LUMINOSITY MEASUREMENT AT ILC

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(on behalf of the FCAL Collaboration)

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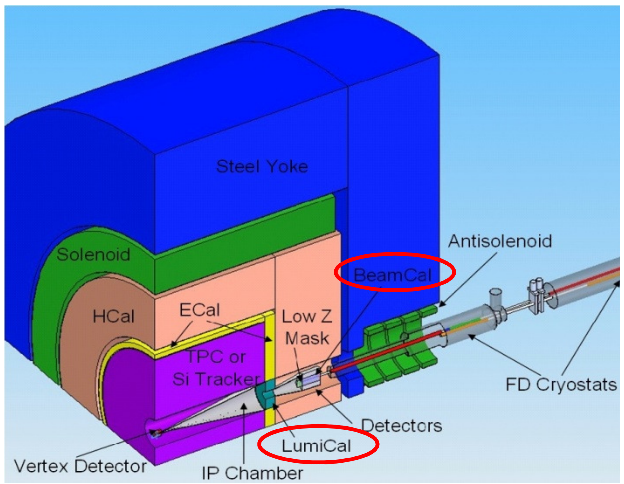
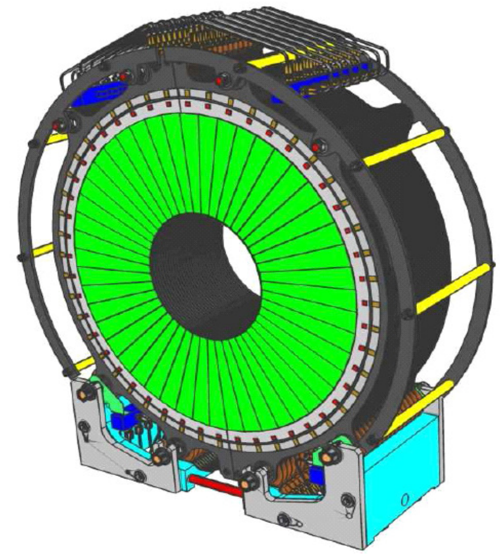
- IFIN-HH Bucharest, Romania
- VINCA Inst. of Nuclear Science, Belgrade, Serbia
- CERN, Switzerland
- Argonne National Lab, Upton, USA
- University of Colorado, Boulder, USA
- University of Santa Cruz, USA
- SLAC, USA

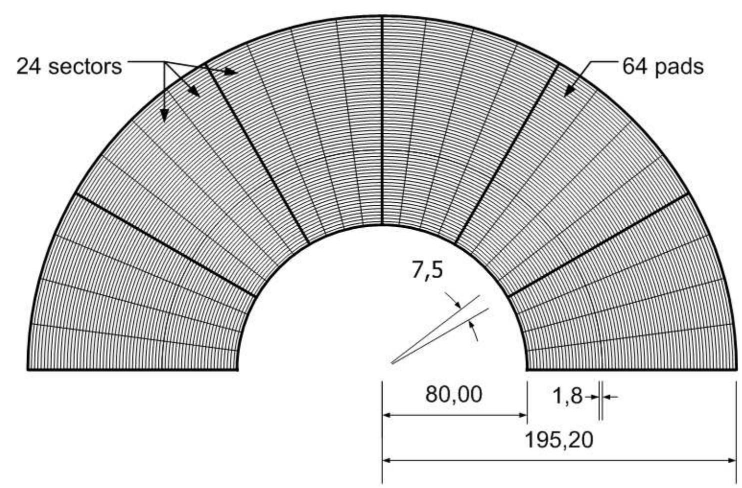
Institutes contributing to LumiCal related studies

Luminometer at ILC



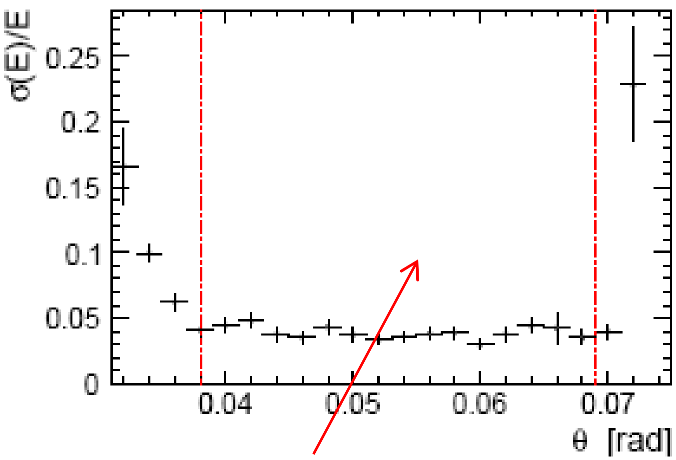


Silicon sensor half plane

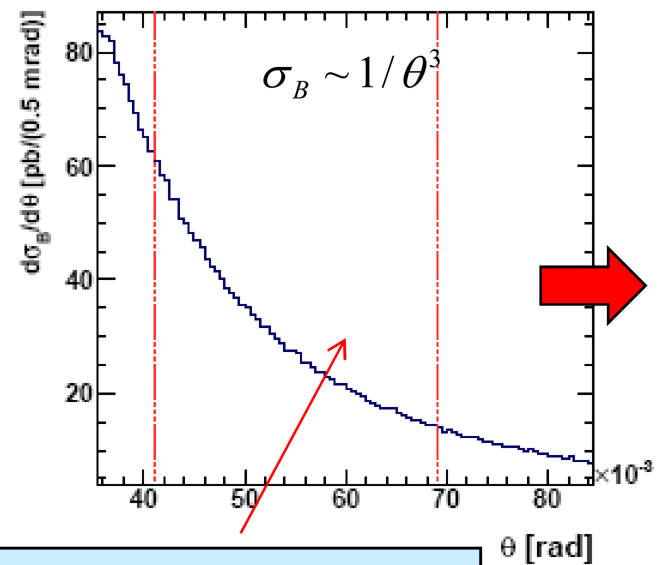


Distance from IP [m]	**2.5**
Geometrical aperture [mrad]	**[31,78]**
Fiducial volume [mrad]	**[38,69]**
Number of layers	**30 W/Si**
Moliere radus [cm]	**1.5**
Sensor azimuthal/radial divisions	**48/64**
Resolution in polar angle [mrad]	**$(2.2\pm0.02)\ 10^{-2}$**
Energy resolution [$GeV^{1/2}$]	**0.21**

LumiCal simulation study

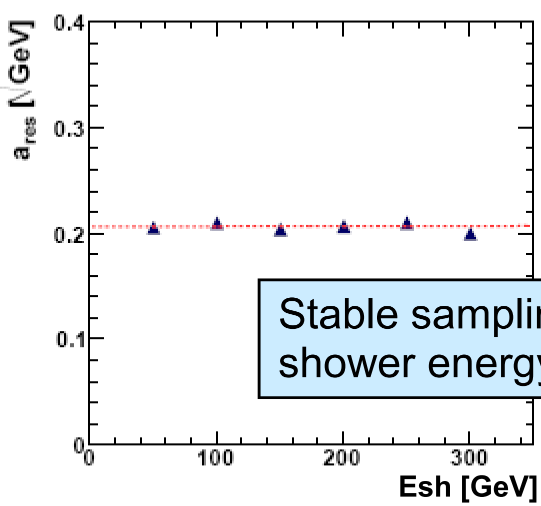


LumiCal fiducial volume

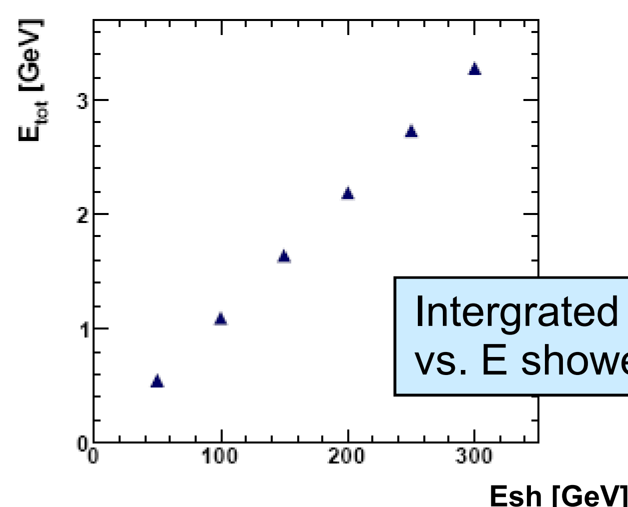


2.1 nb integrated x-sec.

$$\left(\frac{\Delta L}{L}\right)_{stat}^{annual} < 10^{-4}$$



Stable sampling term vs. shower energy



Intergrated deposited E vs. E shower

Luminosity measurement

Integrated luminosity can be determined from the total number of Bhabha events produced in the acceptance region/fiducial volume of the luminosity calorimeter and the corresponding theoretical cross-section

IT IS COUNTING EXPERIMENT, BUT...

$$L_{\text{int}} = \frac{N_{th}}{\sigma_B}$$

real experiment →

$$L_{\text{int}} = \frac{N_{\exp} - \sum_i N_i^{cor}}{\varepsilon \cdot \sigma_B}$$

→

1. To build a device capable of precise reconstruction of E, θ

2. To control (other) systematics

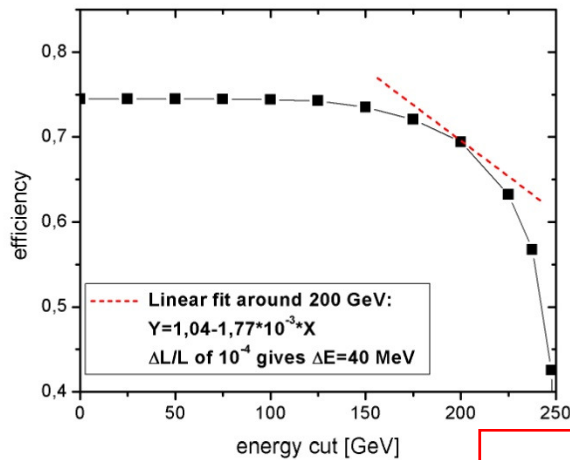
Event selection

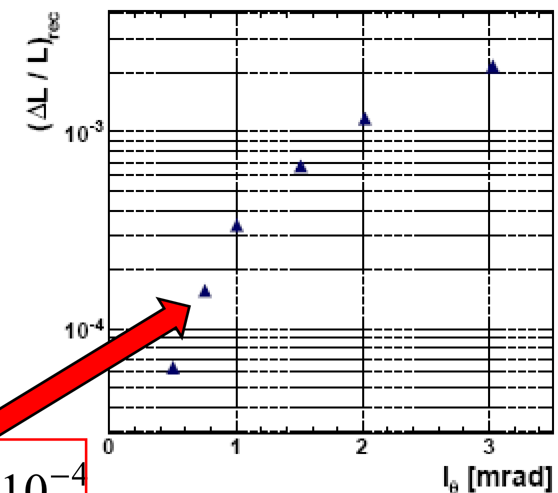
1. **the polar angle of the reconstructed shower must be within the detector fiducial volume at one side and within $\left[\theta_{\min}^{f} + 4mrad, \theta_{\max}^{f} - 7mrad\right]$ at the other.**
2. **total energy deposited in the LumiCal must be more than 80% of the center-of-mass energy**

Luminosity measurement

SYSTEMATIC EFFECTS

$$\frac{\Delta L}{L} = 10^{-4(3)} \Rightarrow 2 \cdot 10^{-4(3)} \, control\ of\ E_{Bhabha}$$



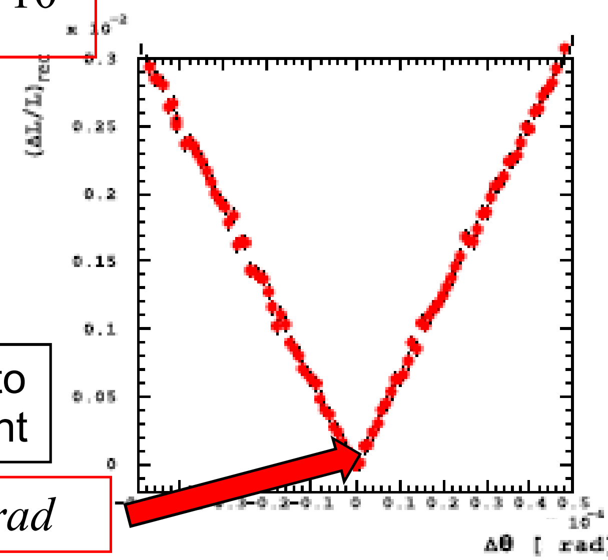


$$l_\theta = 0.8mrad, \frac{\Delta L}{L} = 1.6 \cdot 10^{-4}$$

TO BUILD A DEVICE…

θ reconstruction

Shower develops under a non-zero angle with respect to the probing geometry ⇔ bias in luminosity measurement



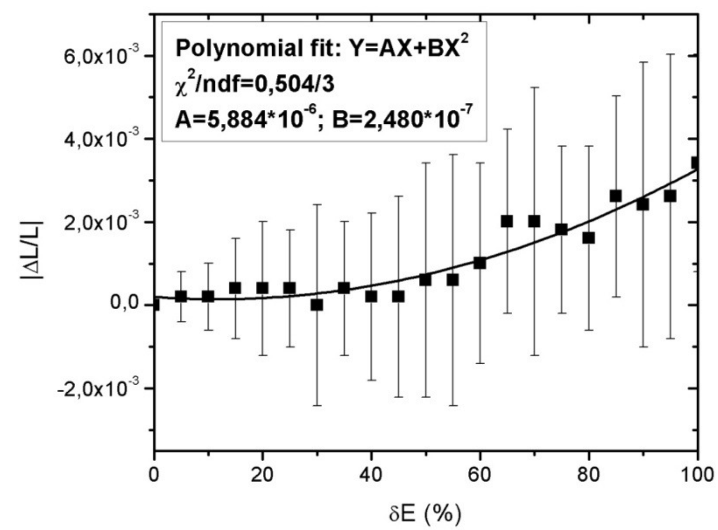
$$\Delta\theta = 3.2 \cdot 10^{-6} \, rad$$

More systematics

TO BUILD A DEVICE…

Energy resolution

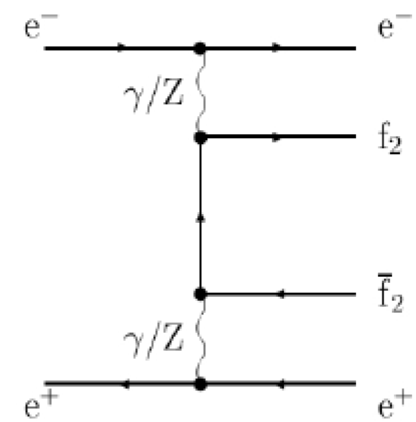
$\frac{\Delta L}{L} = 10^{-4} \Rightarrow 1.5\%$ control of the sampling term δ_E (also called $\alpha_{\_res}$ at slide 4) , or 25% for $\frac{\Delta L}{L} = 10^{-3}$



OTHER SOURCES OF SYSTEMATICS

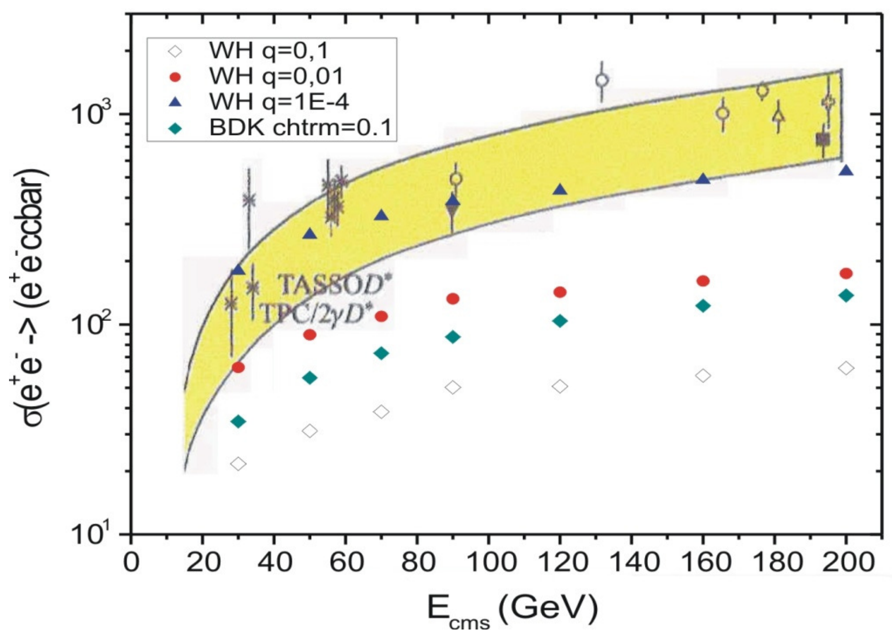
2-γ background

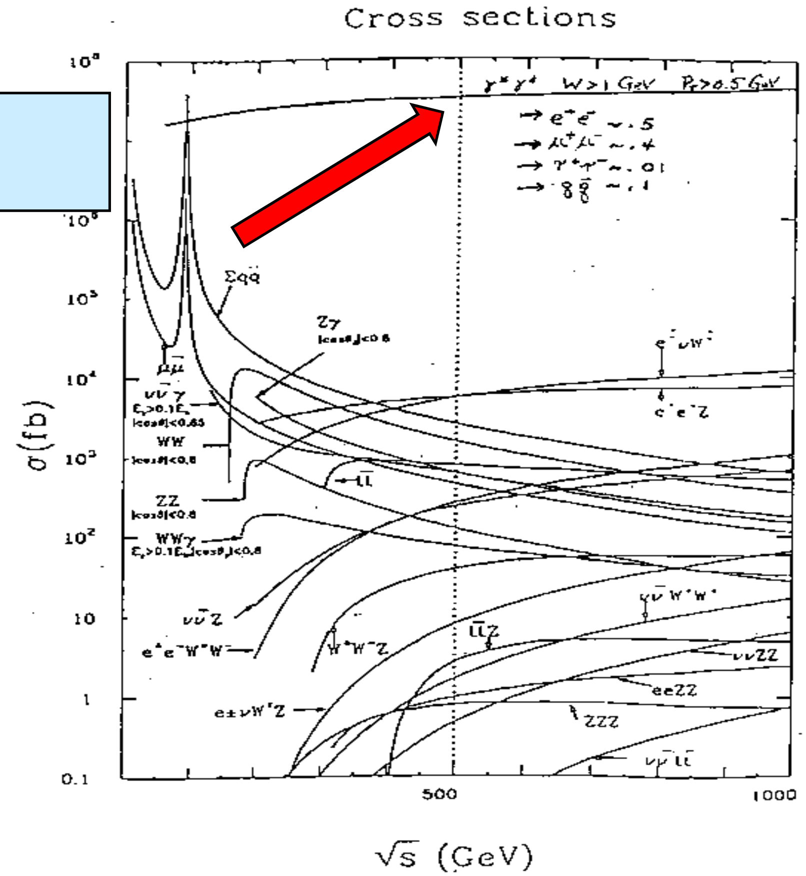
High x-sec ~ 10s nb, spectators close to the beam pipe



More systematics

However, less than 1% of spectators in the LumiCal



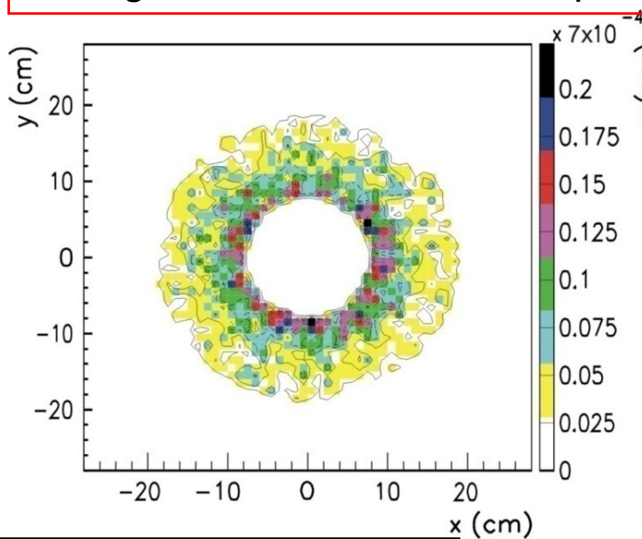


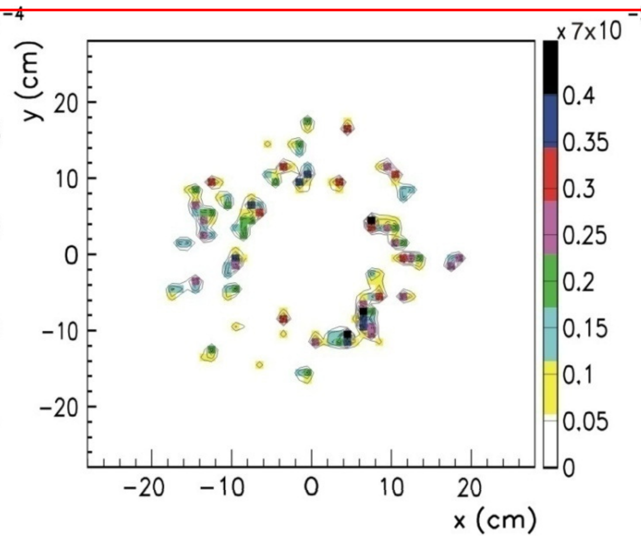
B/S ratio saturates within the same order of magnitude at ILC energies
B/S=2.3 10^{-3} at 500 GeV and B/S = 5.2 10^{-3} at 1 TeV

Sensitivity of background to signal ratio to systematic effects that may come from the uncertainty of detector fiducial volume due to various detector displacements is negligible

More systematics

Background hits on the front plane before and after selection applied

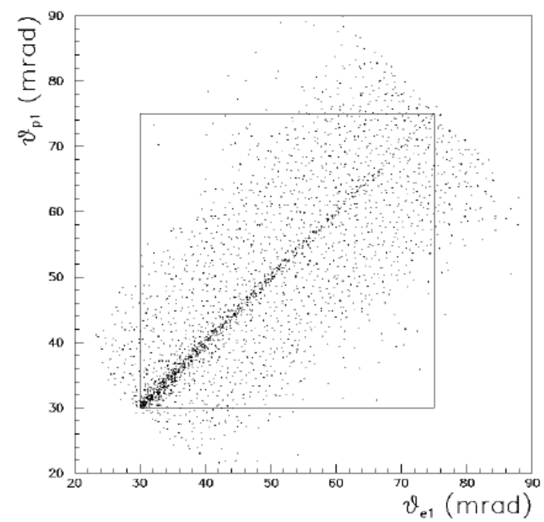




Space charge effects

Beam-beam interactions

- Modification of initial state: **Beamstrahlung** ⇒ $\sqrt{s'} \leq \sqrt{s}$, $\Delta\theta_{ini} \neq 0$, $E_{elec} \neq E_{posit}$
- Modification of final state: **Electromagnetic deflection** ⇒ Bhabha angle reduction (~10^{-2}mrad) + small energy losses



⇒ Total BHabha Suppression Effect (BHSE) ~1.5%

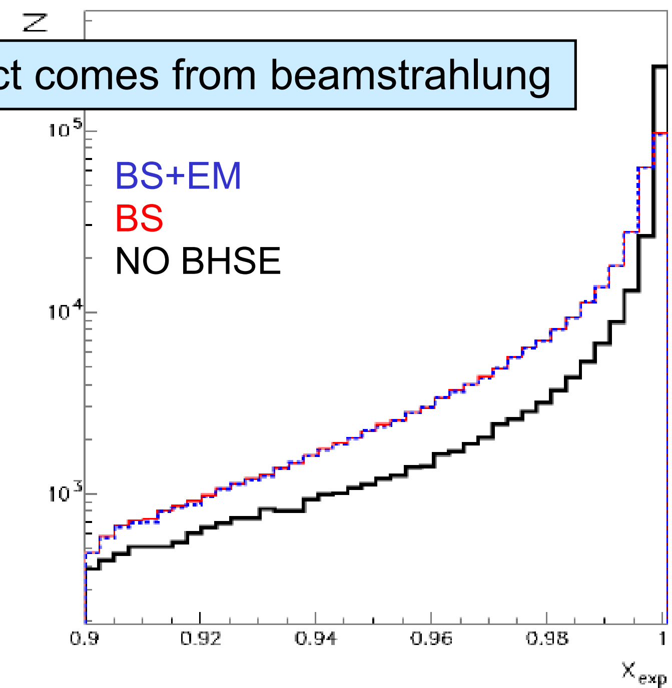
More systematics

Simulation of BHSE measurement

Data-driven method from reconstructed luminosity spectrum by measuring angles in the LumiCal

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

Dominant effect comes from beamstrahlung



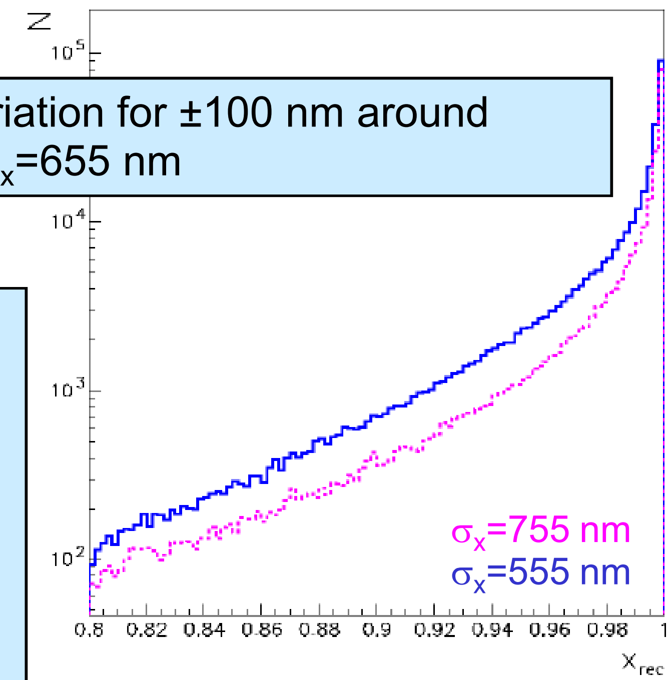
- BHSE from BS can be exp. measured and treated as a bias
- However, to provide Δ(BHSE) ~0.4%(0.1%) beam parameters σ_x and σ_z have to be known within 20%(5%).

Impact of beam-beam effects on precision luminosity measurements at the ILC, C. Rimbault et al., JINST 2:P09001,2007

More systematics

SUMMARY ON SYSTEMATICS

Bunch width variation for ±100 nm around nominal value σ_x=655 nm



- Test beam studies are needed to determine experimental uncertainties of effects that should be taken as corrections (i.e. bias in polar angle).
- Precision determination of Bhabha energy and understanding of detector energy resolution is necessary due to the applied selection.
- NLO calculations at ILC energies are needed both for Bhabha and background processes.
- Dominant effects come from beam-beam interaction (BHSE) and 2-γ processes. Both can be corrected for. In BHSE case the correction is large and require beam parameter control at 20% level or better (BS component), while uncertainty in physics background comes from the error on x-section.

Total systematics

TOTAL SYSTEMATICS at 500 GeV

	Value	Relative uncertainty of the value	$\Delta L/L$
x-sec$_{Bhabha}$ [nb]	2.1	$5.4\ 10^{-4}$ **	$5.4\ 10^{-4}$
σ_θ [mrad]	$2.2\ 10^{-2}$	100% *	$1.6\ 10^{-4}$
$\Delta\theta$ [mrad]	$3.2\ 10^{-3}$	100% *	$1.6\ 10^{-4}$
α_{res} [GeV$^{-1/2}$]	0.21	1.5%	$1.0\ 10^{-4}$
E_{Bhabha} [GeV]	≥ 200	$2.0\ 10^{-4}$	$1.0\ 10^{-4}$
B/S	$2.3\ 10^{-3}$	100%*	$2.3\ 10^{-3}$
BHSE [%]	1.51	9.9% ***	$1.5\ 10^{-3}$
Σ			**$2.8\ 10^{-3}$**

* Upper limit – the size of effect is taken as uncertainty.
** Uncertainty of the theoretical cross-section for Bhabha at LEP energies [OPAL, G. Abiendi et al., Eur. Phys. J C14(2000)373].
*** 5% control of bunch x and z sizes.

Summary

- It has been proven through simulation that it is possible to design luminometer at ILC capable of precision reconstruction of Bhabha energy and polar angle.
- Numerous systematic effects are present and understood (again) at the level of simulation. They amount to $2.8 \cdot 10^{-3}$ systematic uncertainty in luminosity at the upper limit, with the statistical error on luminosity less than 10^{-3} needed for integrated annual luminosity at high energies.
- Most of systematic effects can be taken as corrections once their experimental (test-beam) or theoretical uncertainties are known.
- The largest contribution to the relative error on luminosity comes from collective (beam-beam) effects and physics background. According to the present knowledge, beam-beam effects can not be reduced below 10^{-3} (even if bunch size is controlled at 5% level). However, it doesn't relax the need for detector precision.

To do list

- Sensitivity of the luminosity measurement to changes of the detector fiducial volume implies importance of mechanics and position control of the LumiCal (inner radius, various radial displacements, F-B relative positions, etc.). It is needed to quantify impact of these effects on luminosity measurements within the current detector geometry, as well as to prove in situ mechanical control.
- Test-beam studies are needed to understand experimental uncertainties of some effects (i.e. realistic calibration procedure).
- Space charge effects introduce error in luminosity measurement of order of 10^{-3}. They have to be studied in more details with respect to changes in geometry and at all ILC energies*.
- Finally, for the reason of completeness, theoretical uncertainties at the NLO level are needed for Bhabha and background processes at ILC energies*.
- Final choice of shape and material of the beam-pipe has to be simulated to estimate impact of pre-showering on luminosity measurement. For parallel vs. conical beryllium pipe the effect is estimated to be $O(10^{-4})$.

* the same is true for CLIC

BACKUP

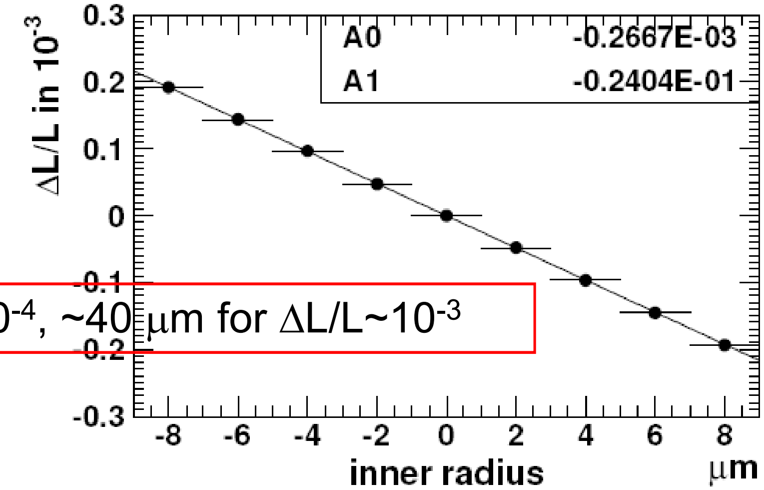
Mechanical issues

Systematic impact on luminosity measurement

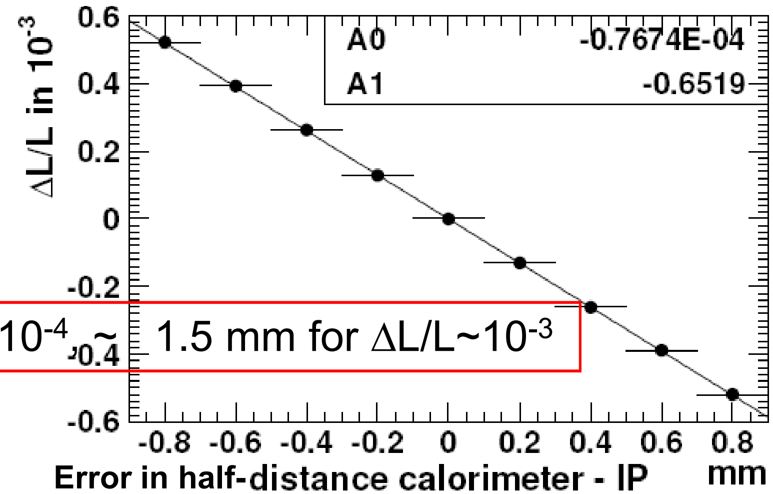
All by A.Stahl, old geometry [26,82] mrad, 3,05 m from IP

IN SITU

- **LPS prototype** monitors LumiCal as a whole object
- Obtained accuracy 0.5μm in the X-Y plane and 1.5μm in z direction – order of magnitude better than required
- Method for measuring displacement of individual sensor layers/inner radius under study



4 μm for $\Delta L/L \sim 10^{-4}$, ~40 μm for $\Delta L/L \sim 10^{-3}$



100 μm for $\Delta L/L \sim 10^{-4}$, ~ 1.5 mm for $\Delta L/L \sim 10^{-3}$