SiPMs for the Scintillating Fibre Tracker at LHCb

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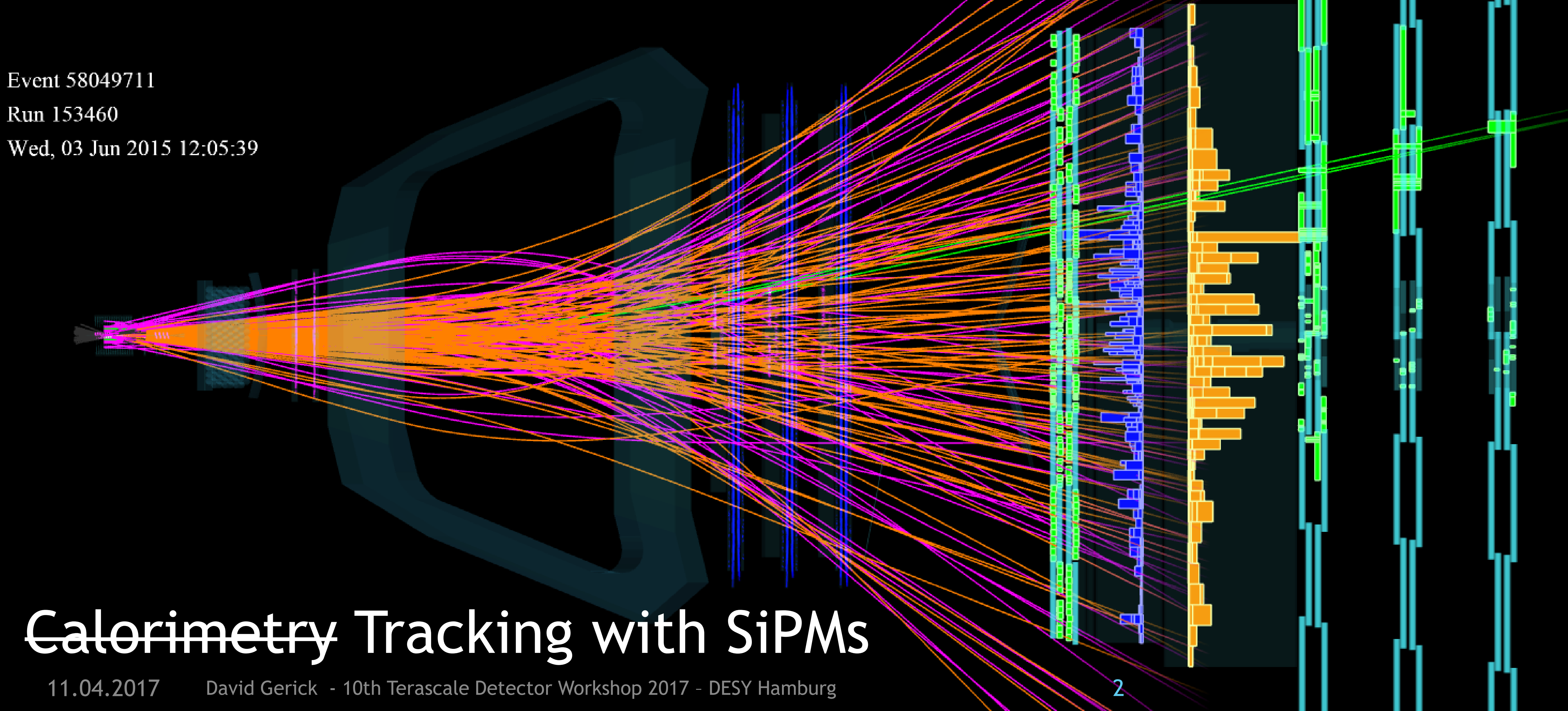
on behalf of the SciFi collaboration

10th Terascale Detector Workshop 2017

DESY, Hamburg

11th of April 2017



~~Calorimetry~~ Tracking with SiPMs

LHCb

Event 58049711
Run 153460
Wed, 03 Jun 2015 12:0

dpg-verhandlungen.de

Verhandlungen

Hamburg 2016 – wissenschaftliches Programm

Bereiche | Tage | Auswahl | Suche | Aktualisierungen | Downloads | Hilfe

T: Fachverband Teilchenphysik

T 94: Kalorimeter III (SiPM)

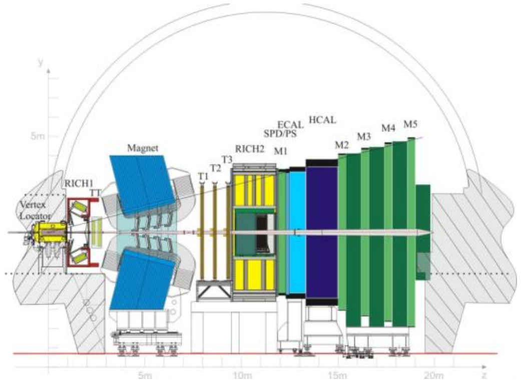
Donnerstag, 3. März 2016, 16:45–18:45, VMP6 HS E

Auswahlstatus für diese Sitzung: nicht ausgewählt

16:45	T 94.1	Optimization of a readout board for mass assembly and light yield measurements with a cosmic ray test stand — •Phi Chau for the C
17:00	T 94.2	Studies on surface-mounted SiPMs in 2015 testbeam of a highly granular hadron calorimeter — •Sascha Krause for the CALICE-D co
17:15	T 94.3	Studies on scintillator tiles and surface-mounted SiPMs for the mass assembly of a highly granular hadron calorimeter — •Yong Liu f
17:30	T 94.4	Scintillator tiles with SiPM readout for calorimetry and fast timing in SuperKEKB commissioning — •Hendrik Windel for the CALICE-I
17:45	T 94.5	Dark noise rates in irradiated silicon photomultiplier arrays — Sebastian Bachmann, Albert Comerma, •David Gerick, Xiaoxue Han, Mitzel, Max Neuner, and Ulrich Uwer for the LHCb collaboration
18:00	T 94.6	Study of the radiation damage of silicon photomultipliers — •Michael Nitschke, Valery Chmill, Erika Garutti, Robert Klanner, and
18:15	T 94.7	Teststand zur elektrischen und optischen Charakterisierung von SiPMs — Thomas Hebbeker, •Carsten Heidemann und Markus Mersc

~~Calorimetry~~ Tracking with SiPMs

today‘s outline



LHCb

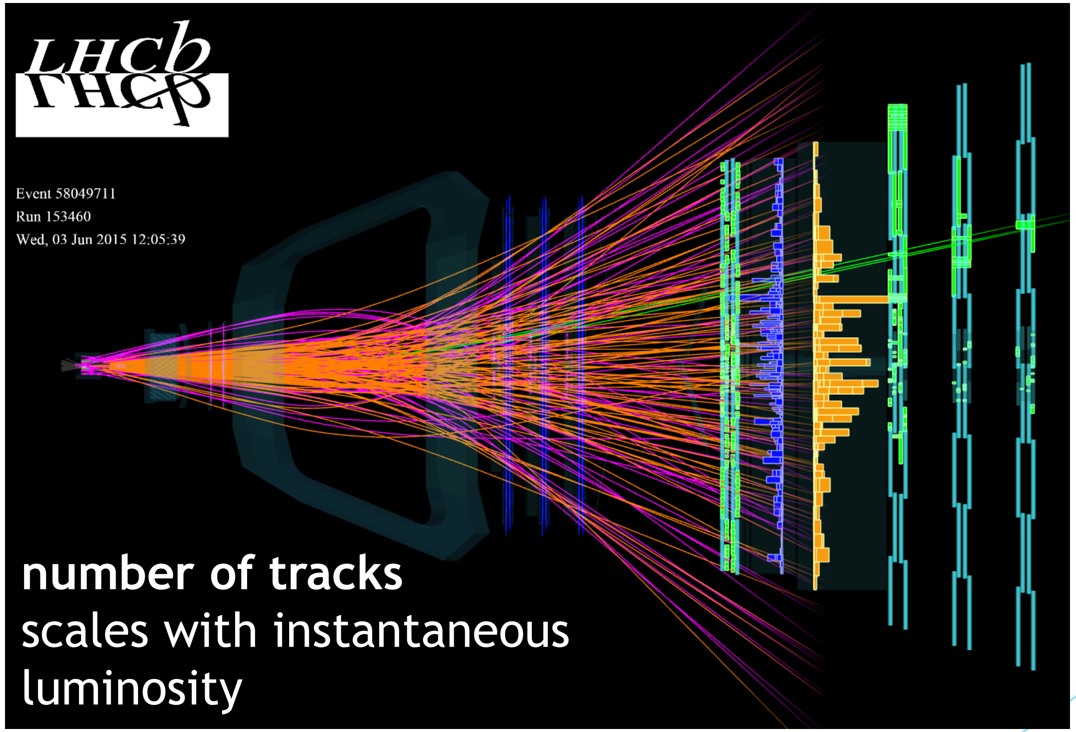
- The LHCb Scintillating Fibre Tracker upgrade

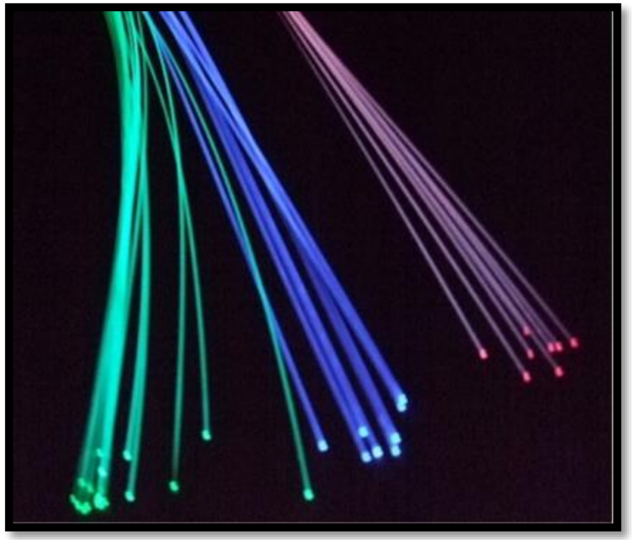
SiPMs

- Introducing 128 channel SiPM arrays
- How do we operate and readout our SiPMs?
- What are the challenges in using SiPMs for SciFi?

LHCb upgrade

- LHCb will undergo various sub-detector upgrades during the LS2 in 2019/20
- **Motivation:**
  - increase instantaneous luminosity by at least a factor 5
- detector read-out at 40 MHz (compared to now: 1 MHz)

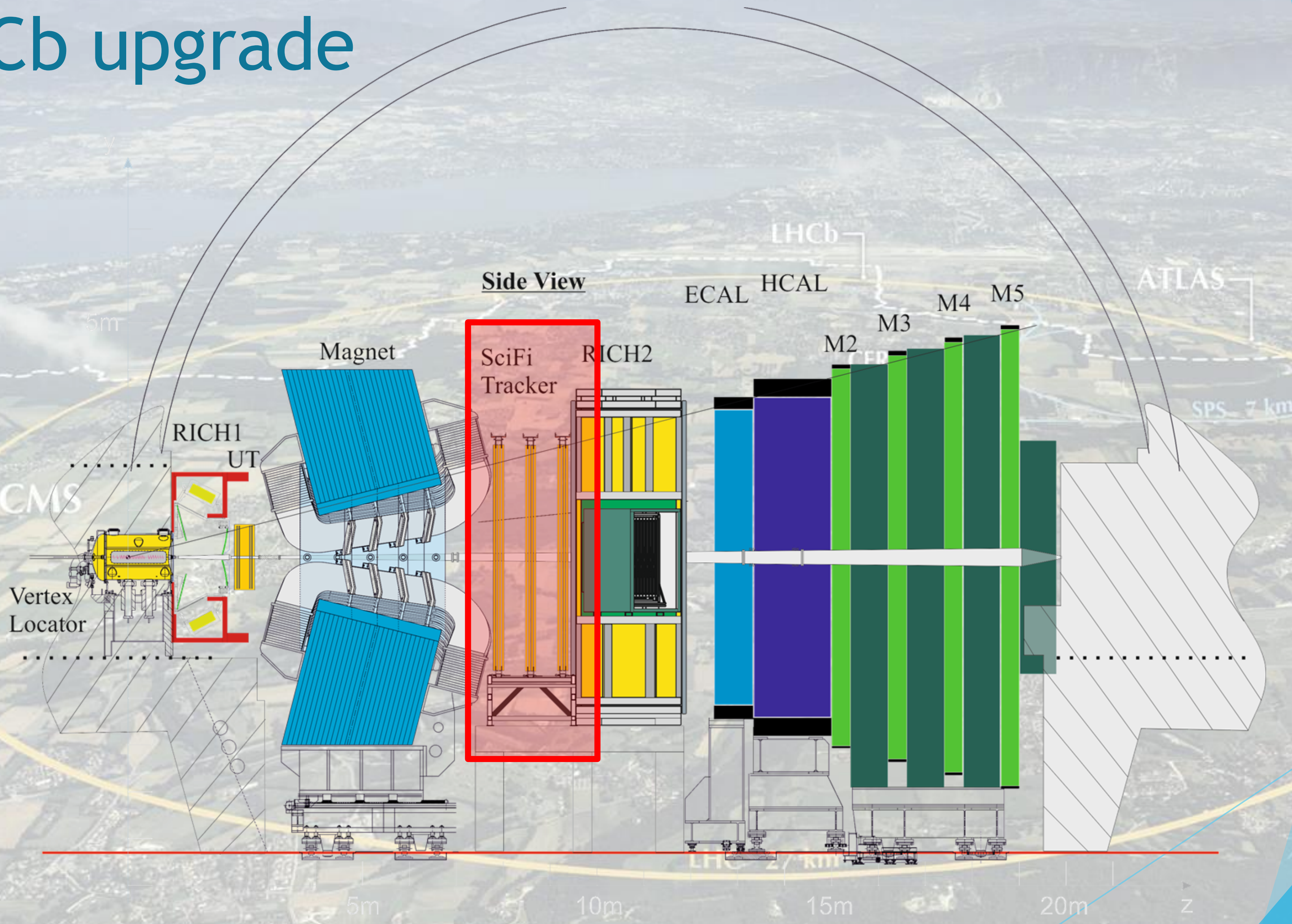




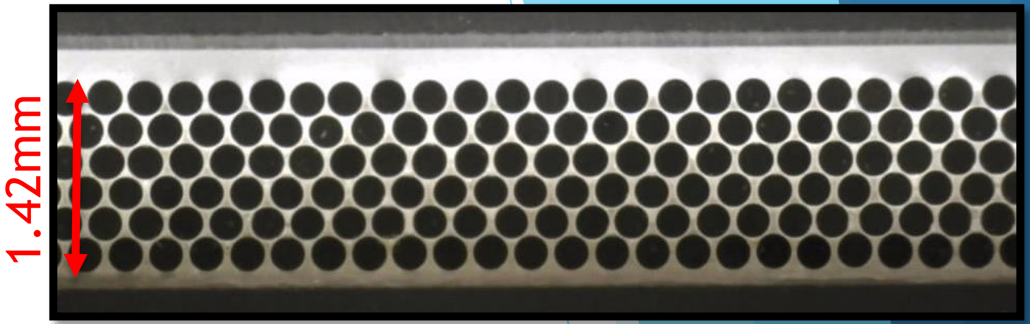
The Scintillating Fibre Tracker

upgrade of the main tracking system during
shutdown of the LHC in 2019/20

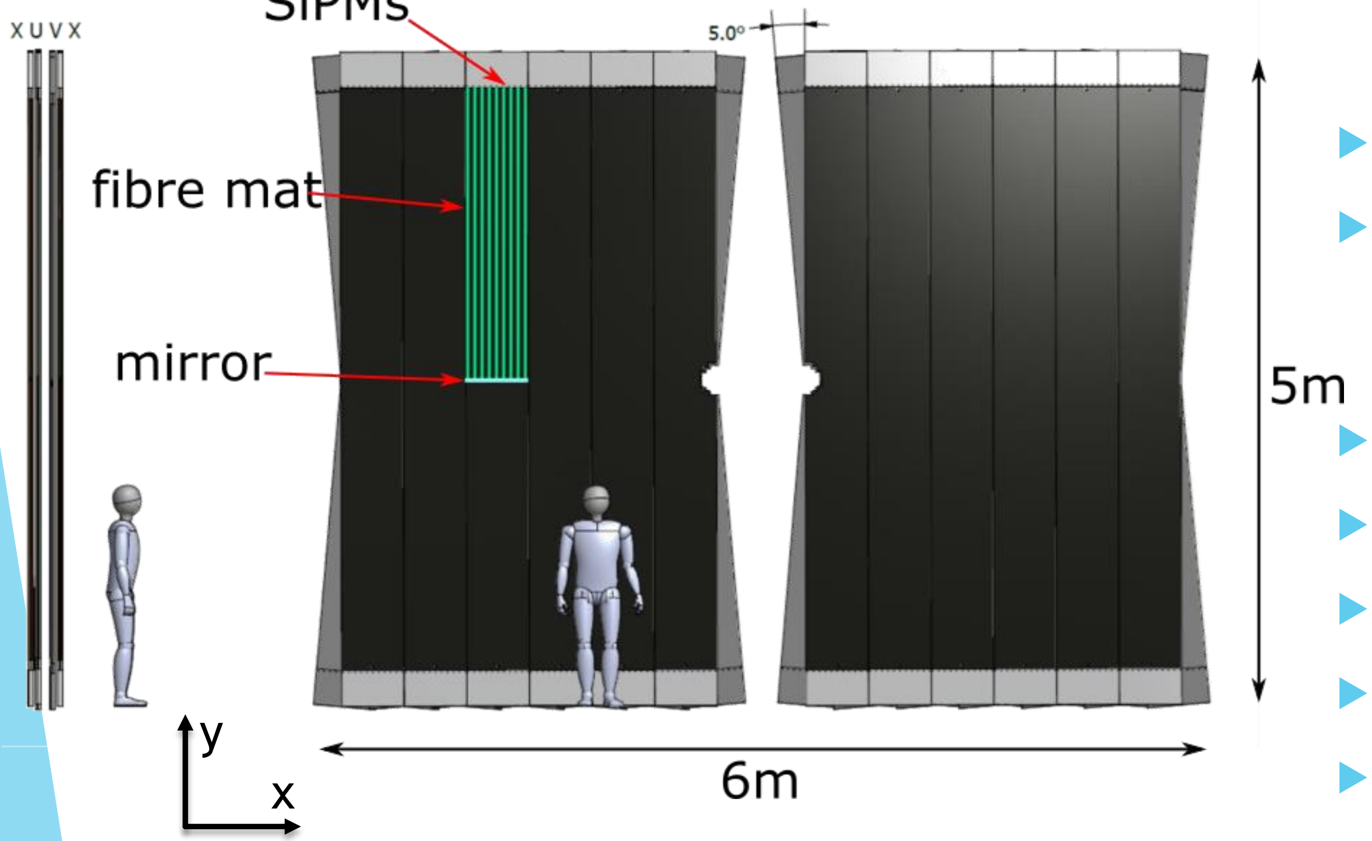
LHCb upgrade



The Scintillating Fibre Tracker



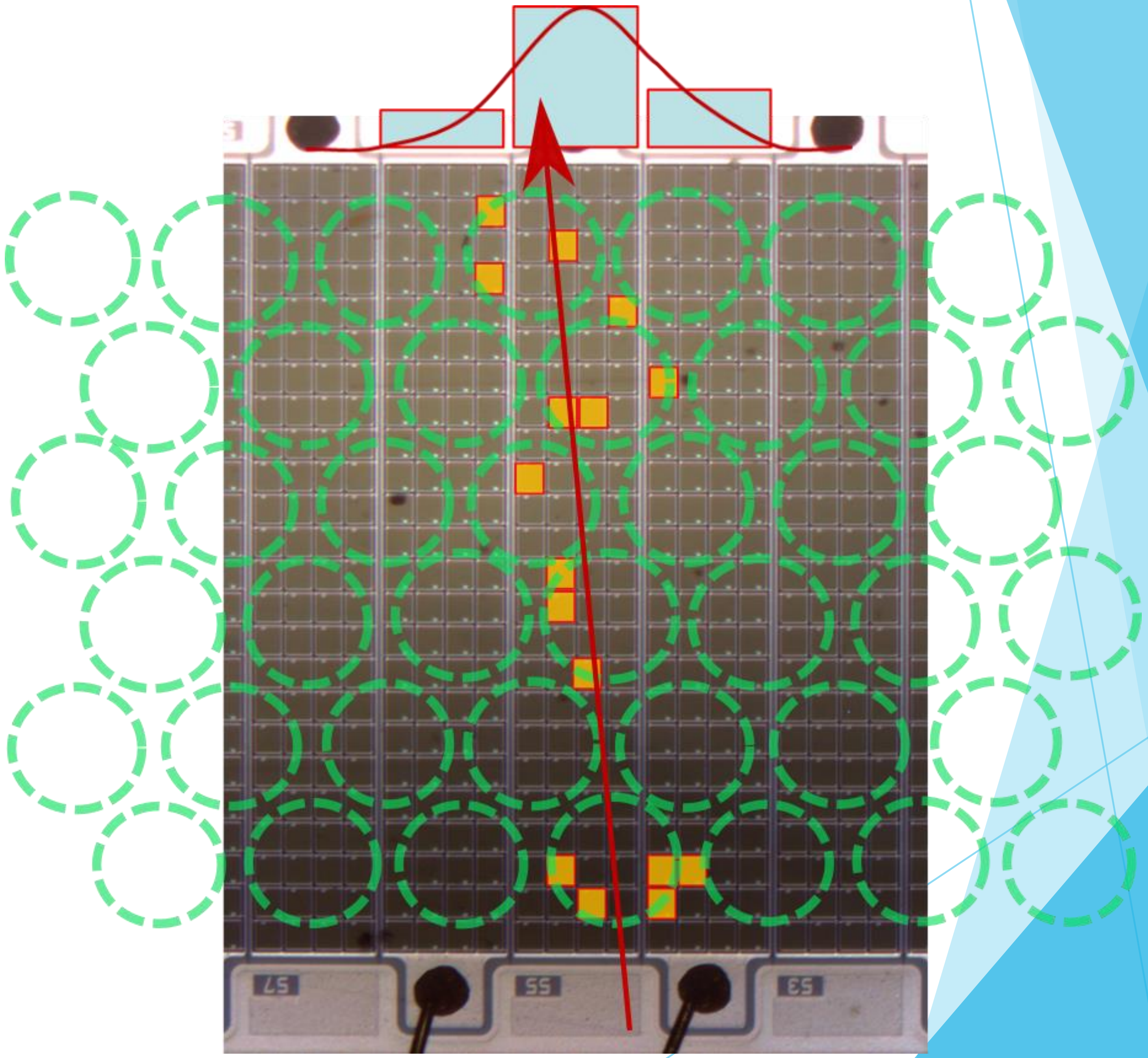
fibre mat cross-section with 6 layers



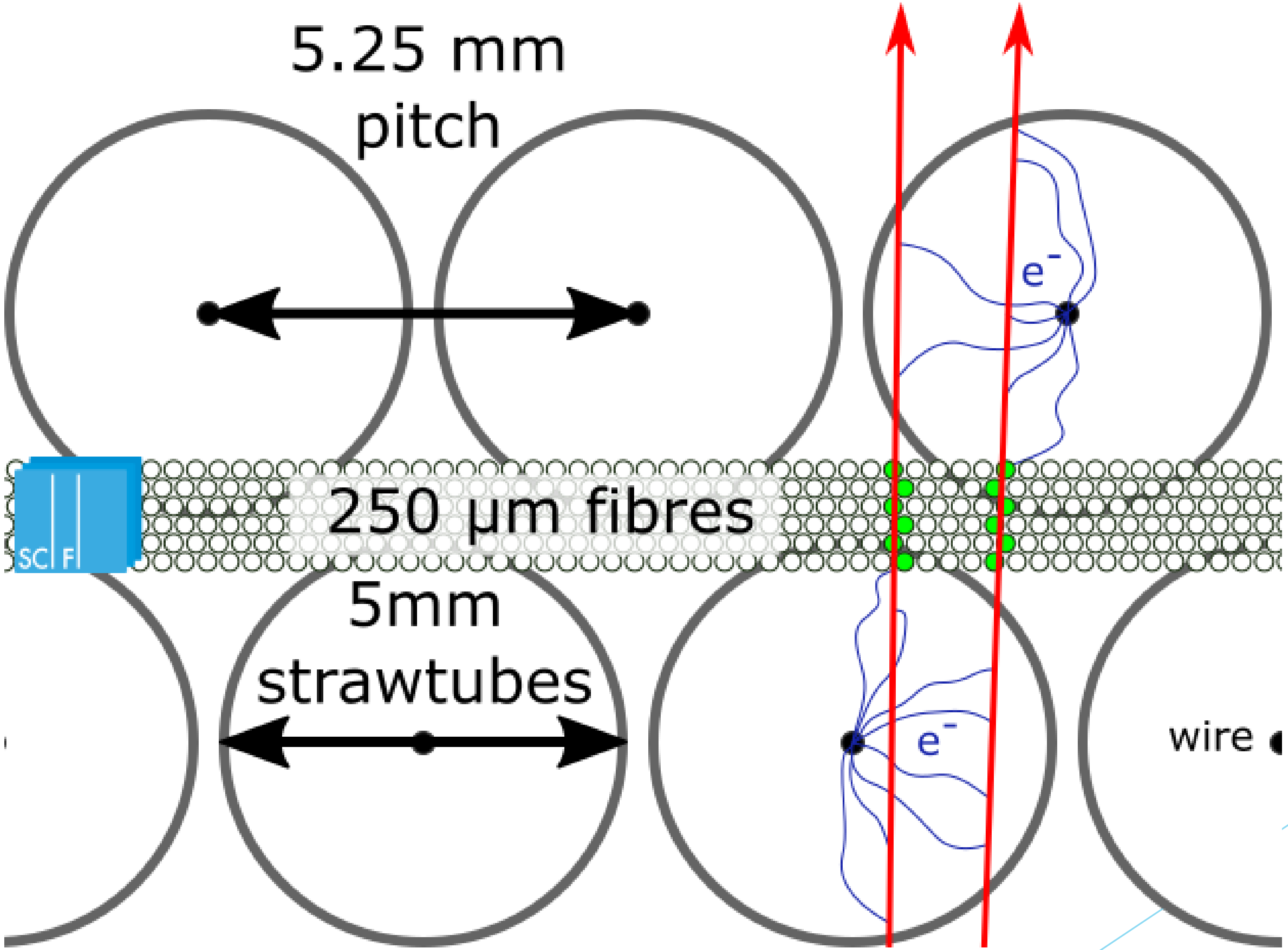
- 3 stations with 4 detection layers
- total area of about 330m^2
  - **largest scintillating fibre tracker ever built**
- fibres are glued into mats
- single hit resolution < 100µm in x
- radiation length < 1%/layer
- more than 500.000 SiPM channels
- 40 MHz read-out

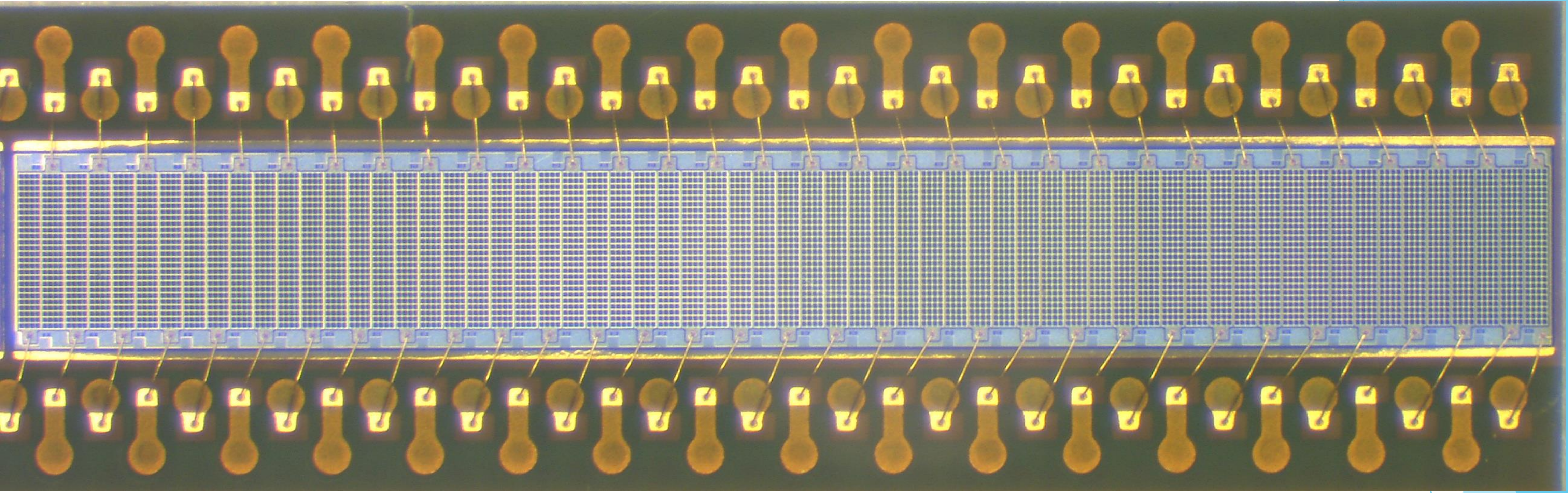
The ensemble of fibres and SiPMs

- fibres and SiPM channels are not individually aligned with respect to each other
  - the light of a single fibre is shared among neighboring channels
- **clustering of channels** determines hit position
- around 30 photons reach the SiPMs per ionizing particle



New versus Old tracking stations





Silicon Photomultipliers

128 channel arrays

Axel Kuonen, EPFL Lausanne

Specifications of the Scintillating Fibre Tracker on the SiPMs

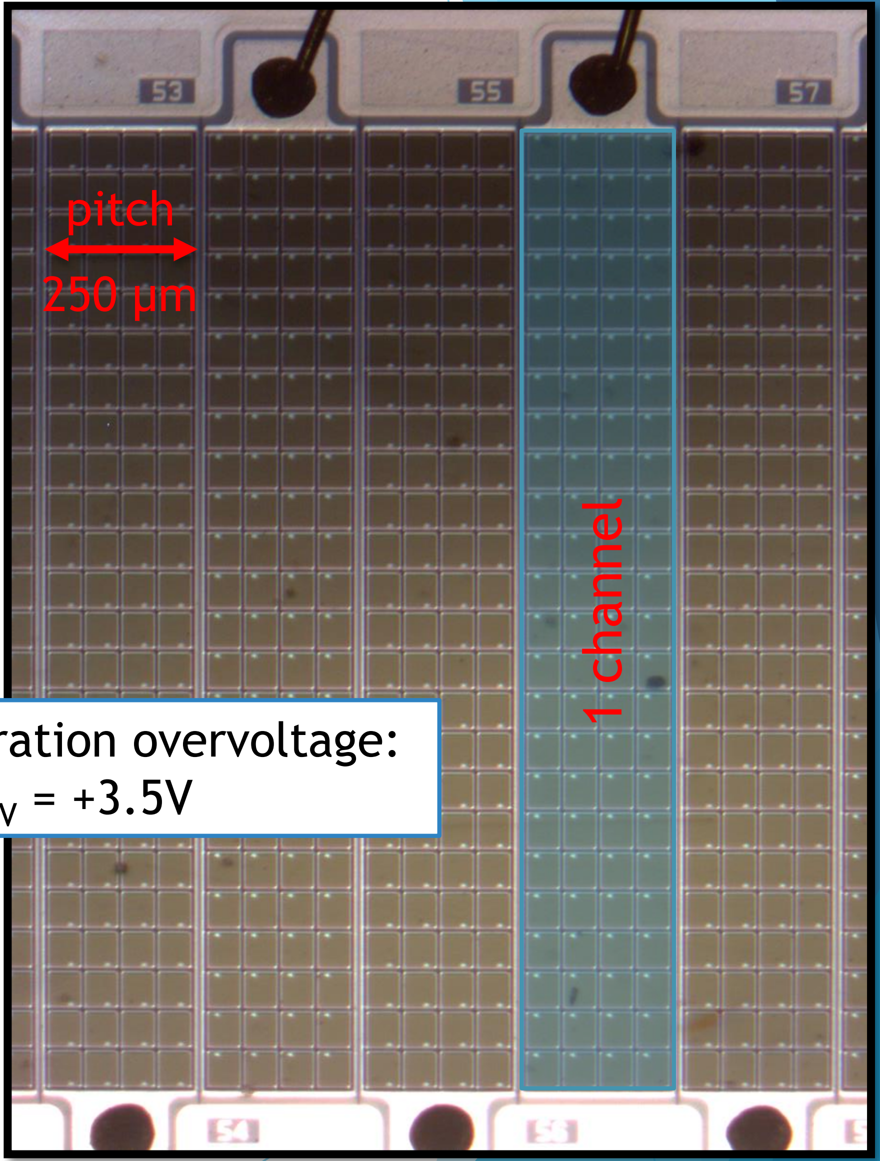
- high granularity and fast signal shapes
  - < 100µm resolution and 40MHz bunch crossing rate
- high photon detection efficiency (PDE) in the optical range
  - only about 30 photons arrive at SiPM
  - emission spectrum of the scintillating fibres is blue to green
- minimize correlated noise
  - afterpulsing, direct- and delayed cross-talk
- low dark noise rate
  - steady increase of DCR with neutron irradiation
  - readout bandwidth limits the exceptable rate of clusters from noise hits

128 channel array SiPMs

- SiPM channel size
  - 4 × 26 pixels à 57.5 × 62.5 µm²
- 128 channels per array → 32.59 × 1.5 mm²

- custom designed SiPM arrays for the SciFi Tracker
  - geometry
  - PDE
  - trench technology
  - …

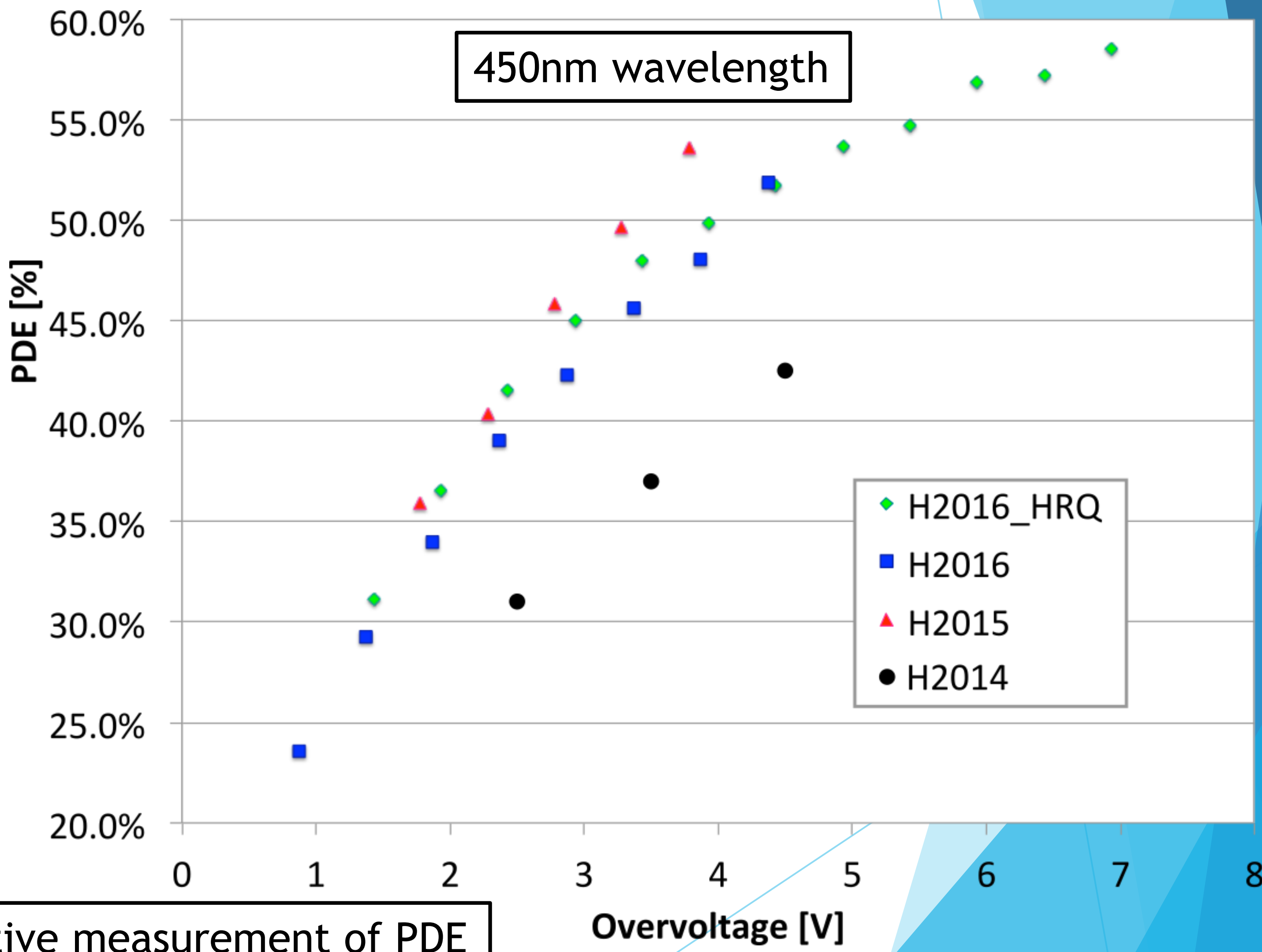
- selected Hamamatsu generations are discussed in the following: H2014, H2015, H2016 & H2016_HRQ



nominal operation overvoltage:
V_{OV} = +3.5V

Photon detection efficiency (PDE) *

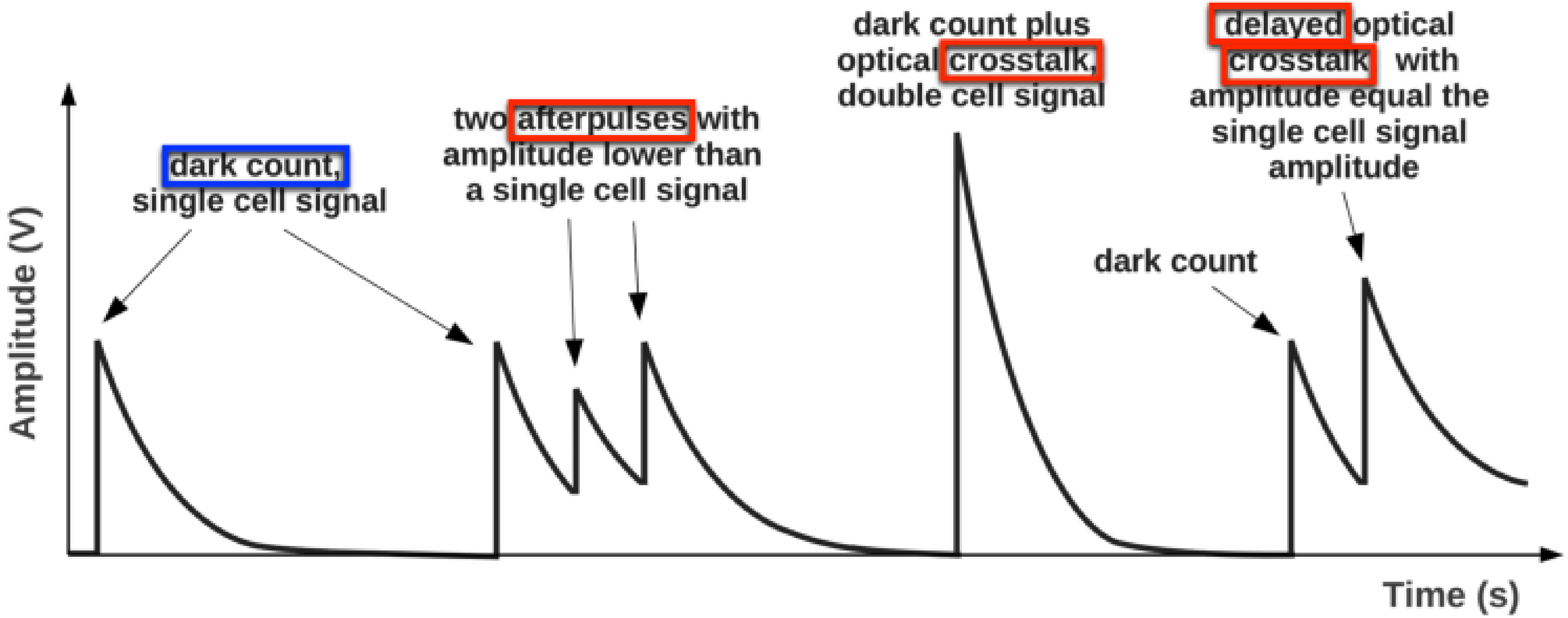
- 2014 → 2015: increase in geometry fill factor
- latest version of H2016_HRQ is can be operated up to beyond V_{OV} = +7V
- slidely higher PDE at 490 nm for all tested devices



*: relative measurement of PDE

Axel Kuonen, EPFL Lausanne

Correlated noise

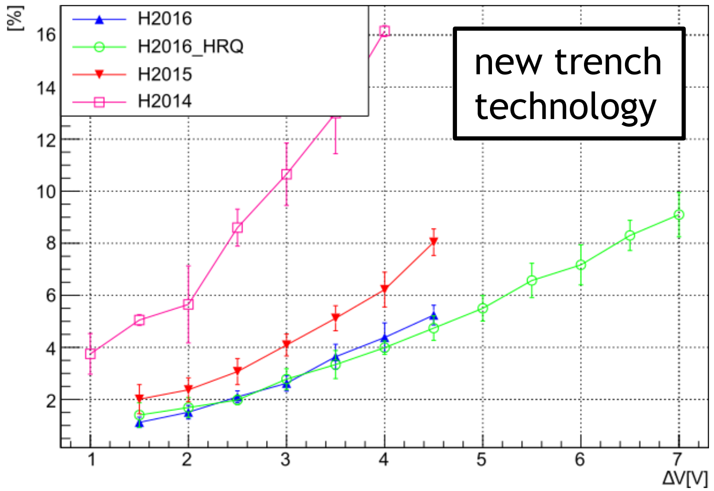


- correlated noise enhances single pixel dark counts
- these signals then exceed higher thresholds

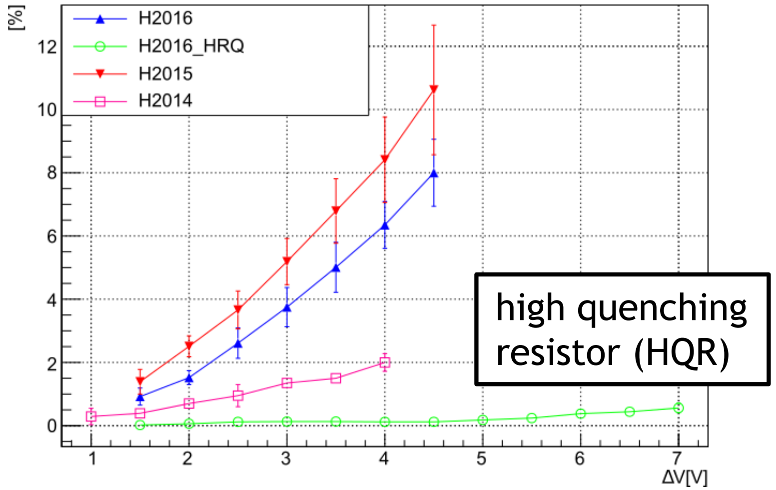
Maria Elena Stramaglia, EPFL Lausanne

Correlated noise evolution

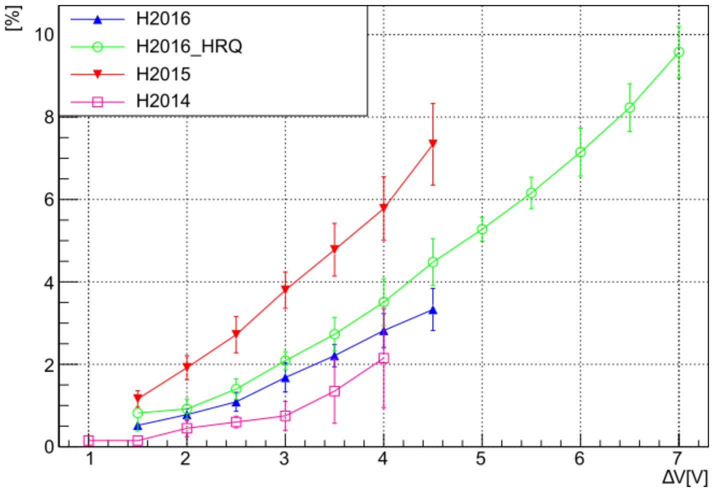
cross-talk



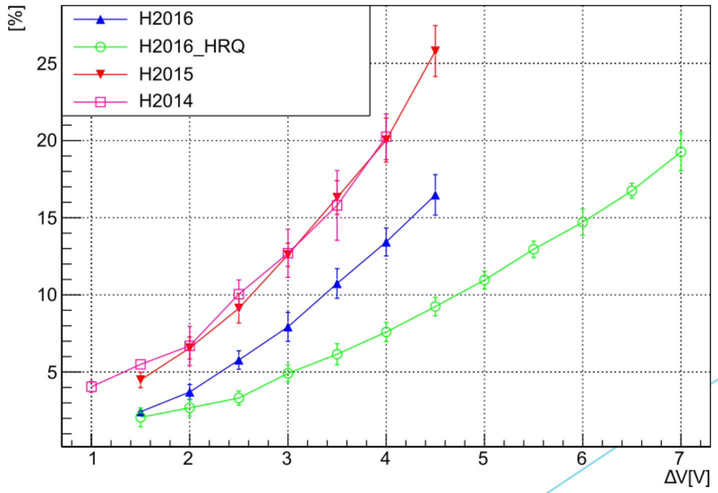
after-pulses



delayed cross-talk



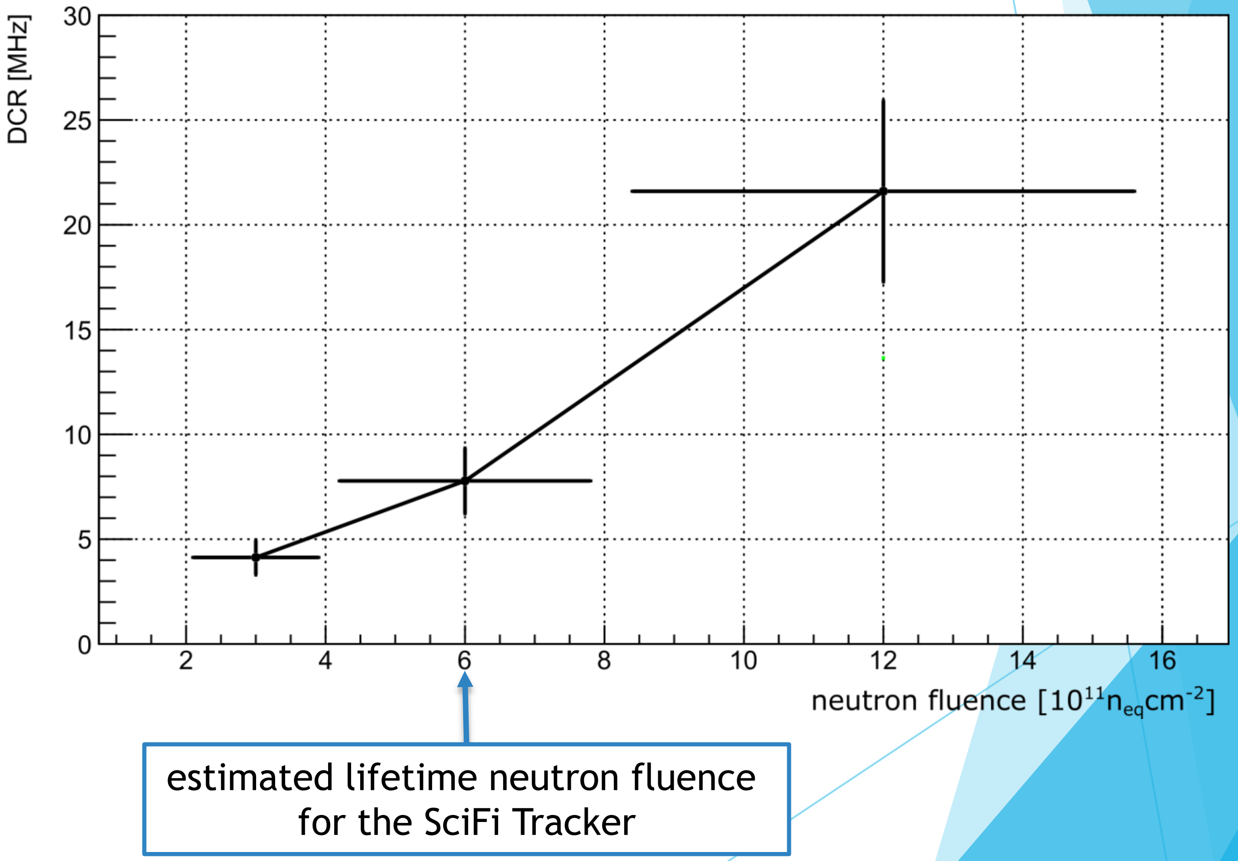
sum of all three components



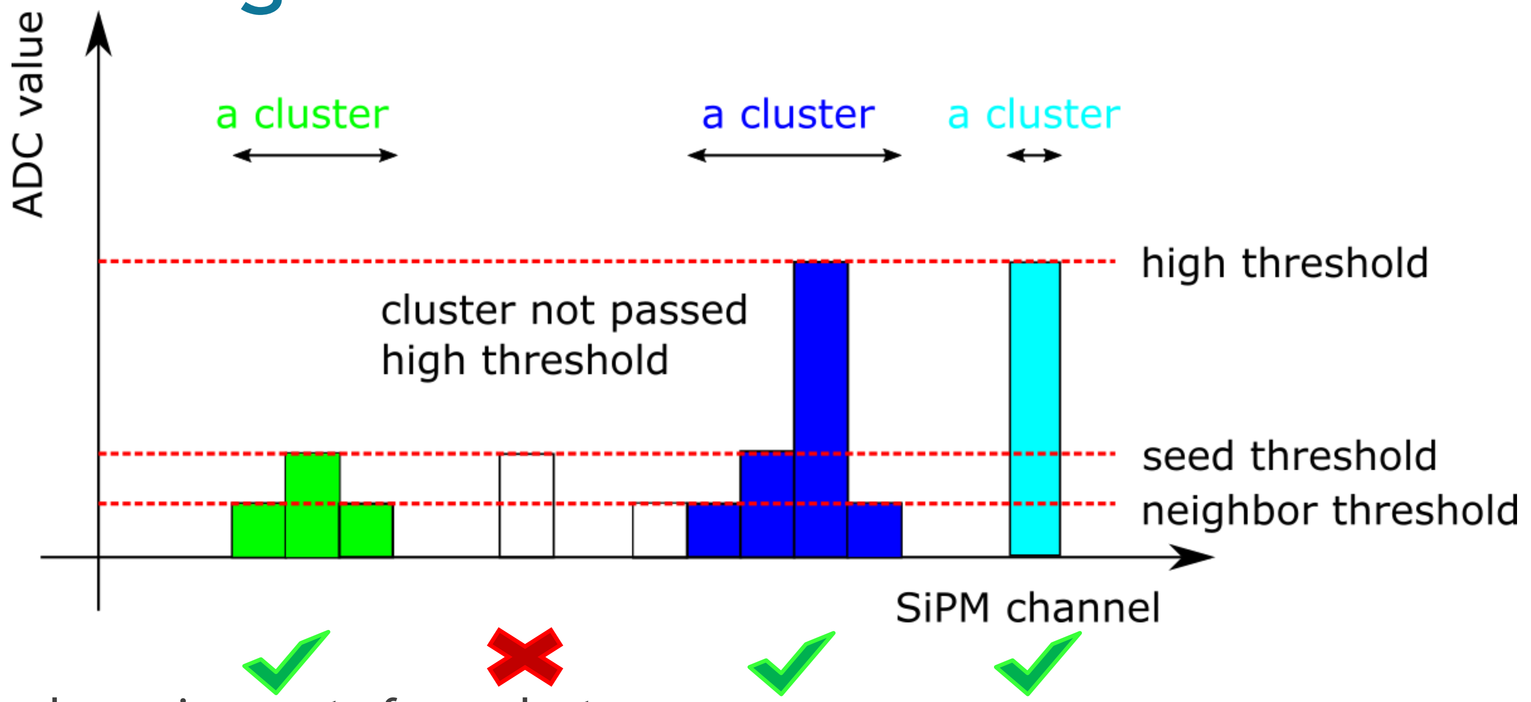
Maria Elena Stramaglia, EPFL Lausanne

Dark count rate of a single channel at T = - 40°C

- measures to reduce the neutron fluence or its damage:
  - PE neutron shielding
  - cooling of SiPMs to T = - 40°C
  - annealing of SiPMs at T = + 30°C during detector shutdown time
- 8MHz → 20% occupancy
- but mostly single pixel signals
- how to deal with this?
  - **channel clustering!!**



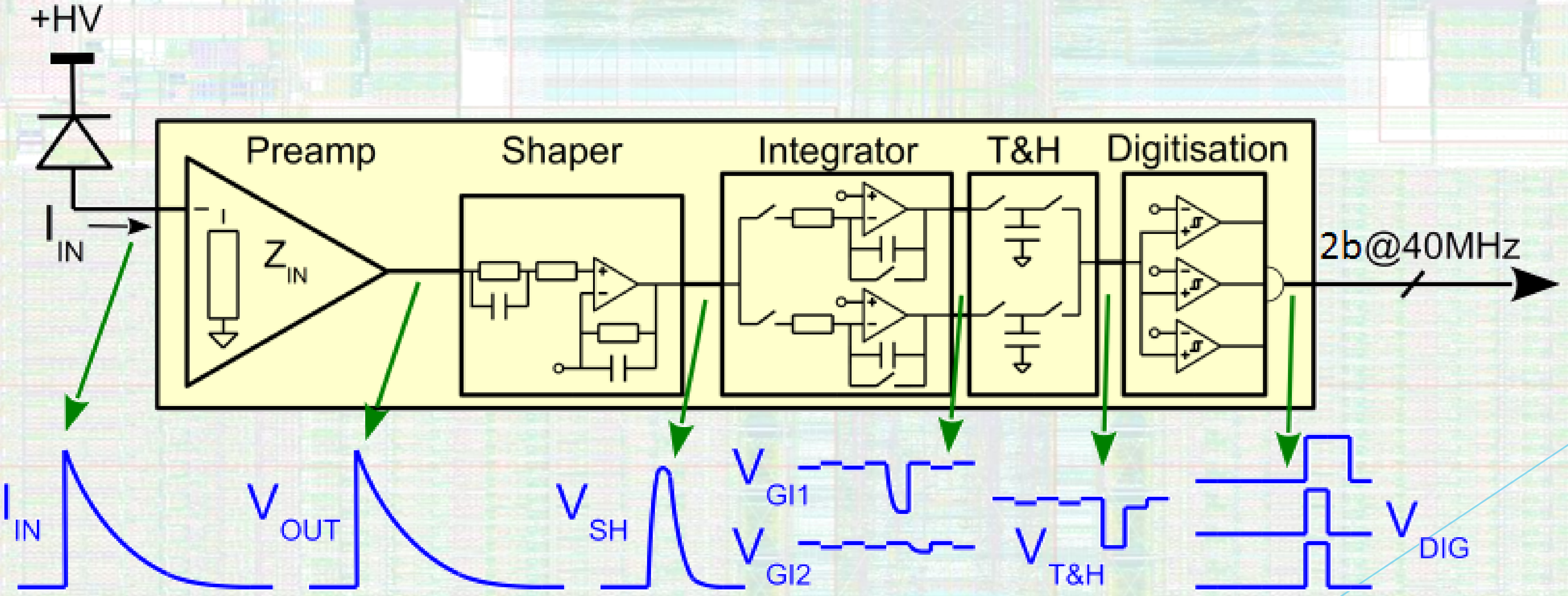
Cluster algorithm



- Minimal requirements for a cluster:
  - One channel above seed threshold and one neighbor channel above low threshold
  - A single channel above highest threshold
- cluster algorithm is implemented into FEE on FPGAs
- huge data reduction through zero suppression directly at detector

The PACIFIC chip

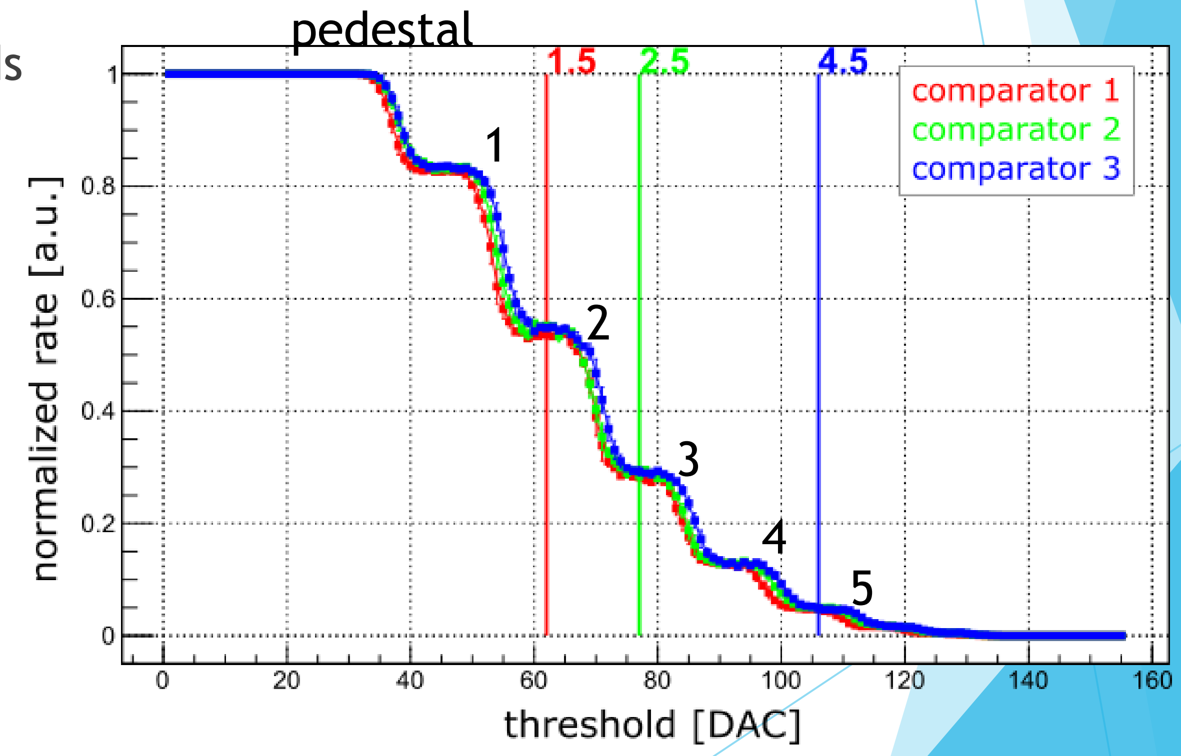
- shaper cuts off long tail component of SiPM signals
- interleaved gated integrators yield to almost zero dead-time
- **only three thresholds** for the digitization of the integrated signals
  - 2bit non-linear output
  - limited amplitude information



Albert Comerma, Physikalisches Institut Heidelberg

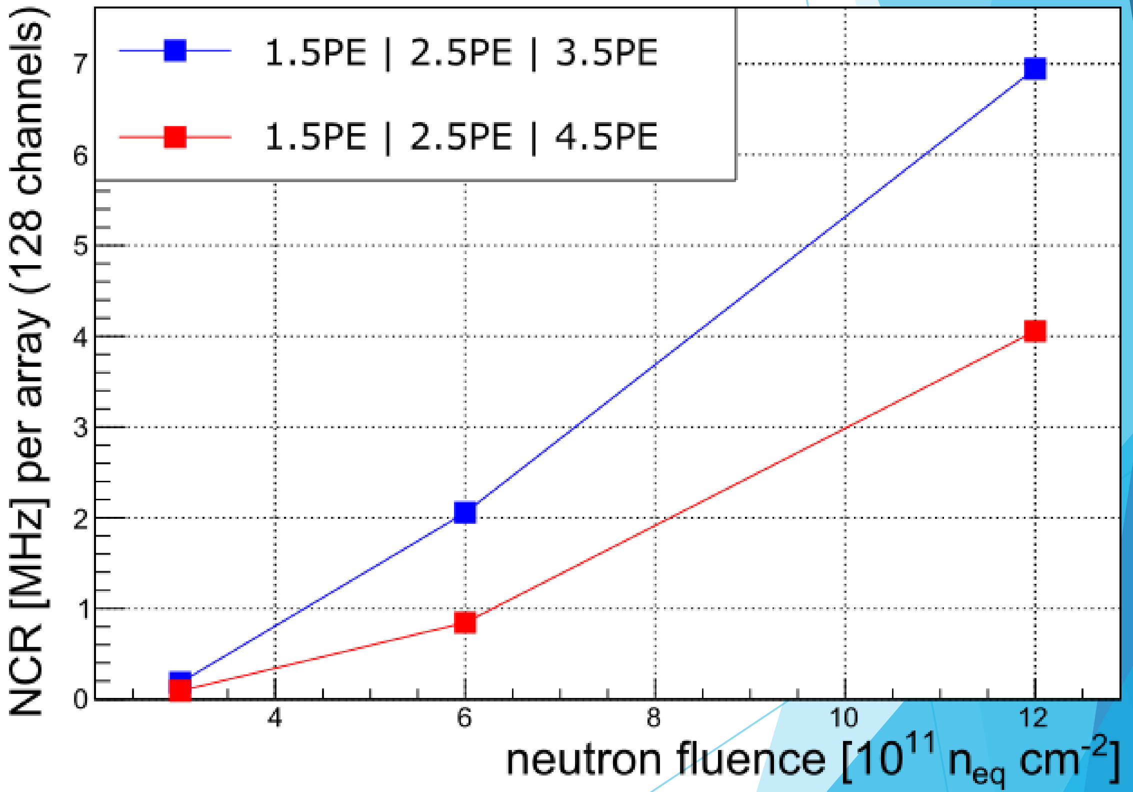
Threshold calibration with sCurve scans

- no full ADC information of SiPM signals
  → **no photopeak spectrum**
- **solution:** scan through ‘local‘ thresholds for every channel
- using a laser light injection synchronized with the PACIFIC clock
- get characteristic steps due to integrated photopeaks
- so called **sCurves**
- gain fit of differential sCurves



Noise Cluster Rate

- from **10MHz** dark count rate per channel down to 2MHz (0.85MHz) of noise cluster rate per array of 128 channels
- very effective suppression of random noise due to clusterization of neighboring channels
- only this makes it **possible to operate irradiated detectors** in the SciFi Tracker
- design maximum of NCR is about 2MHz due to bandwidth limitations



Conclusion

- the latest version of detectors **fulfills all requirements** for the operation in the Scintillating Fibre Tracker for the LHCb upgrade in 2019/20
- **irradiation damage** due to neutron fluence is **under control**
- series production and SiPM testings has been launched
- photo-peak spectra are substituted by **sCurves** (threshold level scans)

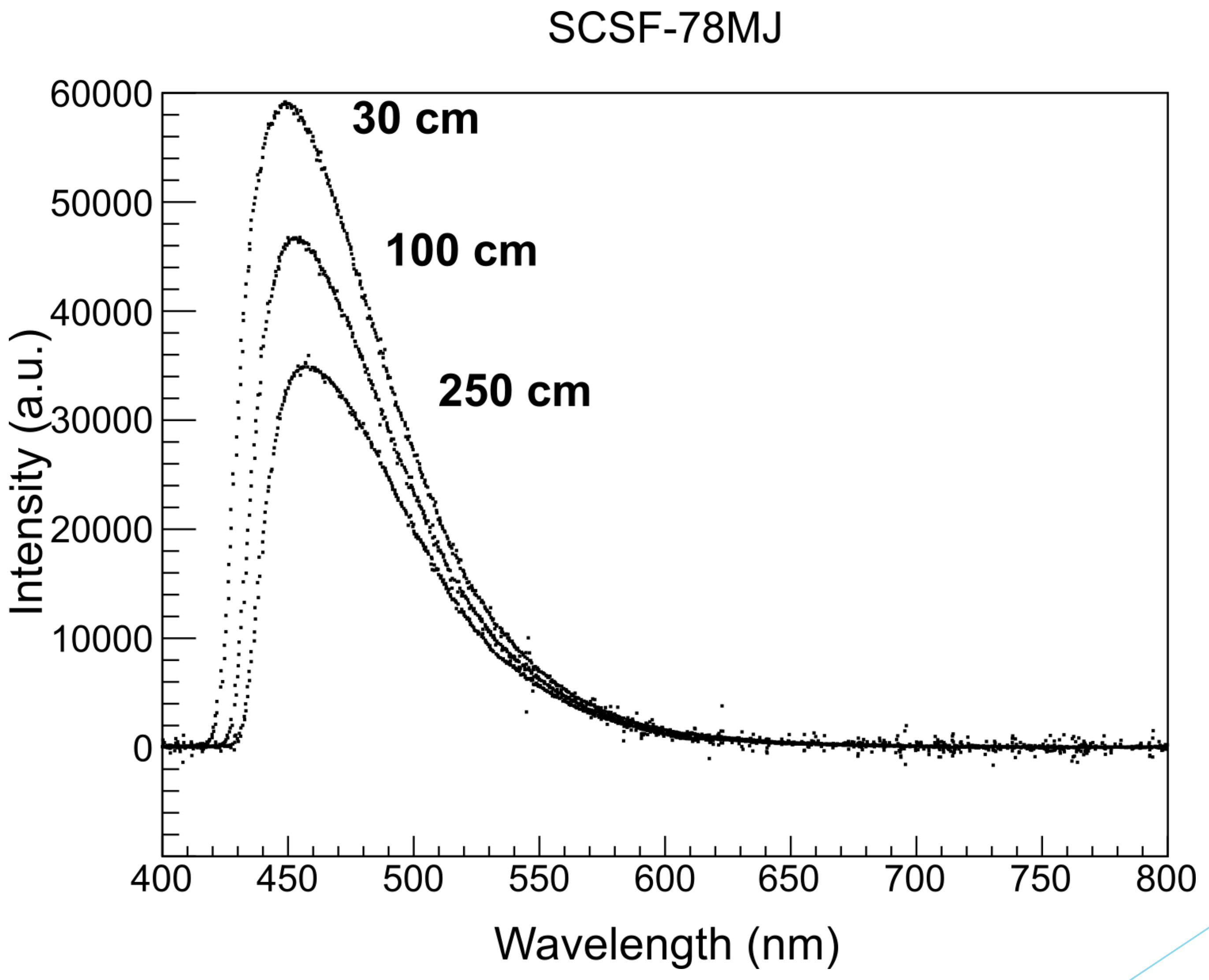
- main challenges:
  - high single hit efficiency versus dark count rate suppression
  - implementation on large scale

That‘s it!

Thank you for your time and attention!

Backup Slides

Scintillation light emission spectrum



Light injection delay scan

- effective gain as a function of the relative delay between the integration window and the light injection