Why is the Brout-Englert-Higgs Mechanism Needed?

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GPSA (Graduate Physics Students Association) Talk

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- Answers to these questions are not known to many outside the field of particle physics.
- I'll try to answer these questions using some basic principles that can be understood with basic conceptual ideas in Quantum Mechanics (QM) and Special relativity

Setup

- $\hbar = c = 1$
  So $E = mc^2 \rightarrow E = m$ (unit GeV will be used.
  $1\ \mathrm{GeV} = 1.602176487 \times 10^{-10}$ *Joules* $\sim$ proton mass)
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- Probability of anything ≤ 1 !! $\rightarrow$ Unitarity

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- These fields are NOT dimensionless:

$$\begin{aligned} \text{Spin-0} &\rightarrow [E] \\ \text{Spin-1/2} &\rightarrow [E^{3/2}] \\ \text{Spin-1} &\rightarrow [E] \end{aligned}$$

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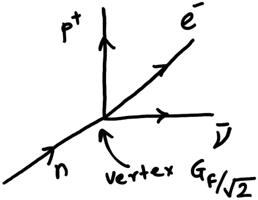
  $\rightarrow$ 'THE PARTICLE' having momentum p

- Story begins with physicists trying to develop a QFT to explain the β-decay: $n \;\rightarrow\; p^+ + e^- + \bar{\nu}_e$



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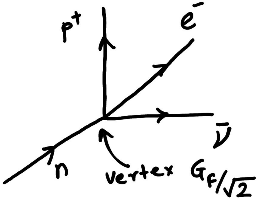

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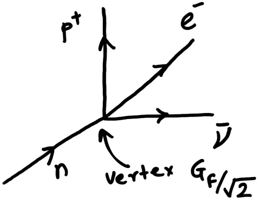

- QFT for Electricity and Magnetism was known $\rightarrow$ Quantum Electrodynamics (QED)
- Try a similar theory empirically:

$$\mathcal{L}_F = -\tfrac{G_F}{\sqrt{2}}\,(\bar{p}(x)\gamma_\mu n(x))\,(\bar{e}(x)\gamma^\mu \nu(x)).... \quad G_F \;\rightarrow \text{Fermi constant}$$

Similarity with QED interactions: $\quad e(\bar{e}(x)\gamma_\mu e(x))\, A^\mu(x)$

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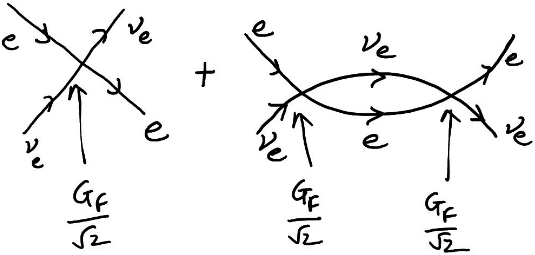
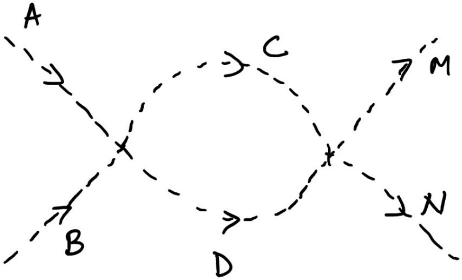
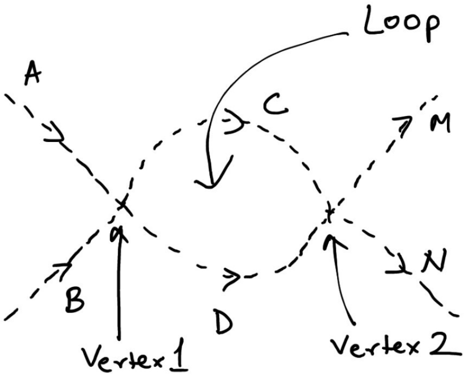
- Agreed with theory on previous slide ‘AT LOW ENERGY’
- Try to study $e\ \bar{\nu}_e \ \rightarrow \ e\ \bar{\nu}_e$ AT HIGH ENERGY



Time for Feynman diagrams!

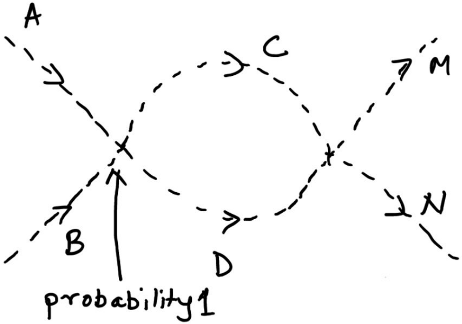


The Heisenberg's uncertainty principle allows violation of energy conservation to create heavy particles for a very short time. But they combine before they can reach the detector. The effect of this can be seen ONLY at high energies.

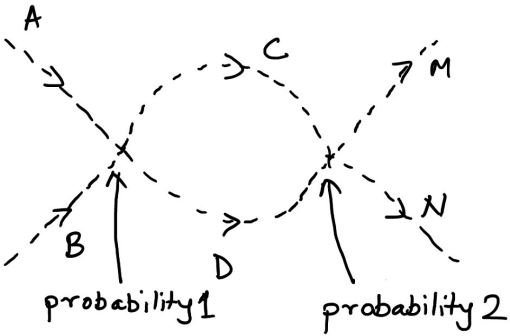


What we want to measure is:

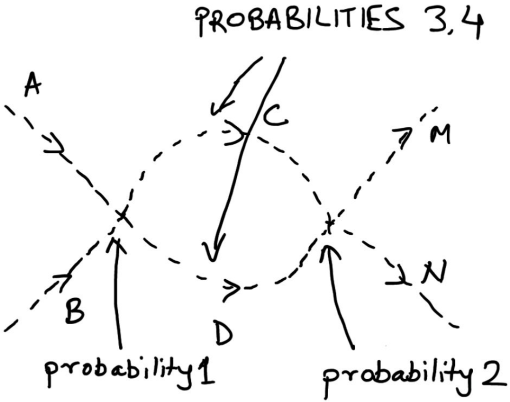
If we send in particles A and B with certain momenta and energies, then how many M and N particles, with what momenta and energies are detected in the detector.



(Probability that A and B interacted to pop out C and D)



(Probability that A and B interacted to pop out C and D) X (Probability that detected M and N originated from interaction between C and D)



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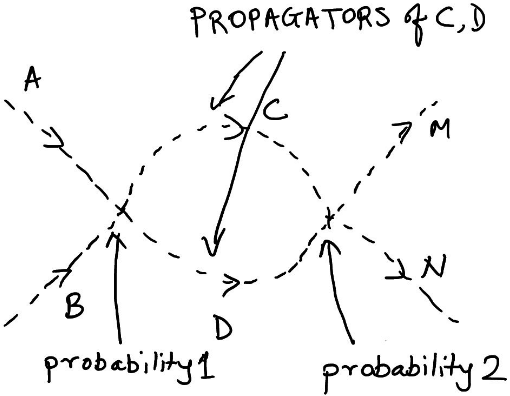
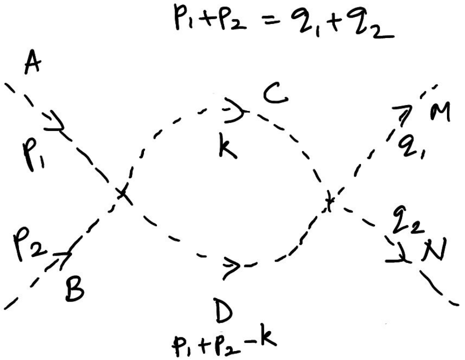
X (Probabilities that C and D coming from A and B are the same that resulted in M and N)

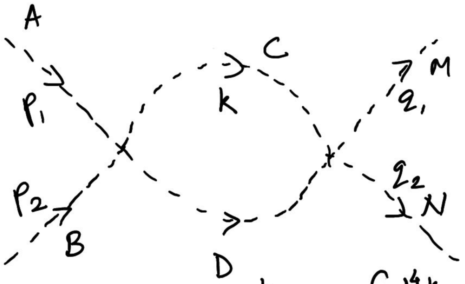


(Probability that A and B interacted to pop out C and D)
X (Probability that detected M and N originated from interaction between C and D)
X (Propagators of C and D)



Energy conservation allows any value and direction of 4-momentum ‘k’

$$p_1 + p_2 = q_1 + q_2$$



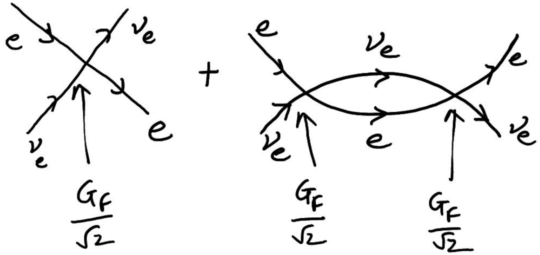
$$p_1 + p_2 - k \Rightarrow \int \frac{d^4 k}{(2\pi)^4}$$

So one needs to integrate over all the values of '3+1 dimensional' k

Not exactly probabilities,

Not exactly probabilities, but more like ‘probability amplitudes’

Back to


e
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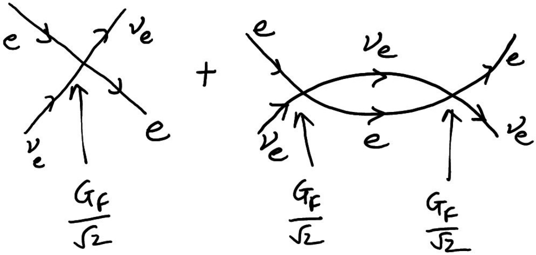

HIGH ENERGY (E) diagram $\sim \infty$

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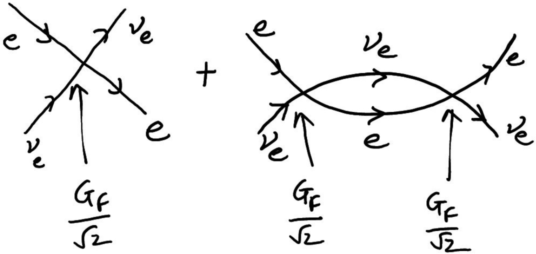

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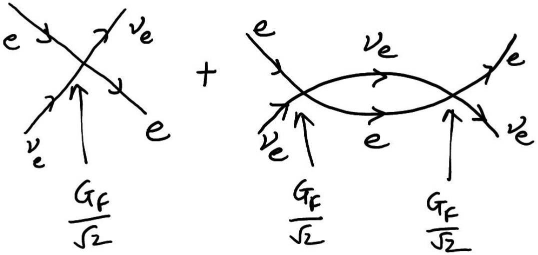

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Probability $\leq 1 \quad \Rightarrow \quad E \lesssim 300$ GeV

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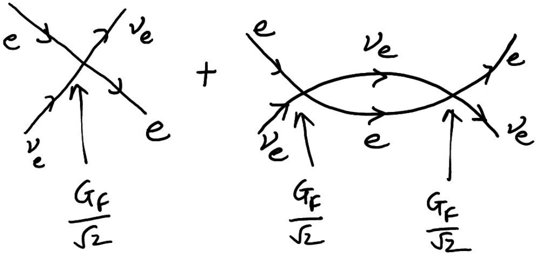
Probability that it happens in a particular way: Partial Wave Analysis



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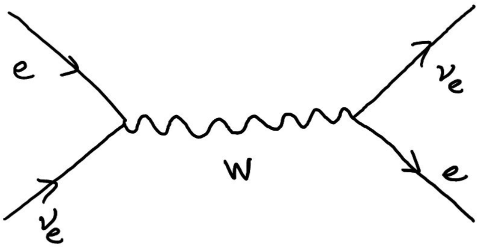
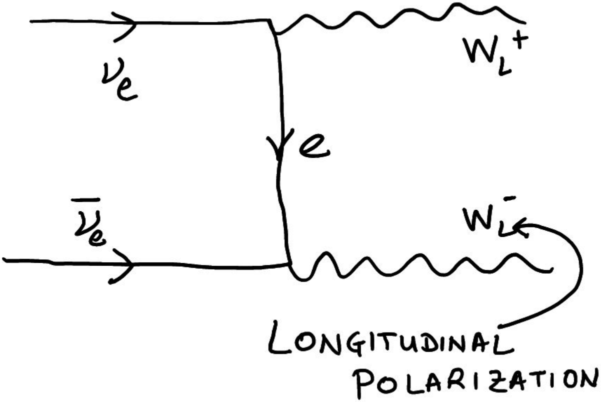
- Replicate QED: $\mathcal{L}_{weak} = \; g\; (\bar{e}(x)\gamma_\mu \nu_e(x))\; W^\mu(x) = g\; J_\mu^{weak}\; W^\mu$,

  W is CHARGED and MASSIVE unlike the photon in QED

  $$\frac{G_F}{\sqrt{2}} = \frac{g}{M_W^2}.$$



Then following diagram is also possible



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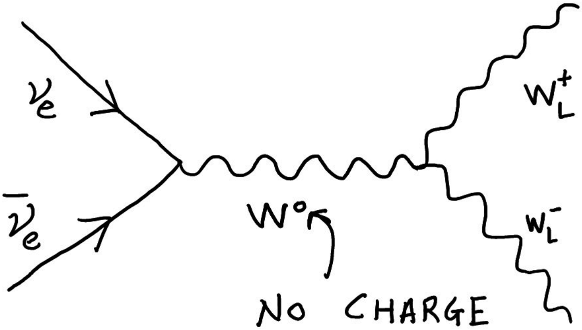
AGAIN PROBLEM IN HIGH ENERGY BEHAVIOR!!!

Add interaction from $\sim \bar{\nu}_e \gamma_\mu W^{\mu,i}\ T^i\ \nu_e$ and $W^\mu W^\rho\ (\partial_\mu W_\rho)$

(T^i are some 3 matrices we have to find such that the cancellation occurs)



- The cancellation requires
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  Absolute 'PHASE' (multiply wave fn. by $\sim Exp(i\alpha)$) of a wave function is 'arbitrary' i.e. even when it changes, the physical properties of the system don't change

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Absolute 'PHASE' (multiply wave fn. by $\sim Exp(i\alpha)$) of a wave function is 'arbitrary' i.e. even when it changes, the physical properties of the system don't change
- In QFT, this phase is PHASE of the symmetry group i.e. transform 'FIELDS' by $\sim Exp(i \sum_a T^a \alpha^a)$ or so
- So under such phase change, the Lagrangian must be invariant

$\rightarrow$ GLOBAL GAUGE INVARIANCE

Masses of W's

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- Problem: mass term like $M_W^2 W_\mu W^\mu$ is not invariant under

  LOCAL $SU(2)$ GAUGE SYMMETRY !!!

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- What if fermions (say, electrons) are massless??
- Recall Bohr radius for a Hydrogen atom:

$$R \propto \frac{1}{m_e}$$

$\Rightarrow$ No m_e $\rightarrow$ No atoms $\rightarrow$ No chemistry!!!

We need something else to give masses to the W's and the fermions!!!!

BROUT-ENGLERT-HIGGS MECHANISM

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Will discuss in the next talk on 11th November (tentative) same time same place

Thank You :)