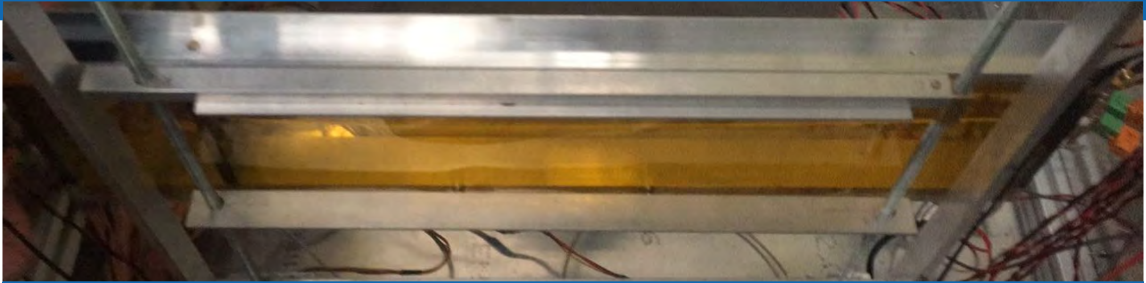
ETH zürich



Testbeam Results for the Mu3e Scintillating Fibre Detector

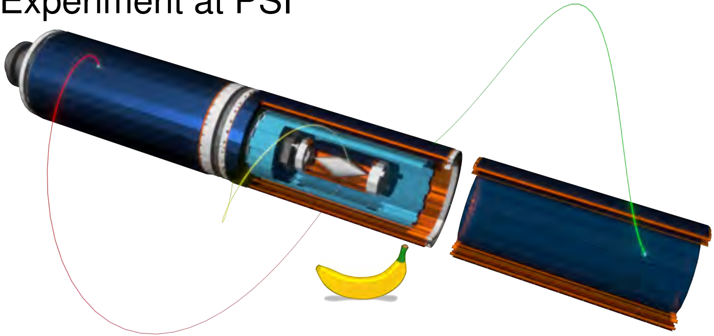
6th Beam Telescopes and Test Beams Workshop 2018

Lukas Gerritzen

on behalf of the Mu3e Fibre Group:

A. Bravar, S. Corrodi, **A. Damyanova**, L. Gerritzen, C. Grab, D. Miranda, A. Papa

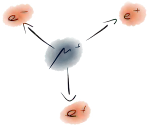
The Mu3e Experiment at PSI



Search for the lepton-flavour violating decay $\mu^+ \to e^+e^-e^+$ (in SM: $\mathcal{BR} < 10^{-54}$)

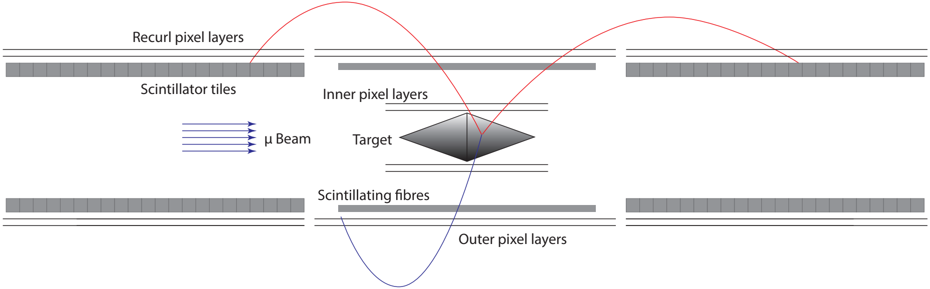
- goal sensitivity $< 10^{-16}$
  current: 10^{-12} (SINDRUM)[a]
- muons decay at rest

- $p_e \lesssim \frac{m_\mu}{2} \approx 53\,\text{MeV}$
- e-tracks bent in 1 T solenoid field



[a] $\mathcal{BR}$ limit at 90 % C.L.

The Mu3e Detector



Tracking: 4 Si Pixel Layers (HV-MAPS)

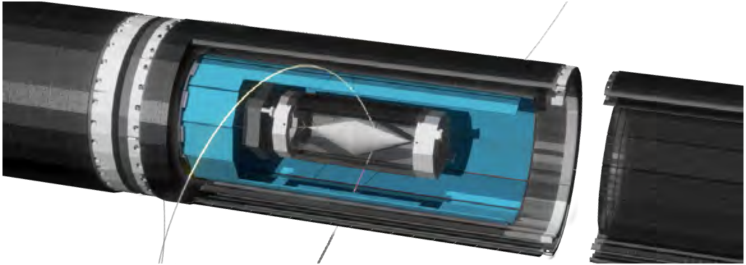
- high efficiency, spatial resolution
- thinned to 50 μm
  $\rightarrow \sim 0.1\,\%\,X_0$ per layer

See also talk by L. Huth

Timing: Scintillating Fibres and Tiles

- $\mathcal{O}(500\,\mathrm{ps})$ (fibres); $\sim 70\,\mathrm{ps}$ (tiles)
- background reduction and charge ID
- light detection with SiPMs

The Mu3e Scintillating Fibre Detector



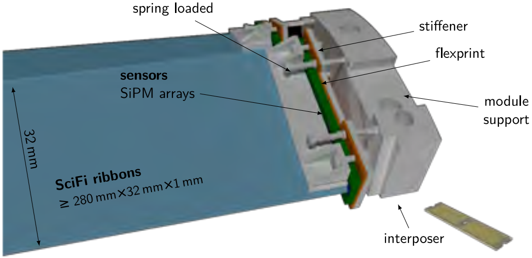
Setup

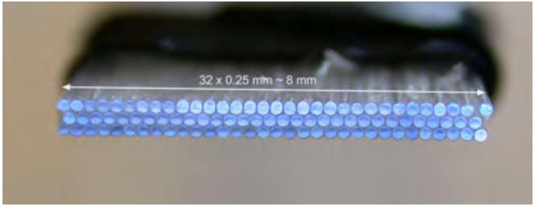
- 12 ribbons (1.6 cm $\times$ 28–30 cm)
- 3 layers of 250 µm fibres
- right below second pixel double layer
- LHCb type: column array SiPMs

Requirements

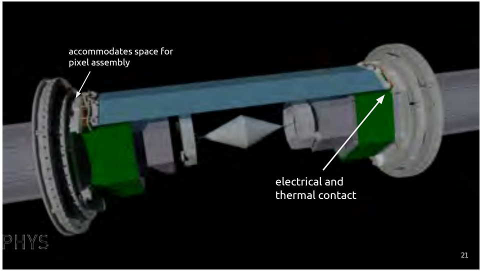
- low material budget ($< 0.5\,\%X_0$, $\lesssim$1 mm)
- high efficiency
- timing < 500 ps
- rates up to 250 kHz/fibre

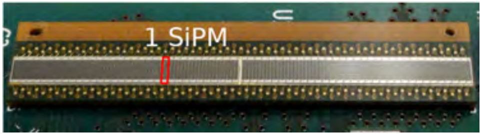
The Mu3e Scintillating Fibre Detector Up Close





final: 128 × 0.25 mm = 32 mm



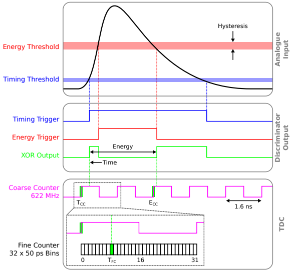


Hamamatsu S13552: column array SiPM: 128 cells, 250 µm × 1.6 mm each

SciFi Readout – custom ASIC: MuTRiG

mixed mode, $\approx$ 50 ps t-stamps

high impedance, opt. differential



Tiles: both Thresholds

Fibres: only Timing-Threshold
and Energy-Flag
"time mode"

	STiC3.1 done	MuTRiG outlook
number of channels	64	32
LVDS speed [Mbit/s]	160	1250
event size [bit]	48	47
time mode	-	26
event rate / chip [MHz]	$\sim$2.6	$\sim$20
time mode	-	$\sim$38
event rate / ch [kHz]	$\sim$40	$\sim$650
time mode	-	$\sim$**1200**
power per channel [mW]	35	35
size [mm x mm]	5x5	5x5

Fibres Under Study

Ribbons (30 cm × 0.8 cm) with 2, 3 or 4 layers of 250 µm thick, round, double cladding fibres.

Kuraray

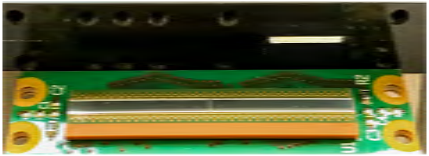
- SCSF 78 MJ with 20 % TiO_2 in glue
- SCSF 81 MJ with 20 % TiO_2 in glue

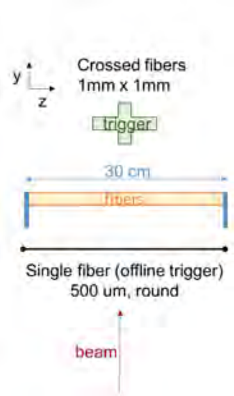
Nanostructured Organosilicon Luminophores

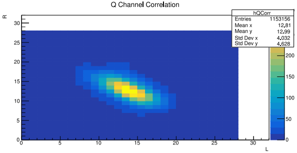
- NOL 11 clear and with TiO_2 in glue

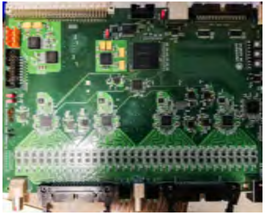
Experimental Setup

- crossed fibres as 1 mm $\times$ 1 mm trigger
- Hamamatsu S13552 (128 channels, trenches, column array SiPM)
- 32 channels readout per side with custom DRS4 board (Uni Geneva)

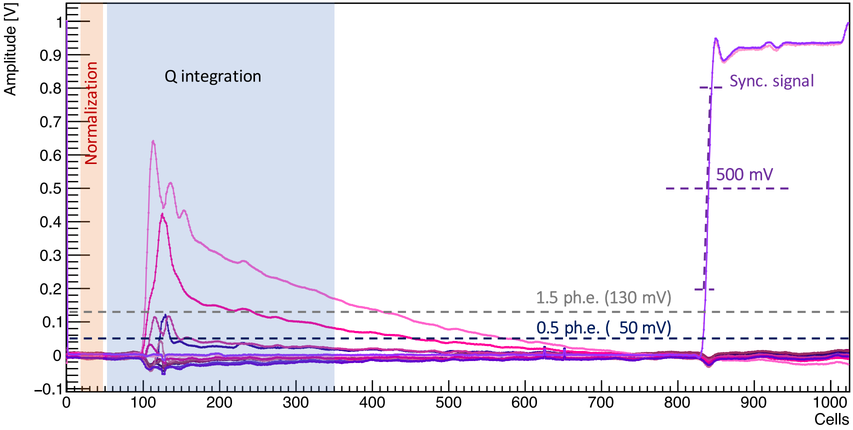






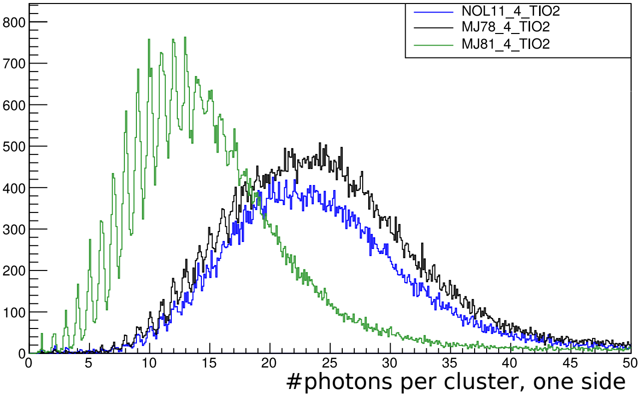


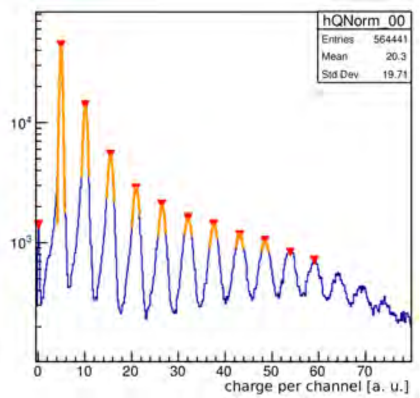
Waveforms



Amplitude [V]
Normalization
Q integration
Sync. signal
500 mV
1.5 ph.e. (130 mV)
0.5 ph.e. (50 mV)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
0
100
200
300
400
500
600
700
800
900
1000
Cells

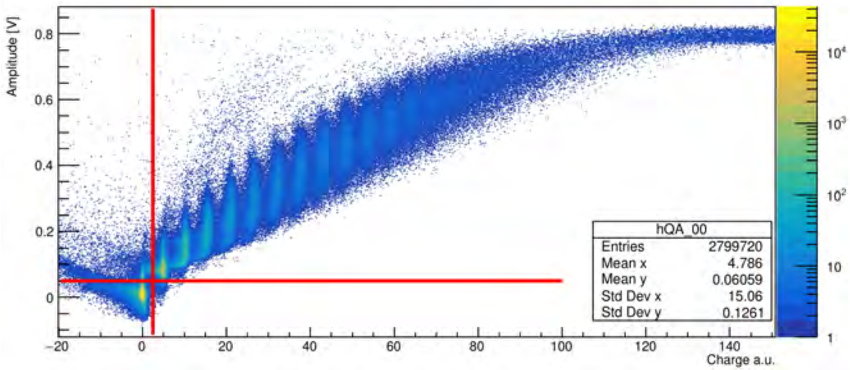
Light Yield





clusters are defined as adjacent SiPM channels

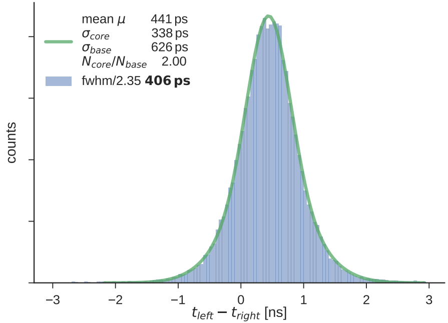
Spectra and Cuts

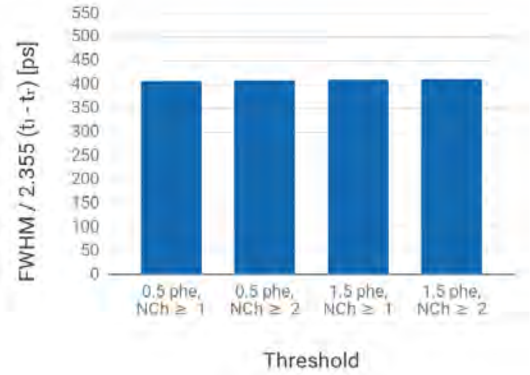


Determine amplitudes corresponding to number of photons using charge.

Charge is not used in the further analysis.

Time Resolution



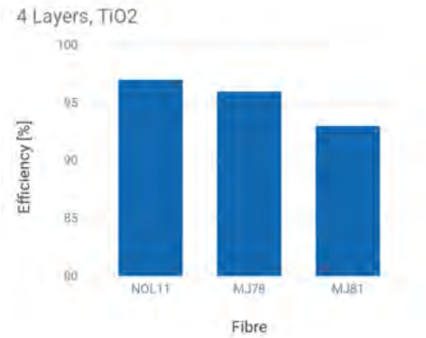


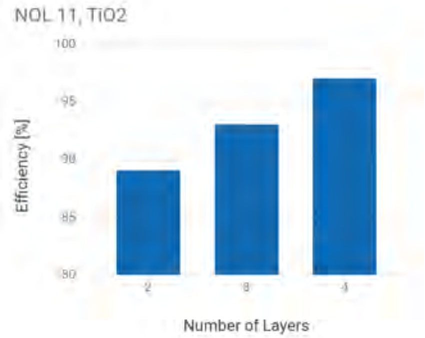
NOL 11, 3 layers, no TiO_2

To study timing: look at difference between first photon left and right.

Efficiencies (threshold 0.5 phe, $N_{\mathrm{Ch.}} \geq 2$ left and right)

$[t \pm 3\,\sigma]$





NOL 11 are very efficient compared to SCSF

Outlook – MuTRiG

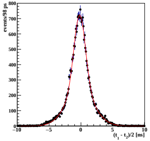
BTTB5

- *last generation* SiPM column array
- *last generation* scifi ribbons
- STiC *predecessor* of MuTRiG

BTTB6 and beyond

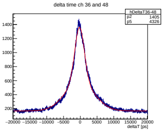
- final SiPM-like column array
- improved ribbon production + (NOL)
- MuTRiG

DRS4 wf (single fibre)



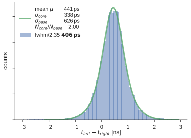
$\sigma = (t_l - t_r) = 2.0$ ns

STiC3.1: one side



$\sigma = (t_l - t_r) = 1.4$ ns

DRS4 wf (clusters)



$\sigma = (t_l - t_r) = 0.4$ ns

MuTRiG

X

$\sigma = (t_l - t_r) = ?$

Summary

- NOL already very efficient and offer light yield comparable to SCSF-78MJ
- no significant difference between ribbons with and without TiO_2 (previous testbeams)

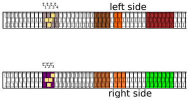
Fibre	#Layers	Eff. ($\pm 3\,\sigma$)	σ first $t_1 - t_2$ [ps]	#phe
78MJ, TiO_2	4	0.96	702	24.6
81MJ, TiO_2	4	0.93	617	13.2
NOL11, TiO_2	2	0.89	511	11.9
NOL11, TiO_2	3	0.93	427	18.2
NOL11, clear	3	0.96	408	16.9
NOL11, TiO_2	4	-	426	23.1
NOL11, clear	4	0.97	432	22.4

BACKUP SLIDES

Data Rate and Clustering

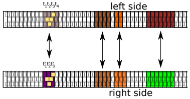
at 10^8 stopped μ/s	event rate [M/s]	data rate [Gbit/s]
SciFi detector	274	
Scintilating Fibres (235k/s/fibre)	1083	
SiPM columns signal (420 k/s/column)	1290	36.1
SiPM columns dark counts ($\sim$300 k/s/column)	922	25.8
SiPM columns total	2211	**61.9**
clustering		**20.0**

clustering per side

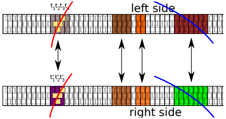


- on FPGA (FE)

match sides

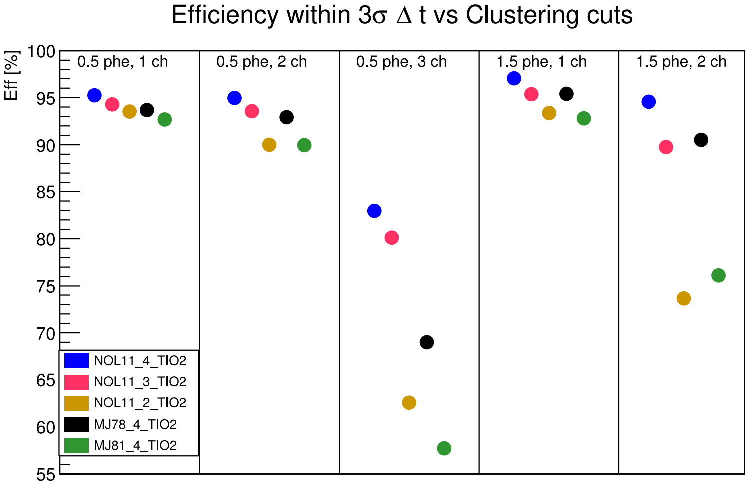


track to cluster match

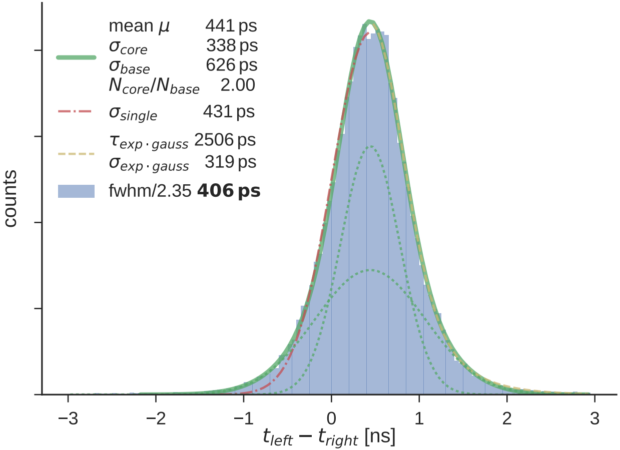


- best timing: use tracking

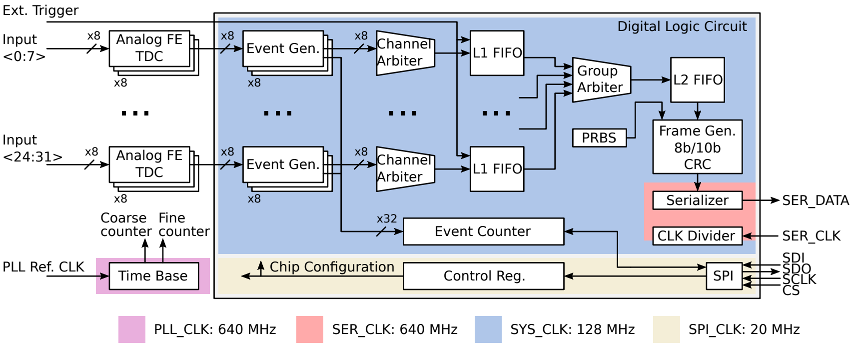
Efficiency for Different Thresholds



Time Resolution: Different Fit Models



MuTRiG



- UMC 180nm CMOS
- analog Front-End + TDC + digital part
- fully differential analog front-end
- high speed data link (1.28 Gbps)

PRBS + 8b/10b at 1.28 GHz: