Braids, loops, and the emergence of the Standard Model

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DISCLAIMER

From Wikipedia

"Dr. Sundance O. Bilson-Thompson is an Australian theoretical particle physicist who has developed ideas in the field of loop quantum gravity. He was a Visiting Academic at the University of Adelaide before becoming a full-time academic at the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, Canada. **He makes terrible puns**. Listen for them during his lectures."

OUTLINE

1. Basic concepts
2. Emergent braided states
3. Interpretation as particles
4. Systematics of the model

SHAMELESS HANDWAVING

- I will be taking the “mental cartoon” of LQG for granted.
  - Networks of connections
  - Dual to tetrahedra of space
- NB No spin labels necessary at this stage

- Consider ribbon networks e.g. as arise in quantum gravity with *non-zero cosmological constant*.
- Assume ribbon networks are *orientable surfaces*
- Otherwise-arbitrary twisting and braiding allowed

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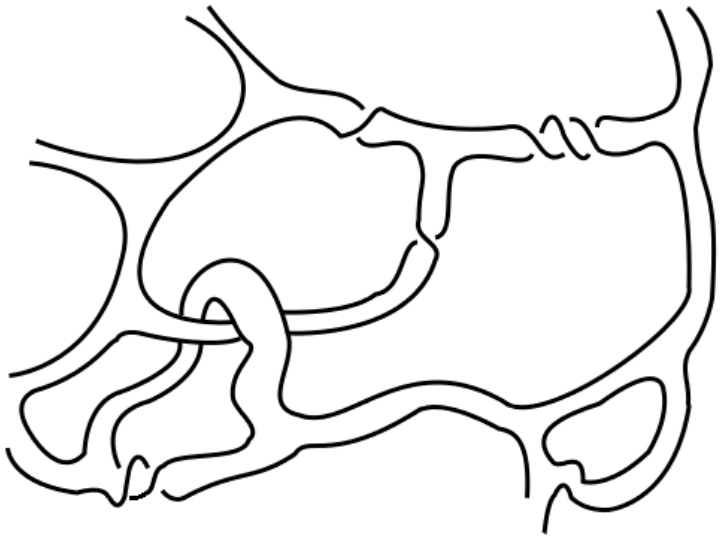
BRAIDED NETWORKS

If arbitrary braiding is allowed;

- Whatever can happen, will



If surfaces are orientable;

- Twists into a given node are all even multiples of $\pm\pi$, and/or zero, or all odd multiples

A LONG-STANDING QUESTION

If nodes represent volume, and links represent area, what information is encoded by braiding/twisting?

- Emergent particle states (says me!)
- This possibility can be illustrated by adapting ideas from ***preon models***

From what?

"Preons? What are they?"

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WHAT PREONS ARE NOT

Preons don’t cause this!!

RISHONS a.k.a. QUIPS (1979)

Describe all 1^{st} generation quarks and leptons as triplets of *rishons* (Harari) or *quips* (Shupe)

- Two types, $\mathbf{T}$ and $\mathbf{V}$, plus anti-particles $\overline{\mathbf{T}}$ and $\overline{\mathbf{V}}$ (Harari's notation)
- $\mathbf{T}$s carry charge $+e/3$, $\overline{\mathbf{T}}$s carry $-e/3$, $\mathbf{V}$s and $\overline{\mathbf{V}}$s neutral
- Assumption: No mixing of anti-rishons and rishons

$$
\begin{array}{lcll}
\overline{\mathbf{TTT}} & = & \mathbf{e}^{-} & (\overline{\mathbf{TTV}}, \overline{\mathbf{TVT}}, \overline{\mathbf{VTT}}) = \overline{\mathbf{u}} \\
\overline{\mathbf{VVV}} & = & \overline{\nu_{\mathbf{e}}} & (\overline{\mathbf{TVV}}, \overline{\mathbf{VTV}}, \overline{\mathbf{VVT}}) = \mathbf{d} \\
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$$

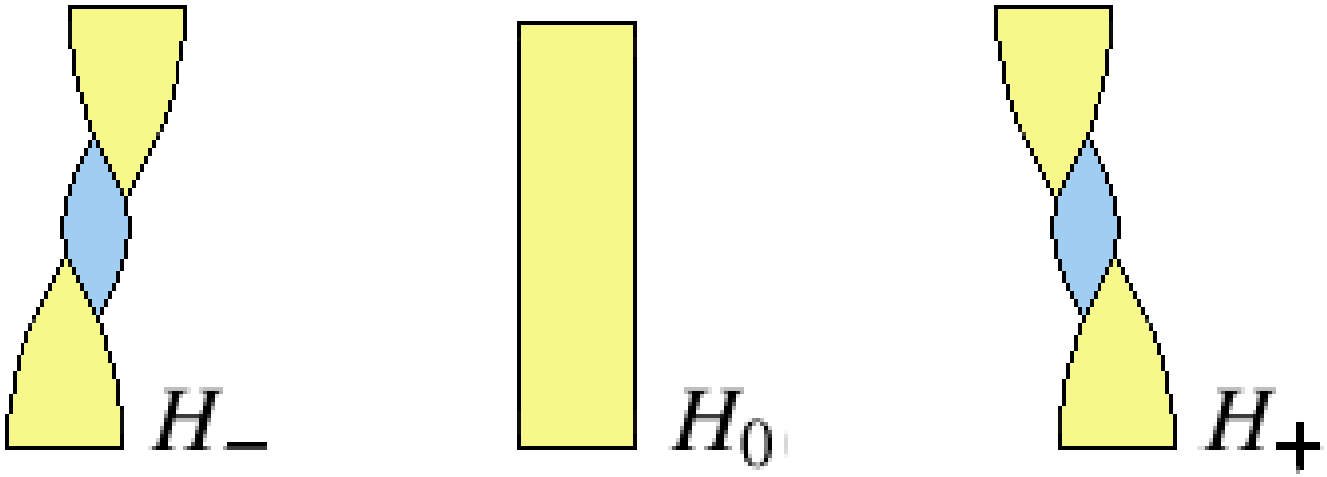
- Permutations equivalent to colour charge

PARTICLE PROPERTIES

generation	quarks		leptons	
1	$u^{+2/3}$	$d^{-1/3}$	e^-	ν_e
2	$c^{+2/3}$	$s^{-1/3}$	μ^-	ν_μ
3	$t^{+2/3}$	$b^{-1/3}$	τ^-	ν_τ
charge	+2/3	−1/3	−1	0

- Explains number/type of fermions (1^{st} generation)
- Explains charge/colour connection
- No matter–anti-matter asymmetry

HELONS - RISHONS WITH A TWIST



- Replace **T**s and **V**s by twisted strands (*helons*).
- Since twists must differ by $\pm 2\pi$, consider H_-, H_0, and H_+.

N.B. Can regard helons as composite = pairs of $\pm\pi$ twists (Tweedles)

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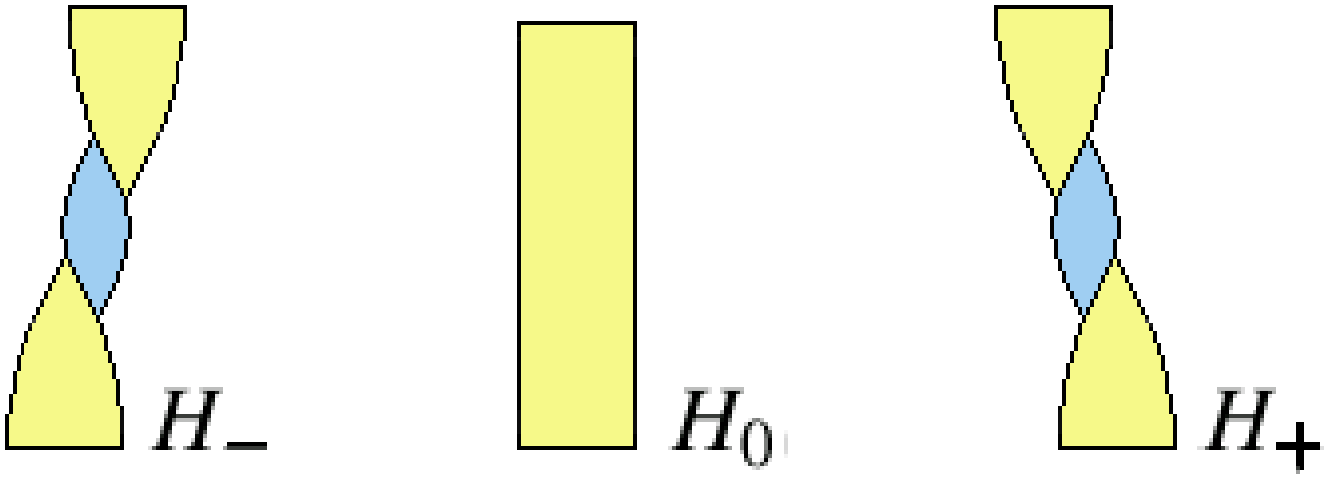

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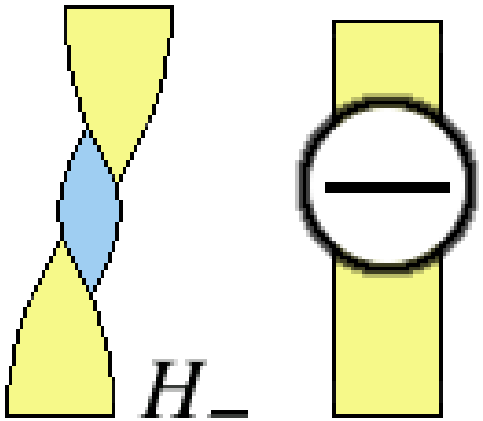
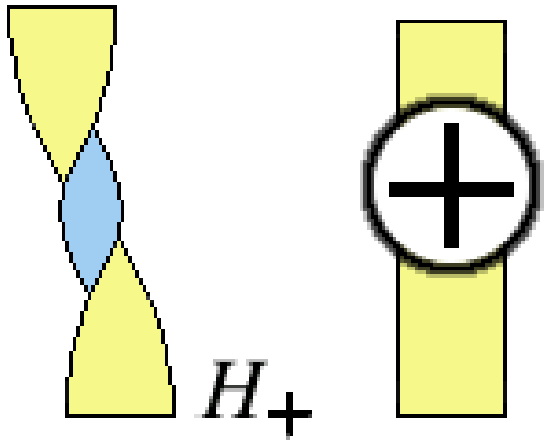




- Regard $\pm 2\pi$ twists as electric charges $\pm e/3$

HELONS vs RISHONS

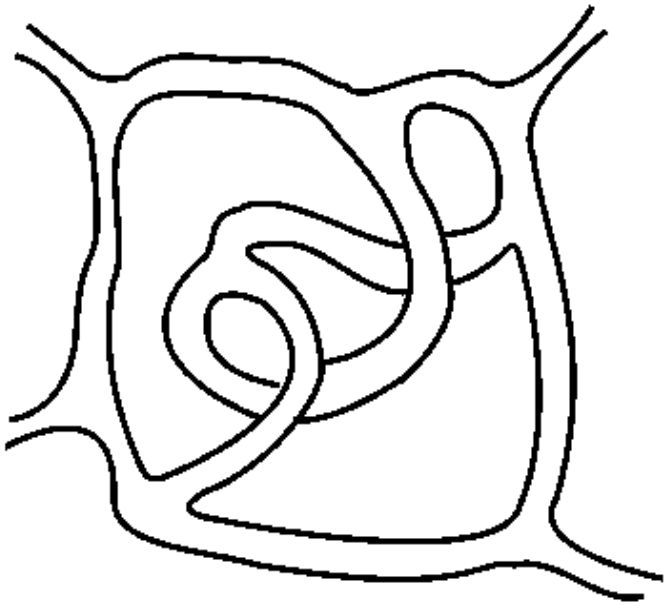
- Like rishons in original model, helons are colourless
- Like rishons, ordering determines colour
- Unlike rishons, we have a *reason why* ordering matters
- Assume triplets with both H_+ and H_- not allowed
- Possible combinations are;

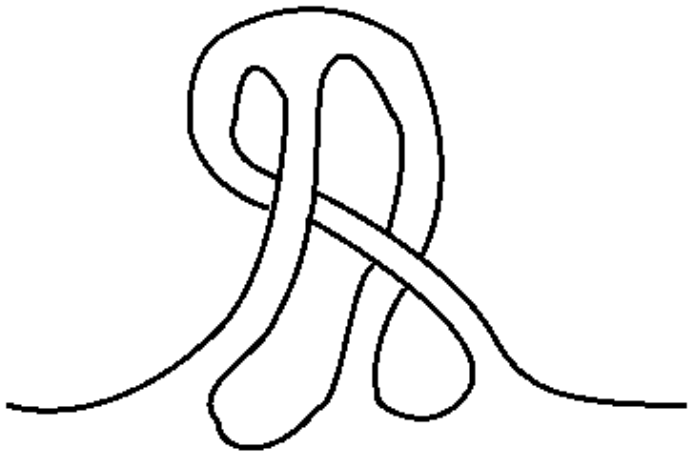
$H_+H_+H_+$	(e^+)	$H_+H_+H_0$	(q_u)	$H_+H_0H_+$	(q_u)	$H_0H_+H_+$	(q_u)
$H_0H_0H_0$	(ν_e)	$H_0H_0H_+$	$(\overline{q}_d)$	$H_0H_+H_0$	$(\overline{q}_d)$	$H_+H_0H_0$	$(\overline{q}_d)$
$H_-H_-H_-$	(e^-)	$H_-H_-H_0$	$(\overline{q}_u)$	$H_-H_0H_-$	$(\overline{q}_u)$	$H_0H_-H_-$	$(\overline{q}_u)$
		$H_0H_0H_-$	(q_d)	$H_0H_-H_0$	(q_d)	$H_-H_0H_0$	(q_d)

NB: No anti-neutrino

COMBINING HELONS

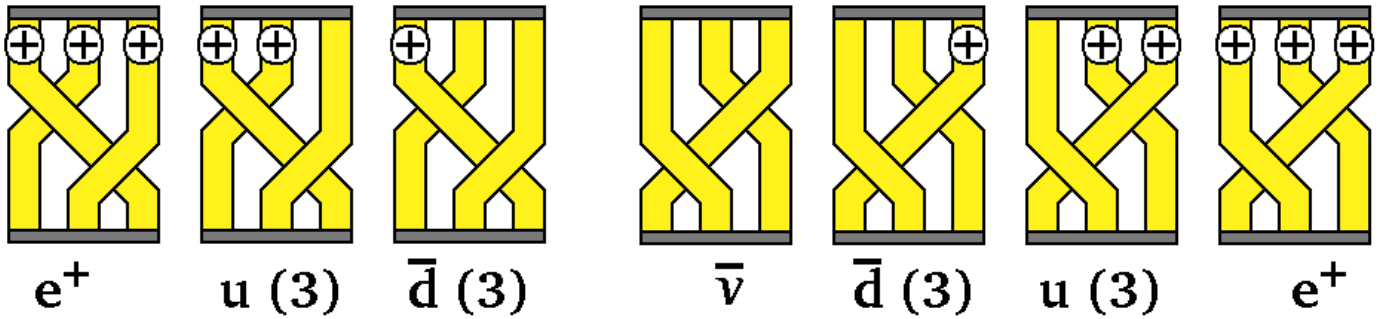
- Consider braided sub-graphs in isolation (for simplicity)
- Remember they are actually attached - even though I don't draw them that way!





FIRST GENERATION FERMIONS

- Construct half the 1st generation fermions from +ve and null twists on a braid



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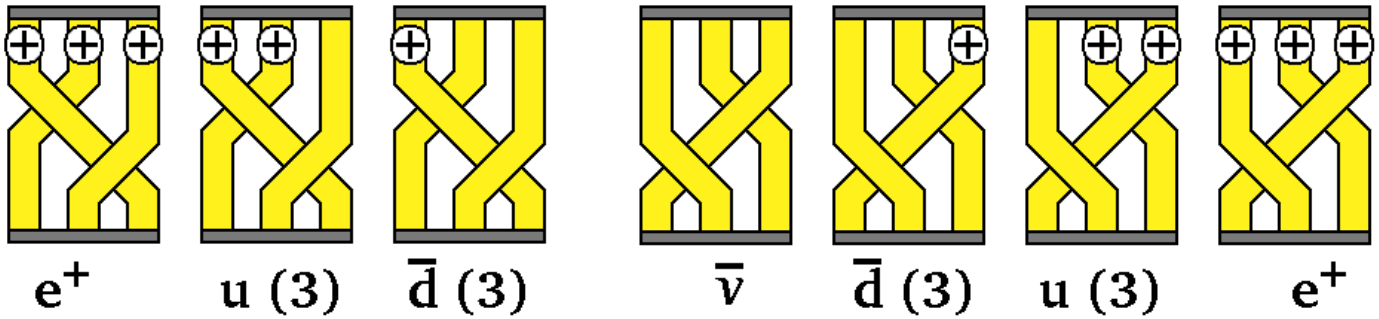

- Construct the anti-particles as mirror images

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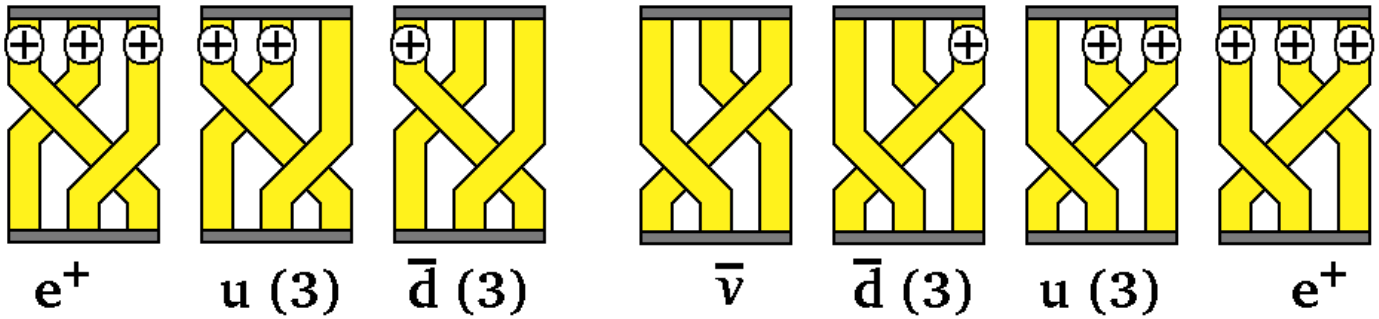

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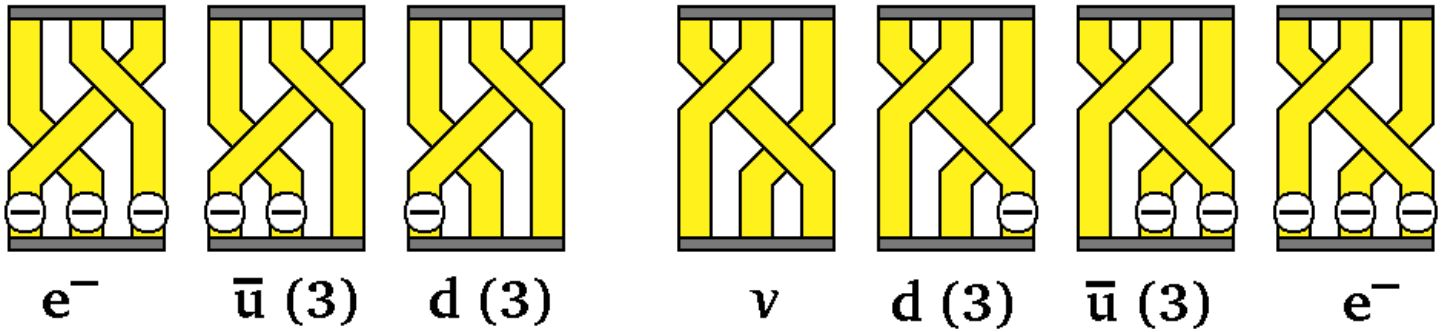
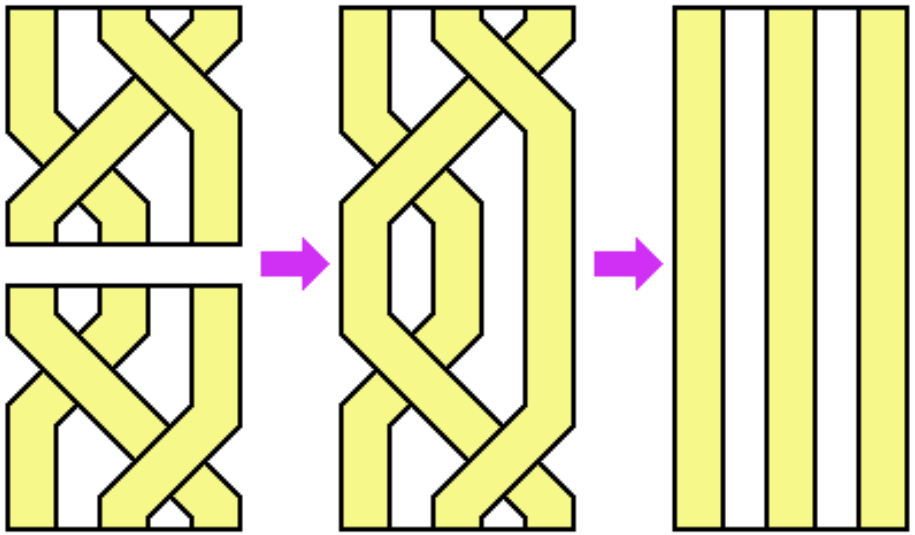


CONSERVATION OF BRAIDS

- Taking the braid product (joining top-to-bottom) looks a lot like particle-antiparticle annihilation



THE MISSING ANTI-NEUTRINOS

- Identify left-right mirroring of a braid (or anti-braid) as P inversion (swapping LH - RH)
- Top-bottom mirroring equivalent to C inversion (swapping particles-antiparticles)

- All fermions are essentially neutrinos. Electric charge is just added to the basic neutrino “framework”
- For each non-zero value of electric charge, Q, there are four combinations of charge and handedness

$$Q > 0\,,\, H = -1 \qquad Q > 0\,,\, H = +1$$
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- If $Q = 0$, there are only *two* possible handedness states - the neutrino and anti-neutrino!

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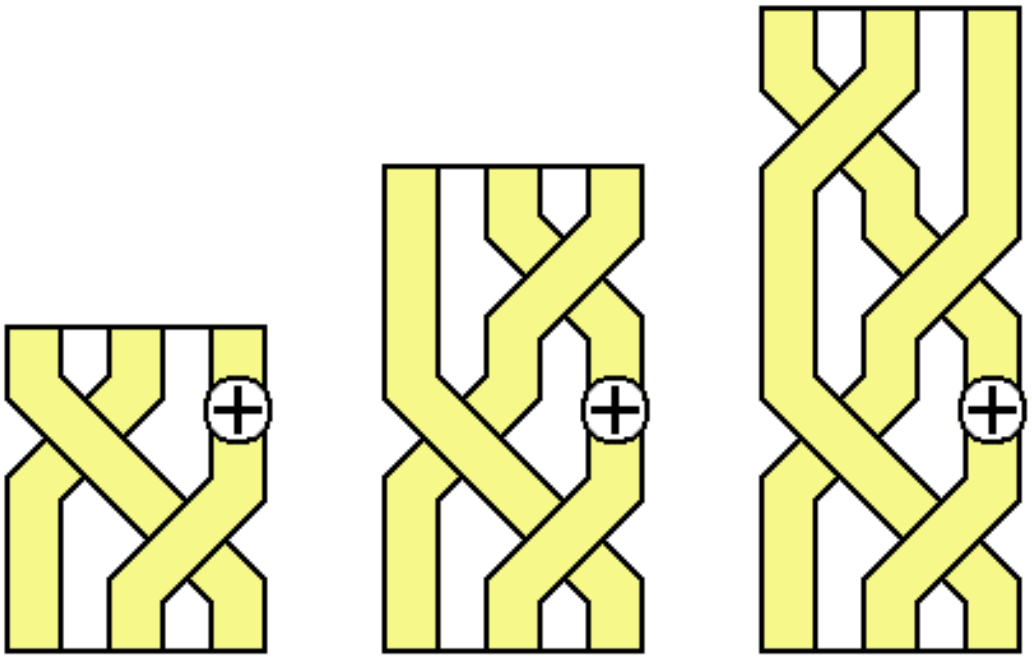
HIGHER GENERATIONS

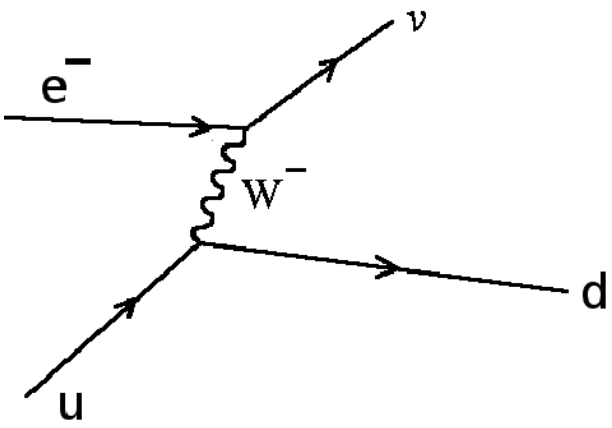
How do we explain 2nd and 3rd generation fermions?

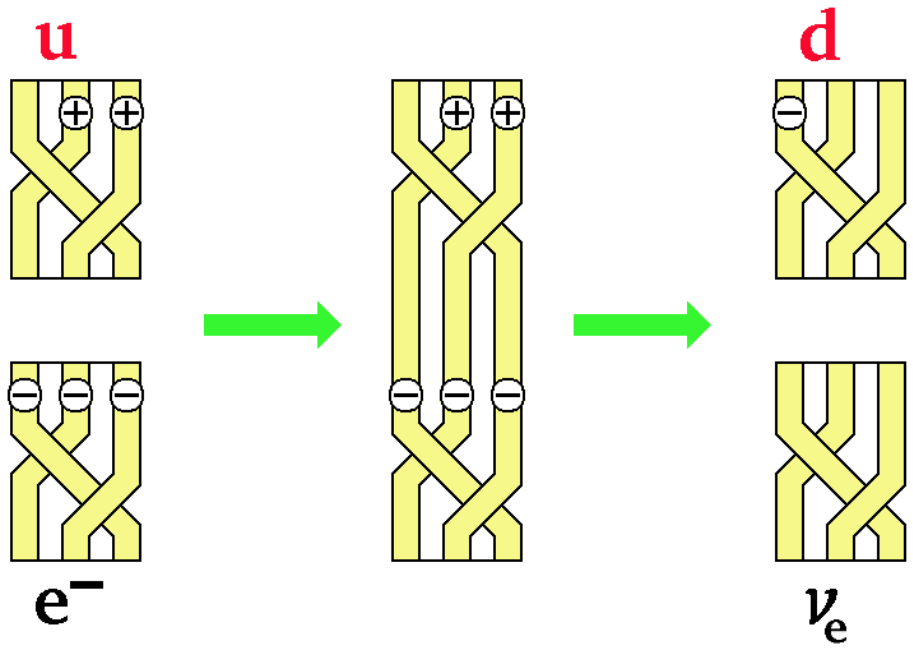
- Higher generations = More complex braiding pattern?



WEAK INTERACTIONS

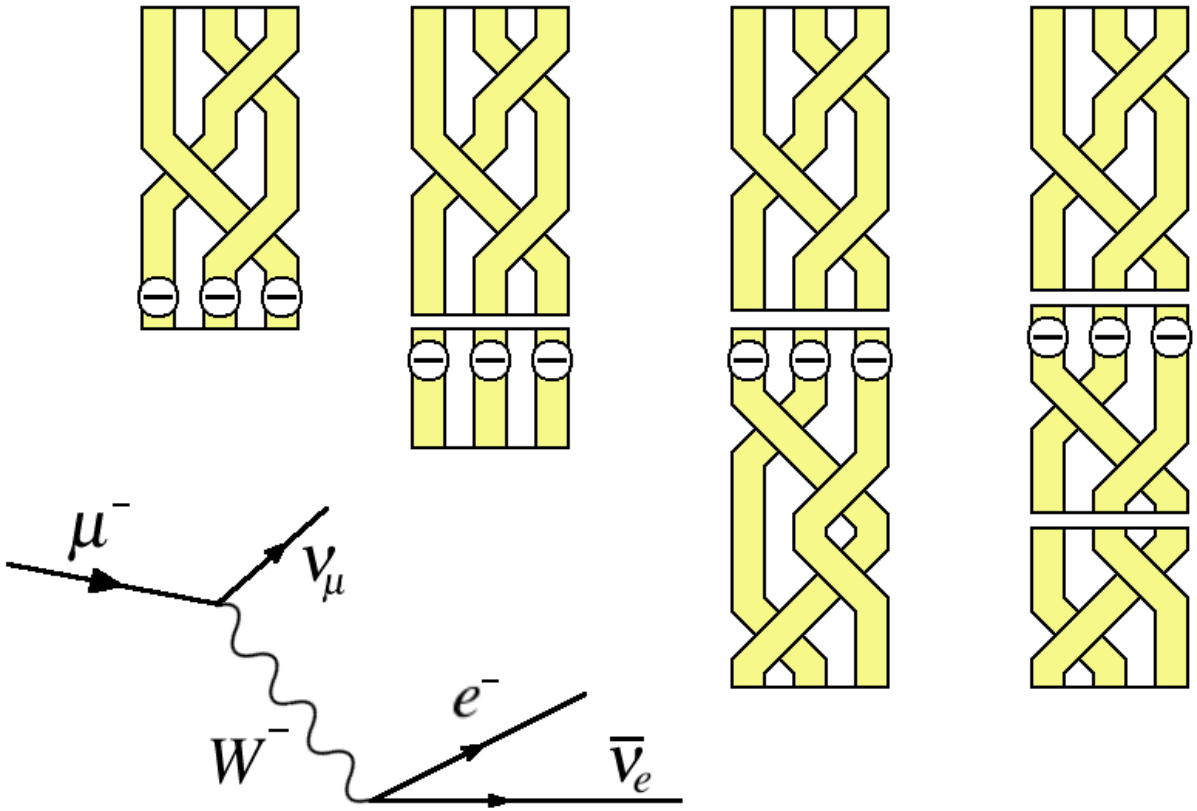
- Link braids top-to-bottom
- Twists can spread up and down the strands
- Hence charges can be exchanged, turning up quarks into down quarks, electrons into neutrinos, and so on





MUON DECAY

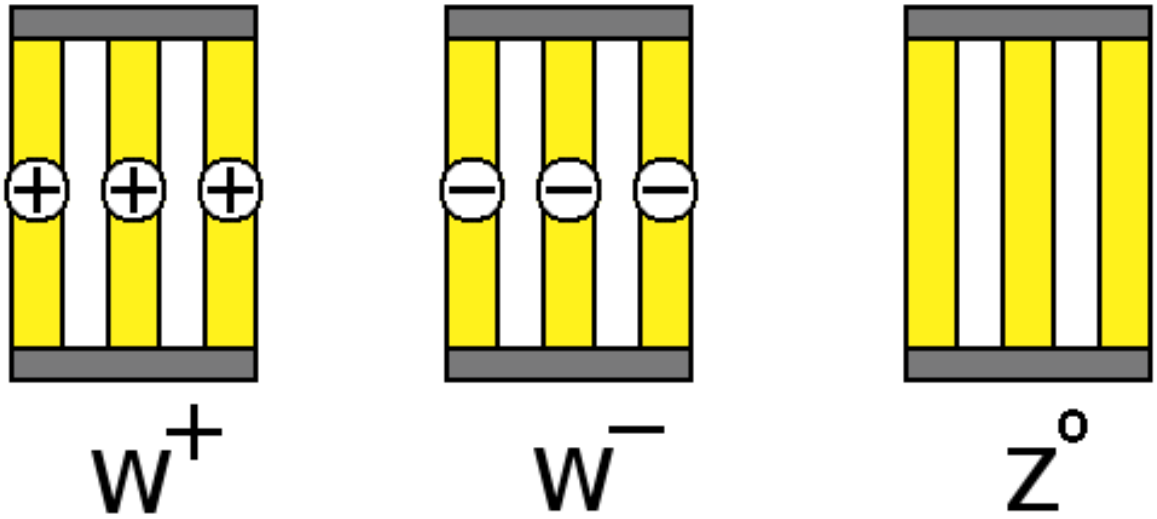
Consider muon decay



Topology requires that a ν_μ be produced

BOSONS

- Weak interactions suggest bosons are braids which induce trivial permutations
- Simplest case;



- Formed by joining top-bottom mirror-images.
- Other braids which induce trivial permutations are possible, in principle

SUMMARY

We can;

- Explain existence of all quarks/leptons
- Explain why neutrinos are only left-handed
- Explain 1:2:3 quark/lepton electric charge ratios
- Explain existence of colour charges
- Explain why only coloured objects have fractional electric charge
- Describe several generations
- Reproduce electroweak interactions
- Electric charge (i.e. twist) is quantised. It's there or it isn't.

THE REST OF THE STORY

We also have...

- A rule for defining colour interactions
- Hypercharge and isospin assignments

We're working on

- Defining different generations precisely
- Finding local moves that allow interactions
- Identifying/predicting any exotic states
- Explaining Cabbibo-mixing/neutrino oscillations

Gracias!

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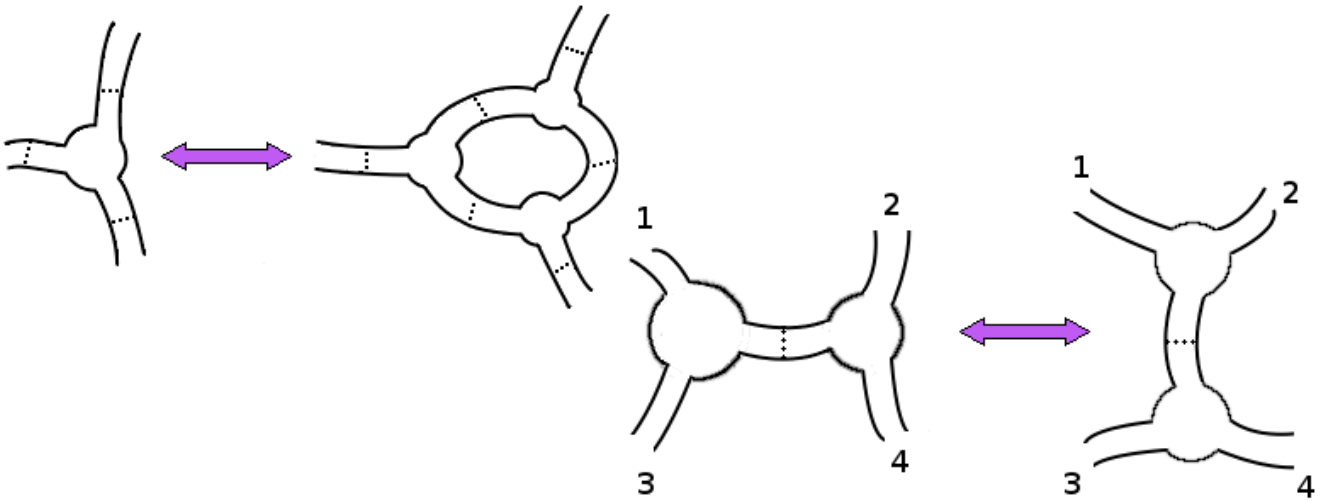
SWAPPING TWIST FOR BRAIDING

- Twists can be turned into braids by flipping nodes over

NEW MOVES

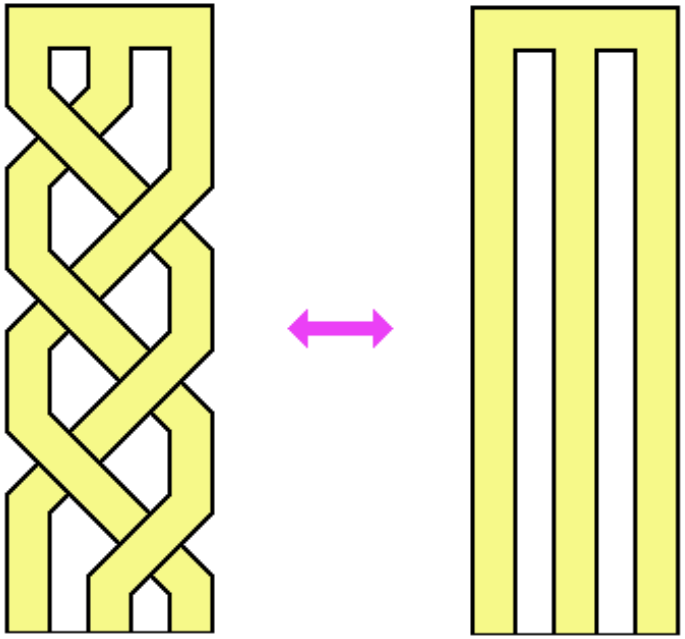
- Braids/twists are invariant under standard local moves.



- To allow the interactions of the *model*, within ribbon networks, we need a new move.

DIRAC SCISSORS AND BELT TRICK

Complex-looking braids, actually trivial!



Related to number of generations? Cabbibo-mixing?

A QUICK RECAP

- The helon model has only a single type of fundamental object (tweedles)
- There are no assumed charges, spins, or other quantum numbers

Assumptions:

- Orientable surfaces
  - Three types of helons
- Tri-valent networks
  - Helons form triplets
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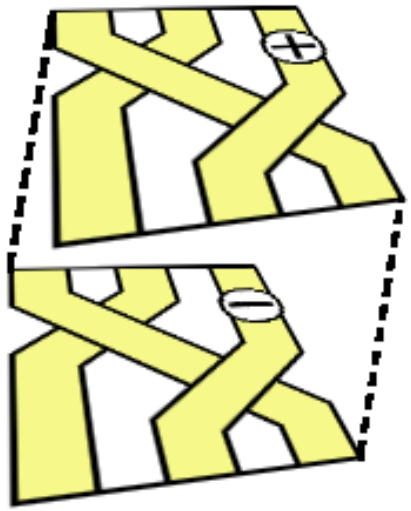
THE COLOUR INTERACTION

- What happens if we require the same charge on all strands?
- Leptons already fulfill this requirement
- Quarks can appear to fulfill this requirement by combining (stacking like pancakes)



BOSONS - THE GLUONS AND PHOTON

- Gluons carrying a colour and an anti-colour are permutations of $+$, $-$, 0