NORMALIZATION IN ALEPH

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Abstract: The design of the Standard Aleph Luminosity detector and of the Very Small Angle Luminosity Monitor (SALM) and its expected performances in the bunch to bunch normalization for measurements with polarized beams will be described.

1. Short description of the design of the Standard Monitor

The Standard Aleph Luminosity monitor consists of two parts, a drift chamber called Small Angle Tracking chamber (SATR) and a shower counter called Luminosity Calorimeter (LCAL). These detectors were designed to measure the absolute Luminosity with a systematic error of less than 2 %. The track detector is built by the University of Siegen and the Luminosity Calorimeter by the Niels Bohr Institute Copenhagen. One aim in the design of the Luminosity Calorimeter has been to make it similar to the Aleph barrel and endcap calorimeters.

As shown in figure 1, the counters are placed close to the beam pipe at about 2.6 meters from the interaction region. The tracking part consists of 9 identical layers of drift tubes. They are stacked one behind the other in z. Compared to the first layer, the second layer is rotated in ϕ by 15 degrees and the third layer by another 15 degrees. This is repeated such that the layers 4,5,6 and 7,8,9 have the same orientation as 1,2,3. Inefficiencies due to overlap of dead zones from tube walls and gas channels are avoided this way and a high energy particle traverses at least 6 sensitive layers. The spatial resolution has been measured in a test beam. It was found to be better than 300 μm per plane. For a particle

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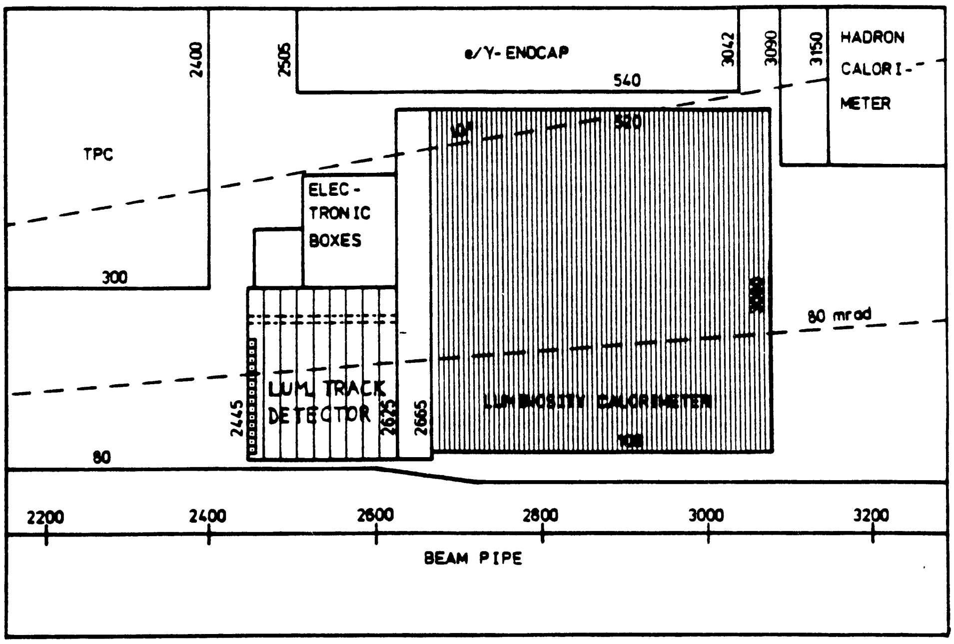

Figure 1: Position of the Aleph Standard Luminosity counter

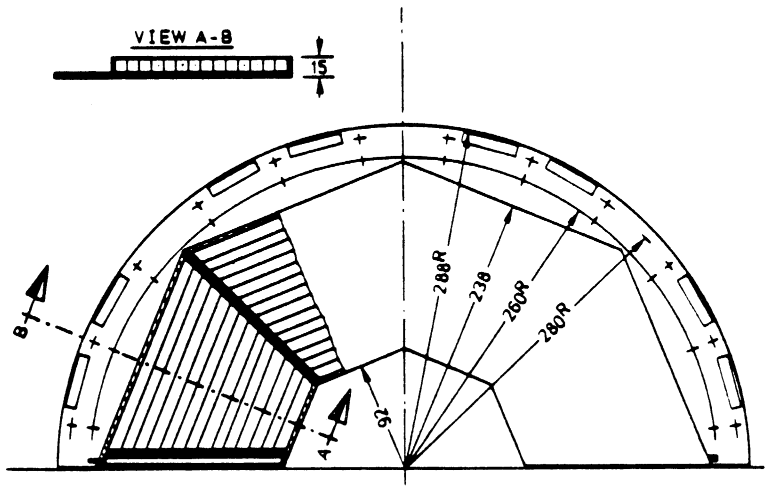

Figure 2: Cut through the SATR in the $r-\phi$ plane

coming from the center of the interaction region the angular resolution is 50 μrad in θ and 4.5 mrad in ϕ. The tracking chamber covers a solid angle of 2π in ϕ and 41 to 91 mrad in θ. There are in total 2016 wires, connected to 1152 read-out channels. More details about the SATR can be found in [1], [2].

The Luminosity calorimeter is a stack of 38 lead converter sheets and chambers adding up to 24 radiation length. The expected energy resolution is $\sigma_E / E = 20\ \% / \sqrt{E}$ (more details [1], [3]). The spatial resolution for high energy electrons is expected to be similar in ϕ and θ and to vary between 1 and 2 mm depending on the position within the calorimeter. The LCAL covers about 95 % of 2π in ϕ and angles of about 53 to 165 mrad in θ.

The combined acceptance of the tracking device and calorimeter is then 95 % in ϕ and 53 to 91 mrad in θ, corresponding to a Bhabha cross section of 27 nb at the energy of the Z. Including losses in cuts and inefficiencies we usually quoted an expected cross section of 25 nb at Z energies corresponding to 0.25 Hz event rate at the design luminosity of 10^{31} cm^{-2} sec^{-1}. A typical run with 100 nb^{-1} Luminosity would contain 2500 Bhabha events in the Luminosity detectors leading to a statistical uncertainty of 2 %. For the bunch to bunch normalization one could consider to use the full θ range of the calorimeter up to 165 mrad in θ which would increase the normalization cross section to 37 nb.

Fast energy sums of the calorimeter will be used in the trigger. The subdivision in ϕ is such, that an acoplanarity cut of about ± 45 degrees can already be applied at the first trigger level. Several trigger schemes will be used simultaneously. A two side coincidence on a high threshold (probably around 40 % of the beam energy) will be used to select the signal. Low threshold and one side downscaled triggers will allow a monitoring of the trigger efficiency. The background from off momentum electrons is expected to be well below the 1 % level. The background will be measured accurately using a delayed coincidence. The delay time will be made equal to the time an electron bunch needs for a full revolution in the LEP ring, in order to compare signal and background for the same bunch configuration.

2. Study of Bunch to Bunch Systematics for the Standard Monitor

Experience at PETRA and PEP has shown that it might be difficult to obtain the absolute luminosity with 2 % precision. Most of the work in design, building and Monte Carlo simulation of the Standard Aleph Luminosity detector has been concentrated in reducing the systematics for the absolute measurement ([4], [5], [6]). The largest error contributions are expected to come from uncertainties in the knowledge of the acceptance, including geometry folded with trigger and reconstruction efficiencies. This and many other uncertainties such as from radiative corrections and positioning errors do not depend on the properties of differently polarized bunch types and will therefor cancel in the relative bunch to bunch normalization. The only remaining errors should be linked to the bunch properties.

The relativ bunch to bunch normalization needed to measure A_{LR} with longitudinally polarized beams can therefor be obtained with potentially higher systematic accuracy than any absolute cross section measurement.

We do not expect problems from background sources. The coincidence rate from off momentum particles will be small and accurately measured. Moreover the different bunch types will have very similar currents and geometry so that remaining uncertainties will largely cancel in the relative measurement. The total flux of energy from synchrotron radiation is small. Its effect would be to add rather homogeneously energies and hence to change the effective trigger thresholds. The differential systematic effect on different bunch types is estimated to be negligible.

We have done Monte Carlo studies to check the uncertainty in the knowledge on the difference between the bunch to bunch geometry on the relative luminosity measurement. The results are summarized in table 1. We studied separately uncertainties in the average bunch position (systematic differences in the mean $<x>$, $<y>$, $<z>$ position between bunches of different polarization) in their size (σ_x, σ_y, σ_z) and mean and sigma of small tilt angles in the interaction region ($<x'>$, $<y'>$, σ_x', σ_y').

Except for z and σ_z the parameters have been varied within their measurement uncertainty as expected to be known from the LEP machine monitors [7] in time intervals of typically 10 minutes. z and σ_z instead will be measured directly using the Aleph central tracking chambers and their errors are purely statistical ($z / \sqrt{N}$ for $<z>$ and about $\sigma_z / \sqrt{2N}$ for σ_z). The number used in table 1 is derived using a bunch length of 33 mm (using dedicated wigglers, 12.8 mm otherwise) and a measurement of the longitudinal bunch size and position using 2500 clean two track events which we should collect in a typical run in the central detector.

The numbers in table 1 have been obtained using a symmetric θ acceptance from 50 to 90 mrad at $\pm$ 2.5 meters from the interaction region. At a small cost of cross section and therefor slightly increased statistical error the dependance on the bunch geometry could be further reduced in making tighter cuts on one side only, as proposed to do for the ALEPH SALM detector. Radiative corrections have been included in the Monte Carlo simulations using the event generator of [8]. They were found to decrease the normalization uncertainty slightly. We studied also how the different error contributions add up and scale with the θ range. It was found that the different uncertainties add up quadratically in very good approximation. Angular uncertainties were found to increase inversely proportional to θ_{min} . The sensitivity on the bunch length, the largest single contribution to the error, decreases with increasing the z distance to the interaction region. For this reason, the ALEPH SALM detector depends less on the bunch length and more on the angular uncertainties of the bunch geometry.

To summarize the result of this chapter we believe that the bunch to bunch normalization can be done using the Standard ALEPH Luminosity detector with high systematic accuracy. Systematic errors from angular and transverse shifts between bunches can be excluded using the information from LEP monitors to well below 1 ‰ . The largest contribution is expected to come from uncertainties in the longitudinal (z) bunch size and position which is measured to better than 1 mm statistical accuracy per run using the ALEPH central detector. The total error of 0.8 ‰ in table 1 should be obtainable per run and could be further reduced averaging over longer periods.

Table 1: *Uncertainties in the bunch to bunch normalization from systematic changes in the bunch geometry*

Parameter at I.R.	typical value	known to	absolute loss in ‰ for typ. val.	systematic uncert. in ‰, $\Delta L_i/L_i$
$<x>$	100 μm	15 μm	0.9	0.14
σ_x	300 μm	10 μm	2.4	0.08
$<y>$	100 μm	5 μm	0.9	0.05
σ_y	12 μm	1 μm	0.1	0.01
$<z>$	1 mm	0.7 mm	0.8	0.59
σ_z	33 mm	0.5 mm	28.0	0.38
$<x'>$	0	2 μrad	0	0.05
σ_x'	175 μrad	5 μrad	2.6	0.08
$<y'>$	0	10 μrad	0	0.24
σ_y'	175 μrad	5 μrad	2.6	0.08
total			O (3%)	0.8 ‰

3. Possible changes in the design to optimize for polarization

As discussed in the previous chapter, we believe that it is possible to obtain a systematic precision at the 1 ‰ level in the bunch to bunch normalization using the Standard ALEPH Luminosity detectors. For the present design the accepted Bhabha cross section in the Luminosity detector equals about the peak Z resonance cross section (both about 25 nb). The detector is limited by the geometry of the LCAL. The detector starts to be efficient at a radius of in average 14 cm or about twice the beam pipe radius. Given the present design and timescale, it will be impossible to make the LCAL efficient down to lower angles approaching the beam pipe radius. A possible upgrade, possibly coinciding with the installation of a smaller beam pipe in the interaction region, would more likely involve a replacement of the track detector by a very compact shower detector with at the same time very good spatial resolution. It has been proposed to study in future a design using tungsten as converter and silicon strips or scintillating fibers as active material. It has been varyfied that in an extended acceptance down to 25 mrad the errors shown in table 1 scale as expected: The errors connected with transverse quantities (x,y) all increase by about 40 % while the errors for the longitudinal quantities (z,σ_Z) decrease by about 40 %. Since errors from z,σ_Z still dominate, the total systematic error would even decrease and errors below 1 ‰ should not be a problem even on the run per run basis.

4. SALM location, design and acceptance

The Small Angle Luminosity Monitor for the ALEPH detector [9] (SALM) consists of four identical calorimeters located symmetrically on each side of the beam pipe with respect to the horizontal (bending) plane, and on each side of the interaction point along the beam (Figure 3). The SALM is presently being built by the group of the Universidad Autonoma de Barcelona.
The main purpose of this detector is to count Bhabha events at the smallest possible angles available in the ALEPH region. In its present location the SALM will be hit by Bhabhas at a rate approximately 20 times higher than the rate hitting the ALEPH main luminosity monitor. The counting rate will be made available on − line, so that the relative LEP luminosity can be constantly monitored.

The four monitors which make up the SALM are located on each side of the beam pipe in the (x − y) plane and on each side of the interaction point. (We use a coordinate system in which the z axis

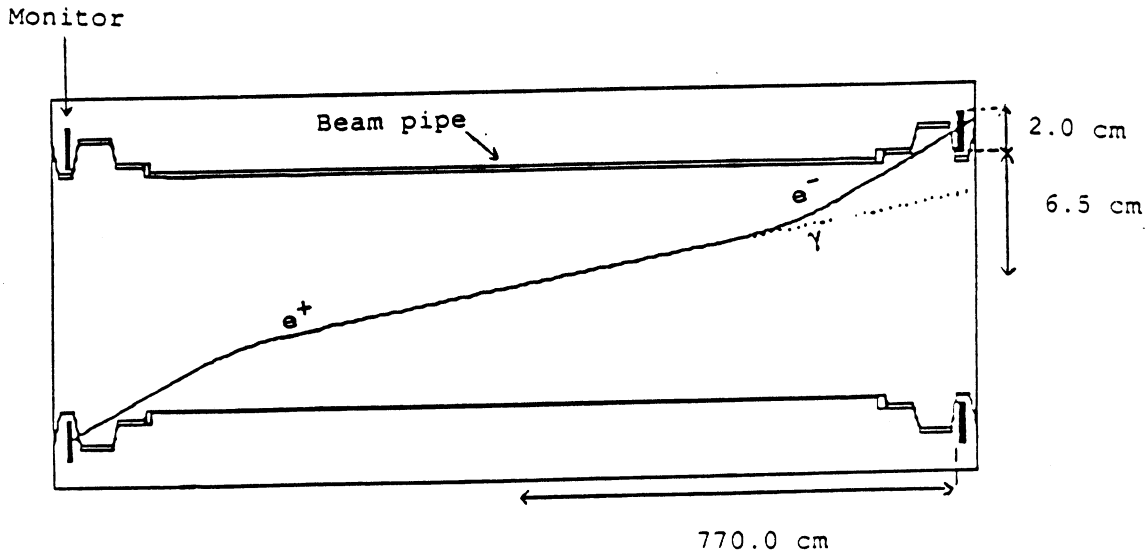

Figure 3: View of the ALEPH detector showing the approximate location of the SALM

is along the beam and the x axis is in the horizontal plane and perpendicular to the beam). The beam pipe is elliptical in the region from 7.66 m to 7.91 m in z, in order to locate the monitors as close as possible to the beam line. The active area of the counters starts at 6.5 cm from the beam.

The superconducting (mini − beta) quadrupole located in the region 3.7 m < z < 5.7 m will defocus Bhabha electrons and positrons going towards the monitors from the interaction point so that the effective minimum angle seen by the monitors is $\theta_{min-eff}$ = 5.1 mrad. On the other hand beam − pipe elements before the region of the monitor define a window such that the maximum acceptance angle in the x − z plane is $\theta_{max-eff} \cong$ 6.7 mrad. In the x direction this translates into an acceptance which is less than 2 cm wide.

Each of the four counters consists of a sampling calorimeter made with tungsten converter sheets interspersed with sampling layers made of plastic scintillator and a plane of vertical silicon strips as described below. The overall shape of the calorimeter is that of a rectangular box of 2 cm × 5 cm × 12 cm as shown in Figure 4 .
The first tungsten layer has four radiation lengths, which are needed to protect the sampling layers from the high flux of synchrotron radiation photons. The next 4 tungsten layers are each 2 radiation lengths thick. The first sampling plane has both a plane of silicon strips and a scintillator layer, while the next four sampling planes have only one layer of scintillator. Finally a thick plate of tungsten 2.1

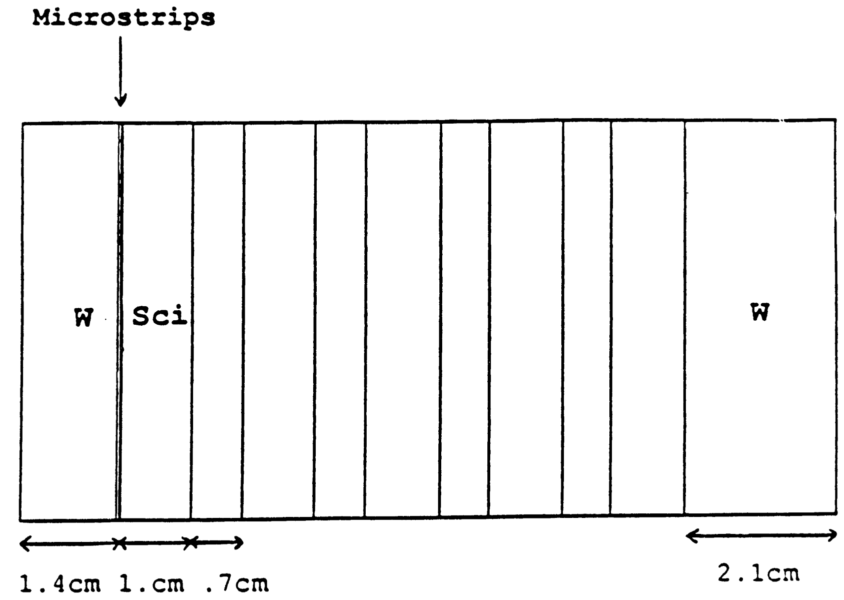

Figure 4: Schematic drawing of the calorimeter

cm (6 radiation lengths) protects the sampling planes from synchrotron radiation photons entering the back of the calorimeter.

The energy resolution with the scintillator read out is dominated by the lateral leakage, since most of the electrons enter the counters very near the edge. Since a Bhabha event is defined as a back to back shower with an energy above a certain threshold the effect of the leakage is to reduce the Bhabha detection efficiency. A detailed simulation using the GEANT program [10] shows that with a threshold energy cut of 60 % the average energy of a totally contained shower, one can obtain an efficiency of 75 %. This efficiency will be improved using shower position information obtained with the sampling plane of vertical silicon strips.

The acceptance of the monitor has been calculated by Monte Carlo taking into account complete Q.E.D. radiative corrections to third order and Z self−energy diagrams [11] as well as the effects of the quadrupole fields. This calculation gives a total acceptance, with the typical running conditions described below, of 0.67 μbarns. With an efficiency for detecting Bhabhas of 75 % this gives a counting rate of 2.5 Hz at a luminosity of 5×10^{30} cm^{-2} sec^{-1}. The statistical precision that can be obtained is thus 5 % in about 2.5 minutes of monitoring time.

5. Bunch to bunch systematics with the SALM

To measure A_{LR} with high precision the aim is to measure the relative luminosity between the various bunch configurations to about 10^{-3}. Statistically this precision can be obtained with the SALM, but it is less clear if systematic differences between bunches with different polarization can be kept at this level.

Systematic errors in the relative luminosity can be induced by possible bunch to bunch changes in the beam geometry, namely in the beam position and divergence, as well as to possible changes in bunch to bunch background rates.

The geometrical effects have been computed with the help of a Monte Carlo program. Beam divergences are simulated by generating e^+e^- beams with directions gaussianly distributed with respect to the $+z$ and $-z$ axis. The resulting Bhabha scattering between the acollinear e^+e^- produces an also accollinear e^+e^- pair in the final state. Since Bhabha events are only counted by the simultaneous observation of e^+e^- showers in a pair of counters located back$-$to$-$back, an increase on the beam divergence produces a decrease on the counting rate. Likewise, a systematic displacement of the collision point from $x=y=z=0$ will decrease the amount of back to back coincidences. A proper simulation of these effects has to include the fact that radiative corrections produce a natural smearing in the angle at which the particles collide, and beam widths smear the exact position of the collision point.

Shown in table 2 below are the nominal values of the beam position ($<x>$, $<y>$, $<z>$), beam widths ($\sigma_x, \sigma_y, \sigma_z$) beam tilts ($<x'>$, $<y'>$, $<z'>$) and beam divergences (σ_x', σ_y' , σ_z') as well as the errors with which these quantities can be measured. The third column in the table shows the "typical" values for these parameters used in the computations explained below. Columns 4 and 6 show the expected maximum bunch to bunch changes and the errors in the measurements of these changes. In the 5th column we show the decrease in the counting rate when the corresponding variable changes by its maximum bunch to bunch change (column 4) from the typical value (column 3) and all the other quantities stay at their typical values. Column 7th is the decrease in counting rate when the change in the corresponding variable is equal to the error in the bunch to bunch difference (column 6) and all the other variables stay at their typical values. In all the calculations the beam energy was 46.1 GeV.

Table 2: Uncertainties in $\Delta L_i/L_i$ to

the bunch to bunch normalization for the SALM

quantity		nom. val.	err.	typ. val.	bunch dif.	to change ‰	bunch error	change ‰
$<x>$	μm	0	300	100	0	0	15	1
σ_x	μm	300	35	300	30	4	10	1
$<x'>$	μrad	0	45	0	0	0	2	3
σ_x'	μrad	175	20	175	18	7	5	2
$<y>$	μm	0	300	0	0	0	5	< 1
σ_y	μm	12	1.5	12	4	< 1	1	< 1
$<y'>$	μrad	0	45	0	0	0	10	< 1
σ_y'	μrad	175	20	175	50	1	5	< 1
$<z>$	mm	0		1	0	0	.7	< 1
σ_z	mm	33		33	0.4	< 1	.5	< 1
column		1	2	3	4	5	6	7

The most important effect comes from the beam divergence and beam tilt in the x direction. The dependence of the acceptance on the beam divergence is shown in more detail in the top curve of Figure 5 . All the other variables were kept at their "typical" values to calculate this curve.

The dependence of the acceptance on beam divergence and beam displacements would be reduced if we were able to define a restricted acceptance region characterized by a smaller area in the front face of the calorimeters. A Bhabha event could be defined by a coincidence of a shower on the inner acceptance region of one counter with a shower anywhere on the opposite counter. For a hit in a given inner region of one counter we can guarantee that the other particle hits the opposite side counter provided the acollinearity angle and the displacement of the beam from the nominal interaction points are smaller than certain values. This effect can be seen in figure 5 where the dependance of the acceptance on σ_x is also shown for two asymmetric acceptances characterized by inner regions of 1.8 and 1.6 cm. The dependance is softer than for the symmetric acceptance, but the gain in precision is not significant since the acceptance is also reduced.

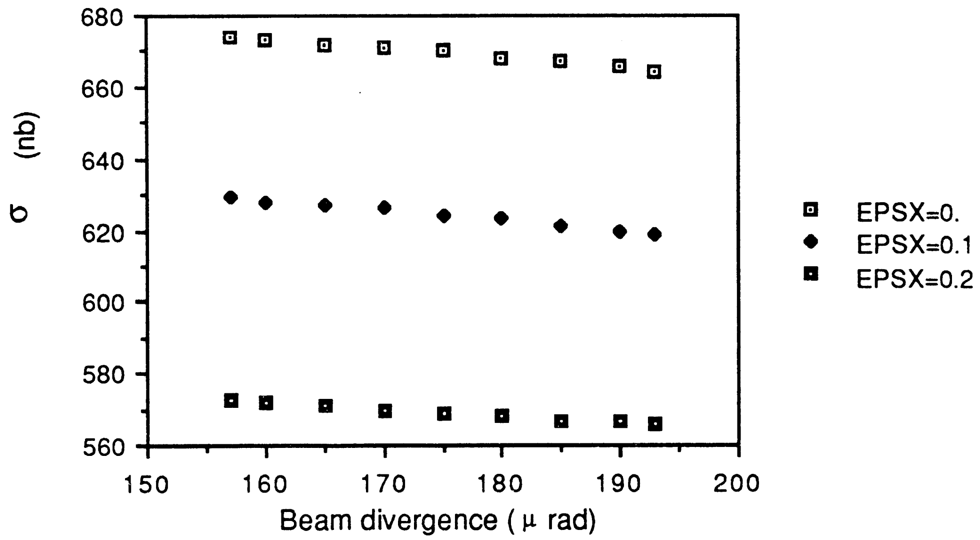

Figure 5: Accepted cross – section in SALM as a function of the beam divergence for three different values of EPSX. EPSX is the distance from the edge of the calorimeter in the front face to the edge of the restricted region.

6. Background in the SALM

Two kinds of background will hit the monitors. One is the synchrotron radiation photons emitted from the quadrupole fields in the straight section around the interaction points. The other is the off – momentum electrons produced by beam gas bremsstrahlung in the straight sections and in the arcs.

The synchrotron radiation backgrounds depends critically on the position of the collimators just behind our calorimeters. [12] The energy spectrum of the photons ranges from 10 keV up to about 5 MeV. Most of them will be absorbed by the thick tungsten layers on each side of the active layers of the calorimeters but a tail remains that can reach these active layers. There are in addition the photons entering the sides of the monitor. The effect of this background will be a small signal present with every beam crossing which will be almost completely suppressed by the threshold cut on the Bhabha triggers.

Off – momentum electrons and positrons reaching the area of the interaction region are produced by beam gas bremsstrahlung in the straight section of the beam pipe around the interaction point as well as in the arcs. New calculations by G. von Holtey [13] led to the design of new collimators.

It should be noted that the background rate can be inferred from rates of showers in a single counter, the rate of simultaneous showers in back to back counters (the signature of Bhabha events) and the rate of back to back showers where one of the showers comes from a given beam crossing and the opposite shower comes from the next crossing of the same bunches. We intend to monitor these three rates in order to measure the background.

References

[1] Aleph Status report CERN/LEPC/84 − 15

[2] The Tracking Device of the Luminosity Monitor, Siegen contribution to the Aleph handbook Nov. 1987

[3] LCAL description for the Aleph handbook, in preparation

[4] E. Neugebauer, ALEPH 87 − 39 Note 87 − 8 and ALEPH 88 − 32 Physic 88 − 11

[5] D. Bernard ALEPH 88 − 29 Physic 88 − 9

[6] J.D. Hansen, ALEPH 88 − 30, Physic 88 − 10

[7] G.v.Holtey , this yellow book

[8] F.A. Berends and R. Kleiss , Nucl. Phys. B228(1983)537 .

[9] E. Fernandez et al., "A Small Angle Luminosity Monitor for ALEPH", ALEPH Note 87 − 93, 1987

[10] R. Brun et al.," GEANT3 ", CERN, DD/EE/84 − 1

[11] J.A. Perlas, "A Bhabha Event Generator for Luminosity Studies", ALEPH Note 88 − 2, 1988

[12] G. Von Holtey and K. M. Potter, "Estimates of the synchrotron radiation background in LEP experiments", CERN/LEP − BI/87 − 05, 1987

[13] G. von Holtey, "Electron Background due to Gas Bremsstrahlung", LEP/BI/Note 87 − 13, August 1987