Big Bang and Baryogenesis from Colliding Branes

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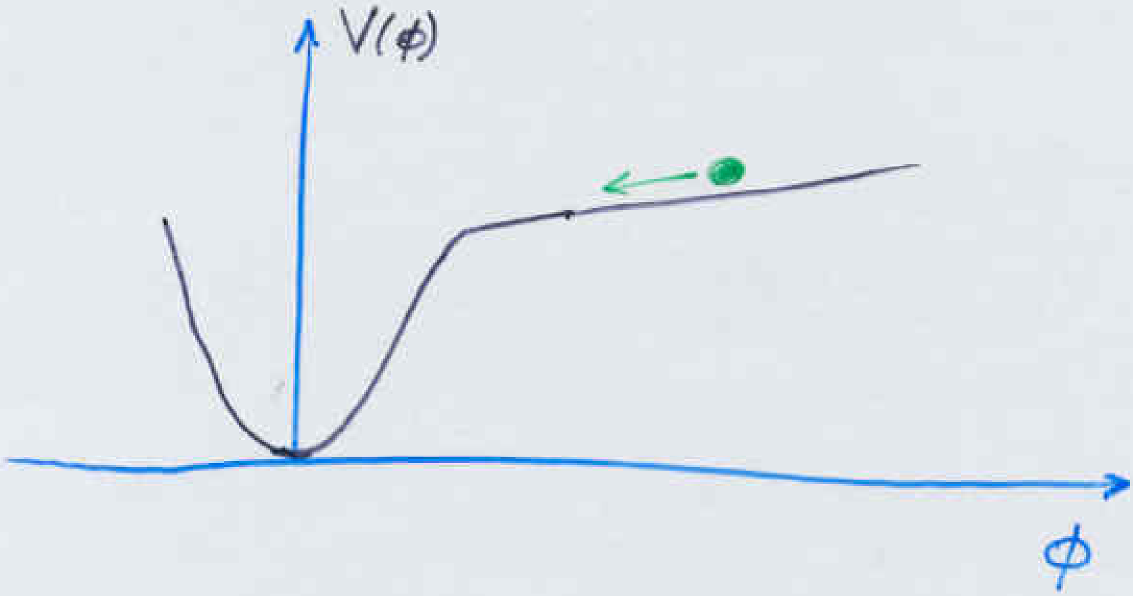
Standard Cosmology

$$ds^2 = dt^2 - a^2(t)\, d\vec{x}^2$$



$$\left(\frac{\dot a}{a}\right)^2 = \frac{\rho(t)}{3M_p^2}$$

$\rho \simeq$ conts $\rightarrow$ $a(t) \sim e^{Ht}$

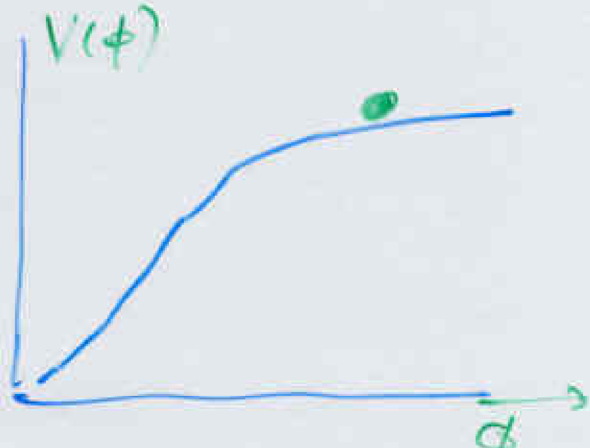
$$H^2 = \frac{\rho}{3M_p^2}$$

Why branes?

In the standard picture we got a problem already at the inflationary stage.

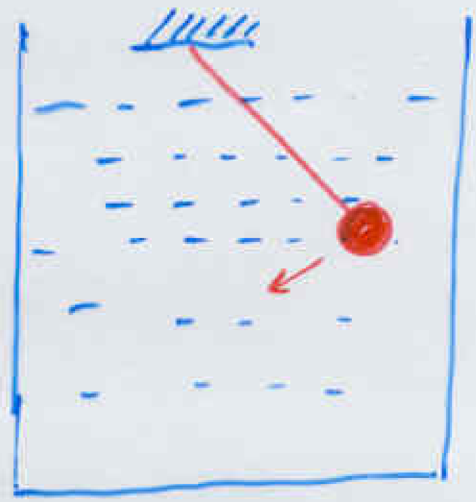
A slow roll problem when quantum gravity is taken into account.

$$\ddot{\varphi} + 3H\dot{\varphi} + \frac{\partial V}{\partial \varphi} = 0$$



$$\downarrow$$

$$\ddot{\varphi} + 3H\dot{\varphi} + V''\varphi + \dots = 0$$



$$H^2 = \frac{\dot{\varphi}^2 + V(\varphi)}{3M_p^2}$$

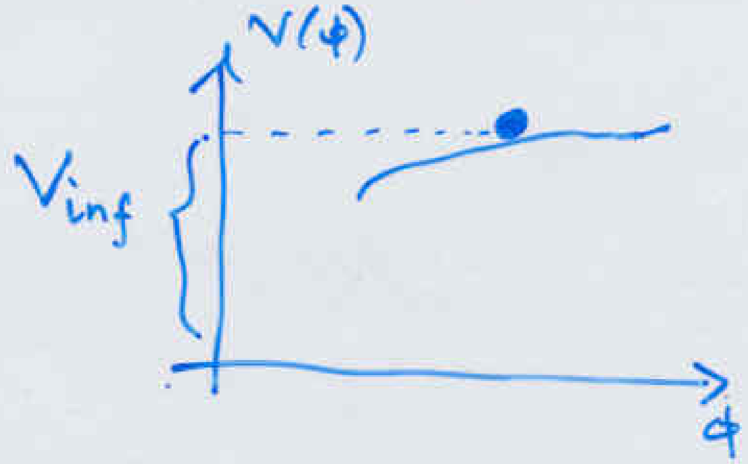
$$\dot{\varphi}^2 \ll V(\varphi)$$

slow roll condition:

$$V'' \ll H^2$$

Let us see how natural is this condition in the view of quantum gravity corrections.

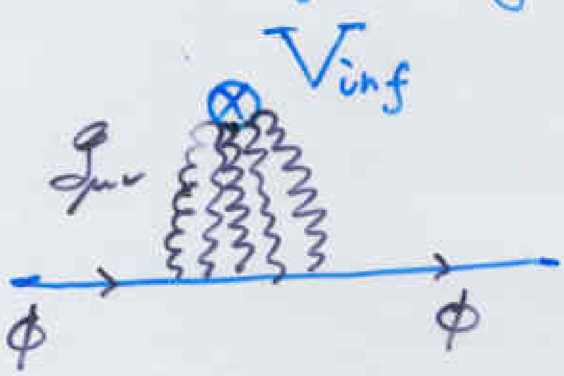
Expand theory about the inflationary trajectory.



$$S = \int d^4x \sqrt{-g} \left[\nabla_\mu \Phi g^{\mu\nu} \nabla_\nu \Phi - m^2 \phi^2 - V_{inf} + \dots \right]$$

slow roll condition $m^2 \ll \frac{V_{inf}}{M_p^2} = 3H^2$

Quantum gravity corrections:



$$\Longrightarrow \quad \Phi^2 \frac{V_{inf}}{M_p^2} = \phi^2 H^2$$

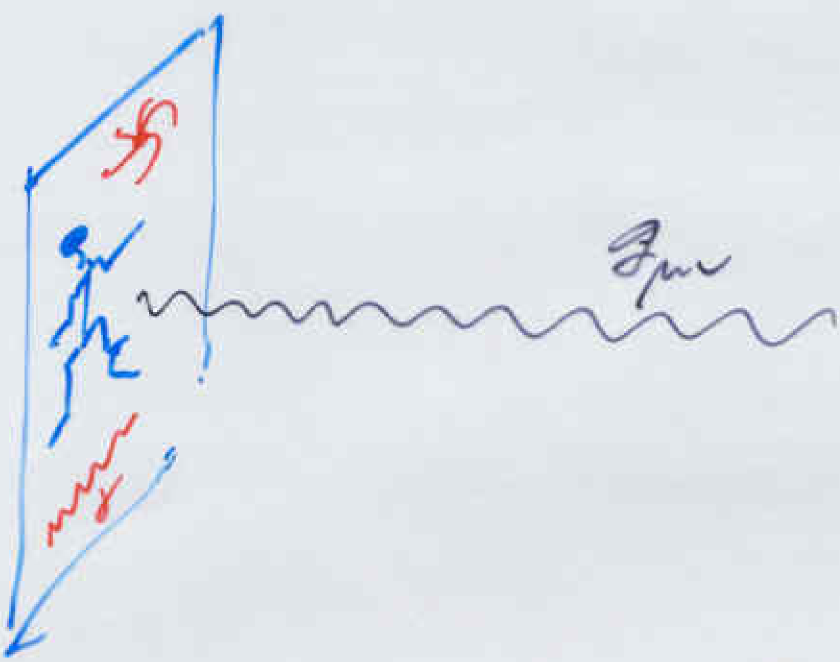
This term is a disaster since it generates mass to inflaton of order H^2!

So terms like $\phi^2 \frac{V_{inf}}{M_p^2} \sim \phi^2 H^2$ cannot be forbidden by any symmetries at effective field theory level.

So they have to be absent because of some selection rules in [redacted] fundamental theory that includes Quantum gravity.

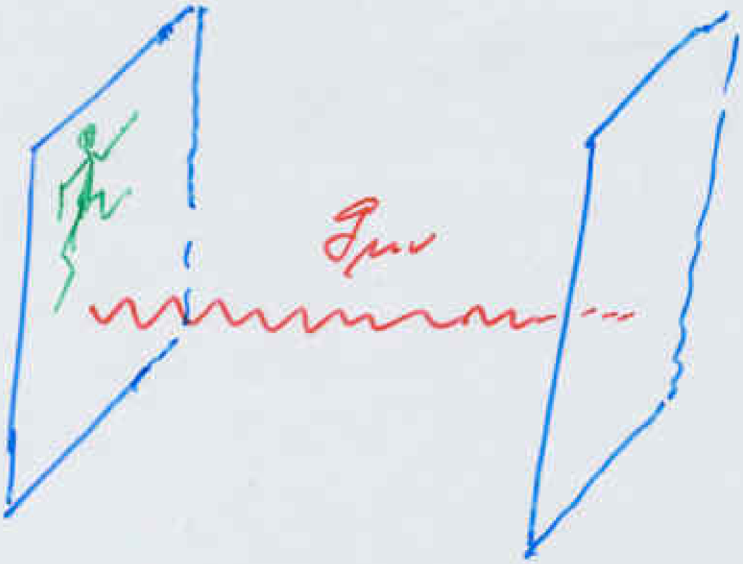
[redacted] example of such situation is "brane inflation": inflation driven by moving branes.

"Braneworld:"



Brane Inflation

H. Tye & G.D. '98

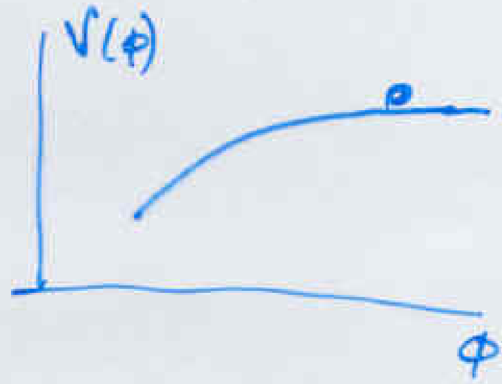


$$V(r) \simeq M^4 \left[1 - \frac{1}{(rM)^{N+1}} \right]$$

When branes move relative to each other, an observer on the brane sees a slowly rolling scalar field

$$\phi = M^2 r$$

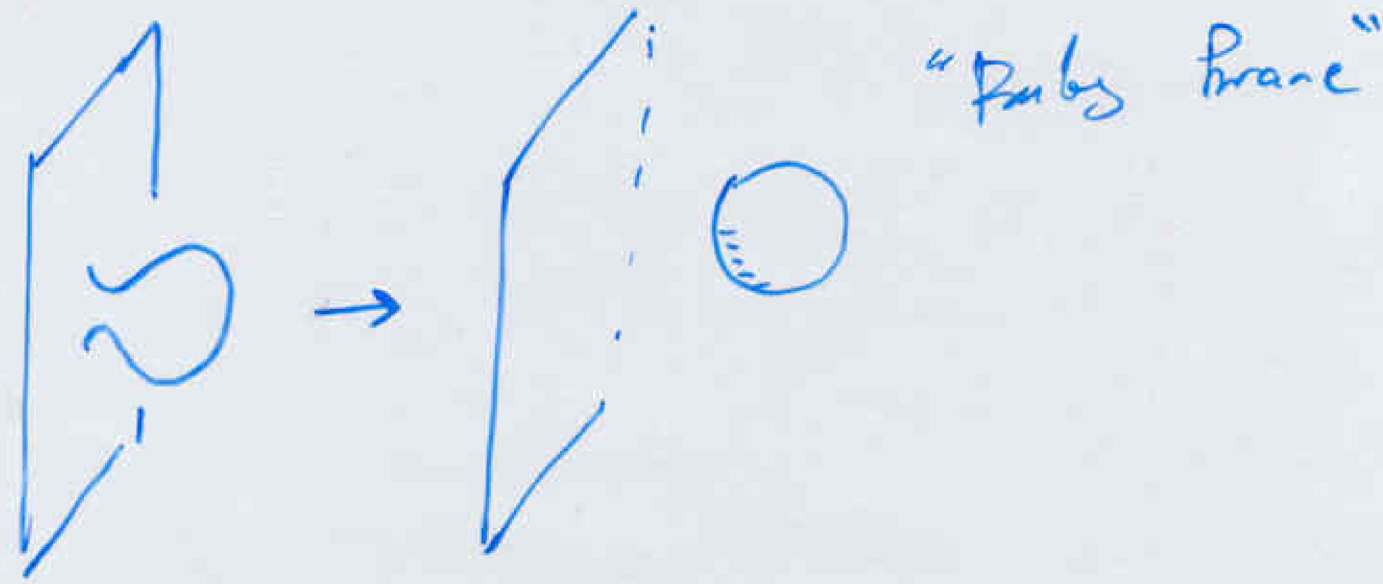
$$V(\phi) = M^4 \left(1 - \left(\frac{M}{\phi}\right)^{N+1} \right)$$

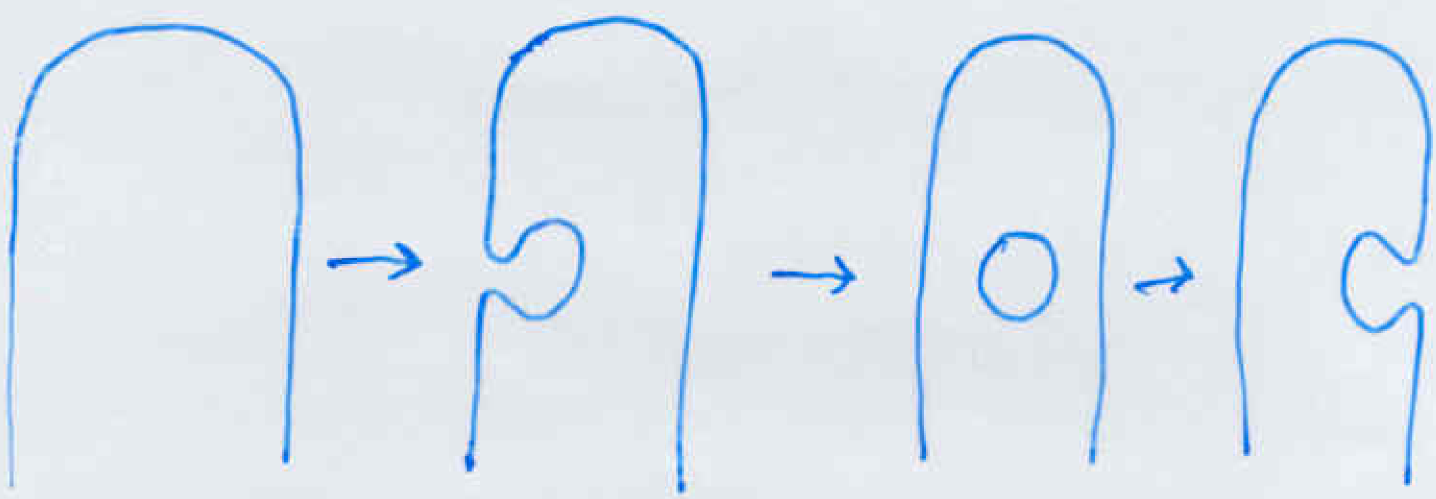


branes fall slowly because at large distances gravity is week. (jus by Gauss's law!). This is just a locality in the extra space and no quantum gravity corrections can change this

Baryon number from colliding branes. (G. Gabadadze & G.D)

In the brane models there is an universal source of baryon number non-conservation.



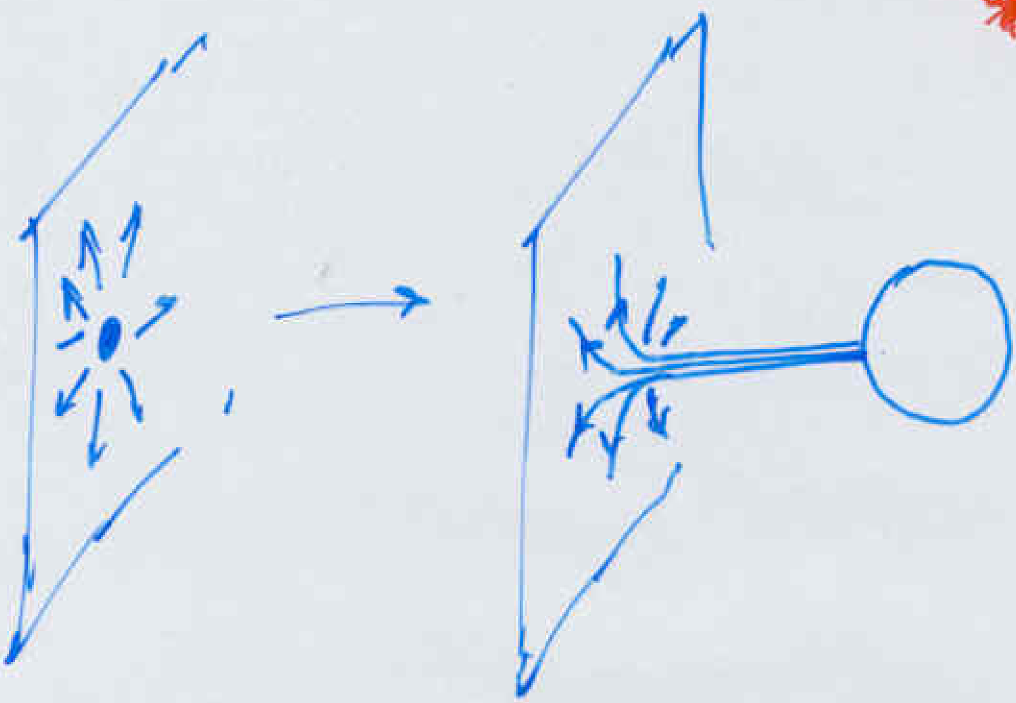


An observer on the brane will see:

$u + d + d = n \longrightarrow X$

Charge must be conserved on the brane if the gauge fields are localized there. This is just because of flux conservation.

Shifman & G.D.



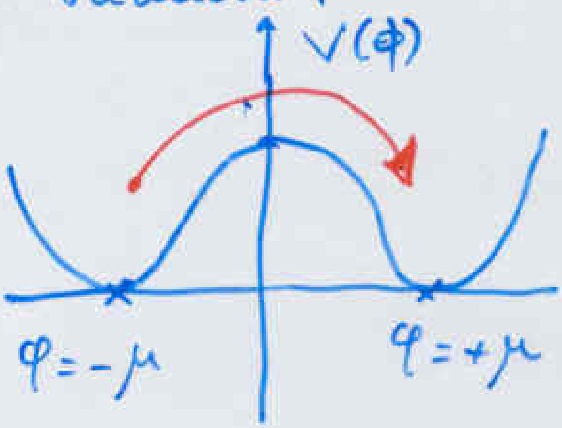
A toy model with brane-collision baryogenesis.

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \varphi)^2 - \frac{1}{4}(\varphi^2 - \mu^2)^2 + \varphi \bar{\Psi} \Psi + i \bar{\Psi} \not{\partial}_{(5)} \Psi$$

there is an exact $U(1)_B$-symmetry

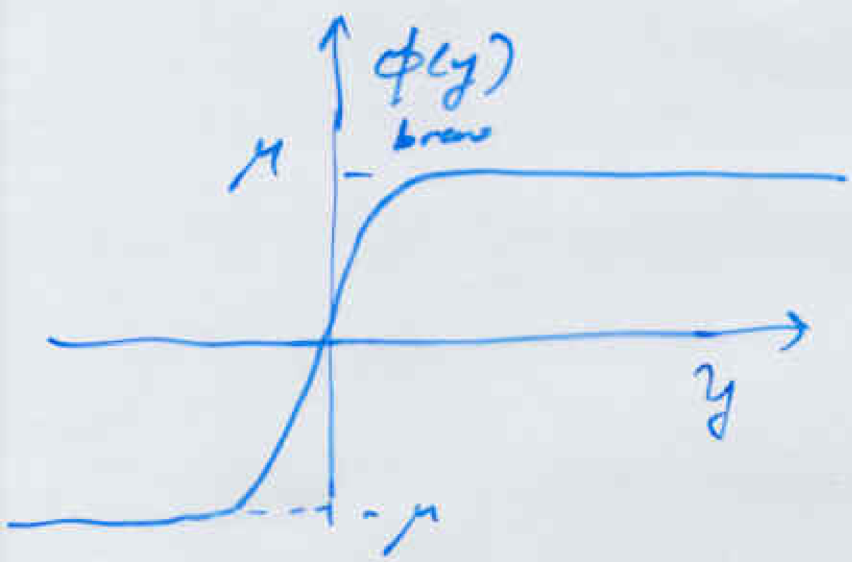
$$\Psi \to e^{i\alpha} \Psi.$$

vacuum:



domain wall solution (brane):

$$\varphi_{brane} = \mu \, th(\mu y)$$



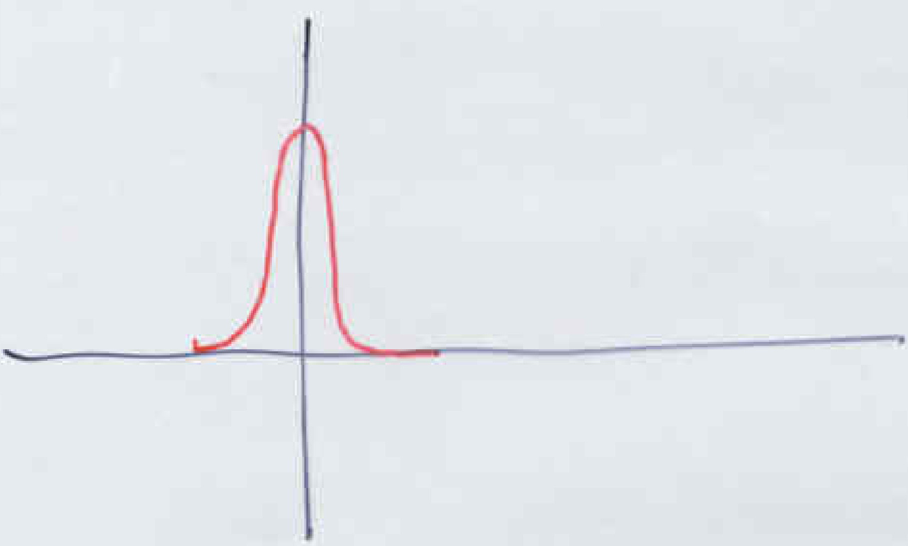
There is a massless fermion localized on the wall:

$$\left\{ i\not{\partial}_{(5)} + \varphi_{\text{brane}}(y) \right\} \psi(x,y) = 0$$

$$\psi(x,y) = \psi_0(x)\, f(y) + \dots \text{ heavy states.}$$

$$i\not{\partial}_{(4)} \psi_0(x) = 0$$

$$f(y) = \frac{1}{e^{y} + e^{-y}}$$



Brane observer sees a massless fermion $\psi_0(x)$ that carries a baryon number.

Now take and double the content.

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \varphi)^2 - \frac{1}{4}(\varphi^2-\mu^2)^2 + i\bar\psi \not{\partial}_5 \psi + \varphi\bar\psi\psi +$$

$$+ \frac{1}{2}(\partial_\mu \varphi')^2 - \frac{1}{4}(\varphi'^2-\mu^2)^2 + i\bar\psi' \not{\partial}_5 \psi' + \varphi'\bar\psi'\psi' +$$

$$+ (\bar\psi\psi')^2 + \dots$$

there is a single $U(1)_B$-symmetry:

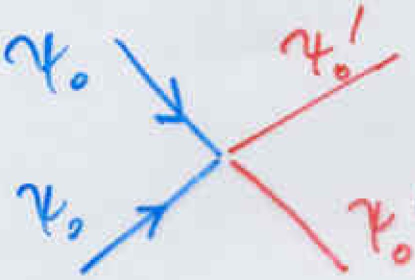
$$\psi \to e^{i\alpha}\psi, \quad \psi' \to e^{i\alpha}\psi'.$$

There are two massless modes localized on different branes.

effective low energy action

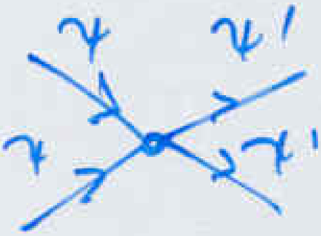
$$\mathcal{L} = i\bar\psi_0 \not{\partial} \psi_0 + i\bar\psi_0' \not{\partial} \psi_0' +$$

$$+ e^{-r(t)\mu}(\bar\psi_0 \psi_0')^2$$



← are exponentially suppressed.

when branes are far there are
__two__ $U(1)_B \otimes U(1)_{B'}$ symmetries.



when branes are close each observer thinks that his/her own $U(1)_B$ is violated!

So baryon number on each brane can be generated in brane collision!

We can generate ΔB at very low temperatures

$T \lesssim 1-10$ GeV !