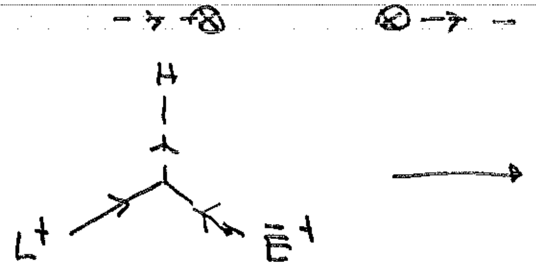
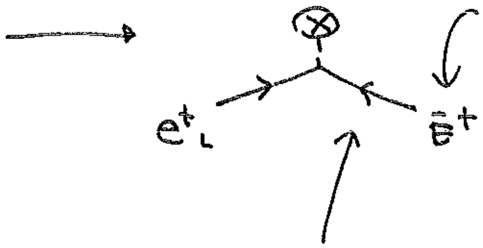
# ELECTROWEAK / CHIRAL SYM BREAKING II

## LAST TIME

only hits $a=2$ component of doublet



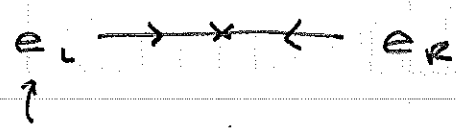

why this notation? no $\dagger = \alpha$, $\dagger = \dot{\alpha}$

$\bar{E}^\dagger = e_R$

have to remember that this is $\dot{\alpha}$

OR: let arrow point from $\dot{\alpha}$ to $\alpha$ index.

"Weyl fermion convention"




$Q = T^3 + Y = -1$ $\quad$ $Q = (Y_{\bar{E}})^\dagger = -1$

$\boxed{\text{this is a mass}}$

changes handedness

↳ CHIRAL SYM BR.

SO: CHIRAL INDICES NOT A GOOD QUANTUM # FOR MASSIVE SPIN-1/2 (FERMIONS)

ANGULAR MOMENTUM STILL CONSERVED → helicity "spin up electron" $\quad e_L \;\; S_z = \uparrow \qquad e_R = \bar{E}^\dagger \;\; S_z = \uparrow$ $\quad$ MASS EIGENSTATE

$e_L \;\; S_z = \downarrow \qquad e_R = \bar{E}^\dagger \;\; S_z = \downarrow$

$e_L^\dagger \;\; S_z = \uparrow \qquad e_R^\dagger = \bar{E} \;\; S_z = \uparrow$

$e_L^\dagger \;\; S_z = \downarrow \qquad e_R^\dagger = \bar{E} \;\; S_z = \downarrow$ $\quad$ "spin down positron"

CHIRAL PARTICLE $\qquad$ CHIRAL PARTICLE

(well def. int. in unbroken phase)

the "physical electron" / "mass eigenstate" is a <u>mixture</u> (QUANTUM) of $e_L$ & $e_R$ & so inherits interactions of both.

$\boxed{\text{Q: DOES } e \text{ talk to } W^\pm \text{?}}$

(if so, what is the other particle?

# GAUGE BOSONS

"force particle" $\longleftrightarrow$ associated w/ GAUGE SYMMETRY

- Always (for us) spin-1 $\rightarrow$ $\mu$ index
  - has to do w/ Derivatives...
- Always talks to objects <u>charged</u> under the gauge sym $\rightarrow$ "has index?"
- <u>Massless</u> when gauge sym. is good.
  - <u>Photon</u>: $A_\mu = \underbrace{(\cdot, \cdot, \cdot, \cdot)}$ 4 deg. of freedom

encodes:

$J^2 = 1$, $J_z = \pm 1, 0$ $\rightarrow$

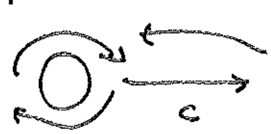
1. Left polarized
2. Right polarized

generic: massless of any non-zero spin have 2 pol's.

3. Longitudinal
4. $\phi$ $\leftarrow$ removed by Gauge sym

none for photon.

<u>Cartoon</u>: polarization <u>along</u> motion




"faster than c"

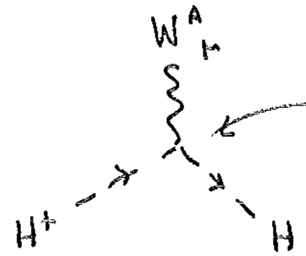
so LONGITUDINAL DOF $\longleftrightarrow$ <u>MASS</u>

<u>contrast to fermion</u>: LH $\oplus$ RH = massive spin 1/2

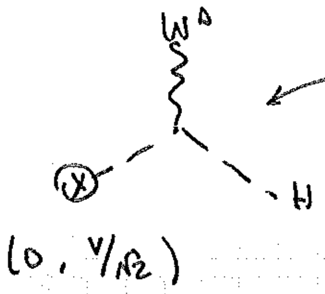
two separate particles

Where do $W^\pm, Z$ get longitudinal pol?

$$H = \begin{pmatrix} H^1 \\ H^2 \end{pmatrix} \qquad \begin{array}{ccc} T^3 & Y & Q \\ \hline 1/2 & 1/2 & 1 \\ -1/2 & 1/2 & 0 \end{array}$$




$T^A = \frac{1}{2}\sigma^A$




$W^{A=1} \cdot \frac{1}{2}(0 \;\; v/\sqrt{2}) \begin{pmatrix} & 1 \\ 1 & \end{pmatrix} \begin{pmatrix} H^1 \\ H^2 \end{pmatrix} = \frac{1}{2} W^1 H^1 \ldots$

$W^{A=2}$ —— " —— $\begin{pmatrix} & -i \\ i & \end{pmatrix}$ —— " —— $= \frac{-i}{2} W^2 H^1 \ldots$

$W^{A=3}$ —— " —— $\begin{pmatrix} 1 & \\ & -1 \end{pmatrix} \begin{pmatrix} H^1 \\ H_2 \end{pmatrix}$

gives $W^3 - H^2$ mix.

UNSURPRISINGLY : $W^+$ mixes w/ $H^1 \to G^+$

$W^-$ mixes w/ $(H^1)^\dagger \to G^-$

We call this Goldstone's mechanism

- "spontaneous" sym. breaking

  $\hookrightarrow \langle H \rangle = (0 \;\; v/\sqrt{2})^T$

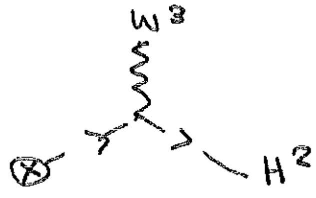
  why? ANALOG OF FERROMAGNET.

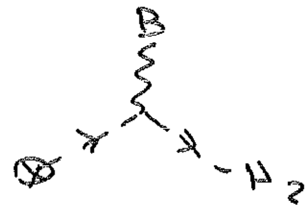
massless goldstones

- if GAUGE sym broken, the gauge boson $\boxed{\text{EATS}}$ the massless dof.

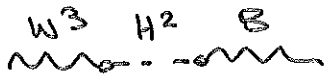
  ↑ incorporates into a MASSIVE SPIN-1

  FACT: this is the only "sensible" way to have massive, fundamental spin-1




so these all mix




$W^3 \rightarrow 2$ dof
$B \rightarrow 2$ dof
$\mathrm{Im}(H^2) \rightarrow 1$ dof

MASSIVE $Z$ : 3 dof
MASSLESS $A$ : 2 dof

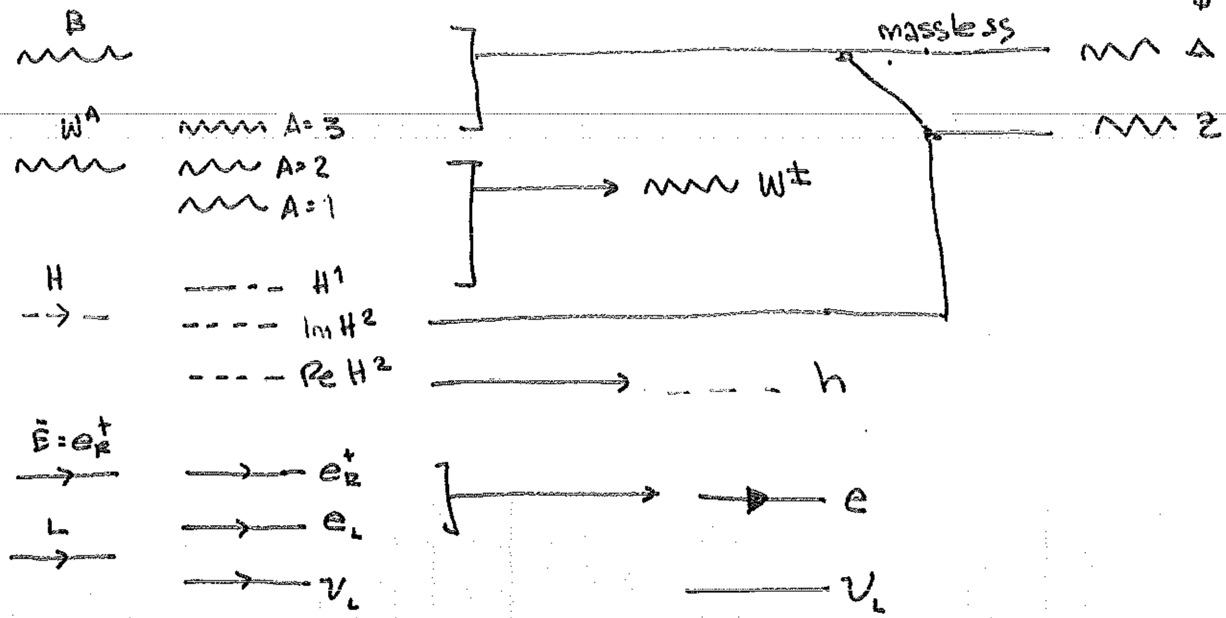

$$|A\rangle = \cos\theta_W |B\rangle + \sin\theta_W |W^3\rangle$$

$$|Z\rangle = -\sin\theta_W |B\rangle + \cos\theta_W |W^3\rangle$$

$\hookrightarrow$ mixes w/ $\mathrm{Im}(H^2)$

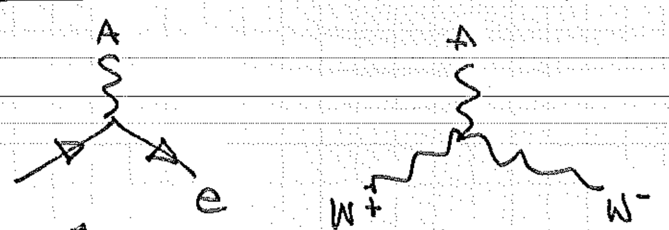
## UNBROKEN PARTICLES

talks to Q




Q: DOES Z TALK TO LH & RH PARTICLES the SAME OR DIFFERENTLY?

## INTERACTIONS (RULES)

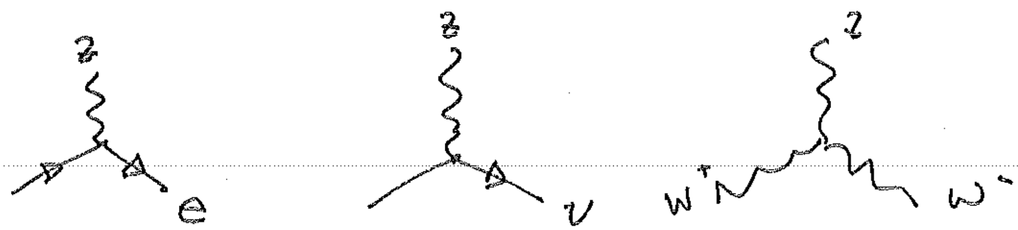



from $B, W^3$ couples to Q

from $W^+W^-W^3$

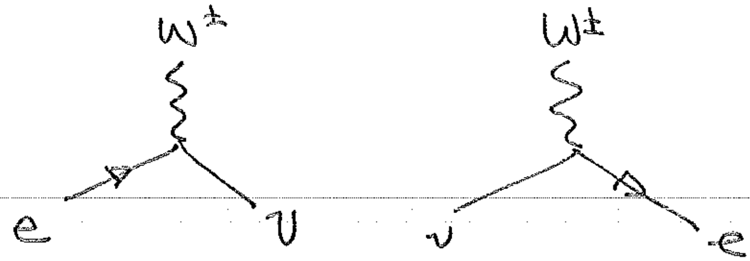
why no $A\nu\nu$?
Y & $W^3$ cancel

why no $AZZ$?
no Q, no $W^3W^3W^3$ vert.

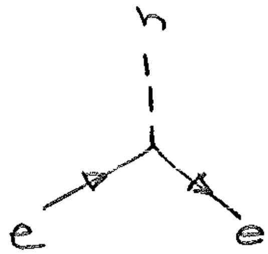



Z is orthog to A, so if $A\nu$ cancels, $Z\nu$ doesn't

from $W^+W^-W^3$




from $W^\pm$ vertex w/ $e_L$

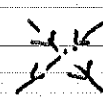



from $HL\bar{E}$ interaction

OTHER VERTICES: $hZZ$, $hWW$

if you talk to ---⊗
to get mass, you talk
to h.

$h^3$, $h^4$ ...

from  ... not so illuminating