The H1 ToF system in 1996 and 1997

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1 Introduction

The Time-of-Flight system (ToF) has been installed in the H1 detector to distinguish background events from physics interactions by their time of flight. This information is used to form Level one (L1) trigger bits in order to veto background events.

2 The H1 ToF system

The H1 ToF system has been modified several times in the last few years. When the BEMC was replaced at the end of 1994 the old ToF system (see section 4.7.1 in [1]) was removed to allow the installation of the hadronic SPACAL. The SPACAL TDC system [4] has taken over many tasks of the old ToF system. In the years 1996 and 1997 three ToF devices were installed in the H1 detector. Environment, electronics and software could be reused from the old ToF system by the new ones. These three devices are the FToF (= "Forward" ToF) which is located in the forward muon system at $z = +7.0$ m (see [2]), the PToF (= "Plug" ToF) at $z = +5.3$ m and the BToF (= "Backward" ToF) placed near the compensator magnet at $z = -3.2$ m. In this report an overview of all existing ToFs is given, but only PToF and BToF are described in detail with respect to their performance.

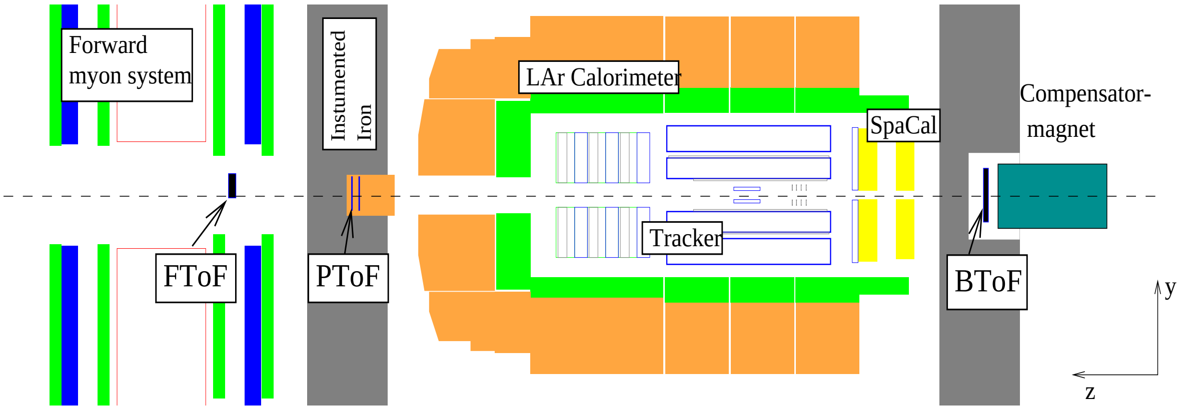

Figure 1: Schematic yz-plane view of the H1 detector

A sketch of the location of the ToF devices can be found in figure 1. Details of the location of the individual scintillators and a diagram of the electronics are included in the appendix.

2.1 The BToF

The BToF consists of four scintillator tiles SCSN 38 where each tile is connected to a Photomultiplier (= PM). Because of the magnetic field that exists at the location of the BToF the use of special photomultipliers (Hamamatsu R5505) is necessary. The scintillator tiles (20 mm thick) are shielded on each side by 2 mm lead. All four pieces have the shape of a semi-circle each with an outer radius of 250 mm and an inner radius of 67 mm. Two scintillator/lead tiles are mounted together forming a layers of full-circle shape. Two of these layers are fixed directly on the beampipe at $z = -3.2$ m one behind the other. A schematic view of one of these walls is given in figure 2.

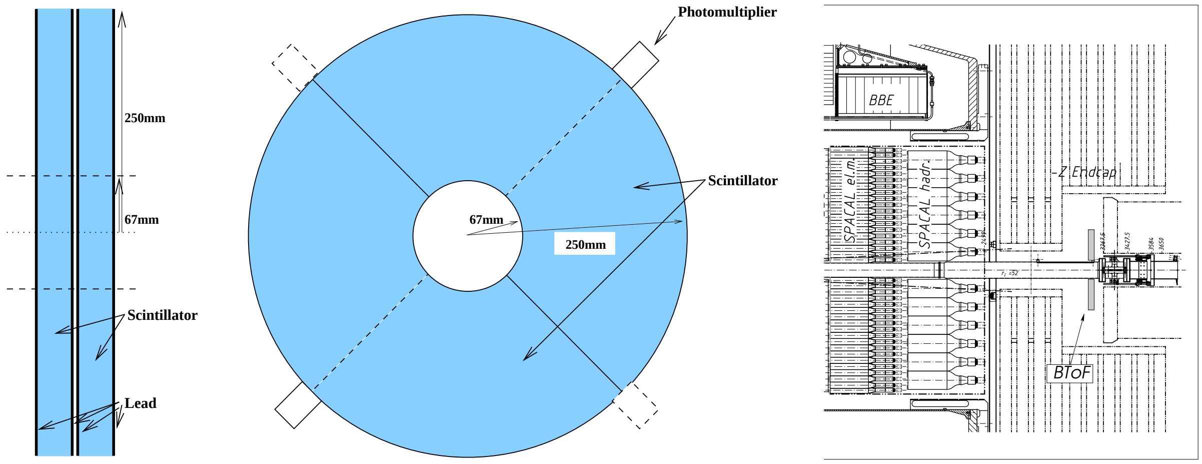

Figure 2: Schematic view of the BToF and its location in the rear H1 detector

The BToF provides three trigger elements (see table 1 for a list of all ToF related trigger elements). The complete time window is 96 ns long, defined by the time between two bunch crossings. This time interval is divided into three parts: The first interval is the background window (= BG), in which proton beam induced background events are detected in time with the proton beam. The second interval is the interaction window (= IA) that identifies particles coming in time with the electron beam. The global window (= GL) is build from the begin of the background up to the end of the interaction time window.

The trigger information formed by the ToF electronics is sent directly to the Central Trigger Logic (= CTL). The timing information of the PMs is digitized by FTDCs (= Flash Time to Digital Converters) in the readout system of the Central Tracker. These FTDC data are recorded eventwise in the bank CRPE (see table 2) accessible for the offline analysis. The information about the time-window that was hit can be found in the BRTE bank. From these banks, CRPE and BRTE, the more user-friendly bank named TOFT (see table 3) is built during the offline reconstruction. The method used to convert FTDC charge data to time information is described in [3].

2.2 The PToF

The eight PToF scintillators are mounted inside the absorber structure of the forward Plug calorimeter [5] at $z = +5.3$ m. Each of the scintillator tiles has an outer dimension of 150 mm $\times$ 150 mm. The shape of the scintillator tiles is adapted to the beampipe to allow an installation close to it. Light-guides are used to transport the light pulses to the PMs. Similar to the BToF special PMs are used (Hamamatsu R2490) due to the presence of magnetic field. A schematic view of the PToF is given in figure 3.

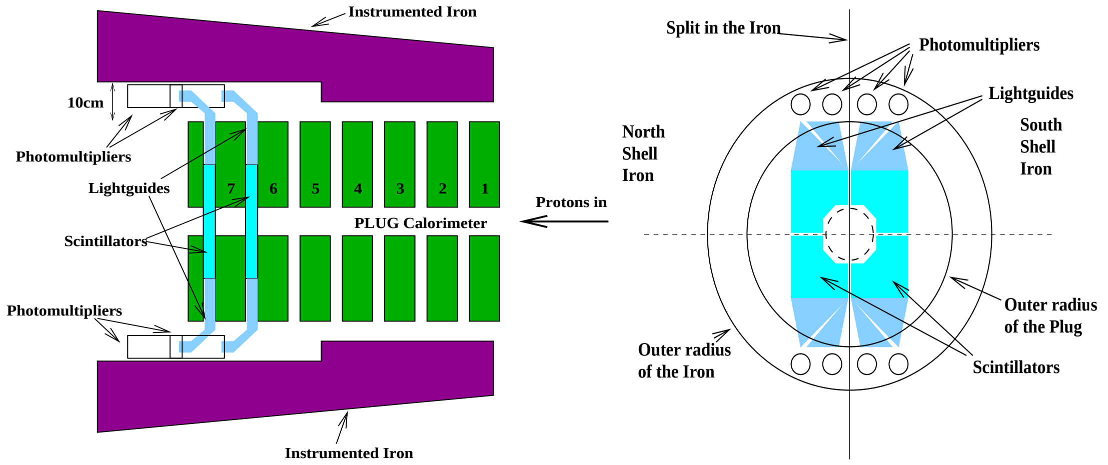

Figure 3: Schematic view of the PToF.

The PToF has three time windows defined in a similar way as the BToF. The global window covers the interval from the beginning of the electron signal to the end of the proton signal. Due to the installation position in the forward region the interaction and background time windows of BToF and PToF are different: The PToF background time window starts when the electron beam passes the Plug. The interval of the interaction time window is defined by the time when the proton beam passes the Plug region. Like BToF data the PToF data are recorded in the CRPE and BRTE banks.

2.3 The FToF

The FToF consists of two layers of scintillator. Each of them has following dimensions: 200 mm $\times$ 600 mm $\times$ 10 mm. The two pieces are separated by 7.5 mm of lead. Two PMs are used to read out the scintillators. These two scintillators are mounted directly above the beam pipe. The FToF uses electronics similar to the BToF and PToF.

Trigger element	Trigger name
64	BToF interaction
65	BToF background
66	BToF global
67	PToF interaction
68	PToF background
69	PToF global
70	FToF interaction
71	FToF background

Table 1: The ToF trigger elements

2.4 The ToF electronics

All ToF devices use the same environment for the ToF measurements. A detailed scheme of the electronic system is given in the appendix. In figure 4b a simplified circuit diagram is shown in order to illustrate the principle of the time of flight measurement.

The signal coming from a photomultiplier is sent to a discriminator, which forms an output pulse. Each discriminator provides a signal for the TDC and FTDC system as well as an output pulse used to form a signal for the CTL. The TDC is a CAMAC based online Time to Digital Converter system which gives immediate diagnostics and the FTDC is a VME based TDC system that is read out every event. In order to determine the time windows these output pulses are gated by three different strobes (figure 4). These strobes (IA,BG,GL) are individually generated inside the ToF system on the basis of the HERA clock signal. PM signals are passed to the CTL only if they appear in a defined time window because of these strobes. As a by-product TDC and FTDC information about these trigger elements are generated and available for online and offline purpose. In order to suppress single hits various coincidences can be formed inside each ToF component.

In summary the following signals are provided by the ToF system:

- For BToF and PToF 3 trigger elements (IA, BG, GL) and in case of the FToF 2 trigger elements (IA, BG) are sent to the CTL
- For the trigger elements of the BToF and the PToF a TDC signal and an FTDC signal of each trigger element is generated
- In case of the FToF a TDC signal for all three trigger bits is produced but the FTDC signal only for the global time window
- For each PM a TDC signal and an FTDC signal is provided

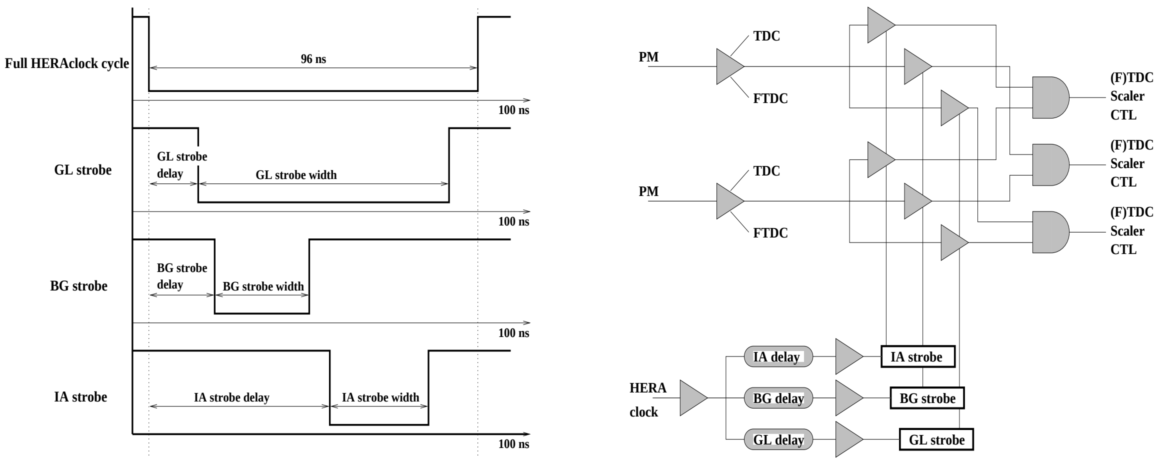

Figure 4: (a) Strobes of the ToF time windows (b) Schematic view of the ToF electronic system.

3 Online monitoring of the ToF system

All ToF related information is monitored on the ToF Macintosh in hall north, room 307, rack B9. The ToF online histograms are produced using TDC information as described above.

Figure 5 shows the online histograms of the FToF. In contrast to the PToF and BToF the FToF time windows are placed only around the proton signal and do not deal with the electron beam. In the TDC window of FToF global trigger (figure 5c) the whole proton signal is seen. Figure 5a demonstrates that the FToF_BG trigger is used to cut the late satellite bunch of the proton beam. This late satellite arrives about 5 ns after the main proton bunch. The interaction trigger (figure 5b) covers the main peak of the proton bunch. During normal beam conditions the satellite bunches are only weakly filled so that no clear satellite signal is visible in the figure.

The TDC distributions of the PToF trigger are shown in figure 6. The PToF global trigger covers both beams. The electron beam arrives first in the PToF, and the proton beam later. The signal of the electrons coincides with the PToF background trigger while the signal from the protons coincides with the interaction trigger. The PToF background trigger is usually produced by synchrotron radiation of the electron beam and backscattered particles from the C3 collimator.

The function of the BToF is illustrated in figure 7. In the plot of the global trigger TDC time both peaks from proton beam and electron beam appear, but now the proton signal, which is the first one, corresponds with the BToF background trigger. This BToF background signal is the most constraining veto in the H1 trigger system, since events of this type would saturate the H1 data stream and hence lead to a large dead time. A BToF background signal is typically caused by proton beam induced beam-gas or beam-wall interactions. The BToF interaction trigger is due to particles travelling in time with the electron beam.

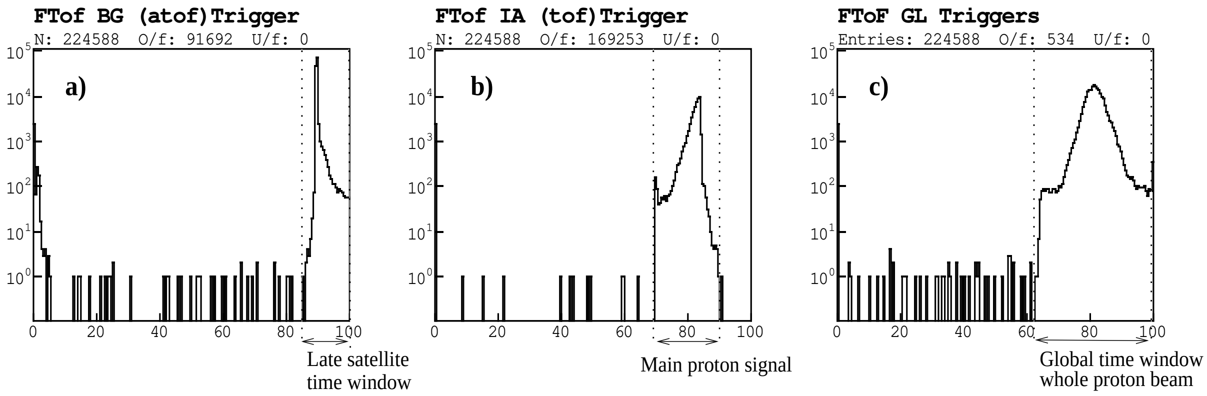

Figure 5: Online TDC display of FToF triggers.

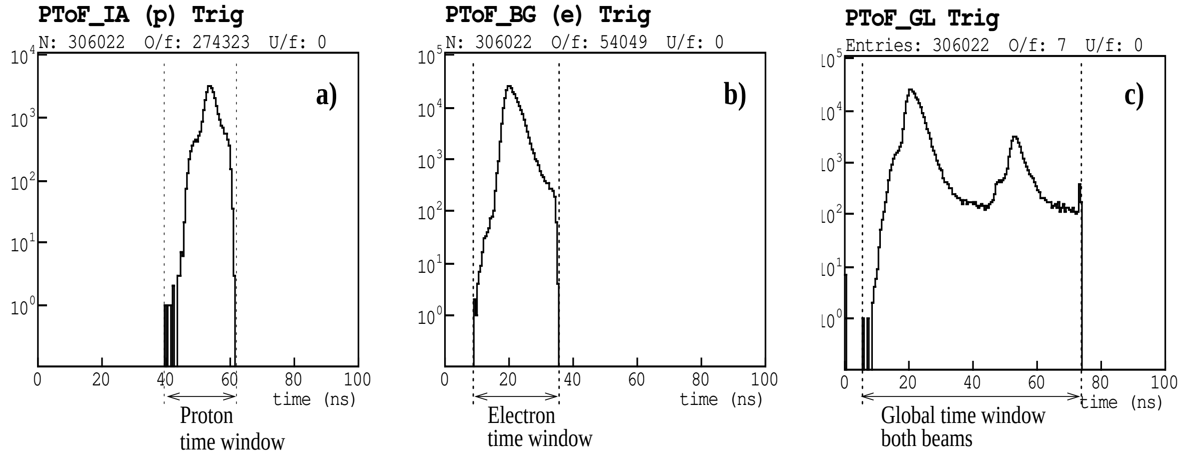

Figure 6: Online TDC display of PToF triggers.

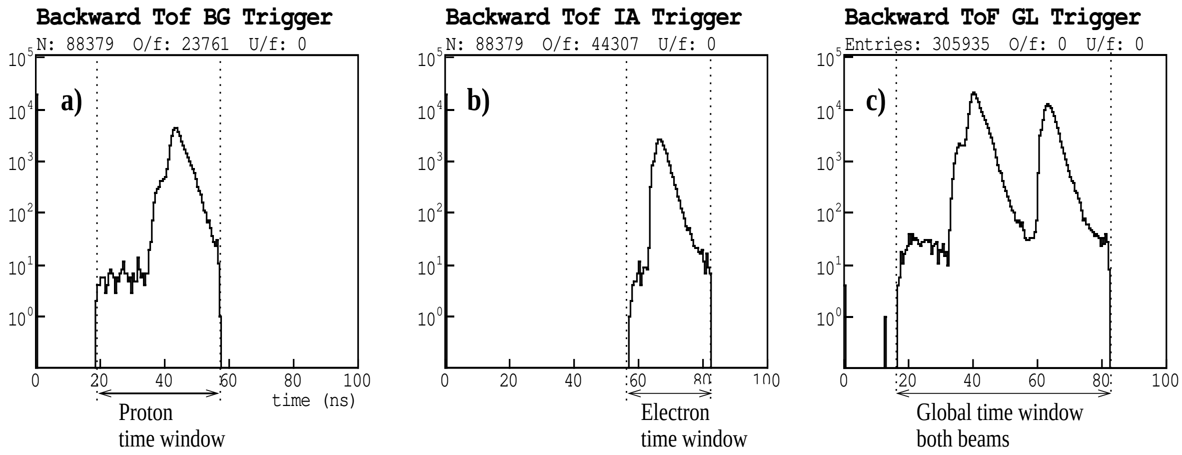

Figure 7: Online TDC display of BToF triggers.

4 Analysis of BToF offline data

4.1 BToF in a Veto-off run

In order to investigate the efficiency of the BToF triggers the BToF_BG veto and other global veto triggers were switched off. During typical beam conditions over 95% of all L1 triggers have the BToF_BG trigger element set. Hence the BToF veto is very important for rejecting the proton induced background. As the BToF_BG veto is switched off the BToF global (figure 8) histogram shows a large fraction of that proton induced background. Only a few events are recorded in the interaction time window as expected in the HERA environment.

In both time windows the trigger elements as recorded in the CTL are set correctly with respect to the FTDC information. The absence of BToF_BG triggers in the interaction time interval demonstrates the proper functionality of the BToF veto. Nevertheless for a few events, only the FTDC information is present but no trigger element is set due to electronic inefficiencies. Note however that this feature does not suppress any genuine physics events.

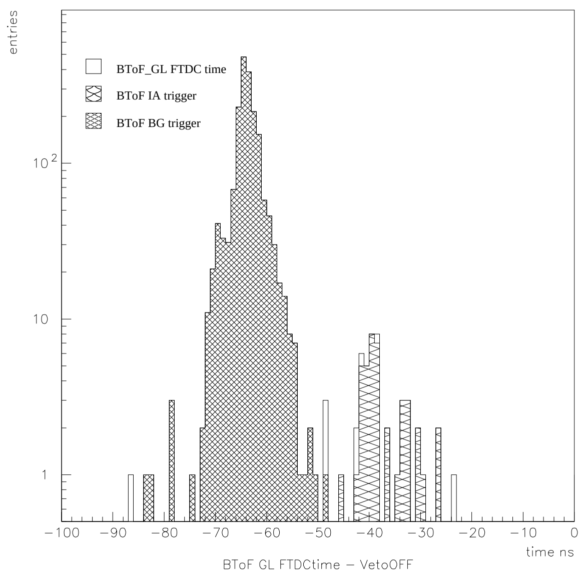

Figure 8: BToF Global FTDC spectrum in a veto-off run.

4.2 BToF in a luminosity run

Figure 9 shows the BToF time distribution observed in the raw data sample of a luminosity run taken in trigger phase 4. There are only a few events that have the BToF_BG trigger set. As all physics sub-triggers at L1 have the BToF veto included, these events are triggered by monitor triggers, which allow to check the detector performance. The amount of these background events depends on the prescale factors of the different monitor triggers. In figure 9a clear separation of physics and background events is visible, which demonstrates the correct adjustment of the ToF time windows.

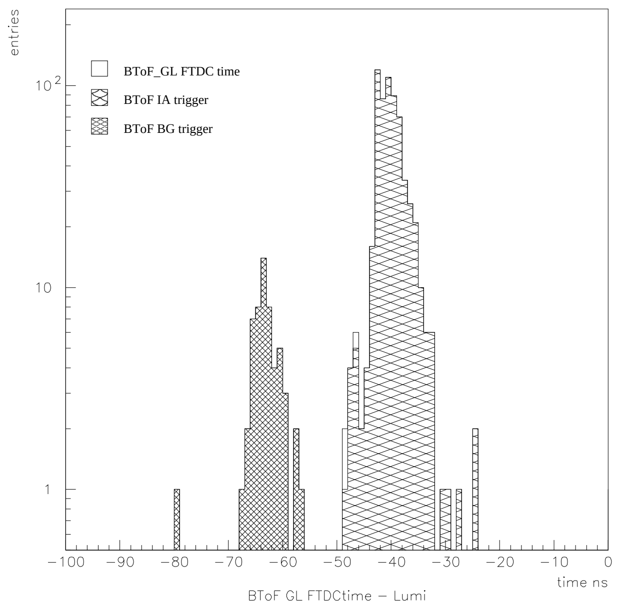

Figure 9: BToF Global FTDC times in a typical lumi run.

The BToF_BG trigger element, which is sent to the CTL, is usually set over five bunch crossings, one before and three after the nominal bunch crossing. This is necessary because many components of the H1 detector produce trigger signals which are spread over more than one bunch crossing (e.g. some LAr trigger elements). Trigger signals that are longer than one bunch crossing or have a wrong t_0 would trigger the detector, if they are not vetoed by the spread BToF_BG trigger. In figure 10 the distribution of all ToF trigger elements is shownfor a L2/L4-transparent run where the ToF veto triggers were not used in the CTL cocktail. That is the reason why all events with the BToF_BG trigger set appear in the data.

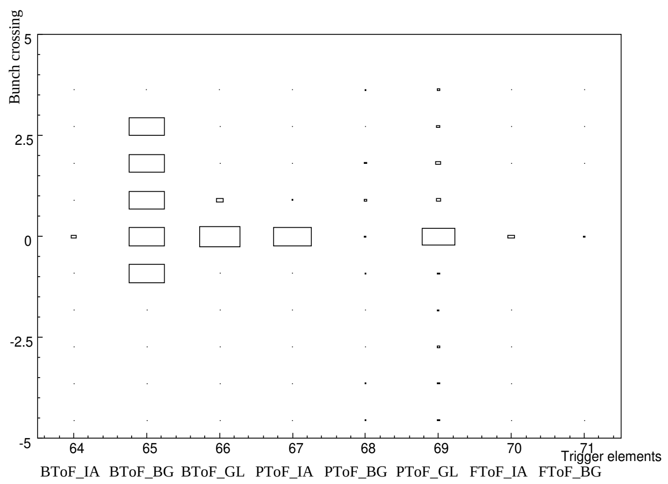

Figure 10: ToF triggers activity over several bunch crossings.

4.3 PToF problems

In the offline analysis a problem became visible which was not seen in the online monitoring historgams: In figure 11 the distribution of the PToF_IA and the PToF_BG trigger is shown for a L2/L4 transparent run. The left peak in figure 11 is due to background activity caused by the electron beam. The right peak is due to electron-proton interaction and/or proton beam activities. It is clearly seen that the PToF_BG trigger works very inefficiently since the left peak is not tagged by the PToF_BG trigger element. On the other hand several events in the right peak are marked by the PToF_BG trigger. Therefore the PToF_BG trigger element was disabled at the begin of the 1997 luminosity period. This malfunction might have been a problem already in the 1996 luminosity period and *needs further investigations with respect to potential veto of genuine physics events.*

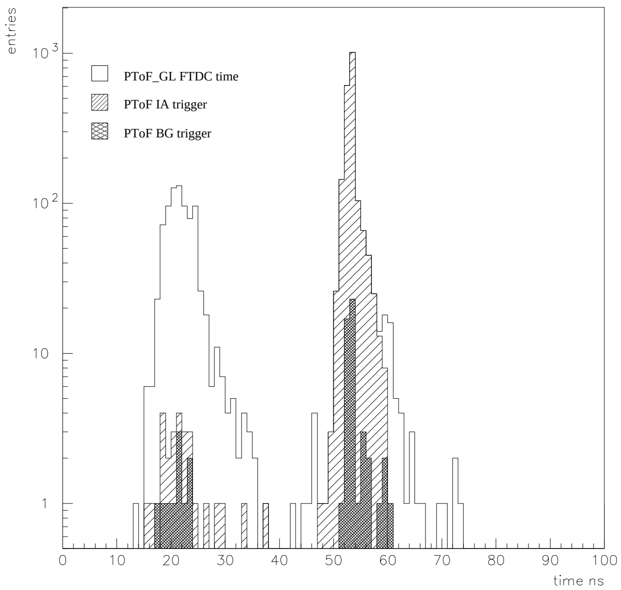

Figure 11: PToF Global FTDC times in a transparent run.

5 Time resolution

The ToF system is expected to provide an exact time information due to the good time resolution of scintillator devices with PM readout. This information is essential to define an accurate trigger and to observe satellite bunches.

In order to determine the time resolution of the H1 ToF system a special run was recorded during stable proton beam. All global veto triggers were switched off to collect a large sample of signals in all ToF scintillators.

5.1 BToF time resolution

As described above for each channel of the BToF an FTDC measurement is provided. In figure 12a the correlation of FTDC time signals of two consecutive BToF counters is plotted. Only events where both PMs had exactly one hit were taken into account. In figure 12b the time difference between these two FTDC measurements is shown. A gaussian fit to this distribution is used to determine the time resolution. The BToF time resolution is found to be $\sigma \approx 0.7$ ns in case of stable proton beam data similar to luminosity data. The mean value is not exactly 0 due to a relative miscalibration of the individual PM channel delays. All other possible combinations of the four counters lead to comparable results.

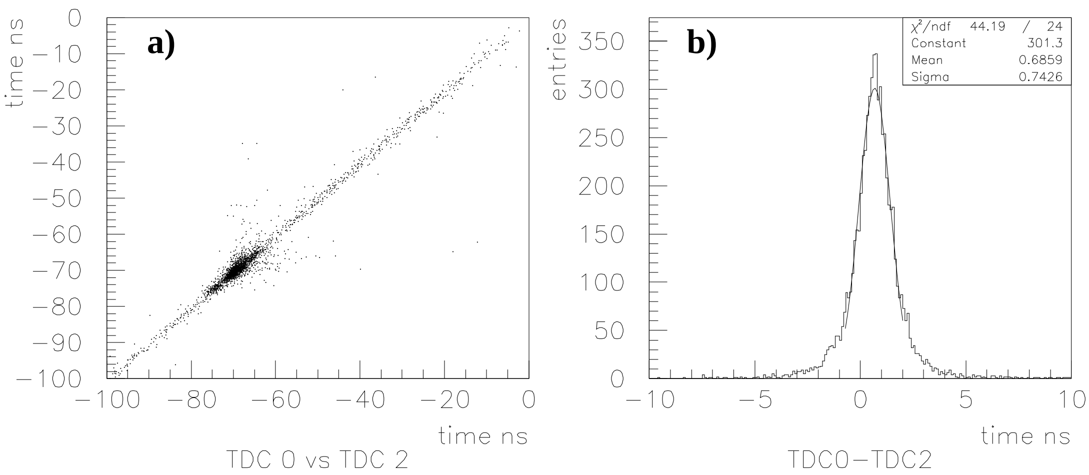

Figure 12: BToF time resolution: (a) TDC time counter 2 versus time counter 0. (b) Time difference of both counters.

5.2 PToF time resolution

For the PToF it is useful to compare the FTDC information of counters positioned behind each other. For one setup of subsequent scintillator tiles the time resolution is shown in figure 13 based on data with proton beam only. The time resolution is determined by a gaussian fit to the time differences. The time resolution was found to be $\sigma = 1$ ns – 1.5 ns for the four combinations (0–4, 1–5, 2–6, 3–7). The shift of the mean value has the same origin as in the BToF case. In case of luminosity runs the measured time resolution of the PToF has nearly the same precision.

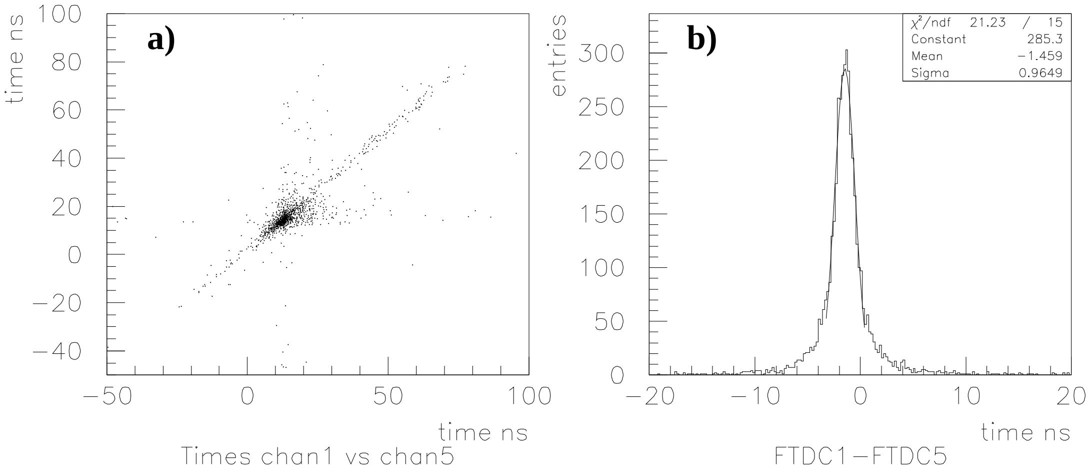

Figure 13: PToF time resolution: (a) FTDC time of counter 1 vs FTDC time of counter 2. (b) Time difference of both walls.

6 Efficiency of the ToF system

6.1 BToF efficiency

According to figure 2 the BToF is located behind the SPACAL inside the backward endcap of the Instrumented Iron. To test the efficiency of the BToF data of stable protons at 820 GeV have been recorded. The used trigger was completely independent of the ToF system and the Instrumented Iron, using only SPACAL calibration triggers.

The principle of this analysis is based on the demand of having a coincidence in both sections of the SPACAL and that part of the Instrumented Iron which is located in between the BToF and the SPACAL. A signal should be observed in the BToF for particles flying along the beampipe hitting both SPACAL and the inner region of the backward endcap.

In the analysis a track is reconstructed using SPACAL information and the hit in the endcap of the Instrumented Iron. This track is extrapolated to the plane of the BToF. In figure 14a the calculated distance of the extrapolated track to the center of the beampipe in the plane of the BToF is shown. The full line shows the extrapolated impact point for all reconstructed tracks. It is possible that per event more than one track may enter this plot. For 99.3% of these selected events a signal of the Vetowall background trigger has been set, demonstrating a proper extrapolation.

The dashed line is due to tracks with response, the dotted line is due to extrapolated tracks without response of the BToF. For large radii the observed behaviour is expected because of the limited acceptance of the BToF (R_{outer} = 25 cm). In the region of the border of the BToF an in-efficiency has to be considered due to the uncertainty of the extrapolation.

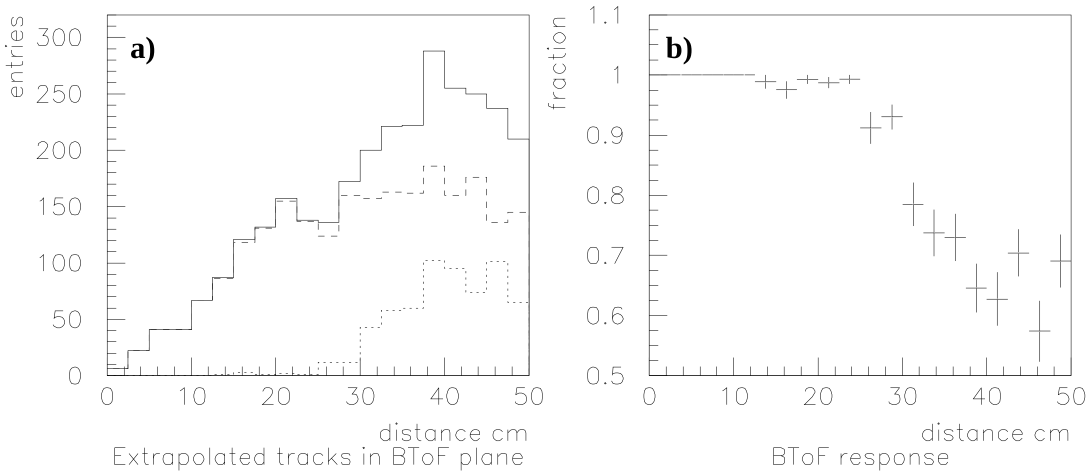

Figure 14: Tracks extrapolated to the BToF.

Any further analysis is restricted to the region $R_{BToF} < 25$ cm. By the division of the plot showing all tracks and that one showing tracks with response in the BToF the efficiency is determined, shown in figure 14b. The inner region of the BToF is fully efficient only in the outer region the efficiency drops from 100% to 97.5%. But here the lack of efficiency may be partly caused by the uncertainty of the extrapolation mentioned above.

As the BToF is mainly used to produce a trigger signal not only a PM signal but also the BToF_BG trigger signal was investigated. The efficiency of the BToF_BG is calculated in the following way:

$$\varepsilon_{BToF\_BG} = \frac{\sharp(\text{events BToF\_BG triggered})}{\sharp(\text{all selected events})}$$

Figure 15 shows ε_{BToF}. The behaviour of ε_{BToF_BG} is very similar to the efficiency discussed above, demonstrating the good functionality of BToF trigger electronics.

From 736 selected events in the acceptance of the BToF ($R_{BToF} < 25$ cm) 725 events have a BToF_BG trigger element set, leading to a trigger efficiency of 98.5% $\pm$ 0.2%, where the error is an estimate including statistical error and systematical errors due to the limited precision of the extrapolation.

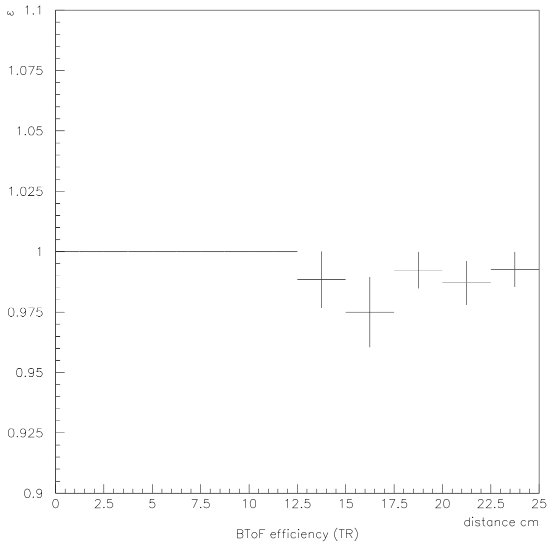

Figure 15: BToF_BG efficiency.

6.2 PToF efficiency

Due to the location of the PToF between the cryostat and a HERA quadrupole magnet inside the Plug calorimeter structure no device is available to supply tracking information close by. Hence another method based only on calorimetric information is used to calculate an efficiency of the PToF.

In order to become independent of PToF triggers a special run was taken with only stable proton beam and a standard trigger setup, but disabled global veto triggers. For high energetic particles in the very forward region it is expected that besides an energy deposition in the Plug calorimeter a signal is measured as well in the PToF. In figure 16a the ratio of events with a PToF signal and all triggered events is plotted versus the measured Plug energy. This ratio can be interpreted as efficiency of the PToF. With

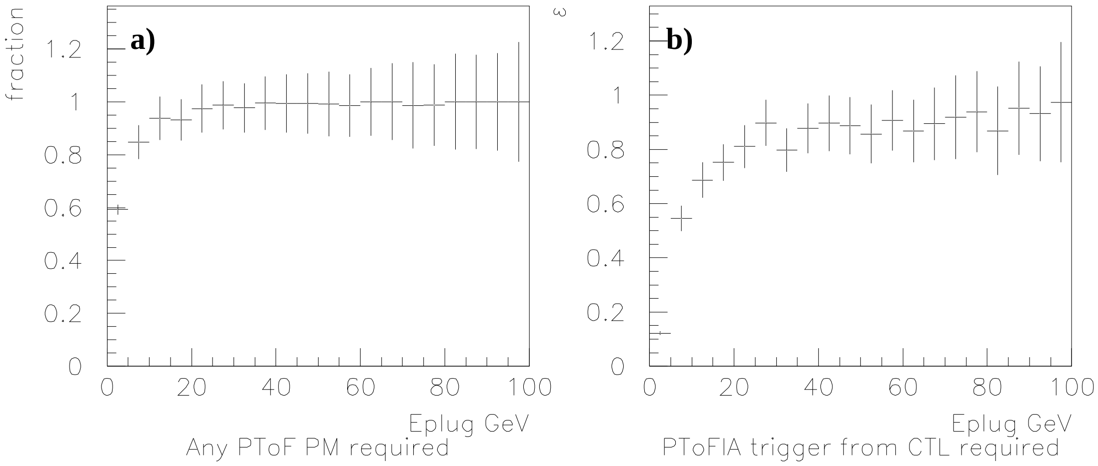

Figure 16: PToF efficiency (a) for PToF PM signals and (b) for the PToF_IA trigger element.

rising Plug energies the efficiency increases. In case of Plug energies beyond 25 GeV about 99% efficiency is reached. For lower energies the efficiency is decreasing but this behaviour is expected due to the possibility of full absorption in the calorimeter structure (44 X_0, 4.3 λ).

Similar to the BToF case the efficiency of PToF trigger elements has been studied. As described above a ratio is calculated using now PToF_IA triggered events and all triggered events irrespectively of the PToF. This ratio is plotted versus the energy, shown in figure 16b. In case of the PToF_IA trigger signal an efficiency of 90% is reached for Plug energies larger than 25 GeV. This efficiency is smaller compared to the PM signals due the demand of a coincidence for the two consecutive PToF planes.

7 Acknowledgements

We would like to thank M. Landon, G. Lopez and D. Wegener for their support. We appreciate the discussions about the soft- and hardware performance of the old and new ToF systems.
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8 References

1. H1 Collaboration, I. Abt et al., NIM A386(1997) 310–396
2. P. Biddulph et al., *Analysis of FToF data*, internal note H1–06/94–362.
3. J. Heatherington et al., *Studies on ToF FTDC data*, internal note H1–08/93–307.
4. http://www-h1.desy.de/~nicholls/SpacalTDC/tdc_home.html
5. W. Hildesheim, V. Riech, M. Seidel, *The Plug Calorimeter Users Guide*, internal note H1–08/94–372.

9 Appendix

9.1 Layout and numbering scheme of the BToF scintillators

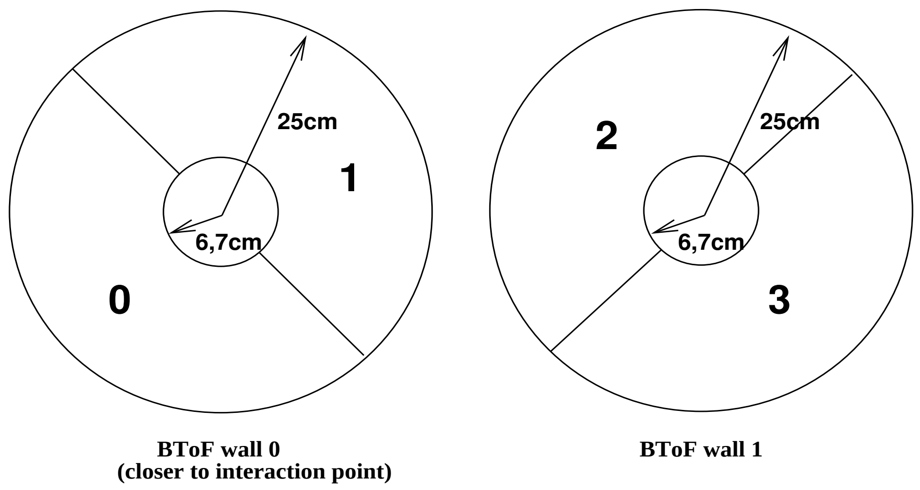


Figure 17: Scintillator positions of the BToF (z=–3.2 m)

9.2 Layout and numbering scheme of the PToF scintillators

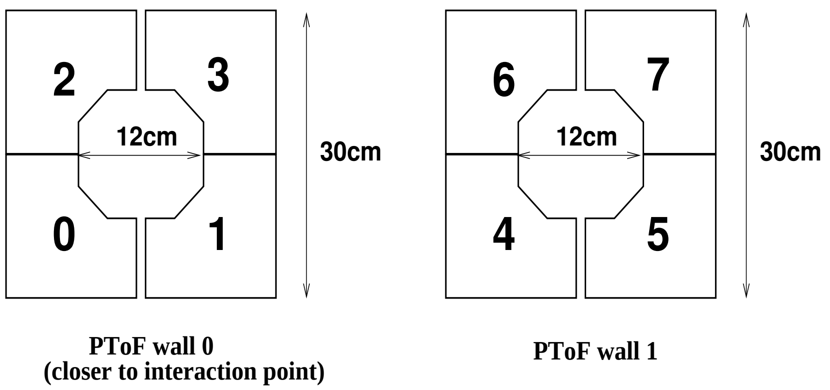


Figure 18: Scintillator positions of the PToF (z=+5.3 m)

9.3 Description of the banks

Channel	Data
16	Charge of BToF_IA FTDC
17	Charge of BToF_BG FTDC
18	Charge of BToF_GL FTDC
24 to 27	Charge of individual BToF counters
32 to 39	Charge of individual PToF counters
41	Charge of PToF_IA FTDC
42	Charge of PToF_BG FTDC
43	Charge of PToF_GL FTDC

Table 2: ToF related channels of CRPE bank

Channel	Data
0 to 3	FTDC time of individual BToF counters
100 to 107	FTDC time of individual PToF counters
109	FTDC time of the PToF interaction trigger
110	FTDC time of the PToF background trigger
111	FTDC time of the PToF global trigger
221	FTDC time of the BToF interaction trigger
222	FTDC time of the BToF background trigger
223	FTDC time of the BToF global trigger
300	FTDC time of the FToF global trigger

Table 3: TOFT bank

9.4 BToF electronic system

See page 17.

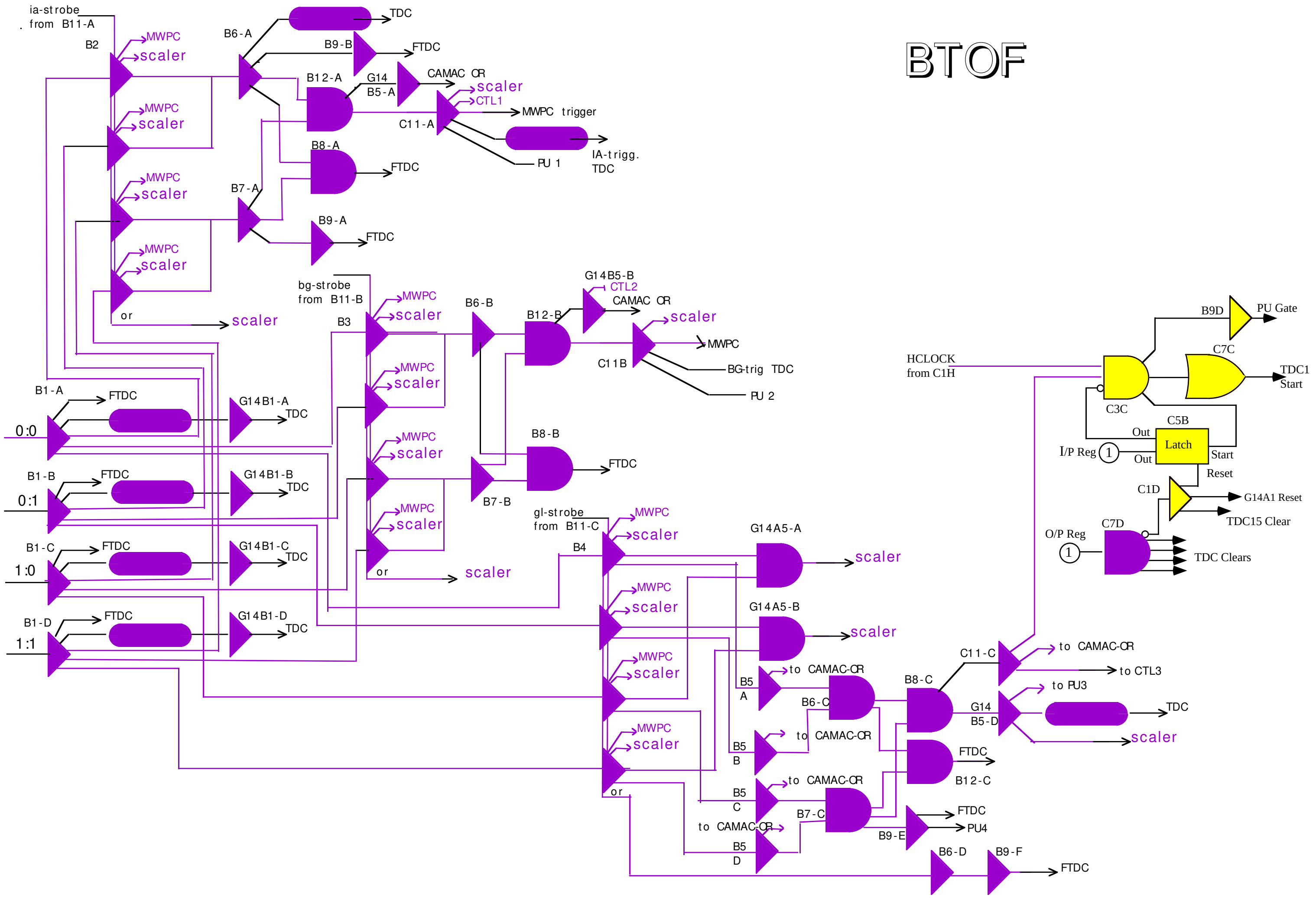
9.5 PToF electronic system

See pages 18 and 19.

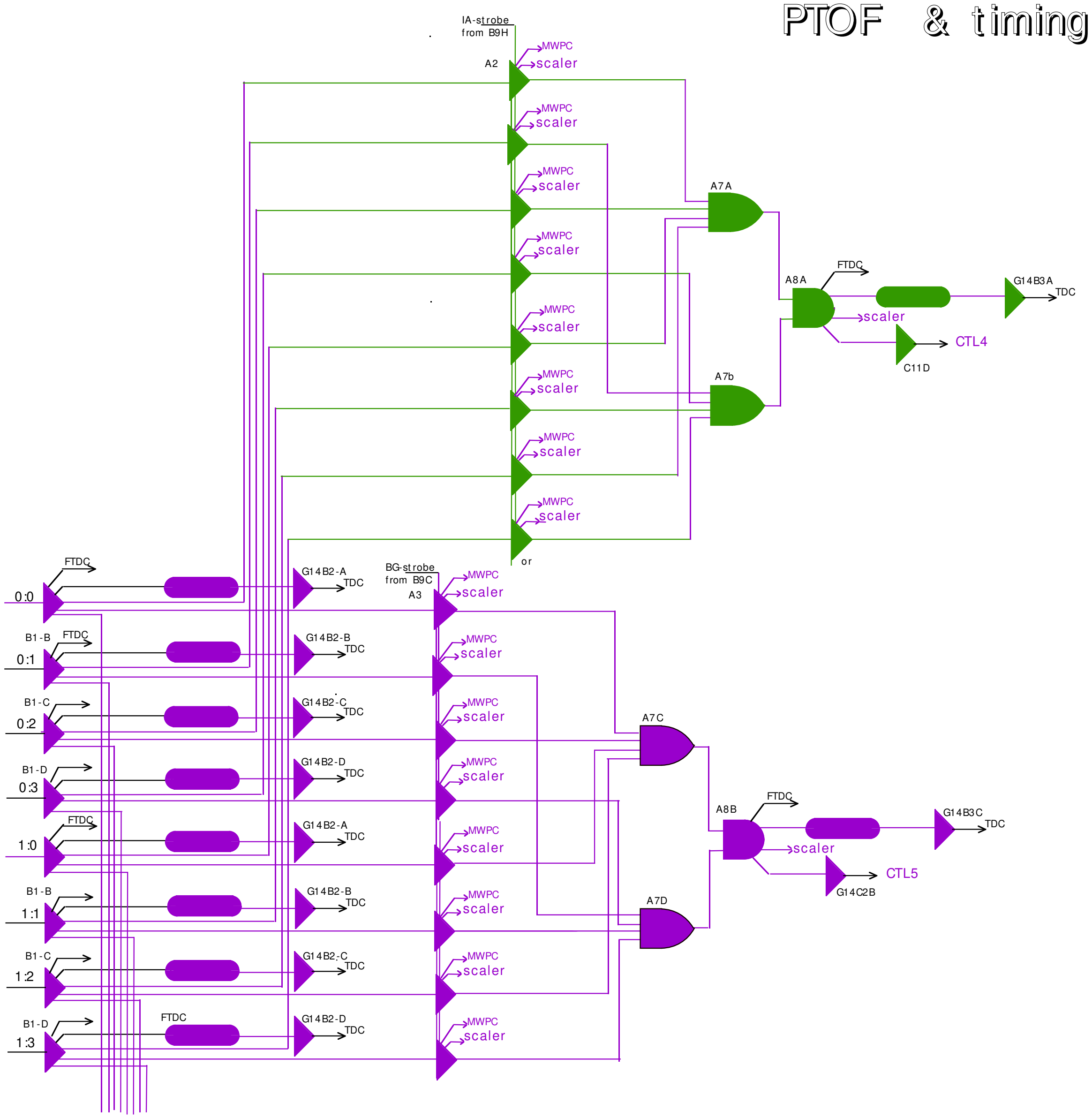
9.6 FToF electronic system

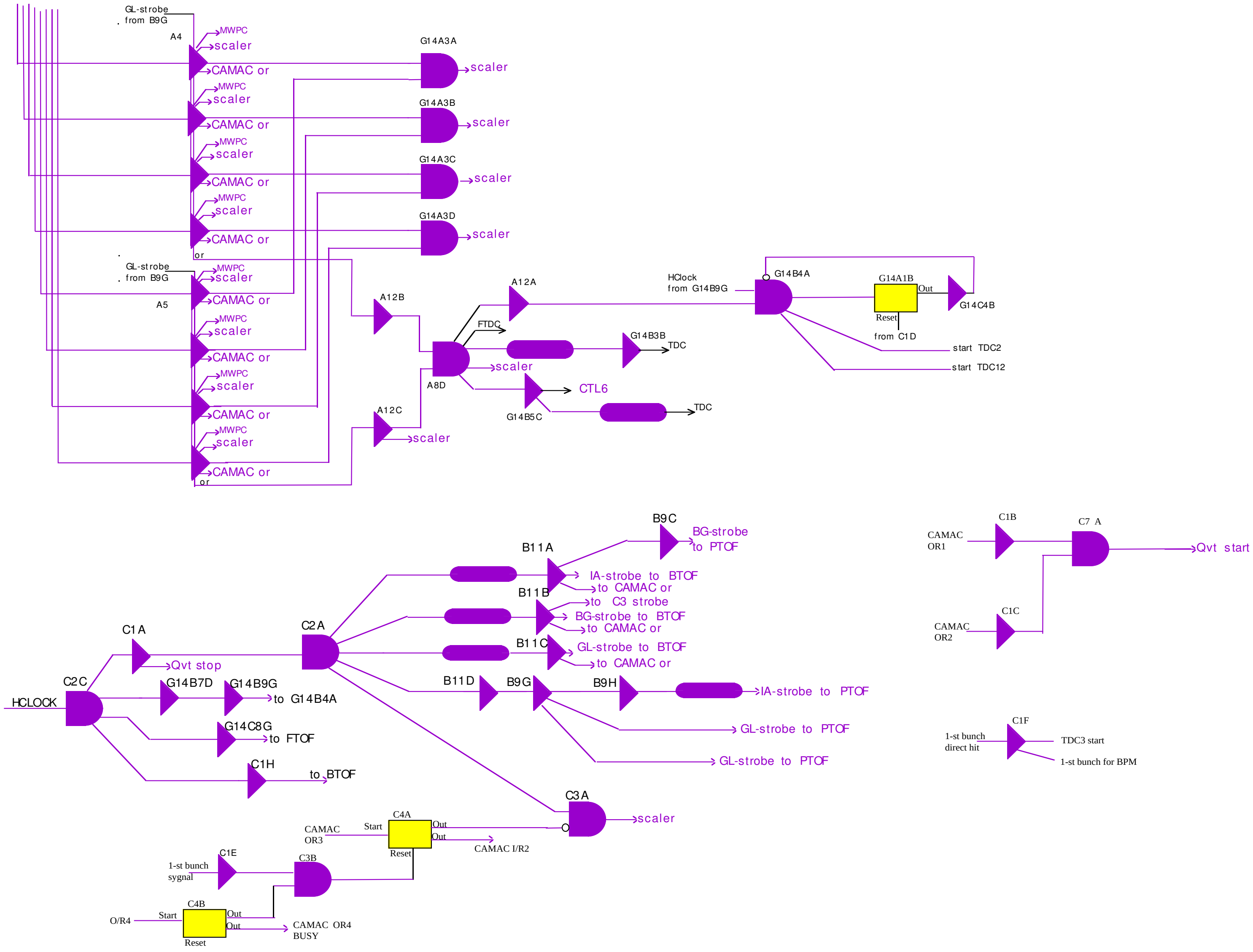
See page 20.

BTOF


ia-strobe
from B11-A
B2
MWPC
scaler
B6-A
TDC
B9-B
FTDC
B12-A
G14
B5-A
CAMAC OR
CTL1
C11-A
MWPC trigger
IA-trigg.
TDC
PU 1
B8-A
B7-A
B9-A
or
B1-A
0:0
G14B1-A
B1-B
0:1
G14B1-B
B1-C
1:0
G14B1-C
B1-D
1:1
G14B1-D
bg-strobe
from B11-B
B3
B6-B
B12-B
G14B5-B
CTL2
C11B
BG-trig TDC
PU 2
B8-B
B7-B
gl-strobe
from B11-C
B4
G14A5-A
G14A5-B
B5
A
B
C
D
to CAMAC-OR
B6-C
B7-C
B8-C
B12-C
B9-E
PU4
C11-C
to CTL3
to PU3
B5-D
B6-D
B9-F
HCLOCK
from C1H
B9D
PU Gate
C7C
TDC1
Start
C3C
C5B
Out
Latch
I/P Reg
1
Reset
C1D
G14A1 Reset
TDC15 Clear
O/P Reg
C7D
TDC Clears

PTOF & timing logic




GL-strobe
from B9G
A4
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from B9G
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A8D
FTDC
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CTL6
G14B5C
HClock
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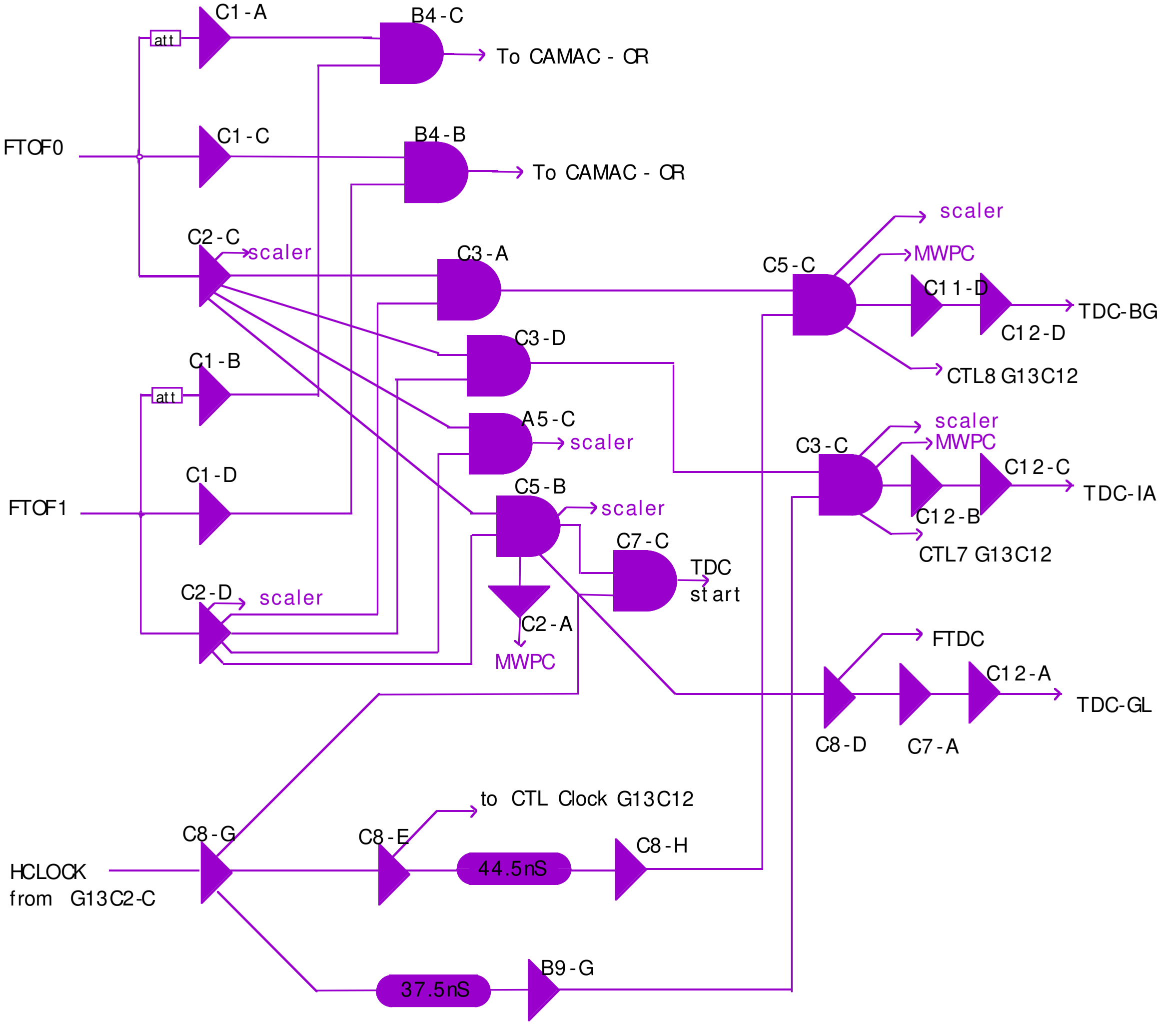
G14B4A
G14A1B
Out
Reset
from C1D
G14C4B
start TDC2
start TDC12
B9C
BG-strobe
to PTOF
B11A
IA-strobe to BTOF
to CAMAC or
B11B
to C3 strobe
BG-strobe to BTOF
B11C
GL-strobe to BTOF
C1A
Qvt stop
C2A
C2C
HCLOCK
G14B7D
G14B9G
to G14B4A
G14C8G
to FTOF
C1H
to BTOF
B11D
B9G
B9H
IA-strobe to PTOF
GL-strobe to PTOF
C3A
CAMAC
OR3
Start
C4A
CAMAC I/R2
1-st bunch
sygnal
C1E
C3B
O/R4
C4B
CAMAC OR4
BUSY
CAMAC
OR1
C1B
C7 A
Qvt start
CAMAC
OR2
C1C
C1F
1-st bunch
direct hit
TDC3 start
1-st bunch for BPM

FTOF



att
C1 - A
B4 - C
To CAMAC - OR
FTOF0
C1 - C
B4 - B
To CAMAC - OR
C2 - C
scaler
C3 - A
C5 - C
scaler
MWPC
C11 - D
C12 - D
TDC- BG
CTL8 G13C12
C1 - B
att
C3 - D
A5 - C
scaler
C3 - C
scaler
MWPC
C12 - C
C12 - B
TDC- IA
CTL7 G13C12
FTOF1
C1 - D
C5 - B
scaler
C7 - C
TDC
start
C2 - D
scaler
C2 - A
MWPC
FTDC
C12 - A
TDC- GL
C8 - D
C7 - A
to CTL Clock G13C12
HCLOCK
from G13C2-C
C8 - G
C8 - E
44.5nS
C8 - H
37.5nS
B9 - G