Beam-beam effects in luminosity measurement for CLIC (and ILC)

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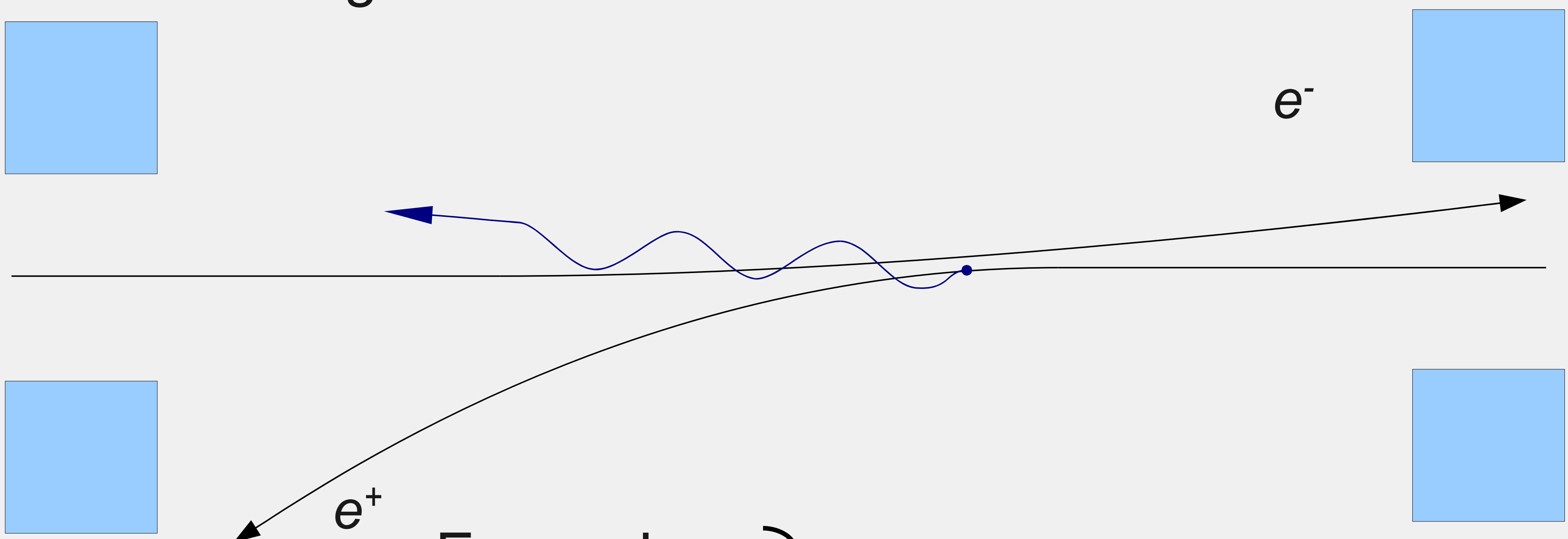
Bhabha scattering

- Luminosity measurement by counting the Bhabha pairs in coincidence

Bhabha scattering

- Deviation from ideally symmetric kinematics due to the emission of *beamstrahlung* and ISR, as well as the electromagnetic deflection

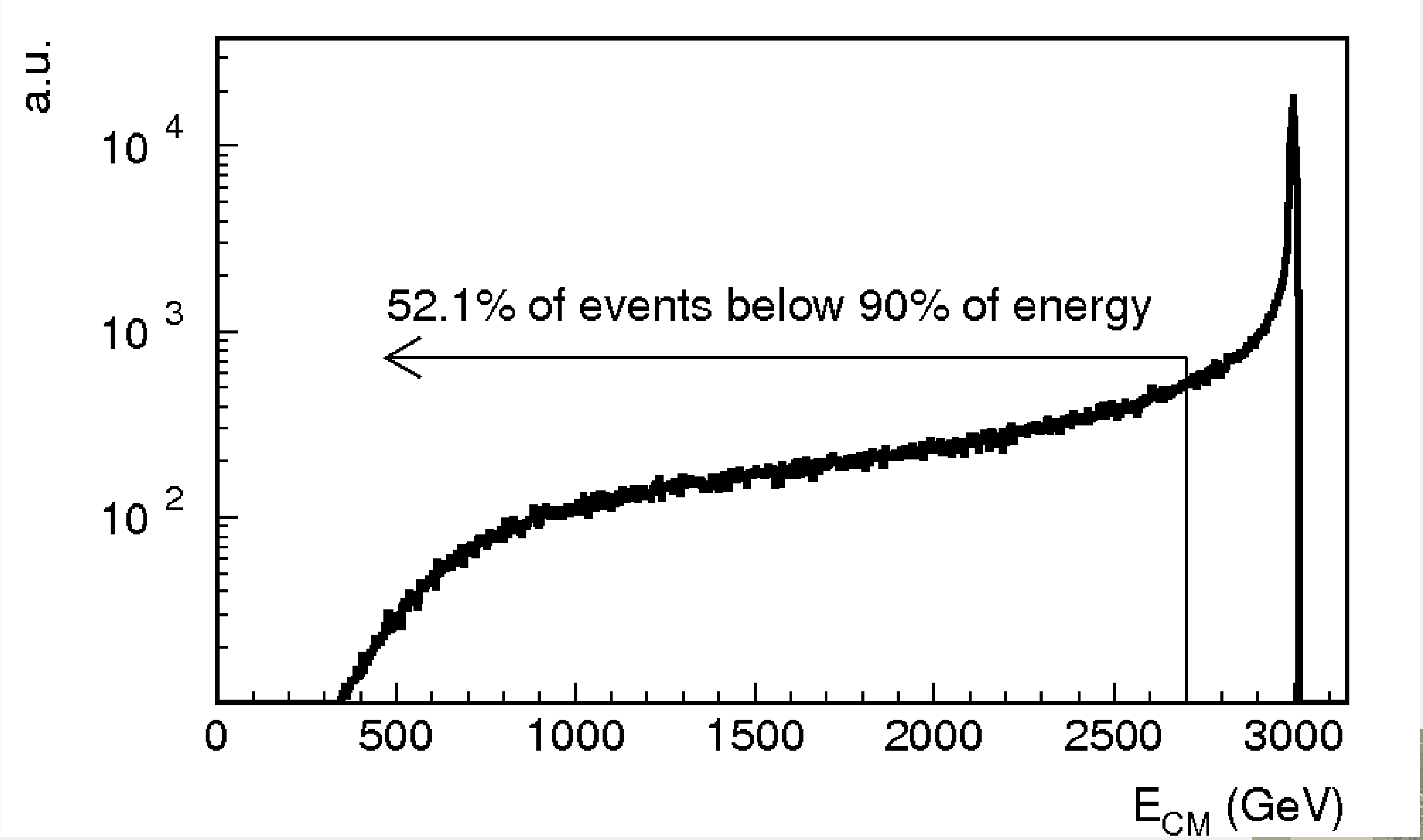


- Energy loss
- Distortion of polar angles

} **Counting bias**

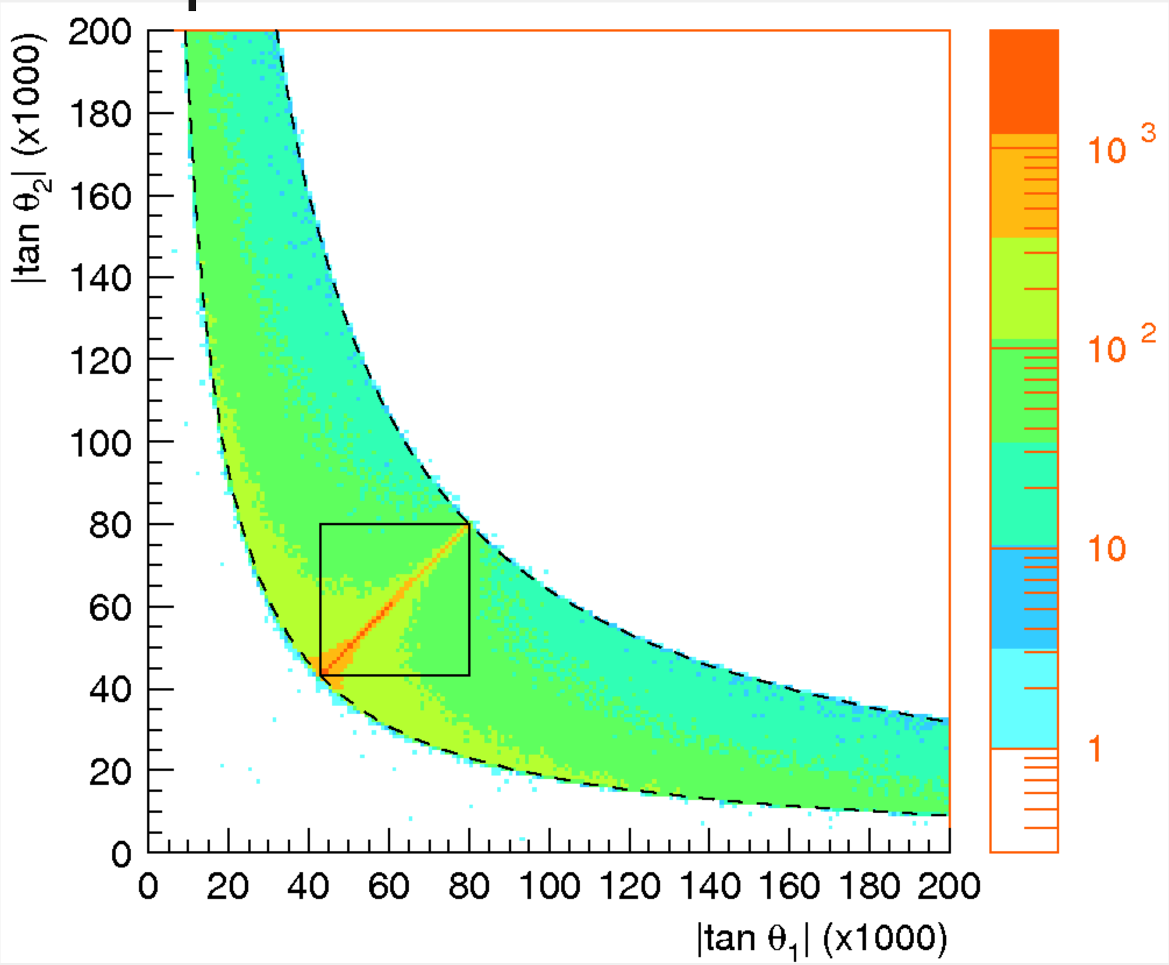
E_{CM} spectrum at CLIC

- CM energies of colliding e^-e^+ pairs in Guinea-PIG



Angular loss at CLIC

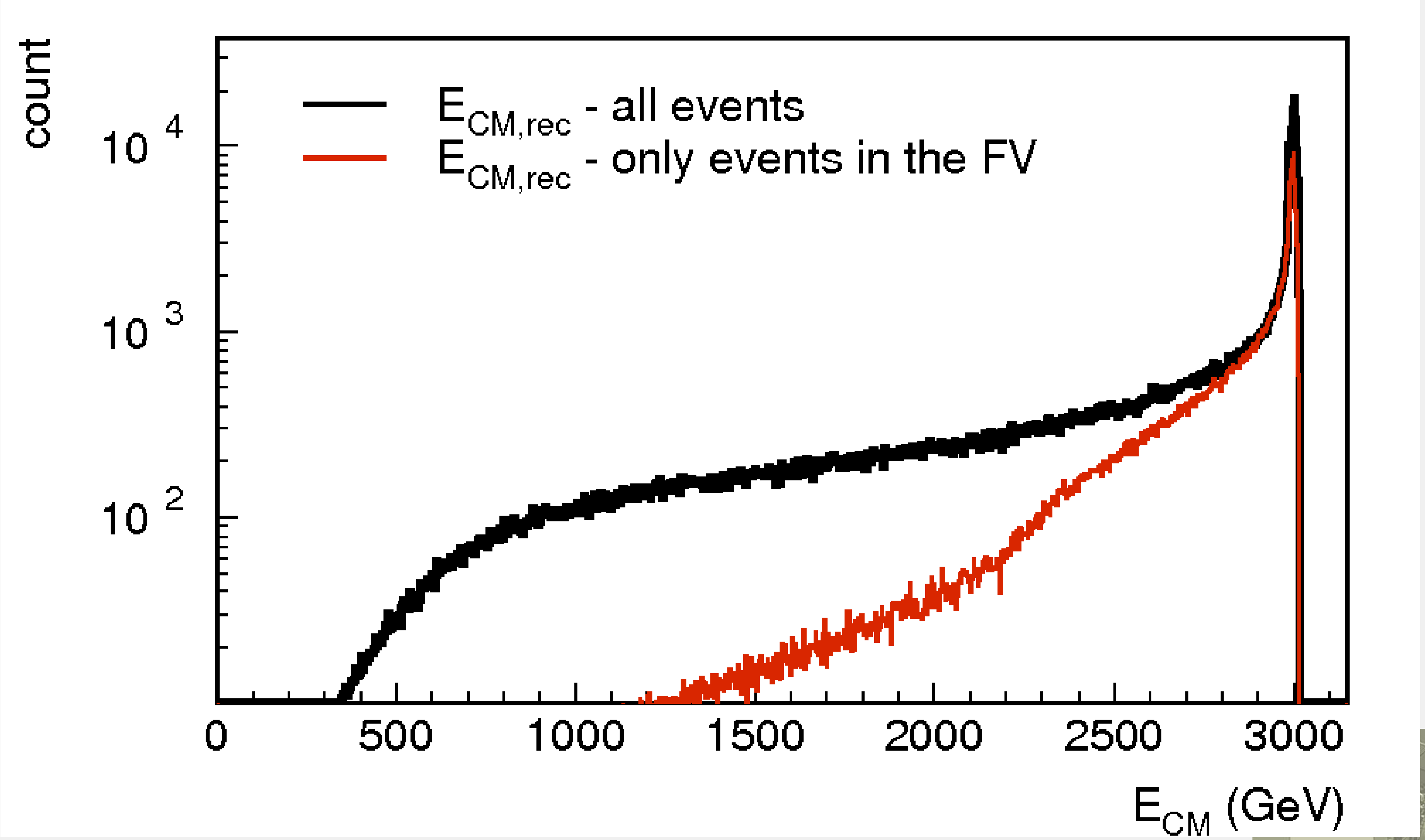
- Distortion of polar angles of the outgoing leptons due to the *beamstrahlung* emission



- Before the inclusion of beam-beam effects, all events inside the FV
- Beam-beam effects simulated by Guinea-PIG
- Polar angles undergo the Lorentz boost along the beam axis (to a very good approximation)

Angular loss at CLIC

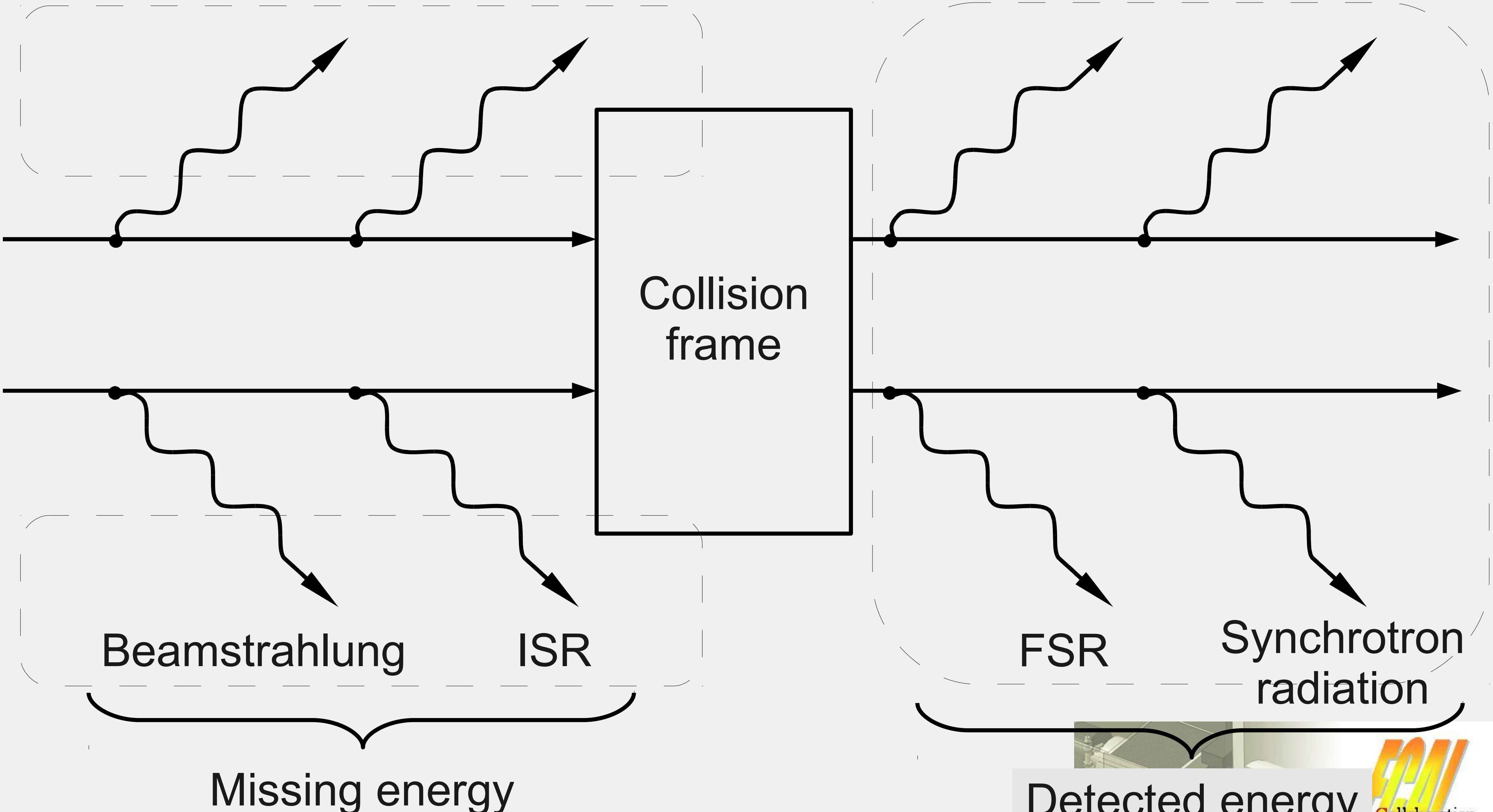
- Angular loss affects the low-*E* tail more, but there is a loss of several % in the peak as well



Specific issues for CLIC

- Most e^-e^+ collisions occur at energies significantly lower than 3 TeV
- The luminosity in the peak is at least as relevant as the integral luminosity
- Reconstruction of the form of the spectrum is important
- Most events in the low-energy tail invisible to the LumiCal

Beam-beam processes affecting luminosity measurement

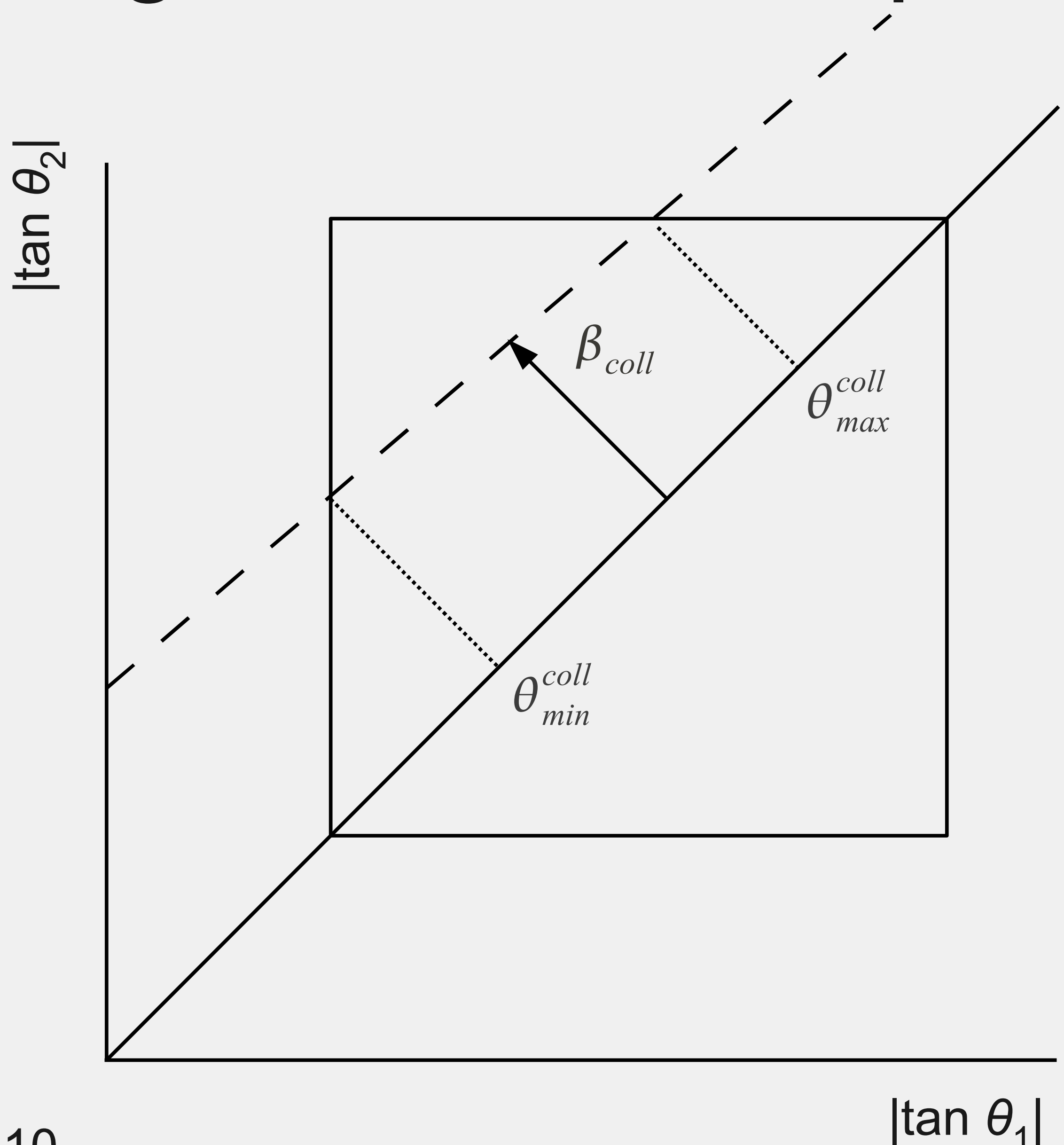


Correction of the BS+ISR angular losses

Beamstrahlung and the ISR miss the calorimeter →

Detected showers reveal kinematical information on the colliding system after emission of the BS and the ISR (s, β_{CM}, θ, …), in the *collision frame*

Deformation of the polar angles of Bhabha pairs



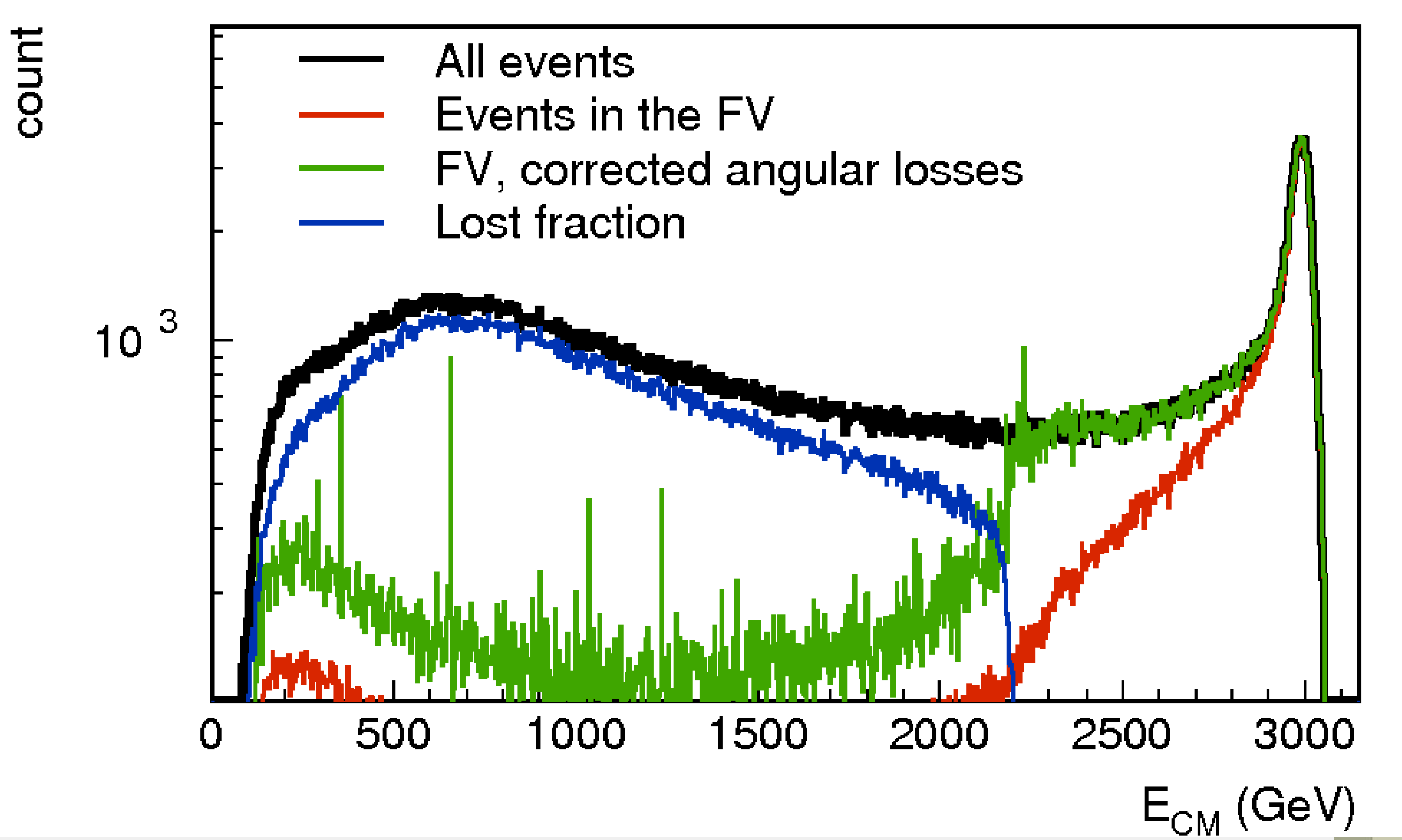
- Among events with a given β_{coll} (dashed line), the angular counting loss can be analytically calculated

- Correct by the appropriate weighting factor

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

Results of the angular-loss correction

- Reconstructed CM energies (after emission of ISR, without correction of the *s*-dependence of the Bhabha xs, LumiCal energy response included)



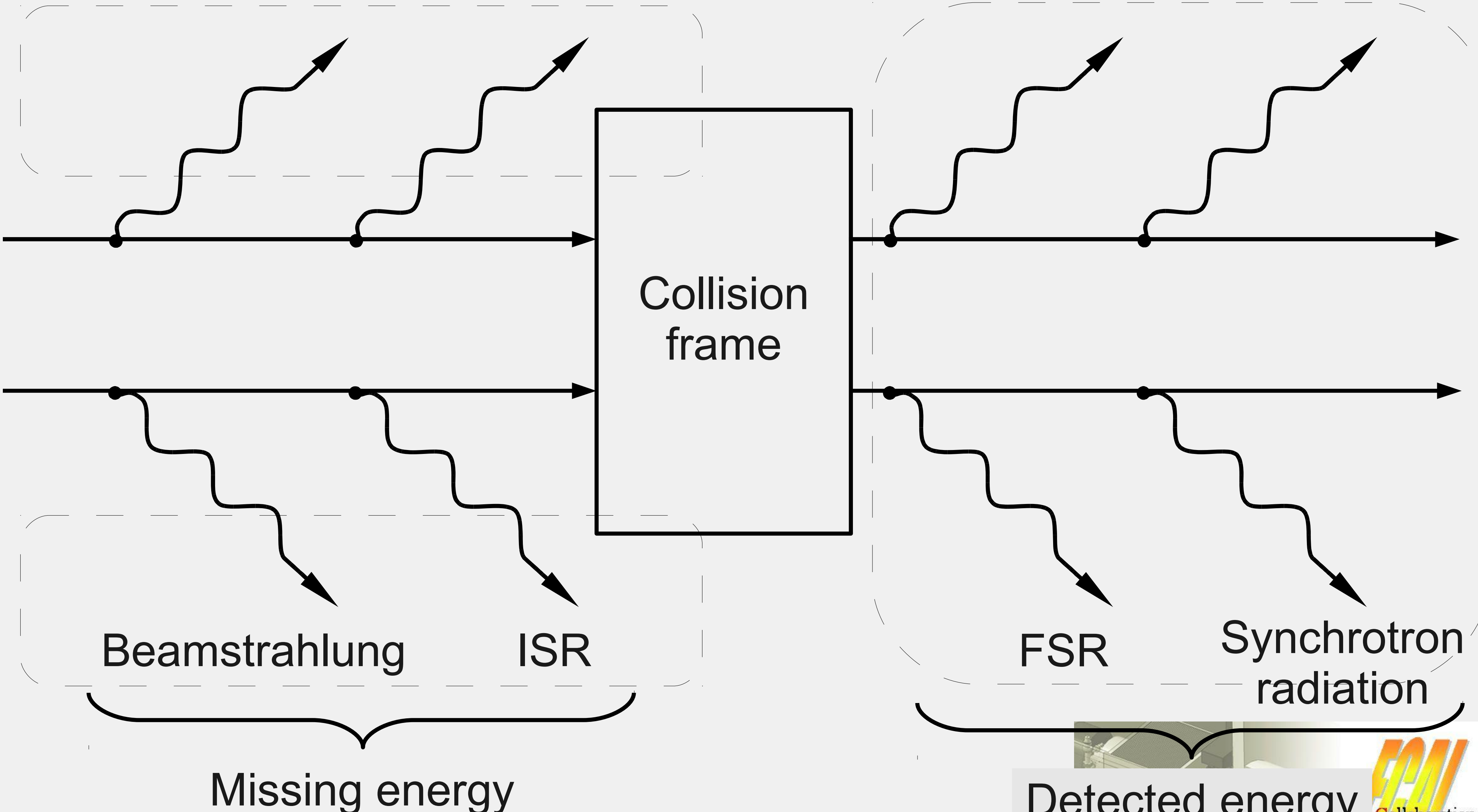
Test of the angular-loss correction

- To quantify the agreement, the integral count in the top 5% of CM energy after correction was compared to the control histogram:

$$\Delta N/N = (0.4 \pm 0.8) \times 10^{-3}$$

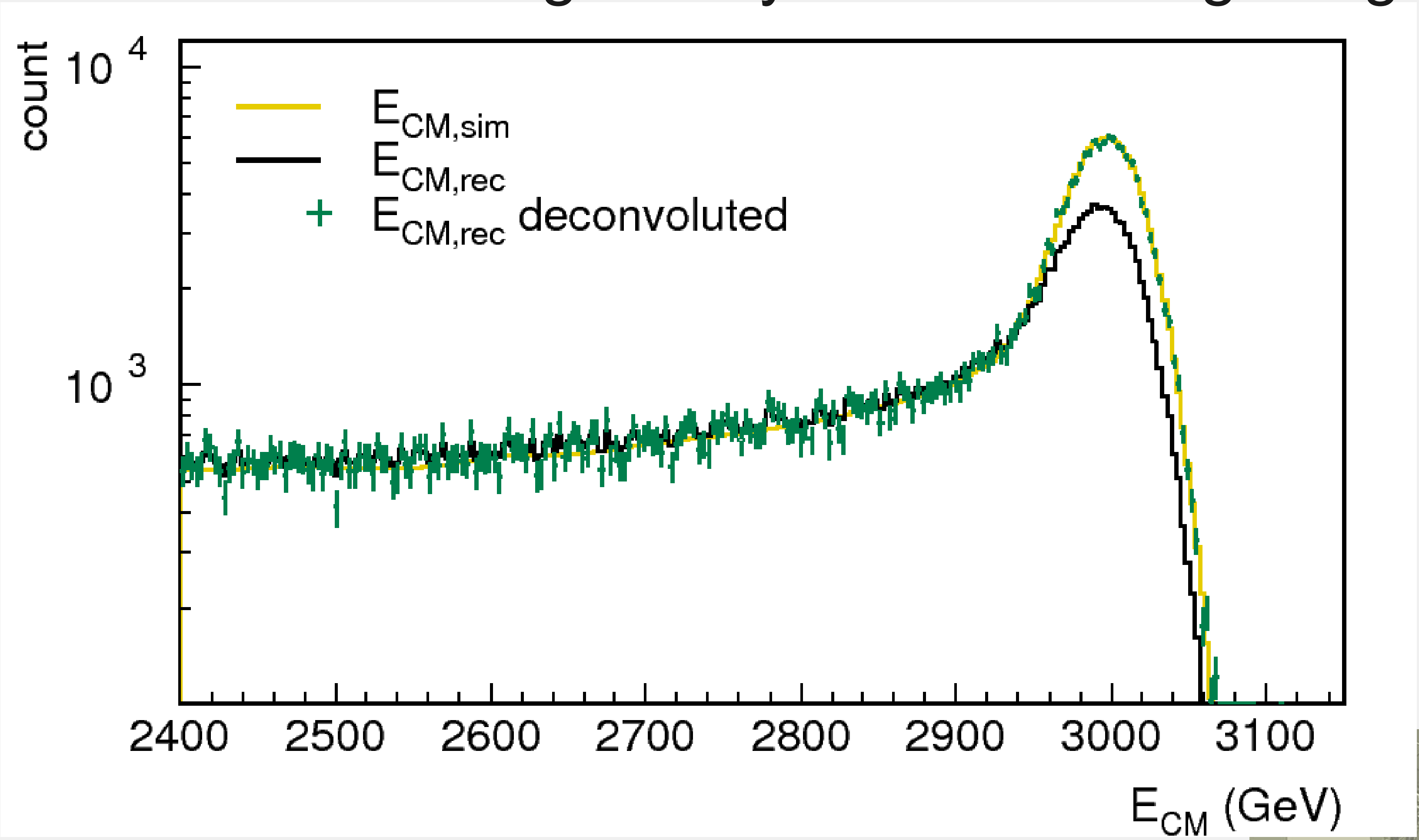
i.e. with the present statistic, there is no significant deviation in the corrected peak

- Relevant CM energy is **before** the ISR
- ISR energy loss deforms the spectrum
- Deconvolution necessary



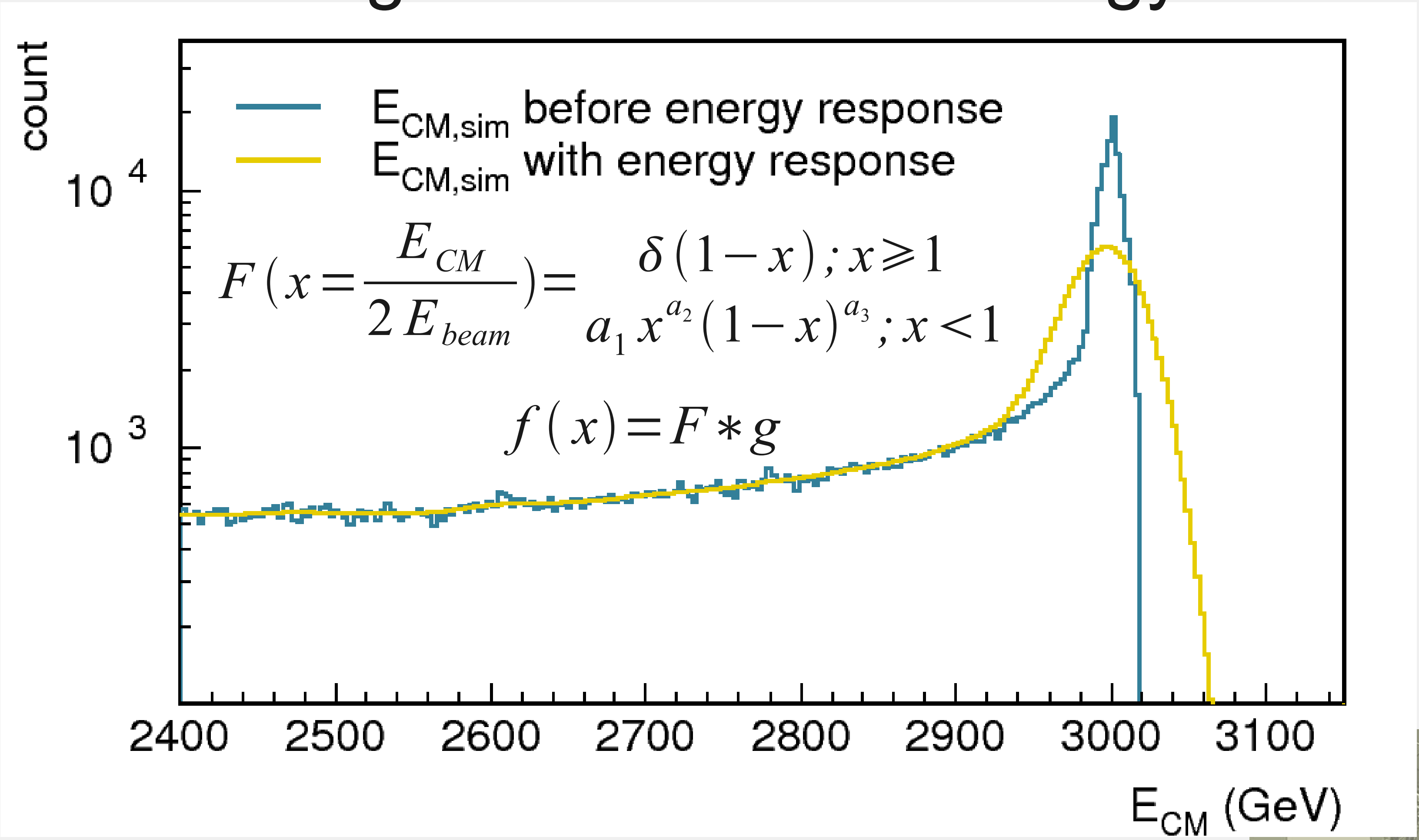
ISR energy loss deconvoluted

- Residual deviation in the top 5%: $(-3.3 \pm 3.2) \times 10^{-3}$
- Bin content weighted by *s'/s* when integrating the peak



Finite energy resolution

- The count in the peak is affected by the smearing due to the finite energy resolution

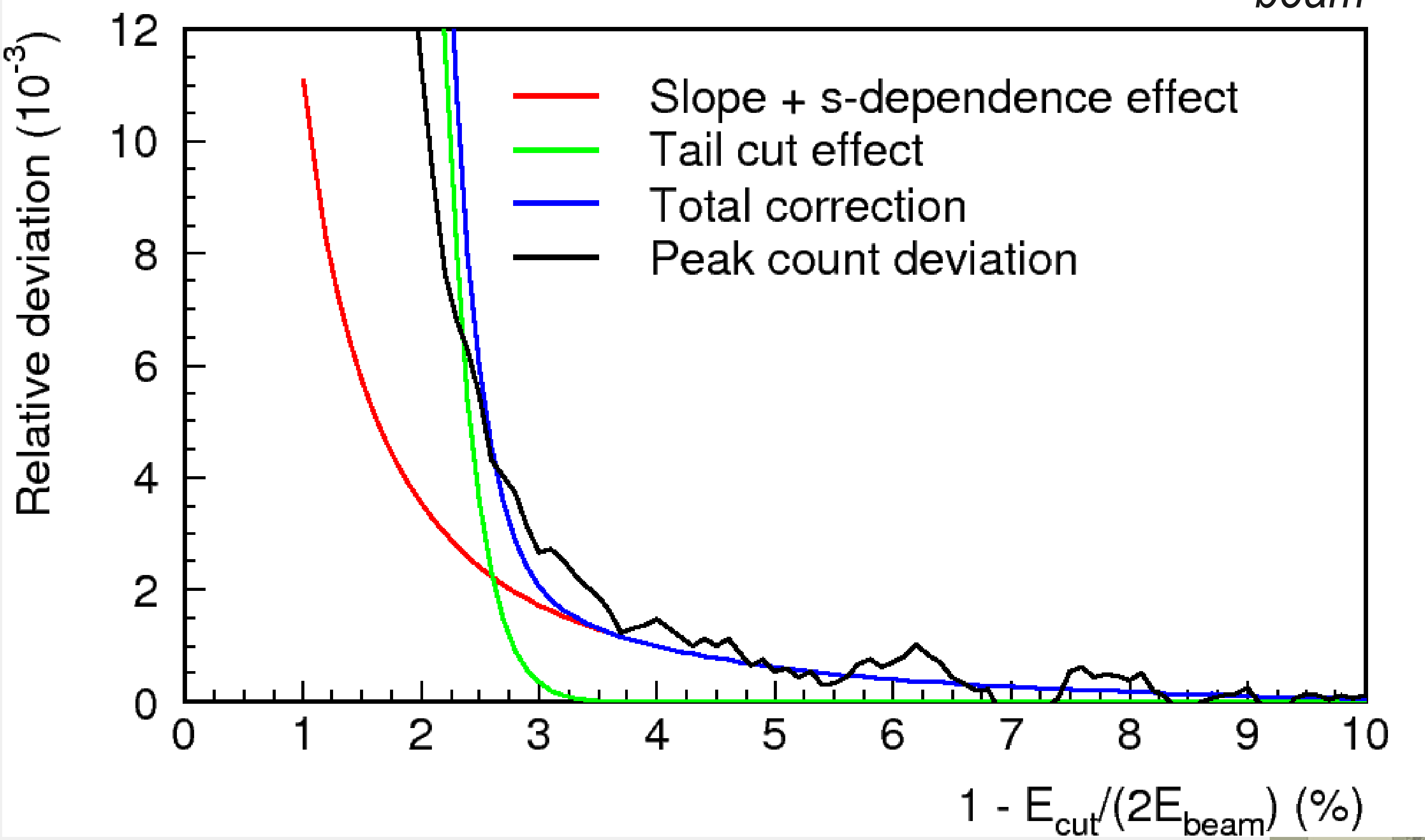


Finite energy resolution

- Peak count deviation due to three effects
  - Cut of the low-energy tail of the Gaussian bell
  - Asymmetric redistribution of counts from each side of the sharp energy cut, due to the slope
  - Weighting error (s'/s)
- These effects can be expressed in terms of the parameters of the energy spread and the underlying functional form of the spectrum
- Correction based on the fitted parameters of the spectrum function and of the energy response

Finite energy resolution

- Safe when sufficiently far from the peak (energy cut at min. 3.5% below $2E_{beam}$)



CLIC - Summary

Step	Residual relative deviation $\Delta N/N$ (10^{-3})
BS+ISR correction	0.4 ± 0.8
Deconvolution	3.3 ± 3.2
Energy resolution	0.08 ± 0.26
EMD (uncorrected)	0.54 ± 0.08
Events with high β_{coll}	< 0.1

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 spectrum can be measured with good precision, the residual uncertainty in the peak is several permille
- Energy reconstruction capability of the LumiCal is crucial for the $\sqrt{s}$ reconstruction at CLIC
- These and some alternative methods applicable at ILC – both the BS and the EMD angular losses can be corrected to better than 1 permille

Thank you!

Additional slides

Guinea-PIG [1]

e^-e^+ collision pairs – incoming momenta p_1, p_2 (collision axis, $\sqrt{s'}$, CM frame)

R $< w\, f(s/s')$?

no

yes

Calculate the collision axis in the CM frame

Rotate and scale the outgoing momenta in the CM frame, then boost back to the lab frame

output

Track...

output

BHLUMI / BHWIDE [2]

Bhabha outgoing momenta fixed $\sqrt{s}$, fixed collision axis

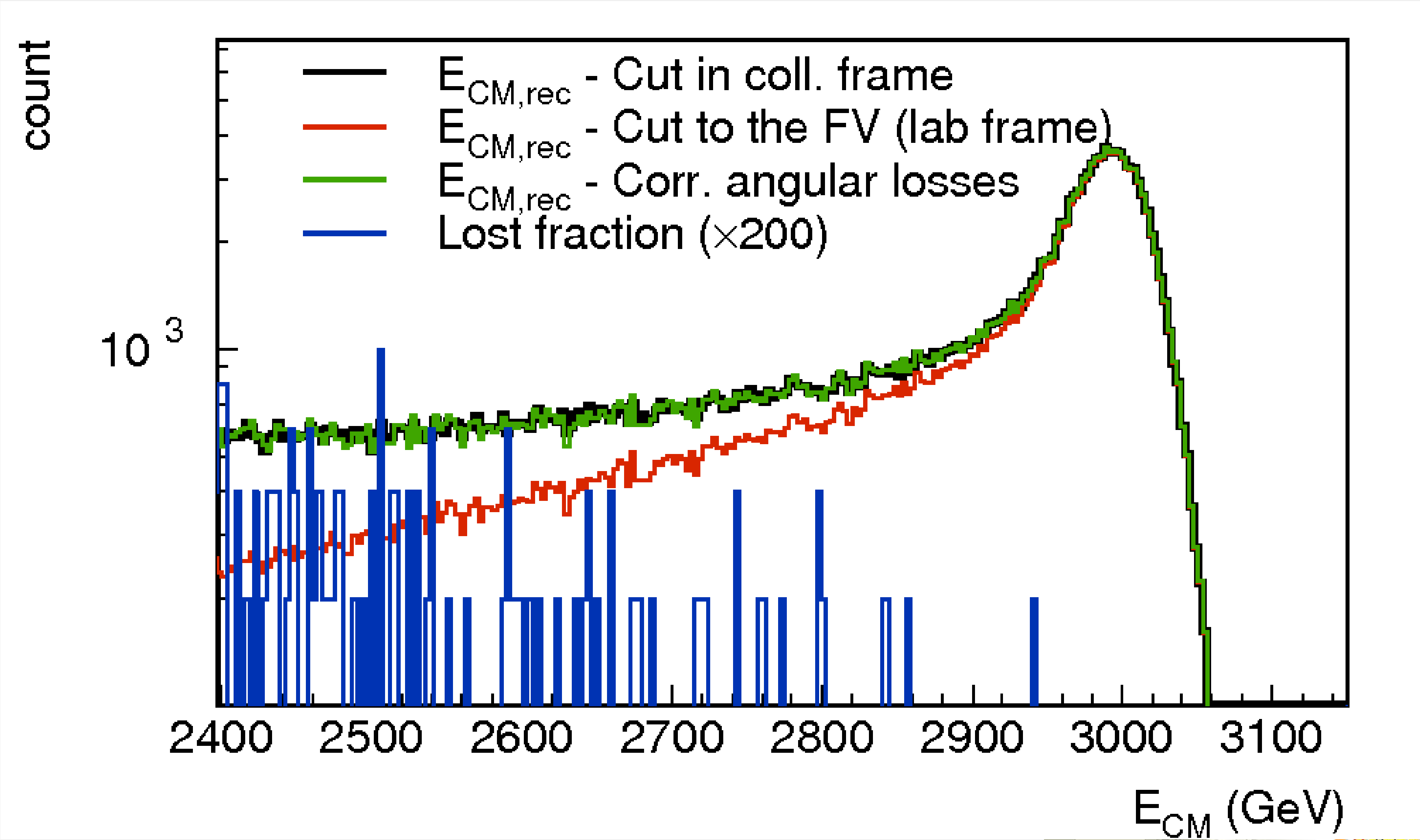
output

[1] D. Schulte, PhD Thesis, Hamburg, 1996
[2] S. Jadach et al., Comp. Phys. Comm. 102, 1997

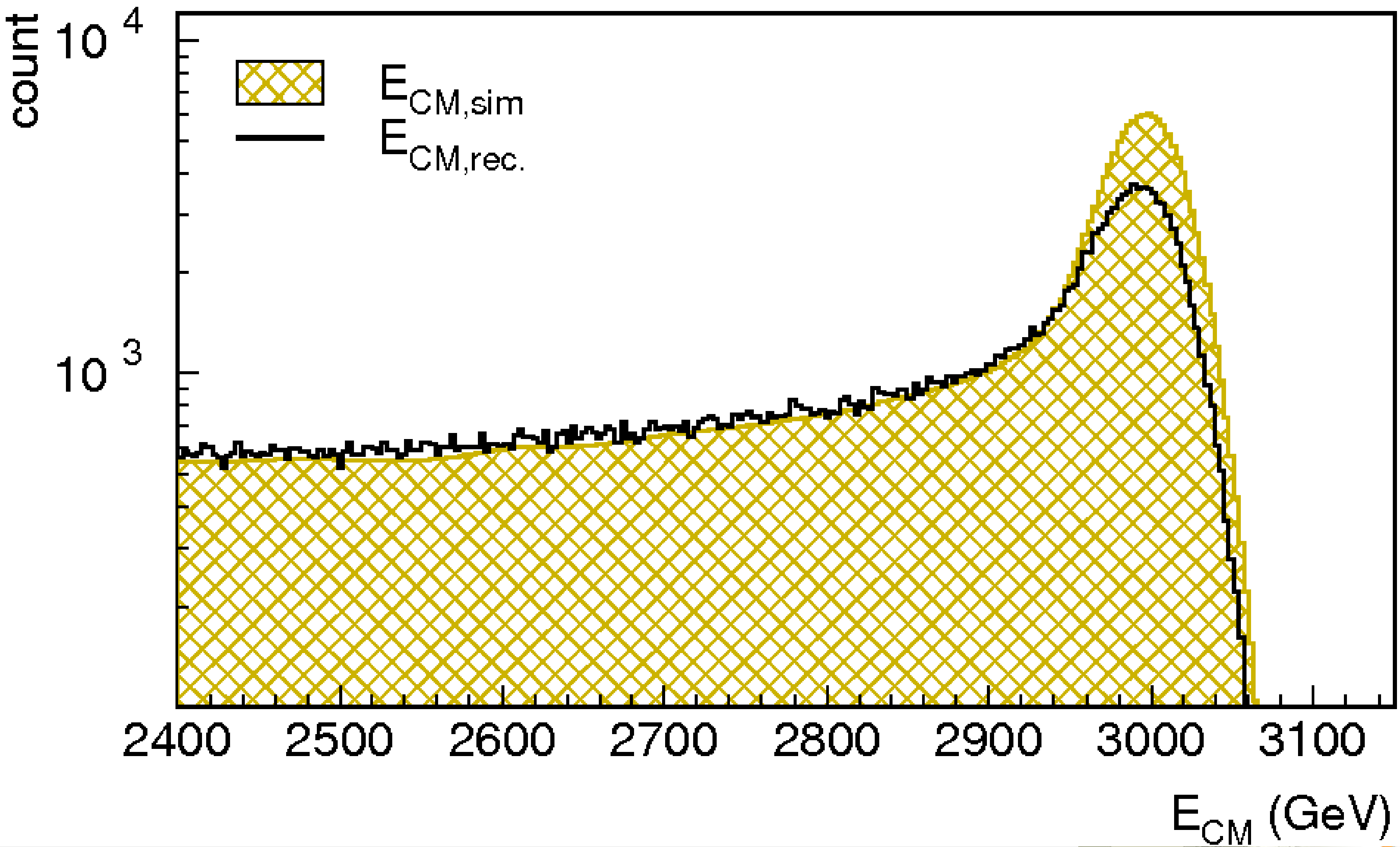
General analysis steps

- Reconstruct the CM energy after ISR
- Correct for the ISR+BS angular counting loss
- Deconvolute the ISR energy loss
- Correct for the effects of the finite energy resolution
- Correct for the EMD angular counting loss

Test of the angular-loss correction



ISR energy loss



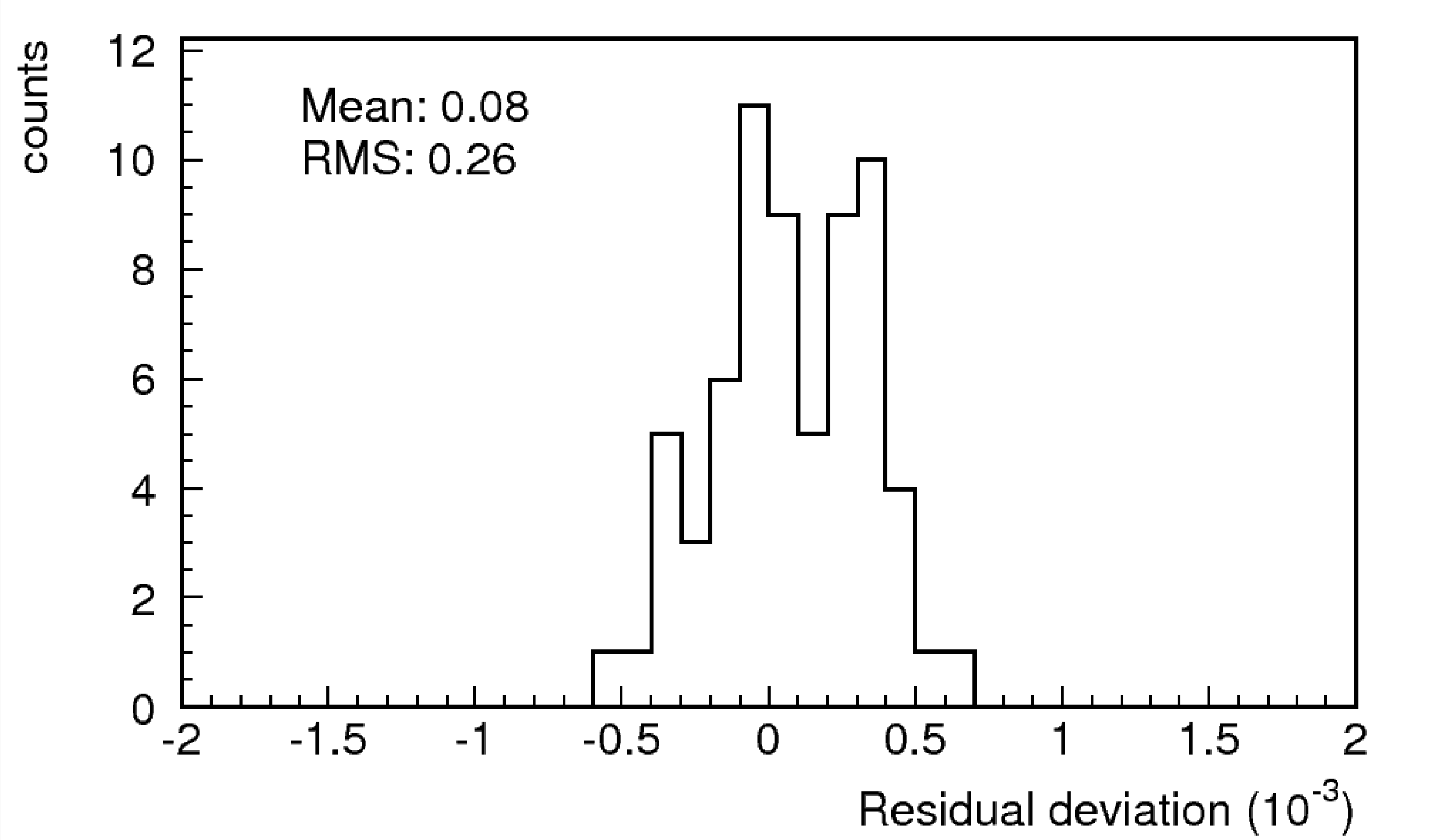
ISR energy loss

$$h(E_{CM,rec}) = \int_0^{\infty} f(E_{CM})\, g\left(\frac{E_{CM,rec}}{E_{CM}}\right) \frac{1}{E_{CM}}\, dE_{CM}$$

- Known distribution $g(x)$ of remaining fractions x of CM energy after emission of ISR
  - Parametrize $g(x)$ and fit to the generator results (BHLUMI, BHWIDE)
  - Discretize the equation for $h(E_{CM})$ and solve for f

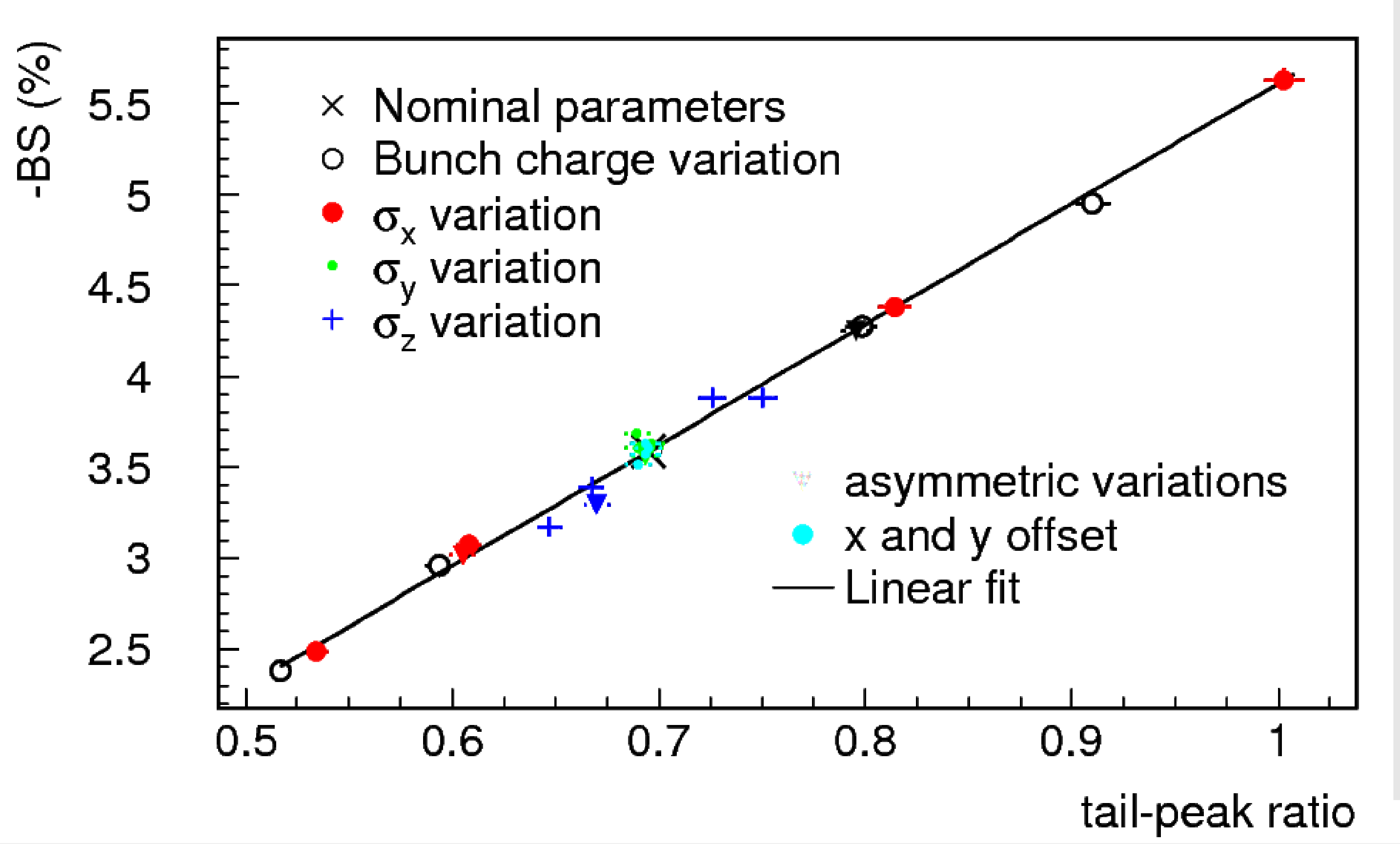
Finite energy resolution

- Residual deviation for peak regions of 3.5% and more



ILC – BS angular losses

- CM energy spectrum reconstructed from polar angles
- The ratio of the tail and peak integrals correlates with the BS component of the BHSE



- Linear fit, independent of the type of beam imperfection
- Depends on the accuracy of the simulation
- Average residual BS **0.04%,** max. **0.13%** (of the order of the stat.unc.)

ILC – EMD angular losses

$$\frac{\Delta L_{EMD}}{L}=\frac{1}{N}\frac{dN}{d\theta}\Delta\theta$$

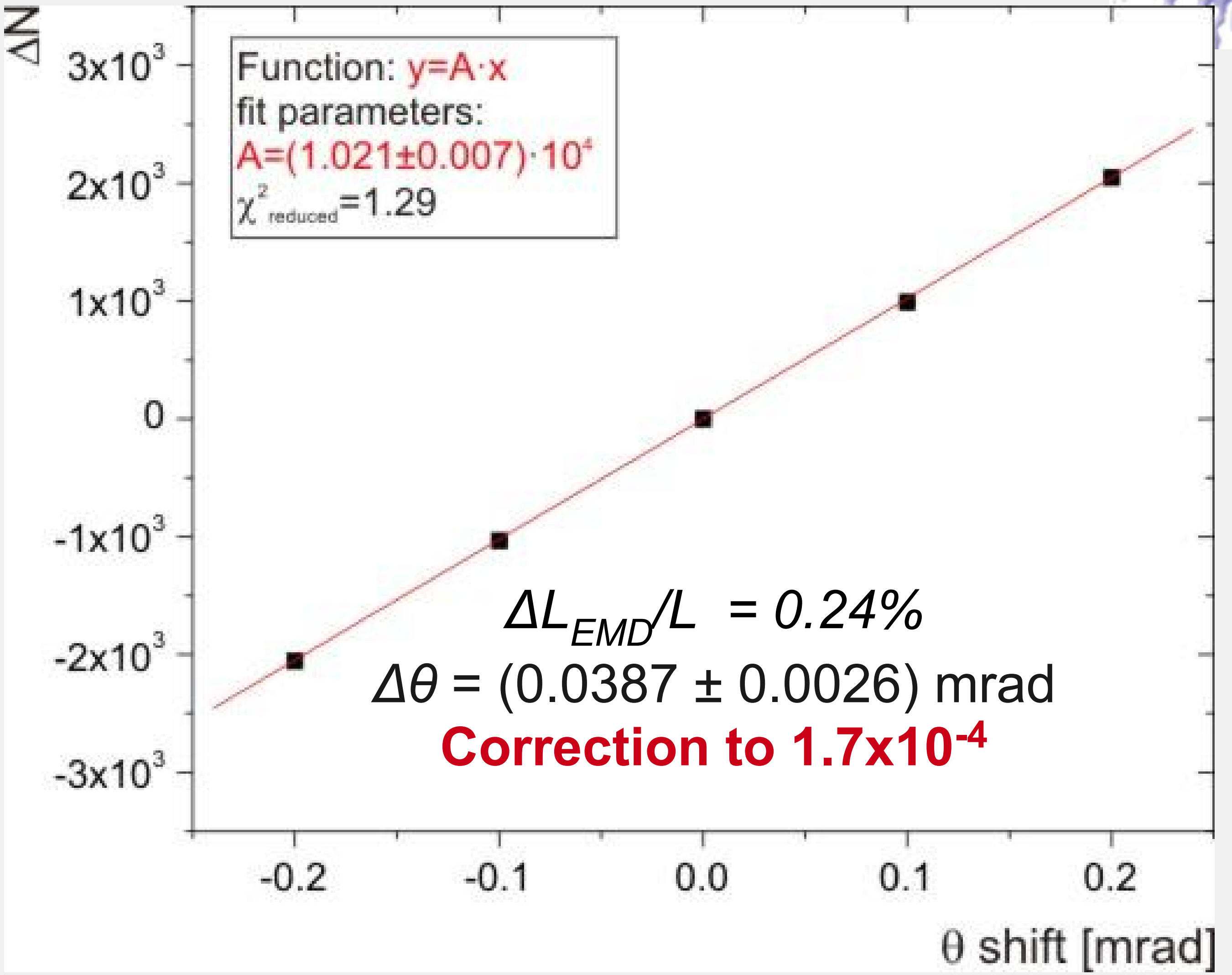
$\frac{dN}{d\theta}$ obtained by data analysis

$$(\Delta\theta)_{sim.}=\frac{(\Delta L_{EMD}/L)_{sim.}}{\left(\frac{1}{N}\frac{dN}{d\theta}\right)_{sim.}}$$

$$\left(\frac{\Delta L_{EMD}}{L}\right)_{exp.}=\left(\frac{1}{N}\frac{dN}{d\theta}\right)_{exp.}\Delta\theta_{sim.}$$

This can be combined with any method for the Beamstrahlung component

ILC – EMD angular losses



$\Delta L_{EMD}/L = 0.24\%$

$\Delta\theta = (0.0387 \pm 0.0026)$ mrad

Correction to 1.7×10^{-4}

Precise estimate obtained by shifting *θ* limits by only ±0.2 mrad
Method vulnerable to beam-parameter uncertainties
Final achievable uncertainty of the order of $\pm 0.5 \times 10^{-3}$