EFT & Beyond

"四方山話"

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Lec I

QFT: Quantum Field Theory

Very successful!

<u>the</u> framework in High Energy Physics

& Physics in General

What? Why? How? ......

"Principle" in QFT

- Poincaré sym. > translation / rotational sym.
  Lorentz sym.

  (Spacetime sym.)

  (internal sym.)
  - Global sym.
  - Gauge sym. "emergent"

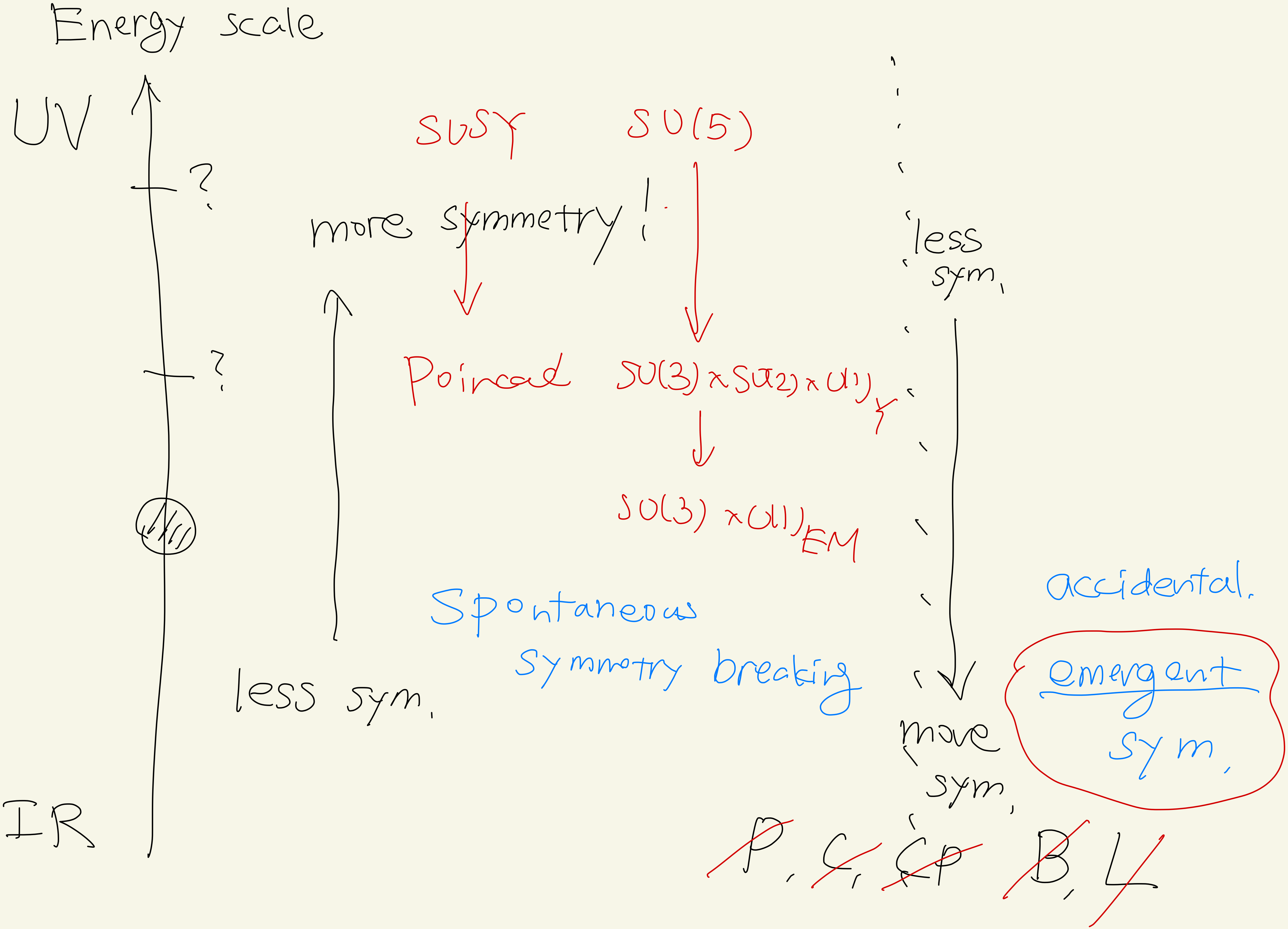
- locality ← cluster decomposition
- unitarity
- causality

(- perturbativity) $\frac{g^2}{4\pi} \ll 1$

⋮

$a, a^\dagger$

→ Effective QFT (EFT)



Energy scale
UV
IR
?
?
more symmetry!
SUSY
SU(5)
Poincaré
SU(3)×SU(2)×U(1)$_Y$
SU(3)×U(1)$_{EM}$
less sym.
Spontaneous symmetry breaking
less sym.
more sym.
accidental.
emergent sym.
P, C, CP, B, L

(Pure) YM

$$A(x) \mapsto g^{-1} A g + g^{-1} dg$$

gauge transf.

Wilson line : gauge-inv. object.

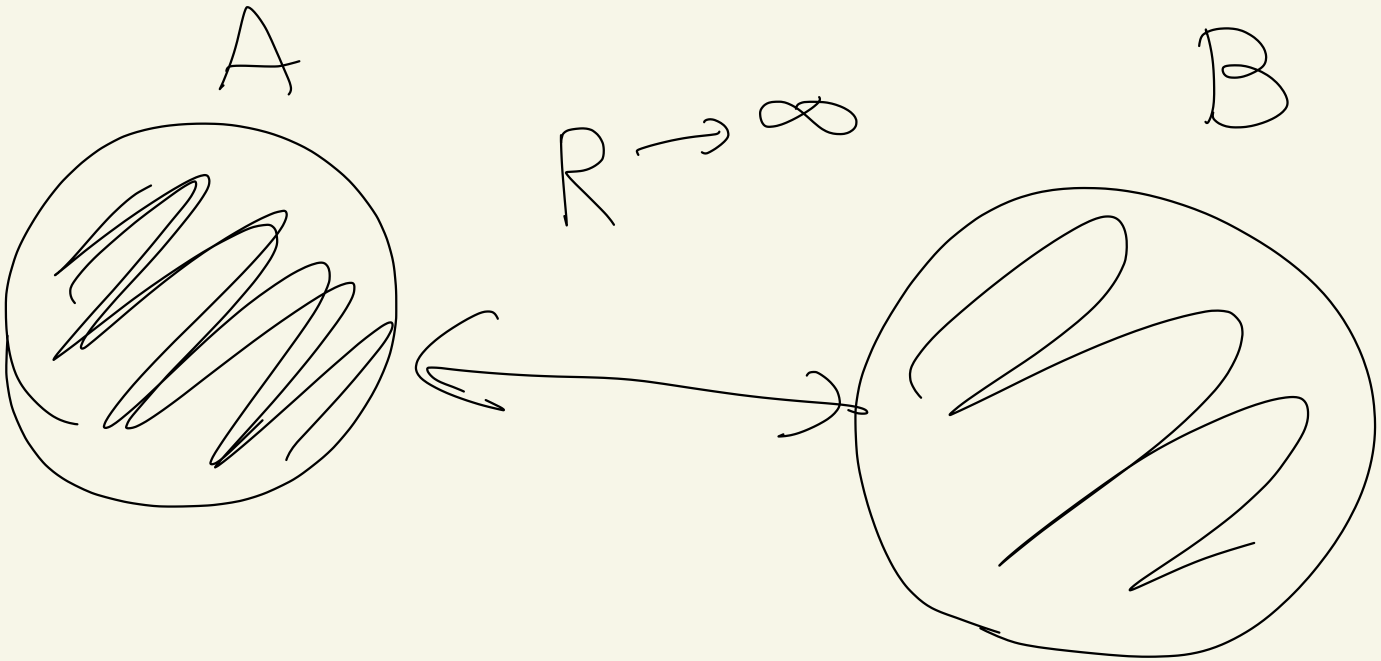
$$W_\gamma = \mathrm{Tr}_R \left(P \exp \int_\gamma A(x) \right)$$

path-order

line path

non-local

$\{\gamma \ni x\}$



$$\langle 0 | O_A(R)\, O_B(0) | 0 \rangle \xrightarrow[R\to\infty]{} \langle 0 | O_A | 0 \rangle \langle 0 | O_B | 0 \rangle$$

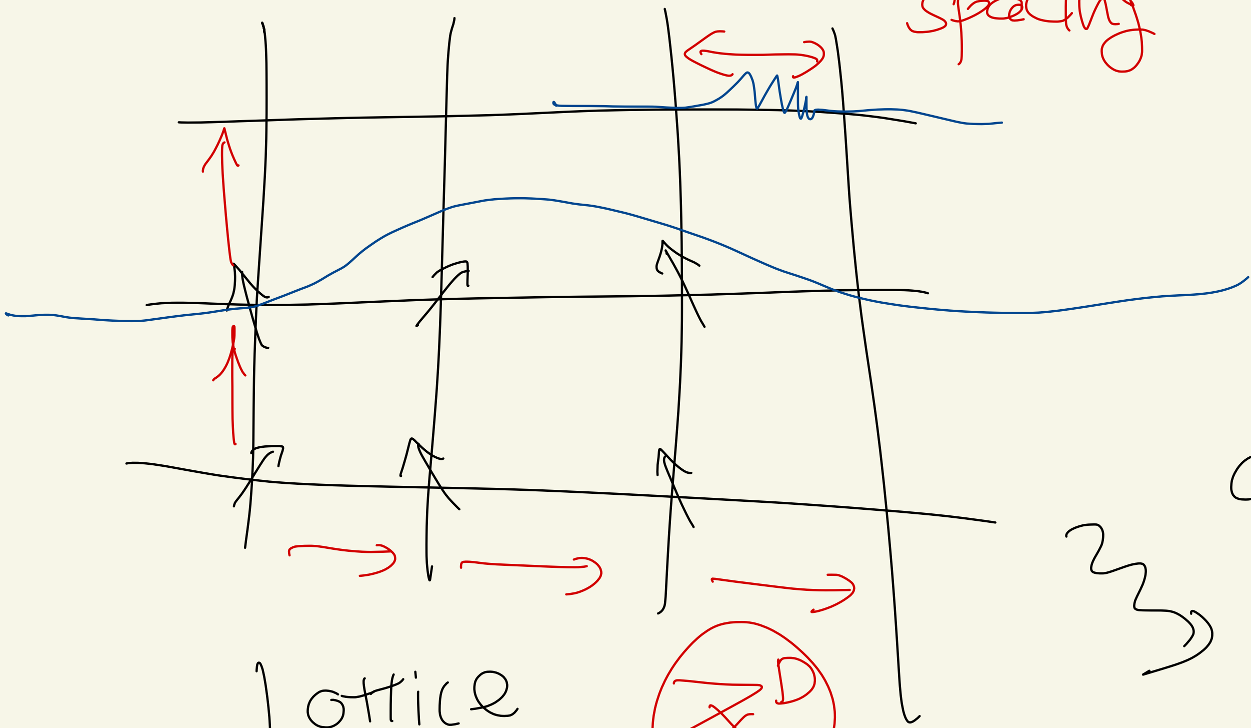
(cluster decomposition)

a : lattice spacing

$\phi(x)$ $\quad x \in \mathbb{R}^{3,1}$

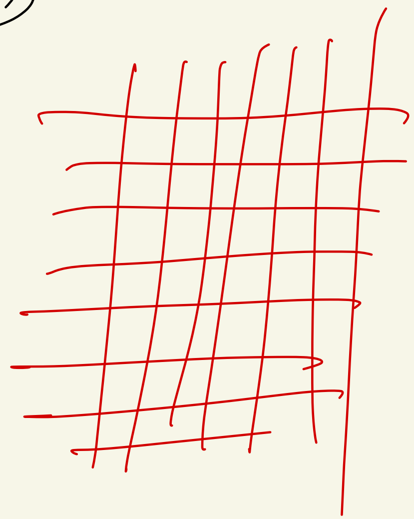
$SO(3,1)$

$SO(4)$



lattice $\quad \mathbb{Z}^D$

$\rightsquigarrow$ continuum limit



QFT

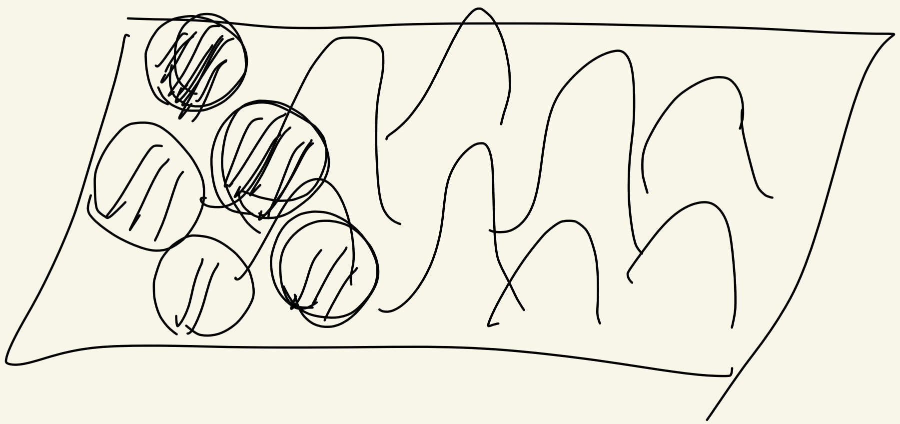
$\rightsquigarrow$

Lorentz

a : UV cutoff.

$E > a^{-1}$: neglected

$a^{-1} = \Lambda_{UV}$



Poincaré sym: emergent?

Spacetime emergent?

UV

separation of energy scale

Λ_{UV} : UV cutoff.

"IR"

energy scale

EFT.

Λ_{IR} : IR cutoff. ⟸ "Asking the right question"

$$\mathcal{L} = \mathcal{L}_0 + \sum_n c_n \mathcal{O}_n$$

finite parameter

(renormalizable
relevant / marginal

∞ parameter

higher-dim. operator,

$\Lambda_{UV}^{|\dim \mathcal{O}_n| - 4}$

D

irrelevant

UV physics

"decoupling"

Decoupling Theorem

Gauge Sym.

massive

$$\mathcal{L} = \frac{1}{4e^2} F^a_{\mu\nu} F^{\mu\nu a} + \bar{\Psi}(i\not{D} - M)\Psi$$

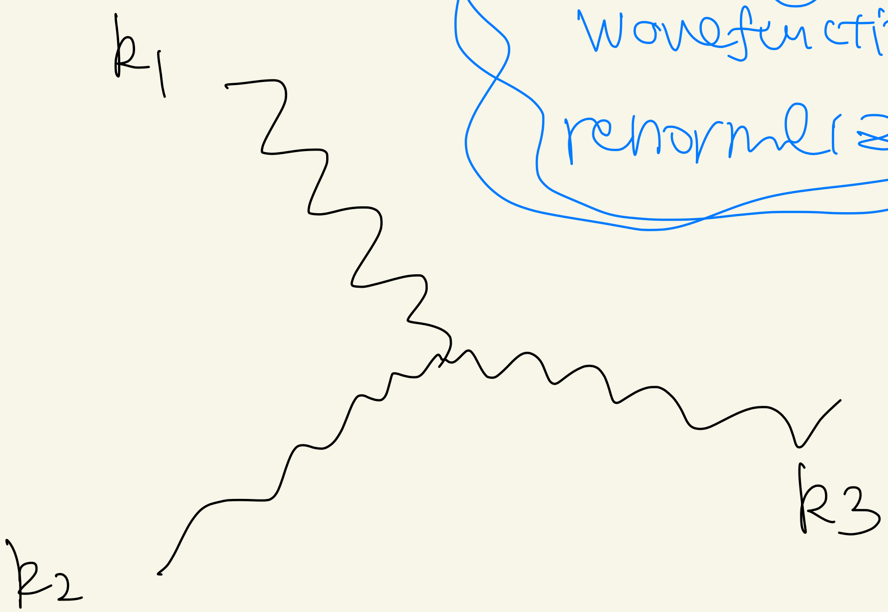
YM

YM + Fermion

heavy

- Coupling wavefunction renormalization

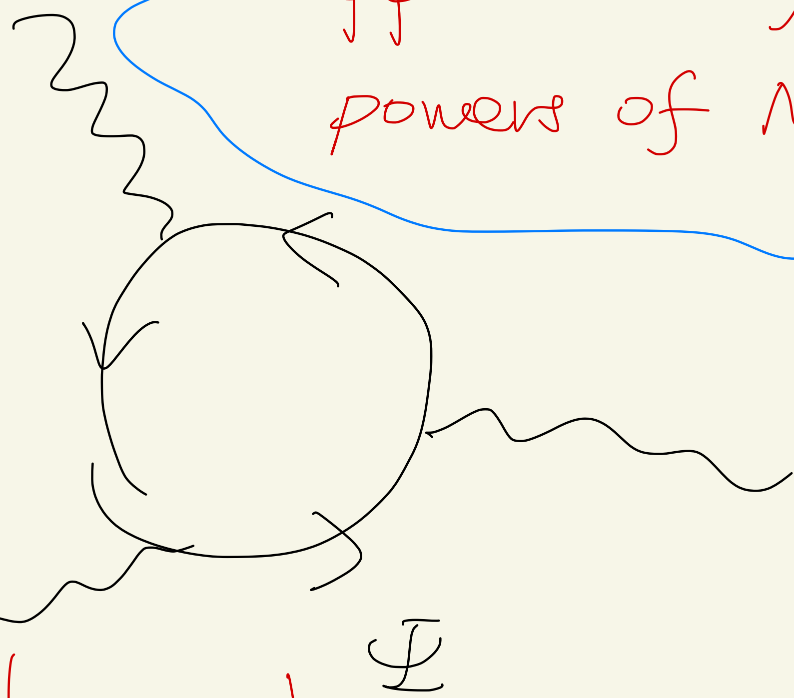
- Suppressed by powers of M



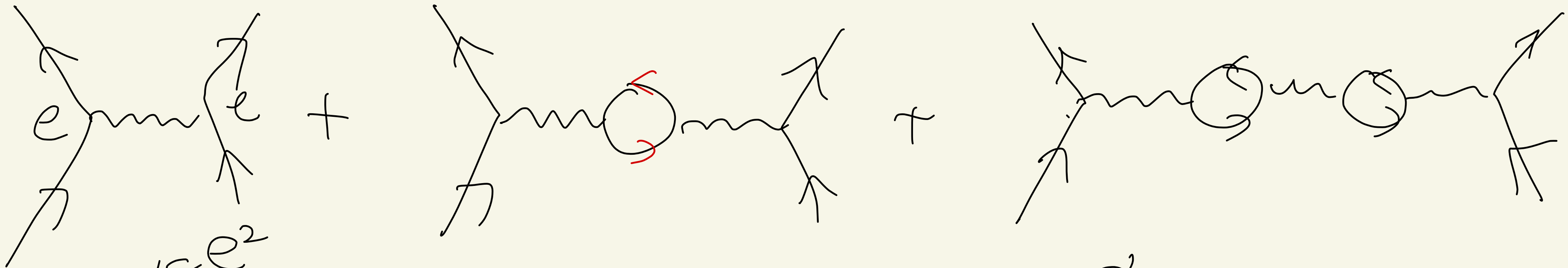
tree

$|k_i| \ll M$

v.s.

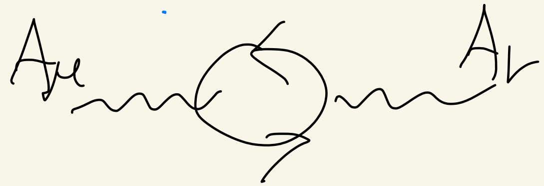


$$\frac{1}{p^2 - M^2} \sim \frac{1}{M^2}$$



$$\alpha = e^2$$

$$\frac{\alpha}{k^2} + \frac{\alpha}{k^2}\,\alpha\Pi\,\frac{1}{k^2} + \frac{\alpha}{k}\,\alpha\Pi\,\frac{1}{k^2}\,\alpha\Pi\,\frac{1}{k^2}$$

$$\Pi^{\mu\nu} =$$ 

$$\frac{\alpha}{k^2}\,\frac{1}{\left(1 - \frac{\alpha\Pi}{k^2}\right)} \qquad \frac{\Pi}{k^2} = \tilde{\Pi}$$

$$= \left(g^{\mu\nu} - \frac{k^\mu k^\nu}{k^2}\right)\Pi(k), \qquad \Pi \to k^2\,\tilde{\Pi}(k^2)$$

$$= \frac{1}{k^2\left(\frac{1}{\alpha} - \tilde{\Pi}(0) - \left(\tilde{\Pi}(k) - \tilde{\Pi}(0)\right)\right)}$$

$\frac{1}{\alpha} - \tilde{\Pi}(0) = 1/\alpha_{eff}$

$\tilde{\Pi}(k) - \tilde{\Pi}(0) \Rightarrow k^2\,\tilde{\tilde{\Pi}} + O(k^4) + \ldots$

$\tilde{\tilde{\Pi}} \sim 1/M^2$