~~today~~: Ben → HW3 short ; HW3 long: tonight

SUGGEST: colloq.
· see also articles online

PRACTICAL: PROJECTS

↳ pick some expt in PARTICLE PHYSICS

↑ NOT NEC the SAME AS A COLLABORATION OR A DETECTOR

↑ not nec. "HEP"

① General motivation → WHAT IS IT MEASURING
→ WHY IS IT IMPORTANT
→ HOW DOES IT WORK?

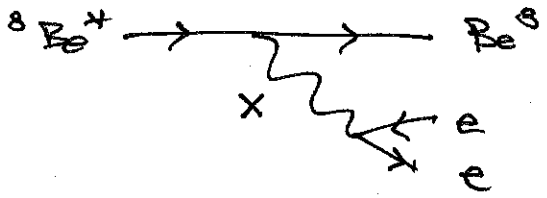
② FEYNMAN DIAGRAM of the PROCESS
↳ explain how the in/out states relate to the EXPT

③ SKETCH of A KEY PLOT (eg RESULTS)
· state: x-axis, y-axis
· expected vs actual / new physics

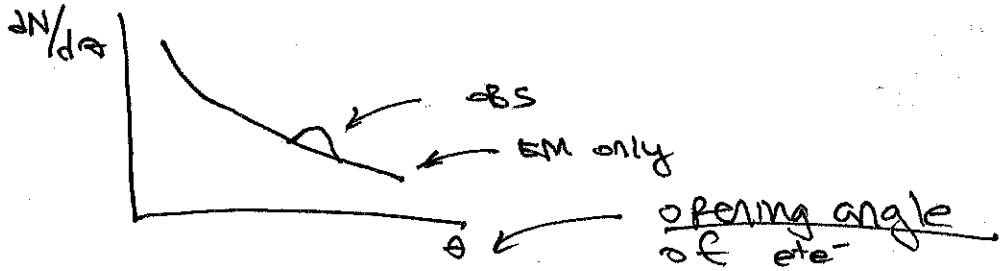
eg talk: Krasznahorkay PRL 116 042501

motivation: new low mass (rel to EW scale) particles using nuclear physics.

DIAGRAM:



PLOT



Where to find expts?
1. WEBPAGE HAS INCOMPL. LIST
2. TEXTBOOK
3. Symmetry Mag

Review: unbroken EW sym

Q^α	$\bar{u}^\alpha$	$\bar{d}^\alpha$	L^α	$\bar{e}^\alpha$	SPIN
Q^i	$\bar{u}$	$\bar{d}$	L^i	$\bar{e}$	SU(2)
$Q_{1/6}$	$\bar{u}_{-2/3}$	$\bar{d}_{1/3}$	$L_{-1/2}$	$\bar{e}_1$	HYPER (U(1))
Q^a	$\bar{u}_a$	$\bar{d}_a$	L	e	SU(3)

Q^a: color; $\bar{u}_a$, $\bar{d}_a$: anti-color

GAUGE BOSONS

Y_μ — U(1): no indices or charge

$(W_\mu)^i{}_j$

$(g_\mu)^a{}_b$

These all have a spin-1 INDEX

↳ use $(\sigma^\mu)^{\dot\alpha}{}_\beta$ to contract spin indices w/ matter.

carry one index, one anti-index } SU(N)

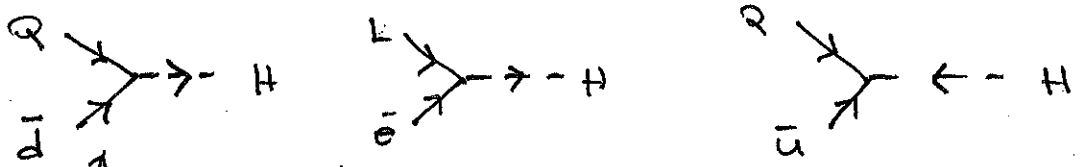
HIGGS

$$\boxed{H^i_{Y=1/2}} = \begin{pmatrix} h^1 \\ h^2 \end{pmatrix}_{Y=1/2}$$

we called these h^u & h^d before

YUKAWA COUPLINGS : HIGGS → MATTER

$$H^\dagger Q \bar{d} \;+\; H^\dagger L \bar{e} \;+\; \underbrace{H Q \bar{u}}_{\text{uses } \varepsilon_{ij}}$$

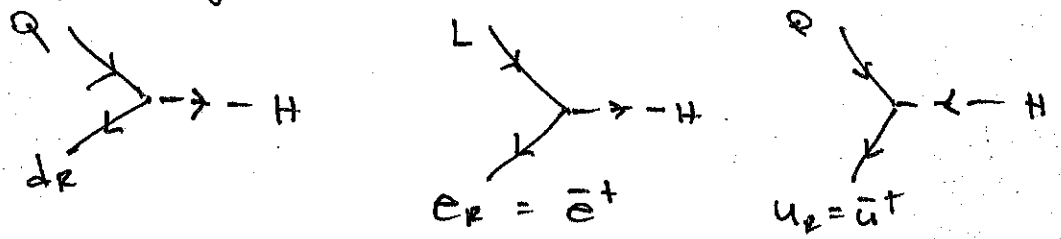


arrow convention
- LH MATTER COMING IN
- CHARGE OF SPIN-0 GOING IN OR OUT

} "Weyl notation"

"RIGHT HANDED DOWN" $(d_R)_i$ $Y = -\frac{1}{3}$

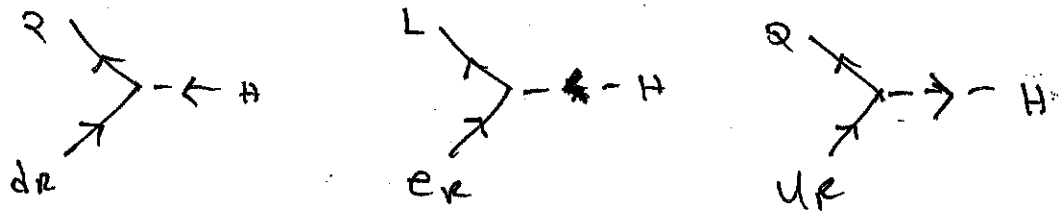
equivalently: $d_R \equiv \bar{d}^\dagger$



$$+ \text{h.c.}$$

$$H Q^\dagger \bar{d}^\dagger \;+\; H L^\dagger e \;+\; H^\dagger Q^\dagger \bar{u}^\dagger$$

$$= H Q^\dagger d_R \;+\; H L^\dagger e_R \;+\; H^\dagger Q^\dagger u_R$$



What we're not talking about yet: GAUGE-GAUGE
GAUGE-HIGGS

what about mass?

RULE

FOR A PARTICLE Φ w/ antiparticle $\Phi^\dagger$:
the particle can have a mass IF you can draw a 2-point graph

or, in other words: can you contract the indices of $\Phi\Phi^\dagger$

CAVEATS: CANNOT USE ANY OTHER PARTICLES
↳ just one Φ, one $\Phi^\dagger$

CANNOT USE DERIVATIVES
(turns out that we can use ∂_μ to "eat up" μ INDEX)

aside: for fermions: ψ^α
can write

$$\partial_\mu (\psi^\dagger)_{\dot\alpha} (\bar\sigma^\mu)^{\dot\alpha} {}_\alpha \psi^\alpha$$

any other indices contract

DERIVATIVE: includes $\partial/\partial t$ term
tells you about time evolution

not a mass term. just says ψ can move in space & time

IN the EW thy, it looks like matter is massless!

↳ the problem is even bigger for the GAUGE bosons, but that's deeper down the rabbit hole.

Ben showed us that none of the "double" particles can have mass.

↳ by the way: if we had a $\bar{\nu}$ particle what would the charges be?

MAY WANT A YUKAWA $HL\bar{\nu}$ analogous to $HQ\bar{d}$

$Y = 1/2 \quad Y = -1/2 \quad \Rightarrow Y = 0$

So $\bar{\nu}$ has NO charges. In fact: $\bar{\nu}^\dagger = \bar{\nu}$

(or $\nu_R \equiv \bar{\nu}^\dagger = \nu_R^\dagger$)

↳ so you CAN WRITE $\nu_R \nu_R = \nu_R^\alpha \nu_R^\beta \varepsilon_{\alpha\beta}$

$\Rightarrow$ the RH neutrino can have mass

... should have mass.

WHAT MASS? thy doesn't have any mass scale ... expect it to be HUGE.

(maybe M_{Pl}?!)

... and so this thing is so heavy we don't expect to see it.

(EW)

Symmetry breaking

see: lec 10 notes on ferromagnets

CLAIM: EW sym $(SU(2) \times U(1))$ is broken

... by a HIGGS VACUUM EXPECTATION VALUE

$$\langle H \rangle = \begin{pmatrix} 0 \\ v/\sqrt{2} \end{pmatrix}_{Y=1/2}$$

$v \approx 246$ GeV

this is a constant "vector" (in $SU(2) \times U(1)$ space) everywhere in spacetime.

order parameter

what this means: I CAN USE $\langle H \rangle$ as another "free" tensor.

it is NOT invariant: it tells you that the symmetry is no good. BUT IT TELLS YOU HOW IT IS NO GOOD.

eg: show how this gives MASS terms.