Polyimide aging studies for the Mu3e experiment

Thomas Theodor Rudzki for the Mu3e collaboration
Universität Heidelberg – Physikalisches Institut

DPG-Frühjahrstagung, Aachen, 28. März 2019

Polyimide irradiation studies

Motivation:

Polyimide is deemed to be a radiation-hard material

But...

Observations of brittle polyimide in particle physics experiments and aerospace application

➔ Either in inert atmosphere (e.g. helium) or vacuum + ionizing radiation

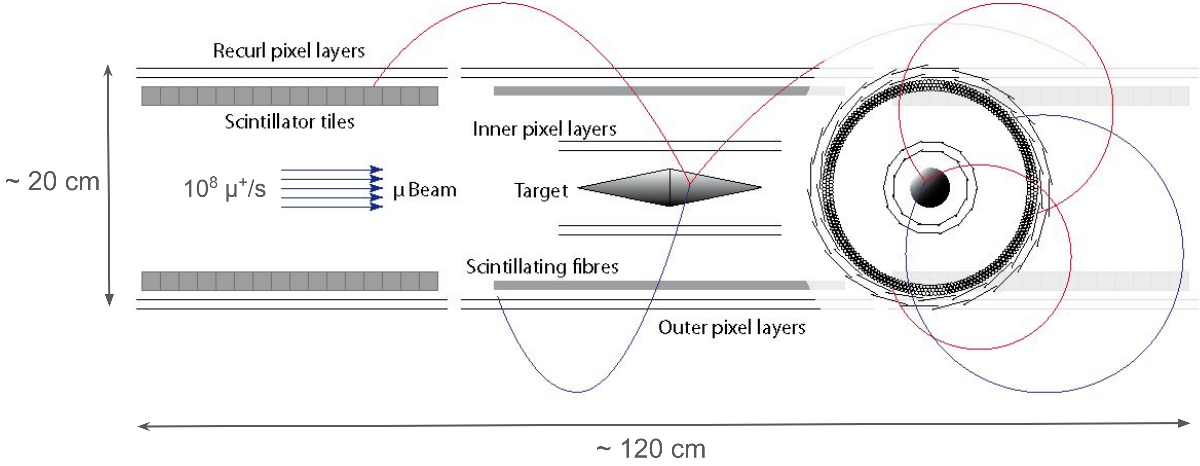
Mu3e:

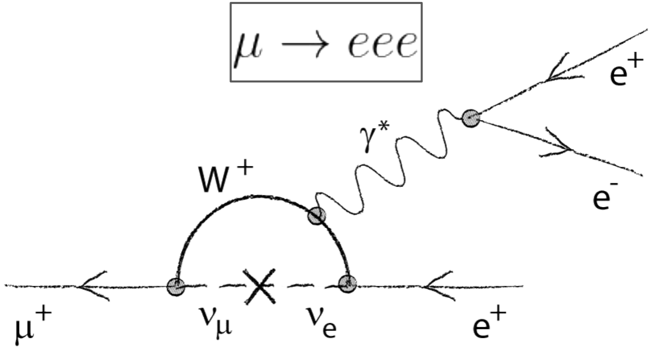
➔ Polyimide serves as support structure of tracking detector

➔ Inert atmosphere (helium) surrounding the material

➔ Irradiation by low-energetic electrons (few MeV)

The Mu3e detector





Aimed sensitivity:

$$\mathcal{B}(\mu \to eee) \leq 10^{-16}$$

Current limit (SINDRUM, 1988):

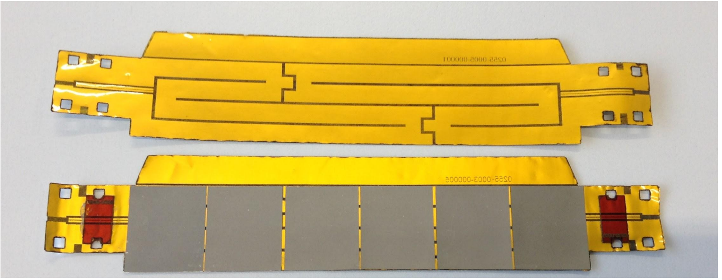
$$\mathcal{B}(\mu \to eee) < 1 \cdot 10^{-12}$$

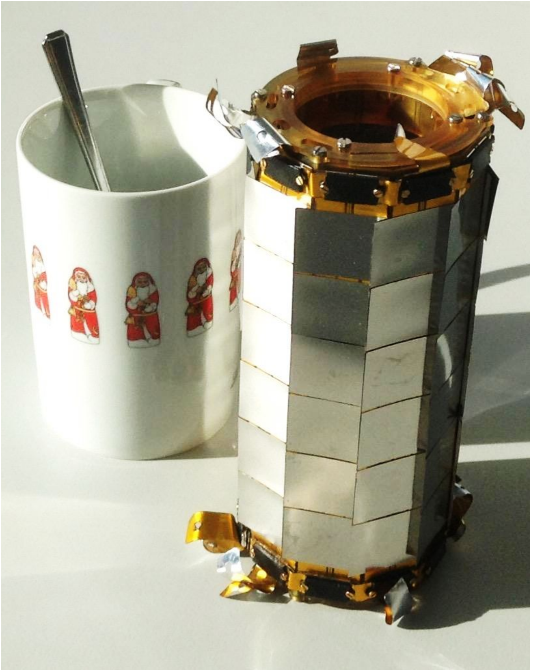
The Mu3e experiment

Background dominated by multiple Coulomb scattering

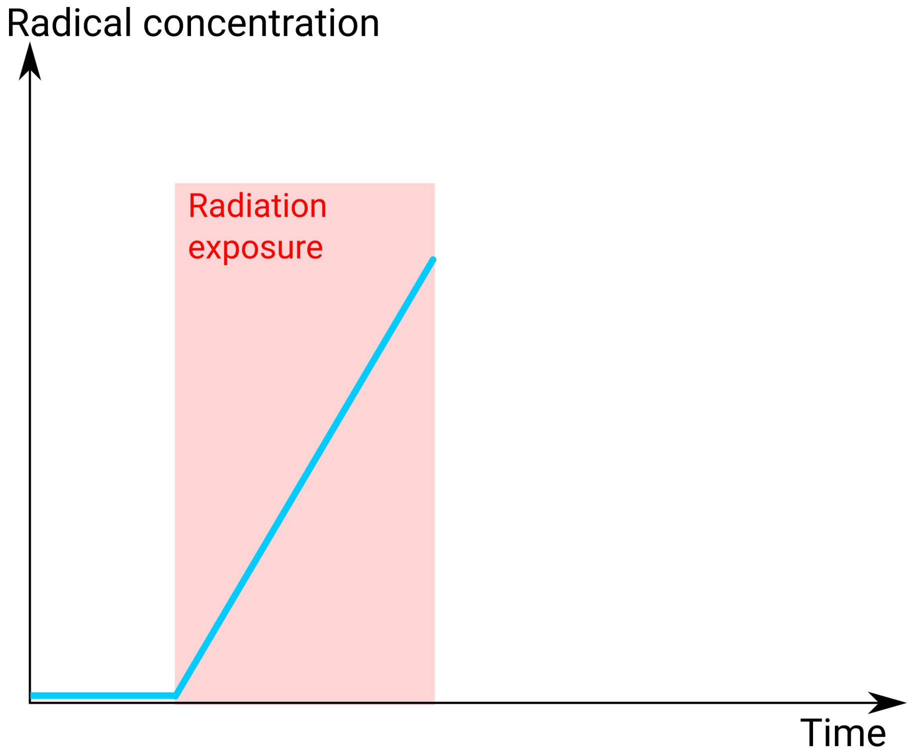
➡ Reduction of material

- Ultra-thin sensors (50 µm HV-MAPS, X/X_0= 0.054 %)
- High-density interconnects as only support structure (polyimide + Al, 50 µm, X/X_0= 0.061 %)
- Gaseous helium as coolant (low Z)



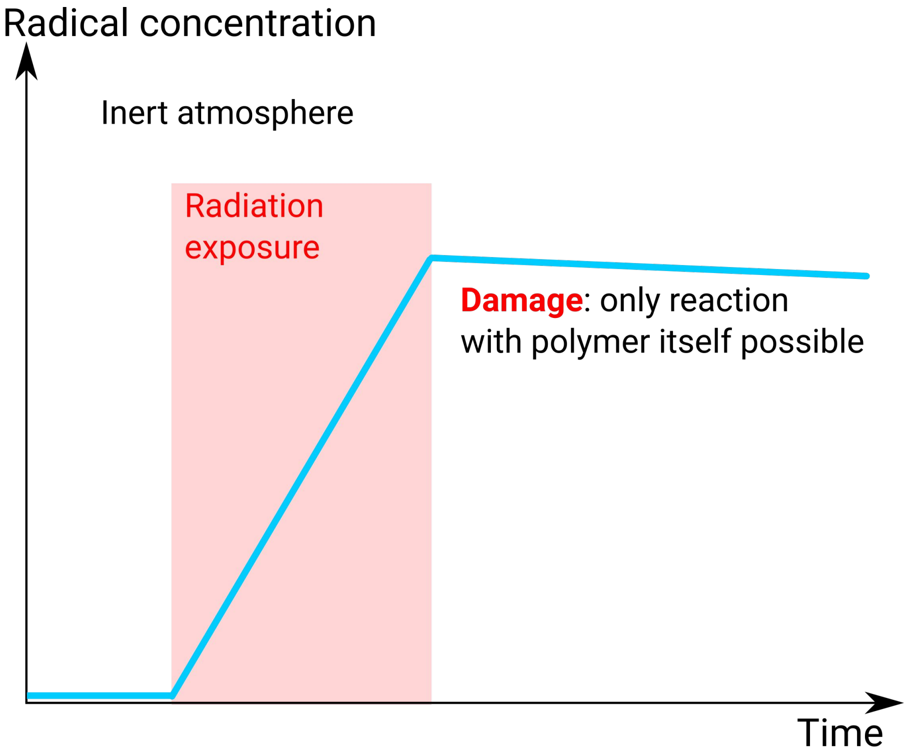


Hypothesis for radiation damage



1. Formation of radicals in irradiated material

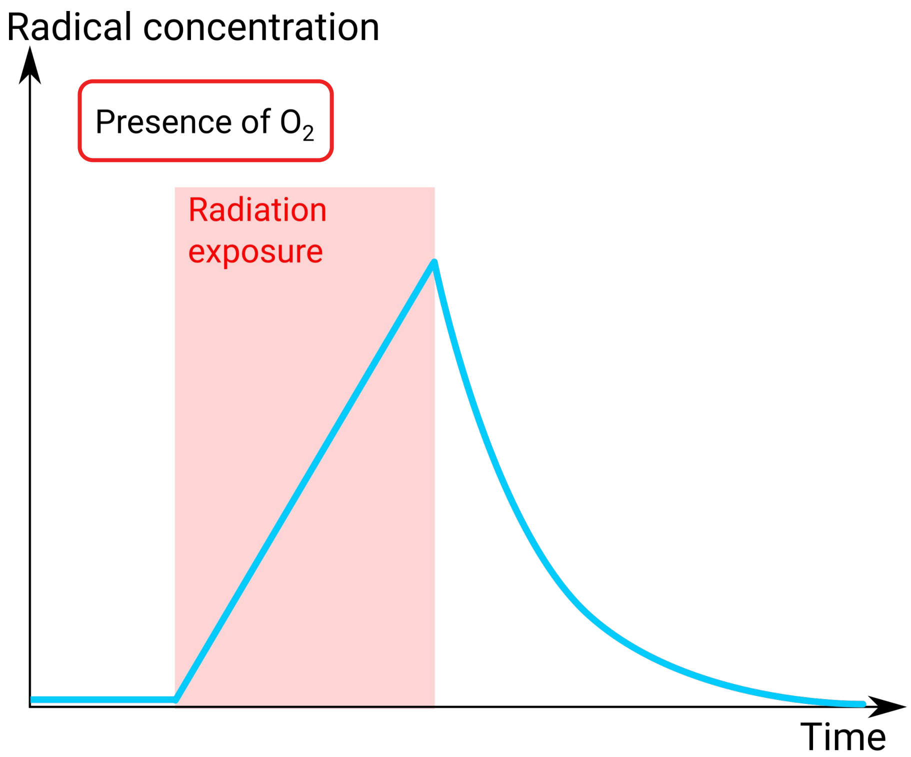
Hypothesis for radiation damage



1. Formation of radicals in irradiated material
2. Reaction of radicals

   Inert atmosphere:
   Radicals decompose material and/or creates cross-links

Hypothesis for radiation damage

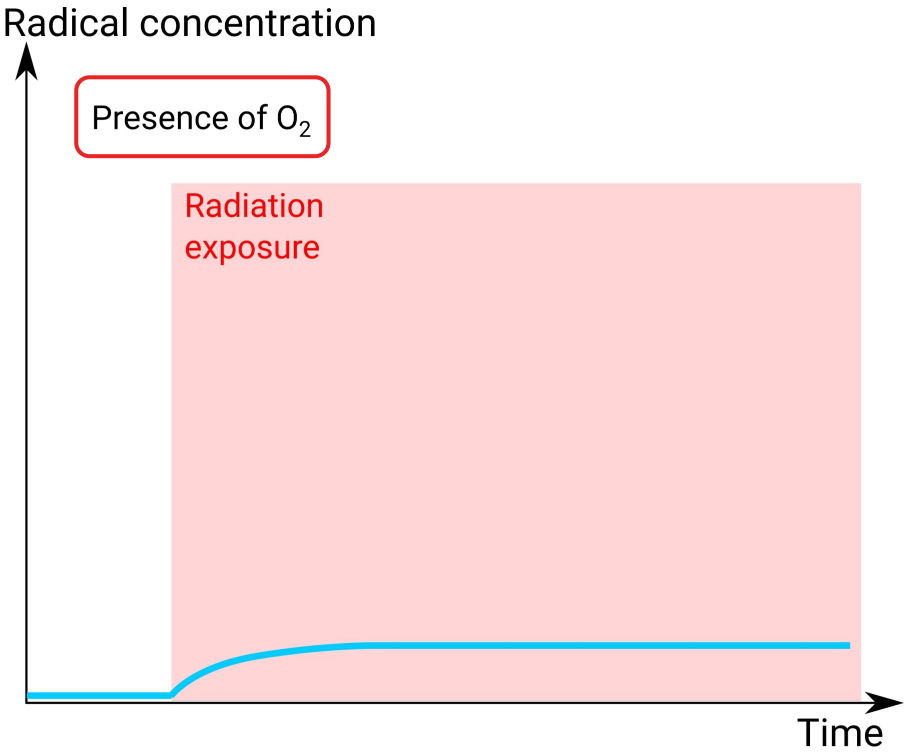


1. Formation of radicals in irradiated material
2. Reaction of radicals

   Inert atmosphere:
   Radicals decompose material and/or creates cross-links

   Oxygenic atmosphere:
   Radicals react with O_2, annealing effect, no decomposition

Hypothesis for radiation damage



1. Formation of radicals in irradiated material
2. Reaction of radicals

   Inert atmosphere:
   Radicals decompose material and/or creates cross-links

   Oxygenic atmosphere:
   Radicals react with O_2, annealing effect, no decomposition

Setup

Goal

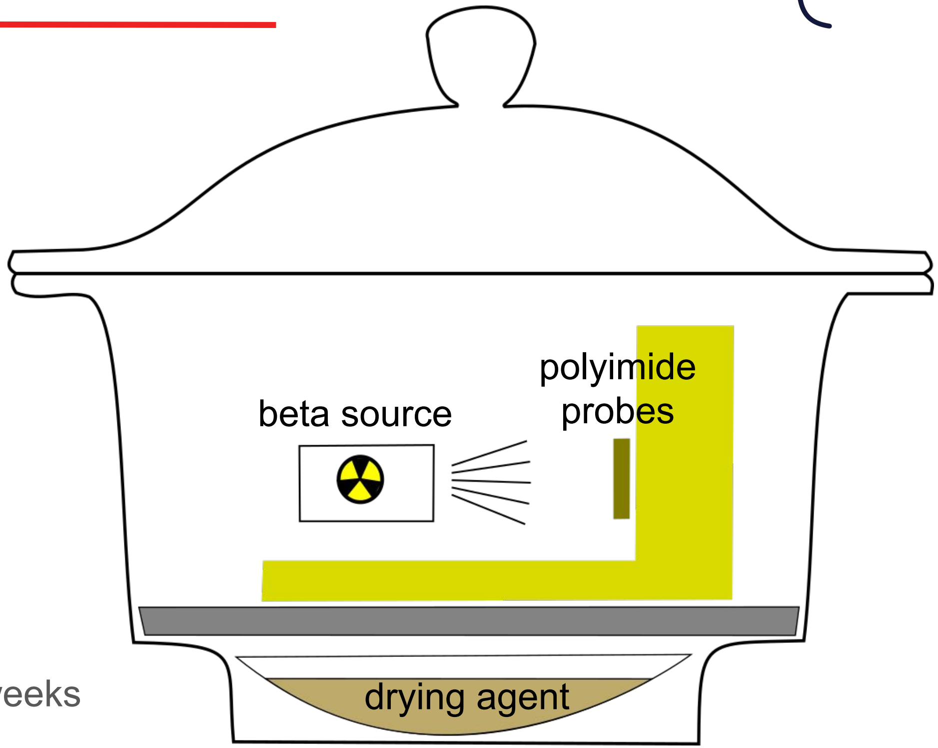
Setup providing controlled conditions:

- inert atmosphere for long time (weeks)
- Use ^{90}Sr beta source for irradiation (~70 MBq)

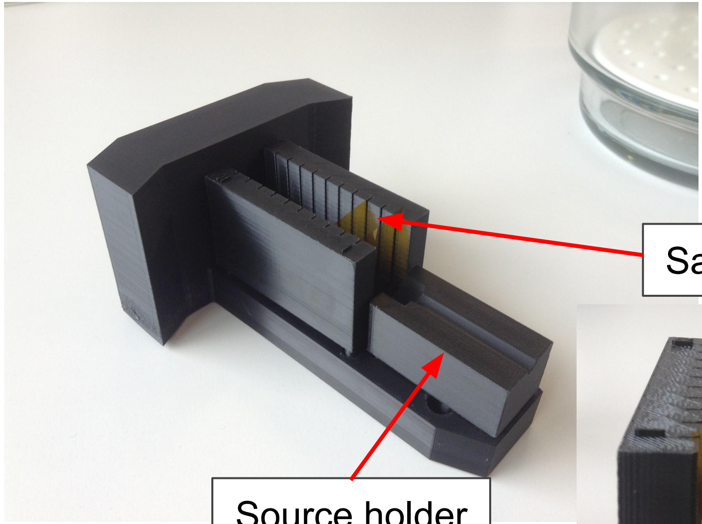
Realization

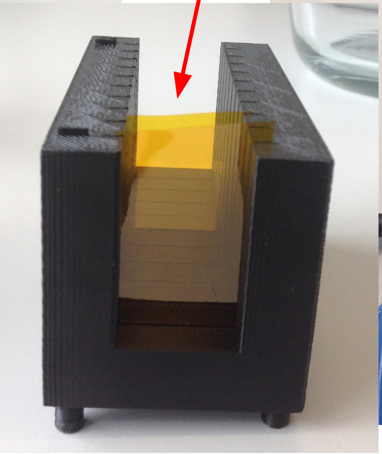
Desiccator setup:

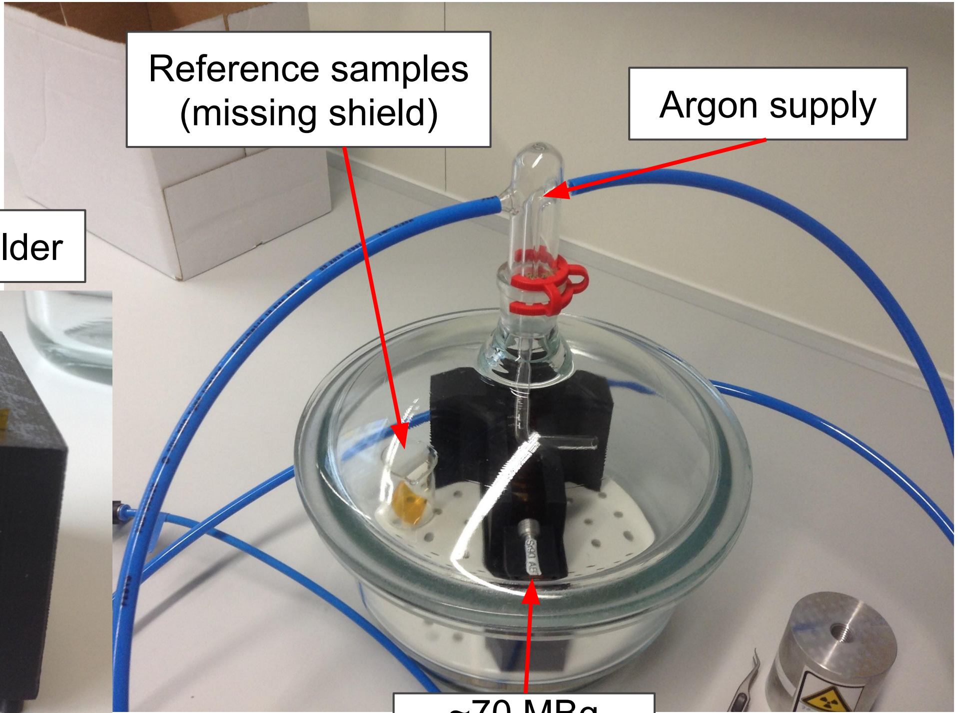
- Filled with inert gas (e.g. Ar, He)
- source and polyimide kept in setup for weeks
- Sample holder for several probes



Setup


Source holder


Sample holder


Reference samples
(missing shield)
Argon supply
~70 MBq
^{90}Sr source

Analysis plan

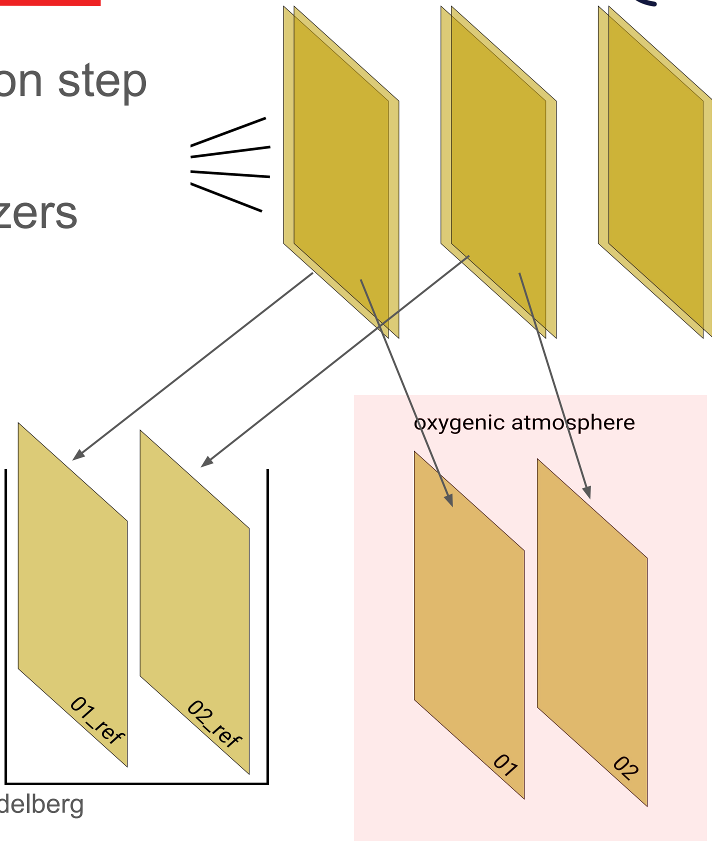
- 10x pairs of samples
- Each pair extracted from sample holder after certain time (1 day, 2 days, …)

  ➡ Various doses
- 1x sample of pair remains **un**irradiated in inert atmosphere
- 1x sample of pair is taken out of desiccator

  ➡ Various waiting times before annealing in oxygenic atmosphere

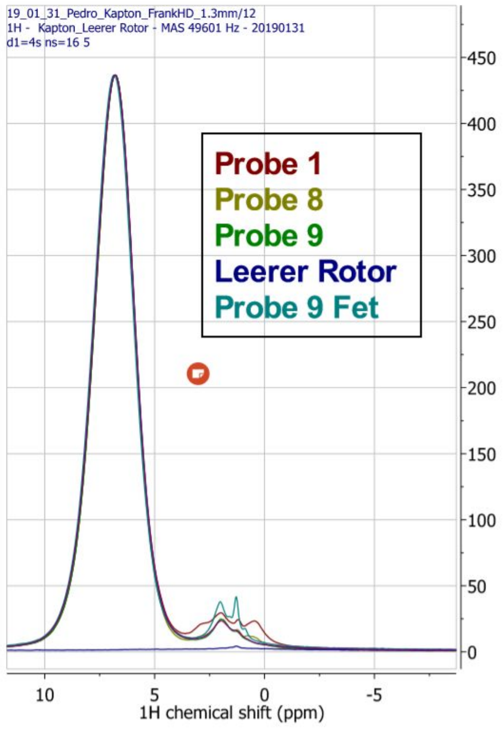
Handling of samples

- Opening lid of desiccator after each irradiation step
- Bottom part is flushed with argon
- The pair of samples is extracted using tweezers
- Separation of the pair
- Minimisation of oxygen/water exposure as much as possible
  - Additional argon flow on extracted samples
  - Fast handling
- Closing setup, flushing with argon



Analysis of irradiated polyimide samples

- Irradiation campaign just started in the week before DPG
  ➡ no results yet
- Analyse chemical changes in material before structural damage
- IR spectroscopy not suited, running into saturation
- NMR spectrum of samples will be taken



Exemplary NMR spectra of polyimide

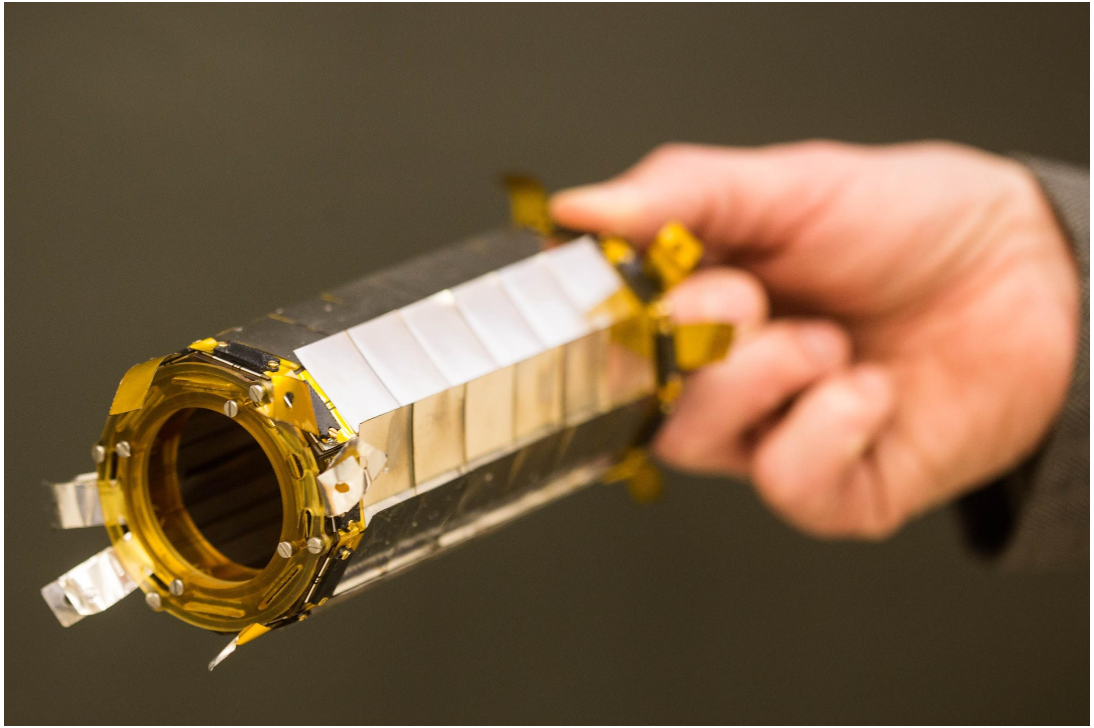
Outlook

- Do we achieve to get brittle polyimide?
  - NMR spectrum of obviously damaged polyimide

    ➡ Endpoint for quantification of radiation damage via NMR
  - If not: tensile strength test (setup?)
- Detailed simulation of ionising dose planned
  - Low-energetic electrons
  - Simulation studies using PENELOPE
- Addition of how much O_2 or H_2O would be needed to prevent polyimide to decompose?

➡ Influence on gas mixture of Mu3e experiment

Thanks for your attention!



Backup

Decay channels of the muon

- $B(\mu \rightarrow e\ \nu_\mu\ \nu_e) \approx 100\ \%$
- $B(\mu \rightarrow e\ \gamma\ \nu_\mu\ \nu_e) = (1{,}4 \pm 0{,}4)\ \%$
- $B(\mu \rightarrow e\ e\ e\ \nu_\mu\ \nu_e) = (3{,}4 \pm 0{,}4) \cdot 10^{-5}$

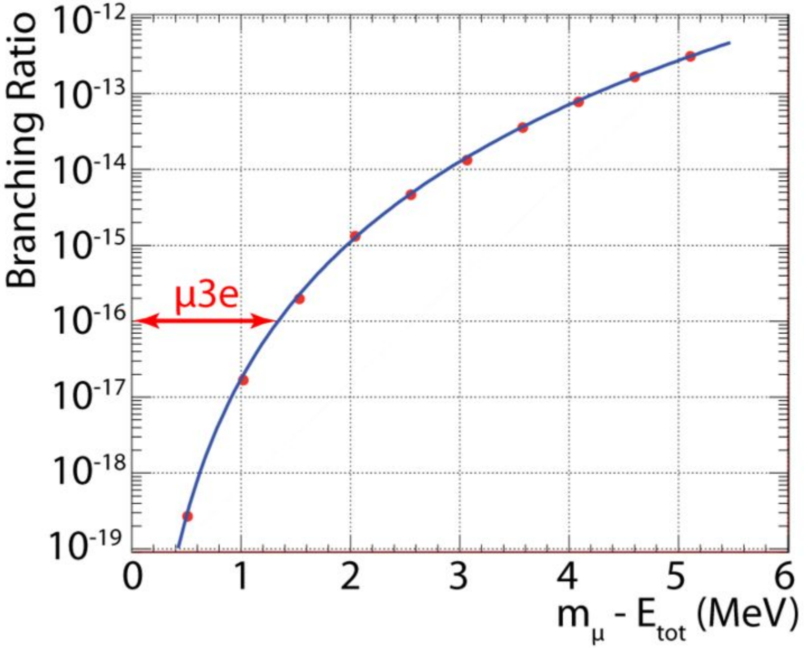
Signal vs. Background

- Good resolution of the invariant mass
  - Suppression of μ → eeevv as signal candidates
  - Resolution of < 1 MeV necessary to reach the aimed sensitivity

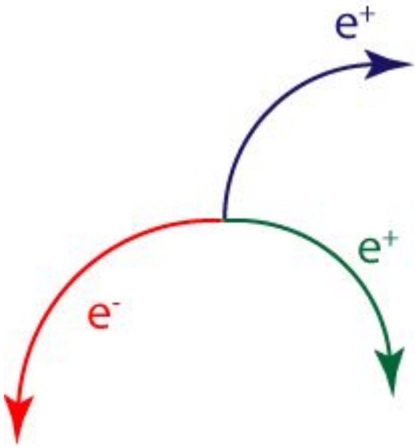
  ➪ **less material budget**
- Suppression of the accidental background

  ➪ **fast detectors**

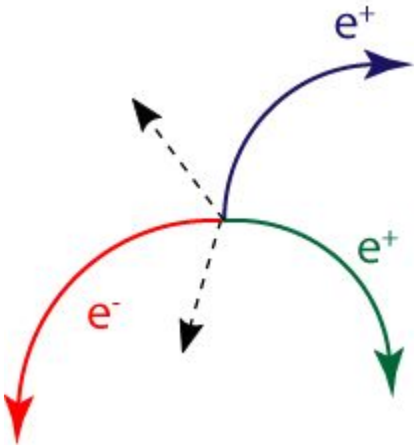
  ➪ **less material budget**



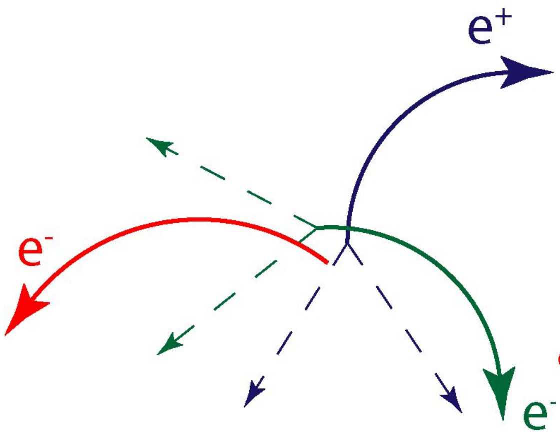
Signal vs. Background



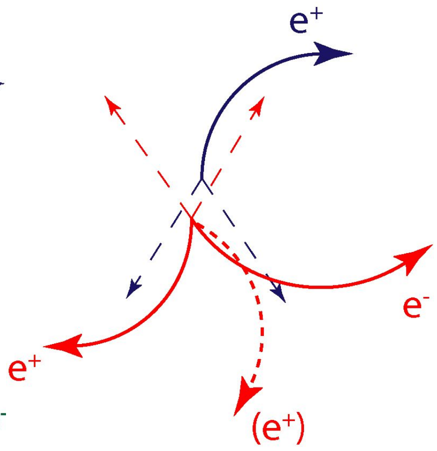
Signal topology



Missing momentum
Due to not detected neutrinos



Accidental background I
Three uncorrelated sources, e.g. 2 el. from $\mu \to e\nu\nu$ & 1 el. from Bhabha scattering



Accidental background II
Electron positron pair from $\mu \to eee\nu\nu$ & electron from $\mu \to e\nu\nu$

Beyond Standard Model Physics in Mu3e