Beam–Beam Scattering Diagrams

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The detection of beamstrahlung visible light, divided in its polarization components, effectively images the beam-beam collision. Monitoring and correction of drifts are discussed. Monitoring of beam jitter is also possible.

1. Introduction.

In a series of recent papers it has been made clear that recovering complete information on beamstrahlung effectively recovers complete information about the beam-beam collision in e^+e^- colliders[1, 2].

The underlying idea is actually a simple one. Given the four Maxwell equations,

$$\begin{aligned} \nabla \cdot \mathbf{E} &= 4\pi\rho, \\ \nabla \times \mathbf{B} - \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} &= \frac{4\pi}{c}\mathbf{J}, \\ \nabla \times \mathbf{E} + \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} &= 0 \\ \nabla \cdot \mathbf{B} &= 0. \end{aligned}$$

the beams are the currents, and beamstrahlung is the emitted EM field. The equations describe the correlation between currents and fields. We know the correlations, and we measure the field to figure out the currents. The fields are vectors, and that is why is necessary to measure their components.

In the recent past large angle beamstrahlung (several milliradians of angle, or $\sim 100/\gamma$) has been considered, because it is advantageous experimentally at low energy colliders (mostly for background suppression). At large angle, beamstrahlung (and all types of synchrotron radiation) exhibits a eight-fold linear polarization pattern, with 100% polarization[2, 3]. In practice observing at certain azimuthal angles is enough to pick out certain polarization components. When all or most of beamstrahlung is considered, like at a NLC, the method is exactly the same, except that all of beamstrahlung has a maximum total polarization of 7/8, so the calibration of the diagrams described below changes a bit. The nature and meaning of the diagrams, though, does not change.

The diagram plots two arrows in the first quadrant, each arrow having as $x-$ and $y-$ components of the beamstrahlung power emitted by each beam. For convenience, the components are normalized (a brief discussion of the normalization constant can be found in [2]). When the beams look like Figure 1 in the tranverse plane, the corresponding diagrams are as in Figure 2. There is a clear correspondence between the beam-beam pattern and the resulting diagram.

The algorithm to make use of these diagrams was worked out in Ref.[2], and is summarized here. A set of four asymmetries is defined and ranked, and the feedback system acts when anyone of the asymmetries becomes significantly different from zero. The wasted luminosity is then expressed as a function of certain partial derivatives. Tuning of a single corrector magnet (dipole, quadrupole, or sextupole) will correct any of the "pathologies" shown in Figure 1. If more than one "pathology" exists, it was also proven that minimization of the asymmetries in their strict ranking order always converges. Finally, by measuring the evolution of the diagram after the first-ranking correction, one can recover information about six of the seven transverse degrees of freedom which exist in a beam-beam collision.

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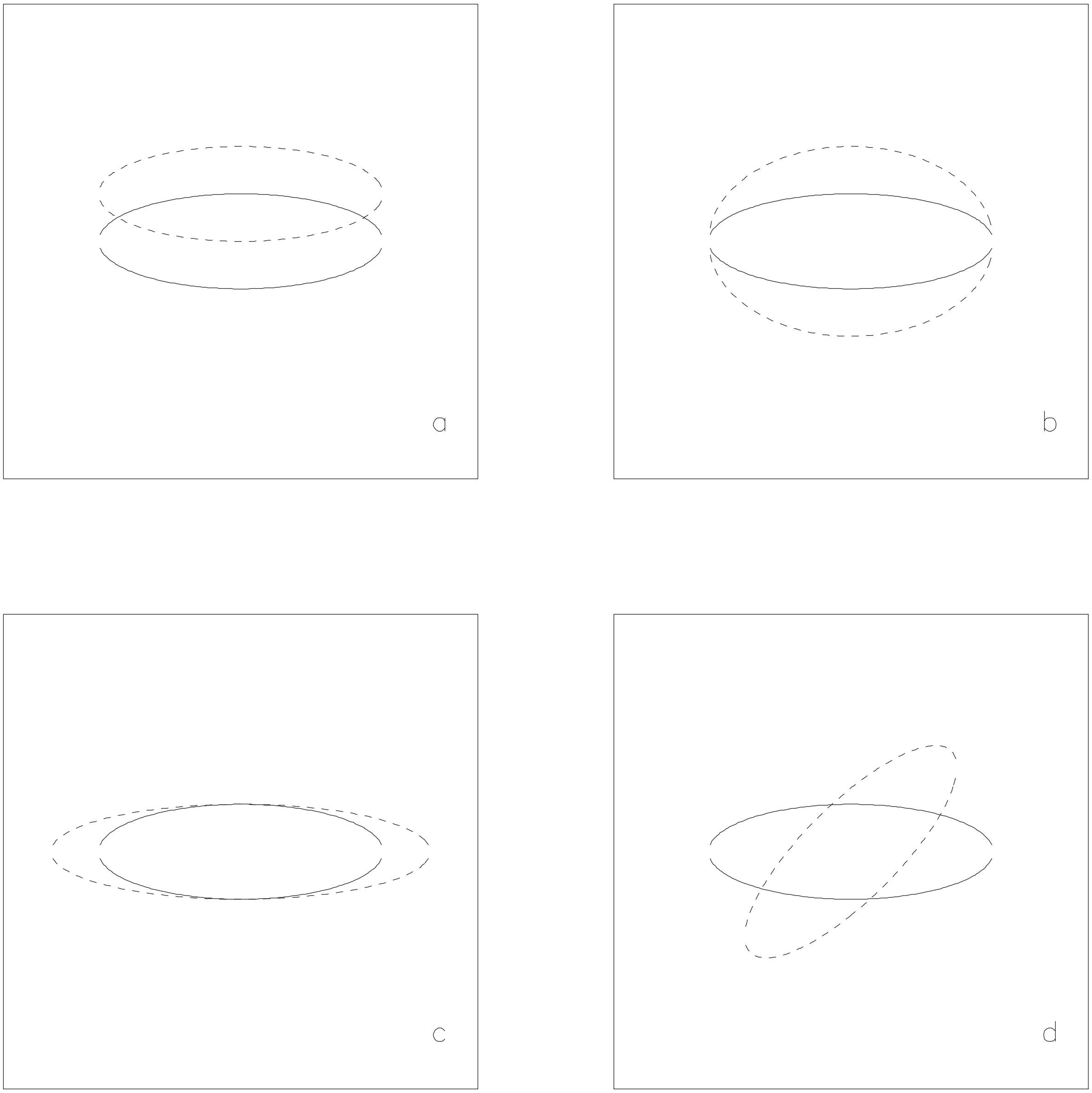

Figure 1: The four beam-beam pathologies that lead to wasted luminosity; a) a $y-$ offset; b) $y-$ bloating; c) $x-$ bloating; and d) a beam-beam rotation. The pathological beam is represented by the dashed ellipse.

The meaning of the diagram is that it can correct the various ways in which a beam can drift away from its nominal location over time. The diagram both diagnoses and corrects drift. It identifies which beam is going bad, which corrector magnet needs to be tuned, and by how much it needs to be tuned. If a machine drifts only (that is, if there is negligible beam jitter) the diagram will provide all of the necessary beam-beam feedback.

2. The Second Diagram.

The first diagram diagnoses, measures, and corrects generalized machine drift. The second diagram diagnoses, measures, but does not necessarily correct generalized beam jitter. Machine jitter is due to the seismic motion of its various components, and the electromagnetic fluctuations of machine components. Machine jitter translates into beam jitter via the Twiss matrix of the machine. What could be purely seismic motion can translate into well-centered but poorly focussed beams at the IP.

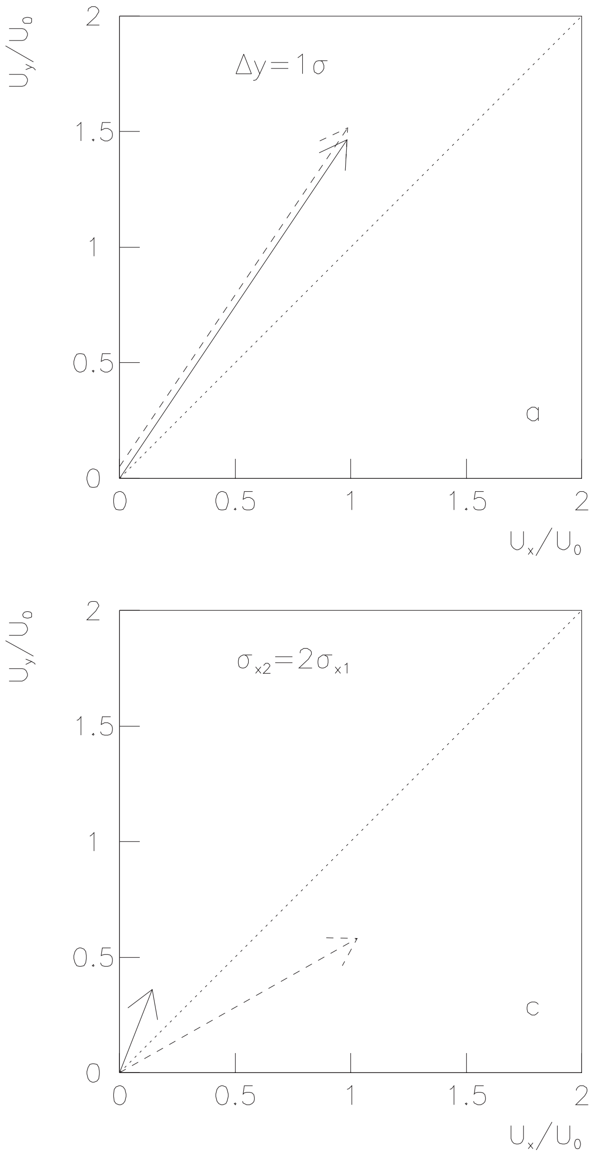

Figure 2: Beamstrahlung diagrams corresponding to the four pathologies of Figure 1. The tips of vectors in part a) are displaced for display purposes. Stiff beams are assumed.

The first diagram measures, collision by collision, the first moment (*i.e.*, the amount) of the various polarized powers $U_{1x}, U_{1y}, U_{2x}, U_{2y}$. The second diagram measures, over a number of collisions, the second moment (*i.e.*, the RMS), of the same four quantities. The beam jitter is related to the jitter of certain beamstrahlung observables.

It goes without saying that, if the beams have no jitter, the RMS of all the involved quantities will be consistent with zero. If the beams jitter, the diagram will jitter in ways that are unique.

Like other techniques that might measure the beam-beam collision, the second diagram will be able to pick out a fundamental oscillation frequency, if it is there. Unlike other techniques, the second diagram picks out also jitter that translates into transverse beam rotation or suboptimal focussing.

In conclusion, there exists a simple, powerful and non-destructive technique to image the beam-beam collision. A large angle beamstrahlung detector is being built right now at CESR [4], funded by the NSF, which should establish the technique as a major piece of instrumentation for the Next Linear Collider.

References

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