Physics background and beam-beam effects

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Collaboration
High precision design

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Outline

- Highlights from the method of luminosity measurement*
    - Correction of angular losses from beam-beam effects
    - Estimate and suppression of background at ILC
- Overview of the systematic uncertainties at ILC

* For details see:

S. Lukić et al., JINST 8 (2013) P05008

I. Božović-Jelisavčić et al., arXiv:1304.4082

Luminosity measurement

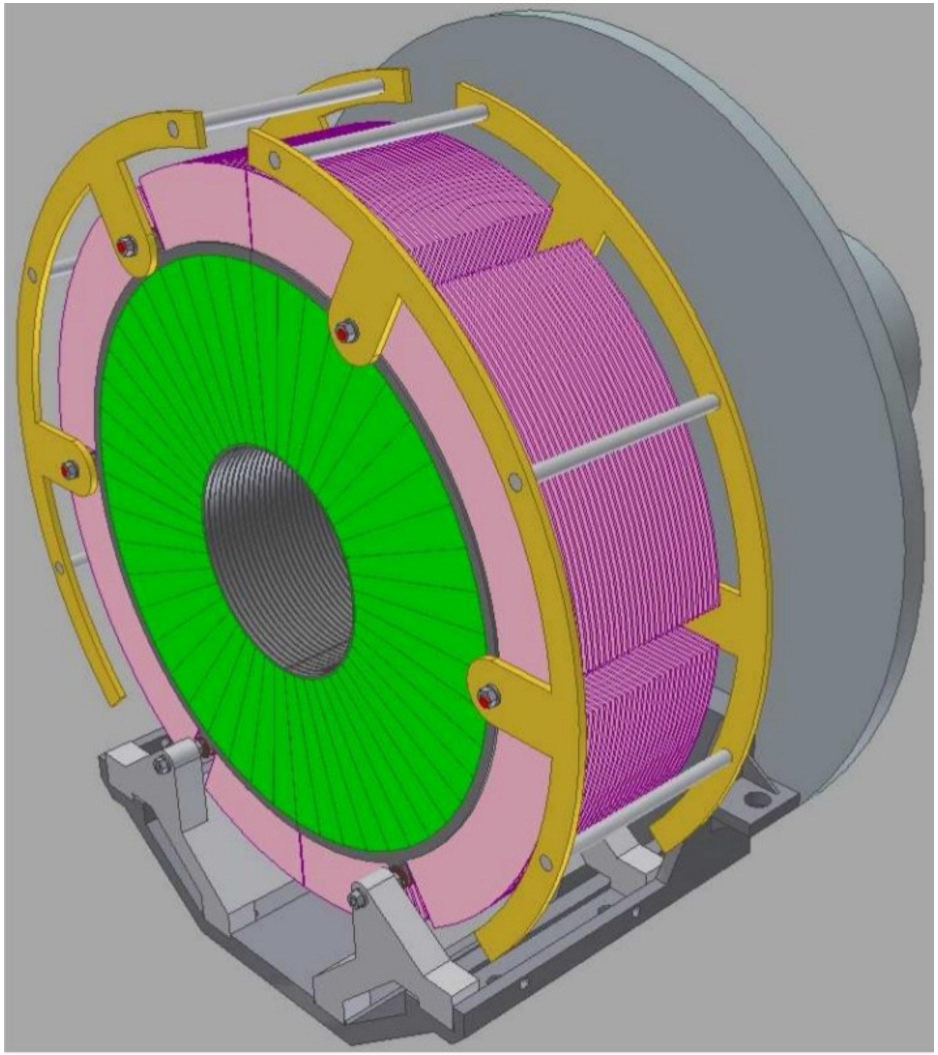
- Using the Bhabha scattering as the gauge process

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

- Precision ~0.6 permille at LEP
- A number of systematic effects limiting precision at future colliders
    - Beam-beam effects $\mathcal{O}(10\%)$
        - *Luminosity >2 orders of magnitude higher than @LEP*
        - *Higher energy*
    - Physics background

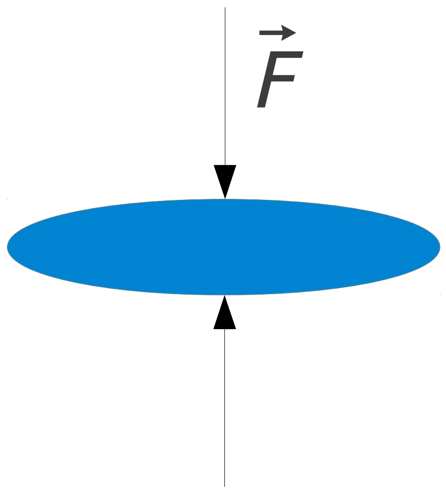
Luminosity Calorimeter

- 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-momentum reconst.
- Fiducial volume (FV) in the angular range 41-67 mrad (2.3-3.8°)



Beam-beam effects

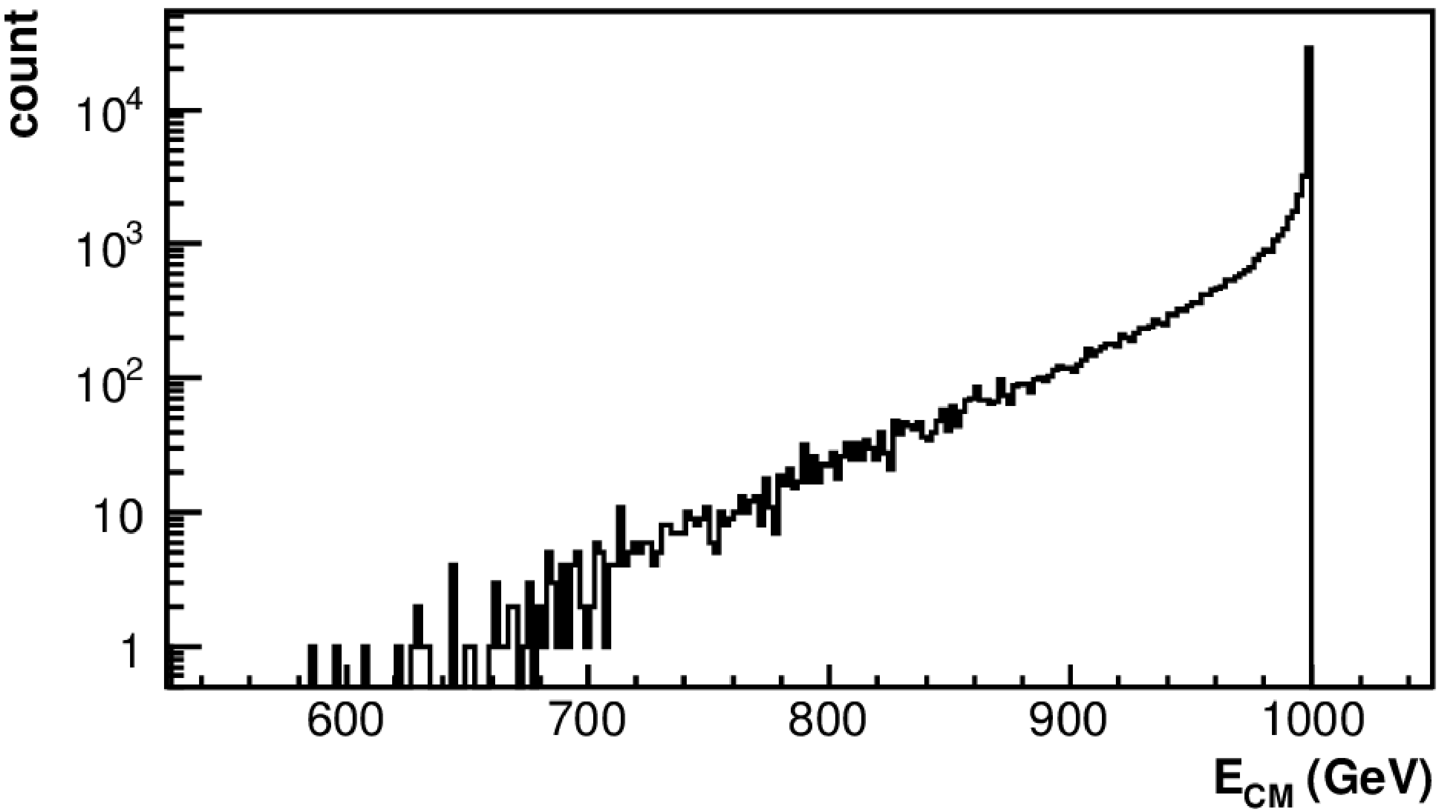
- EM interaction at bunch crossing
  - Lorentz factor $\gamma \sim 10^6$
  - "Pinch" effect – strong focusing of the bunches
  - *Beamstrahlung* (before collision)
    - **Energy loss**
    - Boost along the beam axis – **Counting loss**
  - *EM deflection* of the final charged particles – minor additional counting loss



K. Yokoya and P. Chen, in *Lecture Notes in Physics* vol. 400, pp. 415-445, Springer 1991

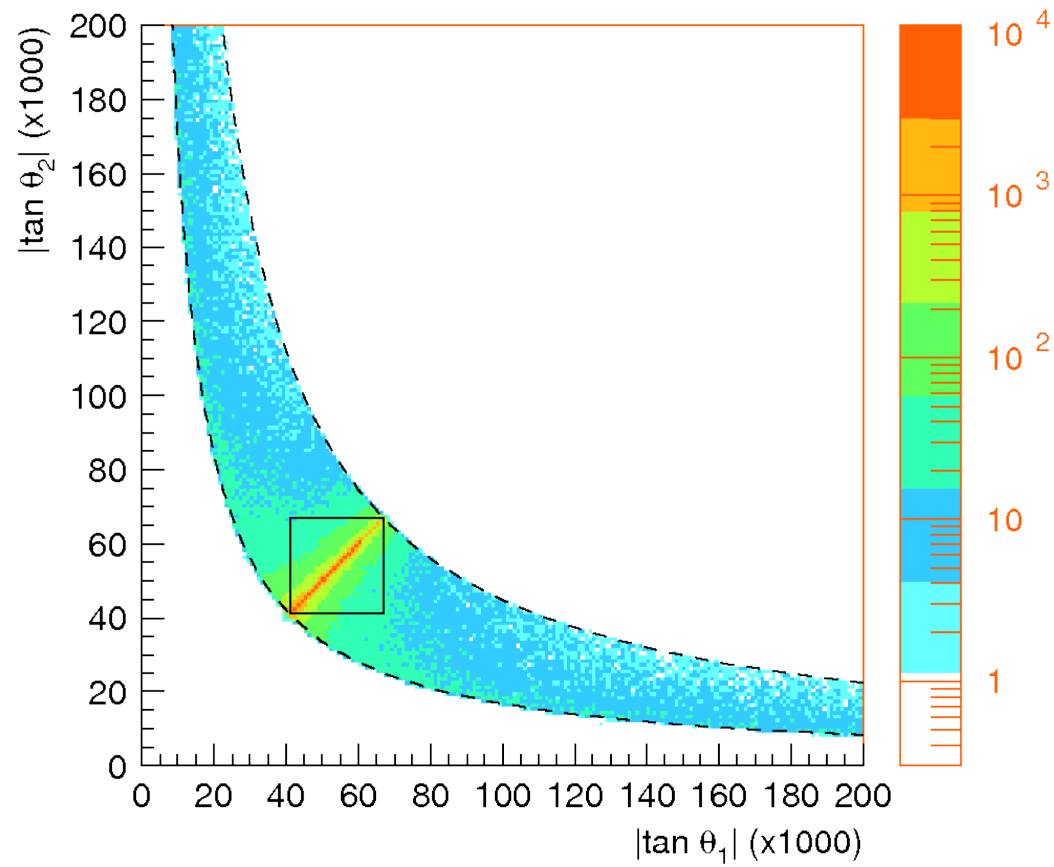
Energy loss

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



Angular loss

- Simulation of Bhabha events using Guinea-Pig and BHLUMI
- Final angles feature Lorentz boost along the beam axis



Correction of the angular loss

- Reconstruct the boost of the *collision frame* from the final angles

$$\beta_{coll} = \frac{\sin(\theta_1 + \theta_2)}{\sin\theta_1 + \sin\theta_2}$$

- For each detected event with the boost β_{coll} there are n events with the same boost for which:
  - The scattering angle satisfies $\theta_{coll} \in [\theta_{min,FV}, \theta_{max,FV}]$
  - One of the final electrons misses the FV because of the boost
- Event-by-event correction weight

$$w(\beta_{coll}) = 1 + n = \frac{\int_{\theta_{min}}^{\theta_{max}} \frac{d\sigma}{d\theta} d\theta}{\int_{\theta_{min}^{coll}}^{\theta_{max}^{coll}} \frac{d\sigma}{d\theta} d\theta}$$

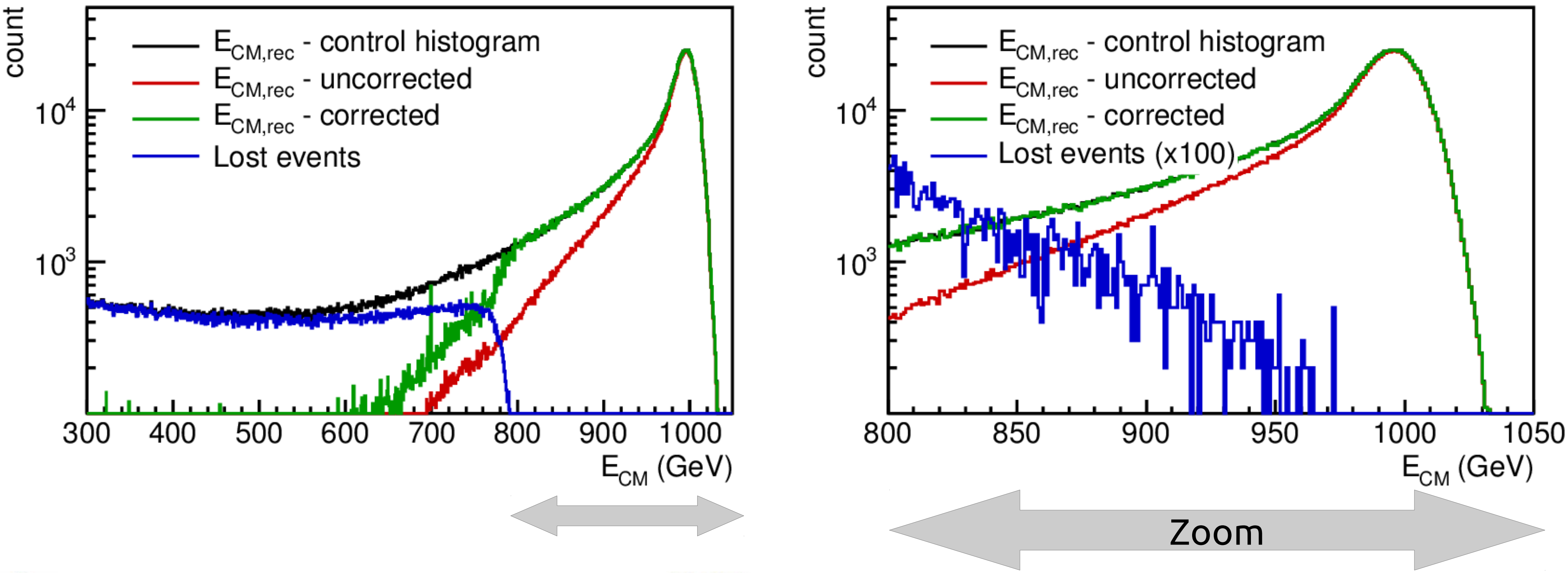
S. Lukić et al., JINST 8 (2013) P05008

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 Guinea-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

- Reconstructed CM energies of Bhabha events



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:
- Deviations in 25 cases of beam-parameter variation agree with zero within statistical uncertainties
- Fractional residual bias in table averaged over 25 simulations

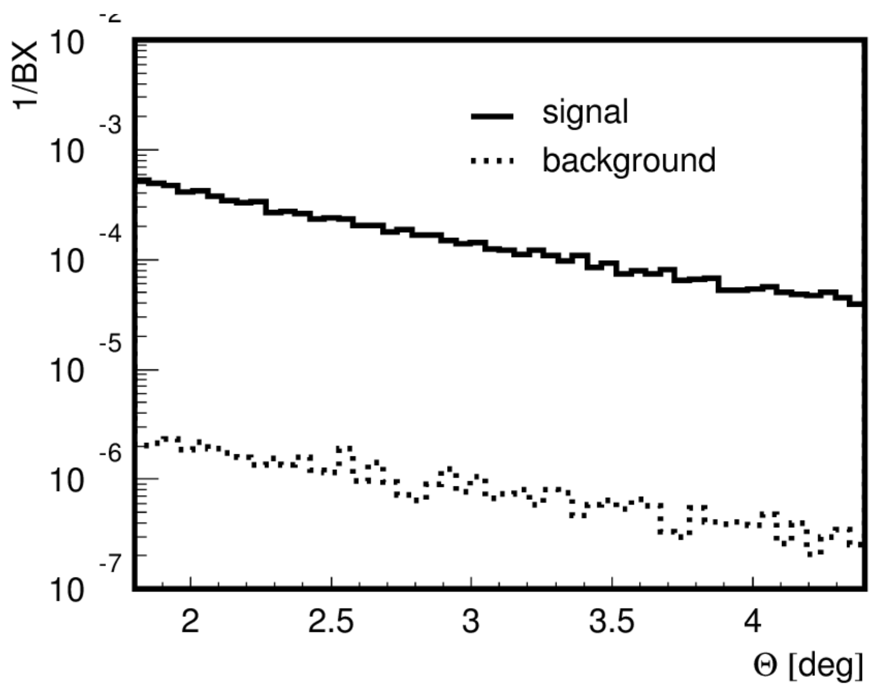
	500 GeV	1 TeV
Before correction	12.8 %	14.0 %
After β_{coll} correction	-1.1×10^{-3}	-0.7×10^{-3}
Fraction $\beta_{coll} > \beta_{max}$	1.5×10^{-3}	1.4×10^{-3}
Corrected	$+0.4 \times 10^{-3}$	$+0.7 \times 10^{-3}$

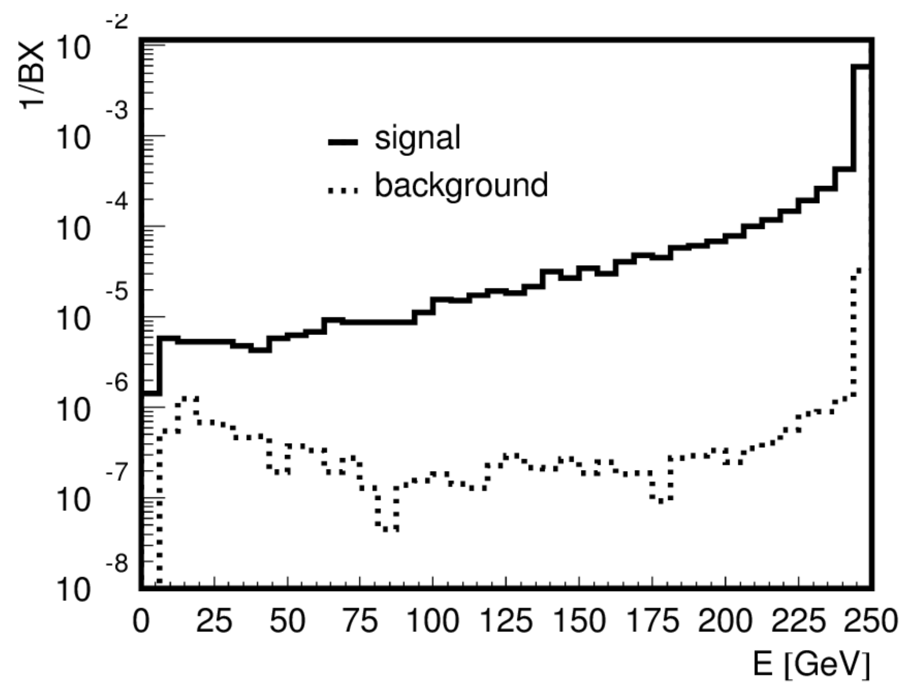
Systematics of the angular correction

- Assumption $\vec{\beta}_{coll} = \beta_{coll} \vec{e}_z$ (corrected)
- Assumption that the Most Energetic Shower contains the electron
- Approximate differential cross section
- Assumption of clean separation of ISR and FSR

Physics background

- Four-fermion processes $e^- e^+ \rightarrow e^- e^+ f \bar{f}$
  - Final electrons at small angles with a large fraction of energy
  - Count relative to Bhabha: 6×10^{-3} @500GeV
    (in the entire spectrum) 2.2×10^{-3} @1TeV





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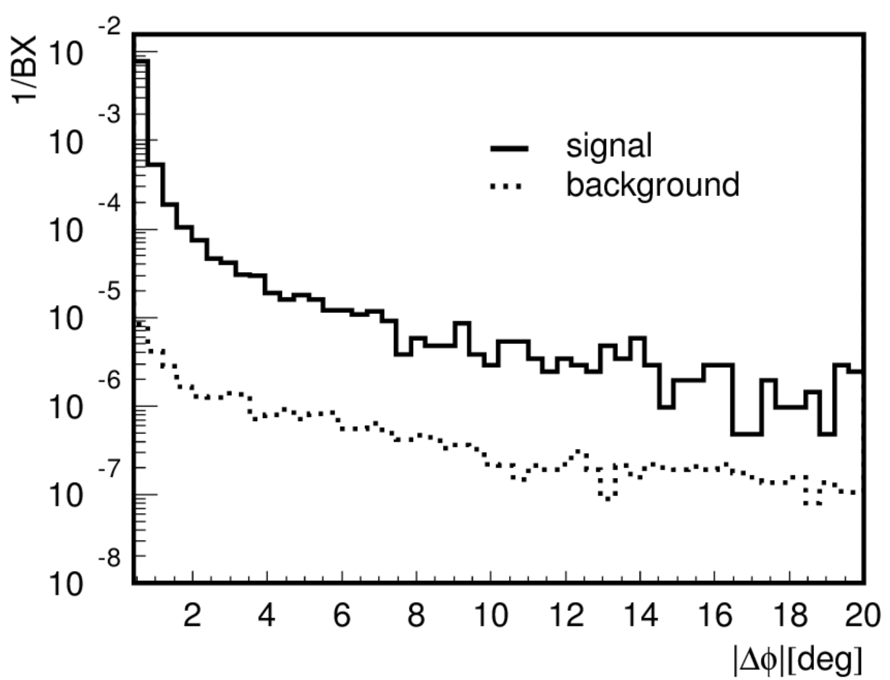
Physics background

- 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
- Acoplanarity cut $|\Delta\varphi| < 5°$
- Background fraction after selection:
  @500GeV: $+2.2\text{x}10^{-3}$
  @1TeV: $+0.8\text{x}10^{-3}$
- Signal efficiency 94%



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Further syst. 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. Abramowicz et al., JINST 5 (2010) P12002
3) A. Stahl, LC note LC-DET-2005-004, DESY, 2005

Summary of systematic uncertainties

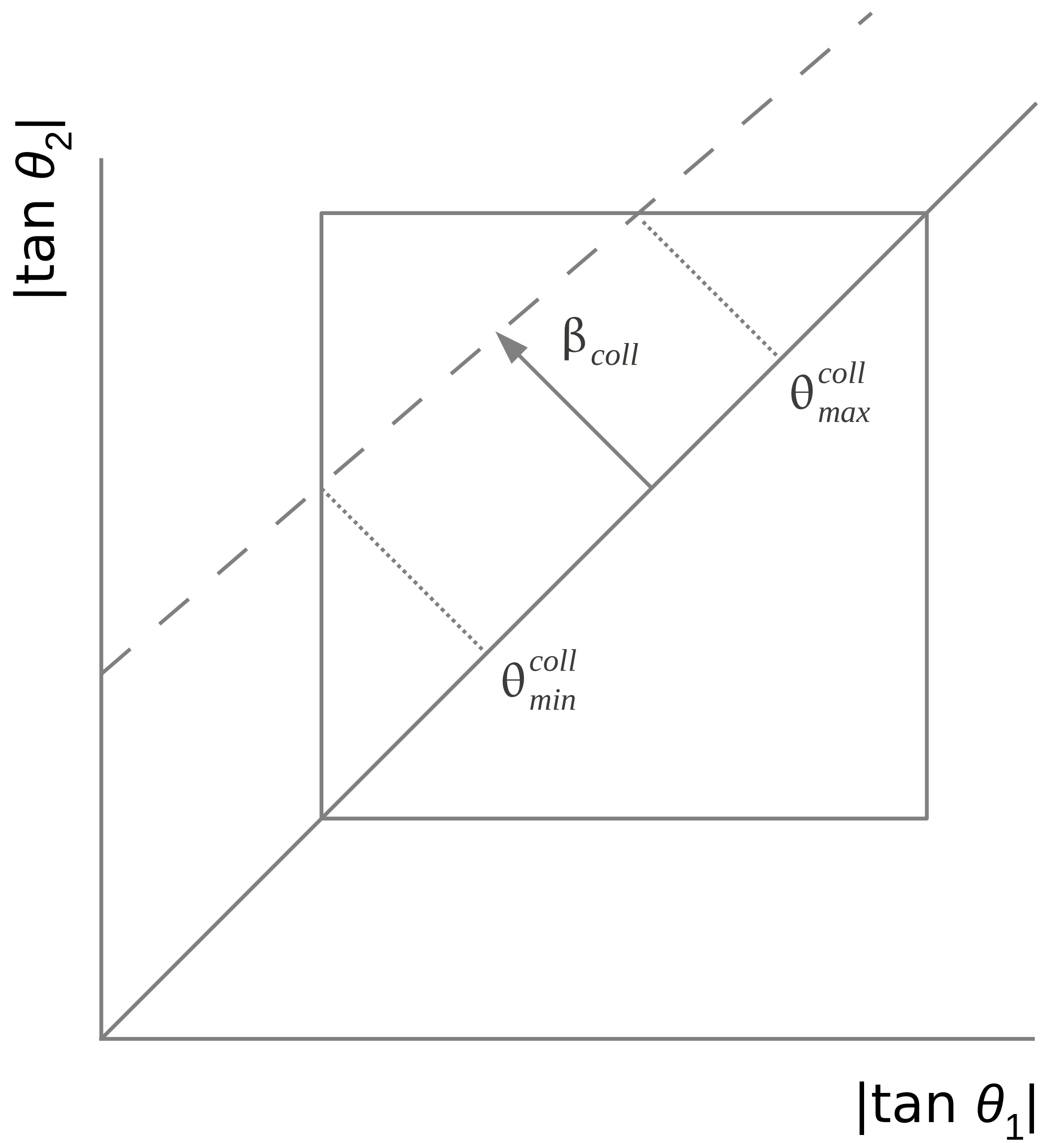
Effect	ΔL/L (500 GeV)	ΔL/L (1 TeV)
Bhabha cross section	5.4×10^{-4}	5.4×10^{-4}
LumiCal σ_θ	1.6×10^{-4}	1.6×10^{-4}
LumiCal $\Delta\theta$	1.6×10^{-4}	1.6×10^{-4}
IP lateral position	1×10^{-4}	1×10^{-4}
Energy resolution	1×10^{-4}	1×10^{-4}
Energy scale	1×10^{-3}	1×10^{-3}
Beam polarization	1.9×10^{-4}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

Conclusions

- At present, we have a method of measuring the luminosity with a precision in the low permille range –
  Good for most measurements !
- There are Physics programmes, notably the Giga-Z, requiring better precision –
  Ongoing work – precise estimate of the Physics background ...

Backup slides

Boost of the polar angles



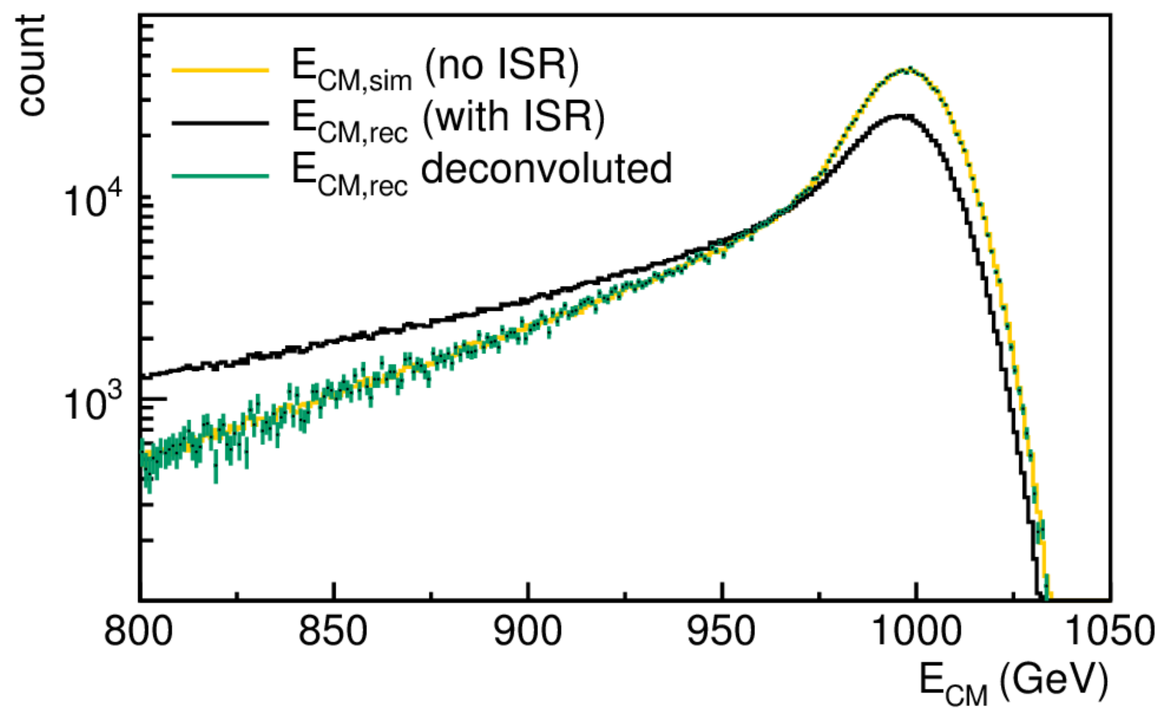
- Among events with a given β_{coll} (dashed line), the angular acceptance loss can be analytically calculated

- Correct by the weighting factor

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

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: $+0.4\times10^{-3}$
  @1TeV: $+0.8\times10^{-3}$



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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}