A multipurpose scintillating fibre beam monitor for the measurement of secondary beams at CERN

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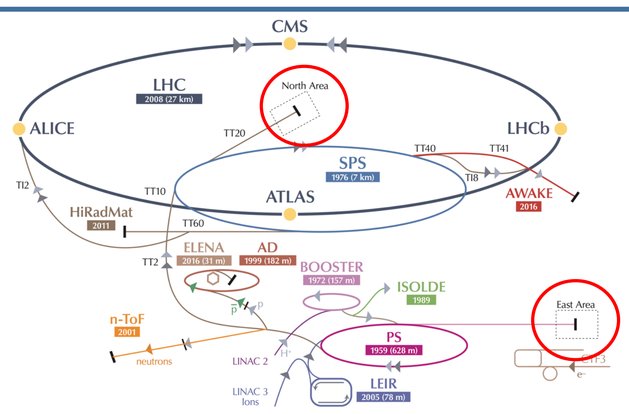
Abstract

A scintillating fibre beam monitor has been developed at CERN for the measurement of low energy and low intensity secondary beams. This monitor can track the passage of individual particles up to intensities of 10^7 particles per second per mm^2, over an active area of ~ 20cm × 20cm, and with a spatial resolution of 1mm. Thanks to an external trigger system, the achieved detection efficiency is ~ 95% and the noise level is kept below 10^{-4} events/second. The simple design of this monitor avoids the common production difficulties of scintillating fibre detectors and makes its maintenance easier, when compared to other tracking detectors, due to the absence of gas or cooling. Using special electronics, a version of the monitor can also be used for time-of-flight measurements, achieving a time resolution of 900ps. Thanks to its versatility, the monitor will perform several functions when measuring the secondary beams of the CERN Neutrino Platform: beam profile measurement, magnetic momentum spectrometry, particle identification through time-of-flight, and trigger generation for the experiments.

Motivation

- Need to replace existing monitors: multi-wire proportional chambers and delay wire chambers.
- New beamlines (Neutrino Platform) with special requirements:
  - Low energies: 1 GeV/c to 12 GeV/c.
  - Low intensities: 100 particles/second.
  - Large active area: ~20 cm × 20 cm.
  - Individual particle tracking, Time-of-Flight.



The experimental areas at CERN

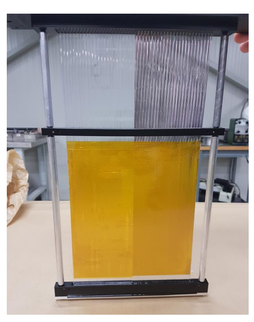
Scintillating fibres

Have emerged as one of the best active materials for a profile monitor:

- Low material budget: x/X_0.
- Good spatial and time resolution.
- Moderate radiation hard.
- Suitable for primary vacuum.
- Large active area.

XBPF (eXperimental Beam Profile Fibre monitor)

- Measures passage of individual particles.
- 192 scintillating fibre Kuraray SCSF-78 of 1mm thickness and square shape.
- Light from every fibre read-out by one Silicon Photomultiplier (SiPM).
- Aluminium mirror glued on one end to increase light collection at SiPM.
- Modular design and vacuum compatible: fibres in vacuum, SiPM in air.

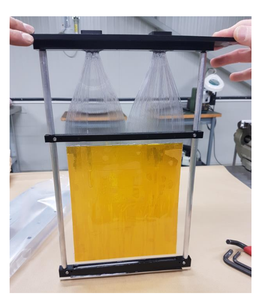


XBPF

XBTF (eXperimental Beam Profile Trigger monitor)

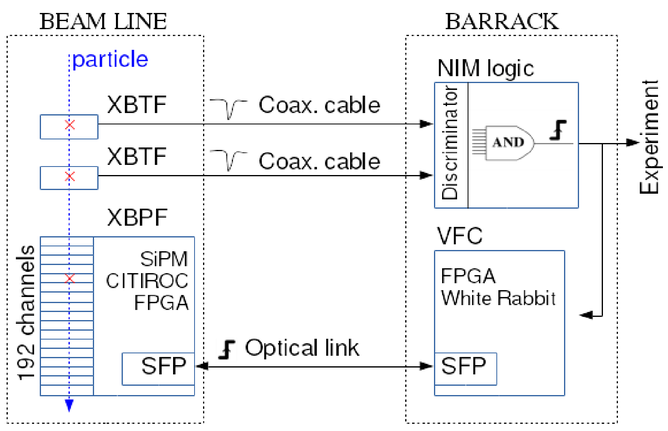
Similar to XBPF, but used as a trigger:

- Fibres grouped together into two bundles.
- Light read-out by PMT H11934-200 from Hamamatsu.
- Suitable for time-of-flight measurements.



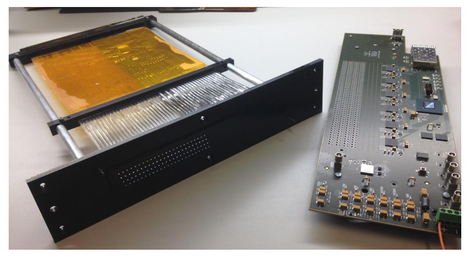
XBTF

Electronics architecture



Front-end

- 192 SiPM S13360-1350 from Hamamatsu.
- Hamamatsu C11204 SiPM power suppy with temperature feedback system.
- 6 CITIROC ASIC: convert SiPM signals to digital in parallel.
- Xilinx FPGA Artix 7: configures CITIROC, reads digital output from CITIROC, packages data and sends it out in 10MHz data stream to Gbit transceiver.
- SFP module with Gbit transceiver to transfer the data via optical link to back-end.



XBPF with its front-end

Back-end

VFC: VME acquisition board developed by CERN BI.

- Decodes data stream coming from front-end.
- Sends control data to front-end.
- Creates and stores the event structure.
- Compatible with White Rabbit.

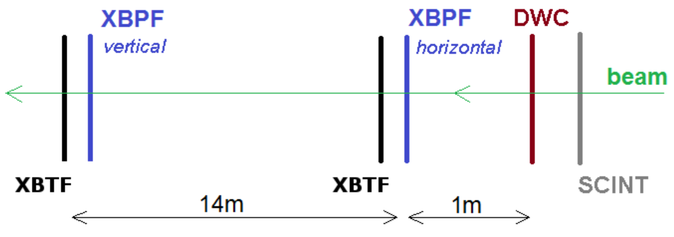
Time-of-flight

Use special electronics in parallel with XBTF acquisition:

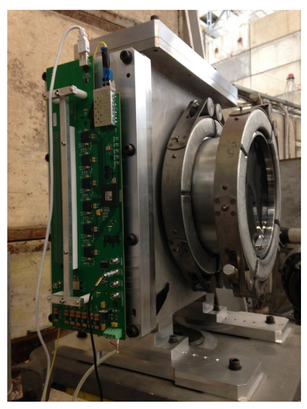
- Constant fraction discriminator to reduce time walk.
- FMC-TDC, a Time-to-digital converter with 81ps time resolution and White Rabbit compatible.

Beam tests and cosmic ray telescope

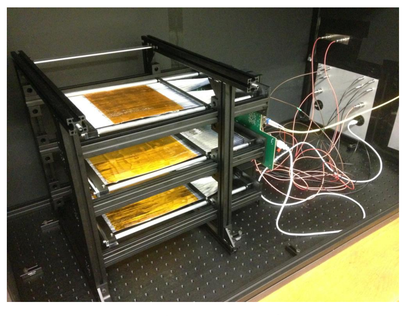
- Two XBPF and two XBTF tested during two weeks in the East Area at CERN with hadron beams of 1 GeV/c to 6 GeV/c and 10^3 to 10^5 particles per second.
- Also tested as a cosmic ray telescope in the laboratory.



Schematic of the beam test layout



XBPF in the East Area

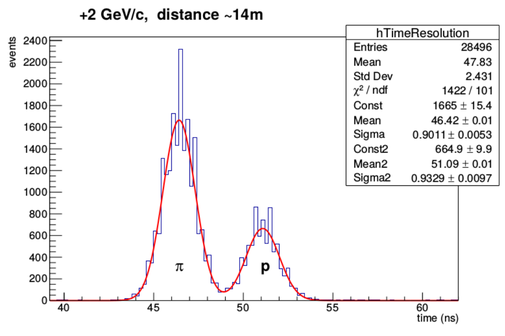


XBPF cosmic ray telescope

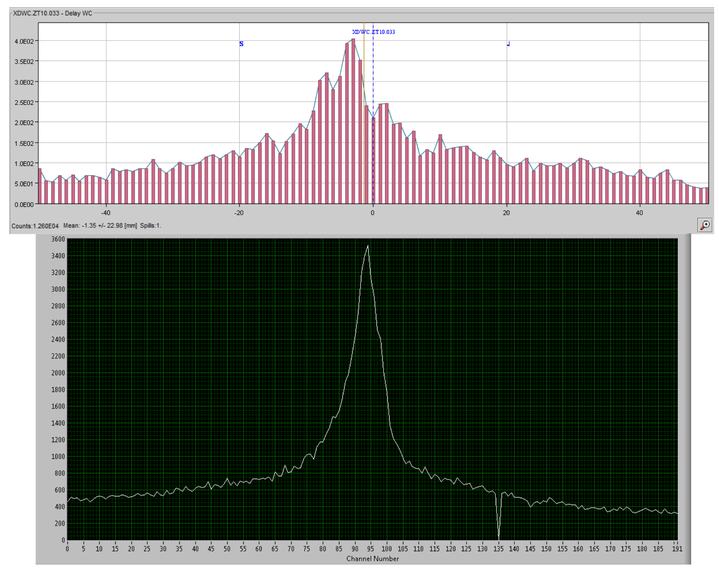
Results

Excellent performance:

- More accurate profiles than present monitors.
- 94% - 95% detection efficiency.
- Time resolution of time-of-flight system: 900ps.



Time-of-flight of a 2 GeV/c pion/proton beam over 14m



Profile of a 6 GeV/c beam of I=1.5·10^5 particles measure by a delay wire chamber (above) and a XBPF (below)

Conclusions

- The XBPF has been successfully tested.
- It can perform better than the current monitors in all beam conditions and add extra functionalities, such as: intensity measurements, individual particle tracking and measurement of the time-of-flight.

Outlook

- Ongoing commissioning of 10 XBPF and 3 XBTF for the CERN Neutrino Platform. The preliminary analysis shows an excellent performance.
- Investigate triggering of the XBPF acquisition by putting two fibre planes in coincidence → avoids requiring the XBTF.
- Investigate discriminators for the time-of-flight with lower time walk.