Proposal for a quartz fibre calorimeter for use with the Cavity Longitudinal Polarimeter at HERA

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Abstract

It is proposed to construct a new electromagnetic calorimeter to measure the Compton photons produced by the Cavity Longitudinal Polarimeter at HERA. The calorimeter will be installed close to the electron beam line, at a distance of 110m downstream of the HERMES detector. A tungsten-quartz fibre sampling calorimeter is proposed to ensure compactness and high radiation hardness. Simulations show that the proposed calorimeter has a linear energy response and an energy resolution stochastic term of $19.2 \pm 0.5\%$. The shower width for 90% energy containment is found to be 0.83 cm.

1 Introduction and Motivation

The Longitudinal Polarimeter and the forthcoming Cavity Longitudinal Polarimeter are situated at distances of 52m and 62m downstream of the HERMES experiment, respectively, at HERA. Both polarimeters work on the principle of Compton scattering polarised laser light off of the polarised HERA electron beam and detecting the scattered photons in a downstream calorimeter.

Currently two calorimeters are operational at a distance of 110m downstream of HERMES - a crystal and a sandwich scintillator calorimeter. However, for operation of the cavity LPOL, neither of these two calorimeters

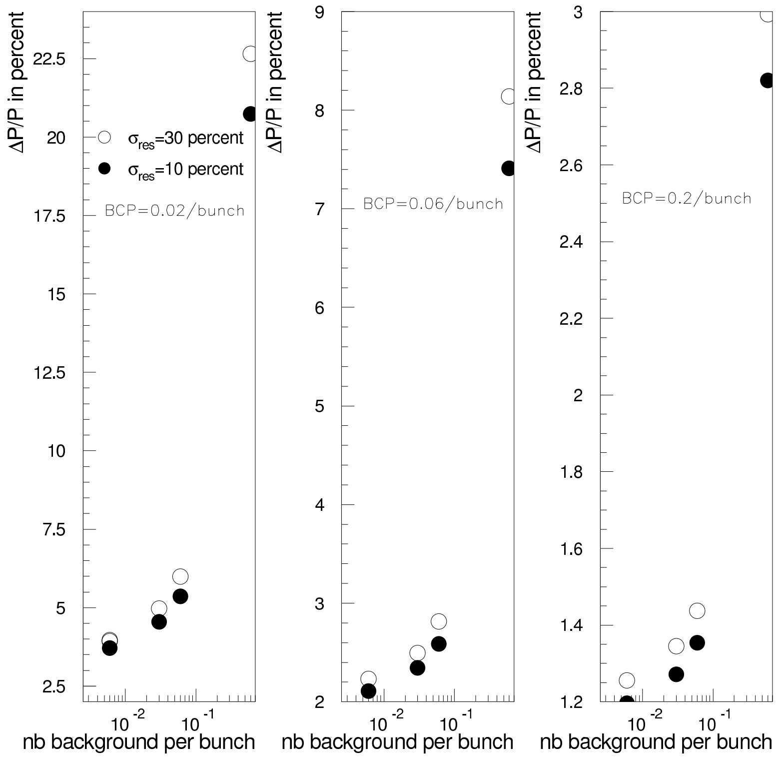

Figure 1: Relative uncertainty on the polarisation measurement determination for different signal rates (=BCP) as a function of bremsstrahlung background rate. Two energy resolutions $10\%/\sqrt{E}$ (white circles) and $30\%/\sqrt{E}$ (black circles) are considered. [1]

will be suitable. The main problem is due to the Compton beam produced from the Cavity LPOL. It is estimated that radiation dose from the Compton beam will be approximately 200 MRad per year - ensuring that neither present calorimeter will be able to withstand prolonged operation. In addition, damage from beam produced radiation has been observed in both calorimeters, meaning that radiation hardness is doubly important.

In addition to radiation hardness, two further requirements are the energy resolution and physical size of the new calorimeter. Studies have shown that a modest energy resolution of $(20-30)\%/\sqrt{E}$ will be sufficient [1]. Figure 1 shows the change in the relative error of the polarisation measurement from the cavity LPOL, as a function of the number of background photons, for energy resolutions of $10\%/\sqrt{E}$ and $30\%/\sqrt{E}$. Secondly, the physical size of the calorimeter is important. At the position of the calorimeter, the Compton photon beam from the LPOL is separated by a distance of only 42mm from the HERA electron beam. However, the electron beam pipe limits the horizontal size of the calorimeter. Hence, the calorimeter should be compact and have a small shower radius to allow the photon energy to be well reconstructed, even when incident near to the edges of the calorimeter.

Due to these requirements, a tungsten-quartz fibre sampling calorimeter is proposed.

2 Design

The design of the calorimeter is based on the H1 Photon detector [2], with some simplifications. The calorimeter will be a tungsten-quartz fibre sampling calorimeter, where the signal is produced from Cherenkov radiation in the quartz fibres. The subsequent Cherenkov photons are transported by the fibres to quartz lightguides and then read out using photomultiplier tubes. Tungsten was chosen as the absorber due to the small transverse and longitudinal shower sizes allowing a small calorimeter to be made. Quartz is used as it is one of the most radiation hard optical materials known - pure fused silica is able to withstand doses of approximately 10^7Gy. Previous designs have utilised quartz fibres to produce and transport Cherenkov photons to photomultiplier tubes to produce a signal [2, 3]. Fibres with a quartz core and quartz cladding are used to provide the highest radiation hardness. Finally, the active volume of the calorimeter is tilted at an angle of 45°. This is close to the Cherenkov angle for the quartz fibres, ensuring that Cherenkov photons from the energetic core of the electromagnetic shower are trapped within the quartz fibres, hence giving the maximum response [3].

A schematic side view of the proposed calorimeter is shown in figure 2. The calorimeter consists of 50 layers of tungsten plates interleaved with layers of quartz fibres. The tungsten plates have dimensions $40 \times 56 \times 1$ mm, hence providing an effective area of 40×40 mm. The quartz fibres have a core diameter of 0.6 mm and an outer diameter of 0.66 mm. The refractive index of the core is $n = 1.45$ and the fibres have a numerical aperture of 0.22. Each layer contains 60 fibres, arranged in the x direction, as shown in figure 3. The total depth of the calorimeter is $20X_0$.

The quartz fibres are arranged into five bundles, shown in figure 4. Each

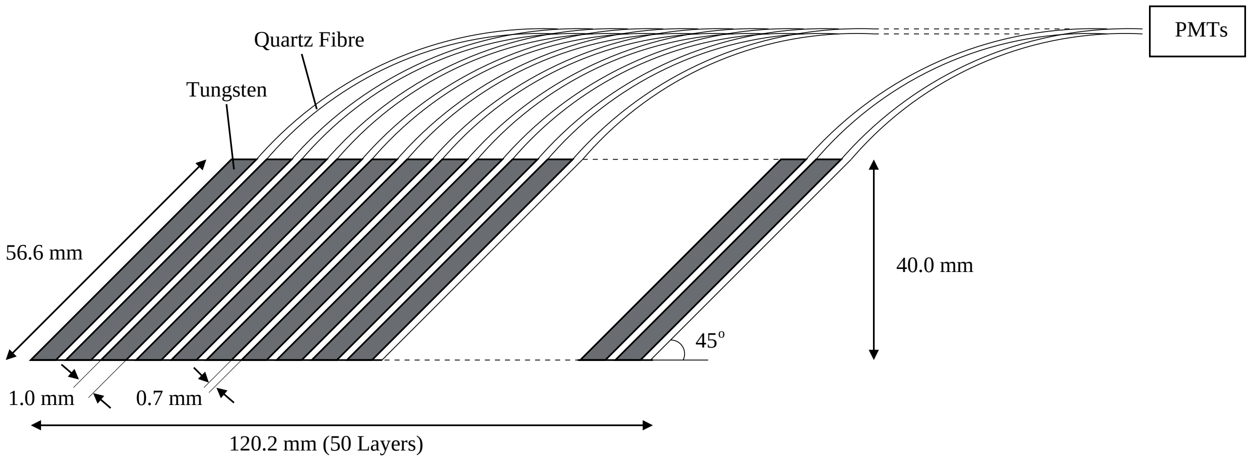

Figure 2: Schematic side view of the tungsten-quartz fibre calorimeter.

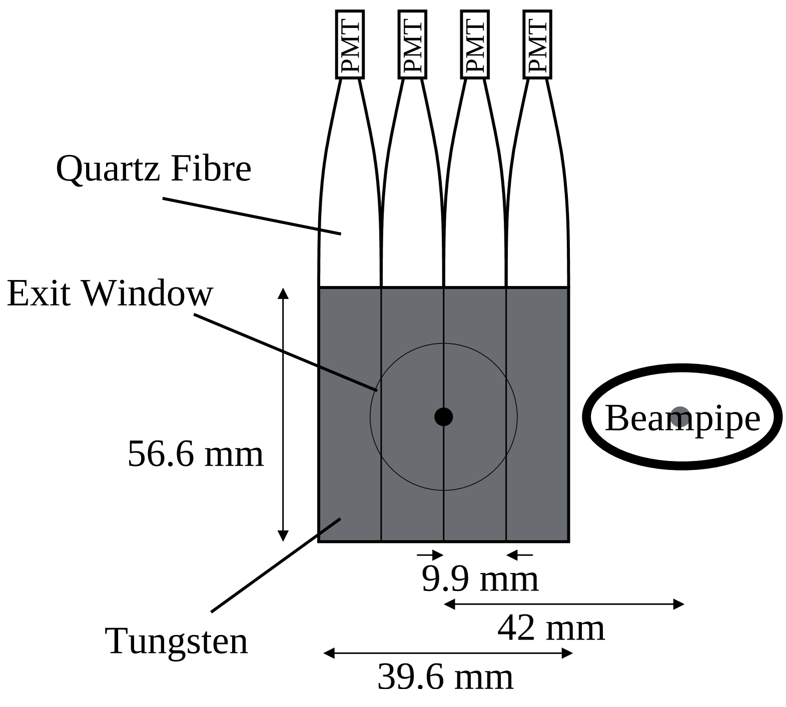

Figure 3: Schematic front view of the tungsten-quartz fibre calorimeter.

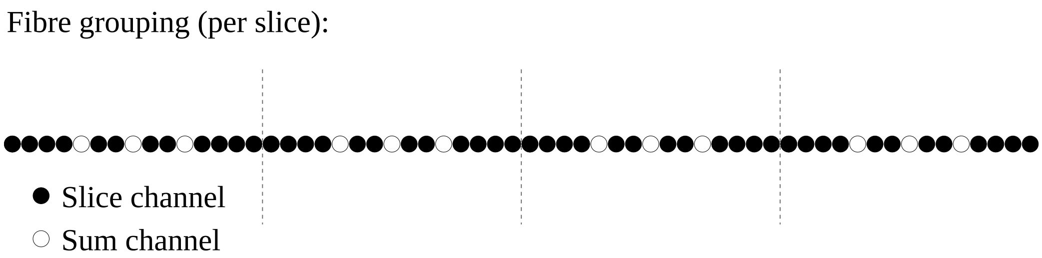

Figure 4: The arrangement of fibres per layer of the calorimeter. The fibres are split into segments, as shown by the grey dashed lines. The fibres shown in black from all layers of each segment are arranged into a single bunch and connected to a PMT. All of the remaining fibres from all layers, shown in white, are bunched together and connected to a further PMT.

bundle illuminates a lightguide, which connects to a PMT to detect the Cherenkov photons. The fibres are split into four segments in x, corresponding to 15 fibres per layer or a width of 9.9mm. In addition, a split quartz plate will provide y position information. From each segment of each layer, 12 of the 15 fibres (shown in black) are taken to the fibre bundle for that segment. The remaining 3 fibres from all segments of all layers (shown in white) are bundled together and connected to a single PMT. This provides a sum channel, only using one PMT, to allow for calibration between the separate segments.

3 Simulation

The calorimeter has been simulated using GEANT3. The Cherenkov photons are generated within the quartz fibres, with wavelengths in the spectral response of the proposed PMTs (300-650 nm). The Cherenkov photons are then tracked along fibres and finally detected by being absorbed in a metal, when the fibres pass out of the top of the active volume. Hence, the calorimeter response is simulated up until the lightguides and PMTs.

The simulation shows the response of the calorimeter is linear, as shown in figure 5 (a), for the range of Compton photon energies produced by the cavity LPOL. The deviations from linearity, shown in figure 5 (b), are less than 1%. At 9 GeV, the Compton edge of the cavty LPOL energy distribution, 790 Cherenkov photons are trapped within the calorimeter fibres.

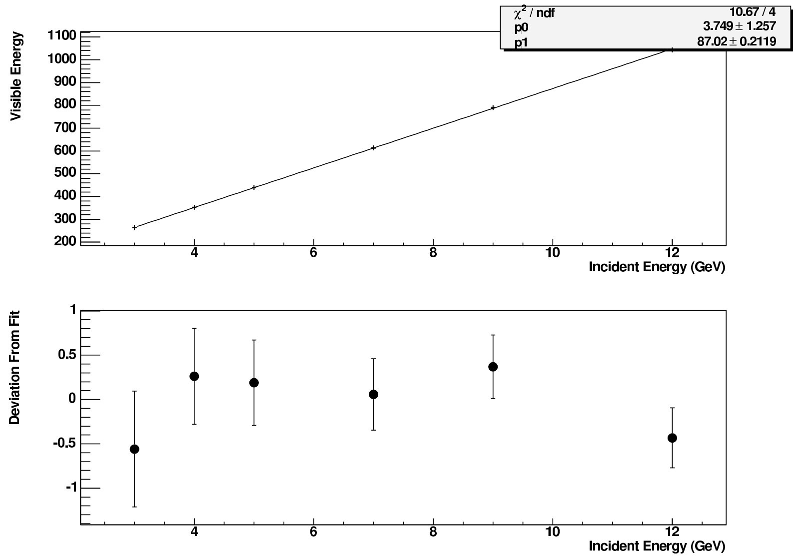

Figure 5: The (a) linearity and (b) deviation from linearity of the simulated calorimeter, for incident photons, as a function of energy of the incident photons.

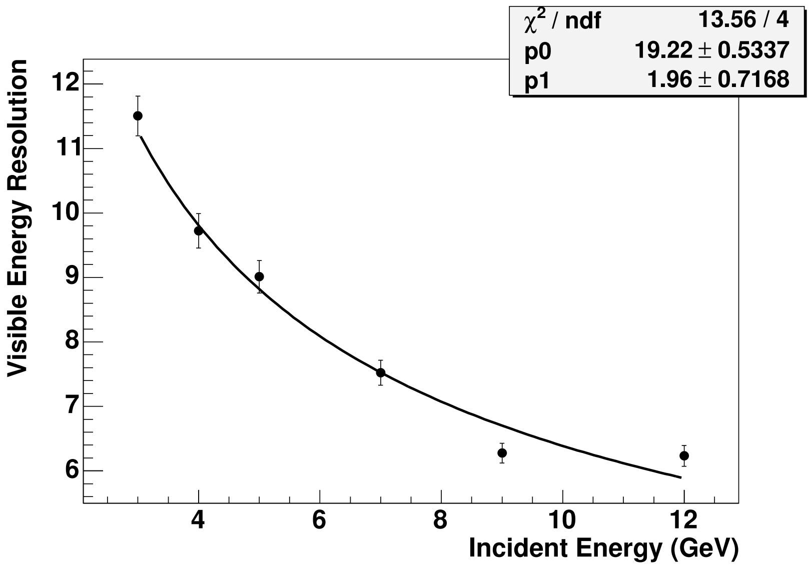

Figure 6: The resolution of the simulated calorimeter, for incident photons, as a function of energy of the incident photons.

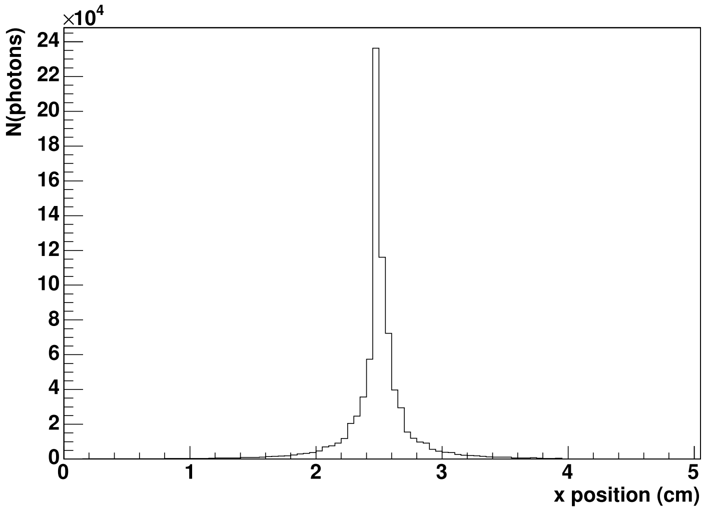

Figure 7: The lateral shower profile of trapped Cherenkov photons for 9 GeV photons, incident at $x = 2.5$cm.

The energy resolution, shown in figure 6, is found to be

$$\frac{\sigma(E)}{E} = \frac{(19.2 \pm 0.5)\%}{\sqrt{E}} \oplus (2.0 \pm 0.7)\% \qquad (1)$$

This is within the range specified for the calorimeter, however the simulation still does not include the efficiency of detection for the PMTs.

The lateral profile of trapped Cherenkov photons for 9 GeV incident photons is shown in figure 7. The shower has a width for 90% energy containment of 0.83 cm. Hence, by sharing the deposited energy between adjacent strips, the x position of the photon beam may be measured.

4 Channel/HV Map

1880V,current limit 1mA,ramp speed is not so important,
100-300V/sec is OK for channel 2 - 2160V,others the same
for channel 3 - 1900V for channel 4 - 2140V

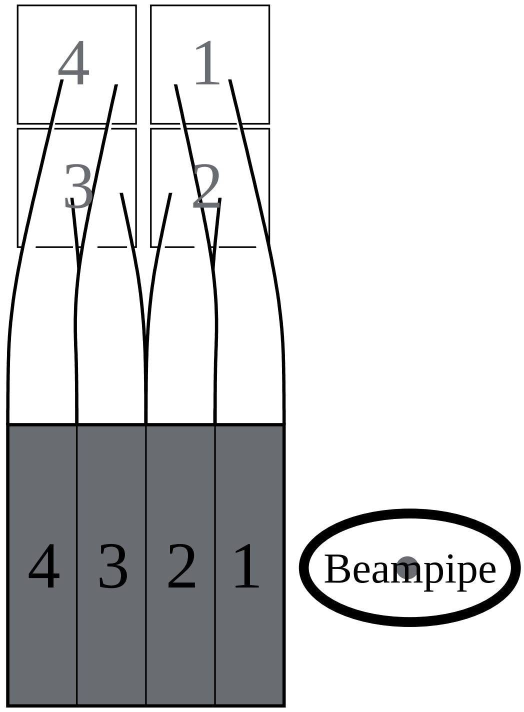

Figure 8: Schematic front view of the tungsten-quartz fibre calorimeter, showing HV channels.

Calo Channel	DAQ Channel
1	3
2	4
3	5
4	6
5(Sum)	7

Figure 9: Mapping PMT in fibre calo to channel in ADC of cavity DAQ.

Calo Channel	Nominal Voltage
1	1880V
2	2160V
3	1900V
4	2140V

Figure 10: PMT nominal voltages

References

[1] C. Pascaud and F. Zomer, *Likelihood treatment of Polarisation Measurements*, POL2000-01/2000

[2] B. Andrieu *et al.*, *Test beam results of the tungsten/quartz-fibre calorimeter for the luminosity measurement in H1*, *Prepared for 9th Conference on Calorimetry in High Energy Physics (CALOR 2000), Annecy, France, 9-14 Oct 2000*

[3] N. Akchurin and R. Wigmans, *Quartz fibers as active elements in detectors for particle physics*, Rev. Sci. Instrum. **74**, 2955 (2003).