Methods for the BHSE correction in luminosity measurement at ILC

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Introduction

Two methods for accurate handling of the beamstrahlung (BS) and one for EMD component of Bhabha Suppression Effect (BHSE) in the luminosity measurement at ILC will be presented.

• Tail-to-peak method determines experimentally the magnitude of the BS component of the BHSE in the integral spectrum by its correlation with the tail-to-peak ratio of the reconstructed CM energy spectrum.

• Compensation method relies on the appropriate selection algorithms to minimize the sensitivity of the BHSE to the beam profile variations.

• EMD component can be calculated in the experiment using a value from simulation

• Collision-frame-velocity method could correct the Beamstrahlung (BS) and ISR part of the BHSE based on the experimental reconstruction of the velocity of the collision rest frame of the Bhabha scattering. However, this method is still under study for ILC (see Strahinja's talk for the CLIC case)

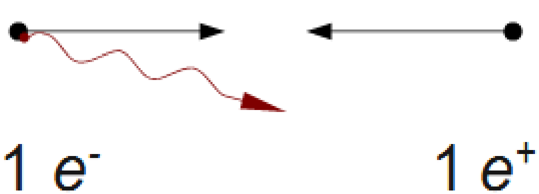
Luminosity measurement and BHSE

Luminosity measurement at ILC - measurement of event rate of the Bhabha scattering in very forward region of the detector, under very low polar angles

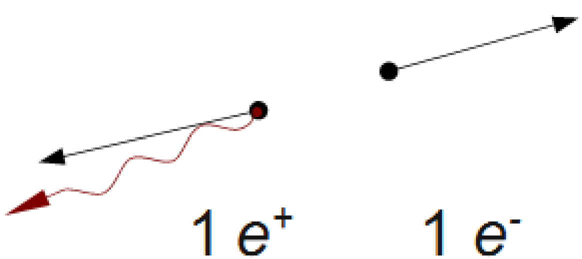
Problems:

- very strong beam-beam space charge effects in e^-e^+ collisions at ILC energies that may introduce large biases in the counting rate
- beamstrahlung, ISR and electromagnetic deflection (EMD) cause deviation from ideally symmetric kinematics of the Bhabha process

beamstrahlung (BS)– fermions emit gammas due to interaction with the EM field of the opposite beam



- **initial state radiation** (ISR) – gamma emission due to interaction with EM field of the particle – collision partner; angles of order of mrad with respect to the beam axis



- **final state radiation** (FSR) - gamma emission due to interaction with EM field of the particle – collision partner; angles of order of mrad with respect to the outgoing particle momentum direction

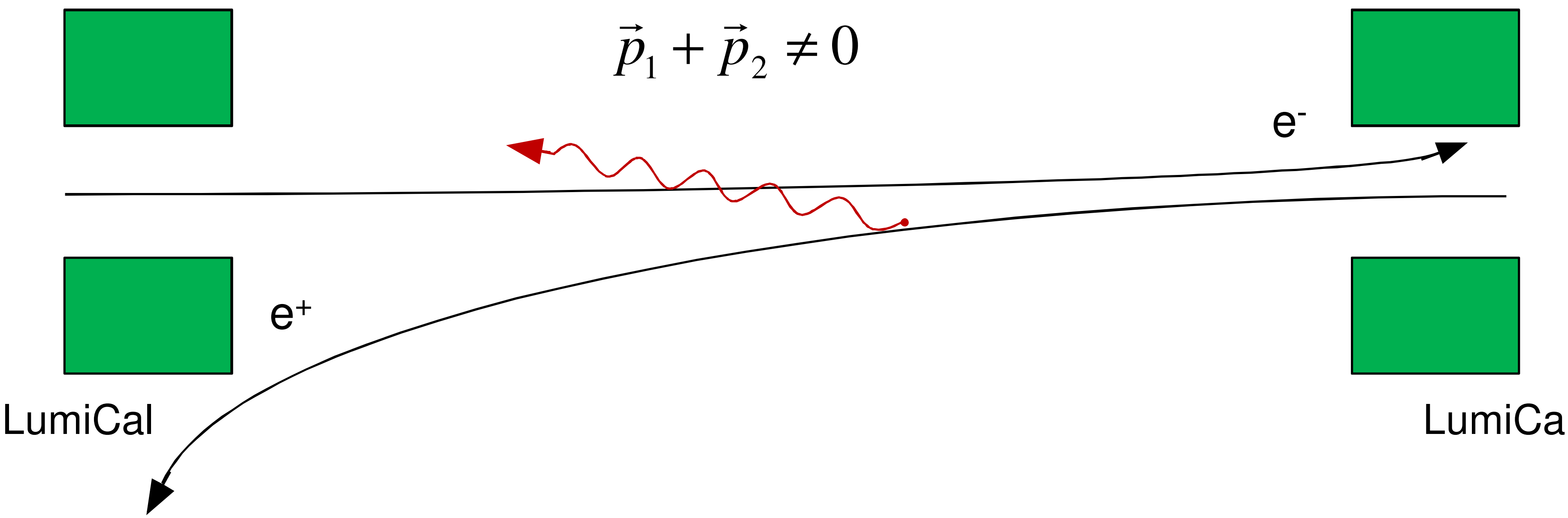
Luminosity measurement and BHSE

BS+ISR:

• asymmetric photon emission - disturbance of the total momentum

$$E_1 + E_2 < 2E_{beam}$$

$$\vec{p}_1 + \vec{p}_2 \neq 0$$



Consequence - systematic error in counting:

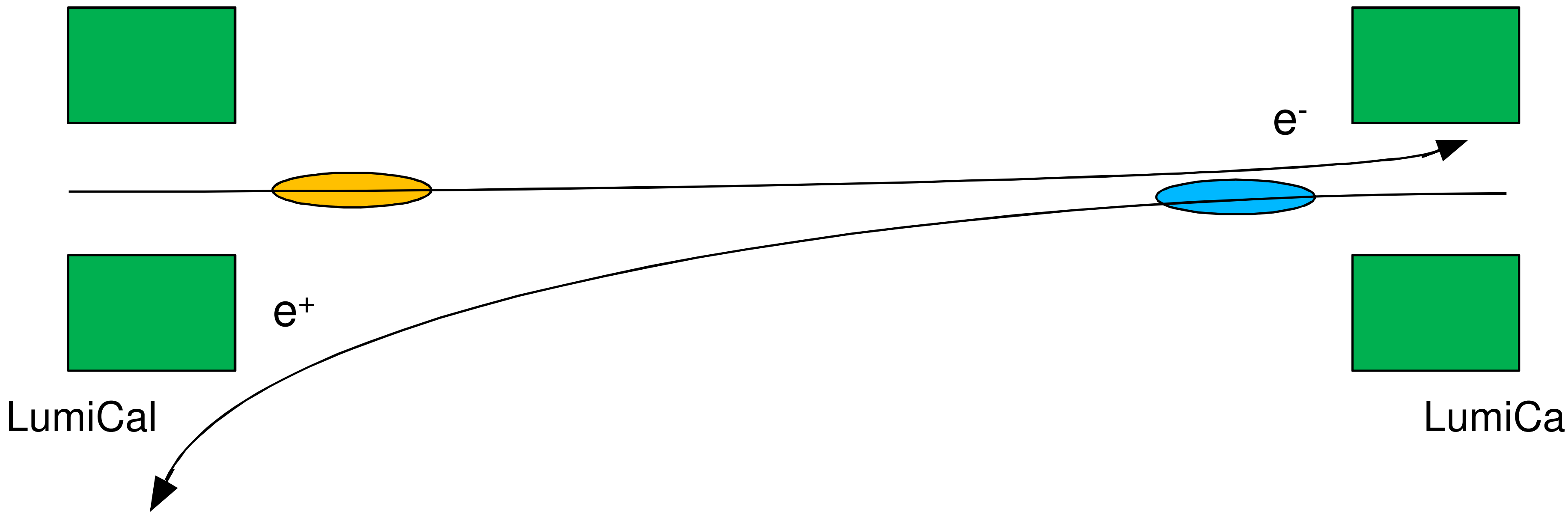
• energy loss
• deformation of polar angles

Luminosity measurement and BHSE

Electromagnetic deflection (EMD)

• deflection of outgoing fermions due to the interaction with the EM field of the moving beam

$$(\Delta\theta)_{EMD} \sim 0.1\, mrad$$



Consequence - systematic error in counting:

• deformation of polar angles

Simulated events

GuineaPig is used to simulate events with nominal beam parameters and with beam imperfections.

- beam energy is 250 GeV,
- fiducial volume between 41 and 67 mrad (ILD geometry),
- only events with $\sqrt{s'} > 400$ GeV were counted towards the luminosity estimates.

Beam imperfections simulated with the Guinea-PIG :

- bunch size and charge symmetric variations of 10 and 20%,
- asymmetric bunch size and charge one-sided 20% variations,
- x- and y-offset by 20% and 100% of the respective bunch RMS widths

Typical sample size ~ 150 000 events
No detector simulation!

The tail-to-peak method

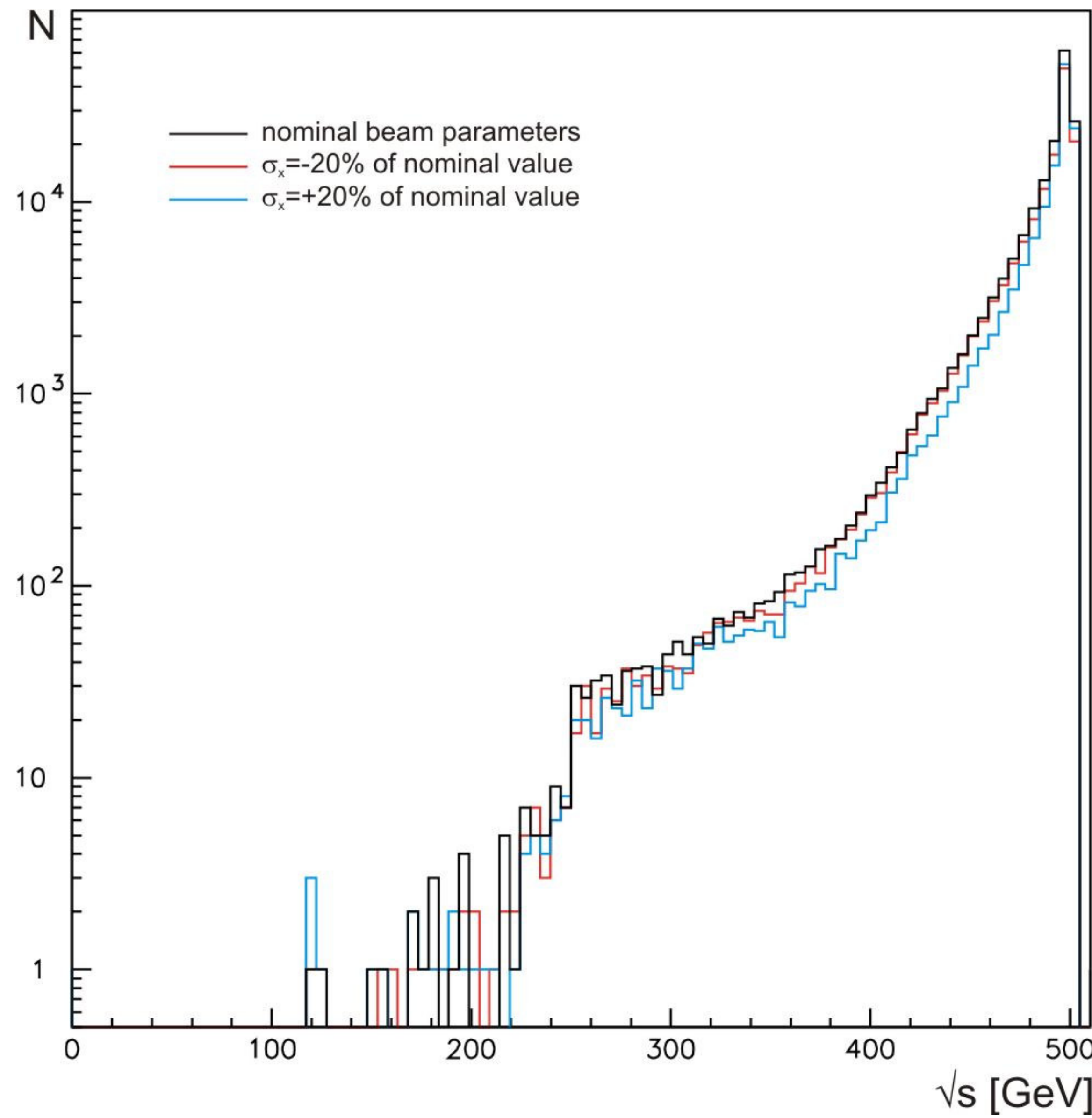
Motivation:
Counting loss due to BHSE is correlated with the radiative energy loss

• BS component estimated by measuring the ratio between integrals of the reconstructed luminosity spectrum in the tail and in the peak.

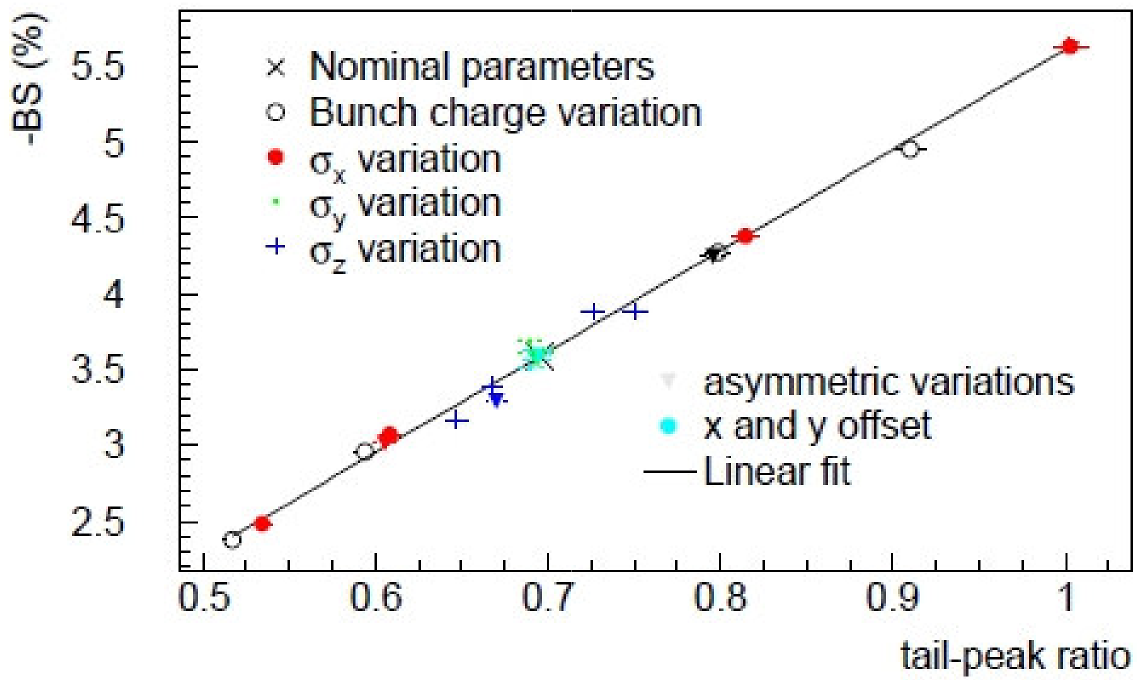
• Tail integral range: 400 to 490 GeV

• Peak integral: from 499 GeV upwards.

• These energy ranges of the tail and the peak can be optimized to maximize the sensitivity.



The tail-to-peak method



• Linear correlation - BS in the integral measurement can be estimated from the mean value of the tail-to-peak ratio, regardless of the fluctuations of the bunch parameters.

• Average residual difference of the BS from the fitted values is 0.041% of the total luminosity,

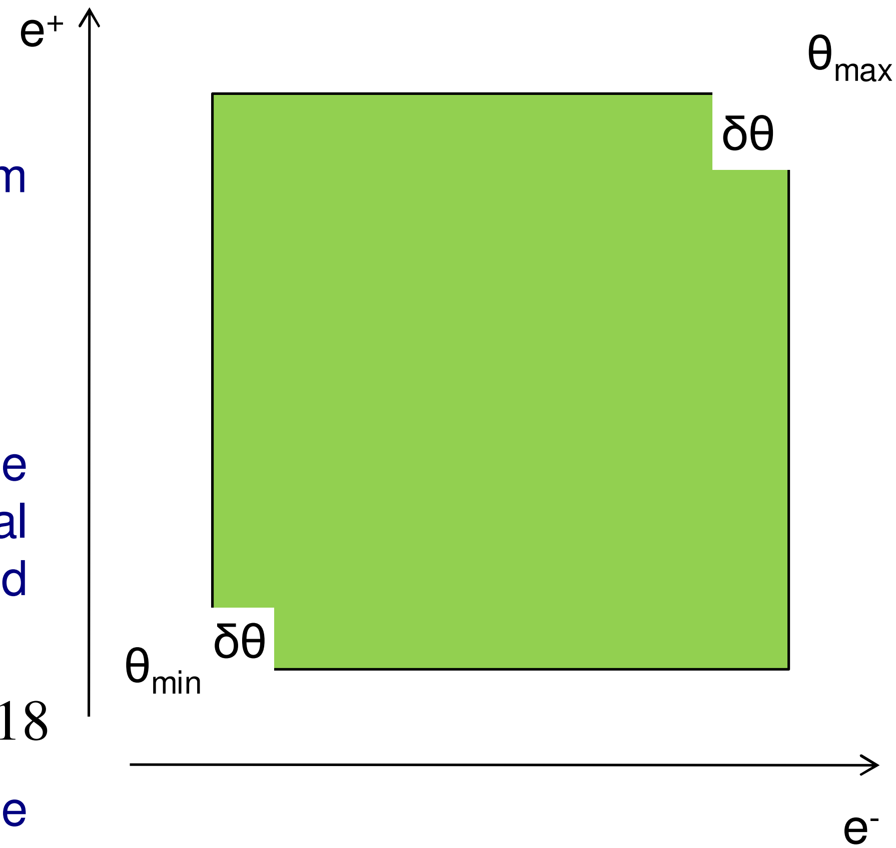
• BS statistical uncertainty ranges from 0.04 to 0.06% of the total luminosity.

The compensation method

• Based on appropriately tailored counting volume (presented at the previous FCAL Workshop in Belgrade by Strahinja).

• Compensates between BS and EMD.

• Can be tuned to optimize BHSE sensitivity to beam parameters.



Complications:

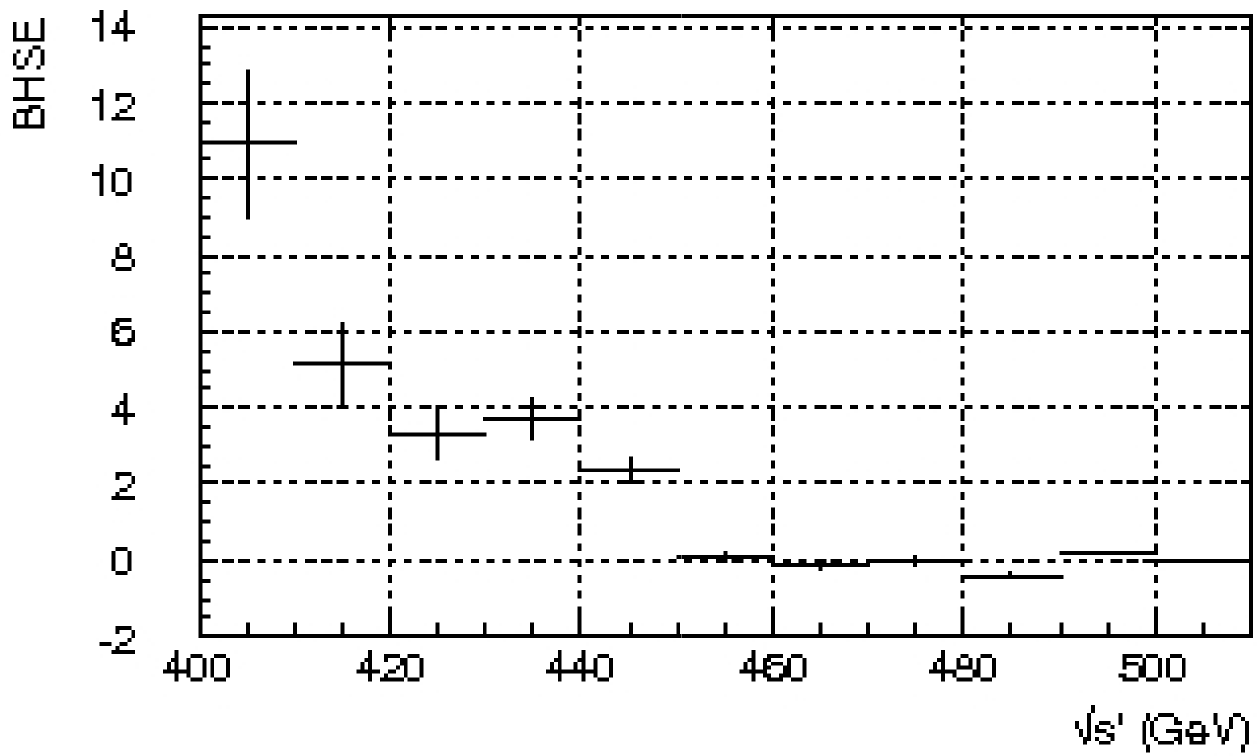
• In order to take into account deformation of the measured √s' spectrum with respect to the nominal one, δθ should be dependent on the reconstructed CM energy.

$$\delta\theta(rad) = -1.0232 \cdot 10^{-4} \cdot \sqrt{s'_{recons.}(GeV)} + 0.05118$$

• More complicated theoretical estimation of the Bhabha x-section for a 'dented volume'.

The compensation method

• The simulated BHSE ranged from -0.073 to 0.097% of the total luminosity (bunch size and charge variations included). The statistical uncertainties of the simulated BHSE were typically around 0.02%.



The EMD component

- EMD shifts the polar angles of the outgoing particles towards smaller angles

- due to the Bhabha cross section θ dependence ($\sim 1/\theta^3$),the net result of EMD is an effective decrease in the Bhabha count

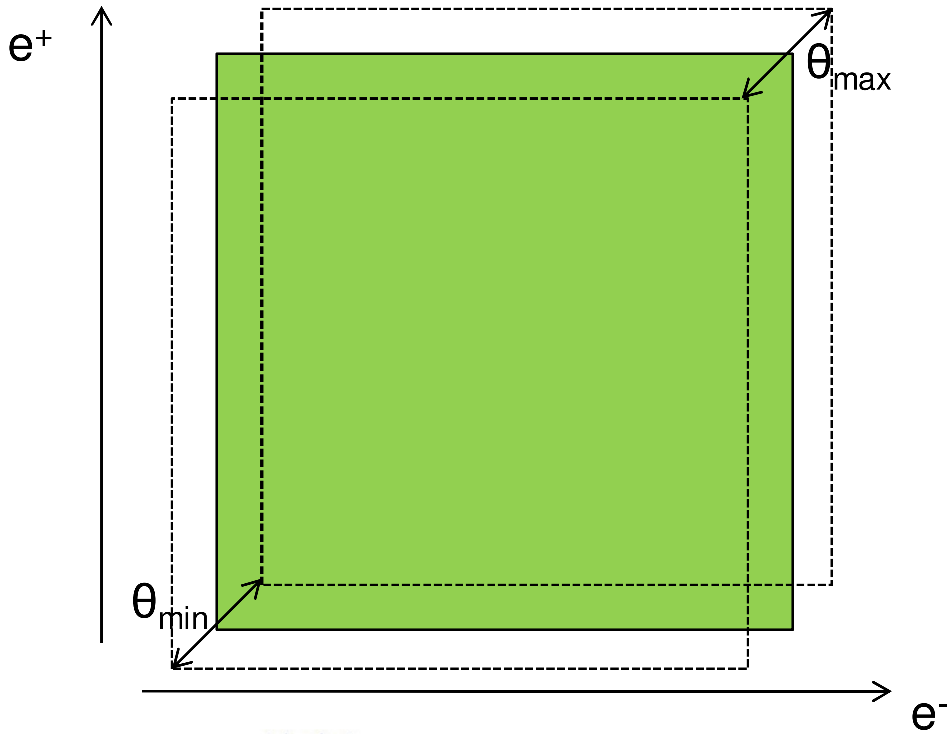
- equivalent to a parallel shift of θ_{min} and θ_{max} by an effective mean deflection Δθ in the opposite directions

- a quantity to measure: $x_{EMD} = \frac{1}{N}\frac{\Delta N}{\Delta \theta}$, where N is the Bhabha count in the fiducial volume, Δθ is a parallel small shift of both θ_{min} and θ_{max} and ΔN is the difference in counts in the “real” and shifted FV.

Procedure

Obtaining x_{EMD}:

• shifting the FV for small increments θ_{shift} and counting the number of events N_{shift} for each θ_{shift}
• calculate $\Delta N = N_{shift} - N_{FV}$, where N_{FV} is the count in FV
• fitting the slope $\Delta N/\Delta\theta_{shift}$
• This can be done both with simulated and experimental data.



Getting the EMD component of the BHSE

- Calculate the EMD component of the BHSE in the simulation as $(\Delta L/L)_{sim} = (\Delta N/N)_{sim}$

- From the quantities obtained in the simulation, calculate the effective mean deflection as:

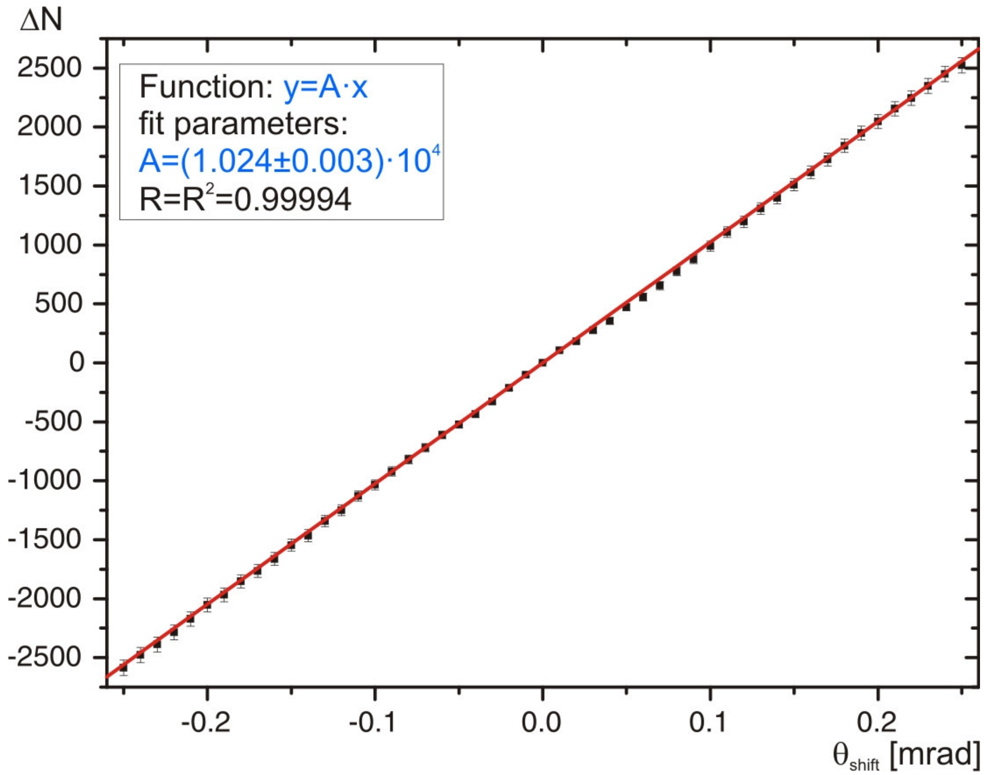
$$(\Delta\theta)_{sim} = \frac{(\Delta L / L)_{sim}}{\left(\frac{1}{N}\frac{dN}{d\theta}\right)_{sim}}$$

- In the experiment, obtain $(dN/d\theta)_{exp}$ in the analysis

- Calculate the EMD component in the experiment as:

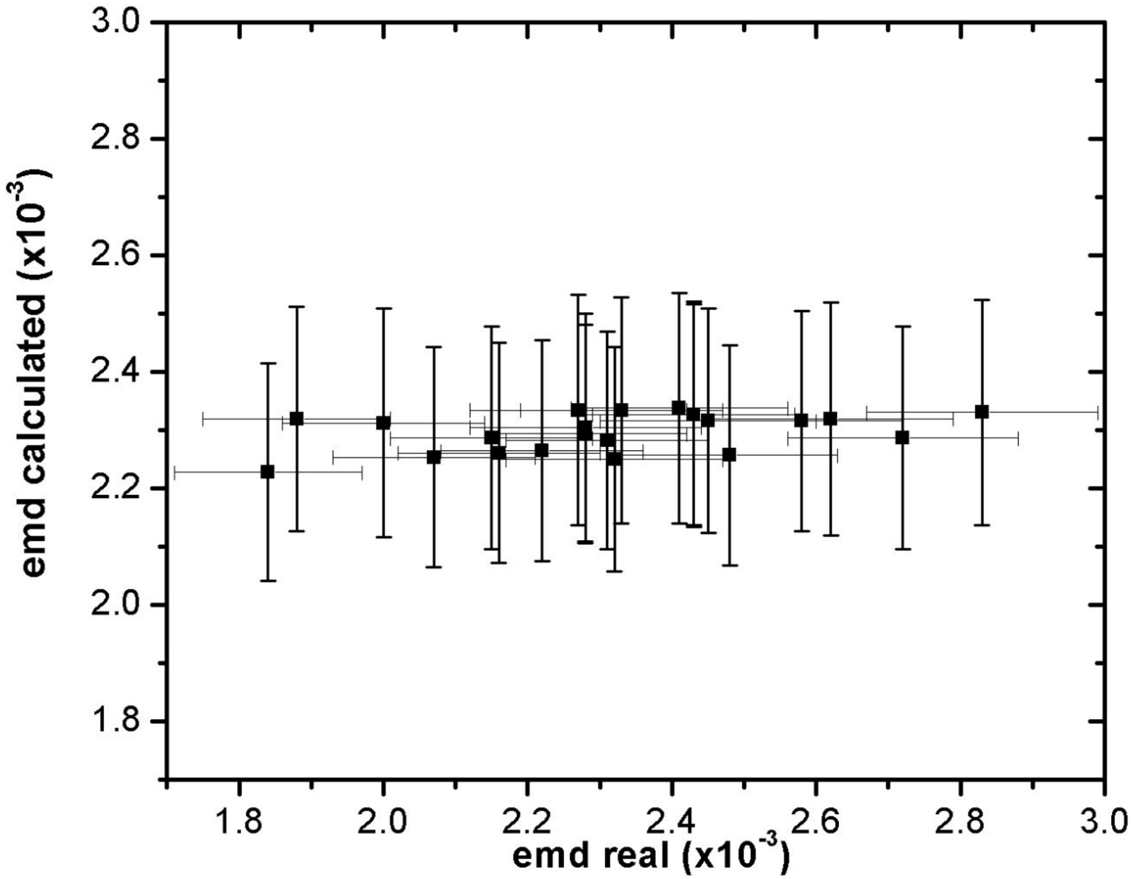
$$\left(\frac{\Delta L}{L}\right)_{\exp} = \left(\frac{1}{N}\frac{dN}{d\theta}\right)_{\exp} (\Delta\theta)_{sim}$$

Getting the EMD component of the BHSE



- $dN/d\theta=(1.024\pm0.003)\cdot10^{4}$ mrad^{-1}
- number of counts in the FV in the simuilation was $N_{FV}\approx165000$
- EMD component of the BHSE was $(\Delta L/L)_{sim}=(2.29\pm0.14)\cdot10^{-3}$
- resulting effective mean deflection is $\Delta\theta=(0.0367\pm0.0023)$ mrad
- uncertainty of $\Delta\theta$ comes from the limited statistics in the simulation, and contributes to a relative uncertainty of $1.7\cdot10^{-4}$ in luminosity.

Testing the method



- Δθ value obtained with the nominal beam parameters
- various beam imperfections assumed (as on slide 7)
- error on EMD estimate due to the beam imperfections results in uncertainty of $\pm 5 \cdot 10^{-4}$ of the total luminosity

Conclusion

Tail-to-peak method:
• corrects BS with a precision that is at least as good as $4{\cdot}10^{-4}$ of the total luminosity.

Compensation method:
• Compensating between BS and EMD, the total BHSE can be reduced close to 0.
• Due to the beam parameter variations error in determination of BHSE results in luminosity uncertainty of 0.1% of the total luminosity.
• Difficultiy: a slight difference between the reconstructed and the real CM energy spectra may introduce an additional uncertainty in the cross section calculation.

EMD component:
• treated separately from the BS.
• Using the simulation, EMD can be determined from the experimental quantities (but not in a completely simulation independent manner).
• Relative uncertainty due to the beam imperfections is below $5{\cdot}10^{-4}$ of the total luminosity. This method can be combined with the tail to peak method.

Backup

The tail-to-peak method

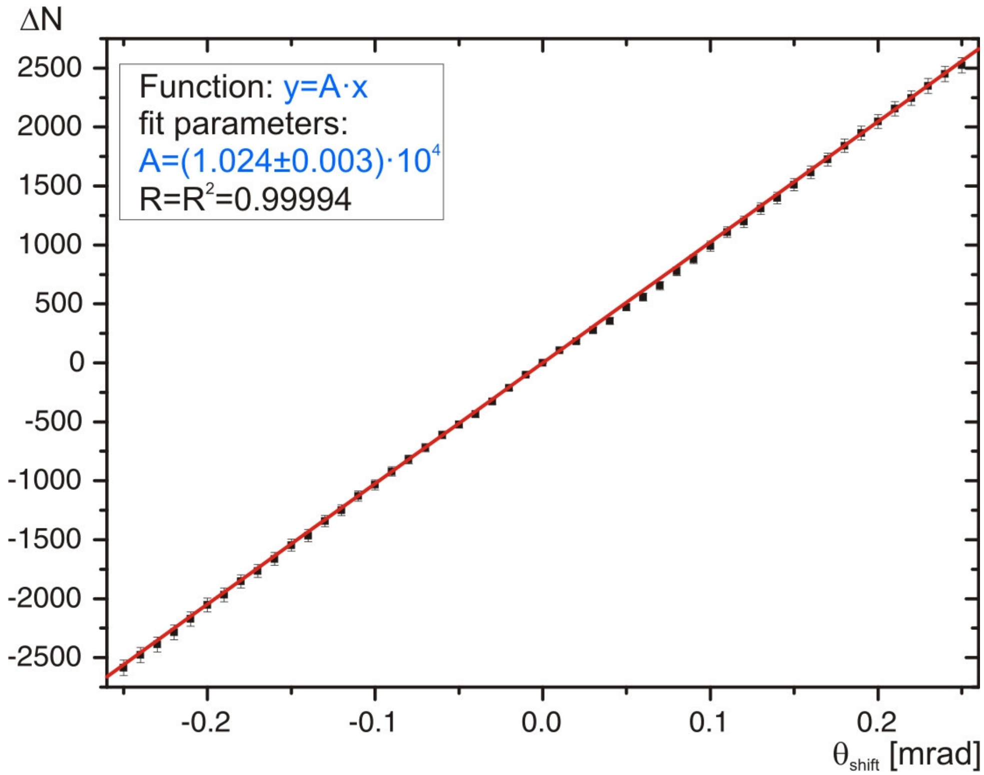
The CM energies are reconstructed as in *:

$$\frac{\sqrt{s'}}{\sqrt{s}} = \sqrt{1 - 2\frac{\sin(\theta_1 + \theta_2)}{\sin(\theta_1 + \theta_2) - \sin\theta_1 - \sin\theta_2}}$$

where θ_1 and θ_2 are are polar angles of the final state charged particles.

* K. Mönig, Measurement of the differential luminosity using bhabha events in the forward-tracking region at TESLA (LC-PHSM-2000-60-TESLA).

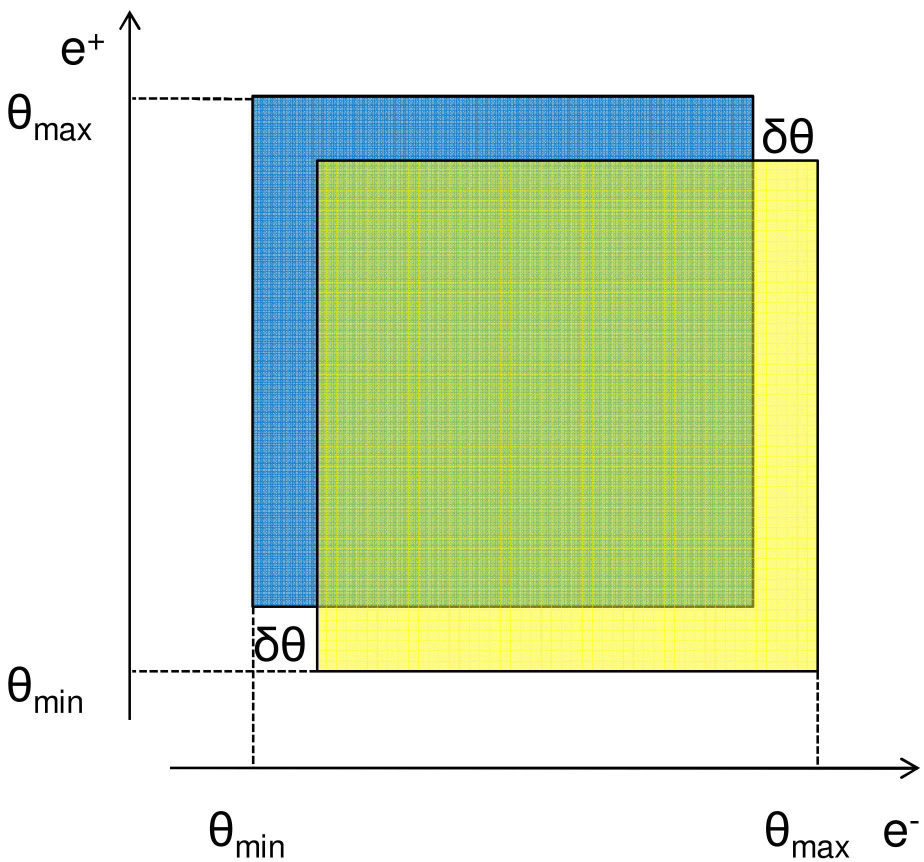
Getting the EMD component of the BHSE



$\Delta N = N_{shift} - N_{FV}$, the difference between counts in the shifted FV ($\theta_{min}+\theta_{shift}$, $\theta_{max}+\theta_{shift}$) and real FV ($\theta_{min}$, θ_{max})

statistical errors of ΔN were estimated as $\delta(\Delta N)=\sqrt{(n_{shift}+n_{FV})}$, because $N_{shift}=N'+n_{shift}$ and $N_{FV}=N'+n_{FV}$, and N' is the number of events inside the intersection of the FV with the shifted FV.

The compensation method



• More complicated theoretical estimation of the Bhabha x-section for a 'dented volume‘:

$$\sigma_{Bhabha} = \sigma_{blue} + \sigma_{yellow} - \sigma_{green}$$