Fibre trackers for the CERN Neutrino Platform
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1. Introduction

The proposed instrumentation is based on scintillating fibres (SciFi) readout with Silicon PhotoMultipliers (SiPM). Several high-energy physics experiments are using or have used SciFi trackers, ex: ATLAS ALFA and LHCb SciFi Tracker.

The new monitors for the Neutrino Platform, also called XBPF and XSCINT, are based on the design of a previous prototype successfully tested at CERN:


![Different profiles measured in the north area with the Scintillating fibres, the Delay wire chamber and the FISC monitors.](image-url)
The desired characteristics of a beam monitor for the CERN experimental areas are close to those of a “tracker” detector:

- Low material budget $x/X_0$
- Precise spatial and time information
- Good rate capability
- Radiation hardness

Get precise information of the passage of the particle whilst minimising any perturbation.

Scintillating fibres (SciFi) cover these requirements

- Sufficient light production: ~8000 photons/MeV deposited, from which between 5-10% is trapped by the fibre
- Very fast rise and decay times: ~1-2 ns
- Wavelength emission peak: ~420 nm (visible blue) matches PMT
- Low light self-absorption: between 3-4 m
- Long radiation length: low scattering and momentum degradation
- Moderate radiation damage: from tens of kGy accumulated doses
- Large detection areas for an affordable cost
- Relatively easy handling, assembly and maintenance
Study of the beam perturbation: radiation length

Multiple scattering depends on the radiation length of the material \((X_0)\)

\[
\theta_0 = \frac{13.6 \text{MeV}}{\beta c p} Z \sqrt{\frac{x}{X_0}}
\]

Where \(\theta_0\) is the RMS of the scattering angle distribution, \(x\) is the thickness of the material, \(p\) the particle momentum, \(\beta c\) its speed and \(Z\) its charge.

We can calculate \(X_0\) for the current BI detectors and compare them:

<table>
<thead>
<tr>
<th>Detector</th>
<th>(x/X_0) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWPC</td>
<td>0.34</td>
</tr>
<tr>
<td>DWC</td>
<td>0.25</td>
</tr>
<tr>
<td>SciFi 1 mm</td>
<td>0.47</td>
</tr>
<tr>
<td>SciFi 0.5 mm</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Theoretically a SciFi monitor could be as good as the Delay Wire Chambers in terms of beam scattering. A great advantage of the SciFi is that they can work in vacuum.
3. Silicon photomultipliers

The best existing solutions to read multiple scintillating fibres are:

- Silicon photomultipliers (SiPM or MPPC)
- Multi-Anode photomultipliers (MA-PMT)

SiPM were favoured for many reasons

**Silicon photomultipliers**: matrix of avalanche photodiodes connected in parallel

**Advantages:**
- High gain: $10^6$
- High detection efficiency: <40% at 450 nm
- Fast rise time: <1ns
- Low jitter → timing applications
- Compact size
- Low voltage
- Potentially low cost
-Insensitive to magnetic fields
- New technology: further development foreseen

**Drawbacks:**
- High dark count rate at room temperature: 100kHz/mm$^2$
- Need cooling for some applications
4. Readout ASIC

CITIROC: an analogue front-end ASIC made by Omega Microelectronics (CNRS-IN2P3-Ecole Polytechnique)

- 32 channels with adjustable SiPM voltage
- Adjustable preamplifiers
- Variable slow shapers, track & hold and peak detector for charge measurement
- Variable fast shaper and discriminators for trigger
- Digital output of the trigger signals
5. First prototype

A first prototype was successfully tested in the H8 beam line of the North Area at CERN:

- Only one plane of 64 square fibres of 1mm thickness with no space between them → covered 64mm of the vertical profile.
- Fibres Saint-Gobain BCF12, 1mm square, multi-cladding. No treatment to avoid cross-talk.
- Used aluminium mirror on one end to increase light collection.
- Read 1 every 2 fibres for simplicity on electronics acquisition → spatial resolution of 2mm.
- Hamamatsu MPPC S13360-1350 as photo detector.
- Used CITIROC evaluation board for electronics readout: 32 channels.
- VME scaler modules for the data acquisition → only profile and intensity measurements.
- Integrated in the vacuum tank of the FISC → fibres in vacuum, MPPC in air.

It monitored different Z=1 beams (electrons, pions, protons…) with momentums from 20 GeV/c to 180 GeV/c and intensities from $10^3$ to $10^6$ particles/spill. It also monitored Pb(82,208) ions.
The array of fibres hanging upside-down for glue drying

Polishing the fibres on the mirror end

Gluing of the fibres

Fibre connector after polishing.
SiPM board with the 32 Hamamatsu MPPC. It is precisely aligned to the fibre connector

The MPPC board plugged onto the CITIROC board
The SciFi monitor installed in H8: the vacuum tank in the centre houses the fibres, while the SiPM and the electronics stay on the outside (left of the figure).
Fibres

DWC

FISC

Fibres intensity

Scintillators intensity

Fibres intensity

DWC

FISC
Profile analysis of 180 GeV/c proton/pion beams

SciFi

Intensity = $3.4 \times 10^4$ particles/second

DWC

Intensity = $8.2 \times 10^4$ particles/second

FISC

Intensity = $6.5 \times 10^5$ particles/second
The SciFi performed better than the other monitors in all intensities.
6. XBPF: particle position and time

The fibre plane is the basic unit

SiPM board:
- Every fibre coupled to a SiPM.
- Hamamatsu MPPC S13360-1350 or the new arrays S13360-2050VE.

Scintillating fibres:
1 layer of 192 fibres,
1mm thickness, square.
Aluminium coating.
192mm x 240mm active area

We have established a collaboration with CERN PH-DT for the assembly of the detectors: they have a large experience with SciFi trackers
7. XSCINT: trigger detector

Same basic unit as the XBPF, but all the fibres go to an individual PMT: Hamamatsu H11934.

- 530 mm² active area
- High quantum efficiency
- High gain
- Fast response
Beam line integration:
8. Electronics

XBPF:
- Front end board: CITIROC ASIC, FPGA, Gigabit optical transceiver
- Back end: VFC -> standard VME board widely used by CERN BE-BI

XSCINT:
- NIM discriminators, Programmable delay module with coincidence

The data will be delivered at the end of the spill in a FESA class, as usually done in the experimental areas.
9. Schedule

MILESTONES:
September 2017:
   1. Validation of prototype in the lab.
   2. Dry-run to test the acquisition chain and the data transfer to the FESA class.

October/November 2017:
   3. Beam tests of the full prototype + electronics in the East Area at CERN. Launch the production after validation of prototype.

February/March 2018:
   4. Assembly of the series.

April 2018:
   5. Commissioning.
Thanks for listening

Questions?
Spare slides
The monitor could perform several functions:
- profile measurement
- magnetic spectrometer
- trigger for the experiments
- time-of-flight
EHN1 Extension - H2 VLE Beam
Schematic Layout

- **BENDs**: MBPL, gap 140mm
- **QUADs**: QPL + QPS
  - Large aperture (200 mm)

**Incoming beam**: 80 GeV/c; high intensity ($\sim 10^6$-$10^7$ pps)

**Attenuated incoming beam**

**Low energy beam**: (0.4 – 12 GeV/c)

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I. Efthymiopoulos, 2016
Time-of-Flight

Due to the nature of a secondary beam, it will have mixture of different particles. One of the requisites of the new instrumentation is to provide particle identification.

![Graph](image-url)
Two methods for particle identification:

- Cherenkov counters: useful for momenta above 4 GeV/c
- Time-of-Flight: for lower momenta
Time-of-flight principle

\[ \Delta t = t_2 - t_1 = \frac{L}{pc^2} \left( \sqrt{m_2^2c^4 + p^2c^2} - \sqrt{m_1^2c^4 + p^2c^2} \right) \]

The time resolution of your system fixes the particle identification.
\[ t_{k\text{th } pe} = \Delta t \]

Conversion depth

\[ + t_{k' \text{ ph}} + t_{\text{transit}} + t_{\text{SPTTR}} + t_{\text{TDC}} \]

Scintillation process
Transit time jitter
Single photon time spread
TDC conversion time

Random deletion 1
Absorption
Self-absorption

Random deletion 2
SiPM PDE

Unwanted pulses
DCR, cross talk
Afterpulses

Electronic noise
Our idea is to use the STiC as readout electronics of the SiPM.

We believe that sub-ns time resolution can be achieved with a combination of:
- 1mm fibres (high photon yield)
- Hamamatsu 13360 (low jitter)
- STiC: specialized ToF ASIC

Other experiments like Mu3e have already achieved similar resolutions.
Alternative readout ASIC

We investigated several commercial ASIC availables.

**NINO**: An ultrafast and low-power front-end amplifier and discriminator ASIC. Developed ALICE ToF system.
- 8 channel differential input/output
- Fast amplifier with less than 1 ns peaking time
- Charge measurement by Time-Over-Threshold

**STiC**: Readout ASIC for SiPM designed to provide very high timing resolution for time-of-flight.
- 64 channels differential/single-ended with adjustable SiPM voltage
- Two thresholds: energy & timing
- TDC timing resolution 20ps
- Serial link 160Mbit/s LVDS