October 20, 2003

MEMO
Luminosity Measurement via Bhabha Scattering: Requirements on Position Reconstruction to Achieve a 10^{-4} Precision

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Abstract

This memo is based on Monte Carlo simulations with the BHLUMI generator of Jadach and Was. It adresses the question how accurately electrons and positrons have to be reconstructed in the TESLA LumCal in order to achieve a precision of 10^{-4} on the luminosity measurement.

1 Method

Bhabha events are simulated with BHLUMI[1] in the phase space region of the TESLA luminosity calorimeter. The simulation is based on a redesign of the forward region for an l^* that allows to place the luminosity calorimeter behind the ECal endcap. The luminosity calorimeter is called LumCal to distinguish it from the LAT and LCal of the TDR design. The design is sketched in fig. 13.

A simple selection is applied to the simulated events (see below). In a first step the position of the electron and positron on the front face of LumCal is calculated. The scattering angles are determined from these positions. The energy of the particles is taken from the tree. In subsequent steps the position and energy are subjected to systematic misreconstructions. The change in the number of accepted events with respect to step 1 gives the systematic error introduced by the respective systematic error. The size of the effects are varied in order to determine the level which is acceptable in order to achieve a 10^{-4} precision on the luminosity measurement. The same event sample is used for all steps so that statistical fluctuations largely cancel.

BHLUMI version 4.04 was used with the following parameters:

Type of generator	BHLUM4
Photon Removal	on
Event weights	off
Random generator	RANMAR
Z^0-contribution	on
QED matrix elements	from BHLUM4
Vacuum polarisation	from ref. 1
center-of-mass energy	250 GeV
min. scattering angle	25 mrad
max. scattering angle	90 mrad
photon infrared cut-off	10^{-4}

The following cuts are applied

- energy: $E\left(e^{+}\right) > 0.8\, E_{\mathrm{beam}}$
  $E\left(e^{-}\right) > 0.8\, E_{\mathrm{beam}}$
- scattering angle of positron: $30\,\mathrm{mrad} < \theta^{+} < 75\,\mathrm{mrad}$
- accollinearity: $\cos\theta_{\mathrm{acol}} > 0.98$

[1]S. Jadach and S. Waş, http::/www.xxxxxx.pl/

2 Findings

2.1 Inner diameter of LumCal

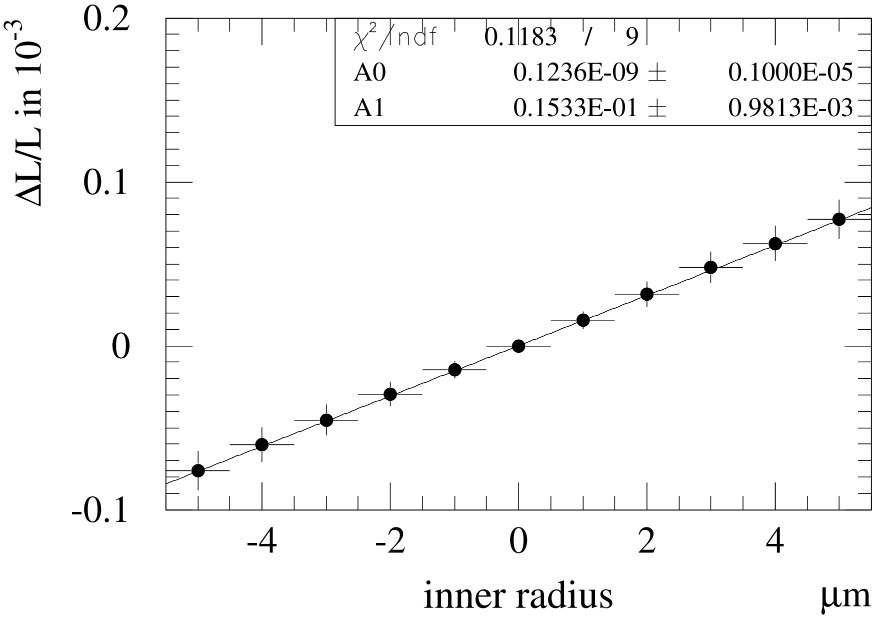

Figure 1: Systematic impact on the luminosity measurement due to a variation of the radius of the calorimeter.

The most critical parameter is the diameter of the calorimeter (see fig. 1), i.e. the distance across the beam pipe from on side of the calorimeter to the other. To simulate this effect the radius of each shower has been increased by the amount indicated on the plot identically to the forward and backward calorimeter. From the fit one calculates that the inner radius has to be controlled to better than 6.5 μm. This applies to the sum of the uncertainties of the mechanical dimension of calorimeter (or more precisely the sensors defining the acceptance cut) and any bias in the reconstruction of the shower position. Such biases could arise from reconstruction algorithm (typically they bias towards the center of a pad), the shape of the pads, the non-perpendicular impact of the particles, transverse shpwer leakage at the inner edge of the calorimeter, variations in gain between pads and others.

2.2 Radial beam position

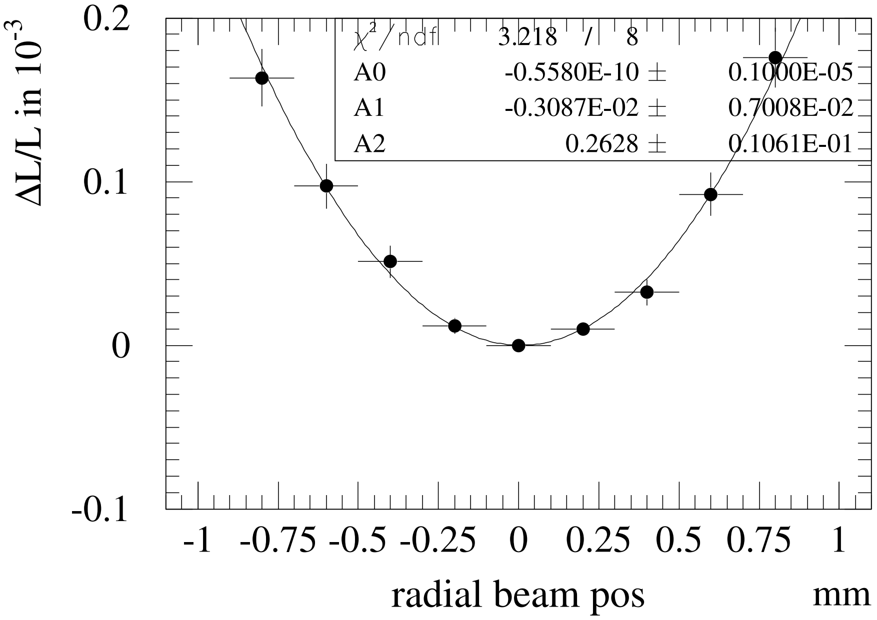

Figure 2: Systematic impact on the luminosity measurement due to a variation of the radial position to the beam.

Fig. 2 shows a radial mispositioning of the detctor with respect to the beam. The detector is offset from the beam axis by the amount indicated. Comparison with fig. 1 shows that this parameter is less critical which can be understood directly. If one would restrict the measurement to a fixed azimuthal angle ϕ the effect of a change in radius of the calorimeter and a radial mispositioning of the detector would have the same effect.However, we do integrate over the full azimutahl angle. The effect of section 2.1 adds up for all azimuthal angles, while the effect of this section cancels between opposite sides. Let's say the beam is offset in the +x direction, then one gains events around $\phi = 0°$ but one looses events around $\phi = 180°$. The effect cancels to first order and therefore depends quadraticly on the offset.

The fit shows that it is sufficient to know the beam position to a few hundred μm. It should not be a proplem to determine the beam position to that accuracy from the BPMs (beam position monitors) of the fast feedback system. Furthermore it can be measured from the bhabhas themselves. An offset of the beam creates an azimuthal asymmetry in the bhabha rate from which the offset can be extracted. Alternatively one can draw a straight line connecting the electron position with the positron position. By overlaying the lines from all events one reconstructs the luminous region and with it the beam offset.

2.3 Longitudinal distance of forward and backward calorimeter

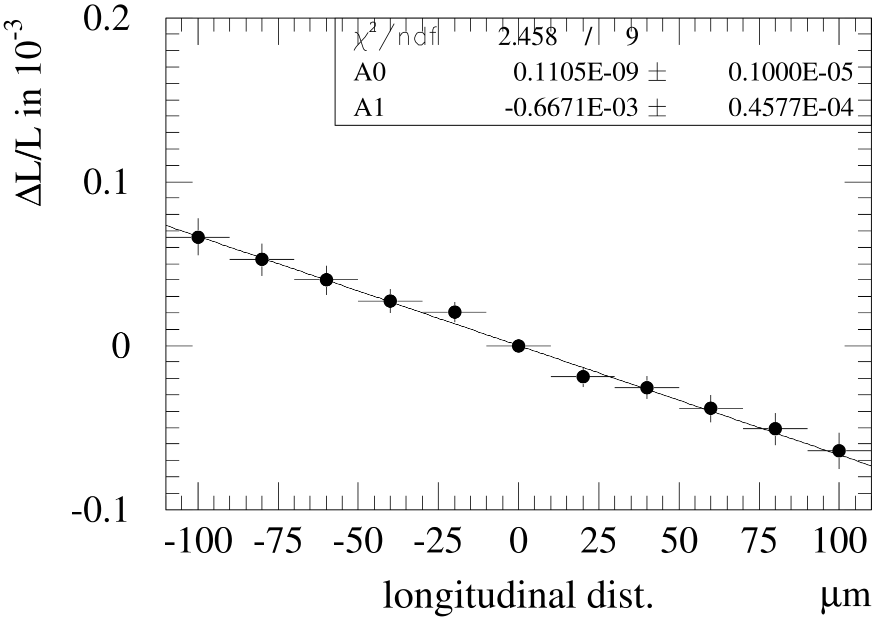

Figure 3: Systematic impact on the luminosity measurement due to a variation of the half-distance between the two calorimeter. The nominal half-distance (IP to calorimeter) is 3050 mm. The two calorimeter are offset by the same amount, but in opposite directions from the IP.

The second critical parameter in terms of detector alignment (besides the inner radius) is the distance between the forward and backward calorimeter along the z-axis. If the two detectors are closer to each other then expected the same shower position reflects a slightly larger scattering angle and therefore a slightly smaller bhabha cross section.

Fig. 3 shows the variation of the extracted luminosity as a function of the half-distance between the two calorimeters. The alignment must be controlled to about 100 μm over a distance of 3 m.

2.4 Longitudinal offset of the interaction point

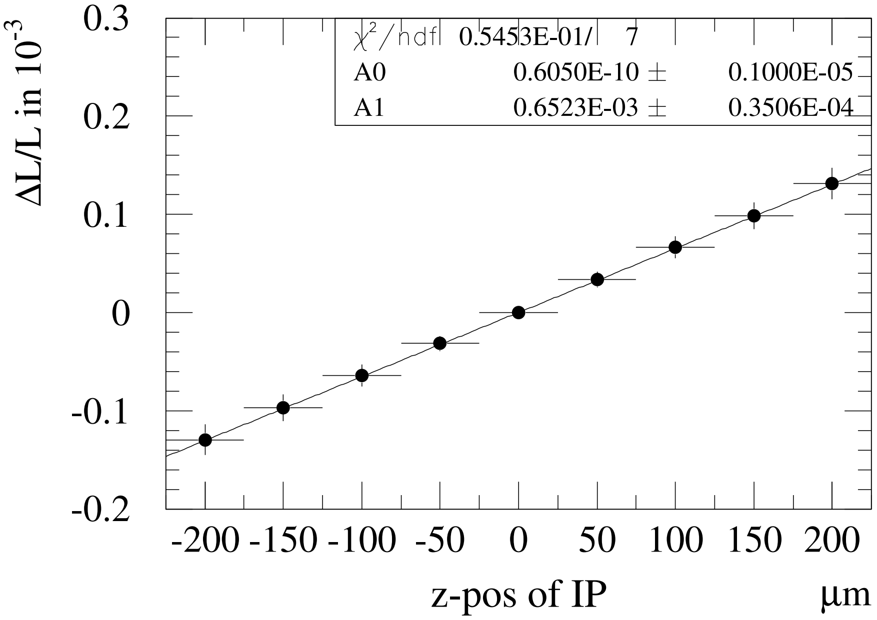

Figure 4: Systematic impact on the luminosity measurement due to a longitudinal offset of the interaction point from the center of the detector.

The figure shows the effect of an offset of the luminous region along the beam direction on the luminosity measurement. The figure seems to indicate that one needs to measure the position of the IP to $\pm 150\ \mu m$ which should be feasible for example from the longitudinal position of muon-pairs in the vertex detector. However, this is an artifact of the selection procedure. The fiducial volume is essentially defined by cut number 2. It uses exclusively the position of the positron in the forward calorimeter. If the beam moves closer to the forward detector (negative offset) the cut corresponds to larger scattering angles and therefore a smaller cross section is derived. In the real analysis, however, one will alternate between the cut on the positron position and the equivalent cut on the electron position. This will cancel the effect to first order.

2.5 Tilt of the calorimeters

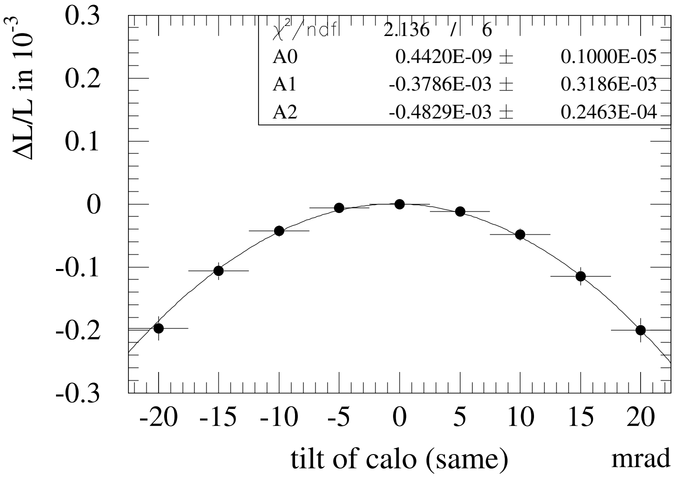

Figure 5: Systematic impact on the luminosity measurement from a tilt of both calorimeter in the same direction.

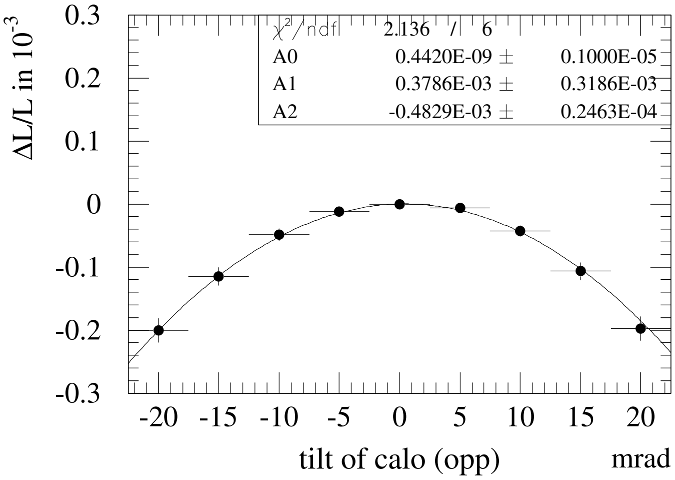

Figure 6: Systematic impact on the luminosity measurement from a tilt of both calorimeter in opposite direction.

Figures 5 and 6 show the error in the luminosity measurement, if the calorimeter are placed not exactly perpednicular to the beam axis. In the first figure the two calorimeters are tilted in the same direction while they are tilted in opposite direction in the second plot. The effective area of the calorimeter as seen from the IP is reduced and therefore the estimated luminosity is too low.

The tolerance on the alignment of the calorimeter is ±10 mrad. This should not be too difficult to achieve. At 10 mrad the outer edge of the calorimeter has already moved by 2.5 mm which should be readily detected by the longitudinal position monitoring system (assuming we have more than one measurement at different azimuthal angles).

2.6 Twist between the two calorimeters

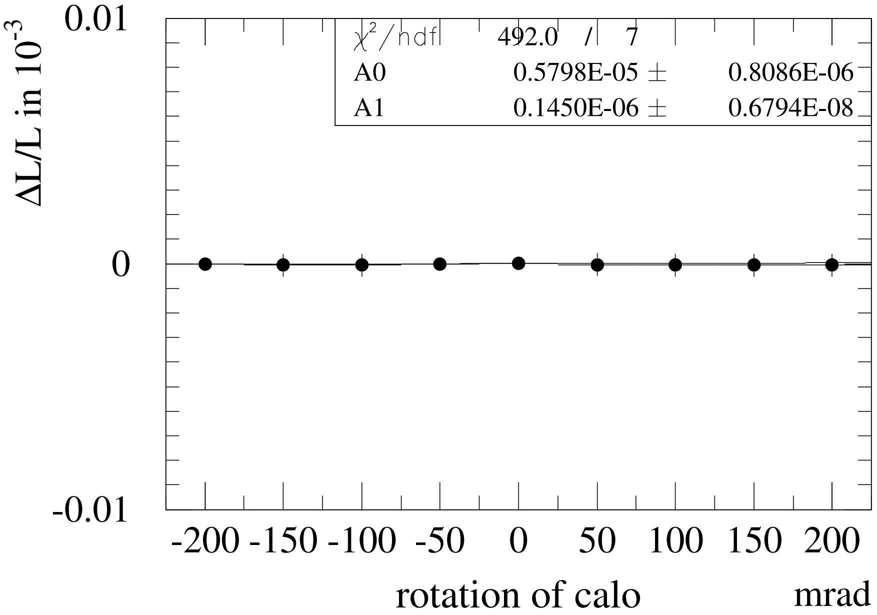

Figure 7: Systematic impact on the luminosity measurement due to a rotation of one of the calorimeters around the beam axis.

Fig. 7 shows hardly any impact from a rotation of the calorimeters around the beam axis. For simplicity only the forward calorimeter was rotated by the indicated amount. Again this is due to the simple selction. The real selection will probably include a cut on the difference in azimuthal angle of the electron and positron shower to reject random coincidences of background particles. The alignment tolerance has to be matched to this cut, but I don't expect a severe problem there.

2.7 Beam tilt

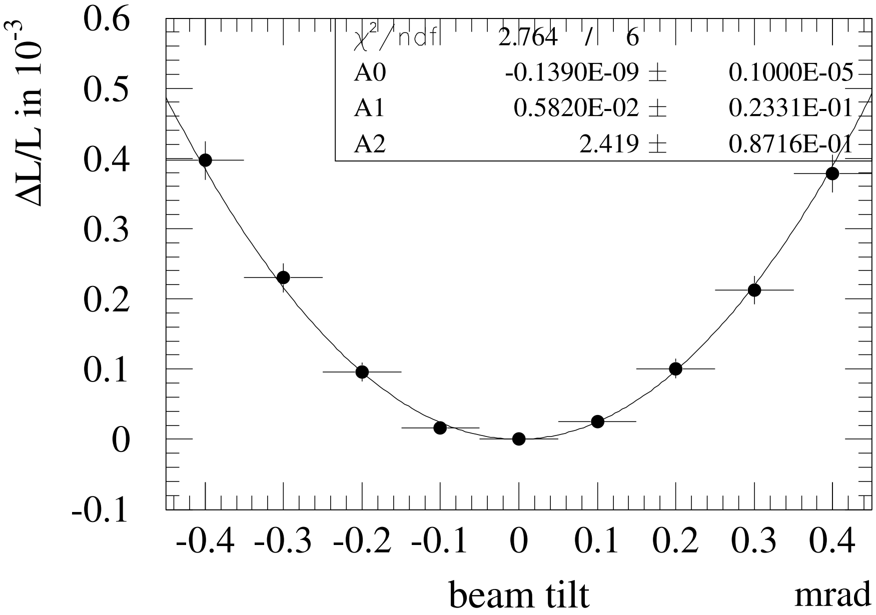

Figure 8: Systematic impact on the luminosity measurement due to a tilt of the beam directions.

If the two beams reach the IP not exactly along the nominal beam axis this will lead to the effect shown in fig. 8. Both beams are assumed to be rotated so that they still collide head-on.

It is sufficient to control this rotation to 0.1 mrad. At such an angle the beams are already offset in the BPMs by about 400 μm which should be easily detectable.

2.8 Beam size at the IP

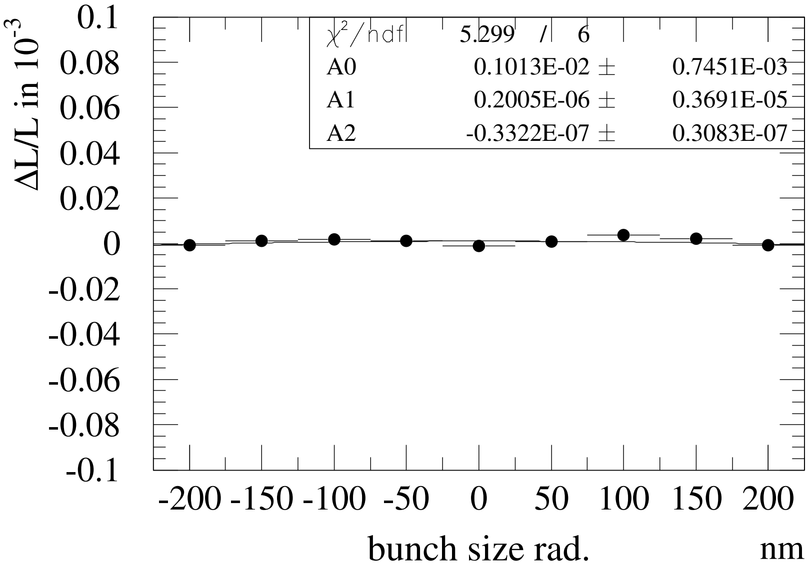

Figure 9: Systematic impact on the luminosity measurement due to a variation of the radius of the calorimeter.

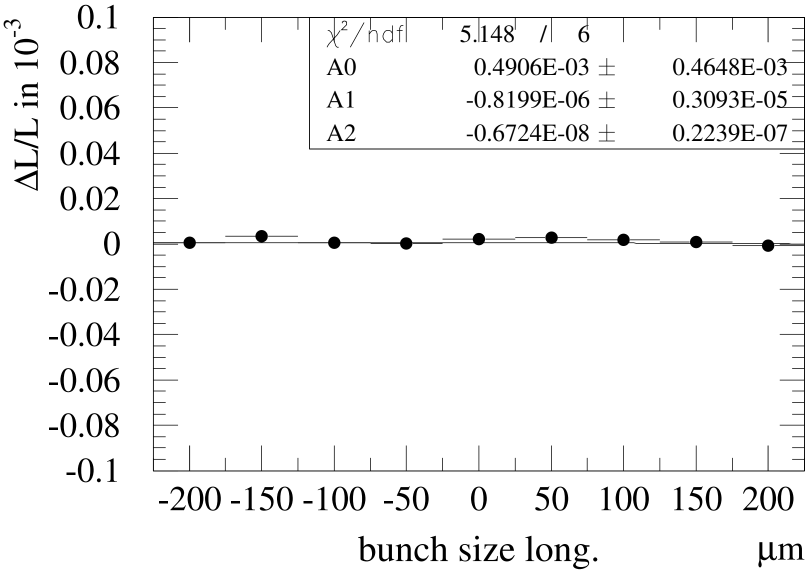

Figure 10: Systematic impact on the luminosity measurement due to a variation of the radius of the calorimeter.

The beams of TESLA have a transverse size of 5 nm by 553 nm and a longitudinal size of 300 μm at the IP. Figures 9 and 10 show the influence of the spacial extension of the luminous region. No relevant variation is visible (this was different at LEP). Therefore all other plots are generated with pointlike interaction region.

2.9 Position resolution

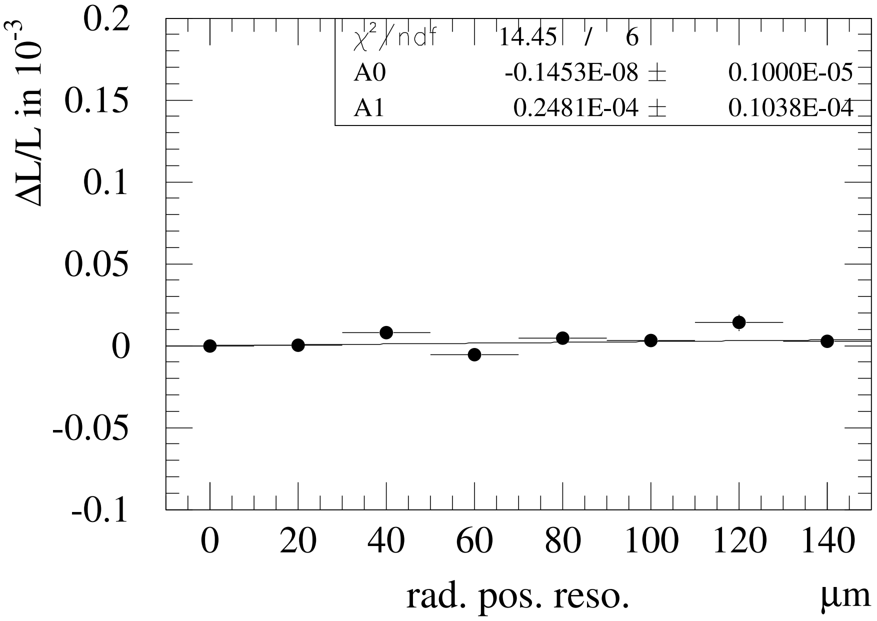

Figure 11: Systematic impact on the luminosity measurement due to the resolution in radial shower position of the calorimeters.

Figure 11 shows the impact of the finite position resolution of the detector. Particles just outside the fiducial volume can be mismeausred to be inside and vice versa. Due the steeply rising cross section at the inner acceptance border on expects an artificial increase in the number of detected events. In fact for a sample of 10^7 events reconstructed with a radial resolution of 100 μm 8283 events were incorectly reconstructed inside the fiducial volume and 8145 were incorrectly lost from the fiducial volume. The overall effect is negligible. But still, a good position resolution is important in many other aspects.

2.10 Energy resolution

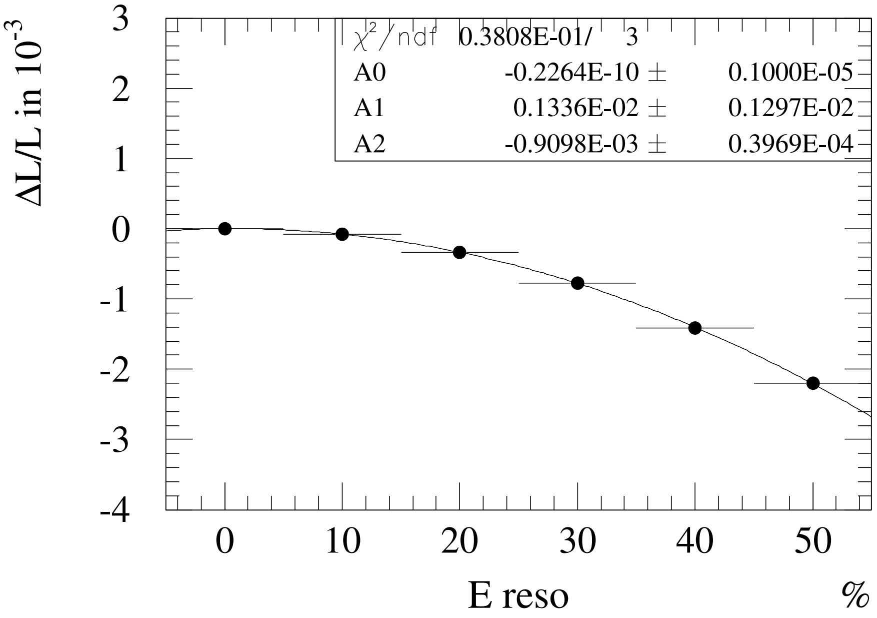

Figure 12: Systematic impact on the luminosity measurement from the energy resolution of the calorimeter.

A finite energy resolution changes the efficiency of the first selection cut ($E > 0.8 E_{\mathrm{beam}}$). An energy dependence of the resolution of the form $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}}$ is assumed. The figure 12 shows dependence on the coefficient a given in %. The true sensitivity depends on the exact cut-value. Tighter cuts create a higher sensitivity. With the cuts given here one needs to understand an energy resolution of $30\,\%/\sqrt{E}$ to at least $2\,\%$ which should be feasible.

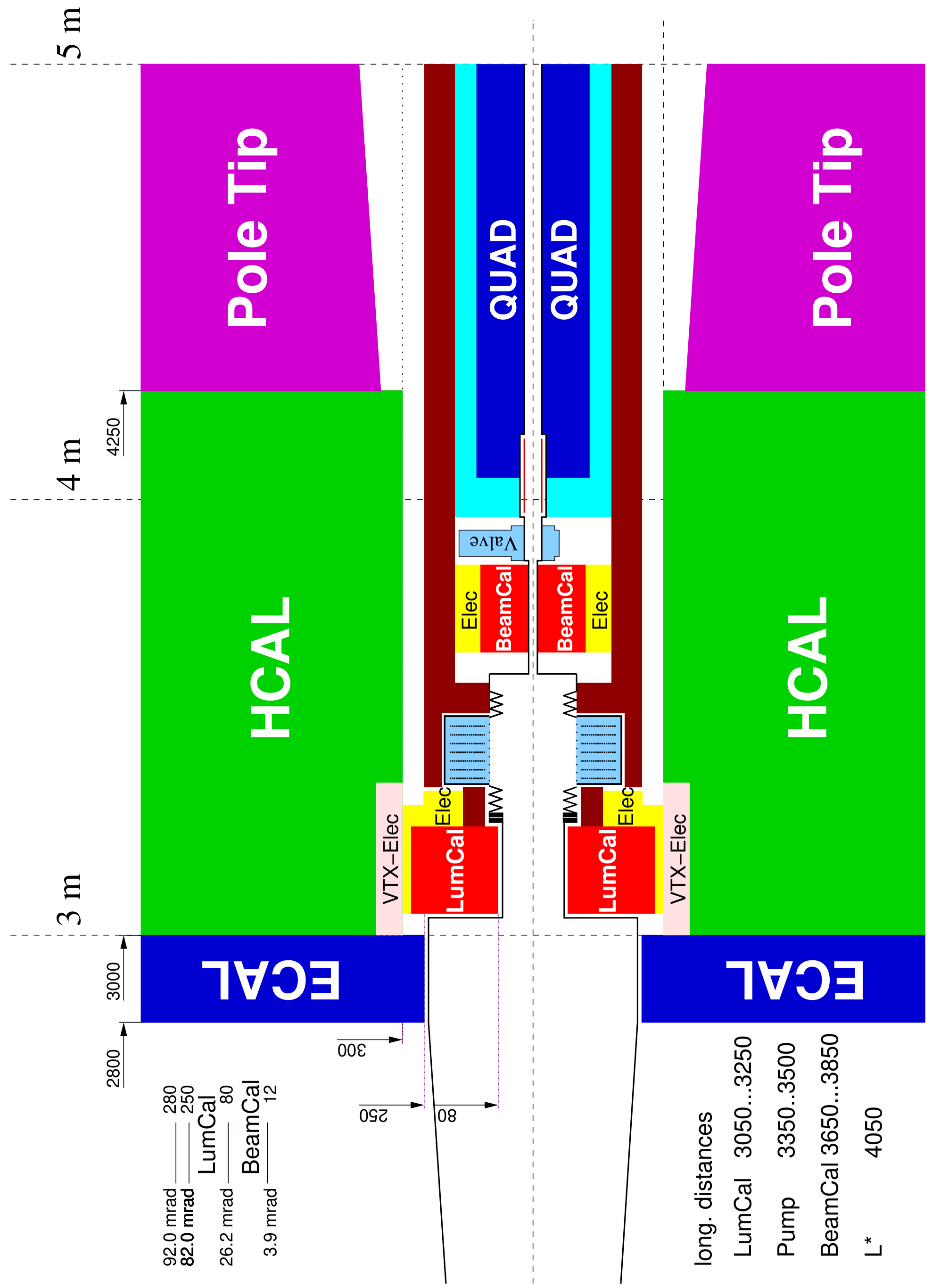

Figure 13: Preliminary redesign of the forward region for a focal length of the final focus between 4 and 5 meters.