Systematic effects in luminosity measurement at ILC

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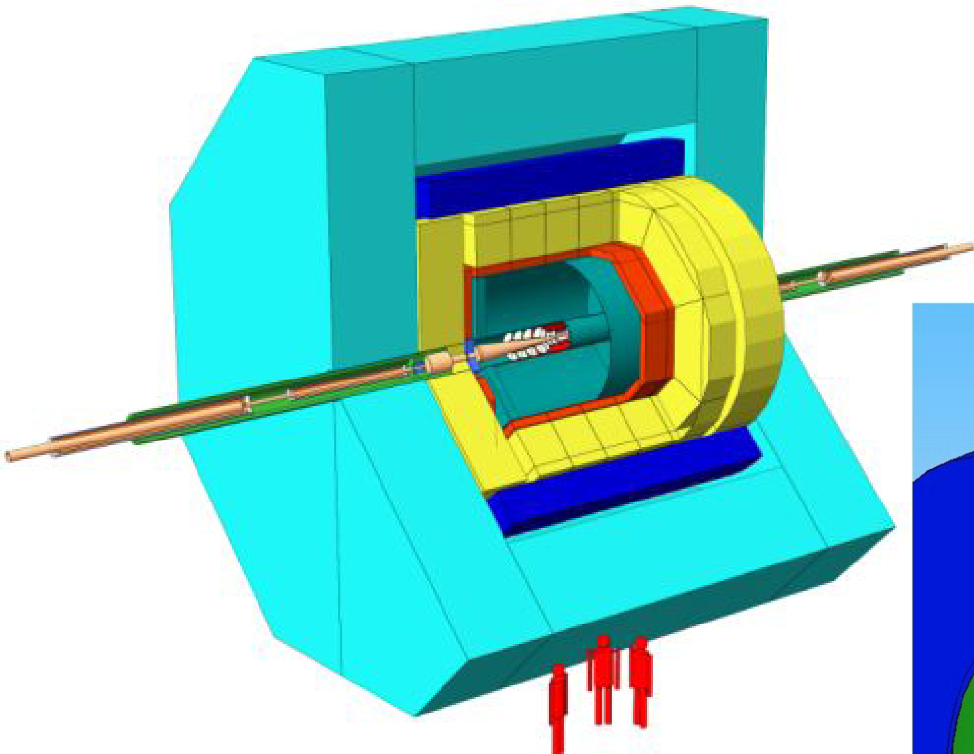
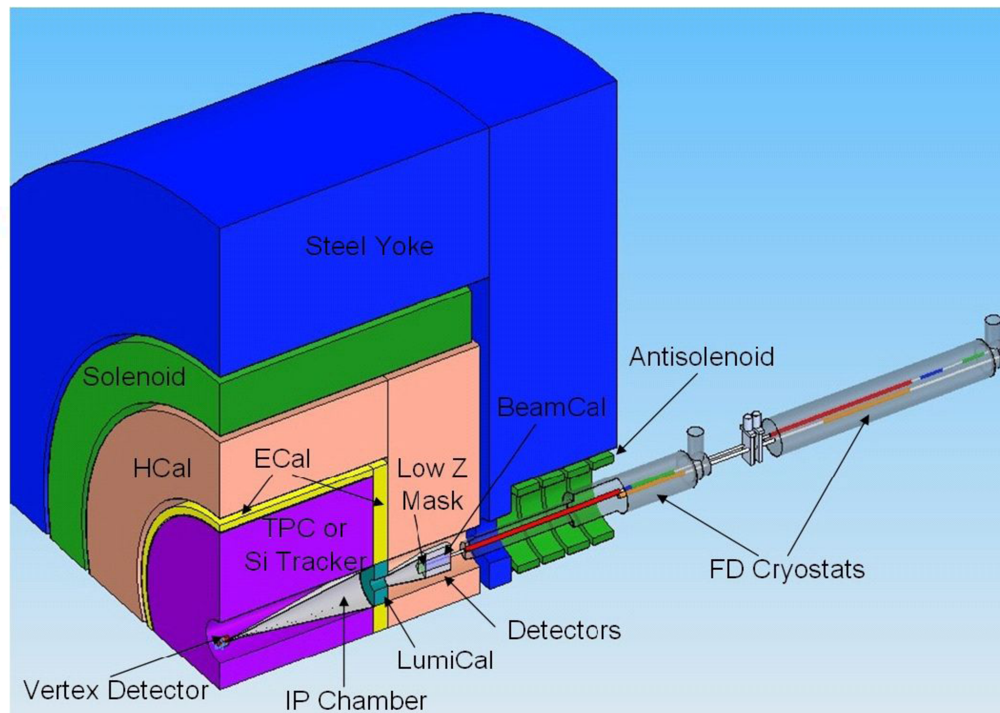
On behalf of the FCAL collaboration

Overview

- Forward region of the ILC, Luminosity Calorimeter
- Luminosity measurement: physics, systematics
- Event selection: Asymmetric cuts + relative energy cut
- Bias of energy scale
- Luminosity vs. E resolution
- Conclusion

Layout of the Forward Region





Calorimetry in the Forward Region

LumiCal

- Precision luminosity measurement $\Delta L/L \sim 10^{-3}$ (10^{-4} GigaZ)

BeamCal

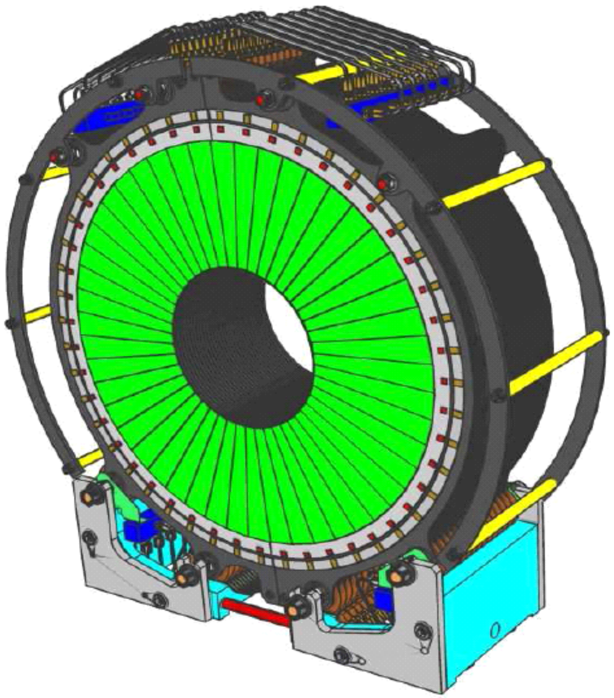
- Beam diagnostics, veto to SM processes in new particle searches (SUSY)

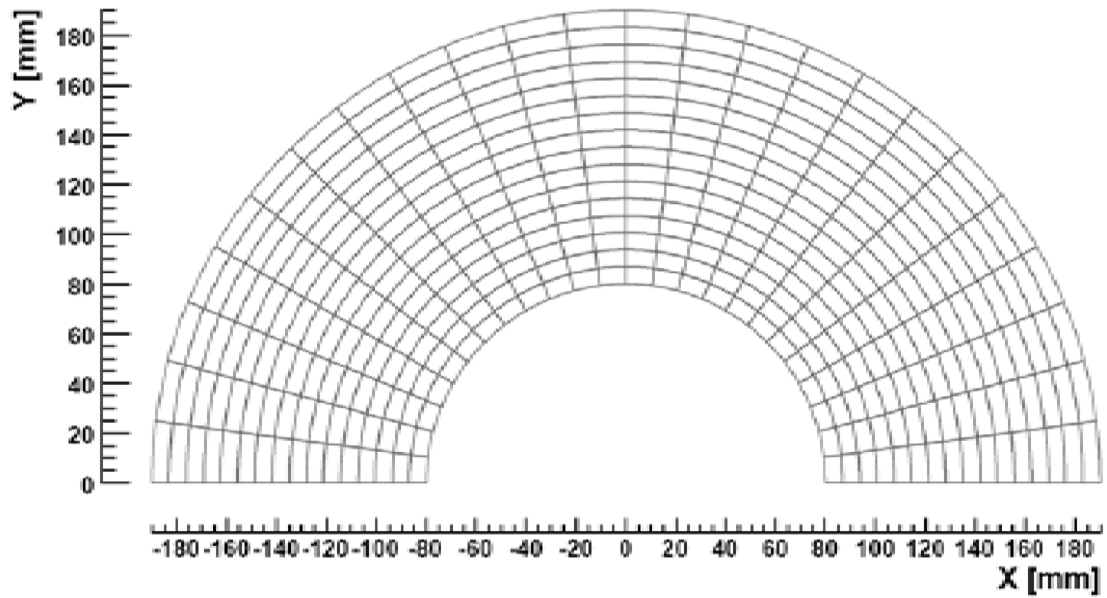
GamCal

- Beam diagnostics, instantaneous luminosity measurement

CHALLENGES: High precision, high radiation dose, high occupancy, fast read-out

Luminosity Calorimeter





(Every fourth segment is drawn)

Geometry:

- r_{min} = 80 mm
- r_{max} = 195 mm
- tungsten thickness = 3.5 mm
- silicon thickness = 0.3 mm

Segmentation:

- 30 layers, 64 radial divisions, 48 azimuthal divisions;
- azimuthal cell size -131 mrad;
- radial cell size - 0.8 mrad;
- z position = 2270 mm

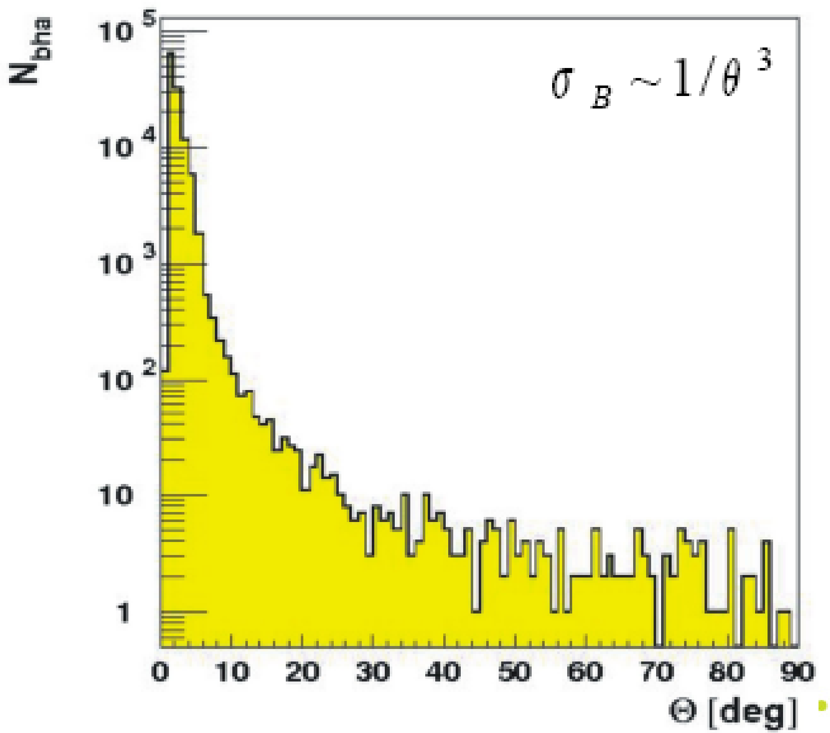
Luminosity measurement at ILC

Integrated luminosity can be determined from the total number of Bhabha events produced in the acceptance region of the luminosity calorimeter and the corresponding theoretical cross-section. Note that $\Delta\theta$ is bias of θ.

$$L_{int} = \frac{N_{th}}{\sigma_B}$$

real experiment →

$$L_{int} = \frac{N_{exp} - N_{bck} - \ldots}{\varepsilon \cdot \sigma_B}$$



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

1. To control systematics

2. To build a device capable of precise reconstruction

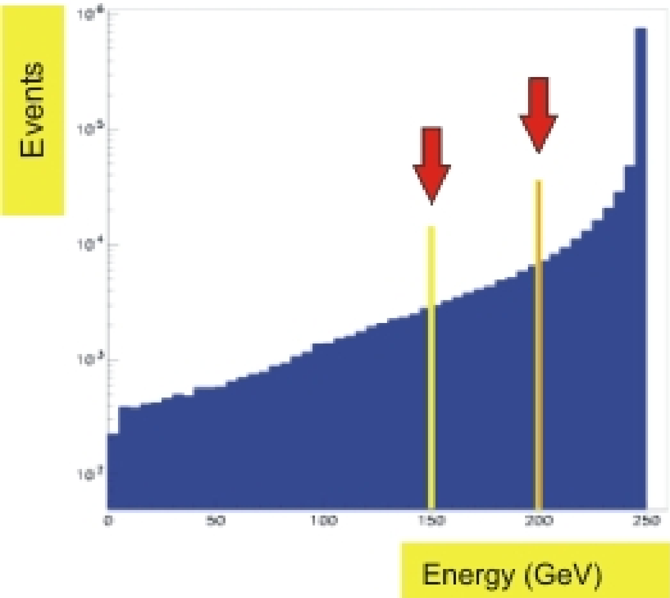
The aim of study

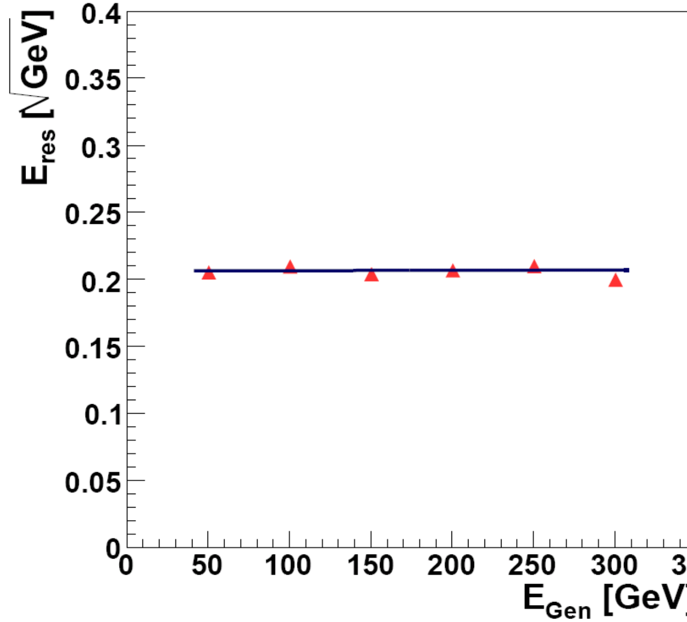
The aim of this study is to optimise event selection taking into account following effects:

- beam-beam deflection;
- physics background;
- energy bias;
- control of energy resolution,

as well as to minimize sensitivity to detector energy resolution and scale.

Energy resolution from the detector design





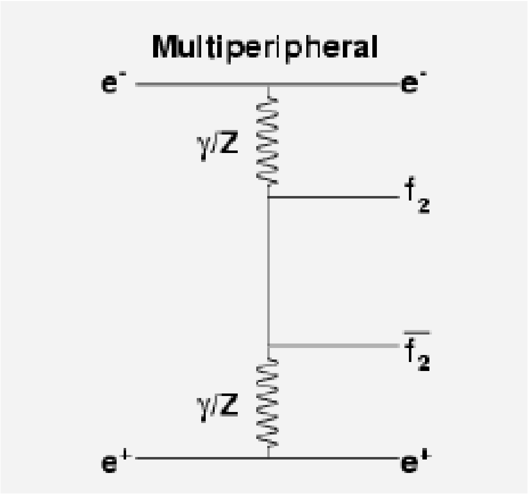
Energy of particles in LumiCal is measured assuming both showers fully contained in the LumiCal. Measured particle energy is, thus, affected by resolution effect. Since the detector is being calibrated under realistic beam conditions, the bias of energy scale can also be present.

$$E_{res} \approx 0.21 \sqrt{(\mathrm{GeV})}$$

$$\frac{\sigma_E}{E} = \frac{E_{res}}{\sqrt{E_{beam}\ (\mathrm{GeV})}}$$

[I.Sadeh, Tel Aviv University, Israel]

Simulation has shown that energy resolution of ~21% √GeV is achievable with the current LumiCal design.



Background electron spectators carry high energy going along the beam pipe, whereas low energetic *ffbar* pairs are mainly deposited in the LCAL.

Simulation performed using WHIZARD:

- 1M 4-lepton and 1M hadronic events;
- total cross section: *(2.05±0.05)* nb;
- contribution of all neutral tree-level processes;
- full polar angle range;
- invariant mass of outgoing lepton > 1 GeV/c^2;
- momentum transferred in photon exchange > 1 GeV/c.

Event selection

Bhabha events are identified by 2 electromagnetic cascades carrying the full beam energy, originating from collinear and coplanar Bhabha particles.

Characteristic topology of Bhabha events allows us to establish a set of criteria to distinguish signal from physics background. Criteria used in this study are:

- asymmetric cuts (next slide)
- relative energy,

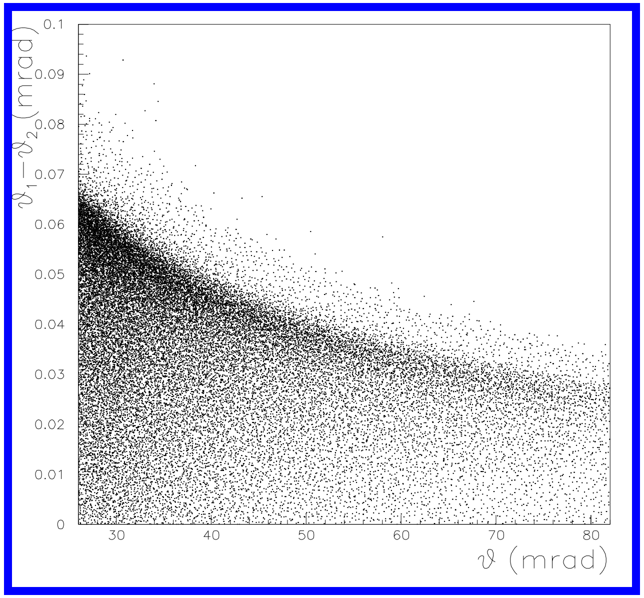
$$E_{rel} = \frac{E_i + E_j}{2 \cdot E_{beam}}$$

Bhabha events *(4.12±0.03) nb* are simulated with BHLUMI, implemented in BARBIE, a GEANT3 based detector simulation of LumiCal [developed by Bogdan Pawlik, Institute of Nuclear Physics, Krakow, Poland].

No crossing angle.

Asymmetric cuts

Signal and background will be additionally affected by the beam-beam interaction effects. They will modify both initial state, through beamstrahlung, and the final state through electromagnetic deflection, resulting in the total suppression of the Bhabha cross-section (BHSE) of order of 4.4%. In order to reduce this hard-controlled effect (to 1.5%), asymmetric theta cuts are used*.



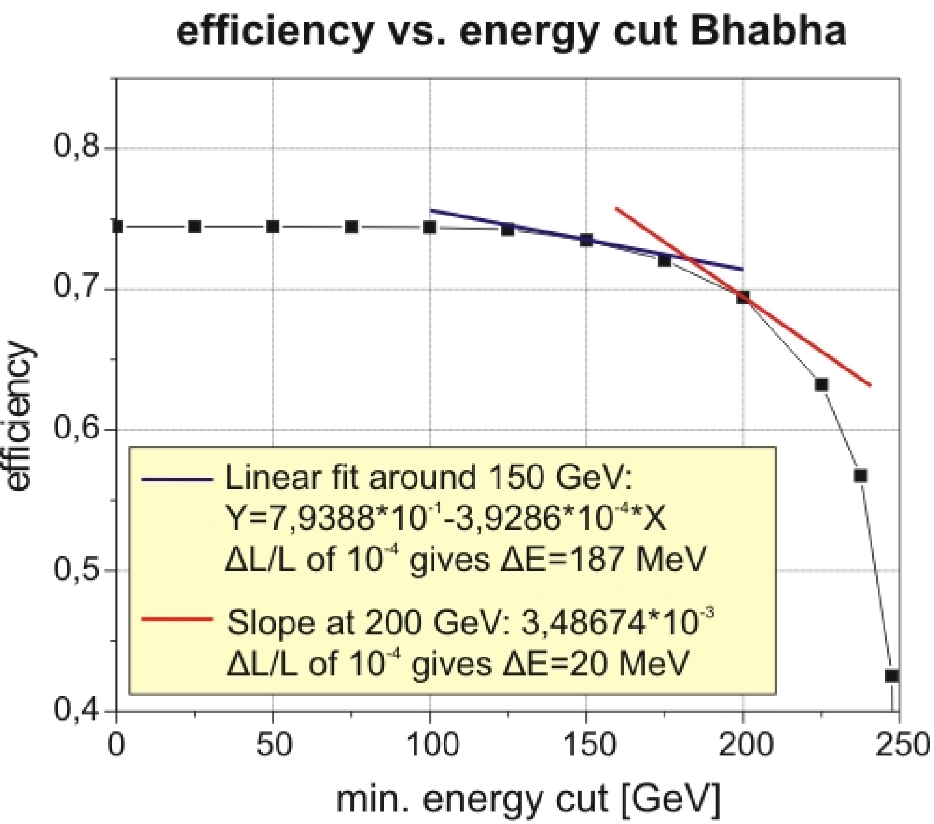
These cuts are applied subsequently to forward and backward sides of the detector, in order to reduce systematics for the IP position and relative position of forward and backward detector.

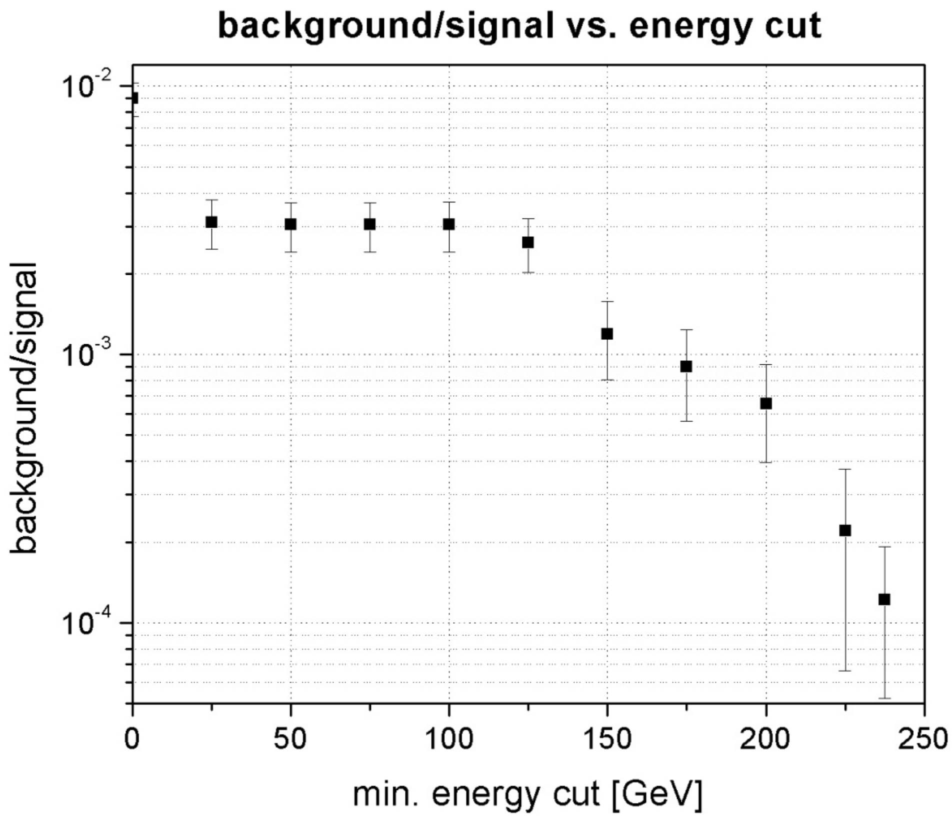
LumiCal angular acceptance for geometry used is 35-87 mrad. Therefore, cuts are set as follows:

- cut 1: 39-80 mrad;
- cut 2: 35-87 mrad.

* Cécile Rimbault (LAL Orsay, France), Impact of beam-beam effects on precision luminosity measurements at the ILC, LCWS 07

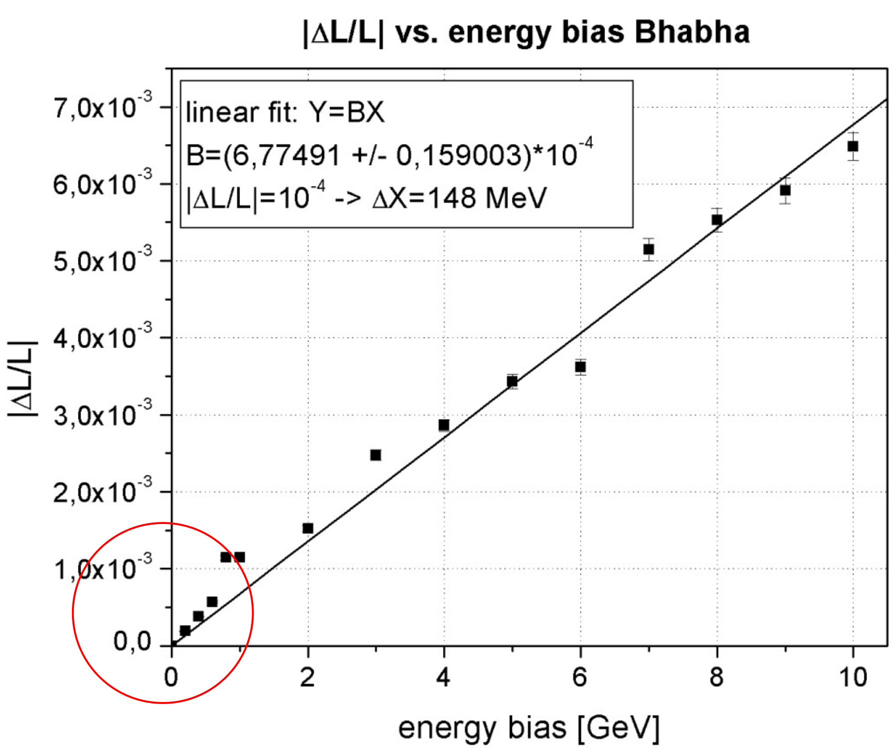
Asymmetric cuts + relative energy cut

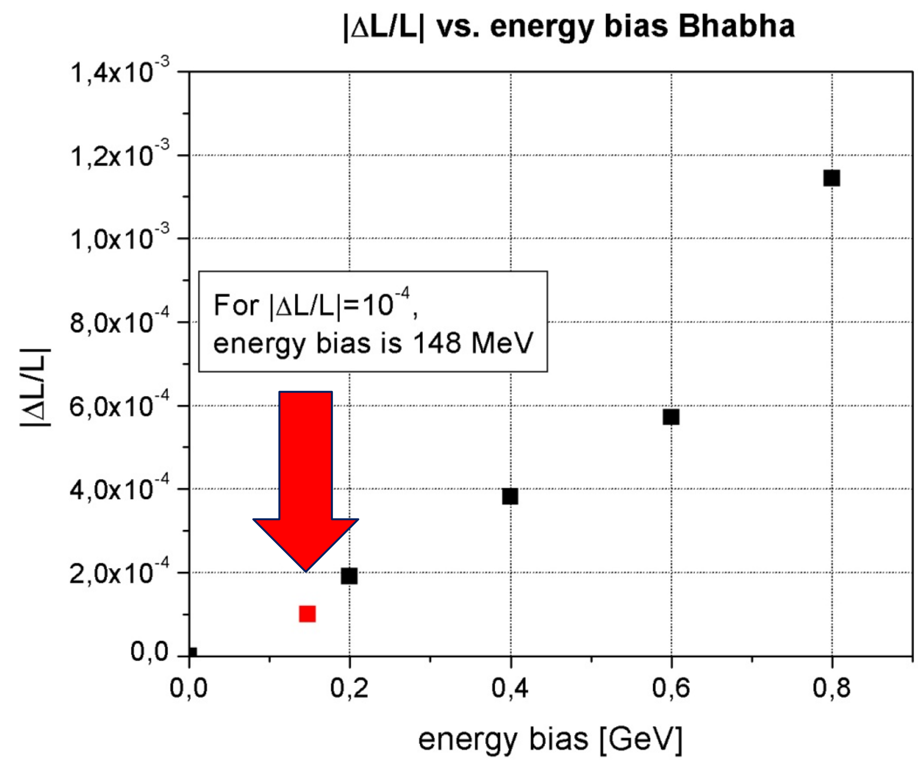




Looser cut on relative energy (60% instead of 80% of beam energy) can be used together with asymmetric theta cut.

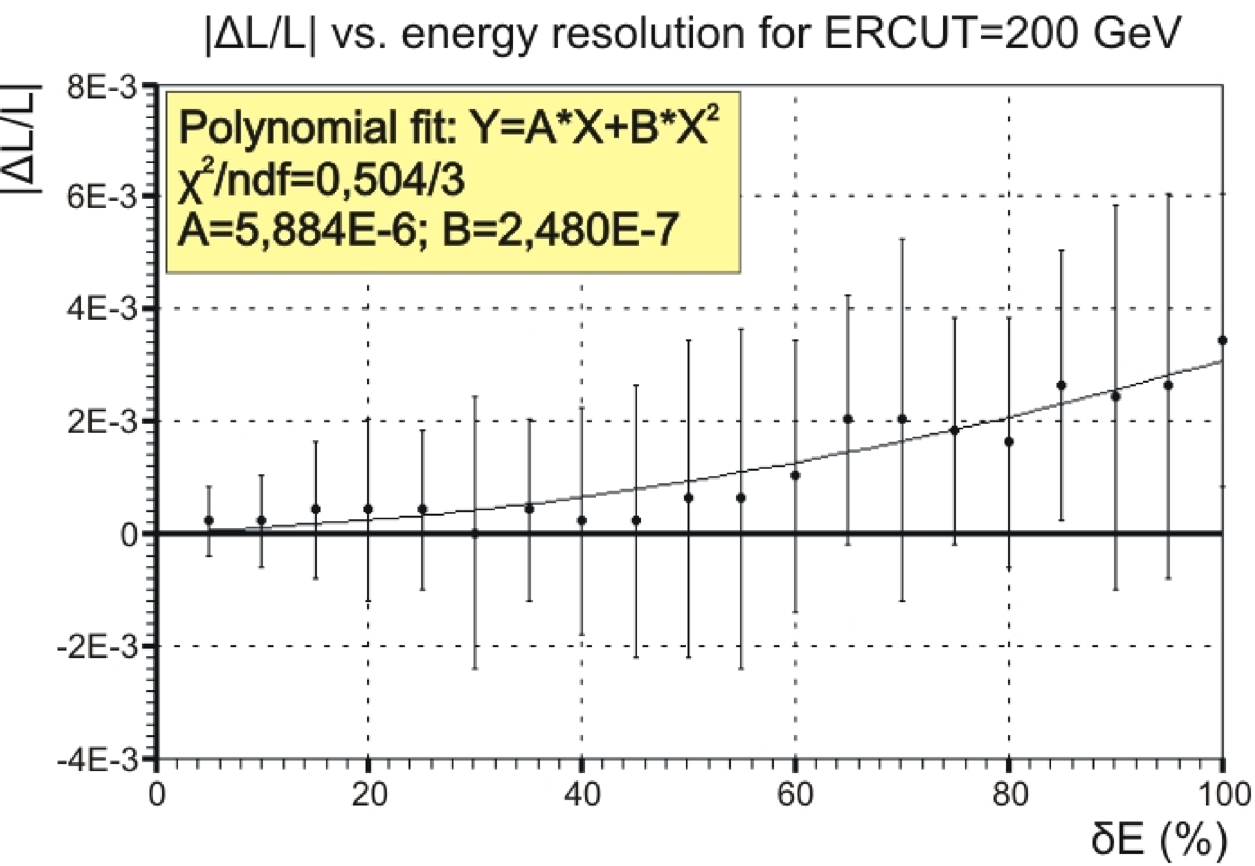
Bias of energy scale





If there is an bias (offset) of energy scale, it should be known with margin of ±148 MeV, if one wants to know luminosity at the level of 10^{-4}.

Luminosity vs. E resolution

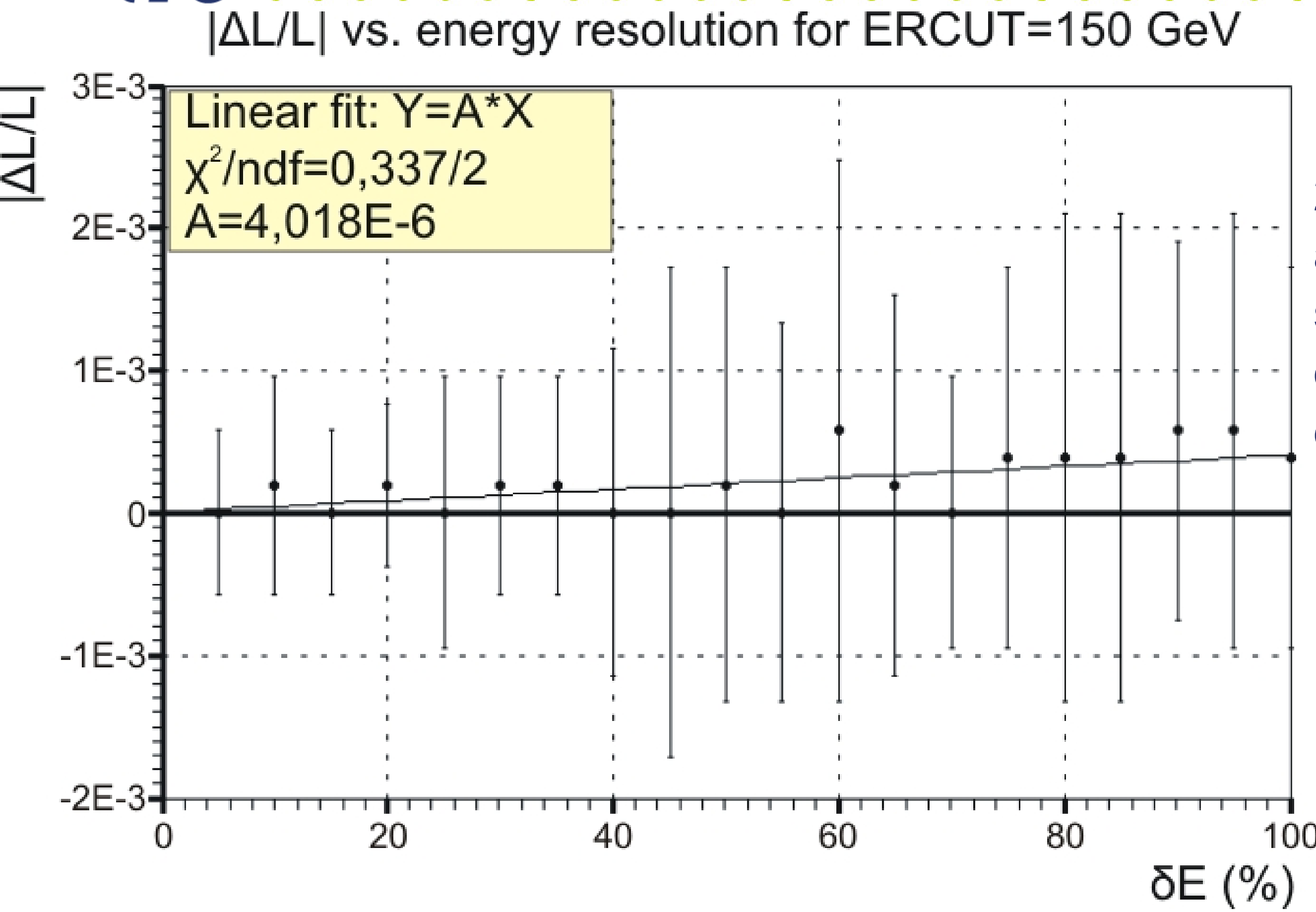


In order to check how well we have to control the resolution, a random number generator is used to smear energy of particles that caused showers in the LumiCal.

For cut on relative energy on 200 GeV, if one wants to achieve luminosity uncertainty below 10^{-4}, uncertainty of energy resolution at 20% should be about 1,5%.

[in consistency with result of A. Stahl, Luminosity Measurement via Bhabha Scattering: Precision Requirements for the Luminosity Calorimeter, LC-DET-2005-004, 2005]

Luminosity vs. E resolution



In both cases (cuts @ 200 and 150 GeV), we are dominated by the statistical dissipation (of order 10^{-3}) due to finite detector resolution.

For cut on relative energy at 150 GeV, polynomial fit is not needed, a very simple linear fit looks quite fine. For luminosity uncertainty of 10^{-4}, we have to control energy resolution at the level of 25%, practically independently of the resolution itself.

Conclusion

Taking into account beam-beam deflection effects, presence of physics background from 4-fermion processes, energy resolution of the detector and possible biases of energy scale, we propose the following selection for luminosity measurement:

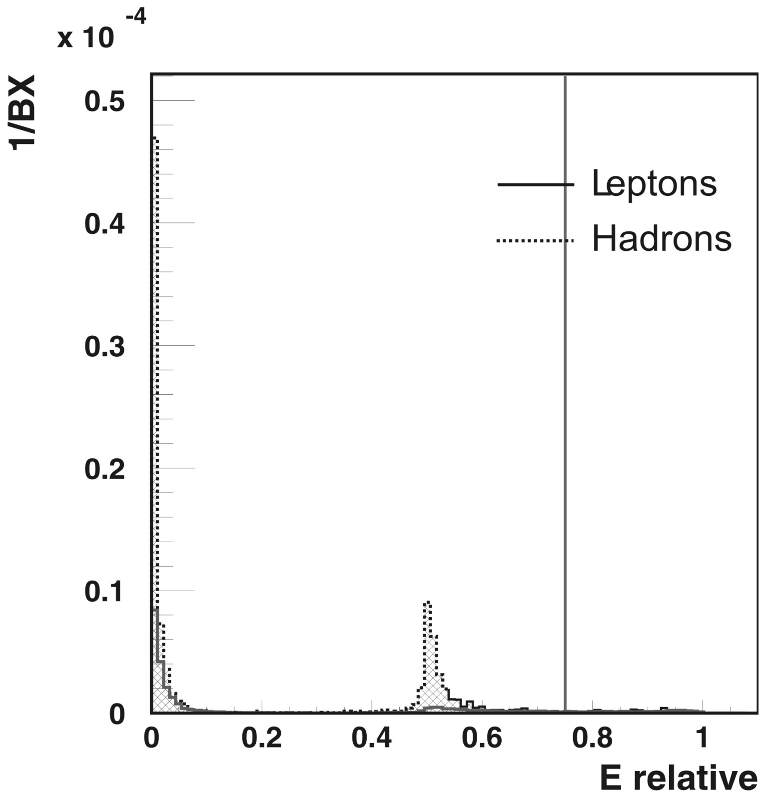
- asymmetric theta cuts;
- relative energy cut at 150 GeV (particles carry at least 60% of the beam energy).

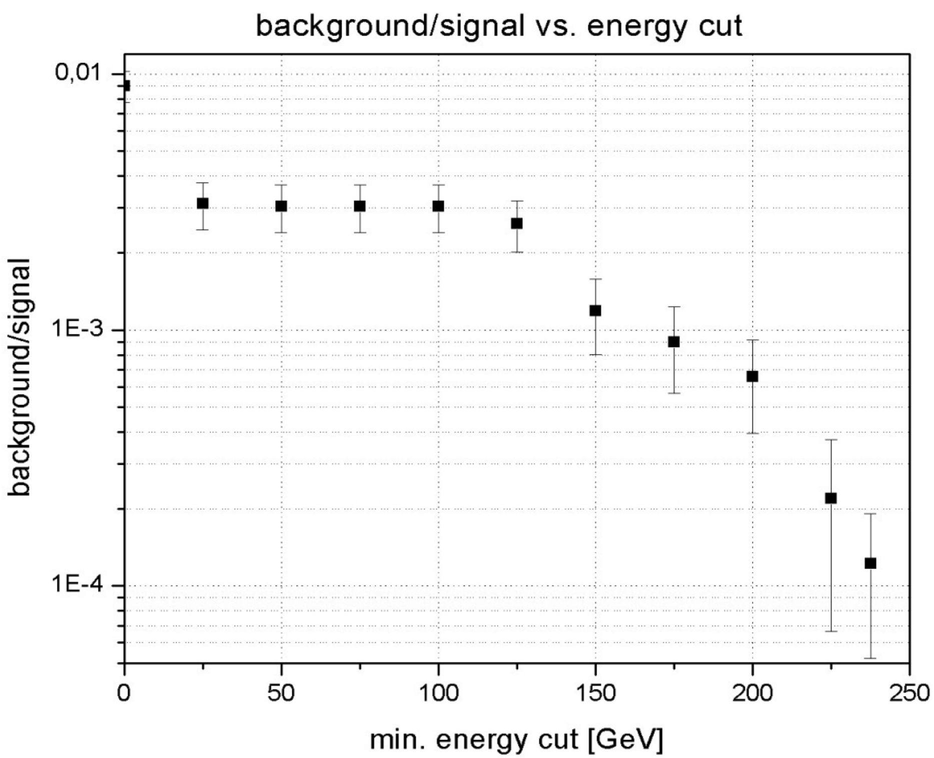
With such selection, systematics from all mentioned sources is kept below 10^{-3}, if we assume that we can really control the beam-beam deflection effects at the level of 10^{-2} and physics background at the level of 10^{-1}.

Energy resolution of the detector should (and certainly will) be controlled better than 25% and the possible bias of energy scale has to be known to approximately 148 MeV, if one wants to know luminosity at the level of 10^{-4}.

Backup slides

Asymmetric cuts + relative energy cut

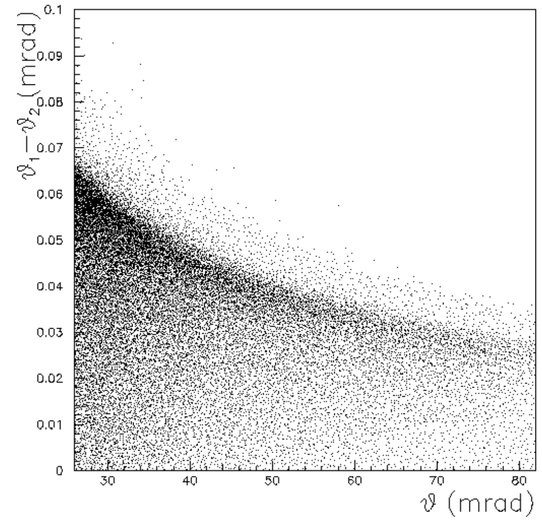




More systematics …

Beam-beam interactions

- **Modification of initial state**: **Beamstrahlung** ➔ $\sqrt{s'} \leq \sqrt{s}$, $\Delta\theta_{ini} \neq 0$, $E_{elec} \neq E_{posit}$
- **Modification of final state**: **Electromagnetic deflection** ➔ Bhabha angle reduction (~10^{-2}mrad) + small energy losses



Total Bhabha Suppression Effect (BHSE) ~1.5%

Luminosity spectrum reconstruction

- **To control the ΔBHSE from beamstrahlung at the level of 10^{-2}, variations in the rec. lumi spectrum $\Delta x/x$ need to be known with the precision of 4.10^{-3}**

Beam parameters control

- **Bunch length σ_z and horizontal size σ_x should be controlled at the 20% level to keep the ΔBHSE from EM deflection at the level of 10^{-3}**

QUITE A TASK IN REALISTIC BEAM CONDITIONS…