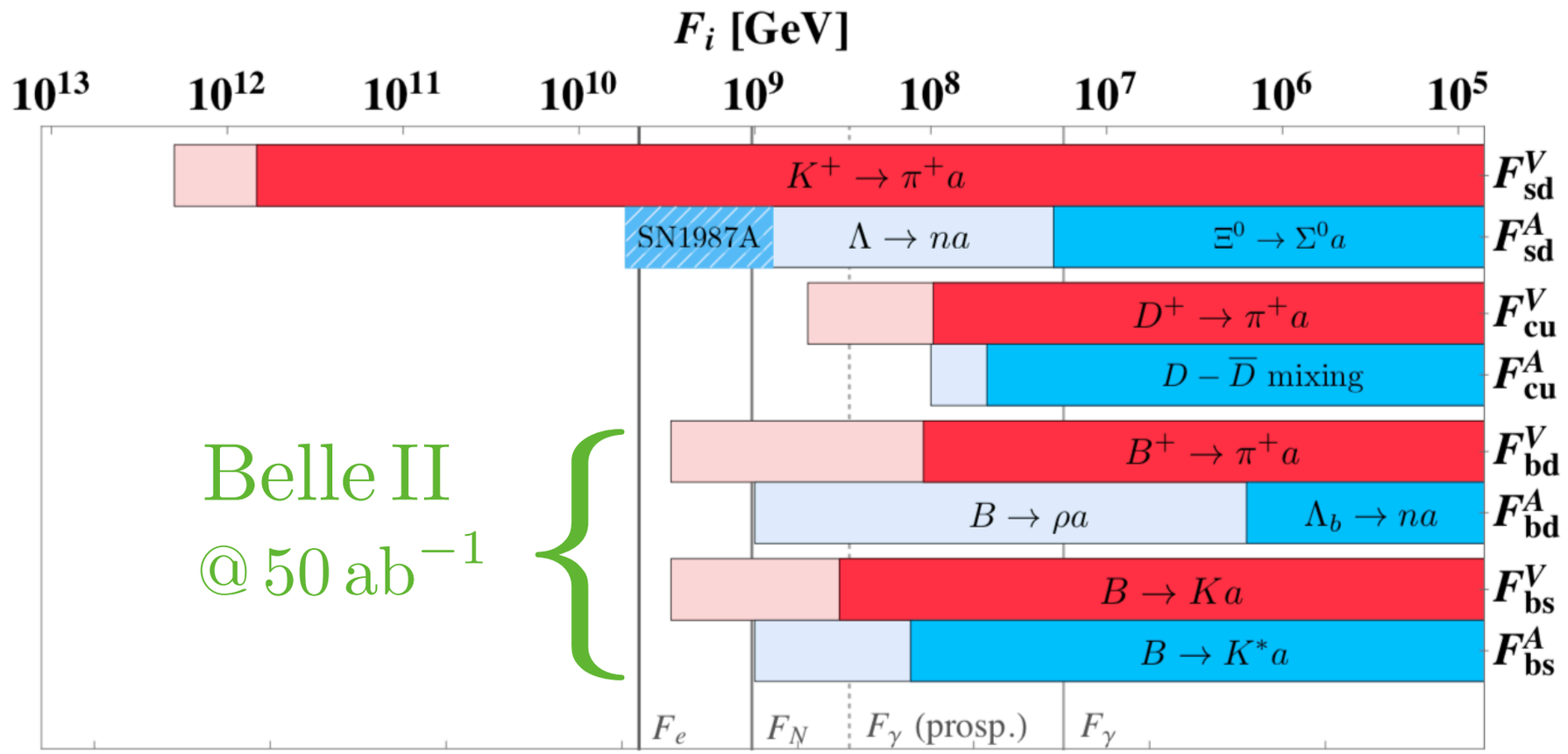
Flavor-violating Axions @Belle II

Robert Ziegler



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based on arXiv:2002.04623 (published in PRD)

with J. Martin Camalich, M. Pospelov, H. Vuong, J. Zupan

The QCD Axion

★ **Motivated** by **strong CP Problem** & **Vanilla Dark Matter candidate**

★ **Single scale** controls interactions and mass

couplings $\sim 1/f_a$ **mass** $\sim m_\pi^2/f_a$

practically massless and stable (need $f_a > 10^7 \mathrm{GeV} \Longleftrightarrow m_a < 1\mathrm{eV}$)

(for heavy >MeV Axions/ALPS @BELLE II see 1709.00009)

★ Can be searched for with

✳ Astrophysics (star cooling via axion emission)

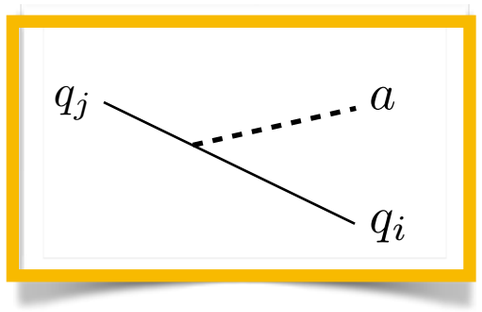
✳ Microwave cavities (conversion to photons)

✳ **Flavor physics (rare decays with missing energy)**

Flavor-violating Axion Couplings

Most general axion couplings to fermions are flavor-violating

$$\mathcal{L}_{\text{eff}} = \frac{\partial_\mu a}{2f_a}\,\overline{f}_i\gamma^\mu\left(C^V_{ij}+C^A_{ij}\gamma_5\right)f_j$$



present whenever axion sector has new sources of flavor violation

possibly connected to origin of SM flavor hierarchies, Wilczek '82

Need to constrain **8 *independent*** flavor-violating quark couplings (w/o tops)

- ✦ 2-body meson decays $K \to \pi a, B \to K a, D \to \pi a, B \to K^* a, \ldots$
- ✦ 2-body baryon decays $\Lambda \to n a, \Lambda_b \to n a, \ldots$
- ✦ Neutral meson mixing typically much **less constraining than meson decays!**

Same signature as SM decays with final state neutrinos $K \to \pi\nu\overline{\nu}, B \to K\nu\overline{\nu}, \ldots$
in 2-body region = vanishing invariant mass of neutrino pair

Constraints on Meson Decays

Experimental bounds often old/non-existent

e.g. no bound in literature on $D^+ \to \pi^+ a, B \to K^* a, B \to \rho a$

Can recast experimental data for neutrino pairs in 2-body region

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		$K^+ \to \pi^+ a$	$D^+ \to \pi^+ a$	$B^+ \to \pi^+ a$	$B^+ \to K^+ a$	
	Decay	sd	cu	bd	bs	
$\propto C_{ij}^V$	$\mathrm{BR}(P_1 \to P_2 + a)$	7.3×10^{-11} [85]	no analysis	4.9×10^{-5} [86]	4.9×10^{-5} [86]	CLEO
	$\mathrm{BR}(P_1 \to P_2 + a)_{\mathrm{recast}}$	no need	8.0×10^{-6} [87]	2.3×10^{-5} [88]	7.1×10^{-6} [89]	BaBar
	$\mathrm{BR}(P_1 \to P_2 + \nu\bar{\nu})$	$1.47^{+1.30}_{-0.89} \times 10^{-10}$ [85]	no analysis	0.8×10^{-5} [90]	1.6×10^{-5} [90]	Belle
$\propto C_{ij}^A$	$\mathrm{BR}(P_1 \to V_2 + a)$			no analysis	no analysis	
	$\mathrm{BR}(P_1 \to V_2 + a)_{\mathrm{recast}}$			no data	5.3×10^{-5} [89]	BaBar
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				$B \to \rho a$	$B \to K^* a$	

- ✦ best data on B-decays from Belle, but don't allow for 2-body recast
  - e.g. in 1303.3719 2-body region cut out to reject bg from radiative decays
- ✦ took BaBar data to get bounds for $B \to (\pi/K/K^*)a$

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$B \to \rho a$ $B \to K^* a$

Interesting target for Belle II

★ **first bounds on 2-body B-decays to vector mesons**

★ **likely to improve old CLEO bounds by order of magnitude**

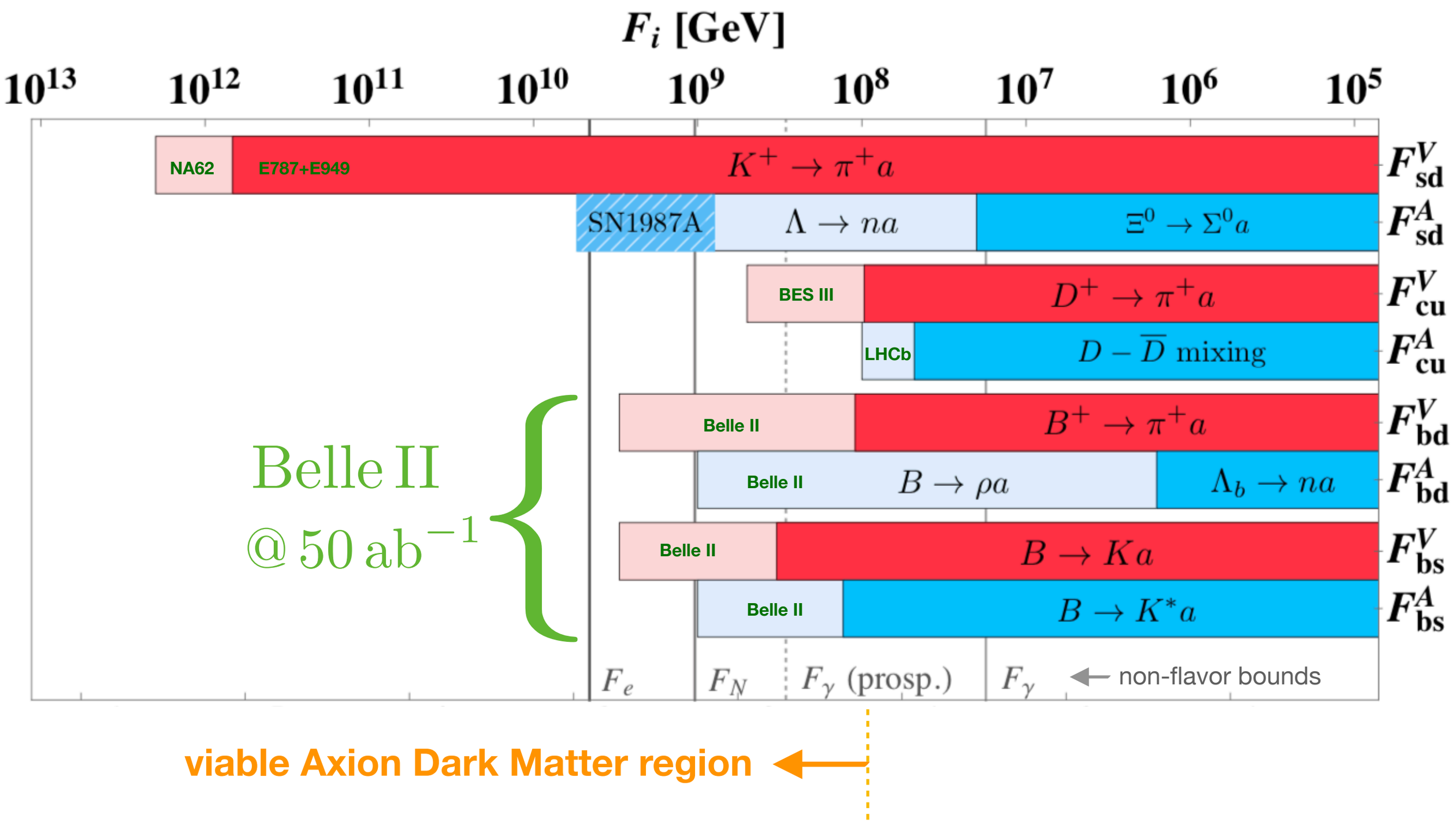
Light vs. Heavy New Physics

Looking for 2-body decays is **sensitive to much higher New Physics scales** than looking for deviations in 3-body decays

$B \to K a$	$B \to K \nu \bar{\nu}$
$\frac{\partial_\mu a}{f_a} \bar{b} \gamma^\mu s$	$\frac{1}{\Lambda^2} \left(\bar{b} \gamma^\mu s\right) \left(\bar{\nu} \gamma_\mu \nu\right)$
$\Gamma \propto M_B^3 / f_a^2$	$\Gamma \propto M_B^5 / \Lambda^4$
$f_a \gtrsim 3 \times 10^5 \,\mathrm{TeV}$	$\Lambda \gtrsim 10 \,\mathrm{TeV}$

(moreover heavy NP typically stronger constrained by mixing than decays)

Present Constraints & Prospects



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Summary

★ The QCD axion
- ✦ is well-motivated by Strong CP Problem and DM
- ✦ is a massless, stable particle
- ✦ **can have large flavor-violating couplings**

★ **Contributes to 2-body B-meson decays with missing energy**

★ 2-body decays are interesting target because can probe much higher NP scales than deviations from SM 3-body decays

★ Full data set of **Belle II could provide bounds of order 10^9 GeV** on effective axion coupling