Example of an elliptical orbit: Halley’s comet. 
http://neo.jpl.nasa.gov/orbits/  Search: Halley. Set the applet to December 1, 1986, and play forward to watch the comet move along its perihelion. Notice Halley’s comet has a clockwise orbit while the planets have a counter-clockwise path. Why is this?

Rutherford Scattering
Ernest Rutherford (with the help of many students, graduate and English majors) discovered this scattering by sending a beam of particles through a thin sheet of gold. The idea is to make the sheet thin enough so that only by luck it has atoms—that is, there will be no overlapping of atoms. Then, send in a beam of particles (photons, α-particles, etc...), and, with the right equipment, you will find that particles are being scattered out the other side! These particles are loose, valence electrons knocked out of the gold shell by the incoming particles. They are seen as sparks against a backboard by a careful observer.

So, how many targets do we see? The average number is determined by:

\[
\text{Average} = nV_{\text{slab}},
\]

where \( n \) = number density and \( V_{\text{slab}} \) = the volume of the slab tested, which can also be written as \( V_{\text{slab}} = Adz \), making the equation:

\[
\text{Average} = n(Adz).
\]

Let’s look at it this way… imagine instead that the slab is instead pizzas set out on the ground in a square array (or round, whatever) and it begins to rain on them. What’s the area of rainfall? What you need to do is not only count all of the raindrops falling but the number that land on the pizzas, which is:

\[
\sigma nAdz = \sigma \text{hit, } \sigma = \text{area of one pizza.}
\]

“\( \sigma \text{hit} \)” is the probability of the pizzas hit.

Now, going back to the slab, the change of radiation intensity behind the slab is then:

\[
dI = \sigma \text{hit},
\]

Here, the number of hits is equivalent to one hit times the number of times a hit was tried. This leads us then to:

\[
dN = a\Delta t \ dI = -\sigma \text{hit} (Ia\Delta t), \text{ where } a = \text{area of target and } Ia\Delta t = N.
\]

\[
dI = -\sigma ndz I
\]

\[
dI/I = -\sigma ndz \rightarrow \ln I = -\sigma ndz + \text{constant}
\]

\[
I = I_0 e^{-\sigma nz} = I_0 e^{-\sigma \lambda}, \text{ where } -\sigma n = 1/\lambda, \text{ and } \lambda = \text{mean free path.}
\]

So \( n = c/l^3 \) and \( \sigma = \vec{l}, l = \text{length.} \)
Therefore, the radiation of particles from the slab diminishes exponentially with intensity (lead blocks are best for blocking radiation, like x-rays at the hospital).

If we pretend that lotteries are 100% fair, for example, the chance that you will win could be 1 in a million. Let’s say that the lottery pays half a million. To be sure you win, you should buy all million tickets. But if each ticket costs one dollar, then you would spend one million dollars on a half-million prize? If you still want a better chance, go ahead and play more but don’t pay out too much. For instance, if you buy five tickets, you increase your chances by five times for only five dollars! So for every N chance better you want, you need to try N times—thus, the earlier mentioned situation where the number of hits is really one hit times the number of times you tried ($n_{\text{hits}} = 1 \times N_{\text{tries}}$).

So you should associate a cross-section as the probability of something happening over the whole. It’s much more simpler and in many cases just as accurate (or as accurate as you can possibly get). Lets take an alpha-particle beam with energy of about 5-6 MeV. If they hit the scintillating screen, the atoms are excited and release light as they settle to a ground state. Take your television or computer monitor. It releases not only a lot of visible light, but x-rays as well. The harmful x-rays, however, are reduced and even blocked by the lead screen of your monitor, which allows photons with the wavelength of regular light to stream through. Also, the space between you and your screen increases the chance that the particles will hit and scatter off of air molecules. Besides, $\alpha$-particles usually pass through substances—they are harmful if swallowed, causing cancer, but usually cause burns on the skin if the particle emitting them is left close to you.

So lets get back to the experiment that lead to the discovery of Rutherford Scattering. You take a substance like Radium and put it in a lead box with a single hole in it. From that hole, a beam of alpha-particles is emitted. If you angle the box so that the beam falls upon a piece of thin matter, such as gold foil, you’ll notice flashes on the screen behind the foil—that’s called scintillation. With different thickness of foil come different wavelengths of the particles seen in the scintillation. Mostly, you will notice that the particles will scatter off axis!

Of course, no one noticed this immediately—mostly due to the biased opinion that scattering would not occur, or atom models of the time would be incorrect. The angle, of scattering, however, was greater than 30°, though only one in eight thousand particles will make it that high. Rutherford, of course, found this odd, so in order to reduce the biased he hired English majors to count the number of flashes at that angle and above. Amazingly, it worked. In later years, the

Geiger counter became more useful when it came to removing bias.
So what is going on here? Well, first of all, let us imagine a fast particle moving along the z-axis:

\[ b = \text{classical impact parameter (distance from the axis of the atom)} \]

If the force (F) is attracting:

Why are the two ‘b’ s the same? Because the path looks the same no matter which direction you travel in! (On the atomic/microscopic level, any action can be reversed. However, on the macroscopic level, this is not always possible—like an egg “unbreaking”). The figure above yields two equations:

\[ \frac{d^2 r}{dt^2} = F, \quad \text{and} \quad \frac{d v}{dt} = \frac{d}{dt} \]

Changing the time direction only changes the direction of the force and velocity vectors!

So how does the scattering angle fit in? Regardless of the sign of the angle, the affect is the same:
As you can see, nothing about the path has changed, just that it angles away from the axis of the atom instead of towards it. The only difference in the force and velocity equations is that the force is now in the opposite direction.