# Precise luminosity measurement at 3 TeV CLIC

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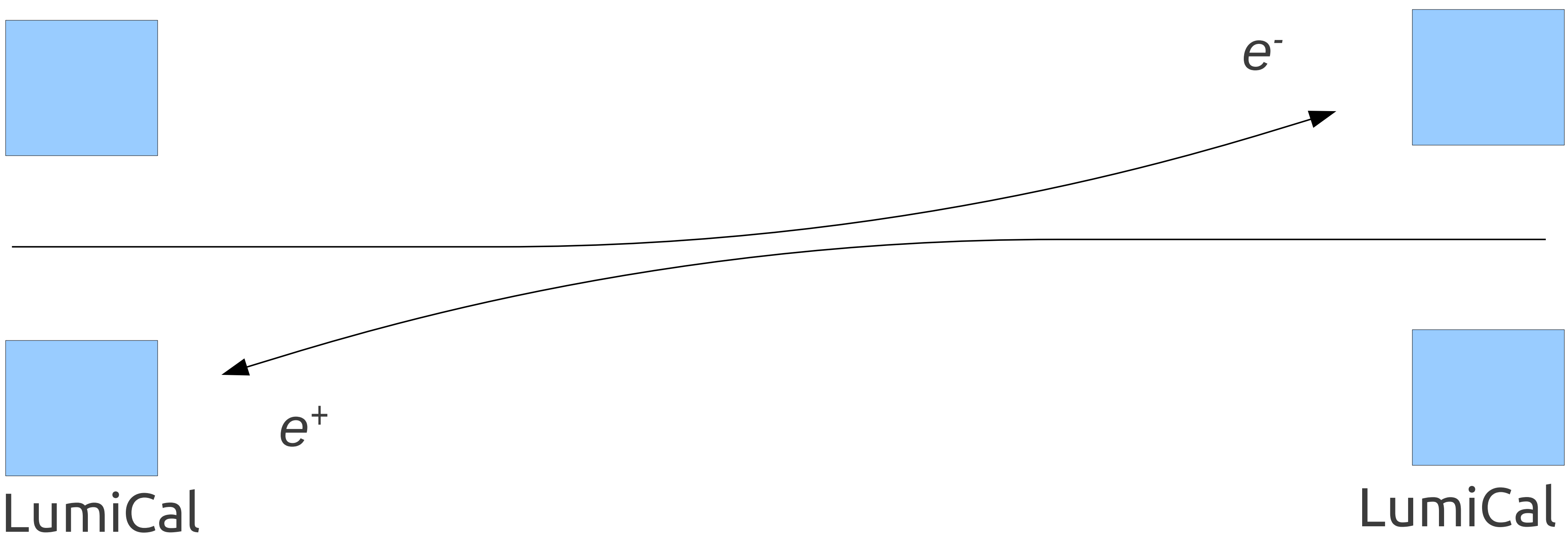
# Luminosity measurement

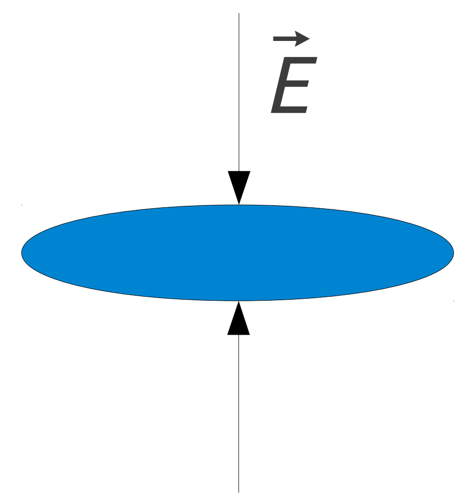
- Counting Bhabha pairs in coincidence
- Precision ~0.6 permille at LEP
- A number of systematic effects limiting precision, *at future colliders notably the beam-beam effects*
  - *Luminosity >2 orders of magnitude higher than @LEP*
  - *Higher energy*

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



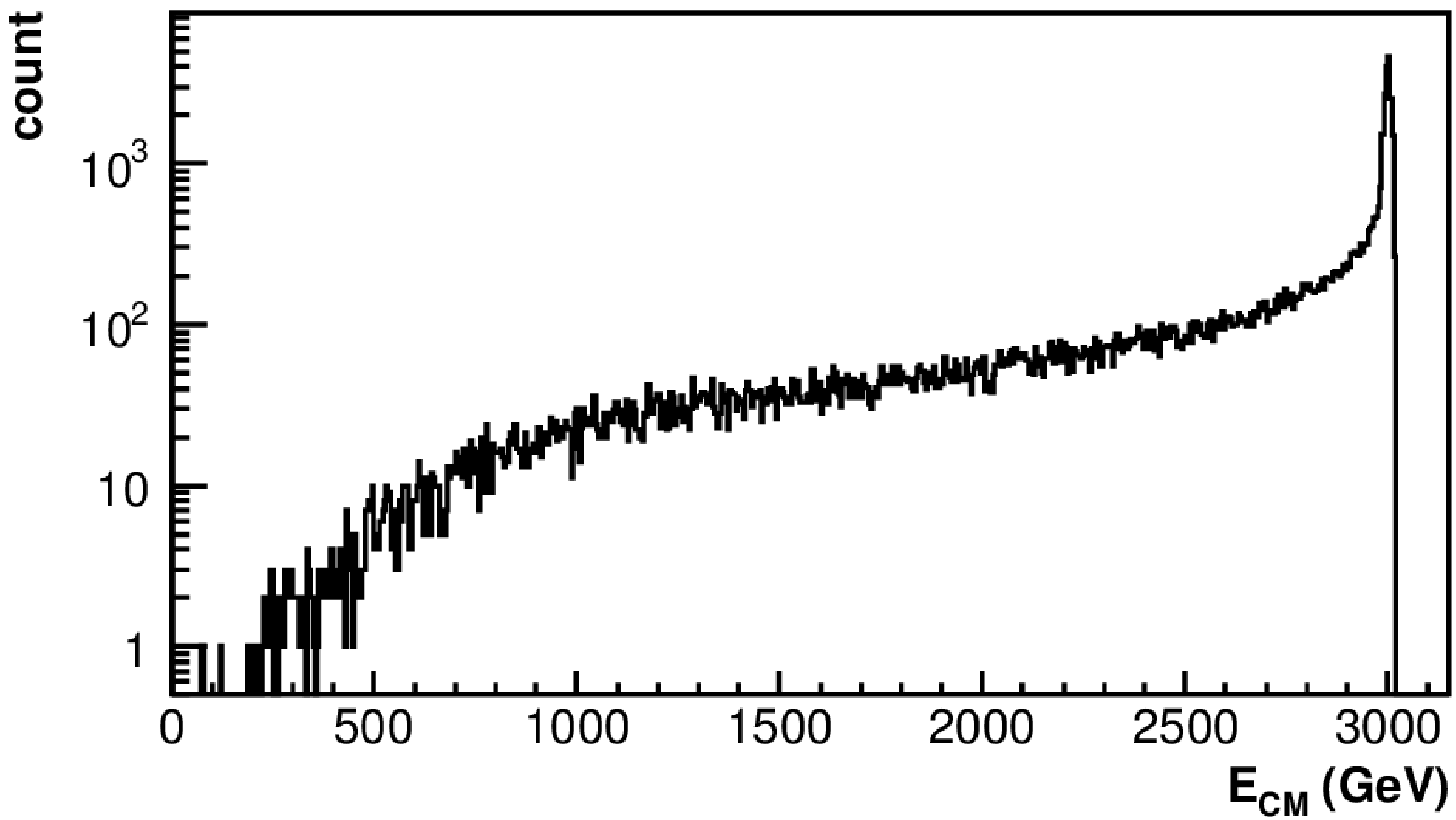
# Beam-beam effects

- EM interaction at bunch crossing
  - $\gamma \approx 6\text{x}10^6$
  - "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



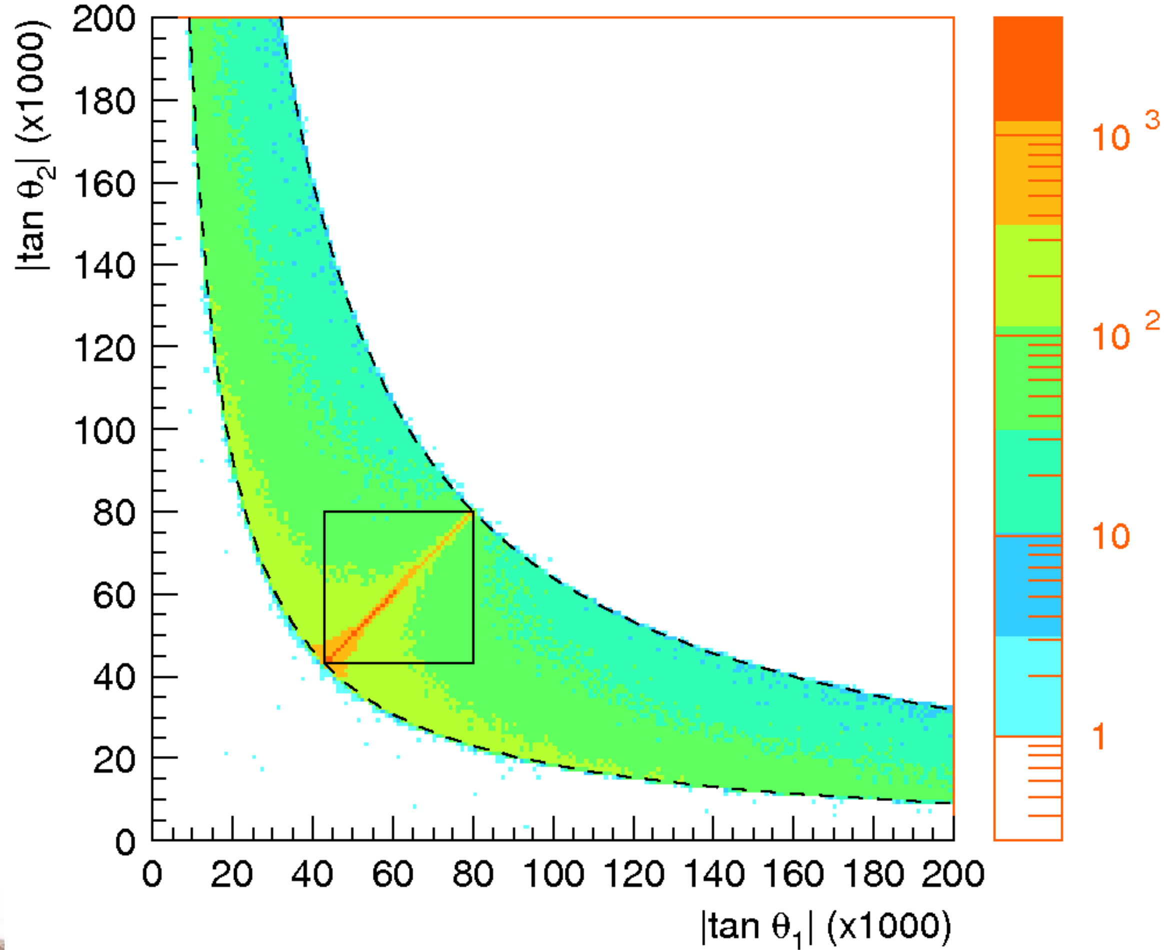
# $E_{CM}$ spectrum at CLIC

- CM energies of colliding $e^-e^+$ pairs in Guinea-Pig



# Angular loss at CLIC

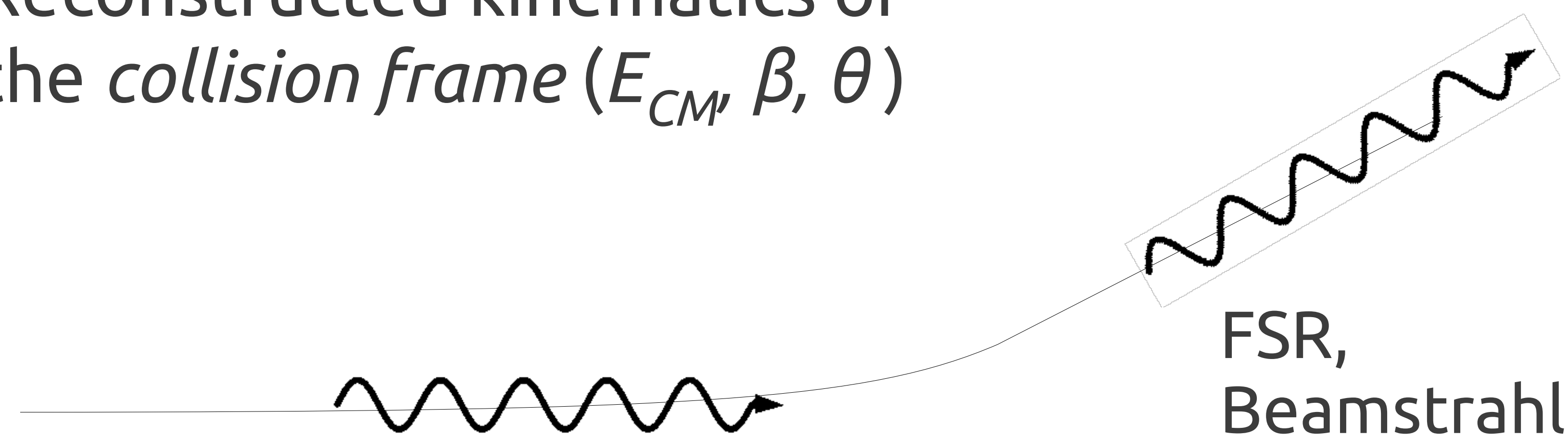
- Distortion of polar angles of the outgoing leptons due to the *beamstrahlung* emission



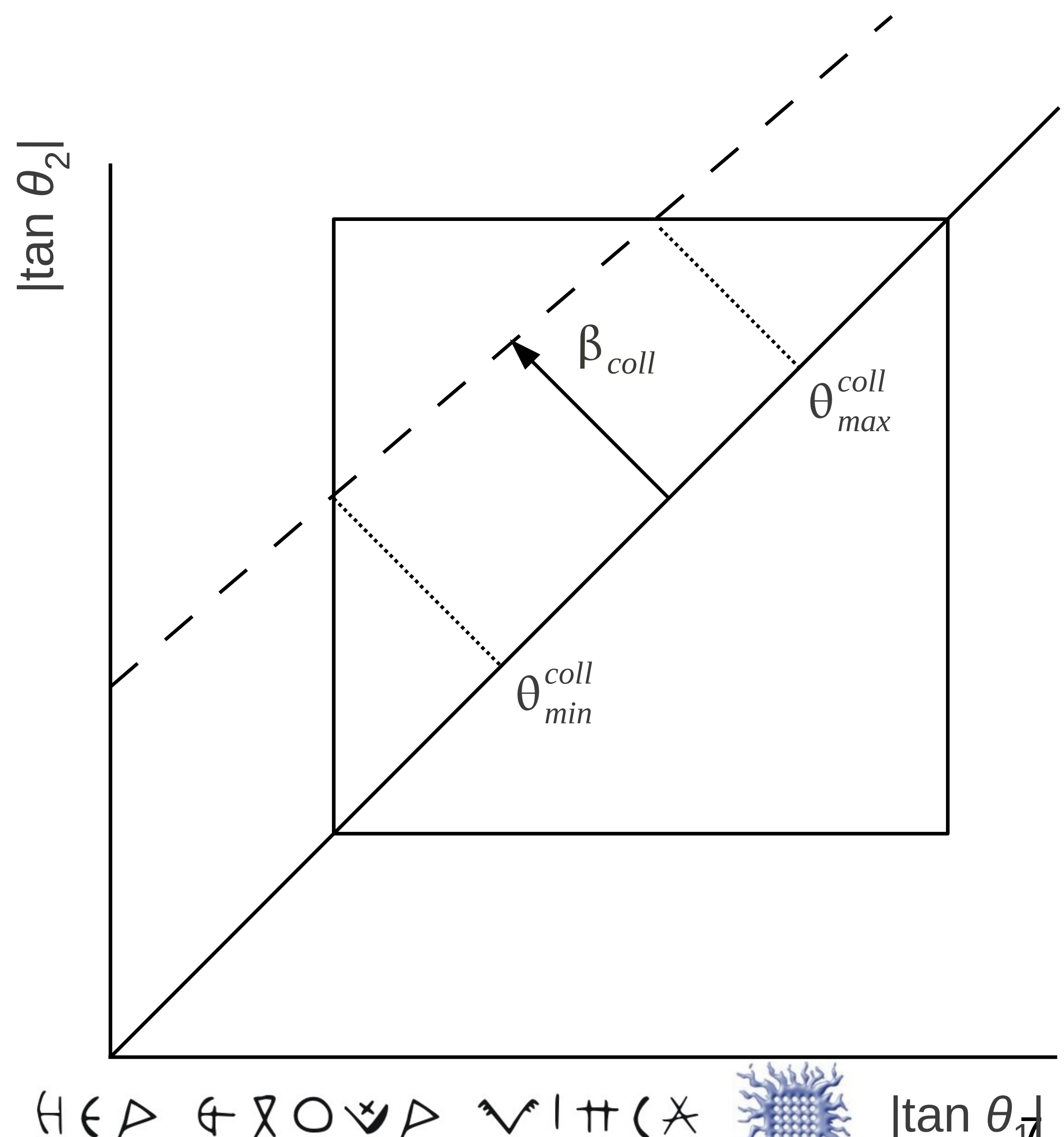

- Beam-beam effects simulated by Guinea-PIG
- Polar angles undergo the Lorentz boost along the beam axis (to a very good approximation)

# 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* ($E_{CM}$, $\beta$, $\theta$)



# Boost of the polar angles

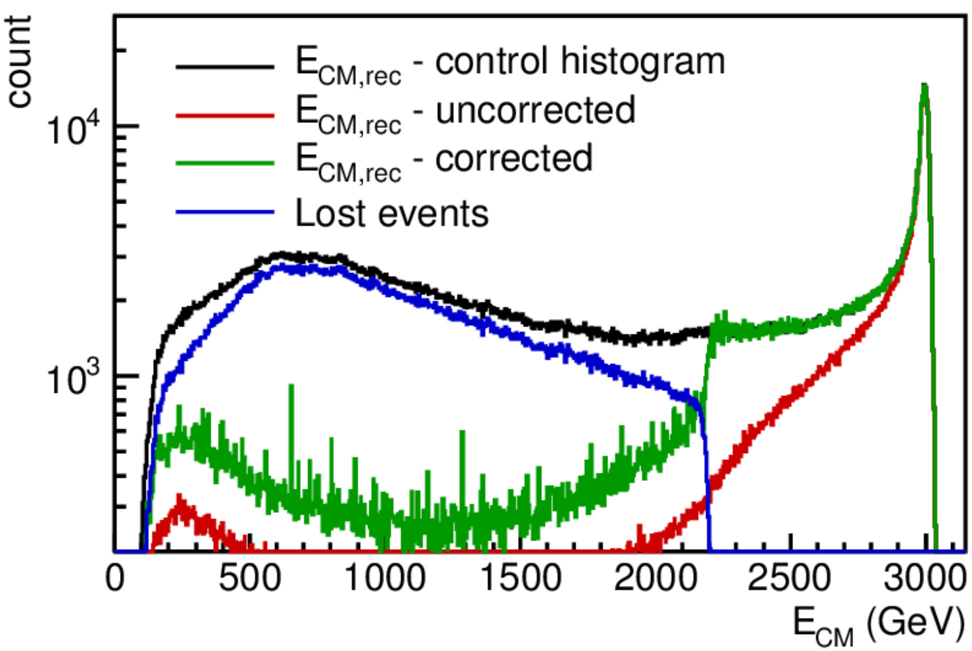


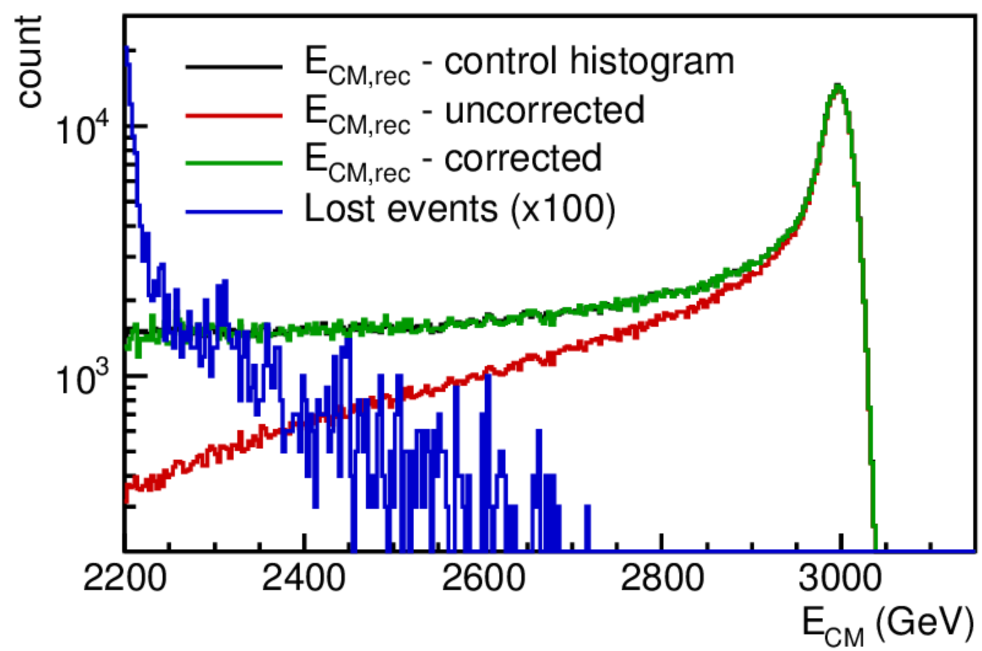

- Among events with a given $\beta_{coll}$ (dashed line), the angular counting loss can be analytically calculated
- Correct by the weighting factor

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

# Test of the angular-loss correction

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



# Test of the angular-loss correction

- To quantify the agreement, the integral count in the top 5% of CM energy and in the tail from 80% to 90% was compared to the control histogram:
  - top 5%: $\Delta L/L = (0.1 \pm 0.4) \times 10^{-3}$
  - 80%-90%: $\Delta L/L = (-3.6 \pm 1.8) \times 10^{-3}$
    (corrected “lost events”): $\Delta L/L = (-0.9 \pm 1.8) \times 10^{-3}$
- No significant deviation in the corrected peak
- Deviation in the tail mostly due to the “lost events” (off-axis ISR)

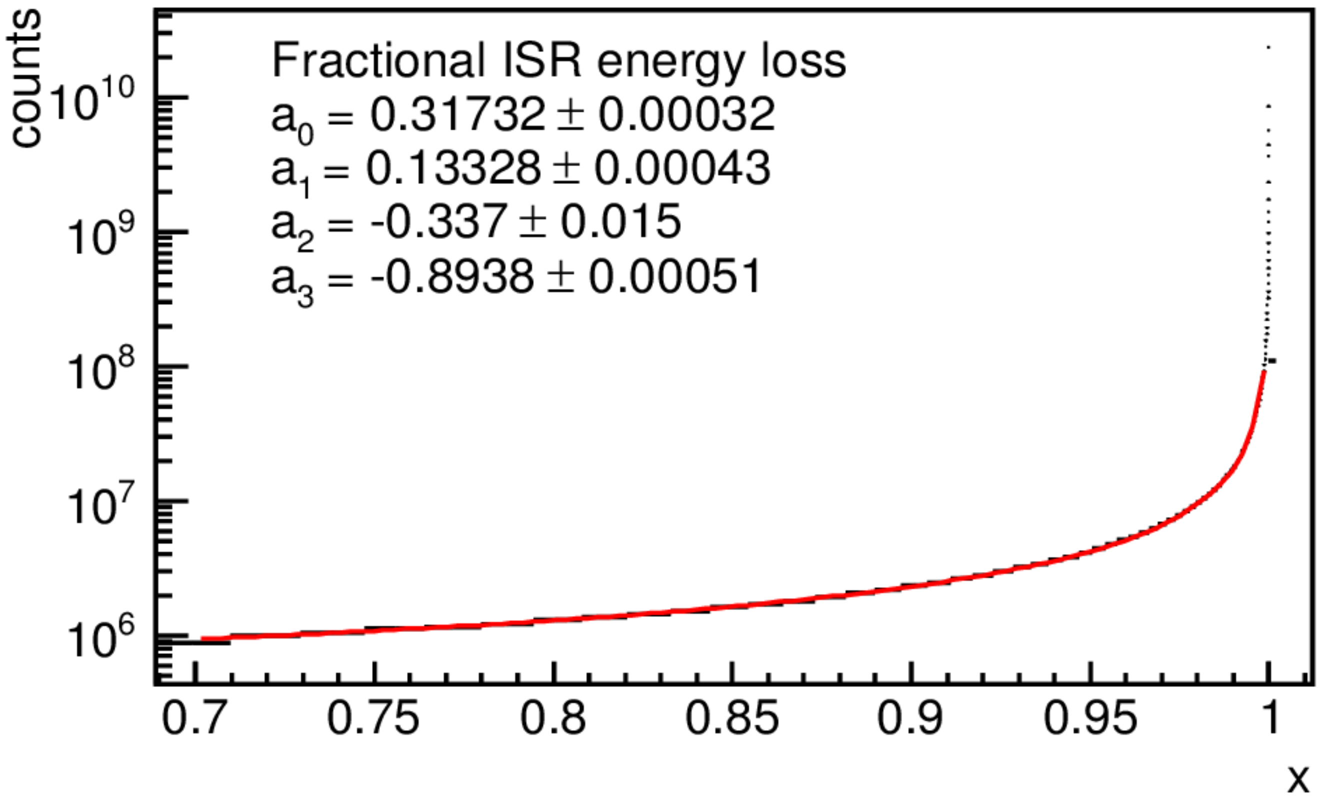
# Systematic effects

- Off-axis ISR $(\vec{\beta}_{coll} \neq \beta \hat{z})$- MC correction reliable
- 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 energy loss deconvolution

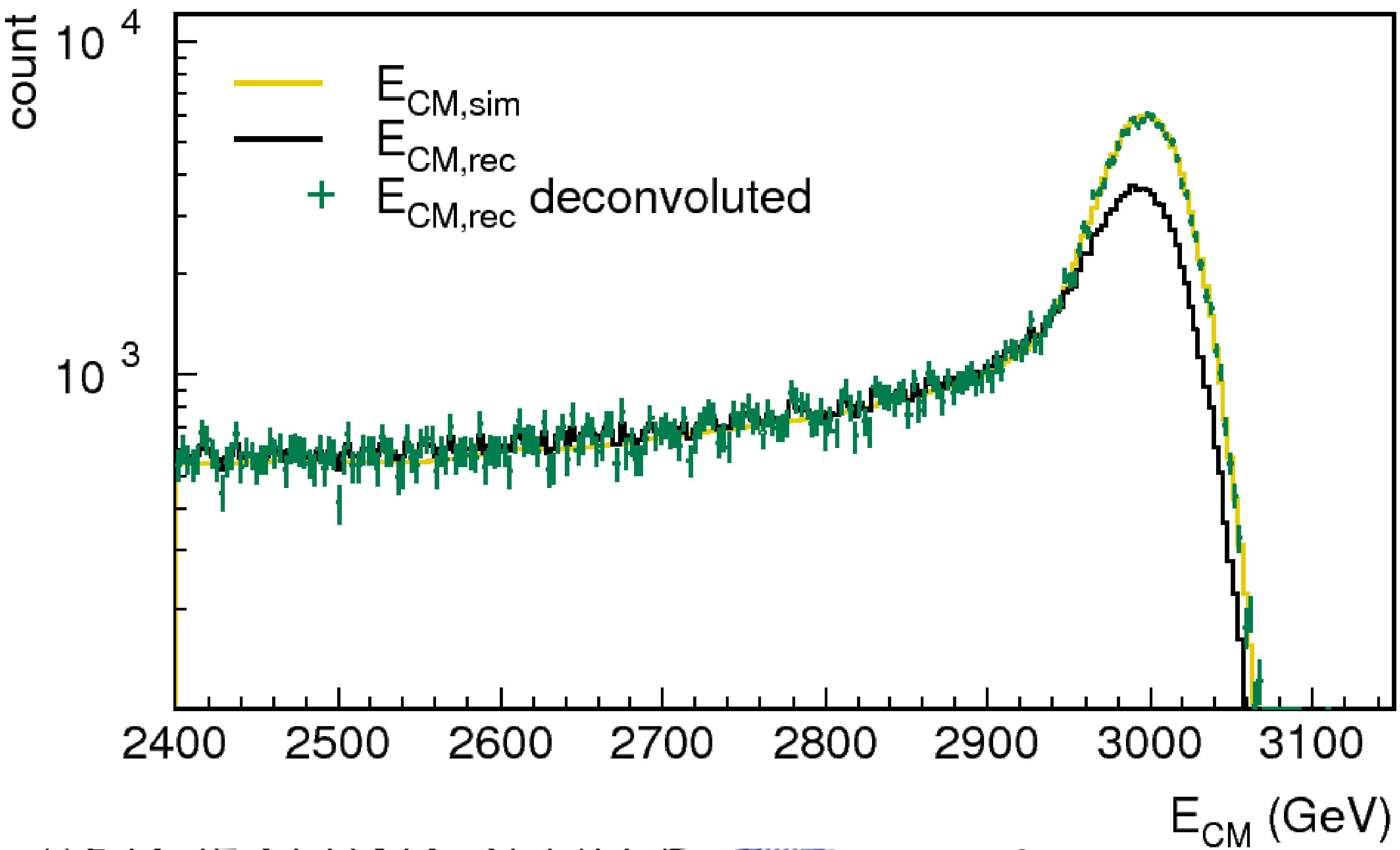
$$h(E_{CM,rec}) = \int_0^{E_{max}} B(E_{CM}) \frac{1}{E_{CM}} \Im\left(\frac{E_{CM,rec}}{E_{CM}}\right) d E_{CM}$$

- ISR distribution parametrized from BHLUMI events



# ISR energy loss deconvolution

- Top 5%: $\Delta L/L$ = (+1.3 ± 2.0) x $10^{-3}$
- 80% - 90%: $\Delta L/L$ = (-2.3 ± 3.9) x $10^{-3}$



# CLIC - Summary

| Step | Top 5% $\Delta L/L$ ($10^{-3}$) | 80% - 90% $\Delta L/L$ ($10^{-3}$) |
|---|---|---|
| BS+ISR correction | -0.1 ± 0.4 | -3.6 ± 1.8 |
| Deconvolution | 1.3 ± 2.0 | -2.3 ± 3.9 |
| Energy resolution | 0.05 ± 0.03 | 0.09 ± 0.09 |
| EMD (uncorrected) | 0.50 ± 0.05 | 1.08 ± 0.08 |
| high $\beta_{coll}$ | < 0.1 | 2.7 ± 0.1 |
| total | 1.4 ± 2.0 | 2.7 ± 4.3 |

# Conclusions

- The luminosity spectrum at CLIC extends down to almost zero CM energy
- Bhabha events at lower energies mostly invisible to the LumiCal
- Above 2200 GeV, the luminosity can be measured with precision of few permille
- The luminosity spectrum reconstructed to within the energy resolution of the luminometer

S. Lukić et al., JINST 8 (2013) P05008
S. Lukić, LCD-Note-2012-008

*ILC case:*
S. Lukić and I. Smiljanić, arXiv:1211.6869
I. Božović-Jelisavčić et al., arXiv:1304.4082

Thank you for your attention