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Semileptonic B decays into final states with heavy sterile neutrinos

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Talk based on work with

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Belle (-II) group at University of Bonn

Sterile neutrinos

- heavy neutrino = Heavy Neutral Lepton
- sterile = gauge singlet
- only interesting, if some other kind of interaction, usually a Yukawa interaction with SM Higgs or extra Higgs doublet or Higgs triplet
- usually studied: mixing scenario

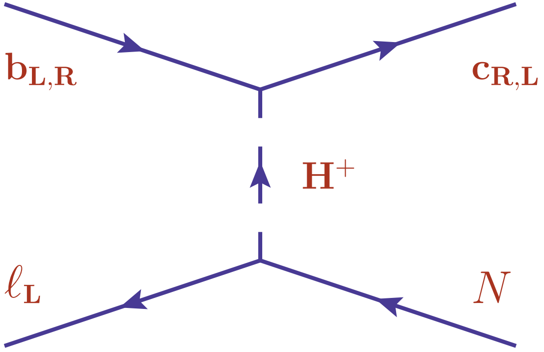
$$\nu_\ell = U_{\ell j} \nu_j + U_{\ell j} N_j$$ with $\ell = e, \mu, \tau,$ and j=1,2,3

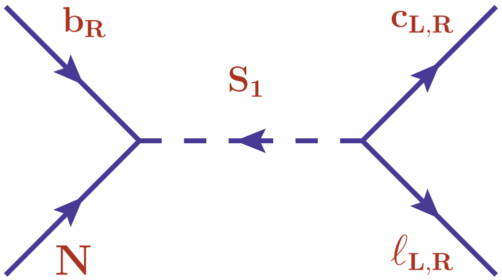
mixing matrix — sterile neutrino

- … but not in this talk

Sterile neutrinos

- Mixing scenarios are better studied with other processes than B decays.

- But could have 

or 

- Sterile neutrino is produced in *B* meson decay.

- We assume that *N* escapes the detector. (true if light enough)

Effective hamiltonian

- Parametrize arbitrary new-physics interaction to dimension 6:

$$\mathscr{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{cb} \Big[(\bar{c}_L \gamma_\mu b_L)(\bar{\ell}_L \gamma^\mu \nu_{\ell,L}) + g_{V_R}^N (\bar{c}_R \gamma_\mu b_R)(\bar{\ell}_R \gamma^\mu N_R) + g_{S_L}^N (\bar{c}_R b_L)(\bar{\ell}_L N_R)$$

$$+ g_{S_R}^N (\bar{c}_L b_R)(\bar{\ell}_L N_R) + g_T^N (\bar{c}_L \sigma_{\mu\nu} b_R)(\bar{\ell}_L \sigma^{\mu\nu} N_R) + \text{h.c.} \Big]$$

SM term

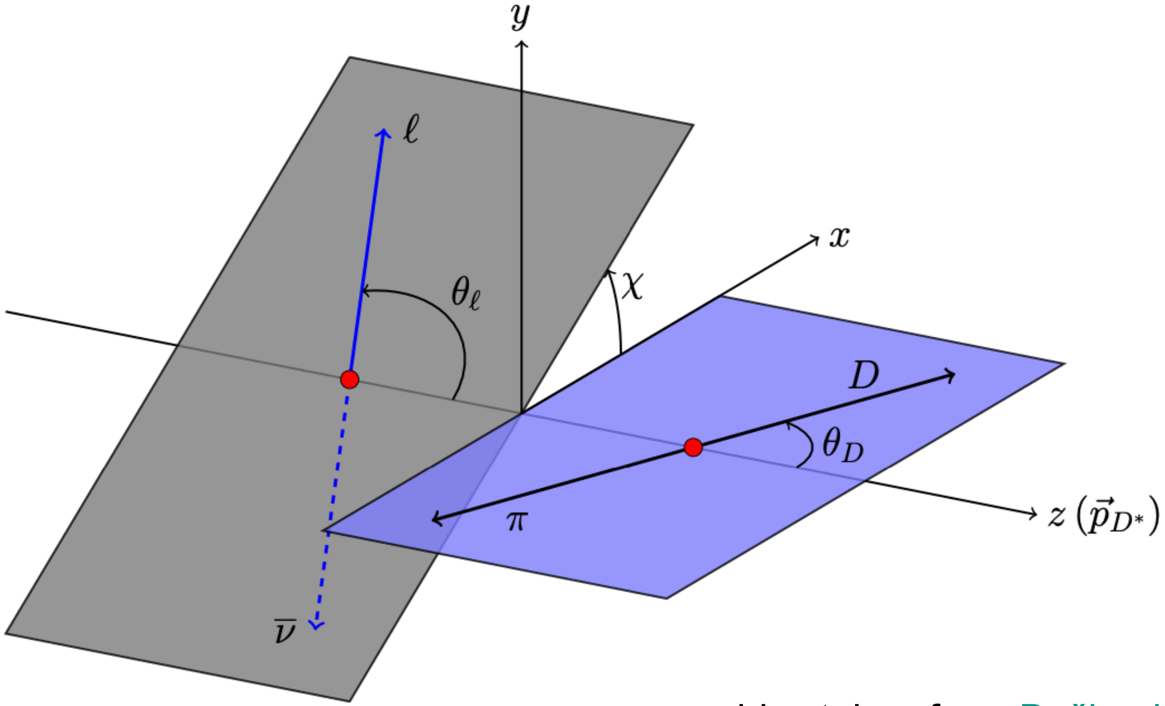
Robinson, Shakya and Zupan, 1807.04753

$B \to D^* \ell N$ at Belle

- For $M_N = \mathcal{O}(1\text{GeV})$ do “bump hunts” in M^2_{miss}. Belle Coll., 2301.07529

- For small M_N the M^2_{miss} distribution does not discriminate between $B \to D^* \ell N$ and $B \to D^* \ell \nu$.
  But angular distributions can reveal effects from new-physics interactions with couplings $g^N_{V_R}$, $g^N_{S_L}$, $g^N_{S_R}$, g^N_T.

Angles of angular distribution



graphics taken from Bečirević et al., 1907.02257

Angular coefficients

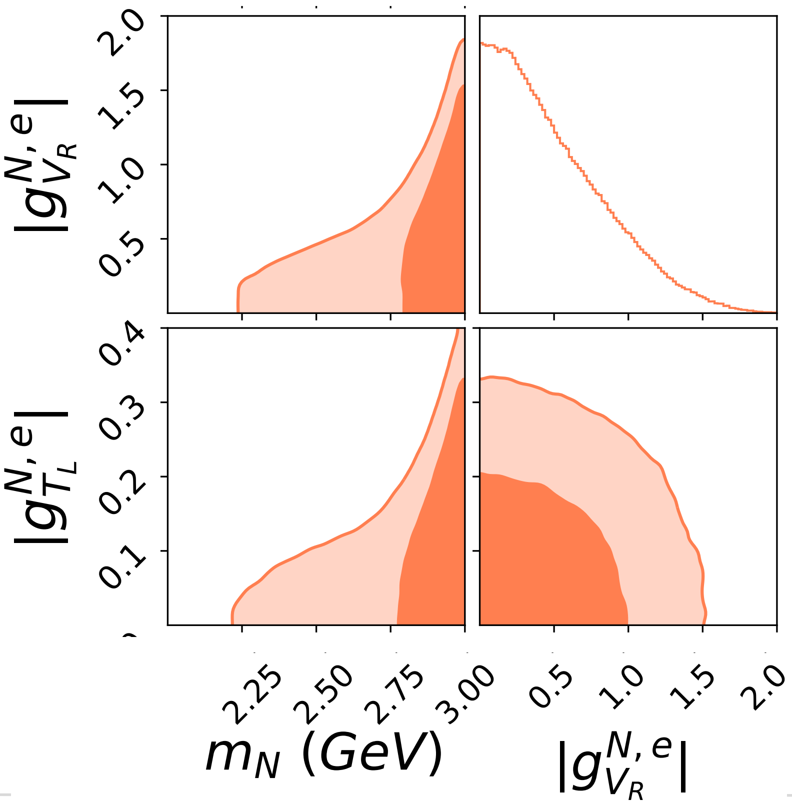
$$\frac{32\pi}{9}\frac{d^4\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_D d\chi} = (J_{1s} + J_{2s}\cos 2\theta_\ell + J_{6s}\cos\theta_\ell)\sin^2\theta_D +$$
$$(J_{1c} + J_{2c}\cos 2\theta_\ell + J_{6c}\cos\theta_\ell)\cos^2\theta_D +$$
$$(J_3\cos 2\chi + J_9\sin 2\chi)\sin^2\theta_D\sin^2\theta_\ell +$$
$$(J_4\cos\chi + J_8\sin\chi)\sin 2\theta_D\sin 2\theta_\ell +$$
$$(J_5\cos\chi + J_7\sin\chi)\sin 2\theta_D\sin 2\theta_\ell +$$

Extract angular coefficients $J_{1s}\ldots J_7$ from experiment.

$g^N_{V_R}, g^N_{S_L}, \ldots$ from angular coefficients

- We have fitted angular coefficients J_i to recent Belle data
- Bayesian analysis, fitted parameters: (g^N_j, m_N, FF), one Wilson coefficient $g^N_{V_R}, g^N_{S_L}, \ldots$ at a time.
- Result insensitive to choice of form factors (FNAL/MILC, JLQCD,…)

Results

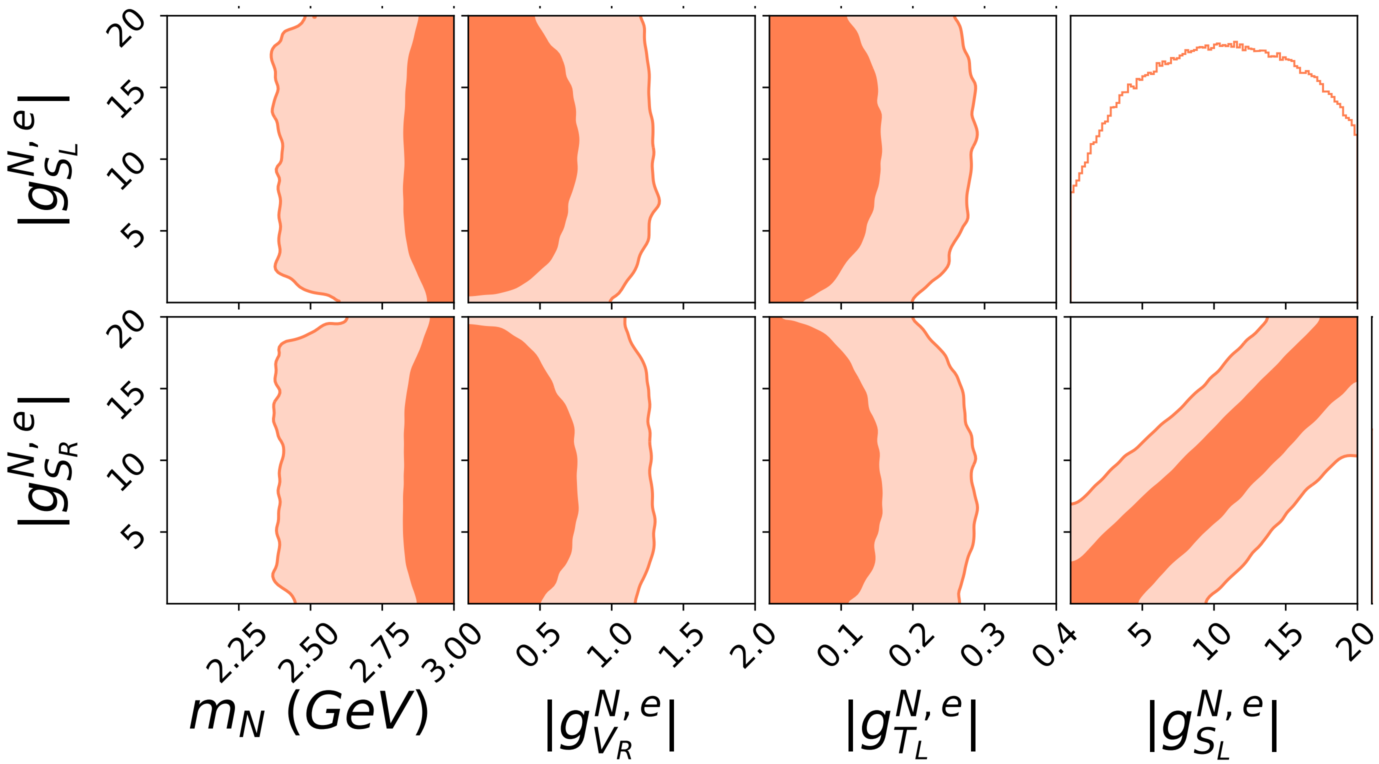


Posterior distribution for $B \to D^* e N$

- M_N distribution just for illustration, Belle has vetoed $M_N > 50$ MeV
- lower right: $g^N_{V_R}$ vs. g^e_T

  dark: 1σ light: 2σ

Results



- $g_{S_L}^N$ vs. $g_{S_R}^N$ has trivial flat direction
- no evidence for non-zero new-physics couplings

Other constraints

- Constraints from $B \to D^*\mu + E_{\text{miss}}$ seach look similar, no hint of $B \to D^*\mu N$.
- Bounds on $\mathcal{B}(B \to K^{(*)} + E_{\text{miss}})$ constrain $g_{S_R}^N$ and g_T^N by SU(2) symmetry,

e.g.: $$g_{S_R}^N(\bar{c}_L b_R)(\bar{\ell}_L N_R) \subset g_{S_R}^N\Big[(\bar{c}_L b_R)(\bar{\ell}_L N_R) + \underbrace{(\bar{s}_L b_R)(\bar{\nu}_L N_R)}_{\text{drives } B^+ \to K^+ + E_{\text{miss}}}\Big]$$

$\mathcal{B}(B \to K^{(*)} + E_{\text{miss}})$ dat imply $g_{S_R}^N, g_T^N \lesssim 0.01$.

Felkl, Giri, Mohanta, Schmidt, 2309.02940

$\Rightarrow \quad B \to D^*\ell + E_{\text{miss}}$ not competitive for $g_{S_R}^N$ and g_T^N.

Summary

- One can search for heavy sterile neutrinos N in $B \to D^* \ell \nu$ data; $B \to D^* \ell N$ can reveal itself via
  - bumps in M^2_{miss} (good for heavy N) or
  - changes in angular distributions (good for light N and new interactions (scalar, tensor,...)
- Scenarios tested in B decays involve new interactions, e.g. charged-Higgs or leptoquark mediated decays, not suited for $\nu - N$ mixing scenarios.
- No hints for $B \to D^* \ell N$ found in Belle data.

Siegen nightwatchman