Status of the Mu3e Tile detector

Elizaveta Nazarova, Konrad Briggl, Hans-Christian Schultz-Coulon, Jan Küpperbusch, Erik Steinkamp, Anna Dunz

for the Mu3e collaboration

DPG Spring Meeting

08.03.2024

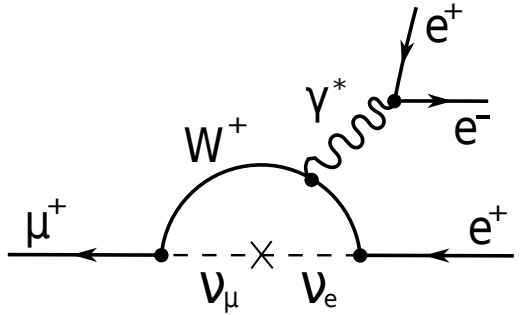
Kirchhoff Institut für Physik, Universität Heidelberg

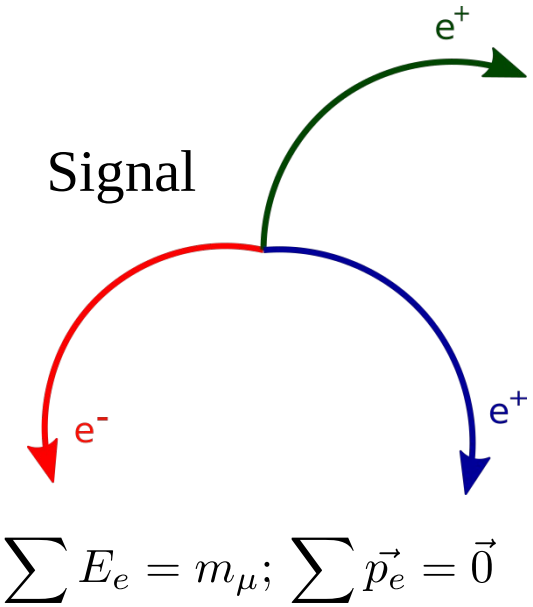
Overview

- Mu3e Experiment
- Mu3e Tile detector
  - Overview
  - Production
  - QA measurements
- Integration into the experiment
- Conclusions & Outlook

The Mu3e experiment

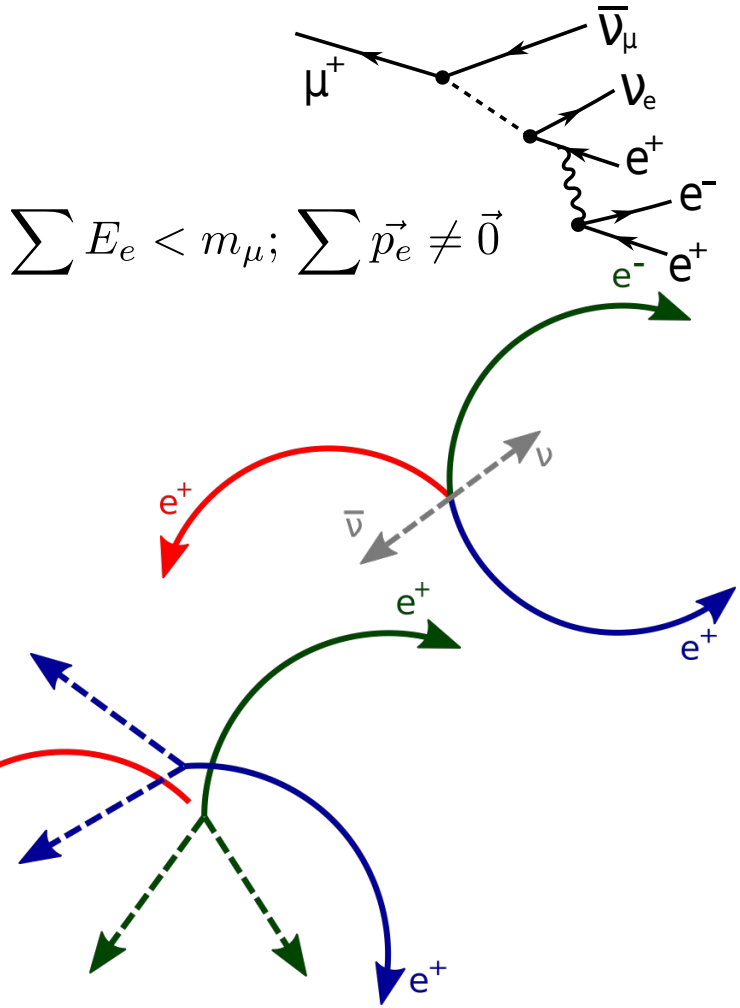
- Search for Charged Lepton Flavour Violation
  - $\mu^+ \to e^+e^+e^-$ ($\mu \to 3e$)
  - Highly suppressed in SM (with neutrino mixing):
  - $\mathrm{Br}_{\mu\to 3e} \approx 10^{-54}$
  - Probe for physics beyond SM
- Current limit (SINDRUM, 1988)
  - $\mathrm{Br}_{\mu\to 3e} < 10^{-12}$
- Goal for Mu3e experiment
  - $\mathrm{Br}_{\mu\to 3e} < 10^{-16}$ (Phase 1: $\mathrm{Br}_{\mu\to 3e} < 2 \times 10^{-15}$)
- Stopping target experiment at PSI (Switzerland)
  - High-intensity muon beam ($1 \times 10^8 \mathrm{Hz}$)



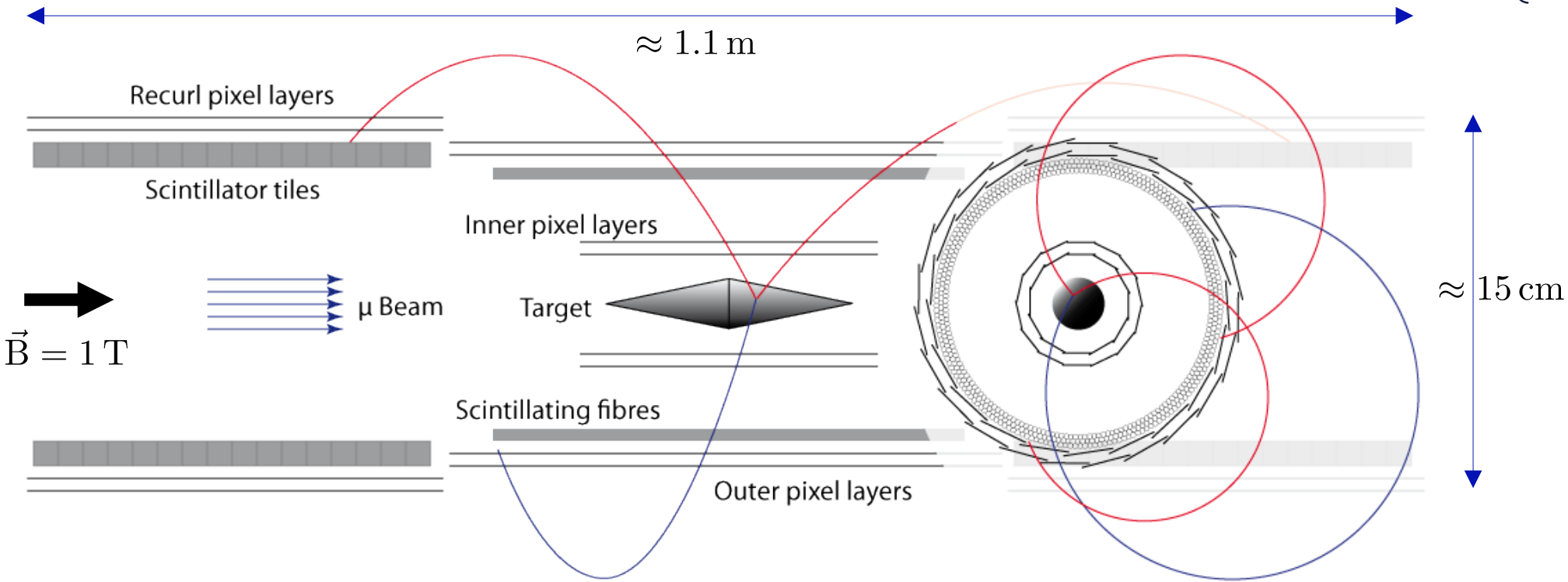


$$\sum E_e = m_\mu; \sum \vec{p_e} = \vec{0}$$

- Background contributions need to be reduced
  - Internal conversion
  - Combinatorial background
- Precise momentum and vertex measurement
  - Pixel tracker
- Precise timing measurement
  - Scintillating Fibre (Fibre detector)
  - Scintillating Tile (Tile detector)

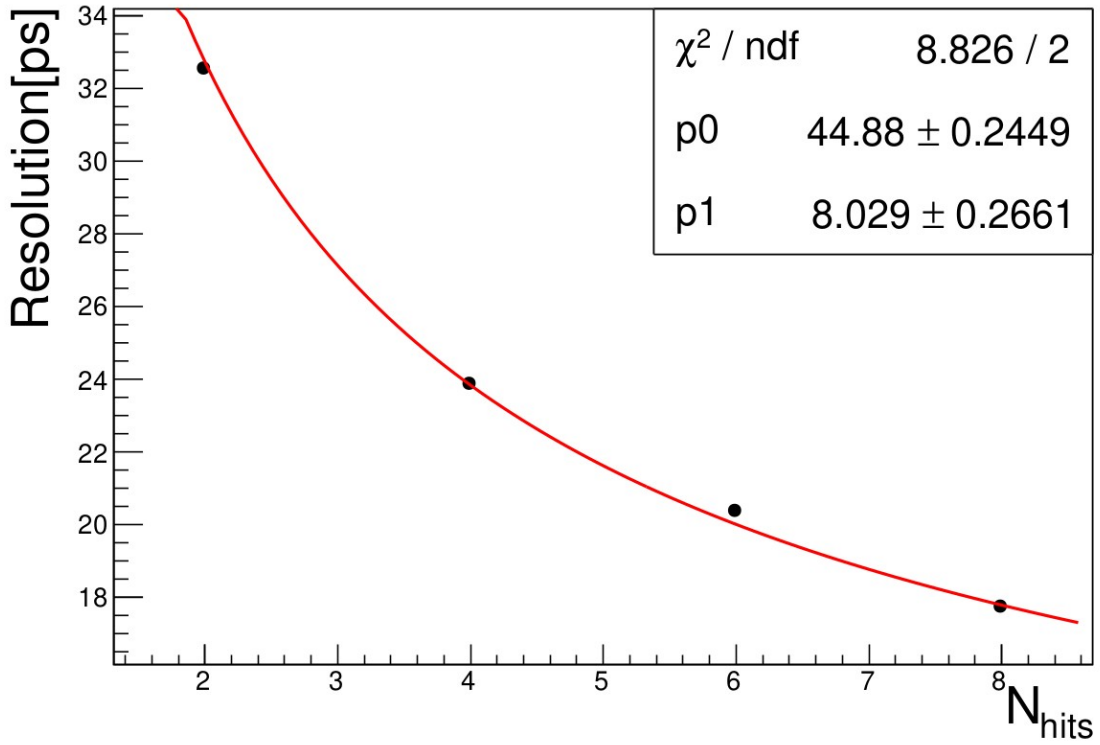


The Mu3e experiment (Phase 1)



- ~ 10^8 muon/s on the target
- Vertex resolution ~ 0.5 mm
- Momentum resolution < 1 MeV
- Timing resolution < 500 ps (Fibre) and < 100 ps (Tile)

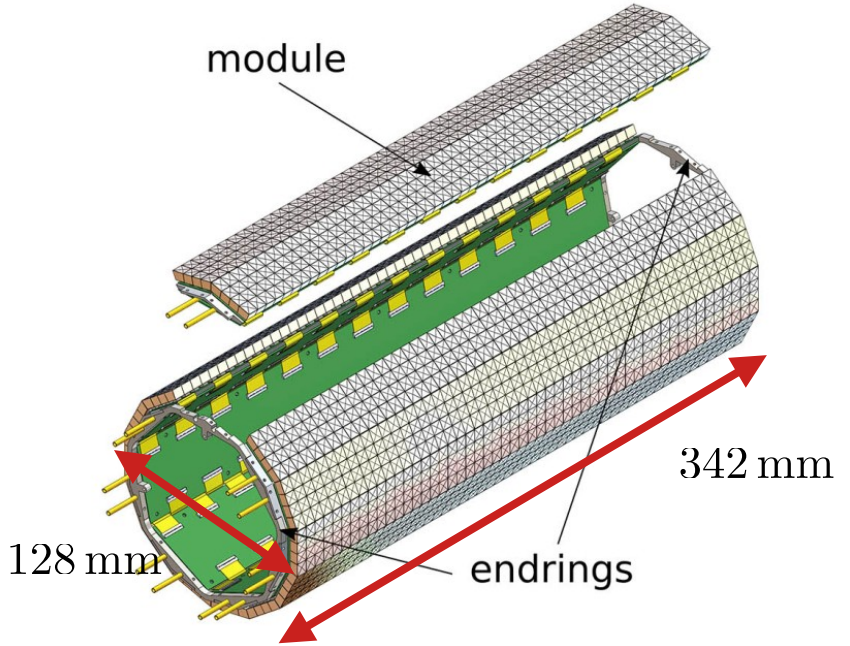
The Mu3e Tile detector

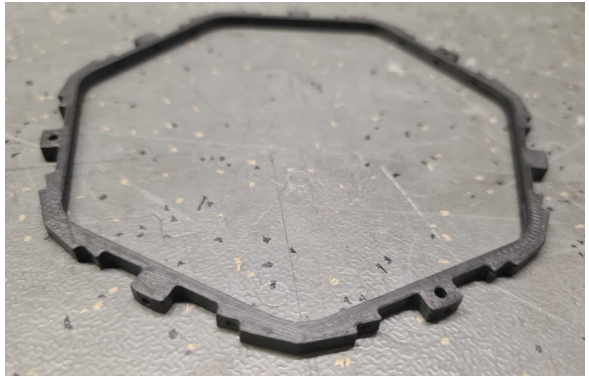


- Single channel timing resolution ~ 45 ps
- Resolution ~ 20 ps for high-multiplicity events

The Mu3e Tile detector

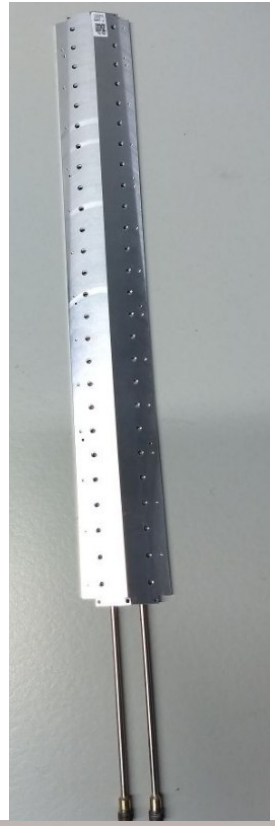
- **Recurl station** (2)
  - 7 modules per station
  - mounted on beampipe
    - 3D-printed PEEK endrings
- **Tile module** (14)
  - 26 tile matrices per module
  - readout electronics board (TMB)
    - 13 ASICs (MuTRiG)
  - support structure & liquid cooling
- **Tile matrix** (364, 182 for 1st station)
  - ~ 25 x 25 mm²
  - 16 channels (tiles+SiPMs)
  - SIPMs: 3x3 mm²
  - Tiles: 6x6x5 mm² (plastic scintillator)

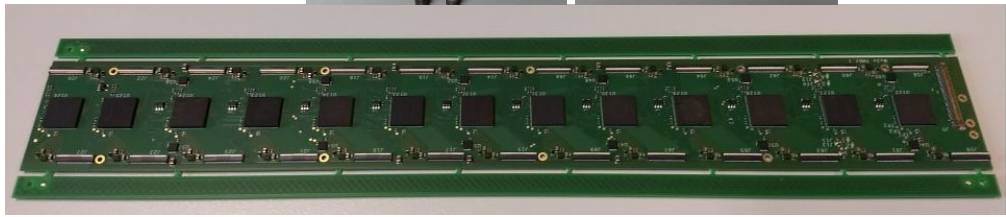




The Mu3e Tile detector

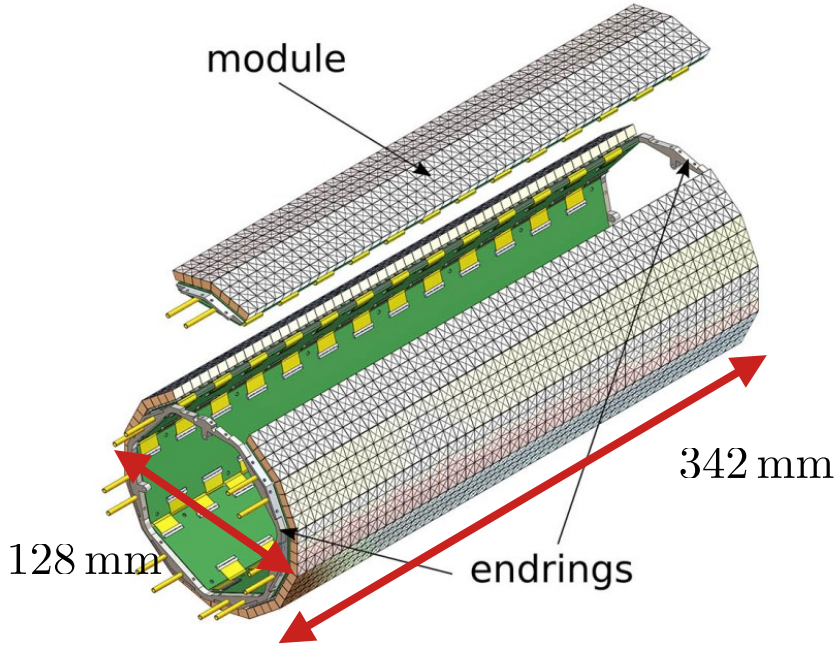
- **Recurl station** (2)
  - 7 modules per station
  - mounted on beampipe
    - 3D-printed PEEK endrings
- **Tile module** (14)
  - 26 tile matrices per module
  - readout electronics board (TMB)
    - 13 ASICs (MuTRiG)
  - support structure & liquid cooling
- **Tile matrix** (364, 182 for 1st station)
  - ~ 25 x 25 mm²
  - 16 channels (tiles+SiPMs)
  - SIPMs: 3x3 mm²
  - Tiles: 6x6x5 mm² (plastic scintillator)



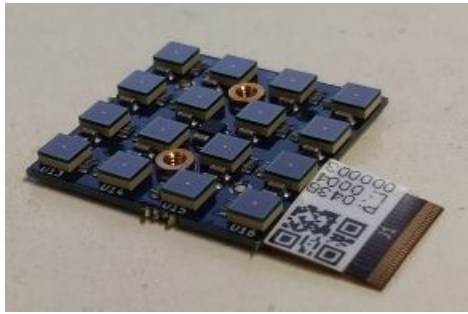


The Mu3e Tile detector

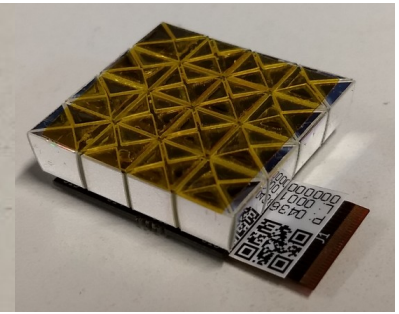
- **Recurl station** (2)
  - 7 modules per station
  - mounted on beampipe
    - 3D-printed PEEK endrings
- **Tile module** (14)
  - 26 tile matrices per module
  - readout electronics board (TMB) **– 14%**
    - 13 ASICs (MuTRiG)
  - support structure & liquid cooling **– 100%**
- **Tile matrix** (364, 182 for 1st station)
  - ~ 25 x 25 mm² **– 56% (~25% tested)**
  - 16 channels (tiles+SiPMs)
  - SIPMs: 3x3 mm² **– 56%**
  - Tiles: 6x6x5 mm² (plastic scintillator)



SIPM matrix

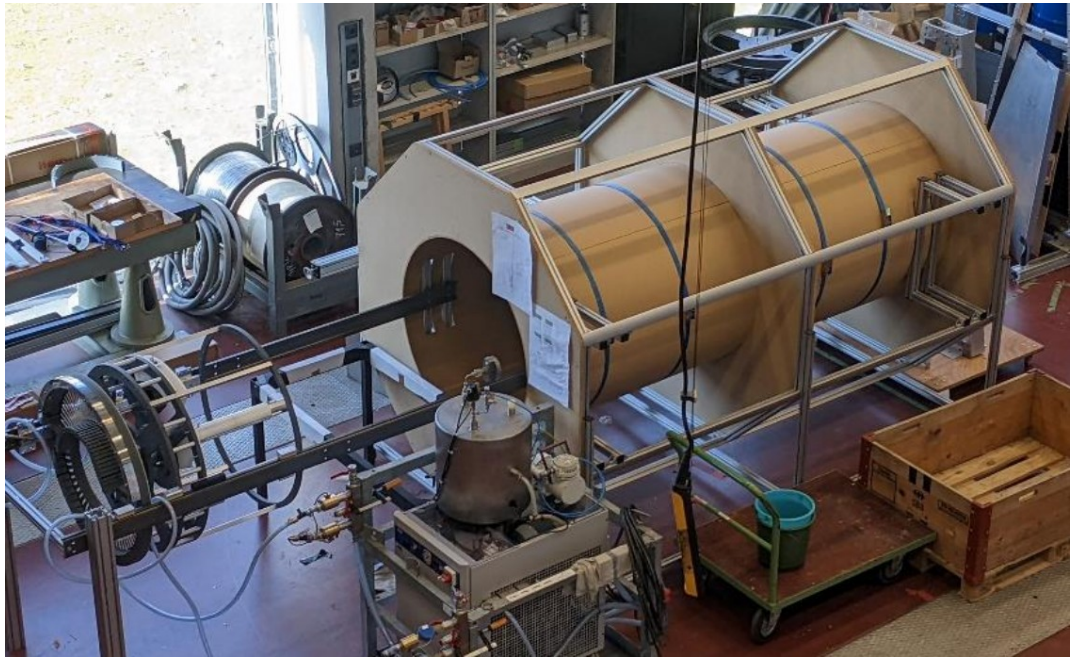


Tile matrix



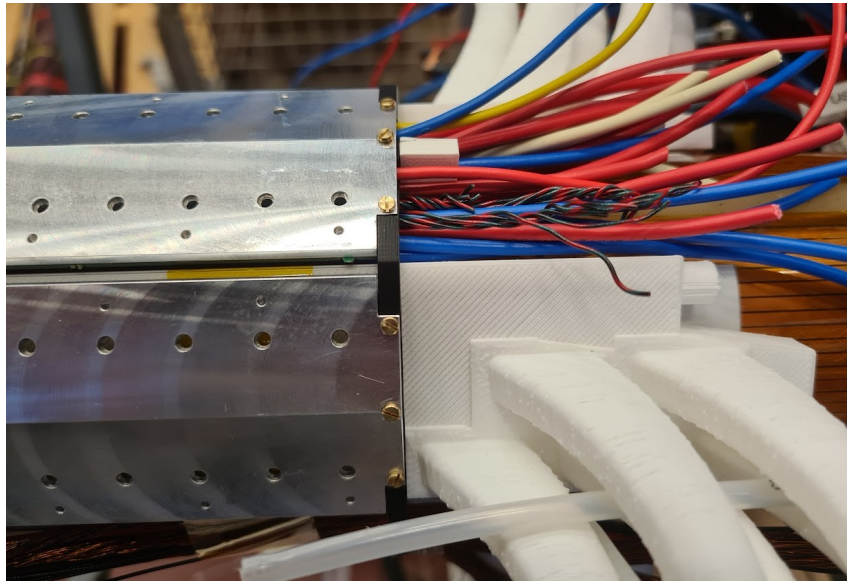
Detector integration

- Integration of one station into the experiment — mid 2024
- Limited space for installation of detector cables and pipes
  - Restricted due to beam pipe and other services
- Full-size mock-up in Heidelberg for testing
  - Cabling and mechanics
  - Cooling
  - Tile detector integration
- QA of the produced components of the detector
  - SIPM matrices
  - Tile matrices
  - MuTRiGs
  - Tile modules

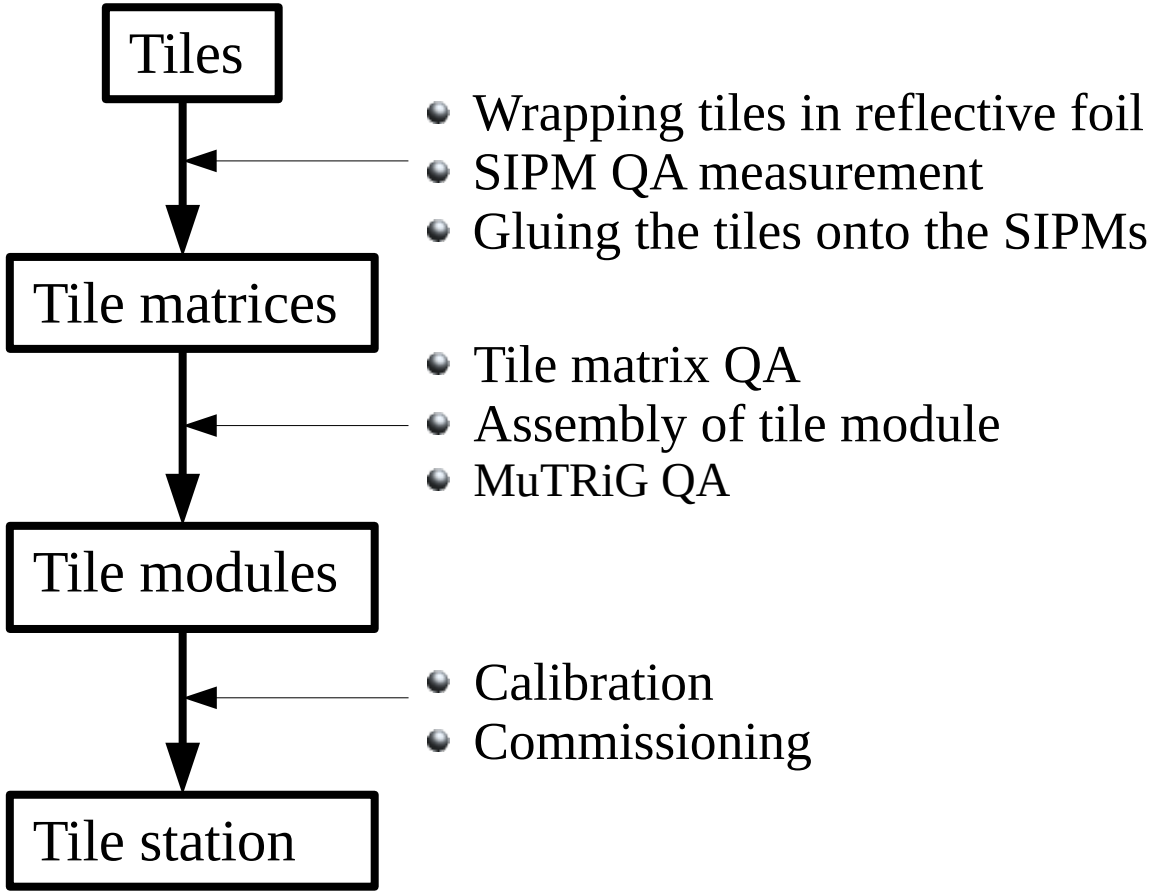


Detector integration

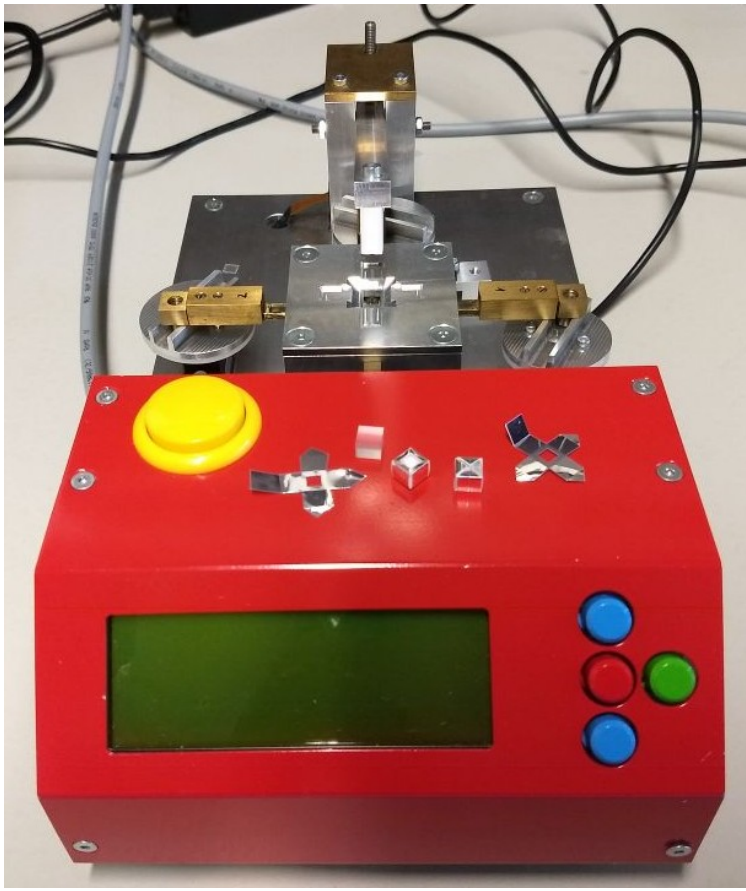
- Integration of one station into the experiment — mid 2024
- Limited space for installation of detector cables and pipes
  - Restricted due to beam pipe and other services
- Full-size mock-up in Heidelberg for testing
  - Cabling and mechanics
  - Cooling
  - Tile detector integration
- QA of the produced components of the detector
  - SIPM matrices
  - Tile matrices
  - MuTRiGs
  - Tile modules



Production: tile matrix

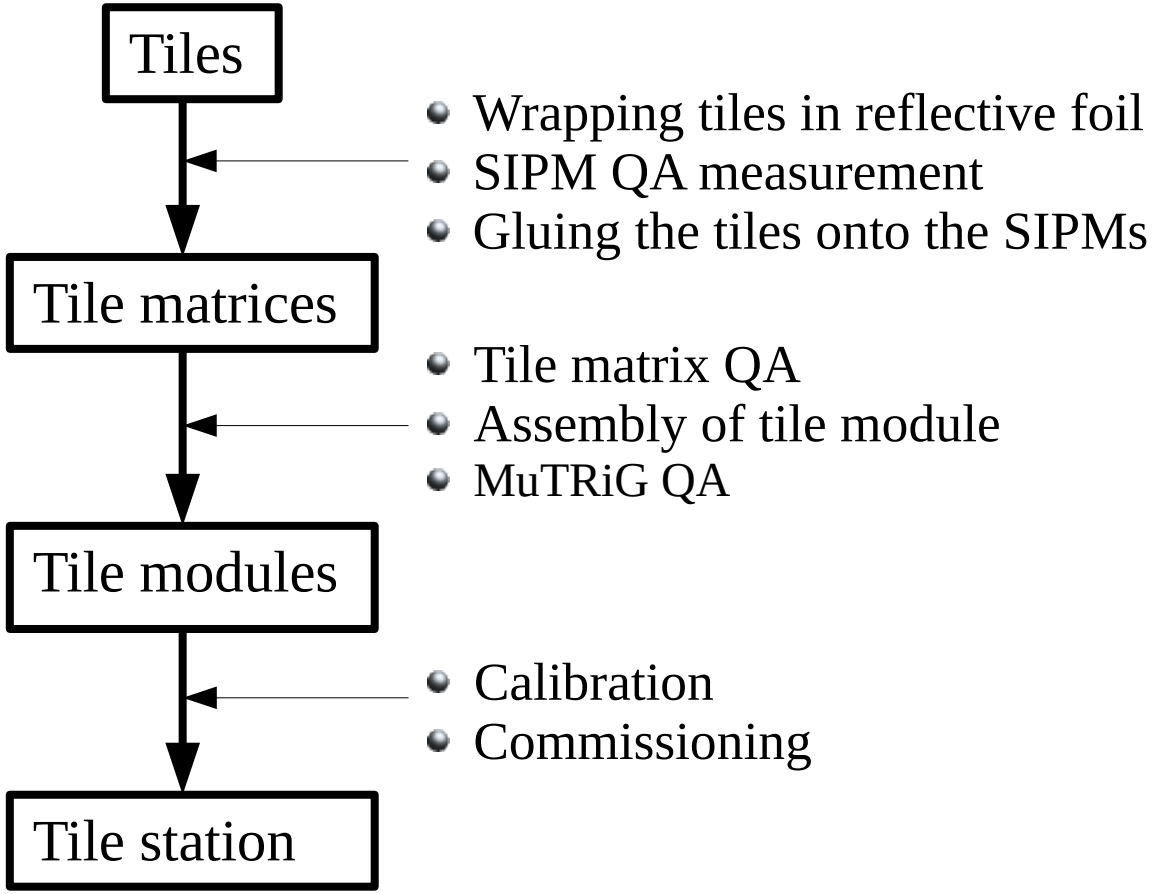


- Wrapping tiles in reflective foil
- SIPM QA measurement
- Gluing the tiles onto the SIPMs
- Tile matrix QA
- Assembly of tile module
- MuTRiG QA
- Calibration
- Commissioning



Wrapping station

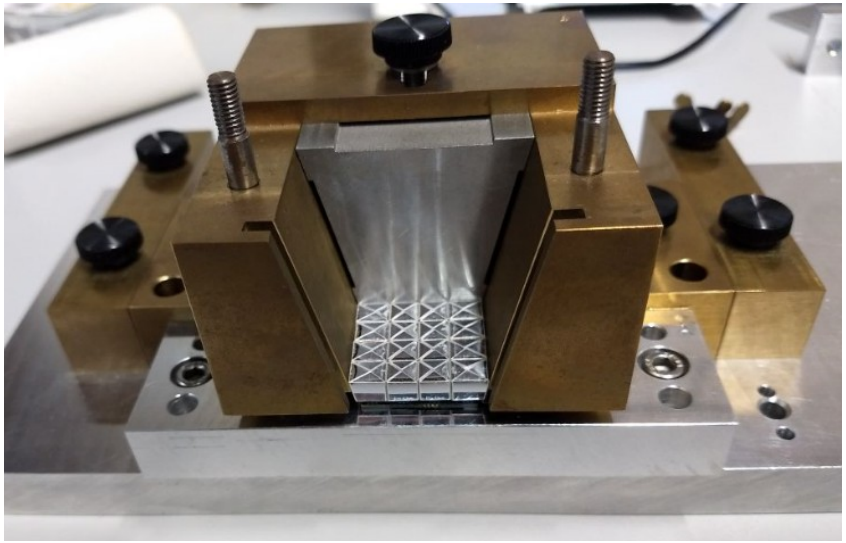
Production: tile matrix



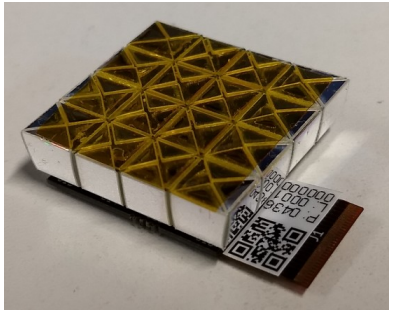
- Wrapping tiles in reflective foil
- SIPM QA measurement
- Gluing the tiles onto the SIPMs

- Tile matrix QA
- Assembly of tile module
- MuTRiG QA

- Calibration
- Commissioning

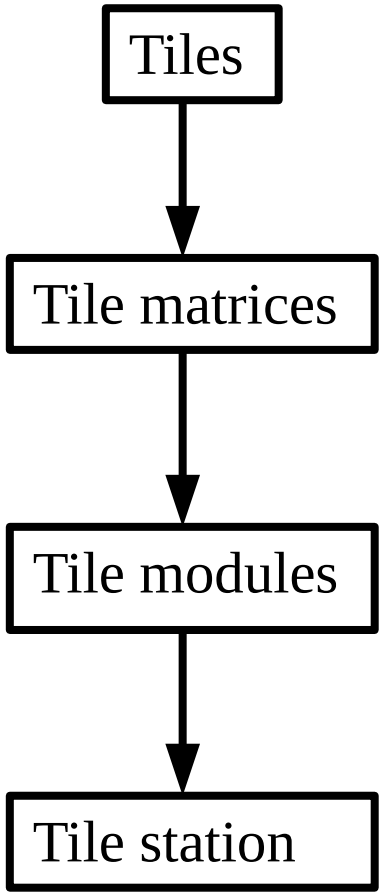


Gluing station



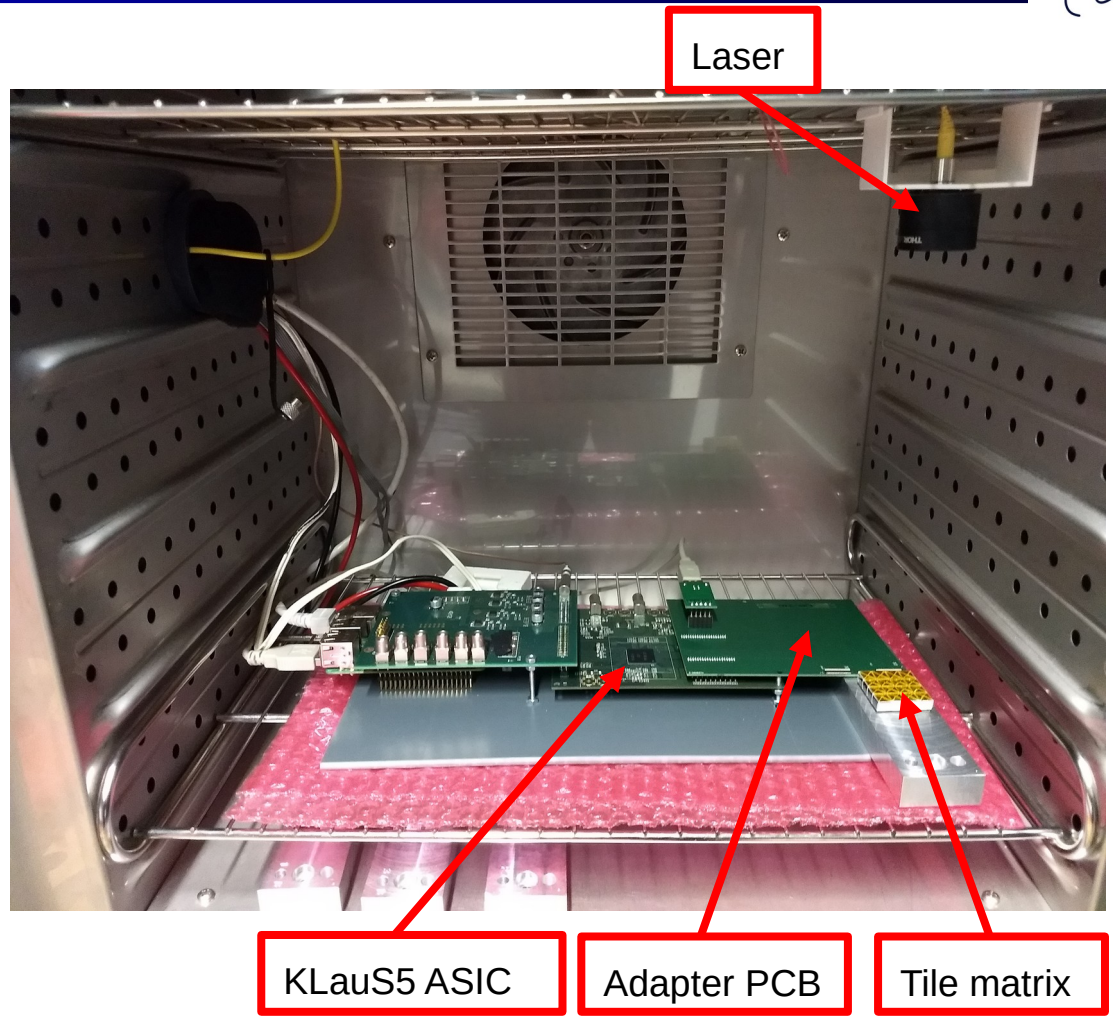
Tile matrix

Matrix characterization & QA



Setup fot QA measurement

- Breakdown voltage & gain measurement for SIPM (Laser)
- Light Yield measurement for tile matrices (Na-22 source)



Matrix characterization & QA

Tiles

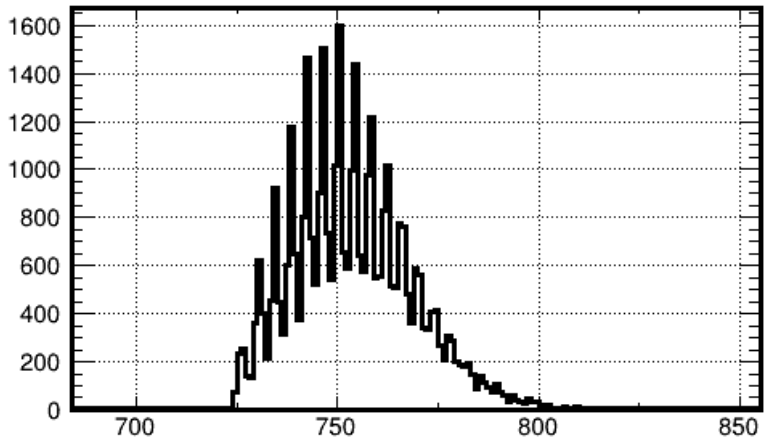
Tile matrices

Tile modules

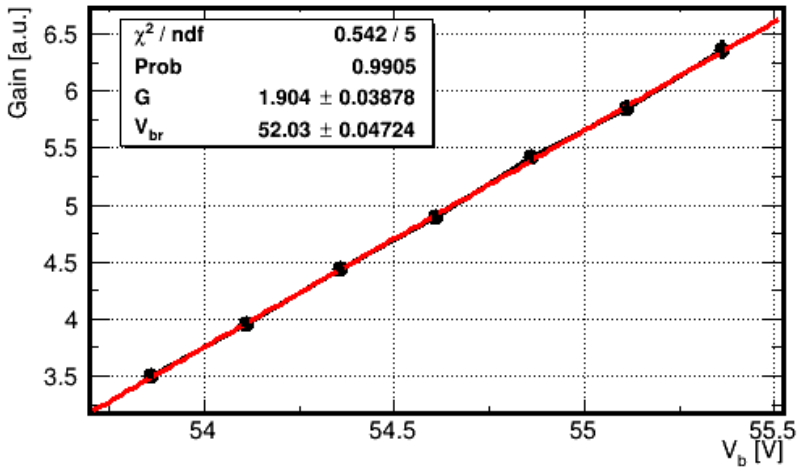
Tile station

QA measurement:
SiPM matrix

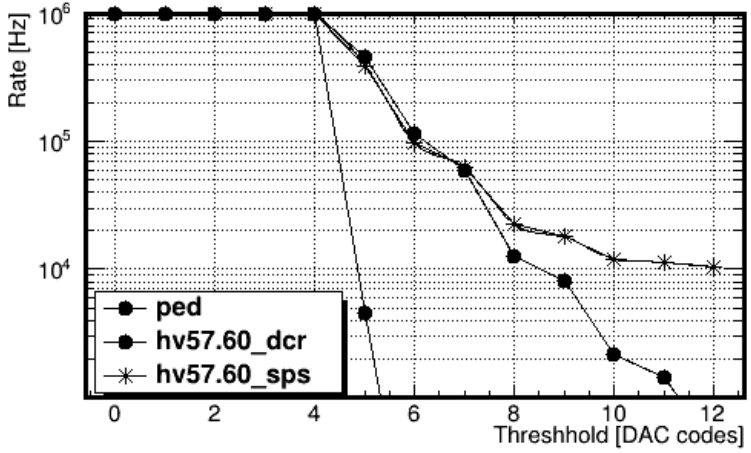
SPS



Gain fit



Noise rates



Matrix characterization & QA

Tiles

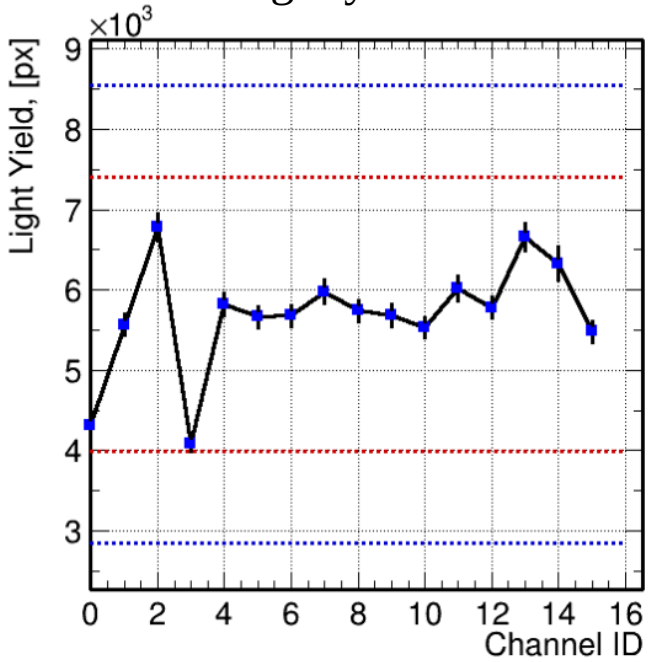
Tile matrices

Tile modules

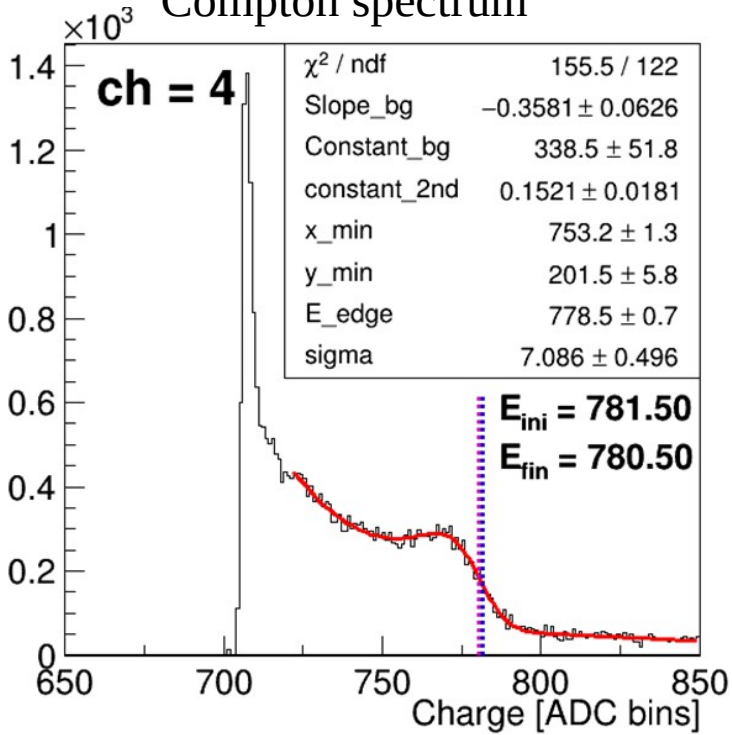
Tile station

QA measurement:
Tile matrix

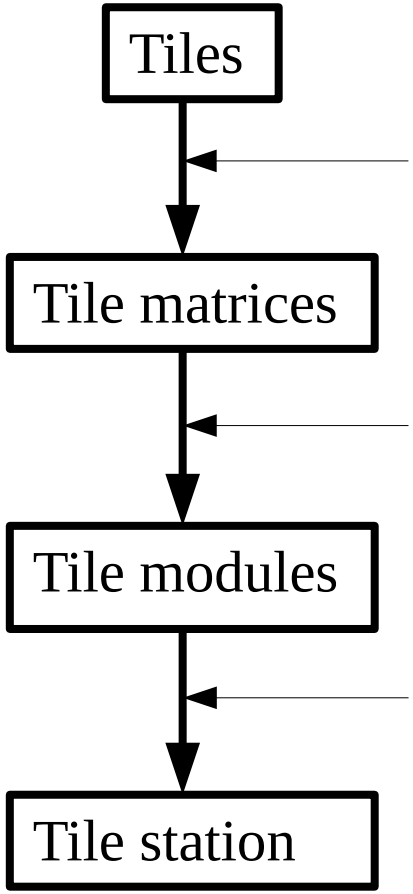
Light yield



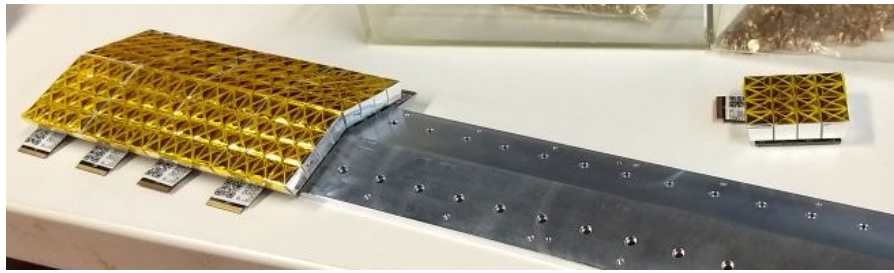
Compton spectrum



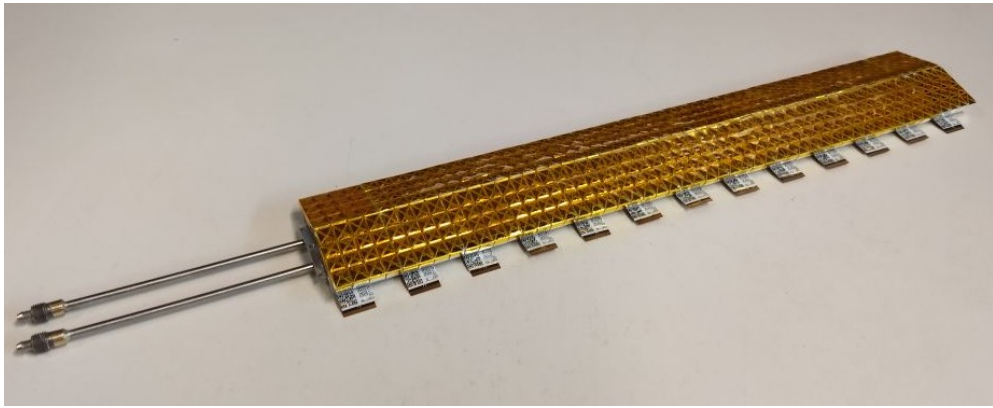
Production: tile module



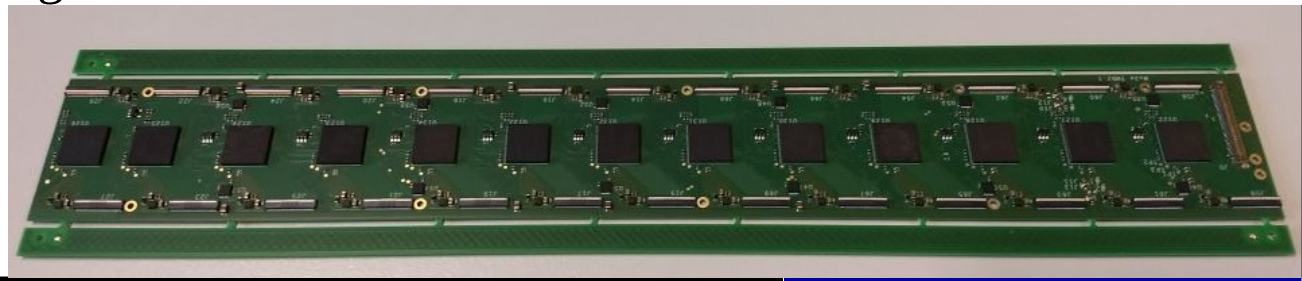
- Wrapping tiles in reflective foil
- SIPM QA measurement
- Gluing the tiles onto the SIPMs



- Tile matrix QA
- Assembly of tile module
- MuTRiG QA



- Calibration
- Commissioning



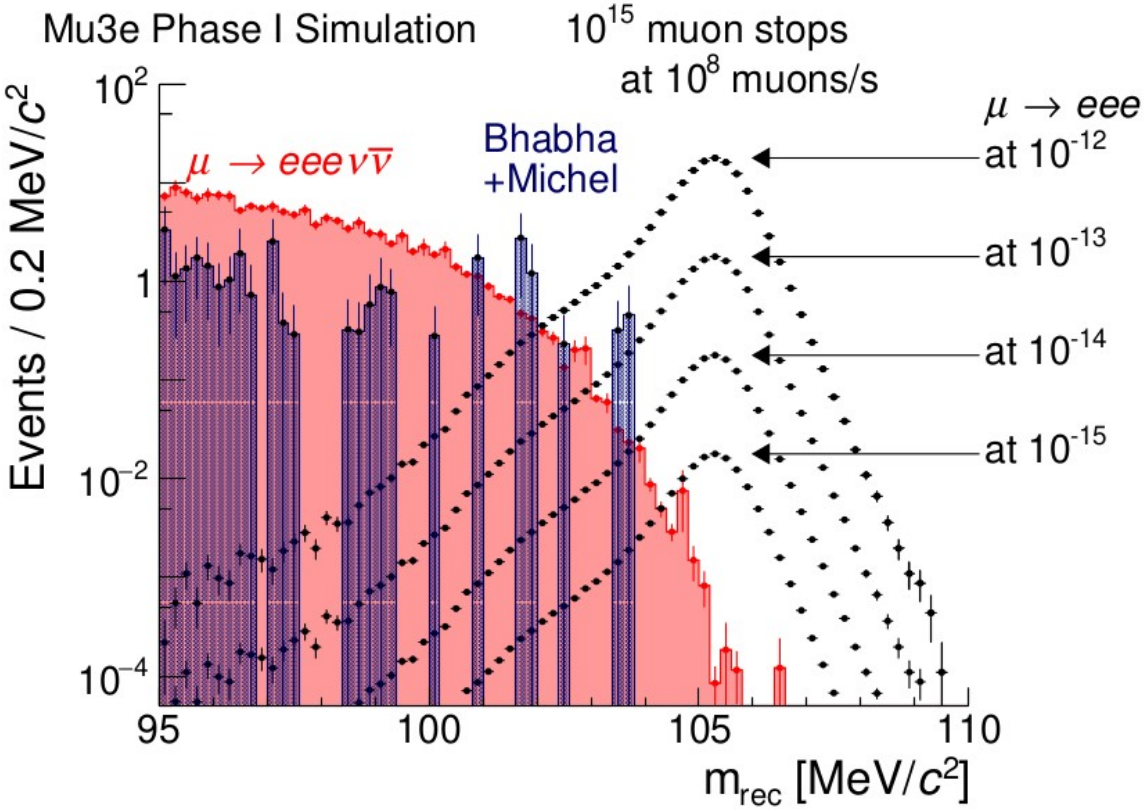
Conclusions & Outlook

- Designs of all detector components are finalized
- Production of detector components is on-going
- Characterization and QA of the components is under way
- Outlook:
  - Assembly of the tile modules
  - Calibration of the modules
  - Commissioning
  - Integration of one station into the experiment - mid 2024

Conclusions & Outlook

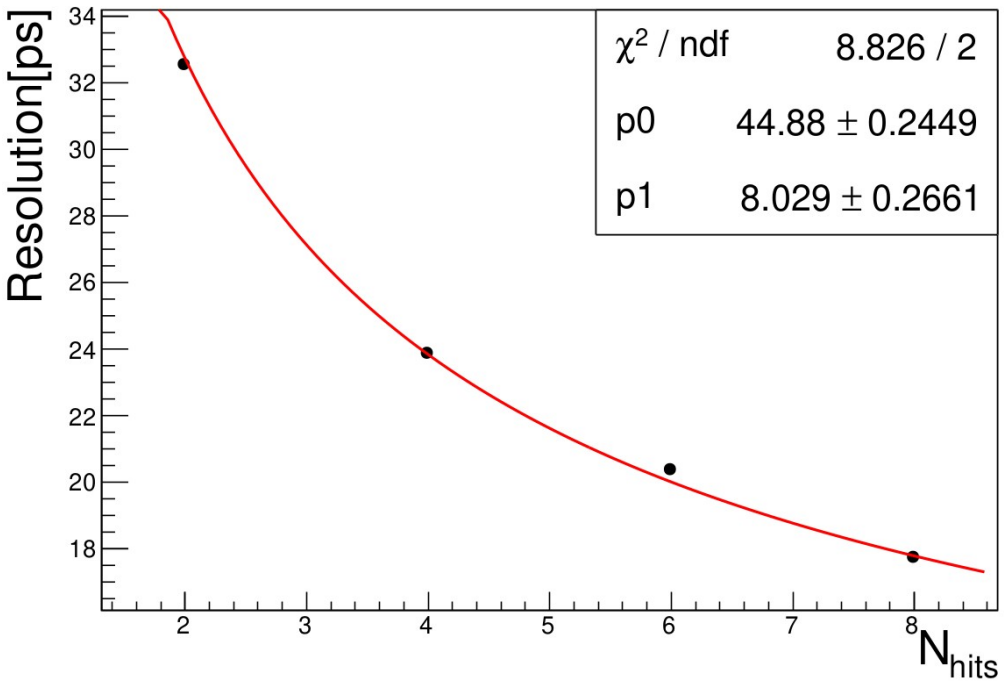
Thank you for your attention!

BackUp



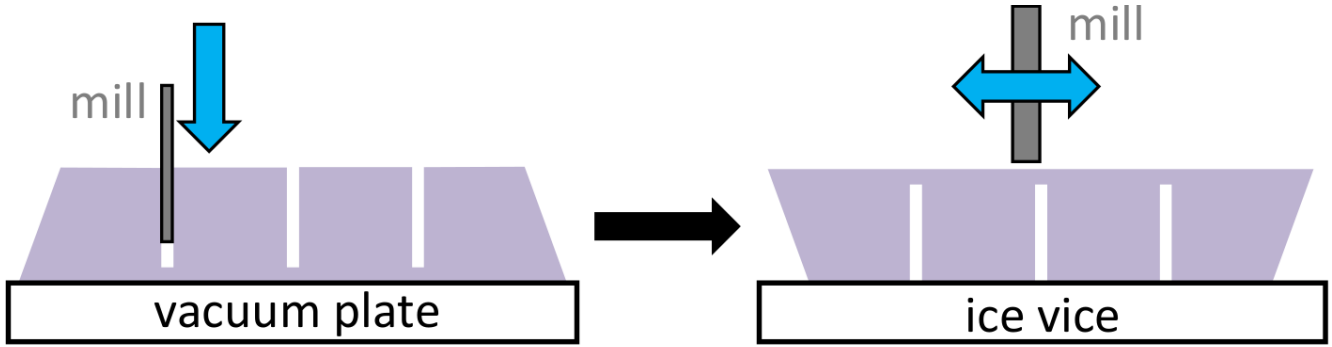
- invariant mass for signal events at various branching fractions and events from radiative decays with internal conversion
- accidental background from combinations of Bhabha pairs and Michel electrons
- The center-of-mass momentum is required to be < 4 MeV/c

BackUp



$$\sigma_t(N_{hits}) = \sigma_t^{single}/\sqrt{N_{hit}} \oplus \sigma_t^{const}$$

- Single channel timing resolution ~ 45 ps
- Resolution ~ 20 ps for high-multiplicity events
- Even-odd analysis: hits are grouped based on channel position and time difference



- Large-scale tile production using ice-vice system
- Small tiles are difficult to mill/polish
- Freeze-clamp to a plate during machining (-10°C)
- Cut out full matrices from scintillator plate
- production time per matrix < 30 minutes