Proposal for LHC Detector R&D

TOPOLOGICAL TRIGGER DEVICE USING SCINTILLATING FIBRES AND POSITION-SENSITIVE PHOTOMULTIPLIERS

V. Agoritsas¹, N. Akchurin², J. Dufournaud³, R. Giacomich⁴, A. M. Gorin⁵, K. Kuroda⁶, A. P. Mes chanin⁵, C. Newsom², S. B. Nurushev⁵, Y. Onel², N. Oshima⁶, G. Pauletta⁴, A. Penzo⁴, V. E. Rakhmatov⁵, V. R. Rykalin⁵, G. Salvato⁴, P. Schiavoni⁴, D. Sillou⁵, V. Solovyaynov⁵, F. Takeuchi⁷, V. Vasiliev⁵, V. G. Vasil’chenko⁵, A. Villari⁴, R. Yamada⁶ and T. Yoshida⁸

Abstract

An approach to a high-quality Level-1 trigger is proposed on the basis of a topological device that will be realized by using scintillating fibres and position-sensitive photomultipliers, both of which are considered as potential candidates for new detector components, thanks to their excellent time characteristics and high radiation resistance. The device is characterized, in particular, by its simple concept and reliable functioning, which are a result of the mature technologies employed. In the LHC environment, the major interests of such a scheme reside in its capability to select high-\( p_T \) tracks in real time, in its optional immunity against low-\( p_T \) tracks and loopers, as well as in its effective links to other associated devices within the complex of a vertex detector.

1) CERN, Geneva, Switzerland
2) Iowa University, Iowa, USA
3) LAPP, Annecy, France
4) INFN, Italy (Messina, Trieste and Udine)
5) IHEP, Serpukhov, USSR
6) FNAL, Batavia, USA
7) Kyoto-Sangyo University, Kyoto, Japan
8) Osaka City University, Osaka, Japan

*Spokesperson
1. Introduction

In anticipation of the new collider experiments that are likely to begin in the near future, presumably in less than 10 years, it would seem that now is the time to reconsider the concepts of the relevant detectors in the quest for "simplicity and reliability". The expected high performance of the future colliders will inevitably lead to serious problems occasioned by the tremendous density of tracks in time and space.

Under such a new regime of event detection and tracking, it is quite important to foresee a "transparent" network capable of instantaneously providing the spatial information on incoming events, which can be integrated into the Level-1 trigger, because a classical trigger based on "calorimeter only" will be badly affected by pile-up of the energy deposits and by its statistical fluctuation, coming from accumulated minimum-bias events. In addition, such a device having a high resolving time will provide a possibility of "matching" in-time showers (or tracks) observed in the associated calorimeter (or tracking device).

We propose to develop a "topological" trigger device (TTD), on the basis of recent progress in the techniques of scintillating fibre (SciFi), and position-sensitive photomultiplier (PSPM).

2. Basic Features

Among the several types of radiation detectors, the "scintillator" can be classified as a most "simple and reliable" sensor, meaning that it operates without having any "active" elements - neither inside itself nor in its proximity - such as sensitive wires or electrodes at high/low voltage, or integrated preamplifiers, or multiplexers. It is simply a "passive" element, converting ionizing tracks into scintillation light and transmitting the light signals to a photosensitive device, which can be located "outside" the highly-radiative area. This feature represents the great advantage of such a SciFi detector when it is installed inside the hermetic structure of a vertex detector.

The same philosophy was adopted in our choice of the readout device for SciFi (Section 3). Among the different types of photosensitive devices, such as optoelectronic systems (image intensifiers, followed by a CCD) [1], solid-state photomultipliers[2], avalanche photodiodes [3], and so on, the classical photomultiplier technique is continuing to provide a solid technical basis in many high-energy experiments because of its inherent merits: fast response, high gain, low noise, etc., in addition to its simple and reliable way of functioning. Furthermore, recent progress in modern photomultipliers, incorporating fine-grid or fine-mesh dynodes, has brought new dimensions to this mature technology, e.g. position sensitivity [4] and immunity to the magnetic field [5]. In particular, the position sensitivity, together with a real-time digitizer such as that developed by our collaboration [6], will afford an elegant solution to the problem of high flux density of charged particles in the LHC environment. For example, a currently used PSPM, the R2486, provides more than 100 line-pairs per tube with the aid of a suitable centroid method.
In Fig.1 we present the basic scheme of our readout system, which is characterized by an interpolation property of delay line [7]. A series of anodes are connected to a suitable delay line at an interval $\Delta D$, which is shorter than the rise-time of pulses coming from the anodes. The spread of secondary electrons, $w_0$, is generally wider than the anode spacing, so that for a point-like source on the photocathode a few number of anodes deliver pulses of different amplitudes. Constant fraction discriminators (CFDs) are adjusted in such a way that they are triggered at the centre of gravity of the folded pulse coming from the delay line. The impact position $X$ is thus determined simply by measuring the time difference between the left- and right- propagating signals $t_L$ and $t_R$:

$$X = v_p(t_L - t_R)/2,$$

with a precision (following our semi-empirical formula),

$$\Delta X = \frac{0.8 w_0}{\alpha \sqrt{N_{pe}}} \text{ in FWHM},$$

where, $v_p$ is the propagation speed of pulses inside the delay line, $N_{pe}$ is the number of photoelectrons per hit, $\alpha$ is the magnification factor of the SciFi array from the fiducial area to the photocathode.

![Diagram](image)

**Fig.1**: Readout of SciFi by delay-line method

Digitization of the hit position can be carried out in real time by using a second delay line to which a series of discriminators are connected at suitable intervals, chosen by taking into account the space resolution $\Delta X$. The principle of the digitizer, shown in Fig.2, is in fact very close to that of the mean-timer currently employed for compensating the time spread of scintillation light along large counters. For simplicity, the CFDs are omitted in this figure, and signals are presented along the whole loop of a delay line 2D as if they were normalized in
width and height. As shown in Fig.2a, the signals propagating towards the left (L) and the right (R) meet again in the lower part of the loop, and the folded pulse comes out through whichever discriminators correspond to the hit position. Note that the transit time of the anode signal, $t_{\text{out}} - t_{\text{in}}$, is always equal to $D$, independent of the hit position.

![Diagram of real-time digitizer](image)

Fig.2: Principle of real-time digitizer

This "simultaneity" of the digital outputs will also provide a possibility of handling multihit events as illustrated in Fig.2b. For example, for a double-hit event there are four combinations of the left and right pulses, which give four folded-pulses, each exceeding the threshold of the discriminators. However, providing the double hits are separated by $\Delta t$ on the delay line, the transit time for the bad combinations, i.e. $L(1) + R(2)$ and $L(2) + R(1)$, is shifted by $\pm \Delta t/2$, so that the false positions can be eliminated by a coincidence with respect to a suitable reference time given, for example, by the last dynode or by an external counter.

Another important aspect of such a timing requirement is the high rejection of low-$p_{\perp}$ charged particles travelling through the strong solenoid field of the vertex detector. This interesting feature of the real-time digitizer is presented in Section 4, in connection with the geometric structure of the TTD.

The simultaneity of the above-mentioned digital outputs has been confirmed experimentally in a previous study, using a SciFi hodoscope [6] dedicated to an experiment at Fermilab [8].
3. Choice of Photosensitive Device

In spite of the fact that quite a number of photosensitive devices are capable of reading SciFi, our choice is in fact rather limited by the high rate capability and the high resolving time that are required for such a trigger device to be operational under the LHC environment.

Essential factors that are in favour of a PSPM are as follows:

i) excellent matching of the PSPM to the SciFi in time characteristics, which allows us to take full advantage of the fast response of plastic scintillators, typically \( \leq 1 \text{ ns} \) in rise-time and \( \leq 10 \text{ ns} \) in light-output duration [9];

ii) high gain with low noise, in addition to the immunity against any RF noise which may occur in a real LHC environment;

iii) promising features in the spatial resolution already exploited in several recent applications [6,10];

iv) possibility of profiting from an external magnetic field to improve, not only the spatial resolution, but also the S/N ratio [11];

v) simple and reliable operation, as well as a high radiation hardness that has been empirically proven over a long time.

The PSPMs actually available on the market can be classified into four categories, following the mechanical structure of the dynodes employed. Some characteristics of the typical examples are listed in Table 1.

The grid dynode was originally conceived by us, as early as 1968, for the purpose of localizing the secondary electrons by means of an axial magnetic field [4]. Although the intrinsic spatial resolution is, at present, rather modest without an axial magnetic field, its high performance in the stability and linearity of gain, as well as the immunity to any "external" magnetic field (up to \( \sim 100 \text{ G} \)), have been fully demonstrated in a massive application of such tubes (with single anodes) used in the OPAL electromagnetic calorimeter [12].

The second type, incorporating fine-mesh dynodes, is distinguished by its particular immunity of gain, and a considerable improvement of the intrinsic resolution under a strong axial magnetic field [13].

Compared to these two types, a merit of the Venetian-blind type is the possibility of detecting single photoelectrons thanks to its opaque dynode structure against the primary electrons. However, the response curve, as a function of light-spot position, has very long tails [14]; this might impede a correct application of the centroid method. Anyway, a cross-talk of \( \sim 20\% \) (in x) seems to us too low for a good reconstruction of the impact position, or too high to carry out an independent counting.

The RTC tube belongs to another category, which is conceived for minimizing the cross-talk between the adjacent anodes [15]. It has a high gain (\( \sim 10^7 \)) and a short rise-time (\( \sim 4.8 \text{ ns} \)), but the number of pixels is at present limited to \( 8 \times 8 = 64 \).

Such a PSPM "without cross-talk" seems at first sight to be more advantageous, in particular, for the treatment of multihit events. This is however generally not true for the following reasons:
Table 1. Different types of PSPM

<table>
<thead>
<tr>
<th>Dynode Structure</th>
<th>Grid (triangular bars)</th>
<th>Fine mesh</th>
<th>Venetian blind</th>
<th>Flat plate with fine holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical example</td>
<td>R2486 (or R2487)</td>
<td>R4140</td>
<td>R4135</td>
<td>XP4702</td>
</tr>
<tr>
<td>Size</td>
<td>3&quot; round (3&quot; square)</td>
<td>3&quot; square</td>
<td>3&quot; square</td>
<td>6 cm round</td>
</tr>
<tr>
<td>Fiducial area</td>
<td>40 x 40 (55(x) x 45(y))</td>
<td>40 x 40</td>
<td>58 x 56</td>
<td>18 x 18</td>
</tr>
<tr>
<td>No. of dynode stages</td>
<td>12</td>
<td>16</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Typical HV (V)</td>
<td>1200</td>
<td>2500</td>
<td>1700</td>
<td>1800</td>
</tr>
<tr>
<td>Gain</td>
<td>~ 1 x 10^6</td>
<td>~ 1.5 x 10^6</td>
<td>~ 10^7</td>
<td>~ 10^7</td>
</tr>
<tr>
<td>No. of anodes</td>
<td>16 + 16 (18 + 17)</td>
<td>16 x 16 = 256</td>
<td>28 (x) + 8 (y)</td>
<td>8 x 8 = 64</td>
</tr>
<tr>
<td>Intrinsic spatial resolution</td>
<td>~ 8 mm FWHM</td>
<td>~ 6 mm FWHM</td>
<td>~1.8 mm FWHM (10 kG)</td>
<td>~1.8 mm FWHM (10% max)</td>
</tr>
<tr>
<td>Rise-time (ns)</td>
<td>~ 5.5</td>
<td>~ 2.7</td>
<td>~ 5.2</td>
<td>~ 4.8</td>
</tr>
<tr>
<td>Immunity to magnetic field (axial) (G)</td>
<td>~ 300</td>
<td>~ 10^4</td>
<td>~ 80^a</td>
<td>~ 150</td>
</tr>
<tr>
<td>Detection of single photoelectrons.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Unknown</td>
</tr>
<tr>
<td>Cross-talk btw adjacent anodes</td>
<td>~ 60%</td>
<td>~ 50%</td>
<td>~ 20% (x)</td>
<td>~ 5% (y)</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Hamamatsu Photonics</td>
<td></td>
<td>RTC (Philips)</td>
<td></td>
</tr>
</tbody>
</table>

a) Roughly estimated from the lateral width of the dynode lamella.

- the cross-talk should appear not only inside but also outside the PSPM (optical cross-talk) unless very careful precautions are taken to avoid it [16],
- contrarily, if a suitable cross-talk is optically introduced, the final resolution is generally improved without any important loss in the two-hit resolution [17].

Our conceptual study, as described in Section 4, is based on the grid-type PSPM for the following reasons:

i) cost effectiveness, in particular the cost per fiducial photocathode surface, which is an important factor for the readout of ~ 10^5 fibers per sublayer;

ii) facility of future improvements by scaling down the size of the dynode structure, following a scaling property of the Lorentz equation [4];

iii) possible improvement for detecting single photoelectrons by making a staggered
double grid-layer per stage.

Note that simple mechanical structure of the grid dynode (parallel grid bars with a triangular cross-section) is well suited for the scale-down, compared with the other structures\(^1\), in particular that employed in XP4702. In fact, a new dynode, scaled down by a factor of 2 from that employed in the commercial tubes, has been successfully realized by the Technical Service Group at CERN. A project for constructing an upgraded PSPM on this basis is actually in progress within the framework of the CERN-USSR Co-operation [18].

Following the scaling property, such a new PSPM should provide space and time resolutions two times better than those indicated in Table 1 for R2486.

Note also that point (iii) concerns the collection efficiency of the first dynode, which is quite important for a good detection of weak signals such as those expected in SciFi tracking devices.

4. Conceptual Design and Expected Performances

A conceptual structure of the TTD is shown in Fig. 3. It consists of two cylindrical hodoscopes, RH1 and RH2, of radii 50 cm and 100 cm respectively, covering a pseudorapidity range \(-1.5 \leq \eta \leq 1.5\).

![Conceptual structure of the TTD](image)

*Fig. 3 : Conceptual structure of the TTD*

Each hodoscope consists of a triplet of SciFi layers (U-V-Z) made of 1 mm or 0.5 mm diameter fibres aligned coherently along a stereo angle (say \(\sim 15^\circ\)) with respect to the z-axis. We assume the effective thickness of the sublayer to be \(\sim 5\) mm (\(\sim 1.2\% X_0\)), so that the number of photoelectrons per minimum-ionizing particle is approximately equal to the number already referred to in our previous study (i.e. 10 to 15). Because of the high resolving time

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\(^1\) The actual size of the fine-mesh (with a pitch of \(\sim 20\) \(\mu\)m) seems to be already close to the limit of the scaling-down. In addition, the inherent low opacity of the mesh excludes the possibility of detecting single photoelectrons.
required for such a trigger device, each RH is divided at the central plane ($\eta = 0$) into two parts, which are less than 2 m in length. Hence, the maximum transit time of light is less than $\sim 12$ ns [9]. The scintillation light is transmitted, through high-transmission optical fibres (for example, undoped polymethyl methacrylate), to PSPMs located beyond the eventual flux-return yoke of the solenoid.

The SciFi array can be read out by mapping the peripheral length of, say, 50 mm into six segments of $\sim 8$ mm, which are stretched to $\sim 40$ mm each and aligned in parallel on the photocathode at intervals of $\sim 8$ mm. This provides an image magnification factor of $\alpha \sim 5$.

The associated electronics of each segment are illustrated in Fig.4. The selecting gate digitizer (SGD), which is a slightly modified version of the real-time digitizer, should improve the resolving time; the normalized pulses from the CFDs ($t_L$ and $t_R$) will be used only to open "local gates" for switching the fast pulses coming directly from the timing anode (or the last dynode). This scheme has been studied by a Monte Carlo simulation [20] and appears to be promising for the treatment of multihit events. Note also that such a scheme is transparent to successive events provided the corresponding pulses are separated in time inside the delay line. Based on commercially available PSPMs (type R2486), and assuming that there are $\sim 130$ tubes per sublayer, the probability of pile-up (in other words, the occupancy), is $\sim 5\%$ for the most irradiated part of the TTD at a luminosity of $\sim 10^{34}$ cm$^{-2}$s$^{-1}$.

Some expected performances of the TTD are summarized in Table 2. The two-hit resolution of such a readout scheme, based on the centroid method, can be defined by the intrinsic resolution of the PSPMs, $w_0 = 8$ mm (FWHM), which turns out to be $\sim 0.7$ mm on the fiducial area.

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**Fig. 4 : Associated electronics**
As an indication, note that the delay line currently used in our prototype has $\Delta t/\Delta x = 1 \text{ ns/mm}$ and will produce a shift of $\Delta s/2 \approx 5 \text{ ns}$.

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Table 2. Expected performances of the TTD

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial resolutions</td>
<td>$\sigma_{\phi} = 150 \mu\text{m per sublayer}$</td>
</tr>
<tr>
<td></td>
<td>$= 90 \mu\text{m with triplets}$</td>
</tr>
<tr>
<td></td>
<td>$\sigma_z = 400 \mu\text{m}$</td>
</tr>
<tr>
<td>Two-hit resolution</td>
<td>$= 0.7 \text{ mm}$</td>
</tr>
<tr>
<td>Resolving time per hit</td>
<td>$= 0.5 \text{ ns}$</td>
</tr>
<tr>
<td>Total time spread</td>
<td>$\leq 12 \text{ ns}$</td>
</tr>
<tr>
<td>Occupancy</td>
<td>$\sim 5%$ (on RH1)</td>
</tr>
</tbody>
</table>

(at $L = 10^{34} \text{ cm}^2\text{s}^{-1}$)

5. **Original roles of the TTD in the LHC environment**

The TTD will play several original roles in the real LHC environment.

5.1 **Low-$p_{\perp}$ rejection**

As illustrated in Fig.5, the real-time digitizer (or the SGD) is intrinsically insensitive to low-$p_{\perp}$ particles travelling through the strong solenoid field of the vertex detector. For example, a charged particle of a few hundred MeV/c in an axial magnetic field of 2 T will hit RH1 at an incident angle of $\geq 30^\circ$, so that the light-spot on the photocathode will spread over $\geq 10 \text{ mm}$ (if $\alpha = 5$). Denoting the corresponding time spread of the anode signal inside the delay line by $\Delta s^2$, the transit time $t_{\text{out}} - t_{\text{in}}$ will be shortened by $\Delta s/2$. Therefore the reference-time signal $t_0$ arriving at $t_{\text{in}} + D$ cannot exit through the gate, which is open at $(t_{\text{in}} + D) - \Delta s/2$.

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Fig.5: Immunity of the real-time digitizer against low $p_{\perp}$ tracks
5.2 Jet assignment and jet topology

Local enhancement of the charged-particle multiplicity can be detected in real time by sending the digitized outputs to majority logic units or to a suitable current integrator through a simple delay line as shown in Fig.6.

![Fig.6: Jet assignment](image)

5.3 High-$p_T$ selection

With an axial magnetic field, there is the possibility of selecting high-$p_T$ tracks, such as the electron pairs or jets produced by $Z^0$ or $W^\pm$, by using the coincidence between RH1 and RH2. As illustrated in Fig.7, when a track comes from a point-like source at the vertex, the coincidence between the corresponding bins in the radial direction defines the threshold of the $p_T$ selection, which in turn depends on the track-finding sagitta precision. For the spatial resolution $\sigma_\rho = 100 \mu m$ and $B = 2T$, the highest threshold is $\approx 250$ GeV/c. Of course, a lower threshold can be chosen by grouping the respective adjacent bins of the RH1 and RH2 digitizers. The probability of having a false coincidence due to the minimum-bias events should be very low, thanks to the insensitivity of the real-time digitizer to low-$p_T$ tracks [21], and a fine segmentation of local coincidence, not only in $\phi$ but also in $\eta$ [22]. A quantitative check by means of Monte Carlo simulation is actually in progress, and the result will be available soon.

5.4 Time structure of hits in the z-direction

Another interesting feature of the TTD is the possibility of measuring the time structure of hits inside the SciFi array. This can be performed by using high-density TDCs, as shown in Fig.8, gated by the "first arriving hit" or by the bunch-front signal.

![Fig.8: Gated by the "first arriving hit" or by the bunch-front signal](image)
Such a TOF measurement has, in fact, been proposed for the SSC (Kuhlen et al.) [9] with a view to separating overlapping events in a single bunch with a resolving time of $\sim 50$ ps. For our TTD, which is based on R2486-type tubes, we expect a much more modest resolution, say of the order of 0.5 ns, which still allows us to investigate the hit topology inside local segments of $\sim 10$ cm in the $z$-direction. In a higher-level trigger or in off-line analysis, this redundancy in the $z$-coordinate will help to carry out more easily
- the linkage between U-V sublayers, and
- the elimination of "out-of-time" events, including loopers.

The map of "in-time" events thus selected by the TTD can be used later in order to "pin up" in-time tracks or showers detected by other associated apparatus such as fine-tracking devices, calorimeters, etc.

The expected functions of the TTD are presented in Fig.9 as an information flow-chart. The real-time information, such as jet-assignment, high-$p_\perp$ selection, etc., will be combined with the calorimetric information in order to define an "improved" Level-1 trigger. On the other hand, the map of in-time events will serve to eliminate out-of-time tracks and showers accidentally observed in the relevant devices.

Such a selection of in-time events, in addition to the high quality of the "hybrid" calorimeter+TTD trigger, will make the reconstruction of candidate events much easier.
segments per tube), and by a factor of 8 in the occupancy, i.e. (factor of 4 in space) x (factor of 2 in time).

For example, an improvement by a factor of 2 in PSPM resolutions will improve the TTD's spatial

resolutions by a factor of 4, i.e. (factor of 2 in space resolution) x (factor of 2 in the number of array

segments per tube), and by a factor of 8 in the occupancy, i.e. (factor of 4 in space) x (factor of 2 in time).

6. R&D Programme, Timescale and Milestones

The major items of R&D that are needed in order to concretize the TTD design are:

i) optical and mechanical studies of the SciFi array and optical-fibre light-guide;

ii) improvements and modifications to the PSPM;

iii) R&D of subnanosecond electronics relevant to the TTD;

iv) Monte Carlo simulations of the original functions of the TTD under the LHC environment.

The first item includes the construction of a generic prototype of a superlayer segment in
order to study a) the mechanical precision of the fibre layout, b) the connection of SciFi to the
optical fibres, c) the mapping scheme, as well as, d) the optical contact between fibre bundles
and the PSPM, etc. Measurements of the light transmission will be carried out beforehand on a
test bench in order to optimize the design parameters of the TTD.

Concerning the PSPM itself, the present design of the TTD is based on the
commercially available tubes, with a minor modification to the anode structure. However, a

drastic improvement in the occupancy as well as in the spatial resolutions can hopefully be
expected with a new PSPM that is being developed by the LAPP-CERN-IHEP Collaboration
[18]. It is worth mentioning that, for a given number of PSPM tubes, the performance of the

TTD increases by several orders of magnitude with respect to the improvement of the PSPM's
time and space resolution.

Fig.9: Possible links of the TTD to the associated subsystems: L₅, linkage of

in-time showers; L₆, linkage of in-time tracks; TL, trigger logics

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segments per tube), and by a factor of 8 in the occupancy, i.e. (factor of 4 in space) x (factor of 2 in time).
The goal of the third task is to achieve the final design of the associated electronics: e.g. the SGD module, the high-density TOF, the subnanosecond coincidence circuit for high-$p_T$ selection, etc. It includes also a preliminary study on the miniaturization of certain electronic modules, such as gatable discriminator, high-density TDC, etc.

Following our previous work, the problem of discontinuity between adjacent digitizer modules should be carefully studied in order to maintain a homogeneous detection efficiency. This is also important for the high rejection efficiency of the real-time digitizer against low-$p_T$ tracks (Fig.5), because a narrow split of the anode pulse at the boundary may produce an output signal corresponding to the incoming/outgoing point of the track on the SciFi array. A study of such "inter-module" logics is also one of the important subjects to be investigated.

Some of the above-mentioned investigations will efficiently be guided by Monte Carlo simulations: as a matter of fact, the upgraded PSPM mentioned in Section 3 is already based on a detailed simulation of secondary electron trajectories [4,23]. The main investigations additionally foreseen in our future programme are:

- full simulation of PSPM + SGD, taking into account all the statistical fluctuations, to study the rejection efficiency for low-$p_T$ tracks and loopers (see Fig.5), as well as the lower limit of the two-hit resolution;
- simulation of the local coincidence (see Fig.7), to study the rejection efficiency for minimum-bias events in addition to the detection efficiency for Higgs going to four leptons, $W^+W^-$, etc.;
- study of the topological algorithms for defining the best strategies of the Level-1 trigger-constraints for different physics issues.

The fact that the above-mentioned developments are essentially based on substantially mature technologies, and on our preliminary work carried out over the last several years, would be a great advantage compared with some other projects for new detectors currently requiring "high technological" R&D. The timescale of our basic R&D will indeed be relatively short (~ 2 years) so that all the fundamental data necessary for an eventual design of the full-scale TTD will be available before the end of 1993.

Apart from some full-term developments on specific items, such as the upgrade of the PSPM, the miniaturization of electronic modules, etc., our programme can approximately be scheduled as follows:

**Spring 1991** - basic investigations on the SciFi array, optical-fibre guide, etc.;
- construction of a test-bench of PSPM for multi-anode calibration;
- study of a compact delay line for the real-time digitizer.

**Summer 1991** - test and calibration of modified PSPMs;
- construction of SciFi array and light-guide prototypes.

**Fall 1991** - test of the first series of the upgraded PSPM;
- construction and preliminary tests of a prototype "high-resolution hodoscope" with the associated electronics available at present.
Spring 1992 - test of the high-resolution hodoscope on a test beam at CERN.
Summer 1992 - improvements and tests of the above prototype to achieve the expected spatial resolutions (Table 2);
- design of a generic prototype of the TTD (~ 1/30 in azimuthal angle, ~ 1/2 in ∆η).
Fall 1992 - construction of the generic prototype with improved electronics, installation and preliminary tests at CERN.
Spring 1993 - tests of the prototype on a beam line at CERN;
- improvements in the associated electronics to attain the expected time characteristics, in particular the counting rate capability $\geq 10^7$/s per segment (see Fig.4);
- confirmation of the original roles of the TTD such as the rejection of low-$p_\perp$ tracks, the selection of high-$p_\perp$ tracks, etc., under simulated experimental conditions.
Summer 1993 - final tests, evaluation of data.
Fall 1993 - all data available for an eventual design of the full-scale TTD.

7. Share of responsibility and funding profile

7.1 Share of responsibility

The R&D programme will be carried out in two phases:

During the first period, Spring 1991 to Summer 1992, some items of the R&D can be investigated as homework of the participating groups according to their technical facilities. A tentative share of responsibility is given in Table 3.

Table 3. Share of responsibility (tentative)

<table>
<thead>
<tr>
<th>R&amp;D subject</th>
<th>Prime responsibilitya)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgraded PSPM</td>
<td>IHEP (CERN, LAPP)</td>
</tr>
<tr>
<td>Modifications of commercial PSPMs</td>
<td>CERN (LAPP, INFN)</td>
</tr>
<tr>
<td>Studies on SciFi and optical fibre</td>
<td>IHEP (LAPP)</td>
</tr>
<tr>
<td>Select.-gate digitizer</td>
<td>LAPP (INFN)</td>
</tr>
<tr>
<td>Electronics</td>
<td>INFN (LAPP)</td>
</tr>
<tr>
<td>Local coincidence</td>
<td>INFN (Iowa)</td>
</tr>
<tr>
<td>TOF (high-density TDC)</td>
<td>Iowa (INFN)</td>
</tr>
<tr>
<td>Trigger logic</td>
<td>FNAL (Kyoto-Sangyo, Osaka, Iowa)</td>
</tr>
</tbody>
</table>

a) This is to express prime but "not sole" responsibility. Groups indicated in brackets will be involved in parallel R&D efforts.
During the second period, Summer 1992 to Fall 1993, the main effort will be concentrated on tests of the TTD prototypes using a beam at CERN. Improvements and modifications of the prototypes in different parts will be brought, in principle, under the responsibility of the groups concerned.

7.2 Funding profile

According to the share of responsibility, we foresee a funding profile of the project as shown in Table 4. The total expense for materials amounts to about 540 kSF, which will be distributed over three years from 1991.

Table 4. Financial resources (in kSF)

<table>
<thead>
<tr>
<th>Cost estimates</th>
<th>CERN</th>
<th>FNAL</th>
<th>IHEP</th>
<th>INFN</th>
<th>Iowa</th>
<th>LAPP</th>
<th>Kyoto Osaka</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upgrade</td>
<td>100</td>
<td>40</td>
<td></td>
<td>60(^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified</td>
<td>80</td>
<td>40</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibres</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical</td>
<td>75</td>
<td>40</td>
<td>50(^b)</td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scintil.</td>
<td>25</td>
<td></td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select. g.d.</td>
<td>50</td>
<td></td>
<td>25</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loc. coinc.</td>
<td>25</td>
<td></td>
<td>10</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOF</td>
<td>80</td>
<td></td>
<td>40</td>
<td>15</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trig. logic</td>
<td>50</td>
<td></td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical workshops</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consum. materials</td>
<td>25</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (materials)</td>
<td>540</td>
<td>120</td>
<td>135</td>
<td>120</td>
<td>55</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>

Computer time (h)
(IBM equivalent) : 5400  1800  500  700  700  700  1000

\(^a\) Equivalent to \(\sim\) 10 prototype PSPMs
\(^b\) Equivalent to \(\sim\) 20 km optical fibres

7.3. Funds and facilities requested from CERN

The request from CERN for this project is summarized in Table 5. Additionally, we will need a laboratory of \(\sim 30 \text{ m}^2\) (extensible to \(\sim 50 \text{ m}^2\) in 1992) for the preparation and assembly of the TTD prototypes, as well as some offices for the outside participants.

4) Subject to approval by the funding institutions.
Table 5. Funds and facilities requested from CERN

<table>
<thead>
<tr>
<th>Item</th>
<th>1991</th>
<th>1992</th>
<th>1993</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funds for materials (kSF)</td>
<td>50</td>
<td>50</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td>Travel &amp; subsistences for Collab. meetings (kSF)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Contract labour (kSF)</td>
<td>30</td>
<td>30</td>
<td>15</td>
<td>75</td>
</tr>
<tr>
<td>(Technicians in man-years)</td>
<td>(1/2)</td>
<td>(1/2)</td>
<td>(1/4)</td>
<td></td>
</tr>
<tr>
<td>TOTAL (kSF)</td>
<td>90</td>
<td>90</td>
<td>45</td>
<td>225</td>
</tr>
<tr>
<td>Computer time (h)</td>
<td>500</td>
<td>800</td>
<td>500</td>
<td>1800</td>
</tr>
<tr>
<td>Test-beam time (weeks)</td>
<td>1</td>
<td>3 x 1</td>
<td>2 x 1</td>
<td>6</td>
</tr>
</tbody>
</table>

8. Conclusion

We have presented an approach to a topological trigger device based on SciFi and PSPM. The interesting aspects of such a device are:

i) its simple concept and reliable operation;

ii) the well-established technologies employed;

iii) its unique and original roles in the LHC environment;

iv) its effective links to other associated devices within the complex of a vertex detector.

Our first priority is oriented towards seeking a "high-quality" Level-1 trigger, which is of fundamental importance in particular in the search for rare events, such as the production of heavy bosons at the LHC. However, the technical developments that are relevant to the present device will have several key issues relating to other types of experiments, not only at the LHC but also at the SSC, UNK, etc.

References

   J.P.Fabre et al., CERN/EF/4147H/TG/mnb.


