Dark Matter from vector-like Technicolor. Part II.

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Model of vector-like Technicolor with two Techni-quark generations and zero hypercharge contains a number of diquark states (bound states of Techni-quarks). We consider a triplet of scalar Techni-baryons - B-baryons (diquarks) as possible carriers of the Dark Matter. As it follows from direct calculations of mass splitting between components of the triplet, its neutral component is the lightest. Due to smallness of the splitting all possible coannihilation processes of this Technicolor Dark Matter were taken into account in analysis of the Dark Matter relic abundance formation. The scenario predicts value of B-baryons mass $\simeq 1\,\mathrm{TeV}$ and gives strong relation between some model parameters which can be interesting for the LHC.

1 Introduction

The vector-like Technicolor model based upon SU(2) confined gauge symmetry was previously studied in articles [1, 2], some important details were discussed also in the [3] and in the report of V. Beylin at this Workshop. Namely, the model contains doublet of Techni (T)-quarks

$$\tilde{Q} = \begin{pmatrix} U \\ D \end{pmatrix}, \qquad (1)$$

having hypercharge $Y_{\tilde{Q}} = 0$. There arise heavy composite diquark scalar states possessing an additional conserved quantum Techni-baryon number T_B

$$B^+ = UU,\ B^- = DD,\ B^0 = UD,\ T_B = +1$$

$$\overline{B}^+ = \overline{UU},\ \overline{B}^- = \overline{DD},\ \overline{B}^0 = \overline{UD},\ T_B = -1$$

$$\tilde{\pi}^+ = U\overline{D},\ \tilde{\pi}^0 = \frac{1}{\sqrt{2}}(U\overline{U} - D\overline{D}),\ \tilde{\pi}^- = \overline{U}D,\ T_B = 0.$$

The model considered operates with vector-like interaction of Dirac type T-fields, all needed parts of the Lagrangian can be extracted from references above. Preliminary, we estimate B-baryon masses as $\simeq 1 - 2\,\mathrm{TeV}$. However, it is necessary to calculate mass splitting in the B-triplet to reach the conclusion that the lightest triplet component can be the Dark Matter (DM) particle. Besides, a smallness of the mixing between (standard) Higgs boson (here we do not introduce a composite scalar state that is insufficient for the case) and $\tilde{\sigma}$-meson (an analog of low-energy $\sigma-$ meson) is used to provide an agreement with measured characteristics of the SM Higgs boson with $M_h \approx 125\,\mathrm{GeV}$. Remind that T-mesons, T-baryons and other bound states of T-fermions are introduced in the framework of Techni-sigma model in an analogy with low-energy hadron physics.

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2 T-baryon mass splitting

The mass splitting between charged and neutral components of the T-baryon triplet occurs due to loop contributions (corresponding diagrams are shown in Fig.1). Non-zero mass splitting follows from electroweak interaction only, because of all Techni-strong exchanges cancel each other.

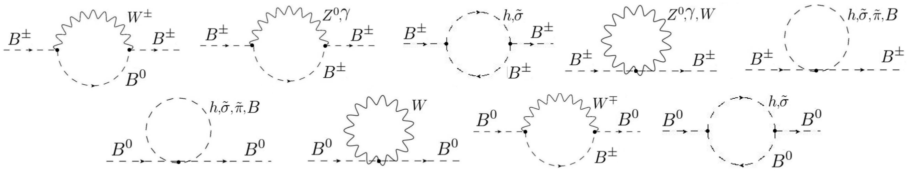

Figure 1: T-baryon triplet mass splitting one-loop diagrams

Due to EW character of interaction, exact formula for T-baryon mass splitting involves known masses and couplings from the Standard Model (SM), so T-baryon mass (M_B)remains the only free parameter. For the mass splitting we get:

$$\begin{aligned}\Delta M_B = \frac{g_2^2 M_W^2}{16\pi^2 M_B} \Bigg(& ln\left(\frac{M_Z^2}{M_W^2}\right) - \beta_Z^2 \ln(\mu_Z) + \beta_W^2 \ln(\mu_W) \\ & - \frac{4\beta_Z^3}{\sqrt{\mu_Z}} \left[arctg\left(\frac{2-\mu_Z}{2\sqrt{\mu_Z}\beta_Z}\right) + arctg\left(\frac{\sqrt{\mu_Z}}{2\beta_Z}\right)\right] \\ & - \frac{4\beta_W^3}{\sqrt{\mu_W}} \left[arctg\left(\frac{2-\mu_W}{2\sqrt{\mu_W}\beta_W}\right) + arctg\left(\frac{\sqrt{\mu_W}}{2\beta_W}\right)\right] \Bigg)\end{aligned} \tag{2}$$

where $\mu_V = M_V^2/M_B^2$, $\beta_V = \sqrt{1-\mu_V/4}$ and G_F is Fermi constant. We found that ΔM_B depends on M_B very weakly (see Fig.2), so we use the value $\Delta M_B \approx 160\,\mathrm{MeV}$ in a very wide interval of M_B masses. Importantly, $\Delta M_B \ll M_B$.

3 Cosmological evolution

Cosmological evolution of T-baryon (as the DM) density in the early Universe is determined by annihilation processes. Annihilation of T-baryons can take place in two phases: high-symmetry and low-symmetry phase, in other words, before or after the EW phase transition epoch. Here we consider T-baryon abundance formation mainly in the low-symmetry phase. This means that the T-baryon mass must be less than 2 TeV, so freeze-out temperature, $T_f \simeq \frac{M_B}{20}$ less than the EW phase transition temperature $T_{EW} \sim 100 - 200\,\mathrm{GeV}$.

To calculate T-baryon abundance we use following relation from Ref. [4]:

$$\Omega_{TB} \simeq 0.2 \left[\frac{(\sigma v)_{ann}^{DM}}{(\sigma v)_{tot}}\right] \tag{3}$$

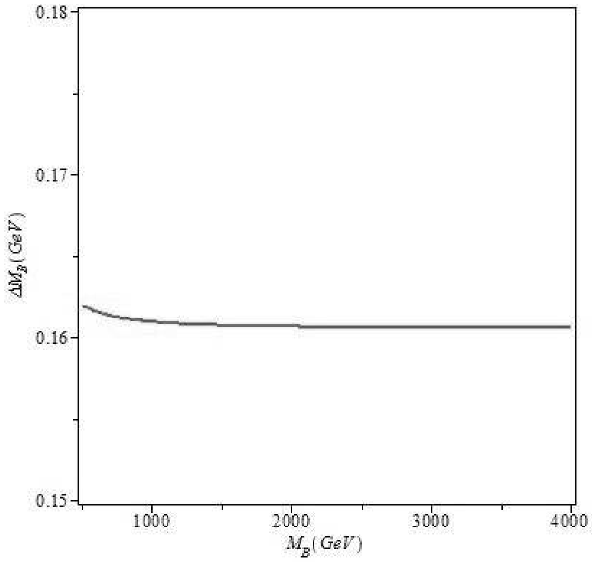

Figure 2: T-baryon triplet mass splitting as function of M_B

$$(\sigma v)^{DM}_{ann} \simeq 2.0 \times 10^{-9} GeV^{-2} \tag{4}$$

To estimate some parameters of the model, we compare calculated relative density of the model DM with experimental data of WMAP nine-year mission [5] $\Omega_{CDM}h^2 = 0.1138 \pm 0.0045$. In an analogy with conventional baryons, it can be T-Baryon asymmetry which is crucial for the scalar T-baryon Dark Matter amount (it is essential in the case of large T-baryon-scalar couplings). So, the T-baryon asymmetry can completely determine the amount of such DM in the present Universe in the case of too fast annihilation rates.

Because of relatively small mass splitting, charged T-baryons have a large lifetime, $\sim (4-5)$ ns; this value is comparable with the time of the low-symmetry phase start. This means that the charged T-baryons do participate in the formation of the DM relic abundance. Therefore, processes of all B-triplet components coannihilation should be taken into account. We perform this procedure with the known approach from Ref. [6], for example, and it uses following equations:

$$\sigma_{eff} = \sum_{ij}^{N} \sigma_{ij} \frac{g_i g_j}{g_{eff}^2} (1+\Delta_i)^{3/2} (1+\Delta_j)^{3/2} exp\left(\frac{-M_B(\Delta_i+\Delta_j)}{T}\right)$$
$$g_{eff} = \sum_{i=1}^{N} g_i (1+\Delta_i)^{3/2} exp\left(\frac{-M_B\Delta_i}{T}\right),\ \Delta_i = \frac{M_i - M_B}{M_B} \tag{5}$$

Making use of this equation we will assume that the initial density of all components of the T-baryon triplet is essentially the same.

All types of annihilation and coannihilation processes are listed in Table 1. (see also Fig.3). Totally there are 52 processes, 25 of them are different and united into groups. Cross sections for these processes has been calculated analytically in the leading approximation: $s \simeq 4M_B^2\left(1+\frac{v^2}{4}\right)$, $v \ll 1$ which corresponds to Cold DM consideration.

Table 1: List of B-baryons (co)annihilation channels

Initial states	Final states	Types of final particles
$B^+\overline{B}^+(B^-\overline{B}^-)$	$W^+W^-, \gamma\gamma, ZZ, \gamma Z, f\overline{f}$	EW fields
$B^+\overline{B}^+(B^-\overline{B}^-)$	$\tilde{\pi}^+\tilde{\pi}^-, \tilde{\pi}^0\tilde{\pi}^0, hh, \tilde{\sigma}\tilde{\sigma}, h\tilde{\sigma}$	TC fields
$B^\pm\overline{B}^0(B^0\overline{B}^\mp$	$\gamma W^\pm, ZW^\pm, l\overline{\nu}_l, \overline{l}\nu_l, u\overline{d}, d\overline{u}$	EW fields
$B^\pm\overline{B}^0(B^0\overline{B}^\mp$	$\tilde{\pi}^0\tilde{\pi}^\pm$	TC fields
$B^0\overline{B}^0$	$W^+W^-, ZZ, f\overline{f}$	EW fields
$B^0\overline{B}^0$	$\tilde{\pi}^+\tilde{\pi}^-, \tilde{\pi}^0\tilde{\pi}^0, hh, \tilde{\sigma}\tilde{\sigma}, h\tilde{\sigma}$	TC fields
$B^\mp\overline{B}^\pm$	$W^\mp W^\mp, \tilde{\pi}^\mp\tilde{\pi}^\mp$	EW and TC fields

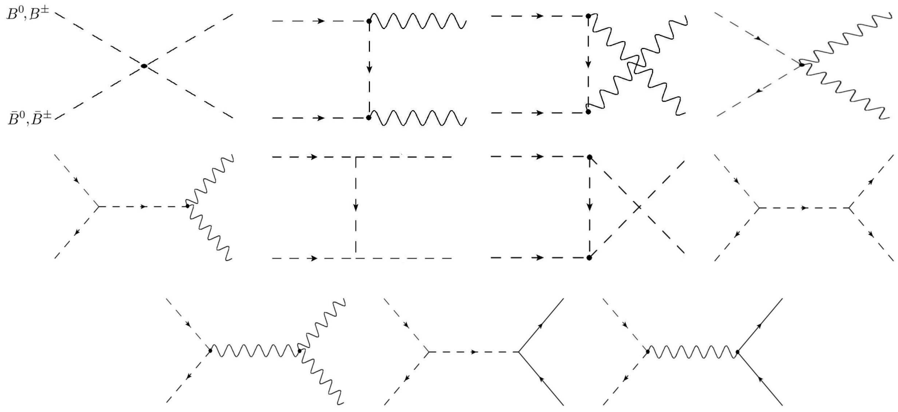

Figure 3: Types of coannihilation diagrams

In general, this cross section depends on a large number of parameters: particle masses and scalar self-coupling constants. In numerical analysis we consider for simplicity simple vector-like Technicolor scenario in the near-conformal regime setting all scalar self-couplings approximately equal each other (basic conclusions are unaltered in this case).

$$g_{B,i} = g_{TC} = \frac{M_{\tilde{Q}}}{u},\ M_{\tilde{Q}} \simeq \frac{M_B}{2} \tag{6}$$

So, in this simplified scenario we have only three independent free parameters: M_B, $m_{\tilde{\pi}}$, $\Delta m_{\tilde{\sigma}}$. Here, instead of $M_{\tilde{\sigma}}$ we use following linear combination: $\Delta m_{\tilde{\sigma}} = M_{\tilde{\sigma}} - \sqrt{3}m_{\tilde{\pi}}$; it relates Higgs and T-$\tilde{\sigma}$ mixing behavior with this combination: $S_\theta \to 0$ corresponds to $\Delta m_{\tilde{\sigma}} \to 0$.

4 T-baryon DM relic abundance

To calculate relic density of the Technicolor DM it is necessary to get T-baryon kinetic (co)annihilation cross section, namely, we consider annihilation of charged T-baryons with its antiparticles in different channels (see Fig.4).

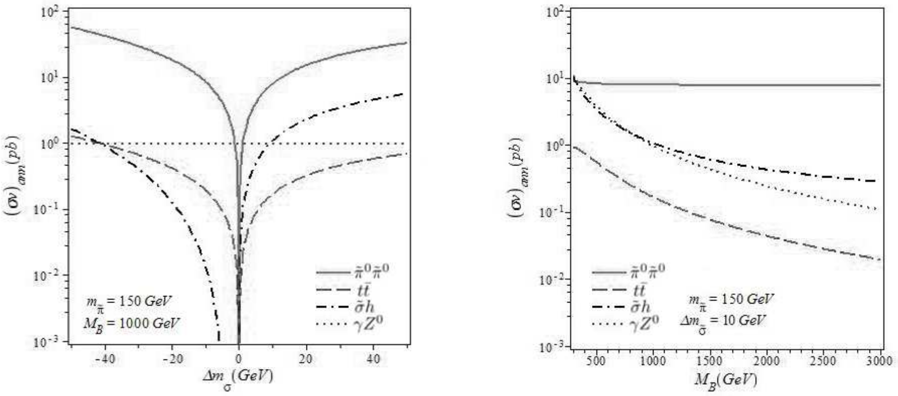

Figure 4: Cross-sections of coannihilation in various channels

From this qualitative analysis we conclude that T-baryon (co)annihilation cross sections in the scalar (pseudoscalar) and spinor channels vanish in the limit of small $h - \tilde{\sigma}$ mixing. So, in the limit relic DM density is determined only by T-baryons annihilation to the SM vector bosons. Now, with kinetic cross sections in hand we can calculate the model DM relic density as it was mentioned before. First, we show that the processes of coannihilation play an important role in the DM formation. We demonstrate here the ratio of relic abundances calculated with and without account of coannihilation processes as a function of different parameters. Obviously, inclusion of the coannihilation is reasonable both from qualitative and quantitative viewpoint: it changes kinetic cross section value substantially, see Fig.5.

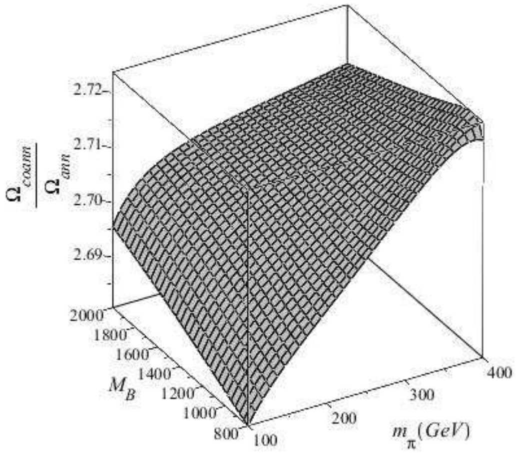

Figure 5: Ratio of relic abundances calculated with and without account of coannihilation

Then, we present in Fig.6 relic abundance of T-baryon DM depending on various theoretical parameters, experimental value of the DM relic density marked with the horizontal bar. From the analysis it follows that the most important parameters for the relic density are M_B and $\Delta m_{\tilde{\sigma}}$, and dependence on T-pion mass is relatively weak.

As to other parameters values, we identify a lower limit of the T-baryon mass as $M_B \simeq 1.0\,\text{TeV}$ and upper

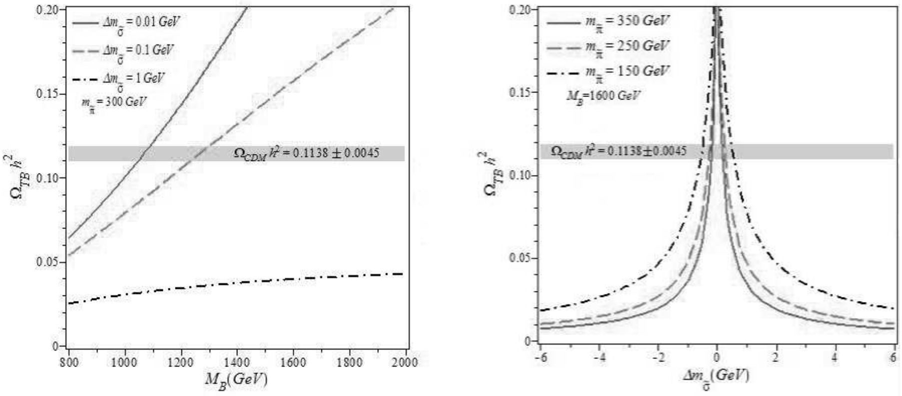

Figure 6: T-baryon relic abundance as a function of M_B and $\Delta m_{\tilde\sigma}$, $m_{\tilde\pi}$ is a free parameter

limit for $|\Delta m_{\tilde\sigma}| \simeq 1.5\,\mathrm{GeV}$. Note, in principle mass of T-pions can be considered as large - up to 1 TeV, however it corresponds to small $\Delta m_{\tilde\sigma} \leq 0.01\,\mathrm{GeV}$ and $m_{\tilde\sigma} \simeq 600\,GeV$. Let's remind also that we consider the Dark Matter consisting of T-baryons only, and do not analyze hypothesis of the DM asymmetry.

5 Summary and conclusions

T-baryon sector from the Technicolor model with vector-like interaction has been considered, it is suggested that the lightest component of the T-baryon triplet is the cold DM specimen. It was found from direct calculations that mass splitting in the T-baryon triplet is very small, $\Delta M_B \simeq 0.16\mathrm{GeV} \ll M_B$, so we must take into account coannihilation processes. All needed cross sections was calculated analytically in the leading approximation. Quantitative analysis results in conclusion that symmetric T-baryon DM formation in the low-symmetry phase is possible only under specific parameter values: $M_B = 1 - 1.2\,\mathrm{TeV}$ and $|\Delta m_{\tilde\sigma}| \leq 1\,\mathrm{GeV}$. This value of $\Delta m_{\tilde\sigma}$ is in agreement with the smallness of Higgs and T-sigma mixing following from previous studies [1]. Also, this implies that there is strong relation between T-sigma and T-pion masses $M_{\tilde\sigma} - \sqrt{3}m_{\tilde\pi} \approx 0$. So, from astrophysical data on the DM relic abundance there are follow (under the DM carriers and structure of interactions assumptions) estimates of the model parameters. Prediction for M_B and relation between $m_{\tilde\sigma}$ and $m_{\tilde\pi}$ can be useful for future LHC experiments. Note, interesting question on the T-pion stability and possibility for the DM to be multicomponent including stable T-pions will be discussed in the next paper.

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