Title: Topological preon models: a braid new world

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Abstract: Preon models enjoyed considerable popularity during the early 1980s, but have seen little progress since then. I will describe a correspondence between one of the more successful preon models and a simple game involving the twisting and braiding of ribbons, subject to straightforward topological conditions. This reproduces the fermions and gauge bosons of the standard model, as well as the electromagnetic, weak and colour interactions. The prospect that such structures may occur naturally within Loop Quantum Gravity will be discussed

Topological preon models: a braid new world

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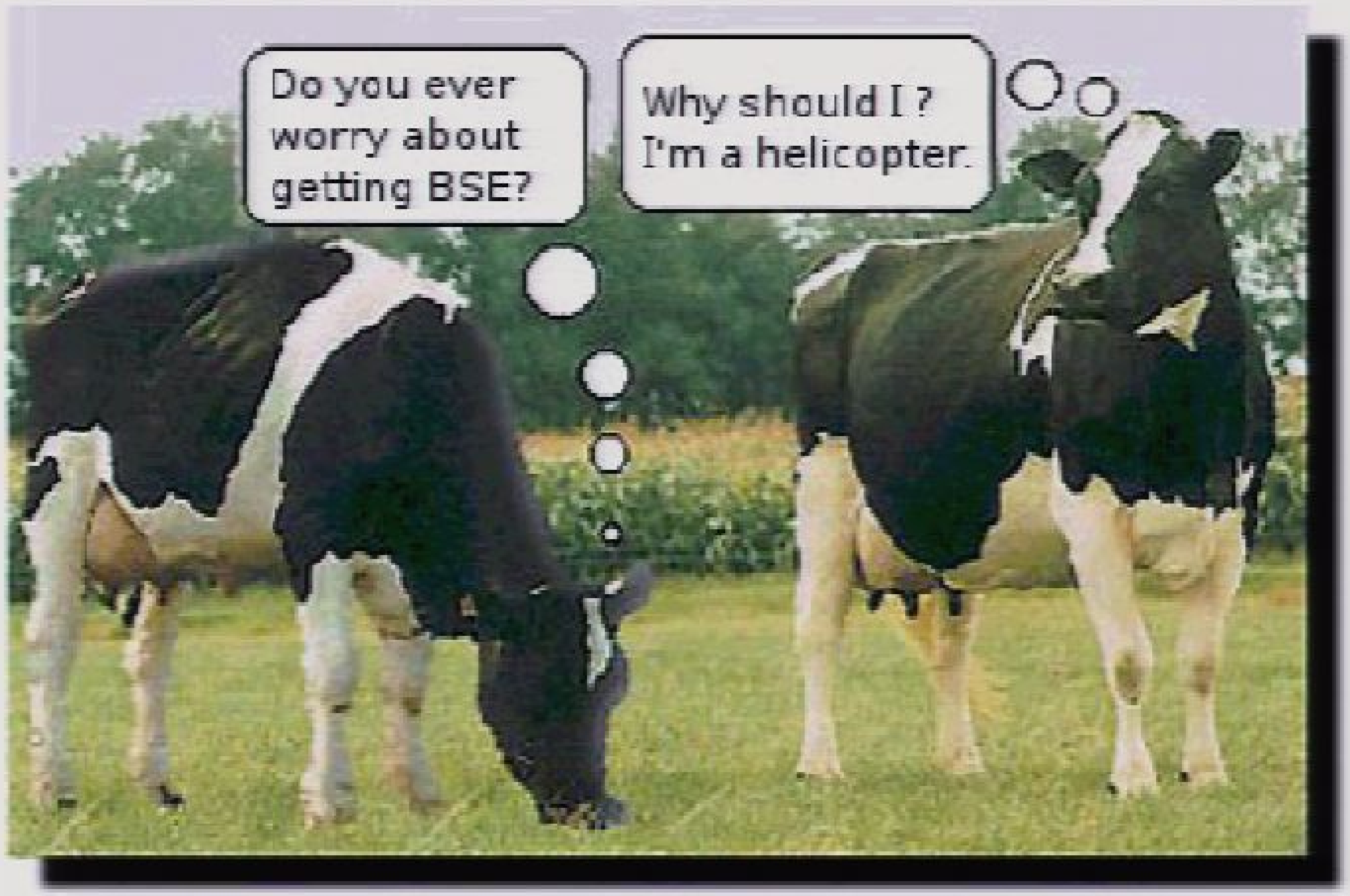
WHAT PREONS ARE NOT



Preons don't cause this!!

OUTLINE

- Shortcomings of the Standard Model
- Rishons
- Helons
- Phenomenology and systematics
- Connection to LQG?
- Discussion
- Conclusions

THE STANDARD MODEL

Matter is composed of quarks and leptons (plus anti-particles)

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

- All normal matter formed from 1st generation particles
- Four forces;
  - electromagnetic
  - weak
  - colour
  - gravity
- These particles and forces are regarded as fundamental

SHORTCOMINGS

The standard model makes excellent predictions, however there are unsatisfying features

Unanswered questions

- Why three colours?
- Why four forces?
- Why three generations of particles? Are there more?
- Why do electric charges of electron and proton balance perfectly?

SHORTCOMINGS

The standard model makes excellent predictions, however there are unsatisfying features

Arbitrary values and rules

- Approximately 20 parameters, e.g. masses, α_s, G_F, weak mixing angles θ_1, θ_2, θ_3
- Only coloured particles have fractional electric charges. Why?
- Coloured particles are confined. Why?

BEYOND THE STANDARD MODEL

We want a simple, powerful successor to the SM. There have been many candidates e.g.

regarding quarks/leptons as fundamental

- Supersymmetry
- String theory, M-theory
- Problems: Imply extra particles/forces/dimensions (not observed), swap old questions for new?

regarding quarks/leptons as composite

- Preons (Pati & Salam 1974; Pati, Salam, Strathdee)
- Rishons (Harari 1979; Shupe; Harari & Seiberg)
- Problems: (see below)

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- Rishons (Harari 1979; Shupe; Harari & Seiberg)
- Problems: (see below)

THE COMPOSITE APPROACH

- Composite models have worked in the past

molecules → atoms → nuclei → nucleons → quarks

- Although there is no direct evidence for quark/lepton substructure, it is the least radical proposal.
- Why not try again?

RISHONS a.k.a. QUIPS

Describe all 1st generation quarks and leptons as triplets of spin-$\frac{1}{2}$ objects called *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)
- Ts carry charge $+e/3$, $\overline{\mathbf{T}}$s carry $-e/3$, Vs and $\overline{\mathbf{V}}$s neutral.
- Assumption: No mixing of anti-rishons and rishons

$$
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WHAT HAVE WE GAINED?

Pros:

Rishons explain;

- Number/type of fermions
- Charge/colour connection
- No matter–anti-matter asymmetry

Cons:

- Philosophically, labeling rishons 1st, 2nd, 3rd is just as arbitrary as assigning colour
- No experimental evidence of substructure
- Need dynamics e.g. Why no spin-$\frac{3}{2}$ triplets?

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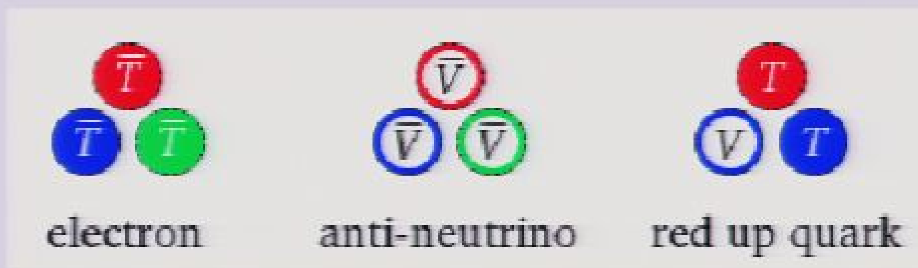
POSSIBLE DYNAMICS

Harari proposed dynamics could be either;

Conservative

A gauge theory

- In the 1980s colour (and hypercolour) were added



- Hypercolour → Hypergluons → Hypermess!
- More complex than quark model, yet most later preon models include hypercolour anyway!

POSSIBLE DYNAMICS

...or;

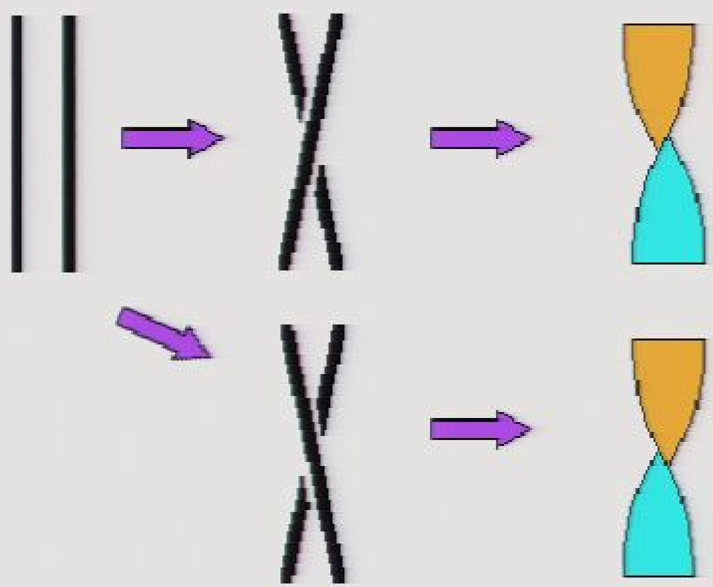
Radical

A different approach of some sort...

- That was the state of matters circa 1981
- Gradually people lost interest in preons, for various reasons
- Rishon/Quip model started well
- Let's think outside the box, try a "radical" proposal, and see where it gets us!

STARTING LINE

- Treat fundamental objects as lines, not points
- Consider two lines that cross each other
- The crossing can be left-handed, or right-handed
- Equivalent to a half-twist in a strand of material



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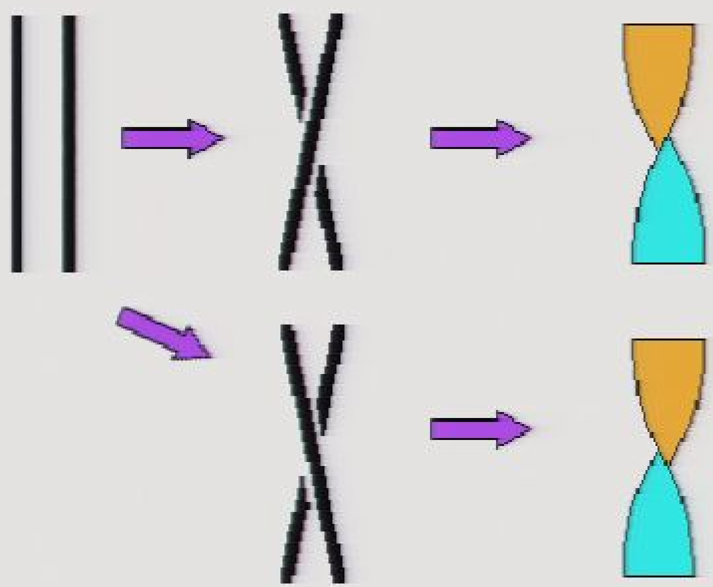


TWEEDLES

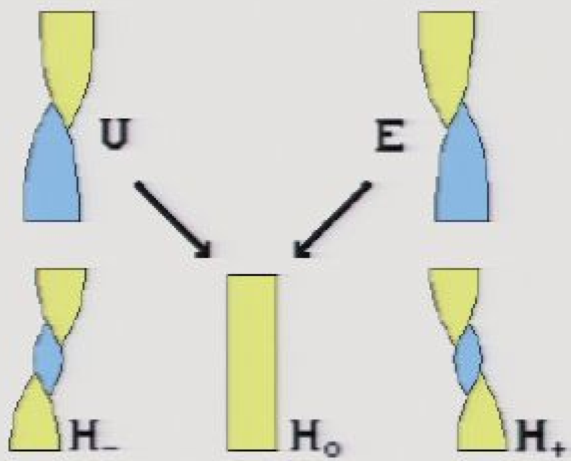
- Two varieties, left- and right-handed - call them "dum" (U) and "dee" (E)
- Use the generic name "tweedles"

Combining tweedles into pairs we get three composites

- $EE = H_+$
- $UU = H_-$
- $UE \equiv EU = H_0$

HELONS

- Tweedles are twists through $\pm\pi$
- Pairs of tweedles are helical - call them *helons*
- Identify twist through $\pm 2\pi$ with electric charge $\pm e/3$



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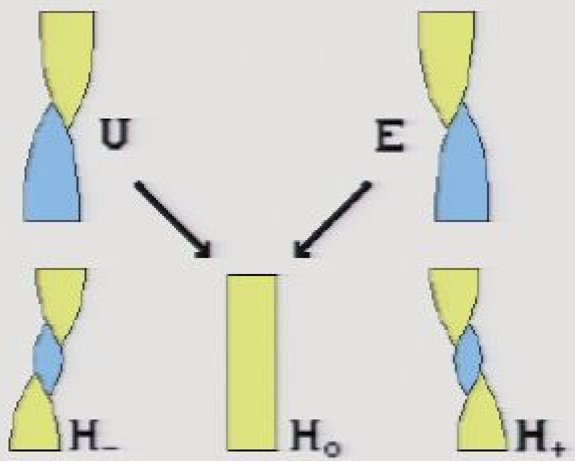

THE RISHON MODEL - WITH A TWIST!

Identify helons with rishons as follows;

- $T \rightarrow H_+$
- $\overline{T} \rightarrow H_-$
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We are back to the rishon model, with a slight modification ($V \equiv \overline{V}$)

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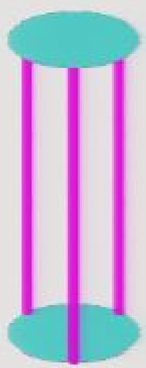
COMBINING HELONS

- Consider a triplet of helons
- Rotationally invariant. Can't tell 1st, 2nd, 3rd helons apart



- Not Rotationally invariant anymore. 1st, 2nd, 3rd helons are distinct!
- Remember each helon can be of three types ≡ charges of $+e/3, 0, -e/3$

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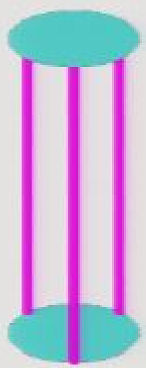

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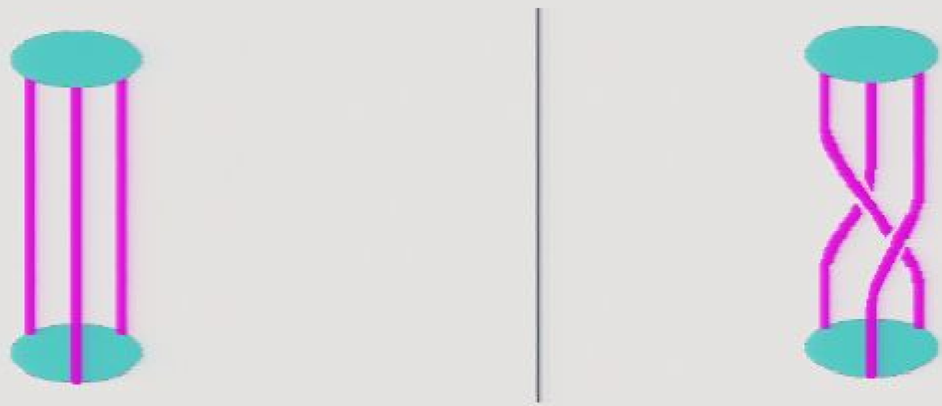

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HELONS vs RISHONS

- 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

A QUICK RECAP

- Tweedle pairs form H_+, H_-, and H_0
- The cost is having two levels of subparticles;

The payoff:

- Explain existence of all quarks/leptons (except anti-neutrino)
- Explain why quark/lepton electric charge ratios are exactly 1:2:3
- Explain existence of colour charges
- Explain why only coloured objects have fractional electric charge
- Electric charge (i.e. twist) is quantised. It's there or it isn't.

A QUICK RECAP

- Rishons were assumed to carry quantum numbers of spin and electric charge (and hypercolour too, from 1981)
- The helon model has only a single type of fundamental object
- There are no assumed charges, spins, or other quantum numbers

Assumptions:

- Tweedles form pairs, called helons
- Helons form triplets
- No charge mixing (i.e. H_+ and H_- not allowed together)

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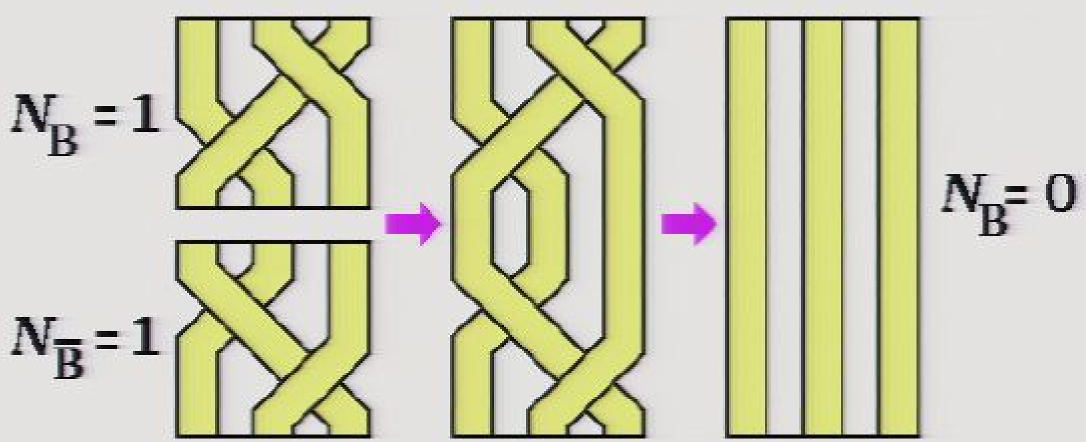
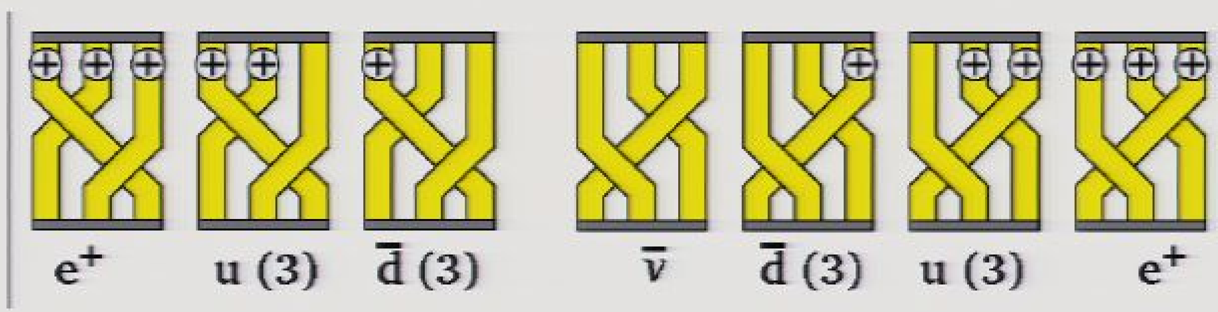
CONSERVATION OF BRAIDS

- Call the top-to-bottom mirror image of a braid an "anti-braid" (arbitrary choice)
- Define total "braid number" $N_B^{\text{Total}} = N_B - N_{\overline{B}}$
- When we join braids and/or anti-braids, N_B^{Total} is always conserved



FIRST GENERATION FERMIONS

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



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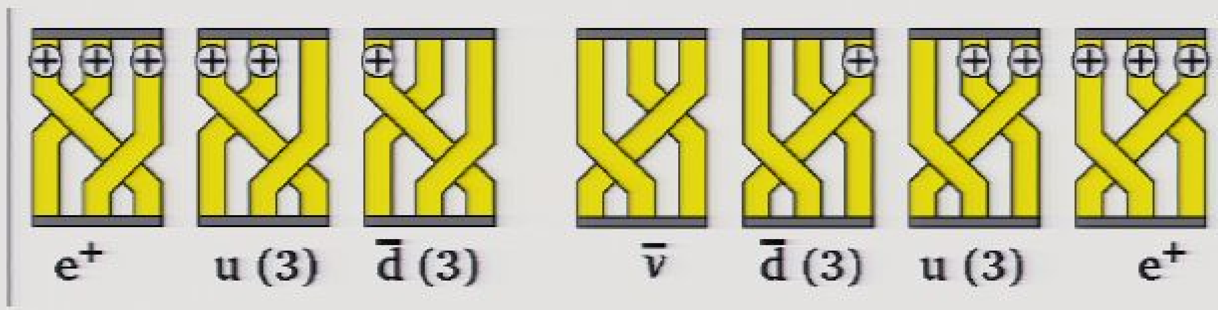
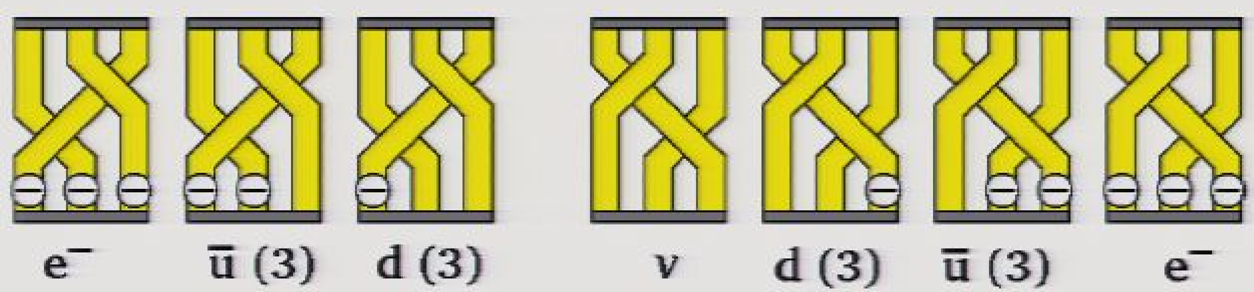


- Construct the anti-particles as mirror images (anti-braids)



THE MISSING ANTI-NEUTRINOS

- All fermions are essentially neutrinos. Electric charge is just added to the basic neutrino "framework"
- Left-right mirroring of a braid (or anti-braid) gives us helicity states of fermions ($H = \pm 1$) - equivalent to P inversion
- Top-bottom mirroring equivalent to C inversion
- For each non-zero value of $|Q|$, there are four combinations of charge and helicity

$$Q > 0,\ H = -1 \qquad Q > 0,\ H = +1$$
$$Q < 0,\ H = -1 \qquad Q < 0,\ H = +1$$

- If $Q = 0$, there are only *two* possible helicity states - the neutrino and anti-neutrino!

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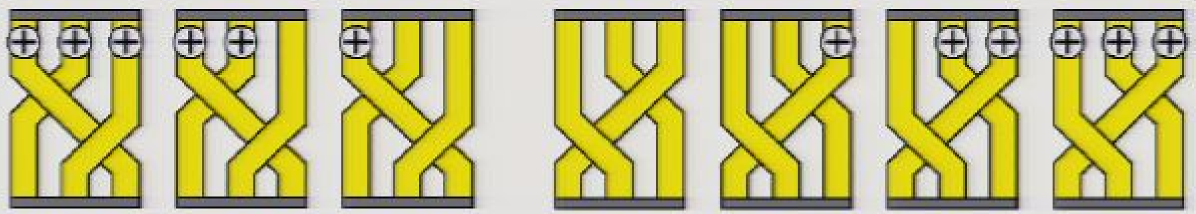
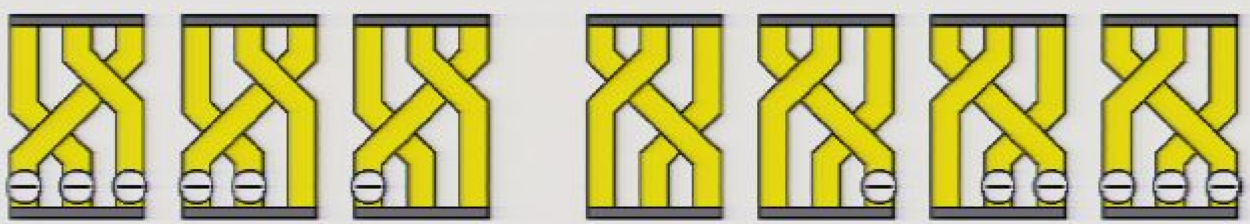


- Construct the anti-particles as mirror images (anti-braids)



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QUANTUM NUMBERS

- Assign $\beta = +1$ to braids, $\beta = -1$ to anti-braids
- Define Ω = one-third the number of "more positive" helons, minus one-third the number of "less positive" helons
- Let $N(x)$ be the number of objects of type x

$$\Omega = \beta\left(\frac{1}{3}N(H_+) + \frac{1}{3}N(H_-) - \frac{1}{3}N(H_0)\right)$$

- Charge of any fermion is given by

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QUANTUM NUMBERS - PART 2

- With these assumptions it follows that

$$Q = \frac{1}{2}(\beta + \Omega)$$

- For quarks $\beta/2$ reproduces third component of isospin Ω equivalent to hypercharge (baryon number)
- For leptons $\Omega/2$ reproduces third component of isospin β equivalent to hypercharge (lepton number)
- Thus we reproduce the Gell-Mann–Nishijima relation;

$$Q = I_3 + Y/2$$

- No equivalents to S, C, B, T, L_e, L_μ, L_τ

LEPTON NUMBER

- Let $\beta(x)$ be the β value associated with fermions of type x

Total lepton number equals;

$$
\begin{aligned}
L &= \beta(e^+)N(e^+) + \beta(e^-)N(e^-) + \beta(\overline{\nu_e})N(\overline{\nu_e}) + \beta(\nu_e)N(\nu_e) \\
&= N_{\mathrm{B}}(H_+H_+H_+) + N_{\mathrm{B}}(H_0H_0H_0) \\
&\quad - N_{\overline{\mathrm{B}}}(H_-H_-H_-) - N_{\overline{\mathrm{B}}}(H_0H_0H_0) \\
&= N_{\mathrm{B}} - N_{\overline{\mathrm{B}}} \\
&= N_{\mathrm{B}}^{\mathrm{Total}}
\end{aligned}
$$

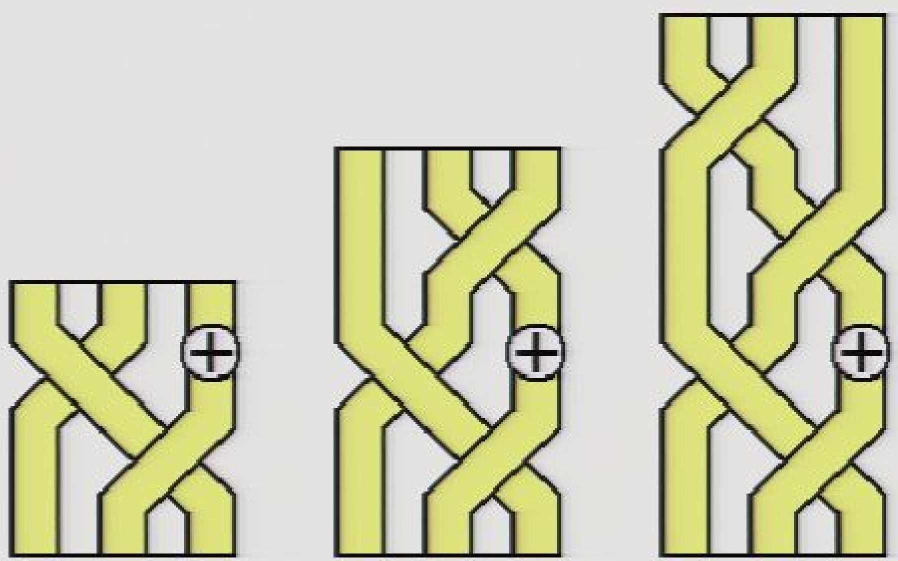
- Conservation of braids implies conservation of lepton number
- Equivalent argument applies to quarks and baryon number

HIGHER GENERATIONS

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

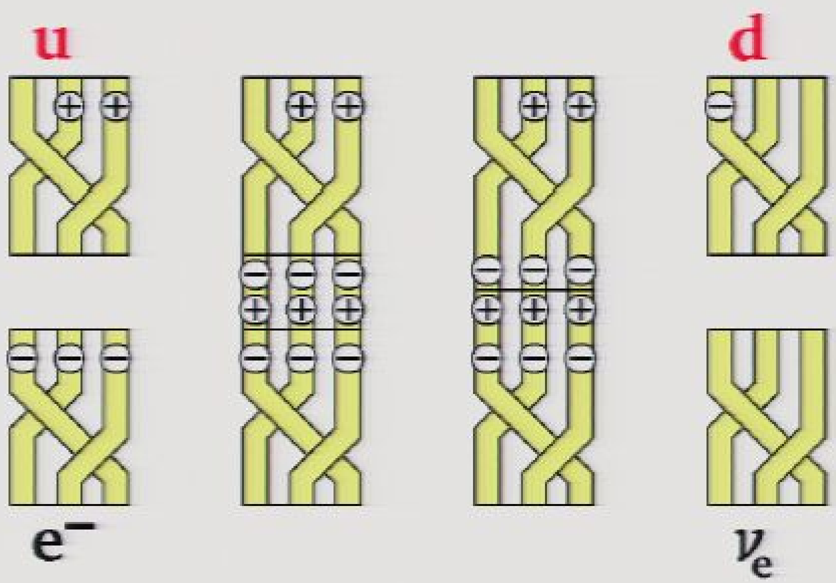
Here's one possibility

- Excited states = More complex braiding pattern
- (The braids shown here are for example only)



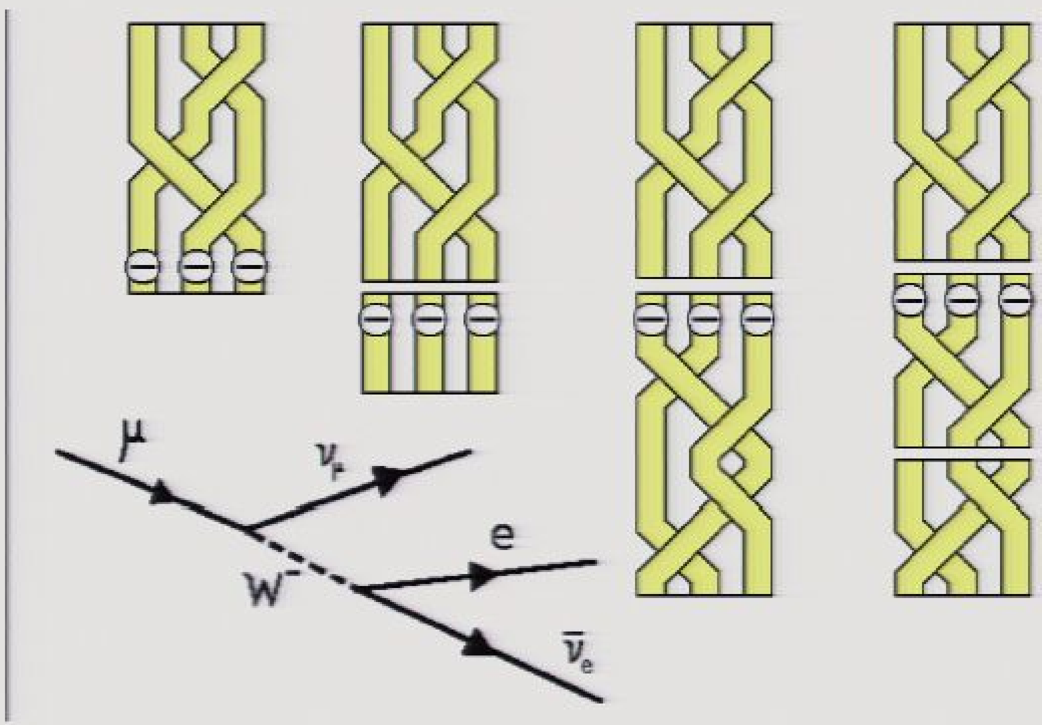
WEAK INTERACTIONS

- Link braids top-to-bottom (just the *braid product*)
- 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

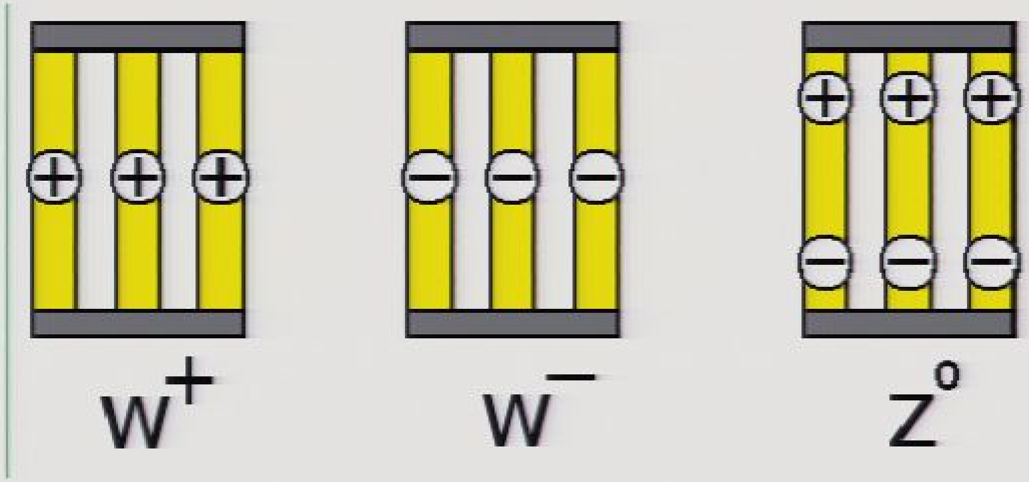
Consider muon decay



Topology requires that a ν_μ be produced

BOSONS

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



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- Other braids which induce trivial permutations are possible, in principle

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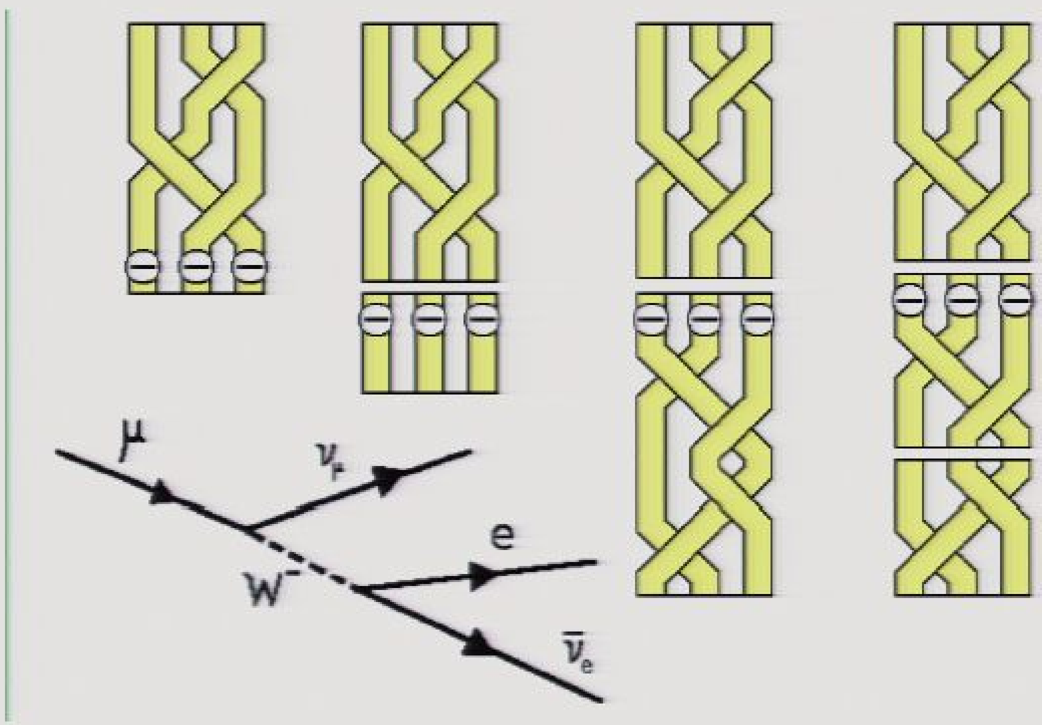

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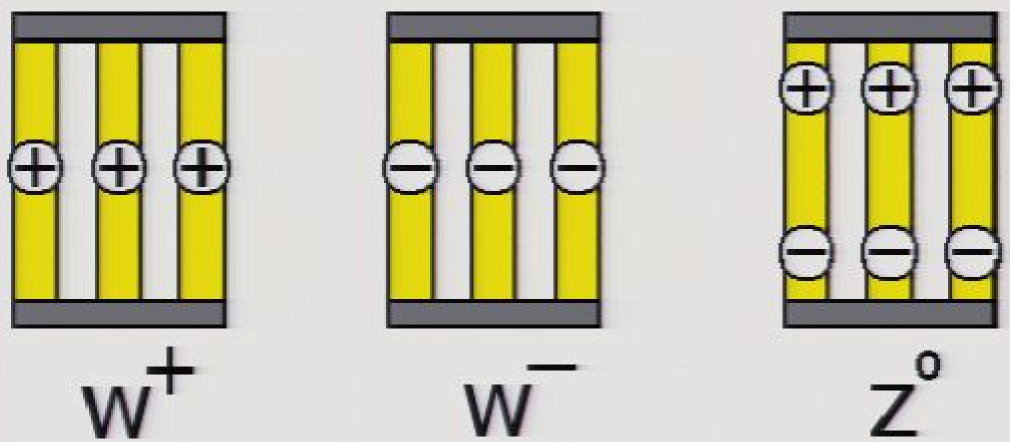

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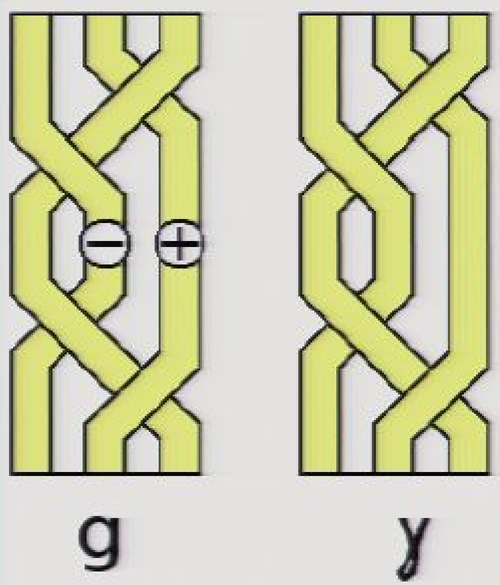
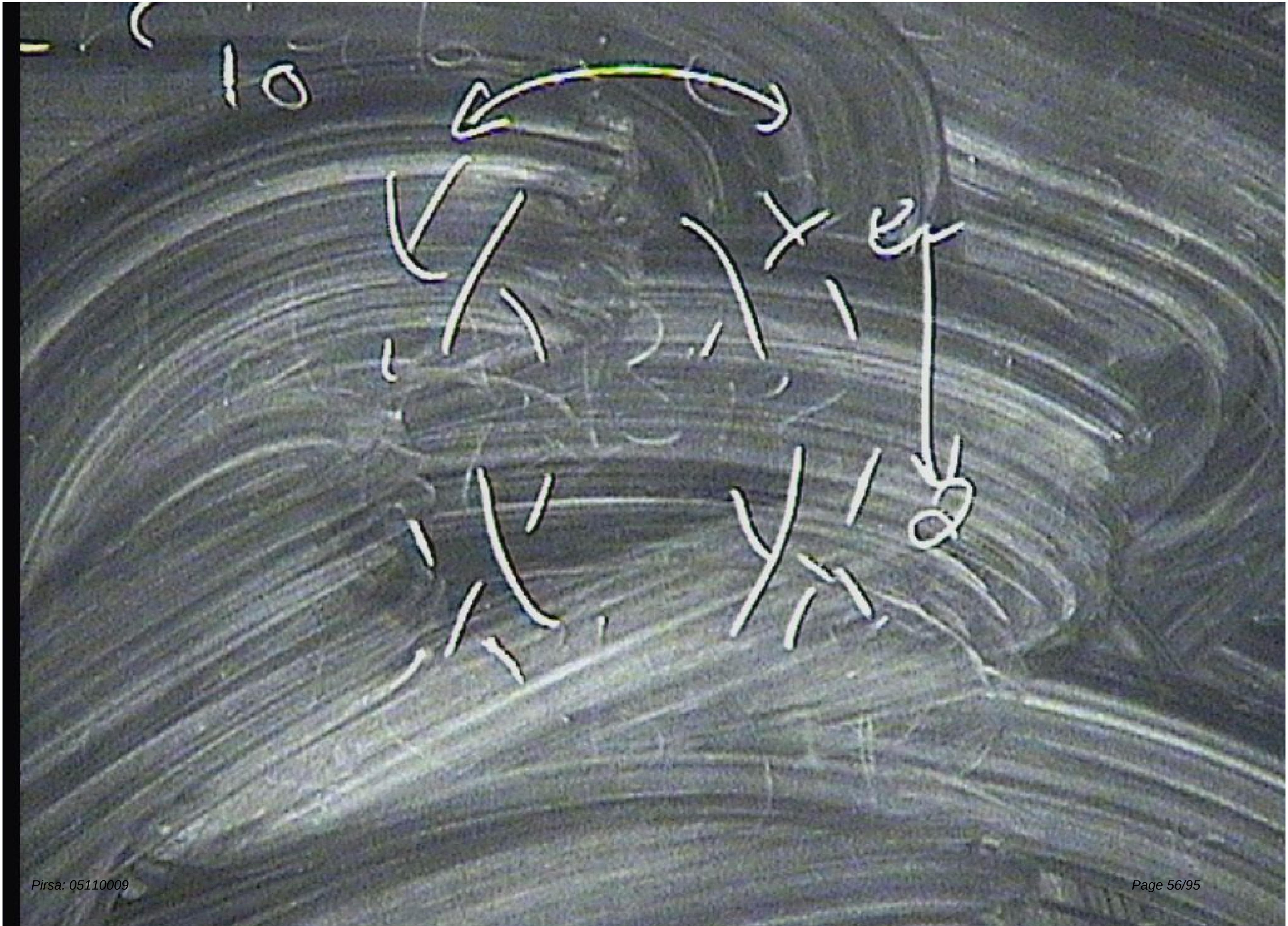
BOSONS - THE GLUONS AND PHOTON

- Gluons are permutations of +, -, 0
- Photon same as Z^0, but with zero charge explicitly

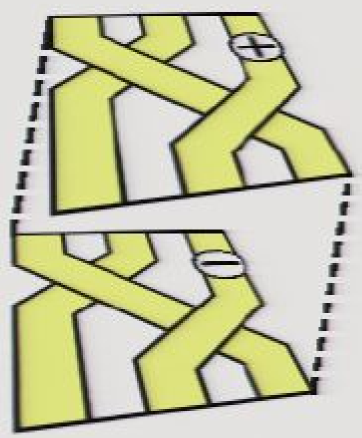


- We should say W^0 and B instead of Z^0 and γ, to be consistent with GWS. This doesn't change the basic concept



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)



BUILDING MESONS

- When we stack braids we will write helon triplets one-above-the-other

$$H_0H_0H_-\ (q_d) \quad \Rightarrow \quad \begin{matrix} H_0H_0H_-\ (q_d) \\ H_0H_0H_+\ (\overline{q_d}) \end{matrix}$$

$$\Downarrow$$

$$\begin{matrix} H_0H_0H_-\ (q_d) \\ H_-H_-H_0\ (\overline{q_u}) \end{matrix}$$

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BUILDING HADRONS

$$H_0H_0H_-\ (q_d) \Rightarrow \begin{array}{l} H_0H_0H_-\ (q_d) \\ H_0H_+H_+\ (q_u) \end{array} \Rightarrow \begin{array}{l} H_0H_0H_-\ (q_d) \\ H_0H_+H_+\ (q_u) \\ H_+H_0H_+\ (q_u) \end{array}$$

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THE STORY SO FAR

- We have all the right fermions, with all the right charges
- We have only left-handed neutrinos, right-handed anti-neutrinos
- We have all the right bosons
- We have electroweak and colour interactions
- We have conservation laws
- We have a correspondence with known quantum numbers

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- If only we had gravity... but that would just be greedy!

GREED

IS

GOOD !!

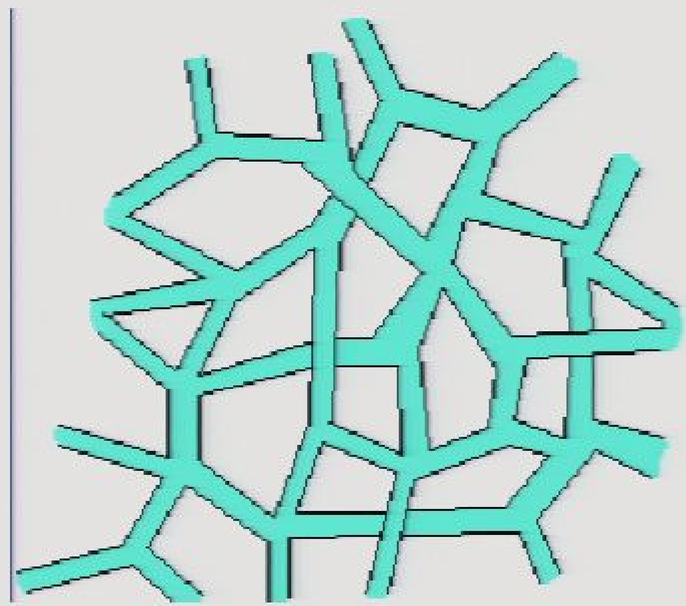
THE LOOP QUANTUM GRAVITY CONNECTION

What follows is collaborative work with
Fotini Markopolou and
Lee Smolin
at the Perimeter Institute

RIBBONS

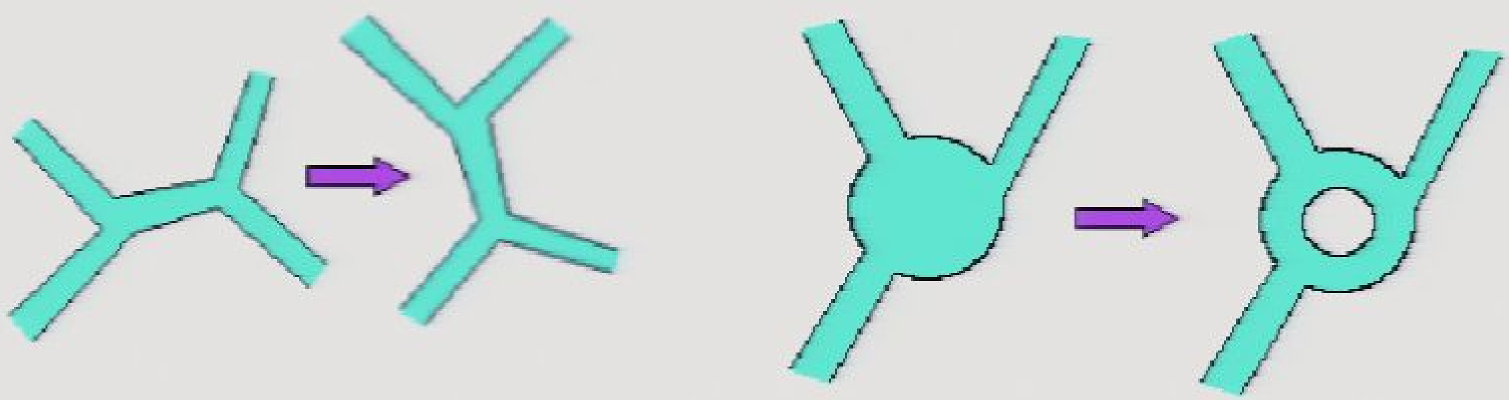
We modify the spin networks in LQG.

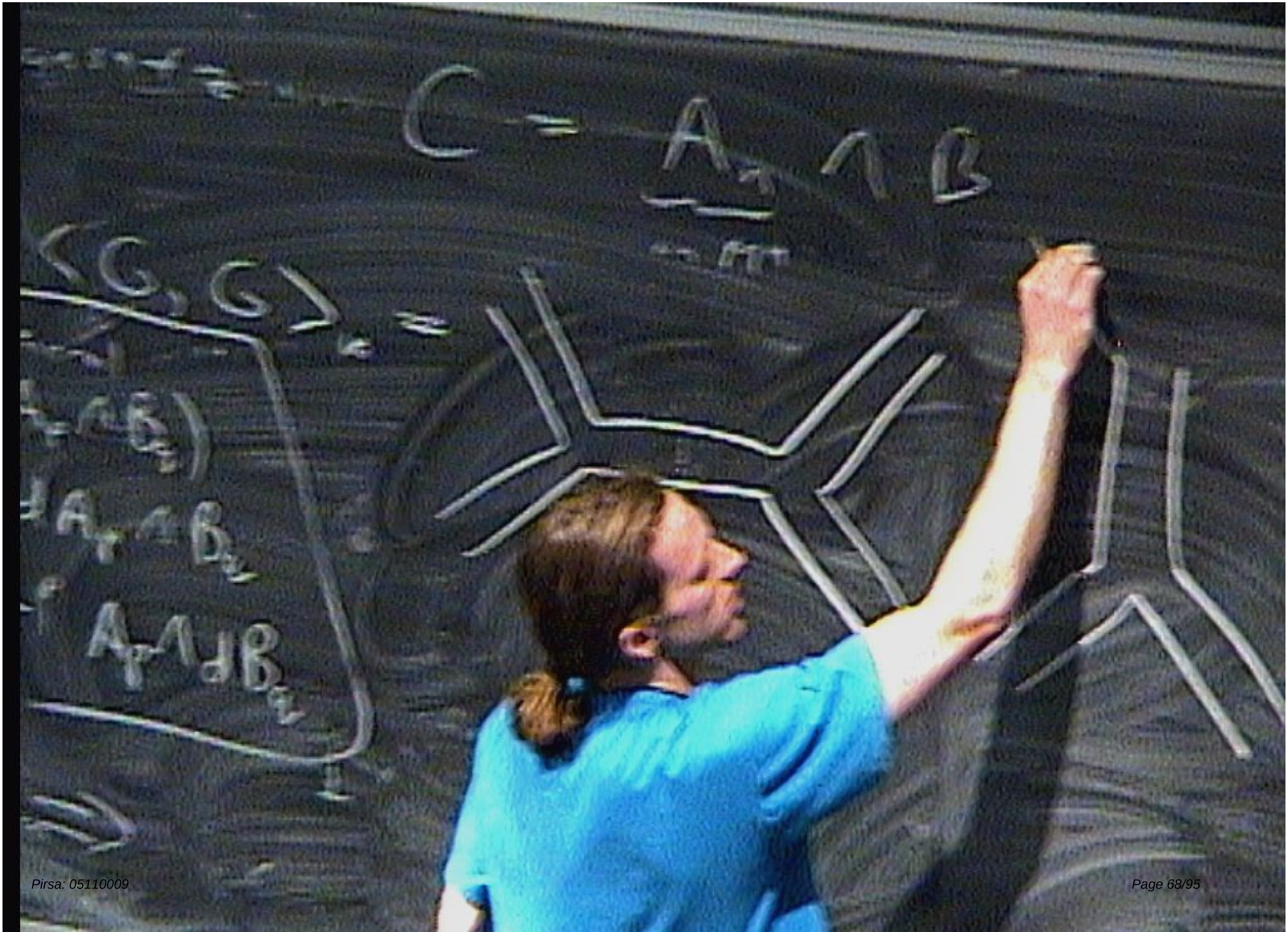
- No spin labels on links
- Links become ribbons (i.e. they are "framed")

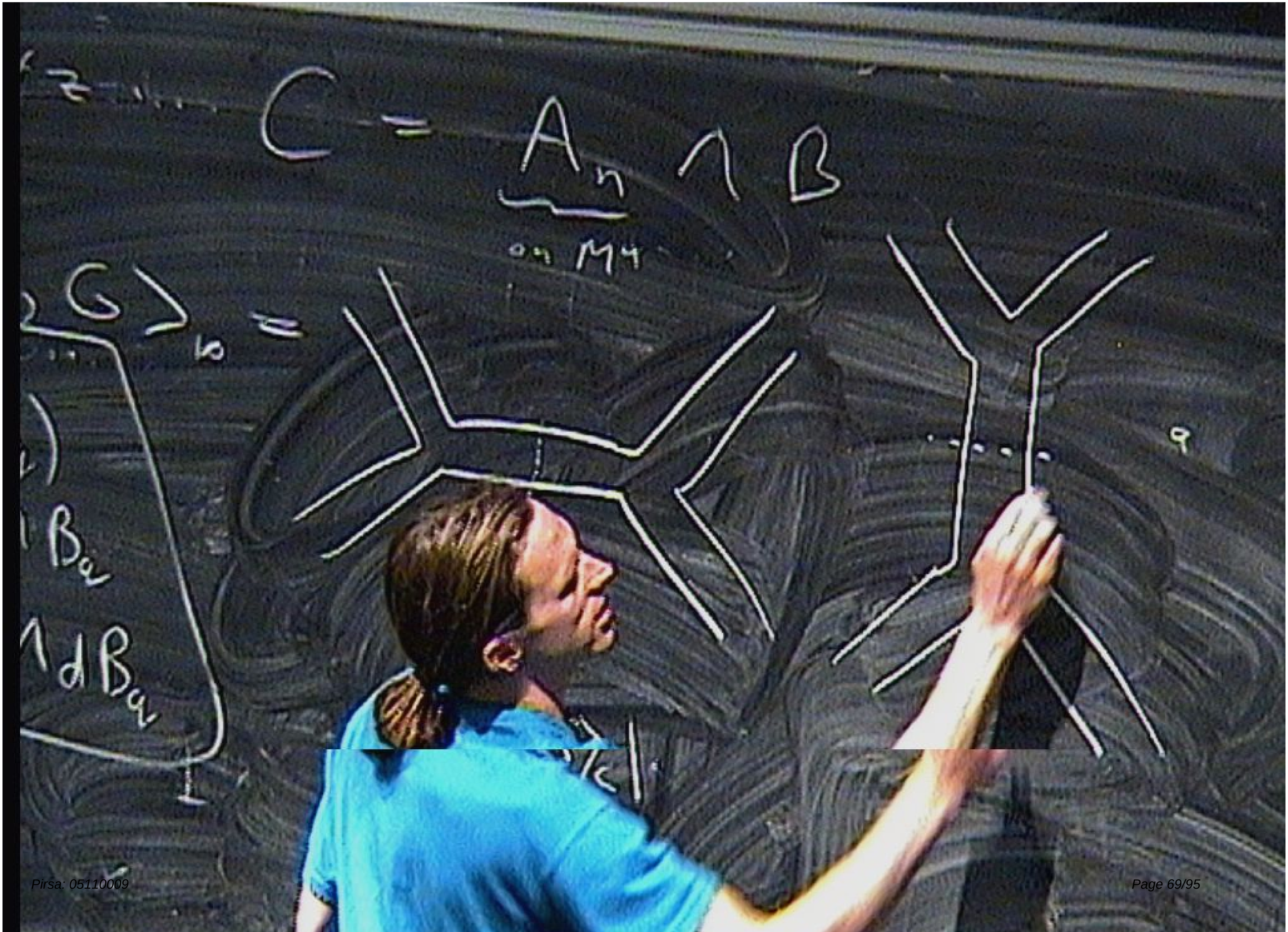


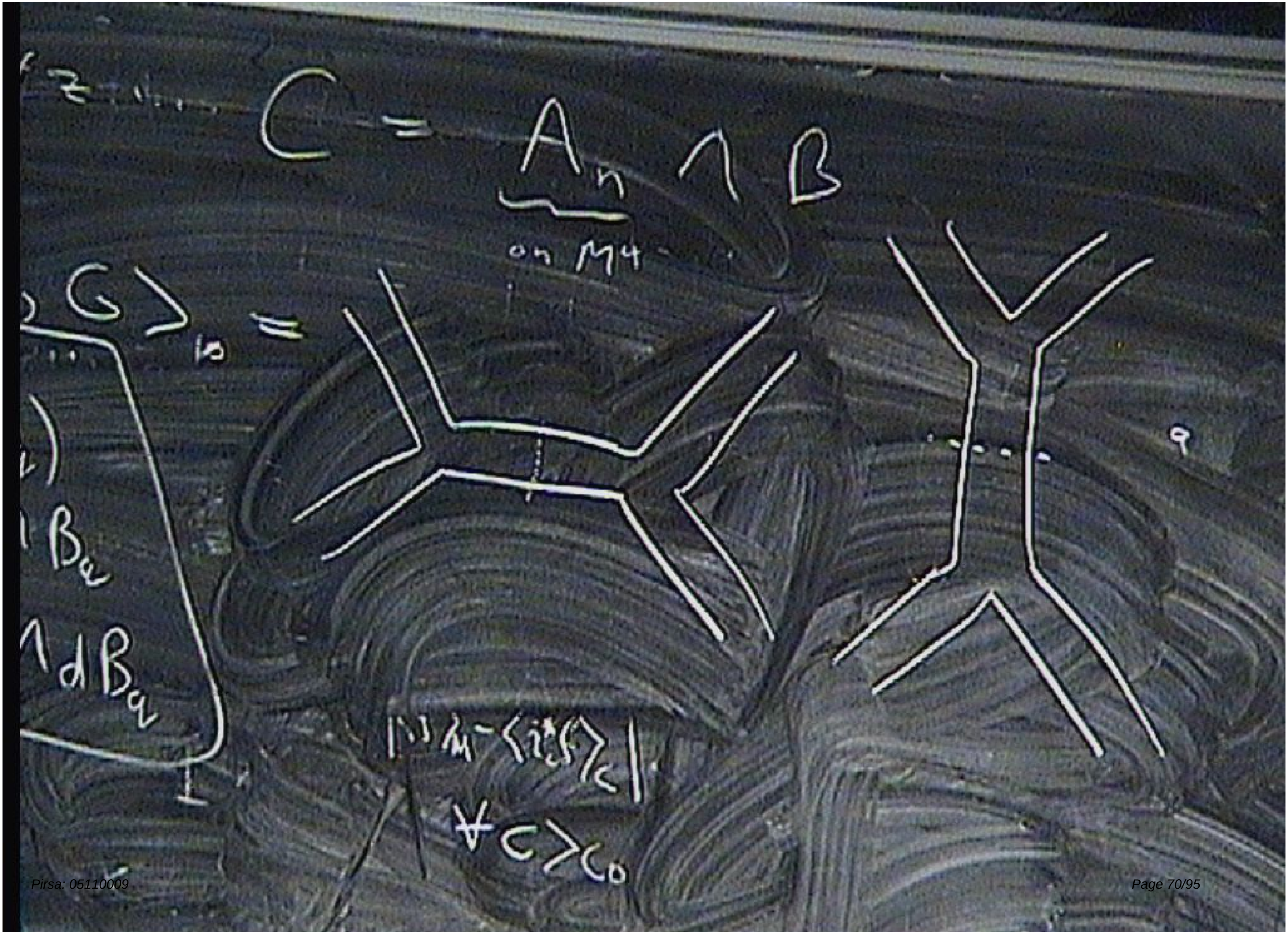
RIBBON MOVES

- We allow the ribbon graphs to evolve by a series of local moves
- This creates the equivalent of spin foam




C = A ∧ B

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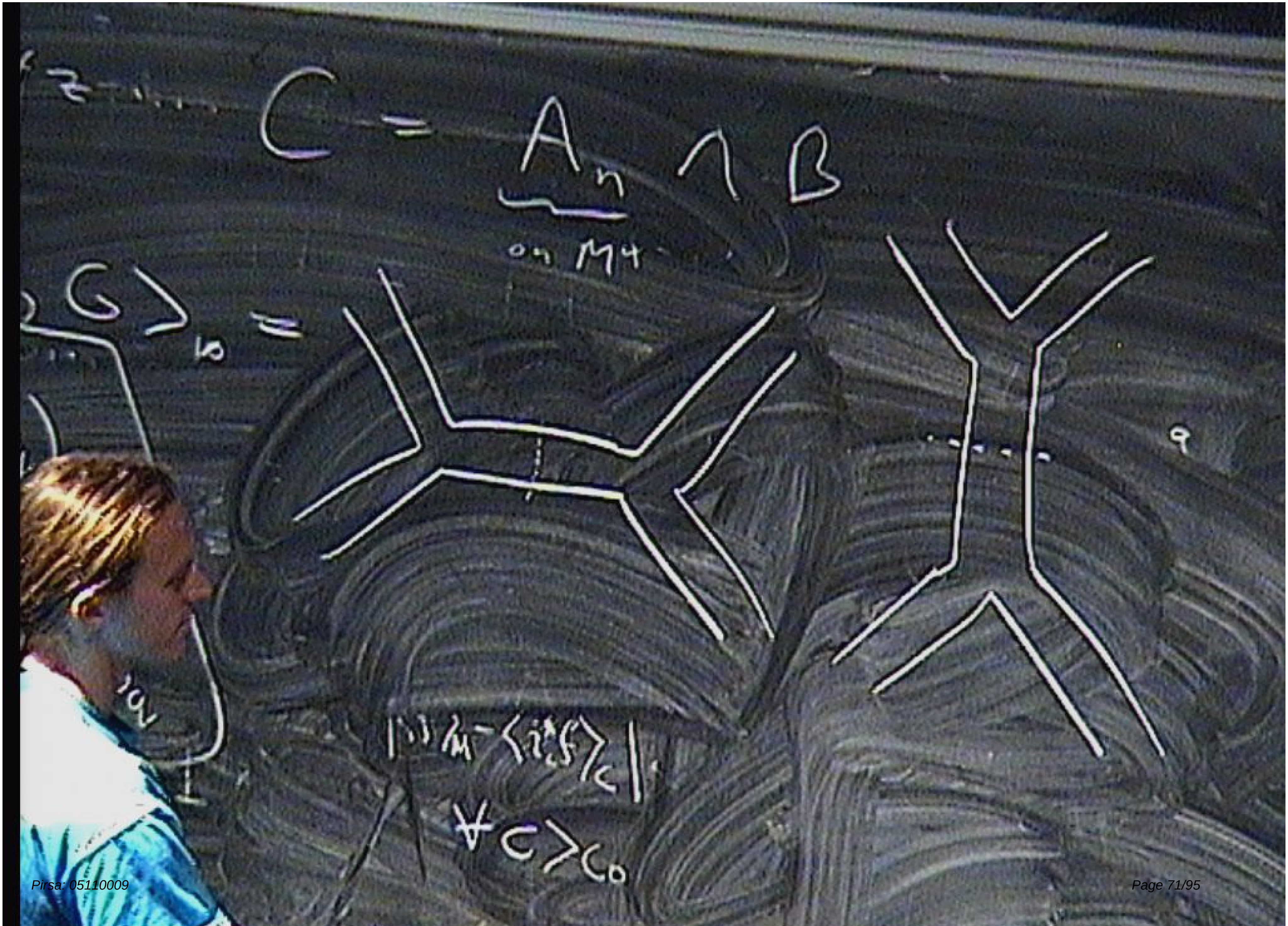
on M4
∀c > c_0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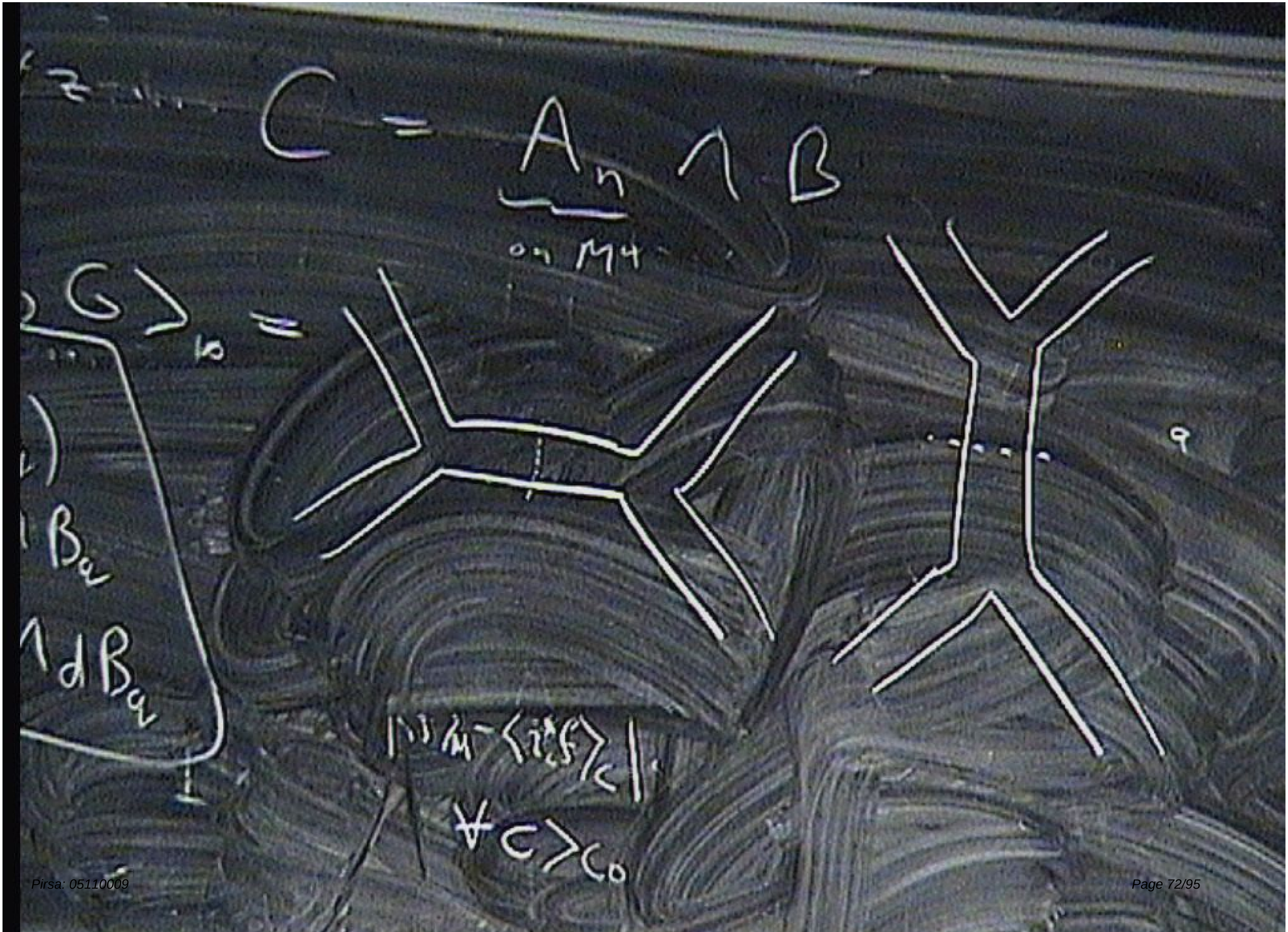
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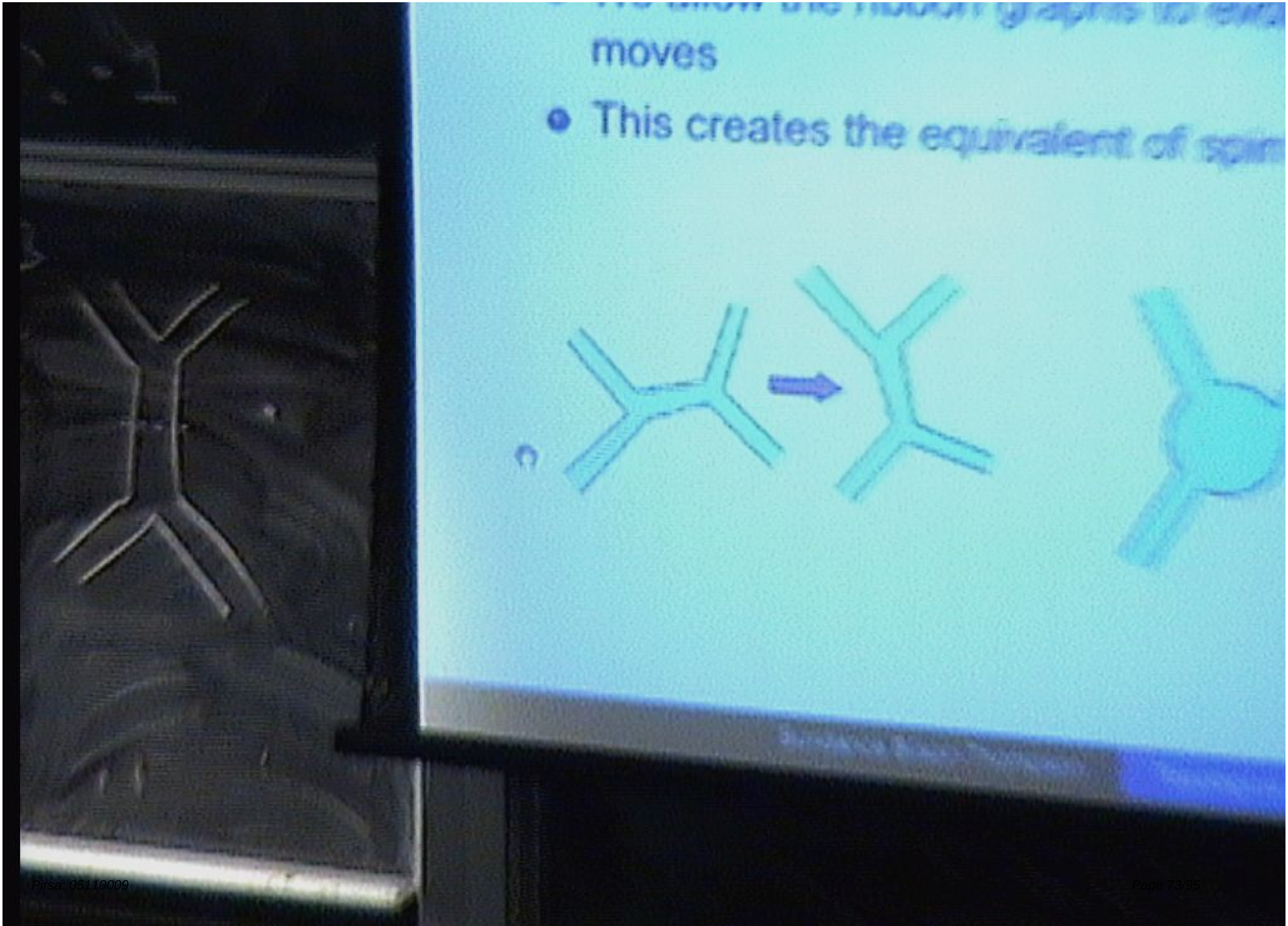
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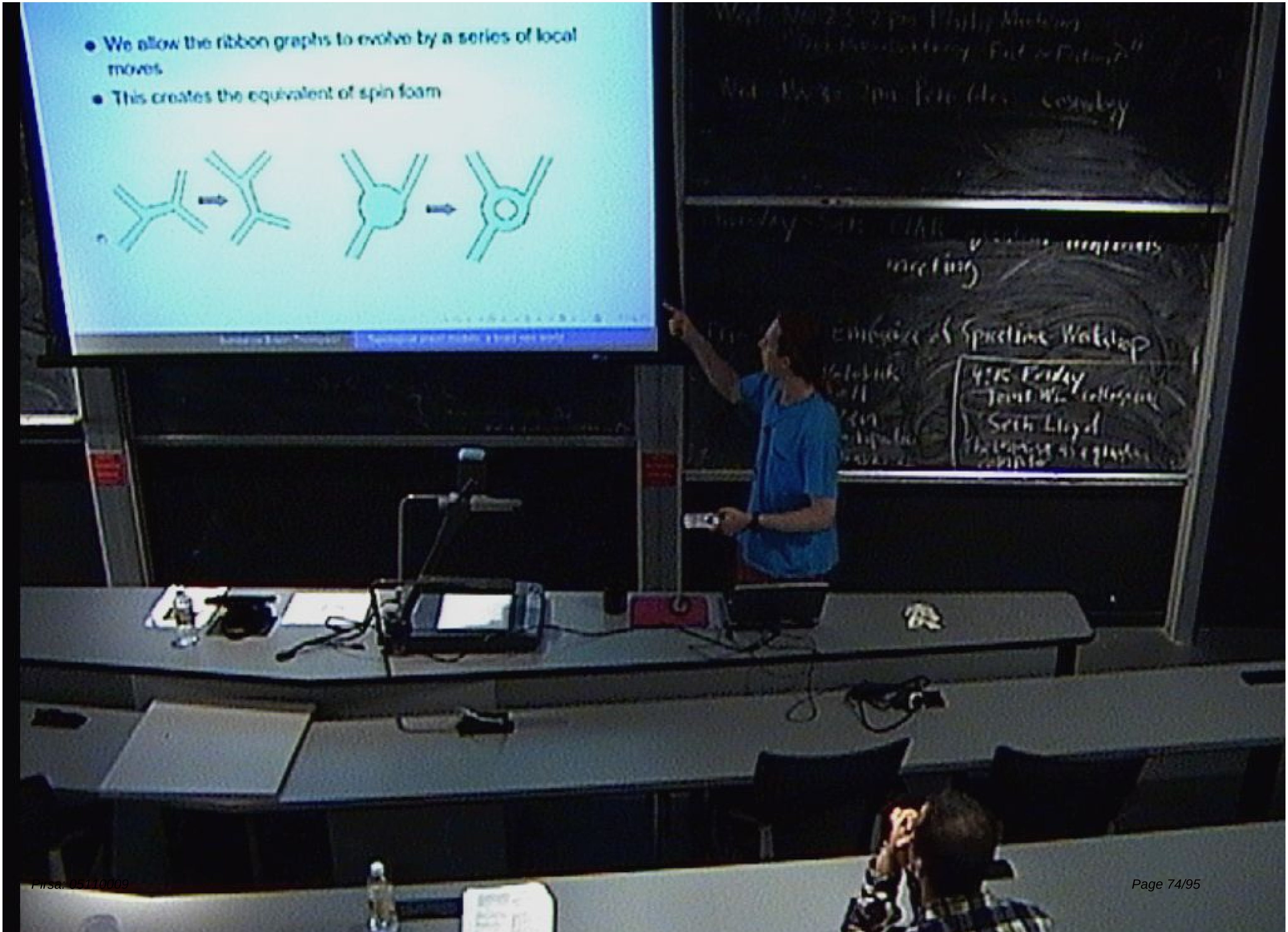
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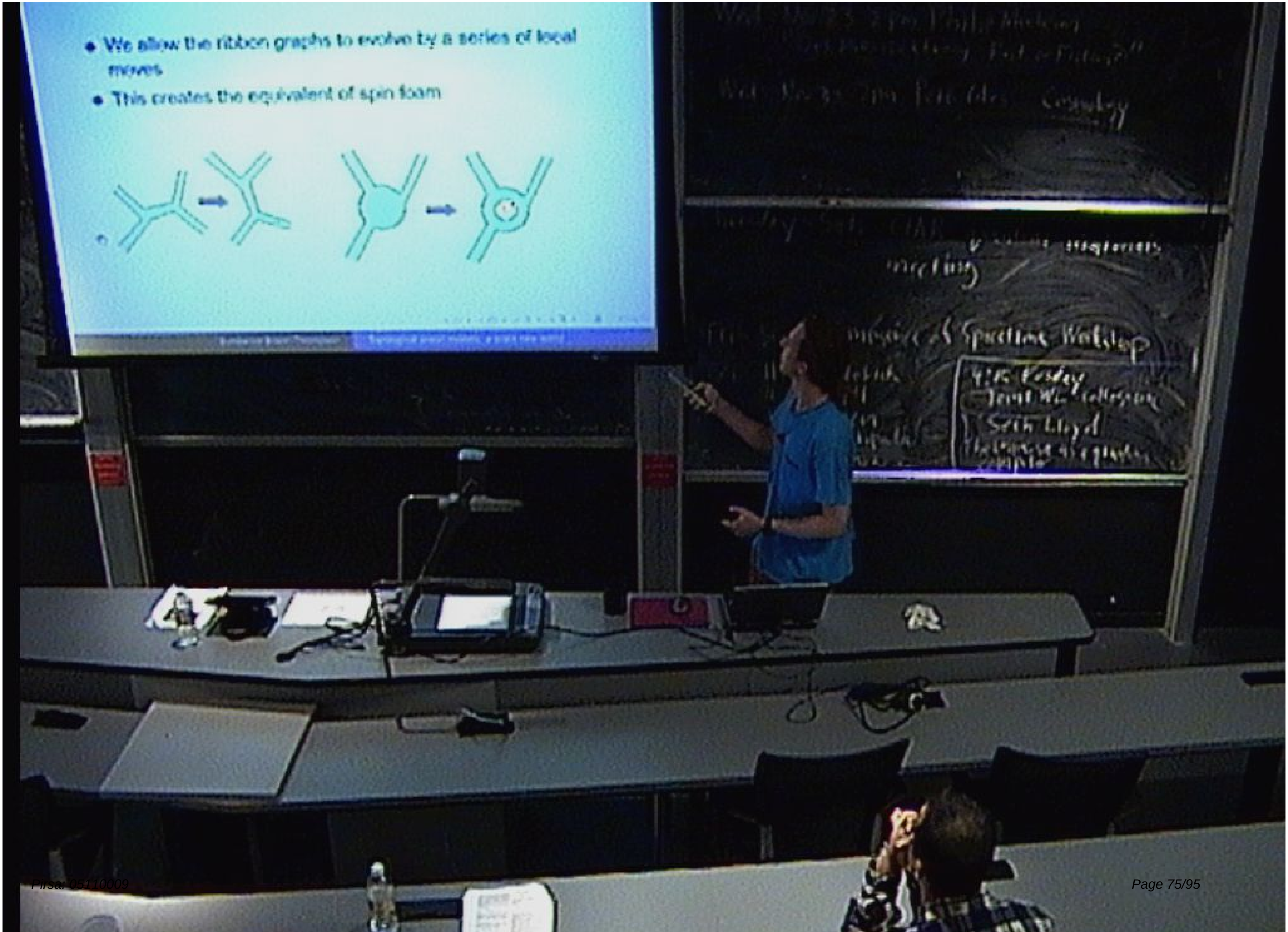
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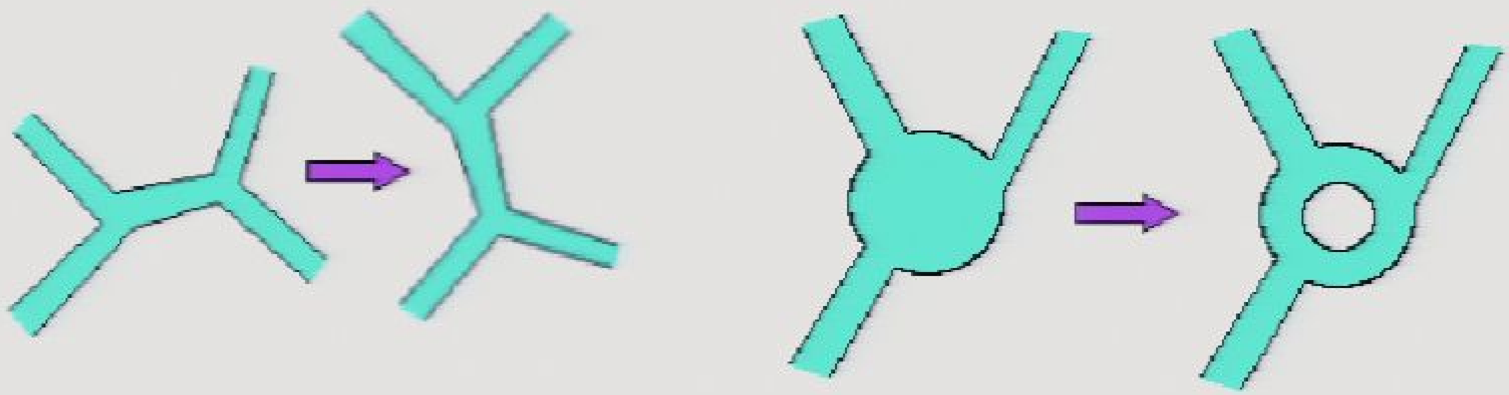

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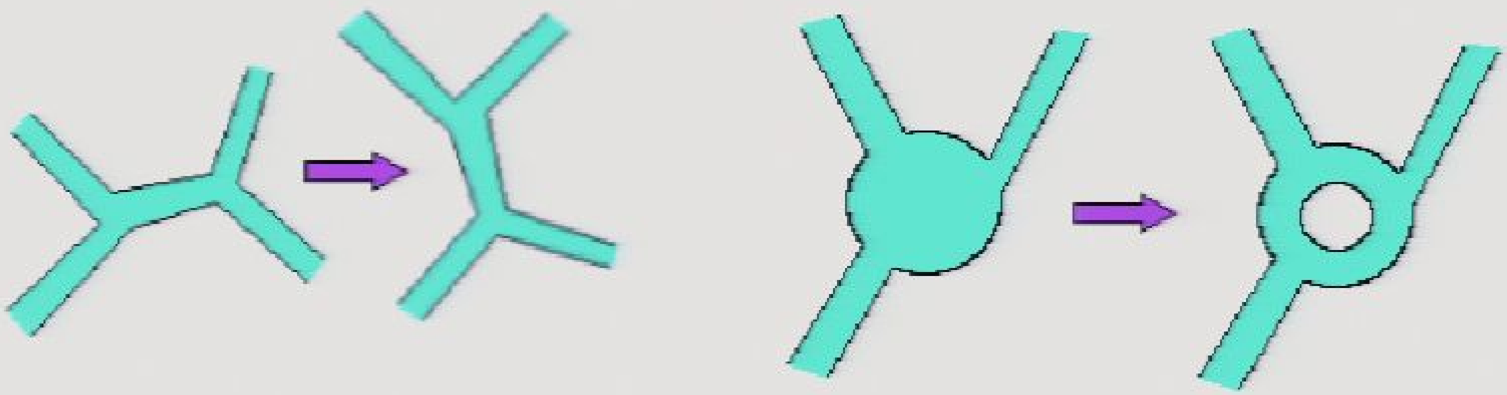
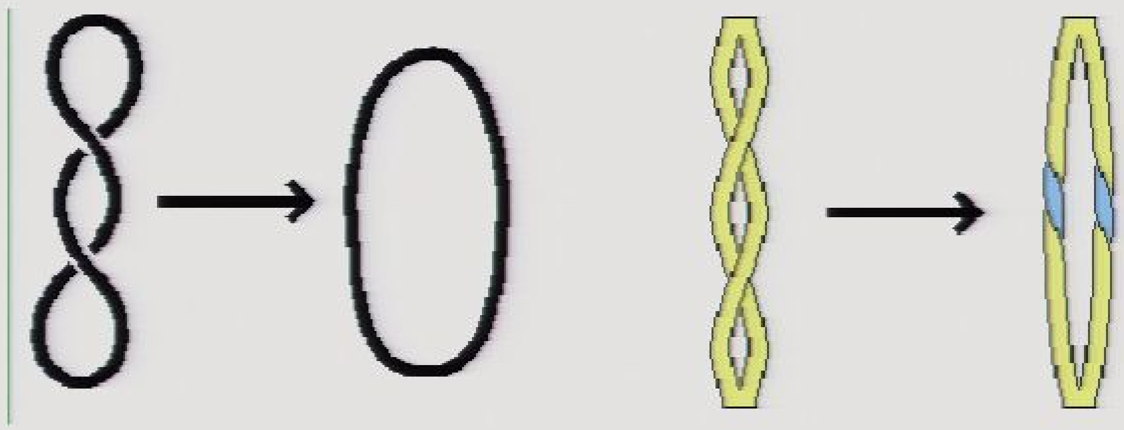


CONSERVED QUANTITIES

- Since the ribbons have width, we can exchange crossing and twists



- We are interested in finding quantities which are conserved under local moves
- Such quantities will be constant in time

WHAT REMAINS TO BE DONE?

The helon model is encouraging, but far from complete

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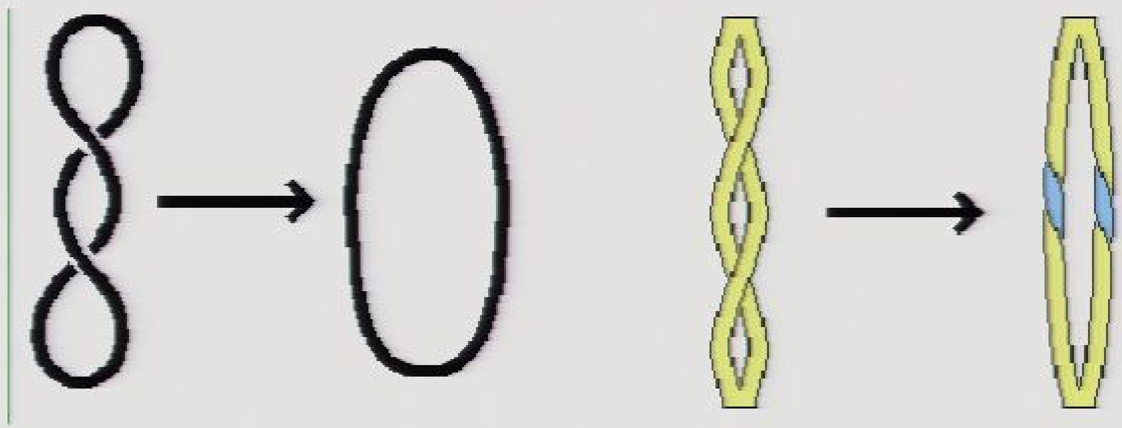

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- What about anomalies?
- What rules govern the formation of higher generations? Is there an upper limit?

CONCLUSIONS

What we started with

- Simple lines or edges
- A small set of rules, inspired by topology
- We didn't need to assume the quantum numbers in the rishon model

CONCLUSIONS

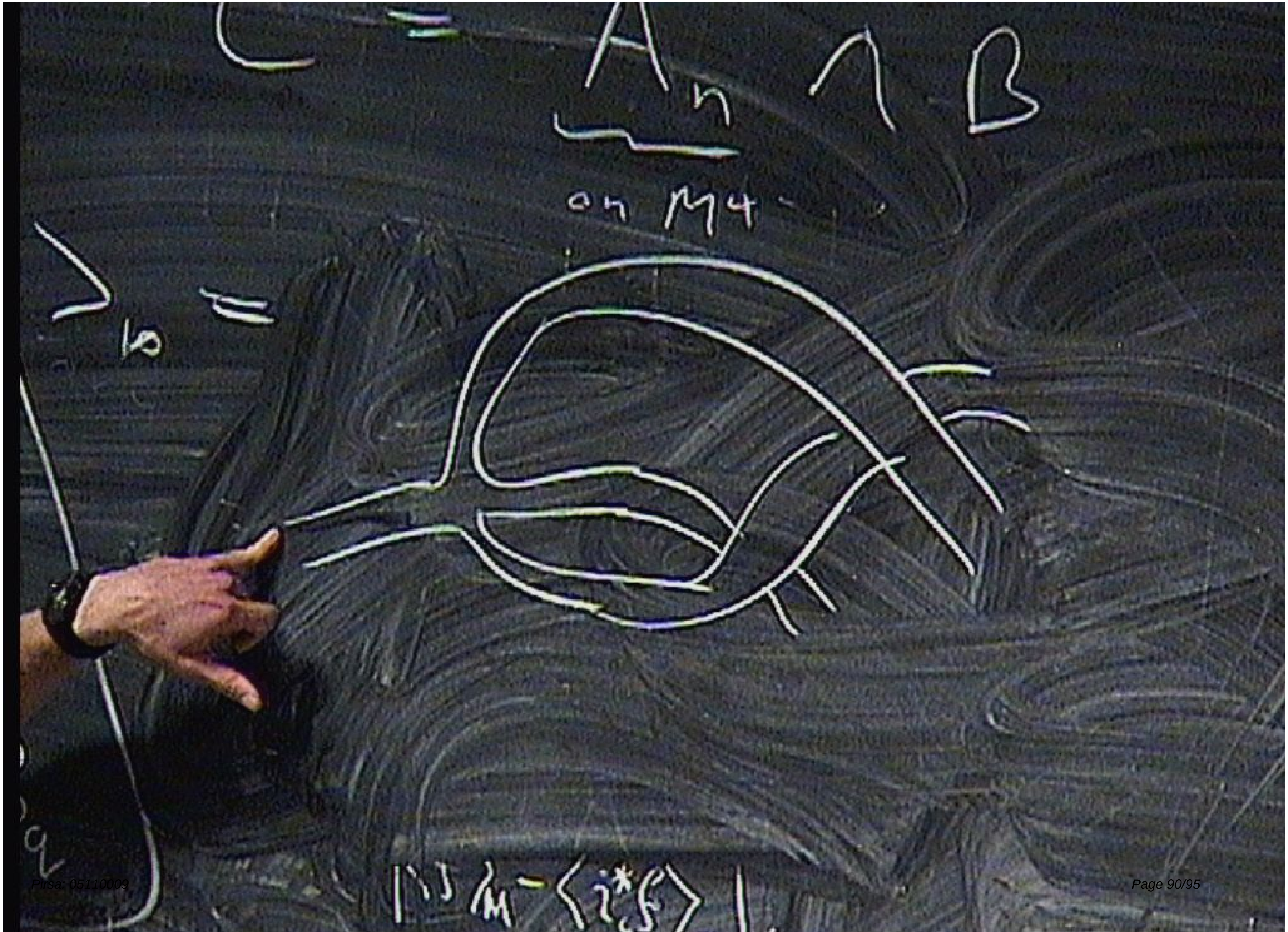
What we have achieved

- Reproducd all the 1^{st} generation fermions
  - correct colour and electric charges
  - no extra particles
  - only left-handed neutrinos
- Quantities that look like lepton number, baryon number, hypercharge
- Can describe electromagnetic, weak, and colour interactions

CONCLUSIONS

Current goals

- Adapting the helon model into the framework of loop quantum gravity
- If successful this will
  1. Incorporate gravity and spacetime with the standard model
  2. simplify LQG (possibly)
  3. give us a description of spacetime, matter, and the four forces based in geometry without the need for extra dimensions, particles, etc.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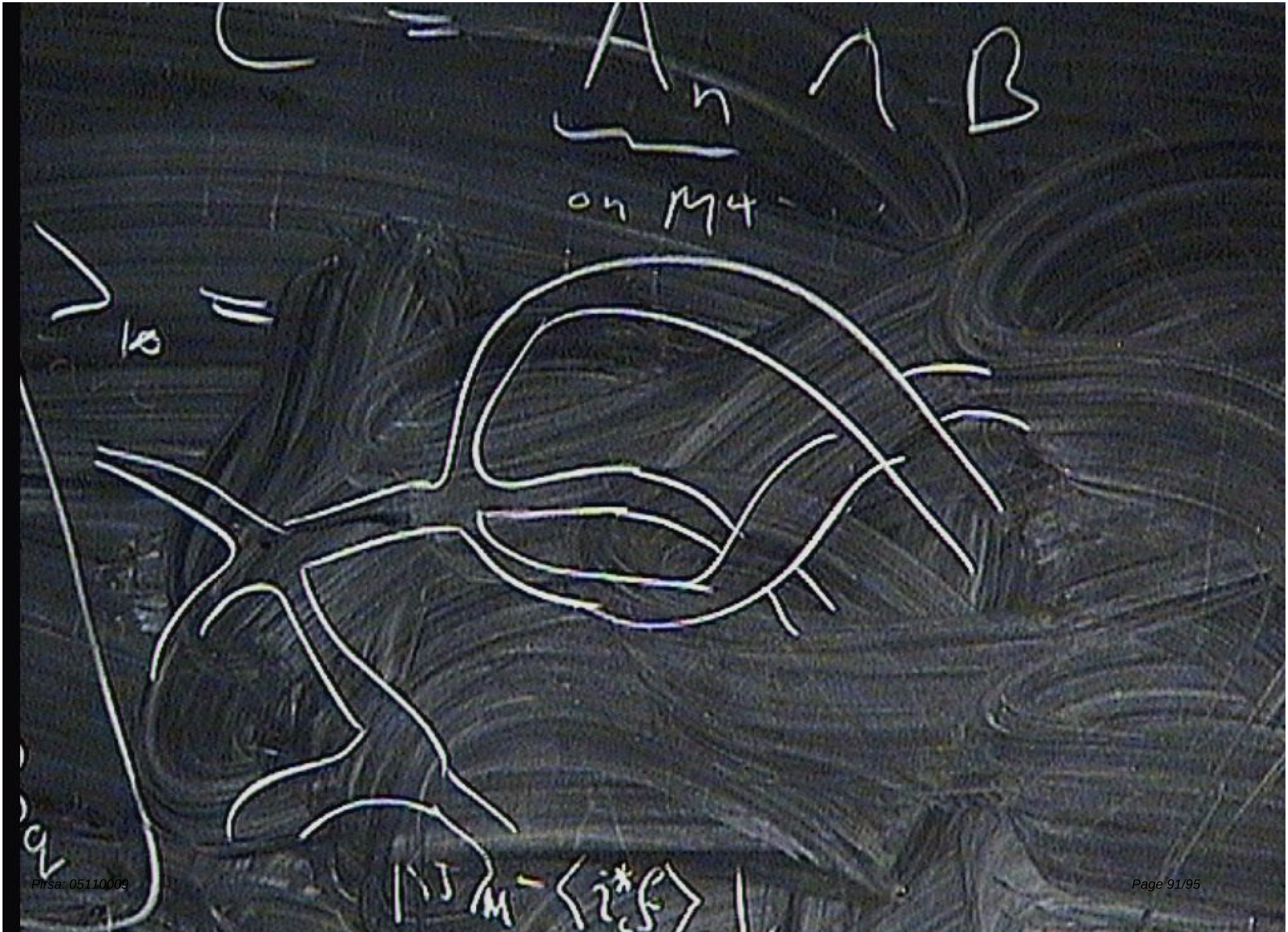
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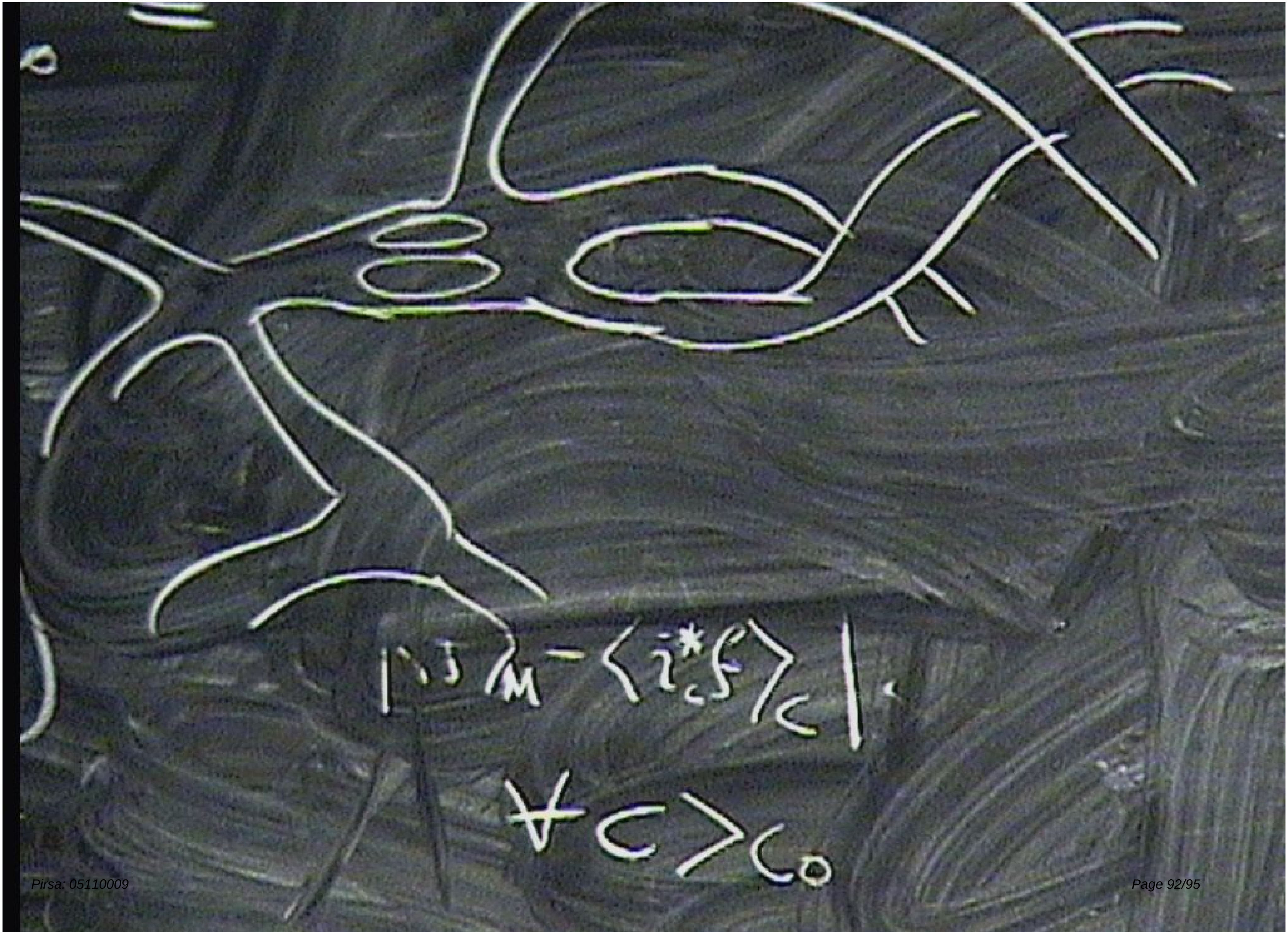
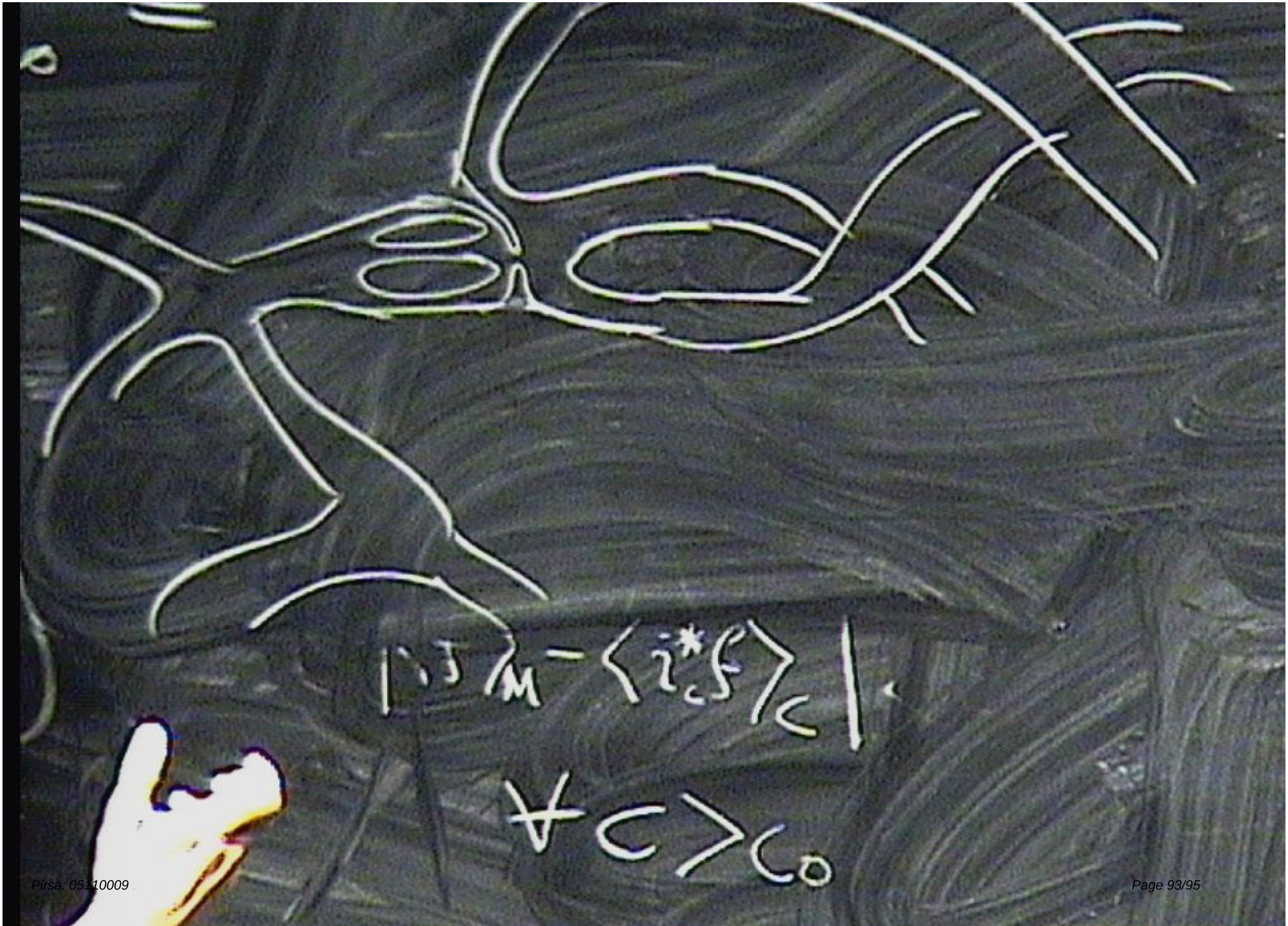

$\forall c > c_0$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