Systematic effects in the Luminosity measurement at circular e^+e^- colliders

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Outline

Section 1

Introduction

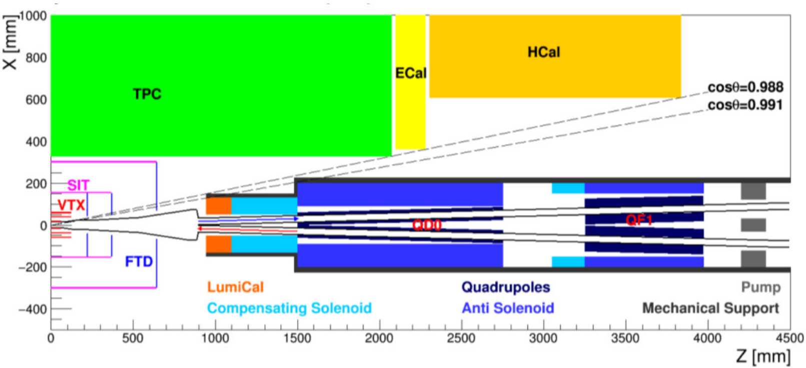
Circular colliders

Same bunches revolve and collide many times.

- Beam structure is not limited by the accelerator pulse
- Lower requirement of luminosity per bunch
- Much larger beam size than at linear colliders
- Almost negligible beam-beam effects

The list of systematic effects is somewhat different than at LC, and with different priorities.

Generator level study using the CepC case

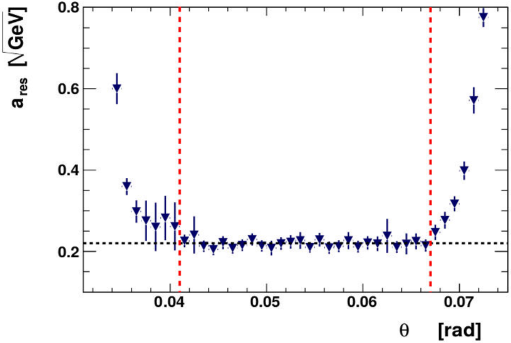


LumiCal: Tentative location at CepC
(S. Hou, CepC MDI meeting May 19th 2017)
Geometrical coverage: $r_{\rm in} = 25$ mm, $r_{\rm out} = 100$ mm
Distance of the front plane from IP: $d_{\rm IP} = 950$ mm

Section 2

LumiCal fiducial volume

FCAL experience



Determination of the fiducial volume of the ILC LumiCal
(H. Abramowitz et al., JINST P12002, 2010)

- ILC LumiCal positioned at 2.5 m from the IP
- Energy resolution poor in the outer 10 mrad of the angular coverage
  $\rightarrow$ Distance $d > 25$ mm from the edge of the luminometer required for accurate energy measurement.

Projection onto the tentative LumiCal for CepC

- CepC LumiCal is smaller and closer to the IP (0.95 m).
- Fiducial range $r_{\mathsf{in,f}} = 50$ mm, $r_{\mathsf{out,f}} = 75$ mm,
  $\rightarrow \theta_{\mathsf{in,f}} = 52.6$ mrad, $\theta_{\mathsf{out,f}} = 78.9$ mrad
  (Only $\sim 1/3$ of the geometrical angular coverage)
- These are rough numbers needed to start working. Exact numbers may change with a dedicated study.

Section 3

Scope and method

Long list (evolving)

- Uncertainty (bias) of the beam energies
- Energy spread of the beams
- Physics background
- Uncertainty of the LumiCal inner radius
- Offset of the relative position of LumiCal vs. IP
- Fluctuations of the relative position of LumiCal vs. IP
- Tilt of the LumiCal axis
- Azimuthal twist of the LumiCal halves
- Uncertainty of the beam polarization (if polarized beams)
- Uncertainty of the detector sampling term
- Machine-related backgrounds (interactions with the beam halo etc.)

All effects will be explained in some detail in the following.
Underlined effects are studied or planned in the present work.

Procedure

1. Samples are generated using BHLUMI Bhabha event generator:
   - $E_{CM} = 250$ GeV [1]
   - Final particle theta range from 45 to 85 mrad (includes a ~ 7 mrad margin outside of the FV to allow non-collinear FSR to contribute)
   - Statistics 3×10^7 events
2. Bias or smearing is applied to the final momenta, or to the counting cuts, according to one systematic effect at a time
3. Particle paths are projected to the front Lumical plane.
4. Close-by particles are summed to imitate cluster merging
5. Condition to count an event: one particle on each side of the IP with:
   - $E > 0.5 E_0$, where E_0 is the nominal beam energy
   - $r_{\text{in,f}} < r < r_{\text{out,f}}$

[1] The correct E_{CM} @ CepC is 240 GeV– the study will be rerun at 240 GeV

Section 4

Results

Symmetric beam energy bias

Definition

- Sum of the biases of incident beam energies $\Delta E_{0,e^+} + \Delta E_{0,e^-}$
- Produces a bias ΔE_{CM} of the mean CM energy of the e^+e^- collisions.

Effects on the Luminosity measurement:

- Cross section bias: $xs_{Bh} \propto 1/s \quad \rightarrow \quad \Delta xs/xs \propto 2\Delta E_{CM}/E_{CM}$
  $\rightarrow$ Requirement: $\Delta E_{CM}/E_{CM} < 5 \times 10^{-4}$
- Acceptance bias due to the energy cut on the final particles is negligible in comparison.

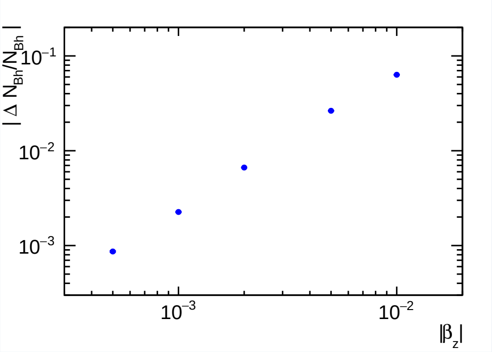
Antisymmetric beam energy bias

Definition

Asymmetry of the incident beam energies $E_{0,e^+} - E_{0,e^-} \neq 0$ produces a longitudinal boost β_z of the event.

Effects on the Luminosity measurement:

10^{-3} acceptance loss per ca. 0.5×10^{-3} beam energy asymmetry.



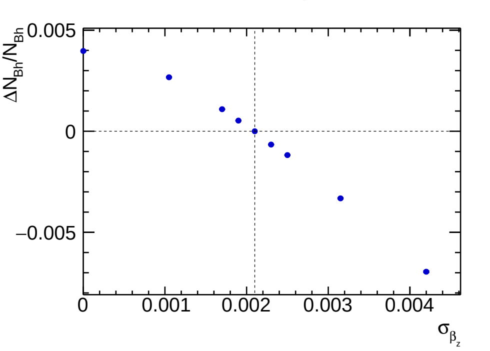
β_z distribution due to the beam energy spread

Definition

- Beam energy spread causes a distribution of β_z event-by event.
- Has to be corrected using information on the beam energy spread

Effects on the Luminosity measurement:

$\sim 10^{-3}$ acceptance bias for a 20% uncertainty of the beam energy spread.



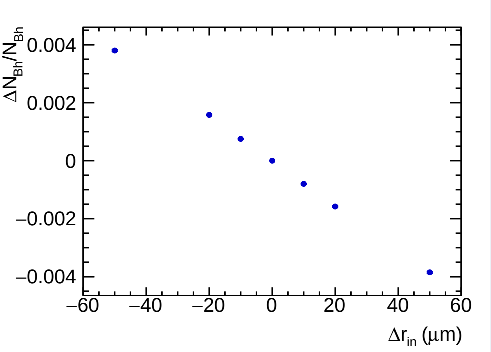
Inner radius of the LumiCal fiducial volume

Definition

Precision of the LumiCal dimensions determines the precision of the local coordinate system in which the hit locations are measured.

Effects on the Luminosity measurement:

10^{-3} acceptance bias per $\sim 13\ \mu$m bias of $r_{\mathrm{in,f}}$.



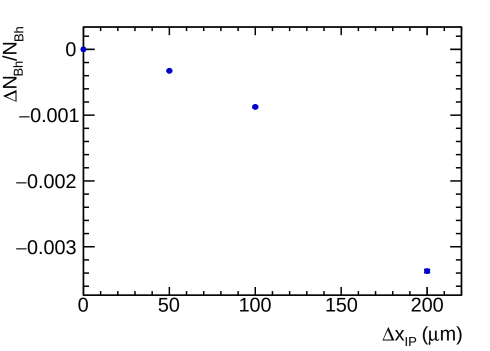
Radial offset of the IP w.r.t. LumiCal

Definition

Radial distance between the LumiCal axis and the beam axis.
Caused by Lumical misplacement or beam offset.

Effects on the Luminosity measurement:

Shifted angular acceptance region → 10^{-3} bias per ca. 100 µm offset.

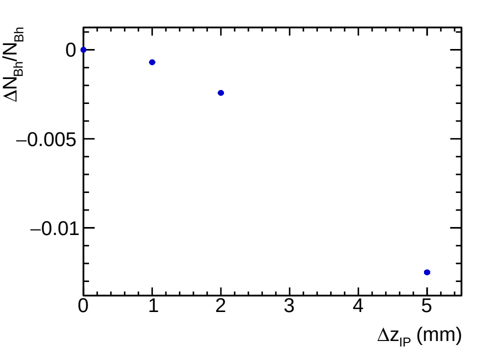


Axial offset of the IP w.r.t. LumiCal

Definition: IP is not at the center along z between the Lumical halves.

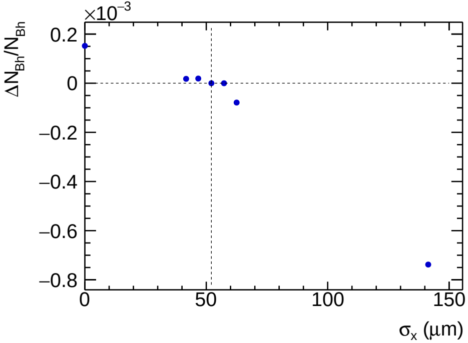
Effects on the Luminosity measurement:

- Antisymmetrically shifted angular acceptance region.
- 10^{-3} acceptance loss per 1.4 mm axial offset.
- Implies a requirement on the synchronisation of the colliding beams of better than ~ 1 ps



Uncertainty of the transverse beam size

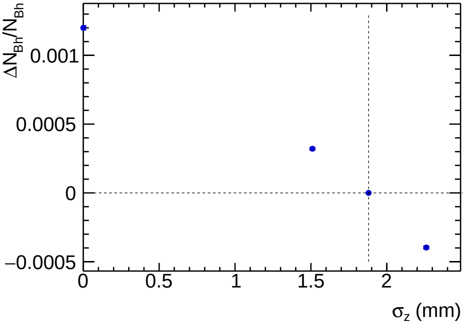
- Bhabha events see different angles to LumiCal depending on:
  - Position within the bunch
  - Fluctuations of the relative position of LumiCal w.r.t. IP along x.
- Acceptance bias smaller than 10^{-4} for σ_x beam size uncertainty of 20%.
- Fluctuations of the relative position of LumiCal w.r.t. IP must remain within ~ 100 μm.



Relative Bhabha acceptance bias as a function of σ_x.
Nominal value marked by the dashed lines.

Uncertainty of the longitudinal beam size

- Effective longitudinal IP location varies event by event due to:
  - Longitudinal position within the bunch
  - Fluctuations of the relative position of LumiCal w.r.t. IP along z.
- Acceptance bias $\sim 4 \times 10^{-4}$ for σ_z beam size uncertainty of 20%.
- Fluctuations of the relative position of LumiCal w.r.t. IP must remain within ~ 1 mm.



Relative Bhabha acceptance bias as a function of σ_z.
Nominal value marked by the dashed lines.

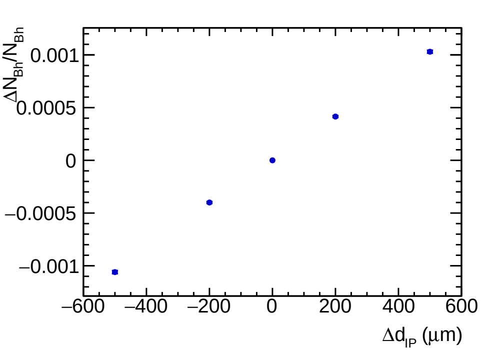
Distance between the LumiCal and the IP

Definition

Distance uncertainty between the IP and each of the LumiCal halves.

Effects on the Luminosity measurement:

10^{-3} acceptance bias per ca. 500 µm distance bias.



Remaining effects planned for the generator level study

Tilt of the LumiCal axis

Definition: Non-zero angle between the LumiCal axis and the beam axis
Effect on the Luminosity measurement: Shifted acceptance region

Azimuthal twist of the LumiCal halves

Definition: Rotation of the LumiCal halves around the axis by different angles.
Effect on the Luminosity measurement: Bias in the acoplanarity measurement (if acoplanarity cuts applied)

Section 5

Summary and outlook

Summary of the results

Requirements on beam delivery, MDI and LumiCal installation, needed to limit **individual** systematic effects to 1×10^{-3}. Preliminary.

Parameter	unit	limit
E_{beam} bias	MeV	60
$\frac{\delta\sigma_{E_{beam}}}{\sigma_{E_{beam}}}$		20%
r_{in}	μm	13
Δx_{IP}	μm	100
Δz_{IP}	mm	1.4
Beam synchronisation	ps	1
$\sigma_{x\ \text{IP}}$	μm	100
$\sigma_{z\ \text{IP}}$	mm	1
Δd_{IP}	μm	500

Conclusions and outlook

- Systematic effects in the luminosity measurement at CepC are studied using generator samples of Bhabha events.
- First order estimates of various systematic effects are given
  - Pure geometrical acceptance effects (+ xs effect of E_{CM})
  - Interaction with the detector is not simulated (yet)
  - Merging of close-by final particle showers (FSR) is approximated.
- Requirements on the beam delivery, Lumical dimension and positioning precision are being set.
- Some corrections are still needed (e.g. E_{CM})
- The full list of systematic effects is currently evolving

Further studies:

- Physics backgrounds (using the relevant generators, eg. WHIZARD)
- Detector effects (by detector simulation)