

# REMINDER: PARTICLE CONTENT OF THE STANDARD MODEL

$e^-$	$\mu^-$	$\tau^-$	} X 2 FOR ANTIPARTICLES
$\nu_e$	$\nu_\mu$	$\nu_\tau$	
$u$	$c$	$t$	
$d$	$s$	$b$	
$u$	$c$	$t$	
$d$	$s$	$b$	
$u$	$c$	$t$	
$d$	$s$	$b$	
$u$	$c$	$t$	
$d$	$s$	$b$	

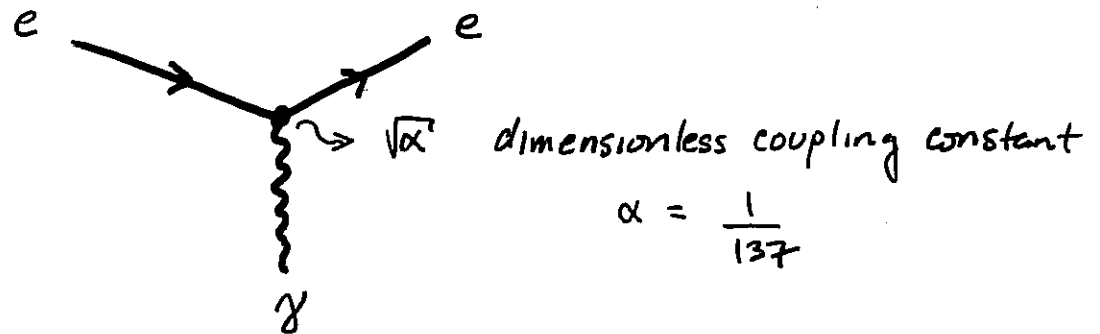
$\gamma$   
 $W^+, W^-$   
 $Z^0$   
 $g$

} GAUGE BOSONS

WE WILL IGNORE  
THE HIGGS BOSON  
FOR THE TIME BEING

→ Note that there are actually 8 DIFFERENT gluons, each of which carries a colour and an anticolour.

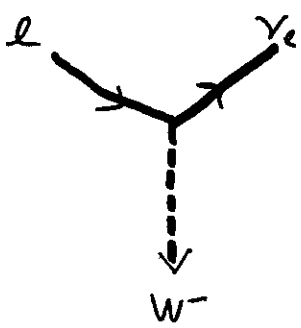
# QUANTUM ELECTRODYNAMICS (QED)



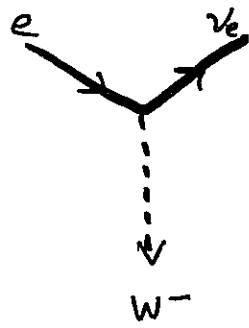
- THIS IS THE ONLY INTERACTION VERTEX IN THE THEORY OF QUANTUM ELECTRODYNAMICS!
- EVERY POSSIBLE PROCESS IN THE THEORY CAN BE DESCRIBED BY FEYNMAN DIAGRAMS INVOLVING ONLY VERTICES OF THIS FORM
- WE WILL DO SOME EXAMPLES IN CLASS
- NOTE THAT FOR SMALL COUPLING CONSTANTS DIAGRAMS WITH MORE VERTICES CONTRIBUTE LESS, SINCE EACH VERTEX CONTRIBUTES A FACTOR OF  $\sqrt{\alpha}$  TO THE CORRESPONDING AMPLITUDE (SO  $\propto$  TO THE PROBABILITY).

# CHARGED WEAK INTERACTION

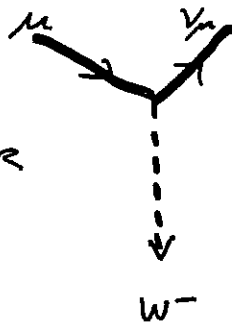
MEDIATED BY THE  $W^\pm$



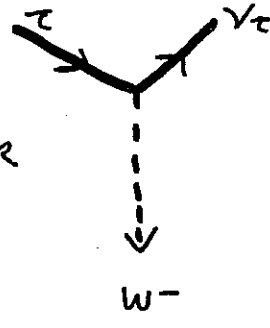
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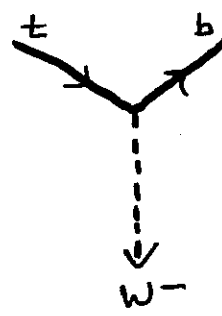
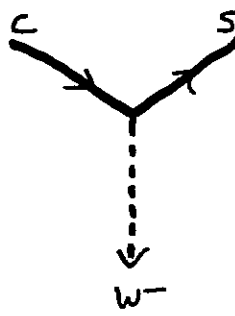
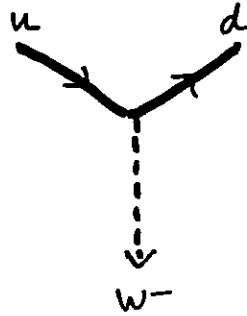
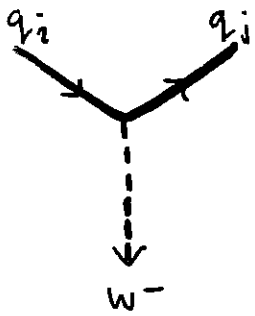
OR



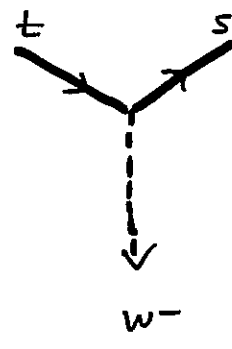
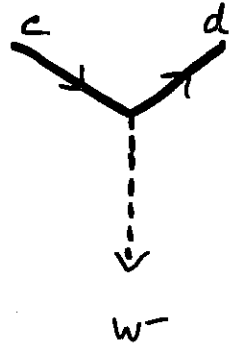
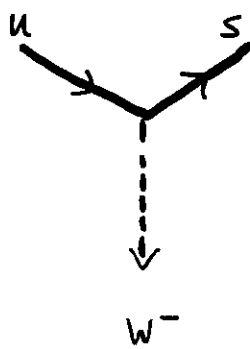
OR



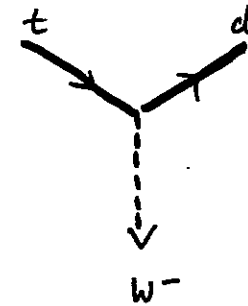
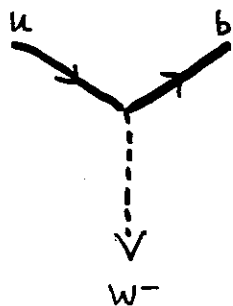
LEPTONS



QUARKS

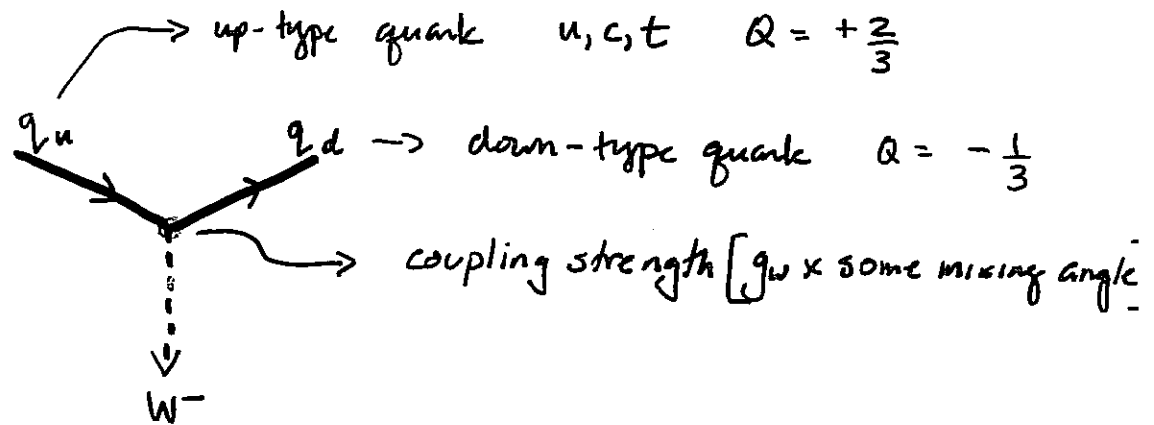


ALLOWED  
VERTICES

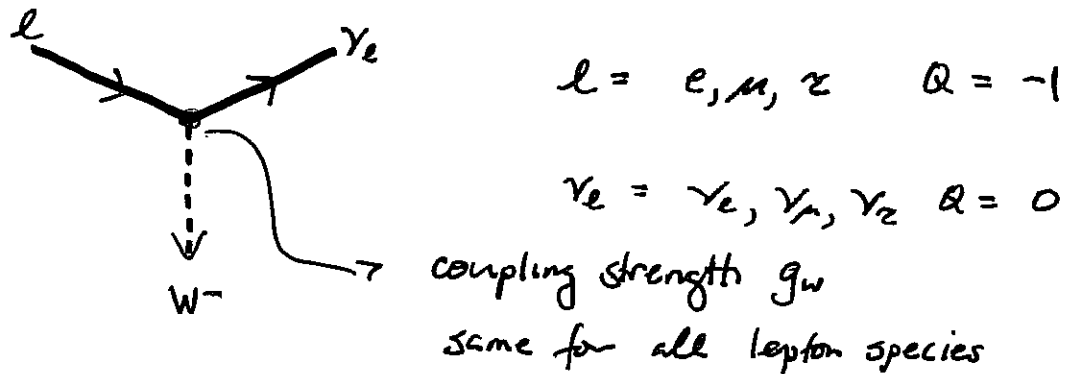


# CHARGED WEAK INTERACTION (AGAIN)

QUARKS



LEPTONS

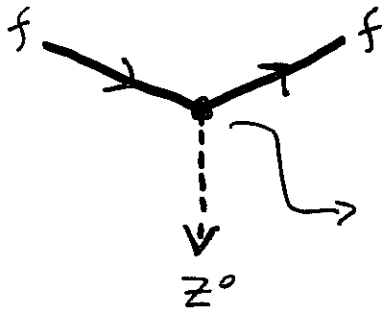


NOTE THE FOLLOWING

- DIFFERENT TIME ORDERINGS OF THE SAME FUNDAMENTAL VERTEX REPRESENT DIFFERENT TRANSITIONS
- THERE IS NO KINEMATICS HERE. ALL THESE DIAGRAMS REPRESENT ARE ALLOWED "CONNECTIONS" OR "COUPLINGS" OF THE VARIOUS PARTICLE SPECIES.
- ANY PROCESS IN THE STANDARD MODEL MUST BE BUILT ONLY OUT OF (COMBINATIONS OF) ALLOWED VERTICES.

NB CHARGED PARTICLES ALSO HAVE INTERACTION VERTICES WITH PHOTONS, JUST LIKE THE  $e e \gamma$  VERTICES IN QED

# NEUTRAL WEAK INTERACTION

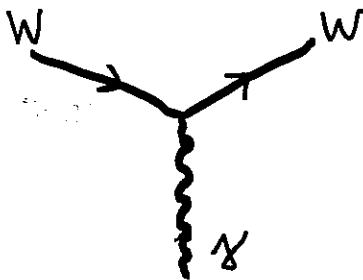


$$f = u, d, s, c, b, t, e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau$$

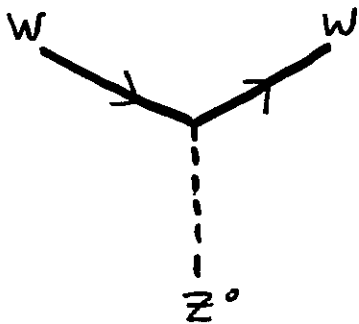
coupling strength depends on nature of  $f$ .

Similar to  $\gamma$  coupling to the electron in QED

## OTHER ALLOWED VERTICES



must exist!  $W$  is electrically charged



analogous to  $WW\gamma$  coupling but for weak interaction

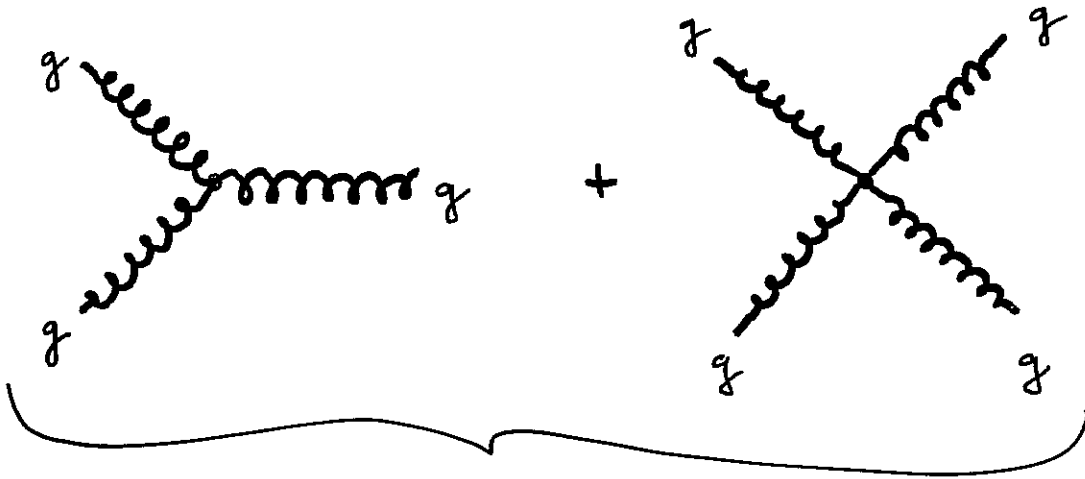
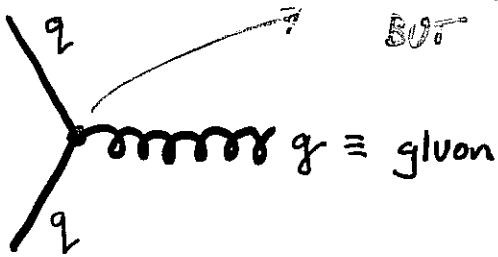
+  $W^+W^-Z^0Z^0$ ,  $W^+W^-W^+W^-$ ,  $W^+W^-\gamma\gamma$  couplings

[NOT SHOWN]

# QUANTUM CHROMODYNAMICS (QCD)

couplings the same for each species of quark  
BUT different for different colours

REMEMBER colour is a "charge"  
so this is true by definition.



WE WILL NOT OFTEN LOOK AT THESE VERTICES

BUT THEY ARE IMPORTANT PARTS OF THE THEORY.

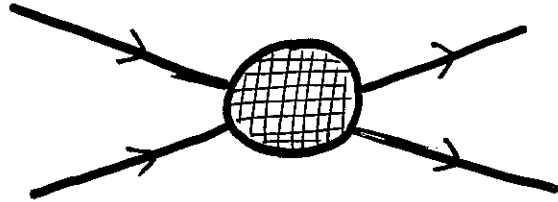
IT IS THE EXISTENCE OF THESE VERTICES THAT

IS RESPONSIBLE FOR THE FACT THAT QUARKS

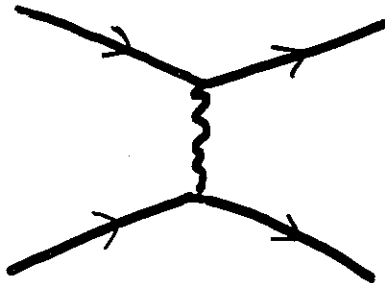
EXIST ONLY INSIDE BOUND STATES (HADRONS)

# IDENTICAL FINAL STATE PARTICLES

CONSIDER THE PROCESS  $e^-e^- \rightarrow e^-e^-$  IN QED



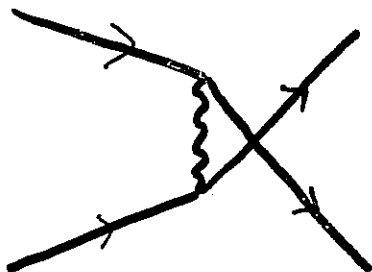
WE HAVE DRAWN THIS BEFORE AS



BUT WE DO NOT KNOW WHAT HAPPENS IN THE BLOB



CANNOT DISTINGUISH THIS FROM



WE WILL DISCUSS THE  
REASON THAT THESE ARE DISTINCT  
DIAGRAMS

[TRY IDENTIFYING A TELERACH CASE]