COMPASS NOTE 2011-5

TECHICAL SUMMARY OF THE LARGE ANGLE SPECTROMETER TRIGGER

Authors:
N. du Fresne, J. Bieling, C. Seiffert, A. Zimmermann,
J. Barth, J. Pretz, E.M. Kabuss, J. Bernhard

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1 Introduction

For future data taking, i. e. Drell-Yan and GPD, a new trigger system was constructed to enlarge the muon trigger acceptance towards large Q^2. At large scattering angles, target pointing in vertical direction is an adequate trigger concept, provided at least two hodoscopes with a large enough distance can be installed in the experiment. Therefore it was decided to set up a pair of trigger hodoscopes with horizontal slabs for target pointing. To reach large Q^2 the hodoscopes have to be positioned in the Large Angle Spectrometer (LAS) of the experiment, where not much space was left for additional detectors. The positions were chosen to have the maximum distance in between both hodoscopes. One of the hodoscope is situated behind the Muon Filter 1 (MF1: a 60 cm iron wall in between the Muon Wall 1 detectors) for muon identification. The second one was installed directly in front of RICH-1, thus the resulting distance between the two hodoscopes is 10.2 m.
In May 2010 the new hodoscopes were installed in the spectrometer. Each hodoscope consists of vertical scintillator slabs, and has a central hole. The light produced by charged particles that cross the scintillator material is detected with photo multiplier tubes (PMT) on both sides of the scintillator slabs. The target pointing is set up with the help of a coincidence matrix of all H1 and H2 channels. The geometry and the position of the hodoscopes define the matrix pattern.
The size of the H2 hodoscope is given by the size of the Muon Wall 1 (MW1) to ensure good tracking to the hodoscope. MF1 absorbs all hadrons to ensure that only muons hit H2. The central hole is given by the aperture of SM2, the acceptance of the Small Angle Spectrometer (SAS). The size of the slabs or the granularity is given by the requirements of the Drell-Yan (DY) programme and by the angular spread of the scattered muons due to multiple scattering in the material of the target and the absorber. With the chosen granularity it will be possible to distinguish events from the absorber and the actual target during the DY measurements. The hodoscope H2 is split into two halves to allow for easy triggering on muon pairs produced in DY reactions. This also avoids very long scintillator slabs.
When H2 position and size are fixed, the H1 position and the slab size depends only on the target position. The H1 size is symmetric and slightly bigger than needed for the muon run; in the DY programme the target region is shifted by a few meters upstream, to be able to distiguish between particles coming from the target and the absorber. The central hole of H1 consists of an air light guide system. For DY the central hole region has to be enlarged.
Both, the matrix and the meantimer are located on an FPGA (Field programable Gate Array) chip on a GANDALF board. The trigger signal consists of the signal with the matrix condition and the veto signal (V_{tot}) of the COMPASS veto system.
The hodoscope H1 was craned in on the 20^{th} of May. First it was moved to the garage position on a rail system (parallel to DC04, ST02 and ST03) and then carefully sled in. The PMTs were installed with the detector in beam position. To slide out H1 the PMTs have to be dismounted or at least uncabled.
The hodoscope H2 was craned in the 19^{th} of May with the central shielding and PMTs already mounted, the outer shielding had to be removed, so that the hodoscope fits in between the yellow support frame of SM2.

2 H1

2.1 Dimension and Position

The hodoscope H1 has a size of 2300 mm × 1920 mm and consists of 32 horizontal scintillator strips. It has a central hole of 500,mm × 240 mm, so the total active area is 4.3 m^2. H1 is located in front of the RICH detector at a Z-position of 582 cm in the COMPASS reference system. The exact position can be found in the survey report (https://edms.cern.ch/document/1078666).
The mechanical structure was planned and set up by the INFN Trieste group. The frame is made of BOSH aluminium rods. Deformation studies of the BOSH profile have been done, see figure 3. The studies were performed, assuming that 350 kg are attached on the center of the bar. The maximum deformation is 3.6 mm. An aluminium rail system has been attached to the yellow RICH support frame, on which H1 can be rolled into the beam position or the garage position for maintenance. The available place for H1 was approx. 30 cm
In figure 1 and 2 technical drawings of H1 are shown.

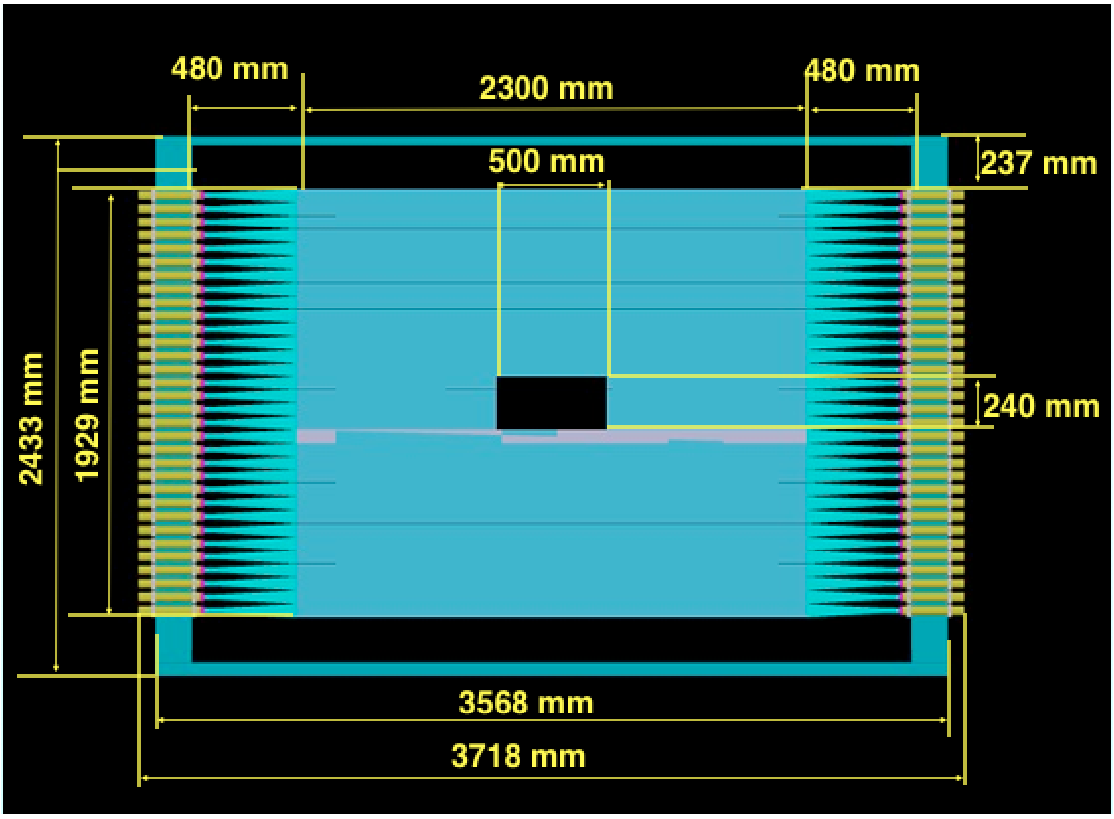

Figure 1: Schematical Drawing of H1 with the dimensions of the aluminium frame

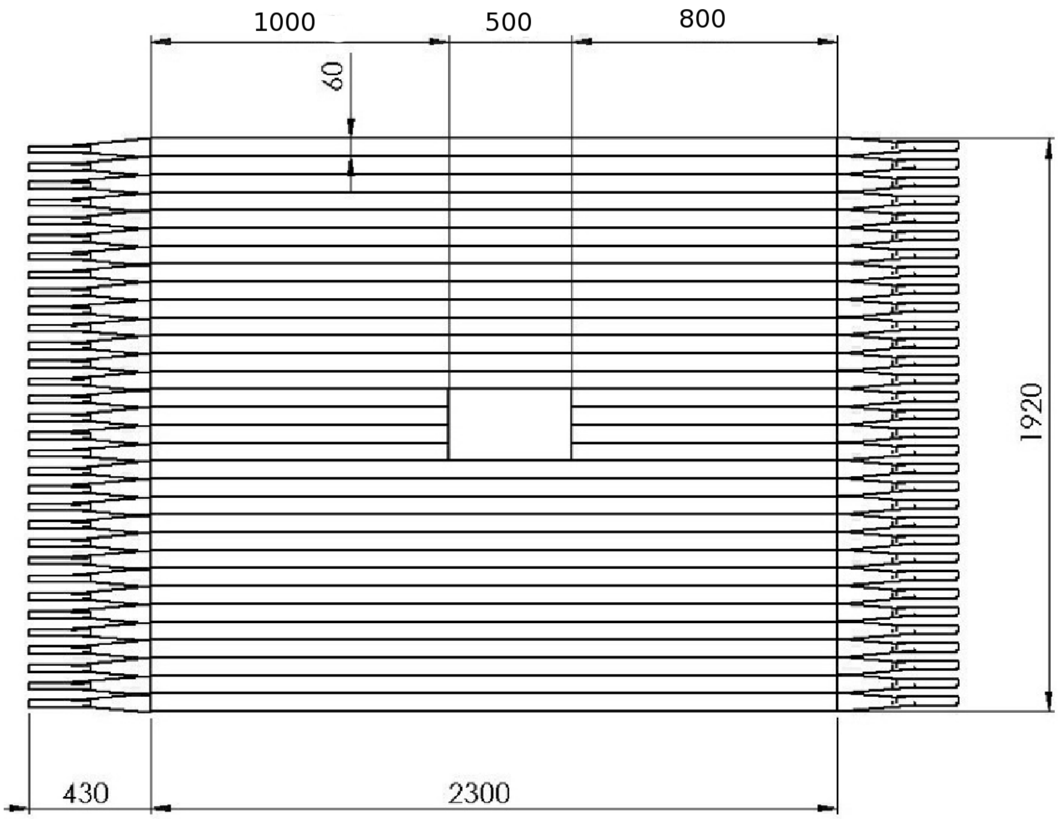

Figure 2: Schematical Drawing of H1

2.2 Substructure and Hole

H1 is divided into five subsections: 2 groups of 7 slabs for the outer region of the hodoscope (top and bottom), 2 groups of 6 slabs for the inner region and one group of 6 slabs for the central hole region. Each group is shifted towards the other groups (in Z) to avoid dead regions. This can be seen in figure 4.

The central hole matches with the acceptance of SM2, it had to be shifted by 10 cm towards the Jura side due to the bending of SM1. To maintain the double sided read out, the central slabs at the hole are individually connected with a high reflective foil to create an air light guide. This high reflective ESR foil (Enhanced Specular Reflector) was produced by 3M. The central hole group consist of 4 air light guide slabs and two normal long slabs. In figure 6 the central hole package with the air light guides is shown. The principles of the air light guide have been tested in Mainz and are described in the diploma thesis of C. Seiffert and A. Zimmermann.

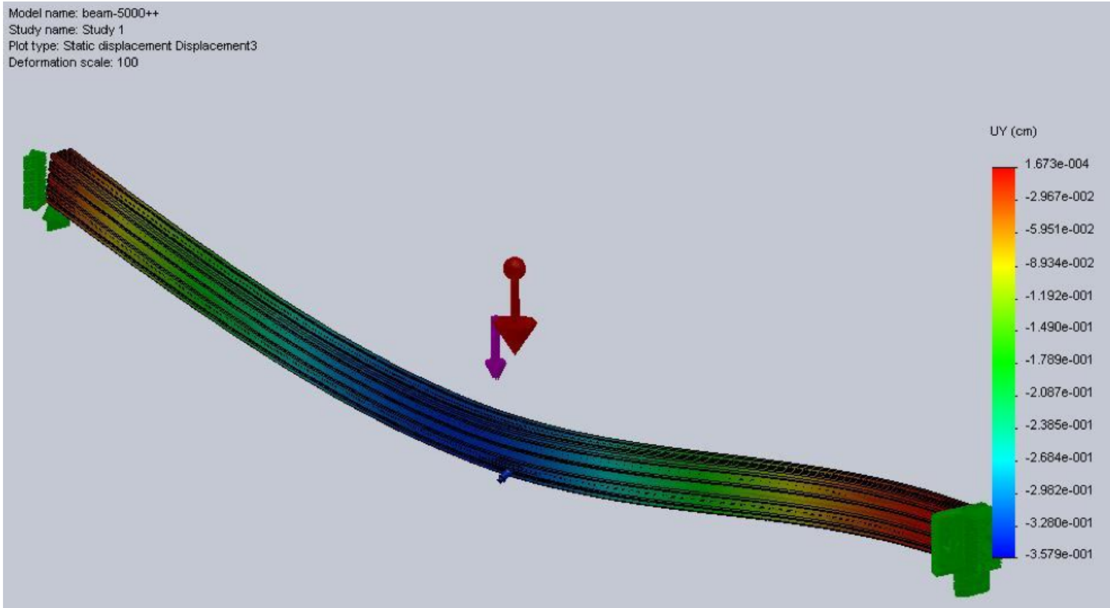

Figure 3: Deformation studies of the H1 frame

2.3 Scintillator Slabs and Light Guides

The scintillator material is BC408 from St. Gobain. The normal slabs are 230 cm long, 6 cm wide and 1 cm thick. The slabs for the hole region are 100/80 cm long (for the hole shift). Each single slab was packed in 0.2 mm thick aluminised mylar foil and the whole group was packed in 0.5 mm thick black foil for light tightness.

To collect the light, polished fish tail light guides made of PMMA[1] were glued to both ends of the scintillator slabs. The light guides are 48 cm long. The length of the guides was chosen such that the PMT and the shielding are outside of the RICH acceptance. Multiple scattering in front of the RICH could spoil the identification of charged particles. Figure 24 shows a technical drawing of the H1 light guides.

[1] Poly(methyl methacrylate)

Figure 4: Side view of H1 with Rohacell structure, light guides, PMTs and the Bosh aluminium frame. The group staggering can be seen.

2.4 Read-out, PMT and Shielding

The read out of each scintillator strip is done on both sides by PMTs of the type XP2982 or XP2900 (in the outer region). XP2982 is a fast, 11-stage, 1 1/8 inch photomultiplier tube with a bi-alkali cathode (www.photonis.com/upload/industryscience/pdf/pmt/XP2982.PDF). The voltage divider was designed at the University of Warsaw, Poland. The circuit diagramm is shown in figure 23.

Due to the interference of the target solenoid field and SM1 the PMT had to be shielded with a double layer of μmetall (thickness: 0.2 mm) surrounded by a 4 mm thick cylindric soft iron tube with an outer diameter of 46 mm and a length of 290 mm. Inbetween those magnetic shielding there is a 0.2 mm thick capton foil for insulation. An aluminium ring fitting on the cylindric part of the light guide is used to attach the soft iron shielding. The PMTs and their voltage dividers are mounted on the end cap for the shielding with a spring as place holder. The PMT is inserted into the soft iron shielding and hold in place with the end cap. Inside the magnetic shielding the spring pushs the detection window of the PMT onto the light guide. In figure 5 all parts of the H1 read out are shown.

The shielding performance was tested during beam time by switching SM1 on and off. No visible change of the analog signal was observed.

To keep the attenuation low, thick cables (COAX C-50-6-1 50 OHM) are used for the signals. On the hodoscope itself, thin patch panel cables (C-50-3-1) are used because of their flexibility. The following table shows the length of the different cables for H1 and H2. The cable length is dictated by the H2 position and its distance to the veto barrack, where the analog signals are processed. The cable length of H1 is around 13 m longer due to the time of flight of the scattered muon between H1 and H2 and effects like light propagation in the scintillator slabs and the signal transit time difference in the PMTs.

Cable type	**Length**	**Usage**
C-50-3-1	3 m	patch pannel cable for H1
CABL COAX C-50-6-1 50 OHM	63 m	signal cable to the veto baracke H1
C-50-3-1	10 m	patch pannel cable for H2
CABL COAX C-50-6-1 50 OHM	50 m	signal cable to the veto baracke H2

Figure 5: Dismounted read out of H1: connectors, soft iron shielding, end cap with spring and voltage divider, PMT XP2982, front cap for the light guide, μ metal shielding and the capton insulation.

2.5 Mechanical Stability

The groups of scintillator slabs are attached to the aluminium frame at the soft iron shieldings with clamps. Due to the length and the thickness of only 1 cm of the scintillators, each group had to be reinforced with a casing with a very low material budget composed of ROHACELL (1 cm and 2 cm thickness) and fiber glass strips. Each group of H1 has 2 cm of Rohacell IG 31 (0.032 g/cm^3 density) on one side and 1 cm of Rohacell IG 51 (0.052 g/cm^3 density) on the other side. These parts were glued with ARALDITE to a rectangular envelope around the scintillator groups to avoid sagging and vibrations of the groups. ROHACELL is a structural foam with low density and high mechanical stability. The ROHACELL fiber glas casing is also mandatory for the stability of the air light guide group. Figure 4 shows an overview of H1 with the Rohacell casing, the light guides, the shielding and the Bosh aluminium frame. The different groups are mounted on top of each other, so the weight is distributed on the clamped soft iron shielding and the supported ROHACELL/fiber glass casings.

Figure 6: View on the air light guide of H1. The high reflective foils are inside the brown casing

2.6 High Voltage and Threshold

The nominal voltage for the XP2982 PMT is around 1600 V. Each channel has been tuned individually during spill by observing the muon band on an oscilloscope.
The high voltage is provided by a SY1527 crate from CAEN with two 48 channel modules. Two distribution boxes (A1932 Radiall to SHV Cable adapter) distribute the HV to the single channels of H1. In 2011 the distribution boxes and the HV modules will be exchanged by 24 channel ones, similar to the H2 high voltage system. The 24 channel boxes are more suitable for high voltage monitoring.
The analog signals are converted to digital signal constant fraction discriminators. The threshold of the discriminator CAEN CFD V812 has been set to 16 mV.

2.7 Time Resolution of H1

The time resolution of the software mean time t_{mean} with respect to the BMS is shown in the following figure. Both TDC information t_1 and t_2 of one slab are used for that information.

$$\frac{t_1 + t_2}{2} = t_{\text{mean}}$$

The average resolution of each slab is approx. 250 ps, see figure 7.
This two uppermost and two lowermost slabs are currently not used in the set up of 2010/2011. They will be used for the DY measurement, during which the target cell is shifted upstream by serveral meters.

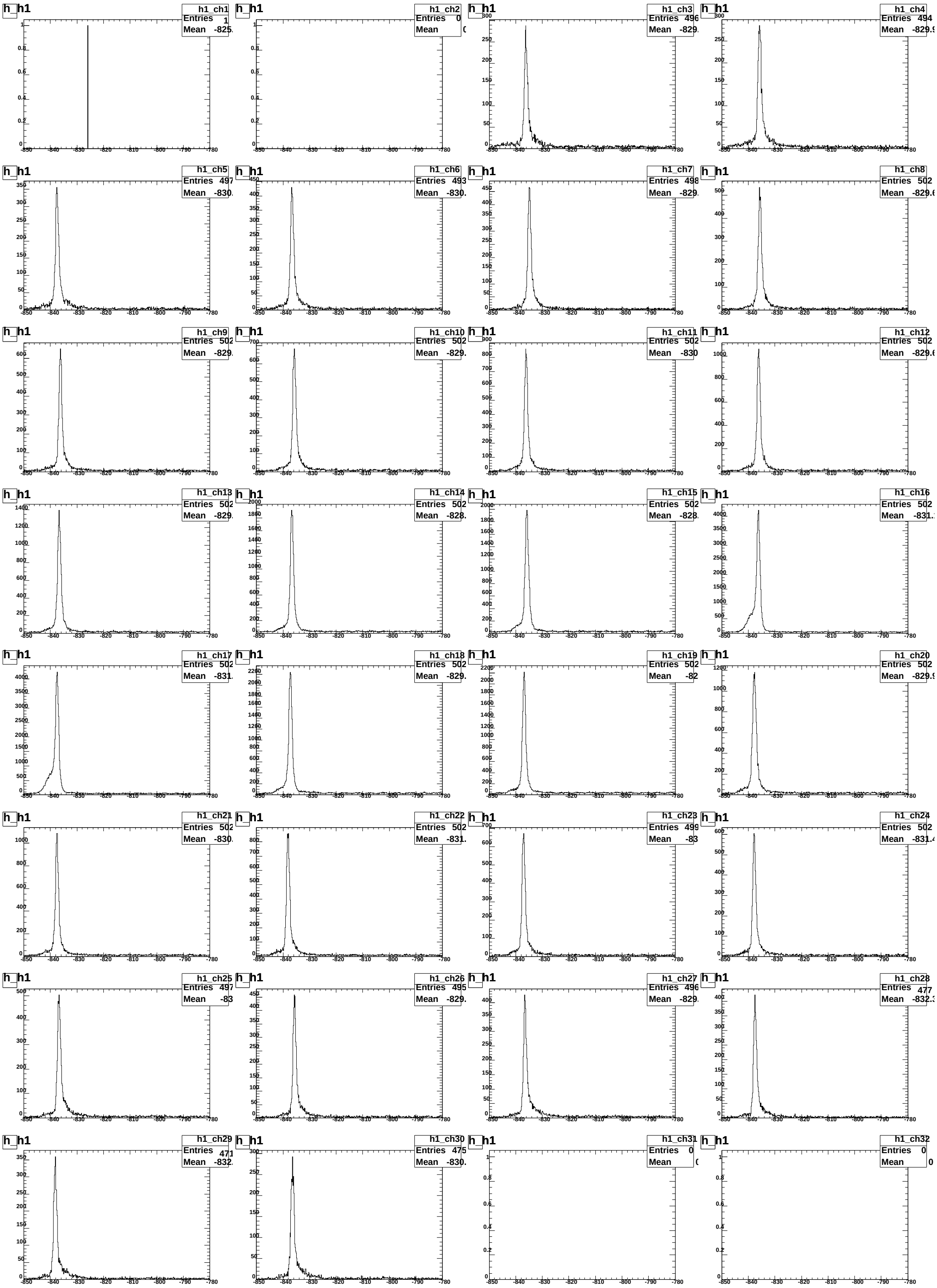

Figure 7: H1 Timing of mean timer (in nanoseconds)

3 H2 hodoscope

3.1 Dimension and Position

The hodoscope H2 has a size of 4995 mm × 4197 mm and a central hole of 1495 mm × 781 mm, and thus a total active area of 19,8 m^2. It was installed directly in front of the second spectrometer magnet (SM2). This corresponds to +1600 cm in the Z-axis of the COMPASS reference system. The exact position can by seen in the survey report (https://edms.cern.ch/document/1078666). The total mass of the hodoscope is 2.5 tons. The mechanical structure, which holds the individual scintillator slabs and the frame were designed and produced by the Torino group.
H2 is attached to a cross beam bar resting on the yellow support frame of SM2. Serveral equipements are attached to the same cross bar: MA01, MF1, MA02, PA02 and GM06. H2 is located between GM06 and SM2. Due to lack of space the width of H2 had to stay below 25 cm

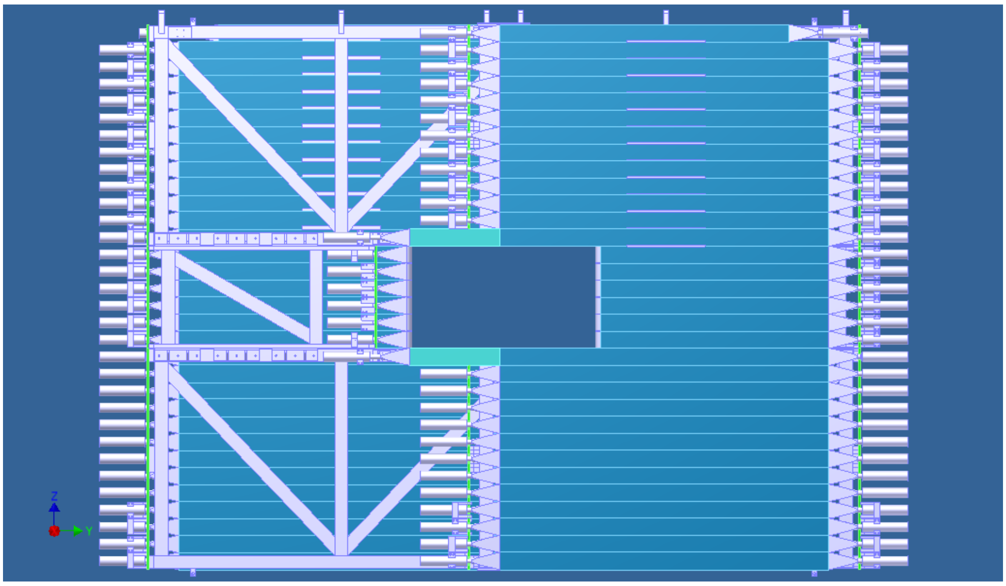

Figure 8: Technical drawing of H2

3.2 Substructure and Hole

H2 is divided into two pieces, Y1 on the Jura side and Y2 on the Salève side (H2_Y1 = H2J and H2_Y2 = H2S). Each half consists of 32 scintillator slabs. The slabs are staggered with an overlap of 2 mm to avoid acceptance holes. The hodoscope halves Y1 and Y2 have an overlap of 50 mm. The gap between Y1 and Y2 in Z is 50 mm. H2 has 128 readout channels.
The hole of H2 has the same size as the hole of Muon Wall 1 (MW1) and is centered around the beam axis leading 6 shorter scintillator slabs on each side in the hole region.

3.3 Scintillator Slabs and Light Guides

For H2 BC408 was used, too. The standard slabs are 252.5 cm long, 13.6 cm wide and 2 cm thick. For different regions in H2, the slabs had to be cut to the appropriate size. After cutting the surface had to be machined with a diamond tool turning machine to get a transparent surface. Each slab of H2 was wrapped in a layer of crumpled mylar foil for light reflection and a layer of black foil for light tightness.
For the light collection fishtail light guides were produced. As design template the light guides of the HO04 were used. Some modifications on the light guide had to be done depending on the type of H2 scintillator slabs.
Special bent light guides have been design and manufactured for the short slabs at the hole side. Half, hollow cylindric PMMA piece with a radius of 4.5 cm bring the PMTs with its shielding out of the hole and out of the acceptance of the Small Angle Spectrometer. Figure 26 in the appendix shows the bent light guide for the slabs surrounding the hole.
The following slabs were used in H2:

- Short: the top-most slab was shortened by approx. 30 cm because of its interference with the mechanical structure on SM2.
- Normal: the standard slabs which were used for the largest part of H2
- Bent: with the bent light guide the magnetic shielding of the PMTs are turned by 180° because otherwise the 2 kg shielding would disturb the acceptance for the small angle spectrometer and would cause particle showers. Due to the staggering the light guides on the hole region have smaller width than the scintillator slabs (130 mm instead of 136 mm).
- Long: the slabs directly above and below the hole are extended with 630 mm PMMA slabs to have the PMT shielding out of the SM2 acceptance , in figure 8 the plexiglas is marked with light blue.

name of element	quantity	length	function
Short	2	2217 mm	top slabs
Normal	46	2525 mm	normal slabs
Long	4	2525 mm + 630 mm PMMA	slabs around the hole
Bent	12	1775 mm	bend light guided slabs

Figure 9: Picture of H2 taken during installation

3.4 Readout, PMT and Shielding

The read out of the H2 scintillator slabs is done on both sides by 9813KB PMTs. The PMTs and voltage dividers were used in 2008 and 2009 in the recoil proton detector (RPD). The 9813KB is a 51mm (2 Inch) diameter, end window photomultiplier with blue-green sensitive bialkali photocathode and 14 BeCu dynodes of linear focused design (http://www.electrontubes.com/pdf/9813B.pdf).
A changeover to new PMTs of the type 9814KB is planned to be done at the end of the year 2011. The new PMT are slightly shorter and have 12 BeCu dynodes.
H2 is situated directly in front of SM2, so soft iron shielding had to be used to ensure PMT performance. However, the SM2 fringe field is lower than the one from SM1.
Like in H1 metal rings are attached to the cylindric part of the light guide to hold the soft iron shielding in place. The PMT with the voltage divider casing (with springs to prevent PMT entrance window damage) is screwed to the shielding. A CERN standard soft iron shielding was used for H2, for additional shielding μ-metal tubes around the PMTs were used. The soft iron shielding has a diameter of 80 mm, a length of 36 cm and a thickness of 5 mm. Figure 10 shows a dismounted readout for H2.
As described in the H1 section, thick COAX cables are used for signals. Patch panels for the flexible cables are put on top of SM2.

Figure 10: Dismounted readout of H2: soft iron shielding, μ metal shielding, attachement cap and ring, casing including the voltage divider and the PMT

3.5 Mechanical Stability

The support structure and the suspension for the H2 hodoscope was designed and built by the Torino and Dubna groups. The support consists of six separate pieces and a suspension bar. The main requirements were to make this support as thin as possible due to the lack of space budget and to allow to install it close to the SM2 magnet in the region with the presence of the magnetic field (below 0.01 Tesla). To fulfill the requirement the structure was built from aluminum with only the photo multiplier tube holders made from stainless steel. The support structure was simulated and optimized using CAD tools. This procedure defined the fixation positions between the frames and between the frame and the suspension bar. With the simulated weight of 2.5 tons the maximum deformation of the frames was reduced to only 4.3 mm (for the external angles of the lower frames).
H2 is hold by a cross bar resting on the SM2 support frame and is also fixed to the ground.
The scintillator slabs are attached to the soft iron shieldings with clamps to the frame. Each clamp is insulated with teflon sheets, this can be seen in figure 11. In addition, each slab is supported in the middle with broad hooks.

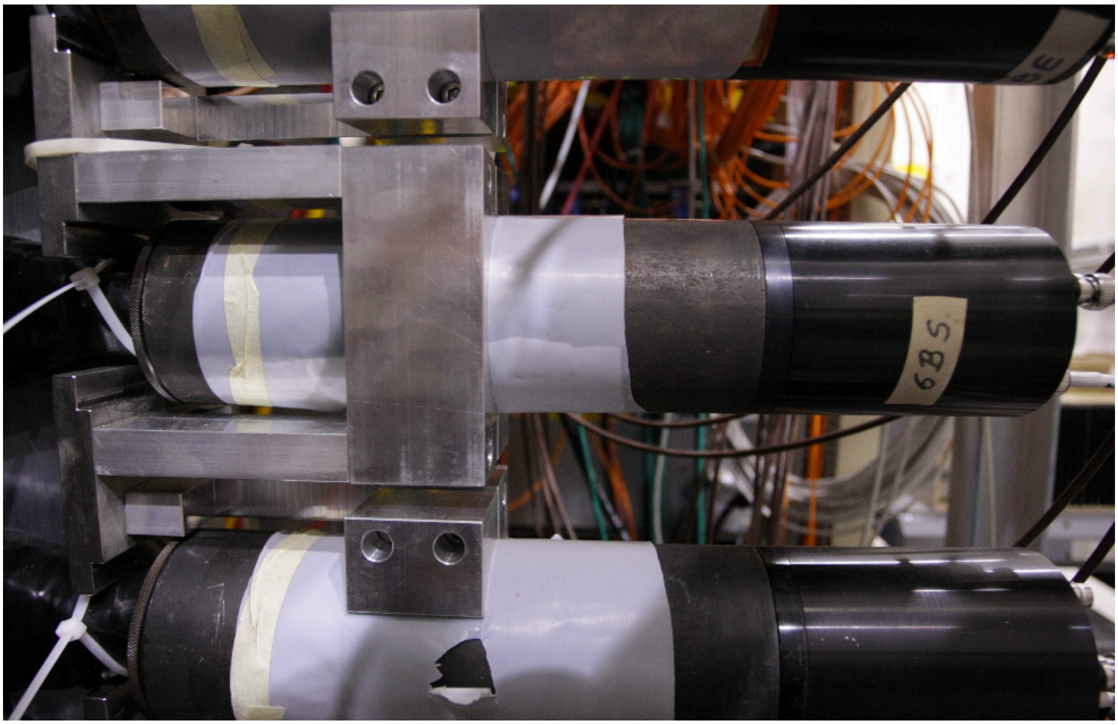

Figure 11: Clamps with capton insulation for support of the H2 soft iron shielding

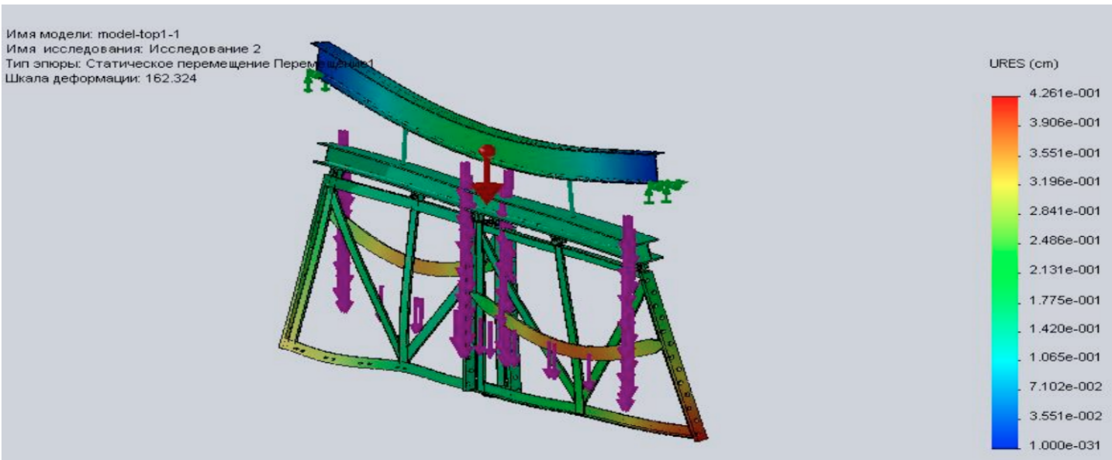

Figure 12: Deformation of the H2 frame trough magnetic field and gravitation.

3.6 High Voltage and Thresholds

The high voltage is provided by a SY1527 crate from CAEN. Six distibution boxes of the type A1535N from CAEN (three on each side of the hodoscope) with 24 channel supply the 128 PMTs.
Each channel was individually tuned during the spill with an oscilloscope for optimal HV settings. The HV varies between 1400 and 2000 V. The new PMT 9814KB will have a slightly lower high voltage but with a higher current. The threshold of the discriminator is set to 32 mV which is around $\frac{1}{3}$ of the average analog muon signal in spill.

3.7 Timing

The two figures 13 and 14 show the mean timer timing for each hodoscope halves H2S and H2J. The timing is measured by both TDC of the PMTs of one slab. As decribed in the next section, the digital signals are split in two parts. One for the GANDALF board and the other for the TDC. Trigger timing corrections done on the GANDALF cannot be seen on the TDC.

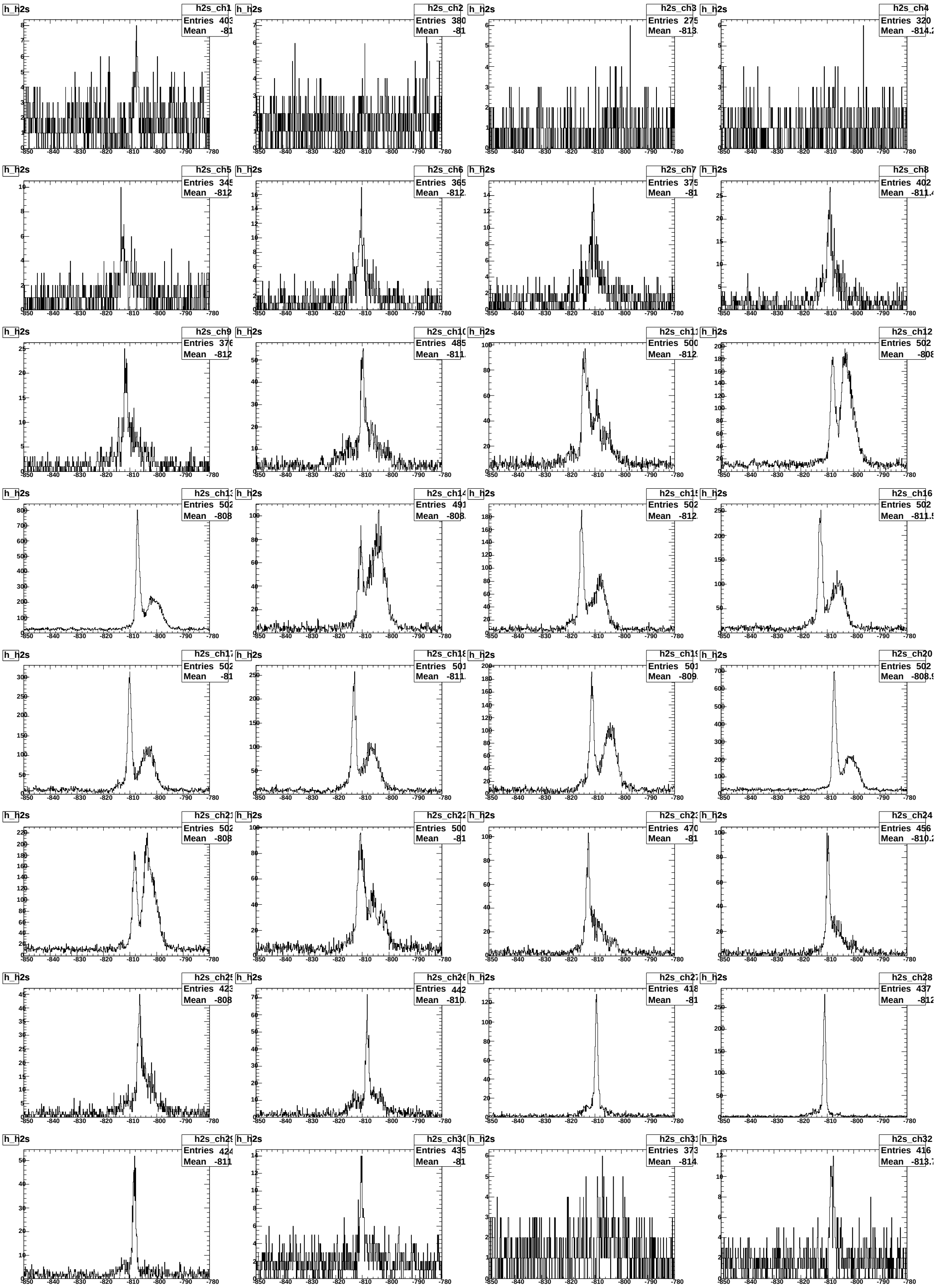

Figure 13: H2S timing of the mean timer (in nanoseconds)

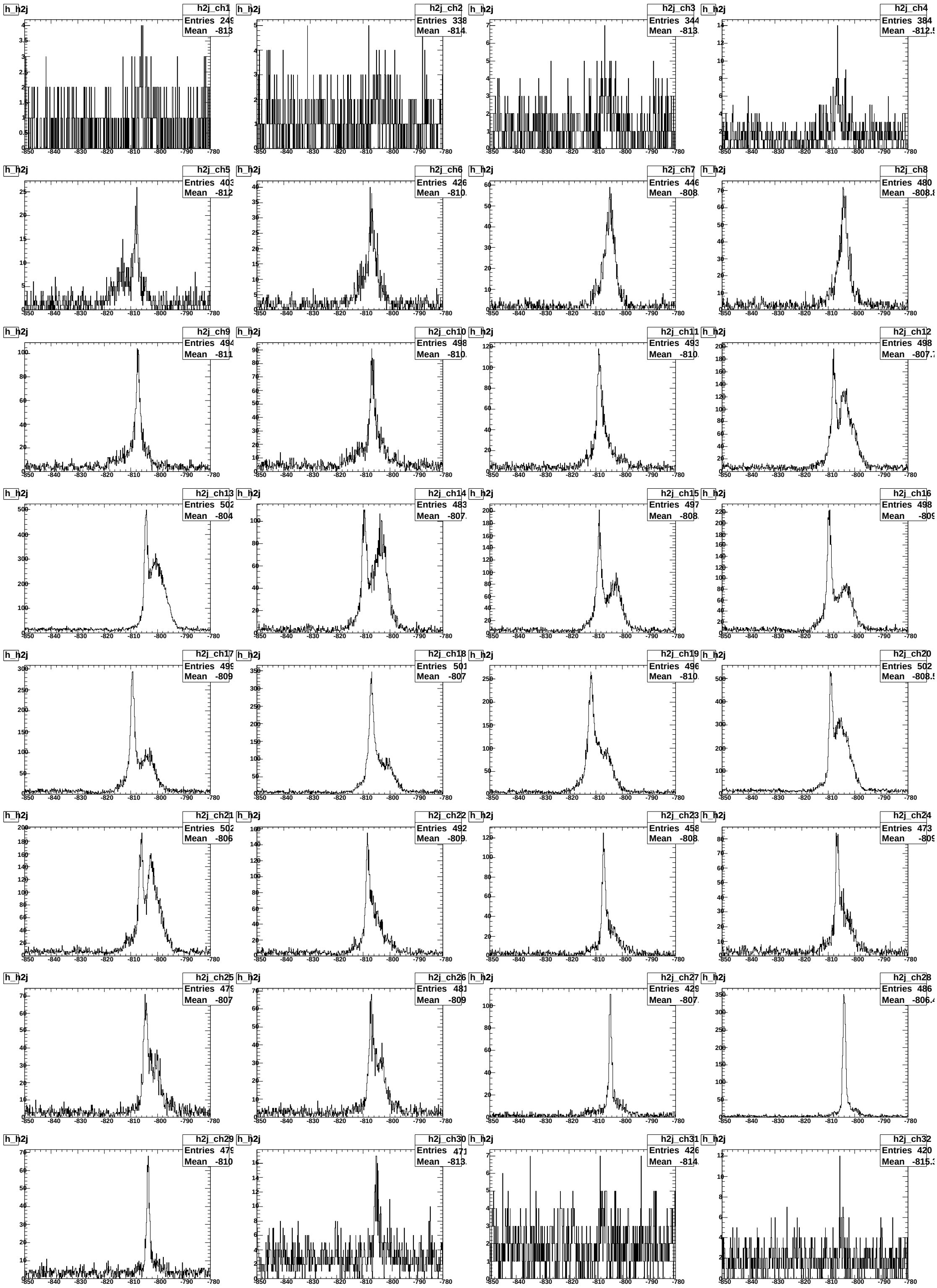

Figure 14: H2J timing of the mean timer (in nanoseconds)

4 Trigger Electronics

The analog signals (64 from H1 and 128 from H2) are sent to the veto barrack via low-loss coax cables on the first floor of the COMPASS hall. Each channel is discriminated with a Constant Fraction Dicriminator (CFD) on a CAEN V812 board. This CFD has a dead time adjustable from 150 ns to 2 μs per channel (the lowest dead time possible is chosen). The output gate width can be adjusted from around 15 ns to 250 ns, we set 15 ns for H1 and 25 ns for H2. It has Lemo inputs and double ECL outputs. Both ECL outputs are converted to LVDS, one is sent to a TDC for time measurement, the other one is brought to the GANDALF module via adapter cards[2]. Both the mean timers and the matrix circuit are programmed on the FPGA of the GANDALF board. The digital signal for H1 has to be split into two (using an active LVDS splitter) in order to provide the signals for two GANDALF boards (one for H1/H2S mean timing and coincidences, one for H1/H2J).

In the next subsection the principles of the mean-timer and the coincidence matrix will be discussed. The total setup and all devices used can be seen in figure 20.

4.1 Introducing the GANDALF Board

The GANDALF is a multi-purpose FPGA board which has been developed originally by the Freiburg group to analyze the signals of the Recoil Proton Detector. They developed a very generic design to obtain a high flexability: The board can be equipped with mezzanine cards (2x) providing 64 LVDS inputs, 64 LVDS outputs or 8 analog inputs (see figure 15). The actual signal analysis is performed by an FPGA (Virtex 5 by Xilinx), allowing different logic functions to be implemented.

Constructed as 6U-VME64x/VXS modules, the GANDALF boards can be controlled via VME bus (load configuration into FPGA, read and write FPGA memory) by simple shell scripts executed on the VME CPU. For convenience, we installed a web server on this PC and created a web interface which executes these shell scripts according to user action. Thus the mean timer as well as the trigger matrix can be configured deeper knowledge of the hardware implementation.

4.2 Description of the FPGA-based mean timer and trigger-matrix

The mean timers are constructed using the tapped delay line method as illustrated in figure 17. Its dynamic range is 23 ns, which defines the maximum offset between the left and the right input signal. Even though this range is sufficient for the slabs of H1 and H2 (width of 2.5m at most), we implemented a veto in each mean timer to suppress any output if the offset of the input signals exceeds the dynamic range to prevent false outputs.

Since there are 32 slabs in each of the hodoscopes, one needs 64 parallel mean timers per GANDALF board. All these mean timers work independently from each other. Their outputs are connected to the matrix coincidence (see figure 18). During the calibration of the system, the different slabs must be timed in. For this purpose, one uses two types of delay-elements:

- small IODELAYs (64 steps of 75ps) right after the signals enter the FPGA

[2] Robinson-Nugents plugs are adapted to Honda ones

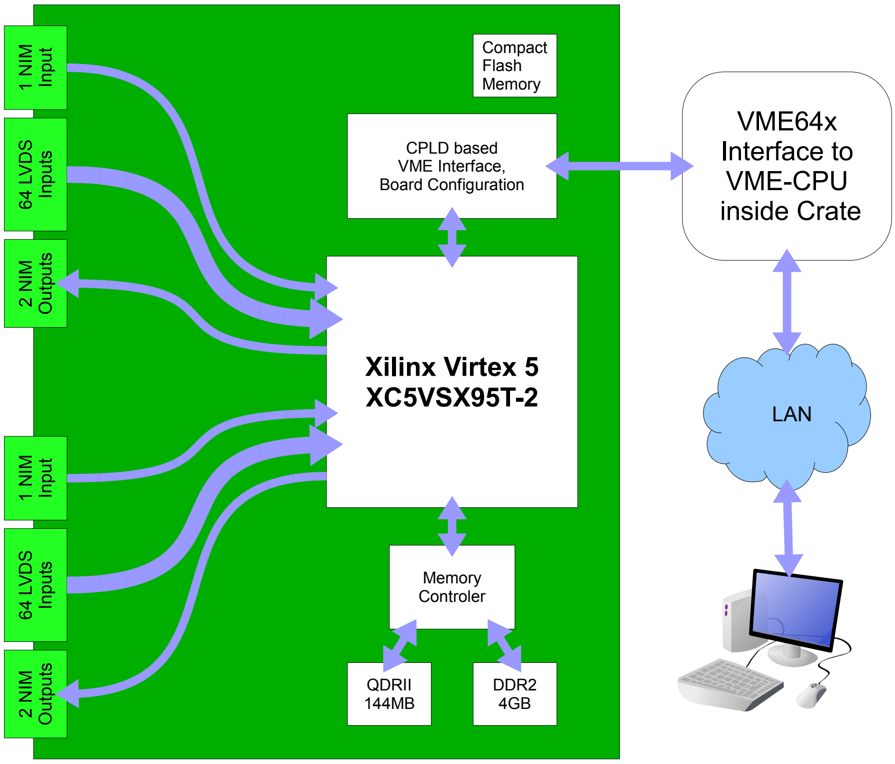

Figure 15: Simplified layout of the GANDALF-Board.

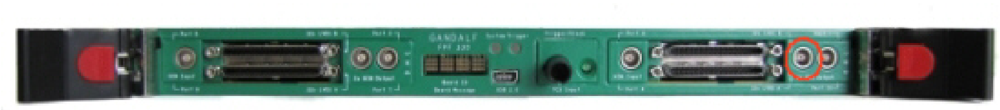

Figure 16: GANDALF-Board (front view).

- large SWITCH-DELAYs (21 steps of about 1ns) before the signals enter the matrix coincidence

These delays can be changed, saved and loaded via the web-interface.

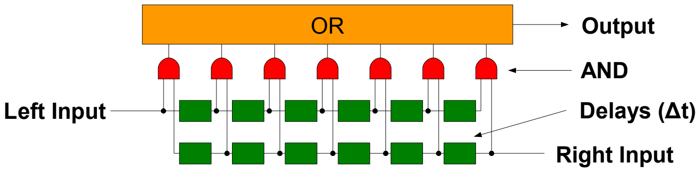

Figure 17: Construction of a mean timer with two tapped delay lines

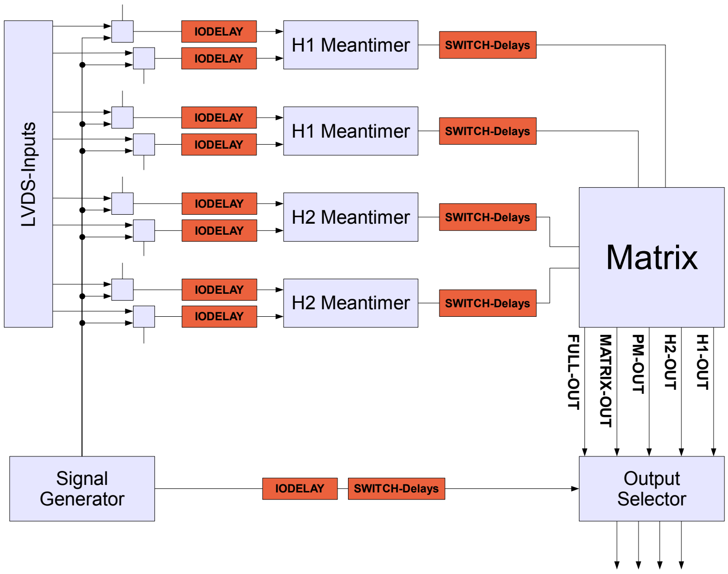

Figure 18: Simplified sketch of the elements which have been implemented on the FPGA.

Inside the matrix coincidence, each of the 32 H1 slabs have to be compared to each of the 32 H2 slabs. To minimize the complexity, the 1024 parallel coincidence checks are partially serialized. As shown in figure 19, the signal of a given slab of H1 is crossing each slab of H2. The resulting offsets are compensated by additional delays outside the matrix, thus guaranteeing that two simultaneous signals of H1 and H2 will always reach the correct matrix pixel head on. The pixel marked as #2 for example will be reached by both signals after $a_1 + a_2 + a_3 + b_1 + b_2$. Since the total time needed in the matrix (including the additional delay outside) is the same for any of the 64 matrix inputs, simultaneous inputs will reach the upper right corner of the matrix at the same time, thus functioning as an `OR` for each hodoscope (`H1-OUT`, `H2-OUT`),as well.

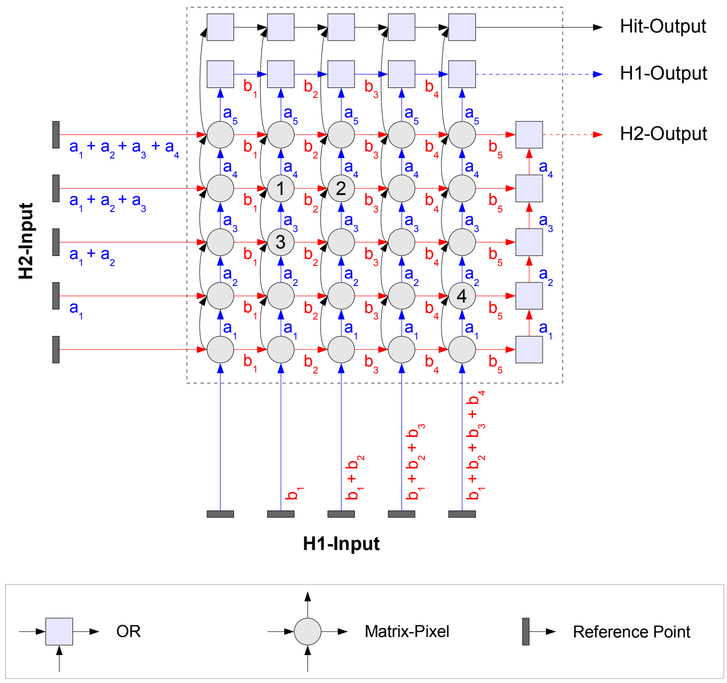

Figure 19: Simplified sketch of the matrix circuit.

The actual coincidence information of all active pixels is produced by an additional hit-channel. Besides `H1-IN`, `H2-IN`, `H1-OUT` and `H2-OUT`, which are used to pass the slab signals through the matrix, each matrix pixel features a `HIT-IN`, a `HIT-OUT` and a `HIT-ENABLE`. If there is already a signal on `HIT-IN`, it is simply passed on to `HIT-OUT`. If the hit-channel is clear and the matrix pixel enabled, the logic AND of `H1-IN` and `H2-IN` is given on `HIT-OUT`.

Since it was not possible to construct the hit-channel with the same timing as the main matrix circuit, `HIT-OUT` is being retimed with `H1-OUT` to obtain the final `MATRIX-OUT`, which preserves the original timing. Since the hit-channel is faster, the maximum offset between `HIT-OUT` and `H1-OUT` is about 7 ns if the lower left pixel has fired. Therefore, the width of the discriminator gates of H1 must be larger than 7ns, otherwise the hit-information of the lower left pixels will get lost.

The matrix circuit provides the following signals:

- `H1-OUT`: OR of all H1-inputs
- `H2-OUT`: OR of all H2-inputs
- `FULL-OUT`: `H1-OUT` OR `H2-OUT`
- `HIT-OUT` (also know as PM-OUT = pure matrix): output of the hit-channel
- `MATRIX-OUT`: the trigger signal, i.e. the retimed pure matrix signal (`H1-OUT` AND `HIT-OUT`)

A supplementary alignment signal is without any use in the COMPASS setup. It is a self-generated periodic signal with a large jitter, there is no need to use it.

As shown in figure 16, the GANDALF-Board provides 4 outputs (there is a design flaw in the release used in 2010, which actually leaves us with only 3 independent outputs). To be able to use all relevant signals, an output selector to freely assign the above signals to a specific output was included. This is done by using the web-interface.

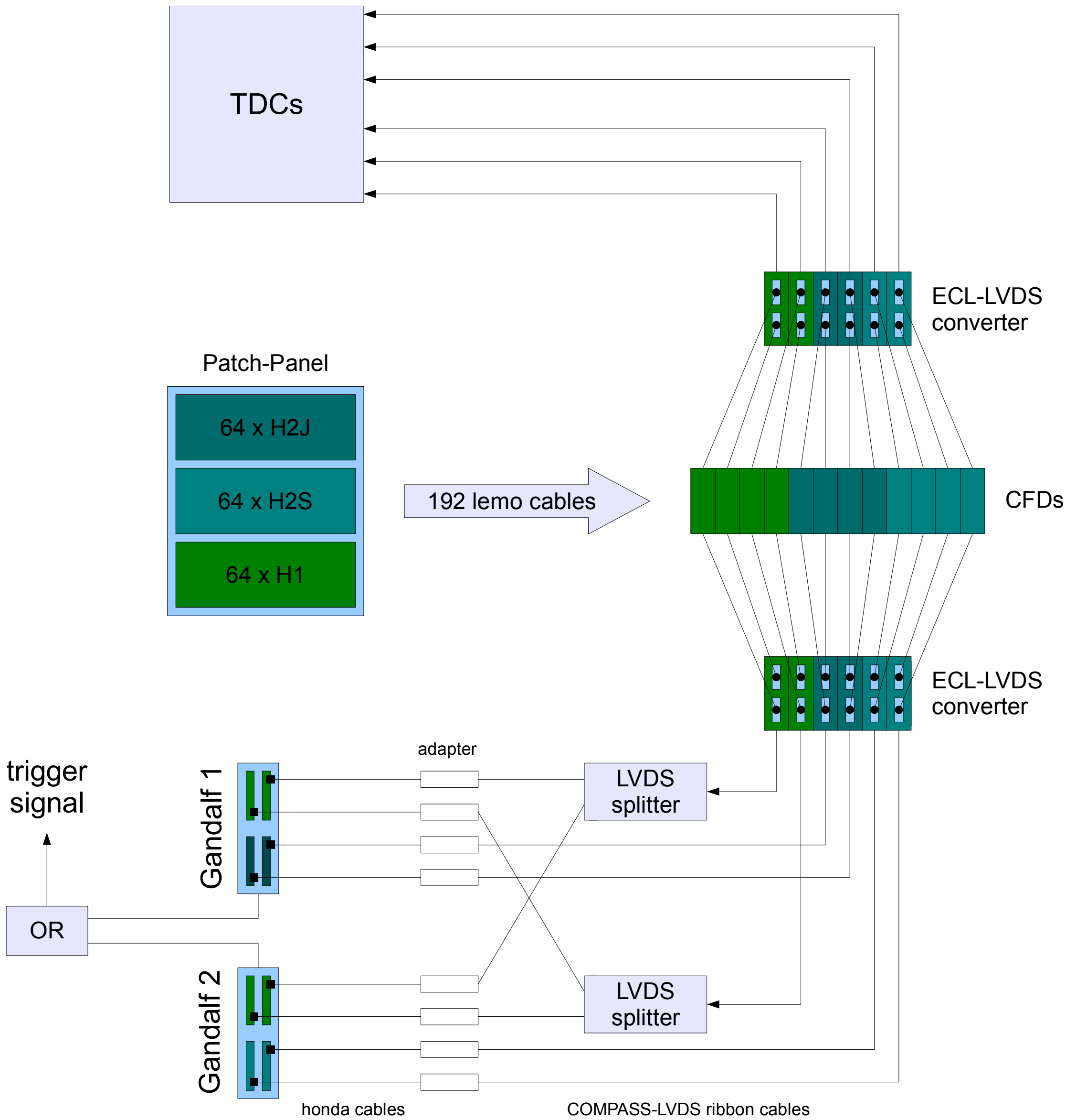

Figure 20: Interconnection of the different devices of the LAS-Trigger.

4.3 Some additional technical information

To reach the highest possible time resolution, the system has been designed as a pure logical unclocked circuit. The tapped delay lines consist of 54 identical delay elements with an overall dynamic range of 23ns, leading to an internal time-resolution of one single mean-timer of about 210 ps. However, due to a temperature dependent propagation time through the FPGA, this resolution cannot be seen on the outputs. A detailed measurement showed that the jitter adds up to about 280 ps (RMS). The total propagation time from the input signal through the mean timer and the matrix circuit to the output amounts to about 100 ns.

The final resolution of the time calibrated system can be seen in figure 21. The time resolution of the LAST (0.9 ns) is comparable to the time resolution of the Outer Trigger (1.3 ns).

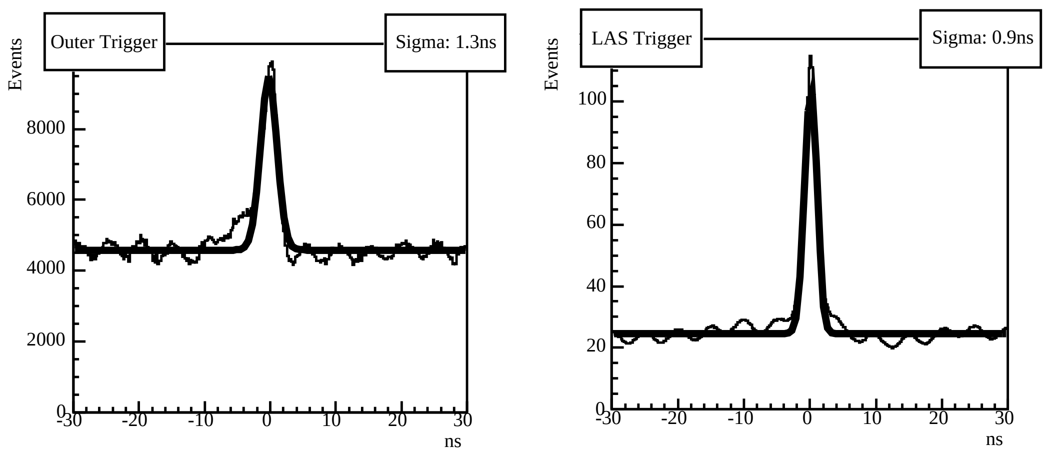

Figure 21: Time resolution of the Outer Trigger (1.3 ns) and LAST (0.9 ns)

Another useful measurement is shown in figure 22. The data of a test run is verified by calculating the mean time from the recorded left and right input signals (taken from the TDCs) and comparing it to the recorded trigger signal (one slab only). Calculated and FPGA generated mean time show a good agreement.

4.4 Calibration of the system

A coarse calibration has been done first by adding small cables (of 2-8ns length) before the signals reach the discriminators. The fine calibration has been done via the above mentioned IODELAYS and SWITCHDELAYS using the web interface. Single mean-timers were switched on one-by-one, pulses were fed to the TEST input of the discriminators and its outputs were checked and aligned with respect to the test signal with an oscilloscope.

Further information can be found in the diploma thesis of John Bieling (in german).

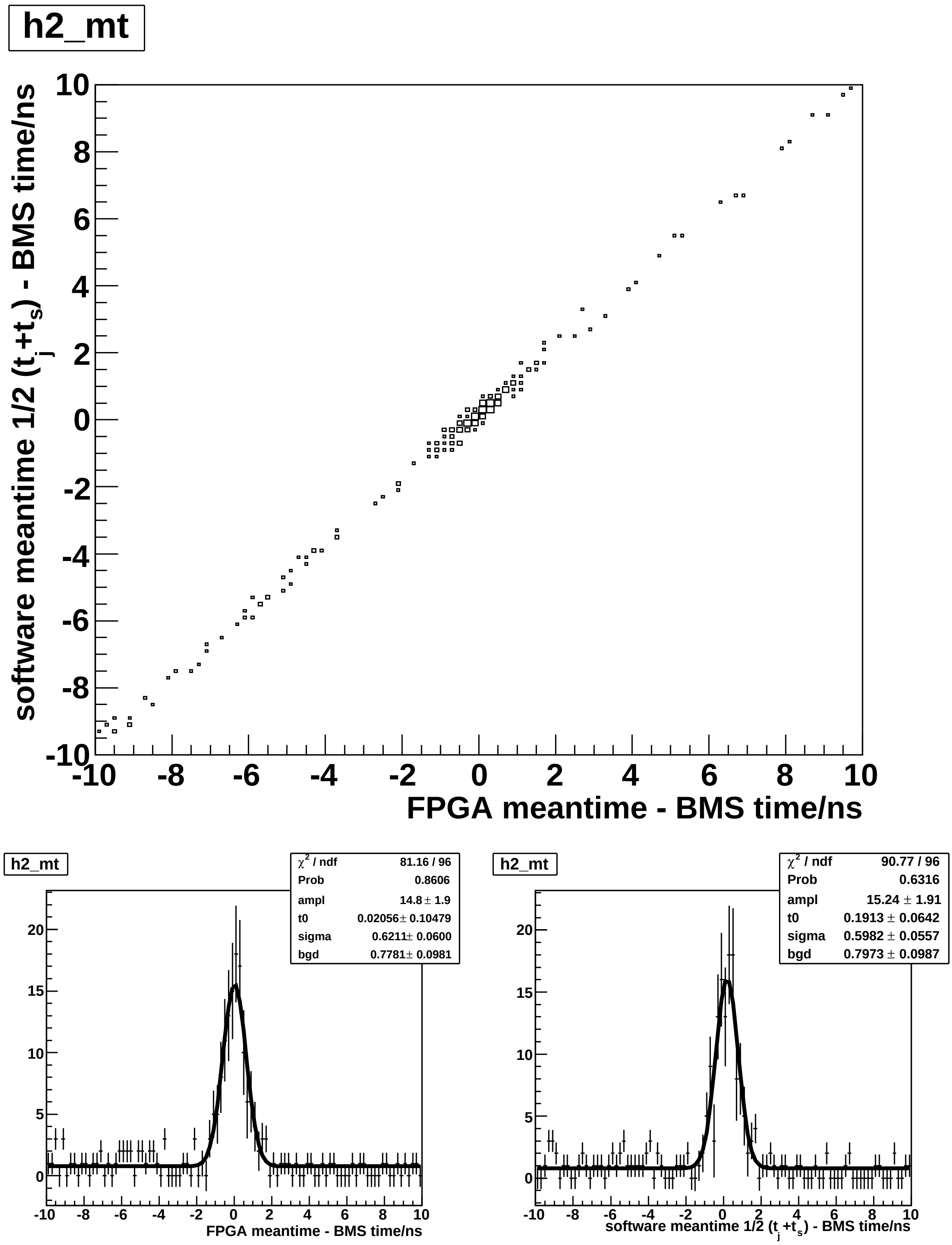

Figure 22: Software mean time vs. hardware mean time

5 Appendix

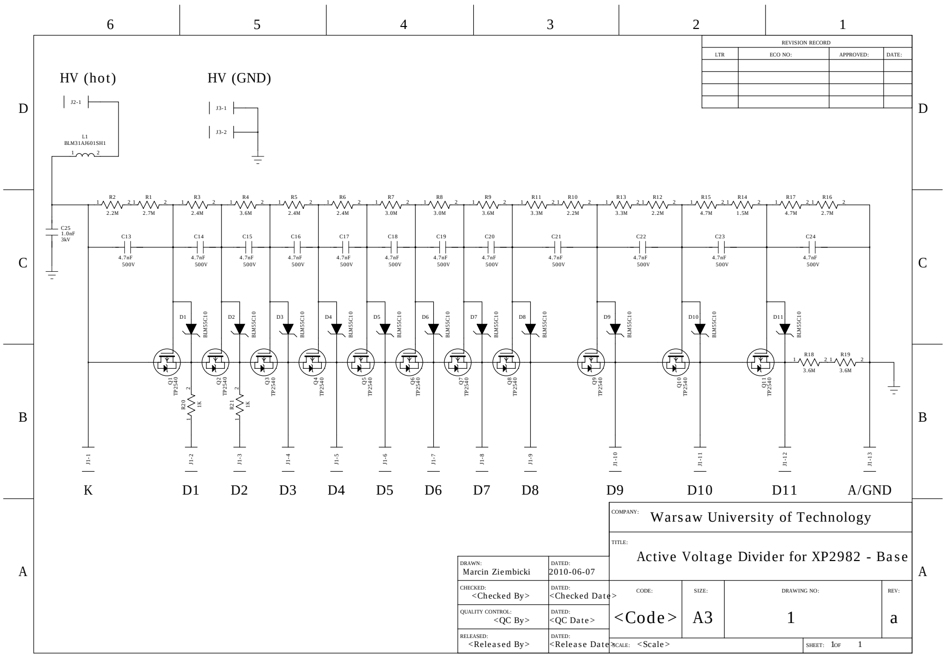

Figure 23: The circuit diagramm of the H1 voltage divider designed and produced in Warsaw

	H1	H2
Height [mm]	1920	4197
Length [mm]	2300	4995
Size of Slabs LxWxD	2300x60x10	2525x136x20
Hole Height [mm]	240	781
Hole Width [mm]	500	1495
PMT type	XP2982	EMI 9813KB
nominal voltage [V]	1600	1800
Threshold [mV]	16	32
Length patch panel cable [m]	3	10
Length signal cable [m]	63	50
Diameter shielding [mm]	48	80
Thickness shielding [mm]	4	4
Z position [cm]	582	1600
hole shift [cm]	-10	0
# of channels	64	128

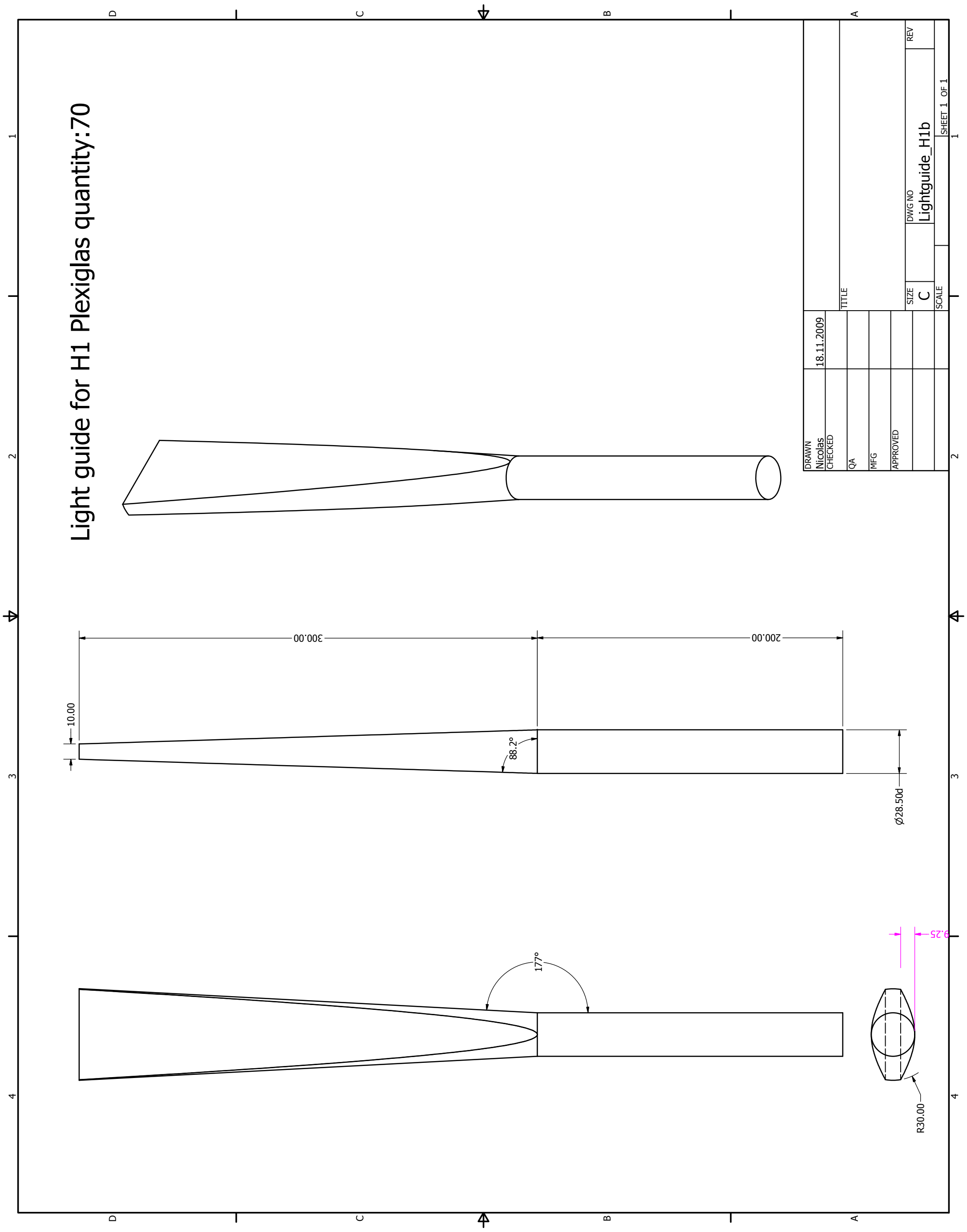

Figure 24: Technical drawing of the H1 light guides

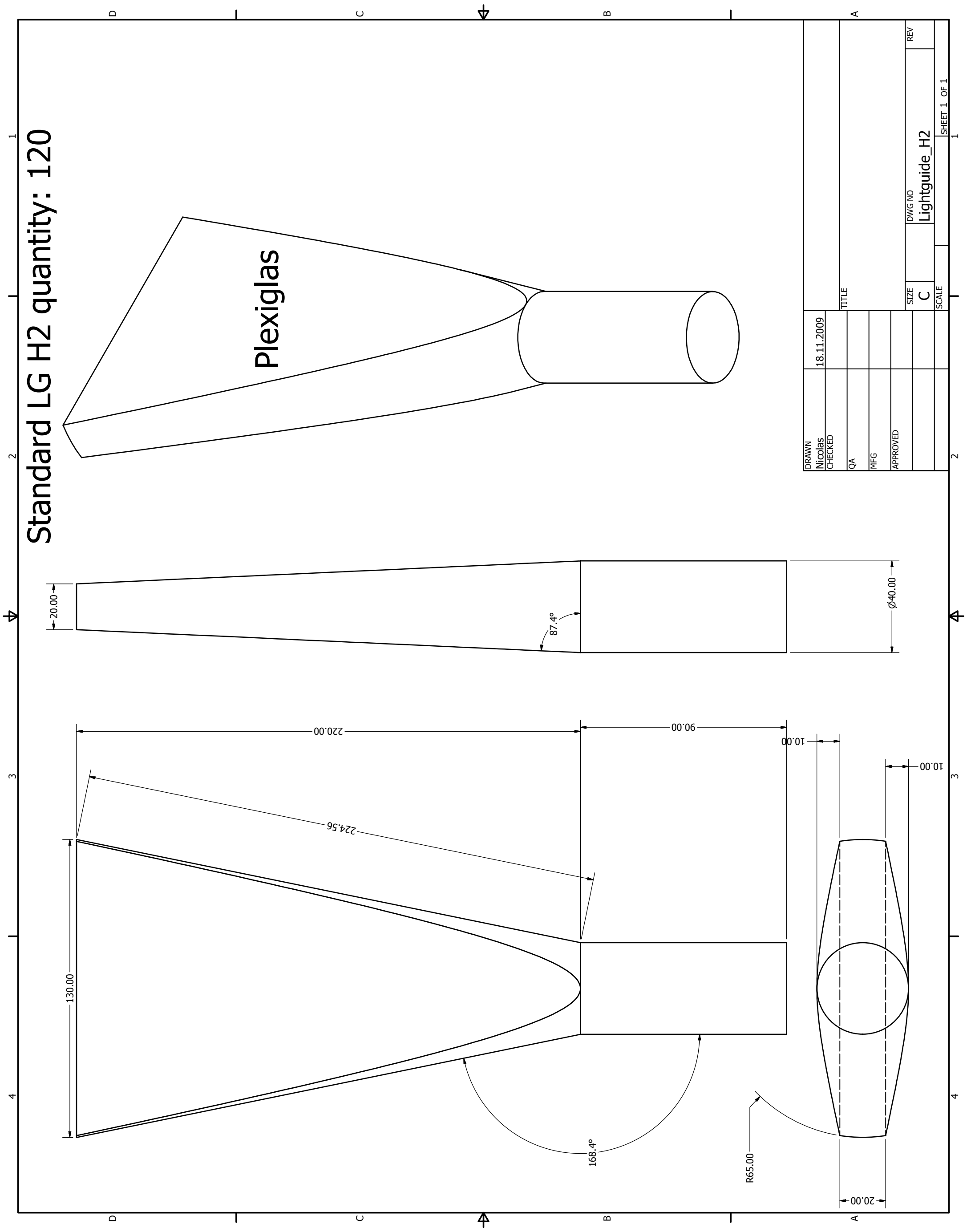

Figure 25: Technical drawing of the H2 light guides

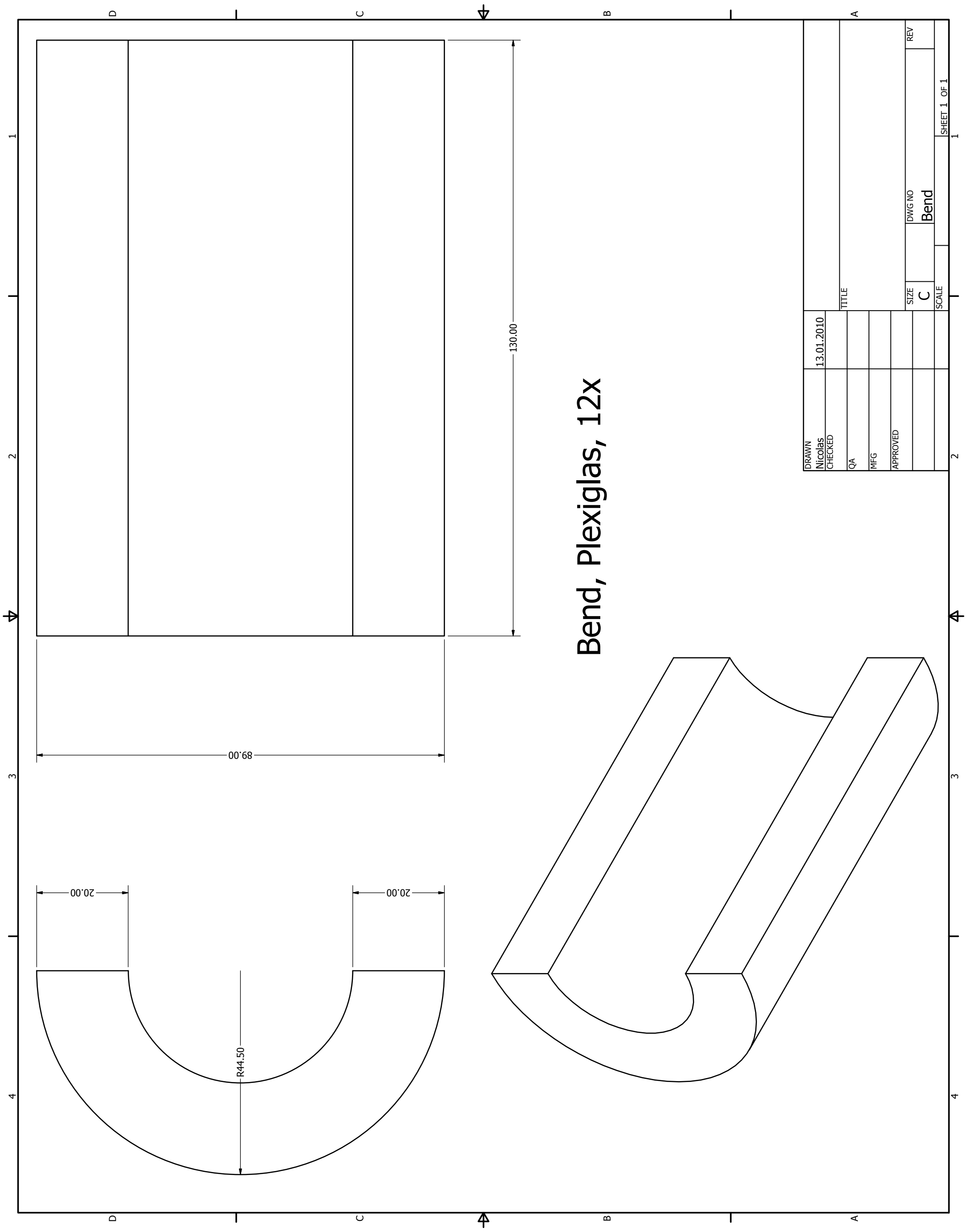

Figure 26: Technical drawing of the H2 bent part of the light guide for the hole