Physics background as a systematic effect in luminosity measurement at ILC

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Introduction

- Luminosity calorimeter is being designed for precise determination of the total luminosity by measuring the number of Bhabha events produced in the detector acceptance region

- Precision of luminosity measurement of order of 10^{-4} is required at ILC for the calculation of the cross-sections and precise EW measurement

- Due to the comparable track rate (to the signal) in the luminosity calorimeter, physics background from 4-fermion processes are considered to be one of the main systematic effects

- Signal separation with respect to physics background and beam-beam interaction will be discussed

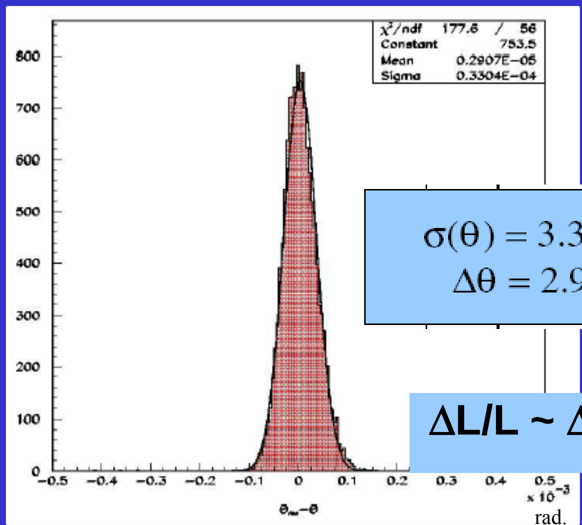
Luminosity measurement

- Integrated luminosity at ILC will be determined from the total number of Bhabha events N_{bha} produced in the acceptance region of luminosity calorimeter LCAL and the corresponding theoretical cross-section, corrected for selection efficiency and background events misidentified as Bhabha events

$$L_{int}=N_{bha}/\sigma_B \quad \rightarrow \quad L_{int}=(N_{exp}-N_{bck})/\varepsilon\cdot\sigma_B$$

- Bhabha cross-section at small angles is given , to the lowest order, by :

$$d\sigma/d\theta \approx 32\,\pi\,\alpha^2 / (s\,\theta^3)$$



$\sigma(\theta) = 3.3*10^{-5}$ rad
$\Delta\theta = 2.9*10^{-6}$ rad

$\Delta L/L \sim \Delta\theta / \theta_{min}$

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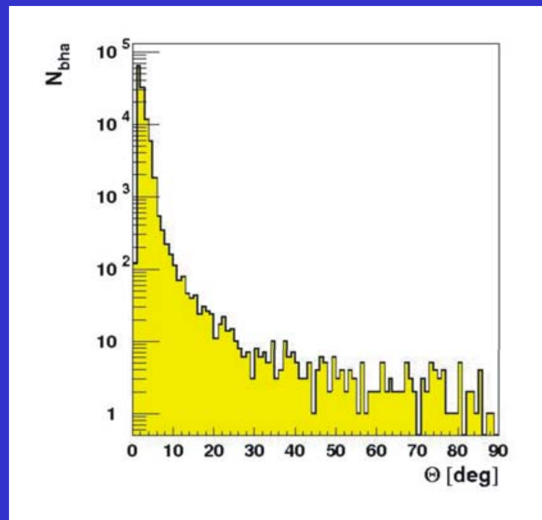


Current design of luminosity calorimeter

– Compact em sandwich calorimeter – 30 longitudinal layers of silicon sensors followed by tungsten absorber

– Z=2270 from IP

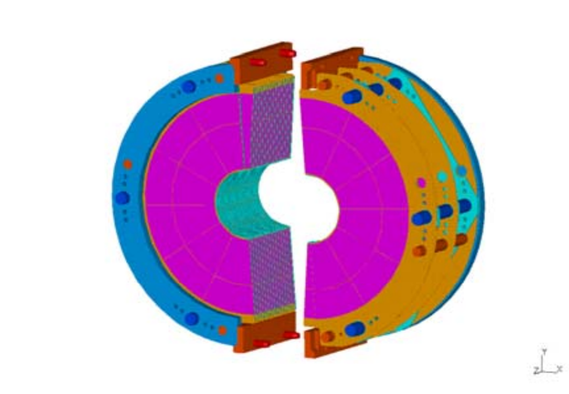
Polar angle range

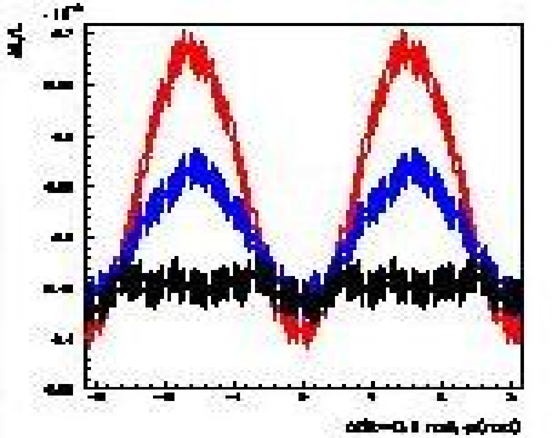
* X-angle 14 mrad = 44 – 155 mrad

(head-on = 26 - 155 mrad)

- sensor planes are segmented radially and azimuthally into pads (96*48)

- in case of x-angle case LCAL is centred along outgoing beam to avoid phi-dependent systematic shift of Δ **L/L**





Report for the ILC Detector R&D panel Instrumentation of the very forward region

Detector simulation and event generation

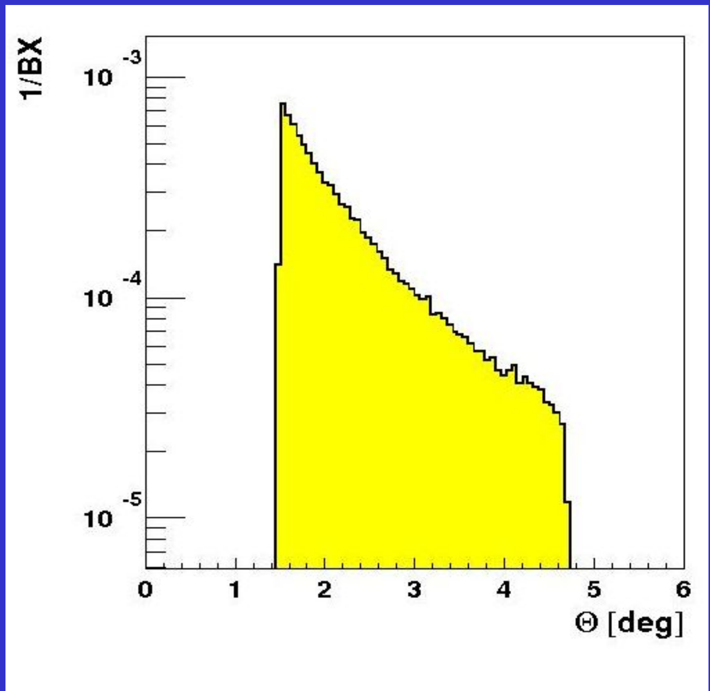
- Detector was simulated with Geant 3 based detector simulation BARBIE, at 500 GeV cms energy, assuming luminosity calorimeter coverage between 26 and 82 mrad, sensor planes are alternately segmented into 120 azimuthal and 64 radial strips ('strip design')

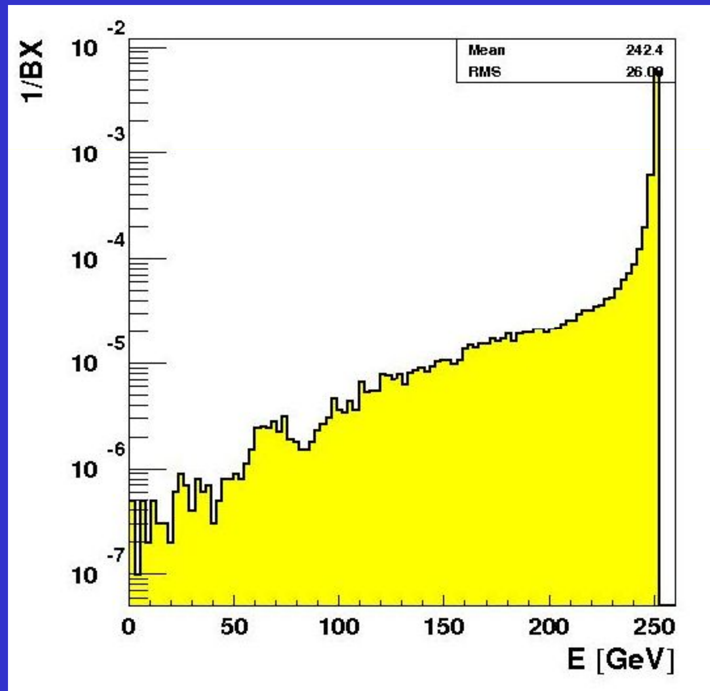
- Signal of 10^5 Bhabha events has been generated with BHLUMI small angle Bhabha generator, with cross-section (4.58 ± 0.02) nb. (Both s and t channels have been included, vacuum polarization, and initial state radiation.) Track rate of 8 x 10^{-3} was found in the lumical

- NC four-fermion processes are generated at the tree-level, with WHIZARD multiparticle event generator, with the track rate comparable to signal in the luminosity calorimeter . We have generated 10^6 leptonic $(e^+e^- \rightarrow e^+e^- l^+l^-)$ $(l=e,\mu)$ events and 10^5 hadronic $(e^+e^- \rightarrow e^+e^- qq)$ $(q=u,d,s,c,b)$ events with the total cross-section of (2.68±0.03) nb

Properties of signal

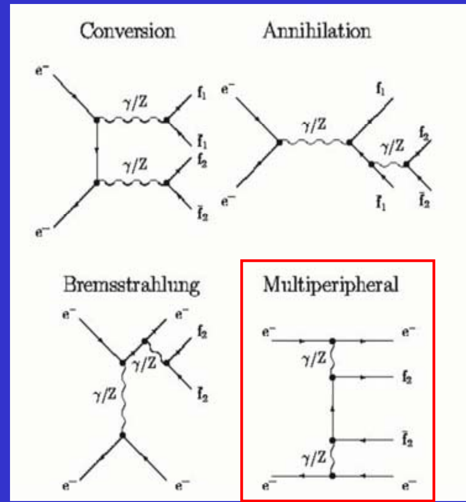
- Bhabha events are characterized by two em clusters, with the full beam energy, that are back-to-back in azimuthal and polar angle.
- Based on this topology , separation criteria for signal from background can be derived

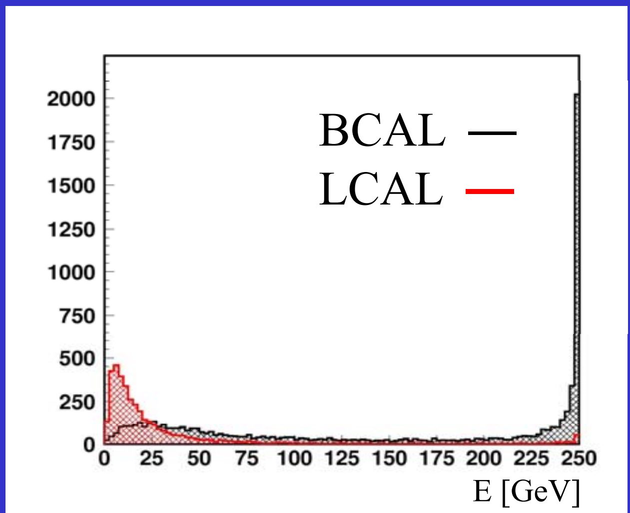


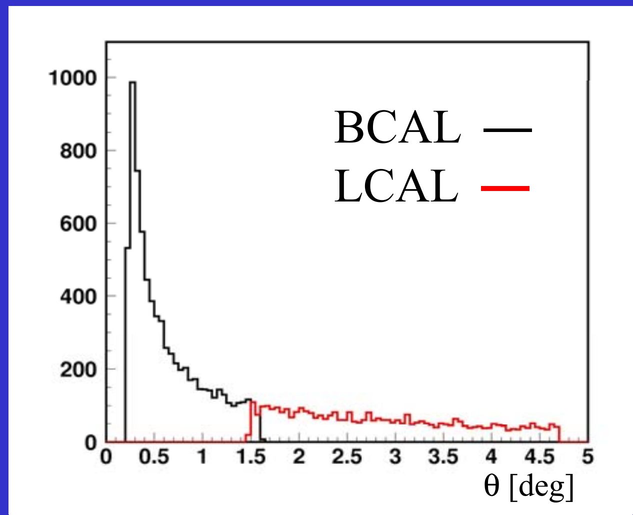


Background properties

- Leading order diagrams contributing to NC four-fermion production, are dominated by multiperipheral processes by factor 10 ^{3} (at LEP)
- Outgoing (highenergetic) e^+e^- are emitted along the beampipe, while lowenergetic ff pairs are distributed over a wider polar angle range, thus most of the energy is deposited in beam calorimeter (BCAL)







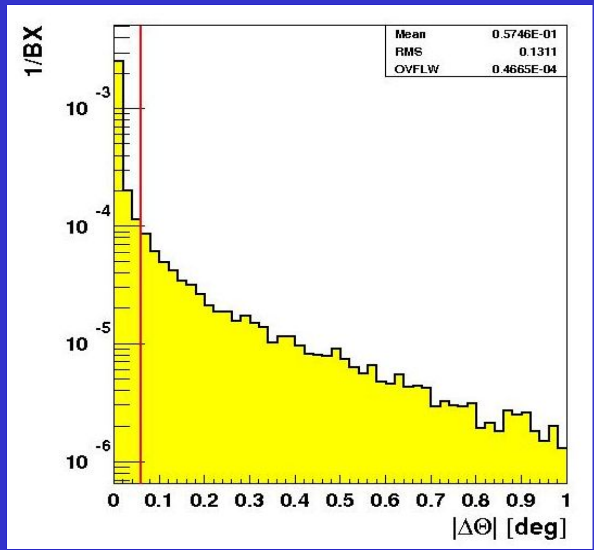
Discrimination of signal from background

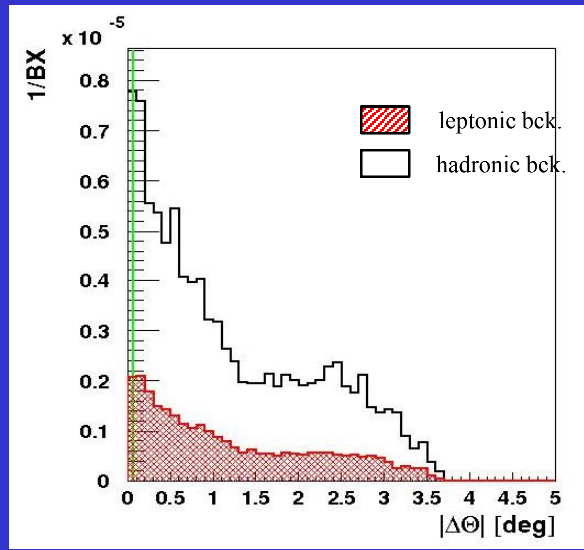
Tough rates of signal and background are comparable in the luminosity calorimeter, properties of Bhabha events allow isolation cuts to be applied :

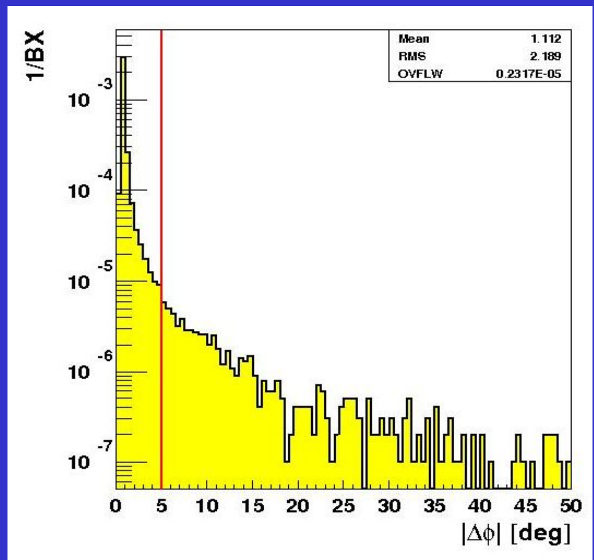
- Acollinearity cut $|\Delta\theta|< 0.06$ deg
- Acoplanarity cut $|\Delta\varphi|< 5$ deg
- Energy balance cut $|E_{F(R)}-E_{B(L)}|<0.1\ E_{min}$

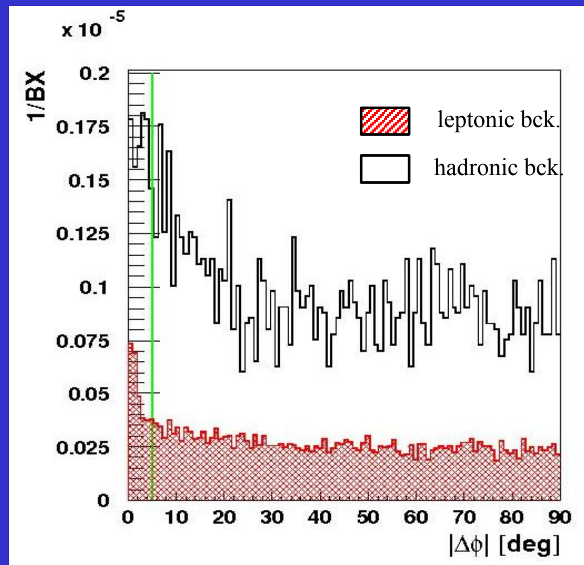
  $E_{min}=\min(E_{F(R)}-E_{B(L)})$
- Relative energy cut $(E_F+E_B)/2E_{beam}>0.75$

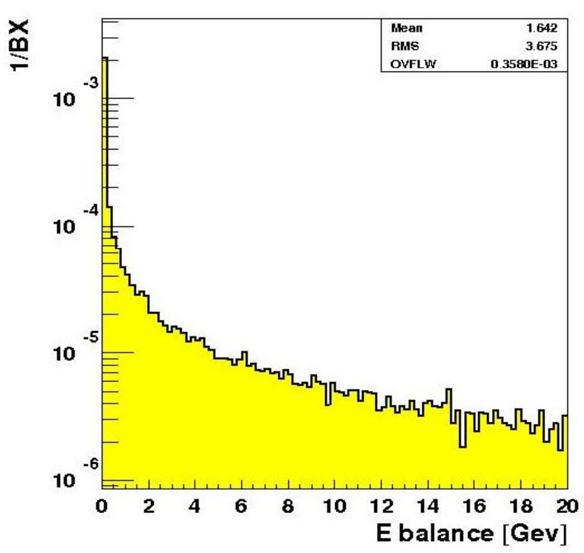
Isolation cuts are applied assuming ideal reconstruction and 100 % reconstruction efficiency (latter it will be shown that detector resolution does not affect the suppression of background)

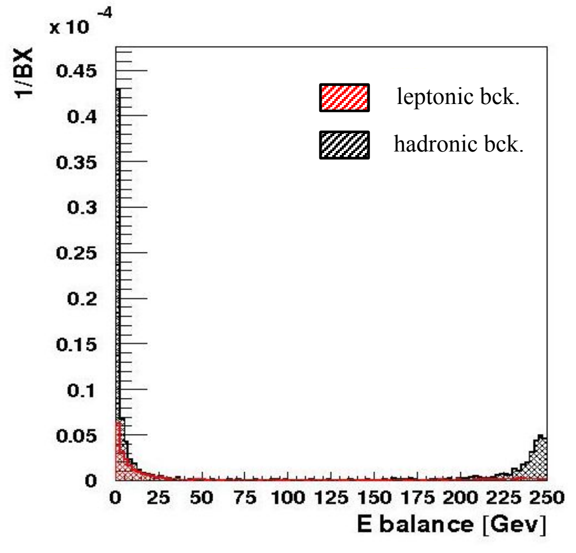

1/BX
Mean 0.5746E-01
RMS 0.1311
OVFLW 0.4665E-04
|ΔΘ| [deg]

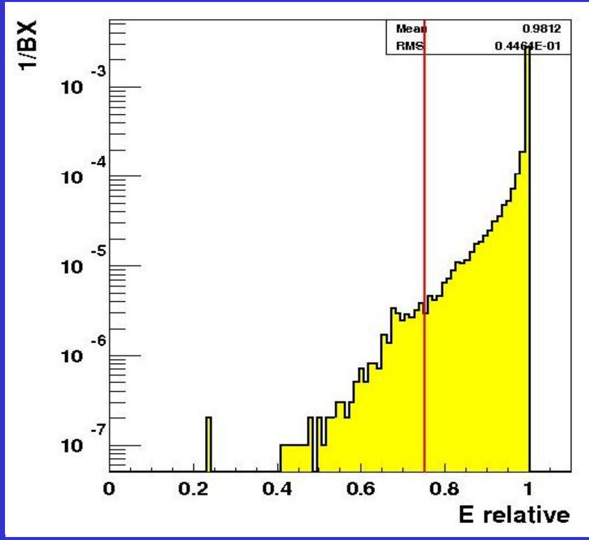

x 10 -5
1/BX
leptonic bck.
hadronic bck.
|ΔΘ| [deg]

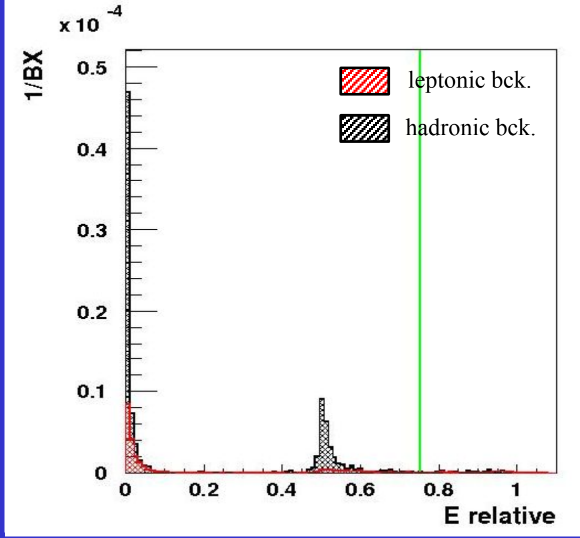

1/BX
Mean 1.112
RMS 2.189
OVFLW 0.2317E-05
|Δφ| [deg]


x 10 -5
1/BX
leptonic bck.
hadronic bck.
|Δφ| [deg]


1/BX
Mean 1.642
RMS 3.675
OVFLW 0.3580E-03
E balance [Gev]


x 10^-4
1/BX
leptonic bck.
hadronic bck.
E balance [Gev]

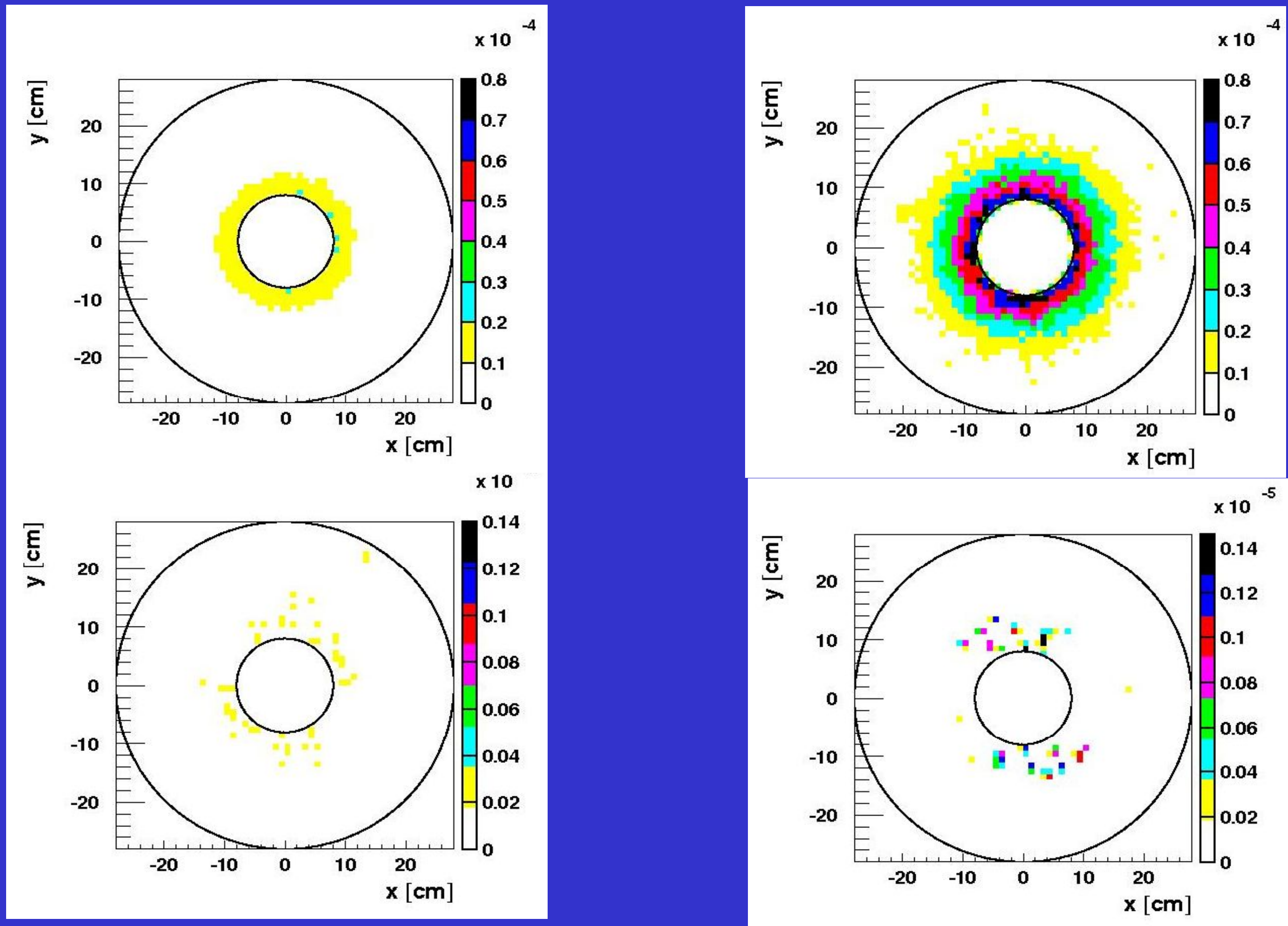

1/BX
Mean 0.9812
RMS 0.4464E-01
E relative


x 10^-4
1/BX
leptonic bck.
hadronic bck.
E relative

Selection and rejection efficiencies

	Bhabha selection efficiency		Leptonic background rejection efficiency	Hadronic background rejection efficiency
1. $\|\Delta\theta\| < 0.06$ deg	81.87 %		95.20 %	95.27%
2. $\|\Delta\varphi\| < 5$ deg	97.96 %		89.53 %	90.42 %
3. $E_{bal} < 0.1\ E_{min}$	90.61 %		94.58 %	95.45 %
4. $E_{rel} > 0.75$	99.08%		88.73 %	95.96 %
B/S (1,2,3)	**$1.3 \cdot 10^{-4}$**	**80.6 %**	99.38 %	99.78 %
B/S (1,2,4)	**$2.6 \cdot 10^{-4}$**	**80.8 %**	99.26 %	99.47 %

Projection of hits at the front plate of the luminosity calorimeter for leptonic (left) and hadronic (left), before (up) and after down) applying the set of isolation cuts (1,2,3)



B/S ratio and occupancy for different detector designs

- It has been shown that the separation power of the proposed cuts is equally good for the both studied LCAL designs. The ratio of 1.57×10^{-4} of B/S is found for the pad design.

- Occupancy is however reduced due to the azimuthal granulation of radial sectors, and for physics background it is, again, more then 20 times less then the signal.

- Occupancy of luminosity calorimeter is dominated by pairs converted from beamstrahlung: ~ 10 times more than signal (over 100 times more then physics background)

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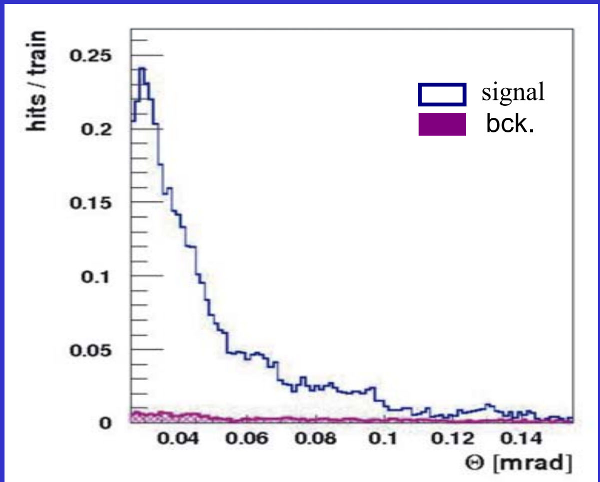
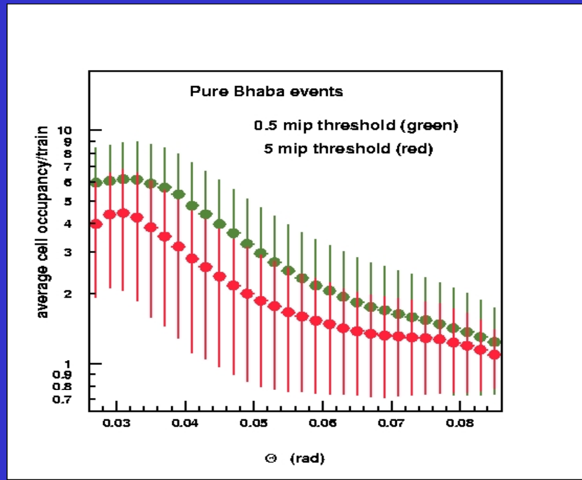
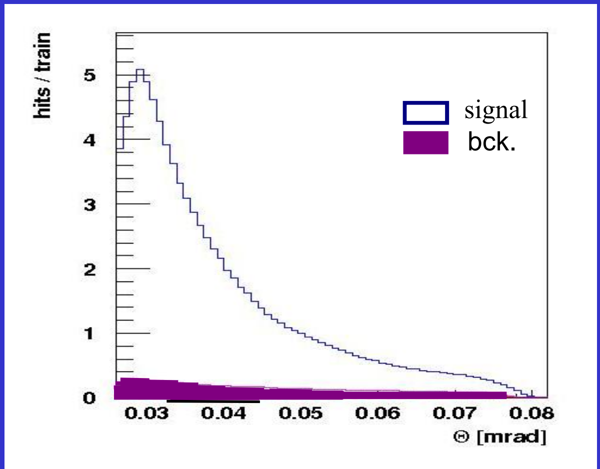


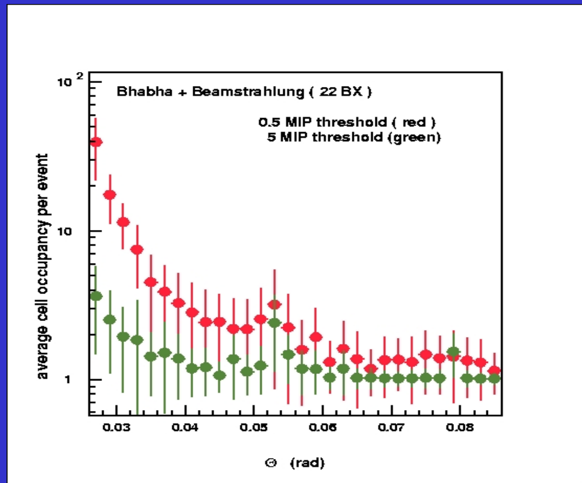
“Pad” design of LCAL



“strip” design – only Bhabha



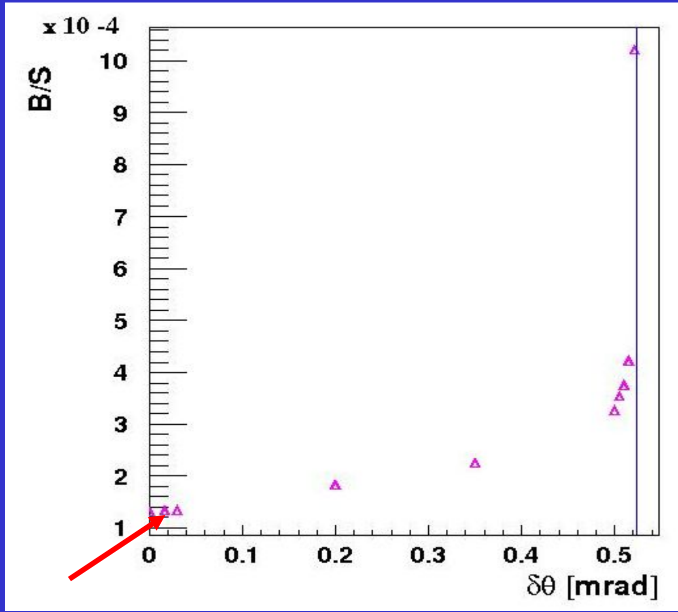
“Strip” design of LCAL



“strip” design –Bhabha + beamstrahlung

Design requirements from physics background

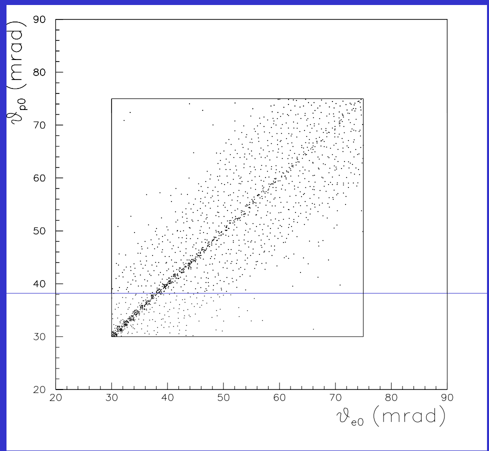
- In order to maintain background to signal ratio to the required level of 10^{-4}, the minimal required detector resolution is far above the achieveable detector resolution in θ (of order 10^{-2} mrad)

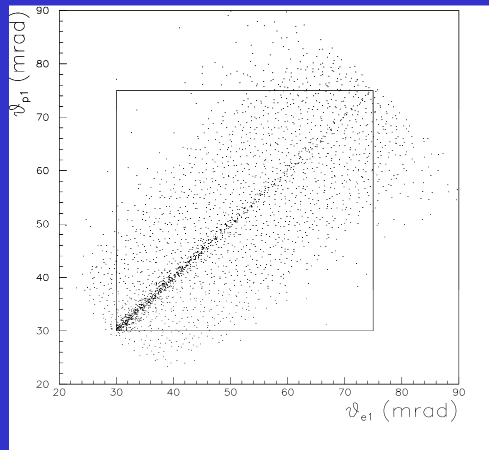


B/S ratio vs. absolute error in polar angle

Physics background and beam-beam deflection

- Signal and background will be affected by the beam-beam interaction. Beamstrahlung and em deflection will modify 4-vectors of both initial and final state (4.4 % BHSE)





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If luminosity is measured with the following selection:

- $E_{rel}>0.8$
- $30<|\theta|<75$ mrad (subsequently applied to e^+ and e^-)

beam-beam interaction results in Bhabha suppression of ~1%

	Bhabha selection efficiency	**Leptonic background rejection efficiency**	**Hadronic background rejection efficiency**
1. $30<\|\theta\|<75$ mrad	64.99 %	42.11 %	41.95 %
2. $E_{rel}>0.8$	98.50 %	90.74 %	96.57 %
All cuts (1,2)	64.33 %	93.69 %	97.48 %
B/S	**1.87×10^{-3}**		

Selection and rejection efficiencies for signal and background for selection optimized to beam-beam interaction

Conclusion

- It has been shown that, due to the characteristic topology of Bhabha events, it is possible to establish more then one set of selection criteria to keep the background from four-fermion NC processes within the level of 10^{-4} of background to signal ratio. The average loss of signal is of order of 20%, that however can be improved if needed by tuning the cut-off values

- Physics background would occupy the read-out system approximately 20 times less then signal and more then 100 times less then the machine background from converted pairs. The latest design reduces occupancy more then a factor of 10 with respect to the former designs, due to the azimuthal segmentation of sensor rings.

- In order to reach the required separation from signal to physics background, there are no particular requirements on luminosity calorimeter resolution

- If the event selection for luminosity measurement is based on relative energy and alternated polar angle acceptance, background is enlarged in respect to signal to the level of 10^{-3}. This is due to the loss of Bhabha statistics of more then 1/3 of the signal.
- For all studied selections of the signal, the corresponding component of the systematic error of luminosity is less then 10^{-4}

<u>However, to get final conditions for luminosity measurement, holistic treatment of all sources of systematic error is needed. In addition, the same has to be done for the Giga Z option.</u>