Charged Q-balls in gauge mediated SUSY breaking models

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Motivations

- After Affleck-Dine baryogenesis, spatial inhomogeneities of Affleck-Dine field grow into non-topological solitons called **Q-balls**, which are typically neutral.
- We hope Q-balls survive until present universe and contribute to Dark Matter.
- In Gauge Mediated SUSY Breaking Models, Q-balls are stable against decay into nuclei, but may decay into leptons, which are typically lighter than nuclei.

: − Decay into charged leptons

→ Q-balls are electrically charged

: **Charged Q-balls**

− Stability of baryonic component

→ Charged Q-balls may survive in the universe.

: **Charged Q-balls as Dark Matter?**

Affleck-Dine Baryogenesis

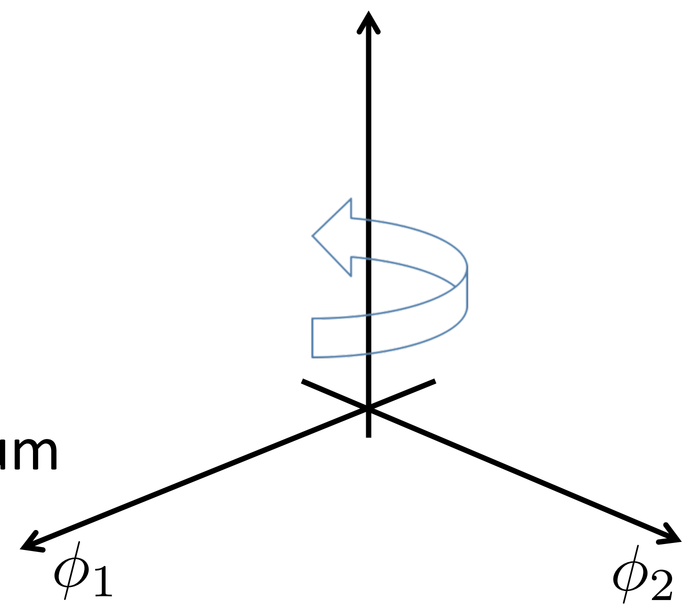
Affleck, Dine (1985)

- Dynamics in phase direction of Baryonic(Leptonic) scalar fields in MSSM(squark, slepton) can generate Baryon Asymmetry.

$$n_B \sim i(\phi^* \dot{\phi} - \dot{\phi}^* \phi)$$

$$\sim \boxed{r^2 \dot{\theta}} \; (\phi = r e^{i\theta})$$

: analogous to angular momentum

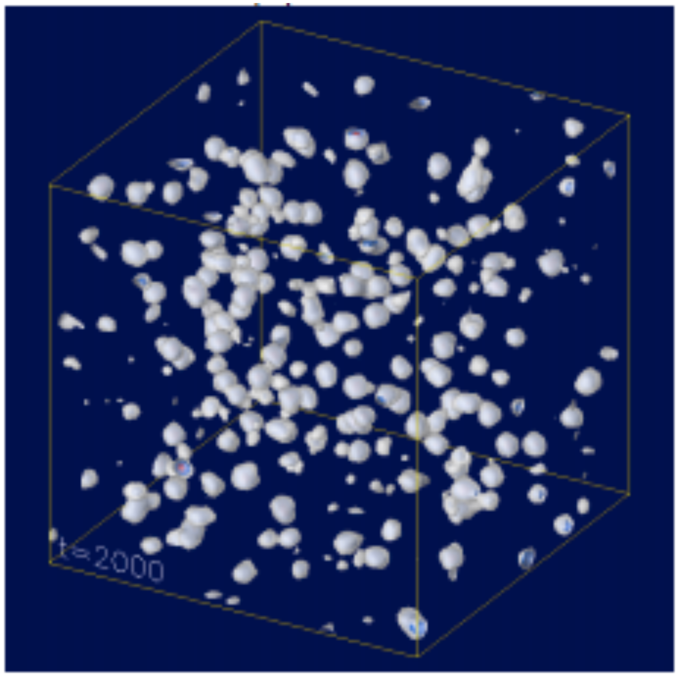


Q-ball formation

A. Kusenko, M. Shaposhnikov (1998)

- After Affleck-Dine baryogenesis, spatial inhomogeneities of the scalar field grow into non-topological solitons called **Q-balls.**

- Conserved Charge:
  Baryon(Lepton) number



T. Hiramatsu, M. Kawasaki, F. Takahashi (2010)

Gauge Mediation Type Q-ball

Dvali Kusenko Shaposhnikov (1998)

$$E = \frac{4\pi\sqrt{2}}{3} M_F Q^{3/4},$$

$$\omega \equiv \frac{dE}{dQ} = \sqrt{2}\pi M_F Q^{-1/4}$$ < proton mass(Q>>1)

: Stable against decay into nuclei

$$R = \frac{\pi}{\omega} \qquad (M_F \sim 10^6 \mathrm{GeV})$$

Charged(Gauged) Q-ball(1-scalar)

K. Lee, J. A. Stein-Schabes, R. Watkins and L. M. Widrow (1989)

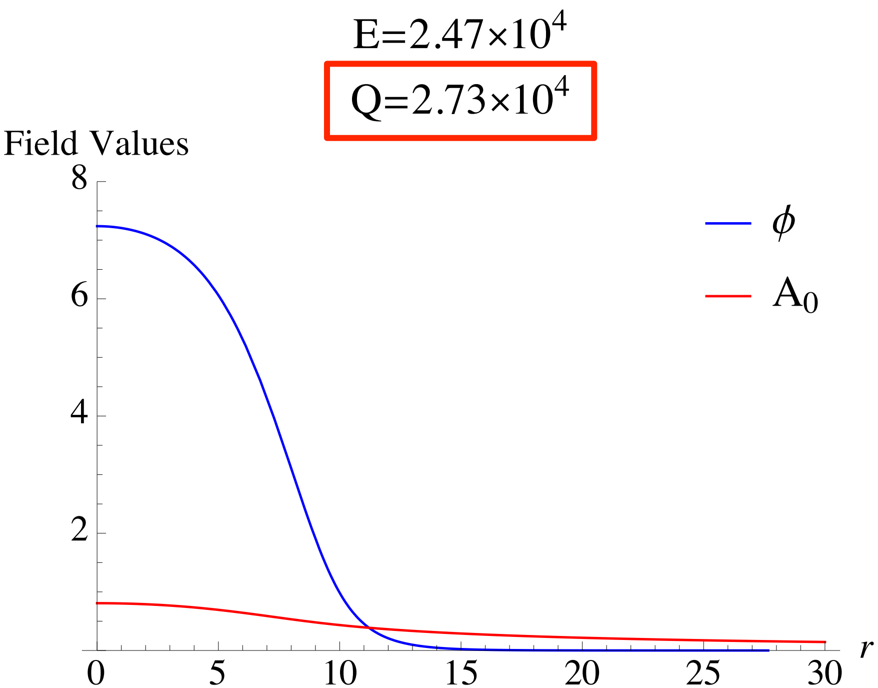
- Baryonic(Leptonic) scalar field with local U(1) charge + U(1) gauge field
- As a U(1) gauge field, consider only Coulomb potential, neglecting magnetic field, or electric current.

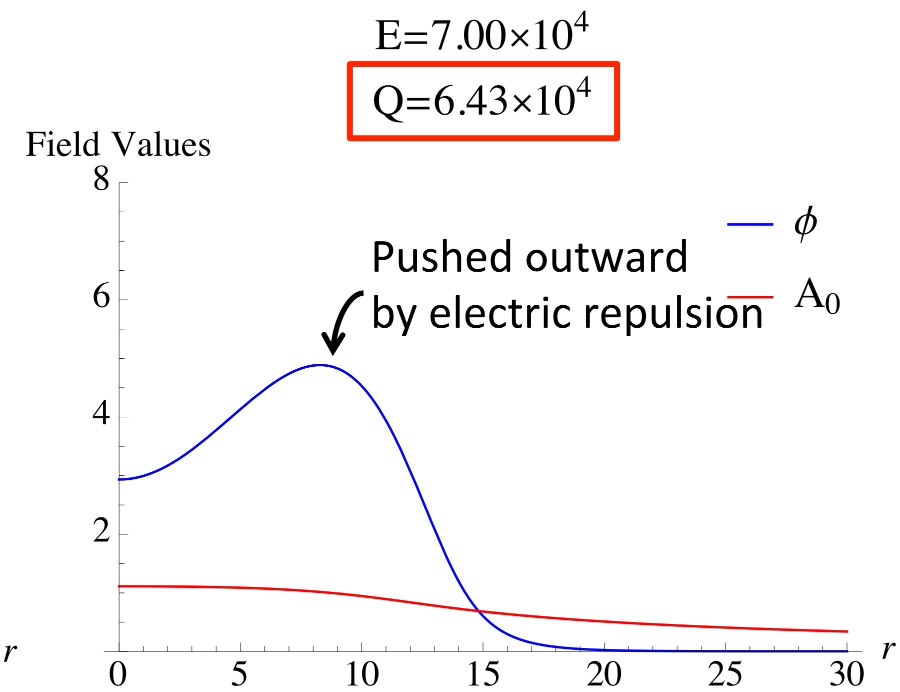
: Neglect electrodynamical effects, and consider only electrostatic solutions.

Charged(Gauged) Q-ball(1-scalar)

K. Lee, J. A. Stein-Schabes, R. Watkins and L. M. Widrow (1989)

- Gauge Mediation Model





Charged Q-ball(2-scalar)

- Baryonic(Leptonic) scalar fields

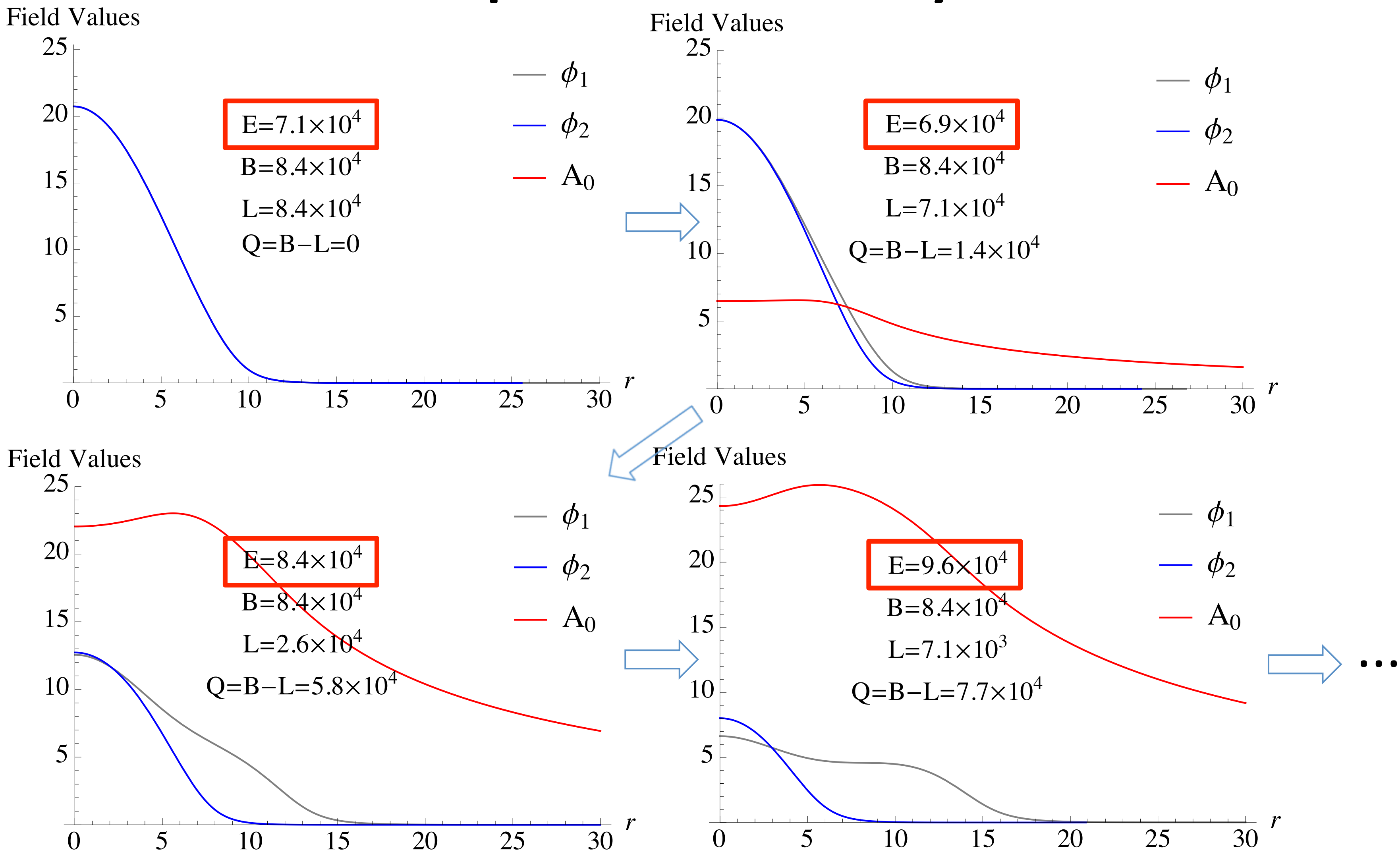
B=1

$$\Phi_1, \quad \Phi_2$$ ← L=1

Local U(1) Charge=(+1,-1)

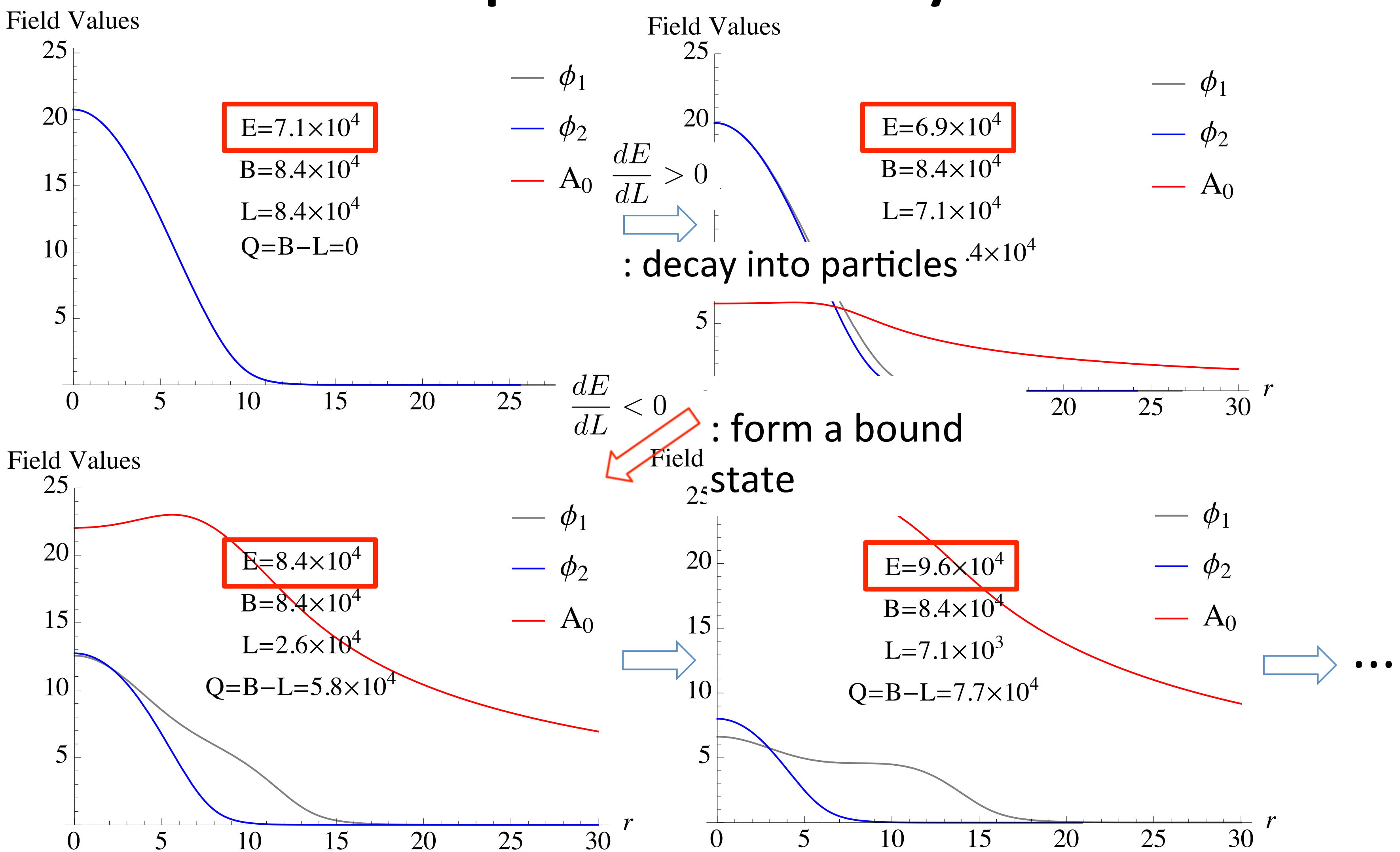
+ U(1) gauge field (Coulomb potential,
neglecting magnetic field or
electric current)

Leptonic decay



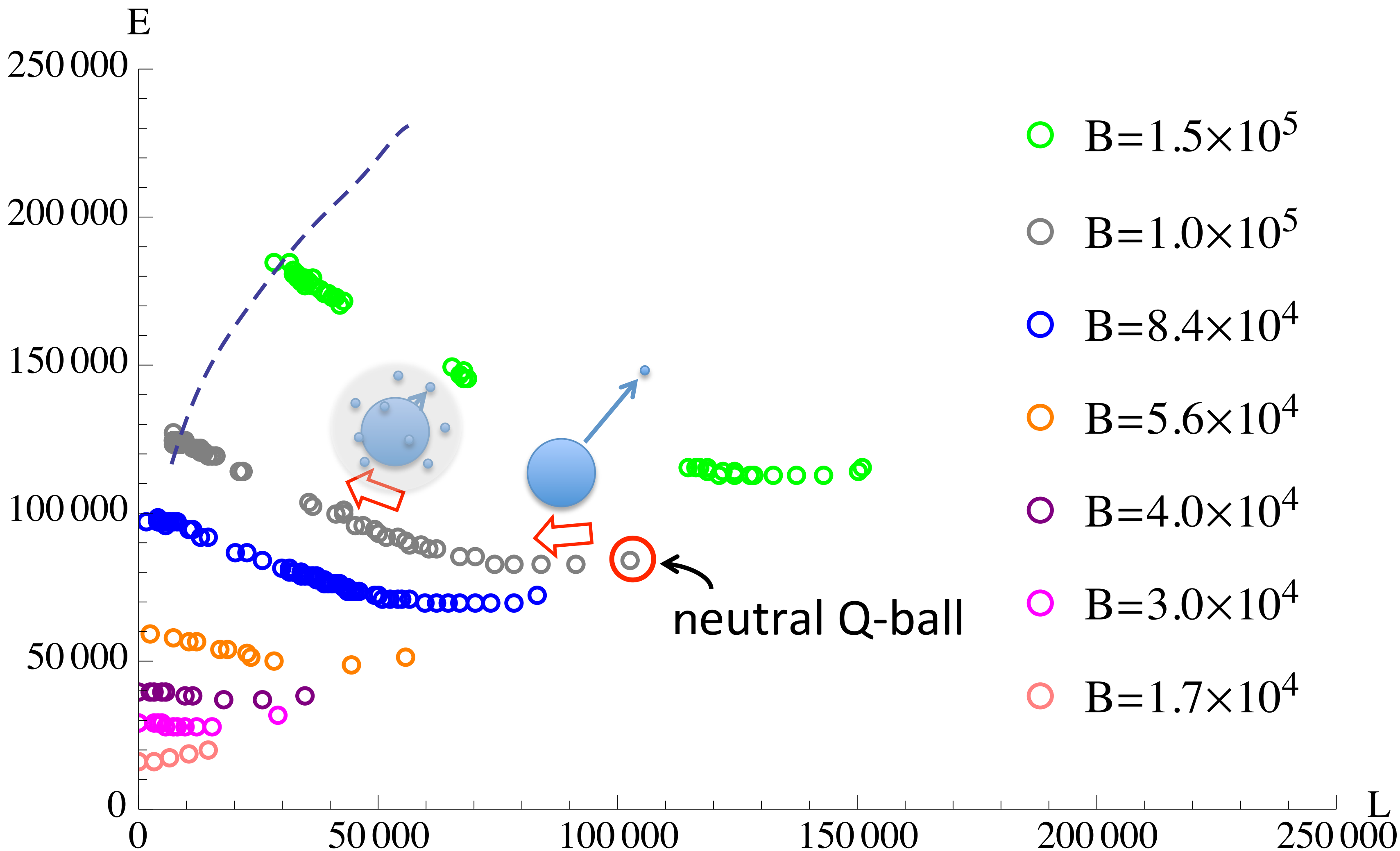
: Coulomb potential arises.

Leptonic decay



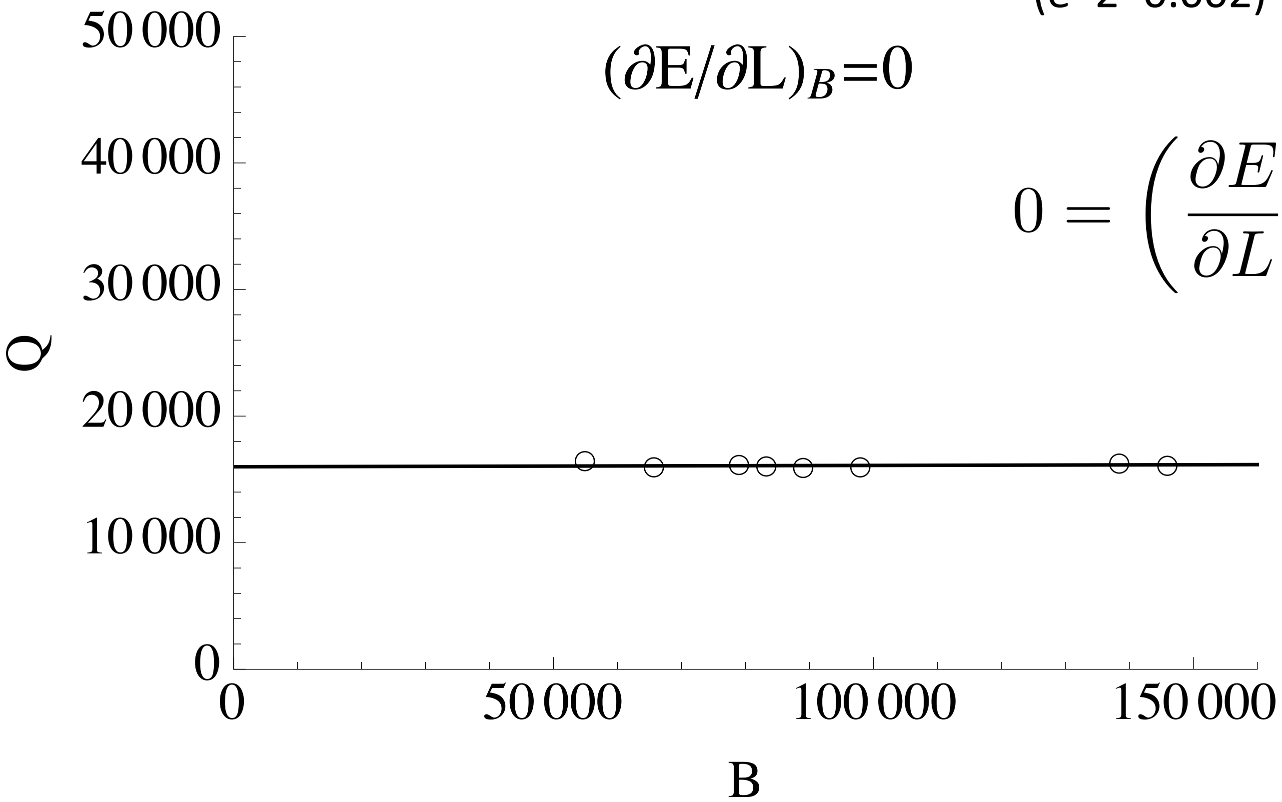
→ a Leptonic cloud is formed.

Leptonic decay



Leptonic decay

(e^2=0.002)



$$0 = \left(\frac{\partial E}{\partial L}\right)_B \simeq \omega_{0L} - \frac{e^2 Q}{4\pi R_L}$$

$$\simeq \omega_{0L} - \frac{e^2 Q}{4\pi^2}\omega_{0L},$$

$$Q = \frac{4\pi^2}{e^2}.$$

Extension to larger Q-balls

- Large Q-balls cannot form the cloud:

  Q-ball size > Cloud radius(～ Bohr radius)

- Threshold : Q-ball size ～ Bohr radius

$$\rightarrow B \sim 10^{36}(M_F/10^6\mathrm{GeV})^4$$

: For $B \gtrsim 10^{36}(M_F/10^6\mathrm{GeV})^4$, evolution stops at $Q = 4\pi^2/e^2$, so that charged Q-balls with $Q = 4\pi^2/e^2$ survive in the universe.

Extension to larger Q-balls

- Large electric field → electron-positron pair production (Schwinger process).

: prevents further growth of the electric charge of the Q-ball.

$$E_S = \frac{m_e^2}{e} = \frac{eQ_S}{4\pi R^2} = \frac{eQ_S}{4\pi^3}\omega_{0B}^2 = \frac{eQ_S}{2\pi}M_F^2 B^{-1/2},$$

$$Q_S \sim \frac{4\pi^2}{e^2}\left(\frac{M_F}{10^6\mathrm{GeV}}\right)^{-2}\left(\frac{B}{10^{39}}\right)^{1/2}$$

Extension to larger Q-balls

- Pair creation occurs at spatial interval about Compton length.

→ When the size of Q-ball becomes smaller than Compton length $(R < 1/m_e \Leftrightarrow B \lesssim 10^{38})$,

the electric charge of the Q-ball can grow until

$$E_S = \frac{m_e^2}{e} = \frac{eQ_S}{4\pi(1/m_e)^2},$$

$$\boxed{Q_S = \frac{4\pi}{e^2}}$$

Conclusions