Beam-beam effects in luminosity measurement at CLIC

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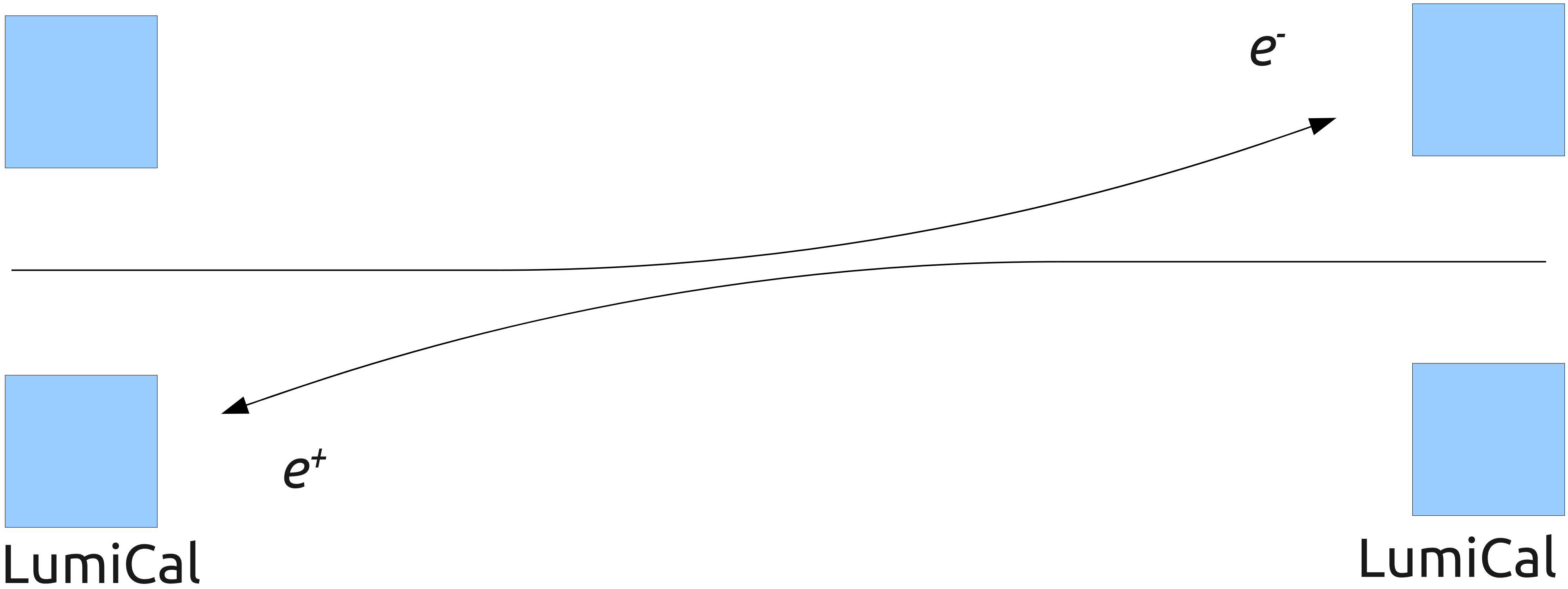
Outline

- Luminosity measurement and the beam-beam effects
- Beam-beam effects: CLIC vs. ILC
  - Specific issues for CLIC
- Correction of the BS+ISR angular losses for CLIC
- Deconvolution of the ISR energy loss for CLIC
- Correction of the counting bias due to the finite energy resolution of the LumiCal for CLIC
- Summary and conclusions

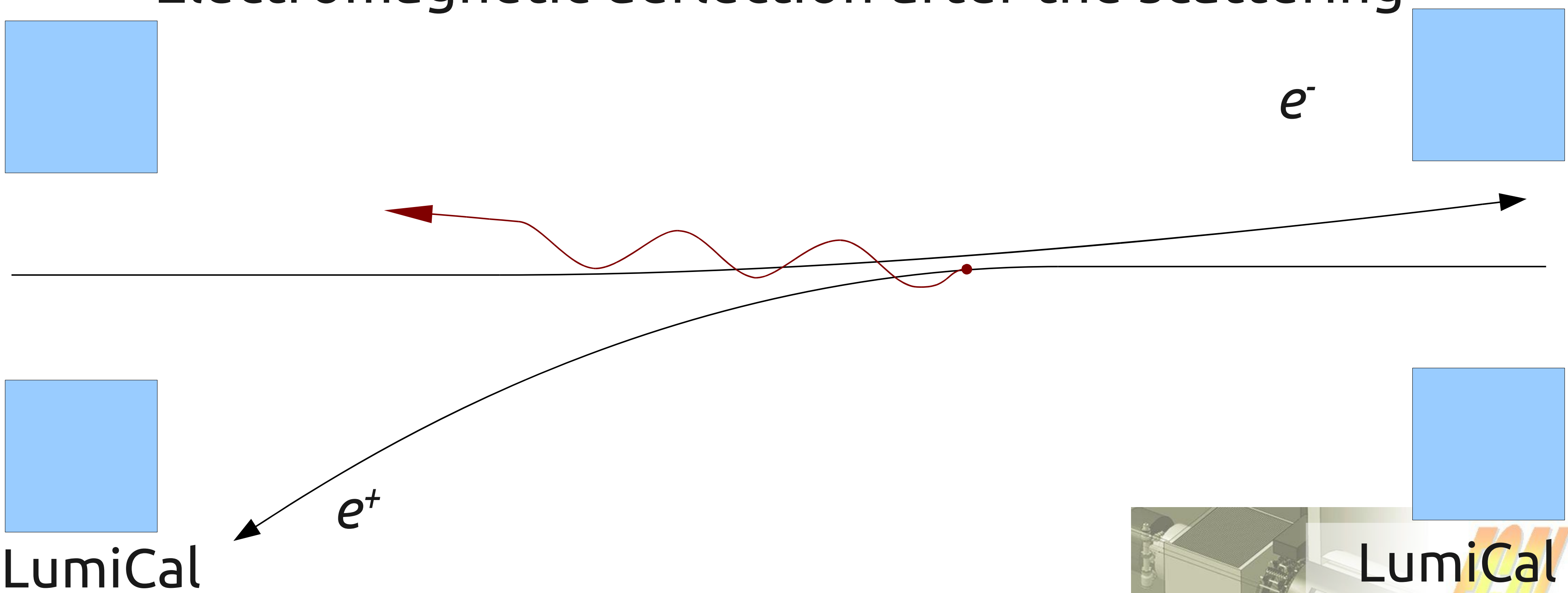
Bhabha scattering

- Luminosity measurement by counting the Bhabha pairs in coincidence



Systematic effects

- Deviation from ideally symmetric kinematics
  - Emission of beamstrahlung and ISR **along the beam axis** before the scattering
  - Electromagnetic deflection after the scattering



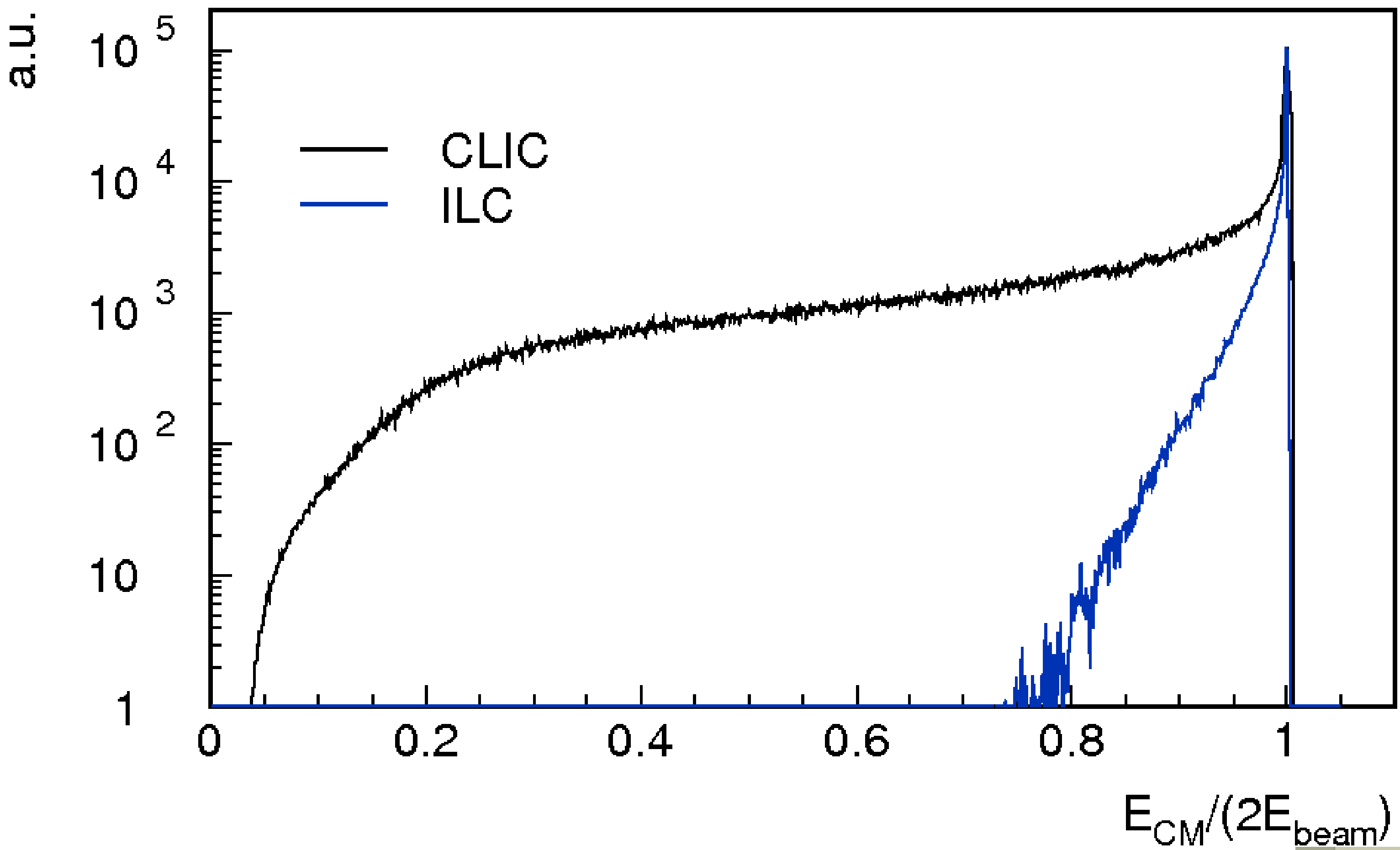
Systematic effects

- Angular losses
  - BS+ISR
  - EMD
- E_{CM} spectrum distortion
  - ISR

Counting bias

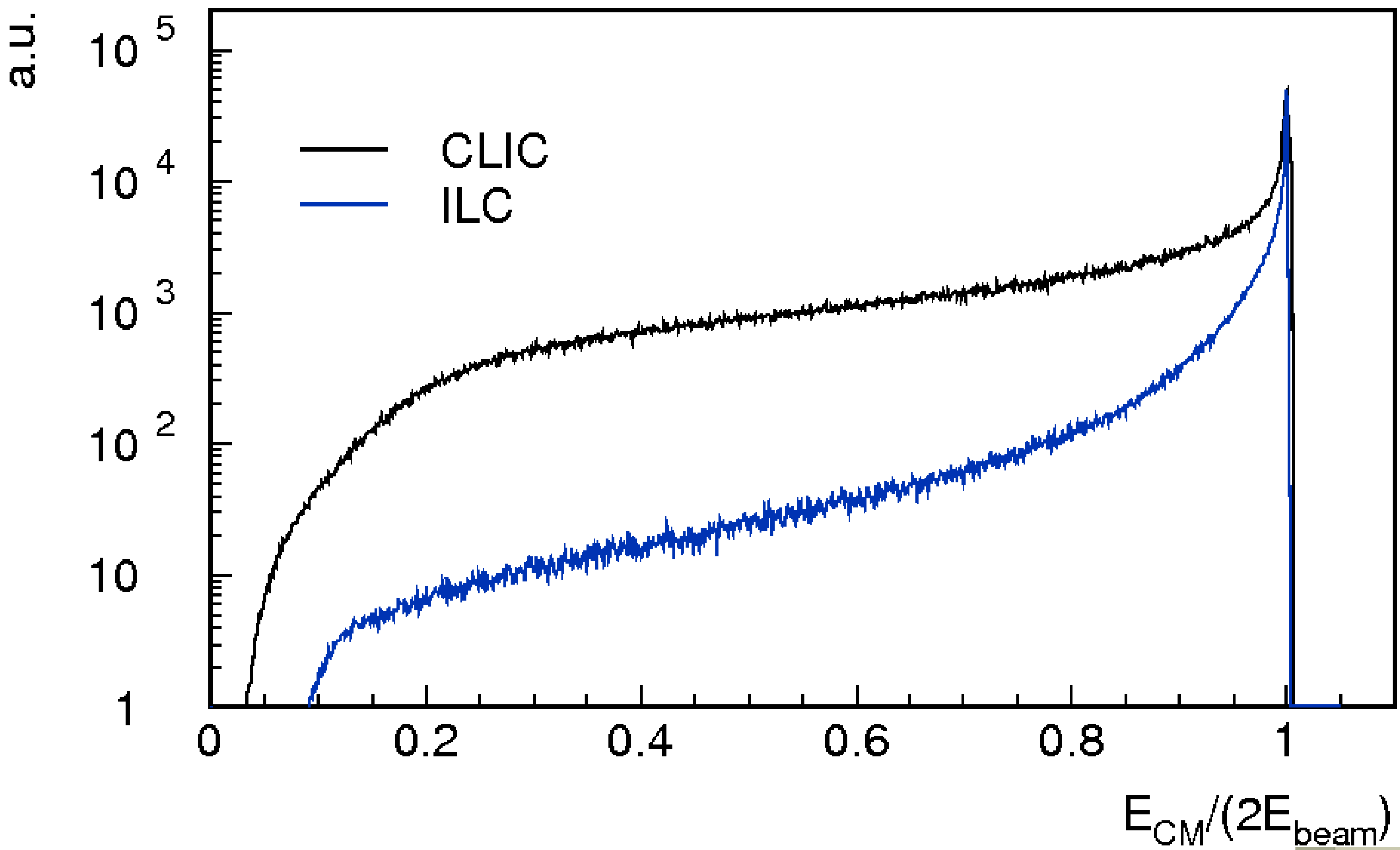
E_{CM} spectrum

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

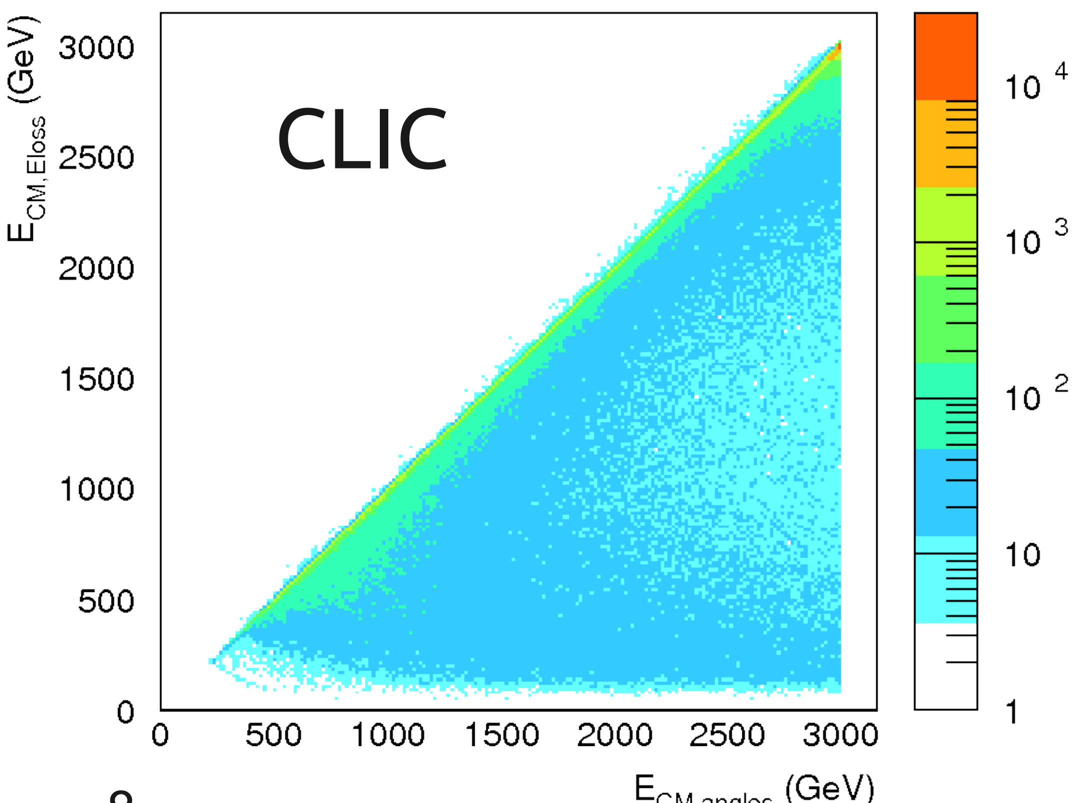


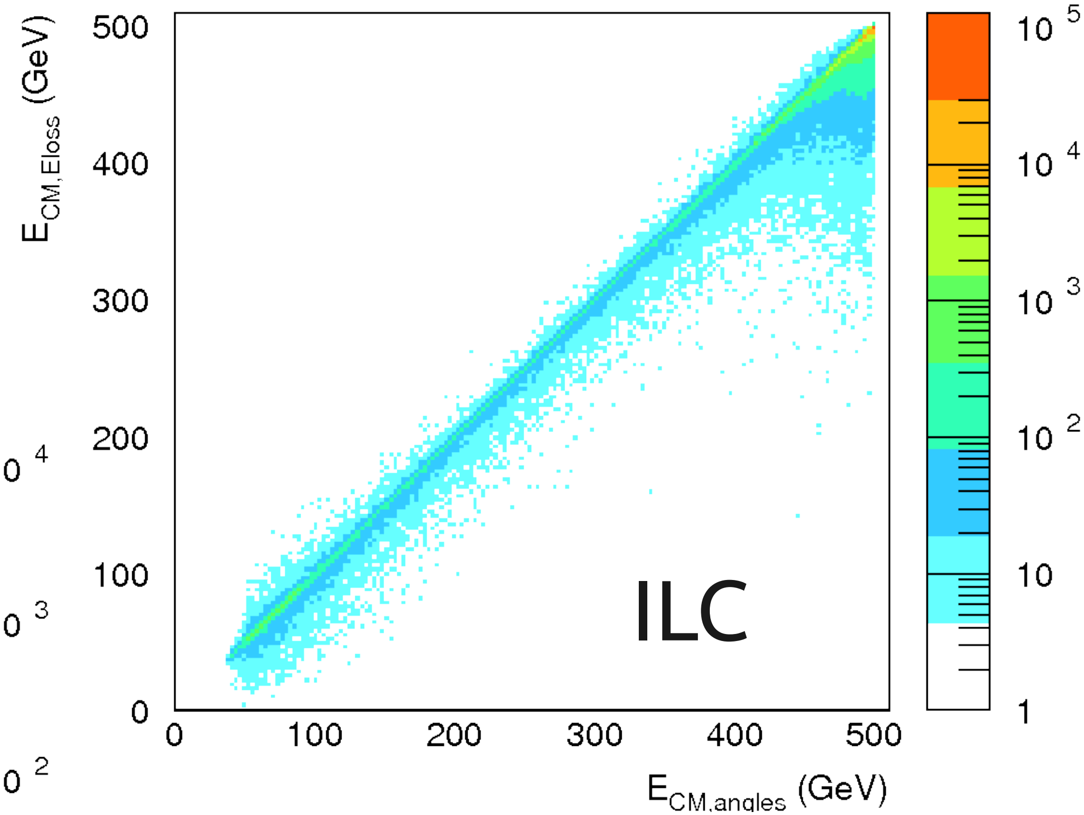
E_{CM} spectrum

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



E_{CM} spectra (after ISR) by particle 4-momenta vs. by polar angles





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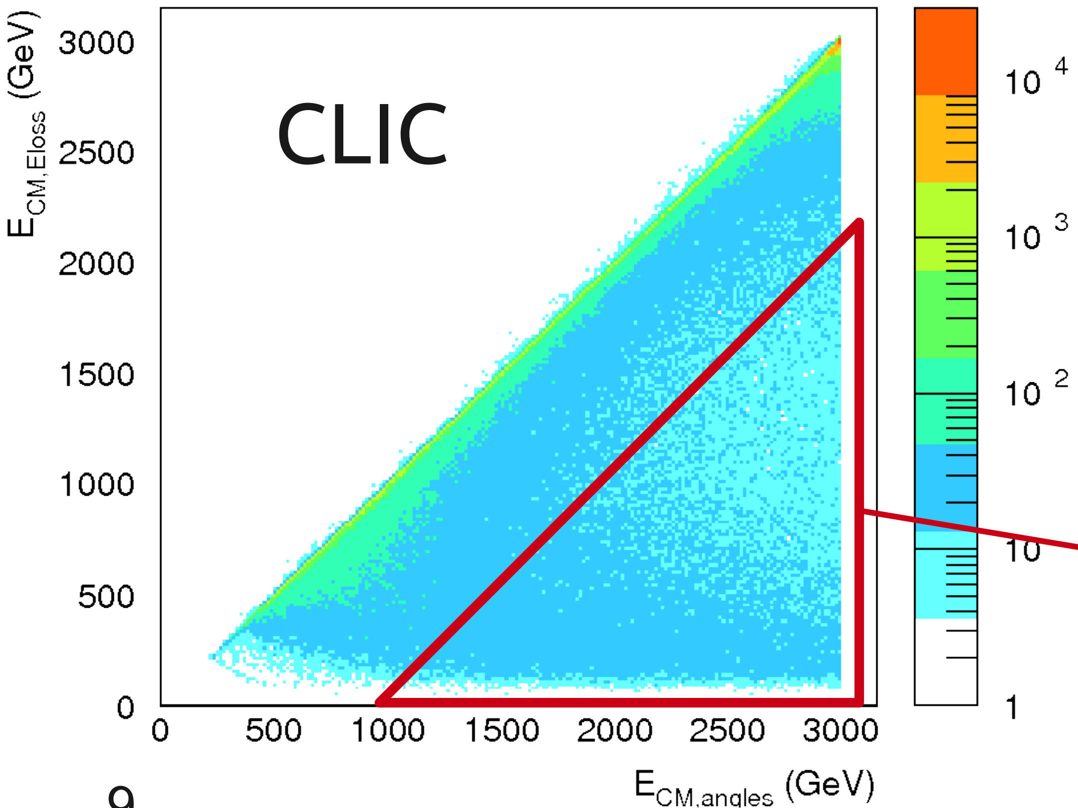
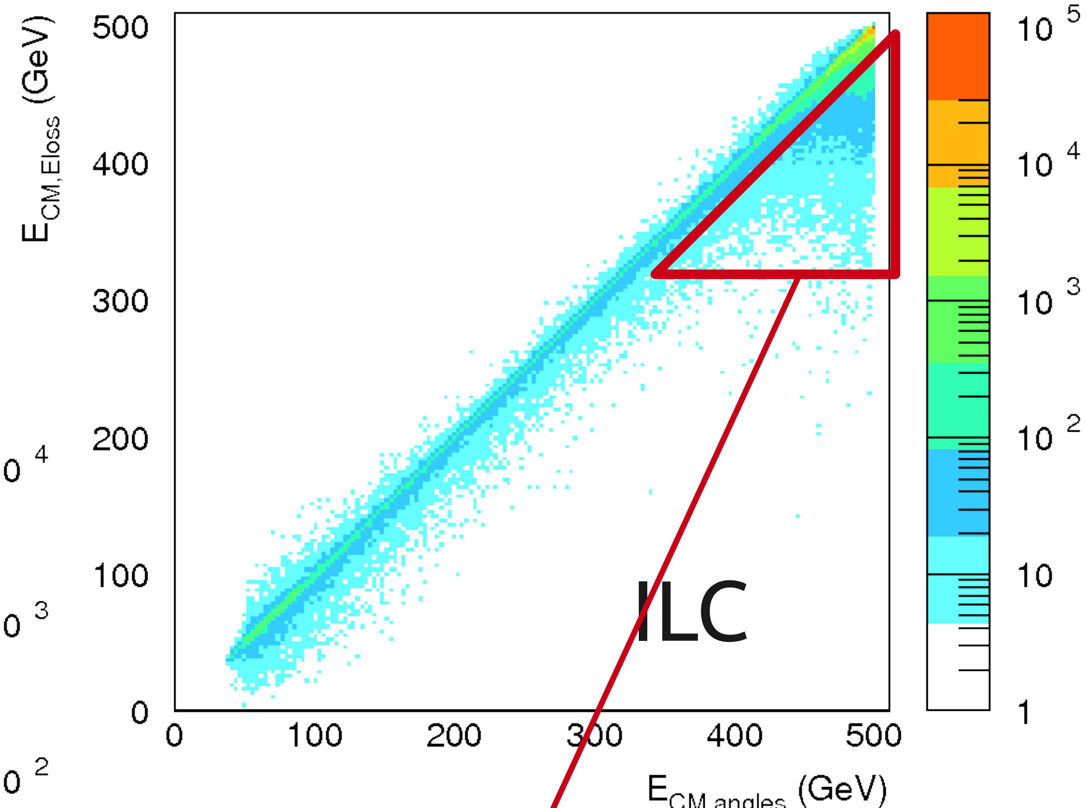
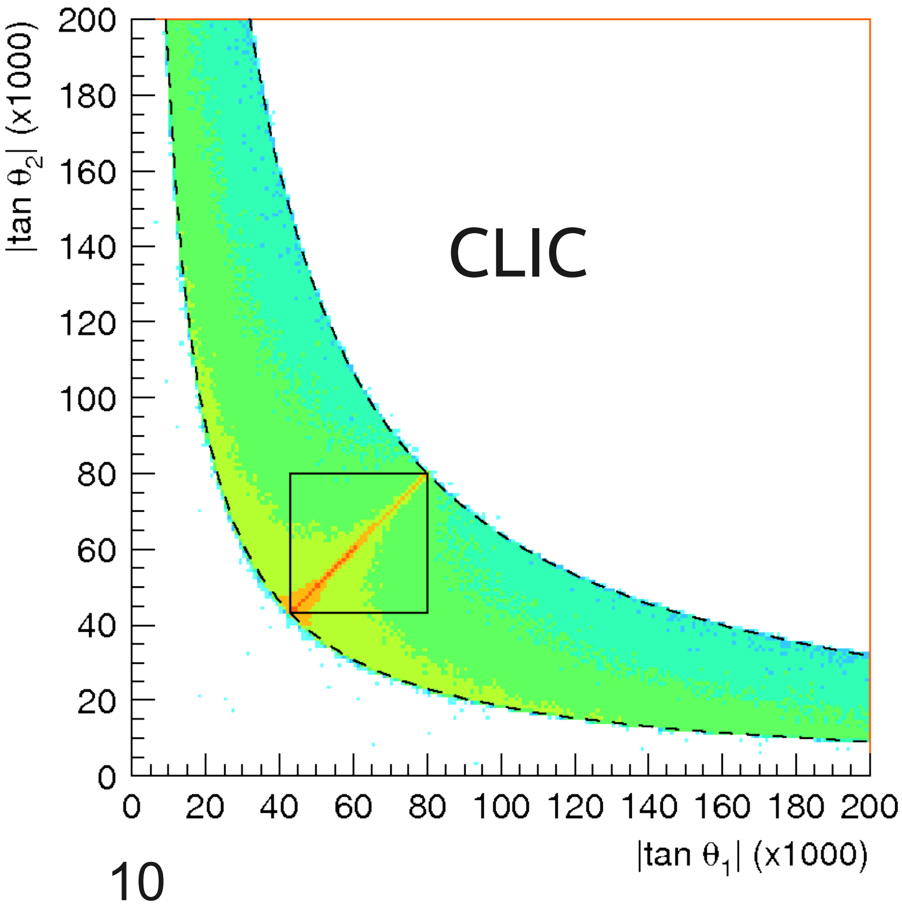


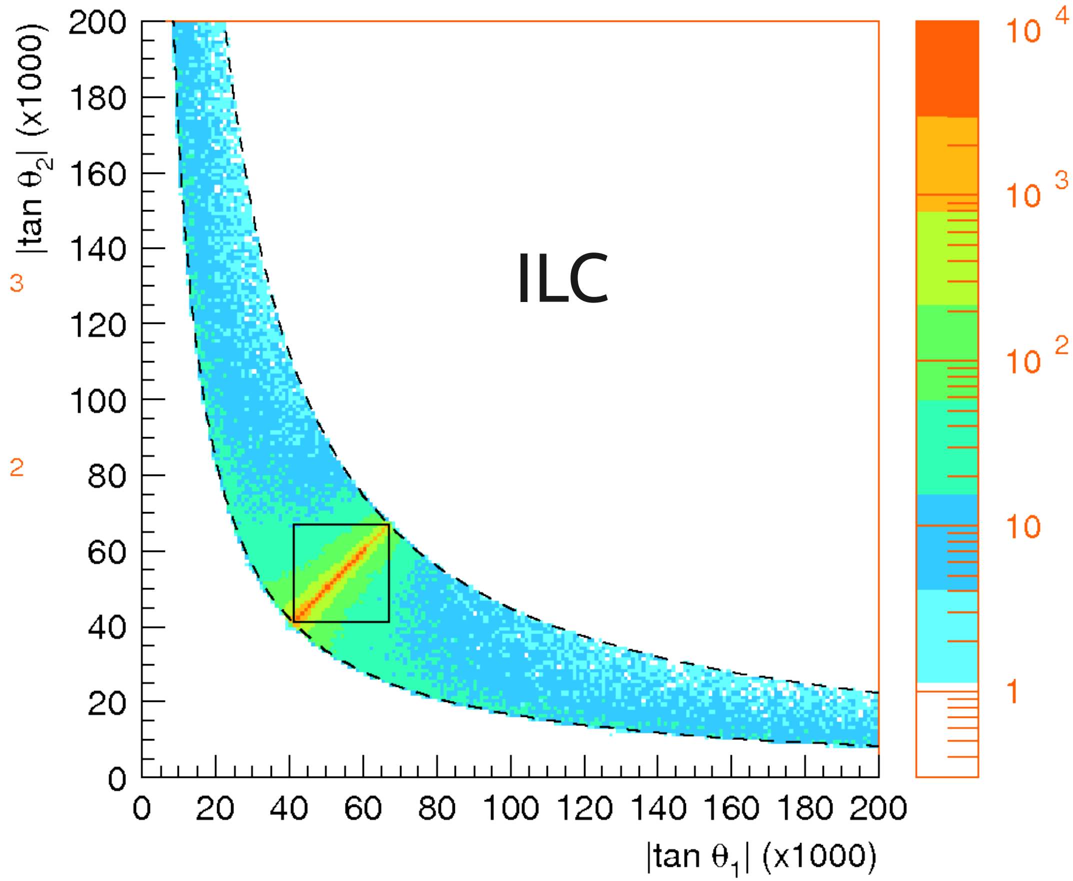


Emission of photons in both directions

Angular loss

- Distortion of polar angles due to BS+ISR emission along the beam axis



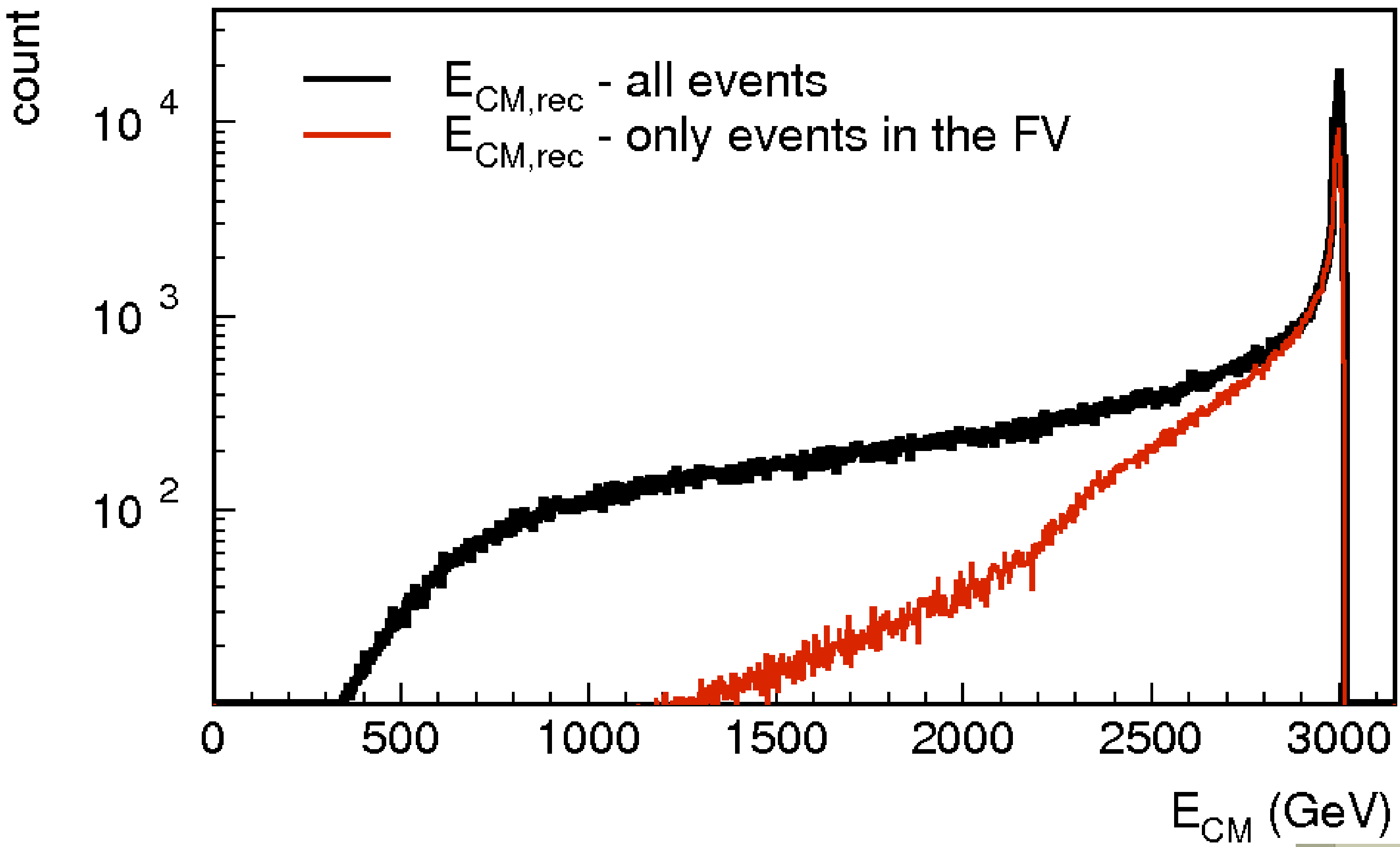


CLIC

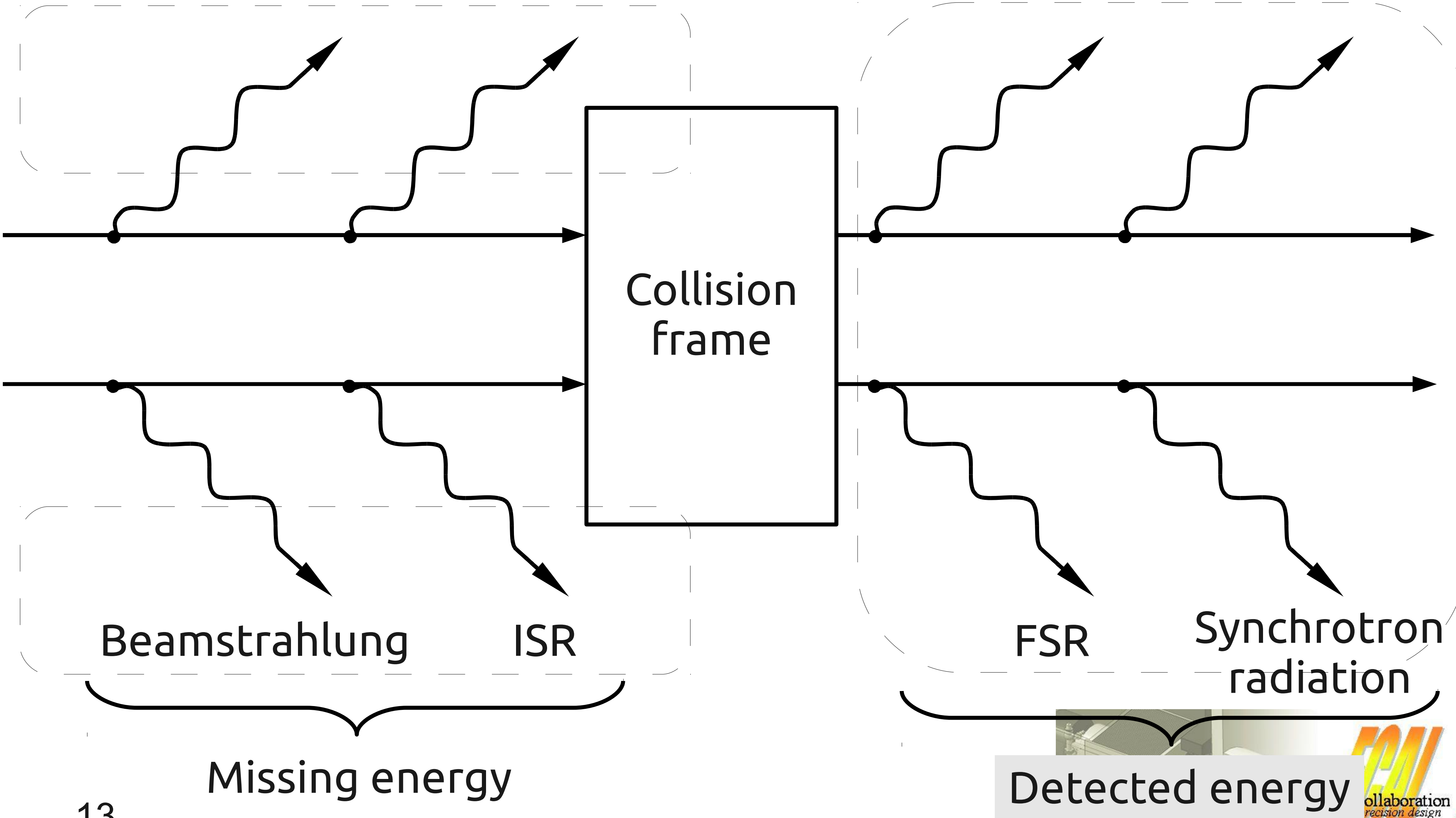
- Very intense beam-beam effects
- Most e^-e^+ collisions occur at energies significantly lower than 3 TeV
  - The luminosity in the peak is an important parameter
  - Reconstruction of the form of the spectrum is important
- Energy reconstruction by polar angles has difficulties due to the frequent emission of photons in both directions

Angular loss by E_{CM} at CLIC

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



Beam-beam processes affecting luminosity measurement

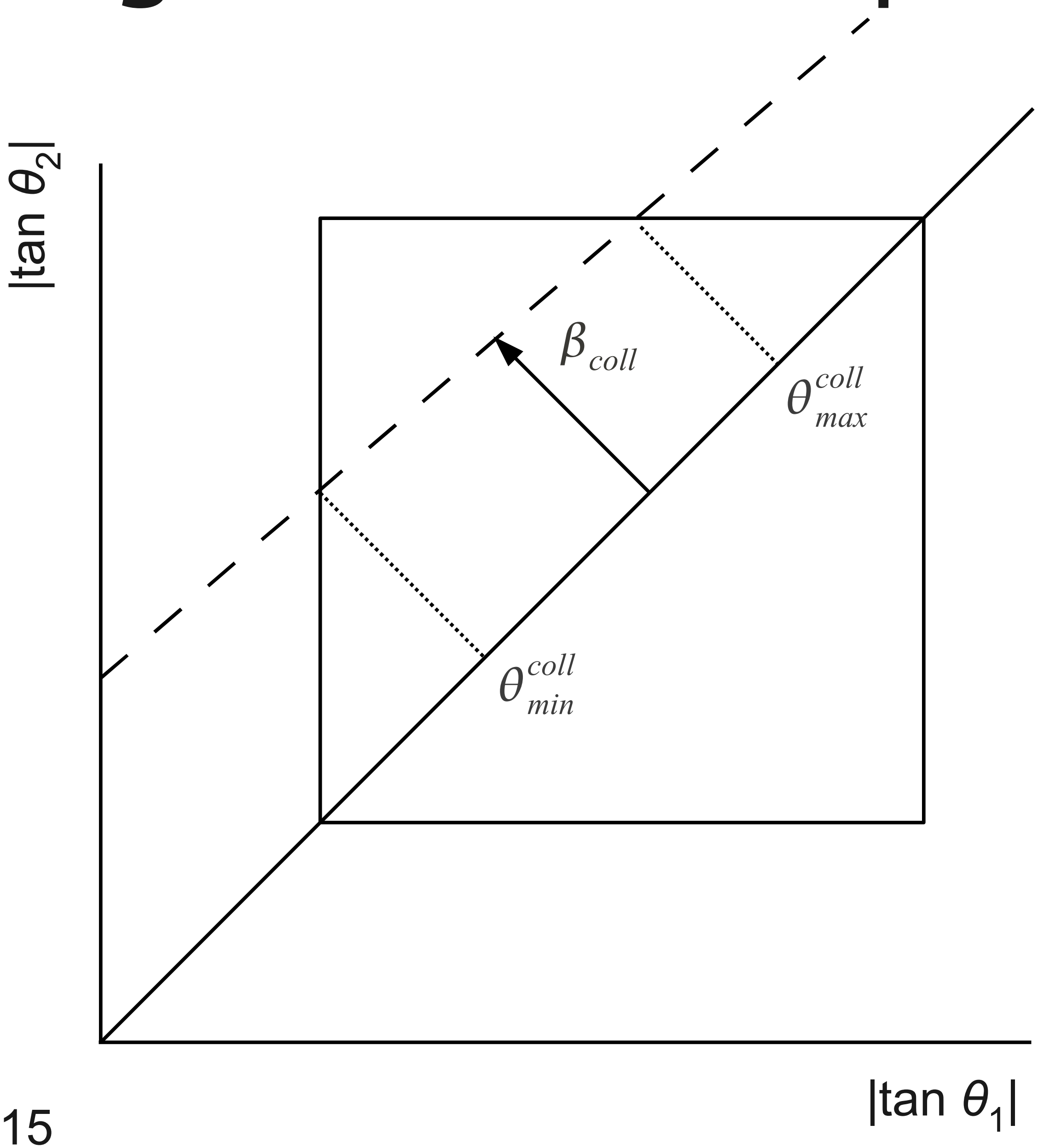


Correction of the BS+ISR angular losses

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_{coll}, 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

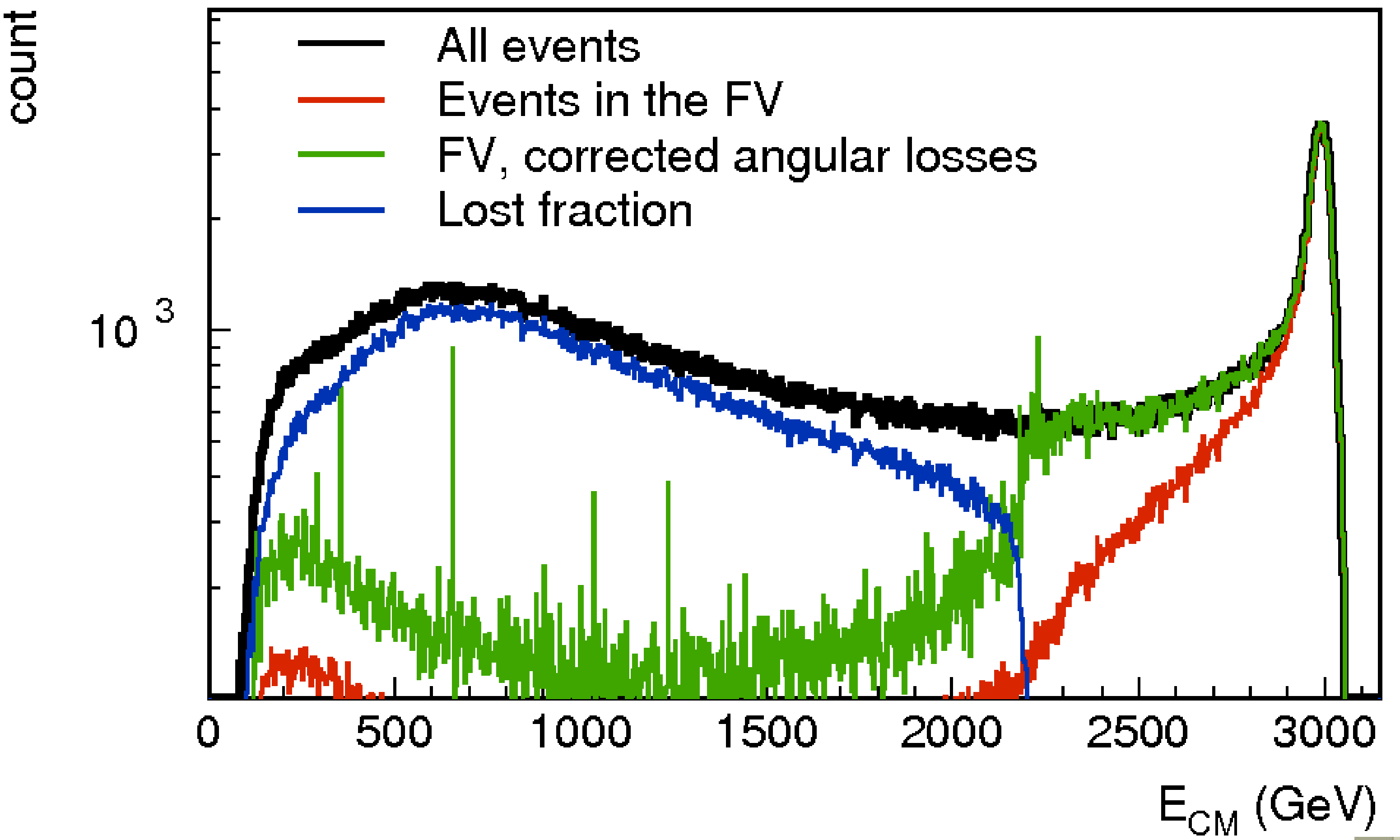
$$w(\beta_{coll}) = \frac{\int_{\theta_{min}}^{\theta_{max}} \frac{d\sigma}{d\theta} d\theta}{\int_{\theta_{min}^{coll}}^{\theta_{max}^{coll}} \frac{d\sigma}{d\theta} d\theta}$$

Assumptions

- Necessary
  - $\vec{\beta}_{coll} = \beta_{coll} \vec{e}_z$
  - All ISR is lost, all FSR is added up in the calorimeter
- Convenient
  - $\frac{d\sigma}{d\theta} \propto \frac{1}{\theta^3}$

Results of the angular-loss correction

- Reconstructed CM energies (after emission of ISR,
  - without correction of the *s*-dependence of the Bhabha xs,



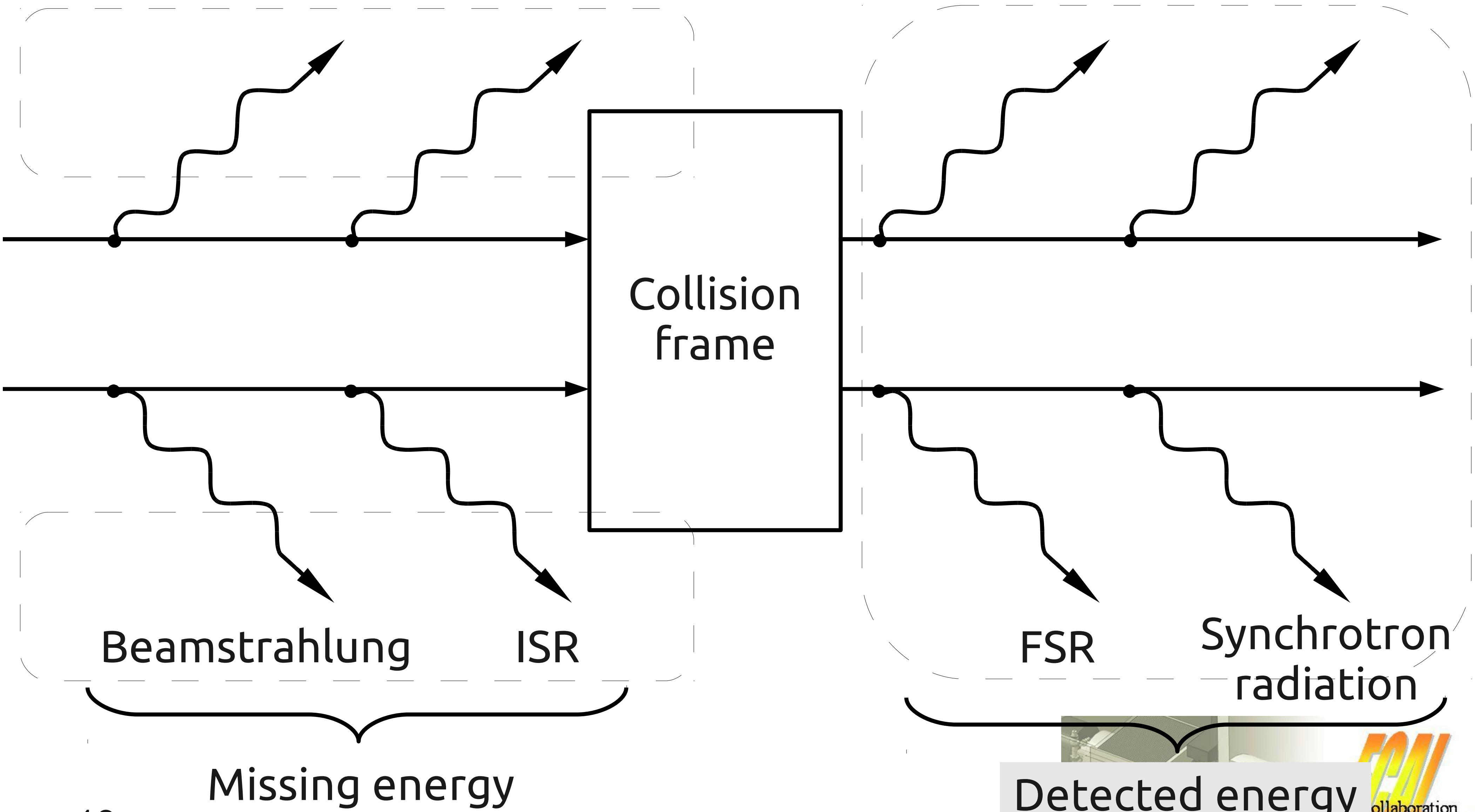
- LumiCal energy response included,

- collinear outgoing photons added)

Results of the angular-loss correction

- Deviation in the integral count in the top 5% of energy with respect to the control histogram:
  - Before correction: $(\Delta N/N)_{top5\%} = 3.7\ \%$
  - After correction: $(\Delta N/N)_{top5\%} = (-0.4 \pm 0.8) \times 10^{-3}$
    i.e. with the present statistic, no significant deviation in the corrected peak
  - Lost fraction: $(n_{lost}/N)_{top5\%} = (0.016 \pm 0.012) \times 10^{-3}$ (negligible)
- In the region of 80-90% of CM energy:
  - Before correction: $(\Delta N/N)_{80\text{-}90\%} = 42\ \%$
  - After correction: $(\Delta N/N)_{80\text{-}90\%} = (-6.2 \pm 4.4) \times 10^{-3}$
  - Lost fraction: $(n_{lost}/N)_{80\text{-}90\%} = (1.2 \pm 0.1) \times 10^{-3}$

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



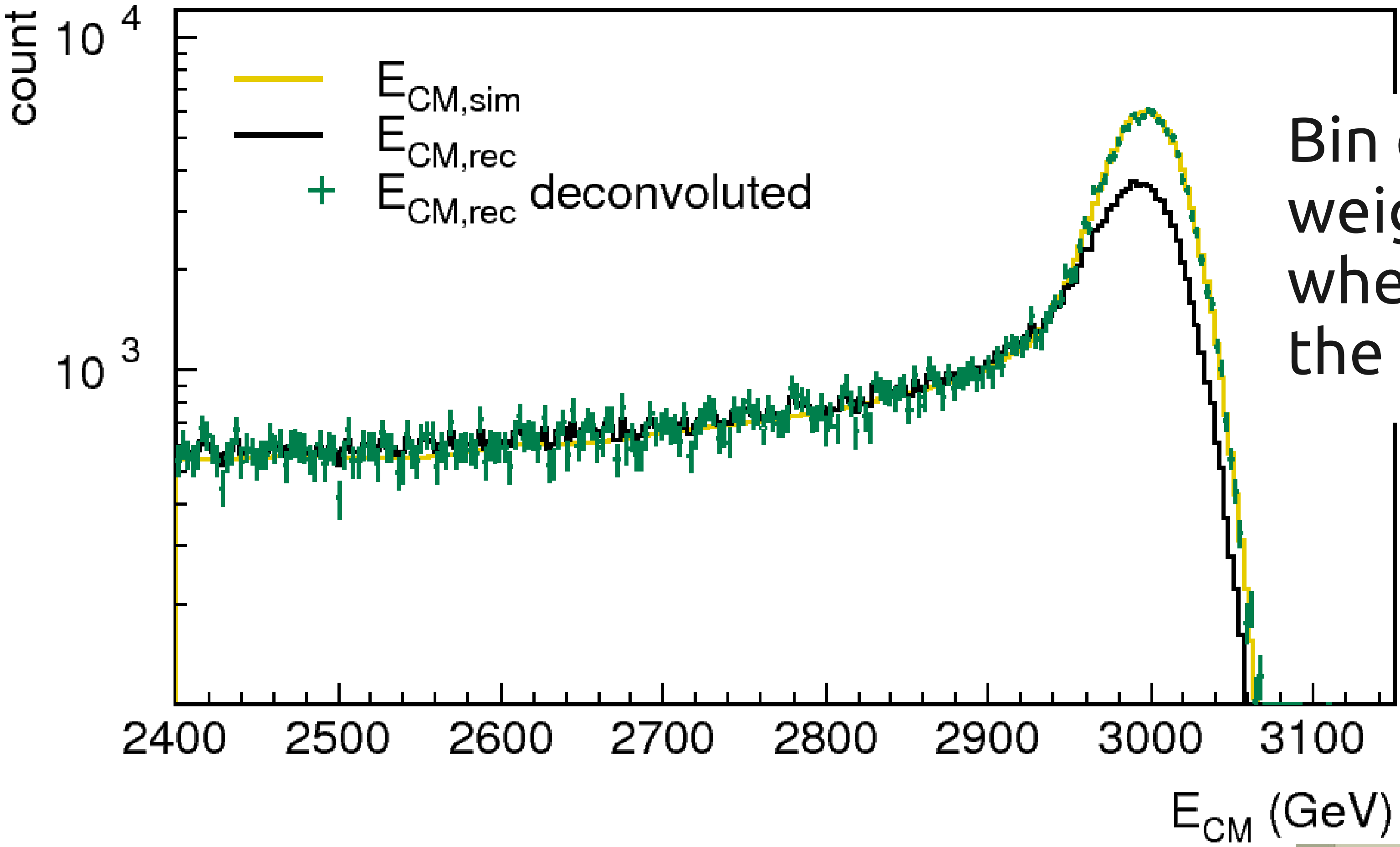
ISR energy loss

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

- 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*

ISR energy loss deconvoluted

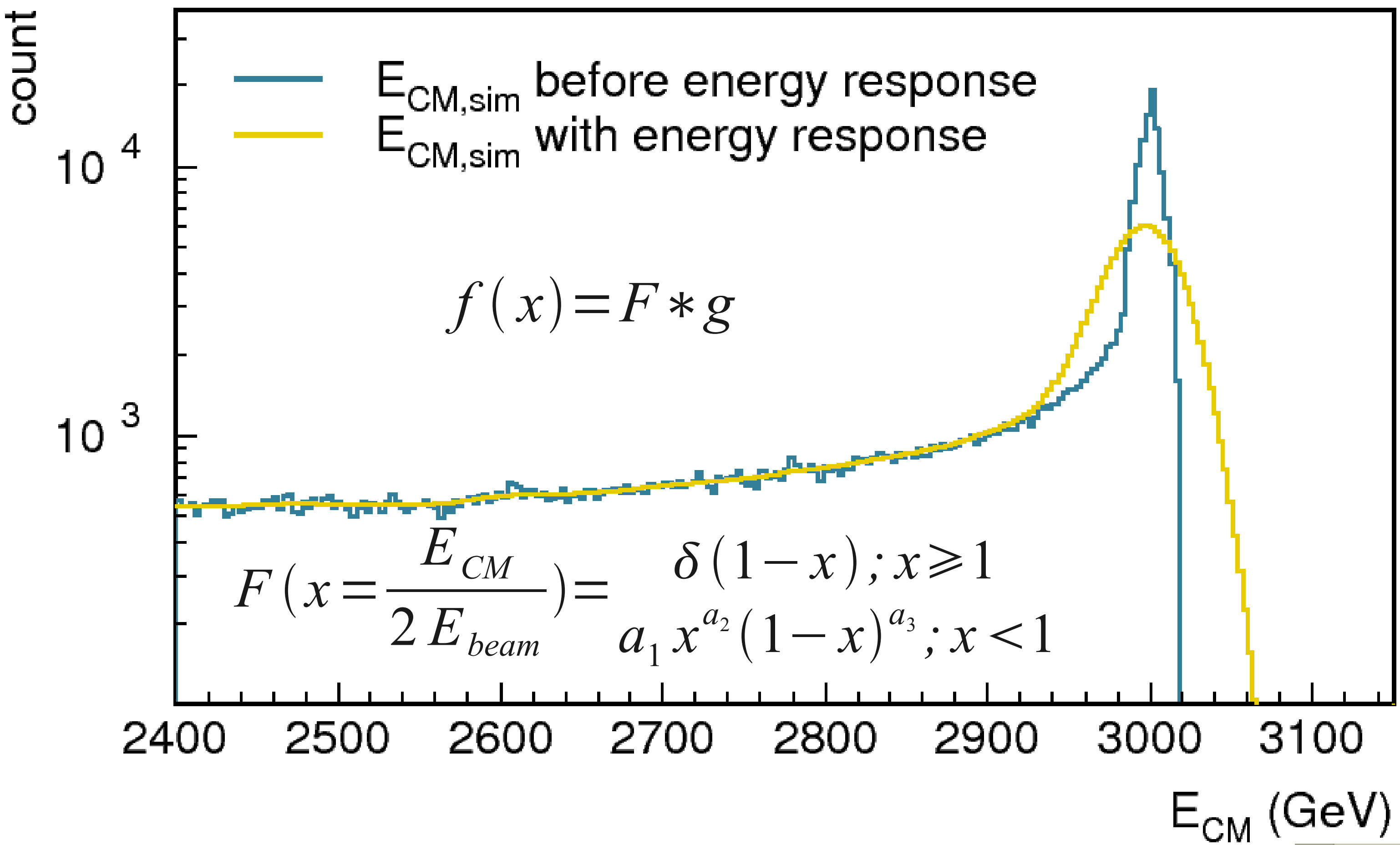
- Residual deviation in the top 5%: (-3.4 ± 3.4) x 10^{-3}
- Residual deviation in 80-90%: (42.8 ± 7.1) x 10^{-3}



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

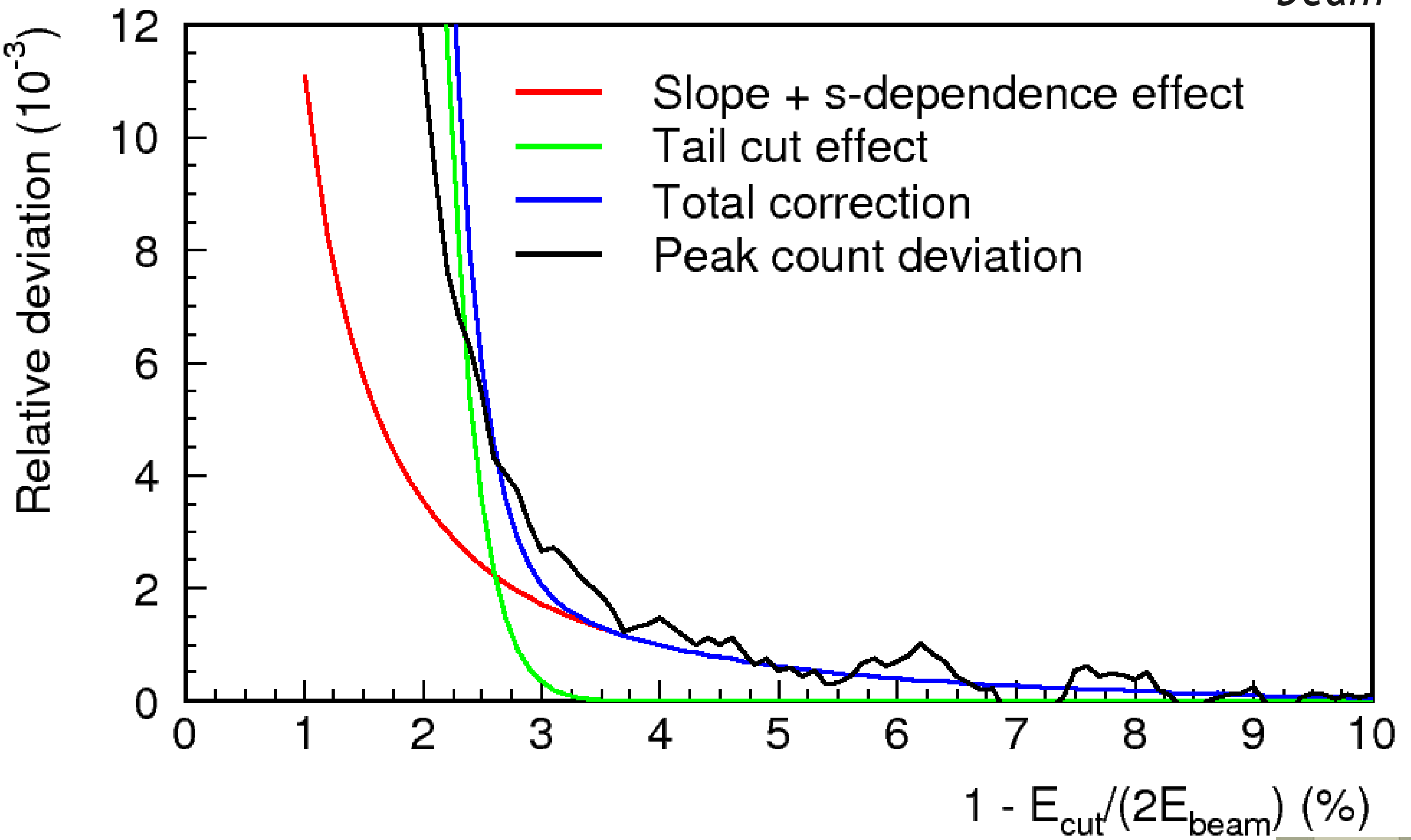


Finite energy resolution

- 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

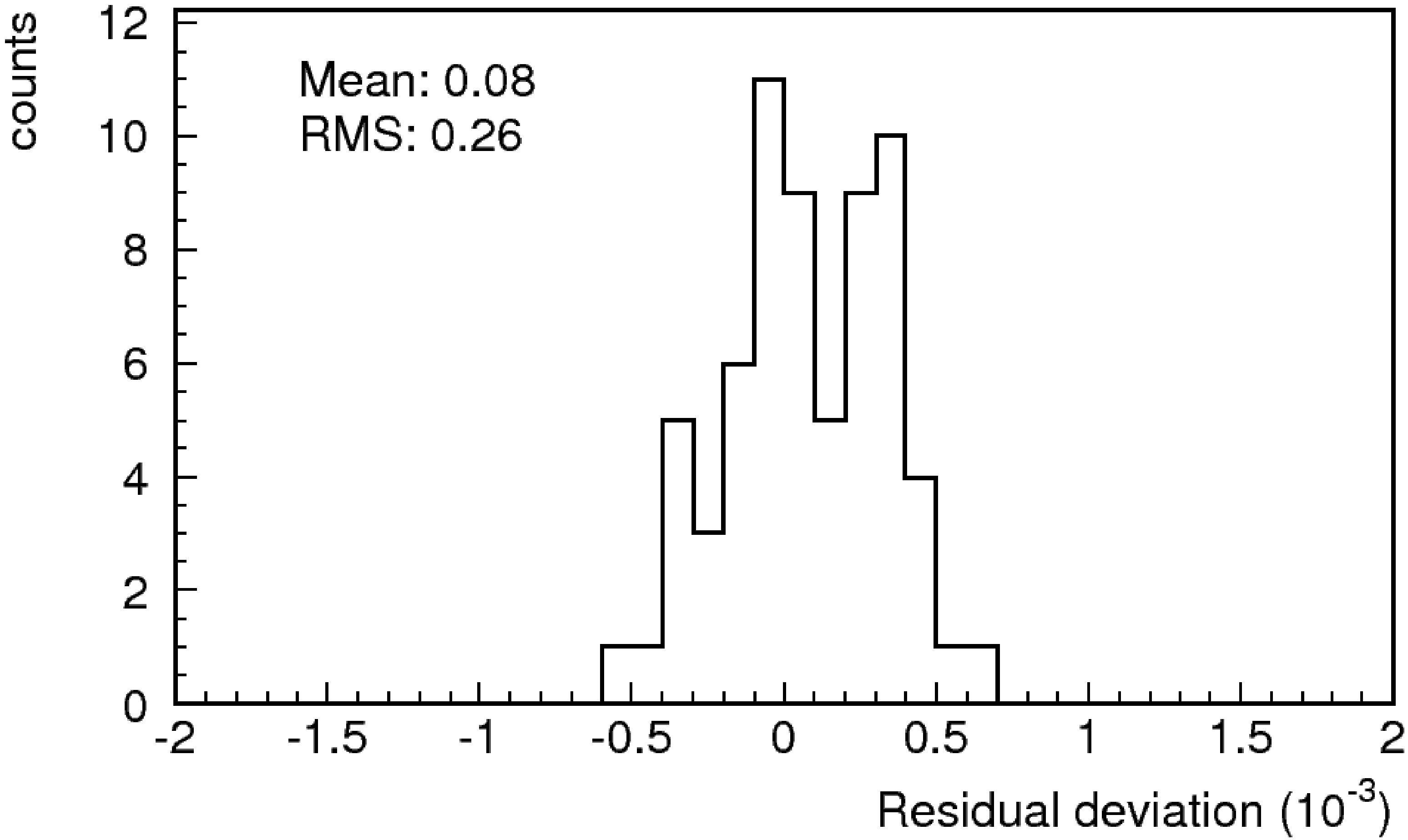
Finite energy resolution

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



Finite energy resolution

- Residual deviation for peak regions of 3.5% and more



CLIC - Summary

Step	Residual relative deviation $\Delta N/N$ (10^{-3}) in the top 5%
BS+ISR correction	0.4 ± 0.8
Deconvolution	3.4 ± 3.4
Energy resolution	0.08 ± 0.26
EMD (uncorrected)	0.54 ± 0.08
Events with high β_{coll}	0.016 ± 0.012

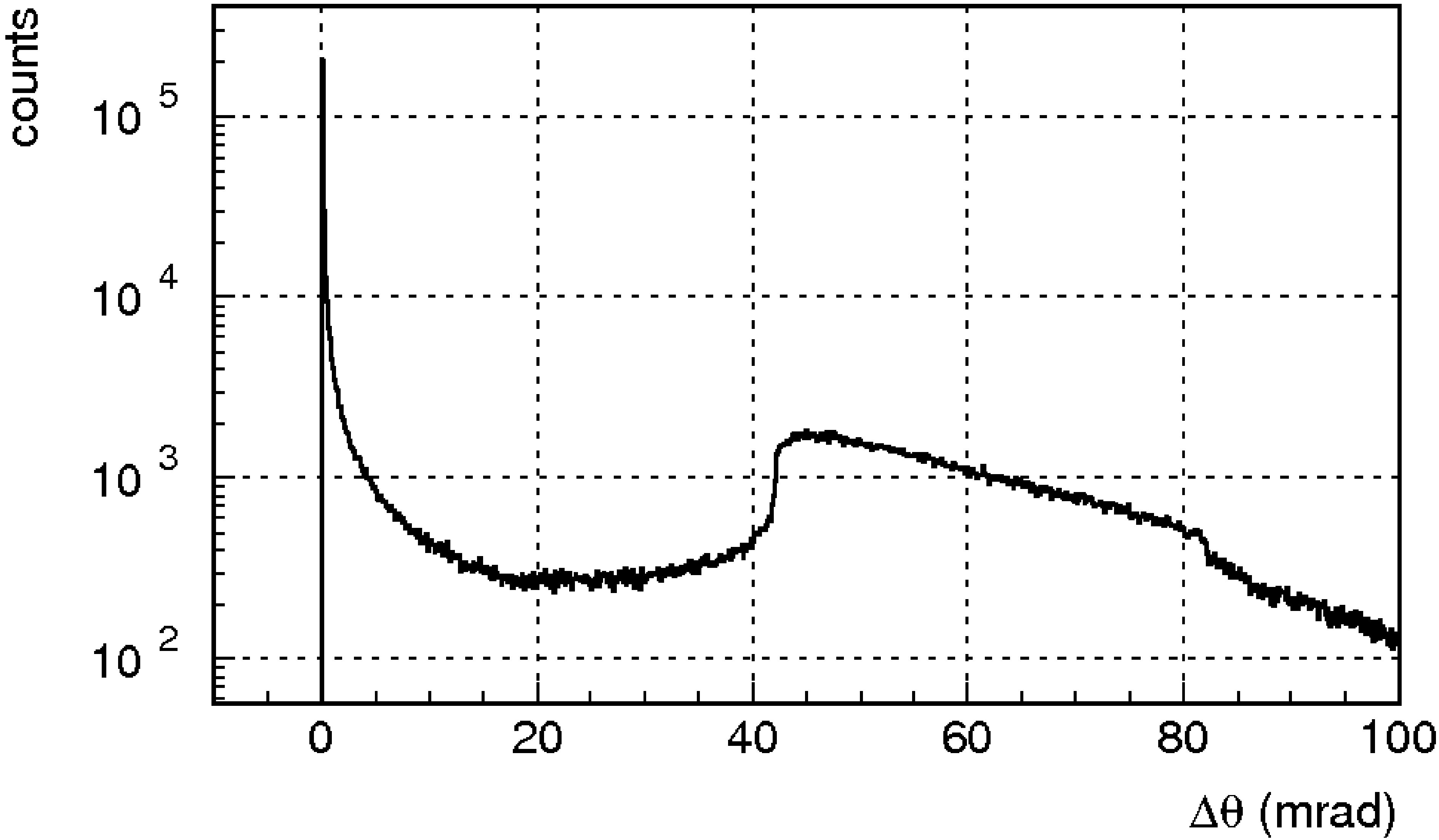
Conclusions

- The lumi spectrum at CLIC extends down to almost zero CM energy
- Bhabha events at lower energies mostly invisible to the LumiCal
  → Use LumiCal to precisely measure the absolute luminosity in and near the peak
- Above 2200 GeV, the luminosity spectrum can be measured with good precision, the residual uncertainty in the peak is several permille,
- The deconvolution error in the tail is several percent
- Energy reconstruction capability of the LumiCal is crucial for the $\sqrt{s}$ reconstruction at CLIC
- Complementary measurement of the form of the spectrum needed
  - At angles wider than LumiCal acceptance
  - Using the reconstructed 4-momenta of the outgoing particles
  - Normalize by the LumiCal measurement above 2.2 TeV

Thank you!

Additional slides

Fermion – BS photon angles



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

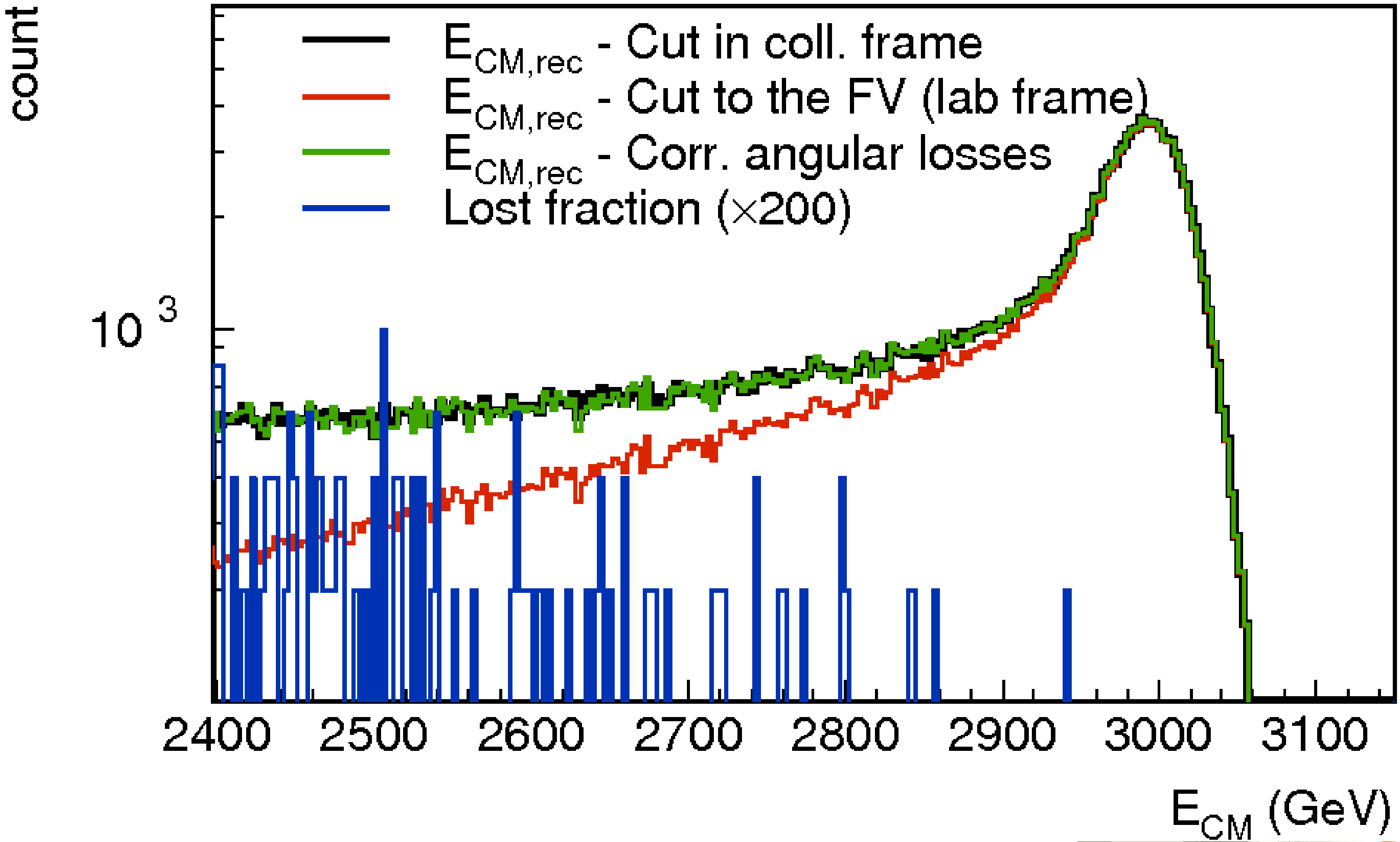
[1] D. Schulte, PhD Thesis, Hamburg, 1996

[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