Potential and challenges of the very forward detectors in physics measurements at linear colliders

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1. Context and purpose of the very forward region
2. Luminosity measurement
3. Low-angle particle identification
4. Conclusions

Context and purpose of the very forward region

Instrumentation of the very-forward region

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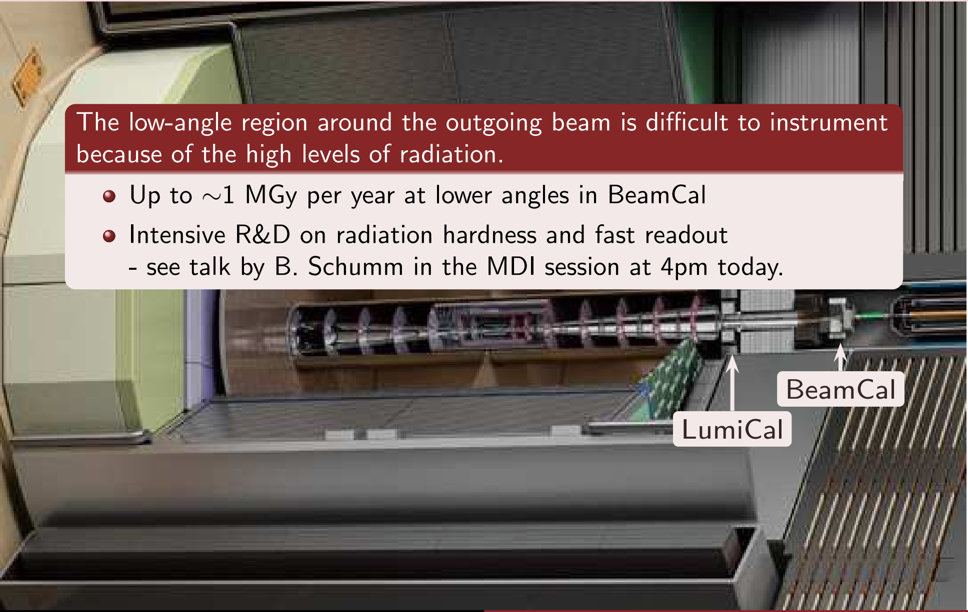
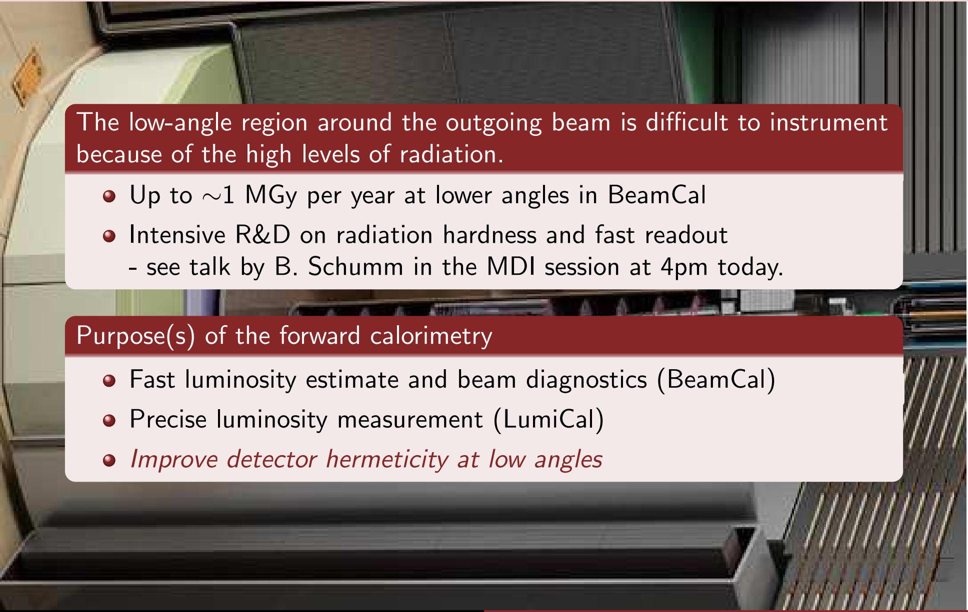


The low-angle region around the outgoing beam is difficult to instrument because of the high levels of radiation.

- Up to ∼1 MGy per year at lower angles in BeamCal
- Intensive R&D on radiation hardness and fast readout
  - see talk by B. Schumm in the MDI session at 4pm today.

Instrumentation of the very-forward region



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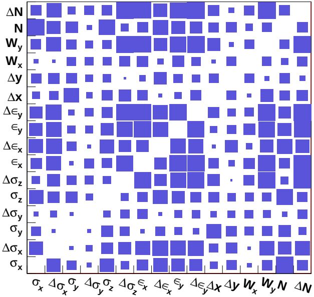
Purpose(s) of the forward calorimetry

- Fast luminosity estimate and beam diagnostics (BeamCal)
- Precise luminosity measurement (LumiCal)
- *Improve detector hermeticity at low angles*

Beam parameters: Challenge of a correlated parameter set

- Measurable distributions of beam-induced backgrounds at very low angles can be used to reconstruct the beam parameters
- Measurement in BeamCal [1,2] and in the pair monitor [3,4]
- Effective correlations between different beam parameters make the reconstruction difficult



Correlation diagram for the effect of different beam parameters on the diagnostic quantities (from [1])

[1] Grah & Sapronov, JINST 3 (2008) P10004
[2] A. Stahl, LC-DET-2005-003 (2005)
[3] K. Ito et al., arXiv:0901.4151 (2009)
[4] K. Ito et al., arXiv:0901.4446 (2009)

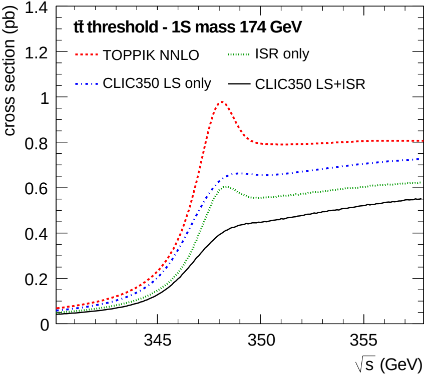
Luminosity: Matching the precision potential of LC

Integrated luminosity

Permille precision required to match the precision of most planned cross section measurements

Luminosity spectrum

- Requirements quantified per case
- Top-pair threshold scan: uncertainty of the luminosity spectrum peak width below 20% required



Influence of the luminosity spectrum on the top-pair threshold scan (K. Seidel et al., Eur. Phys. J. C (2013) 73:2530)

Very forward particle identification

Analyses with missing-energy signature

Processes with spectator electrons are an important source of background – electrons escaping at low angles mimick missing energy

Other analyses that could potentially profit from tagging low-angle particles

- ZZ-fusion
- Search for the dark matter
- More topics might open up if other types of particles can be tagged.

Information limited to (finely segmented) calorimetry

- Calorimetric energy measurement
- Precise measurement of the polar angle
- In principle, discrimination between types of particles possible by the shower profile (e.g. hadrons vs. EM particles)

Luminosity measurement

Low-angle Bhabha scattering

- High cross-section → good statistics
- Theoretically well known cross-section → precise calculation
- Relative uncertainty achieved at LEP $\approx 0.6 \times 10^{-3}$
- Experimental signature: High-energy electrons at low angles **in coincidence** on both sides of the IP

Event selection in the luminosity measurement

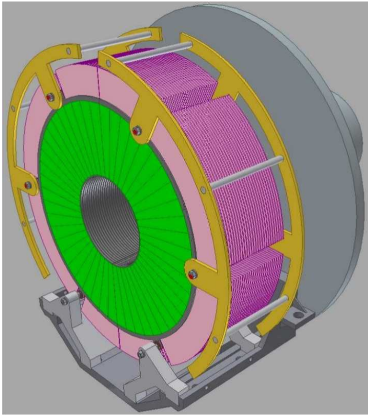
$$L = \frac{N_{Bh}(E_{1,2}^{lab}, \Omega_{1,2}^{lab})}{\sigma_{Bh}(E_{1,2}^{CM}, \Omega_{1,2}^{CM})}$$

$E_{1,2}$ – Energies of the final particles
$\Omega_{1,2}$ – Angles of the final particles

Luminosity precision depends critically on precise application of the event-selection criteria

The luminosity calorimeter

- Twin Si-W sampling calorimeters
- 30/40 layers (ILC/CLIC)
- At ca. 2.5 m from the IP, centered around the outgoing beam
- Segmented in r, ϕ
- Molière radius 11 mm
- Precise reconstruction of the 4-momenta of the showers
- Fiducial volume in the angular range 41–67 mrad (ILC) or 43–80 mrad (CLIC)

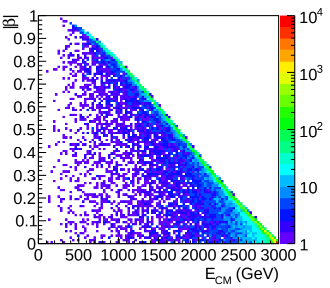


LumiCal sketch

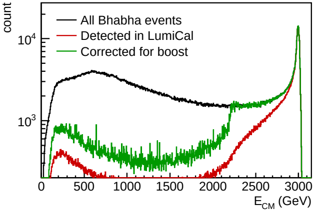
Beam-beam effects

- Average beamstrahlung parameter $\langle \Upsilon \rangle \approx \frac{5}{6} \frac{N r_e^2 \gamma}{\alpha \sigma_z (\sigma_x + \sigma_y)}$ [1]
- Average radiated energy $\Delta E \propto \Upsilon^2 \sigma_z$ [2]
- Beamstrahlung is random
  - Asymmetric energy loss
  - Boost of the CM frame
  - Acollinearity of the final particles
- Bhabha counting loss $\mathcal{O}(10\%)$ in the upper 20% of the spectrum [3]
- Boost can be calculated from the final particle angles [4]:
  - **Event-by-event correction**
  - Uncertainty after correction below 10^{-3}

[1] **Yokoya and Chen, KEK Preprint 91-2**
[2] **D. Schulte, PhD Thesis, Uni Hamburg, 1996**
[3] **C. Rimbault et al., JINST 2 (2007), P09001**
[4] **S. Lukic et al., JINST 8 (2013), P05008**



Correlation of the CM energy with the boost of the CM frame after Beamstrahlung



CM energy spectrum of Bhabha events compared to events detected in LumiCal

Some other systematic effects

LumiCal positioning

- Positioning requirements to achieve permille luminosity precision :
    - Inner diameter of the LumiCal must be known to better than $40\mu m$
    - Relative radial offset w.r.t the IP precision several 100 μm
    - Longitudinal distance between the halves must be known to 1 mm
- Laser alignment system under development at IFJ PAN, Cracow (see talk by B. Schumm in the MDI session at 4pm today)

Intrinsic reconstruction uncertainties

- Polar angle: $\Delta\theta = 3.2 \times 10^{-3} mrad; \quad \sigma_\theta = 2.2 \times 10^{-2} mrad$
- Energy: $\frac{\sigma_E}{E} = \frac{0.21}{\sqrt{E/GeV}}$

Backgrounds

- Dominant type: $e^+e^- \rightarrow e^+e^- f\bar{f}$
- Background-to-signal cross-section ratio of the order 10^{-3}
- Theoretical calculations for the correction as yet unavailable. Precision at LEP: 20% of the full-size background contribution

Current calculation of the total uncertainty at ILC

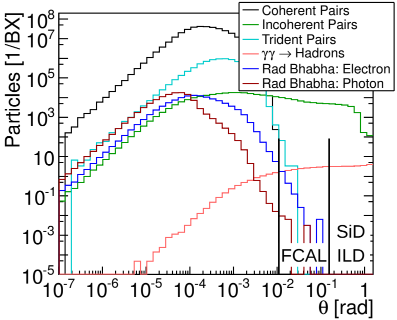
Source of uncertainty	500 GeV (10^{-3})	1 TeV (10^{-3})
Bhabha cross section	0.54	0.54
Polar-angle resolution	0.16	0.16
Polar-angle bias	0.16	0.16
IP lateral position	0.1	0.1
IP longitudinal position	0.1	0.1
Energy resolution	0.1	0.1
Energy scale	1	1
Beam polarization	0.19	0.19
Correction of angular losses due to the boost of the CM frame	0.4	0.7
ISR deconvolution	0.4	0.8
EMD correction	0.5	0.2
Physics background (uncorrected)	2.2	0.8
Total	2.6	1.8

H. Abramowicz et al., JINST 5 (2010), P12002
I. Božović-Jelisavčić et al., JINST 8 (2013), P08012
S. Jadach, hep-ph/0306083

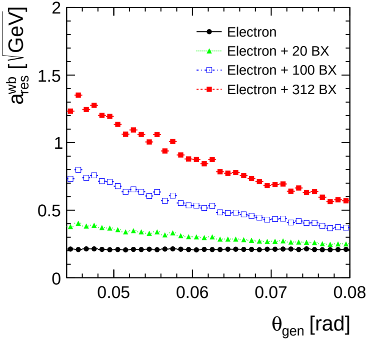
Low-angle particle identification

Beam-induced backgrounds

- High energy doses, particularly at lower angles
  - Lower-energy particles buried in the beam-induced background
  - Energy measurement affected by the fluctuation of the background



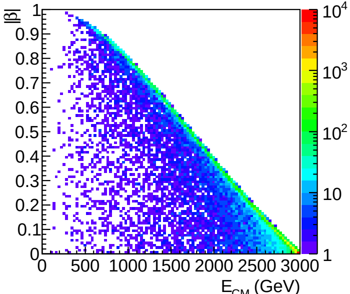
Angular distribution of beam-induced backgrounds at 3 TeV CLIC (Dannheim and Sailer, LCD-Note-2011-021) Angular ranges of FCAL and main detector are indicated



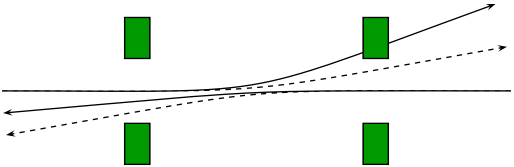
Effect of background depositions on electron energy resolution in LumiCal (R. Schwarz, FCAL workshop Nov 2012, CERN)

Bhabha rate with the 2D luminosity spectrum $f^*(\sqrt{s},\beta)$

Because of the boost of the CM of Bhabha events, there is a dramatic increase of the one-side-hit probability in the FCAL.



High energy loss correlates with high boost



Boost of the outgoing angles of a Bhabha event

	1.4 TeV CLIC	3 TeV CLIC
$\sigma_{Bh}(s)$ (nb)	2.3	0.51
$\sigma_{Bh,eff}(tag, f^*(\sqrt{s},\beta))$ (nb)	> 5	> 10
$p(n_{hit} \geq 1; 20BX; s)$	9%	4%
$p(tag; 20BX; f^*(\sqrt{s},\beta))$	$> 30\%$	$> 30\%$

Angular cut: 15 mrad $\leq \theta \leq$ 140 mrad

Reduction of coincident Bhabha rate by cuts

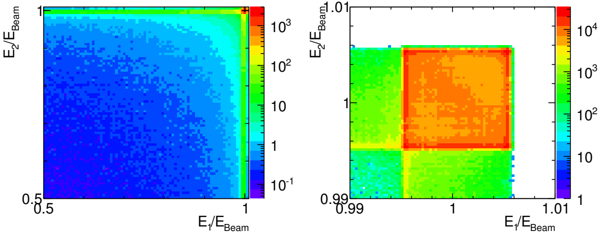
- Introduce additional tagging cuts:
- Example (from the $h \to \mu\mu$ analysis at 1.4 TeV): $\theta > 30 mrad$, $E > 200 GeV$
  - E cut well above sensitivity limit
  - Probability to tag a Bhabha event in 20 BX at 1.4 TeV: $p_{Bh} \approx 7\%$
- Work in progress:
  - Realistic (and fast) simulation of very-forward particle tagging under development (CERN, Vinča Belgrade)
  - Bhabha event generator (for low- and wide-angle Bhabha events, backgrounds etc.) under development (Belarusian state University)

Conclusions

- **LumiCal**
  - Luminosity precision in the 10^{-3} range near the peak of the luminosity spectrum
  - Challenges:
    - Precise calculation of the background contribution
    - Measurement of the tail of the luminosity spectrum (large acollinearities → vulnerable to backgrounds; must measure at large angles – see A. Sailer and S. Poss, LCD-Note-2013-008 (2013))
- **BeamCal**
  - Essential for fast luminosity monitoring, beam-parameter control, as well as electron tagging
  - Challenges: Intense backgrounds, high radiation doses, fast readout
- **Particle tagging** (BeamCal + LumiCal + ECAL below 8°)
  - Available information: particle energy, angle and rough distinction of type
  - Beam-induced background makes reconstruction of particles below certain energy difficult, especially at low angles (BeamCal)
  - Coincident Bhabha events impose energy and angular cuts

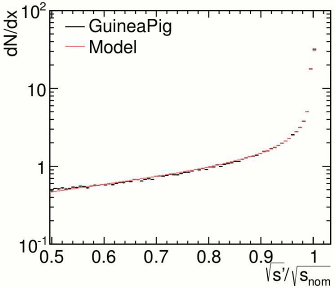
Backup slides

Luminosity spectrum from wide-angle Bhabha



2D luminosity spectrum

- Use wide-angle Bhabha events
- Fit of a luminosity spectrum model as a function of three observables: Acollinearity and the energies of both final electrons
- Data from the entire detector is used
- Excellent reconstruction of the spectrum shape
- Percent-level precision down to $0.5\sqrt{s_{nom}}$



Reconstructed spectrum

A. Sailer and S. Poss, LCD-Note-2013-008

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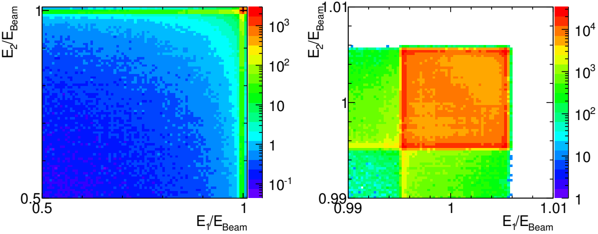

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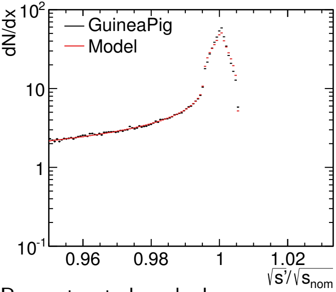

Reconstructed peak shape

A. Sailer and S. Poss, LCD-Note-2013-008