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We consider planar directed last-passage percolation on the square lattice with general i.i.d. weights and describe the geometry of the full set of semi-infinite geodesics in a typical realization of the random environment. The main tool is the Busemann functions viewed as a stochastic process indexed by the asymptotic direction. In the exactly solvable exponential model we give a complete characterization of the uniqueness and coalescence structure of the entire family of semi-infinite geodesics. Part of our results concerns the existence of exceptional (random) directions in which new interesting shock structures occur.

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