Baryogenesis from R-parity breaking: the role of flavour

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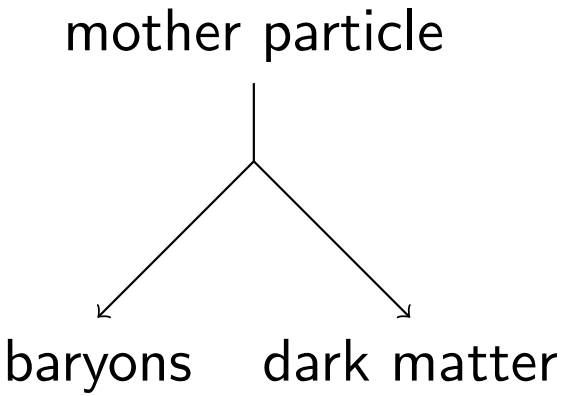
Starting point

We observe:

$$\frac{\Omega_{\Delta B}}{\Omega_{DM}} \sim \frac{1}{5} \qquad \text{whereas} \qquad \eta \equiv \frac{n_B}{n_\gamma} = \frac{n_b - n_{\bar{b}}}{n_\gamma} \approx 6 \times 10^{-10}$$

Why so similar? Common origin?

Possible explanation: Out-of-equilibrium decay:



Implementation

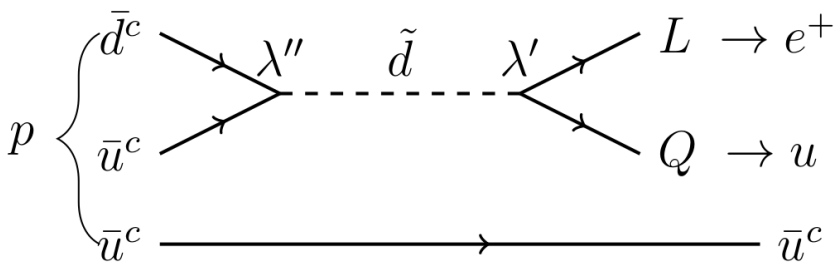
MSSM (Minimal Supersymmetric Standard Model) $\Rightarrow$ DM-candidates with R-parity violation $\Rightarrow$ SUSY-particles decay into SM-particles

just one R-parity violating operator:

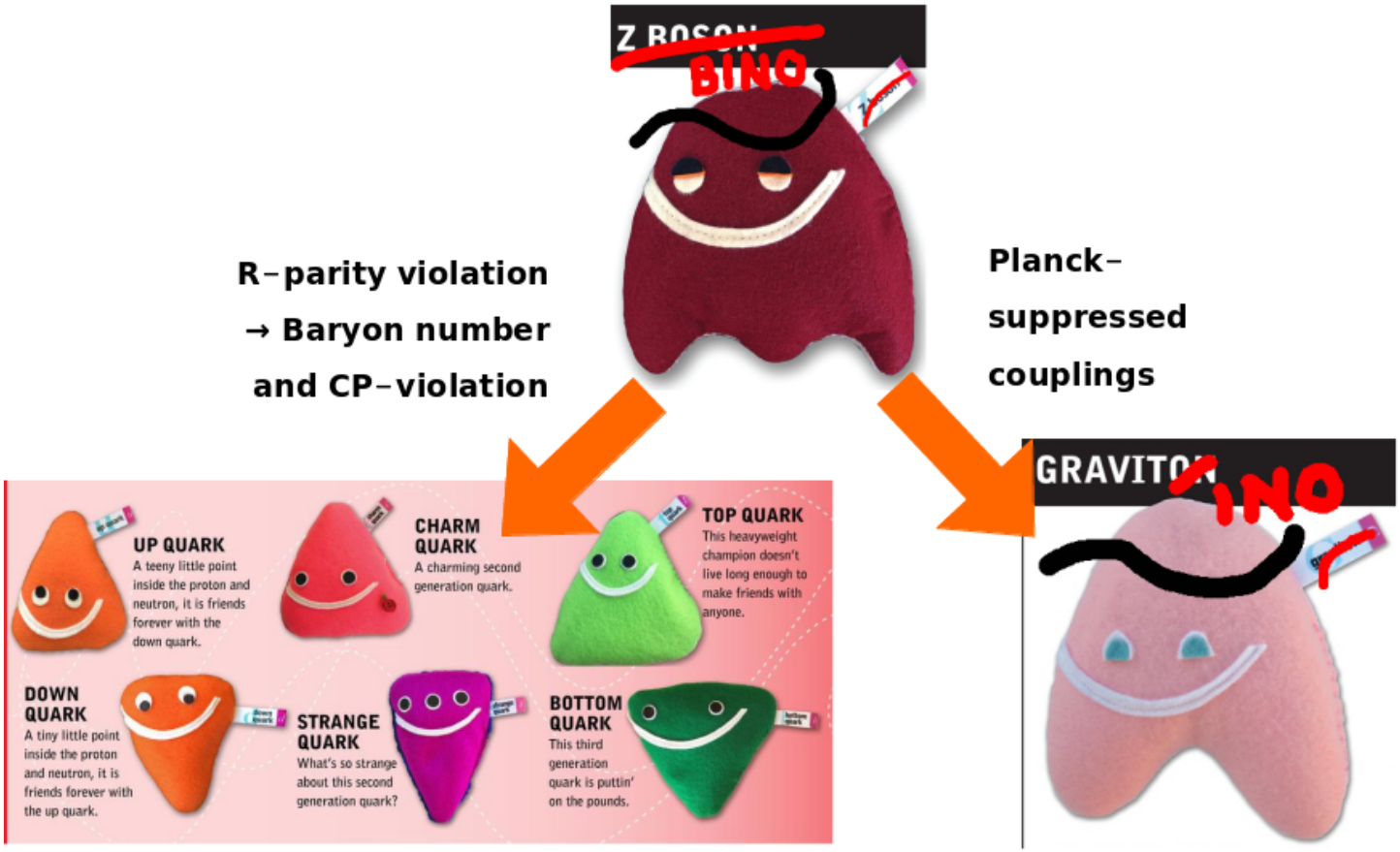
$$\lambda'' U^c D^c D^c$$

$\Rightarrow$ B-violating but:
constraints from proton stability are avoided:

(None of this:)

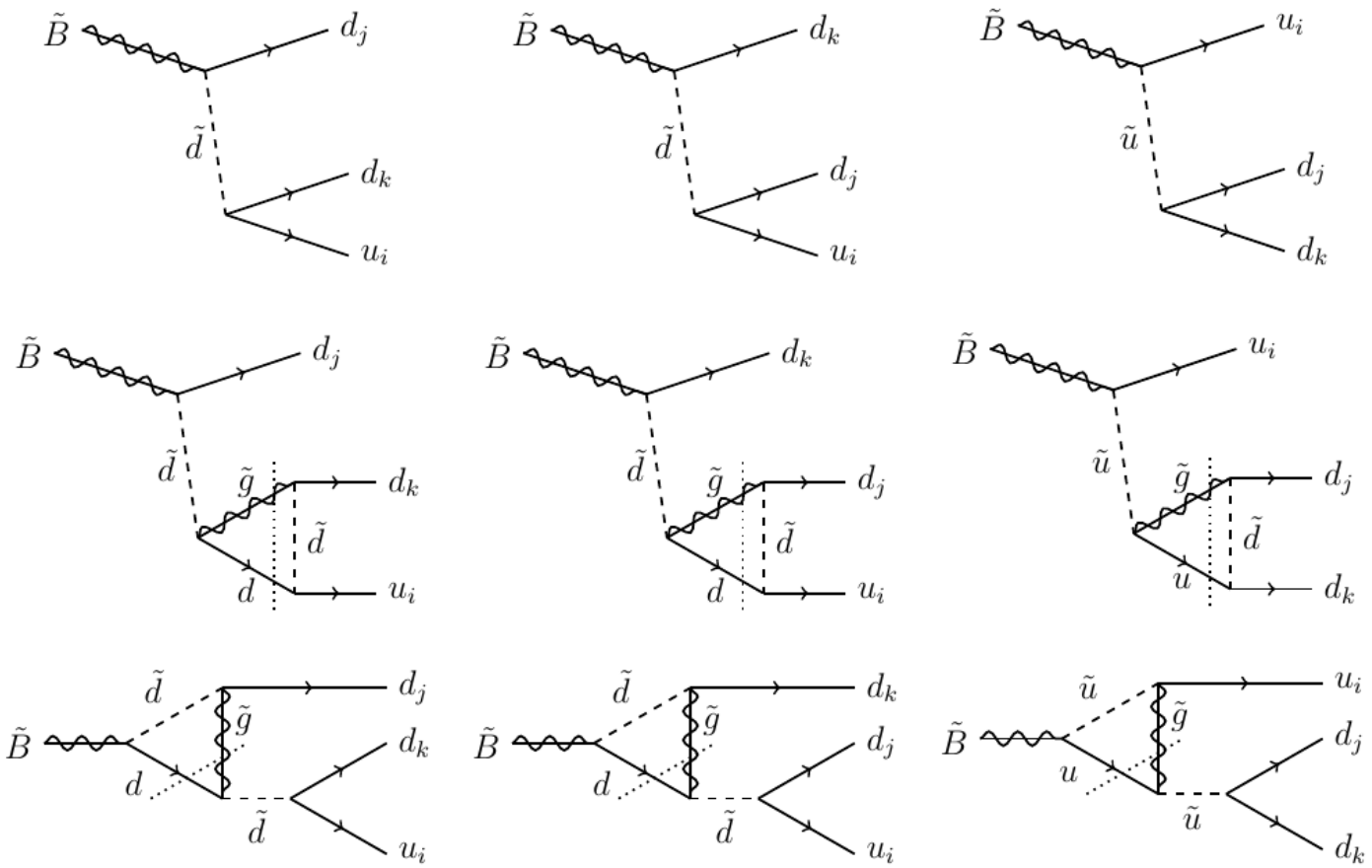


Implementation



Generation of the baryon asymmetry

The contributing diagrams are:



The Project

Aim: Improve previous studies (enlarge the parameter space) by

- including additional diagrams
- allowing for non-degenerate squark masses
- considering the flavour structure (in the squark-mixing matrices)

$\Rightarrow$ Flavour effects in the decay and wash-out?

$\Rightarrow$ **Natural explanation of the ratio of baryon-to-DM densities?**

Y. Cui, JHEP **1312** (2013) 067 doi:10.1007/JHEP12(2013)067 [arXiv:1309.2952 [hep-ph]].
G. Arcadi, L. Covi and M. Nardecchia, Phys. Rev. D **89** (2014) no.9, 095020 doi:10.1103/PhysRevD.89.095020 [arXiv:1312.5703 [hep-ph]].
G. Arcadi, L. Covi and M. Nardecchia, Phys. Rev. D **92** (2015) no.11, 115006 doi:10.1103/PhysRevD.92.115006 [arXiv:1507.05584 [hep-ph]].

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Thank you.

See you soon, here:

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MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Starting point

We observe:

$$\frac{\Omega_{\Delta B}}{\Omega_{DM}} \sim \frac{1}{5} \qquad \text{whereas} \qquad \eta \equiv \frac{n_B}{n_\gamma} = \frac{n_b - n_{\bar{b}}}{n_\gamma} \approx 6 \times 10^{-10}$$

Why so similar ?

Possible explanation:
Contemporary production of the BAU and of DM from the out-of-equilibrium decay of a mother particle

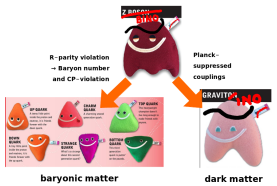
$\Rightarrow \Omega_{\Delta B} \sim \Omega_{DM}$ if both production mechanisms are suppressed by comparably small numbers.

Implementation

MSSM with the R-parity (and baryon number-) violating operator

$$\lambda'' U^c D^c D^c$$

$\Rightarrow$ avoid constraints from proton stability
$\Rightarrow$ R-parity violation: superpartners decay into SM-particles.

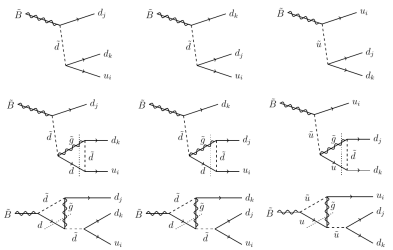


All three **Sakharov conditions** are satisfied:

- **Baryon number violation** in the R-parity violating coupling $\lambda'' U^c D^c D^c$
- **CP-violation** from the interference between tree-level- and one-loop-contributions to the decay of the bino into quarks
  Nanopoulos-Weinberg equality at lowest order:
  $|\langle f|T|X\rangle|^2 - |\langle X|T|f\rangle|^2 = -2\,\mathrm{Im}\left[\left(\sum_h \langle f|T|h\rangle\langle h|T^\dagger|X\rangle\right)\langle f|T^\dagger|X\rangle\right]$
- **Departure from equilibrium** The bino $\tilde{B}$ decays after freezing out.

Generation of the BAU

The contributing diagrams are:



Interactions

R-parity violating vertex:

$$\mathcal{L}_{udd} \ni 2\varepsilon^{\alpha\beta\gamma}\lambda''_{ijk}\left[\Gamma^{u*}_{RKi}\tilde{u}_{K\alpha}\overline{d^c}_{j\beta}P_R d_{k\gamma} + \Gamma^{d*}_{RKj}\tilde{d}_{K\beta}\overline{u^c}_{i\alpha}P_R d_{k\gamma}\right] + h.c.$$

where $\tilde{q}_K$, $K = 1,\dots,6$ are the squark mass eigenstates, $\tilde{q}_{Li}$ and $\tilde{q}_{Ri}$, $i = 1,\dots,3$ are the left- and right-handed squarks. λ''_{ijk} is antisymmetric in j, k.

Neutralino-sfermion-fermion vertex:

$$\mathcal{L}_{\tilde{\chi}\tilde{f}f} \ni \overline{\tilde{\chi}}(\Gamma^f_{LKi}g^{LL}_{\tilde{\chi}}P_L + \Gamma^f_{RKi}g^{RR}_{\tilde{\chi}}P_R)f_i\tilde{f}^*_K$$

Here $\tilde{\chi} = \tilde{B}, \tilde{G}$ and $f, \tilde{f} = u, \bar{u}, d, \bar{d}$. $g^{LL,RR}_{\tilde{B},\tilde{G}}$ are the usual coupling constants of the bino and the gluino:

$$g^{LL}_{\tilde{B}} = -\sqrt{2}g_1(Q_f - T_3) \quad g^{RR}_{\tilde{B}} = -\sqrt{2}g_1 Q_f \quad g^{LL}_{\tilde{G}} = -\sqrt{2}g_3 \quad g^{RR}_{\tilde{G}} = \sqrt{2}g_3$$

Previous works

- Y. Cui, JHEP **1312** (2013) 067 doi:10.1007/JHEP12(2013)067 [arXiv:1309.2952 [hep-ph]].
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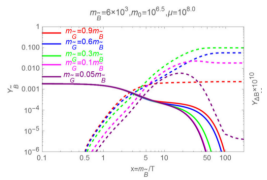
Arcadi et al. (2015): The correct DM and baryon relic densities can be obtained in this set-up with

- **a bino mass, 50 TeV $< m_{\tilde{B}} <$ 100 TeV**
- **a gluino NLSP mass, 15 TeV $< m_{\tilde{G}} <$ 60 TeV and**
- **a gravitino mass, 100 GeV $< m_{\tilde{g}} <$ a few TeV.**



Bino (solid ligns) and baryon yields (dashed ligns) for fixed $m_{\tilde{B}}$, m_0 (squark masses), μ (the suppression factor of $\tilde{B}\tilde{B} \to HH^*$ pair annihilation), $\lambda = 0.3$ and for four values of $m_{\tilde{G}}$ ranging from 0.05 $m_{\tilde{B}}$ to 0.9 $m_{\tilde{B}}$. Plot taken from Arcadi et al. (2015)

These results where obtained for the case of

- **degenerate right-handed down-type squarks**
- **flavour-diagonal mixing matrices Γ**
- **zero quark masses.**

Outlook

Aim: Improve the study (enlarge the parameter space) by

- **including additional diagrams**
- **allowing for non-degenerate squark masses**
- **considering the flavour structure (in the Γs)**

$\Rightarrow$ **Flavour effects in the decay and wash-out ?**
$\Rightarrow$ **Natural explanation of the ratio of baryon-to-DM densities ?**

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