Status of the Mu3e tile detector

DPG Spring Meeting

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HighRR

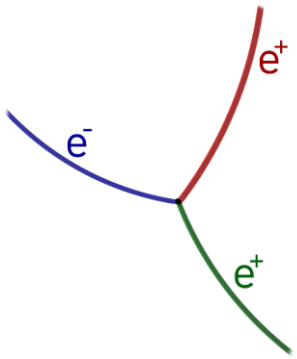
HGSFP

The Mu3e experiment

- search for charged LFV decay $\mu^+ \rightarrow e^+e^+e^-$
  - SM (including ν mixing): $B_{\mu\rightarrow 3e} \approx 10^{-54}$
- current upper limit: $B_{\mu\rightarrow 3e} < 10^{-12}$ (SINDRUM, 1988)
  → aim of Mu3e: $\mathbf{B_{\mu\rightarrow 3e} < 10^{-16}}$
- stopping target experiment at PSI in Switzerland
  → high-intensity muon beam

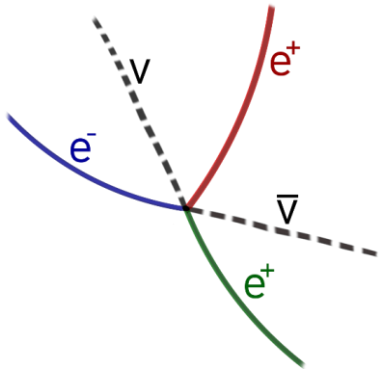
- background sources:
  - internal conversion $\mu \rightarrow eee\nu\nu$
  → excellent momentum resolution
  - combinatorial background
  → precise vertex and time information

signal



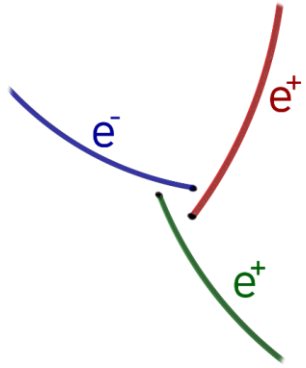
$\sum E_e = m_\mu$, $\sum \vec{p}_e = \vec{0}$

internal conversion decay



$\sum E_e < m_\mu$, $\sum \vec{p}_e \neq \vec{0}$

combinatorial background

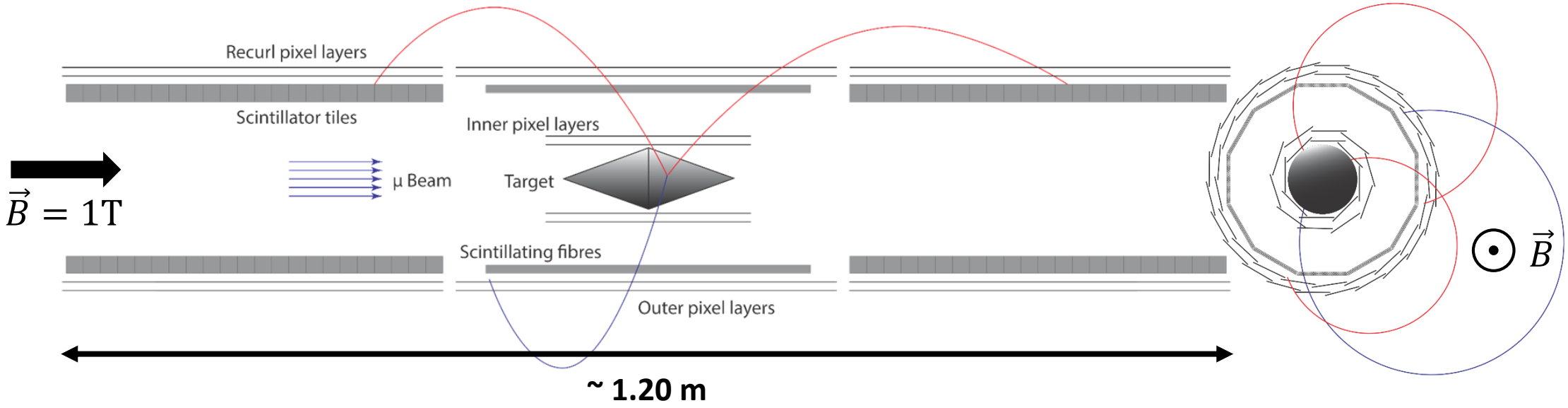


$\sum E_e \neq m_\mu$, $\sum \vec{p}_e \neq \vec{0}$,
$t_1 \neq t_2 \neq t_3$

Experimental design

- precise vertex and momentum measurements → pixelated tracking detector
- precise time determination → timing detectors
- tile detector requirements:
  - timing resolution ≤ 100 ps
  - compact design with high granularity
  - up to 80 kHz per channel

see talk of Alexandr Kozlinskiy (T 96.5)



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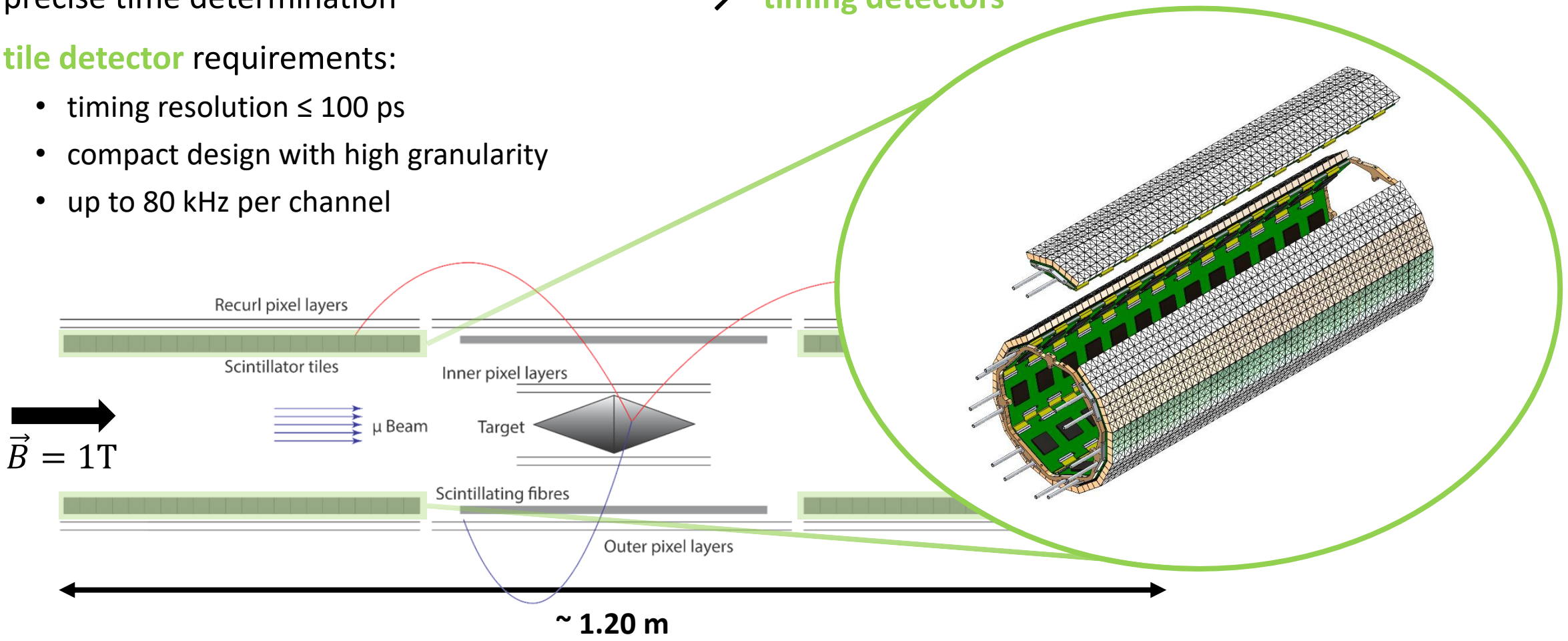
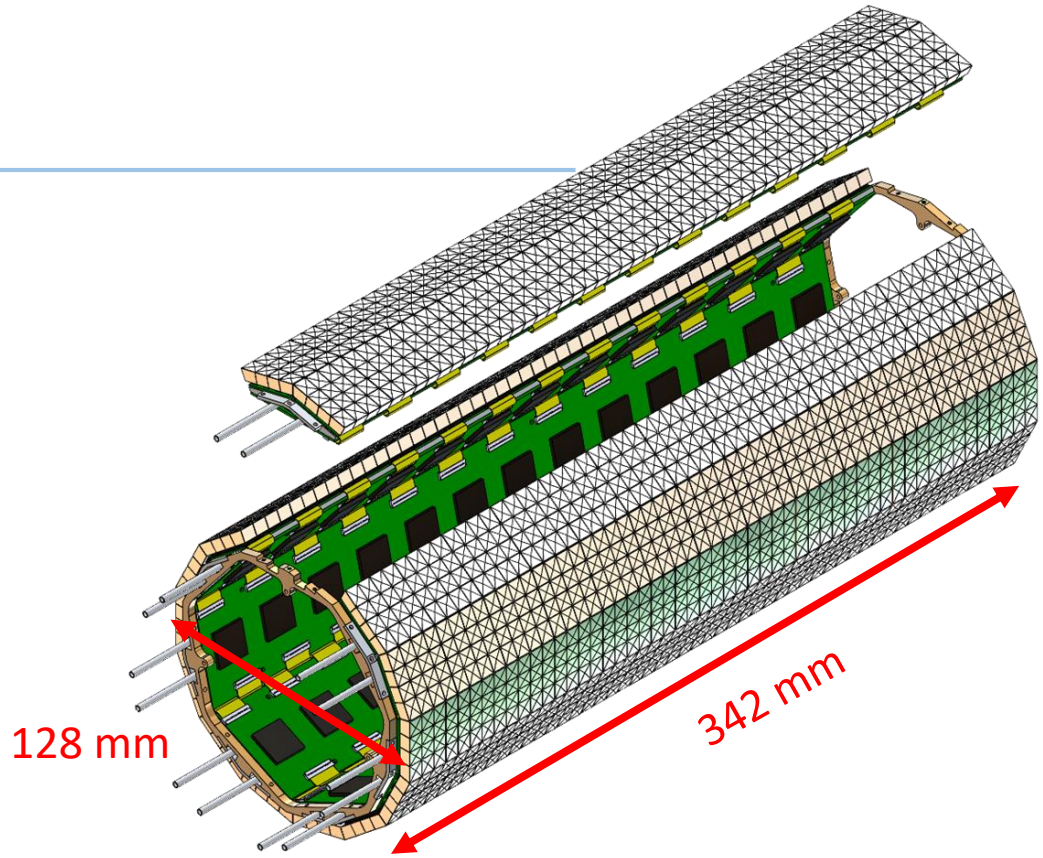
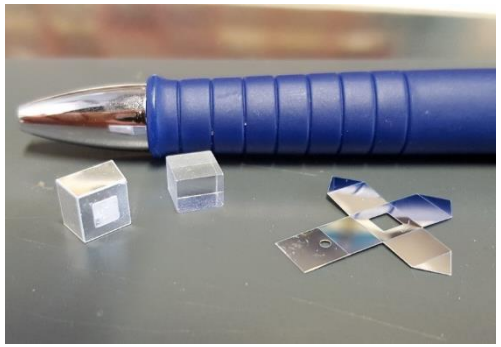


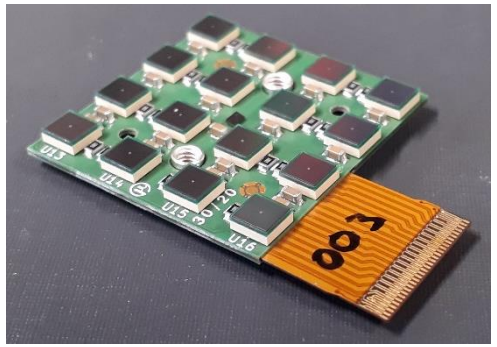
Tile detector structure

- **recurl station** (x2)
  - 7 modules per station
  - mounted on beampipe using PEI endrings
- **module** (x14)
  - 26 tile matrices
  - tile module board (TMB) for read-out
    - hosting 13 custom-designed ASICs (MuTRiG)
  - aluminium support & cooling structure
- **tile matrices** (x364)
  - 16 channels (tiles + SiPMs)
  - tiles: ~6x6x5 mm³, fast plastic scintillator (EJ-228)
  - SiPMs: 3x3 mm², 50 µm pitch (S13360-3050VE MPPC)

→ in total ~5800 channels



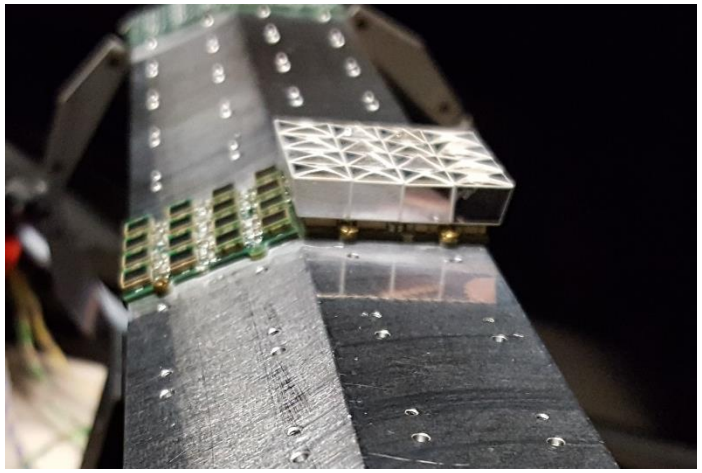




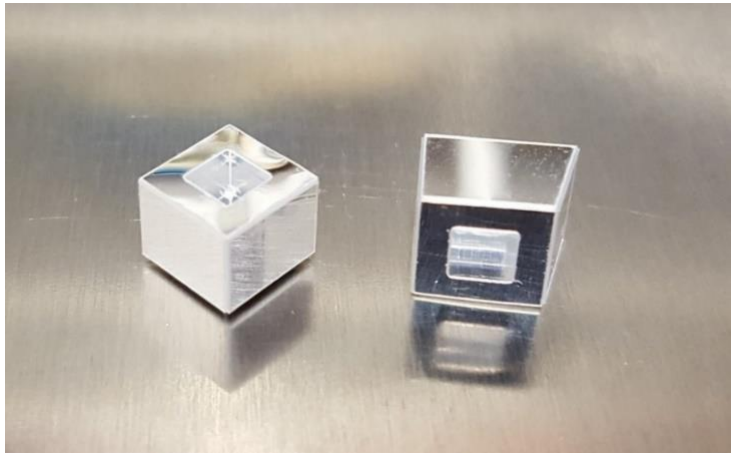
Development and production status

- **detector design validation** with first prototypes
  - optimisation of tile matrix and mechanical design
  - average time resolution of **< 40 ps** with excellent uniformity
  - focus in 2021: irradiation studies of SiPMs

see talk of Tiancheng Zhong (T 96.3)

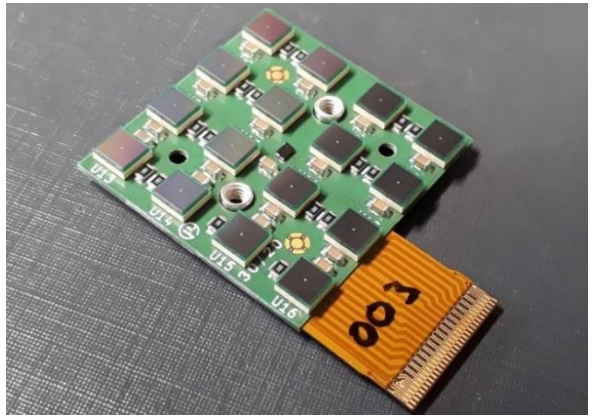


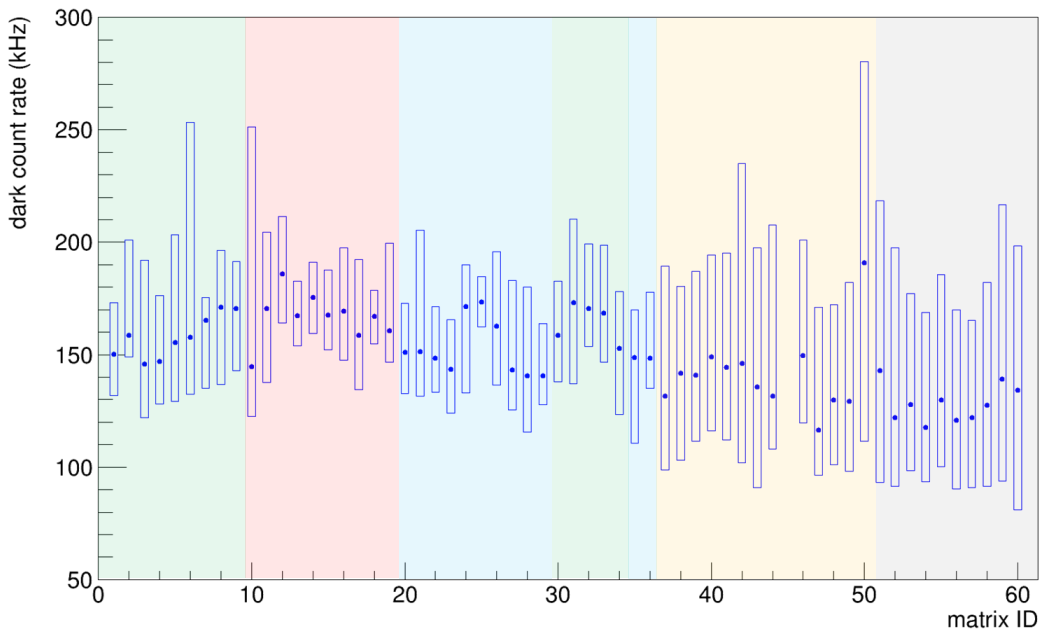
- **detector component production and assembly**
  - assembly of sensor matrices in-house
    - tile milling, wrapping, gluing
    - quality control
  - focus in 2021: pre-production of 2 modules



Pre-production in 2021

- **60 SiPM matrices assembled and tested**
  - **59 working & within specifications**
  - **1 with broken temperature sensor (reparable)**
- 36 tile matrices assembled
  - quality control procedure developed
  - characterisation of light-yield using Na-22 source
- first version of TMB received in spring 2021
  - not functional, redesign required
  - TMB2 now finished and in production
    - custom industry-standard package for ASICs
    - working cabling scheme for overall detector integration





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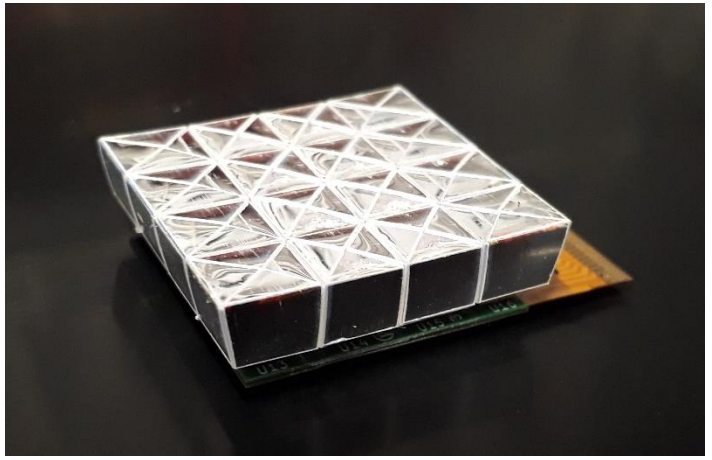

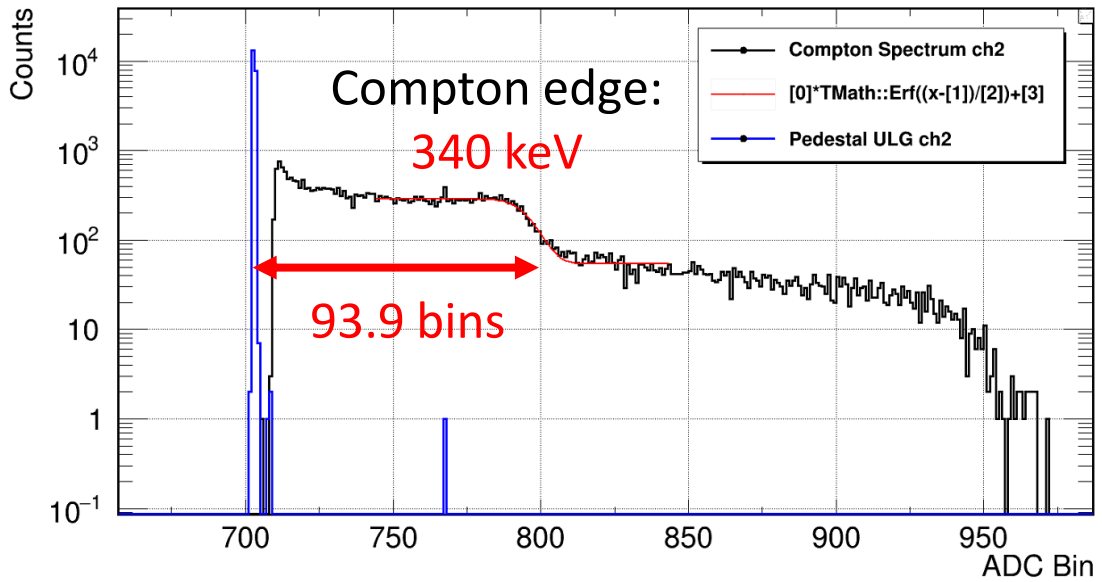

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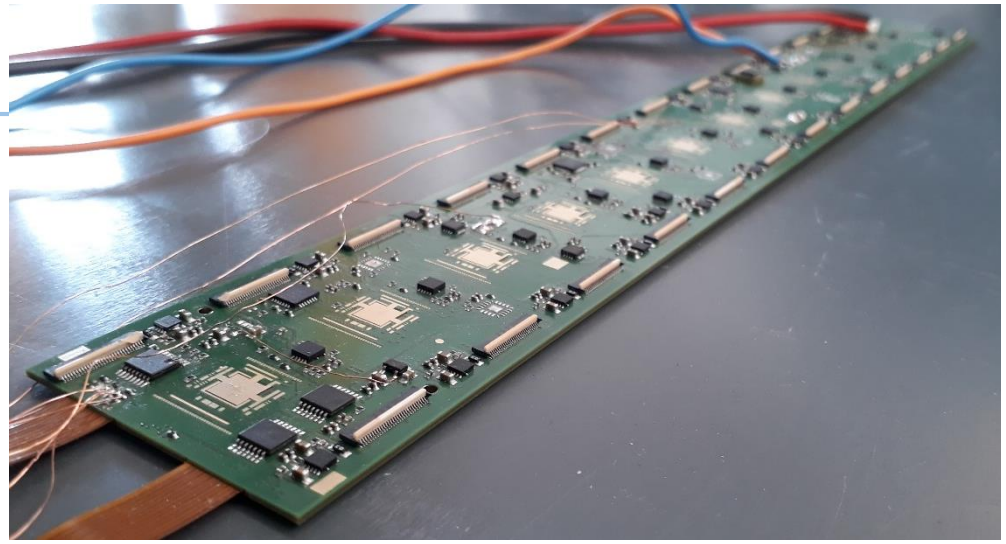
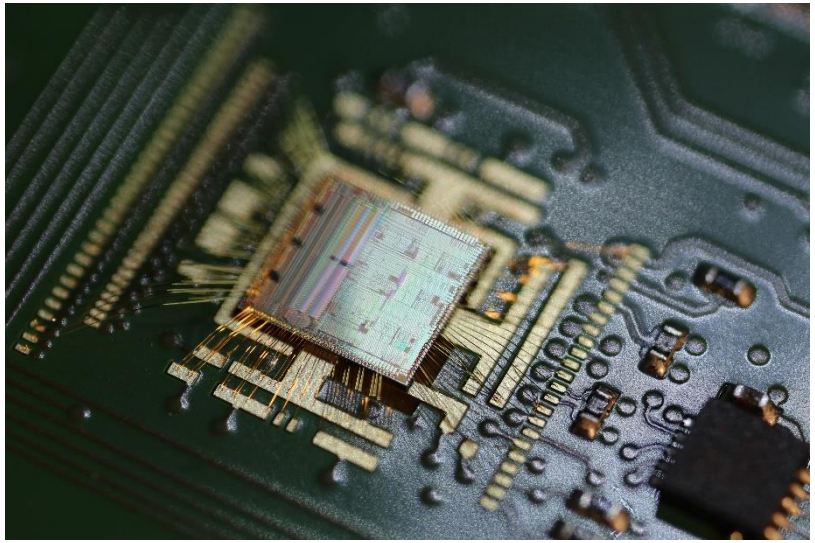




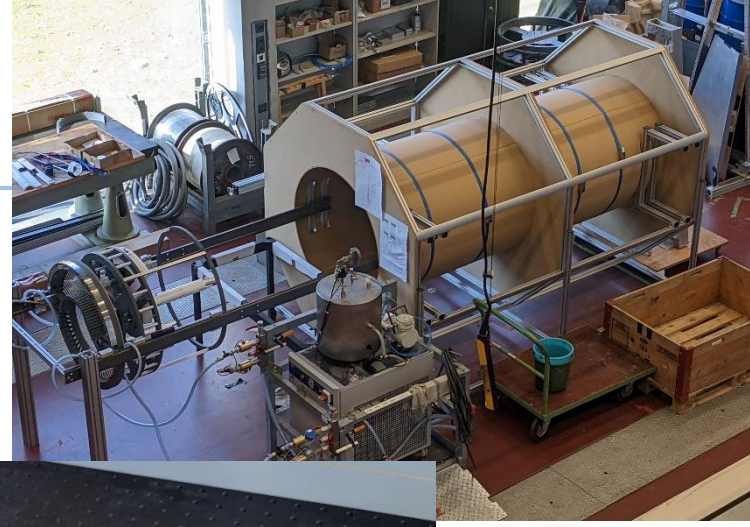
Integration of services

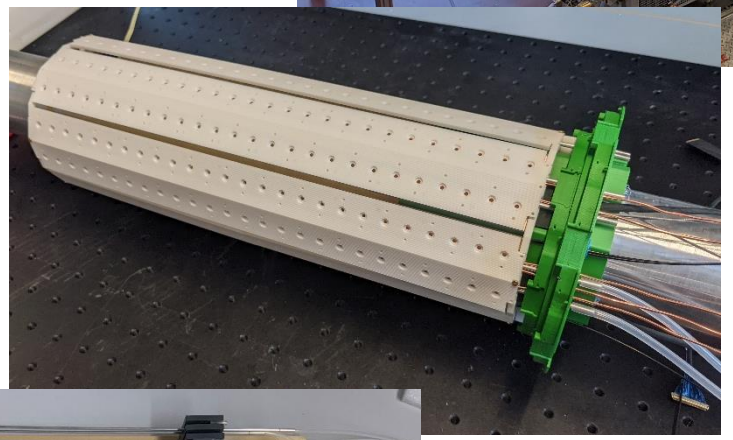
- very limited space for routing of tile detector pipes and cables
  - restricted by beampipe and other services
- difficult to evaluate in CAD model

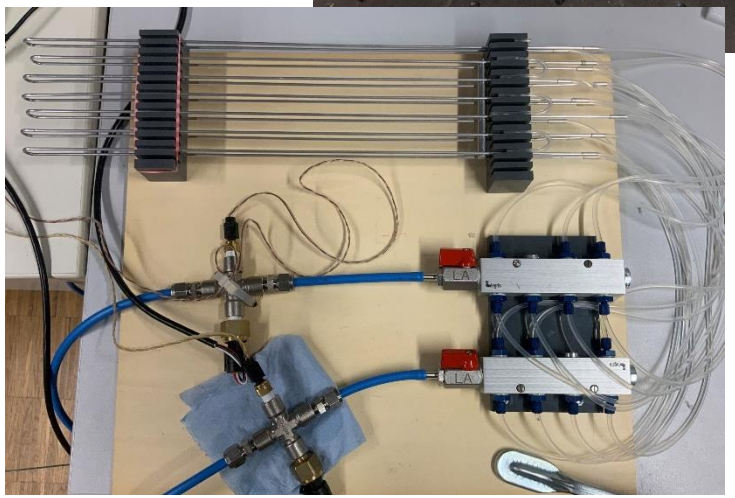
→ **production of dedicated mock-ups:**

  - full-size mock-up for experiment integration
  - tile detector mock-up for cabling and mechanics
  - cooling mock-up for one recurl station (7 circuits)

- cooling and cabling finalised,
  no showstoppers observed







Outlook for 2022

- **full sensor matrix production**
  - scintillating tile production on-going
  - production of SiPM matrices in summer 2022
- **TMB production and design validation**
  - characterisation and full board testing
- **finalisation of detector integration and mechanics**
  - services (cabling, cooling,…) concluded
  - design and produce dedicated assembly tools
- **full module commissioning**
  - calibration at DESY testbeam facility
  - integration run at PSI at the end of the year

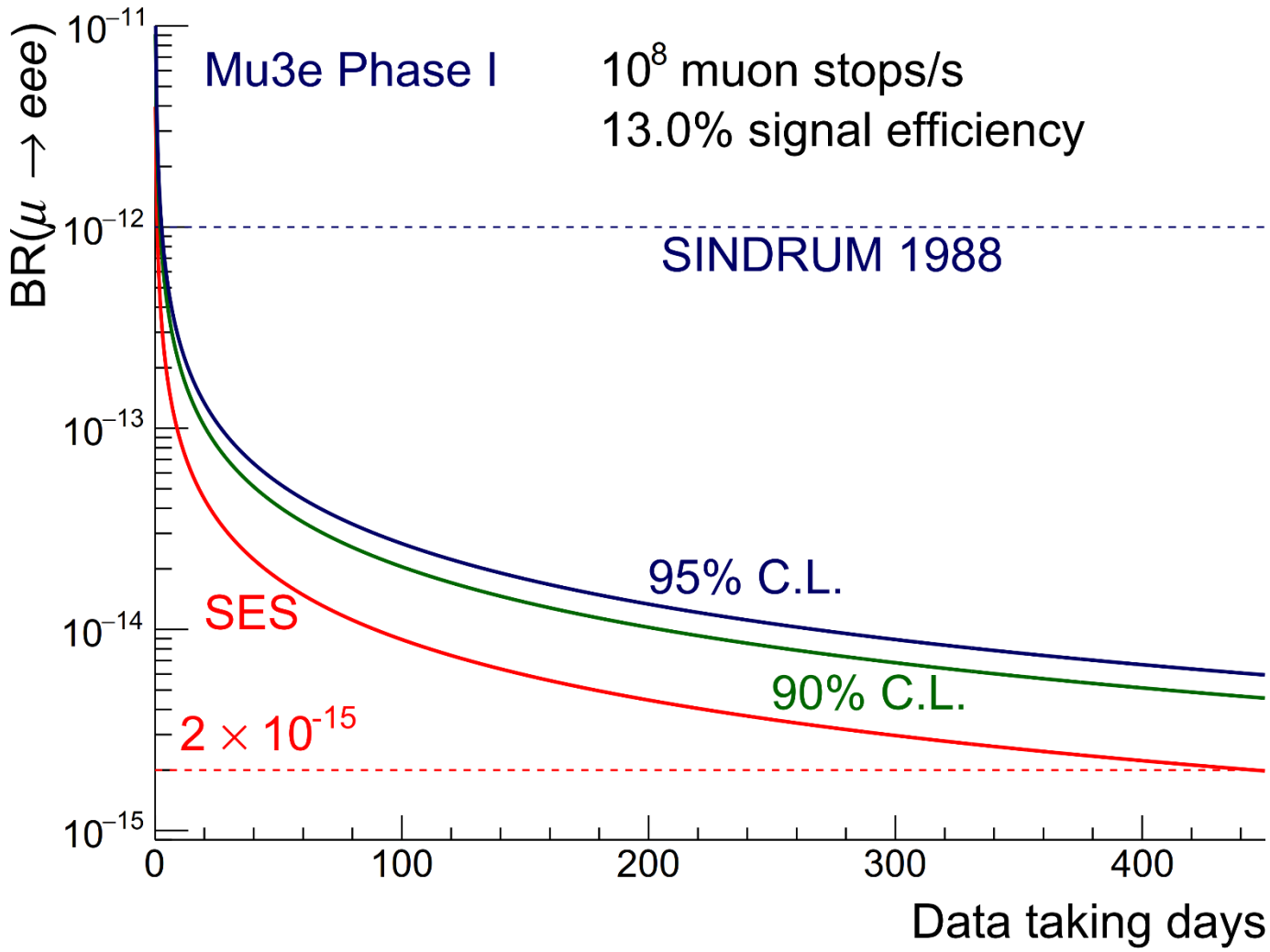
  →validate operation at high rates and in magnetic field

→ **long-term plan for 2023: integrate one full station into experiment**

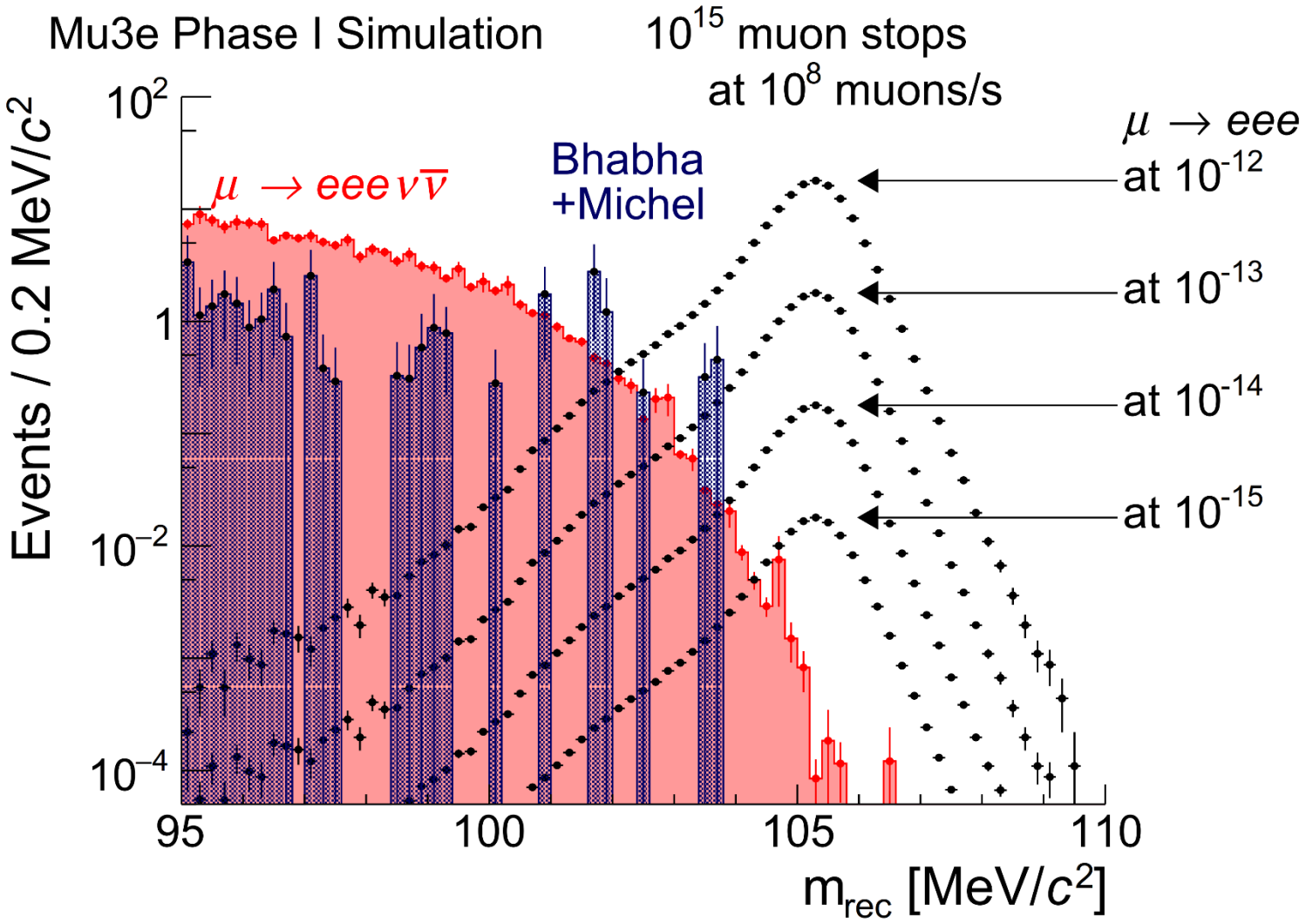
Thank you for your attention!

Appendix

Mu3e sensitivity



Experimental background

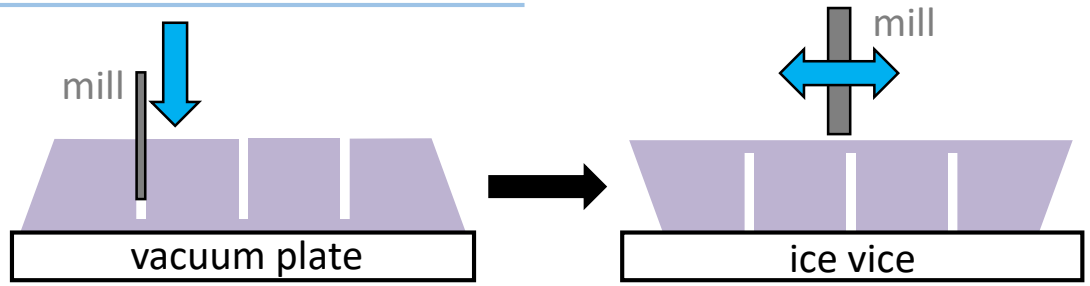


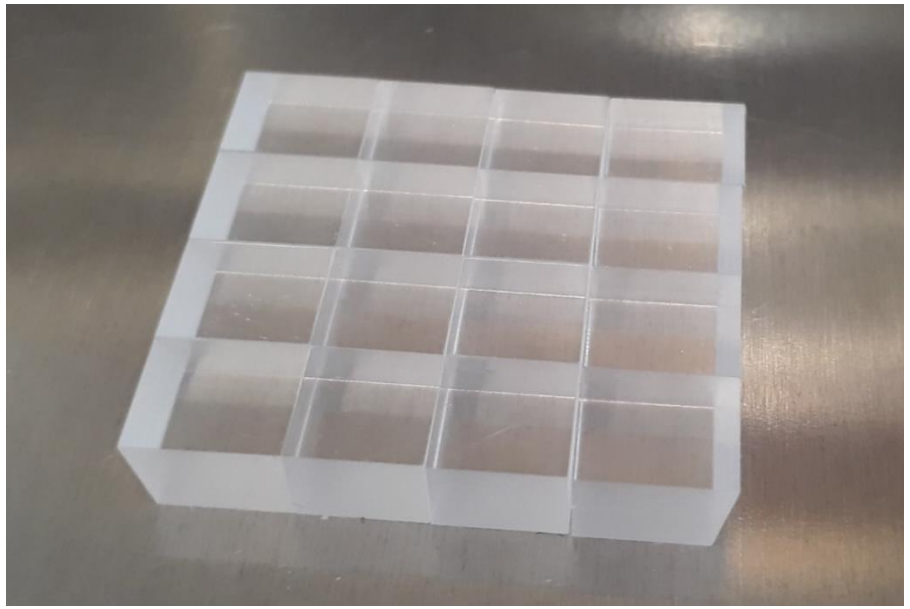
Tile production and wrapping

- large-scale tile production using ice-vice system
  - challenge: small tiles are difficult to mill/polish

  → freeze-clamp to a plate during machining (-10°C)
  - one step further: cut out full matrices from scintillator plate
- production time per matrix **< 30 minutes**
  - reminder: we need 26*7*2 = 364 matrices for Mu3e Phase I

  →**2-3 months production time**



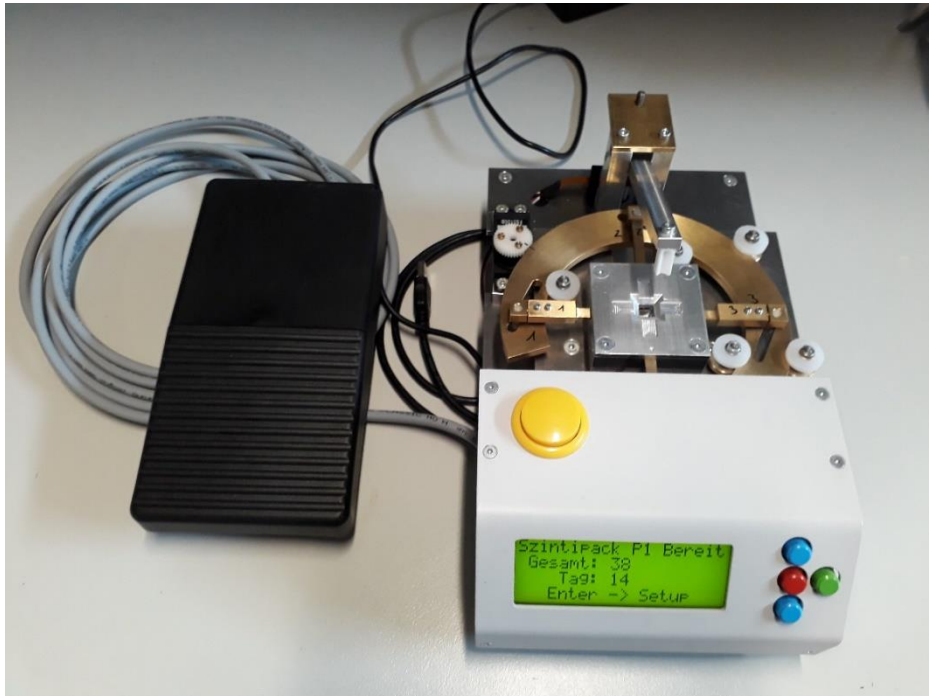


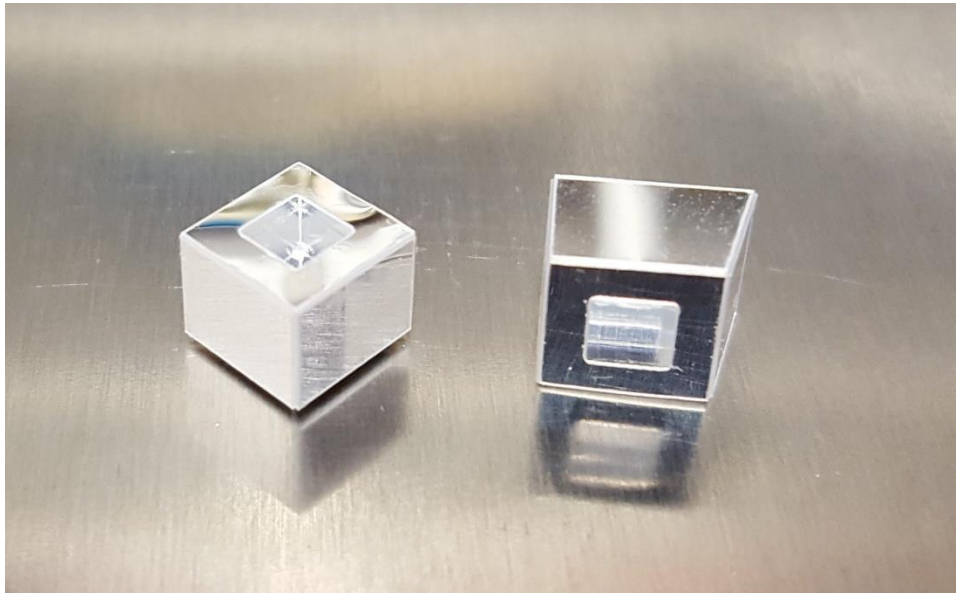
Tile wrapping

- wrapping of tiles with reflective foil to reduce optical cross-talk
- original wrapping tool design using CAD software

  → 3D-printed prototype

  → "upgrade" to (semi-)automatic solution for easier handling and faster production

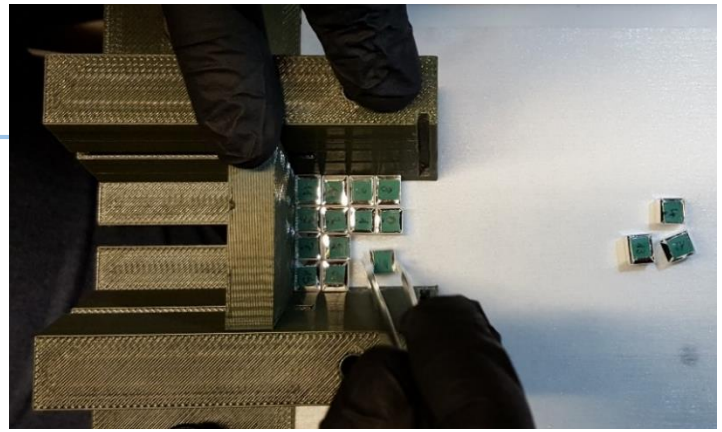


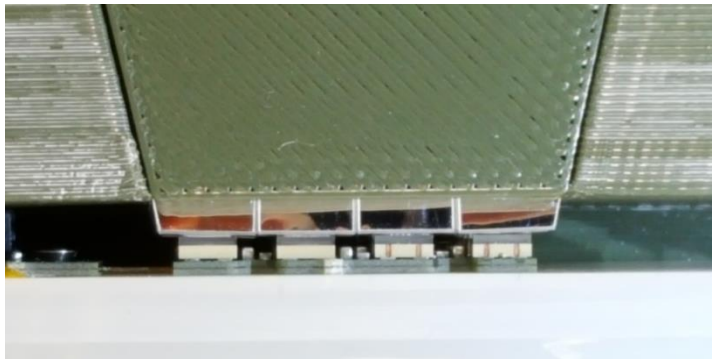


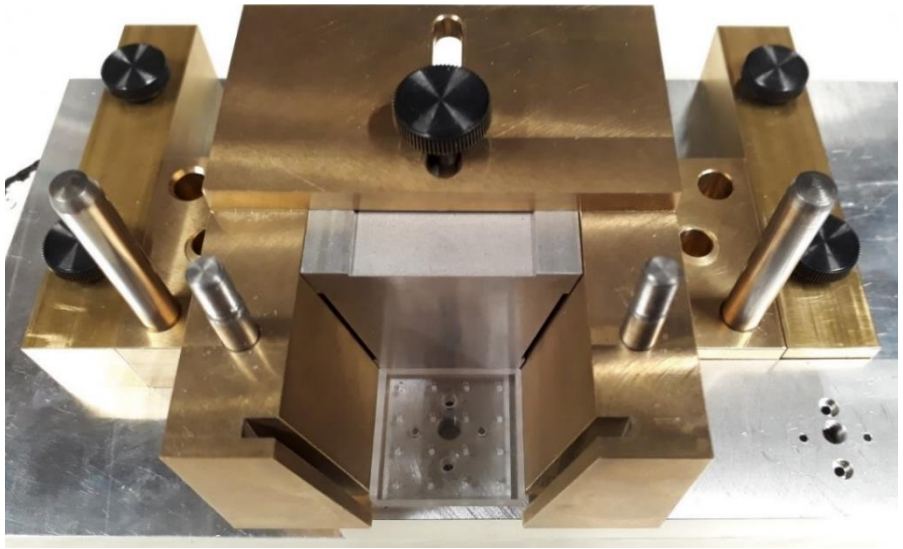
Tile gluing

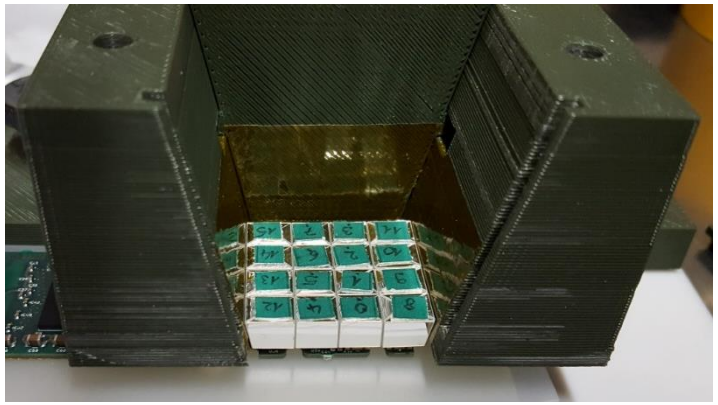
- attach tiles to SiPMs using light-transmitting glue
- glue full tile matrix (4 x 4 tiles) all at once
  - tight space constraints
  - curing time of glue ≈ 24h
- 3D-printed prototype

  → production of final tools @ institute‘s workshop









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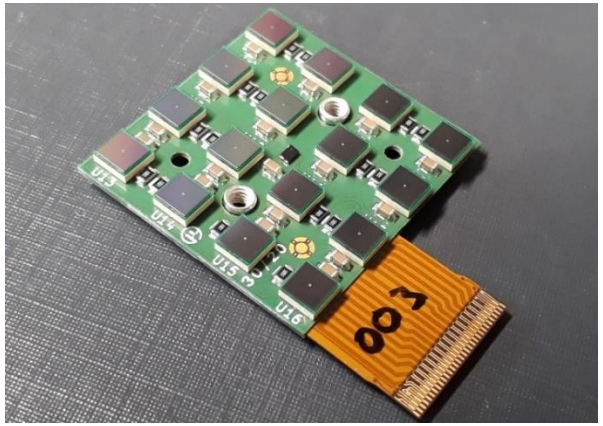
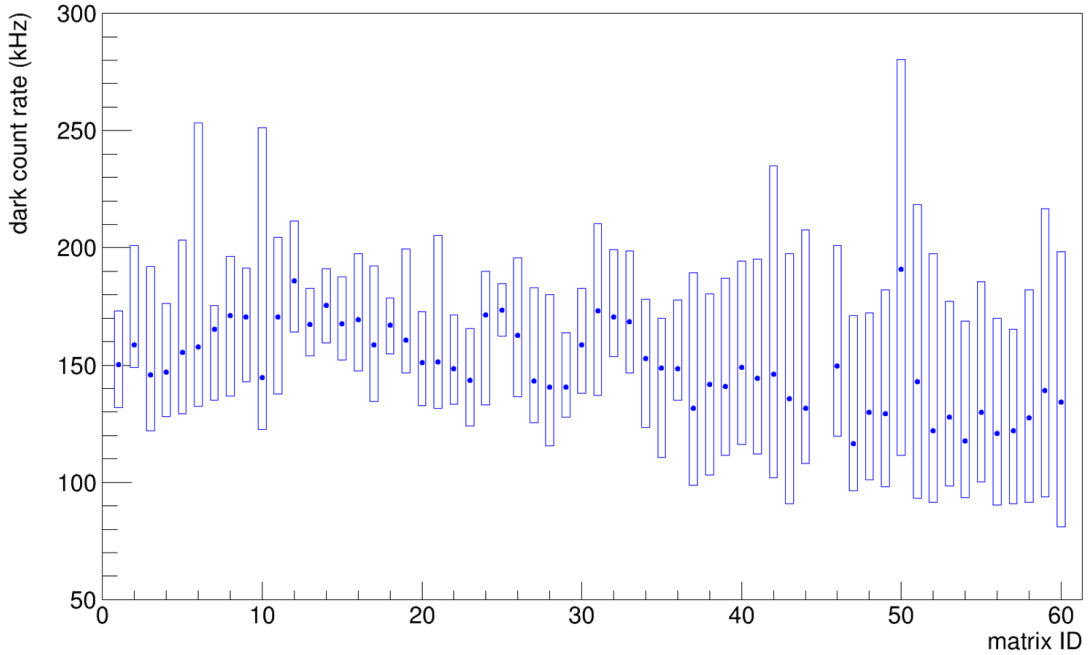
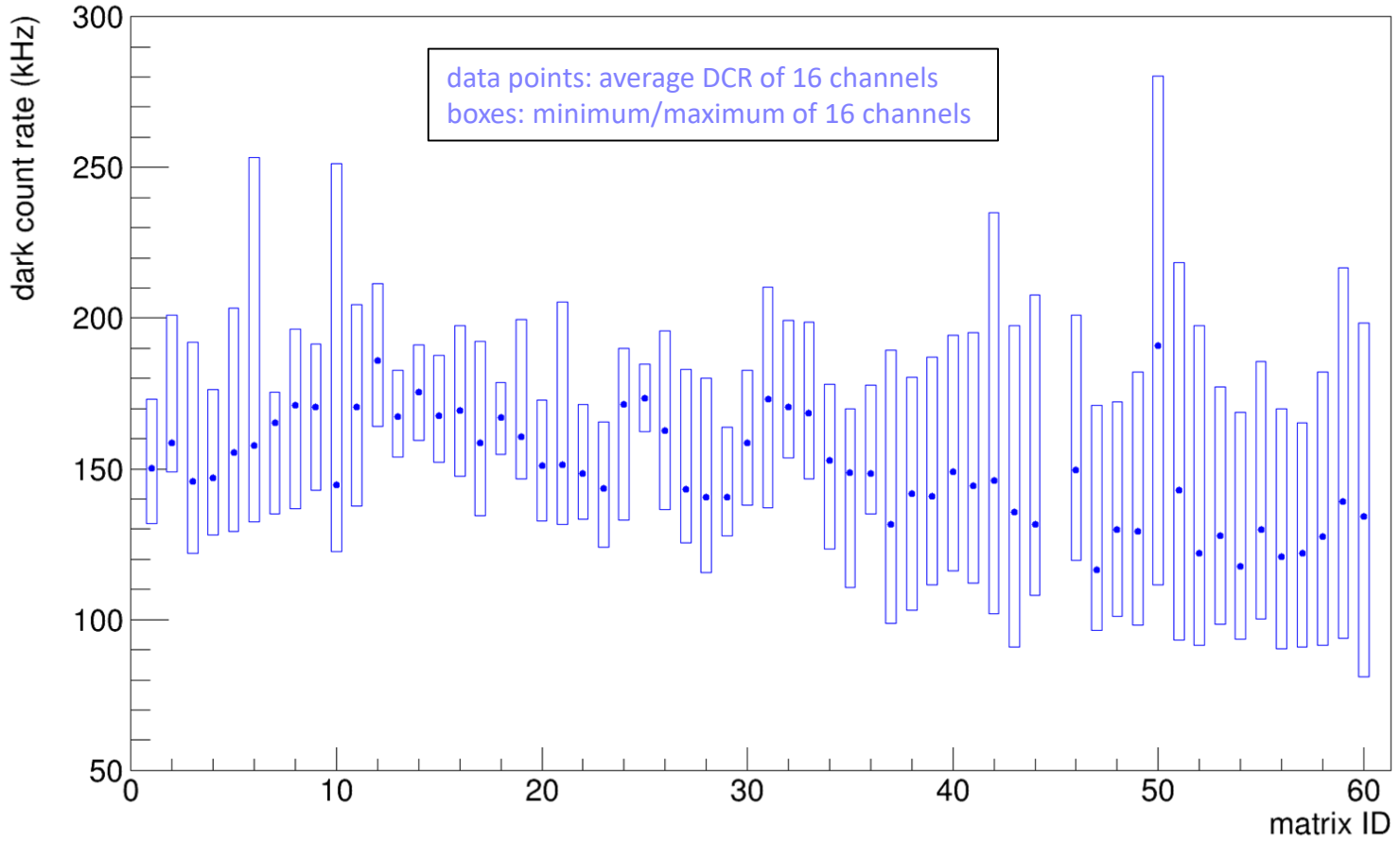
    - ASICs now packaged in custom BGA
    - cabling solution found





SiPM matrix QA

- 60 matrices tested in 2021
  - **59 working and within specs**
  - 1 with broken temperature sensor → will be reworked



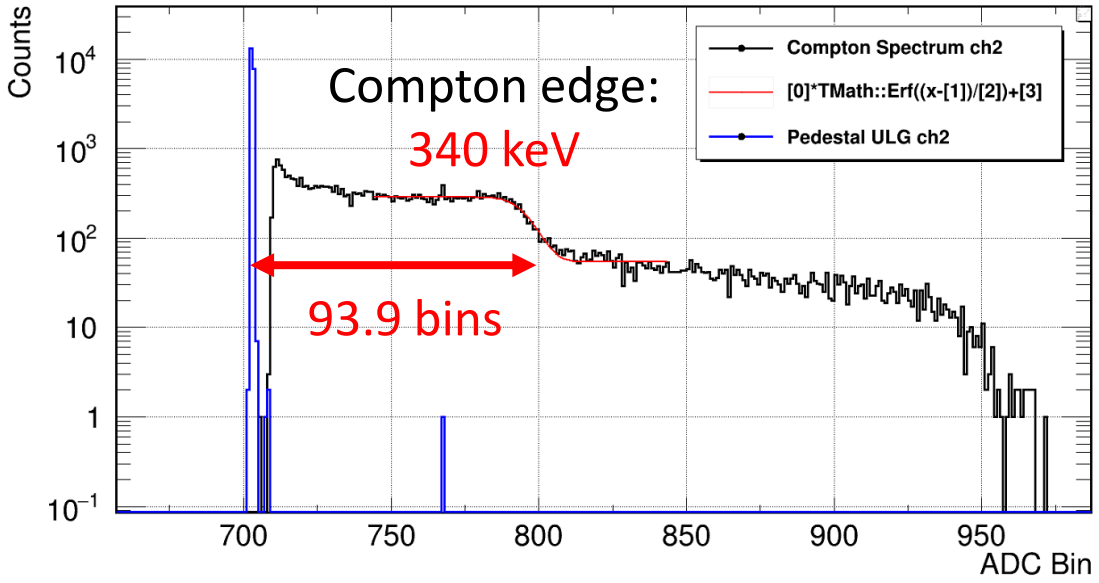
Tile matrix QA

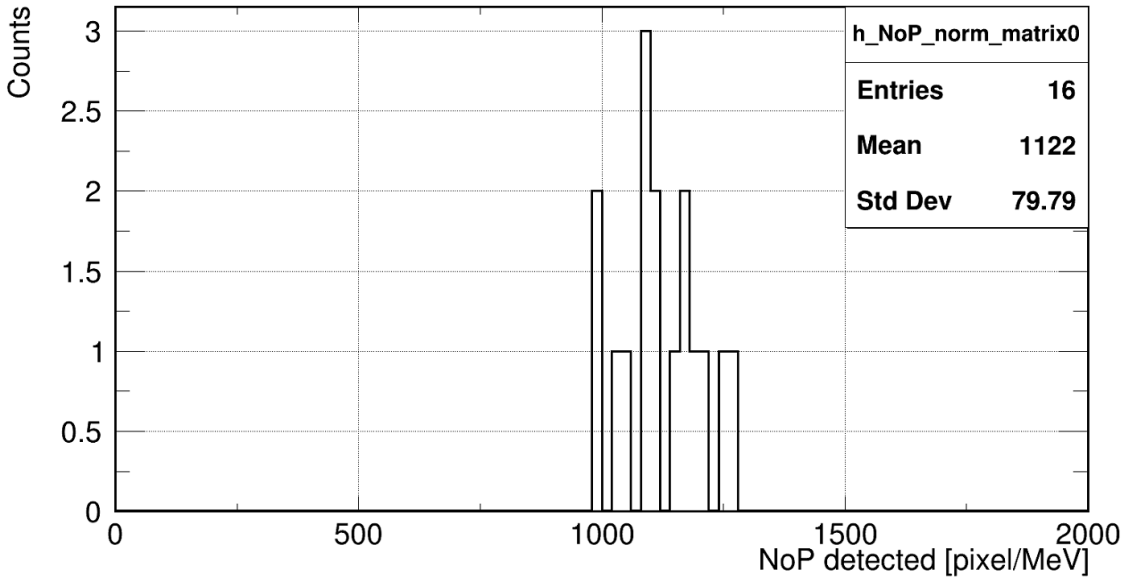
setup:

- SiPM high voltage: 55 V
- room temperature + water cooling
- radioactive source: Na-22

measurements:

- **light yield**: number of fired pixels per energy
- SiPM gain
  → map ADC bins of ASIC to number of fired SiPM pixels
- Na-22 spectrum with Compton edge
  → map ADC bins of ASIC to energy of Compton edge





Integration of services

- main challenge for services: **compact experiment layout**
  - limited space for routing of tile detector pipes and cables
  - central station services must be fed through as well
- tile detector implications:
  - beampipe and helium cooling ducts on the inside, pixel layers on the outside
  - need small pipes and cables, plus low mating-height connectors
- difficult to evaluate in CAD model

→increased use of different mock-ups in Heidelberg