A Scintillating Fibre Tracker for the SND@LHC Detector

Innovative Detector Technologies and Methods

Guilherme Soares
On the behalf of the SND@LHC Collaboration
gmachado@cern.ch

14 September 2023

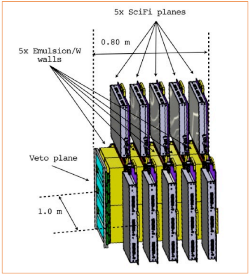
Index

Introduction

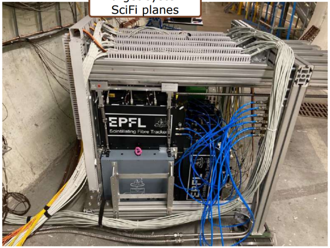
Scintillating Fiber Goals :

- Resolve tracks in between the Emulsion Bricks Spacial resolution $\approx$ 100 μm
- Timestamp Neutrino events in the Target
- Assist measuring EM shower energy

With Run 3 data available and both in-lab and test beam data, we can properly characterise the SciFi modules.



Target system SciFi planes



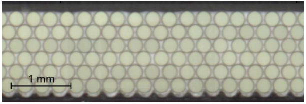
Scintillating Fiber Detector

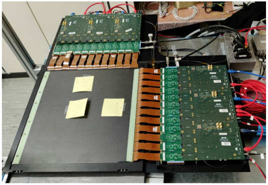
Full System :

- 5 Stations
- X and Y Planes with readout
- **3 Fibre Mats** per plane
- Developed by the same team as the SciFi in LHCb
- Water cooling and heat sink present

Mats :

- 133 mm width and 390 mm length
- 6 stacked layers of Kuraray SCSF-78MJ Plastic
- S13552 SiPM Hamamatsu multi-channel array readout
- TOFPET2 ASIC based FEE

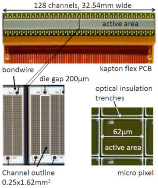




Front End Electronics Readout

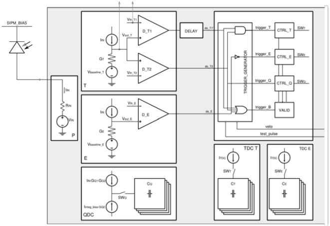
SiPM Array :

- 128 Channels divided in 2 halves
- 250μm wide channels
- 32.54 mm wide
- 200μm die gap in the middle
- 400μm gap between first channel in consecutive arrays
- Readout by 2 TOFPETs



TOFPET2 ASIC :

- 24 per SciFi Plane
- 64 TOFPET channels with independent logic
- Signal amplification and digitisation
- Discriminators for timing, triggering and energy measuring
- Global digital clock at 160 MHz ($\approx$ 6.25 ns)
- Timing resolution $<$ 50 ps



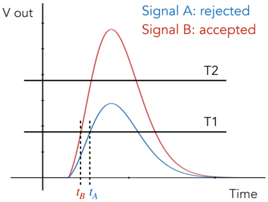
TOFPET Trigger Settings

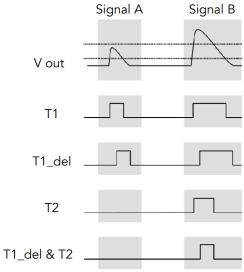
TOFPET discriminators contain 64 different input biases (programable in DAC counts)

Discriminators T_1 and T_2 used for triggering and timing

Different **trigger modes** :

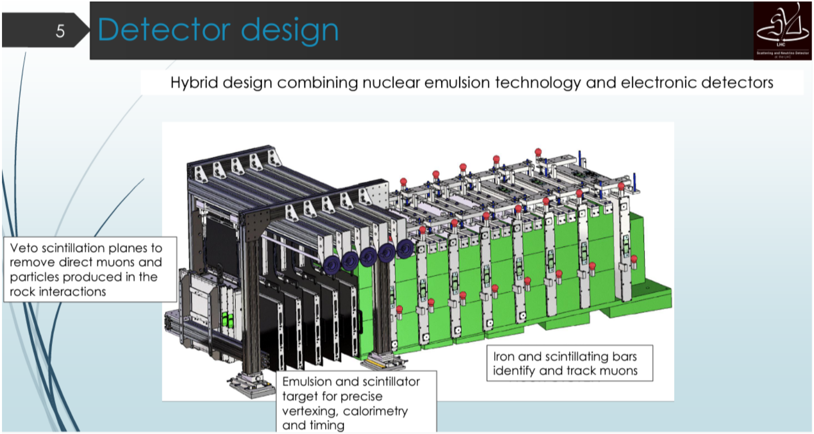
- **Dual Trigger Threshold** (DTT)
  - T_1 triggers digitisation
  - Dead time due to Dark Counts
- **Fast Dark Count Rejection** (FDCR)
  - T_2 triggers digitisation
  - Timestamp reintroduced through a delay in T_1





SND@LHC in TI18

Refer to slide 4 for more details, or Federico's previous presentation for an overview.



Testbeam

Hadronic Calorimeter calibration testbeam in the H8 beam line on CERN's North Area

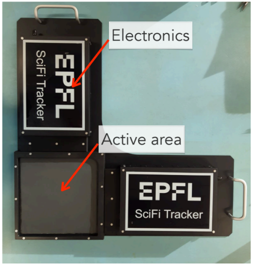
SciFi provides interaction vertex, beam profile information and its performance can be studied

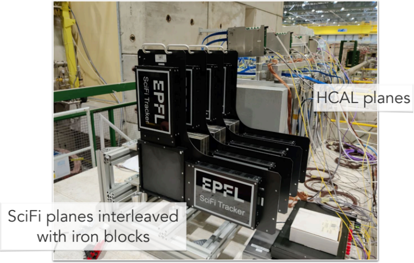
May 24th to June 7th

Variable π energies (mostly 180 GeV)

Setup :

- 4 Stations
- X and Y Planes with readout
- Smaller Modules ($13 \times 13 cm^2$)
- 8 TOFPET2 ASIC per plane
- Interleaved with iron blocks during second week (to emulate emulsion target)

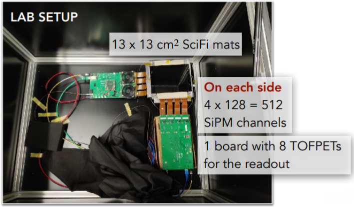




Laboratory

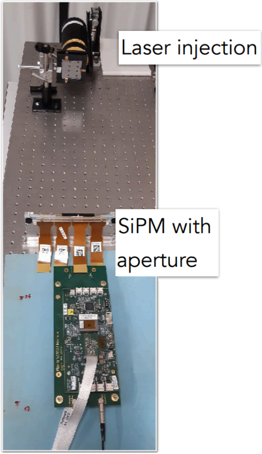
Time Coincidence Setup

- 2 Overlapped SciFi Planes
- Prototype Station for Testbeam
- $13 \times 13\text{cm}^2$ Active Area
- ^{90}Sr Electron Source
- DTT and FDCR tested



QDC Calibration

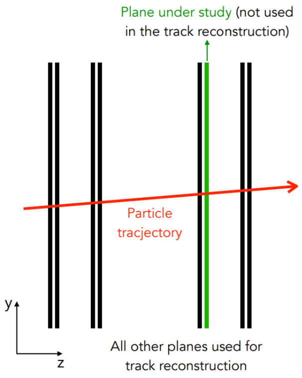
- Direct Laser Injection
- Tuneable Laser Intensity
- Aperture for SiPM Array
- No more than **5 channels** active at a time
- 100kHz Frequency



Detection Efficiency

Calculating Detection Efficiency :

- Select a reconstructed track from the SciFi
- Ignore plane under study
- **TI18** :
  - Require $\geq$ 3 SciFi clusters in X and Y to fit the track projections
  - For plane in question, search for a cluster (no residual requirements due to low noise)
- **Testbeam**
  - Require $\geq$ 2 SciFi clusters in X and Y to fit the track projections
  - For plane in question, search for clusters near the extrapolated position



Efficiency given by :

$$\text{Eff} = \frac{\sum_{\text{tracks}} \Phi(\text{tracks, planes})}{\#\text{Reconstructed Tracks}}$$

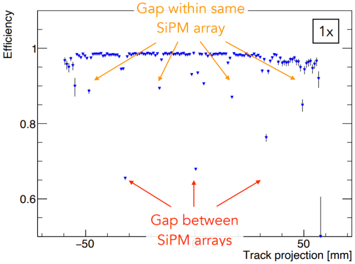
Where the cluster found in the extrapolated track is :

$$\Phi(\text{track,plane}) = \begin{cases} 1 & \text{if (track extrap. - cluster pos.)} < 2 \times \text{channel size} \\ 0 & \text{otherwise} \end{cases}$$

Detection Efficiency

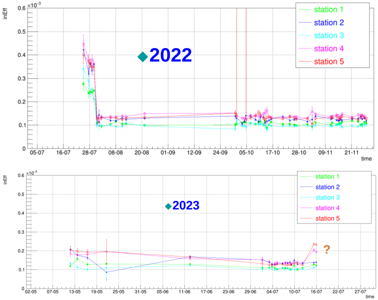
Testbeam results :

- Drops in efficiency in dead zones
- Single Plane Efficiency $> 95\%$



TI 18 results :

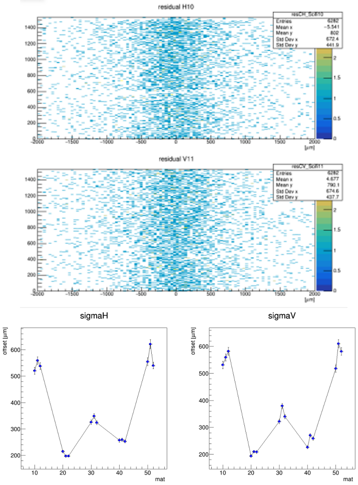
- Detection Efficiency constant throughout Run 3
- Station **Inefficiency** $< 2 \times 10^{-4}$
- Plane inefficiency is correlated
- Single **Plane Efficiency** $> 99\%$
- Base efficiency between gaps $\approx 99.8\%$



Position Resolution

Estimating Spacial Resolution through SciFi mat alignment :

- Choose SciFi tracks (Analogous selection to previous study)
- Find Distance of Closest Approach (DOCA) from SciFi Clusters to Extrapolated Track
- Minimize DOCA with respect to X, Y and 3 Rotation Angles
- Shift SciFi mats by constants obtained
- Plot Residuals
- Obtain spatial resolution from Gaussian fit

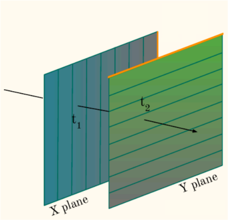


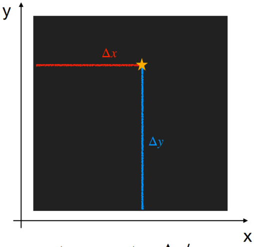
With **TI18 data from 2022**, the spatial resolution is within $180\mu\text{m} < \sigma_{x,y} < 620\mu\text{m}$

Time Resolution

Calculated 2 different ways :

- Find fitted tracks
- Check **Stations** with **exactly 1 cluster**
- Consider hit timing the earliest timing in the cluster
- Correct for light propagation through fiber ($v = 15$cm/ns)
- **Between Planes :**
  - Plot time differences for each mat combination
- **Between Stations :**
  - Take mean time from both planes in the station (X and Y)
  - Plot time difference for each station combination





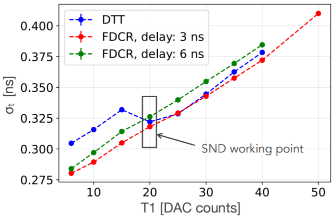
$$t_{x,\,\mathrm{corr}} = t_x - \Delta y / v$$

$$t_{y,\,\mathrm{corr}} = t_y - \Delta x / v$$

Time Resolution

Results from the Laboratory measurements

Laboratory setup allows exploring the Bias threshold applied on the $\mathbf{T}_1$ and $\mathbf{T}_2$ discriminators



TI18 results have data for the different $\mathbf{T}_1$ delays applied during FDCR acquisition mode

Default mode (3ns delay) provides the best resolution

Consistent with Laboratory results

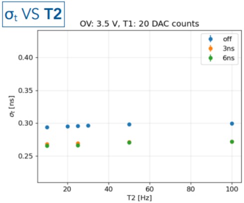
Stations	off	3ns	6ns
1 - 2	355	353	332
1 - 3	359	332	353
1 - 4	375	354	372
1 - 5	371	348	345
2 - 3	388	333	353
2 - 4	365	353	369
2 - 5	373	347	368
3 - 4	361	327	382
3 - 5	355	352	361
4 - 5	380	357	408
Average	**368,2**	**345,6**	**364,3**

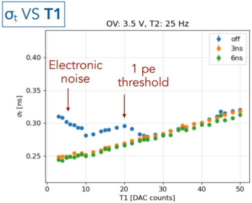
Time Resolution

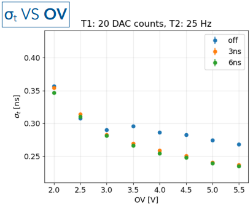
Testbeam Data

Varied $\mathbf{T}_1$, $\mathbf{T}_2$ and the SiPM Over Voltage (OV)

Plane	Time res. [ns]	Uncertainty [ns]
1x	0.351	0.003
1y	0.373	0.004
2x	0.366	0.003
2y	0.371	0.002
3x	0.369	0.002
3y	0.377	0.003
4x	0.394	0.002
4y	0.394	0.002







- σ_t seems stable with regards to confirmation threshold T_2

- Lack of Dark Count Rejection deteriorates σ_t
- σ_t improves at lower T_1

- σ_t improves at higher Over Voltage
- Once again, Dark Count presence degrades σ_t

Energy Measurements

TOFPET can measure energy through 2 methods :

- Time over Threshold (ToT)
- **Charge to Digital Converter (QDC)**
  active over a programmable period of time

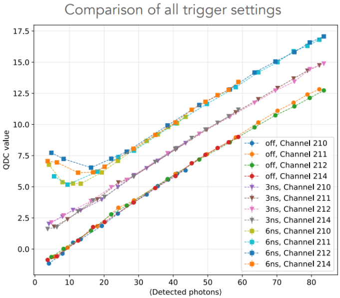
QDC should yield more accurate results

System calibrated through VATA (High energy resolution that resolves single-photon peaks) for the SiPMs

Can then replace FEE with the ones for SND@LHC and study the QDC response as a function of the laser intensity !

Raw SiPM response not too promising

Issues at low intensities (SciFi range)



Energy Measurements

TOFPET can measure energy through 2 methods :

- Time over Threshold (ToT)
- **Charge to Digital Converter (QDC)**

  active over a programmable period of time

QDC should yield more accurate results

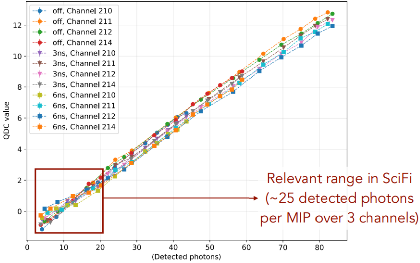
System calibrated through VATA (High energy resolution that resolves single-photon peaks) for the SiPMs

Can then replace FEE with the ones for SND@LHC and study the QDC response as a function of the laser intensity !

Raw SiPM response not too promising

Issues at low intensities (SciFi range)

However, this **can be corrected, and the different offsets can be solved** as well !



Conclusion

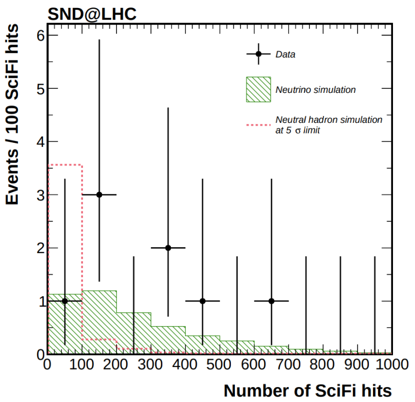
The SciFi is major success !

- Spatial resolution $\approx 300\mu$m
- Time resolution $\approx$ 350ps
- SciFi fulfilled the goals of detecting neutrinos
- Progress was done towards incorporating the SciFi in the energy measurement

Conclusion

The SciFi was integral in observing collider neutrinos for the first time ! ! !

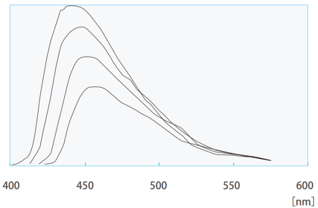
Thank you



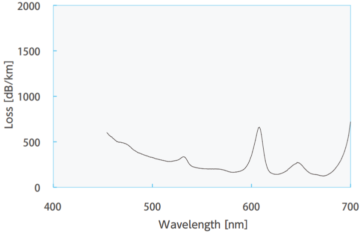
SCSF-78MJ Plastic

Description	Emission		Decay Time [ns]	Att.Leng.[2] [m]	Characteristics
	Color	Peak[nm]			
SCSF-78	blue	450	2.8	>4.0	Long Att. Length and High Light Yield

SCSF-78

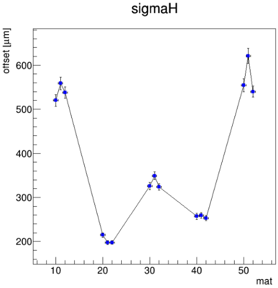


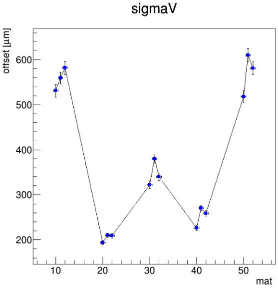
SCSF-78



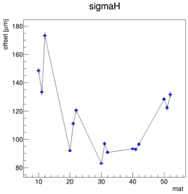
Position Resolution

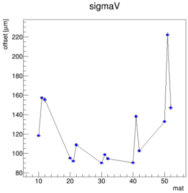
TI18 :





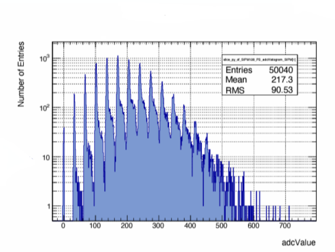
H6 Testbeam :
September 2021



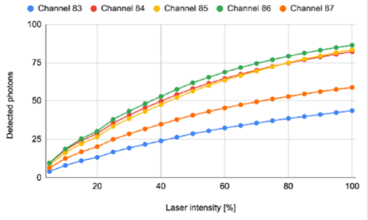


Laser Calibration

VATA Profile ⇒

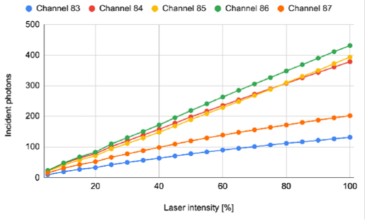


detected photons (fired pixels)

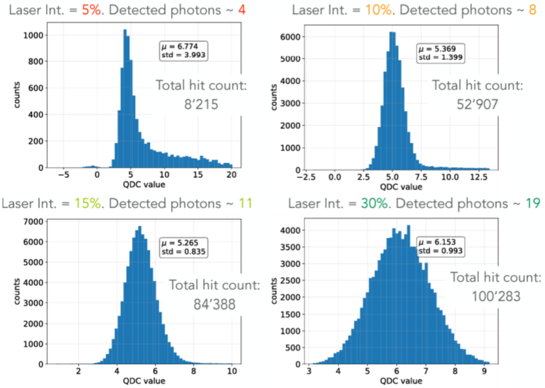


Known relation between incident and detected photons for SiPM

incident photons



Low Intensity Problems for FDCR at 6ns



- 1 kHz Laser
- 100 seconds
- Expected 10^5 Hits at low T_2 threshold

Detection Efficiency very low for low intensities

Tails of distributions become pronounced

Very likely due to small signal shape, making falling edge of T_2 appear before 6 ns