Timing Detectors
Status Report

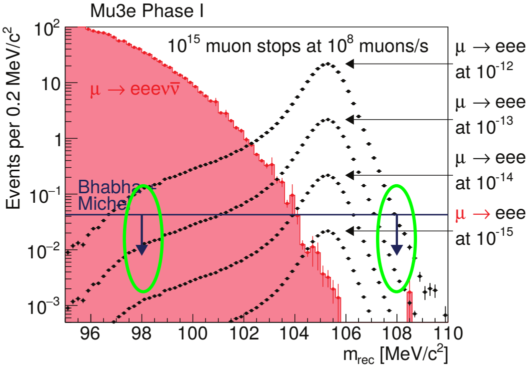
Simon Corrodi for the Mu3e Fibre group

6th February, 2017, BVR 48, PSI

The Timing Detectors: Motivation

Accidental background

Dominant: Bhabha + Michel

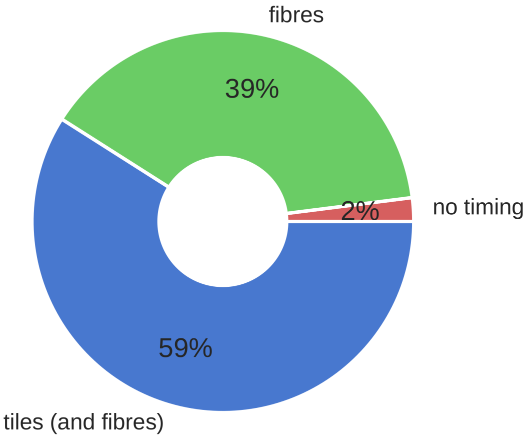


Performance Studies: dedicated presentation

The Timing Detectors: Motivation

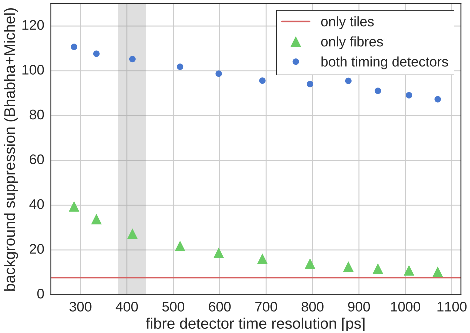
Situation

Fraction of reconstructed tracks (Michel decay, $\geq$6 hits) with **dominant** timing from corresponding detector.



Impact: Background Suppression

Accidental: Bhabha pair + Michel

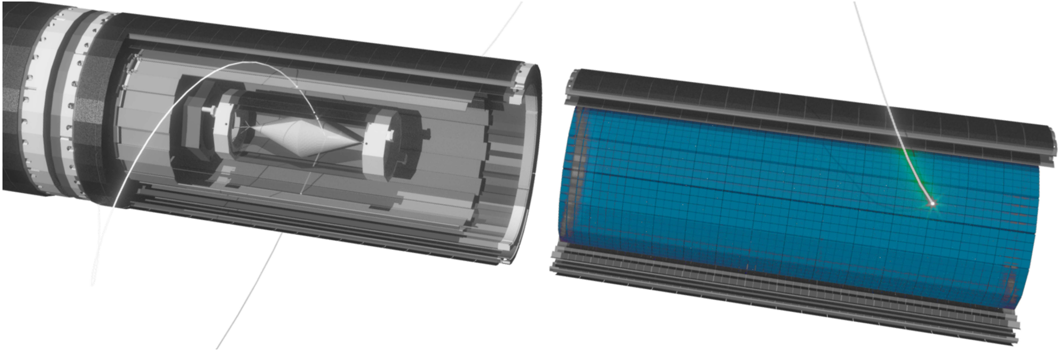


$\sigma_{\text{tiles}} = 70\,\text{ps}$, $\varepsilon_{\text{fibre}}$ and λ_{fibres} as in squared fibres.

Impact: Charge Identification

Time resolution $\lesssim 0.5\,\text{ns}$ allows reliable charge identification for recurling ($\geq$8 hits) tracks.

The Tile Detector: Overview



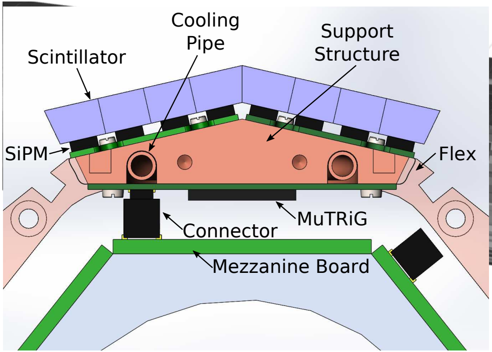
Components

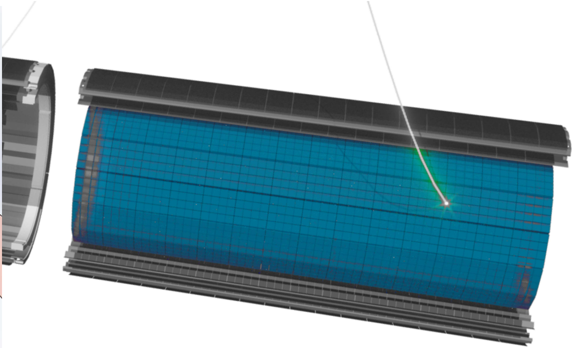
- cylindrical at max $\sim 6.3\,\mathrm{cm}$; $36.4\,\mathrm{cm}$ long
- 56 x 56 tiles of $6.5 \times 6.5 \times 5.0\,\mathrm{mm}^3$
- $3 \times 3\,\mathrm{mm}^2$ single SiPM per tile
- mixed mode ASIC: MuTRiG

Requirements

- as efficient as possible; close to 100 %
- time resolution better than 100 ps
- up to 50 kHz per tile/channel

The Tile Detector: Overview





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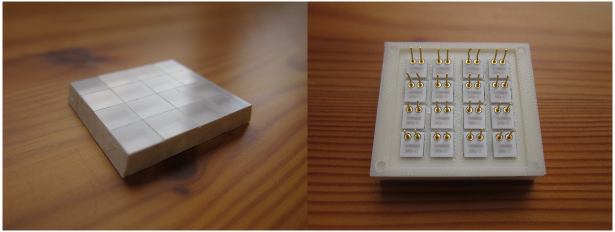
The Tile Detector: Prototype

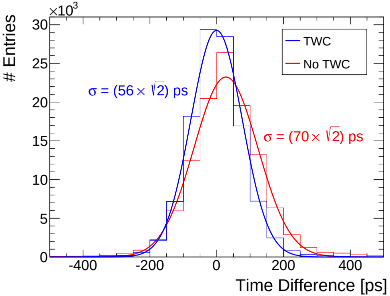
Prototype



- 4×4 channel BC408
- $7.5 \times 8.5 \times 5.0\,\text{mm}^3$
- Hamamatsu S10362-33-050C ($3 \times 3\,\text{mm}^2$)
- readout with STiC2

Results

time resolution

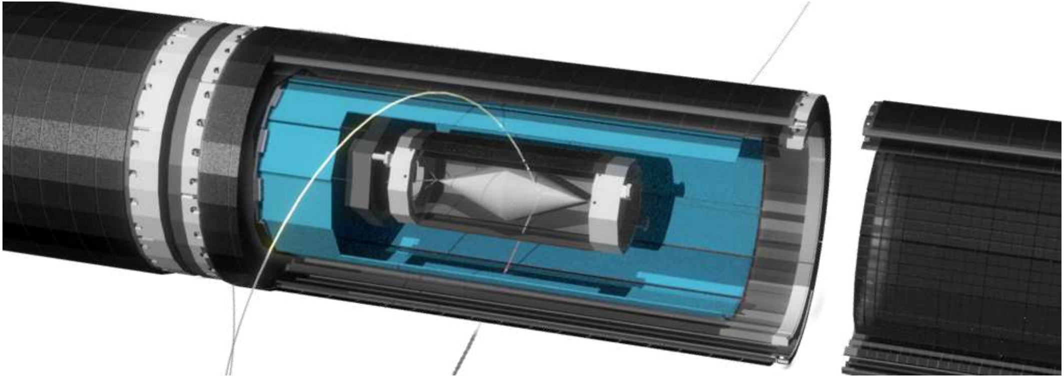


$\boldsymbol{\sigma_t = 56\,\text{ps}}$ (with TWC)

$\varepsilon_d \geq 99.7\,\%$

requirements fulfilled

The Fibre Detector: Overview



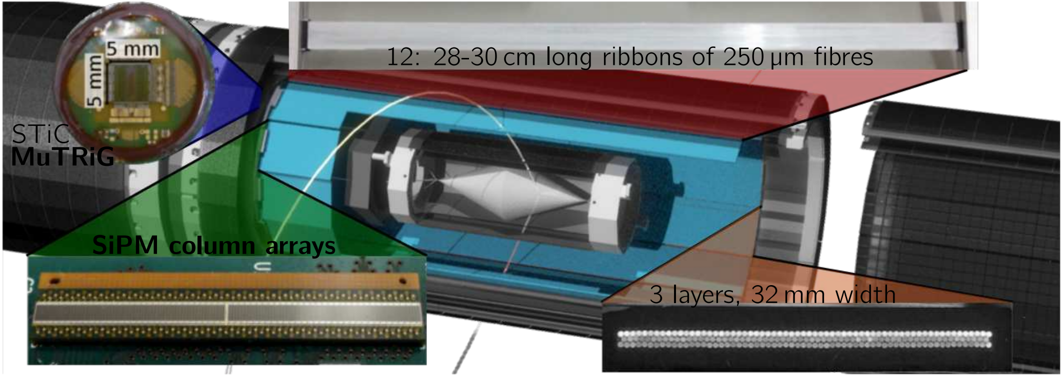
Components

- cylindrical at $\sim$ 6 cm; 28-30 cm long
- 3-4 layers of 250 µm fibres in 12 ribbons
- SiPM column arrays
- mixed mode ASIC: MuTRiG

Requirements

- as thin as possible; $\leq 0.5\,\%$ X/X_0 (1 mm)
- as efficient as possible; close to 100 %
- time resolution better than 500 ps
- up to 250 kHz/fibre; **very limited space**

The Fibre Detector: Overview



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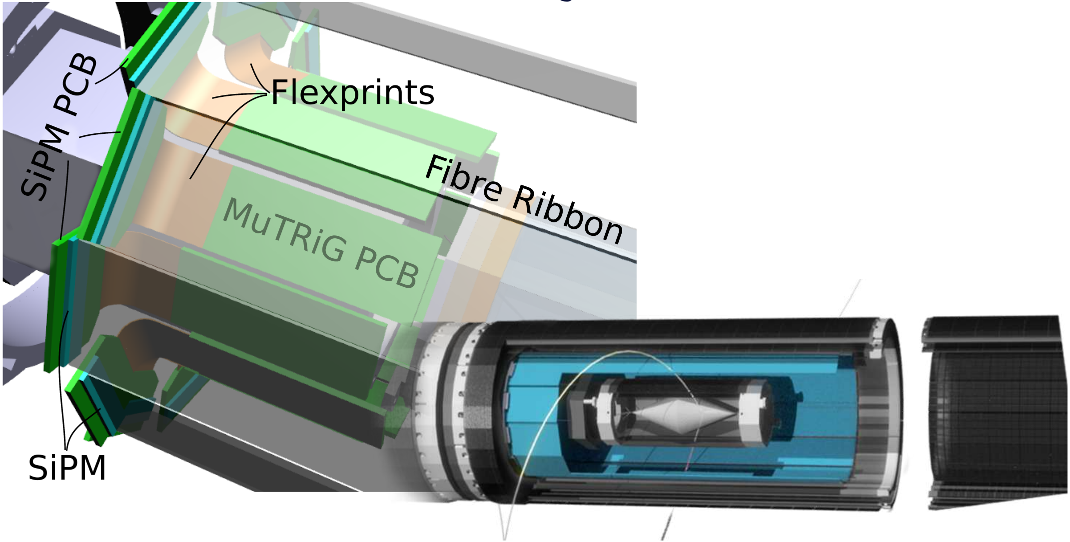
The Fibre Detector: Mechanical Design



bottom line: **very limited space**

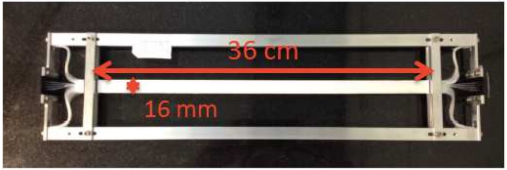
The Fibre Detector: Prototypes

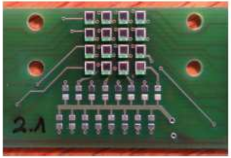
4 layers, 250 µm fibres; in lab and at PSI PiM1 115-215 MeV/c, pre-amps + digitizer (DRS4)

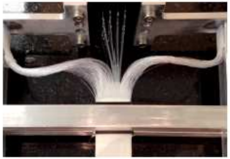
Squared Fibres

50 cm long fibres
additional Al coating
Saint Gobain BCF-12
Hamamatsu S13360-1350CS
($1.3 \times 1.3\,mm^2$, 50 µm pitch, trenches)

Round Fibres

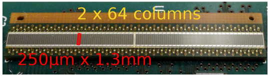






45 cm long fibres
optional TiO_2 in glue
Kuraray SCSF-81M
Hamamastu S12571-050P
($1 \times 1\,mm^2$, 50 µm pitch)

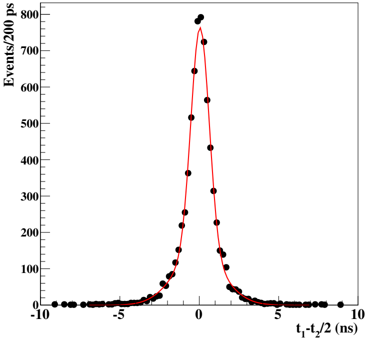
SiPM column arrays



(same sensors as LHCb)

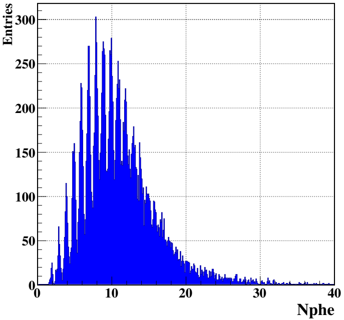
The Fibre Detector: Squared Results

Time Resolution (single layer)



$\boldsymbol{\sigma} = (t_l - t_r)/2 = \mathbf{700\,ps}$

Number of Photons (single layer)



Summed photons from both sides. (0.5 phe, AND)

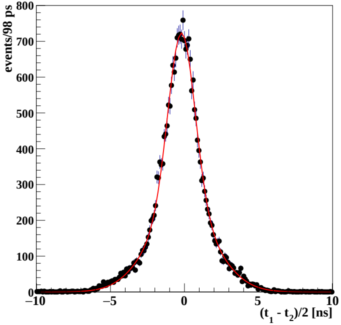
Efficiency

ε_{single} [%]	OR	AND
0.5 phe	97	71
1.5 phe	79	34

ε_{triple} [%]	OR	AND
0.5 phe	>99	**95**
1.5 phe	97	67

The Fibre Detector: Round Results

Time Resolution (single layer)



$$\boldsymbol{\sigma} = (t_l - t_r)/2 = \mathbf{1.0\,ns}$$

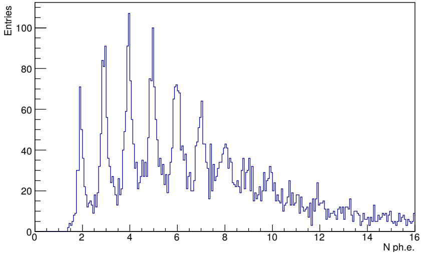
Efficiency

$\varepsilon_{\text{single}}$ [%]	OR
0.5 phe	95±9

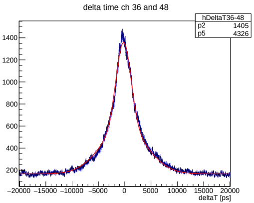
$\varepsilon_{\text{triple}}$ [%]	OR	AND
0.5 phe	97±1	70*
1.5 phe	90*	

*SP: 190 GeV/c protons

Number of Photons (single layer)



Summed photons from both sides.*(0.5 phe, AND)



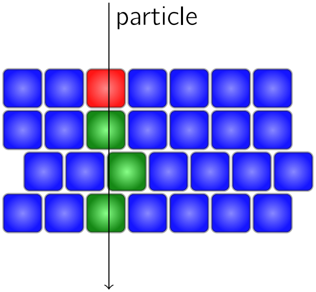
SiPM column array with STiC3.1

$$\sigma = (t_l - t_r)/\sqrt{2}$$
$$= 1.0\,\text{ns}$$

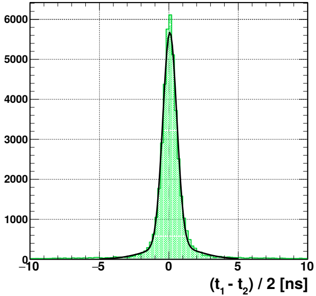
The Fibre Detector: Confirming Time Resolution Extrapolations

squared fibre prototype in lab and PSI PiM1 215 MeV/c testbeam

trigger
offline selection:
hits in 3 layers



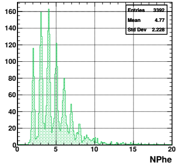
3 layers time resolution
lab: $\mathcal{O}(520\,\text{ps})$
testbeam $\mathcal{O}(\mathbf{550\,ps})$



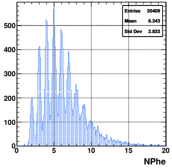
Remarks

- confirms extrapolations (BVR47)
- tracks in experiment: additional angle in θ

$\theta = 0^\circ$



$\theta \approx 45^\circ$



$\rightarrow$ increased path length
$\rightarrow$ increased time resolution

- **requirements fulfilled**

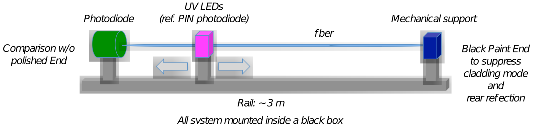
The Fibre Detector: Fibre Characterization

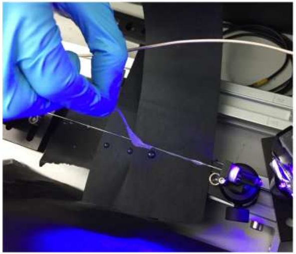
Setup $(\lambda_{att} = \lambda_{att}(x, \lambda))$

idea: use in series production

source LEDs: UV (285 nm); visible(405 nm)

measurement: intensity and spectrum





Simulation indicates

defferent surfaces (glisur)

ideal: perfect (polished, 1.)

real: more realistic (ground, 0.985, 0.98, 0.5)

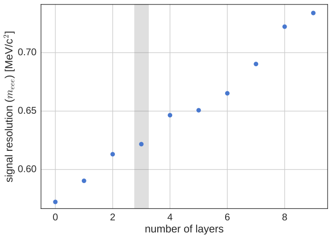
$$\lambda_{ideal} \approx 1754\,\text{mm}$$
$$\lambda_{real} \approx 369\,\text{mm}$$

material	n	light loss bare	light loss Al
outer cladding	1.42		
optical cement	1.56	~40 %	≤1 %
Araldite rapid	~1.5	~30 %	≤1 %
optical grease	1.465	~20 %	≤1 %

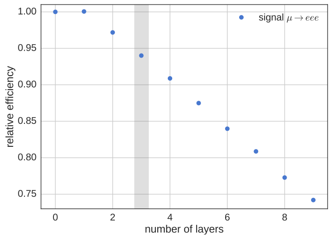
The Fibre Detector: Number Of Layers (squared)

Implications on Tracking

invariant mass (m_{eee}) resolution

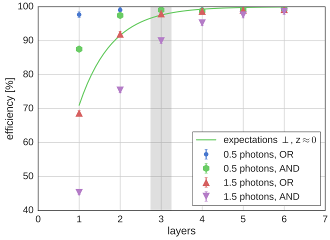


relative efficiency for $\mu \to eee$ ($\sim \varepsilon_{\text{track}}^3$)

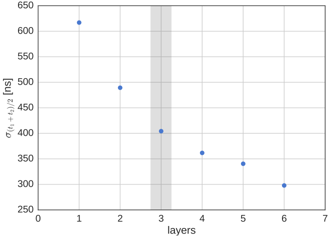


Impact on Timing (from target region)

fibre detector efficiency

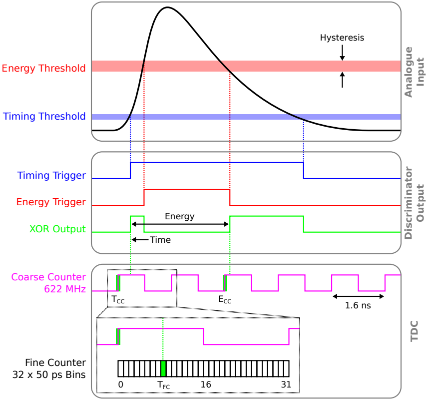


fibre detector time resolution



The Timing Detectors: Readout Electronics

mixed mode, ≈ 50 ps timestamps
high impedance, optional differential



Tiles: both Thresholds
Fibres: only Timing-Threshold *"time mode"*

	STiC3.1 in use	**MuTRiG** received end Jan.
number of channels	64	32
LVDS speed [Mbit/s]	160	1250
8b/10b encoding	yes	yes
event size [bit]	48	47
time mode	-	26
event rate / chip [MHz]	∼2.6	∼20
time mode	-	∼38
event rate / ch [kHz]	∼40	∼650
time mode	-	∼1200
power per channel [mW]	35	35
size [mm x mm]	5x5	5x5
number of PLLs	2	1

The Fibre Detector: Outlook

Milestone	BVR 47	BVR 48
SiPM array selection	Q2/16	✓
Full **simulation** and reconstruction of Fibre detector	Q3/16	✓
Full **Fibre characterization**		✓
SiPM **radiation** hardness	Q3/16	
Decision on **fibre type** (round or square) and SiPM	Q1/17	**Q2/17**
Construction of a **technical prototype** for the fibre mechanics (attachment, cooling, services)	Q4/16	**Q2/17**
Construction of a **readout prototype** including SiPM arrays, PCB, power distribution and slow control	Q4/16	**Q3/17**
Manufacturing and quality management strategy for fibre **ribbon/module production**	Q1/17	**Q3/17**
MuTRiG integration	Q2/17	**Q3/17**
Fibre **readout integration** into experiment DAQ and slow control (Midas)	Q2/17	**Q3/17**
Fibre detector **alignment and calibration scheme**	Q2/17	**Q3/17**
Full prototype (fully integrable)		**Q1/18**

The Tile Detector: Outlook

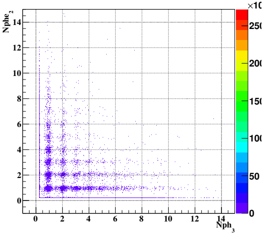
Milestone	**BVR 47**	**BVR 48**
R&D phase completed	✓	
Full **simulation** and reconstruction of Tile detector	✓	
prove SiPM **radiation hardness** with Sr90	Q2/16	✓
detailed **mechanical design** and TileFEB design	Q4/16	✓
prototype of support structure & cooling		**Q2/17**
prototype of TileFEB (with STiC3.1)		**Q3/17**
32 channel technical prototype (support, cooling, FEB, STiC3.1)		**Q4/17**
MuTRiG test and integration		**Q4/17**
develop QA scheme		**Q1/18**
Mass production strategy for scintillator tiles		**Q1/18**
Readout integration into DAQ and slow control		**Q2/18**
Full prototype		**Q4/18**

Appendix

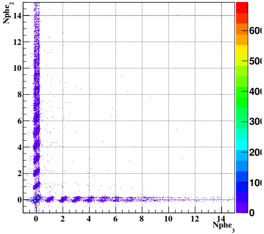
The Fibre Detector: Optical Isolation

Aluminum coating

no additional Al



with additional Al



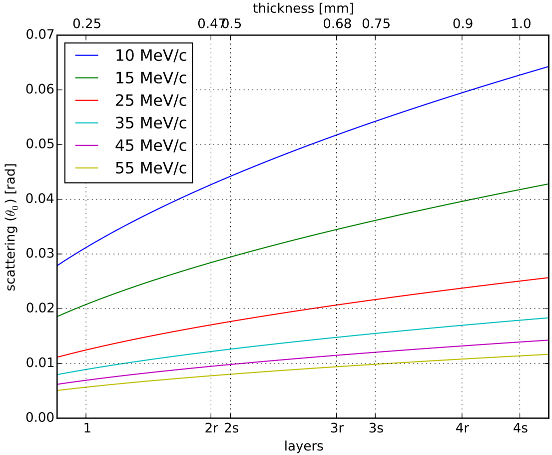
- significant cross-talk reduction
- ∼60 % yield increase
  (see. Fibre Characterization)

TiO_2 in glue

- crosstalk-reduction (ribbon dependent)
- 10-20 % yield increase (diffuse)
- ∼10 % cluster size reduction

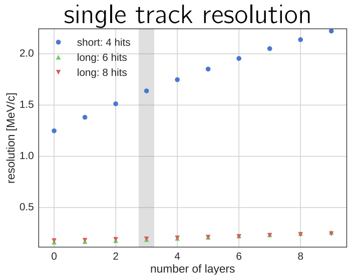
Multiple Coulomb Scattering

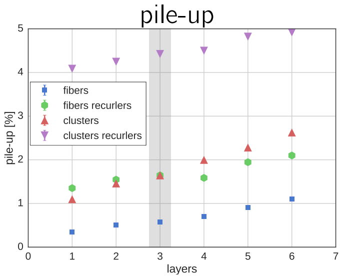
$$\theta_0 = \frac{13.6\,\mathrm{MeV}}{\beta c p} z \sqrt{x/X_0}\left[1 + 0.038 \ln x/X_0\right]$$

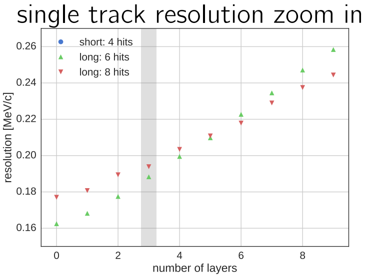


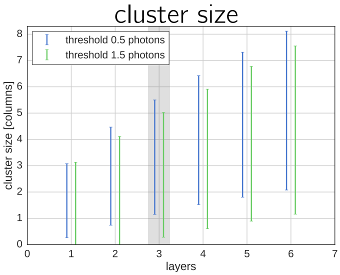
Caution: θ_0 with of Gaussian for central 98 %. The larger tails are not described with this.

The Fibre Detector: Number Of Layers

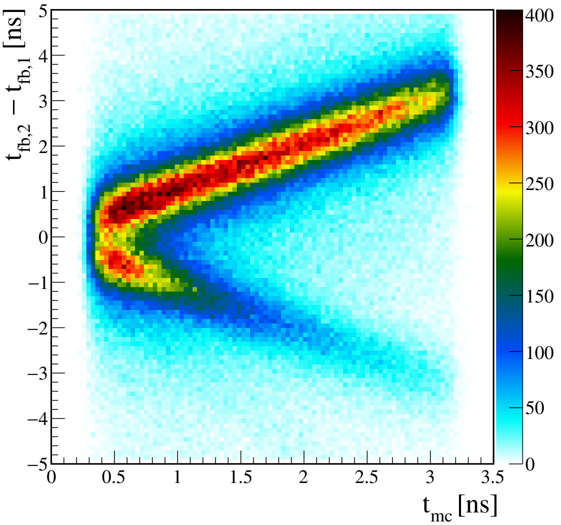






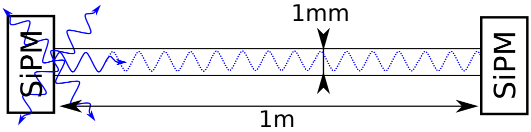


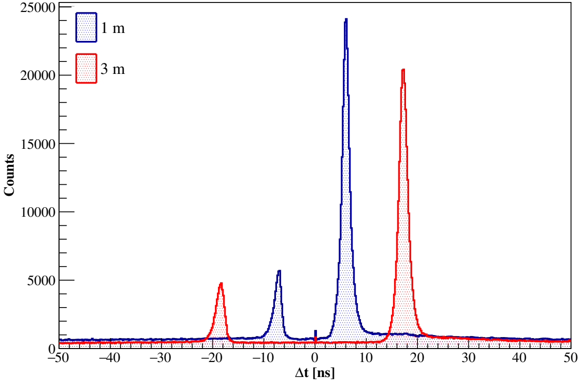
Charge Identification



Time difference between fibre clusters assigned to **recurling** (long 8-hits track) as function of distance along trajectory. The upper branch corresponds to the correct charge assignment and direction of rotation and the lower branch to the wrong charge assignment.

Fibre Mediated Dark Counts ($\mathcal{O}(5\,\%)$)



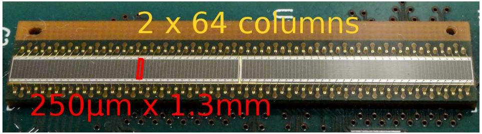


Fibre Properties

	round	square
company	Kuraray	Saint-Gobain
core	Polystyrene (PS)	
type	SCSF-81M	BCF12
inner cladding	Acrylic (PMMA)	
outer cladding	Fluor-acrylic (FP)	
cladding [%]	3/1	4/2
refractive index	1.59/1.49/1.42	1.60/1.49/1.42
density [g/cm^3]	1.05/1.19/1.43	1.05
light yield [ph/MeV]	$\sim$8000	
trapping efficiency [%]	5.4	7.3
capture angle [deg]	26.7	27.4
attenuation length [m]	>3.5	>2.7
decay time [ns]	2.4	3.2
emission peak [nm]	437	435

SiPM

Hamamatsu S10943 (older version)

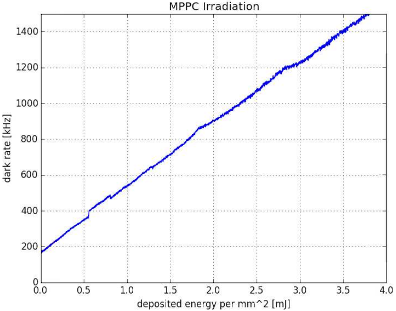


property	value
breakdown voltages	slightly below 55 V
temperature coefficient	53.7 mV K^{-1} at 25°
crosstalk at ΔV =2 V	∼4 %
crosstalk at ΔV =4 V	∼16 %
PDE peak	470 nm
PDE at ΔV =2.5 V	32 %
PDE at ΔV =4.5 V	45 %
geometrical fill factor	61 %
epoxy layer	100 µm to 120 µm

Radiation Damage

expectations:

- e^+/e^- flux: 0.9/1.7 MHz mm^{-2}
- integrated flux per year: $0.8/1.4 \cdot 10^{10}$ e^+/e^- mm^{-2}
- dose per year: 55/97 mJ; 24/42 Gy

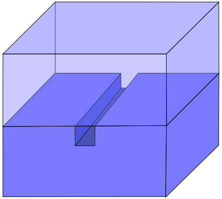


The Fibre Detector: Fibre Alignment Studies

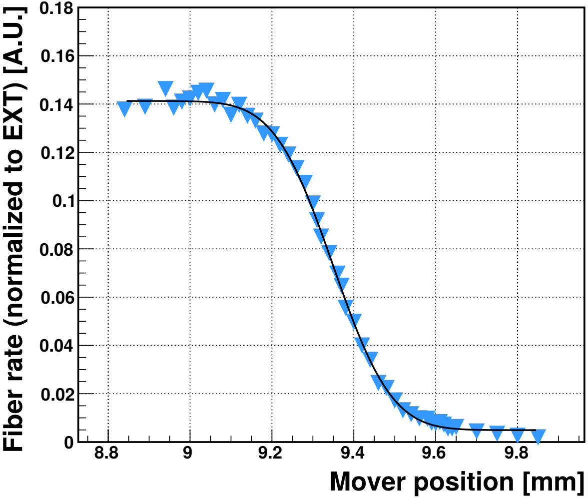
Collimator

plexiglass, $1 \times 1\,\mathrm{mm}^2$ hole

external trigger



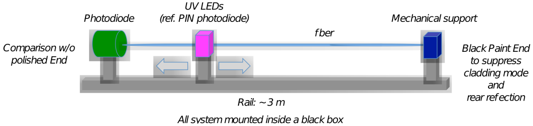
allows alignment studies of $\mathcal{O}(10\,\mu\mathrm{m})$



The Fibre Detector: Fibre Attenuation Length $\lambda_{att} = \lambda_{att}(x, \lambda)$

Setup

for use during series production



measurement: intensity and spectrum

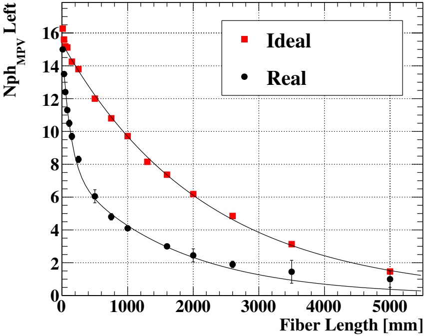
sources: UV (285 nm); visible(405 nm) LEDs

Simulation

different surfaces (glisur)

ideal: perfect (polished, 1.)

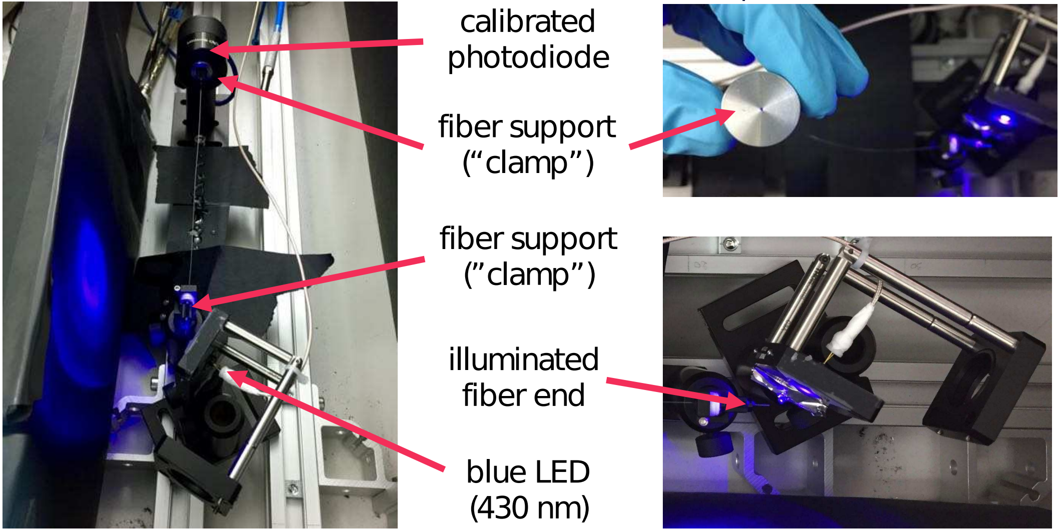
real: more realistic (ground, 0.985, 0.98, 0.5)



$\lambda_{ideal} \approx 1754\,\text{mm}$

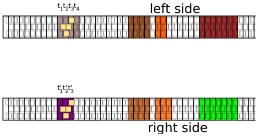
$\lambda_{real} \approx 369\,\text{mm}$

The Fibre Detector: Fibre Characterization Setup



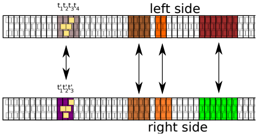
Stability of the LED + photodiode power meter: better than 1 %
Also touching the mounted fiber affects the light transmission by at most 1 %

The Fibre Detector: Clustering

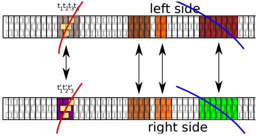


clustering per side

- potentially on FPGA
- dark count reduction, bandwidth reduction

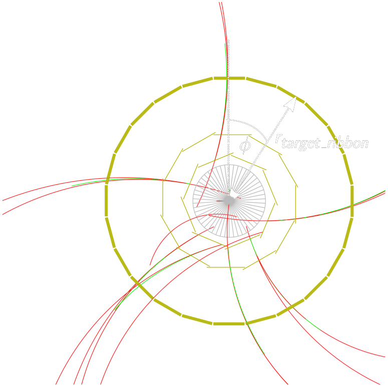


match sides



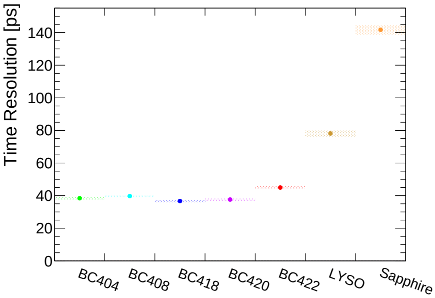
track to cluster matching

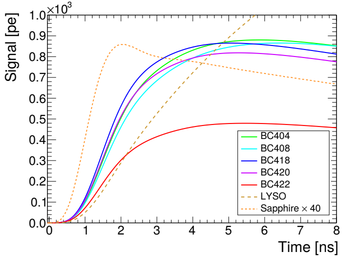
- current implementation $\varepsilon > 95\,\%$
- tracking information: extract best timing (path length)

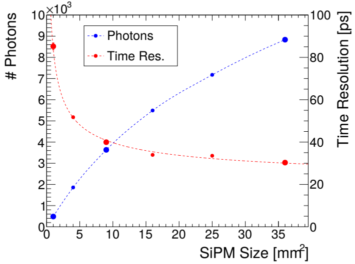


Event display at $\sim 10^8$ stopped muons/s in one 50 ns frame.

The Tile Detector



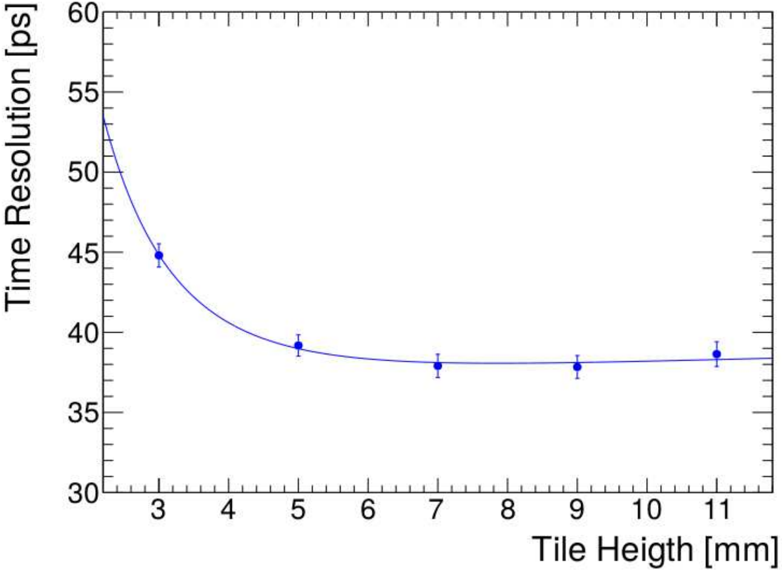




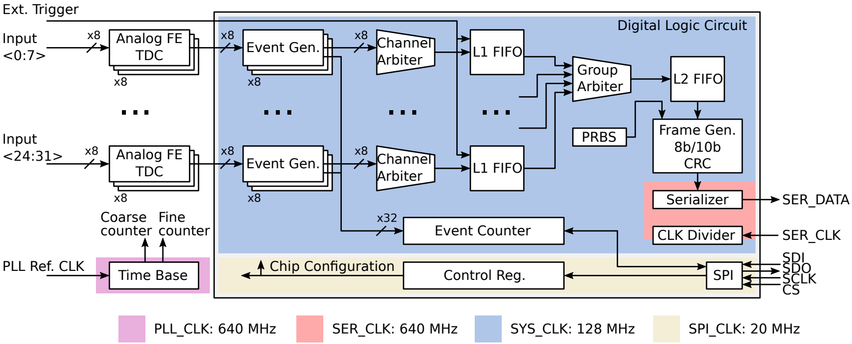
Saint Gobain BC418

- coated with TiO_2
- nominal yield 10 200 photons/MeV (mu3e: ∼900)
- rise time 0.5 ns, decay time 1.4 ns
- emission peak 391 ns

The Tile Detector



MuTRiG



- UMC 180nm CMOS
- analog Front-End + TDC + digital part
- fully differential analog front-end
- high speed data link (1.28 Gbps)
- external trigger
- event counter for each channel, separate data path
- configurable data structure

PRBS + 8b/10b at 1.28 GHz: