Fibre Detector Development for the $\mu^+ \rightarrow e^+e^-e^+$ Experiment

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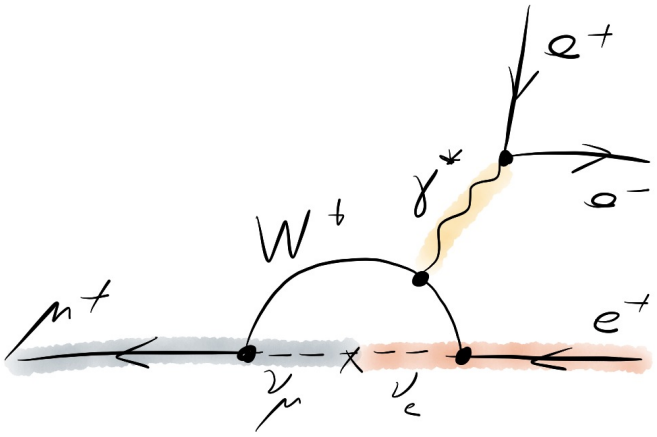
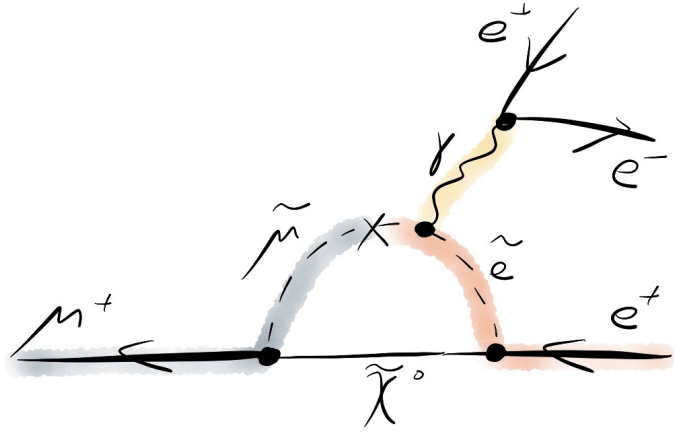
UZH and ETHZ PhD Seminar 2014

Lepton Flavor Violating Decay $\mu^+ \rightarrow e^+e^-e^+$

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



$B < 10^{-50}$



sensitive to new physics

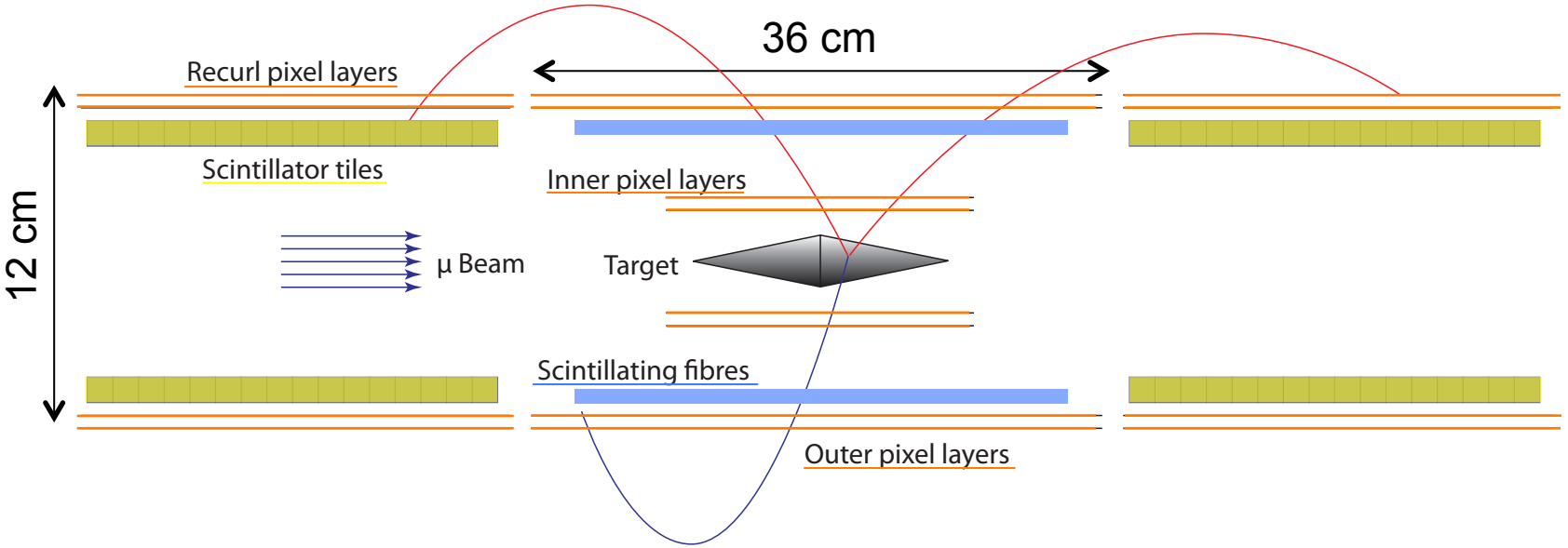
Design Parameters

- aimed sensitivity: B(μ→eee) < 10^{-16}
- stopped muons per second: $2 \cdot 10^{9}$
- main background: $\mu \rightarrow eee\nu_e\nu_\mu$, with B = $3.4 \cdot 10^{-5}$
- electron energies 0 – 53 MeV

we need:

- high vertex and time resolution: O(100 μm)m, O(several 100 ps) combinatorial background
- precise measurement of momentum: $\mu \rightarrow eee\nu_e\nu_\mu$ background
- thin detectors (< 50 μm): multiple scattering

Detector Overview

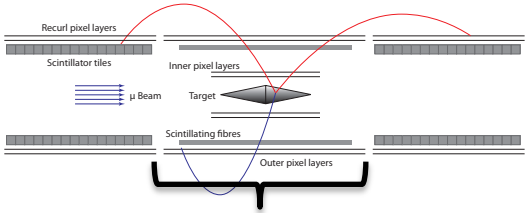


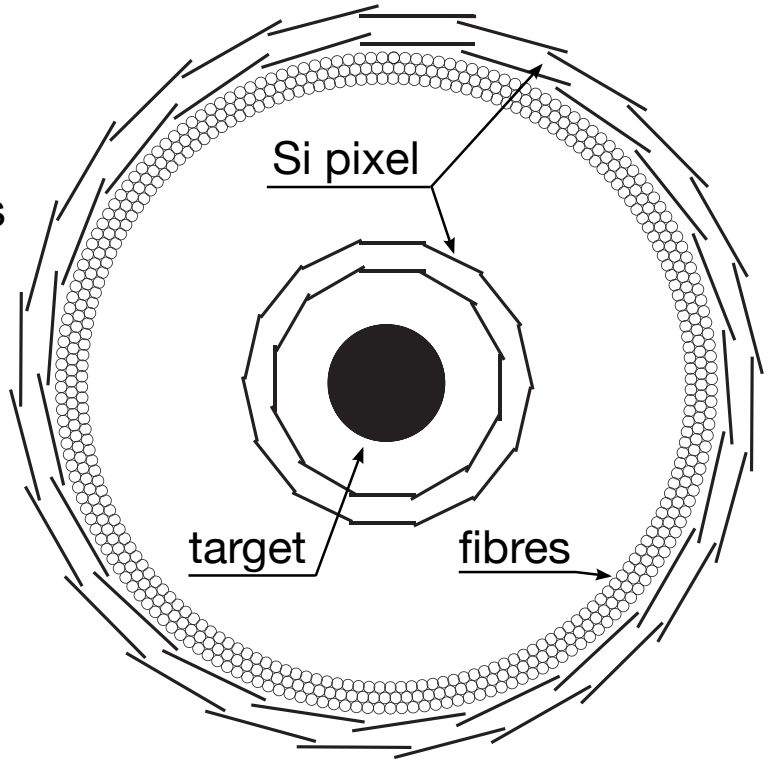
- homogeneous magnetic field (~1 T)
- Al double cone to stop the muons
- Si pixel tracker
- scintillating fibres
- scintillating tiles

- 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

Scintillating Fibres

- time resolution goal: several 100 ps
- three to five layers
- used as detectors and light guides
- length: 36cm
- fibre diameter: 250 µm
- about 4500 fibres
- readout at both fibre ends with silicon photonmultipliers (SiPM)





center module front view

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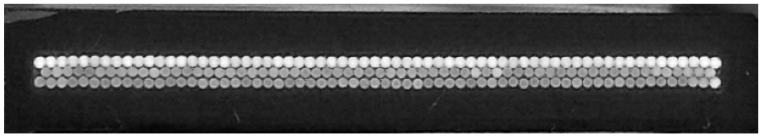
fibres glued together as modules
→ ribbons



16mm

ribbon prototype production:
Antoaneta Damyanova, UniGe

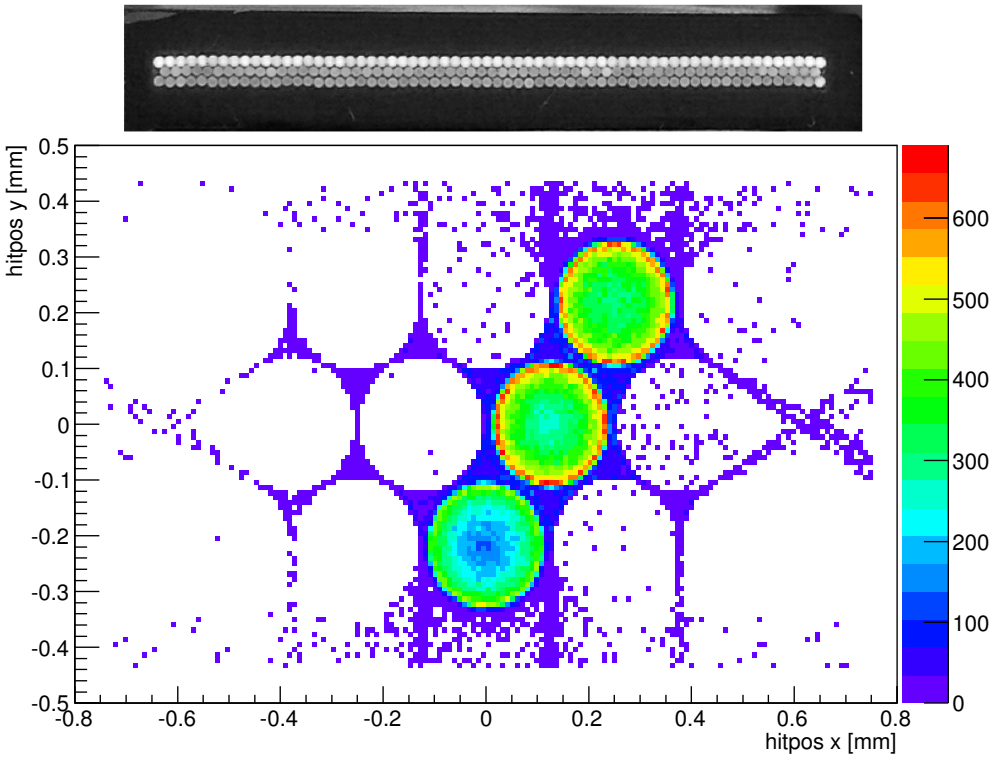
from the presentation last year: simulation

simulation of:

- scintillation process
- light propagation
- SiPM detection

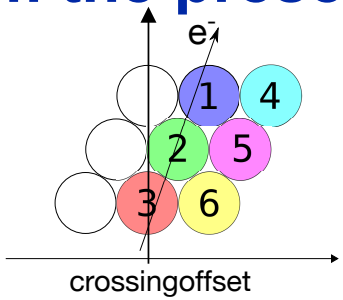
configurable:

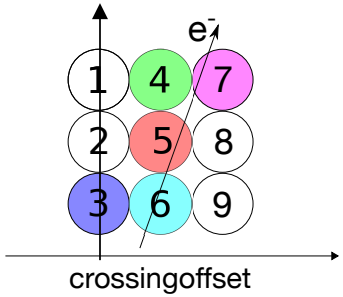
- fibre shape
- roughness
- coating (e.g. TiO)
- stacking

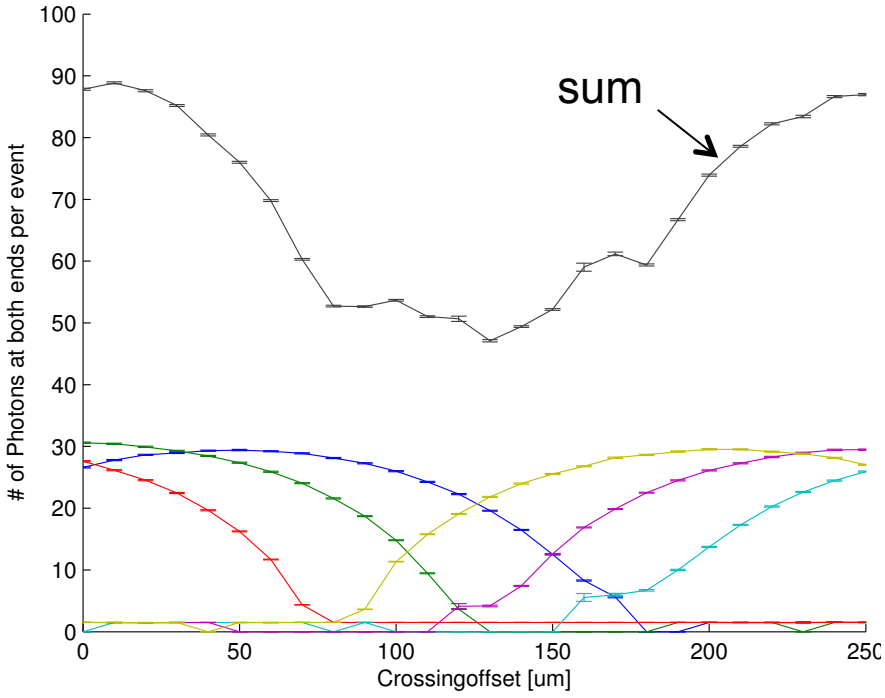


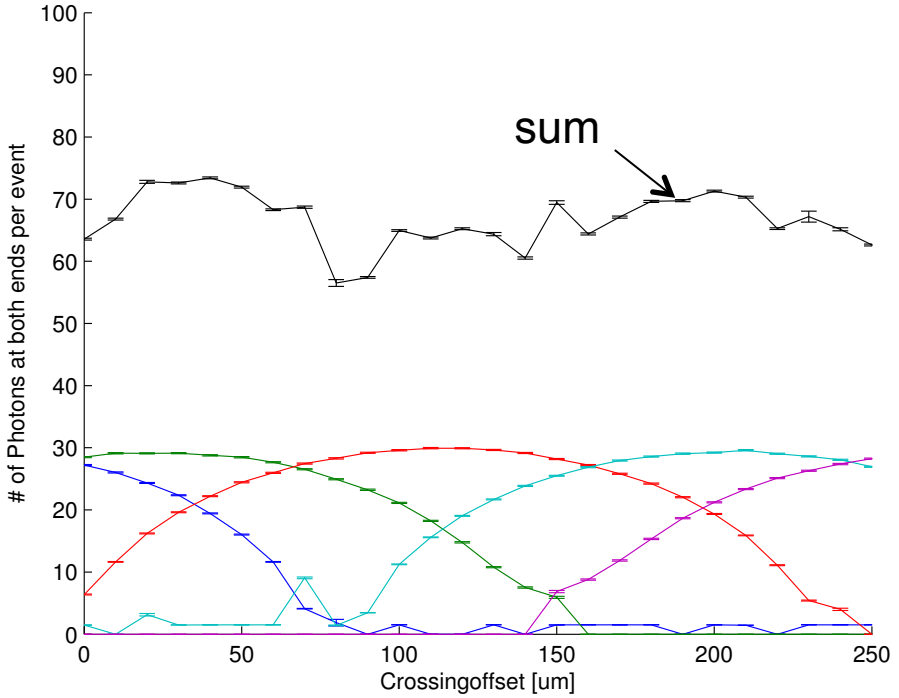
photon distribution at ribbon end
(integrated over 10000 events)

from the presentation last year: simulation



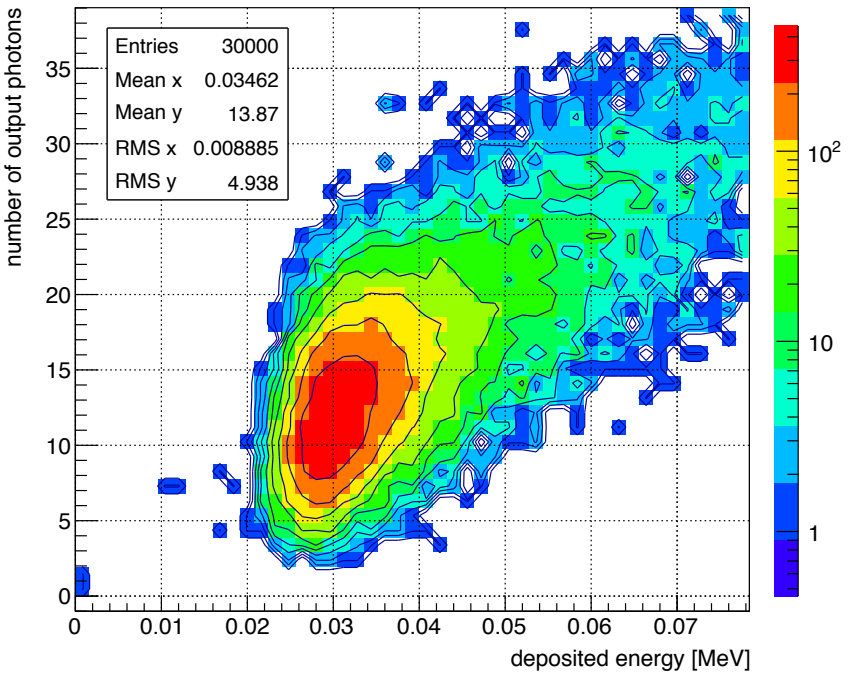


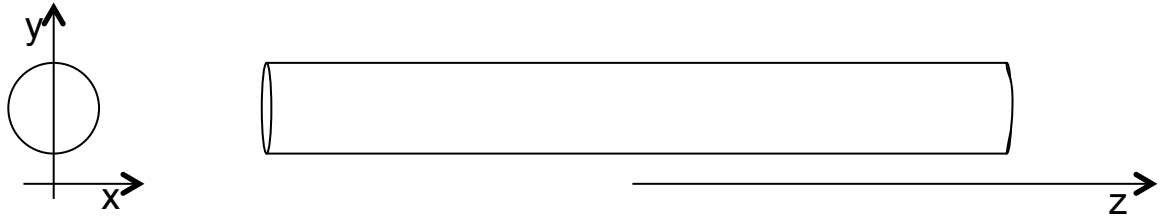




Photon Yield Parametrization

- simulation of the complete detector geometry
- individual photon tracks not interesting
- parametrization of the fibre simulation in combination with a SiPM response simulation [1]
- photon yield depending on energy deposit and *z*-position of fibre (*x*,*y*−position only via d*E*/d*x*)
- keep only “measured” SiPM signals



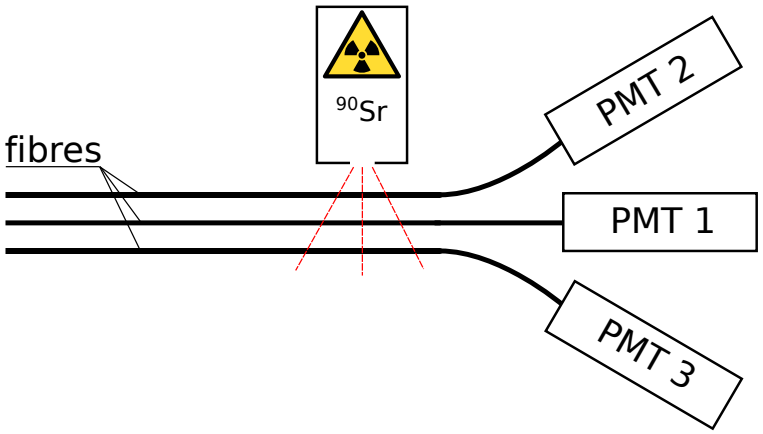


[1] P. Eckert et al., JINST 7 (2012) P08011

Comparison of simulation and real world

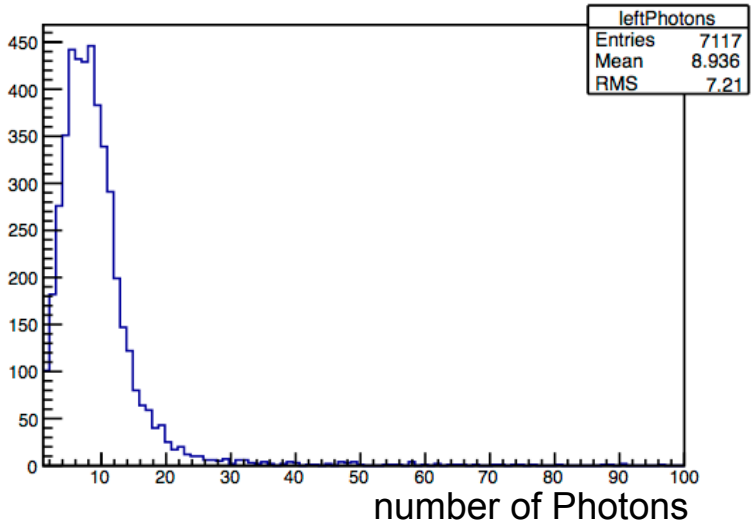
Lab setup:

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

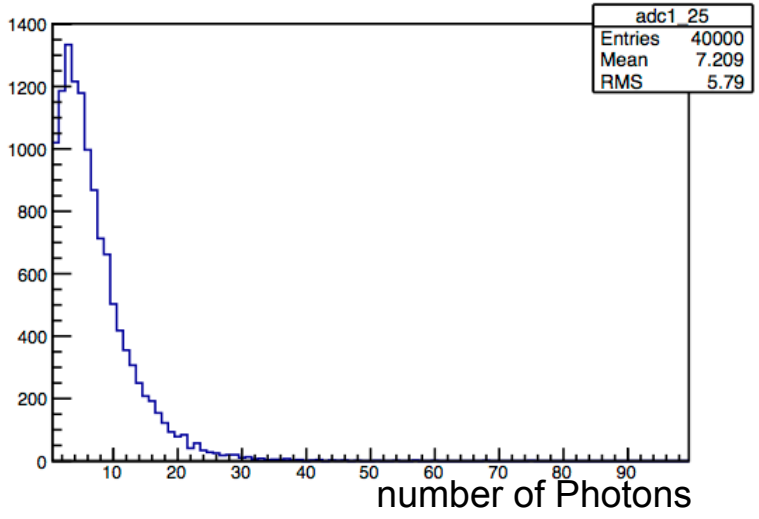


Lab Setup Comparison

Simulation



Measurement

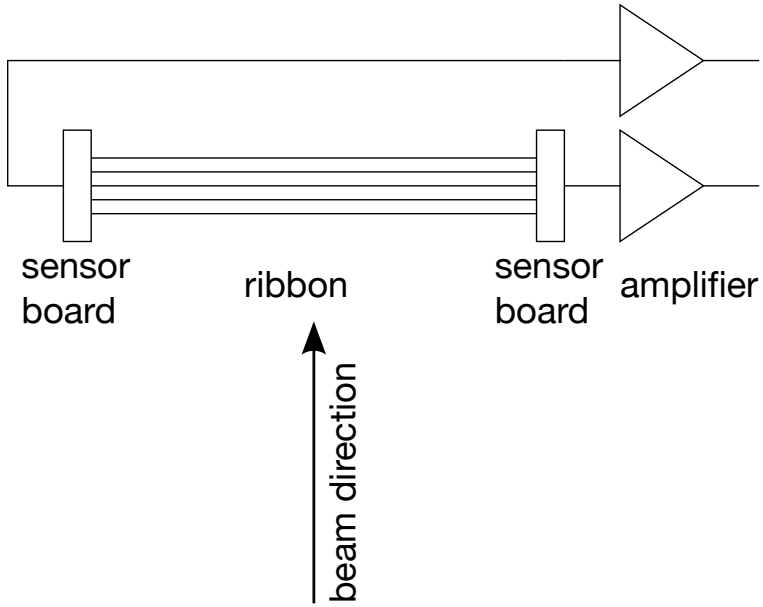


fibre crossing in the middle (at 18cm),
in this scenario uncoated fibres are used

Test Beam Hardware Development

UZH, UniGE, ETHZ

- test beam campaign to verify simulation
- compare different ribbons
- evaluate amplifier electronics (electronics design heading for ASIC integration)
- modular design: different ribbons, sensors and amplifiers combinable
- multichannel readout (2x16 channels) (aiming for 2x32 channels)
- readout with waveform digitization



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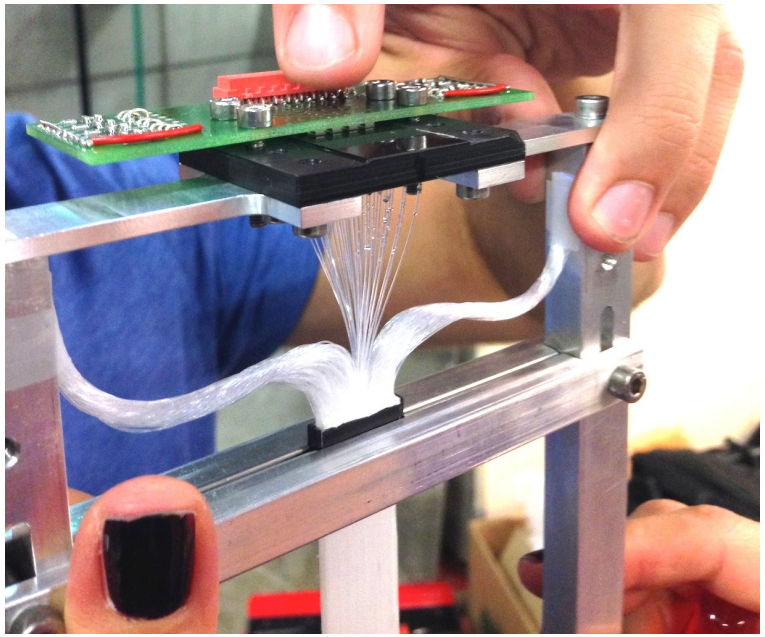
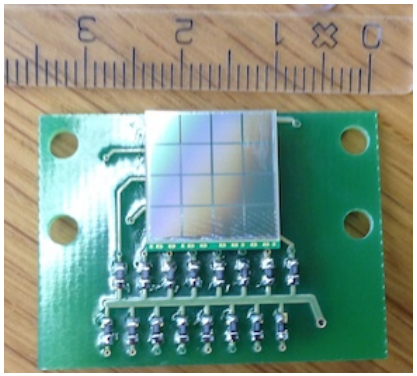
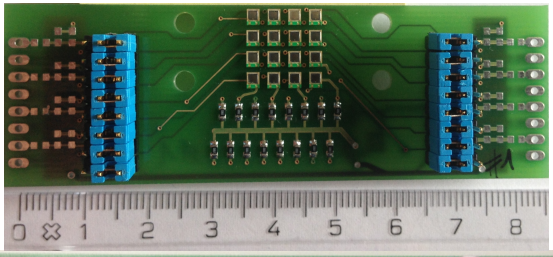


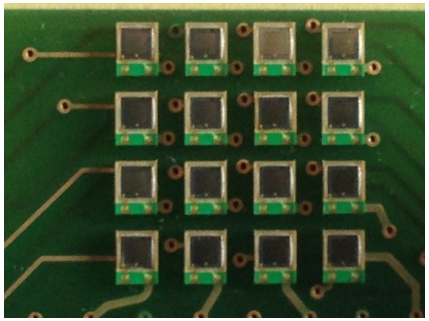
Test Beam Hardware Development



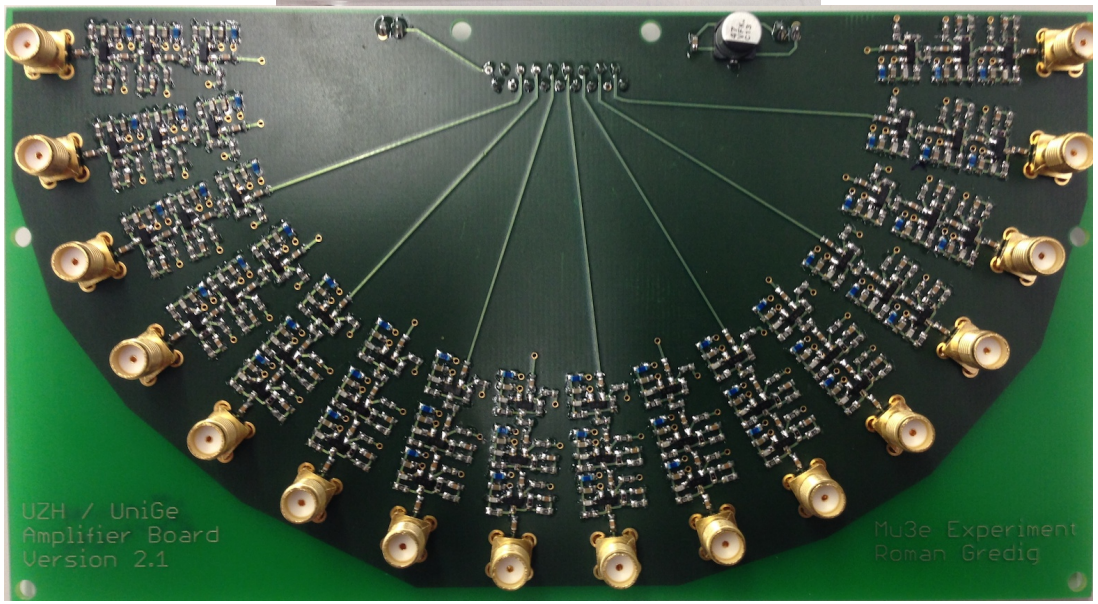
old version: monolithic 4x4 SiPM array
active area 3x3 mm^2



new version sensorboard:
indivual 1x1mm^2 SiPM

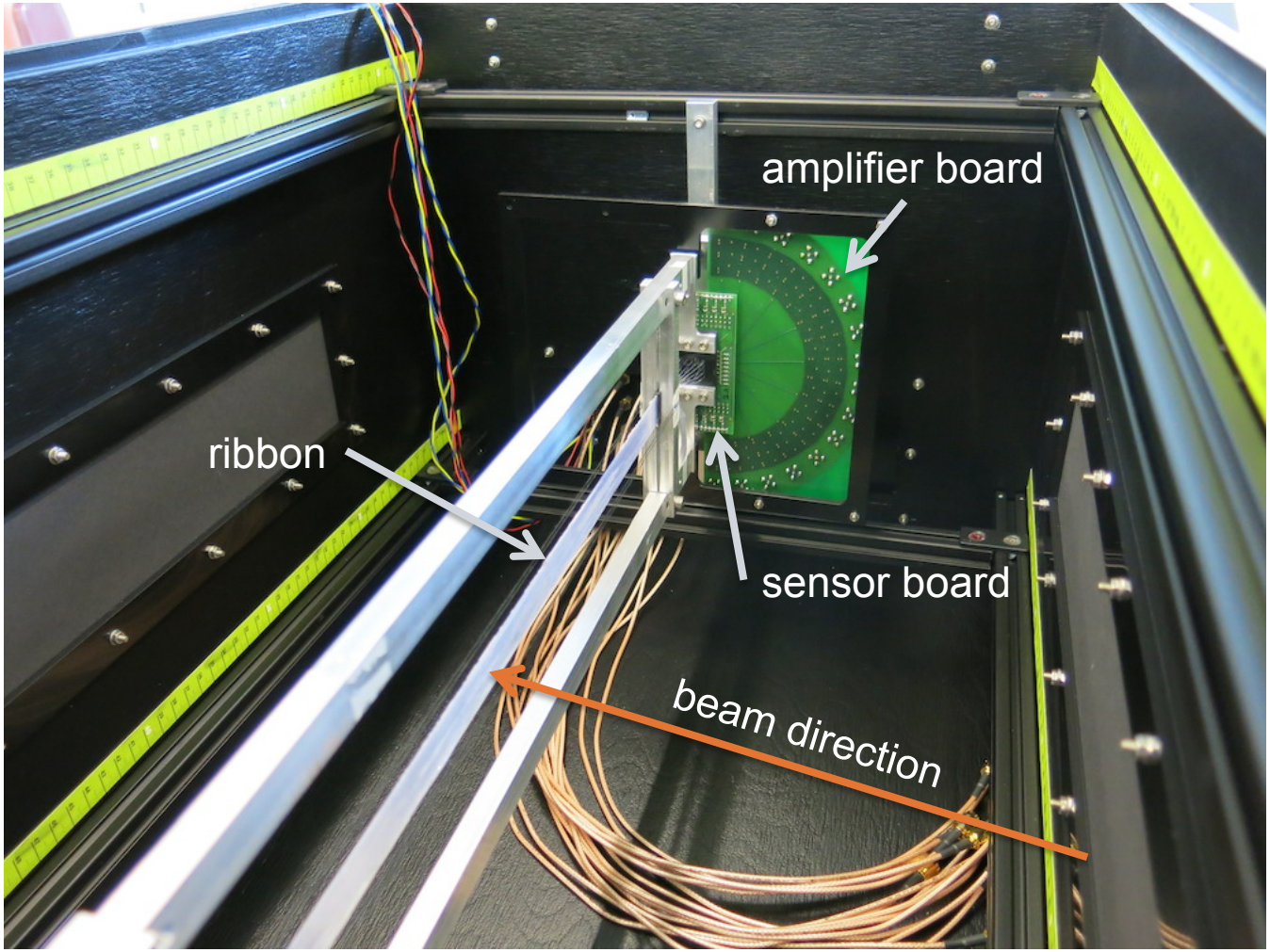


zoom of daughterboard sensors,
active area per SiPM 1x1mm^2



16 channel amplifier board

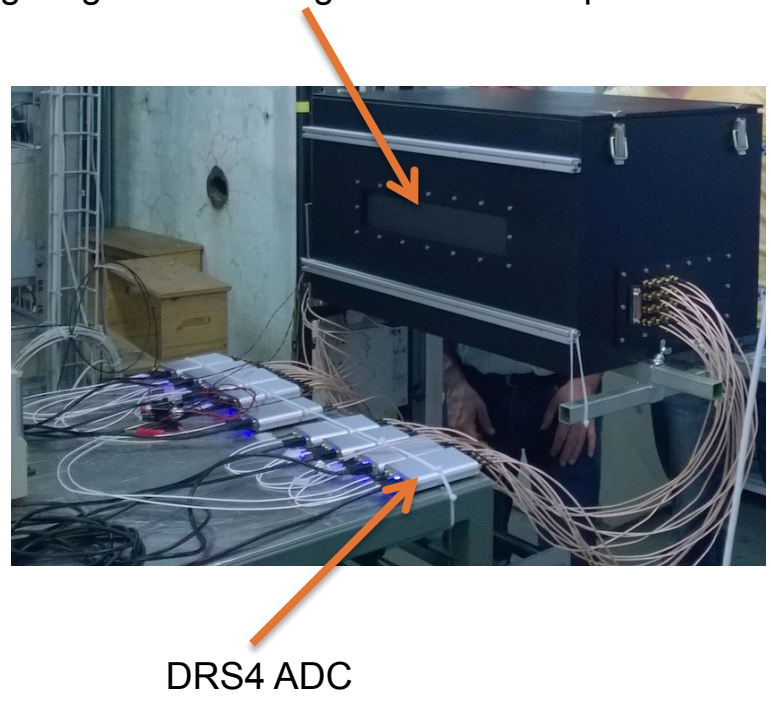
Test Beam Hardware Development



Test Beam Hardware Development

DAQ System:

- PSI DRS4 5GS/sec ADC [2]
- evaluation board works like an oscilloscope
- each evaluation board has 4 channels
  → daisy chain
- finally 9 boards were working
- time resolution about 185 ps

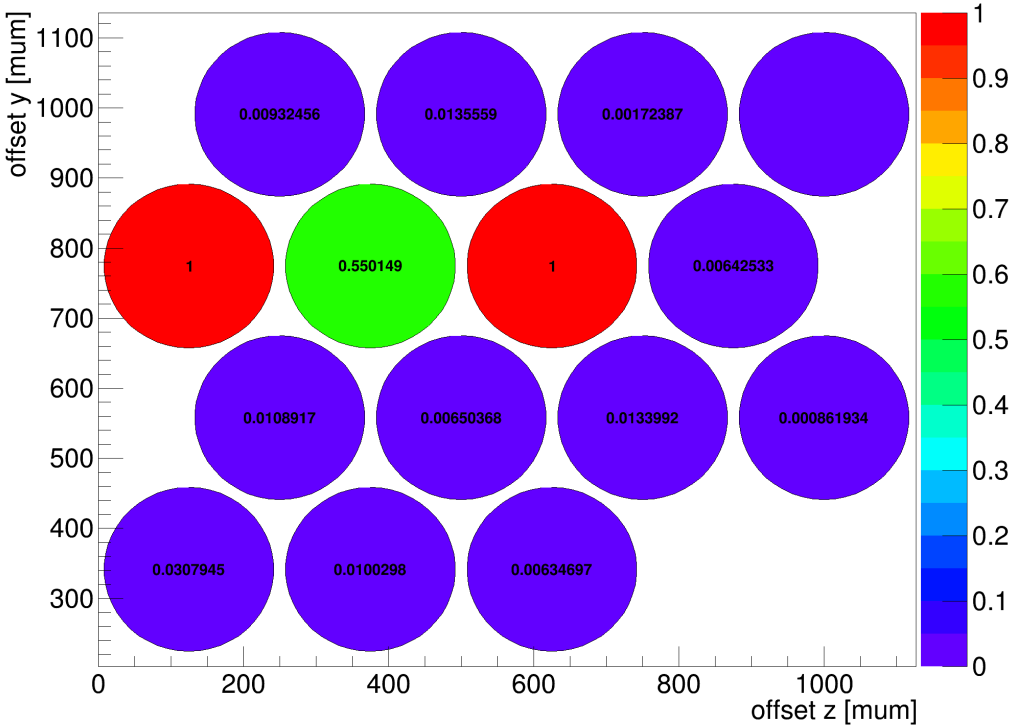


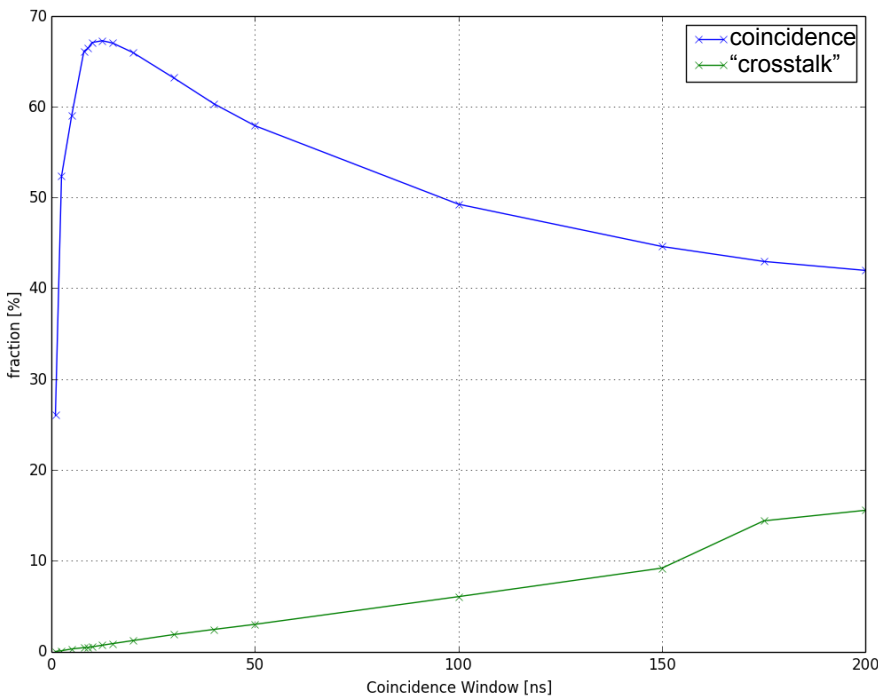
[2] S. Ritt, Electronics for the μ → eγ experiment, Nucl. Instrum. Meth. A494 (2002) 520–525

Preliminary Testbeam Results

coincidences and crosstalk? sensors have high dark count rates >100kHz

Trigger: 2 fibres & external, 20ns window





analysis tools in cooperation with Simon Corrodi, ETHZ

Outlook

- detailed analysis of testbeam data
- can we achieve required time resolution?
- how will the fibres be read out:
  → individually vs. column wise
- mechanical studies:
  → how to build the fibre detector in the end

Time schedule:

2014: detector construction and magnet procurement start

2016: central part of the detector

2017 – 2020: complete detector with high intensity muon beamline