Introduction: Heavy Loopers

A charged heavy particle produced at the LHC may have a small transverse momentum (p_T), which makes it hard to travel through the inner detector (ID) due to the bending caused by the magnetic field. The standard ATLAS tracking algorithm usually requires a minimal amount of hits to reconstruct a track, which means the particle has to pass a minimal number of layers. Therefore there exists a certain p_T threshold, for a given charge, for the particle to be reconstructable hypothetically. This becomes more critical when exotic multiple charged particles are considered as the p_T threshold is lower as explained below. In this short note, I performed some simple calculations to extract those thresholds. Such a particle will spiral along the z-axis, leaving hits in the first few layers of the ID with a clear pattern. We can name this signature as the "Heavy Loopers".

Obtain Track p_T via Radius, Charge and Magnetic Field

Starting from simple approximation:

$$\cdot\frac{v^2}{r} = m \cdot q \cdot B \tag{1}$$

One gets:

$$p_\mathrm{T} = q \cdot B \cdot r \tag{2}$$

Performing a simple dimensional analysis:

$$\begin{gathered} = [J][A^{-1}][L^{-2}], \\ [r] = [L], \\ [q] = [e], \\ [qBr] = [J][A^{-1}][L^{-1}][e], \\ [A] = [C][T^{-1}], \\ [J] = [C][V], \\ [qBr] = [V][T][e][L^{-1}] = 3e10 \cdot [\frac{eV}{c}] = 0.3 \cdot [\frac{GeV}{c}] \end{gathered} \tag{3}$$

As a result, in ATLAS ($B = 2$ Tesla), a unit charge particle ($q = 1$), with a track radius of one meter ($r = 1$ meter), has a p_T of 0.6 GeV.

Critical p_T for Loopers

Let us assume that to make such a looper escape the tracking reconstruction, it should not pass more than four tracking layers. The fourth pixel layer has a radius of 122.5 mm. As a result, the critical track radius is therefore 61.25 mm. Using Equ.3, this gives a p_T of 0.036 GeV. Such low p_T particles is only abundant if the production threshold is very close to 13 TeV to have a very small Q.

However, in the context of multiple charged particles, this threshold vary. For a particle with $q = 10$, this threshold reaches 0.36 GeV. If the critical track radius is loosened to be the fifth layer of the ID, which is the first layer of the SCT, corresponding to a radius of 299 mm, the threshold becomes 1 GeV. Figure 1 shows the p_T for a given charge-radius combination.

Experimental Signatures

Particles with p_T below the threshold wil spiral along the z-axis in the ID as illustrated in Figure 2. Due to the energy lost the separation in z decreases in practice. However a strong correlation still present between the hits left, forming a series of hits on the same ID layer with nearly evenly separation in z (z-line). For a multiple charged particle, those hits are highly ionizing. If the particles are not completely stable so that they decay after traveling for a certain distance in z, this gives us a displaced vertex + z-lines. These are interesting signatures that have not been considered so far.

Discussion

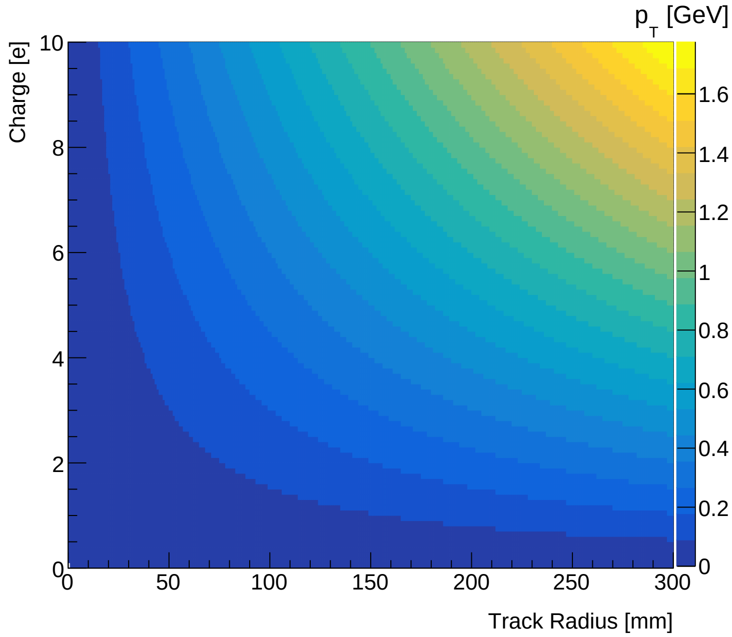

Figure 1: Distribution of p_{T} for a given charge (y-axis) and a given track radius (x-axis).

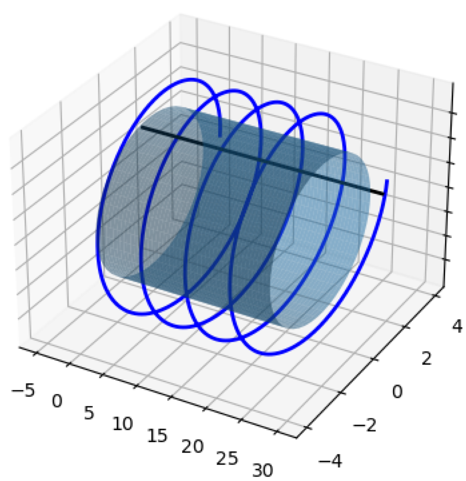

Figure 2: Illustration of the “Heavy Looper” signature.

The “Heavy Looper” signature, or in general, the “Looper” signature, may rise, for instance the soft pions produced in many BSM scenarios. In the context of heavy stable multiple charged particle, when the particle has a very large charge and extremely heavy (closing to the collision energy), the “Heavy Looper” signature appears. In this note, I only considered the case where standard track reconstruction is likely to fail, but in principle we do not have to place this constraint. As long as the charged particle can re-enter the ID volume, signatures similar to “Heavy Looper” still show up. To be continued.