TRACKING DOWN QUIRKS AT THE LHC

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OUTLINE OF THIS TALK

1. WHAT ARE QUIRKS?
2. WHY SHOULD WE CARE?
3. HOW DO WE FIND THEM?

WHAT ARE QUIRKS?

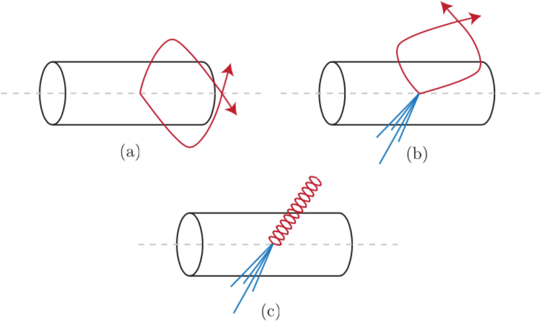
- Particles charged under a new, confining gauge group.
- New gauge force confines at a scale $\Lambda \ll m_Q$, where m_Q is the mass of the lightest quirk.
- Lightest quirk is stable.

QUIRK PHENOMENOLOGY IS QUIRKY

Compare to QCD:

$$m_{u,d} \ll \Lambda_{QCD} \rightarrow \text{hadronisation.}$$

In the case of quirks, the flux tube does not break, but instead exerts a force on the quirks → macroscopic oscillations!



A NOTE ON PRONUNCIATION

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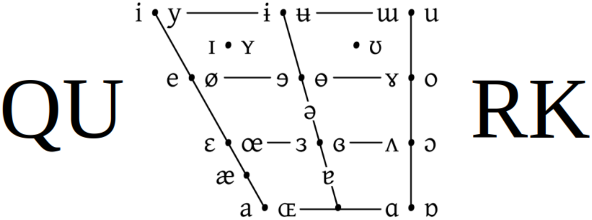
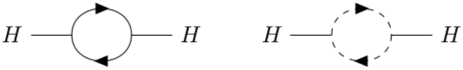


MOTIVATION

Quirks can appear in models of “neutral naturalness”, for instance:

- Folded SUSY
- Little Higgs

In these models, the particle which cuts off the top loop correction to the Higgs mass is *not* charged under QCD.



$SU(3)$ $SU(3)'$

Often less constrained than models with coloured ‘top partners’.

QUIRK DETECTION

Characteristic amplitude of oscillation:

$$d \sim 2\ \text{cm}\ (\gamma - 1)\left(\frac{m_Q}{100\ \text{GeV}}\right)\left(\frac{\text{keV}}{\Lambda}\right)^2$$

- $\Lambda \gtrsim 30$ keV: oscillation length smaller than detector resolution ($\sim 100\ \mu$m).
- $\Lambda \lesssim 100$ eV: oscillation length of order the size of the detector, or larger.

INTERMEDIATE REGIME

In the intermediate regime

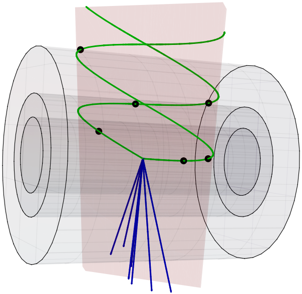
$$100 \text{ eV} \lesssim \Lambda \lesssim 10 \text{ keV}$$

the oscillation length scale is comparable to the size of the detector.

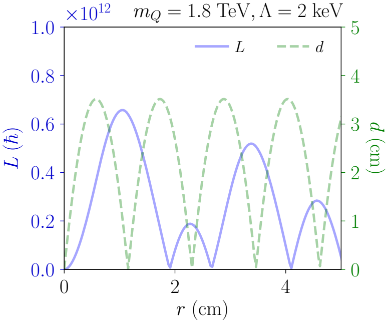
Unusual tracks not reconstructed by conventional algorithms.

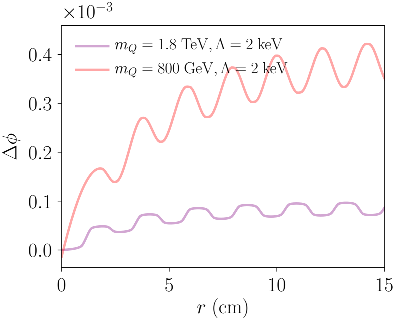
Key observation: particles subject to a central force leave hits that, to a good approximation, lie in a plane.

Can we fit a plane to a candidate event with a large number of background hits – $\mathcal{O}(1000)$ per layer?



QUIRK DYNAMICS





Angular momentum (L, in units of $\hbar$) of the quirk/antiquirk system, and the distance between the quirks (d), as a function of the radial distance (r) of their centre of mass from the origin.

Angular drift ($\Delta\phi$) of the quirk plane as a function of the radial distance (r) of the centre of mass from the origin.

PLANE-FINDING ALGORITHM

Optimal plane minimises mean-squared distance between the candidate points and the plane.
Define

$$d^2 = \boldsymbol{n}^T \boldsymbol{T} \boldsymbol{n}$$

where $\boldsymbol{n}$ is a unit vector normal to the plane and

$$\boldsymbol{T}(\{\boldsymbol{x}_a\}) = \frac{1}{N-1} \sum_{a=1}^{N} \boldsymbol{x}_a \boldsymbol{x}_a^T .$$

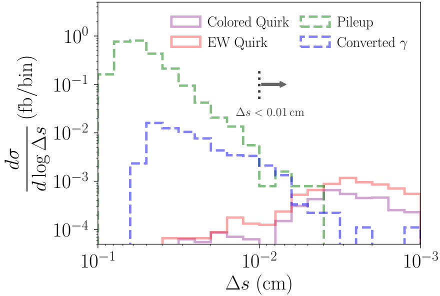
This matrix has useful properties:

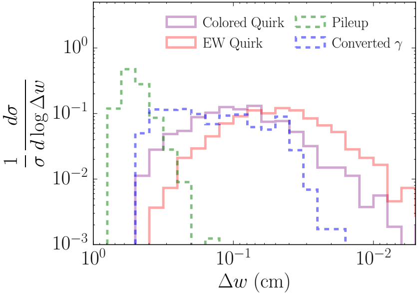
- Smallest eigenvalue $\Delta s^2 \to$ minimum value of d^2, associated eigenvector is normal to the optimal plane.
- Next smallest $\Delta w^2 \to$ corresponds roughly to the width of the quirk oscillation.
- Third eigenvector gives direction of motion of the quirk pair.

SELECTING CANDIDATE POINTS

1. Start at outer layer, collect all pairs of hits with $\Delta\phi < 0.1$ and $\Delta z < 2$ cm.
2. Do the same for the next layer.
3. Construct four hit combinations (pairs of pairs) and compute $\boldsymbol{T}$ for each one. Reject any combinations with $\Delta s < 0.05$ cm and $\Delta w < 1$ cm.
4. Loop over remaining layers, add hits to candidate planes if doing so does not increase Δs or Δw by a factor of 3.
5. Final cuts on remaining candidate planes: $\Delta w < 1$ cm. If more than one plane survives, selects the one with the smallest Δs.

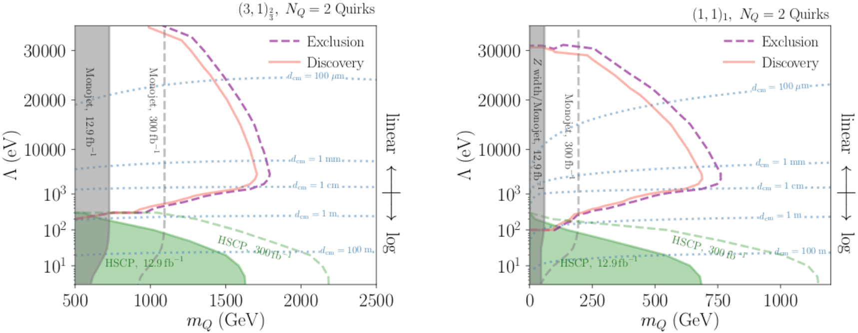
SIGNAL/BACKGROUND DISCRIMINATION





Signal and background distributions for Δs and Δw. The signal benchmarks for coloured (EW) quirks are $m_Q = 1.8$ TeV and $\Lambda = 2000$ eV ($m_Q = 800$ GeV and $\Lambda = 4000$ eV).

RESULTS



Exclusion and discovery limits for coloured and EW quirks.

CONCLUSIONS

- Quirks are generic predictions of many well-motivated models.
- Difficult to search for using conventional methods.
- We propose a method to efficiently search for quirks, using the fact that their trajectories lie in a plane.

Thanks for your attention!