Composite Neutrinos and Baryogenesis Identity

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Abstract

Excited leptons that share the lepton numbers with the Standard Model leptons, but have larger masses, are predicted in the theories of compositeness. I will discuss the bounds on the excited neutrino masses that are still allowed to be of order 1 TeV. Then I will introduce possible generation of the baryon asymmetry of the universe using these new particles. The discussed baryogenesis does not contradict to the small masses of the observable neutrinos and the proton stability.

Outline

Introduction on Compositeness and Excited Leptons

Motivation for physics beneath lepton-quark level

Indications on possible nonfundamentality of the SM fermions

- Large number of them: $\{e^-, \nu, u, d$ and their antiparticles$\} \times 3$ generations;
- Fractional electric charge of quarks;
- Arbitrary fermion masses and mixing parameters;
- Similarity between leptons and quarks in the SM flavor and gauge structure;
- Dark matter, cosmic-ray anomalies, etc.

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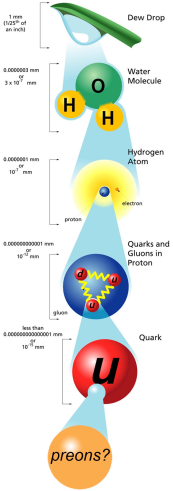
Alternative possibility with non-elementary ℓ and q is considered in the models of particle compositeness.

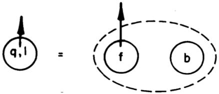


Many theories of compositeness use various names of the fundamental particle subcomponents: *subquarks, maons, alphons, quinks, rishons, tweedles, helons,* ***haplons****, Y-particles, primons. . .*

Most commonly fermion subcomponents are referred as **preons** [Pati, Salam, 1974].

Typically models of fermion compositeness predict **new heavy composites**, which can be constructed using their sets of preons: *excited fermions, fermionic color multiplets, new gauge bosons, etc.*

Some compositeness models



[Pati, Salam and Strathdee, '74]

[Akama, Chikashige and Terazawa, '77]

New composites in Haplon Models [Fritzsch, '81,...]

These models are based on the symmetry $SU(3)_c \times U(1)_{em} \times SU(N)_h$, and contain the two cathegories of colored preons (haplons): fermions $\alpha^{-1/2}$ and $\beta^{+1/2}$, and scalars $x^{-1/6}$, $y^{+1/2}$, ...

SM particles: $\nu_e = (\bar{\alpha}\bar{y})_1$, $e^- = (\bar{\beta}\bar{y})_1$, $d = (\bar{\beta}\bar{x})_3$, $W^- = (\bar{\alpha}\beta)_1$, ...
New composites: leptoquark $(\bar{x}y)_{\bar{3}}$, leptogluon $(\bar{\beta}\bar{y})_8$, ...

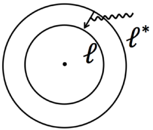
Another possibility is the multipreon states: e^* $(\bar{\beta}\bar{x}\bar{y}x)_1$, etc.
This case gets more points from recent discoveries [Aaij et al., '15] of the multiquark states due to similarity between QCD and haplon dynamics.

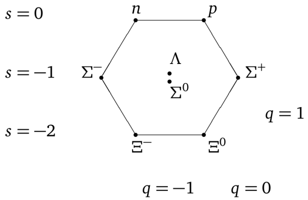
Mass bounds for some heavy composite fermions

- Color (anti)sextet quarks q_6: $m_{q_6} > 84\,\text{GeV}$ [CDF: Abe, PRL 63, 1447]
  $(\bar{3} \times \bar{3} = 3 + \bar{6})$
- Color octet neutrinos ν_8: $m_{\nu_8} > 110\,\text{GeV}$ [CDF: Barger, PL B220, 464]
  $(3 \times \bar{3} = 1 + 8)$
- Color octet charged leptons ℓ_8: $m_8 > 86\,\text{GeV}$ [CDF: Abe, PRL 63, 1447]

More recent

- New bound on ℓ_8 mass: $m_8 > 1.2\,\text{TeV}$ [Goncalves-Netto et al., '13]
- Leptoquarks LQ: $m_{LQ} > 845\,\text{GeV}$ [CMS PAS EXO-12-041]
  (1st generation)
- Excited ℓ^* and q^*: $m^* \gtrsim 1\,\text{TeV}$ [ATLAS, CMS]





Excited lepton shares the leptonic quantum number with one of the SM leptons and has larger mass.

Compare to **baryon octet** - proton, neutron and "excited" baryons.

Essentially, ℓ^* can be lighter than leptoquarks and leptogluons due to the absence of color dressing.

Notice that some kinds of excitations of the leptons and quarks may be not stable (like the bound states of t quark).

Contact interactions for the SM fermions f and the excited fermions f^* are usually written in the color-singlet chirally invariant form as

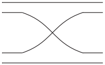
$$\mathcal{L}_{\rm CI} = \frac{g_*^2}{2\Lambda^2} j^\mu j_\mu, \quad j^\mu = \sum_{\alpha=L,R} (\eta_\alpha \bar{f}_\alpha \gamma^\mu f_\alpha + \eta'_\alpha \bar{f}^*_\alpha \gamma^\mu f^*_\alpha + \eta''_\alpha \bar{f}^*_\alpha \gamma^\mu f_\alpha) + \text{H.c.},$$

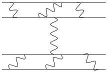
where Λ is the contact interaction scale, $g_*^2 = 4\pi$, and the new parameters $\eta^j \leq 1$ assigned in the fermion current j^μ.

However **more generic form** for the contact interactions is [PDG2016]

$$\begin{aligned}\mathcal{L}_{\rm CI} &= \frac{g_*^2}{2\Lambda^2} \sum_{\alpha,\beta=L,R} \left[\eta_{\alpha\beta}(\bar{f}_\alpha \gamma^\mu f_\alpha)(\bar{f}_\beta \gamma^\mu f_\beta) + \eta'_{\alpha\beta}(\bar{f}_\alpha \gamma^\mu f_\alpha)(\bar{f}^*_\beta \gamma^\mu f^*_\beta)\right. \\ &+ \left.\tilde{\eta}'_{\alpha\beta}(\bar{f}^*_\alpha \gamma^\mu f^*_\alpha)(\bar{f}^*_\beta \gamma^\mu f^*_\beta) + \eta''_{\alpha\beta}(\bar{f}_\alpha \gamma^\mu f_\alpha)(\bar{f}^*_\beta \gamma^\mu f_\beta) + \text{H.c.} + \ldots\right],\end{aligned}$$

since it has more free parameters, e.g., the 3 scales of $\eta_{\alpha\beta}$, $\eta'_{\alpha\beta}$ and $\tilde{\eta}'_{\alpha\beta}$ can be different, and can not arise from the 2 scales of η_α and η'_α.





Contact interactions may proceed by the constituent exchange, if the fermions have common constituents, and/or by exchange of the binding quanta of the new interaction that couples to the constituents of both particles.

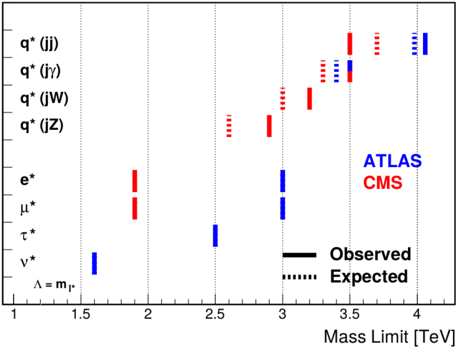
Problem: The scale of constituent binding energies ($\gtrsim 1$ TeV) is much larger than the SM fermion masses.

't Hooft, Dimiopoulos, Raby and Susskind in 1980 developed mechanisms to understand how forces which operate on the TeV scale (or above) can conspire to produce the light SM particles. Generically this requires the chiral current conservation, and involves the anomaly cancellation between the massless composite states and the fundamental fermions.

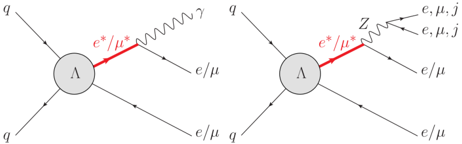
(In particular, hierarchies of light fermion masses may come from the secondary mass generation.)

Other ways to solve this problem are aslo discussed in the literature.

Mass bounds for excited fermions assuming $m_{f^*} = \Lambda$



[PDG2016; ATLAS: Aad, New J. Phys. 15, 093011; JHEP1508, 138]

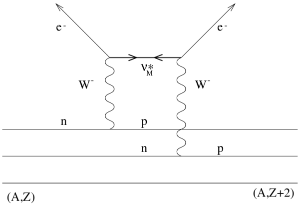


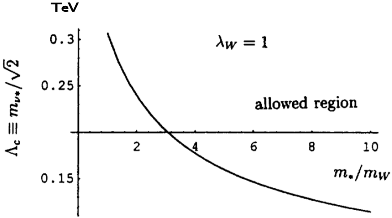
$m_{e^*(\mu^*)} < 2.45\ (2.47)$ TeV [CMS: Khachatryan, JHEP1603, 125]

$0\nu2\beta$ decay bound for excited Majorana neutrino

Composite N_M (ν_M^*) in the neutrinoless double beta decay is discussed:

- O. Panella and Y. Srivastava et al., '94, '97
  (their bound is stronger by one order of magnitude)
- E. Takasugi, '95, '97:





The lower bound on the composite scale $\Lambda_c \equiv m_{\nu*}/\sqrt{2}$ as a function of m_*/m_W.

For '94 limit of Heidelberg-Moscow exp.: $T_{1/2}(^{76}\mathrm{Ge}) > 5.6 \times 10^{24}$ yr.

Current bound is few times stronger: $T_{1/2}(^{76}\mathrm{Ge}) > 3 \times 10^{25}$ yr [1307.4720,1606.04886].

Notice that the usual assumption of $\Lambda \simeq M^*$ with the nearly maximal coupling constants η^j is not very natural for the effective interactions.

The fundamental couplings that bound together preons are expected to be large. However the "residue" couplings between the composites are expected to be relatively small.

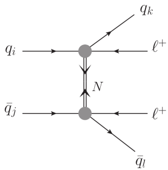
Then the other choice of $\Lambda \gg M^*$ with the nearly maximal η^j mimics the natural case with small η^j. Hence relatively light excited fermions f^* and even relatively small compositeness energy threshold are not excluded:

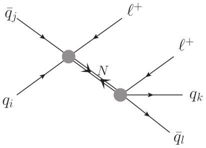
$$M^* \sim \Lambda \lesssim 1 \text{ TeV}$$

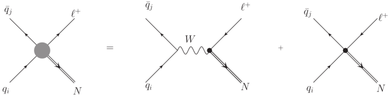
$$\eta^j \ll 1, \quad \frac{\Lambda}{\sqrt{\eta^j}} \gg M^*$$

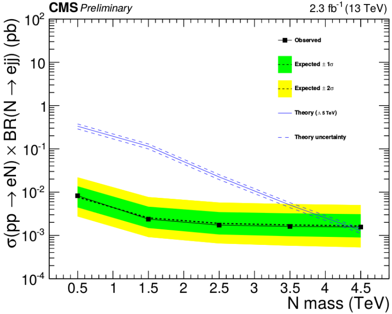
In this case the contact interactions can be observed at the **high-luminosity** LHC run, and even at the less energetic factories.

LHC bounds on composite neutrino $\nu^* \equiv N$ mass

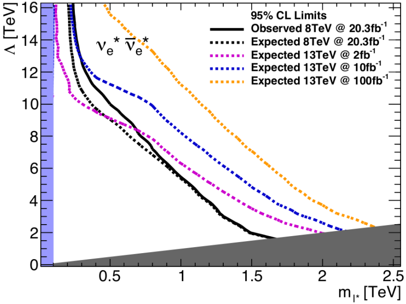








CMS bound on N_M mass for $\Lambda = 5$



ATLAS bounds on Λ vs. N_D mass

Hence $\frac{\sqrt{\eta''}}{\Lambda} \lesssim \frac{1}{5\ \text{TeV}}$ for N_M, and can be few times larger for Dirac N.

The limit of

$$\Lambda > \mathbf{a}^2 M^* \qquad \text{with} \qquad \eta'' = 1$$

very roughly translates to

$$\eta'' < \frac{1}{\mathbf{a}} \qquad \text{with} \qquad \Lambda = M^*.$$

Hence the discussed bounds will look more optimistic in coordinates η'' vs. M^* rather than Λ vs. M^*.

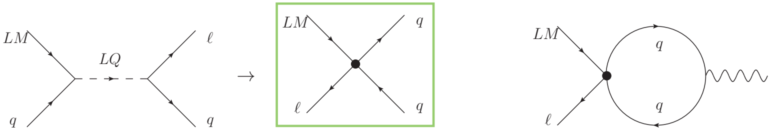
Example: the ATLAS limit of $\Lambda \gtrsim 20$ TeV for $M^* \simeq 200$ GeV and $\eta'' = 1$ reads as: $\eta'' \lesssim 0.1$ for $\Lambda \sim M^* \simeq 200$ GeV.

Leptomesons in Baryogenesis and Neutrino Masses

Leptomesons (LM) - excited leptons that at low energies interact with the SM fermions dominantly through contact terms.

(Do not miss with the bound states of $\ell_8^+\ell_8^-$ [Pitkänen, '90].)

Example: $\Lambda \sim M_{LQ} \ll \min(\Lambda_{\rm GM}, \frac{4\pi}{\eta''}\frac{\Lambda^2}{m_q})$



where $\Lambda_{\rm GM}$ is the scale of the gauge-mediated interactions

$$\mathcal{L}_{\rm GM} = \frac{1}{2\Lambda_{\rm GM}} \overline{LM}\, \sigma^{\mu\nu} \left(gF\frac{\tau}{2} W_{\mu\nu} + g'F'\frac{Y}{2} B_{\mu\nu} \right) P_\alpha L + \text{H.c.}$$

One of the most important observations, which can not be explained within the SM, is the baryon asymmetry of the universe

$$\eta_B \quad = \quad \frac{n_B - n_{\bar{B}}}{n_\gamma} = 7.04 \times \frac{n_B - n_{\bar{B}}}{s} \sim 6 \times 10^{-10},$$

which is derived indirectly by the two methods:

- CMB spectrum (n_γ) and anisotropies (n_B/n_γ) by modeling the acoustic oscillations of the baryon/photon fluid
- relic abundances of light elements: D, ^{3}He, ^{4}He, ^{7}Li,... using the predictions of nucleosynthesis

Baryogenesis (BG) mechanisms - possible scenarios of dynamical generation of η_B during the evolution of the universe from a hot early matter-antimatter symmetric stage.

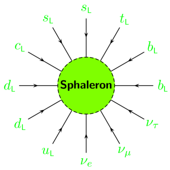
Majority of these scenarios discussed in the literature satisfy the three Sakharov ['67] conditions:

- Violation of baryon number symmetry;
- Violation of C and CP symmetries (to produce an excess of B over $\bar{B}$)
- Departure from thermal equilibrium (since $\langle B \rangle = 0$ in equilibrium)

The SM does not provide a successful BG due to the lack of *CP* violation and not strongly first order electroweak phase transition to achieve the departure from thermal equilibrium.

Though in the economical SM extensions η_B can be generated through the thermal **leptogenesis** (LG) mechanism where the lepton number asymmetry is produced in the out-of-equilibrium decays of heavy Majorana particles, and further the SM sphaleron processes convert it into the baryon asymmetry.

(Sphaleron transitions are effective at $T > T_{\rm EWSB} \sim 100$ GeV.)



However LG in the supersymmetric generalizations of the SM suffers from the **gravitino problem**, which comes from the too high reheating temperature related to the strong lower bound on the right-handed neutrino mass (Davidson-Ibarra bound). To avoid this problem the resonant mechanisms of LG were introduced.

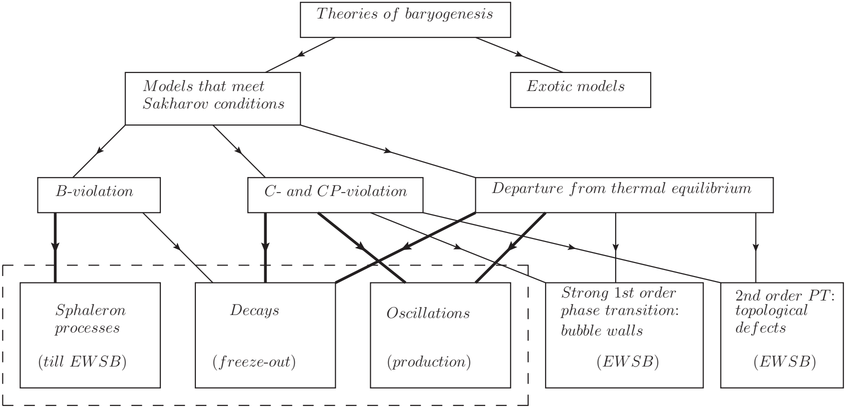


Figure : Types of BG and ways they meet Sakharov conditions.

The bold arrows are relevant to present consideration.

(Models that satisfy these conditions in a nontypical way are not specified here.)

Can neutral leptomesons provide the successful BG?

Similarly to the sterile neutrino case, depending on the properties of LMs the deviation from thermal equilibrium can occur at:

- **production**
  (so-called BG from oscillations [Akhmedov, Rubakov, Smirnov '98])
- **freeze-out and decay**
  (thermal LG [Fukugita, Yanagida '86])

In both scenarios for the case of LMs one should replace the Yukawa interaction $Y\bar{\ell}N_R\phi$ by the contact one. Possible effects are promising.

BG from LM oscillations

Once created in the early universe neutral long-lived LMs oscillate and interact with ordinary matter. These processes do not violate the total lepton number $L^{\rm tot}$ (for Dirac LMs). However the oscillations violate CP and therefore do not conserve individual lepton numbers L_i for LMs. Hence the initial state with all zero lepton numbers evolves into a state with $L^{\rm tot} = L + \sum_i L_i = 0$ but $L_i \neq 0$.

At temperatures $T \ll \Lambda$ the LMs communicate their lepton asymmetry to neutrinos ν_ℓ and charged leptons ℓ through the effective interactions, e.g., B-conserving (and L-conserving for Dirac LMs) vector couplings

$$\sum_{\psi_\ell, f, f'} \sum_{\alpha,\beta=L,R} \left[\frac{\epsilon^{\alpha\beta}_{ff'\psi_\ell}}{\Lambda^2} (\bar{f}_\alpha \gamma^\mu f'_\alpha)(\bar{\psi}_{\ell\beta}\gamma_\mu \ell^0_{M\beta}) + \frac{\tilde{\epsilon}^{\alpha\beta}_{ff'\psi_\ell}}{\Lambda^2} (\bar{\psi}_{\ell\alpha}\gamma^\mu f'_\alpha)(\bar{f}_\beta \gamma_\mu \ell^0_{M\beta}) \right] + \text{H.c.}$$

where $\psi_\ell = \ell, \nu_\ell$, constant $\overset{(\sim)}{\epsilon} = 4\pi\eta''$ can be real, f and f' denote either quarks or leptons such that $Q_{f_\alpha} + Q_{f'^c_\alpha} + Q_{\psi_{\ell\beta}} = 0$, and $\ell^0_M \equiv N_\ell$ is the neutral LM flavor state that is related to the mass eigenstates N_i as

$$N_{\ell\alpha} = \sum_{i=1}^n U^\alpha_{\ell i} N_i, \qquad \ell = e, \mu, \tau.$$

Suppose that LMs of **at least one type** i remain in thermal equilibrium until the time of EWSB $t_{\rm EW}$ at which sphalerons become ineffective, and those of **at least one other type** j come out-of-equilibrium by $t_{\rm EW}$. Hence the lepton number of the former (later) affects (has no effect on) the baryogenesis. In result, the final baryon asymmetry after $t_{\rm EW}$ is nonzero.

At the time $t \gg t_{\rm EW}$ all LMs decay into the leptons and the quarks (hadrons). For this reason they do not contribute to the dark matter in the universe, and do not destroy the Big Bang nucleosynthesis.

The system of n types of singlet LMs of a given momentum $k(t) \propto T(t)$ that interact with the primordial plasma can be described by the $n \times n$ density matrix $\rho(t)$. In a simplified picture this matrix satisfies the kinetic equation

$$i\frac{d\rho}{dt} = [\hat{H}, \rho] - \frac{i}{2}\{\Gamma, \rho\} + \frac{i}{2}\{\Gamma^p, 1 - \rho\},$$

where Γ (Γ^p) is destruction (production) rate, and effective Hamiltonian is

$$\hat{H} = V(t) + U\frac{\hat{M}^2}{2k(t)}U^\dagger,$$

where $\hat{M}^2 = \mathrm{diag}(M_1^2, \dots, M_n^2)$, and V is a real potential.

The 4-particle interaction cross section that contributes to the destruction rate is

$$\sigma(a+b\to c+d)=\frac{C}{4\pi}|\epsilon|^2\frac{s}{\Lambda^4}\propto s, \qquad [\ \sigma_N \propto s^{-1} \text{ for } N_R \text{ in ARS model}\ ]$$

where a, b, c and d denote the four interacting particles (f, f', ψ_ℓ and ℓ^0_M), $C=\mathcal{O}(1)$ is the constant that includes the color factor in the case of the interaction with quarks, and s is the total energy of the process.

The respective $2 \leftrightarrow 2$ scattering rate density for $M_i \ll T \ll \Lambda$ reads

$$\gamma \quad = \quad \frac{6C}{\pi^5} g_a g_b \, |\epsilon|^2 \frac{T^8}{\Lambda^4}, \qquad [\ \gamma_N \propto T^4\ ]$$

where g_a is the number of internal degrees of freedom of the particle a. Then the interaction rate that equilibrates LMs is

$$\Gamma \propto |\epsilon|^2 \frac{T^5}{\Lambda^4} \qquad [\ \Gamma_N \propto T\ ]$$

The conditions that LMs of type N_i remain in the equilibrium till the time of the EWSB t_{EW}, while N_j do not, can be written as

$$\begin{aligned} \Gamma_i(T_{EW}) &> H(T_{EW}), \\ \Gamma_j(T_{EW}) &< H(T_{EW}), \end{aligned}$$

where the Hubble expansion rate H is

$$H(T) \approx 1.66 g_*^{1/2} \frac{T^2}{M_{\text{Planck}}},$$

where M_{Planck} is the Planck mass, and $g_* \sim 10^2$ is the number of relativistic degrees of freedom in the primordial plasma.

These Γ are suppressed by the factor of $(T_{EW}/\Lambda)^4$ with respect to the Higgs mediated interaction rate in usual BG via sterile neutrino N_R oscillations. Hence the couplings ϵ can be significantly larger than the Yukawa couplings Y for N_R. In particular, for $\Lambda \gtrsim 10$ and 30 TeV we have $\epsilon \gtrsim 10^{-4}$ and 10^{-3}, respectively $[Y \gtrsim 10^{-7}]$.

Hence the considered scenario of the BG via neutral LMs can be relevant for the LHC and next colliders without unnatural hierarchy of couplings.

The asymmetry transformed to usual leptons by t_{EW} can be estimated as

$$\frac{n_L - n_{\bar{L}}}{n_\gamma} = \frac{1}{2} \sum_j |S_j^M(t_{EW}, 0)|^2_{CP-\text{odd}},$$

where the factor $1/2$ accounts for the photon helicities, and $S^M = U^\dagger S U$ is the evolution matrix in the mass eigenstate basis ($S(t, t_0)$ is the non-unitary evolution matrix corresponding to the operator $\hat{H} - (i/2)\Gamma$).

In the case of three LM mass states the *CP*-violating effects come from the Jarlskog determinant related to their mixing matrix U. However extra LM mass states can enrich the picture of *CP* violation.

Also additional *CP*-violating phases may come from the active neutrino sector similarly to the BG from N_R oscillations [Asaka, Shaposhnikov '05].

BG from LM decays

Suppose that the neutral LMs are Majorana particles ($N_\ell = N_\ell^c$). Consider their out-of-equilibrium, CP- and L-violating decays in the early universe.

The relevant interactions can be written as

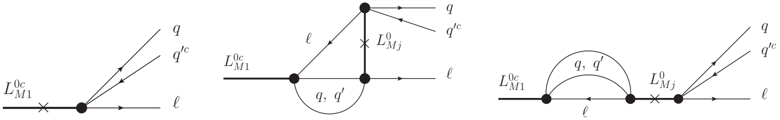
$$
\begin{aligned}
& \frac{\epsilon^{\alpha R}_{ff'\psi_\ell}}{\Lambda^2}(\bar{f}_\alpha \gamma^\mu f'_\alpha)(\bar{\psi}_{\ell R}\gamma_\mu N_\ell) + \frac{\epsilon^{S}_{ff'\psi_\ell}}{\Lambda^2}(\bar{f}_R f'_L)(\bar{\psi}_{\ell L} N_\ell) \\
+ \quad & \frac{\epsilon^{T}_{ff'\psi_\ell}}{\Lambda^2}(\bar{f}\sigma^{\mu\nu} f')(\bar{\psi}_{\ell L}\sigma_{\mu\nu} N_\ell) + \text{H.c.}
\end{aligned}
$$

To be more specific in the following we consider the term

$$
\frac{\lambda_{\ell i}}{\Lambda^2}(\bar{q}_\alpha \gamma^\mu q'_\alpha)(\bar{\ell}_R \gamma_\mu N_i),
$$

where $\lambda_{\ell i} = \epsilon^{\alpha R}_{qq'\ell} U^R_{\ell i}$ is the complex parameter.

Consider the interference of tree and one-loop diagrams



Final CP asymmetry produced in decays of the lightest LMs $N_1 \equiv L^0_{M1}$

$$\varepsilon_1 = \frac{1}{\Gamma_{\text{tot}}} \sum_\ell [\Gamma(L^0_{M1} \to \ell_R q_\alpha q'^c_\alpha) - \Gamma(L^{0c}_{M1} \to \ell^c_R q^c_\alpha q'_\alpha)],$$

can be **non-zero** if $\text{Im}[(\lambda^\dagger\lambda)^2_{1j}] \neq 0$. Using the total width of L_{M1}

$$\Gamma_{\text{tot}} = \sum_\ell [\Gamma(L^0_{M1} \to \ell_R q_\alpha q'^c_\alpha) + \Gamma(L^{0c}_{M1} \to \ell^c_R q^c_\alpha q'_\alpha)] \simeq \frac{1}{128\pi^3} (\lambda^\dagger\lambda)_{11} \frac{M_1^5}{\Lambda^4},$$

the condition for the decay parameter $K \equiv \Gamma_1/H(T = M_1) > 3$ (required in the strong washout regime) translates into the limit

$$(\lambda^\dagger\lambda)_{11} \gtrsim 4 \times 10^{-7} \times \left(\frac{\Lambda}{10\ \text{TeV}}\right)^4 \times \left(\frac{1\ \text{TeV}}{M_1}\right)^3.$$

Example:

The discussed effective LM-quark-quark-lepton vertex can be realized, e.g., through the exchange of $SU(2)_L$ singlet scalar leptoquark S_{0R} with $Y = 1/3$.

Relevant interaction terms in the Lagrangian can be written as

$$-\mathcal{L}_{\rm int} \quad = \quad (g_{ij}\, \bar{d}^c_R L^0_{Mi} + f_j\, \bar{u}^c_R \ell_R) S^j_{0R} + \text{H.c.}$$

Then the above expressions are valid with the replacements $\lambda \to g f^*$ and $\Lambda \to M_{S_{0R}}$. The relevant for the BG values of the new couplings of $|g| \sim |f| \sim 0.01 - 0.1$, can be interesting for the collider searches.

Notice that the new contributions to the CP asymmetry coming from the interferences with the one-loop diagrams that originate from the self-energy corrections to the leptoquark propagator cancel each other (for less than 3 interaction constants).

The final baryon asymmetry can be written as

$$\frac{n_B - n_{\bar{B}}}{s} = \left(-\frac{28}{79}\right) \times \frac{n_L - n_{\bar{L}}}{s} = \left(-\frac{28}{79}\right) \times \frac{\varepsilon_1 \kappa}{g_*},$$

where n_B, n_L and n_γ is the baryon, lepton and photon number density, respectively; s is the entropy density, and $\kappa \leq 1$ is the washout coefficient.

To exactly determine κ the complete set of Boltzmann equations should be solved.

Using the resonant CP asymmetry of

$$\varepsilon_i \sim \frac{\mathrm{Im}\{[(\lambda^\dagger\lambda)_{ij}]^2\}}{(\lambda^\dagger\lambda)_{ii}(\lambda^\dagger\lambda)_{jj}} \frac{\Gamma_j}{M_j} \frac{M_i M_j}{M_i^2 - M_j^2} \sim \mu^{-1} \frac{\Gamma_1}{M_1}$$

the observed baryon asymmetry $\eta_B \sim 6 \times 10^{-10}$ can be produced for the decay parameter of $K \sim 100$ with the degeneracy factor of

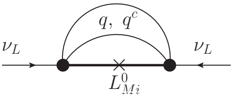
$$\mu \equiv \frac{M_2 - M_1}{M_1} \lesssim 10^{-6} \times \left(\frac{M_1}{1\ \mathrm{TeV}}\right).$$

Neutrino masses from LMs

For Majorana LMs among the considered generic interactions the terms

$$\frac{\epsilon^S_{ff\nu_\ell}}{\Lambda^2}(\bar{f}_R f_L)(\bar{\nu}_{\ell L}\ell^0_{MR}) + \frac{\epsilon^T_{ff\nu_\ell}}{\Lambda^2}(\bar{f}_R\sigma^{\mu\nu} f_L)(\bar{\nu}_{\ell L}\sigma_{\mu\nu}\ell^0_{MR}) + \text{H.c.}$$

can generate the two-loop contributions to the light neutrino masses m_{ν_ℓ}.



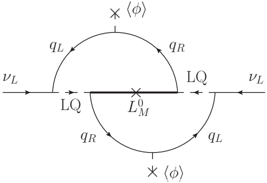


Figure : Discussed contribution to m_ν in case of $f = q$: effective diagram (left), and its particular realization in the model with leptoquarks LQ (right).

Naive estimate gives

$$m_{\nu_\ell} \sim \sum_i \frac{(\epsilon\, U^R_{\ell i})^2}{(16\pi^2)^2}\ \frac{M_i^3 m_f^2}{\Lambda^4},$$

Then present bound of $m_\nu \lesssim 2$ eV can be easily satisfied.

Conclusion

New scenarios of the baryogenesis in the models with leptomesons are introduced, which do not contradict to the observed neutrino masses and the proton stability.

The discussed baryogenesis mechanisms may take place at relatively low temperatures that can be interesting for the collider searches, and does not lead to analog of the gravitino problem.

It is my pleasure to thank
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THANK YOU FOR YOUR ATTENTION!

Backup Slides

The important difference from the standard LG is that the Davidson-Ibarra bound on the heavy neutrino masses M_N is in general not applicable to LM masses.
(This bound comes from the see-saw relation $m_\nu = v^2 Y^T \frac{1}{M_N} Y$).
Then the LM masses can be $M_{LM} \ll M_N \gtrsim 10^9$ GeV.

In both cases the required reheating temperature is not too high and analog of *gravitino problem* does not exist in the model with LMs.

Quark and lepton compositeness should manifest itself at low energies in **contact interactions** (lowest dim. interactions with 4 SM fermions)

$$L = \frac{g^2}{2\Lambda^2}[\eta_{LL}\bar{\psi}_L\gamma_\mu\psi_L\bar{\psi}_L\gamma^\mu\psi_L + \eta_{RR}\bar{\psi}_R\gamma_\mu\psi_R\bar{\psi}_R\gamma^\mu\psi_R + \eta_{LR}\bar{\psi}_L\gamma_\mu\psi_L\bar{\psi}_R\gamma^\mu\psi_R],$$

where Λ is the scale of compositeness, and $\eta_{\alpha\beta}$ can be selected as either ±1 or 0, e.g., $\Lambda = \Lambda^{\pm}_{LL}$ for $(\eta_{LL}, \eta_{RR}, \eta_{LR}) = (\pm1, 0, 0)$.

Present limits on $\Lambda_{\psi\psi\psi\psi}$ [PDG 2016]

$\Lambda_{\psi\psi\psi\psi}$	Bound on Λ^+_{LL} (Λ^-_{LL}), TeV	Experiment
Λ_{eeee}	> 8.3 (> 10.3)	RVUE - LEP2
$\Lambda_{ee\mu\mu}$	> 8.5 (> 9.5)	L3 (ALEPH)
$\Lambda_{ee\tau\tau}$	> 7.9 (> 7.2)	ALEPH, DLPHI (OPAL)
$\Lambda_{\ell\ell\ell\ell}$	> 9.1 (> 10.3)	DLPHI (ALEPH)
Λ_{eeqq}	> 23.3 (> 26.4)	LEP2, etc.
$\Lambda_{\mu\mu qq}$	> 12.5 (> 16.7)	ATLAS
$\Lambda_{\ell\nu\ell\nu}$	> 3.1 [for $\Lambda^{\pm}_{LR}$]	SPEC - TRIUMF
$\Lambda_{e\nu qq}$	> 2.81	CDF
Λ_{qqqq}	> 9.9	CMS

However dominant effects of compositeness may come from $\psi\psi gg$, $\psi^*\psi\psi\psi$, etc.

Problem is that simple assignment of preons violates Heisenberg's uncertainty principle, giving the *mass paradox*: sum of the masses of preons, which compose a SM fermion, should exceed the mass of this fermion.

Possible solutions of mass paradox

- Classical limit ($\hbar \to 0$, $N_c \to \infty$, etc.)
- Confined preons with either small or zero mass ['t Hooft, 1980; Dimiopoulos, Raby and Susskind, 1980; Yu. P. Goncharov, 1312.4049]
- Nonlocality (includes application of SUSY and string theory methods)
- Large binding force between preons, cancelling their mass-energies

Historical excurse

When the electron spin was discovered, Uhlenbeck and Goudsmit proposed (in 1925) that it comes from rotation of the electron charge sphere. However Lorentz argued that the surface of the sphere would have a tangential speed $v = 137c$ *to produce the accurate spin angular momentum.*

However in the picture of rotating wavepacket [Chuu, Chang, Niu, 2010] the minimum intrinsic radius of the Dirac electron wavepacket is 137 times larger than the classical electron radius used in Lorentz's argument. Hence even tightest possible electron wavepacket does not have to rotate faster than the speed of light.

May spin of the SM electron (and other fermions) have similar origin?

Can the intrinsic structure be responsible for the rotation?

Particles from gravity site

“It is commonly recognized now that black holes are akin to elementary particles" [A. Burinskii, 1212.2920] Matching of metrics:

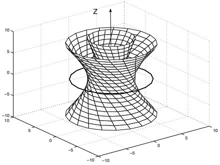
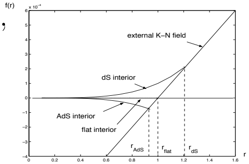


Figure 1: Congruence of the lightlike lines $k^\mu(x)$ is focused on singular ring, creating twosheeted Kerr space.

$$
\begin{aligned}
g_{\mu\nu} &= \eta_{\mu\nu} + 2Hk_\mu k_\nu, \\
H &= \frac{mr - e^2/2}{r^2 + a^2\cos^2\theta}
\end{aligned}
$$



Electron may be explained by a regular solution (charged, spinning and gravitating) of Kerr-Newman geometry (in the thin-wall approximation).

In non-abelian case this solution predicts a disk-like core of e^- formed by the Higgs field, which is spinning and oscillating, and is bounded by a closed circular current of the Compton radius. [A. Burinskii, 1003.2928]

KN solution has gyromagnetic ratio $g = 2$ as of the Dirac electron, and the gravitational field as expected for e^- from asymptotics.