

# SM symmetries

(1)

	discrete	Lie (continuous)
spacetime	P, T	Poincaré,
internal	C	$SU(3) \otimes SU(2) \otimes U(1)$ , $SU(3)_F$ $U(1)_B$ , $U(1)_L$ , ...

Q1: Can we extend Poincaré?

→ conformal

- not a symmetry

- massless QCD - ~~should~~ be almost conformal  $m_Q \ll m_g, \Lambda_{QCD}$

conserved current for dilatations symmetry  $x^\mu \rightarrow \lambda x^\mu$

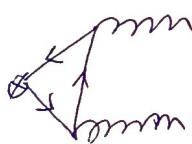
$$D_\mu = x^\nu T_{\mu\nu} \quad \text{energy-momentum tensor}$$

~~$\partial^\mu D_\mu = (\partial^\mu x^\nu) T_{\mu\nu} + x^\nu (\partial^\mu T_{\mu\nu}) = T^\nu_\nu = 0$~~

~~Also, in QCD~~  $\langle P | T^\mu_\mu | P \rangle = 2M_P^2$   $\rightarrow$  would be if QCD is conformal

$$\text{real classical QCD}$$

$$T^\mu_\mu = \sum_m \bar{q} q + \underbrace{\frac{\alpha_s}{6\pi} F_{\mu\nu} F^{\mu\nu}}_{\text{QM corrections}} \neq 0$$



↳ anomaly: when QM breaks the symmetry of classical  $\mathcal{L}$

$$\langle P | T^\mu_\mu | P \rangle - \text{on the lattice}$$

-  $M_P$  is not due to Higgs but due to massless gluons via trace/conformal anomaly

S2: Can we mix internal and spacetime symmetries

old idea:  $SU(6)$  quark model:

$$SU(6): \begin{pmatrix} u^\uparrow \\ u^\downarrow \\ d^\uparrow \\ d^\downarrow \\ s^\uparrow \\ s^\downarrow \end{pmatrix} \quad \begin{matrix} \text{works} \\ \text{only in} \\ NR \end{matrix}$$

the only way: SUSY:

$$\begin{pmatrix} e_L \\ \tilde{e}_L \end{pmatrix} \leftarrow \text{left electron}$$

$$\begin{pmatrix} \gamma \\ \tilde{\gamma} \end{pmatrix} \leftarrow \text{left neutrino}$$

$$\begin{pmatrix} \tilde{e}_L \\ \gamma \end{pmatrix} \leftarrow \text{scalar selection}$$

$$!! \quad \{ Q_{\text{SUSY}}, Q_{\text{SUSY}}^* \} = 2 \nabla^\mu P_\mu$$

$\uparrow$   
 $(1, \vec{\nabla})$

$$Q_{\text{SUSY}} |B\rangle = |F\rangle$$

$\tilde{e}_L \quad e_L \quad \text{--- should have}$   
 $\gamma \quad \tilde{\gamma} \quad \text{the}$   
same mass

↓  
SUSY breaking

## 53 : Accidental symmetries of SM

Underlying principles of SM:

1. Gauge  $SU(3)_c \times SU(2)_L \times U(1)_Y$  symmetric, Lorentz sym.
2. Higgs mechanism (with 1 Higgs  $\phi_{SU(2)}$ )
3. Matter is chiral fermions  $(\bar{u}_L, u_L, \bar{d}_L, d_L, \bar{\nu}_L, \nu_L)$

4. renormalisability

$$L_{SM} = \bar{q} (\not{D}) q - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \sqrt{\phi} + (D_\mu \phi)^2 + \frac{1}{2} \bar{q} \gamma^\mu \not{D}_\mu \phi$$

PERFECT! nothing can be added!

$$(\not{D}_1 \not{D}_2) (\not{F}_{\mu\nu} \not{F}^{\mu\nu}) ?$$

$$\rightarrow M = \infty$$

All coupling constants in SM are dimensionless!

$$[g] = \text{GeV}^{-1} \quad (\text{so } S = \int d^4x \mathcal{L} \text{ would be dimensionless})$$

$$[\bar{q} \not{D}^\mu q] = 4 \Rightarrow [u] = \frac{3}{2}$$

$$[\bar{q} \not{F}^\mu \not{F}^\nu q] = [\partial_\mu A_\nu / \partial^\mu A^\nu] = 1$$

$$[g \bar{q} \not{A}^\mu \not{q}] = 4 \Rightarrow [g] = 0$$

$$L \supset m \bar{q} q \quad [m] = 1 \quad \supset m^2 \phi^2$$

rule of thumb: couplings with negative dimension  $\Rightarrow$  non-renorm. theory

$$[g \bar{q} \not{A}_\mu \not{A}^\mu \not{q} \not{F}_{\nu\lambda} \not{F}^{\nu\lambda}] = 4 \Rightarrow [g] = -4$$

(4)

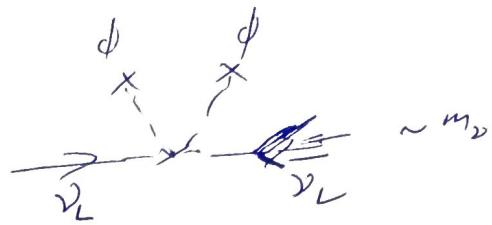
$$V_L = \cancel{g'} \cancel{g} \cancel{g} \cancel{g} \cancel{L} \quad L = g' \cancel{L} \cancel{\phi} \cancel{\phi} L$$

$$\frac{3}{2} \frac{3}{2} \frac{3}{2} \frac{3}{2} = 6$$

$$[g'] = -2$$

$\rightarrow$  so no renormalizable

B-violating vertices

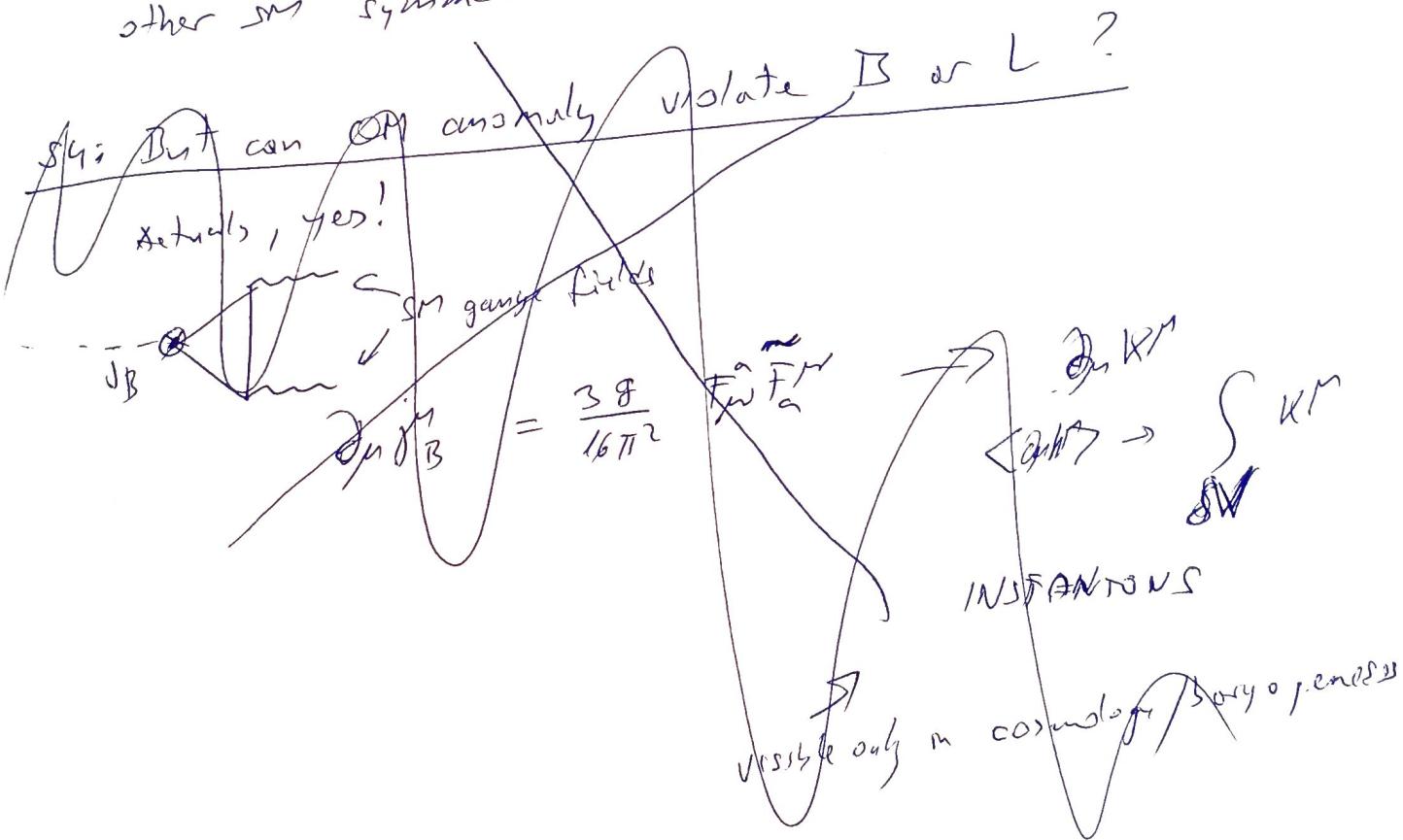


$$\Delta L = 2$$

$$\text{Wess-Zumino operator} \quad L = g' \cancel{L} \cancel{\phi} \cancel{\phi} L$$

$$[g'] = -1$$

$B$ ,  $L$ -conservation is a consequence of other symmetries.



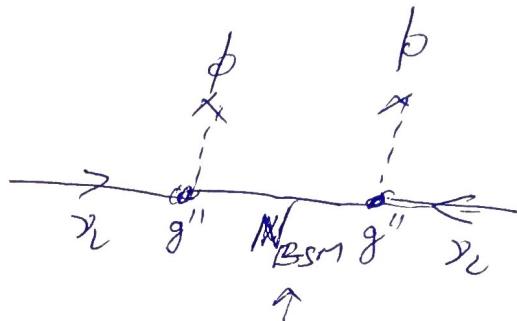
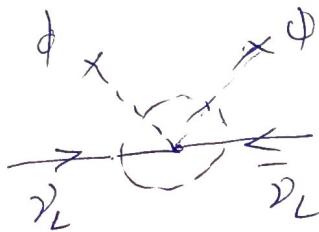
## §4: Violation of B & L by BSM physics

(5)

SM as an effective theory?



BSM will not be constrained and will violate B & L!



$$\frac{1}{\sqrt{M_{BSM}^2}} \propto \frac{1}{m_{BSM}}$$

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{g'^2}{M_{BSM}} \bar{\psi} \phi \psi_L + \frac{\lambda}{M_{BSM}^2} \bar{\psi} \psi_L + \dots$$

$m_\nu \rightarrow$  easiest to see!

$$m_\nu \sim \frac{v^2}{M_{BSM}} \leftarrow \text{explain small } m_\nu !$$

$$\hookrightarrow M_{BSM} \sim 10^{15} \text{ GeV} \approx \text{Planck Energy}$$



$$\tau_{probe} \sim 10^{34} \text{ yr}$$

SS: No global symmetries in the nature? (Only gauge)

- BH evaporation violates B, L, ... Only  $U(1)_{em}$  survives because of Q connection to flux at  $\infty$  (Gauss)
- String th., AdS/CFT support this