Impact of beam-beam effects on precision luminosity measurements at the ILC

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Impact of beam-beam effects on precision luminosity measurements at the ILC

- Principle of luminosity measurement using Bhabha scattering
- Modifications due to beam-beam effects
- Consequences on reachable luminosity precision
- Dependence with the bunch parameters and energy
- Summary and conclusions

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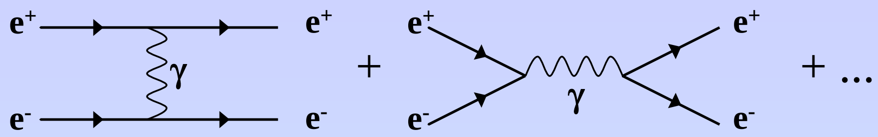
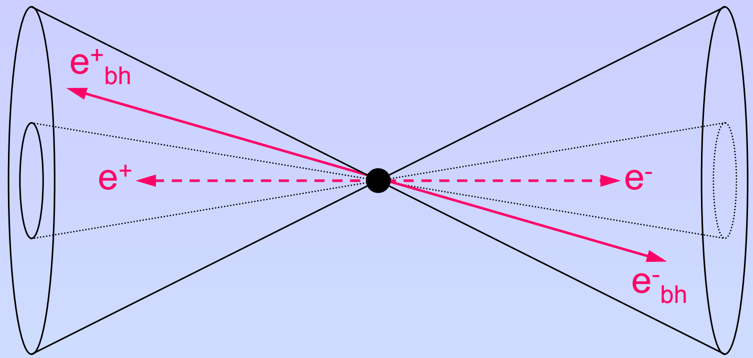
Luminosity measurement in the LumiCal using Bhabha scattering at small angles





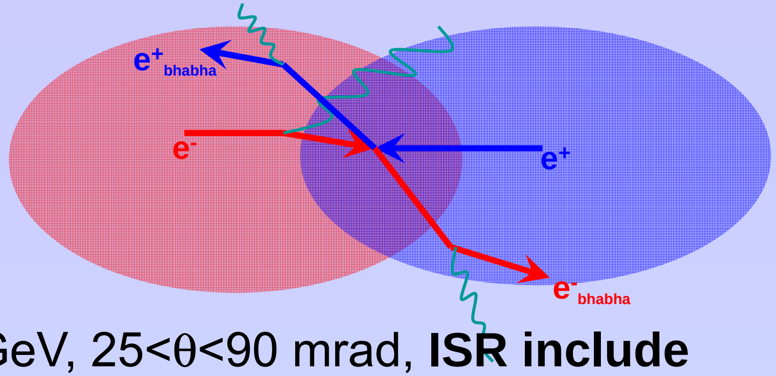
- Bhabha particles are detected in coincidence in the luminosity monitor LumiCal covering a range of 26.2 to 82 mrad.

- $\mathcal{L} = N_{Bh}/\sigma_{Bh}$ from counting rate ➔ **integrated luminosity** ($\Delta\mathcal{L}/\mathcal{L}$: 10^{-3}-10^{-4})

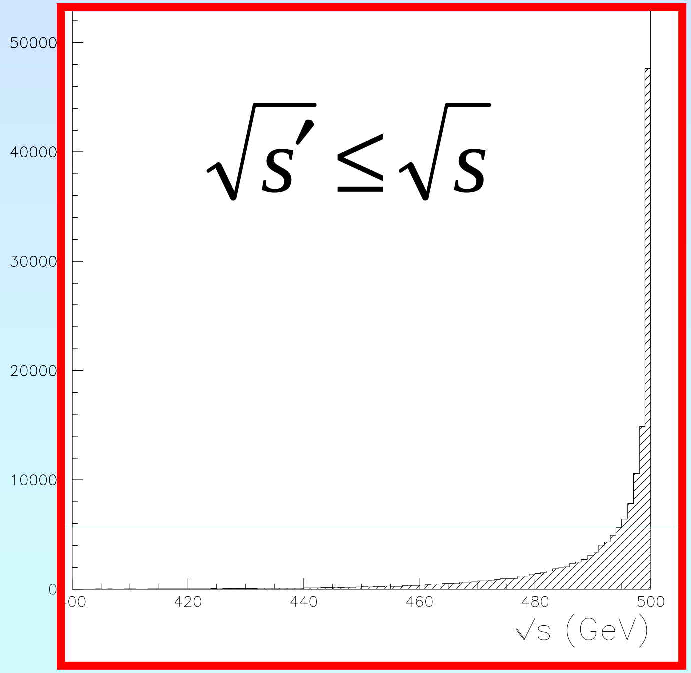
$$\frac{d\sigma_{Bhabha}}{d\vartheta} \approx \frac{32\pi\alpha^2}{s}\frac{1}{\vartheta^3}$$

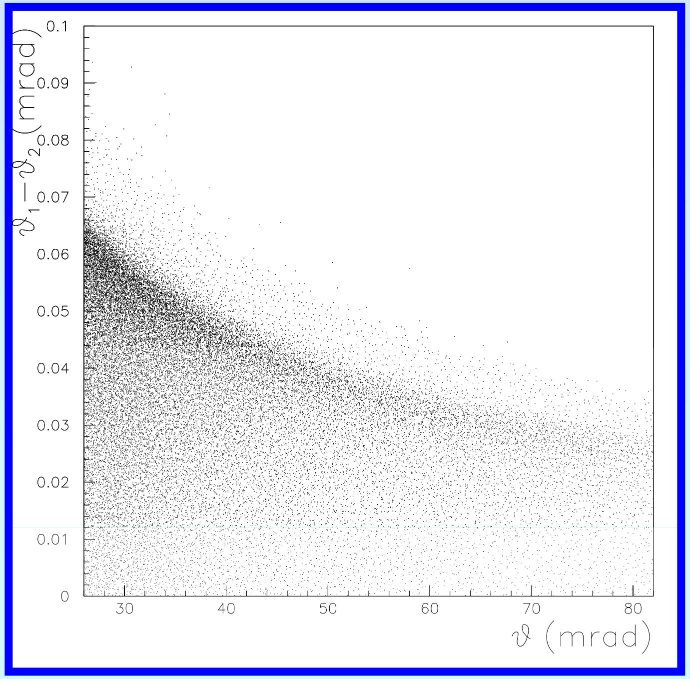
- Measurement of energy and scattering angle of the Bhabhas ➔ **luminosity spectrum reconstruction**

Beam-Beam effects on Bhabha scattering



- Bhabhas are produced with BHLUMI, √s = 500 GeV, 25<θ<90 mrad, **ISR include**
- Beam-Beam effect treatment with GUINEA-PIG (Nominal beam param. used for simul.)
    - **Modification of initial state**: **Beamstrahlung** ➔ √s'≤√s, $\Delta\theta_{ini} \neq 0$, $E_{elec} \neq E_{posit}$
    - **Modification of final state**: **Electromagnetic deflections** ➔ bhabha angle reduction (~10^{-2}mrad) + small energy losses





Consequences on integrated luminosity measurement:

Reduction of Bhabha counting rate

First study with the following selection cuts :

$30 < \theta_{bhabha} < 75$ mrad and $E_{bhabha} > 0.8\ E_{beam}$

➔ **Suppression of Bhabha particles : $(N_{theor} - N_{exp})/N_{theor}$**

Due to modification of initial state = beamstrahlung: $(-3.78 \pm 0.04)\%$

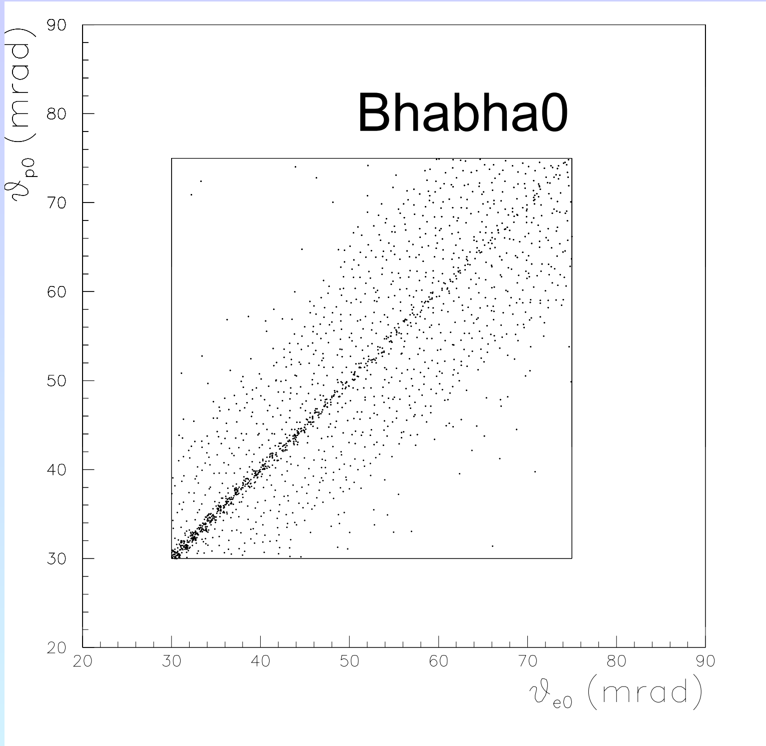
Due to modification of final state = EM deflections: $(-0.65 \pm 0.02)\%$

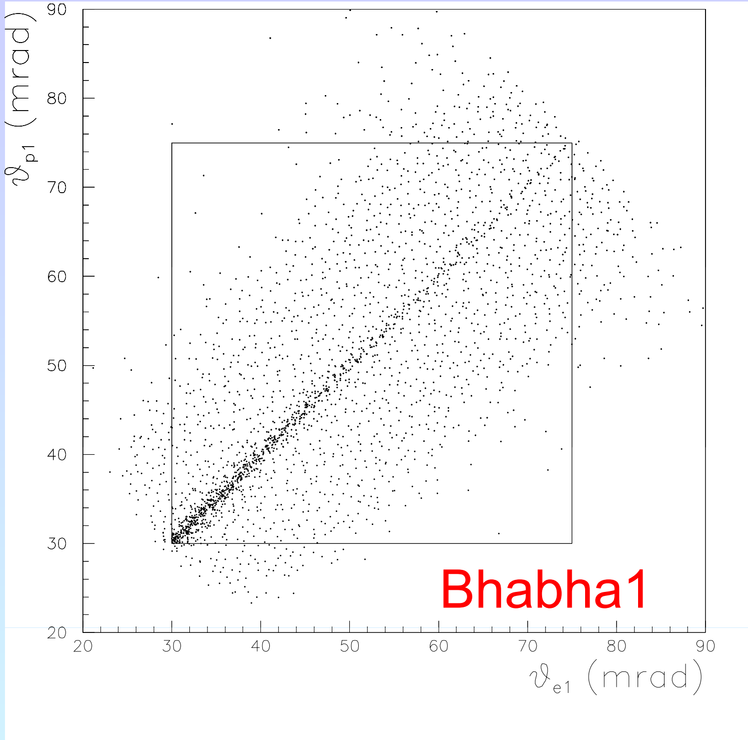
Total BHabha Suppression Effect (BHSE): $(-4.41 \pm 0.05)\%$

Why is there such an important Bias ?

Reduction of Bhabha counting rate

Angular cuts optimization





Beamstrahlung ➔ enhancement of acollinearity:

$<\Delta\theta_0> = 1.27$ mrad $<\Delta\theta_1> = 2.00$ mrad

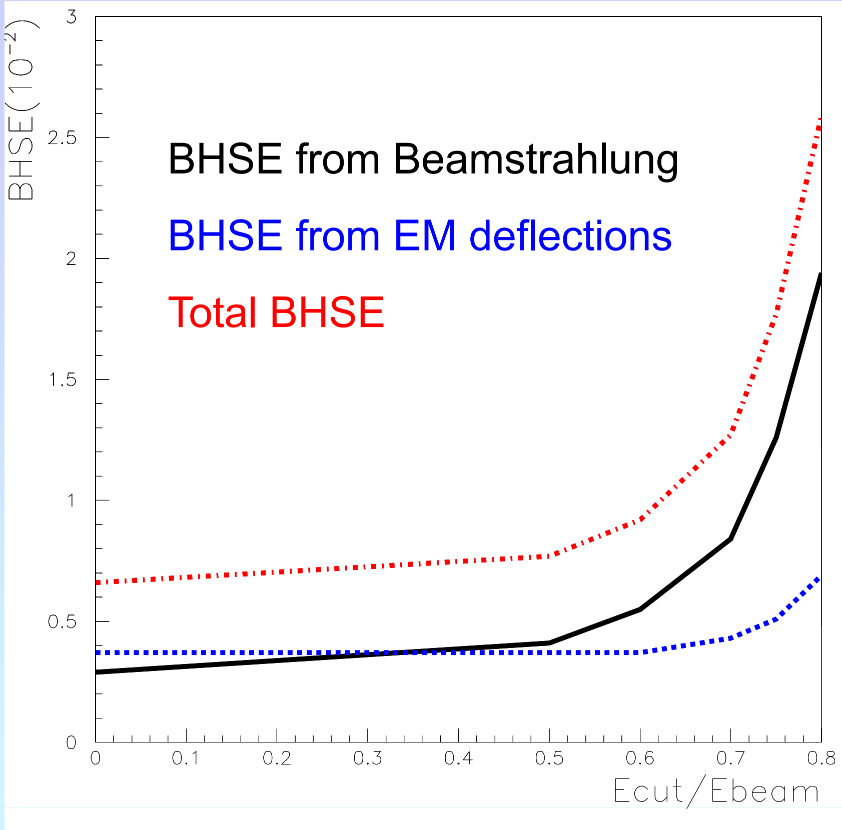
The angular cut should not be symmetric: new **asymmetrical** cuts

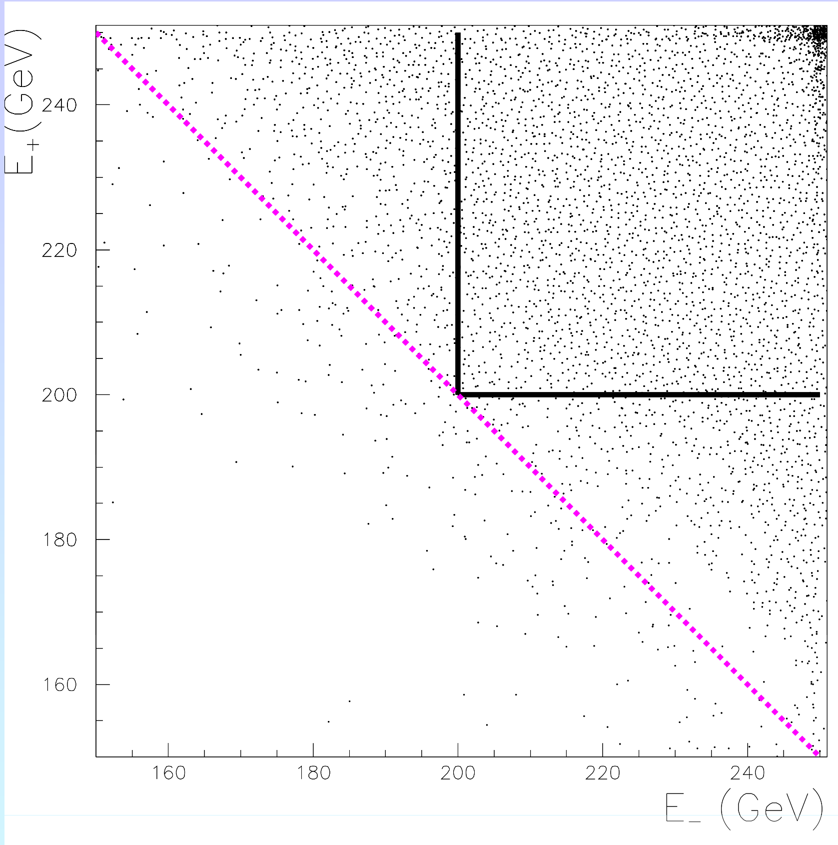
30 mrad$<\theta_{-+}<$75 mrad & 26.2 mrad$<\theta_{+-}<$82 mrad

ref. A. Stahl LC-DET-2005-004

Reduction of Bhabha counting rate

Energy cuts optimization





Beamstrahlung & EM deflections: Bhabha energy reduction + energy asymmetry enhancement ➔ use global energy cut: $E_+ + E_- > 0.8\sqrt{s}$

Consequences on integrated luminosity measurement:

Reduction of Bhabha counting rate

Suppression of Bhabha particles inside the selection cuts $30<\theta_{bhabha}<75$ mrad and $E_{bhabha} > 0.8\ E_{beam}$:

Due to modification of initial state = beamstrahlung: $(-3.78 \pm 0.04)\%$

Due to modification of final state = EM deflections: $(-0.65 \pm 0.02)\%$

Total BHabha Suppression Effect : $(-4.41 \pm 0.05)\%$

Suppression of Bhabha particles inside the optimized selection cuts

30 mrad $<\theta_{1,2}<$ 75 mrad & 26.2 mrad $<\theta_{2,1}<$ 82 mrad and $E_{+}+E_{-} > 0.8\sqrt{s}$:

Due to modification of initial state = beamstrahlung: $(-1.03 \pm 0.04)\%$

Due to modification of final state = EM deflections: $(-0.48 \pm 0.02)\%$

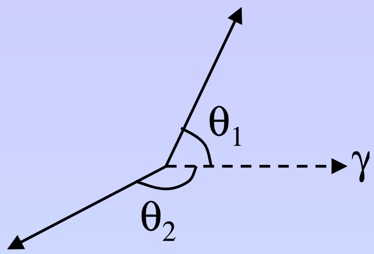
Total BHabha Suppression Effect : $(-1.51 \pm 0.05)\%$

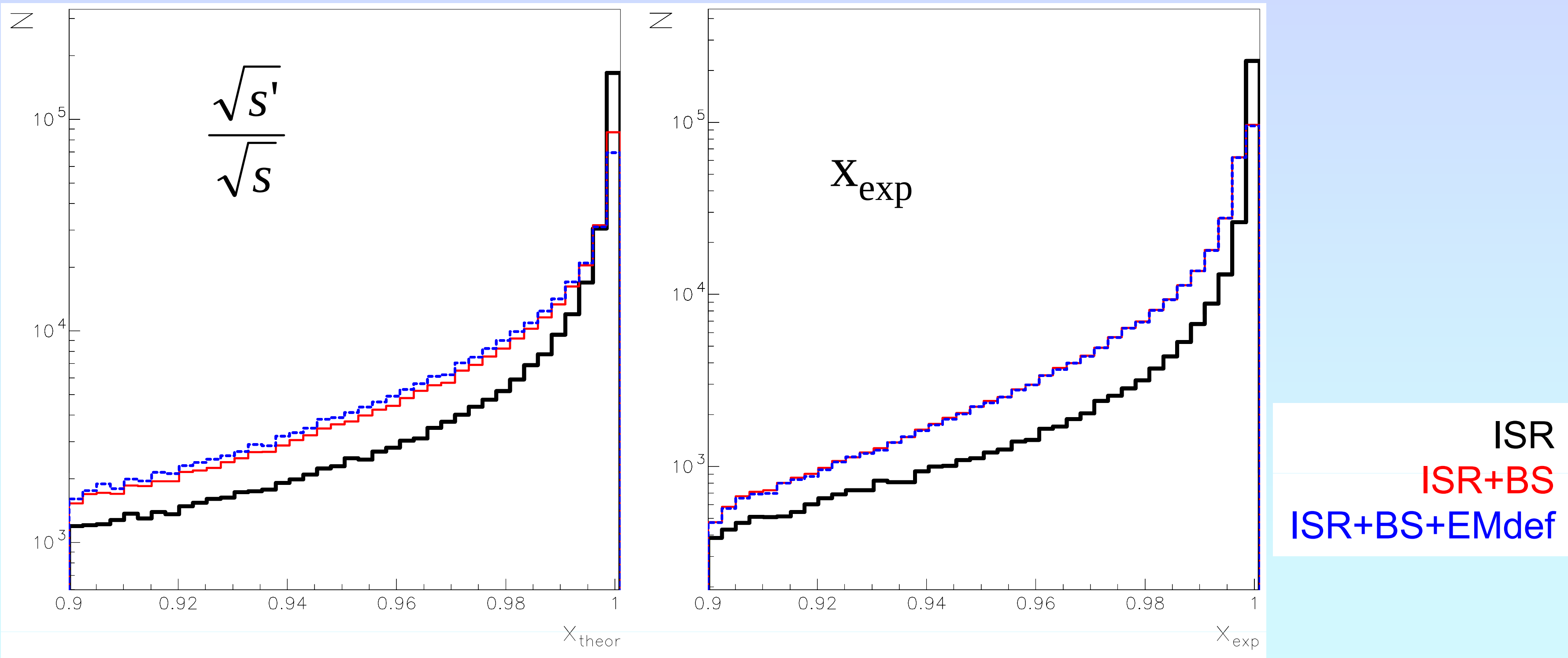
➔ The bias on integrated luminosity measurement is reduced about a factor 3 with asymmetric angular cuts and global energy cut

Reconstruction of luminosity spectrum from lumical

from K. Mönig   ref. LC-PHSM-2000-60-TESLA

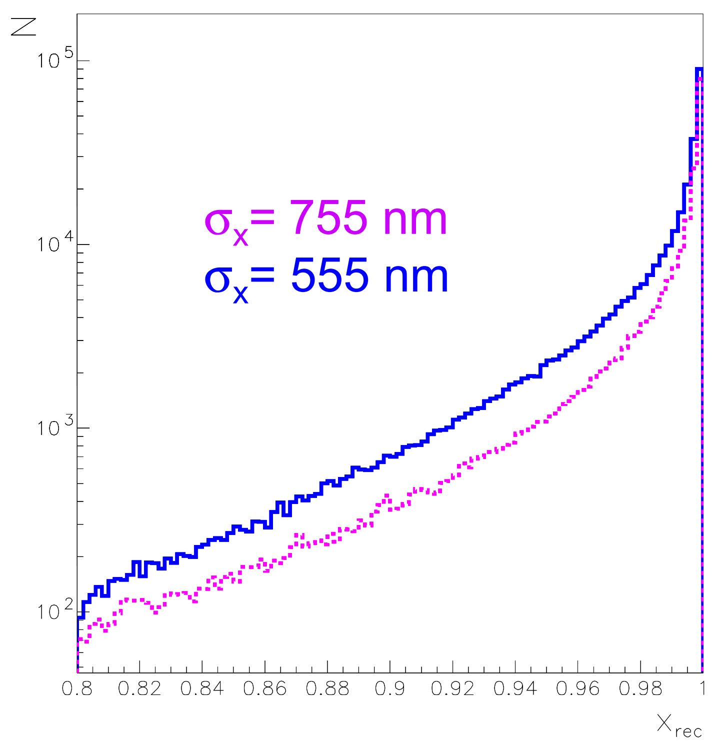
$$x_{theor} = \frac{\sqrt{s'}}{\sqrt{s}} \approx \sqrt{1 - 2\frac{\sin(\theta_1+\theta_2)}{\sin(\theta_1+\theta_2) - \sin\theta_1 - \sin\theta_2}} = x_{exp}$$





Experimentally EM deflections have no impact on the reconstructed lumi spectrum

Required reconstruction accuracy to control the BHSE

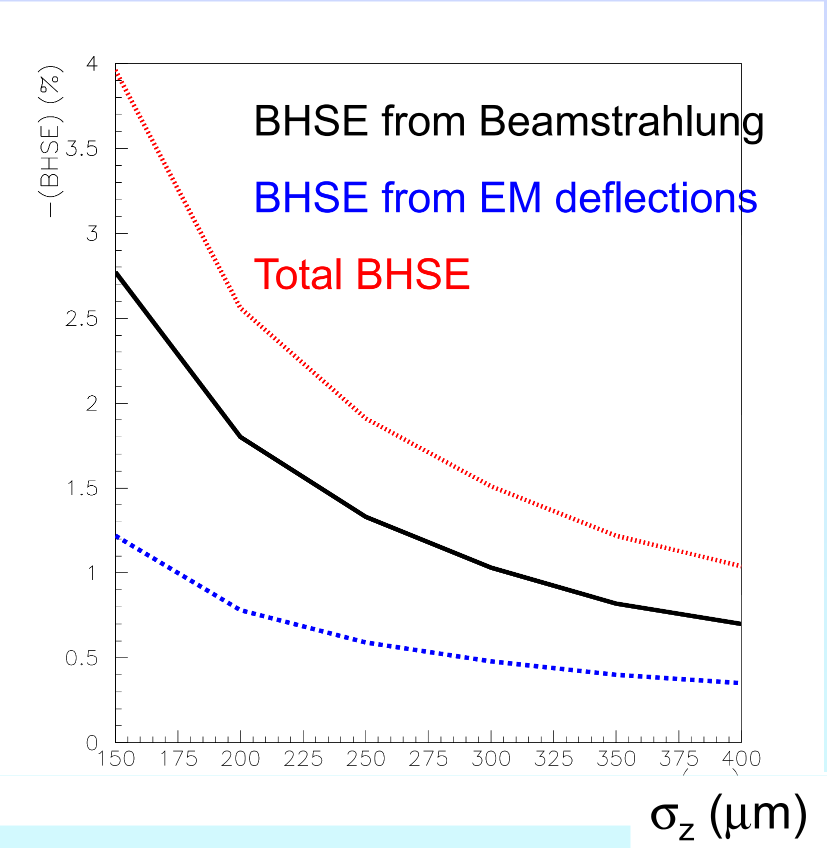


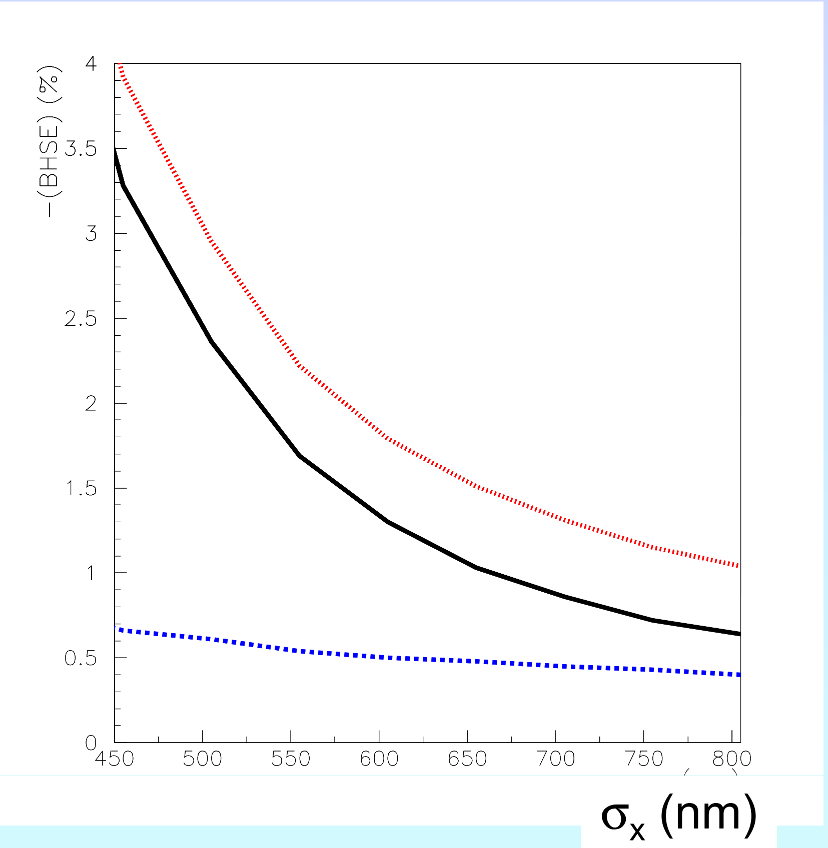
σ_x [nm]	$\mathcal{L}$ [μb^{-1}]	$\langle x_{rec} \rangle$	BHSE [%]
555	1.8	0.976	-2.22
755	1.2	0.980	-1.14
Δ		**$4\ 10^{-3}$**	**$1\ 10^{-2}$**

- Modification of beamstrahlung with beam parameters
  - ➔ modification in luminosity spectrum and mean value
  - ➔ modification in BHSE
- To control the bias on integrated lumi at 10^{-3}, variations in the rec lumi spectrum need to be known with a precision of 4.10^{-4}
- Fitting the shapes of the lumi spectra ➔ improvement of sensitivity to beam parameter variation

Sensitivity of BHSE to beam parameters

• BHSE is insensitive to beam offsets, Δ_x and $\Delta_{y,}$, and to longitudinal shifts of the bunch waist
• BHSE is insensitive to the vertical size of the bunch
• BHSE has strong dependence on bunch length, σ_z, and horizontal size, σ_x





Sensitivity of BHSE to beam sizes

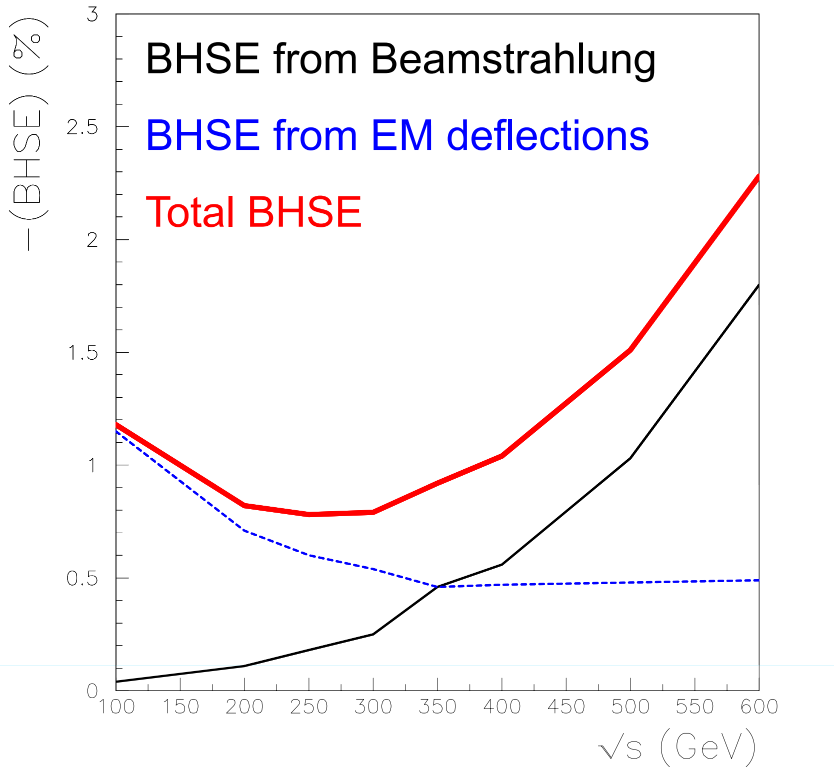
$\frac{\Delta\sigma_z}{\sigma_z}$	$\Delta BHSE_{bslung}[\%]$	$\Delta BHSE_{EMdef}[\%]$	$\Delta BHSE[\%]$
20%	-0.40 $+0.25$	-0.15 $+0.10$	-0.50 $+0.30$
10%	-0.20 $+0.15$	-0.07 $+0.05$	-0.25 $+0.15$
5%	-0.10 $+0.05$	-0.03 $+0.02$	-0.15 $+0.05$

$\frac{\Delta\sigma_x}{\sigma_x}$	$\Delta BHSE_{bslung}[\%]$	$\Delta BHSE_{EMdef}[\%]$	$\Delta BHSE[\%]$
20%	-1.10 $+0.35$	-0.10 $+0.08$	-1.20 $+0.40$
10%	-0.40 $+0.20$	-0.04 $+0.04$	-0.45 $+0.25$
5%	-0.20 $+0.10$	-0.02 $+0.02$	-0.20 $+0.10$

Sensitivity of BHSE to energy

ILC should enable physics runs initially for energies from the Z boson mass to 500 GeV
➔ In this energy range beam-beam effects are strongly modified

Constant beam optical parameters



Relative Energy lost by Beamstrahlung :

$$\delta \propto \frac{N^2\gamma}{\sigma_x^2\sigma_z} \propto \frac{N^2\gamma^2}{\varepsilon_x^*\beta_x\sigma_z}$$

$$\mathcal{L} = \frac{N^2}{4\pi\sigma_x\sigma_y} H_D = \frac{N^2\gamma}{4\pi\sqrt{\varepsilon_x^*\beta_x\varepsilon_y^*\beta_y}} H_D$$

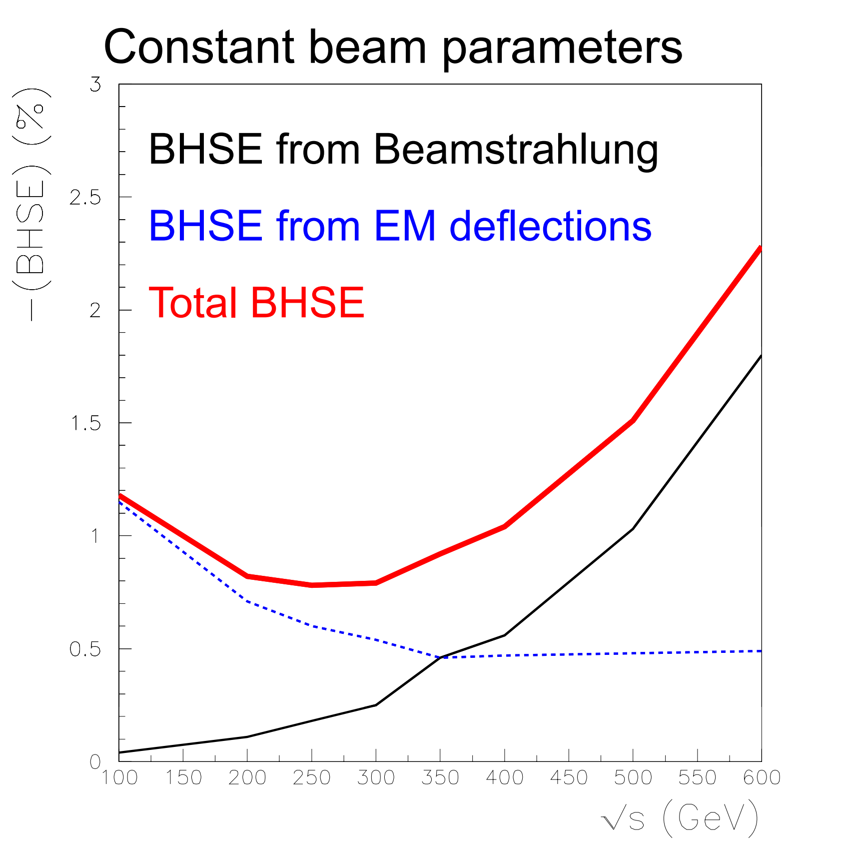
$$\mathcal{L} \propto \sqrt{\frac{\delta}{\varepsilon_y}} \frac{P_{beam}}{E} H_D$$

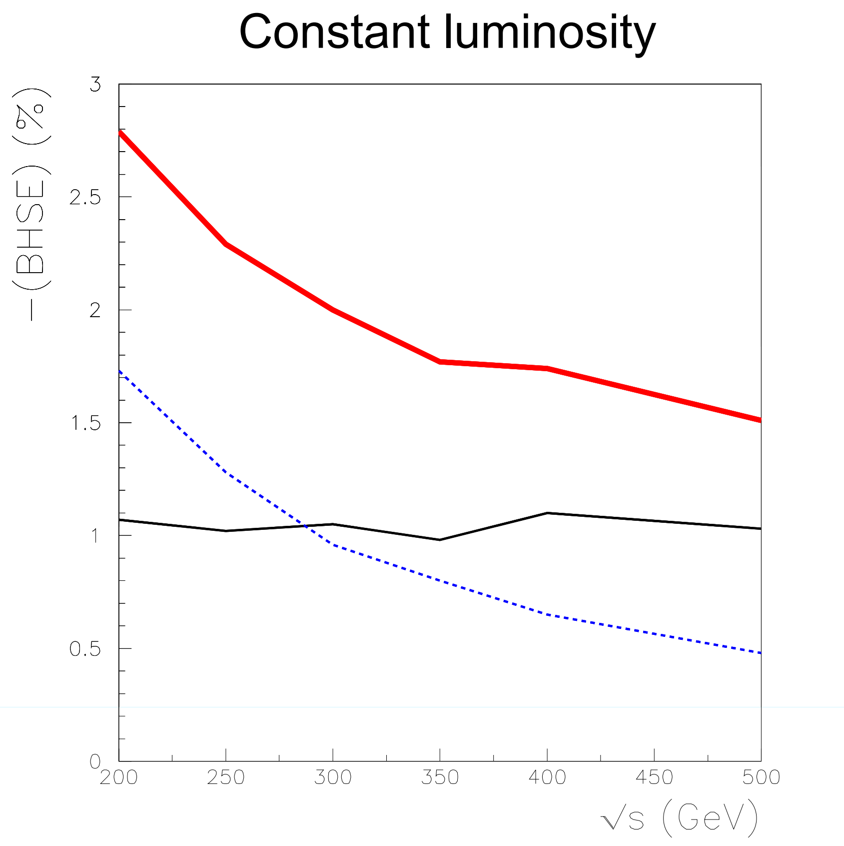
Beam angular deflections :

$$x', y' \propto \frac{Nx, y}{\gamma\sigma_{x,y}\sigma_x} \propto \frac{N\sigma_{x,y}}{\gamma\sigma_{x,y}\sigma_x} \propto \frac{N}{\sqrt{\gamma}\sqrt{\varepsilon_x^*\beta_x}}$$

Sensitivity of BHSE to energy

ILC should enable physics runs initially for energies from the Z boson mass to 500 GeV
➔ In this energy range beam-beam effects are strongly modified





At low energy, EM contribution of BHSE becomes dominant, reaching few 100*10^{-4}

Summary & Conclusions - 1

• Beam-beam effects on Bhabha scattering increase acollinearity (+0.7 mrad) and energy asymmetry on the Bhabha particles ➔ Need to find a compromise with background suppression cuts

• This leads to a **bias on the integrated luminosity measurement of few 10^{-2}**

• This BHSE mainly arises from beamstrahlung (for Nominal ILC)

• The reconstructed luminosity spectrum in the LumiCal is almost not modified by EM deflections ➔ beamstrahlung can be measured from the lumi spectrum reconstruction

• To control the bias on luminosity measurement at 10^{-3}, we would need to reconstruct luminosity spectrum mean value with a precision of 4 10^{-4}. But a fitting procedure of the lumi spectrum would enable to reach better precision.

• Main dependences are from the horizontal and longitudinal sizes of the bunch. A precision of 20% is needed on their knowledge to limit the error on BHSE from EM deflections to about 10^{-3}.

Summary & Conclusions - 2

• No direct way to control experimentally the bias from EM deflections, but measurements of beam angular divergence in extraction line could provide a way to monitor lumi bias from σ_x variations. For σ_z ?
➔Need to use a simulation tool: CAIN, GUINEA-PIG and GUINEA-PIG++ for further studies.

http://flc.web.lal.in2p3.fr/mdi/BBSIM/bbsim.html

https://trac.lal.in2p3.fr/GuineaPig

• For the GigaZ option, a precision of 10^{-4} is needed for the luminosity, while the bias from EM deflections is >100 x 10^{-4}... ➔ need more complete studies.

• "Impact of beam-beam effects on precision luminosity measurements at ILC", C. Rimbault, P. Bambade, K. Mönig, D. Schulte, EuroTeV-Report-2007-017, JINST 2 P09001.

Status of GUINEA-PIG++ simulation

Work develop at LAL with Guy Le Meur and François Touze

- GP++ use configuration management environment **CMT** ➔ easy compilation
- GP++ versioning, updating and releasing achieved with **SVN**
- GP++ is distributed on the web software development tool **TRAC**:

https://trac.lal.in2p3.fr/GuineaPig

- GP++ code can be run both on 32-bit and **64-bit** computers.
- New keyword **rndm_seed** allows to choose the random generation seed.
- Physics simulation improvement: easy interface to apply **beam-beam effects on Bhabha** event input files + photons treatment.
- Automatic GRID sizing option.
- All results are now in the main output file, with units !!!
- Time performance optimization: parallel computation in development.