

$$|\Omega\rangle = \lim_{T \rightarrow \infty (1-i\epsilon)} \left( e^{-iE_0(T+t_0)} \langle \Omega | 0 \rangle \right)^{-1} e^{-iH(T+t_0)} |0\rangle$$

$$e^{-iHT} |0\rangle = e^{-iE_0 T} |\Omega\rangle \langle \Omega | 0 \rangle + \sum_{n \neq 0} e^{-iE_n T} |n\rangle \langle n | 0 \rangle$$

$$\langle 0 | e^{-iHT} = \langle 0 | \Omega \rangle \langle \Omega | e^{-iE_0 T} + \sum_{n \neq 0} \langle 0 | n \rangle \langle n | e^{-iE_n T}$$

$$\langle \Omega | = \lim_{T \rightarrow \infty (1-i\epsilon)} \frac{\langle 0 | U(T, T_0)}{e^{-iE_0(T-t_0)} \langle 0 | \Omega \rangle} =$$

$$U(t, t_0) = e^{iH_0(t-t_0)} e^{-iH(t-t_0)}$$

دعوى  $\langle \Omega | \stackrel{?}{=} (|\Omega\rangle)^\dagger$

$$H |\Omega\rangle = E_0 |\Omega\rangle$$

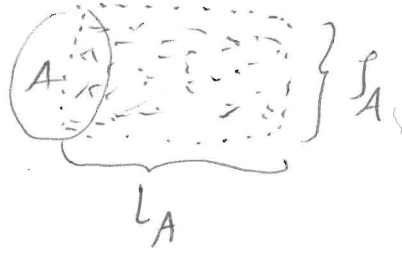
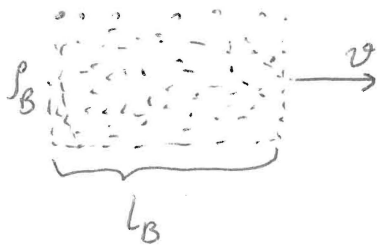
$$\langle \Omega | H = E_0 \langle \Omega |$$

$$(|\Omega\rangle)^\dagger = \lim_{T \rightarrow \infty (1-i\epsilon)} \frac{e^{iH(T-t_0)} |0\rangle \langle \Omega | + |n\rangle \langle n|}{e^{+iE_0(T-t_0)} \langle \Omega | 0 \rangle} =$$

$$= |\Omega\rangle + \lim_{T \rightarrow \infty (1-i\epsilon)} \sum_{n \neq 0} \frac{e^{iE_n(T-t_0)} \langle n | 0 \rangle}{e^{+iE_0(T-t_0)} \langle \Omega | 0 \rangle}$$

②  $|\Omega\rangle + \lim_{T \rightarrow \infty (1-i\epsilon)} \frac{e^{-iE_n(T+t_0)} \langle n | 0 \rangle}{e^{-iE_0(T+t_0)} \langle \Omega | 0 \rangle}$

ص ۱



$$\sigma = \frac{\text{سطح مقطع برخورد}}{\text{تعداد رویداد}} = \frac{\rho_A l_A \rho_B l_B A}{\text{تعداد رویداد}}$$

[ $\sigma$ ]

We will assume that both the range of the interaction between the particles and the width of the <sup>individual</sup> ~~individual~~ particle wavepackets are small compared to the beam diameter.

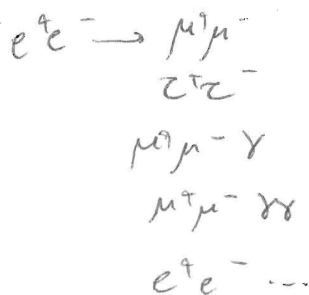
$$\text{تعداد رویداد} = \sigma l_A l_B \int d^2x \rho_A(x) \rho_B(x)$$

↑  
اتصال دیرری سافت

آر فرمات مات

$$\text{تعداد رویداد} = \frac{\sigma N_A N_B}{A}$$

سطح مقطع جزئی



$$\frac{d\sigma}{d^3p_1 d^3p_2 \dots d^3p_n}$$

$$\frac{d\sigma}{d^3p_1 d^3p_2} \xrightarrow{\delta^4(\sum_i p_i - \sum_f p_f)} \frac{d\sigma}{d\Omega}$$

$\Gamma = \text{decay rate}$

$$\Gamma = \frac{\text{تعداد واپاشی در واحد زمان}}{\text{تعداد ذرات حاضر}}$$

$$\tau = \Gamma^{-1} = \text{طول عمر}$$

$$\tau \ln 2 = \text{نیمه عمر}$$

Unstable state

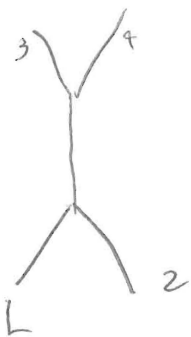
resonance

(non-relativistic quantum mechanics  
unstable atomic state)

Breit-Wigner formula

$$\Gamma \propto \frac{1}{E - E_0 + i\frac{\Gamma}{2}}$$

$$\sigma \propto \frac{1}{(E - E_0)^2 + \frac{\Gamma^2}{4}}$$



$$E_p = \sqrt{\vec{p}^2 + m^2}$$

$$\frac{1}{p^2 - m^2 + i0} \approx \frac{1}{2E_p(p^0 - E_p + i\frac{m}{E_p}\frac{\Gamma}{2})}$$

↓  
Lorentz invariant  
دستگاه کوانتم

$$U = \langle \text{final state} | e^{-iHt} | \text{initial state} \rangle$$

$$|\varphi\rangle = \int \frac{d^3k}{(2\pi)^3} \frac{1}{\sqrt{2E_k}} \varphi(k) |k\rangle$$

$$\text{free theory: } |k\rangle = \sqrt{2E_k} a_k^\dagger |0\rangle$$

$$\langle \varphi | \varphi \rangle = 1 \iff \int \frac{d^3k}{(2\pi)^3} |\varphi(k)|^2 = 1$$

$$P = \left| \underbrace{\langle \varphi_1 \varphi_2 \dots}_{\text{out}} \mid \underbrace{\varphi_A \varphi_B}_{\text{in}} \right|^2$$

$$|\varphi_A \varphi_B\rangle$$

$$|p_A p_B\rangle_{\text{in}}$$

حالت با مقادیر مشخص



$$|\varphi_A \varphi_B\rangle_{\text{in}} = \int \frac{d^3k_A}{(2\pi)^3} \int \frac{d^3k_B}{(2\pi)^3} \frac{\varphi_A(k_A) \varphi_B(k_B) e^{-i b \cdot k_B}}{\sqrt{2E_A 2E_B}} |k_A k_B\rangle_{\text{in}}$$

$$\langle \varphi_1 \varphi_2 | = \prod_f \int \frac{d^3p_f}{(2\pi)^3} \frac{\varphi_f(p_f)}{\sqrt{2E_f}} \langle \text{out } p_1 p_2 \dots |$$

آمارهای مکانی نهایی را اندازه گیری  
 مکان را در وقت طول موج دوری که اندازه گیری کردیم

de Broglie

$$\langle p_1 p_2 \dots | k_A k_B \rangle_{in} = \lim_{T \rightarrow \infty} \underbrace{\langle p_1 p_2 \dots |}_T \underbrace{| k_A k_B \rangle}_{T}$$

$$\lim_{T \rightarrow \infty} \langle p_1 p_2 \dots | e^{-iH(T)} | k_A k_B \rangle$$

$$\langle p_1 p_2 \dots | k_A k_B \rangle_{in} \triangleq$$

$$\langle p_1 p_2 \dots | S | k_A k_B \rangle_{in}$$

$$S = 1 + iT$$

$$\langle p_1 p_2 \dots | iT | k_A k_B \rangle = (2\pi)^4 \delta(k_A + k_B - \sum p_f) i\mathcal{M}(k_A k_B \rightarrow p_f)$$

3  $\rightarrow$  many

invariant matrix element  $\mathcal{M}$

$$\langle p_1 p_2 \dots | iT | k_A k_B \rangle = (2\pi)^4 \delta(k_A + k_B - \sum p_f) i\mathcal{M}(k_A k_B \rightarrow p_f)$$

$$P(A, B \rightarrow 1, 2, \dots, n) = \left( \prod_f \frac{d^3 p_f}{(2\pi)^3} \frac{1}{2E_f} \right) \left| \langle p_1 \dots p_n | \varphi_A \varphi_B \rangle_{in} \right|^2$$

20

$$N = \sum_{\substack{\text{all incident} \\ \text{particles } i}} P_i = \int d^2 b n_B P(b)$$

$$\sigma = \frac{N}{n_B N_A} = \frac{N}{n_B \times 1} = \int d^2 b P(b)$$

$$d\sigma = \left( \prod_f \frac{d^3 p_f}{(2\pi)^3} \frac{1}{2E_f} \right) \int d^2 b \left( \prod_{i=A,B} \int \frac{d^3 k_i}{(2\pi)^3} \frac{\varphi_i(k_i)}{\sqrt{2E_i}} \right) \int \frac{d^3 \bar{k}_i}{(2\pi)^3} \frac{\varphi_i^*(\bar{k}_i)}{\sqrt{2\bar{E}_i}} \times e^{i b \cdot (\bar{k}_B - k_B)} \left( \langle \{P_f\} | \{k_i\} \rangle_{in} \right) \left( \langle \{P_f\} | \{\bar{k}_i\} \rangle_{in} \right)^*$$

$$\int d^2 b e^{i(\bar{k}_B - k_B) \cdot b} = (2\pi)^2 \delta^2(k_B^\perp - \bar{k}_B^\perp)$$

$$\left( \langle \{P_f\} | \{k_i\} \rangle_{in} \right) = i \mathcal{M}(\{k_i\} \rightarrow \{P_f\}) (2\pi)^4 \delta^+(\sum k_i - \sum P_f)$$

$$\left( \langle \{P_f\} | \{\bar{k}_i\} \rangle_{in} \right)^* = -i \mathcal{M}^*(\{\bar{k}_i\} \rightarrow \{P_f\}) (2\pi)^4 \delta^+(\sum \bar{k}_i - \sum P_f)$$

$$\int d\bar{k}_A^\perp d\bar{k}_B^\perp \delta(\bar{k}_A^\perp + \bar{k}_B^\perp - \sum P_f^\perp) \delta(\bar{E}_A + \bar{E}_B - \sum E_f)$$

$$= \int d\bar{k}_A^\perp \delta\left(\sqrt{\bar{k}_A^2 + m_A^2} + \sqrt{\bar{k}_B^2 + m_B^2} - \sum E_f\right) \Big|_{\bar{k}_B^\perp = \sum P_f^\perp - \bar{k}_A^\perp}$$

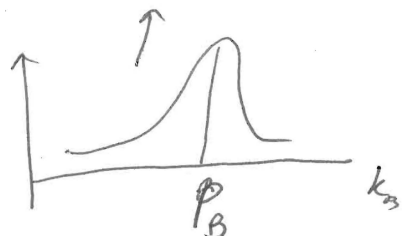
$$= \frac{1}{\left| \frac{\bar{k}_A^\perp}{\bar{E}_A} - \frac{\bar{k}_B^\perp}{\bar{E}_B} \right|} = \frac{1}{|v_A - v_B|}$$

90

توانی گذشتگی روی  $P_A, P_B$ 

$$d\sigma = \left( \prod_f \frac{d^3 p_f}{(2\pi)^3} \frac{1}{2E_f} \right) \frac{|M(p_A, p_B \rightarrow \{p_f\})|^2}{2E_A 2E_B |v_A - v_B|} \int \frac{d^3 k_A}{(2\pi)^3} \int \frac{d^3 k_B}{(2\pi)^3}$$

$$|\varphi_A(k_A)|^2 |\varphi_B(k_B)|^2 (2\pi)^4 \delta^4(k_A + k_B - \sum p_f)$$



میانگین  
4.78

$$\int d^3 k_A |\varphi_A(k_A)|^2 = 1$$

$$d\sigma = \frac{1}{2E_A 2E_B |v_A - v_B|} \left( \prod_f \frac{d^3 p_f}{(2\pi)^3} \frac{1}{2E_f} \right)$$

$$\times |M(p_A, p_B \rightarrow \{p_f\})|^2 (2\pi)^4 \delta^4(p_A + p_B - \sum p_f)$$

$$\int d\pi_n = \left( \prod_f \int \frac{d^3 p_f}{(2\pi)^3} \frac{1}{2E_f} \right) (2\pi)^4 \delta^4(P - \sum p_f)$$

↓  
relativistically invariant n-body phase space

$$\frac{1}{E_A E_B |v_A - v_B|} = \frac{1}{|E_B p_A^2 - E_A p_B^2|} = \frac{1}{|\sum_{\mu, \nu} p_A^\mu p_B^\nu|}$$

C.O.M

تحت شرایط لورنتس

$$\vec{P}_1 = -\vec{P}_2$$

$$\int d\pi_2 = \int \frac{d p_1 p_1^2 d\Omega}{(2\pi)^3 2E_1 2E_2} (2\pi) \delta(E_{C.M} - E_1 - E_2)$$

✓

$$E_1 = \sqrt{p_1^2 + m_1^2}$$

$$E_2 = \sqrt{p_1^2 + m_2^2}$$

$$\int d\pi_2 = \int d\Omega \frac{p_1^2}{16\pi^2 E_1 E_2} \left( \frac{p_1}{E_1} + \frac{p_1}{E_2} \right)^{-1} = \int \frac{d\Omega}{16\pi^2} \frac{|p_1|}{E_{cm}}$$

بجس  
ع. پ. وایبرت رهم بخوانید  
توان درانی

$$\int d\pi_2 = \int d\cos\theta \frac{1}{16\pi} \frac{2|p_1|}{E_{cm}}$$

$$\left( \frac{d\sigma}{d\Omega} \right)_{c.m.} = \frac{1}{2E_A 2E_B |v_A - v_B|} \frac{|p_1|}{(2\pi)^2 4E_{cm}} |M(p_A, p_B \rightarrow p_1, p_2)|^2$$

آرگی ذرات ورودی و خروجی هم باشد:

$$\left( \frac{d\sigma}{d\Omega} \right)_{cm} = \frac{|M|^2}{64\pi^2 E_{cm}^2} \quad (\text{جای می})$$

$$d\Gamma = \frac{1}{2m_A} \left( \prod_f \frac{d^3 p_f}{(2\pi)^3} \frac{1}{2E_f} \right) |M(m_A \rightarrow \{p_f\})|^2 (2\pi)^4 \delta^4(p_A - \sum p_f)$$

نیم - T ۱۱۸۸

$\sim \frac{1}{\Delta E} \rightarrow$  intrinsic width

$\pi \rightarrow \nu, \mu$   
wave packet

این فرمول کلی هست. کاری نداریم که ذرات نهایی مشابهند یا خیر.

البته محاسبه‌ی  $M$  برای وقتی که ذرات مشابهند یا نه کلاً فرق دارد.

$$\frac{1}{n!} \quad \text{تعداد تمام اتصالات} \\ \text{تعداد ذرات مشابهی}$$

محاسبه‌ی ماتریس  $S$  از دیارامی فاینمن

$$\langle p_1 p_2 | S | k_A k_B \rangle = \lim_{T \rightarrow \infty} \langle p_1 p_2 | e^{-2iHT} | k_A k_B \rangle$$

وایبر  $\neq$  فصل ۳ - تئوری پراکندگی

$$H = H_0 + V$$

$$H_0 |\varphi_\alpha\rangle = E_\alpha |\varphi_\alpha\rangle$$

$$\langle \varphi_\alpha | \varphi_\alpha \rangle = \delta(\alpha - \alpha')$$

$$H \psi_\alpha^{\pm} = E_\alpha \psi_\alpha^{\pm}$$

$\nearrow^{in} \rightarrow^{out}$

$$\int d\alpha e^{-iE_\alpha \tau} g(\alpha) |\varphi_\alpha^\pm\rangle \rightarrow \int d\alpha e^{-iE_\alpha \tau} g(\alpha) |\varphi_\alpha\rangle$$

$$\tau \rightarrow -\infty$$

$$\tau \rightarrow \infty$$

$$|\varphi_\alpha^\pm\rangle = \Omega(\mp\infty) |\varphi_\alpha\rangle \quad \Omega(\tau) = e^{iH\tau} e^{-iH_0\tau}$$

$\nearrow^{in} \rightarrow^{out}$

Ex

$$S_{\beta\alpha} = \langle \psi_{\beta}^{-} | \psi_{\alpha}^{+} \rangle = \langle \varphi_{\beta} | \Omega^{+}(+\infty) \Omega(-\infty) | \varphi_{\alpha} \rangle$$

$$= \langle \varphi_{\beta} | S | \varphi_{\alpha} \rangle$$

$$S = \Omega^{+}(+\infty) \Omega(-\infty) = U(+\infty, -\infty)$$

$$U(z, z_0) = \Omega^{+}(z) \Omega(z_0) = e^{iH_0 z} e^{-iH(z-z_0)} e^{-iH_0 z_0}$$

$$\begin{cases} U(z, z_0) = 1 \\ \frac{d}{dz} U(z, z_0) = e^{iH_0 z} \underbrace{(H_0 - H)}_{-iH_I} e^{-iH(z-z_0)} e^{-iH_0 z_0} = \underbrace{e^{iH_0 z} e^{-iH(z-z_0)} e^{-iH_0 z_0}}_{U(z, z_0)} \end{cases}$$

$$U(t, t_0) = T \exp \left[ -i \int_{t_0}^t dt' H_I(t') \right]$$

$$\langle p_1, p_2 | p_A, p_B \rangle_0 = \sqrt{2E_1 2E_2 2E_A 2E_B} \langle 0 | a_1 a_2 a_A^{\dagger} a_B^{\dagger} | 0 \rangle$$

$$= 2E_A 2E_B (2\pi)^6 \left( \delta^3(p_A - p_1) \delta^3(p_B - p_2) + \delta^3(p_A - p_2) \delta^3(p_B - p_1) \right)$$

$$S = \mathbb{1} + iT$$



10

$$\langle P_1 P_2 | S | P_A P_B \rangle = \langle P_1 P_2 | T \left( -i\lambda \int d^4x \Phi_I^4(x) \right) | P_A P_B \rangle_0$$

$$= \langle P_1 P_2 | \mathcal{N} \left( -\frac{i\lambda}{4!} \int d^4x \Phi_I^4(x) + \text{Contractions} \right) | P_A P_B \rangle_0$$

$$\begin{aligned} \Phi_I^{\dagger}(x) |p\rangle_0 &= \int \frac{d^3k}{(2\pi)^3} \frac{1}{\sqrt{2E_k}} a_k e^{-ik \cdot x} \sqrt{2E_p} a_p^{\dagger} |0\rangle \\ &= \int \frac{d^3k}{(2\pi)^3} \frac{e^{-ik \cdot x}}{\sqrt{2E_k}} \sqrt{2E_p} (2\pi)^3 \delta^3(k-p) |0\rangle \end{aligned}$$

$$= e^{-ip \cdot x} |0\rangle$$

$$\overline{\Phi_I}(x) |p\rangle = e^{-ip \cdot x} |0\rangle$$

$$\langle p | \overline{\Phi_I}(x) = \langle 0 | e^{ip \cdot x}$$

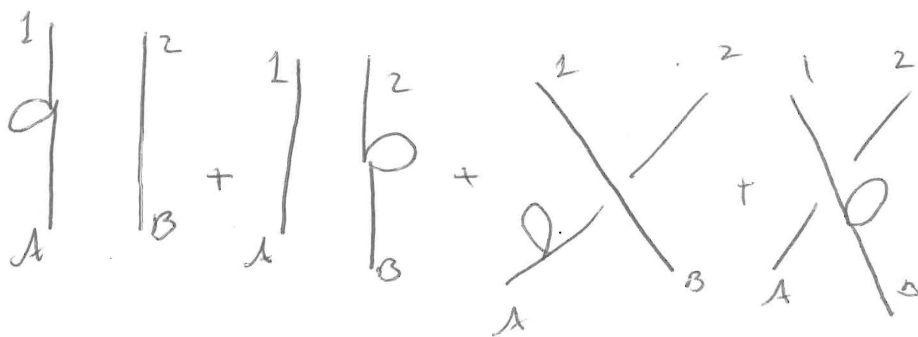
Contractions  $\rightarrow$  ماترِس

$$\overline{\varphi\varphi\varphi\varphi} \quad \overline{\varphi\varphi}\varphi\varphi \quad \overline{\varphi\varphi}\overline{\varphi\varphi}$$

$$-\frac{i\lambda}{4!} \int d^4x \langle P_1 P_2 | \overline{\varphi\varphi} \overline{\varphi\varphi} | P_A P_B \rangle_0$$

$$= 8 \times \left( \begin{array}{c} 1 \\ A \end{array} \begin{array}{c} 2 \\ B \end{array} + \begin{array}{c} 1 \\ A \end{array} \begin{array}{c} 2 \\ B \end{array} \right)$$

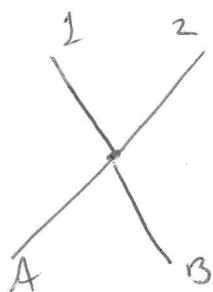
11



11

Only fully connected diagrams, in which all external lines are connected to each other contribute to the T-matrix.

$\varphi\varphi\varphi\varphi$



$$= 4! \frac{-i\lambda}{4!} \int d^4x e^{-i(P_1 + P_3 - P_2 - P_4) \cdot x}$$

$i\mathcal{M}(2\pi)^4$

$$\mathcal{M} = -\lambda$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{cm} = \frac{\lambda^2}{64\pi^2 E_{cm}^2}$$

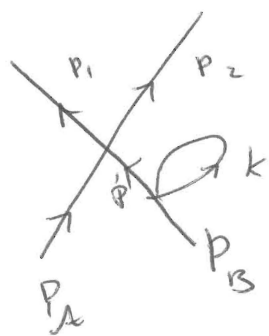
$\Downarrow$

$$\sigma_{tot} = \frac{\lambda^2}{32\pi E_{cm}^2} \quad \leftarrow \text{قبل !}$$

$$\langle P_1, P_2 | iT | P_A P_B \rangle = X + \text{diagram 1} + \text{diagram 2} + \dots$$

$$+ (X \text{ with } \text{diagram 3}) + \dots + (X \text{ with } \text{diagram 4}) + \dots$$

$$+ \text{diagram 5}$$



$$= \frac{1}{2} \int \frac{d^4 p'}{(2\pi)^4} \frac{i}{p'^2 - m^2} \int \frac{d^4 k}{(2\pi)^4} \frac{i}{k^2 - m^2}$$

$$\times (-i\lambda) (2\pi)^4 \delta^4(P_A + p' - P_1 - P_2)$$

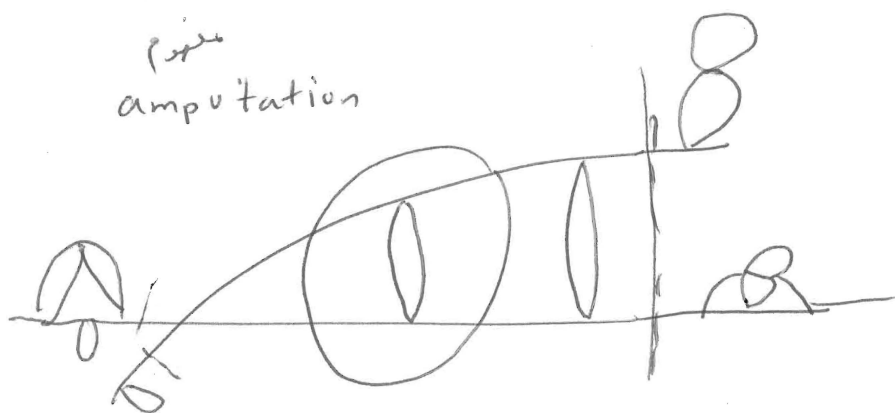
$$\times (-i\lambda) (2\pi)^4 \delta^4(P_B - p')$$

$$\frac{1}{p'^2 - m^2} \Big|_{p' = P_B} \frac{1}{p_B^2 - m^2} = \frac{1}{0}$$



$$|P\rangle \rightarrow |p\rangle$$

amputation



$$i\mathcal{M} (2\pi)^4 \delta^4(P_A + P_B - \sum P_f) = \left( \begin{array}{l} \text{Sum of all connected amputated} \\ \text{Feynman diagrams} \end{array} \right)$$

↑  
no vacuum bubbles

①   $P_F(x-y)$

②   $(-i\lambda) \int d^4x$

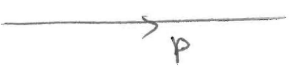
$e^{-ip \cdot x}$

نسبت با متغی  $\lambda$  متغی از جابجانه

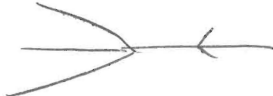
③   $P$

4 Divide by symmetry factor

### momentum space Feynman rules

  $\frac{i}{p^2 - m^2 + i\epsilon}$

  $= -i\lambda$

  $= 1$

= بقای تبار (تکانه زاویه ای جی ۰)

$$= \int \frac{d^4P}{(2\pi)^4}$$

تقسیم بر ضرب تبار

12

Feynman rule for Fermion

$$T(\psi(x) \bar{\psi}(y)) = \begin{cases} \psi(x) \bar{\psi}(y) & x^0 > y^0 \\ -\bar{\psi}(y) \psi(x) & x^0 < y^0 \end{cases}$$

Feynman propagator

$$S_F(x-y) = \int \frac{d^4 p}{(2\pi)^4} \frac{i(\not{p} + m)}{p^2 - m^2 + i\epsilon} e^{-ip \cdot (x-y)} = \langle 0 | T \psi(x) \bar{\psi}(y) | 0 \rangle$$

$$T(\psi_1 \psi_2 \psi_3 \psi_4) = (-1)^3 \psi_3 \psi_1 \psi_4 \psi_2 \quad \text{if } x_3^0 > x_1^0 > x_4^0 > x_2^0$$

$$N(a_p a_q a_r^\dagger) = (-1)^2 a_r^\dagger a_p a_q = (-1)^3 a_r^\dagger a_q a_p$$

$$T[\psi(x) \bar{\psi}(y)] = N[\psi(x) \bar{\psi}(y)] + \overbrace{\psi(x) \bar{\psi}(y)}$$

$$\overbrace{\psi(x) \bar{\psi}(y)} \triangleq \begin{cases} \{ \psi^\dagger(x), \bar{\psi}(y) \} & x^0 > y^0 \\ -\{ \bar{\psi}^\dagger(x), \psi(y) \} & x^0 < y^0 \end{cases} = S_F(x-y)$$

$$\overbrace{\psi(x) \psi(y)} = \overbrace{\bar{\psi}(x) \bar{\psi}(y)} = 0$$

$$N(\overbrace{\psi_1 \psi_2 \bar{\psi}_3 \bar{\psi}_4}) = -\overbrace{\psi_1 \bar{\psi}_3} N(\psi_2 \bar{\psi}_4) = -S_F(x_1 - x_3) N(\psi_2 \bar{\psi}_4)$$

Wick's theorem

$$T[\psi_1 \bar{\psi}_2 \psi_3 \dots] = N[\psi_1 \bar{\psi}_2 \psi_3 \dots + \text{all possible contractions}]$$

10

نظري بابا

$$H = H_{\text{Dirac}} + H_{\text{Klein-Gordon}} + \int d^3x \, g \bar{\Psi} \Psi \phi$$

$$f(p) + f(k) \rightarrow f(p^-) + f(k^-)$$

$$\langle p', k^- | T \left( \frac{1}{2!} (-ig) \int d^4x \bar{\Psi}_I \Psi_I \Phi_I \right) (-ig) \int d^4y \bar{\Psi}_I \Psi_I \Phi_I \right) | p, k \rangle$$

$$\langle \Psi_I | p, s \rangle = \int \frac{d^3p'}{(2\pi)^3} \frac{1}{\sqrt{2E_{p'}}} \sum_{s'=p'} a_{s'}^{s-} u^{s-}(p') e^{-ip' \cdot x} \sqrt{2E_p} a_p^{s+} | 0 \rangle$$

$$= e^{-ip \cdot x} u^s(p) | 0 \rangle$$

$$\langle p, s | \bar{\Psi}_I$$

$$\langle p', k^- | \frac{1}{2!} (-ig) \int d^4x \bar{\Psi} \Psi \phi (-ig) \int d^4y \bar{\Psi} \Psi \phi | p, k \rangle$$

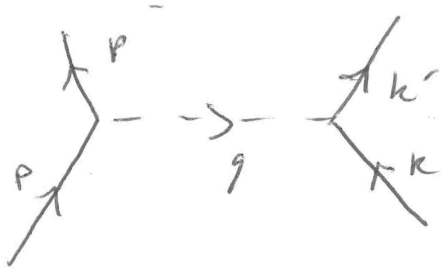
$$= (-ig)^2 \int \frac{d^4q}{(2\pi)^4} \frac{i}{q^2 - m_\phi^2} (2\pi)^4 \delta^4(p' - p + q)$$

$U_p$  to a minus sign

$$\times (2\pi)^4 \delta^4(k - k - q) \bar{u}(p') u(p) \bar{u}(k) u(k)$$

$$\frac{1}{2!} \rightarrow i\mathcal{M}$$

$$i\mathcal{M} = \frac{-ig^2}{q^2 - m_\phi^2} \bar{u}(p') u(p) \bar{u}(k) u(k)$$



### ① propagators

$$\overline{\Phi(x)} \Phi(y) = \text{---} \xrightarrow{q} \text{---} = \frac{i}{q^2 - m_\phi^2 + i\epsilon}$$

$$\overline{\Psi(x)} \Psi(y) = \text{---} \xrightarrow{p} \text{---} = \frac{i(\not{p} + m)}{p^2 - m^2 + i\epsilon}$$

### ② $\psi$

$$\text{---} \text{---} \text{---} = -ig$$

### ③

$$\overline{\Phi(12)} \text{---} \xrightarrow{q} \text{---} = 1$$

$$\langle q | \Phi = - \text{---} \text{---} \text{---}$$

$$\overline{\Psi} |p, s\rangle = \text{---} \text{---} \text{---} = u^s(p) \quad \langle p, s | \overline{\Psi} = \text{---} \text{---} \text{---} = \bar{u}^s(p)$$

$$\overline{\Phi} |k, s\rangle = \text{---} \text{---} \text{---} = \bar{v}^s(k) \quad \langle k, s | \Psi = \text{---} \text{---} \text{---} = v^s(k)$$

- عکس - ۳ - انداز - بقای تکانه

IV

کتابت دوس، سکتی ہو  
 $\frac{1}{n!}$   $n!$

no symmetry factor for Yukawa  $\phi \psi$

particle number flow

دوس، سکتی ہو



$$\sim \bar{u}(p_3) \frac{i(\not{p}_2 + m)}{p_2^2 - m^2}$$

$$\frac{i(\not{p}_1 + m)}{p_1^2 - m^2} u(p_0)$$

Sign convention

علامت سنی

$$|p, k\rangle \approx a_p^\dagger a_k^\dagger |0\rangle$$

$$\langle p', k' | a_k a_{p'}$$

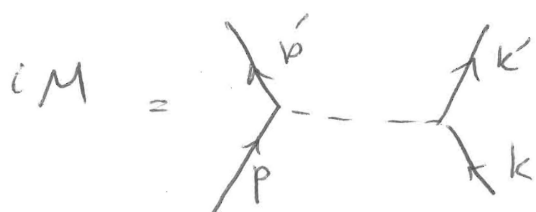
$$\langle p', k' | (\bar{\psi}\psi)_x (\bar{\psi}\psi)_y | p, k \rangle \sim \langle 0 | a_k a_{p'} \bar{\psi}_x \psi_x \bar{\psi}_y \psi_y a_p^\dagger a_k^\dagger | 0 \rangle$$

$\Rightarrow (-1)^2 = 1$

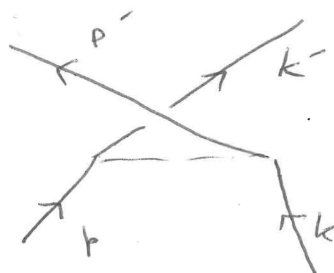
$$\langle p', k' | (\bar{\psi}\psi)_x (\bar{\psi}\psi)_y | p, k \rangle$$

(-1)

17



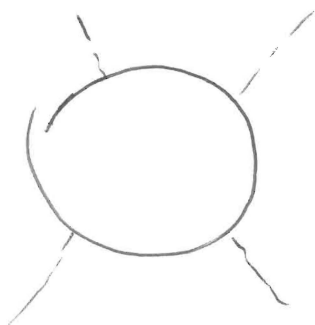
+



$$= (-ig)^2 \left( \bar{u}(p') u(p) \frac{1}{(p' - p)^2 - m_\phi^2} \bar{u}(k') u(k) \right.$$

$$\left. - \bar{u}(p') u(k) \frac{1}{(p' - k)^2 - m_\phi^2} \bar{u}(k') u(p) \right)$$

$\overbrace{\psi \psi}^{\text{commutes}}$



$$\begin{aligned} & \overbrace{\psi \psi \psi \psi \psi \psi} \\ &= (-1) \text{tr} [\overbrace{\psi \psi \psi \psi} \overbrace{\psi \psi \psi \psi}] \\ &= (-1) \text{tr} (S_F S_F S_F S_F) \end{aligned}$$

فیسین ہوا!