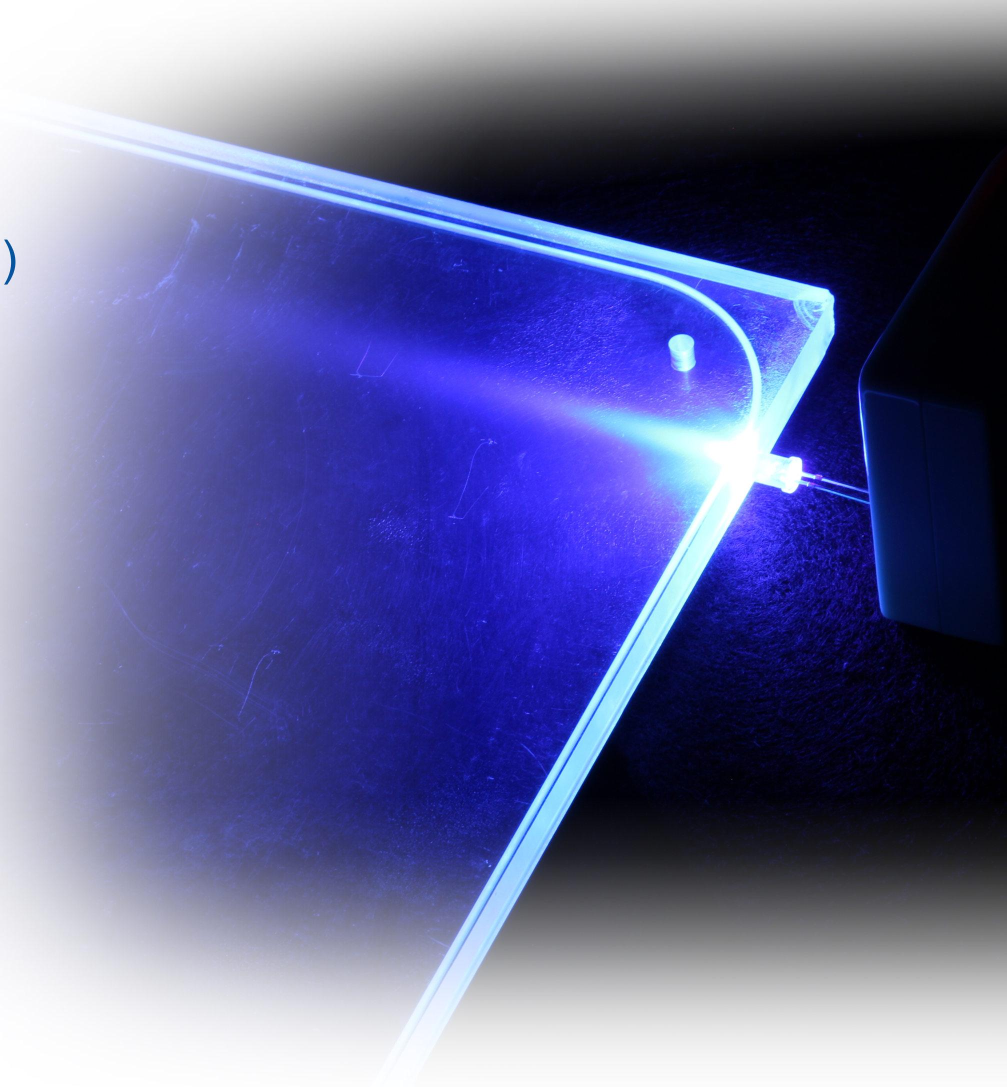
LHC Run-2 Readiness: CMS HCAL with SiPMs

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University

04.03.2015 – 8th Terascale Detector Workshop

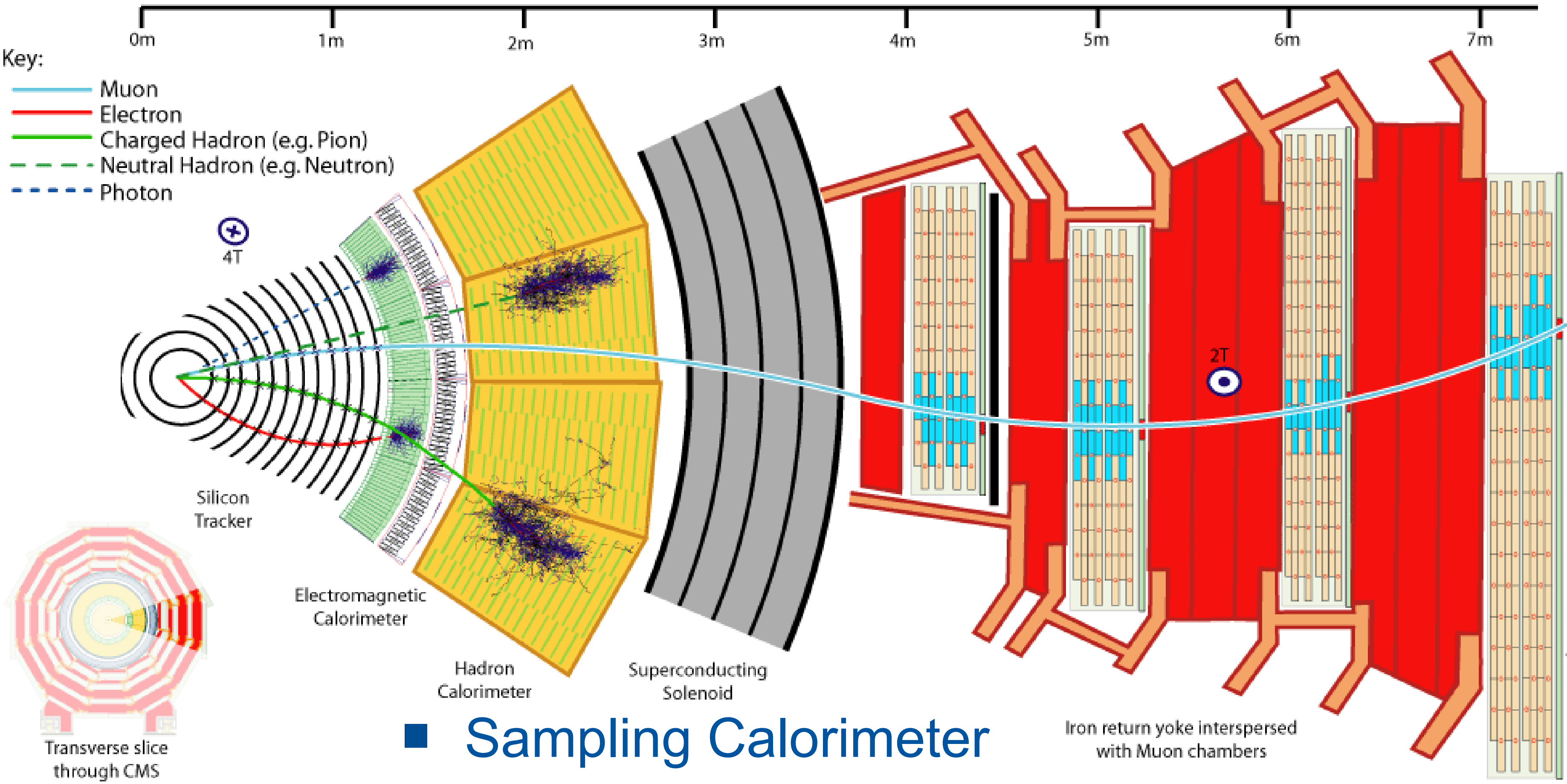
Outline

- The CMS HCAL System
  - ➔ Outer Hadron Calorimeter (HO)
- The HO upgrade
  - ➔ Installed hardware
  - ➔ Upgrade timeline
- Commissioning
  - ➔ In-time commissioning
  - ➔ Local cosmic runs
- Summary



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

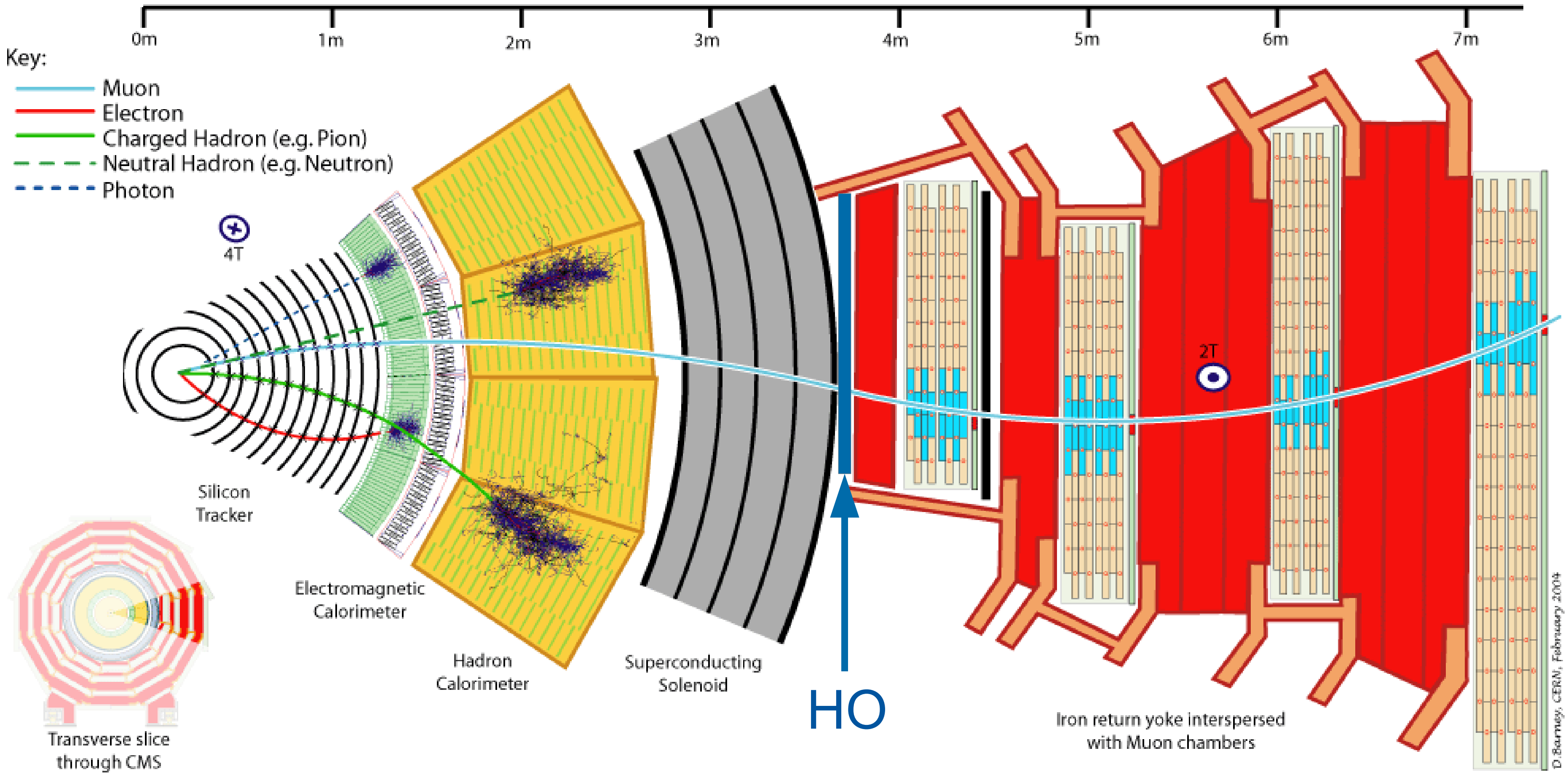
CMS central hadron calorimeter



- Sampling Calorimeter
  - → Brass absorber
  - → Plastic scintillator
  - → 8-10 λ thickness

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Outer Hadron Calorimeter (HO)

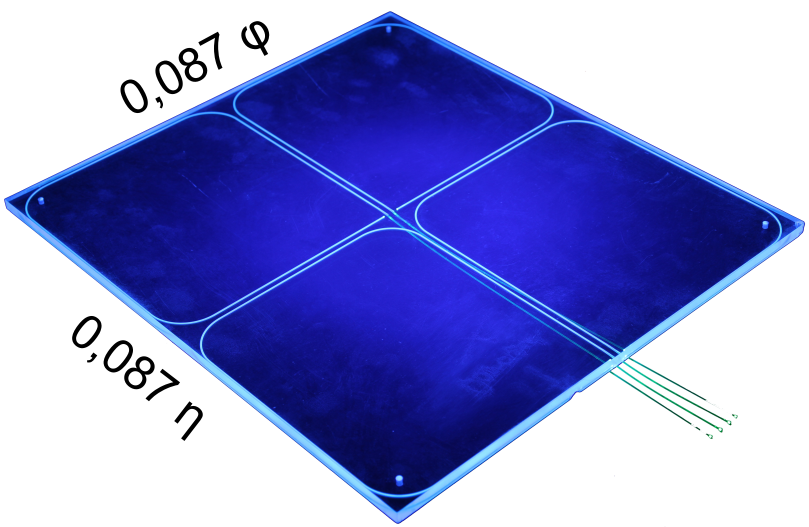


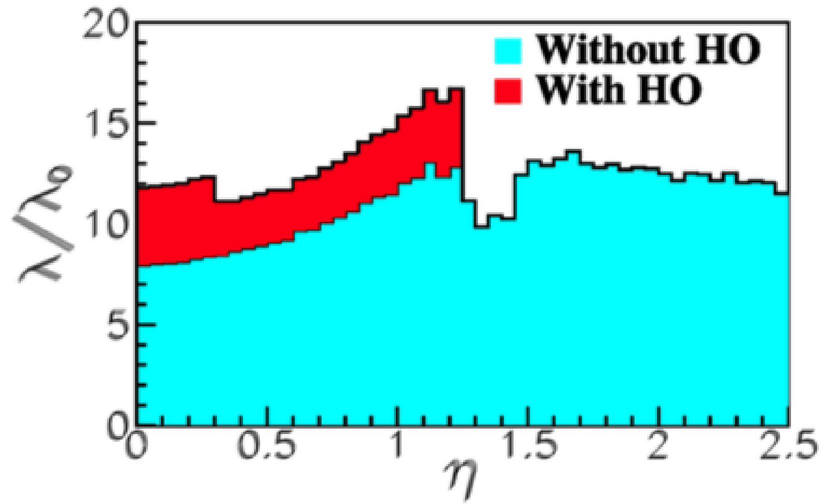
- Increase calorimeter thickness by using an additional layer (tail catcher)

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Outer Hadron Calorimeter (HO)

- Tail catcher for the central hadron calorimeter
- Plastic scintillator tiles (BC 408)
- Photon collection using WLS fibers
- Light transmission using clear fibers
- Readout with SiPM (former HPDs)

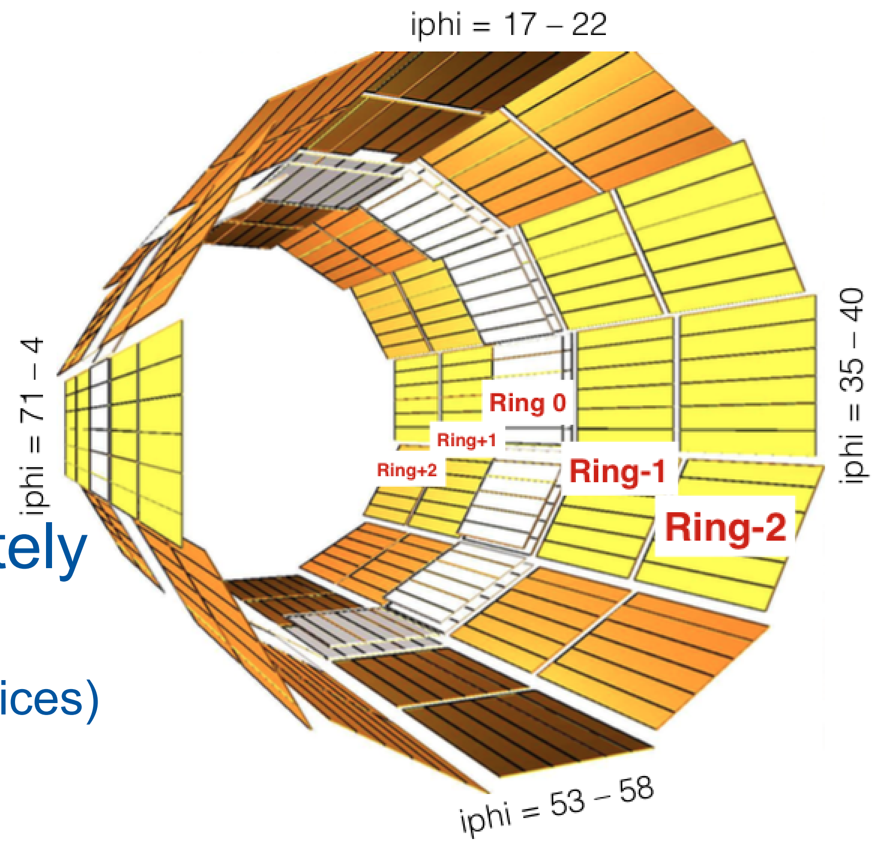




Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

HO Layout

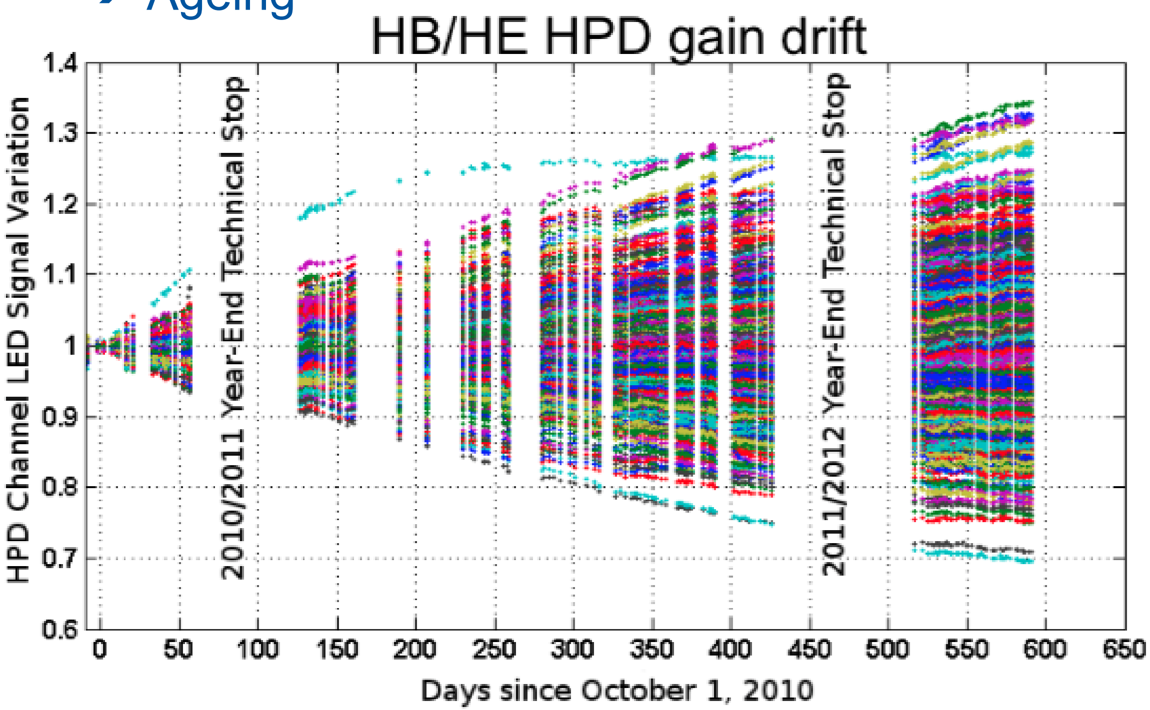
- Located in the 5 barrel wheels of CMS
- 30 tiles in η direction (ieta)
- 72 tiles in φ direction (iphi, 12 sectors with 6 trays)
- 2 layers in Ring 0
- Each η-φ-tile is read out separately
  - ➔ 2154 channels (6 missing because of unequipped areas due to detector services)
- Dark channels for noise measurement and calibration
  - ➔ Over all 2376 channels

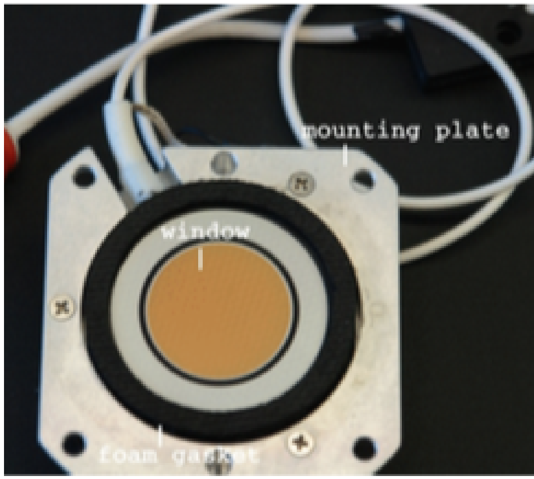


Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Hybrid Photodiode (HPD) issues

- HO used HPDs initially
- Not optimal for HO conditions:
  - ➔ Problems with running in fringe field of CMS magnet
  - ➔ Low gain and photo detection efficiency
  - ➔ Ageing





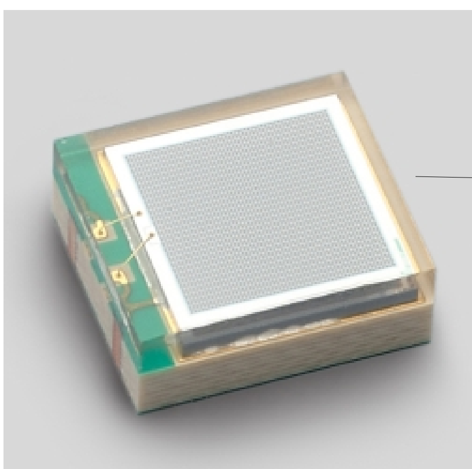
Hybrid-Photo-Diode (HPD)

→ Use SiPM

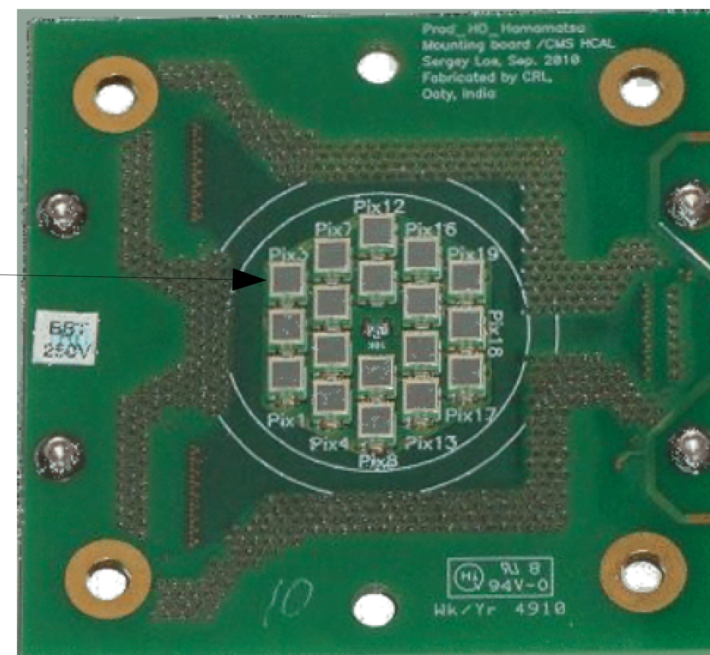
- Insensitive to magnetic field
- Comparatively small bias voltage

New SiPM equipment

- Hamamatsu MPPC S10931-050P
  - ➔ Selected for high uniformity of operating parameters
- (3 x 3) mm^2 active area
- 50 µm cell pitch
- Gain-Temperature-Dependency ~8% / K
- Operating voltage ~70 V



Reproducing form factor of HPD

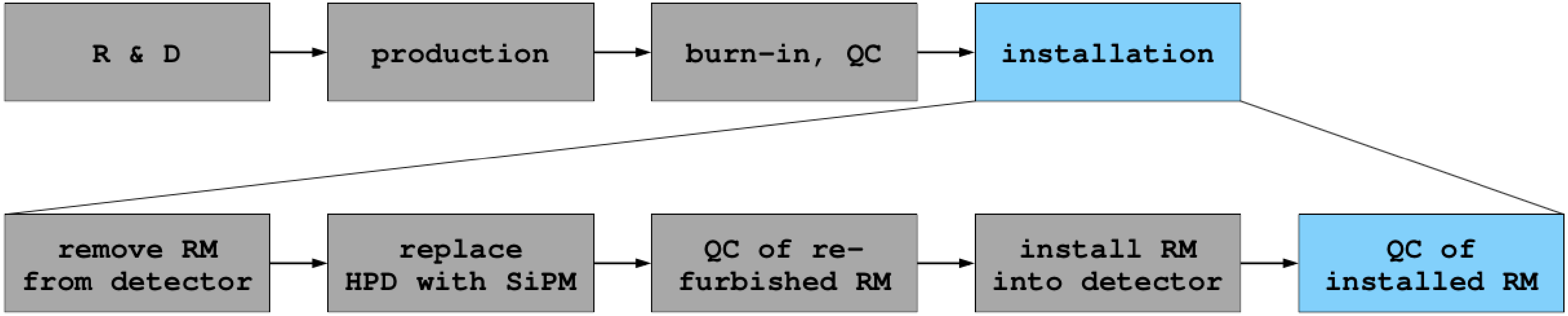


Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

HO Upgrade Plan

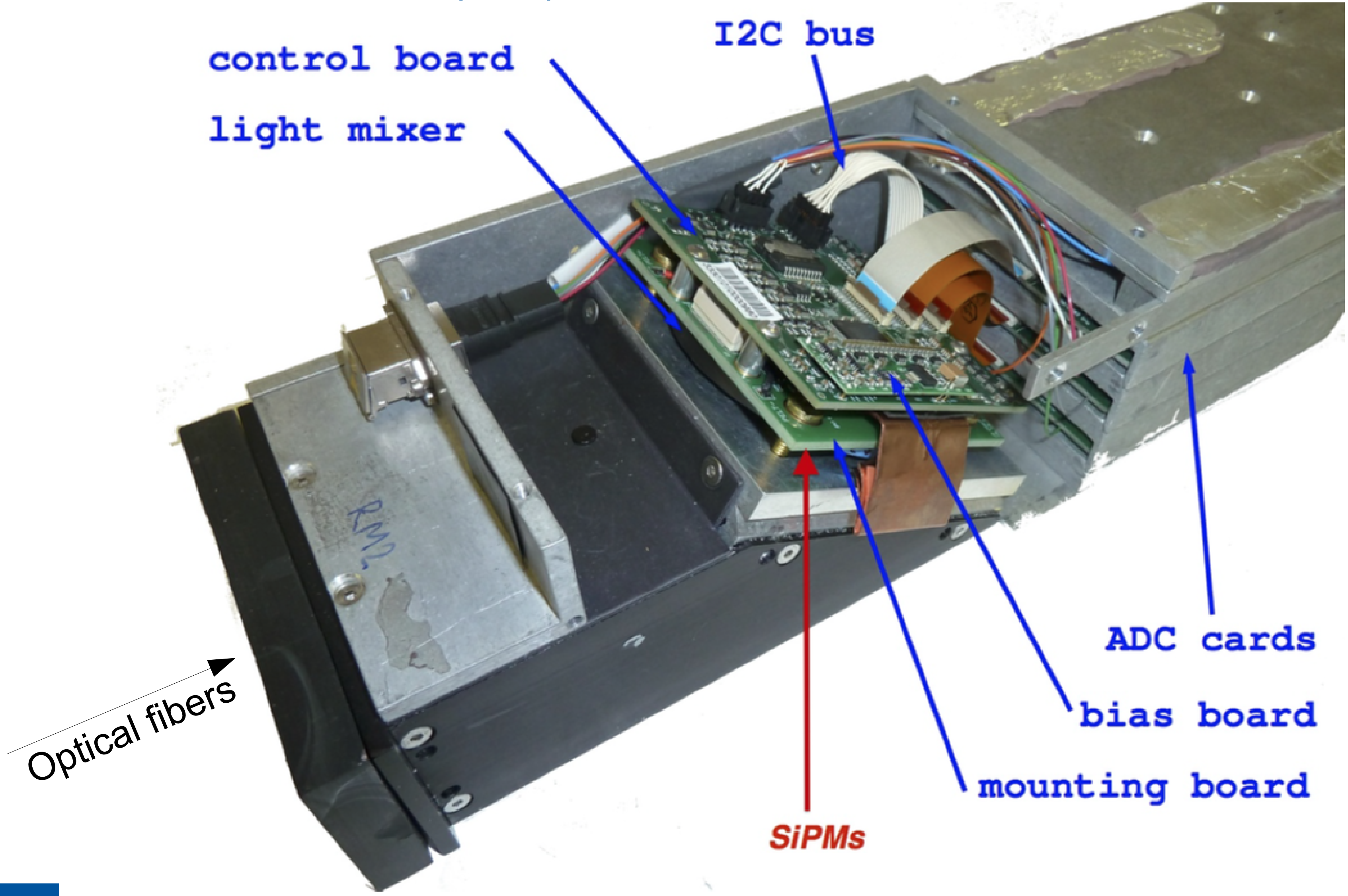
III. Physikalisches Institut A | RWTH AACHEN UNIVERSITY

- System design validated during last years in laboratory, test-beam and on the detector
- HPD replacement design as drop-in
  - ➔ Existing readout-modules (RM) and electrical/optical couplings reused
- Installation and commissioning of installed RMs
- Validation of installation and calibration with cosmics.



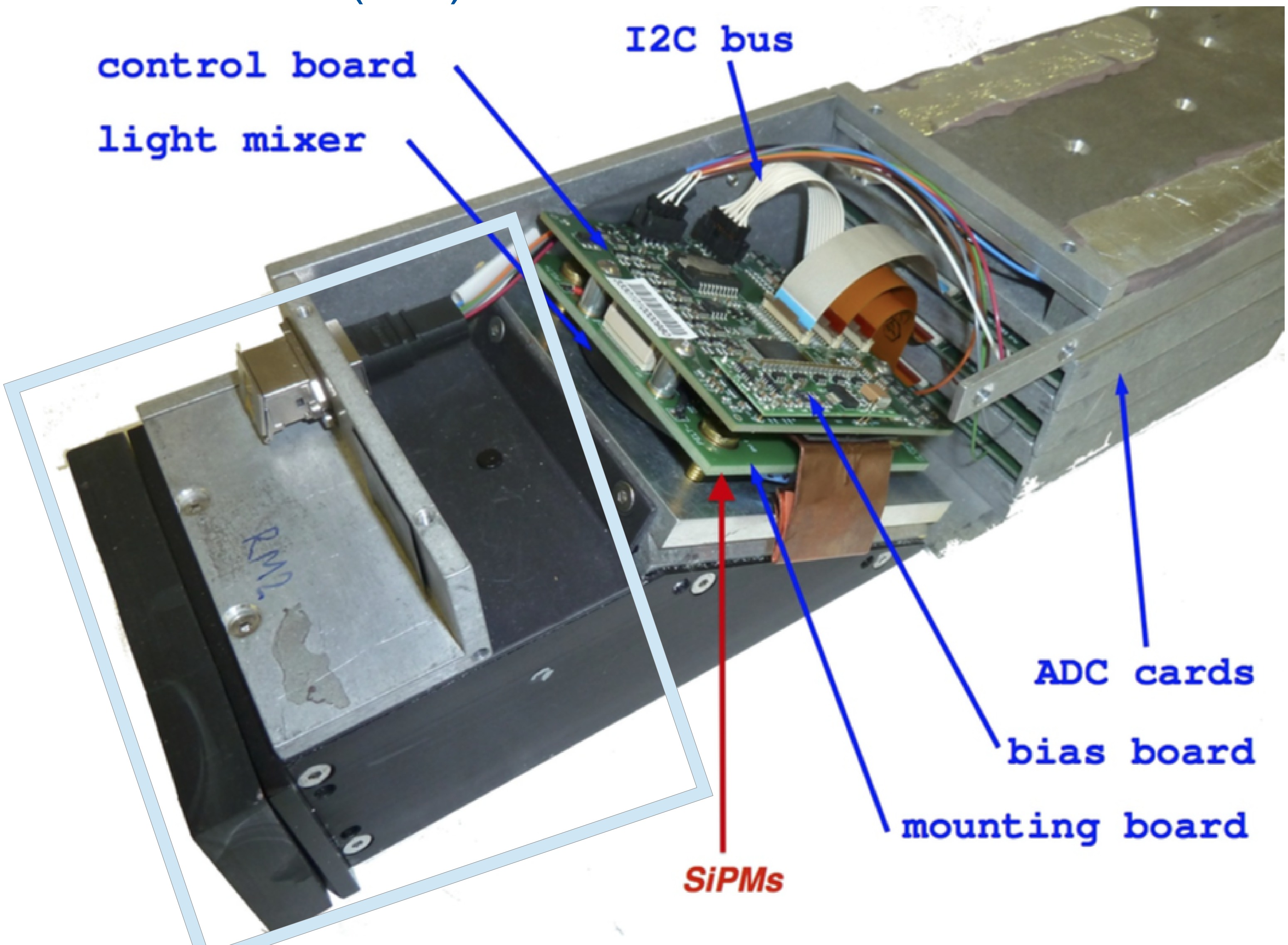
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Readout Module (RM)



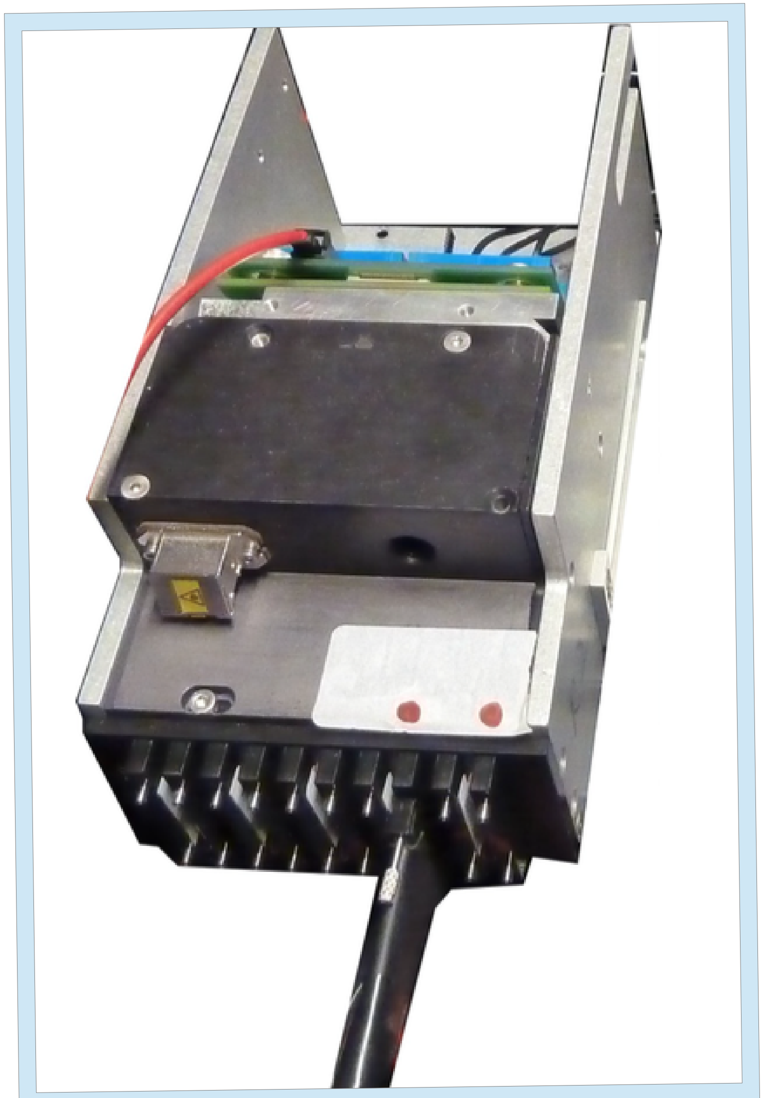
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Readout Module (RM)

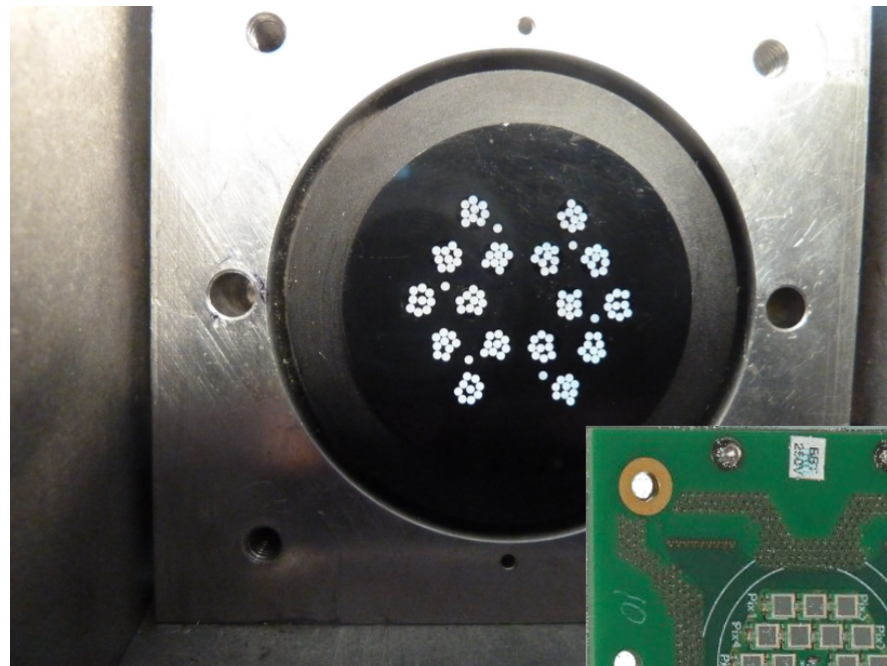


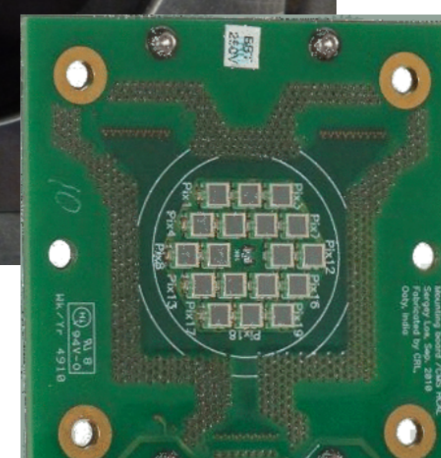
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

HO Hardware



- Optical decoder unit (ODU) routes fibers from one HO tile to the SiPM





Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Upgrade time line

- Upgrade design validated in laboratory, test-beam and detector
- Installation and commissioning of installed SiPM
- Validation of installation and calibration with cosmic muons

R & D	Production	burn-in, QC	installation	commissioning
till 2011	2011/2012	2012	2013/2014	2013/2014

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Upgrade time line

- Upgrade design validated in laboratory, test-beam and detector
- Installation and commissioning of installed SiPM
- Validation of installation and calibration with cosmic muons

R & D	Production	burn-in, QC	installation	commissioning
till 2011	2011/2012	2012	2013/2014	2013/2014

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

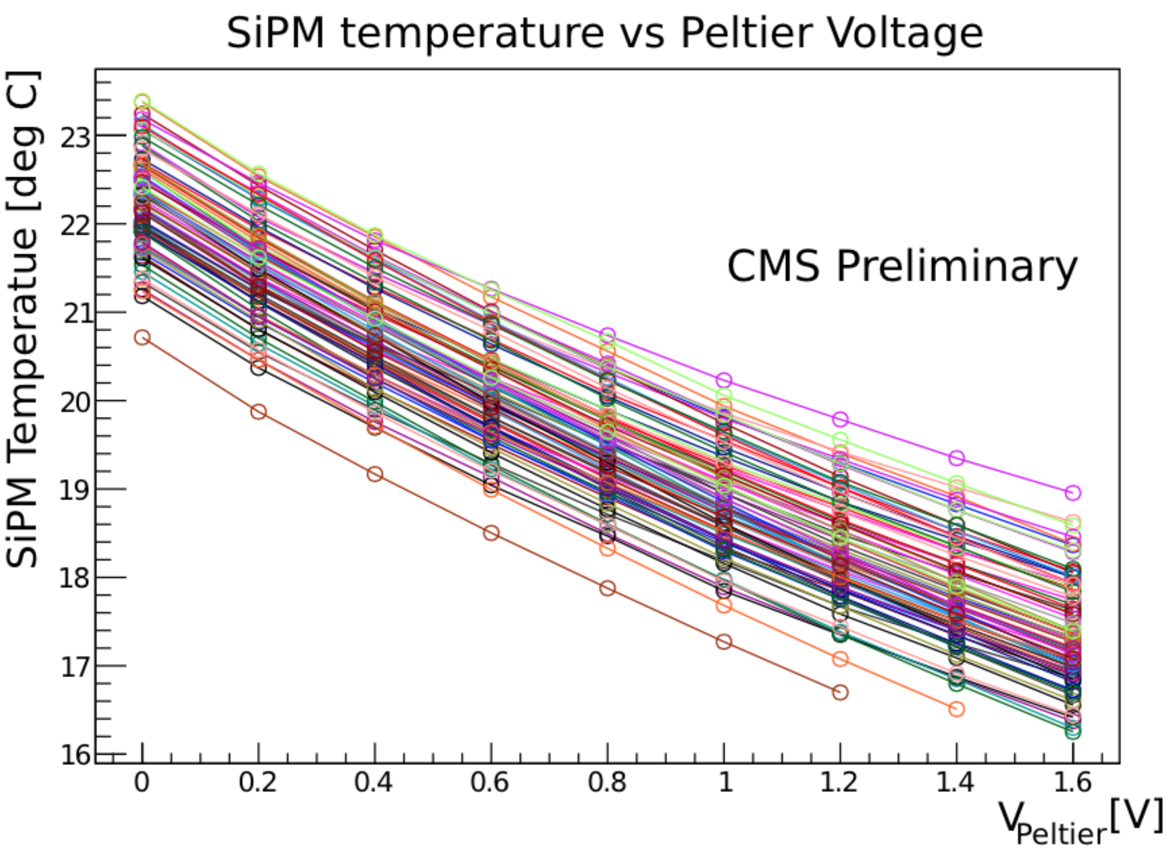
Commissioning

- Basic commissioning → During installation
  - ➔ Light tightness
  - ➔ Communication
- Adjustment of
  - ➔ Gain
  - ➔ Pedestal
  - ➔ Break down voltage

  as function of temperature
- Further commissioning using cosmics
  - ➔ Local/Global runs
- Final commissioning with first interactions

Temperature stabilization of SiPMs

- Cooling with Peltier elements
  - ➔ Ambient temperature in CMS cavern about 20°C
- Operate each SiPM board at its own temperature
- Working point – 0.3 V to reduce power dissipation

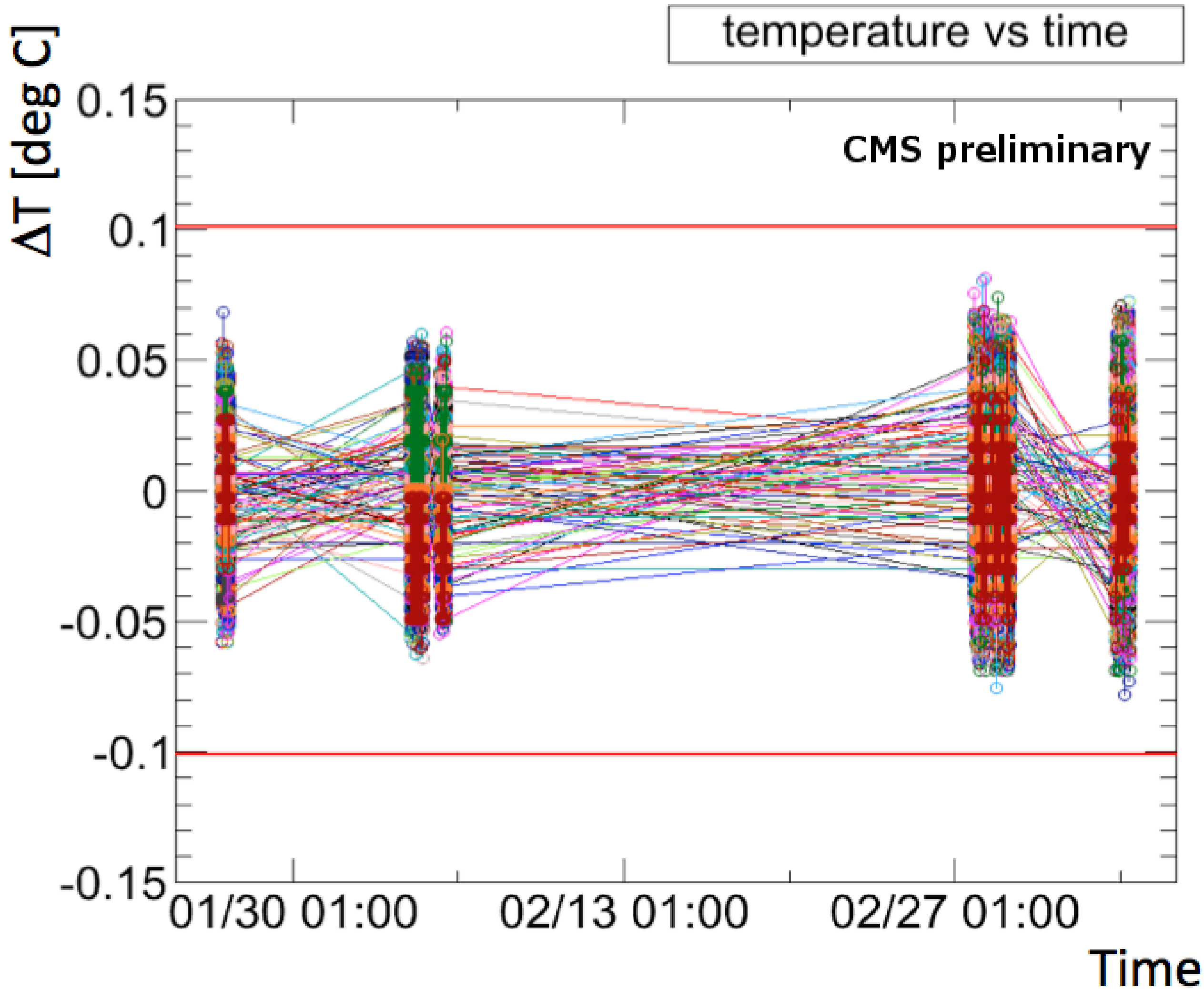


Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Temperature stabilization of SiPMs

- Temperature stable over wide time domain (approx. 1 month)
- Variation < 0.1°C

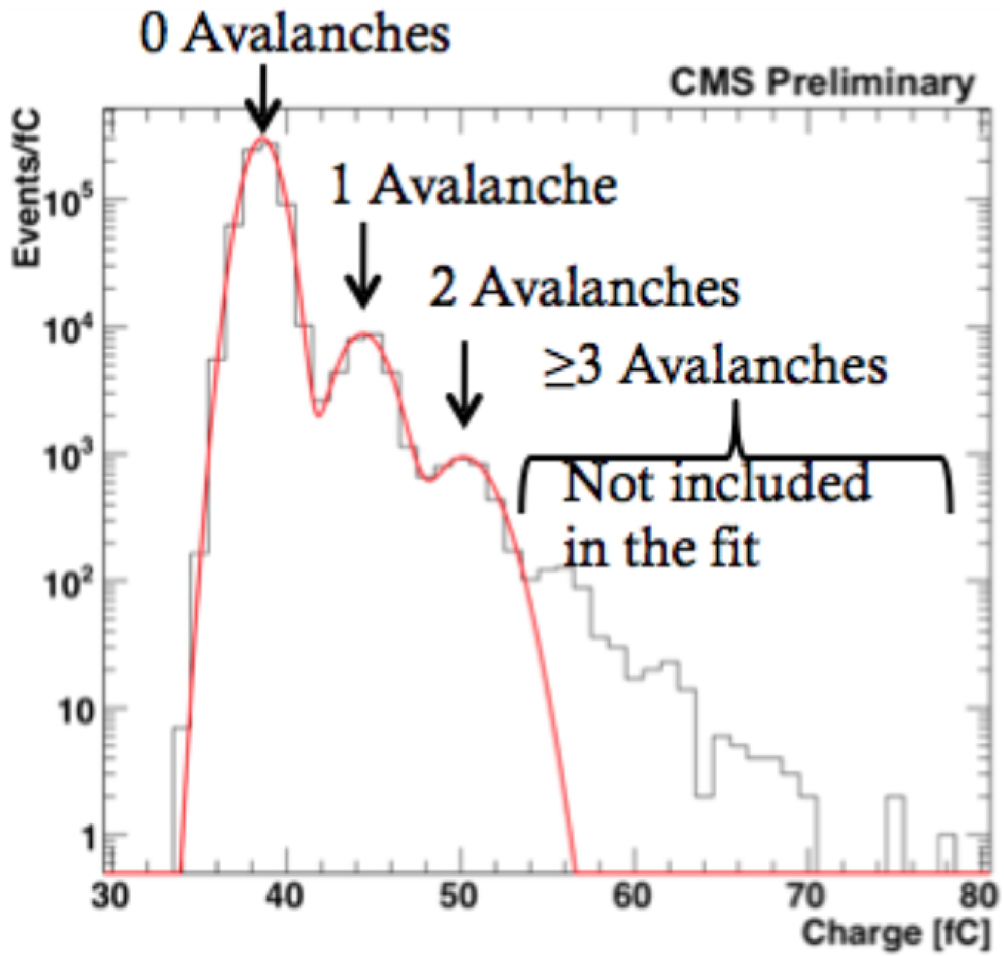
  → Corresponds to < 5 mV bias voltage change



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Gain determination method

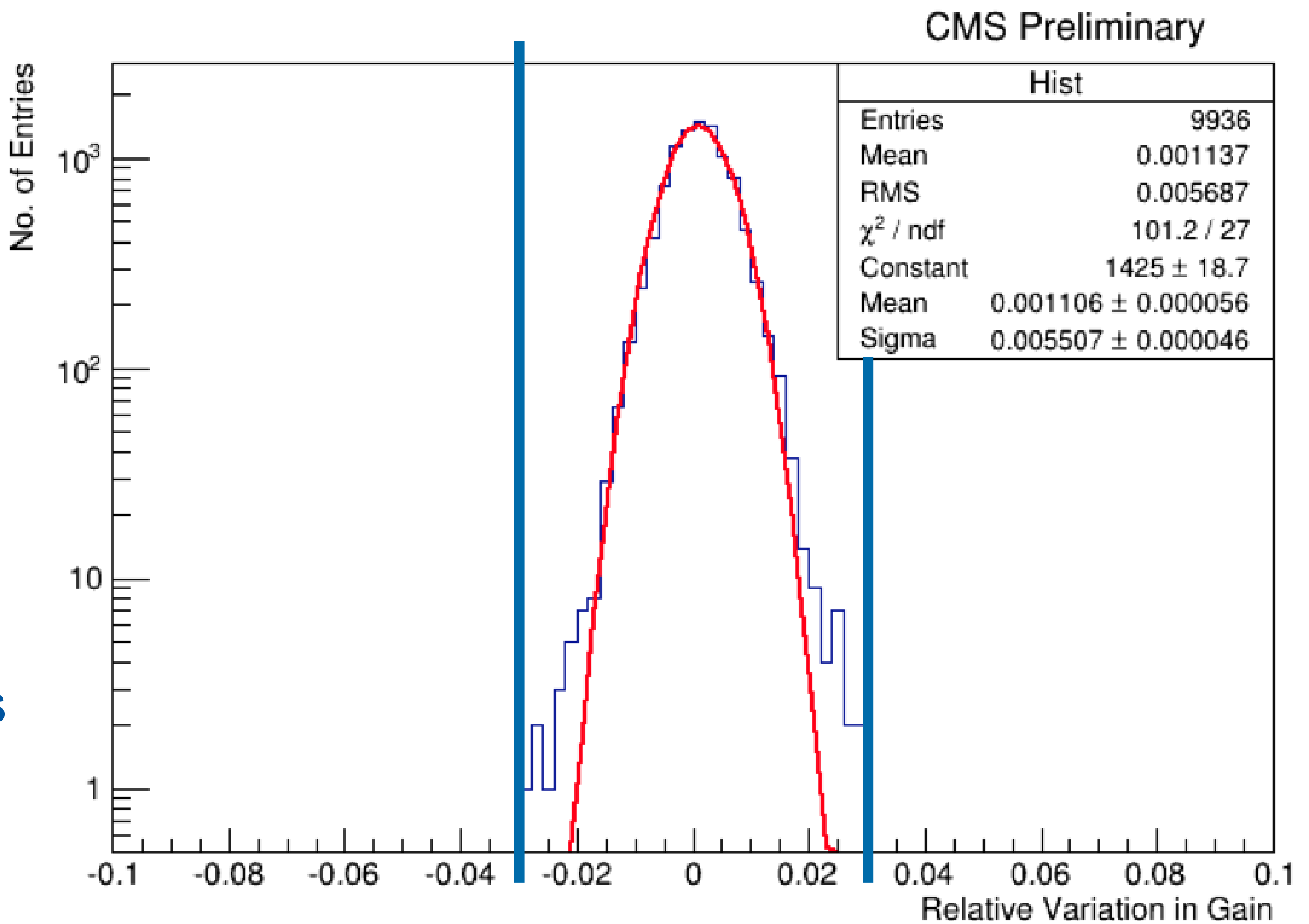
- Observe dark noise spectrum of SiPMs
- Fit photo-equivalent peaks
  - ➔ Typically 0-2 avalanches
- Determine charge difference between neighboring peaks



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

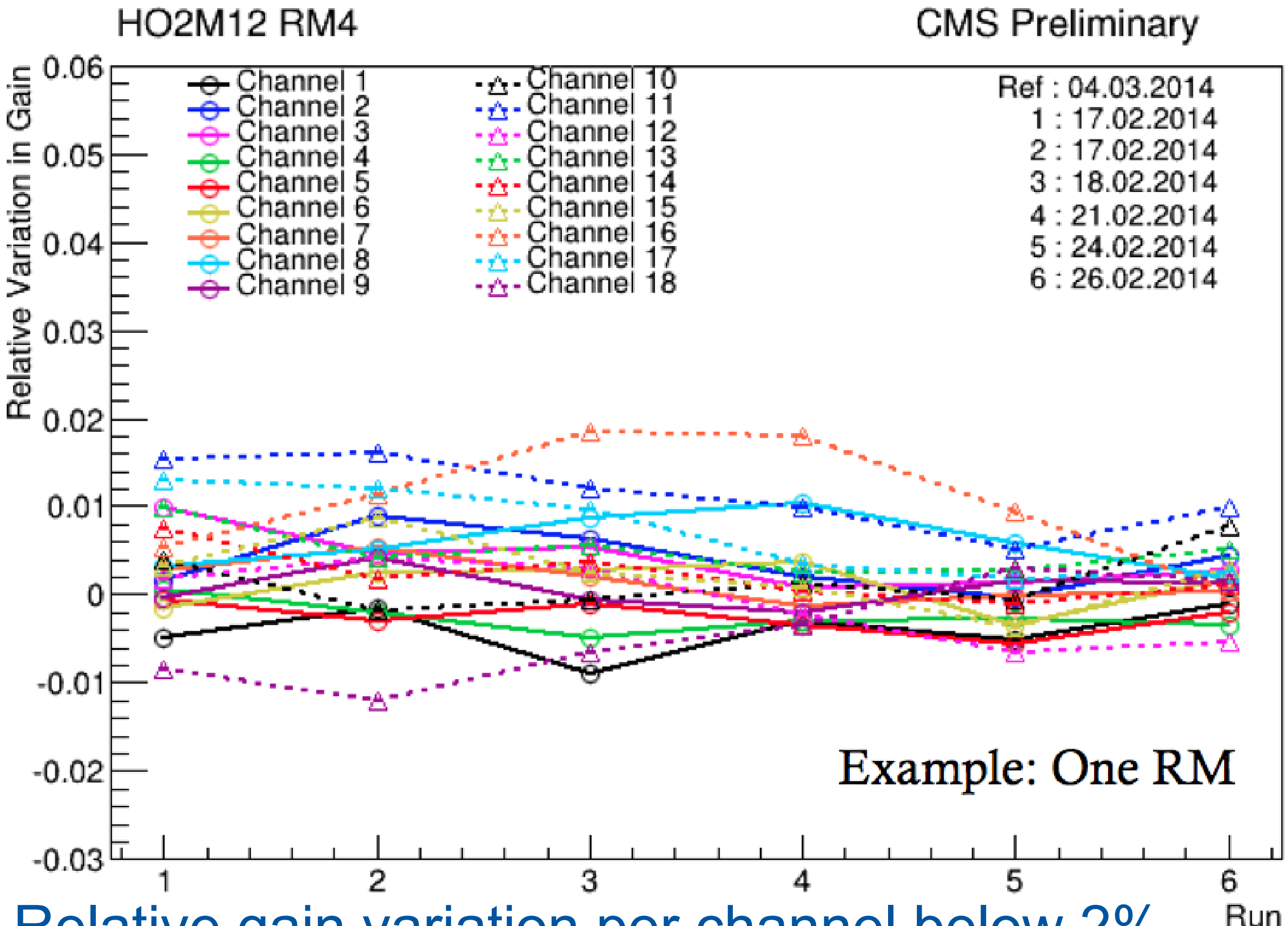
Gain determination

- Variation in gain is stable within 3 % with an uncertainty of the distribution of 0.6% for all channels



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Gain determination (time dependency)



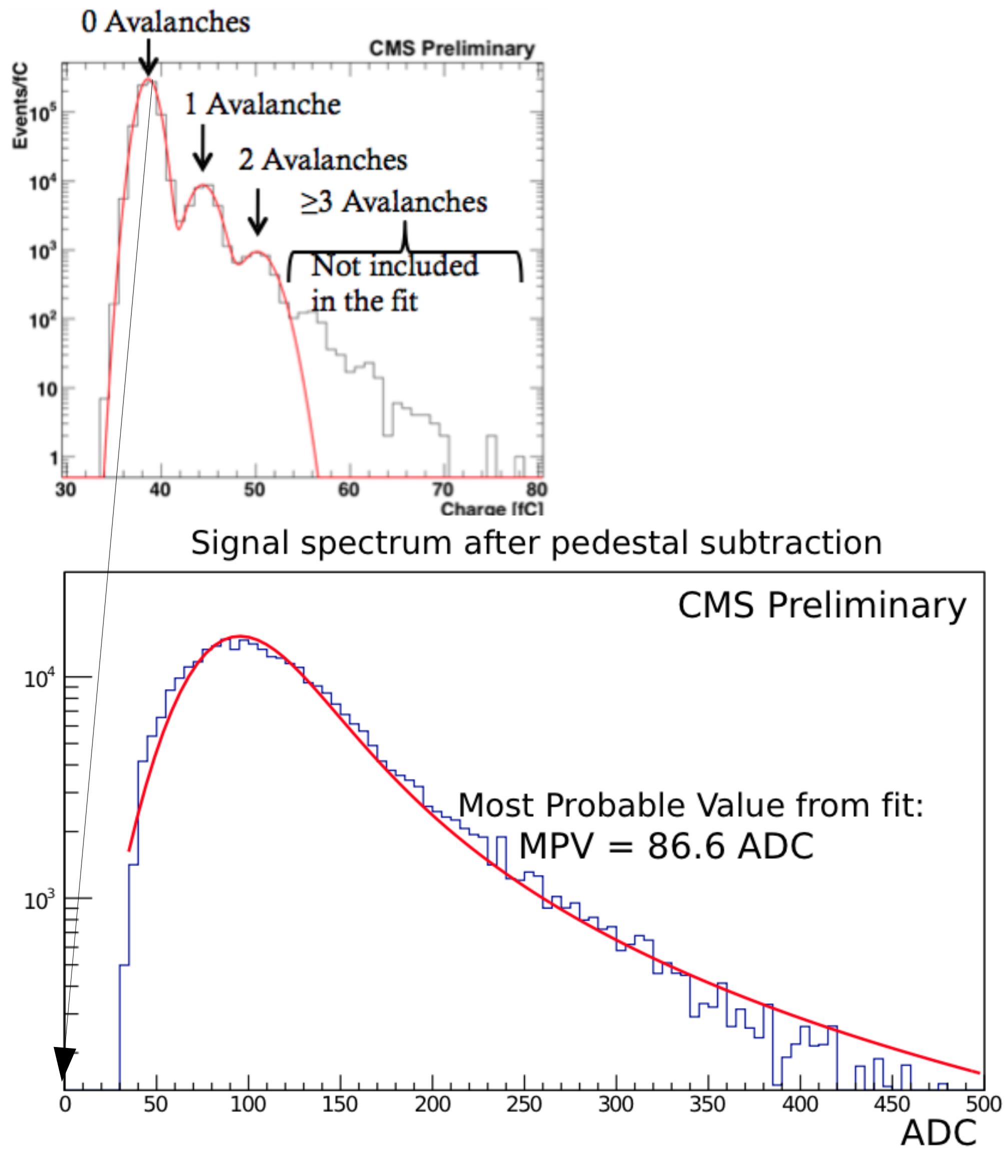
- Relative gain variation per channel below 2%

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Pedestal subtraction

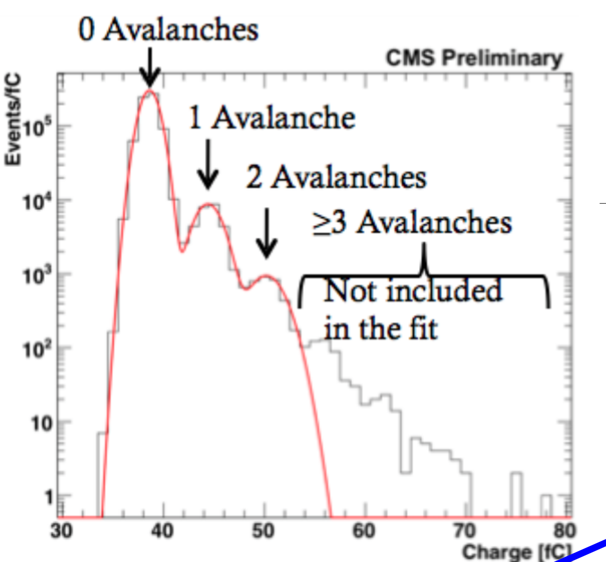
- Find pedestal (0 avalanches)
- Adjust to 9 ADC counts per QIE time slice (25 ns)
- Integrate over 4 time slices

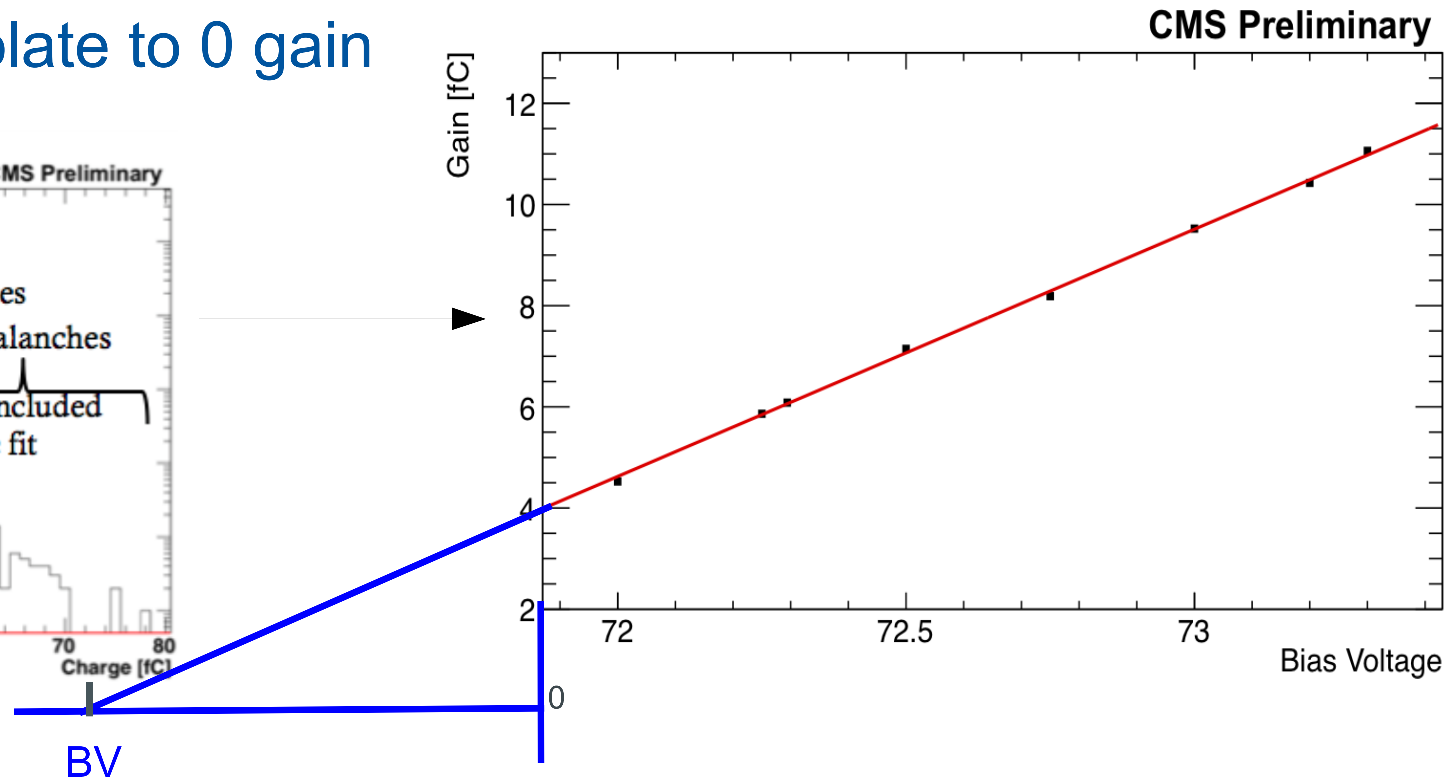
  → 36 ADC counts
- Signal well above pedestal



Break down voltage determination
Pedestal method

- Measure gain for different bias voltages
- Fit linear function
- Extrapolate to 0 gain



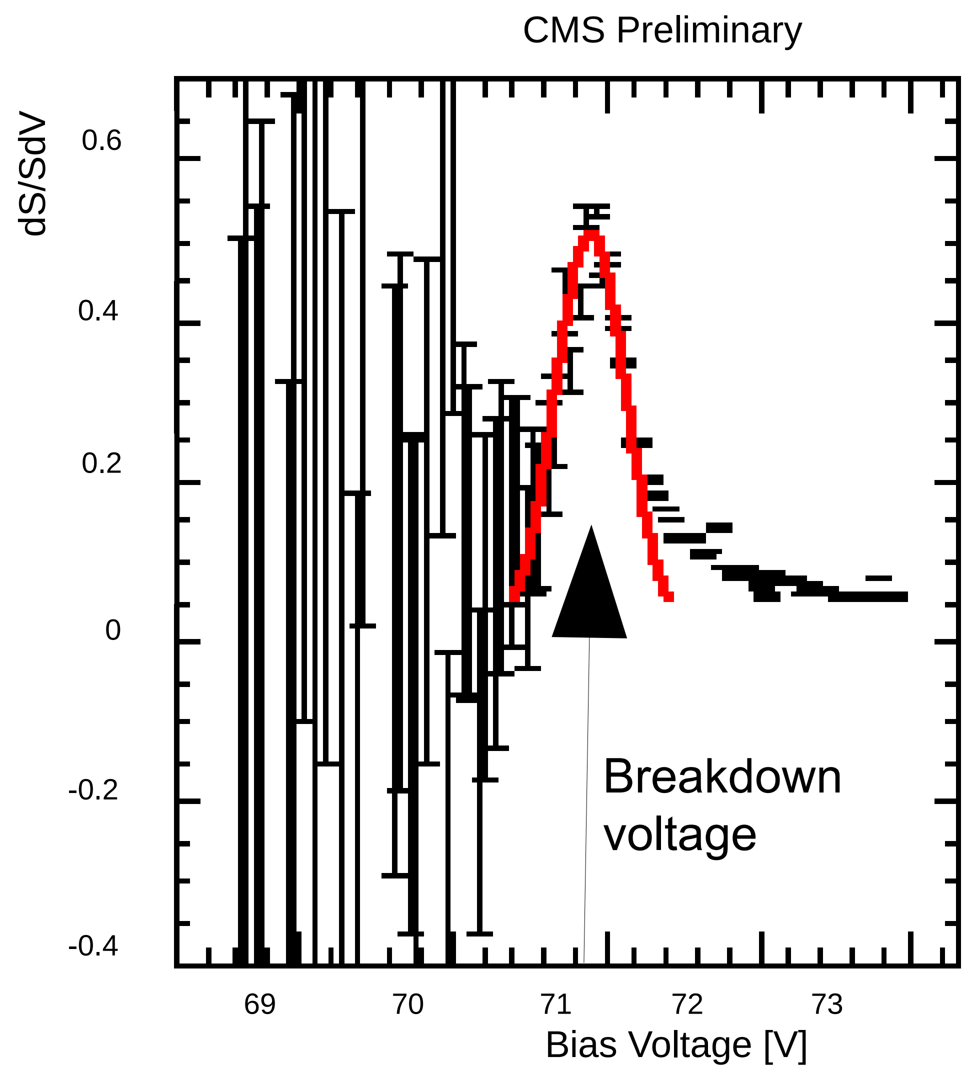


Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Break down voltage determination
LED method

- Pulse SiPMs with LED
- Measure signal height
- Vary bias voltage

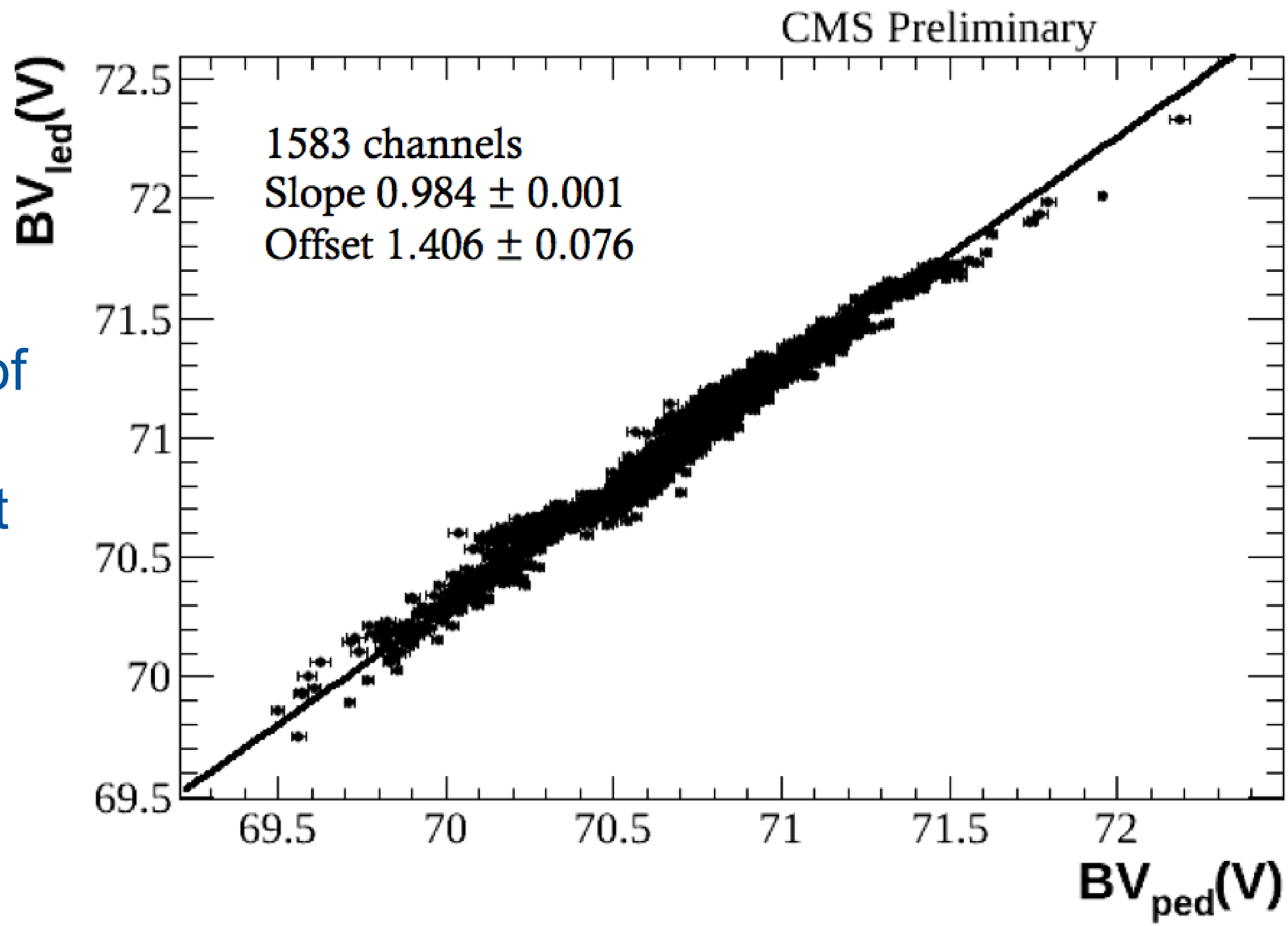
- Calculate differential signal strength



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Break down voltage determination
Method comparison

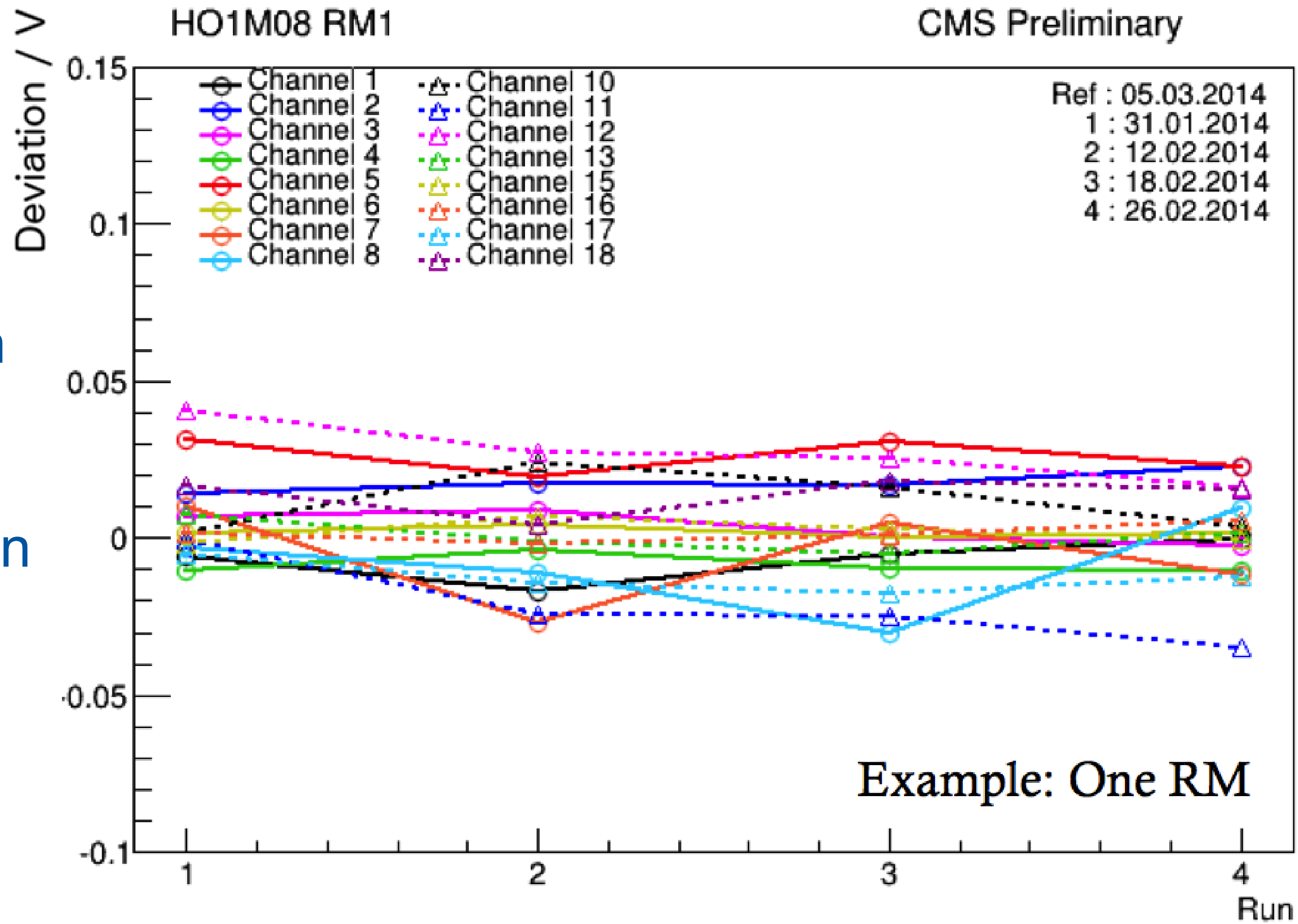
- Systematic difference between methods
- Local offset of 0.3 V at working point
- Slope very close to 1
- Use LED method



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Break down voltage determination
Time stability

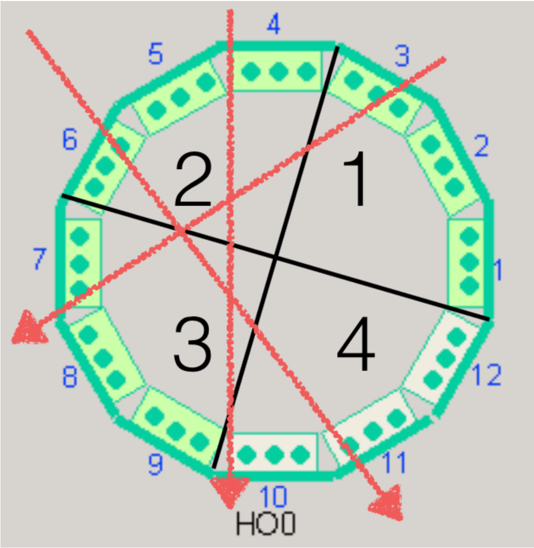
- SiPM breakdown voltage fluctuates by less than 0.05 V



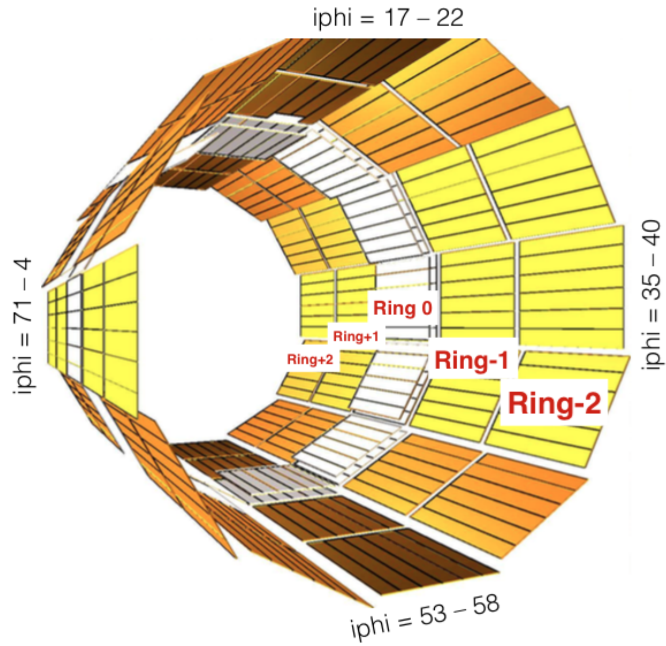
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Local Trigger Setup

- Each ring divided into 4 quadrants
- Trigger threshold 40 ADC counts / 1 Time Slice (TS)
- Coincidence between any top sector (1,2) with and bottom sector (3,4)
- 1 TS delay between top and bottom

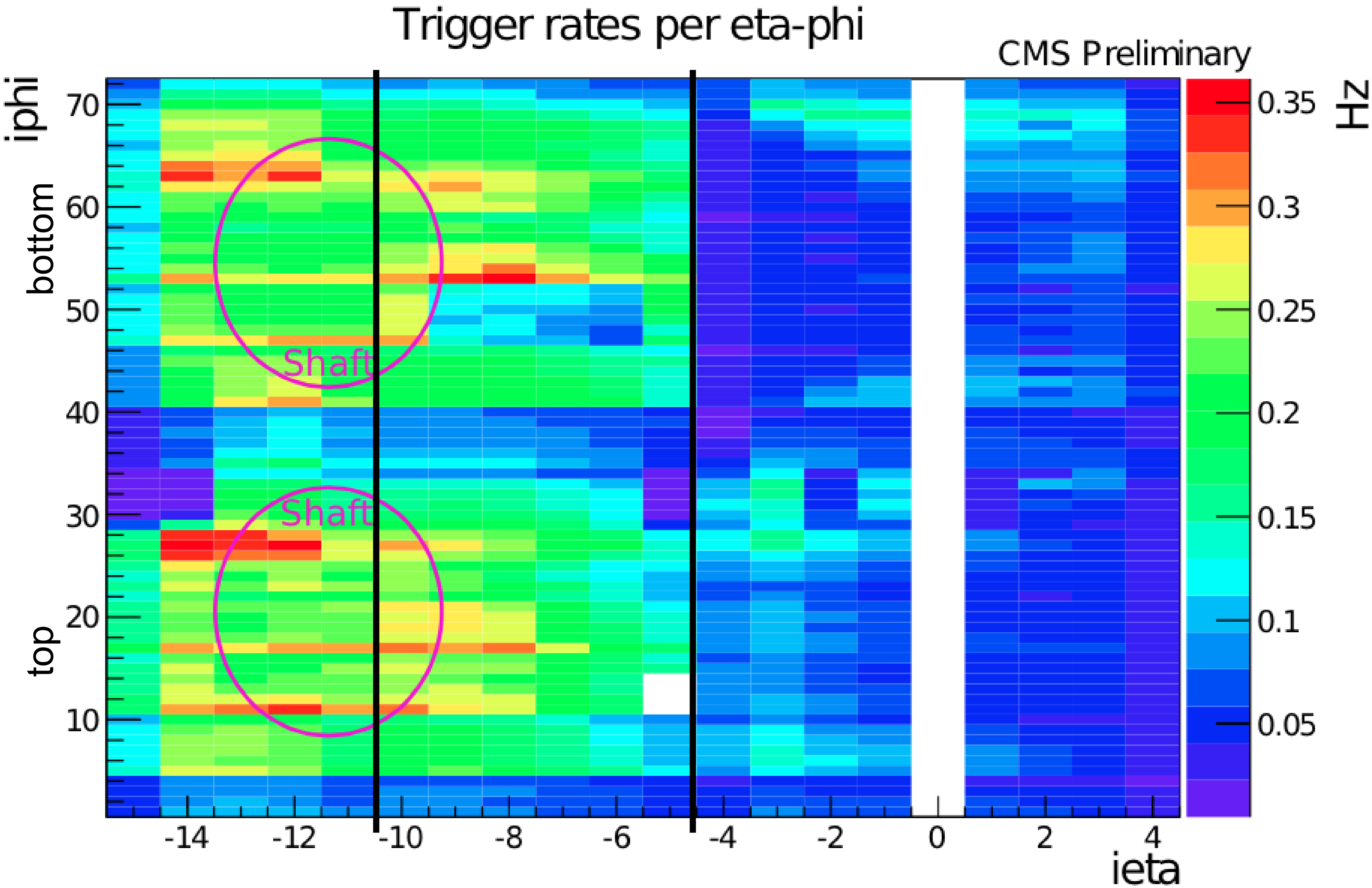


Rings 0,-1,-2 were used



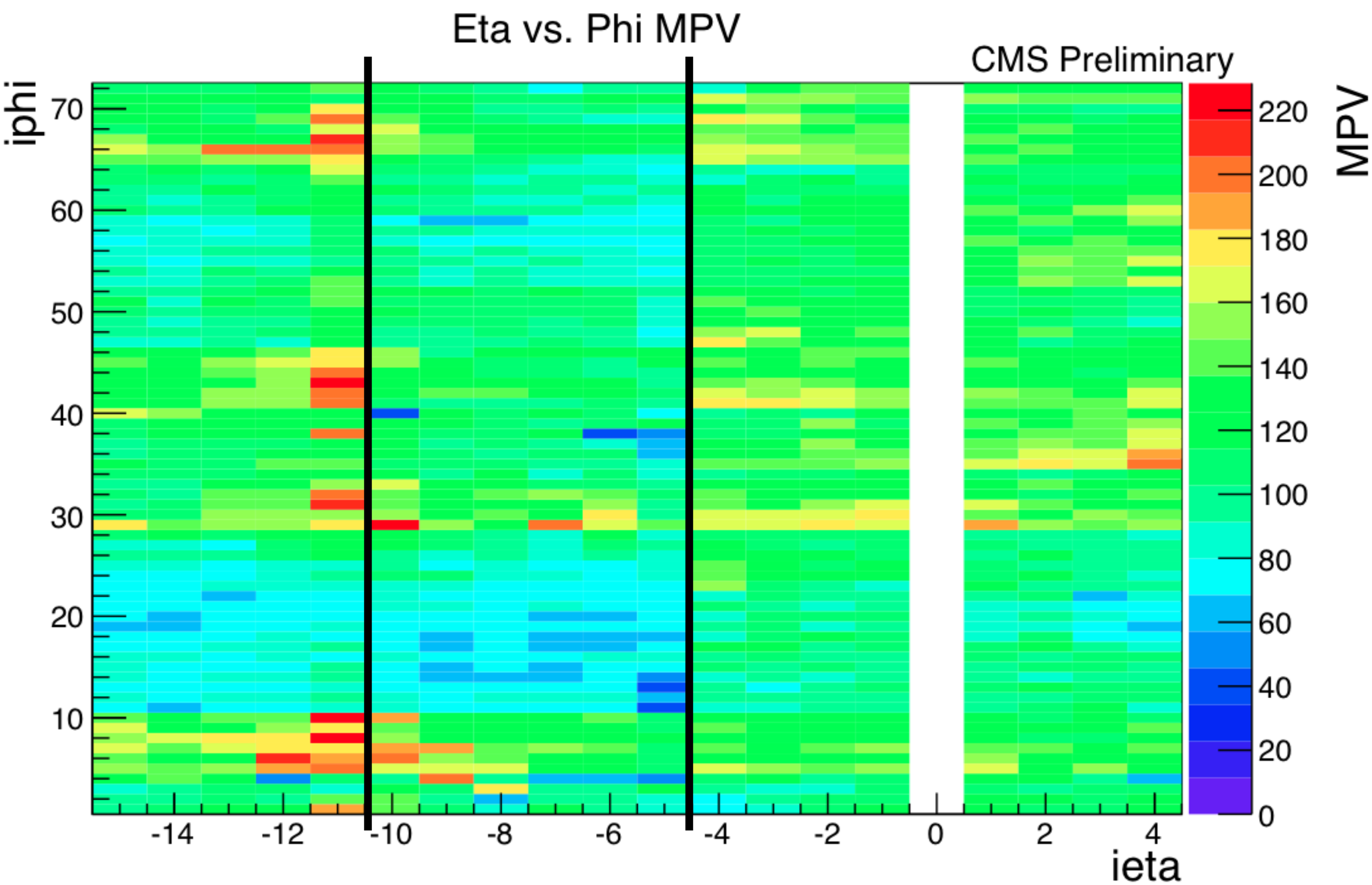
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Trigger rates local run



Most probable (MPV) ADC value

- Φ variation due to angle of muons
- η variation (wheel 1+2) mainly due to length of optical fibers
- Double layer in ring 0



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Muon angle correction

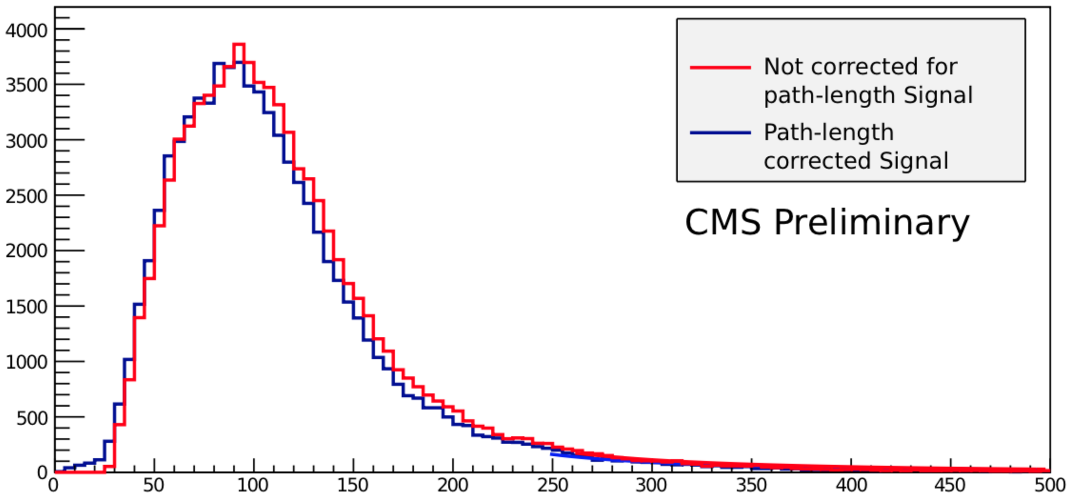
- Muon signals are altered because of different track path lengths in tile
- MIP distribution is shifted
- Signal has to be corrected by cosine of incident angle

- In each event the muon track is build for the two tiles with highest signal
- Cosine is calculated and signal values of the two tiles are corrected for

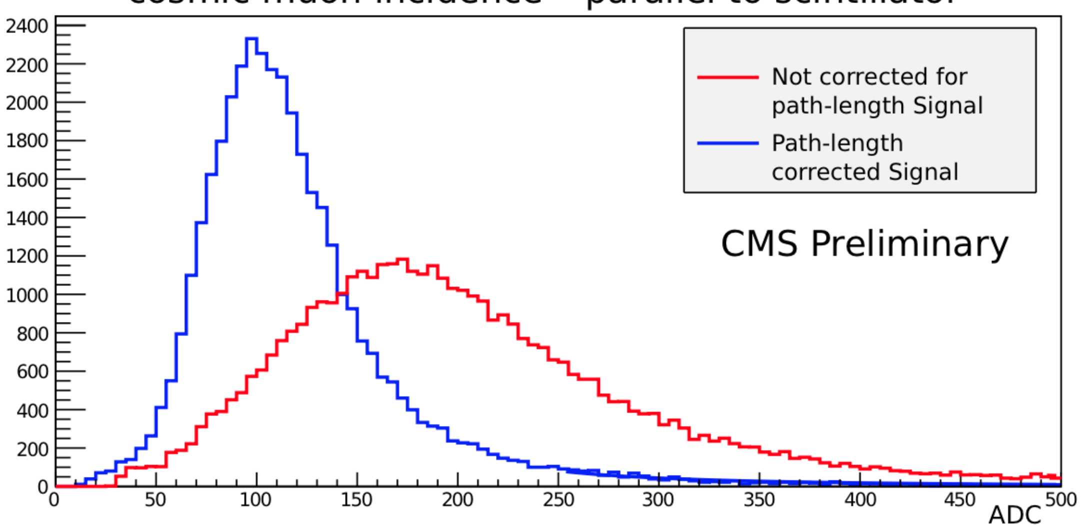
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Muon angle correction

cosmic muon incidence ~normal to scintillator



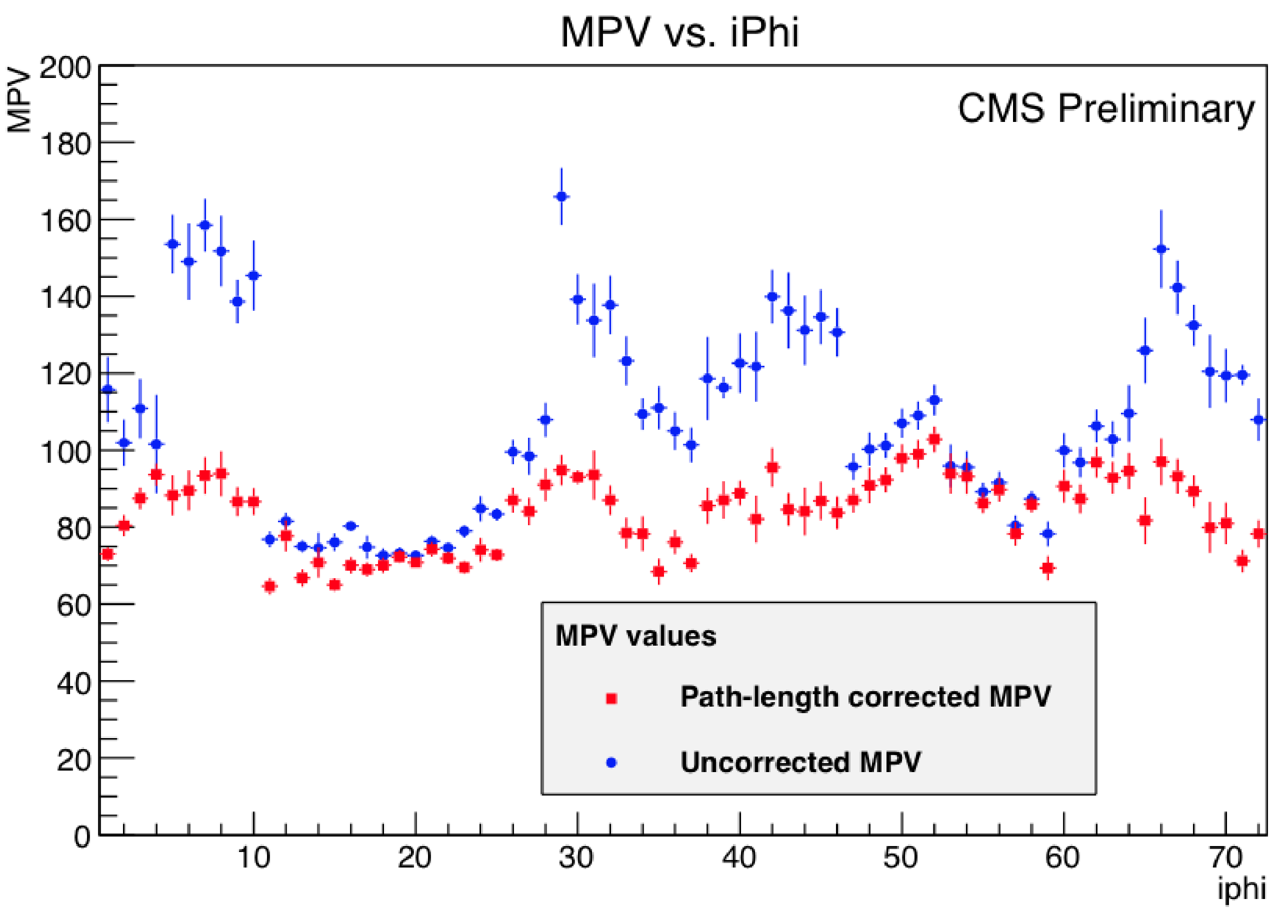
cosmic muon incidence ~parallel to scintillator



- No effect for scintillators normal to muon incidence angle
- Corrected distribution for parallel scintillators fits expectation

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Muon angle correction

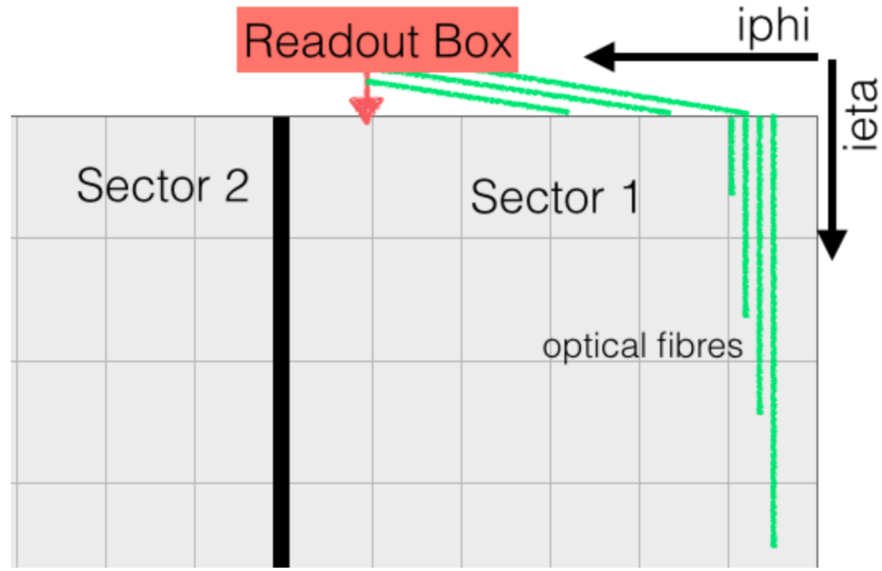


- MPV values are more uniform after path-length correction
- Remaining non-uniformity is due to different length of fibers, which connect the SiPMs to scintillating tiles (~20 cm – 250 cm)

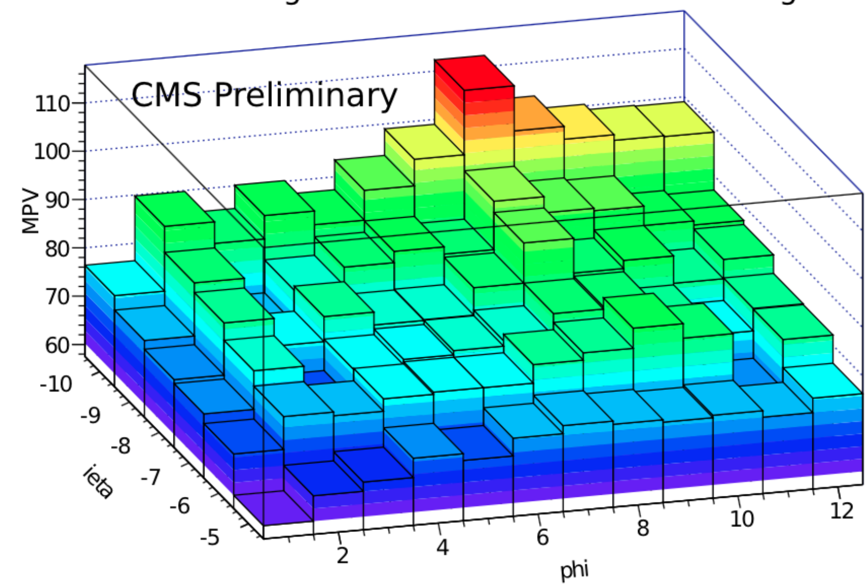
Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Most probable value for one Readout Box

- All sectors within the same wheel are the same from the cabling point of view
- Readout Module's position is clearly visible
  - ➔ ieta increase is due to fibre length in the scintillator
  - ➔ iphi decrease is due to fibre length to the readout module



MPV averaged over all readout boxes in Ring-1



Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Summary

- HO is fully equipped with SiPMs
- Commissioning of all channels has been performed
- Reliable methods for determination of breakdown voltage and gain
- Stable operation
- Thorough study of muon detection efficiency (see also PhD thesis by Yusuf Erdogan “Conceptual investigations of a trigger extension for muons from muons from pp collisions in the CMS experiment”)
- Commissioning after LHC startup

HO is ready for RUN 2!

Florian Scheuch
III. Physikalisches Institut A, RWTH Aachen University | 04.03.2015

Thank you for your attention!

Florian Scheuch

III. Physikalisches Institut A
RWTH Aachen University
Templergraben 55
52056 Aachen

www.physik.rwth-aachen.de/institute/institut-iiia/