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Measurement of the radiation field in CDF

Saverio D'Auria[c], Andrew Hocker[d], Susan McGimpsey[a],
Kostas Kordas[e], Richard J. Tesarek[a], Steven Worm[b]

[a] *Fermilab, Batavia, IL 60563, USA*
[b] *Rutgers University, Piscataway, NJ 05549, USA*
[c] *University of Glasgow, Glasgow G12-8QQ UK*
[d] *University of Rochester, Rochester, NY 14627, USA*
[e] *University of Toronto, Toronto, Ontario M5S-1A7, Canada*

Abstract

The radiation field in the tracking volume has been measured both with dosimeters and using the silicon current. The two measurements agree within a few percent and show that in the present detector the dose rate agrees with predictions based on runI data, with a slightly less steep dependence on distance from the beam. For the innermost SVX layer the average fluence rate is 1.3×10^{10} cm^{-2}/pb^{-1}. Variations of the fluence with the polar angle have been measured, as an effect of 3.1 mm displacement of the beam with respect to the detector axis.

1 Introduction

The CDF experiment studies interactions of colliding proton-antiproton beams at energy 1.98 TeV in the centre of mass. The silicon tracker is the detector closest to the interaction point and is exposed to radiation from both interactions and beam losses. An accurate measurement of the radiation field is important to estimate the lifetime of the present detector, to design the detector upgrade for the high luminosity run-IIb and to add new information to the models of the radiation field that are used for Large Hadron Collider detectors. We have used two methods to measure the radiation in the CDF tracking volume: Thermo-luminescence Dosimeters (TLD) the current of the silicon detector. TLD's are an industrial standard and are very accurate, but they need to be placed, collected and read out individually. The CDF tracking volume is not easily accessible: long periods of accelerator shutdown are needed to collect and replace the dosimeters.

The detector bias currents and the temperature history are continuously recorded as a part of the experiment control system. We show here that they can be used to monitor the radiation field but they suffer of relatively larger systematic errors.

2 The CDF silicon tracker

The CDF silicon tracker can be separated in three subdetectors: Layer-00 is the innermost layer, at about 1.5 cm from the beamline; it is made of single-sided silicon microstrip detectors that are arranged in 12 wedges along the polar angle ϕ that are made of alternated "wide" and "narrow" sensors, and 6 segments along the beam direction (z), each segment is made of a chain of 2 sensors, connected to each other by wire bonds. The SVX consists of 5 layers of double-sided sensors arranged in 12 wedges in ϕ and 6 electrical segments in z that cover a region of ± 45 cm from the interaction point, from 2.7 to 12.5 cm in radius. The ISL is the outer part of the silicon tracker. It fills the region between 16 and 25 cm from the beamline and is about 2 m long. A more detailed description of the CDF silicon tracker can be found elsewhere [1, 2].

3 Measurements with TLDs

TLDs are a very accurate and standard method of radiation monitoring, but they require a large amount of handling. A more detailed description of our TLD measurements is reported in [3]. We have used two types of Harshaw LiF TLD: the TLD-600 are sensitive to neutrons and gammas because they are made of isotopically pure ^6Li while the type TLD-700 is mainly sensitive to ionizing radiation, as it is made of isotopically pure ^7Li. The TLD-700 are 4.2 mm in diameter and are 0.9 mm thick, the TLD-600 measured $3.4 \times 3.4 \times 0.9$mm^3. 3 TLD chips of each type were grouped in G-10 holders; we placed a total of 146 holders in various locations: on the outer screen of the ISL, on the outer screen of the SVX ond on the end plate of the calorimeter, at the edge of the tracking volume. The TLD have been individually calibrated with a ^{137}Cs reference source at the Fermilab Radiation Physics Calibration Facility: the chip to chip variation was 2.7% for 1 Rad exposure, calibrations were reproducible within 1%. Data from two exposure periods are reported here: February 23 to May 1 and May 1 to October 8 of 2001. The contribution from beam loss and from collisions could be separated using the different ratio of losses to luminosity in these two periods and assuming the superposition of the effects to be linear.

4 Current measurement

The current of a silicon sensor can be expressed as the sum of 4 components: a "bulk current" due to generation processes in the volume of the semiconductor, a surface current, due to generation processes at the interface with the oxide layer, an edge component, due to the cutting of the crystal and a stray component that takes into account any leakage in cables and circuit boards. In our case, there is an additional component due to ionization because the current is measured while collisions are taking place. If the variations of surface, edge and stray currents are sufficiently low the increase of bulk current due to radiation damage dominates over other effects. It has been shown that the increase in bulk current is proportional to the integrated particle flow (fluence) and is independent of features of the silicon crystal such as resistivity, growth method and dopant, for high resistivity silicon [4]. The increase of current is: $\Delta I_{bulk} = \alpha \Phi V$ where V is the active volume of the detector and Φ is the fluence. The value of α depends on the particle type and energy. For minimum ionizing particles we have used $\alpha = 3.0 \times 10^{-17}$ A/cm at 20^{o}C [4]. The reverse current depends on the temperature; the parameter α has the same functional dependance on temperature as the current, so all current measurement were scaled to 20 C. Temperature corrections can be quite large, so it is important to use a realistic thermal model for detector modules (or ladders). The temperature of the cooling channels is recorded every 30 s. The channels run underneath the sensors in case of L-00, so the sensor temperature is relatively uniform. In case of SVX, the cooling channels run at both ends of the ladders, where the two Beryllia hybrid circuits that carry the readout chips are glued above and below the silicon sensor. The temperature of the SVX ladders is not uniform, but can be modeled with a constant gradient of about 2 K/cm in the area in between the hybrids and about 0.1 K/cm in the exposed silicon.

The current changes of each power supply [5] are recorded every 10 s. The calibration of the nA-meter has been checked on a subsample of modules and was found within the specifications. The current sensitivity was set to 10 nA for L-00 and L0, L1 and L3 of SVX. For all the other sensors it was set to 1 μA due to the higher average of initial current. The present analysis only considers a 3 month period from January 1 to March 30 2002, during which the delivered luminosity was 16 pb^{-1}. Therefore only data from the 4 layers that have high-sensitivity nA-meters could be used.

Operationally, the bias to the silicon detector is turned on only after the beam is successfully injected and is turned back to 2 V bias before dumping the stored beam. During this time, that can be as long as 24 hours, the current of each silicon element is approximately constant: the time average, or also the maximum reading, can be used to represent the element's current during each store. The current is then scaled to its value at 20 C using the measured temperature and a thermal model of the detector element. The delivered luminosity is recorded by the CDF luminosity monitor[6] and the value for each store is available from a database. For each detector element the current was plotted against the integrated luminosity and a linear fit was performed after removing the data points that correspond to known anomalies. An example of data is shown in fig. 1. The slope is proportional to the average fluence rate (cm^{-2}/pb^{-1}) that crosses the sensor surface. Given the large number of points the error on the slope is quite small. Not all the sensor module have the expected positive correlation between current and integrated luminosity. In general for sensors that already start with a large current the current changes don't follow this simple model, indicating that other effects are play a role. Only 24 out of 242 sensor elements fall in this category and have been excluded from the analysis.

5 Data Analysis

At present, the Tevatron beam is displaced by $\delta = 3.1$ mm with respect to the axis of the silicon detector. The distance of each sensor element from the beam depends on the polar angle: $R(\phi) = \sqrt{R_0^2 + \delta^2 - 2\delta R_0 \cos(\phi + \phi_o)}$ therefore a modulation in the fluence rate is expected. While in SVX it is masked by ladder to ladder variations, this effect is evident in L-00 as shown in fig. 2, where a sinusoidal fit is superimposed. The beam position that was measured this way is in good agreement with the position measured accurately by tracking physics events: the discrepancy is 0.07 radians in angle and 1.7 mm in beam displacement.

In order to extract the variation of the radiation field along the beam axis we took the fuence rate average in ϕ for SVX and the offset parameter of the sinusoidal fit for L-00. The data are shown in fig. 3, the fluence rate is consistent with being constant in z, within the range of the silicon detector. The slightly higher fluence rate for the inner layer close to the centre of the detector (z=0) is unexpected and is presently under investigation.

In case of the TLD measurements a fit was performed assuming a power law dependance of the dose rate D on the distance R from the beamline $D = aR^{-\gamma}$, for each z position. The z-dependance of the dose is shown in fig. 4: this measurement spans a larger volume than the current measurements. The dose rate increase in the forward/backward regions is clearly visible also in fig. 5, where the exponent and the factor a are reported as a function of the position along the beam.

A comparison between the two methods shows a good overall agreement: comparing the extralpolation of the TLD measurements to the L-00 current measurements we get an average discrepancy of 10%, as shown in fig 6.

However the exponent γ that we obtain from a fit of current measurements is lower than the one we obtain with TLDs absolute measurements. We are investigating possible causes of systematic errors.

6 Conclusions

The radiation field in the inner tracking volume of the CDF experiment at the Tevatron collider has been measured with two methods. The TLD measurements are very accurate and offer a good absolute calibration. The fluence rates measured with the silicon currents have a larger systematic effects but the two methods agree well in the overall estimation of the dose. The systematic effects are under investigation: in particular the current method gives a less steep dependance on the distance. The temperature models of SVX ladders are under review.

From the detector point of view the minimum ionizing particle fluence rate measured from the silicon current is 1.30×10^{10} cm^{-2}/pb^{-1} at the innermost SVX layer. This value is in agreement with the expectations. The outer layers may be receiving a dose rate that in the worst case is up to 30% larger than the expected central value. Given the safety margins, the design lifetime in excess of 2 fb^{-1} can be achieved under normal operating conditions.

A large variation of the fluence rate along the polar angle for the innermost silicon layer is due to an off-axis beam. The options of displacing the detector or the beam or both are presently under study. When a considerably larger integrated luminosity will be delivered this study will be extended to the layers that have μA-meters with 1 μA sensitivity.

References

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[5] Power Supplies were custom made by CAEN.

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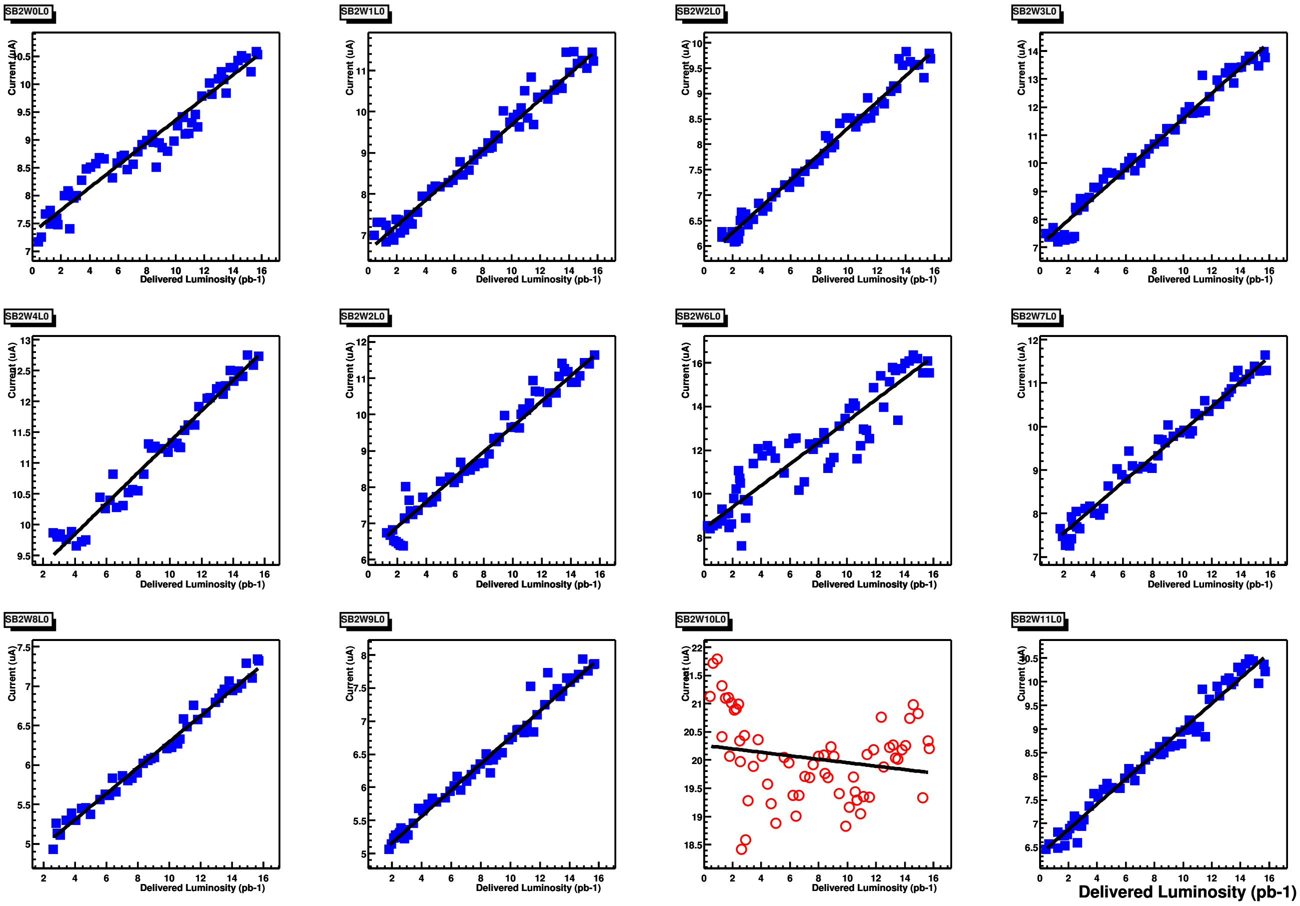

Figure 1: Current vs. delivered luminosity for the 12 sensors of the third SVX z-section from the west, inner layer. For sensor no. 10 the initial current is a factor of 3 higher than the others and other effects mask the current variation due to particle fluence.

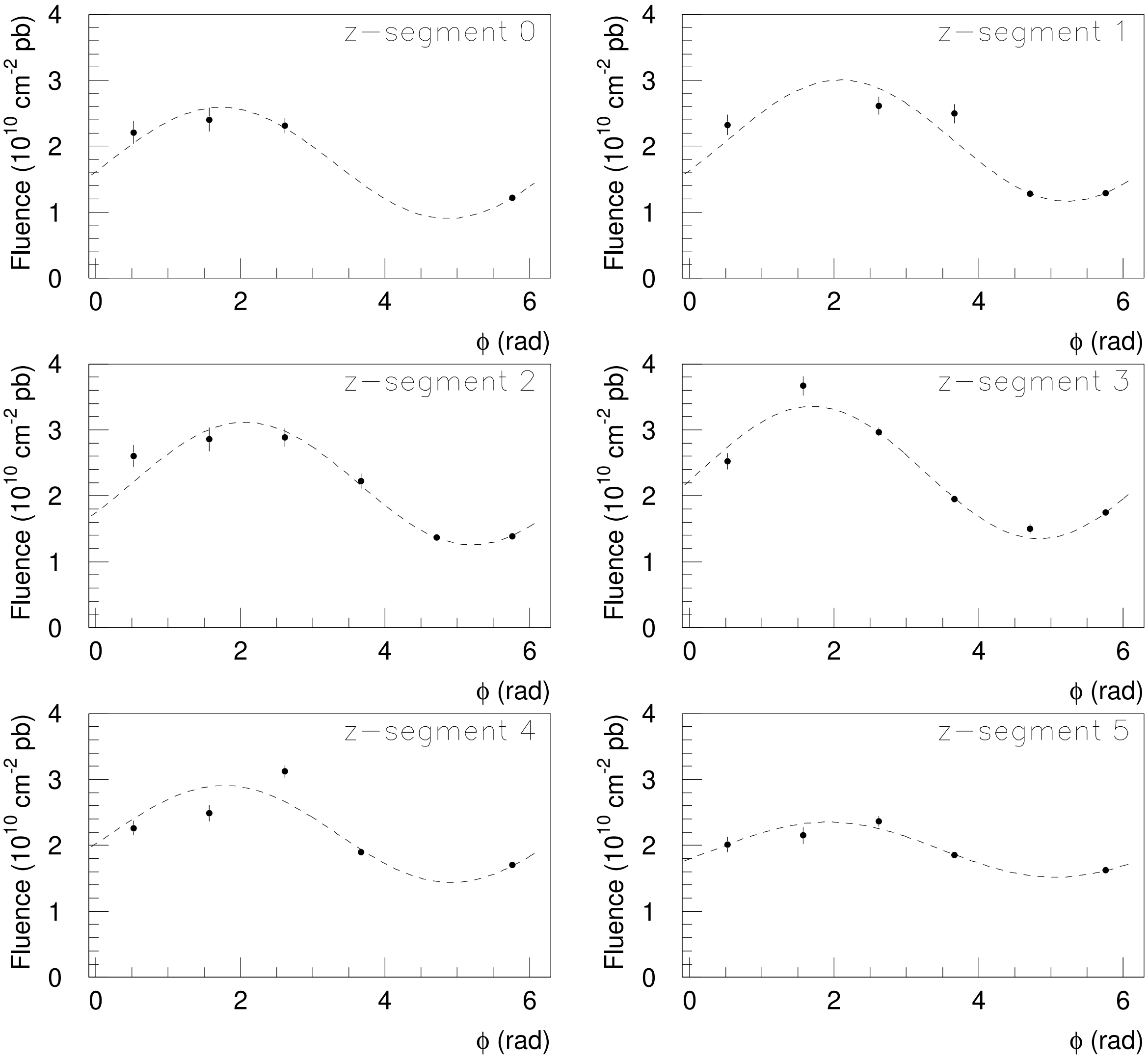

Figure 2: Distribution of fluence vs. azimuthal angle as measured from the currents of the 6 z-segments of L00 'wide' sensors. Superimposed are fits with a sinusoidal function.

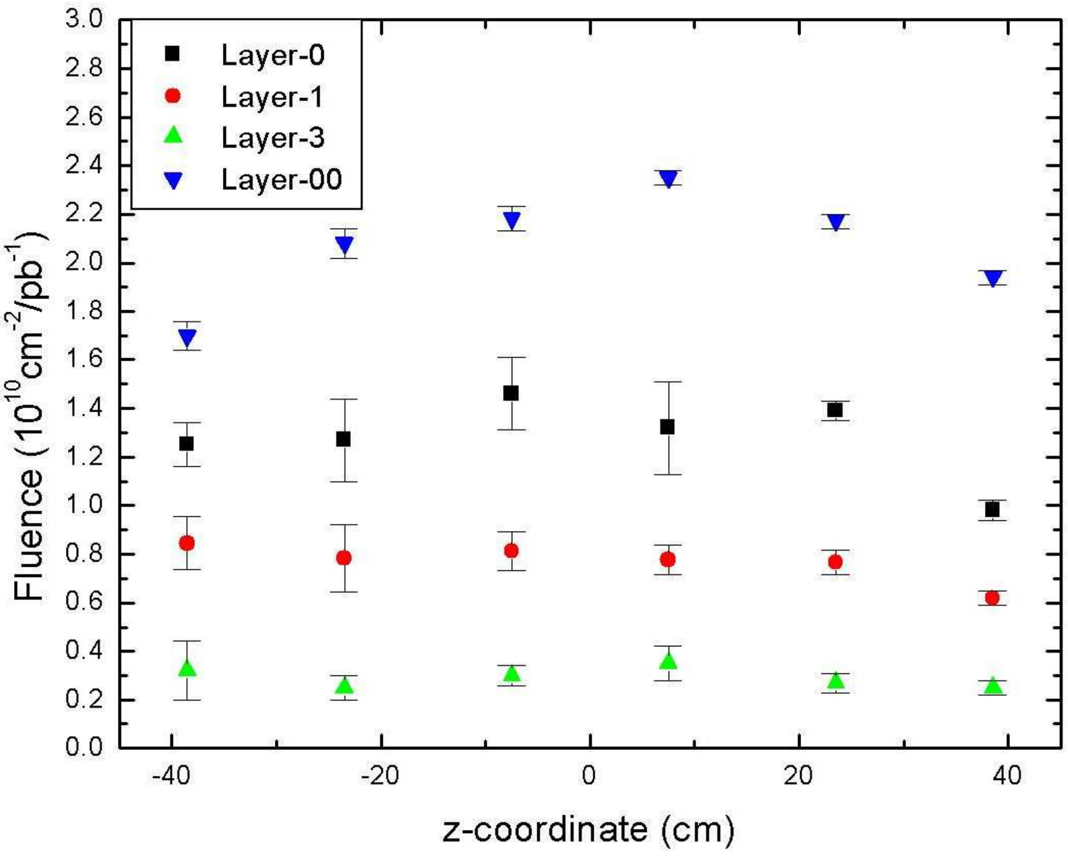

Figure 3: z-dependance of fluence as measured from the sensors' current. These data are average values in ϕ for each z segment. For SVX the errors are calculated from the RMS of the distributions of measurements. For L00 they are the errors on the fit parameter.

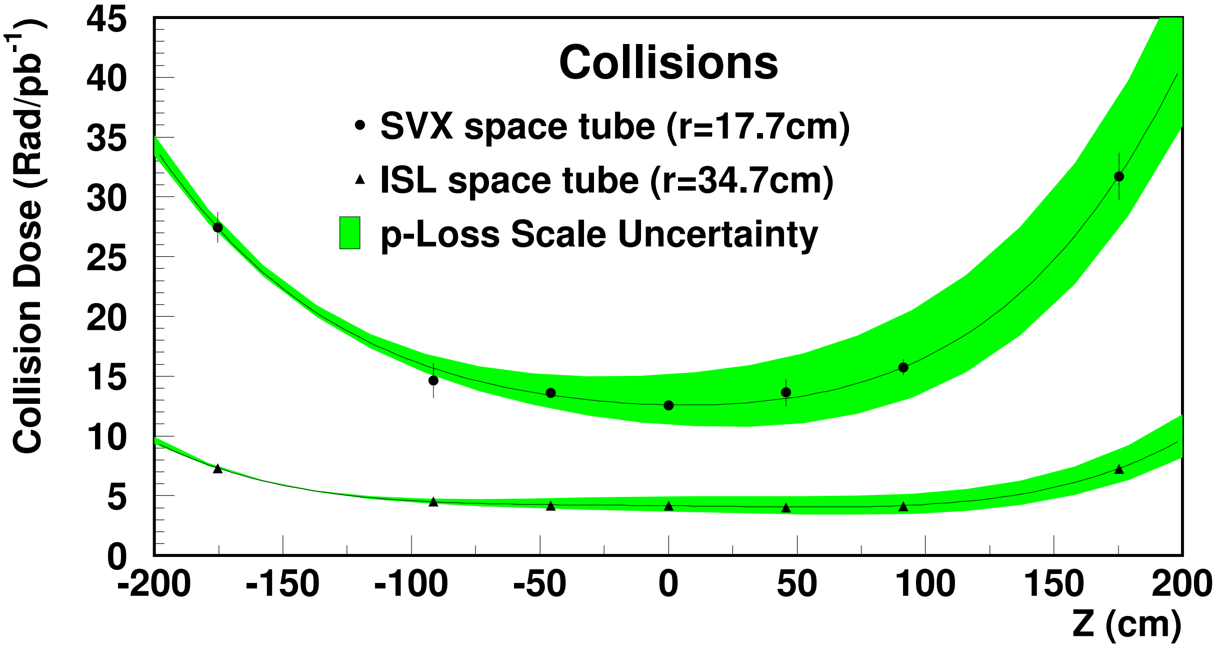

Figure 4: Component of the radiation dose due to collisions as measured with the TLDs is plotted against the distance along the beam line for the two distances from the beam.

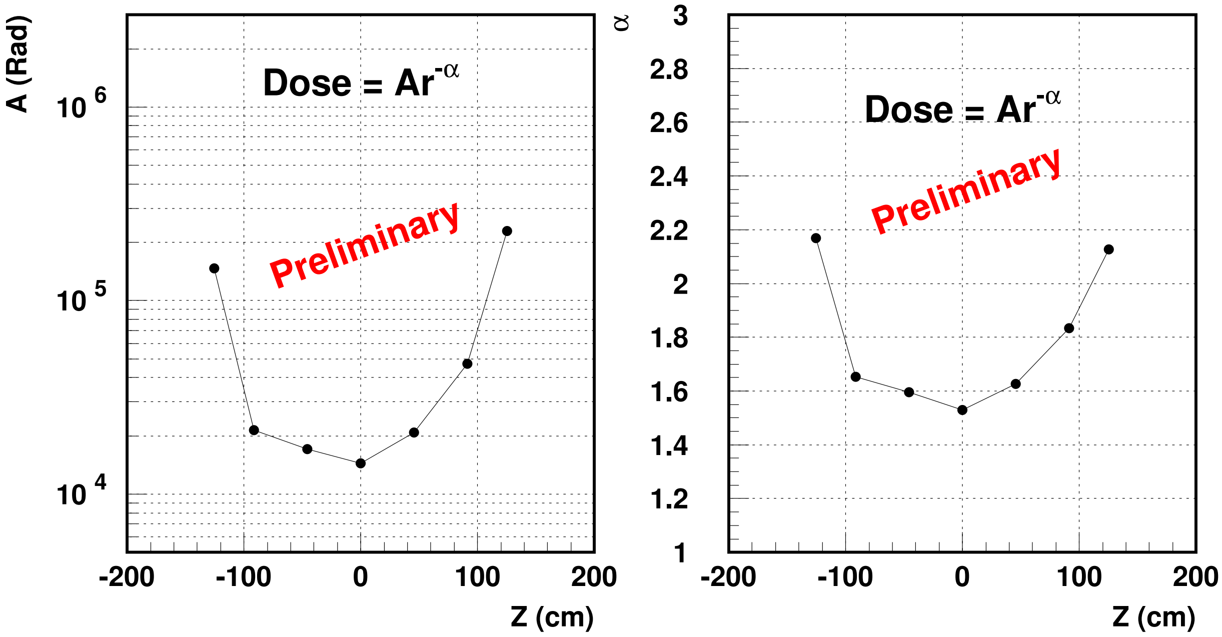

Figure 5: Fit parameters as a function of the distance from the interaction point along the beam axis as measured with the TLD.

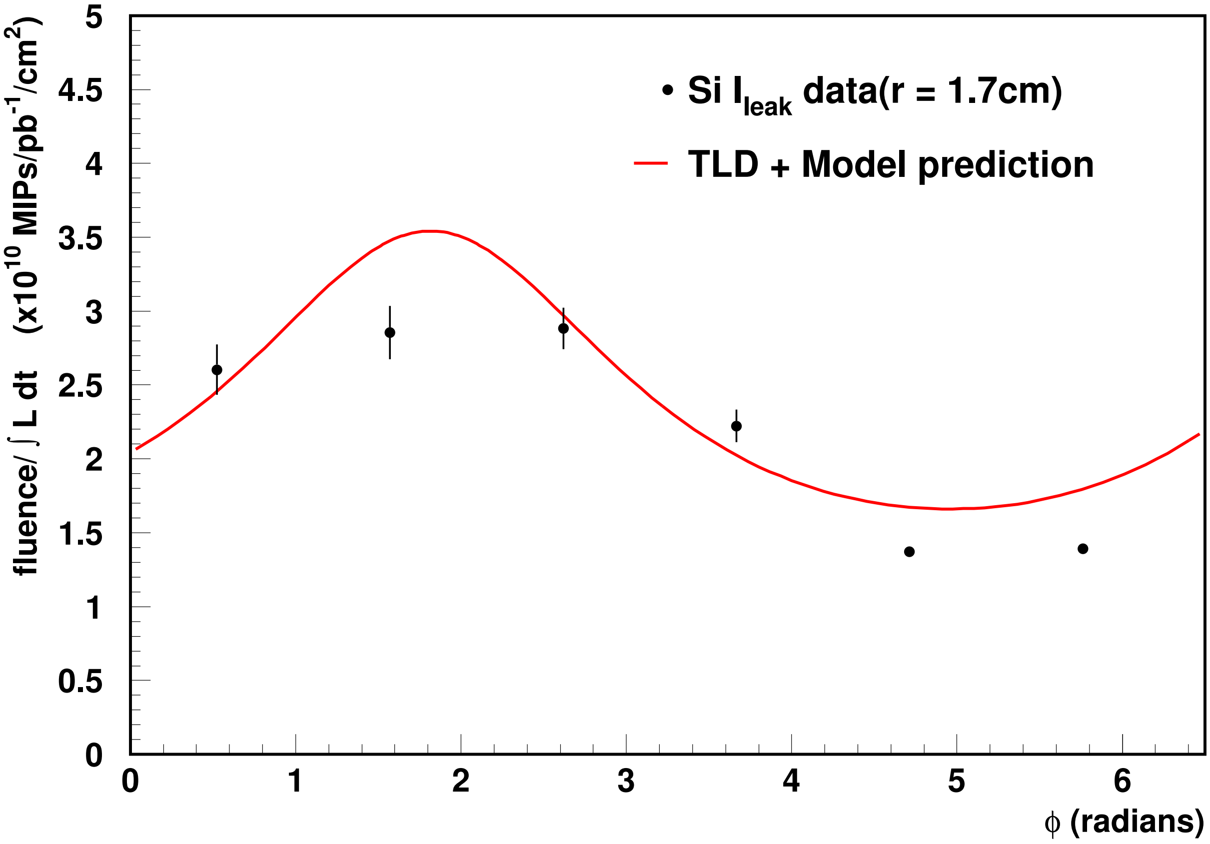

Figure 6: Measurements from L-00 currents are compared with an estrapolation of the TLD measurements to R = 1.66 cm.