Scintillating Fibers for High Resolution Time Measurements?

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on behalf of the Mu3e Fibre Group

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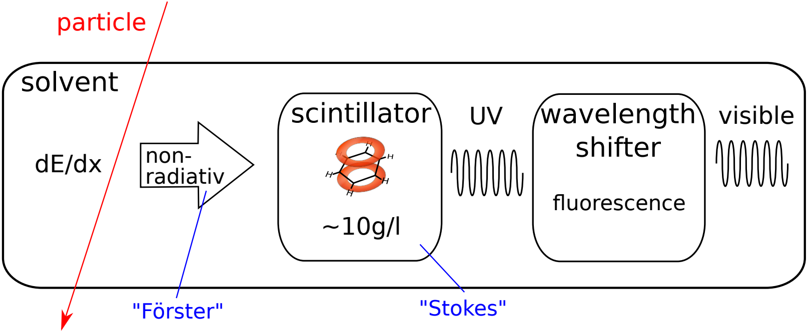
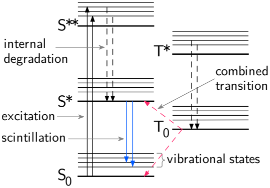
Scintillation: Organic Plastic Scintillators

Polystyrene (PS) + dopants (scintillator, wavelength shifter)

or Polyvinyltoluene (PVT)





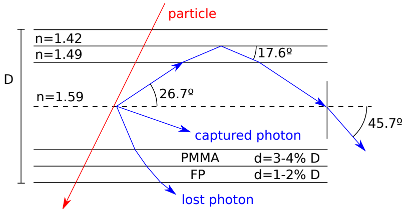
Stokes-shift

(decay not to S_0) makes fibres transparent.

scintillation: $\mathcal{O}(1\,\text{ns})$

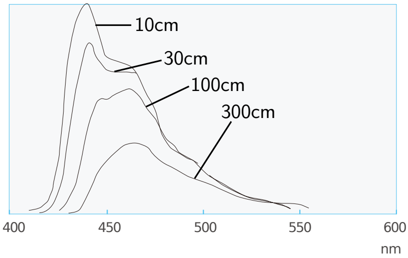
(Scintillating) Fibers

part	material	n
core:	polystyrene (PS)	1.59
cladding I:	polymethyl methacrylate "plexiglas" (PMMA)	1.49
cladding II:	fluorinated polymer (FP)	1.42



$$\Theta_{\text{total reflection}} = \arcsin\left(\frac{n_{\text{cladding}}}{n_{\text{core}}}\right)$$

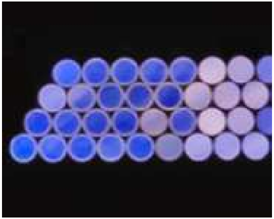
Kuraray: SCSF-81M



	Kuraray SCSF-81M	Saint-Gobain BCF-12
decay time [ns]	2.7	3.4
attenuation [m]	> 3.5	2.7
yield [phot/keV]	~ 8	~ 8

Scintillating Fibers

round

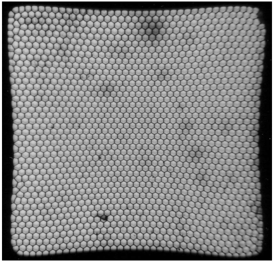


Mu3e prototype,
4 layers 250 µm.

squared

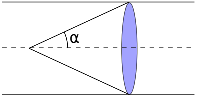
MEG II proposal:
“active target”.

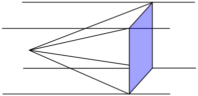
hexagonal



CERN RD7 1989,
bundle out of 60 µm.

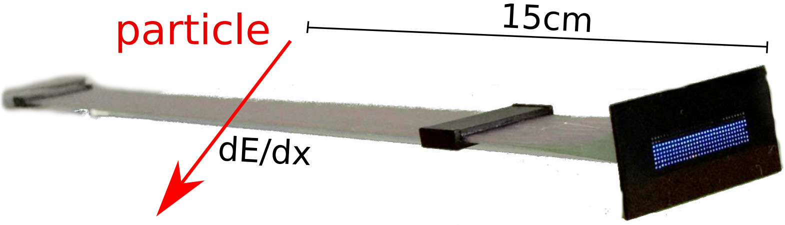
$$\varepsilon_{\text{capture}} \geq \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\alpha} \mathrm{d}\varphi \mathrm{d}\Theta$$





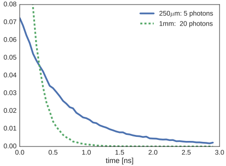
$\varepsilon \geq$ [%]	cladding single	cladding double
round	3.1	5.4
square	4.4	7.3

Scintillating Fibres Summary



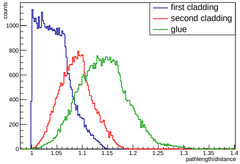
$\frac{dE}{dx}$ (160 MeV e^-)	d_{fibre}	yield	ε_{cap}	d_{att}	$\varepsilon_{\text{detection}}$	
200 $\frac{\text{keV}}{\text{mm}}$	210 µm	$\sim 8\ \frac{\text{ph}}{\text{keV}}$	5.4 %	95 %	30 %	$\approx$ **5**

photon statistics



$\times$

pathlength in fibres

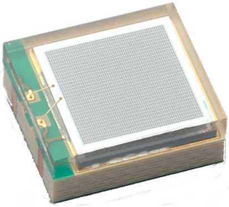


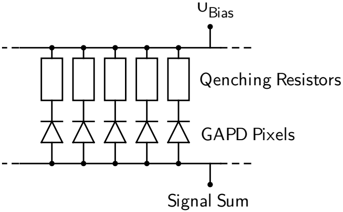
PDE: $\approx \exp\left(-t \cdot (\tau/n)^{-1}\right)$

PDE: "*flat*" : $d_{\text{hit-det}} \cdot 12\,\% \cdot \left(\frac{c}{n}\right)^{-1} \approx 7\,\text{ps} \cdot d[\text{cm}]$

Silicon Photomultipliers

Arrays of avalanch photo diodes (APD) in Geiger mode.

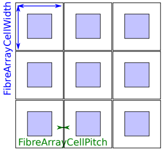




- gain up to 10^8
- photon detection efficiency $30 - 50\%$
- moderate HV, compact, B-field resistant
- dark counts $\mathcal{O}$(MHz)

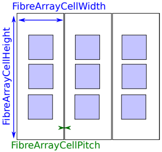
pixel: 10-100 µm, sensors: 1-6 mm, arrays ...

Single



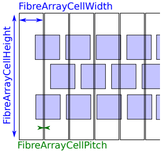
- most information
- fan-out needed
- max channels

Fan-Out & Columns



- collect more light in the same cells
- optimization on event structure

Columns



- easy: no fan-out
- granularity of SiPM ∼ fibres

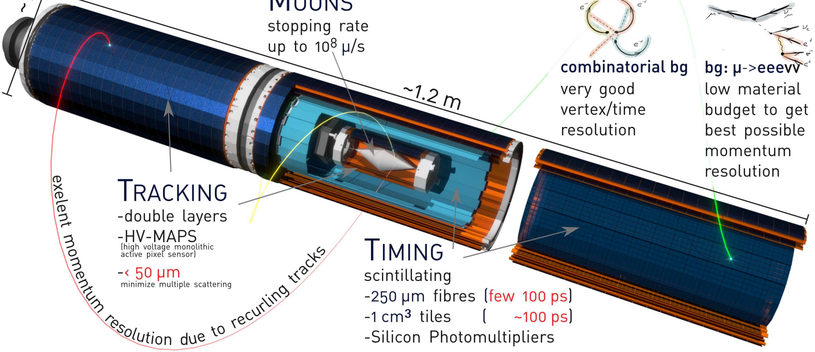
The Mu3e Experiment

An Experiment Searching for the Lepton Flavour Violating Decay

$$\mu^+ \longrightarrow e^+ e^- e^+$$

$BR_{SM} \ll 10^{-50}$
Any observation is a sign for new physics.

$B(\mu \to eee) < 1.0 \cdot 10^{-12}$ (SINDRUM, 1988)
Mu3e: find or exclude μ->eee at a 10^{-16} level



Muons
stopping rate up to 10^8 μ/s

Tracking
-double layers
-HV-MAPS
(high voltage monolithic active pixel sensor)
-< 50 μm
minimize multiple scattering

Timing
scintillating
-250 μm fibres (few 100 ps)
-1 cm³ tiles (~100 ps)
-Silicon Photomultipliers

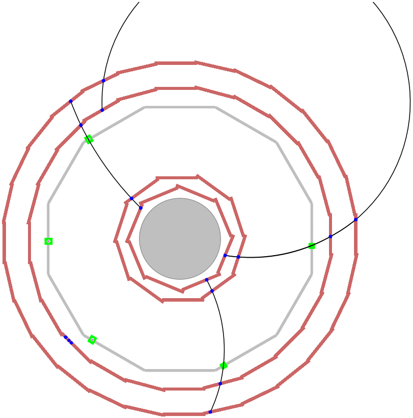
exelent momentum resolution due to recurling tracks

Requirementrs

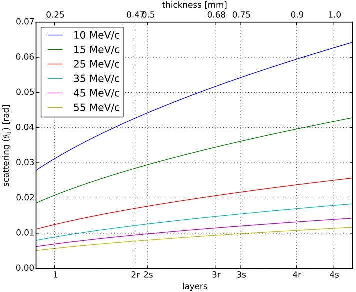
combinatorial bg
very good vertex/time resolution

bg: μ->eeeνν
low material budget to get best possible momentum resolution

Mu3e: Scintillating Fibres for Timing



Multiple Coulomb Scattering



Requirements

- high track efficiency($\sim$99 %)
- excellent timing ($<$1 ns)
- low material budget ($x/X_0 \leq$0.5 %)
- moderate granularity

Used Fibre Configuration

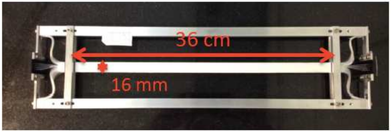
- 3-4 fibre-layers
- catch first photons (both sides)
- readout outside of acceptance
- 250 µm fibres, SiPM columns

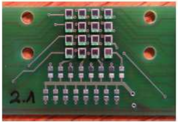
Prototypes (4 layers, 250 μm)

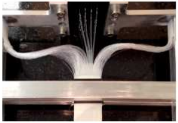
Squared Fibres (PSI)

50 cm long fibres
additional Al coating
Saint Gobain BCF-12
Hamamatsu S13360-1350CS

Round Fibres (GE, ZH)



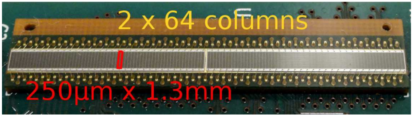




36 cm long fibres
optional TiO_2 in glue
Kuraray SCSF-81M
Hamamastu S12571-050P

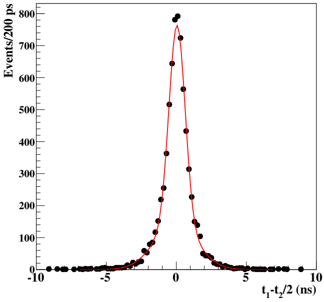
. . . .

SiPM column arrays (LHCb)



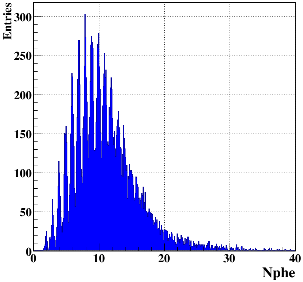
Square Results

Time Resolution



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

Number of Photons:



Summed photons from both sides.

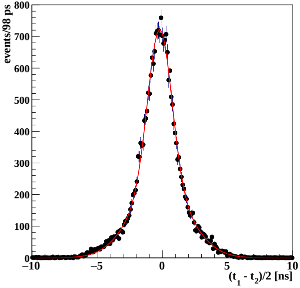
Efficiency:

$\varepsilon_{\text{single}}$ [%]	OR	AND
0.5 phe	97	71
1.5 phe	79	34

$\varepsilon_{\text{triple}}$ [%]	OR	AND
0.5 phe	>99	95
1.5 phe	97	67

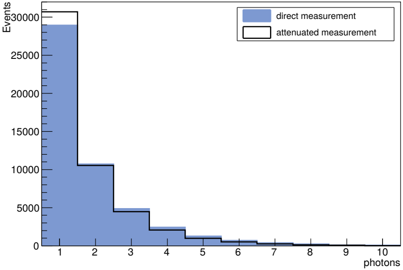
Round Results

Time Resolution



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

Number of Photons:



One side, different distances

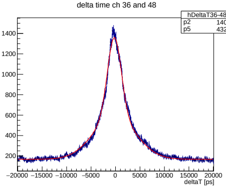
(6.5 cm and 49.5 cm).

Efficiency:

$\varepsilon_{\text{single}}$ [%]	OR	AND
0.5 phe	65±9	70*
1.5 phe	90*	

*SPS proton data

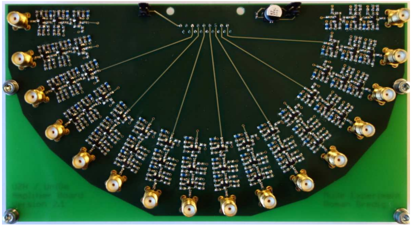
SiPM column array and STiC



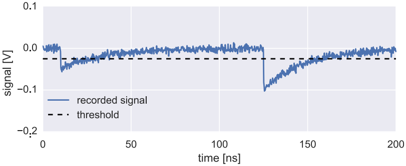
$$\sigma = (t_l - t_r)/\sqrt{2}$$
$$= 1.0\,\text{ns}$$

Readout: pre-amplifiers & DRS4 evaluation (PSI)

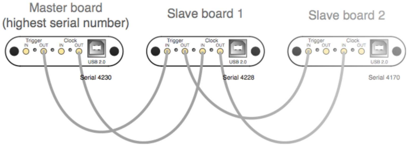
Custom pre-amplifiers



full waveforms



up to 8 **DRS4 v5** 4-channel evaluation board daisy chain

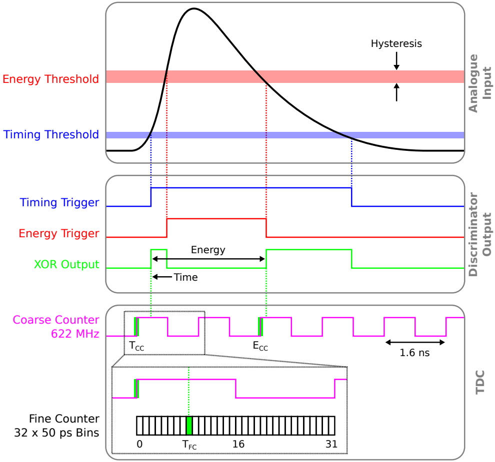


- 5 Gsps, up to 2048 values
- common trigger
- DAQ: $\mathcal{O}(100\,\text{Hz})$
- jitter per board $\approx 130\,\text{ps}$

Many more:

VME TDC, QDC; STiC, TOFASIC, NINO*, PETA*, KLausS, TRIROC, ...

Readout ASIC: STiC/MuSTiC (KIP Heidelberg)



fibre detectors: timing threshold

STiC3.1 available

64 chs, max 2.6 Mevents/s/chip

used DAQ: 700 kevents/s/chip

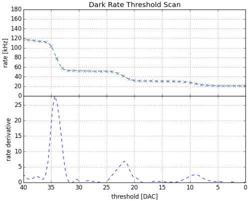
- jitter: $\mathcal{O}(30\,\text{ps})$
- self triggering

MuTRiG development

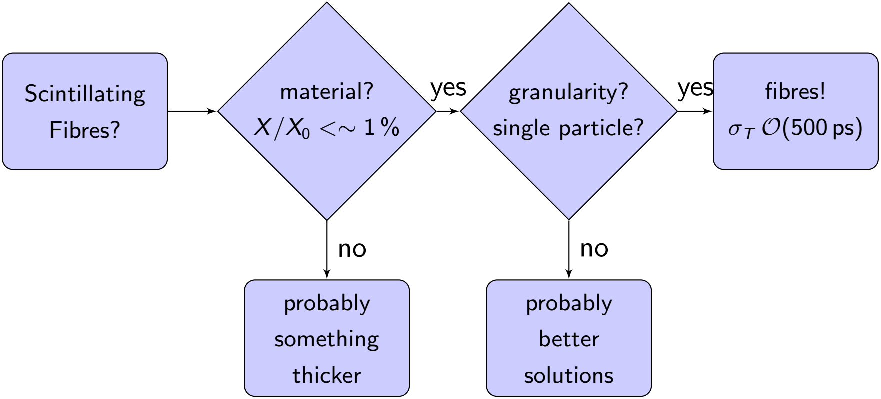
32 chs, max 1.1 Mevents/s/ch

+ external trigger

operation only with timing threshold



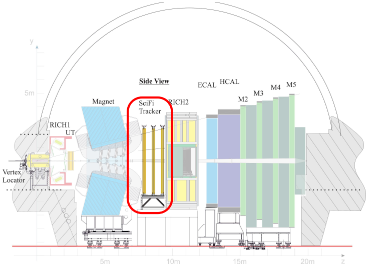
Scintillating Fibres for High Resolution Time Measurements?



Appendix

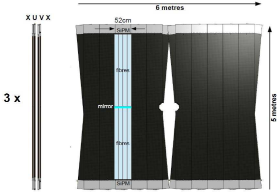
Scintillating Fibre Trackers

LHCb upgrade



LHCb tracker upgrade TDR.

6 layers: 250 µm fibres



NA61/Shine

fixed target experiment

tracking of incoming beam

configuration	*resolution* σ_x	ε
single layer	$\sim$ 130 µm	90 %
5 layers	$\sim$ 160 µm	95 %

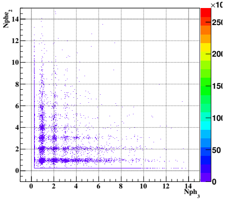
common

- high hit efficiency($\sim$99 %)
- low material budget ($x/x_0 \leq 1$ %)
- readout outside of acceptance
- tracking – high granularity
- time resolution: resolve banch (25 ns)

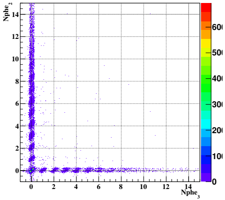
Crosstalk

Al coating

no additional Al



with additional Al



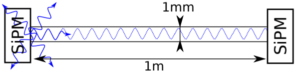
- significant cross-talk reduction
- $\sim$60 % yield increase (diffuse)

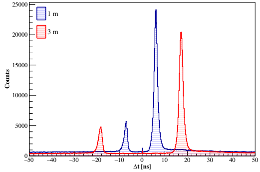
material	n	light loss bare	light loss Al
optical cement	1.56	$\sim$40 %	$\leq$1 %
Araldite rapid	$\sim$1.5	$\sim$30 %	$\leq$1 %
optical grease	1.465	$\sim$20 %	$\leq$1 %

TiO_2 in glue

- crosstalk-reduction (ribbon dependent)
- 10-20 % yield increase (diffuse)
- $\sim$10 % cluster size reduction

Fibre mediate dark counts





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