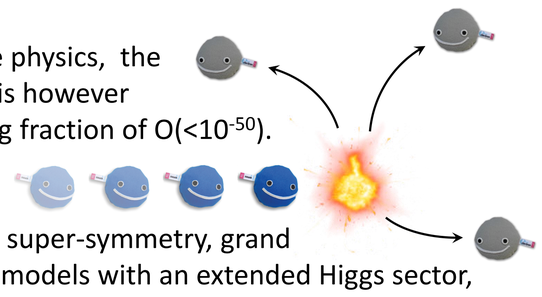
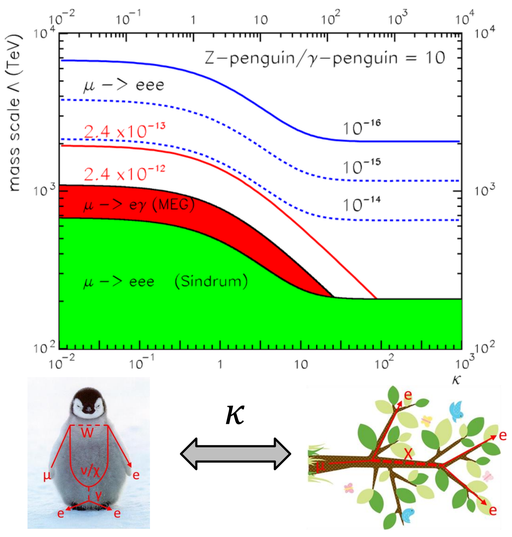
The Mu3e Tile Detector

KIRCHHOFF-INSTITUT FÜR PHYSIK

The μ→eee Decay

In the Standard Model of elementary particle physics, the decay μ→eee can occur via lepton mixing. It is however suppressed to an unobservable low branching fraction of O(<10^{-50}). Any observation of μ→eee would be a clear signal for new physics, and many models predict enhanced lepton flavor violation, e.g. super-symmetry, grand unified models, left-right symmetric models, models with an extended Higgs sector, large extra dimensions etc. Since the LFV proceeds via virtual particles – either in penguin loops or at tree level, the μ→eee decay allows to probe mass scales far beyond the reach of direct searches, like at the LHC.





Signal
- Three coincident electron tracks from the same vertex with $\Sigma E_e = m_\mu$

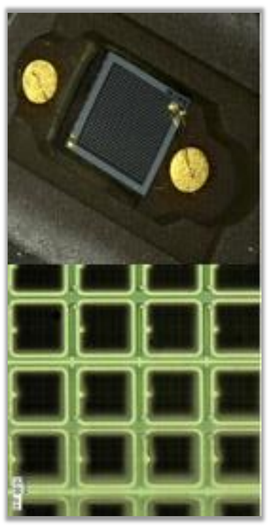
Backgrounds
- Radiative decay with internal conversion μ→eeevv (BR 3.4 × 10-5)

⇒ **Best possible momentum resolution**

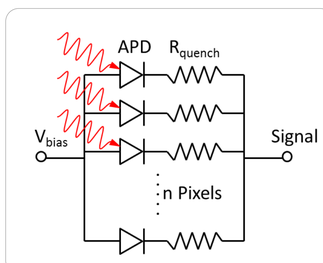
- Accidental coincidences of tracks from Michel decays with electron-positron pairs from Bhabha scattering, photon conversion etc.

⇒ **Excellent vertex and timing resolution**

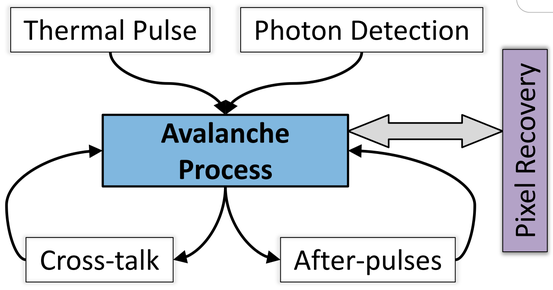
Silicon Photomultipliers (SiPM)



Working principle
- Array of pixels (typ. 100 -10.000 / mm²)
- Pixel signal independent of #photons
- Pixels connected to common output
- #detected photons ↔ #fired pixels



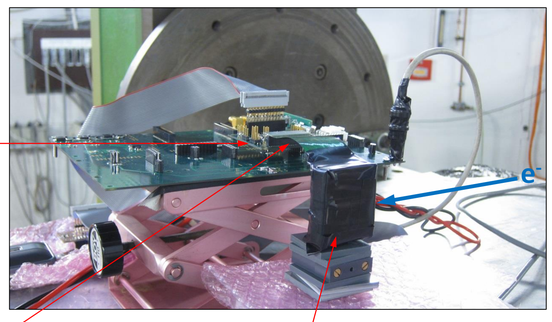
Signal Generation

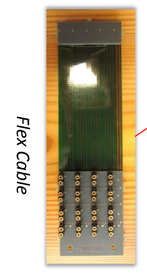


Tile-Detector Prototype

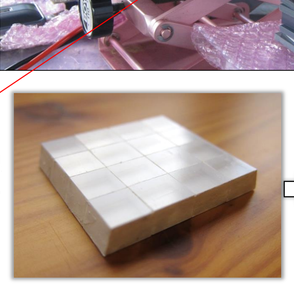
Testbeam Setup @ DESY

STiC Board

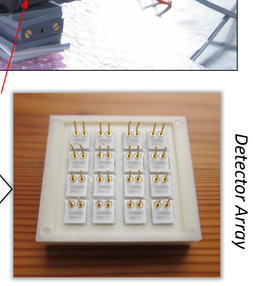




Flex Cable



Tile Array



Detector Array

Detector Requirements
- Time resolution < 100 ps
- Maximum efficiency
  ⇒Minimal signal pileup

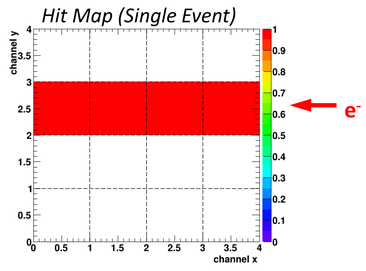
Challenges
- High hit/data-rate O(MHz)
- High radiation dose
- Space constraints

First prototype
- 4x4 channels
- STiC 2 readout chip
- Flex-print connection

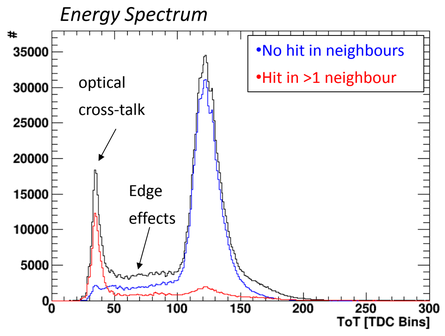
Testbeam Results
- ≈70 ps time resolution
- ≈98% efficiency
- Dead-time ≈150 - 300 ns
  - Pile-up < 3% for phase I
- Optical cross-talk observed

⇒ ***Baseline requirements for phase I fulfilled***
- *Only some minor optimization needed*

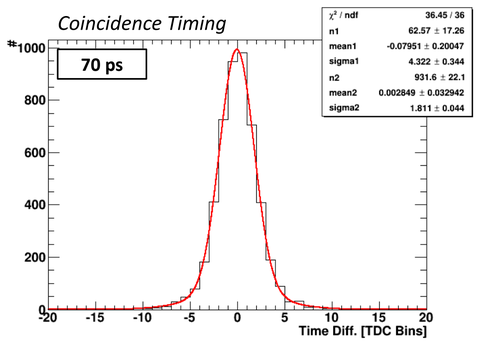
Hit Map (Single Event)



Energy Spectrum



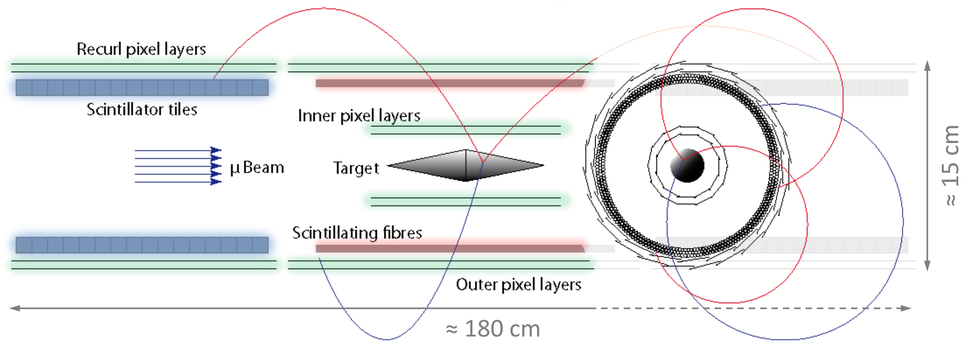
Coincidence Timing



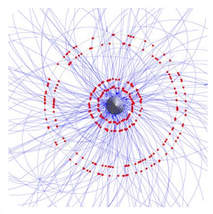
The Mu3e Experiment

Tracking & Vertexing
- Aimed momentum resolution ≈ 0.3 MeV/c^2
- Aimed vertex resolution ≈ 200 μm
- Extremely low material budget required

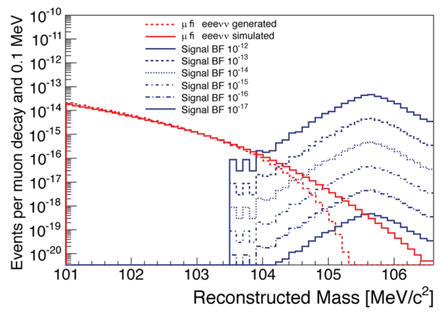
⇒ HV-MAPS, thinned to < 50 μm



High Rates
- High intensity muon beam @ PSI
- Phase I: 1x10^8 μ/s
- Phase II: 2x10^9 μ/s

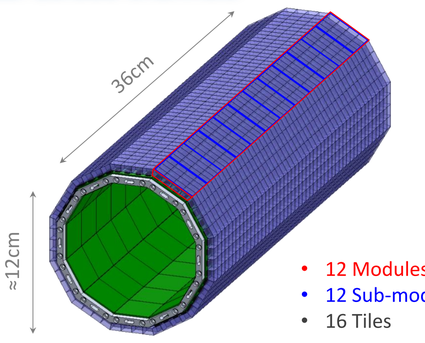


Sensitivity
- Goal: One in 10^{16}
- Pushes current limits by factor 10^4



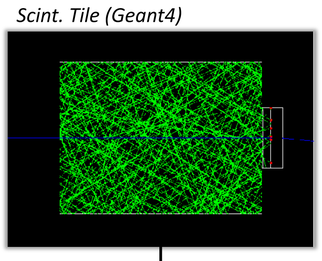
Timing
- Aimed time resolution < 100 ps
- Fibre tracker (central region)
- Tile detector (outer region)

Tile Detector
- Scintillator tiles – 7.5x8.5x5 mm^3
- **Silicon Photomultiplier (SiPM) readout**
- Ca. 10.000 channels

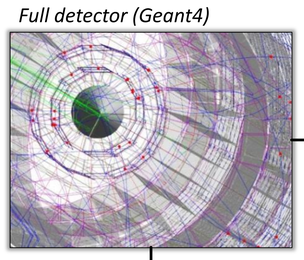


Simulation Framework

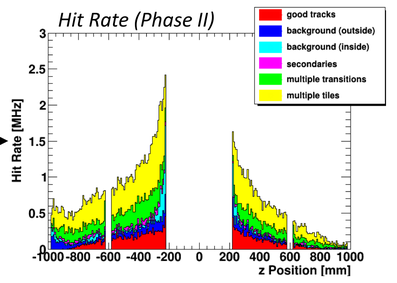
Scint. Tile (Geant4)



Full detector (Geant4)



Hit Rate (Phase II)



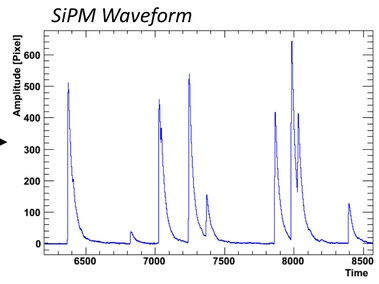
Detector Simulation
- Single tile sim. (Geant4)
  ⇒Optical properties
- Full detector sim. (Geant4)
  ⇒Hits linked to SiPM sim.
  ⇒Signal waveform for every channel!

⇒*Optimize detector design & study performance*

GosSiP – Generic framework for the simulation of Silicon Photomultipliers

SiPM Simulation

SiPM Waveform

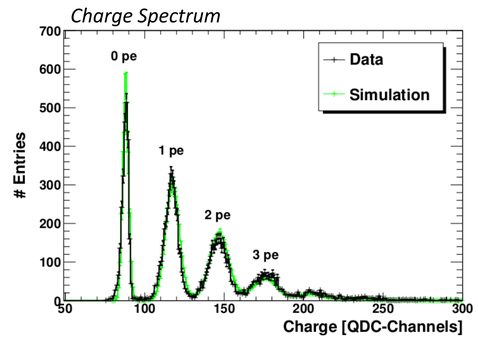


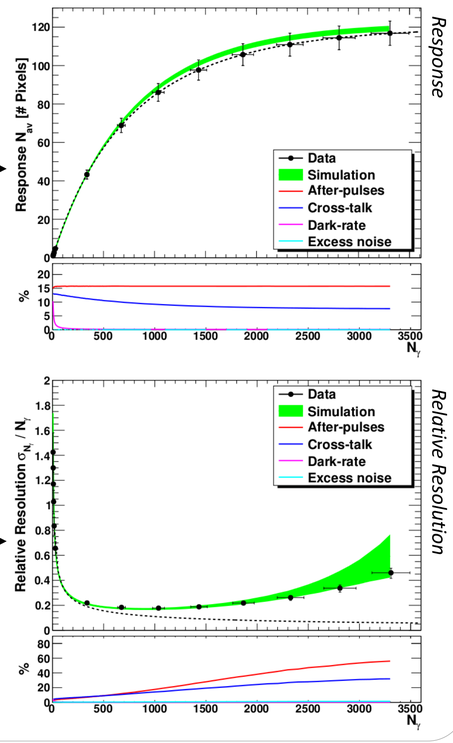
The SiPM response is complex:
- Correlated & uncorrelated noise
- Pixel recovery effects
- Depends on light spot properties

⇒ Monte Carlo model needed

GosSiP
- Detailed SiPM simulation
- Input: Basic SiPM & light pulse parameters
- Model for full dynamic range

Charge Spectrum





Contact: Patrick Eckert – patrick.eckert@kip.uni-heidelberg.de