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**Title:** Novel detectors and algorithms for electron nano-crystallography  
**Issue Date:** 2015-12-03
Chapter 2

Design of cameras for TEM systems based on Medipix detector family
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Chapter image: design schematics show in a simple way the intricate design decisions that were made, to build a camera that is safe to use. (Fig 2.3)
2.1 Introduction

The detector is one of the most important focus points for the development of electron nano-crystallography, as the method has been developed in the past 8 years. During this time many different detectors and housings have been designed to be used in different transmission electron microscopes (TEMs). The past five years this effort has been intensified to design better and more robust housings for longer lasting experiments; minimizing the chance for damage of the electronics and optimizing the overall stability. In this chapter I describe the basic technology behind the Medipix-type Timepix detector and how it behaves in TEM and I explain how these detectors can be build into TEMs by using three examples of the most important camera iterations (the preconditions, solutions, possible problems and bottlenecks).

2.2 Chip, readout and software

Late in the 1990s the first Medipix collaboration was formed at CERN in cooperation with Nikhef. The goal was to design a functional hybrid detector to detect quanta of all types and energies with medical applications in mind, hence the name Medipix. A decade later the Medipix 2 consortium was looking for a successor. Three main types of Medipix-2 have been designed and produced so far: Medipix-2, Medipix-2 MXR and the Timepix (note the number abbreviation). Currently the Medipix 3 collaboration is in full swing and has designed the Medipix-3 (RX) and Timepix-3 chip. At the moment of writing the Medipix-4 collaboration is being formed. A short overview of the chips and their characteristics (Source: Wikipedia & Medipix collaboration website).
2.2.1 Chip versions

- Medipix-1: 64x64 pixels (4k) with a 170 μm pixel pitch. It had a speed of 2 MHz per pixel with a counting depth of 15-bit. (Bisogni et al., 1998)
- Medipix-2: 256x256 pixels (65.5k) with a 55 μm pixel pitch. Instead of the Medipix-1 it had a upper and lower energy threshold, the maximum count rate was 100kHz per pixel. (Llopart et al., 2002)
- Medipix-2 MXR: Successor of the Original Medipix-2 chip. It has a better temperature control, stability and pixel overflow. Also it has an increased radiation hardness. (Medipix, CERN)
- Timepix: By dropping the upper threshold from the Medipix-2 it has the ability to use a Time Over Threshold (TOT) and Time Of Arrival (TOA) mode. The amount of energy is being counted by the TOT mode and the TOA mode measures the time between a trigger pulse and the arrival of the charge into each pixel. (Llopart et al., 2007)
- Medipix-3: This has the same pixel lay-out as the Medipix-2 chip however when binned to pixels of 110 micrometer it has 8 different energy thresholds as well as 4 thresholds with continuous read-out. Also improvements have been made in the energy resolution by having a real time charge sharing correction. (Ballabriga et al., 2011)
- Timepix-3: The spiritual successor of the Timepix (note: there is no Timepix-2). Where all other chips are having a frame based read-out, the Timepix-3 has an event driven read-out system. Therefore as soon as a pixel gets triggered above the set threshold the signal will be recorded along with the location.

Table 2.1: Comparison table between currently available chips.

<table>
<thead>
<tr>
<th></th>
<th>Medipix2</th>
<th>Timepix</th>
<th>Medipix3</th>
<th>Medipix4</th>
<th>Timepix4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel side (μm)</td>
<td>55</td>
<td>55</td>
<td>55/110</td>
<td>55</td>
<td>y</td>
</tr>
<tr>
<td>Technology (nm)</td>
<td>250</td>
<td>250</td>
<td>130</td>
<td>130</td>
<td>65</td>
</tr>
<tr>
<td># pixels in x and y</td>
<td>256</td>
<td>256</td>
<td>256/128</td>
<td>256</td>
<td>512/256/128</td>
</tr>
<tr>
<td>Readout architecture</td>
<td>Frame based Sequential RW</td>
<td>Frame based Sequential RW</td>
<td>Frame based Continuous RW</td>
<td>Data driven/ frame based</td>
<td>Frame based Continuous RW</td>
</tr>
<tr>
<td>Charge summing and allocation mode (CSM)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td># thresholds</td>
<td>2 (window discriminator)</td>
<td>1</td>
<td>2/4/8 Seq RW 1/4 Cont RW</td>
<td>1</td>
<td>?</td>
</tr>
<tr>
<td>ToT/ToA</td>
<td>No</td>
<td>ToT (14 bit) OR ToA (14 bit, 12ns precision)</td>
<td>No</td>
<td>ToT (10 bit) AND ToA (14 bit, 12ns precision)</td>
<td>No</td>
</tr>
<tr>
<td>Front end noise (e rms)</td>
<td>110</td>
<td>100</td>
<td>80(SPM) 174(CSM)</td>
<td>62</td>
<td>≤ 80 (SPM) 174 (CSM)</td>
</tr>
<tr>
<td>Peaking time (ns)</td>
<td>150</td>
<td>100</td>
<td>120</td>
<td>30</td>
<td>&lt; 120</td>
</tr>
<tr>
<td>Max count rate (Mc/mm²/s)*</td>
<td>826</td>
<td>-</td>
<td>826 (SPM 55μm) 164 (CSM 55μm) 376 (SPM 110μm) 28 (CSM 110μm)</td>
<td>0.43 (data driven)</td>
<td>x5 Medipix3</td>
</tr>
<tr>
<td>Number of sides available for tiling</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

*Depends strongly on exact conditions of threshold, sensor material and energy of illumination

Brown indicates parameters which are still to be defined
In this thesis both Medipix-2 (chapter 4) and Timepix (chapter 6) detectors were used to measure data. However, all detectors that are still actively used are of the Timepix type. The reason is that the Timepix has an increased stability over the Medipix-2. Also, there is no need for an upper threshold because the highest energy particles in a TEM are the electrons emitted from the gun. Since the Medipix-2 is no longer in active use and therefore only the Timepix will be discussed in depth in this chapter.

2.2.2 Chip design

The Timepix chip is a hybrid detector (A semi-conducting material is bump-bonded to an electronics layer). In our case we only used a semi-conductor made out of a single Si crystal, but others types like GaAs and CdTe do exist. The latter two have different characteristics. Because of the higher density (Z value) of the detector layer they will make the electrons scatter more locally, this will increase the spatial resolution of the data. However there are drawbacks: (i) more electrons will backscatter and get “lost”; (ii) require more equalization, because of irregularities in their crystal structure; (iii) more difficult and therefore more expensive to be produced. (Zwerger et al., 2007; Hamann et al., 2015; Rasif, 2015).

When a high energy particle (in TEM mostly electrons and X-rays) scatters through the sensor layer, an electron/hole pair cloud is created. By putting a bias over the sensor layer, the positive (or negative, depending on the type semi conductor) charge cloud is conducted to the ASIC (application-specific integrated circuit) electronics. In the analogue part of the electronics the deposited energy is amplified and, if the total energy is higher than a calibrated threshold energy setting (per pixel), the energy peak will result in counts in the digital part of the electronics. (Fig. 2.1).

The Timepix offers three different counting modes: (i) Standard counting mode (CM). If the signal in a pixel is above the threshold the counter will increase by one (independent of how much charge is deposited above the set energy threshold). (ii) Time Over Threshold (TOT). If the energy deposited in the pixel electronics is higher than the energy threshold the capacitor is slowly depleted. During this depletion the amount of clock cycles is counted. This gives a measure of the amount of energy deposited (Fig. 2.1). (iii) Time Of Arrival (TOA). This mode is, for now, not very useful in EM. If the TOA is triggered a time stamp is being made.

In the work described in chapter 4 & 6, usually a combination is used of four single chips together bonded with a single Silicon layer: a Medipix or Timepix Quad.
2.2.3 Silicon layer characteristics, scattering and data quality

When electrons go through the sensitive Silicon layer they will start scattering. While scattering through the Silicon the electron will gradually lose energy by generation of Bremstrahlung (X-ray). Scattering is the main contributor to the generation of electron-hole pairs. If the incident electron has a higher energy, it will scatter further through the Silicon. Therefore using lower energies for TEM will result in better counting statistics, since the chance that the electron will also deposit energy in neighboring pixels will be reduced. Early in the track through the silicon the angles at which the electron scatters are usually low because of forbidden angles. When the electron loses more energy scattering events will occur more regularly and the angles at which the electron scatter can scatter are greater. This explains why most of the energy deposition is localized late in its track through the silicon. The tracks of these electrons through the silicon layer have been thoroughly simulated and tested for the Medipix-2 at different energies (Mcmullan et al., 2007; Mcmullan et al., 2009; Faruqi & McMullan, 2011) (Fig. 2.2).

It is possible to use the scattering at high energies in silicon as an advantage by using the Timepix-3. It could allow us to track the scattering paths of the electrons. The timing, the amount of charge deposited in multiple pixels as well as the shape of the charge cloud will all be required for determining the position of impact. The sharpness of the image could improve significantly. This would only work if every impact can be considered separate (high speed read-out and low dose would be needed). Early tests and simulations show that this technique is promising, but more experiments are required and therefore it is not described in this thesis.
Figure 2.1: Counting modes in Timepix chip. (Left) Once the charge cloud from the incident quanta reaches the ASIC, the signal is amplified and if the signal is over a certain threshold the counter is increased by one. (Right) Once the charge cloud from the incident electron reaches the ASIC, the signal is amplified and if the signal is over a certain threshold the clock cycles are counted till the capacitor is depleted and is energy level is below the threshold. (Source: ASI, 2015)

Figure 2.2: Monte Carlo simulations of electron scattering. Different materials and at different energies. The horizontal lines simulate pixels of 55 micrometer wide. (Faruqi & McMullan 2011)
2.2.4 DQE

The Data Quantum Efficiency (DQE) of Medipix type chips with a Silicon sensor layer is excellent for energies of 120 keV and lower. Higher energies than 120 keV will result in lower DQE (Mcmullan et al., 2007; Mcmullan et al., 2009). This is the result of the larger distance over which electrons at higher energies loose their energy. This can lead to counts in other pixels than the one of impact, especially if the energy threshold is set very low. If the threshold is set to a higher energy the DQE can be improved. However, the change increases where the electron is not counted at all (because of an electron scattering over multiple pixels and in each pixel depositing an energy which is to low to be accepted). Therefore, when setting the energy threshold (THL) level, one must compromise between having a chance of charge sharing or loosing electrons. This effect can be reduced by using a more dense (higher Z) semi-conductor as sensor, resulting in a better DQE for electrons at higher energies.

There is a quantitative way to describe the quality of detector performance (DQE). The DQE is a combination of the Modulation Transfer Function (MTF) and the Noise Power Spectrum (NPS). The MTF describes how much of the contrast information can be transferred from the object to the image at each resolution. The MTF is a Fourier transform of the Point Spread Function (PSF).

\[ \hat{g}(PSF) \equiv MTF \]

DQE is the Signal to Noise Ratio (SNR) of the signal reported by the detector divided by the SNR of the signal. The relation between DQE and MTF/NPS can be found in equation 2.1.

\[ \text{DQE}(\omega) = \frac{n_{out}^2 * MTF(\omega)}{n_{in} * NPS(\omega)} \]

Eq. 2.1: \( n_{out} \) is the average signal of output image, \( n_{in} \) is input electronic dose, \( \omega \) is the single spatial frequency variable (Shaw, 1978)

This formula shows why the DQE of a Medipix-2 type detector degrades at higher energies and lower THL: electrons are counted in wrong pixels or double counted in two neighboring pixels and the incoming electron dose is no longer in line with the recorded image. This lowers the MTF and increases the NPS. By setting the THL high it is possible to mask the double counts while losing electrons (this influences the DQE by lowering the NPS but increasing the input electron dose to the average signal of the output). However the Medipix still has a good SNR because of having a negligible (electronic) read out noise, which improve the DQE significantly over standard CCD cameras, which have dark-current and read-out noise. (Mcmullen et al., 2009)
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In low dose electron nano-diffraction, the DQE alone is insufficient as an estimator of data quality. The following properties of a detector describe the quality of a detector for diffraction better than the DQE: (i) High dynamic and linear range of multiple incident electrons in a pixel. (ii) Exact count of the deposited electrons in a Bragg spot compared to other Bragg spots. (iii) Having almost no read-out noise to catch even the faintest Bragg spots of up to three electrons above the electron background noise. (iv) High contrast between very bright Bragg spots and nearby very weak Bragg spots. (v) Relative radiation hardness of the detector. (For examples see chapter 6). All of these properties are combined in the Medipix type detectors. The THL should be chosen in such a way that fits the experiment (e.g. If the THL is chosen low, the data quality will deteriorate slightly, because double counts will be recorded).

2.2.5 Timepix ASIC

Electronics of one single pixel can be described as a single very small 1D detector and is of a complicated design because of the space constrains in combination with the used semi-conductor technology. A simple scheme shows the analogue and digital electronics of a single pixel (Fig. 2.3). After the energy has been deposited in the silicon the energy will be (in the form of electron-hole pairs), under influence of a bias be multiplied in an amplifier of the ASIC and then be send to the Discriminator. Here the Threshold (THL) setting for this chip is compared to the incoming energy and if necessary the Threshold output is corrected for each pixel individually with a maximum value of 4 bits. Then, if a pixel is supposed to be masked (because of being dead, bright or unstable) the counter will be overwritten and a ‘zero’ is communicated. From this point the information enters the digital part of the ASIC. At this point the reference clock is introduced as well as the shutter. The signals are then synchronized over the other pixels in the column and the read-out clock (frame time) starts to collect the amount of counts detected in this frame which is then send off to the 14 bit register to be added to the ‘line’ read-out.
2.2.6 Read-out

The read-out system is the hub between the computer/software and the chip. It is a two way gated transportation hub for Data Acquisition Commands (DACs) towards the chip and frame read out towards the computer. The read-out system is usually also responsible for supplying the bias voltage of the Silicon layer as well as the power for the chip.

Two different read-out systems have been used in our projects. For the Medipix-2 we used a USB1.1 (Vykyda et al., 2006) and the FITPix read-out system with a USB connector (Kraus et al., 2011). Since the chips were of older Medipix versions, continuous read-write was not possible. Also the read-out was not able to supply enough power for the total power consumption of a quad. Therefore, the detector (Chip & Read-out) only supported 3.3 fps with a maximum 50% dead time (DT) per second. This combination was used in the chapter about rotational crystallography of protein crystals (chapter 4).

For the Timepix chip we used the RELAXD board, designed by Nikhef (Visser et al., 2011). This read-out board utilizes the full potential of a 1Gb ethernet connection. Therefore, it supports a maximum of 120 fps for a single Timepix Quad with a DT of 8.3 ms per frame. For the experiments with the Timepix we usually set the exposure per frame to 100 ms, which resulted in a total 9.1 fps.
2.2.7 Software

Control of data acquisition requires sending instructions to the chip and getting the frame information back. The instruction set for the Medipix-2 and Timepix are well documented within the collaboration, and therefore many basic instruction sets exist. However, working with them requires advanced knowledge of command-line shells. For our work we used two software packages with a user interface: Pixelman (Turecek et al., 2011) and SoPhy (ASI, 2015). To operate the detector using USB read-out boards, Pixelman is the best solution and SoPhy is optimized to be used with the Timepix chip and Relaxd read-out board. Both these software packages support alignment scripts for: (i) chip equalization, where the different pixels are equalized based on the noise edge of the chip.;(ii) dead, bright and noisy pixel detection.

The scripts make the tedious work of alignment much easier. Since the noise edge is far away from the operating THL value, the chip to chip alignment still requires manual adjustments. Sophy is able to align 16 or more individual chips.

While these software packages are mainly designed for alignment and chip testing, they have been further developed for X-ray imaging and diffraction and in the case of SoPhy also Mass Spectrometry. Currently (2015) we only use the SoPhy software package. In the near future this package will contain a module specially designed for ED, which removes many small and inconvenient user problems (e.g. live image and data acquisition at two different fps). Sophy is able to store images in .txt, .tif and .bin formats.

Figure 2.3: Simplified schematic of the counting electronics of a Timepix chip. (Source: Medipix consortium)
2.3 Camera design

2.3.1 Cooling

The first camera systems designed for the Medipix-2 v1.3 detector were not actively cooled (Georgieva et al., 2011) (chapter 4). However, we found that not cooling the detectors or read-out could lead to a problem: when the temperature is not stable, several DACs could become unstable (Lower Threshold: THL and THS mainly). The main problem is that the different chips of a quad detector are equalized for a certain threshold energy. Chips do not have the same behavior to shifts in temperature. Therefore if a detector is heated during operation and impact of electrons, the energy calibrated to a set THL will also slightly change for the different chips. At 50-60 °C also an increase in electronic noise becomes noticeable. Because of these two effects in new camera iterations the cooling systems were improved with the aim to keep a stable temperature.

The first iteration of the camera series supported a Medipix on a Quad Nikhef carrier board and a Fitpix (Vykydal et al., 2006) read-out. In an early designs this detector was only passively cooled to the outside air by a copper bridge, this was improved in the second version by actively cooling the detector to a CPU water-cooling system at RT. Early results made clear that not only the detector but also the read-out needed active cooling. This led to the believe that Timepix chip cameras (“Laural” and “Hardy”) should be actively cooled by Peltier water-cooling systems. Peltier cooling in vacuum is difficult to implement, therefore the Peltier cooling system was mounted outside the vacuum. This system made it possible to minimize any DAC fluctuations and to cool a system to be stable within 0.1°C at any outputs between 4W to 30W in the vacuum. (Figure 2.4 shows the test set-up and results at different power loads).

2.3.2 YEOL 1010 Medipix camera

This camera is build into the image plate chamber of the YEOL 1010 by modifying the original bottom flange to support a copper-through-flange cooling block. A “snap black” supports the Nikhef Medipix2 carrier board and the hot parts of the USB2.0 FITPIX are cooled directly to the main copper pylon supporting the detector. With the active water-cooling added to the bottom of this pylon, the read-out board and detector were within design specifications at a maximum of 40° (Fig. 2.5).
2.3.2.1 Chip & read-out modifications

The Nikhef quad carrier board was powered through the USB read-out board. Tests showed that the power supply was insufficient for stable operation of the Quad Medipix-2 detector. This problem was solved by supplying the power directly to the carrier board by two external lab power supplies.

2.3.2.2 Software

Pixelman was used to acquire images and to send acquisition data to the detector (DAC and exposure times) (Turecek et al., 2011). The software was licensed with the purchase of the USB read-out board from Prague. (Kraus et al., 2011). The data was acquired on a computer that was fitted with an Intel Celeron Dual Core 2400 GHz chip and 4 GB of RAM.

Figure 2.4: Cooling test set-up and results. (Left) By using a 5 Ohm resistor and isolating it in vacuum, all heat needs to be removed in the same way as the heat produced in the chips. (Right) Temperature test results. While still a stable temperature is reached at 30W heat production the temperature can not be kept at the set temperature of 17 °C.

Figure 2.5: 3D 90° cut of the YEOL 1010 camera housing.
2.3.3 Quad Timepix for a Titan Krios “Hardy”

The camera was designed to be positioned at the bottom of a Titan Krios electron microscope at the “Eagle” position. Important design requirements were vibration, weight and cooling.

2.3.3.1 Chip & read-out

This design supports multiple Timepix Quad detectors with 300 µm Silicon sensor layer. The chip was mounted on a Nikhef carrier board and with a Kapton flex cable connected to the Relaxd read-out board (Visser et al., 2011). The carrier board was glued to a gold coated copper snap block.

2.3.3.2 Pod design

The camera pod was designed in such a way that all components are connected to the bottom flange of the pod, therefore it is possible to redesign the bottom flange to support other (new) detectors. The lead shielding and vacuum pod can then be re-used and a new flange can be designed (figure 2.8d). To support the chips of the detector and to cool them a copper bridge was vacuum soldered in the stainless steel bottom flange. The copper bridge was soldered directly to the RVS flange without using any heat isolating material (for example: ceramics). This is possible because the thermal conductivity (k) of copper (401 W/mK) is much higher then that of stainless steel (RVS 430F) (16 W/mK). Therefore if the copper is sufficiently cooled the stainless steel will have almost no influence on the active cooling.

The lead pieces were designed according to the specifications of FEI company (FEI, 2015). A maze structure prevents any secondary X-rays to exit the lead shield. The lead shield has a minimum thickness of 15 mm in all directions and made of a special alloy (with 5% Antimony, Sb; can be tooled and is stronger then ‘pure’ lead). The bottom shield part was designed to feed all cables and water cooling hoses from the outside to the detector. A 3D printed piece was implemented in the lead shield for easy cable management.

The chips were clamped in pairs on the copper bridge and were connected with flex cables to the read-out boards. The flex cables were placed on the bottom support flange in custom small flanges. The flex cables were glued in the flanges with stycast 2850 and hardener 11. A shield of 1mm lead with a top layer of 1mm of aluminum covers everything except the detector layer. The read-out boards were cooled by two separate CPU water coolers without a Peltier element. This whole was isolated from the copper bridge which cools the Timepix chips. (Figure 2.6 shows different 3D cuts of the camera design)
Figure 2.6: 3D design drawings of the “Hardy” Krios camera. (a) Bottom to top view of the read-out and cooling of the non vacuum part. (b) 180 Degree cut. (c) 90 Degree cut. (d) 90 Degree cut of the bottom vacuum flange supporting all detector parts and cooling. This part can easily be redesigned to mount other detectors or newer versions of the Medipix brand detectors.

Figure 2.7: Design schematic for: cable management, sensors, data transport and interlocks.
2.3.3.3 Cooling

The water copper parts were mounted with four custom XSPC Raystorm CPU cooling blocks mounted in pairs for both the Timepix chips as well as the read-out boards. The read-out boards were directly water-cooled by the cooling blocks and the detectors were cooled by a Peltier element. The Peltier elements (Multicomp MCPF-071-14-11) had a ΔT of 70° maximum at a voltage of 8.8V. The Peltier system with water cooling was able to cool 60W to a stable 3 degrees below ambient temperature. Tests showed that this set-up was able to keep the chips cooled within 0.1°C from the required temperature (Fig 2.5). The water is cooled to RT by four 120mm fans mounted on a Black Ice GT Xtreme 560 radiator and was pumped by a Laing DDC-1 Plus MCP355 12V Pump.

2.3.3.4 Safety

Because the detector and read-out requirement is to be always powered, interlocks were implemented in case of failure. If any of the interlocks is triggered the full system will go in an emergency shutdown. There are three interlocks: (i) a moisture meter inside the lead shielding. Because moisture can form on cooled parts this value should be less then 70% when ΔT between the air and cooled areas is ~5 °C; (ii) a computer with software to monitor water flow, temperature and fans. If a value is reaching a preset level but also if the computer and/or power fails the interlock will open; (iii) power control and temperature control of the Peltier regulator. If the power fails or the temperature at the chip position reached a preset level (30°) the interlock will be triggered. A schematic of the cable management, interlocks etc. can be found in figure 2.7.

2.3.3.5 Software and Hardware

The software ‘SoPhy’ was supplied by ASI (ASI, 2015). It is robust and has easy access to DACs. When it is used in a Real Time Linux environment the maximum speed of the detector is 80 fps for 4 synchronized Quads or 120 fps for a single Quad. The operating system and software were installed on a 12 core 2.4GHz intel Xenon Dell 7200 computer with an SSD and 16GB of RAM. The system was connected to the read-out boards by an intel 4 port 1Gbit Intel I340-T4 ethernet card.
2.3.4 Single quad Timex design “Laurel”

This design was based on the “Hardy” design. It could be transported to different locations and to be used on different microscopes, hence simplicity. This camera supports a single Quad Timepix chip. The initial design also contains no fail saves apart from a manual temperature monitor. The acquisition software SoPhy was used and the custom build computer supports a single i7 quad core at 2.8GHz, 8 GB of RAM.

2.3.4.1 Pod design

The camera is of similar design as the “Hardy” camera. The snap block of the chip was redesigned so the detector can be mounted more easily to the copper cooling bridge. Since only one chip needs to be cooled a single copper pylon was vacuum soldered in the flange. The flex cable flange is redesigned to hold only one flex cable and instead of using an isolated cooling block the read out board is cooled directly to the copper bridge. The whole system was cooled by one Peltier assembly. The lead pieces have been redesigned for simplicity. A single cone of lead was designed to fit around the vacuum chamber. The cables and water hoses then are feed through a final lead piece with a maze structure. The interface to the microscopes is easy to redesign and a redesign for a different microscope usually involves a different interface flange and lead mantle pieces (figure 2.10).

2.3.4.2 Cooling

The system is cooled by a single Peltier (Multicomp MCPF-071-14-11), XSPC Raystorm CPU water-cooler, Black Ice GT Xtreme 280 radiator and a Laing DDC-1 Plus MCP355 12V Pump.
2.4 Discussion

The designs described in this chapter can still be improved (e.g. simplicity, access to the chip assemblies, alignment). The new Timepix-3 detector require a complete redesign of the camera housing. Especially when it comes to radiation safety, careful and precise design decisions need to be made.

In early iterations, detector failures made it clear that stable cooling and power are very important to prevent electronic failures. Cooling and power stability have a big impact on data quality. It is possible to simplify the “Hardy” design by improving the alignment of different parts (e.g. lead shielding and chip positions). Also, the read-out area could be improved by using a more simplified design. The “Laurel” design should support the same kind of safety features for emergency shut-down.
Figure 2.8: 3D design drawings of the “Laurel” Juelich camera. (a) Bottom to top view of the read-out and cooling of the non vacuum part. (b) 180 Degree cut. (c) 90 Degree cut. (d) 90 Degree cut of the bottom Vacuum flange supporting all detector parts and cooling.