Fibre Sub-detector Status Report

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BV47 8th February 2016
Paul Scherrer Institut

Summary

The fibre detector

- Overview
- Impact on the experiment

Reminder from BV46

- Previous activities in one shot

Results with New detector prototypes

- with squared and round fibres coupled to standalone electronics

Readout electronics

- STiC and MuSTiC

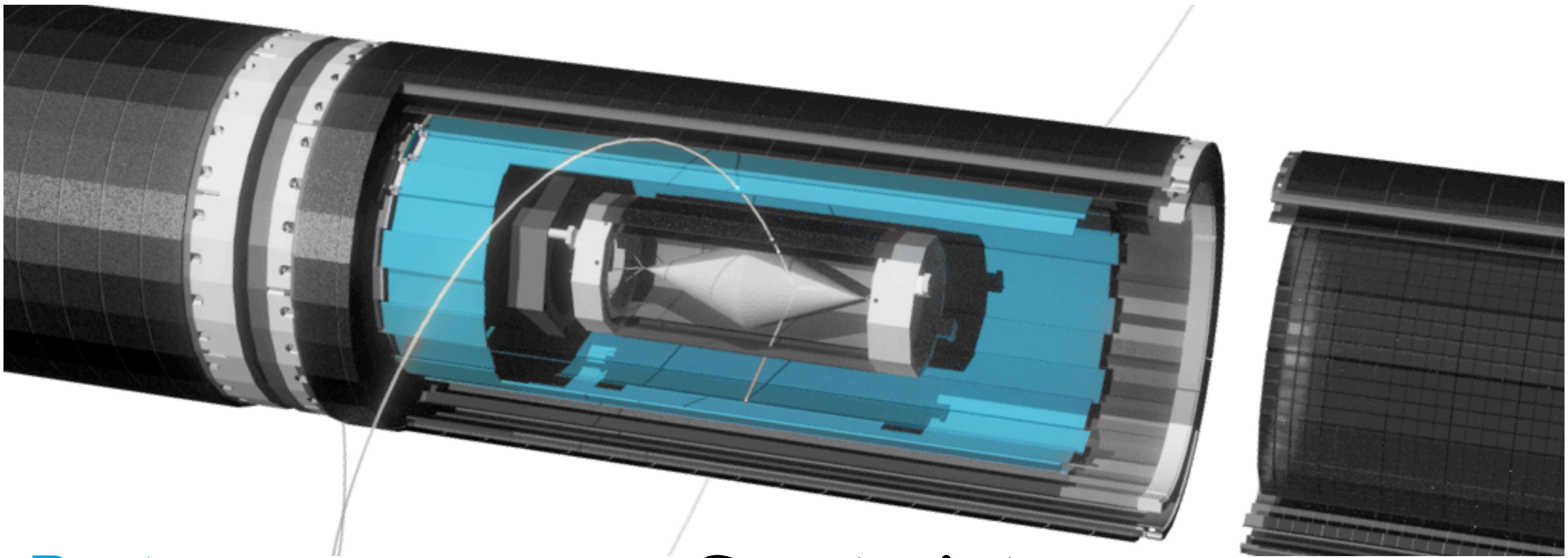
Detector integration

- Mechanics, Cooling, Cabling...

Milestones/Next steps

The fibre detector

Overview



Parts

- cylindrical at ~ 6 cm (radius); length of 28-30 cm;
- 3-4 layers of round or square multi-clad 250 μm fibres
- fibres grouped onto SiPM array
- MuSTiC readout

Constraints

- high detection efficiency $\varepsilon > 95\%$
- time resolution $\sigma < 1$ ns
- < 900 μm total thickness
  < 0.4 % X_0
- rate up to 250 KHz/fibre
- very tight space for cables, electronics and cooling

Detector impact into the experiment:
Accidental Background suppression

Additional suppression factor due to timing detectors

- Dominant combination: e^+/e^- pair with common vertex, coincidence (Bhabha)
  e^+ (Michel)
- Hypothesis:

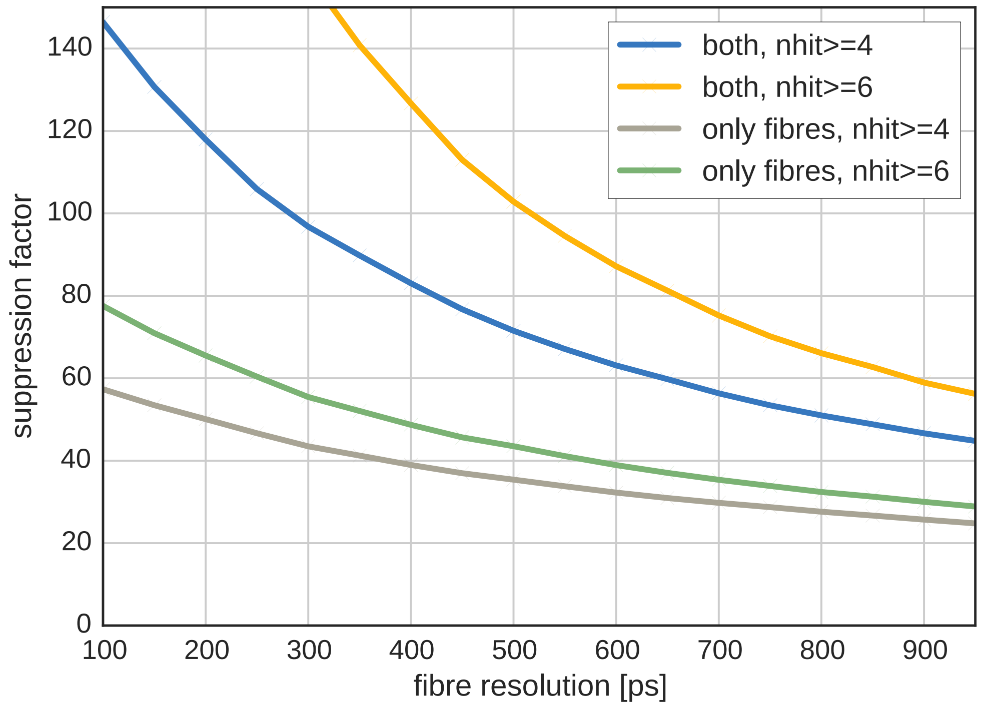
  reconstructed tracks (grouped in ≥4 hits and ≥6 hits)

  fully efficent tile detector with 60 ps resolution

  95% fibre ribbon efficiency with 500 ps resolution

s_fact	fibres	tiles	both
≥4 hits	35	5.3	72
≥6 hits	44	5.3	102

s_fact = suppression factor



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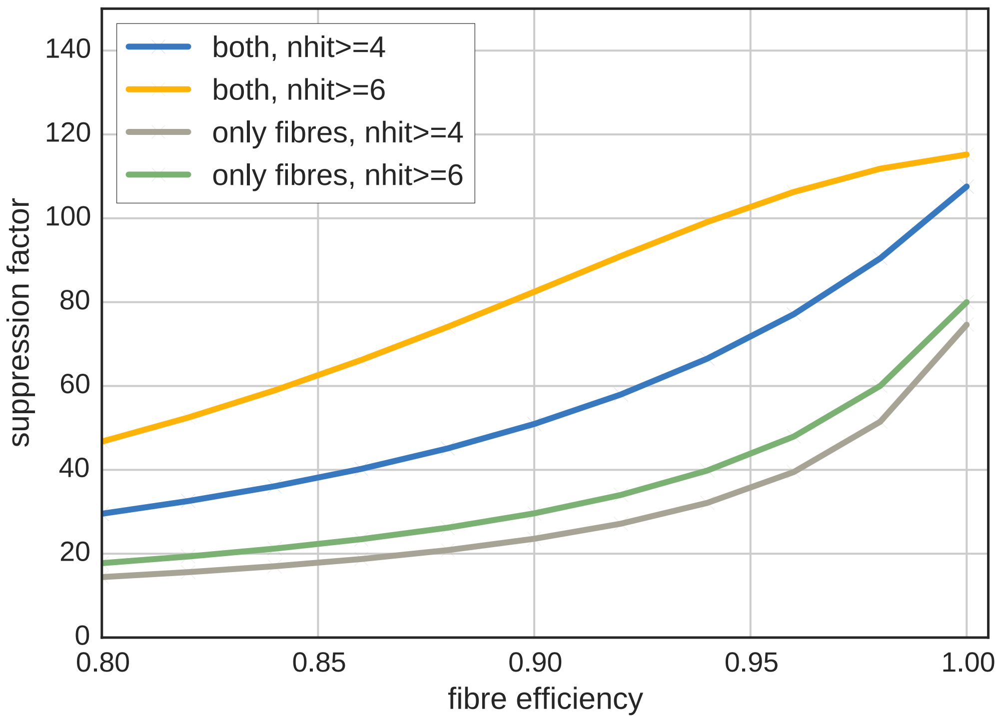


Reminder from BV46

Prototype development in One Shot

Squared fibre prototype

- Hamamastu S12825-050C (1.3 x1.3 mm^2)
- **2** staggered layers
- 250 x 250 um^2 Saint-Gobain BCF 12 fibre
- Fibre Length: 20 cm
- **Individual** fibre readout
- Double Readout
- **Negligible fibre optical cross-talk < 1%**

Results:

ε(OR)> 97 %

σ (**double** hit, **thr > 0.5 phe**) ~ 400 ps

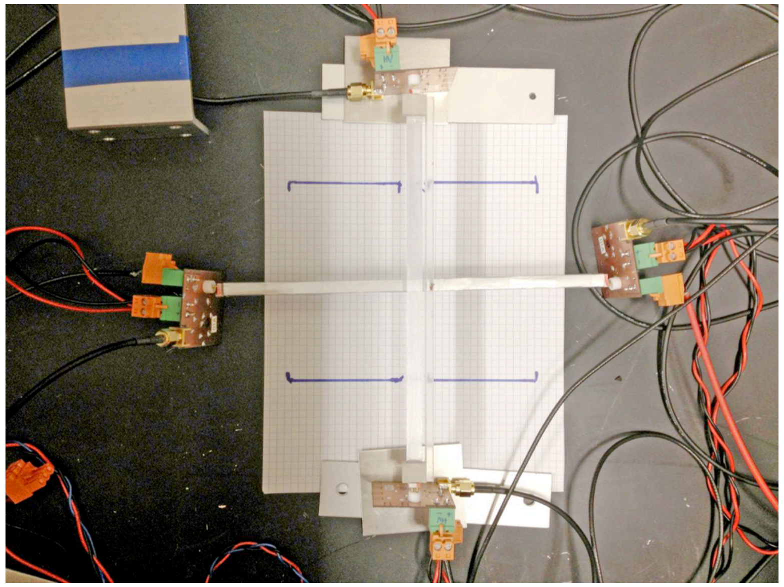
Round fibre prototype

- Hamamastu S12573-050P (3 x3 mm^2)
- **3** staggered layers
- 250 um diam Kuraray SCSF-81M fibre
- Fibre Length: 20 cm
- **Bundle** readout
- Double Readout

Results:

ε(OR) > 95 %

σ (**bundle**, **thr > 2 phe**) ~ 400 ps



Results with new prototypes
Squared fibres

The Large Prototype

- a segmented and versatile detector
- each fiber independent element

Aim

- detector design and performance assessment
- emphasis: different layer combination study

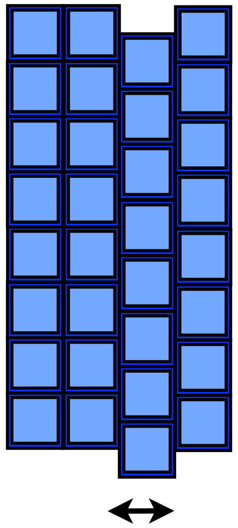
What's new

- More channels: 64
- Longer and New fibres:

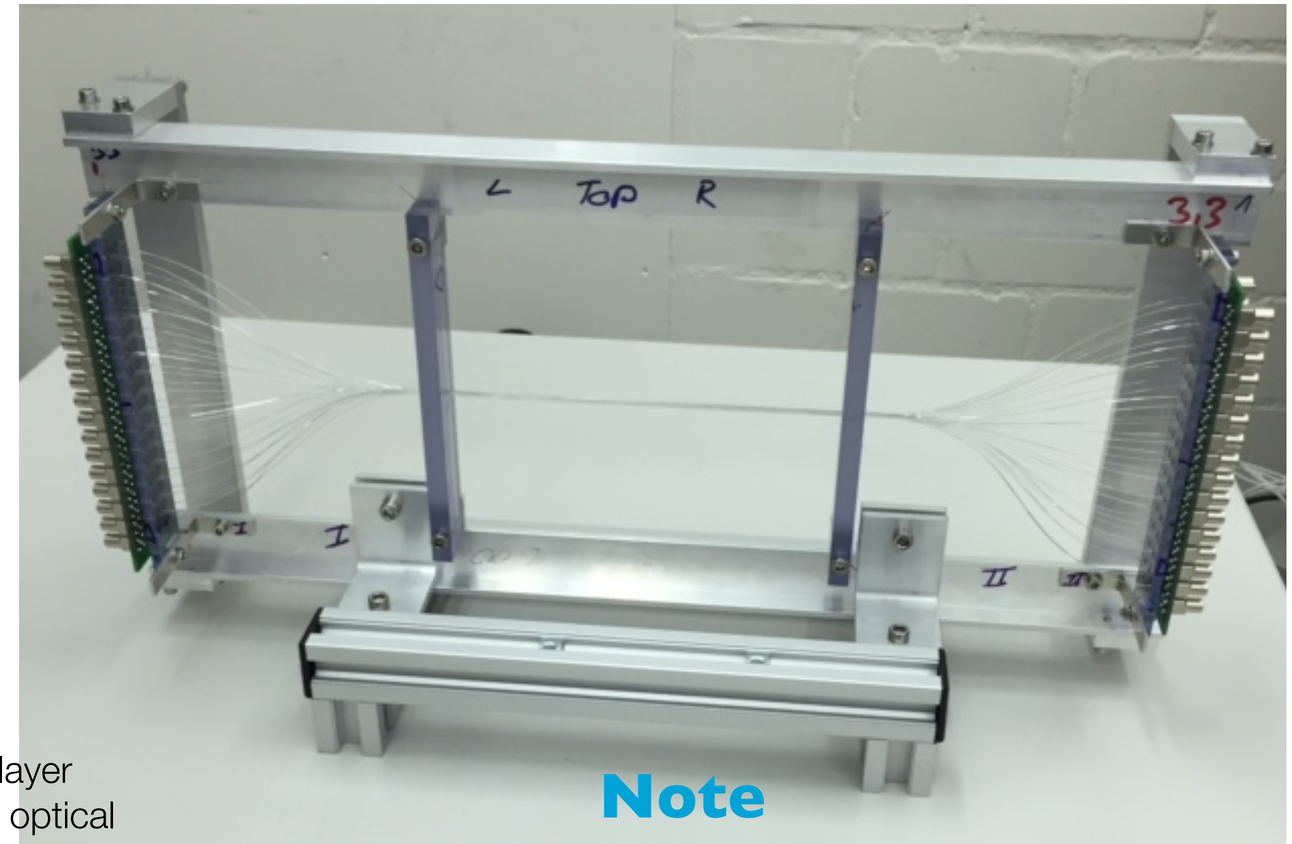
  L~ 50 cm and new Saint Gobain multiclad BCF12 production
- Four fibre layers
- New SiPM series

  Hamamatsu S13360-1350CS

Fibre assembly
(lateral view)



~265 um/layer including the optical cement

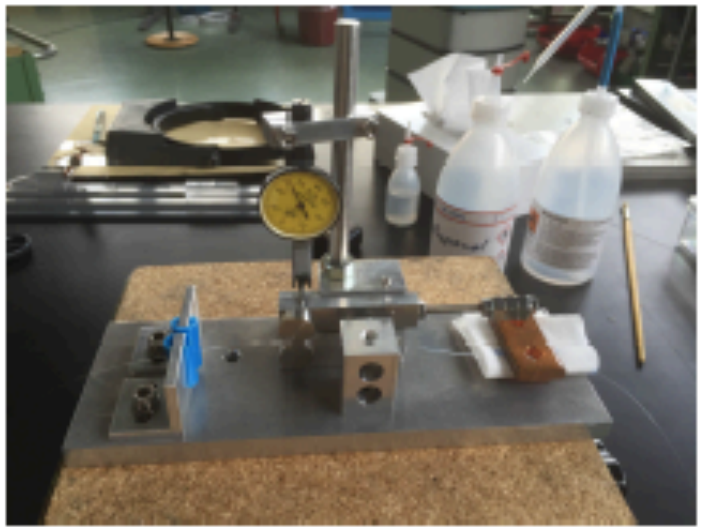


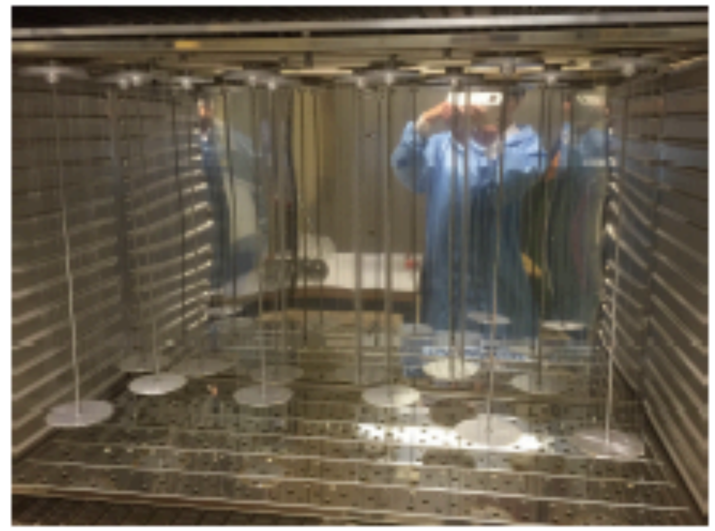
Note

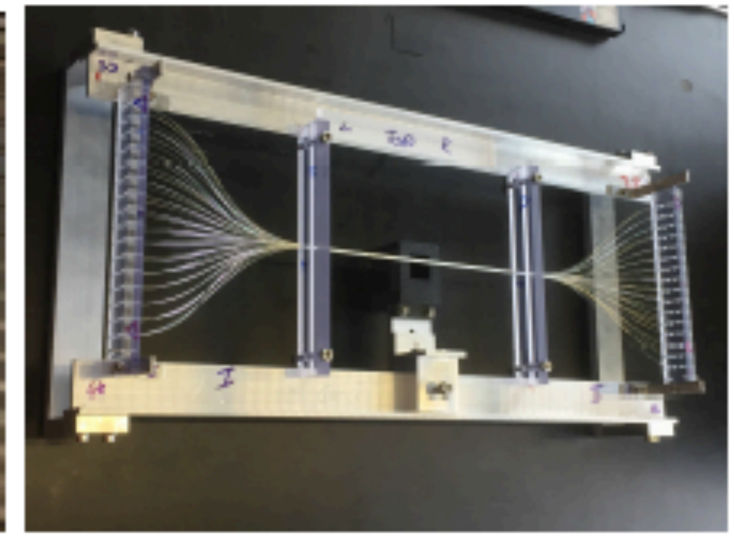
- Squared 250 x 250 um^2 fibres
- 100 nm Al coating (Evaporation)
- Double readout

Prototype production chain

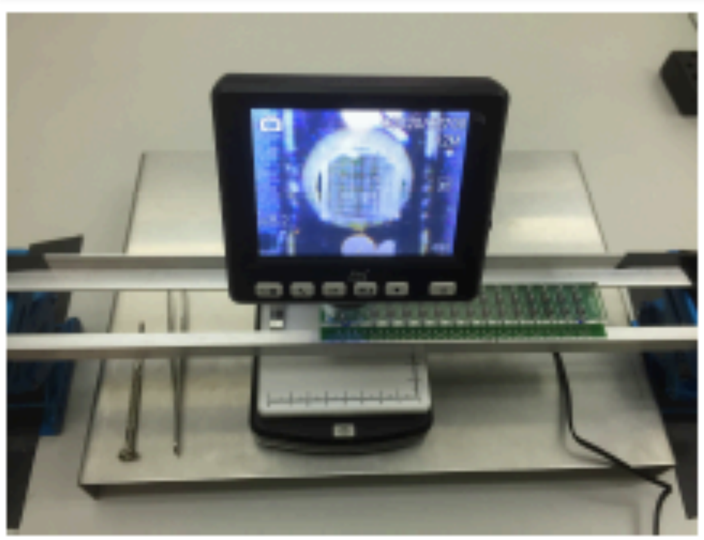
Squared fibres

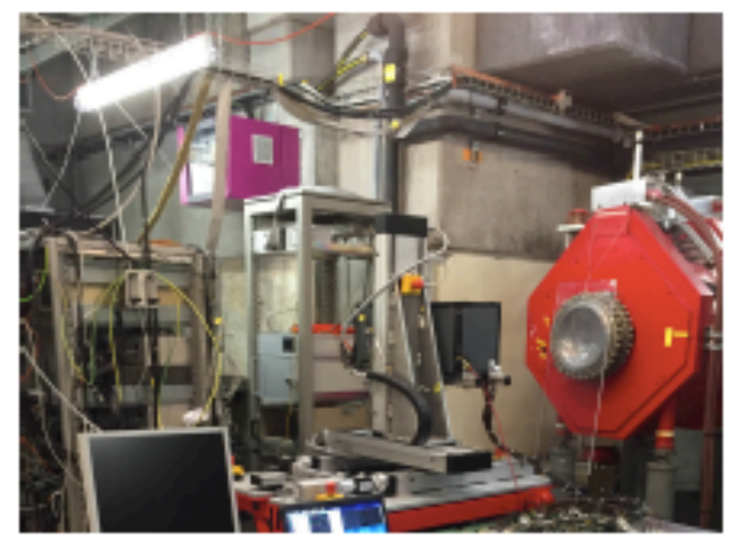






Fiber selection → Fiber coating → Fiber mounting



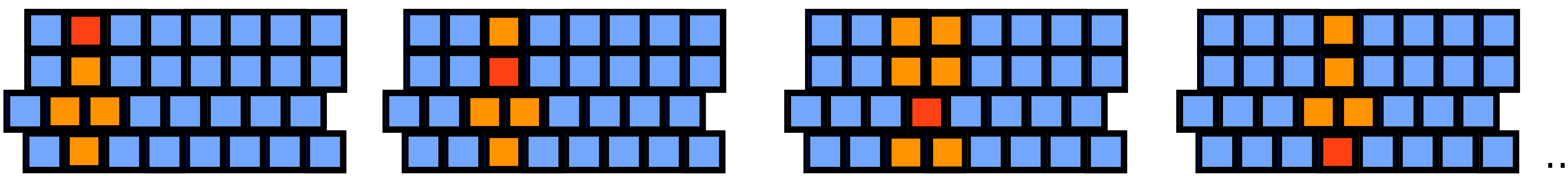


SiPM alignment → SiPM/ Preamp characterization → Measurement

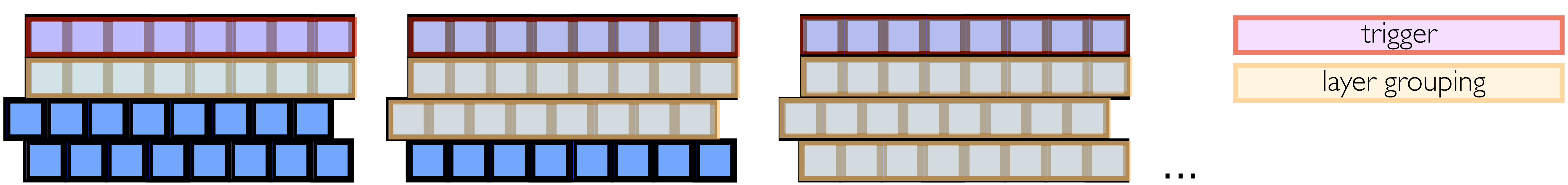
Prototype performance overview

Squared fibres

- Measurements using
  - ^{90}Sr-source (m.i.p. selection with an external thick plastic scintillator)
  - e^+ beam (e.g. πM1/PSI with p = 115 MeV/c)
- All channels worked | Homogeous response | Detection efficiency consistent with the previuos prototype
- Several triggers (: trigger, fired fibres)



- Offline different layer grouping configurations/trigger



Prototype performance: individual fibre readout

Squared fibres

- Not foreseen during phase I
- Mandatory to explore in depth the prototype performances

Detection efficiency

ε(OR) ± 2 [%]	Q > 0.5 phe	Q > 1.5 phe
Single layer	97	79
Double layer	> 99	94
Triple layer	> 99	97

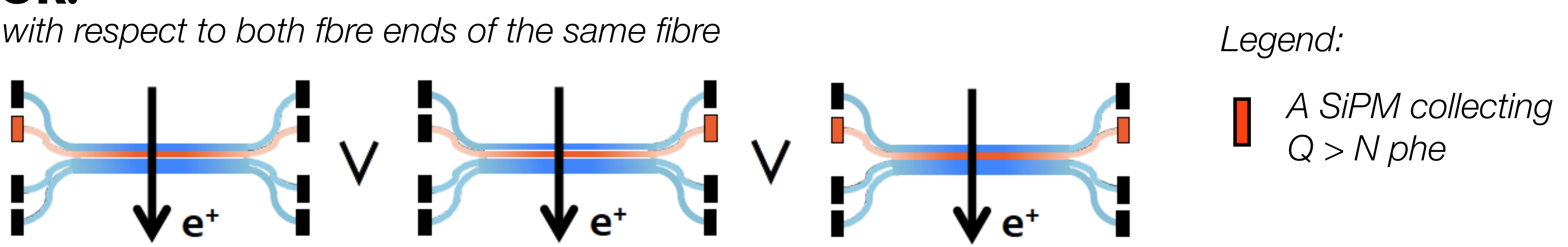
definition: ε (single or double layer) = (# Detected Events) / (# Telescope Events)

definition: ε (triple layer) = (# Detected Events) / (# Triggered Events)

note: for the different layer configurations always ORed fibres

OR:

with respect to both fibre ends of the same fibre



Prototype performance: individual fibre readout
Squared fibres

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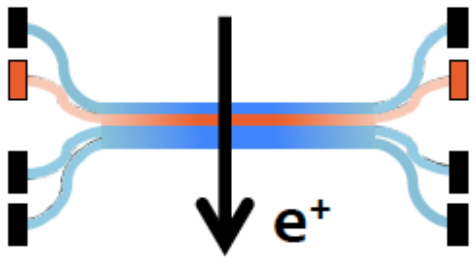
- Mandatory to explore in depth the prototype performances

Detection efficiency

ε(AND) ± 2 [%]	Q > 0.5 phe	Q > 1.5 phe
Single layer	71	34
Double layer	89	54
Triple layer	95	67

definition: ε (single or double layer) = (# Detected Events) / (# Telescope Events)
definition: ε (triple layer) = (# Detected Events) / (# Triggered Events)
note: for the different layer configurations always ORed fibres

AND:
with respect to both fibre ends of the same fibre



Legend:

A SiPM collecting Q > N phe

Prototype performance: individual fibre readout

Squared fibres

- No foreseen during phase I
- Mandatory to explore in depth the prototype performances

Detection efficiency

ε(AND) ± 2 [%]	Q > 0.5 phe	Q > 1.5 phe
Single layer	71	34
Double layer	89	54
Triple layer	95	67

Timing Resolution

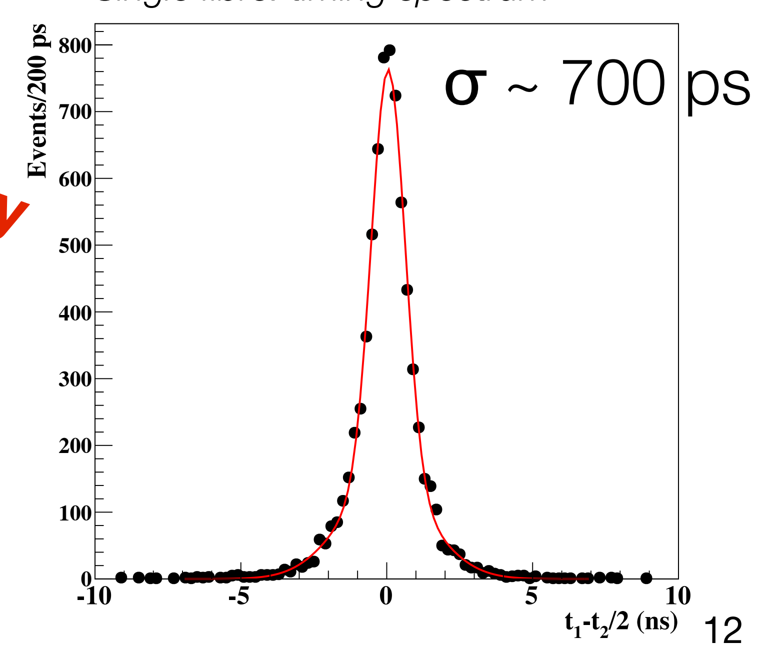
Preliminary

σ ± 20 [ps]	Q > 0.5 phe	Q > 1.5 phe
Single hit	700	600
Double hit	590	420*
Triple hit	510	350*

definition: $\sigma = \sigma[t(left)-t(right)]/2$

(*): extrapolated

Single fibre: timing spectrum



Prototype performance: offline array readout

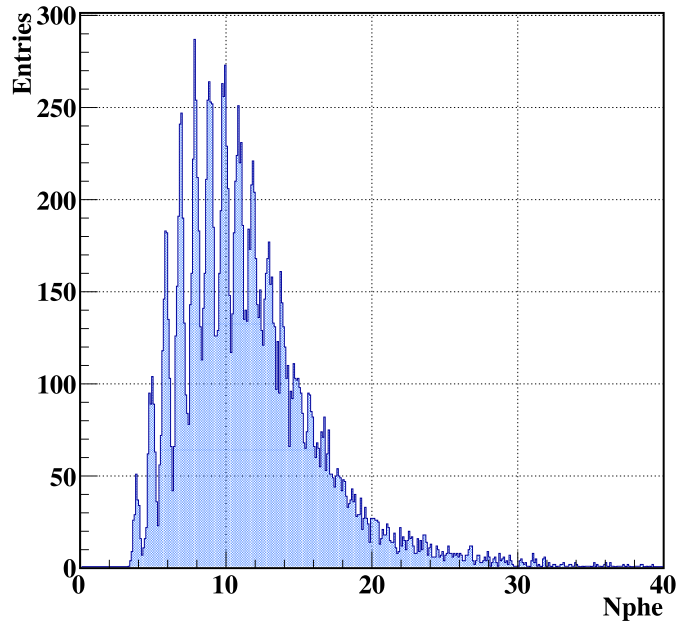
Squared fibres

- Array readout: baseline solution
- Sum of charge of fired fibres/event (offline "array readout") then apply cuts

Detection efficiency

ε(AND) ± 2 [%]	Q_{array} > 0.5 phe	Q_{array} > 1.5 phe
Single layer	71	34
Double layer	93	75
Triple layer	96	88

Offline array readout:
charge spectrum (Q_{array} > 1.5 phe)



Performances

Extrapolated

- Three layers | Optimized "array readout"

(ε[%] , σ [ps], S/N*)	Q_{array} > 0.5 phe	Q_{array} > 1.5 phe
Triple layer	(> 95, ~ 500, >10)	(> 85, ~ 400, > 50)

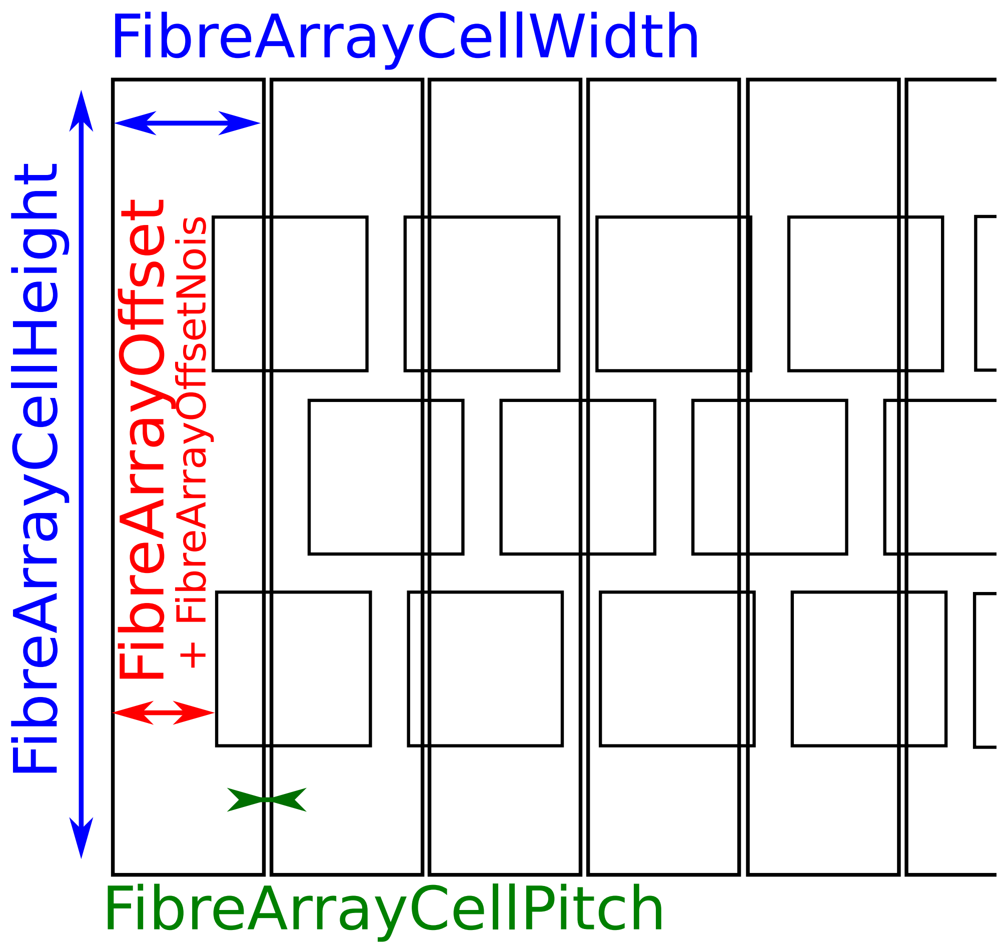
(*) Stopped muon rate: 10^8 μ/s

Array readout schemes

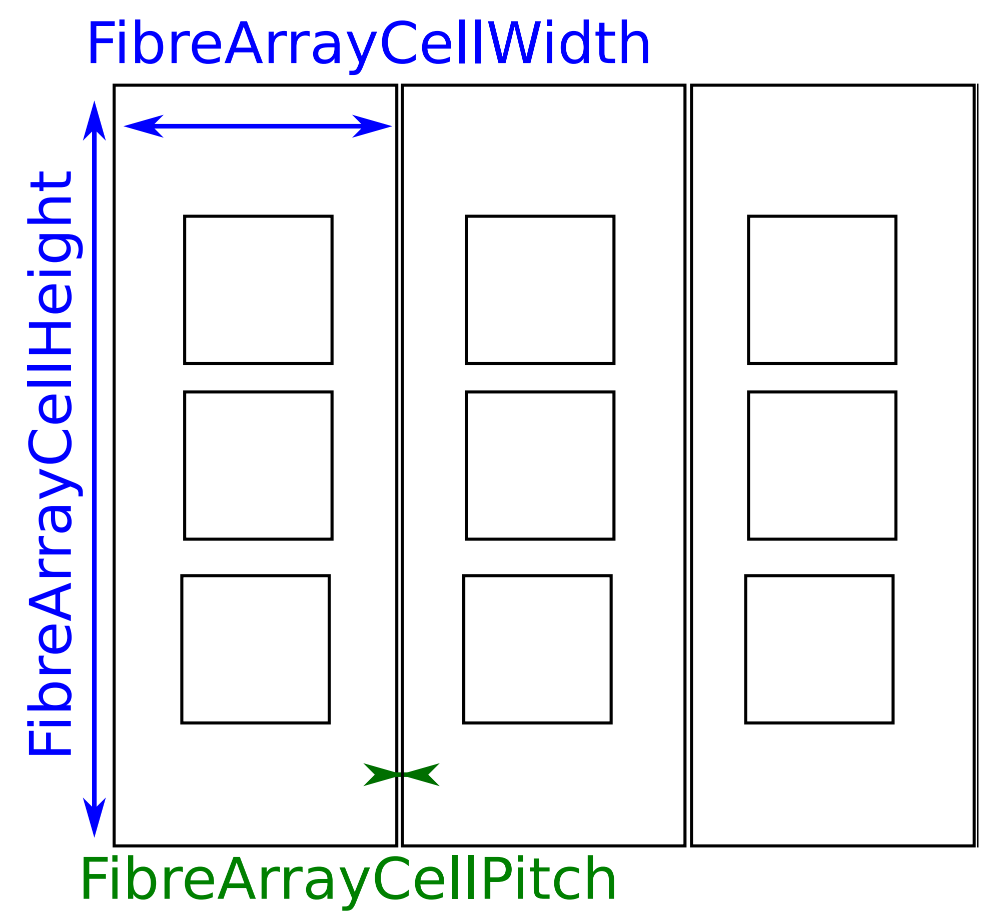
Squared fibres

- Working stage
- Fitting the available space

Array readout without fan-out



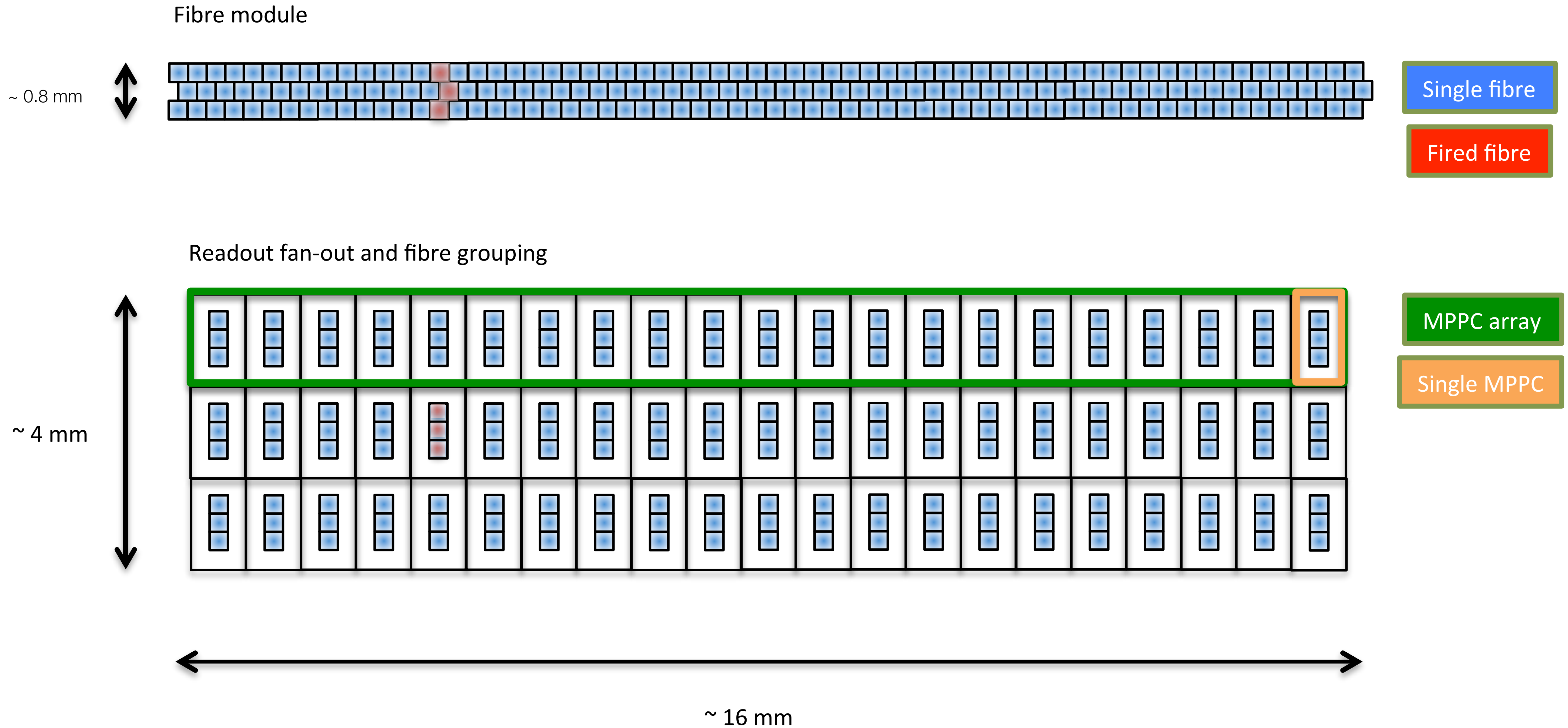
Array readout with fan-out



Array readout scheme with fan-out
Squared fibres

- Working stage
- Fitting the available space

Array readout with fan-out

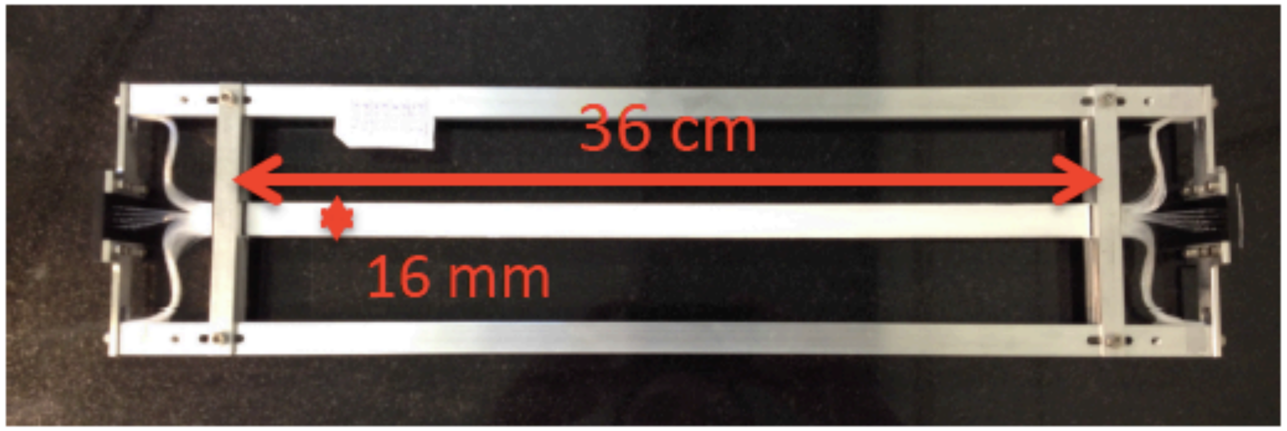


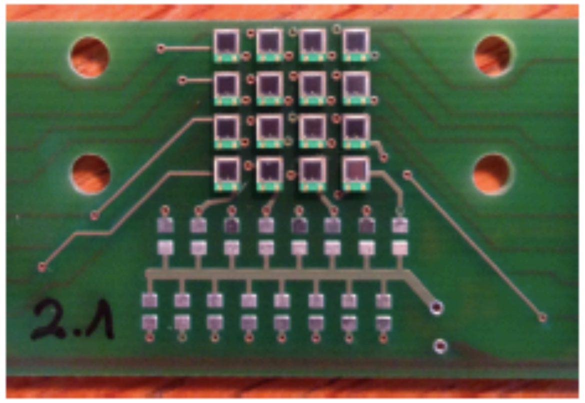
Results with new prototypes

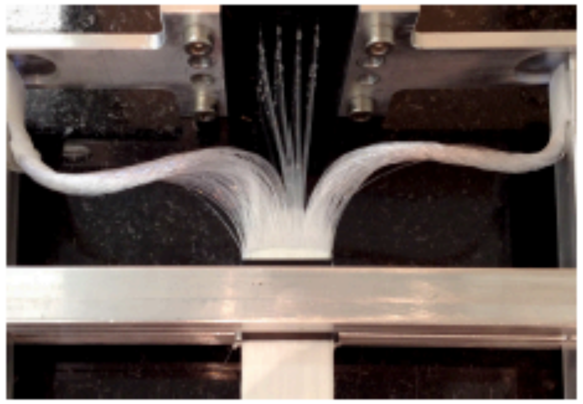
Round fibres

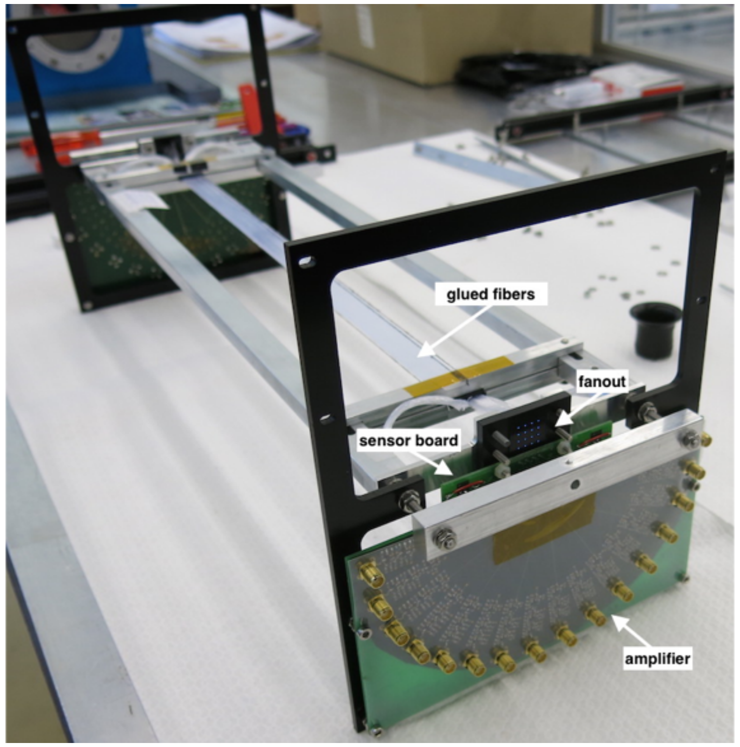
Individual fibre readout

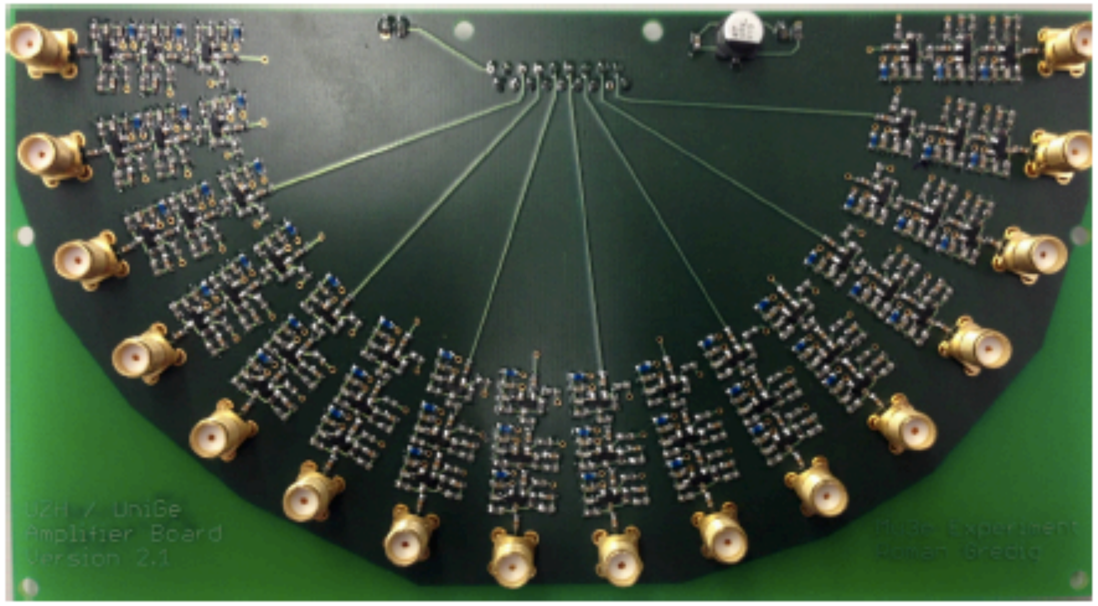
- 2 Prototypes, with/out TiO_2 coating
- Hamamastu S12571-050P
- 4 layers
- 250 um diam Kuraray SCSF-81M fibre
- Fibre Length: 36 + 2x4 cm
- 32 equipped fibres with SiPM
- Double Readout







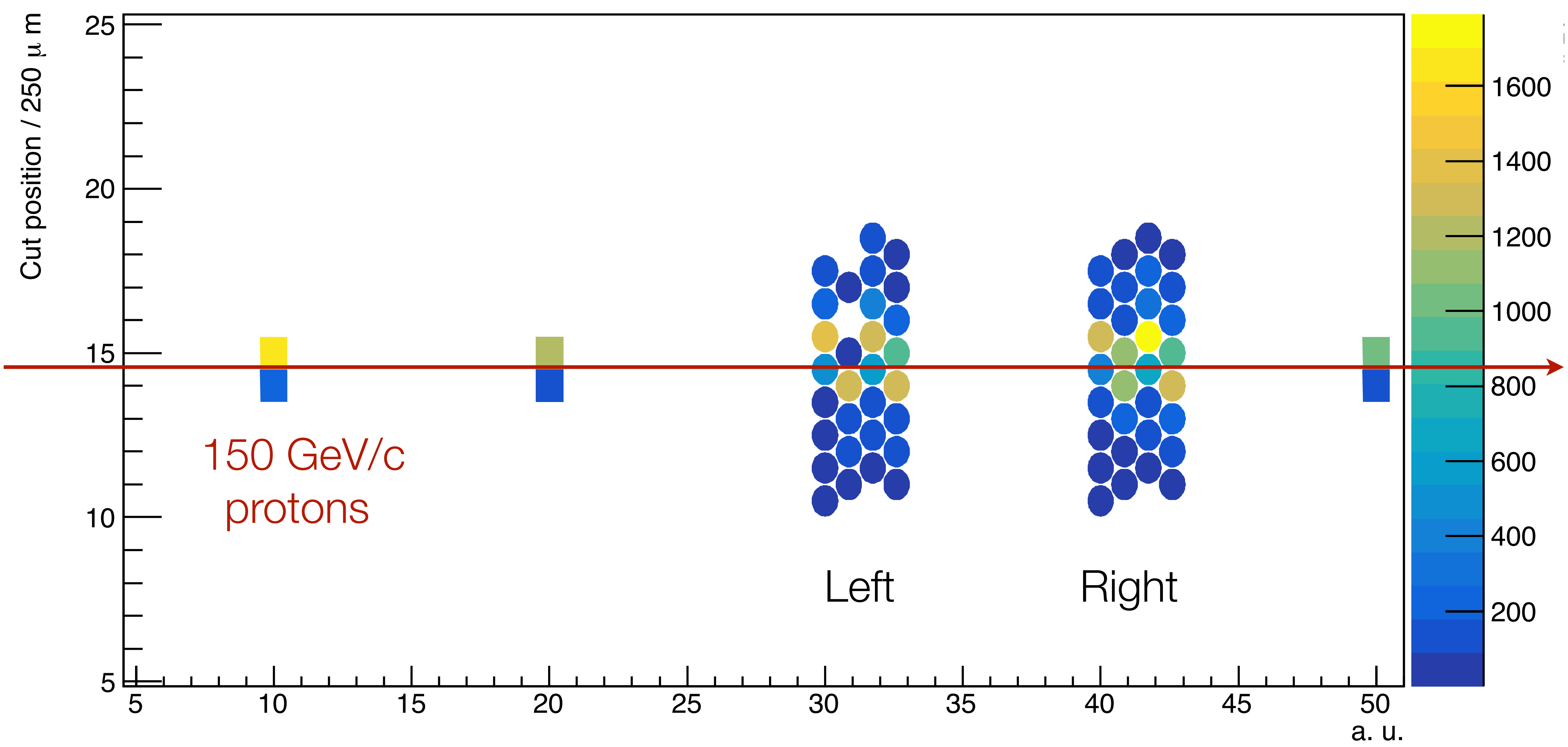




Prototypes performance

Round fibres

- A sample track



Prototypes performance

Round fibres

Overview and Detection efficiency

	Nphe/ch	ch/Event	σ [μm]	ε(OR)[%]
4 layers, no coating single SiPM	3	7	155	95
4 layers, TiO_2 coating single SiPM	3.6	5.5	133	95

- 20% TiO_2 coating effect:

  reduced optical cross-talk

  improved position resolution

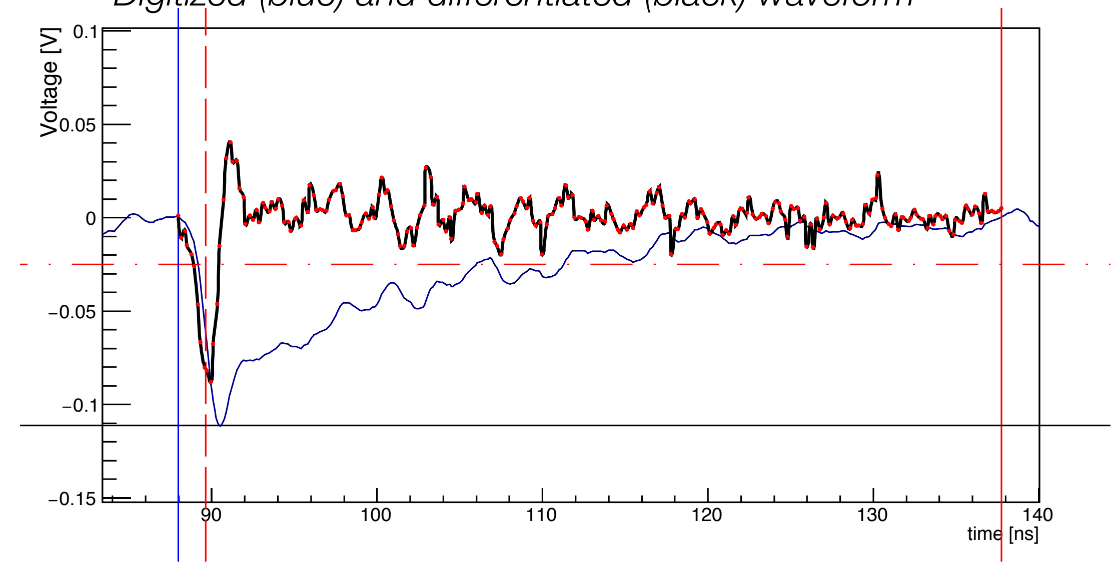
Prototypes performance

Round fibres

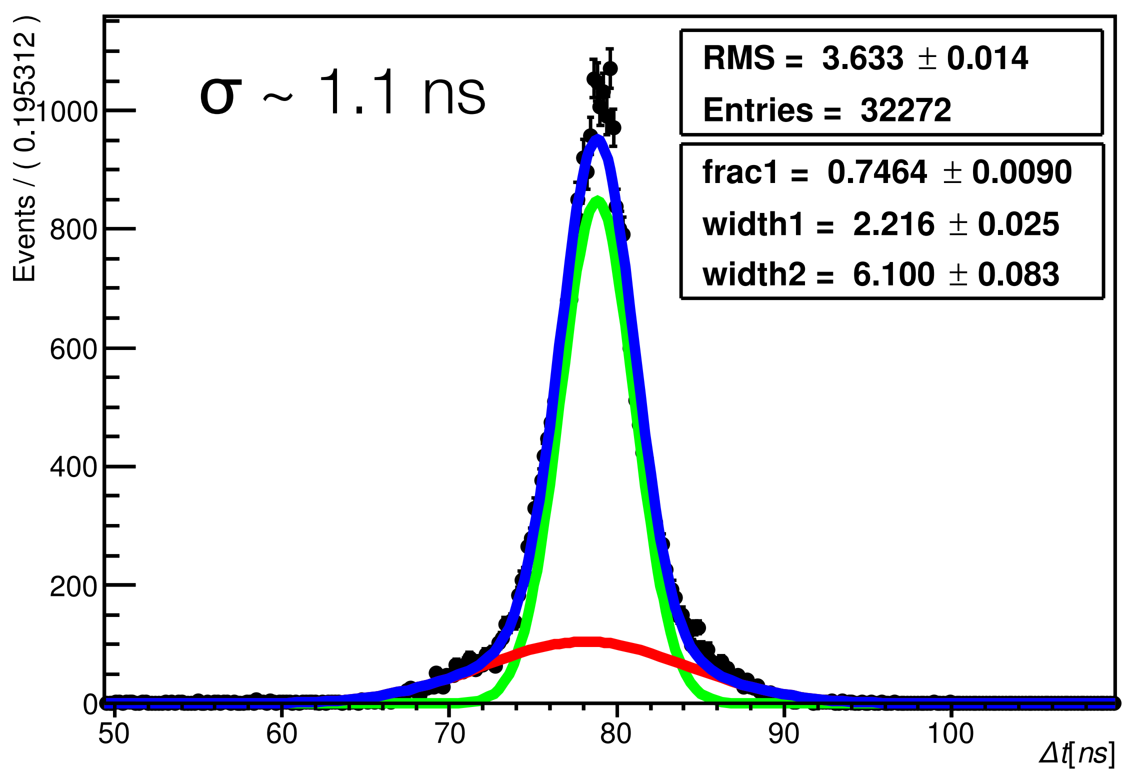
Timing Resolution

- Photon counting via signal integral
- Timing is the centroid of the negative peak in the differentiated waveform
  - no time-walk

Digitized (blue) and differentiated (black) waveform

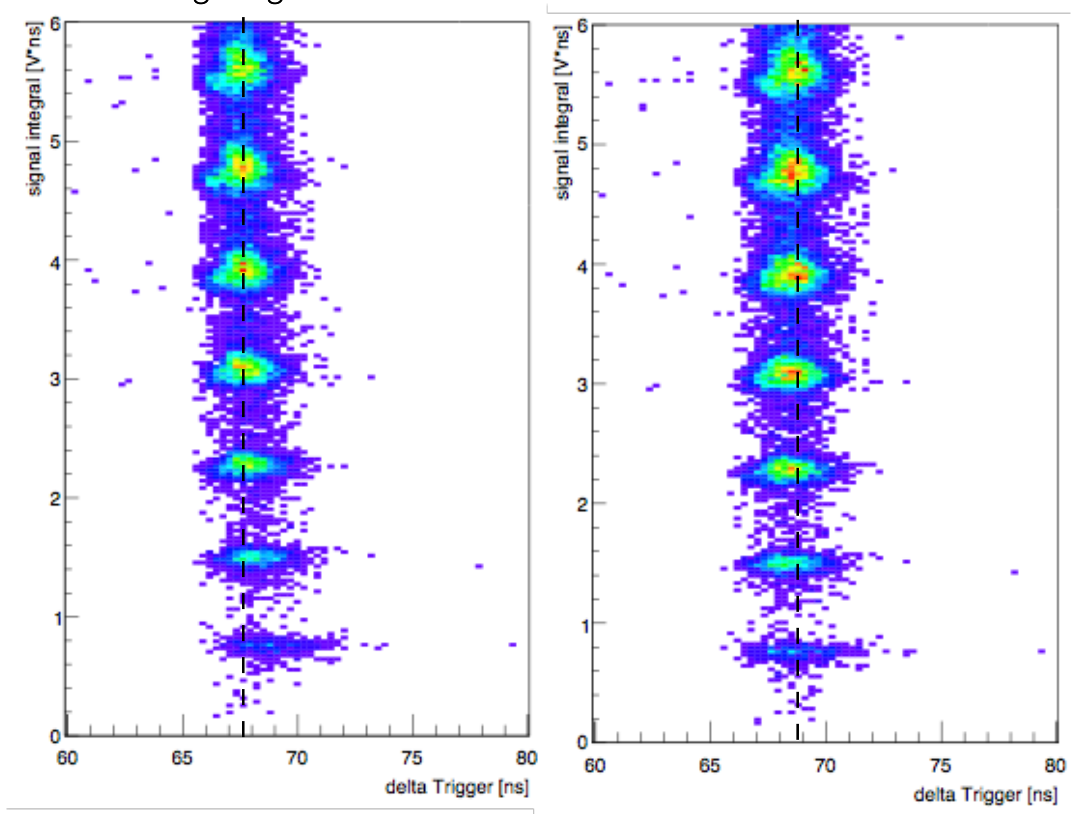


Single fibre: timing spectrum



definition: $\sigma = \sigma[t(left)-t(right)]/2$

Leading Edge *Centroid*

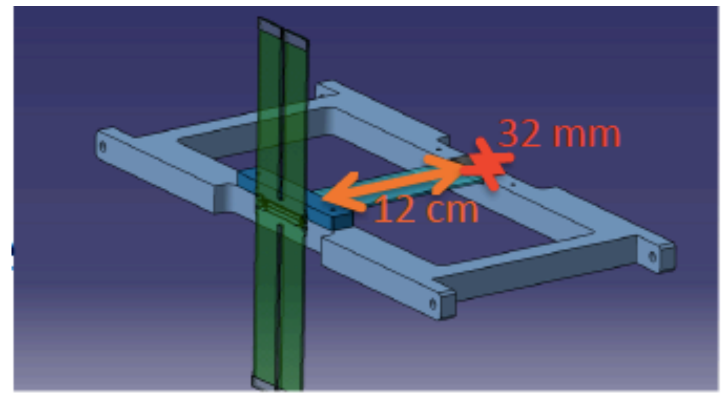


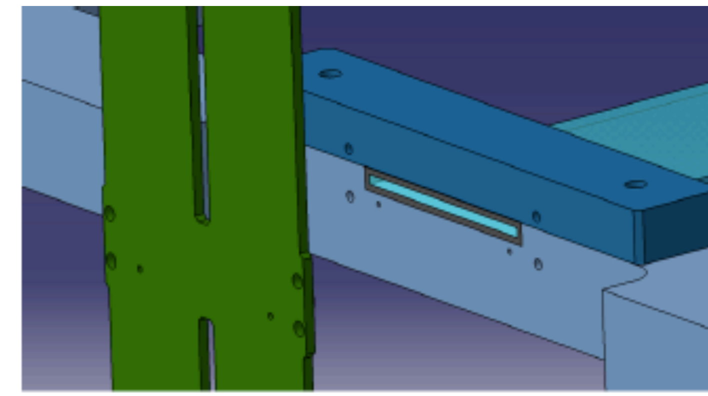
Array readout: first prototypes

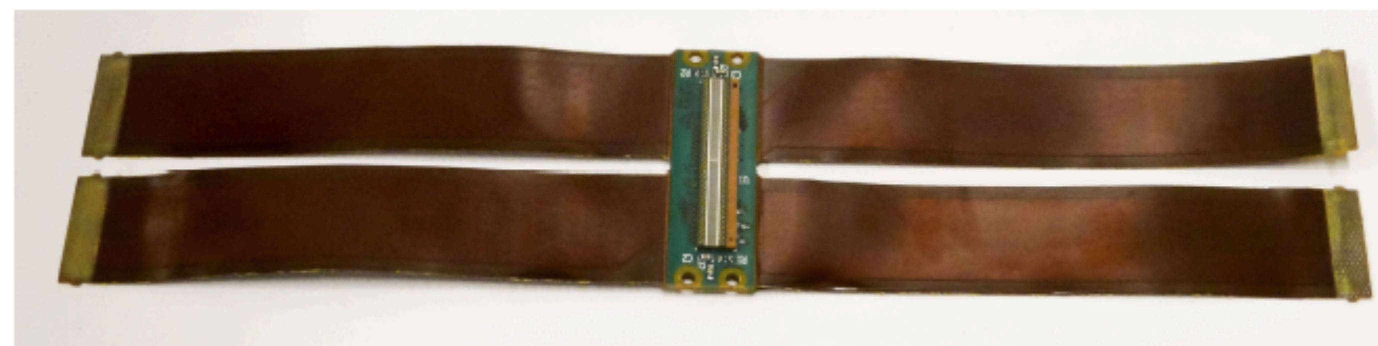
Round fibres

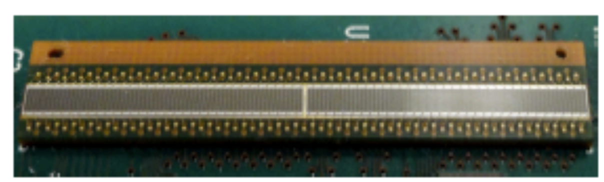
Array readout

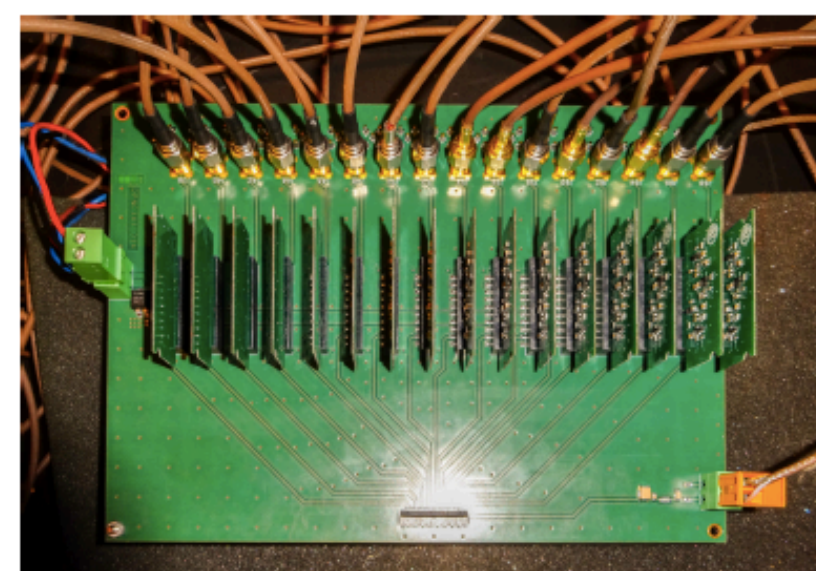
- 2 Prototypes, without TiO_2 coating
- Hamamastu S10943-3183
  - 0.23 x 1.5 mm^2 channel area
  - 57.5 x 62.5 um^2 pixel area
  - 128 (64 x 2) channels
- 2 and 5 layers
- 250 um (diam.) Kuraray SCSF-81M fibre
- Fibre Length: 12 cm
- Fibres Readout on one side only







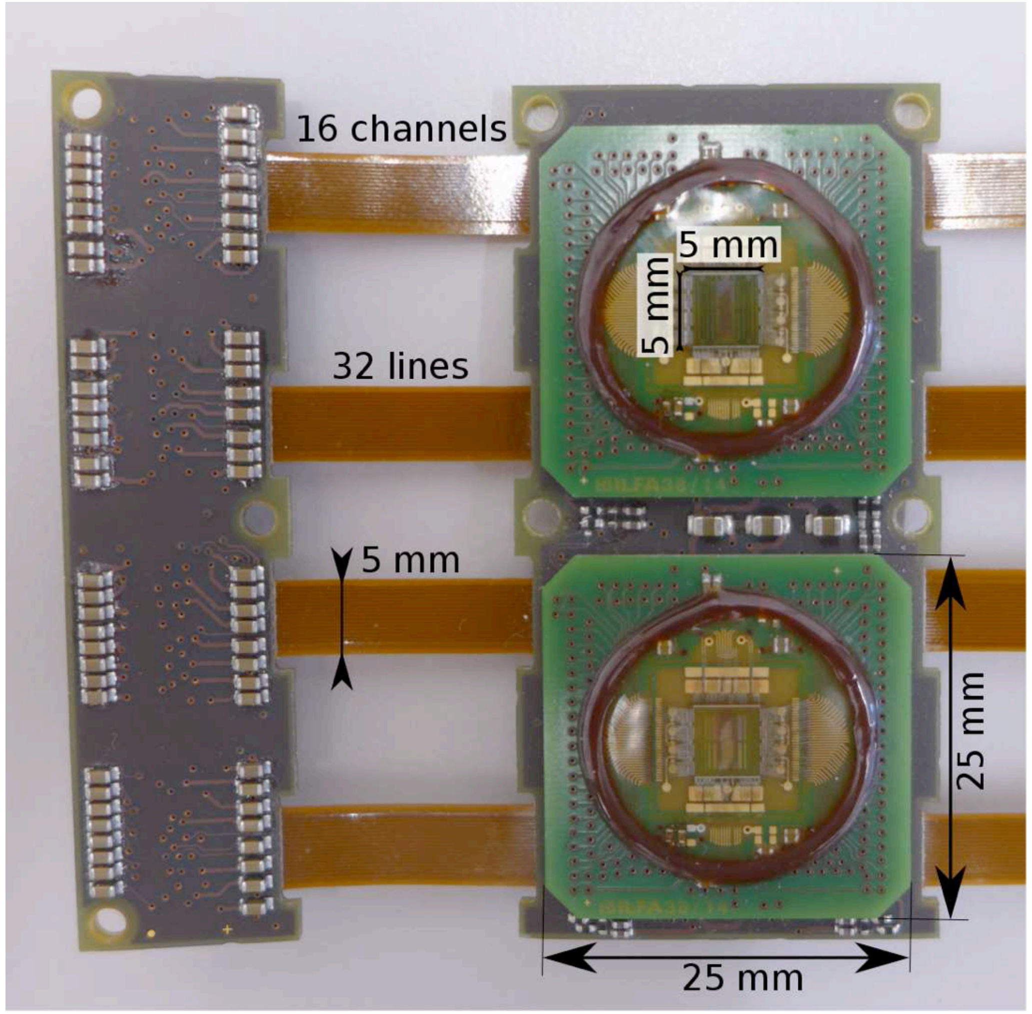




Readout electronics

Requirements: different fibre groupings/SiPM arrays - **baseline**

- **1536** (1536-9216) channels
- **1044** (350-1300) kHz/channel
- < 100 ps time information [charge beneficial, possibly 2nd threshold]
- very tight space constraints (48 ASICs)

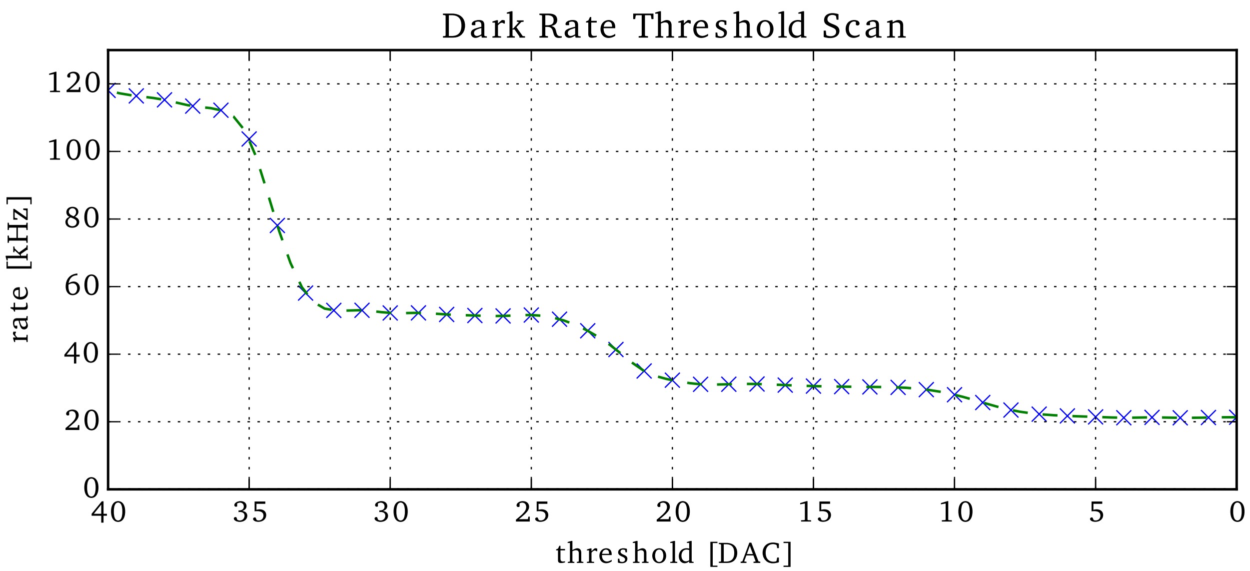


STiC3.1	MuSTiC
in our hands (fibre group)	in development ready: end 2016
64 channels	32 channels
160 Mbit/s links	1250 Mbit/s links
~40 kevents/s	~1200 kevents/s
no charge for fibre signals	possibly 2nd threshold

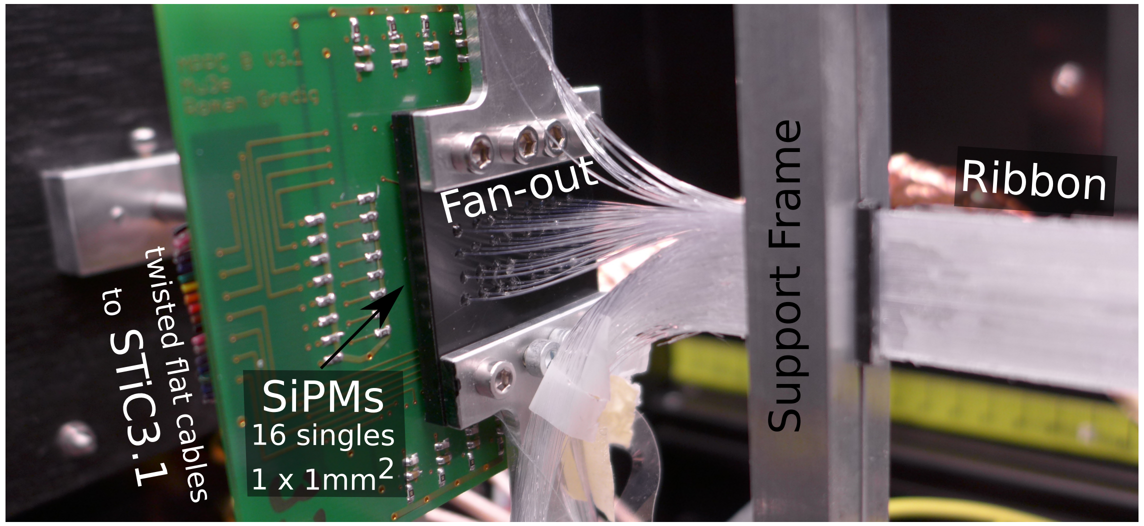
Readout electronics: concept

STiC3.1:

confirmed standalone DAQ measurements of round prototype



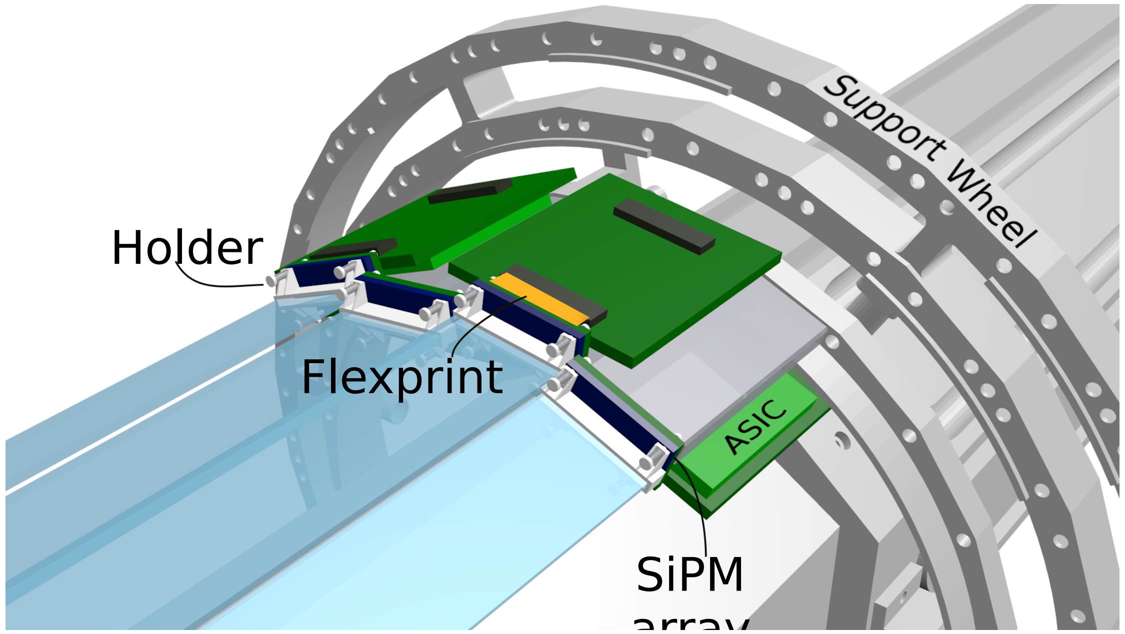
STiC3.1 threshold scan with dark counts



Round fibre prototype connected to STiC

Integration (working stage)

- 64 columns SiPM arrays (1.3 x 0.25| 0.75 mm^2 cells)
- 1readout board per ribbon/side
  - 2 (Mu) STiCs
  - interface to DAQ/slow control
  - HV and test pulse distribution

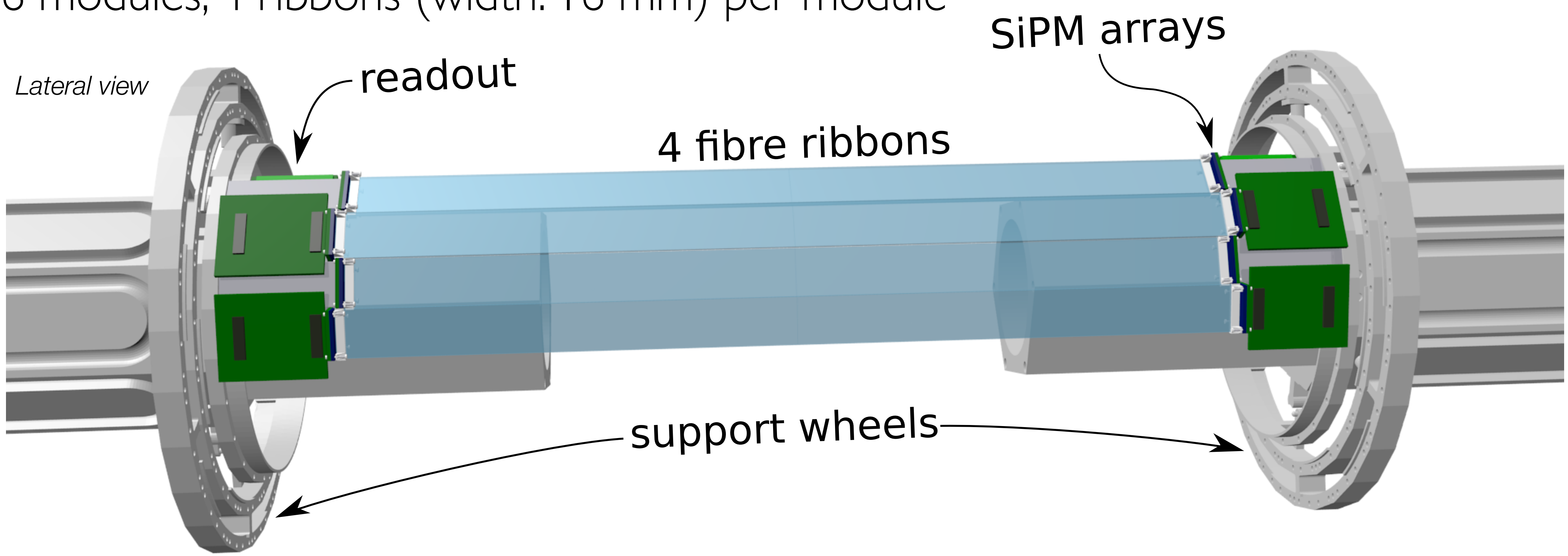


Dimensions of available components taking into account

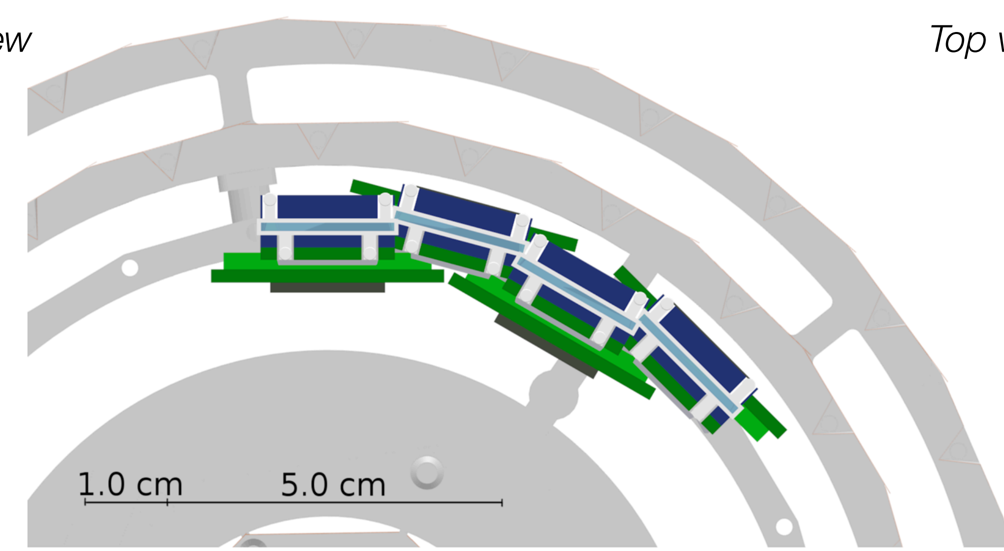
Detector integration

- Fibre structure attached on same support wheel as pixel layers ribbons (at 6 cm) displace in r-(3 mm) and z-(1 cm) direction
- 6 modules, 4 ribbons (width: 16 mm) per module

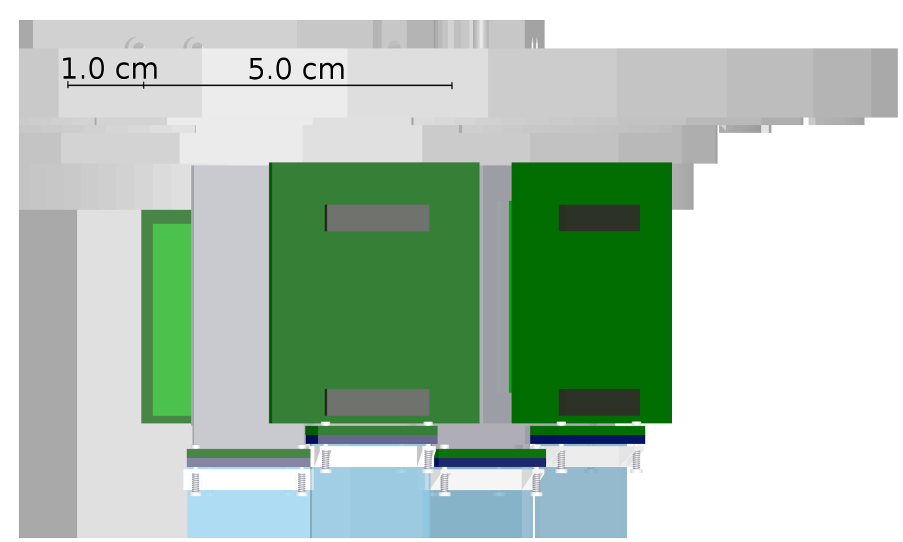
Lateral view



Front view



Top view



Milestones/Next steps

SiPM Array design/selection	(Q2/16)
Full simulation and reconstruction of Fibre Detector	(Q3/16)
SiPM radiation hardness	(Q3/16)
Construction of a technical prototype for the fibre mechanics (attachment, cooling, services, possibly fibre fan-out)	(Q4/16)
Construction of a readout prototype including SiPM arrays, PCB, power distribution and slow control	(Q4/16)
Decision on fibre type (round or square) and SiPM	(Q1/17)
Manufacturing and quality management strategy for fibre ribbon/module production	(Q1/17)
MuSTiC integration	(Q2/17)
Fibre readout integration into experiment DAQ and slow control (Midas)	(Q2/17)
Fibre detector alignment and calibration scheme	(Q2/17)

Conclusions/Outlook 1/3

- The fibre detector crucial to suppress the accidental backgrounds
- The challenge: high detector efficiency (> 95%) and good timing resolution (<1ns)
  - minimal amount of material (< 0.4% X_0)
  - strong spatial constraints (electronics, cable, cooling etc.)

Conclusions/Outlook 2/3

- Several prototypes built with standalone electronics and DAQ
  - Squared Fibre Large Prototype performances:

    (ε[%] (triple layer), σ [ps] (single hit), σ [ps] (triple hit)) = (> 95, ~700, ~500)
  - Round fibre "single readout" Prototype performances:

    (ε[%] (fourth layer), σ [ps] (single hit)) = (> 90, ~1100)
- Extrapolating to the final detector: requirements well met

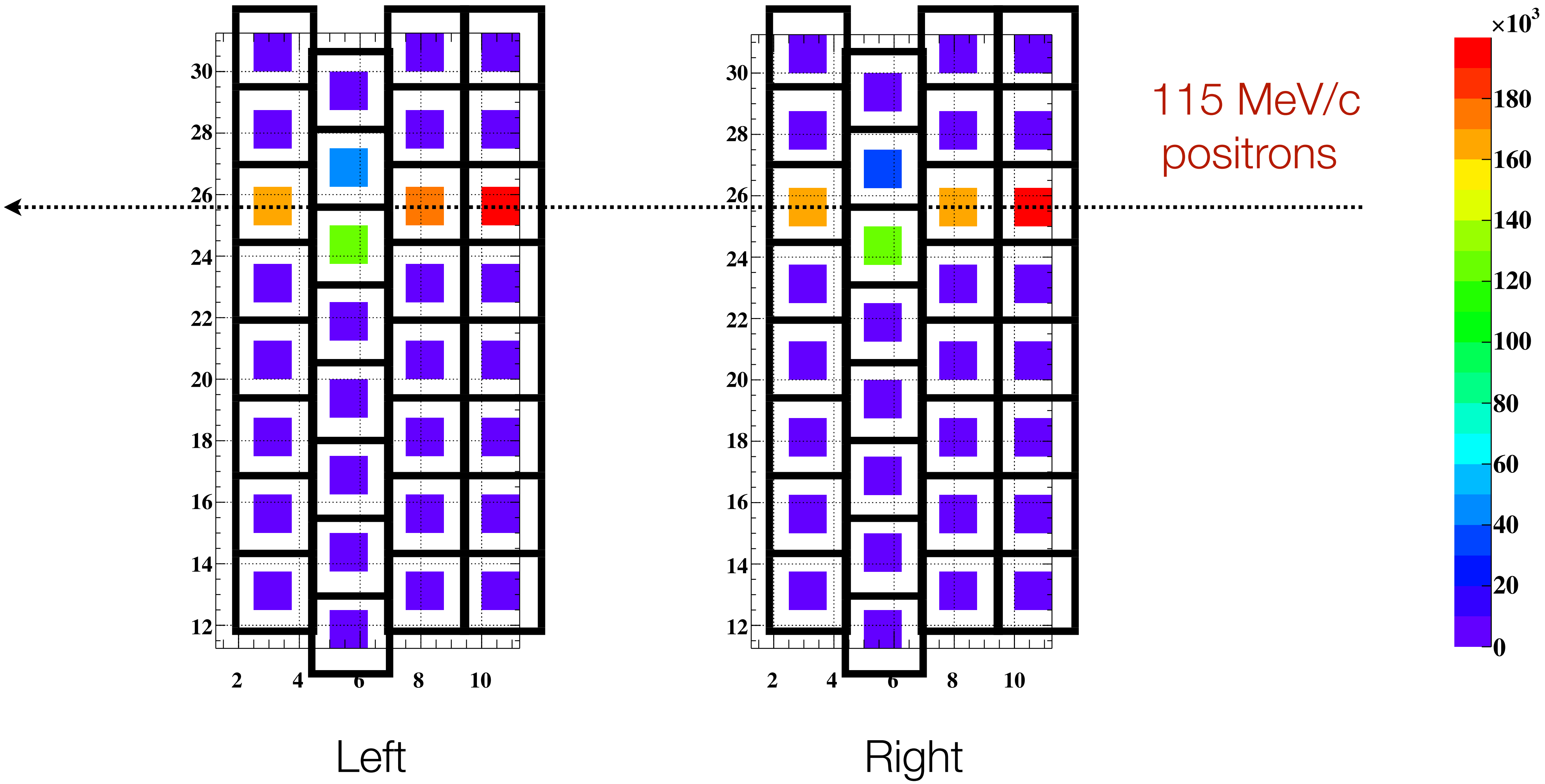
Conclusions/Outlook 3/3

- STiC 3.1 coupled to fibres:
  confirmed standalone DAQ measurements
- Detector integration into the experiment:
  all parts included into technical drawings
- Detailed milestones/next steps up to the middle of next year

Backup

Prototypes performance
Squared fibres

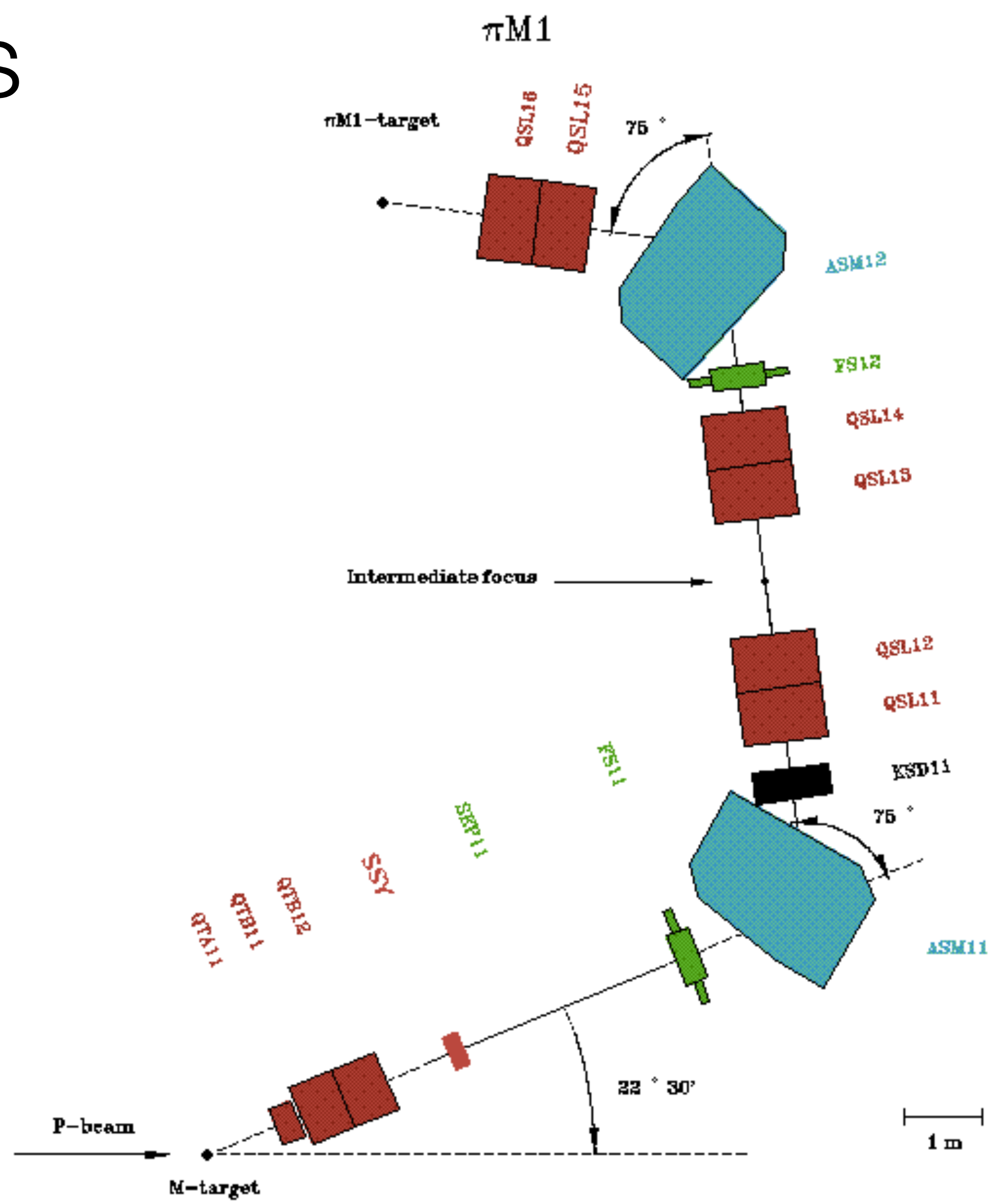
- A sample track

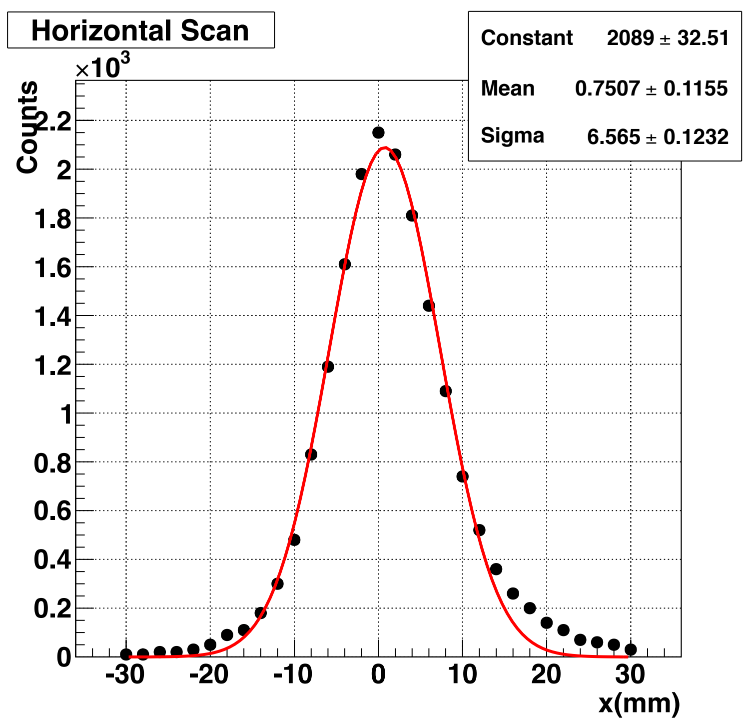


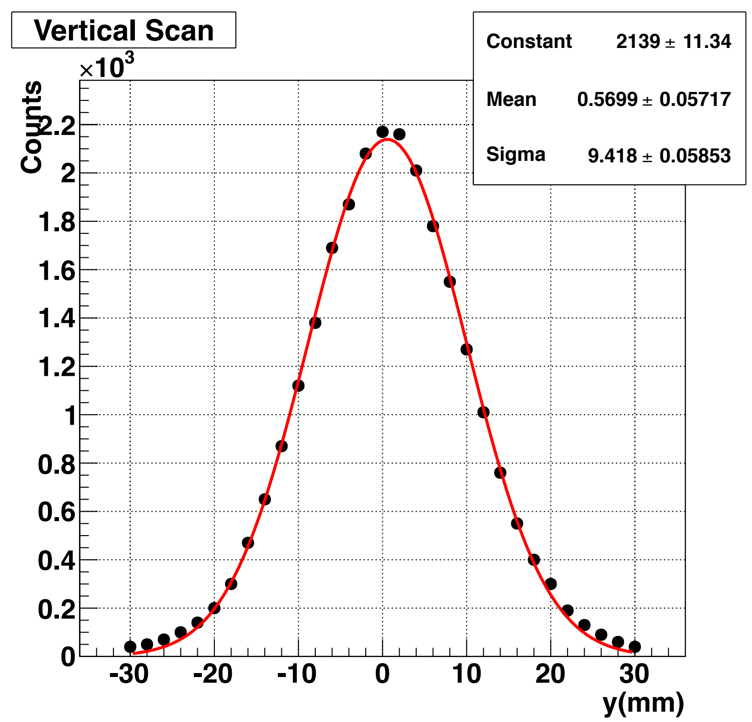
The piM1 beam line conditions

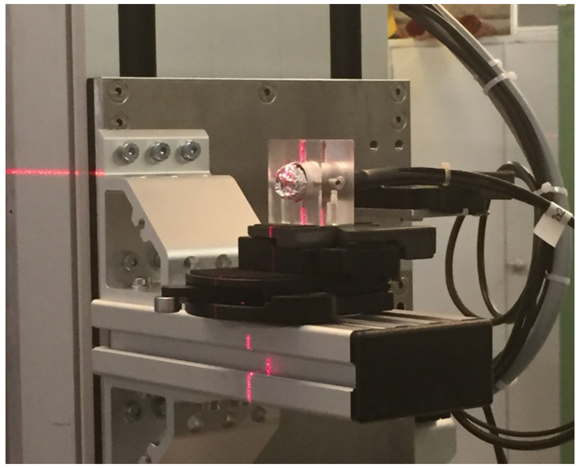
Squared/Round fibres

- p = 115 MeV/c
- FS12 fully open
- FS11 partially open
- Beam size: $(\sigma_x, \sigma_y) = (6.6, 9.4)$ mm
- Total rate: $1.75 \; 10^6$ p/s @ 2.2 mA
- 90% positrons, rest muons and pions



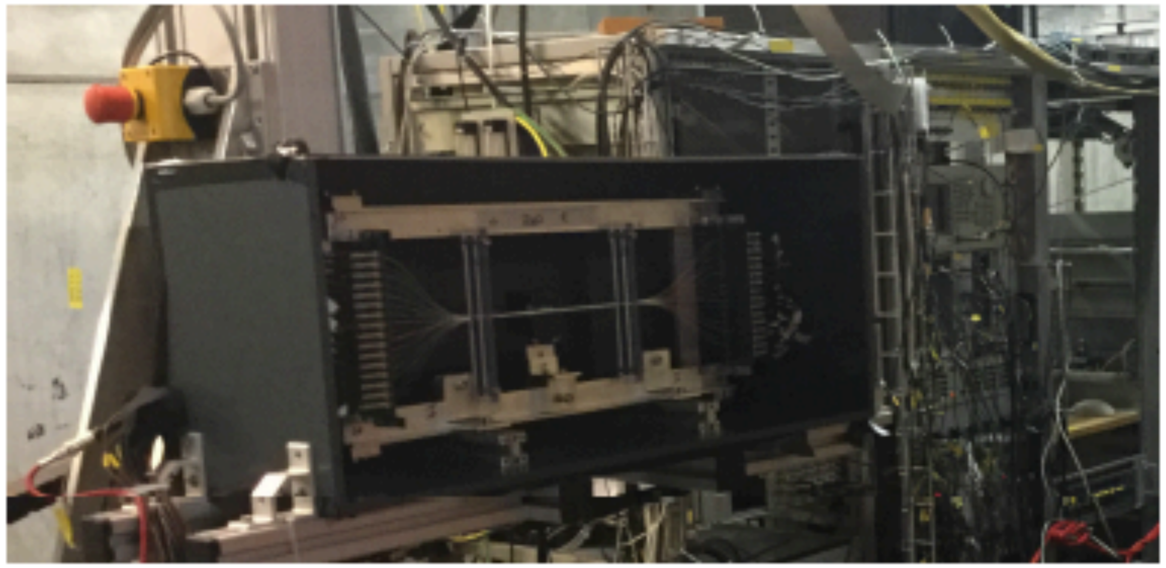


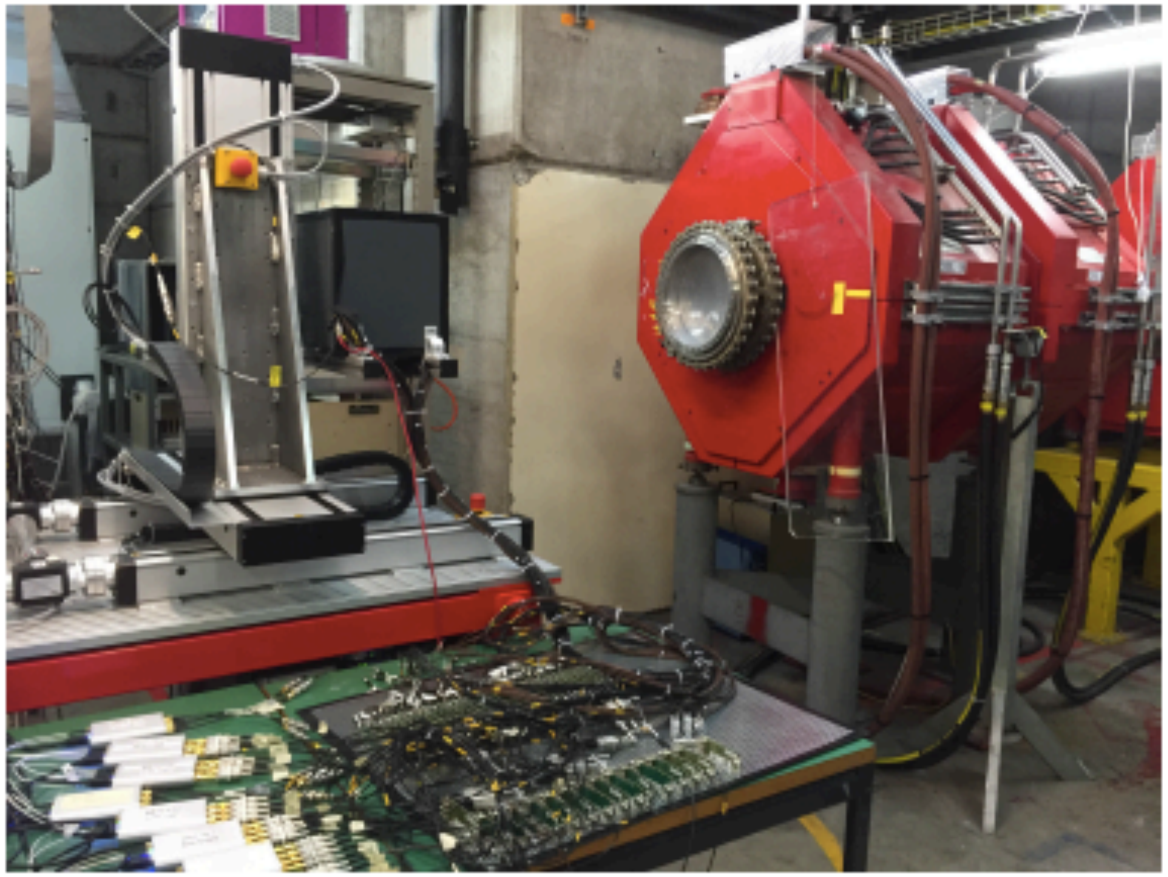




Pill counter: BC400 diam. 2 x length 2 mm^2 coupled with PMT

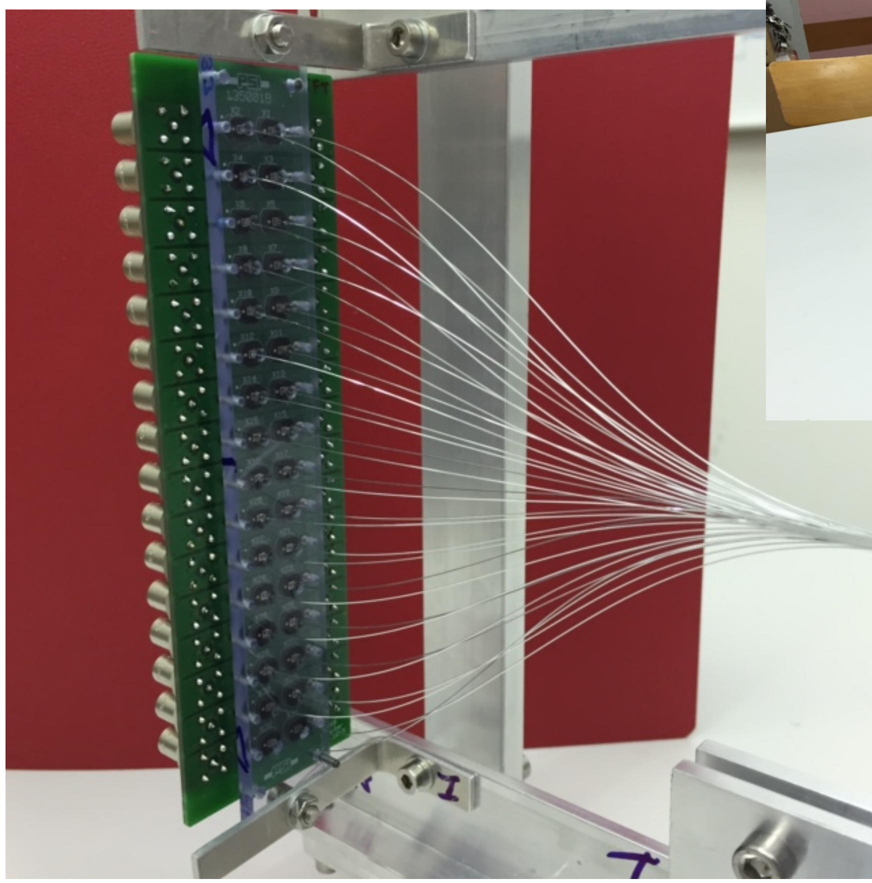
The Large prototype (squared fibres) in PiM1

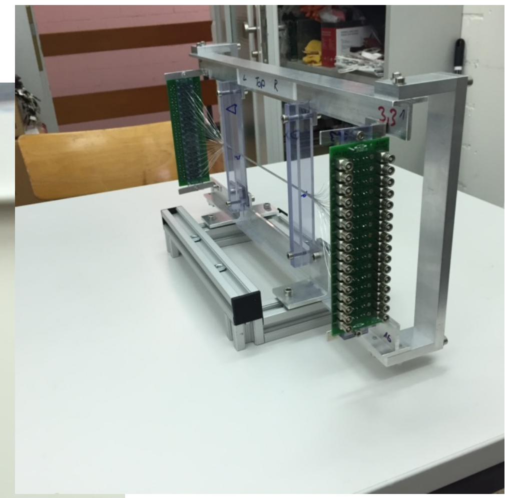


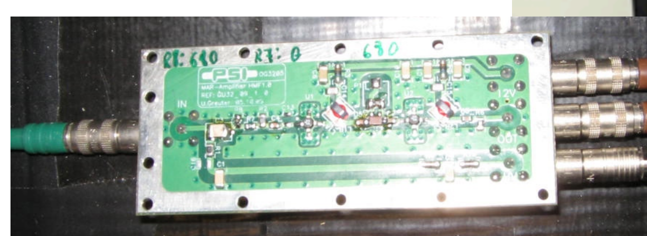


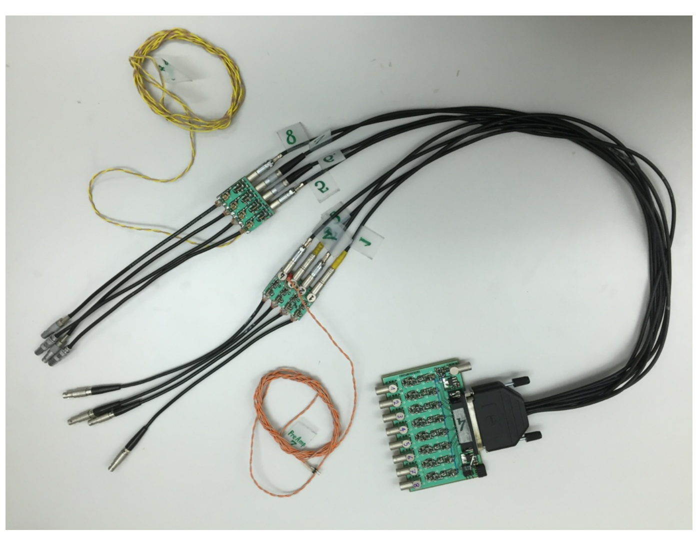
More Pictures about the Large Prototype

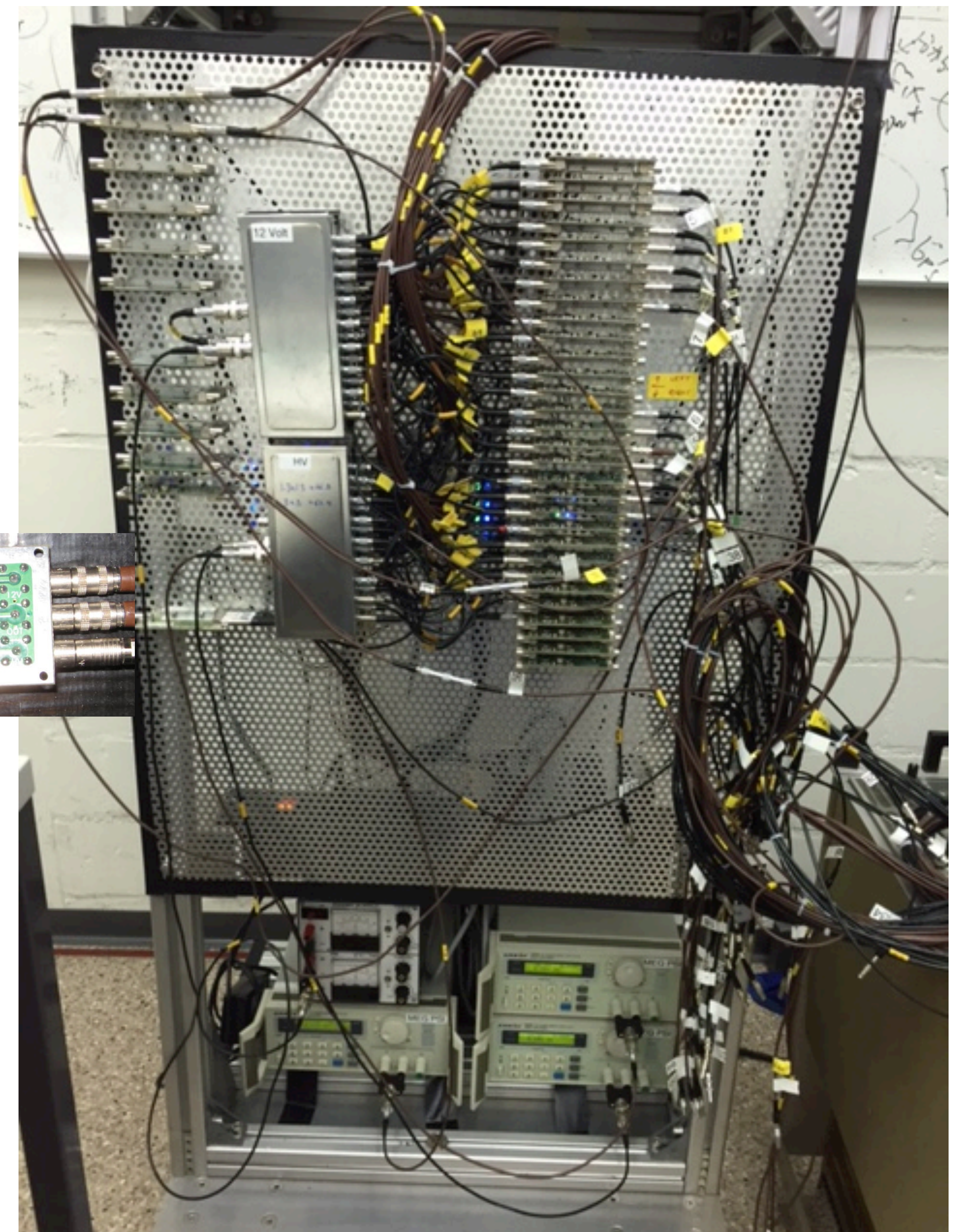
Squared fibres







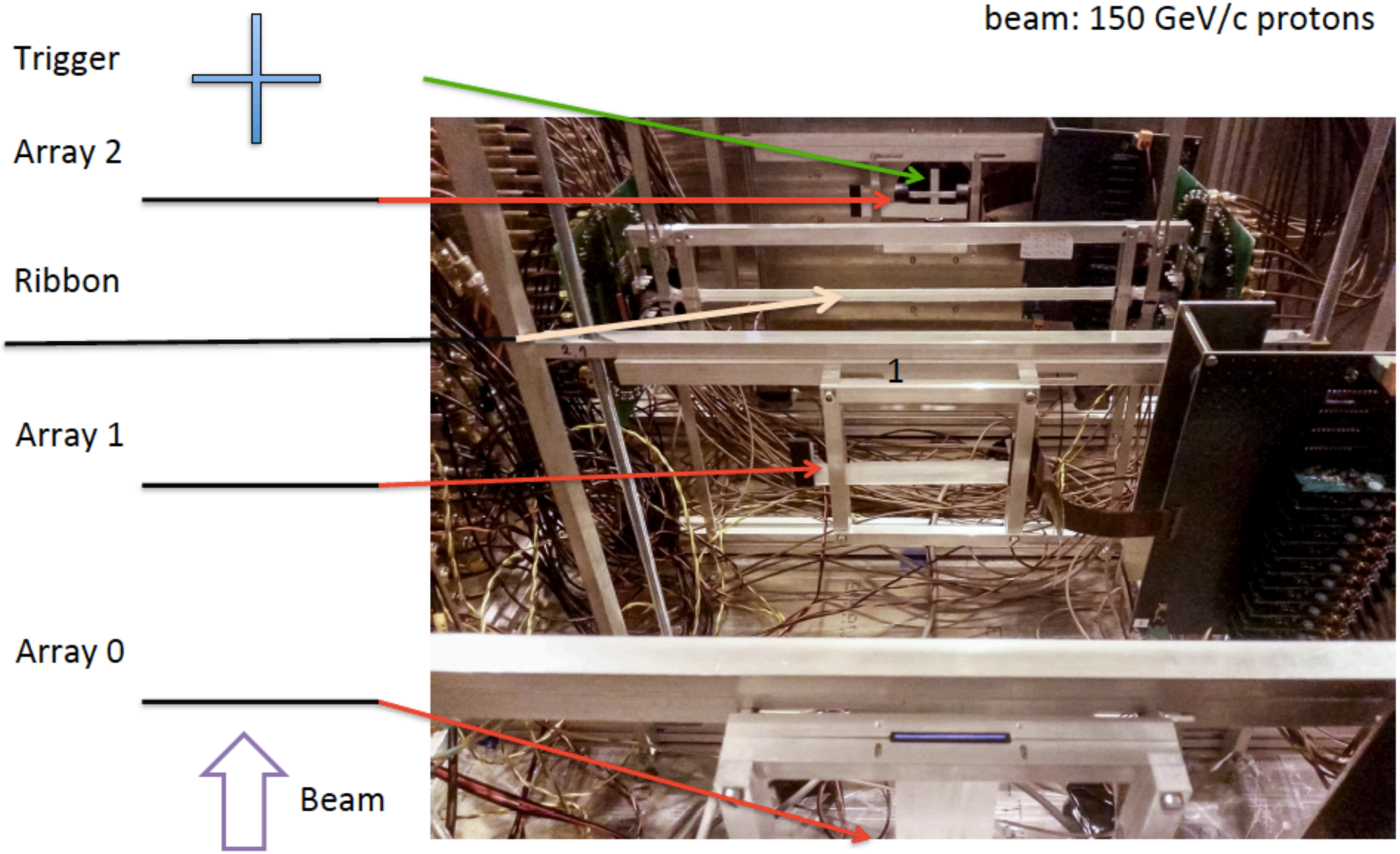




The Round fibre prototypes at CERN

Test beam setup

beam: 150 GeV/c protons

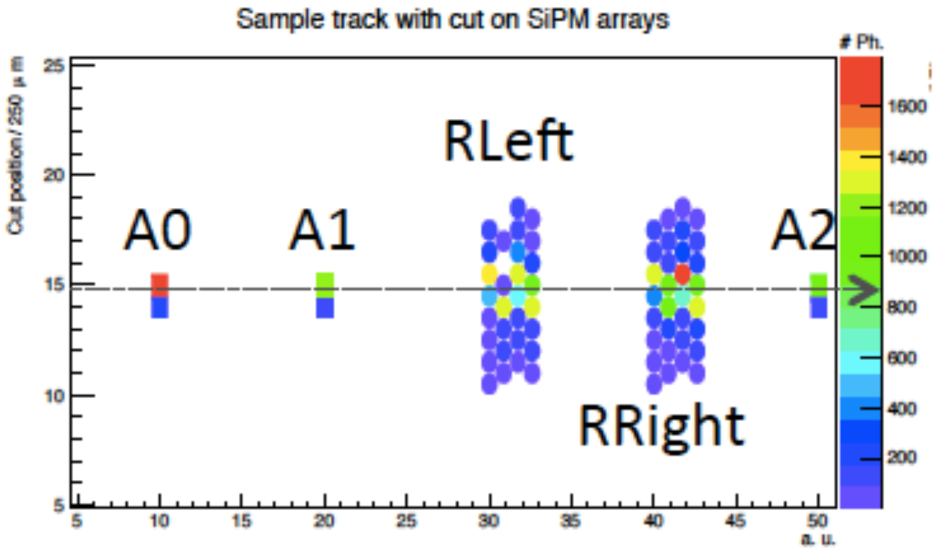


- VME DAQ: CAEN V775 TDC , CAEN V792 QDC, CFD – custom

Prototypes performance

Round fibres

Detection efficiency



A hit in the fiber is accepted if the sum of the photoelectrons detected is ≥ 3 ph.e.

Ribbon, No caoting

OverVoltage [V]	Av. Np.e./ch	Pos σ (μ)	Efficiency	# Ch / event
0.5	2.4	148	0.78	4.8
1.0	2.7	125	0.85	4.9
1.5	2.9	133	0.90	5.8
2.0	3.0	155	0.95	7.0

Ribbon, 20% TiO2

OverVoltage [V]	Av. Np.e./ch	Pos σ (μ)	Efficiency	# Ch / event
0.5	2.7	148	0.73	4.3
1.0	3.0	133	0.85	4.5
1.5	3.3	135	0.90	4.9
2.0	3.6	133	0.95	5.5

Array, 5 layers, No coating

OverVoltage [V]	Av. Np.e./ch	Pos σ (μ)	Efficiency	# Ch / event
2.0	4.2	165	0.96	2.5
2.5	4.4	158	0.97	2.9
3.0	4.0	160	0.97	3.0
3.0	4.0	170	0.96	3.0

Array, 2 layers, No coating

OverVoltage [V]	Av. Np.e./ch	Pos σ (μ)	Eff	# Ch / event
57.5	2.8	167	0.82	2.8

Detector impact into the experiment:

Background suppression

Internal Conversion

- $\mu \rightarrow eee\nu\nu$

no timing suppression

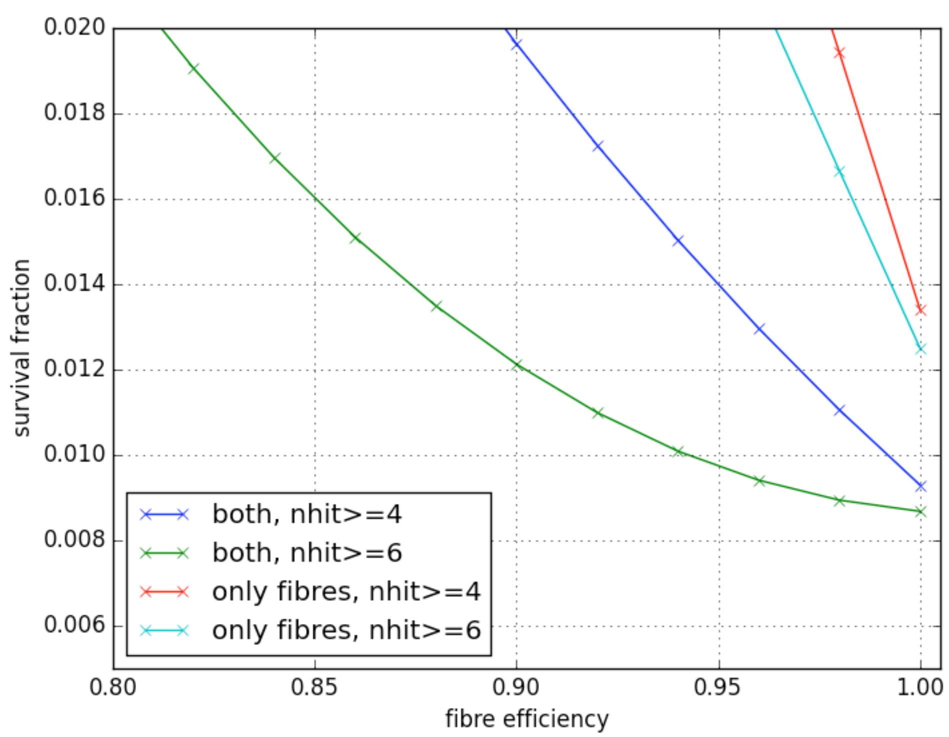
Accidental Background

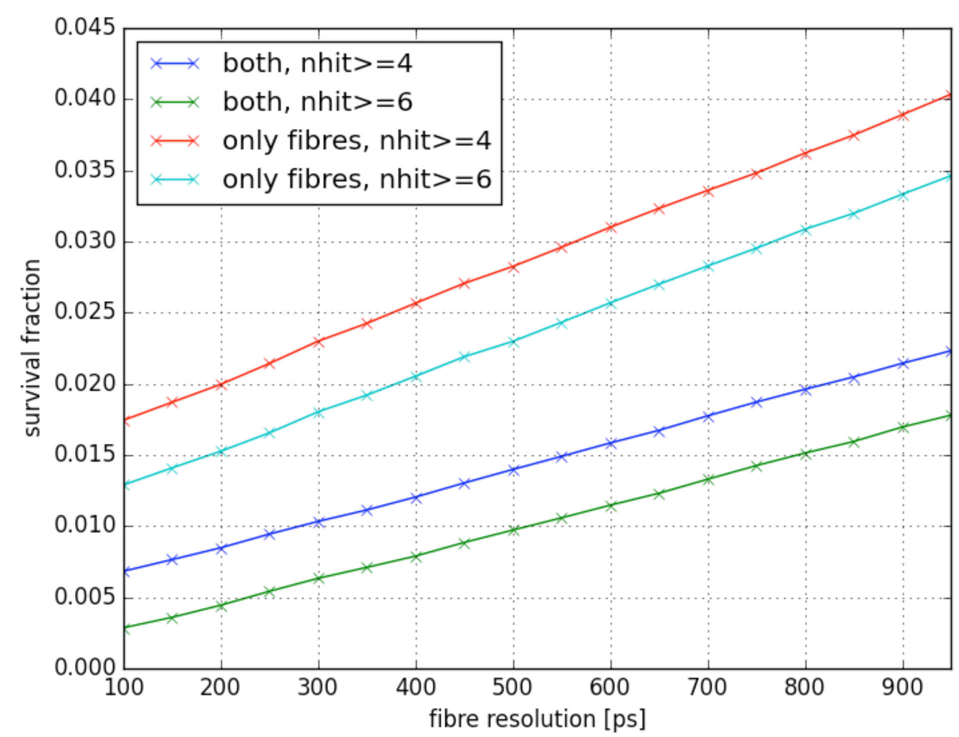
- Two Michel's e^+ and one e^- , where $E_{tot} \sim m_\mu$ and $\sum p_i \sim 0$
- Dominant combination: e^- scattered off by e^+ (e.g. Bhabha), where e^+/e^- common vertex, coincidence

Additional suppression due to timing detectors

- fully efficent tile detector with 60 ps resolution
- 95% fibre ribbon efficiency with 500 ps resolution

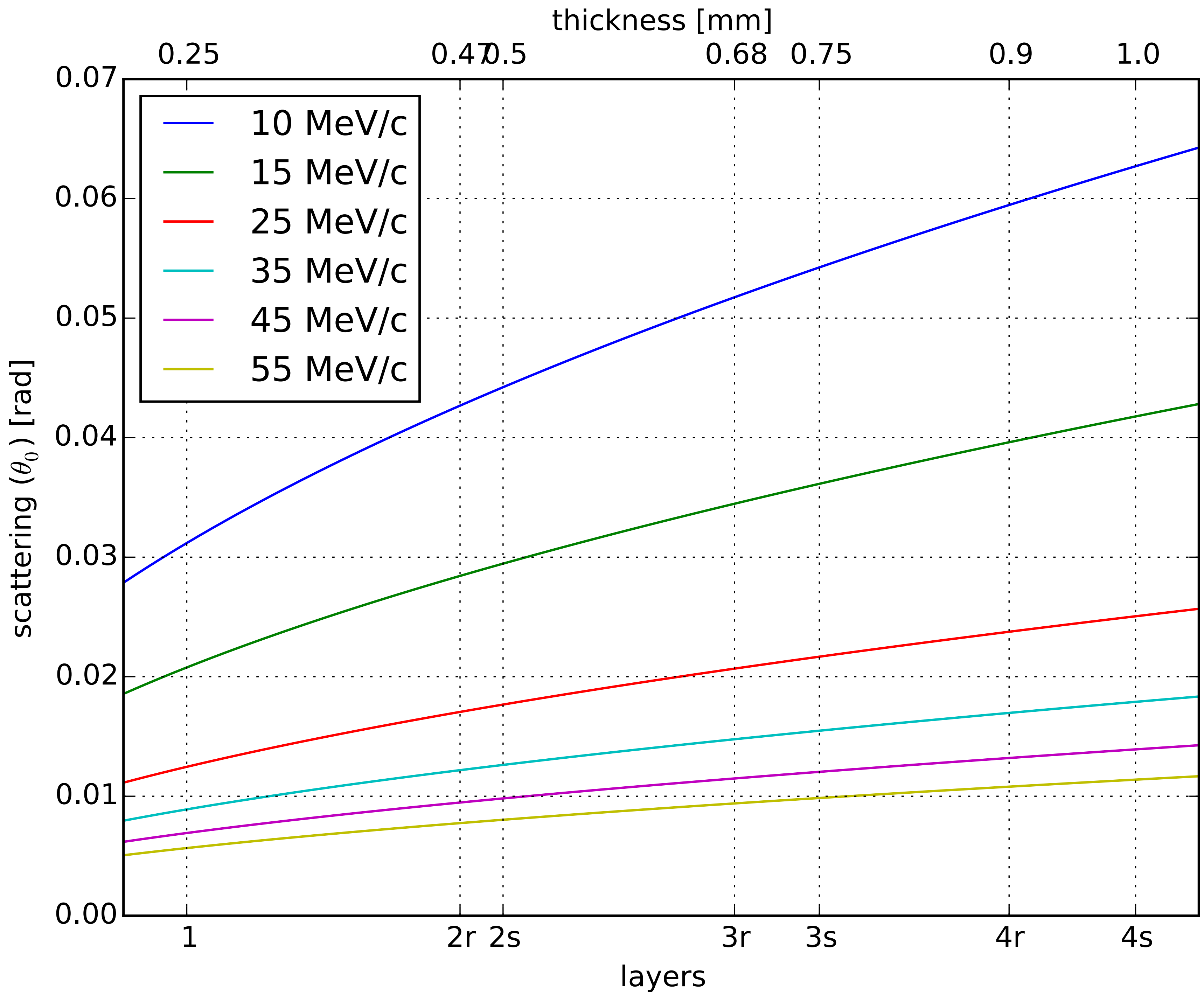
	fibres	tiles	both
≥4 hits	35	5.3	72
≥6 hits	44	5.3	102





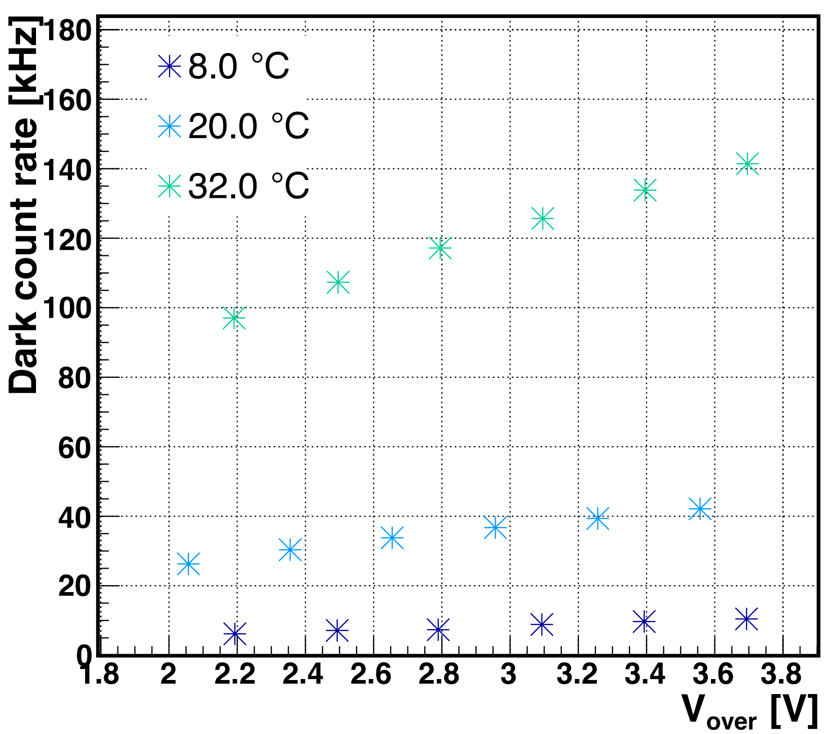
Multiple Scattering

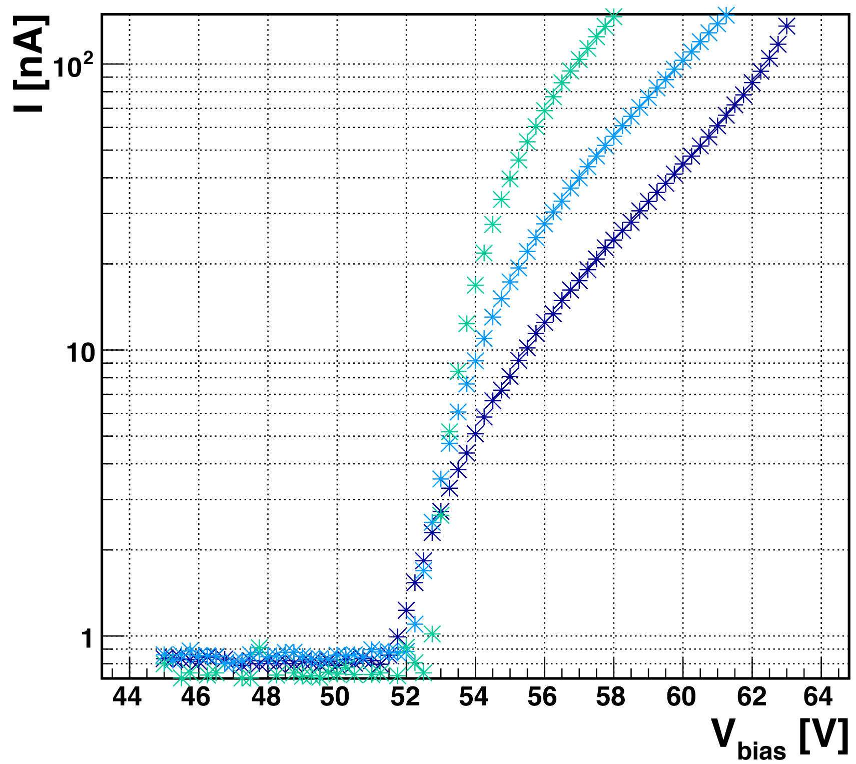
- Round fibre n; Squared fibre n-1



Example of curves for SiPM Characterization

Hamamatsu photosensors





	S13360	S12825
V_{bd} [V]	53 ± 5	65 ± 10
$(V_{op} - V_{bd})$ [V]	3.0	2.6
PDE (at V_{op}) [%]	40	35
gain (at V_{op}) [10^6]	1.7	1.25
geometrical fill factor [%]	74	62
dark count (at V_{op}) [kcps]	90-270	170-350
crosstalk (at V_{op}) [%]	1	40
temperature coef. (mV/° C)	54	60

new