LumiCal study 2017.10.25

The Z line-shape is measured with the dominant reaction of $Z \to qq$ of a cross-section of 41 nb. The luminosity of e^+e^- interaction is measured by detection of elastic scattering of e^+e^-, the Bhabha interaction, which is well interpreted by the QED and the Monte Carlo calculation (e.g. BHlumi) is precise to better than 0.1%.

The Bhabha event counting is most sensitive to the θ angle of a fiducial region for detection of electrons by a pair of forward luminosity calorimeters (LumiCal) on both sides of the interaction position (IP). The typical setting of $\theta_{min} < 30$ mRad provides Bhabha cross sections of > 50 nb. The systematic errors on Bhabha event counting is approximately expressed for the precision identifying events passing θ_{min} cut by

$$\Delta L/L \sim 2\Delta\theta/\theta_{min}. \tag{1}$$

Assuming the luminosity measurement is required for $\Delta L/L \sim< 10^{-3}$, the error allowed at $\theta_{min} = 30$ mRad is $\Delta\theta < 15$ μRad, corresponding to the electron impact position at $z = 1$ m of $r < 15$ μm in radius. The systematic error is dominated by

i) mechanical alignment of detector (e.g. silicon strips) in $r - \phi$ plane and in z to IP.

ii) detector resolution, and bias in θ; for example, the boost and bending to electron trajectory and the multiple scattering.

The alignment of LumiCal elements may be carefully assembled to be better than 5 μm. The intrinsic resolution for the θ of electron impact position shall also be pursued to be minimal. The error on the mean of θ_{min} can be small ($\sigma/\sqrt{n}$, n are events at θ_{min}), however, the offset of the mean is the dominant systematic uncertainty. For example, assuming the electron impact positions are measured by silicon strips, with the θ_{min} set at the center between two strips with a gap typically of ≥ 20 μm. The θ_{min} set at the center may be bias by the charge collection mechanism of the two strips, that shall be calibrated for e.g. magnetic field effect.

To accomplish a systemic error of less than 5 μm, by the LumiCal, an external calibration system is necessary. shall calibrate Assuming that we provide a simple tracking system for

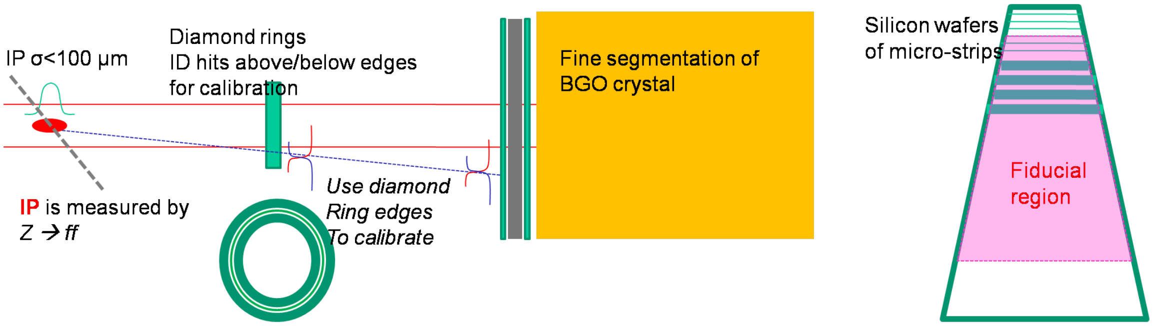

Figure 1: Tracking of Bhabha electrons for the precision to 10^{-4} on the mean of error of the fiducial θ_{min} cut, (~ 1 μm in radius at z = 1 m). A diamond or silicon ring between the e^+e^- interaction point and the LumiCal provide extrapolation position of Bhabha electrons on the LumiCal for calibration to the precision of the error of mean on θ_{min} to 1 μm, corresponding to 10^{-4} on luminosity measurement.

Bhabha electrons as is illustrated in Fig. 1. By adding a ring of Silicon or Diamond detector in front of LumiCal, the trajectory of electrons from IP is predicted. And thus provides a tool for calibration of the LumiCal alignment and the distribution of intrinsic resolution. The LumiCal may be segmented in fine-pitch of silicon strips to reach a resolution of < 5 μm. The tracking of electrons will calibrate the mean of θ_{min} to the ~ 1 μm level to reach a luminosity measurement precision of 10^{-4}.

The calorimeter of LumiCal, for detection of electrons, can be made of any traditional technology such as the BGO in longitudinal segmentations. The LumiCal shall be able to identify photons also. Therefore the calorimeter in fine segmentation is desirable. A crystal calorimeter shall provide much simpler readout electronics compared to a sandwiched Si-W device having the readout system sticking out on the side.

The beam-crossing of 33 mRad introduces a boost to scattered electrons corresponding to a 16.5 mRad shift in horizontal direction off the CEPC ring center. Distribution of Bhabha events are simulated (with BHlumi) accordingly and are shown in Fig. 2. A Bhabha event is detected requiring both electron and positron detected. The boost causes loss of electrons (on -x direction) to the beam pipe. Assuming a beam-pipe opening corresponding to $\theta_{min} = 20$ mRad, the boost results to a acceptance of $\theta_{min} = 36.5$ mRad at the horizontal axis. To compensate the loss of acceptance for Bhabha events, the beam pipe opening shall be minimized to ~ 20 mRad, in particular for the vertical direction, so as to gain an integrated Bhabha cross section of > 50 nb in the fiducial region of LumiCal.

The LumiCal with the front plate at $z = \pm 1$ m is inserted into the detector tracking volume of $z = \pm 2$ m. The electron shower leaking off the edge of LumiCal outer radius contaminates the tracking volume. The effect is investigated with a GEANT simulation assuming a Si-W calorimeter of twenty decks, each is composed of a 2 mm air gap and a $1X_0$ tungsten (3.5 mm thick) layer. The air-gap has a layer of silicon wafer of 0.3 mm thick. An event display is illustrated in Fig. 2.

The geometry of the LumiCal is configured with the outer radius extending to 100 mm

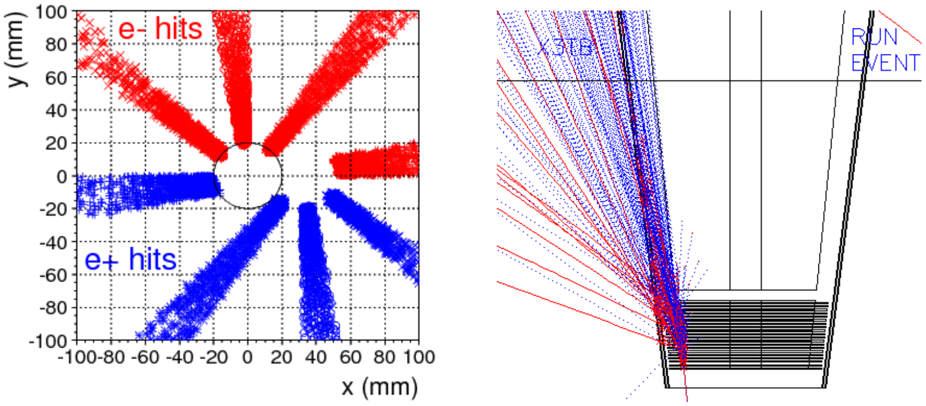

Figure 2: Bhabha events of BHlumi simulation at Z-pole is plotted for events selected in ϕ (every 45 degrees) for both electrons (red) and positrons (blue) on $r - \phi$ planes of LumiCal at $z = 1$ m, boosted by the beam-crossing angle of 33 mRad. Detector simulation is used to estimate shower leakage at the edge of LumiCal, assuming a Silicon-Tungsten sandwich in TUBE or CONE shape.

at $z = 1$ m in two configurations:

i) a TUBE shape assembled in disks of fixed dimension ($r = 25 - 100$ mm);

ii) a CONE shape with the outer radius extended radially from IP of $\theta = \text{atan}(100/1000)$ ($r = 100$ mm at $z = 1$ m).

An iron cone surrounding the LumiCal is implemented at $\cos\theta = 0.992$ ($\theta = 126.6$ mRad) assuming a thickness of 5 mm. It is used to estimate filtering of shower secondaries mostly of low momentum (< 100 MeV).

An electron shower leakage at the edge of the TUBE configuration is maximized with the electron trajectory traversing off the middle layers of the LumiCal. The numbers of shower secondaries filtered by the 5 mm Fe-cone are listed in Table 1 for 50 and 125 electrons at angles well contained (40 mRad) and at the edge LumiCal.

The CONE configuration is intended to have the electron trajectory contained within the calorimeter. A denser calorimeter (e.g. by reducing the width of air-gap in the Si-W stacking) shall have the shower secondaries distributed narrower within. Consequently the leakage at the edge is distributed intensively in a short z region. The 5 mm Fe cone can filter a large fraction of them, to less than one thousand shower secondaries traversing through.

	50 GeV electrons		125 GeV electrons	
	TUBE	CONE	TUBE	CONE
θ (mRad)	N_{enter}/N_{pass}	N_{enter}/N_{pass}	N_{enter}/N_{pass}	N_{enter}/N_{pass}
40	15.4/5.6	13.6/5.8	38.0/16.0	35.8/14.7
90	392/155	173/76	1028/399	434/19.7
95	501/290	367/152	2389/720	937/382
98	762/216	860/284	1718/473	2176/725
99	553/140	1331/367	1102/273	3306/915

Table 1: Shower secondaries reaching a 5 mm Fe-cone at $\cos\theta = .992$ are counted for 50 and 125 GeV electrons at incident angles near the outer radius (100 mRad) of LumiCal configurations in TUBE and CONE shapes. The average numbers are listed for shower secondaries enter and passing through the Fe-cone of 5mm in thickness.