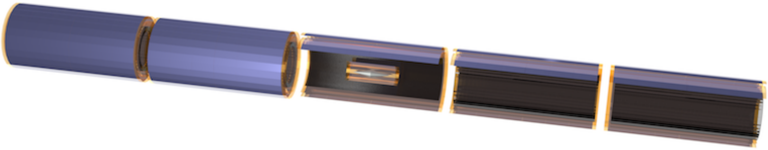
University of Zurich[UZH]
Physik–Institut

Simulation of the performance of the scintillation fibres for the Mu3e experiment

Annual meeting of the swiss physical society 2014

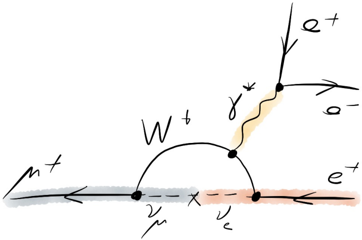
Roman Gredig



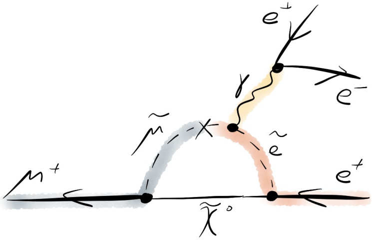
Lepton Flavor Violating Decay

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

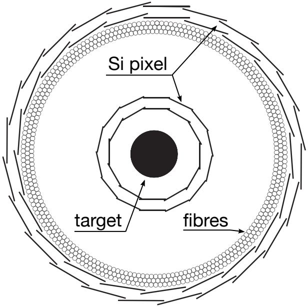
We need:

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

Scintillating Fibres

How to reach better time resolution

- time resolution goal: $\mathcal{O}$(several 100 ps)
- scintillating double cladding plastic fibres
- three to five layers
- used as detectors and light guides
- readout at both fibre ends with silicon photomultipliers (SiPM):
  ⇒ each fibre individually or column by column
- fibre length: 36 cm
- fibre diameter: 250 µm
- about 4500 fibres



center module front view

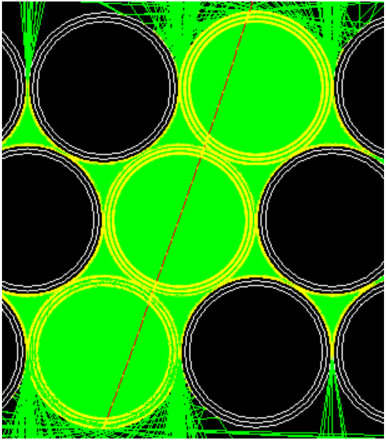
Optical Simulation

Simulation of:

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

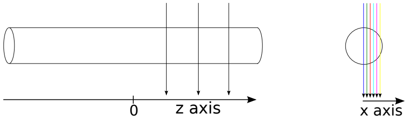
configurable:

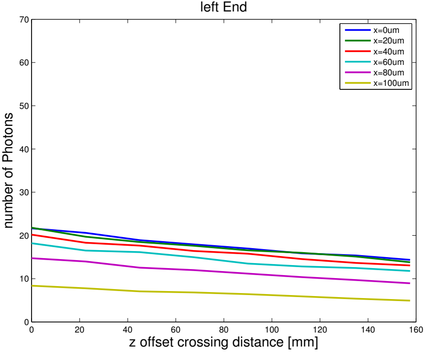
- fibre shape
- roughness
- coating (e.g. TiO)
- stacking

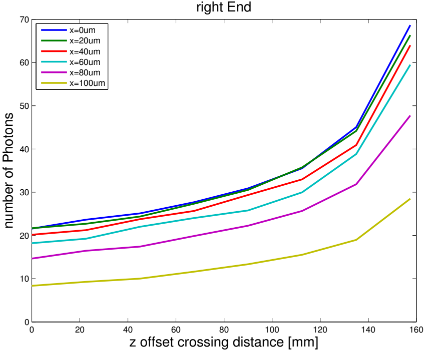


Optical Simulation

Photon Yield







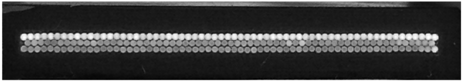
Fibre Ribbon

how to stack the fibres?

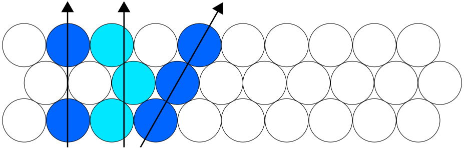
- feasibility (mechanical)
- minimizing dead material
- simplify readout
- single fibre vs. column by column readout
- simulation of different scenarios
- example: crossing with mean angle ($\sim 20^\circ$)

top view

front view



prototype build by Antoaneta Damyanova, UniGE



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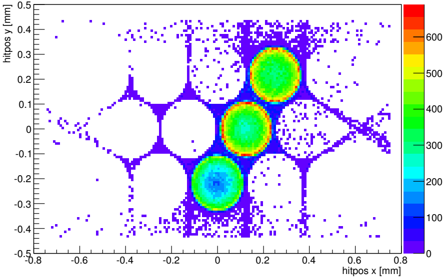
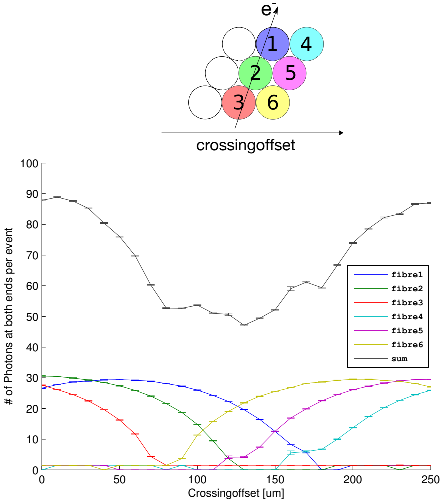
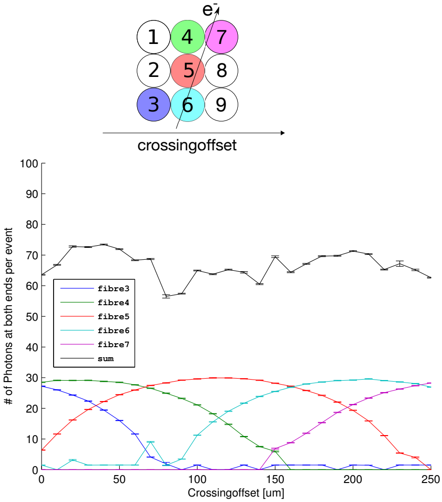


photon distribution at ribbon end (integrated over 10 000 events)


e-
1
4
2
5
3
6
crossingoffset
# of Photons at both ends per event
Crossingoffset [um]
fibre1
fibre2
fibre3
fibre4
fibre5
fibre6
sum


e-
1
4
7
2
5
8
3
6
9
crossingoffset
# of Photons at both ends per event
Crossingoffset [um]
fibre3
fibre4
fibre5
fibre6
fibre7
sum

Photon Yield Parametrization

speed up detector simulation

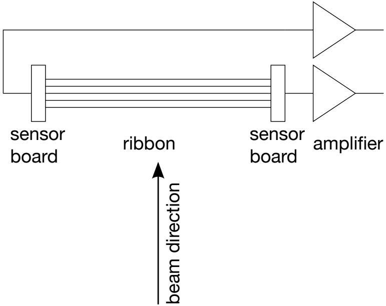
- simulation of the complete detector geometry
- individual photon tracks not interesting
- parametrization of the fibre simulation in combination with a SiPM response simulation [1]
- time resolution $\approx 400\,\mathrm{ps}$
- photon yield depending on energy deposit and z-position of fibre ($x, y-$position only via $\mathrm{d}E/\mathrm{d}x$)
- keep only “measured” SiPM signals

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

Test Beam Hardware Development

ETHZ, UniGe, UZH

- test beam campaign to verify simulation
- compare different ribbons
- evaluate amplifier electronics (electronics design heading for ASIC integration)
- modular design:
  different ribbon, sensors and amplifiers combinable
- multichannel readout (2x32 channels)
- readout with either waveform digitization or QDC/TDC



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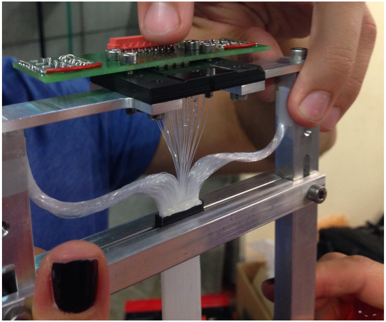

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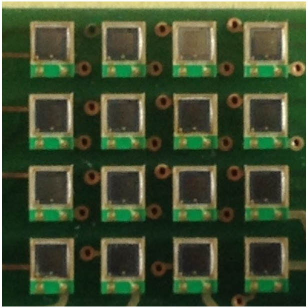
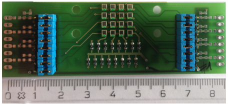
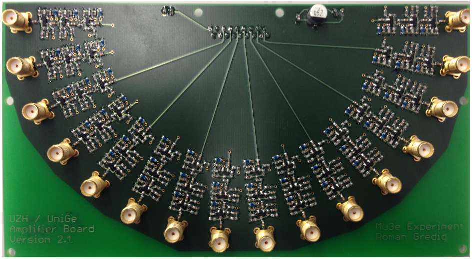


zoom of daughterboard sensors,
active area per SiPM 1 $\times$ 1 mm^2



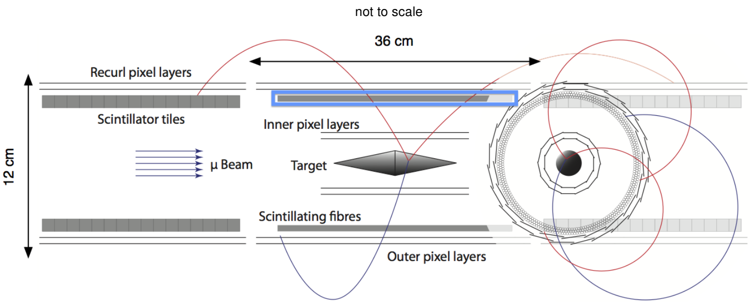


Conclusions and Outlook

- simulation toolkit to understand fibres
- time resolution demands can be fulfilled
- modular framework to test ribbons prepared
- detailed analysis of ribbons needed
  $\Rightarrow$ waiting for beam...
- final SiPM mask not decided yet

Backup

Detector Overview



- homogeneous magnetic field ($\sim$ 1 T)
- Al double cone to stop the muons
- Si pixel tracker
- scintillating fibres
- scintillation tiles