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Collimator R&D

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Abstract

The importance of collimator R&D with test beam facilities is demonstrated with the example of ILC collimator studies at SLAC End Station A. Related LHC collimator aspects and longer term plans are addressed.

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1 Introduction

Test beams have proven to be crucial for many developments in accelerator and detector physics. The importance of test beams for the collimator development is discussed. Both, accelerator and detector physics profit from collimator studies. On the detector side most significant is the vertex detector which has the smallest aperture (radius) at the interaction point. Vertex detector design aspects (e.g. innermost radius, occupancy due to background rate and required radiation tolerance) and collimator design studies are related. Precise collimation of the beam halo could prevent beam losses near the interaction region that could cause unacceptable backgrounds in the detector. The collimator design must be optimized for minimal beam disturbance and maximal detector protection. Particular attention is devoted to wakefields induced by the collimators. The optimization of the collimator shape requires simulations and test beam studies. The challenges involved in the collimator design with tight apertures are related to wakefields that deflect the beam and increase the emittance. Much progress has been made in recent years in the collimator development with dedicated ILC studies [1, 2, 3, 4]. At the LHC collimator design studies are crucial for the protection of the accelerator and are a challenge owing to the large stored energy of the beam [6].

2 SLAC's End Station A (ESA) Test Facility

In 2006 and 2007 two collimator test beam studies took place each year. The collimator wakefield measurements project is T-480. The collaborating institutions have been Birmingham University, UK; CCLRC ASTeC, UK; CCLRC Engineering Department, UK; CERN, Switzerland; Manchester University, UK; Lancaster University, UK; DESY, Germany; TEMF TU Darmstadt, Germany; and SLAC, USA.

The two sets of test beam measurements performed at the SLAC ESA facility in 2006 showed the world-wide cooperation in this field of research which is expressed by Jonathan Dorfan in SLAC Today, May 8, 2006: "Living the "I" of the ILC It's Happening Right Here. Here at SLAC. ... Forty physicists from 15 institutions are participating in a two-week run, completing today, for ILC beam tests at the End Station A facility. ... To make these tests realistic and useful, the researchers need a beam which has the challenging bunch parameters needed for the ILC. There is only one place in the world where that is possible: here at SLAC. The unique SLAC electron beam is transported faithfully to End Station A, where a mature user facility, ideally suited to efficient and effective testing, exists."

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2.1 Collimators for Study at ESA in 2006

In the 2006 test beam studies at ESA eight collimator shapes, which were produced in UK and shipped to SLAC, were tested. These tests are aimed at measuring the wakefield kick from the collimator structures. At SLAC a single beam line brings primary electrons from the main linac to End Station A, with energies up to 28.5 GeV. The energy spread is 0.2% and the beam spot size about $(x, y) = (100, 600)\mu$m. The pulse repetition rate was 10 Hz.

The eight different collimator types have been assembled in two sandwich structures. The schematic view and design parameters of the collimators are shown in Figs. 1 and 2, and a picture of the collimators is given in Fig. 3. In the 2006 ESA test beam experiment the wakefield kick on the beam from the collimators was studied. The collimators, grouped in two sandwiches, were placed into the beam. The kick of the beam due to wakesfields has been measured with BPMs placed before and after the collimators.

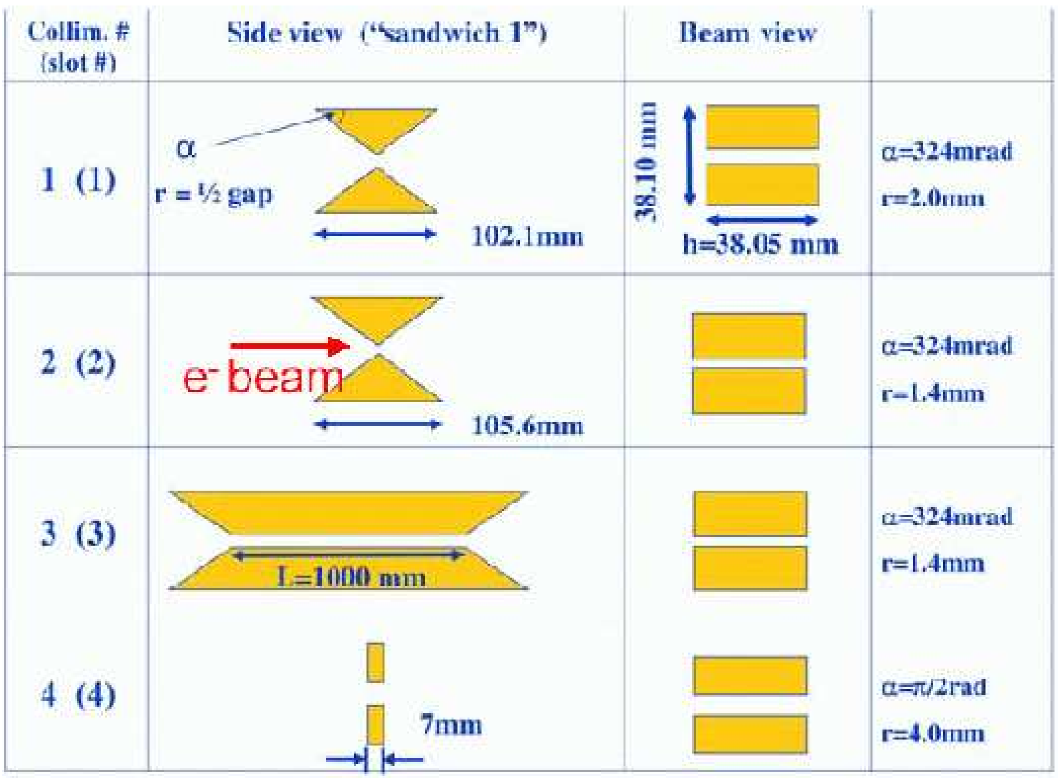

Figure 1: Collimator designs for wakefield measurements. Sandwich 1.

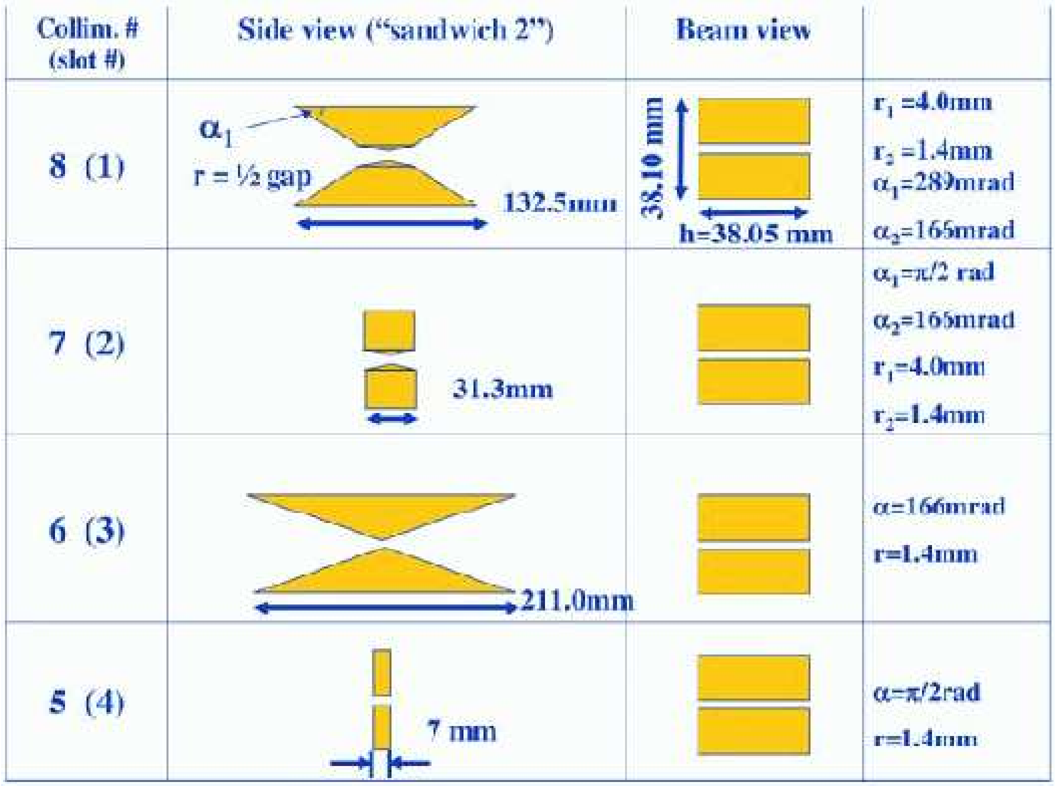

Figure 2: Collimator designs for wakefield measurements. Sandwich 2.

Figure 3: Produced collimator jaws for wakefield measurements. The longest pair of collimators is shown in the front of the picture and has a length of 1m.

2.2 Schematic View of Collimator Test Beam Experiment

The schematic view of the collimator test beam setup is shown in Figs. 4 and 5. A detailed description of the beam optics is given in Ref. [5]. A picture of the vacuum box containing one collimator sandwich with four collimators is shown in Fig. 6. The mover box allows the different collimators to be pushed into the beam with precision alignment. As a reference, the mover box also contains one empty position where the beam can pass through without a collimator.

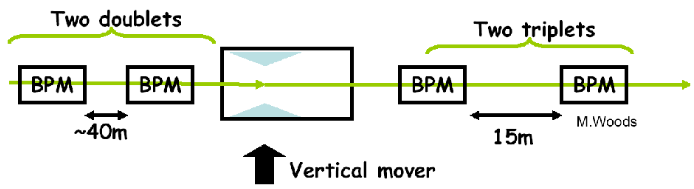

Figure 4: Experimental setup at ESA for collimator wakefield measurements. The collimator jaws are placed in the mover box, as indicated by the flash.

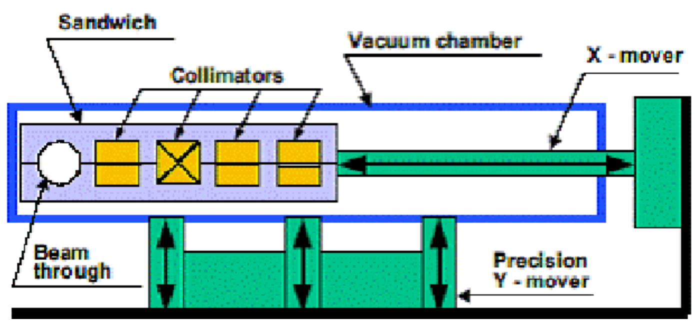

Figure 5: Schematic view of the mover box in the experimental setup at ESA for collimator wakefield measurements.

Figure 6: Mover box at ESA for measurements of beam kick factors from wakefield measurements induced by different collimator designs.

2.3 Preliminary Results from ESA Test Beam Runs

The test beam experiments in 2006 showed the expected effect of the wakefields on the beam deflection. The size of the deflection depends on the position of the beam with respect to the center of the collimator pairs. A beam passing through the center of the collimators pairs is not deflected. The test beam results are summarized in Fig. 7 for four collimator designs positioned in sandwich 1. The variation of the beam kick factors on the collimator position, and the collimator design is demonstrated. The experiment confirms that the collimator in sandwich 1 slot 4 has the smallest kick factor compared to the other collimators, as it is expected from the larger aperture.

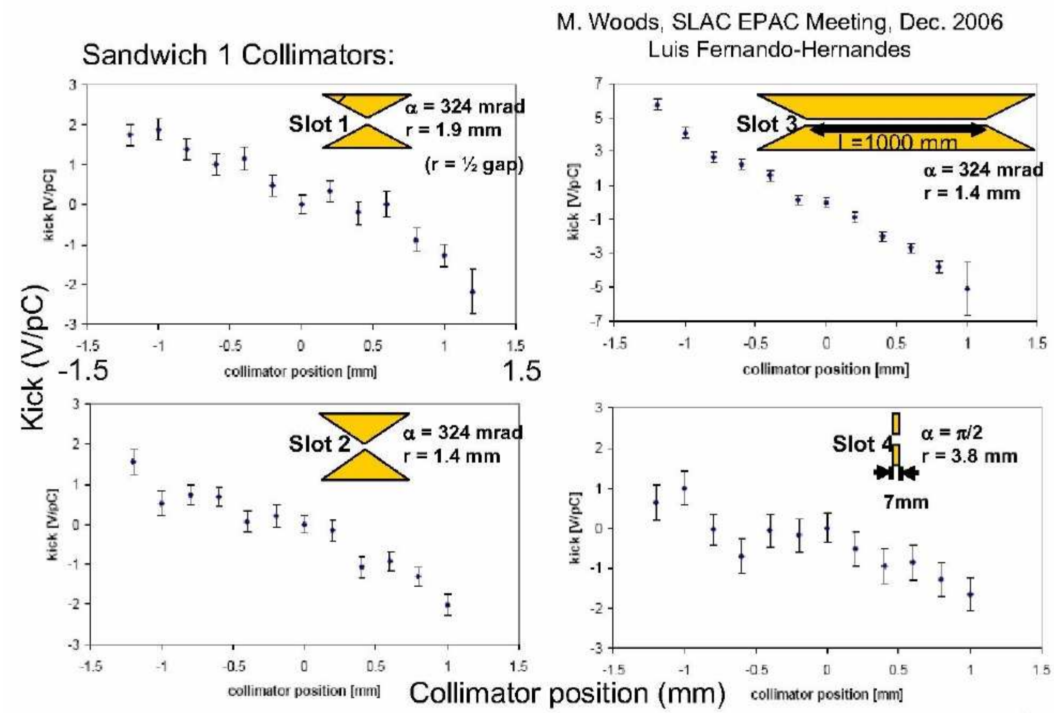

Figure 7: Preliminary Results from collimator wakefield measurements at ESA in 2006. The different collimator shapes and sizes lead to different beam kicks as a function of the collimator position.

2.4 Towards a Comparison of Simulation and Measurements

Precision simulations of the wakefield effects are very challenging and the test beam results are particularly important for comparisons with the modelling. The goal is a determination of kick factors with less than 10% uncertainty. Preliminary results towards a detailed comparison of test beam data and simulations are summarized in Fig. 8.

2.5 2007 Measurements at ESA

Based on first results from 2006 ESA measurements a new set of collimators were produced for 2007 measurements and applied in two test beam runs. The new set of collimators explore the following aspects: shorter collimators, surface roughness, shallow tapers, non-linear tapers (exponential).

preliminary

Collimator	Measured Kick Factor V/pc/mm (χ^2/dof) Linear fit	Measured Kick Factor V/pc/mm (χ^2/dof) Linear + Cubic Fit	Analytic Prediction[1] Kick Factor V/pc/mm	3-D Modelling Prediction[1] Kick Factor V/pc/mm
1	1.4 ± 0.1 (1.0)	1.2 ± 0.3 (1.0)	1.1	1.7
2	1.4 ± 0.1 (1.3)	1.2 ± 0.3 (1.4)	2.3	3.1
3	4.4 ± 0.1 (1.5)	3.7 ± 0.3 (0.8)	6.6	7.1
4	0.9 ± 0.2 (0.8)	0.5 ± 0.4 (0.8)	0.3	0.8
5	1.7 ± 0.3 (2.0)	1.7 ± 0.3 (2.2)	2.3	6.8
6	1.7 ± 0.1 (0.7)	2.2 ± 0.3 (0.5)	2.4	2.4
7	0.9 ± 0.1 (0.9)	0.9 ± 0.3 (1.0)	2.3	2.7
8	3.7 ± 0.1 (7.9)	4.9 ± 0.2 (2.6)	2.3	2.4

[1]Assumes 500-micron bunch length

Figure 8: Preliminary results from collimator wakefield measurements at ESA in 2006. Some differences between simulation and measurement are still larger than the goal of 10%. New BPM calibrations and refined simulations are under study.

One collimator of the 2007 test beam studies is identical with that used in the 2006 runs in order to study systematic uncertainties in the measurement precision. Two test beam runs at the SLAC ESA took place in 2007, one in April and one in July. For these runs the beam optics is described in Ref. [7].

3 LHC Collimator R&D (R. Assmann et al)

Test beam studies were performed between 2004 and 2006 with the SPS beam similar to the LHC beam structure (7μs pulse) [6]. The energy density with 2MJ/mm^2 is about 0.5% of the LHC beam. In particular, survival of shock impact tests have been performed. Figure 9 (from [6]) shows the energy density versus the particle energy for the collimator studies. Up to 500 kW impact on a jaw and 7 kW absorbed is expected. The LHC collimator is shown in Fig. 10.

4 Some Future Collimator Activities

For the LHC Phase II, collimator studies continue to play an important role in the accelerator design. A new test stand at CERN will be possible in 2009 which allows to study larger luminosities. Collaboration with SLAC through the US LHC Accelerator Research Program (LARP) is ongoing. Further aspects of future collimator test facilities are discussed in the EU Framework 7 proposal EuCARD (European Coordination for Accelerator Research and Development) [8]. They focus on material damage studies and high density protons beams. Phase II collimator development is addressed in the work package ColMat (Collimators & Materials for higher beam power beam) and the test facility described in the work package HiRadMat (High Radiation Material). The planned start of EuCARD is January 2009. Furthermore, the GADGET (Generation And Diagnostics Gear for tiny EmiTtance) is discussed within the EU Framework 7 project preparation. Regarding collimators for future wakefield test beam designs the BPM resolution and calibration, and their locations are important aspects. Furthermore, the possibility of a precise measurement of the bunch length is important for a detailed comparison of wakefield measurements and simulations.

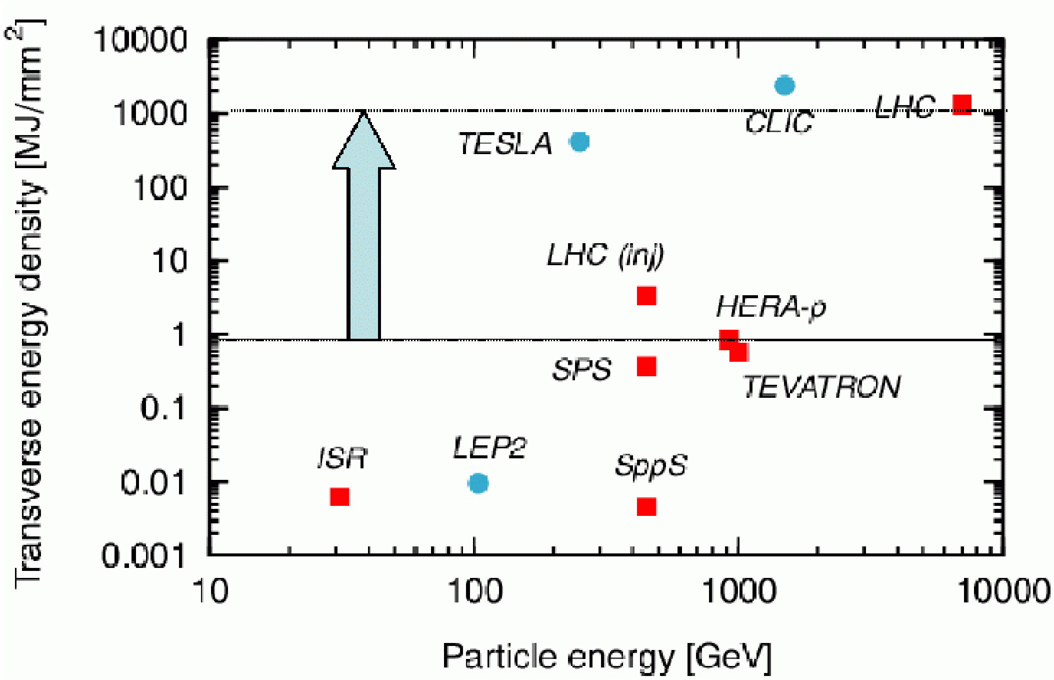

Figure 9: Energy density versus particle energy for collimator studies [6]. Note the very large energy density for the LHC.

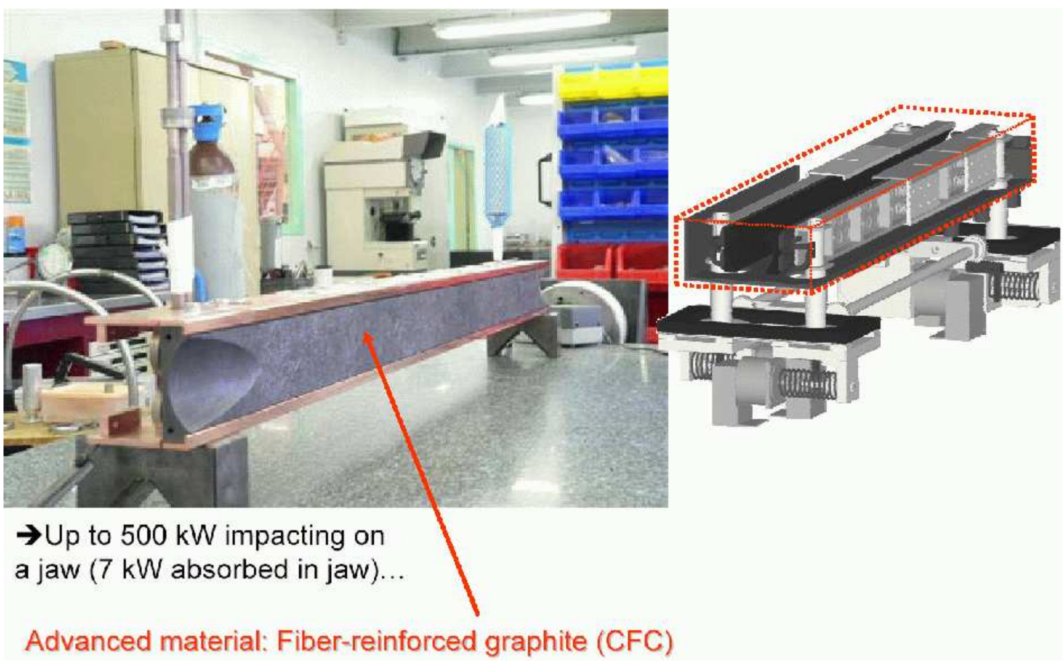

Figure 10: LHC collimator test setup at CERN and schematic view of high precision mechanical collimator structure.

5 Conclusions

Test beam facilities are very important for the collimator development, both at the ILC and LHC. From detailed measurements at the SLAC Endstation A test beam facility the influence of collimators on the beam (kick factors for beams off-axis) have been measured. These measurements guide simulations and material design studies. For collimator design studies the numerical calculations are very complex due to the large collimator size compared to the small bunch size. The impact of the wakefields on the beam is an important design consideration for the collimators. In addition to the wakefield aspect other collimator design aspects are important, like the beam optics, the interaction region layout, design and shaping of the masking, and the inner radius of the vertex detector.

At the LHC the large energy densities are a challenge for the collimator design. The focus is laid on the survivability (machine protection) and only to a lesser extent on the wakefield aspect. Test beam facilities remain an important aspect in the future for the verification and tuning of the required simulations and material studies.

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