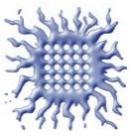
Luminosity measurement at 500 GeV and 1 TeV ILC

I. Božović-Jelisavčić[1], S. Lukić[1], M. Pandurović[1], I. Smiljanić[1]

and the FCAL Collaboration

[1]Vinča Institute of Nuclear Sciences, University of Belgrade, Serbia

HEP GROUP VINCA



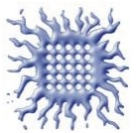
FCAL Collaboration
High precision design

Luminosity measurement at ILC

- Measurement using the Bhabha scattering as the gauge process

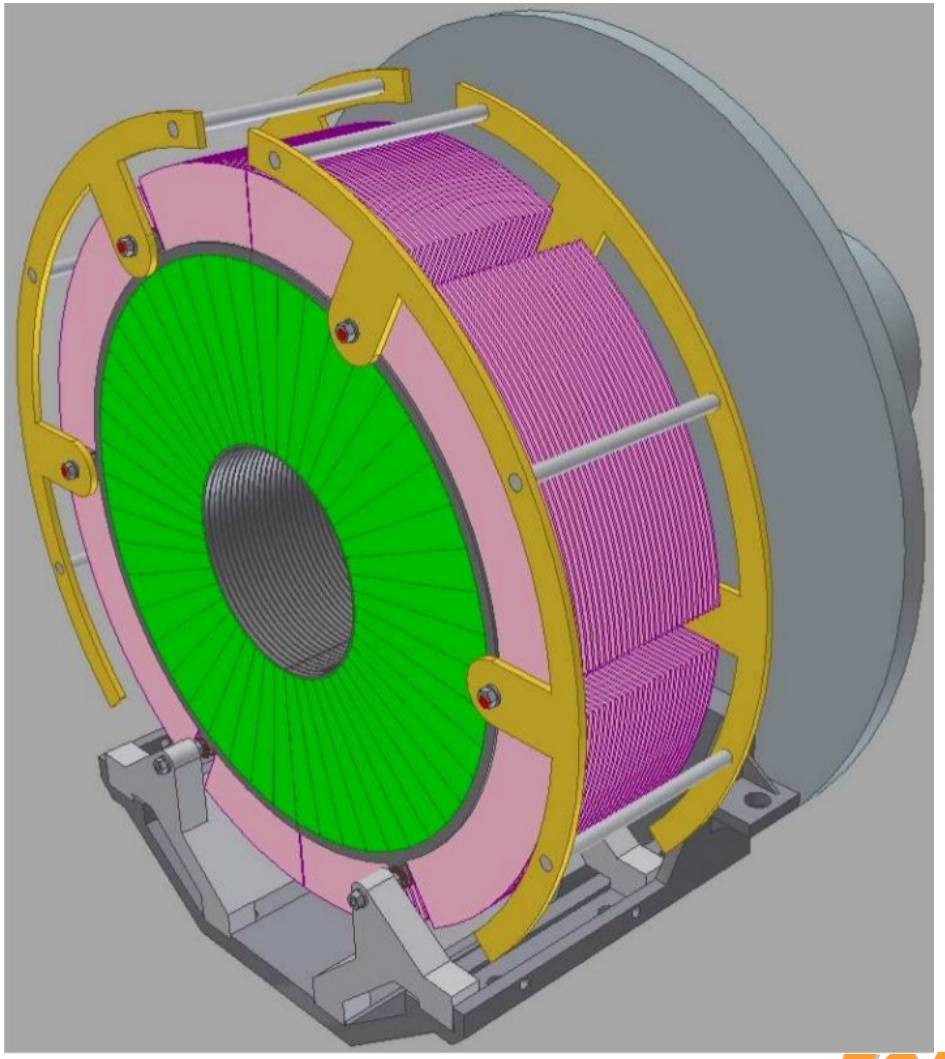
$$L = \frac{N_{Bh}\left(\Xi\left(E_{1,2}^{lab}, \Omega_{1,2}^{lab}\right)\right)}{\sigma_{Bh}\left(Z\left(E_{1,2}^{CM}, \Omega_{1,2}^{CM}\right)\right)}$$

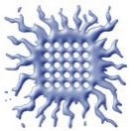
- Precision ~0.6 permille at LEP
- A number of systematic effects limiting precision, *at future colliders notably the beam-beam effects*
  - *Luminosity >2 orders of magnitude higher than @LEP*
  - *Higher energy*



Luminosity Calorimeter

- Two W-semiconductor sandwich-calorimeters (30 layers)
- One at each side of the IP, at 2.5 m
- Segmentation in r, φ
- Molière radius ~1cm
- 4-vector reconstruction
- Fiducial volume in the angular range 41-67 mrad (2.3-3.8°)

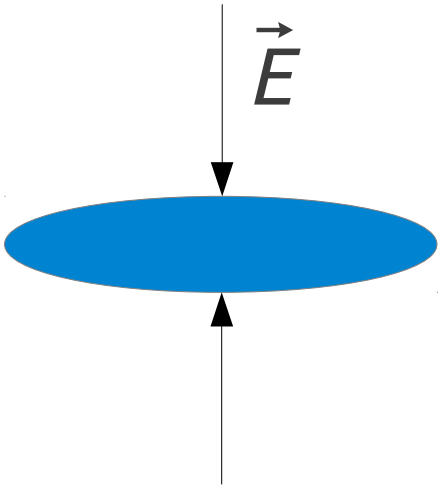




Collaboration
High precision design

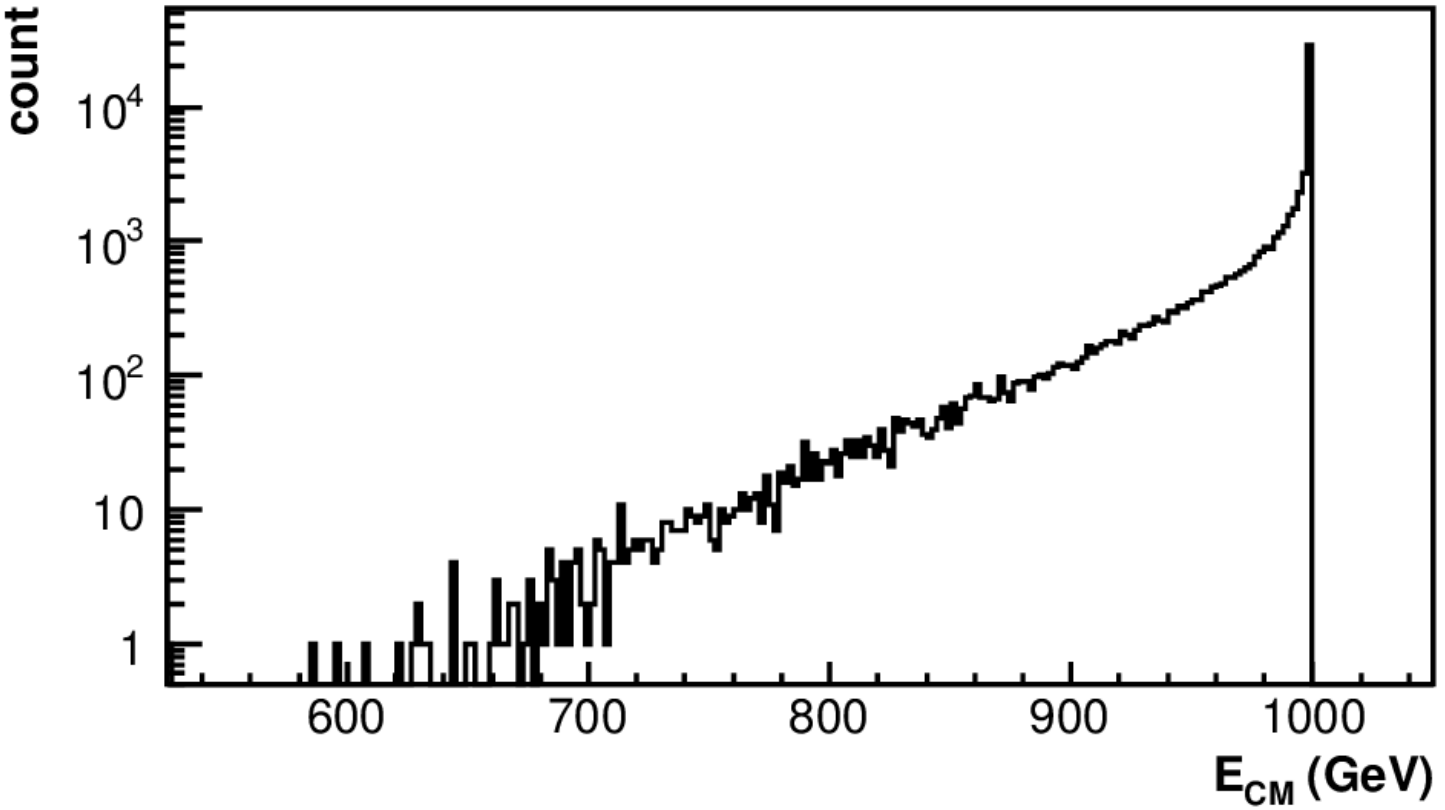
Beam-beam effects

- EM interaction at bunch crossing
  - $\gamma \sim 10^6$
  - “Pinch” effect – strong focusing of the bunches
  - *Beamstrahlung* (before collision)
    - **Energy loss**
    - Shift of CM in the phase space – **Counting loss**
  - *EM deflection* of the final charged particles – minor additional counting loss



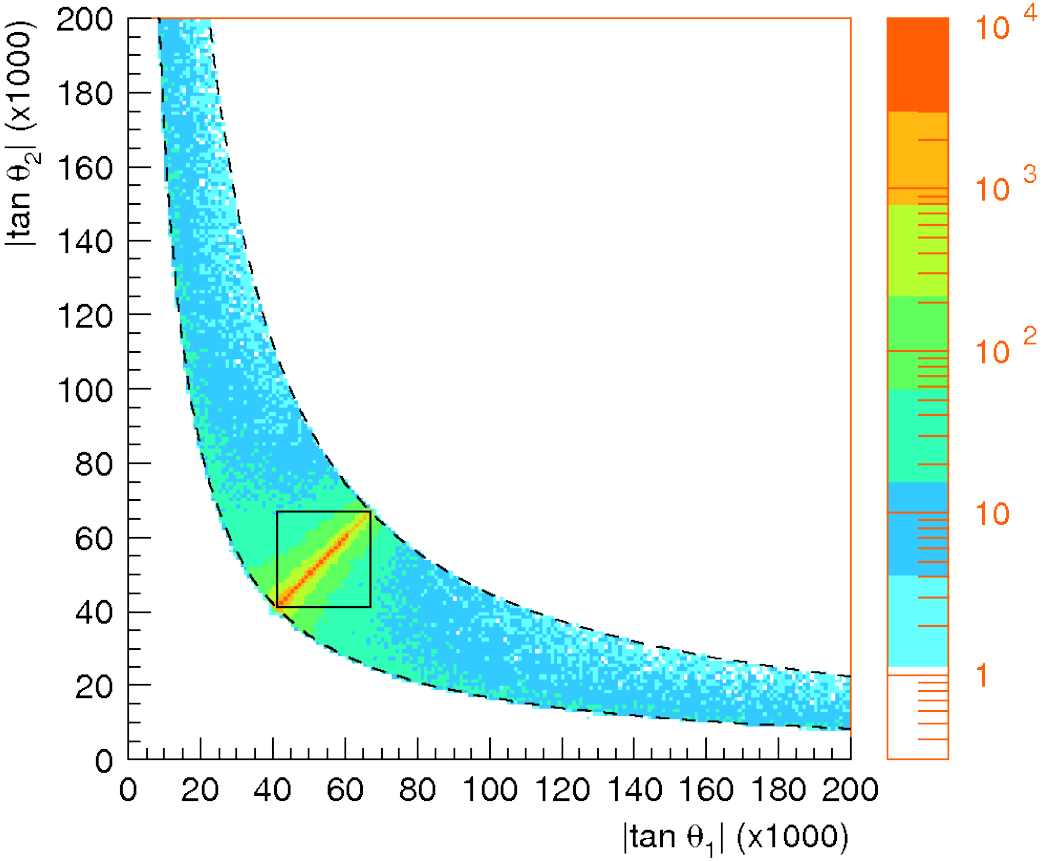
Energy loss

- Luminosity spectrum at 1TeV ILC
  (Guinea-Pig, beam parameters from ILC TPR 2011)



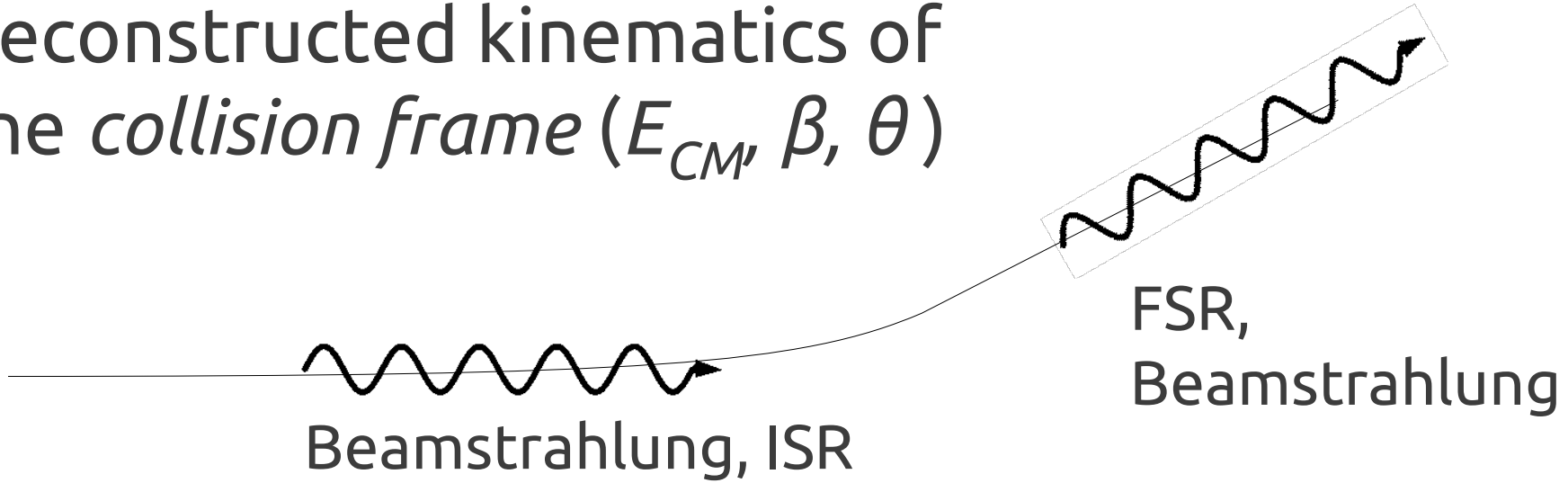
Angular loss

- Final angles of the electron vs. the positron (Simulation of Bhabha events using Gunea-Pig and BHLUMI)
- Final angles show Lorentz boost along the beam axis

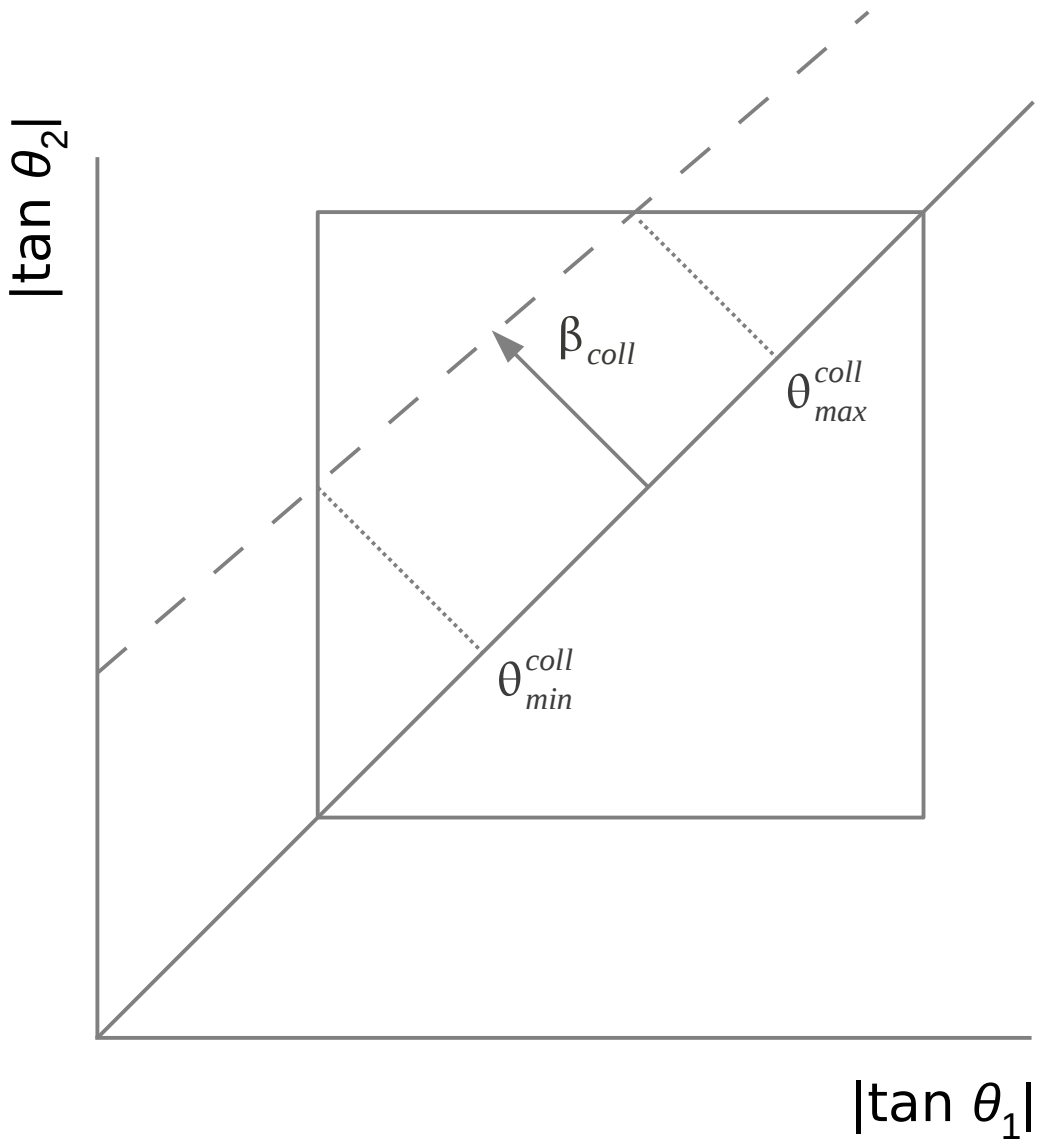


Bhabha scattering and the beam-beam effects

- ISR and Beamstrahlung *before collision* escape detection
- FSR and Beamstrahlung of the final particles summed with electrons in the calorimeter
- Reconstructed kinematics of the *collision frame* (E_{CM}, β, θ)



Boost of the polar angles



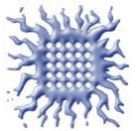
- Among events with a given β_{coll} (dashed line), the angular acceptance loss can be analytically calculated

- Correct by the weighting factor

$$w(\beta_{coll}) = \frac{\int_{\theta_{min}}^{\theta_{max}} \frac{d\sigma}{d\theta} d\theta}{\int_{\theta^{coll}_{min}}^{\theta^{coll}_{max}} \frac{d\sigma}{d\theta} d\theta}$$

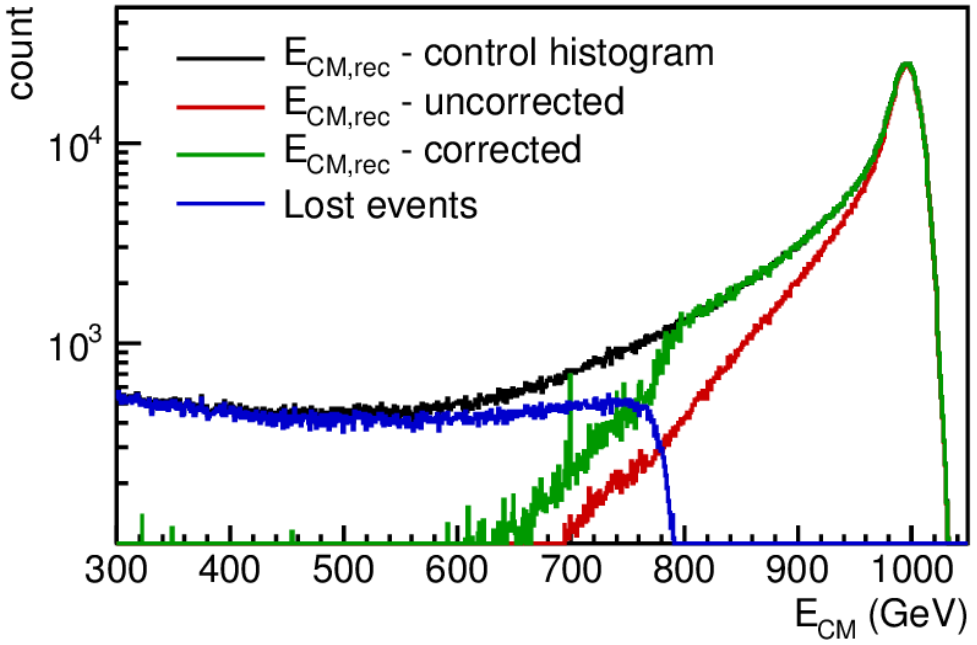
Test by simulation

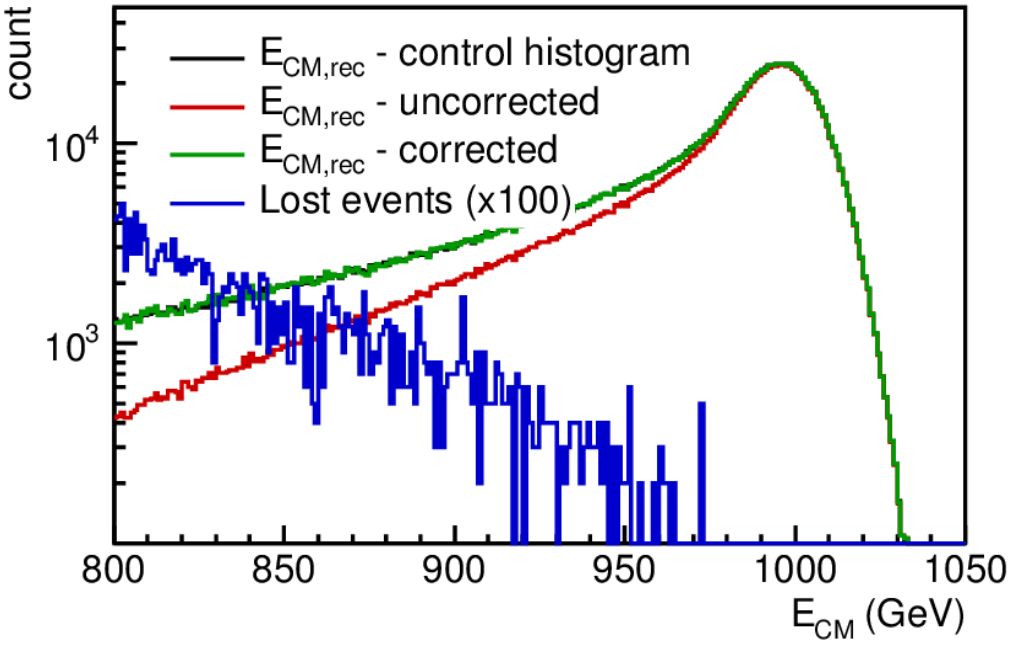
- Bhabha events
  - Initial 4-momenta generated by Guinea-Pig
  - Final 4-momenta generated by BHLUMI at a fixed energy, then scaled and Lorentz-transformed into the Guinea-Pig frame
  - Tracking of final electrons in Gunea-Pig
- Interaction with the detector (approximation)
  - Summation of all 4-momenta within 1 Molière radius of the most energetic shower inside FV
  - E and θ smearing by addition of random Gaussian fluctuation matching detector resolution
- Beam-parameter variations
  - q, $\sigma_{x,y,z}$ variation by ± 10% ± 20%
  - Beam misalignment in x and y by up to 1 σ beam size
  - Total 25 simulations at 500 GeV and 25 simulations at 1 TeV



Results of the angular-loss correction

- Guinea-Pig + BHLUMI
- CM energies of Bhabha events
  (after emission of ISR, LumiCal energy response included)

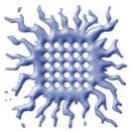




Results of the angular-loss correction

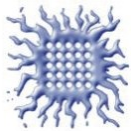
- To quantify the agreement, the integral count in the top 20% of CM energy after correction was compared to the control histogram:
- Results for 25 cases of beam-parameter variation agree within statistical uncertainties
- Fractional residual bias averaged over 25 sims

	500 GeV	1 TeV
Before correction	12.8 %	14.0 %
After β_{coll} correction	-1.1×10^{-3}	-0.7×10^{-3}
Fraction $\beta_{coll} > \beta_{max}$	1.5×10^{-3}	1.4×10^{-3}
Corrected	$+0.4 \times 10^{-3}$	$+0.7 \times 10^{-3}$



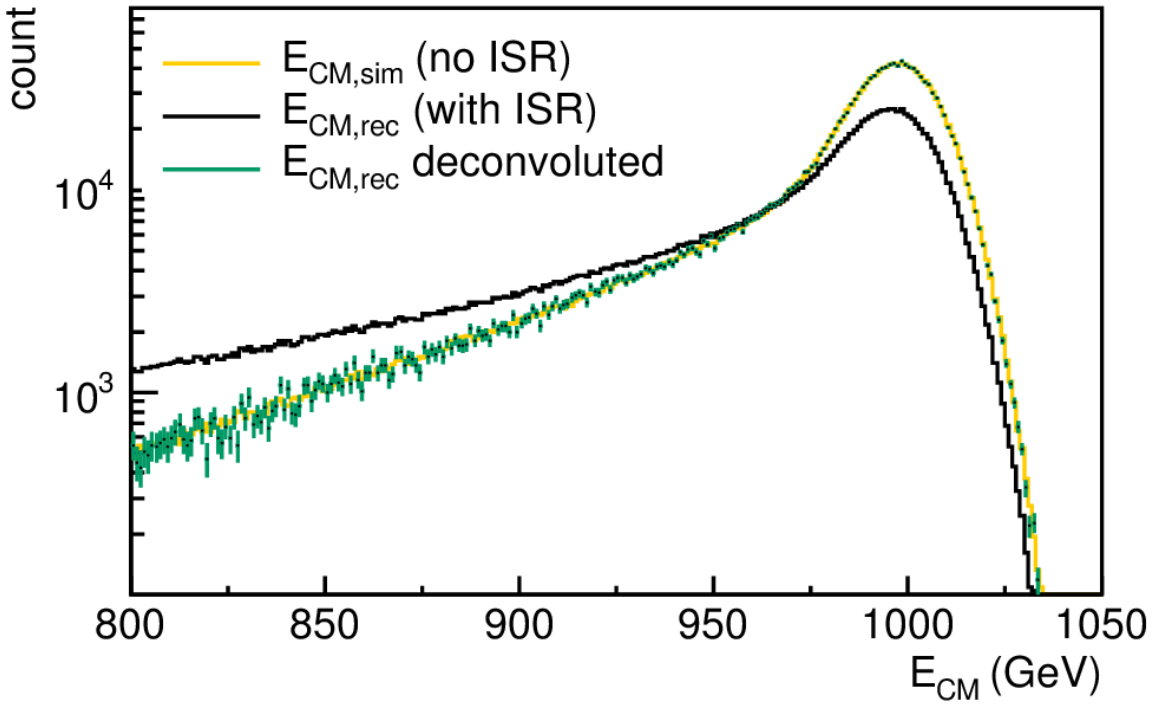
Systematic effects

- Off-axis ISR (the “lost” events)
- Most energetic shower occasionally not containing the final electron
- Simplified expression for $d\sigma/d\theta$ $(\sim\theta^{-3})$
- Assumption of clean separation of ISR from FSR



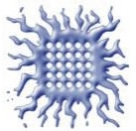
ISR deconvolution

- Required as a basis for the cross-section calculation
- Useful for the reconstruction of the luminosity spectrum in the upper 20% of *E*
- Fractional residual bias:
  @500GeV: $+0.4 \times 10^{-3}$
  @1TeV: $+0.8 \times 10^{-3}$



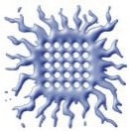
Requirements on the cross-section calculation

- For the integral luminosity in the upper 20% of energy, the Bhabha cross section should be calculated as follows:
  - Initial CM energy sampled from the normalized ISR-deconvoluted spectrum
  - Bhabha scattering angle within the limiting angles (θ_{min}, θ_{max}) of the FV
  - Lab-frame final angles unbounded
  - Final CM energy > $0.8E_0$
- Accuracy unknown, but there is no apparent reason why it should be worse than 10^{-3}



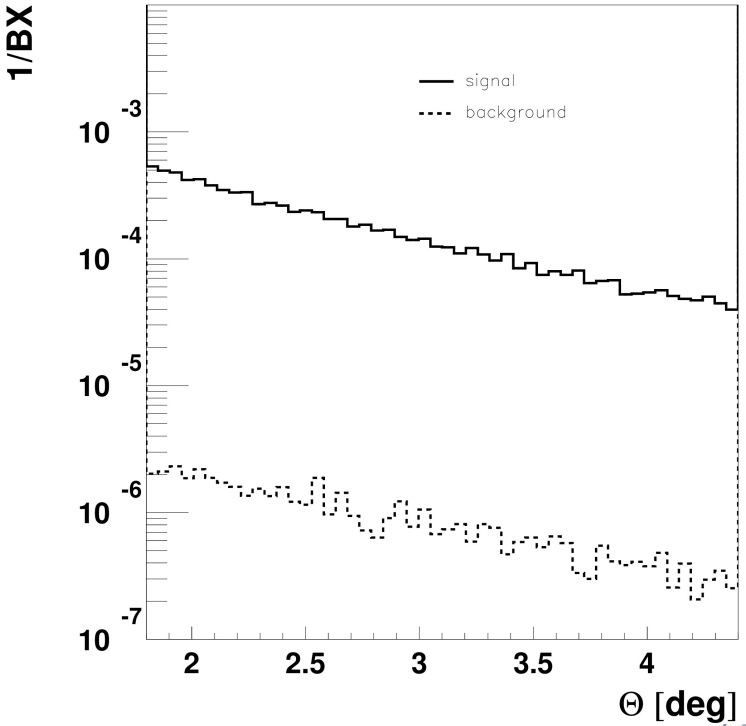
EMD counting loss

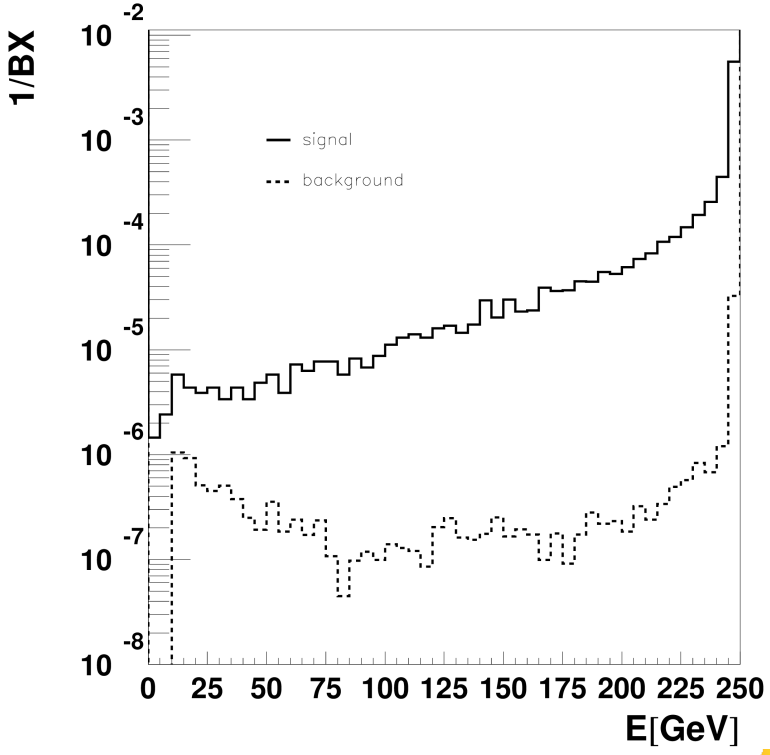
- Deflection of final electrons in the EM field of the opposing bunch *after leaving the bunch profile*
- Counting bias -2.4×10^{-3} @500 GeV, -1.1×10^{-3} @1 TeV
- Correlates with the bunch charge and the σ_z size.
- Little to no sensitivity to the bunch *x*, *y* profile
- So far no beam-diagnostic quantity that would allow clean determination of the EMD without correlation to other beam parameters
- MC correction with undetected beam-parameter variations
  → uncertainty 0.5×10^{-3} @500 GeV, 0.2×10^{-3} @1 TeV



Physics background

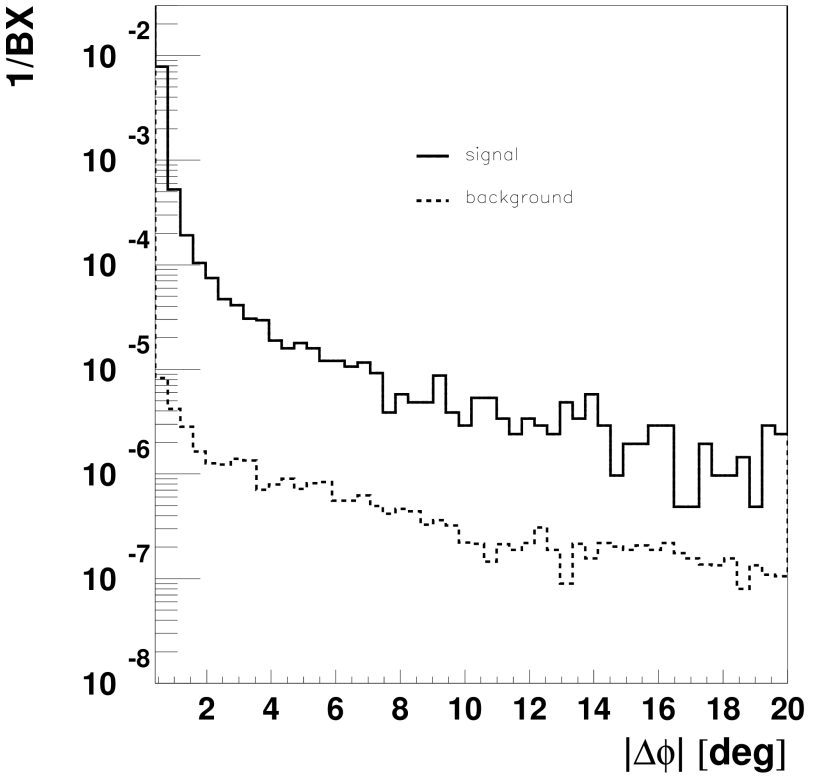
- Four-fermion processes $e^- e^+ \to e^- e^+ f \bar{f}$
- Final electrons at small angles with a large fraction of energy
- Simulation (generator level) BHLUMI V4.04 and WHIZARD V1.4
- Count relative to Bhabha: 6×10^{-3} @500GeV
  (in the entire spectrum) 2.2×10^{-3} @1TeV





Physics background

- Reduction of background by selection criteria
  - To be equally applicable to the experimental count and the cross-section calculation, selection cuts must be invariant w.r.t the longitudinal boost
- E_{CM} cut removes the low-energy background peak, and the acollinear events
- Acoplanarity cut $|\Delta\varphi| < 5°$
- Background fraction after selection (including hadronization):
  @500GeV: $+2.2 \times 10^{-3}$
  @1TeV: $+0.8 \times 10^{-3}$
- Signal efficiency 94%



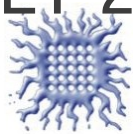
Further systematic uncertainties (from other studies)

- Bhabha cross-section unc. – **??** (at LEP [1] 5.4×10^{-4})
- LumiCal polar angle resolution [2] – 1.6×10^{-4}
- Polar angle reconstruction bias [2] – 1.6×10^{-4}
- IP lateral position uncertainty [3] - 1×10^{-4}
- Energy resolution effect [2] – 1×10^{-4}
- Energy scale [2] – 1×10^{-3}
- Beam polarization [2] – 1.9×10^{-4}

1) A. Arbuzov et al., Phys. Lett. B 383 (1996) 238

2) H. Abramowitz et al., JINST 5 (2010) P12002

3) A. Stahl, LC note LC-DET-2005-004, DESY, 2005



Summary of systematic uncertainties

Effect	ΔL/L (500 GeV)	ΔL/L (1 TeV)
Bhabha cross section	5.4×10^{-4}	5.4×10^{-4}
LumiCal σ_θ	1.6×10^{-4}	1.6×10^{-4}
LumiCal $\Delta\theta$	1.6×10^{-4}	1.6×10^{-4}
IP lateral position	1×10^{-4}	1×10^{-4}
Energy resolution	1×10^{-4}	1×10^{-4}
Energy scale	1×10^{-3}	1×10^{-3}
Beam polarization	1.9×10^{-4}	1.9×10^{-4}
Beamstrahlung+ISR (sim-independent corr.)	-1.1×10^{-3}	-0.7×10^{-3}
Beamstrahlung+ISR (full correction)	$+0.4\times10^{-3}$	$+0.7\times10^{-3}$
EMD	0.5×10^{-3}	0.2×10^{-3}
Phys. background	2.2×10^{-3}	0.8×10^{-3}
Total	**2.6×10^{-3}**	**1.6×10^{-3}**