

Luminosity Measurement at PEP-N  
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On-Line Luminosity

An on-line monitor is required for tuning and monitoring the machine. It is desirable that it provide a measurement with 10% or better accuracy, and fluctuations of less than 1% at a refresh time of less than 1 second. The PEP-2 monitor, based on observing single bremsstrahlung at zero degrees to the positron direction at collision, described in Ref. [1] seems appropriate. Single bremsstrahlung, or radiative Bhabha scattering, has a differential cross section, integrated over electron and positron angles, of:

$$\frac{d\sigma}{d\omega} = \frac{4\alpha r_0^2}{\omega} \frac{E - \omega}{\omega} (V - 2/3) \left[ \ln \frac{m}{q_{min}} - 1/2 \right] \quad (1)$$

where  $V = \frac{E-\omega}{E} + \frac{E}{E-\omega}$  and  $q_{min} = \frac{m}{4\gamma^2} \frac{\omega}{E-\omega}$ . Here  $E$  is the initial electron or positron energy,  $\gamma = E/m$  and  $r_0 = e^2/m$ . The angular distribution of the  $\gamma$ s is strongly forward with angular width  $\sim \gamma^{-1}$ .  $\frac{d\sigma}{d\omega}$  is a function only of  $\omega/E$  so the flux of  $\gamma$ s at  $\sim 0^\circ$  to the LER is independent of  $s$ .

The momentum transfer for this process can be remarkably small, corresponding to a very large impact parameter  $\rho$  and leading to screening effects which must be taken into account. If we choose  $E=3$  GeV and  $\omega > 300$  MeV,  $q_{min} = 0.410^{-9}$  MeV and  $\rho_{max} = 0.05$  cm which is greater than the transverse size of the beams in PEP-N. The consequence is that the cross section is cut off at a momentum transfer  $\sim q_{min}$ . This problem has been treated by various authors and the following result by Burov and Derbenev is quoted by Ref. [2] for the case of a for a Gaussian beam density where the transverse beam size is smaller than characteristic impact parameters:

$$\frac{d\sigma}{d\omega} = \frac{4\alpha r_0^2}{\omega} \frac{E - \omega}{\omega} (V - 2/3) \left[ \ln \frac{\Delta_y \Delta_z}{\lambda_C (\Delta_y + \Delta_z)} + \ln 2 + c/2 + \frac{V - 5/9}{V - 2/3} \right] \quad (2)$$

where  $c = 0.577$  and  $\Delta_y$  and  $\Delta_z$  are the rms transverse beam dimensions.  $\lambda_C$  is the electron Compton wavelength ( $m^{-1}$ ). The sensitivity of this effective cross section to variation of the PEP-N beam is approximately a 3.5% increase for a doubling of the radius. Despite this modest sensitivity, the dependence on beam size and shape introduces uncertainty that is undesirable for an absolute luminosity measurement. The background to radiative Bhabhas at  $0^{circ}$  is synchrotron radiation and beam-gas bremsstrahlung. At PEP-II, a Cerenkov shower counter is used with a threshold sufficiently high to be immune to the SR. The beam-gas background is apparently not a problem.

The interaction region should be designed so that such a monitor can be installed, which requires a clear aperture, suitable window, and space for the monitor. At PEP-2, the monitor is installed at 8m from the interaction point. We also want this monitor well downstream of the detector.

#### Off-Line Luminosity

The accurate and precise determination of integrated luminosity required for the experiment will be obtained from QED processes observed in the detector. We require a 1% or better measurement for each inverse picobarn of running. The available processes are Bhabha scattering and annihilations into muon pairs and gammas. We consider them individually in the context of the standard detector design. Our luminosity determination will be similar to that of BABAR, described for example in Touramanis' talk at the 2/2001 BABAR Collaboration Meeting. The BABAR determination is based on wide-angle ( $> 45^\circ$ ) Bhabhas and muon pairs. The systematic error is contributed to by the Monte Carlo (1-2%) and cut stability (1%), for an overall 2%. The annihilation to 2 photons has a greater systematic uncertainty, at least 3%, since the event rate is sensitive to mass and the geometrical acceptance is less well defined (angles for photons are not measured as well as those for charged particles).

In PEP-N the experimental situation is somewhat different. Since the calorimeter has relatively coarse spatial resolution ( $\sigma \sim 2.5$  cm), it is not possible to accurately define the acceptance for photons, leading to an unacceptably large systematic error for the 2 photon annihilation rate. Since the lumi-

osity is much smaller than for BABAR and we seek 1% uncertainties on a point-by-point basis, we must accept Bhabha and especially muon pair events at smaller polar angles, which requires good angular measurements at small angles to adequately define the acceptance. To obtain a 1% statistical error for each inverse pb we require  $> 10,000$  events for an integrated cross section of  $> 10$  nb. On the other hand the PEP-N detector is simpler and we may do better in the Monte Carlo simulation, which is the dominant error for the BABAR luminosity. In particular one particle for all Bhabha and muon pair events will be seen by the forward planar tracking chamber and electromagnetic and hadron calorimeters.

### Geometry

These (approximate) geometrical parameters are taken from the current detector layout. The beam pipe is expected to have a 5 cm radius and the default is 2.5 mm of aluminum. We assume  $4\pi$  tracking with 200 micron resolution for radii  $< 60$  cm, planar forward tracking with 200 micron resolution at  $z=120$  cm with unhindered aperture of  $\pm 23^\circ$ , planar forward electromagnetic calorimetry at  $z=180$  cm with  $\pm 36^\circ$  aperture and planar forward hadron calorimetry at  $z=220$  cm with  $\pm 27^\circ$  aperture. The forward hadron calorimeter will be used for muon ID.

### Bhabhas

Both electron and positron can be identified at all angles since we have nearly  $4\pi$  tracking and electromagnetic calorimetry. In order to get adequate statistics we must take advantage of the large forward cross section and count events in which one particle strikes the forward tracking chamber and forward electromagnetic calorimeter. It will certainly be helpful to identify the backward electron as well. The cross section, as seen in Table is well over 100 nb at all energies. For good control of systematics, it will be useful to define an acceptance at a relatively large positron angle. This avoids relying on events in which the  $e^+$  passes very obliquely through the beam pipe and reduces the angular accuracy and precision required to define the acceptance. However we wish events in which the forward track passes directly into the forward tracking chamber, missing the barrel calorimeter, as shown for example in Fig. 3. We give cross sections integrated between positron laboratory

angles of  $0.3$  ( $17.2^\circ$ ) and  $0.4$  ( $22.9^\circ$ ). As seen in Figure 2, the corresponding electron appears at  $28^\circ$ - $40^\circ$  at  $\sqrt{s} = 1.4$  GeV and  $97^\circ$ - $114^\circ$  at  $\sqrt{s} = 3$  GeV, and is detected in the barrel calorimeter which extends backward to  $157^\circ$ . We will not be limited statistically in the Bhabha measurement. The acceptance determination requires that we measure angles to about  $1.5$  mr which should be relatively straightforward using the well defined interaction point and the forward tracking chamber about  $120$  cm from the interaction point with spatial resolution  $\sim 200\mu\text{m}$ . Multiple scattering is a consideration here. At  $17.2^\circ$ , the effective thickness of the  $2.5$  mm Al beam pipe is  $.095$  radiation lengths for a rms multiple scattering angle of  $1.1$  mr. We can't tolerate a much thicker beam pipe.

#### Muon pairs

The muon pair cross section is much smaller and to obtain adequate statistics we would have to accept events at much smaller angles. Table gives the integrated cross section between laboratory angles of  $0.1$  ( $5.7^\circ$ ) and  $0.4$  ( $22.9^\circ$ ). Even so the statistics will be marginal at the largest center of mass energies. The smaller angles would then require more precise angular measurements for the acceptance determination, i.e. about  $0.5$  mr. However the multiple scattering for a very forward muon passing obliquely through the beam pipe is much larger, i.e. at  $5.7^\circ$ , the effective beam pipe thickness is about  $28\%$  of a radiation length and the rms multiple scattering angle is about  $2$  mr. A substantially thinner beam pipe would be required, or one with an angled window which is not obviously feasible at small angles. Muon pairs will be useful as a rough check of the Bhabha measurement but it will hard to obtain a precise luminosity because of statistical and systematic uncertainties.

#### Conclusion

Using Bhabhas, the PEP-N detector as proposed should produce integrated luminosity measurements with the desired  $1$ - $2\%$  accuracy for individual points representing about  $1\text{ pb}^{-1}$  of integrated luminosity. Muon pairs will be useful as a check although the muon pair luminosity will not generally have the required statistical accuracy.

## References

- [1] Ecklund, S; Field,C; Mazaheri,G. A fast luminosity monitor system for PEP-II. SLAC-PUB-8688, Oct 2000. Submitted to Nucl.Instrum.Meth.
- [2] A.E.Blinov *et al.*. Luminosity measurement with the MD-1 Detector at VEPP-4. *Nuc. Inst. Meth.* A273 (1988), 31-39.

$e^-$ energy	$E_{cm}$	$\theta_{min}^l$	$\theta_{max}^l$	$\cos(\theta_{max}^{cm})$	$\cos(\theta_{min}^{cm})$	$\sigma$ (nb)
0.100	1.114	0.300	0.400	0.171	-0.120	280.499
0.200	1.575	0.300	0.400	0.477	0.222	174.436
0.300	1.929	0.300	0.400	0.618	0.404	152.080
0.400	2.227	0.300	0.400	0.699	0.517	143.612
0.500	2.490	0.300	0.400	0.752	0.594	139.480
0.600	2.728	0.300	0.400	0.789	0.650	137.151
0.700	2.946	0.300	0.400	0.816	0.692	135.706
0.800	3.150	0.300	0.400	0.837	0.725	134.748
0.900	3.341	0.300	0.400	0.854	0.752	134.080
1.000	3.521	0.300	0.400	0.868	0.774	133.596

Table 1: Cross sections for Bhabhas.

$e^-$ energy	$E_{cm}$	$\theta_{min}^l$	$\theta_{max}^l$	$\cos(\theta_{max}^{cm})$	$\cos(\theta_{min}^{cm})$	$\sigma$ (nb)
0.100	1.114	0.100	0.400	0.856	-0.120	62.416
0.200	1.575	0.100	0.400	0.925	0.222	25.226
0.300	1.929	0.100	0.400	0.950	0.404	14.103
0.400	2.227	0.100	0.400	0.962	0.517	9.093
0.500	2.490	0.100	0.400	0.969	0.594	6.372
0.600	2.728	0.100	0.400	0.974	0.650	4.721
0.700	2.946	0.100	0.400	0.978	0.692	3.641
0.800	3.150	0.100	0.400	0.981	0.725	2.895
0.900	3.341	0.100	0.400	0.983	0.752	2.358
1.000	3.521	0.100	0.400	0.985	0.774	1.958

Table 2: Cross sections for  $\mu$  pairs.

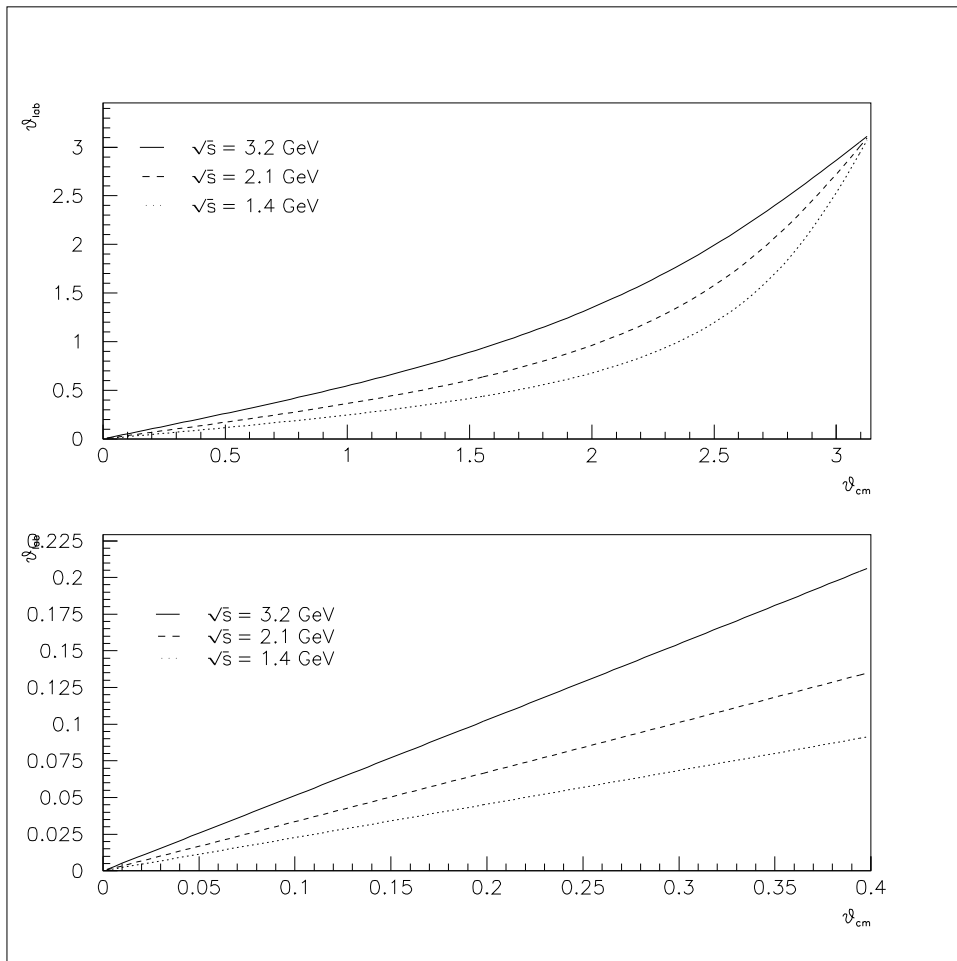


Figure 1: Bhabhas:laboratory v. center of mass angles.

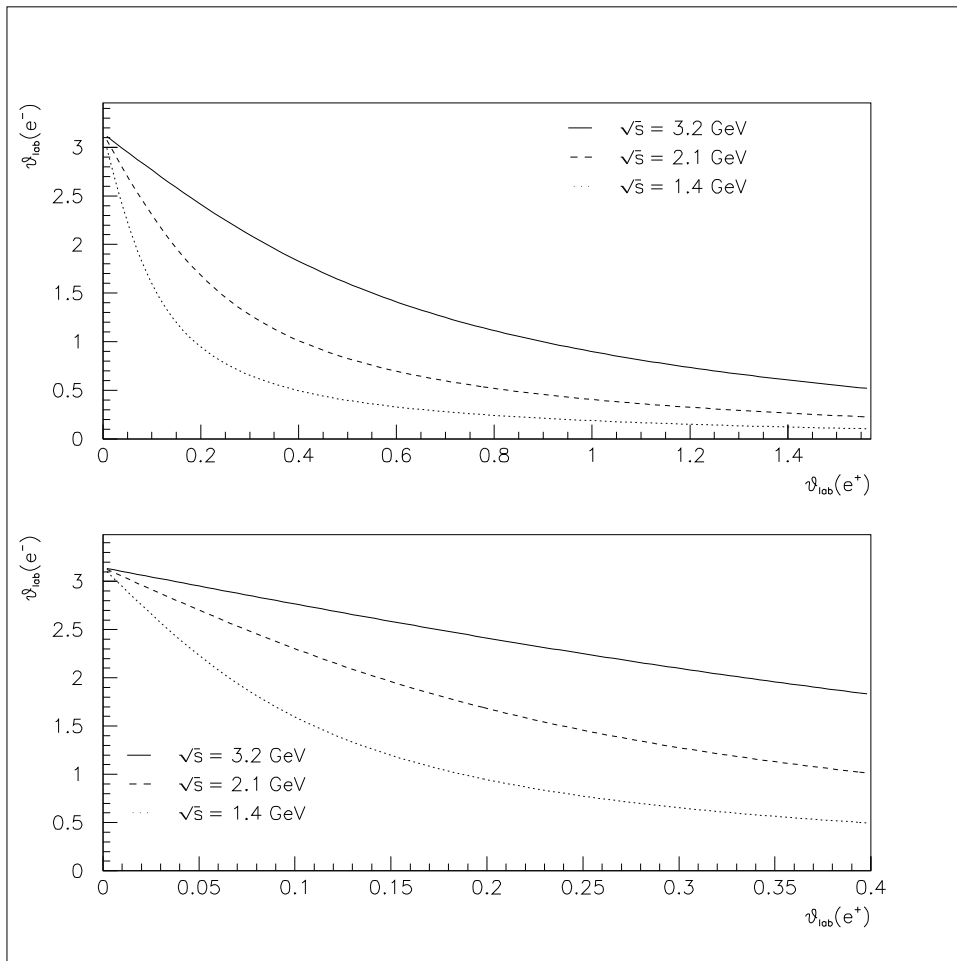


Figure 2: Bhabhas: electron v. positron laboratory angles.



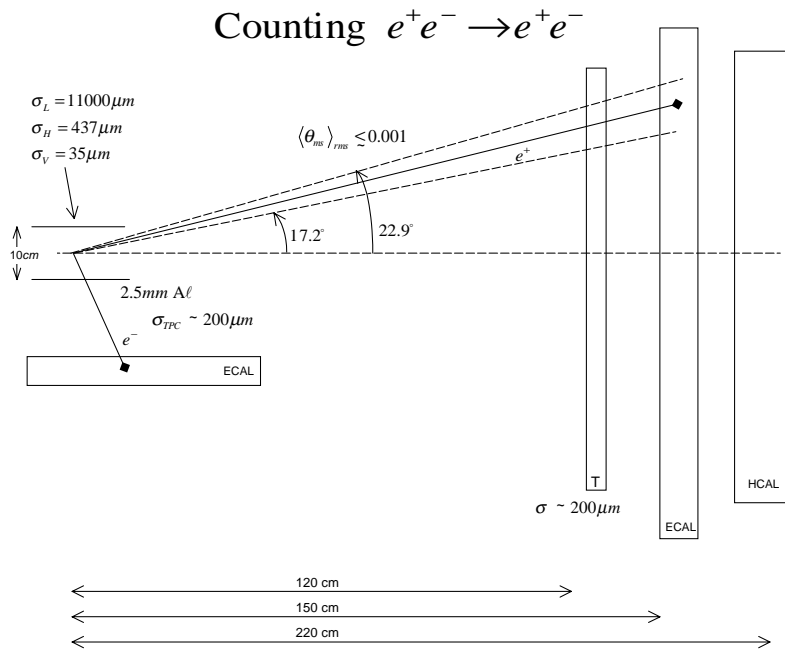


Figure 3: Geometry for counting Bhabha scatters.