

# New Signals at the LHC

## from a 'Hidden Valley'

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## Hidden Valley

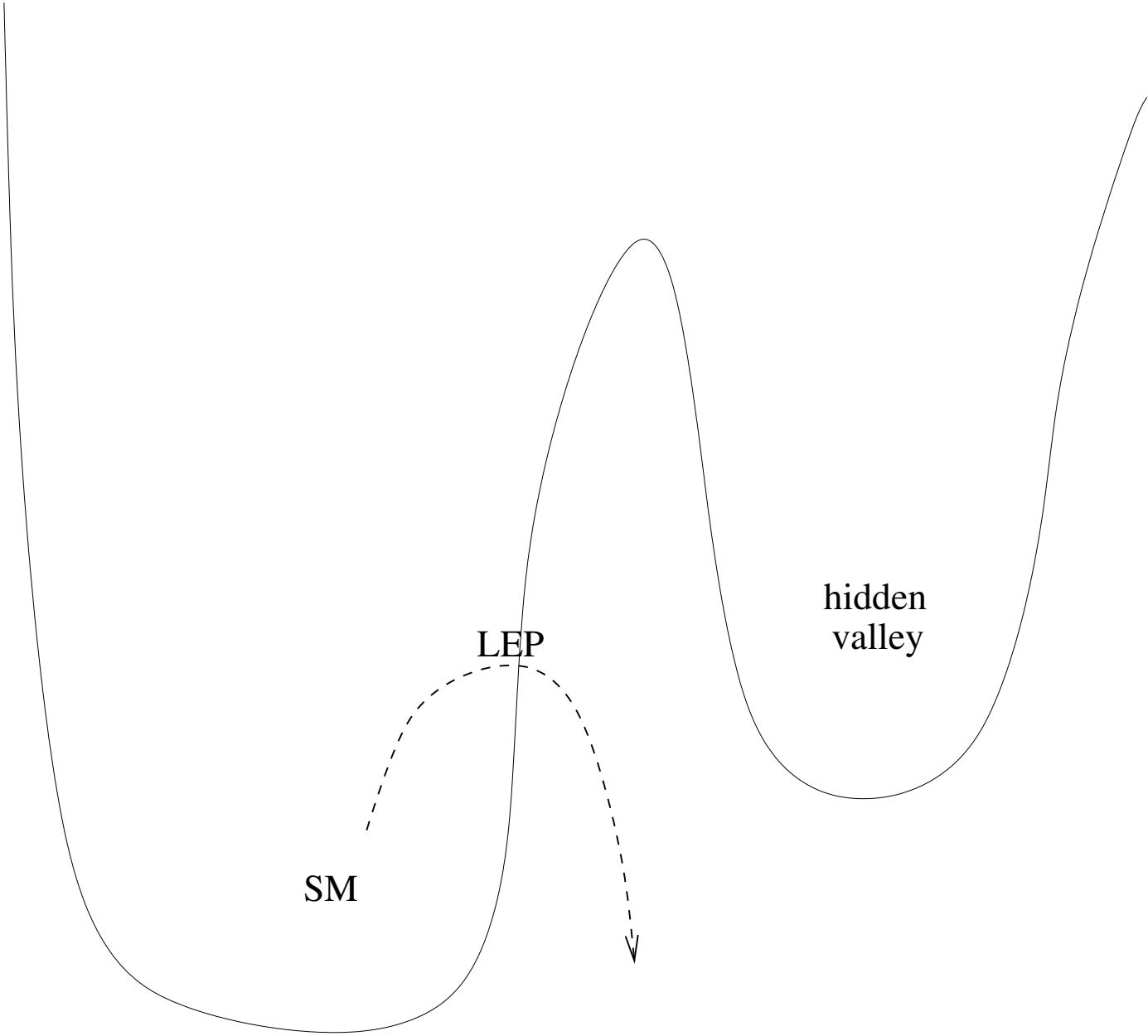
What *is* a “hidden valley”?

And why does it give unusual and interesting signals at the LHC?

Many top-down constructions of the standard model in various GUT and string theory contexts have suggested extra  $U(1)$  factors.

Many string constructions also suggest extra **nonabelian** factors to which standard model fields do not couple.

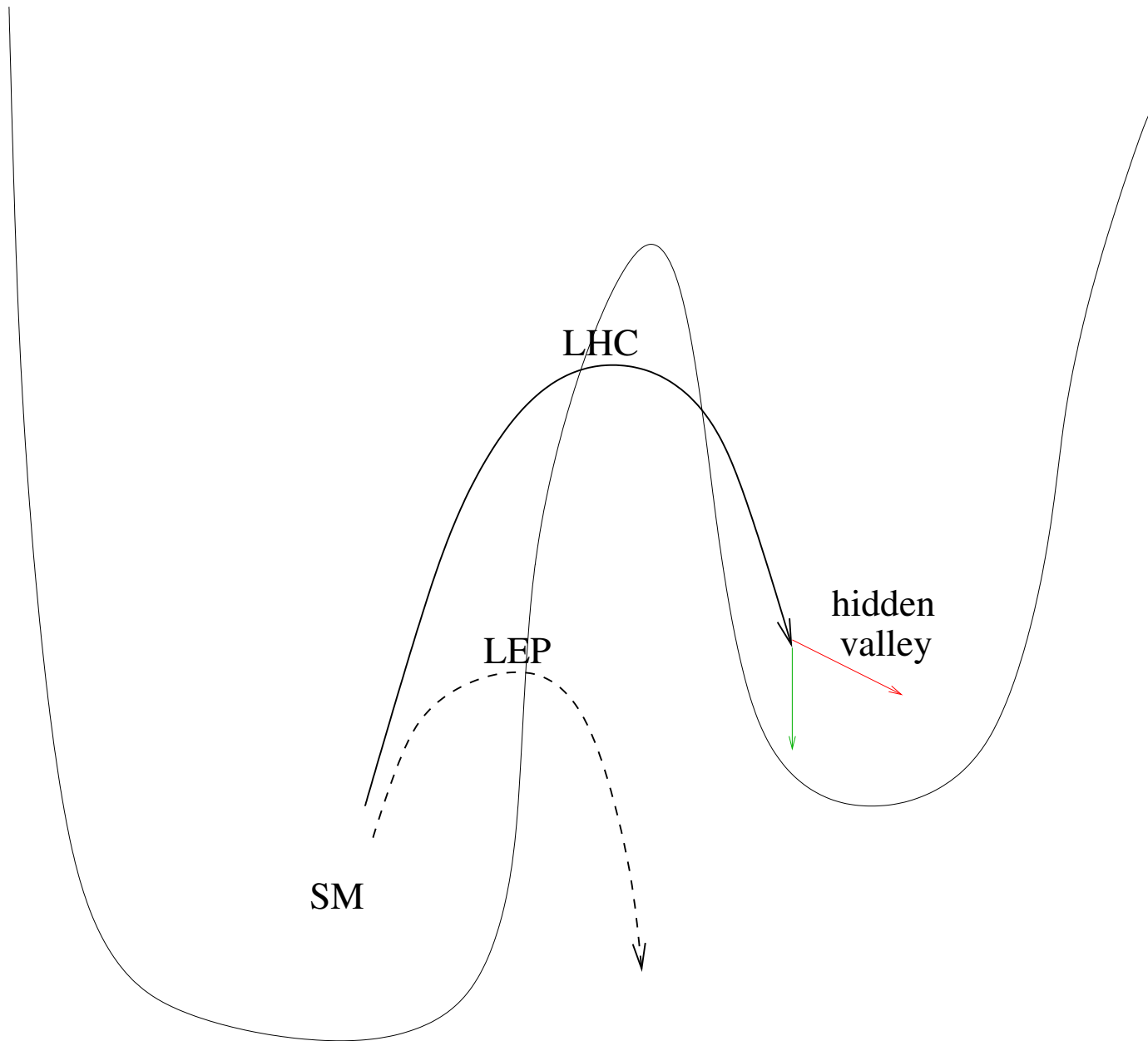
Little has been done on their phenomenology. Here we will see that if the nonabelian factor is confining, the resulting signals are accessible, though potentially very challenging, at the LHC (and possibly the Tevatron as well.)



SM

LEP

hidden  
valley



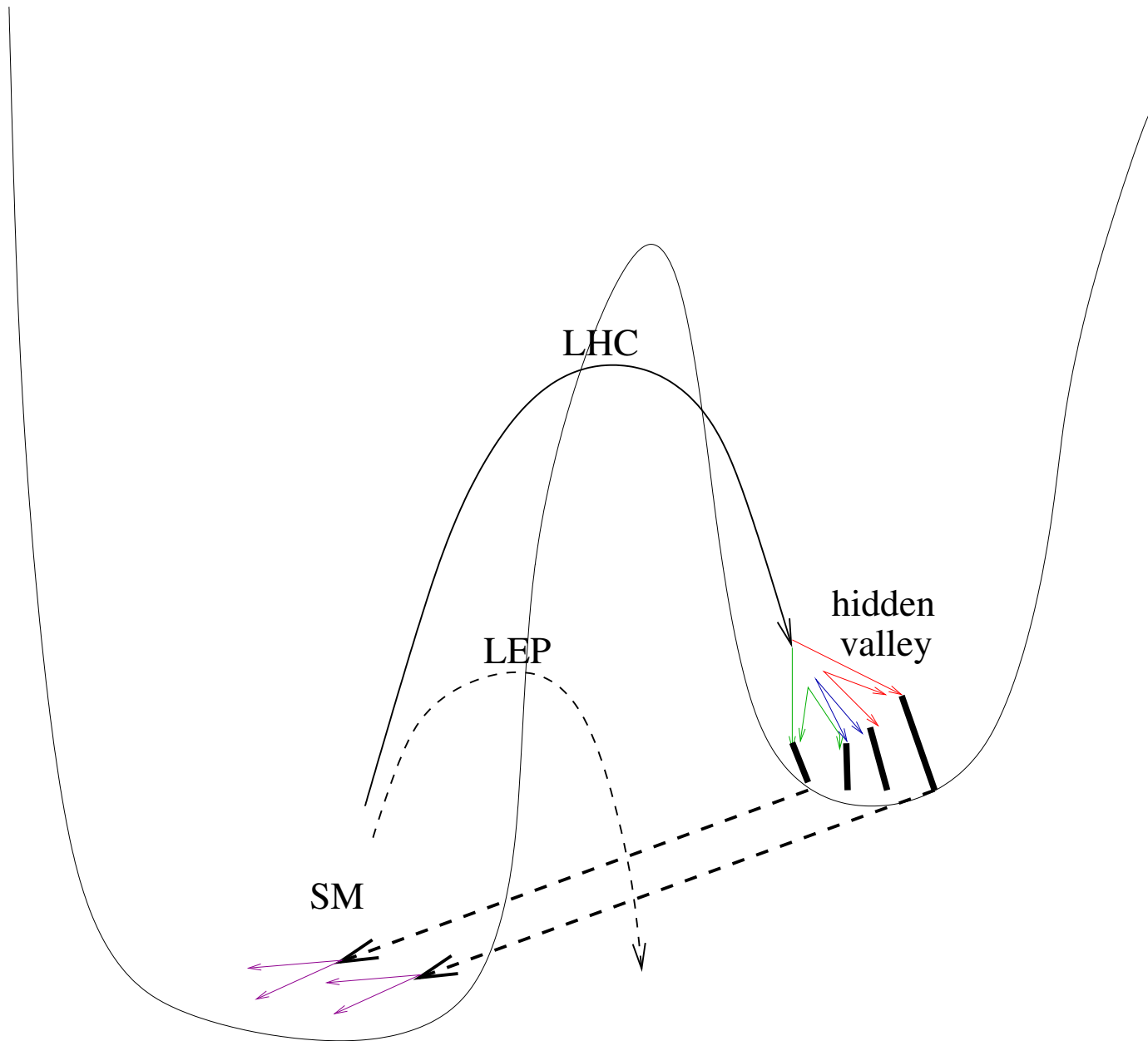


Illustration: Let's consider the following theory –

	$q_i$	$\bar{u}_i$	$\bar{d}_i$	$\ell_i$	$e_i^+$	$N_i$	$U$	$\bar{U}$	$C$	$\bar{C}$	$H$	$\phi$
$SU(3)$	<b>3</b>	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>
$SU(2)$	<b>2</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>1</b>
$U(1)_Y$	$\frac{1}{6}$	$-\frac{2}{3}$	$\frac{1}{3}$	$-\frac{1}{2}$	1	0	0	0	0	0	$\frac{1}{2}$	0
$U(1)_\chi$	$-\frac{1}{5}$	$-\frac{1}{5}$	$\frac{3}{5}$	$\frac{3}{5}$	$-\frac{1}{5}$	-1	$q_+$	$q_-$	$-q_+$	$-q_-$	$\frac{2}{5}$	2
$SU(n_v)$	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	$\mathbf{n}_v$	$\overline{\mathbf{n}}_v$	$\mathbf{n}_v$	$\overline{\mathbf{n}}_v$	<b>1</b>	<b>1</b>

The  $U(1)$  is **broken** at  $v' \sim 5$  TeV

The  $SU(n_v)$  **confines** at  $\Lambda_v \sim 10 - 1000$  GeV

Suppose  $m_C, m_U \ll \Lambda_v$

This is like QCD with  $N_f = 2$ ; the light particles are “v-pions”

$$\pi_v^+ \sim U\bar{C}, \quad \pi_v^- \sim \bar{U}C, \quad \pi_v^0 \sim U\bar{U} - C\bar{C}$$

$$\pi_v^+ \sim U\bar{C}, \quad \pi_v^- \sim \bar{U}C, \quad \pi_v^0 \sim U\bar{U} - C\bar{C}$$

*Caution:* the  $\pm$  is an **v-isospin** label.

**All three pions are electrically neutral!**

If  $C, U$  are stable, so are  $\pi_v^\pm$ ; they are undetectable.

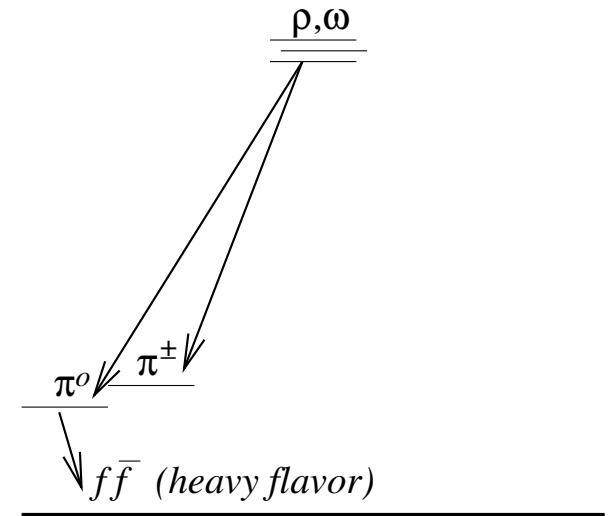
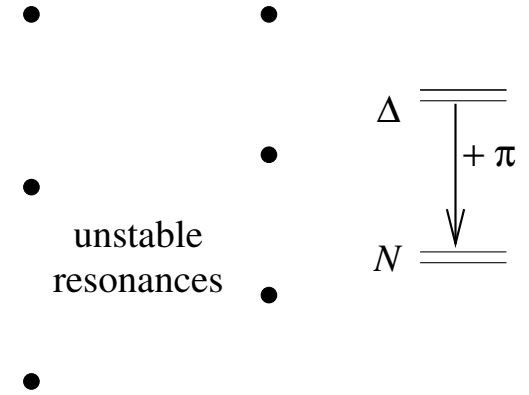
But not  $\pi^0$ .

$$\pi_v^0 \sim Q\bar{Q} \rightarrow [Z']^* \rightarrow f\bar{f}$$

$$\text{Pseudoscalar} \Rightarrow \text{Br}(\pi_v \rightarrow f\bar{f}) \propto m_f^2$$

**v-Pion Decays to Heavy Flavor**

(though no relation to Higgs)



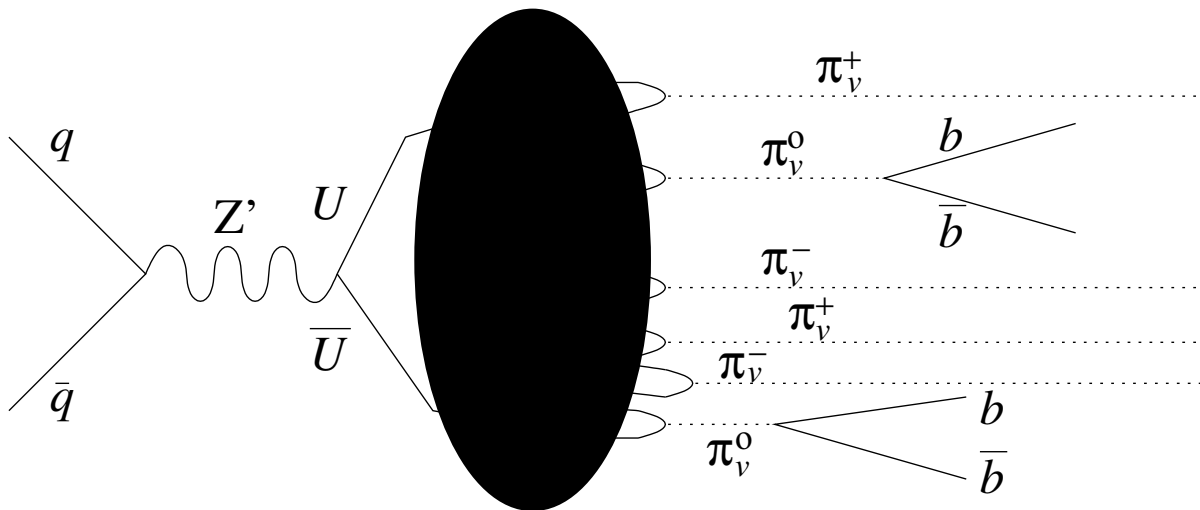
Partial spectrum and decay modes  
in the two-light-flavor regime

## Production

LEP limits:  $m_{Z'}/g' > 10 \text{ TeV}$  (but caveats)

LHC production: Cross-sections 5-500 fb typical

$q\bar{q} \rightarrow$  v-hadrons analogous to  $e^+e^- \rightarrow$  hadrons:



Sample event in two-light-flavor regime

*Reminder:  $\pi^\pm$  are neutral*

## Large Multiplicity!

$m_{Z'}/\Lambda_v$  small :        2–3 v-hadrons

$m_{Z'}/\Lambda_v$  moderate :  $\sim$  3–7 v-hadrons

$m_{Z'}/\Lambda_v$  large:        v-jets of v-hadrons

$\sim$  2/3 of v-hadrons are invisible

$\sim$  1/3 decay to  $b\bar{b}$ ,  $c\bar{c}$ ,  $\tau^+\tau^-$

Signal?! Many different final states with many  $bs$ , missing energy.

- Event selection?
- What happens if an event has 5 decaying v-hadrons?
- What does a soft v-jet really look like?

Simulation package not available yet but *should be ready by mid-summer*.

Possible (if  $\Lambda_\nu$  small and/or  $m'_Z/g'$  large)

$\pi_\nu^0$  mass 10 - 50 GeV, lifetime  $\sim$  picoseconds, even nanoseconds.

**Displaced vertices?!**

*In vertex detector? tracker? calorimeter?*

Could be important in reducing backgrounds and permitting discovery

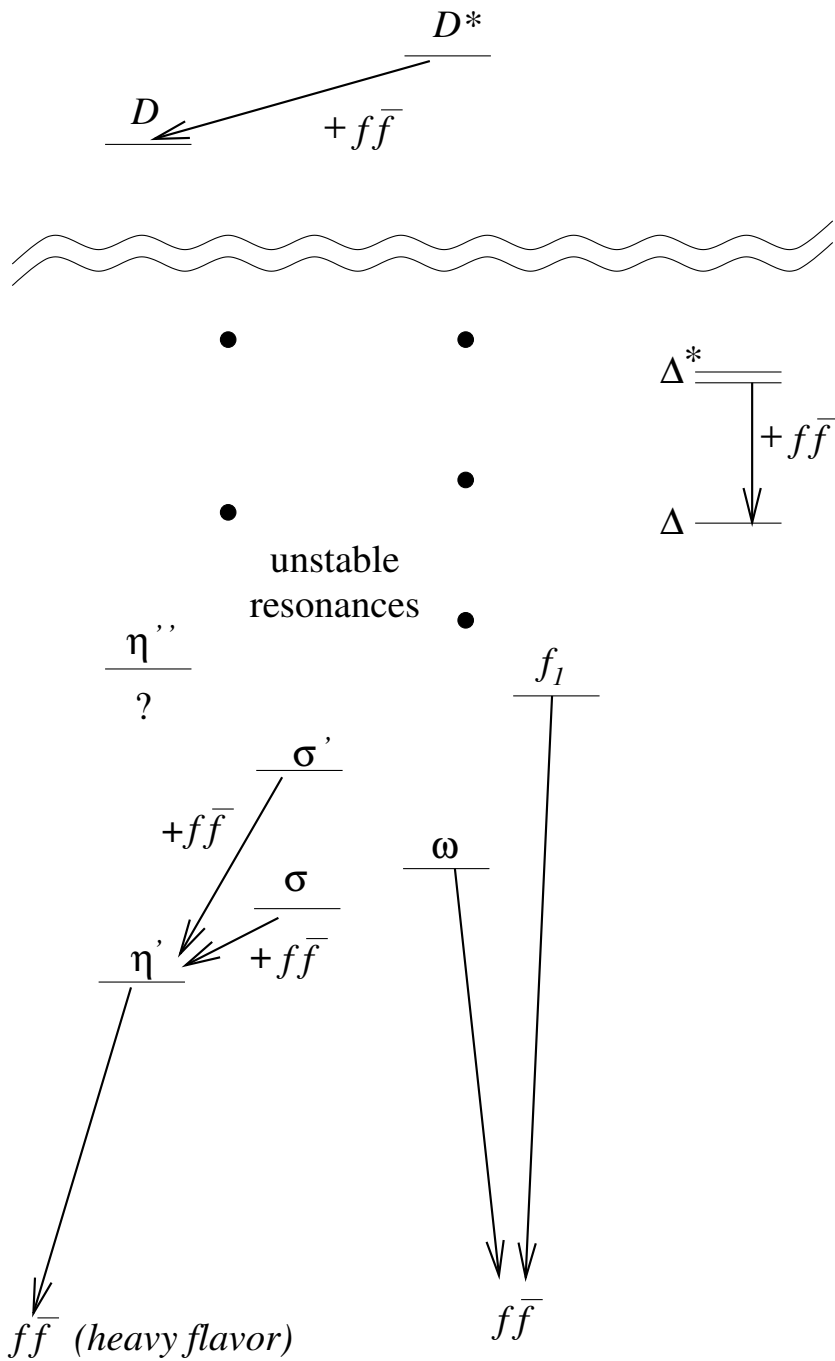
Needs special purpose analysis at Tevatron – also at LHC?

But the physics may **not** be QCD-like.

*What if  $m_C > \Lambda_v > m_U$ ?*

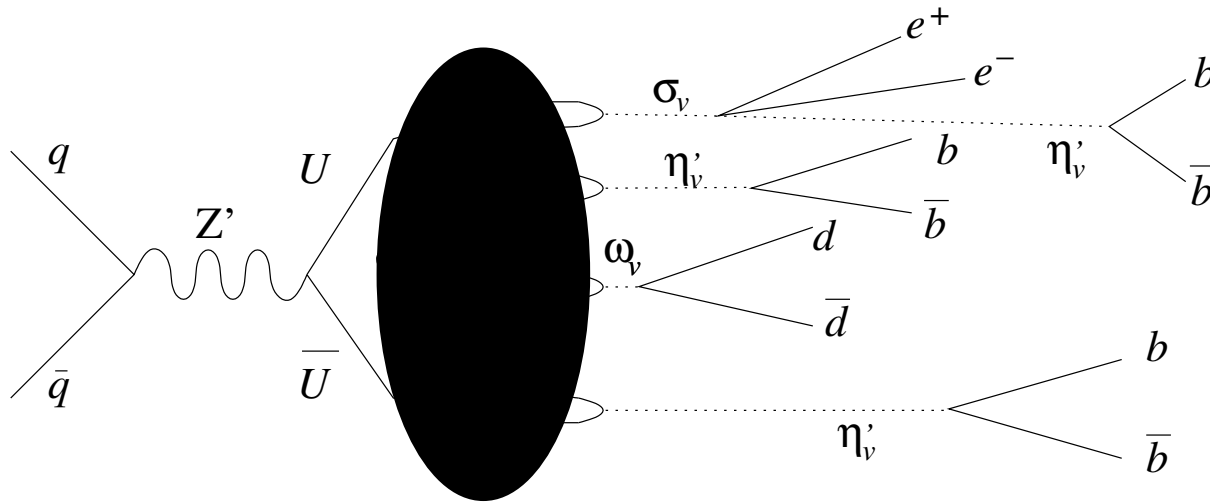
But the physics may **not** be QCD-like.

*What if  $m_C > \Lambda_v > m_U$ ?*



Guess at partial spectrum and decay modes in the one-light-flavor regime

The decay chains are now different; less missing energy, can get light lepton pairs and ordinary jets.



Sample event in one-light-flavor regime

... and maybe displaced vertices.

Again, simulation package a bit more difficult but will be developed.

Finally, Higgs mixing can lead to decays to  $\nu$ -hadrons.

Dealt with only briefly so far.

Stay tuned for more details.

- Hidden valley models can produce many neutral resonances with diverse masses, lifetimes, decay modes
- Many v-hadrons may be produced simultaneously; the numbers may be large and jetty structure (if any) may be hidden
- The experiments are not guaranteed to detect this, but should be capable of it. There are many issues: Triggering? Event selection? Jet definition in busy events? Detector issues with highly displaced vertices?
- To this end, simulation packages will be needed
- The model shown here is illustrative; a totally different model is also given in the paper for contrast, with very different signals. Many other classes of models can be imagined.
- The world could be stranger than we expect; we must keep our imaginations alive and ensure that we don't miss crucial phenomena simply because we didn't look for them