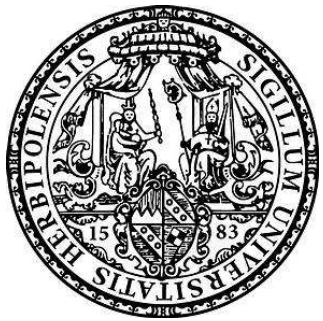
Resonant Dirac Leptogenesis on Throats

Andreas Bechinger

Würzburg University



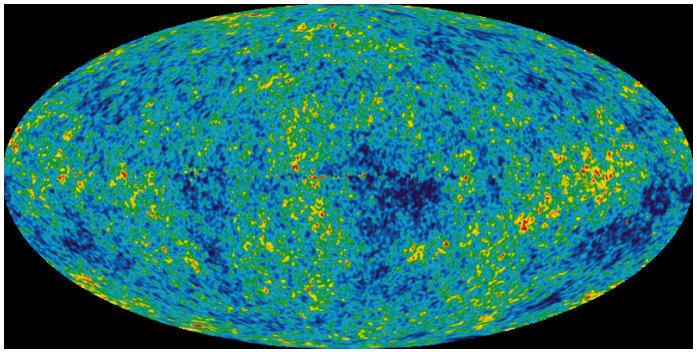
Neutrino masses and LFV at the LHC
November 25th 2009 / Würzburg

In collaboration with Gerhart Seidl

Based on: 0907.4341

Outline

Baryon asymmetry in the Universe: $Y_B = \frac{n_B - n_{\bar{B}}}{s}$



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- Cosmic Microwave Background

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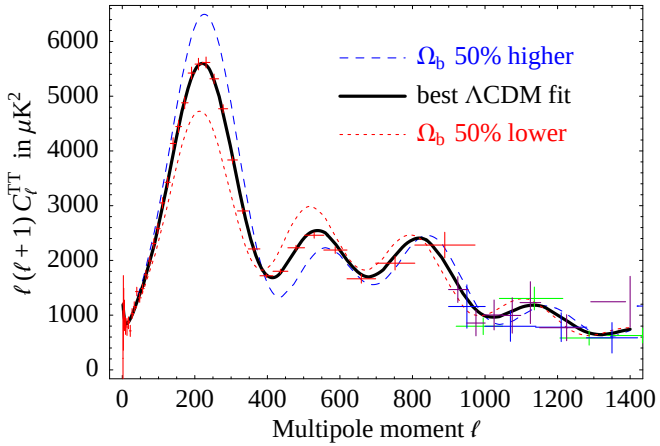

Strumia (2006)

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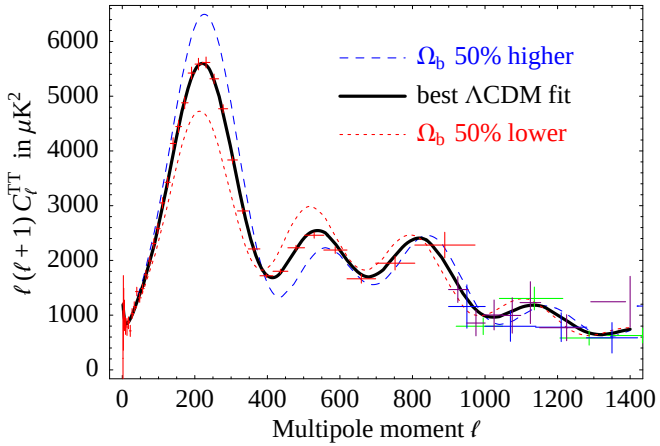

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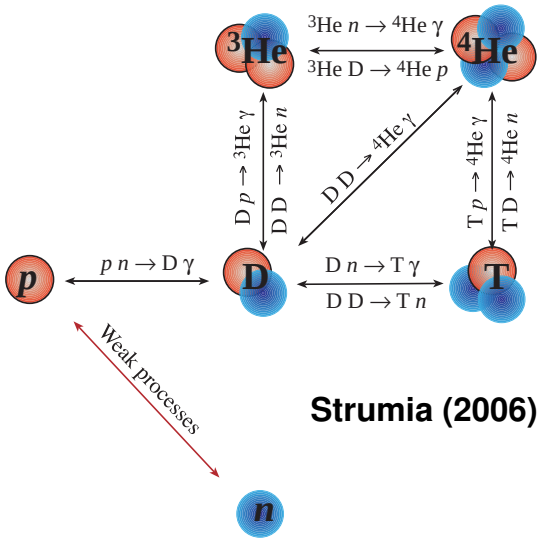

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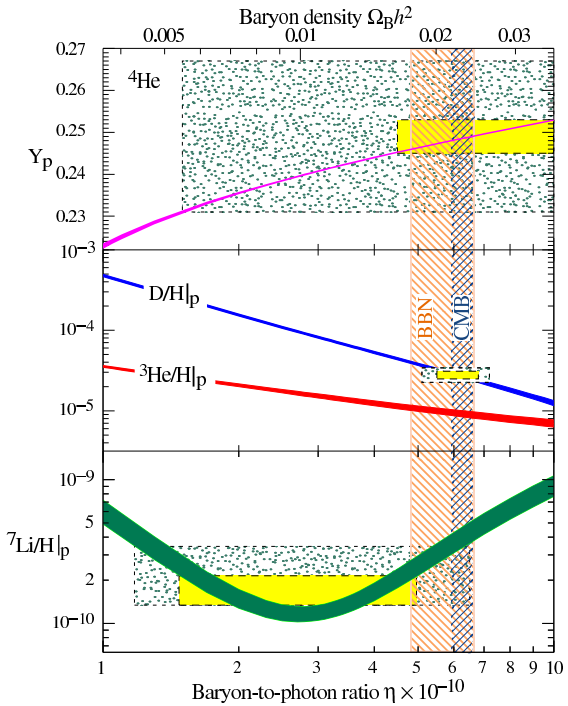

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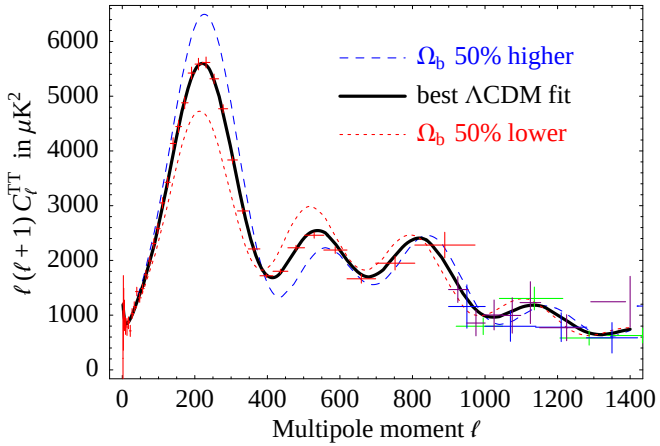

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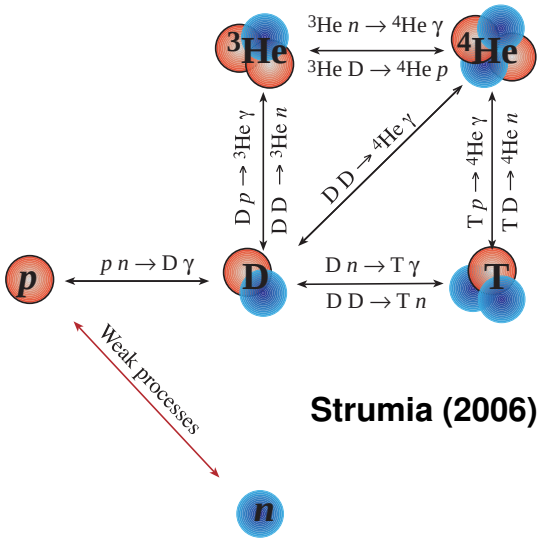

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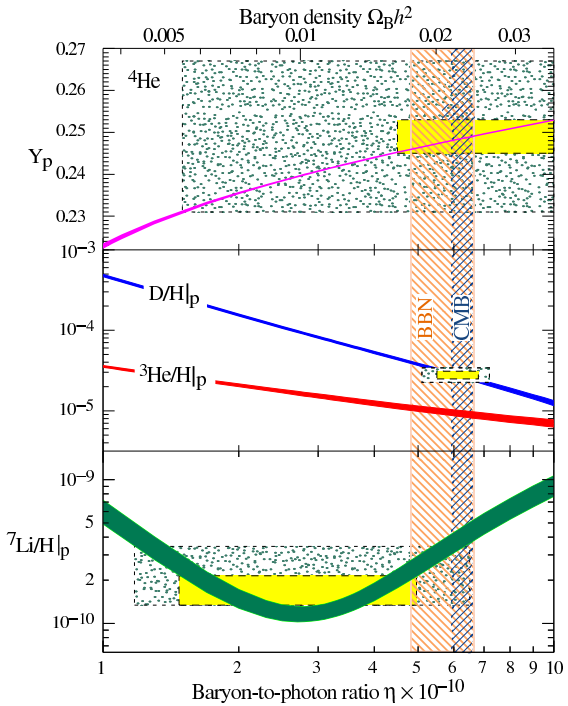

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↷ $Y_B = (8.62 \pm 0.27) \cdot 10^{-11}$

↷ Physics beyond the SM

ν masses: $m_\nu/m_t \sim 10^{-12}$ $\curvearrowright$ Physics beyond the SM

Dirac vs. Majorana νs

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Dirac vs. Majorana νs

Leptogenesis

Majorana νs: CP violating decays of heavy N_R

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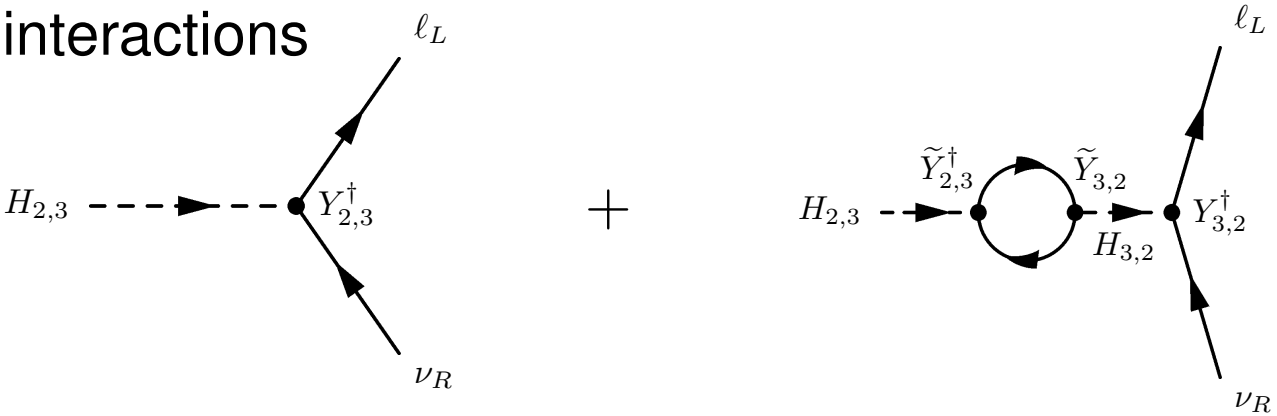

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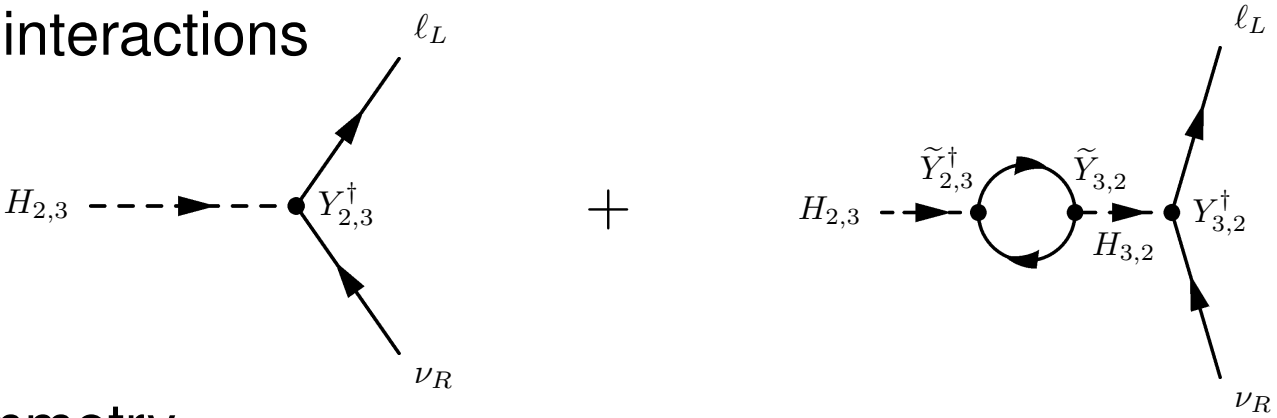

CP asymmetry

$$\epsilon_2 \approx \frac{\mathrm{Im}\left[\mathrm{tr}(Y_2^\dagger Y_3)\,\mathrm{tr}(\widetilde{Y}_2^\dagger \widetilde{Y}_3)\right]}{8\pi\,\mathrm{tr}(\widetilde{Y}_2^\dagger \widetilde{Y}_2)} \frac{M^2(H_2)}{M^2(H_3) - M^2(H_2)}$$

Extra Dimensions: Heavy KK excitations

Kaluza (1921), Klein (1926)

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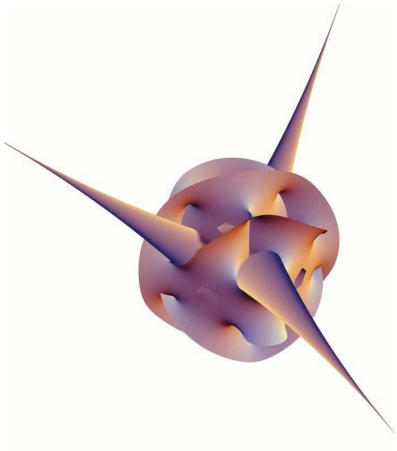
Multi-throats:

Multi-throat geometry

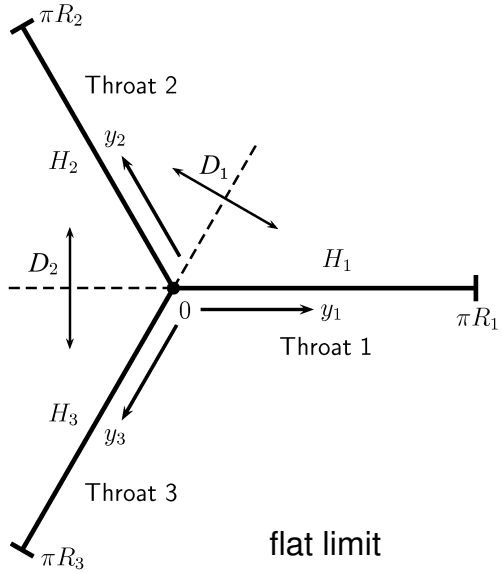
Cacciapaglia, Caski, Grojean, Terning (2006)

Solutions of super gravity

Klebanov, Strassler (2000)



Calabi-Yau manifold



flat limit

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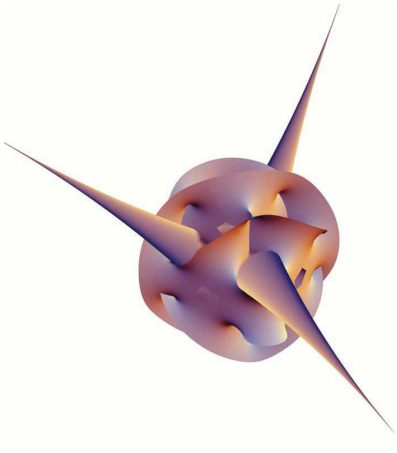

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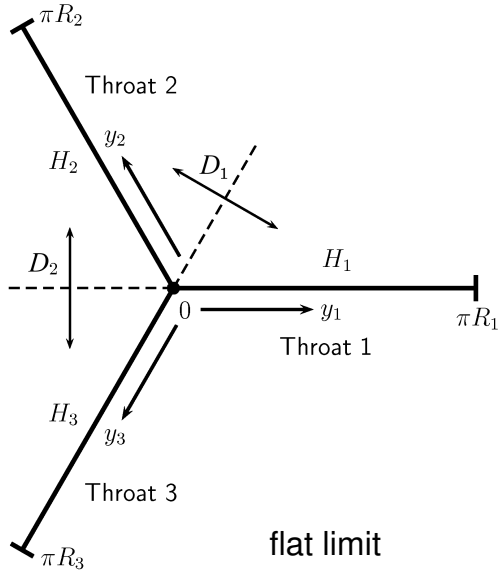


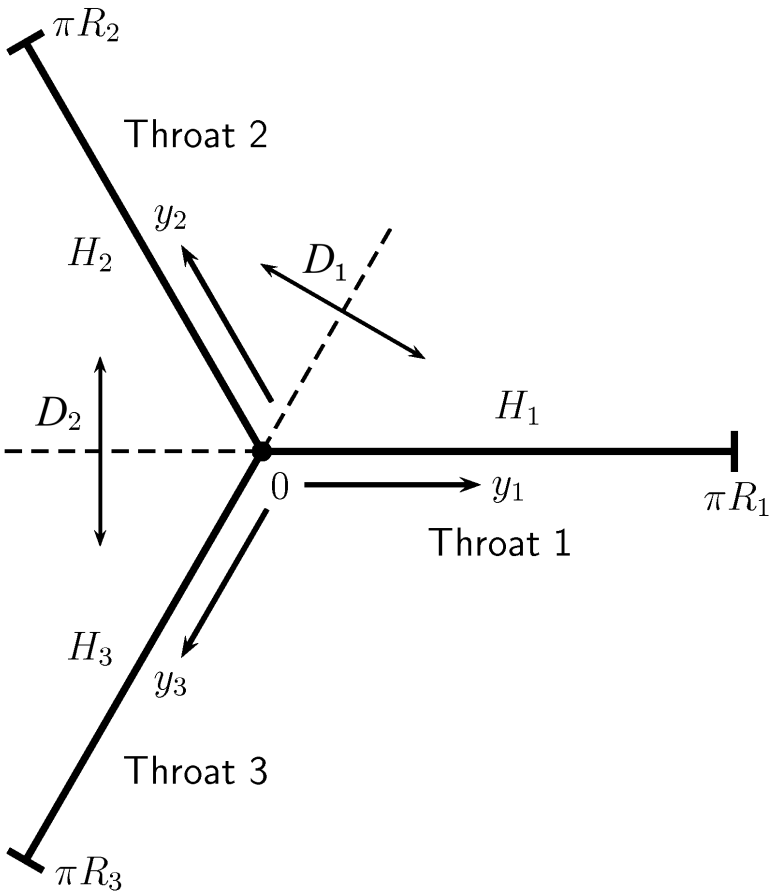
flat limit

Advantages:

- Wavefunction localization (at different points)
- Different KK spectra due to boundary conditions
- Separation of particles
- Correlations due to exchange symmetries

$\longrightarrow$ works also in the limit of flat 5D spacetimes!

Field content and localization



throat geometry

- 3 Higges separated on 3 throats: zero mode only on throat 1 (BCs)
  $\rightarrow \quad \left\langle H_1^{(1)} \right\rangle = v/\sqrt{2}$ on throat 1

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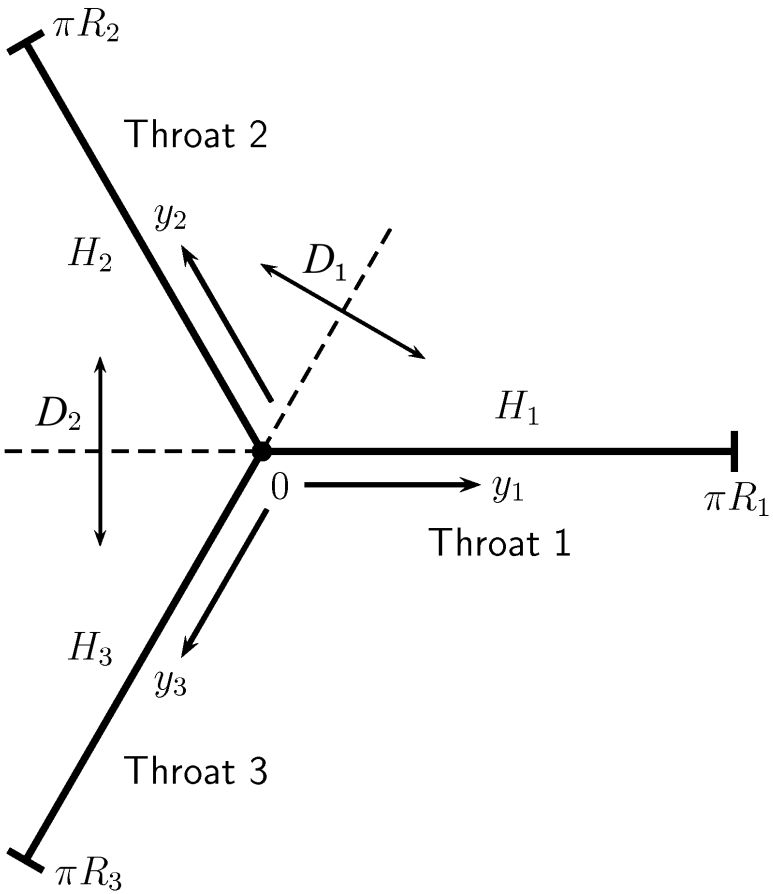

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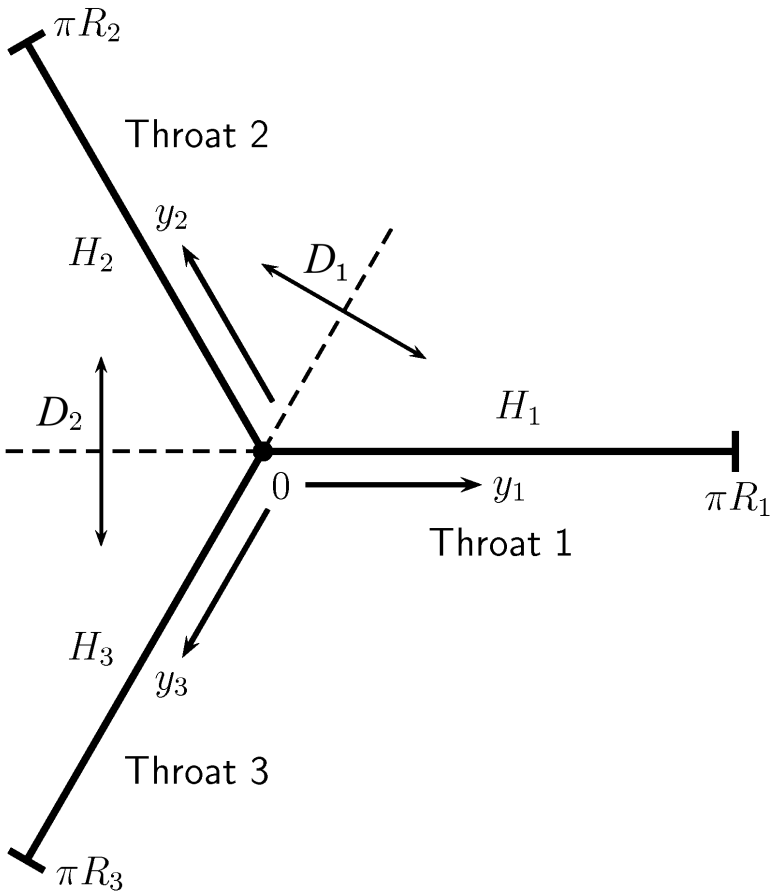

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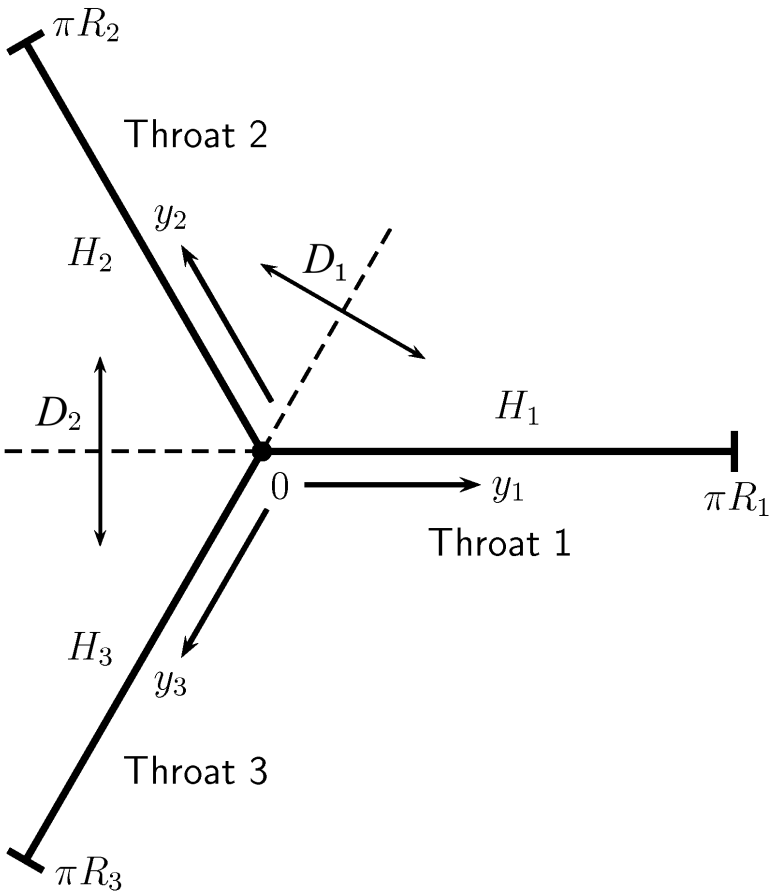

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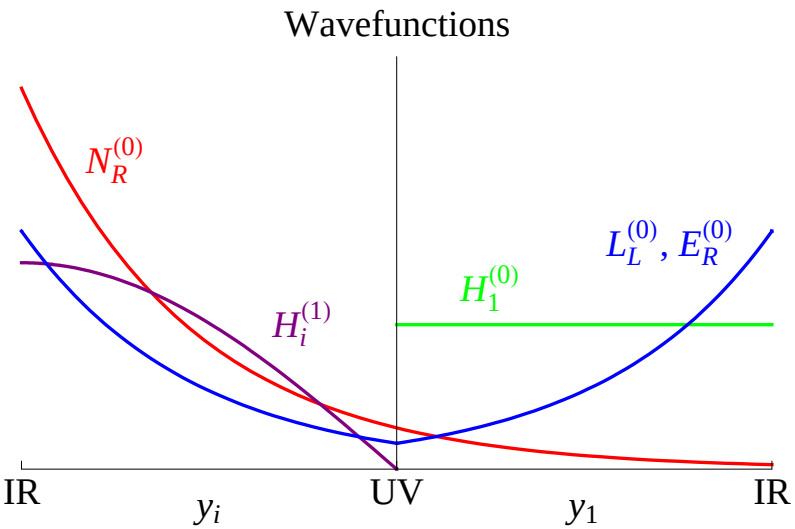
- Discrete exchange symmetries:

$$D_1 : H_1 \leftrightarrow H_2, \ \Psi_{1,a} \leftrightarrow \Psi_{2,a}, \quad y_1 \leftrightarrow y_2$$

$$D_2 : H_2 \leftrightarrow H_3, \ \Psi_{2,a} \leftrightarrow P^{\Psi}_{ab}\Psi_{3,b}, \quad y_2 \leftrightarrow y_3$$

Multi throat geometry $\curvearrowright$ leptonic zero modes @ $y_i = \pi R_i$



wavefunction localization

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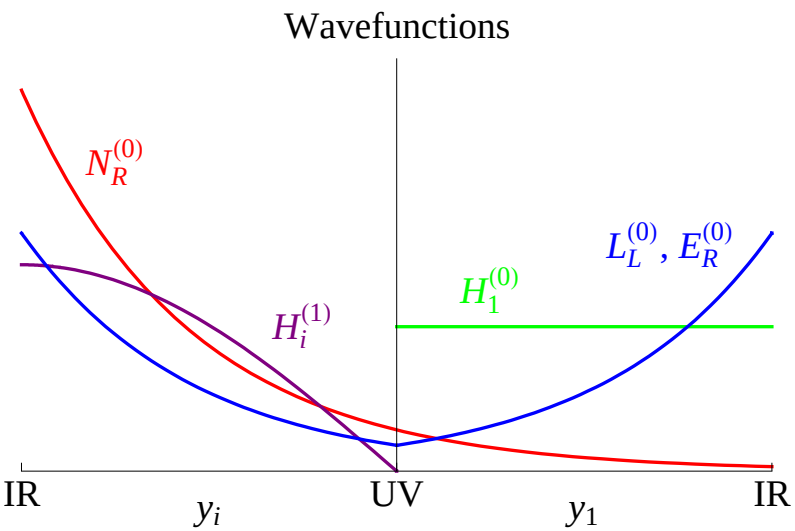

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Discrete symmetries D_1 and D_2:

- Protection of small relative Higgs mass splitting
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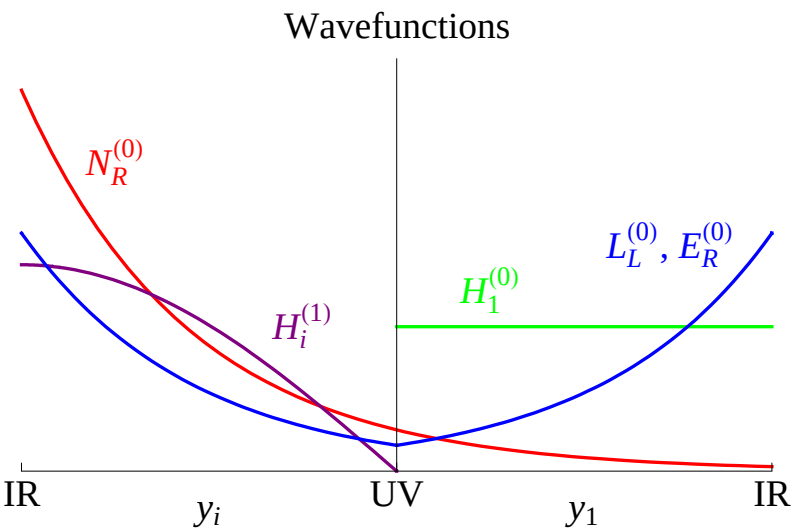

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  $Y_1 \sim e^{-2\pi R|m^N|}\, Y_{2,3}$
  related by exp. rescaling
  (m^N neutrino bulk mass)

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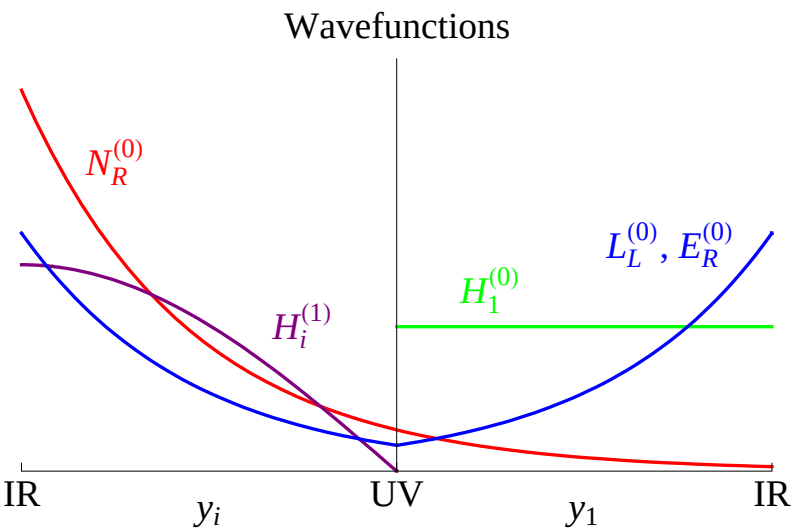

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- connecting leptogenesis and ν mixing parameters
  $\rightarrow$ model testable in future ν oscillation experiments

Connection between BAU and ν mixing parameters

Discrete symmetry D_2: $\quad Y_2 = P^L Y_3$

$$\curvearrowright \quad \mathrm{tr}(Y_2^\dagger Y_3) = \mathrm{tr}(Y_3^{\mathrm{diag}\,\dagger} U_{\mathrm{PMNS}}{}^\dagger P^{L\,\dagger} \underbrace{U_{\mathrm{PMNS}}}_{U_\ell^\dagger U_\nu} Y_3^{\mathrm{diag}})$$

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$$P^L = \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

(representation of $\Delta(24)$, generates Z_4 subgroup)

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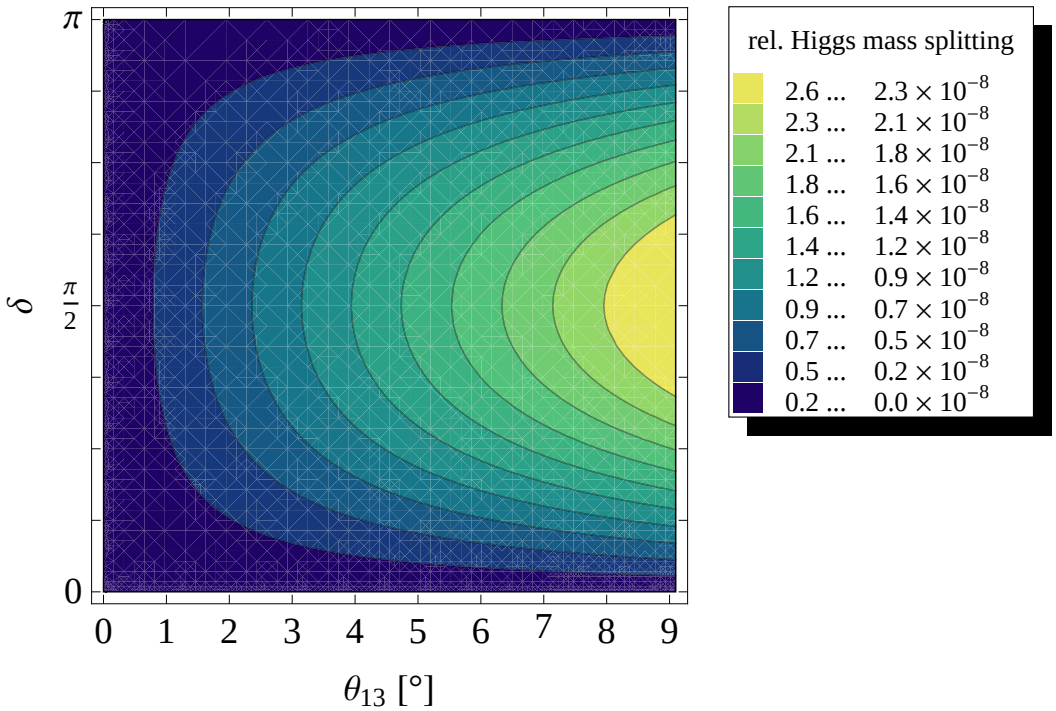

Correlation between θ_{13} and δ

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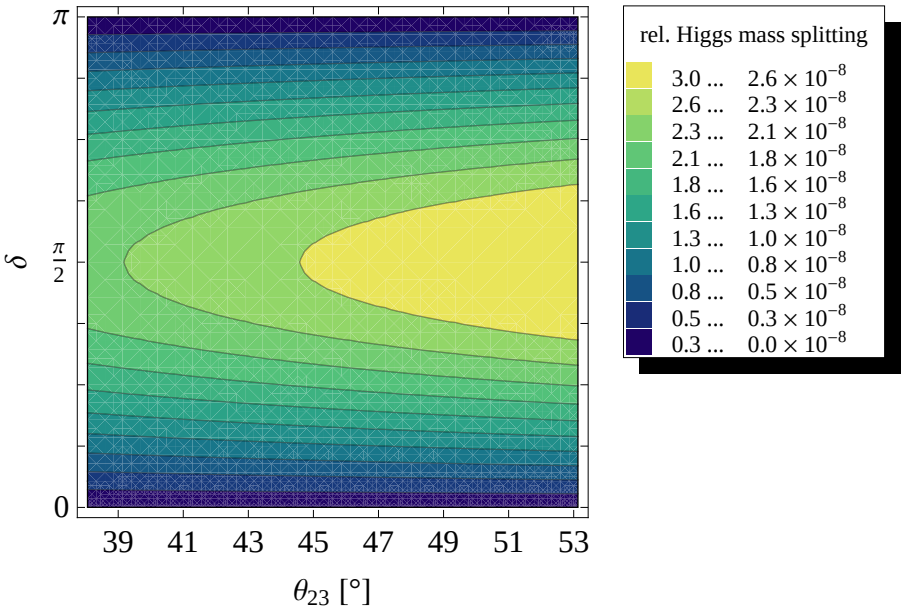
$$Y_B = (8.26 \pm 0.27) \times 10^{-11}$$
$$\theta_{12} = 33.2°,\ \theta_{23} = 45.0°$$

Connection between BAU and ν mixing parameters



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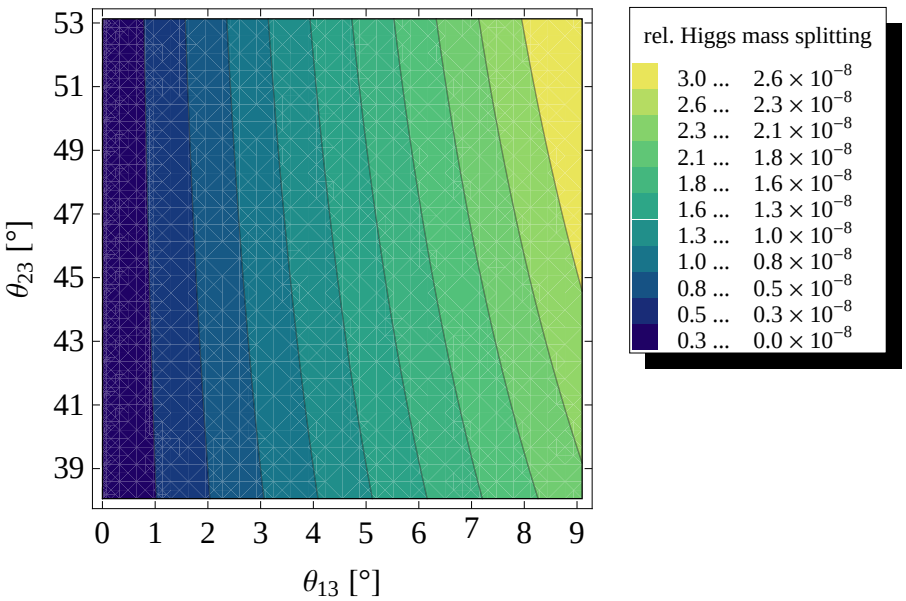


Correlation between θ_{23} and θ_{13}

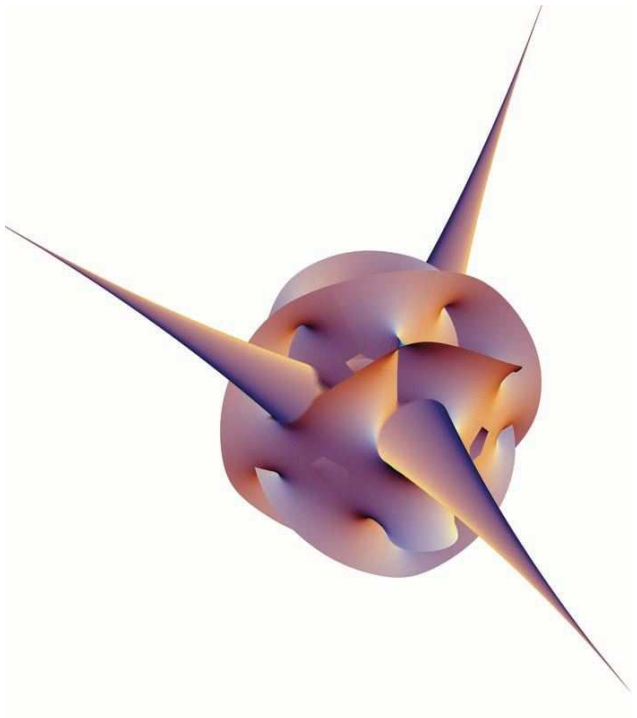
$$\theta_{13} = 9.1^\circ \qquad \delta = \frac{\pi}{2}$$

$$\theta_{12} = 33.2^\circ \quad \text{and} \quad Y_B = (8.26 \pm 0.27) \times 10^{-11}$$

Resonant leptogenesis on Throats

- Model on three 5D throats: G_{SM} & discrete symmetries D_i
  - Extra dimension: KK excitations as decaying states
  - Throats: Field separations & localization
  - Discrete symmetries: (i) degenerate scalar masses
    (ii) constraining Yukawa couplings
- Resonant Dirac Leptogenesis
- Correlation between low scale observables & high scale variables
  - ↷ Model testable at future collider and neutrino oscillation experiments, e.g. neutrino factories
- Multi throat geometries offer also an interesting approach to inflation, flavor symmetries, GUTs etc.

Thank you for your attention !!!



Cacciapaglia, Caski, Grojean, Terning (2006)

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Initial symmetry: $B_{L/R} = L_{L/R} = 0$

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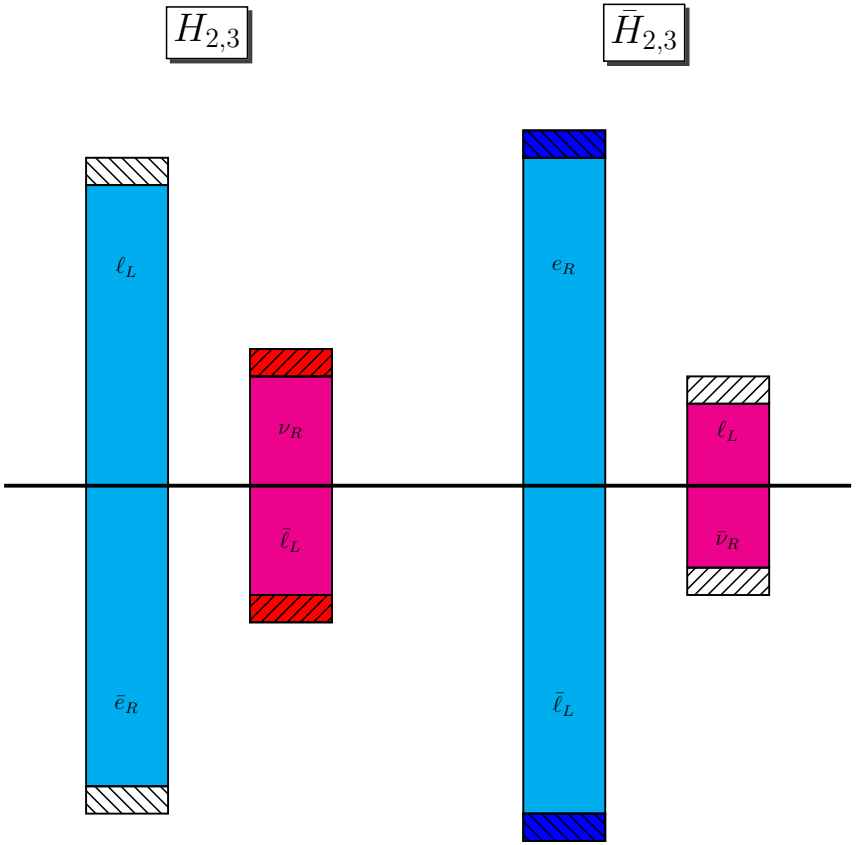

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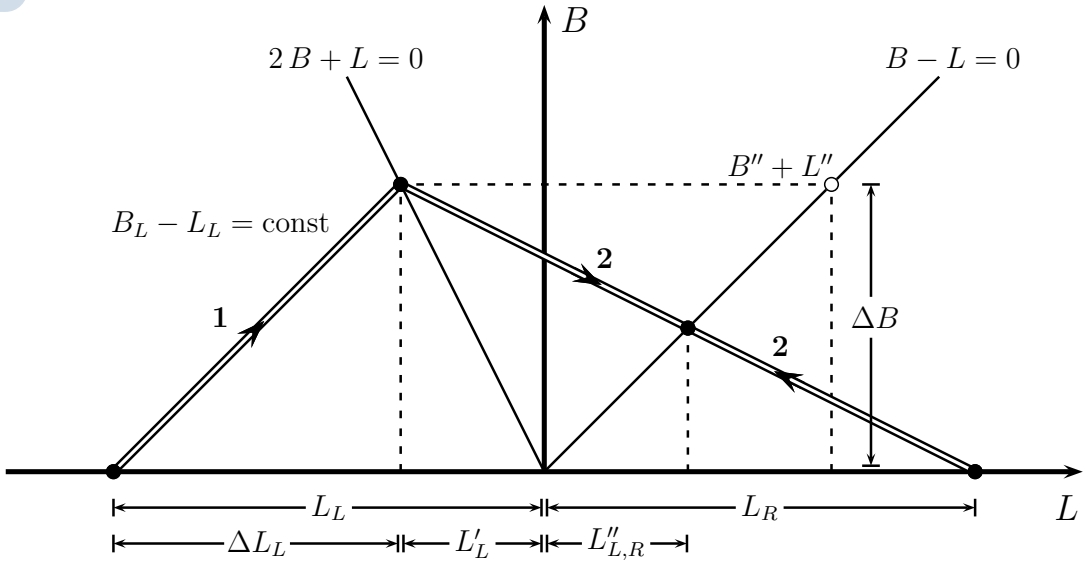

$SU(2)_L$ Sphalerons affecting only LH sector dominate at $T > T_c$

$\curvearrowright$ $B_L - L_L$ conserved but $B_L + L_L$ violated until $2B_L + L_L = 0$
(LR equilibration processes in baryonic sector are fast)

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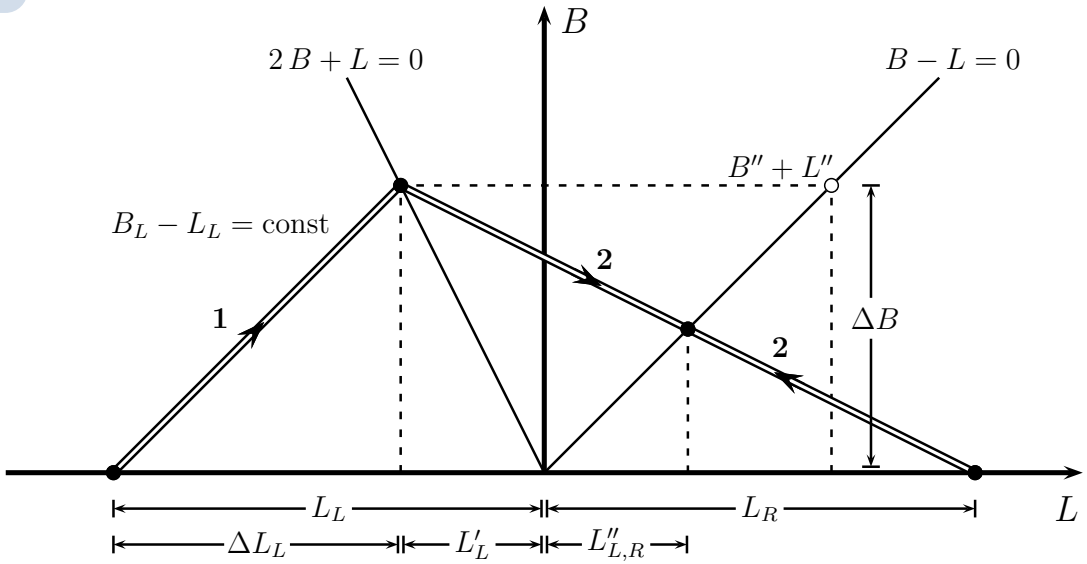

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↷ $B_L - L_L$ conserved but $B_L + L_L$ violated until $2B_L + L_L = 0$
(LR equilibration processes in baryonic sector are fast)

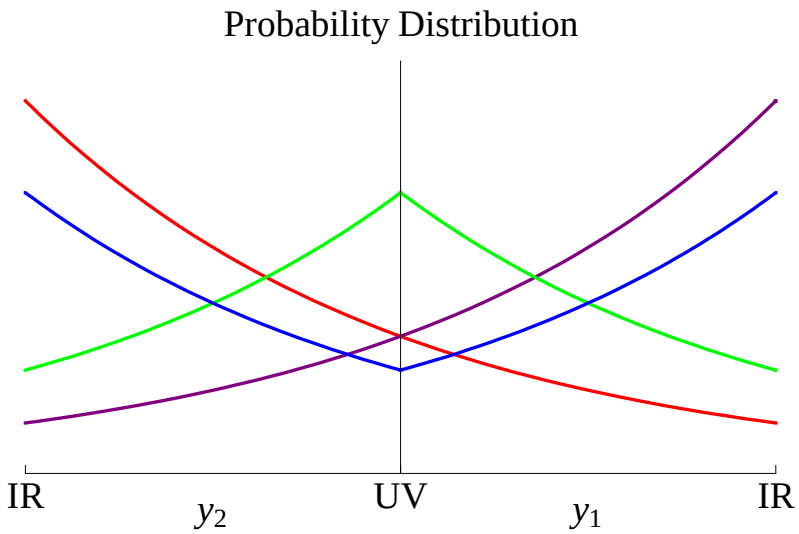
At $T < T_c$ LR equilibration takes over

↷ Final asymmetries: $L = \Delta L_L = B = \Delta B$

Fermions on an interval

Fermions in 5D vector-like

$$\mathcal{L}_i = \frac{\mathrm{i}}{2}\,\bar{\Psi}_i \Gamma^M \overleftrightarrow{\partial_M} \Psi_i - m_i^{\Psi} \bar{\Psi}_i \Psi_i$$



$m_1 = m_2 < 0$ $\quad$ $m_1 = m_2 > 0$

$m_1 > 0,\ m_2 < 0$ $\quad$ $m_1 < 0,\ m_2 > 0$

Cacciapaglia, Caski, Grojean, Terning (2006)

$$\Psi_L^{(0)}(x, y_i) = A_0^{\Psi} \exp(-m_i^{\Psi} y_i)\, \psi_L^0(x)$$

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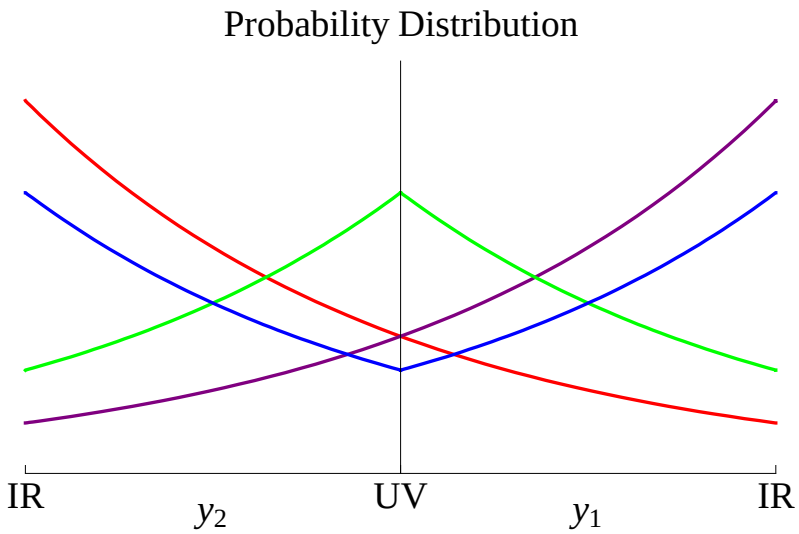
Throats connected by $\mathcal{S}_{\mathsf{UV}}$

$$\mathcal{L}_{\mathsf{UV}} = (m^{\Psi})^{\frac{1}{2}} \mathcal{K}_{ij}^{\Psi} \bar{\Psi}_{Li} \xi_{Rj}^{\Psi} + \text{h.c.}$$

$$\mathcal{K}_{ij}^{\Psi} \propto \begin{pmatrix} \delta & -\delta \\ -1 & -1 \\ 1-\delta & 1+\delta \end{pmatrix}$$

↷ mass splitting on loop level



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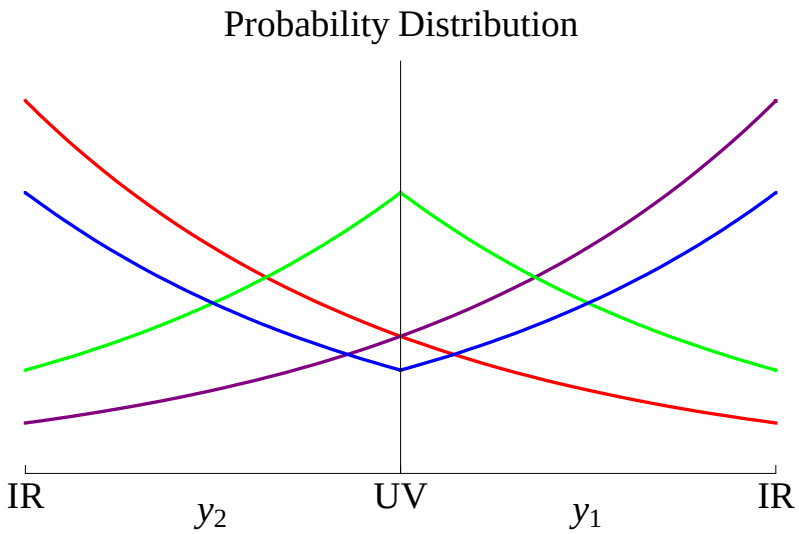

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$$N_{Li}|_{\pi R^-} = Y_i^5 H_i L_{iL}|_{\pi R^-}$$

↷ N_L discontinuous at $y = \pi R$ (L_L continuous)

Fermion Boundary Conditions

5D fermions ($\Psi = L, E, N$)

$$\Psi_i = \begin{pmatrix} \Psi_{Li} \\ \Psi_{Ri} \end{pmatrix}$$

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$$\Psi_i = \begin{pmatrix} \Psi_{Li} \\ \Psi_{Ri} \end{pmatrix}$$

Brane-localized Yukawa couplings
$\curvearrowright$ discontinuities of L_{Ri}, E_{Li}, N_{Li}

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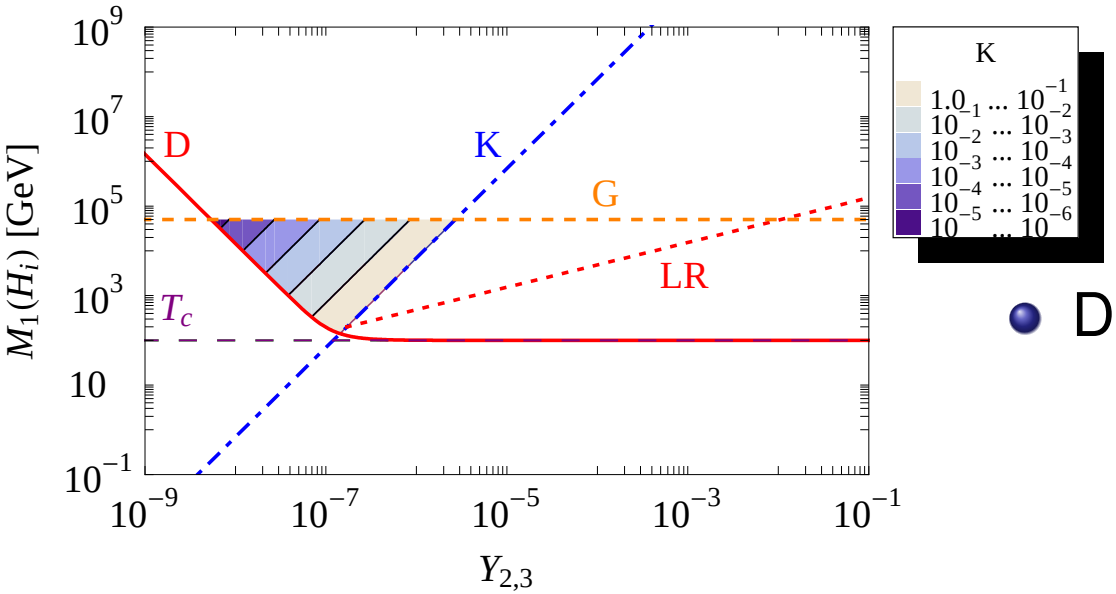
BCs at the IR branes

$$\begin{aligned} \bar{L}_{Ri}|_{\pi R_i^-} &= -(Y_i^5 H_i \bar{N}_{Ri} + \widetilde{Y}_i^5 \widetilde{H}_i \bar{E}_{Ri})|_{\pi R_i^-} \\ E_{Li}|_{\pi R_i^-} &= \widetilde{Y}_i^5 \widetilde{H}_i L_{Li}|_{\pi R_i^-} \\ N_{Li}|_{\pi R_i^-} &= Y_i^5 H_i L_{Li}|_{\pi R_i^-} \end{aligned}$$

($\pi R_i^- \equiv \pi R_i - \epsilon$ for $\epsilon \to 0$)
Note: L_{Li}, E_{Ri}, and N_{Ri}, continuous over the whole interval

Bounds on the Yukawa couplings



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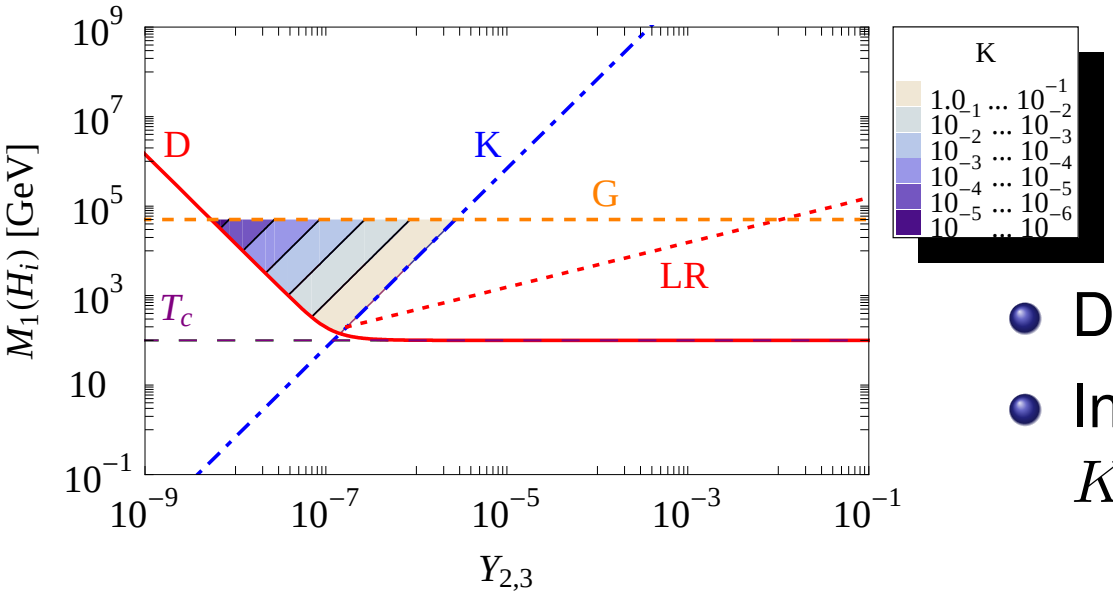

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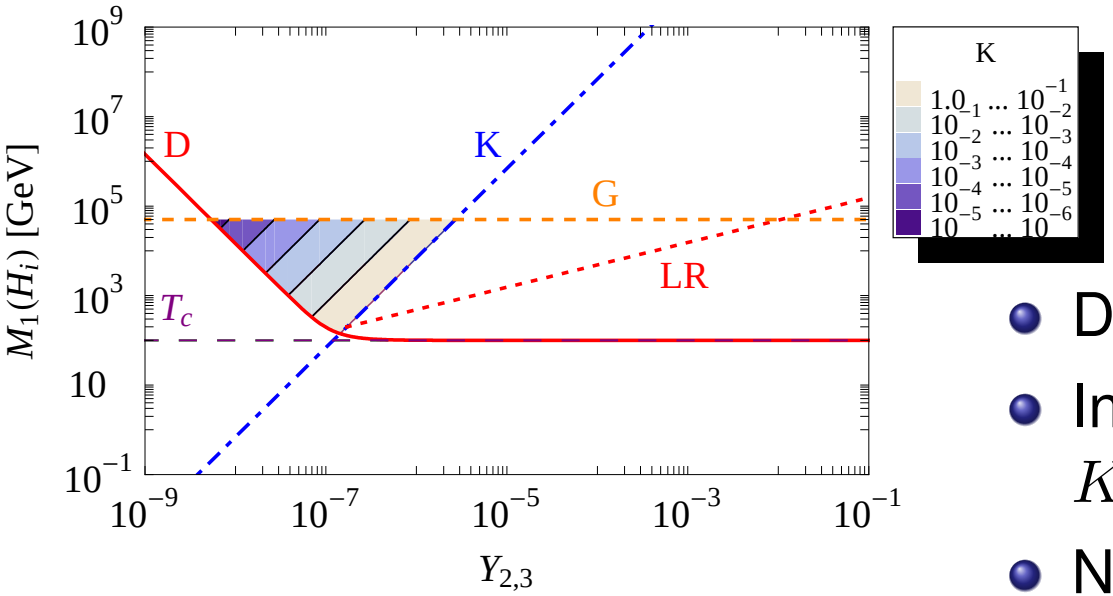

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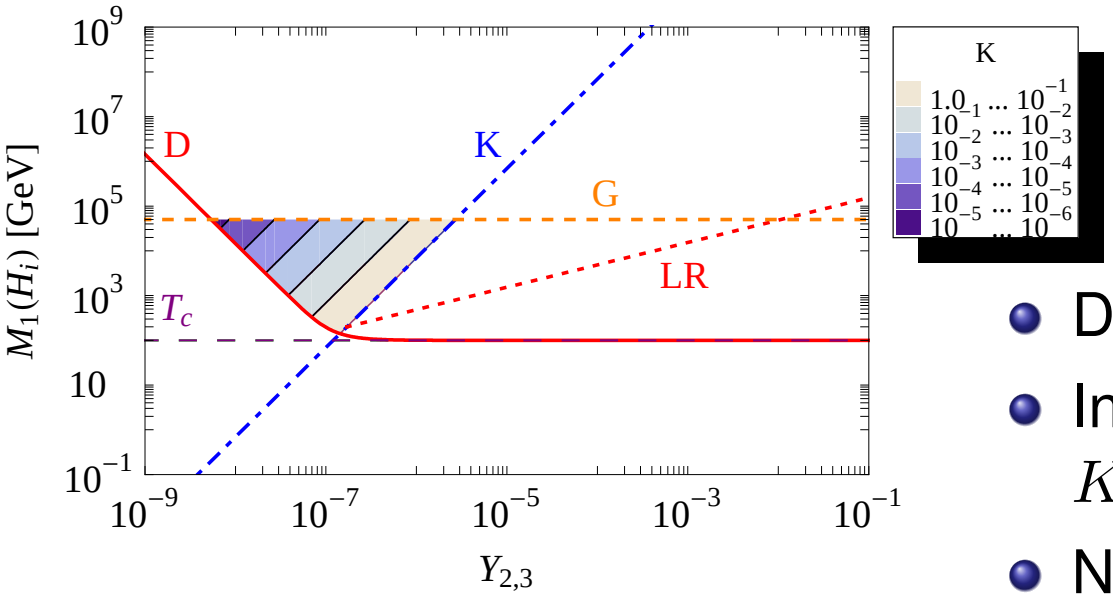

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Graviton bound:

Late decay of KK gravitons spoil BBN $\leftrightarrow$ $\Gamma_{G^{(n)}} \sim n_D \frac{M_n^3(G)}{M_{\text{Pl}}^2}$