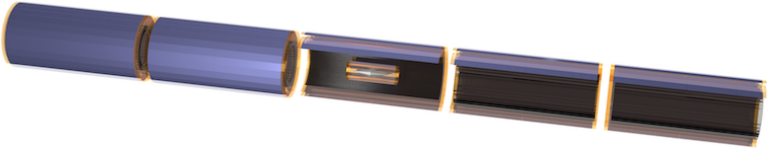
University of Zurich[UZH]

Physik-Institut

Search for the rare decay $\mu^+ \to e^+e^-e^+$

2nd CHIPP Workshop on Detector R&D

Roman Gredig

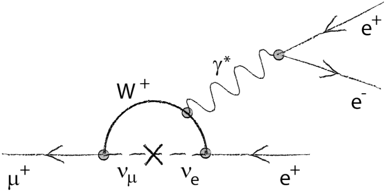


Outline

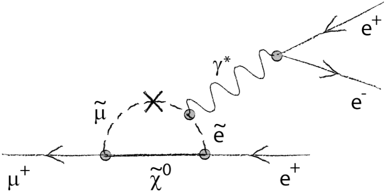
Lepton Flavor Violating Decay

Search for the lepton flavor violating decay $\mu^+ \rightarrow e^+e^-e^+$

- Lepton flavor not conserved
- we know it from neutrino oscillation
- but the charged leptons?



$\mathcal{B} < 10^{-50}$



$\Rightarrow$ sensitive to new physics

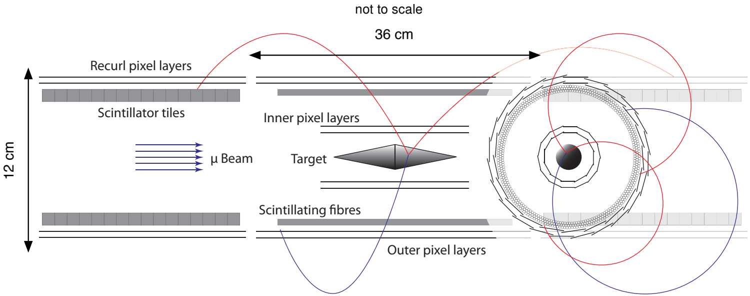
Design Parameters

- aimed sensitivity: $\mathcal{B}(\mu \to eee) < 10^{-16}$ (first phase: 10^{-15})
  (current limit: $\mathcal{B}(\mu \to eee) < 10^{-12}$, SINDRUM 1988)
- stopped muons per second: $2 \cdot 10^{9}$ (first phase: $2 \cdot 10^{8}$)
- main background: $\mu \to eee\nu_e\nu_\mu$, with $\mathcal{B} = 3.4 \cdot 10^{-5}$ and accidentals
- electron energies 0 – 53 MeV

We need:

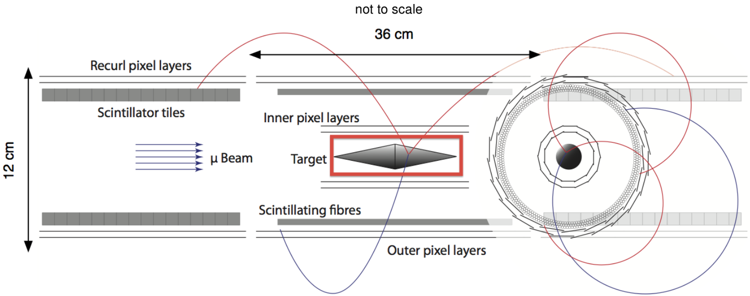
- high vertex and time resolution: $\mathcal{O}(100\,\mu\text{m})$, $\mathcal{O}(\text{several } 100\,\text{ps})$: combinatorial background
- precise measurement of momentum ($\ll 1$ MeV):
  $\mu \to eee\nu_e\nu_\mu$ background
- thin detectors ($< 50\,\mu\text{m}$): multiple scattering

Detector Overview



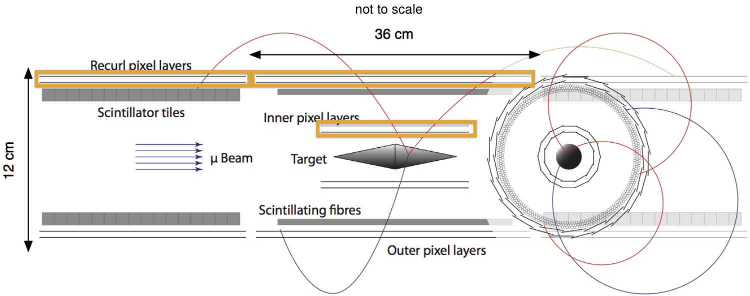
- homogeneous magnetic field ($\sim$ 1 T)
- Al double cone to stop the muons
- Si pixel tracker
- Scintillating Fibres
- Scintillation Tiles

Detector Overview



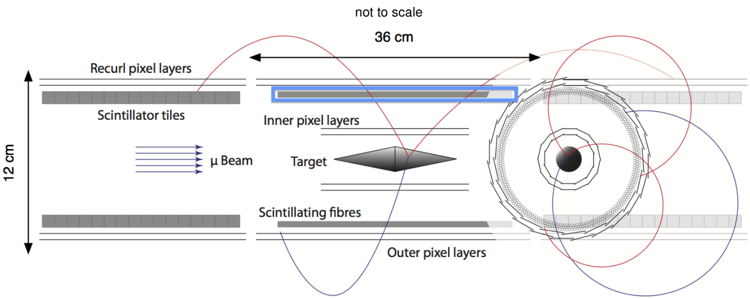
- homogeneous magnetic field ($\sim$ 1 T)
- Al double cone to stop the muons
- Si pixel tracker
- Scintillating Fibres
- Scintillation Tiles

Detector Overview



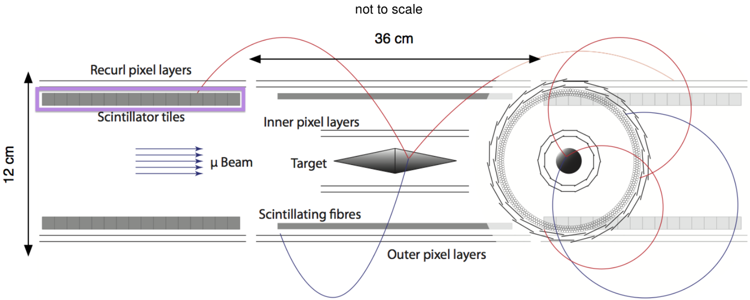
- homogeneous magnetic field ($\sim$ 1 T)
- Al double cone to stop the muons
- Si pixel tracker
- Scintillating Fibres
- Scintillation Tiles

Detector Overview



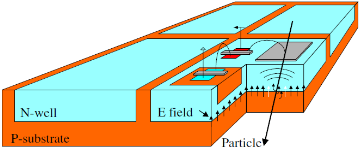
- homogeneous magnetic field ($\sim$ 1 T)
- Al double cone to stop the muons
- Si pixel tracker
- Scintillating Fibres
- Scintillation Tiles

Detector Overview



- homogeneous magnetic field ($\sim$ 1 T)
- Al double cone to stop the muons
- Si pixel tracker
- Scintillating Fibres
- Scintillation Tiles

Silicon Pixel Detector



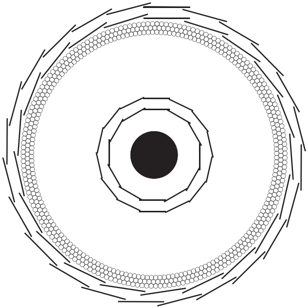
- $< 50\,\mu m$ thickness
- active sensors
- low noise, low power consumption
- $80 \times 80\,\mu m^2$ pixel size
- time resolution: ~ 20 ns
  $\Rightarrow$ better timing needed
- see also Ivan Perić's presentation yesterday

Scintillating Fibres

Swiss Contribution

How to reach better time resolution:

- scintillating double cladding fibres
- three to five layers
- used as detectors and light guides
- readout at fibre end with silicon photomultipliers (SiPM):
  $\Rightarrow$ either each fibre individually or column by column
- fibre length: 36 cm
- fibre diameter: 250 µm
- $\approx$ 4500 Fibres



center module front view

Optical Simulation

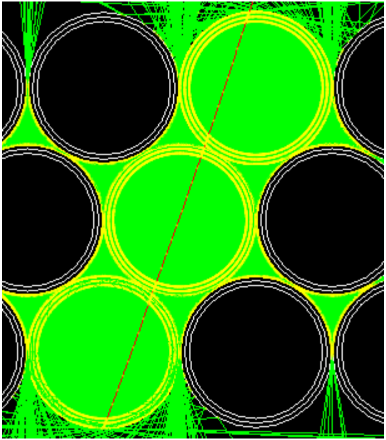
Zürich Contribution

Simulation of:

- scintillating process
- light propagation
- SiPM detection at both ends of fibres

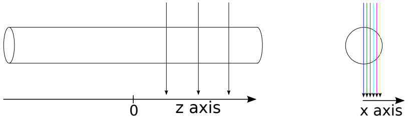
a lot of configurations possible:

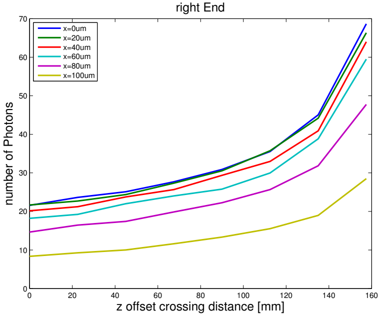
- fibre shape
- roughness
- coating (e.g. TiO)
- stacking

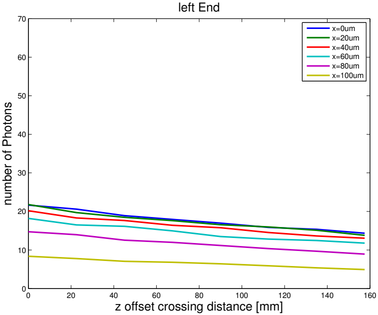


Optical Simulation

Photon Yield



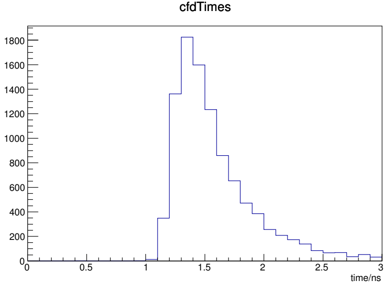




Optical Simulation

Simulation of the SiPM Response

- photon flux at fibre end used to simulate SiPM signal
- gives first estimation of time resolution
- SiPM response “GosSiP” [1]
- time resolution of about 400 ps possible
  (fwhm @ constant fraction discriminator)

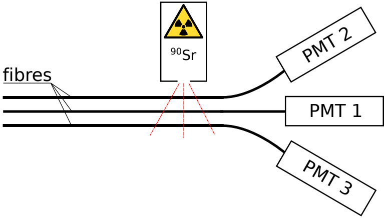


[1] P. Eckert et al., JINST 7 (2012) P08011

Test Setup

Fibre Readout

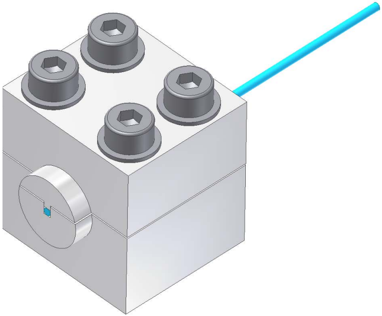
- align three fibres in a row
- irradiate fibres with ^{90}Sr source
- use first and last fibre as trigger
- measure number of photons leaving the middle fibre



Test Setup

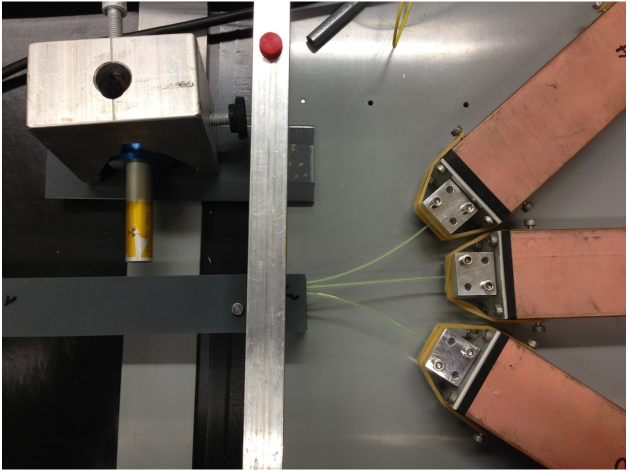
Fibre Coupling to PMT

- holder of the fibre end
- diamond milling of the holder with the fibre after clamping ⇒ smooth surface
- still some problems to be solved



Test Setup

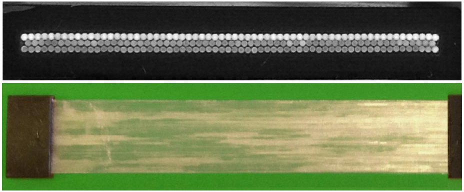
Fibre Coupling to PMT



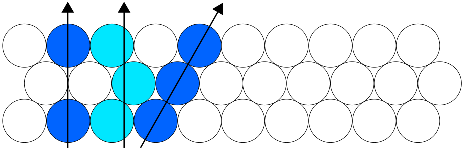
Fibre Ribbon

how to stack the fibres?

- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)



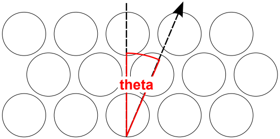
prototype build by Antoaneta Damyanova, UniGE



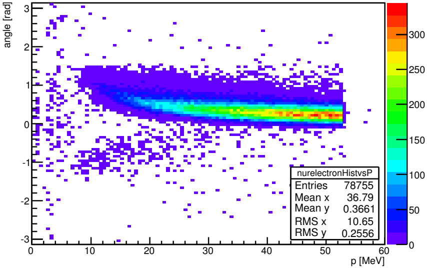
Fibre Ribbon

how to stack the fibres?

- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)



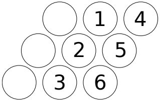
fibre crossing angle

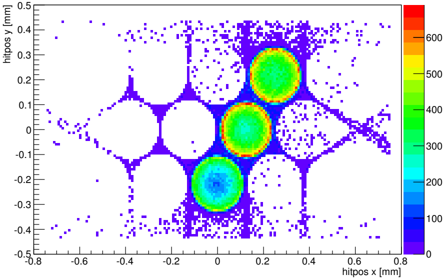


Fibre Ribbon

how to stack the fibres?

- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)

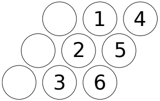


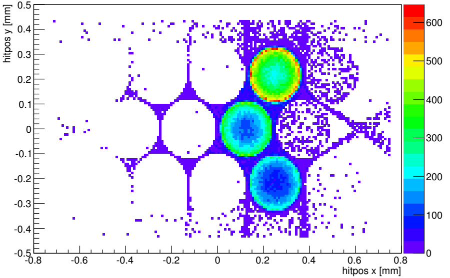


Fibre Ribbon

how to stack the fibres?

- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)

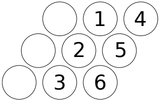


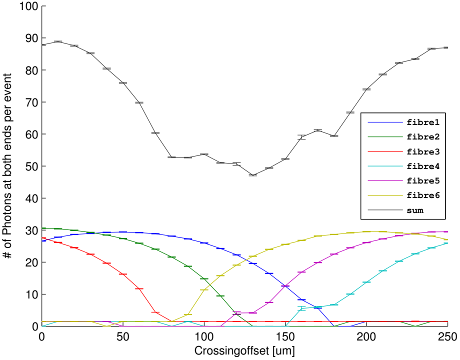


Fibre Ribbon

how to stack the fibres?

- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)



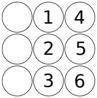


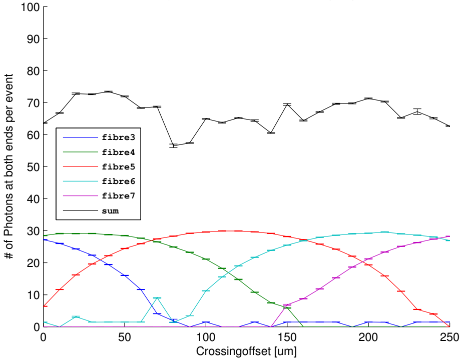
most probable value

Fibre Ribbon

how to stack the fibres?

- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)

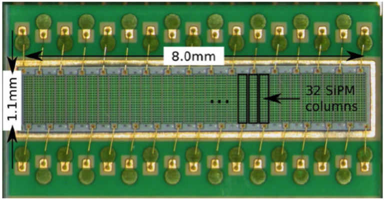




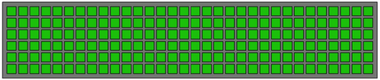
most probable value

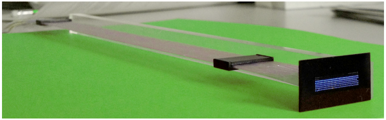
Coupling to the SiPM

single fibre vs. column by column readout



- 64 channel monolithic device à la LHCb
- 250 µm “pitch”, 50 µm pixels
- common bias voltage

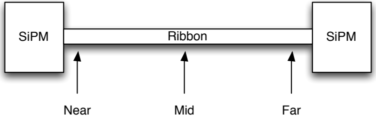


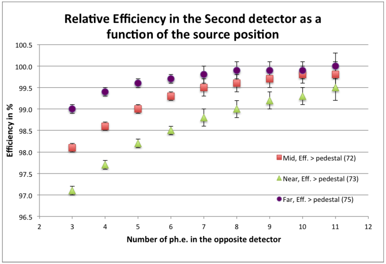


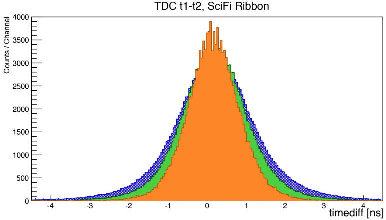
- monolithic device with 6 x 32 independent sensors
- $0.4 \times 0.4\,\text{mm}^2$ with 100 µm pixels and 100 µm spacing
- (bias voltage regulated for each sensor $\Delta U \sim 0.5\,\text{V}$)

Ribbon Performance

UniGE: β source crossing the ribbon







blue: $\geqslant$ 3 ph.e., green $\geqslant$ 7 ph.e., orange: $\geqslant$ 11 ph.e.

Swiss Responsibilities

component	who
beam	PSI
target	PSI (+ Heidelberg)
SciFi tracker	UniGE, UZH, ETHZ, PSI
timing electronics	PSI, UniGE, UZH, ETHZ
slow control	PSI
infrastructure	PSI

Time Schedule

Letter of Intent	January 2012
Research Proposal	January 2013
Technical Review	January 2014
Stage I	2015 – 2017
Stage II	2018+

The Mu3e Collaboration

- DPNC, University of Geneva
- Physics Institute, Heidelberg University
- KIP, Heidelberg University
- ZITI Mannheim, Heidelberg University
- Paul Scherrer Institute (PSI)
- Physik–Institut, University of Zurich
- Institute for Particle Physics, ETH Zurich