

Title: Intro to Supersymmetry 14

Date: Nov 01, 2007 12:30 PM

URL: <http://pirsa.org/07110010>

Abstract:

→ See is a Legendre transform writ a source.

→ Since it's a Legendre transform wrt a source
of a generating functional
for the connected corr. functions

$$iW[J] = \ln Z[J]$$

⇒ S_{eff} is a Legendre transform w.r.t a source of a generating functional for the connected corr. functions

$$W[J] = \ln Z[J]$$

$$S_{\text{eff}}(\hat{\phi}) = W[J] - \int d^4x J(x) \hat{\phi}(x)$$

⇒ S_{eff} is a Legendre transform w.r.t a source of a generating functional for the connected corr. functions

$$W[J] = \ln Z[J]$$

$$S_{\text{eff}}(\hat{\phi}) = W[J] - \int dx J(x) \hat{\phi}(x)$$

$$\hat{\phi}(x) = \frac{\delta W[J]}{\delta J(x)}$$

→ $S_{\text{eff}}(\varphi)$

derivative

approximation

→

$$S_{\text{eff}}(\Phi)$$

derivative
approximation

$$\int d^4x [-V_{\text{eff}}(\Phi)]$$

→ $S_{\text{eff}}(\vec{\varphi})$

derivative
approximation

$$\int d^4x \left[-V_{\text{eff}}(\vec{\varphi}) - \frac{1}{2} (\partial\vec{\varphi})^2 \right] Z(\vec{\varphi}) +$$

→ $S_{\text{eff}}(\vec{\varphi})$

derivative
approximation

$$\int d^4x \left[-V_{\text{eff}}(\vec{\varphi}) - \frac{1}{2} (\partial\vec{\varphi})^2 Z(\vec{\varphi}) + \dots \right]$$

$\rightarrow S_{\text{eff}}(\phi) \stackrel{\text{derivative approximation}}{=} \int d^4x \left[-V_{\text{eff}}(\phi) - \frac{1}{2} (\partial\phi)^2 \right] Z(\phi)$

\rightarrow we do not quantize eff actions.

$$\rightarrow S_{\text{eff}}(\vec{p}) \stackrel{\substack{= \\ \uparrow \\ \text{derivative} \\ \text{approximation}}}{=} \int d^4x \left[-V_{\text{eff}}(\vec{p}) - \frac{1}{2} (\partial \vec{p})^2 Z(\vec{p}) \right]$$

→ we do not quantize eff actions.

⇒ Remember in QFT, observables are time-ordered correlation functions.

$V_{\text{eff}}(\hat{\Phi}) =$
↖
Zinn-Justin
book

$$V_{\text{eff}}(\hat{\Phi}) = -$$

Zinn-Juskis
book

$$V_{\text{eff}}(\hat{\varphi}) =$$

Zinn-Jackiw
book

$$- \sum_{n=0}^{\infty} \frac{1}{5^n}$$

$$[\hat{\varphi}(x)]^n$$

$$V_{\text{eff}}(\hat{\varphi}) = -$$

Zinn-Jasthi
book

$$\sum_{n=0}^{\infty} \frac{1}{n!} \langle \hat{\varphi}^n \rangle$$

$$[\hat{\varphi}(x)]^n$$

$$V_{\text{eff}}(\hat{\varphi}) = - \sum_{n=0}^{\infty} \frac{1}{n!} V^{(n)}(\underbrace{0,0,0,0}_{n \text{ zeros}}) [\hat{\varphi}(x)]^n$$

Zinn-Jasthi
book

$$V_{\text{eff}}(\hat{\varphi}) = - \sum_{n=0}^{\infty} \frac{1}{n!} \Gamma^{(n)}(\underbrace{0,0,0,0}_{n \text{ zeros}}) [\hat{\varphi}(x)]^n$$

Zinn-Jacobson
book

$\Gamma^{(n)}$ are the computed correlation functions
of our QFT at zero momenta.

$$\underline{V_{\text{eff}}(\hat{\varphi})}$$

$$=$$

-

$$\sum_{n=0}^{\infty} \frac{1}{n!}$$

$$I_{\Gamma}^{(n)}$$

$$\left(\underbrace{0, 0, 0, 0}_{n\text{-terms}} \right)$$

[

Zinn-Justin
book

$\Gamma^{(n)}$ are the computed correlation functions of our QFT at zero momentum

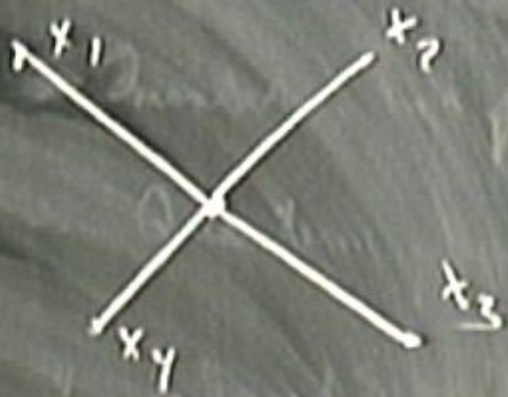
$$\underline{V_{\text{eff}}(\hat{\varphi})} = - \sum_{n=0}^{\infty} \frac{1}{n!} \Gamma^{(n)}(\underbrace{0,0,0,0}_{n\text{-zeros}}) [\hat{\varphi}(x)]^n$$

Zinn-Jacob
book

$\Gamma^{(n)}$ are the amputated correlation functions
of our QFT at zero momenta.

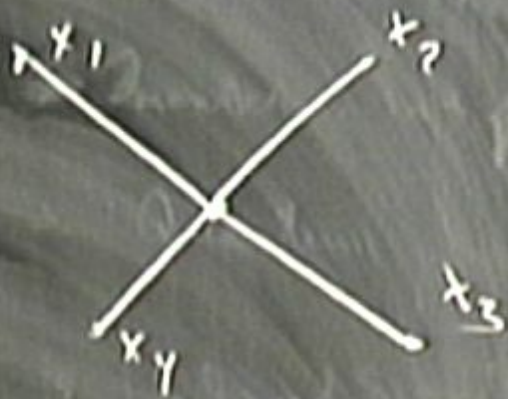
$$\langle (P(x), Q(x)) \rangle = G^{(2)}(x)$$

$$\langle T(\rho(x), \rho(0)) \rangle = G^{(0)}(x)$$



$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\rho(x_1) \cdot \rho(x_2)) \rangle$$

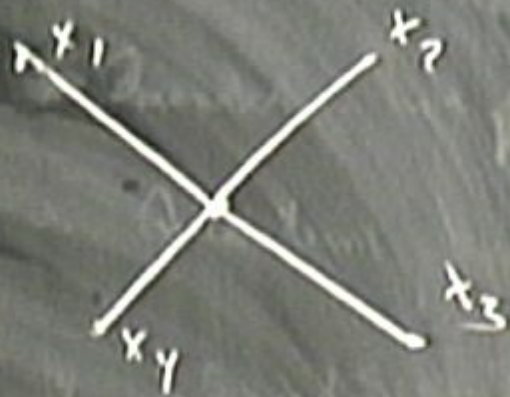
$$\langle T(\rho(x), \rho(0)) \rangle = G^{(0)}(x)$$



$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\rho(x_1) \cdot \rho(x_2)) \rangle$$

$$P^{(4)}(x_1, \dots, x_n) =$$

$$\langle T(\varphi(x), \varphi(0)) \rangle = G^{(2)}(x)$$



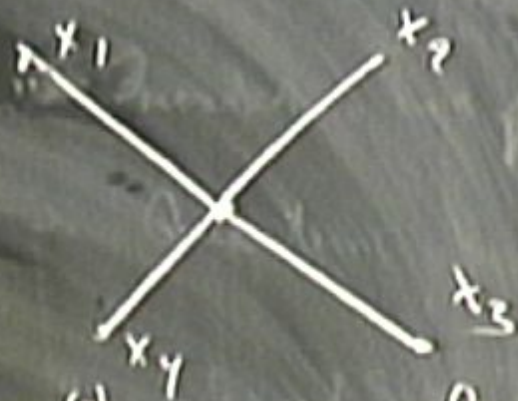
$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\varphi(x_1) \cdot \varphi(x_2)) \cdot \varphi(x_3) \cdot \varphi(x_4) \rangle$$

$$P^{(4)}(x_1, \dots, x_n) = \frac{G^{(4)}(x_1, \dots, x_n)}{\prod \text{propagators}(x_i \rightarrow x_j)}$$

$$P(x_1, x_2, x_3, x_4) = \langle T(P_1(x_1) \cdots P_n(x_n)) \rangle$$

$$P(x_1, \dots, x_n) = \frac{G^{(n)}(x_1, \dots, x_n)}{\prod \text{propagators}(x_i, x_j)}$$

$$\langle T(\dots, \varphi(0)) \rangle = G^{(0)}(x)$$

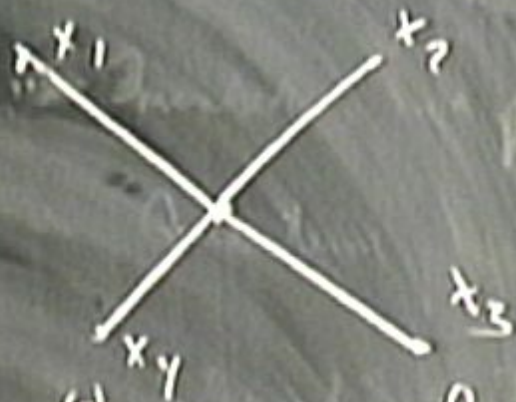


$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\varphi(x_1) \cdot \varphi(x_2)) \rangle$$

$$P^{(4)}(x_1, \dots, x_n) = G^{(4)}(x_1, \dots, x_n)$$

$$G^{(2)}(k_1, \dots, k_n) = \int \frac{Dd^4 x_i}{(2\pi)^4} e^{+ik_i x_i} \prod \text{propagators}(x_i - x_j)$$

$$\langle T(\varphi(x), \varphi(0)) \rangle = G^{(2)}(x)$$

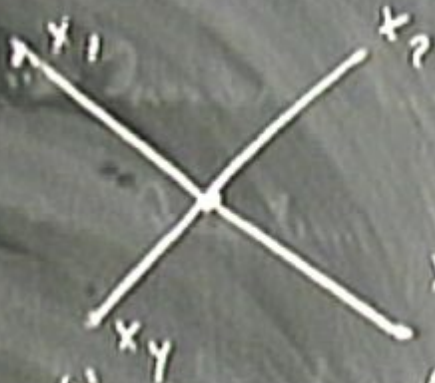


$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\varphi(x_1) \cdot \varphi(x_2)) \cdot \varphi(x_3) \cdot \varphi(x_4) \rangle$$

$$P^{(4)}(x_1, \dots, x_n) = \frac{G^{(4)}(x_1, \dots, x_n)}{\prod \text{propagators}(x_i, x_j)}$$

$$G^{(2)}(k_1, \dots, k_n) = \int \frac{D^4 x_i}{(2\pi)^4} e^{+ik_i x_i} G^{(n)}(x_1, \dots, x_n)$$

$$\langle T(\varphi(x), \varphi(0)) \rangle = G^{(2)}(x)$$



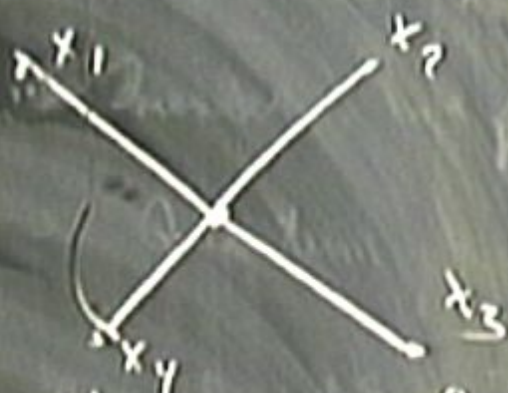
$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\varphi(x_1) \cdot \varphi(x_2)) \cdot \varphi(x_3) \cdot \varphi(x_4) \rangle$$

$$P^{(4)}(x_1, \dots, x_4) = \frac{G^{(4)}(x_1, \dots, x_4)}{\prod \text{propagators}(x_i \rightarrow x_j)}$$

$$G^{(2)}(k_1, \dots, k_2) = \int \frac{D^4 x_i}{(2\pi)^4} e^{+ik_i x_i} G^{(2)}(x_1, \dots, x_2)$$

$$2\pi \int_{k_1}^{k_2} \delta(k_1 + \dots + k_n) \mathcal{G}(k_1, \dots, k_n) = \int \dots$$

$$\langle T(\varphi(x), \varphi(0)) \rangle = G^{(0)}(x)$$



$$G^{(4)}(x_1, x_2, x_3, x_4) = \langle T(\varphi(x_1) \cdot \varphi(x_2)) \rangle$$

$$P^{(4)}(x_1, \dots, x_n) = \frac{G^{(4)}(x_1, \dots, x_n)}{\prod \text{propagators}(x_i \rightarrow x_j)}$$

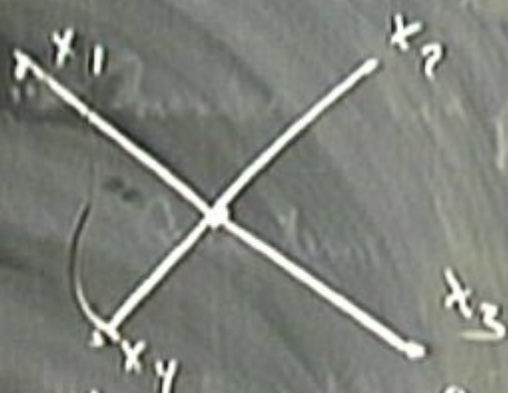
$$Z \int d^4x_i \delta(x_i) G^{(n)}(k_1, \dots, k_n) = \int \frac{D^4x_i}{(2\pi)^4} e^{+i k_i x_i} G^{(n)}(x_1, \dots, x_n)$$

$$P^{(4)}(k_1, \dots, k_n) =$$

$$\frac{1}{P_i + m^2}$$

$$\hat{\varphi}(x) = \frac{\delta W[J]}{\delta J(x)}$$

$$\langle T(\varphi(x), \varphi(0)) \rangle = G^{(0)}(x)$$



$$G^{(2)}(x_1, x_2, x_3, x_4) = \langle T(\varphi(x_1) \cdot \varphi(x_2)) \rangle$$

$$P^{(4)}(x_1, \dots, x_4) = \frac{G^{(4)}(x_1, \dots, x_4)}{\prod \text{propagators}(x_i \rightarrow x_j)}$$

$$Z \int d^4x_i e^{i \int d^4x_i \mathcal{L}(x_i)} G^{(n)}(k_1, \dots, k_n) = \int \frac{D^4x_i}{(2\pi)^4} e^{i \int d^4x_i \mathcal{L}(x_i)}$$

$$G^{(n)}(x_1, \dots, x_n)$$

$$\frac{1}{p^2 + m^2} = \Delta_i$$

$$P^{(4)}(k_1, \dots, k_4) =$$

$$\hat{\varphi}(x) = \frac{\delta W[J]}{\delta J(x)}$$

$\int dx_1 \dots dx_n$

$$G^{(n)}(k_1, \dots, k_n) = \int \prod d^4 x_i \frac{e^{i \sum k_i x_i}}{(2\pi)^n} G^{(n)}(x_1, \dots, x_n)$$

$$\Rightarrow G^{(n)}(k_1, \dots, k_n) = \prod \Delta(k_i)$$

$$\hat{\varphi}(x) = \frac{\delta W[J]}{\delta J(x)}$$

$$\begin{aligned}
 & \mathcal{P}^{(n)}(x_1, \dots, x_n) = \frac{e^{i\phi}}{\prod \text{propagators}} \\
 & \mathcal{G}^{(n)}(k_1, \dots, k_n) = \int \frac{D^4 x_i}{(2\pi)^4} e^{+i k_i x_i} \mathcal{G}^{(n)}(x_1, \dots, x_n) \\
 & \mathcal{F}^{(n)}(k_1, \dots, k_n) = \Delta(k_i)
 \end{aligned}$$



$$\chi = \frac{\delta W[\chi]}{\delta J(x)}$$

Order by order in perturbation theory.

$$V = \underline{u^2}$$

Order by order in perturbation theory.

$$V = \frac{m^2}{2!} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

Order by order in perturbation theory.

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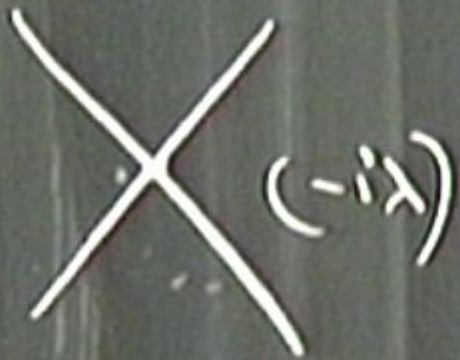
Order by order in perturbation theory.

$$V_{\text{class}} = \frac{m^2}{2!} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

~~$(-i\lambda)$~~

Order by order in perturbation theory.

$$V_{\text{class}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$

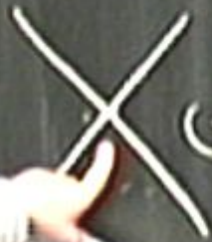


+ loop correction



Order by order in perturbation theory.

$$V_{\text{cl.}} = \frac{m^2}{2!} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$



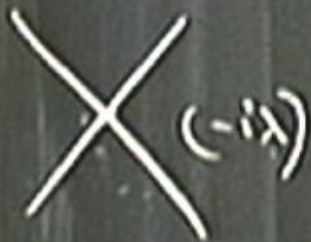
$(-i\lambda)$

+ loop correction

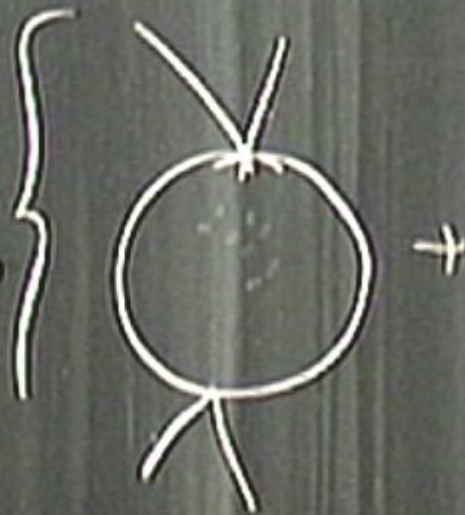


Order by order in perturbation theory.

$$V_{\text{class}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$

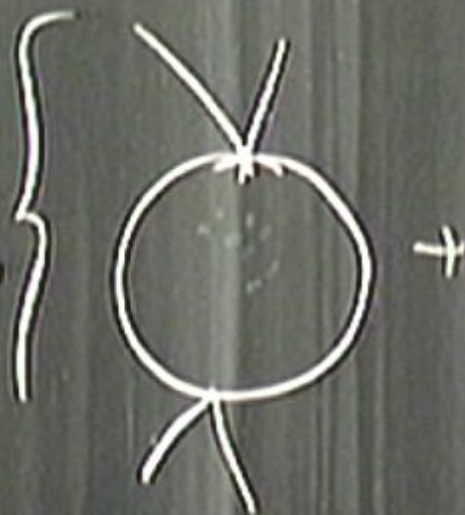
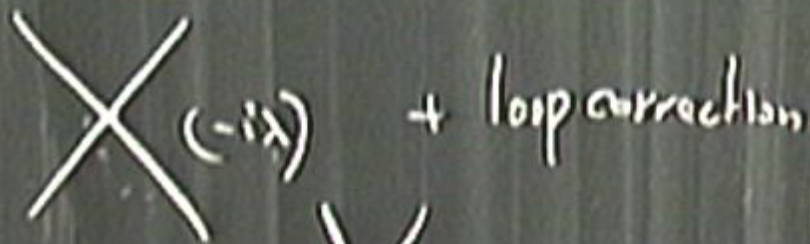


+ loop correction



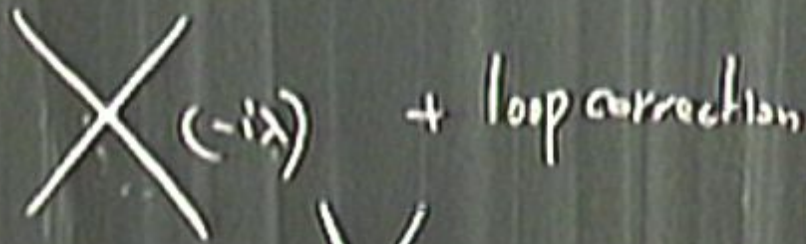
Order by order in perturbation theory.

$$V_{\text{class}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$

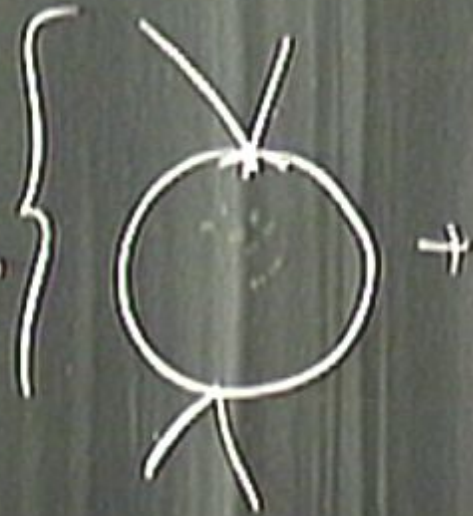


Order by order in perturbation theory.

$$V_{\text{class}} = \frac{m^2}{2!} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

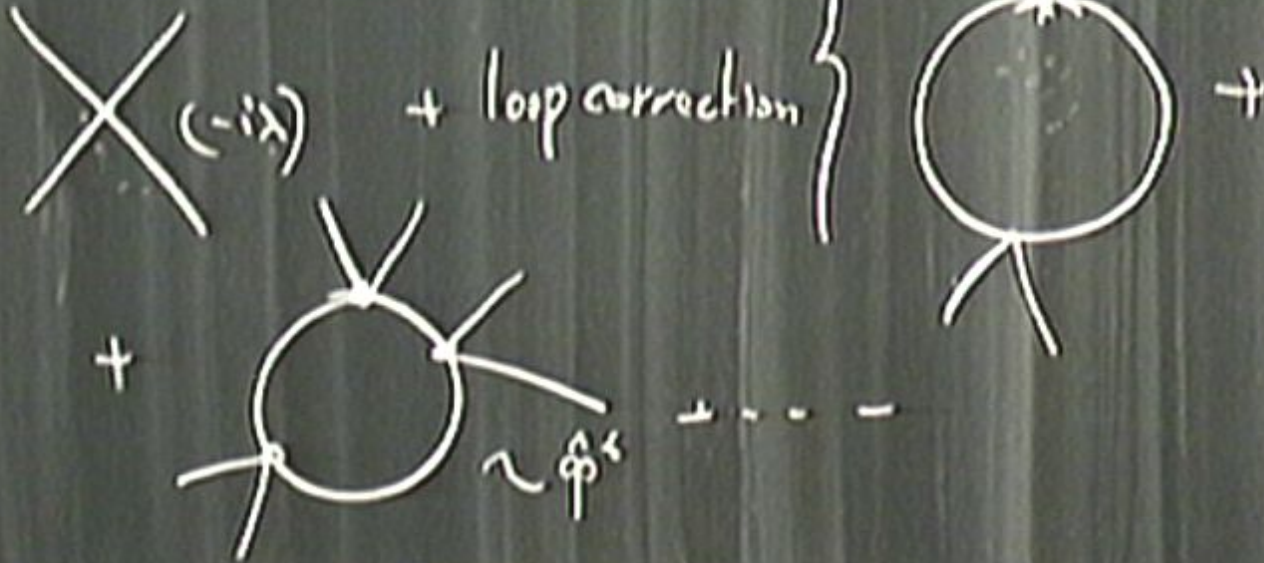


+



Order by order in perturbation theory.

$$V_{\text{cl.}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$



$$\underline{V_{eff}(\hat{\phi})} = - \sum_{n=0}^{\infty} \frac{1}{n!} \underbrace{V^{(n)}(0,0,0)}_{n=0 \text{ order}} [\hat{\phi}(x)]^n$$

is complete

Zinn-Jacob
book

$n(n)$ are the computed correlation
of our QFT at zero

$$\underline{V_{eff}(\hat{\phi})} = - \sum_{n=0}^{\infty} \frac{1}{n!} \underbrace{\Gamma^{(n)}(0,0,0)}_{n=0} [\hat{\phi}(x)]^n$$

is computed to 1-loop order

Zinn-Justin
book

$\Gamma^{(n)}$ are the computed correlation functions
of our QFT at zero momenta.

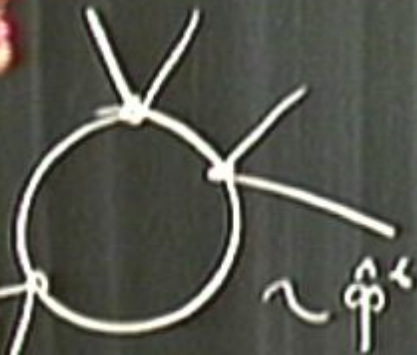
Order by order in perturbation theory.

Coleman-Weinberg

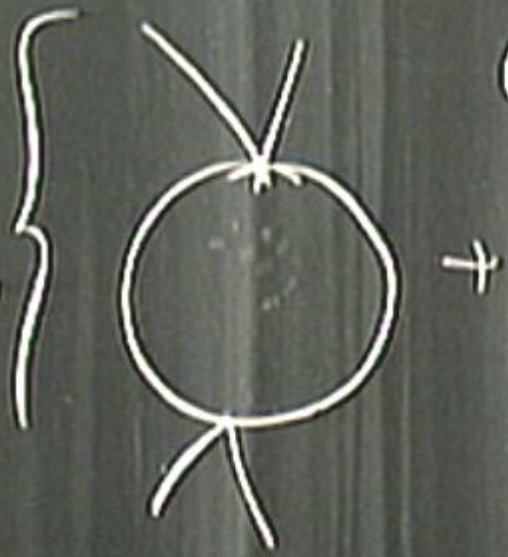
$$V_{\text{class}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$

Cheng-Li

+ loop correction



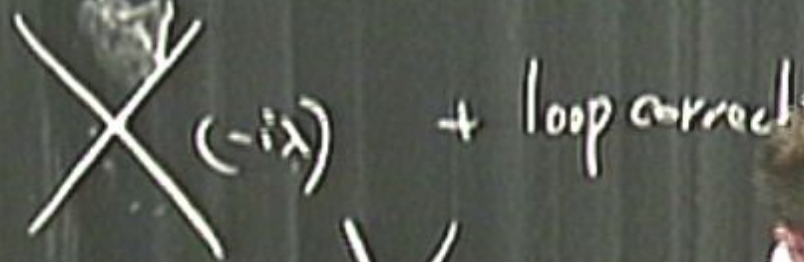
→ - - - -



Order by order in perturbation theory.

Coleman-Weinberg

$$V_{\text{class}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$



Cheng-Li
Zinn-Justin

$$V_{eff} = \frac{1}{2} m \dot{\varphi}^2$$

$$\hat{p} = p$$

$$V_{\text{eff}} = \frac{1}{2} m^2 \phi^2 + \frac{\lambda}{4!} \phi^4$$

$$\dot{p} = \dot{\varphi}$$

$$V_{eff} = \frac{1}{2} m^2 \varphi^2 + \frac{\lambda}{4!} \varphi^4 +$$

$$+ \frac{m_{eff}^4(\varphi)}{64\pi^2} \left[\hbar \frac{m_{eff}^2(\varphi)}{m^2} + \dots \right]$$

$$\dot{\varphi} = \varphi$$

$$V_{\text{eff}} = \frac{1}{2} m^2 \varphi^2 + \frac{\lambda}{4!} \varphi^4 +$$

$$+ \frac{m_{\text{eff}}^4(\varphi)}{64\pi^2} \left[\ln \frac{m_{\text{eff}}^2(\varphi)}{m^2} + \dots \right]$$

$$m_{\text{eff}}^2(\varphi) = m^2 + \frac{\lambda}{2} \varphi^2$$

$$\rightarrow S_{\text{eff}}(\hat{\varphi}) = \int d^4x \left[-V_{\text{eff}}(\hat{\varphi}) - \frac{1}{2}(\partial\hat{\varphi})^2 \right]$$

$$\hat{\varphi} = \varphi$$

$$V_{\text{eff}} = \frac{1}{2} m^2 \varphi^2 + \frac{\lambda}{4!} \varphi^4 +$$

$$+ \frac{m_{\text{eff}}^4(\varphi)}{64\pi^2} \left[\hbar \frac{m_{\text{eff}}^2(\varphi)}{m^2} + \dots \right]$$

$$m_{\text{eff}}^2(\varphi) = m^2 + \frac{\lambda}{2} \varphi^2$$

arbitrarily
scale m

$$\rightarrow S_{\text{eff}}(\varphi) = \int d^4x \left[-V_{\text{eff}}(\varphi) - \frac{1}{2}(\partial\varphi)^2 \right] \mathcal{L}(\varphi)$$

$$\dot{\varphi} = \varphi$$

$$V_{\text{eff}} = \frac{1}{2} m^2 \varphi^2 + \frac{\lambda}{4!} \varphi^4 +$$

$$+ \frac{m_{\text{eff}}^4(\varphi)}{64\pi^2} \left[\hbar \frac{m_{\text{eff}}^2(\varphi)}{m^2} + \dots \right]$$

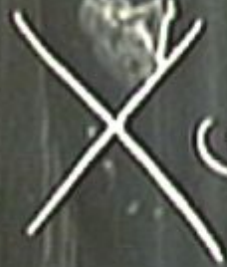
$$m_{\text{eff}}^2(\varphi) = m^2 + \frac{\lambda}{2} \varphi^2$$

arbitrarily
scale m

Order by order in perturbation theory.

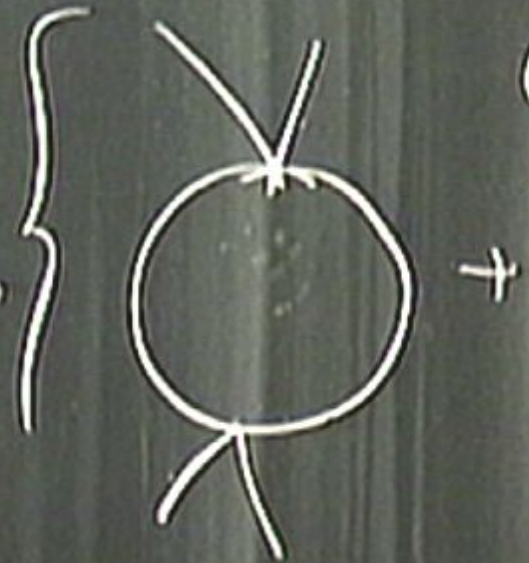
Coleman

$$V_{\text{class}} = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$



$(-i\lambda)$

+ loop correction



+



+

$$\rightarrow S_{\text{eff}}(\hat{\varphi}) = \int d^4x \left[-V_{\text{eff}}(\hat{\varphi}) - \frac{1}{2} (\partial \hat{\varphi})^2 \right]$$

$$\hat{\varphi} = \varphi$$

$$V_{\text{eff}} = \frac{1}{2} m^2 \varphi^2 + \frac{\lambda}{4!} \varphi^4 +$$

$$+ \frac{m_{\text{eff}}^4(\varphi)}{64\pi^2} \left[\ln \frac{m_{\text{eff}}^2(\varphi)}{m^2} + \dots \right]$$

$$m_{\text{eff}}^2(\varphi) = m^2 + \frac{\lambda}{2} \varphi^2$$



$$V_{\text{eff}} = \frac{1}{2} m^2 \varphi^2 + \frac{\lambda}{4!} \varphi^4 +$$

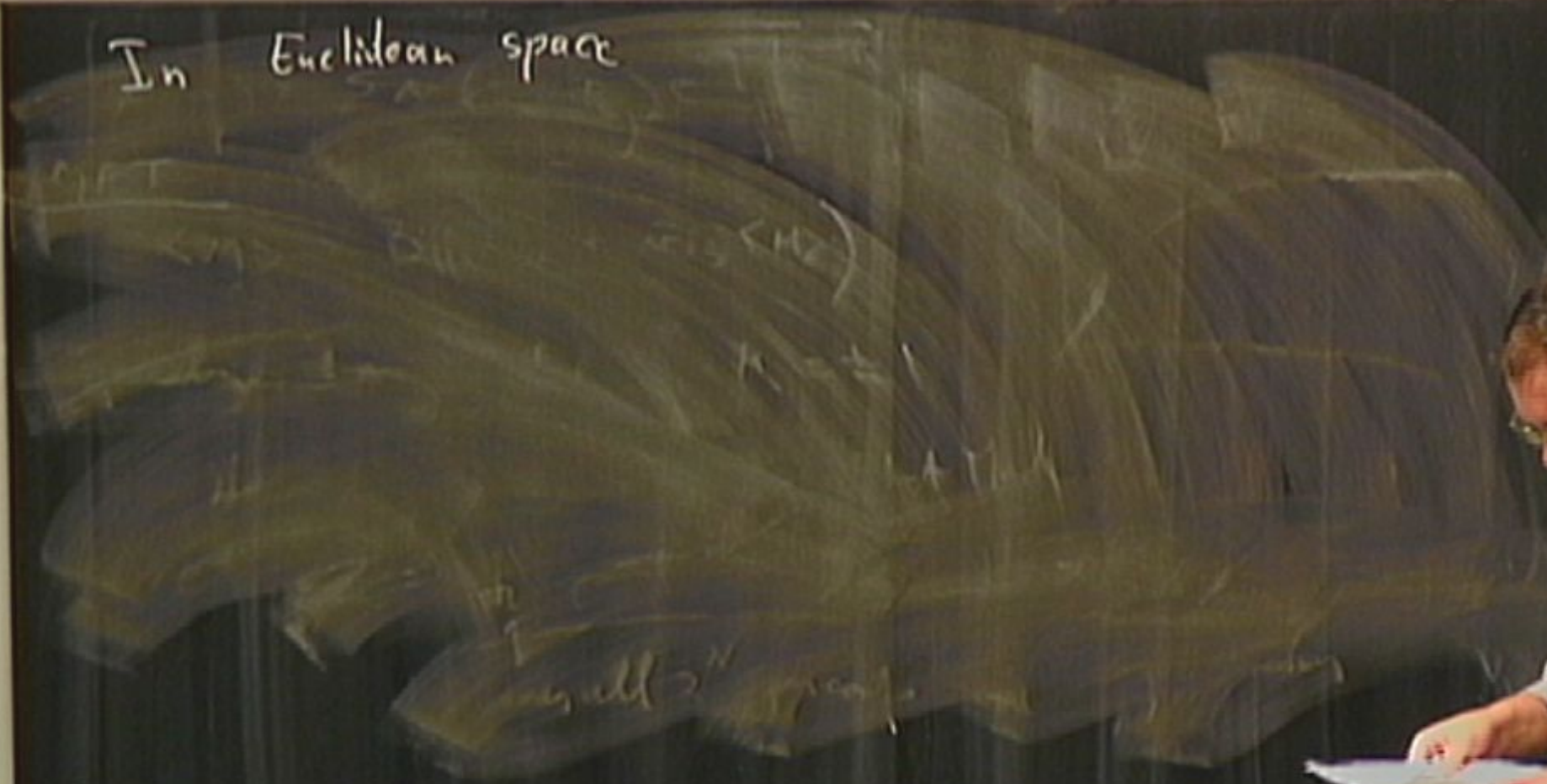
$$+ \frac{m_{\text{eff}}^4(\varphi)}{64\pi^2} \left[\hbar \frac{m_{\text{eff}}^2(\varphi)}{m^2} + \dots \right]$$

$$m_{\text{eff}}^2(\varphi) = m^2 + \frac{\lambda}{2} \varphi^2$$

arbitrary
scale m

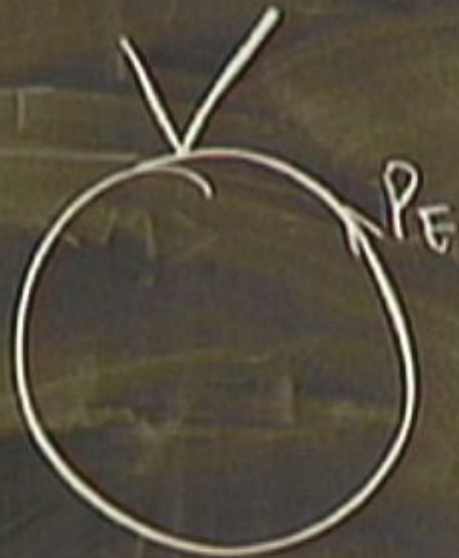
(A) \mathbb{R}^n \mathbb{R}^m \mathbb{R}^k

In Euclidean space

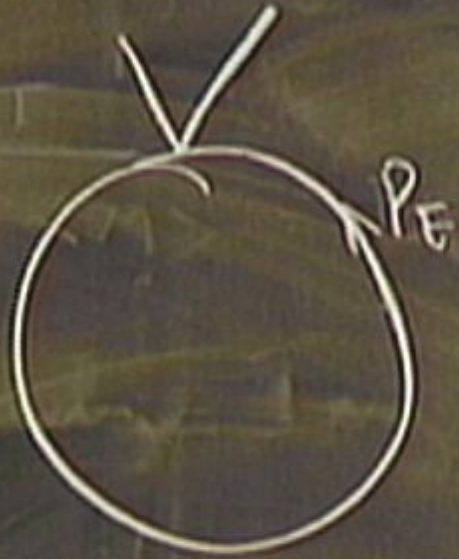


\mathbb{R}^n \mathbb{R}^m \mathbb{R}^k

In Euclidean space

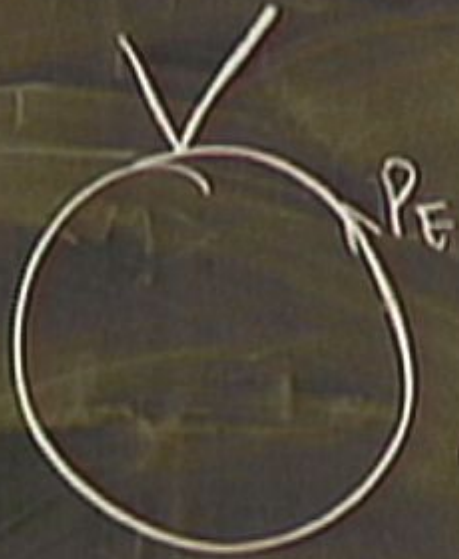


In Euclidean space



$|PE|$

In Euclidean space



$$|P_E| < \Lambda$$

$$\sim \Lambda^2$$

In Euclidean space



$$|P_E| < \Lambda$$

$$\sim \Lambda^2$$

Λ is a cutoff

(

(A) In Euclidean space

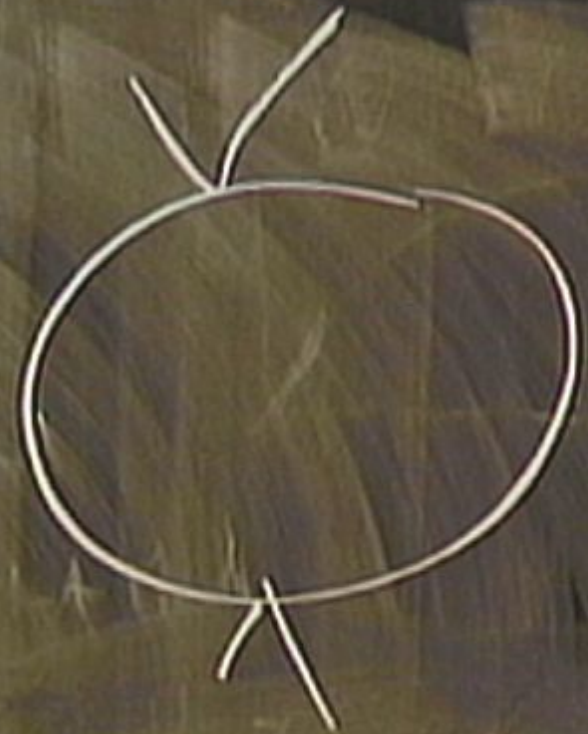


$$|p_E| < \Lambda$$

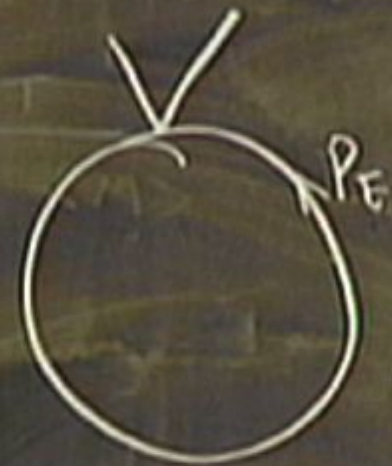
$$\sim \Lambda^2$$

Λ is a cutoff

(regularization)

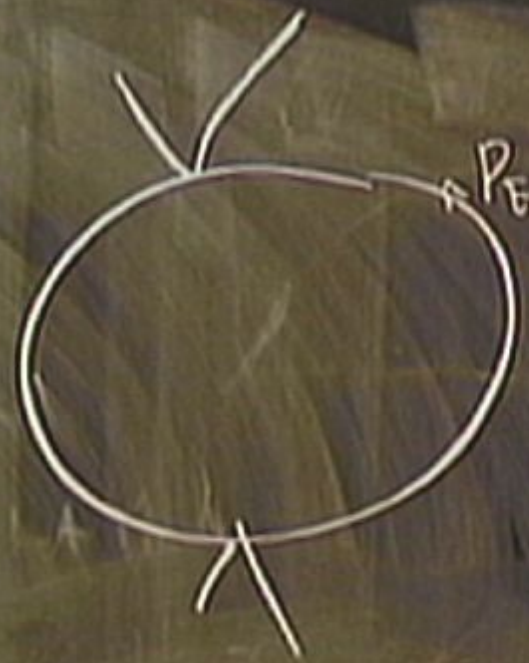


In Euclidean space



$$|P_E| < \Lambda$$

$$\sim \Lambda^2$$

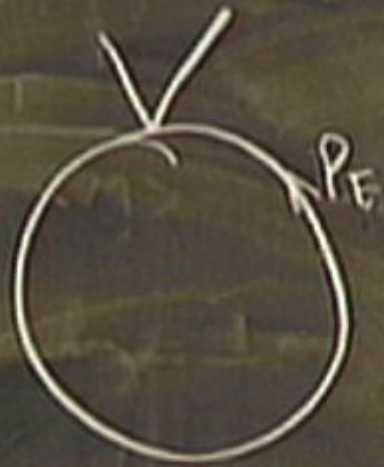


$$|P_E| < \Lambda$$

$$\sim \ln \Lambda$$

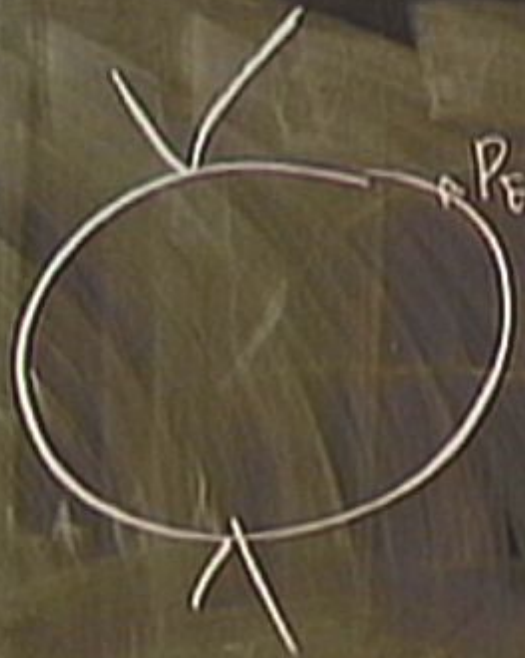
Λ is a cutoff
(regularization)

In Euclidean space



$$|p_E| < \Lambda$$

$$\sim \Lambda^2 + *$$



$$|p_E| < \Lambda$$

$$\sim \ln \Lambda$$

Λ is a cutoff
(regularization)

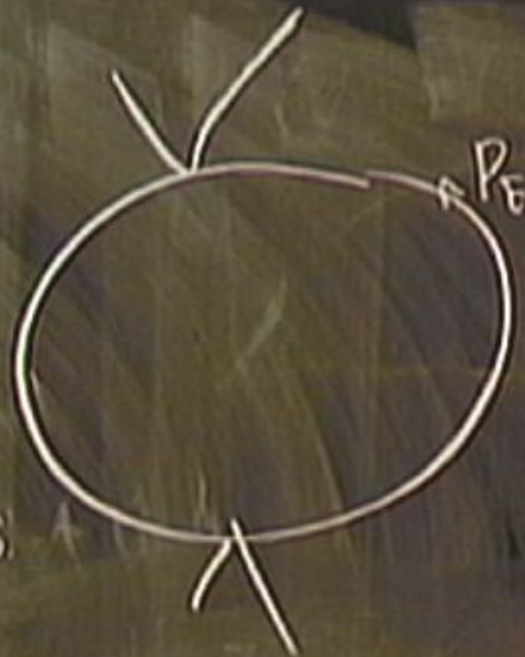
In Euclidean space



$$|P_E| < \Lambda$$

$$+ \text{---} \times \text{---}$$

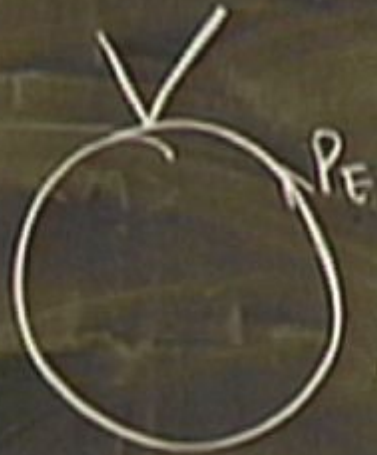
↑
Power
counterterms



$$|P_E| < \Lambda$$

Λ is a cutoff
(regularization)

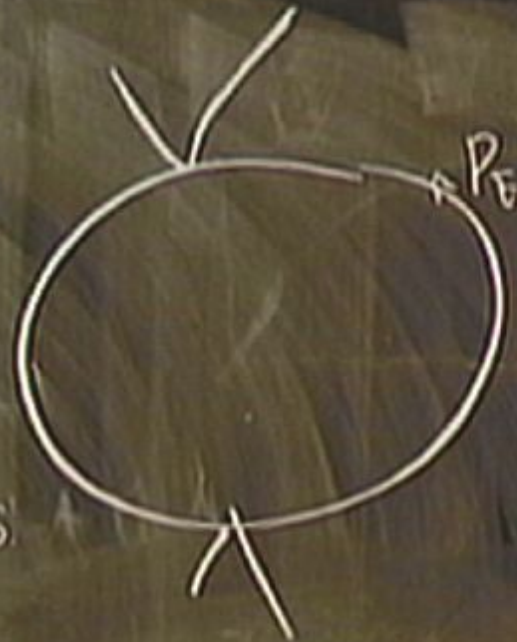
In Euclidean space



$$|P_E| < \Lambda$$
$$\sim \Lambda^2$$



Power
counterms



$$|P_E| < \Lambda$$
$$\sim \ln \Lambda$$



Λ is a cutoff
(regularization)

⇒ Regularization can be implemented in any
QFT

⇒ Regularization can be implemented in any

QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

⇒ Regularization can be implemented in any

QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{\Lambda^2}$$

⇒ Regularization can be implemented in any
QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

$$P(s) = \prod_{i=1}^n \Delta(x_i - x_j) \quad \frac{1}{1+i^2} = \Delta i$$

Order by order in perturbation theory

Collman-Weinberg

$$V = \frac{m^2}{2!} \phi^2 + \frac{\lambda}{4!} \phi^4$$



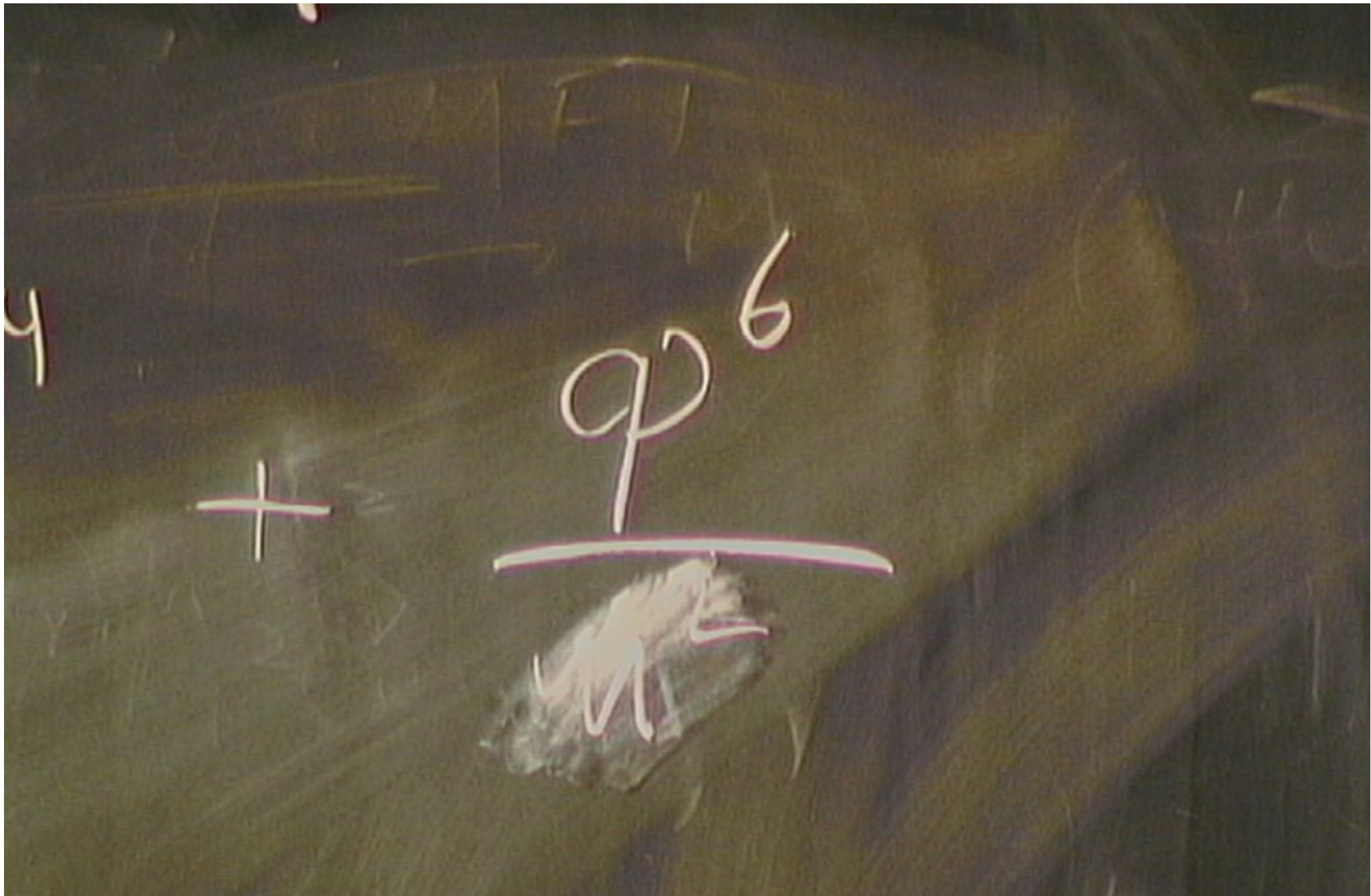
$(-i\lambda)$ + loop correction



Cheng-Li
Zinn-Justin



$\sim \phi^4$ - - -



⇒ Regularization can be implemented in any
QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

$$\Rightarrow V(\varphi)_{\text{regularized}} = \frac{m^2 \varphi^2}{2} + \varphi^2$$

→ Regularization can be implemented in any

QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

→

$$V(\varphi)_{\text{regularized}} = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum$$

$\int \frac{d^4 k}{(2\pi)^4} \frac{1}{k^2 + m^2}$

⇒ Regularization can be implemented in any
QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

⇒ $V(\varphi)$ Regularized
IR loop $\ll \Lambda$

$$V(\varphi) = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum_{h \geq 2} \frac{\varphi^{2h}}{h!}$$

⇒ Regularization can be implemented in any
QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

⇒ $V(\varphi)$ Regularized
IR Prop $\ll \Lambda$

$$V(\varphi) = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum_{n \geq 4} \frac{\varphi^n}{n!}$$

QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

$$V(\varphi) = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum_{n \geq 4} \frac{\varphi^n}{\Lambda^n}$$

Regularized

Λ Prop $K \Lambda$

$n \geq 4$
 n even

⇒ Regularization can be implemented in any
QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

⇒ $V(\varphi) = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum_{n \geq 4} \frac{\varphi^n}{\Lambda^{n-4}} C_n$

Regularized
 $\Lambda_{loop} \ll \Lambda$

→ Regularization can be implemented in any

QFT

$$V(\varphi) = \frac{m^2}{2} \varphi^2 + \frac{\lambda \varphi^4}{4!} + \frac{\varphi^6}{6!}$$

→ $V(\varphi)_{\text{regularized}} = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum_{\substack{n \geq 4 \\ n \text{ even}}} \frac{\varphi^n}{\Lambda^{n-4}} C_n(m, \lambda, m)$

$1 \text{ loop} \ll \Lambda$

\Rightarrow In renormalizable QFT we have
finite # of counterterms

$$\Gamma(\mathcal{L}, \mathcal{P}, \mathcal{R})$$

\Rightarrow In renormalizable QFT we have
finite # of counter terms
such that

V_{eff}

$\Gamma(x) \sim \mathcal{P}(x)$

\Rightarrow In renormalizable QFT we have
finite # of counter terms
such that

$$V_{\text{eff}} = V_{\text{eff}}^{(\text{bare})}$$

$$\Gamma(x) \sim \mathcal{P}(x)$$

\Rightarrow In renormalizable QFT we have
finite # of counter terms
such that

$$V_{\text{eff}} = V_{\text{eff}}^{(\text{bare})} + V_{\text{eff}}^{(\text{counter terms})}$$

\Rightarrow In renormalizable QFT we have
finite # of counter terms
such that

$$V_{\text{eff}} = \underbrace{V_{\text{eff}}^{(\text{bare})}} + \underbrace{V_{\text{eff}}^{(\text{counter terms})}}$$

\Rightarrow In renormalizable QFT we have
finite # of counter terms
such that

$$V_{\text{eff}} = \underbrace{V_{\text{eff}}^{(\text{bare})} + V_{\text{eff}}^{(\text{counter terms})}}_{\text{A independent}}$$

\Rightarrow In renormalizable QFT we have
finite # of counter terms
such that

$$V_{\text{eff}} = \underbrace{V_{\text{eff}}^{(\text{bare})} + V_{\text{eff}}^{(\text{counter terms})}}_{\text{independent physical}}$$

$\Lambda \rightarrow \infty \Rightarrow V_{\text{eff}}$

⇒ In nonnormalizable QFT

$\text{Sec}(P)$

derivative

$C_1 \rightarrow$

⇒ but it is not gauge invariant

Parameter

invariant

gauge invariant

$$\int dx \left[-\text{Vers}(i) \right]$$

$$\frac{1}{2} \left(\frac{\partial}{\partial t} \right)^2$$

⇒ In unrenormalizable QFT
IS not possible to remove Λ -dependence.

\Rightarrow In unrenormalizable QFT
IS not possible to remove Λ -dependence.

\Rightarrow

[Faded handwritten text, likely describing the renormalization process and the role of the cutoff Λ in unrenormalizable theories.]

\Rightarrow In nonrenormalizable QFT
IS not possible to remove Λ -dependence.

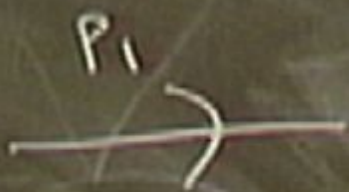
\Rightarrow V_{eff} in nonrenorm QFT.

\Rightarrow In nonrenormalizable QFT
IS not possible to remove Λ -dependence.

\Rightarrow V_{eff} in nonrenom QFT will crucially
depend on a particular way

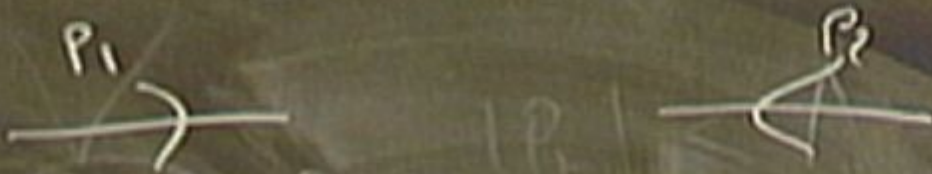
In which you regularize divergent integrals

Euclidean space



$$S = (P_1 + P_2)^2$$

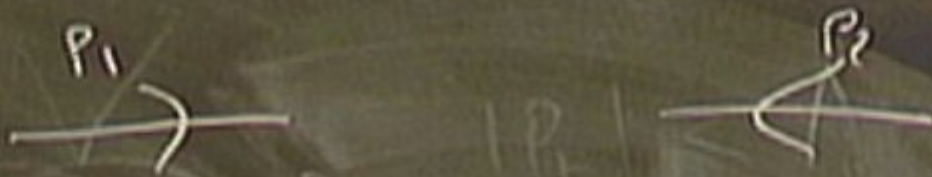
In Euclidean space



$$s = (p_1 + p_2)^2$$

$$s \ll \Lambda$$

Euclidean space

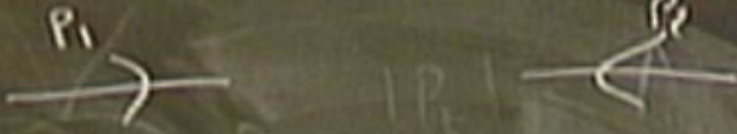


$$s = (P_1 + P_2)^2$$

$$s \ll \Lambda^2$$

$$\text{Vee} \left(P, s \ll \Lambda^2 \right)$$

Euclidean space



$$S = (p_1 + p_2)^2$$

$$S \ll \Lambda^2$$

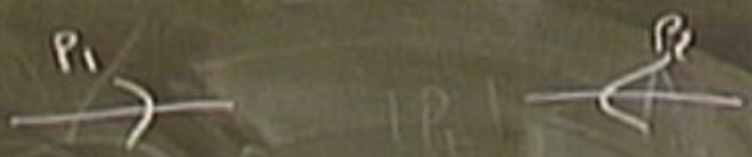
$$V_{\text{eff}}(p, S \ll \Lambda^2)$$

$$= \frac{m^2 p^2}{2} + \frac{\lambda p^4}{4!}$$

$$+ \sum_{n \geq 4} \frac{p^n}{\Lambda^{4-n}}$$

$\mathbb{R}^1 \subset \mathbb{A}^1$

Euclidean space

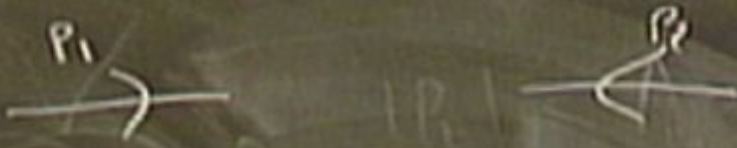


$$S = (p_1 + p_2)^2$$

$$S \ll \Lambda^2$$

$$V_{\text{eff}}(p, S \ll \Lambda^2) = \frac{m^2 p^2}{2} + \frac{\lambda p^4}{4!} + \sum_{h \geq 4} \frac{p^h}{\Lambda^{4-h}}$$

Euclidean space



$|p_1| < \Lambda$

$$S = (p_1 + p_2)^2$$

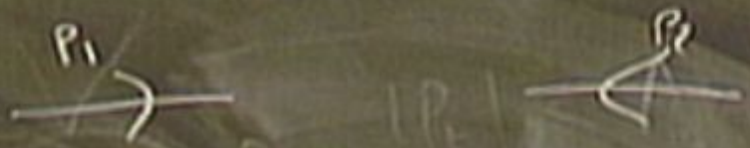
$$S \ll \Lambda^2$$

$$\text{Vee} \left(\mathcal{P}, S \ll \Lambda^2 \right) = \frac{m^2 p^2}{2} + \frac{\lambda p^4}{4!} + \sum_{h \geq 4} \frac{p^h}{\Lambda^{4-h}}$$

In nonrenormalizable QFT
IS not possible to remove Λ -dependence

V_{eff} in nonrenom QFT will crucially
depend on a particular way
in which you regularize divergent integrals

Euclidean space



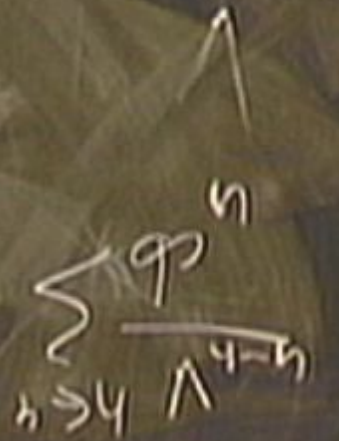
$$S = (p_1 + p_2)^2$$

$$S \ll \Lambda^2$$

$$\text{Vee} \left(\varphi, S \ll \Lambda^2 \right)$$

$$= \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} + \sum_{h \geq 4} \frac{\varphi^h}{\Lambda^{4-h}}$$

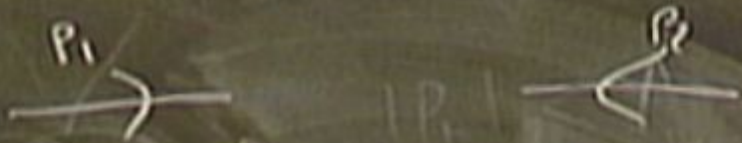
$|p_i| < \Lambda$



In unrenormalizable QFT
IS not possible to remove Λ -dependence

V_{eff} in nonrenom QFT will crucially
depend on a particular way
in which you regularize divergent integrals

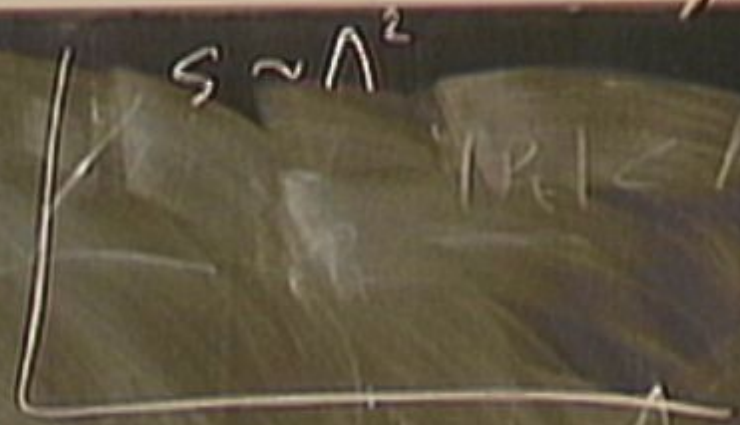
Euclidean space



$$s = (p_1 + p_2)^2$$

$$s \ll \Lambda^2$$

$$\text{Vene } \left(\varphi, s \ll \Lambda^2 \right) = \frac{m^2 \varphi^2}{2} + \frac{\lambda \varphi^4}{4!} \mp \sum_{h \geq 4} \frac{\varphi^h}{\Lambda^{4-h}}$$



$\xi \sim \Lambda^2$
 extra states are created

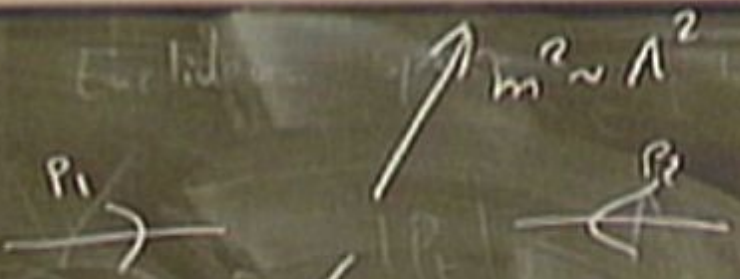
$$= \frac{m^2 \mu}{2}$$

$$\int \frac{d^4 p}{\Lambda^{4-s}}$$

$S \sim \Lambda^2$
extra states are created

$$= \frac{m^2 \phi^2}{2} + \frac{\lambda \phi^4}{4!} + \dots + \frac{\phi^5}{\Lambda^{4-5}}$$

Euclidean



$$S = (p_1 + p_2)^2$$

$$S \ll \Lambda^2$$

$S \sim \Lambda^2$
extra states are created

$$V_{\text{eff}}(p, S \ll \Lambda^2) = \frac{m^2 p^2}{2} + \frac{\lambda p^4}{4!} + \sum_{h \geq 4} \frac{p^h}{\Lambda^{4-h}}$$

ordered by order in perturbation theory
nonrenorm QFT require a UV completion

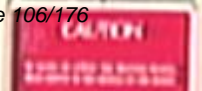
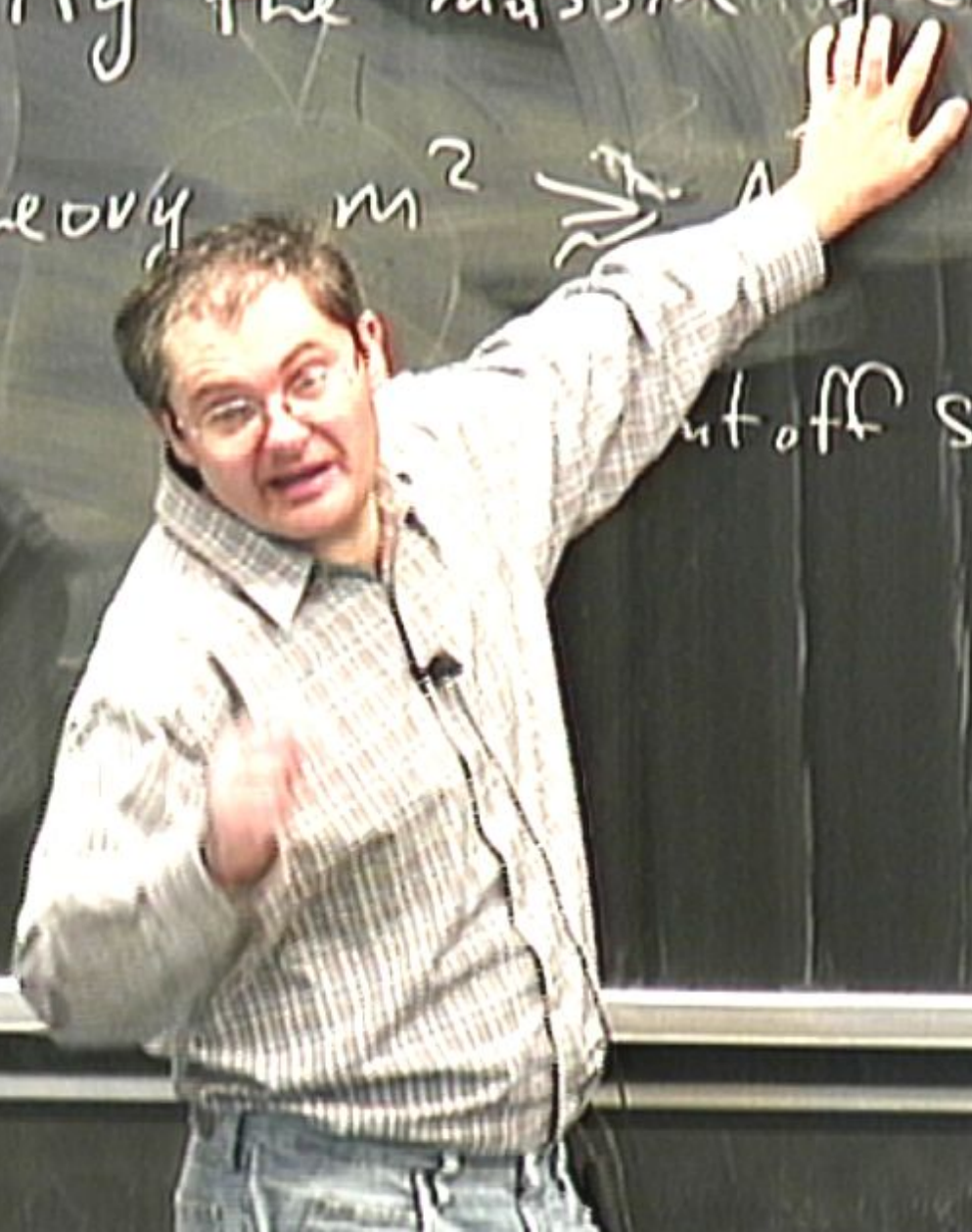
(we + ...)

Cheng-Li

Order by order in perturbational theory
nonrenorm QFT require a UV completion

(we need to specify the massive spectrum
of nonren theory $m^2 \rightarrow \Lambda^2$
cut off scale)

... & Γ require a UV completion
to specify the massive spectrum
nonren theory $m^2 \sim \Lambda^2$ (cutoff scale)



In gravity

$$v_g R \rightarrow$$

$$v_g \left[R + \# \frac{R^2}{m_{pl}^2} + \frac{\# R^3}{m_{pl}^4} + \dots \right]$$

In gravity

$$v_g R \rightarrow \sqrt{-g} \left[R + \# \frac{R^2}{m_{pl}^2} + \frac{\# R^3}{m_{pl}^4} + \dots \right]$$

$$\mathbb{R} \ll m_{pl}^2$$

In gravity

$$V_g R \rightarrow \sqrt{-g} \left[R + \# \frac{R^2}{m_{pl}^2} + \# \frac{R^3}{m_{pl}^4} + \dots \right]$$

$$R \ll m_{pl}^2$$

$$\hookrightarrow \sim m_{pl}^2$$

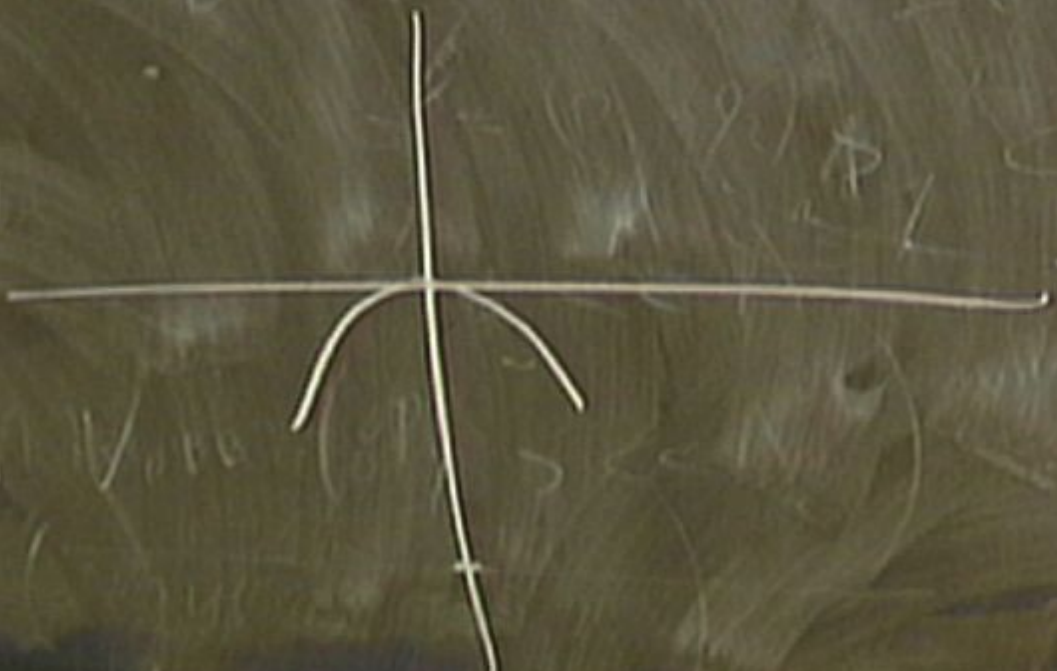
$$V(\Phi) = -\frac{m^2}{2} \Phi^2 + \frac{\lambda}{4!} \Phi^4$$

$m^2 > 0$
 $\lambda > 0$



$$V(\Phi) = -\frac{m^2}{2} \Phi^2 + \frac{\lambda}{4!} \Phi^4$$

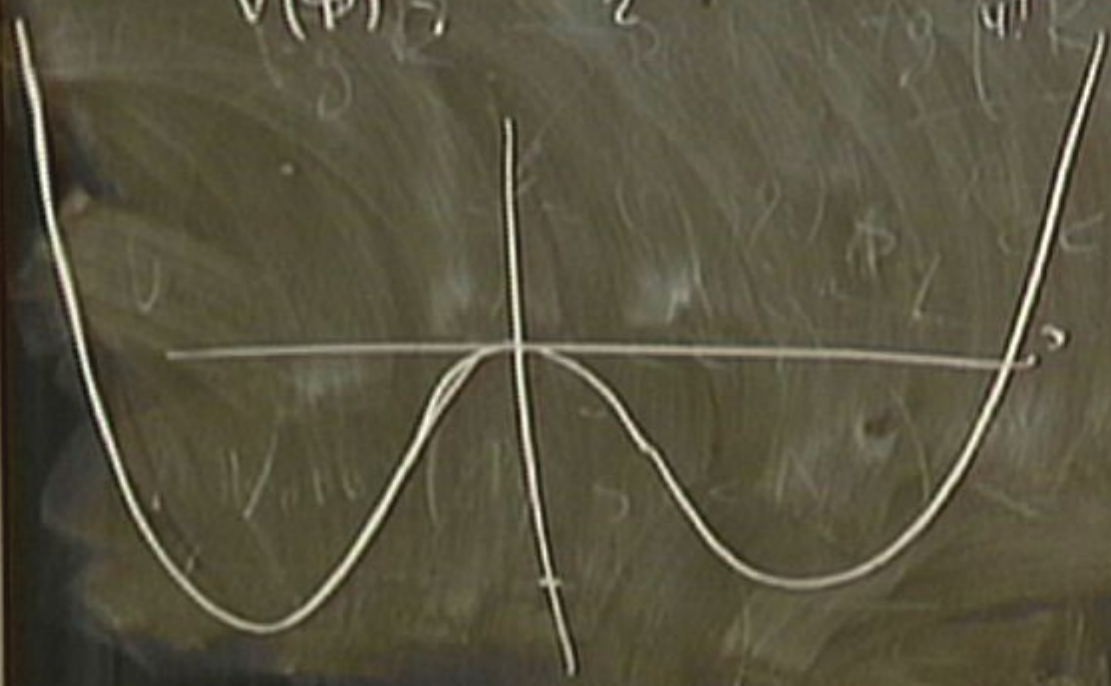
$m^2 > 0$
 $\lambda > 0$



$$V(\varphi) = -\frac{m^2}{2} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

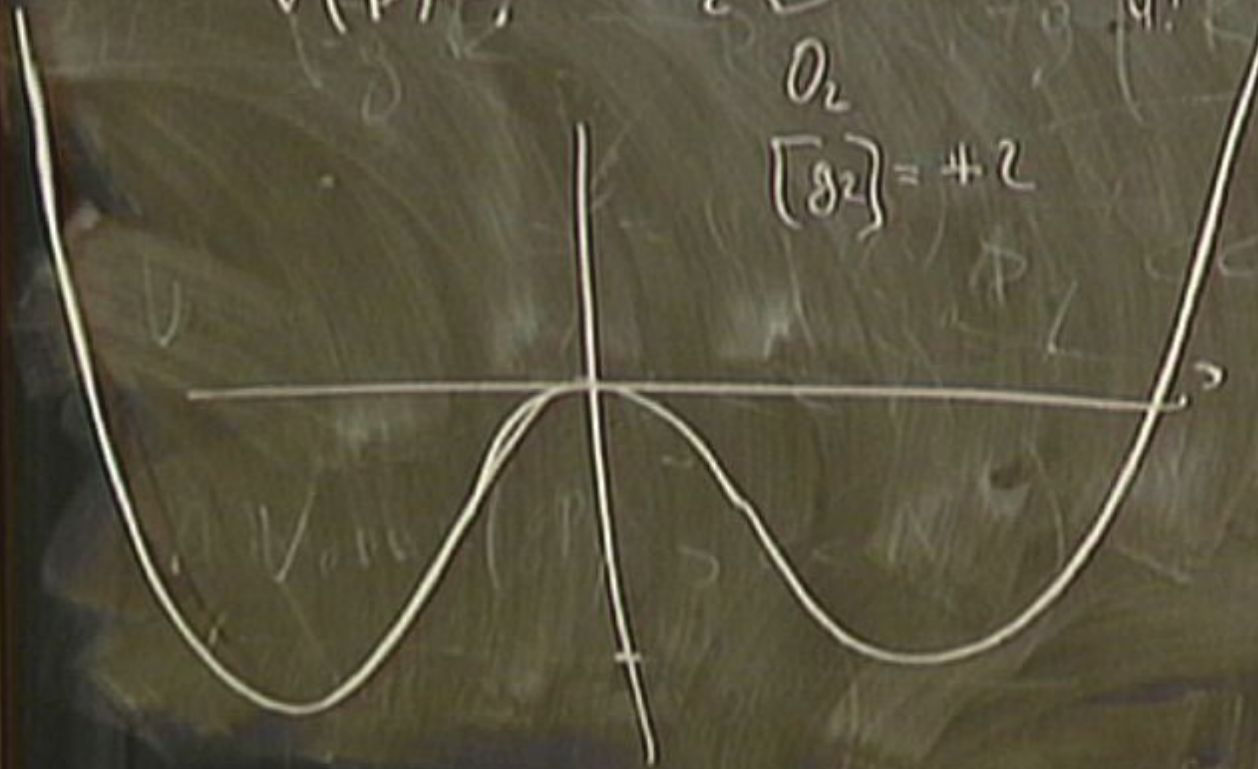
$$m^2 > 0$$

$$\lambda > 0$$



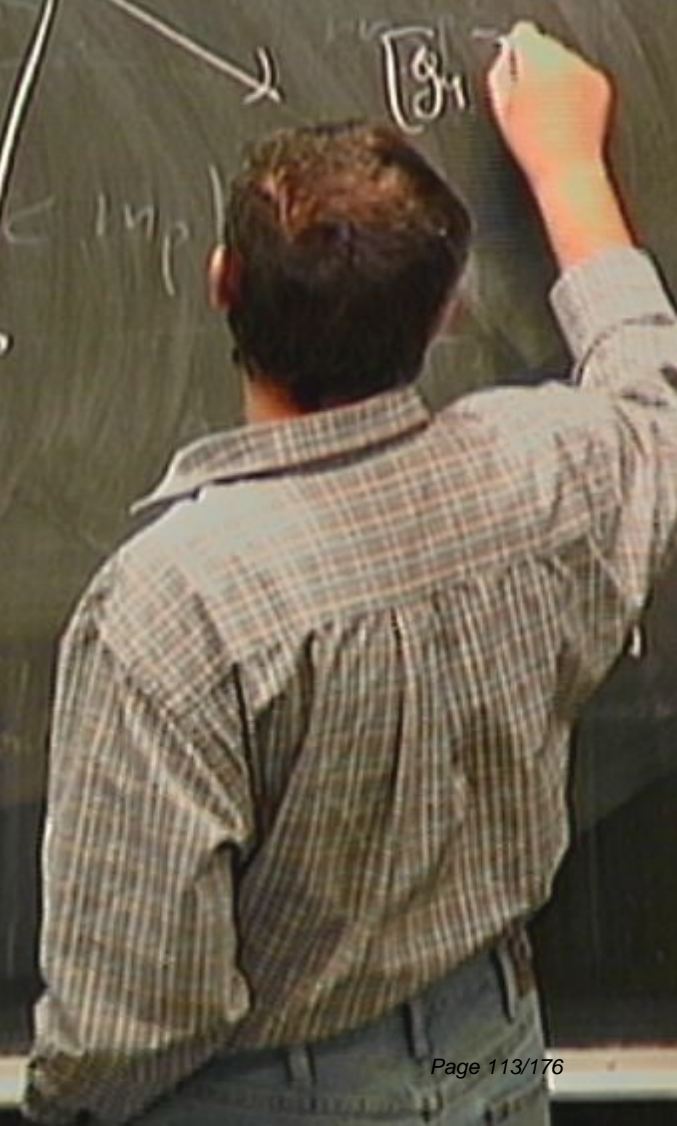
$$V(\phi) = -\frac{m^2}{2} \phi^2 + \frac{\lambda}{4!} \phi^4$$

$m^2 > 0$
 $\lambda > 0$



$$[\delta_2] = +2$$

$$[\delta_1]$$



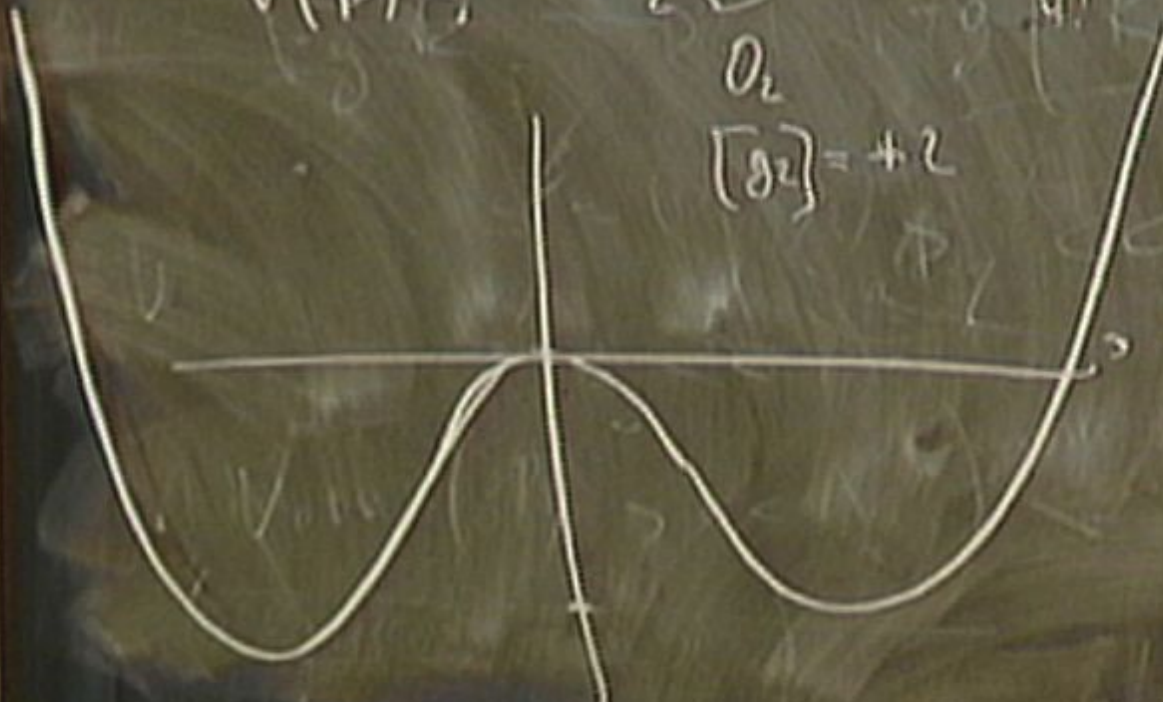
$$V(\varphi) = -\frac{\mu^2}{2} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

$$[g_2] = +2$$

$$\mu^2 > 0$$

$$\lambda > 0$$

$$[g_1] = 0$$



$$V(\varphi) = -\frac{m^2}{2} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

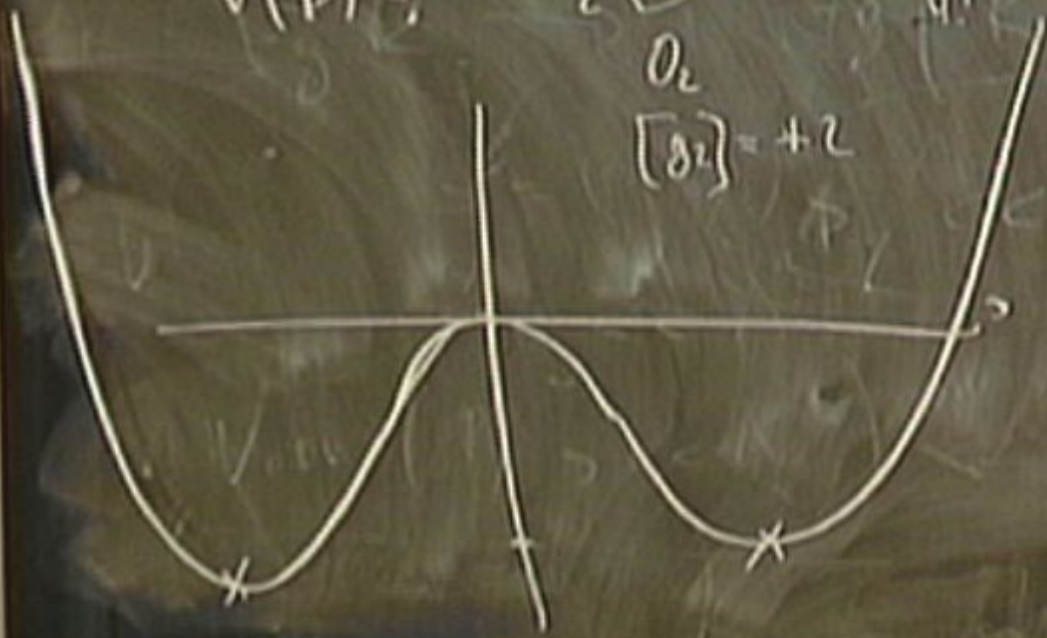
$$[g_2] = +2$$

$$m^2 > 0$$

$$\lambda > 0$$

$$[g_1] = 0$$

$V_{eff}(\varphi)$ exactly



$$V(\varphi) =$$

$$-\frac{m^2}{2} \varphi^2 + \frac{\lambda}{4!} \varphi^4$$

$$\rightarrow 0_1$$

$$m^2 > 0$$

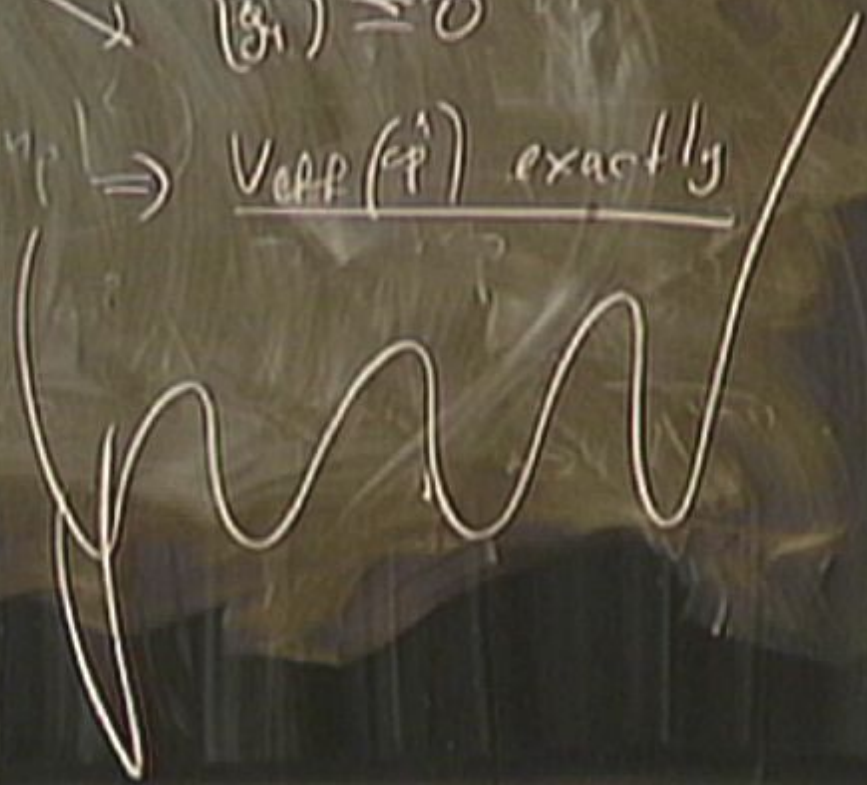
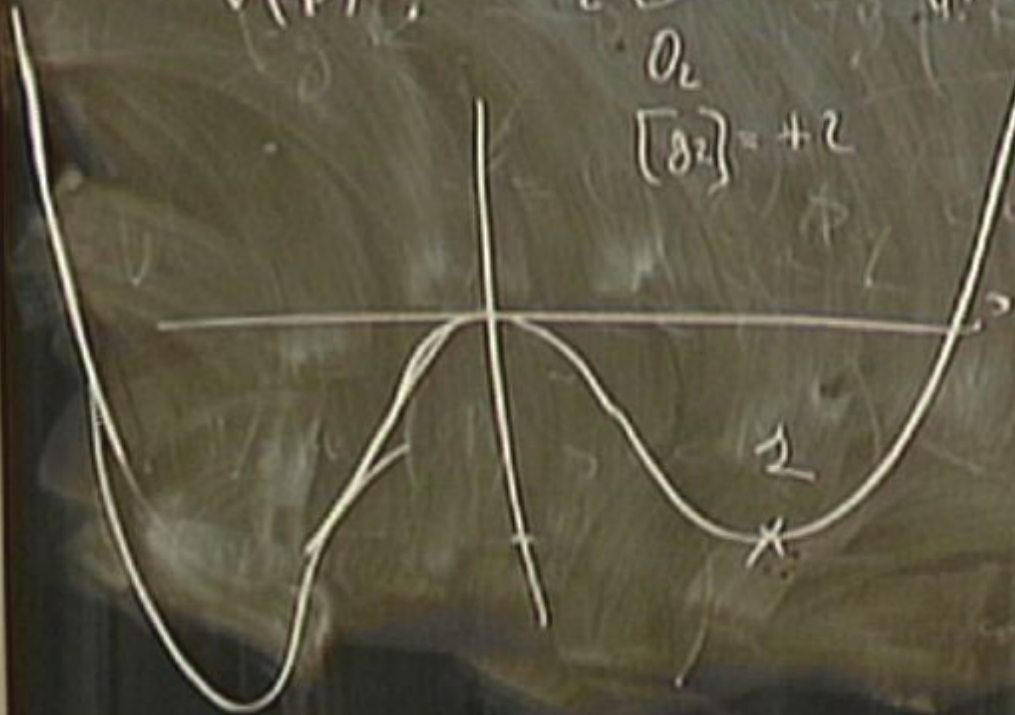
$$\lambda > 0$$

$$0_2$$

$$[\beta_2] = +2$$

$$[\beta_1] = 0$$

\Rightarrow $V_{\text{eff}}(\varphi)$ exactly



⇒ Co-existence power constraints require small variability of SISO QFT

(we need to specify the maximum spectrum of your controller)

cut-off freq

Consider power counting renormalizability of SUSY QFT
 renormalizability require $\Delta < 4$

$$\mathcal{L} = \int d^4\theta K(\Phi, \bar{\Phi})$$

the mass dimension of K is Δ

Consider power counting renormalizability of SUSY QFT
 require on-shell renormalizability

$$\mathcal{L} = \int d^4\theta K(\Phi, \bar{\Phi}) + \int d^2\theta W(\Phi)$$

Consider power counting renormalizability of SUSY QFT
require \mathcal{L} to be renormalizable

$$\mathcal{L} = \int d^4\theta K(\Phi, \bar{\Phi}) + \int d^2\theta W(\Phi) + h.c.$$

Kähler potential

superpotential

$$\{Q_i, \bar{Q}_i\} = 2P_{ai} = 20^{ai} P_m$$

... of T will ...
 ... a particular ...
 ...



$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii} P_m$$

$$[P_m] = +1$$

$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii} P_m$$

$$[P_m] = +1 \Rightarrow [Q_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii}^{\text{or}} P_m$$

$$[P_m] = +1 \Rightarrow [Q_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$Q_i \sim \frac{\partial}{\partial \theta^i}$$

$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii} P_m$$

$$[P_m] = +1 \Rightarrow [Q_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$Q_i \sim \frac{\partial}{\partial \theta^i}$$

$$\bar{Q}_i \sim -\frac{\partial}{\partial \bar{\theta}^i}$$

$$\{ Q_\pm, \bar{Q}_\pm \} = 2P_{\pm i} = 2\sigma_{\pm i}^{\alpha\beta} P_m$$

$$[P_m] = +1 \Rightarrow [Q_\pm] = [\bar{Q}_\pm] = \frac{1}{2}$$

$$Q_\pm \sim \frac{\partial}{\partial \theta^\pm}$$

$$\bar{Q}_\pm \sim -\frac{\partial}{\partial \bar{\theta}^\pm}$$

$$[Q_\pm] = +\frac{1}{2}$$

$$\{Q_k, \bar{Q}_i\} = 2P_{ki} = 2\sigma_{ki}^{\text{or}} P_m$$

$$[P_m] = +1 \Rightarrow [Q_k] = [\bar{Q}_i] = \frac{1}{2}$$

$$Q_k \sim \frac{\partial}{\partial \theta^k}$$

$$\bar{Q}_i \sim -\frac{\partial}{\partial \bar{\theta}^i}$$

$$[Q_k] = +\frac{1}{2} \Rightarrow [\theta^k] = [\bar{\theta}_i] = -\frac{1}{2}$$

$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii}^m P_m$$

$$[P_m] = +1 \Rightarrow [Q_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$Q_i \sim \frac{\partial}{\partial \theta^i}$$

$$\bar{Q}_i \sim -\frac{\partial}{\partial \bar{\theta}^i}$$

$$[d\theta] =$$

$$[Q_i] = +\frac{1}{2} \Rightarrow [\theta^i] = [\bar{\theta}_i] = -\frac{1}{2}$$

$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii}^m P_m$$

$$[P_m] = +1 \Rightarrow [Q_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$Q_i \sim \frac{\partial}{\partial \theta^i}$$

$$\bar{Q}_i \sim -\frac{\partial}{\partial \bar{\theta}^i}$$

$$[\theta^i] = [\bar{\theta}^i] =$$

$$[Q_i] = +\frac{1}{2} \Rightarrow [\theta^i] = [\bar{\theta}^i] = -\frac{1}{2}$$

$$\{Q_i, \bar{Q}_i\} = 2P_{ii} = 2\sigma_{ii}^m P_m$$

$$[P_m] = +1 \Rightarrow [Q_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$Q_i \sim \frac{\partial}{\partial \theta^i}$$

$$\bar{Q}_i \sim -\frac{\partial}{\partial \bar{\theta}^i}$$

$$[\theta^i] = [\bar{\theta}^i] = +\frac{1}{2}$$

$$[Q_i] = +\frac{1}{2} \Rightarrow [\theta^i] = [\bar{\theta}^i] = -\frac{1}{2}$$

$$[S] = 0 \Rightarrow [L] = 4$$

$$[S] = 0 \Rightarrow [L] = 4$$

$$[d^4\theta] = 4 \cdot \frac{1}{2} = 2$$

\Rightarrow Consistent power counting requires renormalizability of SUSY QFT
 renormalizability of QFT requires $\epsilon \ll \Lambda$

$$\mathcal{L} = \int d^4\theta K(\Phi, \bar{\Phi}) + \int d^2\theta W(\Phi) + h.c.$$

Kähler potential

superpotential

19.4 QFT

+ h.c

rotation,

$$\{ \theta_i, \bar{Q}_i \} = 2 P_{ii} = 2 \sigma_{ii} P_{ii}$$

$$[\theta] = +1 \Rightarrow [\theta_i] = [\bar{Q}_i] = \frac{1}{2}$$

$$\frac{\partial}{\partial \theta}$$

$$\bar{Q}_i \sim -\frac{\partial}{\partial \theta}$$

$$[\partial \theta] = \left[\frac{\partial}{\partial \theta} \right] = +\frac{1}{2}$$

$$+\frac{1}{2} \Rightarrow [\theta_i] = [\bar{\theta}_i] = -\frac{1}{2}$$

$$[S] = 0 \Rightarrow [L] = 4$$

$$[d^4\theta] = 4 \cdot \frac{1}{2} = 2 \Rightarrow [k] = +2$$

$$[d^2\theta] = 2 \cdot \frac{1}{2} = 1 \Rightarrow [w] = +3$$

$$[S] = 0 \Rightarrow [L] = 4$$

$$[d^4 \theta] = 4 \cdot \frac{1}{2} = 2 \Rightarrow [k] = +2$$

$$[d^2 \theta] = 2 \cdot \frac{1}{2} = 1 \Rightarrow [w] = +3$$

$$\Rightarrow WZ\text{-modul} \quad k = \varphi \bar{\varphi}$$

$$[S] = 0 \Rightarrow [L] = 4$$

$$[d^4\theta] = 4 \cdot \frac{1}{2} = 2 \Rightarrow [k] = +2$$

$$[d^2\theta] = 2 \cdot \frac{1}{2} = 1 \Rightarrow [W] = +3$$

$\Rightarrow WZ$ -modell

$$K = \varphi \bar{\varphi}$$

$$[\varphi] = 1$$

... the paper about the non-normalizability of the SFT Φ regularized as Φ_ϵ

$$\Phi = \phi(y)$$

$$\int d^4x \phi(x) \int d^4y \psi(y)$$

... paper about the renormalizability of SYM Φ

$$\bar{\Phi} = \left(\phi(y) + \sqrt{2} \theta \psi(y) + \theta^2 F(y) \right)$$

Consider the power series for the renormalizability of SUTY Φ

$$\bar{\Phi} = \left(\phi(y) + \sqrt{\epsilon} \theta \psi(y) + \theta^2 F(y) \right)$$

$$y = x + i\theta\sigma\bar{\theta}$$

Consider the power series expansion of Φ in terms of θ for the QFT

$$\Phi = \phi(y) + \theta \psi(y) + \theta^2 F(y)$$

$$y = x + i\theta r \bar{\theta}$$

$$[\Phi] = +1$$

For the power series expansion of the normalizability of Ψ for QFT

$$\bar{\Phi} = \phi(y) + \theta \psi(y) + \theta^2 F(y)$$

$$y = x + i\theta \sigma \bar{\theta}$$

$$[\Phi] = +1$$

$$[\phi] = +1 \quad \leftarrow \text{scalar}$$

$\frac{1}{2} = \frac{1}{2} \quad \frac{3}{2} \quad \frac{1}{2} \quad \frac{1}{2}$

$$\Phi = \phi(y) + \sqrt{2} \theta \psi(y) + \theta^2 F(y)$$

$$y = x + i\theta\sigma\bar{\theta}$$

$$[\Phi] = +1$$

$$[\phi] = +1$$

scalar

$$[\psi] = +\frac{3}{2}$$

mass dimension of a free fermion

Suppose the superpotential is $W = \frac{1}{2} m \phi^2 + b \phi + c$ (QFT)

$$\bar{\Phi} = \phi(y) + \sqrt{2} \theta \psi(y) + \theta^2 F(y)$$

$$y = x + i \theta \sigma \bar{\theta}$$

$$[\Phi] = +1$$

$$[\phi] = +1$$

scalar

$$[\psi] = +\frac{3}{2}$$

mass dimension of a free fermion

$$[F] = +2$$

WZ model was identified

$$w(p_i) = \underbrace{v_i p_i + \mu_{ij} p_i p_j + \lambda_{ijk} p_i p_j p_k}_{WZ}$$

nbsm

WZ model was identified

$$W(\varphi_i) = \underbrace{v_i \varphi_i + u_{ij} \varphi_i \varphi_j + \lambda_{ijk} \varphi_i \varphi_j \varphi_k}_{WZ}$$

$$[W] = 2$$

$$[\varphi_i] = +1$$

nlbm

WZ model was identified

$$W(\varphi_i) = \underbrace{v_i \hat{\varphi}_i + \mu_{ij} P_i \varphi_j + \lambda_{ijk} \varphi_i \varphi_j \varphi_k}_{WZ}$$

$$[W] = \sum [\varphi] = +1 \quad \text{nb sum}$$

(1)

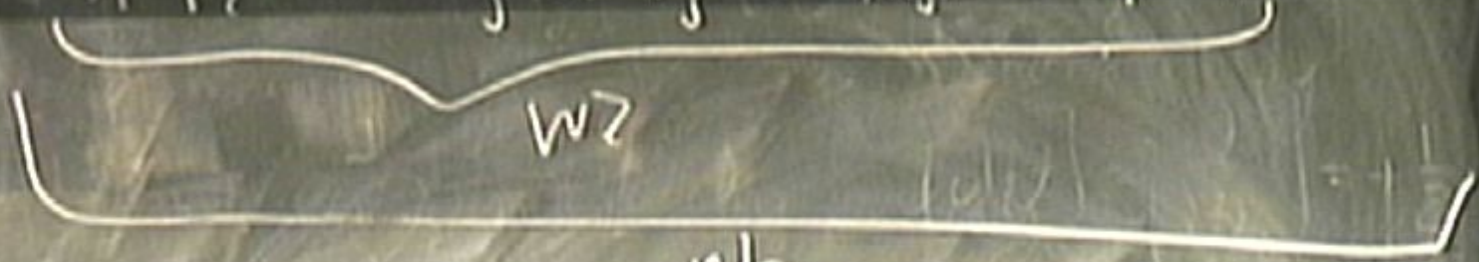
WZ model was identified

$$W(\varphi_i) = \underbrace{v_i \varphi_i^{\Delta} + u_{ij} \varphi_i^2 \varphi_j^2 + \lambda_{ijk} \varphi_i^3 \varphi_j^k \varphi_k^i}_{WZ}$$

$$[W] = 3 \quad [v_i] = +2 \quad [u_{ij}] = +1 \quad [\lambda_{ijk}] = 0$$

$$[v_i] = +2 \quad [u_{ij}] = +1 \quad [\lambda_{ijk}] = 0$$

$$W(\varphi_i) = v_i \varphi_i + u_{ij} \varphi_i \varphi_j + \lambda_{ijk} \varphi_i \varphi_j \varphi_k$$



$$[W] = 2 \quad [A] = +1 \quad n \text{ km}$$

$$[v_i] = +2 \quad [u_{ij}] = \Delta \quad [\lambda_{ijk}] = 0$$

$$v \propto |a\omega|^2$$

WZ model was identified

$$W(\varphi_i) = \underbrace{v_i \hat{\varphi}_i^{\Delta} + \mu_{ij} \varphi_i^2 \varphi_j^2 + \lambda_{ijk} \varphi_i^3 \varphi_j^k \varphi_k^i}_{WZ}$$

$[W] = 2$ $[\hat{\varphi}_i] = +1$ $n \leq m$

$[v_i] = +2$ $[\mu_{ij}] = \Delta$ $[\lambda_{ijk}] = 0$

$v \propto |m|^{-2}$

In WZ model all couplings $g_n \geq 0$

In $\mathcal{N}=1$ WZ model all couplings $\tau_{ij} \geq 0$

→ WZ model picks up most general
susy renormalizable

In WZ model all couplings $(g_n) \geq 0$

→ WZ model picks up most general
susy renormalizable QFT for
 $\mathcal{N}=1$

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$$W(\varphi_i) = \underbrace{v_i \varphi_i^{\Delta} + u_{ij} \varphi_i^2 \varphi_j^2 + \lambda_{ijk} \varphi_i^3 \varphi_j^k \varphi_k^i}_{WZ}$$

$[W] = 2$ $[\varphi_i] = +1$ n.b.m.

$[v_i] = +2$ $[u_{ij}] = \Delta$ $[\lambda_{ijk}] = 0$

$v \propto |m|^2$

⇒ using ~~the~~ internal potential to determine $[\Phi] = +1$

QFT

$V(\Phi)$

isospin

\mathbb{R}^3

→ using Nernst potential to determine

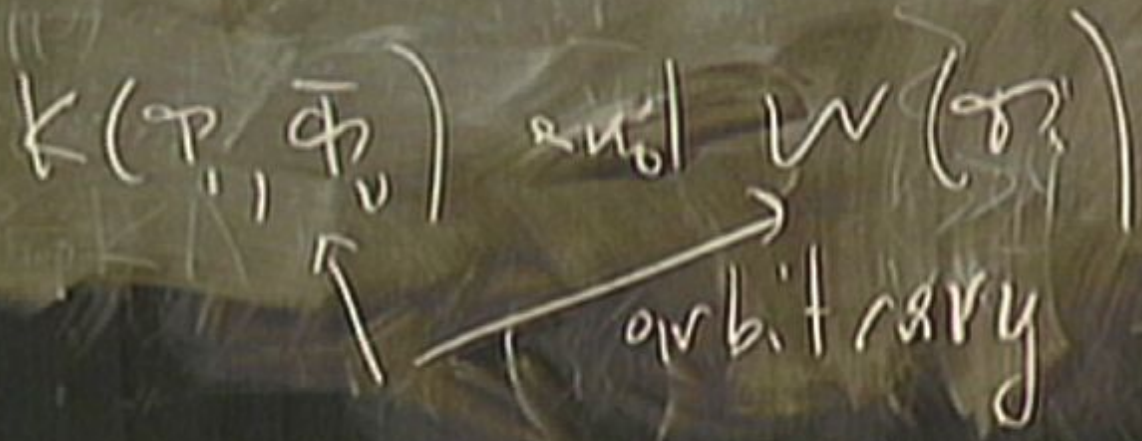
$$QF = 1$$

$$[\phi] = +1$$

→ "Kinetic scaling"

⇒ using Kähler potential to determine $[\Phi] = +1$

⇒ "Kinetic scaling"
How do we deal with nlsms?



\Rightarrow $\hbar/3m$ must be an effective QFT

force # of particles
(...)
independent
 \rightarrow ...
 \Rightarrow ...
 \rightarrow ...

\Rightarrow $\hbar/3m$ must be an effective QFT

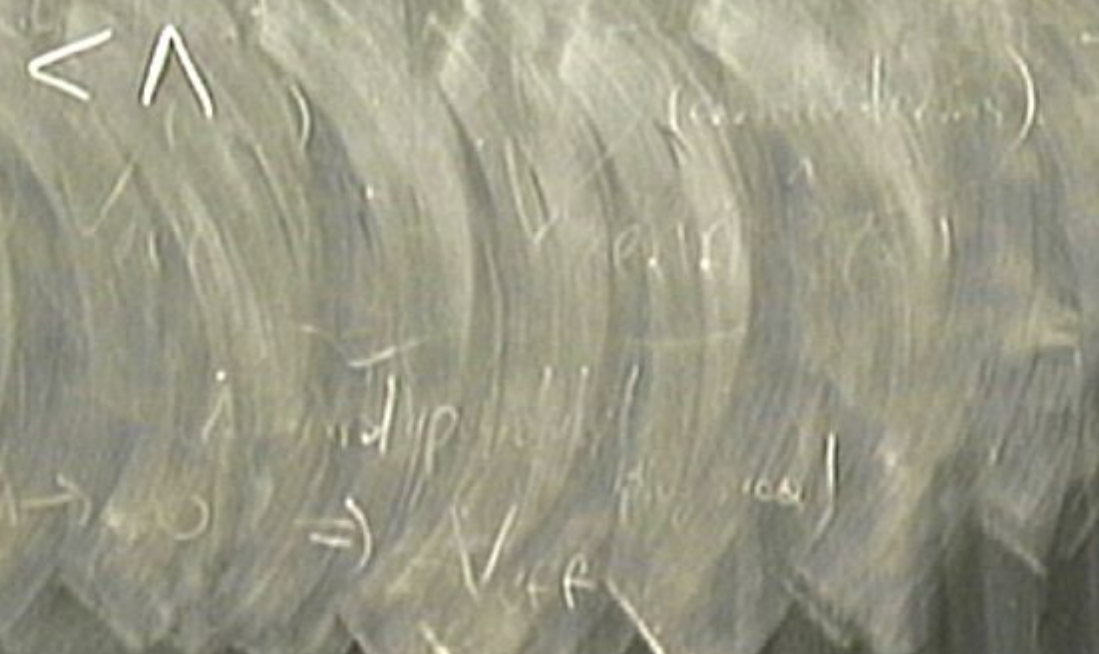


\Rightarrow $\hbar/\rho m$ must be an effective QFT
valid below some cut off scale \wedge

\Rightarrow $\hbar/\rho m$ must be an effective QFT
valid below some cut off scale Λ

$\Rightarrow E < \Lambda$

\Rightarrow



\Rightarrow $\hbar/\rho m$ must be an effective QFT
valid below some cut off scale Λ

\Rightarrow $E \ll \Lambda$
can be trivially satisfied if I choose $E=0$

$\rightarrow \dots \Rightarrow \dots$

\Rightarrow h/s m must be an effective QFT
valid below some cut off scale Λ

\Rightarrow $E \ll \Lambda$
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\Rightarrow susy effective field theories are
useful

\Rightarrow h/s m must be an effective QFT
valid below some cut off scale Λ

\Rightarrow $(E \ll \Lambda)$ $(0 \ll \Lambda)$
can be trivially satisfied if I choose $E=0$

\Rightarrow s/sy effective field theories are
useful

\Rightarrow V_{eff}

\Rightarrow h/s m must be an effective QFT
valid below some cut off scale Λ

$$\underbrace{E \ll \Lambda}$$

$$(0 \ll \Lambda)$$

can be trivially satisfied if I choose $E=0$
s/sy effective field theories are
useful and valid to study vacuum properties
of the theory

\Rightarrow h/m must be an effective QFT
valid below some cut off scale Λ

\Rightarrow $(E \ll \Lambda)$ $(0 \ll \Lambda)$
can be trivially satisfied if I choose $E=0$

\Rightarrow sys effective field theories are
useful and valid to study vacuum properties
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WZ model was identified

$$S_{\text{eff}} = \int d^4x \left[-V_{\text{eff}}(\varphi) + (\partial\varphi)^2 \mathcal{L}(\varphi) \right]$$

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⇒ vacua ??

WZ model was identified

$$S_{\text{eff}} = \int d^4x \left[-V_{\text{eff}}(\rho) + (\partial\rho)^2 \mathcal{L}(\rho) \right]$$

\Rightarrow vacuum ??

\Rightarrow with constant (or slowly vary)

WZ model was identified

$$S_{\text{eff}} = \int d^4x \left[-V_{\text{eff}}(\varphi) + \frac{(\partial\varphi)^2}{2} \right]$$

⇒ vacuum ??

⇒ with constant (or slowly varying fields)

WZ model was identified

$$S_{eff} = \int d^4x \left[-V_{eff}(\varphi) + \cancel{(\partial\varphi)^2} \mathcal{L}(\varphi) \right]$$

⇒ WKB??

⇒ with constant (or slowly varying fields)

⇒

derivative terms are not important

WZ model was identified

$$S_{\text{eff}} = \int d^4x \left[-V_{\text{eff}}(\tau) + \cancel{(\partial\tau)^2} \mathcal{L}(\tau) \right]$$

⇒ warcua ??

⇒ with constant (or slowly varying fields)

⇒ Kähler potential in up to w/ scaling must be irrelevant

derivative terms are not important

WZ model was identified

$$S_{eff} = \int d^4x \left[-V_{eff}(\varphi) + \cancel{(\partial\varphi)^2} \cancel{E(\varphi)} \right]$$

\Rightarrow vacua ??

derivative terms are not important

\Rightarrow with constant (or slowly varying fields)

\Rightarrow Kähler potential in nFDM w.r.t scaling must be irrelevant