The Scintillating Fibre Tracker for the LHCb Upgrade
Experience from Production and Assembly

Forum on Tracking Detector Mechanics 2019
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on behalf of the
LHCb SciFi Tracker Group
1. LHCB EXPERIMENT: LS2 UPGRADE

- LHCb LS2 work inventory, overall schedule and status
- Replacement of the downstream tracking system

2. THE SCIFI TRACKER DETECTOR

- Layout overview
- SciFi Modules
- SciFi global supporting structure
- Assembly phase
- Survey of the first station
LHCB EXPERIMENT: LS2 UPGRADE
LHCb is a Single-arm forward spectrometer studying CP violation in the interactions of b-hadrons (can help to explain the matter-antimatter asymmetry), new physics and deviation from the standard model.

Main objectives of the upgrade operation:
- Increase the amount of data collected \([9 \text{ fb}^{-1} (\text{RUN 1&2}) \rightarrow 50 \text{ fb}^{-1} (\text{end of RUN 4})]\)
- Increase instantaneous luminosity \([4\cdot10^{32} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 2\cdot10^{33} \text{ cm}^{-2}\text{s}^{-1}]\)
- Replace the 1 MHz L0 hardware trigger with a software trigger with 40 MHz readout

Many activities ongoing also in surface at point 8.
### LHCb LS2 point 8 pit activities Overall Schedule (EDMS document ID: 1826213)

<table>
<thead>
<tr>
<th>Qtr 1, 2019</th>
<th>Qtr 2, 2019</th>
<th>Qtr 3, 2019</th>
<th>Qtr 4, 2019</th>
<th>Qtr 1, 2020</th>
<th>Qtr 2, 2020</th>
<th>Qtr 3, 2020</th>
<th>Qtr 4, 2020</th>
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<tbody>
<tr>
<td>Dec</td>
<td>Jan</td>
<td>Feb</td>
<td>Mar</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
<td>Jul</td>
</tr>
<tr>
<td>SHIELDING WALL EDMS 2009421</td>
<td>INSTALL Detector</td>
<td>REMOVE Beam Pipe</td>
<td>REMOVE DETECTORS</td>
<td>REMOVE SERVICES</td>
<td>INSTALL Services</td>
<td>REMOVE LAMINATE - Long Distance</td>
<td>INSTALL Detector</td>
</tr>
</tbody>
</table>

**IN**
- Velo Pixel
- RICH1
- RICH2 MapMT
- UT
- SciFi
- Neutron Shielding
- R/O Electronics
- DAQ

**OUT**
- Velo
- TT
- RICH1
- RICH2/HPD
- IT
- OT
- M1
- SPD
- Lead
- PS
- R/O Electronics
- DAQ

+ New services, cooling capability/type and infrastructure

**Run3 2021**

**MUCH HAS BEEN DONE**

**STILL MANY THINGS TO BE DONE**

**NO DELAYS**

**NO ACCIDENTS**

**SO FAR**

**BRING FORWARD SUB-ACTIVITIES WHEN POSSIBLE**

**FORMER DETECTORS REMOVED**
Two of the main LHCb particles tracking sub-detectors, the Outer Tracker (based on gas drift tubes) and the Inner Tracker (silicon micro strips), have to be replaced by a new single technology (scintillating fibres read out by silicon photomultipliers) tracking detector, the SciFi, with a completely different tracking technology, to satisfy the change of requirements for the upgrade.

**Requirements:**
- Hit efficiency $\sim 99\%$
- $\sigma_x < 100 \mu m$ (in the bending plane)
- $X/X_0 \leq 1\%$ per detection layer
- 40 MHz readout (25 ns)
- 35 kGy close to the beam pipe for fibres
- $6 \times 10^{11}$ $n_{eq}/cm^2$ for the SiPMs

**Track Reconstruction Efficiency**
- Pattern Recognition
- Material Interactions – Multiple Scattering
- Data Rate – Efficiency
- Signal/Noise Ratio – Life Time
• The SciFi half stations will be inserted in the LHCb bridge where the OT and IT were supported.
Dismantling of the OT and IT has been already done
THE SCIFI TRACKER DETECTOR
The SciFi tracker consists of three stations (4 layers each) located between the dipole magnet and the RICH2.

- The active part is based on 2.42 m long scintillating fibres with a diameter of 250 µm, readout by silicon photo-multipliers (SiPM).

- The new Scintillating Fiber Tracker covers a total detector area of 340 m² and provides a spatial resolution better than 100 µm (~ 70-80 µm from test beam investigations) in the bending direction.

**Working principle**

- When a charged particle passes through a scintillating fibre it deposits its energy through ionisation subsequently transformed into light by the scintillating process.

- Only a small portion (10.8%) of the scintillating photons is trapped in the fibre.

- The SiPMs are placed at one end of the fibre outside the acceptance.

- A mirror is placed at the inner end.
The scintillating fibre mat is the detection element of the SciFi tracker and needs to be manufactured with high mechanical accuracy.

To produce the mats, a threaded winding wheel ($d=86$ cm) with a pitch of 0.275 mm is used.

- The accuracy of the first layer is guaranteed by the thread machined in the surface of the wheel. Each successive layer uses the fibres below as a positioning guide.
- An epoxy loaded with TiO$_2$ is applied during winding to holds the fibres together.
- The alignment pins are essential for the positioning of the fibres mat with other parts (Endpieces and SIPMs).
- A precise cut of the full mat is perform at the end of the whole process.
- Fibre mats are still **fragile** after taking them off the winding wheel
- The fibre mats are **protected with a Kapton foils** on both sides to ensure a **thin protection film and improve light tightness**
- A glued **poly-carbonate Endpiece** is the connection that precisely align fibre mat with SiPMs on one side and with the **mirror on the other side**

**FOIL GLUING ON FIBRES MAT**

**FIXING OF ENDPIECES**

**CUTTING (DIAMOND HEAD)**

- A precise diamond milling of the end of the cast fibre mats and Endpieces is done to provide a **smooth flat surface** against which the SiPM is pressed
- The **quality of the optical cuts, surface roughness and its uniformity** is measured by an **high precision microscope**
- **In total about 1300 fibre mats, using about 11.000 km fibres , have been created**
THE SCIFI TRACKER DETECTOR

SciFi Modules – Modules structure

- Each full SciFi Tracker detector plane is divided into 12 individual detector components (Modules), 10 basic modules and 2 modules with a circular cut out to accommodate the beam pipe
- A fibre module is the assembly of multiple mats into a rigid structure (carbon-fibre/honeycomb sandwich)
- Two half-panels are placed on opposite sides of the fibre mats to provide the required strength and stiffness
- A Nomex honeycomb core is chosen for its low mass (32 kg/m³), fire and smoke properties.
- The half-panel consists of a honeycomb core 19.8mm thick with a 0.2 mm CFRP skin bonded on one side

Assembling process
- Araldite glue is applied to the fibre mats and Endpieces surface
- A carbon-fibre/honeycomb half-panel is placed on the fibres mat and pressed by a vacuum foil (8 hours cure)
- A second carbon-fibre/honeycomb half-panel is glued on the other side with a similar process
The panel material has been chosen to provide the maximum strength while having the lowest material budget.

The Endpieces lie outside the detector acceptance and are not considered in the material budget computation.

**CARBON-FIBRE/HONEYCOMB HALF-PANEL**

**FE STRUCTURAL INVESTIGATIONS (EXAMPLES)**

**MASS AND MATERIAL BUDGET FOR A SINGLE MODULE**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (micron)</th>
<th>Layers</th>
<th>X0 (cm)</th>
<th>%X0</th>
<th>kg/m³</th>
<th>mass (kg)</th>
<th>%mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibres + glue(Ti02)</td>
<td>1350</td>
<td>1</td>
<td>33.2</td>
<td>0.407</td>
<td>1180</td>
<td>4.10</td>
<td>0.20</td>
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<tr>
<td>Nomex Core</td>
<td>19700</td>
<td>2</td>
<td>1300</td>
<td>0.303</td>
<td>32</td>
<td>3.03</td>
<td>0.15</td>
</tr>
<tr>
<td>CF skin</td>
<td>200</td>
<td>2</td>
<td>27.56</td>
<td>0.145</td>
<td>1540</td>
<td>1.53</td>
<td>0.08</td>
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<tr>
<td>Araldite Glue</td>
<td>260</td>
<td>2</td>
<td>36.1</td>
<td>0.144</td>
<td>1160</td>
<td>1.50</td>
<td>0.07</td>
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<tr>
<td>Black Kapton Foil</td>
<td>25</td>
<td>4</td>
<td>35</td>
<td>0.029</td>
<td>1410</td>
<td>0.36</td>
<td>0.02</td>
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<tr>
<td>Polycarbonate</td>
<td>10000</td>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
<td>1200</td>
<td>1.78</td>
<td>0.09</td>
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<tr>
<td>Alu Endplugs</td>
<td>19700</td>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
<td>2700</td>
<td>8.00</td>
<td>0.39</td>
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<tr>
<td>Sidewalls</td>
<td>200</td>
<td>2</td>
<td>27.56</td>
<td>0.145</td>
<td>1540</td>
<td>0.30</td>
<td>0.02</td>
</tr>
</tbody>
</table>

- **Total %X0 = 1.03%** (1.18% at sidewalls)
- **Total Mass = 20.6 kg** (plus CB flanges)

The mechanical properties of the Modules have been optimized by a preliminary FEA and verified by experimental tests.
The ROB (SiPMs, cooling system and readout systems) and the supporting pins (interface with the SciFi global structure) are the last parts to be assembled to finalize the Module.

**THE SCIFI TRACKER DETECTOR**

*SciFi Modules – Interfaces*

- The modules supporting pins are the interfaces that permit the modules to be attached to the global supporting structure, the C-Frame.
- Several kinematic and FEA studies have been performed to optimize the modules structural behaviour.
The SciFi modules are linked on the SciFi supporting structures with their own kinematic that guarantee a proper fixation and stability to the active components.

- The SciFi modules are hyper statically connected to the C-Frame to improve their stability behaviour.
- The modules could contribute to the global structure stiffness and be deformed following a deformation of the global supporting structure.

- The modules required flatness is smaller than 300 µm.
- A proper fixation that avoid additional forces and deformation in the modules is mandatory.
• The rails (top and bottom) could be not perfectly aligned each other in all the points. Based on the survey carried out for the present top rails (CERN document: EDMS 756237) and bottom rails (CERN document: EDMS 771336), a difference up to 11 mm could be present. The rails will be realigned but it is not expected a better precision

• An adjusting system is needed mainly for two important reasons:
  ➢ The half-stations are relatively close. The smaller gap between half-stations of the same station is around 2 mm. A precise, reliable and functional adjusting system have to be used to properly set the relative position of the half-stations
  ➢ An enough precise positioning of the detectors is need as input for the particles track-based alignment software to improve the software efficiency. A precise, reliable and functional adjusting system have to be used to properly set the absolute position of the stations
A straight forward solution, for the fixing of a rigid body, for which the position have also to be adjusted in the space, usually by an individual movement of the supports, is to arrange an isostatic constraint configuration (with the constraints arranged in a proper configuration).

A straight forward solution, for the fixing of a rigid body on fixed supports (like rails) along which the rigid body have to be moved, is to arrange an isostatic constraint configuration (with the constraints arranged in a proper configuration).

**THE SCIFI TRACKER DETECTOR**

*SciFi global supporting structure – Kinematic*

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- A straight forward solution, for the fixing of a rigid body on fixed supports (like rails) along which the rigid body have to be moved, is to arrange an isostatic constraint configuration (with the constraints arranged in a proper configuration).
- To recreate the proper kinematic on the real structure, dedicated systems have been studied and produced.
- The $U_x$ DoF has been blocked with a device, located on the bottom part, that allow a controlled movement.

**GLOBAL STRUCTURE KINEMATIC**

**TOP CARRIAGE**

4 DoF: $U_x, R_x, R_y, R_z$
2 CONSTRAINS: $U_y, U_z$

4 DoF: $U_x, R_x, R_y, R_z$
2 CONSTRAINS: $U_y, U_z$

"VIRTUAL" SPHERICAL POINT OF ROTATION
To recreate the proper kinematic on the real structure, dedicated systems have been studied and produced.

The $U_x$ DoF has been blocked with a device, located on the bottom part, that allow a controlled movement.
The assembling of Modules with ROB and the detector stations is carried out directly at CERN (Point 8).

A dedicated building and a “grey” room has been built for the assembly operation.
In the Grey room, the modules are equipped with the Cold Box and several functional tests are performed.

The cosmic bench is mainly used to perform tests, electrical checks of the SiPMs and channels, check the calibration of the light injection system and a complete functional investigation of the full system (module+Cold Box) using cosmic ray.
In the assembly hall, the global structure is assembled and surveyed and successively equipped with services (cooling, dry gas and electrical) and the modules are installed and connected to the services.
A survey of the first SciFi station equipped with the Modules have been carried out

Photogrammetry has been used to estimate the Modules planarity

The precision of the measurement technique is around 80 µm

The standard deviation from the best fit plane is 342 µm (excellent precision for a such large area)

The data tracking software is able to divide the global plane in sub-planes

The maximum standard deviation obtained for sub-planes is 96 µm
CONCLUSIONS AND ADDITIONAL CONSIDERATIONS

- The overall LHCb upgrade planning for LS2 has been presented.

- The upgrade activities (mainly the dismantling of the existent detectors and cables/pipes upgrade) are on schedule.

- A new tracking system is needed to meet the requirements for RUN 3 and 4.

- The LHCb SciFi tracker, part of the upgraded LHCb tracking system, will be the largest scintillating fibre tracker ever built, using 11,000 km of fibres.

- An overview of the design, construction and assembly of the SciFi detector and its main components have been presented.

- The creation of the active components (the Modules) was a delicate operation and required quality controls during each phase.

- The global supporting structure has been study accurately to provide a stable and stiff support for the Modules.

- The assembly of the 12 stations is a long process requiring large effort from all the institutes involved.

- The construction of the detector is in an advanced state. Installation of the first 6 detector frames will start end 2019. The construction of all 12 C-Frames will be finalised by spring 2020.
THANK YOU FOR YOUR ATTENTION
BACK-UP SLIDES
- Dedicated weakly video, with the LHCb LS2 activities, can be found at the LHCb collaboration website:
  