveshifting fibers and transmitted via clear fibers

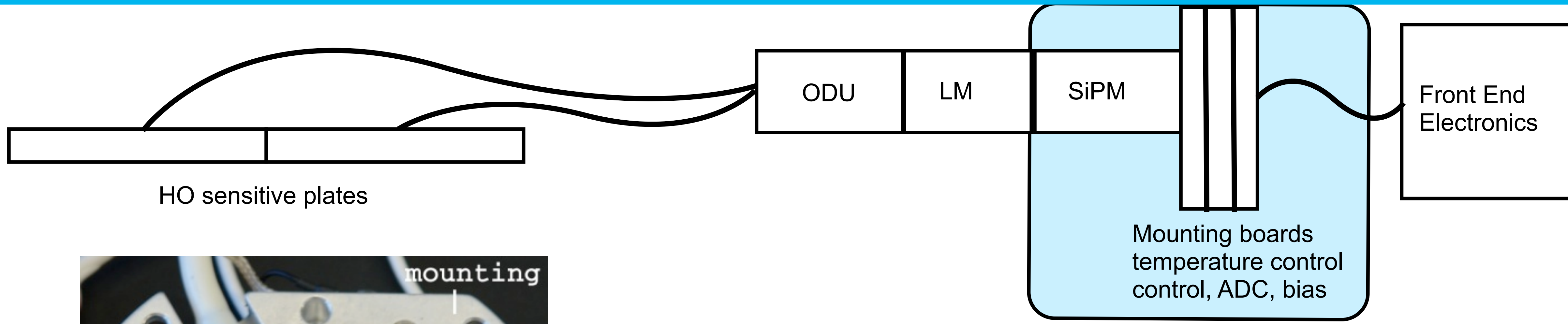
Optical Decoder unit



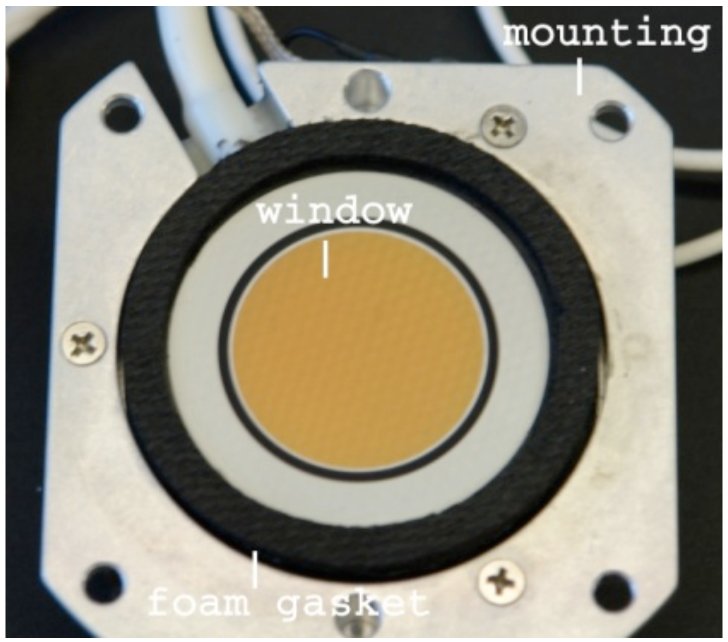


- Optical Decoder Unit (ODU) connects optical fibers to photo-sensor
- Routes fibers from one projective tower to one readout channel
- Charge integrating amplifier and digitizer ASIC (QIE8)
- Two types in HO
  - Ring 0 with 9 fibers
  - Ring 1/2 with 5 fibers

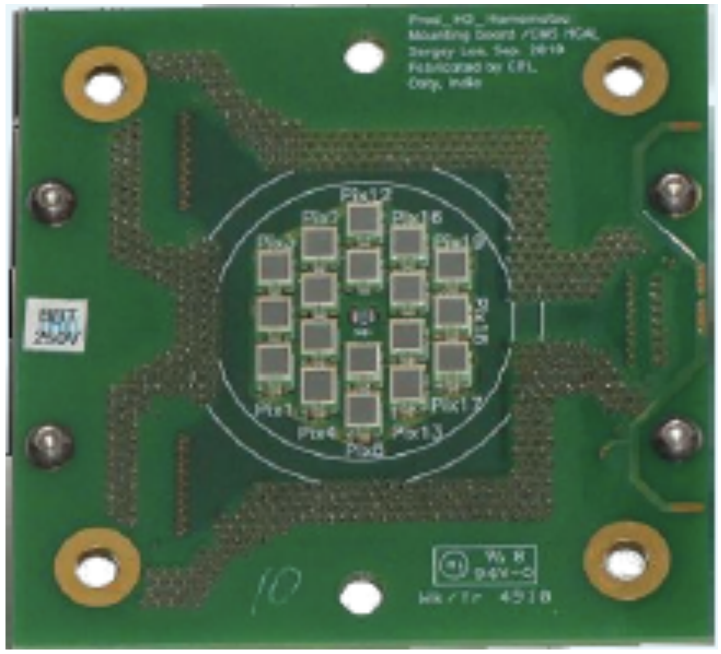
SiPM and mounting boards



HPD (old)



SiPM (new)



- The SiPM is the photo-sensitive devise
- Array of µm APD pixels
- Operated in Geiger mode
- Common Readout:

$$\text{Signal} = \sum_{fired} Q_{pixel}$$

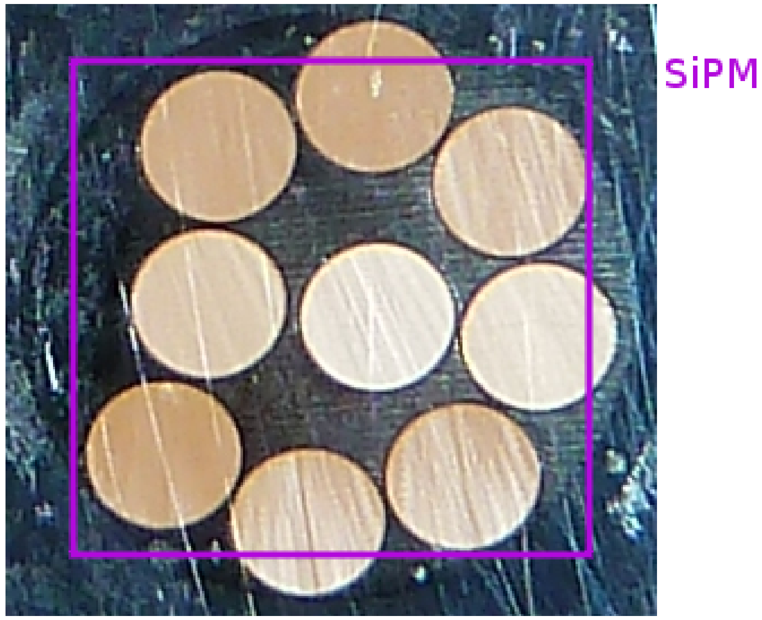
- quantized output signal
- temperature dependent gain
- radiation sensitive

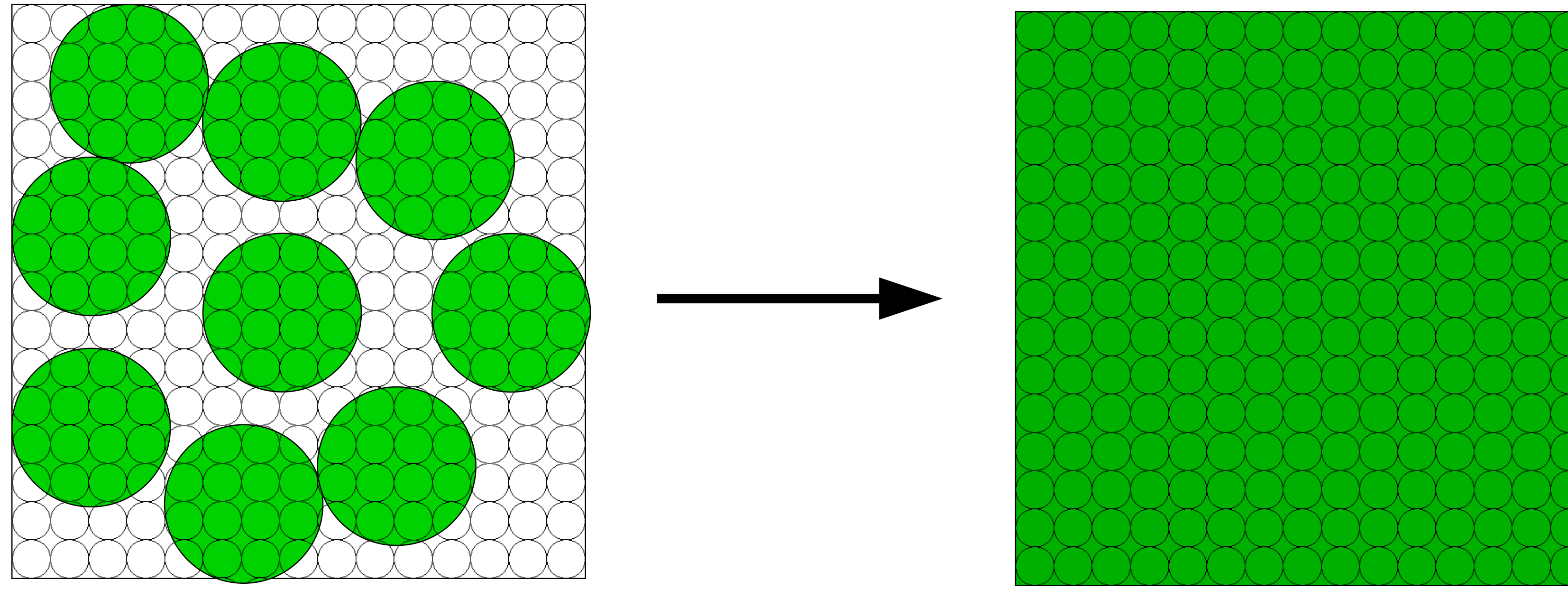
Design specifications

"Drop-in" Design

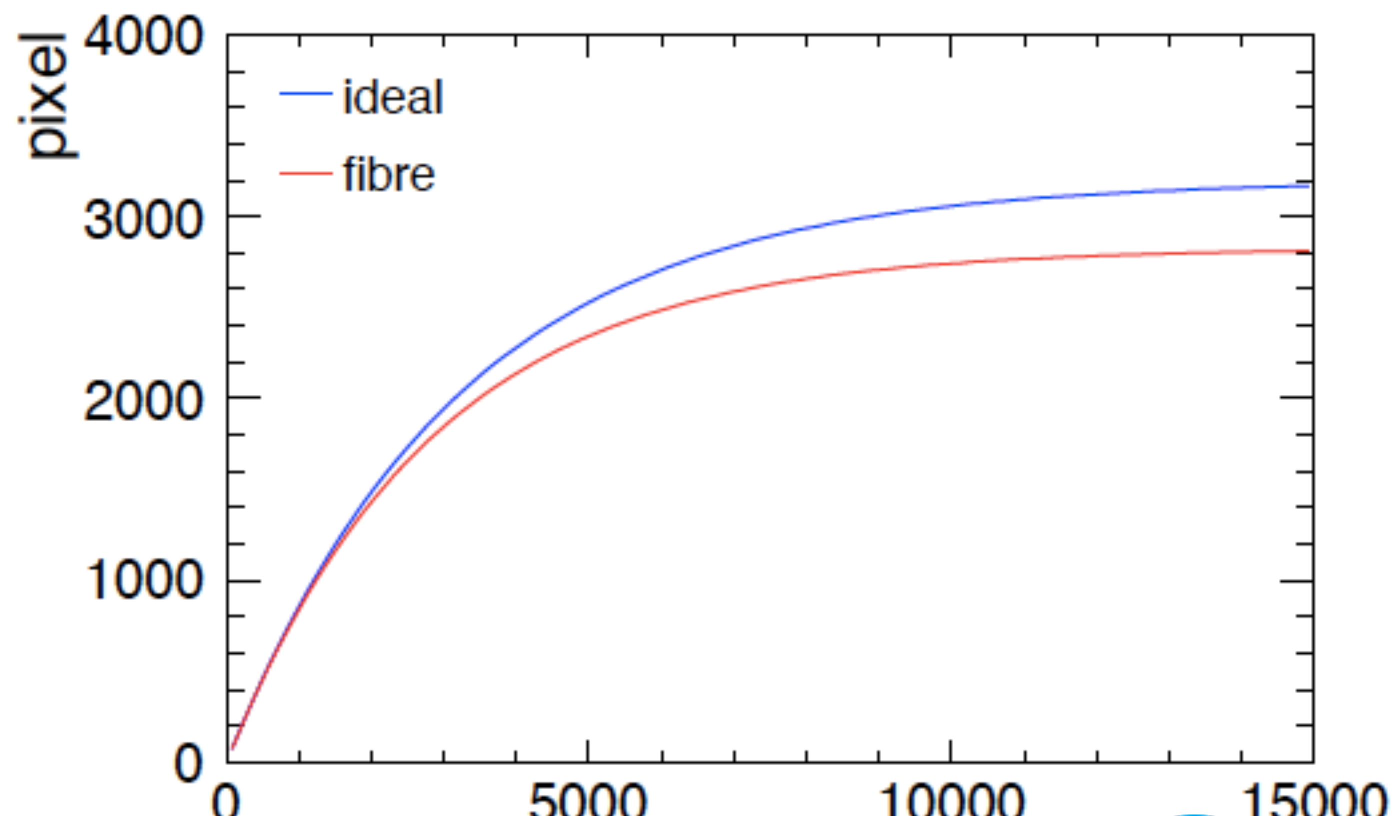
- Sensor choice: Hamamatsu MPPC
  - $3 \times 3\,\mathrm{mm}^2$ area
  - $50\,\mu\mathrm{m}$ pixel pitch $\rightarrow N_{\mathrm{pix}} = 3600$
  - $\tau_{\mathrm{pix}} = 14\mathrm{ns}$
  - $\frac{\mathrm{d}G}{\mathrm{d}T} = -\frac{8\%}{\mathrm{K}}$
- Constrains:
  - Keep ODU $\rightarrow$ optical coupling
  - Keep ASIC $\rightarrow$ electrical coupling, dynamic range matching
  - Keep mechanical design of readout module $\rightarrow$ space limitation
- Solution:
  - 3-card pack
    - SiPM mounting board matching ODU geometry
    - control board with Peltier cooling and individual bias adjustment
    - bias voltage card to generate 100 V bias locally
  - light-mixer to distribute light of single fibres

Maximizing sensitive area

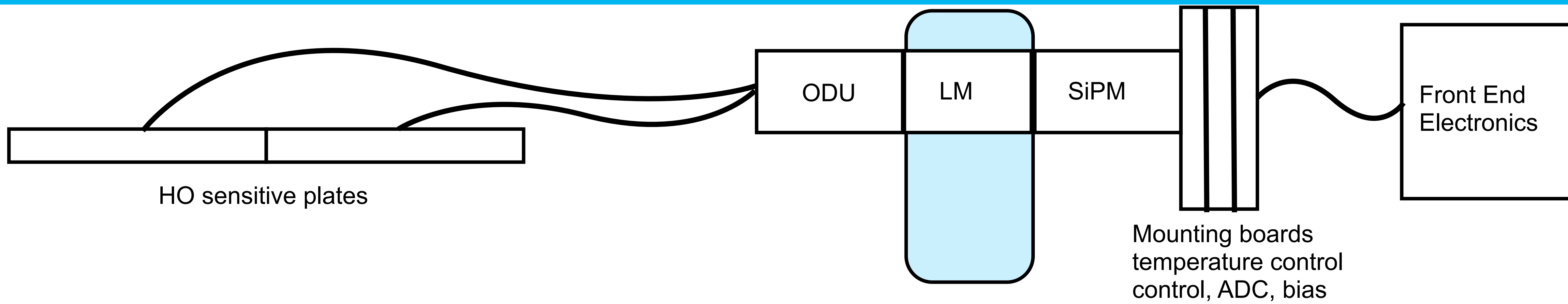


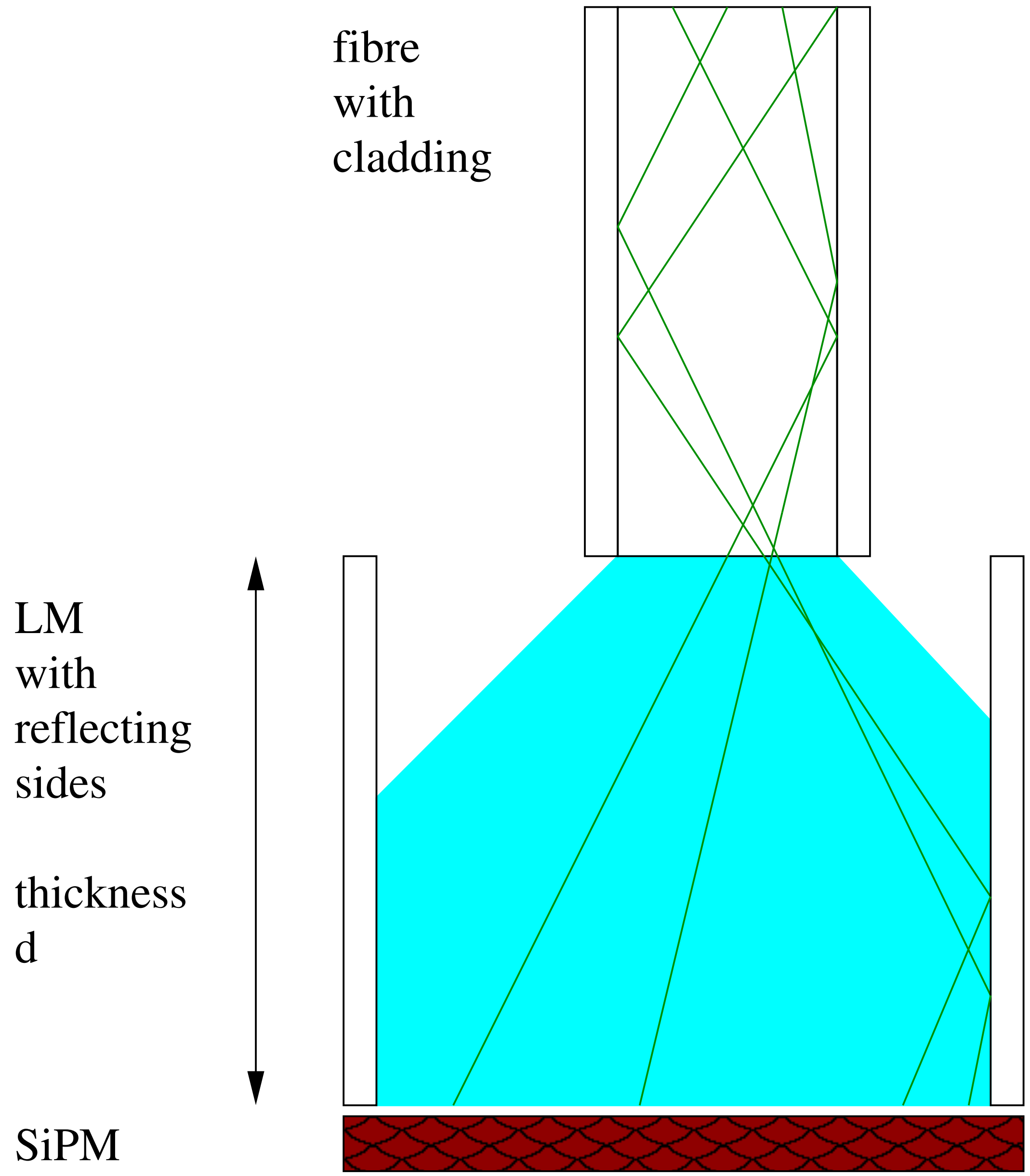


- **>** Direct coupling of ODU fiber bundles results in dark areas
  - Reducing number of sensitive pixels
- **>** Ring 0 fibre bundle extends over SiPM edge
  - Inhomogeneous response
- **>** Need to distribute the light
  - Light Mixers



Goals of the Light-mixers

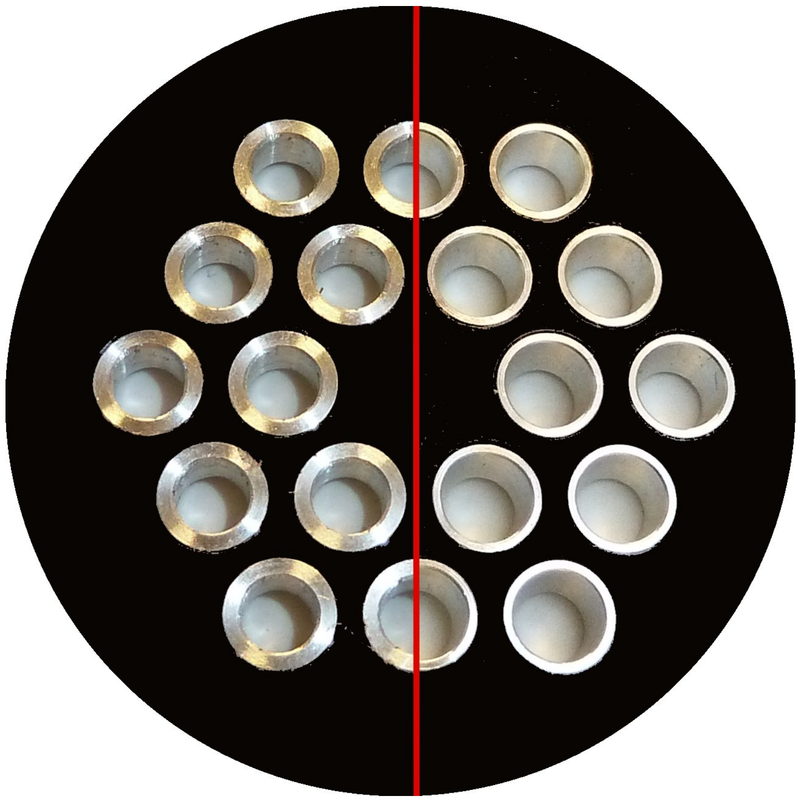




- Match Ring0 fiber to SiPM size
  - Maximize number of pixels
- Use light as efficiently as possible
- Maximize dynamic range
- Accomplished by distributing the light
- While avoiding light leakage and absorption

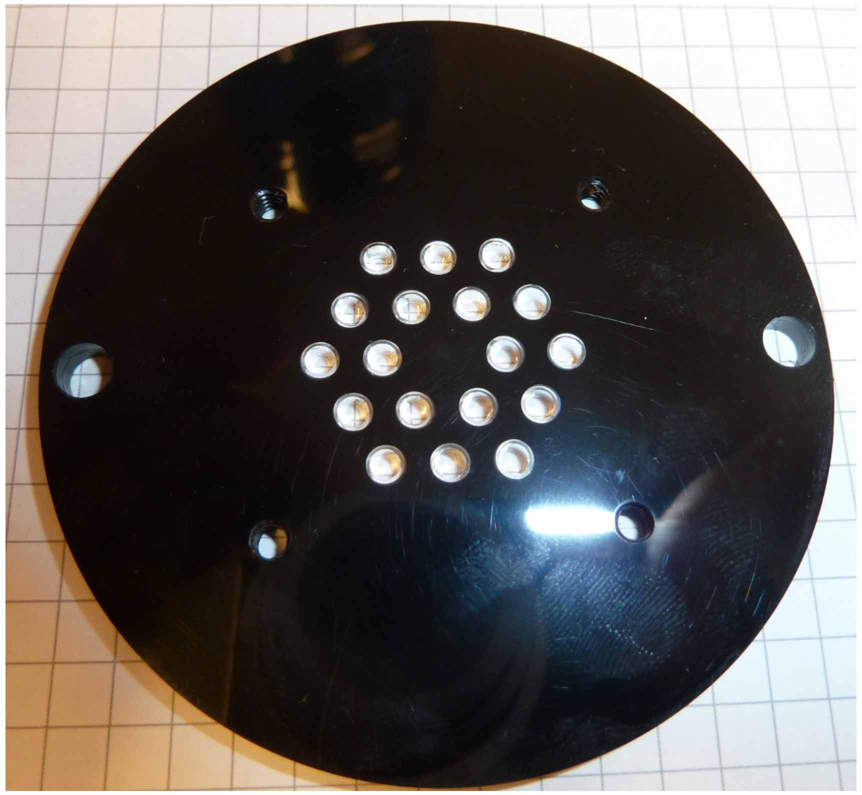
Light mixer Prototypes

DESY



- Aluminum inserts
- cylindrical & conical
- 2-7mm thick

Notre Dame



- thick optical fiber
- special surface polishing
- cylindrical
- 4 & 6mm thick

Need to determine optimal design of the light mixer

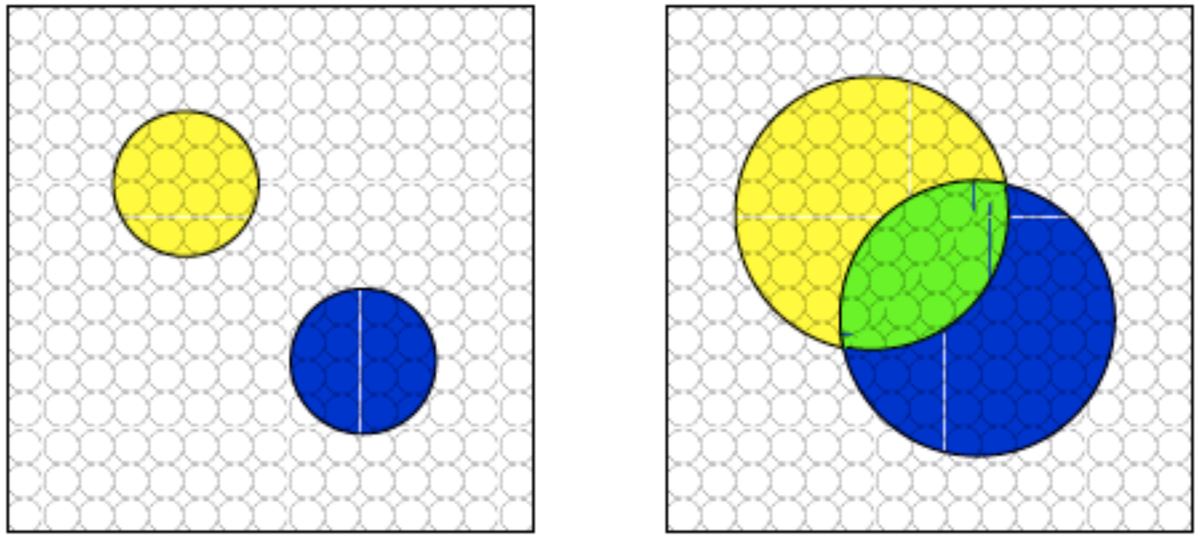
Measurement principle

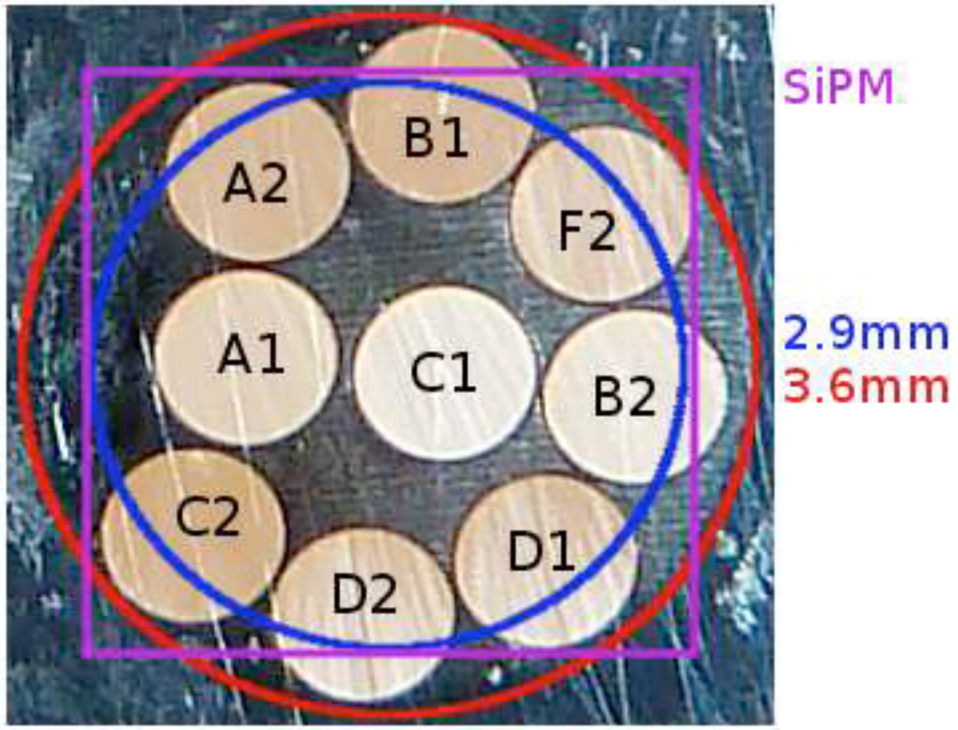
Saturation

- SPE allows to scale SiPM in pixel equivalents
- PMTs give a linear reference for the input light
- assume slope of 1 at origin to set LED light scale

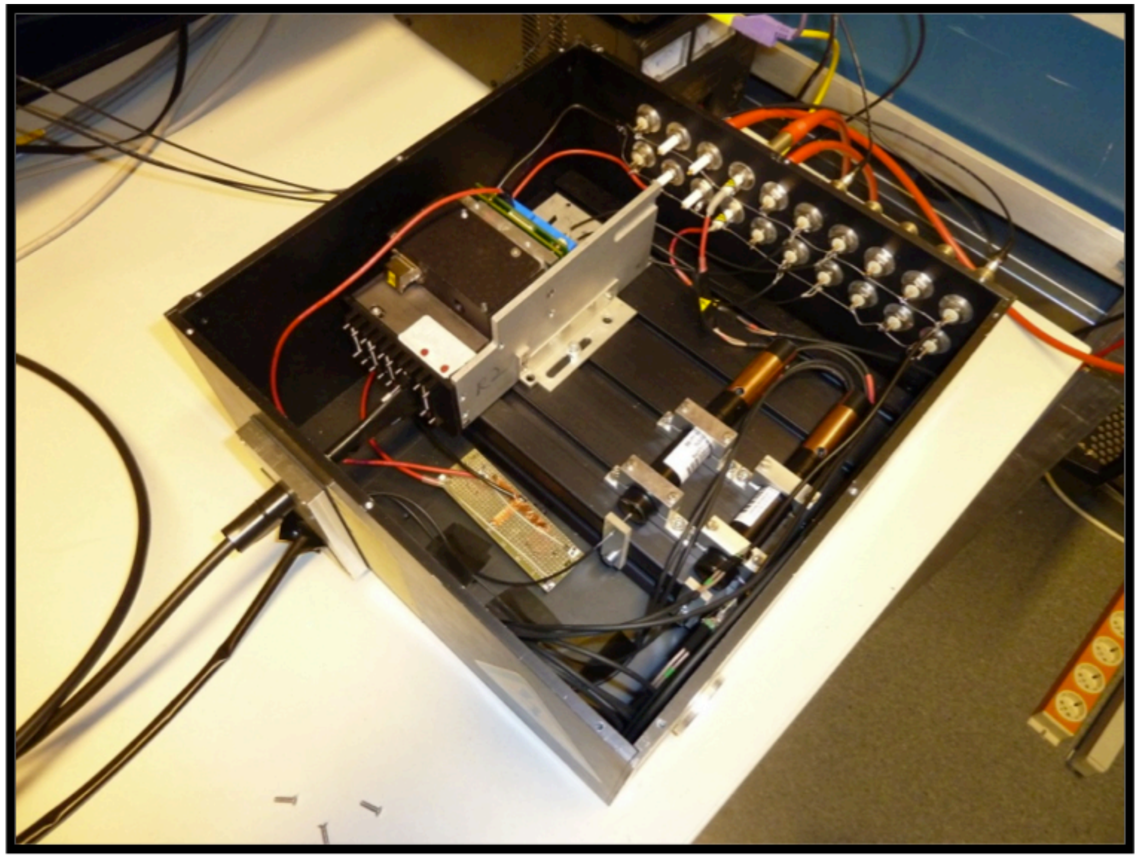
Fibre to Fibre Variation

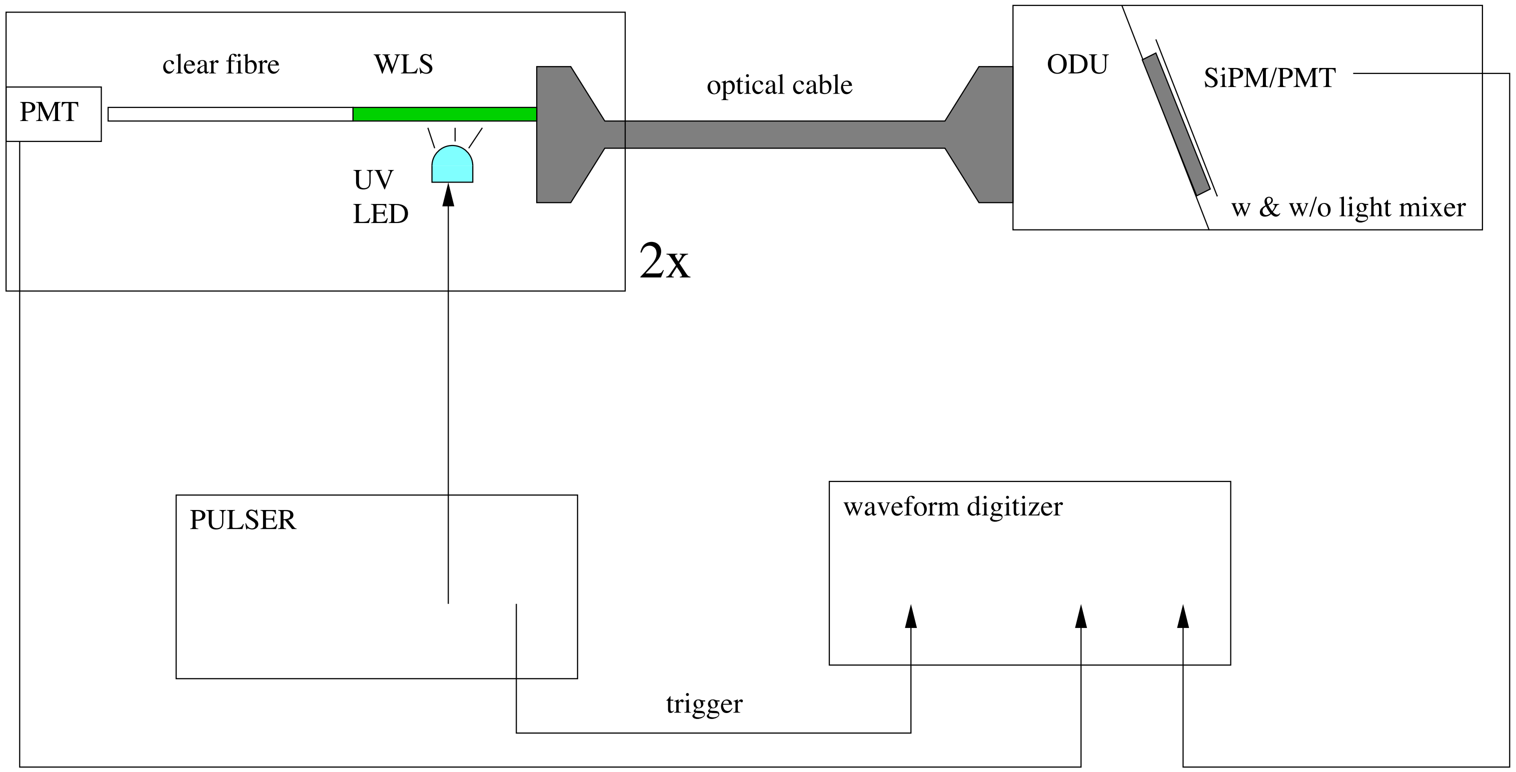
- calibrate LEDs, fibres, and ODU with large area PMT
- study of ODU plugging reproducibility: $\approx 2.5\%$
- use same x-axis scale for all measurements





Laboratory Measurement





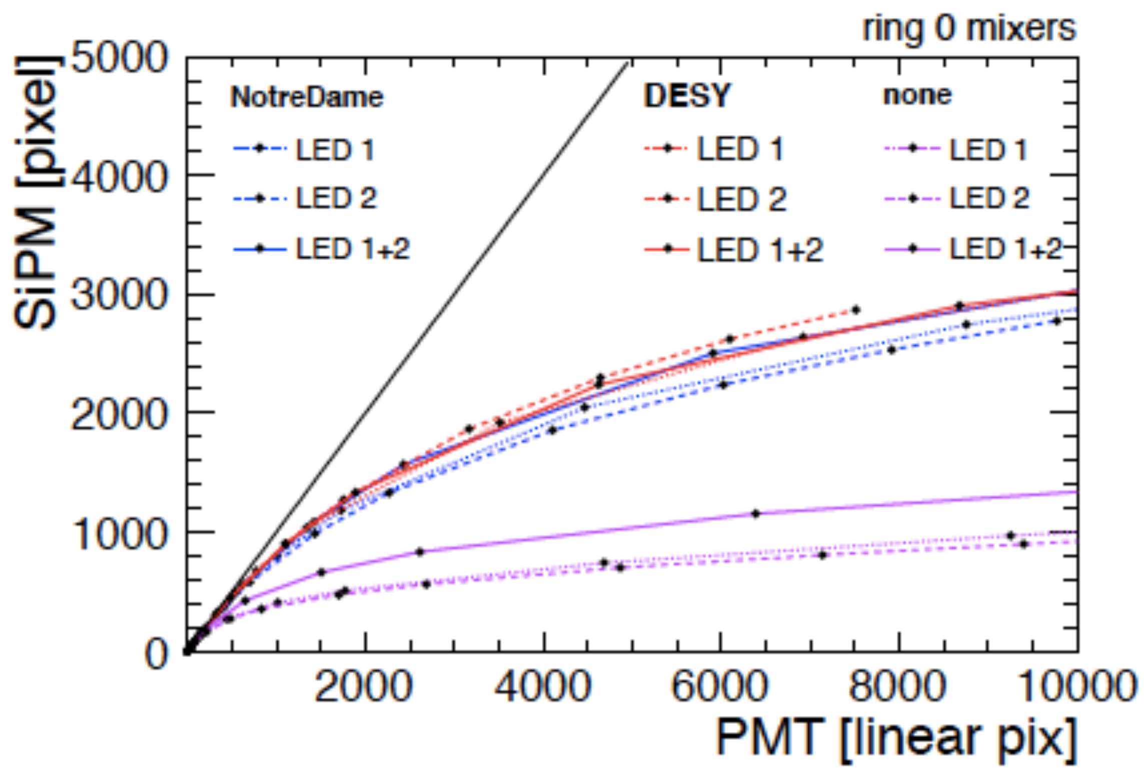
> Setup

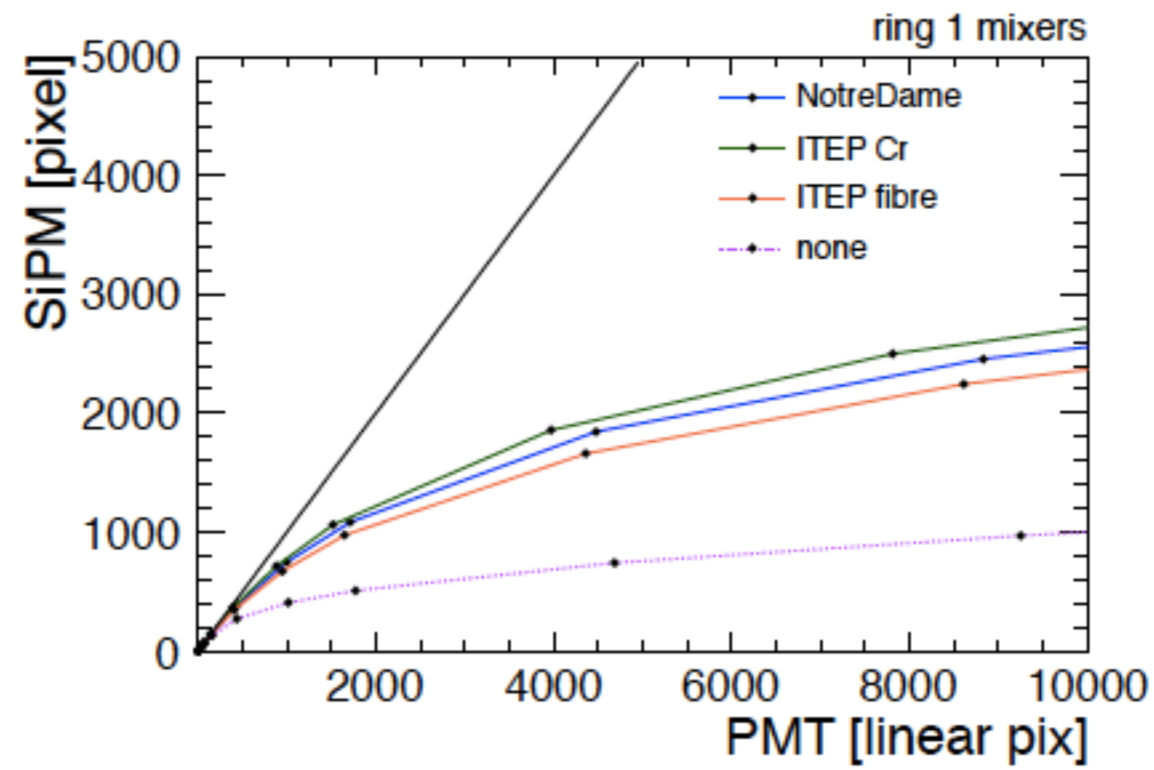
- Two independent LEDs
- Monitoring with PMT
- Charge integrating DAQ
- possibility of SPE resolution

> Goals

- Understand single fiber behavior
- proof-of-principle of light mixing
- study saturation
- study fiber-to-fiber variations

Results - Saturation





R0

- both mixers show a clear reduction of saturation compared to no mixer
- no difference between both mixers when using two fibres

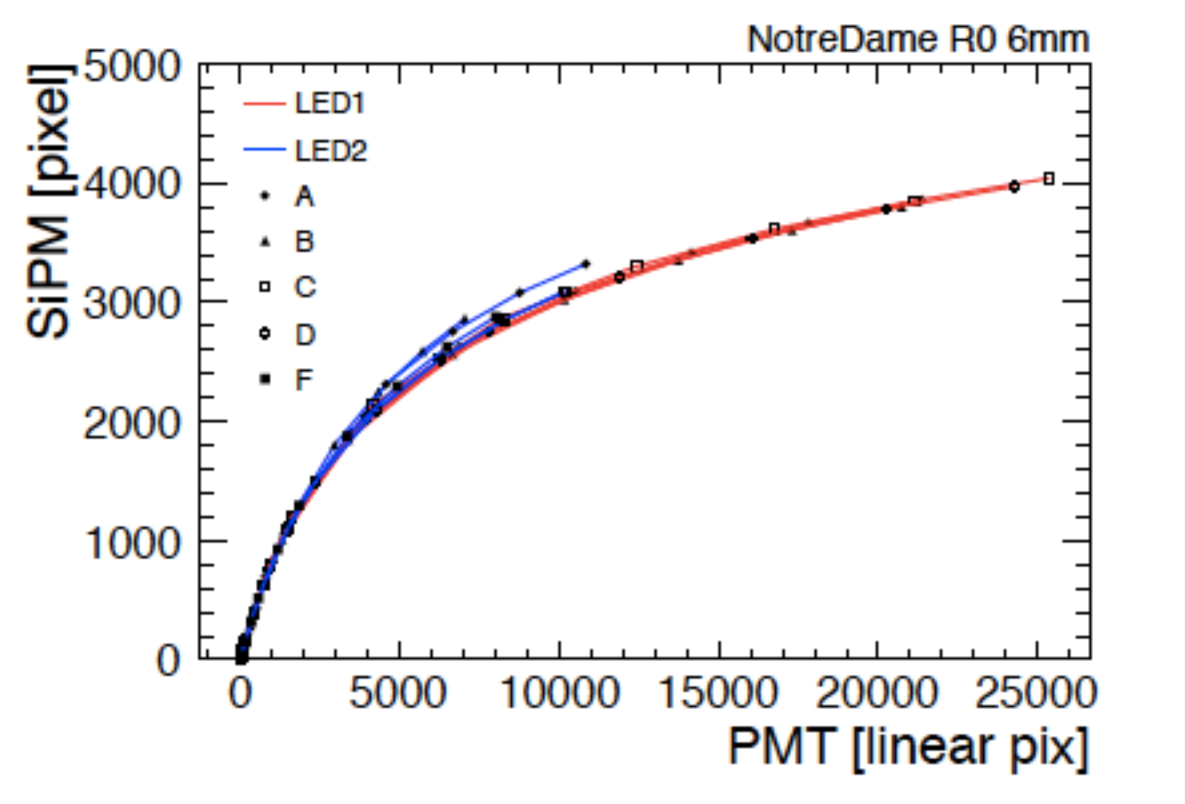
R1

- all mixers show a clear reduction of saturation compared to no mixer
- no preference selectable from single fibre measurement

B. Lutz (CALOR 12)

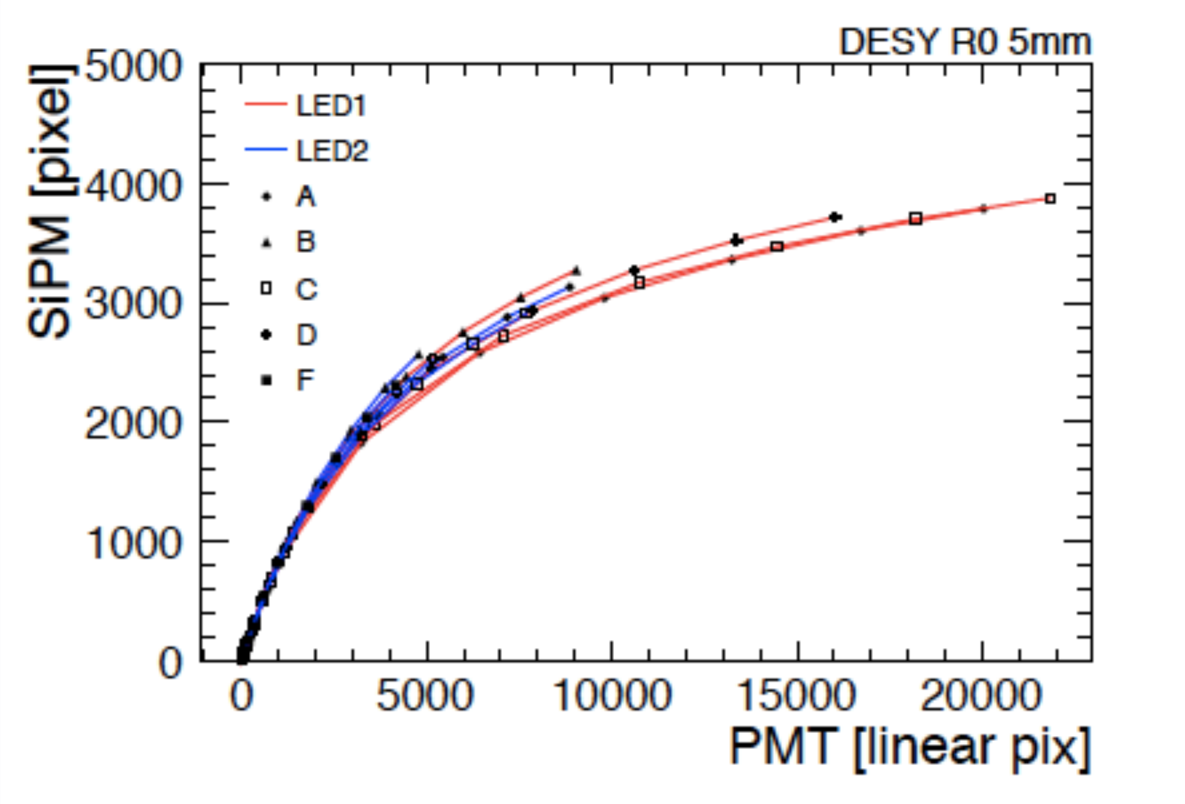
Results - Fiber-to-Fiber

Notre Dame



- good homogeneous saturation behaviour over all plugs
- slight variation in outer fibres

DESY

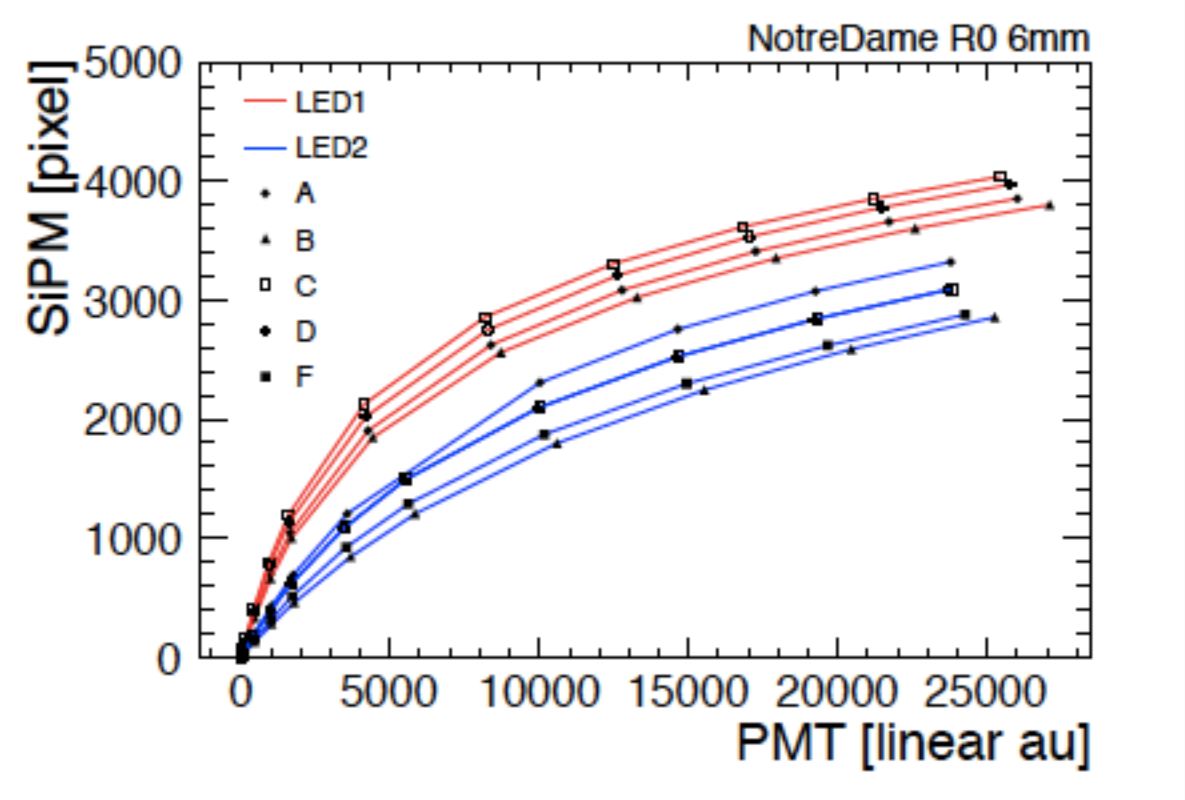


- reasonable good saturation behaviour
- less homogeneous than Notre Dame

B. Lutz (CALOR 12)

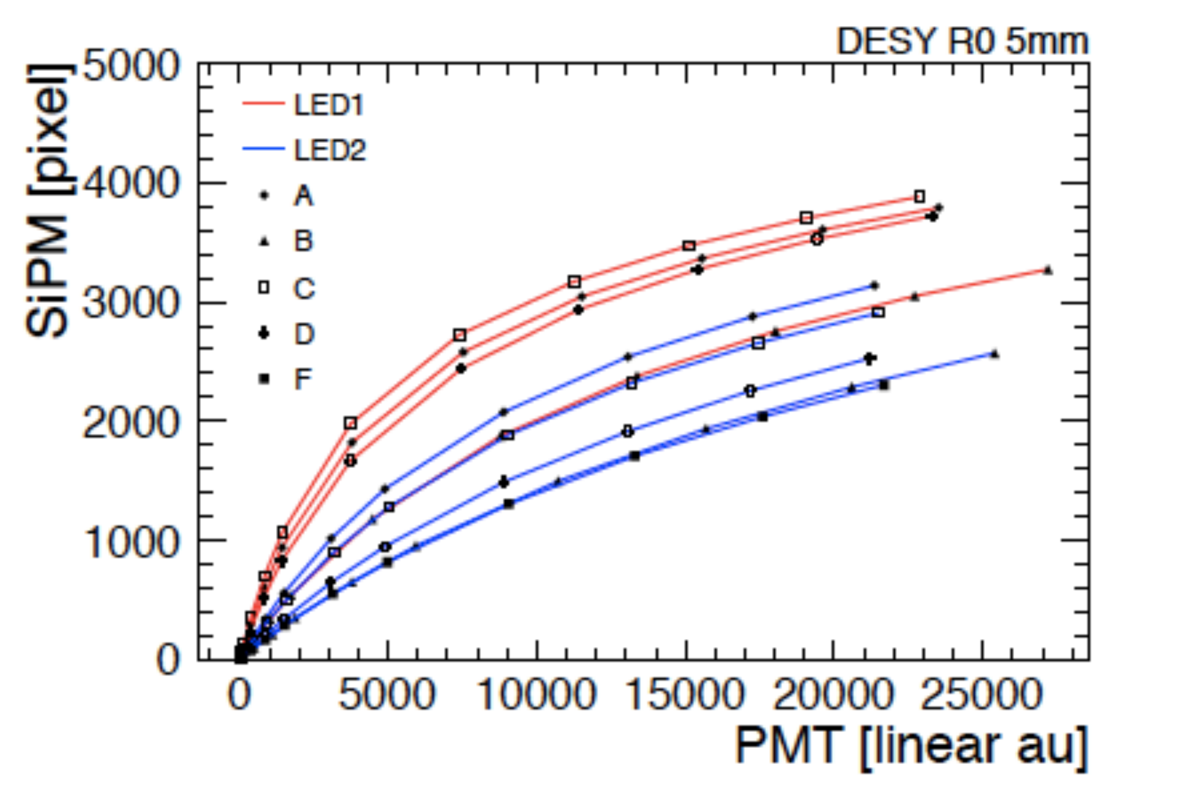
Results - Fiber-to-Fiber

Notre Dame



- fibres within SiPM acceptance show good homogeneity
- significant and varying light loss for LED 2 fibres, which are near the side of the mixer
  - this was already expected as the inner diameter of the used fibres was slightly smaller than optimal
  - next version will be corrected

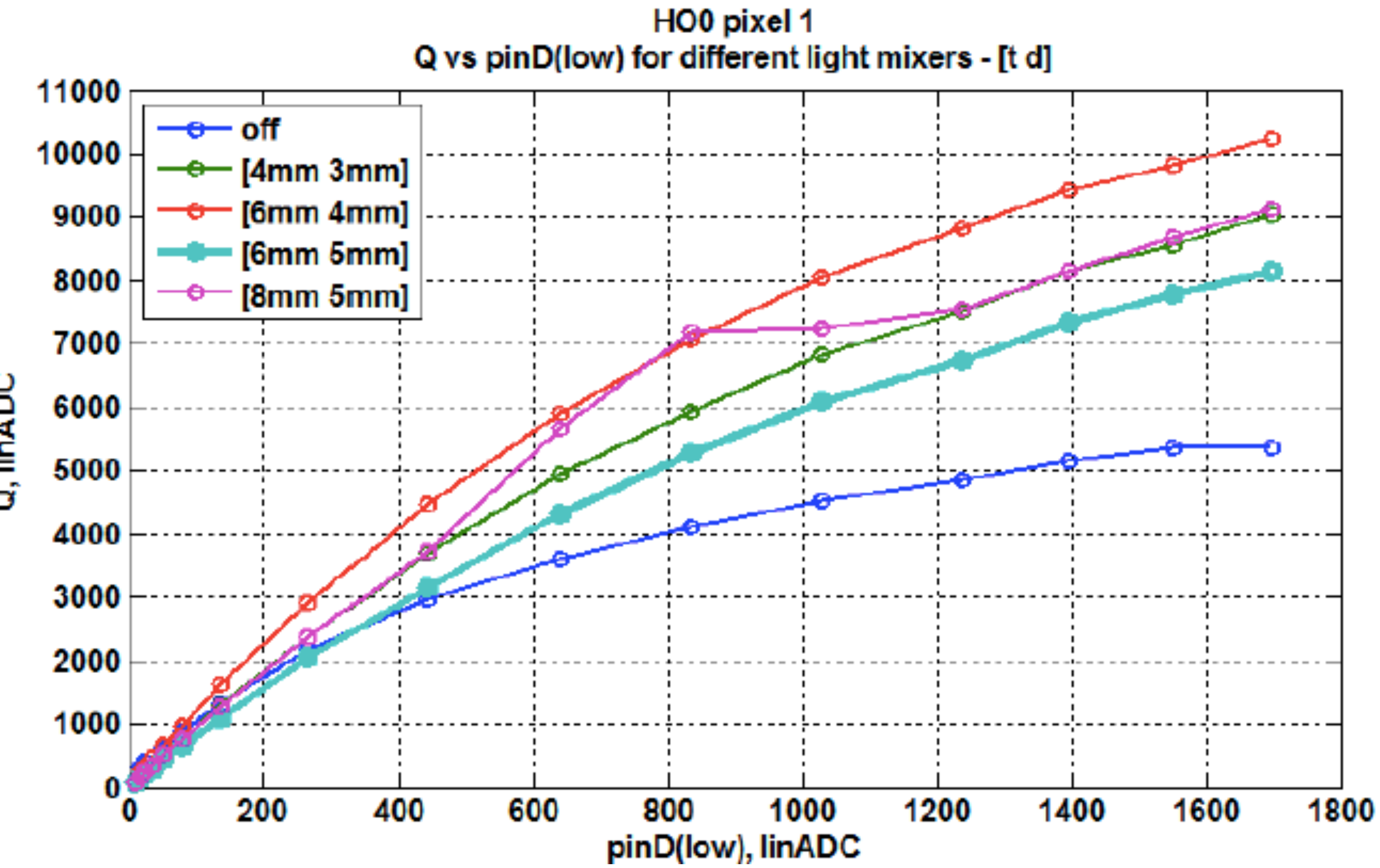
DESY

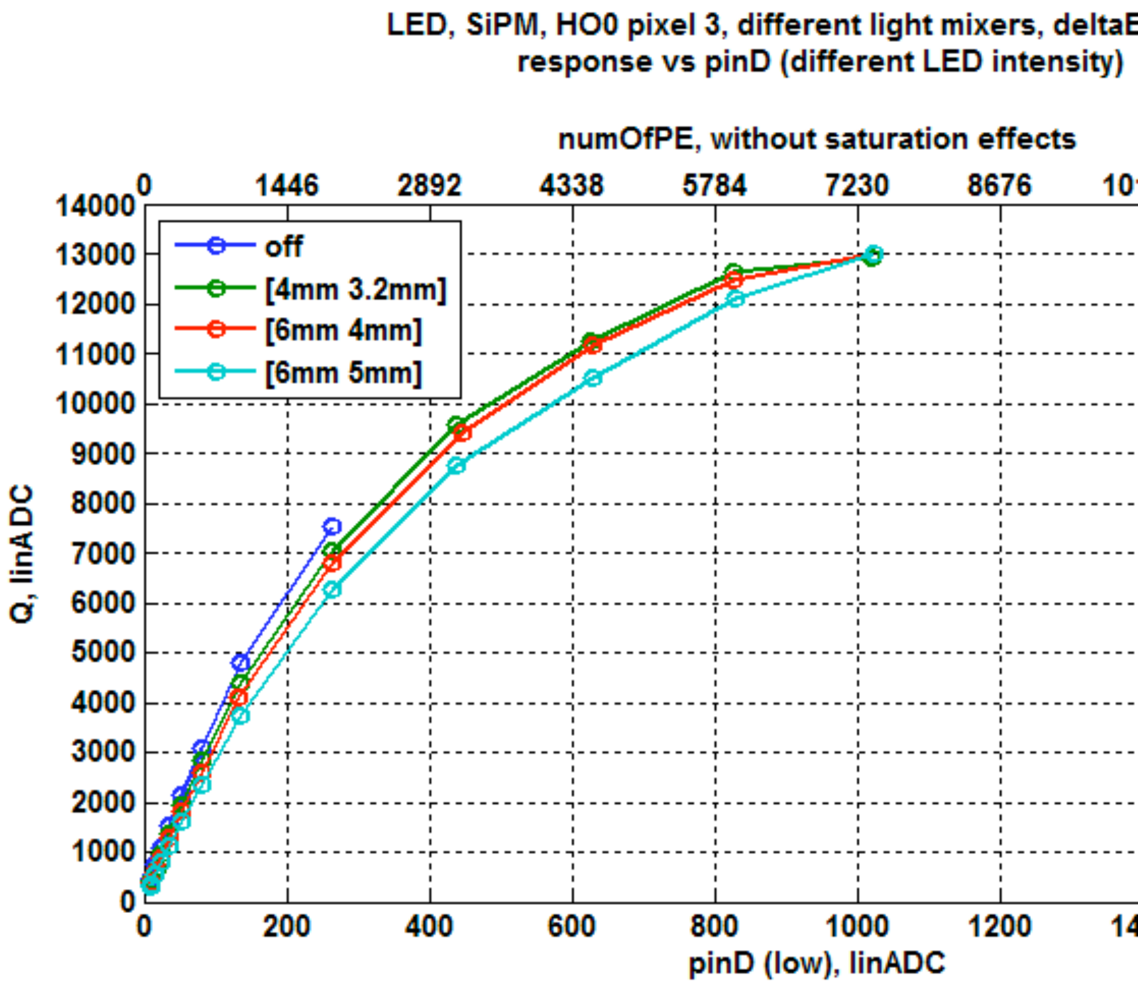


- significantly stronger variations than Notre Dame, especially for outer fibres
- generally stronger light loss

B. Lutz (CALOR 12)

Varying thickness and depths of light mixers





> By optimizing the depth and thickness of the chosen light mixer we can optimize the gain from light mixing

Test Beam

- Slice of the detector is put in front of a variable energy muon or pion beam
- Tests response in real beam conditions
- focused beam to test response of the scintillating tiles
- Involved in data-taking and analysis by students and post-docs

Test Stand

Facility

- test-stand in 904
- using P5 type electronics
- reading HO RBXs

Data Logging[a]

- data base storage of measurements
  - fully automatised for slow control data
  - higher level analysis results added via predefined data-formats
- transparent tracking of electronics card IDs in all data streams
- aggregated display in WBM

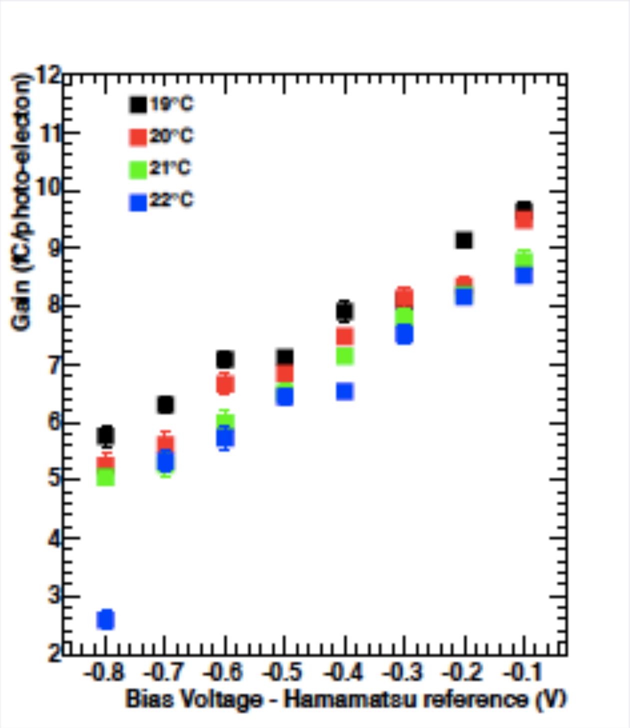
[a] see talk by U. Joshi

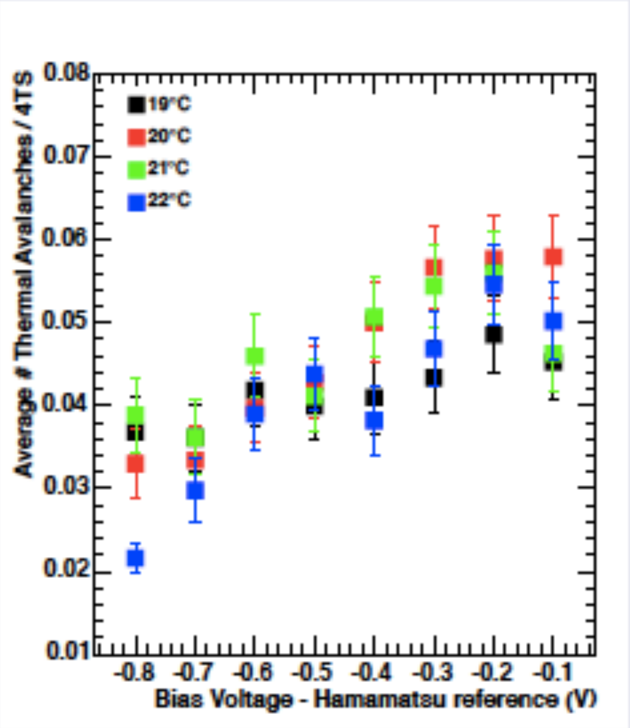
Measurements

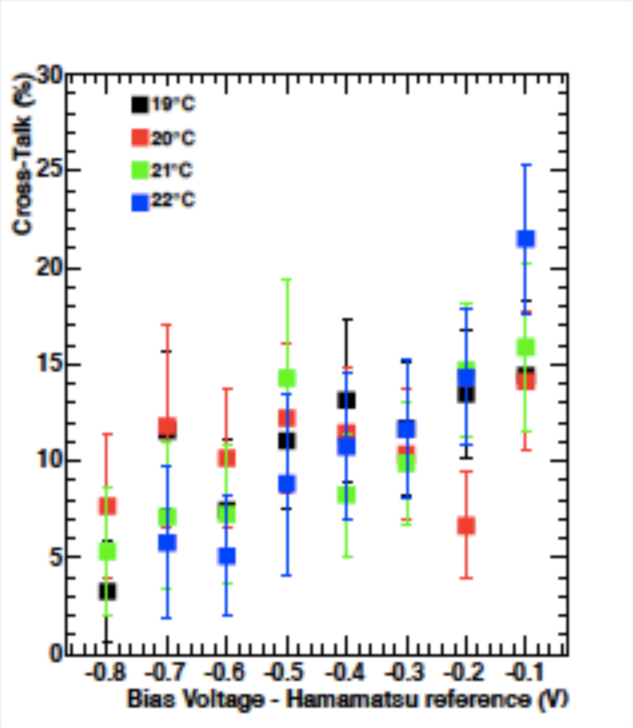
- slow control
  - current sensor offset
  - temperature sensor offset
- SiPM
  - breakdown voltage (I-V-scan)
  - gain
  - dark noise
  - inter-Geiger-pixel crosstalk
- system test
  - temperature stabilisation
  - noise performance
  - gain stability

First test-stand results

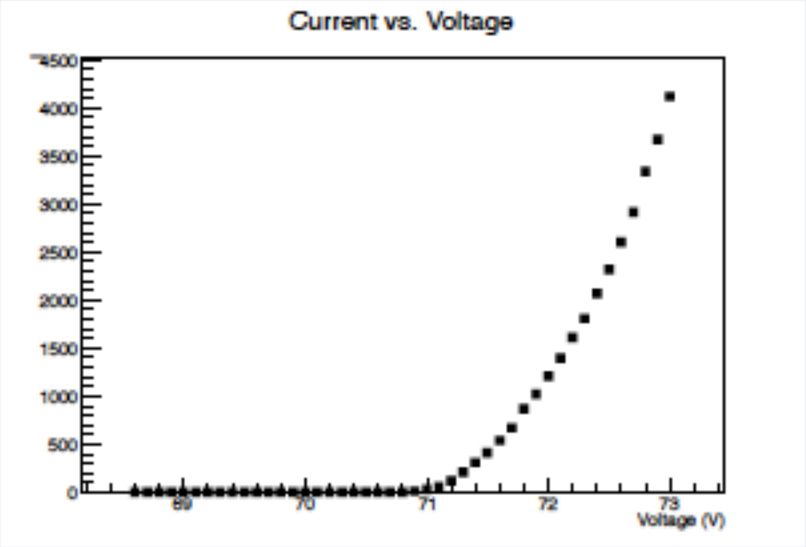
Gain, Noise, and X-Talk (B 28)

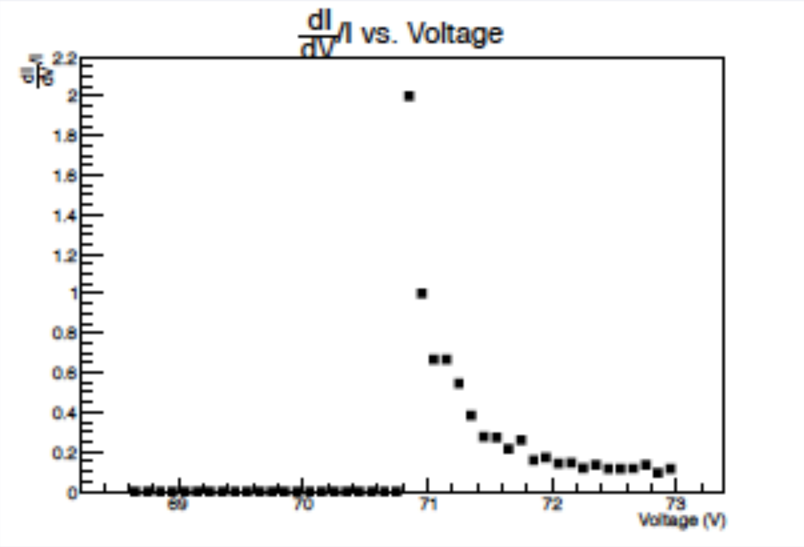


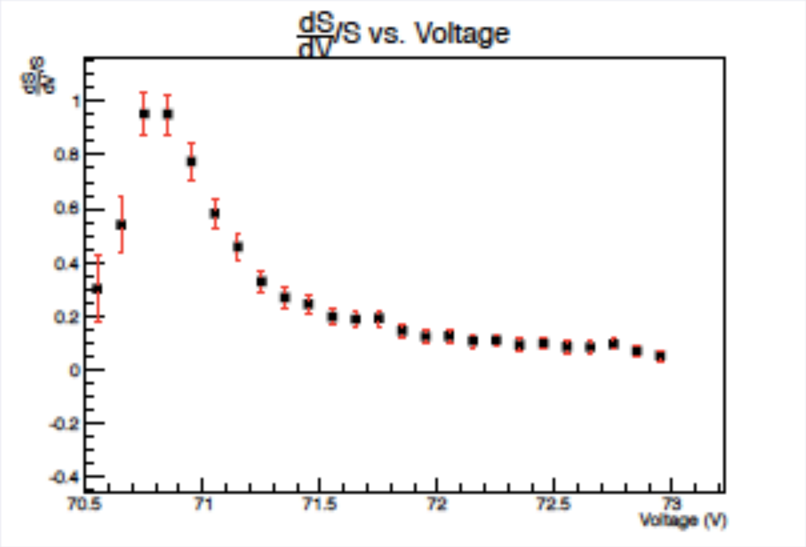




Bias Voltage Scan (904)







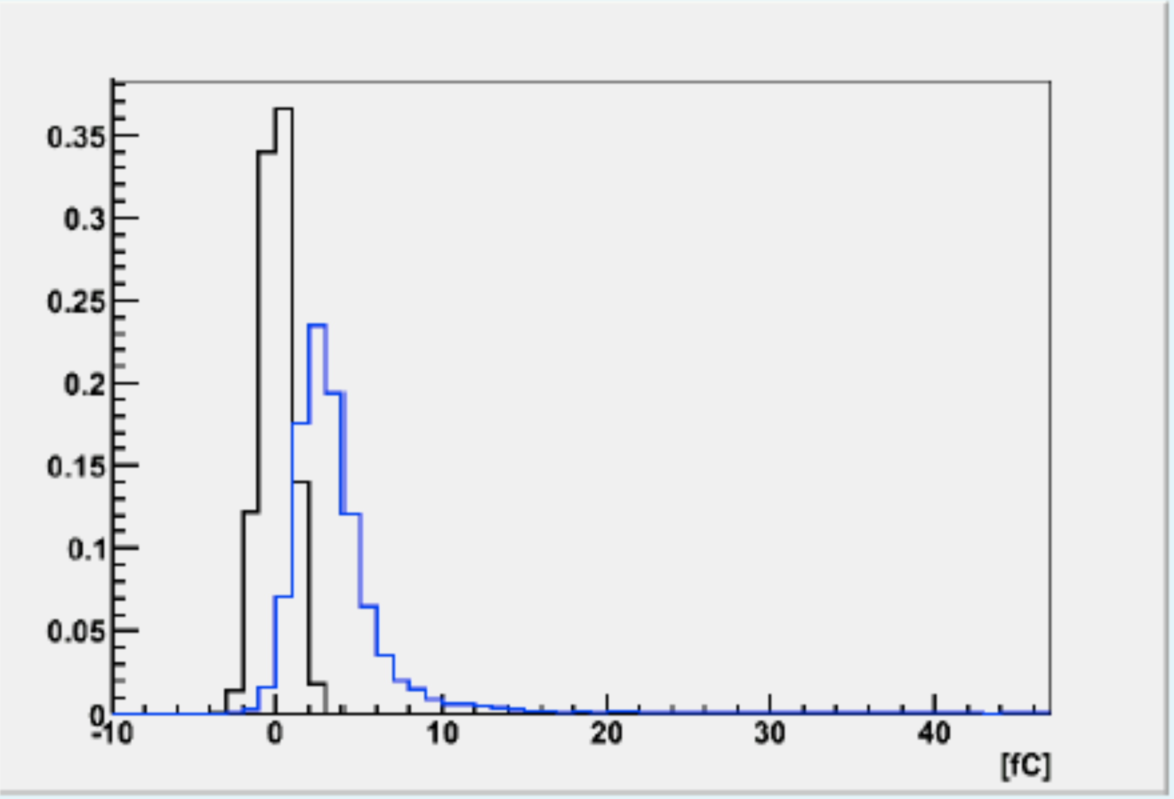
Summary

- CMS has put in place a plan to replace the HPDs in the HCAL
- The HO will be the first part of HCAL to be undergo this upgrade
  - Scheduled start during Long Shutdown 1 in ~March 2013
- An optimal light mixer design has been studied and approved at DESY
- The response and saturation of the SiPMs has been studied by DESY scientists
- A complete testing and quality assurance program is being carried out by DESY members at CERN
- The full upgrade has shown to be a great improvement to the object-id and calibration used by the entire CMS physics program
  - Full upgrade simulations performed by the DESY group
- German contribution significant and indispensable at every step
- Special thanks to Benjamin Lutz (DESY) who performed most of this analysis and preparations

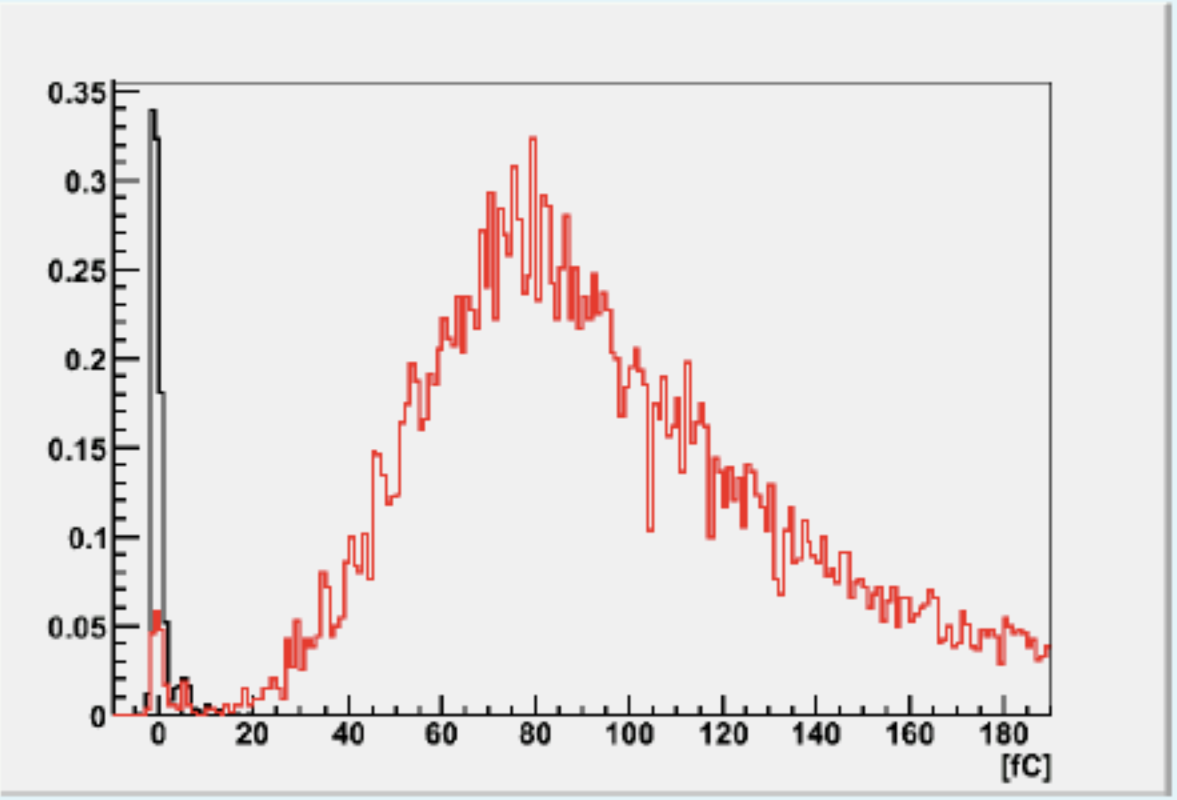
Backup Slides

Signal-to-background

HPD

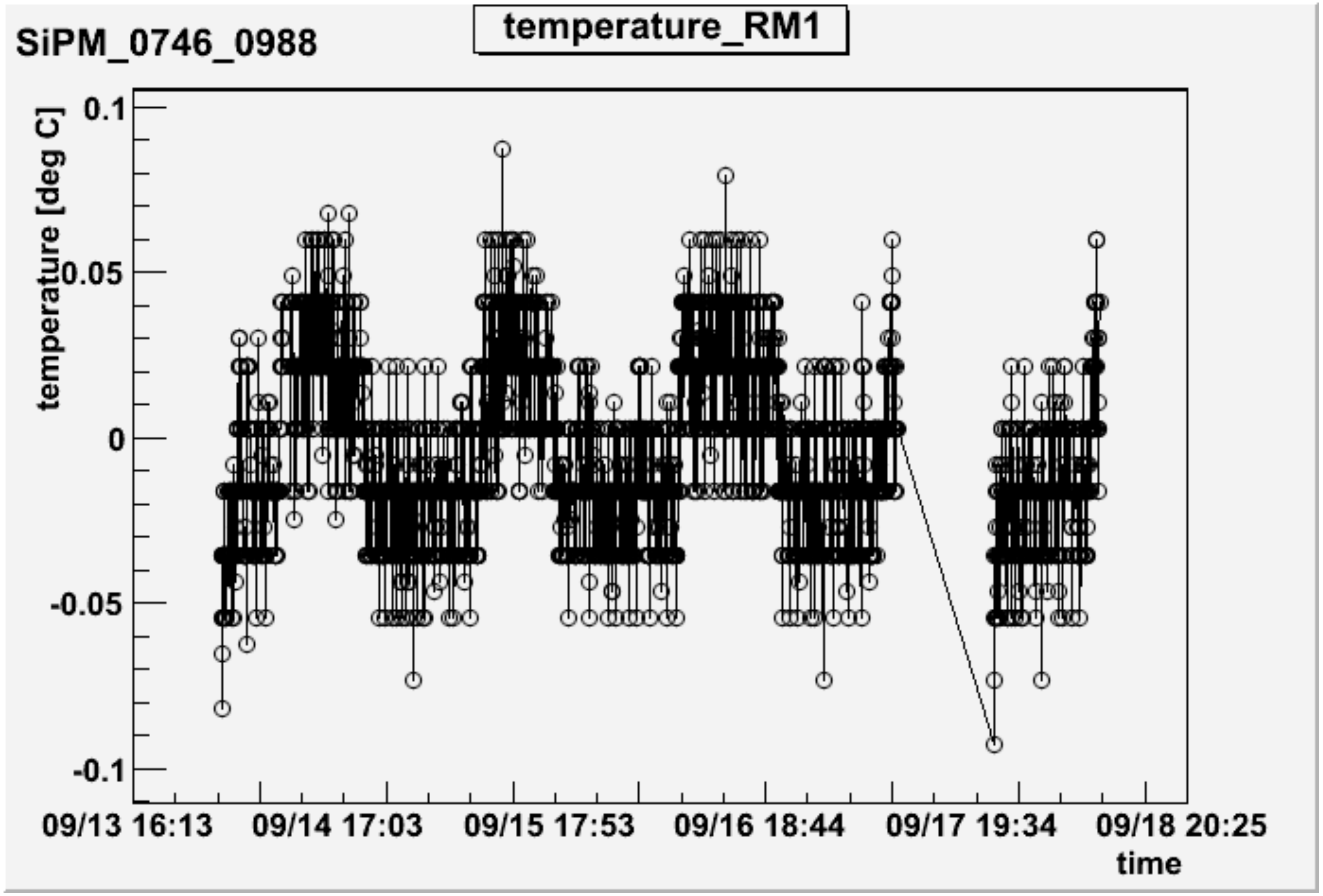


SiPM



- Drastically better signal to noise with SiPM
- HO can help to ID muons

Temperature stability vs. time



- A temperature stability of about 0.1C is needed
- These results are being realized at the test beam