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Fibre trackers for the CERN Neutrino Platform

Inaki Ortega on behalf of CERN BE–BI–EA

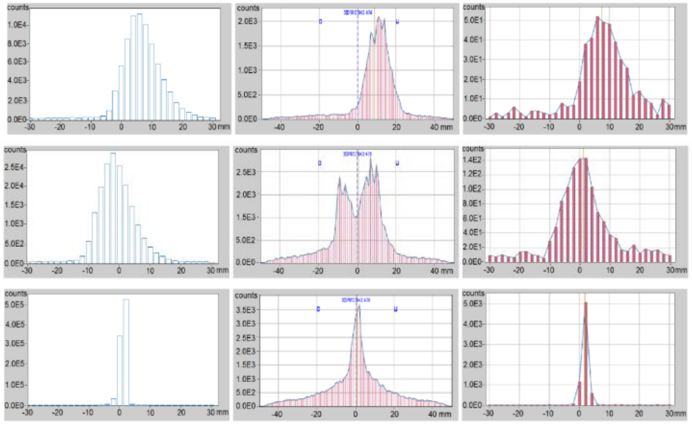
1. Introduction

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:

Ortega, I., et al. "A scintillating fibre beam profile monitor for the experimental areas of the SPS at CERN." Journal of Physics: Conference Series. Vol. 763. No. 1. IOP Publishing, 2016.

SciFi *DWC* *FISC*



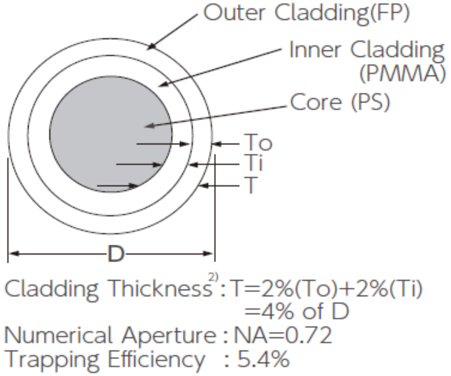
Different profiles measured in the north area with the Scintillating fibres, the Delay wire chamber and the FISC monitors.

2. Scintillating fibres

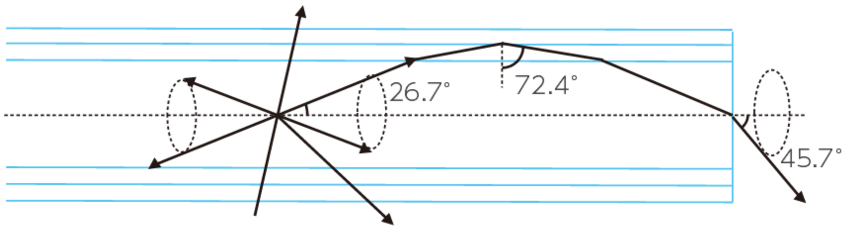
The desired characteristics of a beam monitor for the CERN experimental areas are close to those of a “tracker” detector:

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

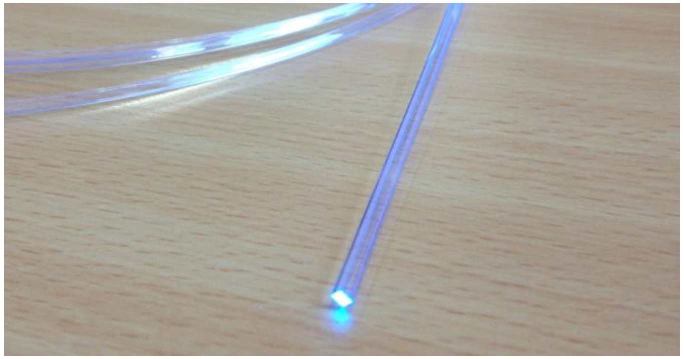
} Get precise information of the passage of the particle whilst minimising any perturbation.



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

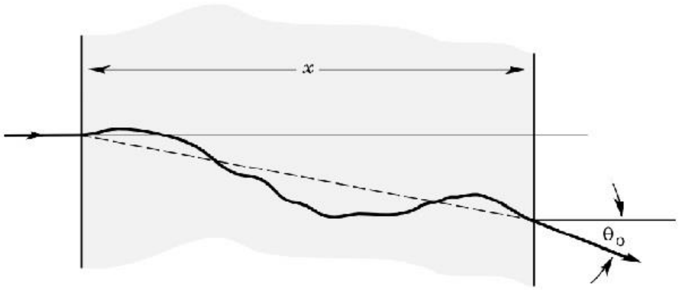


Study of the beam perturbation: radiation length

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

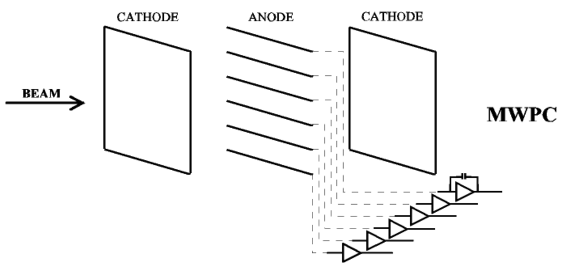
$$\theta_0 = \frac{13.6 MeV}{\beta c p} Z \sqrt{\frac{x}{X_0}}$$

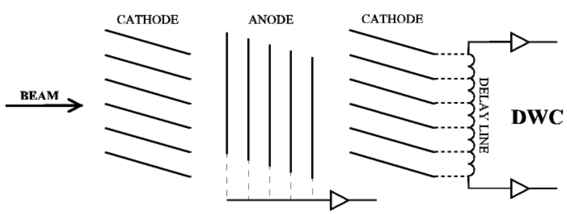
Where θ_0 is the RMS of the scattering angle distribution, x is the thickness of the material, p the particle momentum, βc its speed and Z its charge



We can calculate X_0 for the current BI detectors and compare them

Detector	x/X_0 (%)
MWPC	0.34
DWC	0.25
SciFi 1 mm	0.47
SciFi 0.5 mm	0.24





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.

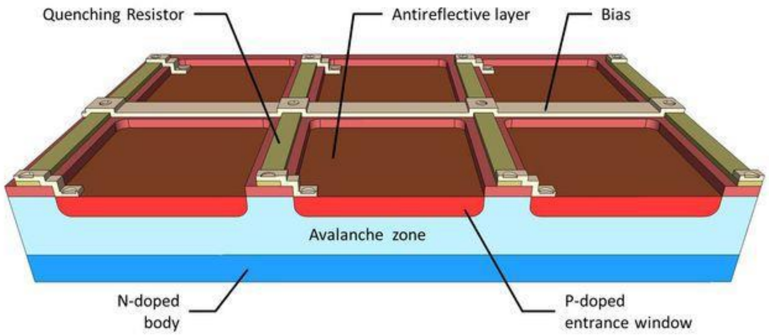
3. Silicon photomultipliers

The best existing solutions to read multiple scintillating fibres are:

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

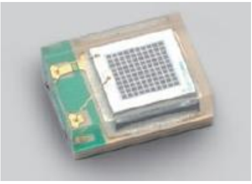
} SiPM were favoured for many reasons

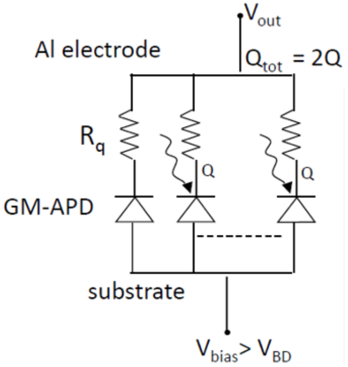
Silicon photomultipliers: matrix of avalanche photodiodes connected in parallel



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





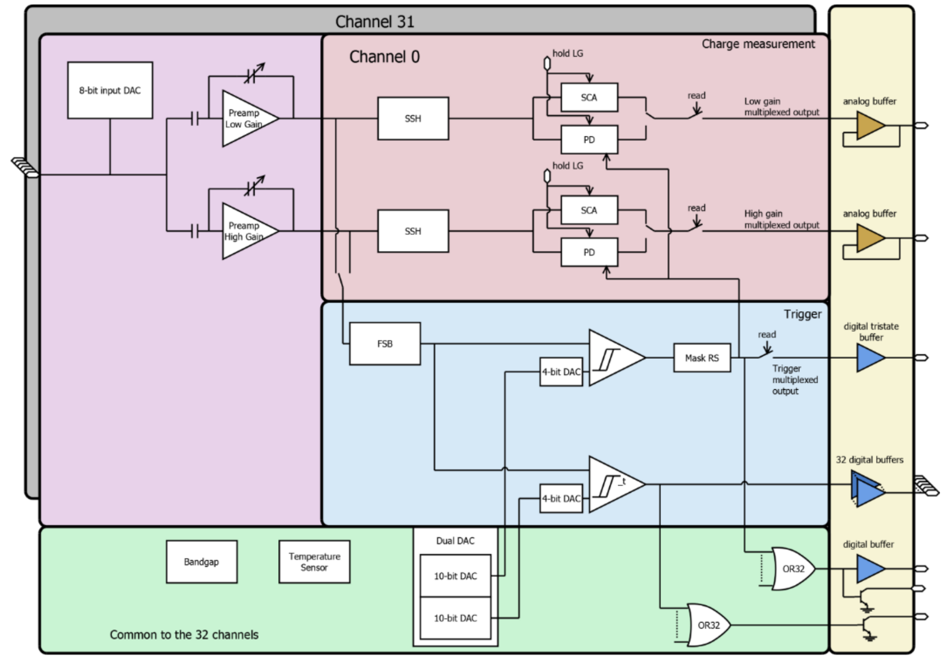
Drawbacks:

- 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

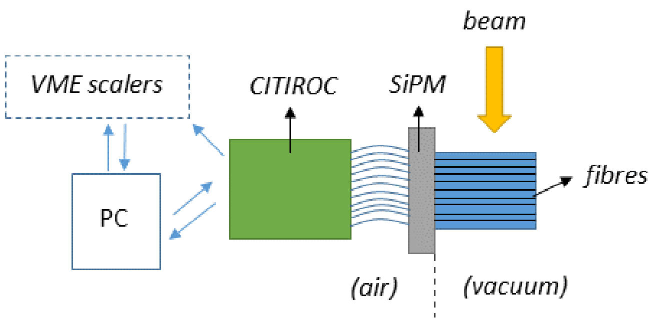


CITIROC's Block diagram

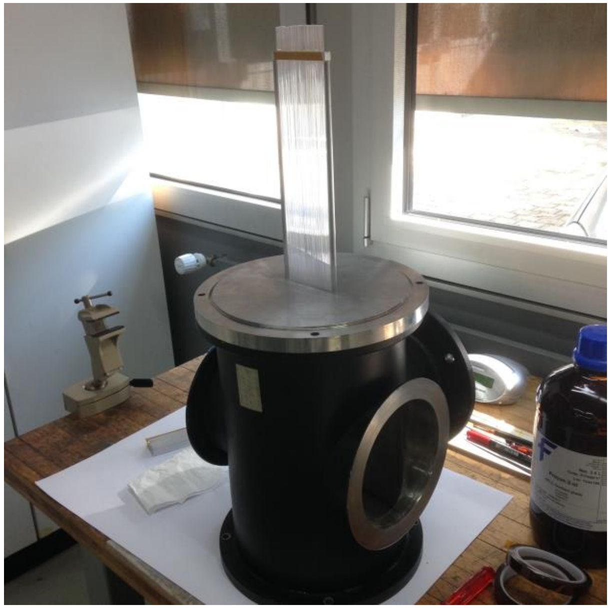
5. First prototype

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

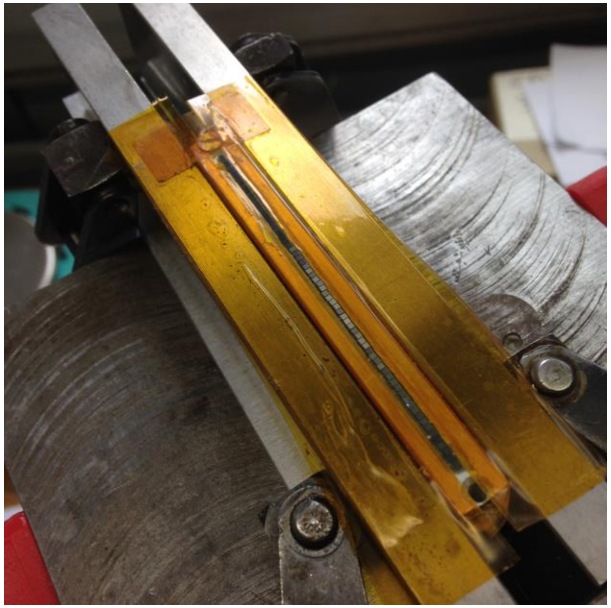
- Only one plane of 64 square fibres of 1mm thickness with no space between them → covered 64mm of the vertical profile.
- Fibres Saint-Gobain BCF12, 1mm square, multi-cladding. No treatment to avoid cross-talk.
- Used aluminium mirror on one end to increase light collection.
- Read 1 every 2 fibres 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.



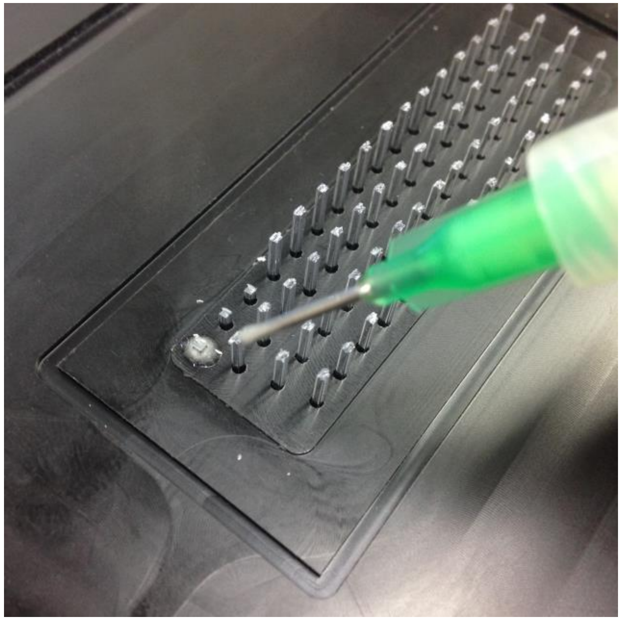
It monitored different Z=1 beams (electrons, pions, protons…) with momentums from 20 GeV/c to 180 GeV/c and intensities from 10^3 to 10^6 particles/spill. It also monitored Pb(82,208) ions.



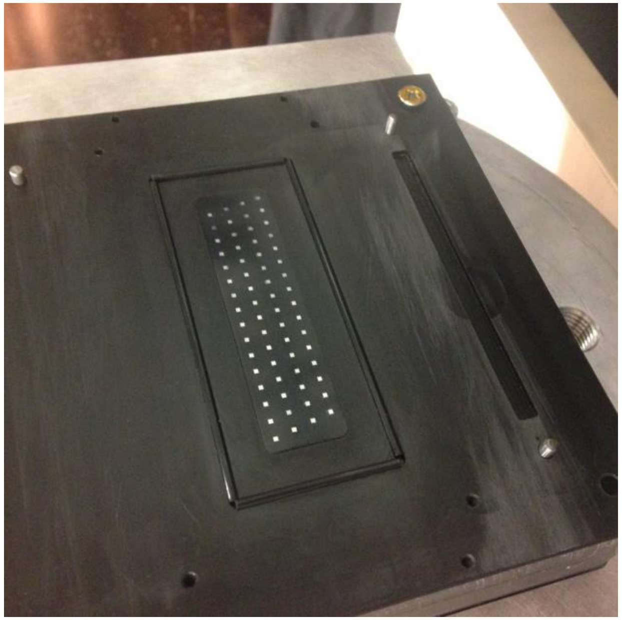
The array of fibres hanging upside-down for glue drying



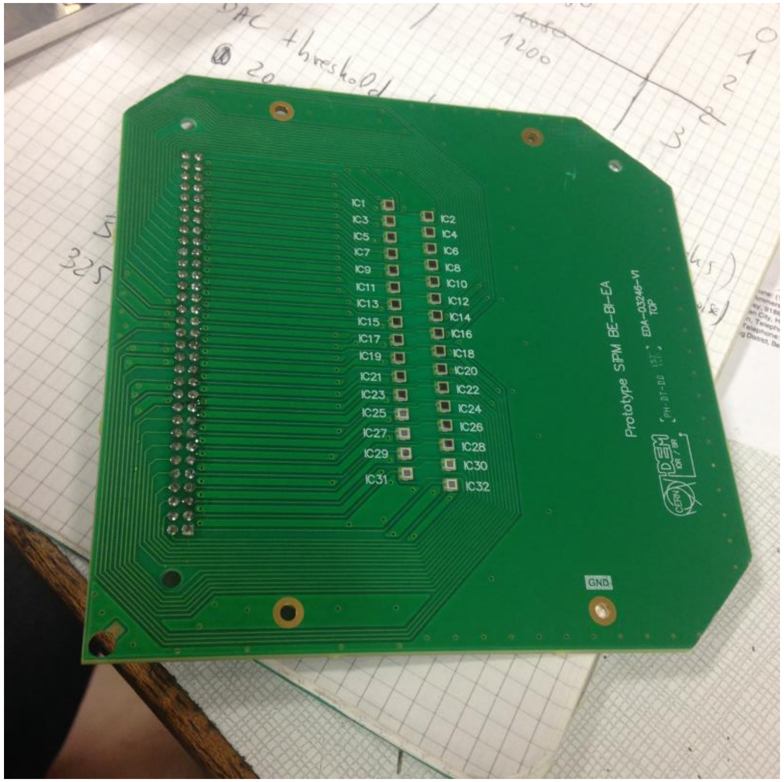
Polishing the fibres on the mirror end



Gluing of the fibres

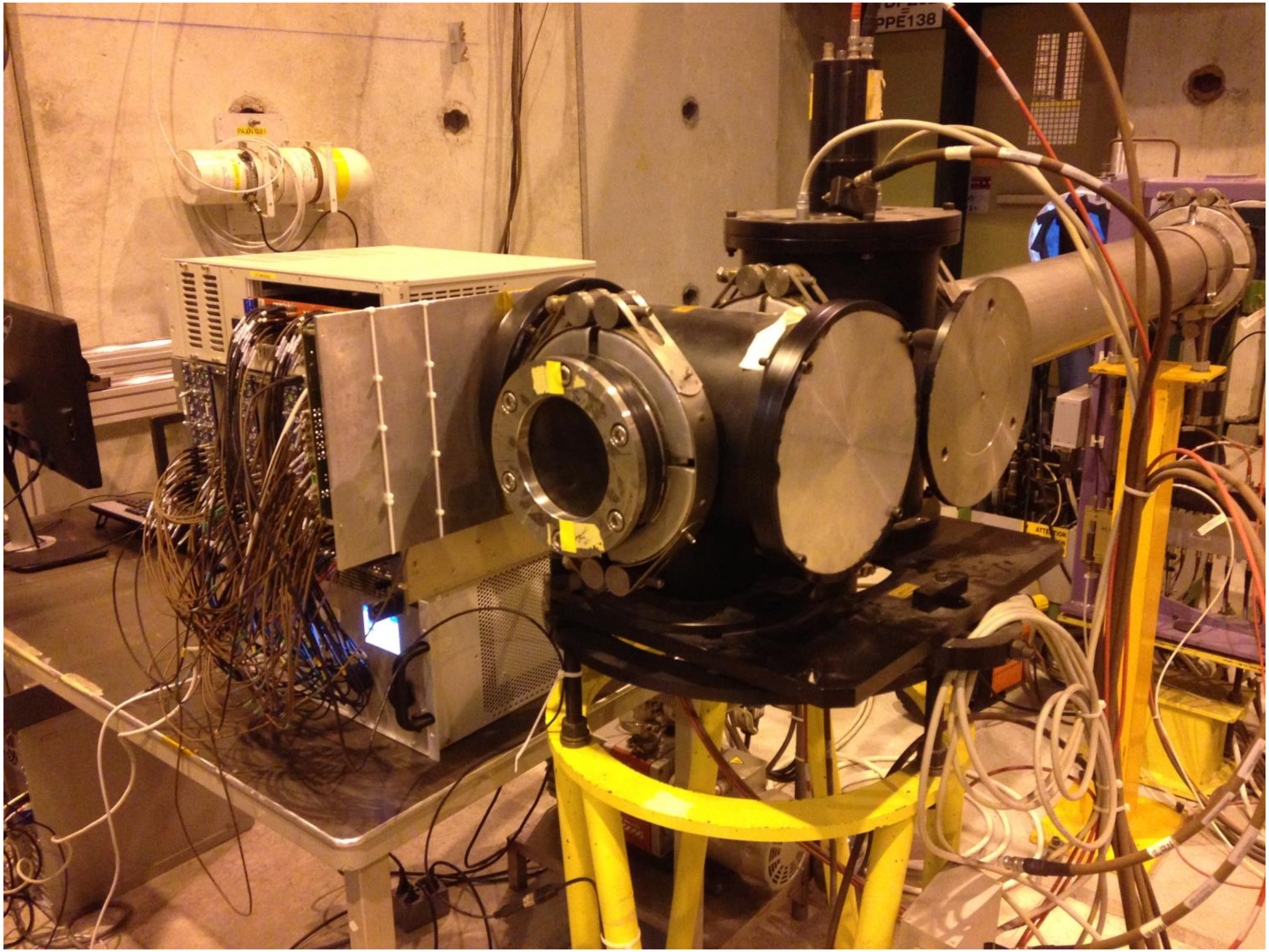


Fibre connector after polishing.

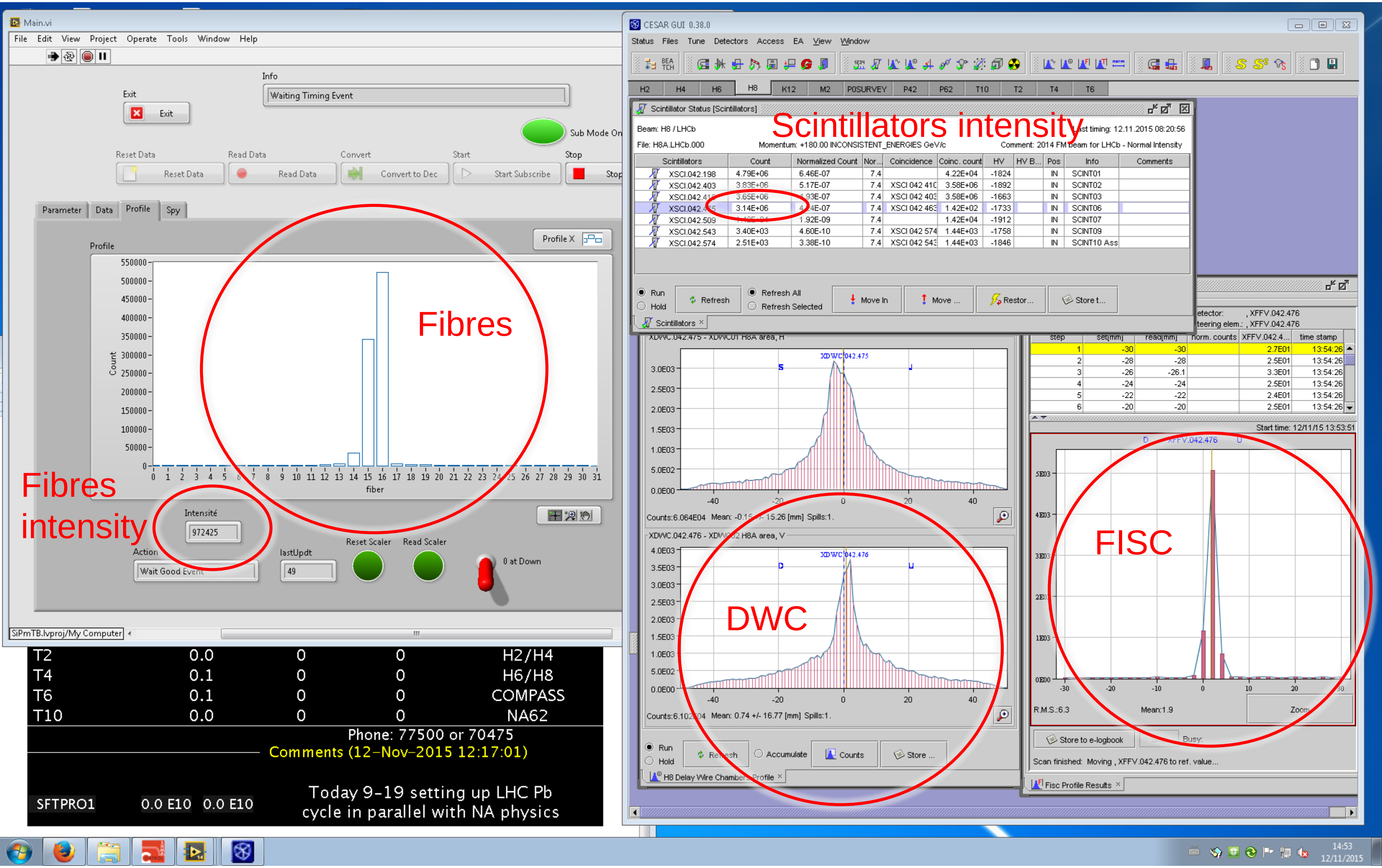


SiPM board with the 32 Hamamatsu MPPC.
It is precisely aligned to the fibre connector

The MPPC board plugged onto the CITIROC board



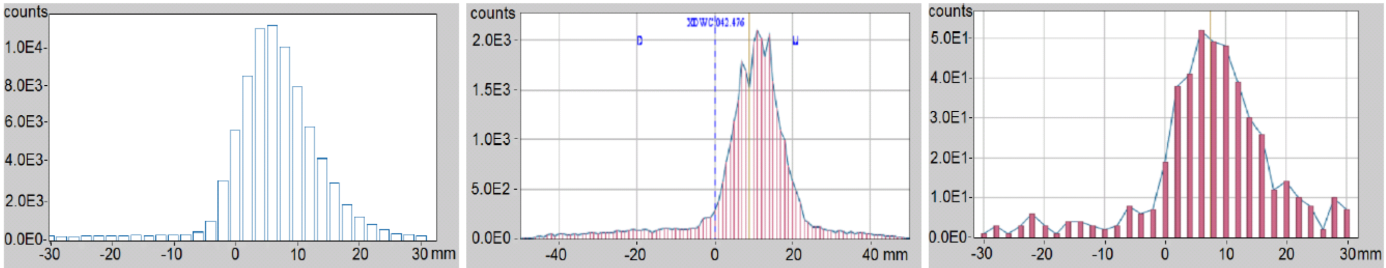
The SciFi monitor installed in H8: the vacuum tank in the centre houses the fibres, while the SiPM and the electronics stay on the outside (left of the figure).



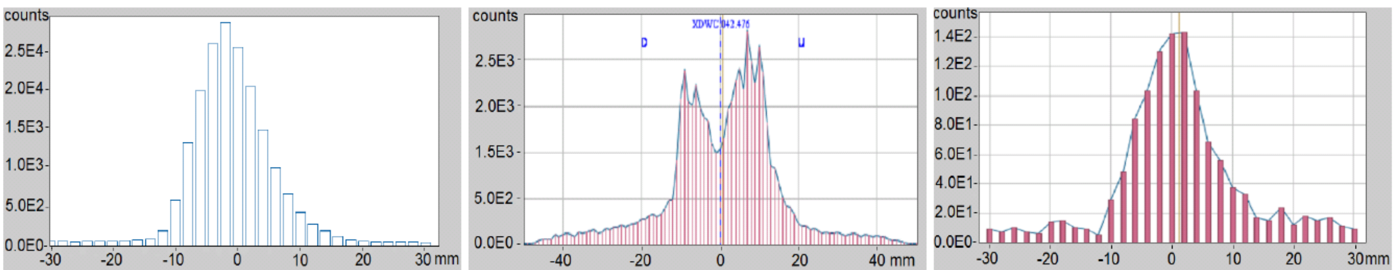
Scintillators intensity
Fibres
Fibres intensity
DWC
FISC
Main.vi
CESAR GUI 0.38.0
Scintillator Status [Scintillators]
Beam: H8 / LHCb
File: H8A.LHCb.000
Momentum: +180.00 INCONSISTENT_ENERGIES GeV/c
Comment: 2014 FM beam for LHCb - Normal Intensity
Info
Waiting Timing Event
Profile
Intensité
972425
Wait Good Event
lastUpdt
49
Reset Scaler
Read Scaler
T2 0.0 0 0 H2/H4
T4 0.1 0 0 H6/H8
T6 0.1 0 0 COMPASS
T10 0.0 0 0 NA62
Phone: 77500 or 70475
Comments (12-Nov-2015 12:17:01)
SFTPRO1 0.0 E10 0.0 E10
Today 9-19 setting up LHC Pb cycle in parallel with NA physics
H8 Delay Wire Chambers Profile
Fisc Profile Results

Profile analysis of 180 GeV/c proton/pion beams

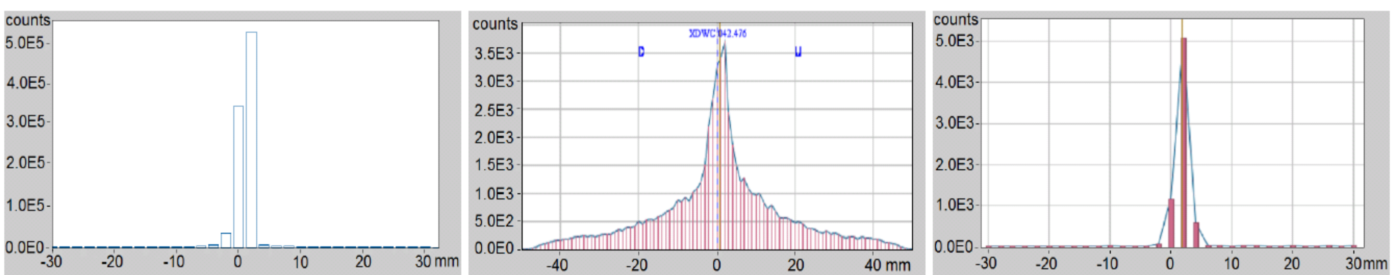
SciFi *DWC* *FISC*



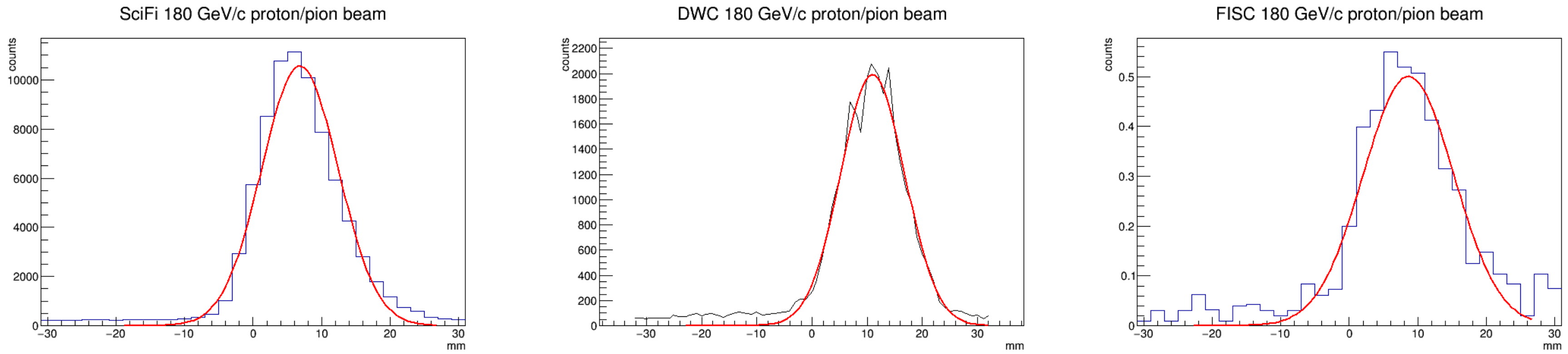
Intensity = 3.4×10⁴ particles/second



Intensity = 8.2×10⁴ particles/second



Intensity = 6.5×10⁵ particles/second

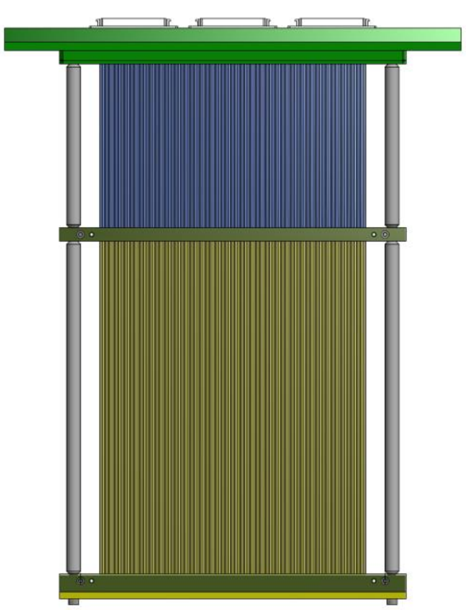


Intensity(particles/s)	σ(mm) **SciFi**	σ(mm) **DWC**	σ(mm) **FISC**
3.4×10^4	5.6	5.8	6.6
8.2×10^4	5.4	11.2	6.2
6.5×10^5	0.9	4.0	1.1

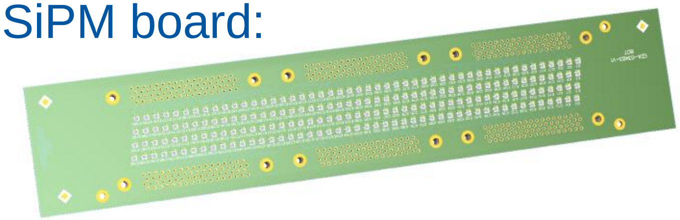
The SciFi performed better than the other monitors in all intensities.

6. XBPF: particle position and time

The fibre plane is the basic unit



SiPM board:

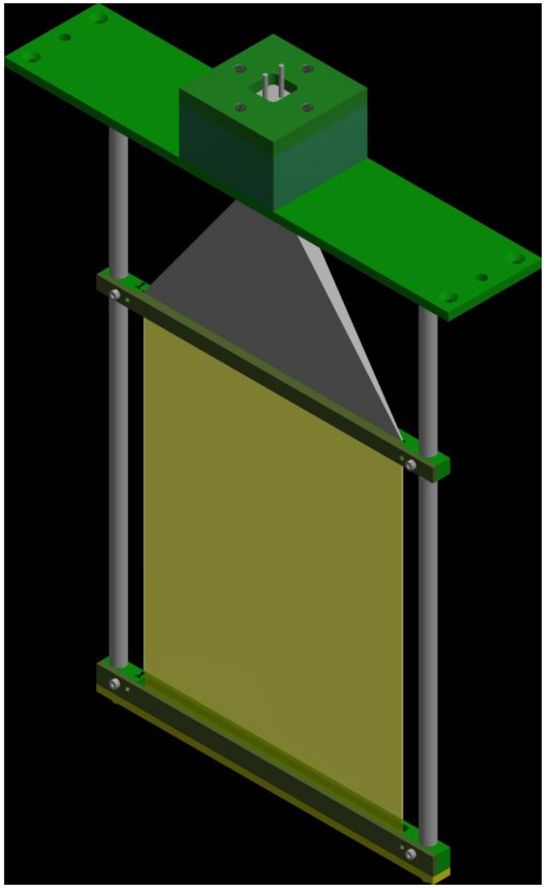


- Every fibre coupled to a SiPM.
- Hamamatsu MPPC S13360-1350 or the new arrays S13360-2050VE.

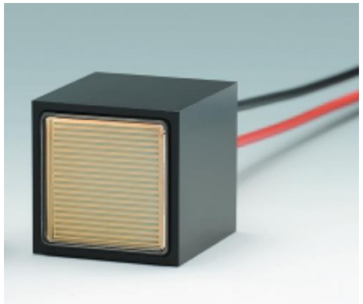
Scintillating fibres:
1 layer of 192 fibres,
1mm thickness, square.
Aluminium coating.
192mm x 240mm active area

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

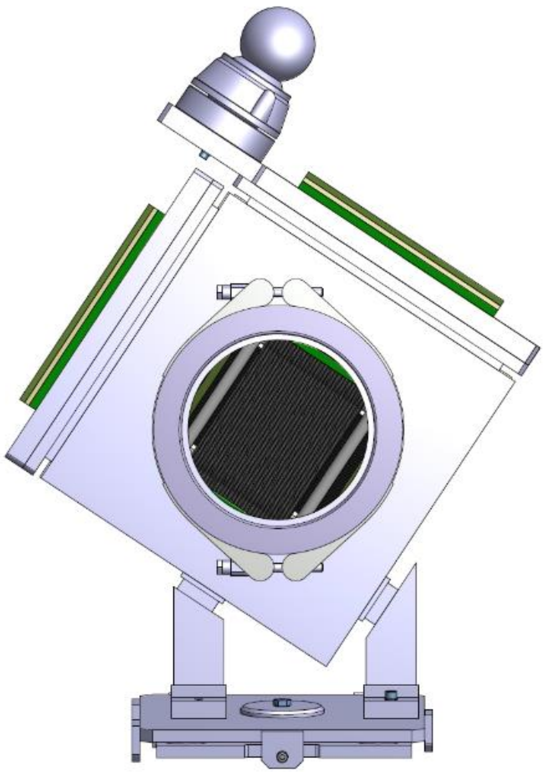


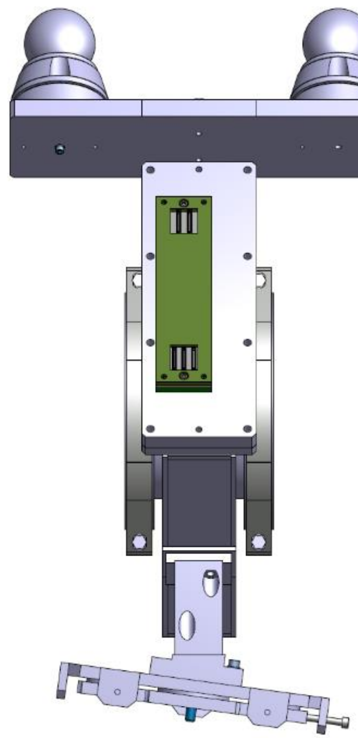
Same basic unit as the XBPF, but all the fibres go to an individual PMT: Hamamatsu H11934.

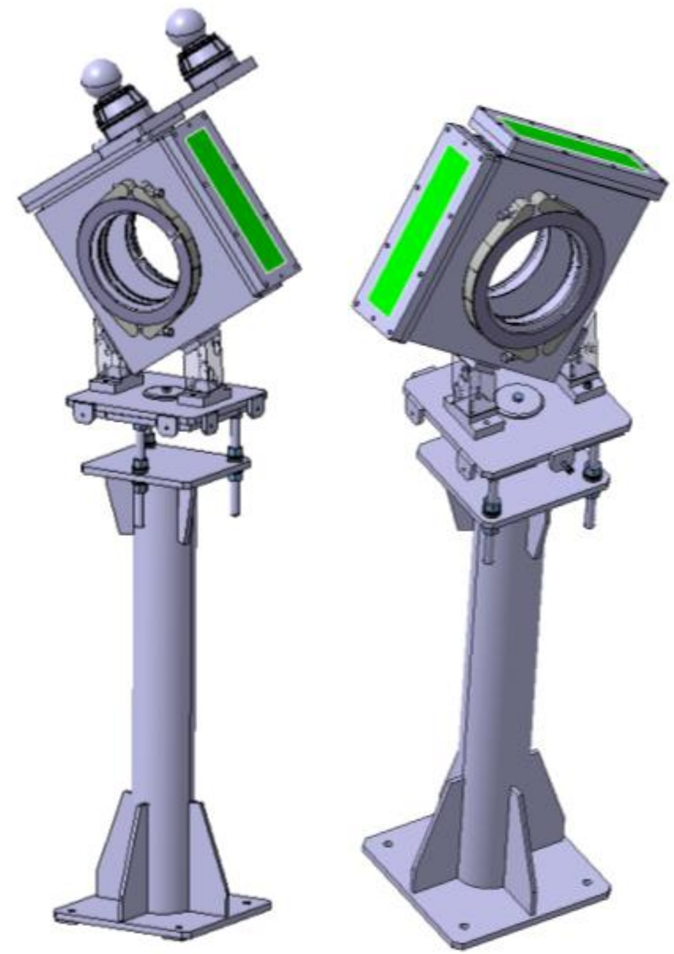


530 mm2 active area
High quantum efficiency
High gain
Fast response

Beam line integration:







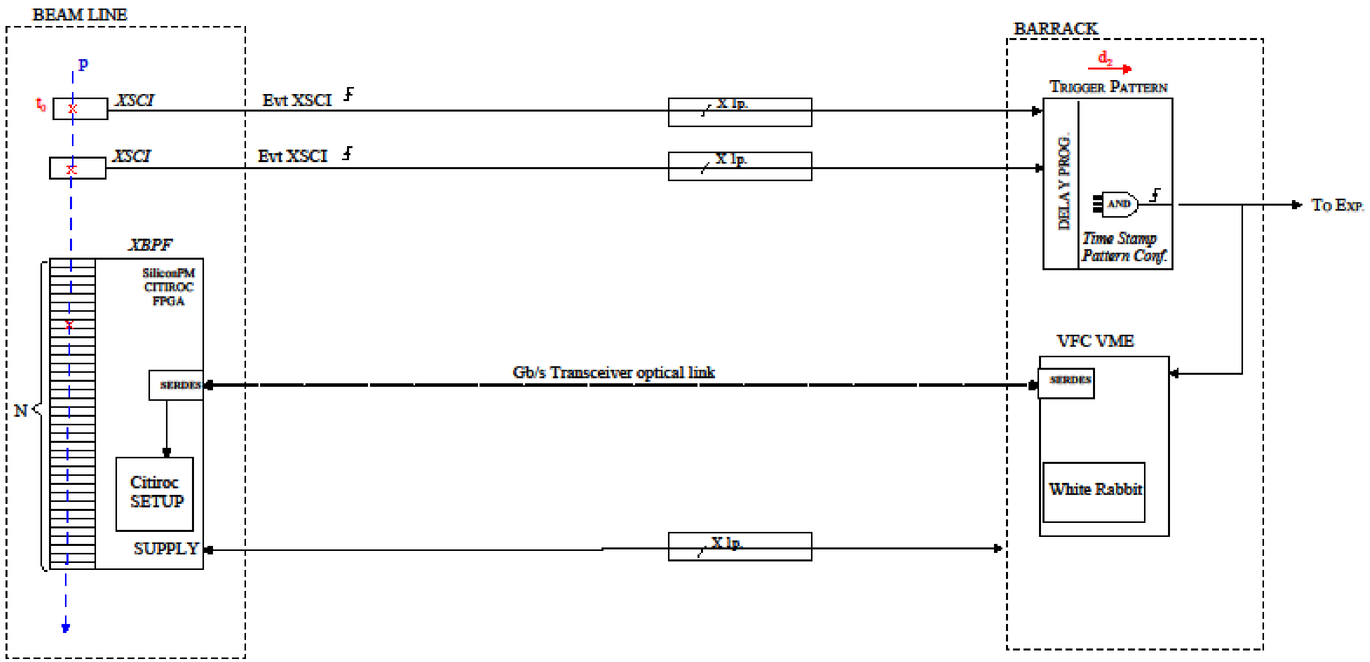
8. Electronics

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.

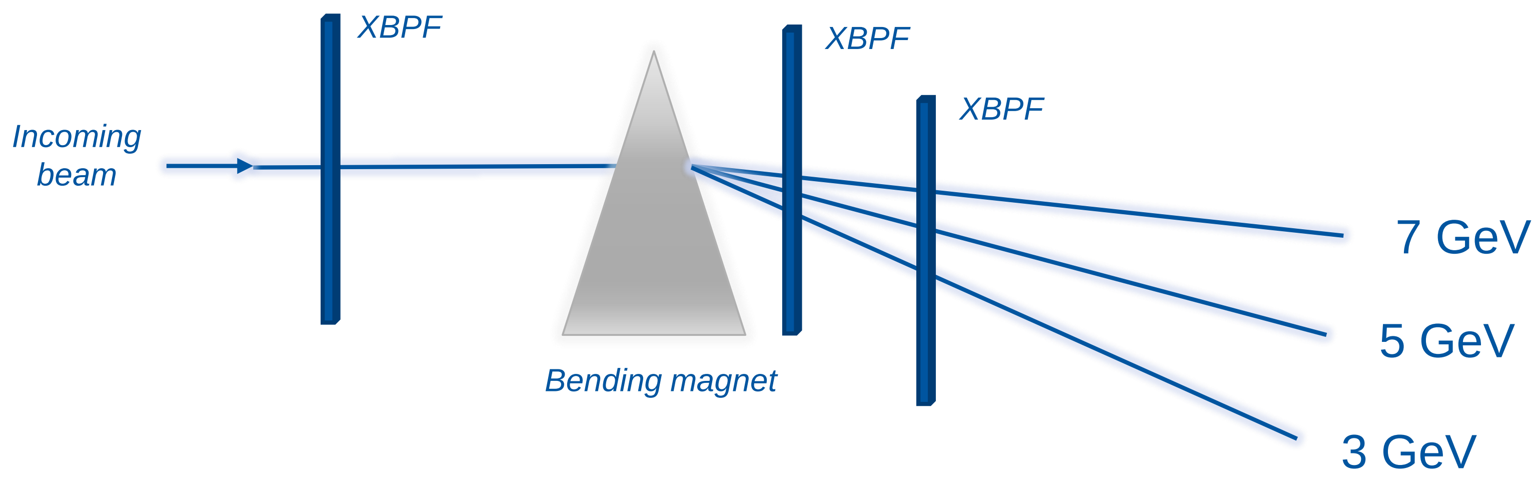
Thanks for listening

Questions?

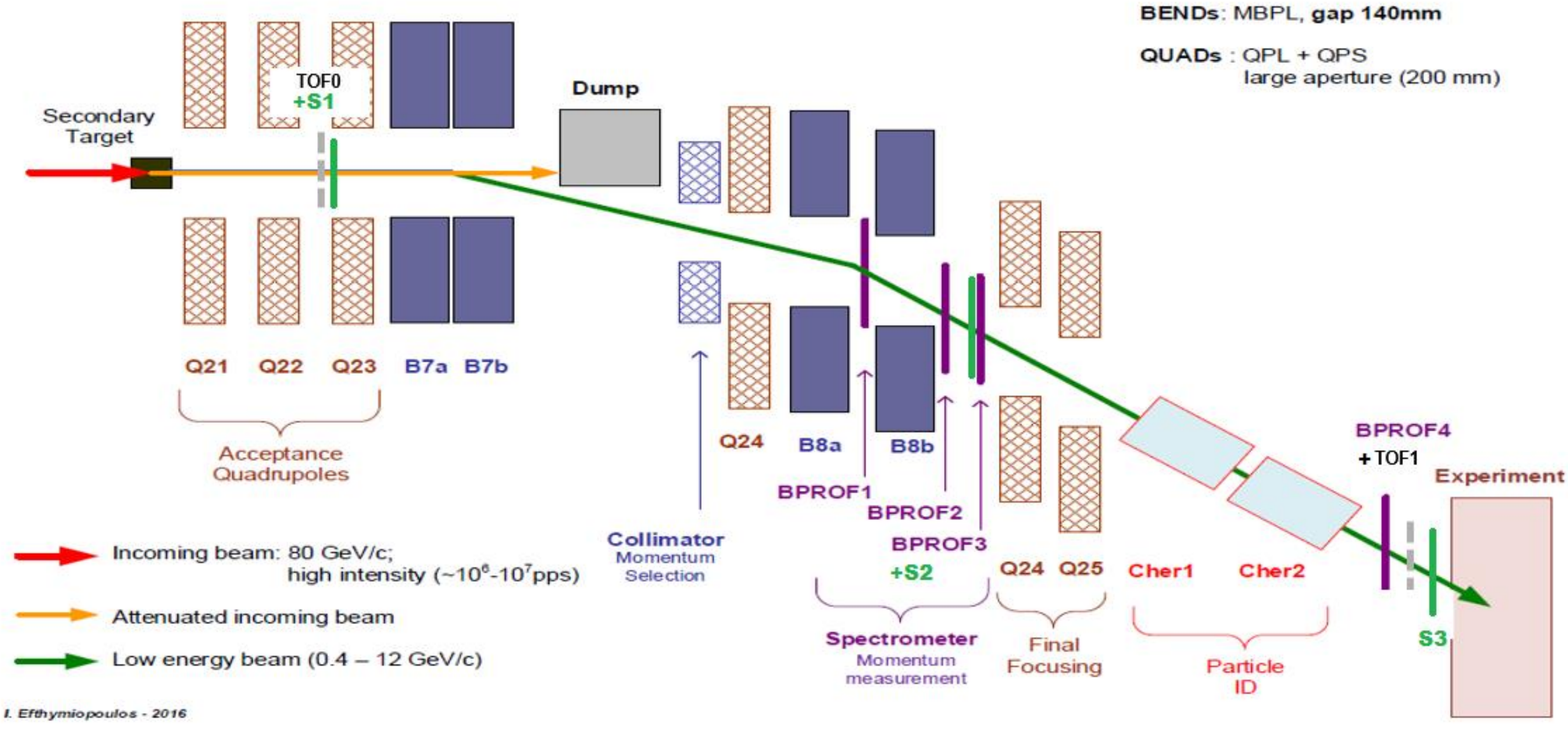
Spare slides

The monitor could perform several functions:

- profile measurement
- magnetic spectrometer
- trigger for the experiments
- time-of-flight

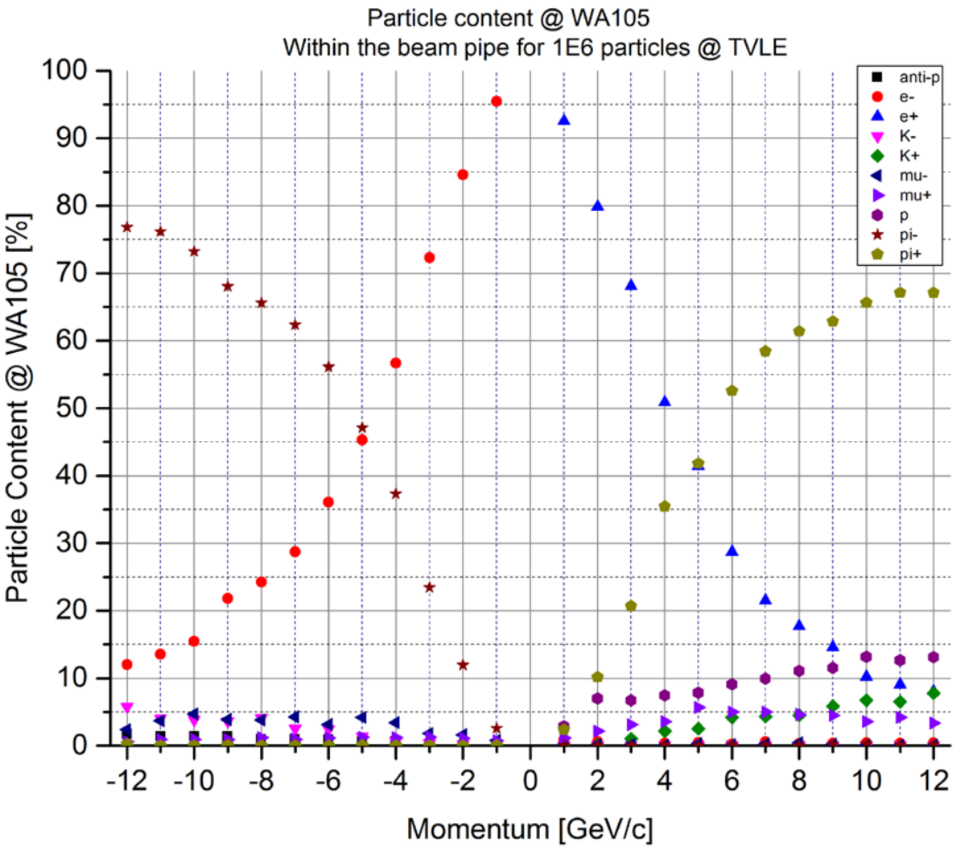


EHN1 Extension - H2 VLE Beam
Schematic Layout



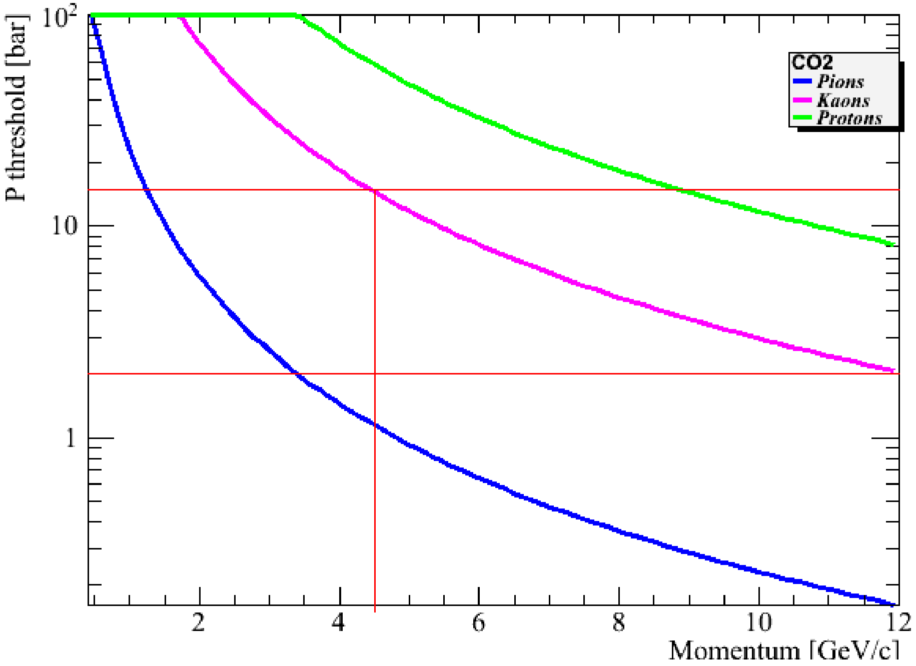
Time-of-Flight

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.



Two methods for particle identification:

- Cherenkov counters: useful for momenta above 4 GeV/c

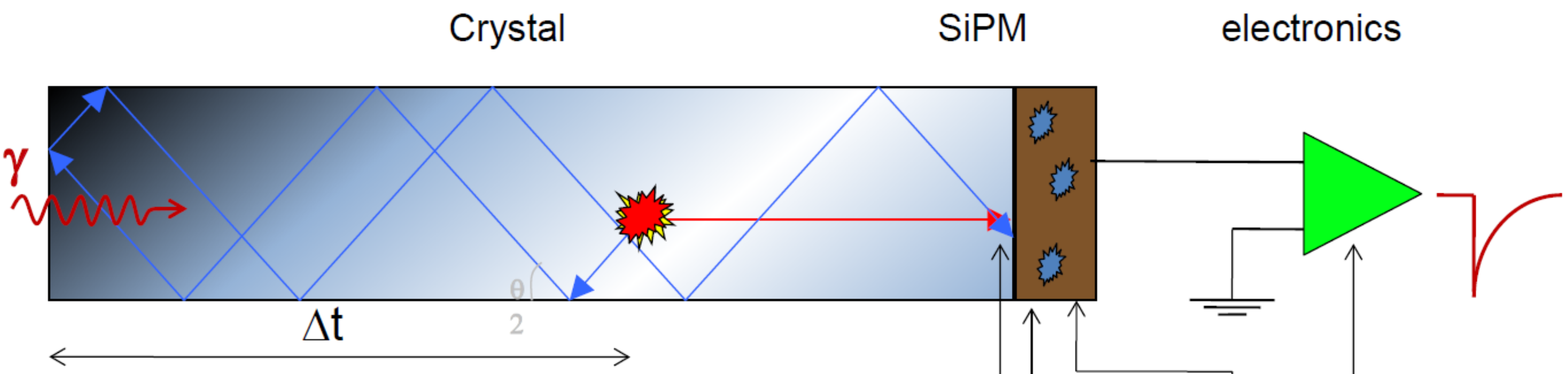


- Time-of-Flight: for lower momenta

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



$t_{kth\ pe} = \Delta t + t_{k'\ ph} + t_{transit} + t_{SPTR} + t_{TDC}$

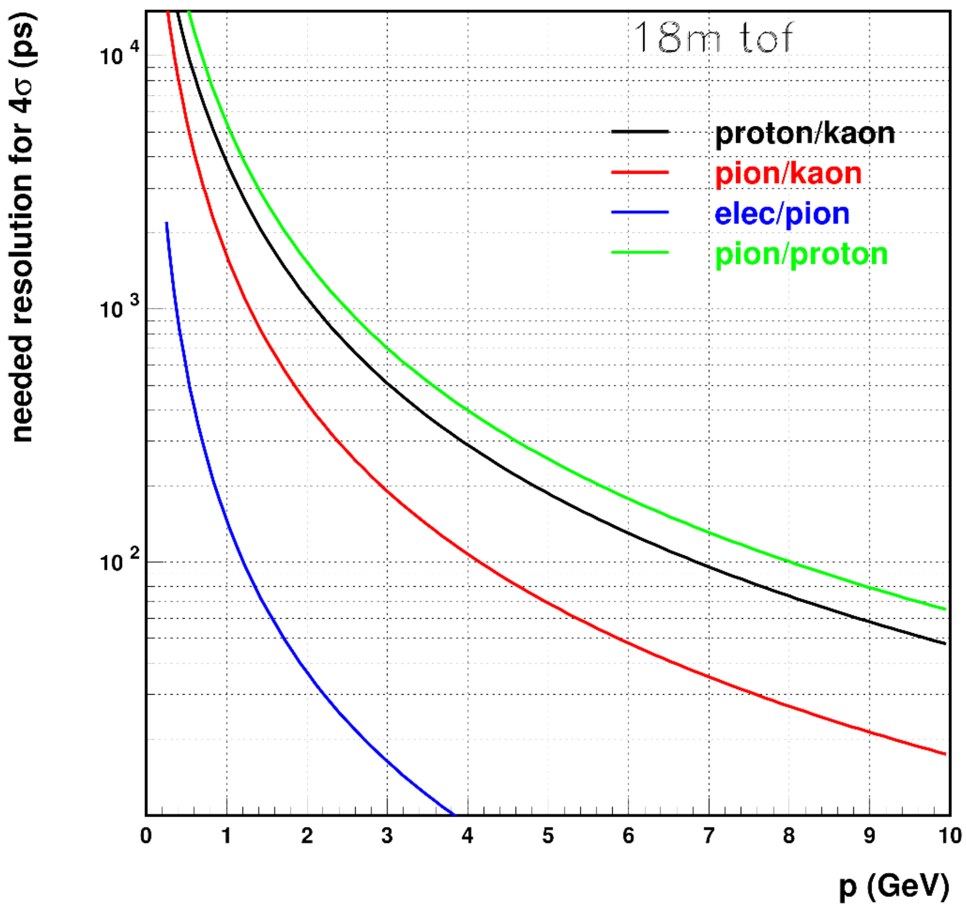
- Δt: Conversion depth
- $t_{k'\ ph}$: Scintillation process
- $t_{transit}$: Transit time jitter
- t_{SPTR}: Single photon time spread
- t_{TDC}: TDC conversion time

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

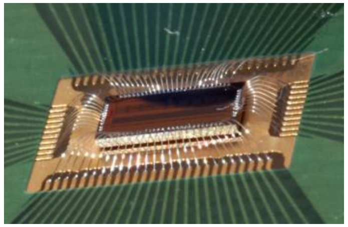
Other experiments like Mu3e have already achieved similar resolutions.

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



NINO chip

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

STiC ASIC

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