Large scale characterization and quality assurance tests for CALICE AHCAL "engineering prototype"

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ICASIPM

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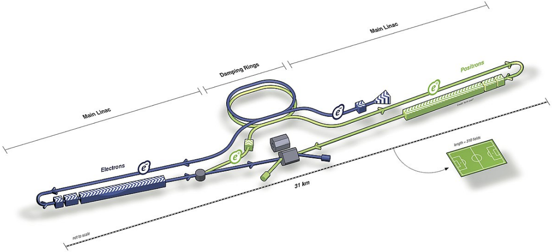
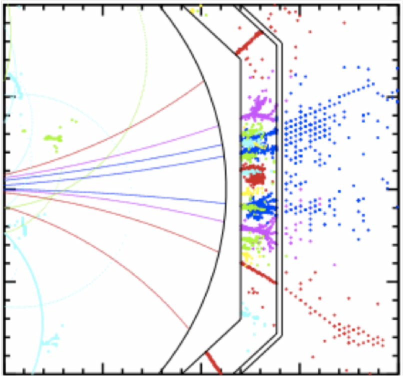
KIRCHHOFF-INSTITUTE FOR PHYSICS

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

High Granular Calorimeters

- International Linear Collider (ILC):
  - Under discussion in Japan
  - $\sqrt{s}$ =250-500 GeV, up-gradable to 1 TeV
  - 31 km long, superconductive RF cavities
- High granular calorimeters:
  - Motivated by requirements from precision physics programs at future lepton colliders
  - Prerequisite for Particle Flow reconstruction
- Particle Flow Reconstruction:
  - Aim to improve the jet energy resolution
  - Connecting information from all sub-detectors
    - Charged particles measured in Tracker
    - Photons measured in Electromagnetic Calorimeter (ECAL)
    - Neutral hadrons measured in Hadronic Calorimeter (HCAL)
  - Separate energy depositions from close-by particles: high granularity is essential

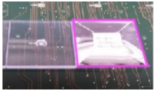


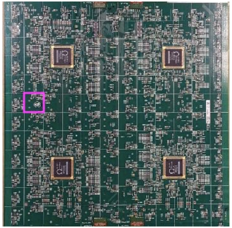


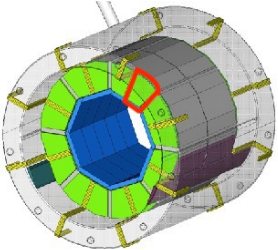
M.A. Thomson: NIMA 611 (2009) 25-40

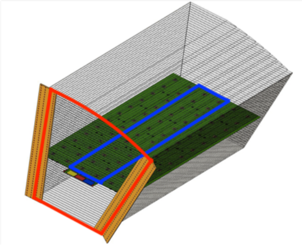
Scintillator based hadronic calorimeter (AHCAL)

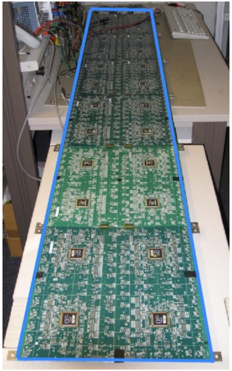
- Sandwich calorimeter based on scintillator tiles ($3 \times 3\ cm^2$) readout using SiPMs
- Fully integrated electronics
- HCAL Base Unit (HBU): $36 \times 36\ cm^2$, 144 channels, 4 ASICS
- High granularity: **8M** channels
- Technological prototype: demonstrate **scalability** to full detector



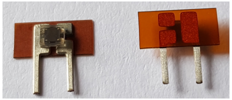




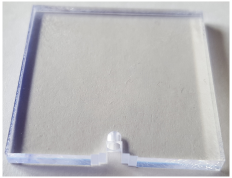




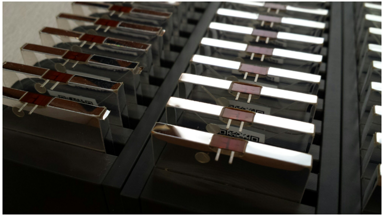
Old tile design



- physical prototype since 2006
- Channel Design (2014):
  - Complex tile design
  - Individual tile warpping (laser cutted, semi-automatic assembly)
  - Plastic scinitllator machined manually
  - SiPMs soldered to pins and glued to kapton
  - Sensor glued to Tile



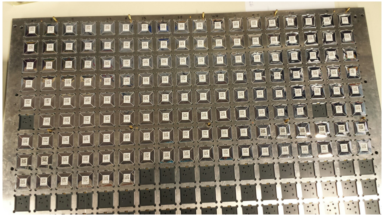
- QA:
  - Test cell (Tile+SiPM) before assembly on HBU
  - Full SiPM characterization
  - Light yield estimation for fixed over voltage



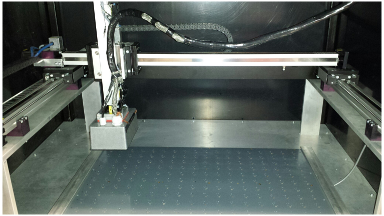
- Production flow:
  - SiPM soldered and glued to Kapton
  - Scintillator machining (manual)
  - Tile wrapping
  - Sensor glued to tile (manually)
  - QA test
  - Detector solder to HBU (manually)

Old Tile tester

- Tester plate:
  - Can hold up to 220 Tiles
  - Dedicated connectors for the SiPMs pins
  - Dedicated holes for laser input
- Tester head:
  - Assembled on XYZ stage
  - Include 12 fibers (measure 12 channels simultaneously)
  - Include integrated electronic (Klaus ASIC)
  - Connection to SiPMs with spring loaded pins
  - HV supply
- Output:
  - Breakdown voltage
  - LY at a fixed over voltage
  - DCR



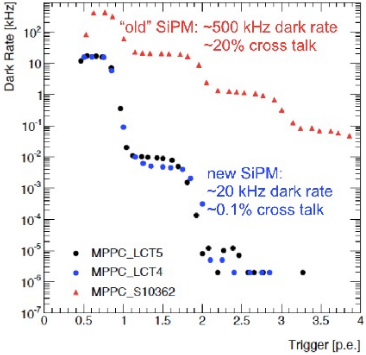
Tester plate



moving stage with tester head

Engineering prototype - new design

- Engineering prototype goals:
  - Large scale - 24,000 channels
  - Scalability to full detector
  - Automatized production!
  - Improvement in uniformity and performance with compare to the physics prototype
- New generation of industrial SiPM:
  - Dramatically reduced DCR
  - Increase PDE
  - Better signal-to-noise ratio
  - After-pulses and inter-pixel cross-talk rates reduced
  - Noise rate decreases quickly with threshold leads to more stable operation
  - Excellent uniformity (operating voltage, gain) → simplified calibration
  - High over-voltage operation → reduced temperature sensitivity



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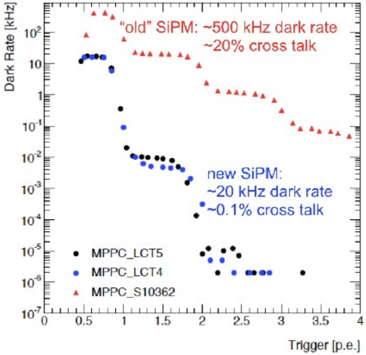
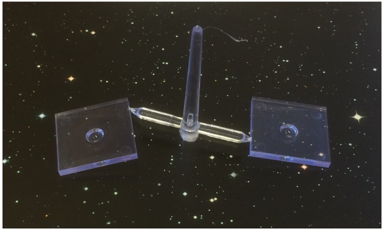


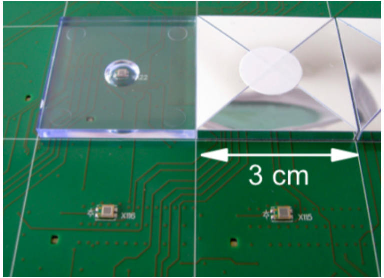
Allow re-design of tile-SiPM concept

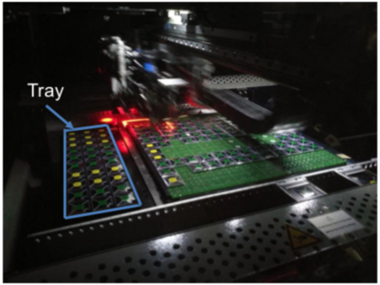
New detector design

- SMD SiPM → directly soldered on the HBU
- Simpler tile design
  → allow injecting moulding (tile/min, Lebedev Physics Institute)
- Tile wrapping using fully automatic machine (Uni. Hamburg)
- Tile assembly using pick and place machine (Uni. Mainz)



Injected mould tiles





Automatic placing of tiles

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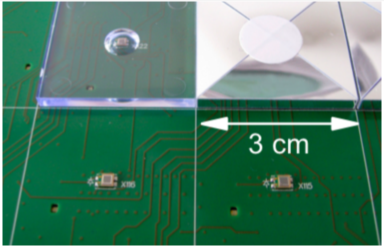
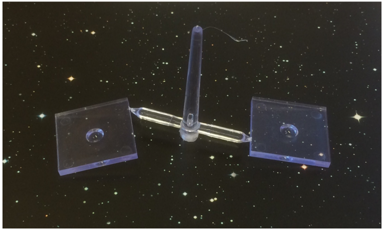
QA tests in two steps

- SiPM QA before soldering
- Test tile+SiPM after assembly





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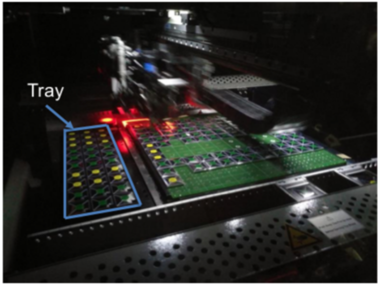

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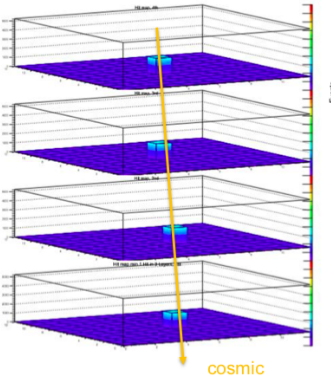
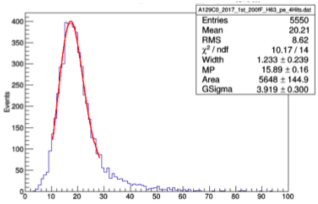
QA tests in two steps

- SiPM QA before soldering
- Test tile+SiPM after assembly (Mainz University)

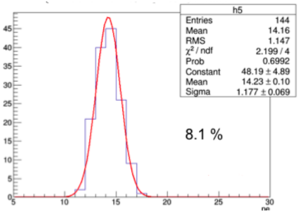


Cosmic setup

Stable temperature!



MIP response



Light yield spreads

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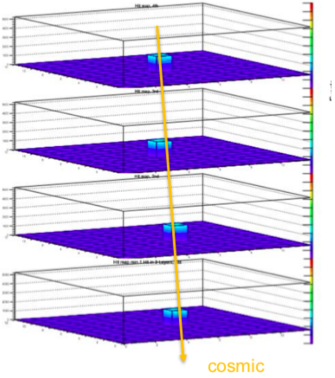
QA tests in two steps

- SiPM QA before soldering (Heidelberg University)
- Test Tile+SiPM after assembly



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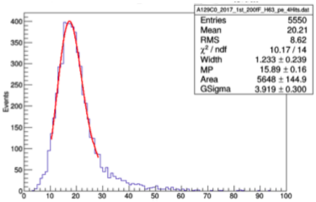

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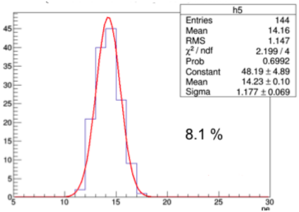


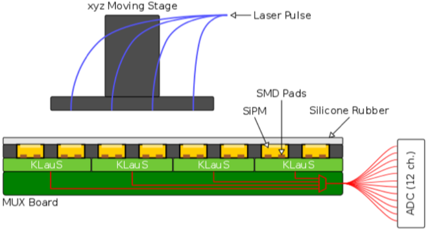
Light yield spreads

SiPM QA requirements

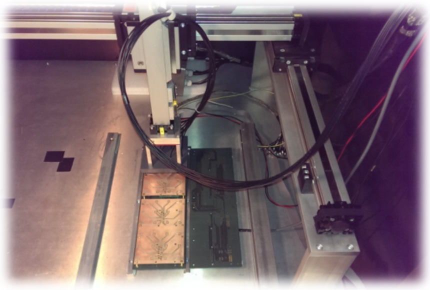
- Setup requirements:
  - Readout SMD SiPM without soldering
  - **Scalable** design
  - **Fast** testing
- SiPM requirements (@25°C, 5 V OV):
  - $\sim$ 2700 pixels, pixel size 25 μm
  - DCR $<$ 500 kHz
  - Cross-talk $<$ 3%
  - PDE (@420 nm) $>$ 20%
  - Gain $> 3 \times 10^5$
  - $dV/dT < 1\%$ of excess bias voltage ($\sim$50 mV/k)
  - Breakdown voltage min-max spread 200 mV within a batch
  - For quality assurance: test a small sample (4% from each batch)
- Accept maximum 1 outlier from each batch of 600 Sensors

SiPM QA setup

- System components:
  - Laser head with 12 optical fibers
  - Base plate:
    - Up to 144 SMD SiPMs
    - RO - 12 KlauS2 ASICs
    - Multiplexing of Klasu2 output signals to 12 channels ADC
  - Fiber/SiPMs spacing compatible to HBU
- Advantages:
  - Measure 48 SiPMs in $\sim$8 min
  - Can be used both for SMD SiPM QA or on equipped HBU
  - Modular - can be easily scaled up the no. of channels
- Disadvantage:
  - Manually placed the SiPMs
  - Need to take SiPMs out of the sealed tape



SMD SiPM schematic view

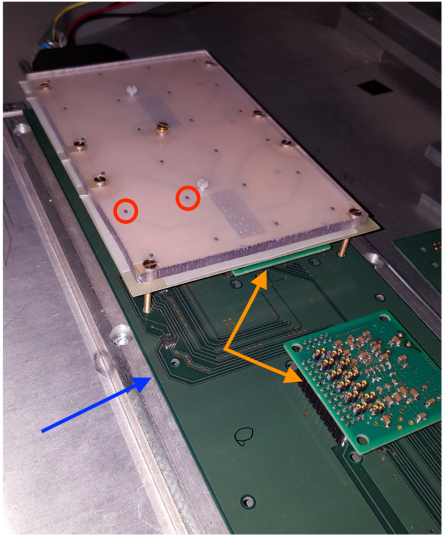


SMD SiPM Setup with fiber fan-out

Single base plate

- 24 SiPMs
- Multiplex PCB
- 2 Klaus ASICs

- Current prototype have 2 module (up to 48 SiPMs)
- The design is modular and can be scale up if needed for mass production



SMD SiPM base plate

Measurement procedure

Measurement:

- Using low intensity light spectra
- The setup is inside an oven with constant temperature of 25°C
- Measure the SPS spectrum for voltage range of 1 V to 7 V above breakdown (Hamamatsu datasheet) at step size of 0.1 V
- For the sample measured during night re-measure for temperatures (10,15,20,25,30,35,40°C)

Analysis:

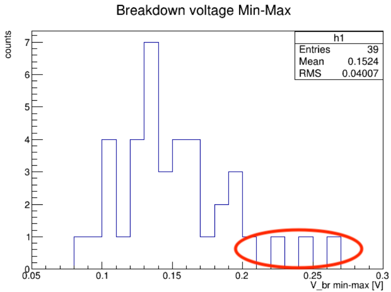
- Extract from each SPS spectrum the gain using FFT
- Extract the breakdown voltage for each temperature and SiPM from linear fit of gain vs. voltage
- Estimate the DCR from SPS using Poisson statistics:

$$DCR = -ln(\frac{N_0}{N_{tot}}/\Delta t) \qquad (1)$$

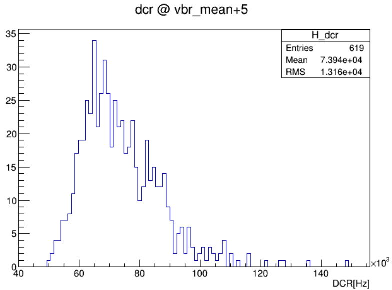
- Estimate CT upper limit from the DCR spectrum
- extract for each SiPM the temperature coefficient from linear fit of the breakdown voltage vs. temperature (for available samples)

* the gain is measured in arbitrary units $\rightarrow 13 \sim 3 \times 10^5$ (the requirement)

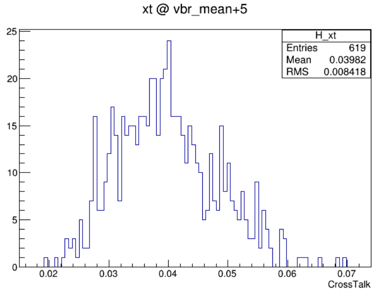
Example results



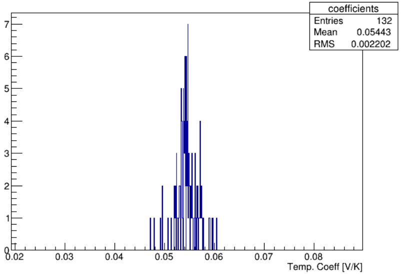
breakdown voltage min-max spread



DCR spread



Cross-talk spread



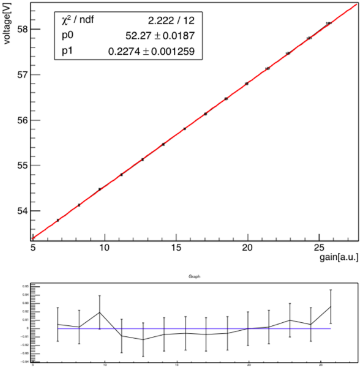
Temperature coefficient spread

Results

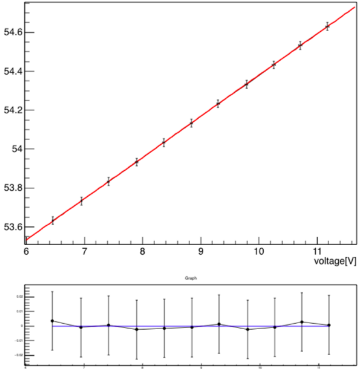
- DCR $<$ 500 KHz **OK!**
- Gain $> 3 \times 10^5$ **OK!**
- $dV/dT < 1\%$ **OK!**
- V_{bd} spread min-max within a batch 200 mV **OK!** (only 4 outlier)
- Cross-talk $< 3\%$ **OK**
  - include some after-pluses
  - due to much lower DCR can tolerate increase in CT
- PDE (@420 nm) $> 20\%$ - didn't measure yet (difficult without soldering)

Issues

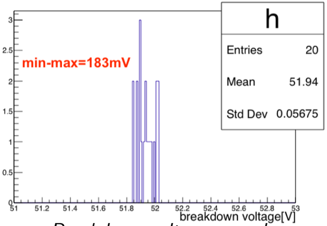
- Temperature control
- Light tight
- Non-linearity
  - Systematic in all
  - Residual < 10 mV
  - Possible voltage drop
- Not biasing the spread



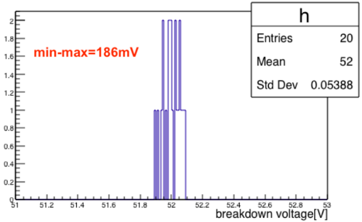
Example Voltage Vs. Gain full range



Example Voltage Vs. Gain small range



Breakdown voltage spread



Breakdown spread

Summary

- A large scale engineering prototype was build this year (24k channels)
- New test benches for QA of SMD SiPMs were designed
- Test benches are easily scaled up
- Fast SiPM characterization (∼10 sec per SiPM)
- All SiPM batches passed the requirements
- Good uniformity in SiPM parameters observed
  - Will allow to test less SiPM in the future
- Small non linearity in gain curves didn't bias the spread measurement
- For large scale version, an active cooling will be designed

Calorimeter for ILC

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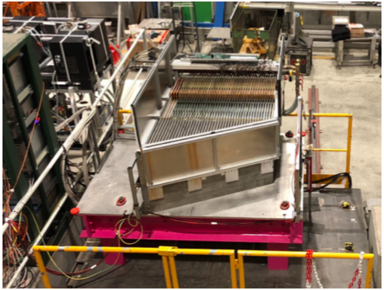
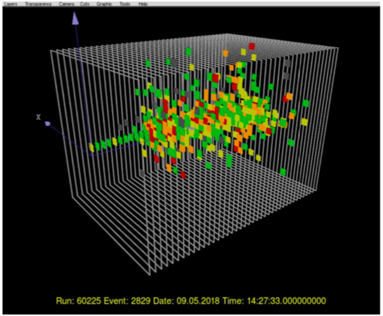
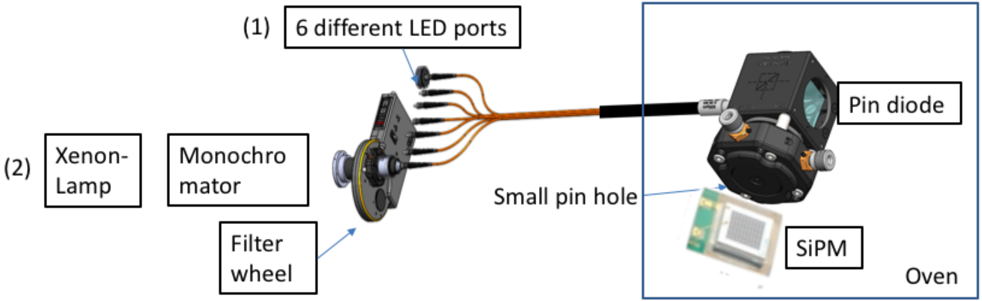
AIDA 2020





backup Slides

PDE setup



Work principle: