Production Description

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Introduction
LHCb Detector Upgrade

Motivation: Increase significantly the physics reach, especially for very rare decays

Limitations:
• 1MHz hardware trigger rate
• Detector occupancy

Major tracking upgrade of LHCb (for after LS2, ≥2020, 50fb⁻¹)

• DAQ: a 40 MHz full readout
• New VELO
• RICH: new photon detectors and readout
• Calorimeters: remove SPD/PS and new readout
• Muon System: remove M1 and new readout
• Tracking system: replace TT with new silicon strip detector (UT) and IT&OT with SciFi tracker (scintillating fibres with SiPM readout)

Th. Kirn, M. Wlochal
LHCb SciFi Tracker

General layout of the detector geometry:
3 stations with 4 planes each X-U-V-X (stereo angle 5°)

Requirements

- Hit detection efficiency:
  single hits ~ 99%
- Low material budget for single detector layer
  ~1% $X_0$
- Spatial resolution better:
  100 µm in x-direction
- 40 MHz readout
  without dead time
- Radiation environment:
  Fibres: up to 35 kGy,
  SiPMs: approx. $1 \cdot 10^{12}$ n/cm$^2$ fluence
  + 100 Gy ionizing dose

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LHCb Scintillating Fibre Tracker: Principle

- Staggered layers of Ø250 μm fibres form a fibre mat
- Readout by arrays of SiPMs. 1 SiPM channel extends over the full height of the mat.
- Pitch of SiPM array should be similar to fibre pitch. Light is then spread over few SiPM channels. Centroiding can be used to push the resolution beyond p/sqrt(12).

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Scintillating Fibres and SiPMs as Photodetectors: The SciFi tracker is following the technology developed by the PERDaix detector (balloon experiment), Beam Gas Vertex (BGV) Detector and a Muontomograph

- Fibre Mats: Length: 30cm – 100cm, width: 32-64 mm, Layers:4-5

Th. Kirn, M. Wlochal
LHCb SciFi Tracker

- **144 modules** in 12 layers
- **360 m²** total area
- Module Carriers made out of CF skin and Nomex honeycomb
- **1 Module** consists of **8 fibre mats** *(1152 mats)*
- Fibre mats *(6 layers per mat)* run in vertical direction *(L≈ 2 x 2.5m)* sandwiched in module carriers *(1.1% X0)*,
- Fibres: Ø 250µm, L=2.5m, **total length >10,000 km**
- Fibres interrupted in mid-plane *(y=0)* and mirrored
- Read out at top and bottom with SiPM arrays *(128 channels, 250 µm pitch)*
- 590k SiPM channels
- SiPMs + FE electronics + services in a “Readout Box”

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LHCb SciFi Tracker: Scintillating Fibres

Kuraray SCSF-78MJ fibres: $\phi (250 \pm 15) \ \mu m$, 6 fibre layers per mat, each layer with 512 fibres with length 2.5m $\rightarrow$ 10,000 km fibres

(Scintillator)
Polystyrene core with 2 dyes

Only a few photons after 2.5m

300 photons per MIP produced (only 5% captured)

$\lambda_{\text{Emission}} = 460\text{nm}$

$\frac{dE}{d\lambda} (\text{a.u.})$

2015: 370 cm

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Light transmission of scintillating fibre decreases under irradiation, (up to 35 kGy expected near the beam pipe over the upgrade lifetime).

A mix of low dose, low rate xray, gamma and high rate, high dose proton irradiations

Up to 35 kGy near beam pipe, Down to 60 Gy in SiPM region
→ Expect a 40% loss of transmitted light created near the beam pipe after 10 years

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Measurement of Fibre diameter profile (along fibre)

Fibre diameter $(250 \pm 7) \, \mu m$,  
But bumps appear $(\text{diameter} \gg 300 \, \mu m)$  
$\approx 1 \text{ per km of fibre} = 1 \text{ per layer of fibre mat}$.  

Possible to remove manually during winding process.

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Threaded winding wheel

- First layer is directly wound onto hub,
- following layers are wound into groove-like depressions of preceding layers
- Need about 8km of fibre for one mat of 6 layers 2.5 meters long
  → 10,000 km of fibre in total

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Foil lamination of SiFi mat is done to protect fibre mat and to make handling and shipping easier.

5 Production center for fibre mats:
2 in Russia (Kurchatov),
2 in Germany (RWTH Aachen, TU Dortmund) and 1 in Switzerland (EPFL Lausanne)
LHCb SciFi Tracker: Fibre Mat Modules:

2 Module Center: Heidelberg Universität, NIKHEF Amsterdam

Fibre mats need to be assembled into a module that can be mounted and placed in the LHCb pit

- 8 mats aligned on a precision table
- Bond a carbon fibre + Nomex core structure to make a strong rigid object → Precision in time in z-direction better than 300 µm

144 Modules, 360 m² total area, 1152 SciFi mats

Material Budget:

- CFRP 200 µm
- Epoxy 75 µm
- Honeycomb 20 mm
- Epoxy 75 µm
- Foil 23 µm
- Epoxy 27 µm

SciFi Mat
- Epoxy 27 µm
- Foil 23 µm
- Epoxy 75 µm
- Honeycomb 20 mm
- Epoxy 75 µm
- CFRP 200 µm

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Production and Quality Control at Fibre Mat Winding Centres

**Winding Centre**
- **Winding**
  - Foil Lamination
  - Gluing Endpieces
  - Transversal Cut
  - Mirror Gluing

**Assembly Centre**
- **Longitudinal Cut**
  - Module Assembly
  - Module Finishing

Online monitoring

1. Fibre mat geometry
2. Optical scan
3. Light yield

1. Fibre mat width
2. Cut quality
3. Light tightness
4. Response to ionizing particles
Fibre Mat
Dimensions and Tolerances
Fibre Mat Dimensions and Tolerances

Scintillating Fibre Mat Final Dimensions:
Length: \((2424 + 0.5)\) mm w/o mirror glued @ 22°C,
Width: \((130.45 – 0.05)\) mm
Height of fibre mat with endpiece \((14.9 – 0.2 + 0.0)\) mm

Endpieces at SiPM side:
Upper Endpiece \((7.7 – 0.1)\) mm, Lower Endpiece \((5.7 – 0.1)\) mm
Accepted spread of fibre mat height (with foils): \((1.45 ± 0.1)\) mm

Positioning of SiPMs on endpieces: mat of 1.45 mm height will be positioned Symmetrically around the middle plane with a maximum spread of ± 75 µm
Height of fibre mat with endpiece \((14.9 - 0.2 + 0.0) \text{ mm}\)

Positioning of SiPMs on endpieces: mat of 1.45 mm height will be positioned symmetrically around the middle plane with a maximum spread of \(\pm 75 \mu\text{m}\)

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Winding Process
Winding Process Steps

1. Preparation of winding wheel
2. Mounting of winding wheel to winding machine
3. Preparation of winding machine
4. Winding of fibre mat
5. Curing of fibre mat (plus lamination of upper side of fibre mat)
6. Unforming of fibre mat
7. Reconditioning of winding wheel
8. Bump Removal
9. Result of winding process
10. Winding Process: Tools, Consumables, FTE
1. Mount winding wheel on rotation cart

2. Cleaning of relevant surfaces for winding process like thread, pin-holes, cutting groove and all surfaces which could have contact with glue.

3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

4. Follow supplier recommendation: Drying last layer of release agent overnight!
1. Mount winding wheel on rotation cart
1. Preparation of Winding Wheel

Attention: Respect Health and Safety Rules for steps 2, 3 and 4 !!!

Do the next steps, cleaning of relevant surfaces, in a ventilated room or/and use in addition a vacuum exhauster and use a breathing mask.
1. Preparation of Winding Wheel

2. Cleaning of relevant surfaces for winding process like thread, pin-holes, cutting groove and all surfaces which could have contact with glue. Cleaning agent: Zywax Surface Cleaner, if necessary acetone and isopropanol

Use dry clean air to blow out pin-holes
1. Preparation of Winding Wheel

2. Cleaning of relevant surfaces for winding process like thread, pin-holes, cutting groove and all surfaces which could have contact with glue. Cleaning agent: Zyvax Surface Cleaner, if necessary acetone and isopropanol.

Remove remaining dirt from wheel
1. Preparation of Winding Wheel

3. Apply Release Agent (Mikon 205) 3 times according to instruction manual.

Use a cloth to apply release agent to winding wheel.
1. Preparation of Winding Wheel

3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

Use a cloth to apply release agent to winding wheel
3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

Fill release agent into cartridge, close cartridge with plug and mount it to cartridge gun
1. Preparation of Winding Wheel

3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

Continue distribution of release agent on wheel
4. Follow supplier recommendation: Drying last layer of release agent overnight!
1. Preparation of Winding Wheel

With 1 time applied Release Agent:
4 fiber mats can be produced, after each fiber mat winding wheel glue residuals need to be removed. Depending of the quality of the unforming one has to decide if a new additional layer of release agent is necessary!

After 4 fiber mats winding wheel must be cleaned completely and new portion of release agent is needed.
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart
2. Drive wheel on handling cart to winding machine
3. Move wheel with crane in front of rotation axis of winding machine
4. Mount winding wheel on rotation axis
5. Mount wheel retainer with a screw to rotation axis.
6. Adjust start and stop parameters in STC software according to winding wheel parameters
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart by
   a) first screwing together axles from cart and storage rack using adapter.
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart by
   a) first screwing together axles from cart and storage rack using adapter.
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart by
   a) first screwing together axles from cart and storage rack using adapter.
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart by
   b) sliding it.
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart

   c) After the transfer unscrew axles again.
2. Drive wheel on handling cart to winding machine.
2. Mounting of winding wheel to winding machine

3. Move wheel with crane in front of rotation axis of winding machine

a) Mount wheel to crane

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2. Mounting of winding wheel to winding machine

3. Move wheel with crane in front of rotation axis of winding machine

b) Move crane with wheel in front of rotation axis of winding motor. Transfer wheel to winding machine via adapter screwed to rotation axis of winding motor.
2. Mounting of winding wheel to winding machine

4. Mount winding wheel on rotation axis
2. Mounting of winding wheel to winding machine

5. Mount wheel retainer with a screw to rotation axis.

6. Adjust start and stop parameters in STC software according to winding wheel parameters.
3. Preparation of winding machine

1. Mount Take-off spool with fibres to STC winding machine
2. Mount fibre to pulleys
3. Start up STC winding machine
1. Mount Take-off spool with fibres (delivered by Kuraray, tested by CERN) to STC winding machine
2. Mount fibre to pulleys as shown in photo

3. Start up STC winding machine
4. Winding of fibre mat

1. Prepare 7 portions of TiO$_2$ in measuring cups using a mesh to prevent clustering of TiO$_2$, protect cups against dust and humidity.

2. Cup 1: Fill Part A (binder) into cup with TiO$_2$ and premix by hand using a metallic spatulae; Prepare mixture of glue and TiO$_2$ (Epotek 301 -2 + 25% TiO$_2$) for layer 1

3. Prepare cartridge with a 0.5mm cone which is used to fill glue into pin holes of winding wheel. Fill glue mixture into cartridge, close cartridge with plug and mount it to cartridge gun

4. Apply mixed glue to wheel before first layer winding

5. Winding of first layer

6. Winding of layer 2 to 6
1. Prepare 7 portions of TiO$_2$ in measuring cups using a mesh to prevent clustering of TiO$_2$, protect cups against dust and humidity.
4. Winding of fibre mat

2. Cup 1: Fill Part A (binder) into cup with TiO₂ and premix by hand using a metallic spatulae
4. Winding of fibre mat

2. Cup 1: Prepare mixture of glue and TiO$_2$ (Epotek 301 -2 + 25% TiO$_2$) for layer 1 using a *smartmix* X2 under vacuum, total mixture weight 31.25 g, Pre-evacuation: 30 sec, Pre-mixing time: 20 sec, Pre-Mixing speed: 150 U/min Mixing time: 5 min, Mixing speed: 200 U/min, Mixing direction change: 10 sec Post-evacuation: 30 sec
4. Winding of fibre mat

2. Cup 1: Prepare mixture of glue and TiO$_2$ (Epotek 301 -2 + 25% TiO$_2$) for layer 1 using a *smartmix* X2 under vacuum, total mixture weight 31.25 g
3. Prepare cartridge with a 0.5mm cone which is used to fill glue into pin holes of winding wheel. Fill glue mixture into cartridge, close cartridge with plug and mount it to cartridge gun.
4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:

a) Cover the transversal cutting groove on the wheel with kapton tape

b) Apply glue to pin holes of winding wheel with the cartridge gun

c) Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue

d) Apply glue to pin holes of winding wheel with the cartridge gun to refill pin holes

e) Clean transversal cutting groove
4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
   a). Cover the transversal cutting groove on the wheel with kapton tape
4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
b) Apply glue to pin holes of winding wheel with the cartridge gun
4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue
4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
   c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue using a wiper
4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue using a wiper.
4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue using a wiper
4. Apply mixed glue to wheel before first layer winding:

d). Apply glue to pin holes of winding wheel with the cartridge gun to refill pin holes if necessary
4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
e) Clean transversal cutting groove
4. Winding of fibre mat

5. Winding of first layer:

a) Fix the fibre with a screw on the edge of winding wheel outside the thread.

b) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread.

c) If step b) is ok, increase the speed to full winding speed of 1.3 m/s.

d) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding speed again. If the bump creates an error, wind the fibre back, clean it with isopropanol, and try to wind again. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.
5. Winding of first layer:

e) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding to detect winding errors. If you or your online monitoring system detects an error, stop the winding. Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.

f) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.
4. Winding of fibre mat

5. Winding of first layer:

a) Fix the fibre with a screw on the edge of winding wheel outside the thread
4. Winding of fibre mat

5. Winding of first layer:

b) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread.
5. Winding of first layer:

c) If step b) is ok, increase the speed to full winding speed of 1.3m/s
5. Winding of first layer:

d) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.
5. Winding of first layer:

d) cont.: If the bump is $\leq 350 \, \mu m$, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again. Cleaning with isopropanol: a) “Close” wash up system
4. Winding of fibre mat

5. Winding of first layer:
   d) cont.: If the bump is $\leq 350 \, \mu m$, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again.

Cleaning with isopropanol: a) “Close” wash up system
5. Winding of first layer:
   d) cont.: If the bump is $\leq 350 \, \mu m$, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again. Cleaning with isopropanol: b) Charge wash up system with isopropanol
5. Winding of first layer:

   d) cont.: If the bump is \( \leq 350 \, \mu m \), continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again.

Cleaning with isopropanol: c) wind fibre back
5. Winding of first layer:
d) cont.: If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.
4. Winding of fibre mat

5. Winding of first layer:

e) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding to detect winding errors. If you or your online monitoring system detects an error, stop the winding.

Laser Scope for error detection during winding of fibre mat

No Error

Detected Error → stopped winding

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4. Winding of fibre mat

5. Winding of first layer:
e) cont.: Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.
5. Winding of first layer:

f) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.
4. Winding of fibre mat

6. Winding of layer 2 to 6:

a) First apply binder and second apply hardener to the next cup of glue.

b) Apply glue to surface of the previous wound layer.

c) Fix the fibre with a screw on the edge of winding wheel outside the thread.

d) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread-like depressions created by the preceding layer.

e) If step d) is ok, increase the speed to full winding speed of 1.3 m/s.
6. Winding of layer 2 to 6:

f) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding speed again. If the bump creates an error, wind the fibre back, clean it with isopropanol, and try to wind again. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.

g) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding to detect winding errors. If you or your online monitoring system detects an error, stop the winding. Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.
4. Winding of fibre mat

6. Winding of layer 2 to 6:

h) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.

i) Repeat these steps to the chosen amount of layers

j) Remove unnecessary glue on the side of winding wheel after the 6\textsuperscript{th} wound layer
4. Winding of fibre mat

6. Winding of layer 2 to 6:

a) First apply binder and second apply hardener to the next cup of glue.

For Cup 2 to 5:

First: Fill Part A (binder) into cup with TiO₂ and premix by hand using a metallic spatulae;

Second: Prepare mixture of glue and TiO₂ (Epotek 301 -2 + 25% TiO₂) for layer 2 to 5 using a smartmix X2 under vacuum, total mixture weight 21.88 g per layer

For Cup 6: Same procedure as before but total mixture weight 31.25 g

Cup 7: Spare
4. Winding of fibre mat

6. Winding of layer 2 to 6:

b) Apply glue to surface of the previous wound layer.
4. Winding of fibre mat

6. Winding of layer 2 to 6:

c) Fix the fibre with a screw on the edge of winding wheel outside the thread
6. Winding of layer 2 to 6:

d) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread-like depressions created by the preceding layer.

e) If step d) is ok, increase the speed to full winding speed of 1.3 m/s
4. Winding of fibre mat

6. Winding of layer 2 to 6:

f) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. If the bump is \( \leq 350 \, \mu\text{m} \), continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding speed again. If the bump creates an error, wind the fibre back, clean it with isopropanol, and try to wind again. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.
4. Winding of fibre mat

6. Winding of layer 2 - 6:

g) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding process to detect winding errors. If you or your online monitoring system detects an error, stop the winding.

Laser Scope for error detection during winding process

Detected Error → stopped winding

No Error
6. Winding of layer 2 - 6:
g) cont.: Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 “bump removal”) and start winding again.
4. Winding of fibre mat

6. Winding of layer 2 to 6:

h) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.
4. Winding of fibre mat

6. Winding of layer 2 to 6:

i) Repeat these steps to the chosen amount of layers

j) Remove unnecessary glue on the side of winding wheel after the 6th wound layer
5. Curing of fibre mat

1. Mount winding wheel on rotation cart
2. Lamination of fibre mat side without alignment pins directly after winding of 6th fibre layer
3. Move rotation cart with winding wheel to parking position.
4. Keep winding wheel rotating on rotation cart for 12h till polymerisation is advanced and glue will not drop down of the wheel.
5. Move rotation cart to storage rack.
6. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack.
7. Keep curing of fibre mat on going till 48h are reached
5. Curing of fibre mat

1. Mount winding wheel on rotation cart.
   a) Move rotation cart in front of the winding wheel.
5. Curing of fibre mat

1. Mount winding wheel on rotation cart.
   b) Screw axles of rotation cart and rotation motor of winding machine together using the adapter.
5. Curing of fibre mat

1. Mount winding wheel on rotation cart.
   b) Screw axles of rotation cart and rotation motor of winding machine together using the adapter.
5. Curing of fibre mat

1. Mount winding wheel on rotation cart.
   c) Slide wheel from winding machine over to rotation cart
5. Curing of fibre mat

1. Mount winding wheel on rotation cart.
   c) Slide wheel from winding machine over to rotation cart and unscrew the adapter
2. Lamination of fibre mat side without alignment pins directly after winding of 6\textsuperscript{th} fibre layer

a) Directly after the 6\textsuperscript{th} fibre layer winding place and roughly adjust foil with overlength (ca. 200 mm) on surface of the fibre mat side without alignment pins. Place the centre of the foil on the alignment pin hole which is located opposite to the cutting groove on the winding wheel. From this starting point wipe the foil roughly with a cloth to the left and to the right till you reach the cutting groove.
b). Mount first clamp to winding wheel at the position of the edge of the cutting groove.

c). Fold foil around the clamp, cut away part of overlength in the middle of the clamp and fix foil with tape to the clamp.
5. Curing of fibre mat

d). Starting from clamp wipe out air bubbles and distribute glue more homogenous between foil and mat by using a bathroom wiper.
5. Curing of fibre mat

e). After homogenization of glue below foil and removing of air bubbles cut away roughly overlength at other end of foil using a scissor. Lift foil using a tape and cut.
5. Curing of fibre mat

f). Place protection plate at cutting position below foil at incipient crack for endpiece position.
g). The position of incipient crack has to be measured with a bendable steel ruler (remove disturbing screws before). In principle this measurement must be done once per winding wheel and mark position on wheel using a pencil.
5. Curing of fibre mat

h). Cut foil to correct length using a scalpel and a straight edge.
5. Curing of fibre mat

i). Remove cutted foil piece and protection plate.
j). Remove remaining few air bubbles using the wiper again and distribute excess glue homogeniously over rest part of the fibre mat.
5. Curing of fibre mat

k). To avoid possibility of fibre mat cracking during unforming glue an additional cracking protection foil piece close to not foil protected cutting groove.
5. Curing of fibre mat

1). Place and mount second clamp on foil so that 1 to 2 mm of foil is sticking out of clamp.
m). Result of 1\textsuperscript{st} foil lamination

Arc length = 126.5
m). Result of 1\textsuperscript{st} foil lamination

Clamps on top of foil, screwed against wheel rim

Drilled hole for security plates
5. Curing of fibre mat

m). Result of 1\textsuperscript{st} foil lamination
3. Move rotation cart with winding wheel to parking position.
5. Curing of fibre mat

3. Keep winding wheel rotating on rotation cart for 12h till polymerisation is advanced and glue will not drop down of the wheel.
4. Move rotation cart to storage rack.
5. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack.
5. Curing of fibre mat

5. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack.
5. Curing of fibre mat

Curing of fibre mat for 48 h
6. Keep curing of fibre mat on going till 48 h are reached.

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6. Unforming of fibre mat

1. Move storage jig with winding wheel and fibre mat to cutting position in front of long table.
2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel.
3. Loosen fibre mat from winding wheel using a round plastic stick. Start loosening of the mat at the transversal cutting groove.
4. Protect fibre mat using a foam.
5. Place shelf with protected fibre mat in storage rack where the mat is stored waiting for the next production step.
6. Unforming of fibre mat

Unforming of fibre mat from winding wheel:
1. Move storage jig with winding wheel and fibre mat to cutting position in front of long table.
2. Use a hot blade to cut the fibre mat at the position of the transversal
2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel. After cutting remove immediately remaining plastic on edge of hot blade by using a metal brush.
6. Unforming of fibre mat

2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel
6. Unforming of fibre mat

3. Loosen fibre mat from winding wheel using a round plastic stick. Start loosening of the mat at the transversal cutting groove.
6. Unforming of fibre mat

Unforming of fibre mat from winding wheel:
3. Move storage jig with winding wheel and fibre mat to unforming position above a long table
3. Loosen fibre mat from winding wheel using a round plastic stick. Continue loosening of the mat around the wheel. Start loosening of the mat at the transversal cutting groove.
3. Loosen fibre mat from winding wheel using a round plastic stick. Start loosening of the mat at the transversal cutting groove.
6. Unforming of fibre mat

3. Continue loosening of the mat around the wheel.
6. Unforming of fibre mat

3. Continue loosening of the mat around the wheel till end of fibre mat on wheel is reached. Loosen fibre mat from kapton tape.
6. Unforming of fibre mat

4. Protect fibre mat using a foam. Fix foam to shelf using an Velcro® fastener.

Th. Kirn, M. Wlochal
6. Unforming of fibre mat

5. Place shelf with protected fibre mat in storage rack where the mat is stored waiting for the next production step.
7. Reconditioning of fibre mat

1. Removal of glue residuals from winding wheel
2. Cleaning of winding wheel after production of 4 fiber mats, go to step 3.

Preparation of Winding Wheel
1. Removal of glue residuals from winding wheel:
Use a nylon block, scotch brite and a brush to remove the glue residuals from
winding wheel. If necessary apply release agent again.
2. Cleaning of winding wheel (similar as cleaning of winding wheel in step 1:
„Preparation of Winding Wheel“.
After production of 4 fiber mats the release agent has to be re-done, go to step 1 of
Winding Process, „Preparation of Winding Wheel“. 
8. Bump Removal

1. If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.

2. When the winding is continued and the bump creates an error, wind the fibre back by cleaning it with isopropanol.

3. Position and embed the fibre in the groove in the PTFE of the bump removal station.

4. Fix the fibre with magnets and clamps to cutting station.

5. Place fibre into the groove above cutting piece which is clamped by linear slip table.

6. Cut bump out of fibre.

7. Remove cutting block.

8. Fibre glueing, which is an eye controlled process by stereo microscope.
8. Bump Removal

Removal of Bumps which create always errors during winding.

Th. Kirn, M. Wlochal
8. Bump Removal

1. If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.

2. When the winding is continued and the bump creates an error, wind the fibre back by cleaning it with isopropanol.
8. Bump Removal

3. Position and embed the fibre in the groove in the PTFE of the bump removal station.
8. Bump Removal

4. Fix the fibre with magnets and clamps to cutting station
8. Bump Removal

5. Place fibre into the groove above cutting piece which is clamped by linear slip table. Use a head magnifying glass.
8. Bump Removal

6. Cut bump out of fibre.

Block will be removed after cutting
6. Cut bump out of fibre.
7. Remove cutting block
8. Bump Removal

8. Fibre glueing, which is an eye controlled process by stereo microscope

Magnification about 30X - 40X
8. Fibre glueing: a) check that cut is as rectangular as possible
8. Fibre glueing: b) Check alignment of the fibers in the jig
8. Fibre glueing: c) bring fiber ends close together
8. Fibre glueing: d) Applying glue with a needle tip. (UV-glue: Epotek OG 603)
8. Bump Removal

8. Fibre glueing: e) cure glue using an UV-lamp
8. Fibre glueing: Result: little bump of glue around two fiber ends
8. Fibre glueing: Result: little bump of glue around two fiber ends, which creates no errors during winding and is placed at cutting position of fibre mat on wheel.
Result of Winding Process

Scintillating Fibre Mat: Dimensions: Length: 2650mm, Width approx. 140 mm

Th. Kirn, M. Wlochal
Winding Process: Tools

- Winding wheels, QTY 3 to 4
  (Diameter 817 mm, width 140 mm, weight 64 kg, thread with 275 µm pitch)
Tools: Winding Machine

- STC Winding Machine QTY: 1
- Lump & Neck detector to detect bumps QTY: 1
- Laser Scope to detect errors during winding QTY: 1
- Scintillating Fibres QTY: 8 km per mat, 2000 km
TOOLS:

- Glue mixer Smartmix X2 (Amman Girrbach GmbH, Dürrenweg 40, 75117 Pforzheim, Germany) QTY: 1
- Accuracy scale (0.01g sensitivity) QTY: 1
- Cartridge mastic gun Fisnar (Vieweg GmbH, Gewerbepark 13, 85402 Kranzberg, Germany) QTY: 1
- Squeegees with soft rubber edge ca. 150 mm wide QTY: 20
- Antistatic brush Pro-Ject (Audio Trade GmbH, Schenkendorfstrasse 29, 45472 Mülheim/Ruhr, Germany) QTY: 3
- Support for mat handling and transportation Item 240 mm wide, 2775 mm long, 40 mm high QTY: 15
- Breathing protection MSA 200 LS (MSA Deutschland GmbH, Thiemannstr. 1, 12059 Berlin, Germany) QTY: 1 per person
TOOLS:

- Safety glasses MSA Perspecta GH 3001  QTY: 1 per  person
- Magnifying glasses for controlling the winding hub  QTY: 2
- Tool for turning the winding wheel during curing, continuously adjustable in height and speed controlled (rotation cart)  QTY: 1
- Tool for handling the winding wheel, continuously adjustable in height (handling cart)  QTY: 1
- Storage rack for winding wheels  QTY: 1
- Storage rack for fibre mats  QTY: 2
- Handheld vacuum cleaner  QTY: 1
- Small mobile crane for the handling of the winding hub (e.g. DEMA WK21HM)  QTY: 1
- Electrically heated blade  QTY: 1
Winding Process: Tools

Tools for bump removal:

- Linear slip table
- Micrometer Head $P=0.01\text{mm}$
- Head magnifying glass
- Tool with a standard piece of a razor blade
- Stereo microscope
  Magnification about $30X - 40X$

Th. Kirn, M. Wlochal
CONSUMABLES:

- Mixing tumblers for Smartmix X2  QTY: ≥ 5
- Single use protective gloves  QTY: 2500
- Cartridges, plugs for cartridge gun  QTY: 250
- Nozzles for cartridge gun  QTY: 250
- Plastic cups for glue or titanium oxide  QTY: 500
- Sifter for titanium oxide  QTY: 1
- Metallic spatulae  QTY: 5
- Paper towels for cleaning  QTY: 2500
- Dispenser for Tesa adhesive tape  QTY: 2
- Cotton cloth  QTY: 250
CONSUMABLES:

- Small side cutter QTY: 2
- Allen wrench with handgrip A/F 2.5 mm QTY: 2
- Brass brushes for the cleaning of the winding hub QTY: 25
- Lintless cloths for the cleaning of the winding hub QTY: 500
- Cleaning agent Zywax for the cleaning of the winding hub QTY: 5l
- Release agent Mikon 205 (Lange & Ritter GmbH, Dieselstr. 25, 70839 Gerlingen, Germany) QTY: 5l
- Disposable pipette, QTY: 250
- Epoxy glue Epotek 301-2 QTY: 50 kg (200g per mat)
- TiO2, QTY: 12.5 kg
- Q-tips, QTY: 500
CONSUMABLES:

- Narrow roller, QTY: 500
- Wide roller, QTY: 100
- Isopropanol
- Acetone
## Winding Process

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Wheel Preparation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Mount winding wheel on rotation cart</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Cleaning of wheel surface</td>
<td>30 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Apply release agent 3 times</td>
<td>30 min</td>
<td>1</td>
</tr>
<tr>
<td>Wait in between</td>
<td>90 min</td>
<td>0</td>
</tr>
<tr>
<td>4. Drying of last layer release agent</td>
<td>12 hour</td>
<td>0</td>
</tr>
<tr>
<td><strong>Σ 70 min</strong></td>
<td><strong>1</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Σ 13.5 hour</strong></td>
<td><strong>0</strong></td>
<td></td>
</tr>
<tr>
<td>Process/Step</td>
<td>Time</td>
<td>FTE</td>
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<tr>
<td>--------------</td>
<td>--------</td>
<td>-----</td>
</tr>
<tr>
<td><strong>2. Mounting of winding wheel to winding machine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Transfer winding wheel from storage rack to handling cart</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Drive wheel on handling cart to winding machine</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Move wheel with crane in front of rotation axis of winding machine</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Mount winding wheel on rotation axis</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Mount wheel retainer with a screw to rotation axis</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Adjust start and stop parameters in STC software according to winding wheel parameters</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>Σ 28 min</td>
<td></td>
<td>1</td>
</tr>
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### Winding Process

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mount Take-off spool with fibres to STC winding machine</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Mount fibre to pulleys</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Start up of STC winding machine</td>
<td>4 min</td>
<td>0</td>
</tr>
<tr>
<td>Σ 6 min</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Σ 4 min</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
## Winding Process

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4. Winding of fibre mat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Preparation of 7 cups with TiO2</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Prepare glue (cup 1-6)</td>
<td>42 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Prepare cartridge (before layer 1)</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Apply mixed glue to wheel before first layer winding</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Winding of first layer</td>
<td>40 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Winding of layer 2 to 6</td>
<td>200 min</td>
<td>1</td>
</tr>
<tr>
<td><strong>Σ 307 min</strong></td>
<td><strong>Σ 307 min</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>
## Winding Process

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<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5. Curing of fibre mat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Mount winding wheel on rotation cart</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Lamination of fibre mat side without alignment pins directly after</td>
<td>45 min</td>
<td>1</td>
</tr>
<tr>
<td>winding of 6th fibre layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Move rotation cart with winding wheel to parking position</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Keep winding wheel rotating on rotation cart for 12h till polymerisation</td>
<td>12 h</td>
<td>0</td>
</tr>
<tr>
<td>is advanced and glue will not drop down of the wheel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Move rotation cart to storage rack</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Dismount winding wheel and mount it to storage rack by screwing together</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>again the axles using the adapter and sliding the wheel to the rack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Keep curing of fibre mat on going till 48h are reached</td>
<td>36 h</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Σ 67 min</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Σ 48 h</td>
<td>0</td>
</tr>
</tbody>
</table>
## Winding Process

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Unforming of fibre mat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Move storage jig with winding wheel and fibre mat to cutting position in front of long table</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Loosen fibre mat from winding wheel</td>
<td>18 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Protect fibre mat using a foam</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Place shelf with fibre mat in storage rack</td>
<td>1 min</td>
<td>2</td>
</tr>
<tr>
<td>Σ 30 min</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Σ 1 min</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
# Winding Process

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Reconditioning of winding wheel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Removal of glue residuals from winding wheel</td>
<td>20 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Cleaning of winding wheel</td>
<td>30 min</td>
<td>1</td>
</tr>
<tr>
<td>Σ 50 min</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
# Winding Process

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>8. Bump removal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. If bump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.</td>
<td>1 min</td>
<td>0</td>
</tr>
<tr>
<td>2. When the winding is continued and the bump creates an error, wind the fibre back by cleaning it with isopropanol.</td>
<td>7 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Position and embed the fibre in the groove in the PTFE of the bump removal station.</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Fix the fibre with magnets and clamps to cutting station</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Place fibre into the groove above cutting piece which is clamped by linear slip table.</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Cut bump out of fibre</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Remove cutting block</td>
<td>0 min</td>
<td>1</td>
</tr>
<tr>
<td>8. Fibre glueing, which is an eye controlled process by stereo microscope</td>
<td>3 min</td>
<td>1</td>
</tr>
<tr>
<td>Σ 15 min</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Σ 1 min</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
2nd Foil Lamination and Glueing of Endpieces
Raw fibre mats still fragile after unforming from winding wheel, situation already improved when the 1\textsuperscript{st} foil lamination is done directly after the winding of the 6\textsuperscript{th} fibre layer on the wheel, but → handling protection is needed to avoid damage to fibre mats

→ Foil lamination of SiFi mat is done to protect fibre mat and to make handling and shipping easier.
0. Quality Control of Endpieces 163
1. Lamination of fibre mat side with alignment pins 165
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves at readout side and mirror side. 193

Foil Lamination and Endpiece Glueing: Tools, Consumables, FTE 198
At all production site precision jigs are used to check that the endpiece parts fulfill the dimensions and tolerances before they are glued to fibre mats.

Check of dimensions and precision holes of

- mirror endpiece
- readout endpiece

Th. Kirn, M. Wlochal
At all production site precision jigs are used to check that the endpiece parts fulfill the dimensions and tolerances before they are glued to fibre mats.

Check of dimensions and precision drilled holes for SiPM mounting to readout endpiece.
1. Lamination of fibre mat side with alignment pins

1. Prepare the foil for the fibre mat side with alignment pins
   - Prepare foil strip with overlength for the side of the fibre mat with alignment pins! Place foil straight on a flat surface, straightness can be reached by using a precision edge of a ruler
1. Prepare the foil for the fibre mat side with alignment pins:
   - Place the aperture plate on the foil.
1. Prepare the foil for the fibre mat side with alignment pins:
   - Cut holes for the alignment pins out of the foil by using a paper drill
1. Lamination of fibre mat side with alignment pins

1. Prepare the foil for the fibre mat side with alignment pins:
   - Remove cutted foil pieces out of holes for the alignment pins.
1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Take aluminium shelf with protected fibre mat out of storage shelf and place it on a table, remove protective foam
1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Place fibre mat on a clean aluminium shelf
1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Fix fibre mat to aluminium shelf with adhesive tape on both end sides
1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Cut away glue residuals from the longitudinal sides of the fibre mat
1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Clean the fibre mat with isopropanol
1. Lamination of fibre mat side with alignment pins

3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination:
   - Place foil on lamination table and fix it with an adhesive tape or/and a weight
1. Lamination of fibre mat side with alignment pins

3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination:
   - Clean foil quickly with acetone
3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination:
   - After cleaning flip foil over to half of its size. Position the flipped foil next to the fibre mat.
1. Lamination of fibre mat side with alignment pins

4. Prepare epotek glue 301 with TiO2 for the lamination (QTY: 20g, Mixing ratio: 80/20)
1. Lamination of fibre mat side with alignment pins

5. Check foil geometry on fibre mat: Lay down the flipped foil onto the surface of the mat, adjust it roughly and check that foil and pin-positions fit to fibre mat. Fasten the end of the foil onto the support.
1. Lamination of fibre mat side with alignment pins

5. Check foil geometry on fibre mat: Flip upper half of foil back by using a plastic stick.
1. Lamination of fibre mat side with alignment pins

5. Check foil geometry on fibre mat: If geometry is ok then flip back upper half of foil.
1. Lamination of fibre mat side with alignment pins

6. Apply epotek glue 301 on first half of the fibre mat surface with alignment pins.
1. Lamination of fibre mat side with alignment pins

6. Apply epotek glue 301 on first half of the fibre mat surface with alignment pins! Keep the alignment pins free of glue!
1. Lamination of fibre mat side with alignment pins

7. Lay down the flipped half of foil onto the with glue prepared surface half.
7. Lay down the flipped half of foil onto the with glue prepared surface half. Wrap foil around fibre mat end and fix it with a weight.
1. Lamination of fibre mat side with alignment pins

8. Apply epotek glue 301 on second half of the fibre mat surface with alignment pins! First flip second half of foil to the before glued part.
1. Lamination of fibre mat side with alignment pins

8. Apply epotek glue 301 on second half of the fibre mat surface with alignment pins! Keep the alignment pins free of glue!
1. Lamination of fibre mat side with alignment pins

9. Lay down the second half of foil onto the now with glue prepared surface again. Adjust foil so that punched holes fit to alignment pins.
1. **Lamination of fibre mat side with alignment pins**

10. Squeeze out all air bubbles using a squeegee. Start from the middle of the fibre mat towards the outsides.
1. Lamination of fibre mat side with alignment pins

10. Squeeze out all air bubbles using a squeegee. Start from the middle of the fibre mat towards the outsides.
10. Squeeze out all air bubbles using a squeegee. Start from the middle of the fibre mat towards the outsides.
1. Lamination of fibre mat side with alignment pins

10. Squeeze out all air bubbles using a squeegee. Start from the middle of the fibre mat towards the outsides.
1. Lamination of fibre mat side with alignment pins

11. Cure over night, curing time minimum 12h
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout and mirror side.

The glueing of the endpieces will be done in the foil lamination jig.

1. Prepare epoxy glue AW106. (QTY: 4g)
2. Position endpiece halves on clamps. Upper clamp has an additional 50µm kapton tape around upper endpiece clamp. Apply epoxy glue AW106 onto the endpieces for the readout side.
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout and mirror side.

The glueing of the endpieces will be done in the foil lamination jig.

2. Apply epoxy glue AW106 onto the endpieces for the mirror side.
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and mirror side.

3. Place and adjust the fibre mat in the jig with the alignment pins, fix and screw the clamps for the endpieces together.
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and mirror side.

3. Place and adjust the fibre mat in the jig with the alignment pins, fix and screw the clamps for the readout endpieces together. Tighten the screws with a torque of 0.8 Nm

4. Apply pressure readout side, remove leaking glue
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and mirror side

5. Fix and screw the clamps for the mirror endpieces together. Tighten the screws with a torque of 0.8 Nm
6. Apply pressure mirror side, remove leaking glue. Place support under free fibre mat end.
7. Cure over night, curing time minimum 12h
Foil Lamination and Endpiece Glueing: Tools

TOOLS:

- Multi purpose foil lamination and endpiece glueing jig, QTY: 1
- Narrow roller, QTY: 1
- Leifheit rubber wiper to push down the foil onto the mat, QTY: 1
- Hole punch 10 mm to punch out the holes for the alignment pins, QTY: 1
- Paper drill for the hole cut, QTY: 1
- Aperture plate, QTY: 1
- Forceps, QTY: 1
- Side cutter, QTY: 1
- Torque wrench, QTY: 1

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Foil Lamination and Endpiece Glueing
Consumables

- Foil black 0.025 mm, QTY: 6m per mat, 1.5 km in total
- Adhesive tape to fix the foil, QTY: 105 m
- Scotch brite (3M), QTY: 10
- Epotek 301, QTY: 10 kg
- TiO2, QTY: 3,5 kg
- Disposable pipette, QTY: 250
- AW106 (Araldit), QTY: 1.5 kg
- Single use protective gloves, QTY: 250
- Roller, small ones QTY: 500, wide ones QTY: 100
- Isopropanol
- Acetone

Th. Kirn, M. Wlochal
Foil Lamination and Endpiece Glueing Consumables

Consumables:

- Upper Endpiece half readout side, QTY: 250
- Lower Endpiece half readout side, QTY: 250
- Upper Endpiece half mirror side, QTY: 250
- Lower Endpiece half mirror side, QTY: 250
## Foil Lamination and Endpiece Glueing

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
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<tbody>
<tr>
<td><strong>1. Lamination of fibre mat side with alignment pins</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Prepare the foil for the fibre mat side with alignment pins</td>
<td>15 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Prepare fibre mat side with alignment pins for foil lamination</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination</td>
<td>15 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Prepare Epotek glue 301 for the lamination</td>
<td>7 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Check foil geometry on fibre mat</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Apply epotek glue 301 on first half of the fibre mat surface with alignment pins</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Lay down the flipped half of foil onto the with glue prepared surface</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>8. Apply epotek glue 301 on second half of the fibre mat surface with alignment pins</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>9. Lay down the second half of foil onto the now with glue prepared surface again</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>10. Squeeze out all air bubbles using a squeegee</td>
<td>25 min</td>
<td>1</td>
</tr>
<tr>
<td>11. Cure over night, curing time minimum 12h</td>
<td>12 h</td>
<td>0</td>
</tr>
<tr>
<td><strong>Σ</strong> 107 min</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Foil Lamination and Endpiece Glueing

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout and mirror side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Prepare epoxy glue AW106</td>
<td>7 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Position endpiece halves on clamps. Upper clamp has an additional 50µm kapton tape around upper endpiece clamp. Apply epoxy glue AW106 onto the endpieces for the readout side.</td>
<td>7 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Place and adjust the fibre mat in the jig with the alignment pins, fix and screw the clamps for the readout endpieces together.</td>
<td>5 min</td>
<td>2</td>
</tr>
<tr>
<td>4. Apply pressure, remove leaking glue</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Fix and screw the clamps for the mirror endpieces together. Tighten the screws with a torque of 0.8 Nm</td>
<td>10 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Apply pressure, remove leaking glue. Place support under free fibre mat end.</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Cure over night, curing time minimum 12h</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Σ</strong> 34 min</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Σ 5 min</strong></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Th. Kirn, M. Wlochal
Transverse Cut - Optical Cut
1. Position and align fibre mat on cutting jig 205
2. Pre-Cut on readout side using a saw blade to cut away overlength 206
3. Transversal Cut - Optical Cut on readout side using a diamond head 207
4. Repeat Pre-cut on mirror side 207
5. Repeat optical cut on mirror side 207
6. Acclimatisation and measurement of fibre mat length 208
7. Final optical cut mirror side 208
8. Transversal – Optical Cut: Tools, FTE 210
1. Position and align fibre mat on cutting jig

Multi Purpose Jig at Milling Machine

Cutting Jig Lower Half

Positioning of Fibre Mat

Fix Fibre Mat on Cutting Jig

Th. Kirn, M. Wlochal
2: Pre-Cut on Readout Side using a Saw Blade to cut away overlength

Saw Blade
Speed: 250 m/min, Feed Value: 0.001 mm/tooth

Overlength piece
3: Transversal Cut - Optical Cut on Readout Side using a diamond head

Diamond tip milling head
Speed: 200 m/min
Feed Value: 0.003 mm/tooth
Infeed Depth: 0.03 mm

Step 4 & 5: Repeat Pre-Cut and Optical Cut on Mirror Side

Th. Kirn, M. Wlochal
6. Acclimatisation and Measurement of Fibre Mat Length

Gap between Fibre Mats at mirror positions: 2 mm
Nominal Length of Fibre Mat (2424 + 0.5) mm

7. Final optical cut mirror side if necessary
Saw Blade
Speed: 250 m/min, Feed Value: 0.001 mm/tooth

Diamond tip milling head
Speed: 200 m/min, Feed Value: 0.003 mm/tooth, Infeed Depth: 0.03 mm

Th. Kirn, M. Wlochal
TOOLS:

• Multi purpose jig for transversal cut, QTY: 1
• Saw blade, QTY: 9
• Diamond head, QTY: 2
• Geometry jig or 3d-measurement machine, QTY: 1
## Optical - Transversal Cut

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Position and align fibre mat on cutting jig</td>
<td>5 min</td>
<td>2</td>
</tr>
<tr>
<td>2. Pre-Cut on readout side using a saw blade to cut away overlength</td>
<td>15 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Transversal Cut - Optical Cut on readout side using a diamond head</td>
<td>40 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Repeat Pre-cut on mirror side</td>
<td>15 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Repeat optical cut on mirror side</td>
<td>40 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Acclimatisation and measurement of fibre mat length</td>
<td>240 min</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Final optical cut mirror side if necessary</td>
<td>(40 min)</td>
<td>(1)</td>
</tr>
<tr>
<td><strong>Σ 140 min</strong></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Σ 5 min</strong></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>Σ 240 min</strong></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Th. Kirn, M. Wlochal
Mirror Glueing
1. **Place fibre mat and tools on a table.**  
2. **Cleaning of fibre surface.**  
3. **Glue two strips of double-sided adhesive tape to metal plate with respect to fibre mat width plus overlength.**  
4. **Remove protective cover of double-sided adhesive tape**  
5. **Glue two strips of Kapton tape on double-sided adhesive tape. The second strip is partial overlapping the first strip.**  
6. **Glue mirror foil to second (upper) Kapton tape, position fibre mat over mirror.**  
7. **Cut Kapton tape with mirror to length corresponding to width of fibre mat and loose tape from metal plate**  
8. **Remove protective cover of mirror.**  
9. **Prepare epoxy glue epotek 301 and apply it to mirror using a soft brush or Q-tip.**
10. **Fold Kapton tape with mirror around the fibre mat. Glue Kapton tape to mirror endpiece**

11. **Remove Kapton tape from endpiece precision holes**

12. **Mount mirror glueing jig to mirror endpiece of fibre mat**

13. **Fix jig by clicking bushings into holes of mirror endpiece**

14. **Screw inner bar of jig against glued Kapton tape and mirror.**

15. **Curing time minimum 12h**

16. **After curing remove glueing jig**

17. **Mirror Glueing: Tools, Consumables, FTE**
1. Place fibre mat and tools on a table.
Mirror Glueing

2. Cleaning of fibre surface.
3. Glue two strips of double-sided adhesive tape to metal plate with respect to fibre mat width plus overlength.
4. Remove protective cover of double-sided adhesive tape.
5. Glue one strip of Kapton tape (adhesive side pointing up) on double-sided adhesive tape.
6. Glue mirror foil to Kapton tape, position fibre mat over mirror.
Mirror Glueing

7. Cut Kapton tape with mirror to a length corresponding to width of fibre mat and loose tape from metal plate.
7. Cut Kapton tape with mirror to a length corresponding to width of fibre mat and loose tape from metal plate. Cut Kapton tape on all sides to endpiece width with a reversed scalpel.
7. Cut Kapton tape with mirror to a length corresponding to width of fibre mat and loose tape from metal plate. Flip cutted pieces to side.
8. Remove protective cover of mirror.
9. Prepare epoxy glue Epotek 301 (maximum 2g) and apply it to mirror using a soft brush or a Q-tip.
10. Fold Kapton tape with mirror around the fibre mat. Glue Kapton tape to mirror endpiece.
10. Fold Kapton tape with mirror around the fibre mat. Glue Kapton tape to mirror endpiece.
10. Fold Kapton tape with mirror around the fibre mat. Glue Kapton tape to mirror endpiece.
11. Remove Kapton tape from endpiece precision holes
12. Mount mirror glueing jig to mirror endpiece of fibre mat
13. Fix jig by clicking bushings into holes of mirror endpiece
14. Screw inner bar with a telfon cover against glued Kapton tape and mirror. Apply a torque of 0.1 Nm, start screwing from point 1 to 5.
15. Curing time minimum 12h
16. After curing remove glueing jig
Mirror Glueing: Tools

1. Table, QTY: 1
2. Metal plate, QTY: 1
3. Magnifying glass, QTY: 1
4. Forcipes, QTY: 1
5. Mirror glueing jig with an inner bar coated with teflon cover, QTY: 10
6. Pressure roller, QTY: 1
7. Plastic sheet (5mm thickness), QTY: 1
8. Torque wrench, QTY: 1
Mirror Glueing: Consumables

1. Scalpel / blade       QTY: 1 / 50
2. Q-Tips, QTY: 250
3. Mirror Foil 3M (5-0.5) mm height, 135.0 mm length, QTY: 32 m
4. Kapton tape, QTY: 100 m
5. Double-sided adhesive tape, QTY: 10 m
6. Epotek 301, QTY: 0.5 kg
## Mirror Glueing

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Place fibre mat and tools on a table</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>2. Cleaning of fibre surface</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Glue double-sided adhesive tape to metal plate with respect to fibre mat width plus overlength</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Remove protective cover of double-sided adhesive tape</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Glue one strip of Kapton tape (adhesive side pointing up) on double-sided adhesive tape.</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>6. Glue mirror foil to Kapton tape, position fibre mat over mirror.</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Cut Kapton tape with mirror to a length corresponding to width of fibre mat and loose tape from metal plate.</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>8. Remove protective cover of mirror.</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>9. Prepare epoxy glue epotek 301 and apply it to mirror using a soft brush or a Q-tip</td>
<td>7 min</td>
<td>1</td>
</tr>
</tbody>
</table>
Mirror Glueing

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Fold Kapton tapes with mirror around the fibre mat. Glue Kapton tape to</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>mirror endpiece.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Remove Kapton tape from endpiece precision holes</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>12. Mount mirror glueing jig to mirror endpiece of fibre mat</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>13. Fix jig by clicking bushings into holes of mirror endpiece</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>14. Screw inner bar of jig against glued Kapton foil and mirror.</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>15. Curing time minimum 12h</td>
<td>12 h</td>
<td>0</td>
</tr>
<tr>
<td>16. After curing remove glueing jig</td>
<td>3 min</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ \Sigma 27 \text{ min} \quad 1 \]

\[ \Sigma 12 \text{ h} \quad 0 \]

Th. Kirn, M. Wlochal
Result of Fibre Mat Production Process
Result of Fibre Mat Production Process

Scintillating Fibre Mat: Final Dimensions: Length: $(2424,0^{+0.1}_{-0.3})$ mm, Width: 140 mm

Scintillating Fibre Mat side with alignment pins.
On this side the lamination foil is below both endpiece halves (readout and mirror side)
Scintillating Fibre Mat side without alignment pins. On this side the lamination foil ends in front of readout endpiece half and runs below mirror endpiece half.

Endpiece half readout side

Endpiece half mirror side
Quality Control
1. Principle of Fibre Mat Production and Quality Control 243
2. Online Monitoring during Winding 244
3. Optical Scan of Fibre Mat at readout and mirror side 247
4. Light Yield Measurement 257
5. Information of Fibre Mat Production into Database 278
6. Quality control of winding wheels 284

Th. Kirn, M. Wlochal
Quality Control

- Winding
  - Foil Lamination
  - Gluing Endpieces
  - Transversal Cut
  - Mirror Gluing

Winding Centre:
1. Fibre mat geometry
2. Optical scan
3. Light yield

- Longitudinal Cut
  - Module Assembly
  - Module Finishing

Assembly Centre:
1. Fibre mat width
2. Cut quality
3. Light tightness
4. Response to ionizing particles

Online monitoring
Online Monitoring during Winding

Th. Kirn, M. Wlochal

Laser Scope for error detection during winding process
Laser Scope for online monitoring

Measurement of fibre shadow position

ΔM value = 63 pixels = 98.4 µm
Laser Scope for online monitoring

Laser Scope for error detection during winding process

No Error

Detected Error → stopped winding

Th. Kirn, M. Wlochal
Optical Scan of fibre mat at readout and mirror side

- The fibre mat sides (readout and mirror) are scanned to check the quality of the winding pattern of the fibre mat by using a commercial scanner in vertical scan mode.
- By scanning the mat irregularities, cracks and blind fibres can be detected.
- The mirror is glued to the mat after the optical scan.

LED array on contact with mat
Setup consists of
• multipurpose jig,
• commercial scanner (4800dpi),
• Laptop for readout of scanner
• LED-array to illuminate fibre mat from far end
1. Take fibre mat and place it on multipurpose jig of optical scanner setup
2. First fix position of mat close to scanner by screwing upper clamp against lower one.
3. Second fix position of mat at far end by screwing upper clamp against lower one.
4. Move scanner towards face side of fibre mat using translation stage, stop on contact
5. Start scanning of the fibre mat face side.
6. Rotate mat after scanning, fix positions again and repeat scan of other face side.
7. Start scanning of the fibre mat face side.
8. Unmount fibre mat from scanner setup and place it in storage rack.
1. Take fibre mat and place it on multipurpose jig of optical scanner setup
2. First fix position of mat close to scanner by screwing upper clamp against lower one.
3. Second fix position of mat at far end by screwing upper clamp against lower one.
4. Move scanner towards face side of fibre mat using translation stage, stop on contact.
5. Start scanning of the fibre mat face side.
6. Rotate mat after scanning, fix positions again and repeat scan of other face side.
7. Start scanning of the fibre mat face side.
8. Unmount fibre mat from scanner setup and place it in storage rack.
1. Take fibre mat and place it on multipurpose jig of optical scanner setup
2. First fix position of mat close to scanner by screwing upper clamp against lower one.
3. Second fix position of mat at far end by screwing upper clamp against lower one.
4. Move scanner towards face side of fibre mat using translation stage, stop on contact.
5. Start scanning of the fibre mat face side.
6. Rotate mat after scanning, fix positions again and repeat scan of other face side.
7. Start scanning of the fibre mat face side.
8. Unmount fibre mat from scanner setup and place it in storage rack.
Scanned Image

- Longitudinal cut
- SiPM mounting holes
- End pieces
- Fiber layers

Optical Scan

Th. Kirn, M. Wlochal
**Optical Scan**

- Software uses circle detection algorithm of openCV library
- After detection fibres are assigned to different layers
- Analysis takes about a minute for each scan
Scan – Results Readout Side:

Fibre centre positions (FiMa-Do_20160219_SiPM)

- Layer 0: width = 100.54 \mu m
- Layer 1: width = 121.71 \mu m
- Layer 2: width = 116.42 \mu m
- Layer 3: width = 111.13 \mu m
- Layer 4: width = 116.42 \mu m
- Layer 5: width = 116.42 \mu m

Average layer distance: (216.15 \pm 15.55) \mu m

Distance between adjacent fibres

- Layer 0: (274.85 \pm 5.49) \mu m
- Layer 1: (274.89 \pm 6.32) \mu m
- Layer 2: (274.81 \pm 6.99) \mu m
- Layer 3: (274.84 \pm 6.80) \mu m
- Layer 4: (274.79 \pm 6.60) \mu m
- Layer 5: (274.97 \pm 7.42) \mu m

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Scan – Results Mirror Side:

Fibre centre positions (FiMa-Do_20160219_Mirror)

- Layer 0: width = 137.58 μm
- Layer 1: width = 135.29 μm
- Layer 2: width = 116.42 μm
- Layer 3: width = 127.00 μm
- Layer 4: width = 137.58 μm
- Layer 5: width = 127.00 μm

y positions of fibre centres

- Average layer distance: (211.03 ± 15.25) μm
- Mean ± rms:
  - Layer 0: (1606.97 ± 26.53) μm
  - Layer 1: (1393.72 ± 24.36) μm
  - Layer 2: (1194.41 ± 24.05) μm
  - Layer 3: (974.12 ± 23.37) μm
  - Layer 4: (754.45 ± 24.40) μm
  - Layer 5: (551.84 ± 22.96) μm

Distance between adjacent fibres

- Mean ± rms:
  - Layer 0: (274.96 ± 7.08) μm
  - Layer 1: (274.79 ± 7.39) μm
  - Layer 2: (274.76 ± 7.06) μm
  - Layer 3: (274.83 ± 6.55) μm
  - Layer 4: (274.87 ± 8.41) μm
  - Layer 5: (274.88 ± 7.75) μm

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## Optical Scan

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Take fibre mat and place it on multipurpose jig of optical scanner setup</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>2. First fix position of mat close to scanner by screwing upper clamp against lower one</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>3. Second fix position of mat at far end by screwing upper clamp against lower one</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td>4. Move scanner towards face side of fibre mat using translation stage, stop on contact</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Start scanning of the fibre mat face side.</td>
<td>7 min</td>
<td>0</td>
</tr>
<tr>
<td>6. Rotate mat after scanning, fix positions again and repeat scan of other face side</td>
<td>5 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Start scanning of the fibre mat face side</td>
<td>7 min</td>
<td>0</td>
</tr>
<tr>
<td>8. Unmount fibre mat from scanner setup and place it in storage rack</td>
<td>2 min</td>
<td>1</td>
</tr>
<tr>
<td><strong>Σ 13 min</strong></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Σ 14 h</strong></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Light Yield Measurement – Sr\(^{90}\) - setup

- The scintillation fibre mats are excited by electrons from a radioactive Sr\(^{90}\) – source (endpoint energy of beta-spectrum is 2MeV) which are passing through the fibre mat and the trigger counters below the mat.
- The created light in the fibres is lead via total reflection to the readout end of the fibre mats. The light is detected by SiPM arrays, which are covering the full height and width of the mat.
- The signal of the SiPM-arrays are digitized by a front-end board with SPIROC-chips and a USB-board for the data acquisition.
- The full readout chain is calibrated by a light injection system similar to the one used for the LHCb-SciFi-Modules where scratched fibres with a diameter of 1mm emit light which shines through the polycarbonate endpiece directly into the SiPM-arrays.
- The light yield is measured at the position close to the mirror for quality check, because this position is the most critical one in the LHCb SciFi tracker close to the beam pipe.
- The measurement of the light yield at three other positions along the fibre mat is possible to determine the attenuation length of the fibres.
Light Yield Measurement – Sr90 setup

Th. Kirn, M. Wlochal
SiPM arrays are mounted on a translation stage and can be moved back and forth. Between the fibre mat and the SiPM will always be a reproducible gap of 100 µm.
SiPM arrays are mounted on a translation stage and can be moved back and forth. Between the fibre mat and the SiPM will always be a reproducible gap of 100 µm.
Light Yield Measurement

Moveable tray in which the Sr90-source can be placed.
1. Take fibre mat and place it on multipurpose jig of Sr90-setup
2. Adjust fibre mat on readout position and fix position by screwing upper clamp to lower clamp at readout position
3. Fix position of fibre mat at mirror side by screwing upper clamp to lower clamp
4. Move SiPM array into measurement position
5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side
6. Close lighttight box
7. Start measurement
8. Open lighttight box and put Place Sr90-source in lead bunker
9. Unmount fibre mat from multipurpose jig, take it out of lighttight box and put it back to storage rack
Light Yield Measurement

1. Take fibre mat and place it on multipurpose jig of Sr90-setup
2.a Adjust fibre mat on readout position
2.b Fix position by screwing upper clamp to lower clamp at readout position
3. Fix position of fibre mat at mirror side by screwing upper clamp to lower clamp.
4. Move SiPM array into measurement position
4. Move SiPM array into measurement position
5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side (~10 MBq source, 140 mm above fibre mat)
5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side.
Light Yield Measurement

6. Close lighttight box
Light Yield Measurement

7. Start measurement

8. Open lighttight box and put Place Sr90-source in lead bunker

9. Unmount fibre mat from multipurpose jig, take it out of lighttight box and put it back to storage rack
Light Yield Measurement Data Taking and Analysis

- Calibration, particle, and housekeeping data stored together in a root file
  - 1k random trigger events → pedestal
  - 4k light injection events → gain
  - 500k particle events → light yield, cluster width
  - 300 MB raw data files → backup to raid at the institute

- Cluster finding
  - ADC values expressed in pixels for each channel
    \[ \text{pixels} = \frac{(\text{ADC} - \text{pedestal})}{\text{gain}} \]
    (no crosstalk or pixel saturation correction)
  - find channels with a signal > 2.5 pixel seed
  - add neighboring channels until the signal < 1.5 pixels

- Light yield is sum of all pixels in cluster, cluster width is its length

- Only single cluster events are used
Light Yield Measurement Online Display

- Qt-based GUI
- mat name is entered with a bar code scanner
- online analysis during data taking
- same software is used to
  - take data
  - loop over previously taken raw data
- analysis results are saved as
  - ROOT file and
  - summary pdf and csv files

Th. Kirn, M. Wlochal
Software

- software provides a two page pdf file with most relevant physical properties (see next page) as well as csv file for further analysis
- direct comparison to reference mat
- voltage, current, and temperature data available
- shipped with fiber mat and uploaded to database
Light Yield Measurement Report

- Light Yield
- Cluster Width
- Pedestal
- Gain
- Housekeeping

Th. Kirn, M. Wlochal
# Light Yield Measurement

<table>
<thead>
<tr>
<th>Process/Step</th>
<th>Time</th>
<th>FTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Take fibre mat and place it on multipurpose jig of Sr90-setup</td>
<td>2 min</td>
<td>2</td>
</tr>
<tr>
<td>2. Adjust fibre mat on readout position and fix position by screwing upper</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>clamp to lower clamp at readout position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Fix position of fibre mat at mirror side by screwing upper clamp to lower</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>clamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Move SiPM array into measurement position</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>5. Place Sr90-source on moveable tray and move source to measurement position</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>close to mirror side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Close lighttight box</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>7. Start measurement</td>
<td>5 min</td>
<td>0</td>
</tr>
<tr>
<td>8. Open lighttight box and put Place Sr90-source in lead bunker</td>
<td>1 min</td>
<td>1</td>
</tr>
<tr>
<td>9. Unmount fibre mat from multipurpose jig, take it out of lighttight box</td>
<td>2 min</td>
<td>2</td>
</tr>
<tr>
<td>and put it back to storage rack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ 6 min</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Σ 4 min</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Σ 5 min</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

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The fibre mat sides (readout and mirror) are scanned to check the quality of the winding pattern of the fibre mat by using a commercial scanner in vertical scan mode. By scanning the mat irregularities, cracks and blind fibres can be detected. The mirror is glued to the mat after the optical scan.
Information of Fibre Mat Production into Database

- Each fibre mat is assigned a production slip
- For each production step is noted:
  - date and operator
  - used materials (fibers, glue etc.) and tools
  - further comments (e.g. occurring problems)
- Removed fiber bumps, mat thickness and missing alignment pins noted
- production slip is scanned and archived at production center
Information of Fibre Mat Production into Database

- Each production step is also entered into the LHCb SciFi production database
- Entries updated daily based on production slips

Table of existing fiber mats

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Information of Fibre Mat Production into Database

- All entries for a mat summarized on an overview page
- Fibre mats get unique ID and barcode including this ID
- QR code with link to overview page created as well
- Sticker with codes printed and applied to the Fibre mat's end piece
Information of Fibre Mat Production into Database

- Scan / photo of production slip
- Scans of mat end faces and QA results
  - optical survey
  - Sr90 measurement
Information of Fibre Mat Production into Database

- Database also includes entries on
  - fiber spools (lot number, diameter measurements etc.)
  - consumables like epoxy to track which mat was created with which batch
Quality control of winding wheels (for new or reworked wheels only)

1. Mount winding wheel to winding machine.
3. Optical inspection of thread and pin-holes for burrs and sharp edges which can distort winding process or damage fibre during winding.
4. If necessary remove burrs and edges with 3M-scotch brite.
Quality Control of delivered wheel (new or after rework) before usage of it for fibre mat production:

1. Mount winding wheel to winding machine.


Tolerances should be better than 100µm.

Diameter 817 mm, Thread-Width 140 mm

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3. Optical inspection of thread and pin-holes for burrs and sharp edges which can distort winding process or damage fibre during winding

4. If necessary remove burrs and edges with 3M-scotch brite